Session-conference of the Nuclear Physics Section of the PSS RAS, dedicated to the 70th anniversary of V.A. Rubakov

NEW TECHNIQUE OF ION IDENTIFICATION IN ACCELERATOR MASS SPECTROMETRY USING LOW-PRESSURE TPC WITH GEM READOUT

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February 20, 2025

Outline

1. Accelerator mass spectrometry
2. New concept of ion identification. Proof of Concept.
3. Experimental setup
4. Measurements of energy spectra and track ranges
5. Recent results with AMS

Isotopes used for dating

Analyzed isotopes	Half life	Stable isotopes	Stable isobars
^{10}Be	1,39 million years	^{9}Be	^{10}B
^{14}C	5730 years	^{12,13}C	^{14}N*
^{26}Al	717 thousand years	^{27}Al	^{26}Mg*
^{36}Cl	301 thousand years	^{35,37}Cl	^{36}Ar*, ^{36}S
^{41}Ca	102 thousand years	^{40,42,43,44}Ca	^{41}K
^{129}I	15,7 million years	^{127}I	^{129}Xe*

* *- isobars that do not form stable negative ions.*

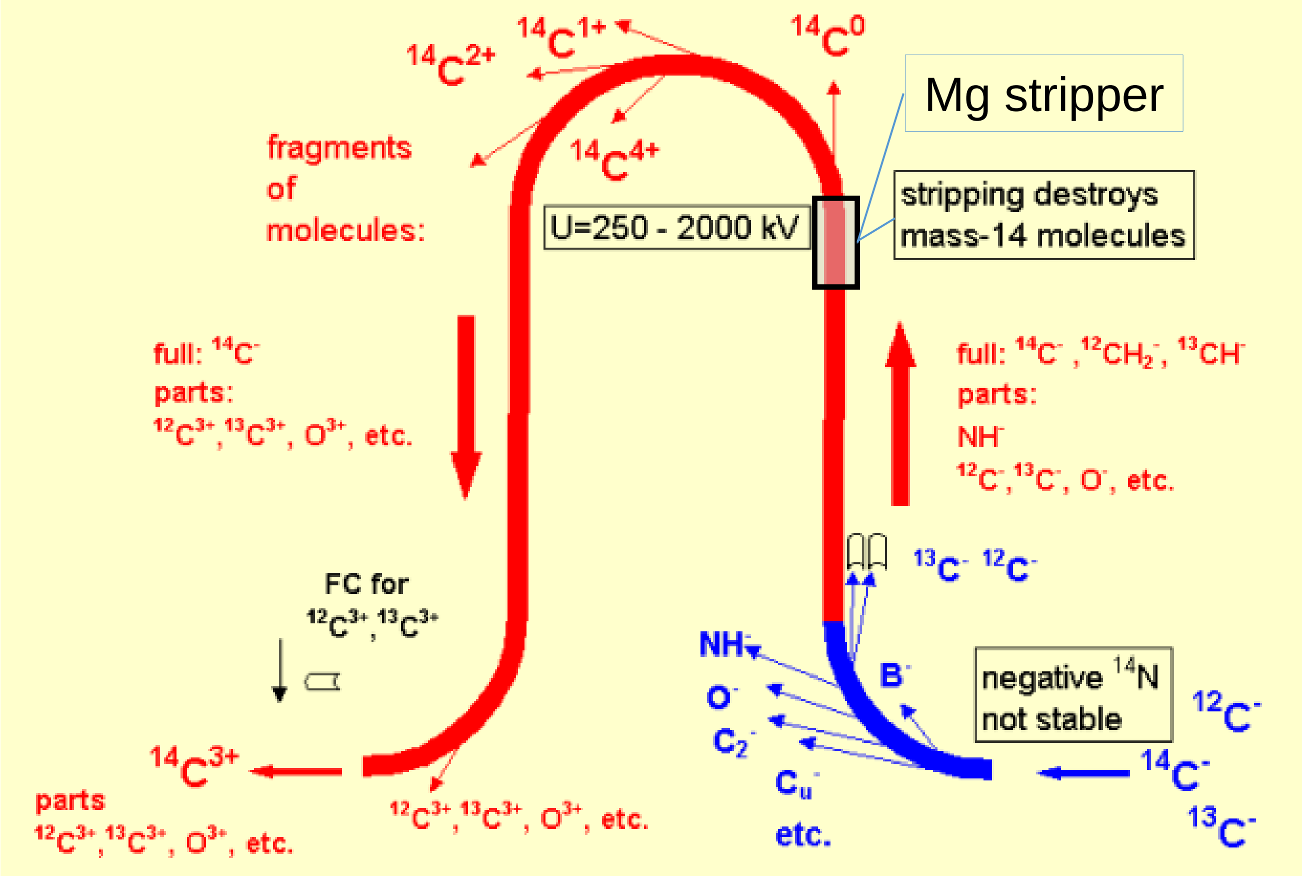
In the current AMS BINP setup the time-of-flight technique is used for the carbon isotopes separation. But that technique has a serious problem of separating the isobars - different chemical elements having the same atomic mass. The typical example are radioactive isotopes ^{10}Be and ^{10}B.

Accelerator mass spectrometry

Accelerator mass spectrometry (AMS) is an ultra-sensitive method of counting individual atoms. Usually it is the rare radioactive atoms with a long half-life. The archetypal example is ^{14}C which has a half-life of 5730 years and an abundance in living organisms of 10^{-12} relative to stable ^{12}C isotope.

AMS facilities operate in more than 100 physical laboratories worldwide, two of them are located in Novosibirsk at Geochronology of the Cenozoic Era Center for Collective Use and Novosibirsk State University.

BINP AMS



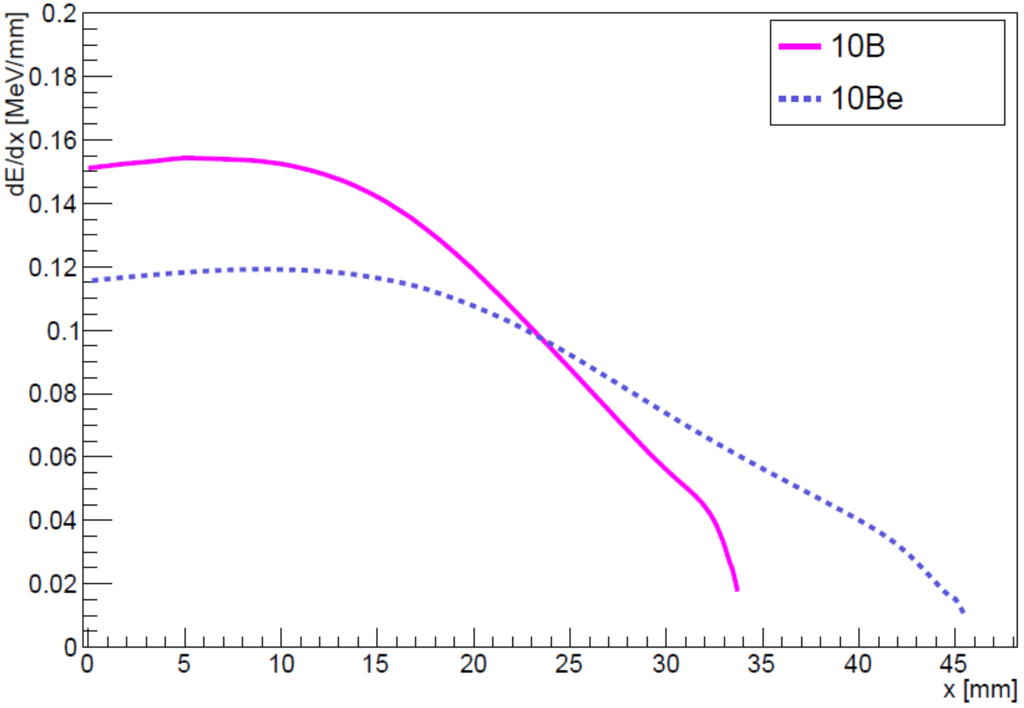
BINP AMS provides reliable separation of a pure beam of radiocarbon ions from the accompanying ion background.

1. Formation of an ion beam from atoms of the test sample
2. Ion selection at low energy
3. Ion acceleration
4. Recharging of atomic ions and destruction of molecular ions in magnesium target
5. Ion selection in a high voltage terminal
6. Ion acceleration
7. Ion selection at high energy
8. Identification and counting of ions

Traditional concept of ion identification at AMS

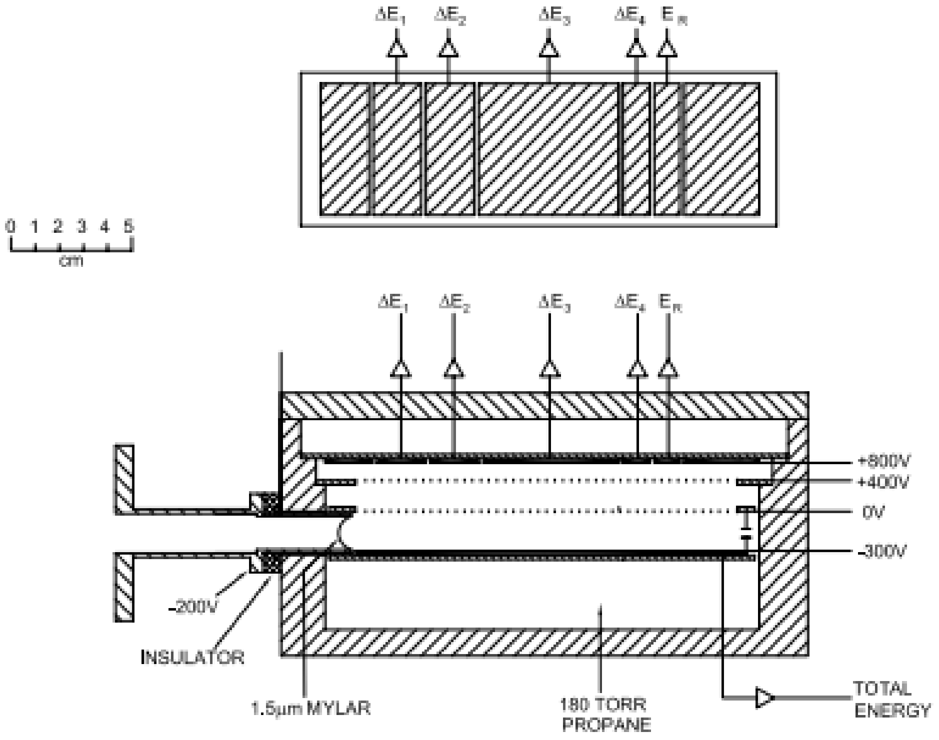
Detectors used to count the AMS isotope:

- silicon detectors;
- time-of-flight systems (*BINP AMS*);
- ionization chambers.



Ions track lengths at 50 Torr of i-C_4H_{10}

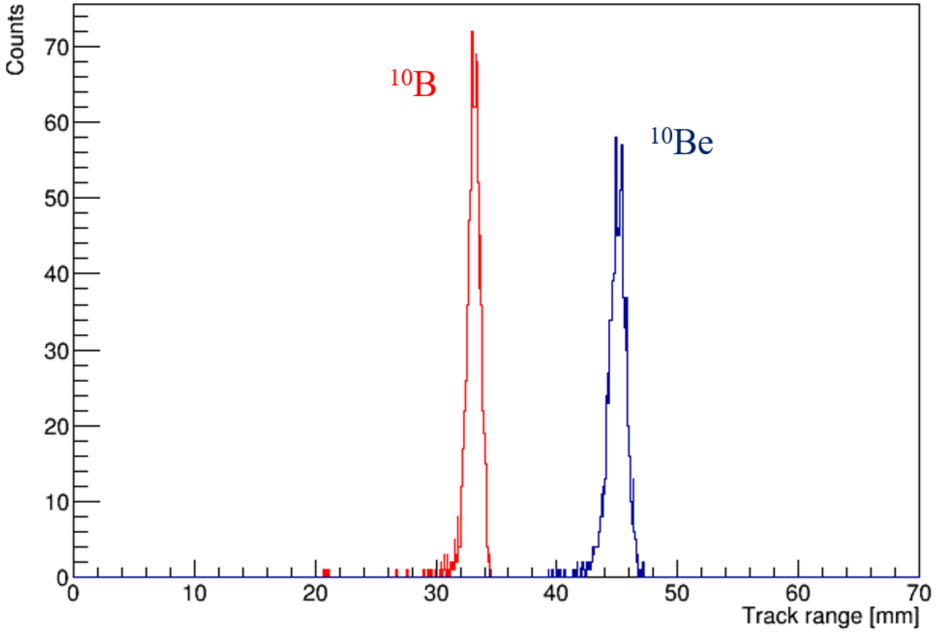
ΔE-E detectors



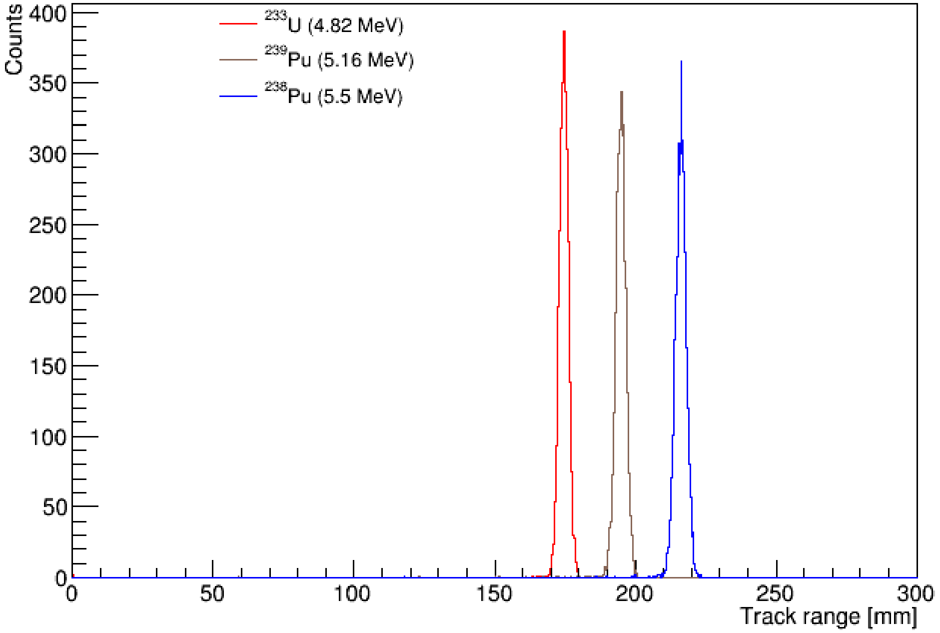
A cross section through the multi-element ionization chamber. The upper panel shows a plan view of the anode electrode.

Proof of concept: measuring track ranges

SRIM (The **S**topping and **R**ange of **I**ons in **M**atter Software) –
is a collection of software packages which calculate many features of the transport of ions in matter.



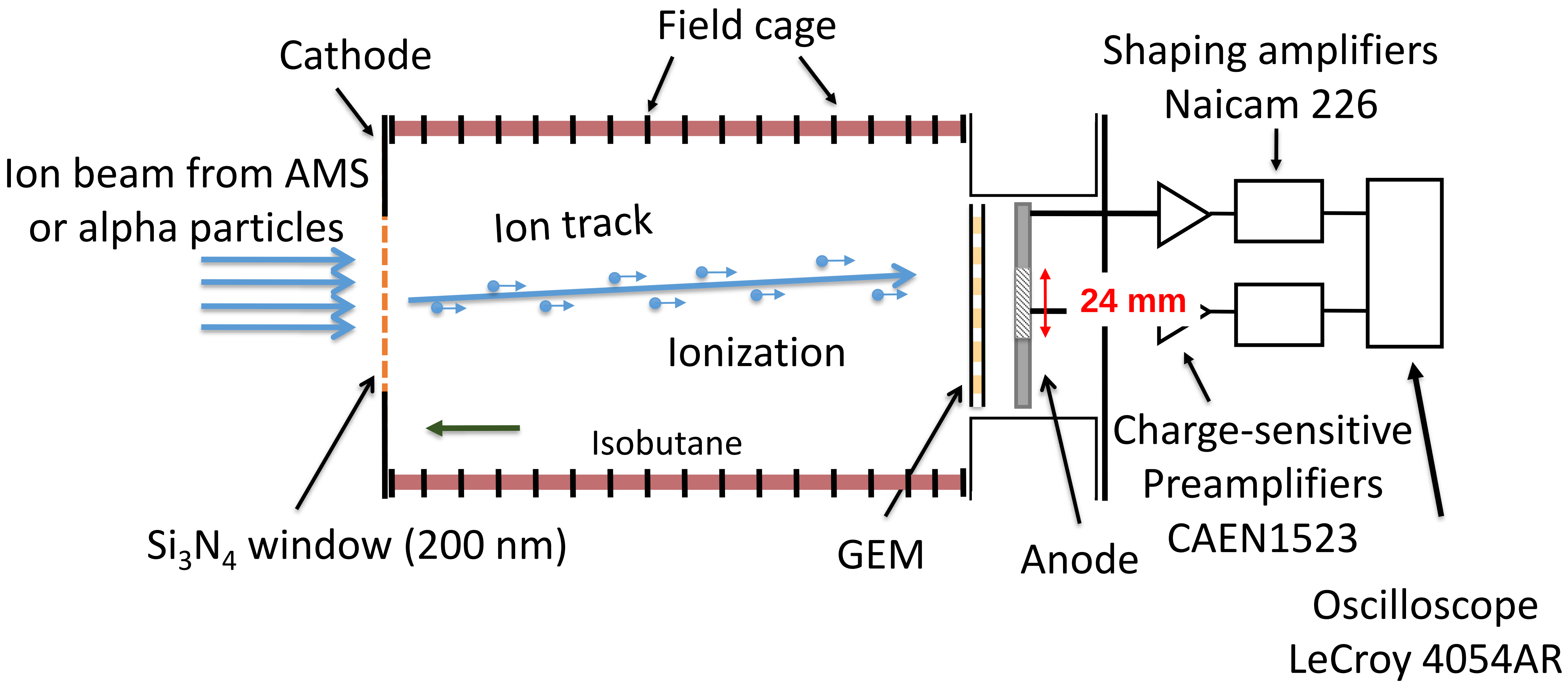
Track ranges distributions in the low-pressure TPC for 4.025MeV ^{10}B and ^{10}Be ions for 200 nm silicon nitride window and 50 torr isobutane, obtained using SRIM simulation.



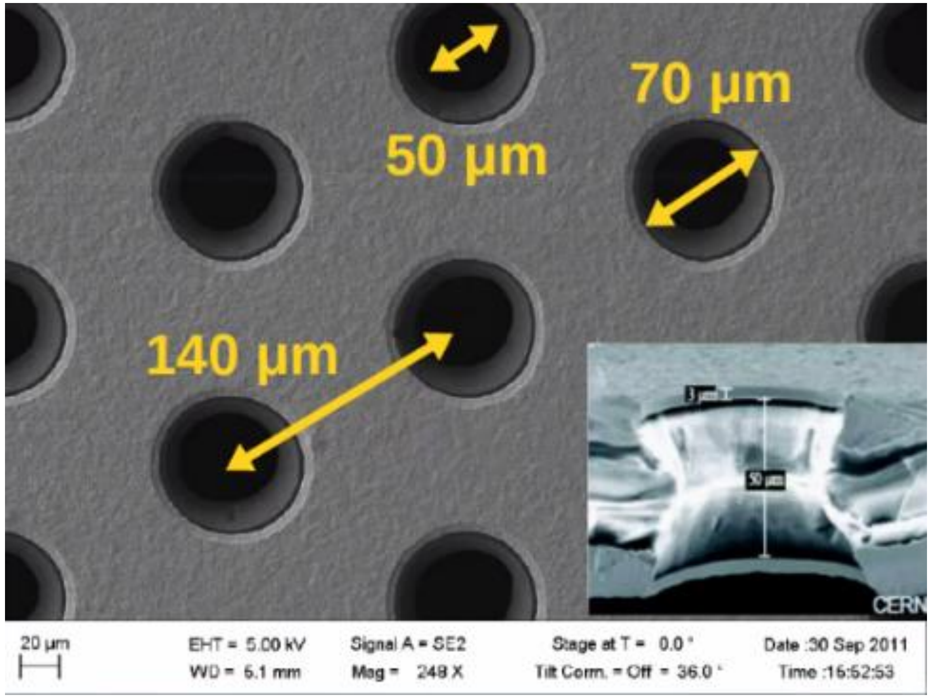
Ion ranges distributions in the low-pressure TPC for alpha particles with different energies for 200 nm silicon nitride window and 50 torr isobutane, obtained using SRIM simulation.

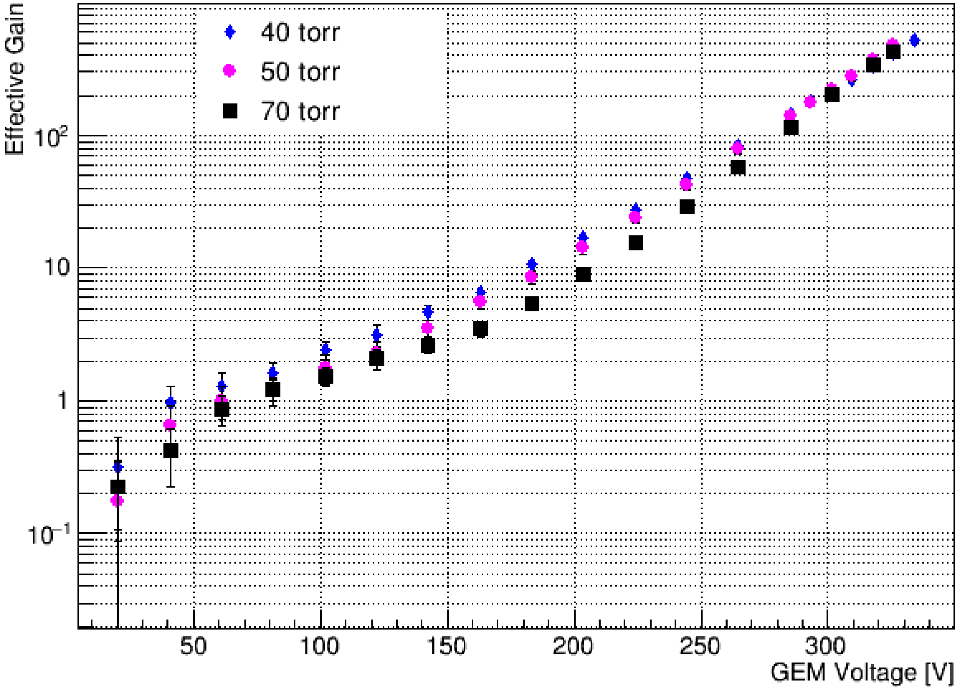
New concept of ion identification: low-pressure TPC

Schematic layout



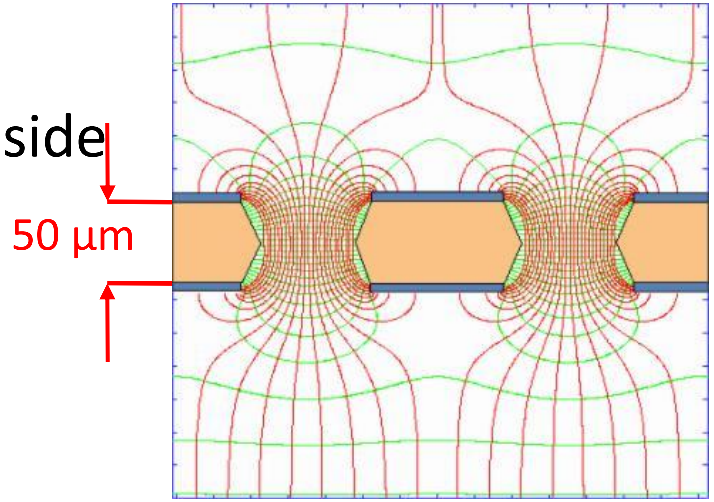
Effective gain of GEM



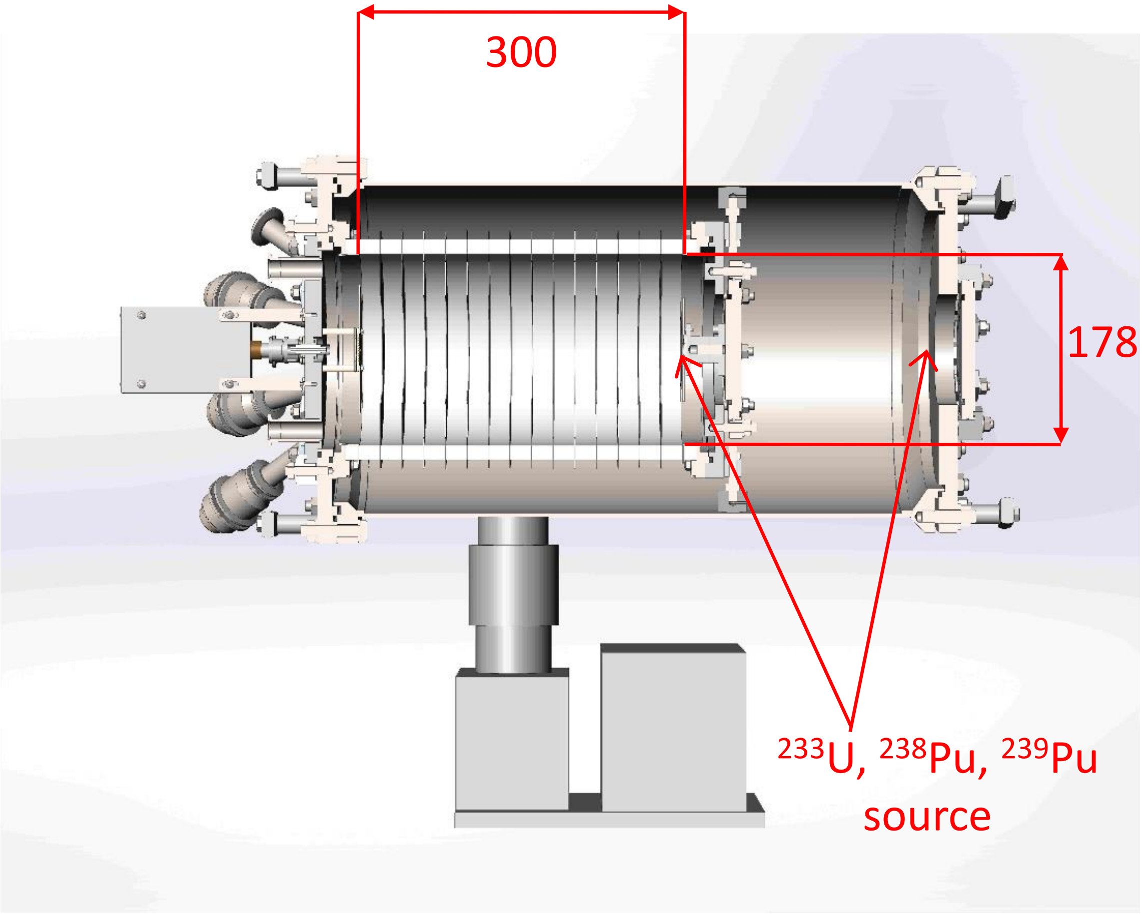


GEM effective gain as a function of the voltage in isobutane at pressures varying from 40 to 70 torr in the low-pressure TPC.

Electric field inside the holes.

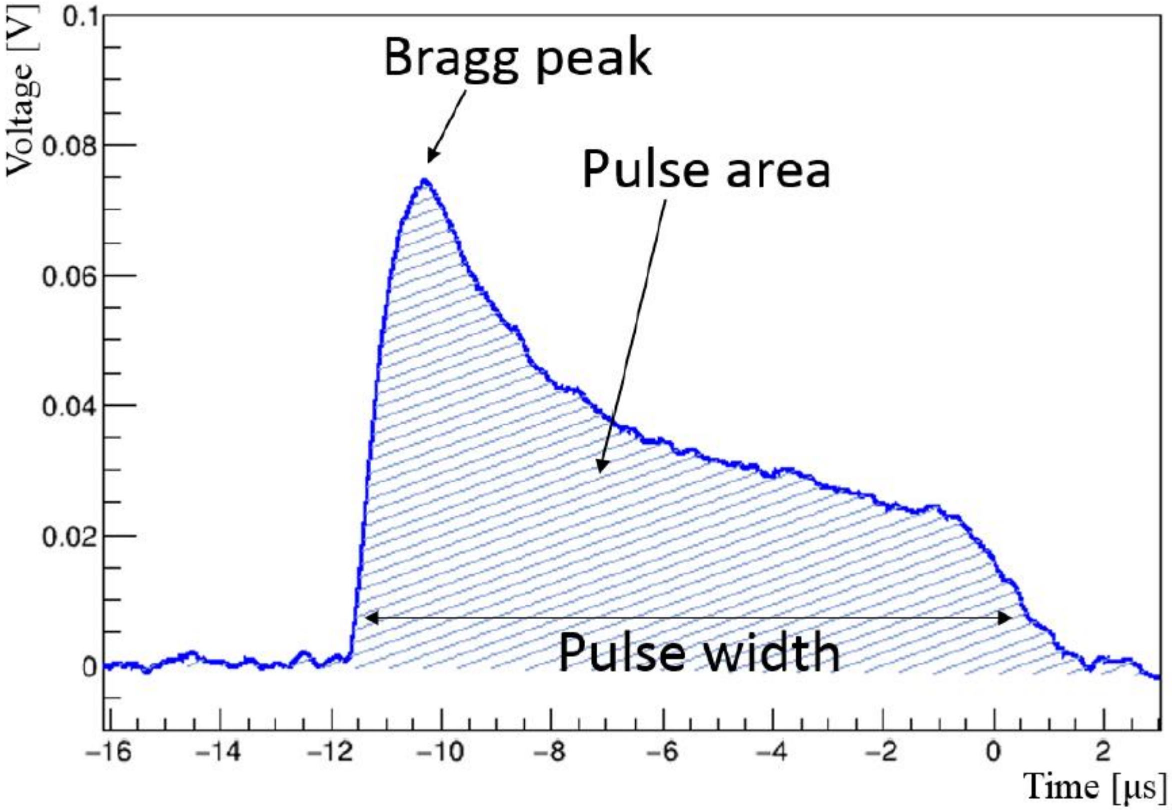


TPC Prototype: Principle of operation



Diameter – 178 mm
Length – 300 mm

Typical waveform shape of the signal from the alpha particle in low-pressure TPC

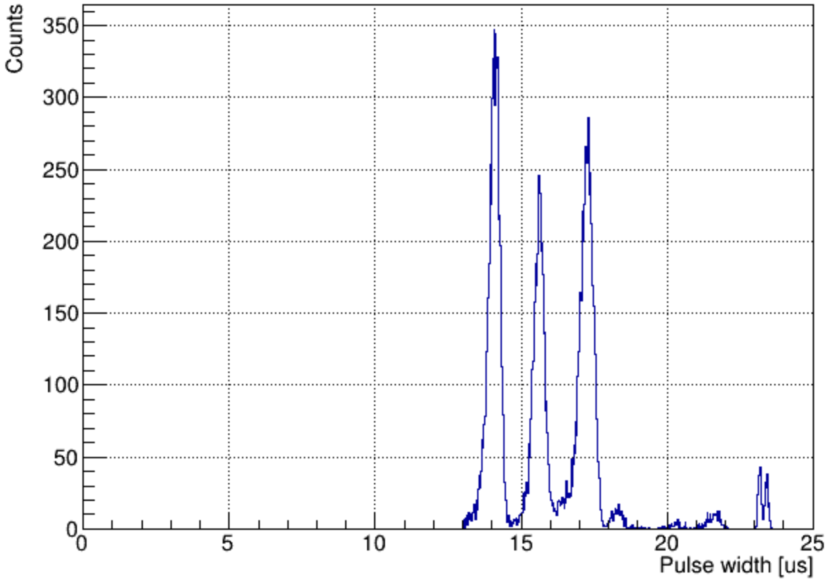


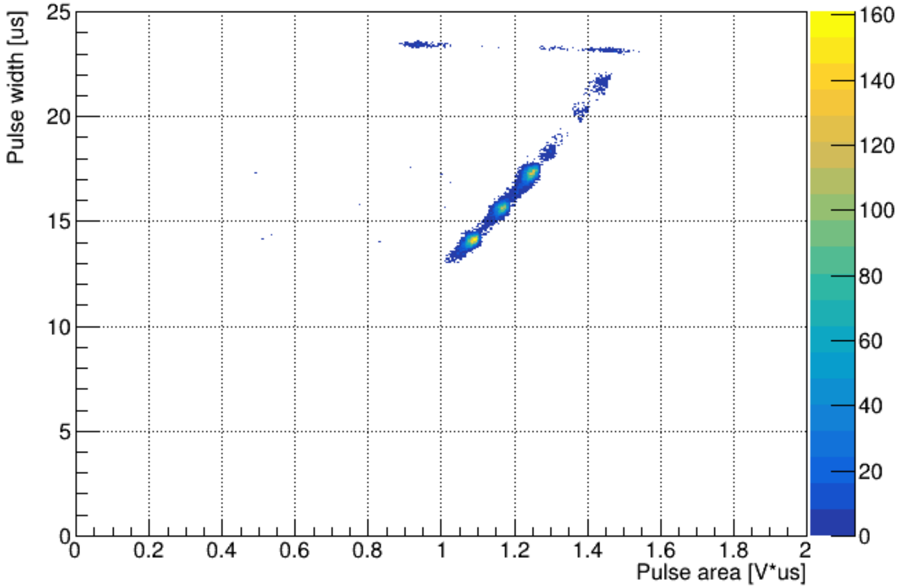
pulse width -> track range
pulse area -> energy

Test installation

The measurement of track ranges

The alpha-particle source
^{233}U, ^{239}Pu, ^{238}Pu

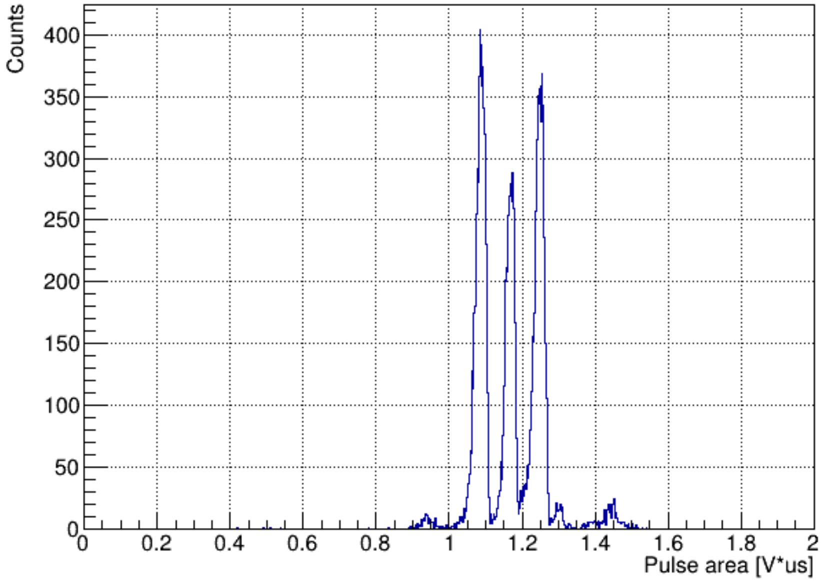




Pressure = 50 Torr
Gain = 225
Shaping time = 200 ns

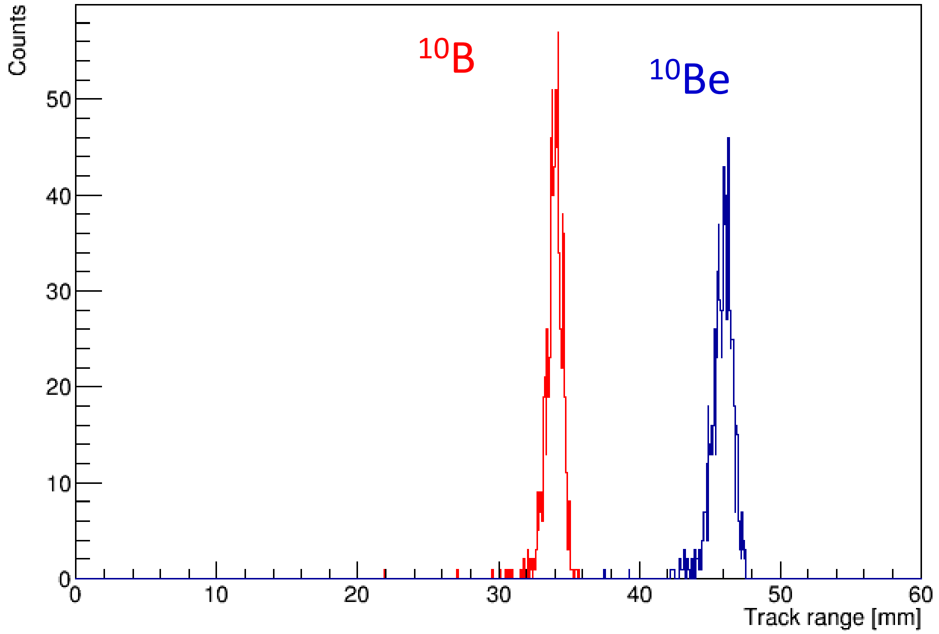
2D plot of pulse width versus pulse area and their axis projection spectra for alpha particles from ^{233}U (4.8 MeV), ^{239}Pu (5.2 MeV) and ^{238}Pu (5.5 MeV) source, measured in low-pressure TPC in Isobutane at 50 Torr and GEM gain of 225. FWHM is 9 mm, which corresponds sigma of 3.82 mm.

The pulse width and pulse area spectra reflect those of the track range and energy.



Results

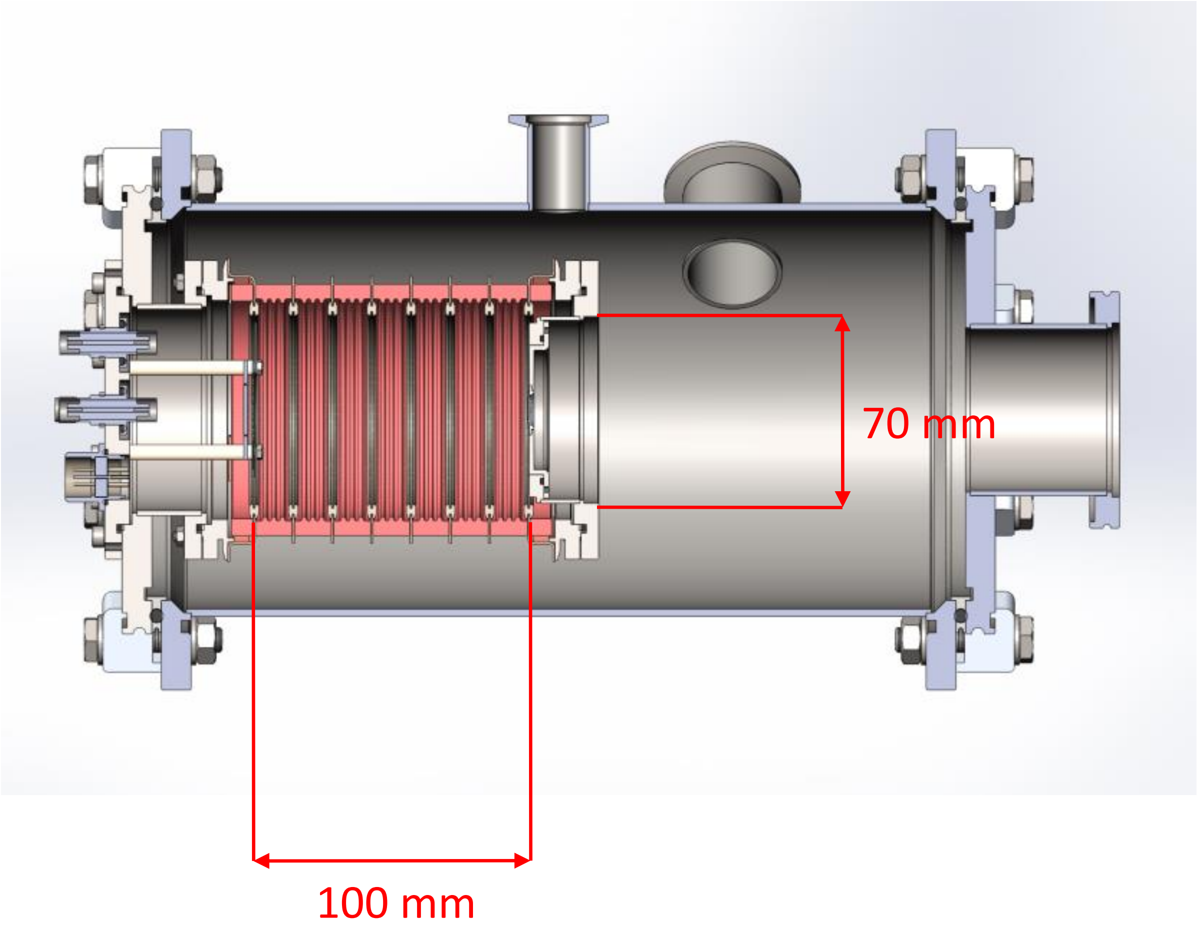
Source	Shaping time	Gain	Pressure	Sigma/Range, %	Separation in sigma between two peaks
3 isotopes	200 ns	225	50 Torr	12.04	3.13



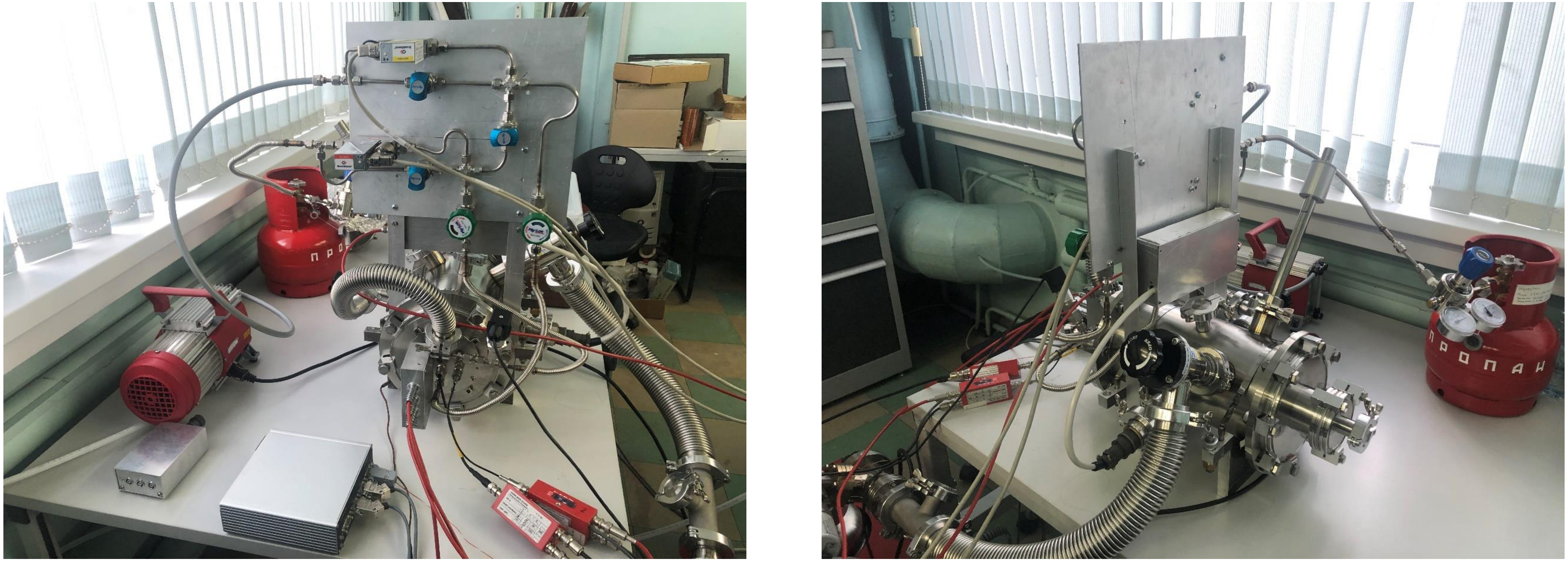
Spectra of ion ranges for ^{10}B and ^{10}Be with energy 4.025 MeV in Isobutane at 50 Torr simulated with SRIM.

Using these results and SRIM code simulations, it is shown that isobaric boron and beryllium ions can be effectively separated at AMS, providing efficient dating at a 10 million years scale. This technique will be applied in the AMS facility in Novosibirsk.

TPC for BINP AMS

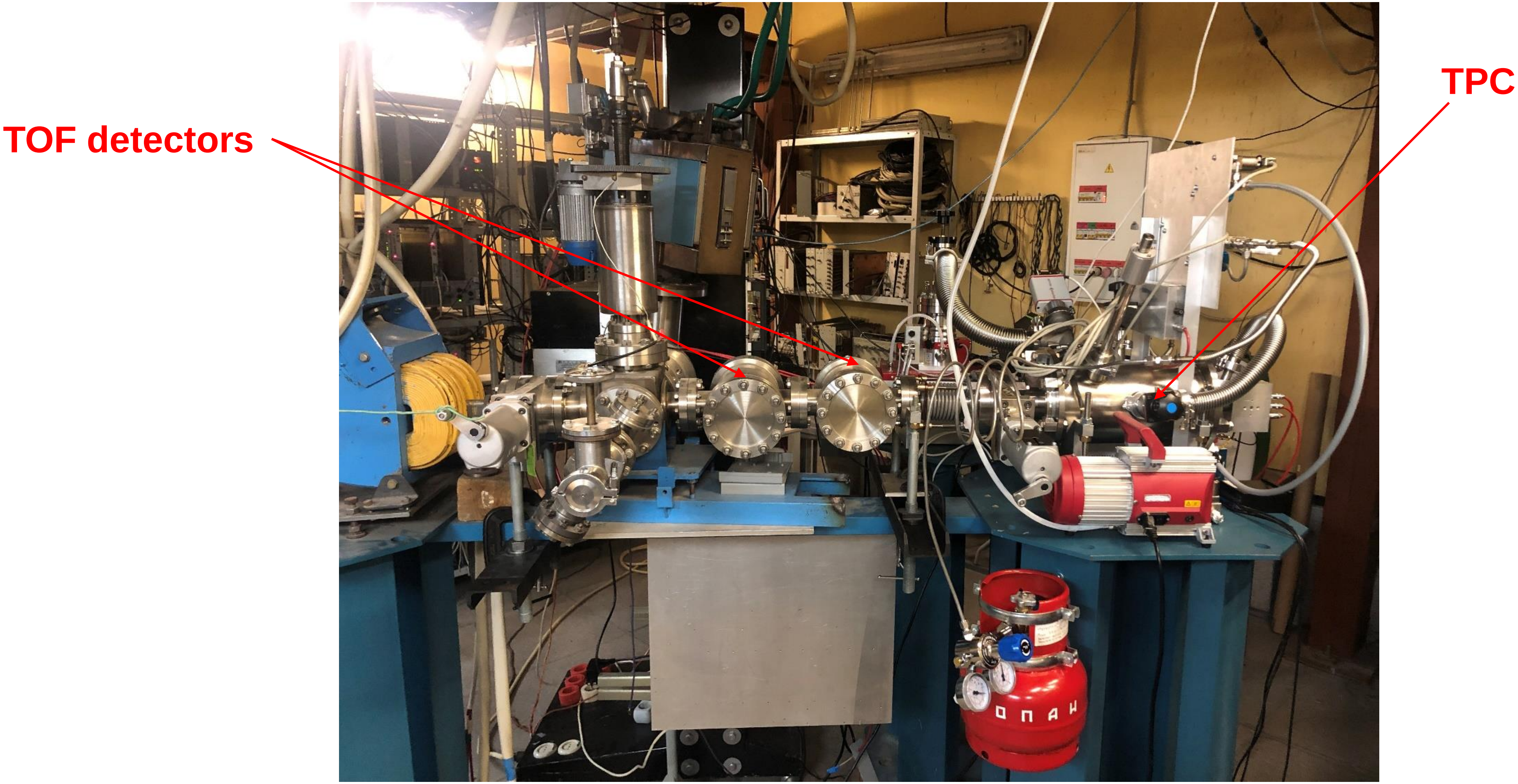


TPC for BINP AMS

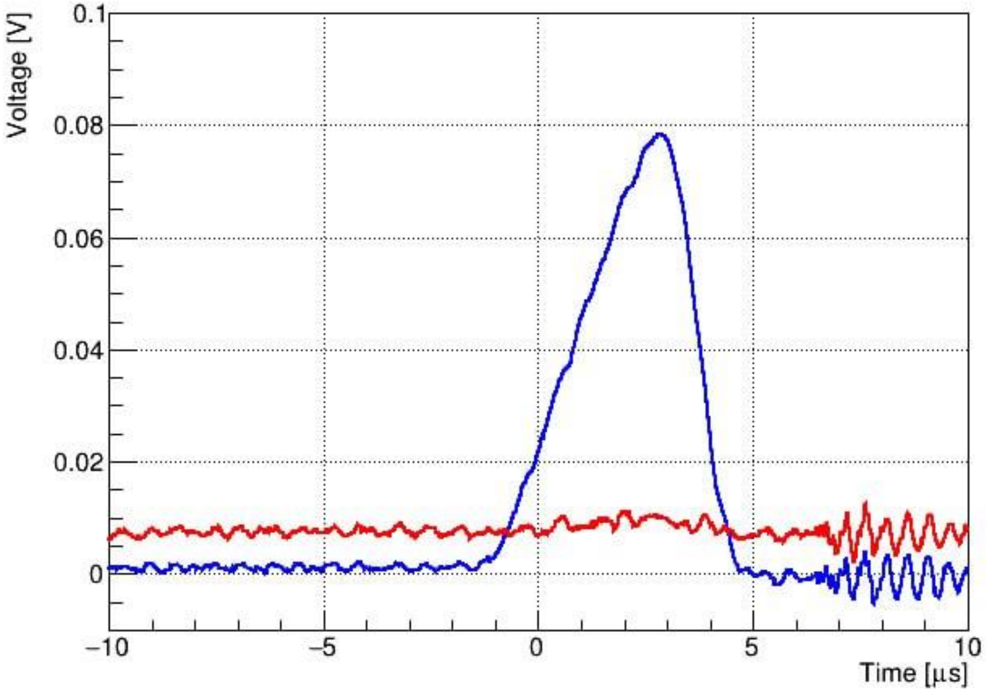


Test of the low-pressure TPC in laboratory, before installation.

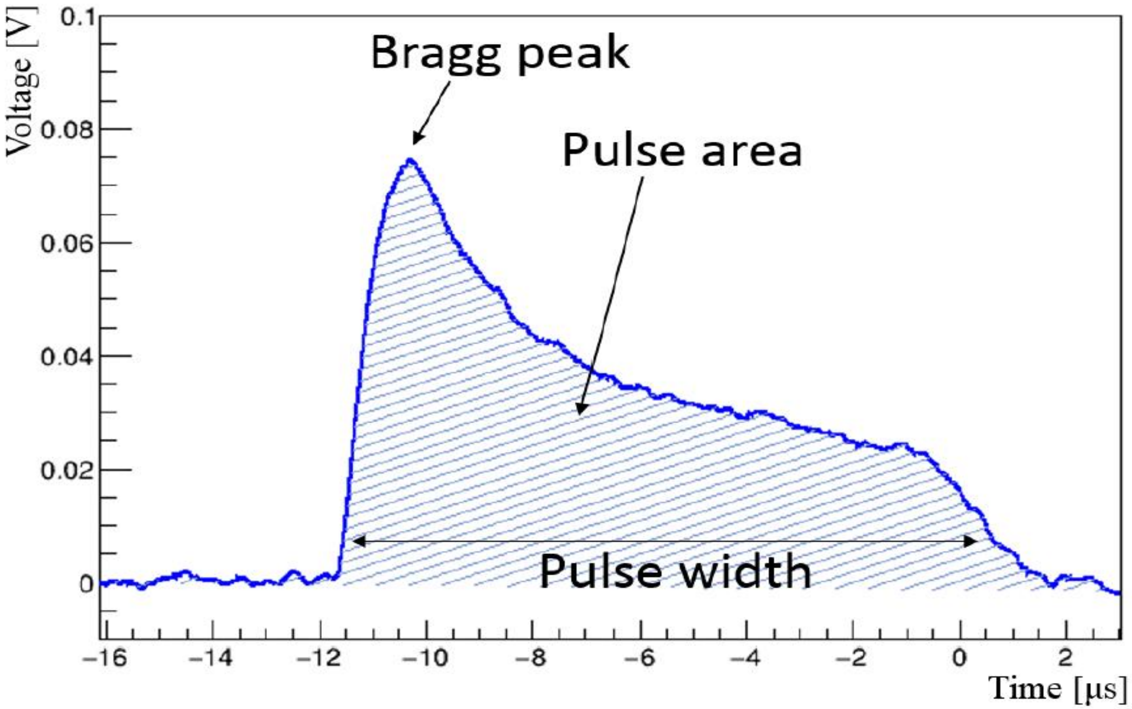
Installation of TPC on BINP AMS



Signal from ^{14}C and ^{4}He

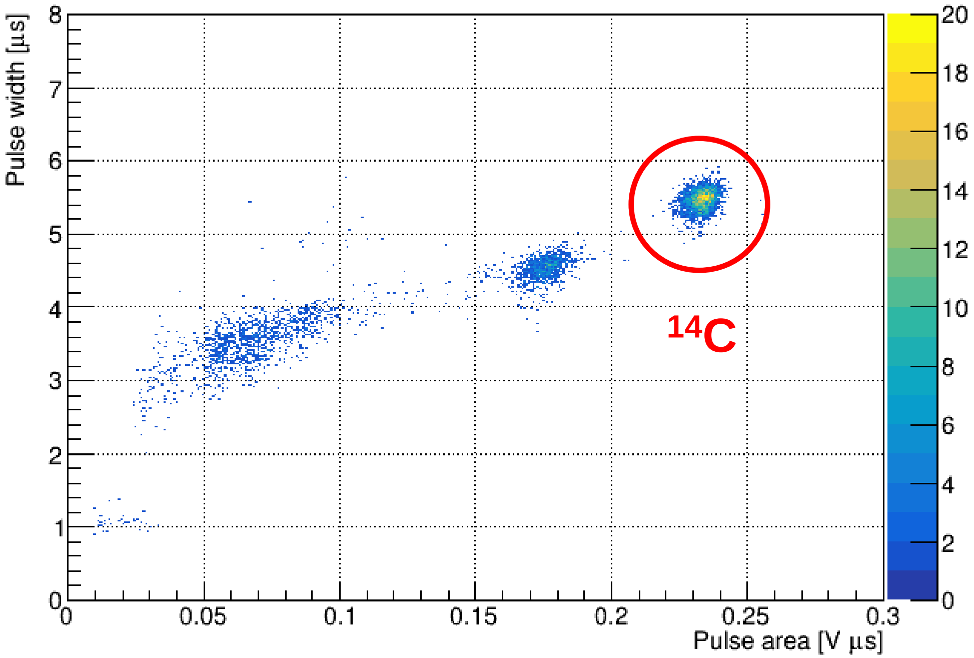


Signal from 4MeV ^{14}C ion

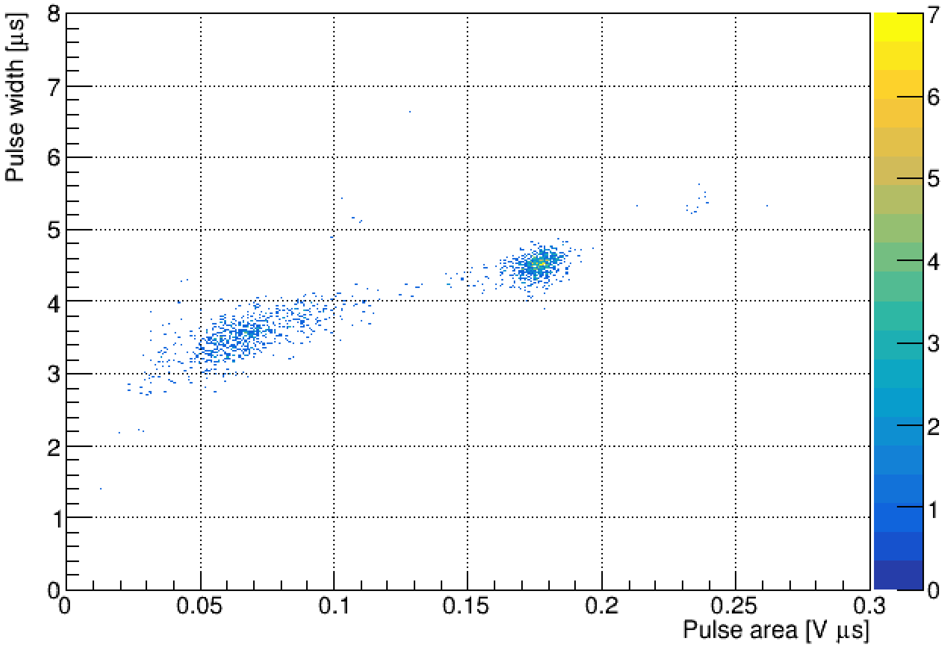


Signal from 5.1 MeV alpha particle

Results on carbon beam



Sample with “alive” carbon sample



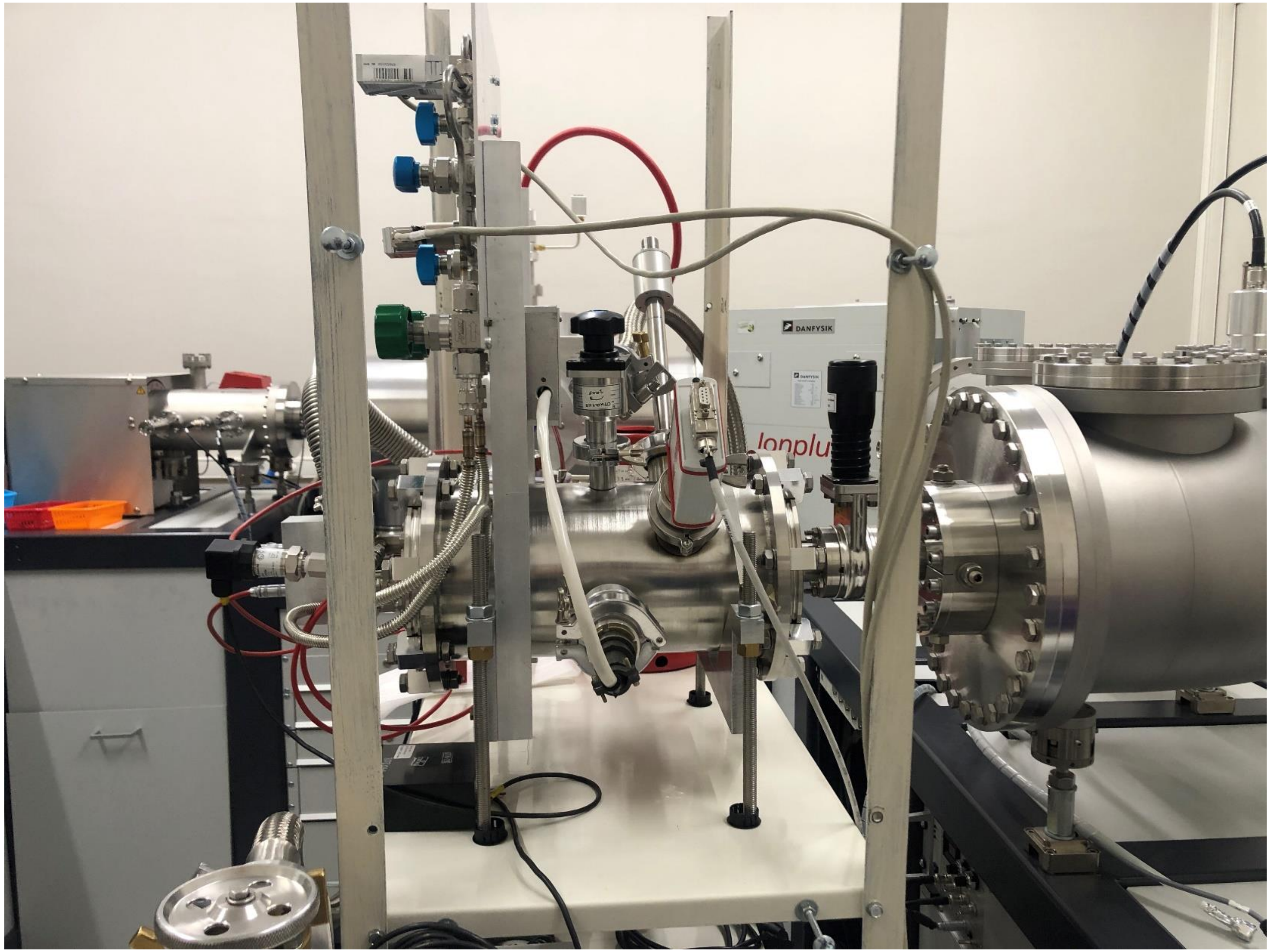
Sample with “dead” carbon sample

Conclusion

- A new concept of the detector for the accelerator-based mass spectrometer was proposed for identifying ions by their stopping range in gas;
- A low-pressure TPC prototype, based on this concept, have been made and successfully tested;
- The TPC have been installed on AMS;
- First results on ^{14}C beam are promising;
- We are preparing to the tests with ^{10}Be samples.

Thank you for your attention!

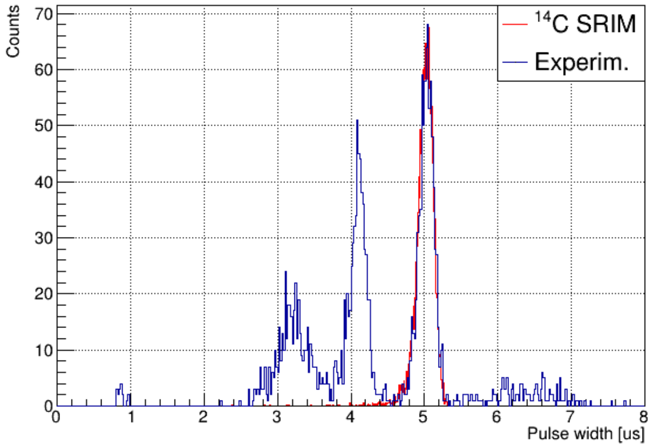
Installation of TPC on MICADAS

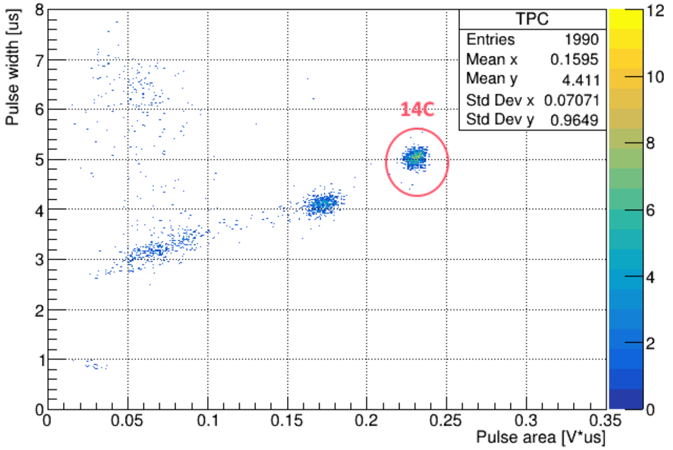


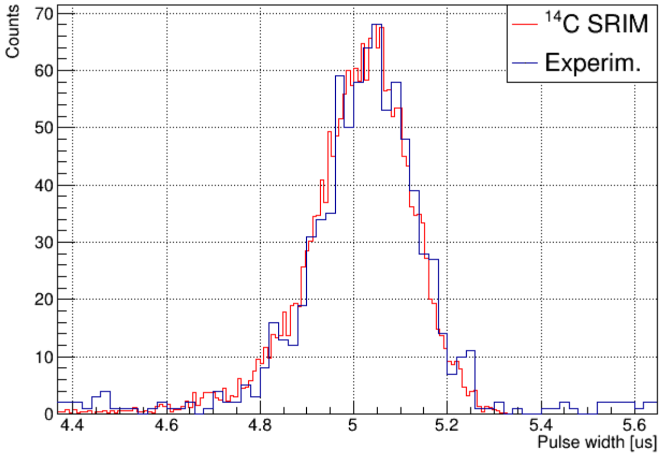
Backup slides

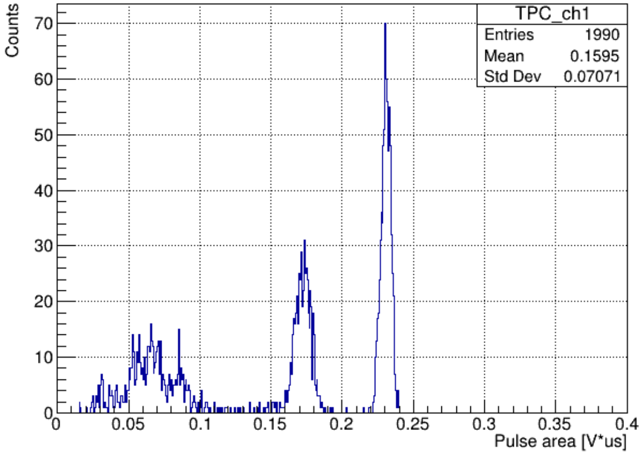
PSS RAS session

Results on carbon beam

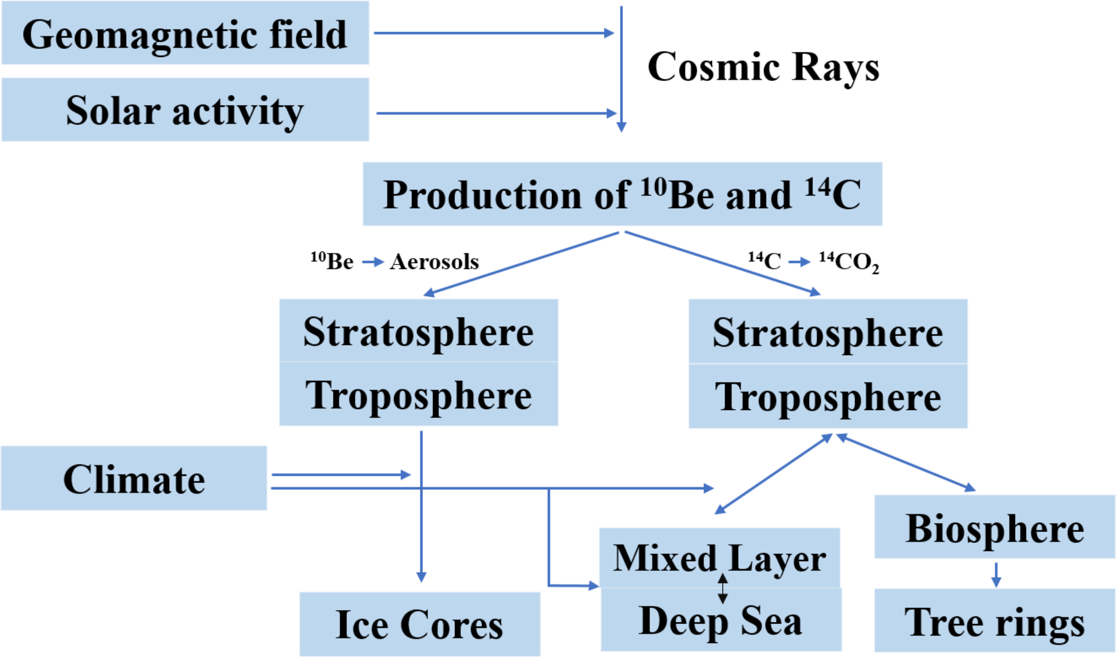








Formation and application ^{10}Be



Geomagnetic field
Solar activity
Cosmic Rays
Production of ^{10}Be and ^{14}C
^{10}Be → Aerosols
^{14}C → $^{14}CO_2$
Stratosphere
Troposphere
Stratosphere
Troposphere
Climate
Biosphere
Mixed Layer
Deep Sea
Tree rings
Ice Cores

Application in-situ and meteoric ^{10}Be:

- exposure dating to identified the growths and decays of the Antarctic ice sheet;
- understanding ice shelf collapse history;
- paleomagnetic excursions history reconstructions using ice cores;
- understanding the erosion rates using depth profiles of mid latitudes outcrops;
- identifying the timing of formation of the impact crater and so forth.

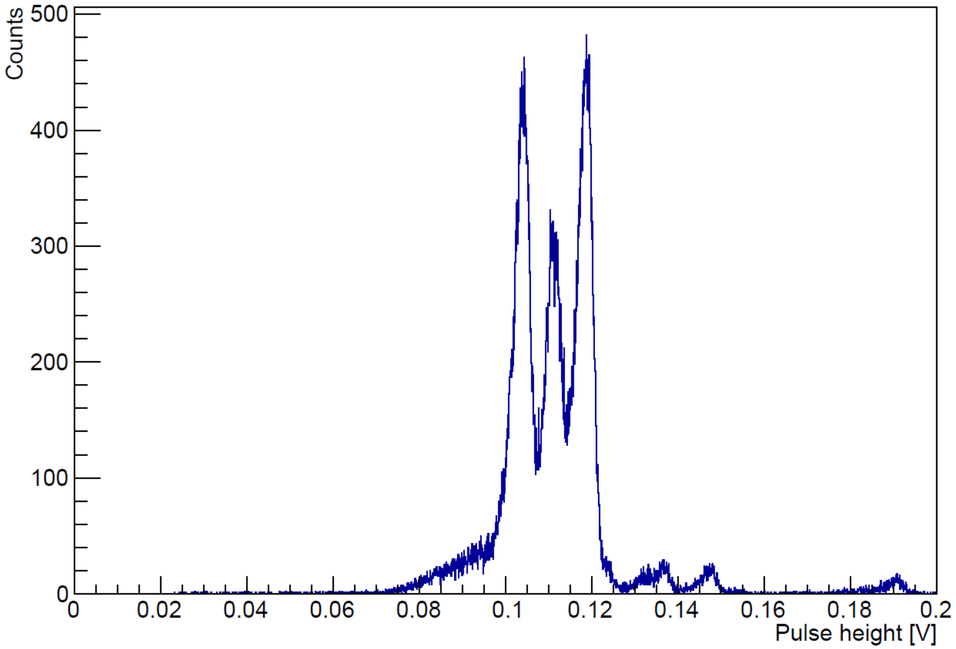
Time intervals of dating:

- **^{14}C** from 300 years to 40-60 thousand years
- **^{10}Be** from 1 thousand years to 10 million years

Measurements of energy spectra using semiconductor detector

Alpha particle source– ^{233}U, ^{239}Pu , ^{238}Pu

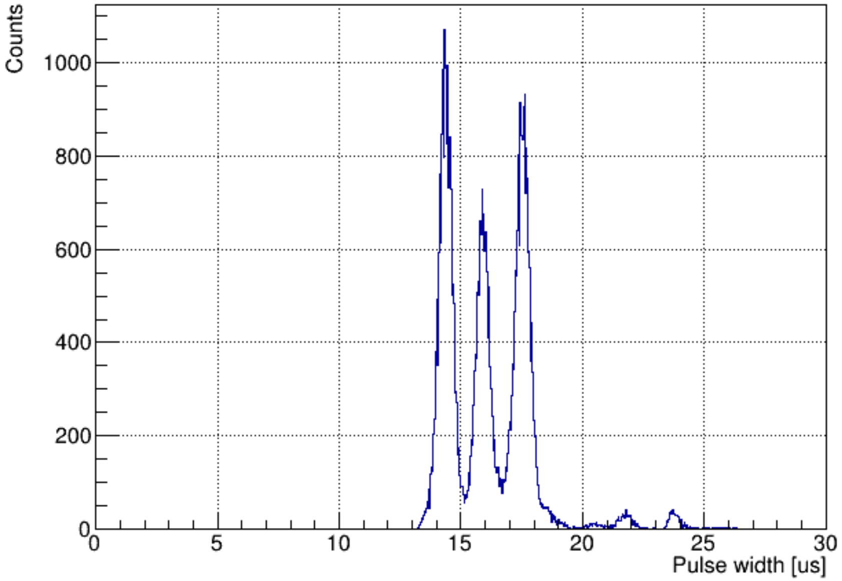
Si Charged Particle Radiation Detectors for Alpha Spectroscopy

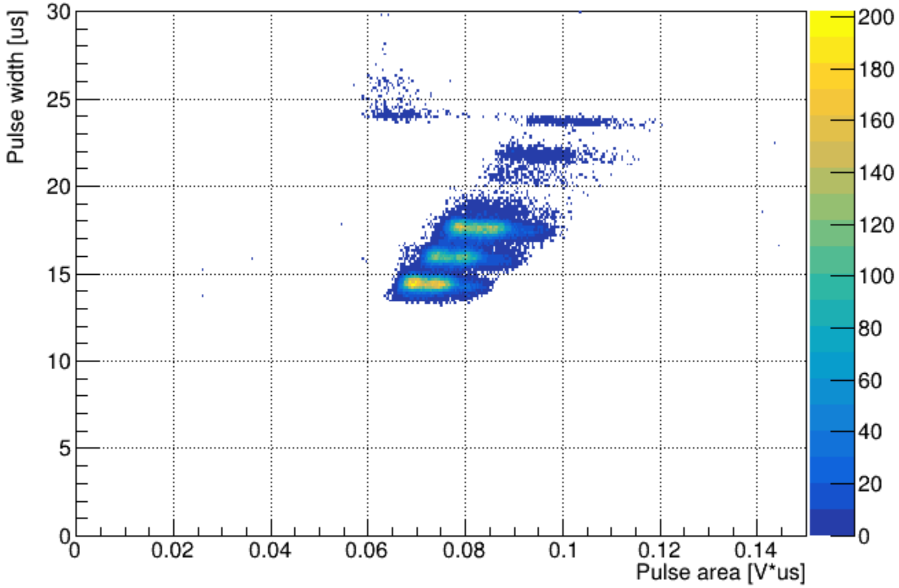


Energy spectrum of alpha particles from ^{233}U (4.8 MeV), ^{239}Pu (5.2 MeV) and ^{238}Pu (5.5MeV) sources, measured using semiconductor detector

The measurement of track ranges

The alpha-particle source
^{233}U, ^{239}Pu, ^{238}Pu

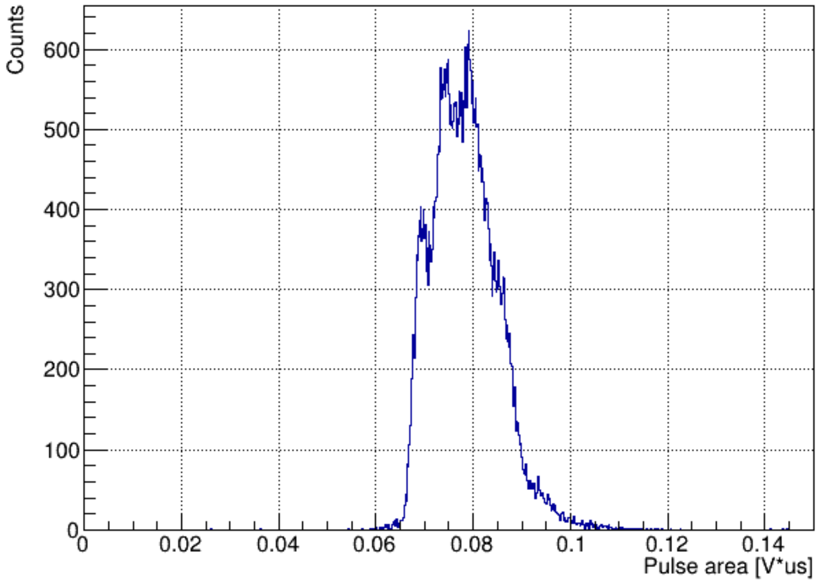




Pressure = 50 Torr
THGEM Gain = 67
Shaping time = 200 ns

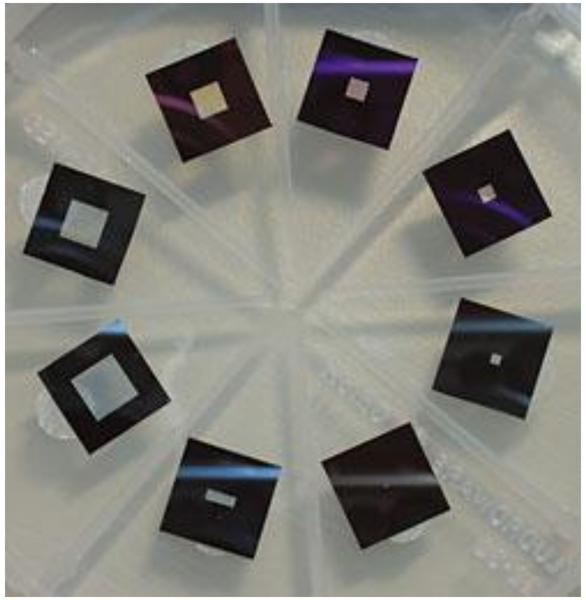
2D plot of pulse width versus pulse area and their axis projection spectra for alpha particles from ^{233}U (4.8 MeV), ^{239}Pu (5.2 MeV) and ^{238}Pu (5.5 MeV) source, measured in low-pressure TPC in Isobutane at 50 Torr and THGEM gain of 67.

The pulse width and pulse area spectra reflect those of the track range and energy.



Silicon nitride membrane windows

Silson



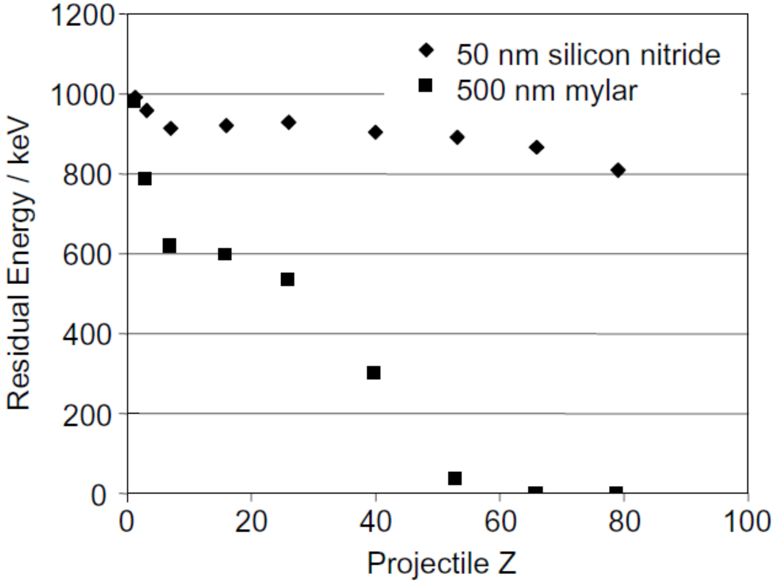


Fig. 1. Remaining energy after passage of 1 MeV ions through a 50 nm silicon nitride and a 500 nm mylar window. TRIM calculation [2].

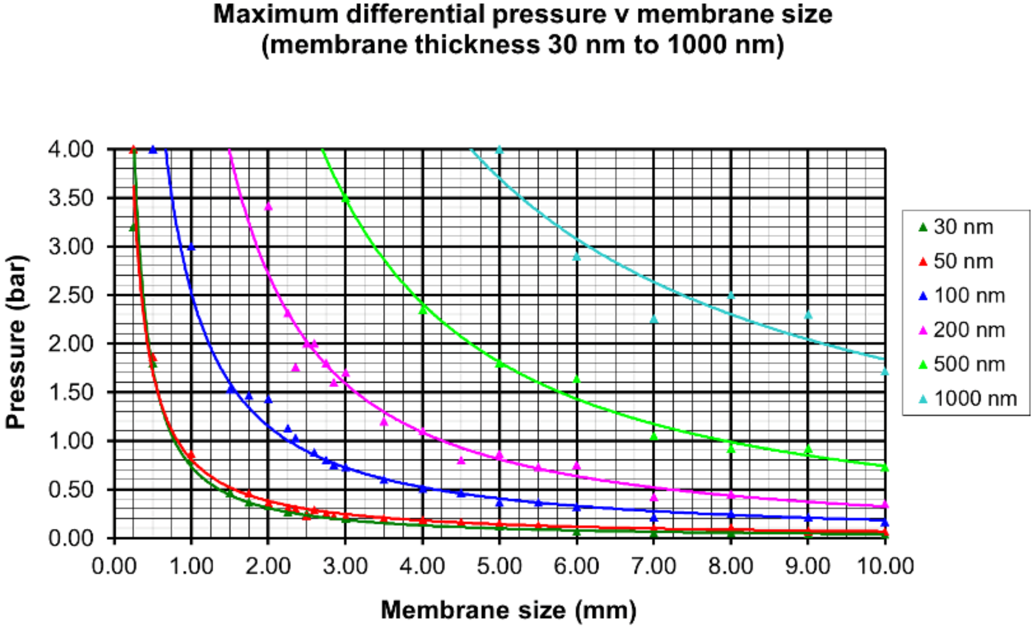
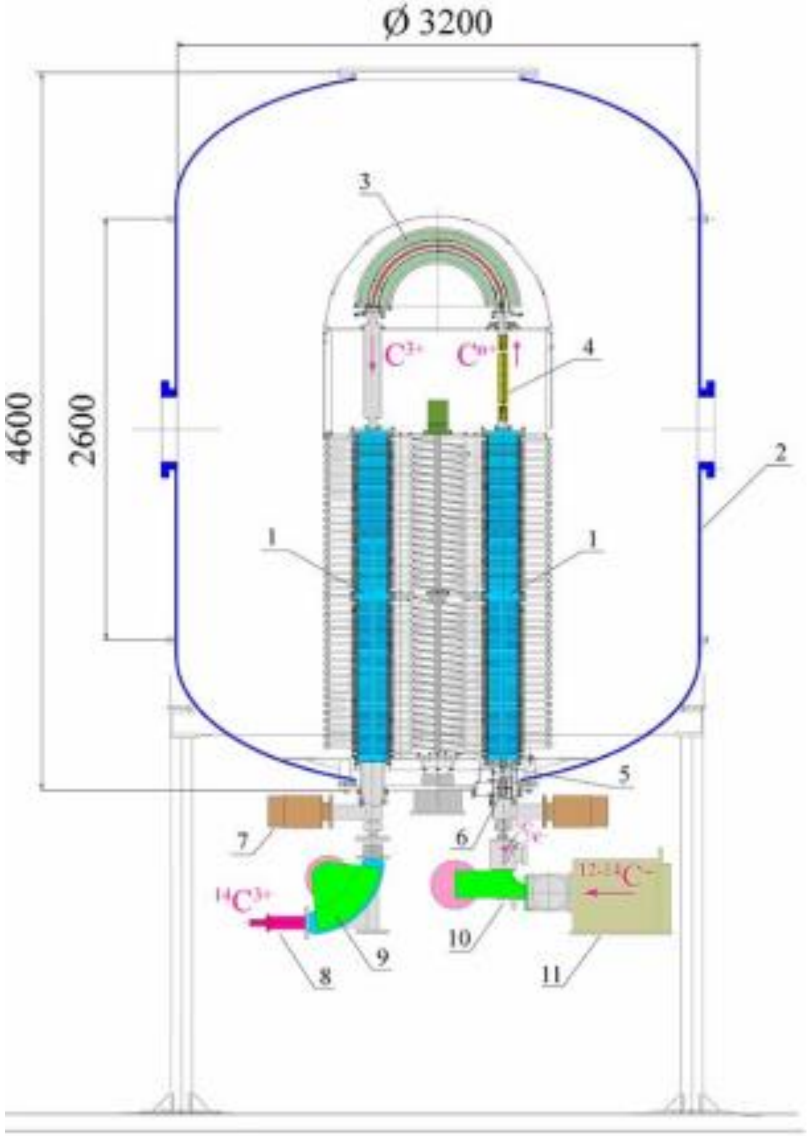


Figure of silicon nitride membrane windows

M. Dobeli et al., Nucl. Instr. and Meth. B, 219-220 (2004) 415-419 doi:10.1016/j.nimb.2004.01.093

BINP AMS



BINP AMS characteristics:

- magnesium vapor target for molecular destruction localized site of molecular breakdown;
- sorting of ions by energy immediately after the destruction of molecular ions; effective screening of fragments of molecules; the energy of the pieces of the molecule is always less than the energy of the molecule;
- time-of-flight detector for registering the moment of ions arrival.

BINP AMS scheme:

1 – accelerator tube, 2 – accelerator body, 3 – electrostatic turn on 180°, 4 – magnesium vapor target , 5 – corrector, 6 – electrostatic lens, 7 – vacuum pump, 8 – ion detector, 9 – high energy dipole magnetic spectrometer, 10 – low energy dipole magnetic spectrometer, 11 – ion source.