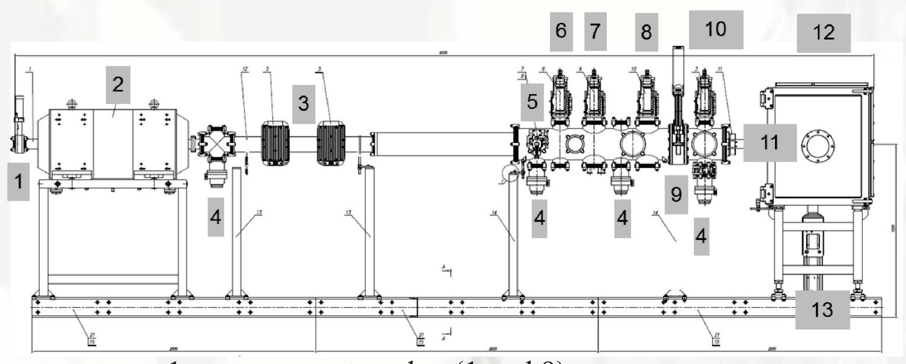
HEAVY ION BEAM FLUX AND IN-SITU ENERGY MEASUREMENTS AT HIGH LET.

S.V.Mitrofanov[1], I.V.Kalagin[1], V.A.Skuratov[1], Yu.G.Teterev[1], V.S.Anashin[2].

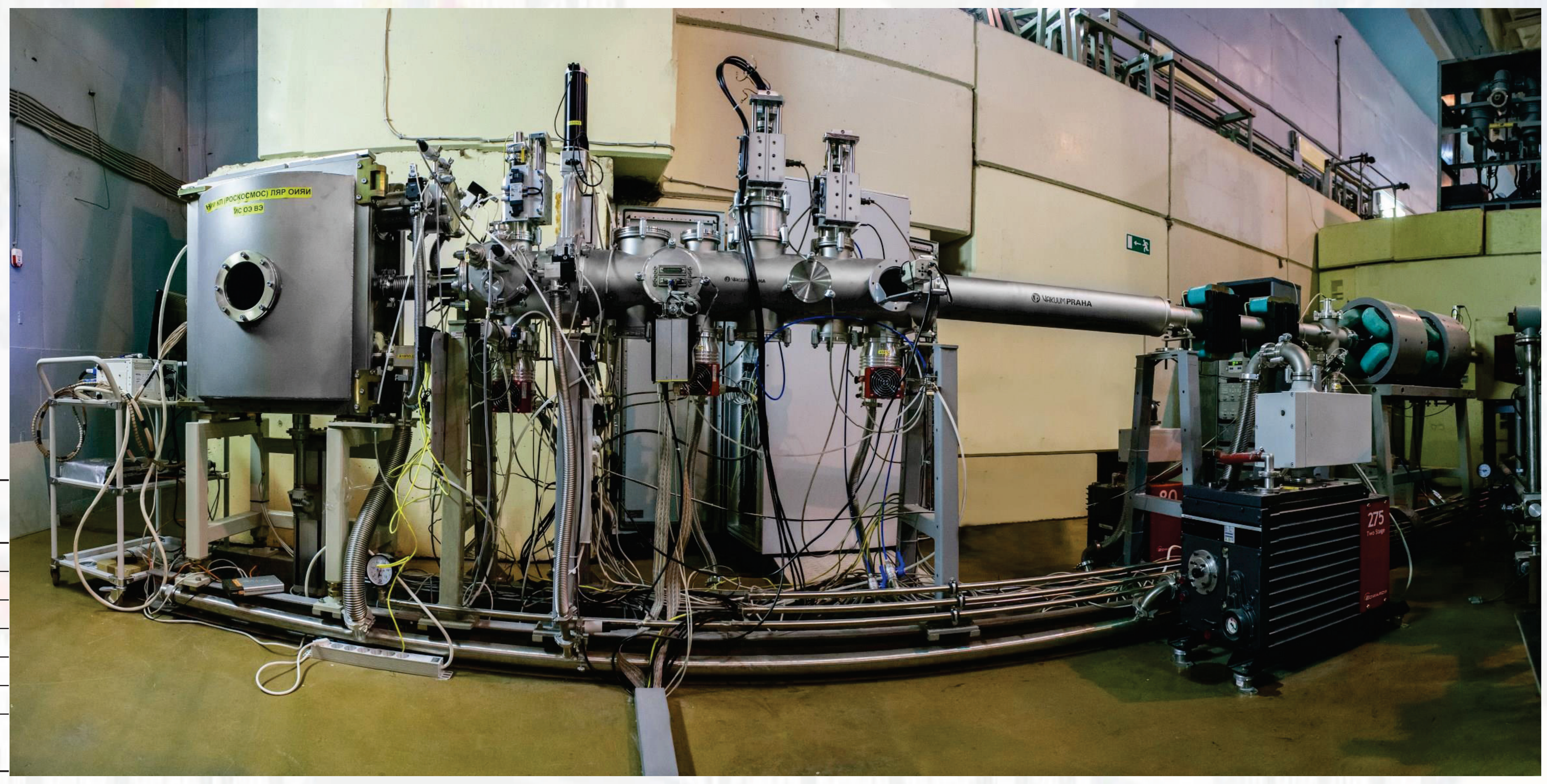
1. Flerov Laboratory of Nuclear Reactions, Joint Institute for Nuclear Research, Dubna, Russia
2. Branch of Joint Stock Company United Rocket and Space Corporation – Institute of Space Device Engineering, Moscow, Russia

The Russian Space Agency with the TL ISDE involvement has been utilizing ion beams from oxygen up to bismuth delivered from cyclotrons of the FLNR JINR accelerator complex for the SEE testing during last seven years. The detailed overview of the diagnostic set-up features used for low intensity ion beam parameters evaluation and control during the corresponding experiments is presented. Special attention is paid to measurements of ion flux and energy at high LET levels and evaluation of ion beam uniformity over large (200x200 mm) irradiating areas. The online non-invasive (in-situ) time of flight technique designed for low intensity ion beam energy measurements based on scintillation detectors is considered in details. The system has been successfully commissioned and is used routinely in the SEE testing experiments.



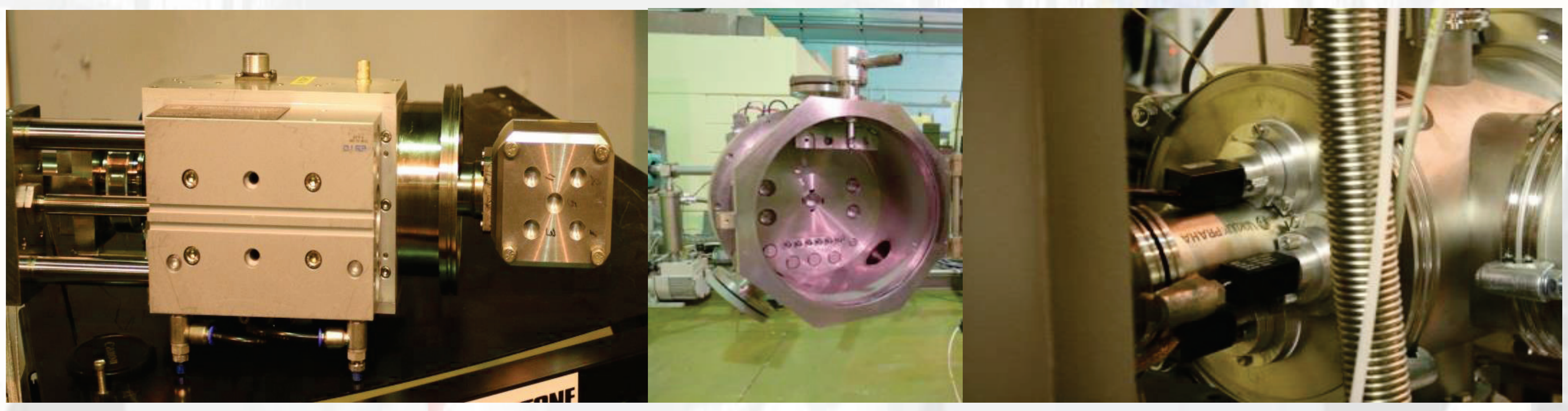
1. vacuum gate valve (1 and 9)
2. quadrupole lenses
3. steering magnets
4. turbo molecular pumps
5. beam monitoring system (5, 6, 8, 10, and 11)
7. energy measurement system
12 the user target chamber
13 remote movement

Accelerated ion	Extracted ion	Energy, MeV	LET, MeV/(mg/cm^2)	Ion flux, cm^{-2}s^{-1}
$^{16}O^{2+}$	$^{16}O^{8+}$	56±3	4.5	1 ÷ 10^5
$^{22}Ne^{3+}$	$^{22}Ne^{10+}$	65±3	7	1 ÷ 10^5
$^{40}Ar^{5+}$	$^{40}Ar^{16+}$	122±7	16	1 ÷ 10^5
$^{56}Fe^{7+}$	$^{56}Fe^{23+}$	213±3	28	1 ÷ 10^5
$^{84}Kr^{12+}$	$^{84}Kr^{32+}$	240±10	41	1 ÷ 10^5
$^{136}Xe^{18+}$	$^{136}Xe^{46+}$	305±12	67	1 ÷ 10^5
$^{209}Bi^{22+}$	$^{209}Bi^{58+}$	490±10 (820±20)	95 (100)	1 ÷ 10^5

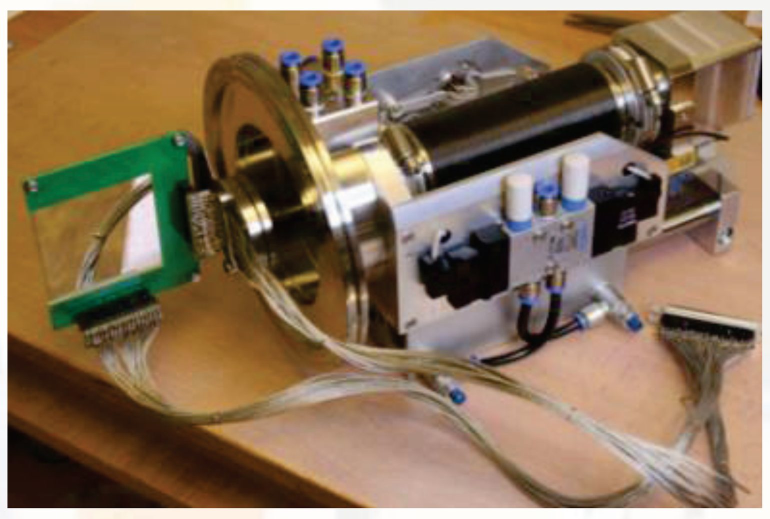


- ✓ Dedicated beam-lines for SEE testing (up to 60 AMeV) ions (O, Ne, Ar, Fe, Kr, Xe, Bi)
- ✓ Irradiation area: up to 200*200 mm*mm.
- ✓ Beam uniformity 10÷30%
- ✓ Beam flux 10 ÷ 10^5 cm^{-2}s^{-1}
- ✓ Two operating testing modes: at atmospheric (ATM) pressure and at vacuum (VAC) of 10 mBar.
- ✓ The DUT frame could be remotely moved in X-Y directions (to place the DUT into the beam spot area with accuracy 0.1 mm) and can be tilted to the ion beam direction within 0÷90 degrees using turning gear.
- ✓ Installation of degraders set.

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

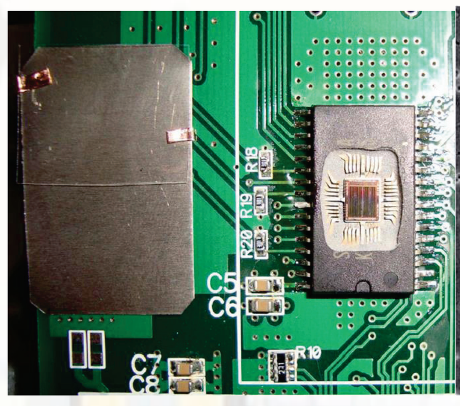


Fine tuning of the beam uniformity: using double side Si strip detector

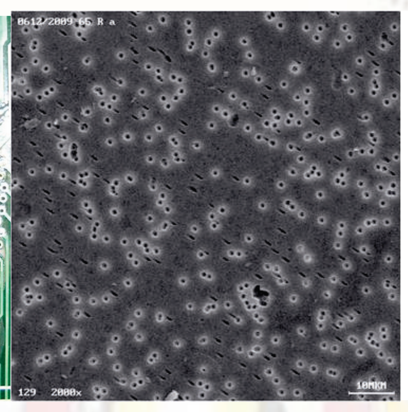


- Fully covering the beam spot
- Beam profile 64 x 64 mm^2 , strip width = 4 (2) mm.
- Dual axes (X – Y) orthogonal detection

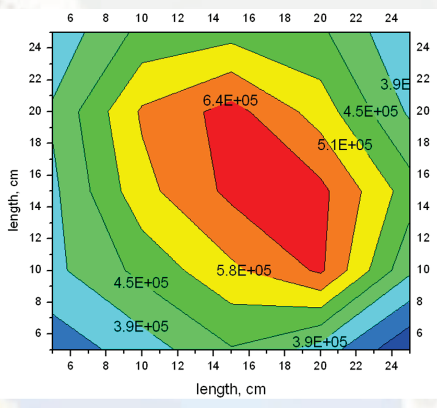
Ion flux is controlled by using polycarbonate or polyethylene terephthalate track detectors placed in close vicinity of any testing device in all irradiation runs.



Polymer track detector and the DUT



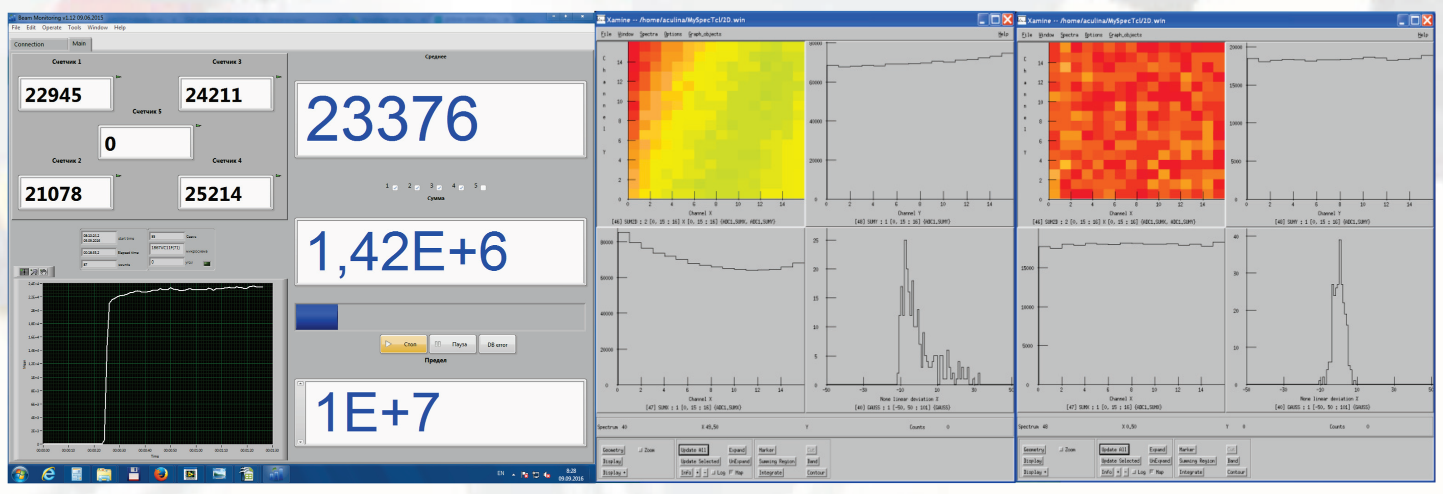
SEM micrograph of polymer track detector



Ar beam distribution over the irradiating area.

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

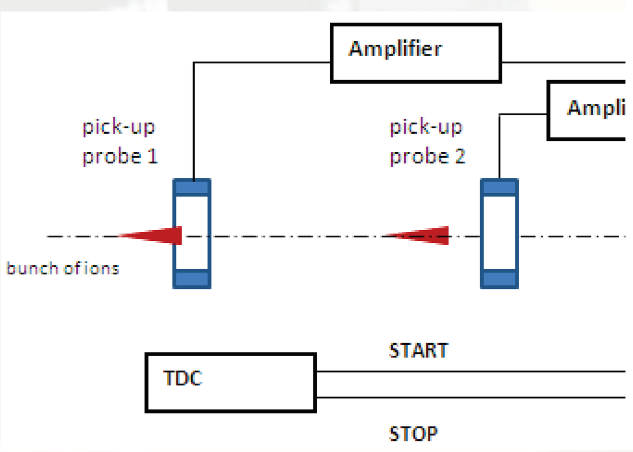
Nondestructive beam monitoring during irradiation – viewing beam around DUT



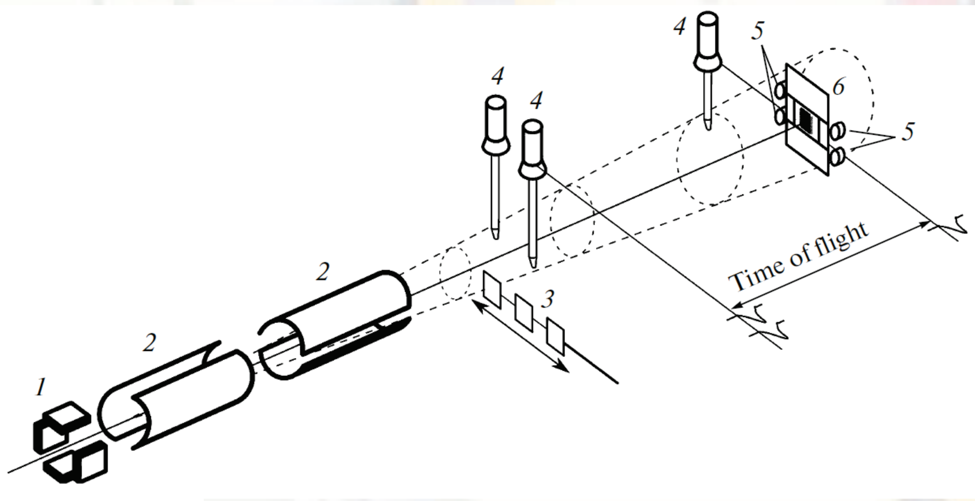
The ion beam control system visualization.

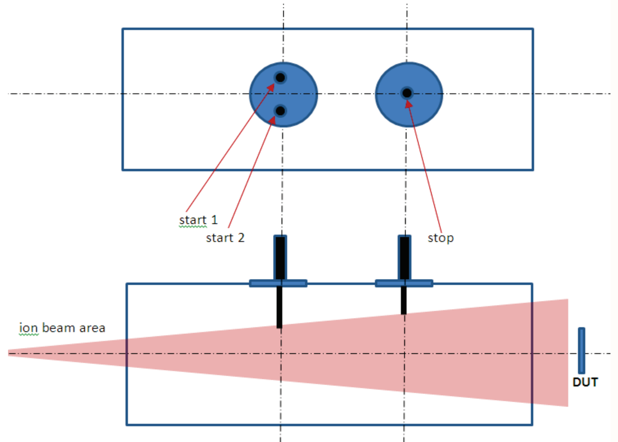
Measurements of the energy during tests.

We realized the online noninvasive time of flight technique in a substance similar to the pickup probes method, with the difference of using here scintillation detectors instead. Detectors with a substantially smaller size compared with the scanning beam cross section are used. They are mounted on the periphery of the scanning ion beam in such a way that they don't overshadow each other and the device under test, as shown at figures below.



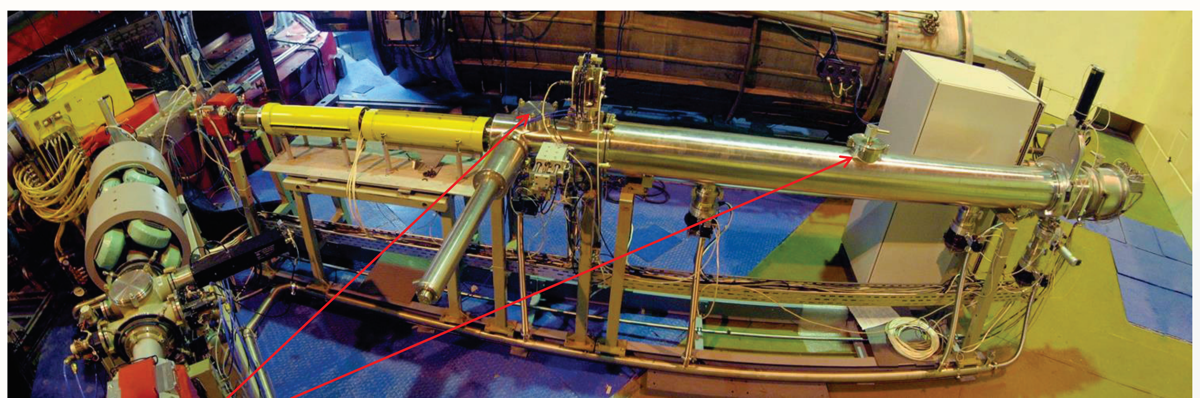
Well-known scheme of the TOF set-up measurements

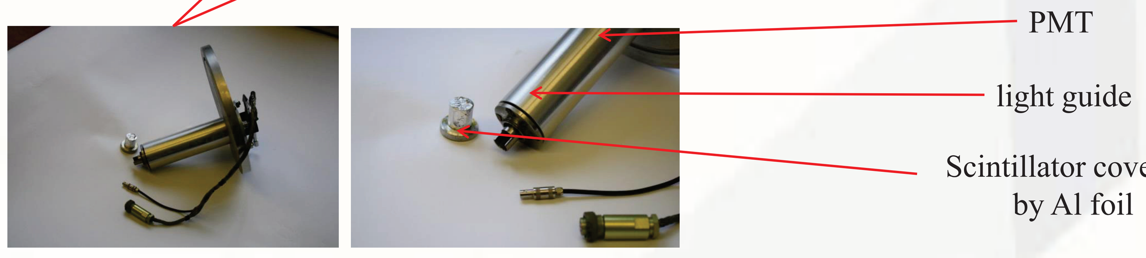




Scheme of the ion beam transport line and experimental set up for SEE testing at the U400M cyclotron:
1—Beam positioning magnet; 2—X–Y magnetic scanning system; 3—set of degrading foils; 4—scintillation detectors; 5—proportional counters; and 6—device under test.

TOF energy measurement sensors base is L=1.602 m.





Comparison of the measured and calculated (SRIM) Ar ion energy

Ta degrader thickness, μm	Measured time of flight, ns	Ion energy, MeV/nucleon	
		measured	calculated
0	42 ± 0.5	7.53 ± 0.16	7.53 ± 0.16
5	46 ± 0.5	6.28 ± 0.14	6.28 ± 0.17
9	50 ± 0.5	5.32 ± 0.10	5.21 ± 0.18
12.5	56 ± 0.5	4.24 ± 0.08	4.28 ± 0.19
15	61.5 ± 0.5	3.51 ± 0.06	3.47 ± 0.20

List of the measured energy values for different ion species

Ion	Beam energy, MeV/nucleon
^{40}Ar	33,5
^{56}Fe	29,5
^{20}Ne	53
^{132}Xe	24,5
^{84}Kr	27
^{16}O	62
^{209}Bi	15.5

TOF summary

The main features:

In-situ measurement:

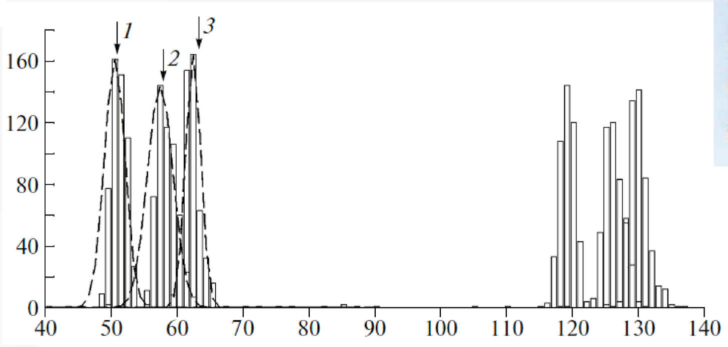
- system checked with wide energy range
- the possibility of surgical intervention;
- wide energy range measurement;
- no needs to calibrate like semiconductor detectors;

Reliability

- High radiation resistance (scintillators are changed after approximately 1000 hours of operation)

Crosscheck

The time of flight spectrum measured for Ar ions with the DRS4 Evaluation Board after passage of 9 (*1*), 12.5, (*2*) and 15 μm (*3*) Ta degrader foil. The maxima were extrapolated using the gauss function to accurately determine the center of distribution.

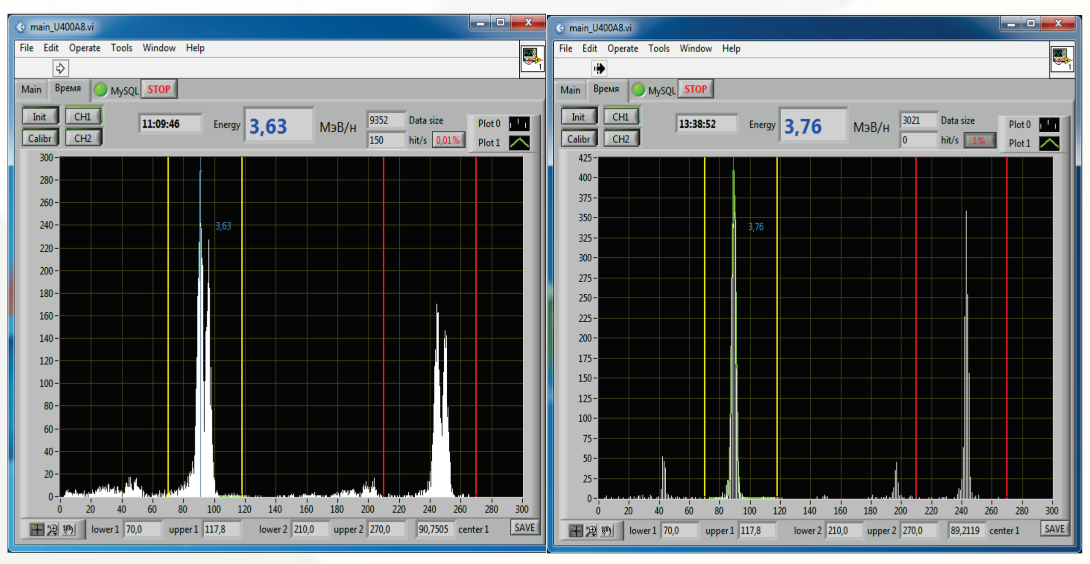


USB oscilloscope DRS4 Evaluation Board produced in PSI, Switzerland.

SmartTDC01

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

Comparison of Ar ion energy measured with the SmartTDC01 and with the PSI DRS4 Evaluation Board



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.

International Beam Instrumentation Conference IBIC 11 - 15 September 2016 Barcelona

14th September 2016, Barcelona