# Detector developments for the Super-FRS and tests at the FRS

Chiara Nociforo

GSI Helmholtzzentrum für Schwerionenforschung
Darmstadt - Germany

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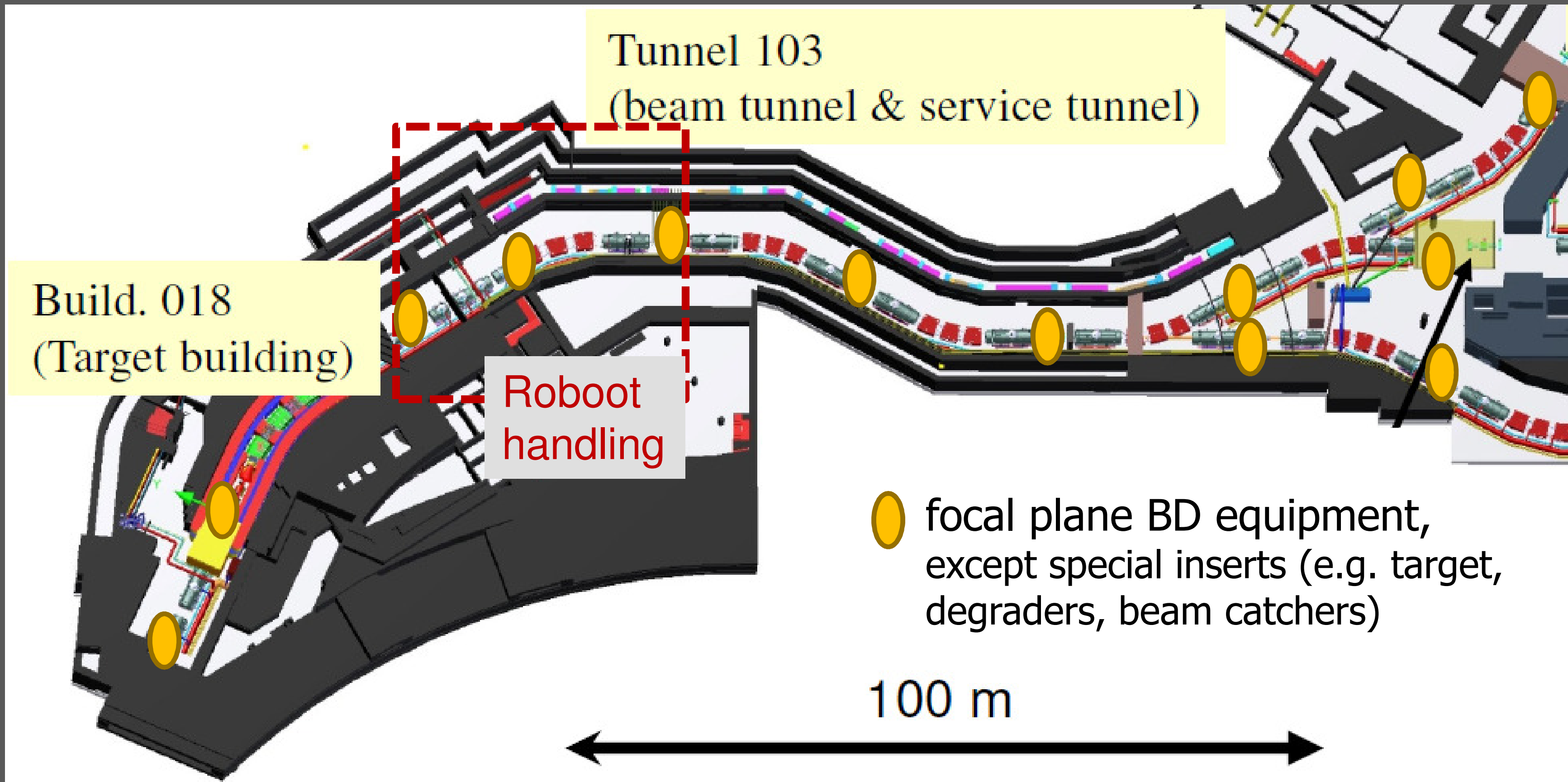
- **Beam Diagnostics (BD) of the Super-FRS**
  - overview
  - standard equipment
  - standard detector requirements
- **Particle identification detectors (PID)**
  - Super-FRS vs FRS
  - new detector developments
  - tests in 2014

# Overview


Tunnel 103
(beam tunnel & service tunnel)
Build. 018
(Target building)
Roboot
handling
focal plane BD equipment,
except special inserts (e.g. target,
degraders, beam catchers)
100 m

# Standard detection system

We distinguish between operation with fast- (i.e. up to the ring branch) and slow-extracted beams (up to the high- and low-energy branch).

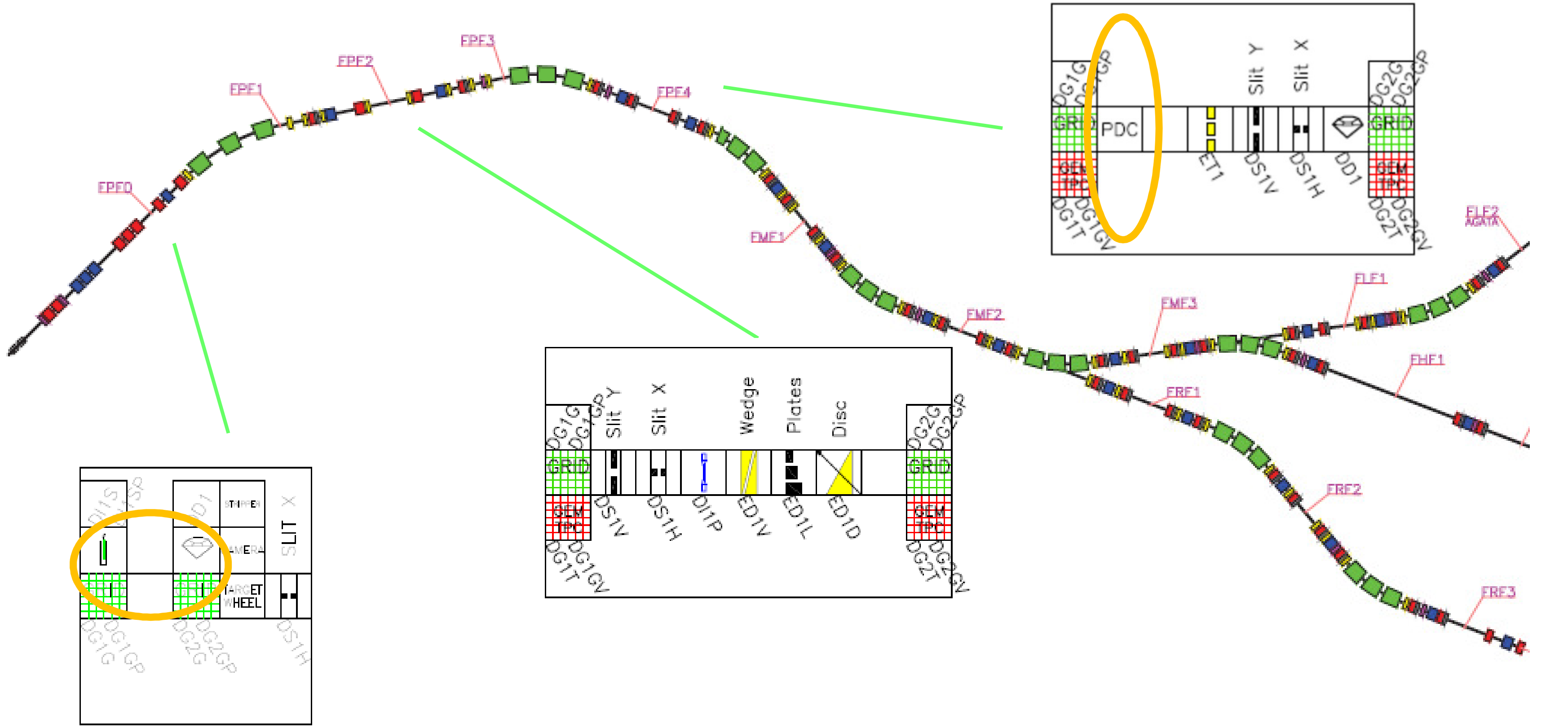
Concerning in-ring experiment the main information to be provided are:

1) **beam intensity**
2) **transverse beam profile**
3) **deviation from nominal beam optics**

The other experiments, beside the information 1) and 3), need in addition the information on fragment timing, positions and energy loss.

# Layout of the Super-FRS beam line

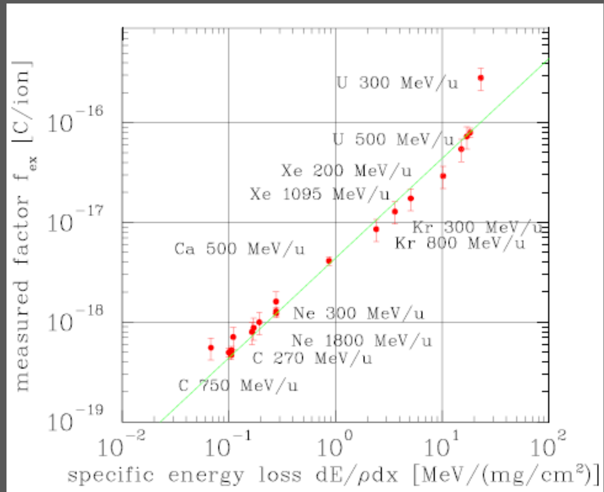
Beam diagnostics at the pre-separator




Intensity 10^12 /s <10^10 /s <10^9 /s <10^7 /s <10^5 /s

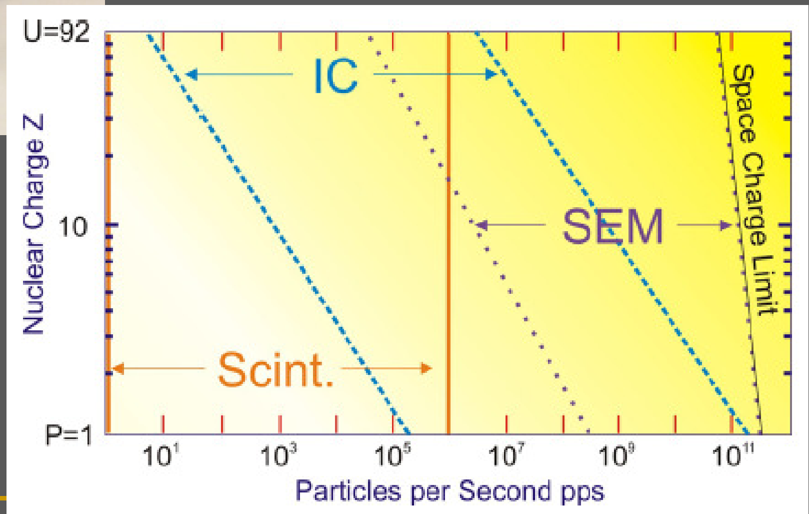
# Beam intensity measurements

**Particle Detection Combination (PDC)**

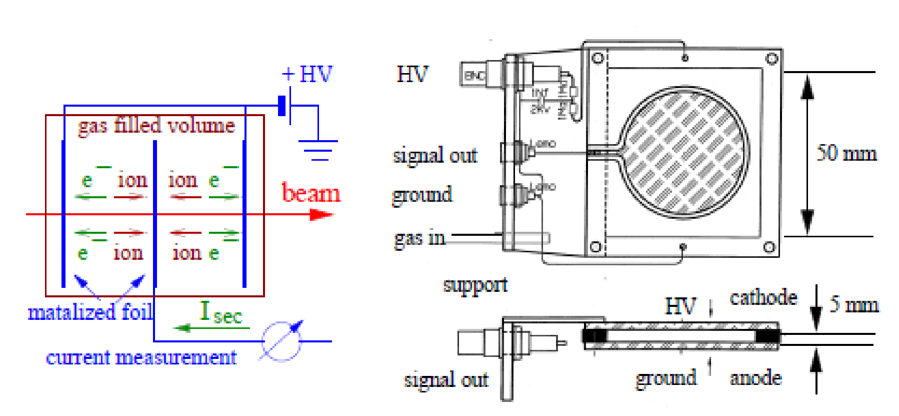

Located at FPF0 and FPF4

- Plastic scintillator
- Ionization Chamber (IC)
- Secondary Electron Monitor (SEM)

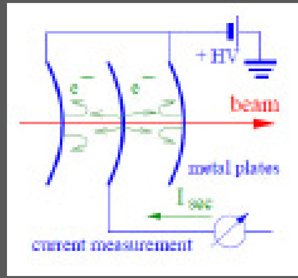


# PDC

## IC

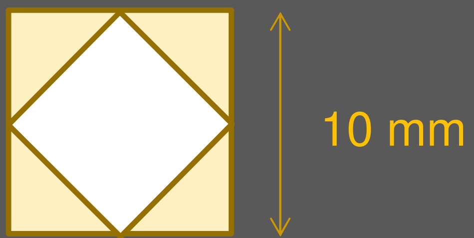



## SEM in vacuum part




| | |
|---|---|
| material | pure Al (≃99.5%) |
| thickness | 100 $\mu$m |
| number of electrodes | 3 |
| active surface | 80 × 80 $mm^2$ |
| distance between electrode | 5 mm |
| voltage | 100 V |

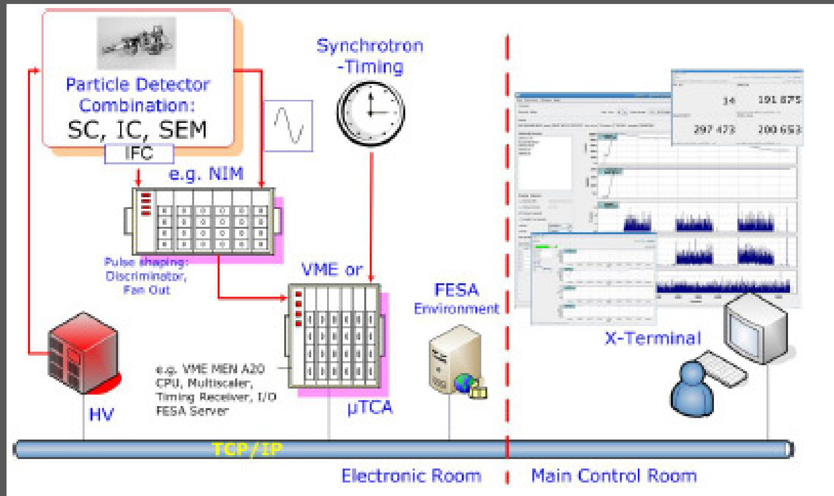
## Diamond replaces the SCI




Issue at FPF0:

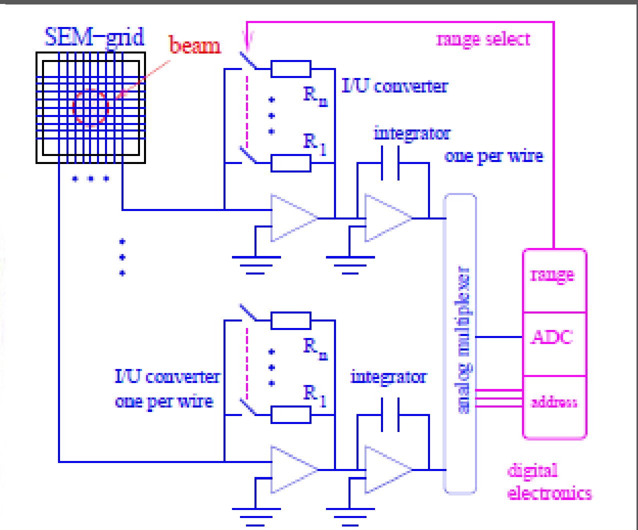
- smaller size, not standard (HEBT)

## Signals and data flow



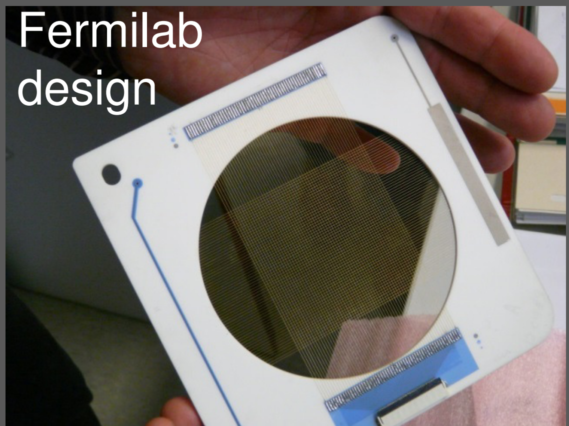

Special care for signal transportation and FEE location due to the high radiation level.

# SEM-grid


Typical specifications

| | |
|---|---|
| Diameter of the wires | 0.1 mm |
| Spacing | 0.8 to 2 mm |
| Length | 50 to 100 mm |
| Material | W-Re alloy |
| Isulation of the frame | PEEK |
| Numbers of wires | 64/plane or 32/plane |
| Max. power rating in vacuum | 1 W/ mm |
| Min. sensitivity of I/U-conv. | 1 nA/V |
| Dynamic range | $1:10^6$ |
| Number of ranges | 10 typ. |
| Integration time | 1 µs to 1 s |




- special care of beam high power (Ti, C wires), heating and material stress
- wire-spacing simulations

| | | |
|---|---|---|
| FPF0 | $5\times10^{11}$ $^{238}$U/spill | Ø ≈15 mm |
| Separator | $\leq10^{8}$ ions/spill | Ø ≈100 mm |

SEM-grid & position ladders
Finnish in-kind

# PID at the Super-FRS

- **Increasing intensity of radioactive beams** requires detecting system with high-rate capability.

- **Clean full PID on event-by-event basis**

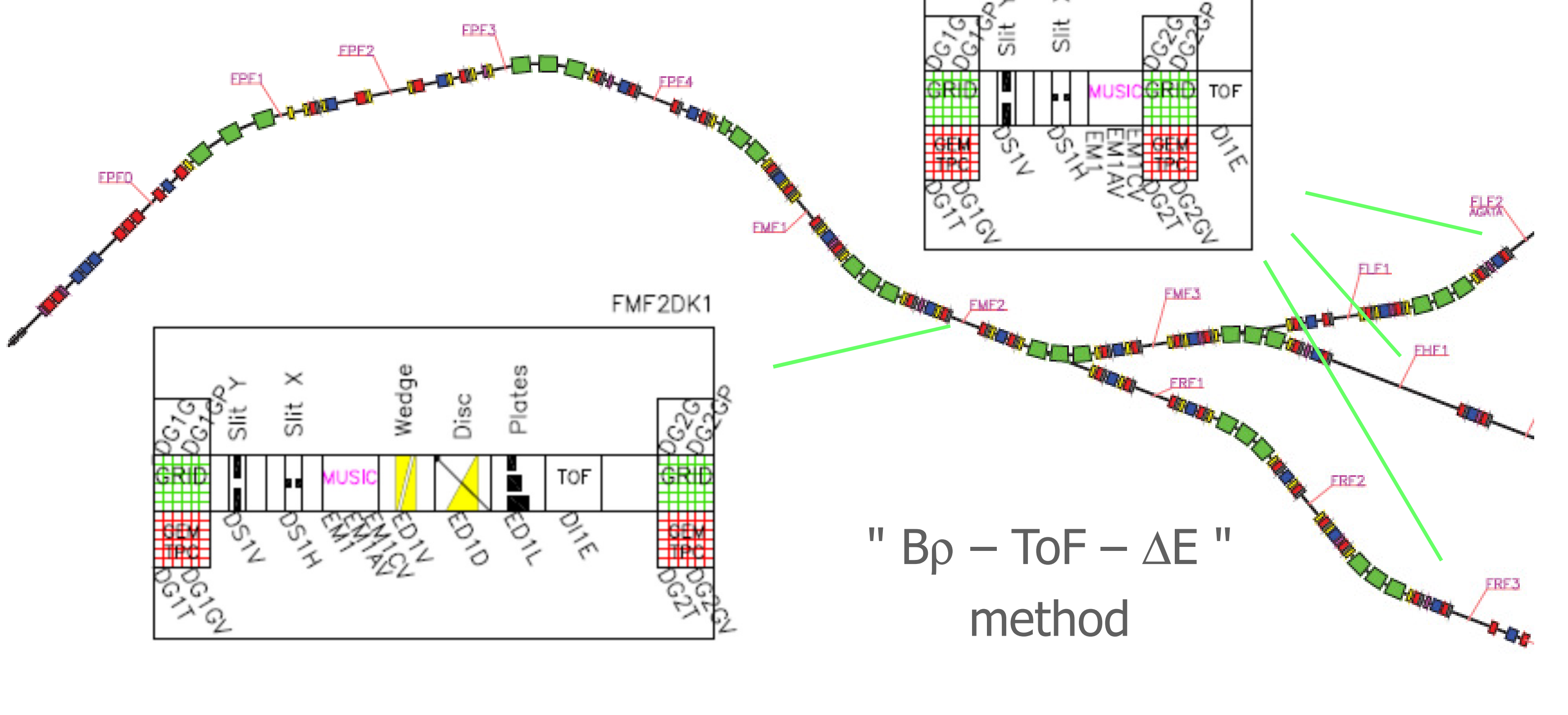
  → momentum tagging $\Delta x \sim 1mm$

  → charge resolution $\Delta Z \sim 0.2e$

  → ToF measurements $\Delta ToF \sim 100ps$ (FWHM) **A≈200**

# Layout of the Super-FRS beam line

Operation mode with slow-extracted beams & PID




| Intensity | $10^{12}$ /s | $<10^{10}$ /s | $<10^{9}$ /s | $<10^{7}$ /s | $<10^{5}$ /s |
|---|---|---|---|---|---|

# Standard PID detectors at FRS

TPC-x,y position @S2,S4

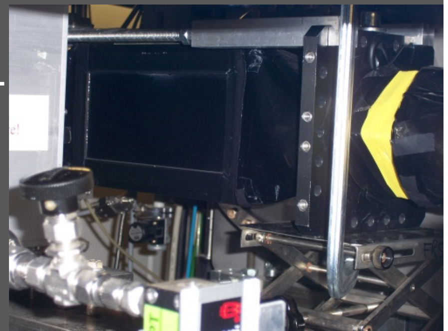
$$Z \leftarrow -dE/dx = \mathrm{f}(Z, \beta)$$

$$A/Q = \frac{B\rho}{\gamma\beta m_u}$$

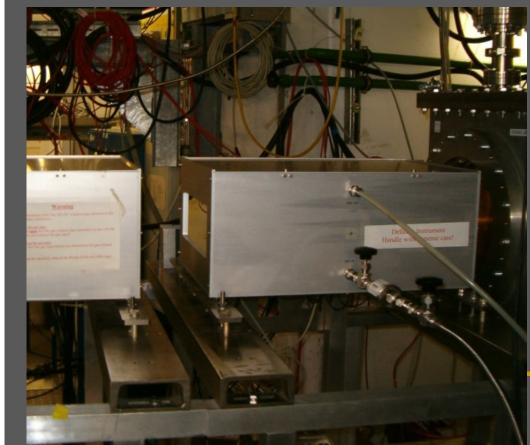
$$A = \frac{T_{\mathrm{KE}}}{(\gamma - 1) m_u}$$

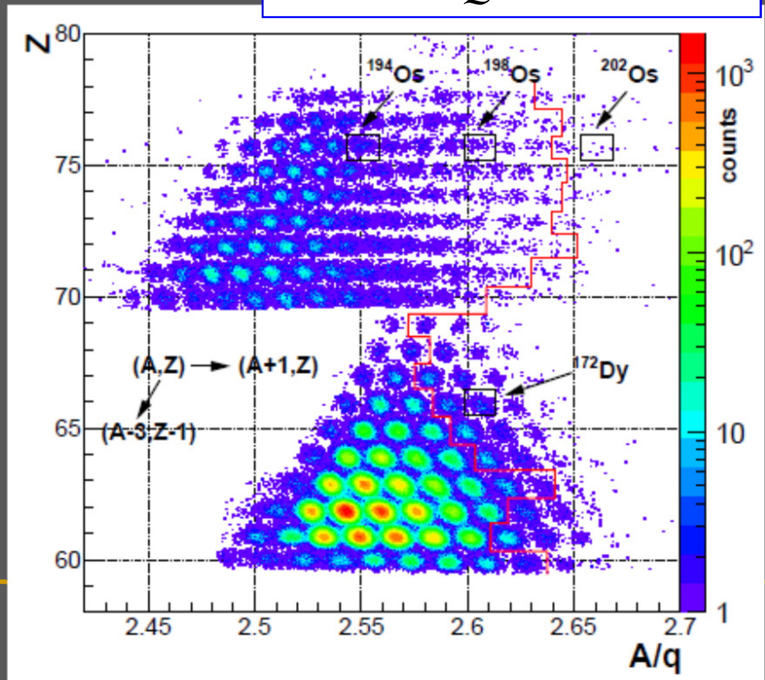
$$Q = \frac{A}{A/Q}$$

Plastic scintillator (ToF) @TA,S1 S2,S3, S4,S8

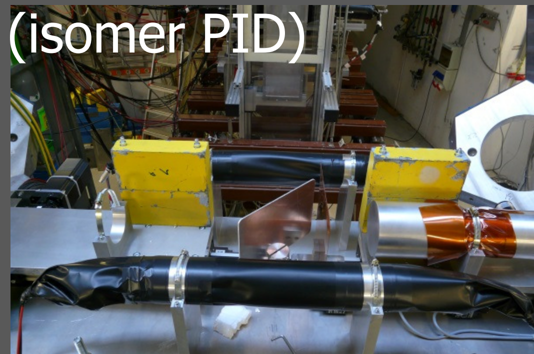


MUSIC ($\Delta$E) @S2,S4






HPGe @S4 for isomer γ-decay measurement (isomer PID)

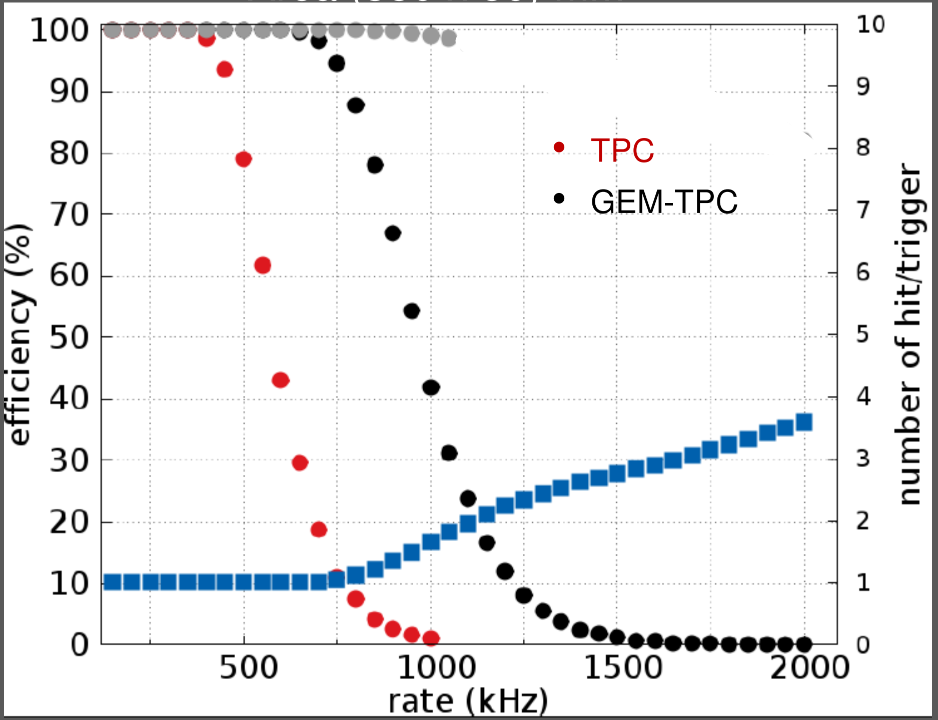


J. Kurcewicz et al., *PLB* 717 (2012) 371

# High-rate solution

Simulations
- trigger window <2 μs
- hit mixing starts @750 kHz

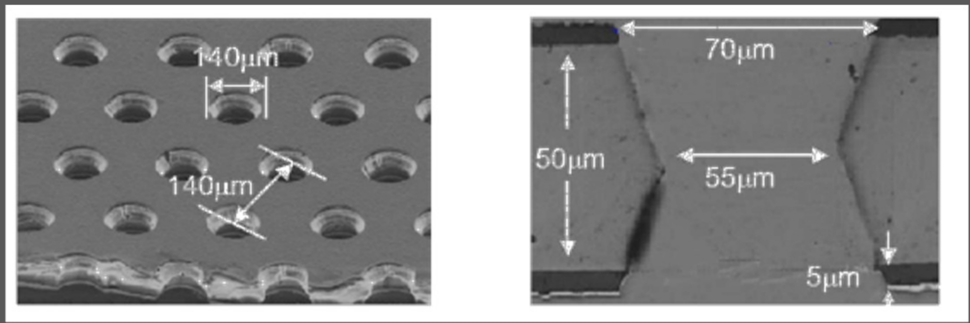
Area (380 x 80) mm$^2$




A. Prochazka et al., *GSI report* (2012)

# Triple GEM detector

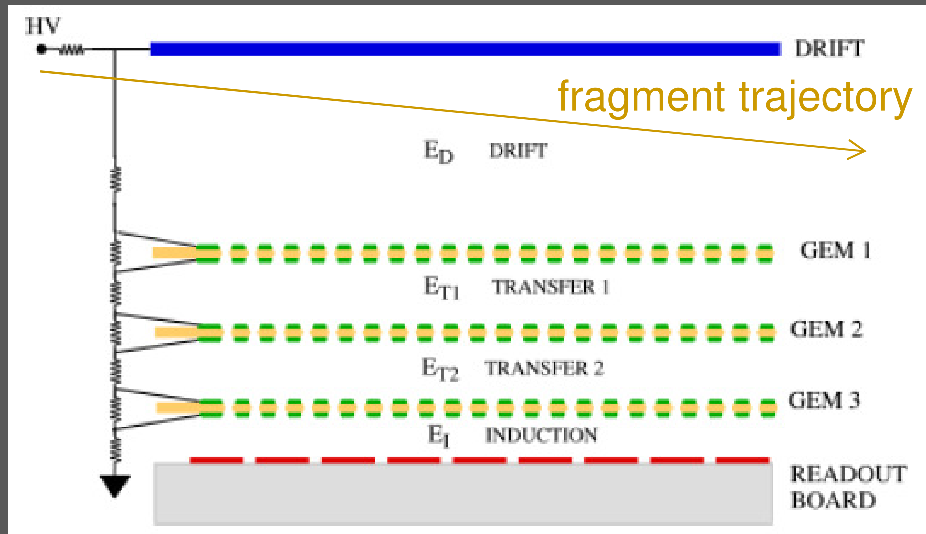
Gas Electron Multiplier




http://gdd.web.cern.ch/GDD/

F. Sauli, *NIM A* 386 (1997) 531

at the Super-FRS the drift will be ≥ 80 mm !



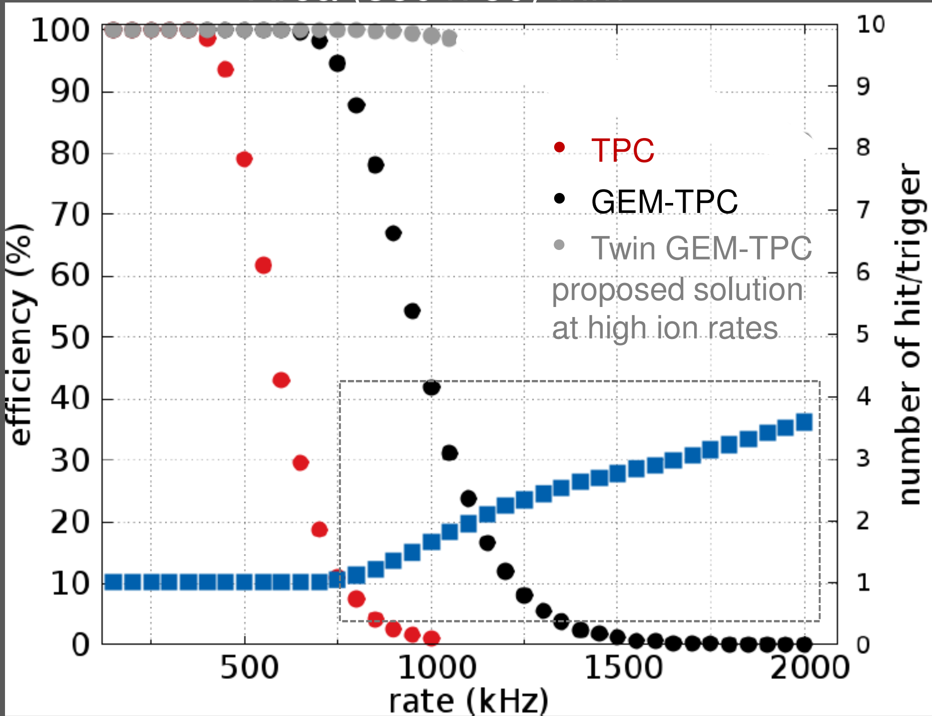

Three foils configuration advantages:

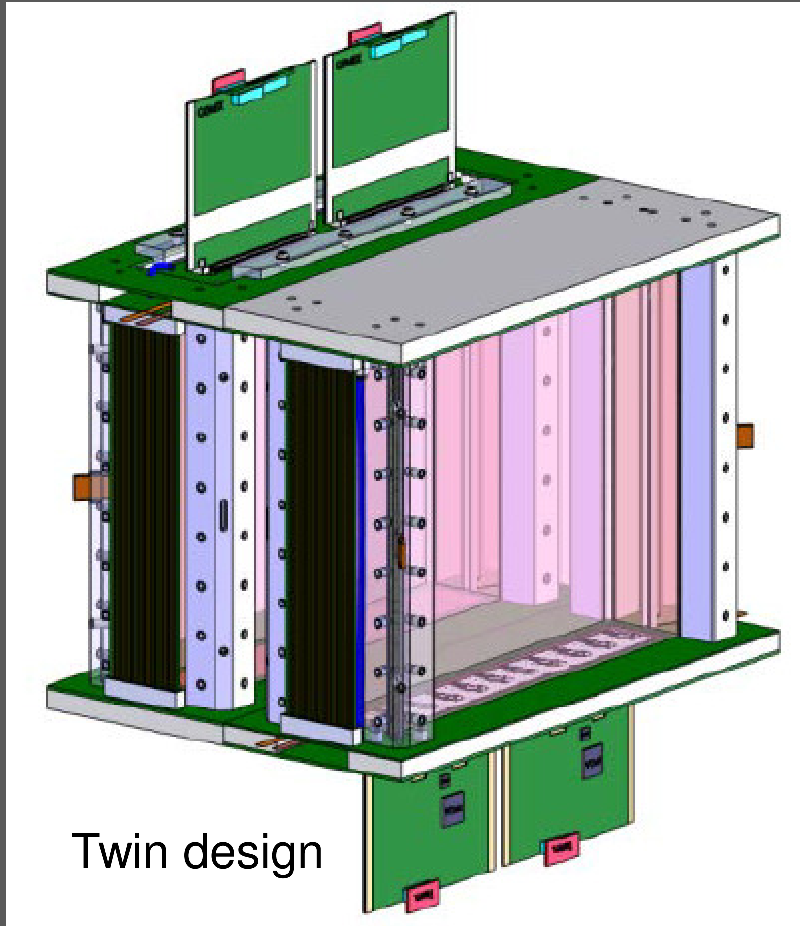
- reduced discharge probability (i.e. higher gains achievable)
- ion feedback effects suppression

# High-rate solution

Simulations
- trigger window <2 μs
- hit mixing starts @750 kHz

Area (380 x 80) mm²




A. Prochazka et al., *GSI report* (2012)

# Particle tracking at the Super-FRS

Gas detector based on GEM technology

- 32 units
- pos resolution $\sigma$ <1 mm
- active area 380/200mm x 80mm
- max rate up to $10^7$/spill
- high dynamic range (> 1000)
- multi-channel FEE → ASIC for time (and energy) measurements,
  link board to compress and multiplex data,
  zero suppression data,
  readout dead-time free 1-10 MHz

Finnish in-kind contribution to FAIR

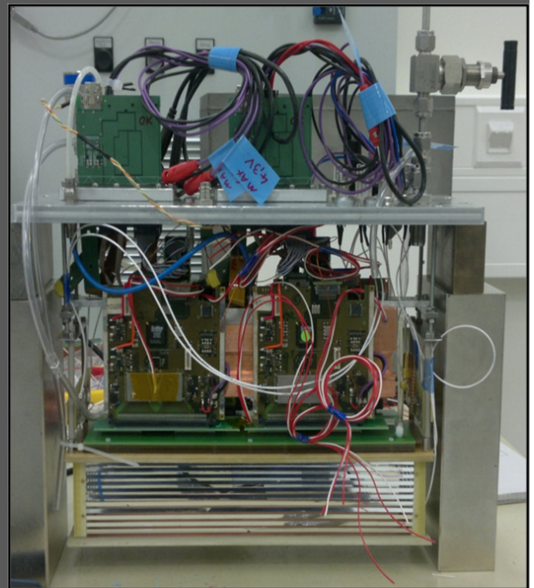
# FAIR GEM-TPC detector

Finnish in-kind contribution to FAIR is fixed to 32 GEM-TPC detectors for Super-FRS beam diagnoses and tracking

GEM-TPC detector R&D is currently ongoing at Helsinki / HIP together with GSI, University of Jyväskylä and CUB Bratislava.

Previously, three prototypes have been completed and successfully tested at FRS.

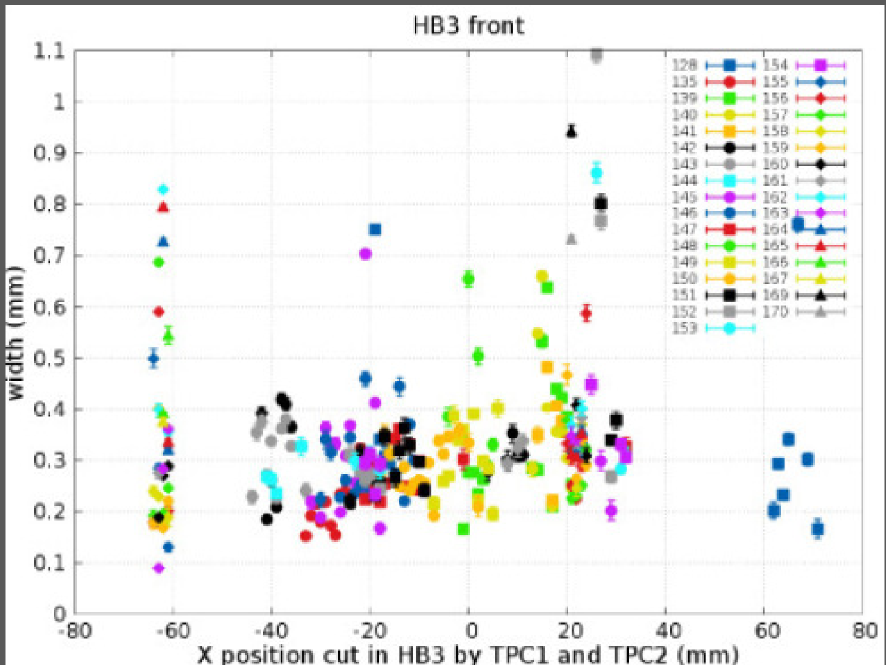
Currently, GEMEX board- based on n–XYTER chip- is being designed and produced, and  a new twin GEM-TPC prototype, i.e. GEM-TPC detector with two field cages in one housing box, is being constructed.



HB3 (Helsinki-Bratislava-#3) GEM-TPC prototype with GEMEX readout cards incl. nXYTER chip

# Test results of HB3

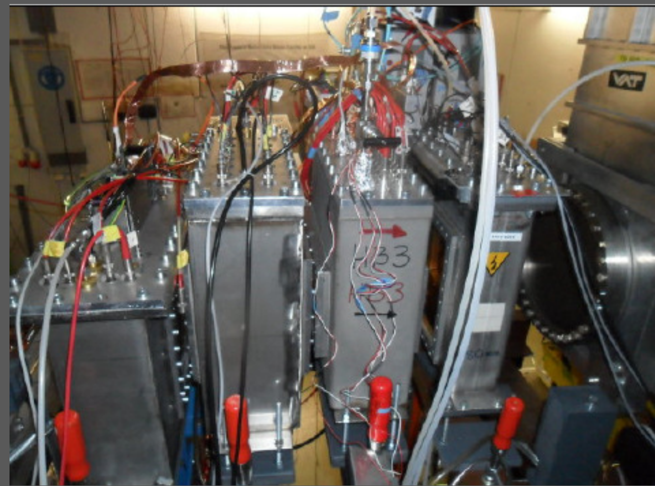
Performed at FRS with 700 MeV/u $^{197}$Au beam.

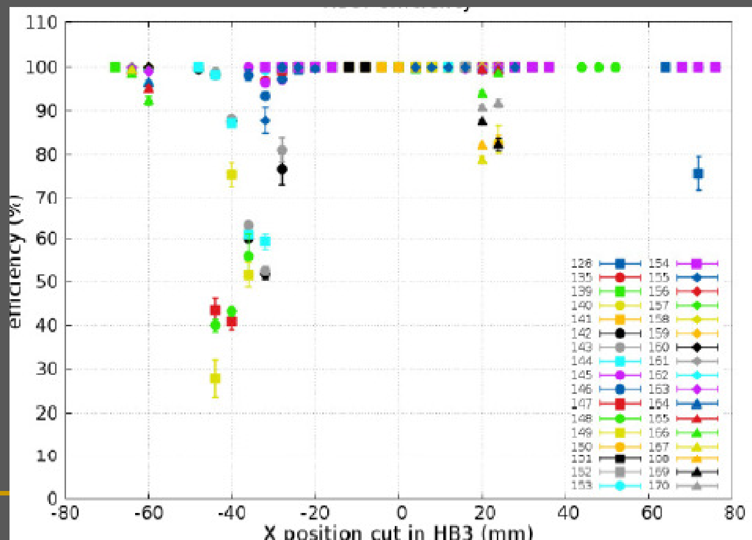



F. Garcia et al., *GSI report* (2012)

HIP
CUB
GSI

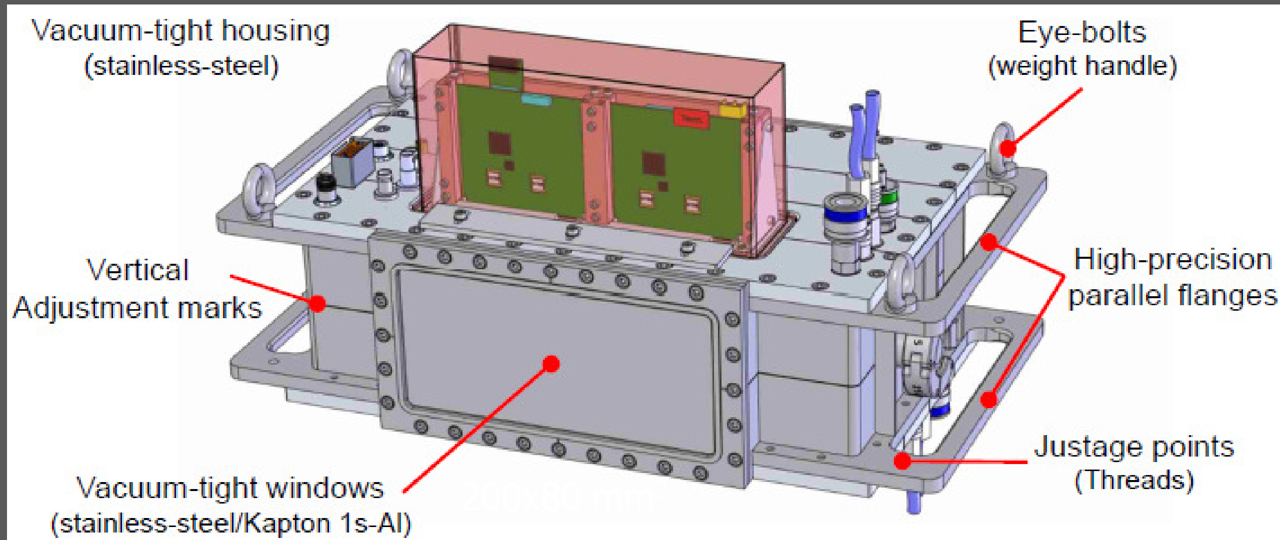
GEM +
GEMEX
readout





# Twin GEM-TPC tests

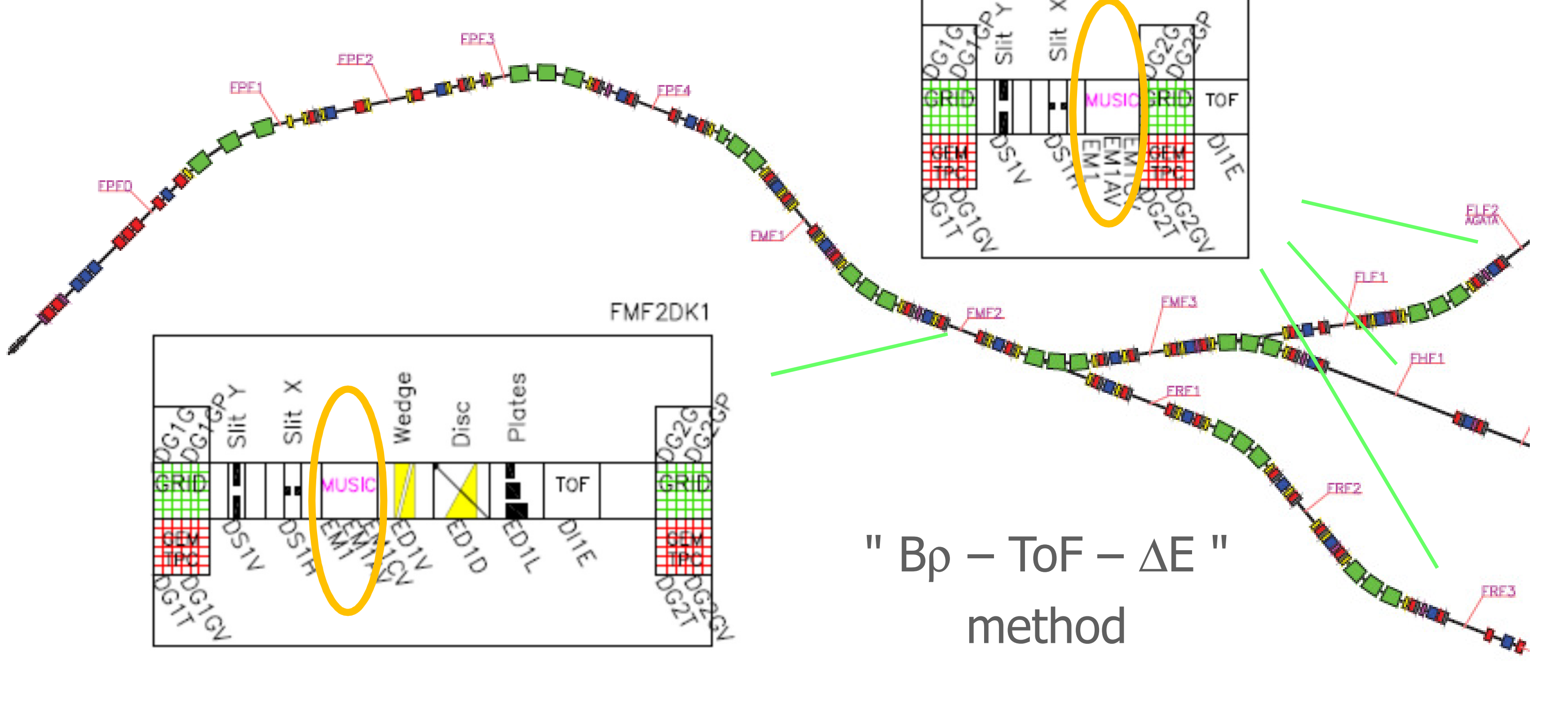
- test of HGB4-1 at Jyväskylä  in <u>May</u> with high intensity p
  - mechanical assembling will be at GSI
  - readout electronics : PCB ordered, GEMEX1c delivery in April
  - NXYTER software/GUI developed




- S417 beam time test of HGB4-2 at FRS in <u>July</u>

# Layout of the Super-FRS beam line

Operation mode with slow-extracted beams




| Intensity | $10^{12}$ /s | $<10^{10}$ /s | $<10^{9}$ /s | $<10^{7}$ /s | $<10^{5}$ /s |
|---|---|---|---|---|---|

# Standard ΔE detector

A suitable ΔE detector needs to have

- good energy resolution
- high counting rate capability
- 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
- large-scale detector easy to fabricate

**Multiple Sampling Ionization Chamber (MUSIC)**

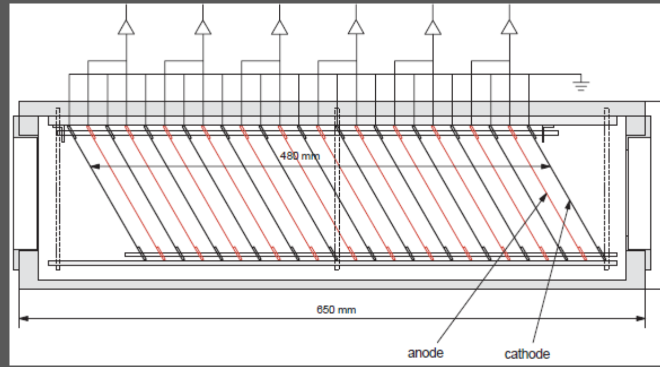
# MUSIC tests with A≈200 fragments

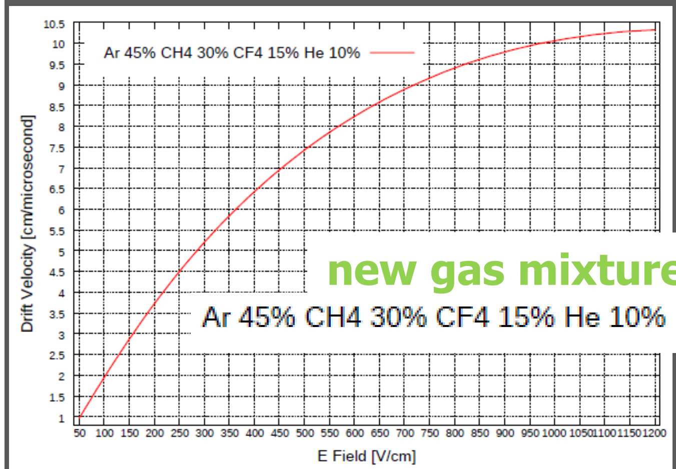
## a) TEGIC design

K. Kimura et al., *NIM A* 538 (2005) 608

- 530x210x560 $mm^3$
- electrodes: 30° tilted plates
- P10 gas
- readout FEBEX3a (65Ms/s, 12-bit) or SIS3302

R. Gernhäuser (TUM) et al.

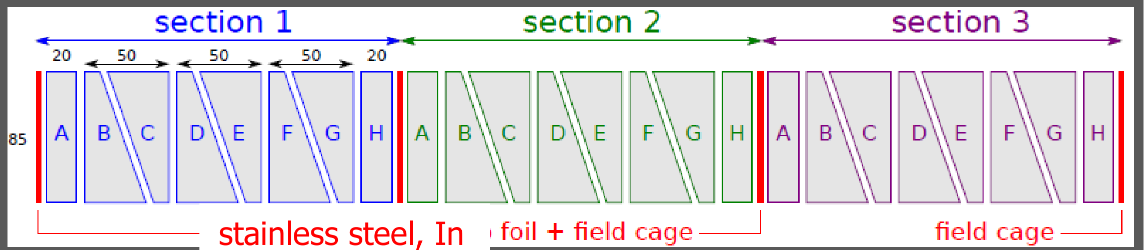



new gas mixture

Ar 45% CH4 30% CF4 15% He 10%

## b) CEA/GSI Triple Music



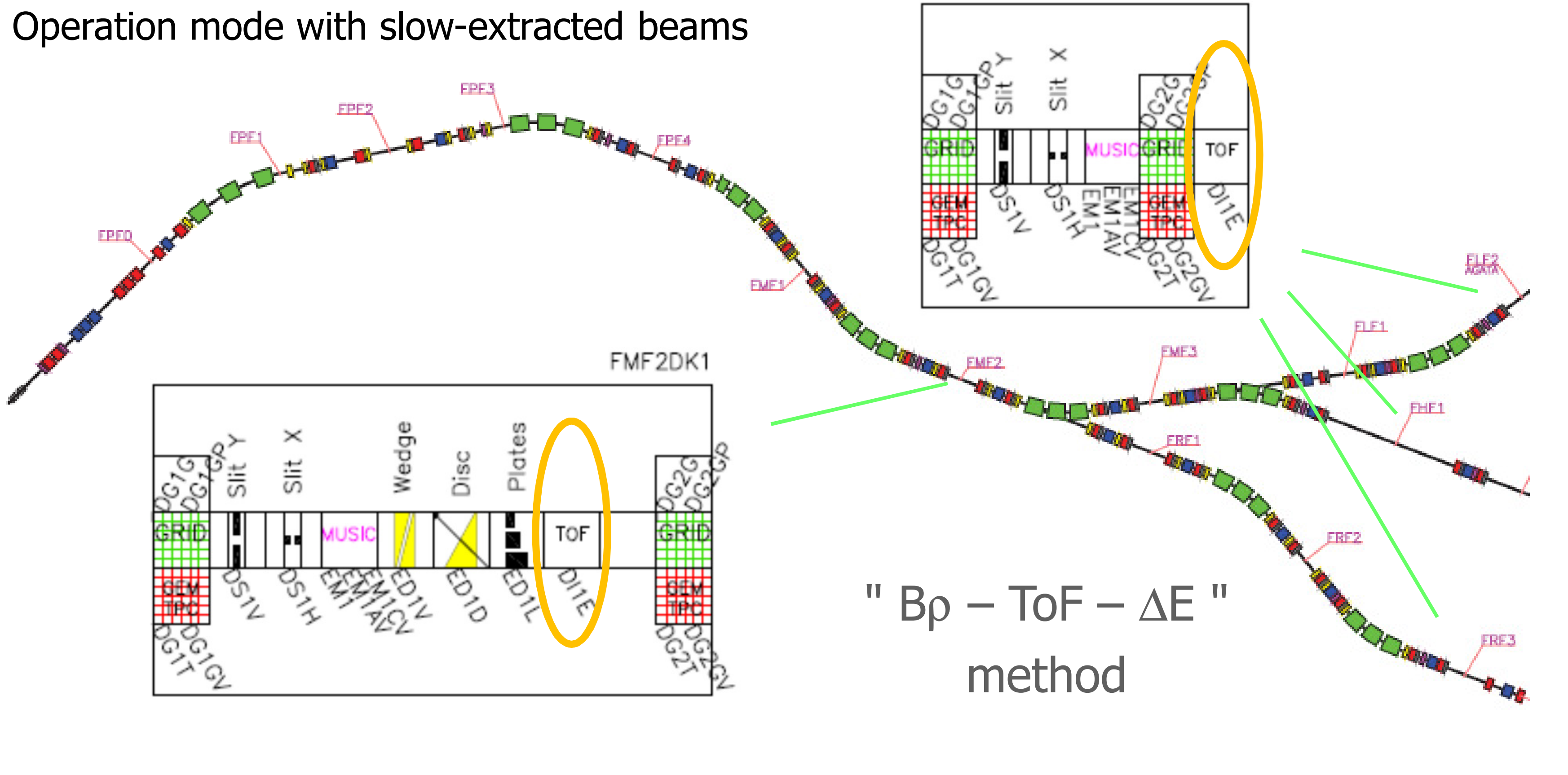

57 cm

- readout MADC32 Mesytec

J. Taieb (CEA),
B. Voss et al.

# Layout of the Super-FRS beam line

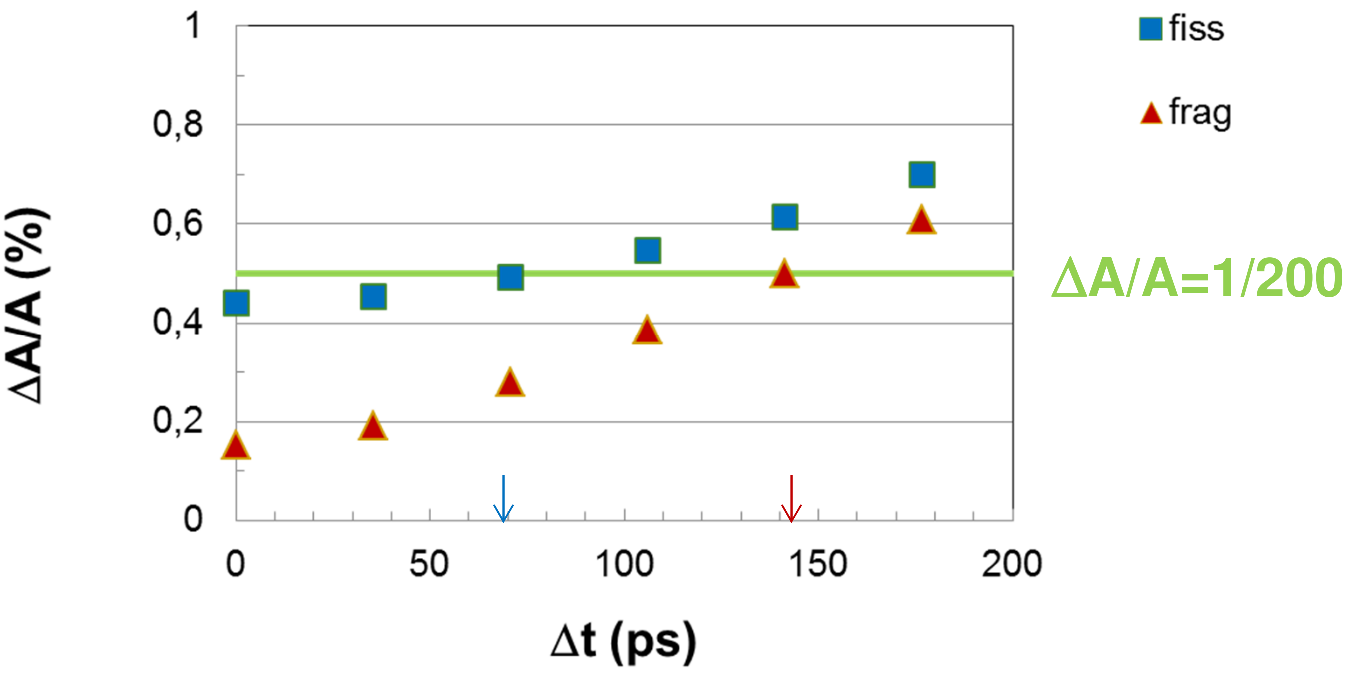
Operation mode with slow-extracted beams




| Intensity | $10^{12}$ /s | $<10^{10}$ /s | $<10^{9}$ /s | $<10^{7}$ /s | $<10^{5}$ /s |
| --- | --- | --- | --- | --- | --- |

# Resolution

Monte Carlo simulations (MOCADI)




C. Nociforo, 2014 *JINST* 9 C01022

# ToF focal plane detectors

**Radiation hard detector (diamond, silicon)**

- 4 units
- time resolution $\sigma$ <50 ps
- active area 380/200mm x 50mm
- max rate 500 Hz/mm$^2$
- high precision time distribution and time stamping

pcCVD-DD → (200 x 40) mm$^2$ , 20 units 20x20x0.3 mm$^3$

50 strips/units , in total 1000 chs

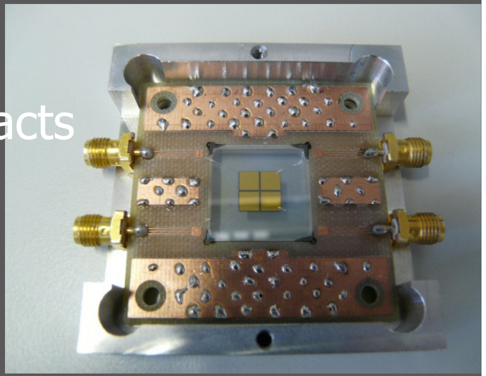
- 100 days operation @1MHz: 1.08x10$^{11}$ ions/cm$^2$

Absorbed dose = 4.36x10$^5$ Gy ($^{238}$U@350 MeV/u)

# Irradiation tests in Dubna

Performed at ACCULINNA separator with 40.5 MeV/u $^{40}Ar$ beam, detector operated in vacuum.

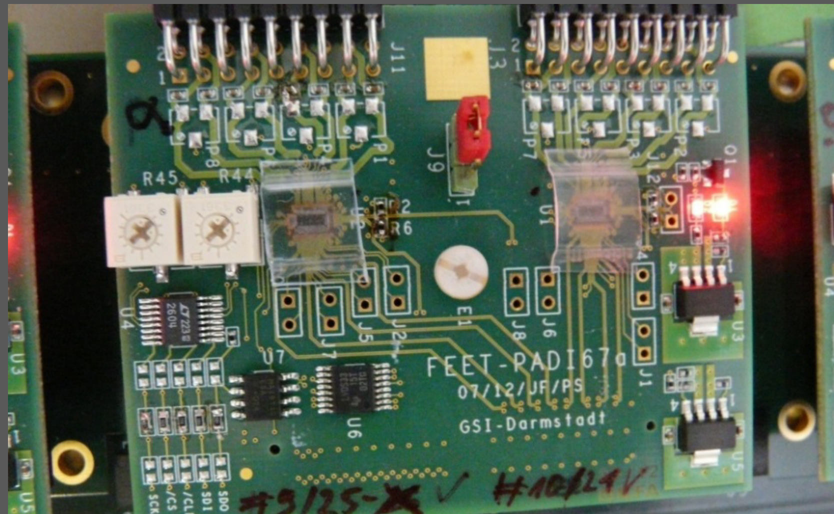
- Diamond
  - new sample (E6) pcCVD-DD(20x20x0.3)mm$^3$ with 4 Al contacts
  - $\Delta E$~20-600 MeV (DBA amp, $V_{in}$ < 50 mV), CCE ≥10%
  - $10^{11}$ ions/cm$^2$ (at least a factor $10^3$ more to see any effect)
  - data analysis in progress (scope & VFTX)



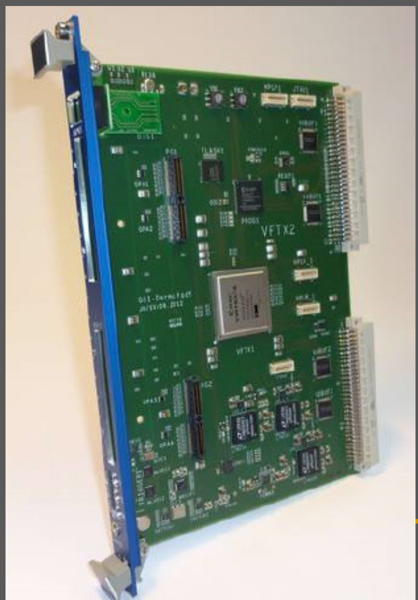
- Silicon
  - n-type, cooled down to -8°C
  - different area and thicknesses (0.1-0.3mm)
  - Q~14pC, risetime ~200ps (for 1cm$^2$)
  - $10^{13}$ ions/cm$^2$ (in 0.3mm Si corresponds to a dose of ~6x$10^6$Gy)
  - data analysis in progress (PADI6+VFTX)

# Electronics with ToT capability

- **PADI** ASIC 0.18 μm CMOS
  - rise time < 500 ps
  - 30 fC <Q< 2000 fC
  - $\sigma_{tE}$ < 15 ps
  - LVDS digital outputs
  - 350 MHz bandwidth




M. Ciobanu et al., IEEE Transactions on Nuclear Science, vol.58, no. 4, pp. 2073-2083, Aug. 2011



- **VFTX** (28 chs) VME FPGA TDC
  - LVDS inputs
  - 200 MHz clock (external & internal)
  - $\sigma_t$ < 10 ps

GSI-DL
GSI-EE

(https://www.gsi.de/fileadmin/EE/Module/Dokumente/vftx1_8.pdf)

# ToF tests

- Diamond
  - FEE (PADI7): PCB ordered, test foreseen in April (Cave C)
  - strip metallization (Cr/Au) at GSI
  - S417 beam time at FRS in July

C. Nociforo, 2014 *JINST* 9 C01022

F. Schirru, M. Kis, et al.

- Silicon
  - S417 beam test at FRS in July with Au beam

V. Eremin (St.Petersburg, O. Kiselev, et al.

- Cherencov
  - test in April (Cave C)

N. Kuzminchuk, B. Voss, et al.

# Summary

- **Developments of the BD system of the in-flight magnetic separator Super-FRS ideal for the next-generation exp with RIBs are ongoing according to the timeline**

- **Fast PID detectors and FEE are crucial to obtain a clean PID of large Z and fission fragments**

→ the GEM-TPC collaboration and project is well consolidate

→ results obtained with solid state radiation hard material are very promising

→ new prototypes are being prepared in GSI, Helsinki, CEA, TUM and St. Petersburg in view of 2014 beam time.