The FAIR MUSIC

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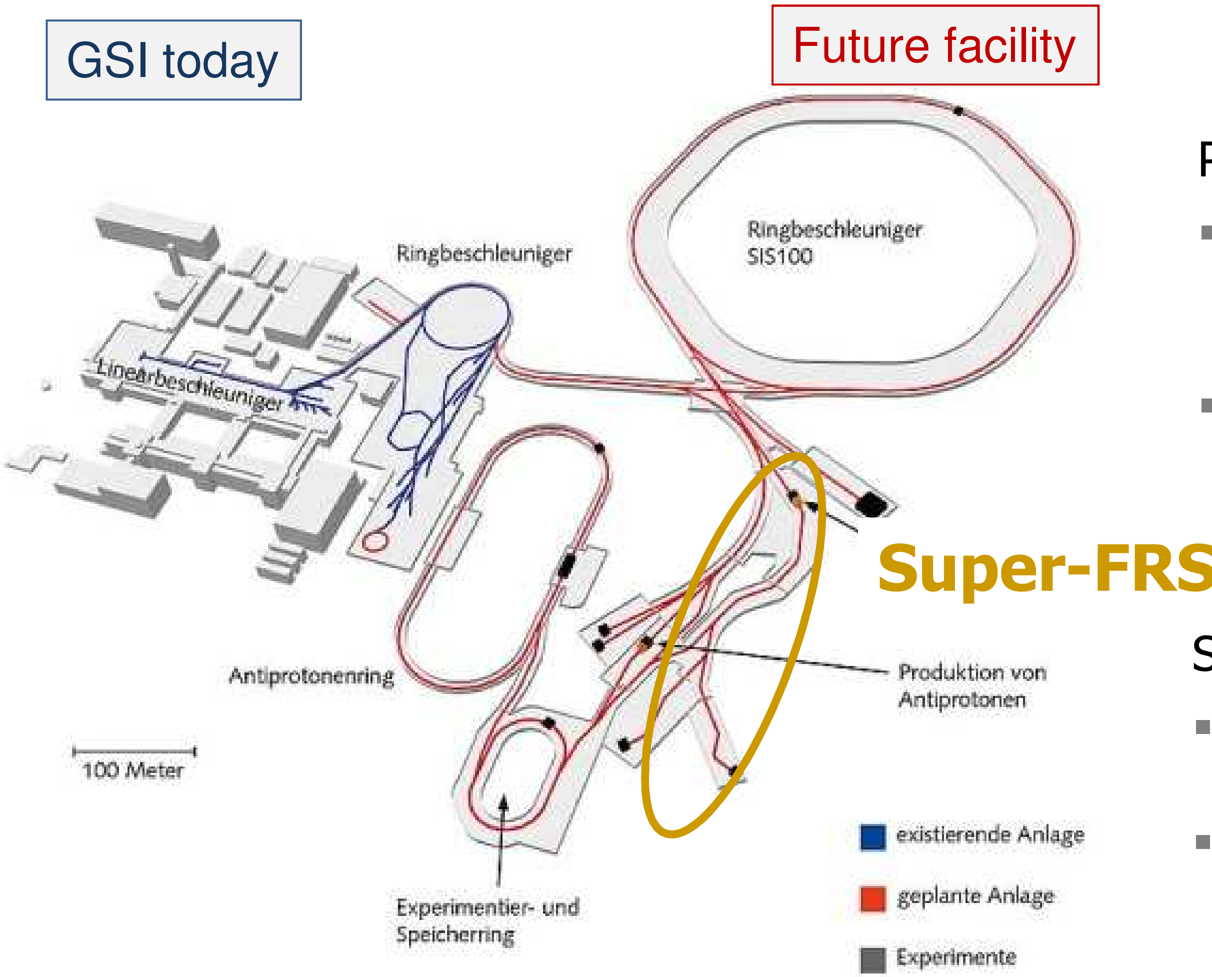
Contents

- Introduction
  - intro of Super-FRS
  - ID of relativistic ions via Bρ –ToF – ΔE method
- ΔE requirements
  - ΔE detectors at GSI
  - limitations and advantages
- Super-FRS MUSIC
  - energy deposition and resolution
  - simulations
- Electronics
  - MUSIC FAIR board
- Summary & outlook

The FAIR in-flight facility



Primary Beams

- 5×10^{11} $^{238}U^{28+}$ (pulsed) 3.5×10^{11} $^{238}U^{28+}$ (DC) @1.5 GeV/u
- factor **100** in intensity over present

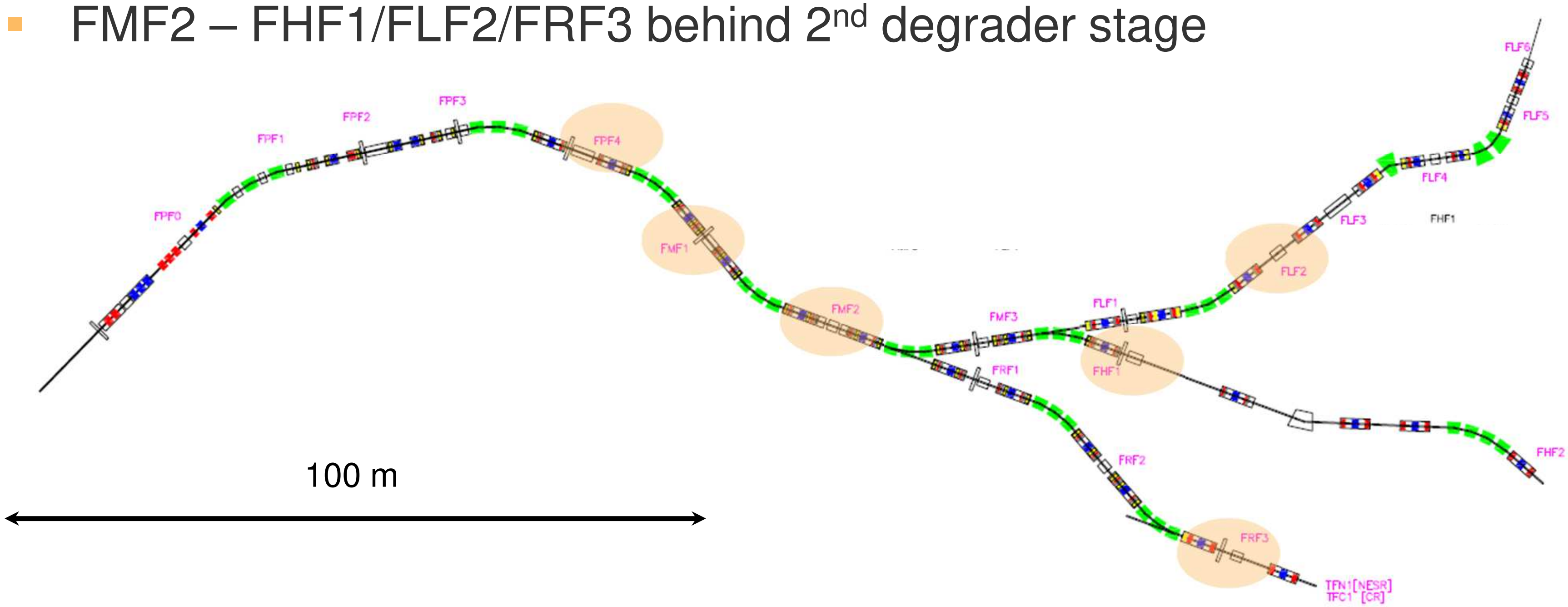
Secondary Beams

- broad range of RIBs up to 1-2 GeV/u
- up to factor **10000** in intensity over present

Super-FRS ID

Slow-extraction mode (spill: 0.5 – 10 s)

- FPF4 – FMF2 behind 1st degrader stage
- FMF2 – FHF1/FLF2/FRF3 behind 2nd degrader stage



The ion separation and identification by a combined event-by-event analysis of magnetic rigidity (**Bρ**), time-of-flight (**ToF**) and energy deposition (**ΔE**) in order to get unambiguous identification in charge **Z** and mass numbers **A** of the ion beams.

Super-FRS ID

Slow-extraction mode (spill: 0.5 – 10 s)

- FPF4 – FMF2 behind 1st degrader stage
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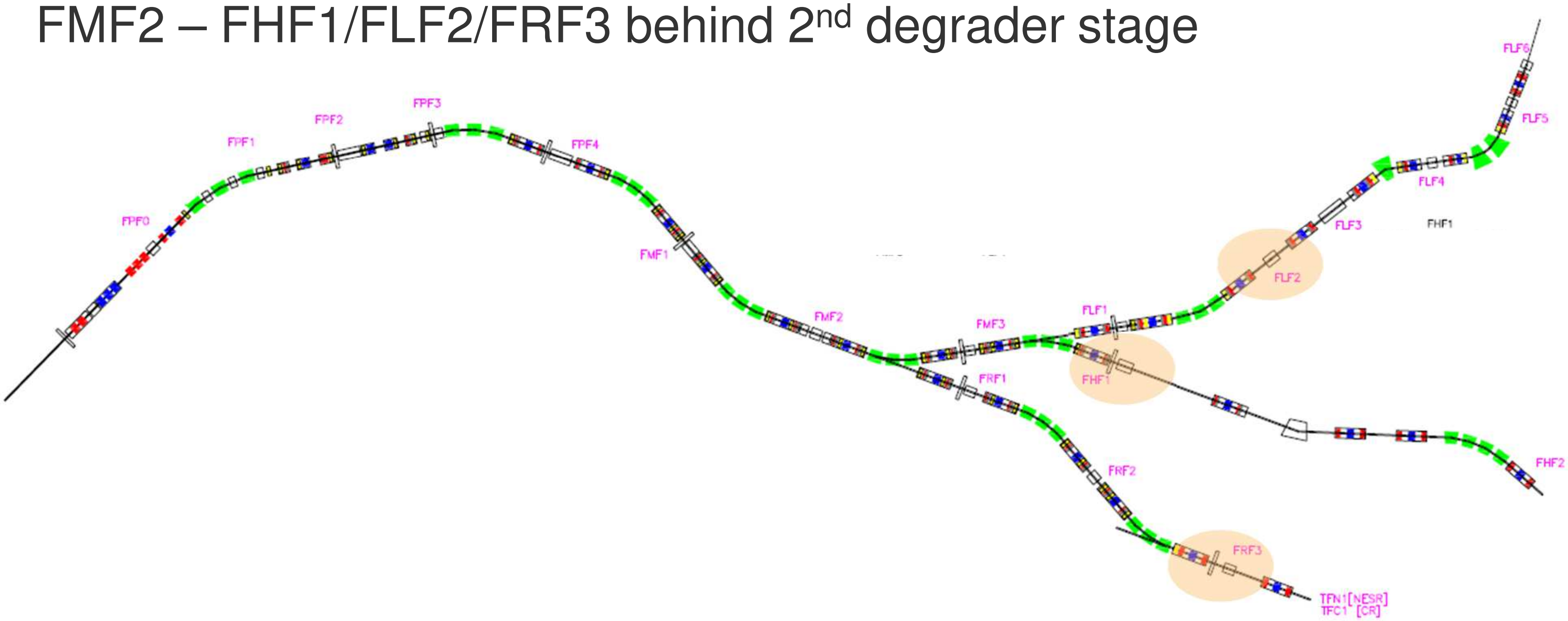


1. $\Delta\mathbf{x}$, $\Delta\theta$, $\Delta\mathbf{y}$, $\Delta\varphi$ obtained in ion trajectory reconstruction
2. Δ**ToF** required in mass region A > 200
3. Δ**E** resolution needed to separate Z and disentangle charge states

NUSTAR prototypes

$B\rho$

SFRS GEM-TPC

F. García et al., *NIM A* 884 (2018) 18

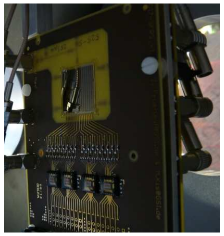
R3B SciFib det.

ToF

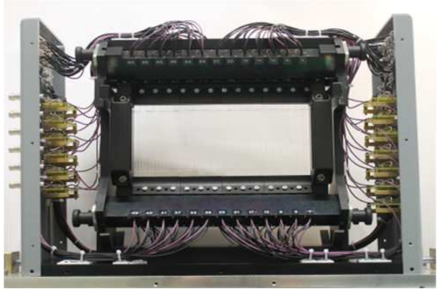
LYCCA
start det.

R. Hoischen et al.,*NIM A* 654 (2011) 354

SFRS
DIA strip det.

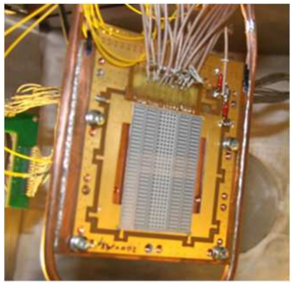


F. Schirru et al.,
J. Phys. D:
Appl. Phys. 49 (2016) 215105



HISPEC/
DESPEC
Finger det.

ΔE



SFRS
Si strip det.

V. Eremin et al., *NIM A* 796 (2015) 158

Travelling
MUSIC

ΔE requirements

A suitable ΔE detector needs to have

- good energy resolution ($\Delta Z < 0.3$)
- high counting rate capability (pile-up correction)
- robustness against beam bombardment

Gas ionization chambers are

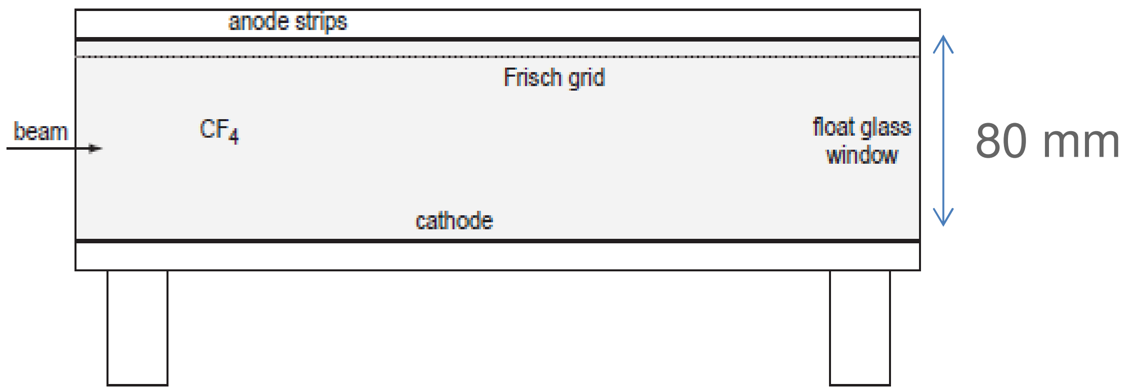
- extremely stable if equipped with gas flow system
- can provide energy resolution as good as that of semiconductor detectors
- charge-state selective
- large-scale detector easy to fabricate

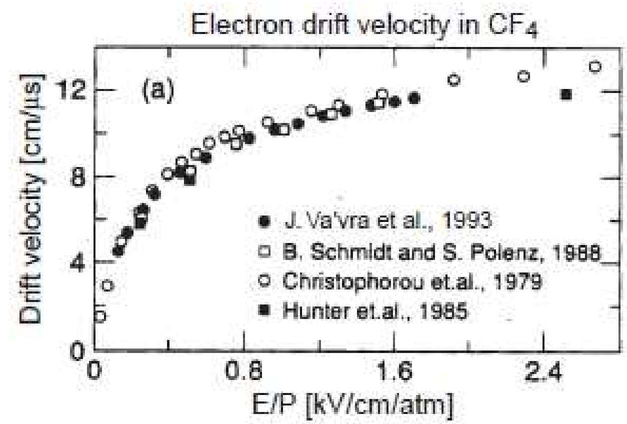
↓

Multiple Sampling Ionization Chamber (MUSIC)

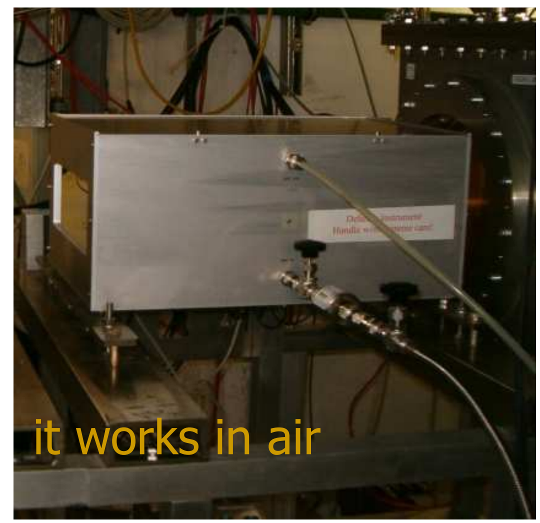
MUSIC80

8 anode strips with 400 mm active length





- very good homogeneity of the field (D263 float glass)
- stable for particle rates up to 200 kHz, overall DC-coupling is used, which avoids rate dependent baseline drift
- 3 preamp types to cover the full range

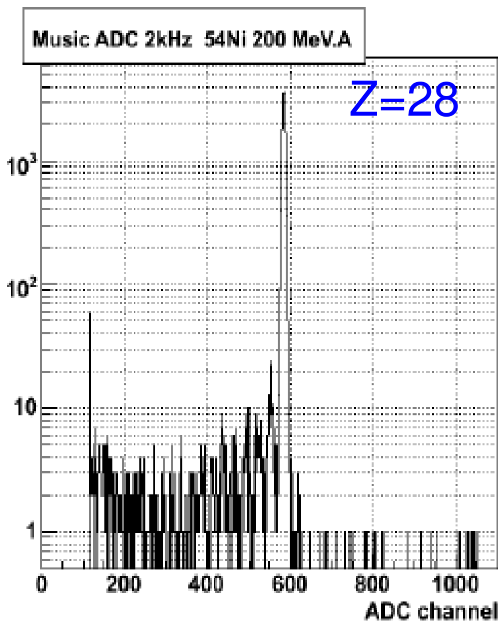


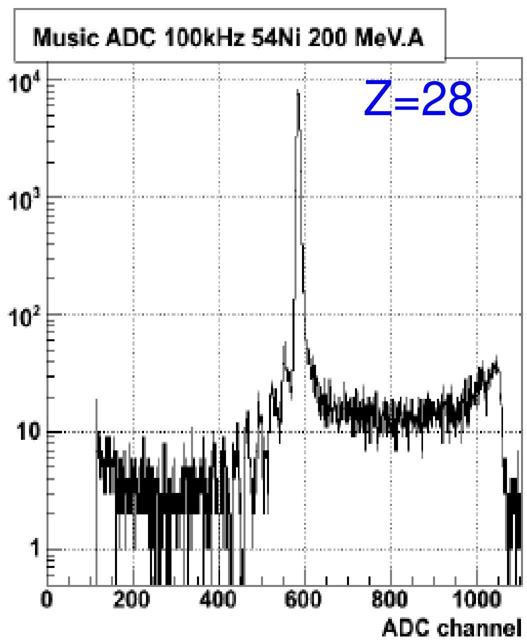
TU Munich

http://www-w2k.gsi.de/frs/technical/FRSsetup/detectors/music.asp

Count rate limit

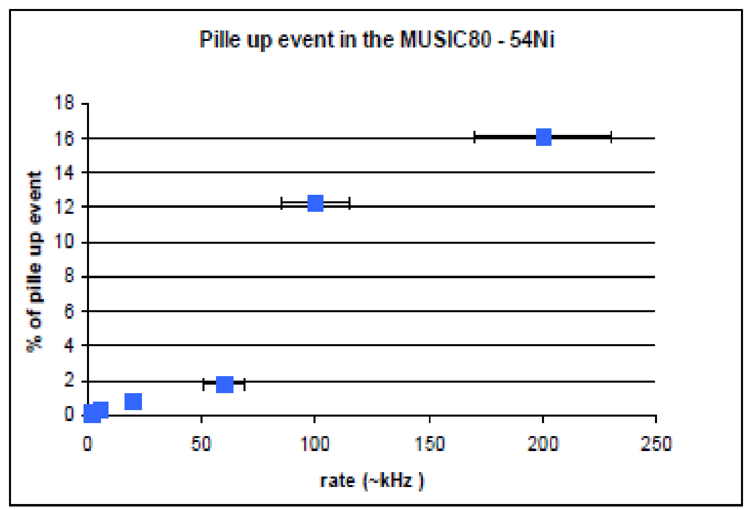
... but it is not fast enough to resolve the signals of individual beam particles at intensity > 30-40 kHz.



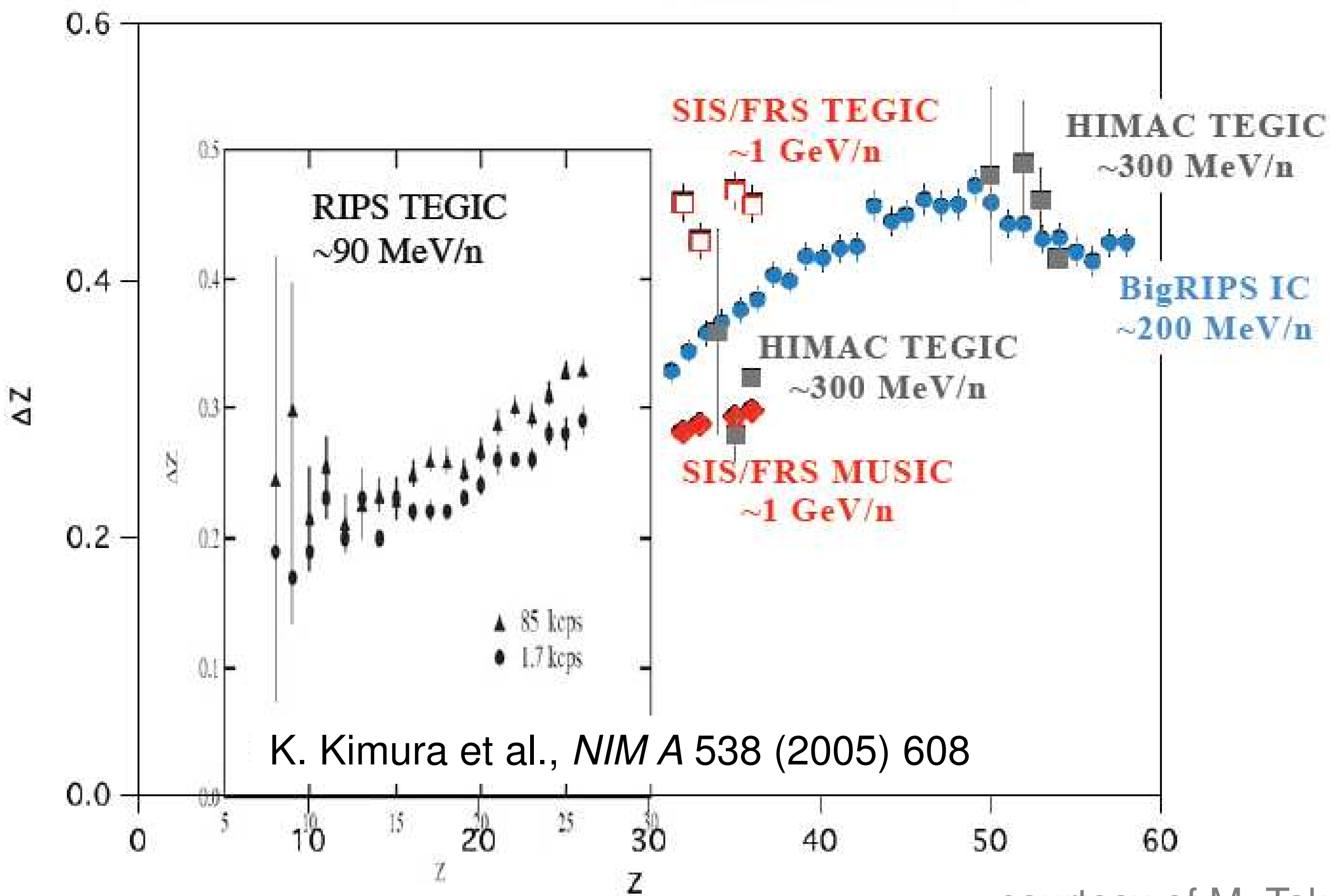


courtesy of H. Schaffner, S. Pietri

Pile-up in the MUSIC shaper output gives wrong Z identification.



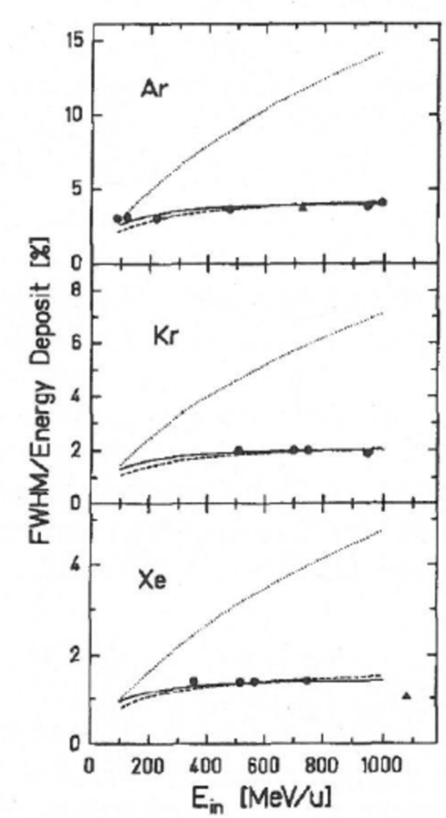
Comparison of Z resolution



courtesy of M. Takechi

Dominant effects

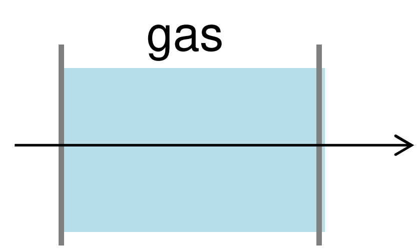
- charge-changing (CC) probability (energy, Z, gas)
- δ-electrons escape in the IC volume



M. Pfützner et al., *NIM B* 86 (1994) 213

$$E_D = C_A \cdot E_{loss}$$

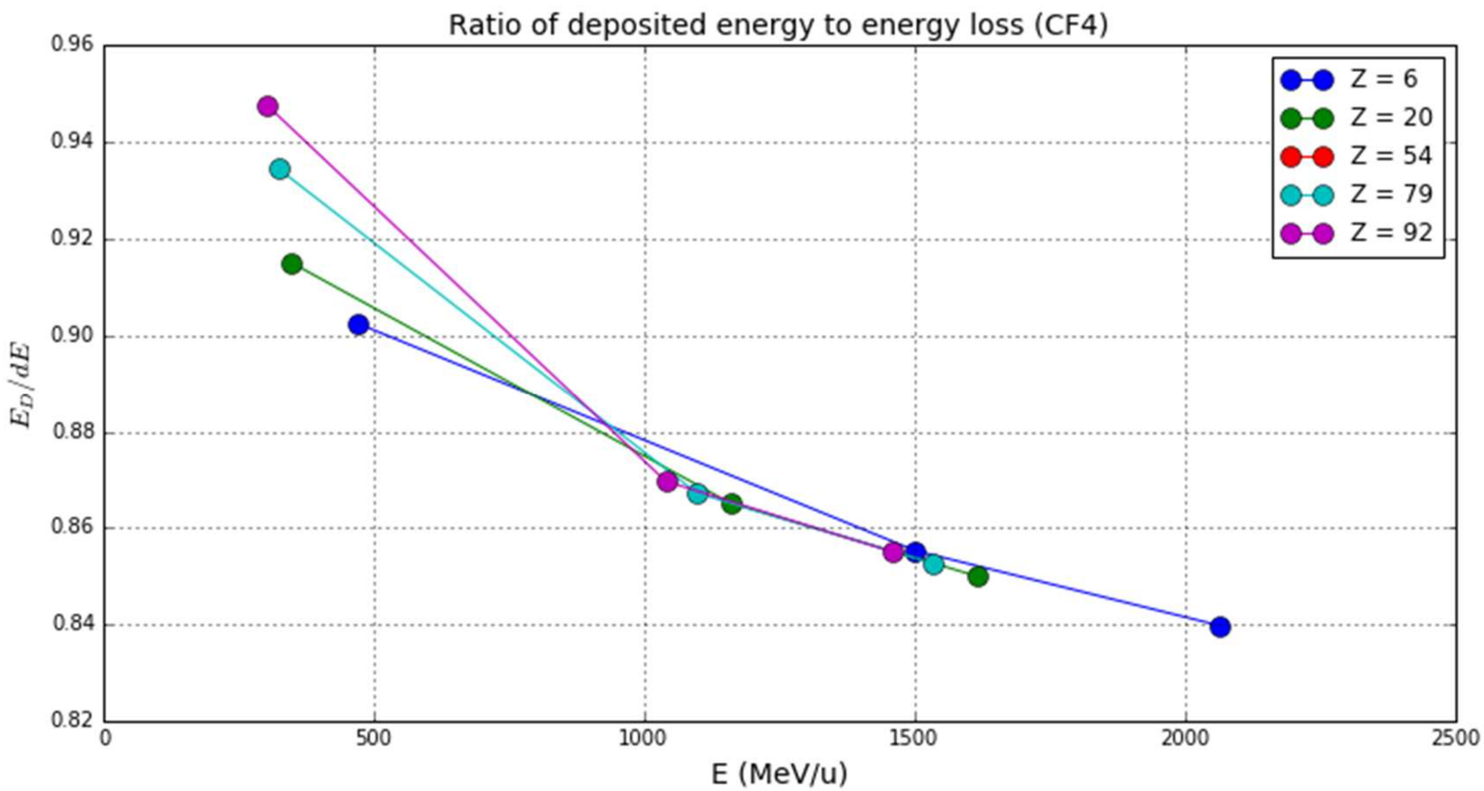
$$\frac{\sigma_Z}{Z} \simeq \frac{\sigma_{E_D}}{2E_D}$$



Large correction factors needed to predict the “escaped” energy width for Z > 79 and E > 400 MeV/u

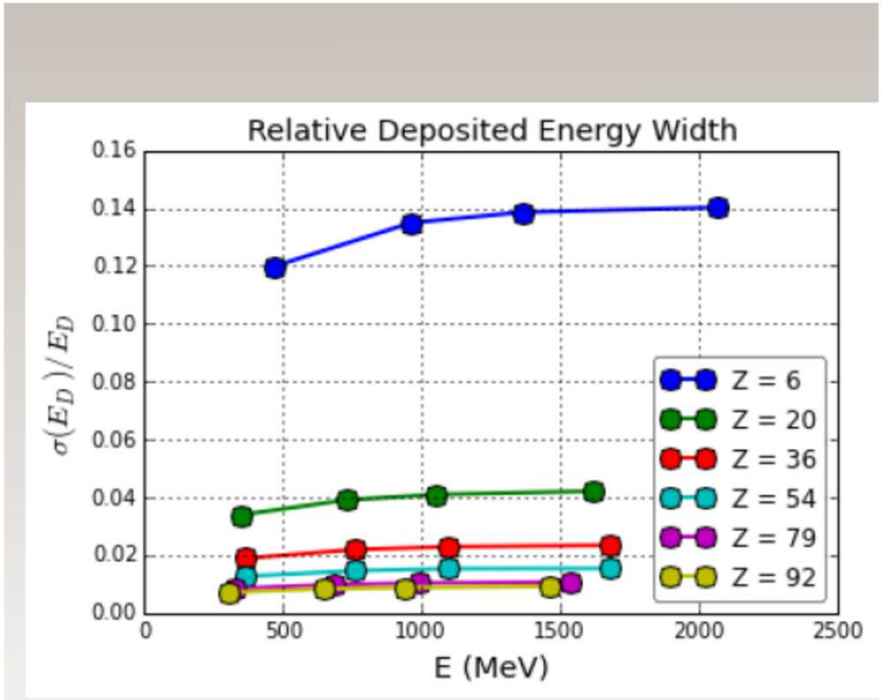
Correction factor

- correction factors for E_D and σ_{ED} calculated using GEANT4
- E_{loss} and its RMS obtained by ATIMA



Relative deposited energy width

Straggling caused by energy loss straggling and other statistical processes (delta electron escape) inside the IC gas volume

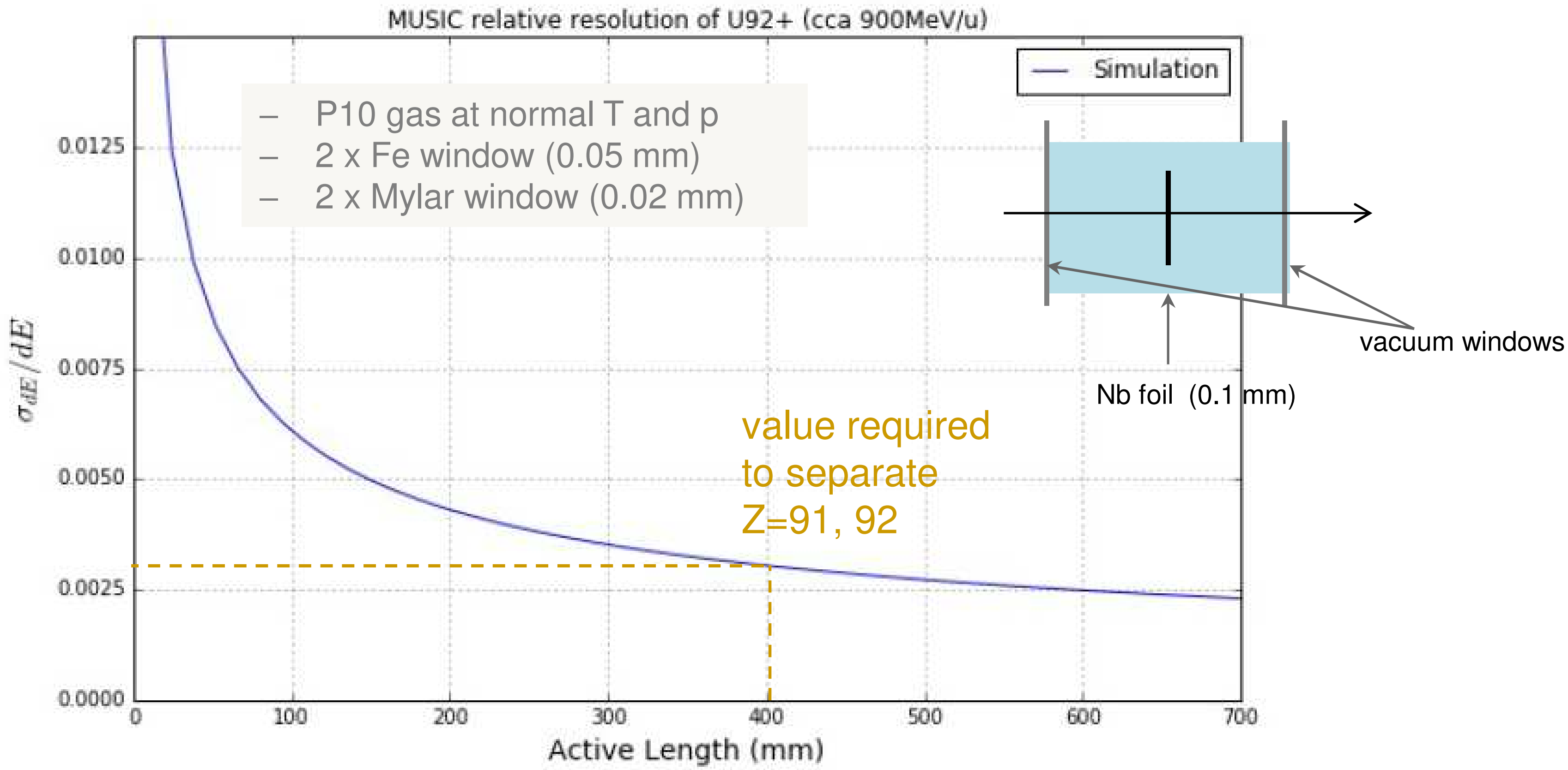


Simulations performed by A. Prochazka shows that a GEANT4 ionization model better in agreement with the data is achievable.

Additional contributions to the Z resolution:

- straggling σ_{T0} caused by incoming energy spread (T0) due to energy loss in front the IC
- straggling due to incoming angular scattering in the matter in front of the IC

Gas active length



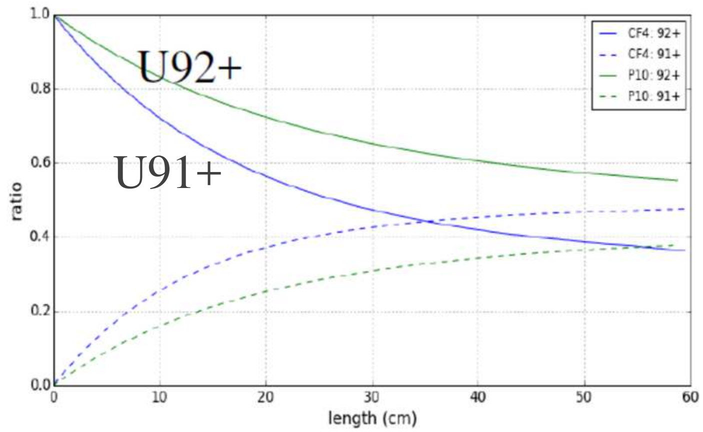
- vertical design of the electric drift fields
- 2-stage design (Nb stripper) for charge state selection

f-ds-bd-87e_sfrs_de_detector_v5.0

Electron exchange probability

GLOBAL + MOCADI

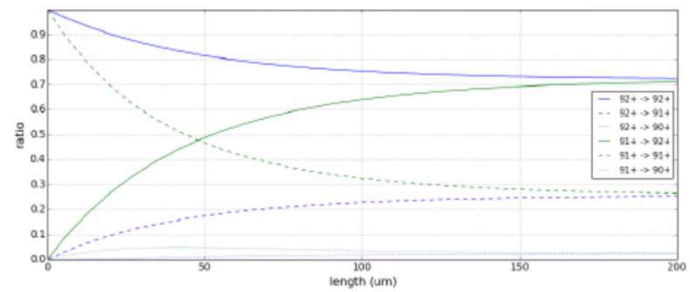
U @ 500 MeV/u



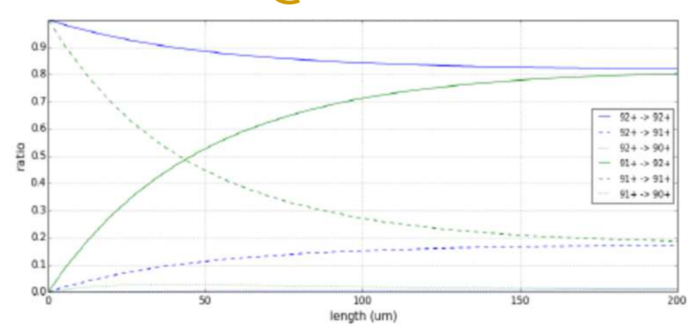
CF4 92+
…… CF4 91+

P10 92+
…… P10 91+

U @ 700 MeV/u

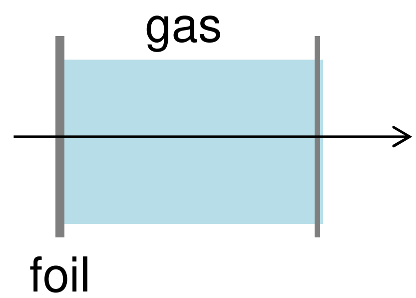


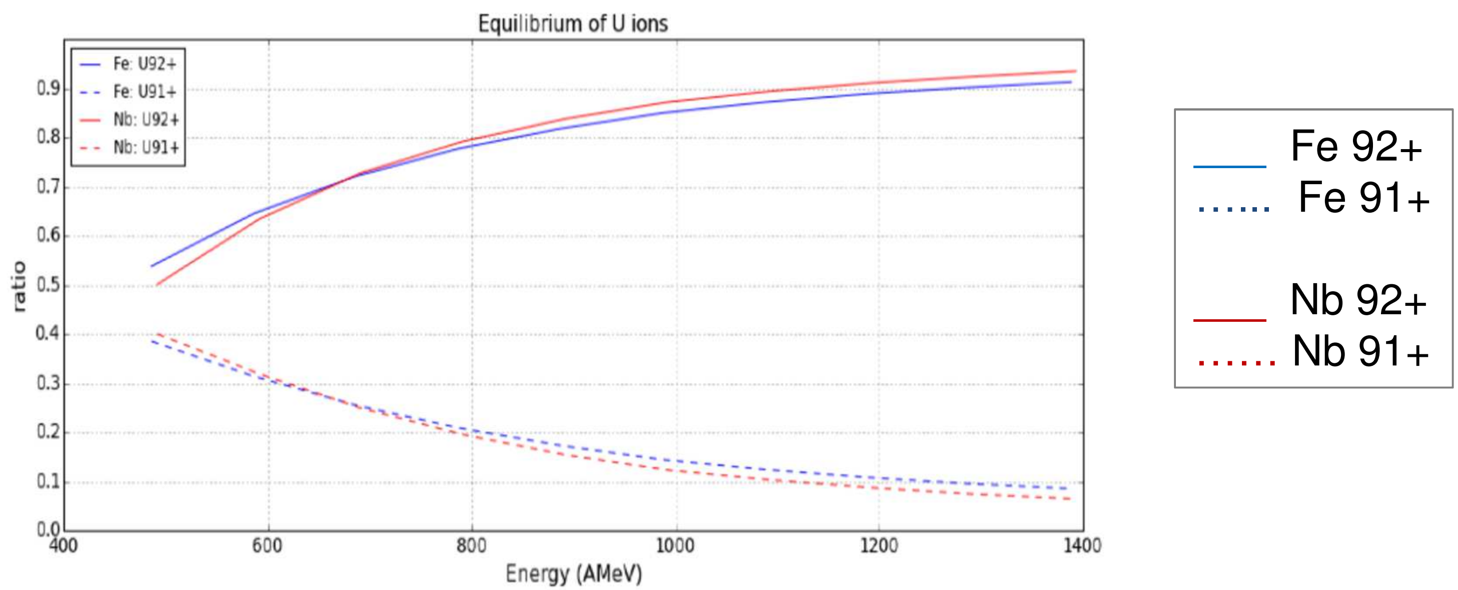
U @ 900 MeV/u



It is more convenient for the in-flight ID if the ions arrive with the highest velocity (asymmetric distribution q≈Z)

Charge state equilibrium

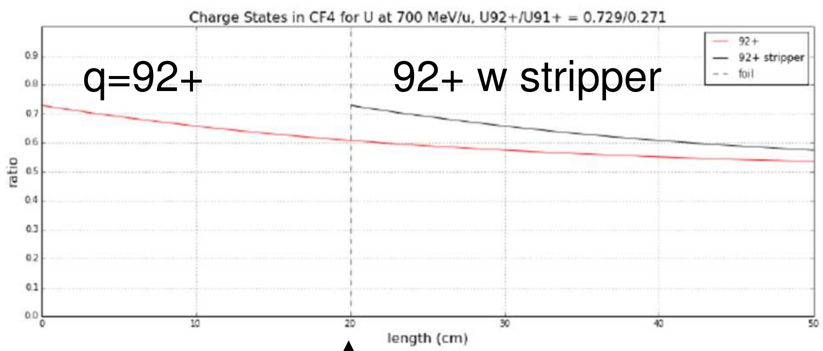


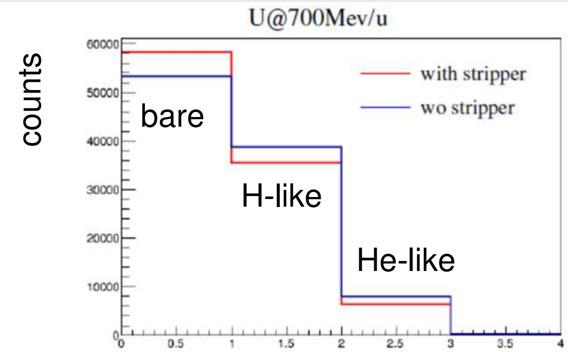


- equilibrium thicknesses of a Nb foil are 0.14-0.16 mm

Charge state distribution q

CF_4

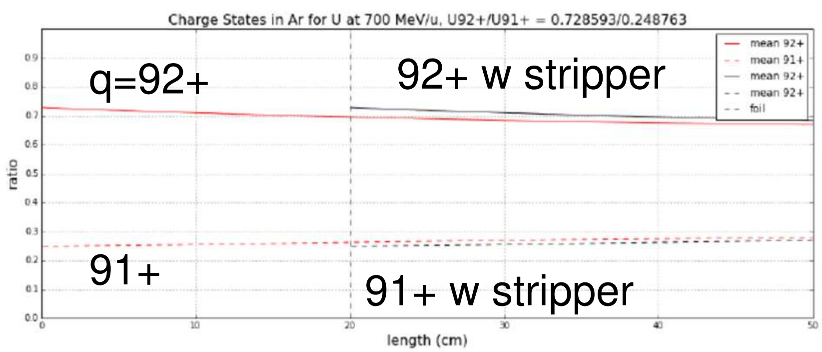


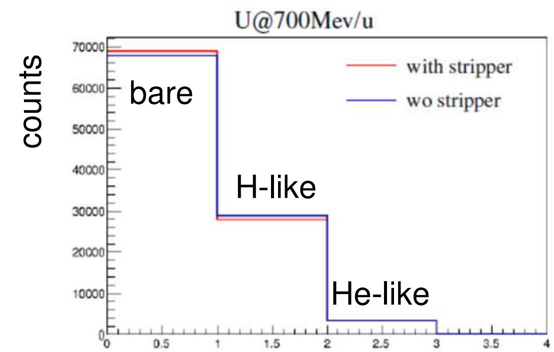


e- at 40 cm

at 20 cm

Ar

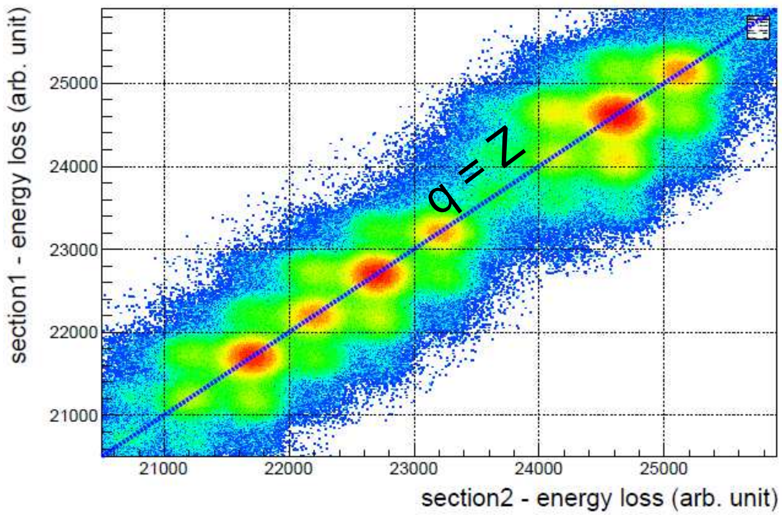


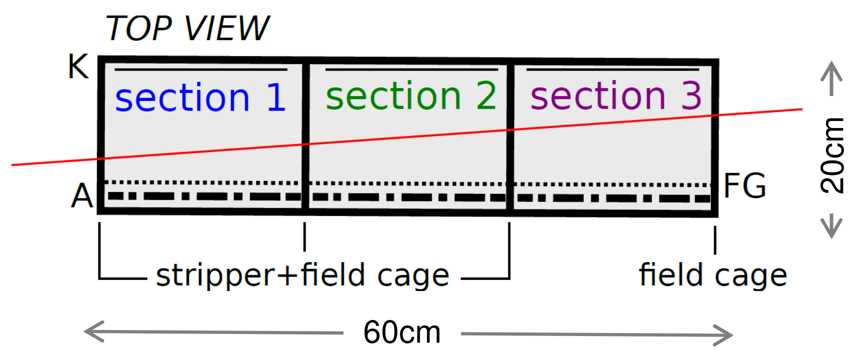


e- at 40 cm

The stripper resets the charge state equilibrium of the incoming ion, permitting a second charge measurement. The Z of the ion is assigned as being the maximum of the q between each volume.

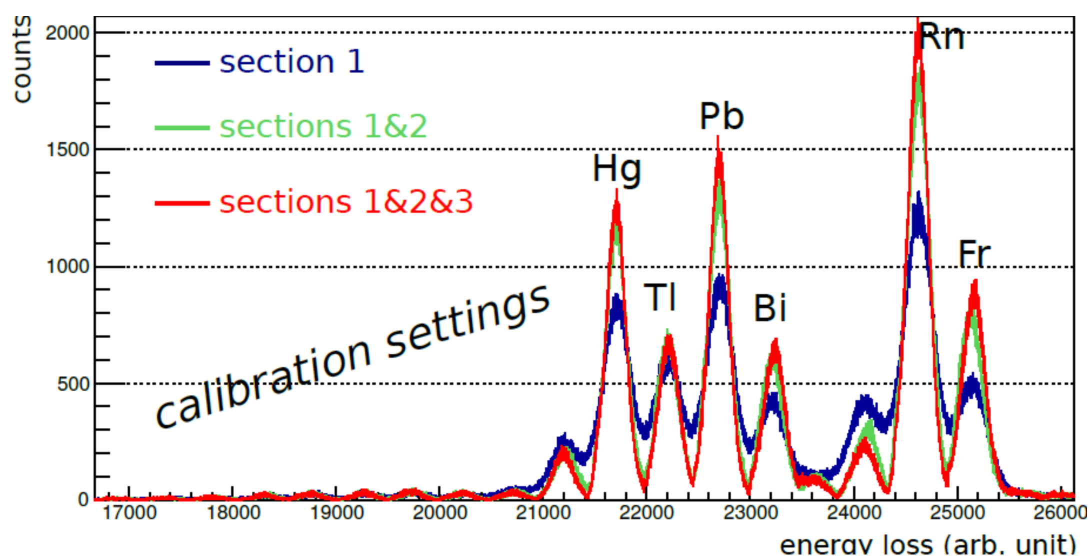
Triple MUSIC



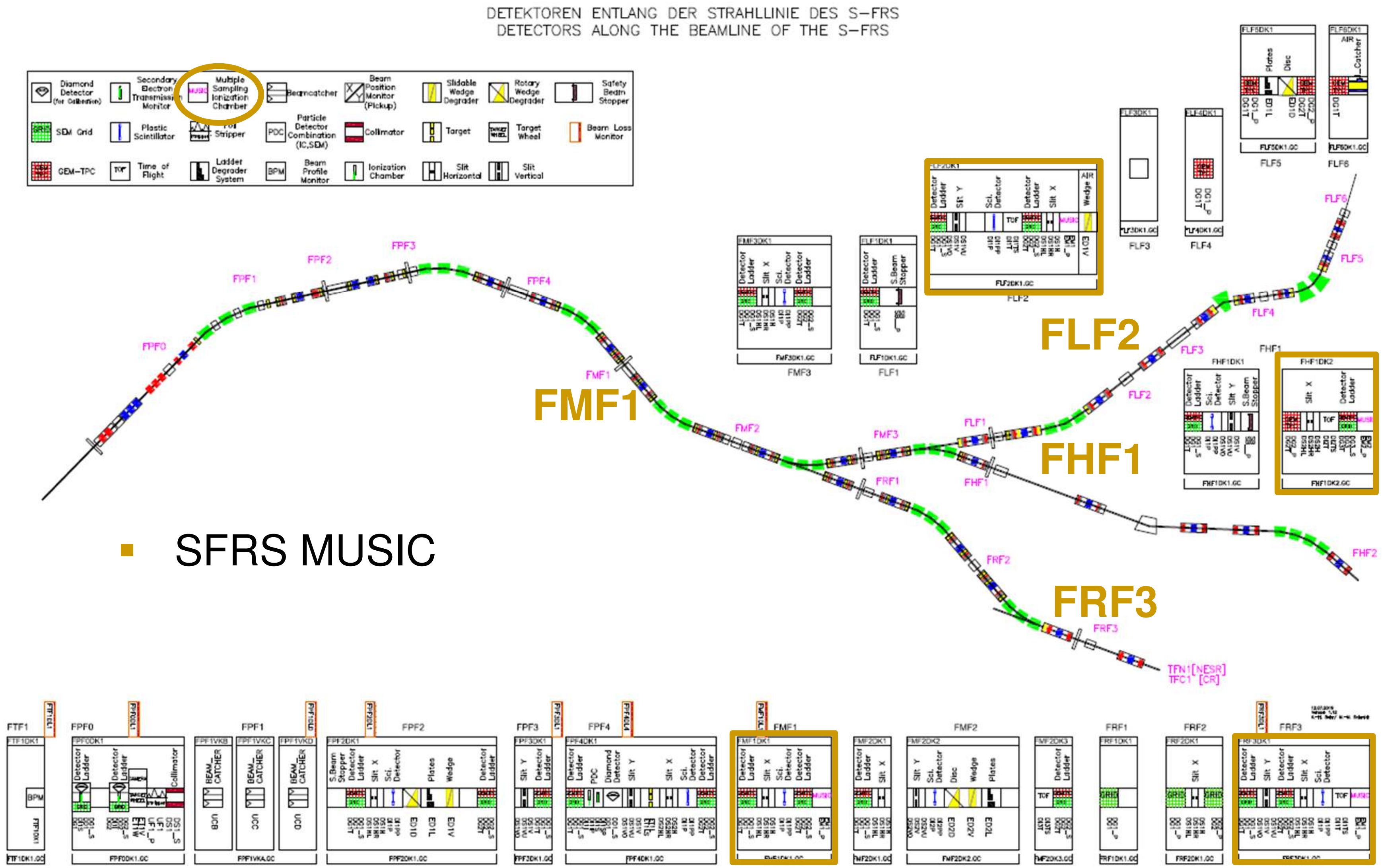


courtesy of A. Chatillon

- Built at DTL (B. Voss) for the SOFIA campaign
- 3-stage for the best charge state identification
- horizontal drift, segmented anodes

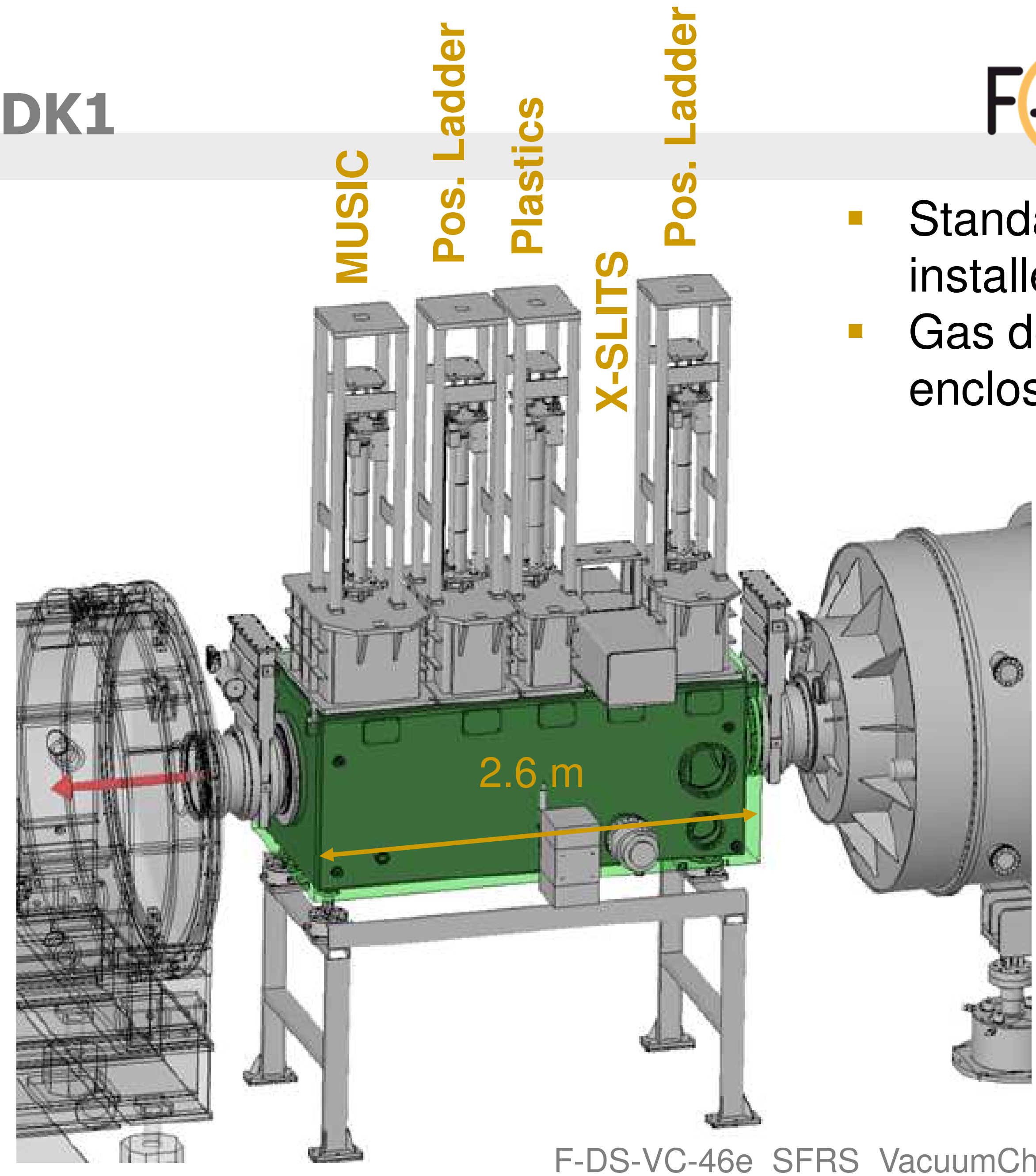


Super-FRS layout



- SFRS MUSIC

FMF1DK1

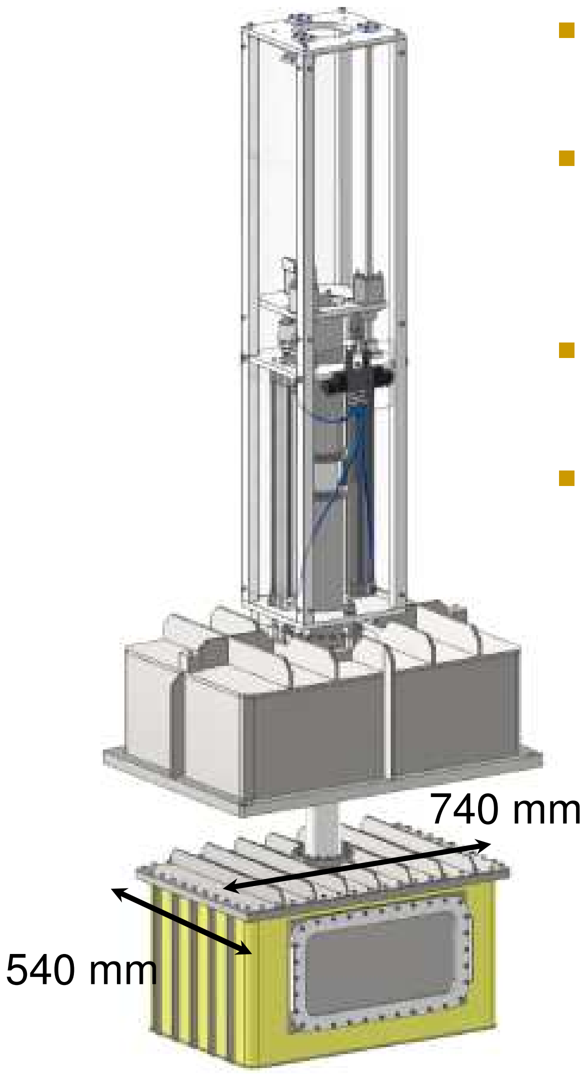


- Standard equipment is installed in vacuum
- Gas detectors are enclosed in a “pocket”

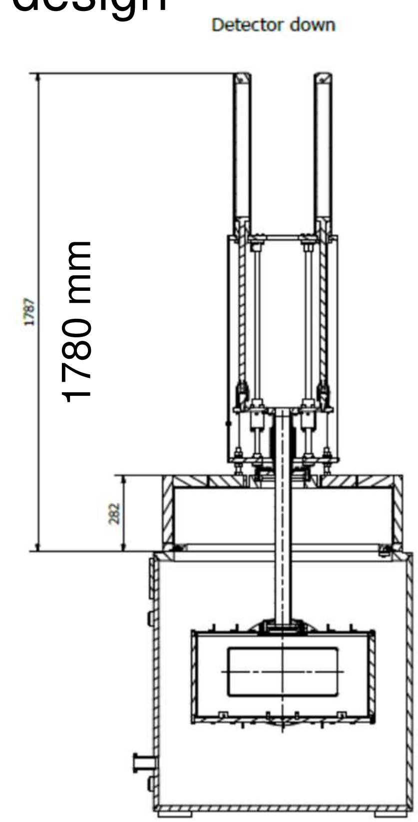
F-DS-VC-46e_SFRS_VacuumChambers_Focal_Planes_v2.6

FoS Super-FRS MUSIC

- Finnish in-kind contribution to FAIR
- Contract signed at the end of 2017, GSI-DTL will contribute with the field cage design
- CDR approved in Oct 2019
- Electronics



3D model of MUSIC drive and pocket
by J. Tuunanen (JYFL Jyväskylä)



MUSIC electronics

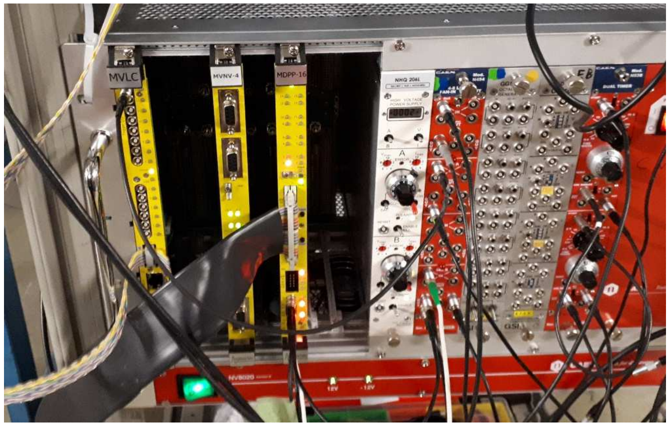
- Preamp by CEA DAM (J. Taieb) tested at the FRS since 2015, delivered in 2019 and already in use.

- Mesytec agreed in designing the signal chain from motherboard and preamplifiers up to digitalization
  - 17-ch charge sensitive amplifier board: differential, fast, low noise, full dynamic range, low power consumption and low failure rate
  - controller 1 GBit ethernet / USB 3 MVLC
  - time and amplitude digitizer MDPP16-D
  - power supply MVNV-4

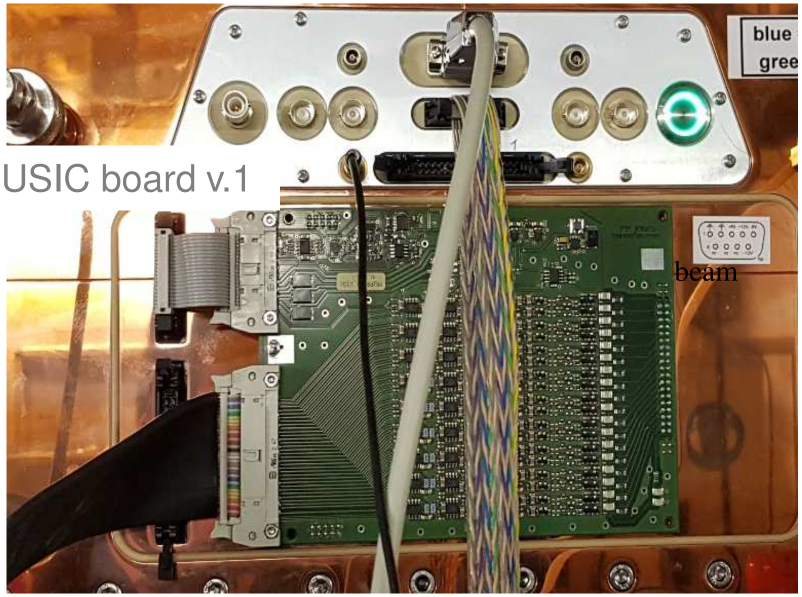
Delivered to GSI Oct 2019

Adaptation started in Jan 2020

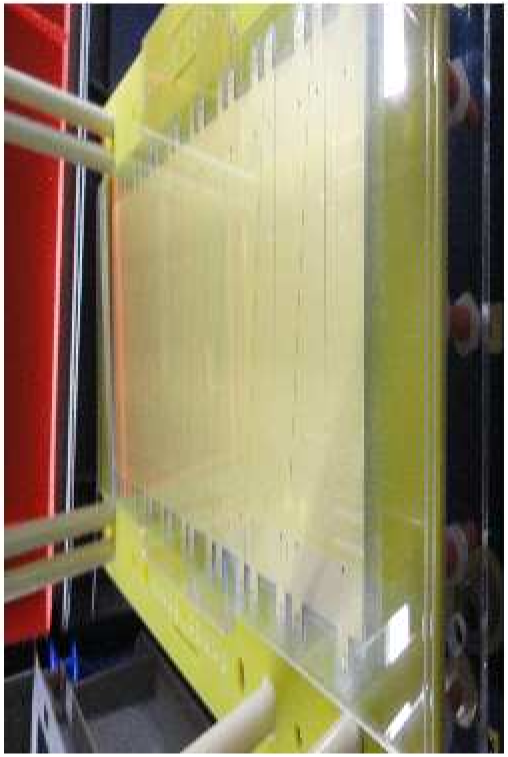
Tested in May 2020 with B. Voss and J. Galvis Tarquino



Preamp board prototype



- Adaptation to an existing MUSIC at GSI-DTL



8-anode pad-plane

Anodes ⟷ Channels

Detector side	Panel	Connector side
	Screen J	Imon1
Anode 1 (last in the beam)	I	Ch 0
Anode 2	H	Ch 2
Anode 3	G	Ch 4
Anode 4	F	Ch 6
Anode 5	E	Ch 8
Anode 6	D	Ch 10
Anode 7	C	Ch 12
Anode 8 (1st in the beam)	B	Ch 14
	Screen A (alpha source)	Imon2

Prototype at F2-FRS

HV settings: U_{cath} = -4200 V, U_{an} = 200 V

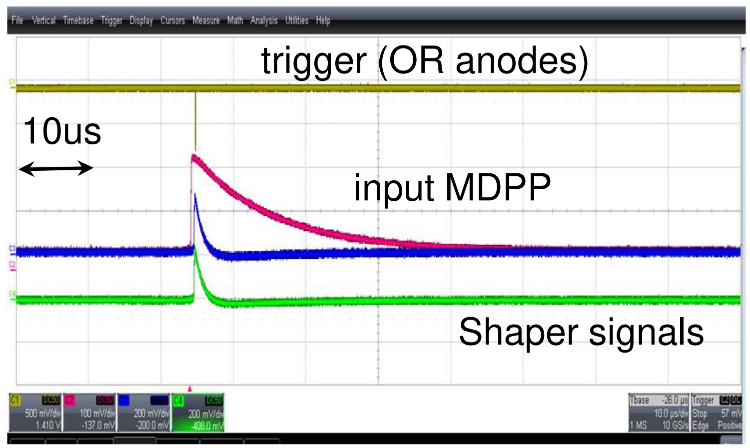
- Active area: 220x100 mm^2
- Active length: 300 mm
- Anode: 8 segmented
- Drift: horizontal
- Distance cathode-grid: 220 mm
- Distance grid-anode: 2.2 mm

- Cu stripper at TA: 90 mg/cm^2
- TA-F2: Bi^{83+} selected by slit cut

^{209}Bi @900MeV/u

Gas: P10, ΔE_{gas}= 555 MeV

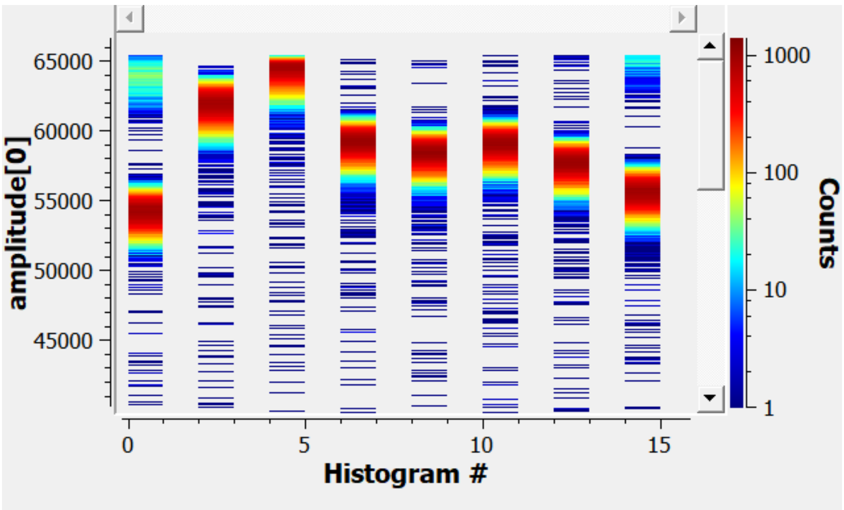
sens. 1.5 pC



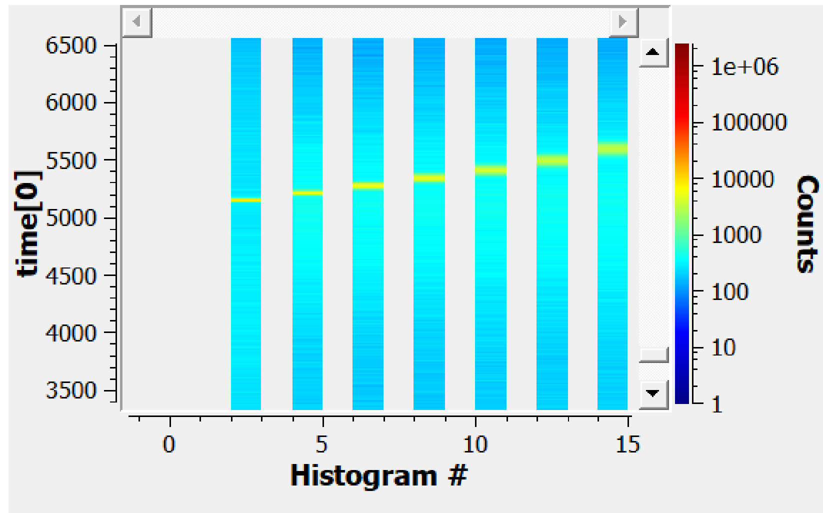
Run #8

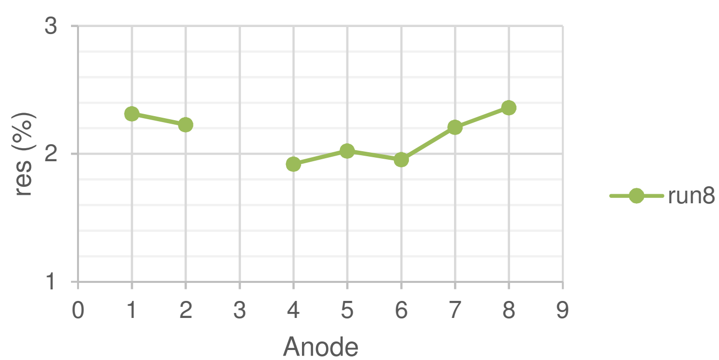
sens. 1.5 pC
sh. time = 10 x 12,5 ns; gain = 700

Amplitude vs Anode



Time vs Anode

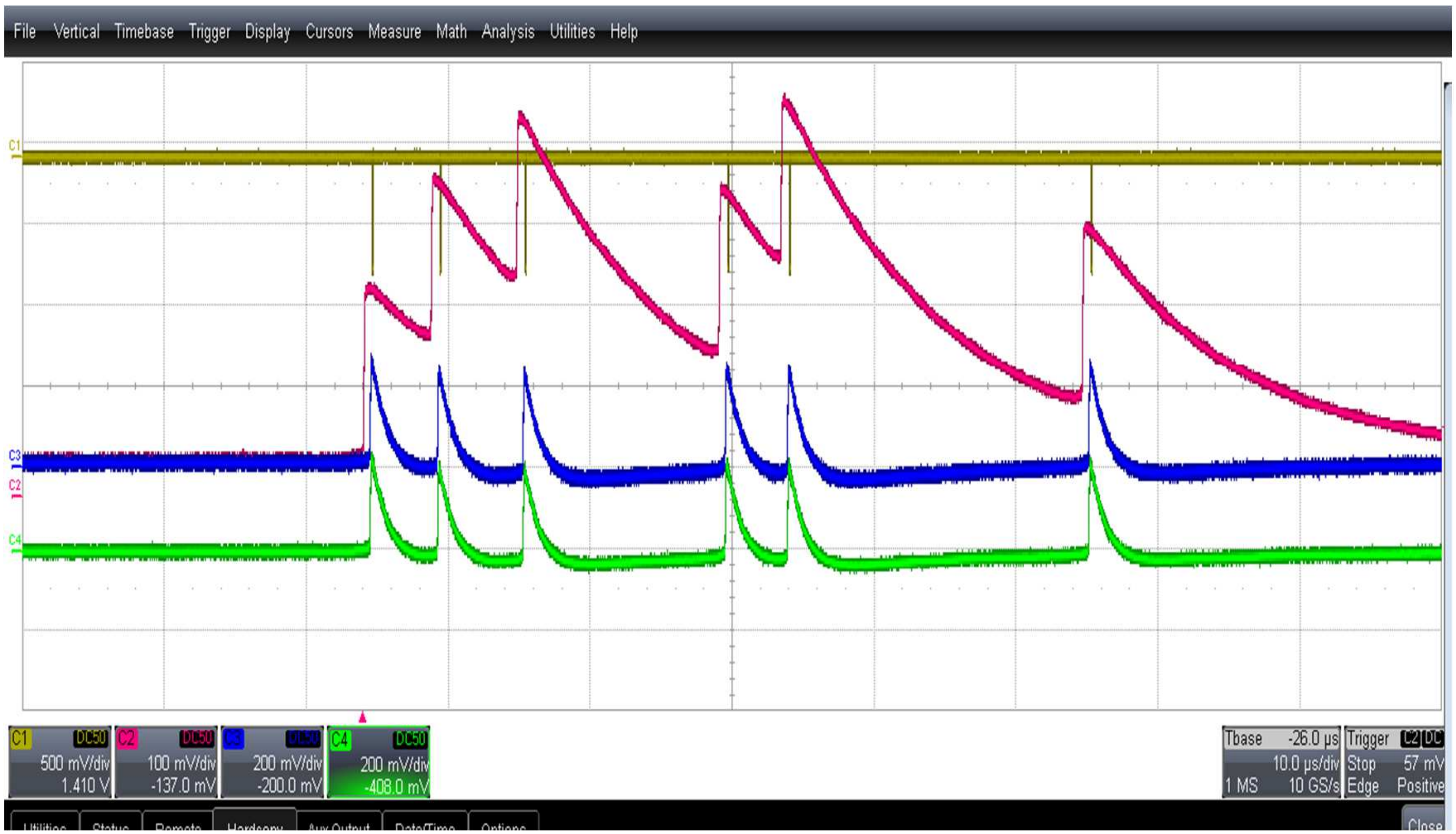




Low mean rate (4-5 kHz)

Pile-up

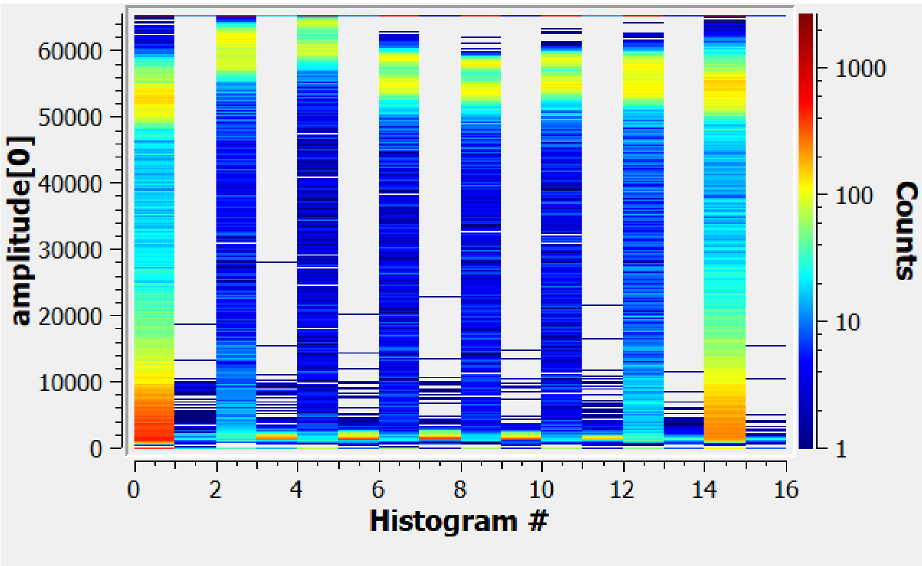
^{209}Bi @900MeV/u



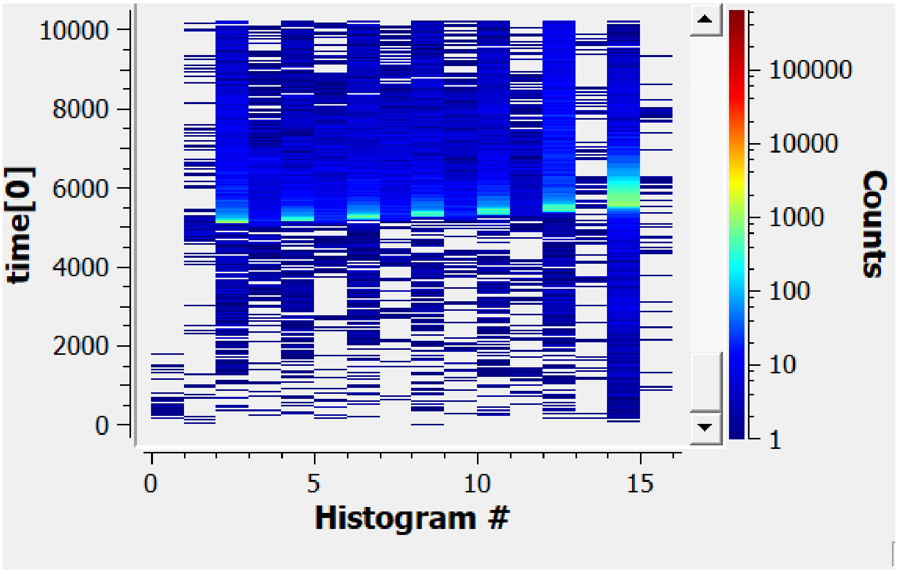
Run #10

sens. 1.5 pC
sh. time = 10 x 12,5 ns; gain = 800

Amplitude vs Anode



Time vs Anode



At high mean rate (> 2-3 MHz) time jump is visible

Summary

Charge identification of heavy relativistic ions flying through a magnetic separator like the Super-FRS:

- ΔE gas detectors represent the most suitable choice because of the good energy resolution and robustness

- ΔE gas detectors must work with fast amplifiers and digitizers (pile-up treatment) for higher rate capability

- Stripper between MUSIC sections helps

- FoS Super-FRS MUSIC

  detector will be build at the GSI-DTL

  integration and optimization of the Mesytec pream board

  beam time 2021/22 approved

  FDR foreseen by the end of 2021

Outlooks

About the coming design:

- removable stripper between two volumes, inserted or not, depending on the fragment setting, i.e. limiting angular spreading or cleaning up Z misidentification in case of high Z and low energy ion beams

- the anode segmentation to permit higher rate and lower pile-up event

- use of lower Z window (for instance Ti) of the vacuum pocket to reduce the angular straggling in all Super-FRS gas detectors.

FAIR MUSIC collaborators

- T. Blatz, C. Karagiannis, C. Nociforo, J. Galvis Tarquino, B. Voss
- T. Grahn, J. Tuunanen
- R. Schneider

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JYVÄSKYLÄN YLIOPISTO

mesytec