Development of Diamond Detectors for ToF measurements at the Super-FRS

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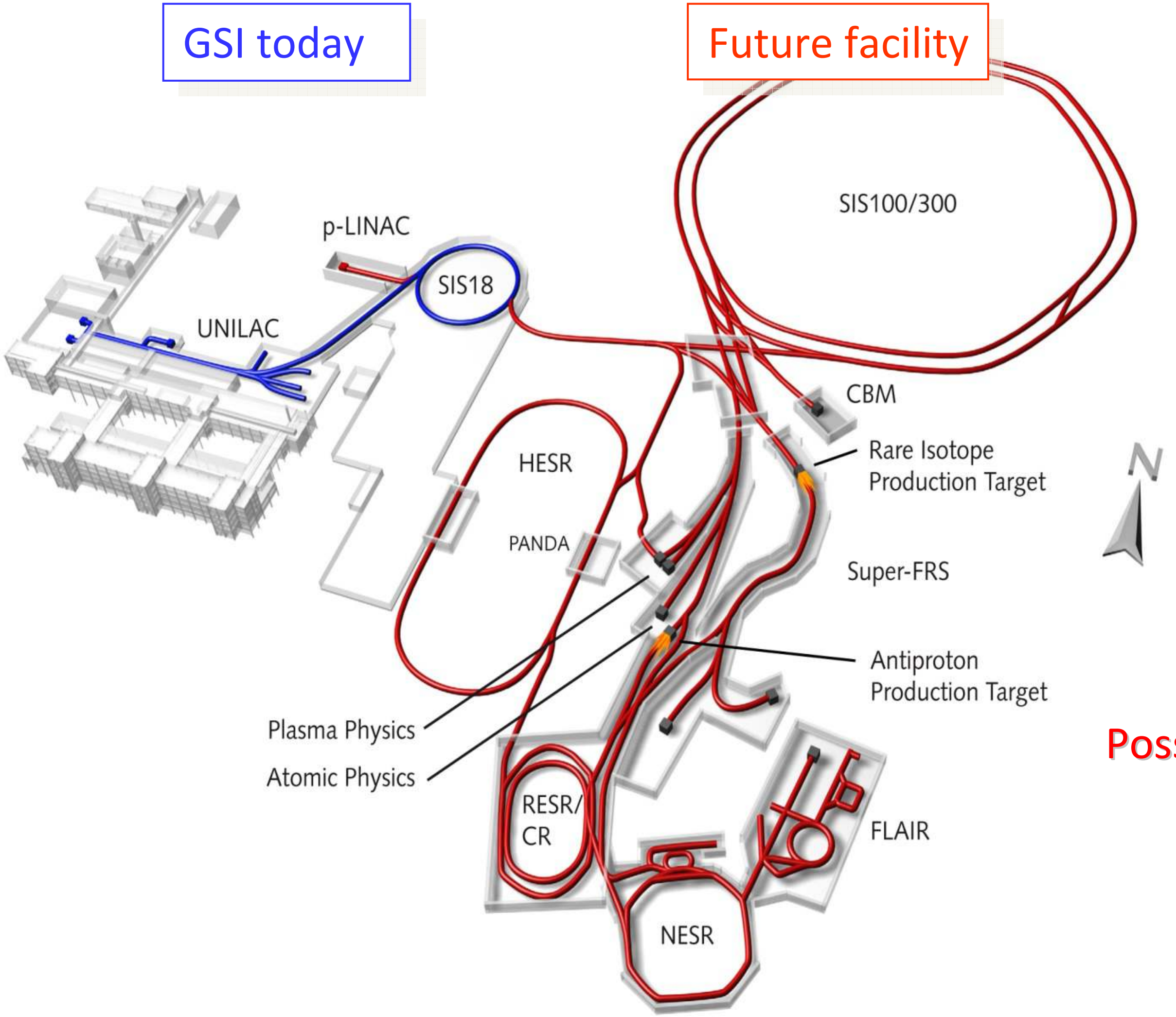
Outline

- The Super-FRS @ FAIR
- Detector requirements for the Super-FRS
- Diamond detectors: results so far and future beam tests
- Summary

The Super-FRS @ FAIR

FAIR: Facility for Antiproton and Ion Research



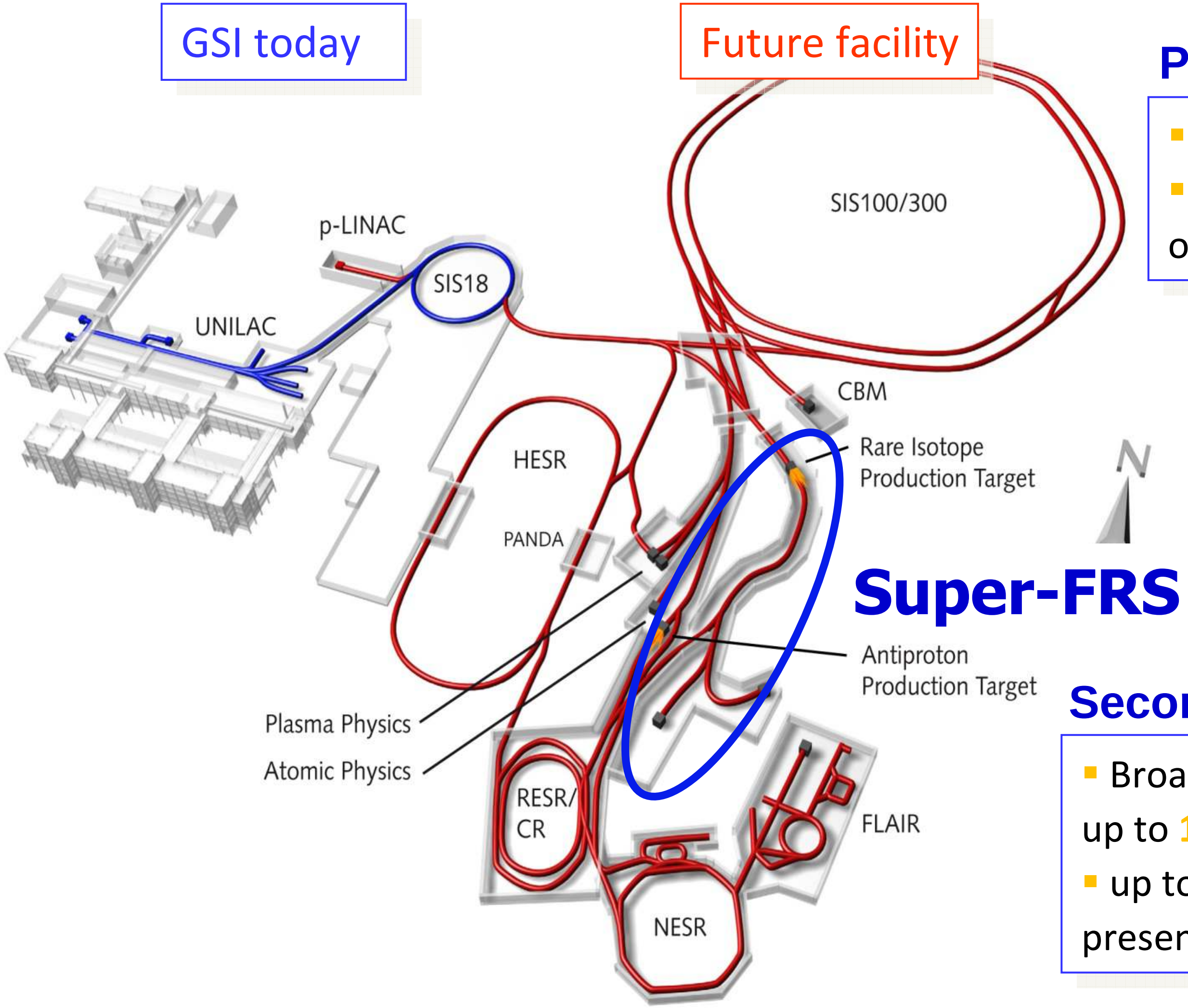
Bρ = 100 Tm :
29 GeV protons
for pbar production;
2.716 GeV/u $^{238}U^{28+}$

Bρ = 300 Tm :
34 GeV/u $^{238}U^{92+}$ for
heavy ion collisions

Possibility to create pulsed beams

Time structure:
pulsed (50-90ns)
quasi DC (SIS-300)

The NUSTAR facility @ FAIR



Primary Beam

- $5\cdot10^{11}$ $^{238}U^{28+}$/s @1.5-2GeV/u
- factor 100-1000 in intensity over present

Secondary Beams

- Broad range of radioactive beams up to 1.5 - 2 GeV/u
- up to factor 10 000 in intensity over present

Layout and design parameter of the Super-FRS

Projectile:
- Elements p - U
- Energy up to 1.5 GeV/u
- Intensity up to 10^{12} /s (depending on element)
- DC or pulsed operation

Design Parameters:

$\varepsilon_x = \varepsilon_y = 40\ \pi$ mm mrad

$\Phi_x = \pm 40$ mrad

$\Phi_y = \pm 20$ mrad

$\Delta P/P = \pm 2.5$ %

$B\rho = 2 - 20$ Tm

$R_{ion} = 750 / 1500$

(first / second stage)

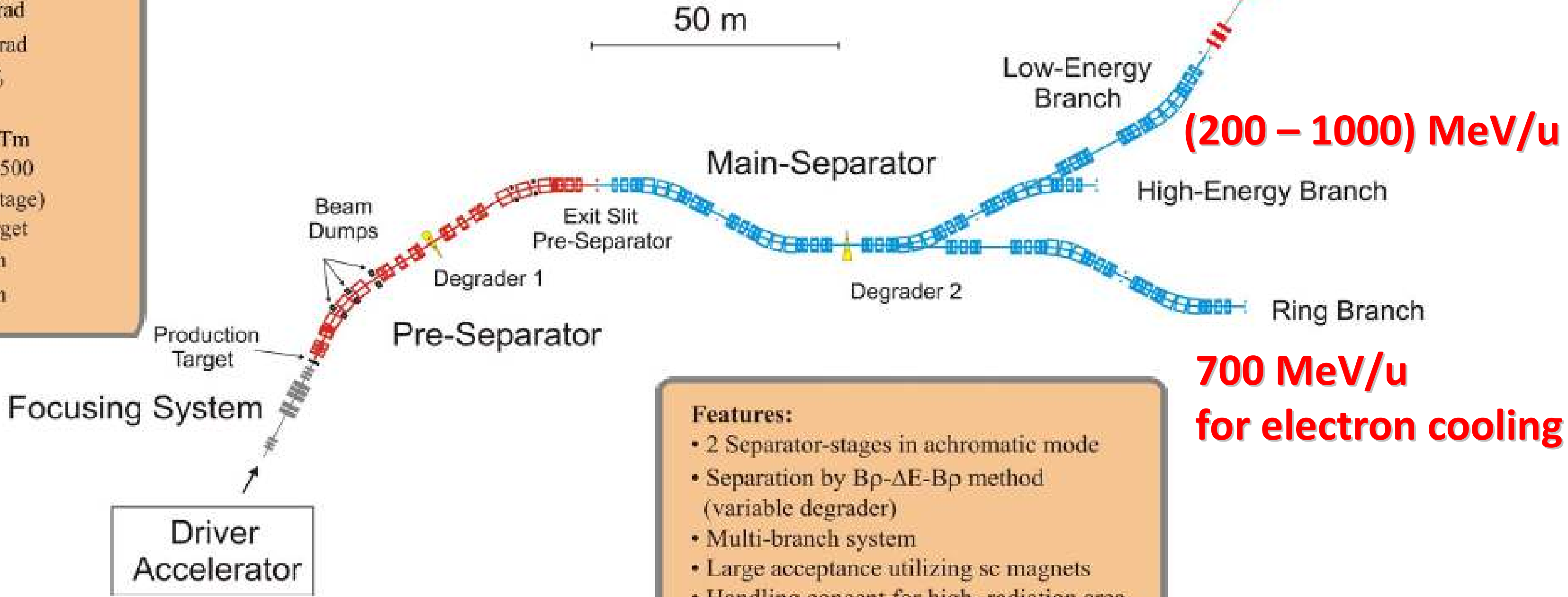
Spot size on target

$\sigma_x = 1.0$ mm

$\sigma_y = 2.0$ mm

Goal: Larger Acceptance

The parameters reflect on the detector construction. Bigger geometry (170 – 380 mm) and have bigger rate capability.



Features:
- 2 Separator-stages in achromatic mode
- Separation by Bρ-ΔE-Bρ method (variable degrader)
- Multi-branch system
- Large acceptance utilizing sc magnets
- Handling concept for high- radiation area

Martin Winkler, Annual NuSTAR Meeting, GSI, March.3–5, 2010

Detector requirements for the Super-FRS

Why do we need special detectors?

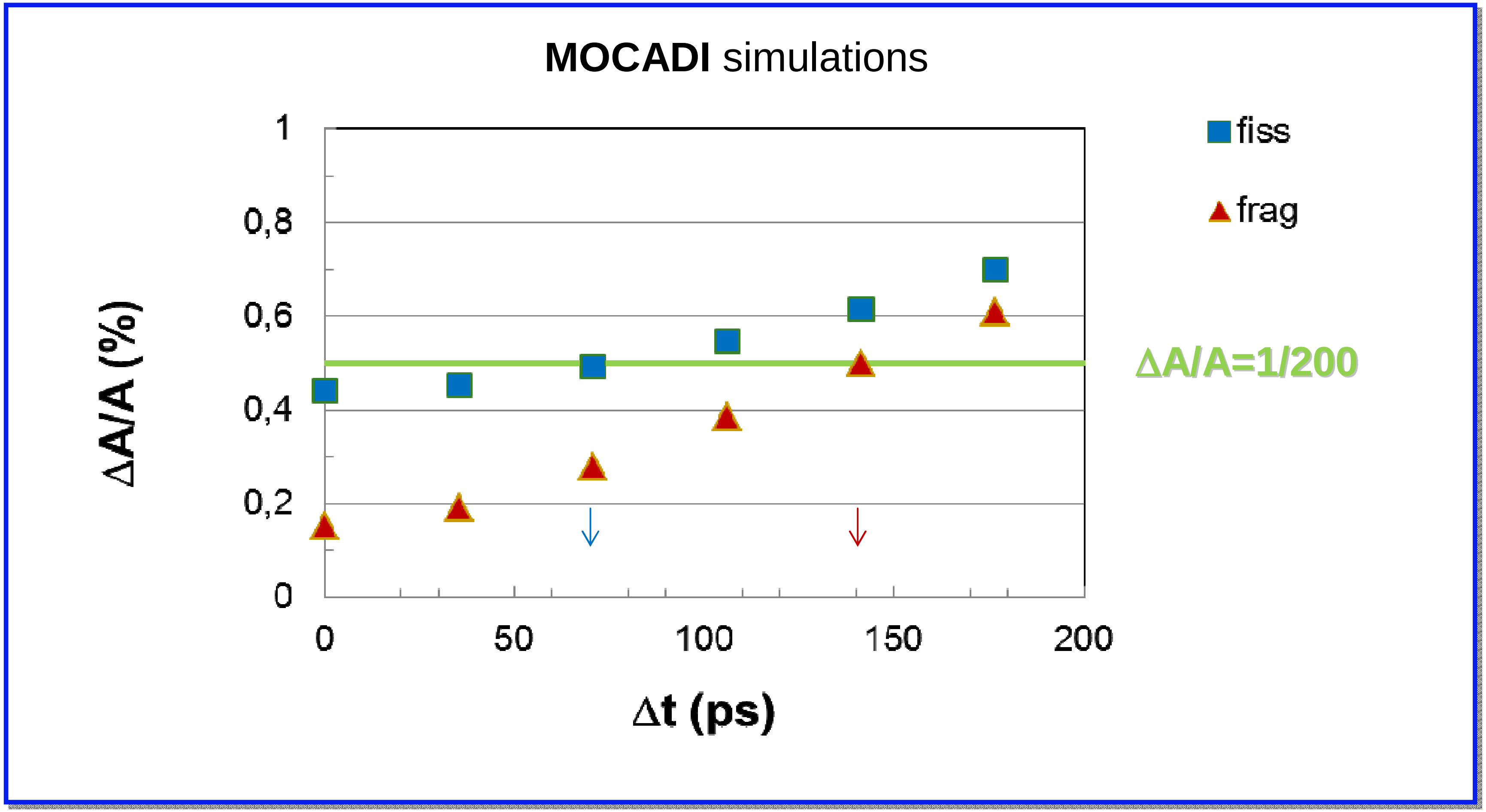
Increasing in the intensity of radioactive beams

It requires new developments in detecting system & electronics

Clean full PID on event-by-event basis

→ momentum tagging $\Delta x \sim 1mm$
→ ToF measurements $\Delta ToF \sim 100ps$ (FWHM)

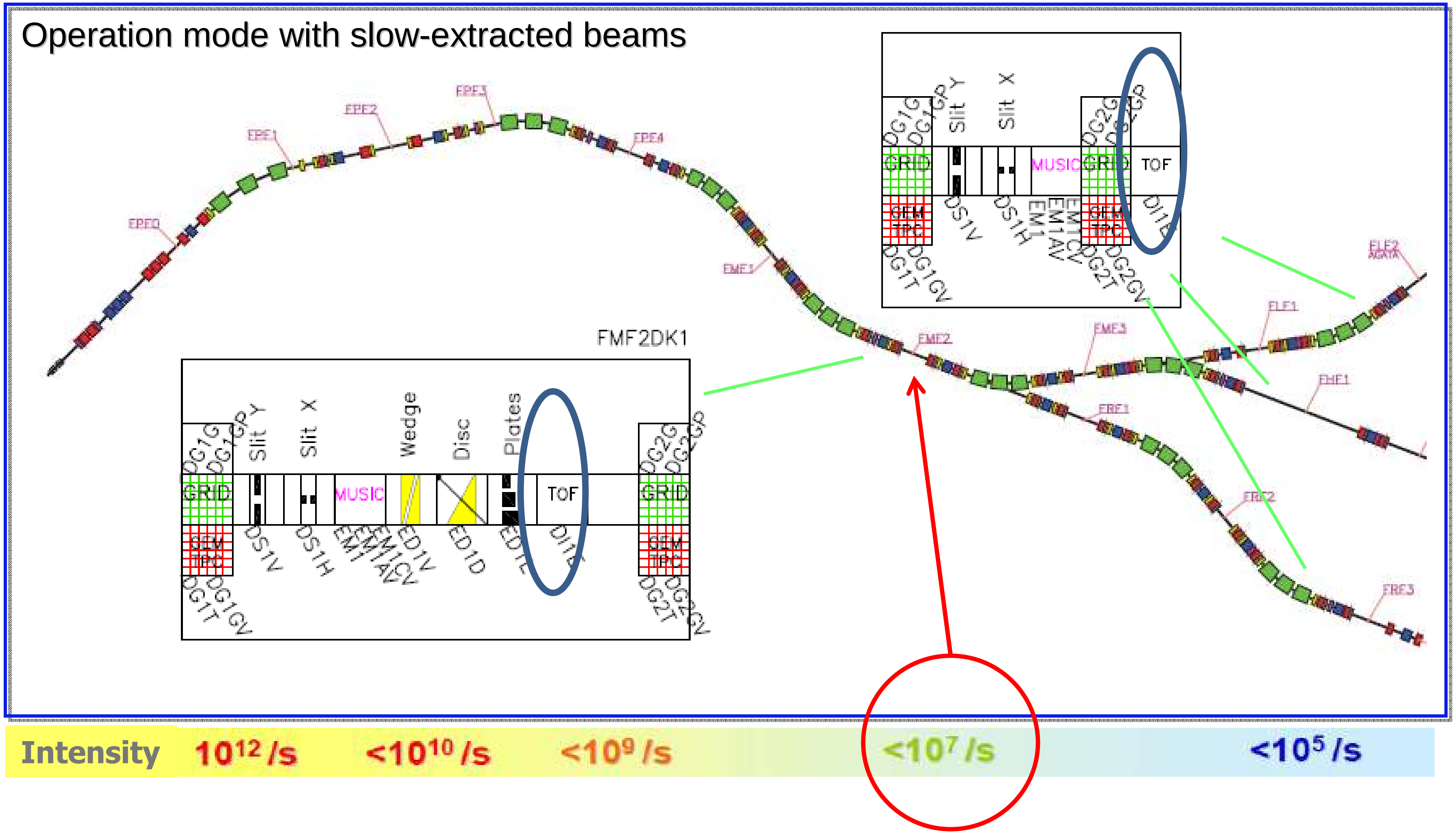
Detector resolution



MOCADI code (http://web-docs.gsi.de/~weick/mocadi/)

Layout of the Super-FRS beam line

Operation mode with slow-extracted beams



Diamond detectors: current developments and future beam tests

ToF focal plane detectors

Radiation hard detector: diamond, silicon

- 4 units
- time resolution σ <50 ps
- active area 380/200mm x 50mm
- max rate 500 Hz/mm^2
- fast and multi-channel integrated FEE electronics

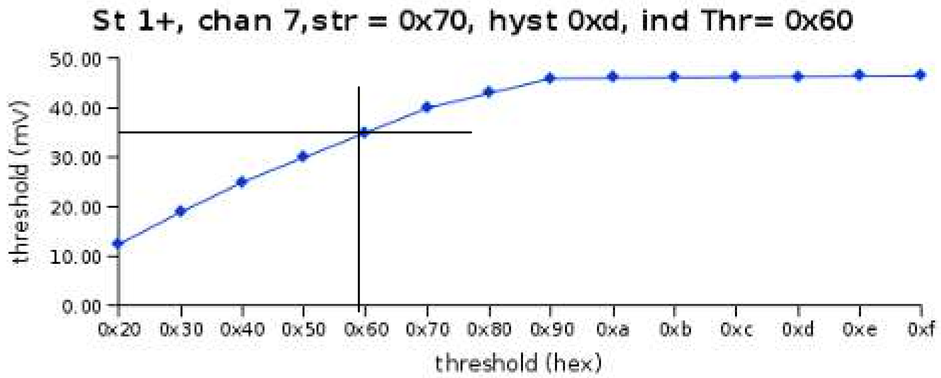
Example: pcCVD-DD, (200 x 40) mm^2, 20 units 20x20x0.3 mm, 50 strips/units

1000 channels!!!

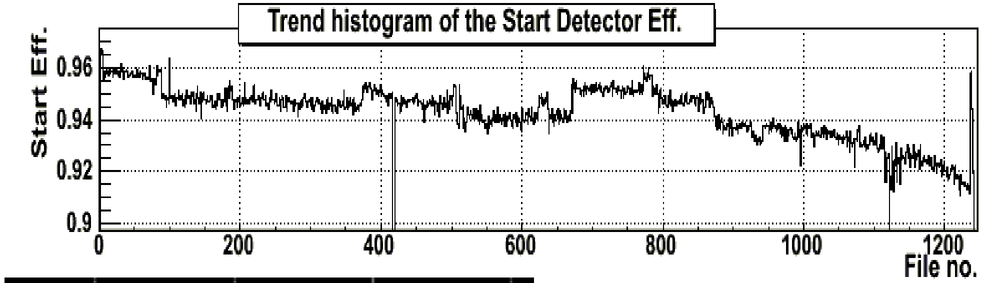
- 100 days operation @1MHz 1.08×10^{11} ions/cm^2

Absorbed dose = 4.36×10^5 Gy ^{238}U@350 MeV/u

Radiation hardness study with Au beam - amplitude reduction

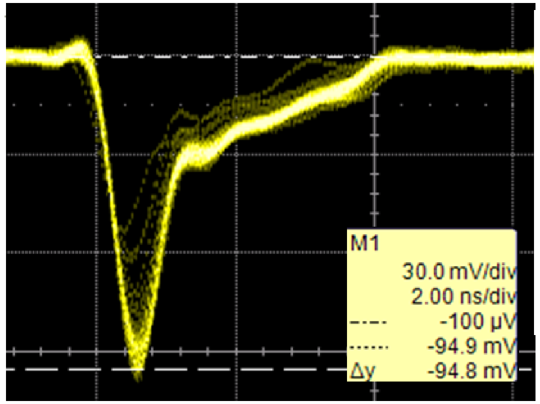


Threshold characteristics (Aug11): cut amplitudes lower than 35mV



+ 30 % DAQ off + 30 % beam times in 2010

→ 3.04 x 10^{11} Au ions / mm^2



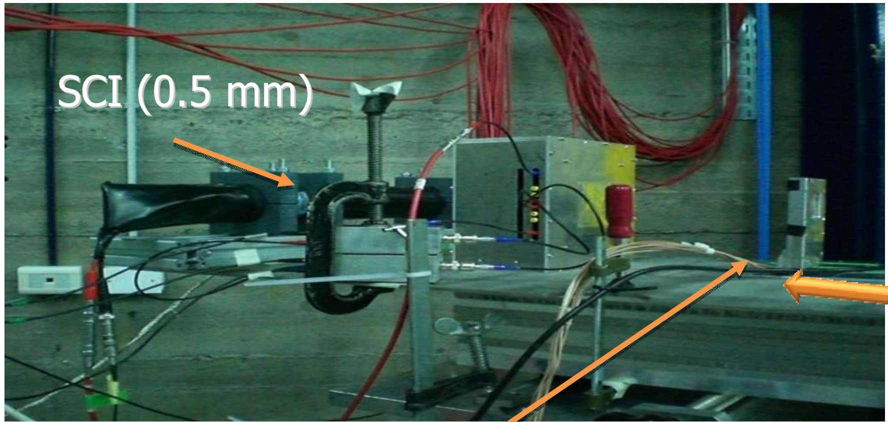
Analog signals, Au beam, HV: 100V, Amplitude: 94 mV

- ➔ 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 measurment needed [1Grad = 10^7 Gy]

Jerzy Pietraszko, ADAMAS 1st Workshop, GSI, Darmstadt, 16-18 December 2012

TODD experiment (2012)

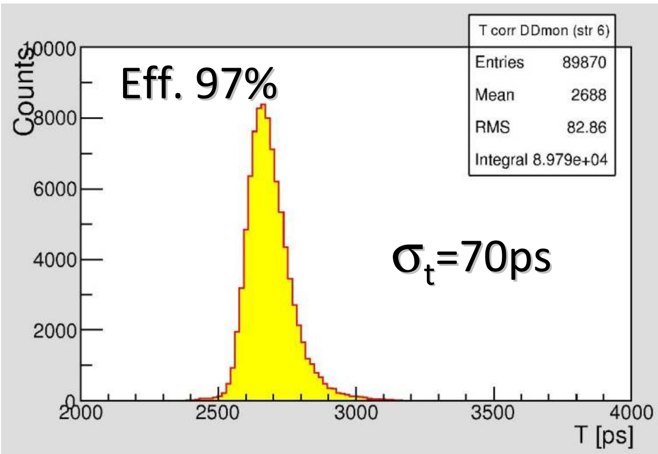
C beam@80MeV/u at LNS



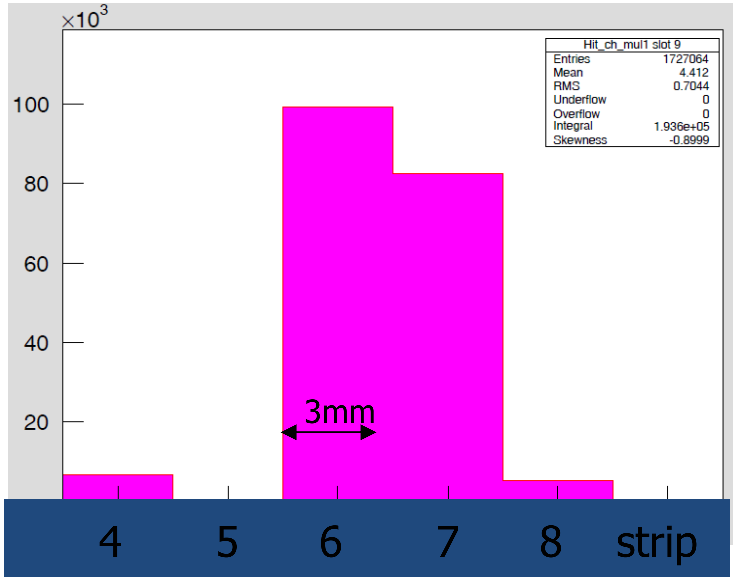
pcCVD-DD strip detector (30x30x0.36mm) **D2**

pcCVD-DD monitor (10x10x0.6mm) **D1**

- Electronics: DBA4 + LED + FPGA TDC (6chs, RMS=17ps)
- ToF D1-SCI: σ_t=70 ps , 3x8 mm^2, gated (66.5ps TAC)
- ToF stip6(D2)-SCI: σ_t=105 ps

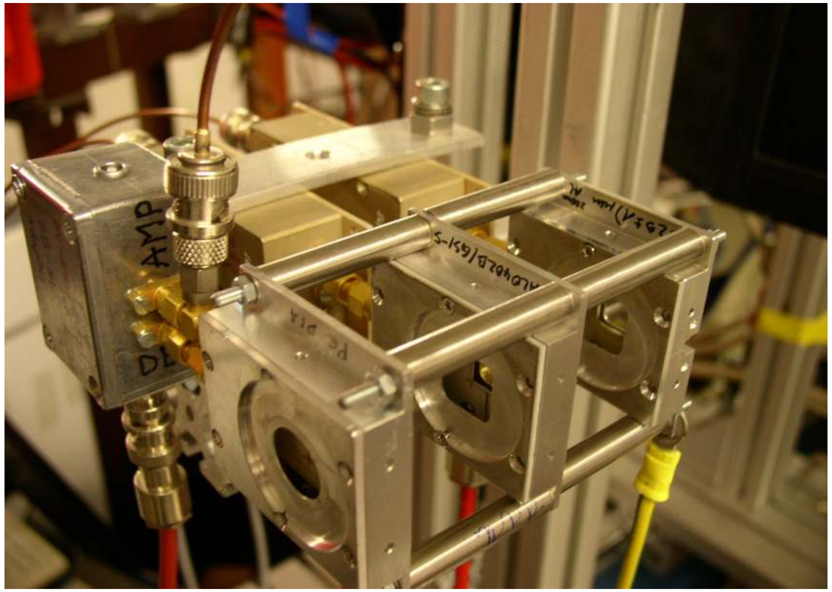


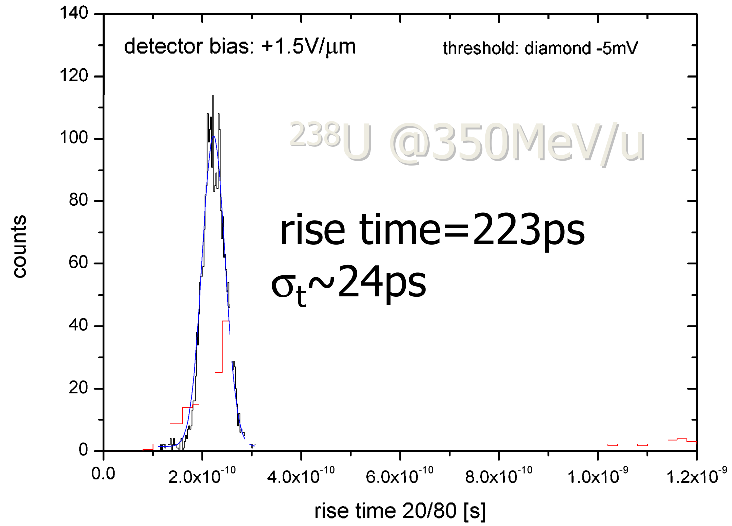
GSI, TUM, LNS coll.

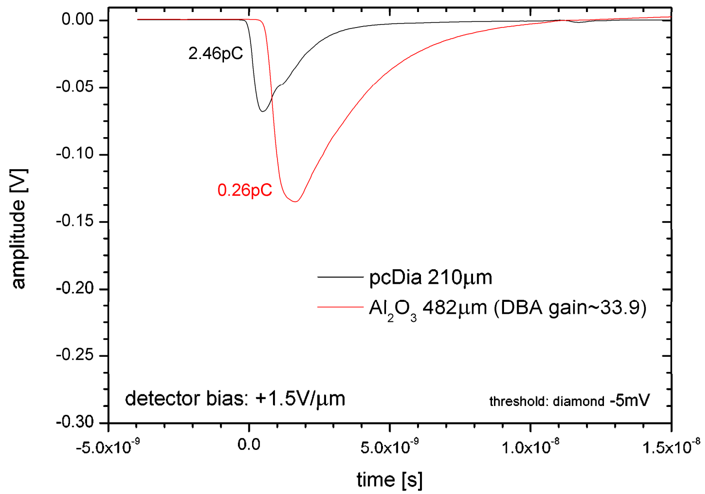


Diamond time properties

pcCVD-DD 10x10x0.2 1 mm



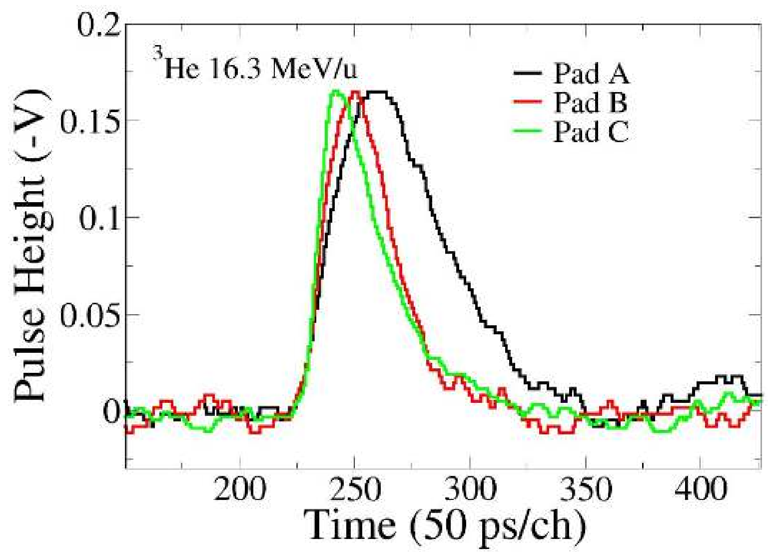


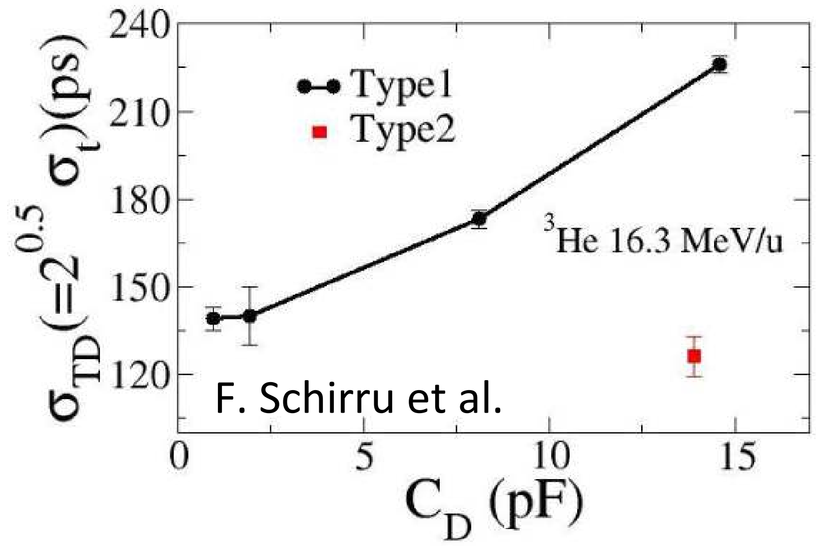


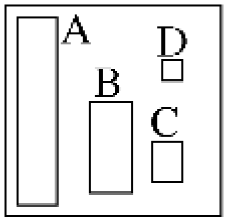
- digital waveform sampled (20 GS/s scope)
- small charge collection Q=2.46pC

M. Träger GSI-DL

The role of capacitance







Type 1 (Au)
20x20x0.3 mm

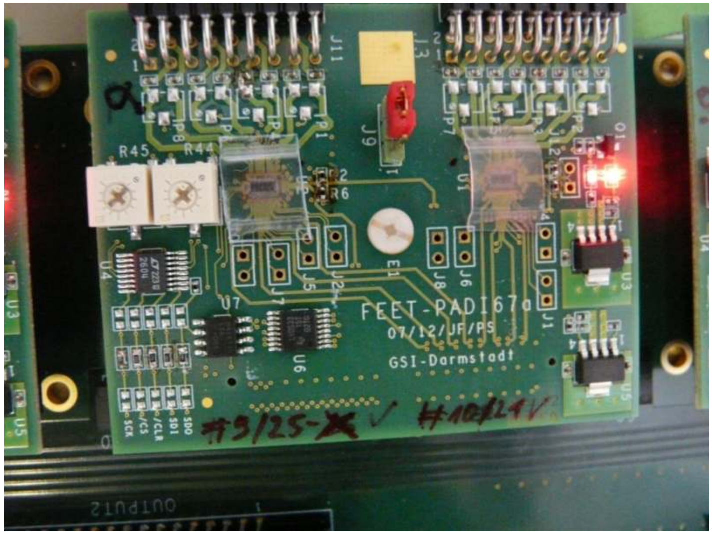
- The rise time increases with the capacitance
- The electronic resolution scales as $C^{1/2}$
- Results are in line with the theoretical predictions

Strip area: 90, 50, 12 and 6 mm^2 -> 14.6, 8.1, 2.0 and 1.0 pF)

(*) Type 2: commercial detector based on DLC electrodes

Electronics with ToT capability

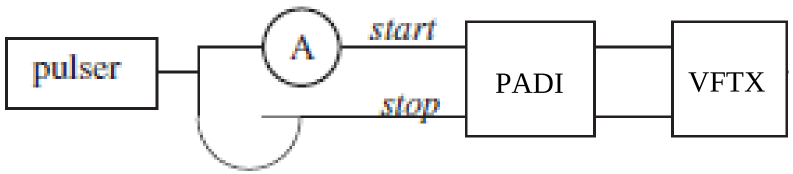
- **PADI4** ASIC 0.18 μm CMOS
  - rise time < 500 ps
  - 30 fC <Q< 2000 fC
  - σ_{tE} < 15 ps
  - LVDS digital outputs
  - 350 MHz bandwidth

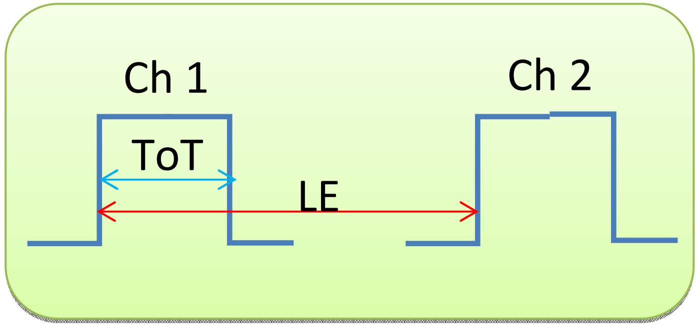


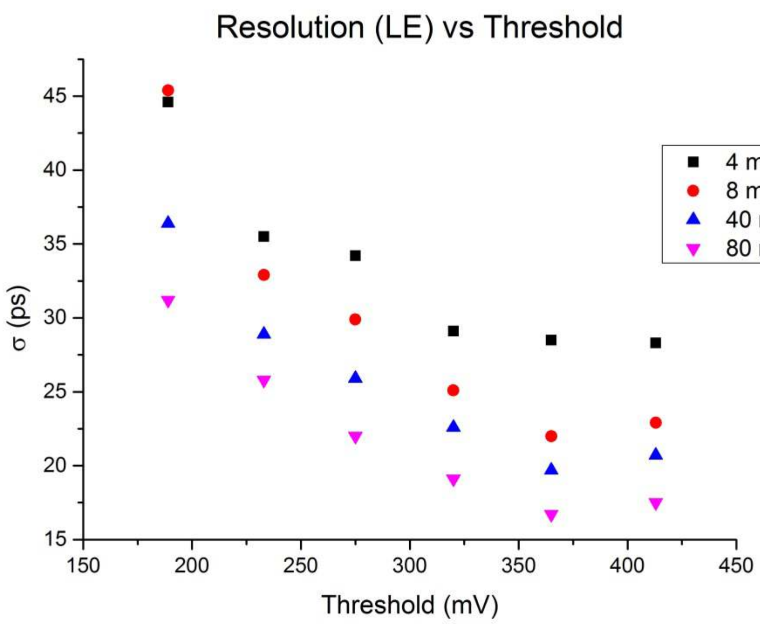
- **VFTX** (28 chs) VME FPGA TDC
  - LVDS inputs
  - 200 MHz clock
  - σ_t < 10 ps

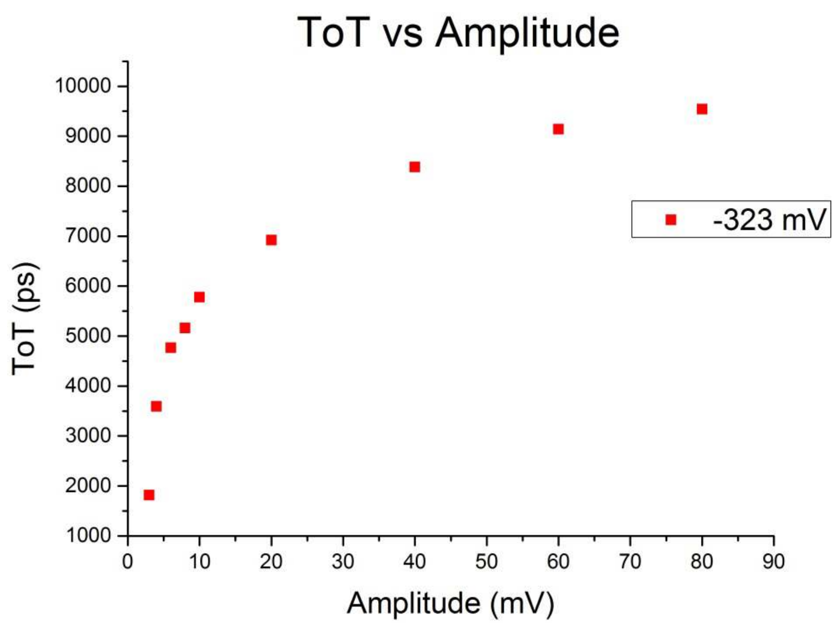
M. Ciobanu GSI-DL
J. Fruehauf GSI-EE

VFTX + PADI results

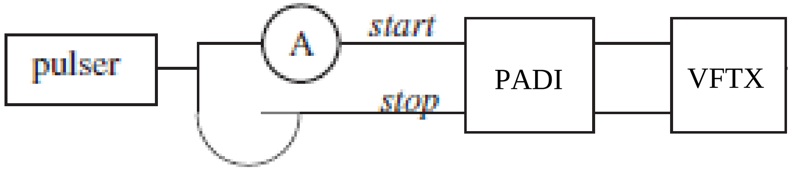


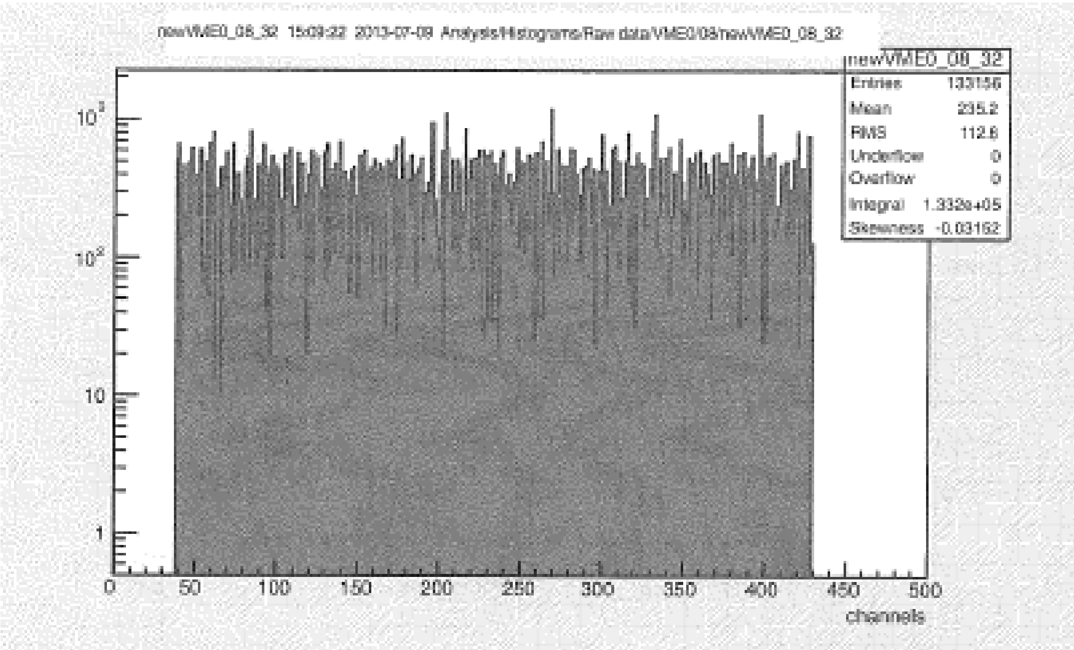






VFTX calibration





If the hit distribution in the histogram, their total number N and the period of the counter clock is known, the real bin width (in ps) can be calculated as:

$$W_i(\text{ps}) = \frac{N_i \cdot 5000(\text{ps})}{N}$$

(for a 200 MHz system clock).

The corresponding time of a bin is then derived as follows:

$$T_i = \sum_{k=1}^{i-1} W_k + \frac{W_i}{2}$$

Expected (2014) radiation hardness tests

Where	Isotope	Energy (GeV/u)	Intensity (p/s)
Dubna	^{20}Ne	0.054	10^7
Catania	^{12}C	0.062	10^9
GSI	^{238}U / ^{197}Au	0.35 – 1.0	10^6

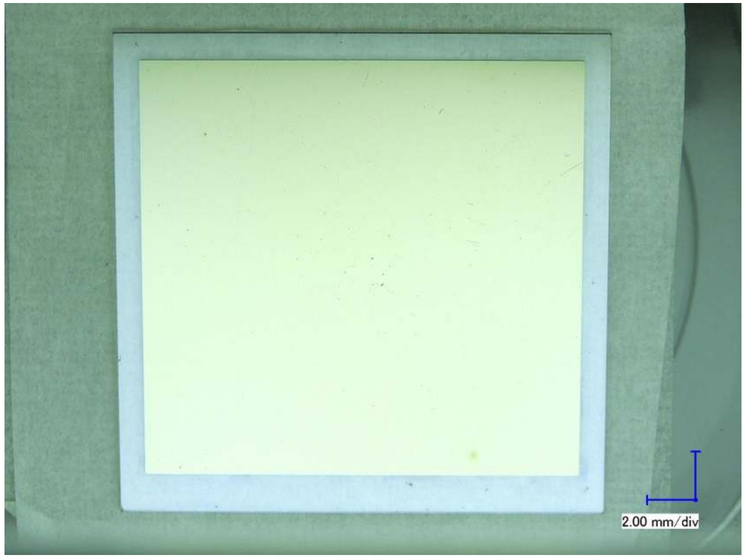
In Dubna, are expected signals 20 mV in amplitude for the Si detectors. Considering the lower CCE for the pcCVD it is foreseen to have 5 mV signals.

Looking at the previous results for 5 mV signal and considering a threshold of 320 mV, the achievable resolution is expected to be 30 ps. It is very promising!

Such tests will also allow to understand the effects on the radiation hardness according to the different type of isotope used to irradiated the diamond samples.

Diamond detector design

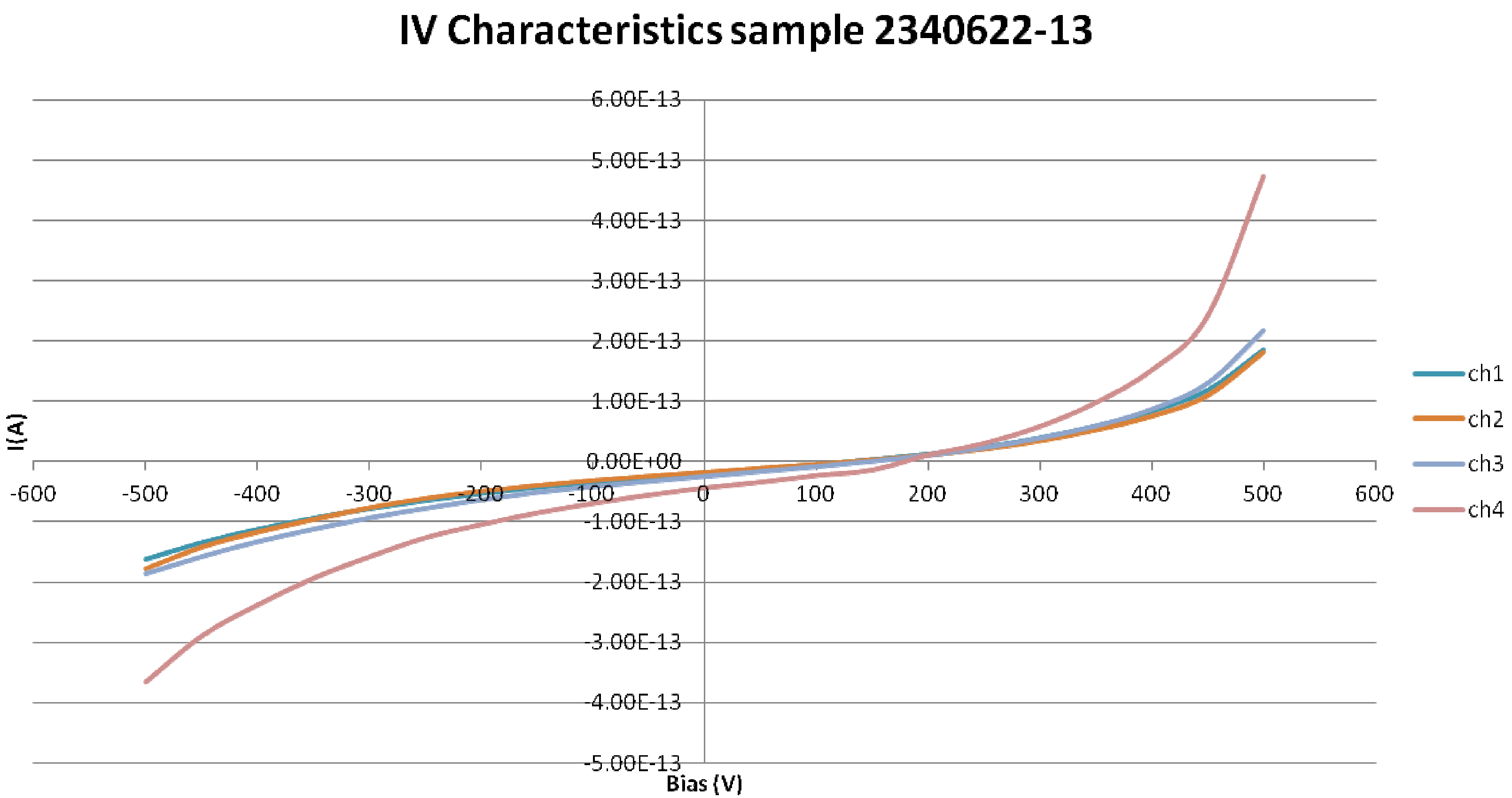
pcCVD -DD **20x20x0.3 mm**



Detector processing:

- Electrode metallization with Cr/Au with thickness 50/100 nm
- Photolithography by laser followed by etching
- 8 strips (1 mm) + 16 strips (0.5 mm) – Gap 60 µm
- Annealing of the device at 500º in Ar

Leakage current tests



Summary

The new facility FAIR will be able to provide beams with high intensity and energy which requires new developments in detecting system & electronics.

For a clean full particle identification, detectors having spatial and timing resolution of $\Delta x \sim 1mm$ and $\Delta ToF \sim 100ps$ (FWHM) are required.

At the Super-FRS, 4 radiation detector units (1 START + 3 STOP) should be installed with total active area of 380/200mm x 50mm.

Detectors based on diamond samples are a possible solution (not the only one!): first tests performed on diamond samples have shown the capability of the material to withstand the expected beam intensities at the Super-FRS.

First tests on the electronics are also very promising.

Acknowledgment

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Technische Universität München

R. Gernhäuser, M. Winkel

Characteristics of Diamond vs Silicon

- Wider bandgap energy
  cooling not needed
- Larger carrier mobility
  stronger E field
- Fast signal collection
  typical rise-time ~ 100 ps
- Radiation hardness and no doping
- Low noise (in principle)
  low dielectric constant (ε_r= 5.7) – low capacitance

	Silicon	Diamond
Bandgap Energy E_g(eV)	1.13	5.47
e-h Prod. Energy(eV)	3.6	12.84
e^- Mobility(cm^2/Vs)	1500	2200
h^+ Mobility(cm^2/Vs)	600	1600
Breakdown Volt.(V/cm)	3×10^5	10^7

Back

Diamond detectors

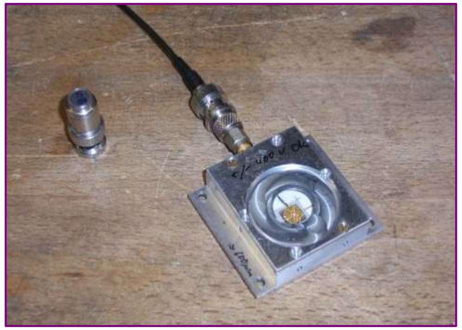
borrowed from GSI detector lab

- ***PCCVD monitor*** (**D1**)

  size (10x10) mm^2 , 600 μm thickness

  Cr-Au metallization (200 nm)

  V = -/+ 600 Volts



- ***9 strips PCCVD detector*** (**D2**)

  size (30x30) mm^2 , 360 μm thickness, 9 strips (3 mm pitch)

  Ti-Au electrods (200nm)

  V = -/+ 400 Volts

  C = 10 pF/strip