Детектор ионов на основе время-проекционной камеры низкого давления для ускорительной масс-спектрометрии

**А. Е. Бондарь, А. Ф. Бузулуцков, В. В. Пархомчук,
А. В. Петрожицкий, А. В. Соколов, Е. А. Фролов,
Т. М. Шакирова**

**Сессия-конференция секции ядерной физики
Отделения Физических Наук РАН
10 - 12 марта 2020 г.**

Outline

1. Accelerator mass spectrometry
2. SRIM simulation
3. Experimental setup
4. Measurements of energy spectra using semiconductor detector
5. Measurements of track ranges using TPC

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.

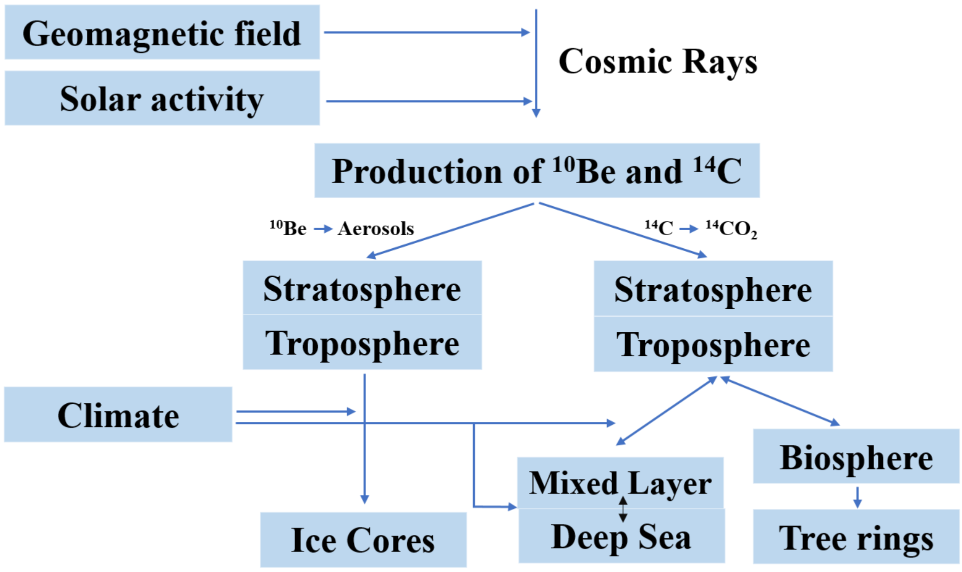
AMS facilities operate in more than 100 physical laboratories worldwide, one of which is located in Novosibirsk at Geochronology of the Cenozoic Era Center for Collective Use.

Isotopes used in AMS

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

In the current AMS BINP setup the time-of-flight technique is used for the isotopes separation. But that technique there is 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.

Formation and application ^{10}Be



Application in-situ and meteoric 10Be:

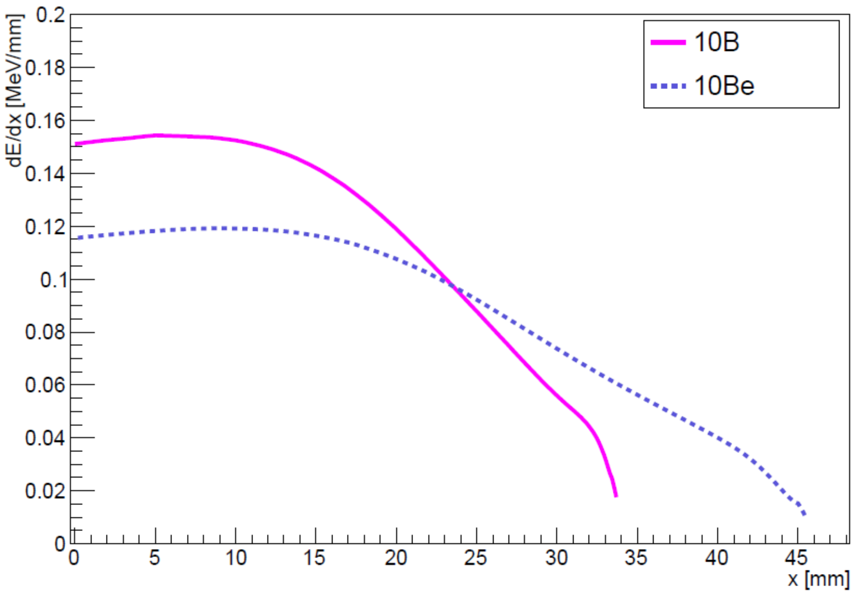
- exposure dating to identified the growths and decays of the Antarctic ice sheet;
- understanding ice shelf collapse history;
- paleomagnetic excursions history reconstructions using ice cores;
- understanding the erosion rates using depth profiles of mid latitudes outcrops;
- identifying the timing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

Time intervals of dating:

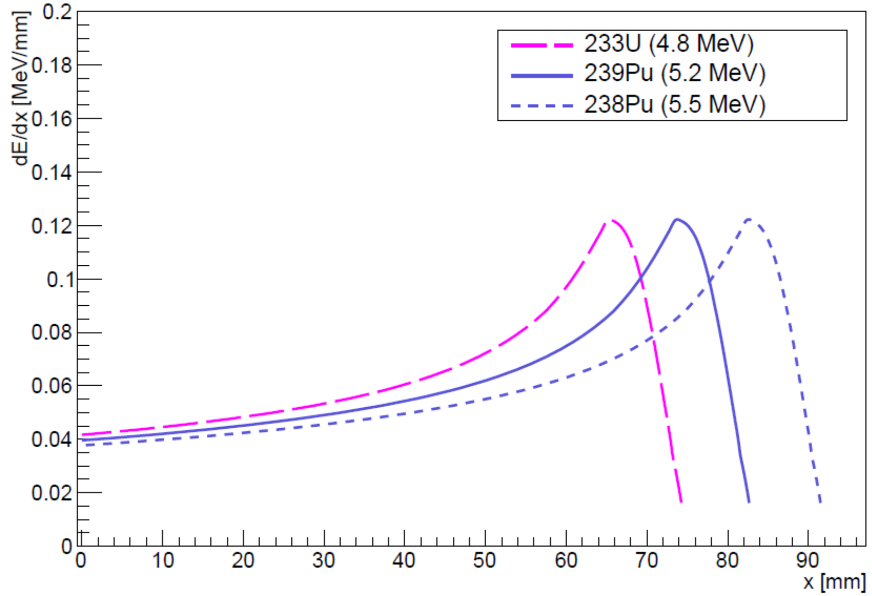
- ^{14}C from 300 years to 40-60 thousand years
- ^{10}Be from 1 thousand years to 10 million years

SRIM simulation

*SRIM - The stopping and range of ions in matter



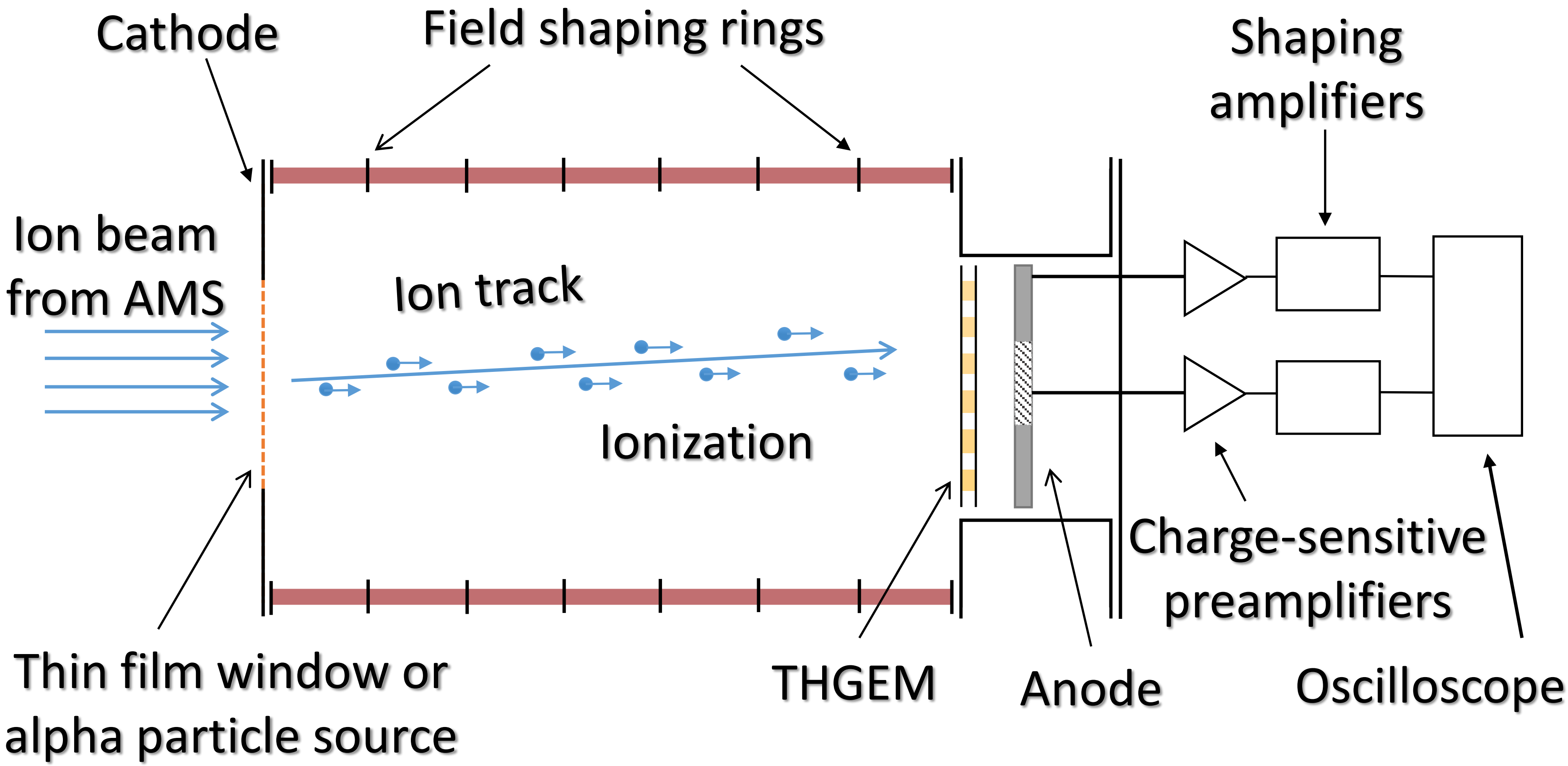
Energy loss as a function of distance in Isobutane for ^{10}B and ^{10}Be with an energy of 4.025 MeV at 50 Torr



Energy loss as a function of distance in Isobutane for alpha particles with different energy at 120 Torr

- Ionization losses and track ranges are different for boron and beryllium, so they can be separated with good accuracy.
- To study the method of isobars separation used a triple alpha particle source.

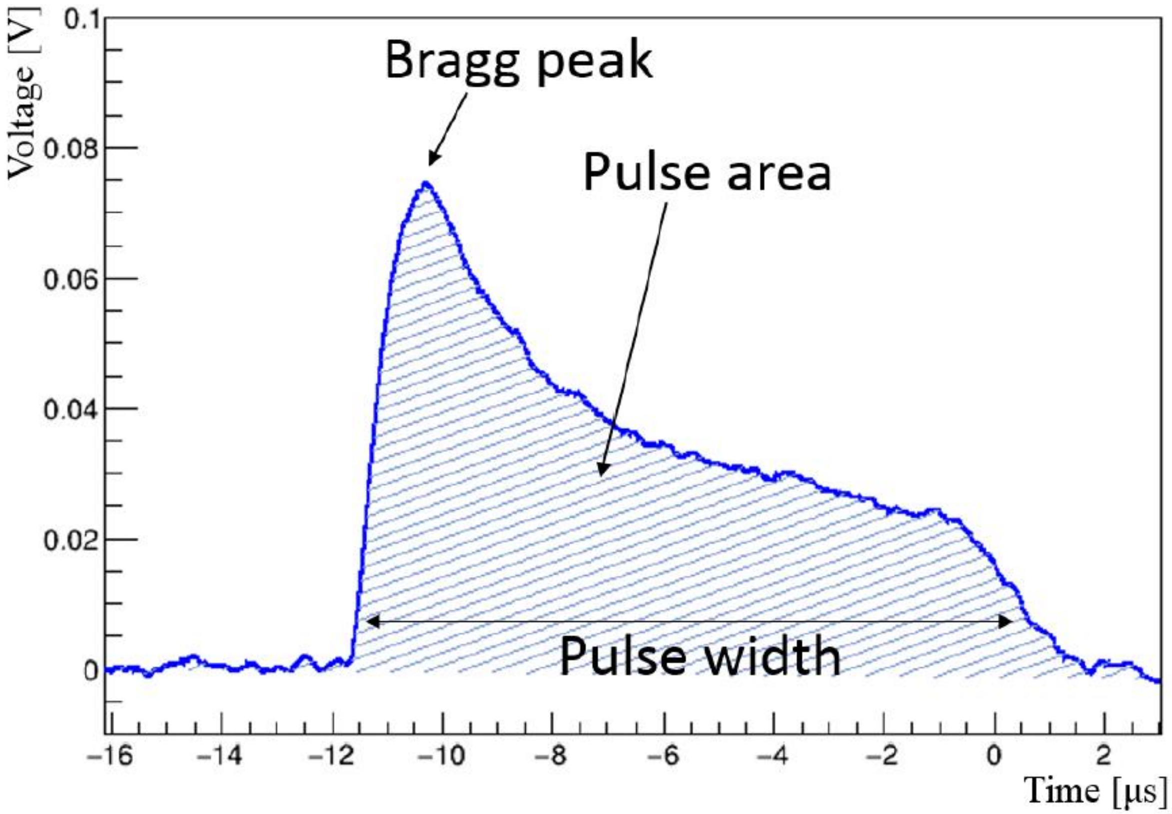
Principle of operation



Schematic layout of the low-pressure TPC

Principle of operation

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

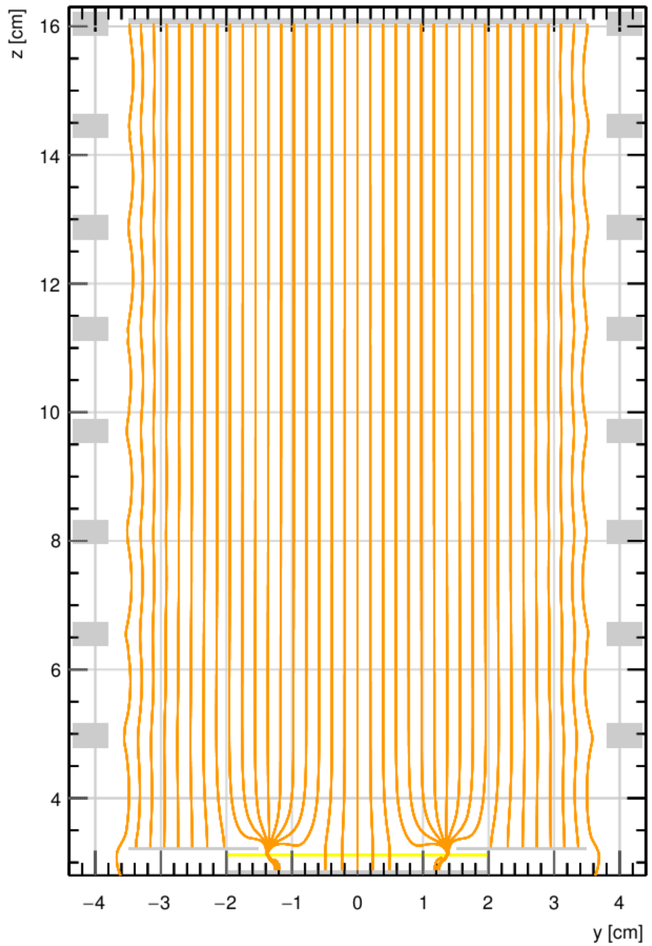


pulse width ~ track range

pulse area ~ energy

Electric field simulation

To simulate an electric field inside the low-pressure TPC, the following programs were used: **Gmsh**, **Elmer** and ***Garfield++.***



Simulated electric field lines in low-pressure TPC

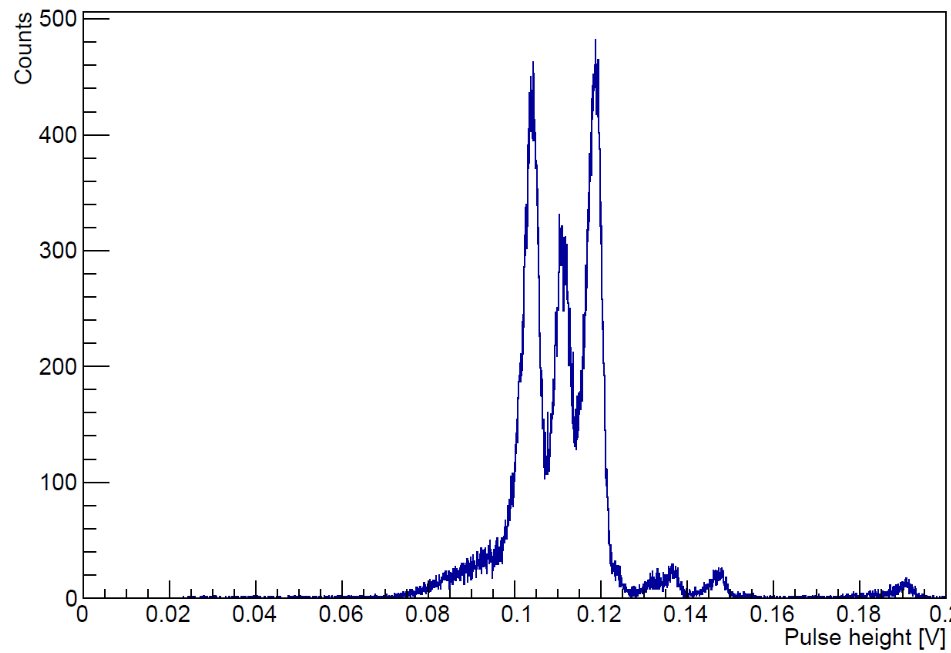
Figure of the lower flange with installed THGEM

Measurements of energy spectra using semiconductor detector

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

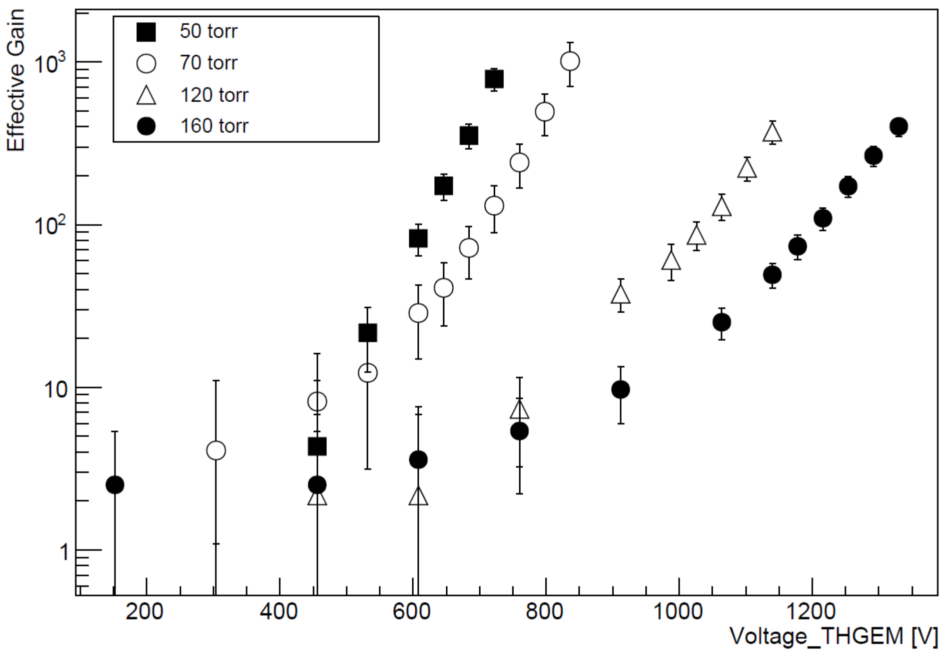
$E_\alpha = 4{,}816$ МэВ $\quad E_\alpha = 5{,}499$ МэВ $\quad E_\alpha = 5{,}157$ МэВ

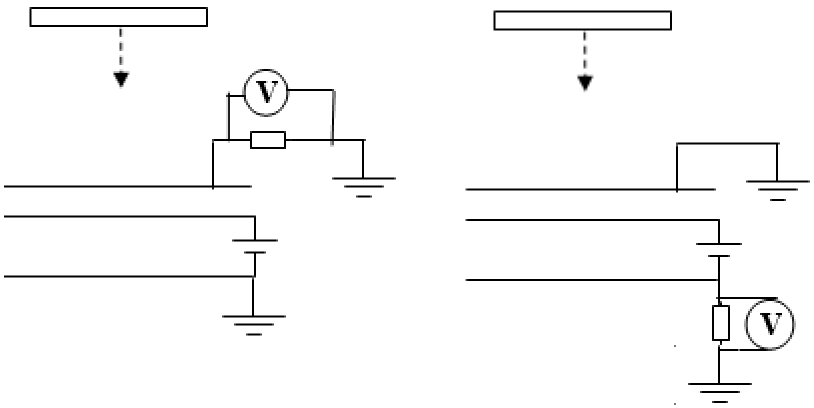
Si Charged Particle Radiation Detectors for Alpha Spectroscopy



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

Effective gain of THGEM

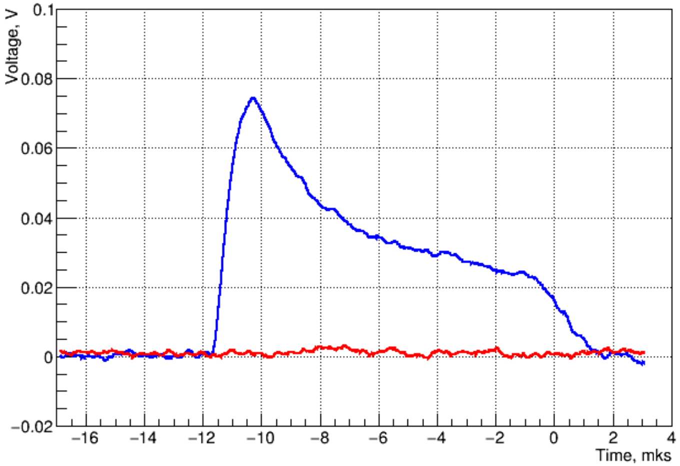


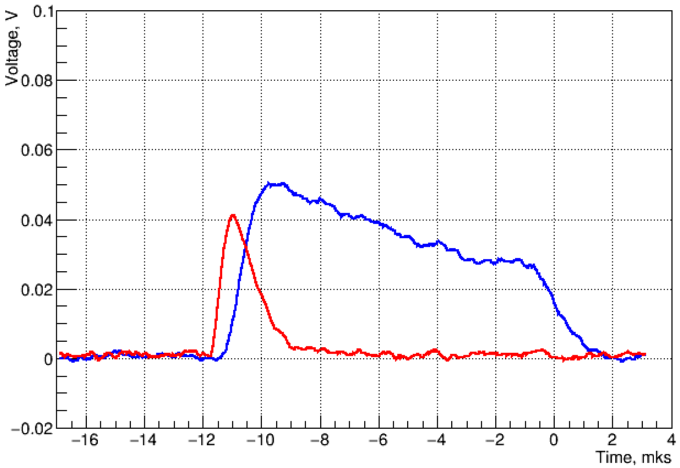


THGEM effective gain as a function of the voltage in Isobutane at pressures varying from 50 to 160 Torr in the low-pressure TPC

The scheme of effective gas gain measurement

Selecting orthogonal anode tracks



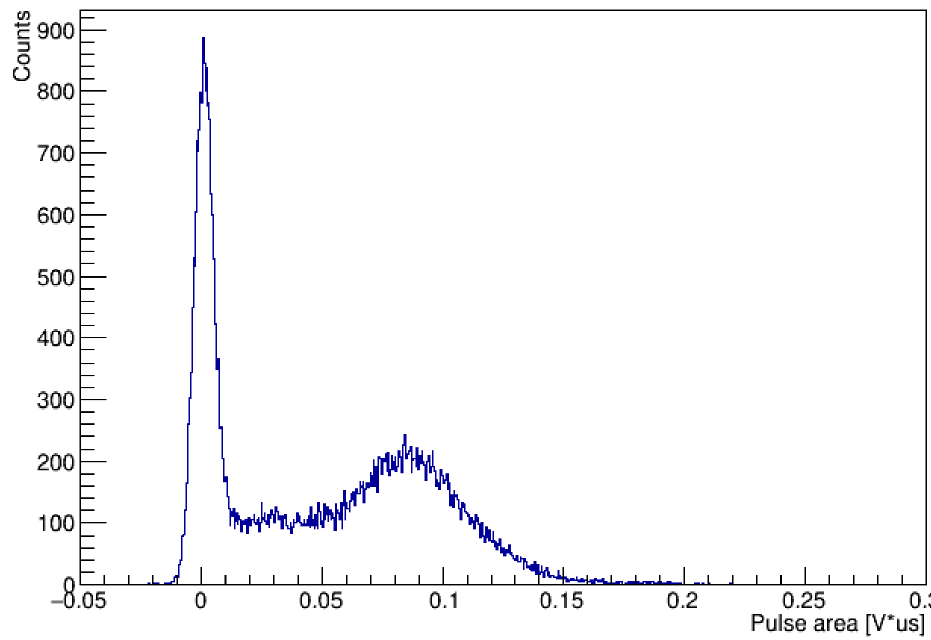


Typical signal waveform from alpha particle

----- signal from the central part of the anode

----- signal from the external part of the anode

(p=120 торр, U=1200 В)

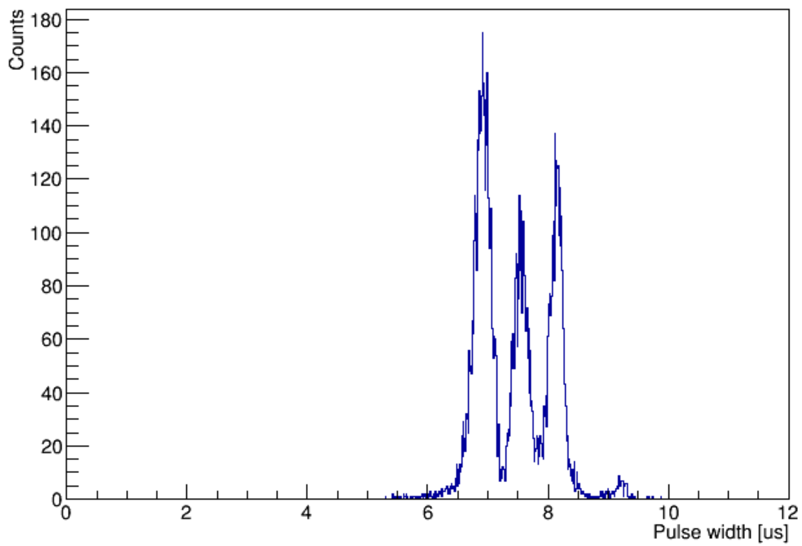


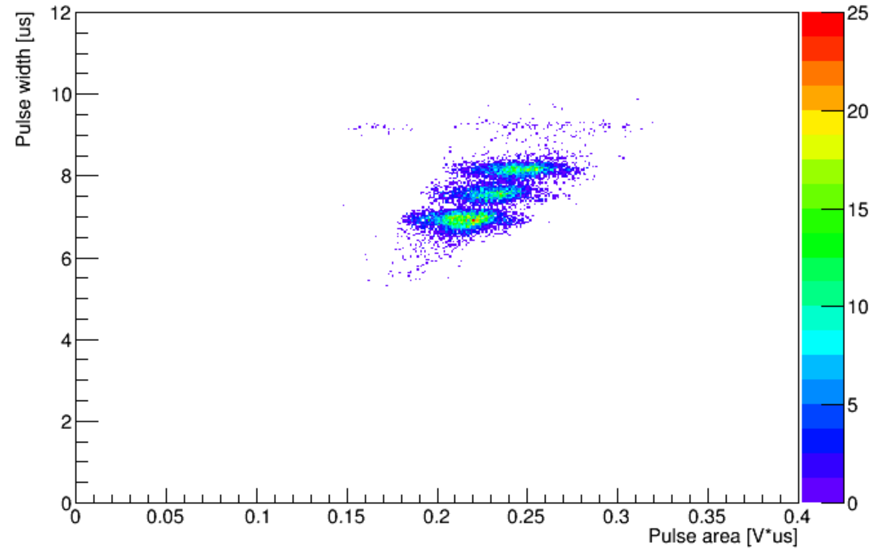
Pulse area spectrum of alpha particles from ^{233}U (4.8 MeV), ^{239}Pu (5.2 MeV) and ^{238}Pu (5.5 MeV) sources from external part of the anode, measured in low-pressure TPC in Isobutane at 120 Torr

The measurement of track ranges

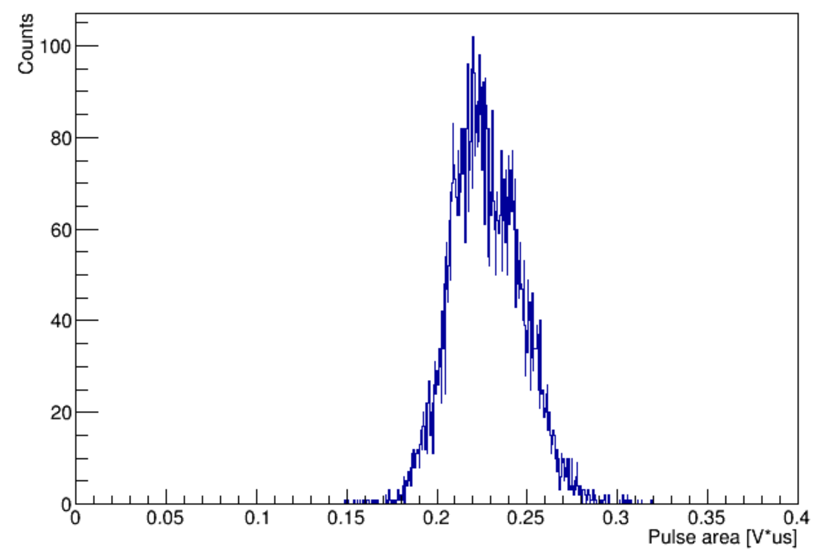
The alpha-particle source – ^{233}U, ^{238}Pu, ^{239}Pu $E_{\alpha} = 4{,}816$ МэВ $E_{\alpha} = 5{,}499$ МэВ $E_{\alpha} = 5{,}157$ МэВ

Pressure = 120 Torr **Gain = 60** **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 120 Torr and THGEM gain of 60. The pulse width and pulse area spectra reflect those of the track range and energy.

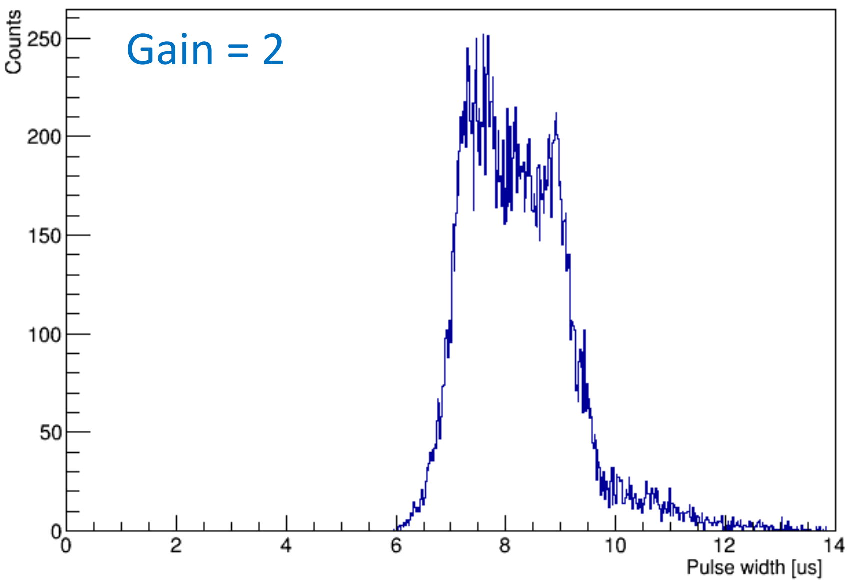


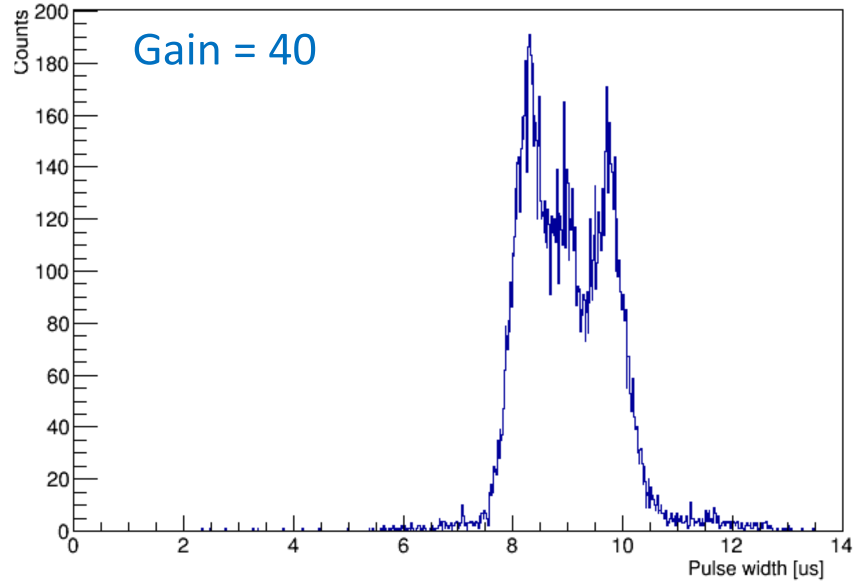
The measurement of track ranges with different gain

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

$E_\alpha = 4{,}816$ МэВ $\quad E_\alpha = 5{,}499$ МэВ $\quad E_\alpha = 5{,}157$ МэВ

Pressure = 120 Torr **Shaping time = 500 ns**

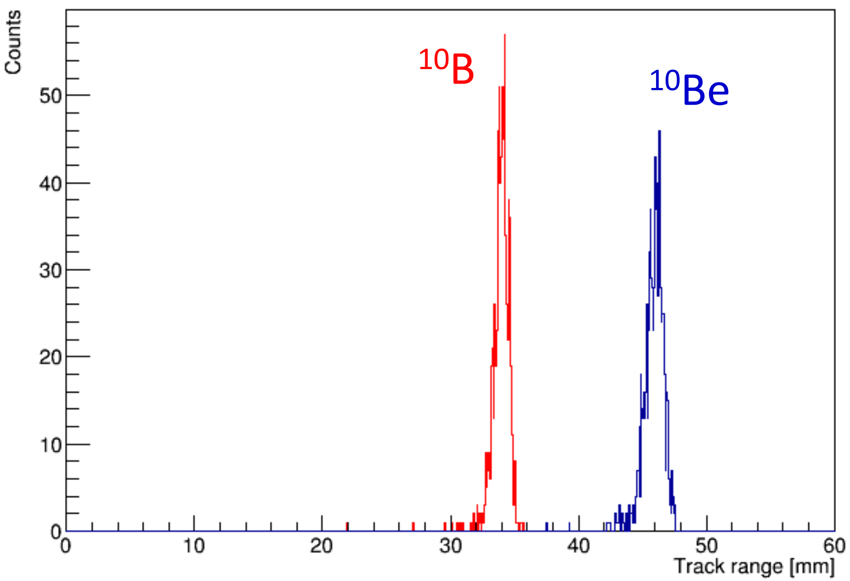




The lines of alpha particles are worse separated with less effective gain of THGEM and longer shaping time of amplifier

Results

Source	Shaping time	Gain	Pressure	Sigma/Range, %	Separation in sigma between two peaks
3 isotopes	500 ns	40	120 Torr	3.2	3
3 isotopes	200 ns	40	120 Torr	2.2	4
3 isotopes	200 ns	60	120 Torr	1.3	6



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

Using these results and SRIM code simulation, we see that the isobaric boron and beryllium ions (having range difference of 32%) can be effectively separated at the level exceeding 10 sigma

Silicon nitride membrane windows

Silson

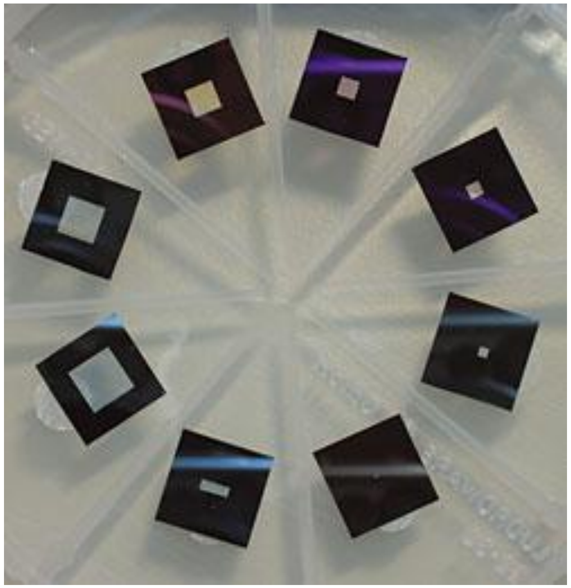


Figure of silicon nitride membrane windows

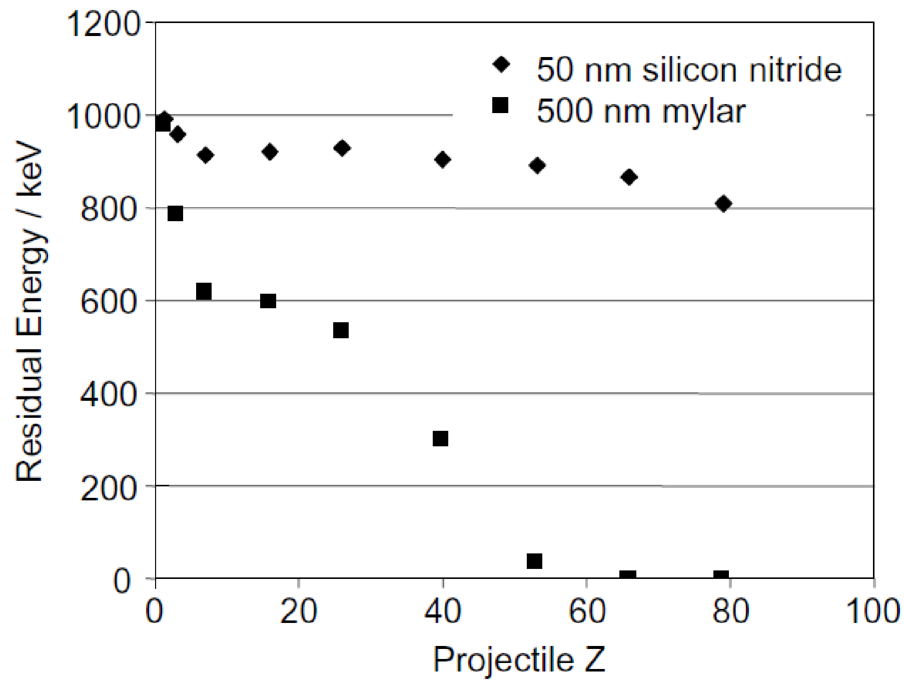
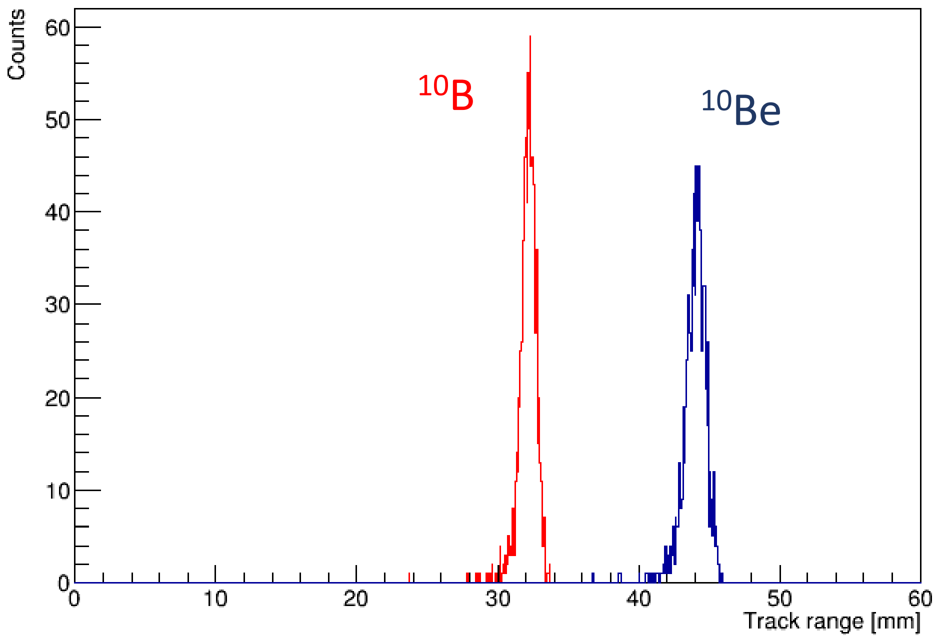


Fig. 1. Remaining energy after passage of 1 MeV ions through a 50 nm silicon nitride and a 500 nm mylar window. TRIM calculation [2].

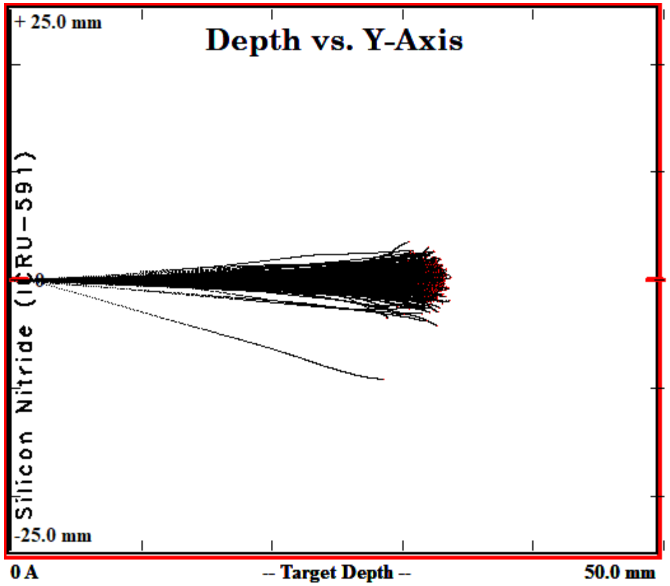
M. Dobeli et al., Nucl. Instr. and Meth. B, 219-220 (2004) 415-419 doi:10.1016/j.nimb.2004.01.093

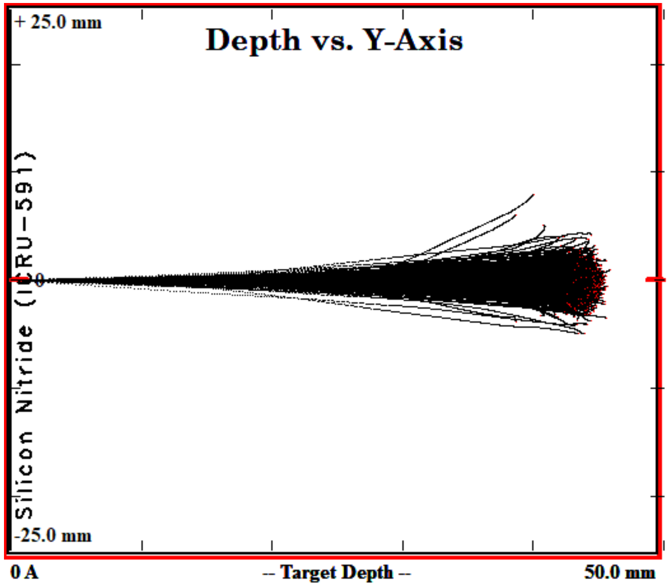
SRIM simulation

*SRIM - The stopping and range of ions in matter

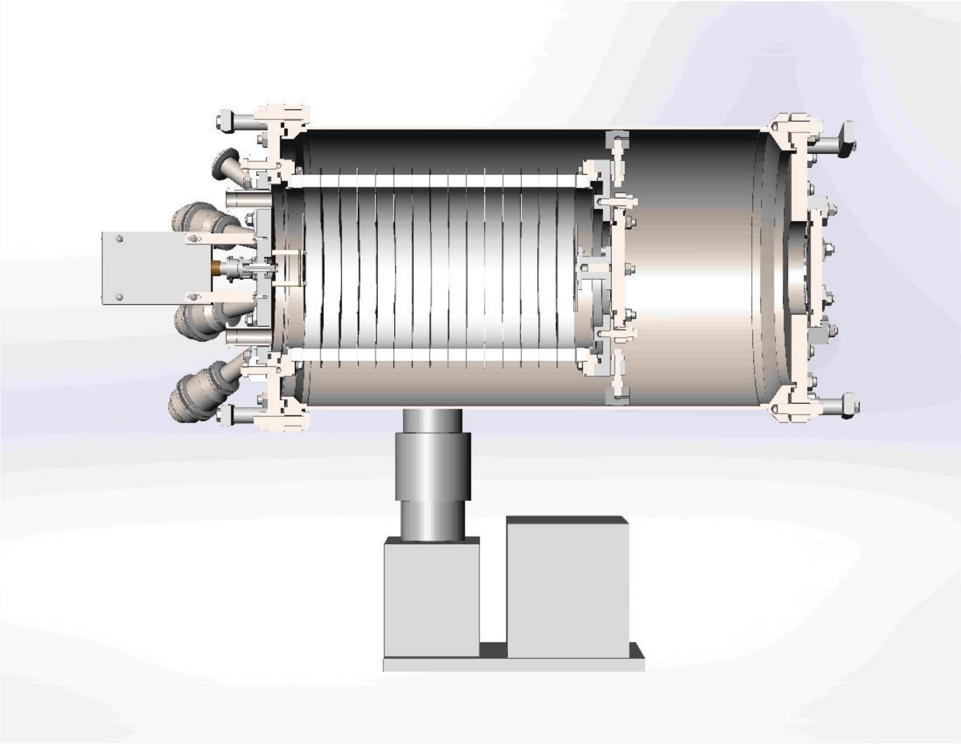


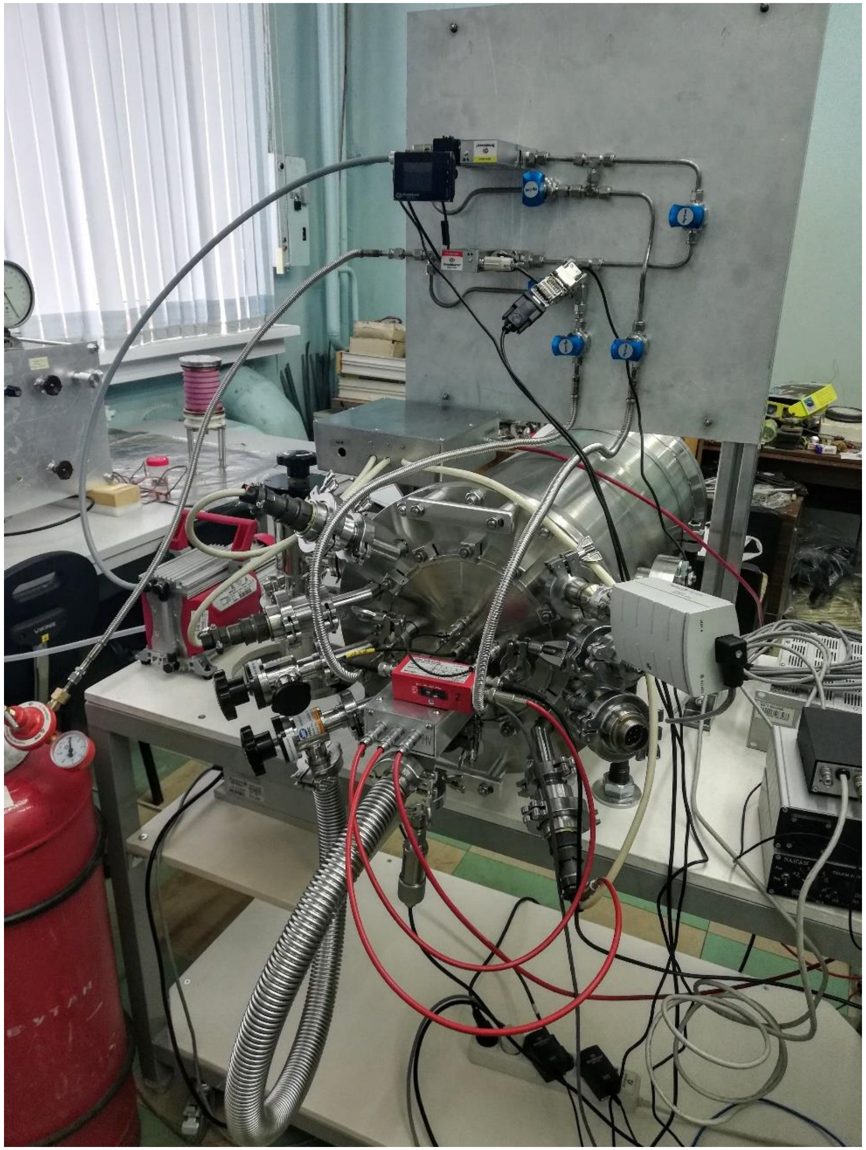
Spectra of track ranges for ^{10}B and ^{10}Be with energy 4.025 MeV in 200 nm silicon nitride and Isobutane at 50 Torr





New TPC configuration





Diameter – 178 mm
Length – 300 mm

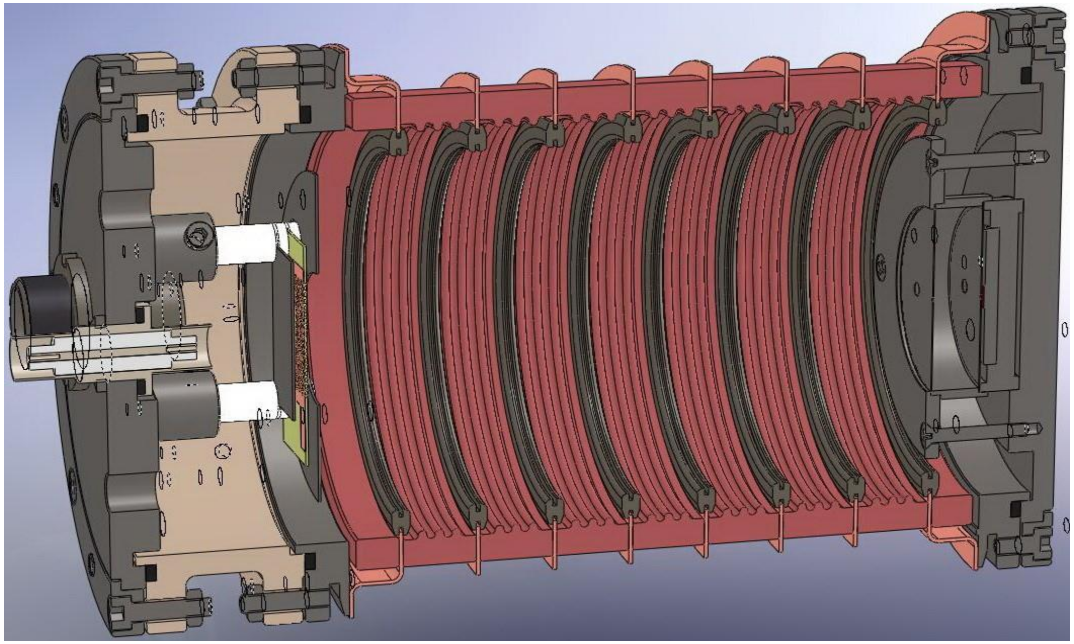
Summary

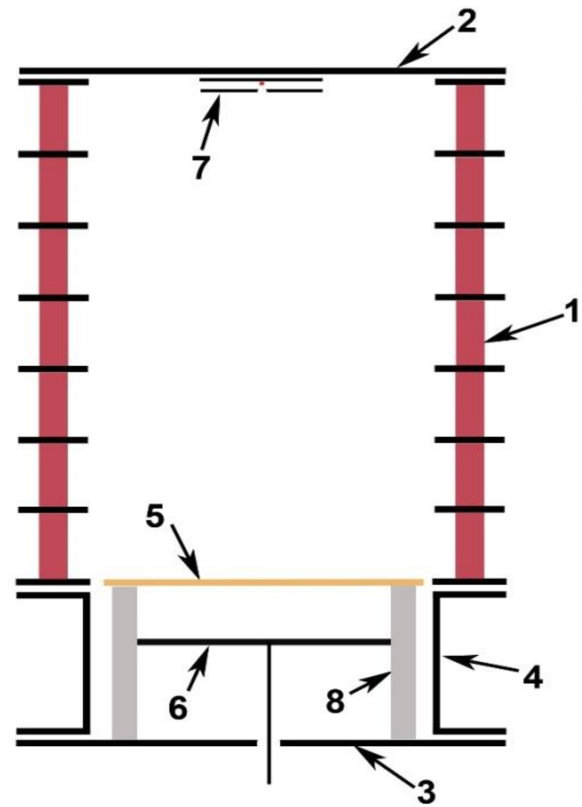
- ✓ The low-pressure TPC with THGEM readout was developed and successfully tested in our laboratory.
- ✓ The track ranges of alpha-particles were measured in the TPC with a rather high accuracy, reaching 1.3%. Based on these results and SRIM code simulations, one may conclude that the isobaric boron and beryllium ions (having range difference of 32%) can be effectively separated in AMS, at the level exceeding 10 sigma, by measuring the ion track ranges.
- ✓ This technique is expected to be applied in the AMS facility in Novosibirsk for dating geological objects, in particular for geochronology of Cenozoic Era.

Thanks for your attention!

Backup slides

Construction





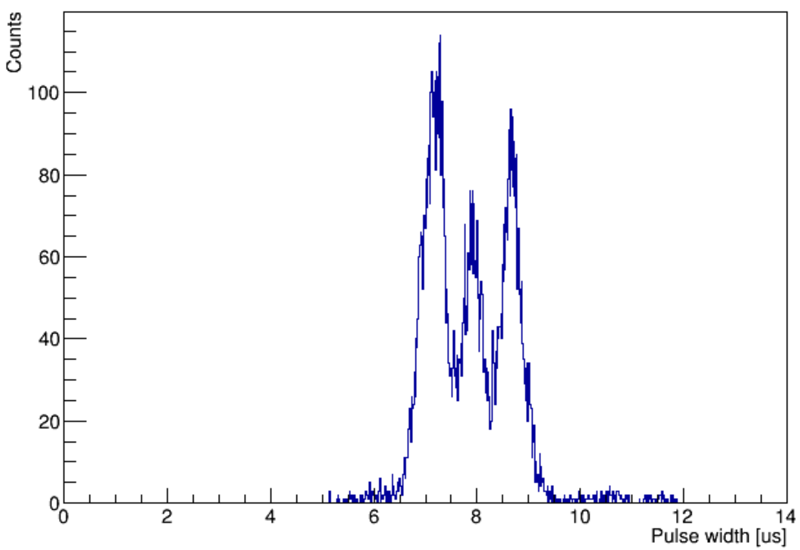
Diameter 76 mm
Length 130 mm

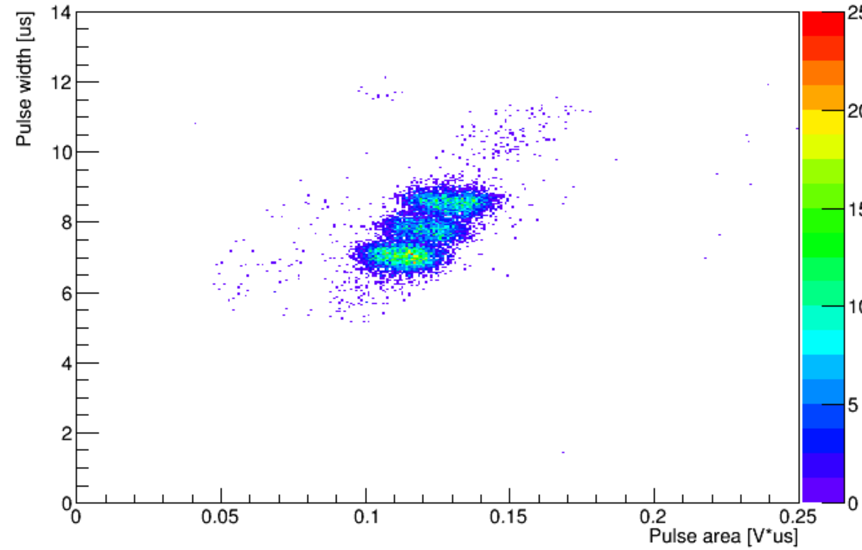
TPC construction: 1 – field shaping rings, 2 – removable top flange,
3 – removable bottom flange, 4 – transitional gap, 5 – THGEM, 6 – sectioned anode, 7 – alpha particle source,
8 – caprolon rods

The measurement of track ranges

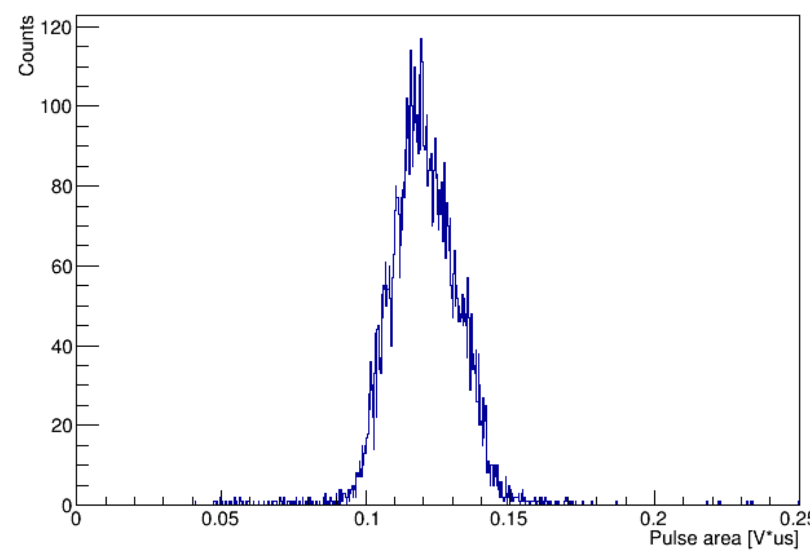
The alpha-particle source – ^{233}U, ^{238}Pu, ^{239}Pu $E_{\alpha} = 4{,}816$ МэВ $E_{\alpha} = 5{,}499$ МэВ $E_{\alpha} = 5{,}157$ МэВ

Pressure = 120 torr **Gain = 40** **Shaping time = 200 ns**





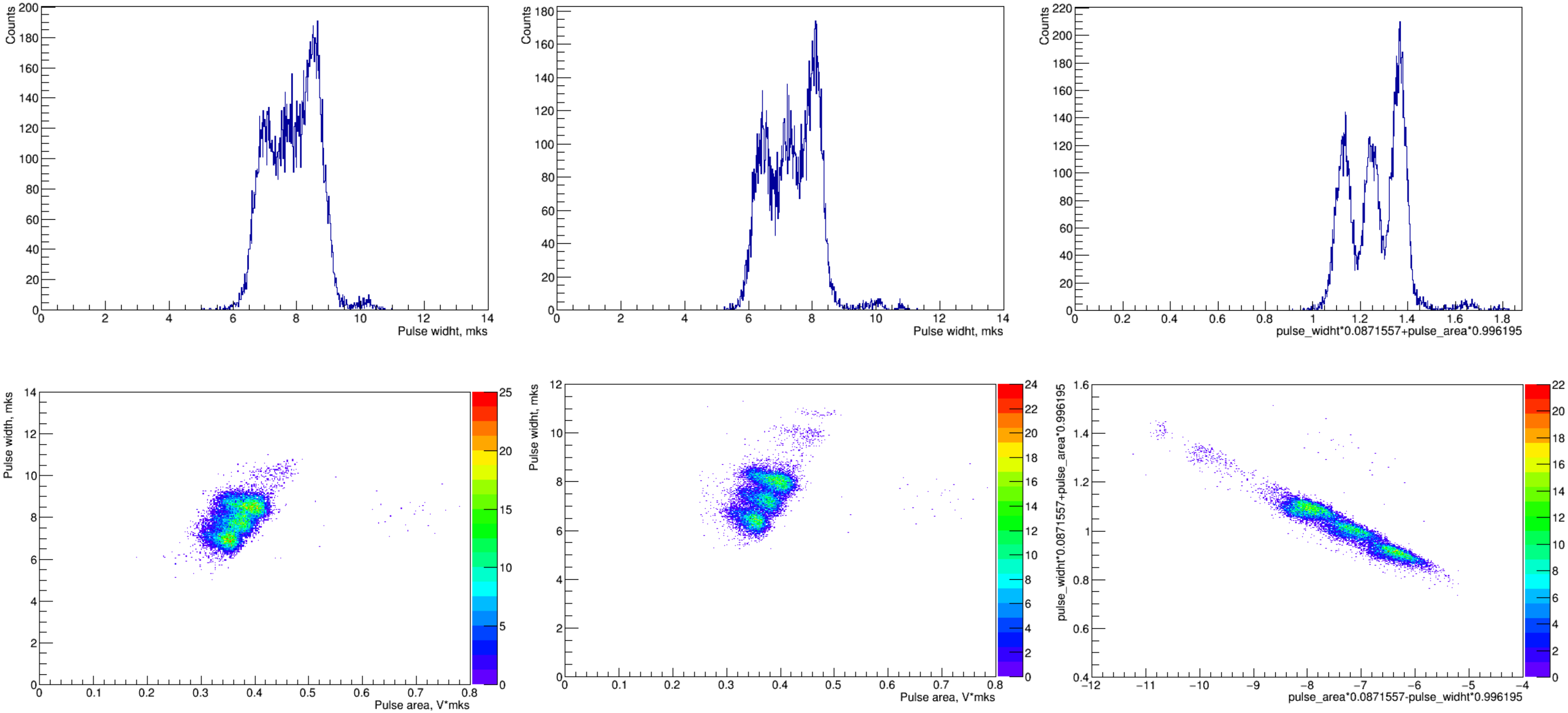
2D plot of pulse width versus pulse area and their axis projection spectra for alpha particles from ^{233}U (4.8 MeV), ^{239}Pu (5.2 MeV) and ^{238}Pu (5.5 MeV) source, measured in low-pressure TPC in Isobutane at 120 Torr and THGEM gain of 40. The pulse width and pulse area spectra reflect those of the track range and energy.



The measurement of track ranges

Источник α – частиц – ^{233}U, ^{238}Pu, ^{239}Pu

Pressure = 120 torr **Gain = 220** **Shaping time = 200 ns**



Fixed threshold Constant fraction threshold Rotation 83^{o}