Detector developments for the Super-FRS

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Introduction to the **Super-FRS** at FAIR

- new concept in-flight RIB production and separation methods
- comparison FRS − Super-FRS

Technical challenges – **high intensity and high resolution** – in particle identification (PID)

Recent **developments & in-beam tests** of Super-FRS focal plane detector prototypes.
Primary Beams
- $5 \times 10^{11} \ 238\text{U}^{28+} \ (\text{pulsed})$
- $3.5 \times 10^{11} \ 238\text{U}^{28+} \ (\text{DC})$
  @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
Layout of the Super-FRS

Design Parameters:
\[ \varphi_s = \varphi_y = 40 \pm 20 \text{ mrad} \]
\[ \Delta\varphi/P = \pm 2.5\% \]
\[ B_n = 2 - 20 \text{ Tm} \]
\[ R_n = 750 / 1500 \text{ (first / second stage)} \]

Spot size on target
\[ \sigma_s = 1.0 \text{ mm} \]
\[ \sigma_y = 2.0 \text{ mm} \]

Features:
- Two Separator-stages
- Multi-branch system
- Large acceptance utilizing sc magnets
- Handling concept for high-radiation area

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2-stage separation

- e.g. $^{100}$Sn

- Strong reduction of contaminants
- Optimization of fragment rate
- Main separator used for secondary reaction studies

Fragmentation of $^{124}$Xe @ 1 GeV/u

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**PID detector prototypes**

**Twin GEM-TPC**
(x, y)
Partner: Helsinki IP

**Segmented plastic scintillator (ToF)**
Partner: IFJ Krakow

**Silicon (ΔE, x, y)**
Partner: St. Petersburg

**Triple MUSIC (ΔE)**
Partner: CEA

\[
Z \leftarrow - \frac{dE}{dx} = f(Z, \beta)
\]

atomic number

\[
A / Q = \frac{B \rho}{\gamma \beta m}\]

Z ≠ Q charge state

**Bρ – ToF – ΔE method**

**Other diagnostics (ToF)**

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- **Clean full PID on event-by-event basis**
  - momentum tagging $\Delta x \sim 1\text{mm}$
  - ToF measurements $\Delta \text{ToF} \sim 100\text{ps (FWHM)}$
  - charge resolution $\Delta Z \sim 0.2e$

$\sigma_x = 0.5\text{mm}$
$\sigma_t = 20\text{ns}$

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

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ToF focal plane detectors

- units working in vacuum
- active area $10 - 10^4$ mm$^2$
- total rate 1-10 MHz
- high precision time distribution and time stamping over 100 m

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

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

- 100 days operation @1MHz: $1.08 \times 10^9$ ions/mm$^2$

Absorbed dose = $4.4 \times 10^5$ Gy ($^{238}$U@350 MeV/u)

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Radiation hardness study with Au beam - amplitude reduction

Threshold characteristics (Aug11):
cut amplitudes lower than 35mV

Analog signals, Au beam, HV: 100V Amplitude; 94 mV

After 3.04 x 10^{11} Au ions / mm^2 about 5% of signals below 35 mV

Total absorbed dose: 7.9 Grad (312 MeV / Au ion)
Amplitude reduction by a factor of 2.7
Precise CCE measurement needed

1 Grad = 10^7 Gy

Jerzy Pietraszko, ADAMAS 1st Workshop, GSI, Darmstadt, 16-18 December 2012
Diamond in-beam tests

Feb 2014
First test of (E6) pcCVD-DD samples at ACCULINNA separator with 40.5 MeV/u $^{40}$Ar beam
- 4 Al contacts, $\Delta E \sim 20-600$ MeV (DBA amp, $V_{in} < 50$ mV)
- total rate $10^{11}$ ions/cm$^2$, test with $\alpha$ particles

Aug 2014
First ToF measurements at FRS with 900 MeV/u $^{197}$Au beam with (E6) pcCVD-DD 20x20x0.3 mm$^3$
- 16-strip design: (1x18) mm$^2$ each (0.15 mm gap), $C = 4.3$ pF/strip
- metallization: 50nm/100nm (Cr/Au) by photolithography (GSI-DL)
- PADI7, gain $\sim 250$, 4x4chs

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Electronics with ToT capability

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

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

(M. Ciobanu et al., IEEE Transactions on Nuclear Science, vol.58, no. 4, p. 2073, Aug. 2011)

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S2-S4 Detector resolution

\[ \sigma_{DD} = \sqrt{\sigma_{TOF}^2 - \sigma_j^2} = \sqrt{(45.7)^2 - (15)^2} = 43.2 \text{ ps} \]

\[ \sigma_{intr,DD1} = 25 \text{ ps} \]

\[ \sigma_{intr,DD2} = 35 \text{ ps} \]

Measured PADI/VFTX intrinsic time resolution: 15 ps (\(\sigma\))
May 2015
Series of irradiation of \(10^7 \text{ } ^{12}\text{C/mm}^2 \text{s} \) @62 MeV/u followed by data taking via digital scope (10 GS/s) at low rate to monitor the time resolution and CCE of pcCVD-DD (0.3mm) and scCVD-DD (0.09mm)

- new chip PADI7D, 8x2 chs (distance reduced), new threshold control
- beam current measured by ionization chamber IC
Minimum absorbed dose = $1.8 \times 10^6 \text{ Gy} \ (^{12}\text{C}@62 \text{ MeV/u})$

$\approx 400$ days operation

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Digital waveform analysis

$^{12}\text{C}\@62\text{MeV/u}$

after 40 hours

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$220 \text{ mV}$

$640 \text{ ps (DBA el.)}$
The in-flight magnetic separator Super-FRS under construction at FAIR is ideal for the next-generation experiments with RIBs

ToF detectors are crucial to obtain a clean PID; results of in-beam tests of strip diamond detectors (processed in house) performed in conditions similar to that of the Super-FRS show that $\sigma_t \sim 25$ ps is achievable

Preliminary results of irradiation tests on pcCVD-DD sample does not show any damage after an absorbed dose of $1.8 \times 10^6$ Gy.
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