The new PID equipment of the Super-FRS

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  separation method and PID of relativistic ions

- Super-FRS PID detectors

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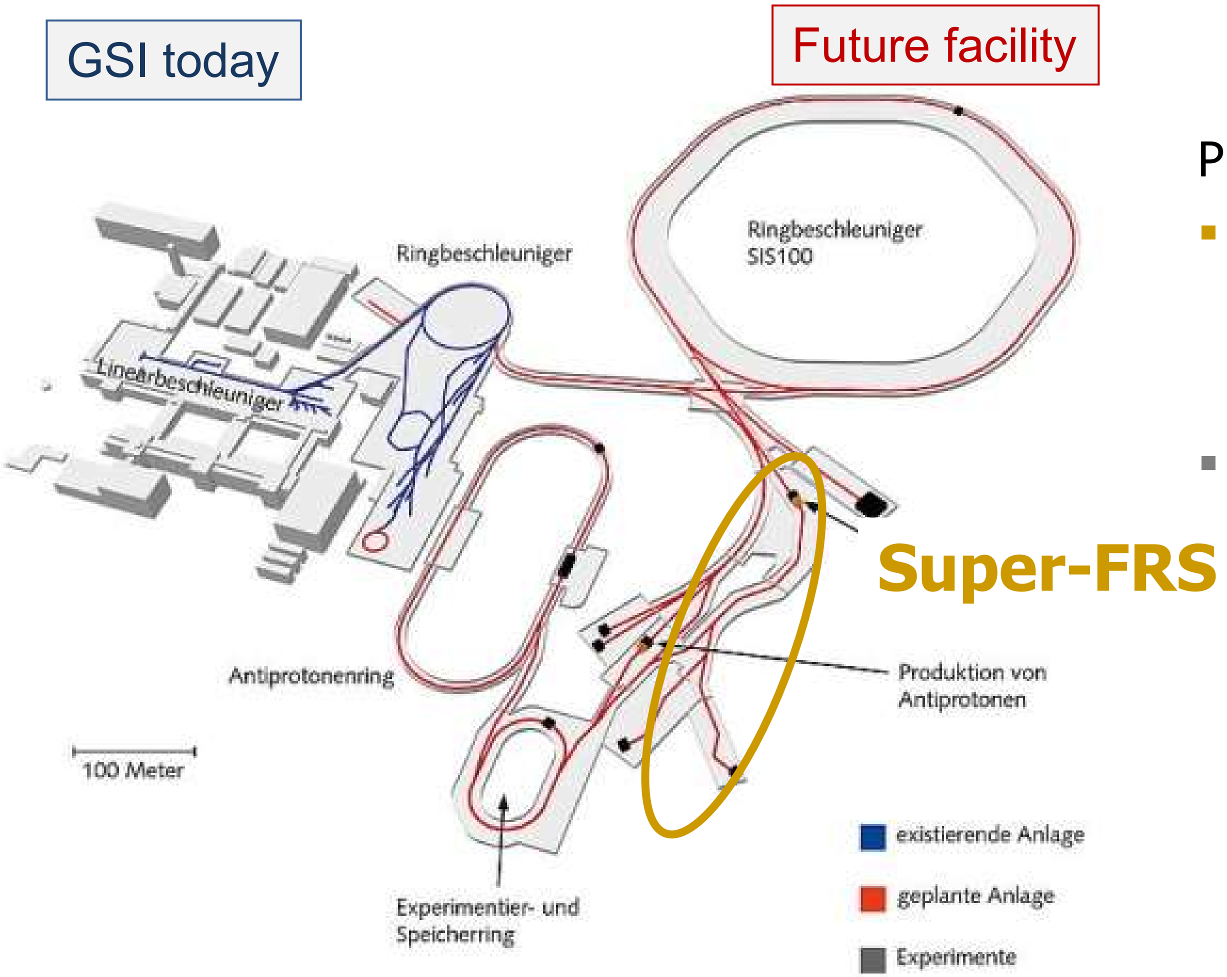
- First results of the in-beam Super-FRS detector tests at GSI

  achievement and restrictions

- Summary

The NUSTAR in-flight facility



Primary Beams

- Early Science (SIS18)

  5x10^{9} ^{238}U/spill at 1 GeV/u

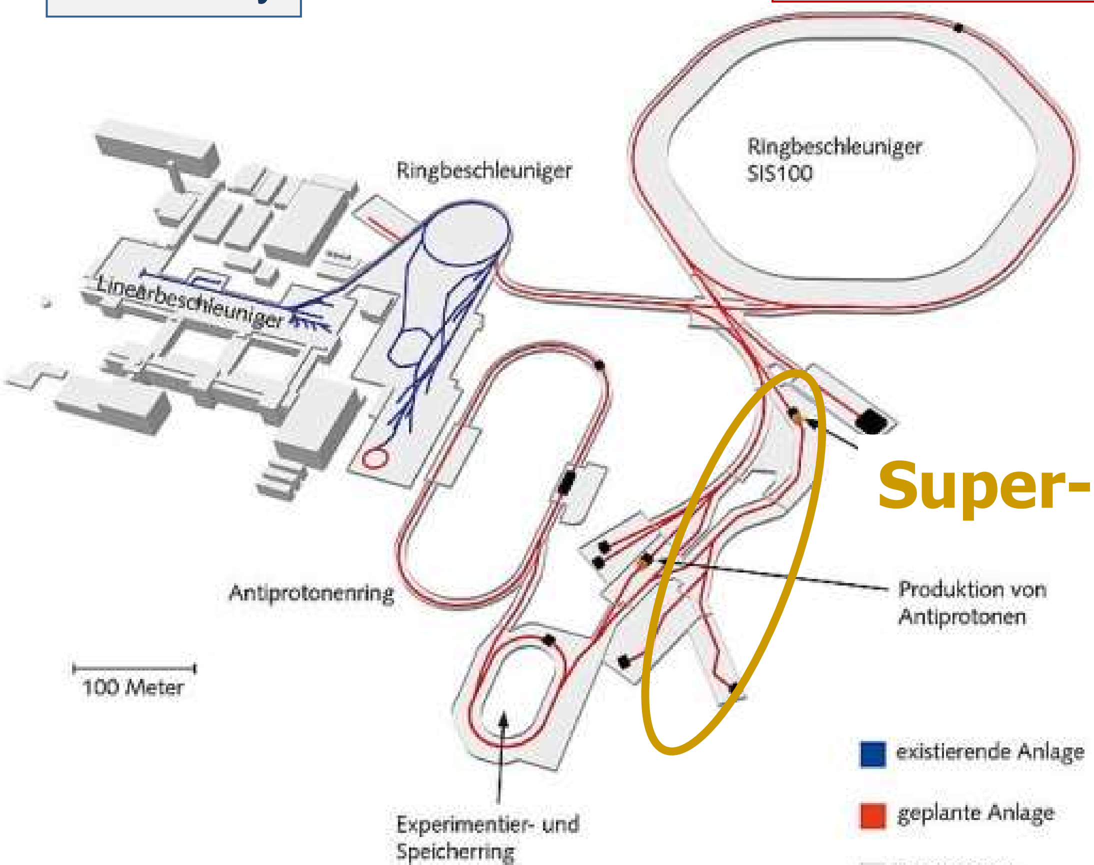
- First Science (SIS100)

  2x10^{10} ^{238}U/spill at 1.5 GeV/u

The NUSTAR in-flight facility

GSI today

Future facility



Primary Beams

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  5×10^{9} ^{238}U/spill at 1 GeV/u

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  2×10^{10} ^{238}U/spill at 1.5 GeV/u

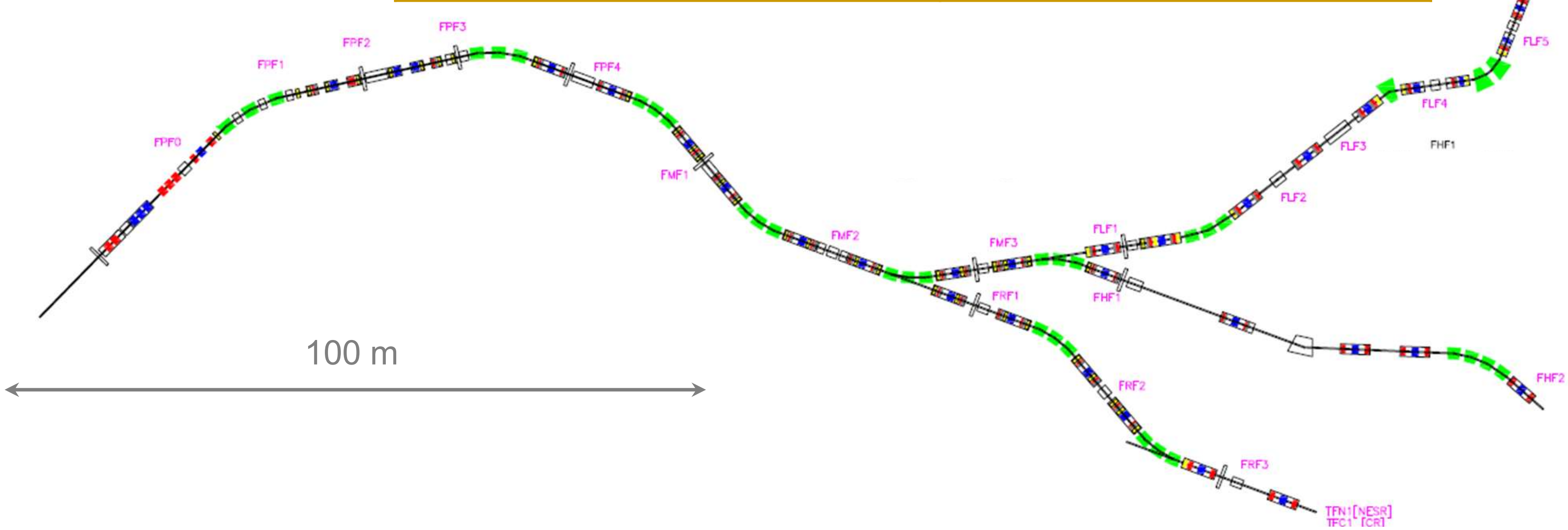
Secondary Beams (HEB)

- broad range of RIBs up to 1-2 GeV/u
- factor ≥ **100** in intensity over present (Cave C)

Super-FRS layout

Main Parameters

Magnetic rigidity	2 - 20 Tm
Emittance	$\varepsilon_x = \varepsilon_y = 40\ \pi$ mm mrad
Angular acceptance	$\sigma = \pm 40$ mrad, $\phi = \pm 20$ mrad
Momentum acceptance	± 2.5 %
1st order resolution (σ_x=1mm, σ_y=2mm)	750 (1st stage), 1500 (2nd stage)



M. Winkler et al., *NIM B* 266 (2008) 4183

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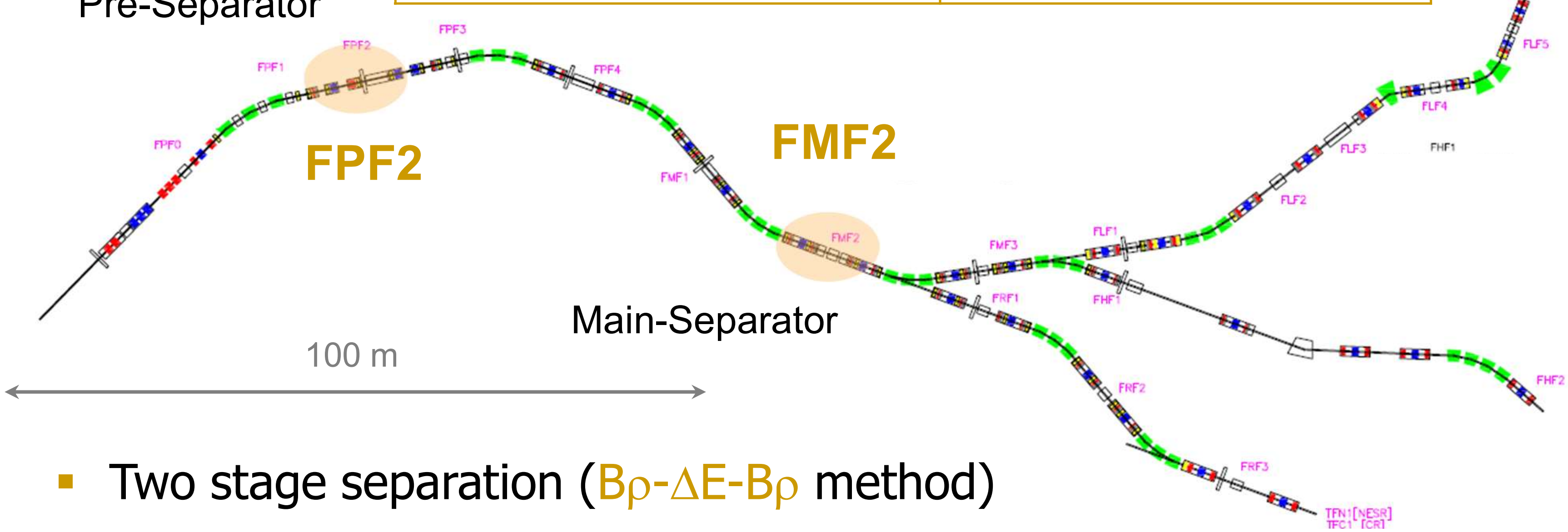

- Two stage separation (Bρ-ΔE-Bρ method)

M. Winkler et al., *NIM B* 266 (2008) 4183

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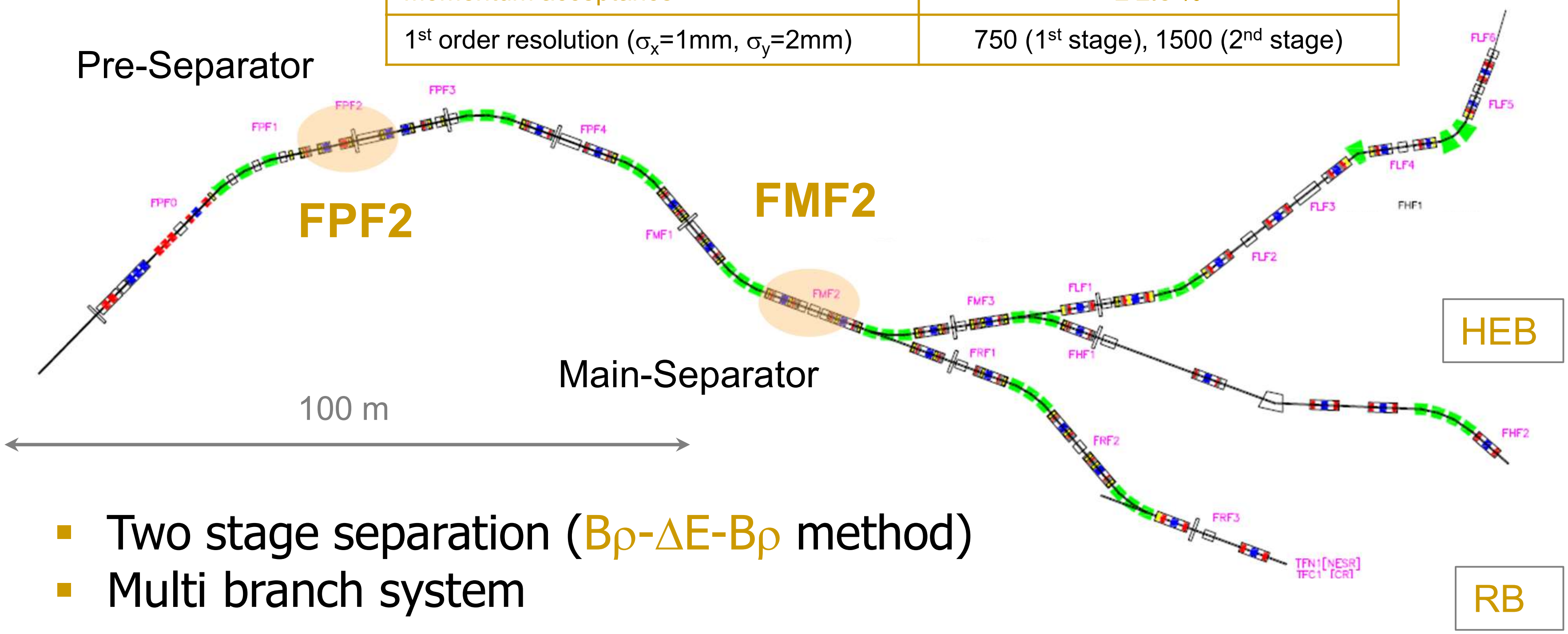

- Two stage separation (Bρ-ΔE-Bρ method)
- Multi branch system

M. Winkler et al., *NIM B* 266 (2008) 4183

Super-FRS layout

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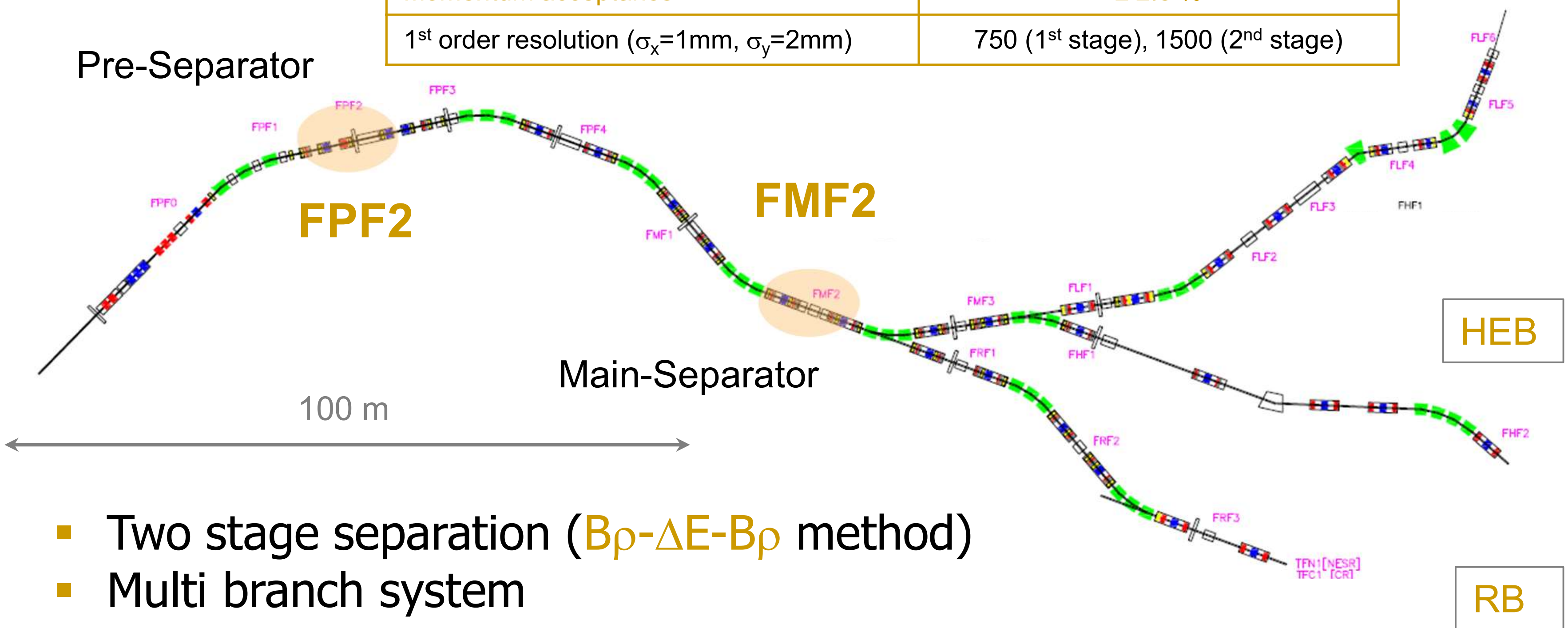


- Two stage separation (Bρ-ΔE-Bρ method)
- Multi branch system
- Large acceptance using s.c. magnets
- Handling concept for high radiation area

M. Winkler et al., *NIM B* 266 (2008) 4183

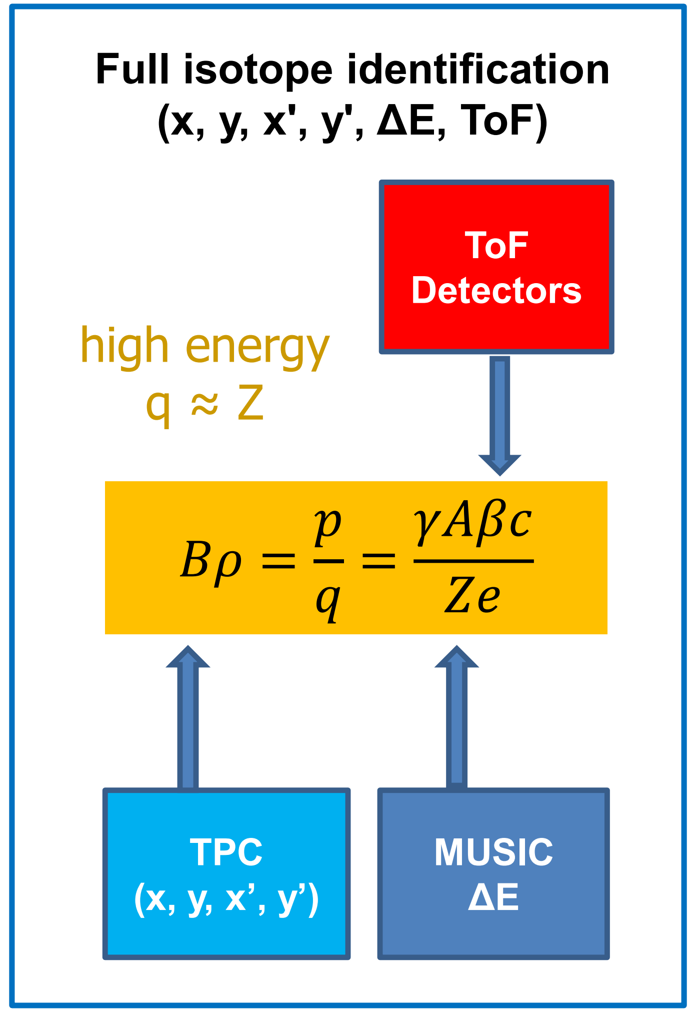
Bρ-ToF-ΔE method

For almost all **NUSTAR** experiments, the separator is to be treated as the first part of the experimental setup.

The beam particles entering the different branches have to be identified and their longitudinal and transverse momentum components should be known.

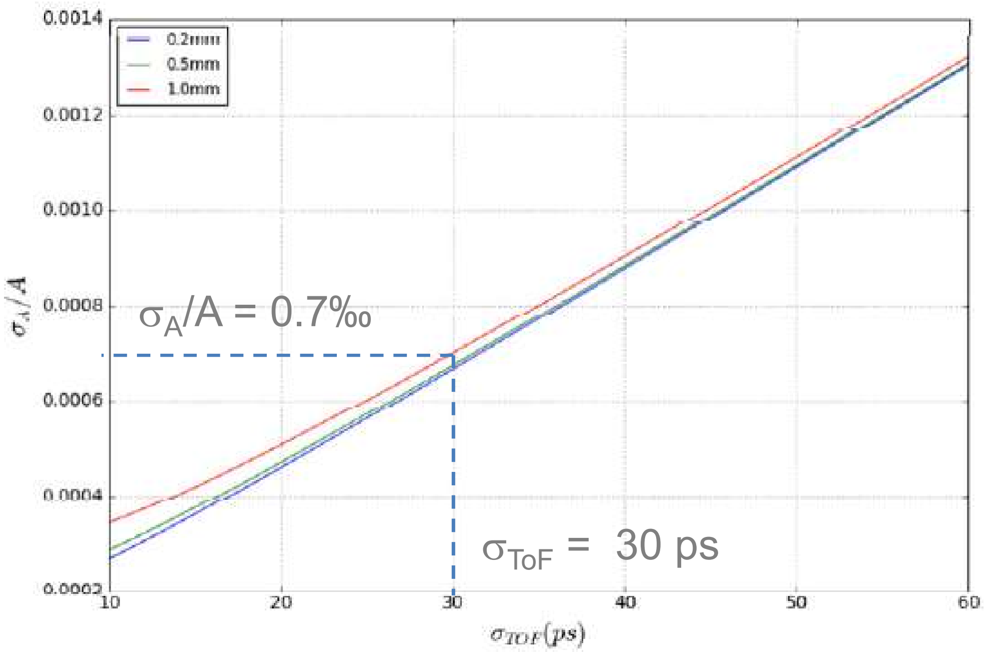
In-flight **PID** event-by-event requirements:

Bρ	ToF	Δ*E*
Δx ~1mm	ΔT <100ps	ΔE_{dep} ~2%



Requirement on A/q separation

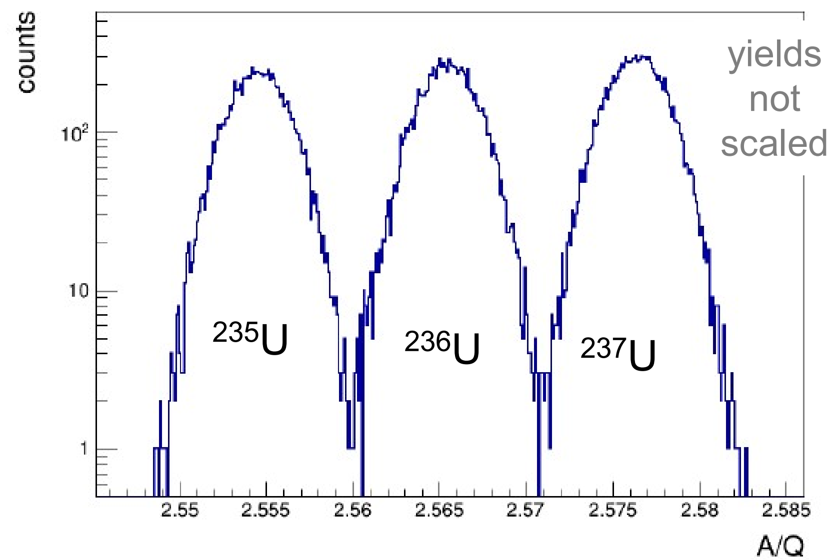
- Clean full isotope identification on event-by-event basis



$$\frac{\Delta A}{A} \approx \frac{\Delta B\rho}{B\rho} + \gamma^2 \frac{\Delta ToF}{ToF}$$

β = 0.8, L = 55 m

Monte Carlo simulations (MOCADI)



σ_x = 0.5 mm, σ_t = 20 ps

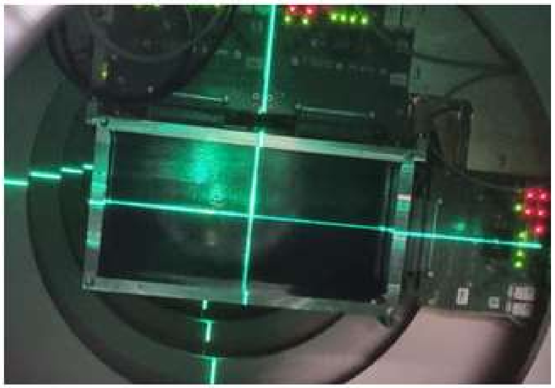
C. Nociforo, 2014 *JINST* 9 C01022

PID detectors

Bρ

ToF

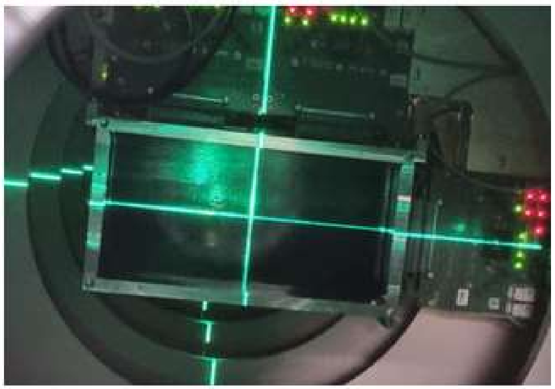
Δ*E*



X and Y layers of fiber SCSF-78J (Kururay) 0.5 mm square area coupled to MPPC S13552 by Hamamatsu and read out by ROB3 – FPGA TDC with ToT (σ= 200 ps).

PID detectors

Bρ



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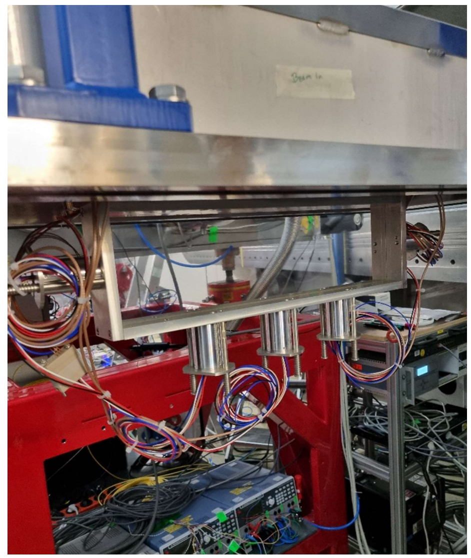
ToF

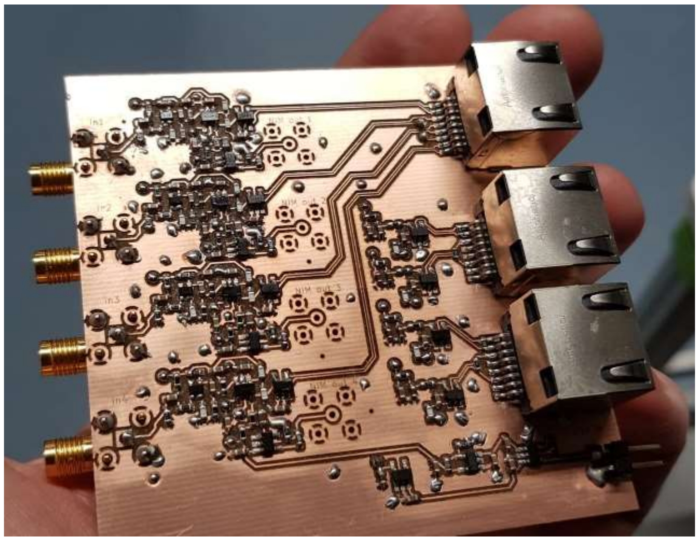


Non-segmented EJ-230 (400x100x1) mm^3 size coupled to H14211-210 Hamamatsu PMT read out by SFRS-PEAKS1 and TAMEX4 (σ=10 ps).

ΔE

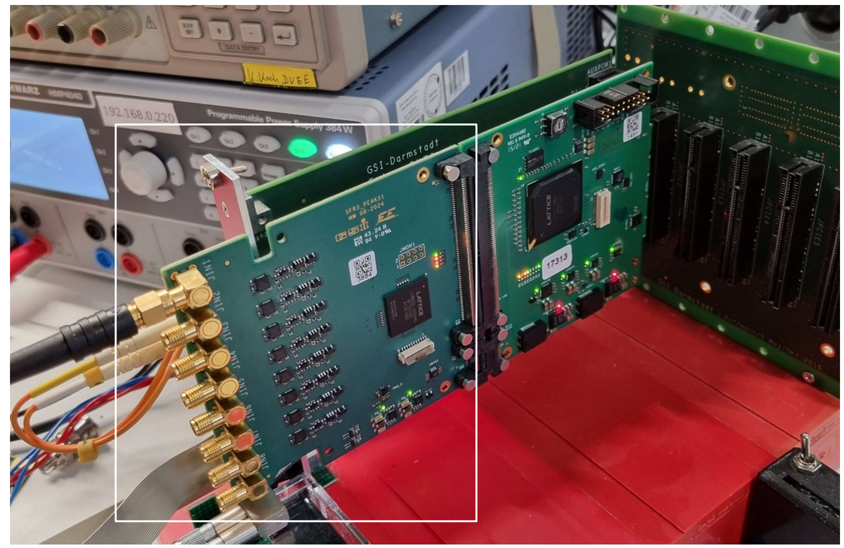
Analogue fast processing electronics

4-ch prototype tested in 2023-2024



Design by M. Wiebusch (GSI)

8-ch SFRS-PEAKS1 tested in 2025

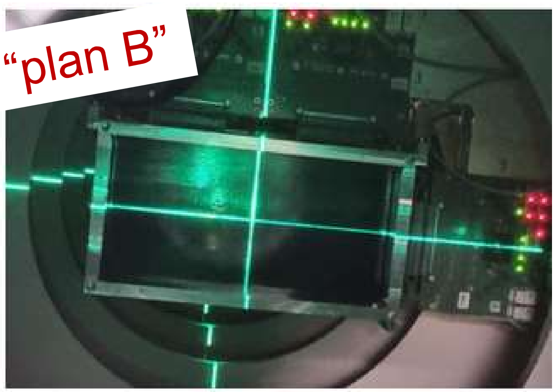


For rising time up to 1-2 ns, both have ToT = $t_{\text{leading}} - t_{\text{trailing}}$ capability

The final board equipped with integrated attenuation/amplification stage provides additionally the “Energy” signals for the walk correction.

PID detectors

Bρ



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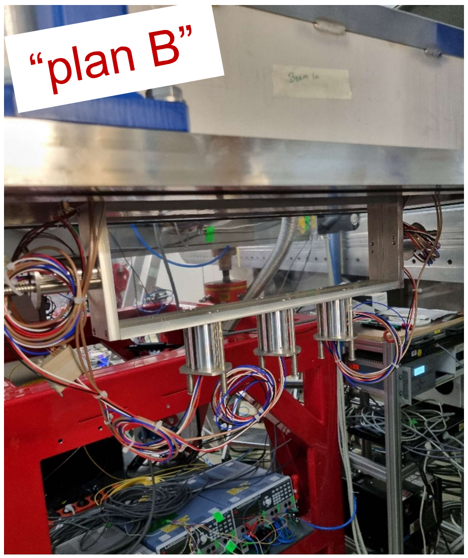
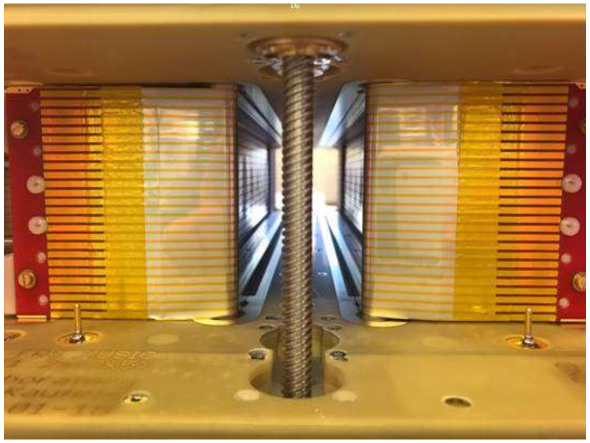
ToF



Non-segmented EJ-230 (400x100x1) mm^3 size coupled to H14211-210 Hamamatsu PMT read out by SFRS-PEAKS1 and TAMEX4 (σ=10 ps).

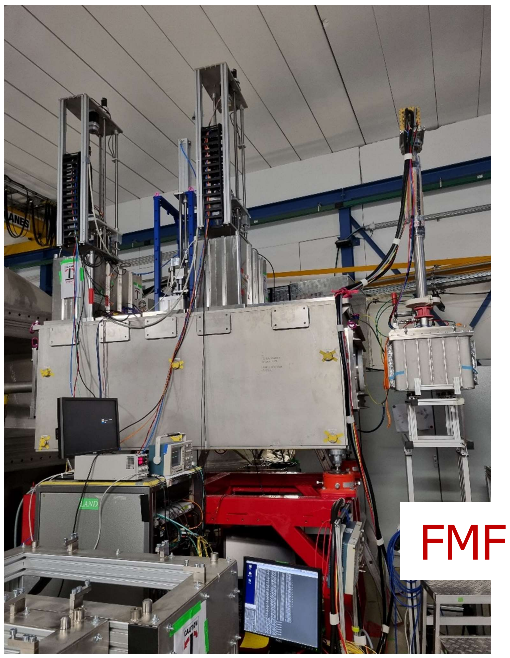
Δ*E*



Ionization chamber with two field cages separated by a strip foil and segmented anodes coupled to Mesytec preamplifier MUPR-18 and digitizer MDPP32-D.

"Plan B" for commissioning and ES

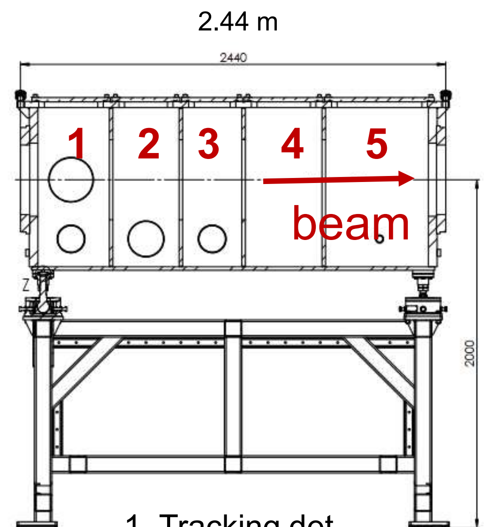
Focal plane chamber



FMF1DK1 commissioning

- 2 First of Series (FoS) Super-FRS diagnostic chambers delivered in 2023

- FMF1DK1 suitable for pre-assembly and detector tests



1. Tracking det.
2. X-slit
3. ToF det.
4. Tracking det.
5. MUSIC det.

It allowed to performed the first in-beam tests of

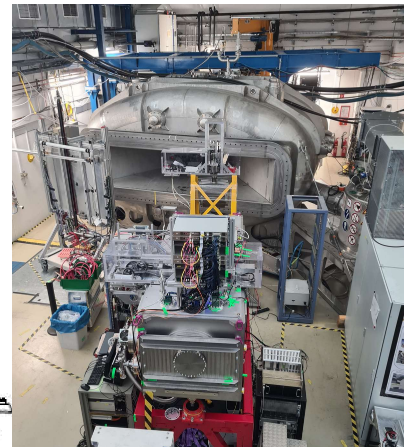
- 2x FoS SFRS Scintillating Fibers
- 1x FoS SFRS Plastic Scintillators
- 1x FoS SFRS MUSIC

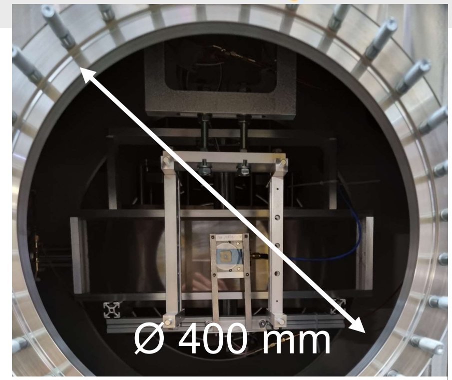
with U, C, Ag SIS18 beams at 0.5-1 GeV/nucleon delivered to Cave C.

Beam test in 2023

Cave C

enough space to use the Super-FRS diagnostic chambers

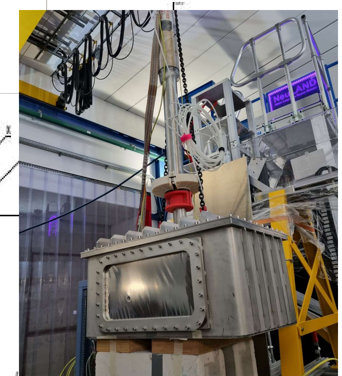




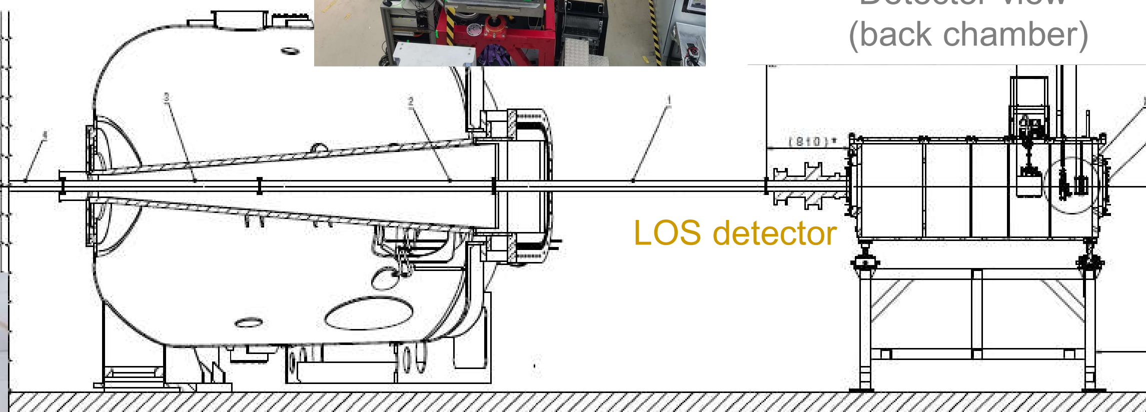
Detector view (back chamber)

FoS ToF detector

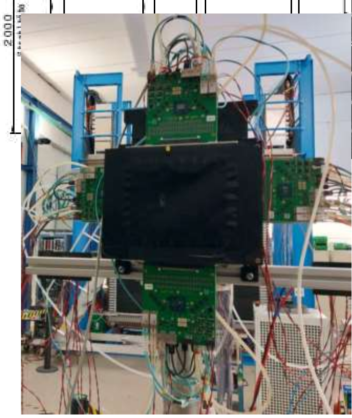
FoS MUSIC det



Slow extr.
1 AGeV ^{238}U



LOS detector



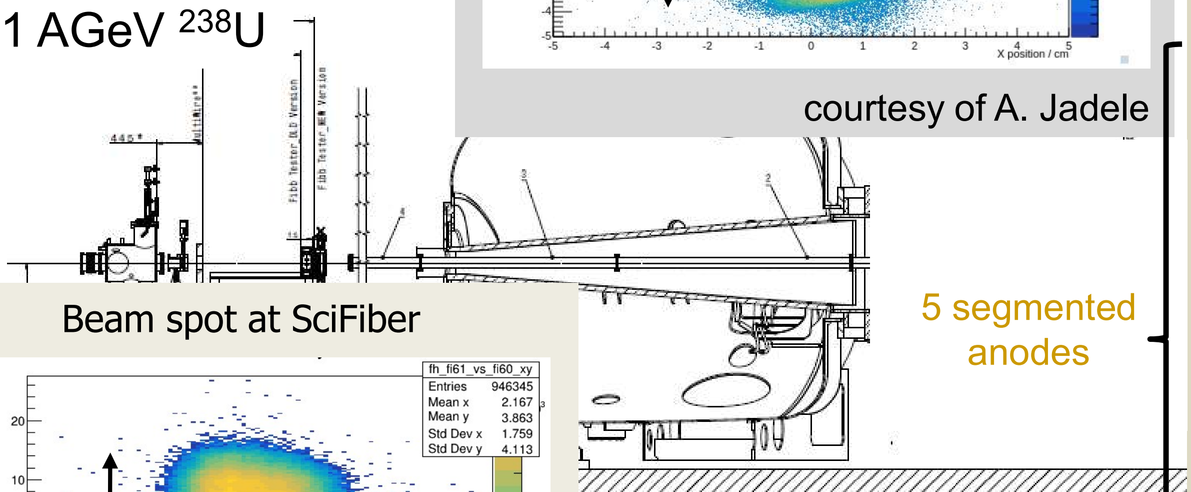
2 x SciFiber detectors

Instructive engineering run (Dec 2023):

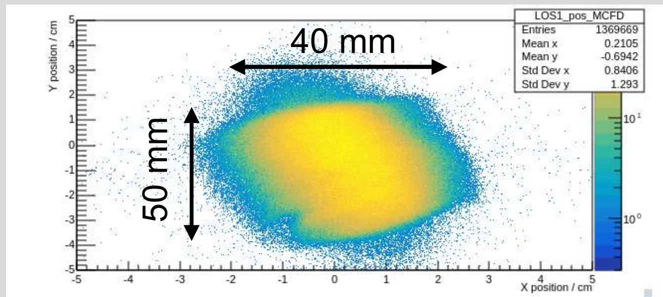
- ✓ First operation of the SFRS diagnostic chamber
- ✓ First run of full size SFRS prototypes (SCI, MUSIC, SciFiber det.)
- ✓ First training of the SFRS diagnostics team and estimate of focal plane commissioning w/wo beam

Beam test in 2023

Slow extr.
1 AGeV ^{238}U



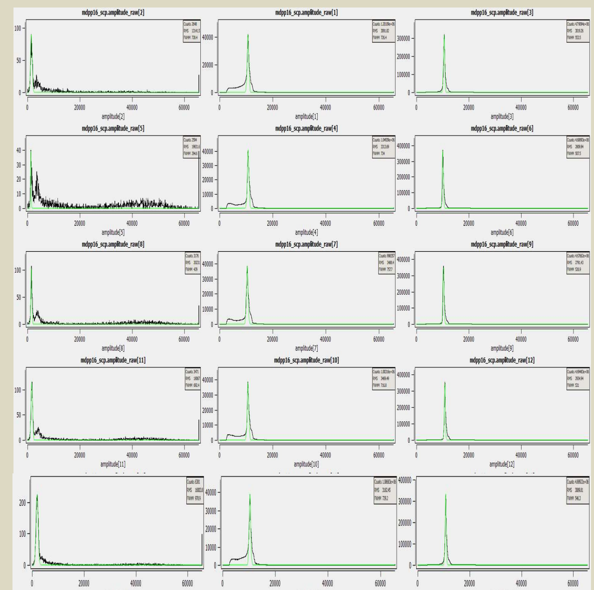
Beam spot at LOS



courtesy of A. Jadele

b
e
a
m

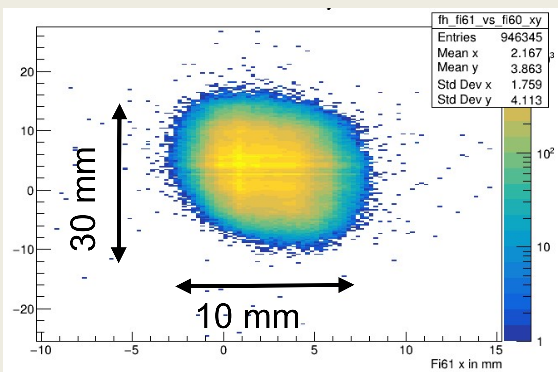
MUSIC amplitude



courtesy of D. Urner

5 segmented
anodes

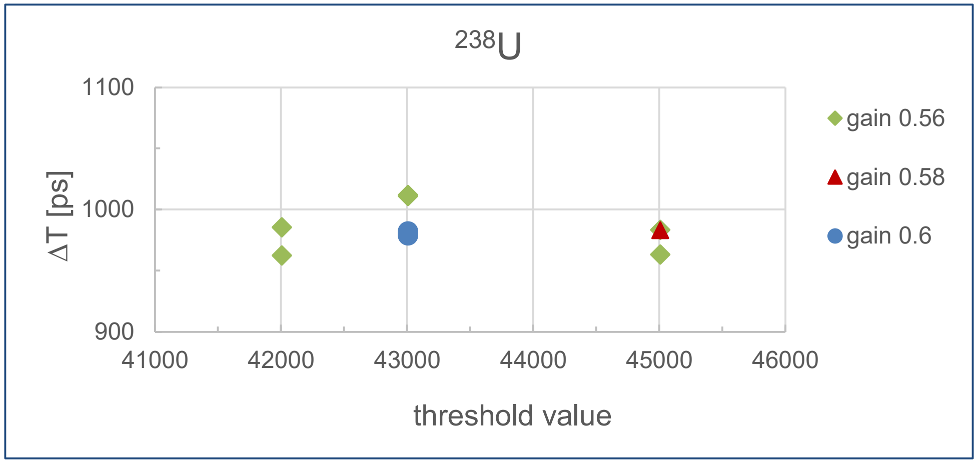
Beam spot at SciFiber

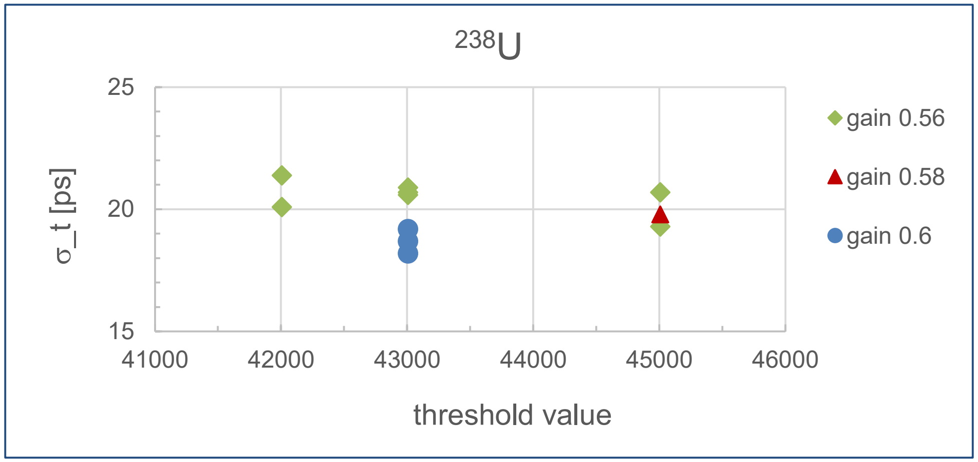


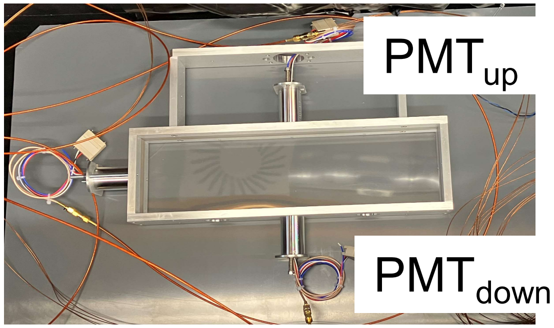
courtesy of M. Heil

Resolution - U ions

$\Delta T = t_{PMT\ up} - t_{PMT\ down}$







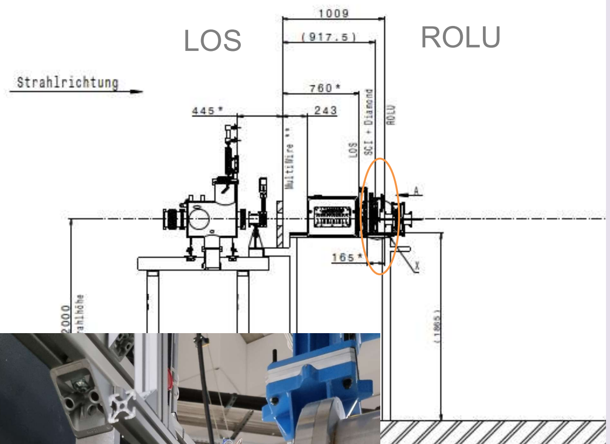
Results for hit multiplicity = 1

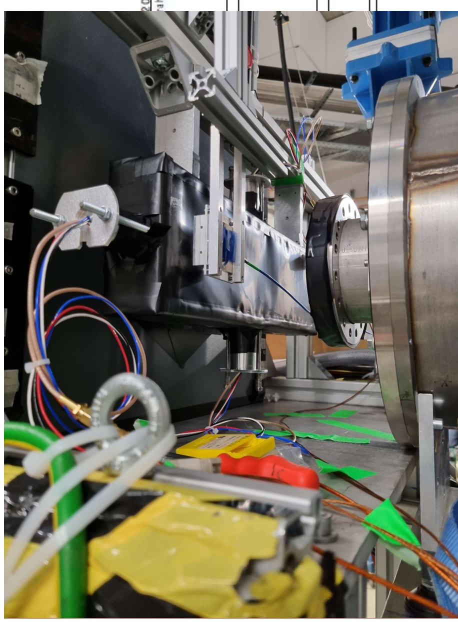
$\sigma_t \approx 20$ ps

for U beams is within the specs

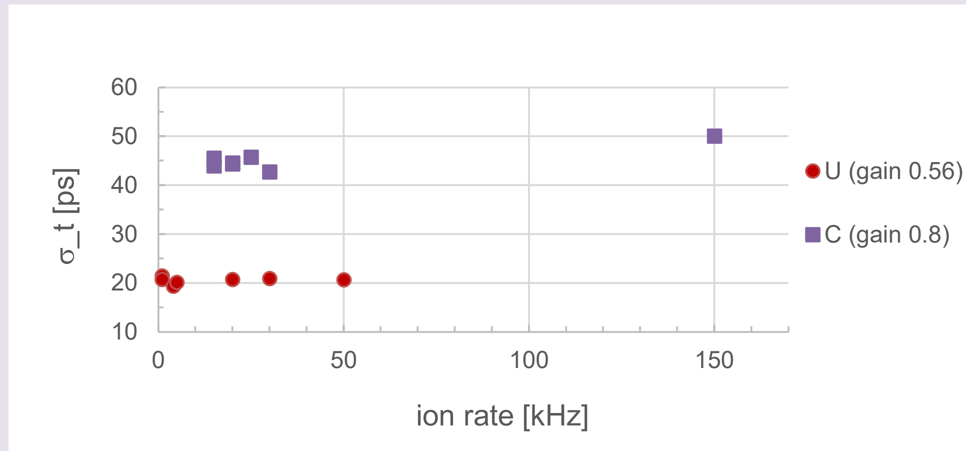
Cave C setup - 2024

Slow extr.
860 AMeV ^{12}C

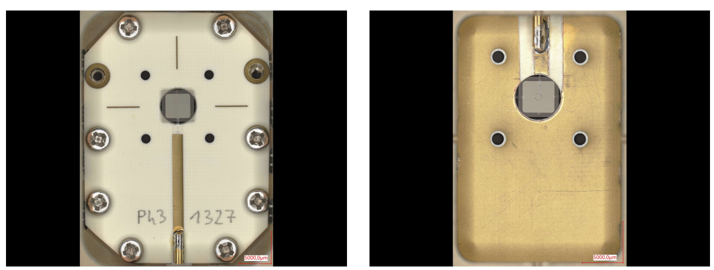




Rate dependence



Diamond active area ≈ 1mm^2



4x4mm^2 size ~480um thickness, Al electrodes

σ_t < 50 ps

for C beam up to 150 kHz

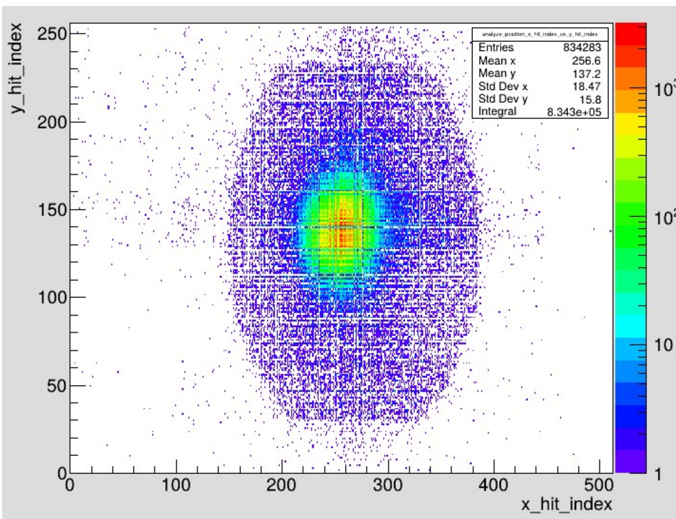
Beam test in 2025

Slow extr.
1 AGeV ^{107}Ag

Overall DAQ system synchronized

White Rabbit switches

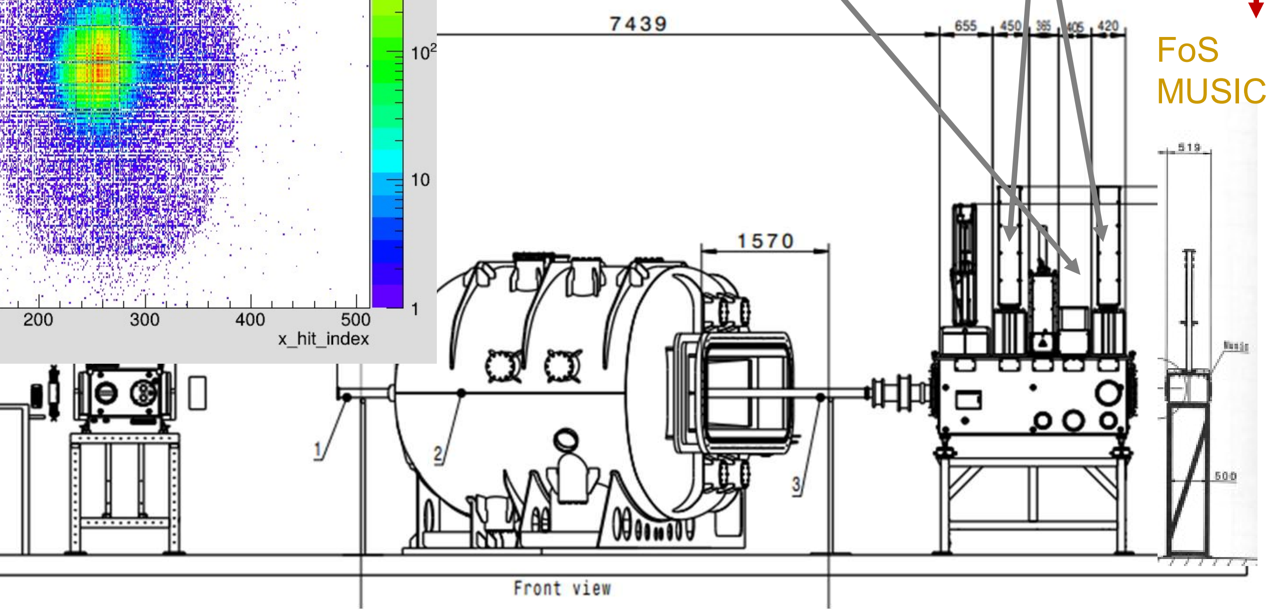
Beam spot at the 2nd SciFiber



2x FoS SciFiber dets

FoS
ToF det

FoS
MUSIC det



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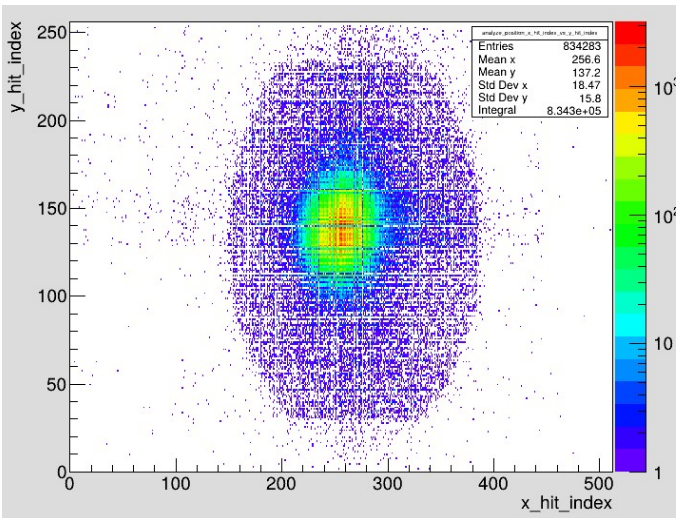
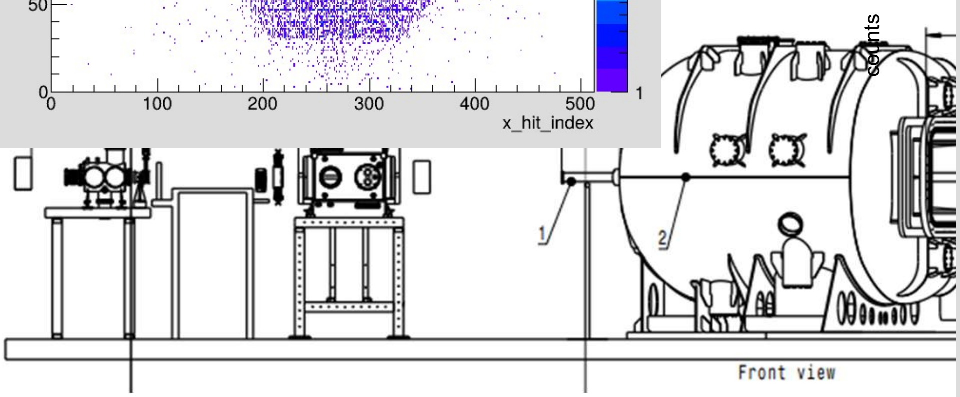
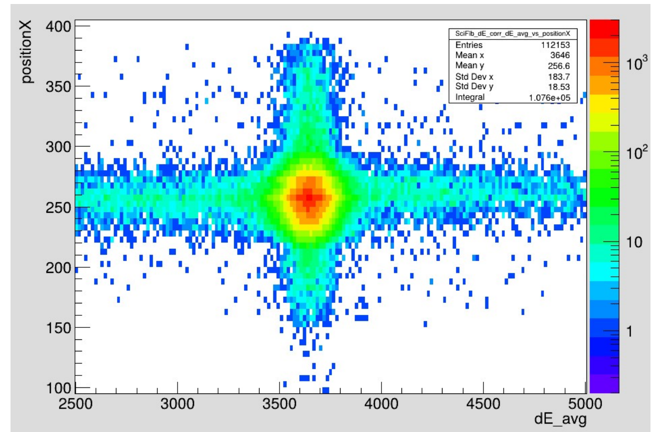
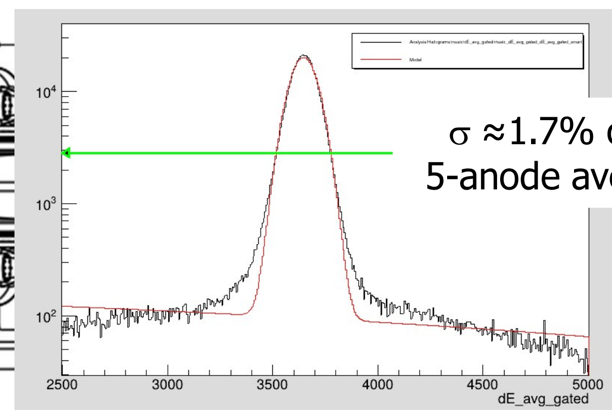




X SciFib vs dE MUSIC



dE MUSIC



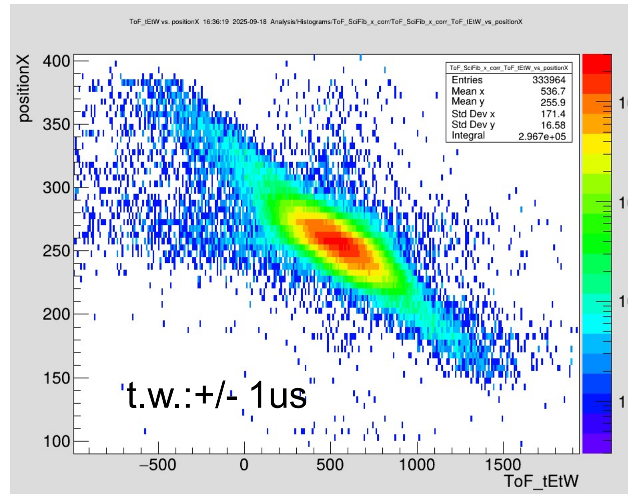
σ ≈1.7% over
5-anode average

Beam test in 2025

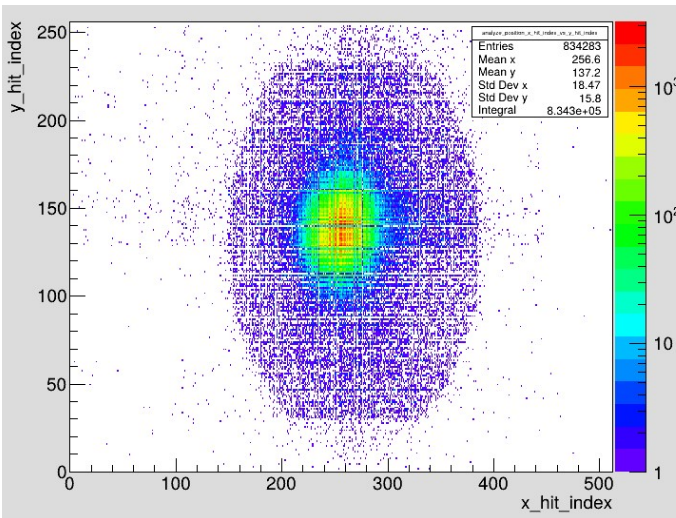
Slow extr.
1 AGeV ^{107}Ag

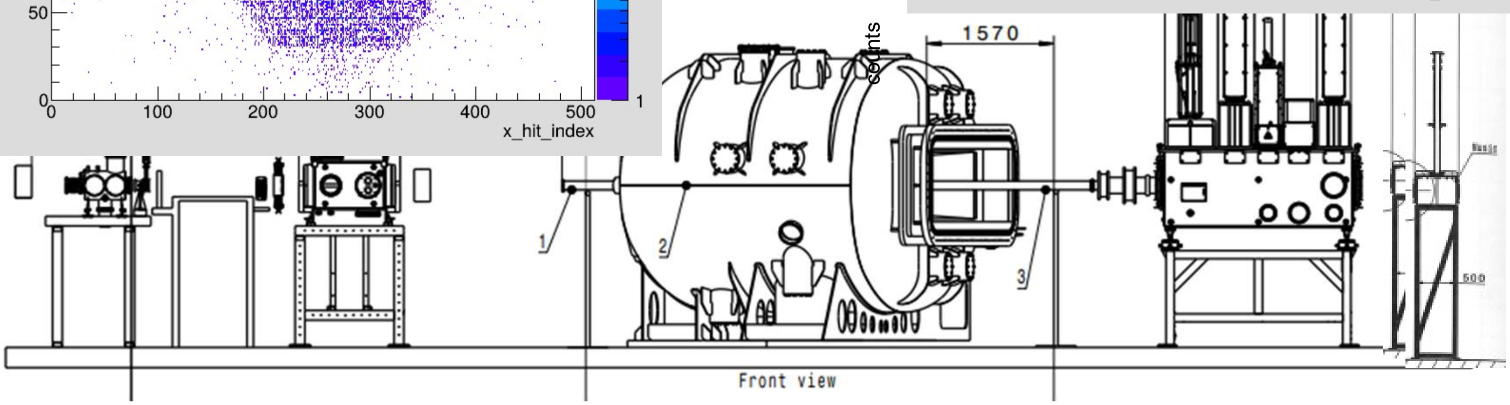
Overall DAQ system synchronized

X SciFiber vs ΔT



Beam spot at the 2nd SciFiber



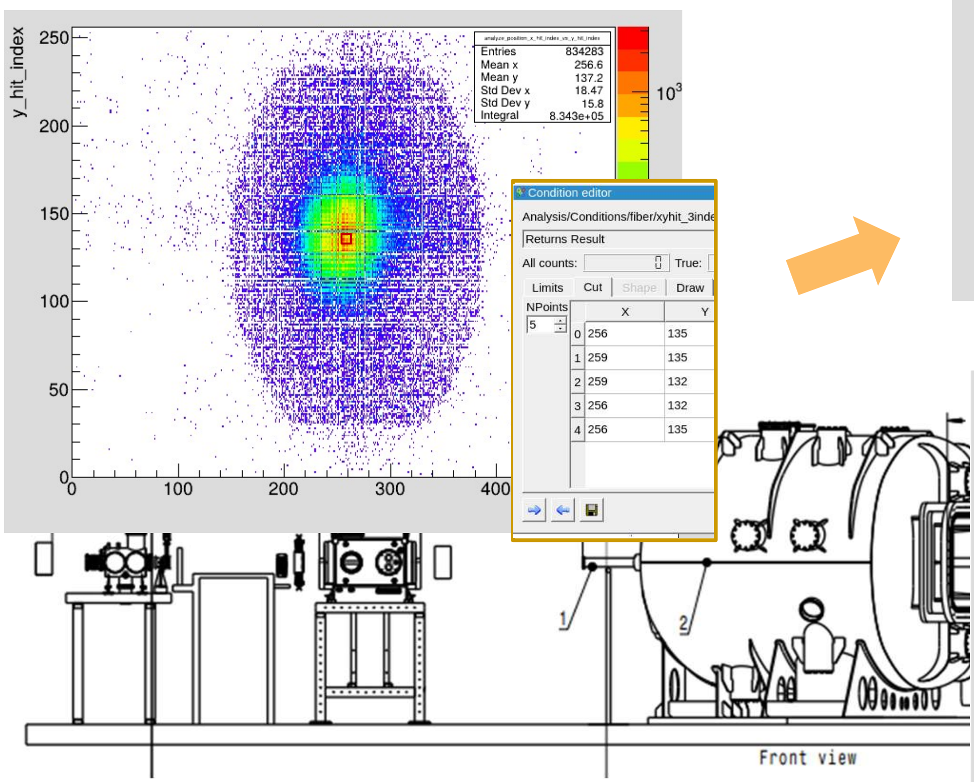


Beam test in 2025

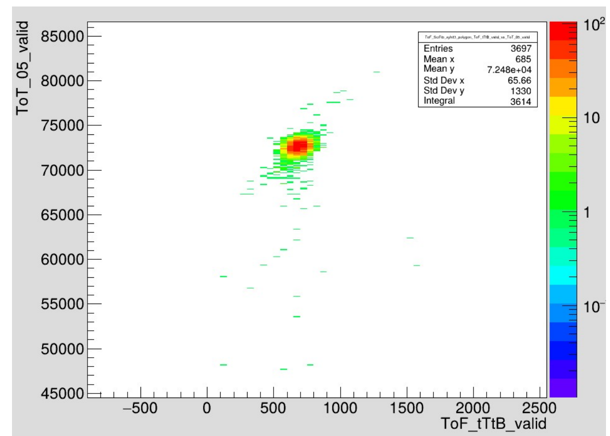
Slow extr.
1 AGeV ^{107}Ag

Gating on position

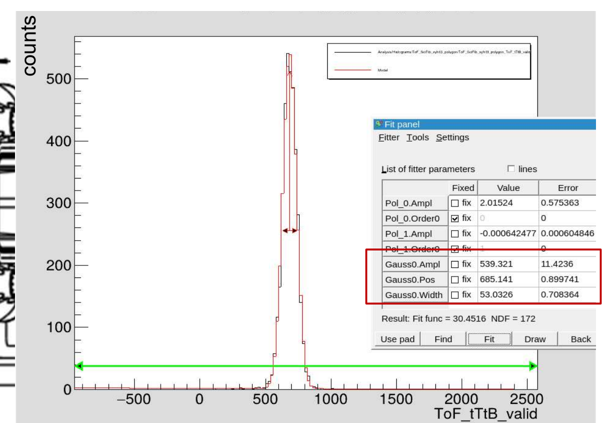
Beam spot at the 2nd SciFiber



SCI ToT vs ΔT



SCI ΔT



Summary and future plans

- Large active area **PID detectors** required because of the larger phase space of the Super-FRS (≈2 higher of FRS) were designed for Early Science operation at FAIR.

- Unique components having challenging technological functionalities were successfully tested with beam in Cave C thanks to an intense work of the Super-FRS beam diagnostic team in **2023-2025**.

- In parallel to the procurements and installations for the Super-FRS commissioning, ongoing developments are carried on with **radiation-resistant detectors** (diamond, Si, SiC) for First Science and beyond

such that the Super-FRS will be well suited to nuclear experiments at the forefront of science.

Super-FRS beam diagnostics team (2023-2025)

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