INSTITUTE OF NUCLEAR AND PARTICLE PHYSICS

NATIONAL CENTER FOR SCIENTIFIC RESEARCH DEMOKRITOS

ACTIVITIES REPORT
2019

EDITORS:

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October 2020

Institute of Nuclear & Particle Physics,
NCSR "Demokritos"
Aghia Paraskevi, 15310, Athens, Greece

http://www.inp.demokritos.gr

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Overview

The Institute of Nuclear and Particle Physics (INPP), at NCSR Demokritos, has as its mission the experimental and theoretical research, scientific excellence and innovation in High-Energy Physics, Nuclear Physics and Astro-Particle Physics as well as their applications in line with the National Research and Innovation Strategy for Smart Specialization.

The experimental and theoretical research in High Energy Physics focuses on the study of elementary particles and their interactions. INPP participates in the CMS and ATLAS experiments of the LHC at CERN. The Detector Instrumentation Laboratory (DIL) and the Data Acquisition, Monitoring and Analysis Laboratory (DAMA) of INPP, develop innovative detector technologies and instrumentation along with applications in science and innovation.

Nuclear Physics research focuses on Nuclear Structure, Nuclear Reactions, Nuclear Astrophysics and the study of interactions of X-rays with matter. The INPP hosts a 5.5. MV Tandem accelerator, a unique research infrastructure in Greece that is open to external users from Greece and abroad. The Tandem accelerator laboratory is an interdisciplinary open-access research infrastructure with innovative applications covering the fields of cultural heritage, environment, energy, human health and the development and testing of advanced materials and detectors. The XRF laboratory focuses on cultural heritage, environmental monitoring and biomedicine and offers technology transfer and on-site analytical services to museums, archaeological sites and other institutions.

The Astro-Particle Physics group participates in the development, deployment, data acquisition and data analysis of the kilometer cube underwater neutrino telescope in the Mediterranean, KM3NeT. The INPP hosts the Laboratory of Assembly, Testing and Calibration of the Digital Optical Modules, the basic units of the KM3NeT telescope. The INPP supports also the Deep-Sea Technology and Astro-Particle Physics Research Infrastructure in South-West Peloponnese (Kalamata, Pylos, Methoni).

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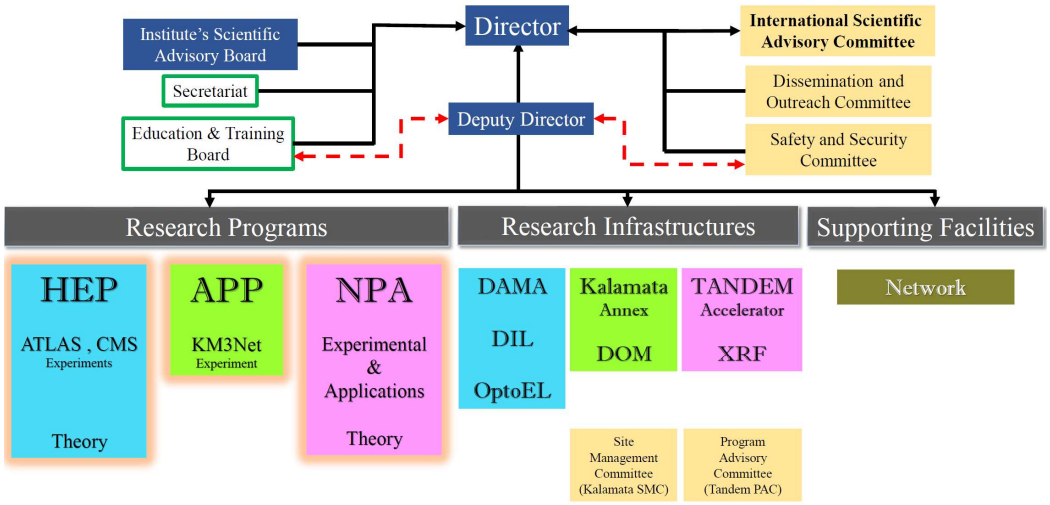
Organizational Chart



May 2018

Director :	Dr. C. Markou
Deputy Director :	Dr. M. Axenides
Administration :	G. Kareli, Secretary M. Simantirakis, Administration
Institute Scientific Advisory Board:	T. Geralis (Chair) D. Daskalakis G. Savvidy G. Stavropoulos
International Scientific Advisory Committee :	Prof. C. Bachas Prof. A. Bracco Prof . D. Charlton Prof. Y. Karyotakis Prof. K. Kokkotas Prof. M. Lewitowicz Prof. F. Linde

Scientists in charge:	**High Energy Physics**	- Dr. T. Geralis: HEP-ATLAS & DAMA - Dr. D. Loukas: HEP-CMS & DIL - Dr. G. Savvidy: HEP-Theory
	Nuclear Physics & Applications	- Dr. D. Bonatsos: Nuclear Structure Theory - Dr. S. Harissopulos: NPA-Experimental Nuclear Physics & Applications – Tandem - Dr. A. Karydas: XRF Laboratory & Applications
	Astroparticle Physics	- Dr. C. Markou: APP-KM3NeT

Personnel

The lists below reflect the INPP personnel as of the 31st of December 2019.

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The evolution of Personnel versus year for the period 2013 – 2019 appears in the following figures.

Mobility

During 2019, Dr. S. Harissopoulos was on leave of absence in the International Atomic Energy Agency, Vienna.

In June 2019, Dr. P. Dimitriou returned from her leave of absence in the International Atomic Energy Agency, Vienna.

In 2019, Ioannis Kazas was hired as a Special Scientific Officer, Grade C.

Dr. G. Stavropoulos was promoted to Director of Research (Researcher A').

Dr. A. Belias resigned in December 2019.

Dr. G. Savvidy went into retirement as of the 31st of December 2019.

Funding Programs in 2019

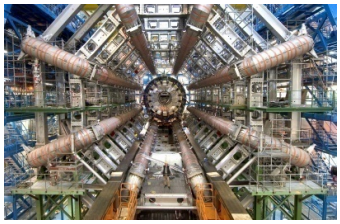
Research in INPP was mainly funded by the following programs with funding sources including National funding initiatives, the Horizon 2020 E.U. program as well as a limited number of contracts with the private sector.

Prog. ID	Title	Principal Investigator	Starting date	Finishing date	Budget
10231	Non destructive analyses with x-rays	Andreas Karydas	1/4/1998	31/5/2022	50,000.00 €
10461	Support for INPP	INPP Director	28/7/1998	27/1/2022	45,000.00 €
10881	Detection devices systems	Dimitrios Loukas	1/12/2002	31/12/2021	35.000,00 €
11041	Technologies for education and development	Theodoros Geralis	11/12/2002	21/12/2021	50.000,00 €
11458	Particle Phenomenology	Kostas Papadopoulos	1/3/2007	28/2/2022	90,000.00 €
11551	Fusion – Radiation studies	Anastasios Lagoyannis	1/12/2008	31/12/2020	50,000.00 €
11776	KM3NeT support activities	Christos Markou	1/1/2013	31/12/2021	59,000.00 €
11821	Irradiation studies	Anastasios Lagoyannis	1/7/2013	5/7/2019	6.000,00 €
11893	LIBRA	Sotirios Harissopulos	1/9/2014	31/8/2020	200,000. 00 €
11985	ENSAR 2 — H2020	Sotirios Harissopulos	1/3/2016	29/2/2020	60,000.00 €
12147	KM3NET 2.0 - Astroparticle and Oscillations Research with Cosmics in the Abyss (ARCA and ORCA)	Christos Markou	1/1/2017	31/10/2020	487,500.00 €

12157	Analytic applications using synchrotron techniques	Andreas Karydas	10/3/2017	9/3/2021	15,000.00 €
12164	Highly Miniaturized ASIC Radiation Detector	Dimitrios Loukas	7/3/2017	25/5/2020	40,987.00 €
12209	ESSnuSB (H2020)	George Fanourakis	1/1/2018	31/12/2021	64,953.00 €
12217	ORASY	INPP Director	1/4/2018	31/12/2020	282,000.00 €
12239	CALIBRA	Sotirios Harissopulos	1/1/2017	31/12/2021	3,422,000.00 €
12246	RENA II	George Fanourakis	1/6/2018	31/2/2020	55,870.00 €
12300	Holographic Applications of Quantum Entanglement (HAPPEN)	Georgios Pastras	2/11/2018	1/11/2020	182.598,94 €
12301	Development and Implementation of the MIXMAX Technology	George Savvidy	1/2/2019	31/12/2019	31.000,00 €
12312	Detector Development and Technologies for High Energy Physics (DeTANet)	Theodoros Geralis	11/2/2019	10/2/2022	125.962,67 €
12335	GEANT4-based particle simulation facility for future science mission support	Anastasios Lagoyannis	1/4/2019	30/4/2022	120.935,00
12356	Access to Ion and Neutron Beams at NCSR "Demokritos"	Anastasios Lagoyannis	13/6/2019	12/6/2024	3.000,00 €

High Energy Physics

High Energy Experimental Physics - ATLAS



Personnel:	Theodoros GERALIS (Team representative)
	Georgios FANOURAKIS (Retired)
	Georgios STAVROPOULOS
PhD Students:	Maria Myrto PRAPA
	Olga ZORMPA (since 7/2019)
Master Students:	Kostantinos DAMANAKIS
	Olga ZORMPA (up to 7/2019)
Diploma Students:	Vassilis BLANAS
Technicians:	Ioannis KISKIRAS
Practical Work Students:	Artemis GIANNIOTI

1. Introduction

The INPP_ATLAS group is a relatively new group admitted as a full member of the ATLAS Collaboration in October 2017. The group activities are within the ATLAS New Small Wheel (NSW) Muon Upgrade for Phase I. The INPP_ATLAS group in 2017 has undertaken the following responsibilities: 1) Taking over part of the NSW L1DDC and ADDC electronic cards testing, including setup and development of the needed test benches; 2) NSW integration at CERN; 3) Long term maintenance for detectors and electronics after the NSW installation; 4) Provision and maintenance of monitoring/data quality software for the NSW.

In June 2018 the NSW management, in agreement with the INPP_ATLAS group, gave full responsibility for the design, study, production, commissioning and integration of the Repeater boards, which are essential components for the sTGC Trigger data path in NSW.

Currently the Repeaters Project is the major INPP_ATLAS project within NSW. In 2018 the INPP_ATLAS group concentrated in two main activities: 1) Test setups for the L1DDC and ADDC boards and the Database recording, 2) The Repeater boards design and production. As reported in the 2018 INPP Annual Report the first task was accomplished to the level of setting up the Test Bench systems but the production of the cards and their subsequent testing took place in 2019. The Repeater boards reached the design level of the final version and the preparation for the preproduction was advance enough.

In 2019 the major activities of the INPP_ATLAS group were:

1) Completion of the L1DDC and the ADDC boards testing with the Test Benches installed at INPP/ELEA;
2) Preproduction of the Serial and LVDS repeaters, final production, commissioning and integration;
3) Participation in the commissioning of the sTGC detector for NSW;
4) Multithreading reconstruction software; porting of the existing Muon spectrometer code and development of the reconstruction software for the NSW.

2. Test setups for the L1DDC and the ADDC boards

The Trigger and Data Acquisition of the NSW is depicted in Figure 1. The main components of the system are: 1) The Front End cards (left green frame), MMFE8 for Micromegas and pFEB and sFEB for the sTGCs, 2) The data concentrator cards L1DDC, 3) The trigger cards ADDC for the Micromegas and Pad Trigger, Router and Rim-L1DDC for the sTGC. On the right side, the off detector part of the Data Acquisition is visible, which is build around the Felix system.

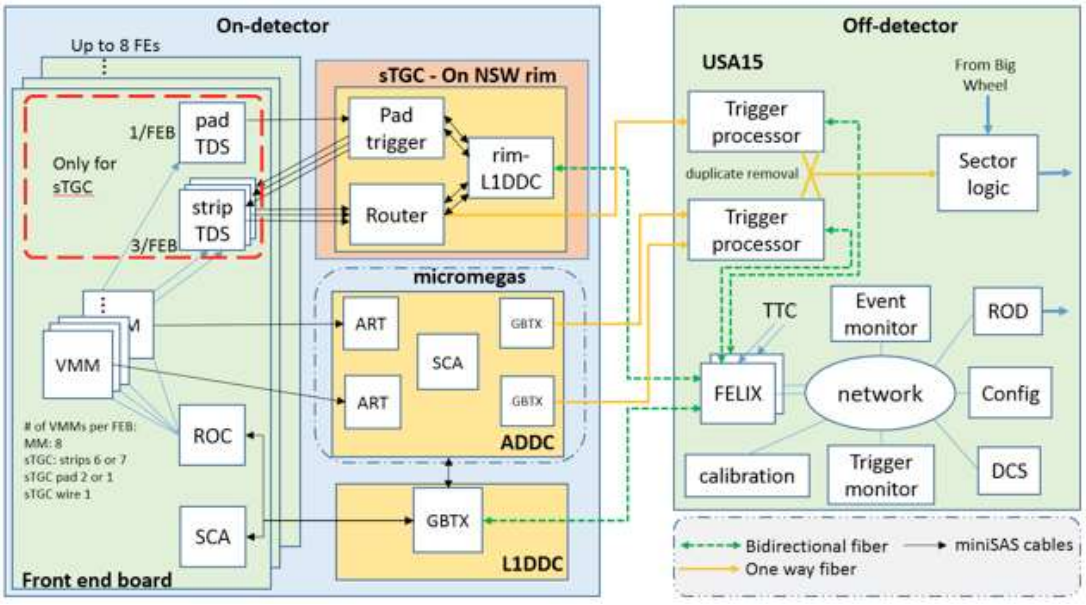


Figure 1. Schematic of the Readout and Data Acquisition system of the NSW.

The ADDC test setup

The INPP_ATLAS group has undertaken the responsibility to test all six hundred Micromegas ADDC trigger boards.

The setup consists of: 1) One Xilinx platform VC707, Virtex 7, 2) One custom mezzanine card plugging to the two FMC connectors on VC707,3) Clock generator CDCE62005, 4) 9 Twinax cables to connect the ADDC card to the mezzanine, 5) Optical fibers to close the loop with the mezzanine and the VC707, 6) Power supply for the ADDC, 7) Fans for cooling the ADDCs, 8) A control PC for connecting to the VC707 via TCP/IP and running Vivado for downloading the firmware, 9) Antistatic protection: antistatic pad, antistatic wristlets and proper grounding.

In Figure 2 you can see a picture of the test setup at the DAMA Laboratory in INPP/NCSR Demokritos and the GUI that controls the ADDC testing.

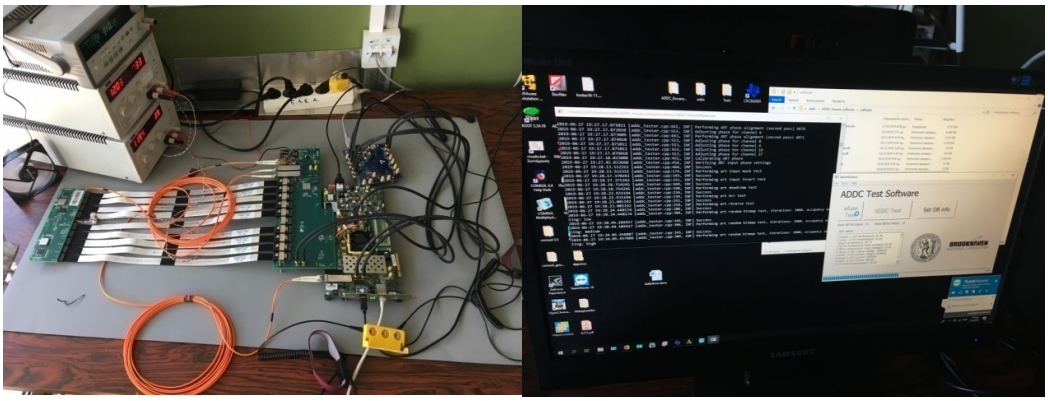


Figure 2. ADDC boards test setup (left) and the GUI on the controlling PC (right)

In September 2018 the whole setup was ready but the production of the ADDC boards was delayed up to 2019. All 600 ADDC boards have been tested in Demokritos and they were delivered at CERN. The tests started in June 2019 and were completed in September 2019. The test setup equipment is similar to the Test Bench for the Repeaters and is currently used in that activity.

The L1DDC test setup

The setup consists of: 1) One Xilinx platform VC709, Virtex 7, 2) One custom made mezzanine card plugging to the FMC connector on VC709, 3) Twinax cables to connect the L1DDC card to the mezzanine, 4) Clock generator CDCE62005, 5) Optical fibers to close the loop with the mezzanine and the VC709, 6) Power supply for the L1DDC, 7) Fans for cooling the L1DDCs, 8) A control PC for connecting to the VC709 via TCP/IP and running Vivado for downloading the firmware, 9) Antistatic protection: antistatic pad, antistatic wristlets and proper grounding.

In Figure 3 you can see a picture of the test setup at the DAMA Laboratory in INPP/NCSR Demokritos and the GUI that controls the L1DDC testing. L1DDCs exist in two versions for the sTGCs and for the Micromegas.

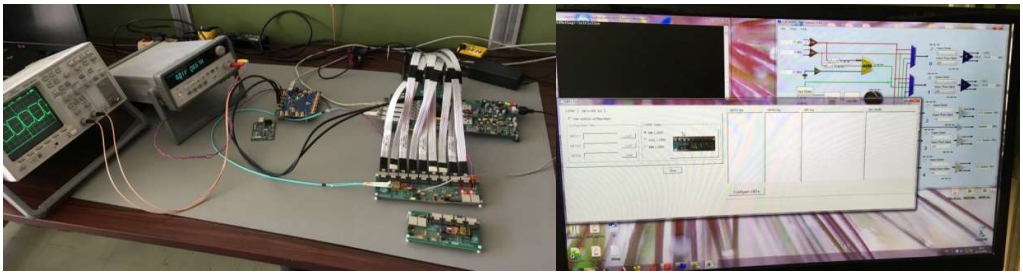


Figure 3. L1DDC boards test setup (left) and the GUI on the controlling PC (right)

In September 2018 the whole setup was ready but the production of the L1DDC boards was delayed up to 2019. The total of L1DDC boards were distributed in 4 testing centers and our group tests about 200 L1DDC boards. The VC709 is appropriate to emulate the BNL712 board of the ATLAS Felix DAQ and will be used in that activity from now on.

The database handling

G. Fanourakis has worked on the handling of the database for the registration of the electronics components. Every group of boards is registered when delivered from the company and consequently their status is updated after the test result is known. In Figure 4, a snapshot of the database page is shown.

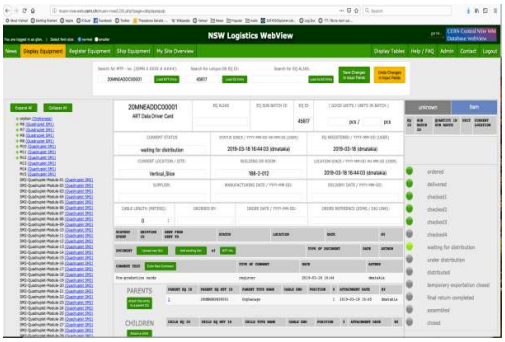


Figure 4. Snapshot of the NSW Logistics web page (database) for the registration of the ADDC and the L1DDC boards after their testing.

All the ADDC and L1DDC cards that were tested in Demokritos were recorded in the Muon database together with all history in their testing (delivery, shipping, testing, repairing, accepted).

3. The Repeater boards design, production and commissioning

In the initial design of the Readout System, the Front End (FE) cards were close to the Trigger and the Data Concentrator cards, which finally had to move to the outside part of wheels on the spokes. The distance between them became large enough (6.25 m) and provoked a high attenuation which necessitated the use of Serial and LVDS repeaters boards. NCSR Demokritos had the full responsibility for the justification for their use and consequently the design, fabrication, commissioning and integration of the two types of repeaters. Serial Repeaters are used for the fast signals of 4.8 Gbps and LVDS Repeaters for the slower signals of 640 Mbps. The schematic of the NSW electronics and data flow is shown in Figure 5 with the sTGC related part in the upper left corner. The Rim-crates are located at the outer part of the Wheels near the spokes (Figure 5, right).

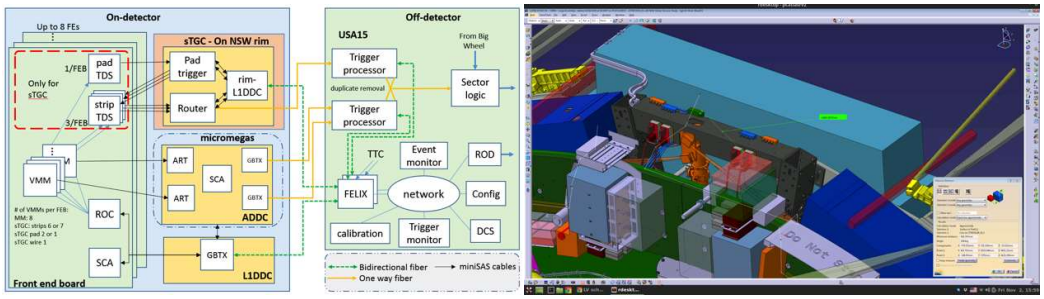


Figure 5. NSW Electronics and Data Flow (left). The Rim-crate location in the outer part of the wheel (right).

The connections between the pFEB, the sFEB and the Pad Trigger and Router are done using the 3MMiniSAS cables. The MiniSAS twinax ribbon cable attenuation at 10 GHz is 4.9 dB/m for the Silver coated cable (Ag on 30 AWG Cu). Silver Plated twinax cables were finally preferred because they present better attenuation at higher frequencies and have lower prices. We have worked on the selection of the cable characteristics that would be appropriate for the NSW and come from the requirements for the operations of the NSW Readout System Details of this systematic study will be given in the next annual report.

Serial Repeater boards (SRL1R) – pFEB to Pad Trigger and sFEB to Router

We have worked in collaboration with the Weizmann Institute of Science for the design of the SRL1R boards. A 3D drawing of the Serial Repeater and a prototype board is shown in Figure 6: two MiniSAS connectors with the cables plugged, two Nano-Fit power supply connectors and the jumper connector in the middle. Nano-Fit connectors were installed on either side to allow routing the 2.5 V power cable from the L1DDC boards without bending, irrespectively of their relative position. Two connectors per repeater minimize bending the power cables from the L1DDC and enables connecting a second repeater in parallel. The repeater chips are placed on the backside of the PCB to allow contact with the copper pad of the shielding for passive cooling. This is sufficient since the power consumption of the board is only 213mW.

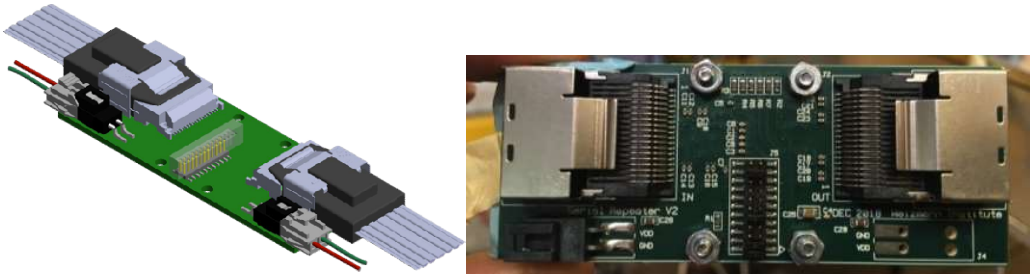


Figure 6. 3-D schematic of the SRL1R repeater card (left) and a prototype (right)

We have taken care of the design of the shielding as well as the proper grounding: SRL1R is enclosed in a shielding cage, which provides continuity of the input and output cable shields. Cable shield, cable drain and side-bands are connected together and to the enclosing shielding box. Shield of power cable is connected to the cage of L1DDC and it is unconnected at the repeater side. We have adopted the option of the shielding cage: Copper box of two parts as shown in Figure 7 (schematic and 3D simplified drawing). Thermal pad is placed between the repeater chip and the copper box lower surface. The rest of the surface will be isolated with dielectric or thermal pad.

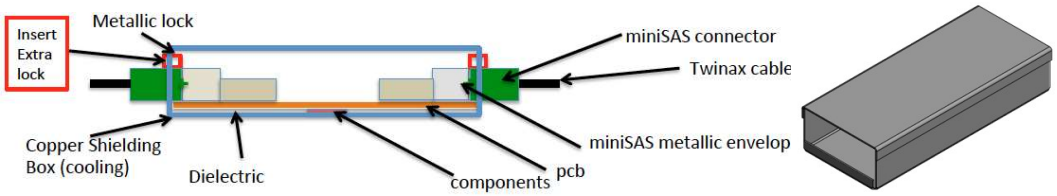


Figure 7. Schematic of the shielding box. Drawing of the metallic box.

A preproduction of 30 SRL1R repeaters was launched in January 2019 and subsequently exhaustive tests were performed on their functionality. The test setup we used was provided by the Michigan University group and consisted in the data integrity transmission (BER < $5x10^{-14}$) and the study of the eye diagram. In Figure 8we show the eye diagram in the connection between the sFEB and the Router without (left) and with (right) repeater. A second repeater is used at the end of the line in order to mimic the presence of repeater in the router module.

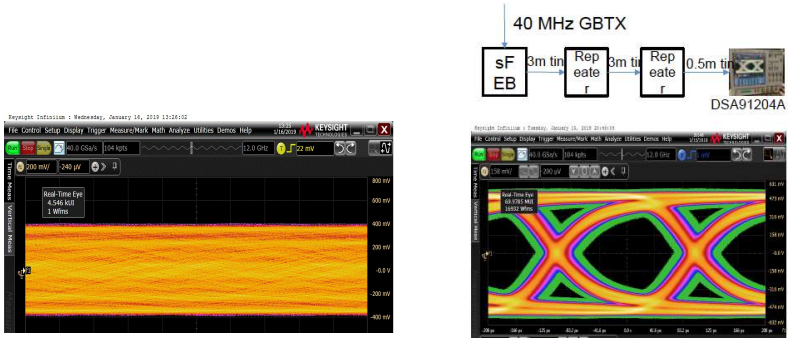


Figure 8. Eye diagram for the sFEB to Router connection without (left) and with (right) Repeater

Different cable combinations were tested and given the availability of the cables (only tin coated and specific lengths) we could not conclude safely that repeaters are not needed. The decision was on the safe side, in order to guarantee signal transmission and also to order in time the 3M twinax cables that needed specific custom made order requiring lead time of about 4 months.

Thermal tests and calculations

Even though the consumption of one SRL1R repeater is only 213 mW, the tidiness of the cables, gas pipes, water cooling pipes requires some precaution for the passive cooling of the SRL1Rs. We have performed calculation of the thermal dissipation given the SRL1R power consumption and its geometry. Also we have measured with thermal probes the SRL1R temperature during operation. Figure 9 shows the simulation using COMSOL of the temperature profile near the Serial Repeater chip when the copper shielding is used. The value agrees very well with the measured temperature of 28°C using thermal probe.

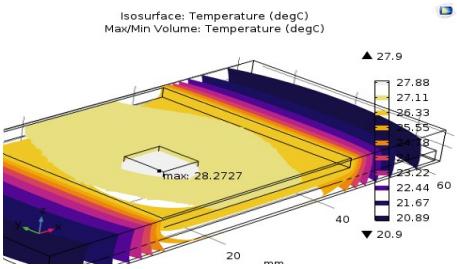


Figure 9 Simulation of the temperature profile on the SRL1R repeater.

We have monitored the temperature over long periods. The temperatures registered are given in the table below:

Testing condition	Temperature
SRL1R in open air (VS), temperature on chip	34°C
SRL1R with copper pad, open air (probe on copper pad)	30°C
SRL1R with shielding, in the cable bundle, wrapped with plastic bag (probe on copper pad)	22 – 28°C

LVDS Repeaters boards (LVD1R) – Pad Trigger to sFEB

As for the serial repeaters we have collaborated with the Weizmann Institute of Science to design the LVDS Repeaters prototypes. The initial planning was to use a single LVD1R for

the slow (640 Mbps) connection from Pad Trigger to the sFEBs. Nonetheless, the higher power consumption of the LVD1R (1 Watt/board) forced us to use cooling. It was thus decided to place it on the spokes behind the Large Sectors and to group six LVD1R on one card, the LVD6R.

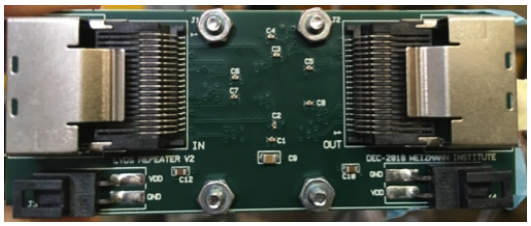


Figure 10. Photo of the LVD1R_V0 repeater card

Operational tests were performed in collaboration with the Michigan University. The tests showed the necessity of the LVDS repeaters in the same spirit as it was explained previously.

We have tested the LVD1R on wedge (see above tests for the SRL1Rs) for their functionality. All LVD1R cards were tested and found to function properly in short and long (overnight tests with BER ~ 10^{-14}). As their consumption is much higher (~1 Watt/board) it would endanger their functionality. The temperature of the LVD1R in the open air with the copper pad went up to 40°C. The LVD1R will not be used in the final system but instead 6-tuple boards with 6 LVD1Rs, the LVD6R, will be used instead with proper cooling. This is the subject of the following paragraphs on the LVD6R boards.

3.1 Location and Cables

An important task was the location of the Repeaters, in order to be efficient, to receive their power supply and cooling as well as the type of cables and lengths. The selected cables were the 3M Twinax with silver coating which have optimum properties. The cable lengths were dictated by the end points and a quantization of their length in order to fulfill the Trigger timing requirements. We have coordinated this task and proposed the final cable lengths and layout.

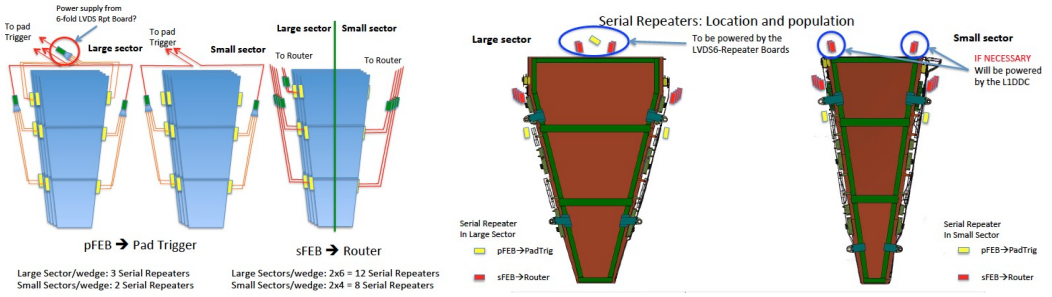


Figure 11. Location of the SRL1Rs for the pFEB and the sFEB links

The total number of SRL1R is 768 with most of them being located near the edges of the wedge and the total number of LVD6R is 128 which will be placed behind the spokes of the large sectors.

3.2 The LVD6R boards – Pad Trigger to sFEB connection in final layout

The LVD6R boards will be used for the Pad Trigger to sFEB connection at 640 Mbps. LVD6R boards will be placed only on the spokes behind the Large Sectors, thus on every spoke we will have four boards serving the Large Sector and four of the nearby Small sectors. This is shown in the schematic of Figure 12.

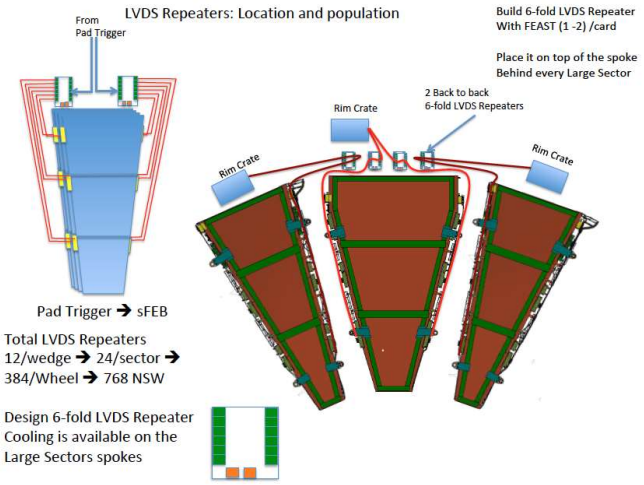


Figure 12 Schematic diagram of the placement of the LVD6R on the spokes behind the Large Sectors

4.1 The LVD6R_V0 board

The design of the LVD6R is a copy-paste of the LVD1R design with the difference that the power supply of the 2.5 V comes from one FEASTMP_CLP module (Figure 13). The FEAST module is placed in the middle of the board in order: 1) To have them aligned in the back-to-back placement of the LVD6R doublets (see Figure 14) and avoid possible interference with the repeater channels of the opposite board and 2) To have all the input twinax cables on one side and all the output cables on the opposite side. Both LVD6R will be fixed on the cooling bar, so the repeater chips and the FEAST will be in thermal contact with the cooling bar through thermal pads. The shielding box will be supported, through the four holes in the corners of the PCBs.

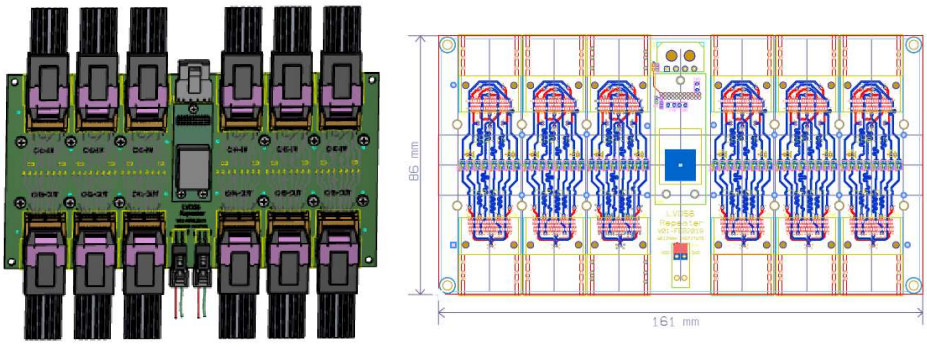


Figure 13 The LVD6R board 3D-schematic (left) and electronic design (right)

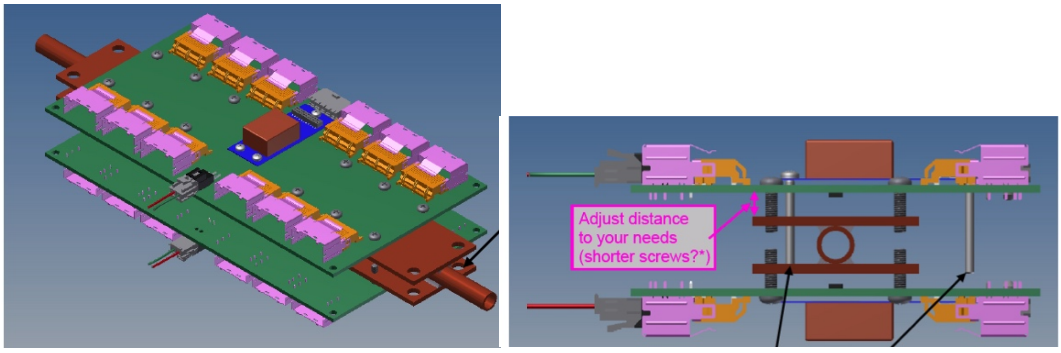


Figure 14 Schematic of the doublet LVD6R connected to the cooling copper bar. The tube in the middle for the cooling water circulation is visible.

For the preproduction, we have assembled 5 LVD6R boards which are enough to equip one sector. Two essential tests were performed with the LVD6R, one concerning their proper functionality (particularly with the use of the FEASTMP_CLP module) and second, the cooling test. Those tests are described in the following sections.

LVD6R functionality tests

Three LVD6R were assembled and have been tested successfully. For every LVD6R card, every one of the six LVDS channels was tested in the Vertical Slice Lab with the same setup as described in Sections 3.1 and 3.2. Every channel was tested in a short test with BER $< 10^{-11}$ and selected channels at random were tested for long periods with BER $< 10^{-13}$. The data transmission was not possible to test under simultaneous operation because of lack of front end cards.

LVD6R Mechanical support and Cooling

The LVD6R boards will be mechanically supported on the spokes behind the large sectors. Figure 15 shows the cooling bar, LVD6Rs fixed on the cooling bar, two schematic views of the whole system consisting of: the cooling bar, the four LVD6R boards and the shielding box and a schematic of the whole system supported on the spoke. The cooling pipes are also shown.

We have tested the LVD6R concerning the heat dissipation and the temperature profiles under intense operation. We have been transmitting data through all six LVDS channels without checking for the data integrity. We have used a monitoring system with seven temperature probes: one for each of the six LVDS channels and one for the FEASTMP. We have placed the probes on top of the repeater chips, covered by a 1mm thick thermal gap pad. The "sandwich" was then clamped to the cooling bar with screws (see Figure 16).

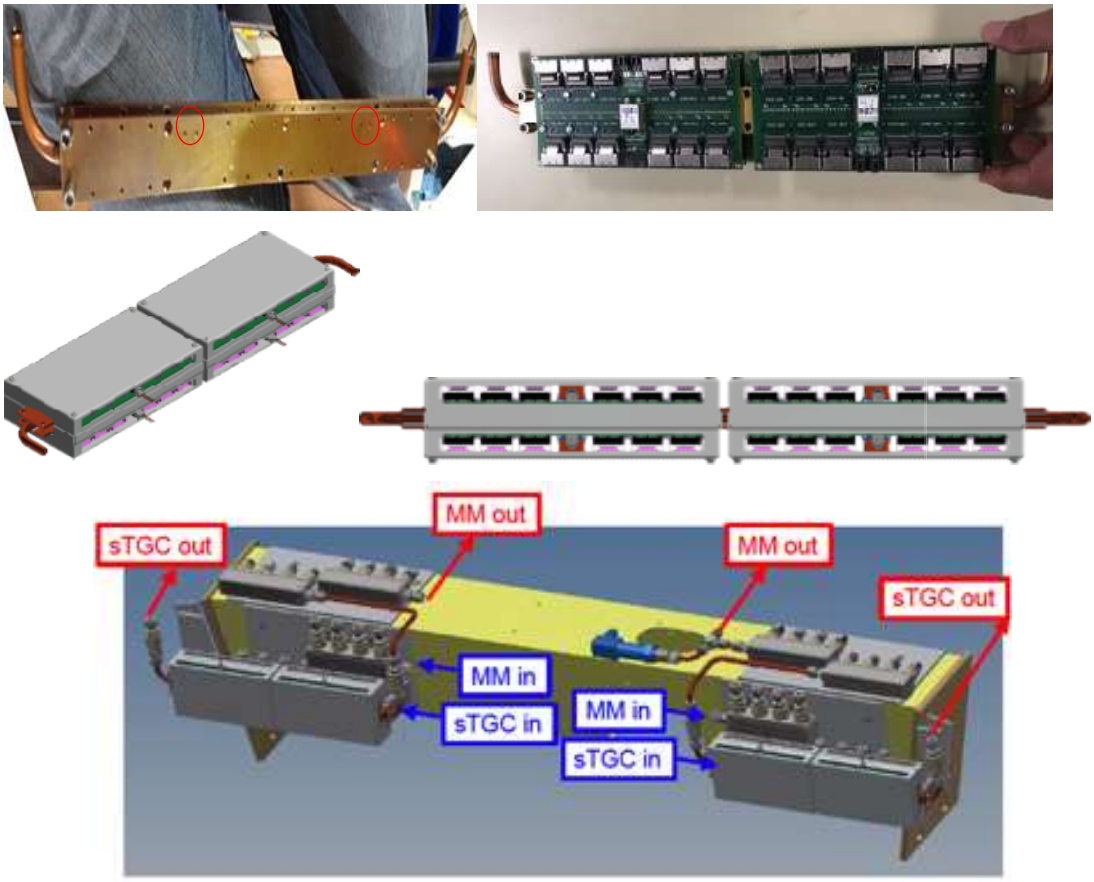


Figure 15 Top left: Cooling bar. Top right: Cooling bar with the LVD6R fixed on it. Bottom left and middle: Schematic of the whole system (Cooling bar, four LVD6R and the Shielding boxes). Bottom right: Full system mechanical fixed on the spoke.

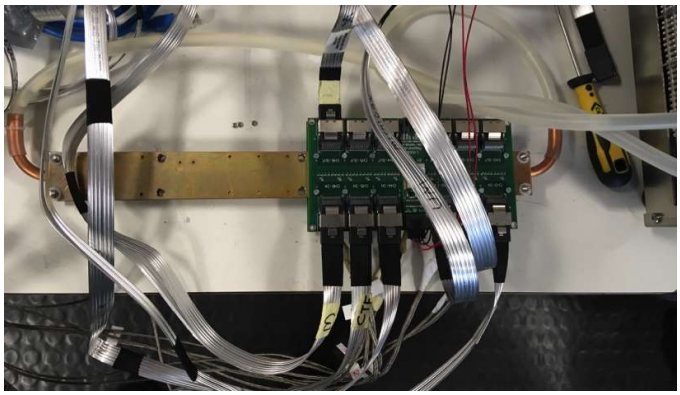


Figure 16 Photo of the setup for the LVD6R temperature monitoring. Two LVD6R are fixed on the cooling bar that is connected with pipes to the chiller. Six twinax cables (input) are connected and seven thermal probes.

When operating the LVD6R in the open air, the temperature reaches 45°C. Connecting the LVD6R to the cooling bar, the temperature of the LVDS drops to about 37 - 38°C and that of the FEAST to about 40°C. Connecting the bar to the chiller without water circulation we note yet another drop to 32°C on the LVDS and 36°C on the FEASTMP. Operating the

chiller with water temperature at 23°C (as it will be in normal NSW operation), the temperature of the LVDS drops to about 26°C and that of the FEAST (opposite side of the PCB) to around 28°C. Figure 17 shows the evolution in time of the temperature with the chiller connected, without and with water flow.

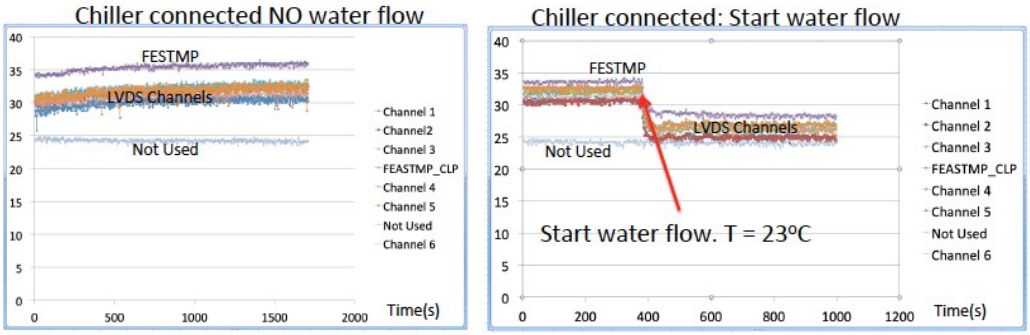


Figure 17 FEAST and LVDS buffers temperature under operation without water flow (left) and with water flow (right). The step on the temperature drop is visible when water starts flowing.

We have simulated the temperature of the LVD6R with Comsol and the data fit very well with the simulation. Figure 18 shows the temperature distribution around the LVDS buffer chips.

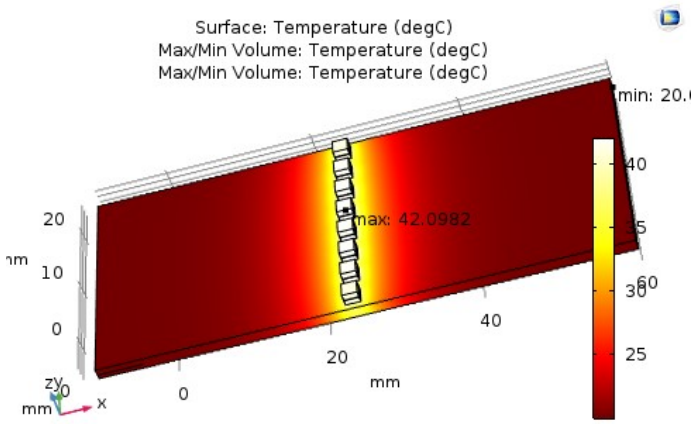


Figure 18 Comsol evaluation of the LVDS repeater chips under operation. Maximum temperature is estimated to be 42°C, while the measured one is 45°C.

Concluding, the LVD6R are fully validated concerning their functionality and the data integrity during data transfer. The cooling of the board and the FEAST are very effective and much below their operation limits.

Final production

The final production of the SRL1R cards has been launched in September 2019 and 850 boards were delivered by the end of October 2019. All copper shielding boxes (850) have been ordered and are expected to be delivered by the 15th of November 2019. The

production of 70 LVD6R (half of the total) is completed beginning of November 2019 and the shielding boxes are expected to be delivered by the 15th of November 2019. The production of all the boards and the shielding boxes were performed with Greek companies. The boards (SRL1R and LVD6R) are being tested using a dedicated Test Bench system that was developed by the INPP_ATLAS group. This is described in the next session.

Test Bench for the repeaters QA/QC

The INPP_ATLAS group has developed a test bench for the QA/QC of the 850 SRL1R boards and the 140 LVD6R. The system in based on the Xilinx VC707 platform. A mezzanine card was especially designed to provide connectivity to the repeaters. It plugs on the FMC connectors of the VC707 and allows testing of two SRL1R cards simultaneously or one LVD6R. Figure 19shows a repeater Test Bench. Two systems are currently used, one in the ELEA Lab at Demokritos and a second one at the Vertical Slice Lab at CERN.

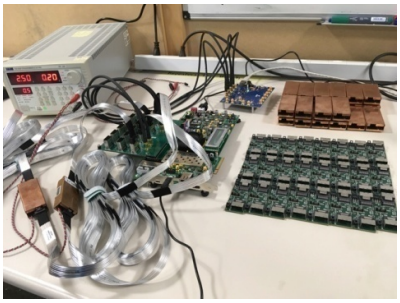


Figure 19 The repeaters Test Bench system. The VC707, the mezzanine card, the Clock generator, the power supply and the connectivity to two SRL1Rs are shown. On the right 16 SRL1Rs are shown together with about 20 copper shielding boxes.

5. Software development

In summer 2019 the ATLAS management decided to financially support the INPP ATLAS group towards creating in "Demokritos" a group for the development of the ATLAS software. The commitments undertaken by the INPP ATLAS group are in the fields of reconstruction and alignment in the muon system of ATLAS. The group has already succeeded on developing and including in the official ATLAS software a, multi-thread safe, algorithm of the alignment procedure in the muon system.

6. Conclusions

Concluding, the INPP_ATLAS group has fulfilled the following tasks during 2019:

1) Completion of the QA/QC of 200 L1DDC and 600 ADDCs boards
2) Significant advancement of the Repeaters Project which included: 1) Design and pre-production of the repeaters, 2) Functionality tests and cooling studies, 3) Production Readiness Review and procurement of all components and the PCBs for the full production, 4) Full production of the SRL1Rs and production of half of the

LVD6R, 5) Full production of the Shielding boxes, 6) Design and realization of the repeaters Test Bench.

3) Significant work on the migration of the ATLAS Muon Spectrometer and the NSW software to multithreading programming.

Responsibilities

T. Geralis: Member of the Muon subdetector Institutes Board

T. Geralis: Member of the NSW Electronics Coordination Group.

Presentations in the ATLAS internal meetings in 2019

42 Talks were given by members of the INPP_ATLAS in the internal ATLAS meetings in the frame of the Muon Spectrometer, the NSW Electronics meeting and the NSW Electronics Coordination meeting.

Funding of the ATLAS Demokritos activities

There are three main sources of funding for the ATLAS/Demokritos group, of which the INPP has contributed at a minimal level:

1) The ATLAS Collaboration supported our group at a maximal level and without it very little would have been achieved. We received financial support for : 1) Muon reconstruction software (6 months of subsistence payment to G. Stavropoulos), 2) NSW upgrade - Repeaters and sTGC Trigger – 4 months of subsistence payment to T. Geralis, 3) Support to students – 3 months of subsistence payment to O. Zormpa, 4) Support to Technician – 4.5 months of subsistence payment to I. Kiskiras and 5) Support for all the development of the repeaters (project of ~ 100 kEuros).
2) The Detanet ESPA program supports the ATLAS activities for the years 2019 – 2021 with the total of ~50 kEuros. Mainly purchased infrastructure for the ADDC and the L1DDC testing, as well as some funding for personnel and for mobility.
3) The INPP program ORASY, supported the ATLAS/Demokritos group with 15 kEuros for mobility, some consumables and personnel.

Publications

The INPP_ATLAS group entered the ATLAS authorship in October 2018. The first publications appeared in the journals in 2019 and they are presented in the following list together with the citation summary, as produced from INSPIRES for the year 2019.

1. G. Aad et al. [ATLAS], "Measurement of soft-drop jet observables in pp collisions with the ATLAS detector at √s =13 TeV," Phys. Rev. D 101, no.5, 052007 (2020) doi:10.1103/PhysRevD.101.052007 [arXiv:1912.09837 [hep-ex]].

2. G. Aad et al. [ATLAS], "Measurement of isolated-photon plus two-jet production in pp collisions at √s = 13 TeV with the ATLAS detector," JHEP 03, 179 (2020) doi:10.1007/JHEP03(2020)179 [arXiv:1912.09866 [hep-ex]].

3. G. Aad et al. [ATLAS], “Search for chargino-neutralino production with mass splittings near theelectroweak scale in three-lepton final states in √s=13 TeV pp collisions with the ATLAS detector,” Phys.Rev. D 101, no.7, 072001 (2020) doi:10.1103/PhysRevD.101.072001 [arXiv:1912.08479 [hep-ex]].

4. G. Aad et al. [ATLAS], “Measurement of the transverse momentum distribution of Drell–Yan lepton pairs in proton–proton collisions at √s = 13 TeV with the ATLAS detector,” Eur. Phys. J. C 80, no.7, 616 (2020) doi:10.1140/epjc/s10052-020-8001-z [arXiv:1912.02844 [hep-ex]].

5. G. Aad et al. [ATLAS], “Search for long-lived neutral particles produced in pp collisions at

√s = 13 TeV decaying into displaced hadronic jets in the ATLAS inner detector and muon spectrometer,” Phys. Rev. D101, no.5, 052013 (2020) doi:10.1103/PhysRevD.101.052013 [arXiv:1911.12575 [hep-ex]].

6. G. Aad et al. [ATLAS], “Searches for electroweak production of supersymmetric particles with compressed mass spectra in √s = 13 TeV pp collisions with the ATLAS detector,” Phys. Rev. D 101, no.5, 052005(2020) doi:10.1103/PhysRevD.101.052005 [arXiv:1911.12606 [hep-ex]].

7. G. Aad et al. [ATLAS], “Search for direct stau production in events with two hadronic τ -leptons in √s = 13 TeV pp collisions with the ATLAS detector,” Phys. Rev. D 101, no.3, 032009 (2020) doi:10.1103/PhysRevD.101.032009 [arXiv:1911.06660 [hep-ex]].

8. G. Aad et al. [ATLAS], “Measurement of the Z(→ ℓ+ℓ−)γ production cross-section in pp collisions at √s = 13 TeV with the ATLAS detector,” JHEP 03, 054 (2020) doi:10.1007/JHEP03(2020)054 [arXiv:1911.04813 [hep-ex]].

9. G. Aad et al. [ATLAS], “Measurement of the azimuthal anisotropy of charged-particle production in Xe + Xe collisions at $\sqrt{s_{NN}}$ = 5.44 TeV with the ATLAS detector,” Phys. Rev. C 101, no.2, 024906 (2020) doi:10.1103/PhysRevC.101.024906 [arXiv:1911.04812 [nucl-ex]].

10. G. Aad et al. [ATLAS], “ATLAS data quality operations and performance for 2015–2018 data-taking,” JINST 15, no.04, P04003 (2020) doi:10.1088/1748-0221/15/04/P04003 [arXiv:1911.04632 [physics.ins-det]].

11. G. Aad et al. [ATLAS], “Measurement of differential cross sections for single diffractive dissociation in √s = 8 TeV pp collisions using the ATLAS ALFA spectrometer,” JHEP 02, 042 (2020) doi:10.1007/JHEP02(2020)042 [arXiv:1911.00453 [hep-ex]].

12. G. Aad et al. [ATLAS], “Transverse momentum and process dependent azimuthal anisotropies in $\sqrt{s_{NN}}$ = 8.16 TeV p+Pb collisions with the ATLAS detector,” Eur. Phys. J. C 80, no.1, 73 (2020) doi:10.1140/epjc/s10052-020-7624-4 [arXiv:1910.13978 [nucl-ex]].

13. G. Aad et al. [ATLAS], “Z boson production in Pb+Pb collisions at √sNN= 5.02 TeV

measured by the ATLAS experiment," Phys. Lett. B 802, 135262 (2020) doi:10.1016/j.physletb.2020.135262 [arXiv:1910.13396 [nucl-ex]].

14. G. Aad et al. [ATLAS], "Evidence for electroweak production of two jets in association with a Zγ pair in pp collisions at √s = 13 TeV with the ATLAS detector," Phys. Lett. B 803, 135341 (2020) doi:10.1016/j.physletb.2020.135341 [arXiv:1910.09503 [hep-ex]].

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16. G. Aad et al. [ATLAS], "Search for new resonances in mass distributions of jet pairs using 139 fb^{-1} of pp collisions at √s = 13 TeV with the ATLAS detector," JHEP 03, 145 (2020) doi:10.1007/JHEP03(2020)145 [arXiv:1910.08447 [hep-ex]].

17. G. Aad et al. [ATLAS], "Search for direct production of electroweakinos in final states with one lepton, missing transverse momentum and a Higgs boson decaying into two b-jets in pp collisions at √s = 13 TeV with the ATLAS detector," Eur. Phys. J. C 80, no.8, 691 (2020) doi:10.1140/epjc/s10052-020-8050-3 [arXiv:1909.09226 [hep-ex]].

18. G. Aad et al. [ATLAS], "Search for the Higgs boson decays H → ee and H → eμ in pp collisions at √s = 13 TeV with the ATLAS detector," Phys. Lett. B 801, 135148 (2020)

doi:10.1016/j.physletb.2019.135148 [arXiv:1909.10235 [hep-ex]].

19. G. Aad et al. [ATLAS], "Search for squarks and gluinos in final states with same-sign leptons and jets using 139 fb^{-1} of data collected with the ATLAS detector," JHEP 06, 046 (2020) doi:10.1007/JHEP06(2020)046 [arXiv:1909.08457 [hep-ex]].

20. G. Aad et al. [ATLAS], "Combined measurements of Higgs boson production and decay using up to 80 fb^{-1} of proton-proton collision data at √s = 13 TeV collected with the ATLAS experiment," Phys. Rev. D 101, no.1, 012002 (2020) doi:10.1103/PhysRevD.101.012002 [arXiv:1909.02845 [hep-ex]].

21. G. Aad et al. [ATLAS], "Measurement of azimuthal anisotropy of muons from charm and bottom hadrons in pp collisions at √s = 13 TeV with the ATLAS detector," Phys. Rev. Lett. 124, no.8, 082301 (2020) doi:10.1103/PhysRevLett.124.082301 [arXiv:1909.01650 [nucl-ex]].

22. G. Aad et al. [ATLAS], "Search for light long-lived neutral particles produced in pp collisions at √s = 13TeV and decaying into collimated leptons or light hadrons with the ATLAS detector," Eur. Phys. J. C 80, no.5, 450 (2020) doi:10.1140/epjc/s10052-020-7997-4 [arXiv:1909.01246 [hep-ex]].

23. G. Aad et al. [ATLAS], "Performance of electron and photon triggers in ATLAS during LHC Run 2," Eur.Phys. J. C 80, no.1, 47 (2020) doi:10.1140/epjc/s10052-019-7500-2 [arXiv:1909.00761 [hep-ex]].

24. G. Aad et al. [ATLAS], "Search for flavour-changing neutral currents in processes

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26. G. Aad et al. [ATLAS], "Measurements of top-quark pair differential and double-differential cross-sections in the ℓ+jets channel with pp collisions at $\sqrt{s}$ = 13 TeV using the ATLAS detector," Eur. Phys. J. C 79, no.12, 1028 (2019) doi:10.1140/epjc/s10052-019-7525-6 [arXiv:1908.07305 [hep-ex]].

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28. G. Aad et al. [ATLAS], "Measurement of angular and momentum distributions of charged particles within and around jets in Pb+Pb and pp collisions at $\sqrt{s_{NN}}$ = 5.02 TeV with the ATLAS detector," Phys. Rev. C100, no.6, 064901 (2019) doi:10.1103/PhysRevC.100.064901 [arXiv:1908.05264 [nucl-ex]].

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doi:10.1140/epjc/s10052-019-7512-y [arXiv:1907.10862 [hep-ex]].

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[arXiv:1907.10037 [hep-ex]].

35. G. Aad et al. [ATLAS], "Measurement of the inclusive cross-section for the production of jets in association with a Z boson in proton-proton collisions at 8 TeV using the ATLAS detector," Eur. Phys. J.C 79, no.10, 847 (2019) doi:10.1140/epjc/s10052-019-7321-3 [arXiv:1907.06728 [hep-ex]].

36. G. Aad et al. [ATLAS], "Searches for lepton-flavour-violating decays of the Higgs boson in √s = 13 TeV pp collisions with the ATLAS detector," Phys. Lett. B 800, 135069 (2020) doi:10.1016/j.physletb.2019.135069 [arXiv:1907.06131 [hep-ex]].

37. G. Aad et al. [ATLAS], "ATLAS b-jet identification performance and efficiency measurement with t.t events in pp collisions at √s = 13 TeV," Eur. Phys. J. C 79, no.11, 970 (2019) doi:10.1140/epjc/s10052-019-7450-8 [arXiv:1907.05120 [hep-ex]].

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39. G. Aad et al. [ATLAS], "Measurement of W◦æ-boson and Z-boson production cross-sections in pp collisions at √s = 2.76 TeV with the ATLAS detector," Eur. Phys. J. C 79, no.11, 901 (2019) doi:10.1140/epjc/s10052-019-7399-7 [arXiv:1907.03567 [hep-ex]].

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13 TeV pp collisions with the ATLAS detector," JHEP 06, 144 (2019) doi:10.1007/JHEP06(2019)144 [arXiv:1902.08103 [hep-ex]].

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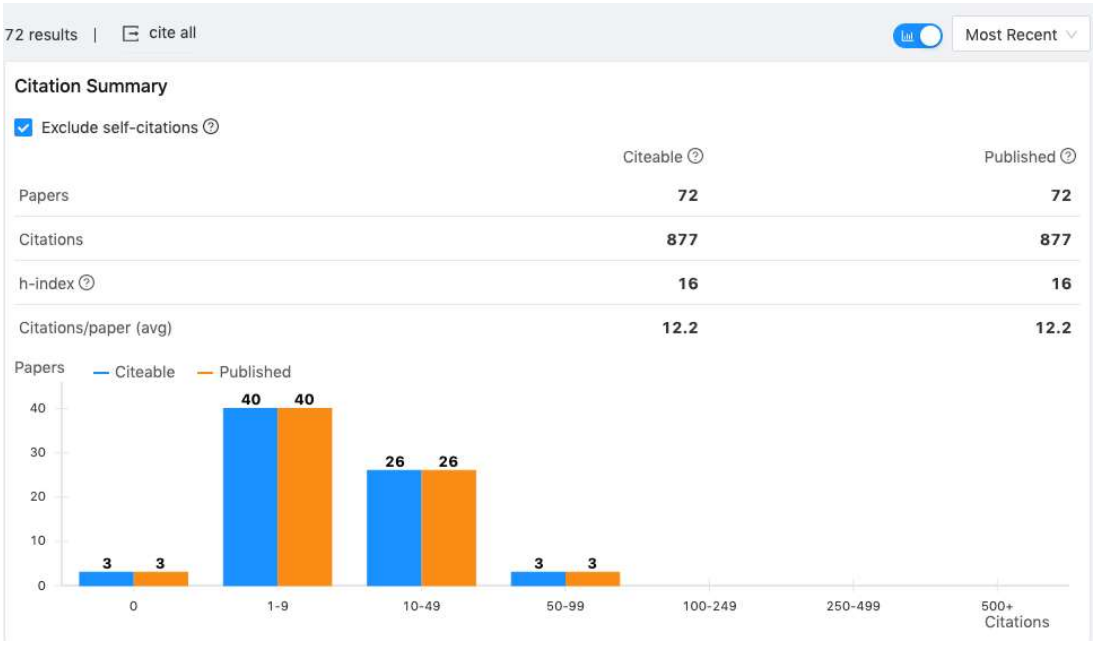
Citation summary excluding self-citations or RPP citations

Citation summary for publication list as created by INSPIRES for the whole of the year 2019. 72 publications found in international refereed journals:



Citation Summary for the Demokritos/ATLAS group

High Energy Experimental Physics – CMS

A) The INPP_CMS group (as of October 1st, 2019)

The INPP CMS group has the following members assigned 100% to the CMS/Tracker project:

Researchers: G. Anagnostou, G. Daskalakis, A. Kyriakis, D. Loukas*

Doctoral students: P. Asenov, P. Assiouras, G. Paspalaki

Non-Doctoral students: G. Billis, A. Papadopoulos

Electronics Engineer: I. Kazas

Administration: M. Barone

* D. Loukas is the group representative

B) The INPP_CMS activities during 2019

During 2018 the INPP_CMS group was active in two different directions:

1. Physics analysis using the pp collision data at = 13 TeV
2. The CMS Upgrade effort devoted to the physics potential and the required sub-detectors CMS upgrades.

Physics Analyses

1- Search for final states with 2 invisible particles in the 2-Dimensional mass space G. Anagnostou, G. Daskalakis

CMS Notes: CMS AN-2019/097, CMS AN-2019/066

Conferences: Dark Matter Identification – Connecting Theory and Signature Space, Mainz, April 2019

Short Description: A simultaneous search for both a new heavy top partner and a new heavy charged gauge boson is performed using collision data recorded by the CMS detector corresponding to 35.9 fb^{-1} of integrated luminosity at = 13 TeV. The final state has two charged leptons, two jets and missing transverse energy due to the invisible neutrinos. The analysis is based on a two-dimensional mass reconstruction of the TT' system.

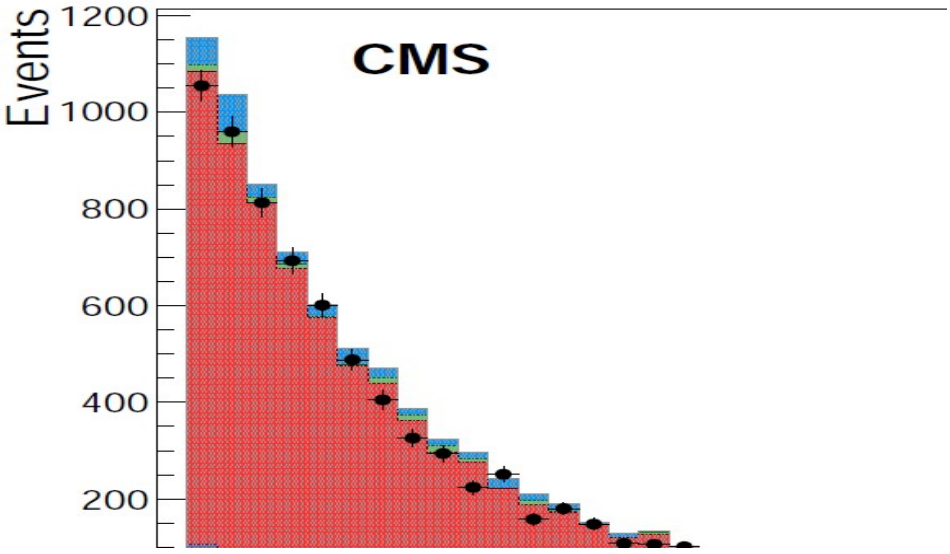


Figure 20: Missing transverse energy after selection, for the first 35 fb^{-1}.

2- Search for Exotic Particles, G. Daskalakis

Publication: CMS Collaboration, CMS PAS EXO-19-019, http://cds.cern.ch/record/2684757/files/EXO-19-019-pas.pdf

CMS Analysis Note: CMS AN-2018/253, CMS AN-2019/101

Short description: A search for physics beyond the standard model is presented using electron or muon pairs with high invariant mass. A data set of proton-proton collisions collected by the CMS experiment at the LHC at sqrt(s)= 13 TeV recorded in years 2016 to 2018 and corresponding to a total integrated luminosity of up to 140 fb^{-1} is analyzed. No significant deviation is observed with respect to the expectation from the standard model backgrounds. Upper limits are set on the ratio of the production cross section times branching ratio of a new narrow di-lepton resonance to that of the Z boson and converted into lower limits on the masses of various hypothetical particles. A Z'_{SSM}(Z'_{ψ}) particle, arising in the sequential standard model (superstring-inspired model)is excluded below a mass of 5.15 (4.56) TeV at 95% confidence level.

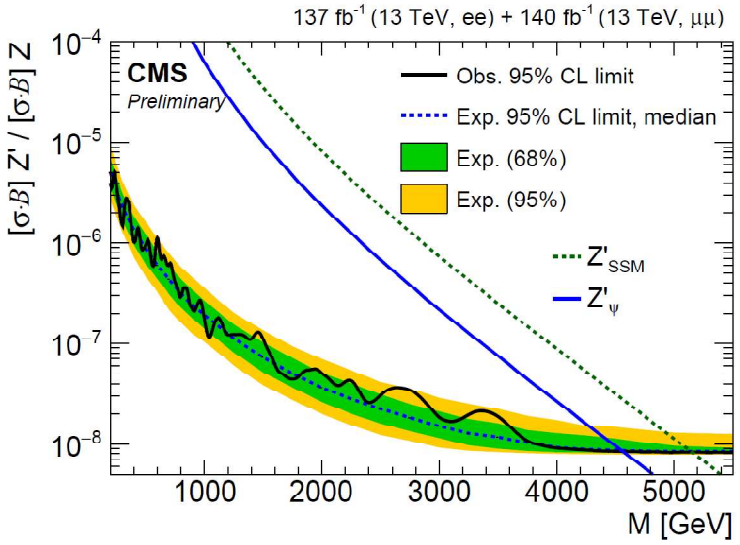


Figure 21: The upper limits at 95% CL on the product of production cross section and branching fraction for a spin-1 resonance with a width equal to 0.6% of the resonance mass, relative to the product of production cross section and branching fraction of a Z boson, for the combination of the di-electron and di-muon channels. The shaded bands correspond to the 68% and 95% quantiles for the expected limits. Theoretical predictions for the spin-1 Z'_{SSM} and Z'_{ψ}resonances are shown for comparison.

3- Searches for heavy resonances at the LHC, G. Daskalakis La Thuile 2019 - Les Rencontres de Physique de la Valléed'Aoste, 10-16 March 2019, La Thuile, Aosta Valley, Italy
G. Daskalakis for the ATLAS and CMS collaborations : CMS CR-2019/087 https://agenda.infn.it/event/17057/contributions/84869/attachments/61728/73742/LaThouile2019-HeavyResonances-Daskalakis.pdf

4- Exotic searches at CMS/LHC, G. Daskalakis, HEP-2019: Conference on Recent Developments in High Energy Physics and Cosmology, 17-20 Apr 2019, Athens (Greece) https://indico.cern.ch/event/783781/contributions/3386527/attachments/1832740/3001908/Exotic_Searches_at_CMS_v2.pdfreece

5 - Search for supersymmetry in final states with photons and missing transverse momentum in proton-proton collisions at 13TeV, A. Kyriakis, G. Paspalaki

Publication: CMS Collaboration, JHEP06 (2019) 143, https://doi.org/10.1007/JHEP06(2019)143

Short Description: Supersymmetry (SUSY) and the Minimal Supersymmetric Standard Model are extensions of the standard model (SM) that provide explanations for several outstanding issues with the SM. In particular, SUSY addresses the large quantum corrections to the mass term in the Higgs potential and provides a viable dark matter candidate. Models with general gauge-mediated (GGM) SUSY breaking have the additional benefit of naturally suppressing flavor violations in the SUSY sector. GGM models can have a wide range of features but typically result in final states that include the gravitino (G) as the lightest supersymmetric particle (LSP). A search for GGM SUSY in final states involving two photons and missing transverse momentum was performed using the data sample,

corresponding to an integrated luminosity of 35.9 fb^{-1} of pp collisions at a center-of-mass energy 13 TeV, collected with the CMS detector in 2016. No evidence for a significant deviation from standard model expectation is observed. For values of the neutralino mass between 500 and 1500 GeV, gluino masses up to 2.02TeV and squark masses up to 1.74TeV can be excluded.

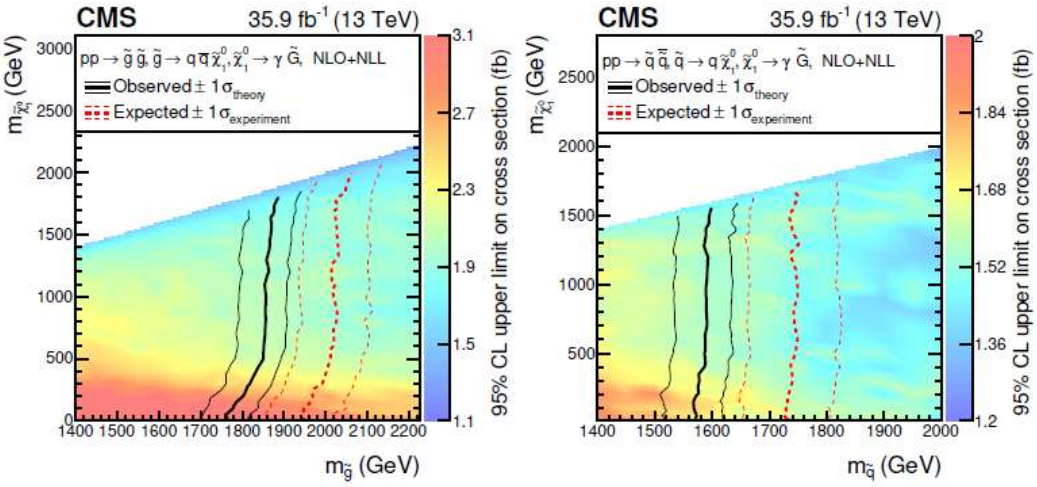


Figure 22: The 95% confidence level upper limits on the gluino (left) and squark (right) pair production cross sections as a function of gluino or squark and neutralino masses. The contours show the observed and expected exclusions assuming the NLO+NLL cross sections, with their one standard deviation uncertainties

Institutional Reviews:

1- "Search for heavy Higgs bosons decaying to a top quark pair in proton–proton collisions at √s = 13 TeV", CMS PAPER HIG-17-027.
2- "A search for the standard model Higgs boson decaying to charm quarks", CMS PAPER HIG-18-031.

CMS Upgrade activities during 2019

Contribution of INPP to the CMS Tracker Project (2019)

Operation of the Current Tracker Detector:

"A Historic Data Quality Monitor (HDQM) tool for the CMS Tracker Detector", A. Kyriakis, D. Loukas, A. Papadopoulos

Publication: CMS Collaboration, EPJ Web of Conferences 214, 05030 (2019), https://doi.org/10.1051/epjconf/201921405030

Short Description: The Historic Data Quality Monitor (HDQM is a framework developed by the Tracker group of the CMS collaboration to monitor the time evolution of sensitive quantities of the Tracker systems. It runs in servers provided by the central CMS DQM group and the development of new features is under consideration. Such new features may include the use of a database scheme instead of a collection of JSON files, the addition of extra information by adopting a bin width proportional to the run duration and the possibility to fit interactively the trends plots. This framework is flexible enough to permit the extension of its use to the other CMS sub-detectors since the core software will remain unchanged while new observables under consideration can be to the web interface via JSON files.

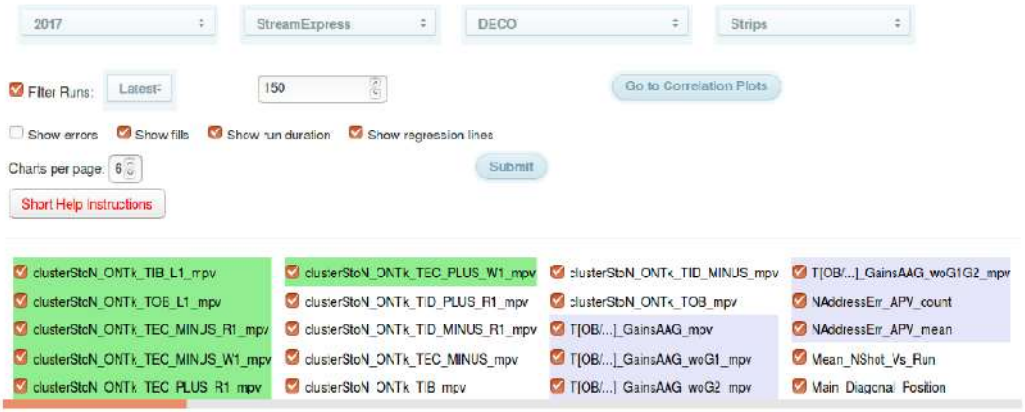


Figure 23: Main page of the HDQM Web Interface with a possible user selection related to the CMS Silicon Strip Tracker Detector.

C) INPP_CMS planning for 2019 and beyond

C.1 "DAQ for the Phase II CMS Pixel Detector", I. Kazas

In 2019, our group continued the development of the firmware for the Inner Tracker DAQ and also contributed to the development of the software. A fully functional system has been brought up which can perform several calibration routines and can communicate electrically with up to 8 single chips, 10 double-chip modules or 5 quad-chip modules. The firmware implementation was enhanced to support communication with multiple chips and modules and also to provide communication interface with external clocking and triggering sources. To do that, a new Command Processor Block is implemented, which allows the system to address and control each chip/module individually. Moreover, the readout scheme for the data from the chip(s) has been updated to aggregate data from all the front-end devices and perform on-board event formatting. Readout data are stored in a DDR3 memory located on the FC7 board and then transferred to the software for further analysis.

On the software side, the low-level communication with the board is handled by a middleware API layer, implemented in C++, which wraps the firmware calls and handshakes into abstracted functions. A C++ object-based library is used to describe the system components (Chips, Modules, and Boards) and their properties (values, status). Finally, several higher-level utilities are included to perform chip testing and calibration routines. Parameters concerning the chip(s) configuration and the calibration settings are stored in .xml configuration files. ROOT is used to display and analyze the resulting data; a sample output of an S-curve plot is depicted in figure 24.

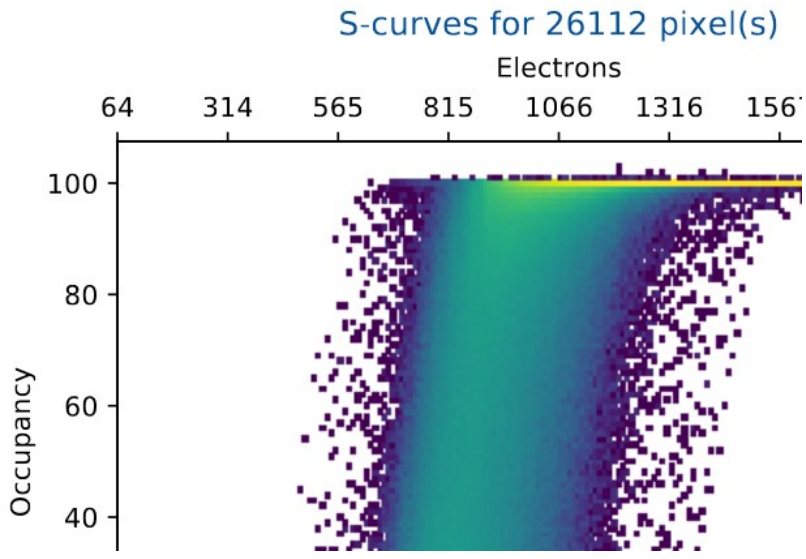


Figure 24: S-Curve Plot for the calibration of the Linear front-end of RD53A acquired with IT μDTC DAQ system.

C.2 "The CHROMIE Telescope", P. Assenov, A. Kyriakis, D. Loukas

Conference: P. Asenov et al, Commissioning and simulation of CHROMIE, a high-rate test beam telescope, 21st International Workshop on Radiation Imaging Detectors, 7-12 July 2019, Kolympari, Greece,

https://indico.cern.ch/event/774201/contributions/3429218/attachments/1875592/3088581/Asenov_iWoRiD_2019_v7.pdf.

A high-rate telescope, which could handle particle rates up to 200 MHz/cm^2 (the highest rate of a Phase-2 Outer Tracker Module is 50 MHz/cm^2) has been designed and set up in the beam line H6 of the test-beam North Area at CERN, where the Super Proton Synchrotron (SPS) supplies the different experiments with high-energy particles. It is called CHROMIE (CMS High Rate telescOpe MachInE) and has a resolution of the order of ~10μm - 20μm with a 100 x 150 μm^2 pixel size. CHROMIE consists of eight layers with some dead areas, each containing two CMS Phase-1 BPIX modules (Grade C, active area of 2 x 16.2 x 64.8 mm^2) in a frame, four layers in front of the Device Under Test (DUT), and four layers behind it. All the telescope layers have been rotated by a 20° tilt angle about the x-axis and a 30° skew angle about the y-axis to allow charge sharing between pixels. CHROMIE has been designed for a large DUT (box size = 550 x 350 x 40 mm^3) and its readout system is CMS-standard.

Our group has developed a standalone simulation program based on the Geant4 toolkit to predict the response of the CHROMIE telescope under various types of particle beams, which could set a potential base for future simulations of any particle telescope. This program could be used for estimating unknown beam parameters through comparison of its output with plots from real data where some magnitudes are unknown. In addition, our group took part in the development of the preliminary tracking algorithm used in the data analysis and investigated the optimization of its seeding efficiency. The program was developed in Python and C++ and added as a separate module to CMSSW (CMS Software). It is called during the analysis of every test-beam run data and consists of a set of steps which are followed every time: Firstly, the clusters from noise hits are removed, secondly, alignment is applied, thirdly, the seeding is performed and finally, the pattern recognition is conducted.

There is currently a good comparison in the resolution and cluster occupancy between the beam test data from a beam test that took place in October 2018 at CERN (where members of our group had been involved) and the simulation results. The visualization of the Geant4 simulated geometry can be seen in Figure 25, while the predicted from the simulation and the real ones from the beam test data X-residuals of a CHROMIE module are presented in Figure 26.

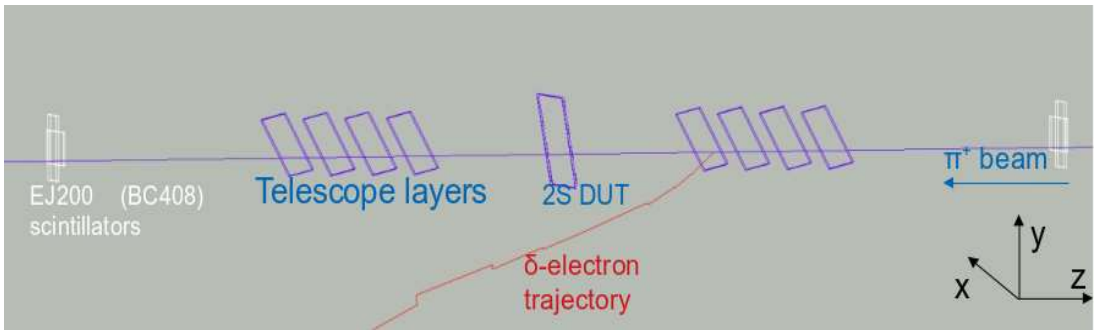


Figure 25: Visualization of the Geant4-simulated geometry of CHROMIE under beam. The DUT is a 2S module: 2 Si sensors (102700μm × 94108 μm × 320 μm), with spacing between the sensors: 2 mm; strip pitch: 90μm; active depth: 240μm.

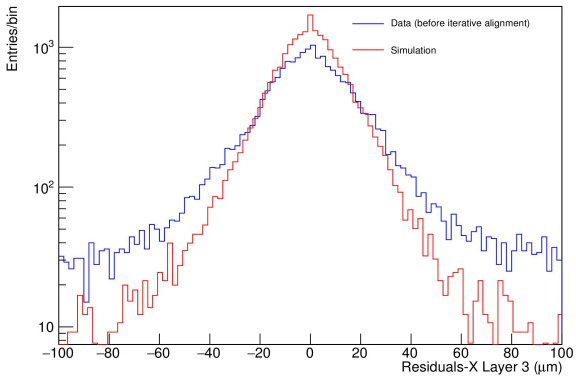


Figure 26: X-residuals for the left module of Layer 3 for a 120 GeV π+ beam (comparison between beam test data before iterative alignment and simulation). Simulation residuals scaled for 26814 valid tracks from the beam test run out of 32536 total events. Standard deviation (beam test): 29.1 μm. Standard deviation (simulation): 19.8 μm.

C3 **"Cobalt-60 gamma irradiation of silicon test structures for high-luminosity collider Experiments"** , P. Assenov, P. Assiouras, A. Bozari, I. Kazas, A. Kyriakis, D. Loukas

Conference: VERTEX 2019, 28th International Workshop on Vertex Detectors, 13 - 18 Oct 2019, Lopud Island, Croatia

Short Description: At the upgrade of the LHC to the HL-LHC the expected integrated luminosity is expected to be up to 3000 fb^{-1}. Therefore new silicon tracking detectors with improved radiation hardness required. For HL-LHC era the expected doses in outer layers of the tracker are expected to be of the order of 10-100 kGy depending on the distance from the beam line (e.g. nominal dose for the CMS Outer Tracker: 77.5 kGy). Systematic program of radiation tests with neutrons and charged hadrons are performed by the CMS and ATLAS collaborations at LHC in view of the upgrade of the experiments, in order to cope a) with the higher luminosity of the HL-LHC and b) the associated increase in pile-up events and

radiation fluxes. We performed complementary radiation studies with ^{60}Co gamma photons in which the doses are equivalent to those that the outer layers of the silicon tracker systems of the CMS experiment during the HL-LHC era will be subjected. In Figure X the IV curve of a test diode structure is shown for different irradiation doses. This test diode is constructed in the same silicon wafer with the tracker sensors thus by checking its features in an indirect way to test the characteristics of the tracker sensor itself. As can be seen the leakage current increases with dose but is but no breakdown was observed up to 1000V bias voltage.

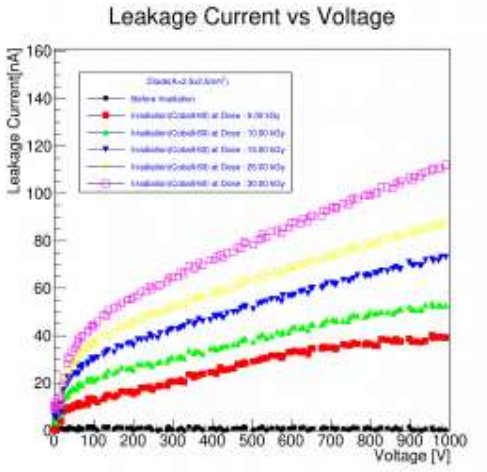


Figure 27: IV curves for a test diode structure for various doses developed in the same silicon wafer with the tracker sensors.

C4 **"Fast calculation of capacitances for silicon detectors with a 3D and 2D numerical solution of the Laplace's equation. Comparison with experimental results and TCAD simulations",** P. Assenov, P. Assiouras, I. Kazas, A. Kyriakis, D. Loukas

Conference: VERTEX 2019, 28th International Workshop on Vertex Detectors, 13 - 18 Oct 2019, Lopud Island, Croatia

Short Description: Work has been done on TCAD simulations and electrical characterization measurements on silicon sensors. More specifically the simulated results by using TCAD were used in order to check the validity of software that we have developed that calculates the capacitances of silicon sensors by using an algorithm for solving the Laplace's equation in three and two dimensions. This is foreseen to be implemented in a web-based application tool and it can be used in order to provide a fast approximation of the capacitances of silicon sensors, before a more sophisticated simulation is made.

The figures 28, 29 below show the comparison for the backplane and interstrip capacitances of a silicon sensor structure (with active thickens of 120 μm) between experimental results

(red histogram), TCAD simulations (green histogram) and calculated results by using the Laplace fast solver (blue histogram). Our simulation is quite close (~ 10%) with respect to the TCAD results.

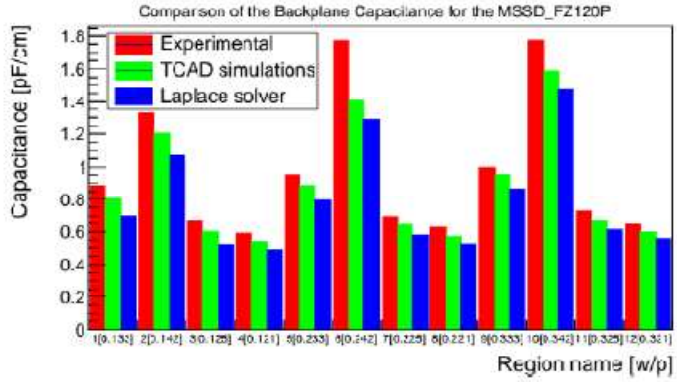


Figure 28: Comparison of the Backplane capacitance of our test sensor calculated by TCAD simulation and our Laplace fast solver. The measurements are also shown.

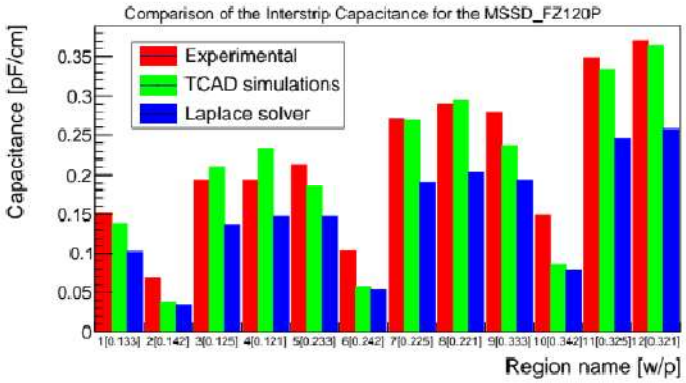


Figure 29: Comparison of the Interstrip capacitance of our test sensor calculated by TCAD simulation and our Laplace fast solver. The measurements are also shown.

Summary of the CMS_INPP publications 2019

1) "Search for top squark pair production in a final state with two tau leptons in proton-proton collisions at $\sqrt{s}$ = 13 TeV", CMS Collaboration (Albert M Sirunyan (Yerevan Phys. Inst.) *et al.*). Oct 28, 2019. CMS-SUS-19-003, CERN-EP-2019-192 e-Print: arXiv:1910.12932

2) "Measurement of properties of $B_{0s} \to \mu^+\mu^-$ decays and search for $B_0 \to \mu^+\mu^-$ with the CMS experiment", CMS Collaboration (Albert M Sirunyan (Yerevan Phys. Inst.) *et al.*). Oct 26, 2019. CMS-BPH-16-004, CERN-EP-2019-215 e-Print: arXiv:1910.12127

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Phys.Lett. B789 (2019) 643-665.

	Citeable papers	Citeable papers excluding self cites	Citeable papers excluding RPP	Published only papers	Published only excluding self cites	Published only excluding RPP
Total number of papers analyzed:	79	79	79	33	33	33
Total Number of citations	323	200	0	212	140	0
Average citentions per paper:	4.1	2.5	0.0	6.4	4.2	0.0
Paper analysis bised on the citations:						
Renowned papers (500+)	0	0	0	0	0	0
Famous papers (250-499)	0	0	0	0	0	0
Very well-known papers (100-249)	0	0	0	0	0	0
Well-known papers (50-99)	0	0	0	0	0	0
Known papers (10-49)	9	3	0	7	3	0
Less known papers (1-9)	44	43	0	24	24	0
Unknown papers (0)	26	33	0	2	6	0
hHEP index [?]	9	7	0	8	7	0

Theoretical High Energy Physics

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Research directions.

The fundamental forces of Nature the electromagnetic, weak and strong interactions are successfully described by the non-Abelian fields. In that description the photon, W-bosons and gluons mediate interaction between smallest constituents of matter - leptons and quarks. The main objectives of the High Energy Theory Group are:

- Firstly the exploration of the physics described by the STANDARD MODEL of FUNDAMENTAL FORCES primarily at the perturbative level through the development of techniques and methods for precise contributions of higher order processes at the LHC and future collider experiments.

Of equal interest is the description of nonperturbative physics (e.g. gluon condensation (publ.9), QCD string, EW-sphalerons) in the determination of the properties of the vacuum of the theory both at zero and at finite temperatures.

More specifically the project (publs.1-6) in High Energy Physics Phenomenology and Computational Physics aims to develop innovative methods and algorithms in order to establish an efficient framework for higher order corrections for multi-particle processes including

- amplitude reduction at the integrand level beyond one-loop,
- the evaluation of multi-loop Master Integrals and
- the application of the above-mentioned techniques to scattering processes at the LHC and beyond.

- Secondly the PHYSICS BEYOND the SM with its possible phenomenology at CERN's LHC and future colliders. This includes super-symmetric and string theory inspired low energy extensions, nonperutbative aspects (novel nontopological soliton states-Qballs), search of effects of higher spacetime dimensions, and the study of novel higher spin tensor particle states.
- The project in Gauge and String theories aims to study the interaction of matter, which carries not only internal charges, but also arbitrary high spins. This extension leads to a theory in which fundamental forces are mediated by integer-spin gauge quanta and the photon, W-bosons and gluons become members of a bigger family of tensor gauge bosons. A new topological mechanism of mass generation is possible in this extension. These predictions can be tested at LHC.
- Thirdly bridging the physics of the SCM(Standard Cosmological Model—ΛCDM) and the physics of the SM. It involves modeling of the invisible sector of our Universe (Dark Matter and Dark Energy) as well as the causal origin of its Large Scale Structure (Inflation).

Topical topics of research are in the research agenda of the group, such as

1. the bridging together of Quantum Field Theory(QFT) and Quantum Gravity (QGr) in the framework of AdS/CFT duality for some string theories
2. the physics involved in the possible resolution of the Black hole information paradox.

- 10dim. String theories and their 11-dim unification scenario of M-theory is a very fertile ground of theoretical research of quantum gravity at the Planck scale. Quantum black holes and cosmological singularities are examples of physical systems where strong gravity effects are manifest and new concepts and principles appear to be at work such as nonlocality and strong chaotic mixing which operate in the framework of the Holographic principle and AdS/CFT correspondence.
- The project on entanglement and geometry (pubs 11-15) aims to study the relation between quantum entanglement and gravity. It does it through the use of the holographic duality which is realized by the employment of tools from the theory of non-linear sigma models and integrability, as well as through the study of entanglement in quantum field theory. The project was supported in 2019 by the "Post-doctoral researchers support" action of the operational programme "Human Resources Development, Education and Lifelong Learning 2014-2020", implemented by the Greek State Scholarship Foundation and co-funded by the European Social Fund - ESF and National Resources of Greece.
- The project (publ.7) on the Small Scale Structure of Spacetime (SSSS) explores the possibility of a Discrete Spacetime structure in strong gravity environments. It proposes a modular finite quantum mechanical model for the AdS2 near horizon geometry for the specific class of extremal black holes. The model is holographic and exhibits desirable properties at the Planck scale such as nonlocality and chaotic mixing (fast scrambling).In the present year of 2019 the existence of a continuum limit to the discrete geometry has been demonstrated (publ. 7) to exist. The property of entanglement is under investigation for composite single particle probes.

- Boundaries and defects play central roles in quantum field theory (QFT) both as means to make contact with nature and as tools to constrain and understand QFT itself. Boundaries in QFT can be used to model impurities and also the finite extent of sample sizes, while interfaces allow for different phases of matter to interact in a controllable way. More formally, these structures shed light on the structure of QFT by providing new examples of dualities and renormalization group flows. The group's present research (publ.23) focuses on three areas: 1) formal and applied aspects of boundary and defect conformal field theory, from anomalies and c-theorems to topological insulators, 2) supersymmetry and duality, from exact computations of new observables to the construction of new theories, and 3) QFT in curved space and gravity, from holographic computations of entanglement entropy to ideas in quantum information theory.
- The study of Non-linear Chaotic Dynamics and Complex Systems involves both research and teaching. It pertains to the interplay between chaotic dynamics and fundamental interactions. Noteworthy results have been obtained in the very past such as the observation of chaos in Yang Mills theories (G. K. Savvidy) as well as more recently in matrix and membrane dynamics of M-theory

Moreover the principles of chaos have been successfully shown to give rise to novel random number generator algorithms (MIX-MAX) with which to make Monte-Carlo Simulations in high energy elementary particle experiments such as the LHC (publ10).

Demokritos has been the hub of the national network of Complex Systems COSA-NaNet which organizes regular seminars on Nonlinear Chaotic Dynamics and Complexity along with a graduate level course on "Special topics on Complex Systems and Applications" in association with the National Technical University of Athens.(see on Teaching-Outreach as well as Summer schools for undergraduate University students . http://complexity2018.demokritos.gr/index.php/el/

The MixMax project (publ.10)

The primary objective of the MIXMAX project (2015-2018; H2020-MSCA-RISE-MIXMAX) was a systematic development of the state of the art new generation of Pseudo Random Number Generators based on Kolmogorov-Anosov C-K systems, which demonstrates excellent statistical properties, into a multidisciplinary usable product. This innovative class of RNG was proposed earlier by G. Savvidy in 1986 and by the members of the network and relies on the fundamental discoveries and results of Ergodic theory. It has been recently tested in many platforms and is evaluated as random number generator in the CMS simulation program. The MixMax generator is now included in:

ROOT (https://root.cern.ch/doc/master/classTRandom.html),

Geant4/CLHEP as default generator
(https://gitlab.cern.ch/CLHEP/CLHEP/blob/develop/ChangeLog)
MixMax was set as default engine since release 2.4.0.0 deployed on November 2017 and in Geant4 since release 10.3.

PYTHIA (http://home.thep.lu.se/~torbjorn/doxygen/MixMax_8h_source.html)

GSL - GNU Scientific Library, the Extensions/Applications

(https://www.gnu.org/software/gsl/)

CMS as default generator
(https://indico.cern.ch/event/731433/contributions/3015654/attachments/1680131/2698971/CMSsim.pdf page 13 ,
https://indico.cern.ch/event/587955/contributions/2937635/attachments/1679273/2706817/PosterCMS_SIM_v4.pdf)

The MIXMAX software has been used in the design of the NASA Solar Neutrino Spacecraft Detector by the group of researchers from NASA and by Wichita State University.

Publications by the theoretical group: 7 publications in refereed journals and 8 on the hep-Archive for the year 2019 which are submitted for publication.

Conferences: international workshops and conferences have been organized in Greece and in Europe.

Grants: 1EU & 6 national grants have been obtained by the theoretical group.

#	Grant/Fellowship	Amount	Period	Scientist in charge
1	CA16201: Unraveling new physics at the LHC through the precision frontier	**520 k€**	**2017-21**	**C. Papadopoulos** **G. Savvidy**
2	HFRI E-12300: Holographic applications of quantum entanglement (HAPPEN)	**200 k€**	**2018-20**	**G. Pastras** **M. Axenides**
3	IKY (postdoc fellows)	**26 k€**	**2017-19**	**G. Pastras**
4	IKY (doctoral fellows)	**30 k€**	**2018-21**	**D. Katsinis**
5	HFRI: Two-loop Amplitude Calculations Based on Intergrand Reduction	**32.4 k€**	**2019-22**	**C. Papadopoulos** **D. Canko**
6	ΕΔΒΜ 103**:** Χαοτική Δυναμική και Μελανές Οπές στη Θεωρία BMN	**50 k€**	**2020-21**	**E. Floratos** **M. Axenides**
7	ΕΔΒΜ 103: Μελέτη διορθώσεων ανώτερης τάξης στο πλαίσιο της Κβαντικής Χρωμοδυναμικής και εφαρμογές στα πειράματα Υψηλών Ενεργειών του LHC	**50 k€**	**2020-21**	**C. Papadopoulos**

Awards/Prizes

Academy of Athens (19/12/2019): "Lykourgeion" prize in theoretical physics to G. Linardopoulos for the paper *Scalar One-point Functions and Matrix Product States of AdS/dCFT*, Phys.Lett., B781 (2018) 238[arXiv:1802.01598].

- Academy announcement
  http://www.academyofathens.gr/el/announcements/press-releases/20191219-0
- NCSR "Demokritos" announcement
  http://www.demokritos.gr/academy-of-athens-prize-to-georgios-linardopoulos/
- INPP announcement
  http://www.inp.demokritos.gr/congratulations-to-george/

ΤΥΧΗΙ ΑΓΑΘΗΙ

ΕΔΟΞΕ ΤΗΙ ΑΚΑΔΗΜΙΑΙ ΑΘΗΝΩΝ

ΓΕΩΡΓΙΟΝ ΛΙΝΑΡΔΟΠΟΥΛΟΝ

ΤΩΙ ΛΥΚΟΥΡΓΕΙΩΙ ΒΡΑΒΕΙΩΙ
ΤΙΜΗΣΑΙ

ΟΤΙ ΤΩΙ ΑΞΙΟΛΟΓΩΙ ΑΥΤΟΥ ΠΟΝΗΜΑΤΙ
«SCALAR ONE-POINT FUNCTIONS
AND MATRIX PRODUCT STATES OF AdS/dCFT»
ΤΗΝ ΠΕΡΙ ΤΗΣ ΘΕΩΡΗΤΙΚΗΣ ΦΥΣΙΚΗΣ ΓΝΩΣΙΝ
ΙΚΑΝΩΣ ΠΡΟΑΓΕΙ

ΑΝΕΙΠΕΙΝ ΔΕ ΤΑΣ ΤΙΜΑΣ ΕΝ ΤΗΙ ΠΑΝΗΓΥΡΙΚΗΙ ΣΥΝΕΔΡΙΑΙ
ΜΗΝΟΣ ΔΕΚΕΜΒΡΙΟΥ ΕΝΑΤΗΙ ΚΑΙ ΔΕΚΑΤΗΙ
ΕΤΟΥΣ ΕΝΑΤΟΥ ΚΑΙ ΔΕΚΑΤΟΥ ΚΑΙ ΔΙΣΧΙΛΙΟΣΤΟΥ

Ο ΠΡΟΕΔΡΟΣ

ΣΤΕΦΑΝΟΣ Δ. ΗΜΕΛΛΟΣ

Ο ΓΕΝΙΚΟΣ ΓΡΑΜΜΑΤΕΥΣ

ΒΑΣΙΛΕΙΟΣ Χ. ΠΕΤΡΑΚΟΣ

Teaching: the group offers courses in quantum field theory for graduate and undergraduate students jointly from NTUA and NCSR-Demokritos, training of graduate students for advanced degrees. Seminars and lectures in summer schools organized by Demokritos for university undergraduate students.

Publications:

1. FCC Physics Opportunities: Future Circular Collider Conceptual Design Report Volume 1, FCC Collaboration (A. Abada *et al.*). Dec. 14, 2018, Eur.Phys.J. C79 (2019) 474, CERN-ACC-2018-0056, DOI: 10.1140/epjc/s10052-019-6904-3.
2. FCC-ee: The Lepton Collider: Future Circular Collider Conceptual Design Report Volume 2, FCC Collaboration (A. Abada *et al.*). Dec. 18, 2018, Eur.Phys.J.ST 228 (2019), 261, CERN-ACC-2018-0057, DOI: 10.1140/epjst/e2019-900045-4.
3. FCC-hh: The Hadron Collider: Future Circular Collider Conceptual Design Report Volume 3, FCC Collaboration (A. Abada *et al.*). Dec. 18, 2018, Eur.Phys.J.ST 228 (2019) 755, CERN-ACC-2018-0058, DOI: 10.1140/epjst/e2019-900087-0.
4. HE-LHC: The High-Energy Large Hadron Collider Volume: Future Circular Collider Conceptual Design Report Volume 4, FCC Collaboration (A. Abada *et al.*). Dec. 18, 2018, Eur.Phys.J.ST 228 (2019) 1109, CERN-ACC-2018-0059, DOI: 10.1140/epjst/e2019-900088-6.
5. Standard model theory for the FCC-ee Tera-Z stage, A. Blondel *et al.*. Sep. 6, 2018, CERN Yellow Rep. Monogr. 3 (2019), CERN-2019-003, BU-HEPP-18-04, CERN-TH-2018-145, IFJ-PAN-IV-2018-09, KW 18-003, MITP/18-052, MPP-2018-143, SI-HEP-2018-21, DOI: 10.23731/CYRM-2019-003, arXiv:1809.01830 [hep-ph]. Cited by 30 records
6. Internal Reduction method for computing Feynman Integrals, Costas G. Papadopoulos, Christopher Wever. Oct. 14, 2019, TUM-HEP-1232/19.
7. The arithmetic geometry of AdS2 and its continuum limit, Minos Axenides, Emmanuel Floratos, Stam. Nicolis. Aug. 19, 2019, arXiv:1908.06641 [hep-th].
8. A simple F(R,ϕ) deformation of Starobinsky inflationary model, D. Canko., Ioannis D. Gialamas, George P. Kodaxis. Jan. 18, 2019, arXiv:1901.06296 [hep-th].
9. From Heisenberg-Euler Lagrangian to the discovery of chromomagnetic gluon condensation, George Savvidy. Oct. 1, 2019, NRCPS-HE-77-2019, arXiv:1910.00654 [hep-th].
10. Spectral Test of the MIXMAX Random Number Generators, Narek Martirosyan, Konstantin Savvidy, George Savvidy. Jun 13, 2018, Chaos Solitons Fractals Solitons and Fractals: the interdisciplinary journal of Nonlinear Science 118 (2019) 242, NRCPS-HE-44-2018, DOI: 10.1016/j.chaos.2018.11.024, arXiv:1806.05243 [nlin.CD].
11. Closed Algebras for Higher Rank, non-Abelian Tensor Gauge Fields, Spyros Konitopoulos. Nov. 5, 2019, arXiv:1911.01901
12. Geometric Flow Description of Minimal Surfaces, Dimitrios Katsinis, Ioannis Mitsoulas, Georgios Pastras. Oct. 15, 2019, arXiv:1910.06680 [hep-th].

13. An Inverse Mass Expansion for the Mutual Information in Free Scalar QFT at Finite Temperature, Dimitrios Katsinis, Georgios Pastras. Jul. 19, 2019, arXiv:1907.08508 [hep-th].
14. Area Law Behaviour of Mutual Information at Finite Temperature, Dimitrios Katsinis, Georgios Pastras. Jul. 10, 2019, arXiv:1907.04817 [hep-th].
15. Salient Features of Dressed Elliptic String Solutions on R×S2, Dimitrios Katsinis, Ioannis Mitsoulas, Georgios Pastras. Mar. 4, 2019, arXiv:1903.01408 [hep-th].
16. Stability Analysis of Classical String Solutions and the Dressing Method, Dimitrios Katsinis, Ioannis Mitsoulas, Georgios Pastras. Mar 4, 2019, JHEP 1909 (2019) 106, DOI: 10.1007/JHEP09(2019)106, arXiv:1903.01412 [hep-th].

Astroparticle Physics

KM3NeT

Coordinator: Dr. Christos Markou

Researchers: Dr. E. Tzamariudaki, Dr. A. Belias

Under work contract: G. Androulakis, C. Bagatelas, S. Koutsoukos, T. Georgitsioti

Ph.D. Students: K. Pikounis, D. Tzanetatos, G. Polydefki, V. Panagopoulos, A. Sinopoulou

Postgraduate Students: D. Stavropoulos, G. Anagnostou

Technical and Support personnel: P.Tsagkli, A.Vougioukas, S.Bakou

Non-doctoral students: G. Zarpapis, A. Voutouras

The main interest of the astroparticle physics group of the Institute of Nuclear and Particle Physics (INPP) is the study of neutrinos from cosmic accelerators. The study of cosmic neutrinos, offers significant advantages towards answering basic questions about the origin and nature of the cosmic rays. Neutrinos, being neutral, are not deflected by interstellar magnetic fields and, unlike photons, are not significantly absorbed by any intervening matter. Thus they point back to their sources over all energy ranges and distance scales, and hence are uniquely valuable as cosmic messengers. In addition, the detection of astrophysical high energy neutrinos would shed light on the question whether the sources of high energy gamma rays observed by the HESS telescope are due to electromagnetic or hadronic processes.

The INPP astroparticle physics group is a member of the KM3NeT collaboration. KM3NeT [*Letter of Intent for KM3NeT 2.0, J.Phys. G43 (2016) no. 8, 084001*] is a distributed Research Infrastructure, member of the ESFRI Road Map that will consist of a network of deep-sea neutrino telescopes in the Mediterranean Sea with user ports for Earth and Sea sciences. Once completed, the telescopes will have detector volumes between megaton and several cubic kilometers of clear sea water. Located in the deepest seas of the Mediterranean, KM3NeT will open a new window on our Universe, but also contribute to the research of the properties of the elusive neutrino particles. With the ARCA telescope, KM3NeT scientists will search for neutrinos from distant astrophysical sources such as supernovae, gamma ray bursts or colliding stars. The ORCA telescope is the instrument for studying neutrino properties exploiting neutrinos generated in the Earth's atmosphere.

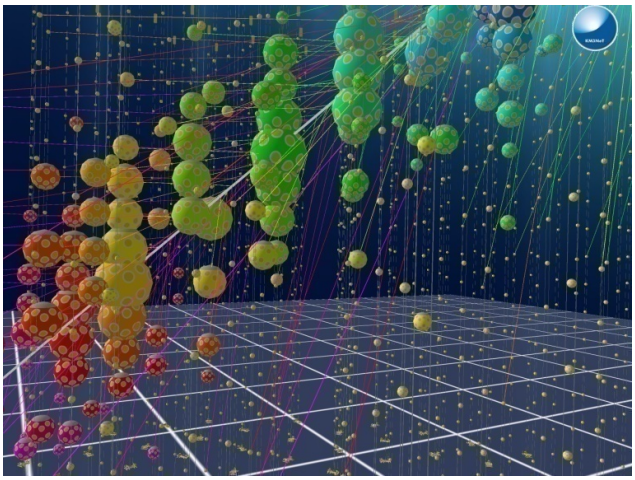

Figure 30: An artists' view of an event as it will be seen from the KM3NeT telescopes

In 2019 the group has been active in the construction, testing, and validation of the KM3NeT detectors and individual components, physics analyses and studies, governance and management.

KM3NeT management and governance

Dr. C. Markou was re-elected (in 2018) as head of the Institution Board (IB) of KM3NeT, for a term of 2 years. As such, among other duties, he represents the KM3NeT IB to the Resources Review Board, and the Scientific and Technical Advisory Committee of the experiment. Dr. C. Markou and Dr. E. Tzamariudaki are members of the KM3NeT Publication committee. In addition, Dr. Tzamariudaki participates in the Conference Committee of the experiment, acts as the Greek-site manager and is a member of the Management Team of the experiment. Dr. E. Tzamariudaki is a member of the Equality, Diversity and Inclusion committee (EDI) of KM3NeT. G. Androulakis is the Quality Assurance/Quality control manager of KM3NeT, member of the Management Team and the Steering Committee of the experiment.

KM3NeT construction

DOM Lab

Since 2016 a DOM integration, validation and testing facility has been established in the premises of INPP (see Fig. 31), funded exclusively through internal funds. Ever since, the lab continues with the integration of DOMs.

Currently the lab employs 2 FTE of skilled personnel, with additional help from other group members as the need arises. The construction for Phase-1 is expected to finish in 2019, with mass rate production for Phase-2 starting immediately afterwards.

In 2019 36 DOMs (2 Detection Units) integrated in INPP facilities, were sent to the DU integration site in Genova in order to be integrated in DUs. During 2019 DOMs were integrated for the validation of new components such as PMT support structures and pressure gauges. The DOM lab has been upgraded in both mechanical tools and scientific equipment in order to reach the mass rate production for Phase-2. Finally, the DOMs of ORCA-DU1 which have been recovered due to an electrical problem have been sent to the INPP DOM lab to be thoroughly tested and then to be refurbished by the end of the year.

Fig. 31: A DOM completed in the INPP DOM laboratory

An additional contribution to the Collaboration are testing and validation efforts concerning the high-pressure testing of the DOM penetrators which are used for powering the DOMs and for data transfer from the DOMs. For these tests, a high-pressure testing chamber, capable of sustaining pressure up to 600 bars (see Fig. 32) is used. The tests are done for a large fraction of the KM3NeT DOM penetrators (more than 40), as the only other similar facility is in NIKHEF, Amsterdam.

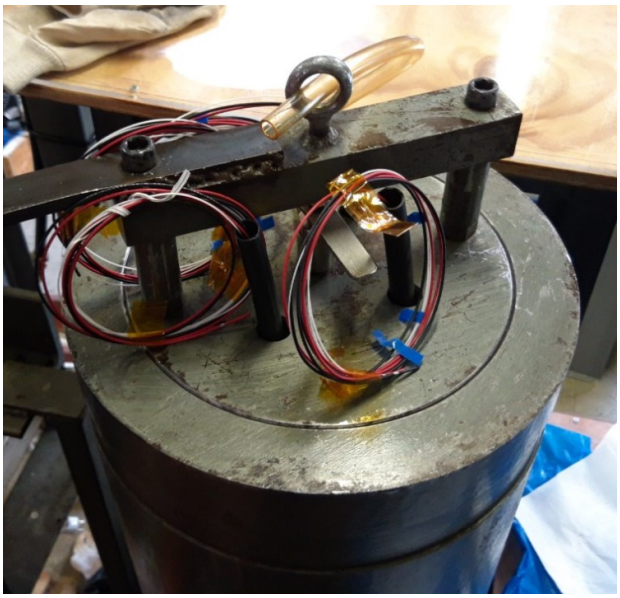

Fig 32: Pressure testing of the penetrators

The group has also undertaken the calibration of the DOM compasses which are mounted on the central logic boards (CLBs). These tests are done for the KM3NeT Collaboration only in the premises of INPP. More than 65 compasses were calibrated in 2019, an activity which is expected to continue over the coming years. A fraction of them was evaluated as new component to be used in DOM integration.

"Analysis of the electromagnetic impact on the piezo-electric acoustic receivers"

G. Zarpapis, C. Bagatelas, S Tsagkli, K. Pikounis.

The precise positioning of the DOMs of the KM3NeT detectors is of critical importance for all physics analyses. For this purpose, a precise positioning system has been developed, based on the time differences between the emission and the detection of acoustic signals. These acoustic signals are transmitted by transmitters at fixed locations on the seabed and they are received by piezo-electric acoustic receivers integrated inside the DOMs. An analysis of the electromagnetic susceptibility of the piezo-electric acoustic receivers due to the PMT High Voltage was conducted.

The acoustic spectra of five different DOMs have been recorded and subsequently analyzed. The acoustic spectra had been recorded in the cases that all PMTs were switched off, all PMTs were set to low voltage (900 V) and in the case that all PMTs were set to nominal high voltage (~1100V). The analysis of these spectra showed that the intrinsic noise of the piezo sensors (all PMTs off) was quite smooth while a flat plateau has been observed with some small peaks in the frequency range of interest (20 kHz:40 kHz - the frequency of the emitter is at 30kHz) when the PMTs were set to nominal voltage. These results are illustrated in the upper and middle plots of Figure 33. Also, the impact that each individual PMT has on the acoustic receiver was studied by setting each individual PMT at nominal high voltage while

keeping the rest 30 PMTs switched off. The analysis of these spectra revealed that the impact of those PMTs located closer to the acoustic receiver is greater than those located farther away. Moreover, the cumulative effect of PMTs being at nominal voltage on the acoustic spectra was studied by successively setting all PMTs to nominal high voltage. Finally, an acoustic signal of 30 kHz was emitted (and subsequently received) when all PMTs had been set to nominal high voltage. The results (illustrated in the lower plot of Figure 33) clearly indicate than the EM impact the PMTs have on the acoustic receiver is negligible to the frequency area of interest, compared to the expected signal strength.

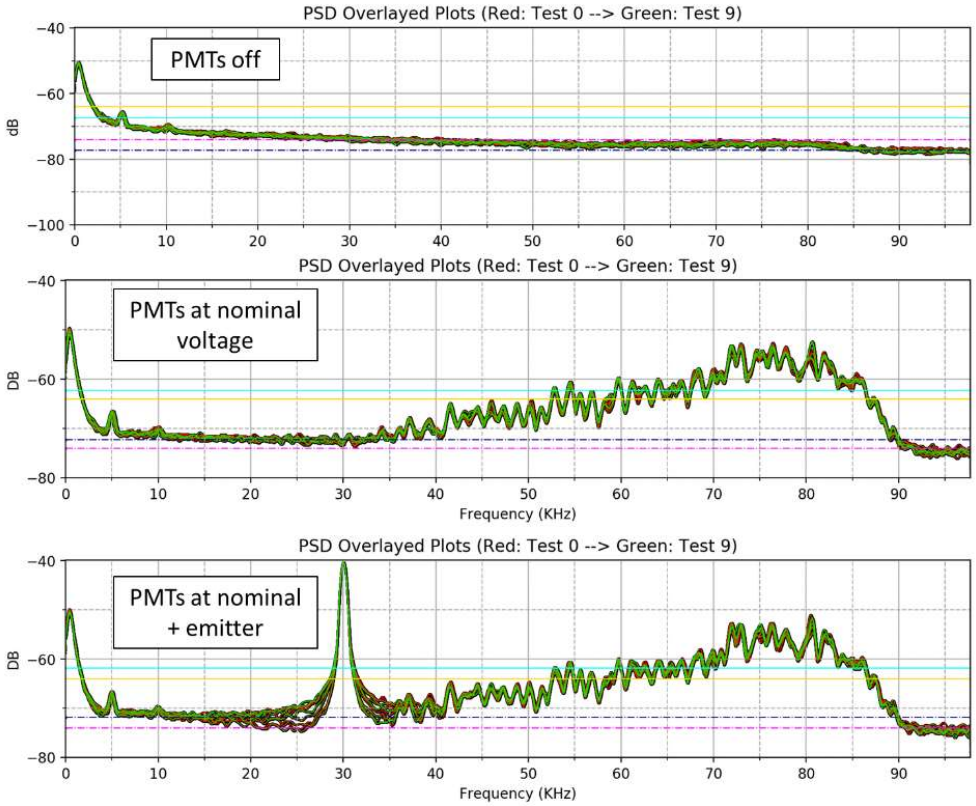

Figure 33: Spectrum of the piezo-electric acoustic receiver for the same DOM when all PMTs were switched off (upper), when all PMTs were set to nominal high voltage (middle) and when an acoustic signal with a frequency of 30 kHz was emitted (lower).

Physics analyses

Several group members have been active in physics analyses, especially for High energy neutrinos to be studied by KM3NeT/ARCA. Most of these were carried out in the context of Ph.D., M.Sc. or diploma theses. These are briefly outlined below.

"Atmospheric Neutrino Candidates from the first data of the KM3NeT/ARCA Neutrino Telescope"

Ph.D. candidate Anna Sinopoulou, Supervisors: E. Tzamariudaki, C. Markou

This work is ongoing and involves the analysis of data collected using the first 2 deployed Detection Units (DUs) of the KM3NeT/ARCA detector and started in July 2018. The analysis focuses on optimizing the selection requirements in order to reject poorly well reconstructed events, while remaining high efficiency for accepting well reconstructed events. In addition, suitable selection criteria for finding atmospheric neutrino candidates and suppressing the background from atmospheric muons were investigated. In order to achieve these goals, detailed comparisons of the data with the atmospheric muon and neutrino Monte Carlo (MC) simulations are mandatory. Initial requirements to suppress badly reconstructed events have been investigated comprising a minimum number of DOMs with hits in time with the reconstructed track, the percentage of uncorrelated hits to be less than a predefined maximum value and a minimum track length (Fig. 34). The angular resolution for both 3D and zenith angles between the true and the reconstructed track for the MC samples was used to evaluate the performance of the analysis requirements which was investigated in terms of efficiency for well reconstructed events and rejection power for badly reconstructed events. After applying the selection criteria, a sample of events was obtained with increased reconstruction reliability (Fig 35).

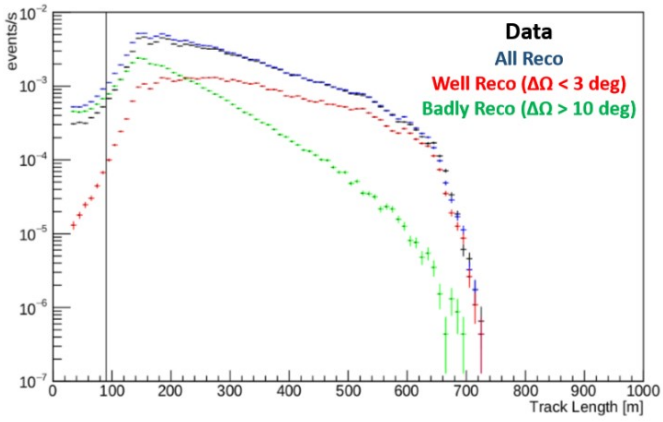

Fig.34: Track length for the data (black), all atmospheric muon MC (blue), well reconstructed atmospheric muon events (red) and badly reconstructed events (green).

Applying these conditions to suppress poorly reconstructed events, several methods and requirements were investigated in order to find suitable criteria to select atmospheric neutrino candidates. The analysis, which is still ongoing, led to 6 atmospheric neutrino candidates in a period of 53.2 days (Fig. 35). In July 2019, the results of this first analysis of KM3NeT/ARCA data were presented in the ICRC 2019 conference and the proceedings of this publication can be found online (https://pos.sissa.it/358/910/pdf).

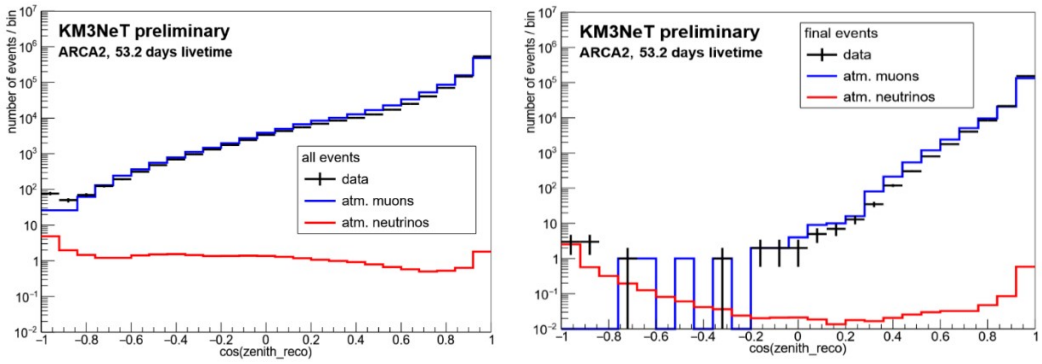

Fig.35. Left: Number of reconstructed events (before applying requirements) as a function of the reconstructed zenith angle for the data (black), atmospheric muon MC (blue) and atmospheric neutrino MC (red) for a period of 53.2 days. Right: Number of reconstructed events for the final sample as a function of the reconstructed zenith angle for the data (black), atmospheric muon MC (blue) and atmospheric neutrino MC (red) for the time period of 53.2 days.

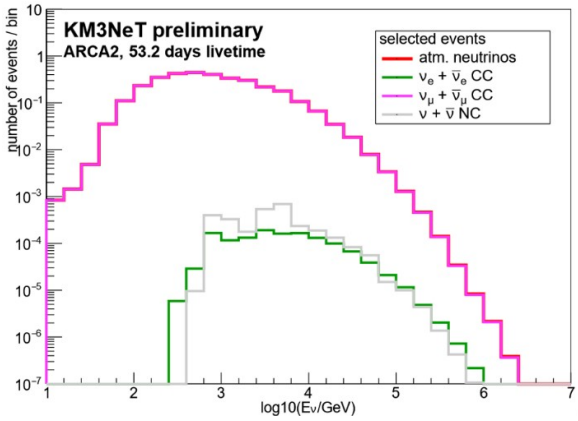

Fig.36. The energy spectrum of the neutrino candidates of the final sample. All the atmospheric neutrino MC is shown in red, the atmospheric muon neutrinos from CC interactions in magenta, the atmospheric electron neutrinos from CC interactions in green and the atmospheric neutrinos from NC interactions in grey.

Anna Sinopoulou has submitted two different proposals for a fellowship in 2018. One group proposal with E.Tzamariudaki, C. Markou and D. Tzanetatos (Ph.D. candidate) was submitted to the "National Strategic Reference Framework" (N.S.R.F.) for the support of the research of young scientists and Ph.D. students. One individual proposal was submitted

to the "Hellenic Foundation for Research and Innovation" (H.R.F.I.) for the support of the research of Ph.D. candidates. Anna submitted a proposal on her Ph.D. thesis with subject: "Study of the neutrino diffuse flux from astrophysical sources with the KM3NeT-ARCA neutrino telescope and study of the data collected as it is constructed". Both proposals were accepted for a fellowship. Since November 2019 Anna is a fellow of the H.R.F.I. She was the 1st to be awarded with this fellowship in the National Technical University of Athens and the 9th in the general classification on physical sciences, with a score of 92/100.

"Monitoring the performance of the first deployed Detection Units of the KM3NeT/ARCA and KM3NeT/ORCA Detectors"

M.Sc. student (currently Ph.D. candidate) Dimitris Stavropoulos, Supervisor: E. Tzamariudaki

An analysis using data from the first detection units of the KM3NeT/ARCA detector deployed off shore Sicily was carried out in order to study the long-term performance of the detector elements. The purpose of this analysis was to evaluate the sedimentation effect which has an impact on the detection rates of the PMTs of the upper hemispheres of the digital optical modules (DOMs). In the four-month time period of the data used in the analysis, the mean rates of the PMTs of the upper hemisphere have a reduction of about 3.6% (1.5% − 5.9%) and 1.9% (0.9% − 4.4%) for DU1 and DU2 respectively. The stronger reduction of the upper hemispheres in DU1 is a result of the longer time DU1 has remained underwater (~6 months).

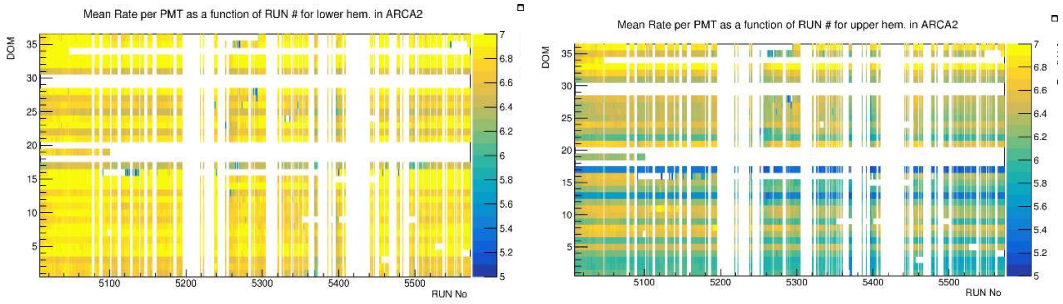

Fig.37. Mean rate per DOM for the lower (left) and upper (right) hemisphere of the ARCA DUs.

The main contributions to the hit single rates detected at DOM level are the K^{40} decays and the bioluminescence activity. While the first is isotropic and stable in time, the bioluminescence activity can fluctuate significantly. The distribution of the mean rates has an average value which is due to the K^{40} background, while sporadic periods with high values of the mean rate correspond to periods with increased bioluminescence activity. The mean rates have been evaluated both for the ARCA (Fig 38) and ORCA (Fig 39) detections units (DUs) deployed in the different sites in order to assess the amount and influence of bioluminescence in the different sites. The mean rates have been evaluated for down-looking PMTs for each DOM of each DU. The peaks due to bioluminescence are visible for the

ORCA DUs, particularly for ORCA DU1. However, this does not affect the physics output since high rate vetoes are applied.

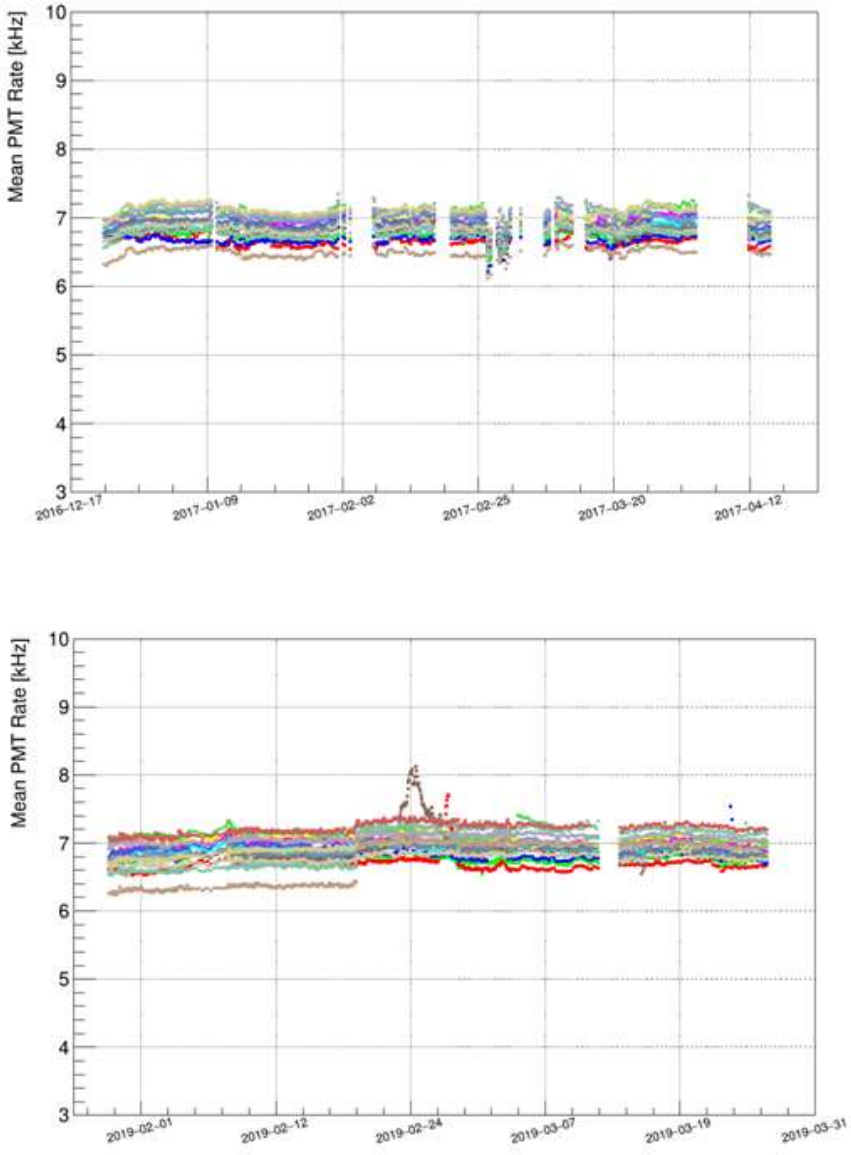

Fig. 38. Mean PMT rates for ARCA DU1 versus time for two different run periods. Top:Runs from the early deployment. Bottom: Recent runs.

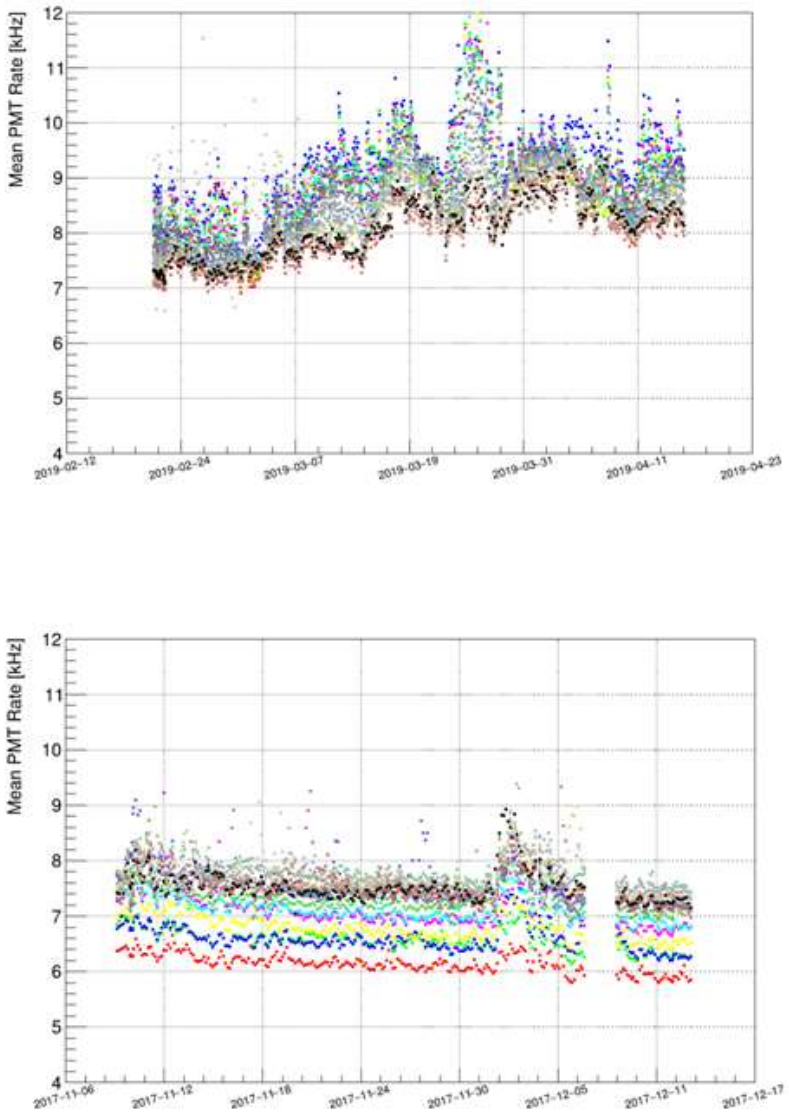

Fig.39: Mean PMT rates for ORCA DU1 (top) and ORCA DU2 (bottom) versus time.

Additionally, the correction factors for the response of the PMTs (PMT efficiencies calculated using coincidence rates from K^{40} decays) have been applied to the detection rates in order to verify the procedure. The monitoring of the mean PMT single rates is proven to be an important unbiased method to study the detector functionality.

"Studies of the potential for Acoustic Detection of Ultra-High Energy Neutrinos",

G. Anagnostou, M.Sc. student, Supervisor: C. Markou

During 2018, Theodoros Chatzistavrou and Georgia Anagnostou investigated the use of a wavelet transformation of the sound spectrum as a way to detect the expected acoustic signal

from an ultra-high energy neutrino interaction. G. Anagnostou has continued the studies towards the detection of acoustic signal from neutrino interactions during by employing a neural network classifier to identify whether a neutrino induced acoustic signal is present in an audio file with ambient sea noise. Real data acquired by hydrophones deployed in the area South of Kalamata in 2018 were used to extract short-duration audio files with ambient sea noise. The input variables to the neural network were derived by the, already developed, wavelet transformation of the sound spectrum analysis. The trained neural network showed excellent accuracy on test samples ranging from more than 99.9% to more than 95.0%, when the amplitude of the neutrino induced acoustic pulse took values from 10% to 2% of the maximum amplitude of the ambient noise, respectively. In the case the amplitude of the neutrino induced pulse was as low as 1% of the maximum amplitude of the ambient sea noise, the accuracy of the neural network on the test sample was at the order of 65%.

The amplitude of the neutrino induced acoustic pulse depends on the energy deposited to the particle cascade, which is not constant. So, the more realistic case of having a distribution of different pulse amplitudes was tested. The amplitude of the neutrino pulse was randomly chosen, using a uniform distribution, from 1% to 10% of the amplitude of the ambient noise of each file. The newly trained neural network with this sample exhibited an excellent classification accuracy of 95% on a test sample. In Fugue 40 the output of the neural network is presented.

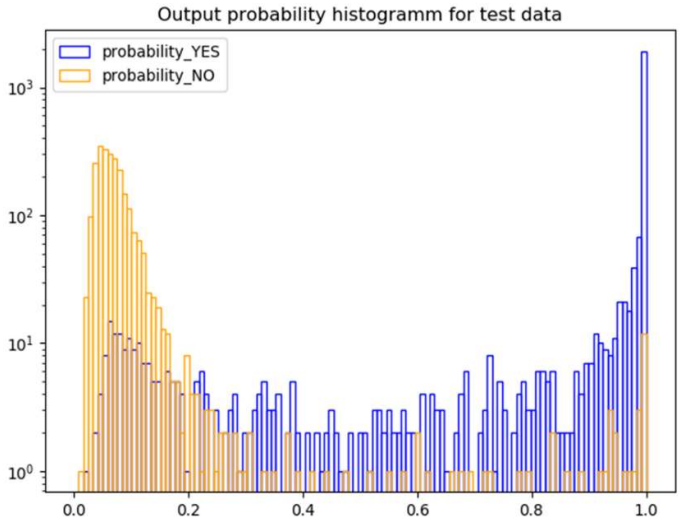

Figure 40: Neural network output values for the test sample. The examples in which a neutrino induced pulse was inserted are shown in blue while the only-noise examples are shown in orange. An example was classified as "containing a neutrino induced pulse" when the neural network output value was above 0.5

Quality Assurance and Quality Control (QA/QC) for KM3NeT

The distributed organization of KM3NeT production induces some special characteristics in the construction of the detector: there are two installation sites, integration of detection units is distributed over more than ten integration sites, qualification and acceptance testing of

components is performed in several testing facilities around Europe and procurement of components is done centrally by individual institutes-budget holders. Under this framework, ensuring uniformity in the production quality and traceability of all those components that travel continuously between European institutes are challenging tasks, requiring a robust QA/QC system.

The quality group of KM3NeT is one of the largest in terms of human resources; it consists by specially appointed local quality supervisors at each institute that participates in the KM3NeT production and as of 2016 is coordinated by the QA/QC manager, Giorgos Androulakis from INPP, NCSR "Demokritos". All members of the quality group, as well as the personnel of the integration facility of INPP are certified as ISO 9001:2015 internal auditors, after attending a seminar organized by G. Androulakis in cooperation with TÜV Hellas in 2017.

The duties of the QA/QC manager are, among others:

- KM3NeT-wide management of non-conformities,
- overseeing the validation and implementation of design changes,
- ensuring traceability of components,
- verifying the compliance of production sites with specifications;
- overseeing the configuration control of all applicable documentation;
- identifying the need and suggesting extra QC when appropriate;
- reporting to oversight committees such as the KM3NeT Institute board (IB),

Scientific and Technical Advisory Committee (STAC) and the Resource review Board (RRB).

Soon after taking over as QA/QC manager, he designed and implemented a fully automated, user friendly and database integrated quality management system in order to make it able to accommodate the increased demands of the upcoming mass production phase. The KM3NeT QA/QC system has been externally reviewed with a positive outcome whereas its coordination, in particular, receives regularly positive feedback from KM3NeT's oversight committees.

By the KM3NeT organogram, G. Androulakis is de facto a member of the Project Steering Committee as well as the Management Team, thus strengthening INPP's involvement in the decision making of KM3NeT. Moreover, under his aforementioned capacity he is continuously working on reinforcing the contribution of INPP in the technical activities of KM3NeT, which has a direct positive impact on the international visibility of our Institute and its personnel in particular. As a result, a series of technical activities such as calibration of positioning boards, qualification of new components, studies to characterize the E/M susceptibility of acoustic sensors and scrutinizing high severity NCRs are routinely performed by our group.

KM3NeT - INFRADEV

In 2017 the KM3NeT-INFRADEV project started, funded by H2020 for a period of 3 years. In the context of this project, Dr. E. Tzamariudaki is the coordinator of Work Package 9, on

"Technology transfer" and Dr. C. Markou is the Coordinator of Work package 10 on "Zero carbon footprint". Members of the group are also involved in most other WPs of the project.

"Measurement of the optical parameters of water"

S. Koutsoukos, G. Zarpapis, A. Vougioukas, E. Tzamariudaki, C. Markou

Commercially available instruments are not well suited for measurements of the optical parameters of the deployment sites as the small length optical base of such instruments requires an increased accuracy of the light intensity measurement. In order to obtain a reliable measurement of the water transparency, an open geometry light measuring system, the Long Arm Marine Spectrophotometer (LAMS), was constructed and was used to measure the transmission length in deep sea during the sea campaigns in 2008 and 2009(see *E.G. Anassontzis et al., Water Transparency Measurements in the deep Ionian Sea, Astroparticle Physics, Vol34, 187-197, 2010*). In the context of Technology transfer (WP 9 of the KM3NeT-INFRADEV project), a new version of the LAMS device is being constructed, keeping the same idea of measuring the transmission length, but simplifying the process by performing in a single deployment, simultaneous measurements at three different distances between emitter and receiver (Fig. 41) instead of three deployments needed for the original LAMS. In this way, the total measurement time can be reduced to just a few (~6) hours, the time being dominated by the time required to deploy and recover the system at the intended water depth. Since the design and operation of the old version of LAMS was successful, it was decided that the changes of the redesigned system be limited to those necessary and cannot be avoided (due to the lack of components which are no longer in production for example), or to small changes that would greatly improve the efficiency of the measurement. The new system will also record data from an external pressure sensor in order to register the depth of the system during deployment.

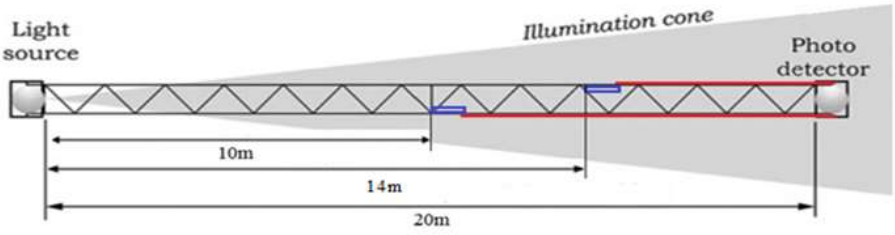

Figure 41: Rough schematic showing the placement of light receivers and light source

The prototype electronics board was delivered in January. The dark current rate of the prototype board was measured, both with and without the photodiodes attached to the board. The dark rate is very low, in the order of 5-20 ADC counts (with the dynamic range of the system being 65535 counts). The output stability was measured in a custom-made dark box, built specifically to test the LAMS PD boards. Figure 42 shows the recorded data from one of the stability tests, showing that the recorded light has a small full width half maximum

value, about 0.3% which is well under the 1% that was initially set as the upper limit value for light intensity uncertainty. Note that in the data analysis a 4-point rolling average will be used that will further decrease the uncertainty if the measured light intensity. The Photodiode board was also checked for the region of linear response, using light attenuation filters to reduce the intensity of the light source. The board was tested powered from a power supply unit for the first tests before using batteries. Once the prototype board was finalized, the three final boards were manufactured, and underwent the same tests for dark current, stability and linearity. The complete system with 3 photodiodes placed in the pressure casings and the light source mounted on the titanium frame is currently tested. Also, the internal support structures that will hold the boards and batteries and all associated cabling is being finalized and tested. Stainless steel pressure casings have also been manufactured to house the electronics and battery packs and are currently pressure tested.

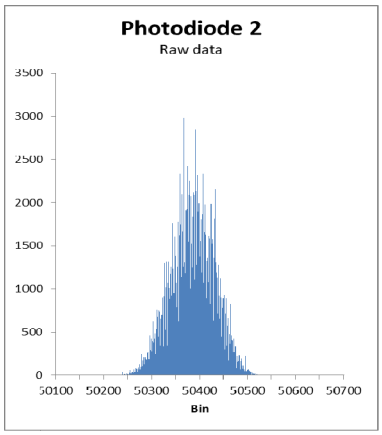

Figure 42: Raw data output histogram from photodiode 2 of the pre-production board with a stable light input.

Figure 43: LAMS photodiode board installed in pressure casing. The USB cable will be connected to the connector in the end cap to allow retrieval of the data.

The board will communicate with a PC via USB connection and custom-made software and will write the measurement data in a text file. The file data output will include the response of the photodiodes, the temperature from the on-board thermometer and the reading from the pressure sensor. The data analysis software developed for the original LAMS system has been recovered and is currently being modified accordingly to cope with the changes in the data format and to allow for an improvement and automation of the analysis procedure. The testing and finalization of the mechanical design of the complete structure and casings, the internal support structure of the casings that will hold the PD boards and the battery packs is ongoing.

"Zero carbon footprint"

The objective of the work package 10 of the KM3NeT-INFRADEV project is to supply energy to the KM3NeT research infrastructures from renewable energy technologies (RET). In 2019the techno-economic prospects were investigated. Several companies were contacted in order to acquire quotations for their available products in the examined locations. In addition, simulations and mathematical models were used for the prediction of the lifetime energy production and life cycle cost of the renewable energy systems. The levelized cost of energy (LCOE) was used as a metric to express the techno-economic prospects. The horizontal axis wind turbine (HAWT) LCOE range is € 0.045-0.070/kWh for Kalamata and € 0.034-0.052/kWh for Capo Passero while the range of the LCOE for the PV plants is € 0.030-0.046/kWh in Kalamata and € 0.027-0.041/kWh in Capo Passero. These values have been calculated for two financial scenarios (i.e. Scenario 1 and 2) and two time-durations of the systems' operation (i.e. 15 and 25 years). The LCOE results for the large-scale systems are depicted in Figure 44.

An analytic report was produced on the techno-economic study and the work was disseminated in the ANTARES-KM3Net collaboration meeting in Warsaw (October 2019). Finally, considering the whole analysis, it is recommended that the main RET for Kalamata area will be a fixed mounted grid-connected PV plant while for the region of Capo Passero is not clear yet whether the main RET will be a grid connected large-scale HAWT or a fixed mounted PV plant.

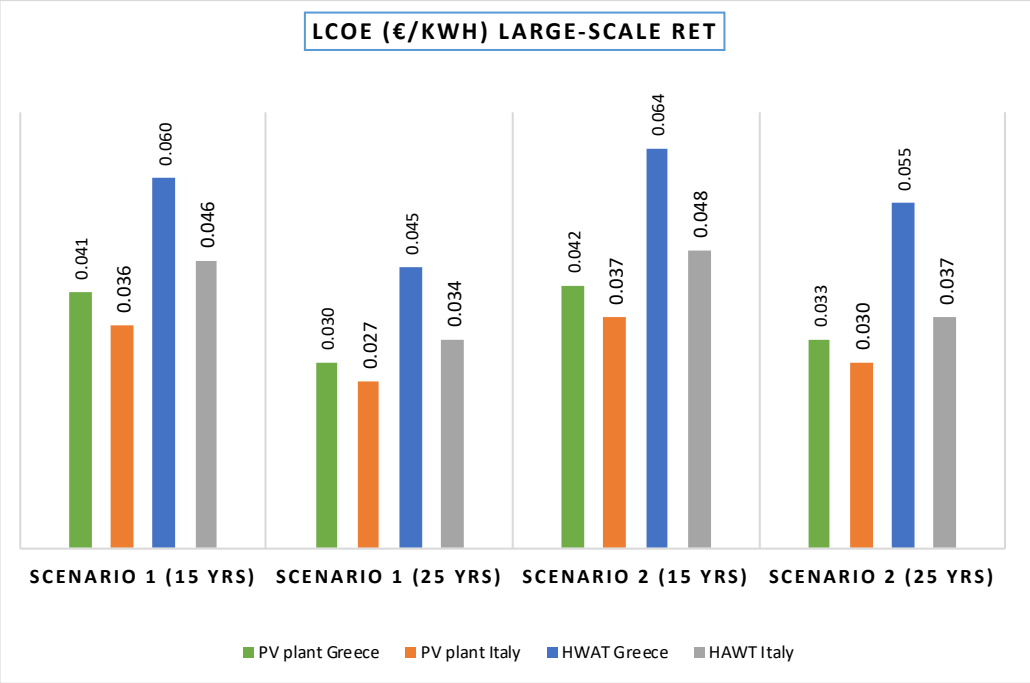

Figure 44: LCOE for large-scale HAWT and PV plant in Greece and Italy

"An Environmental Impact Study for KM3NeT-GR"

The objectives of the KM3NeT-INFRADEV project comprise environmental impact studies for all existent and potential installation sites. In this context, the necessity of a formal Environmental Impact Assessment (EIA) has been questioned for the scenario of an ARCA block at the KM3NeT-GR site offshore Pylos, connected to a shore station at Methoni. Despite the excellent physical characteristics of the area for installation of scientific equipment, there are several environmental constraints that should be taken into account. An environmental impact study has been carried out for which all environmental constraints have been collected, the corresponding regulatory authorities have been consulted for the environmental legal framework of the project and finally, the necessary preceding legal actions were identified. Theenvironmental impact study for the KM3NeT-GR site has been completed and delivered.

"Participation at the 84th International Exhibition of Thessaloniki with exhibits from the KM3NeT experiment."

In the framework of Knowledge and Technology Transfer, we participated in the Thessaloniki International Fair for technology and innovation in September 2019. In the KM3NeT kiosk videos were launched on large TV screens showing the most impressive snapshots from the deployment of KM3NeT Detection Units, posters and slide shows provided information both on the physics goals and the status of KM3NeT, as well as the on

the technical aspects (technical solutions and achievements) of the experiment; a Virtual Reality experience allowed visitors to "dive" to the abyssal depth of the Mediterranean sea and "observe" sea life as well as detection elements of the experiment. A digital optical module (DOM) with a fully integrated lower hemisphere prepared for exhibition purposes was also exhibited. More than 500 visitors among which University students, academics and tech experts were introduced by our team to the KM3NeT physics objectives and technology. Our researchers discussed with the public, answered questions on the physics and presented the technical innovations of the KM3NeT experiment. More than 200 visitors of all ages tried the Virtual Reality experience. This was the first time KM3NeT participated at the International Exhibition of Thessaloniki. It was very successful as both experts and the general public showed great interest in both the scientific goals and the technology of the experiment.

Kalamata Branch

"The Nestor and HCMR cable DAS experiment"

A Collaboration between Université Côte d'Azur, CNRS, Febus-optics, HCMR and the INPP has been established aiming at the distributed sensing of earthquakes and ocean-solid Earth interactions using two orthogonal fiber optic seafloor cables, offshore Methoni, Greece.

Recently, the capacity to turn optical fibers (OF) into seismo-acoustic sensors has been developed. Distributed Acoustic Sensing (DAS), exploits the phase of light that is back-scattered by the inherent inhomogeneities of the silica fiber to provide densely spaced, high-rate measurements of strain. Fiber optic measurements were taken on two offshore cables laid approximately orthogonally, offshore Methoni, south-west of Peloponnese, Greece. The HCMR cable, north-west oriented, is 13 km long and reaches a depth of 1800 m, while the NESTOR cable, south-west oriented, is 26 km long and reaches a depth of 3700 m.

The optical acquisition systems were set to provide longitudinal strain-rate measurements at least every 20 m. The shortest cable is connected to a multi-instrumental underwater station with an ocean bottom broadband seismic sensor, while two temporary broadband seismic sensors were installed on land. The analysis of the data is performed by the group of the Université Côte d'Azur and is ongoing. This activity is expected to continue over the next year.

Future Plans

The Astroparticle Physics group will continue the work in KM3NeT, with emphasis both in the construction and operation of the detector according to the current planning as detailed by the KM3NeT MoU and in the analysis of the data from the detection units deployed. In addition, we will continue to exploit the possibility to initiate activities in the SW Peloponnese site in order to establish a KM3NeT infrastructure based on acoustic detection techniques in the coming years.

Publications (including conference proceedings)

KM3NeT Publications

1) The Control Unit of the KM3NeT Data Acquisition System
by the KM3NeT Collaboration (S. Aiello *et al.*). arXiv:1910.00112 [astro-ph.IM]

2) KM3NeT front-end and readout electronics system: hardware, firmware and software, by the KM3NeT Collaboration (S. Aiello *et al.*). arXiv:1907.06453 [astro-ph.IM]

3) Dependence of atmospheric muon rate on seawater depth measured with the first KM3NeT detection units by the KM3NeT Collaboration (M. Ageron *et al.*). arXiv:1906.02704 [physics.ins-det]

4) Knowledge and Technology Transfer in KM3NeTE. Tzamariudaki and K. Pikounis on behalf of the KM3NeT Collaboration. Published in EPJ Web Conf. 207 (2019) 06001 DOI: 10.1051/epjconf/201920706001

5) Analysis of High Energy Starting Events with the KM3NeT/ARCA detector, K. Pikounis, E. Tzamariudaki and C. Markou on behalf of the KM3NeT Collaboration. Published in EPJ Web Conf. 207 (2019) 02006 DOI: 10.1051/epjconf/201920702006

6) Letter of Interest for a Neutrino Beam from Protvino to KM3NeT/ORCA, A.V. Akindinov et al. Published in Eur.Phys.J. C79 (2019) no.9, 758

7) Sensitivity of the KM3NeT/ARCA neutrino telescope to point-like neutrino sources by the KM3NeT Collaboration (S. Aiello *et al.*). e-Print: arXiv:1810.08499 [astro-ph.HE] Published in Astropart. Phys. 111 (2019) 100-110

Talks/KM3NeT Presentations in International Conferences

1) "KM3NeT: the next generation neutrino detectors", K. Pikounis for the KM3NeT Collaboration. Presented at the "Conference on Recent Developments in High Energy Physics and Cosmology", Athens, Greece, April 2019.
2) "Data from the first detection units of the KM3NeT/ARCA detector", A. Sinopoulou. Presented at the "Conference on Recent Developments in High Energy Physics and Cosmology", Athens, Greece, April 2019.

Nuclear Physics and Applications

Theoretical Nuclear Physics

Nuclear Structure Theory

Head of the group: Dennis Bonatsos (Ph.D. U. Pennsylvania 1985), Director of Research

Postdoctoral research associate: Andriana Martinou (Ph.D. National Technical University of Athens 2018)

Ph.D. graduate students: Ioannis Assimakis (NTUA), Smaragda Sarantopoulou (NTUA), Hadi Sobhani (Shahrood U. of Technology, Shahrood, Iran, co-supervised with Hassan Hassanabadi)

M.Sc. thesis students: Spyridon Peroulis (NTUA)

International collaborators

- Richard F. Casten, Yale U., USA
- Klaus Blaum, Max Planck Institute for Nuclear Physics, Heidelberg, Germany
- Nikolay Minkov, INRNE, Bulgarian Academy of Sciences, Sofia, Bulgaria
- R. Burch Cakirli, Istanbul U., Turkey

Research project: Proxy-SU(3) symmetry

Since 2015 the group has been developing its own theory, the proxy-SU(3) symmetry.

The SU(3) symmetry realized by J. P. Elliott in the sd nuclear shell is destroyed in heavier shells by the strong spin-orbit interaction. On the other hand, the SU(3) symmetry has been used for the description of heavy nuclei in terms of bosons in the framework of the Interacting Boson Approximation, as well as in terms of fermions using the pseudo-SU(3) approximation. We have introduced a new fermionic approximation, called the proxy-SU(3) [R1,R2,R3].

The proxy-SU(3) symmetry appears in heavy deformed even-even nuclei, by omitting the intruder Nilsson orbital of highest total angular momentum and replacing the rest of the intruder orbitals by the orbitals which have escaped to the next lower major shell [R1]. The approximation is based on the fact that there is a one-to-one correspondence between the orbitals of the two sets, based on pairs of orbitals having identical quantum numbers of orbital angular momentum, spin, and total angular momentum. We call them 0[110] pairs of orbitals [R1, R4]. The accuracy of the approximation has been tested through calculations in the framework of the Nilsson model in the asymptotic limit of large deformations, focusing attention on the changes in selection rules and in avoided crossings caused by the opposite parity of the proxies with respect to the substituted orbitals [R1].

Using the new approximate analytic parameter-free proxy-SU(3) scheme, we have made [R2] predictions of shape observables for deformed nuclei, namely β and γ deformation variables, and compared them with empirical data and with predictions by relativistic and non-relativistic mean-field theories. Furthermore, simple predictions for the global feature of prolate over oblate dominance and for the locus of the prolate-oblate shape transition have been made and compared with empirical data [R2,R3]. The mechanism leading to the breaking of the particle-hole symmetry has been clarified. It turns out that this mechanism is based on the SU(3) symmetry, the Pauli principle, and the short range of the nucleon-nucleon interaction, without reference to any specific Hamiltonian [R3].

Outlook

When our group and our international collaborators started taking about the importance of 0[110] pairs [R4] six years ago, the majority of people in the international community were jumping up and down, stating that it is impossible for these pairs to be formed, since they belong to different major shells and therefore cannot meet, because they are very far from each other in energy. By now everybody has swallowed the fact that the protons and the neutrons forming the 0[110] pairs are both lying very close to the Fermi energy, thus the formation of the 0[110] pairs is easy and can take place beyond any doubt.

When our group and our international collaborators started talking, two years ago, about the fact that the highest weight SU(3) irreducible representations have to be used beyond mid-shell in the place of the irreps possessing the highest eigenvalues of the second order Casimir operator of SU(3) [R2,R3,R16], the majority of people in the international community were jumping up and down, stating that the irreps with the highest Casimir eigenvalues should be used, because of the dominance of the quadrupole-quadrupole interaction. By now everybody has swallowed the fact that the restrictions of the Pauli principle are the most important factor to be first taken into account, imposing beyond mid-shell the use of the highest weight irreps instead of the irreps possessing the highest Casimir eigenvalue. Recent work [R11] applying these ideas to the pseudo-SU(3) model also proves this beyond any doubt.

Now that our group started talking about the fact that shape coexistence does not appear everywhere in the nuclear chart, but only in certain regions with specific borders [R5, R7, R9, R14, R15, R16], again the majority of people in the international community are jumping up and down, stating that shape coexistence is due to particle-hole excitations and therefore it can appear everywhere. It will probably take them a year or two to swallow the fact that it is the interplay between the shell model (spin-orbit) magic numbers and the harmonic oscillator magic numbers which decides in which nuclei shape coexistence can appear and of what type this will be.

The proxy-SU(3) symmetry can be used for a wide variety of projects. Preliminary results show, for example, into the following directions. Analytic expressions can be derived for B(E2) ratios within the proxy-SU(3) model, free of any free parameters, and/or scaling factors. The predicted B(E2) ratios are in good agreement with the experimental data for deformed rare earth nuclides. Spectra can also be determined through the use of three-

and/or four body terms [R10]. Important features of two-neutron separation energies can be reproduced in a parameter-free way [R8]. Extension of these ideas to superheavy nuclei is also possible [R13]. An extension of proxy-SU(3) to shells in which protons and neutrons coexist is also possible.

The growing number of invitations for review articles [R5,R6,R7] indicates that proxy-SU(3) is in the upswing.

References

[R1] ``Proxy-SU(3) symmetry in heavy deformed nuclei", D. Bonatsos, I. E. Assimakis, N. Minkov, A. Martinou, R. B. Cakirli, R. F. Casten, and K. Blaum, Phys. Rev. C 95 (2017) 064325 (12 pages+12 pages supplement). arXiv 1706.02282 [nucl-th]

[R2] ``Analytic predictions for nuclear shapes, the prolate dominance and the prolate-oblate shape transition in the proxy-SU(3) model", D. Bonatsos, I. E. Assimakis, N. Minkov, A. Martinou, S. Sarantopoulou, R. B. Cakirli, R. F. Casten, and K. Blaum, Phys. Rev. C 95 (2017) 064326 (12 pages). arXiv 1706.02321 [nucl-th].

[R3] ``Prolate over oblate dominance in deformed nuclei as a consequence of the SU(3) symmetry and the Pauli principle", D. Bonatsos, **Letter to the Editor**, Eur. Phys. J. A 53 (2017) 148 (2 pages). arXiv 1707.03763 [nucl-th].

[R4] ``Emergent collectivity in nuclei and enhanced proton-neutron interactions", D. Bonatsos, S. Karampagia, R.B. Cakirli, R.F. Casten, K. Blaum, L. Amon Susam, Phys. Rev. C 88 (2013) 054309 (5 pages). arXiv 1310.7599 [nucl-th].

Invited Articles in Special Volumes

[R5] ``Magic numbers of cylindrical symmetry", A. Martinou and D. Bonatsos, in Nuclear Structure Physics, ed. A. Shukla and S.K. Patra, CRC Press, to be published. arXiv: 1909.00233 [nucl-th].

Preprints

[R6] ``Proxy-SU(3) symmetry", D. Bonatsos, A. Martinou, et al., **invited review article** in ``Role of symmetries in nuclear physics", Eur. Phys. J. A: Special Topics, ed. A. Jain and V.K.B. Kota, in preparation.

[R7] ``A mechanism for shape coexistence", A. Martinou, D. Bonatsos, et al., **invited review article** in Eur. Phys. J. A, in preparation.

International Conference Articles Published in Journals

[R8] ``Two-nucleon separation energies within the proxy-SU(3) model", S. Sarantopoulou, A. Martinou, and D. Bonatsos, in preparation, to appear in Bulg. J. Phys. (2019). Proceedings of the Workshop on ``Shapes and Dynamics of Atomic Nuclei: Contemporary Aspects" (SDANCA19, Sofia 2019), ed. N. Minkov.

[R9] ``A mechanism for shape coexistence", A. Martinou, D. Bonatsos et al., in preparation, to appear in Bulg. J. Phys. (2019). Proceedings of the Workshop on ``Shapes and Dynamics of Atomic Nuclei: Contemporary Aspects" (SDANCA19, Sofia 2019), ed. N. Minkov.

[R10] ``Proxy-SU(3) symmetry for heavy deformed nuclei: nuclear spectra", D. Bonatsos et al., in preparation, to appear in Bulg. J. Phys. (2019). Proceedings of the Workshop on ``Shapes and Dynamics of Atomic Nuclei: Contemporary Aspects" (SDANCA19, Sofia 2019), ed. N. Minkov.

Articles in International Conference Proceedings

[R11] ``Manifestations of SU(3) symmetry in heavy deformed nuclei", D. Bonatsos, A. Martinou, I.E. Assimakis, S. Sarantopoulou, S. Peroulis, and N. Minkov, to appear in Nuclear Theory '38, Proceedings of the 38th International Workshop on Nuclear Theory (Rila 2019), ed. M. Gaidarov and N. Minkov. arXiv: 1909.01967 [nucl-th].

Articles in Greek Conference Proceedings

[R12] ``N=90 QSPT: Cerium, neodymium, and samarium isotopic chains in the IBM symmetry triangle", P. Koseoglou, V. Werner, N. Pietralla, and D. Bonatsos, to appear in HNPS: Advances in Nuclear Physics :Proceedings of the 27th Annual Symposium of the Hellenic Nuclear Physics Society (Athens, 2018), ed. T. Mertzimekis, G. Souliotis, and E. Styliaris (2019) p. 37-43.

[R13] ``Synergy of nuclear data systematics and proxy-SU(3) in planning future experiments in the superheavies mass region", S.K. Peroulis, S.B. Bofos, T.J. Mertzimekis, A. Martinou, and D. Bonatsos, to appear in HNPS: Advances in Nuclear Physics :Proceedings of the 27th Annual Symposium of the Hellenic Nuclear Physics Society (Athens, 2018), ed. T. Mertzimekis, G. Souliotis, and E. Styliaris (2019) p. 255-258. arXiv: 1811.04823 [nucl-th].

[R14] ``Nucleon numbers for nuclei with shape coexistence", A. Martinou, D. Bonatsos, N. Minkov, T. Mertzimekis, I.E. Assimakis, S. Peroulis, and S. Sarantopoulou, to appear in HNPS: Advances in Nuclear Physics :Proceedings of the 27th Annual Symposium of the Hellenic Nuclear Physics Society (Athens, 2018), ed. T. Mertzimekis, G. Souliotis, and E. Styliaris (2019) p. 96-103. arXiv: 1810.11860 [nucl-th].

[R15] ``Magic numbers for shape coexistence", I.E. Assimakis, D. Bonatsos., A. Martinou, S. Sarantopoulou, S. Peroulis, T. Mertzimekis, and N. Minkov, to appear in HNPS: Advances in Nuclear Physics :Proceedings of the 27th Annual Symposium of the Hellenic Nuclear Physics Society (Athens, 2018), ed. T. Mertzimekis, G. Souliotis, and E. Styliaris (2019) p. 9-16. arXiv: 1811.01071 [nucl-th].

[R16] ``Particle-hole symmetry breaking due to Pauli blocking", D. Bonatsos, I.E. Assimakis, A. Martinou, S. Sarantopoulou, S. Peroulis, and N. Minkov, to appear in HNPS: Advances in Nuclear Physics :Proceedings of the 27th Annual Symposium of the Hellenic Nuclear Physics Society (Athens, 2018), ed. T. Mertzimekis, G. Souliotis, and E. Styliaris (2019). arXiv: 1810.11858 [nucl-th].

Diploma Theses completed

Peroulis, Spyridon, National Technical U. of Athens (09/2019). ``Proxy-SU(3) symmetry in atomic nuclei".

Organization of international schools and conferences

- International Workshop on Shapes and Dynamics of Atomic Nuclei: Contemporary Aspects (SDANCA-19), Sofia, Bulgaria, 10/2019.
  DB: Member of the International Program Committee.
- 35thInternational Physics Congress of the Turkish Physical Society (TPS-35), Konacik, Bodrum, Turkey, 9/2019.
  DB: Member of the Scientific Committee.
- 38th International Workshop on Nuclear Theory, Rila Mountains, Bulgaria (6/2019).
  DB: Member of the International Advisory Committee.

Organization of national schools and conferences

5th Hellenic Institute of Nuclear Physics Workshop on New Aspects and Perspectives in Nuclear Physics (HINPw5), Thessaloniki, 4/2019.

DB: Member of the Organizing Committee.

Participation in international conferences

- International Workshop on Shapes and Dynamics of Atomic Nuclei: Contemporary Aspects (SDANCA-19), Sofia, Bulgaria, 10/2019.
  DB: Invited lecture on ``Proxy-SU(3) symmetry for heavy deformed nuclei: nuclear spectra".
  AM: Invited lecture on ``A mechanism for shape coexistence".
  SS: Invited lecture on `` Two-nucleon separation energies within the proxy-SU(3) model".
- 38th International Workshop on Nuclear Theory, Rila Mountains, Bulgaria. 6/2019.
  DB: Invited lecture on ``Manifestation of SU(3) symmetry in heavy deformed nuclei".
  AM: Invited lecture on ``A mechanism for shape coexistence".

Participation in Greek conferences

- 28thAnnual Symposium of the Hellenic Nuclear Physics Society, Thessaloniki, 5/2019.
  AM: Lecture on ``A mechanism for shape coexistence".
  SS: Lecture on: ``Proxy-SU(3) predictions"
- 5th Hellenic Institute of Nuclear Physics Workshop on New Aspects and Perspectives in Nuclear Physics (HINPw5), Thessaloniki, 4/2019.

DB: Lecture on ``Approximate SU(3) symmetries in heavy nuclei".
AM: Lecture on ``A mechanism for shape coexistence".
IA: Lecture on ``Breaking SU(3) spectral degeneracies in heavy deformed nuclei."

Research Visits and Invited Seminars abroad

DB: Max Planck Institute for Nuclear Physics, Heidelberg, Germany (1/2019).

Research collaboration with K. Blaum, R.F. Casten, and R.B. Cakirli.

Funding

The only support received by the group was the salary of the head of the group (DB) as a permanent researcher, plus 2 months of postdoc salary (2300 euro per month, before tax and insurance) for AM. In addition, SS got a travelling grant of 300 euro from NTUA in order to participate to the SDANCA2019 Workshop.

Andriana Martinou has submitted the following proposals:

1) Ministry of Finance and Development, Partnership Agreement 2014-2020. ``Nucleon separation energies", funding for 15 months for a postdoc (AM) and a Ph.D. candidate (SS), expected to start by the end of 2019. Budget 41,500 euro. Approved.
2) Hellenic Foundation of Research and Innovation, support for postdoctoral researchers, ``Enrichment of theory of nuclei", duration 36 months, budget 200.000 euro. Pending.
3) Greek State Scholarships Foundation, support for postodoctoral researchers, ``Nuclear magnetic moments", duration 24 months, budget 26,400 euro. Pending. Received a grade of 93.75/100, thus it will be obviously approved.

Citations by third parties

Data presented regard the head of the group. All self-citations and citations by coauthors have been omitted. Double citations (article+preprint) are included as one item and counted once. Each paper is counted once, irrespectively of the number of coauthors belonging to the group.

Last revision: 25 December 2018

Citations in the SCI:	**2523**
Other citations in Spires etc:	**721**
Total:	**3244**
h index:	**31**

ResearchGate data as of 20 Oct. 2019

Research items	**221**
Citations	**3070**

Reads **6401**

Nuclear reaction theory and nuclear data

Permanent Staff: Paraskevi Dimitirou

Status

Senior Researcher at INPP: December 2013 – present

Position at International Atomic Energy Agency (leave of absence from INPP): 24 June 2012 - 23 June 2019

Nuclear Astrophysics

Compound nuclear reactions in the statistical regime

One of the main challenges of Nuclear Astrophysics is to explain the origin of the chemical elements in the Universe. For elements heavier than iron, three processes have been identified as responsible for their synthesis, the s, r and p processes. These processes involve series of thermonuclear reactions such as neutron capture, photo-dissociation followed by neutron, proton or alpha-particle emission, nuclear fission and delayed processes. The determination of elemental abundances requires the solution of extensive networks of thousands of these reactions and relies largely on theoretical predictions of thousands of reaction rates or cross sections. Large-scale cross-section calculations are performed with the statistical Hauser-Feshbach model and depend strongly on our knowledge of nuclear properties such as the structure of the nucleus, the density of levels of a hot nucleus, electromagnetic strength functions, particle-nucleus interactions, fission paths and yields We therefore need to develop global microscopic models of these nuclear properties that are able to reproduce the existing data with sufficient accuracy and provide reliable predictions when extrapolating to the experimentally unexplored region of very unstable nuclei.

Our research efforts focus on developing global microscopic models of nuclear properties that are relevant to the p and r processes.

i. For the p process, one of the major sources of uncertainty is the poor knowledge of the alpha-nucleus average potential. We have developed a semi-microscopic global alpha-nucleus optical potential [1], where the real part is derived from appropriate microscopic many-body techniques that take due consideration of the effective nucleon-nucleon interaction and the imaginary part is based on an empirical Woods-Saxon form that takes into account the opening of reaction channels at low projectile energies. This alpha-nucleus optical potential has been successful in reproducing the bulk of the available experimental data. However, new measurements of alpha-induced reaction cross sections on rare-earth nuclei that have been published in the past decade show differences compared to the alpha-OP calculations that need to be investigated. We have been working on developing a revised alpha-nucleus optical potential that takes into account deformation. The first results are promising and now our efforts are focused on validating this deformed alpha-nucleus potential on large-scale calculations and testing its impact on p-process simulations.

ii. Global models of nuclear ingredients of the statistical compound nucleus reaction theory are relevant to all heavy-element nucleosynthesis simulations (s, r, and p processes). We are studying the systematic trends of global nucleon-nucleus optical potentials and electromagnetic strength functions with the aim of improving the empirical parameterization and developing improved global models for large-scale reaction rate calculations [2].
Nucleon-nucleus optical potentials: new parameterizations of the Koning-Delaroche and Bauge, Delaroche, Girod potentials are currently in preparation.

iii. Electromagnetic strength functions: validation of the global QRPA strength functions developed by [3] against all existing radiative proton- and alpha-capture cross section data is underway.

Compound nuclear reactions in the resolved resonance regime

The production of elements lighter than iron in the universe is based mainly on thermonuclear fusion of light elements. Thermonuclear fusion takes place through consecutive cycles involving different fuel elements starting with H and extending all the way to Si. In the laboratory, these reactions occur at very low energies through the excitation of nuclear resonances. When these resonances are resolved, the main method used to describe them is the R-matrix theory.

In the last few years we have been studying thermonuclear reactions in the resolved resonance region using the R-matrix code SAMMY [RSICC-ORNL]. The main purpose is to evaluate all the existing experimental data by considering all reaction channels leading to the same compound nucleus simultaneously. The global fit of all available experimental data is performed with Bayesian inference and includes calculating parameter uncertainties as well as correlations between the uncertainties (covariance matrix).

This work has been performed so far within an international collaboration coordinated by the International Atomic Energy Agency (IAEA) [4] and will continue in the next few years in cooperation with the Technical University of Vienna (TUW) and the IAEA.

The project is closely related to the activities of the Tandem Accelerator Laboratory in the field of Ion Beam Analysis. The evaluated cross sections for light elements in the resolved resonance region are widely used in Ion Beam Analysis applications for surface bulk and depth sampling. On the other hand, the Tandem Accelerator Laboratory group is involved in a series of measurements of cross sections for such applications and are also developing analysis tools that depend on evaluated cross sections [5]. The synergy between the theoretical and experimental efforts in this field is of mutual benefit for both groups.

Nuclear data for basic science and applications

Nuclear data are essential for many applications in the fields of energy, medicine, environmental monitoring, and cultural heritage. Nuclear data are also indispensable for nuclear physics researchers, who need the data to improve their knowledge from existing studies and to plan future activities that may lead to new discoveries. In nuclear astrophysics,

we rely on mass tables and databases of beta-decay data, beta-delayed neutron emission and fission yield data to simulate the r process of nucleosynthesis.

The development of reliable, accurate and precise nuclear data for reactions cross sections and structure and decay properties of fission products and structural material relevant for these applications, relies on a process called 'nuclear data evaluation'. Nuclear data evaluation is based on a critical assessment of all available experimental data and the use of theoretical models and statistical techniques such as Bayesian inference to extract recommended values for cross sections and decay data [6].

Nuclear data for astrophysics

In the past few years, we have been involved in efforts to evaluate all existing data on beta-delayed neutron emission [7] and fission yields [8] and to further validate them against reactor integral data. Our current efforts will focus on (i) investigating the impact of these newly evaluated beta-delayed neutron data on the r-process nucleosynthesis and (ii) evaluating fission yield data for the major actinides ^{235,238}U, ^{239,241}Pu and ^{252}Cf within a new IAEA project.

Nuclear data for monitoring applications

Radioactive-decay data are important for environmental monitoring. The analysis of air, soil and water samples collected in monitoring stations or on-site by international organisations (CTBTO, IAEA) and national institutes rely on the accuracy and precision of the available radioactive decay data.

We are participating together with experts from Canada, Spain, UK, and USA in an international project on Decay Data for Monitoring Applications coordinated by the IAEA. Our task is to evaluate the nuclear structure and decay data of a number of fission products using the methodologies adopted by the international network of nuclear structure and decay data evaluators for the Evaluated Nuclear Structure File and following the guidelines outlined at the expert group meeting organized by the IAEA.

References

[1] "An improved global alpha-nucleus optical potential", P. Dimitriou, C. Grama, S. Goriely, Nucl. Phys. A 718, (2003); P. Dimitriou and M. Axiotis, AIP Conference Proceedings, 891, 281 (2007)

[2] "Cross section measurements of proton capture reactions on Mo isotopes relevant to the astrophysical p process", V. Foteinou, M. Axiotis, S. Harissopulos, P. Dimitriou, et al., Eur. Phys. J. A 55:67 (2019)

[3] "A Reference Database for Photon Strength Functions", S. Goriely, P. Dimitriou, et al., invited review, Eur. Phys. J. A 55:172 (2019)

[4] "Verification of R-matrix calculations for charged-particle reactions in the resolved resonance region for ^{7}Be compound system", I.J. Thompson, R. J. deBoer, P. Dimitriou, et al., invited review,

Eur. Phys. J. A 55:92 (2019)

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A. Lagoyannis, V. Manteigas, M. Mayer, K. Preketes-Sigalas, and P. Dimitriou, submitted to NIMB;

presented at IBA2019.

[6] "IAEA Photonuclear Data Library", T. Kawano, Y-S. Cho, P. Dimitriou, et al., to be published in Nuclear Data Sheets, Special Issue, January 2020

[7] "Reference database for beta-delayed neutrons", P. Dimitriou, I. Dillmann, et al., submitted to Nuclear Data Sheets (2019)

[8] "Effect of Fission Yield Data in the Calculation of Antineutrino Spectra for ^{235}U neutron-induced fission at Thermal and Fast Neutron Energies", A.A. Sonzogni, E.A. McCutchan, T.D. Johnson, P. Dimitriou, Phys. Rev. Lett. 116, 132502 (2016)

Conference proceedings

International Nuclear Physics Conference (INPC2019), 28 July – 2 August 2019, Glasgow,invited talk: "Nuclear Data for Basic Sciences and Applications", to be published in Journ. of Phys. Conferences.

Organisation of conferences

Chair of the Organising Committee of the 7th International Workshop on Compound-Nuclear Reactions and Related Topics (CNR*20), 5-9 october 2020, Athens.

The conference is the 7th of a series of conferences held in Yosemite National Park (2007), Bordeaux (2009), Prague (2011), Sao Paolo (2013), Tokyo (2015) and Berkeley (2018). In keeping with the tradition, the workshop will bring together scientists from the fields of nuclear theory, experiment, data evaluation, nuclear astrophysics and other applications. The aim is to review the current status of experimental and theoretical efforts in compound-nuclear reactions and related areas, discuss new developments and needs for improvement, exchange ideas about how to address these needs and share perspectives on the future of the field.

The conference was awarded to the INPP group by the CNR committee following a review of 3 separate bids. It will be organised by the INPP in the framework of the project "CALIBRA" (MIS 5002799) which is implemented under the Action "Reinforcement of the Research and Innovation Infrastructure", funded by the Operational Programme "Competitiveness, Entrepreneurship and Innovation" (NSRF 2014-2020) and co-financed by Greece and the European Union (European Regional Development Fund), CALIBRA, in collaboration with Los Alamos National Laboratory. The venue will be the National Hellenic Research Foundation in the center of Athens.

Organising Committee

Paraskevi Dimitriou (INPP) - Chair

Michail Axiotis (INPP)

Anastasia Georgiadou (LANL)

Anastasios Lagoyannis (INPP)

Eleni Vagena (INPP)

Proceedings will be published following peer-review in Eur.Phys. J. Web of Conferences. A selection of 15 papers will be pubished in a topical issue on Compound-Nuclear Reactions and Related Topics in Eur. Phys. J. Nuclear Science & Technology.

Conference website: http://www.inp.demokritos.gr/cnr2020

Conference Email: cnr2020@inp.demokritos.gr

Experimental Nuclear Physics

Permanent Staff: Sotirios V. Harissopulos, Anastasios Lagoyannis, Michail Axiotis

Research Associates: Zoi Kotsina, Eleni Vagena, Manousos Ioannis Manousakas

PhD Students: Kostas Preketes-Sigalas, Eleni Ntemou, Giannis Madesis, Aggelos Laoutaris

MSc Students: Eleni Alvanou, Euthimios Daoulas, Stefanos Nanos

Scientific Program

The main activities of the Experimental Nuclear Physics group are implemented at the local TANDEM Accelerator Laboratory (TAL). The scientific program of the team consists mainly of research on nuclear astrophysics and applications on Ion Beam Analysis (IBA) techniques, along with studies in the field of nuclear structure. In the following paragraphs the scientific output of the group is presented, while the activities relevant to the TAL (upgrades, new setups, …) are presented in the relevant section below.

Nuclear Astrophysics

Stellar nucleosynthesis of elements above iron is known to proceed primarily by neutron capture reactions on already formed nuclides, which then decay by emitting electrons (β^- decay), by the so-called s and r processes. Among the stable nuclei that are heavier than Fe, there exist 35 nuclei that lie on the neutron-deficient side of the stability valley between ^{74}Se and ^{196}Hg, which cannot be synthesized by either the s or the r process because stable isobars shield them from the β^- decay of more neutron-rich nuclei. To date, the predictions of the solar-system abundances of these nuclei, the so-called p nuclei, is one of the major puzzles of all models of p-process nucleosynthesis, since although the latter are capable of reproducing these abundances within a factor of 3, they fail in the case of some light p-nuclei around A≈90 with ^{92}Mo and ^{94}Mo being the most striking cases. These discrepancies could be attributed to uncertainties in the pure astrophysical modeling, but nuclear physics uncertainties need also to be considered, since these calculations rely heavily in the use of the Hauser-Feshbach (HF) theory. In view of these problems, it is of key importance to investigate the uncertainties associated with the nuclear properties entering the HF calculations. In this line of research, the group of the TAL reported in 2019 the cross-section measurements of proton-capture reactions on all stable Mo isotopes, except of ^{95}Mo, aiming to provide a sensitive reliability check of the existing nuclear models.

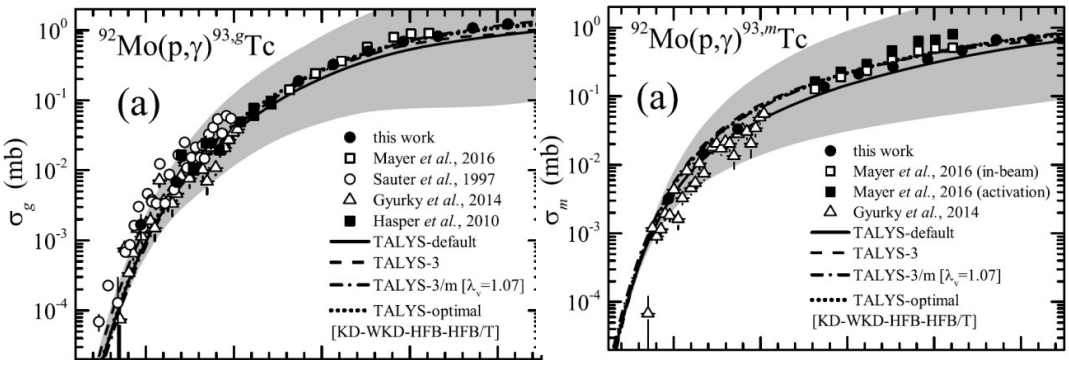

Figure 44: Cross-sections of proton induced reaction on ^{92}Mo along with previous data and HF calculations. On the left panel the cross-sections to the ground state is shown, while on the right one to the first metastable.

Nuclear Structure

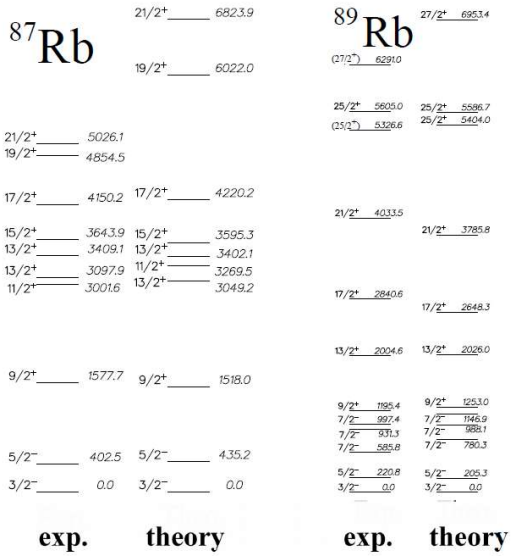

Figure 45 SM calculations for ^{87}RB and ^{89}Rb along with their partial level schemes

The quest of understanding the nucleon interactions is ongoing. The advances on the experimental and accelerative setups allow for more detailed investigations of phenomena and nuclei that were previously unreachable. Alongside, the computational advances have allowed theoretical calculations with very large model spaces, leading to an attempt to refine the theoretical models in order to predict/reproduce the experimental observables. In this line of research, the group of the TAL with their international collaborators, have reported in 2019 on the medium-spin structure of the ^{87,89,91}Rb isotopes, aiming to study the evolution of the level structure with increasing neutron number and to compare with shell-model (SM) calculations. Furthermore, the electric quadrupole matrix elements for the $J^{\pi}=2^{+}\rightarrow 0^{+}$, $\Delta T=0$, $T=1$ transitions across the A=46 isobaric multiplet have been measured, allowing a direct insight into the isospin purity of the states of interest.

Moreover, in collaboration with the NTUA and the UoI, the group published the cross-sections of the ^{193}Ir(n,2n) reaction at neutron energies ranging from 10 to 21 MeV. For the determination of the cross-sections, a new methodology was developed and therein explaned, in order to account for the contribution of the ^{191}Ir(n,γ)^{192}Ir reaction, which is open to low energy parasitic neutrons.

Ion Beam Analysis

For Ion Beam Analysis purposes, the group has continued the activities on improving and enhancing their applicability. Towards this goal, a number of differential cross section

measurements was conducted. In order to improve the use of Elastic Backscattering Spectroscopy the differential cross sections of elastic deuteron scattered on ^{nat}Si, ^{31}P and ^{9}Be were measured in backwards angles. The latter reaction - $^{9}Be(d,d)^{9}Be$ - is of high importance as this cross section is used in the analysis of JET wall tiles and the existing cross sections are discrepant. Moreover, new PIGE related cross section measurements were performed for gamma – ray emitting proton induced reactions on Sodium. The group has also continued the studies of Joint European Torus (JET) wall Tiles in collaboration with the EuroFUSION team of INRASTES. In more details, five sectioned tiles were analyzed (plasma facing and castellation sides) using the $^{12}C(d,p_0)^{13}C$ reaction. The experiment was performed at the microbeam setup at an area of 1500 x 1500 μm^2 with a spatial resolution of 50 x 50 μm^2. The microbeam setup with a proton beam was also used in order to determine the ration of Zr over Hf in ferroelectric samples.

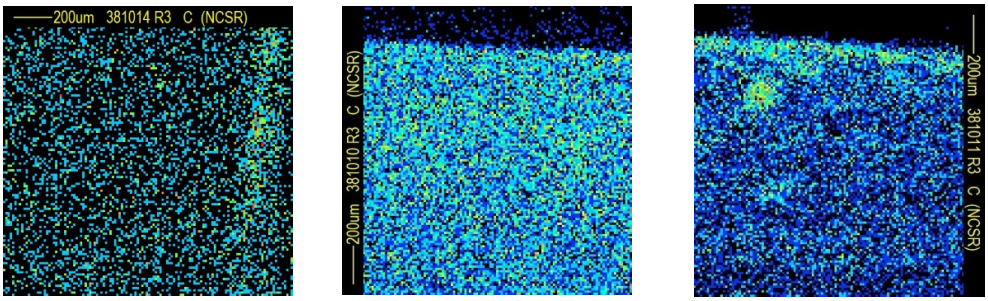

Figure 46: Carbon matrices on the surface and two castellation sides of a JET Tile

Furthermore, the group of Experimental Nuclear Physics of the Institute continued its efforts on the European Space Agency (ESA) project G4G. The project initiated in 2018, when several Geant4 based codes of ESA were reviewed. As a result of the review several improvements/changes were proposed at the beginning of 2019 to ESA for implementation. The proposals were accepted by ESA and the group of the TAL is in the process of implementing them.

Finally, all the external users of the accelerator of the lab have been supported by the group, in order to prepare and conduct their experiments.

Scientific Output

Peer-reviewed Publications

1. Very large permanent polarization in ferroelectric $Hf_{1-x}Zr_xO_2$ grown on Ge substrates by plasma assisted atomic oxygen deposition, by C. Zacharaki, P. Tsipas, S. Chaitoglou, S. Fragkos, M. Axiotis, A. Lagoyiannis, R. Negrea, L. Pintilie, A. Dimoulas, in Applied Physics Letters 114, 112901 (2019). [https://doi.org/10.1063/1.5090036]
2. Cross section measurements of proton capture reactions on Mo isotopes relevant to the astrophysical p process, by V. Foteinou, M. Axiotis, S. Harissopulos, P. Dimitriou, G. Provatas, A. Lagoyannis, H.-W. Becker, D. Rogalla, A. Zilges, A. Schreckling, A. Endres in

The European Physical Journal A 55, 67 (2019). [https://doi.org/10.1140/epja/i2019-12738-x]

3. Study of medium-spin states of neutron-rich $^{87, 89, 91}$Rb isotopes, by D. A. Torres, R. Chapman, V. Kumar, B. Hadinia, A. Hodsdon, M. Labiche, X. Liang, D. O'Donnell, J. Ollier, R. Orlandi, J. F. Smith, K.-M. Spohr, P. Wady, Z. M. Wang, L. Corradi, E. Fioretto, A. Gadea, G. de Angelis, N. Mărginean, D. R. Napoli, E. Sahin, A. M. Stefanini, J. J. Valiente-Dobón, F. D. Vedova, M. Axiotis, T. Martinez, S. Szilner, D. Bazzacco, S. Beghini, E. Farnea, R. Mărginean, D. Mengoni, G. Montagnoli, F. Recchia, F. Scarlassara, C. A. Ur, S. M. Lenzi, S. Lunardi, T. Kröll, F. Haas, T. Faul, M. Hjorth-Jensen, B. G. Carlsson, S. J. Freeman, A. G. Smith, G. Jones, N. Thompson, G. Pollarolo, G. S. Simpson, in The European Physical Journal A 55, 158 (2019). [https://doi.org/10.1140/epja/i2019-12839-6]

4. Determination of the ^{193}Ir(n,2n) reaction cross section and correction methodology for the ^{191}Ir(n,γ) contamination, by A. Kalamara, N. Patronis, R. Vlastou, M. Kokkoris, S. Chasapoglou, A. Stamatopoulos, M. Serris, V. Paneta, M. Axiotis, A. Lagoyannis, S. Harissopulos, I. E. Stamatelatos, in The European Physical Journal A 55, 158 (2019). [https://doi.org/10.1140/epja/i2019-12879-x]

5. Measurement of proton induced γ-ray emission cross sections on Na from 1.0 to 4.1 MeV, by M.Chiari, E.Alves, I.BogdanovićRadović, J.Cruz, L.Csedreki. M.Fonseca, D.Galaviz, A.Henriques, M.Jakšić, A.P.Jesus, O.Kakuee, Á.Z.Kiss, A.Lagoyannis, F.Lourenço, H.Luís, J.Machado, B.Melon, C.K.Nuviadenu, L.Salvestrini, N.Sharifzadeh, Z.Siketić, G.Á.Szíki, Z.Szikszai, P.Teubig, P.Velho, I.Zamboni, M.Zarza, in Nuclear Instruments and Methods in Physics Research Section B 441, 108 (2019). [https://doi.org/10.1016/j.nimb.2017.01.043]

6. Differential cross-section measurements for deuteron elastic scattering on ^{nat}Si for elastic backscattering purposes, by E.Ntemou, X.Aslanoglou, M.Axiotis, M.Kokkoris, A.Lagoyannis, P.Misaelides, N.Patronis, K.Preketes-Sigalas, P.Tsintari, in Nuclear Instruments and Methods in Physics Research Section B 450, 24 (2019). [https://doi.org/10.1016/j.nimb.2018.02.033]

7. Study of differential cross-sections of the ^{14}N(d,α_0,p_0,α_1) reactions suitable for NRA, by M. Kokkoris, X. Aslanoglou, M. Axiotis, A. Lagoyannis, K.Michalakis, P.Misaelides, E.Ntemou, N.Patronis, K.Preketes-Sigalas, P.Tsintari, in Nuclear Instruments and Methods in Physics Research Section B 450, 31 (2019). [https://doi.org/10.1016/j.nimb.2018.08.034]

8. Measurement of differential cross sections of deuteron elastic scattering on ^{31}P for EBS purposes, by E.Ntemou, N.Bligoura, X.Aslanoglou, M.Kokkoris, A.Lagoyannis, F.Maragkos, P.Misaelides, N.Patronis, K.Preketes-Sigalas, in Nuclear Instruments and Methods in Physics Research Section B 459, 84 (2019). [https://doi.org/10.1016/j.nimb.2019.08.030]

9. Differential elastic scattering cross sections for deuterons on ^{9}Be, at energies and angles suitable for elastic backscattering spectroscopy, by E.Ntemou, M.Kokkoris, A.Lagoyannis, K.Preketes-Sigalas, P.Tsavalas, in Nuclear Instruments and Methods in Physics Research Section B 459, 90 (2019). [https://doi.org/10.1016/j.nimb.2019.08.032]

10. MottCalc: A new tool for calculating Mott scattering differential cross sections for analytical purposes, by M.Kokkoris, A.Lagoyannis, F.Maragkos, in Nuclear Instruments and

Methods in Physics Research Section B 461, 44 (2019). [https://doi.org/10.1016/j.nimb.2019.09.022]

11. Differential elastic backscattering cross-sections of the 1–2.4 MeV deuterons on sodium, by E.Ntemou, X.Aslanoglou, N.Bligoura, C.Jeynes, M.Kokkoris, A.Lagoyannis, P.Misaelides, N.Patronis, K.Preketes-Sigalas, in Nuclear Instruments and Methods in Physics Research Section B 461, 124 (2019). [https://doi.org/10.1016/j.nimb.2019.09.044]

12. Isospin dependence of electromagnetic transition strengths among an isobaric triplet, by A.Boso, S.A.Milne, M.A.Bentley, F.Recchia, S.M.Lenzi, D.Rudolph, M.Labiche, X.Pereira-Lopez, S.Afara, F.Ameil, T.Aricig, S.Aydin, M.Axiotis, D.Barrientos, G.Benzoni, B.Birkenbach, A.J.Boston, H.C.Boston, P.Boutachkov, A.Braccol, A.M.Bruce, B.Bruyneel, B.Cederwall, E.Clement, M.L.Cortesg, D.M.Cullen, P.Désesquelles, Zs.Dombràdi, C.Domingo-Pardo, J.Eberth, C.Fahlander, M.Gelain, V.González, P.R.John, J.Gerl, P.Golubev, M.Górska, A.Gottardo, T.Grahna, L.Grassi, T.Habermann, L.J.Harkness-Brennan, T.W.Henry, H.Hess, I.Kojouharov, W.Korten. N.Lalović, M.Lettmann, C.Lizarazo, C.Louchart-Henningg, R.Menegazzo, D.Mengoni, E.Merchan, C.Michelagnoli, B.Million, V.Modamio, T.Moeller, D.R.Napoli, J.Nyberga, B.S.Nara Singh, H.Pai, N.Pietralla, S.Pietri, Zs.Podolyak, R.M.Perez Vidal, A.Pulliap, D.Ralet, G.Rainovski, M.Reese, P.Reiter, M.D.Salsac, E.Sanchis, L.G.Sarmiento, H.Schaffner, L.M.Scruton, P.P.Singh, C.Stahl, S.Uthayakumaar, J.J.Valiente-Dobón, O.Wieland, in Physics Letter B 797, 134835 (2019). [https://doi.org/10.1016/j.physletb.2019.134835]

Presentations in Conferences/Workshops

1. PIGE measurements at the Tandem Lab "Demokritos", talk by A. Lagoyannis, at the 24th International Conference onIon Beam Analysis, Antibes, France, 13-18/10/2019

2. Investigation of Be Marker Tiles using ^{3}He micro – beam, poster by P. Tsavalas, at the 17th International Conference on Plasma-Facing Materials and Components for Fusion Applications, Eindhoven, Netherlands, 20-24/05/2019

3. PIGE measurements at the Tandem Lab "Demokritos" – An overview, talk by A. Lagoyannis, at the 28th Symposium of the Hellenic Nuclear Physics Society, Thessaloniki, Greece, 31/6/2019-1/7/2019

4. Elastic backscattering of deuterons from oxygen between 1500 and 2500 keV, poster by E. Ntemou, at the 24th International Conference on Ion Beam Analysis, Antibes, France, 13-18/10/2019

5. Measurement of deuteron differential elastic scattering cross sections on light elements, at energies and angles suitable for EBS (Elastic Backscattering Spectroscopy), talk by E. Ntemou, at 13thEuropean Conference on Accelerators in Applied Research and Technology (ECAART13 2019), May 5-10, Split, Croatia

6. Differential cross-section measurements of the 31P(p,p'γ)31P reaction for target characterization using the PIGE technique, poster by K. Preketes – Sigalas, at 13th European Conference on Accelerators in Applied Research and Technology (ECAART13 2019), May 5-10, Split, Croatia

7. Differential elastic scattering cross sections for deuterons on ^{9}Be, at energies and angles suitable for EBS (Elastic Backscattering Spectroscopy), poster by E. Ntemou, at

13th European Conference on Accelerators in Applied Research and Technology (ECAART13 2019), May 5-10, Split, Croatia

8. Measurement of deuteron differential elastic scattering cross sections on light elements at energies and angles suitable for EBS (Elastic Backscattering Spectroscopy) talk by E. Ntemou, atthe 28th Symposium of the Hellenic Nuclear Physics Society, Thessaloniki, Greece, 31/6/2019-1/7/2019

Thesis Supervision

- **PhD Thesis**
  1. **A. Kalamara**: "Neutron induced reactions on Ir and Au and production of isomeric states"; NTUA, 2019
  2. **A. Stamatopoulos**: "Study of the ^{240}Pu(n,f) and ^{237}Np(n,f) reaction cross sections at the new experimental area (EAR2) of the CERN n_TOF facility"; NTUA, 2019
- **MSc Thesis**
  1. **G. Alamanos**: "Total cross-section measurement of the ^{203r}Tl(n,2n)^{202r}Tl reaction"; NTUA, 2019
  2. **E. Alvanou**: "Differential cross-section measurements of the ^{nat}Mg(p,p$_0$) reaction relevant to EBS"; NTUA, 2019
  3. **E. Daoulas**: "Characterization of a summing NaI(Tl) detector for reaction studies relevant to nuclear astrophysics"; NTUA, 2019
  4. **E. Mitsi**: "Study of the liquid scintillator BC501A in a field of high-energy neutrons"; NTUA, 2019
  5. **N. Bligoura**: "Differential cross-section measurements of the elastic scattering reaction ^{31}P(d,d$_0$) for analytical purposes"; NTUA, 2019
  6. **F. Maragos**: "Detailed study of Mott scattering for ion beam analysis applications"; NTUA, 2019
  7. **A. Spiliotis**: "Measurement of ^{174}Hf(n,2n)^{173}Hf and ^{176}Hf(n,2n)^{175}Hf reaction cross-sections at 15.3 and 17.1 MeV", NTUA, 2019
  8. **I. Giaritzoglou**: "Experimental study of materials for Radon recursive dosimetry purposes"; UoI, 2019
- **Diploma Thesis**
  1. **N. Salpadimos**: "Material studies with the ion beam techniques RBS and NRA"; University of Patras, 2019
  2. **G. Gkatis**: "Neutron induced reactions on Ge isotopes"; NTUA, 2019
  3. **A. Ziagkova**: "Differential cross-section measurements of the ^{7}Li(p,p'γ_{1-0})^{7}Li reaction relevant to applications";NTUA, 2019
  4. **I. Maroglou**: "Development of wireless remote-control system for the Tandem Accelerator", Western Attika University, 2019

X-ray Spectrometry

Coordinator: Dr. Andreas Germanos Karydas

Researchers: Dr. Vasiliki Kantarelou, Dr. Maria Kaparou, Dr. Georgios Mastrotheodoros, Dr. Manos Manousakas

PhD student: Nikoletta-Kanella Kladouri

MSc Students: Savvina Fotiou, Kalliopi Tsampa

Diploma Student: Sotiria Symeonidou

Fundamental and applied research using synchrotron radiation and Ion Beam Analysis

During 2019, the X-ray spectrometry group accessed two large scale facilities, a synchrotron facility (Elettra Sinchrotrone Trieste, Trieste, Italy for three (3) beamtime slots, and one Ion Beam Analysis (IBA) facility (the C2RMF Accélérateur Grand Louvre d'Analyses Elémentaires, AGLAE located at the Louvre Museum, Paris, France) for one (1) beamtime slot. Apart from the scientifically successful results that were obtained during these experiments, several undergraduate, MSc, PhD and Post-Doc researchers had the opportunity to receive an advanced training and be familiarized and acquainted with modern analytical techniques using X-ray beams and charged particles.

Brief information about the experiments carried out in both facilities and led by A.G. Karydas is summarized below:

1) Elettra Sincrotrone Trieste, proposal #20182037 by M. Kokkoris, entitled: "Study of deep-implanted multilayered structures in silicon wafers with IBA (Ion Beam Analysis) and Grazing Incidence X-ray Fluorescence Spectroscopy", shifts attended by the PhD student E. Ntemou, 30/1-2/2
2) Elettra Sincrotrone Trieste, proposal #20185387 by A.G. Karydas, entitled: "A systematic study of the inelastic LM Resonant Raman scattering process on Au and of the cascade Au-M emission to improve the non-invasive XRF characterization of ancient/historical gold artefacts and of gilding layers", XRF beamline, shifts attended by the MSc student K. Tsampa, 1/3 - 4/3
3) Elettra Sincrotrone Trieste, proposal #20175041 by S. Puri, entitled: "Measurements of different physical parameters for Sb at energies across its Li edge energies using synchrotron radiation.", XRF beamline, shifts attended by the Diploma student S. Symeonidou, 5/3 - 9/3
4) AGLAE, IPERION-CH proposal by M. Kaparou entitled: "Provenance study of Mycenaean Gold" acronym Myc-GoldPro, shifts attended by MSc student K. Tsampa, PhD student N. Kladouriand PostDoc researcher M. Kaparou, 20-24 October 2019 (Fig. 47)
5) Elettra Sincrotrone Trieste, proposal #2019004submitted by S. Puri, entitled: "Study of X-ray production cross-sections and chemical effects at absorption edges of Hafnium compounds with tune-able synchrotron energies"10/12-13/12

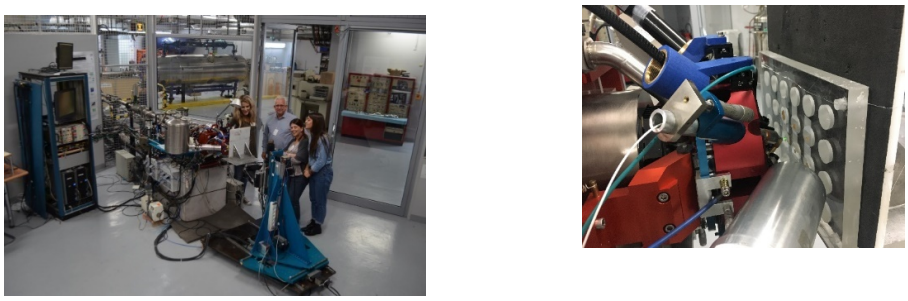

Fig. 47: The X-ray spectrometry group during the Myc-GoldPro proposal beamtime shifts at the AGLAE accelerator in Paris (left). The measuring probe of the AGLAE accelerator during the measurement of Mycenean period gold leaves.

From the beamtime experiments at Elettra Sincrotrone Trieste performed in the last few years, there was a remarkable scientific outcome in 2019 of five (5) peer-review publications covering fundamental research related to the measurement of X-ray fundamental parameters [**1**], but also multidisciplinary research covering characterization of advanced materials [**4**], biomedicine [**6**] and environmental research/ecotoxicology [**7, 8**].

The collaboration with the Department of Basic and Applied Sciences of Punjabi University in India regarding the systematic determination of X-ray fundamental parameters continued. In [**1**], experimental intensity ratios between the L- emission lines of metallic Dy and its compounds were determined and compared with theoretical estimations. It was concluded, that the deviations between measured and theoretical *IL*k/*IL*a (k = γ2,3 and γ4) ratios may be due to the combined influence of the many-body and chemical environment effects (Fig. 48). Moreover, through XANES spectroscopy it was revealed that the*L*3 absorption-edge energy shifts increase linearly with the partial charge on the metal Dy atom.

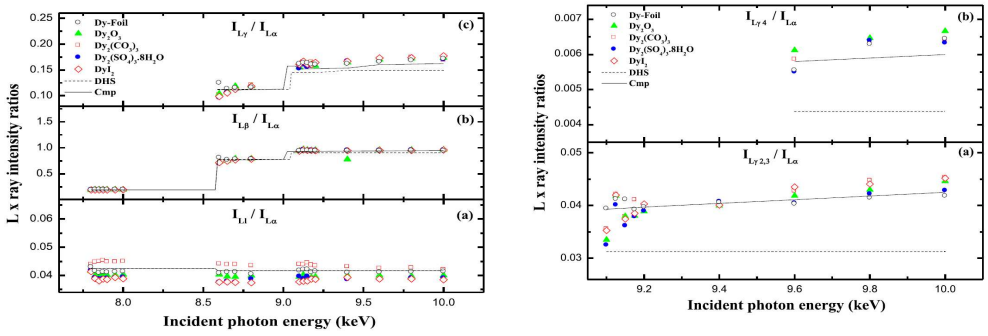

*Fig. 48:Experimental and two sets of theoretical characteristic X-ray intensity ratios as a function of incident photon energy for 66Dy metal foil and its compounds Dy_2O_3, $Dy_2(CO_3)_3$, $Dy_2(SO_4)3.8H_2O$, and DyI_2 (a) (IL*l*/IL*α*), (b) (IL*β*/IL*α*), and (c) (IL*γ*/IL*α*) (left plot) and (a) (IL*γ*2,3/IL*α*) and (b) (IL*γ*4/IL*α*) (right plot) (publication [1])*

In collaboration with National Technical University of Athens, a critical comparison of advanced XRF methods (Grazing Incidence XRF, GIXRF) with Ion Beam Analysis methods (Rutherford/Elastic Backscattering Spectrometry (RBS/EBS) was conducted regarding the depth profile characterization of deep-implanted Argon ions in random direction of Si [1 1 1] polished Silicon crystalline wafers, to quantify the retained doses [**4**]. In this particular study, the results have demonstrated the advantages of GIXRF analysis to characterize even the low dose implanted ions, whereas good agreement was found between the two different techniques for the highest dose implanted Ar ions (Fig. 49).

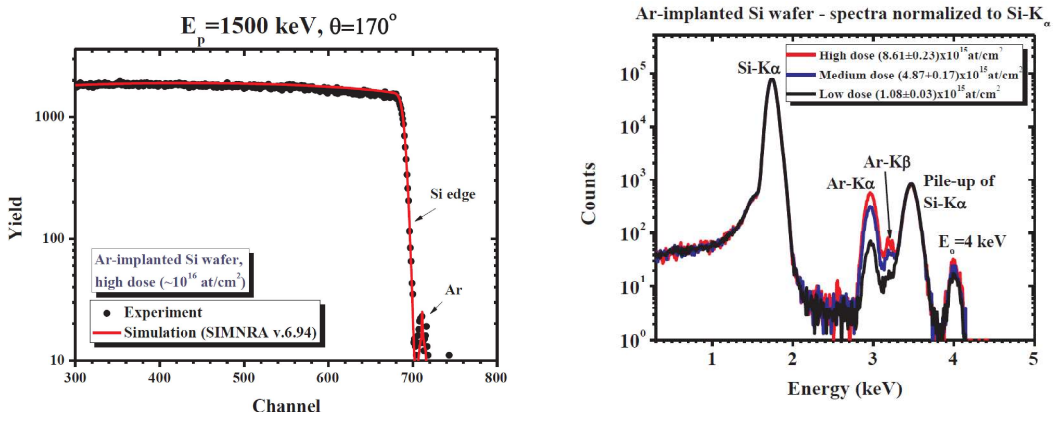

Fig. 49: Experimental and simulated (using SIMNRA v.6.94) RBS/EBS spectra ofthe Ar-implanted Si wafer for the highest dose using1.3 MeV deuterons (left figure). Fig. 4. Typical experimental GIXRF spectra taken at six degrees beam incidence for alldoses, normalized to the Si-Kα intensity. Differences in the implanted doses areevident in the intensities of the corresponding Ar-K lines. (right figure)

In collaboration with colleagues from Poland another synchrotron study provided very promising results (despite the small number of samples examined) regarding the possibility by means of micro-XRF imaging and advanced statistical analysis to differentiate cancerous areas of tissues from healthy ones. The distribution of minor and trace elements ranging from carbon to zinc of seven human ovarian tissue samples was obtained by using micro X-ray fluorescence imaging technique. Next, the K-means clustering and non-negative matrix factorization were applied for image segmentation of acquired elemental distribution maps into three sub-regions corresponding to stromal area, tumor area and unclassified area. The resulted images were confronted with the results of the histopathological examination for selected types of tumors and proved to be of great potential in the investigation on the role of micro and trace elements in tumor biology (Fig. 50).

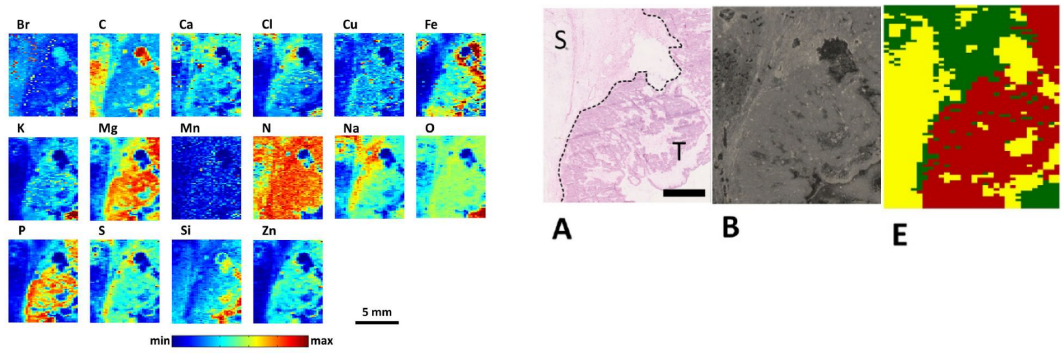

Fig. 50 X-ray fluorescence elemental maps of the ovarian tumor specimen S-EA. The size of the images is 8×9,24mm^2 (32×77 pixels). Data presented in intensities [counts per second] (left figure). Image segmentation for by k-means and non-negative matrix factorization (NNMF) methods (red – tumor area, green – stromal area, yellow - unclassified). A: H& E-stained specimen image - the marker depicts a border between stromal (S) and tumor (T) areas, B: analyzed tissue section image, E: results of NNMF based segmentation. Size of the analyzed area: 8×9.24mm^2 (32×77 pixels), scale bar length 2 mm. (right figure)

The results of an almost four -year systematic study, partly conducted at Elettra Sincrotrene Trieste, were published regarding the mercury (Hg) localization, speciation and ligand environment in edible mushrooms, but also to evaluate its bioavailability [**8**]. The mushrooms (Boletus edulis, B. aereus and Scutiger pes-caprae)were collected at non-polluted and Hg polluted sites and it is characteristic, for example, that mushrooms collected at Hg polluted sites can contain more than 100 μg Hg g−1 of dry mass. This project was led by a group from the Jozef Stefan Institute in Slovenia and the experimental work at Elettra was supported by A.G. Karydas. The results have shown that Hg accumulates mainly in the spore-forming part (hymenium) of the mushroom cap and is mainly coordinated to di-thiols (43–82%), followed by di-selenols (13–35%) and tetra-thiols (12–20%) (Fig. 51). The mercury bioavailability, as determined by feeding the mushrooms to Spanish slugs (known metal bioindicators owing to accumulation of metals in their digestive gland), ranged from 4% (S. pes-caprae) to 30% (B. aereus), and decreased with increasing selenium (Se) levels in the mushrooms. The study concluded that elevated Hg levels in mushrooms fed to the slugs induced toxic effects, but these effects were counteracted with increasing Se concentrations in the mushrooms pointed to a protective role of Se against Hg toxicity through HgSe complexation. Nevertheless, consumption of the studied mushroom species from Hg polluted sites should be avoided.

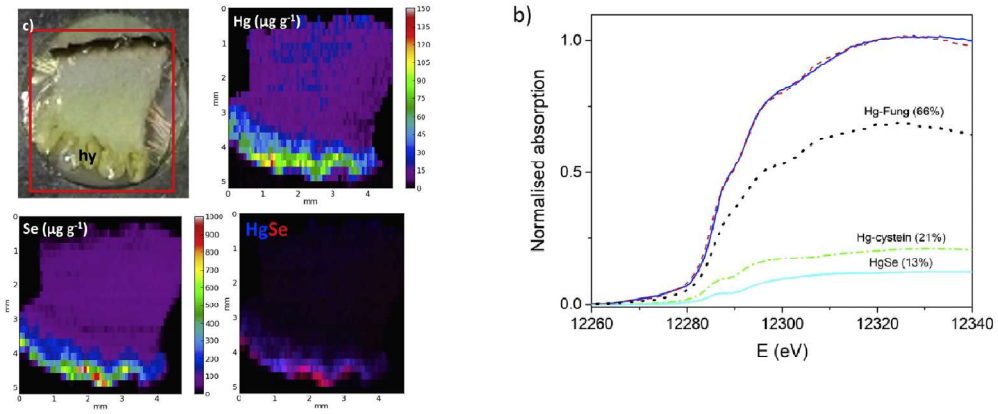

Fig. 51.Mercury and selenium localization in mature sporocarps of Scutiger pes-caprae. The µ-XRF, lateral resolution was 200 µm×100 µm. Hy-hymenium. The coloured vertical bars represent concentration (µg g−1 DM). In the left figure, and in the bottom right corner the co-localization between Hg (blue channel) and Se (red channel) is shown. In the right figure, the Hg L3- XANES spectrum is shown measured on B. edulis cap (Idrija) sample. Blue line – experiment; red dashed line – best-fit linear combination with XANES profiles: 66% of fungal sample Fung, 21% of Hg-cysteine and 13% of HgSe.

Finally, in collaboration with the Technical University of Crete another study, related again with environmental safety, was published in 2019 [**7**]. Part of the work was carried out at the XRF beamline of Elettra Sincrotrone Trieste. This study introduced, studied, and assessed a simple, sensitive, and low-cost method for Hg(II) monitoring and assessment in water matrices and even at trace level. Solid-state membranes were successfully functionalized with different ligands (thiourea, PAR, CCS, dithizone), using as the membrane matrix PVC. TXRF-XANES results revealed that mercury complexes with each of the selected ligands, rather than simply absorbed in the membrane matrix, whereas each membrane was quantitatively assessed in terms of the Hg(II) pre-concentration efficiency using EDXRF analysis. It was found that the PAR ligand appears to have, by and large, the highest efficiency in mercury pre-concentration providing in bottled water detection limit of 0.88 µg L−1, less than the 1 µg L−1 limit set by the World Health organization (WHO) for water intended for human consumption. The important contribution of this work is that, when using the membranes at their simple configuration, i.e. just emerge them in a mater matrix, very low detection limits for Hg detection can be achieved. Furthermore, the solid-state membranes were found to perform very well in environmentally relevant matrices, such as tap and bottled water, even though these contain a large number of ions and, thus, can act as a simple, sensitive, and low-cost indicator not only for aqueous mercury, but possibly for other (heavy) metals.

Outlook

The research related to the evaluation of the accuracy of existing databases of X-ray Fundamental Parameters (FPs) and the reliable quantification of secondary processes that predict the enhancement of the X-ray fluorescence intensities beyond the primary

photoionization process, contributes to the improvement of the traceability of uncertainties in quantitative standardless XRF analysis. The systematic results obtained so far contribute to the needs of the X-ray community and of relevant stakeholders (commercial vendors) to rely on X-ray data of improved accuracy. Moreover, the study of processes, such as the Resonant Raman Scattering provide critical insights into atom relaxation and fluorescence emission processes related also to exotic phenomena triggered by Free Electron Lasers. In the forthcoming years (2020-2021) it is expected to finish evaluation and publish results related to the performed beamtimes within 2019 at Elettra related to determination of X-ray fundamental parameters of Ge, Sb, Re and Au atoms, including Resonant Raman Scattering cross sections. The unintended access at Elettra Sincrotrone Trieste will further support the continuation of the basic research program in X-ray spectrometry, and particular effort will be made to strengthen interdisciplinary collaborations for synchrotron radiation applications.

The successful beamtime at AGLAE in October 2019, where, except for the planned experiment on Mycenaean gold leaves, two other satellite experiments (on Archaic bronzes and Mycenaean glass) were carried out, due to the potential to operate the accelerator overnight, has greatly mobilized the X-ray spectrometry group to take advantage of the available advanced experimental resources and financial support (through the new IPERION-HS project) to carry out systematic work.

Development of laboratory-based and *in-situ* X-ray Fluorescence interdisciplinary applications

In the field of environmental research, the fruitful collaboration with the Environmental Radioactivity Laboratory (ERL) of the Institute of the Nuclear and Radiological Science & Technology, Energy & Safety at NCSR "Demokritos" was further enhanced during 2019 producing two (2) joint publications [**2, 3**] together with international partners. In both projects, the combined experience of the X-ray spectrometry group in the XRF analysis of APM samples and the high expertise of the ERL group in performing precise source apportionment modeling offered key contributions in these two papers. It should be also noted that the work published in [2] was accomplished during the period that A.G. Karydas acted as PhD supervisor of the main author (GerelmaaGunchin).

In the field of geochemistry, another example of the potentialities of the scanning micro-XRF analysis for identifying useful elemental associations in minerals at the microscale was demonstrated in the publication [**5**]. In this work, the micro-XRF spectrometer of the XRF laboratory was utilized to reveal Rare Earth Elements (REE) and Th spatial associations in the geochemistry study of allanite-bearing coastal sands from Northern Greece (fig. 52).This research is highly motivated for the need to extract critical metals from minerals which present economic importance for the industry.

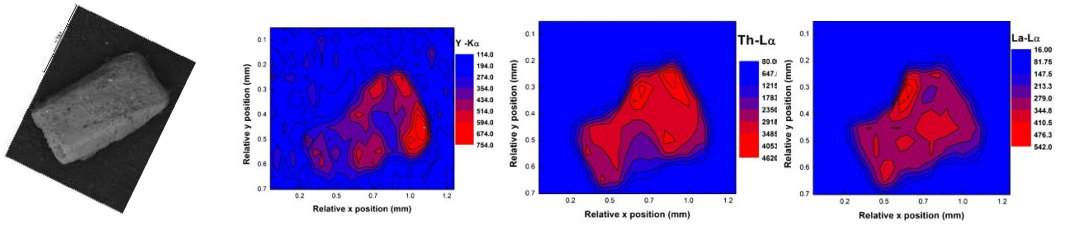

Fig. 52: REE (La), Y and Th μ-XRF elemental maps (right) in an allanite crystal (left) from the Kavala black coastal sands (publication [5]).

In the field of Cultural Heritage, the strong multi-scale collaboration established with the LANDIS laboratory of INFN and CNR in Catania, Sicily, continued and was further strengthened. Joint abstracts were presented in three (3) international conferences, whereas upon invitation in October 2019 of A.G. Karydas, the evaluation of previously acquired MA-XRF imaging data continued and was further advanced. The results of a previous collaboration regarding the MA-XRF imaging of Bronze period wall-paintings at the Mycenaean Palace of Nestor, in Pylos Greece, was accepted for publication in the Journal of Arcaheological Science: Reports ([9], Fig. 53). This work is characterized as an unprecedented application of MA-XRF imaging in the study of Late Bronze Age wall-paintings demonstrating clearly the superior and advanced capabilities of the portable MA-XRF scanning technique compared to the conventional single spot XRF analysis. The application of the MA-XRF imaging technique on the heavily deteriorated pictorial layers of the Nestor's Palace wall-paintings, unraveled hidden iconographic elements and polychromy, thus, allowing to integrate the iconography and perform an objective, scientifically based re-assessment of the accuracy of previously executed wall-painting reconstructions. Moreover, painting materials and artistic techniques of their application were also uncovered, enhancing and further re-confirming the results obtained via other analytical techniques.

The results of another in-situ MA-XRF and pXRF campaign, conducted during November 2018 at the National Arcaheological Museum (NAM) in collaboration with LANDIS-LNS and the archaeologists Dr. E. Konstantinidi and Dr. K. Nikolentzos, were evaluated and a relevant technical internal report was submitted to NAM in February 2018. A characteristic example of the results obtained regarding the distribution of Au-Lαcharacteristic X-ray intensity over more than 50 cm^2 of a gold cup cylindrical surface are presented in Fig. 54.

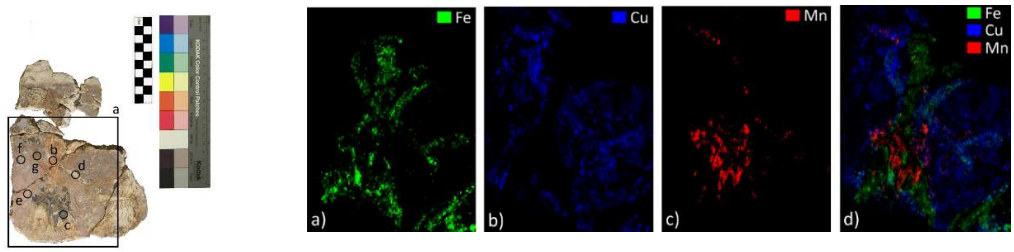

Fig. 53: In-situ MA-XRF imaging of the battle scene fragment from Hall 64, Palace of Nestor at Pylos (left). MA-XRF images of Fe-Kα (Fe-ochre), Cu- Kα (Egyptian Blue) and Mn-Kα (Mn-based mineral pigment) intensities are depicted with green, blue and red colors, respectively, produced by the MA-XRF analysis of the examined area (a) of the Battle Scene are shown together with their RGB correlation. (publication [9]).

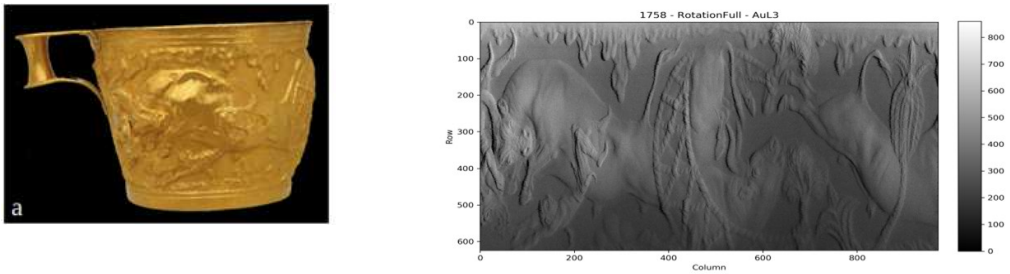

Fig. 54: In-situ MA-XRF imaging and pXRF analysis of a unique Mycenean period Gold cup from Vafeio, Lakonia that it is exhibited at the National Archeological Museum (left). Map of the Au-Lαintensity deduced by means of a combined rotational (280 degrees) and vertical (6 cm) movements. In total, more than a half million XRF spectra were recorded (560000 pixels, 20 ms/pixel) with total measurement duration of 3 hrs. © Photo belongs to National Archaeological Museum, Technical support submitted to NAM, February 2019)

In conclusion, the applied activities of the XRF laboratory have provided key contributions to the following thematic areas:

- Environmental research(publications [2, 3, 7, 8] and abstract 6)
- Biomedicine (publication [6])
- Geochemistry (publication [5])
- Advanced materials characterization (publication [4] and abstract 2)
- Cultural Heritage (publication [9] and abstracts 1, 3, 5, 7-10)

Outlook

Different modalities of the XRF analysis technique are nowadays widely established in many disciplines as a mandatory analytical tool to offer advanced and non-destructive characterization of materials with 2D and 3D spatially resolved elemental information, in-situ, at small laboratories or at large infrastructures (synchrotrons). The continuously improved technical features of new generation X-ray detectors and of the energy-dispersive

pixelated cameras, fast digital signal processors, and X-ray focusing devices, but also the availability of brilliant and miniaturized X-ray sources and fast spectrum analysis packages boost the XRF technology to new eras of analytical applications.

Currently the investigation of the provenance of Mycenaean gold lies centrally in the interests of the research group. Having acquired official study permits to investigate golden artifacts from distinct archaeological sites, namely Aidonia-treasure from Ancient Nemea, Cephalonia, Pieria, Arcadia, and ten (10) emblematic artifacts from the National Archaeological Museum, the application of Macro-XRF imaging is the method of choice. The ultimate aim is to assign the objects under study to specific groups, in terms of origin- whether via mining or alluvial deposits- and create a databank of Mycenaean gold for research reference.

Collaborators from Greek Academic and Research Institutions

- Haricleia Brecoulaki, Institute of Historical Research, The National Hellenic Research Foundation, Athens
- Demetrios Anglos & Sofia Sotiropoulou, Institute of Electronic Structure and Laser, Foundation for Research and Technology-Hellas, Herakleion, Greece, Herakleion, Greece
- Nikolaos Zacharias, Department of History, Archaeology and Cultural Resources Management, University of the Peloponnese
- Konstantinos Eleftheriadis, E.R.L., Institute of Nuclear and Radiological Sciences and Technology, Energy and Safety, N.C.S.R. Demokritos, Greece
- Yannis Bassiakos, Georgios Mastrotheodoros and Eleni Fillippaki, Archaeometry Laboratory, Institute of Nano Science and Nanotechnology, NCSR "Demokritos", Greece
- Michael Kokkoris, Department of Physics, National Technical University of Athens, Greece
- Eleni Konstantinidi and K. Nikolentzos, National Arcaheological Museum
- Maria Katsikini, F. Pinakidou, E. Paloura, Aristotle University of Thessaloniki, School of Physics, Section of Solid State Physics
- Dimitrios Anagnostopoulos, Department of Materials Science & Engineering of the University of Ioannina, Greece

International Collaborators

- Sharon Stocker, Jack Davis, Department of Classical Archaeology, University of Cincinnati
- Sanjiv Puri, Department of Basic and Applied Sciences, Punjabi University, Patiala, Punjab, India
- Andrei Kochur, Rostov State University of Transport Communication, Russia
- Eva Margui, Department of Chemistry, Faculty of Sciences, University of Girona, Spain
- Mateusz Czyzycki and Pawel Wrobel, AGH University of Science and Technology, Faculty of Physics and Applied Computer Science, Poland

- Francesco Paolo Romano and Claudia Caliri, CNR, Istituto per i Beni Archeologici e Monumentali (IBAM) and Laboratori Nazionali del Sud, INFN, Italy
- Jorge Sanchez & Juan Jose Leani, National Scientific and Technical Research Council (CONICET), Argentina
- Alessandro Migliori, Nuclear Science and Instrumentation Laboratory, International Atomic Energy Agency, (IAEA) Laboratories, Austria
- Abdallah Shaltout, Spectroscopy Department, Physics Division, National Research Centre, Cairo, Egypt

Articles in Peer-Review Journals

1. R. Kaur, A. Kumar, M. Czyzycki, (...), A.G. Karydas, S. Puri, "A study of the influence of chemical environment on the Li (i = 1–3) subshell X-ray intensity ratios and the L3 absorption-edge energy for some compounds of 66 Dy using synchrotron radiation", X-Ray Spectrometry, (2019), 1-12 https://doi.org/10.1002/xrs.3002
2. G. Gunchin, M. Manousakas, J. Osan, A.G. Karydas, K. Eleftheriadis, S. Lodoysamba, D. Shagjjamba, A. Migliori, C. Streli, R. Padilla-Alvarez and I. Darby, "Three-Year Long Source Apportionment Study of Airborne Particles in Ulaanbaatar Using X-Ray Fluorescence and Positive Matrix Factorization", Aerosol and Air Quality Research, 19 (2019) 1056–1067 https://doi.org/10.4209/aaqr.2018.09.0351
3. A. Shaltout, S.K. Hassan, S.E. Alomairy, (...), A.G. Karydas, K. Eleftheriadis, "Correlation between inorganic pollutants in the suspended particulate matter (SPM) and fine particulate matter (PM2.5) collected from industrial and residential areas in Greater Cairo, Egypt", Air Qual Atmos Health 12 (2019) 241–250 https://doi.org/10.1007/s11869-018-0645-6
4. M. Kokkoris, E.G. Androulakaki, M. Czyzycki, M. Erich, A.G. Karydas, (...), V. Paneta, S. Petrović, "Argon ions deeply implanted in silicon studied by Rutherford/Elastic Backscattering and Grazing Incidence X-ray Fluorescence spectroscopy", Nuclear Instruments and Methods in Physics Research, Section B: Beam Interactions with Materials and Atoms, 450 (2019) 144–148 https://doi.org/10.1016/j.nimb.2018.08.048
5. I. Tzifas, A. Papadopoulos, P. Misaelides, A. Godelitsas, J. Göttlicher, H. Tsikos, P.N. Gamaletsos, G. Luvizotto, A.G. Karydas, M. Petrelli, F. Noli, V. Kantarelou, A. Kontofakas, A. Hatzidimitriou, "New insights into mineralogy and geochemistry of allanite-bearing Mediterranean coastal sands from Northern Greece", Geochemistry, Volume 79(2) (2019) 247-267 https://doi.org/10.1016/j.chemer.2019.05.002
6. Paweł M. Wróbel, ŁukaszChmur, Maria M. Grzelak, ZdzisławStęgowski, Marek Lankosz, Dariusz Adamek, Robert Jach, Alessandro Migliori, Andreas G. Karydas, "Towards histopathological analysis based on X-ray fluorescence elemental imaging supported by multivariate analysis - Case study of ovarian cancers", Spectrochimica Acta Part B 155 (2019) 4–11

https://doi.org/10.1016/j.sab.2019.02.009

7. Nikolaos Kallithrakas-Kontos, Spyros Foteinis, Eleftheria M. Vazgiouraki, Andreas G. Karydas, JánosOsán, Efthalia Chatzisymeon, "Solid-state polymer membranes for simple, sensitive, and low-cost monitoring of mercury in water", Science of the Total Environment 697 (2019) 134099, https://doi.org/10.1016/j.scitotenv.2019.134099
8. Anja Kavčič,1, KlemenMikuš, Marta Debeljak, Johannes Teun van Elteren, IztokArčon, AlojzKodre, Peter Kump, Andreas Germanos Karydas, Alessandro Migliori, Mateusz Czyzycki, Katarina Vogel-Mikuš, "Localization, ligand environment, bioavailability and toxicity of mercury in Boletus spp. and Scutiger pes-caprae mushrooms", Ecotoxicology and Environmental Safety 184 (2019) 109623 https://doi.org/10.1016/j.ecoenv.2019.109623
9. Hariklia Brecoulaki, Giovanni Verri, Brigitte Bourgeois, Francesco Paolo Romano, Andreas G. Karydas, Claudia Caliri, Elena Martin-Gonzalez, Giorgos Kavvadias, The "lost art" of Archaic Greek painting: revealing new evidence on the Pitsa pinakes through MA-XRF and imaging technique", Technè n° 48, 2019

Technical reports

1. "In-situ MA-XRF imaging and pXRF analysis of Mycenaean gold artifacts from the National Archaeological Museum of Athens", submitted to the National Archaeological Museum of Athens, February 2019
2. "Characterization of tin coatings on copper alloy electrodes", Submitted to the ATC - TSAMPAS BROS S.A., Electrochemical equipment - metal constructions company, July 2019
3. "In-situ micro-XRF analysis of Mycenaean artifacts at the Vravrona Archaeological Museum in Attiki", to be submitted to the Archaeological Museum of Vravrona, December 2019

Abstracts in International Conferences

- 18th International Conference on Total Reflection X-ray Fluorescence Analysis and Related Methods (TXRF 2019, Girona, 25-28 June 2019)

  1. "*Analysis of artists' inorganic pigments containing high Z elements by portable TXRF instrumentation: Study of different quantification approaches*", D. Papadopoulou, I. Queralt, A.G. Karydas, M. Maguregui, E. Marguí, Poster presentation
  2. "*Non-Destructive TXRF determination of trace elements in Zircaloy-4 and Zr- Nb alloys*", Kaushik Sanyal, Buddhadev Kanrar, Nand Lal Misra, Sangita Dhara, Mirta Sibilia, Andreas Germanos Karydas, Poster presentation

- Iberian Joint Meeting on Atomic and Molecular Physics (IBER 2019), 10-13 July 2019

3. "*X-ray fluorescence analysis of Catalonian coinage from the Spanish Succession War (1700 – 1714)*", D. Papadopoulou, I. Queralt, E. Marguí, Estrada, A. Pujol, A.G. Karydas, Poster presentation

4. "*Experimental and theoretical study of the Ge-L emission spectrum excited by tunable synchrotron radiation near and above the Ge K-shell threshold*", A. G. Karydas, A. G. Kochur, S. Symeonidi, M. Czyzycki5, S. Puri, D. Sokaras and Ch. Zarkadas,

Invited Plenary lecture

- 11th International Conference on "Instrumental Methods of Analysis" (IMA-2019), 22-25 September 2019

5. "*Portable XRF spectrometry in the field of Cultural Heritage*", M. Kaparou, H. Brecoulaki, C. Caliri, S. Fotiou, R. Grethe, V. Kantarelou, E. Kokiasmenou, M. Kontimpa, G. Mastrotheodoros, D. Papadopoulou, F. P. Romano, K. Tsampa and Andreas G. Karydas, Oral presentation

6. "*Development and characterization of aerosol reference materials for the calibration of nuclear analytical techniques*", M. Gini, M. Manousakas, V. Kantarelou, V. Vasilatou, M. Chiari, A. G. Karydas, K. Eleftheriadis, Oral presentation

- 7th Symposium of the Greek Archaeometrical Society, Athens, 9-12 October 2019

7. *"Τεχνολογική μελέτη (ΟΜ, μXRF, SEM/EDS) μεταλλικών τέχνεργων από ιερά της Τεγεάτιδας (10ος-7ος αι. π.Χ.)",* Ν.Κ. Κλαδούρη, Α.Γ. Καρύδας, Β. Κανταρέλου, Β. Ορφανού, Ν. Ζαχαριάς, poster presentation

8. "*Advanced micro-XRF scanning methodologies applied for the characterization of Roman wall-paintings*", Savvina Fotiou, Andreas Germanos Karydas, Nikolaos Zacharias, Claudia Caliri, Francesco Paolo Romano, poster presentation

9. *"The XRF laboratory at NCSR "Demokritos": Contribution to Cultural Heritage research",* ,A.G. Karydas, V. Kantarelou, D. Sokaras, V. Argyropoulos, H. Brecoulaki, N. Zacharias, M. Kaparou, N. Kladouri, E. Kokiasmenou, G. Mastrotheodoros, K. Tsampa, C. Caliri and F.P. Romano, Oral presentation

- MA-XRF scanning in Conservation, Art and Archeology, Catania, 15-16 October, 2019

10. *"Macroscopic XRF imaging of Bronze Age Wall-Paintings",* A.G. Karydas, E. Kokiasmenou*, V. Kantarelou, H. Brecoulaki, F.P. Romano, C. Caliri, Oral presentation

Distinctions

- Appointed National delegate of the COST action CA18130, European Network for Chemical Elemental Analysis by Total Reflection X-Ray Fluorescence, ENFORCE TXRF, 2019-2023

- Elected Short Term Scientific (STSM) Manager of the ENFORCE TXRF Cost action, March 2019
- A.G. Karydas was invited to the Joint ICTP-IAEA Advanced Workshop on Portable X-Ray Spectrometry Techniques for Characterization of Valuable Archaeological/Art Objects (smr 3298, 3-14 Jun 2019) to deliver several lectures (~8 hrs.), including demonstration of portable XRF instruments for the analysis of different types of archaeological artefacts
- A.G. Karydas delivered an invited plenary lecture at the Iberian Joint Meeting on Atomic and Molecular Physics (IBER 2019), 10-13 July 2019
- A.G. Karydas acted as external referee for the proposals submitted within Horizon2020 IPERION-CH project (duty carried out over almost the last 10 years) for groups requesting beamtime access at the C2RMF AGLAE accelerator (Accélérateur Grand Louvre d' Analyses Elémentaires) located at the Louvre Museum, Paris, France
- A.G. Karydas was invited from INFN-LNS for scientific collaboration with the LANDIS group (14-18 October 2019)
- A.G. Karydas was selected as end-user of AGLAE to address the Greek group experience to journalists from international media (Monday 20th October 2019)
- A.G. Karydas was invited from C2RMF to attend the kick-out meeting of IPERION-CH (2-25 October 2019)

MSc Diploma Dissertations

1. Dimitra Papadopoulou, "*Protection Conservation and Restoration of Cultural Monuments*" Interdepartmental Program of Postgraduate Studies, Aristotle University of Thessaloniki, January 2019
2. Savvina Fotiou, *«Cultural Heritage Materials and Technologies»* MSc program at the Department of History, Archaeology and Cultural Resources Management, University of the Peloponnese, July 2019
3. Kalliopi Tsampa, National Technical University of Athens, School of Applied Mathematical and Physical Sciences, in progress

Diploma Student

1. Sotiria Symeonidou, National Technical University of Athens, School of Applied Mathematical and Physical Sciences, November 2019

Funding

The only support that the X-ray spectrometry activity was received during 2019 was the salary of the head of the group (Andreas Karydas) as a permanent researcher, plus 1 month of postdoc salary (2300 euros before tax and insurance) for Dr. Vicky Kantarelou. Dr. Maria Kaparou and Dr. G. Mastrotheodoros have cooperated with the XRF group on a volunteer basis (the same holds for Dr. V. Kantarelou from February to April 2019 when she has appointed as a researcher at the ELI facility in Prague, Czech Republic. Dr. Manos Manousakas was fully supported by the Environmental Radioactivity Laboratory of the

INRASTES Institute at the NCSR "Demokritos", to support research and analytical services provided to end-users by the benchtop Epsilon 5 XRF spectrometer that it is installed and operates at the XRF laboratory premises. In this context, Dr. Manos Manousakas has interacted occasionally with the XRF group, in particular during the execution of an IAEA interlaboratory exercise.

TANDEM Accelerator

Permanent Staff: Sotirios V. Harissopulos, Anastasios Lagoyannis, Michail Axiotis, Vassilios Andreopoulos, Emmanouil Tsopanakis

Research Associates: Zoi Kotsina, Eleni Vagena, Manousos Ioannis Manousakas

Chief Operator: Miltiadis Andrianis

PhD Students: Kostas Preketes-Sigalas, Eleni Ntemou, Giannis Madesis, Aggelos Laoutaris

MSc Students: Eleni Alvanou, Euthimios Daoulas, Stefanos Nanos

Since 1973 the INPP of NCSR "Demokritos" hosts the only research accelerator in operation existing in Greece. The accelerator is an electrostatic Van de Graff Tandem accelerator with a maximum acceleration voltage of 5 MV. During the course of 2018 the "Cluster of Accelerator Laboratories for Ion-Beam Research and Applications" - CALIBRA project started its implementation. The aforementioned project (MIS 5002799) is implemented under the Action "Reinforcement of the Research and Innovation Infrastructures" which is funded by the Operational Programme "Competitiveness, Entrepreneurship and Innovation" (NSRF 2014-2020) and co-financed by Greece and the European Union (European Regional Development Fund). The basic milestones of the project are:

- The upgrade of the Tandem and PAPAP accelerators
- The transfer of a donated Cyclotron from the Netherlands
- The procurement of state-of-the art scientific instruments
- The enlargement of the existing user community of the accelerators
- To offer unique education and training opportunities to students

In the context of the project several works have been carried out and presented below.

New instruments and hardware upgrades in 2019

Instruments

During 2018 the group of the Lab started a simulation to characterize the 4πγ-summing NaI(Tl) detector and determine its efficiency (more information can be found in the respective Annual Report). In year 2019 several tests with radioactive sources were performed in order to validate the Geant4 simulation implementation. The simulations were found inline with the experimental data, so a long simulation was performed for several sum-energies and cascade multiplicities and the efficiency of the setup was extracted.

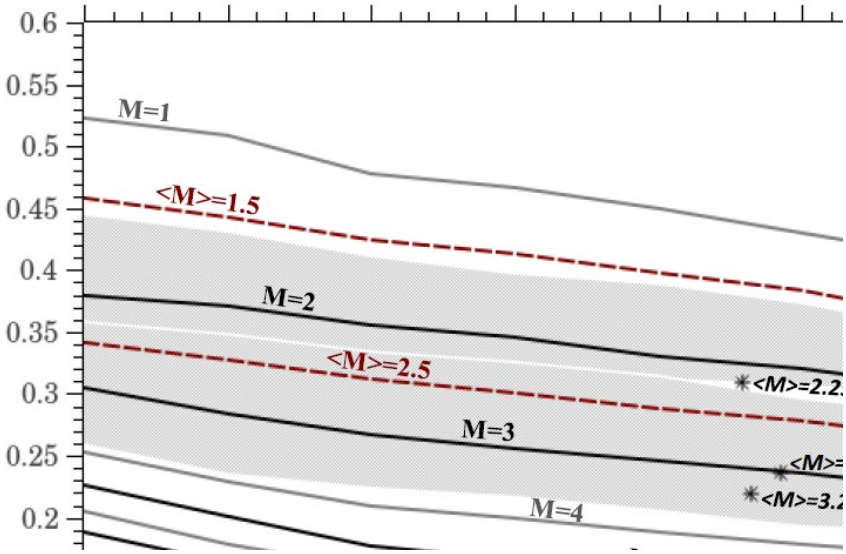

Figure 55: Efficiency of the sum-peak of the "Neoptolemos" detector as a function of the sum-energy and the multiplicity of the cascade

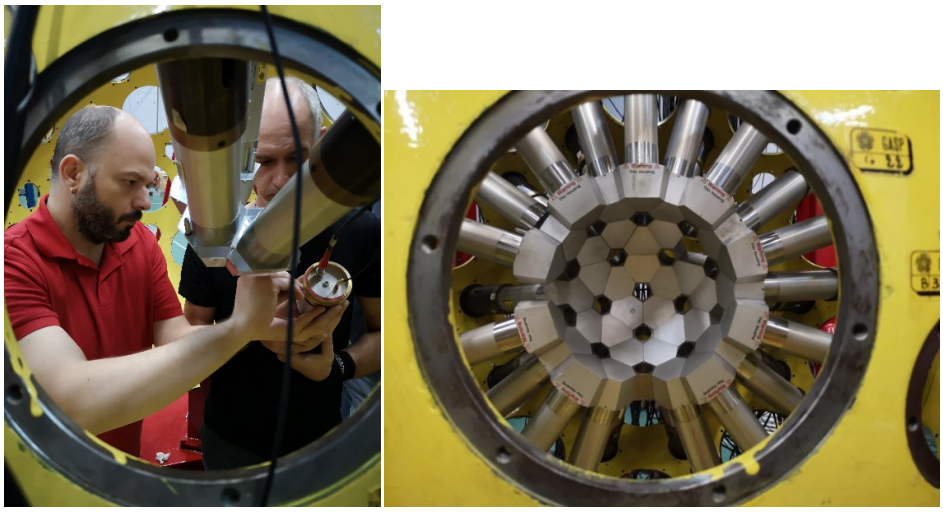

Figure 56: GASPAR in the process of detector mounting. Depicted is the half detector with 37 detectors mounted

Furthermore, as mentioned in last year's Annual Report, the GASPAR detector was being setup. To date, end of 2019, the construction of the detector is complete. The supporting frame is in place and all 80 BGO detectors are installed and tested. Additionally, two of the four non-working detectors were troubleshooted and fixed, while the other two are pending to be repaired. The power supplies are connected to the detectors and are tested and found in good working order, apart from one channel. In order to test the setup as a whole the new digitizers which are on their way are expected.

Accelerator Upgrades

According to the upgrade plans, the control of the Accelerator will be computerized with digital controllers in the accelerator room. Since the power supplies of the magnets were located in the left (red) experimental room, the connection to the controllers would be impossible. In order to overcome this shortcoming, the cabling and the power supplies were relocated in the accelerator room. Furthermore, the vacuum system will be upgraded to turbomolecular pumps. In this context, and since the vacuum flanges used at the accelerator are no longer produced (Dependex flanges), new adaptor flanges are being designed and are to be installed in order to host the new pumps.

Finally, a major troubleshooting/alignment work has been performed at the low energy part of the accelerator. In the course of 2018, a diffusion pump failed, resulting in contaminating the beamline with oil. In the process of decontaminating the line it seems that some focusing element was moved and as a result the transmission of the beam was degraded. With the assistance of an external expert (Mr. Natko Skukan) on accelerators many tests were performed in order to troubleshoot the problem, which was consequently addressed and finally the transmission reached the pre-failure levels. Ongoing tests are conducted in order to further improve the transmission of the accelerator.

XRF laboratory

The X-ray Fluorescence (XRF) laboratory is a unique infrastructure for Greece dedicated in the research and development of X-ray based spectrometric techniques and applications. It includes several in house built portable and commercial benchtop XRF spectrometers in support of field measurements and of ultra-trace elemental analysis of environmental samples. More information can be found at the following link: http://www.inp.demokritos.gr/xrf/

The XRF laboratory is equipped with an apparatus for particle induced monoenergetic X-ray beams, instrumentation for setting up an external ion-beam analysis station, a custom build milli-probe portable XRF spectrometer, a portable micro-XRF spectrometer (the only one in Greece equipped with polycappilary X-ray optics), a benchtop high energy, polarization geometry and multiple secondary targets XRF spectrometer, a Total reflection XRF module and with a chemical laboratory for sample preparation. More information can be found at the following link: http://www.inp.demokritos.gr/xrf/facilities/

The activities of the XRF laboratory are focused towards:

1) The study of fundamental X-ray interactions with matter and de-excitation processes of ionized atoms (see publication [1])

2) The development of analytical methodologies, instrumentation and interdisciplinary applications of X-ray fluorescence and Ion Beam Analysis techniques, with emphasis in the areas of cultural heritage, air pollution and trace element analysis of environmental samples, biomedicine/pharmaceutical, Advanced/Energy materials characterization, geochemistry and in the development of portable XRF instrumentation (see publications [2-9]) and

3) Analytical services in the fields of Cultural Heritage (*in-situ* non-destructive XRF measurements with high spatial and depth resolution), environmental monitoring (Particulate Matter analysis, quantification of toxic trace elements), biomedicine (trace elements in biomedical samples), quality control of advanced and industrial materials, technology and know-how transfer to end-users of XRF techniques. The analytical services provided within 2019 are listed below and special emphasis should be given to the development of an analytical methodology that offers improved characterization of the thickness of tin coatings (between 7μm-15 μm) onto copper and brass electrodes.

Analytical services

1. ATC - TSAMPAS BROS S.A., Electrochemical equipment - metal constructions, "Quality control and characterization of the Sn coating thickness in copper and brass electrodes", June-July 2019
2. Contract with the Antiquities Eforeia of Magnisia, Greece, for the "Provision of analytical services regarding the technical and scientific support of a portable XRF spectrometer that operates at the Archaeological Museum of Volos since 2005" (developed by the XRF laboratory), November 2019
3. Finnish Institute at Athens, "Non-invasive micro-XRF analysis of the chemical composition of twenty (20) bronze objects", September -November 2019

4. Benaki Museum, "Micro-XRF characterization of enamel on Hellenistic gold jewelry, October-December 2019

4) Training of undergraduate and MSc students

During 2019, two MSc theses were completed the one (1) by Dimitra Papadopoulou, entitled "Protection Conservation and Restoration of Cultural Monuments" from the Interdepartmental Program of Postgraduate Studies, Aristotle University of Thessaloniki in, January 2019 and another one (1) by SavvinaFotiou, from the «Cultural Heritage Materials and Technologies» MSc program at the Department of History, Archaeology and Cultural Resources Management, University of the Peloponnese in July 2019

Moreover, during 2019 the XRF laboratory supported exclusively the continuation of one (1) diploma work and one (1) MSc thesis, both students from the National Technical University of Athens students. In addition, six (6) MSc diploma theses were partly supported during 2019, as far as it concerns non-invasive micro-XRF analyses, whereas for one case, in-situ handheld XRF measurements were required for one MSc thesis to analyze the remaining polychromy at the "*Bema of Phaidros*" within the Dionysos Theatre located at the south slopes of the Acropolis hill.

MSc programme on «Conservation of Cultural Heritage», Department of Conservation of Antiquities and Works of Art, University of West Attica

1. S. Vazelaki, "Conservation of a pre-cinema optical toy from the Greek Film Archive collection: The Zoetrope". (Fig. 57)
2. A. Papacharalambous - Kritzali, "Investigation and application of complex gel systems for the selective cleaning of the working drawing (anthivolo), "The Holy Trinity" from the Chioniades painters' workshop. (Fig. 58)
3. N. Tasiouli, "Study and investigation of gel systems in protein substrate stain removal. Application on printed silk fabric of the collection of the National Historical Museum", (Fig. 59)
4. A. Kalliga, "Russian icons from the Benaki Museum collection, 16th - 20th c. Analysis and documentation of materials and techniques based on non-destructive testing techniques" (Fig. 60)
5. K. Kallinteraki, "3D digital survey, documentation and pathology evaluation of the sculpture decoration "Bema of Phaidros", (Fig. 61)

   Cultural Heritage Materials and Technologies» of the Department of History, Archaeology and Cultural Resources Management, University of the Peloponnese
6. S. Kesidis, "Analytical study of two western European Religious Easel Paintings", (Fig. 62)

Fig. 57: The portable micro-XRF spectrometer during the analysis of painting blue material used to cover the surface of a Zoetrope, a pre-cinema optical toy from the Greek Film Archive collection © T. Vazelaki, MSc thesis

Fig. 58 The portable micro-XRF spectrometer during the analysis of inks and deteriorations the working drawing (anthivolo), "The Holy Trinity" from the Chioniades painters' workshop. © A. Papacharalambous - Kritzali, MSc thesis

Fig. 59: The portable micro-XRF spectrometerduring the investigation of pigments on printed silk fabric of the collection of the National Historical Museum, © N. Tasiouli, MSc thesis

Fig. 60: The portable micro-XRF spectrometerduring the analysis of pigments on Russian icons from the Benaki Museum collection, 16th - 20th c. © A. Kalliga, MSc thesis, Benaki museum

Fig. 61: A.G. Karydas and K. Kallinteraki performing in-situ XRF measurements at the "Bema of Phaidros" within the Dionysos Theatre located at the south slopes of the Acropolis hill. © K. Kallinteraki, MSc thesis © Ministry of Culture and Sports /Athens Eforeia of Antiquities. The in-situ measurements were realized with the kind loan of the HHXRF instrument by the University of Peloponnese and the Archaeometry laboratory of Prof. N. Zacharias who is highly acknowledged.

Fig. 62: The portable micro-XRF spectrometer during the analysis of pigments from one western European Religious Easel Painting © MSc thesis of S. Kesidis and E. Kouloumpi

Outreach activities

1. Plenary lecture to the participants of the "Spectroscopy days" cycle of seminars organized by the Institute of Nanoscience and Nanotechnology with the title: "X-ray Fluorescence and Absorption Spectroscopy", 29 May 2019, by A.G. Karydas
2. Matchmaking event to the NCSR "Demokritos" summer school participants for informing and attracting PhD students, 11 July 2019 by M. Kaparou
3. Researchers' night 2019, 27/9/2019, Stand and poster presentation of the XRF laboratory activities, by A. G. Karydas

The DAMA Instrumentation Laboratory

Personnel

Permanent staff:	***T. Geralis***
	G. Stavropoulos
	G. Fanourakis (retired, emeritus researcher)
PhD Students	***M. M. Prapa***
	O. Zormpa (since 7/2019)
Master Students:	***K. Damanakis***
	O. Zormpa (up to 7/2019)
Diploma Students	***V. Blanas***
Practical Students	***A. Giannioti***

The Data Acquisition Monitoring and Analysis (DAMA) instrumentation Laboratory aims at:

- Innovative R&D on Micro Pattern Gaseous Detectors - MPGDs
- Development of MPGD related electronics and DAQ systems
- Dedicated detectors for HEP, Nuclear Physics and applications

DAMA operates since 2000 and its main emphasis is the development of innovative MPGD and in particular Micromegas detectors.

DAMA was the first Laboratory to introduce the Micromegas technology in Greece (2001), promoted their use to the Greek academic community and initiated the most established to date biennial International Conference on MPGDs: "1st International Conference on Micro Pattern Gaseous Detectors - MPGD2009", Kolympari, Crete and was followed by MPGD2011, Kobe, Japan, MPGD2013, Zaragoza, Spain, MPGD2015, Trieste, Italy, MPGD2017, Philadelphia, USA and MPGD2019, La Rochelle, France.

Micro Pattern detectors can adapt to detect practically any kind of radiation: charged particle like cosmic muons, alphas, nuclei, neutrons, X-rays, visible photons and complement other types of detectors with their unique properties. A particular example is the measurement of the X-ray polarization at energies 1 – 10 keV, that can be performed thanks to the possibility for photoelectron tracking in the gas. This application can be used for X-ray polarimetry in Astronomy as well as in nuclear fusion as a tool to map the electric field in the core of the torus.

DAMA Infrastructure

The DAMA Laboratory is located in the ground floor of the INPP Tandem building and occupies an area of about 60 m^2. The main infrastructure is shown below: 1) Three fully equipped test benches for studying MPGDs: Gas distribution, Electronics Racks with NIM modules, HV modules, preamplifiers, amplifiers etc, Oscilloscopes, Workstations, Radioactive sources, 2) Gas Mixer and distribution of premixed gases, 3) Electronics and DAQ systems: VME Data Acquisition (CAEN controller, optical fiber connection, CRAMS, sequencer, ADC unit, Gate generator, etc), SRS - Scalable Readout System (APV FE, 2000 channels readout), FEMINOS readout for TPC mode, Electronics: Racks (1 VME and 4 NIM crates), NIM units, (Multifunction NIM modules, Amplifiers, Discriminators, HV, LV PS Pulse generators, NIM/ TTL/ NIM converter etc), MCAs (2), Preamps, 4) Design packages: Electronics design packages, Finite Element Analysis, DAQ software (Labview, C++), FPGA (Altera, Xilinx) design workstations, FPGA Design platforms.

Figure 20. Clean room: 12 m2 – two rooms Class 10,000 and Class 100,000.

5) Clean room: 12 m^2 – two rooms Class 10,000 and Class 100,000, Microscope (fig. 63)

6) COSMIC STAND. During 2018 the DAMA laboratory infrastructure was further developed. In the frame of Olga Zormpa's master thesis a cosmic stand was designed, and all the necessary preparatory work for its construction was curried through. The designed cosmic stand is shown in fig. 64.

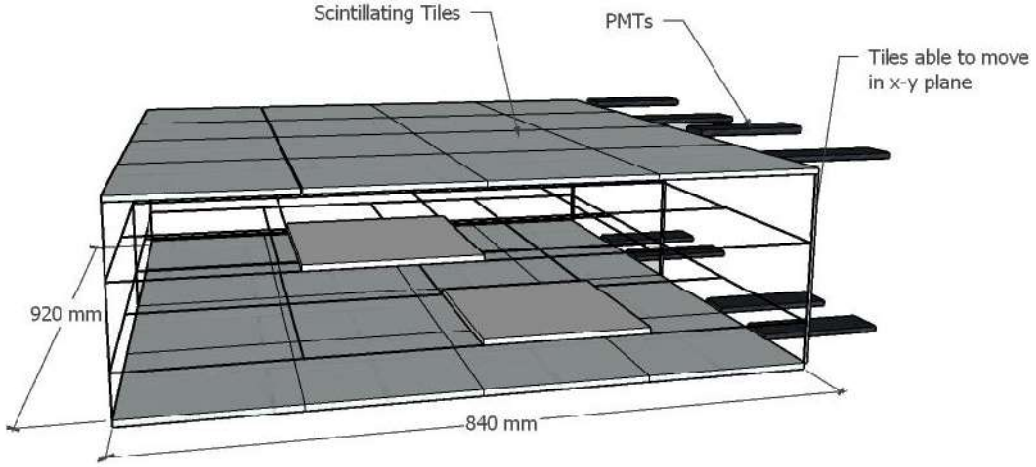

Figure 64. The Cosmic Stand design

The apparatus consists of two layers of scintillating tiles that are read out by photomultipliers. Each layer is organized in two sublayers. The first, "big", sublayer has a size of ~1m^2 and is segmented in 4 "strips" of scintillating tiles that are read out by a photomultiplier each. Attached to this "big" sublayer is the second sublayer which is made of a ~460 cm^2 scintillating tile that is read out by a photomultiplier. This "small" sublayer can move parallel to the plane of the "big" one in small steps (<1mm) with the help of a mechanical construction with step motors. By combining two such layers (as shown in Figure 64) we will be able to trigger with cosmics a detector under study that will be placed between these two layers. By moving the two "small" sublayers accordingly, we will be able to study only small parts of the detectors' under study.

The preparatory work for the construction of such a cosmic stand was completed during 2018 and included the following:

- **Characterization of Hamamatsu R580-12 and Hamamatsu H10682-210 photomultipliers in terms of dark current behavior and single photon response.**
- **Characterization of several scintillating tiles.**

Figure 65 shows the system that was constructed and validated in the ELEA lab. It consists of two layers of scintillating tiles and in this setup is used to study cosmic muons with a resistive Micromegas. On the right side the NIM electronics for the signal handling (discrimination, coincidence, triggering) is shown, together with the signals on the oscilloscope.

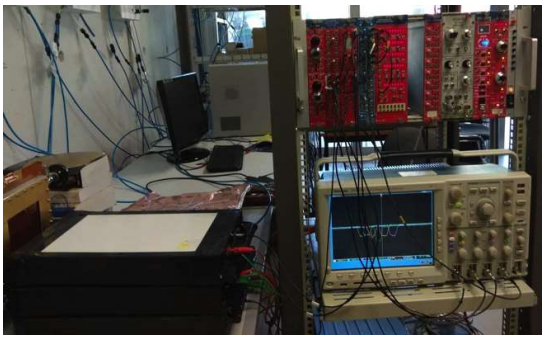

Figure 65 The Cosmic Stand at the ELEA lab, consisting of two scintillating layers (left) and the electronics (right). A resistive Micromegas detector (under the tiles – not visible) is under evaluation.

7) New Gas Mixer system

A new Gas Mixer was designed and its construction started within the frame of Kostas Damanakis Master Thesis in 2018. The new Gas Mixer was planned to have the capability to mix up to three different gases and also to operate gas detectors in absolute pressure different than the atmospheric one in the range 100 mbar – 2 bar. In figure 66 we show the schematic of the new Gas Mixer. Three Bronkhorst Gas flow controllers, which were calibrated for noble gases and for quenchers, one gas buffer to allow for properly mixing the gases and finally after the detector, two pressure regulators, to control the detector pressure from 100 mbar – 500 mbar and from 500 mbar – 2 bar. The schematic with the connectivity of the controller to the different parts of the Gas mixer on one side and of the Control PC on the other side is shown.

The construction of the gas mixing system finished in 2019 and it was fully characterized for its operation.

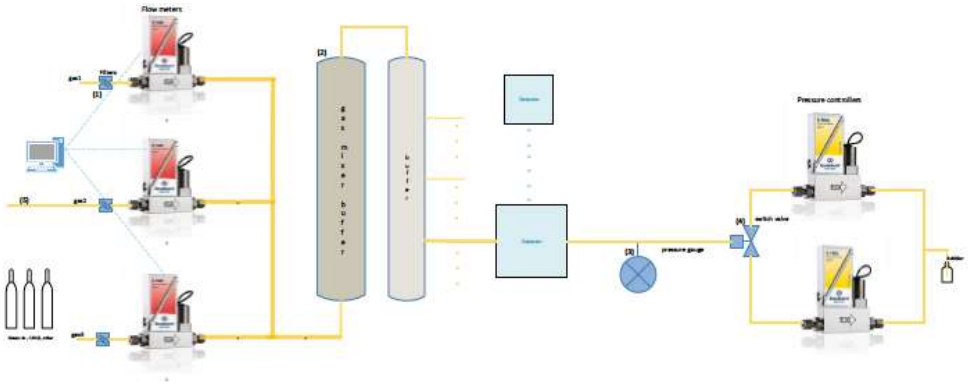

Figure 66. Gas Mixer schematic consisting of three Gas Flow controllers, one gas buffer and two pressure controllers (left).

Figure 21 The New Gas mixer. The filters (dust, oxygen, water) are shown in the bottom part, the 3 gas flow-meters (middle - low), the mixing buffer and the controller (middle – high) and the pressure controllers (not visible), bubblers and pressure gauge (upper part).

Figure 21 shows the New Gas Mixer, which is a realization of the schematic of figure 66 We use filters for dust, Oxygen and water, flow-meters from Bronkhorst, a mixing buffer cylinder, a controller for communication with the PC, two pressure controllers which can control the pressure from 100 mbar – 500 mbar and from 500 mbar – 2 bar. Detailed study, that was based on premixed gases showed its proper operation for flows between 4 – 10 l/h. Below 4 l/h the uncertainty in the gas mixture is quite high due to the uncertainty on the flow of the quencher gas.

DAMA Current Research Activities

The main activity of the DAMA Laboratory is currently within the ATLAS collaboration and it is described in another session.

Ongoing R&D activities are performed on highly promising developments.

A) Resistive Bulk Micromegas for High Rate applications

Collaboration: NCSR Demokritos, LAPP Annecy, CEA Saclay

Detector operation at very high rates is required by experiments in future accelerators like the High Luminosity LHC (HL-LHC), the International Linear Colliders (ILC) or in the Future Circular Collider (FCC). They can be used in high granularity Particle Flow (PF) hadron calorimeters with small thickness at ultra high rates thanks to their discharge quenching. They are also good candidates for operation at high eta at the HL-LHC where they can withstand rates of 10s of MHz/cm^2.

Further development is performed in the frame of the RD51 Common Fund project "Sampling Calorimetry with Resistive Anode MPGDs" – SCREAM. It is a collaboration of six institutions: LAPP Annecy, Weizmann Institute of Science, INPP/NCSR Demokritos, CEA/IRFU Saclay, University of Aveiro and University of Coimbra aiming to develop MPGD technologies appropriate for hadron sampling calorimeters for the ILC but will also provide valuable tests for the operation of MPGDs at very high rates.Our R&D has proven the excellent linearity for the buried resistor technique as well as their excellent behavior concerning spark quenching. New detectors were built with larger dimensions of 30 cm x 30 cm and were brought to the SPS test beam in November 2018. A small prototype calorimeter was built and its performance was studied primarily concerning its behavior in terms of high rates and linearity [REF 1]. The analysis and the produced publication and conference proceedings will be presented in the Annual report for 2019.

Conferences/Publications

[REF 1]*T. Geralis et al., 'Development of resistive anode Micromegas for sampling calorimetry', Proceedings of the MPGD2015 conference in EPJ Web of Conf., 174, 01017 (2018).*

B) Real x-y Segmented Mesh Microbulk Micromegas

Collaboration of INPP/NCSR Demokritos, CEA/IRFY Saclay, University of Zaragoza and CERN.

The Aim of the project is to develop microbulk Micromegas detectors with real x-y structure by segmenting the mesh. The old fashioned way to provide x and y information was a complicated pcb structure with pads on the anode surface and through metalized holes in order to form conductive y strips on a layer beneath the anode. The manufacturing procedure was difficult and fragile with the disadvantage of higher material budget. The new manufacturing process is simpler and leads to mass minimization, which is adequate for rare searches applications but also for neutron beam profilers. Our group proposed and coordinated the effort on the optimization and the design of the Real x-y segmented mesh microbulk Micromegas, which was supported by the RD51 Common Fund.

In 2018 we have tried for a first time Real x-y Segmented Mesh Microbulk Micromegas with a strip pitch of 700 μm. Two practical students (S. Tzanos and V. Blanas) have built and characterized the detectors. The characterization was at the level of studying the stability of the

detector and the gain.In Figure 68. Schematic of the segmented microbulk (upper-left), Photos (upper-right), energy spectra of two types of microbulk with strip pitch of 1mm (lower - left) and 700μm (lower - right)you can see the detector layout (top schematic and photos) and two impressive excellent Energy resolution plots taken with these detectors.

The Master Thesis of Chara Giakoumogiannaki studied the segmented mesh in TPC mode using the Feminos Readout System. Figure 69. Operation of the microbulk in TPC mode. Pulse of nearby strips in cosmic muon event (left) and the corresponding Landau distribution (right).shows a cosmic muon event recorded with the above system. Two strips gave a signal (the two pulses are visible) and on the right a nice Landau distribution is produced wit this data.

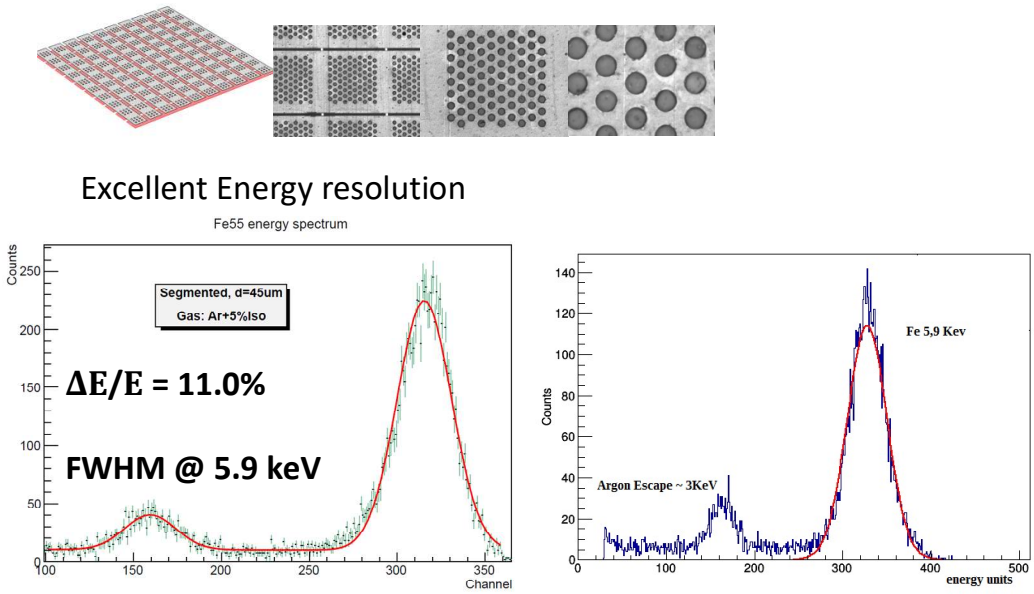

Figure 68. Schematic of the segmented microbulk (upper-left), Photos (upper-right), energy spectra of two types of microbulk with strip pitch of 1mm (lower - left) and 700μm (lower - right)

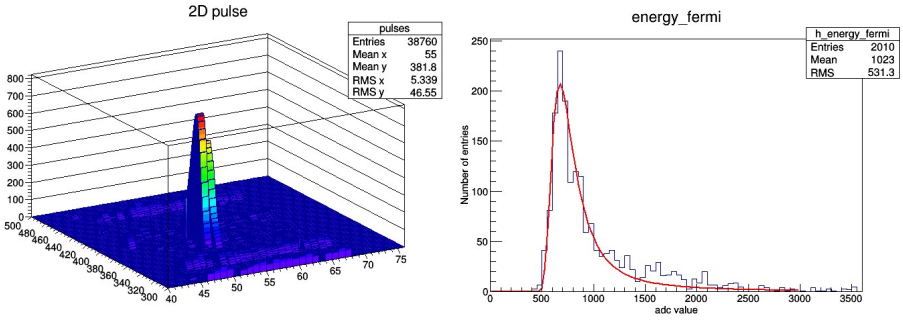

Figure 69. Operation of the microbulk in TPC mode. Pulse of nearby strips in cosmic muon event (left) and the corresponding Landau distribution (right).

The performance for the energy resolution is impressive and reaches an optimum for a gaseous detector of 11% FWHM at 5.9 keV (see Figure 68 69).

Real x-y segmented mesh microbulk Micromegas is very adequate for Rare searches like axion or dark matter thanks to the very low background that can be achieved (~ 10^{-7} cnts/keV/cm^2/s) with its low material budget and additional measures like, low radioactivity shielding, cosmic veto etc.

It is already used in the nTOF collaboration for a neutron beam profiler with excellent results. This is the thinnest neutron detector ever manufactured with only 5 μm + 5 μm of Cu and the remaining polyimide in between the x and y foils. In that frame we have published a relevant paper in 2018 on neutron beam profiling [REF 2].

Conferences/Publications

- [REF 2]*M. Diakaki et al., "Development of a novel segmented mesh MicroMegas detector for neutron beam profiling", NIMA 903(2018) 46-55.*
- [REF 3]*C. Giakoumogiannaki, Master Thesis (2018), Study of a segmented mesh microbulk Micromegas detector using the FEMINOS card.*

C) The r-φ Micromegas

The r-φ Micromegas is with resistive surface especially designed to operate in cylindrical geometry like in the srEDM experiment or the high eta rings at the HL-LHC.

Figure 70 The r-φ Micromegas prototype developed by the INPP group.

This design is made by the INPP group and first prototypes are produced (see Figure 70) and tested in beams at CERN.

D) Micromegas Using micro fabrication Techniques and Graphene

Collaboration: INPP/NCSR Demokritos, INN/NCSR Demokritos

Our primary goal and ambition is to build a Micromegas detector operating with two different gases in the conversion volume and the amplification volume. This idea and the progress towards this goal was presented by our group for a first time at the MPGD2015 in Trieste [REF 4]. Two-gas phase detector separated by a Graphene layer will exploit differences in gas

properties to improve performance. We are studying the electron transparency together with the elimination of the gas atoms or ions transparency through graphene.

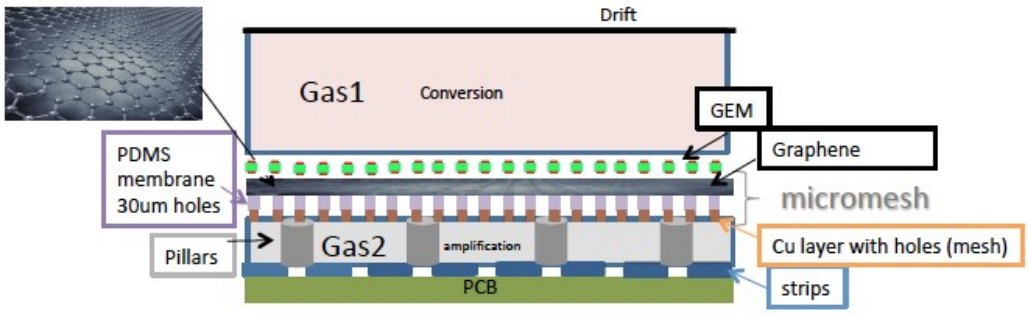

Figure 71. Conceptual design of a Micromegas using micro-fabrication techniques and graphene.

Conferences/Publications

[REF 4] *T. Geralis et al. 'Innovative Micromegas manufacturing with micro-fabrication techniques and use of graphene', oral presentation in MPGD2015, 12 – 15 October 2015, Trieste, Italy*

A.1 "A 2-D localization of a lightly shielded radiation source using a network of small form factor CZT sensors", A. Kyriakis

Conference: A.Kyriakis et al, iWoRiD 2019, 21st International Workshop on Radiation Imaging Detectors, 7-12 July 2019, Kolympari

Short Description: We present a small factor (0.5cm^3) CZT static sensor network consisted of a number of Non-Directional Detectors (NDD) capable to localize bare and lightly shielded radiation sources. The localization is performed with a fusion algorithm based on both analytical and Multivariate Analysis techniques (MVA). The algorithms have been tested using simulated data and verified with experimental data from a static ^{137}Cs source of 7MBq. The localization accuracy of the order of 15cm has been archived in 3D for bare sources and of the order of 20cm in 2D for light shielded sources within a monitored volume of 5m x 2. 8m x 2m.

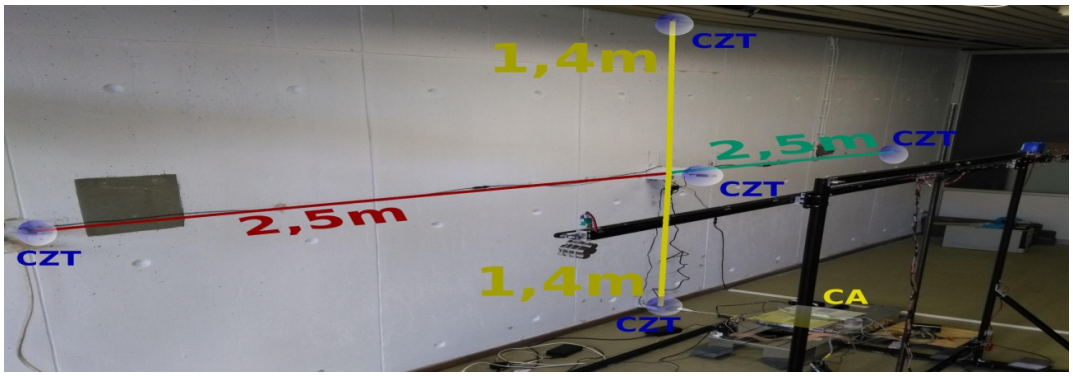

Figure 72: Experimental Setup with a 3D step motor system that positions the radioactive Source (blue box) in the appropriate position. Five sensors in cruciform topology have been mounted on the wall (transparent circles).

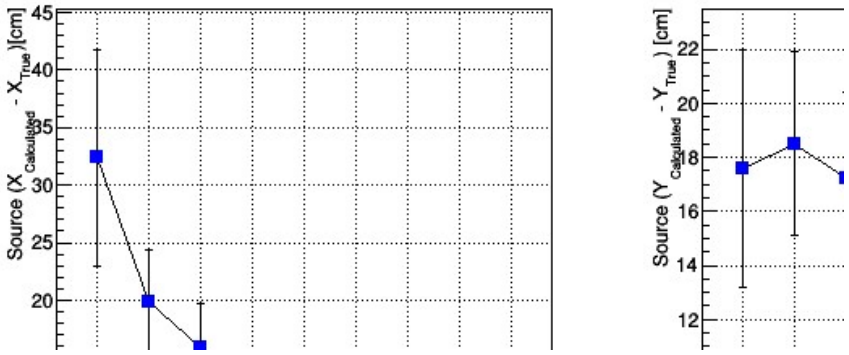

Figure 73: Horizontal (left) and vertical (right) source position accuracy of a light shielded ^{137}Cs radioactive source. An accuracy of less than 20cm can be obtained after an exposure time of 40sec for both horizontal and vertical coordinate of the radioactive source.

A2. **“ A UV photodetector based on ordered free standing MWCNT "** , A. Kyriakis, N Glezos, D Velesiontis, A Stefanou.

Conference: A.Kyriakis et al, iWoRiD 2019, 21st International Workshop on Radiation Imaging Detectors, 7-12 July 2019, Kolympari

Publication: Filatzikioti A, Glezos N, Kantarelou V, et al. Carbon nanotube Schottky type photodetectors for UV applications. *Solid State Electron*. 2019;151(September 2018):27-35. **doi:10.1016/j.sse.2018.10.018**

Short Description: Multiple wall carbon nanotubes (MWCNT) present advantages for optoelectronic applications such as the large effective photo-collector surface as well as the possibility to tune their band gap and absorbance through the growth parameters. The combination of CNTs with conventional semiconductors and metals to form a device presents technological challenges because of the high temperatures required for the production of CNTs and the catalysts used (e.g. Fe). These conditions may result in structural modifications of the substrate specially when the CNT formation temperature approaches the formation temperatures of other layers or even cause metal migration. The use of ordered free-standing MWCNTs for photodevice presents advantages, since they have a tunable absorbance depending on their height while their dense ordering results in a large effective area sensor. Additionally, the bandgap depends on their thickness, thus it is tunable by changing the formation conditions. In this work, we demonstrate a hybrid MWCNT/Si_3N_4/n-Si photodetector based on ordered MWCNTs and evaluate its performance in the UV, visual and near IR spectrum (200-1000nm). Depending on the application the absorbing nanotube layer can be made thick enough (e.g. several millimeters) to enhance radiation absorption and electron-hole pair generation. The best result obtained so far as a UV detector is a 90% Equivalent Quantum Efficiency @ 275nm for a 20μm CNT layer thickness (figure 65). The corresponding photocurrent and the noise levels are shown in figure 66.

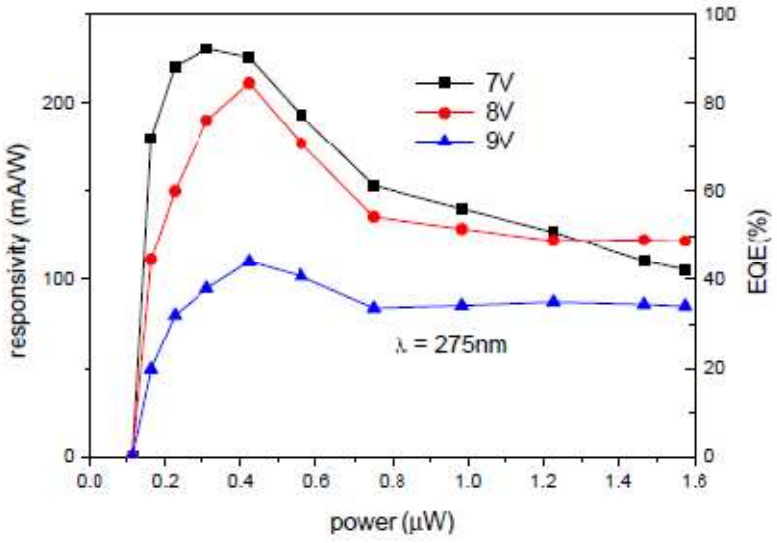

Figure 74: Responsivity / QE as a function of the bias voltage and irradiation power from a LED emitting at λ = 275nm

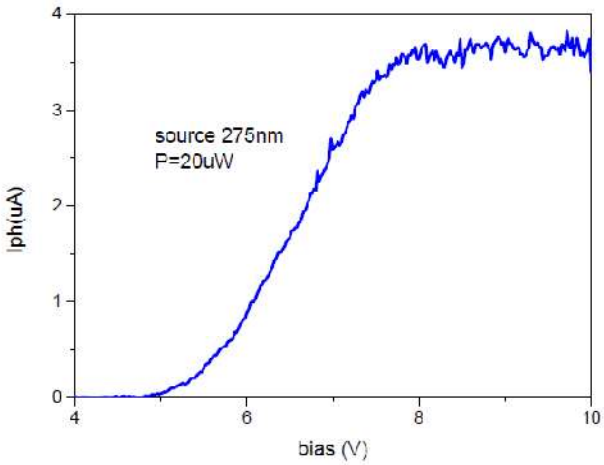

Figure 75. UV photocurrent response of the device vs bias voltage

Conference Organization

iWoRiD 2019, 21st International Workshop on Radiation Imaging Detectors, 7-12 July 2019, Kolympari, (https://indico.cern.ch/event/774201/page/15373-welcome-to-iworid-2019)

Short Description: The International Workshop on Radiation Imaging Detectors are held yearly and provide an international forum for discussing current research and developments in the area of position sensitive detectors for radiation imaging, including semiconductor, gas

and scintillator-based detectors. Topics include processing and characterization of detector materials, hybridization and interconnect technologies, design of counting or integrating electronics, readout and data acquisition systems, and applications in various scientific and industrial fields.

Education and Outreach Activities

Among the activities of the Institute of Nuclear and Particle Physics education is of great importance. In this context, the INPP offers opportunities to both university students and high school and primary school aged children. The main educational activities can be summarized below:

- INPP in collaboration with the National Technical University of Athens (NTUA) organize a program of postgraduate studies which leads to a MSc or a PhD degree. The researchers of the Institute along with professors of NTUA jointly teach classes in this program. Furthermore, researchers of the Institute supervise and guide graduate students for the completion of their degree. During 2019 the following PhD and MSc degrees **have been awarded**:
  - Pikounis Kostantinos, PhD, *E. Tzamariudaki*
  - Stavropoulos Dimitrios, MSc, *E. Tzamariudaki*
  - Bligoura Natalia, MSc, *A. Lagoyannis*
  - Anagnostou Georgia, MSc, *C. Markou*
  - Papadopoulou Dimitra, MSc, *A. Karydas*
  - Damanakis Kostantinos, MSc, *T. Geralis*
  - Zorba Olga, MSc, *G. Stavropoulos*

  The following PhD/MSc efforts are **ongoing**:

  - Katsinis Dimitrios, PhD, *M. Axenides*
  - Asenov Patrick, PhD, *D. Loukas*
  - Assiouras Panagiotis, PhD, *D. Loukas*
  - Anna Stakia, PhD, *G. Daskalakis*
  - Preketes-Sigalas Kostantinos, PhD, *A. Lagoyannis*
  - Demou Eleni, PhD, *A. Lagoyannis*
  - Laoutaris Aggelos, PhD, *A. Lagoyannis*
  - Polideuki Georgia, PhD, *C. Markou*
  - Tzanetatos Dimitrios, PhD, *C. Markou*
  - Panagopoulos Vassilios, PhD, *C. Markou*
  - Sinopoulou Anna, PhD, *E. Tzamariudaki*
  - Stavropoulos Dimitrios, PhD, *E. Tzamariudaki*
  - Asimakis Ioannis, PhD, *D. Bonatsos*
  - Sarantopoulou Smaragda, PhD, *D. Bonatsos*
  - Paspalaki Garyfallia, PhD, *A. Kyriakis*
  - Tsanko Dimiter, PhD, *K. Papadopoulos*
  - Syrrakos Nikolaos, PhD, *K. Papadopoulos*
  - Zorba Olga, PhD, *T. Geralis*
  - Prapa Maria-Myrto, PhD, *T. Geralis*

- Tsampa Kalliopi, MSc, *A. Karydas*

- INPP, through agreements with Universities in Greece, supervise and guide undergraduate students during their Diploma thesis as well as their practical training. Students are trained by participating to the research projects of the Institute in order to acquire a training certificate (about 1-3 months training) or a diploma thesis needed for their graduation (about 6 months training). During 2019nine (9) undergraduate students were trained from the INPP researchers.
    - Maroglou Ilias, Diploma thesis, *A. Lagoyannis*
    - Tsantiri Artemis, Practical Training, *A. Lagoyannis*
    - Voutouras Giorgos, Practical Training, *E. Tzamariudaki*
    - Chasapis Epameinondas, Practical Training, *E. Tzamariudaki*
    - Fotiou Savvina, Diploma thesis, *A. Karydas*
    - Simeonidi Sotiria, Diploma thesis, *A. Karydas*
    - Peroulis Spyridon, Diploma thesis, *D. Bonatsos*
    - Blanas Vassilis, Diploma thesis, *T. Geralis*
    - Giannioti Artemis, Practical Training, *G. Stavropoulos*

- "Cadet Researchers – A life experience" is an educational activity held in NCSR DEMOKRITOS with the initiative of the Institute of Nuclear and Particle Physics. September of 2019 marked the fourth successful year of the activity, organized under the auspices of the Ministry of Education. The purpose of this educational activity is to involve some of the brightest high school students in Attica in experiments held in the laboratories of the Institute of Nuclear and Particle Physics for one week. The aim is to acquaint them with the methodologies involved in everyday research life in the thematic areas of the Institute. The students participate actively in all aspects of experimental work under the guidance of INPP researchers. The selection procedure involves a written examination held in INPP, during the spring break. In 2019, 140 students from 18 schools of Attica participated. 8 students were selected. In September 2019, they visited the INPP laboratories for a week, to participate in experiments related to Nuclear Physics, Particle physics and Astrophysics. The first day of the week was devoted to a series of lectures on topics related to modern physics, while on Friday, the Cadet researchers reported on their findings and results.

- The Institute of Nuclear and Particle Physics of NCSR Demokritos, organizes every year the Particle Physics Masterclasses for high school students. The international particle physics masterclasses are workshops organized by the International Particle Physics Outreach Group (IPPOG, http://ippog.org/). The Masterclasses take place in more than 50 countries and more than 200 universities and research institutes all over the world. In Greece, the participants are the universities of Athens, Thessaloniki, Crete, the National Technical University (NTUA), as well as NCSR Demokritos. During the day, high school students have the opportunity to work together with researchers in high energy physics and analyze particle physics data from the Large Hadron Collider (LHC). Initially, the students attend presentations for particle physics theory, accelerators, detectors and cosmology. Then, in the second part of the masterclass, the students are trained to analyze events from CMS experiment and "discover" by themselves the Higgs Boson. Finally, a teleconference takes place with other high schools around the world participating in the masterclass at the same day. During the conference, the students present and discuss their results and familiarize themselves with the international/multicultural tradition of research in fundamental physics.
  In 2019, INPP organized masterclasses in a) NCSR Demokritos b) EKFE Chania, Crete and c) local masterclasses at high Schools in Athens

  www.physicsmasterclasses.org
  https://physicsmasterclasses.org/index.php?cat=country&page=gr_athen3
  www.facebook.com/InternationalParticlePhysicsMasterclasses
  https://twitter.com/physicsIMC

- In 2019 the "Greek Researcher's Night" was held at the "Hellenic Cosmos, Cultural Centre"at the end of September. The INPP and its researchers participated in the activity by organizing lectures and guided tours to the Institute's laboratories.

- INPP scientists have been members of the organizing committees and have participated as lecturers in Summer Schools for University graduate students and young scientists. The Summer School organized each year by NCSR "DEMOKRITOS" is a two-week course and aims to keep them up-to-date with the latest research developments at the Center and internationally. Speeches are given by Institute members and guest speakers, while participants visit the Institute's laboratory facilities. INPP speakers are ranked at the top positions based on students'evaluation.

Except the NCSR "D" Summer School, INPP & INN scientists organized the lectures at the Aegina's Summer School for high school students from all over Greece.

- INPP researchers are involved in developing and delivering popularized science lectures to public or school audiences. Also, presentations and lectures and guiding tours are being given to schools visiting "Demokritos" and its facilities (among them INPP and the Tandem accelerator) with a few hundred visitors each year.

- Complex Systems and Applications(C.O.S.A.)
  Our theory group research activity on Classical and Quantum Chaotic Dynamics is strengthened with the COSA Initiative. It was kicked off in 2006 by an act of the Council of institute Directors of Demokritos at the scientific recommendation of researchers from the center. Its purpose was to set up an interdisciplinary network of Greek researchers, with NCSR Demokritos as its cross-fertilizing hub. Its aim is to promote the study of the emerging new field of complexity research. It requires the synergy of a variety of concepts, methods and techniques from a variety of fields such as information Science, Nonlinear Sciences-deterministic chaos, non-equilibrium statistical mechanics and Fractal geometry. It equally touches through its insights a wide range of the human scientific endeavor ranging from particle and nuclear physics, cosmology and astrophysics, nanotechnology and mesoscopic physics as well as biology, economics and social sciences.

  COSA's activities are educational and outreach through

  1. a semester course offered for credit in collaboration with the National Technical University of Athens on "Special Topics on Complex Systems"
  2. Annual Summer Schools co-organized on the subject of "Dynamic Systems and complexity" as well as on "Mathematical modeling of Complex systems": 26th school,2019http://complexity2019.ntua.gr/?page_id=212
  3. Cosa seminars on "Nonlinear Science and Complexplexity"