Recent results on the low-pressure GEM-based TPC at an Accelerator Mass Spectrometer

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Outline

1. Accelerator mass spectrometry

2. New concept of ion identification

3. Experimental setup

4. Measurements of energy spectra and track ranges from alpha particles

5. Measurements of energy spectra and ion ranges at AMS

Accelerator Mass Spectrometry

Accelerator mass spectrometry (AMS) is an ultra-sensitive method of counting individual atoms.

Typical application – radiocarbon dating

Date interval – **less than 50000 years to 100 years**

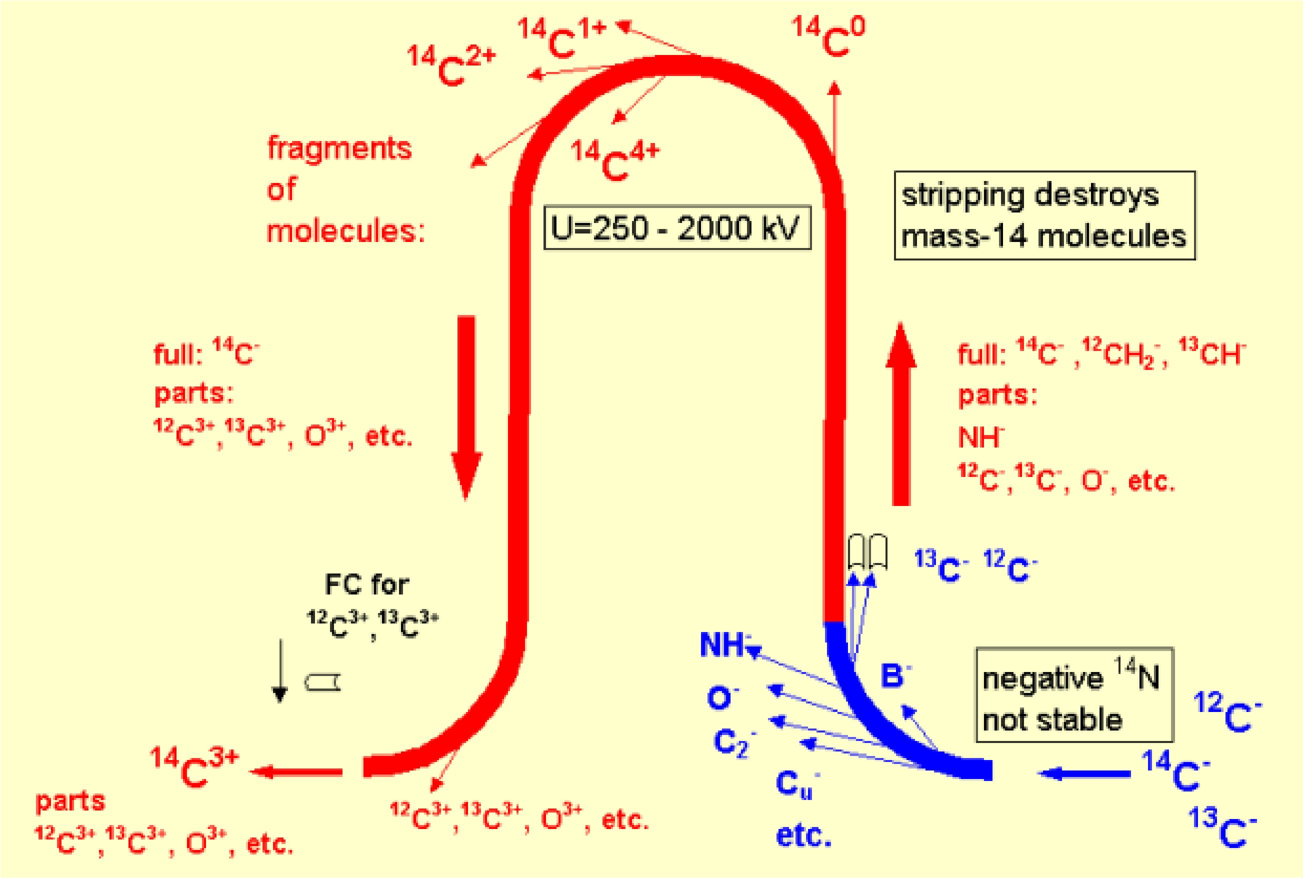
Sample size – **1 mg**

Count rate – **100 Hz**

Accuracy – **0.2 %**

AMS facilities operate in more than 140 physical laboratories worldwide, one of which is located in Novosibirsk at Geochronology of the Cenozoic Era Center for Collective Use.

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
5. Ion selection in a high voltage terminal
6. Ion acceleration
7. Ion selection at high energy
8. Identification and counting of ions

Cosmogenic isotopes

Analyzed isotopes	Half life	Stable isotopes	Stable isobars (background)
^{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	$^{129}Xe^{*}$

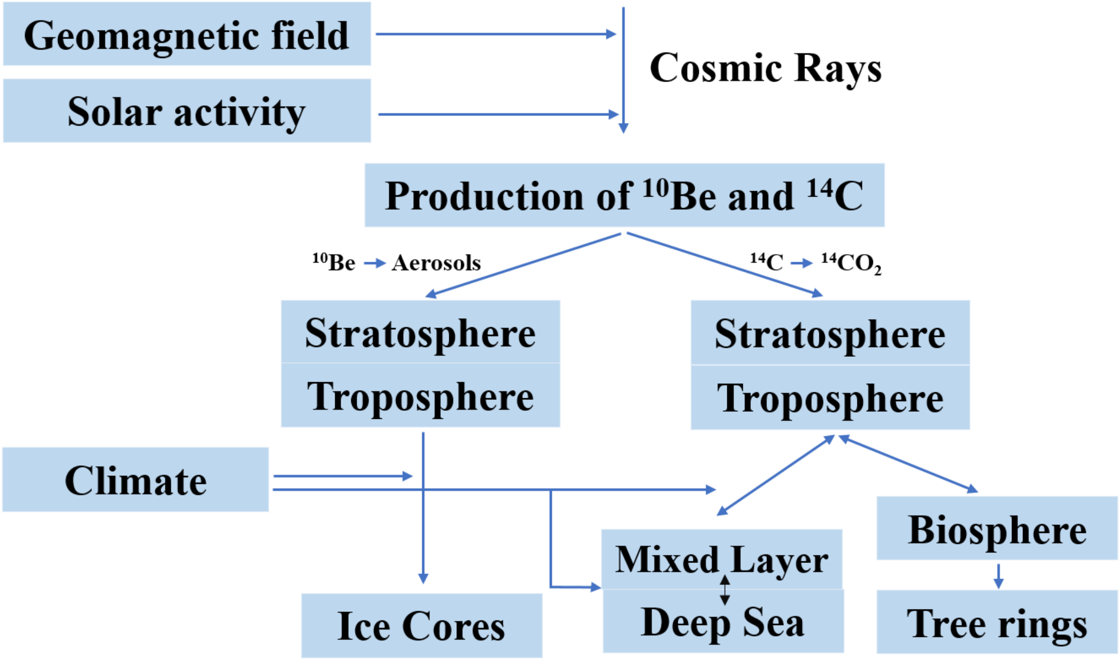
In the current BINP AMS setup the time-of-flight technique is used for the isotopes separation. But that technique has a serious problem of separating the isobars - different chemical elements having the same atomic mass. The typical example is radioactive isotopes ^{10}Be and ^{10}B.

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

Formation and application ^{10}Be

Time intervals of dating:

- ^{14}C from 100 years to 50 thousand years
- ^{10}Be from 1 thousand years to 10 million years



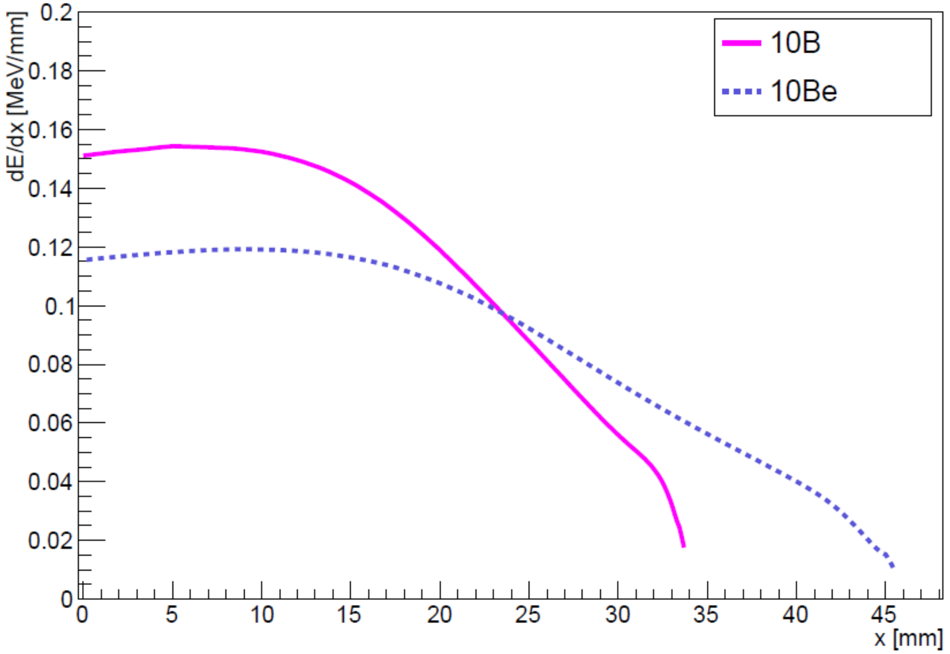
Application in-situ and meteoric ^{10}Be:

- 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.

Traditional concept of ion identification at AMS

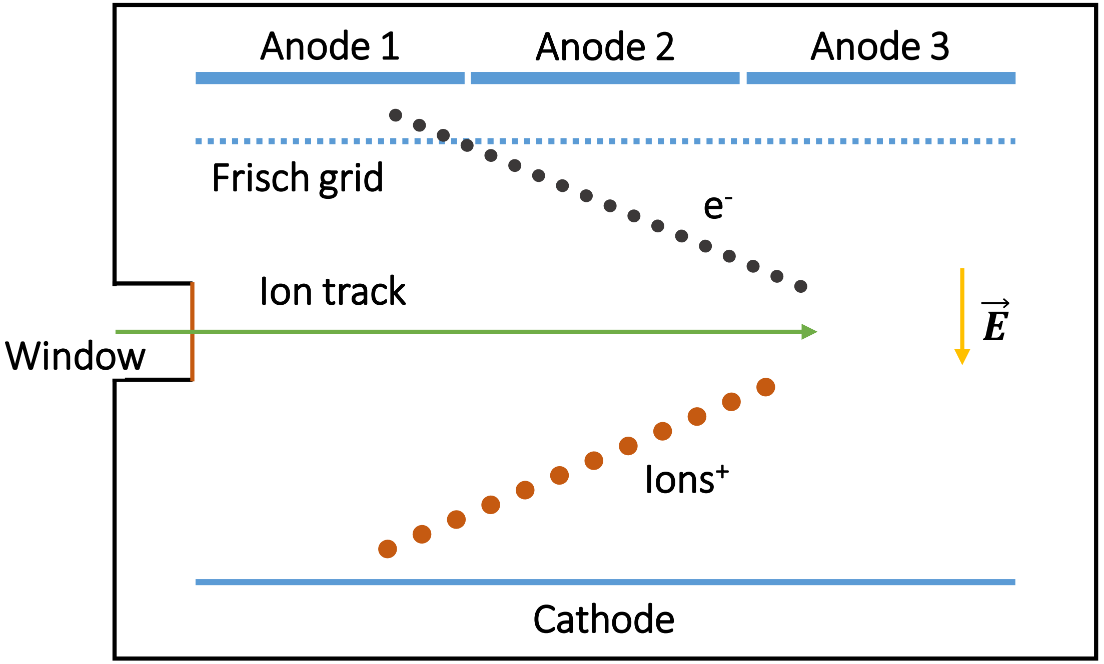
Detectors used to count the AMS ions:

- silicon detectors;
- time-of-flight systems;
- ionization chambers.



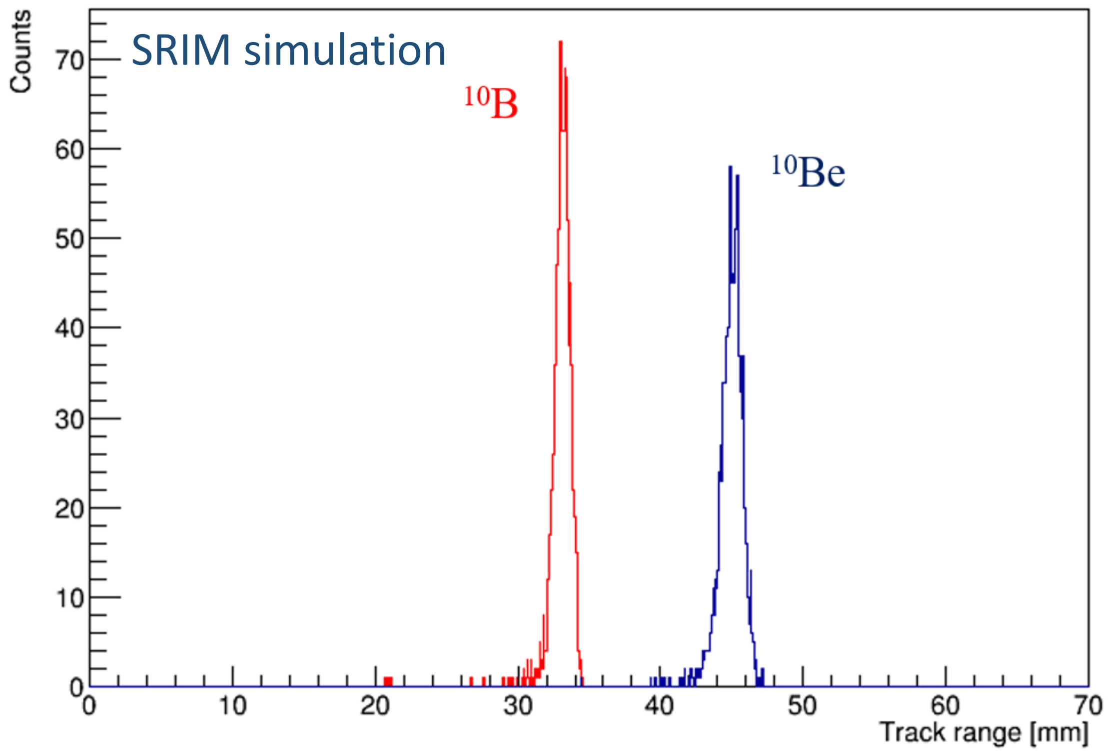
Mean stopping power for ^{10}B and ^{10}Be projectiles against penetration depth in 50 torr isobutane.

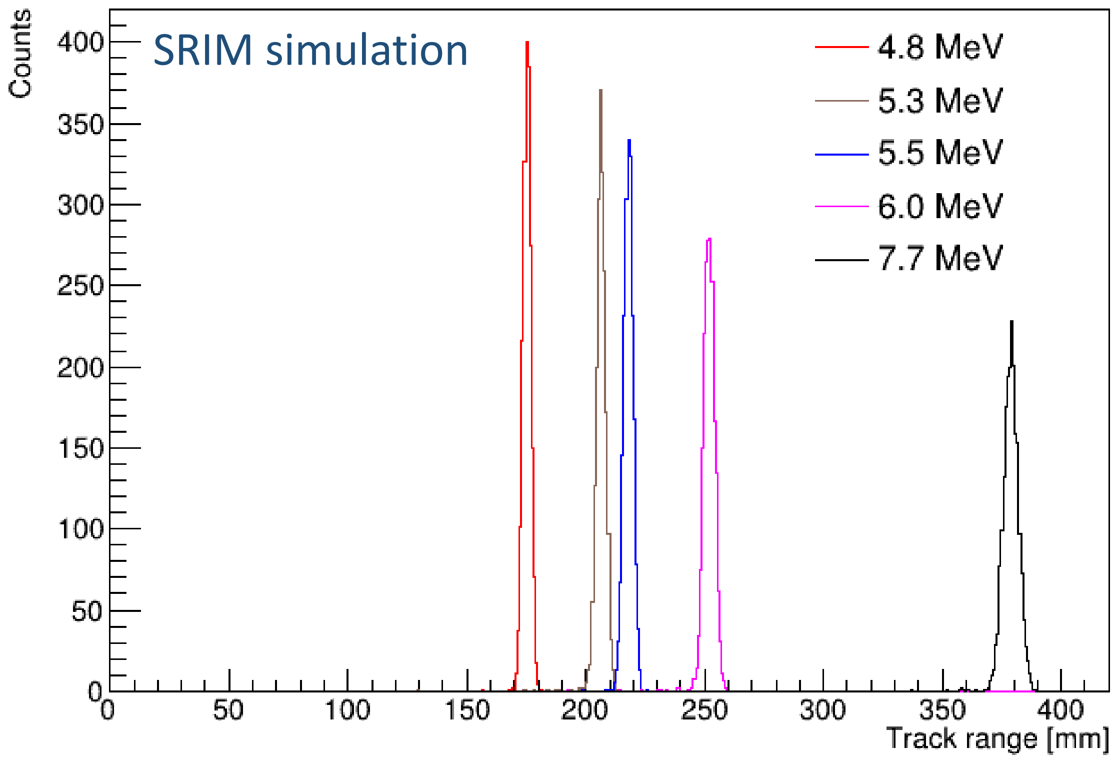
ΔE-E detectors



Schematic drawing of a sample gas ionization detector with split anode. Such a detector is installed at AMS that carry out multi-isotope measurements.

New concept of ion identification: measuring track ranges



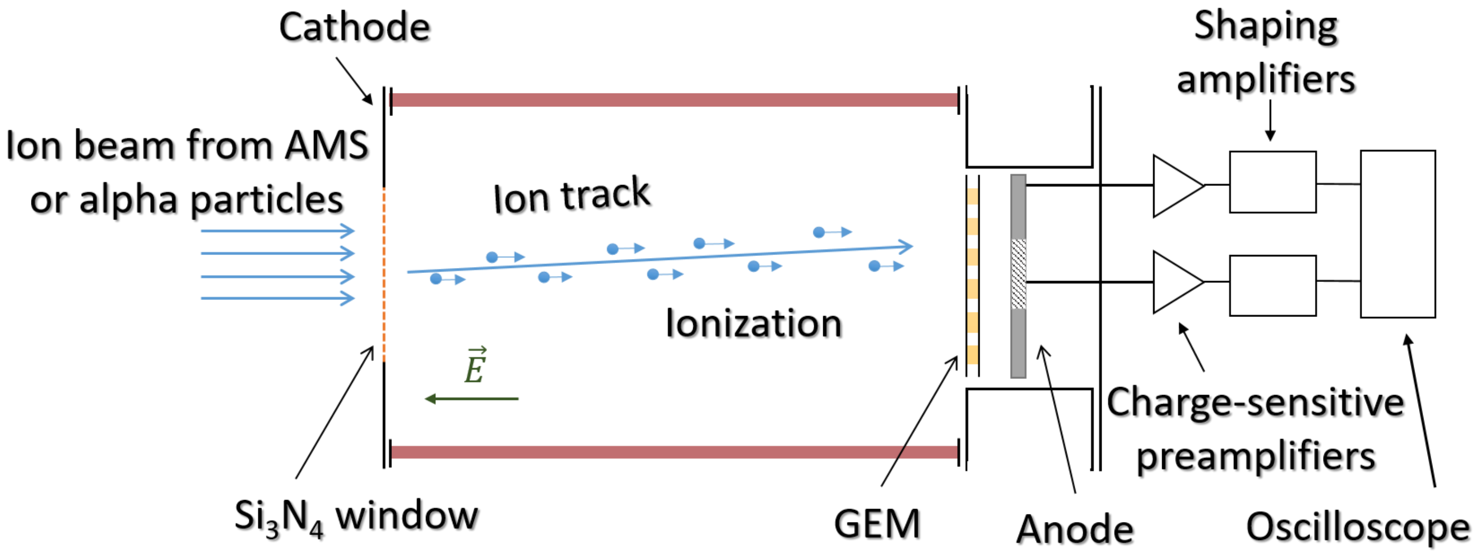


Track ranges distribution of 4 MeV ^{10}Be and ^{10}B passing through 200 nm silicon nitride window into 50 torr isobutane at room temperature.

Track ranges distribution of alpha particles with different energies passing through 200 nm silicon nitride window into 50 torr isobutane at room temperature.

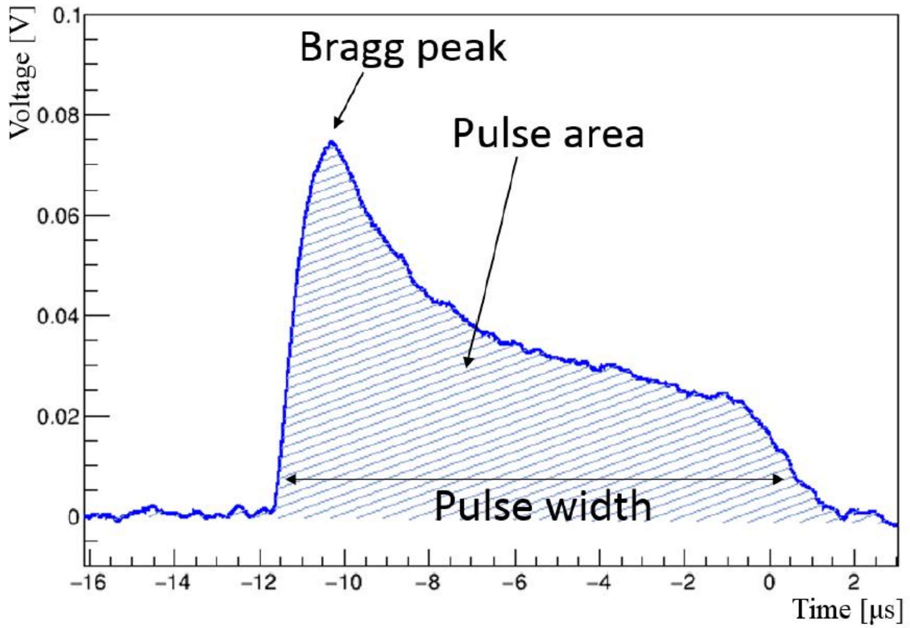
Proof of concept: low-pressure TPC

Schematic layout of the low-pressure TPC



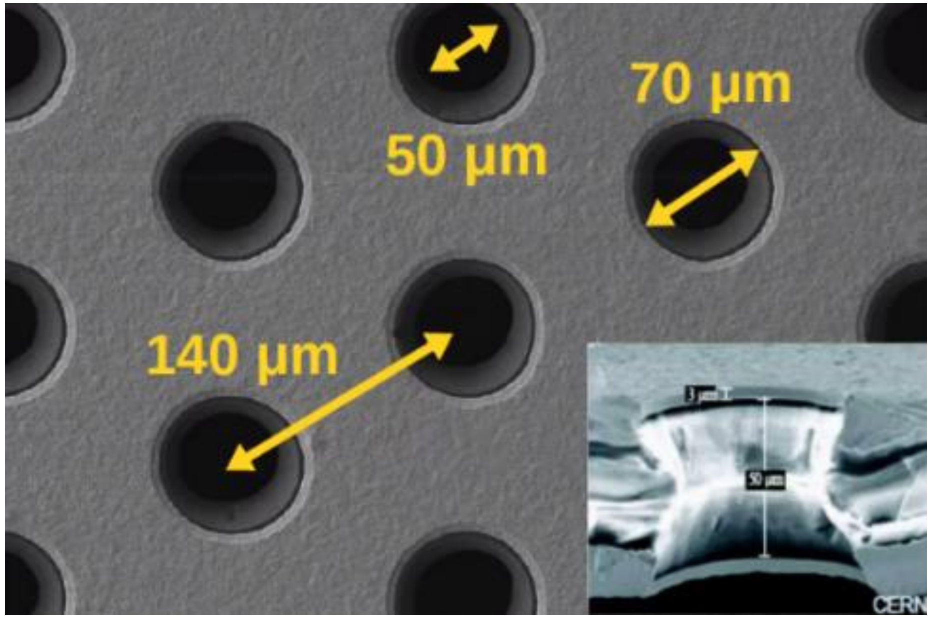
Diameter ≈ 8 cm
Length ≈ 11 cm
Gas filled - Isobutane

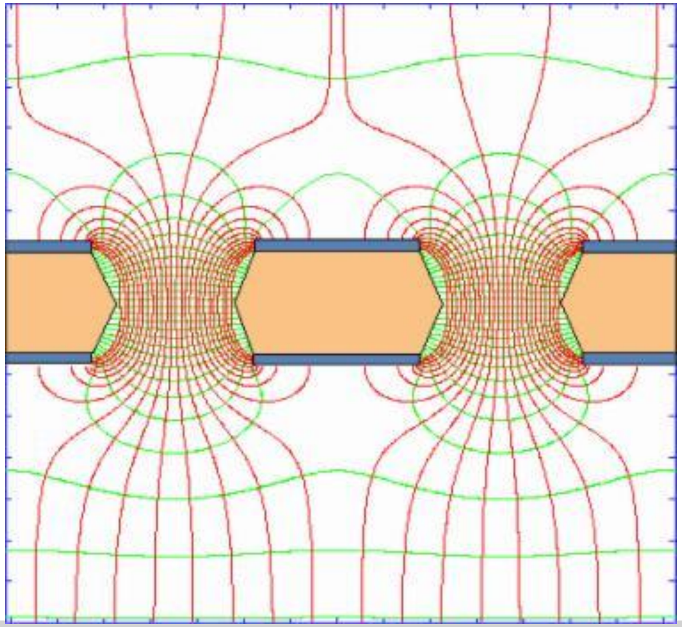
A waveform example from alpha particle in the low-pressure TPC



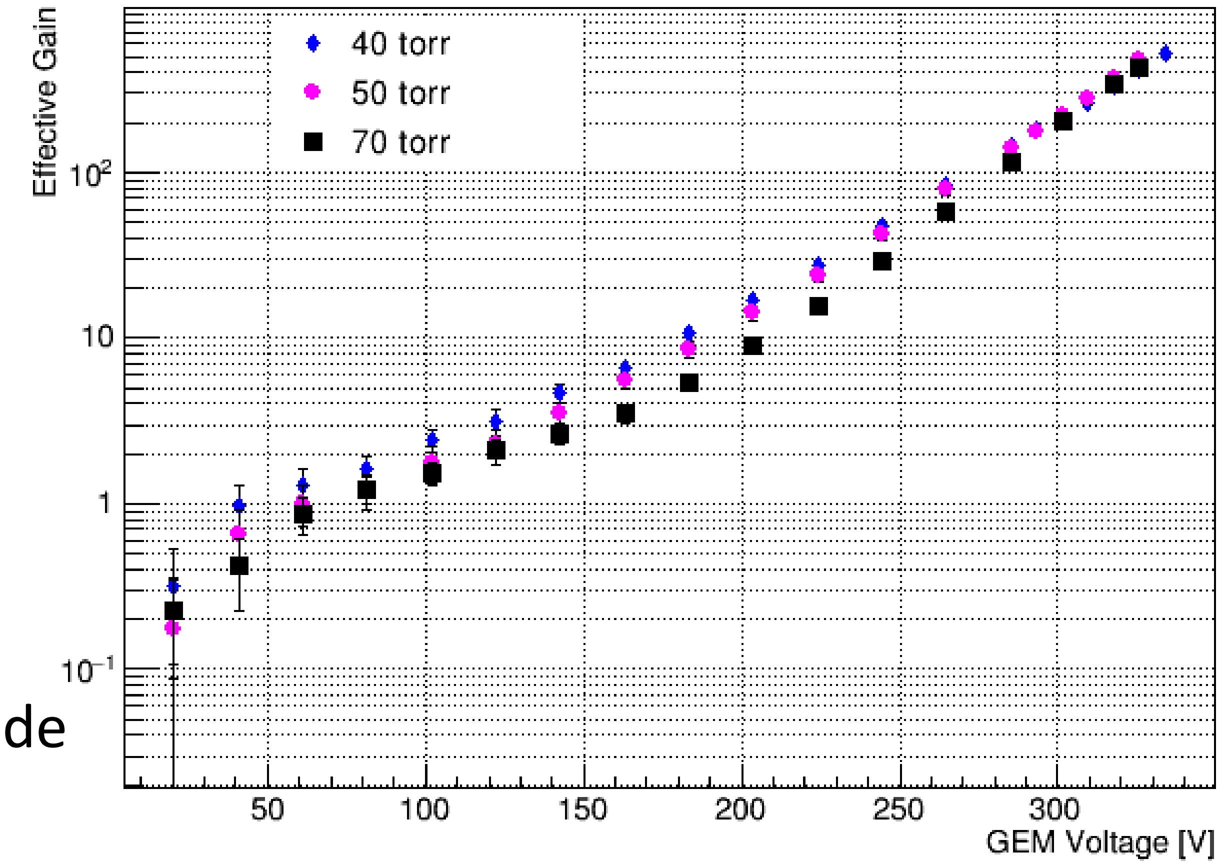
pulse width ~ track range
pulse area ~ energy

Signal amplification with GEM





Electric field inside the holes.



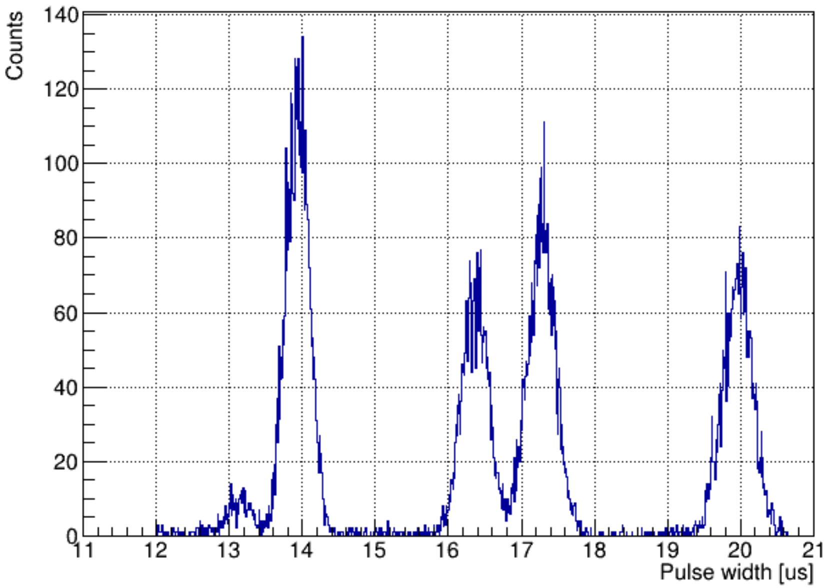
GEM effective gain as a function of the voltage in isobutane at pressures varying from 40 to 70 torr in the low-pressure TPC.

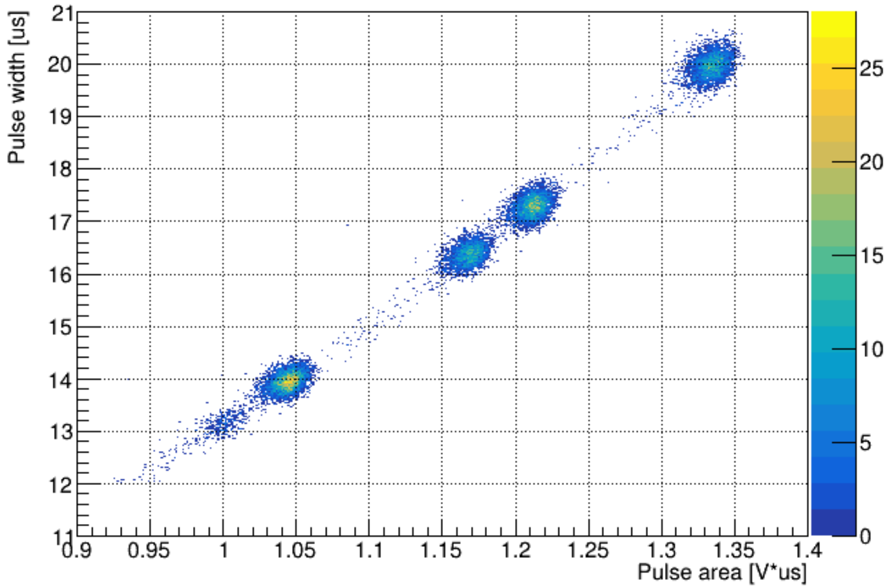
Measurements of energy spectra and track ranges from alpha particles

The alpha-particle source - ^{226}Ra

$E_\alpha = 4.8\ MeV$
$E_\alpha = 5.3\ MeV$
$E_\alpha = 5.5\ MeV$
$E_\alpha = 6.0\ MeV$
$E_\alpha = 7.7\ MeV$

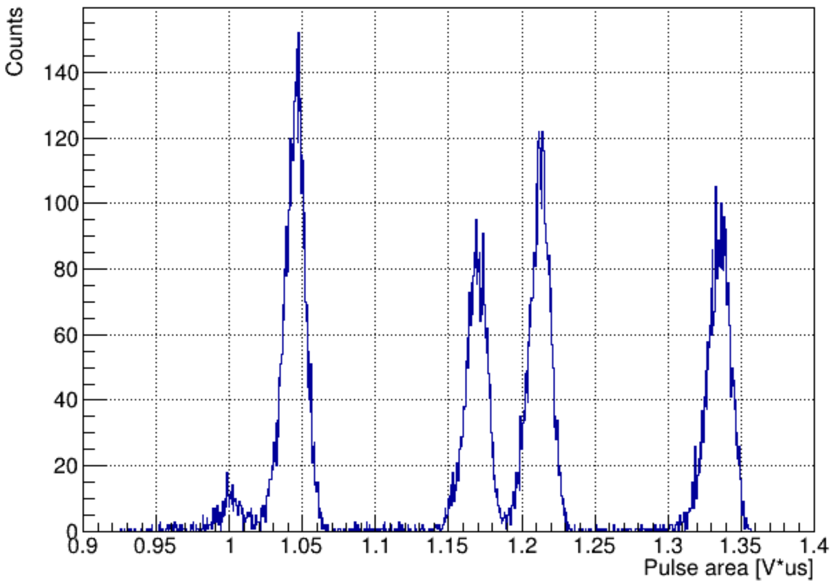
Pressure = 50 Torr
Gain = 225





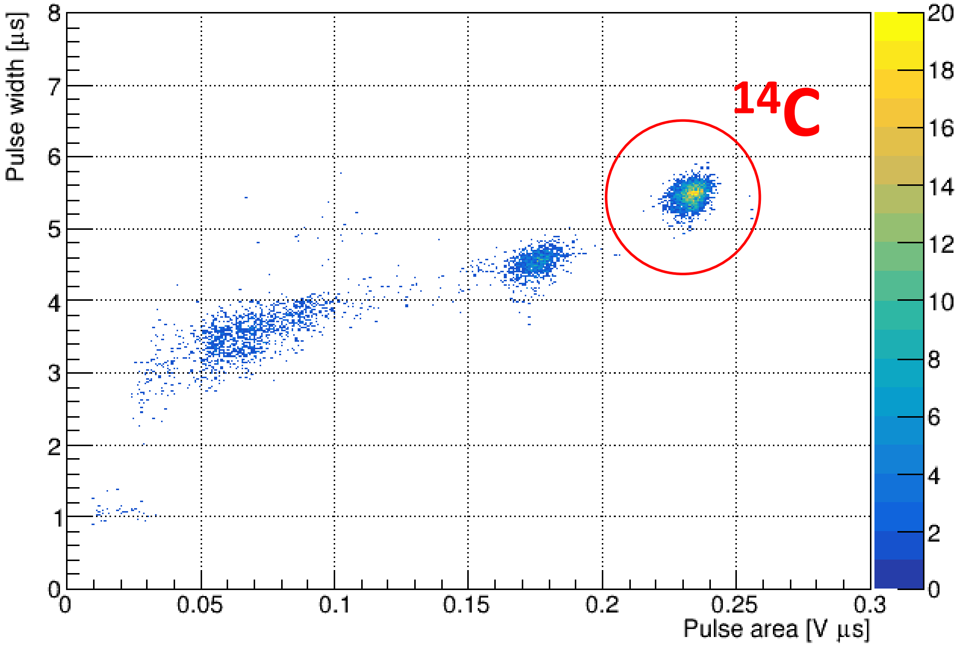
Source	Sigma/Range	Separation level
^{226}Ra	1.13%	5σ

Using these results and SRIM simulations it is shown that isobaric boron and beryllium ions can be effectively separated at AMS at the 5σ level.



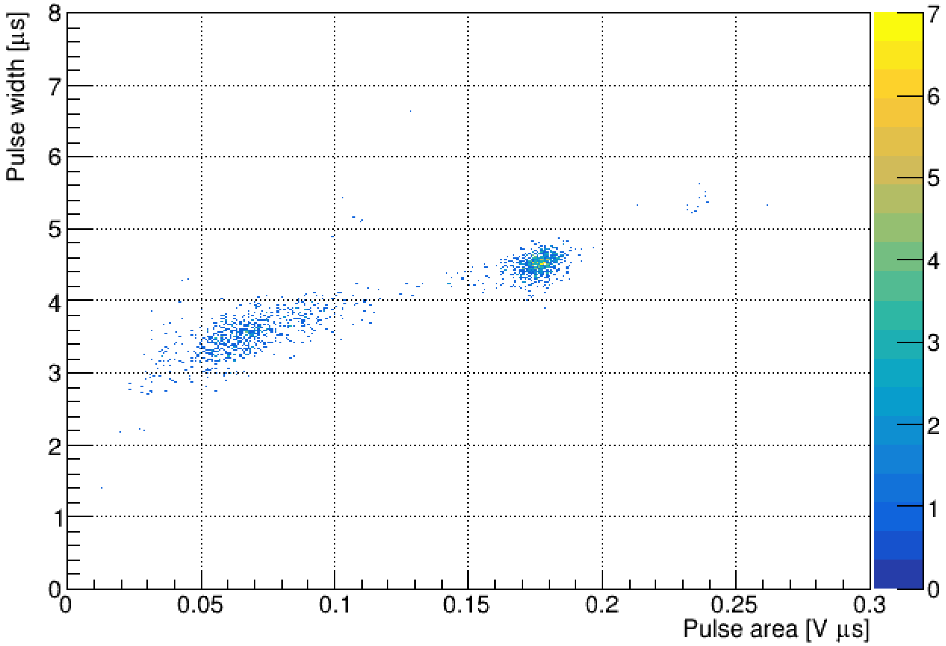
Measurements of energy spectra and ion ranges at AMS

2D plots of pulse width versus pulse area for ions from BINP AMS measured in low-pressure TPC in isobutane at 50 torr.



Reference Sample

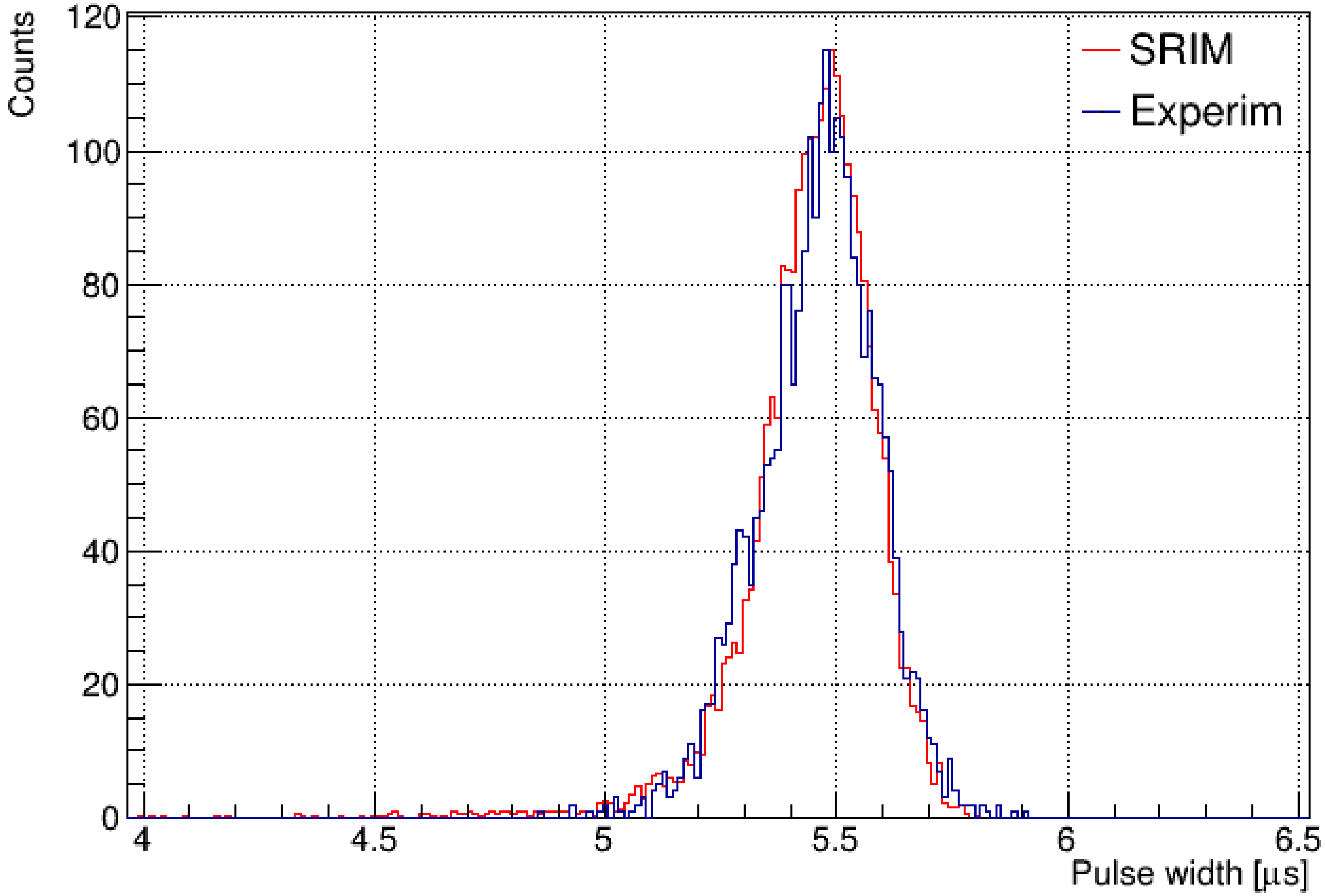
Australian **N**ational **U**niversity standard.
Made from sucrose (sugar) and is one of the IAEA-certified radiocarbon standards.



Background Sample

Blank carbon samples was made from fine-grained dense graphite (dead carbon without 14C).

Carbon-14: experiment vs simulation



Distribution of pulse width from carbon-14 ions. Low-pressure TPC measurements are fitted with simulation using SRIM.

Experiment: υ_{dr} = 0.53 cm/μs

Drift velocity in Isobutane at 50 torr and E = 13.5 V/cm is calculated using Magboltz.

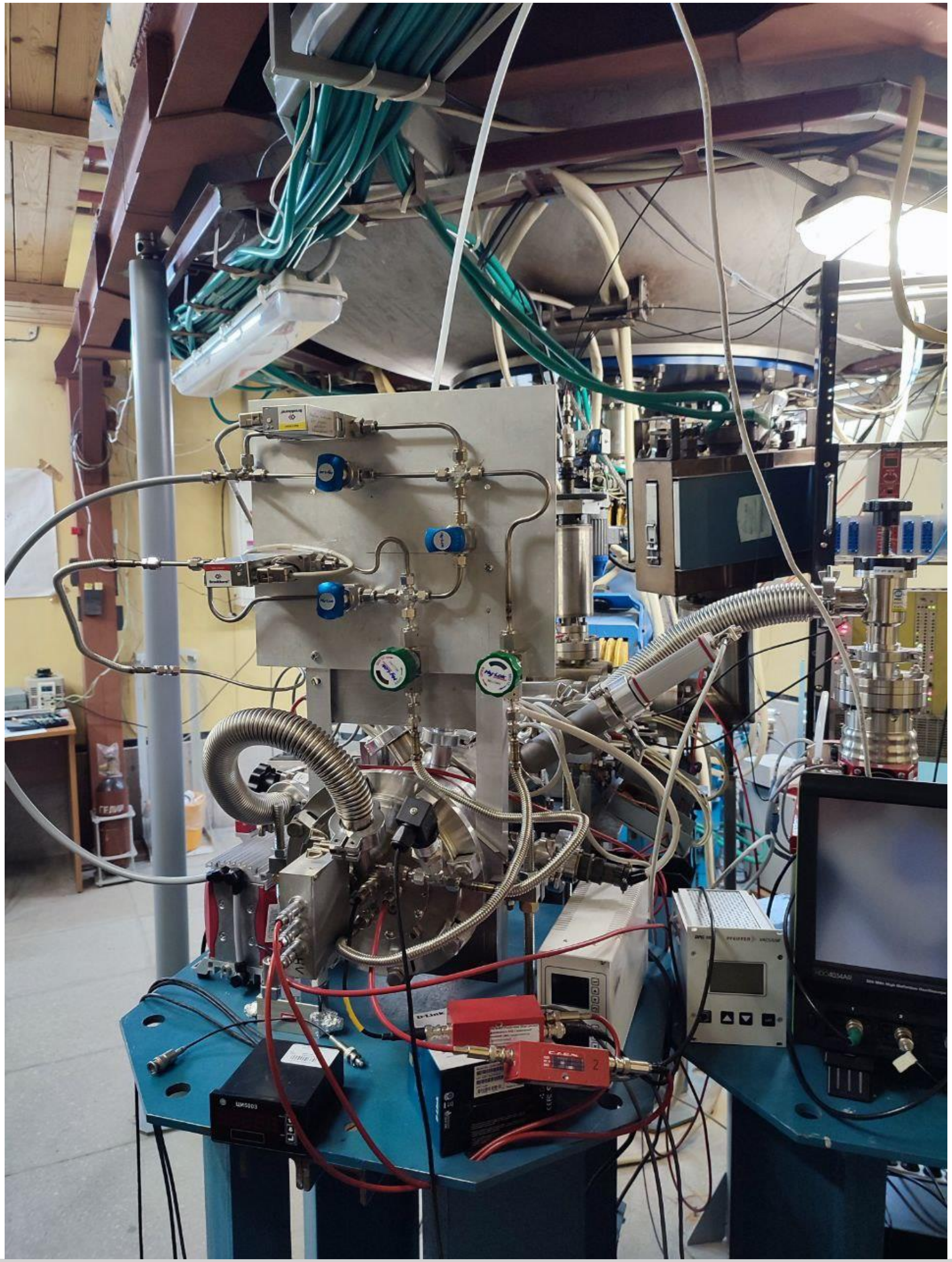
Magboltz: υ_{dr} = 0.58 cm/μs

Experiment and simulation are in good agreement.

There is currently work in progress on determination of experimental errors.

Results

- ✓ We have developed and successfully tested low-pressure TPC with GEM readout for AMS.
- ✓ A new ion identification technique based on measuring both ion track ranges and ion energies in low-pressure TPC has been developed.
- ✓ Using these results and SRIM simulations, it was shown that isobaric boron and beryllium ions can be effectively separated at BINP AMS at a level of 5σ. It provides efficient dating up to 10 million years (for geochronology of Cenozoic Era).
- ✓ Low-pressure TPC was installed at BINP AMS. Measurements were successfully carried out with samples containing radiocarbon.



Thank you for your attention

Backup slides

Silicon nitride membrane windows

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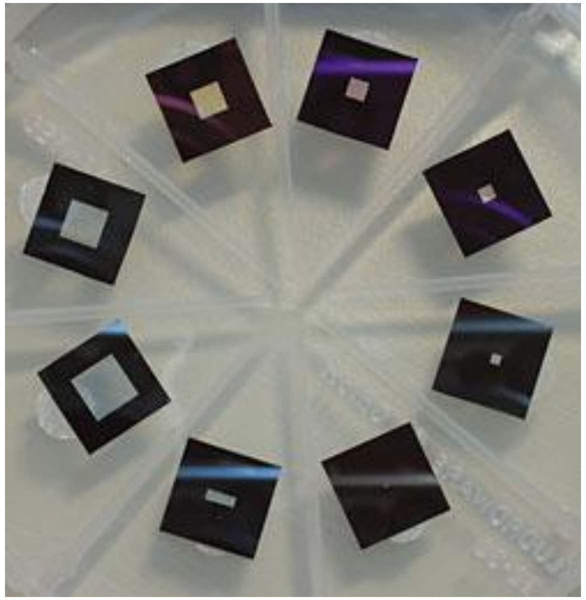


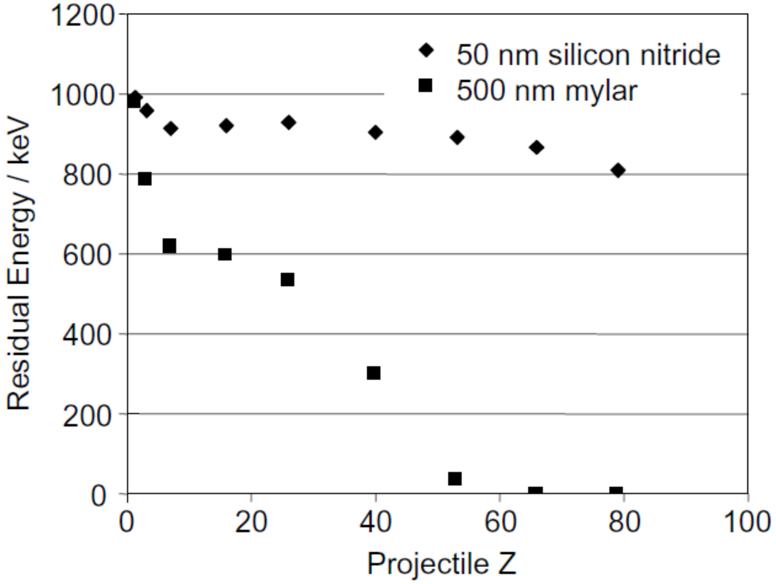


Fig. 1. Remaining energy after passage of 1 MeV ions through a 50 nm silicon nitride and a 500 nm mylar window. TRIM calculation [2].

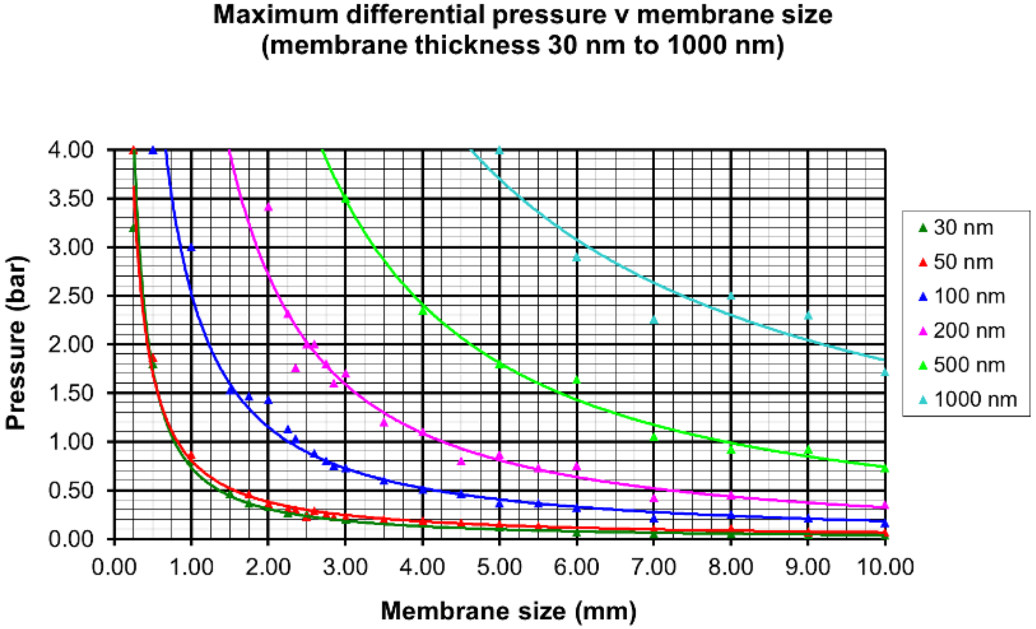
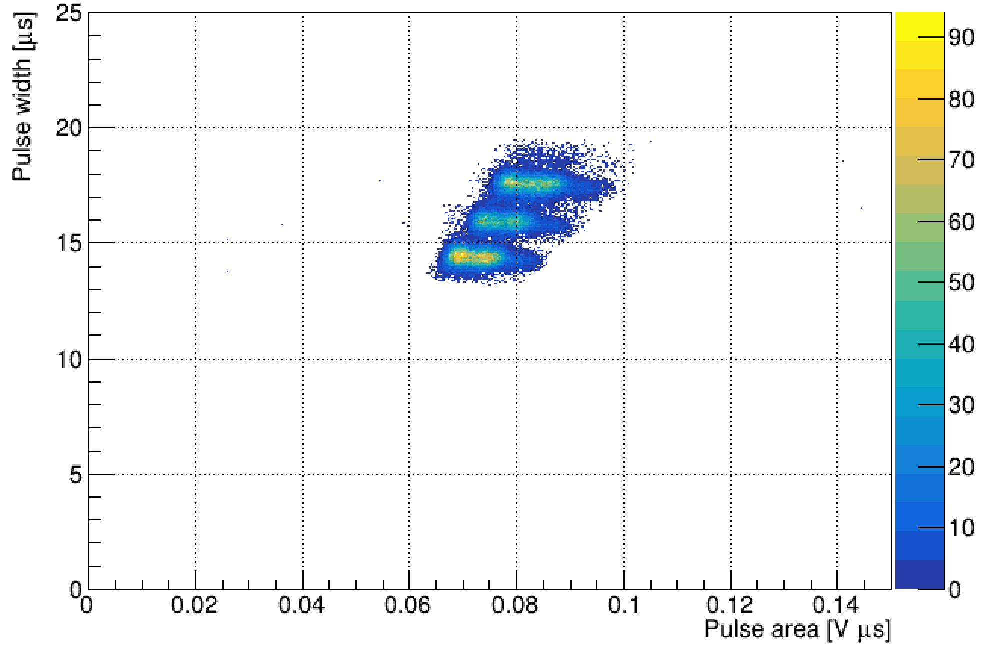


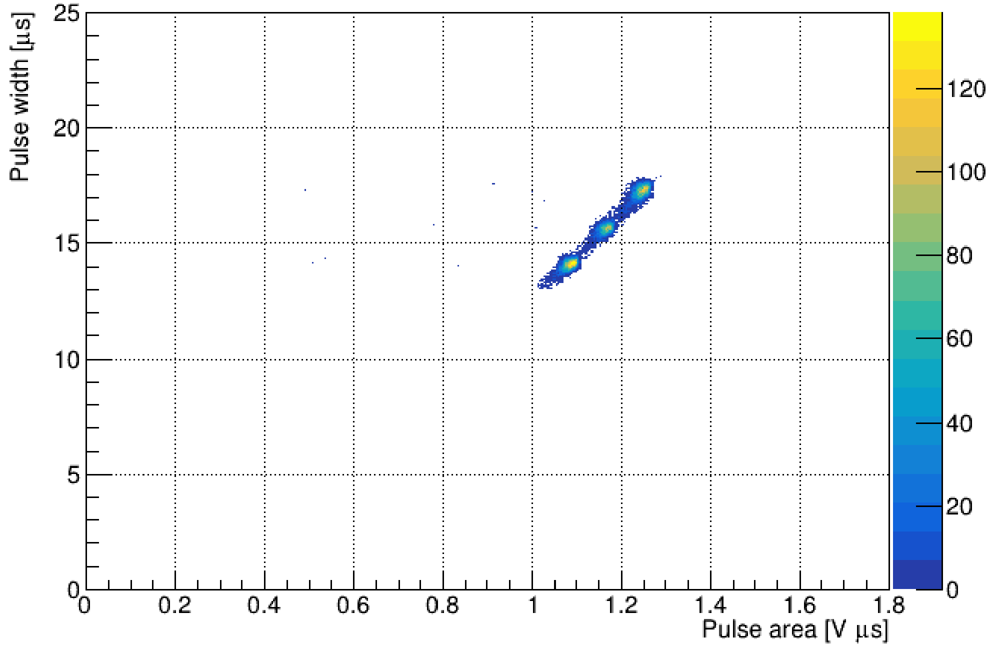
Figure of silicon nitride membrane windows

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

THGEM versus GEM



2D plot of pulse width versus pulse area 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 room temperature using THGEM amplification with gain of 320.



2D plot of pulse width versus pulse area 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 room temperature using GEM amplification with gain of 230.