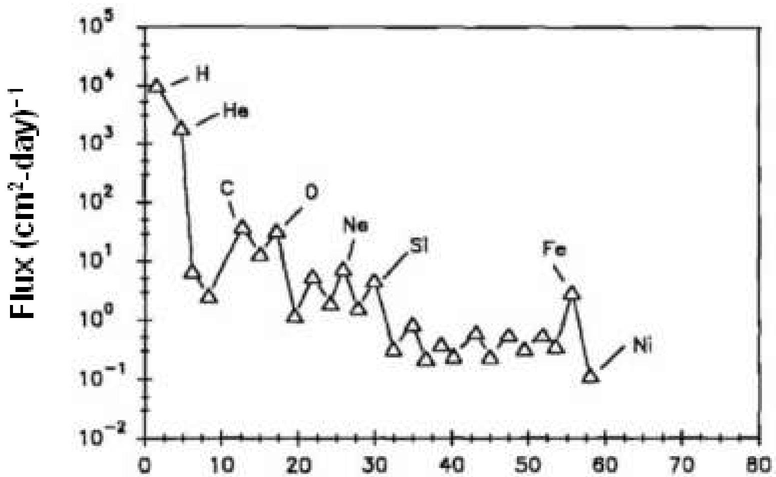
Flerov Laboratory of Nuclear Reactions

SEE testing facility at FLNR accelerators complex: state of art and future plans

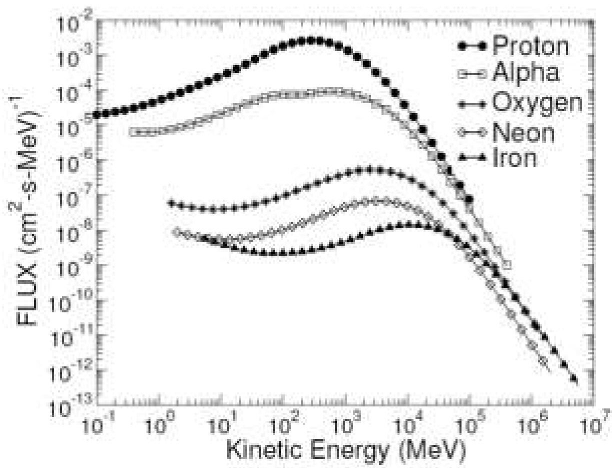
Mitrofanov S. for FLNR & JSC URSC ISDE collaboration

Start point for research :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.

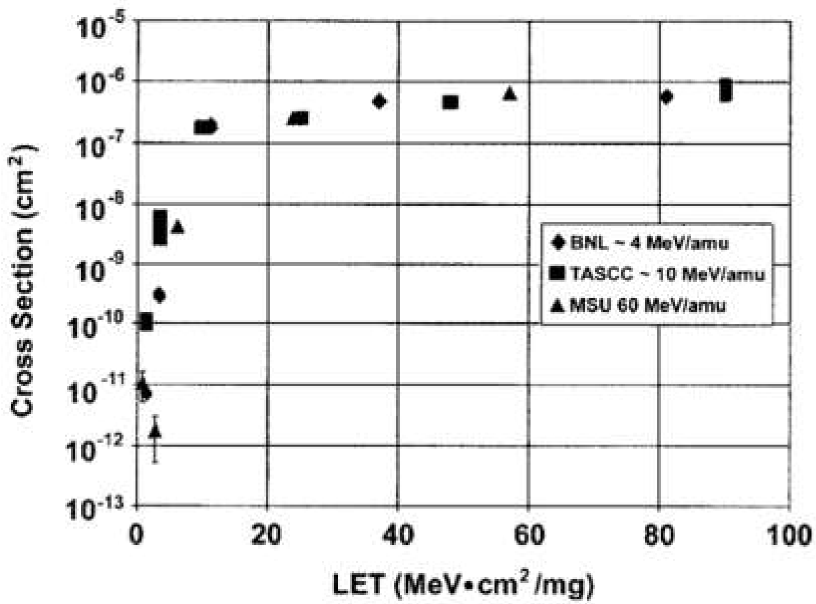


Some estimation of the cosmic ray energy at geostationary orbit of the Earth.

Start point for research :Cosmic ray

In spite of the relatively low contribution, the heavy ions due to the high level of LET have the most damaging effect in relation to the microelectronic components based devices, causing failures. Thus, the reproduction of the effects of a heavy component of cosmic radiation for the prediction of the radiation resistance of electronic components involves the use of low-intensity (10^3 - 10^6 cm^{-2} s^{-1}) of heavy ion beams with the levels of linear energy transfer (LET) in silicon characteristic ion energies 50÷200 MeV / nucleon. Keeping in mind the test the actual integrated circuits which are in metal and plastic enclosures, as well as ready-to-use electronic boards, in model experiments should be used ion beams with energies in the range 5 - 50 MeV / nucleon.

Example cross-section curves



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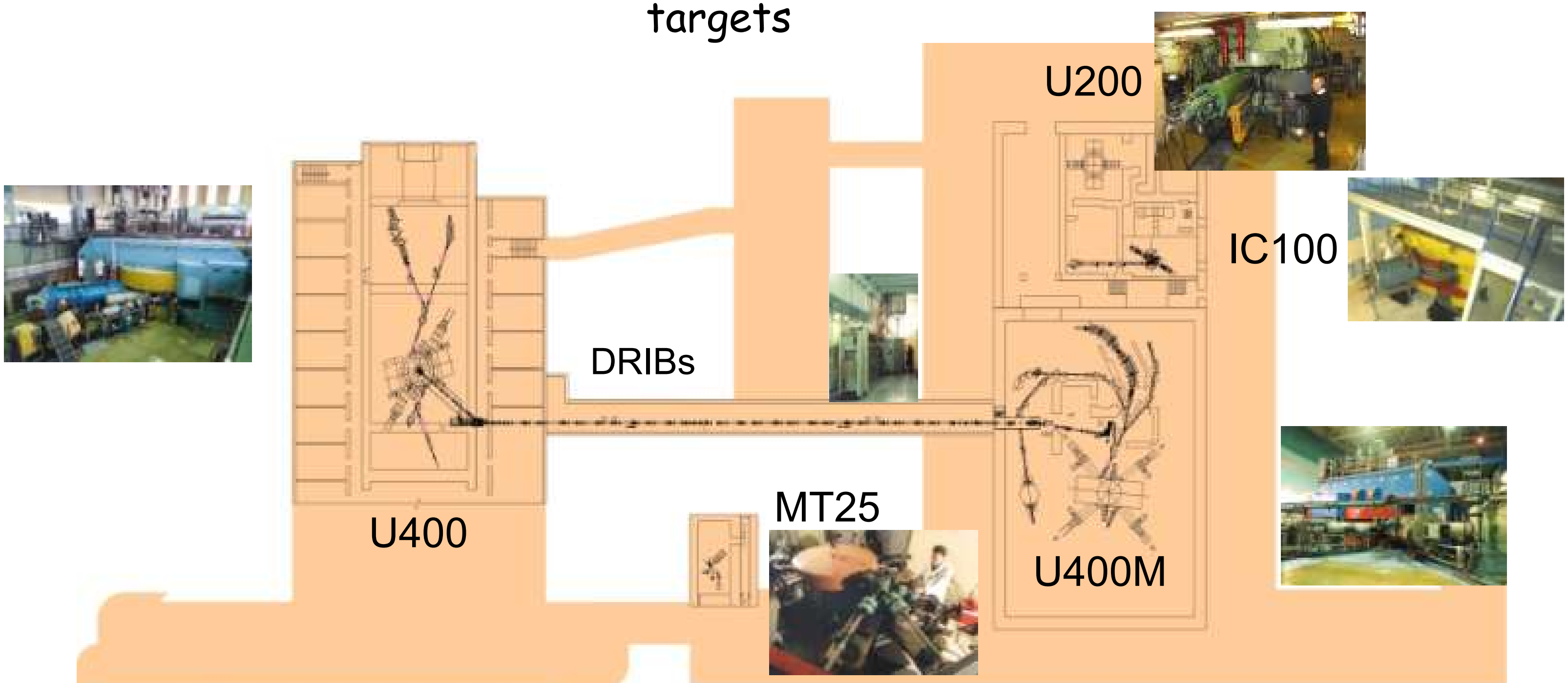
FLNR accelerator complex in 2014.

4 cyclotrons and microtron….

Beam operation time – 5 years review: ~ 15 000 hours/year of the ion beams on physical targets



- U400M - cyclotron R=4м E= 6÷50 MeV/nucleon
- U400 - cyclotron R=4м E=0.5÷20 MeV/nucleon
- U200 - cyclotron R=2м E=3÷15 MeV/nucleon
- IC-100 - cyclotron R=1м E≈1.2;0.5 MeV/nucleon
- MT-25 – electron accelerator E = 25 MeV/nucleon
- DRIBs (**U400M+U400**)^{6}He,^{8}He E = 6 ÷ 13 MeV/nucleon

FLNR accelerator complex.

- U400M - cyclotron R=4м E= 6÷50 MeV/nucleon
- U400 - cyclotron R=4м E=0.5÷20 MeV/nucleon
- U200 - cyclotron R=2м E=3÷15 MeV/nucleon
- IC-100 - cyclotron R=1м E≈1.2;0.5 MeV/nucleon

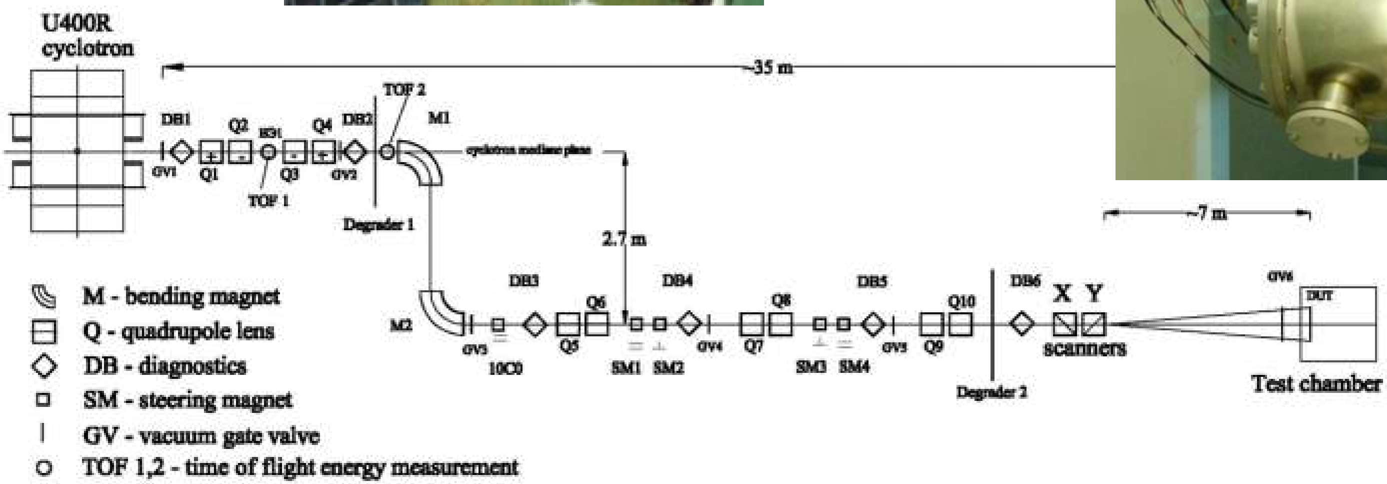
Some crucial points

- LET: up to 100 MeV×cm^2/mg (ion energy 5 - 50 MeV / nucleon)
- Beam intensity: $10^1 \div 10^5$ cm^{-2}s^{-1}
- Beam uniformity: ≤ 30 %
- Energy accuracy: 10 % (LET: ± 10 %)
- Ion range in Si: ≥ 30 mkm (ion energy > 3 MeVnucleon)

Dedicated time for the SEE testing: 2000 hours per year.

Low energy beam line on the base of U400

…first step in 2007



- ✓ The first dedicated beam line for low energy (3-6 MeV/nucleon) SEE testing
- ✓ Irradiation area: 80*160 mm.
- ✓ Bean uniformity better than 30%
- ✓ Beam intensity 1 10^5 cm^{-2}s^{-1} .

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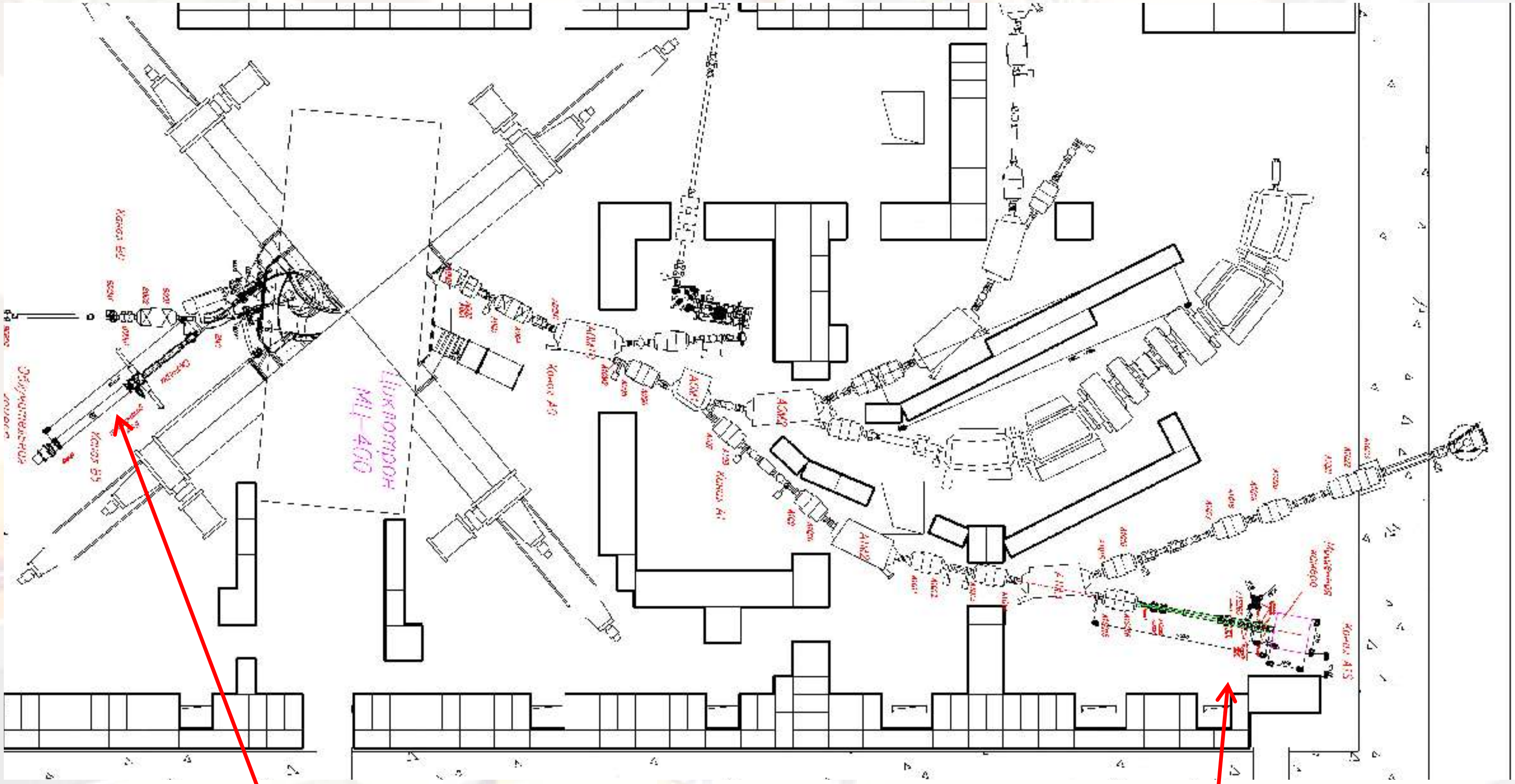
U400M experimental hall.



High energy (14-40 AMeV) ion beam-line

Low energy (3-6AMeV) ion beam-line

Low energy ion beam line.

Bending magnet

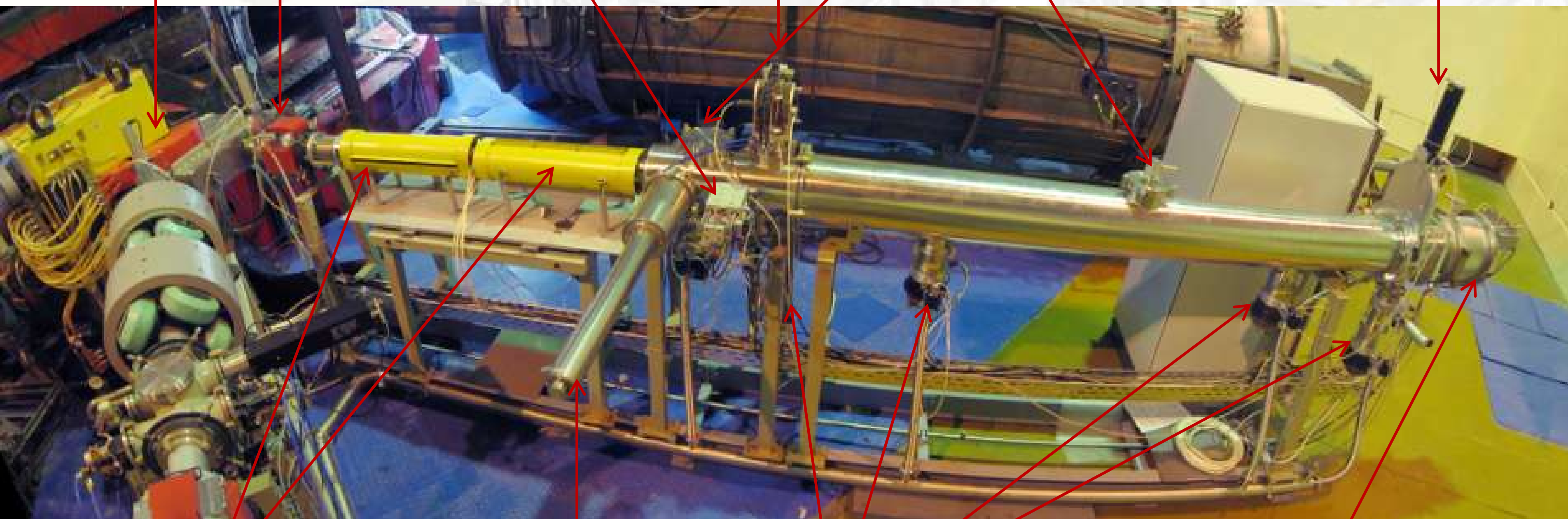
X-Y correction magnets

Luminophore drive

Faraday cup

TOF measurement

Vacuum gate valve



Test chamber

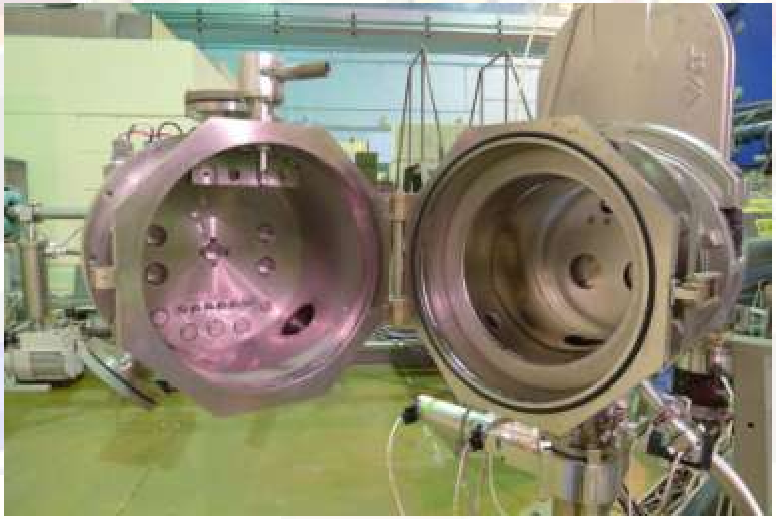
X-Y scanning system (50 Hz)

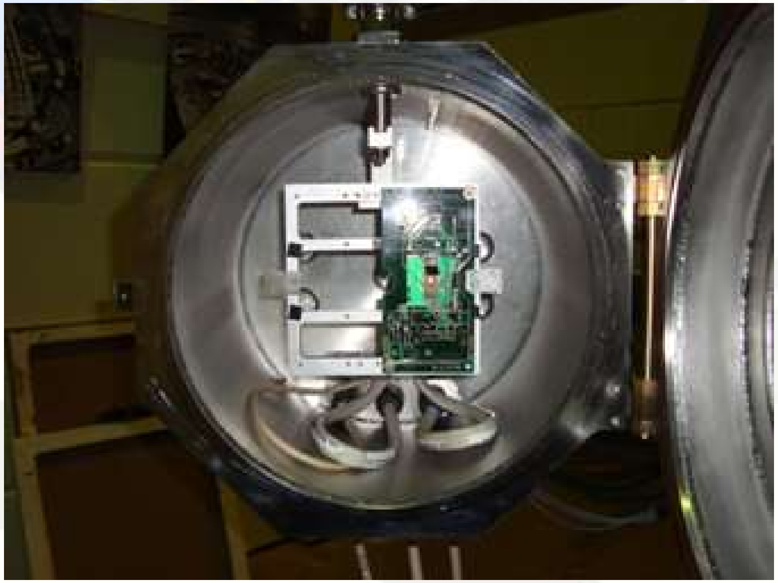
Turbo molecular pumps

Ta foils (5-27 μm) drive

Irradiation chamber for LE

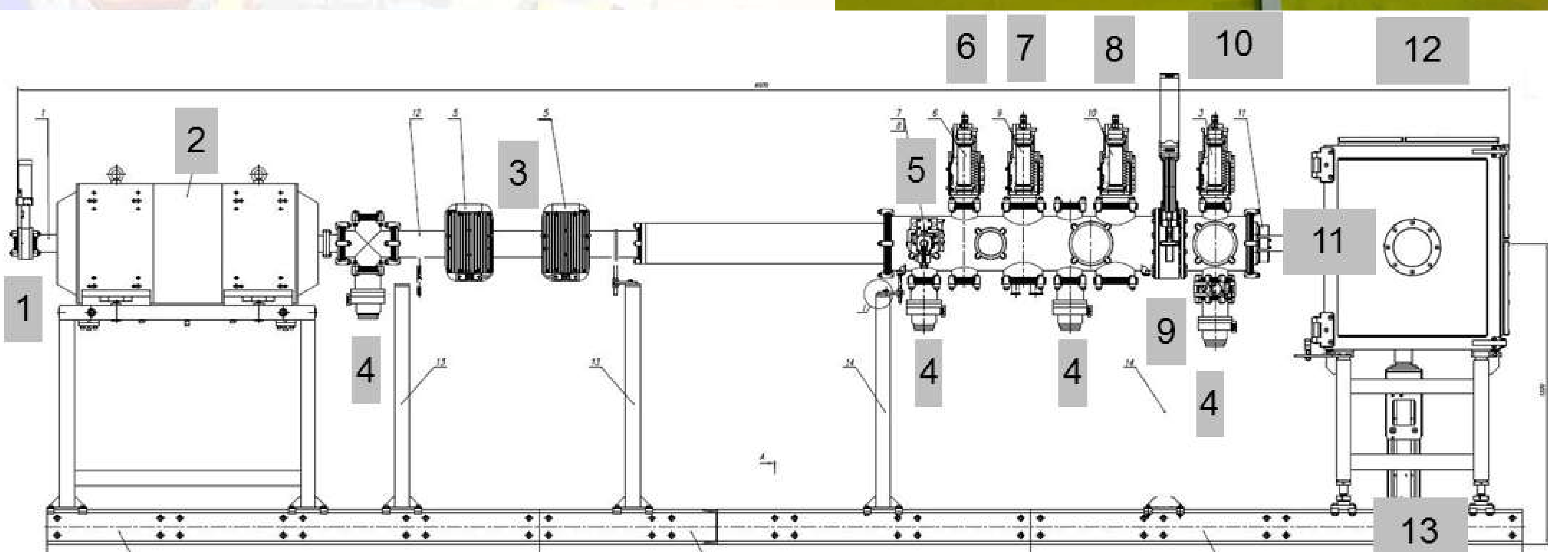
- Dedicated beam-line for high energy (3 6 AMeV) ions (usially Ne, Ar, Kr, Xe, Fe or Bi)
- Irradiation area – 200x200 mm^2.
- Beam uniformity better then 30%
- Beam flux 1 10^5 cm^{-2}s^{-1}





Main components of the high energy beam-line.

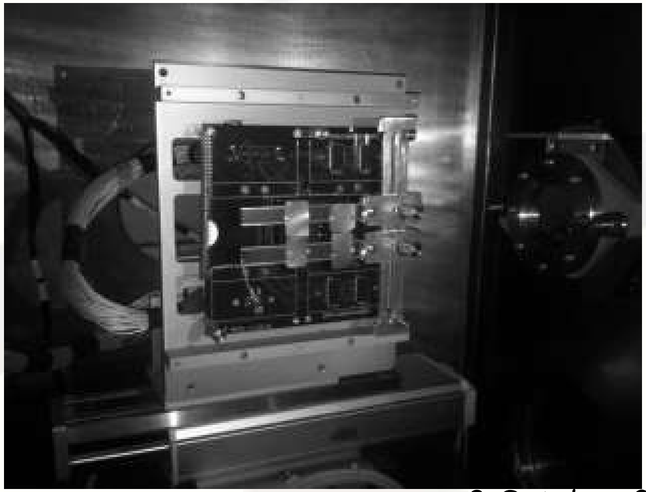
1. vacuum gate valve (1 and 9)
2. quadrupole lenses
3. steering magnets
4. turbo molecular pumps
5. beam monitoring system (5, 6, 8, 10, and 11)
7. energy measurement system
12 the user target chamber
13 remote movement



Irradiation chamber for HE

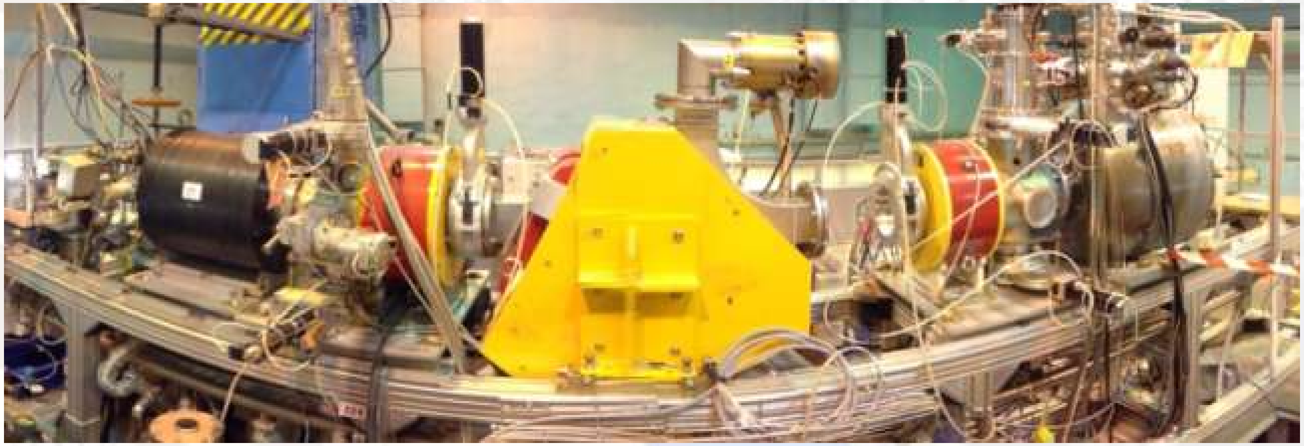
Design of the experimental chamber allows:

- 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.

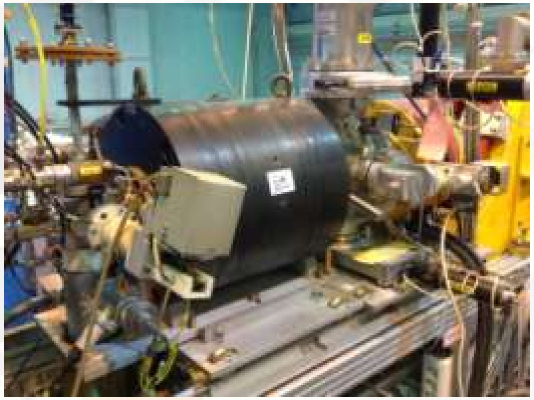


ECR source modernization up to the DECRIS-SC2 level

The main motivation of this update is the production of high charge state heavy ions which could boost the available beam energy and beam currents out of the U-400m cyclotron. On the other hand, another goal of the DECRIS-SC2 is to develop a compact superconducting ECR ion source with a high performance at 14 GHz which allows replace easily old room temperature ion sources from both cyclotrons keeping many existing subsystems.

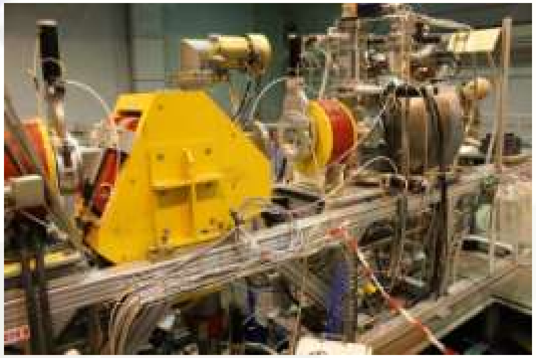


a new ECR ion source is designed for high LET and high penetration of the DUT



DECRIS-2 "warm"

From Li to Xe



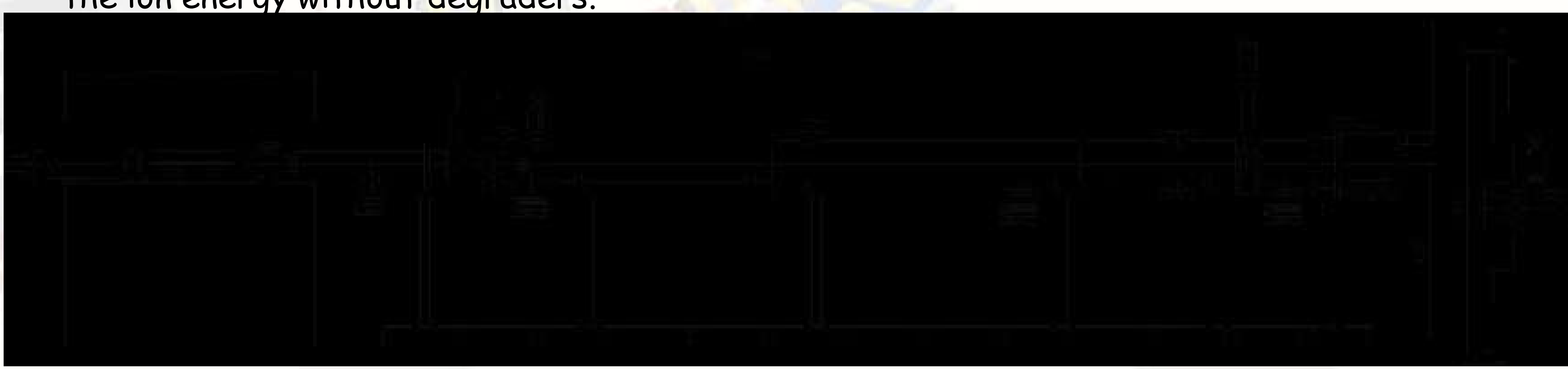
DECRIS-SC2 superconducting

From Kr to Bi

The NEW low energy ion bean line on U400

Main features of the new facility are:

- 200 mm x 155 mm irradiation area
- beam uniformity over irradiation area better then 10%
- Ne, Ar, Fe, Kr, Xe, Bi ions with 3-6 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.



Inside infrastructure

"All include" infrastructure was created in one place in the way to provide to the users the most friendly irradiation procedure. All steps are located in one building. At the end of the run the user has all the information concerning the irradiation he did. During the run the user could control in online mode all the beam parameters like beam energy, flux and uniformity.
Moreover, after the test, the user could obtain all trends information offline using the dedicated server.

- Providing the access to users (including the foreign ones)
- Ensuring of the equipment import and export
- Dedicated rooms for the test preparation and testing itself located near the accelerator.
- Availability of accommodation infrastructure.
- Radiobiological and others researches.

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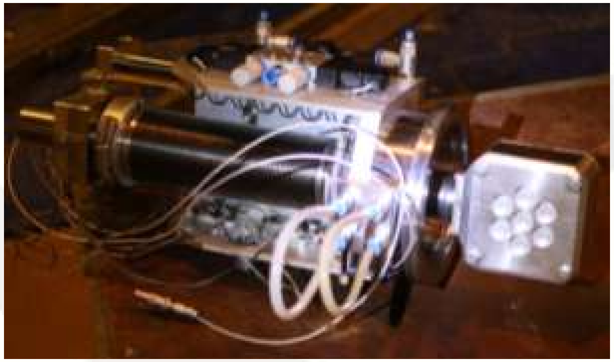
Ion beam parameters to be provided and controlled during the test.

- Providing the LET level up to 100 MeV*cm^2/mg - energy variation.
- Ion range in Si not less than 30 mkm, what corresponds E≥3 MeV/nucleon
- Irradiation area not less 10 cm^2
- Beam uniformity better than 30%
- Beam flux in the range of 10^2 10^5 ions per second per cm^2
- Online energy measurement

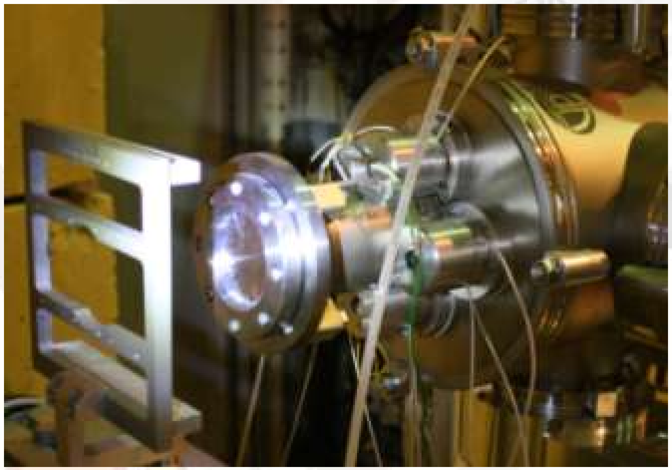
Ion beam diagnostic: Primary tuning

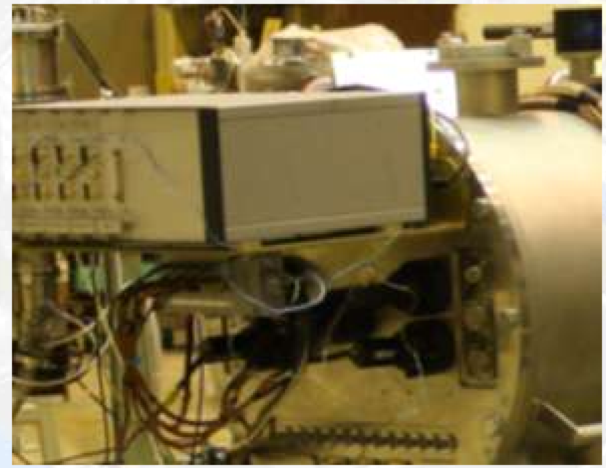
- For the primary beam tuning and flux control we use sets of luminophors and particle detectors - proportional counters and scintillators based detectors.



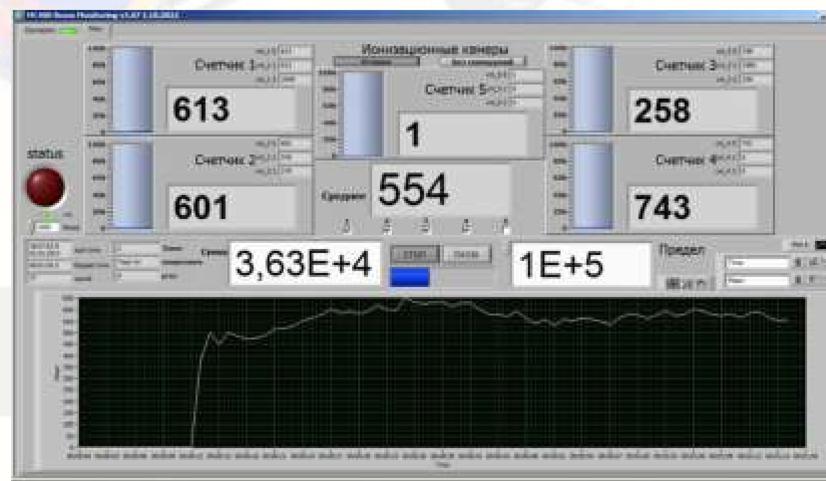
Ion beam diagnostic : Beam flux control

- The beam spatial distribution and flux value are determined using two arrays of five and four active particle detectors- proportional counters and scintillators based detectors.

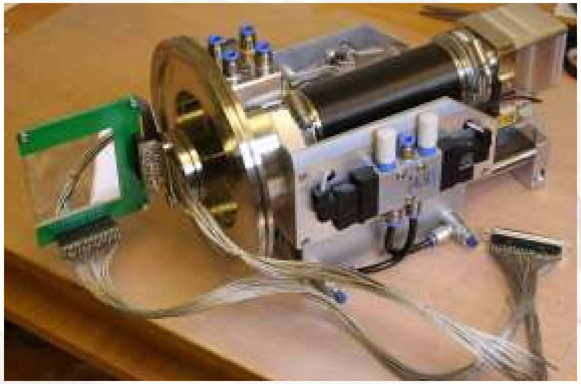




- Ion beam diagnostic software

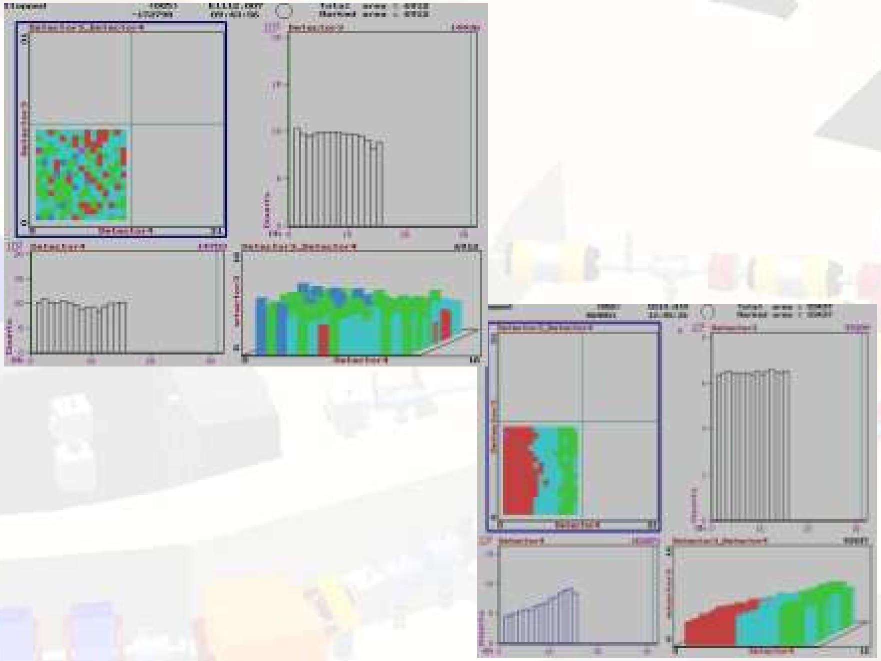


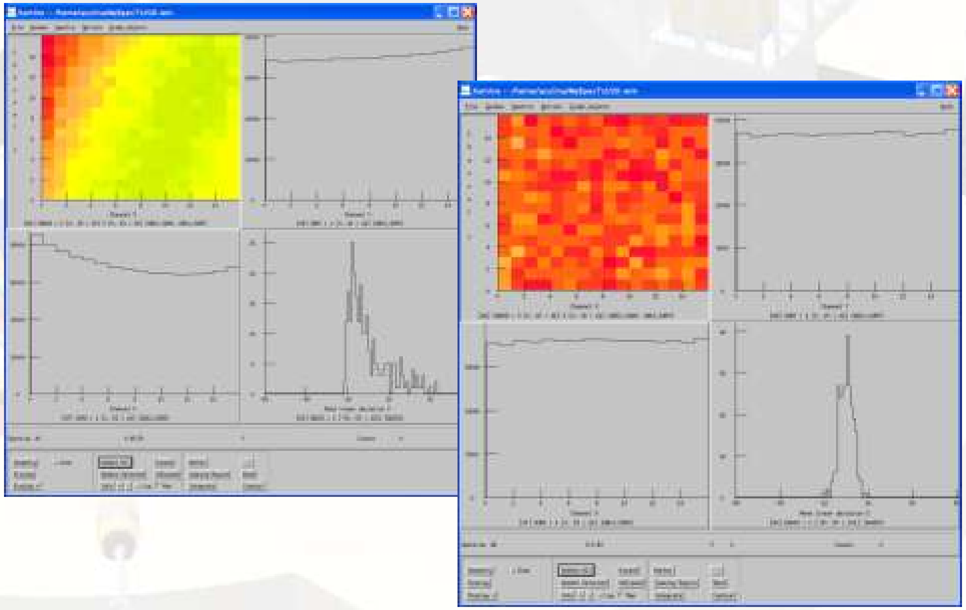
Fine tuning: using double side Si strip detector



Fully covering the beam spot

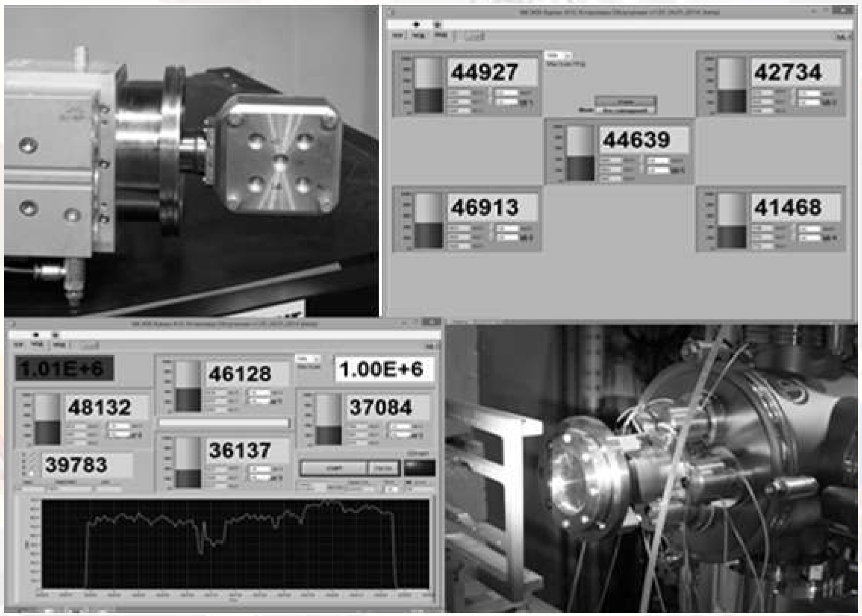
- Beam profile 64 x 64 mm^2 , strip width = 4 mm.
- Dual axes (X – Y) orthogonal detection

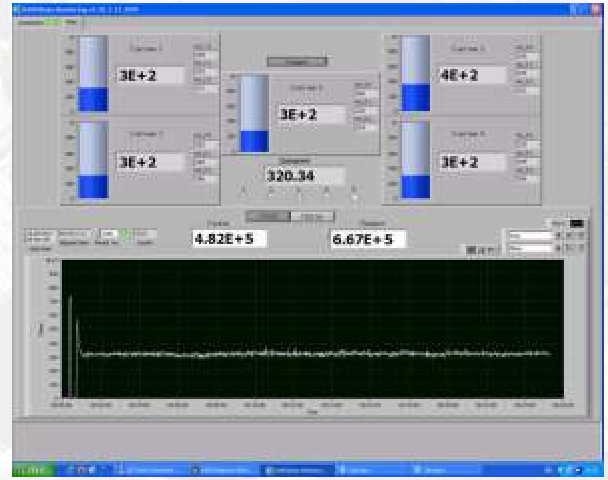


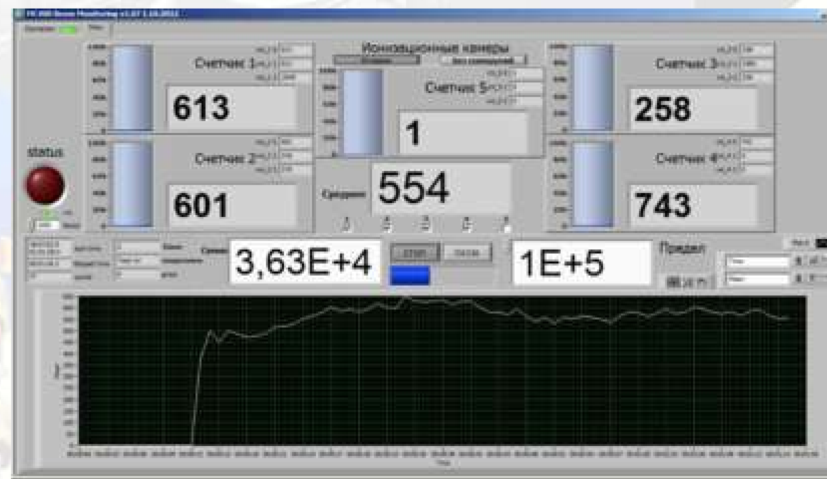


- Spatial ion beam uniformity in irradiation area of 60 mm in diameter is better than 10%

The ion beam control system visualization.





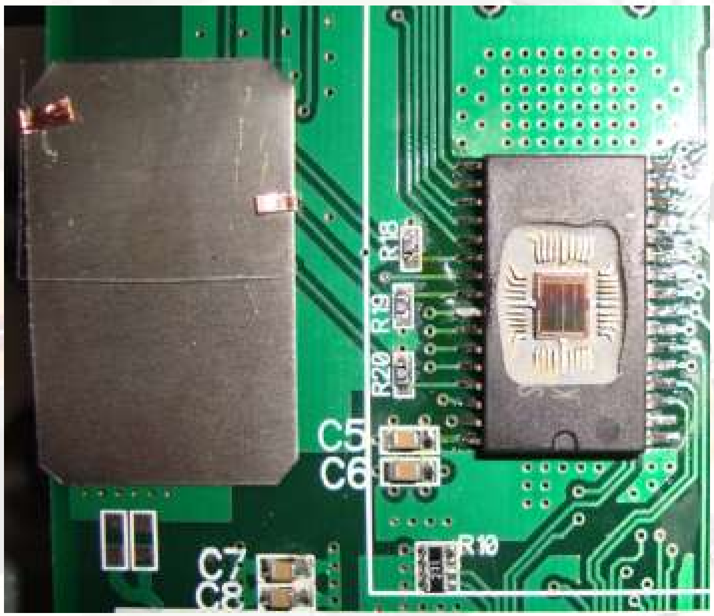


Nondestructive beam monitoring during irradiation – viewing beam around DUT

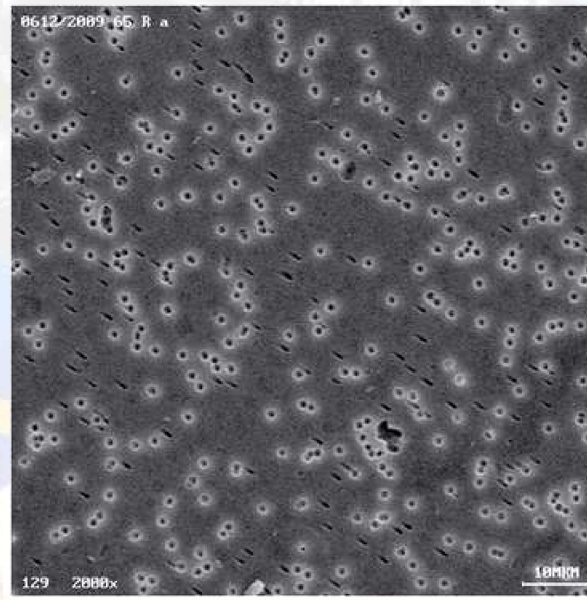
Ion beam diagnostic : Beam flux control/Polymer track detectors

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

LET etching threshold for ion tracks in : polycarbonate – 2.5 MeV/(mg/cm^2)
polyethylene terephthalate – 8 MeV/(mg/cm^2)



Polymer track detector and the DUT

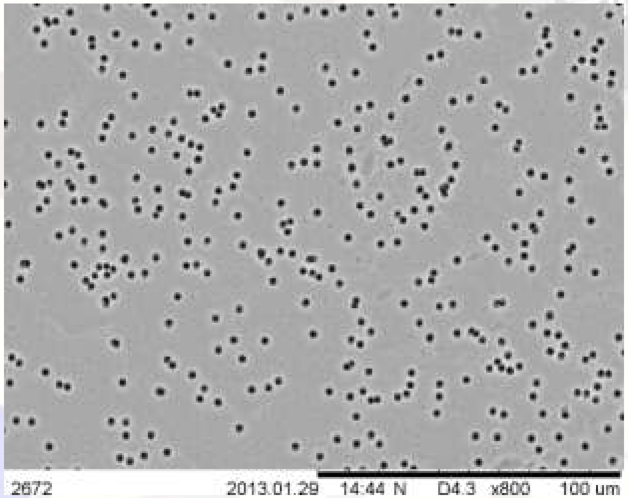


SEM micrograph of polymer track detector

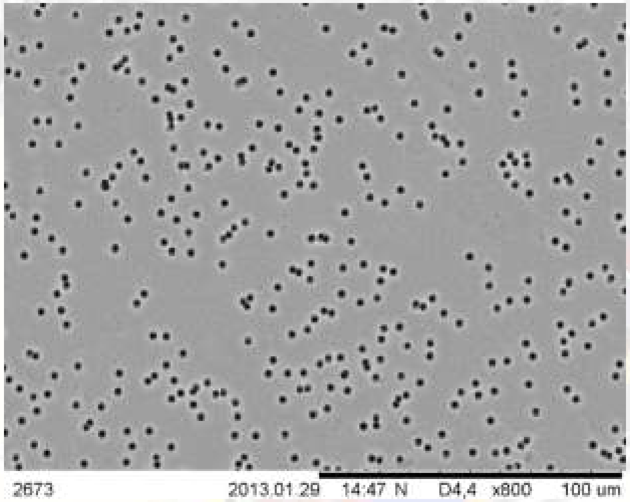
The result usually available for user in ONE hour after irradiation test.

Ion beam diagnostic : Beam flux control/Polymer track detectors

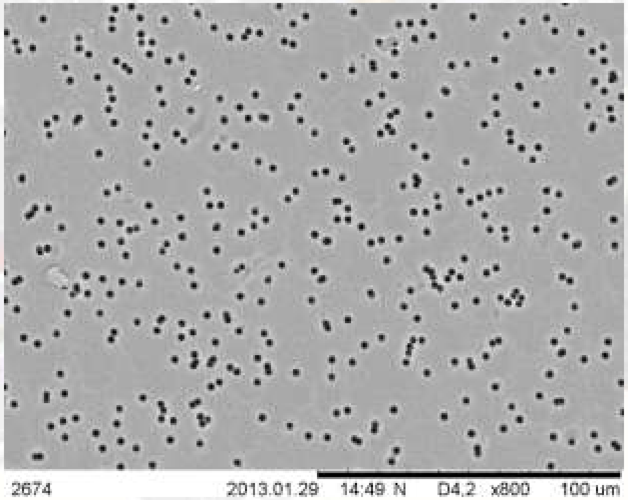
Ar (35.5 MeV/n, ion fluence 10^6 cm^{-2}) + polycarbonate



E =33.5 MeV/n
LET= 5.37
MeV/(mg×cm^2)



E =23.5 MeV
LET =6.8
MeV/(mg×cm^2)

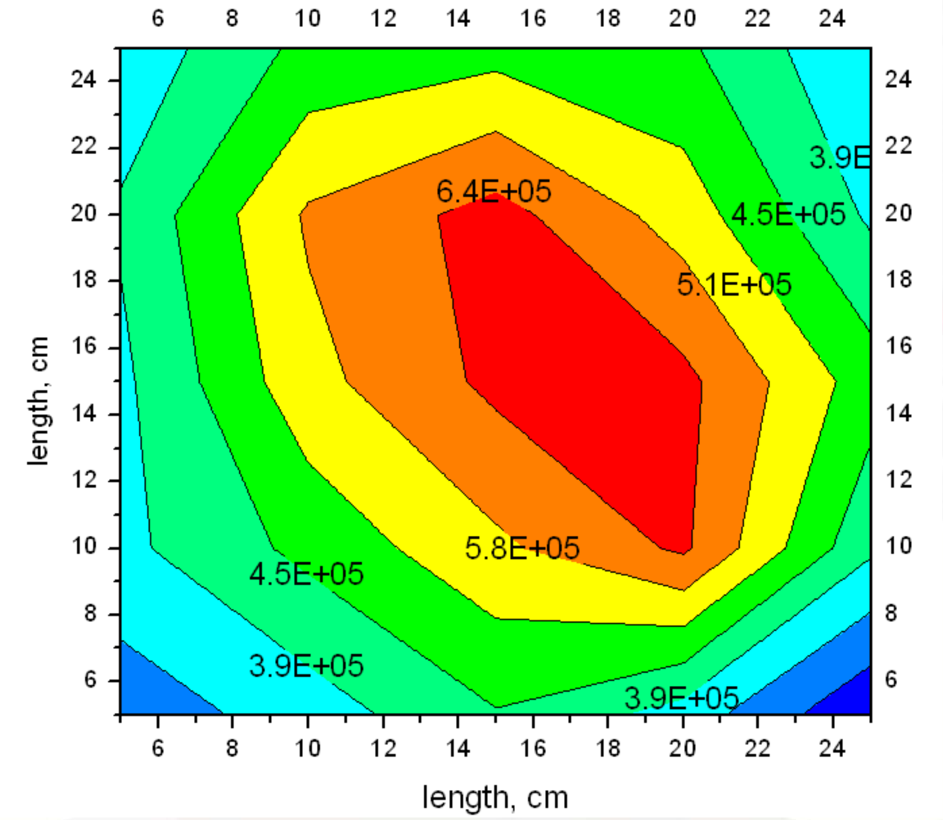


E =9 MeV/n
LET= 13
MeV/(mg×cm^2)

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

Ion beam diagnostic : Beam flux control/Polymer track detectors

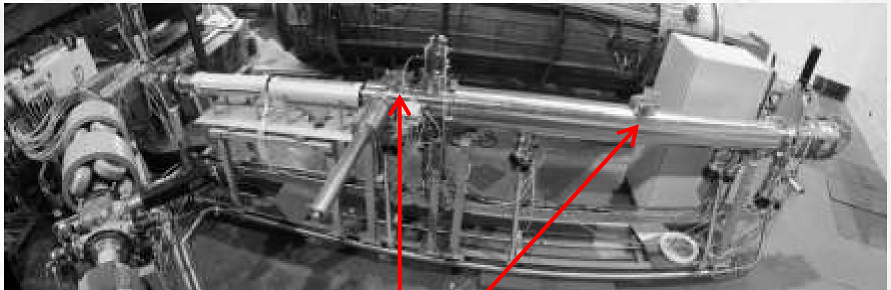
Ion beam distribution over the irradiating area



Ar beam

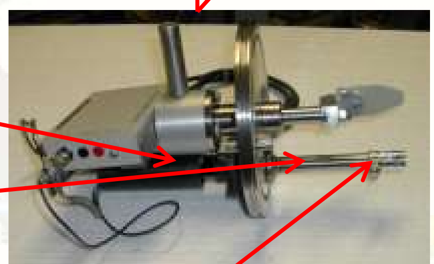
Ion beam monitoring and control

TOF energy measurement sensors, L=1.602 m.



PMT

light guide



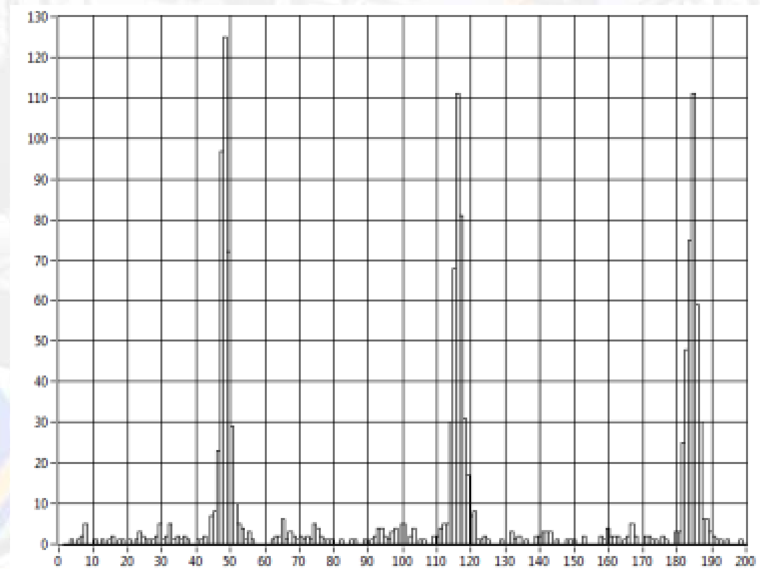
scintillator covered by Al foil

The TOF spectrum measured for Ar ions(initial energy - 301 MeV) at the U400M cyclotron. Total ion energy (after 5 mkm of Ta 250 MeV) is determined by time between zero and first bunch maximum. Time between maxima of bunches corresponds to cyclotron RF frequency.

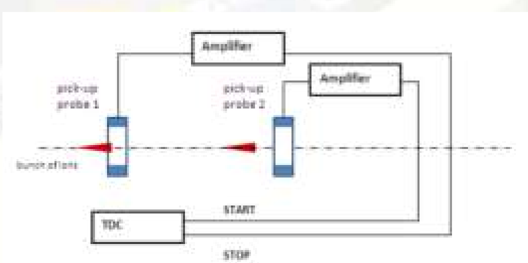
Using degraders and energy variation you have to provide on-line energy measurement

Comparison of the measured and calculated Ar ion energy

counts

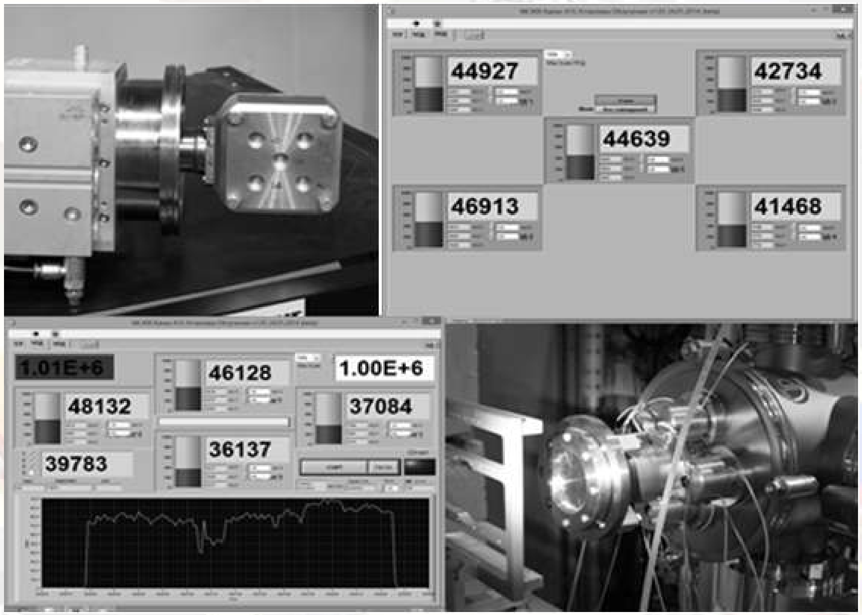


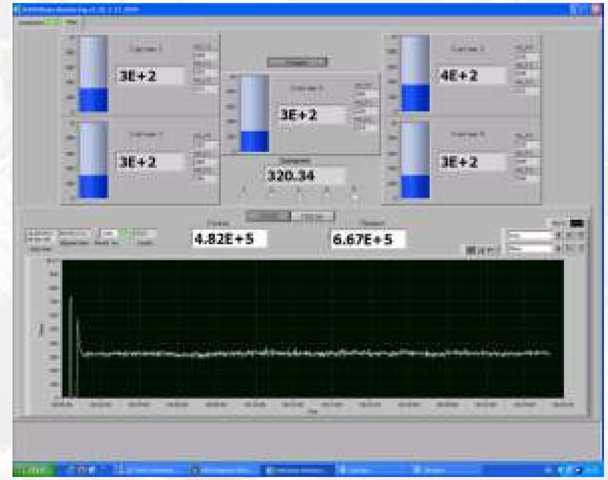
time, ns

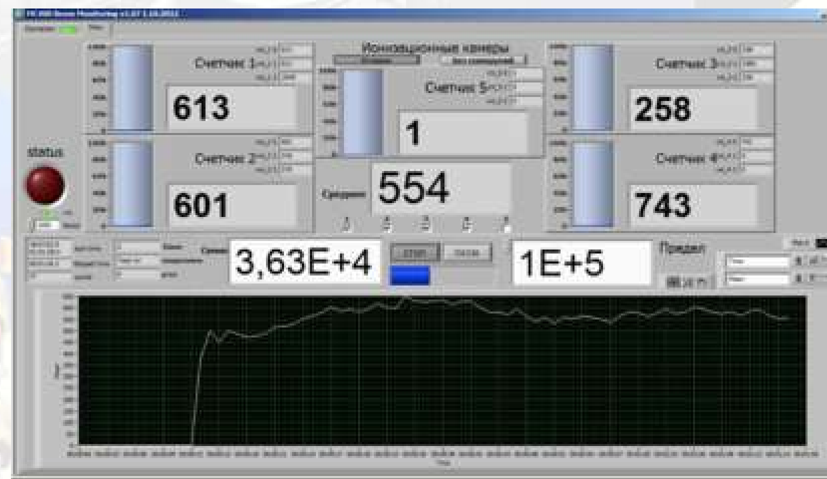


Ta degrader thickness, μm	0	5	9	12,5	15
Measured time of flight, ns	42±0.5	46±0.5	50±0.5	56±0.5	61.5±0.5
Measured energy, MeV/nucleon	7.53±0.16	6.28±0.14	5.32±0.10	4.24±0.08	3.51±0.06
Calculated energy (SRIM), MeV/nucleon	7.53±0.16	6.28±0.17	5.21±0.18	4.28±0.19	3.47±0.20

The ion beam control system visualization.







Nondestructive beam monitoring during irradiation – viewing beam around DUT

Summarizing before future….

- ✓ The test facility was created and now available for worldwide users.
- ✓ Numerical results of the beam flux on DUT in one hour after irradiation !
- ✓ Beam parameters are control under the Russian Federation user and world' requirements.
- ✓ The scientific and technical potential of FLNR in the field of the heavy ion beam diagnostic is engaging in the modernization and further development of monitoring and control systems.

Technical requirement for the future test facility

1. Ion range from B to Bi
2. Energy range 3-50 MeV/nucleon
3. Beam intensity от 10 до $1*10^8$ ions/sec.
4. Beam uniformity: < 20%
5. Irradiation area 200*200 mm.
6. Quick ion change – ion cocktail
7. Working temperature : -25 125 C
8. Pressure inside the test chamber: 10^{-5} 760 torr.
9. Time of the DUT change – 20 min.
10. time to change the ion type:
    - In the framework of cocktail: 15 min
    - Change the cocktail: 4 hour.
11. time of the energy changing: 15 min
12. Time of the beam intensity changing: 5 min
13. All the year availability with the technical maintenance ~ 1 month per year.
14. LET range 1-100 MeV*cm m $^{-2}$ /mg.
15. microbeams

New TEST facility

Radiation tests and radiobiological researches

Realization time – 3 year

Inside:
cyclotron, ion sources,
beam lines, targets rooms
and all engineering system

Beam operation time up to 7000 hours per year

Since 2009 6 cyclotrons was created in FLNR JINR in Dubna.
The 7th is under construction now.

Innovation Special Economic Zone "Dubna"

1. Geography :
   1. Sheremetyevo – Dubna : 1,5 hour
   2. Moscow– Dubna : 2 hour
   3. Tver'– Dubna : 2 hour

2. Federal support for residents

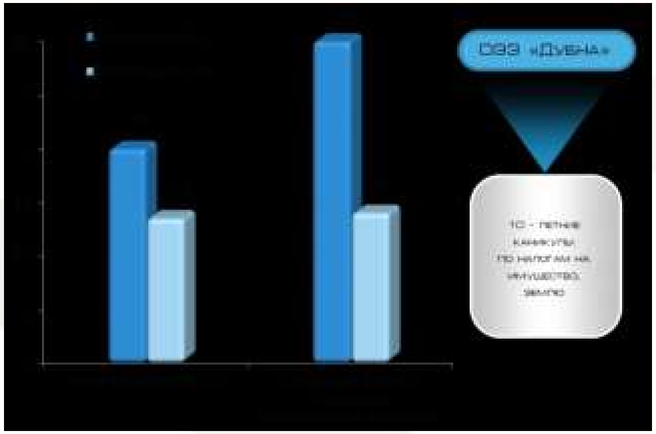
3. Non custom for equipment export - import.

4. New test facility exactly matches the main topics of the zone:

- Nuclear physics (nanotechnology)
- Bio- and medical technologies
- IT (information technologies)
- Complex technological systems design

5. Already exist and operate two cyclotrons (ions of Ar-Xe) with the energy 2,4 MeV/nucleon for the track membrane production

6. Specialized staff are concentrated in Dubna.
   Around 200 specialists in the field of heavy ions accelerator creation and operation.



Thank you for your attention

SEE testing facilities at FLNR accelerators complex: state of art and future plans

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