INSTITUTE OF NUCLEAR AND PARTICLE PHYSICS

NATIONAL CENTER FOR SCIENTIFIC RESEARCH DEMOKRITOS

ACTIVITIES REPORT
2018

EDITORS:

Dr. Ch. Markou, Ms. G. Kareli

October 2019

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

http://www.inp.demokritos.gr

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INSTITUTE OF NUCLEAR AND PARTICLE PHYSICS

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 Astroparticle 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 Astroparticle 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 Astroparticle Physics Research Infrastructure in South-West Peloponnese (Kalamata, Pylos, Methoni).

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Ms. G. Kareli, Secretary INPP
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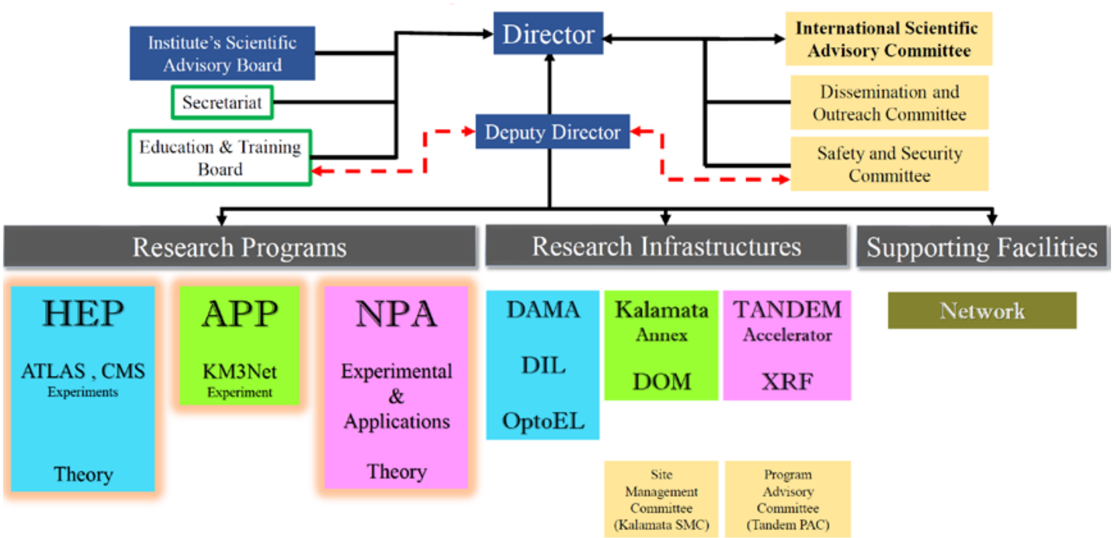
Organizational Chart



May 2018

Director: Dr. Ch. Markou (20/2/2019-today)

Deputy Director: Dr. C. Papadopoulos (9/11/2017-20/1/2019, Acting Director)
Dr. Ch. Markou (21/1/2019-19/2/2019, Acting Director)

Administration: G. Kareli, Secretary
E. Simantirakis, Management

Institute Scientific Advisory Board(E.Σ.I.):

17/6/2016-26/6/2018
- G. Fanourakis(Chairman)
- G. Daskalakis
- D. Loukas
- C. Markou,
  repl. by A. Lagoyannis 28/2/2018
- G. Stavropoulos

27/6/2018-today
- T. Geralis(Chairman)
- G. Daskalakis
- A. Karydas
- G. Savvidy
- G. Stavropoulos

International Scientific Advisory Committee:
- Prof. Nicolas ALAMANOS
- Prof. Ioannis BAKAS (deceased)
- Prof. Angela BRACCO
- Prof. Yannis KARYOTAKIS
- Prof. Karlheinz LANGANKE
- Prof. Christos TOURAMANIS

Scientists in charge:	**High Energy Physics**	· Dr. G. Fanourakis: DAMA & Education Office NCSR-D · Dr. T. Geralis: HEP-ATLAS · 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 & Education INPP

Personnel

The lists below reflect the INPP personnel as of the 31st of December 2018.

Researchers

Dr. Georgios **ANAGNOSTOU**	Senior Researcher	Exp. High-Energy Physics	anagnog@inp.demokritos.gr
Dr. Minos **AXENIDES**	Director of Research	Theoretical Particle &Astroparticle Physics	axenides@inp.demokritos.gr
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Dr. Andreas **KARYDAS**	Director of Research	Exp. Nuclear Physics	karydas@inp.demokritos.gr
Dr. Aristotelis **KYRIAKIS**	Senior Researcher	Exp. High-Energy Physics	kyriakis@inp.demokritos.gr
Dr. Anastasios **LAGOYANNIS**	Senior Researcher	Exp. Nuclear Physics	lagoya@inp.demokritos.gr
Dr. Dimitrios **LOUKAS**	Director of Research	Exp. High-Energy Physics	loukas@inp.demokritos.gr
Dr. Christos **MARKOU**	Director of Research	Exp. High-Energy & Astroparticle Physics	cmarkou@inp.demokritos.gr
Dr. Konstantinos **PAPADOPOULOS**	Director of Research	Theoretical Particle Physics	cgppdo@inp.demokritos.gr
Dr. George **SAVVIDY**	Director of Research	Theoretical Particle Physics	savvidy@inp.demokritos.gr
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Dr. Ekaterini **TZAMARIUDAKI**	Director of Research	Astroparticle Physics	katerina@inp.demokritos.gr

Other Scientific Personnel

Stavroula **TSAGLI**	Physicist	tsagli@inp.demokritos.gr

INPP Administration

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INPP Secretariat

Georgia **KARELI**	Secretary	gkarel@inp.demokritos.gr

Technicians

Vassilios **ANDREOPOULOS**	Electronics	andreo@inp.demokritos.gr
Ioannis **KISKIRAS**	Electronics	kiskiras@inp.demokritos.gr
Emmanuel **TSOPANAKIS**	Workshop technician	mtsop@inp.demokritos.gr
Aggelos **VOUGIOUKAS**	Craftsman	vougioukas@inp.demokritos.gr

Support Personnel

Sophia **BAKOU**	General support	bakou@inp.demokritos.gr

Personnel under fixed term contracts

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Giorgos **ANDROULAKIS**	Physicist	C. Markou	androulakis@inp.demokritos.gr
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Spyridon **KOUTSOUKOS**	Physicist	C. Markou	koutsoukos@inp.demokritos.gr
Georgios **LINARDOPOULOS**	Physicist	M. Axenides	Linardopoulos@inp.demokritos.gr
Maria Andriani **MARTINOU**	Physicist	D. Bonatsos	martinou@inp.demokritos.gr
Garyfalia **PASPALAKI**	Physicist	A Kyriakis	paspalaki@inp.demokritos.gr
Kostas **PIKOUNIS**	Physicist	C. Markou	pikounis@inp.demokritos.gr
Anna **SINOPOULOU**	Physicist	E. Tzamariudaki	Sinopoulou@inp.demokritos.gr
George **SMYRIS**	IT manager	C. Markou	gsmyris@inp.demokritos.gr

The evolution of Personnel versus year for the period 2013 – 2018 appears in the following figures.

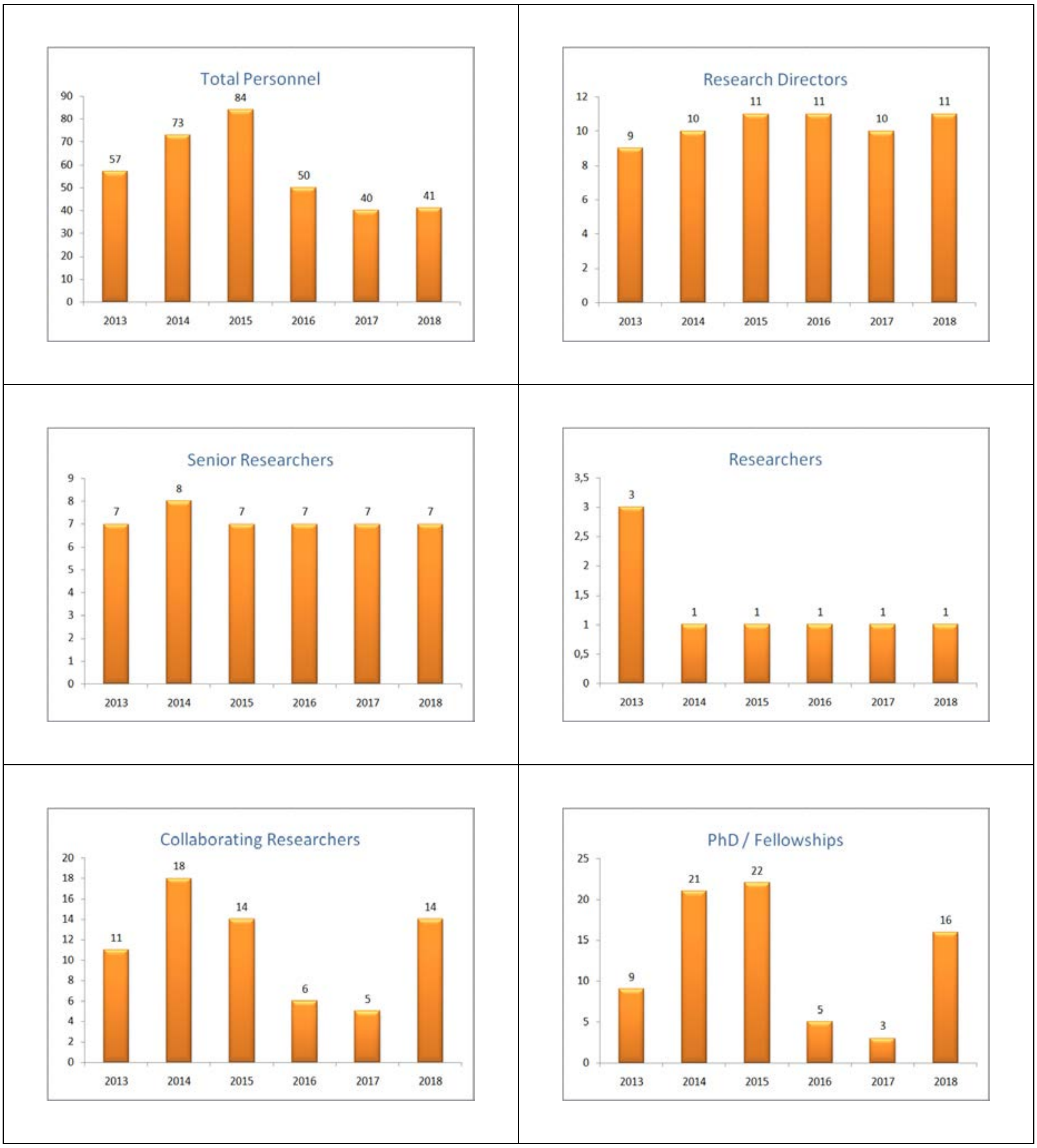


Figure 1: Personnel evolution

Mobility

During 2018, Dr. S. Harissopoulos and Dr. P. Dimitriou were on leave of absence in the International Atomic Energy Agency, Vienna.

In September 2018, Dr. M. Axiotis joined the INPP as a Researcher Grade C, and on the 31st of December 2018 Dr. G. Fanourakis went into retirement.

Funding Programs in 2018

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.

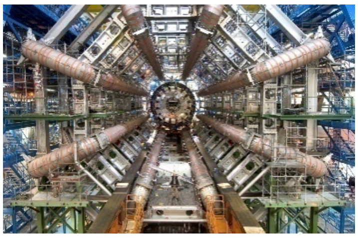
Prog. ID	Title	Principal Investigator	Starting date	Finishing date	Budget
10231	Non destructive analyses with x-rays	Andreas Karydas	1/4/1998	31/5/2022	50,000.00 €
10461	Support for INPP	INPP Director	28/7/1998	27/1/2022	25,000.00 €
10881	Detection devices systems	Dimitrios Loukas	1/12/2002	31/12/2021	35.000,00 €
11041	Techologies 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	Sotirios Harissopulos	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	300,000. 00 €
11900	MIXMAX-Development and Implementation of new generation of Pseudo Random Number Generators (PRNG) based on Kolmogorov-Anosov K-systems	George Savvidy	1/1/2015	31/12/2018	216,000.00 €

11984	RENA	George Fanourakis	1/5/2016	31/1/2018	50,400. 00 €
11985	ENSAR 2 — H2020	Sotirios Harissopulos	1/3/2016	29/2/2020	60,000.00 €
12147	KM3NET 2.0	Christos Markou	1/1/2017	31/12/2019	487,500.00 €
12157	Analytic applications using synchrotron techniques	Andreas Karydas	10/3/2017	9/3/2020	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 €

Research Programs

High Energy Experimental Physics

The ATLAS group



Personnel:

Researchers:	T. Geralis*, G. Fanourakis, G. Stavropoulos
PhD Students:	M. Prapa
Master Students:	K. Damanakis, O. Zormpa
Engineers:	D. Mitrovgenis
Technicians:	I. Kiskiras
Practical Work Students:	E. Logothetis-Agaliotis, V. Blanas, E. Eleftheriou, A. Papaioannou, D. Stasinou, S. Tzanos

* T. Geralis is the group representative

1. Introduction

The INPP_ATLAS group is a new group which was 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 has undertaken the following responsibilities:

- Taking over part of the NSW L1DDC and ADDC electronic cards testing, including setup and development of the needed test benches;
- NSW integration at CERN;
- Long term maintenance for detectors and electronics after the NSW installation;
- 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:

- **Test setups for the L1DDC and ADDC boards and the Database recording.**
- **The Repeater boards design, production and commissioning**

2. Test setups for the L1DDC and the ADDC boards

The Trigger and Data Acquisition of the NSW is depicted in figure 2. 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.

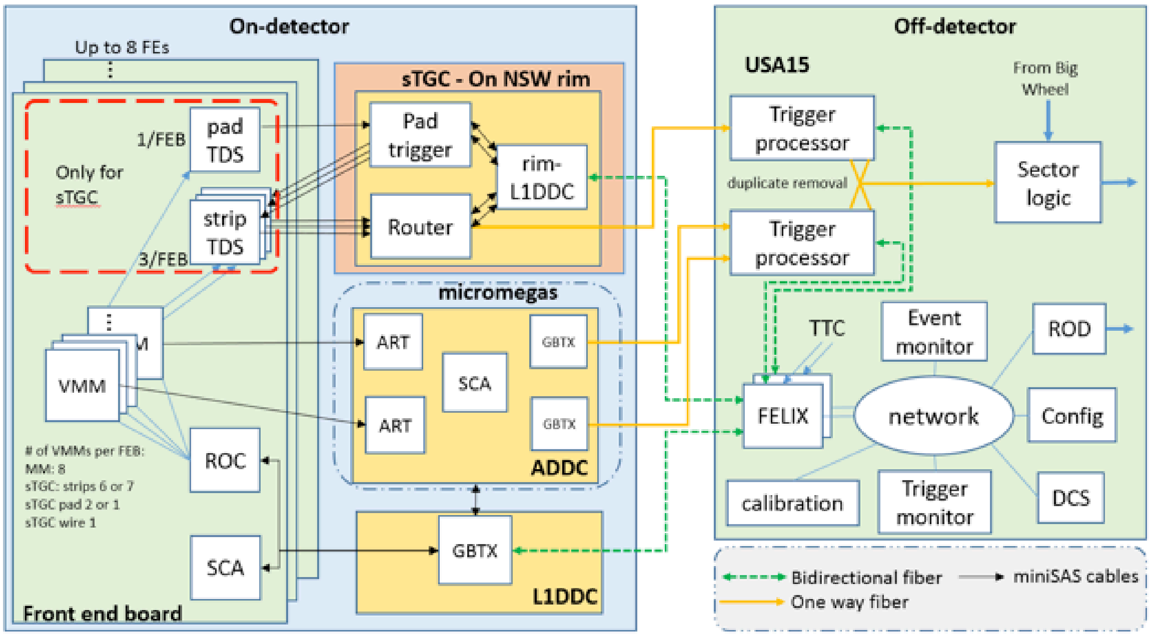


Figure 2: Schematic of the Readout and Data Acquisition system of the NSW.

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 3 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.

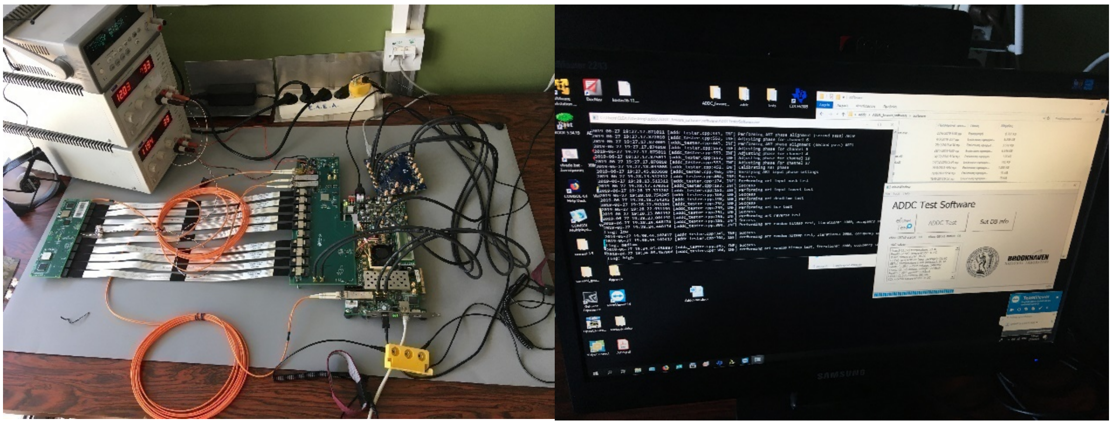


Figure 3: ADDC boards test setup (left) and the GUI on the controlling PC (right)

In September 2018 the whole setup was ready but the production of the ADDC boards was delayed up to 2019. By the time of writing this report (October 2019) all 600 ADDC boards have been tested by the INPP_ATLAS group. Details will be given in the Annual report for the 2019 activities. A presentation of the test setup was given by G. Stavropoulos in September 2018 in the NSW Electronics meeting, which confirmed his qualification as an author in ATLAS.

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 4 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.

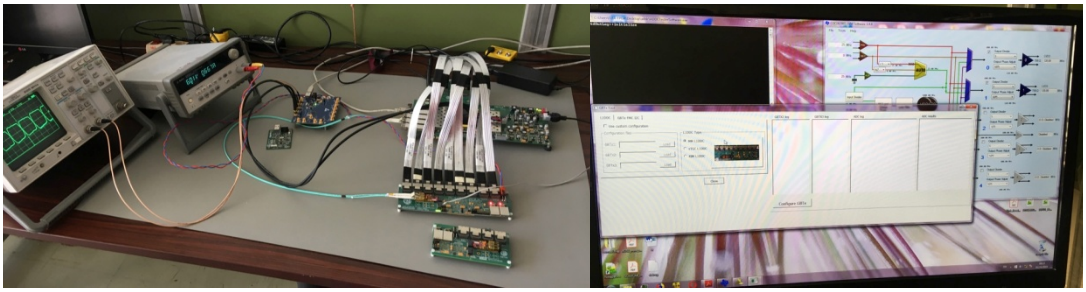


Figure 4: L1DDC boards test setup (left) and the GUI on the controlling PC (right)

In September 2018 the whole setup was ready but the production of the L1DDC boards was delayed up to 2019. By the time of writing this report (October 2019) about 250 L1DDC boards have been tested by the INPP_ATLAS group. All L1DDC cards are shared among 4 testing centers and the INPP_ATLAS group will test a total of 300 L1DDCs. Details will be given in the Annual report for the 2019 activities. A presentation of the test setup was given by T. Geralis in September 2018 in the NSW Electronics meeting, which confirmed his qualification as an author in ATLAS.

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 5, a snapshot of the database page is shown.

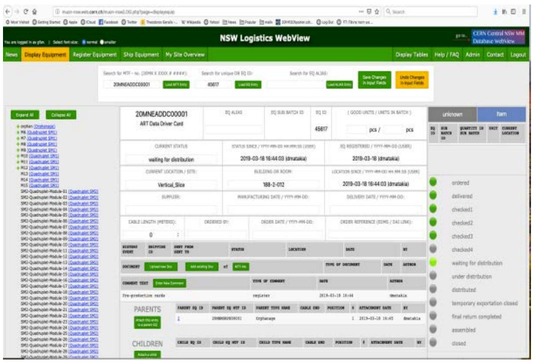


Figure 5: Snapshot of the NSW Logistics web page (database) for the registration of the ADDC and the L1DDC boards after their testing.

A presentation of the test setup was given by G. Fanourakis in September 2018 in the NSW Electronics meeting, which confirmed his qualification as an author in ATLAS.

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 6 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 6, right).

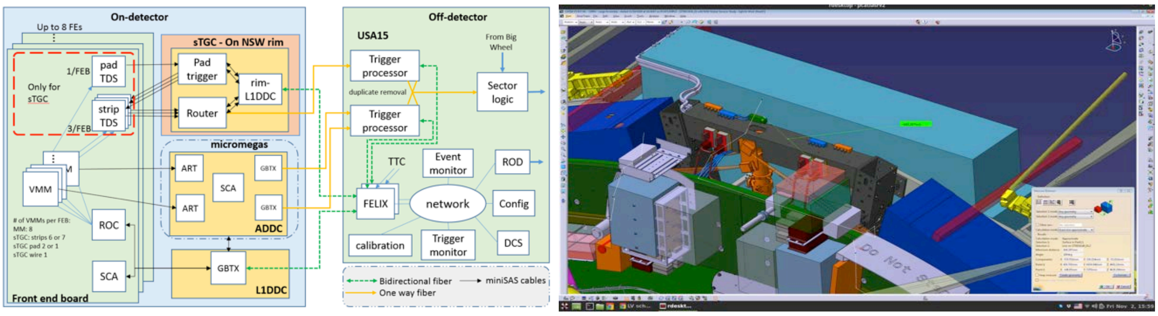


Figure 6: NSW Electronics and Data Flow (left). The Rim-crate location in the outer part of the wheel (right).

The connections between the pFEB, the sFEB and the Pad Trigger and Router are done using the 3M MiniSAS 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 7: 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.

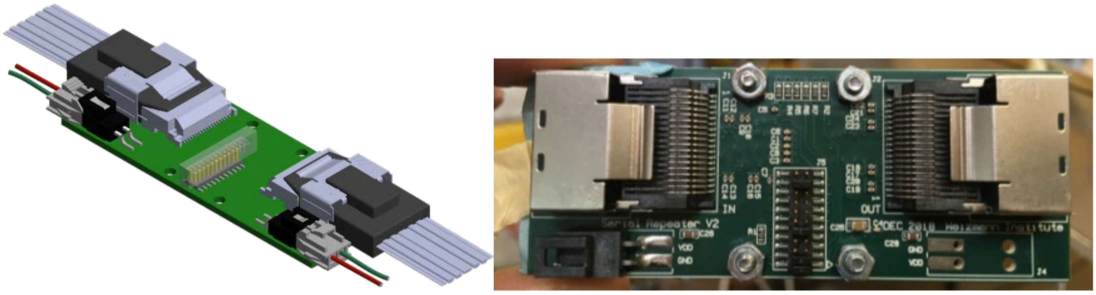


Figure 7: 3-D schematic of the SRL1R repeater card (left) and a prototype (right)

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 8 (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.

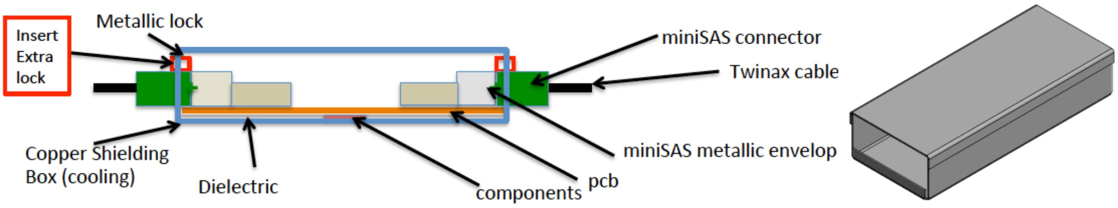


Figure 8: Schematic of the shielding box. Drawing of the metallic box.

A preproduction of 30 SRL1R repeaters was launched in January 2019 and it will be presented in the corresponding INPP Annual report.

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. We describe here the second version of the LVD1R.

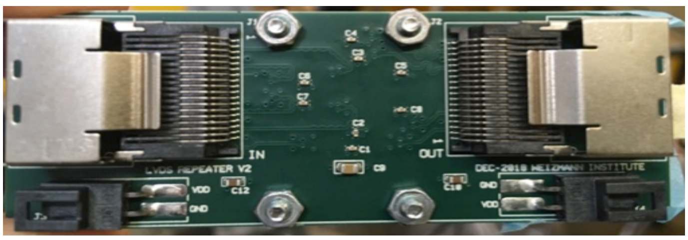


Figure 9: Photo of the LVD1R_V0 repeater card

2.1 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 has 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. We need 15 SRL1R per wedge for the Large Sector while for the Small Sectors we need only 12 per wedge.

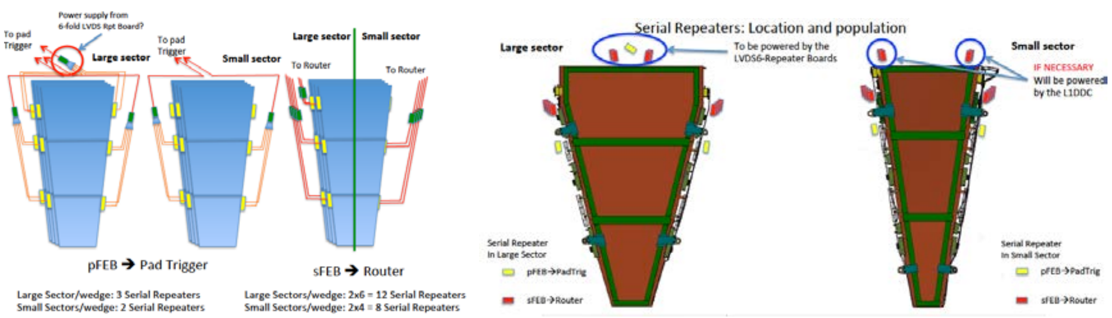


Figure 10: Location of the SRL1Rs for the pFEB and the sFEB links

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.

Concluding, the INPP_ATLAS group has undertaken the responsibility for the production of the Serial and LVDS repeaters. During 2018 INPP_ATLAS group: 1) Investigated the necessity of the Serial (SRL1R) and the LVDS (LVD6R) repeaters and proved that they are needed for the proper data transfer in the Trigger path, 2) Designed the prototype version in collaboration with Weizmann and proceeded to their production, 3) Made provision for all the studies for their cooling in the experiment and 4) Coordinated the effort to specify the placing of the repeaters as well as the cable types and their proper lengths. We should stress that the prototypes were manufactured in Greece with the company Prisma SA. More extensive work for the production of the final product was done during 2019 and will be presented in the Annual report for 2019.

Responsibilities
T. Geralis: Member of the Muon sub detector Institutes Board
T. Geralis: Member of the NSW Electronics Coordination Group.

Presentations in the ATLAS internal meetings in 2018
10 Talks were given by members of the INPP_ATLAS in the NSW Electronics meeting and the NSW Electronics Coordination meeting.

Conferences/Publications

Even though INPP_ATLAS group entered authorship in October 2018, the first publications appeared in the journals in 2019 and will be presented in the next annual report.

The CMS group

A) The INPP_CMS group (as of June 1st, 2018)

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: A. Papadopoulos

Electronics Engineer: I. Kazas

Administration: M. Barone

* D. Loukas is the group representative

B) The INPP_CMS activities during 2018

B.1 The CMS Experiment

The Large Hadron Collider (LHC) [1] is the world's larger and more powerful particle accelerator. The LHC can accelerate protons and heavy ions and has delivered collisions of protons (p), lead ions (Pb) and protons of lead ions: pp, PbPb and pPb.

Operation of the accelerator started in 2009. The 2010-2012 running period is referred as Run 1. In 2010 and 2011 the LHC operated at a center-of-mass energy of 7 TeV. The center-of-mass energy increased to 8 TeV in 2012. Run 1 was followed by a two-year long shutdown, referred to as Long Shutdown 1 (LS1), during which the accelerator and the experiments were consolidated. This allowed starting Run 2 in 2015 that lasted until the end of 2018 with a maximum instantaneous luminosity of 2 x 10^{34} cm^{-2} s^{-1} and center-of-mass energy of 13 TeV. A total of 237.4 fb^{-1} delivered to the CMS experiment [2][3] since 2010.

Thanks to the excellent performance of the LHC, both ATLAS and CMS experiments have been able to achieve a plethora of highly relevant physics results, including the discovery of the Higgs boson in 2012 [3][4], and the measurement of the branching ratios of the rare decays of the neutral B_s and B_0 mesons to two muons[5][6]. Stringent limits have been placed on a large variety of new physics models. The top quark pair production cross section has been determined as a function of $\sqrt{s}$ and the top-quark mass and other top-quark properties have been measured with unprecedented precision [6].

A major upgrade of the LHC injectors is foreseen during the following Long Shutdown (LS2: 2019-2020) to reach a beam energy of 7 TeV for the Run3 (2021-2023). There are very good prospects to accumulate 300 fb^{-1} LHC integrated luminosity during Run3.

The next Long Shutdown 3 (LS3), scheduled to last from 2024 to mid 2026, will be devoted to the preparation of the accelerator and of the experiments for the High Luminosity phase of the LHC (HL-LHC), while certain aspects of these upgrades (e.g. the upgrade of the LHC injector complex) will already happen during LS2. The HL-LHC upgrade will greatly expand the physics potential of the LHC, in particular for rare and statistically limited standard model (SM) and beyond standard model (BSM) processes.

During LS3 the accelerator will be up-graded to enable instantaneous peak luminosities of 5 x 10^{34} cm^{-2} s^{-1} , or even 7.5 x 10^{34} cm^{-2} s^{-1}[7]. While a mean number of pile-up events reached 60 at the highest instantaneous luminosity in 2018, about 140 pileup events on average are expected for an instantaneous luminosity of 5.0 x 10^{34} $cm^{-2}s^{-1}$, increasing to 200 pileup events in the ultimate luminosity scenario. A ten years (2026-2036) operation is foreseen for the HL-LHC phase with an accumulated luminosity of 3000 fb^{-1}. A 1 MeV neutron equivalent fluence of 2.3 x $10^{16}n_{eq}/cm^2$ and a total ionizing dose (TID) of 12 MGy (1.2 Grad) is expected at the center of CMS, where the innermost silicon pixel tracking layers will be installed. Due to high number of pile up events and the unprecedented radiation levels a major upgrade of the CMS experiment is needed in order to maintain the excellent performance of the detector and get profit of the HL_LHC performance. The upgrade is referred to as the CMS Phase-2 Upgrade. The INPP CMS group makes part of the Phase II CMS Silicon Tracker upgrade.

B.2 The Phase II CMS Upgrade

The HL-LHC will allow CMS to reach per cent level precision for many Higgs couplings, including the coupling to muons, which, which has a branching ratio of only ~10^{-4}. The Higgs boson self-coupling is crucial aspect of the Higgs physics as it probes the Higgs field potential. A measurement of the trilinear Higgs boson coupling is expected to become feasible at the HL-LHC.

The processes of weak vector boson scattering are tightly linked to electroweak symmetry breaking and the role of the Higgs boson. They are experimentally challenging, due to small cross sections in the SM and the large and irreducible backgrounds. The luminosity increase provided by the HL-LHC will allow these channels to be explored.

The discovery potential for many BSM studies, including searches for Supersymmetry (SUSY), extra dimensions, and extra gauge bosons, will reach higher masses. New channels with low production cross sections or small coupling strengths will open up. Indirect searches for BSM physics through the measurement of rare decays will particularly profit from the increase in integrated luminosity. The analysis of $B_S^0 \rightarrow \mu^+\mu^-$will become a precision measurement, and the observation of the decay of $B^0$to two muons is expected to reach a significance of 6.8 σ.

In line with the upgrade of the LHC, the CMS experiment needs to be substantially upgraded in order to fully exploit the increased luminosity that will be provided by the HL-LHC. This upgrade is referred to as the CMS Phase-2 Upgrade. The increased levels of radiation require improved radiation hardness of sensors and electronics. The large pileup and the associated particle multiplicity require higher detector granularity, increased bandwidth, and improved trigger capability in order to keep the trigger rate in an acceptable rate without compromising physics performance.

The entire silicon tracking system, presently consisting of pixel and strip detectors, will be replaced. The new Tracker will feature increased forward acceptance, increased radiation hardness, higher granularity, and compatibility with higher data rates and longer trigger latency. In addition, the Tracker will provide tracking information (on tracks above a configurable transverse momentum threshold) to the L1 trigger, information presently only available at the HLT. This will allow the trigger rates to be kept at a sustainable level without sacrificing physics potential.

B.3 Physics Research Activities of the CMS-INPP group

The CMS-INPP data analysis group main goal is the deeper understanding of processes and mechanisms described by the Standard Model (SM) of particle physics and the quest for new symmetries and/or new matter in nature. To fulfill that goal the group has developed a twofold strategy: performs SM measurements and at the same time searches for specific topologies that might reveal the existence of supersymmetry or dark matter at LHC.

Starting with the SM measurements, the objective is to enhance the experience of the team, gained over the past few years based on measurements in the electroweak sector of SM, by investing in studies in the field of top-quarks physics. The data from proton-proton (pp) collisions produced at the CERN LHC provide an excellent environment to investigate properties of the top quark, in the context of its production and decay, with unprecedented precision. Specifically, the measurements of the W boson helicity fractions in top quark decays are very sensitive to the Wtb vertex structure [8][9]. The comparison of the measured W helicity fractions with those estimated from the theory might reveal possible discrepancies from the SM predictions and contribute to a deeper understanding of the underlying physics processes.

After the Higgs boson discovery, many theorists argue that a heavy top partner could explain the scale of the Higgs boson mass via loop cancelations. As such, an important extension of the measurements in the top-quark sector of the SM, will be a search for heavy top partners [10] [11], exploring the $pp \rightarrow T'T' \rightarrow bbWW$process. A new method was motivated/inspired from CMS-INPP analysis team [12][13][14]as a new/different way to search for anything decaying like dilepton top-pairs.

Supersymmetry is one of the most promising theories beyond Standard Model to solve among others the hierarchy problem. The investigation of the existence of Supersymmetry by testing the Models with general gauge mediation (GGM) [15][16]can have a wide range of features. Typically entail a gravitino LSP and a next-to-lightest supersymmetric particle (NLSP) commonly taken to be a neutralino or a stau. The search will be done using data already collected or expected to be collected by the CMS/LHC experiment at 13 TeV center of mass energy during 2017 and 2018.

Our research program includes an extension of the above mentioned analysis at the simulation level in order to study the increase in precisions of the proposed Standard Model measurements as well as the extrapolation of the limits in searches for new physics at HL-LHC.

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.

B.4 Specific Physics Studies of the CMS-INPP group in 2018

1- Search for Exotic Particles, G. Daskalakis

Publication: CMS Collaboration, CMS PAS EXO-18-006, http://cds.cern.ch/record/2308270

CMS Analysis Note: CMS AN-2018/021

Short description: A search for high mass resonances in the dielectron final state is performed using proton-proton collision data at a center-of-mass energy of 13 TeV collected by the CMS experiment at the LHC in 2017. The integrated luminosity corresponds to 41 fb^{-1}. No evidence for a significant deviation from standard model expectation is observed. The sensitivity of the search is increased by combining these data with a previously analyzed set of data obtained in 2016 and corresponding to a luminosity of 36 fb^{-1}. Upper bounds are set on the masses of hypothetical particles that arise in new-physics scenarios.

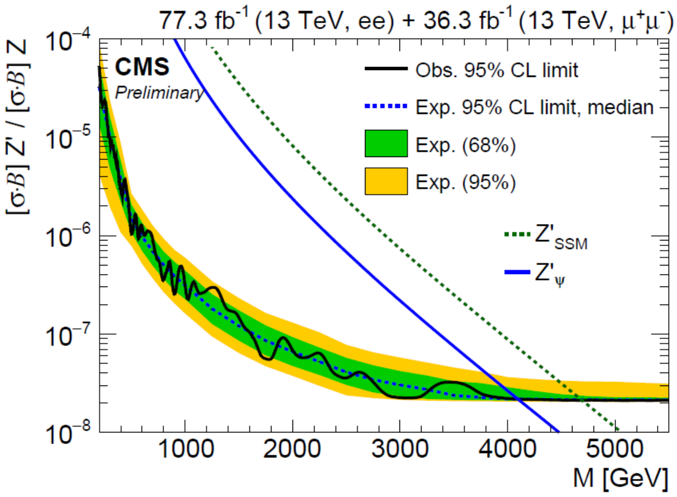


Figure 11: The 95% CL upper limits on the production cross section times branching fraction for a spin-1 resonance with a width equal to 0.6% of the resonance mass, relative to the production cross section times branching fraction for a Z boson, for the combination of 2017 and 2016 datasets. The shaded 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.

2- Search for Exotic Particles, G. Daskalakis

Publication: CMS Collaboration **J. High Energ. Phys. (2018) 2018: 120.**

[**https://doi.org/10.1007/JHEP06(2018)120**](https://doi.org/10.1007/JHEP06(2018)120)

Short description: A search is presented for new high-mass resonances decaying into electron or muon pairs. The search uses proton-proton collision data at a centre-of-mass energy of 13 TeV collected by the CMS experiment at the LHC in 2016, corresponding to an integrated luminosity of 36 fb^{-1}. Observations are in agreement with standard model expectations. Upper limits on the product of a new resonance production cross section and branching fraction to dileptons are calculated in a model-independent manner. This permits the interpretation of the limits in models predicting a narrow dielectron or dimuon resonance. A scan of different intrinsic width hypotheses is performed. Limits are set on the masses of various hypothetical particles. For the Z'_{SSM} (Z'_{ψ}) particle, which arises in the sequential standard model (superstring-inspired model), a lower mass limit of 4.50 (3.90) TeV is set at 95% confidence level. The lightest Kaluza-Klein graviton arising in the Randall-Sundrum model of extra dimensions, with coupling parameters k/M_{Pl} of 0.01, 0.05, and 0.10, is excluded at 95% confidence level below 2.10, 3.65, and 4.25 TeV, respectively. In a simplified model of dark matter production via a vector or axial vector mediator, limits at 95% confidence level are obtained on the masses of the dark matter particle and its mediator.

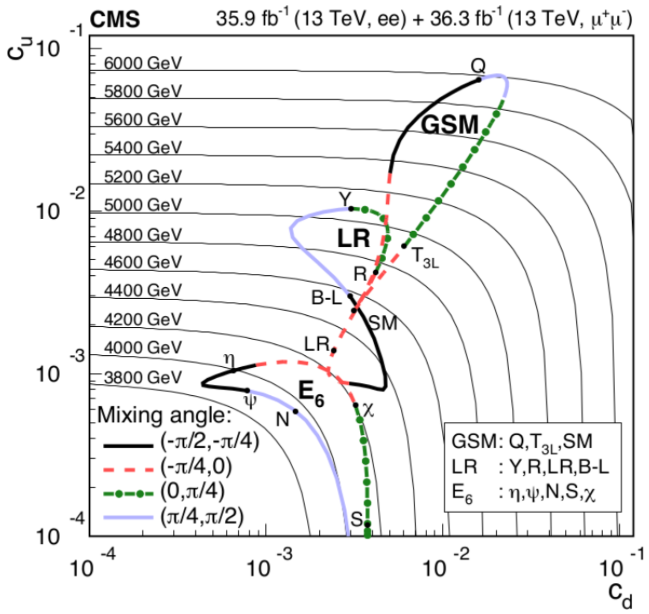


Figure 12: Limits in the (cd, cu) plane obtained by recasting the combined limit at 95% CL on the Z' boson cross section from dielectron and dimuon channels. For a given Z' boson mass, the cross section limit results in a solid thin black line. These lines are labeled with the relevant Z' boson masses. The closed contours representing the GSM, LR, and E6 model classes are composed of thick line segments. Each point on a segment corresponds to a particular model, and the location of the point gives the mass limit on the relevant Z' boson. As indicated in the bottom left legend, the segment line styles correspond to ranges of the particular mixing angle for each considered model. The bottom right legend indicates the constituents of each model class.

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

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. The analytic solutions together with constraints from the parton distribution functions (PDFs) are used to reconstruct the masses of two unknown particles simultaneously. The only assumption used in the mass reconstruction is that each T' decays to a W' and a b quark, with the heavy W' subsequently decaying into an electron or a muon, and a massless particle. Thus, the analysis is performed in a model independent way to target possible signals that may have not been predicted yet. A hypothetical signal, based on the littlest Higgs model is used to set 95% CL upper limits on the production cross section times branching ratio as a function of the T' and the W' mass. The analysis for Run1 was performed as collaboration between Demokritos and Aachen University (PhD thesis of Mrs. Sarah Beranek).

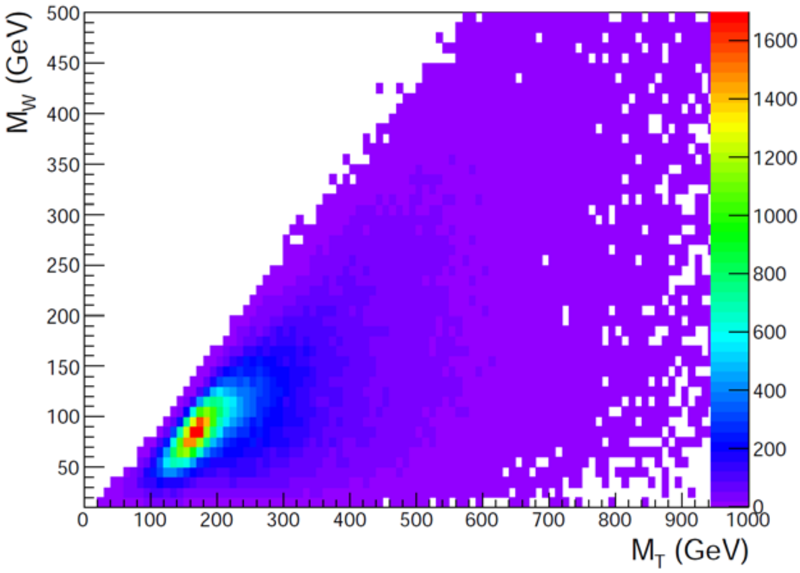


Figure 13: Mass reconstruction in two-dimensional mass space (simulation), showing the mass reconstruction of both top quark and W Boson

The effort in Run2 is focused on analyzing the larger dataset available as well as to start preparations for the application of the method to the measurement of Higgs self-coupling (depending on the manpower).

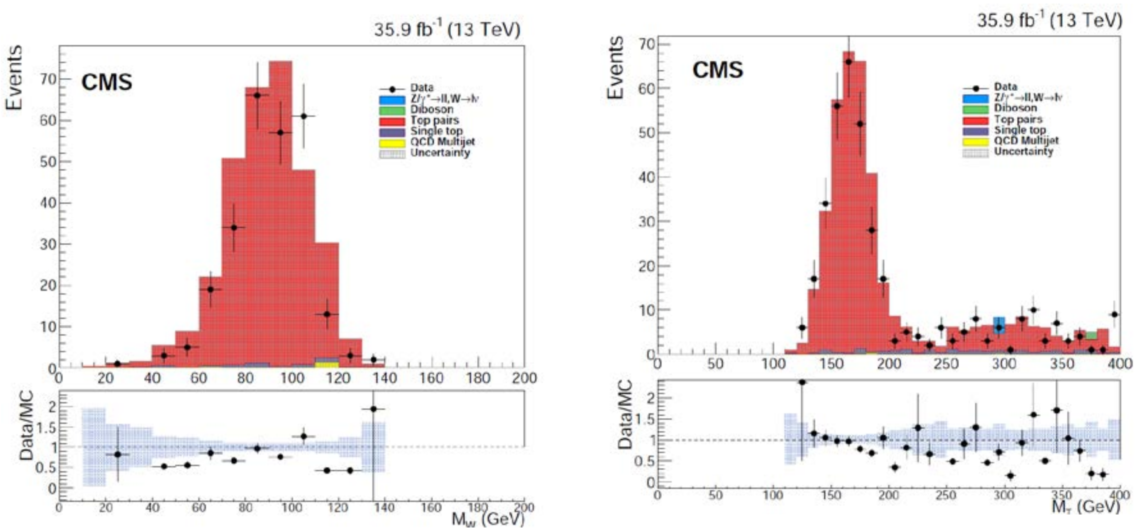


Figure 14: The reconstructed W boson (left) and top quark mass (right) for the first 35 fb^{-1}.

4 - SUSY searches A. Kyriakis, G. Paspalaki

Publications: To be published in JHEP during 2019

Short description: The results of a search for new physics in final states with photons and missing transverse energy are reported. The study is based on a sample of proton–proton collisions collected at a center-of-mass energy of 13 TeV with the CMS detector with data collected during 2016. Two simplified model frameworks are used for the interpretation of the results. The T5gg model assumes gluino pair production and the T6gg model assumes squark pair production. The models assume a 100% branching fraction for the gluinos and squarks to decay as shown in figure 15. The squarks in the T6gg model can be either first or second generation.

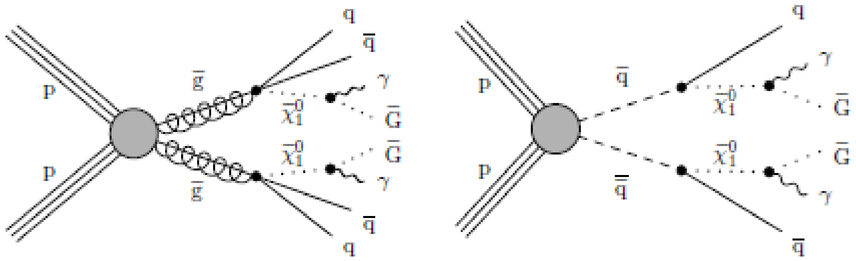


Figure 15: Diagrams showing the production of signal events in the two protons collisions

The full background prediction and the measured p_T^{miss} distribution prior to the fit are shown in figure 16.

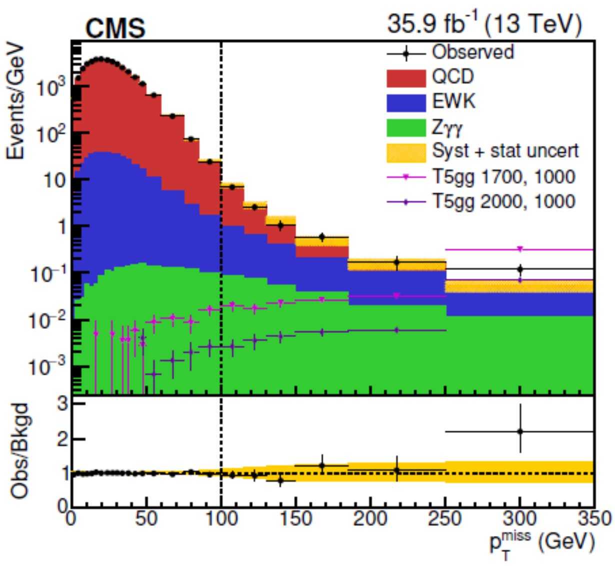


Figure 16: The observed p_T^{miss} distribution in data (black points) and predicted background distributions prior to the fit described in the text.

Analysis Review Committees (ARC):

Georgios Daskalakis participated as ARC member in the publication:

Search for dark matter produced in association with a Higgs boson decaying to a pair of bottom quarks in proton–proton collisions at sqrt(s) =13TeV, Eur. Phys. J. C (2019) 79: 280. https://doi.org/10.1140/epjc/s10052-019-6730-7, EXO-16-050

Institutional Reviews:

1) “Search for heavy Majorana neutrinos in the same-sigh dilepton channel in proton-proton collision at sqrt(s) = 13 TeV ”, CMS Collaboration, CMS Paper EXO-17-028
2) “Search for rare decays of Z boson and Higgs bosons to J/Ψ plus photon sqrt(s) = 13TeV”, CMS Collaboration, CMS Paper SMP-17-012
3) “Inclusive search for supersymmetry using razor variables in pp collisions sqrt(s) = 13 TeV”, CMS Collaboration, CMS Paper SUS-16-017

B.5 Maintenance of the Detector and Service work

The INPP_CMS members contributed to running the experiment with shifts (Shift leader, Central DAQ, Tracker and Online Monitor). They have also undertaken Service work within TriDas, Tracker, DQM, Upgrade physics studies, etc. The INPP_CMS group contribution during 2018, in shifts and service work, corresponds to: 15.14 months worked/24.43 required, i.e. 63% of the required quota. On average INPP_CMS has covered its obligation up to 51, 3% of the required quota.

The INPP-CMS group assumed the responsibility for the update and the upgrade of the Historic Data Quality Monitor (HDQM) of the CMS Tracker:

B.5.1 The HDQM project

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

CMS Notes: CMS IN-2018/004, CMS CR-2018/285

Short Description: The Historic Data Quality Monitor (HDQM) of the CMS experiment is a framework developed by the Tracker group of the CMS collaboration that permits a web-based monitoring of the time evolution of interesting quantities (i.e. signal to noise ratio, cluster size) in the Tracker Silicon micro-strip and pixel.

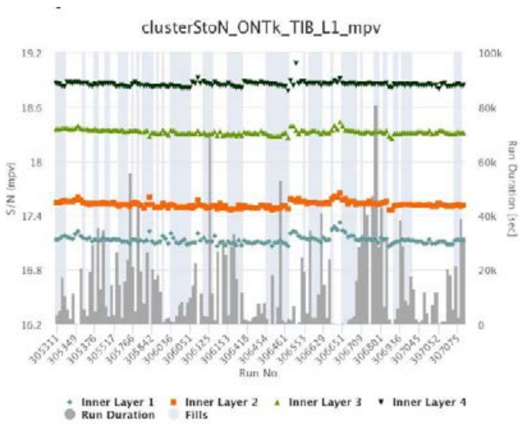


Figure 17: Example of a plot displaying the signal to noise of the Tracker Inner Barrel layers. Runs that belong to the same LHC fill are shown as grey zones as well, while the run duration in seconds is displayed in the right vertical axis.

B.6 Contribution of the CMS-INPP group to the Phase 2 Upgrade

Along with the Research program that includes physics analysis with the Run2 data and simulations of physics possibilities at the HL-LHC, the CMS group of the Institute of Nuclear and Particle Physics (INPP) operating within the National Center for Scientific Research DEMOKRITOS (NCSR "D") is been committed to specific R&D and construction responsibilities associated with the Phase II CMS Silicon Tracker and depicted in pg. 134 of the "*CMS Phase-2 Upgrade of the CMS Tracker Technical Proposal*" document [25].

The present silicon strip detector of the CMS experiment is designed to operate with high efficiency at an instantaneous luminosity of 1.0 x 10^{34} $cm^{-2}s^{-1}$, with an average pileup of 20-40 collisions per bunch crossing and up to an integrated luminosity of 500 fb^{-1}. Performance will be degraded due to radiation damage beyond 500 fb^{-1}. The inner part of the silicon tracker, the pixel detector has already been replaced in 2017/2017 with a new device, the "Phase 1" pixel detector [17]. The performance degradation has been studied extensively and documented in the Technical Proposal for the CMS Phase-2 Upgrade [18].

Accumulated radiation damage in the pixel detector results in reduced charge collection as well as Lorentz angle, leading to decreased charge sharing between pixels and hence to deteriorated spatial resolution and hit efficiency. For the strip detector the most prominent changes are the increase of the depletion depth and the leakage current. While the later can be mitigated by lowering the temperature, the former cannot.

The Phase-2 CMS Tracker will consist of an inner Tracker (IT) based on silicon pixel modules and an Outer Tracker (OT) based on silicon modules with strip and macro-pixel modules. figure 18 shows a sketch of one quarter of Phase-2 CMS Tracker.

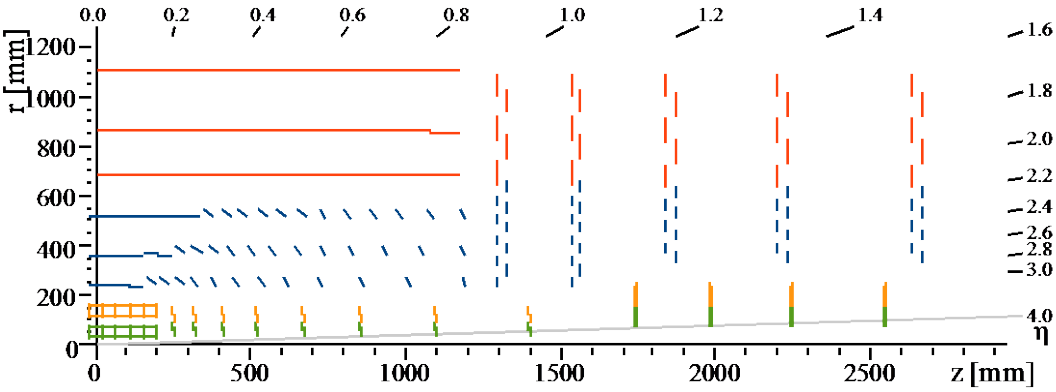


Figure 18: Sketch of one quarter of the Tracker layout in r-z view in the Inner Tracker, the green and orange lines correspond to pixel modules. In the Outer Tracker, the blue lines represent modules made of one strip and one macropixel sensor while the red lines represent modules made of two strip sensors

During 2018, the CMS-INPP group deployed its efforts according to the following lines

- Sensor and Process Quality Control
- Development of Data Acquisition Programs (DAQ) for the Pixel Front End Readout Chip
- Development and construction of a new particle telescope

B.6.1 Sensor and Process Quality Control

The CMS Tracker collaboration is developing a quality assurance (QA) plan that ensures that all sensors fulfil the specification mentioned above and that sensors can be used for module production and later integration into the detector.

The QA plan uses three distinct quality control (QC) mechanisms:

1. Sensor Quality Control (SQC): Characterisation of actual sensors
2. Process Quality Control (PQC): Characterisation of test structures from the same wafers as the actual sensors to monitor production stability
3. Irradiation Test (IT): Irradiation, annealing, characterisation and readout tests of small size and actual sensors to ensure radiation hardness

The production and all QC centres will be monitored and supervised by Sensor Experts Production Panels.

The general workflow of the QC scheme from production to module assembly is shown in figure 20. Note that all sensors will be delivered to CERN first. Sensors are then batchwise distributed to SQC centres while test structures are distributed batchwise among the PQC centres. The sharing of the workload will be determined depending on the utilisation, reliability and current status of the SQC and PQC centres.

The CMS_INPP group is committed to develop a setup for Process Quality Control (PQC) of sensors along with three other laboratories, namely: INFN Perugia, HEPHY Vienna and Brown University. The deployment of the setup is foreseen for the end of 2019. Process Quality Control will ensure that the quality of the production process remains stable throughout production and that any issues are detected as soon as possible.

Process Quality Control will ensure that the quality of the production process remains stable throughout production and that any issues are detected as soon as possible.

Process Quality Control will extract critical process parameters from dedicated test structures in a fast and efficient way to ensure that the sensor production process remains stable and that any issues are detected as soon as possible.

The block of basic PQC structures that will be used for the extraction of the critical parameters is shown in figure 19.

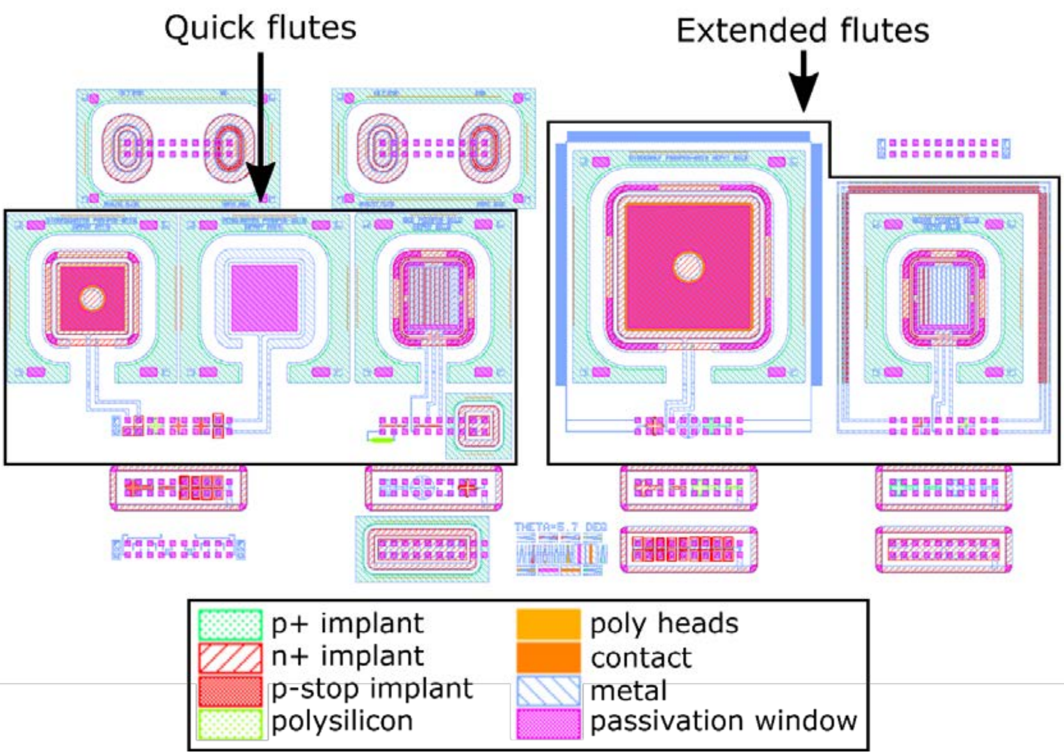


Figure 19: Set of test structures labeled PQC Flutes. The main flutes for standard PQC, "Quick flutes" and "Extended flutes" are marked. The set is included multiple times on all production wafers.

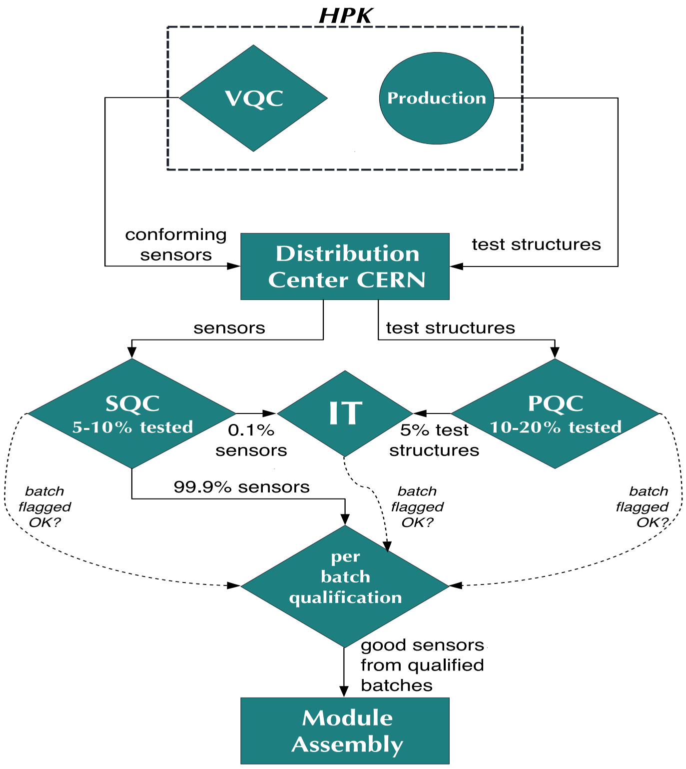


Figure 20: General overview of the CMS Phase II silicon sensors QC flow

B.6.2 The CMS new particle telescope - CHROMIE Beam Test telescope P. Asenov, A. Kyriakis, D. Loukas

Short Description: Tests of the CMS Phase-2 sensors through beam tests is necessary to examine the behavior of silicon sensors in real conditions. Existing CMS technology Beam Test telescopes uses a Monolithic Active Pixel Sensor chip with an integration time of 115.2 μs or 8.68 kHz readout frequency, but the integration time in the Phase-2 tracker modules (and other HL-LHC sensors) is 25 ns, corresponding to 40 MHz (x4600 the today's CMS telescopes readout frequency). Thus, it is obvious that we cannot test Phase-2 tracker modules at nominal rates with the old CMS telescopes. This is the reason why in 2018 our group participated also in the design of the new telescope CHROMIE and CHROMini.

CHROMIE consists of 16 CMS pixel Phase-1 modules while CHROMini of two CMS pixel Phase-1 module planes. CHROMini is expected to be commissioned by the end of 2019 at a new beam line dedicated to tests of the CMS Tracker modules at CYRCé (CYclotron pour la ReCherche et l'Enseignement), a low energy cyclotron for radionuclide production for medical applications, which is located at IPHC (Strasbourg). CYRCé accelerates protons up to 25 MeV with high intensities (up to 100 nA, i.e. 10^{12} protons/second), with an 85 MHz time structure (about twice the LHC frequency) and a Gaussian beam profile.

Our team investigated through a standalone Geant4 simulation program developed by its members if CHROMini could be built of two CMS pixel Phase-1 module planes or alternatively of pixel modules with smaller pixel size and sensor thickness. In the simulation the residuals, the multiple scattering of protons and the cluster size values were optimized when varying the telescope module type, the distance between the telescope modules and the device under test (in the simulations a Phase-2 2S module) and other parameters. The visualization of the simulated geometry can be seen in figure 21, while the angular straggling due to multiple scattering is visible in figure 22 For the simulation we included Phase-1 modules (BPIX) as telescope modules (with pixel size 150x100 μm^2), a PVT scintillator (66.6 mm x 25 mm x 2 mm) in front of the front of the BPIX module and the telescope modules positioned at ± 1 cm from the Device Under Test (DUT) respective side

The simulations has proved that even with large energy deposition (~10 MIPs) and relatively large multiple scattering, a 25 MeV proton beam can be used for tracking with a reasonable resolution. Thus it was shown that the project was feasible and that the beam line and the mini-telescope could be of use for tests under high particle rate and high occupancy, to study the performance and saturation effects vs. track rate, and to monitor in situ effects of radiation damage in the future CMS modules.

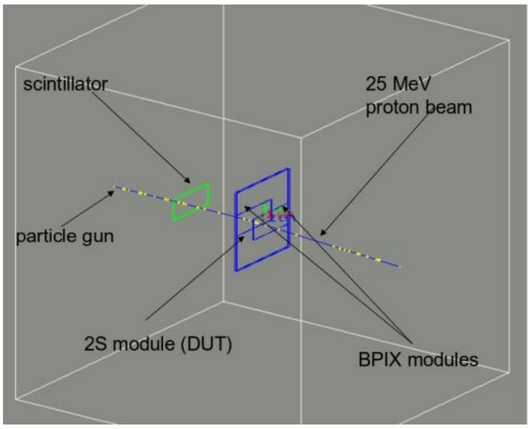


Figure 21: The visualization of the Geant4-simulated CHROMini and a 2S module as DUT.

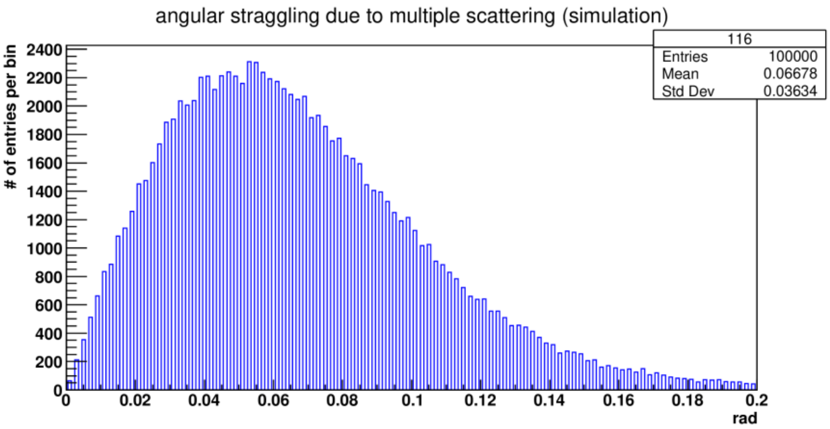


Figure 22: Estimation of the angular straggling due to the multiple scattering of protons in the telescope modules and the modules of the DUT derived from a simulated run of 100000 events.

B.6.3 DAQ for the Phase II CMS Pixel Detector, I. Kazas

Since the second half of 2018, our group is involved in the development of the DAQ for the Inner Tracker pixel chip. RD53A is the prototype pixel chip that will form the basis for the production design of the ASIC that is going to be used in the Inner Tracker during the CMS Phase II Upgrade. It is a joint effort between CMS and ATLAS experiments and contains design variations for testing purposes, making the pixel matrix non-uniform. There are three different front-end architectures to be evaluated and the design revisions from RD53A to production will involve selecting one of the front end variants and uniformly using it everywhere, increasing the pixel matrix size as specified by each experiment, and tailoring the digital functionality according to the experiment specifications.

The NCSR "D" team has undertaken the task to develop the firmware for the Inner Tracker μDTC, which is the CMS testing and development platform for the RD53A chip. It is based on the FC7 FPGA Mezzanine (FMC) Carrier Board and the IPBus protocol (Ethernet-based) to communicate with the host PC, a picture of the hardware setup is depicted in figure xx. The stack for the data acquisition chain consists of the software in the host-PC and the firmware in the FPGA. The software is implemented in C++ and contains the user code to control the testing sequence and the middleware, which handles the low-level communication between the user code and the FPGA. This development will form the basis for the final DTC system of the Phase-II Upgrade and it will help estimate resource usage and potential issues.

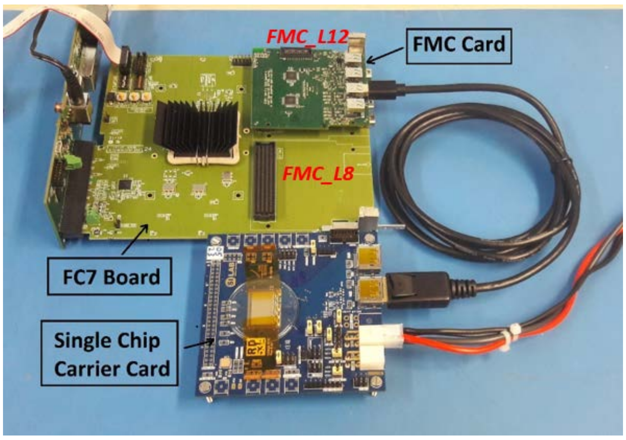


Figure 23: The setup for the IT_uDTC DAQ system hosting a Single Chip.

By the end of 2018, the basic structure of the code was implemented and electrical communication with single chips had been established. The firmware is implemented in VHDL and includes clocking circuits, communication interface with the chip, and Ethernet-based communication with the host PC. The main building blocks of the implemented firmware are described in the following section. The Clock Generator block produces all the required clocks for the rest of the firmware from a single 40.08MHz input clock. The communication interface with the chip is divided in 2 sections, downlink (commands to the chip) and uplink (data from the chip). For the downlink, the Command Controller receives commands either from the software, external triggering sources or commands generated internally by Finite State Machines (FSM) in the FPGA. The commands are prioritized and encoded with a custom serial protocol running at 160 Mbps, as required by the RD53A, and transmitted over a single differential link along with clocking. For the uplink, data are transmitted by RD53A using the Aurora 64b/66b encoding protocol (Xilinx Specific), running at 1.28 Gbps, and the Aurora Receiver on the FPGA side handles the differential input stream and decodes the data. Communication with the host PC is based on the IPBus protocol (developed at CERN) which provides a reliable high-performance control link, by implementing a simple A32/D32 control protocol for reading and modifying memory-mapped resources within FPGA-based hardware devices.

Bibliography

[1] L.Evans and B.Bryant, (editors), «Lhc machine,» *2008 JINST 3 S08001, doi:10.1088/1748-0221/3/08/S08001.*

[2] CMS Collaboration, «The CMS experiment at the CERN LHC,» *2008 JINST 3 S08004, doi:10.1088/1748-0221/3/08/S08004.*

[3] ATLAS Collaboration, «Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC,» *Phys. Lett. B 716 (2012) 1, doi:10.1016/j.physletb.2012.08.020, arXiv:1207.7214..*

[4] CMS Collaboration, «Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC,» *Phys. Lett. B 716 (2012) 30, doi:10.1016/j.physletb.2012.08.021, arXiv:1207.7235..*

[5] CMS and LHCb Collaborations, «Observation of the rare Bs0 → μ+μ− decay from the combined analysis of CMS and LHCb data,» *Nature 522 (2015) 68, doi:10.1038/nature14474, arXiv:1411.4413.*

[6] LHC Top Physics Working Group., *https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCTopWG.*

[7] G. Apollinari et al., «High-Luminosity Large Hadron Collider (HL-LHC): Preliminary Design Report", CERN-2015-005,» *doi:10.5170/CERN-2015-005.*

[8] J. A. Aguilar-Saavedra et al, «Probing anomalousWtb couplings in top pair decays,» *Eur. Phys. J. C 50 (2007) 519, doi:10.1140/epjc/s10052-007-0289-4, arXiv:hep-ph/0605190..*

[9] G. A. Gonzalez-Sprinberg and J. Vidal, «The top quark right coupling in the tbWvertex,» *Eur. Phys. J. C 75 (2015) 615, doi:10.1140/epjc/s10052-015-3844-4, arXiv:1510.02153..*

[10] Martin Schmaltz, David Tucker-Smith, «Little Higgs review,» *Ann.Rev.Nucl.Part.Sci. 55,*

[hep-ph/0502182].

[11] B. Holdom (Toronto U.), W.S. Hou (Taiwan, Natl. Taiwan U.), T. Hurth, M.L. Mangano (CERN), S. Sultansoy (TOBB ETU, Ankara), G. Unel (UC, Irvine), «Four Statements about the Fourth Generation,» *PMC Phys. A3 (2009) 4 , DOI: 10.1186/1754-0410-3-4, arXiv:0904.4698 [hep-ph].*

[12] G.Anagnostou, «Beyond 2 Generations,» *EPJ Web of Conferences 126 04001 (2016) , CMS-CR-2015-293.* .

[13] CMS Collaboration, «Search in two-dimensional mass space for pp→T'T→W'b W'b in the dilepton final state in proton-proton collisions at √s= 8 TeV,» *CMS-PAS-B2G-12-025* .

[14] S.Beranek, «Model independent search for new particles in two-dimensional mass space using events with missing energy, two jets and two leptons with the CMS detector,» *CERN-THESIS-2017-115 ; RWTH-2017-06454.* .

[15] M. Buican, P. Meade, N. Seiberg, and D. Shih, «Exploring General Gauge Mediation,» *JHEP 0903 (2009) 016, doi:10.1088/1126-6708/2009/03/016, arXiv:0812.3668.*

[16] S. Abel, M. J. Dolan, J. Jaeckel, and V. V. Khoze, «Phenomenology of Pure General Gauge Mediation,» *JHEP 0912 (2009) 001, doi:10.1088/1126-6708/2009/12/001, arXiv:0910.2674.*

[17] CMS Collaboration, «CMS Technical Design Report for the Pixel Detector Upgrade,» *CMS Technical Design Report CERN-LHCC-2012-016, CMS-TDR-11, 2012.*

[18] CMS Collaboration,, «Technical Proposal for the Phase-II Upgrade of the CMS Detecto,» *CERN-LHCC-2015-010, LHCC-P-008, CMS-TDR-15-02 (2015).*

[19] C. Foudas, A. Rose, J. Jones, and G. Hall, «A Study for a Tracking Trigger at First Level for CMS at SLHC,» *arXiv:physics/0510227.*

[20] Braga et al., CBC2: A microstrip readout ASIC with coincidence logic for trigger primitives at HL-LH, JINST 11 (2016) C01054, doi:10.1088/1748-0221/11/01/C01054.

[21] RD53 Collaboration, RD Collaboration Proposal: Development of pixel readout integrated circuits for extreme rate and radiation",, Scientific Committee Paper CERN-LHCC-2013-008, LHCC-P-006, 2013..

[22] CERN Council, «The European Strategy for Particle Physics, Updated 2013,» CERN-Council-S/106, [Ηλεκτρονικό]. Available: https://cds.cern.ch/record/1567258/files/esc-e-106.pdf..

[23] D. Chatzistratis, G. Theodoratos, I. Kazas, E. Zervakis , D. Loukas και C. P. Lambropouolos, «Architecture and characterization of the P4DI CMOS hybrid pixel sensor,» *Journal of Instrumentation,* τόμ. 12, 26 September 2017.

[24] «Highly Miniaturised ASIC Radiation Detector,» *ESA Contract number: 4000119598/17/NL/LF.*

[25] CMS Phase II Tracker TDR, «The Phase-2 Upgrade of the CMS Tracker, Technical Design Reports,» CERN-LHCC-2017-009, 2017.

[26] H. Photonics, https://www.hamamatsu.com/eu/en/index.html.

[27] SYNOPSYS, https://www.synopsys.com/silicon/tcad.html.

[28] Cyclotron CYRCÉ - Institut Pluridisciplinaire Hubert CURIEN (IPHC), http://www.iphc.cnrs.fr/-Cyclotron-CYRCE-.html.

[29] A. Aguilar-Saavedra και et al., «"Probing anomalous Wtb couplings in top pair decays",» *Eur. Phys. J. C 50 (2007) 519 doi:10.1140/epjc/s10052-007-0289-4, arXiv:hep-ph/0605190.*.

[30] D0 Collaboration, «"Measurement of the W boson helicity in top quark decays using 5.4 fb-1 of pp collision data",» *Phys. Rev. D 83 (2011) 032009, doi:10.1103/PhysRevD.83.032009, arXiv:1011.6549.*.

[31] CDF Collaboration, «"Measurement of W-boson polarization in top-quark decay using the full CDF Run II data set",» *Phys. Rev. D 87 (2012) 031104(R), doi:10.1103/PhysRevD.87.031104,*.

[32] CDF and D0 Collaborations, « "Combination of CDF and D0 measurements of the W boson helicity in top quark decays",» *Phys. Rev. D 85 (2012) 071106, doi:10.1103/PhysRevD.85.071106, arXiv:1202.5272.*.

[33] ATLAS Collaboration, « "Measurement of the W boson polarization in top quark decays with the ATLAS detector",» *JHEP 06 (2012) 088, doi:10.1007/JHEP06(2012)088, arXiv:1205.2484.*.

[34] CMS Collaboration, « "Measurement of the W-boson helicity in top-quark decays from tt production in lepton+jets events in pp collisions at 7 TeV",» *JHEP 10 (2013) 167, doi:10.1007/JHEP10(2013)167, arXiv:1308.3879.* .

[35] CMS Collaboration, «"Measurement of the W boson helicity in events with a single reconstructed top quark in pp collisions at 8 TeV", J,» *HEP 01 (2015) 053, doi:10.1007/JHEP01(2015)053, arXiv:1410.1154.* .

[36] Nappi C.R. και Ovrut B.A., «C.R. Nappi, B.A. Ovrut,,» *Phys. Lett. B 113 (1982) 175, http://dx.doi.org/10.1016/0370-2693(82)90418-X.*.

[37] CMS Collaboration, «"Search for supersymmetry in events with photons and missing transverse energy in pp collisions at 13 TeV",,» *Phys. Lett. B 769, (2017) 391-412.*

[38] Anagnostou, A. G., "Model Independent Search in 2-Dimensional Mass Space", EPJ Web of Conferences 71, 00006 (2014.

[39] Physics, International Masterclasses Hands on Particle, http://physicsmasterclasses.org/.

[40] V. Valenta et al., "Design and experimental evaluation of compensated bondwire interconnects above 100 GHz", International Journal of Microwave and Wireless Technologies, 2015..

[41] Standard Model, «https://en.wikipedia.org/wiki/Standard_Model».

[42] Frank Hartman, "Evolution of Silicon Sensor Technology in Particle Physics", Springer Trackts in Modern Physics, 2017.

[43] «Physics, International Masterclasses Hands on Particle,» [Ηλεκτρονικό]. Available: http://physicsmasterclasses.org/.

C) INPP_CMS planning for 2019 and beyond

The LHC has delivering pp collisions at 13 TeV at 2018 and our group will continue with extended effort on running the experiment and performing analyses at this new uncharted physics domain. Our group plans to cover the required 4 months of service work/year/author. The analysis work will continue in the same physics directions in order to extend their potential to this new high energy physics front. New analysis will be included in our research program according to the potential that will emerge during the 13 TeV data taking. A list of all the on-going analyses is given below:

1) Search for exotic particles
2) Model independent search in 2-Dimentional mass space
3) Higgs Physics
4) Top Physics

In parallel, the activity on the instrumentation will continue as it is described in the upgrades plans. With the commissioning of the Phase I detectors the CMS experiment is focusing his activities on the maintenance and operation of the current experimental setup and the developmental work for the Phase II upgrade. The first CMS Technical Design Report (TDR) for the Phase II upgrade is the Tracker one and it is now published. Our group contributes with participation to beam tests and electrical measurements of silicon detector prototypes and our silicon lab is one of the four sensors Process Quality Centers (PQC) for the CMS Phase 2 Tracker. Tests on features of silicon structures (MOS, diodes) made in the same wafers as the 2S sensors after irradiation are planned to be performed during 2019.

Summary of the CMS_INPP publications 2018

1. Measurement of the single top quark and antiquark production cross sections in the t channel and their ratio in proton-proton collisions at □s=13 TeV. By CMS Collaboration (Albert M Sirunyan et al.). [arXiv:1812.10514 [hep-ex]].
2. Measurement of the differential Drell-Yan cross section in proton-proton collisions at $\sqrt{s}$=13 TeV. By CMS Collaboration (Albert M Sirunyan et al.). [arXiv:1812.10529 [hep-ex]], Submitted to: JHEP.
3. Event shape variables measured using multijet final states in proton-proton collisions at $\sqrt{s}$=13 TeV. By CMS Collaboration (Albert M Sirunyan et al.), 10.1007/JHEP12(2018)117. JHEP 1812 (2018) 117.
4. Search for leptoquarks coupled to third-generation quarks in proton-proton collisions at $\sqrt{s}$=13 TeV. By CMS Collaboration (Albert M Sirunyan et al.), 10.1103/PhysRevLett.121.241802. Phys.Rev.Lett. 121 (2018) no.24, 241802.
5. Studies of $B^{*s2}(5840)^0$ and $B_{s1}(5830)^0$ mesons including the observation of the $B^{*s2}(5840)^0 \rightarrow B^0 K^0_S$ decay in proton-proton collisions at $\sqrt{s}$=8 TeV . By CMS Collaboration (Albert M Sirunyan et al.), 10.1140/epjc/s10052-018-6390-z. Eur.Phys.J. C78 (2018) no.11, 939.
6. Performance of reconstruction and identification of tau leptons decaying to hadrons and nu_tau in pp collisions at $\sqrt{s}$=13 TeV. By CMS Collaboration (A.M. Sirunyan et al.).10.1088/1748-0221/13/10/P10005.JINST 13 (2018) no.10, P10005.

7. Search for physics beyond the standard model in high-mass diphoton events from proton-proton collisions at $\sqrt{s}$ = 13 TeV. By CMS Collaboration (A. M. Sirunyan et al.). 10.1103/PhysRevD.98.092001. Phys.Rev. D98 (2018) no.9, 092001.
8. Charged-particle nuclear modification factors in XeXe collisions at $\sqrt{s_{NN}}$ = 5.44 TeV. By CMS Collaboration (Albert M Sirunyan et al.), 10.1007/JHEP10(2018)138. JHEP 1810 (2018) 138
9. Observation of Higgs boson decay to bottom quarks. By CMS Collaboration (A. M. Sirunyan et al.), 10.1103/PhysRevLett.121.121801.Phys.Rev.Lett. 121 (2018) no.12, 121801.
10. Measurement of jet substructure observables in ttbar events from proton-proton collisions at $\sqrt{s}$= 13TeV. By CMS Collaboration (A. M. Sirunyan et al.) 10.1103/PhysRevD.98.092014.Phys.Rev. D98 (2018) no.9, 092014.
11. Search for a charged Higgs boson decaying to charm and bottom quarks in proton-proton collisions at $\sqrt{s}$=8 TeV. By CMS Collaboration (Albert M Sirunyan et al.). 10.1007/JHEP11(2018)115. JHEP 1811 (2018) 115.
12. Search for long-lived particles with displaced vertices in multijet events in proton-proton collisions at $\sqrt{s}$=13 TeV. By CMS Collaboration (Albert M Sirunyan et al.), 10.1103/PhysRevD.98.092011. Phys.Rev. D98 (2018) no.9, 092011.
13. Search for pair-produced resonances decaying to quark pairs in proton-proton collisions at $\sqrt{s}$=13 TeV. By CMS Collaboration (Albert M Sirunyan et al.). 10.1103/PhysRevD.98.112014. Phys.Rev. D98 (2018) no.11, 112014.
14. Evidence for the associated production of a single top quark and a photon in proton-proton collisions at $\sqrt{s}$= 13 TeV. By CMS Collaboration (Albert M Sirunyan et al.), 10.1103/PhysRevLett.121.221802. Phys.Rev.Lett. 121 (2018) no.22, 221802.
15. Search for resonances in the mass spectrum of muon pairs produced in association with b quark jets in proton-proton collisions at $\sqrt{s}$ = 8 and 13 TeV. By CMS Collaboration (A.M. Sirunyan et al.), 10.1007/JHEP11(2018)161. JHEP 1811 (2018) 161.
16. Searches for pair production of charginos and top squarks in final states with two oppositely charged leptons in proton-proton collisions at $\sqrt{s}$= 13 TeV. By CMS Collaboration (Albert M. Sirunyan et al.), 10.1007/JHEP11(2018)079. JHEP 1811 (2018) 079.
17. Measurements of the differential jet cross section as a function of the jet mass in dijet events from proton-proton collisions at $\sqrt{s}$=13 TeV. By CMS Collaboration (Albert M. Sirunyan et al.), 10.1007/JHEP11(2018)113. JHEP 1811 (2018) 113.
18. Precision measurement of the structure of the CMS inner tracking system using nuclear interactions. By CMS Collaboration (Albert M Sirunyan et al.), 10.1088/1748-0221/13/10/P10034. JINST 13 (2018) no.10, P10034.
19. Search for heavy resonances decaying into a vector boson and a Higgs boson in final states with charged leptons, neutrinos and b quarks at $\sqrt{s}$=13 TeV. By CMS Collaboration (Albert M. Sirunyan et al.), 10.1007/JHEP11(2018)172. JHEP 1811 (2018) 172.
20. Search for supersymmetry in events with a tau lepton pair and missing transverse momentum in proton-proton collisions at $\sqrt{s}$ = 13 TeV. By CMS Collaboration (Albert M. Sirunyan et al.), 10.1007/JHEP11(2018)151.JHEP 1811 (2018) 151.

21. Measurement of charged particle spectra in minimum-bias events from proton–proton collisions at $\sqrt{s}$=13 TeV. By CMS Collaboration (Albert M. Sirunyan et al.), 10.1140/epjc/s10052-018-6144-y.Eur.Phys.J. C78 (2018) no.9, 697.
22. Search for the decay of a Higgs boson in the llγ channel in proton-proton collisions at $\sqrt{s}$ = 13 TeV. By CMS Collaboration (Albert M. Sirunyan et al.), 10.1007/JHEP11(2018)152.
JHEP 1811 (2018) 152.
23. Search for dark matter produced in association with a Higgs boson decaying to gamma gamma or $\tau^+ \tau^-$ at $\sqrt{s}$ = 13 TeV. By CMS Collaboration (Albert M. Sirunyan et al.), 10.1007/JHEP09(2018)046. JHEP 1809 (2018) 046.
24. Observation of the Z to ψl^+l^- decay in pp collisions at $\sqrt{s}$= 13 TeV. By CMS Collaboration (Albert M. Sirunyan et al.).10.1103/PhysRevLett.121.141801. Phys.Rev.Lett. 121 (2018) no.14, 141801.
25. Search for resonant pair production of Higgs bosons decaying to bottom quark-antiquark pairs in proton-proton collisions at 13 TeV. By CMS Collaboration (Albert M. Sirunyan et al.), 10.1007/JHEP08(2018)152.JHEP 1808 (2018) 152.
26. Search for a singly produced third-generation scalar leptoquark decaying to a τ lepton and a bottom quark in proton-proton collisions at $\sqrt{s}$ = 13 TeV. By CMS Collaboration (A.M. Sirunyan et al.), 10.1007/JHEP07(2018)115.JHEP 1807 (2018) 115.
27. Search for pair-produced resonances each decaying into at least four quarks in proton-proton collisions at $\sqrt{s}$= 13 TeV. By CMS Collaboration (Albert M. Sirunyan et al.), 10.1103/PhysRevLett.121.141802. Phys.Rev.Lett. 121 (2018) no.14, 141802.
28. Measurement of the weak mixing angle using the forward-backward asymmetry of Drell-Yan events in pp collisions at 8 TeV. By CMS Collaboration (Albert M. Sirunyan et al.), 10.1140/epjc/s10052-018-6148-7.Eur.Phys.J. C78 (2018) no.9, 701.
29. Search for narrow and broad dijet resonances in proton-proton collisions at $\sqrt{s}$=13 TeV and constraints on dark matter mediators and other new particles. By CMS Collaboration (Albert M Sirunyan et al.), 10.1007/JHEP08(2018)130.JHEP 1808 (2018) 130.
30. Angular analysis of the decay B^+ to $K^+\mu^+\mu^-$ in proton-proton collisions at $\sqrt{s}$ = 8 TeV. By CMS Collaboration (Albert M Sirunyan et al.), 10.1103/PhysRevD.98.112011.Phys.Rev. D98 (2018) no.11, 112011.
31. Search for beyond the standard model Higgs bosons decaying into a b-bbar pair in pp collisions at $\sqrt{s}$ = 13 TeV. By CMS Collaboration (Albert M Sirunyan et al.), 10.1007/JHEP08(2018)113.JHEP 1808 (2018) 113.
32. Observation of the χ_{b1}(3P) and χ_{b2}(3P) and measurement of their masses. By CMS Collaboration (A. M. Sirunyan et al.), 10.1103/PhysRevLett.121.092002. Phys.Rev.Lett. 121 (2018) 092002.
33. Constraints on models of scalar and vector leptoquarks decaying to a quark and a neutrino at $\sqrt{s}$= 13 TeV. By CMS Collaboration (Albert M Sirunyan et al.), 10.1103/PhysRevD.98.032005. Phys.Rev. D98 (2018) no.3, 032005.
34. Search for an exotic decay of the Higgs boson to a pair of light pseudoscalars in the final state with two b quarks and two tau leptons in proton-proton collisions at $\sqrt{s}$= 13 TeV. By CMS Collaboration (Albert M Sirunyan et al.), 10.1016/j.physletb.2018.08.057. Phys.Lett. B785 (2018) 462.

35. Measurement of the production cross section for single top quarks in association with W bosons in proton-proton collisions at $\sqrt{s}$=13 TeV. By CMS Collaboration (Albert M Sirunyan et al.), 10.1007/JHEP10(2018)117.JHEP 1810 (2018) 117.
36. Search for black holes and sphalerons in high-multiplicity final states in proton-proton collisions at $\sqrt{s}$=13 TeV. By CMS Collaboration (Albert M Sirunyan et al.), 10.1007/JHEP11(2018)042.JHEP 1811 (2018) 042.
37. Search for top squarks decaying via four-body or chargino-mediated modes in single-lepton final states in proton-proton collisions at $\sqrt{s}$ = 13 TeV. By CMS Collaboration (A.M. Sirunyan et al.), 10.1007/JHEP09(2018)065. JHEP 1809 (2018) 065.
38. Measurement of the groomed jet mass in PbPb and pp collisions at $\sqrt{s_{NN}}$=5.02 TeV. By CMS Collaboration (Albert M Sirunyan et al.), 10.1007/JHEP10(2018)161. JHEP 1810 (2018) 161.
39. Search for an exotic decay of the Higgs boson to a pair of light pseudoscalars in the final state of two muons and two tau leptons in proton-proton collisions at $\sqrt{s}$=13 TeV. By CMS Collaboration (Albert M Sirunyan et al.), 10.1007/JHEP11(2018)018. JHEP 1811 (2018) 018.
40. Search for vector-like T and B quark pairs in final states with leptons at $\sqrt{s}$ = 13 TeV. By CMS Collaboration (Albert M Sirunyan et al.), 10.1007/JHEP08(2018)177. JHEP 1808 (2018) 177.
41. Constraining gluon distributions in nuclei using dijets in proton-proton and proton-lead collisions at $\sqrt{s_{NN}}$ = 5.02 TeV. By CMS Collaboration (Albert M Sirunyan et al.), 10.1103/PhysRevLett.121.062002.Phys.Rev.Lett. 121 (2018) no.6, 062002.
42. Measurement of the top quark mass with lepton+jets final states using pp collisions at $\sqrt{s}$=13 TeV. By CMS Collaboration (Albert M Sirunyan et al.), 10.1140/epjc/s10052-018-6332-9. Eur.Phys.J. C78 (2018) no.11, 891.
43. Elliptic flow of charm and strange hadrons in high-multiplicity pPb collisions at $\sqrt{s_{NN}}$ = 8.16 TeV. By CMS Collaboration (A. M. Sirunyan et al.), 10.1103/PhysRevLett.121.082301.
Phys.Rev.Lett. 121 (2018) no.8, 082301.
44. Search for disappearing tracks as a signature of new long-lived particles in proton-proton collisions at $\sqrt{s}$ = 13 TeV. By CMS Collaboration (Albert M Sirunyan et al.), 10.1007/JHEP08(2018)016. JHEP 1808 (2018) 016.
45. Measurement of differential cross sections for Z boson production in association with jets in proton-proton collisions at $\sqrt{s}$ = 13 TeV. By CMS Collaboration (Albert M Sirunyan et al.), 10.1140/epjc/s10052-018-6373-0. Eur.Phys.J. C78 (2018) no.11, 965.
46. Performance of the CMS muon detector and muon reconstruction with proton-proton collisions at $\sqrt{s}$= 13 TeV. By CMS Collaboration (A.M. Sirunyan et al.), 10.1088/1748-0221/13/06/P06015. JINST 13 (2018) no.06, P06015.
47. Measurements of Higgs boson properties in the diphoton decay channel in proton-proton collisions at $\sqrt{s}$ = 13 TeV. By CMS Collaboration (A.M. Sirunyan et al.), 10.1007/JHEP11(2018)185. JHEP 1811 (2018) 185.
48. Observation of ttbarH production. By CMS Collaboration (Albert M Sirunyan et al.), 10.1103/PhysRevLett.120.231801. Phys.Rev.Lett. 120 (2018) no.23, 231801.

49. Search for high-mass resonances in final states with a lepton and missing transverse momentum at √s=13 TeV. By CMS Collaboration (Albert M Sirunyan et al.), 10.1007/JHEP06(2018)128. JHEP 1806 (2018) 128.
50. Search for a heavy right-handed W boson and a heavy neutrino in events with two same-flavor leptons and two jets at √s= 13 TeV. By CMS Collaboration (Albert M Sirunyan et al.), 10.1007/JHEP05(2018)148. JHEP 1805 (2018) no.05, 148.
51. Search for a heavy resonance decaying into a Z boson and a Z or W boson in 2ℓ2q final states at √s=13 TeV. By CMS Collaboration (Albert M Sirunyan et al.), 10.1007/JHEP09(2018)101. JHEP 1809 (2018) 101.
52. Measurement of differential cross sections for the production of top quark pairs and of additional jets in lepton + jets events from pp collisions at √s = 13 TeV. By CMS Collaboration (Albert M Sirunyan et al.), 10.1103/PhysRevD.97.112003. Phys.Rev. D97 (2018) no.11, 112003.
53. Search for new physics in dijet angular distributions using proton–proton collisions at √s= 13 TeV and constraints on dark matter and other models. By CMS Collaboration (Albert M Sirunyan et al.), 10.1140/epjc/s10052-018-6242-x. Eur.Phys.J. C78 (2018) no.9, 789.
54. Search for ttbarH production in the all-jet final state in proton-proton collisions at √s= 13 TeV. By CMS Collaboration (Albert M Sirunyan et al.), 10.1007/JHEP06(2018)101. JHEP 1806 (2018) 101.
55. Search for additional neutral MSSM Higgs bosons in the ττ final state in proton-proton collisions at √s= 13 TeV. By CMS Collaboration (Albert M Sirunyan et al.), 10.1007/JHEP09(2018)007. JHEP 1809 (2018) 007.
56. Search for high-mass resonances in dilepton final states in proton-proton collisions at √s= 13 TeV. By CMS Collaboration (Albert M Sirunyan et al.), 10.1007/JHEP06(2018)120.
JHEP 1806 (2018) 120.
57. Evidence for associated production of a Higgs boson with a top quark pair in final states with electrons, muons, and hadronically decaying tau leptons at √s = 13 TeV. By CMS Collaboration (Albert M Sirunyan et al.), 10.1007/JHEP08(2018)066. JHEP 1808 (2018) 066.
58. Observation of proton-tagged, central (semi)exclusive production of high-mass lepton pairs in pp collisions at 13 TeV with the CMS-TOTEM precision proton spectrometer. By CMS and TOTEM Collaborations (Albert M Sirunyan et al.), 10.1007/JHEP07(2018)153.
JHEP 1807 (2018) 153.
59. Measurements of differential cross sections of top quark pair production as a function of kinematic event variables in proton-proton collisions at √s=13 TeV. By CMS Collaboration (A.M. Sirunyan et al.), 10.1007/JHEP06(2018)002. JHEP 1806 (2018) 002.
60. Search for a heavy resonance decaying into a Z boson and a vector boson in the nunubar qqbar final state. By CMS Collaboration (Albert M Sirunyan et al.), 10.1007/JHEP07(2018)075. JHEP 1807 (2018) 075.
61. Search for third-generation scalar leptoquarks decaying to a top quark and a tau lepton at √s= 13 TeV. By CMS Collaboration (Albert M Sirunyan et al.), 10.1140/epjc/s10052-018-6143-z. Eur.Phys.J. C78 (2018) 707.

62. Jet properties in PbPb and pp collisions at $\sqrt{s_{NN}}$=5.02 $ TeV. By CMS Collaboration (Albert M Sirunyan et al.), 10.1007/JHEP05(2018)006. JHEP 1805 (2018) 006.
63. Search for a heavy resonance decaying to a pair of vector bosons in the lepton plus merged jet final state at $\sqrt{s}$=13 TeV. By CMS Collaboration (Albert M Sirunyan et al.), 10.1007/JHEP05(2018)088. JHEP 1805 (2018) 088.
64. Search for narrow resonances in the b-tagged dijet mass spectrum in proton-proton collisions at $\sqrt{s}$ = 8 TeV. By CMS Collaboration (A. M. Sirunyan et al.), 10.1103/PhysRevLett.120.201801. Phys.Rev.Lett. 120 (2018) no.20, 201801.
65. Measurement of the Lambda_b polarization and angular parameters in Λ_b to J/Ψ, Lambda decays from pp collisions at $\sqrt{s}$= 7 and 8 TeV. By CMS Collaboration (Albert M Sirunyan et al.), 10.1103/PhysRevD.97.072010. Phys.Rev. D97 (2018) no.7, 072010.
66. Search for heavy neutral leptons in events with three charged leptons in proton-proton collisions at $\sqrt{s}$ = 13 TeV. By CMS Collaboration (Albert M Sirunyan et al.), 10.1103/PhysRevLett.120.221801. Phys.Rev.Lett. 120 (2018) no.22, 221801.
67. Measurement of the inelastic proton-proton cross section at $\sqrt{s}$=13 TeV. By CMS Collaboration (Albert M Sirunyan et al.), 10.1007/JHEP07(2018)161. JHEP 1807 (2018) 161.
68. Search for natural and split supersymmetry in proton-proton collisions at $\sqrt{s}$=13 TeV in final states with jets and missing transverse momentum. By CMS Collaboration (Albert M Sirunyan et al.), 10.1007/JHEP05(2018)025. JHEP 1805 (2018) 025.
69. Search for single production of vector-like quarks decaying to a b quark and a Higgs boson. By CMS Collaboration (Albert M Sirunyan et al.), 10.1007/JHEP06(2018)031. JHEP 1806 (2018) 031.
70. Search for lepton-flavor violating decays of heavy resonances and quantum black holes to eμ final states in proton-proton collisions at $\sqrt{s}$=13 TeV. By CMS Collaboration (Albert M Sirunyan et al.), 10.1007/JHEP04(2018)073. JHEP 1804 (2018) 073.
71. Comparing transverse momentum balance of b jet pairs in pp and PbPb collisions at $\sqrt{s_{NN}}$=5.02 TeV. By CMS Collaboration (Albert M Sirunyan et al.), 10.1007/JHEP03(2018)181. JHEP 1803 (2018) 181.
72. Search for dark matter in events with energetic, hadronically decaying top quarks and missing transverse momentum at $\sqrt{s}$=13 TeV. By CMS Collaboration (Albert M Sirunyan et al.), 10.1007/JHEP06(2018)027. JHEP 1806 (2018) 027.
73. Observation of Medium-Induced Modifications of Jet Fragmentation in Pb-Pb Collisions at $\sqrt{s_{NN}}$= 5.02 TeV Using Isolated Photon-Tagged Jets. By CMS Collaboration (Albert M Sirunyan et al.), 10.1103/PhysRevLett.121.242301. Phys.Rev.Lett. 121 (2018) no.24, 242301.
74. Combined search for electroweak production of charginos and neutralinos in proton-proton collisions at $\sqrt{s}$ = 13 TeV. By CMS Collaboration (A.M. Sirunyan et al.), 10.1007/JHEP03(2018)160. JHEP 1803 (2018) 160.
75. Measurement of the Zγ* to tau tau cross section in pp collisions at $\sqrt{s}$ = 13 TeV and validation of tau lepton analysis techniques. By CMS Collaboration (Albert M Sirunyan et al.), 10.1140/epjc/s10052-018-6146-9. Eur.Phys.J. C78 (2018) no.9, 708.
76. Search for new physics in events with two soft oppositely charged leptons and missing transverse momentum in proton-proton collisions at $\sqrt{s}$= 13 TeV. By CMS

Collaboration (Albert M Sirunyan et al.), 10.1016/j.physletb.2018.05.062. Phys.Lett. B782 (2018) 440-467.

77. Search for dark matter and unparticles produced in association with a Z boson in proton-proton collisions at √s= 8 TeV. By CMS Collaboration (Vardan Khachatryan et al.), 10.1103/PhysRevD.97.099903, 10.1103/PhysRevD.93.052011. Phys.Rev. D93 (2016) no.5, 052011, Erratum: Phys.Rev. D97 (2018) no.9, 099903.
78. Observation of Sequential Upsilon Suppression in PbPb Collisions. By CMS Collaboration (Serguei Chatrchyan et al.), 10.1103/PhysRevLett.109.222301, 10.1103/PhysRevLett.120.199903. Phys.Rev.Lett. 109 (2012) 222301, Erratum: Phys.Rev.Lett. 120 (2018) no.19, 199903.

	Citeablepapers	Citeable papers excluding self cites	Citeablepapersexcluding RPP	Publishedonlypapers	Published only excluding self cites	Published only excluding RPP
Total number of papers analyzed:	78	78	78	75	75	75
Total Number of citations	2,749	1,704	2,749	2,69	1,666	2,69
Averagecitentions per paper:	35.2	21.8	35.2	35.9	22.2	35.9
Paper analysis bised on the citations:						
Renowned papers (500+)	0	0	0	0	0	0
Famous papers (250-499)	1	0	1	1	0	1
Very well-known papers (100-249)	3	2	3	3	2	3
Well-known papers (50-99)	10	5	10	10	5	10
Known papers (10-49)	56	45	56	54	44	54
Less known papers (1-9)	8	25	8	7	23	7
Unknown papers (0)	0	1	0	0	1	0
hHEP index [?]	28	20	28	27	20	27

Theoretical High Energy Physics

The Theory Group

Researchers:

M. Axenides (Director of Research, Theoretical Particle &Astroparticle Physics)

C. Papadopoulos (Director of Research, Theoretical Particle Physics)

G. Savvidy (Director of Research, Theoretical Particle Physics)

Postdoctoral Research Associates:

H. Frellesvig, G. Georgiou, S. Konitopoulos, G. Linardopoulos, G. Pastras.

Visiting Scientists: H.Babujian, R. Poghosyan, Hayk Poghosyan, Hamic Poghosyan, K. Savvidy

Adjunct Scientists: E. Floratos (U. of Athens)

PhD students: D. Canko, D. Katsinis, H. Poghosyan, N. Syrrakos

Postgraduate Students: V. Papagrigoriou (Master thesis defense-June 2018), D. Tridimas and N. Tsolis

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, 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.1-8) 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, nonperturbative aspects (novel non-topological soliton states-Qballs), search of effects of higher spacetime dimensions, and the study of novel higher spin tensor particle states.
- The project (publ.14). 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 study of the origin of its Large Scale Structure (Inflation) and Baryogenesis in the very early Universe.

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

1. the bridging between 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 Black hole information paradox.

- The project on entanglement and geometry (pubs 24, 25, 26, 27, 28) 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 2018 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.21) on the Small Scale Structure of Spacetime (SSSS) explores the possibility of a Discrete Spacetime structure. 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 non-locality, entanglement and chaotic mixing (fast scrambling).
- 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.

- An integral part of our activities (both in research and training) is the study of Non-linear Chaotic Dynamics and Complex Systems and various innovative applications. It aims to study the probing of fundamental interaction dynamics with the well developed mathematical methods and techniques of deterministic chaos. Noteworthy results have been obtained in the very past such as the observation of chaos in Yang Mills such as QCD (G. K. Savvidy) as well as more recently:
  - in matrix and membrane dynamics of M-theory (publ.22)
  - Moreover the principles of chaos have been successfully shown to give rise to novel multipurpose pseudo-random number generator algorithms (MIX-MAX) (pubs 10, 11, 13, 15, 16) which are rapidly becoming of standard use at CERN and NASA.

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 (publs.10-11-13-15-16)

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:

a) ROOT (https://root.cern.ch/doc/master/classTRandom.html),
b) 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.
c) PYTHIA
(http://home.thep.lu.se/~torbjorn/doxygen/MixMax_8h_source.html)
d) GSL - GNU Scientific Library, the Extensions/Applications
(https://www.gnu.org/software/gsl/)
e) 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)

f) 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: 23 publications in refereed journals and 5 on the hep-Archive for the year 2018 which are submitted for publication.

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

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

Teaching: the group offers courses in quantum field theory for graduate and undergraduate students from Polytechnic University and Demokritos Center, 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. Progress on two-loop five-point Master Integrals, Costas Papadopoulos, Christopher Wever. 2018, PoS LL2018 (2018) 015, DOI: 10.22323/1.303.0015.
6. 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
7. Cuts of Feynman integrals in Baikov representation, Costas Papadopoulos, HjalteFrellesvig. 2018, PoS RADCOR2017 (2018) 006, DOI: 10.22323/1.290.0006.
8. Higgs Production, Decay, and Related Mathematical Objects, HjalteFrellesvig. 2018., Acta Phys.Polon.Supp. 11 (2018) 365, DOI: 10.5506/APhysPolBSupp.11.365.
9. Quantum-Mechanical interpretation of Riemann zeta function zeros, George Savvidy, Konstantin Savvidy. Sep. 23, 2018, NRCPS-HE-66-2018, arXiv:1809.09491 [math-ph].

10. Correlation Functions of Classical and Quantum Artin System defined on Lobachevsky Plane and Scrambling Time, HrachyaBabujian, Rubik Poghossian, George Savvidy. Aug. 6, 2018, NRCPS-HE-26-2018, YerPhI/2018/45, arXiv:1808.02132 [hep-th].
11. 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 Science118 (2019) 242, NRCPS-HE-44-2018, DOI: 10.1016/j.chaos.2018.11.024, arXiv:1806.05243 [nlin.CD].Cited by 1 record
12. Lecture on Quantum Gravity with Perimeter Action and Gravitational Singularities, George Savvidy. Feb 27, 2018, NRCPS-HE-10-2018, arXiv:1802.09998 [hep-th].
13. Exponential decay of correlations functions in MIXMAX generator of pseudorandom numbers, George Savvidy, Konstantin Savvidy. 2018., Chaos Solitons Fractals 107 (2018) 244, DOI: 10.1016/j.chaos.2018.01.007.
14. Interaction of non-Abelian tensor gauge fields, George Savvidy. Nov. 21, 2017, Phys.Lett. B776 (2018) 440, NRCPS-HE-65-2017, DOI: 10.1016/j.physletb.2017.12.003 , arXiv:1711.08034
15. Artin billiard: Exponential decay of correlation functions, H.R. Poghosyan, H.M. Babujian, G.K. Savvidi. 2018, Teor.Mat.Fiz. 197 (2018) 230.
16. A Priori Tests for the MIXMAX Random Number Generator, Spyros Konitopoulos, Konstantin G. Savvidy. Apr. 3, 2018, arXiv:1804.01563 [physics.data-an].
17. Novel all loop actions of interacting CFTs: Construction, integrability and RG flows, George Georgiou, Konstantinos Sfetsos. Sep. 10, 2018, Nucl.Phys. B937 (2018) 371, DOI: 10.1016/j.nuclphysb.2018.10.018, arXiv:1809.03522 [hep-th].
18. Holographic three-point correlators in the Schrodinger/dipole CFT correspondence, George Georgiou, DimitriosZoakos. Jun. 21, 2018, JHEP 1809 (2018) 026 DOI: 10.1007/JHEP09(2018)026, arXiv:1806.08181 [hep-th].
19. The exact *C*-function in integrable λ-deformed theories, George Georgiou, PantelisPanopoulos, EftychiaSagkrioti, Konstantinos Sfetsos, Konstantinos Siampos. May 9, 2018, Phys.Lett. B782 (2018) 613, CERN-TH-2018-104, DOI: 10.1016/j.physletb.2018.06.023, arXiv:1805.03731 [hep-th].
20. Giant magnons and spiky strings in the Schrödinger/dipole-deformed CFT correspondence, George Georgiou (DemocritosNucl. Res. Ctr.), DimitriosZoakos (Porto U.). Dec. 8, 2017, JHEP 1802 (2018) 173, DOI: 10.1007/JHEP02(2018)173, arXiv:1712.03091 [hep-th].
21. The quantum cat map on the modular discretization of extremal black hole horizons, Minos Axenides, Emmanuel Floratos, Stam Nicolis. Aug. 28, 2016, Eur.Phys.J. C78 (2018), 412, DOI: 10.1140/epjc/s10052-018-5850-9, arXiv:1608.07845 [hep-th].
22. Multipole stability of spinning M2 branes in the classical limit of the Berenstein-Maldacena-Nastase matrix model, Minos Axenides, Emmanuel Floratos, Georgios Linardopoulos. Dec. 18, 2017, Phys.Rev. D97 (2018), 126019, DOI: 10.1103/PhysRevD.97.126019, arXiv:1712.06544
23. Scalar one-point functions and matrix product states of AdS/dCFT, Marius De Leeuw, Charlotte Kristjansen, Georgios Linardopoulos. Feb. 5, 2018, Phys.Lett. B781 (2018) 238, TCDMATH-18-04, DOI: 10.1016/j.physletb.2018.03.083, arXiv:1802.01598 [hep-th].

24. Dressed elliptic string solutions on R×S2, DimitriosKatsinis, IoannisMitsoulas, Georgios Pastras. Jun. 20, 2018, Eur.Phys.J. C78 (2018), 668, DOI: 10.1140/epjc/s10052-018-6129-x, arXiv:1806.07730 [hep-th].
25. Elliptic string solutions on R×S2 and their pohlmeyer reduction, DimitriosKatsinis, IoannisMitsoulas, Georgios Pastras. May 23, 2018, Eur.Phys.J. C78 (2018), 977, DOI: 10.1140/epjc/s10052-018-6429-1, arXiv:1805.09301 [hep-th].
26. An Inverse Mass Expansion for Entanglement Entropy in Free Massive Scalar Field Theory, DimitriosKatsinis, Georgios Pastras. Nov. 7, 2017, Eur.Phys.J. C78 (2018) 282, DOI: 10.1140/epjc/s10052-018-5596-4, arXiv:1711.02618
27. On the Holographic Entanglement Entropy for Non- smooth Entangling Curves in AdS4, Georgios Pastras. Oct. 5, 2017, Fortsch.Phys. 66 (2018) 1700090, DOI: 10.1002/prop.201700090, arXiv:1710.01948
28. Revisiting the O(3) Non-linear Sigma Model and Its Pohlmeyer Reduction Georgios Pastras. Dec 12. 2016, Fortsch.Phys. 66 (2018) 1700067, DOI: 10.1002/prop.201700067, arXiv:1612.03840 [hep-th].

The Astroparticle physics group

Researchers: C. Markou*, 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, T. Chatzistavrou

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

* Dr. C. Markou is the group co-coordinator.

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.

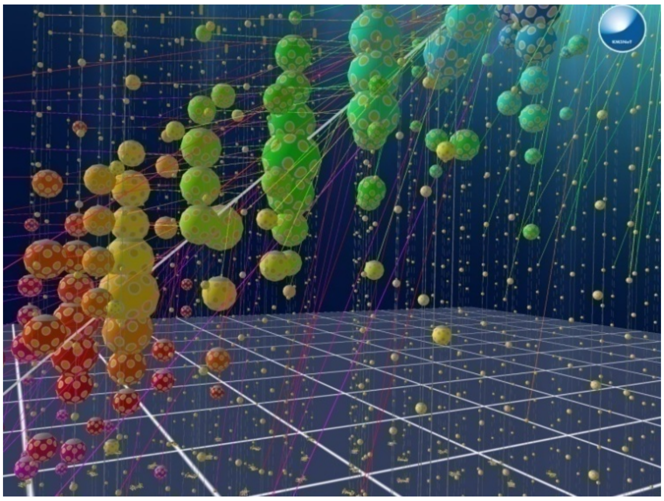


Figure 24: An artists' view of an event as it will be seen from the KM3NeT telescopes

In 2018 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

In May 2018, Dr. C. Markou was re-elected 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. 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 Figure 25), funded exclusively through internal funds. Ever since, the lab continues with the integration of DOMs.

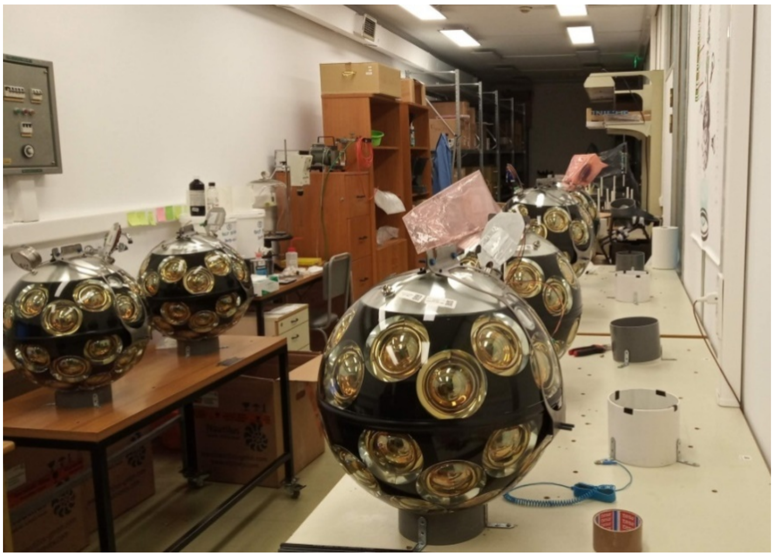


Figure 25: Picture of the DOM laboratory

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 2018 the second set of 18 DOMs corresponding to a full Detection Unit of KM3NeT was successfully completed.

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 Figure 26) is used. The tests are done for a large fraction of the KM3NeT DOM penetrators, as the only other similar facility is in NIKHEF, Amsterdam.

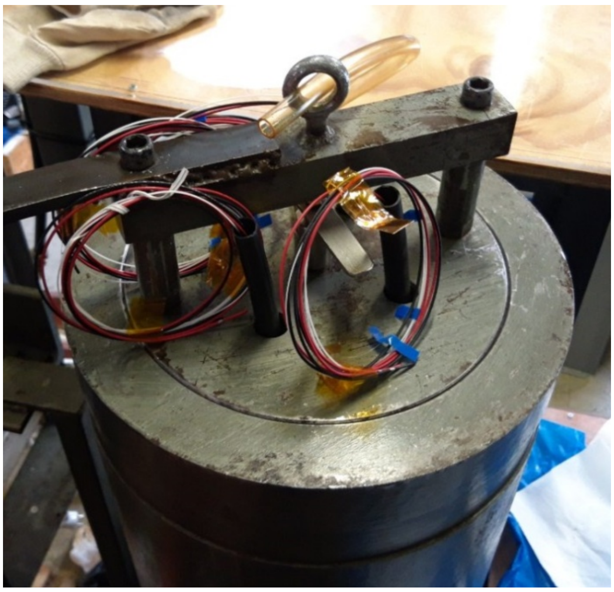


Fig 26: Pressure testing of the penetrators

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 60 compasses were calibrated in 2018, an activity which is expected to continue over the coming years.

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.

<u>"Study of the Discovery Potential of the KM3NeT/ARCA Neutrino Telescope to the Diffuse Astrophysical High Energy Neutrino Flux"</u>

PhD candidate Kostas Pikounis, Supervisors: E. Tzamariudaki, C. Markou

Kostas Pikounis has been involved in the study of the discovery potential of the KM3NeT/ARCA neutrino telescope for a diffuse astrophysical high energy neutrino flux by selecting high energy events starting inside the instrumented volume, using MC simulated events. During this year the whole analysis has been refined and a new, more solid, method to take into account the background has been incorporated. The analysis was endorsed by the KM3NeT Collaboration and the results were made public as KM3NeT official results. To select High Energy Starting Events two tools based on machine learning algorithms (Boosted Decision Trees - BDTs) have been developed. The first one has been optimized to select High Energy Starting Track (HEST) events, resulting to high purity samples of HEST while maintaining a high efficiency on high energy neutrino events.

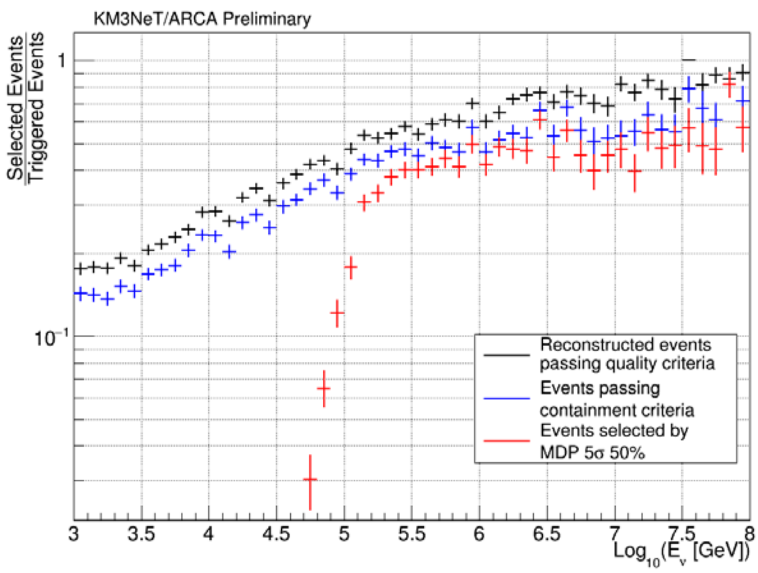


Figure 27: Selection efficiency of true starting track events. In the final step of the selection process the selection efficiency of high energy events is above 40%.

By selecting only HEST events ARCA is expected to make a 3σ and a 5σ discovery of the diffuse astrophysical high energy neutrino flux reported by the IceCube Collaboration in less than 3.5 and 9 years respectively. Using starting track events, the power of the self-veto effect (the rejection of atmospheric neutrinos which are accompanied by atmospheric muons created at the same shower) was investigated. To explore the self-veto effect extensive simulations with CORSIKA program have been conducted in order to create a realistic sample of atmospheric events. Extensive studies have been conducted to evaluate the contribution of the prompt component of atmospheric neutrinos for the various models used in CORSIKA and comparisons with the theoretical models have been made. The analysis of this sample revealed that by selecting starting track events, practically all atmospheric neutrinos accompanied by muons can be rejected. This resulted in a decrease of 30% in the time needed for ARCA to make a discovery of the high energy astrophysical flux using only High Energy Starting Tracks. An equivalent reduction of the atmospheric neutrino background can be expected for all contained events.

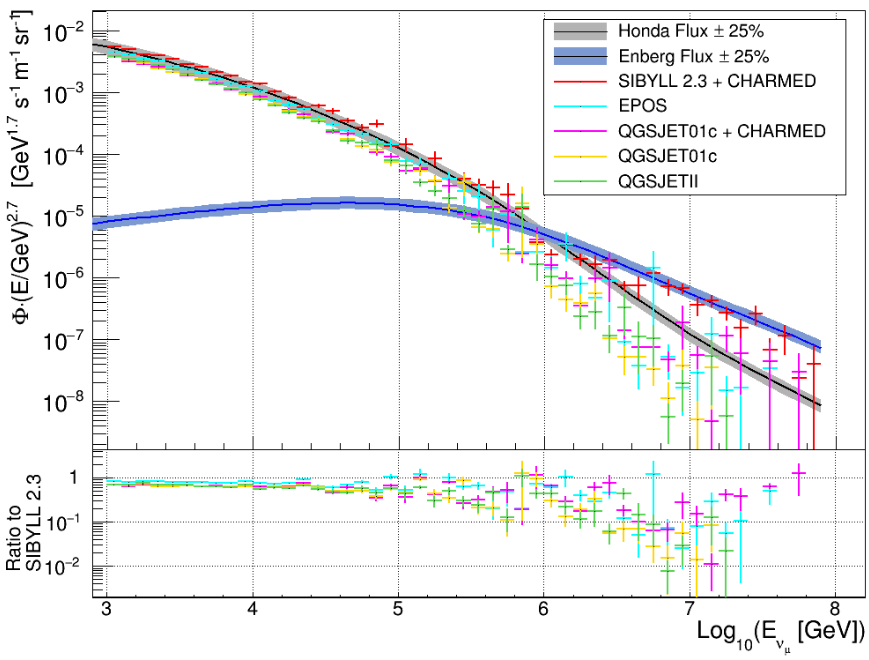


Figure 28: Atmospheric neutrino fluxes at sea level. The output of CORSIKA simulated events using different models and different methods to handle charmed particles in the simulations (points) are compared to theoretical models (Honda and Enberg)

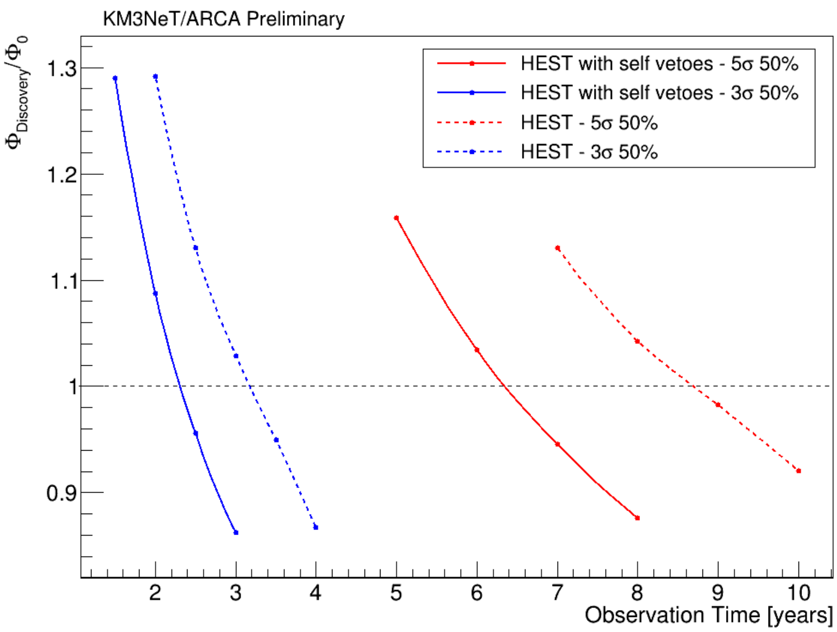


Figure 29: Ratio of the discovery flux factor over the flux factor of the astrophysical high energy neutrino flux reported by IceCube with respect to the observation time in years. Dashed lines: as background events two uncorrelated samples of atmospheric muons and atmospheric neutrinos were used. Solid lines: as background events coming from above the more realistic sample of atmospheric neutrinos accompanied by atmospheric muons, simulated with COSRIKA, has been also included.

A second BDT based tool has been optimized to select high energy contained shower events. By using this tool, a high purity sample of contained shower-like events can be combined while maintaining a high efficiency on high energy neutrino events. By combining these two tools a sample of High Energy Starting Events (HESE) comprising two high purity samples, one of contained shower-like events and one of HEST events has been obtained. Conclusively, ARCA is expected to make a 5σ discovery with 50% and 90% probability using High Energy Starting Events in less than 0.5 years and in approximately 0.8 years, respectively. It should also be noted that a further decrease to the time needed for a discovery is expected by considering the self-veto effect. This analysis has been documented in 2 internal notes and has been presented by K. Pikounis in International Conferences (NEUTRINO 2018, VLVnT 2018).

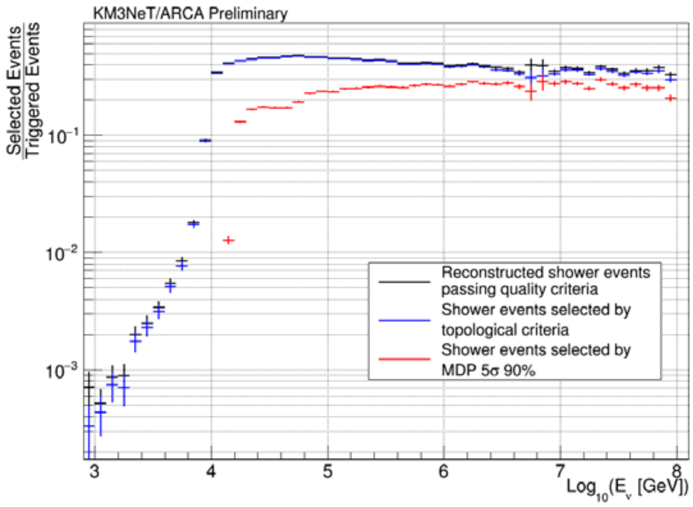


Figure 30: Selection efficiency of true Starting Track events. In the final step of the selection process the selection efficiency of High Energy events compared to triggered events reaches 30%.

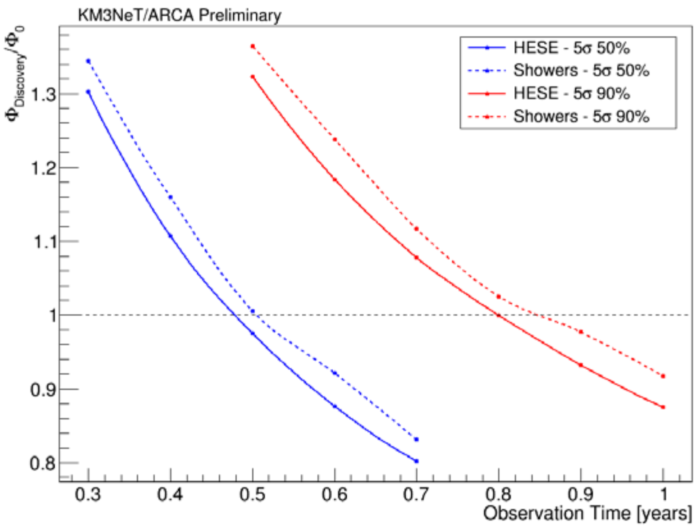


Figure 31: Ratio of the discovery flux factor over the flux factor of the astrophysical high energy neutrino flux reported by IceCube with respect to the observation time in years.

"Studies using alternative configurations of the KM3Net-ARCA detector for the detection of high energy neutrinos", Anna Sinopoulou, MSc Thesis, Supervisor: E. Tzamariudaki.

Anna Sinopoulou defended her MSc. Thesis on February 2018. She studied alternative detector configurations of the KM3NeT/ARCA detector, focusing on the discovery of a diffuse flux of astrophysical neutrinos using muon tracks. Three alternative detector configurations corresponding to sparser detectors have been studied. The effect of a sparser geometry on angular and energy resolution was investigated (Figure 32 left). The advantage of having a sparser detector configuration is the increase in effective area which in turn is expected to result to a better sensitivity and discovery potential for high energy neutrinos (Figure 32 right). Three alternative detector configurations of the KM3NeT-ARCA detector were made by enlarging the distance between the strings to 120m, 150m and 180m in order to increase the effective volume of the neutrino telescope. Taking into account the detector response for all geometries studied, it was concluded that, for a geometry with 150m distance between the detection units, for high energy muons, the quality of the muon track reconstruction is not expected to be inferior to the one obtained using the standard KM3NeT/ARCA geometry. Since an excellent angular resolution is expected also for 150m distance between strings, the gain in effective area results in an improved sensitivity and discovery potential compared to the standard geometry. This work was documented in an internal note on May 2018.

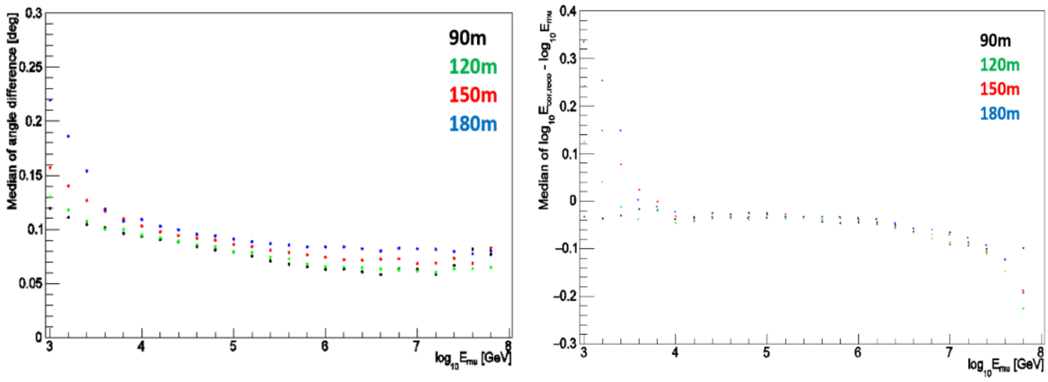


Figure 32: Angular resolution (left) and energy resolution (right) as a function of the true (MC) muon energy for the detector configurations with 90 m -standard geometry (black), 120 m (green), 150 m (red), 180 m (blue) distance between the detection units.

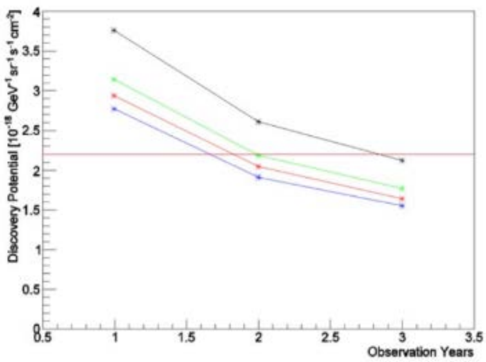


Figure 33: Discovery potential as a function of the observation time for the IceCube flux. The estimation of the discovery potential is shown with black for the standard KM3NeT geometry, green for the 120 m alternative geometry, red for the 150 m alternative geometry and blue for the 180 m alternative geometry.

"Studies on the first data of the KM3NeT/ARCA detector",

Anna Sinopoulou, Ph.D. student, D. Tzanetatos, Ph.D. student, 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 to ensure maximum relevance of the hits used for the track reconstruction with the muon track hypothesis. The number of DOMs with hits consistent with the Cherenkov photons hypothesis is shown in Figure34 and the number of events with hits recorded in both DUs is shown in Figure35.

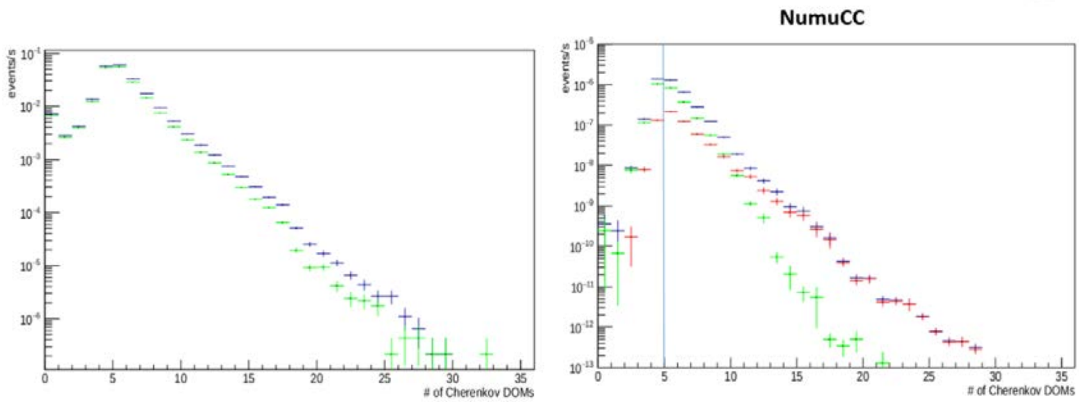


Figure 34: Left: Number of Cherenkov DOMs for data (green) and for atmospheric muon MC (red). Right: Number of Cherenkov DOMs for all atmoshperic neutrino MC events (blue), well reconstructed events (red) and badly reconstructed events (green).

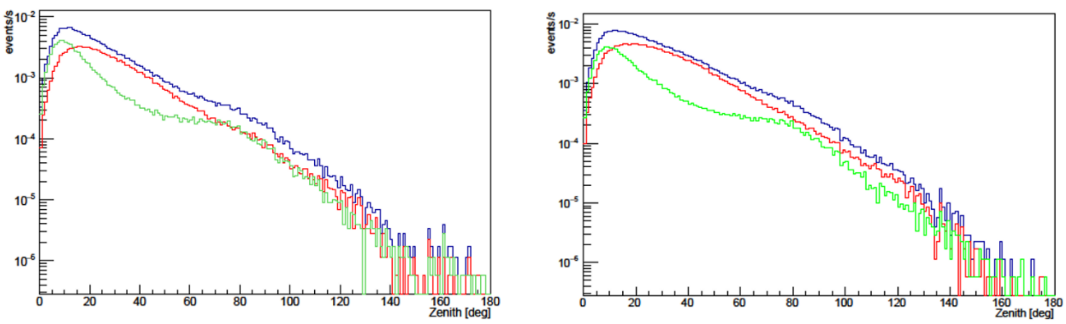


Figure 35: Number of events per second for all the events (blue), events that have hits in both DUs (red) and events that have hits only in one DU (green) for the data (left) and for atmospheric muon MC (right).

“<u>Studies of the potential for acoustic detection of ultra-high energy neutrinos</u>”,

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

The acoustic neutrino detection technique is a novel approach for the detection of the small expected flux of ultra-high energy neutrinos. This approach is based on the Askariyan's thermoacoustic model which implies that the energy deposition of a neutrino induced particle cascade results to a characteristic pressure pulse that propagates in the surrounding medium. The resulting pressure wave has a distinct “pancake”-like topology and the signal is an acoustic bipolar pulse. One major challenge is the detection of this acoustic bipolar pulse over the ambient sea noise, which is addressed by this study.

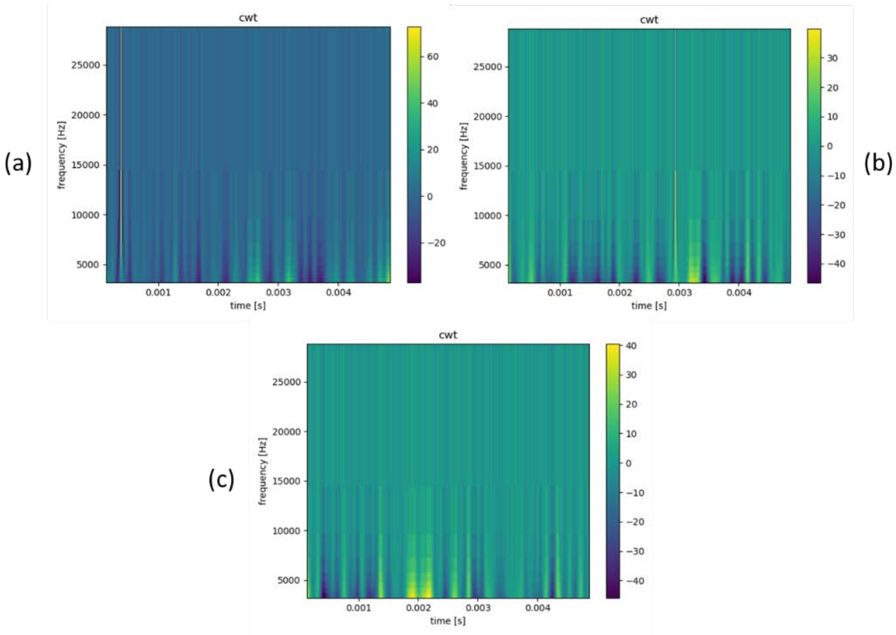


Figure 36: Wavelet correlation coefficients. (a) a neutrino induced pulse with amplitude 10% of the maximum noise amplitude was inserted at time = 0.00038s where all correlation coefficients have high values compared to the rest of the file. (b) a neutrino induced pulse with amplitude 5% of the maximum noise amplitude was inserted at time = 0.00294s, still clearly distinguishable from the ambient noise. (c) a neutrino induced pulse with amplitude 1% of the maximum amplitude was inserted at time = 0.00066s. For such low amplitude compared to the maximum amplitude of the ambient noise, the neutrino induced acoustic pulse is indistinguishable from the ambient noise.

For this study real data acquired by hydrophones deployed in the area South of Kalamata (as described in more detail later) were used to extract short-duration audio files with ambient sea noise. To simulate the signal induced by an ultra-high energy neutrino interaction a bipolar pulse was inserted at a random moment in the noise files. As an optimal way to detect the expected acoustic signal, a wavelet transformation of the sound spectrum was used. The major goal of this analysis was to determine the minimum amplitude of the acoustic pulse induced by the neutrino interaction with respect to the maximum amplitude of the ambient noise that could be clearly detected. Consequently, the amplitude of the neutrino induced acoustic pulse was scaled to a percentage level of the maximum amplitude of the ambient noise for each noise file. The results indicate that when the amplitude of the signal pulse is as low as a few percent of the amplitude of the ambient noise, the values of the wavelet correlation coefficients are high at the exact time when the neutrino induced pulse had been inserted.

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"

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. In the context of Technology transfer (WP 9 of the KM3NeT-INFRADEV project), the construction of a new version of the LAMS device has started, 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 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. One of those necessary changes was the choice of a new photodiode. The light emitter and the support structure of the original LAMS device are utilized, while three autonomous receiver units are redesigned. The new receivers will be housed in custom made cylindrical steel casings facing the light emitter (schematic in figure 1). The new system will also record data from an external pressure sensor in order to register the depth of the system during deployment.

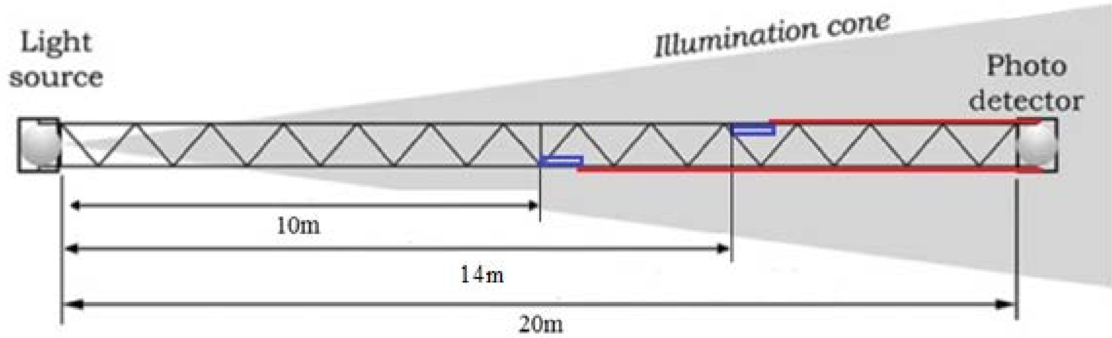


Figure 37: Rough schematic showing the placement of light receivers and light source

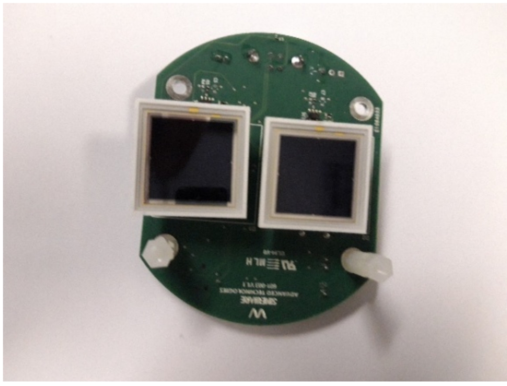


Figure 38: The electronics of the receiver board of LAMS with the two photodiodes - here attached on the prototype board for testing purposes. In the final board the photodiodes will be soldered properly.

The prototype board (picture of the board shown in figure 38) was tested before finalization of the PCB layout. Calibration measurements with the new electronics were performed and the gain of the board was fixed. 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. A preliminary mechanical design of the complete structure and casings has been carried out and the design of 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). The aim was to present the techno-economic assessment of grid-connected photovoltaic (PV) and Wind energy technologies in the locations of Kalamata, Greece and Capo Passero, Italy. In 2018, this study began by reviewing the available meteorological databases and simulation software programs, which built the base for the annual energy prediction of the systems. Moreover, a renewable energy market research was conducted in order to conclude to the available products for the examined locations. Four different types of PV and wind turbines were examined in each location. The two of them are conventional types (PV plants and large-scale horizontal wind turbines) while the other two are the PV façades and the small-scale vertical axis wind turbines that will be used for urban installations. These structures are of high aesthetic value and they will be installed mostly for promotion purposes as they produce less energy and are costlier. Hence, it was decided that almost all the amount (99.5%) of the energy requirements in each location will be met by conventional types of RET while the rest 0.5% will be met by urban small-scale systems.

Kalamata Branch

On February 2018, we deployed 2 hydrophones in the area South of Kalamata, as shown in figure 39, at sea depth of ~1450 m. The hydrophones operated in continuous recording mode for 1 month in order to assess the ambient acoustic load in the area. The 2 hydrophones were recovered and the data are being studied and analyzed. Two indicative snapshots of a quiet period and a ship passing in the vicinity are shown in figure 40. The same data are being used to study and assess the required sensitivity of instrumentation and algorithms in the context of the possibility of building an acoustic neutrino detector.

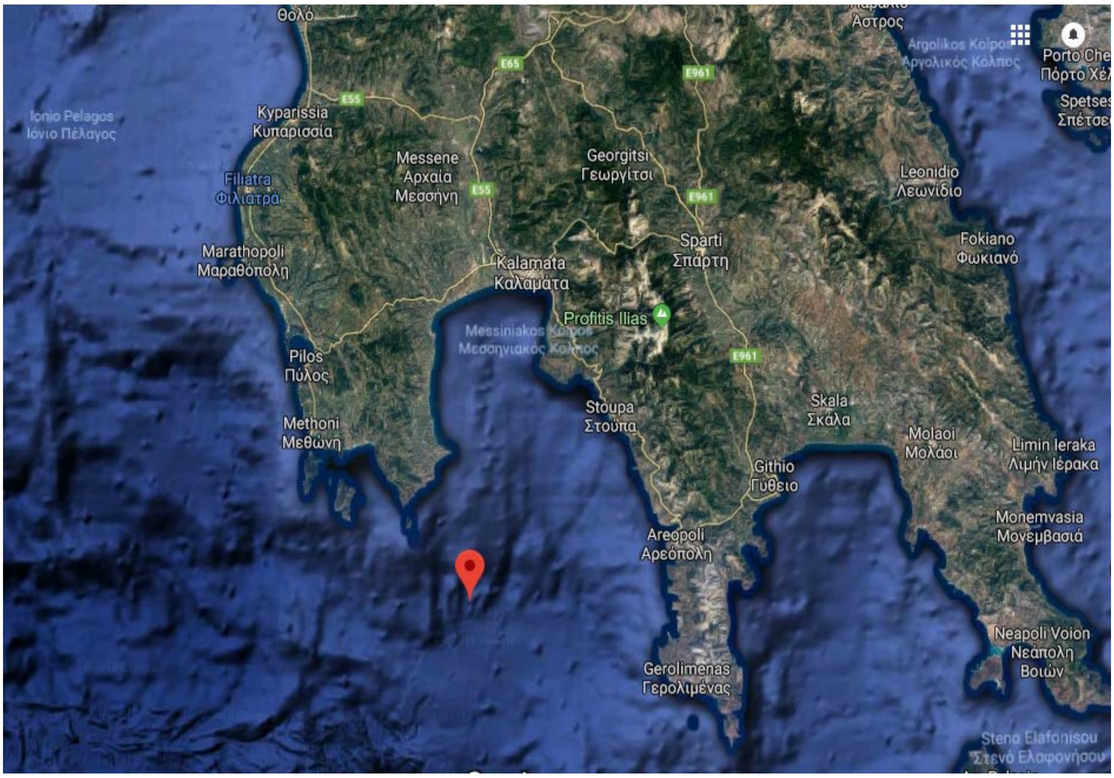


Figure 39: The area in which the 2 hydrophones were deployed, at sea depth of ~1450 m, in February 2018 in the South of Kalamata.

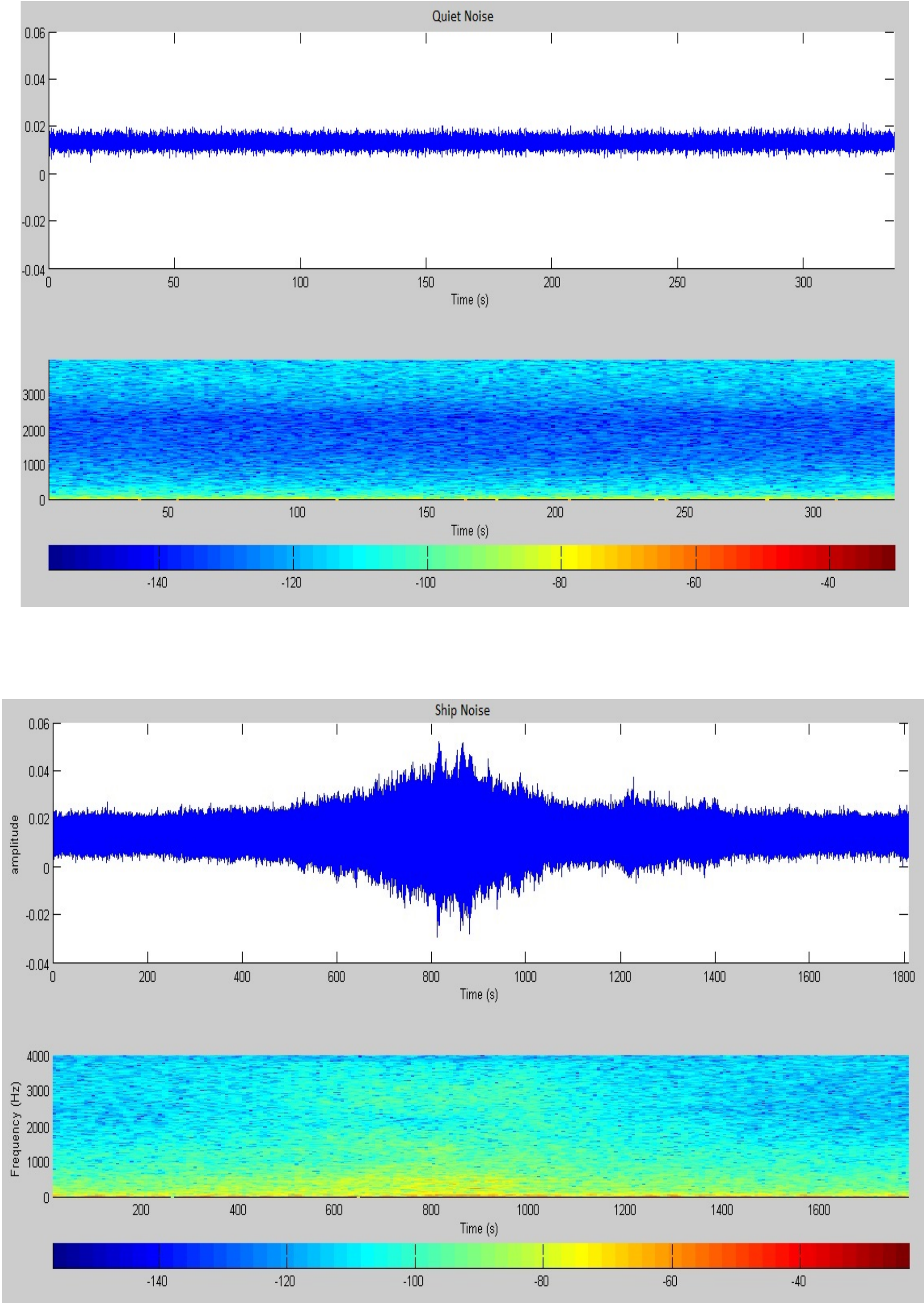


Figure 40: Two indicative snapshots of a quiet period (top) and a ship passing in the vicinity (bottom) are shown.

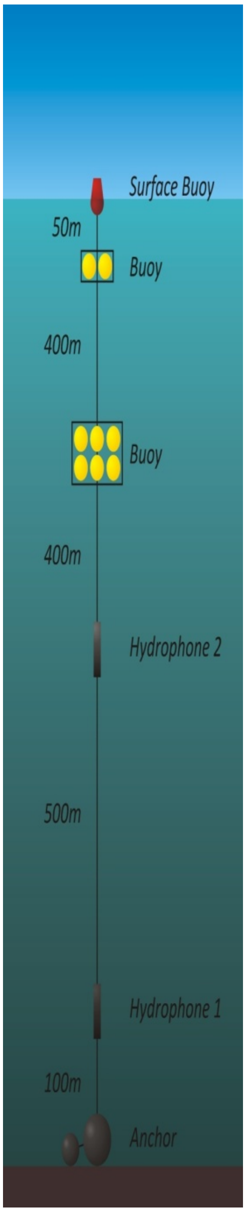


Figure 41: The setup of the deployment of the 2 hydrophones in the area South of Kalamata.

The **Shell Ocean Discovery XPRIZE** is a global competition for innovation in deep sea technology. The Demokritos group has collaborated with XPRIZE in the context of the final phase of the Shell Ocean Discovery competition. The XPRIZE Foundation invited international teams to come to Kalamata. The challenge for the teams participating in the final competition was to explore and map within 24 hours and with a resolution better than five meters a large area of the seafloor of the Mediterranean Sea, off-shore the city of Kalamata on the Peloponnese peninsula of Greece.

The selected area was about 500 km2 with depths up to 4000 m. The teams had to explore at least 250 km2 of the area with their self-developed autonomous technology. Various methodologies have been developed, including autonomous airborne, surface, and sub-surface vehicles. The autonomous devices were launched from a control center in Kalamata, where they had to be recovered again at the end of their explorative mission.

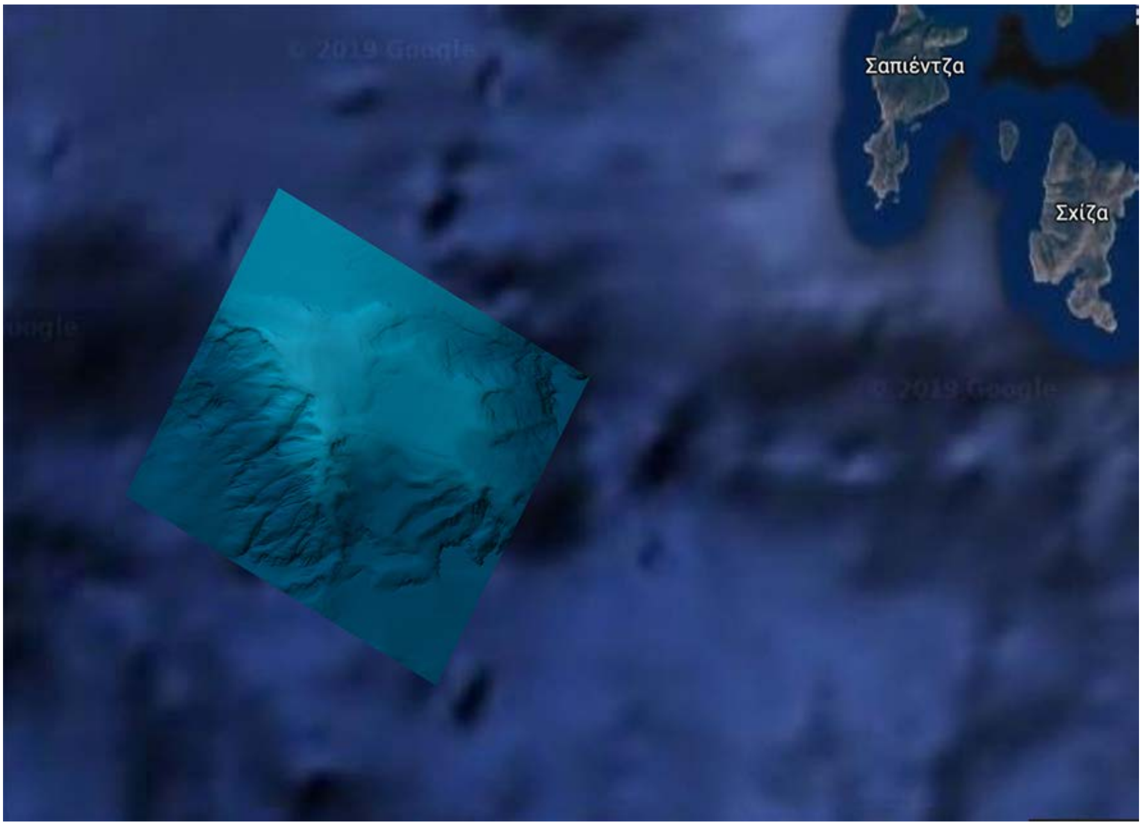


Figure 42: The detailed map in the area including sea depths of 4500m overlaid on a readily available online map.

The high-resolution seafloor maps obtained through the competition have been delivered to INPP to provide additional information on the characterization of the Greek site for KM3NeT.

Future Plans

The Astroparticle Physics group will continue the work in KM3NeT, with emphasis in the construction and operation of the detector according to the current planning as detailed by the KM3NeT MoU. In addition, we will be exploiting 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) Sensitivity of the KM3NeT/ARCA neutrino telescope to point-like neutrino sources by the KM3NeT Collaboration (S. Aiello *et al.*). arXiv: 1810.08499 [astro-ph.HE]
Published in Astropart. Phys. 111 (2019) 100-110

2) Analysis of vertex-contained high energy neutrino events for the KM3NeT/ARCA detector, K. Pikounis and E. Tzamariudaki on behalf of the KM3NeT Collaboration. arXiv:1808.08761 [hep-ex]

3) Characterization of the Hamamatsu photomultipliers for the KM3NeT Neutrino Telescope, by the KM3NeT Collaboration (S. Aiello *et al.*). 2018.
Published in JINST 13 (2018) no.05, P05035

Talks/KM3NeT Presentations in International Conferences

1) "The KM3NeT Digital Optical Module", C. Bagatelas for the KM3NeT Collaboration. Presented at the Workshop "New and Enhanced Photosensor Technologies for Underground/underwater Neutrino Experiments (NEPTUNE)", Naples, Italy, July 2018.

2) "KM3NeT Knowledge and Technology Transfer", K. Pikounis and E. Tzamariudaki for the KM3NeT Collaboration. Presented at the "VLVnT 2018 Very Large Volume Neutrino Telescope", Dubna, organized by the: Joint Institute for Nuclear Research, October 2018.

3) "A HESE analysis with KM3NeT/ARCA Telescope", K. Pikounis for the KM3NeT Collaboration. Presented at the "VLVnT 2018 Very Large Volume Neutrino Telescope", Dubna, organized by the: Joint Institute for Nuclear Research, October 2018.

4) Analysis of vertex-contained high energy neutrino events for the KM3NeT/ARCA detector, K. Pikounis and E. Tzamariudaki on behalf of the KM3NeT Collaboration. Presented at the XXVIII International Conference on Neutrino Physics and Astrophysics, Heidelberg, Germany, June 2018. DOI: 10.5281/zenodo.1300717 (poster)

5) "Positioning calibration in KM3NeT",G. Riccobene and K. Pikounis for the KM3NeT Collaboration. Presented at the "VLVnT 2018 Very Large Volume Neutrino Telescope", Dubna, organized by the: Joint Institute for Nuclear Research, October 2018.

6)"Prospects and Status of the KM3NeT Neutrino Telescope", E.Tzamariudaki for the KM3NeT Collaboration. Presented at the "Conference on Recent Developments in High Energy Physics and Cosmology", Athens, Greece, April 2018.

7) "A Discovery Potential Analysis for the KM3NeT/ARCA Detector", K. Pikounis. Presented at the "Conference on Recent Developments in High Energy Physics and Cosmology", Athens, Greece, April 2018.

8) "Alternative Configurations for the KM3NeT/ARCA Detector", A. Sinopoulou. Presented at the "Conference on Recent Developments in High Energy Physics and Cosmology", Athens, Greece, April 2018.

Measurement of optical parameters of deep-sea water, (G.Stavropoulos)

During 2018 the analysis of the data collected for the project "A method of measuring the optical parameters of deep-sea water", funded by the KRIPIS funding scheme, was concluded. A detailed description of the project is given in the 2015-2017 INPP Report of activities. Figure 43 shows the distribution of photons per laser pulse for the '30° direction', 405 nm laser (dots with statistical errors presented by the size of the dot). The data presented were recorded by the PMT at 40° direction in the 15m configuration. The red line represents the, fitted to the experimental data, theoretical model (simulation). Table 1 summarizes the results of the fit to the experimental data, together with the parameters' statistical errors as calculated from the fit. The systematic errors are also reported. More details on the analysis of the data can be found in the published paper:

Front. Phys., 21 November 2018 | https://doi.org/10.3389/fphy.2018.00132.

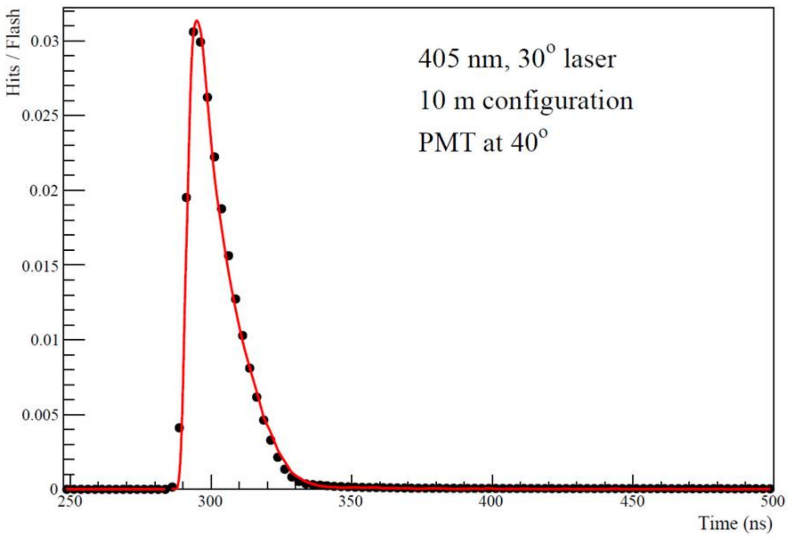


Figure 43: Photons per laser pulse for the '30° direction', 405 nm laser (dots with statistical errors presented by the size of the dot). The data presented were recorded by the PMT at 40° direction in the 15m configuration. The red line represents the, fitted to the experimental data, theoretical model (simulation).

Fitted Parameter	**λ (nm)**	
	405	**520**
L_a **(m) ± (stat) ± (syst)**	35 ± 1 ± 4	25.5 ± 0.8 ± 3
L_s**(m) ± (stat) ± (syst)**	45 ± 1 ± 5	37.5 ± 0.9 ± 4
p**± (stat) ± (syst)**	0.299 ± 0.003 ± 0.006	0.126 ± 0.002 ± 0.004
a_{Mie}**± (stat) ± (syst)**	0.935 ± 0.004 ± 0.007	0.925 ± 0.004 ± 0.006

Table 1: Fit results with statistical and systematic errors (1σ).

References

Front. Phys., 21 November 2018 | https://doi.org/10.3389/fphy.2018.00132.

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)

Diploma thesis students: Spyridon Peroulis (NKUA)

International collaborators

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- 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 nonrelativistic 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,R13], 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.

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,R6,R9,R10,R11], 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 [R12]. Spectra can also be determined through the use of three- and/or four body terms. Extension of these ideas to superheavy nuclei is also possible [R8]. An extension of proxy-SU(3) to shells in which protons and neutrons coexist is also possible.

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].

Articles in International Conference Proceedings

[R5] “Highest weight SU(3) irreducible representations for nuclei with shape coexistence», A. Martinou, D. Bonatsos, N. Minkov, I.E. Assimakis, S. Sarantopoulou, and S. Peroulis, Nuclear Theory '37, Proceedings of the 37th International Workshop on Nuclear Theory (Rila 2018), ed. M. Gaidarov and N. Minkov (Heron Press, Sofia, 2018) 41-51. arXiv: 1810.11870 [nucl-th].

[R6] “Why do Nilsson quantum numbers remain good at moderate deformations?», D. Bonatsos, I.E. Assimakis, A. Martinou, S. Peroulis, S. Sarantopoulou, and N. Minkov, Nuclear Theory '37, Proceedings of the 37th International Workshop on Nuclear Theory (Rila 2018), ed. M. Gaidarov and N. Minkov (Heron Press, Sofia, 2018) 126-136. arXiv: 1810.11866 [nucl-th].

Articles in Greek Conference Proceedings

[R7] “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, p. 37-43.

[R8] “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, p. 255-258. arXiv: 1811.04823 [nucl-th].

[R9] “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, p. 96-103. arXiv: 1810.11860 [nucl-th].

[R10] “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, p. 9-16. arXiv: 1811.01071 [nucl-th].

[R11] “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. arXiv: 1810.11858 [nucl-th].

[R12] “Parameter-independent predictions for nuclear shapes and B(E2) transition rates in the proxy-SU(3) model»,A. Martinou, S. Peroulis, D. Bonatsos, I. E. Assimakis, S. Sarantopoulou, N. Minkov, R. B. Cakirli, R. F. Casten, and K. Blaum, in HNPS: Advances in Nuclear Physics :Proceedings of the 26th Annual Symposium of the Hellenic Nuclear Physics Society (Anavyssos, 2017, ed. C. Tsabaris, R. Vlastou, M. Kokkoris, and D. Patiris (NTUA, Athens, 2018) p. 21-26. arXiv: 1712.04134 [nucl-th].

[R13] “A new scheme for heavy nuclei: proxy-SU(3)», D. Bonatsos, R. F. Casten, A. Martinou, I. E. Assimakis, N. Minkov, S. Sarantopoulou, R. B. Cakirli, and K. Blaum, in HNPS: Advances in Nuclear Physics : Proceedings of the 26th Annual Symposium of the Hellenic Nuclear Physics Society (Anavyssos, 2017) ed. C. Tsabaris, R. Vlastou, M. Kokkoris, and D. Patiris (NTUA, Athens, 2018) p. 6-11. arXiv: 1712.04126 [nucl-th].

Ph.D. Theses completed

Martinou, Antriana, National Technical U. of Athens (01/2018). «Nucleon - Nucleon Interaction in Stable and Unstable Nuclei».

Distinctions

DB: Outstanding Reviewer Award in J. Phys. G: Nucl. Part. Phys. in 2018.

Organization of international conferences

- XI International Conference on Nuclear Structure Properties, Trabzon, Turkey, 9/2018.

DB: Member of the Scientific Committee and the Referee Committee.

- 34th International Physics Congress of the Turkish Physical Society (TPS-34), Konacik, Bodrum, Turkey, 9/2018.

DB: Member of the Scientific Programme Committee.

- 37th International Workshop on Nuclear Theory, Rila Mountains, Bulgaria (6/2018).

DB: Member of the International Advisory Committee.

- 9^{th} International Workshop on Quantum Phase Transitions in Nuclei and Many-Body Systems, Padova, Italy, 5/2018.

DB: Member of the International Advisory Committee.

Participation in Greek schools

- Hellenic Institute of Nuclear Physics School 2018, Ioannina, 10/2018.

DB: Lecture on «Symmetries in Nuclear Structure – The Collective Model».

- Hellenic Institute of Nuclear Physics School 2018, Ioannina, 5/2018.

DB: Lecture on «Symmetries in Nuclear Structure – Shell Model».

Participation in international conferences

37^{th} International Workshop on Nuclear Theory, Rila Mountains, Bulgaria. 6/2018.

DB: Invited talk on "Why Nilsson quantum numbers remain good at moderate deformations?».

AM: Invited talk on «Magic numbers of shape coexistence».

Participation in Greek conferences

27^{th}Annual Symposium of the Hellenic Nuclear Physics Society, Athens, 6/2018.

DB: Lecture on «Particle-hole symmetry breaking due to Pauli blocking».

IA: Lecture on «Magic numbers for shape coexistence»

AM: Lecture on «Nucleon numbers for nuclei withshape coexistence»

SP: Poster on «Synergy of nuclear data systematics and proxy-SU(3) in planning future experiment in the superheavies mass region»

Extended invitations and visits to N.C.S.R. Demokritos

- S. Karampagia, Grand Valley State Univerisy, Allendale, USA, 5-6/2018 (2 months).
- N. Minkov, INRNE, Bulgarian Academy of Sciences, Sofia, Bulgaria, 4/2018 (2 weeks).

Funding

The only support received by the group was the salary of the head of the group (DB) as a permanent researcher, plus 4 months of postdoc salary (2300 euros per month, before tax and insurance) for AM.

The application of the head of the group to the Hellenic Foundation for Research and Innovation was turned down on the following grounds: «This proposal tries to revive the idea of use of group theoretical techniques for the understanding of nuclear structure. It is an elegant approach, which can provide understanding of some pending questions in nuclear structure. In the era of supercomputers, though, it is doubtful if it would compete successfully against the «brute force» approach used all over the world». Our opinion has been expressed above. Everybody in the nuclear structure community in the last several years is talking about shape coexistence, but no supercomputer so far has been able to predict specific regions of shape coexistence as opposed to global appearance of the effect, while our approach does it in a parameter-free way.

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 25 Dec. 2018

Research items	**219**
Citations	**2956**
Reads	**5391**

Experimental Nuclear Physics

Researchers: Sotirios V. Harissopulos,
Anastasios Lagoyannis,
Michail Axiotis (since September 2018)

PhD Students: Kostas Preketes-Sigalas,
Eleni Ntemou

MSc Students: Eleni Alavanou,
Euthimios Daoulas

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, etc) are presented in the relevant section below.

In the field of Nuclear Astrophysics, the research of the group is concentrated on the systematic studies of capture reactions relevant to the nucleosynthesis of the p-nuclei, the so-called p-process mechanism that takes place in certain explosive stellar environments, such as supernovae. This latter mechanism is responsible for the production of certain 35 neutron-deficient nuclei that lie between ^{74}Se and ^{196}Hg, and have been observed to-date only in our solar system. In order to follow this line of research, the group measure cross-sections of proton and alpha capture reactions on medium-mass nuclei by either the γ-angular distributions or the angle-integrated γ-ray yields technique. A complete description of the methods used along with a brief description of the nucleosynthetic p-process and the Hausser-Feshbach (HF) theory are presented in the peer-reviewed topical issue published by S. Harissopulos reported below. In this field, the group published in 2018 cross-section data for proton capture reactions on $^{74, 78, 80}$Se, $^{91, 92}$Zr, ^{127}I and ^{133}Cs along with their respective theoretical HF calculations, in an effort to find the appropriate models that describe better the experimental results.

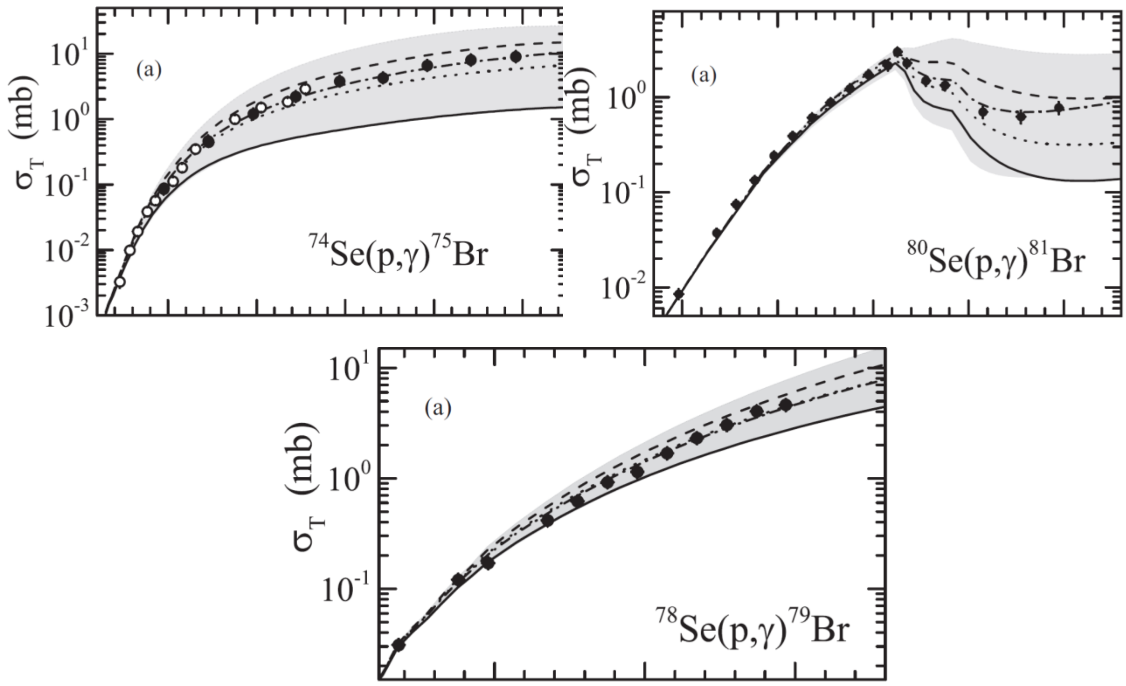


Figure 44: Cross-sections of proton capture reactions on Se isotopes

In the field of Nuclear Structure, in collaboration with the National Technical University of Athens (NTUA) and the University of Ioannina (UoI) studies of neutron induced reactions have been carried out. Accurate cross-sections of these reactions are important for the improvement of safety margins of presently operating power plants as well as for design studies of new nuclear reactors. A noticeable example of the latter are Accelerator Driven Systems (ADS) and generation-IV reactors, which are proposed for nuclear waste transmutation and for fast neutron reactors for long-term sustainability, by burning fissile isotopes that can by constituents of the existing nuclear waste and at the same time produce nuclear energy. On this front, in 2018, the cross-sections of the neutron induced fission reaction of ^{234}U have been measured, along with the (n, 2n) reaction on the lightest Erbium isotope (^{162}Er) and the (n, 2n) and (n, 3n) reactions on ^{191}Ir. Furthermore, the (n, 2n) reaction cross-sections on ^{197}Au have been reported, a reaction which is considered as a standard for high-energy neutron dosimetry and is implemented as a test case for many nuclear reaction model codes.

For Ion Beam Analysis purposes, the group has carried on the activities concerning basic and applied research on proton and deuteron induced reactions. The measurement and benchmarking of differential cross-sections on matter relevant to several IBA techniques (EBS, NRA, PIGE) have been carried out. The retrieved data are important for the study of samples containing the specific elements. More specifically, during 2018 the group has developed a new method for the benchmarking of PIGE related differential cross sections by comparing integrated differential cross sections with measured thick target yields. In addition, the ^{7}Li (d,d$_0$)^{7}Li reaction differential cross section was measured in a wide energy range in order to enhance the applicability of the Elastic Backscattering Spectroscopy method. On the application of the IBA techniques the group in collaboration with the EuroFUSION community has studied tiles of the Joint European Torus (JET) tokamak reactor, in order to understand the mechanisms behind fuel retention and erosion in Plasma Facing Materials and Compounds. In this framework, a number of tiles were measured using the Nuclear Reaction Analysis technique with a deuteron beam in order to measure deuteron and Carbon quantities in Beryllium tiles.

Furthermore, the group of Experimental Nuclear Physics of the Institute, in conjunction with the Institute of Accelerating Systems and Applications (IASA), the NTUA and the UoI has established collaboration with the European Space Agency (ESA). In the context of this collaboration, the members of the lab during 2018 have reviewed some of the Geant4-based ESA's software codes, in order to propose and implement improvements.

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. Measurement of the ^{234}U(n, f) cross-section with quasi-monoenergetic beams in the keV and MeV range using a Micromegas detector assembly, by A. Stamatopoulos, A. Kanellakopoulos, A. Kalamara, M. Diakaki, A. Tsinganis, M. Kokkoris, V. Michalopoulou, M. Axiotis, A. Lagoyiannis, R. Vlastou, in The European Physical Journal A 54, 7 (2018). [https://doi.org/10.1140/epja/i2018-12429-2]
2. Cross-section measurements of capture reactions relevant to p-process nucleosynthesis, by S. V. Harissopoulos, in European Physical Journal Plus 133, 332 (2018). [https://doi.org/10.1140/epjp/i2018-12185-8]
3. Differential cross-section measurements of the elastic ^{7}Li(d,d$_0$) scattering for analytical purposes, by K.Preketes-Sigalas, E.Ntemou, M.Kokkoris, X.Aslanoglou, M.Axiotis, V.Foteinou, S.Harissopulos, A.Lagoyannis, P.Misaelides, N.Patronis, G.Provatas, in Nuclear Instruments and Methods in Physics Research Section B 414, 99 (2018). [https://doi.org/10.1016/j.nimb.2017.10.035]
4. A benchmarking procedure for PIGE related differential cross-sections, by M.Axiotis, A.Lagoyannis, S.Fazinić, S.Harissopulos, M.Kokkoris, K.Preketes-Sigalas, G.Provatas, inNuclear Instruments and Methods in Physics Research Section B 423, 92 (2018). [https://doi.org/10.1016/j.nimb.2018.03.030]
5. ^{197}Au(n,2n) reaction cross section in the 15–21 MeV energy range, by A. Kalamara, R. Vlastou, M. Kokkoris, N. G. Nicolis, N. Patronis, M. Serris, V. Michalopoulou, A. Stamatopoulos, A. Lagoyannis, S. Harissopulos, in Physical Review C 97, 034615 (2018). [https://doi.org/10.1103/PhysRevC.97.034615]
6. Cross section measurements of proton capture reactions on Se isotopes relevant to the astrophysical p process, by V. Foteinou, S. Harissopulos, M. Axiotis, A. Lagoyannis, G. Provatas, A. Spyrou, G. Perdikakis, Ch. Zarkadas, P. Demetriou, in Physical Review C 97, 035806 (2018). [https://doi.org/10.1103/PhysRevC.97.035806]

7. The (n,2n) reaction for the lightest stable erbium isotope ^{162}Er from reaction threshold up to 19 MeV, by E. Georgali, Z. Eleme, N. Patronis, X. Aslanoglou, M. Axiotis, M. Diakaki, V. Foteinou, S. Harissopulos, A. Kalamara, M. Kokkoris, A. Lagoyannis, N. G Nicolis, G. Provatas, A. Stamatopoulos, S. Stoulos, A. Tsinganis, E. Vagena, R. Vlastou, S. M. Vogiatzi, in Physical Review C 98, 014622 (2018).
[https://doi.org/10.1103/PhysRevC.98.014622]

8. ^{191}Ir(n,2n) and ^{191}Ir(n,3n) reaction cross sections in the 15–21 MeV energy range, by A. Kalamara, R. Vlastou, M. Kokkoris, S. Chasapoglou, A. Stamatopoulos, N. Patronis, M. Serris, A. Lagoyannis, S. Harissopulos, in Physical Review C 98, 034607 (2018).
[https://doi.org/10.1103/PhysRevC.98.034607]

Thesis Supervision

MSc Thesis

1. **A. Zyriliou**: "Spectroscopic study of mid-heavy nuclei relevant to angular distributions", NKUA, 2018**.**

Organization of Scientific Events

- **October 3-5, 2018**: **2nd ENSAF workshop**, NCSR "Demokritos", Athens, Greece. Details in: http://www.ensarfp7.eu/activities/networking-activities/ensaf/2nd-ensaf-workshop-1/announcement-2nd-ensaf-workshop

X-ray Spectrometry

Coordinator: Dr. Andreas Germanos Karydas

Post-Doctoral Researchers: Dr. Vasiliki Kantarelou, Dr. Maria Kaparou, Dr. Manos Manousakas

PhD student: Nikoletta-Kanella Kladouri

MSc Students: Dimitra Papadopoulou, Eleni Kokiasmenou, Rebecca Grethe, Savvina Fotiou, Kalliopi Tsampa

Diploma Student: Sotiria Symeonidou

Interns: Rakhami Fatima Azzahra, Maria Kontimpa

Fundamental and applied research using synchrotron radiation

The development and commissioning of a joint Elettra Sincrotrone Trieste and International Atomic Energy Agency (IAEA) multipurpose X-ray instrument called IAEAXspe (see publication **[1]**, A.G. Karydas et al., Journal of Synchrotron Radiation 25 (2018) 189–203), opened the possibility to investigate the uncertainty budget associated with a broad range of X-ray Fundamental Parameters (FPs), either compiled in various databases or estimated by theoretical models. In this framework, the systematic work related with FPs on Dy atoms was continued and X- ray production (XRP) cross sections for the ^{66}Dy L_k (k = l, α, η, $\beta_{2,6,7,15,\beta 1,6}$, $\beta_{1,3,4,6}$, $\beta_{2,7,15}$, $\gamma_{1,5}$, $\gamma_{2,3}$) emission lines have been measured by tuning the incident synchrotron radiation at energies over the range 7.8–9.2 keV and ~10–370 eV above the respective Li (i = 1–3) absorption edges **[2]**. The measured L_k production cross sections were found in moderate agreement with the different sets of calculated values (within the experimental errors), being most of them consistently lower than the different theoretical values.

In another similar study, the total M shell and the Mk (k = ξ, αβ, γ, m) X- ray production cross sections for ^{66}Dy have been also measured at incident photon energies across its Lj (j = 1–3) subshell absorption edge energies, ranging 7.8–9.2 keV**[3]**. This study aimed in particular to investigate the evolution of the probability for cascade decay of Lj subshell vacancies as the tunable incident energy ionizes progressively different ^{66}Dy Lj subshells. The experimental X- ray production cross sections have been compared with different theoretical calculations, whereas the Lj (j = 1–3) subshell to the Mi (i = 1–5) subshell vacancy transfer probabilities were also evaluated **[3]**. This work showed, for example, that the measured Mαβ XRP cross sections (which are the stronger ^{66}Dy M emission lines) are significantly lower than the theoretical ones evaluated from the relativistic Dirac-Fock/Dirac-Hartree-Slater calculations, exhibit a better agreement with those evaluated from the nonrelativistic Hartree-Slater model calculations,however, are consistently lower than these values **[3]**.

The IAEAXspe instrument at ElettraSincrotorne Trieste was also evaluated in terms of its applicability to characterize the elemental composition and structural properties of advanced nanostructured materials (thickness, density, roughness) used in various modern applications. For this purpose, combined grazing incidence XRF and x-ray reflectometry measurements of nanolayers were carried out and a synergistic analysis of the acquired data was developed **[1]**.

Moreover, the analytical performance of the Elettra XRF beamline end-station was systematically evaluated under the TXRF excitation geometry by analyzing different types of aqueous (lake, waste and fresh water) and solid (soil, vegetal, biological) certified reference materials**[2]**. In conjunction with energy absorption measurements under different excitation geometries, the potential of the facility to identify chemical species of the probed atoms contained even in trace amounts was demonstrated in the analysis of air particulate matter [**1, 6**] and biological samples [**1**], respectively.

Targeting novel X-ray spectrometry-based developments for environmental research, a state-of the-art analytical methodology, by which chemical state information on metallic elements is obtained for liquid samples in a fast and simple manner was proposed (see Figure 46). The experiments were carried out at Elettra Sincrotrone Trieste and at the Brazilian Synchrotron Light Laboratory. With the proposed technique, called resonant inelastic X-ray scattering under total reflection geometry (TRIXS), the limitations of conventional X-ray techniques, such as the X-ray absorption spectroscopy, can be overcome allowing the chemical speciation of metallic trace elements in liquid samples by using only a small quantity deposited on polished reflectors. The analytical potential of the TRIXS technique was demonstrated by analyzing contaminated water samples with low concentration of different Cr and Mn compounds and characterizing the different chemical species contained using multivariate methods [**4**].

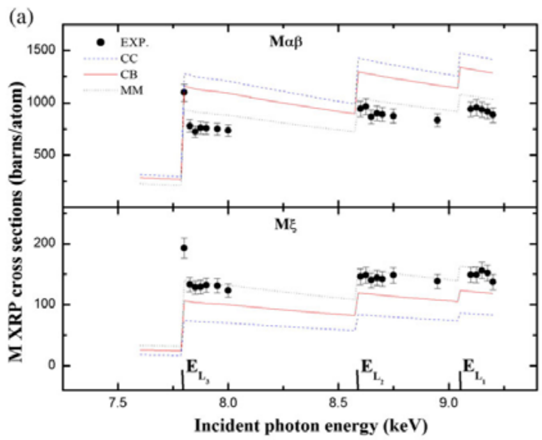


Figure 45: Experimental Mk (k = ξ, αβ) X-ray production (XRP) cross sections (barns/atom) for 66Dy as the function of incident photon energy in comparison with three different sets of respective theoretical values [**3**].

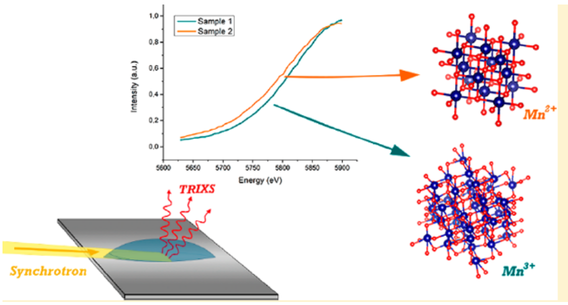


Figure 46: Schematic description of the TRIXS technique. Through the multivariate analysis of the left side (lower energy) of the RRS distribution, different chemical species of the probe element (Mn) can be identified [4].

In collaboration with LANDIS laboratory of INFN-LNS in Catania, a joint feasibility experiment was also performed at Elettra Sincrotrone Trieste (May 2018) with the purpose to obtain scanning-free angular dispersion in the grazing exit emission of characteristic X-rays (GE-XRF) from thin nanostructured materials. This technique has certain advantages with respect to its more common counterpart (GI-XRF analysis). In order to implement the scanning-free angular dispersion, a two-dimensional area imaging MOS-CCD detector (1024×1024 pixels with 13 μm size) was used for energy dispersive detection of fluorescence X-rays. This X-ray detection system is characterized as a Full-Field X-ray Camera (FF-XRC, figure 47a). By applying a deep cooling of the camera and a special novel algorithm based on a single photon counting (SPC) technique in a multi-frame acquisition procedure, anexcellent spectroscopic performance (FWHM<155eV) and Gaussian reconstruction of the characteristic emission spectrum without the presence of peak tails and other artefacts was attained. The set-up developed proved its promising capabilities to characterize structural properties of complex nanostructured materials.

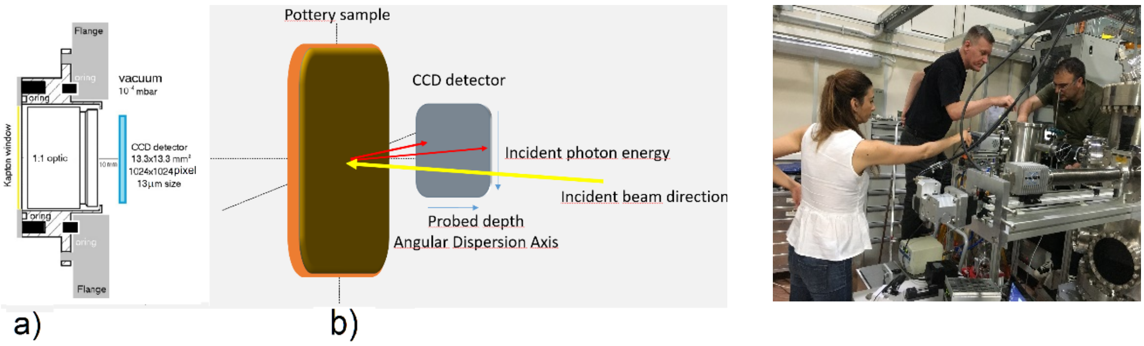


Figure 47: A schematic view of the Full Field X-ray Camera (a) and the basic principle of the proposed Grazing Exit XRF experiment (b) together with a photo from the installation of the set-up at the XRF beamline of ElettraSincrotrone Trieste

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 standard less 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 [**4**].

In the forthcoming years (2019-2020) the systematic experimental work will be continued utilizing synchrotron radiation as an exciting source focusing on the determination of Ge (Z=32), Sb (Z=51), Re (Z=75) and Au (Z=79) fundamental X-ray parameters, the study of the Re-M and Ge-L cascade X-ray emission and the determination of Resonant Raman scattering cross sections.

The unintended access to 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.

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" continued and generated a publication [**9**] utilizing data acquired by the high energy and polarization, secondary target benchtop XRF spectrometer that operates at the XRF premises (Epsilon 5 by PANalytical, The Netherlands). In this work, a yearlong measurement campaign was conducted during the year 2012 in the medium sized coastal Greek city of Patras. PM10 samples were collected once every 3 days, and the PMF model was used for source identification. Seven PM10 emission sources were identified using PMF 5.0 and were, namely, mineral dust (15%), road dust (4.6%), shipping emissions (3.8%), sea salt (11.9%), biomass burning (6.9%), traffic (46.2%), and sulfates (11.6%). The concentration weighted approach was used to investigate if the contributions of the sources identified in the area are affected by long range transportation events, whereas a methodology of estimating the uncertainty of the day to day source contributions was also proposed [**9**].

In the field of Cultural Heritage, the strong multi-scale collaboration established with the LANDIS laboratory of INFN and CNR in Catania, Sicily, was continued and further strengthened. Common abstracts were presented at two international conferences, whereas upon invitation, confocal (3D) measurements were carried out to characterize the stratigraphy and composition of Roman period painted plasters in the framework of SavvinaFotiou MSc diploma work (October 2018). In parallel, the evaluation of previously acquired MA-XRF imaging data was continued and further advanced.

In November 2018, another campaign of in-situ MA-XRF imaging was conducted in collaboration with LANDIS-LNS at the National Archaeological Museum (NAM) in partnership with the NAM archaeologists Dr. E. Konstantinidi and Dr. K. Nikolentzos (figure 48). The project of investigating the provenance of Mycenaean gold at NAM and at selected-key archaeological locations in Greece was triggered and launched by the exciting results obtained by the MA-XRF imaging of the gold signet rings excavated recently from the Griffin Warrior grave at the Palace of Nestor in Pylos, Messenia (2015).

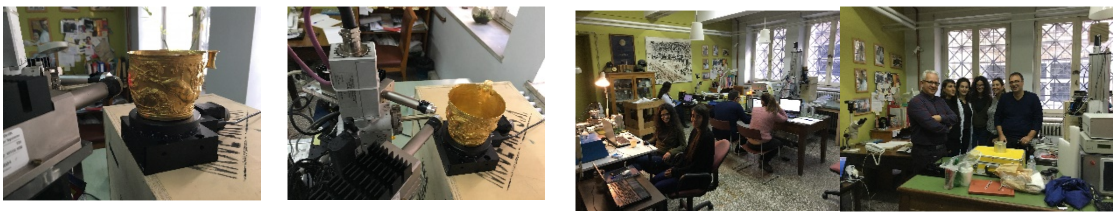


Figure 48: In-situ MA-XRF imaging of important gold Mycenean artefacts exhibited at the National Archeological Museum. In the left two photos the MA-XRF spectrometer probe is shown during the analysis of one of the famous cups from Vafeio, Lakonia.

The portable instrumentation available in the XRF laboratory was utilized in different research projects; just to highlight few of them, silver materials from the Olympia archaeological site including rivets on bronze archaic helmets were characterized in terms of their elemental composition by means of micro-XRF analysis in the framework of the MSc thesis of Rebecca Grethe (May 2018). Also, in collaboration with the Institute of Historical Research at the National Hellenic Research Foundation, wall-painting fragments from the Palace of Nestor were analyzed using the custom developed milli-probe XRF spectrometer at the museum of Chora in Pylos (July 2018), whereas at the archaeological museum of Kalamata the central vitreous bead of a gold necklace, recently excavated from the Griffin Warrior tomb was also examined [**10**].

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

- X-ray spectrometry analytical methodologies (publication [4])
- Environment (publications [5-9])
- Biomedicine (abstracts 1, 2)
- Advanced materials characterization (publication [1])
- X-ray spectrometry instrumentation (publication [1] and abstracts 3, 7, 11)
- Cultural Heritage (publication [10] and abstracts 5, 9, 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.

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
- Nikolas 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
-

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
- 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 LaboratoriNazionali 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. A.G. Karydas, M. Czyzycki, M., J.J. Leani, (...), I. Darby, R.B. Kaiser, "An IAEA multi-technique X-ray spectrometry endstation at ElettraSincrotrone Trieste: Benchmarking results and interdisciplinary applications", Journal of Synchrotron Radiation 25(1), (2018) 189-203, https://doi.org/10.1107/S1600577517016332
2. R. Kaur, A. Kumar, M. Czyzycki, (...), A.G. Karydas, S. Puri, "Synchrotron radiation induced X-ray production cross sections of 66 Dy at energies across its Li (i = 1–3) subshell absorption edges", X-Ray Spectrometry, 47(1), (2018) 11-21, https://doi.org/10.1002/xrs.2800
3. R. Kaur, A. Kumar, M. Czyzycki, (...), A.G. Karydas, S. Puri, "Cascade Mi (i = 1–5) subshell X-ray emission at incident photon energies across the Lj (j = 1–3) subshell absorption edges of 66 Dy", X-Ray Spectrometry 47(4), (2018) 294-304 https://doi.org/10.1002/xrs.2842
4. J.I. Robledo, J.J., Leani, A.G. Karydas, (...), C.A. Pérez, H.J. Sánchez, "Energy-Dispersive Total-Reflection Resonant Inelastic X-ray Scattering as a Tool for Elemental Speciation in Contaminated Water", Analytical Chemistry 90(6), (2018) 3886-3891 https://doi.org/10.1021/acs.analchem.7b04624
5. E. Marguí, M. Hidalgo, A. Migliori, (...), J. Prost, A.G. Karydas, "A first evaluation of the analytical capabilities of the new X-ray fluorescence facility at International Atomic Energy Agency-ElettraSincrotrone Trieste for multipurpose total reflection X-ray fluorescence analysis", Spectrochimica Acta - Part B Atomic Spectroscopy, 145 (2018) 8-19 https://doi.org/10.1016/j.sab.2018.03.016
6. A. Shaltout, M. Harfouche, S.I. Ahmed, M. Czyzycki, A.G. Karydas, "Synchrotron radiation total reflection X-ray fluorescence (SR-TXRF) and X-ray absorption near edge

structure (XANES) of fractionated air particulates collected from Jeddah, Saudi Arabia", Microchemical Journal 137 (2018) 78-84, https://doi.org/10.1016/j.microc.2017.10.001

7. A. Shaltout, S.K. Hassan, A.G. Karydas, (...), P. Wobrauschek, C. Streli, "EDXRF analysis of suspended particulate matter (SPM) from residential and industrial areas in Cairo, Egypt*",* X-Ray Spectrometry, 47(3), (2018) 223-230, https://10.1002/xrs.2830

8. A. Shaltout, S.K. Hassan, A.G. Karydas, (...), P. Wobrauschek, C. Streli, "Comparative elemental analysis of fine particulate matter (PM2.5) from industrial and residential areas in Greater Cairo-Egypt by means of a multi-secondary target energy dispersive X-ray fluorescence spectrometer", Spectrochimica Acta - Part B Atomic Spectroscopy, 145 (2018) 29-35, https://doi.org/10.1016/j.sab.2018.04.003

9. M. Manousakas, E. Diapouli, H. Papaefthymiou, (...), A.G. Karydas, K. Eleftheriadis, "XRF characterization and source apportionment of PM10 samples collected in a coastal city", X-Ray Spectrometry, 47(3), (2018) 190-200, https://10.1002/xrs.2817

10. A.G Karydas, V. Kantarelou and M. Kaparou, "Analysis by portable X-ray Fluorescence of the Central Bead", in "The gold necklace from the Grave of the Griffin Warrior at Pylos", by Jack Davis and Sharon Stocker in Hesperia 87 (2018) 623–632, https://doi.org/10.2972/hesperia.87.4.0611

Abstracts in International Conferences

a. European Conference on X-ray Spectrometry (EXRS2018, 24 June -30 June, Ljubljana, Slovenia)

1. "*Recognition of different types of ovarian cancer tissues by X-ray fluorescence imaging*", by Paweł M. Wróbel, Maria Grzelak, Dariusz Adamek, Łukasz Chmura, Robert Jach, Andreas G. Karydas, Marek Lankosz, Alessandro Migliori

2. "*Comparison of different quantification approaches in X-ray fluorescence imaging of freeze-dried tissue samples*", by P. M. Wróbel, D. Adamek, M. Szczerbowska-Boruchowska, Ł. Chmura, M. Grzelak, R. Jach, A. G. Karydas, M. Lankosz, A. Migliori

3. "*X-ray fluorescence spectrometry beamline at Elettra Sincrotrone Trieste*", by Mateusz Czyzycki, Andreas G. Karydas, Juan J. Leani, Alessandro Migliori, Janos Osan, Mladen Bogovac, Pawel M. Wrobel, Mirta Sibilia, Iva Bozicevic-Mihalic, Mike Kokkoris, Iain Darby, Ralf B. Kaiser and Giuliana Aquilanti

4. "*Optimizing the use of the XMI-MSIM Monte Carlo tool for the simulation of tube excited XRF spectra*", Dimitra Papadopoulou, Vasiliki Kantarelou, Eleni Kokiasmenou, Maria Kontimpa, Tom Shoonjans, Francesco Paolo Romano, Andreas-GermanosKarydas

5. "*pXRF analysis and MA-XRF imaging of Mycenean Wall-Painting pigments from the Nestor's Palace at Pylos*", Eleni Kokiasmenou, Claudia Caliri, Vasiliki Kantarelou, Dimitra Papadopoulou, Maria Kontimpa, Andreas GermanosKarydas, Francesco Paolo Romano, HaricliaBrecoulaki

6. "*Cascade Ge-L X-ray emission enhanced by Resonant Raman Scattering*", **A.G. Karydas**, S. Symeonidi, M. Czyzycki, J. Osan, A. Migliori, M. Kokkoris, S. Puri, D. Sokaras and Ch. Zarkadas, **Oral presentation**

7. "*A mobile Multi-Technique X-Ray scanner for a Real-time 2D and 3D Elemental Imaging of Artworks*", by Francesco Paolo Romano, Claudia Caliri, Andreas GermanosKarydas, Sandra Di Martino, Paolo Nicotra

8. “*Mi (i=1-5) sub-shell X-ray production cross sections at photon energies across the Lj (j=1-3) sub-shell absorption edges of 66Dy*”, by Rajnish Kaur, Anil Kumar, M. Czyzycki, A. Migliori, A. G. Karydas and Sanjiv Puri

b. 5th International Congress Chemistry for Cultural Heritage (CHEMCH 2018, July 3–7 2018 Bucharest Romania, http://www.chemch2018.ro/)

1. “*A systematic evaluation of the PyMca software for the XRF quantification of Cultural Heritage materials*”, Maria Kontimpa, Vasiliki Kantarelou, Dimitra Papadopoulou, Eleni Kokiasmenou, Francesco Paolo Romano, Andreas GermanosKarydas
2. “*In-situ MA-XRF analysis of platinum group element inclusions in Mykenenan gold signet rings*”, Francesco Paolo Romano, Claudia Caliri, Vasiliki Kantarelou, **Andreas GermanosKarydas**, Sharon R. Stocker and Jack L. Davis, **Oral presentation**
3. “*Spatially resolved real time XRF imaging of 2D and 3D objects*”, Francesco Paolo Romano, Claudia Caliri, Andreas GermanosKarydas, Sandra Di Martino, Paolo Nicotra

MSc Diploma Dissertations

1. Eleni Kokiasmenou, "*Portable XRF analysis and MA-XRF Imaging of Mycenaean Wall-Painting Pigments from the Palace of Nestor at Pylos*", Aristotle University of Thessaloniki, Faculty of Engineering, Interdepartmental Program of Postgraduate Studies in Protection, Conservation and Restoration of Cultural Monuments (December **2018**), Supervisor for INPP: A.G. Karydas
2. Rebeca Grethe, “*XRF-analysis of silver objects from Olympia*”, MSc program *«Cultural Heritage Materials and Technologies»* of theDepartment of History, Archaeology and Cultural Resources Management, University of the Peloponnese (**2018**), Supervisor for INPP: A.G. Karydas
3. Dimitra Papadopoulou, “*Protection Conservation and Restoration of Cultural Monuments*”Interdepartmental Program of Postgraduate Studies, Aristotle University of Thessaloniki, **in progress**
4. KalliopiTsampa, National Technical University of Athens, School of Applied Mathematical and Physical Sciences, **in progress**
5. SavvinaFotiou,*»Cultural Heritage Materials and Technologies»* MSc program at theDepartment of History, Archaeology and Cultural Resources Management, University of the Peloponnese, **in progress**

Diploma Student

1. SotiriaSymewnidou, National Technical University of Athens, School of Applied Mathematical and Physical Sciences

Internships

1. Rakhami Fatima azzahra, ENSICAEN, Ecole PubliqueD’ingenieurs Centre de Recherche, France, May-August 2018, Supervisor for INPP: A.G. Karydas
2. M. Kontimpa, January-June 2018, Supervisor for INPP: A.G. Karydas

Funding

The only support that the X-ray spectrometry activity was received was the salary of the head of the group (Andreas Karydas) as a permanent researcher, plus 4 months of postdoc salary (2300 euros per month, before tax and insurance) for Dr. Vicky Kantarelou. Dr. Maria Kaparou has been cooperating with the group on a volunteer basis, whereas Dr. Manos Manousakas was supported by ERL to perform in cooperation with the group environmental research using XRF analysis.

The DAMA Instrumentation Laboratory

Personnel

Permanent Staff:	T. Geralis, G. Fanourakis, G. Stavropoulos
PhD Students:	M. Prapa
Master Students:	K. Damanakis. O. Zormpa
Engineers:	D. Mitrovgenis
Technicians:	I. Kiskiras
Practical Work Students:	E. Logothetis-Agaliotis, V. Blnas, E. Eleftheriou, A. Papaioannou, D. Stasinou, S. Tzanos

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 49: 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 (figure 49)

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 figure 50.

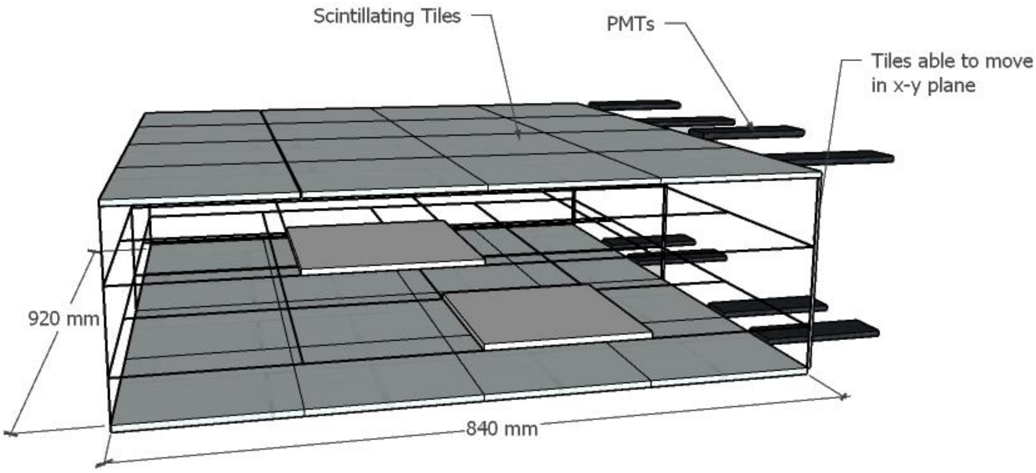


Figure 50: The Cosmic Stand design

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 50) 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.

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 51 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.

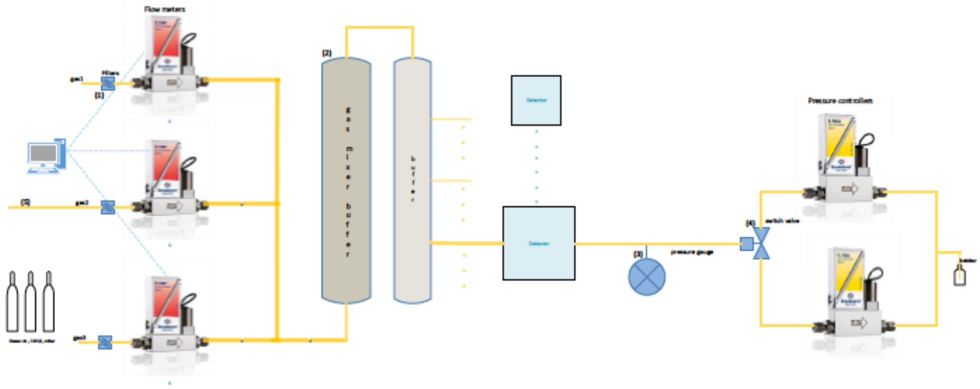


Figure 51: Gas Mixer schematic consisting of three Gas Flow controllers, one gas buffer and two pressure controllers (left).

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 52 the detector layout (top schematic and photos) and two impressive excellent Energy resolution plots taken with these detectors is shown.

The Master Thesis of Chara Giakoumogiannaki studied the segmented mesh in TPC mode using the Feminos Readout System. Figure 53 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 with this data.

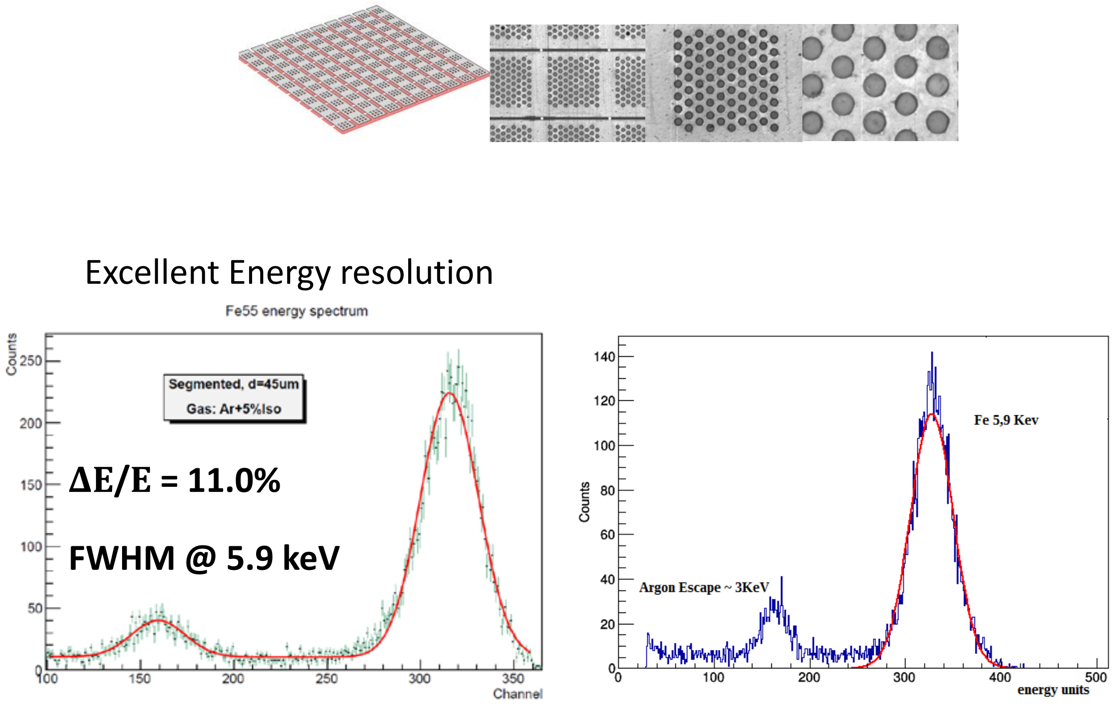


Figure 52: Schematic of the segmented microbulk (upper-left), Photos (upper-right), energy spectra of two types of microbulk with strip pitch of 1mm (lower - left) and 700μm (lower - right)

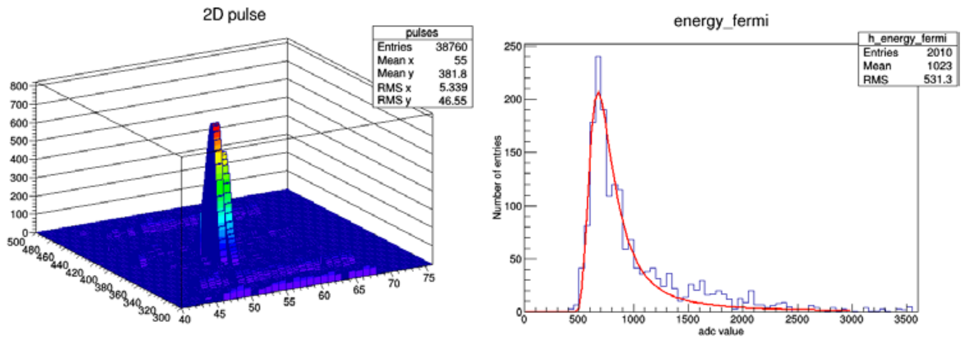


Figure 53: Operation of the microbulk in TPC mode. Pulse of nearby strips in cosmic muon event (left) and the corresponding Landau distribution (right).

The performance for the energy resolution is impressive and reaches an optimum for a gaseous detector of 11% FWHM at 5.9 keV.

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 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.

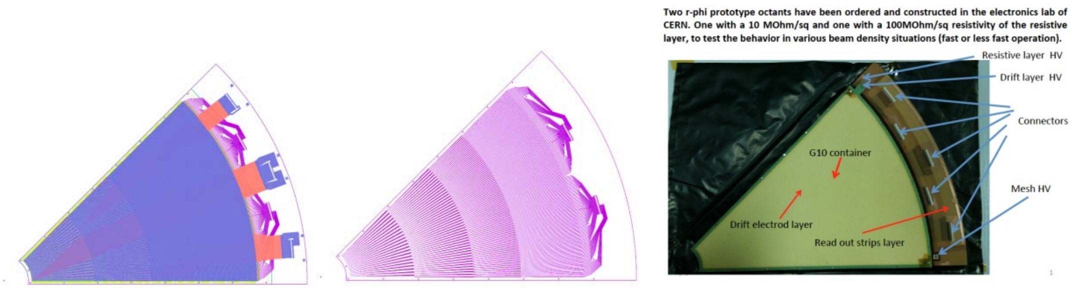


Figure 54: The r-φ Micromegas prototype developed by the INPP group.

This design is made by the INPP group and first prototypes are produced (see Figure 54) 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 were 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.

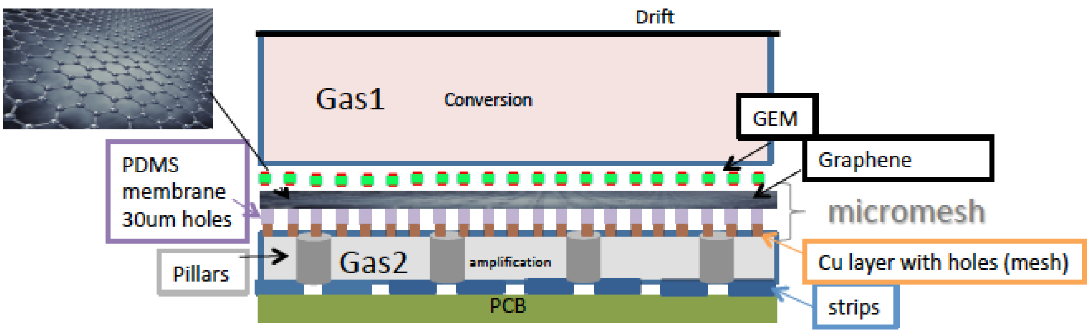


Figure 55: Conceptual design of a Micromegas using micro-fabrication techniques and graphene.

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*

The Detector Instrumentation Laboratory (DIL)

Personnel

Permanent staff:	D. Loukas
	A. Kyriakis
PhD Students:	P. Asenov
	P. Asenov
Electrical Engineers:	I. Kazas
	A Papadopoulos

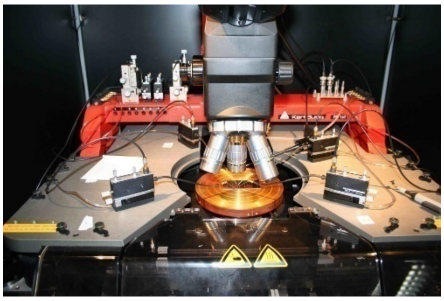
Summary: The Laboratory of Detector Instrumentation is working within INPP and promotes applied aspects of research work on *Micro Scale Assembly and Packaging of Detector Systems*.

Main research topics: Design and development of solid-state detectors (primarily Silicon and CdZnTe) and associated electronics, for spectroscopic and digital imaging applications, instrumentation for High Energy Physics, Astrophysics, Crystallography and Medical science.

Infrastructure:

- Semiautomatic wire bonding machine: Delvotec 5430
- Automatic probe station: Carl Suss P150
- SMD work and rework station: (Fritsh HS 905 &VS925)
- Design tools (Cadence, Sentaurus, OrCaD)
- Electrical Characterization equipment: (HP 4192A, KEITHLEI 6517A)
- Desiccator-Nitrogen-purged low-humidity storage system (TERRA UNIVERSAL)
- Climatic Chamber

Figure 56 presents the basic equipment of the laboratory.



Automatic Probe Station

Electrical Characterization Equipment

Wire Bonder

Climatic Chamber

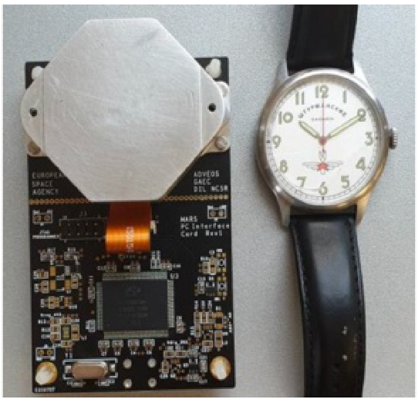
Figure 56: The basic equipment of the Detector Instrumentation Laboratory

***Activities during 2018*:**

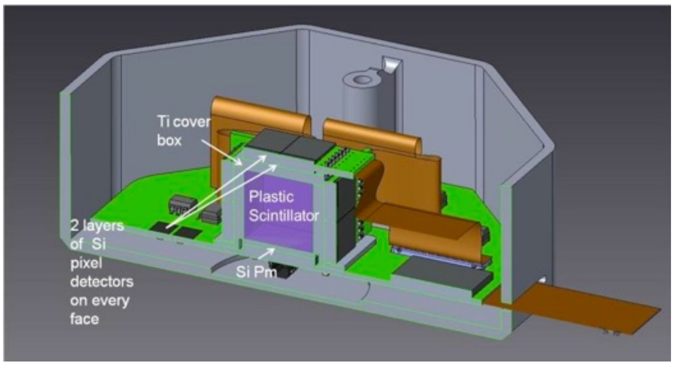
The research activities of the laboratory during 2018 were unfolded across the CMS Phase II Silicon Tracker development and the ESA MIDAS project. The CMS activities of the lab are described in the section of the report associated with the CMS experiment. In what follows are described the activities in the framework of the MIDAS project.

MIDAS is a miniature detector developed with purpose to assess the radiation field parameters near to an astronaut. Part of the device is a spectrometer for fast neutrons. In missions outside the geomagnetic field, fast neutrons are secondary products of the interaction of Galactic Cosmic Ray heavy ions with the materials in the spaceship or even the astronaut body. The Relative Biological Effectiveness of fast neutrons is high. The neutron spectrometer first prototype has been developed, calibrated and used for measuring 252Cf spectra.

The first prototype of the device can be seen in figure 57(a). The conceptual design of the current prototype can be seen in figure 2(b). The core of the device is the "sensitive cube". It consists of a plastic scintillator with neutron/gamma discrimination capability enclosed in a titanium box 1 mm thick. The scintillator dimensions are 7 x 7 x 7 mm3 and its bottom face is connected to a silicon photomultiplier (SiPM) to collect the light signal. The five of the six external surfaces of the titanium box are covered by two layers of silicon pixel sensors. The aluminum enclosure is 1 mm thick, except from a circular area on the top and bottom cover with 0.5 mm thickness, with purpose to let 10 MeV protons reach the detector.



(a)



(b)

Figure 57: (a) The first prototype of the detecting head mounted on a custom data acquisition board. (b) Cross section view of the conceptual design of the second prototype.

The building block of the charged particles measurement system is a depleted monolithic active pixel sensor (DMAPS). Monolithic active pixel sensors (MAPS) (i.e. pixel detectors in which the signal processing electronics reside on the pixel together with the sensing diode) are constructed in standard or dedicated complementary metal oxide semiconductor (CMOS) commercial fabrication processes. They exploit as the sensing volume an epitaxial layer grown on top of the lower quality substrate wafer. The thickness of this layer is usually several μm and the transistors are constructed on top of it. In MAPS the charge generated by the interaction of a passing charged particle with the epitaxial silicon layer is collected mostly by diffusion. Thus, the signal collection is slow and trapping centers created due to the crystal radiation damage can capture the moving charge carriers and render the pixel insensitive to radiation. DMAPS exploit new developments in CMOS fabrication processes: The so-called high voltage add-ons introduced by semiconductor foundries for automotive and power management applications. They use a deep implant layer, some μm below the silicon surface in order to isolate devices placed on top of it. This deep implant layer can be used as collection electrode of a reverse biased diode. The substrate below the deep implant layer can be fully depleted up to a thickness of tens of μm depending also on its resistivity which can be quite elevated (in our case we are using wafer with resistivity 2500 Ohm·cm). In DMAPS charge is collected by drift and for this reason it is fast and much more radiation tolerant. The detection principle in the fabrication technology chosen for MIDAS can be seen in figure 58.

The silicon active pixel detectors of the MIDAS dosimeter have been designed using the LFoundry 150 nm HVCMOS technology and wafers with resistivity of 2 kΩ·cm. The HVCMOS industrial process permits the integration of special transistors, withstanding up to 120 V, with standard low voltage CMOS transistors (1.3 V – 1.8 V). Key element of the technology is the floating logic: A group of PMOS and NMOS transistors can be electrically isolated from the lightly doped p-substrate by a deep n-well. Depending of the technology, the deep n-well can sustain up to 120 V or even more. This implies depletion layers between 15 μm – 100 μm around the deep n-well. By using the p-substrate as the main charge generation region and the isolation deep n-well layer as the charge collection electrode, while the front-end electronics lie on top of the isolation layer, a monolithic detector of charged particles is constructed. It differs from the previous generation of active pixel sensors in two ways: The one is that the circuitry resides on top of the diode and the other is that the charge is collected by drift. The sensor structure is either imported from the gds file of the actual mask layout or it is reproduced with an editor of the Sentaurus TCAD tools suite. The arithmetic solution of the Poisson and the continuity equations as well of additional physical processes were done with the sdevice program using the finite elements method. The snmesh programs were used for the mesh construction. The electrical field inside the sensor, the depletion depth, the leakage current and collection of the charge liberated from an impinging ionizing particle are treated with the "simple device" mode of sdevice. Capacitance calculations are done with the "mixed device" mode, which includes circuit capabilities and interface with SPICE. The 2D simulator of Sentaurus is based on the assumption of a symmetric structure and simulates a device in one plane supposing a device depth of 1 μm. Scaling to the third dimension of the device is done with parameterization.

Figure 59 (left) shows the pixel geometrical dimensions (110 μm x 110 μm) with the perimeter of the deep n-well area (~ 55 μm x ~ 55 μm) that encloses the region where the electronics are placed. Figure 59 (right) shows a cross section along the line AA'. Figure 60 (Top left) shows a detailed cross section along half-length of the line AA'. For a substrate of 2 kΩ·cm and a bias voltage of -30 V, applied to the upper side of the wafer, the depletion region extends up to 60 μm (figure 60, upper right). The leakage current is of the order of 200 pA for biases up to 400 V for a volume of 110 μm x 110 μm x 100 μm. The deep n-well to p-substrate capacitance is ~30 fF while the capacitance between the deep n-well and the psub, which is the enclosed region where the electronic circuitry is developed, is of the order of 1pF. This capacitance poses the main obstacle in the design of low noise electronics and for that reason we resorted to special techniques for signal processing. Current waveforms for various impact points are shown in the bottom of figure 60. Particles crossing the pixel in the borders of the deep n-well result in faster charge collection due to the higher electrical field in these regions. Bottom left of figure 60 shows the waveforms for mip LET = 1.28 x 10^{-5} pC/μm and bottom left for heavy ion LET = 0.1 pC/μm.

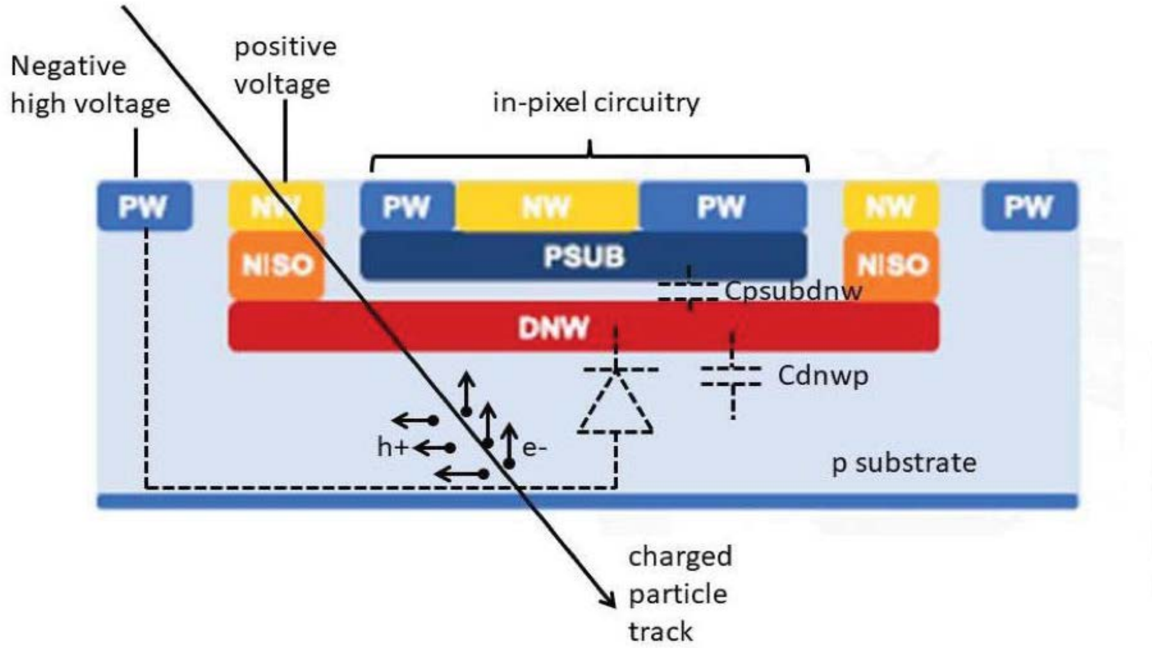


Figure 58: *Schematic cross section of a pixel fabricated using the LFoundry 150 nm process with High Voltage add-on. The deep n type well (DNW) forms a revere biased diode with the p type substrate which is biased at negative voltage (e.g. -28 V). On top of the deep n type well a p type buffer layer (PSUB) provides isolation of the DNW from the transistors placed in the shallow p and n type wells. The charge released in the p substrate drifts towards the DNW which acts as the collecting electrode.*

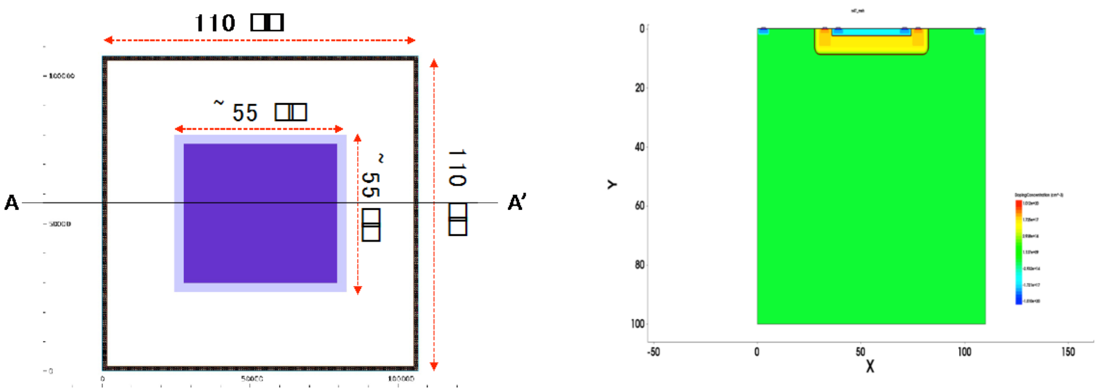


Figure 59: *(Left) The sensor part of the pixel as extracted from the gds masks. (Right) Cross section of the pixel along the line AA' for a detector thickness of 100 µm.*

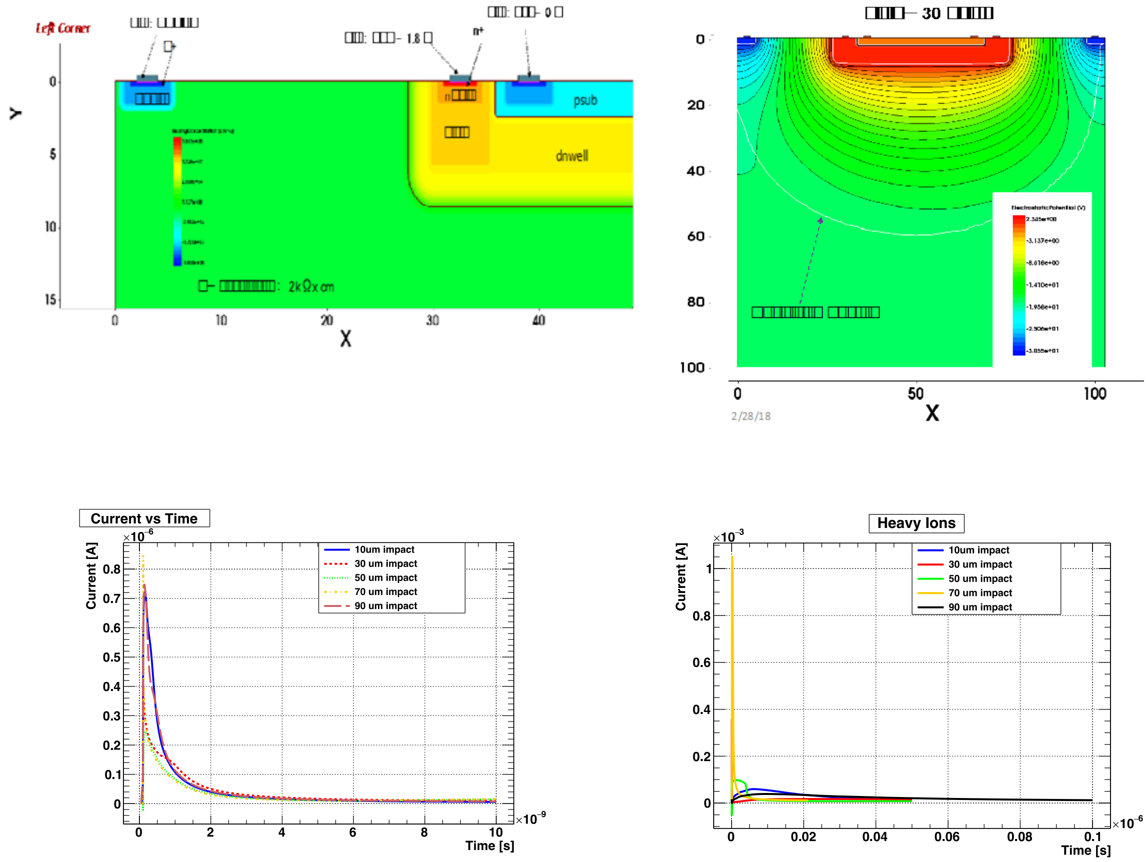


Figure 60: (Top left) Detailed structure of a pixel (electronics omitted) along half-length of line AA'. (Top right) Potential lines and depletion region for a bias of -30 V. (Bottom left) Current waveforms for various impact points of a mip (Bottom right) Current waveforms for various impact points of heavy ions.

TANDEM Accelerator

Permanent Staff: Sotirios V. Harissopulos, Anastasios Lagoyannis, Michail Axiotis (September 2018-), Vassilios Andreopoulos, Emmanuel Tsopanakis

Chief Operator: Miltiadis Andrianis

PhD Students: Kostas Preketes-Sigalas, Eleni Ntemou

MSc Students: Eleni Alavanou, Euthimios Daoulas

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, although it has just started its implementation several works have been carried out and presented below.

New instruments and hardware upgrades in 2018

Beamlines

During the last years and in the near future to come, the experimental setups of the lab have increased resulting in lack of beamlines to host them. In order to overcome this problem, it has been decided to build a new beamline, the R15 in the green experimental hall, along with the relocation of some of the experimental setups, in order to protect sensitive detectors and to create "dedicated" beamlines according to the line of research. In this context the new R15 beamline will host the new summing NaI(Tl) detector, along with relocated from the red experimental hall γ-ray angular distributions setup. During 2018, the group has extended the R15 beamline and has reallocated "Neoptolemos" the new 4πsumming crystal.

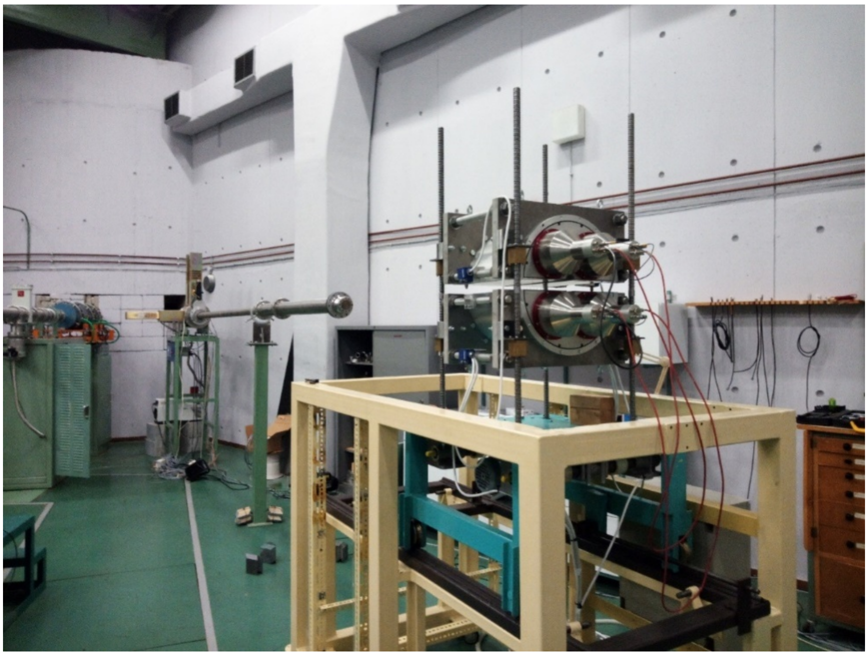


Figure 61: "Neoptolemos" in its new position at the R15 beamline

Instruments

The Experimental Nuclear Physics group of INPP has developed a technique, the 4πγ-summing method, in order to measure capture reactions cross-sections relevant to nuclear astrophysics. This method, that to-date has been used by the group to conduct experiments at the 12"x12" NaI(Tl) single crystal detector of the Dynamitron Tandem Laboratorium (DTL) of the University of Bochum, Germany, is based on the ability of a large volume NaI(Tl) crystal to sum photons up to 15 MeV, or even more with high efficiency. In order to make in-house experiments with better efficiency, a 14"x14" NaI(Tl) segmented in two parts crystal has been acquired by the lab. One of the crucial things on this kind of studies is the determination of its efficiency which depends on the energy of the summed photons along with their multiplicity. During 2018 the characterization of the detector has started by creating a detailed Geant4 detector description in order to simulate the detector's response.

Furthermore, in order to assist the nuclear astrophysics experiments, by an independent measurement of the multiplicity of a reaction, the GASP's BGO Ball has been transferred to the lab. The setup consists of 80 BGO crystals in a spherical geometry covering 80% of the solid angle. It has been decided to install the GASP's BGO Ball to the R60 beamline and the members of the lab have started to set up the supporting structure of the detectors.

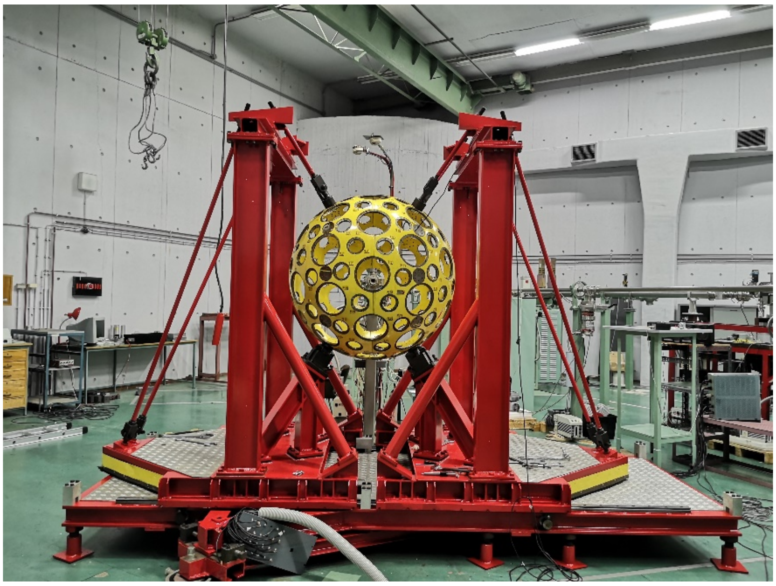


Figure 62: GASPAR's supporting frame in position

X-Ray Fluorescence Laboratory (XRF)

The X-ray Fluorescence (XRF) laboratory is a unique infrastructure for Greece dedicated to 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. The activities of the XRF laboratory (http://www.inp.demokritos.gr/xrf/) are focused towards:

1. The study of fundamental X-ray interactions with matter and de-excitation processes of ionized atoms
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 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
4. Training of undergraduate and MSc students

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 detailed information about the facilities of the XRF laboratory can be found at the following link: http://www.inp.demokritos.gr/xrf/facilities/.

During 2018, the XRF laboratory supported exclusively one (1) diploma work of NTUA undergraduate student and the MSc thesis of five (5) students as listed previously, two (2) from the Interdepartmental Program of Postgraduate Studies, "*Protection Conservation and Restoration of Cultural Monuments*", Aristotle University of Thessaloniki, two (2) from the *«Cultural Heritage Materials and Technologies»* MSc program at the Department of History, Archaeology and Cultural Resources Management, University of the Peloponnese and one (1) from the MSc program of National Technical University of Athens, School of Applied Mathematical and Physical Sciences

In addition, from May-August 2018, an under-graduate student from ENSICAEN, France worked as an intern on the evaluation of the analytical performance of a newly acquired silicon drift detector.

Using the laboratory portable XRF instrumentation, several *in-situ* XRF campaigns were conducted during 2018 aiming to different research objectives, but also in support of analytical services:

1. Archaeological Museum of Olympia (MSc diploma, research, silver objects, figure 63)
2. Archaeological Museum of Chora in Pylos (research, wall-painting fragments)
3. Archaeological Museum of Kalamata (research, Mycenaean bead of a gold necklace, figure 64)
4. Archaeological Museum of Kalymnos (research, polychromy on an archaic statue, figure 65)
5. Archaeological Museum of Vravrona, Attiki (analytical services, Mycenaean copper artifacts, figure 66)

Figure 63: The portable micro-XRF spectrometer during the analysis of silver rivets on copper helmets at the storage room of the Archaeological museum in Olympia (May 2018). Work performed in the framework of the MSc thesis of Rebecca Grethe

Figure 64: The milli-probe XRF spectrometer during analysis of the central bead of a gold necklace excavated from the Griffin Warrior grave by a team of the University of Cincinnati. Archaeological museum of Kalamata (July 2018)

Figure 65: Andreas Karydas during in-situ hand-held XRF measurements of the remaining polychromy on an archaic statue

Figure 66: The micro-XRF spectrometer at the conservation laboratory of the Archaeological museum of Vravrona during the analysis of copper-based Mycenaean artefacts

Applications

Aristometro – A portable device to detect the concentration of oleocanthal and oleacein in olive oil.

Over two thousand years ago, Hippocrates and Dioscorides referred to early harvest olive oil as medicinal. Modern science has identified the polyphenols, or more accurately phenolic compounds, that are health protective and continue to research the effectiveness of these phenols for the prevention and treatment of many of today's chronic illnesses, including heart attack and stroke, high blood pressure, rheumatoid arthritis, obesity, Alzheimer's, Parkinson's, Type II Diabetes and cancer. It is well known that most illness is the result of inflammation and it is the phenolic compound Oleocanthal that is known for its anti-inflammatory properties. Oleocein is a known antioxidant. These compounds are only found in olive oil. In 2012, the EU made a health claim labeling regulation 432-2012. In it is stated that olive oils with polyphenols over 250 mg/kg can put a health claim on the label as it reduces LDL oxidation. In the same year, Dr. Prokopios Magiatis and Dr. Eleni Melliou of the University of Athens discovered a method to accurately measure individual phenolic compounds in olive oil using NMR (Nuclear Magnetic Resonance). The following year they invented a test kit to measure the combined phenolic compounds Oleocanthal and Oleacein. In the heart of this test kit stands the Aristometro, a specially designed and built by INPP, portable spectrometer to detect the concentration of oleocanthal and oleacein in olive oil.

The developed spectrometer succeeded a remarkable performance and gained the first prize of competition "INNOVATION & ENTREPRENEURSHIP 2018" in olive oil sector.


OLIVECHALLENGE
OLIVECHALLENGE

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 an 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 2018 the following PhD and MSc degrees **have been awarded**:
  - Martinou Maria Andriani, PhD, *D. Bonatsos*
  - Papagrigoriou Evaggelos, MSc ,*M. Axenides*
  - Sinopoulou Anna, MSc ,*K. Tzamariudaki*
  - Giakoumogiannaki Chara, MSc, *T. Geralis*
  - Kokiasmenou Eleni, MSc, *A. Karydas*
  - Rebeca Grethe, MSc, *A. Karydas*

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

  - Katsinis Dimitrios, PhD, *M. Axenides*
  - Asenov Patrick, PhD, *D. Loukas*
  - Assiouras Panagiotis, PhD, *D. Loukas*
  - Preketes-Sigalas Konstantinos, PhD, *A. Lagoyannis*
  - Demou Eleni, PhD, *A. Lagoyannis*
  - Laoutaris Aggelos, PhD, *A. Lagoyannis*
  - Polideuki Georgia, PhD, *C. Markou*
  - Tzanetatos Dimitrios, PhD, *C. Markou*
  - Panagopoulos Vasilieos, PhD, *C. Markou*
  - Pikounis Kostantinos, PhD, *A. Tzamariudaki*
  - Sinopoulou Anna, PhD, *A. Tzamariudaki*
  - Asimakis Ioannis, PhD, *D. Bonatsos*
  - Sarantopoulou Smaragda, PhD, *D. Bonatsos*
  - Paspalaki Garyfallia, PhD, *A. Kyriakis*
  - Prapa Maria, PhD*, T. Geralis*
  - Tsanko Dimiter, PhD, *K. Papadopoulos*
  - Syrrakos Nikolaos, PhD, *K. Papadopoulos*
  - Stavropoulos Dimitrios, MSc, *A. Tzamariudaki*
  - Bligoura Natalia, MSc, *A. Lagoyannis*
  - Anagnostou Georgia, MSc, *C. Markou*

- Papadopoulou Dimitra, MSc, *A. Karydas*
- Fotiou Savvina, MSc, *A. Karydas*
- Damanakis Kostantinos, MSc, *T. Geralis*
- Zorba Olga, MSc ,*T. Geralis*

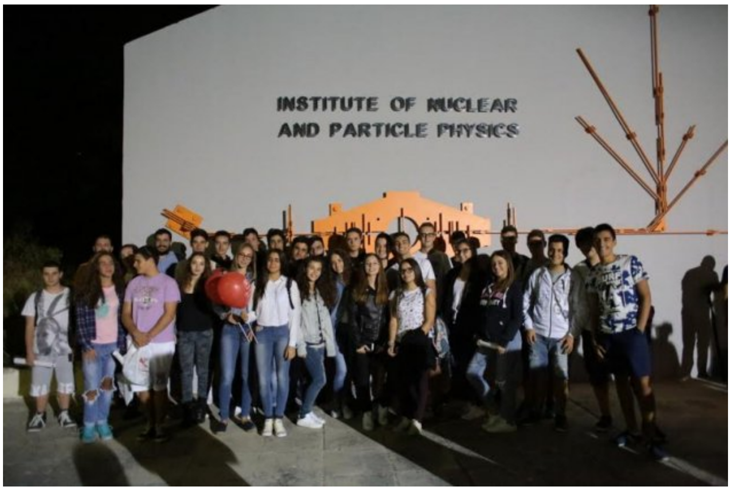
- INPP, through agreements with Universities in Greece, supervise and guide undergraduate students during their Diploma thesis as well as their practical training. Students are trained by participating to the research projects of the Institute in order to acquire a training certificate (about 1-3 months training) or a diploma thesis needed for their graduation (about 6 months training). During 2018 fifteen (15) undergraduate students were trained from the INPP researchers.
    - Kanellos Nikolaos, Practical Training, *D. Loukas*
    - Anagnostopoulou Vasiliki, Practical Training, *A. Lagoyannis*
    - Salpadimos Nikolaos, Diploma thesis, *A. Lagoyannis*
    - Egglezos Panagiotis, Practical Training, *C. Markou*
    - Chatzistavrou Theodoros, Practical Training, *C. Markou*
    - Anastasiou Grigorios, Practical Training, *C. Markou*
    - Zarpapis George, Practical Training, *A. Tzamariudaki*
    - Kontiba Maria, Practical Training, *A. Karydas*
    - Rakhami Fatima Azzahra, Practical Training, *A. Karydas*
    - Blanas Vasilios, Practical Training, *T. Geralis*
    - Eleutheriou Evaggelia, Practical Training, *T. Geralis*
    - Logothetis-Agaliotis Eustathios, Practical Training, *T. Geralis*
    - Tzanos Stamatios, Practical Training, *T. Geralis*
    - Papaioannou Athanasia, Practical Training, *G. Stavropoulos*
    - Stasinou Despina, 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. This action has been already organized for three consecutive years, 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 2018, 125 students from 19 schools of Attica participated. 8 students were selected. In September 2018, 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 Master classes for high school students. The international particle physics master classes are workshops organized by the International Particle Physics Outreach Group (IPPOG, http://ippog.org/). The Master classes 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 master class, 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 master class 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.

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

- In 2018 the “Greek Researcher’s Night” was held at the National Center for Scientific Research “Demokritos” in the beginning of October. 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.

Apart from 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.

- <u>Complex Systems and Applications(C.O.S.A.)</u>

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, no 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":25^{th} school,2018<u>http://complexity2018.demokritos.gr/index.php/el/</u>
3. COSA seminars on "Nonlinear Science and Complexity"