Flerov Laboratory of Nuclear Reactions

Testing of Electronic Components at FLNR JINR Accelerator Complex: Current Status and the 7-Year Roadmap

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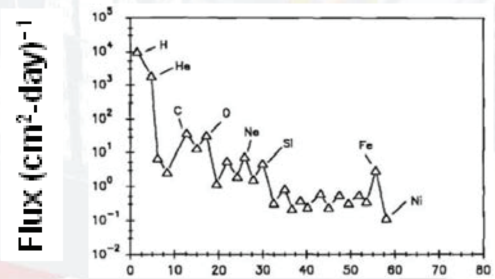
RuPAC , November 23, 2016, Wednesday, 2016

Outline

1. Formulation of the problem
2. Test Standards and Guidelines
3. FLNR SEE testing facility introduction
4. Fitting the problem with U400 and U400M. Benches Zoo.
5. Beam monitoring: detector’ Zoo - ‘’pro et contra”
6. Further steps: R&D, upgrade and modernization.
7. Milli beams: Here be dragons
8. Conclusions

Question point for R&D: Cosmic ray

Of primary cosmic rays, which originate outside of Earth's atmosphere, about 99% are the nuclei (stripped of their electron shells) of well-known atoms, and about 1% are solitary electrons of the nuclei, about 90% are simple protons, i. e. hydrogen nuclei; 9% are alpha particles, **and 1% are the nuclei of heavier elements**.



Cosmic ray flux as a function of atomic mass.

Question – what will be if…

…you have TOO much species in your "sandwich"

…. or ONE is enough???

- *What does it mean for FLNR ??*
- *Using the accelerator complex to irradiate the DUT (Device Under Test) with the heavy ion beams (with well-known characteristics).*

- *What does it mean for Users ??*
- *To observe response and operate the DUT under exposure.*

Test Standards and Guidelines

Electronic industry association

EIA/JESD57

EIA/JEDEC STANDARD

Test Procedures for the Measurement of Single-Event Effects in Semiconductor Devices from Heavy Ion Irradiation

EIA/JESD57

DECEMBER 1996

ELECTRONIC INDUS

ENGINEERING DEPARTME

EIA/JEDEC Standard No. 57

TEST PROCEDURES FOR THE MEASUREMENT OF SINGLE-EVENT EFFECTS IN SEMICONDUCTOR DEVICES FROM HEAVY ION IRRADIATION

Content

EIA/JEDEC Standard No. 57

Contents *(continued)*

European space agency

ESCC
European Space Components Coordination

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SINGLE EVENT EFFECTS TEST METHOD AND GUIDELINES

ESCC Basic Specification No. 25100

ISSUE 1

October 2002

esa

Document Custodian: European Space Agency - see https://escie

SCC	ESA/SCC Basic Specification No. 25100		PAGE 3 ISSUE 1

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So, what's the bottom line?

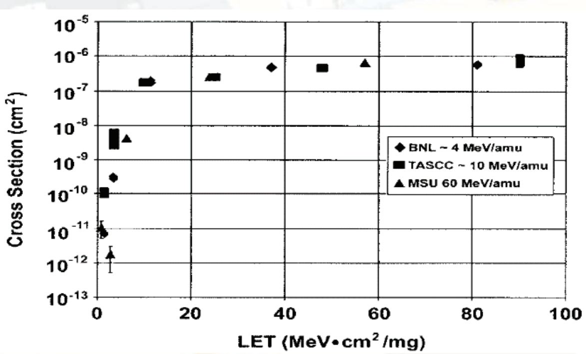
Crucial points for the electronic components testing

- Ion energy: few measurements at different effective LET (linear energy transfer) levels
- Tilting
- Beam intensity: $10^1 \div 10^5$ $cm^{-2}s^{-1}$
- Fluence: $\geq 10^7$
- Beam uniformity: $\pm$ 10 % (over the DUT area)
- Energy accuracy: $\pm$ 10 %
- Ion range in Si: $\geq$ 30 mkm (ion energy > 3 MeV/nucleon)

Beam operation time for testing: 2000 hours per year – based on SEE' symposium reports

Lack of the beam time in the world.

Example cross-section curves for a Matra 32 K 8 SRAM*



Goal:

Obtaining experimental data within Earth limits to predict SEE rate in space.

*IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 50, NO. 3, 2003

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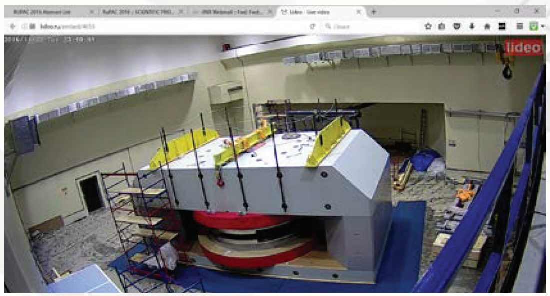
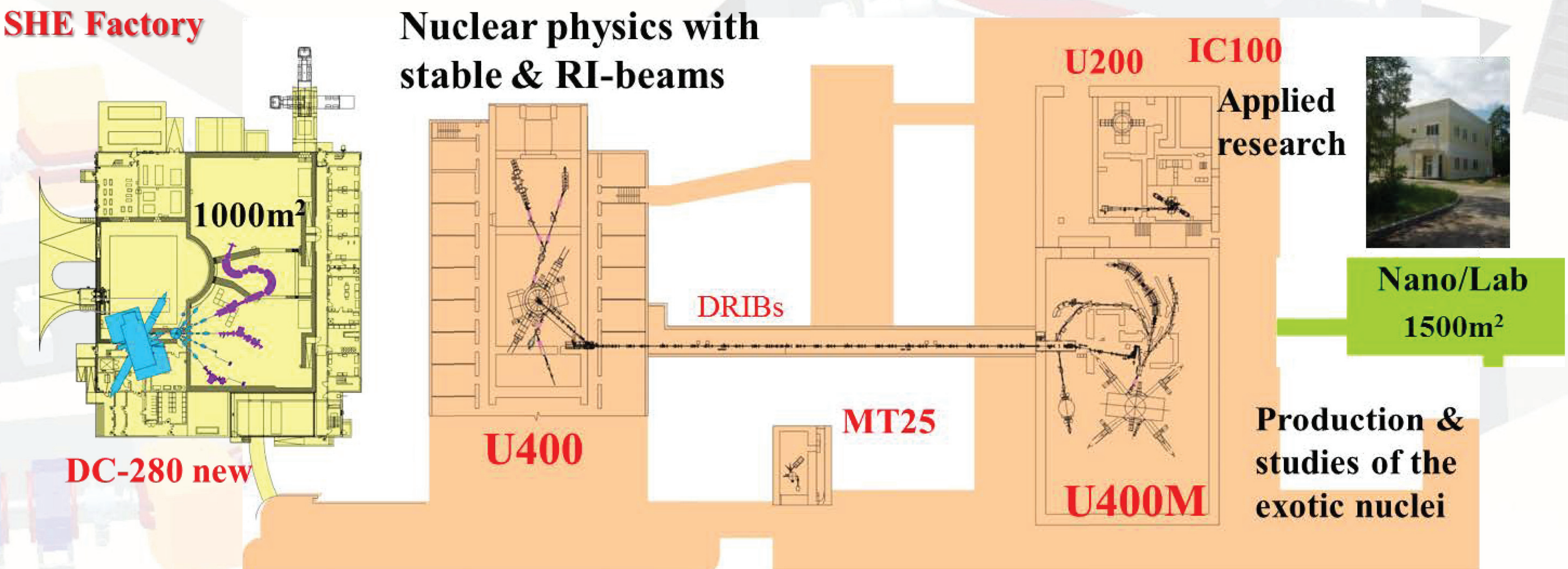
FLNR accelerator complex in 2016.

4 cyclotrons and microtron (e-beams)….

Beam operation time – 7 years review: ~ 15 000 hours/year of the ion beams **ON** physical targets





Does it (FLNR accelerator complex) fit well ?

Ion beam parameters for the SEE testing.

Ions: O, Ne, Ar, Kr, Xe, Fe and Bi

Ion energy 3 - 64 MeV / nucleon (it means LET values: up to 100 MeV×cm2/mg)

Beam intensity: $10^1 \div 10^5$ $cm^{-2}s^{-1}$

Irradiation areas: ø 6 cm, 15.5*20 cm, 20*20 cm

Beam uniformity: 10 ÷ 30 %

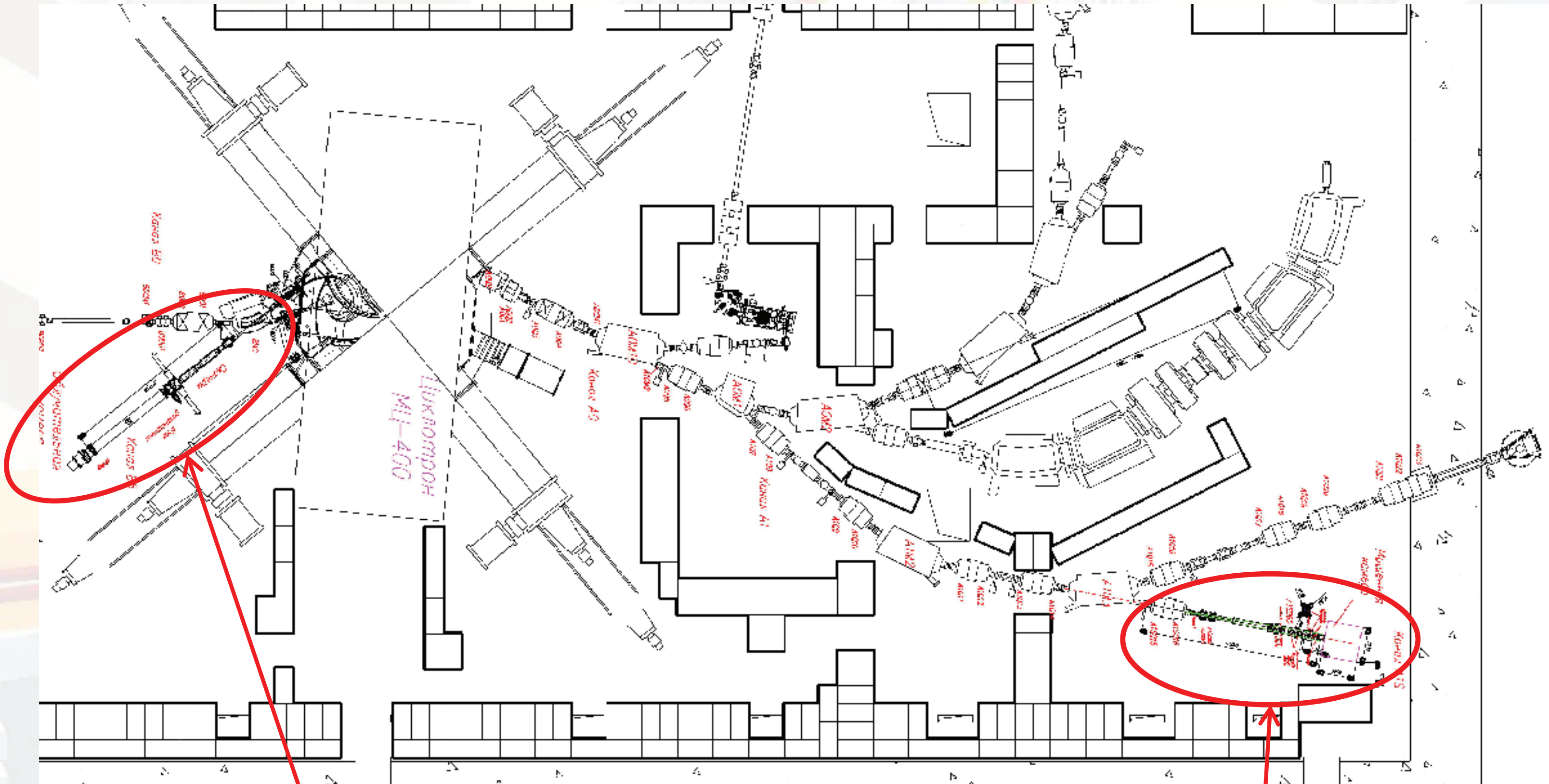
Energy accuracy: 10 %

Ion range in Si: ≥ 30 mkm

Beam operation time, dedicated to SEE testing in 2016 up to date is 2500 hours !!!

2014: 2300 hours
2015: 2100 hours
2016: 2500 hours

U400M experimental hall.



High energy (15.5 - 64 MeV/nucleon) ion beam-line

Low energy (3-6 MeV/nucleon) ion beam-line

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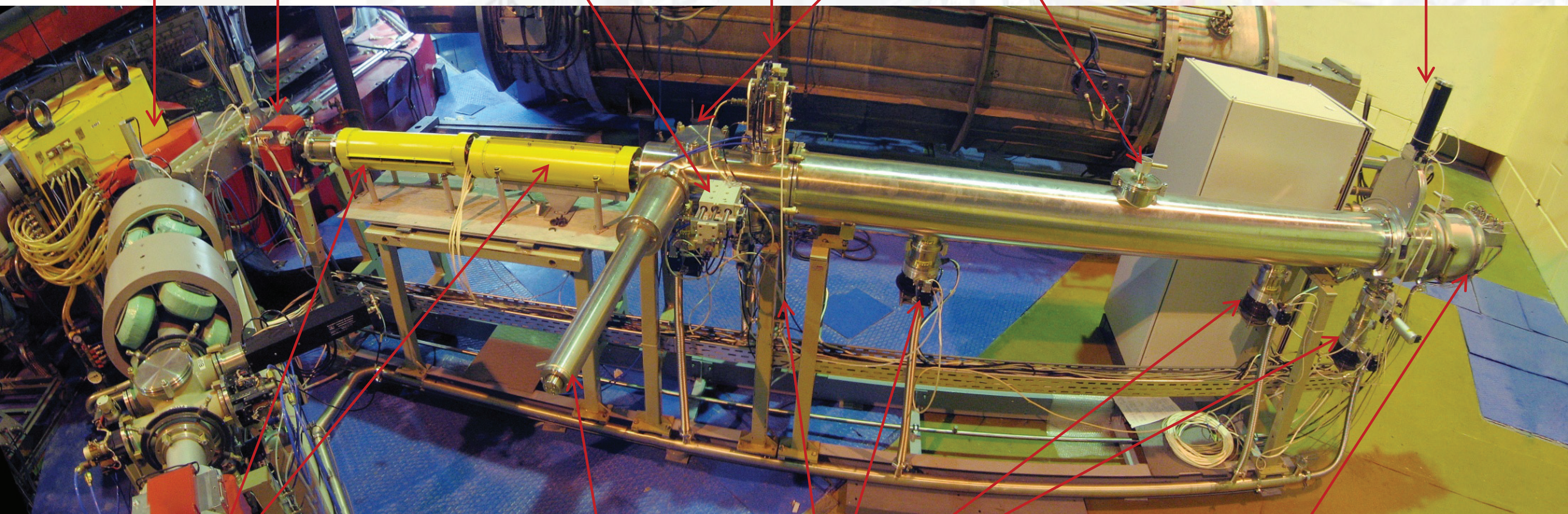
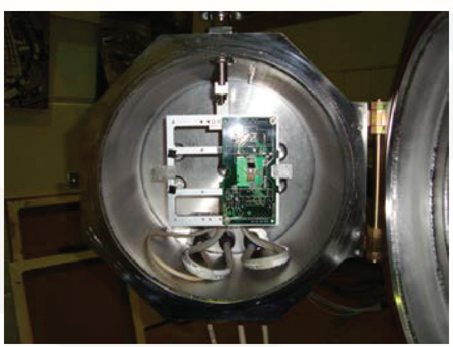
The low energy ion beam line based on U400M.



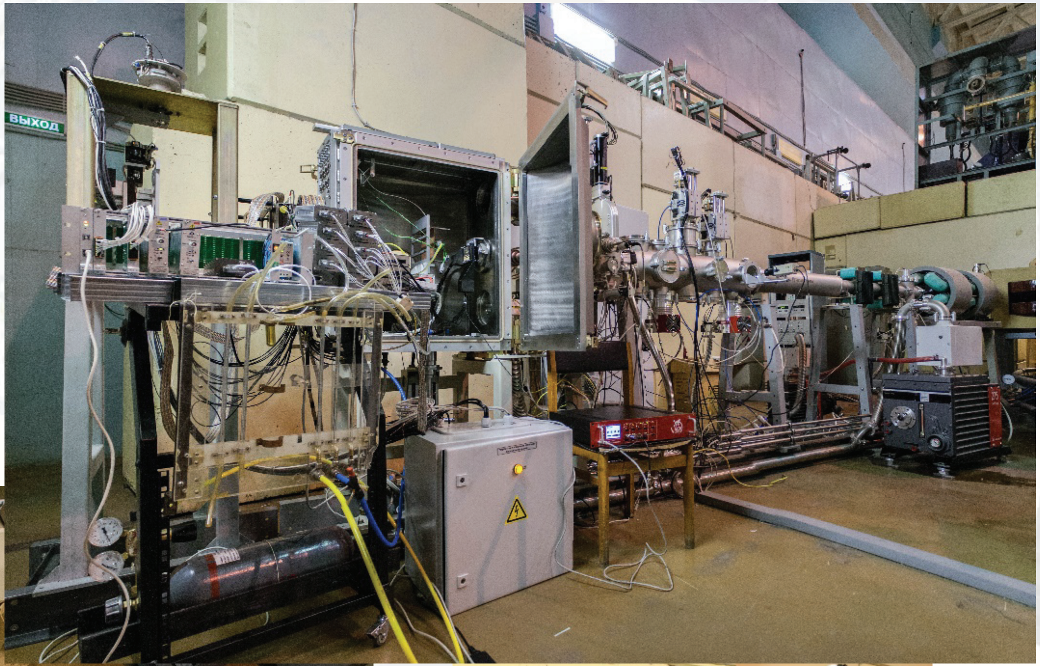


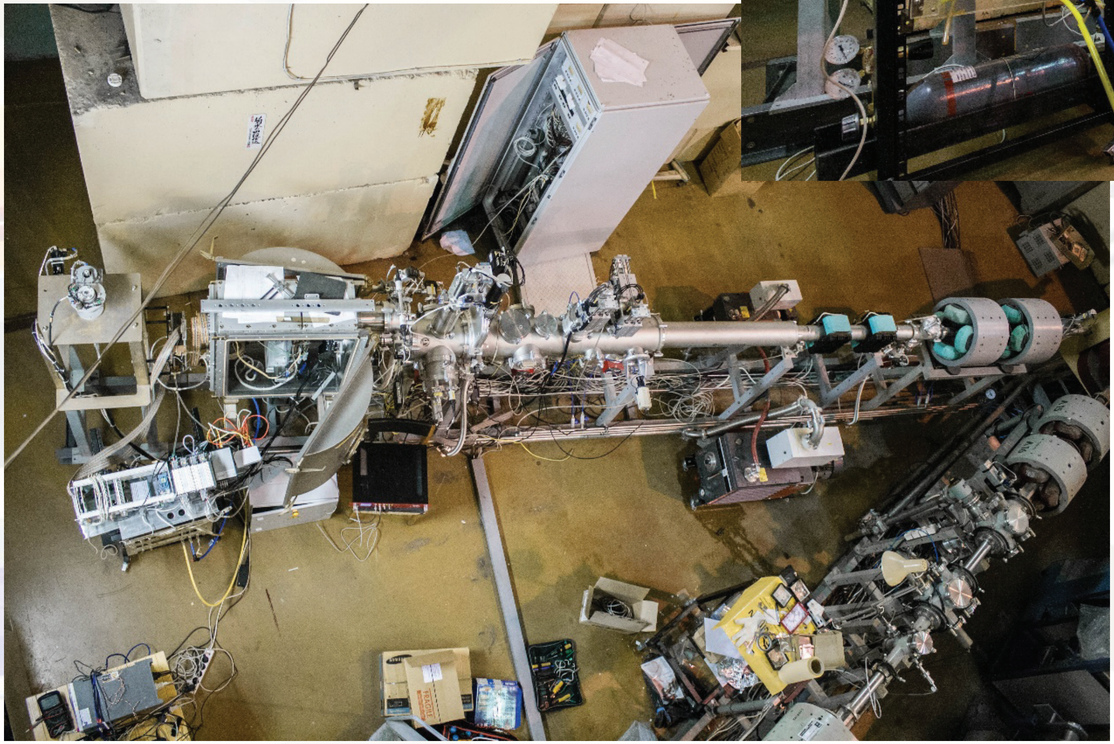
- ✓ Dedicated beam-line for low energy (3 ÷ 6 MeV/nucleon) ions (usially Ne, Ar, Kr, Xe, Fe or Bi)
- ✓ Irradiation area – 200x200 mm^2.
- ✓ Beam uniformity better then 30%
- ✓ Beam flux 1 ÷ 10^5 $cm^{-2}s^{-1}$

The high energy beam-line based on U400M.

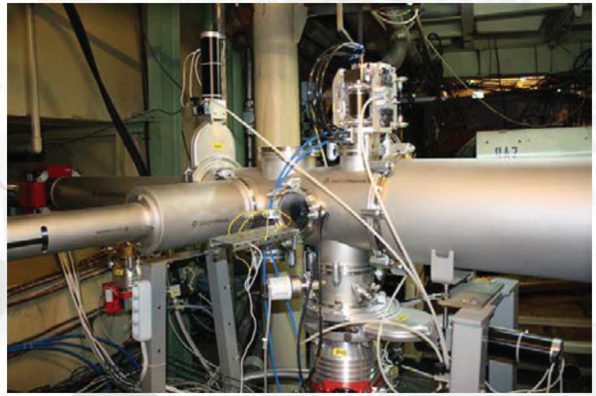
Design of the experimental chamber allows:

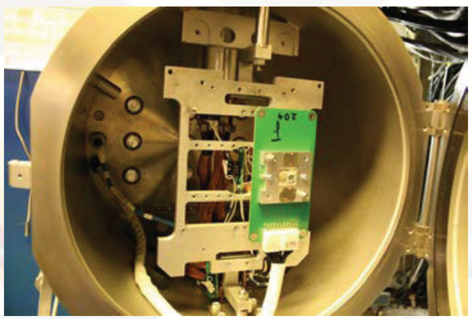
- the SEE testing in vacuum (10^{-2} Torr) and air ambient
- irradiation area of 60 mm in diameter.
- automatic movement of the DUT in two orthogonal axes (X and Y) in respecting of the beam direction (Z).
- to change beam incident angle in the range of 0-90 degrees.
- installation of degraders set.
- Energy 15.5 - 64 MeV/nucleon (done in 2015)
- Beam uniformity better than 20%
- *In 2017 automatic tilting of the DUT will be added*

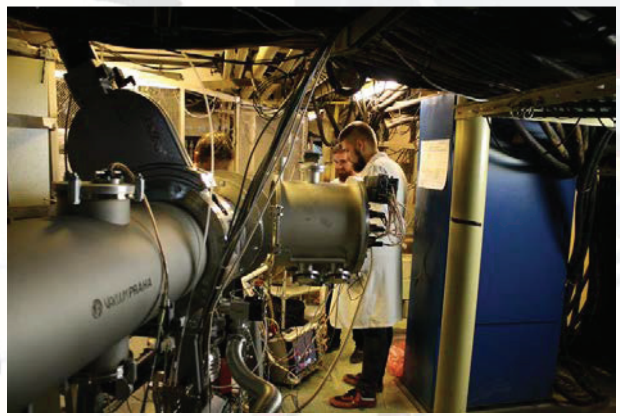


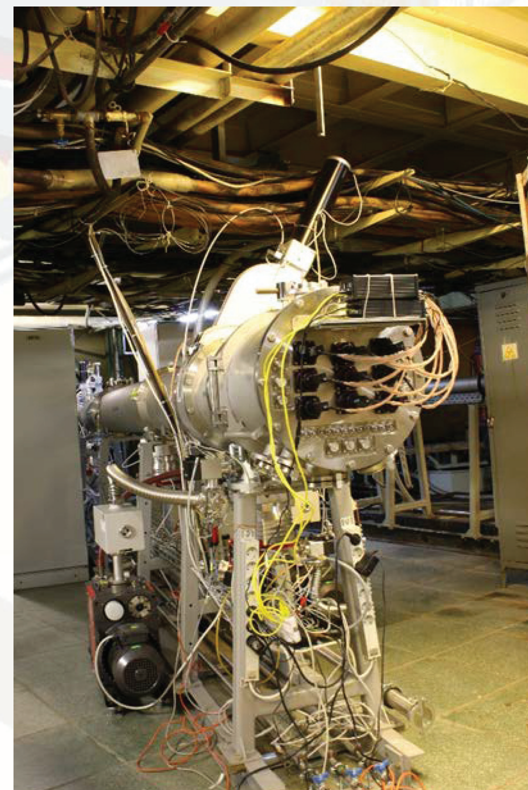


The low energy ion bean line based on U400



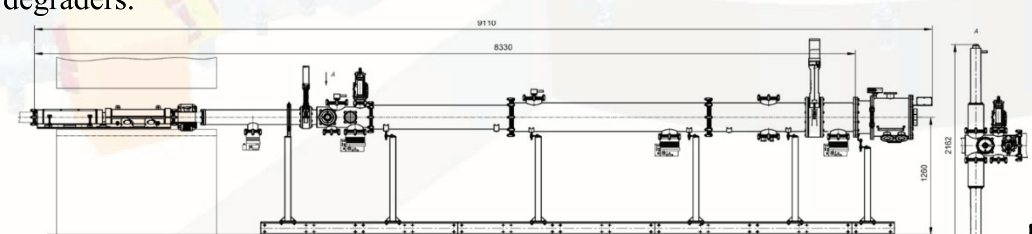






Main features of this facility are:

- 200 mm x 155 mm irradiation area
- beam uniformity over irradiation area better then 20%
- Ne, Ar, Fe, Kr, Xe, Bi ions with 3-9 MeV/nucleon
- LET range of 4.5-100 MeV/(mg/cm2).
- Fluent energy variation in the U400R will allows changing the ion energy without degraders.



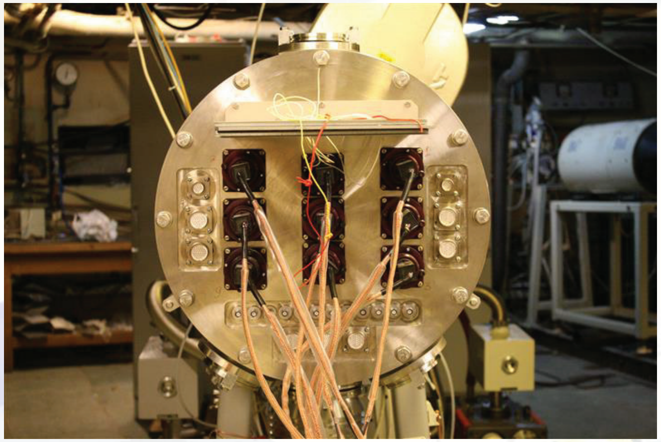
Beam control systems :

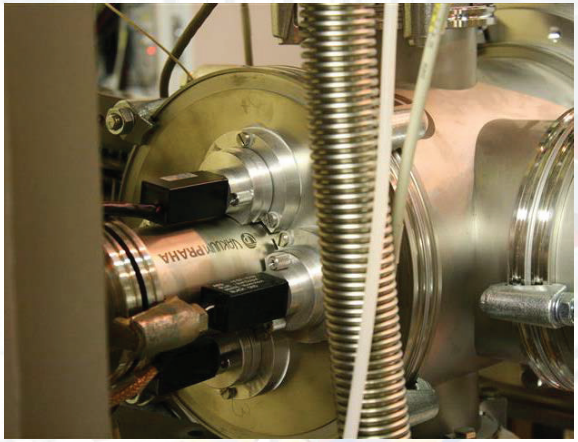
- Beam uniformity – beam profile over irradiation area
- Beam flux in the range of $10^2 \div 10^5$ ions per second per cm^2
- In-situ energy measurement

Detector' Zoo ?

Scintillators based detectors:

To determine the beam spatial distribution and flux value.



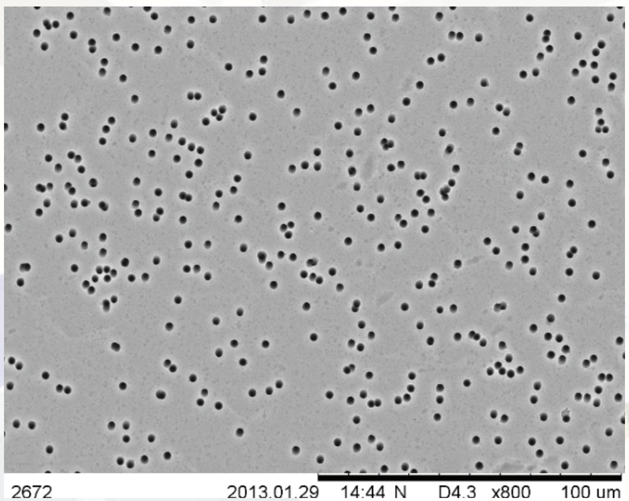


Good stability, easy to use, almost “immortal” detectors – up to 1 month at 10^5 ions per sec.

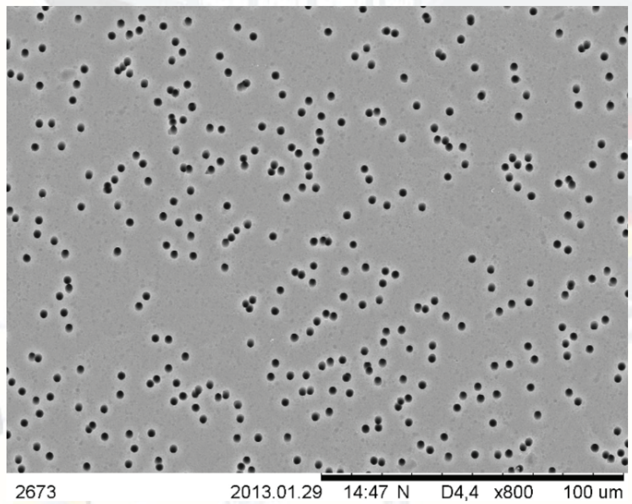
The reference point for the beam fluence value is the “old-school” method – track membrane

- Ion fluence is controlled by using polycarbonate or polyethylene terephthalate track detectors placed in close vicinity of any testing device in all irradiation runs.

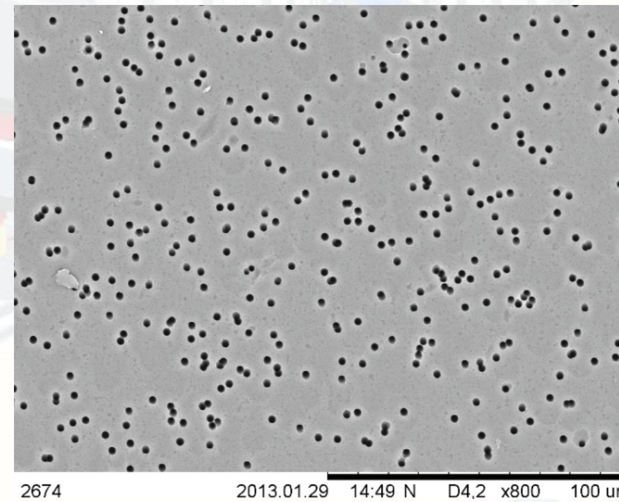
Ar (35.5 MeV/n, ion fluence 10^6 cm^{-2}) + polycarbonate



E =33.5 MeV/n
LET= 5.37 MeV/(mg×cm^2)



E =23.5 MeV
LET =6.8 MeV/(mg×cm^2)



E =9 MeV/n
LET= 13 MeV/(mg×cm^2)

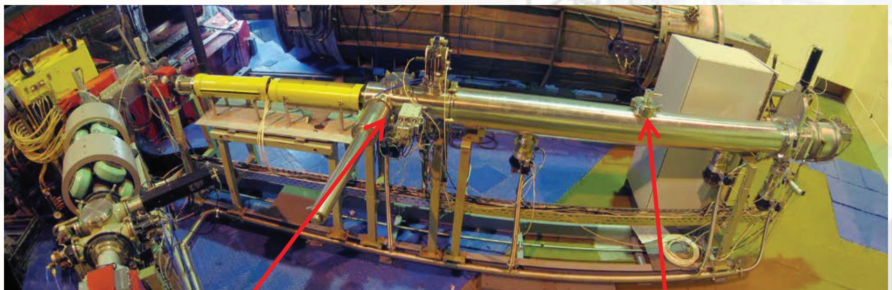
Track etching efficiency is constant over a wide range of ion energy

Scintillators based detectors:

online measurement of heavy ion energy - the low energy line at U400M as example.

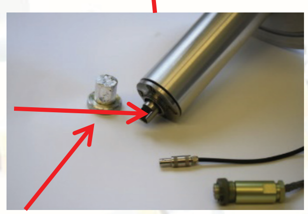
*The second generation of the detectors and data acquisition system

TOF energy measurement sensors base is L=1.602 m.



PMT

light guide

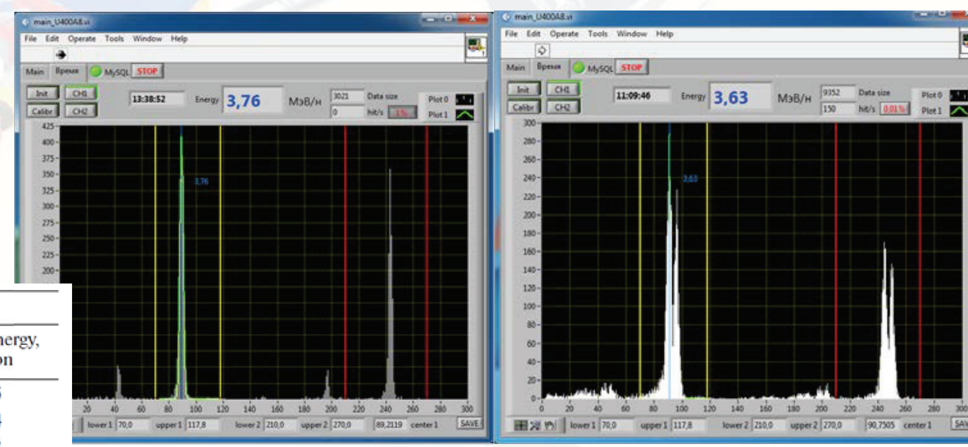


Scintillator covered by Al foil

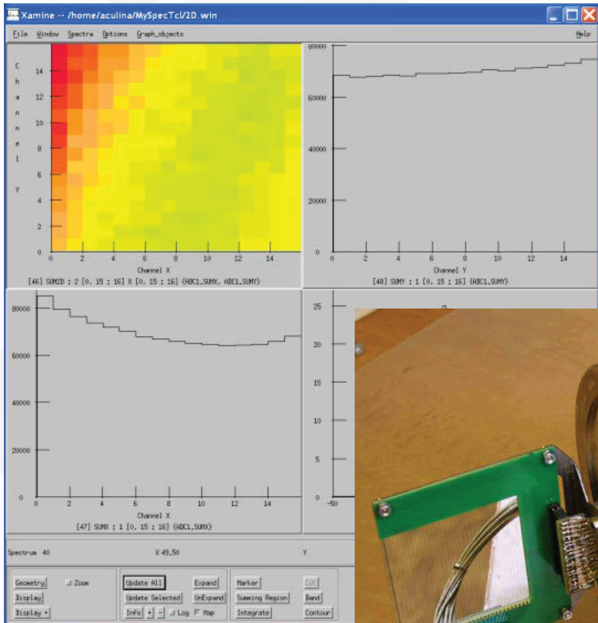
Ta degrader thickness, μm	SmartTDC-01		DRS Evaluation Board	
	measured time of flight, ns	measured ion energy, MeV/nucleon	measured time of flight, ns	measured ion energy, MeV/nucleon
9	50.9 ± 0.5	5.17 ± 0.1	51 ± 0.23	5.15 ± 0.05
12.5	59.1 ± 0.5	3.83 ± 0.07	58 ± 0.23	3.99 ± 0.04
14	61 ± 0.5	3.6 ± 0.06	59.4 ± 0.23	3.7 ± 0.03
15	63.2 ± 0.5	3.56 ± 0.06	61.8 ± 0.23	3.52 ± 0.03

Beam purity

Use of degrading foils additionally allows us to determine the content of impurities in the ion beam. A clean from impurities ion beam corresponds to one peak on the recorded spectrum. An ion beam with impurities results in split peaks on the spectrum after passing the degrader. Intensity ratio of the peaks occurred after splitting corresponds to the proportion of impurities. We could determine energy (LET) of the impurity by the offset of the peak on the spectrum.

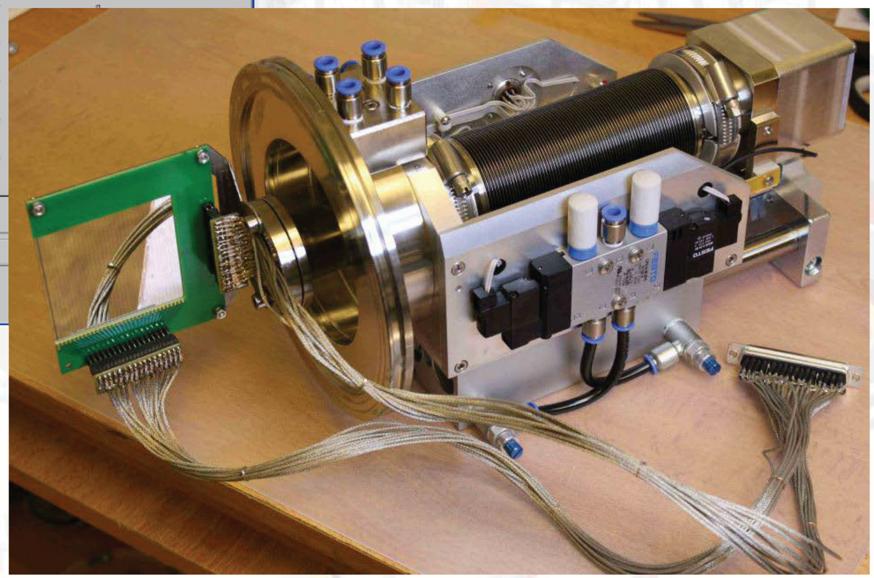


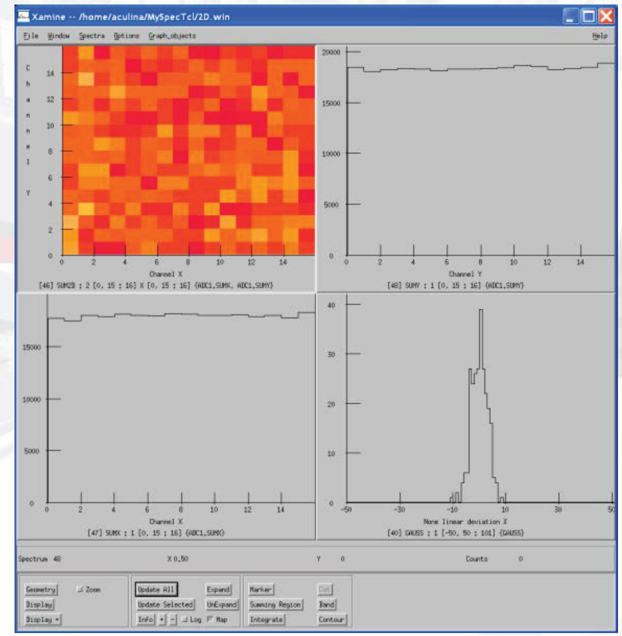
Double side Si strip detector



Fully cover the beam spot

- Beam profile 64 x 64 mm^2 , strip width = up to 1 mm.
- Dual axes (X – Y) orthogonal detection





- A bit more beam intensity , a bit more human factor … and 6000 Euro goes to garbage

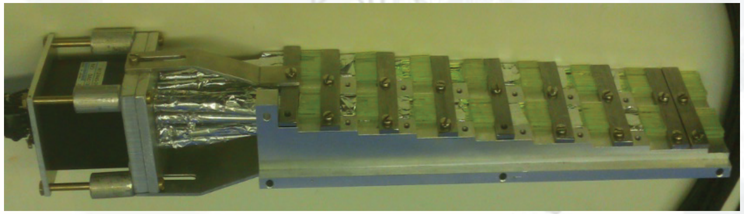
Long time of using = Si detector degrades due to the radiation effects inside.

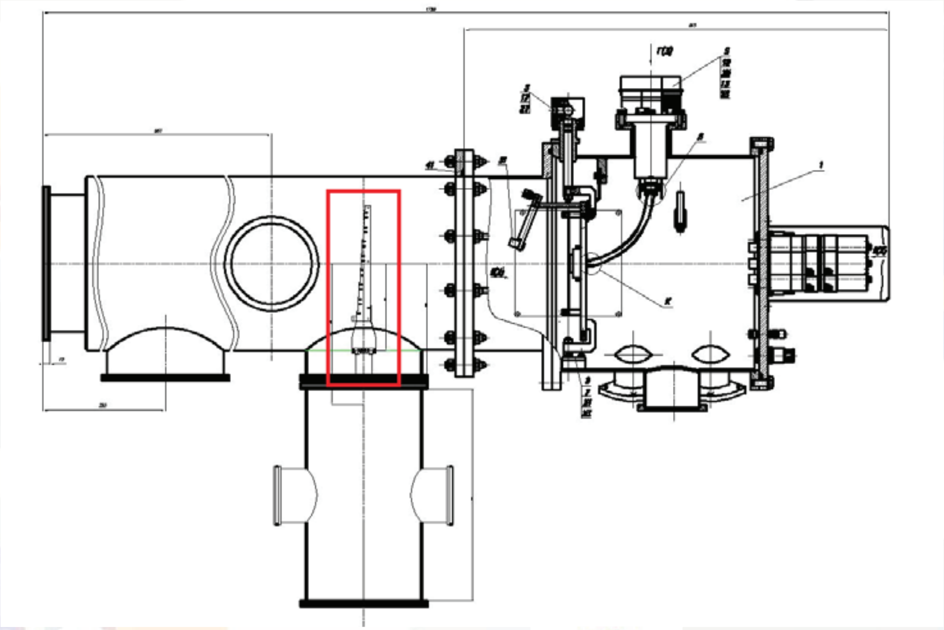
- Fluence more than 10^8 is crutial
- Amplitude decrease
- Pulse to be wider
- Collecting time rising

Impossible to use for the energy measurement due to the charge recombination.

Further steps: R&D, upgrade and modernization.

Due to the huge irradiation areas we need to improve the beam profile control:



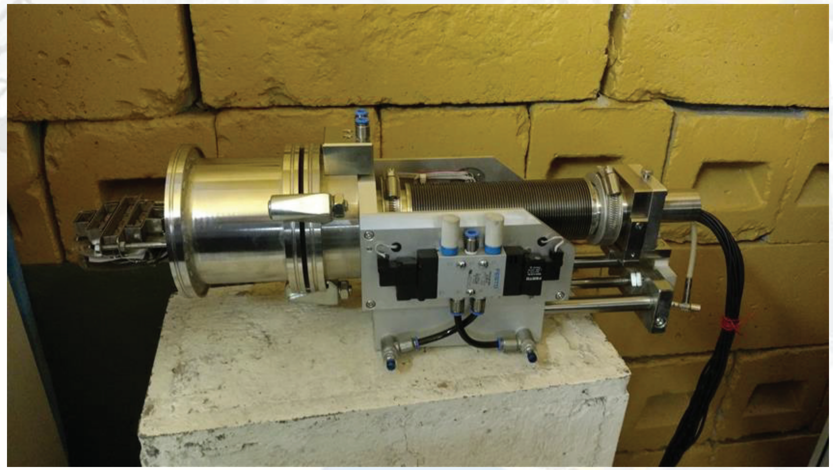


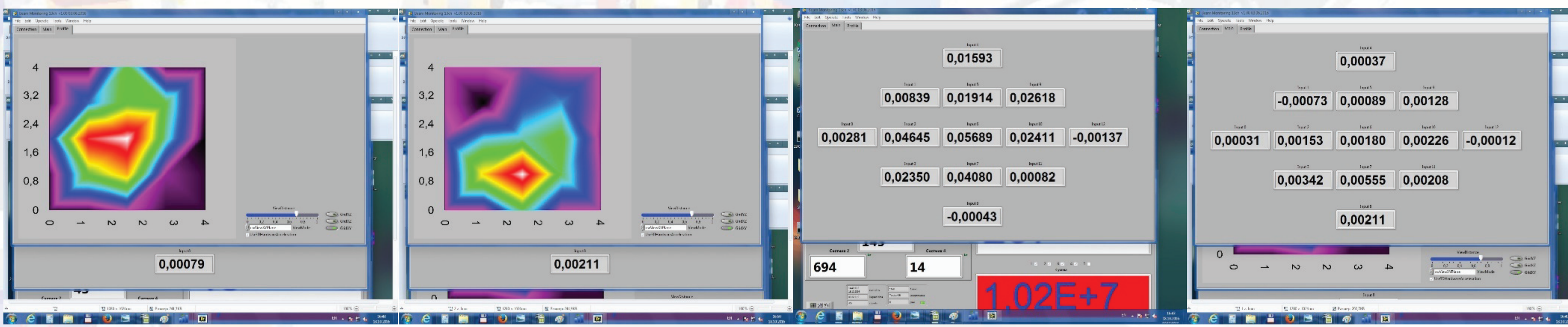
64 - matrix of 1 cm^2 scintillators

!Under construction!

Further steps: R&D, upgrade and modernization.

To reduce the beam tuning time we developed the beam profile control station (covers ø 60 mm) based on secondary electron emission:





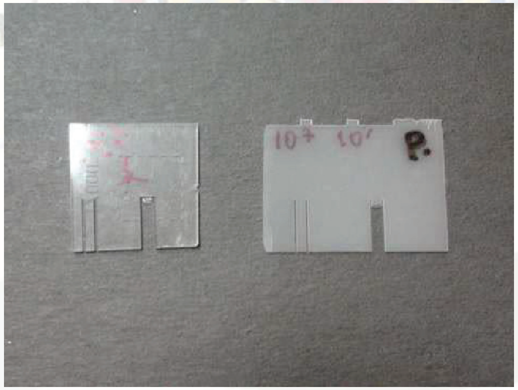
…At least 2 pcs will be build in 2017. 25 channels prototype is in workshop.

!Under construction!

Further steps: R&D, upgrade and modernization.

To reduce the time of the beam fluence control we need to move to CR39 instead of using polycarbonate or polyethylene terephthalate track detectors.

- Fire-and-forget (CR-39 is the most sensitive track detectors that's why it could be successfully used to detect both heaviest and lightest accelerated ions in a wide range of energies).
- Officially introduced in the state register of measuring instruments
- No needs of some chemical procedures during post analyzing
- It gives clear and contrast etched tracks image. Using of CR39 opens up an opportunities for the automatic software calculation of the tracks density.



!Under construction!

Further steps: R&D, upgrade and modernization.

To reduce the time of the beam flux and fluence control we are looking for the calibrated movable “something” based detector.

For example: scintillator base detector

Once it will be calibrated with the CR39 – it will allow us to reduce both the amount of the track detectors and the time of the beam fluence analyzing.

!Under construction!

Milli beams: Here be dragons

Next major step at this field could be the milli-beam project with the 100÷1 micron beam. It could be useful for:

- Medical research
- Radiobiological research
- Materials Science
- Semiconductor research (in the frame of the electronic components design study testing)

!Under thinking and estimation!

Conclusions

1. The test facility for electronic components was updated. The ions up to Bi with the energy up to 64 MeV/nucleon are available for worldwide users since 2015.

2. The beam monitoring systems of the facilities provide both online (beam energy, flux and uniformity) and offline (beam uniformity, absolute control of the dose) beam control. The new prototypes of the detectors were successfully tested to improve the beam control systems.

3. Facility allows quick change of the DUT in irradiation chambers.

4. Time to change the ion energy ~ 10 min.

5. Time to change the ion type: 8÷24 h.

6. Since 2010, more then 3000 devices has been tested.

7. The facility beam operation time are shared between medical, radiobiological and semiconductor research.

8. The “roadmap” of dedicated R&D steps was developed and accepted.

Thank you for your attention and SEE you in 2018 !!!

Testing of Electronic Components at FLNR JINR Accelerator Complex: Current Status and the 7-Year Roadmap

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