Accelerator laboratory of the **Ruđer Bošković Institute**

Laboratory for ion beam interactions
Division of experimental physics,
Zagreb, Croatia

Scientific: Milko Jakšić, Tonči Tadić, Iva Bogdanović Radović, Zvonko Medunić, Stjepko Fazinić

Development: Natko Skukan, Mladen Bogovac,

Postgraduate students: Željko Pastuović, Zdravko Siketić, Marko Karlušić,

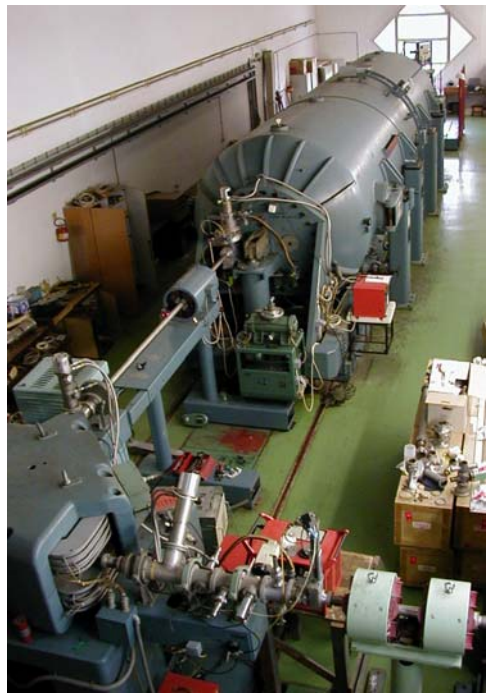
Technical: Andrija Gajski, Željko Periša

Others: Hideshi Muto,

History of accelerators at the **Ruđer Bošković Institute**

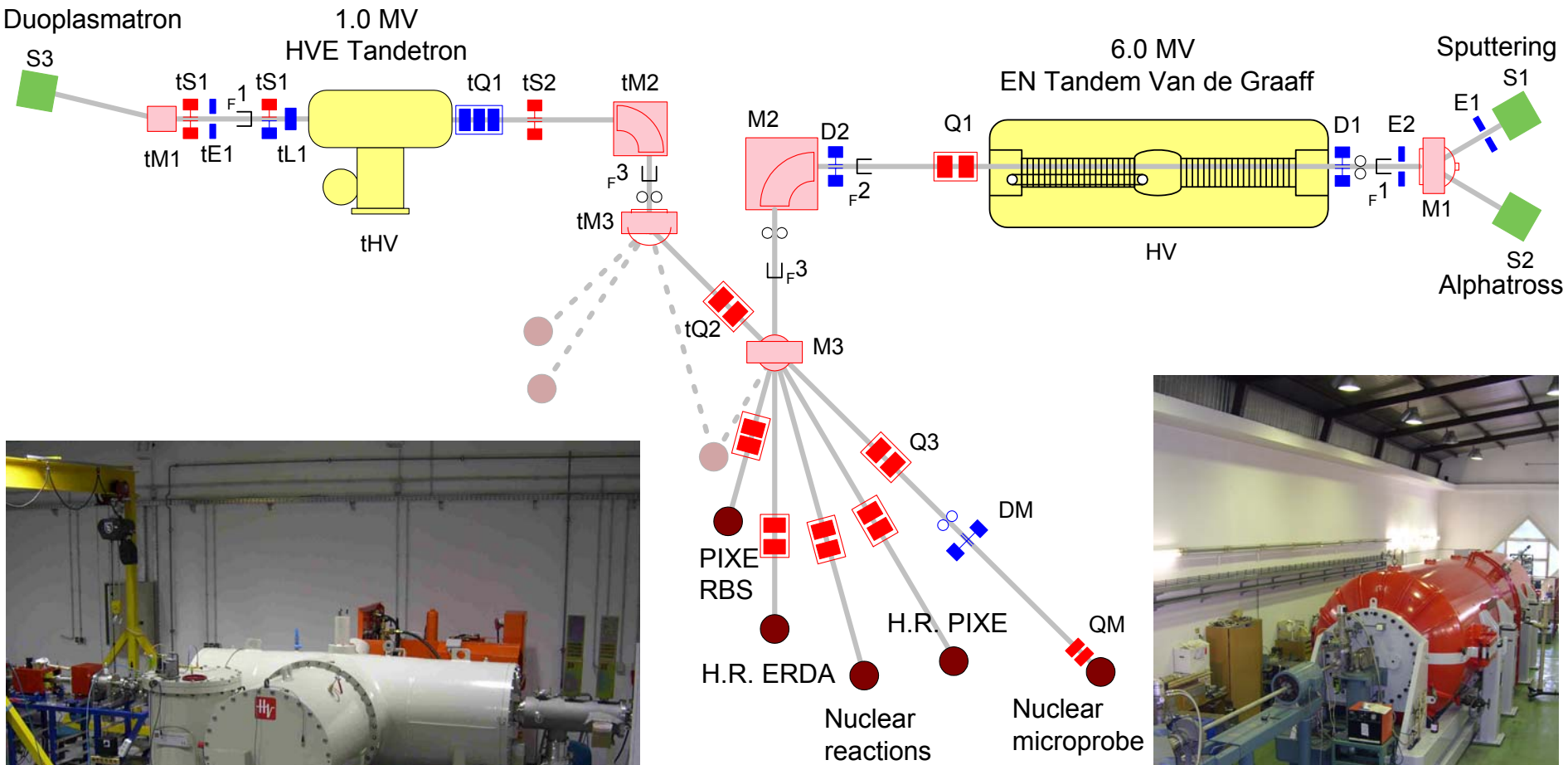
1956.
200 keV
neutron generator

1962.
Cyclotron
(20 MeV deuterons)



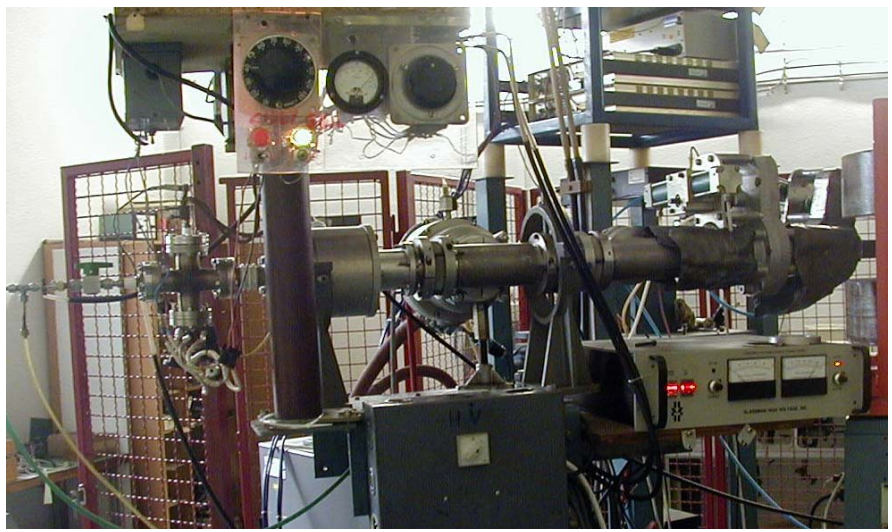
1987 Tandem van de Graaff

Accelerator laboratory – today



• 6.0 MV EN Tandem Van de Graaff

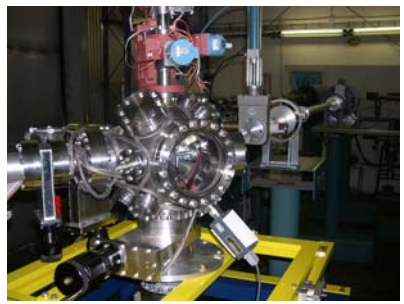
- 1963 – 1984 Rice University, Houston, Texas
- Since 1987 in routine operation in Zagreb
- Two ion sources – Alphatros (H, He), sputtering (Li, C, O,....)
- Five beam lines

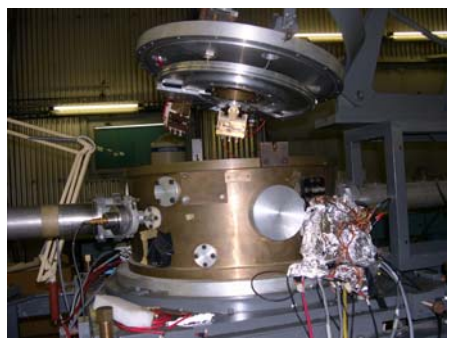


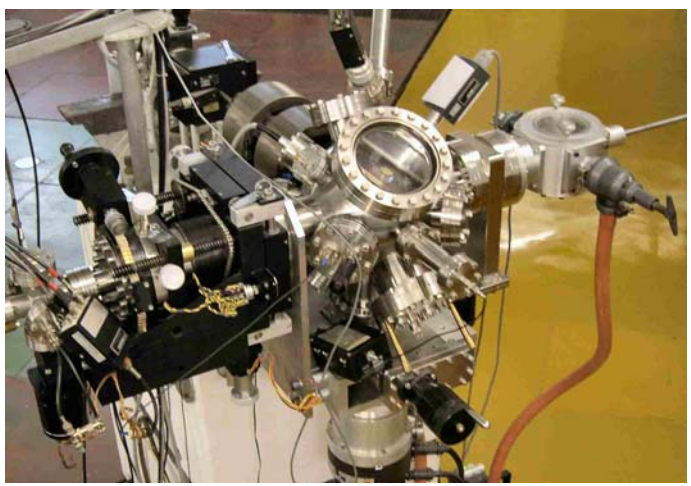
• Beam lines

- Existing beam lines of EN Tandem accelerator

1. IAEA beam line - routine PIXE/RBS
2. TOF ERDA
3. Nuclear reactions chamber
4. High resolution PIXE / ion implant.
5. Nuclear microprobe

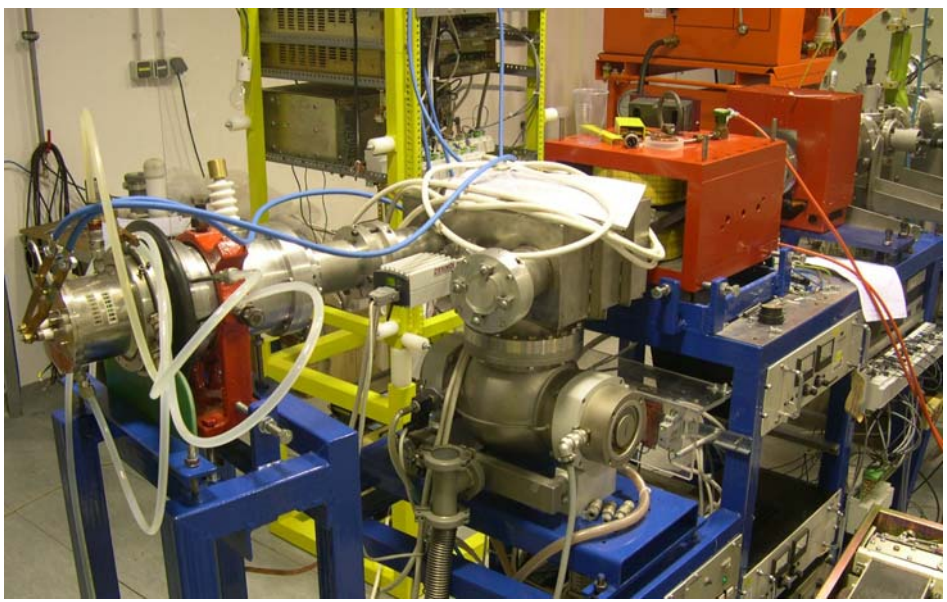


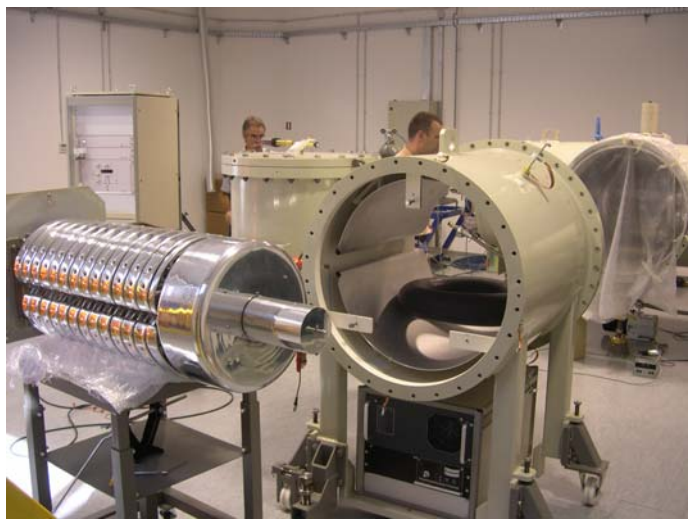




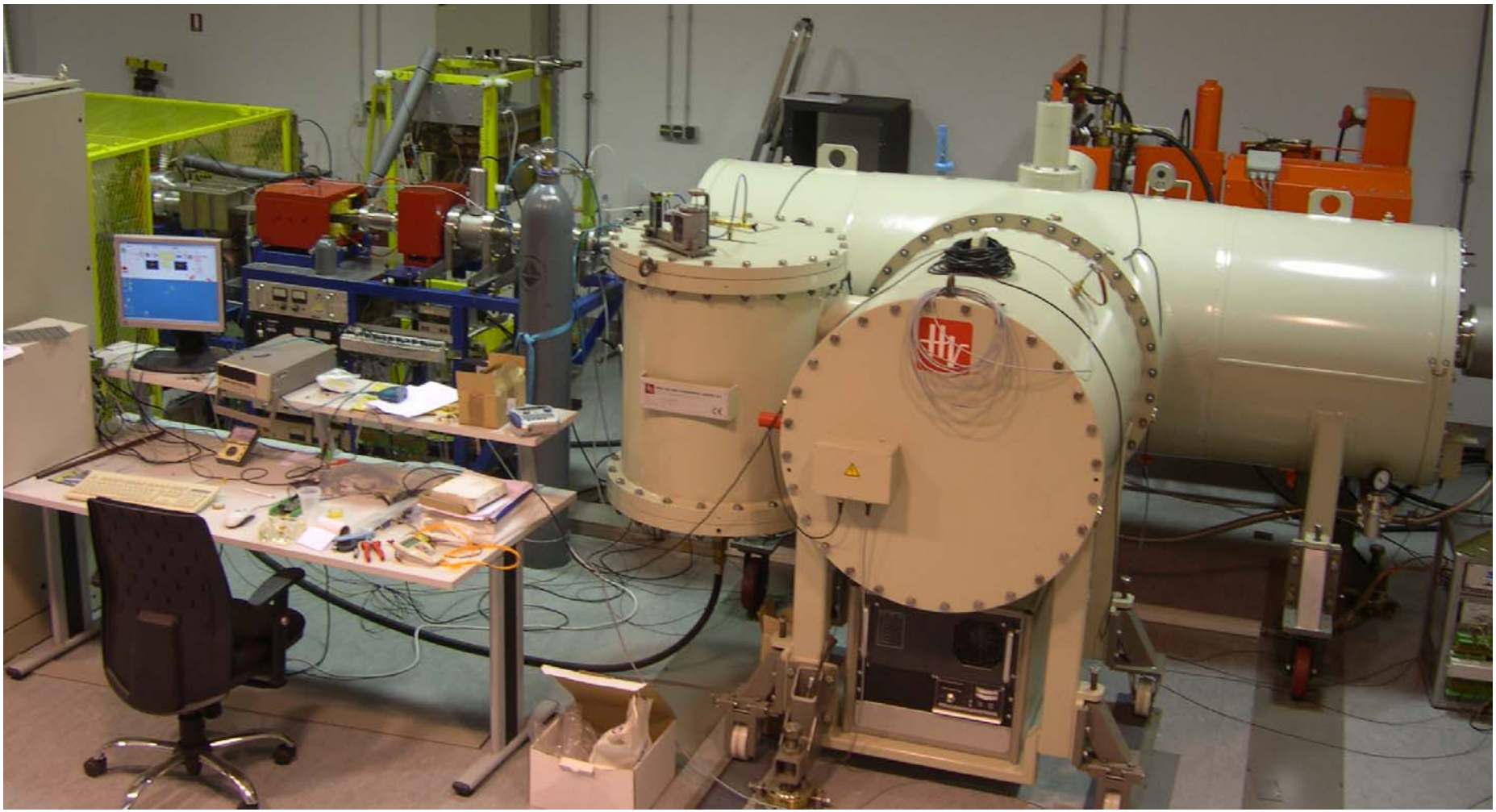
• 1.0 MV Tandetron

- High Voltage Engineering, The Netherlands
  (funded by Ministry of science of Croatia and IAEA)
- Direct extraction duoplasmatron ion source
- Sputtering ion source (planned for 2006)
- Terminal voltage range 0.1 – 1.0 MV, high stability,
  beam currents up to 50 μA



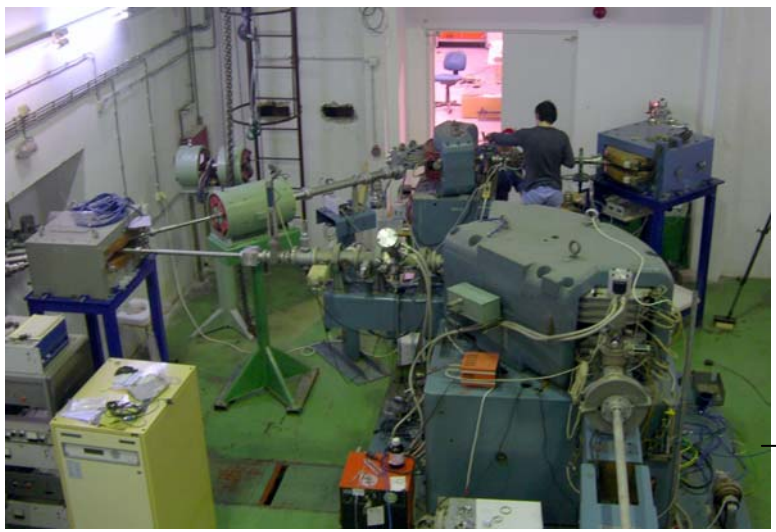


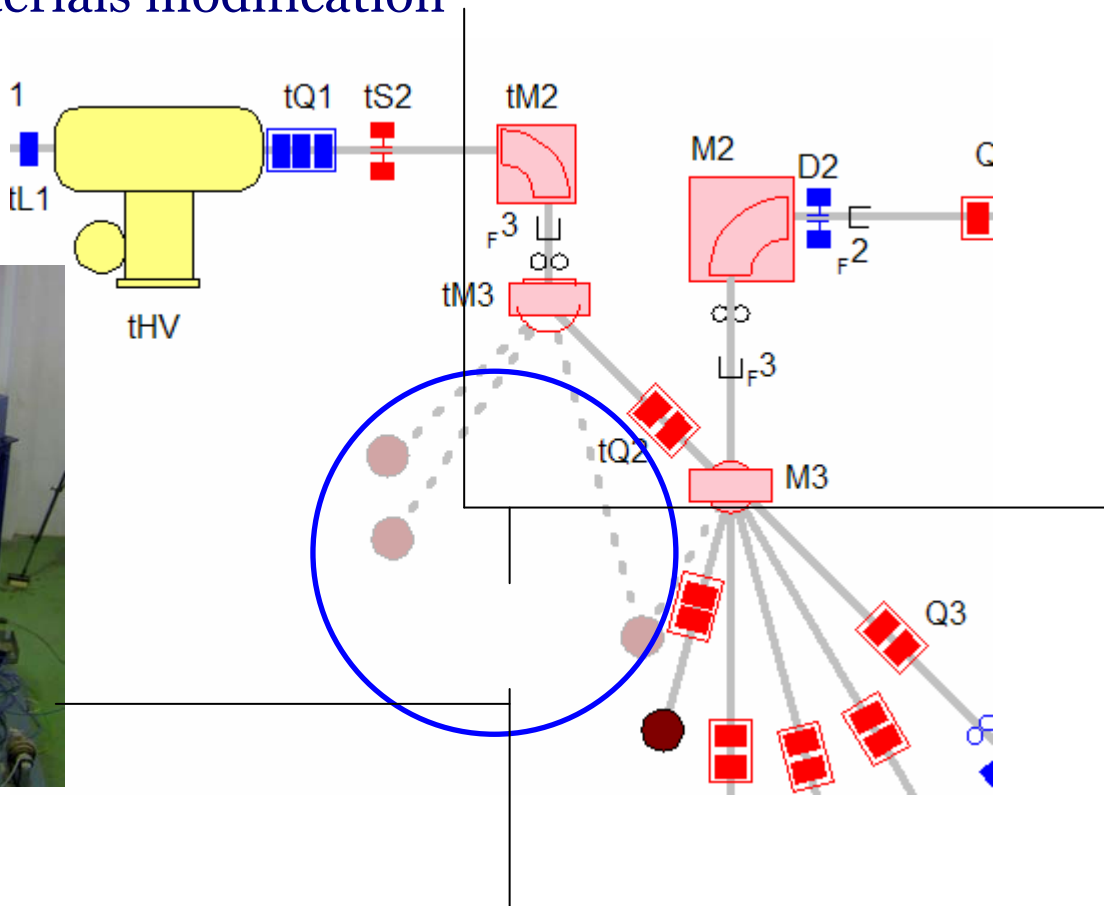
• 1.0 MV Tandetron



• Tandetron beam lines (plans)

- External beam for cultural heritage objects
- New microprobe for heavy ions / low energies
- Two beams chamber for materials modification

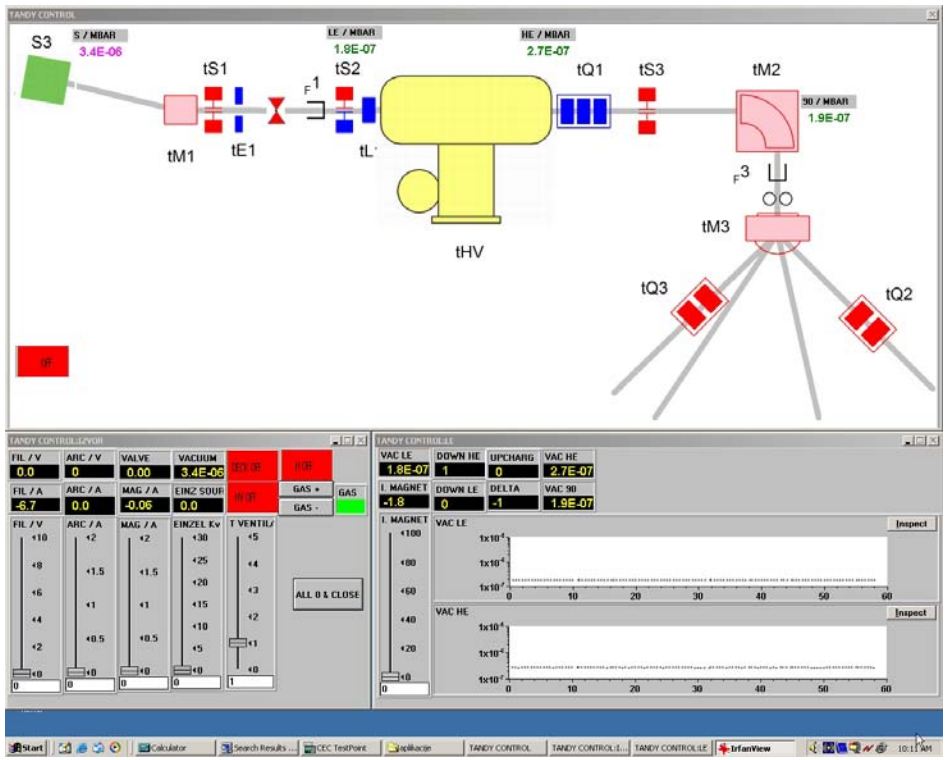




1. New developments

- ACCEL6 & ACCEL1 – accelerator computer control
- Beam optics calculation
- Calculation of electric field distribution
- SPECTOR – data acquisition and sample positioning
- Remote experiments
- New scattering chambers (microprobe and TOF ERDA)

Computer control – ACCEL6 for EN Tandem Van de Graaff and ACCEL1 for Tandetron accelerator



Natko Skukan – IRB
Dejan Đurđenić - Dilogic

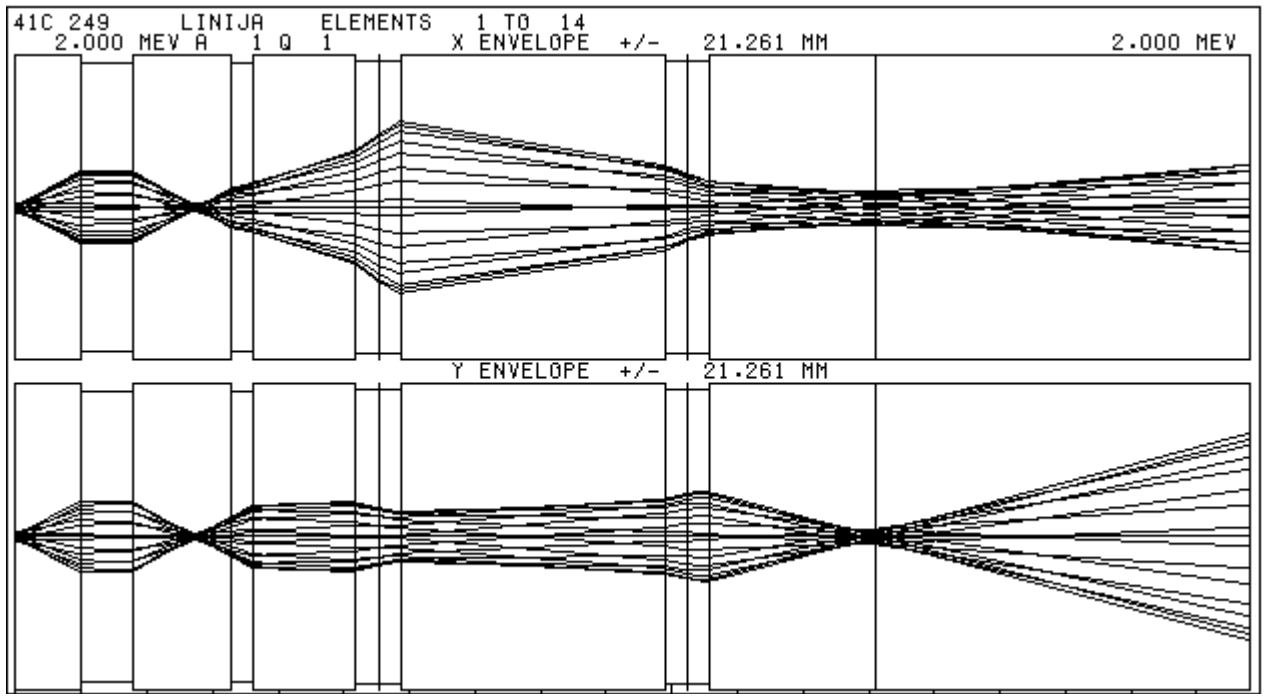
- 16 bit AD/DA modules (8 AD, 8DA) (controls for ion sources, accelerator and beam optics system)
- 8 digital inputs, 8 digital outputs
- Controls are based on TESTPOINT

Capabilities:
Remote control (from remote computers)
Reads beam optics parameters from previous experiments
Calculates changes of parameters for change of energy and/or ion
Security interlock system

Beam optics calculations –
for ion beam from Tandetron to nuclear microprobe

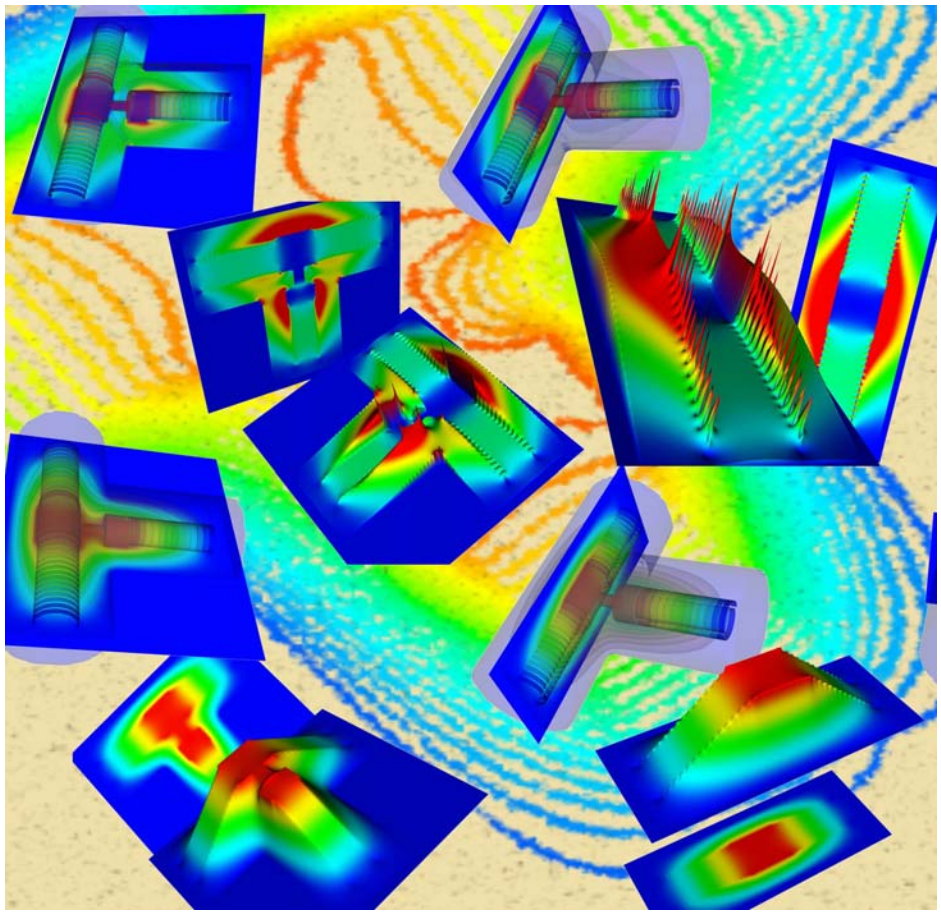
Marko Karlušić

ion beam from Tandetron accelerator



90° mag. sw. mag. quad.1 quad.2 obj. slits

The Robin Hood method – a novel **numerical method** for **electrostatic problems** based on a non-local charge transfer



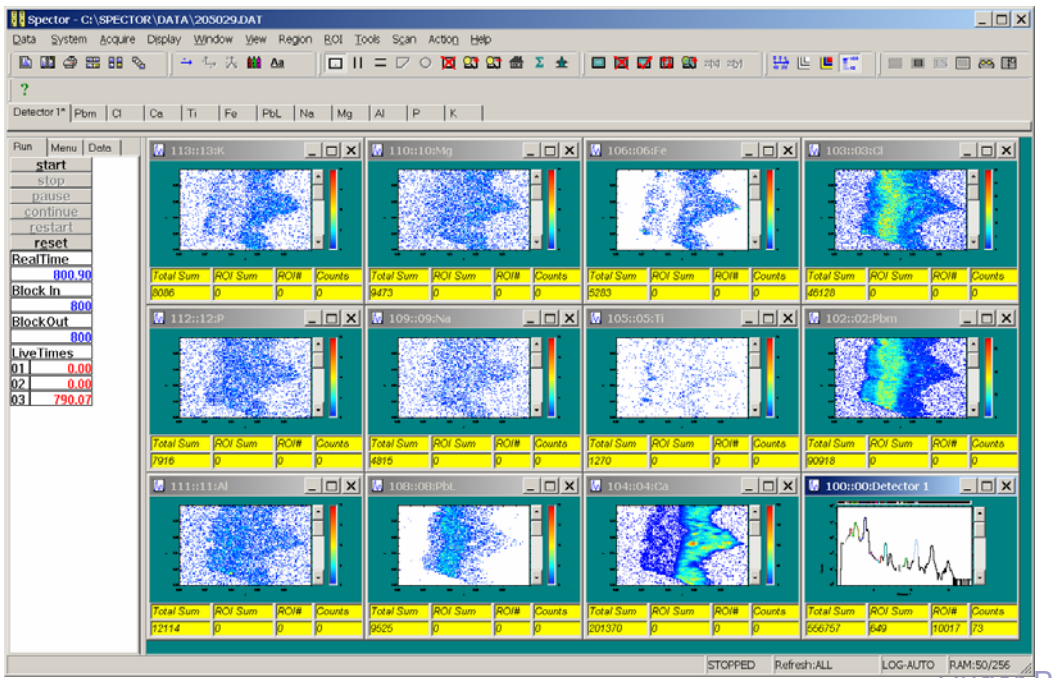
P. Lazić, H. Štefančić, H. Abraham
Theoretical Physics Division

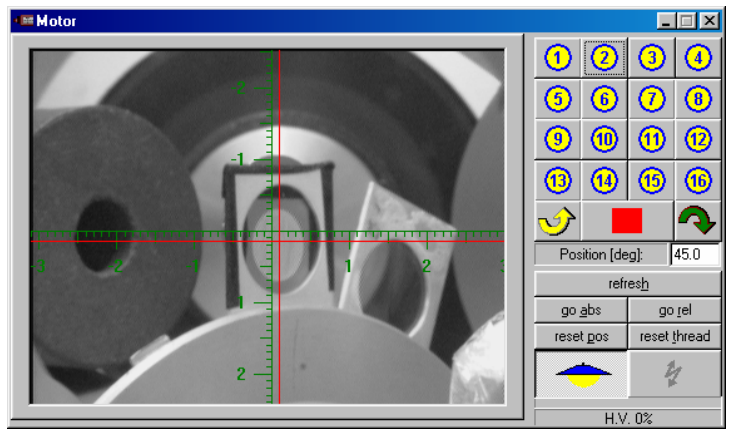
Article available on line at:
http://xxx.lanl.gov/abs/physics/0411192

Solution of electric field and potential with 1.0 MV
inside the Tandteron tank

SPECTOR –
Data acquisition /target positioning & beam scanning software

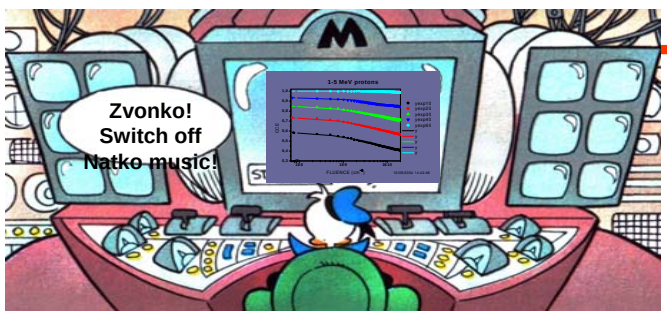
Mladen Bogovac





Long distance accelerator experiment –
In colaboration with INFN & Universita di Torino

N. Skukan, M. Bogovac



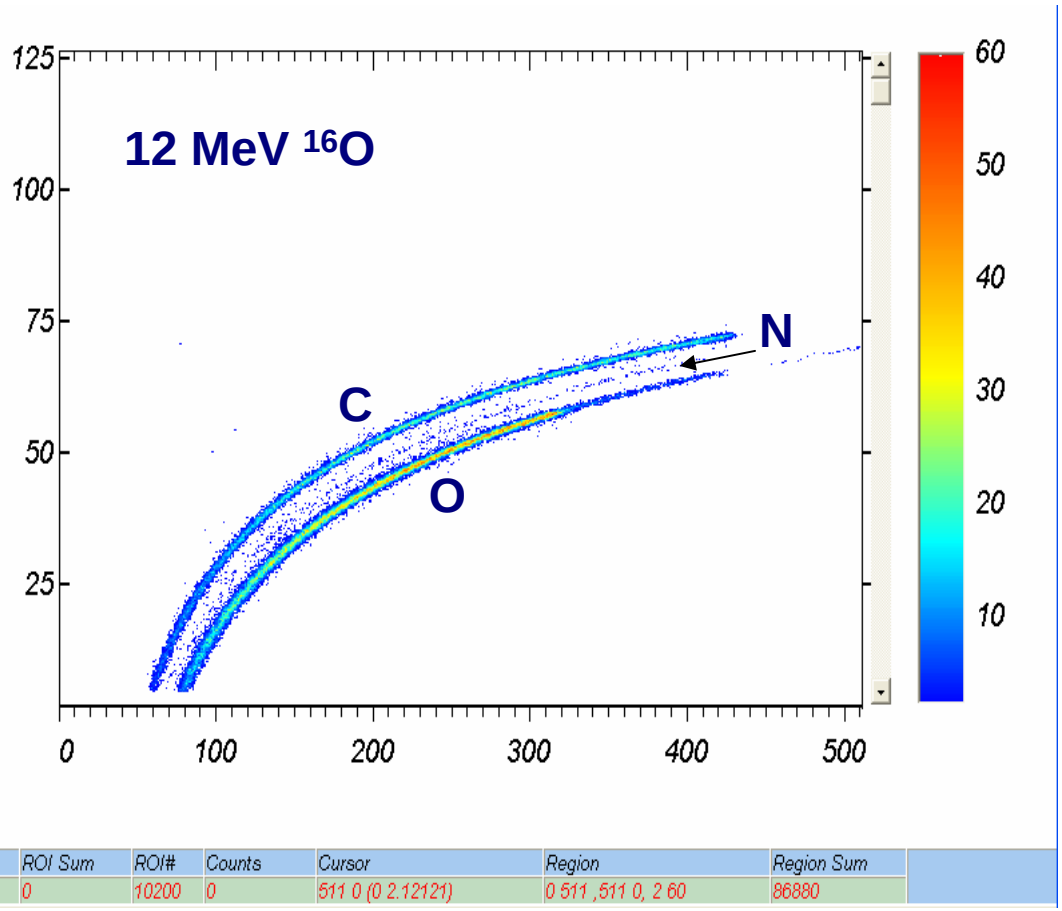
WEB

New microprobe scattering chamber

Z. Medunić, M. Jakšić, A. Gajski

TOF ERDA system

Z. Siketić, I. Bogdanović Radović, A. Gajski

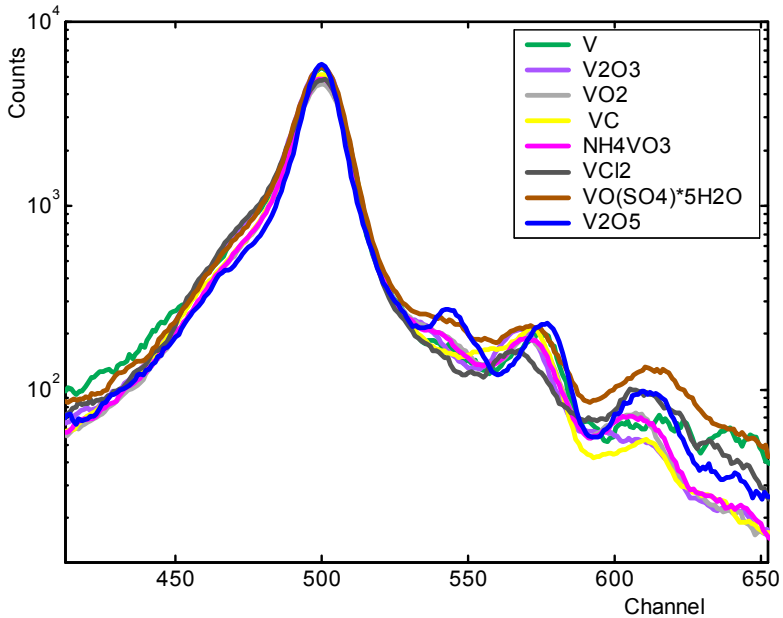


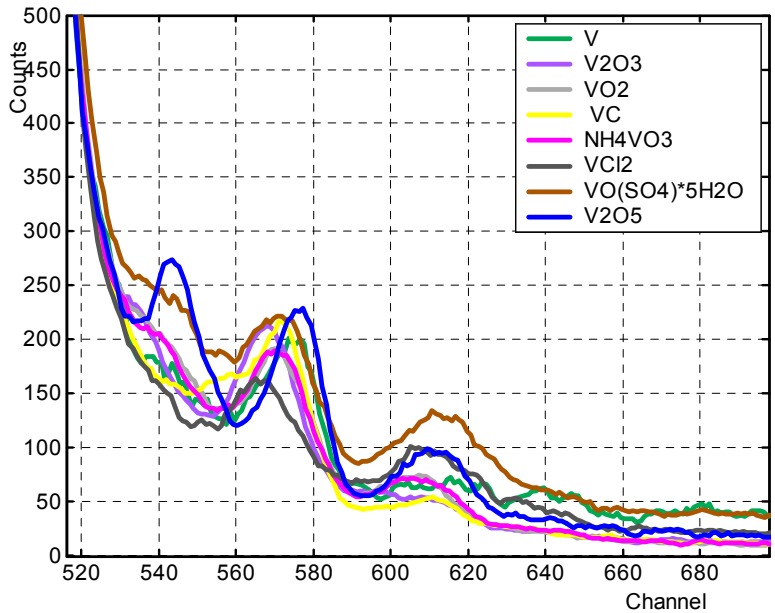
2. Research highlights

- Basic research in nuclear and atomic physics
  1. Light nuclei nuclear reactions
     (Laboratory for nuclear reactions - Đ. Miljanić et al)
  2. Inner shell ionisation, chemical effects
  3. Elastic scattering of light ions, data base
- Materials science and applications
  1. Transport of charge carriers – characterisation/modification
  2. Analysis of thin films (RBS &ERDA) with nm depth resolution
  3. Modification of insulators
- Analytical applications
  1. Cultural heritage objects – HRZ
  2. Technological projects (cement, solar cells)
  3. Air polution monitoring
  4. Other analytical services

• Basic research

- Inner shell ionisation – x-ray spectroscopy
  - ☻ chemical effects in Kβ line of Vanadium





• Basic research

- Elastic scattering of light ions
  - ☻ 2.0 to 6 MeV Li^7 ion beam on hydrogen

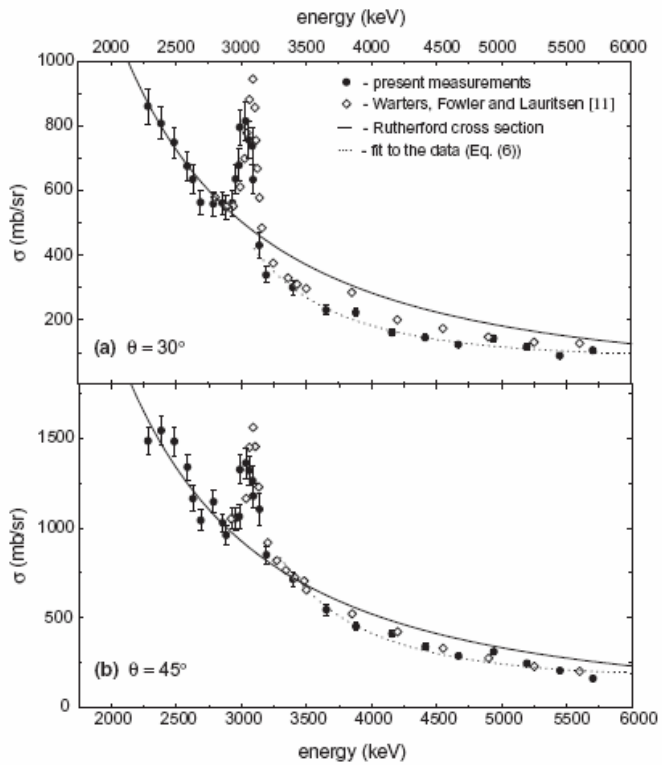
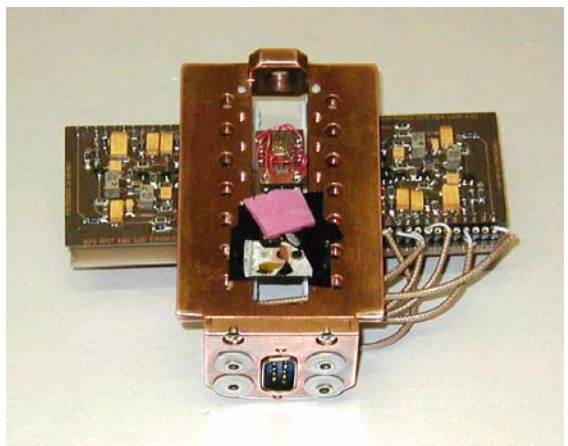


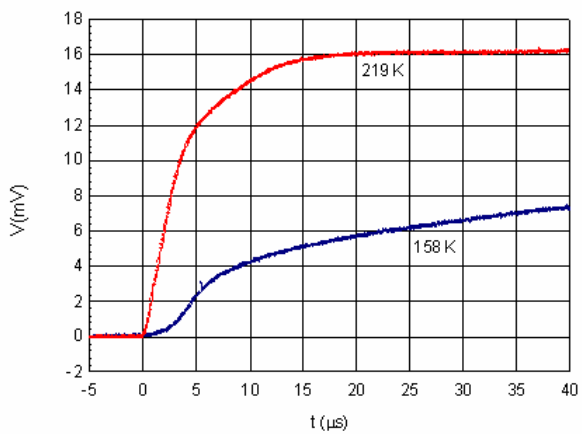
Fig. 2. Energy dependence of the H recoil cross-section (mb/sr) for (a) $\theta = 30°$ and (b) $\theta = 45°$. (●) – present measurements, (◊) – Warters et al. [11]. The solid lines represent the Rutherford cross-sections, and the dotted lines represent fit to the data (Eq. (6)).

• Materials science

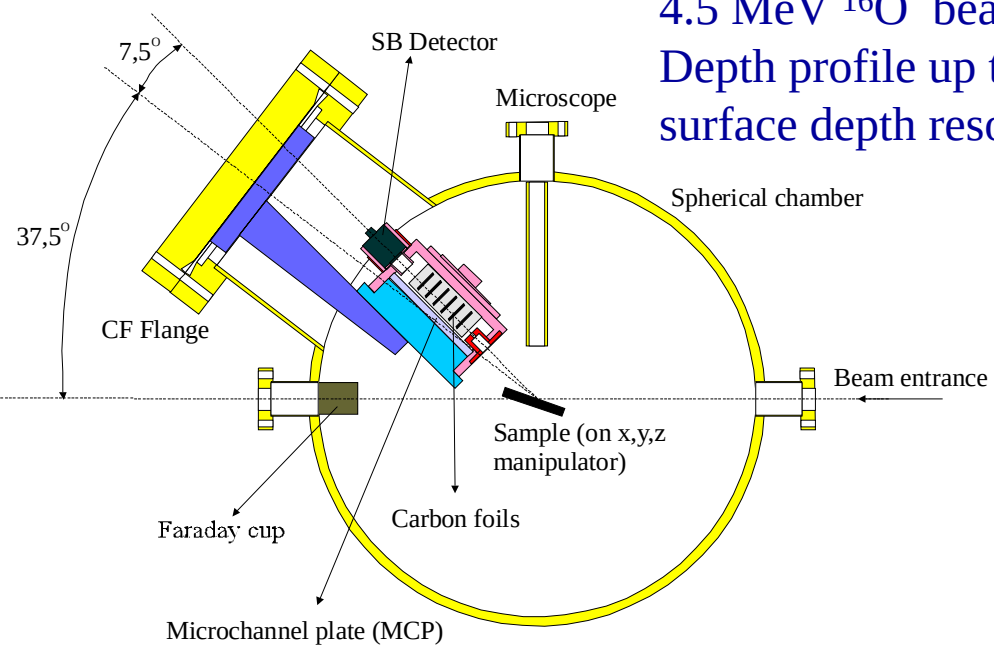
- **Thin film analysis – depth profiling – for nm depth resolution**
  - ☻ RBS Rutherford backscattering – beam of protons, He, Li, C ions
    (nm depth resolution with grazing incidence, or TOF system)
  - ☻ ERDA - IEE system for H only & 3D on nuclear microprobe (O beam)
    - TOF system for other elements (I, Au beam)
    - ☻ ion implantation

- **Study of Charge Transport properties** by Time Resolved and Temperature dependent Ion Beam Induced Charge

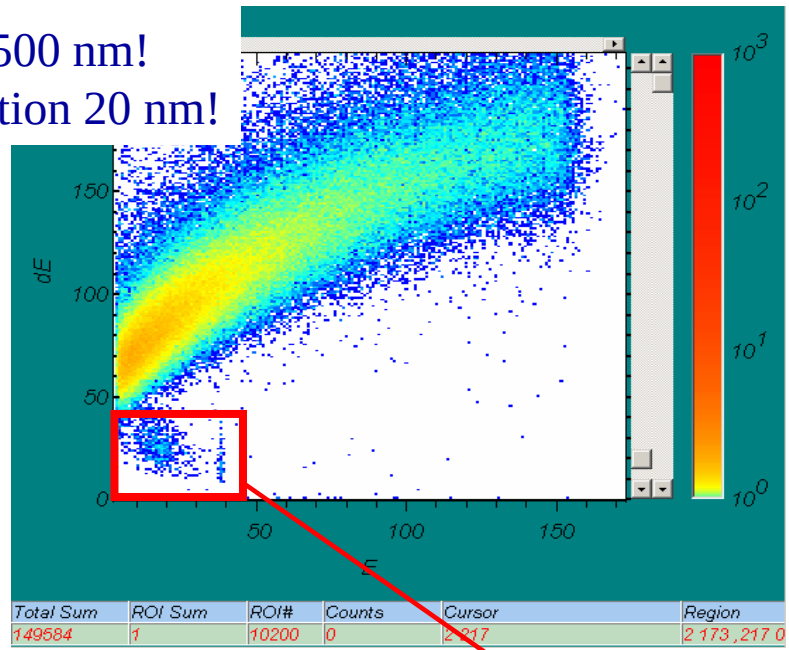


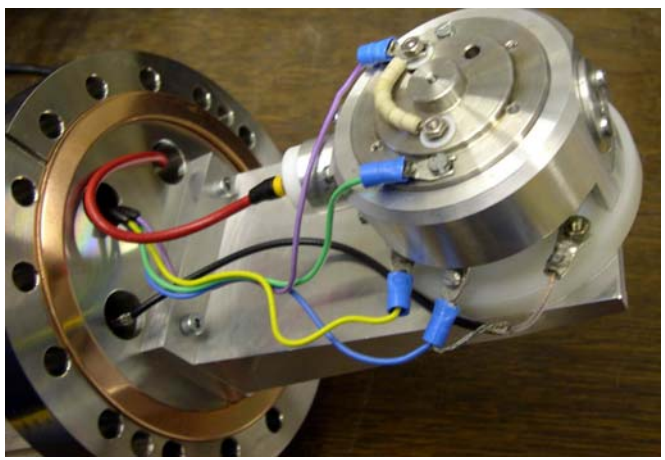


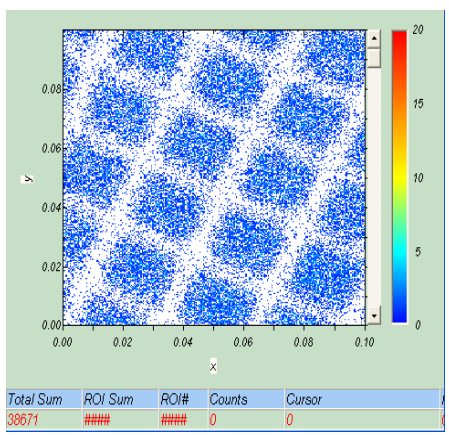
• Thin film analysis – IEE ERDA for hydrogen

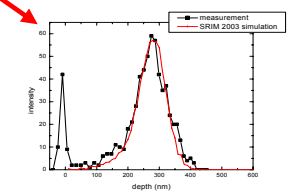


4.5 MeV ^{16}O beam
Depth profile up to 500 nm!
surface depth resolution 20 nm!



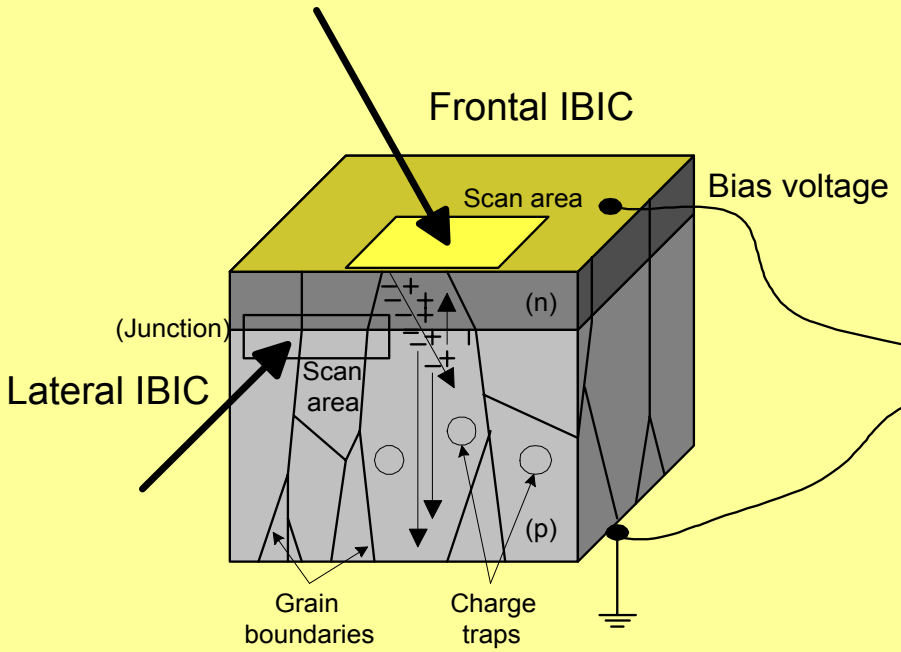






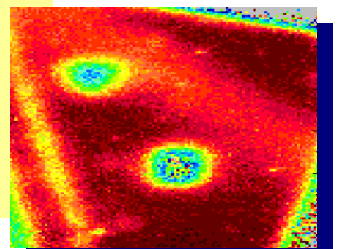
2D distribution
of hydrogen
at 300 nm depth
Scan 500 x 500 µm

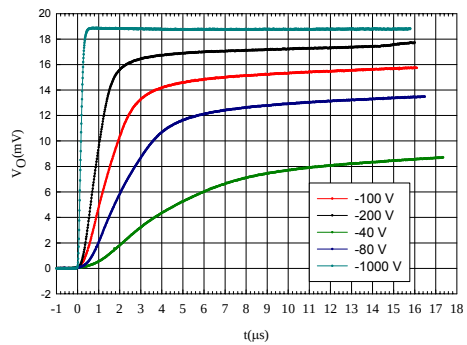
• Study of Charge Transport properties – IBIC technique



Lost Charge
- trapping, detrapping
- recombination (radiative - IL)
- polarisation
- grain boundaries, dislocations, strains,...
- Contacts, dead layers

IBIC pulse



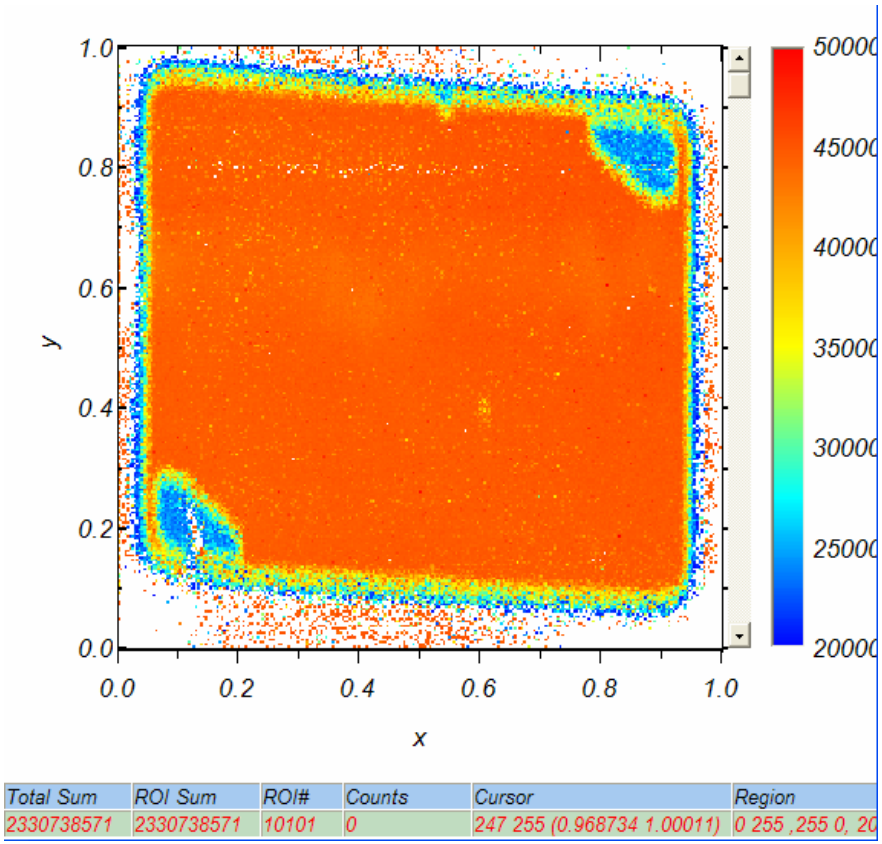


Lateral IBIC
- contribution of both charge carriers
- electric field profile

Frontal IBIC
- short range - surface dead layers
- long range – defects, impurities

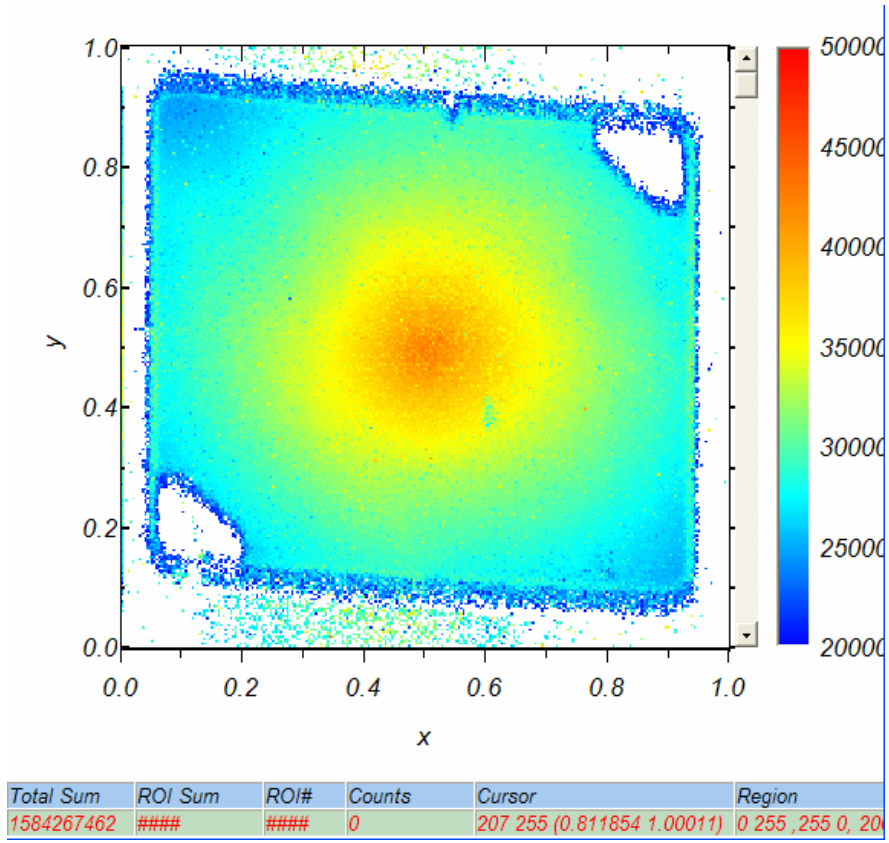
Time Resolved IBIC

- **IBIC analysis of Si pin diodes**
  - ☻ **position dependent radiation damage by 4 MeV O ions**



Total Sum	ROI Sum	ROI#	Counts	Cursor	Region
2330738571	2330738571	10101	0	247 255 (0.968734 1.00011)	0 255 ,255 0, 20

Before irradiation



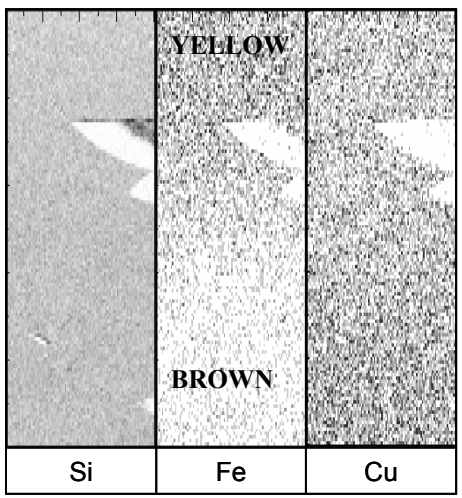
Total Sum	ROI Sum	ROI#	Counts	Cursor	Region
1584267462	####	####	0	207 255 (0.811854 1.00011)	0 255 ,255 0, 20

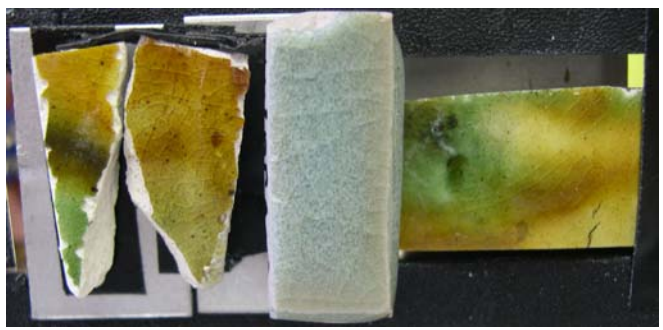
After irradiation

• Applications

Routine analysis will be done in future using Tandetron accelerator !

- **Nuclear microprobe PIXE analysis for cultural heritage (IAEA TC project)**
  - ☻ St. Marko church portal restoration (with HRZ)
  - ☻ XVII century peinter Master HGG (Hans Georg Geiger) SLO/HR cooperation
  - ☻ Chinese porcelain (bilateral project with Beijing)
  - ☻ Other objects (alloys, pigments, ceramics, porcelain, etc)

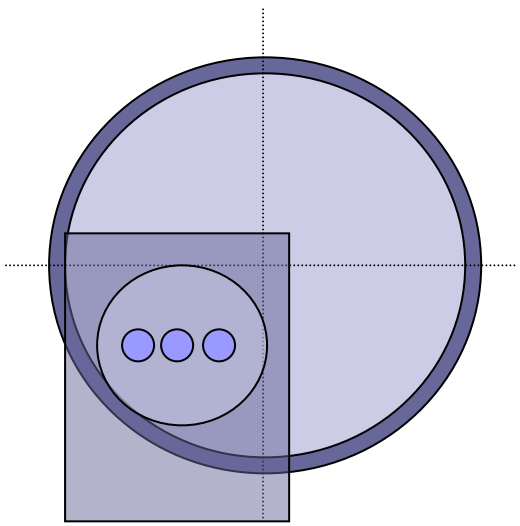


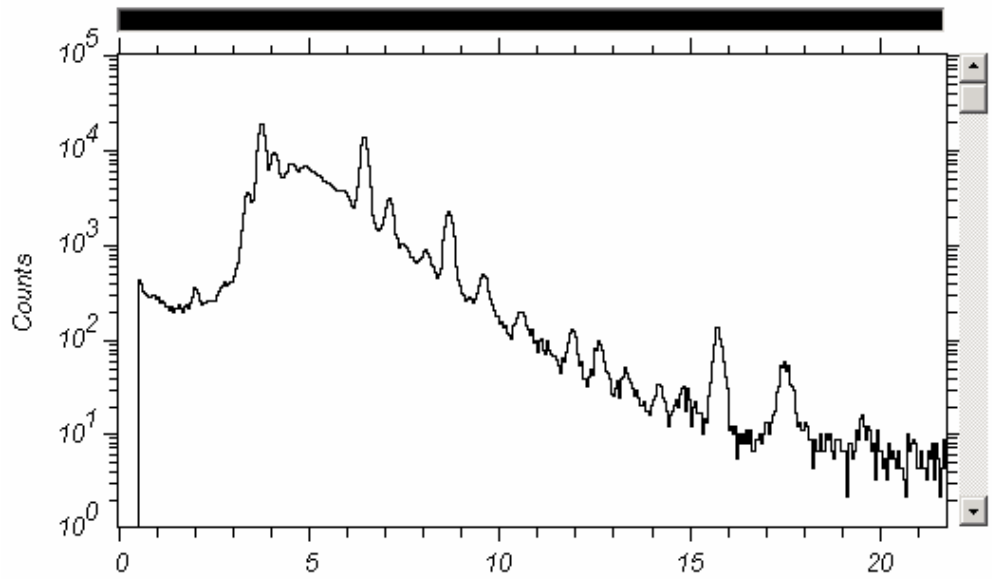


• Applications

- Environmental studies – PIXE analysis of air particulates

- ☻ for NIST - Certified reference materials – homogeneity tests for candidate CRMs and intercomparisons
- ☻ Collaboration with Instutute for Medical Research – national air quality monitoring program
- ☻ Single particle analysis for source recognition



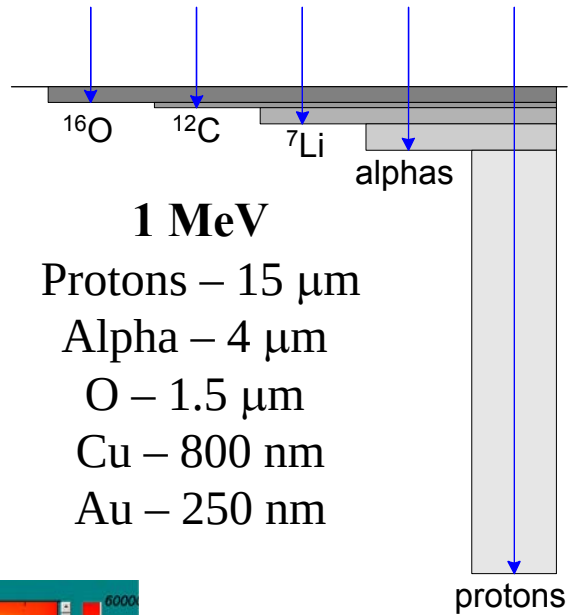


3. New areas

1. Defects

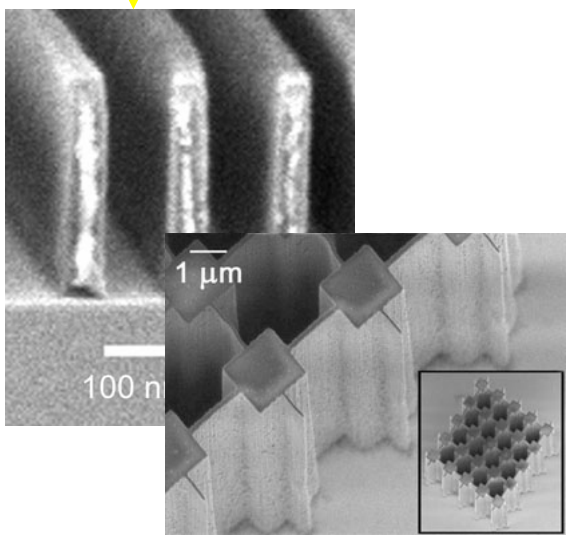
a. 3D radiation damage structures
- Lythography
- Engineering of electronic tranport properties

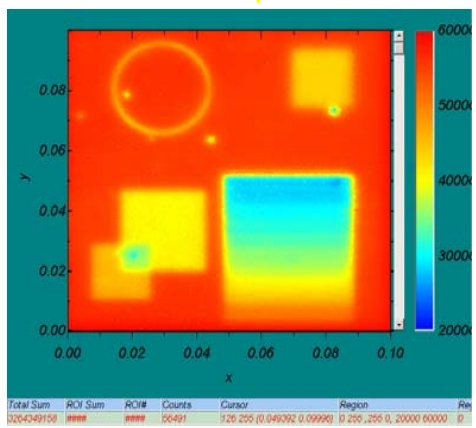
b. Single ion efects (for high energy loss dE/dx)
- Membranes, etc



1 MeV

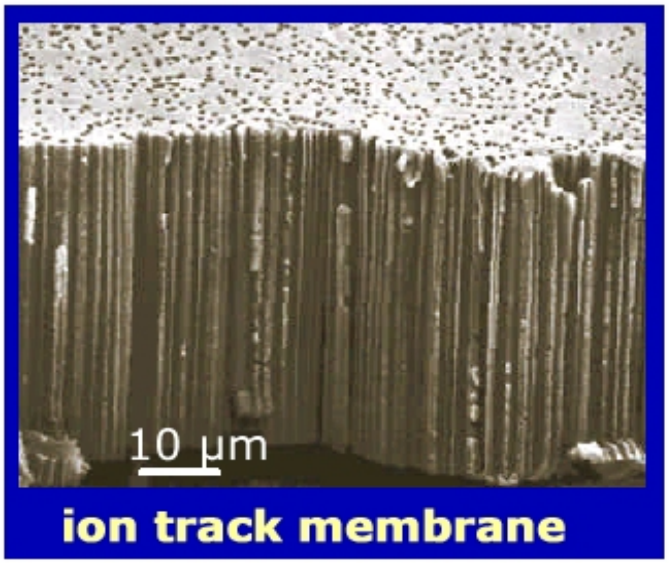
Protons – 15 μm
Alpha – 4 μm
O – 1.5 μm
Cu – 800 nm
Au – 250 nm

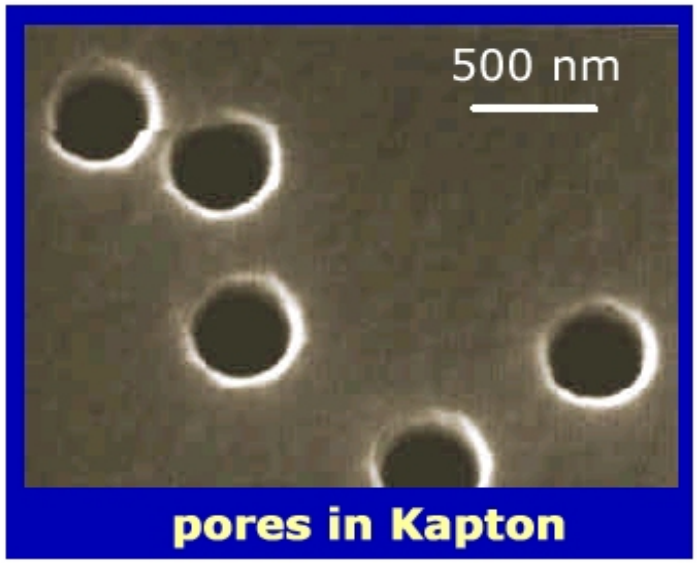


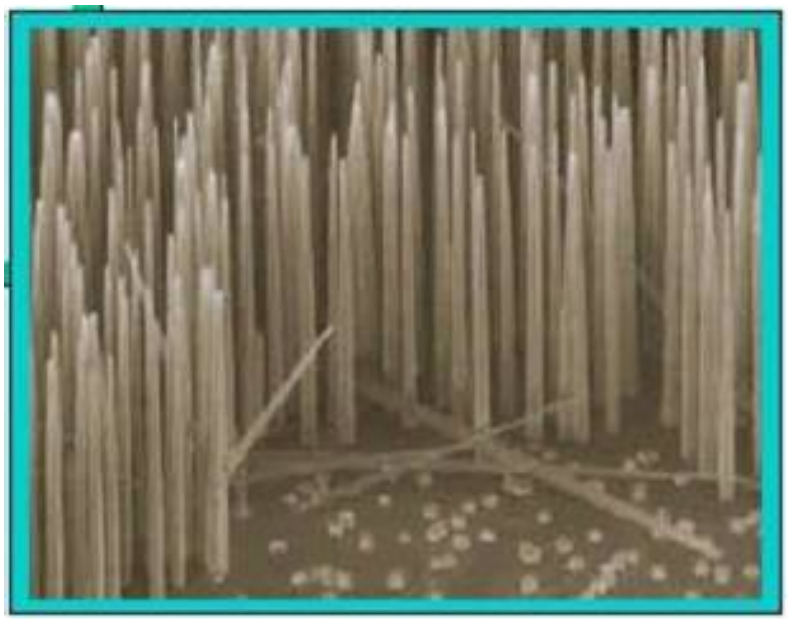


EN tandem:
0.5 – 6 MV

Tandetron:
0.1 – 1 MV

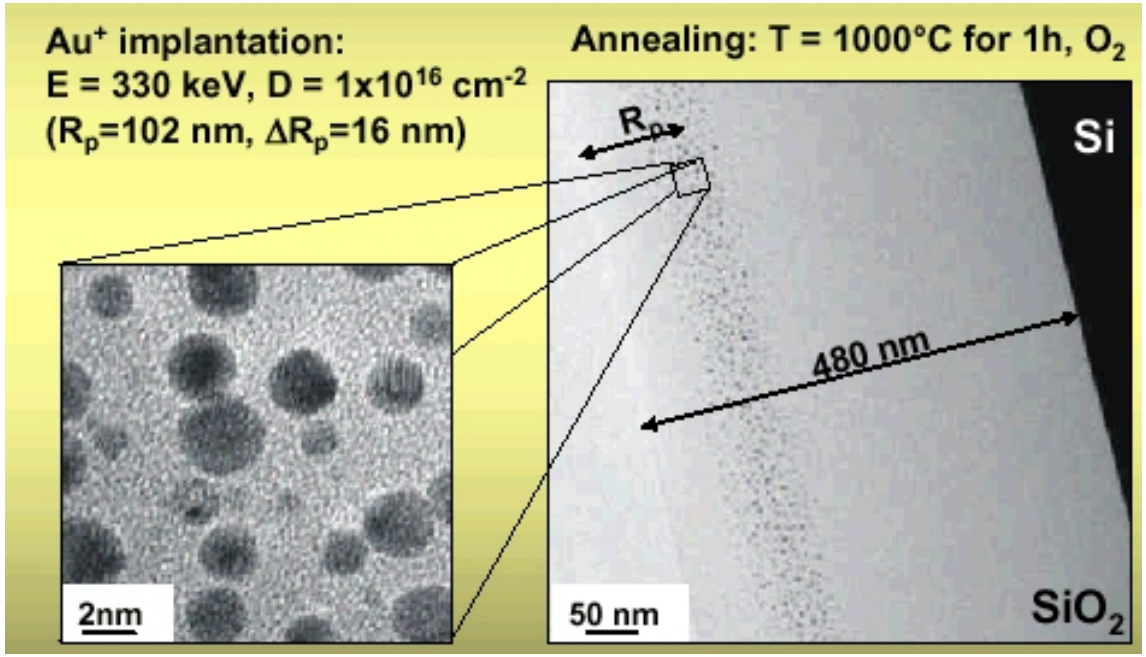

10 µm
ion track membrane

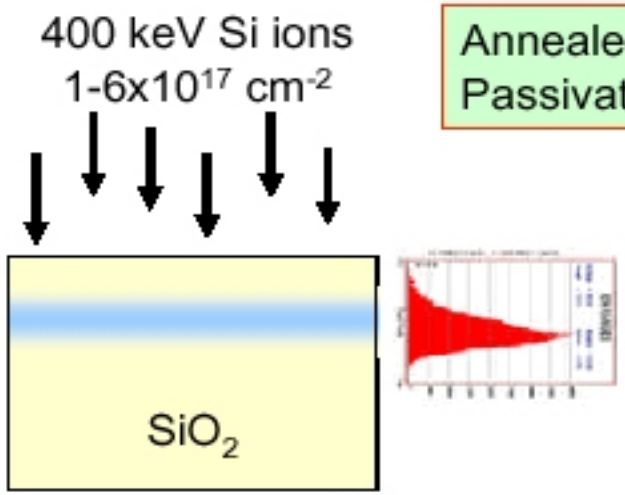

500 nm
pores in Kapton



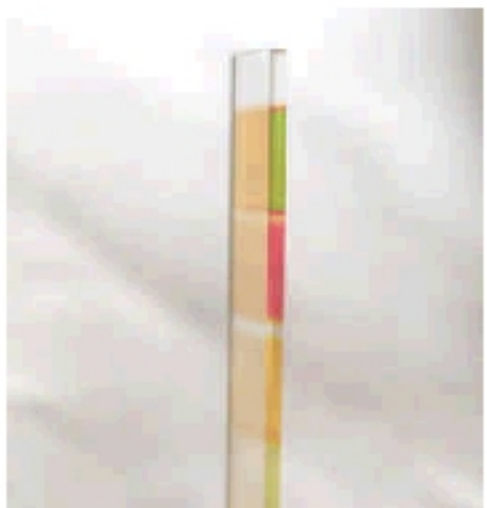
2. Ion Implantation

- IRB – small fluences!
  - but 3D!





Annealed 1100°C in N_2
Passivated 500°C H_2/N_2



- **Waveguides formed by 400 keV Si implants:**

"Particles, particles, particles."

Thank you!