TOF and tracking measurement with Si detectors for SuperFRS

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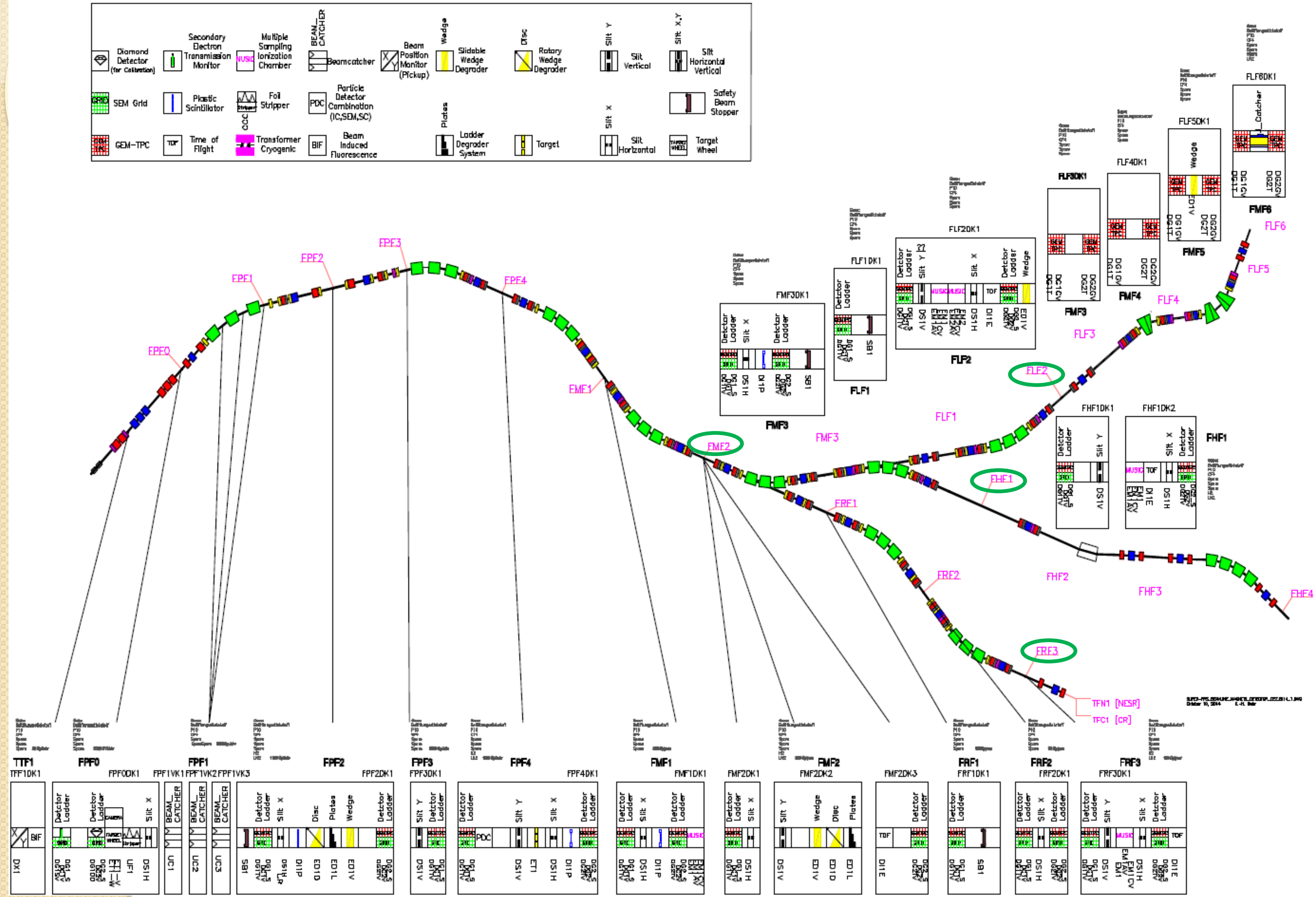
NUSTAR Annual meeting, GSI Darmstadt, 2 – 6 March 2015

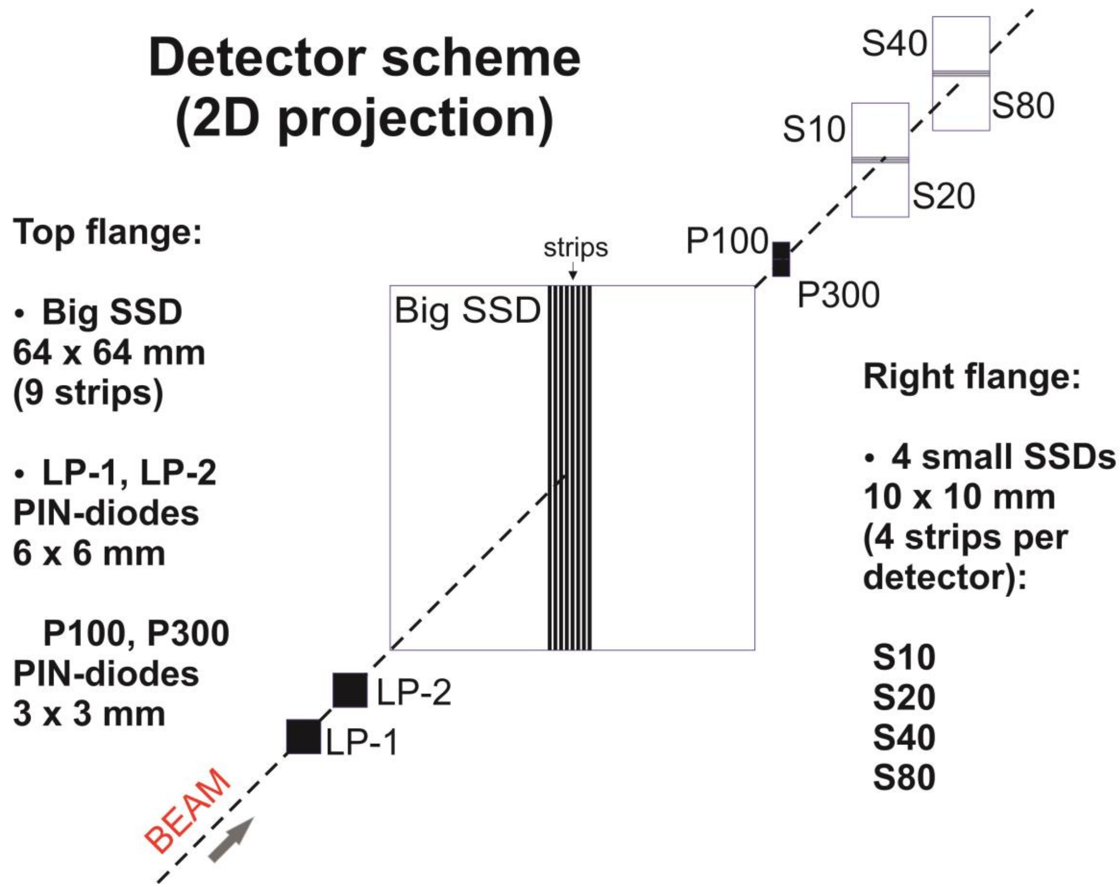


Diamond Detector (for Calibration)
Secondary Electron Transmission Monitor
Multiple Sampling Ionization Chamber
Beamcatcher
Beam Position Monitor (Pickup)
Slidable Wedge Degrader
Rotary Wedge Degrader
Slit Vertical
Slit Horizontal Vertical
SEM Grid
Plastic Scintillator
Foil Stripper
Particle Detector Combination (IC,SEM,SC)
Safety Beam Stopper
GEM-TPC
Time of Flight
Transformer Cryogenic
Beam Induced Fluorescence
Ladder Degrader System
Target
Slit Horizontal
Target Wheel
FPF0
FPF1
FPF2
FPF3
FPF4
FMF1
FMF2
FMF3
FLF1
FLF2
FLF3
FLF4
FLF5
FLF6
FHF1
FHF2
FHF3
FHF4
FRF1
FRF2
FRF3
TFN1 [NESR]
TFC1 [CR]
TTF1
FPF0
FPF1
FPF2
FPF3
FPF4
FMF1
FMF2
FRF1
FRF2
FRF3
FMF3
FLF1
FLF2
FMF3
FMF4
FMF5
FMF6
FHF1

Radiation test in Dubna, february 2014

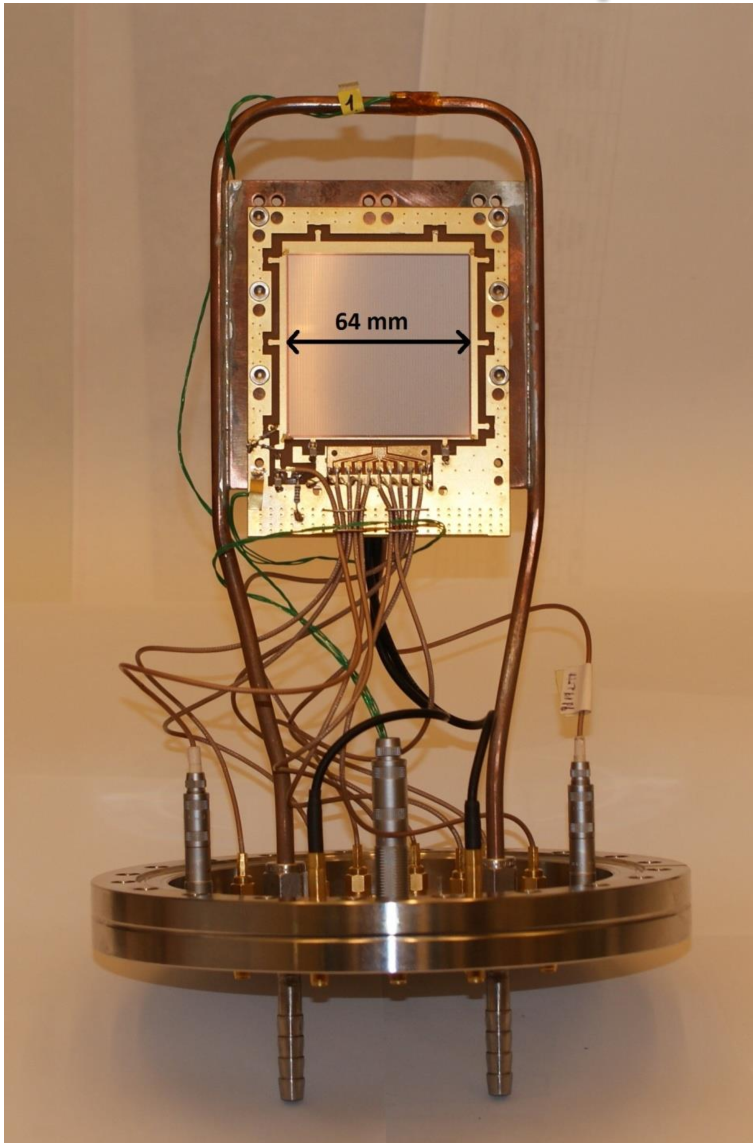
- Aim – time resolution and rad. hardness
- 9 irradiations made
- Maximum dose - $2.3*10^{13}$ ions/cm^{-2} ($\geq 10^{16}$ neutrons/cm^{-2} equivalent?)
- Change of Si bulk material under irradiation
- Almost 100 different Si detectors were irradiated
- I-V characteristics measured before and after (lot of work, practically done)
- Very important (and unique) data will help choosing construction of the final detectors

TOF Detector test, august 2014

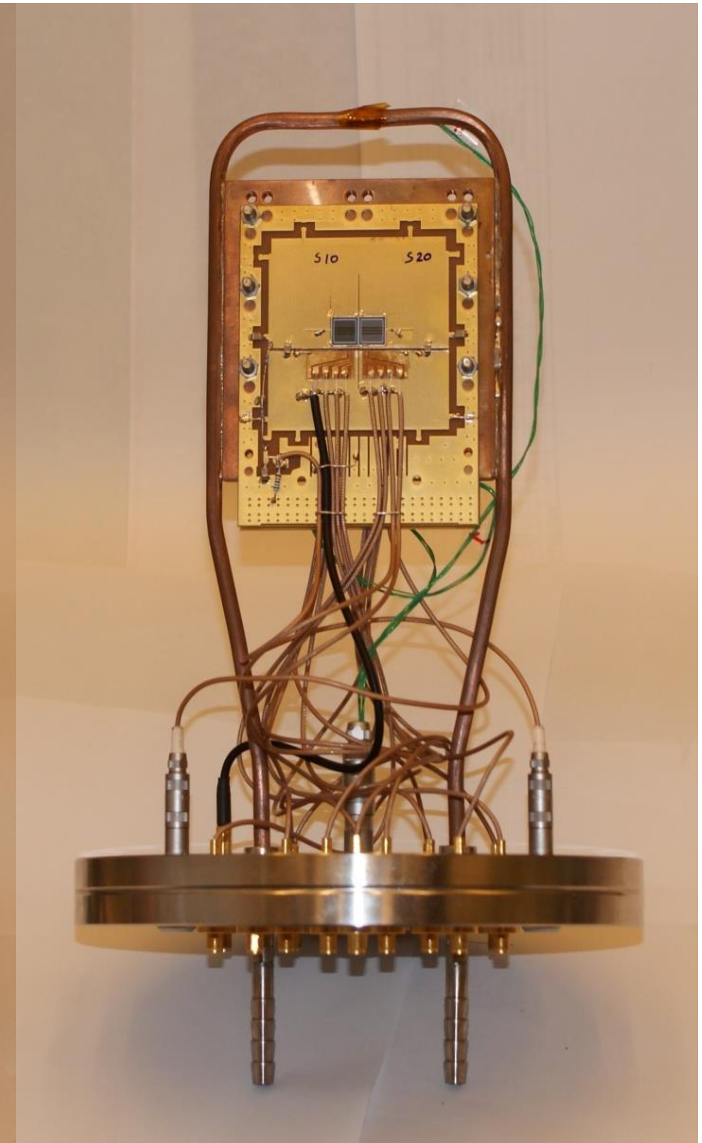


- FRS, ^{197}Au @ 1 GeV/u
- Time resolution vs detector topology
- Time resolution vs readout type - amplifier/discriminator PADI + TDC and waveform digitizers (3.2 Gs/s and 5 Gs/s)

Detector samples

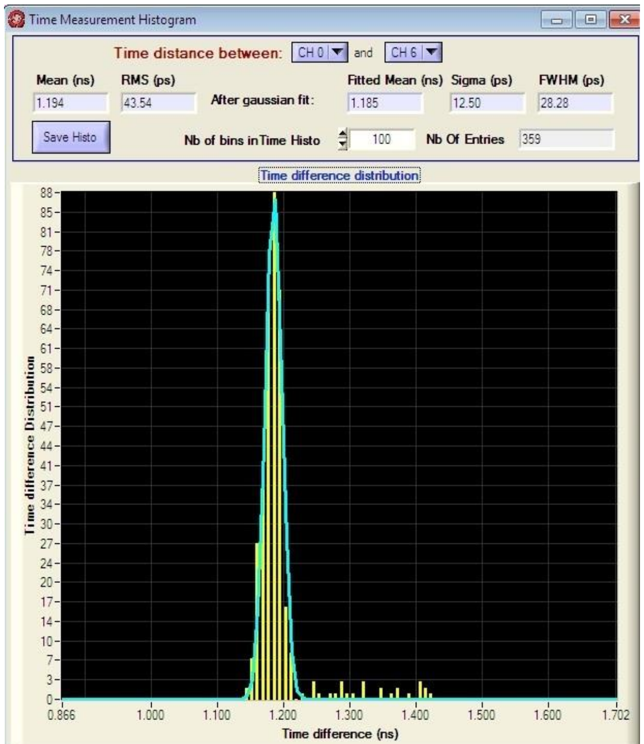


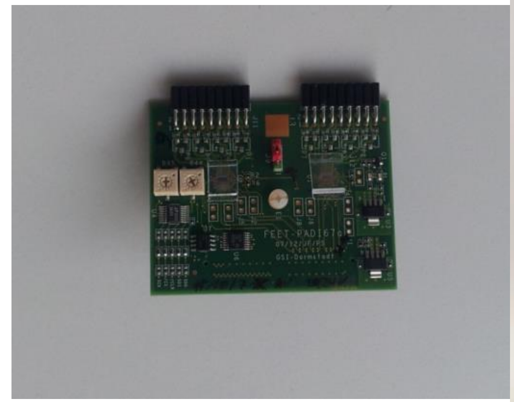
Big SSD



Small SSDs – S10, S20

Time resolution (Au ions)





- Digitised waveforms ⇒ ΔE also possible
- Spline fitting, CFD method for time determination
- ΔT (TOF) ≥13 ps (σ), Big SSD detector vs detector S80

- PADI current amplifier/discriminator + VFTX TDC (20-25 ps internal resolution, up to 10^6 events per channel)
- One VME module – 28 channels
- Leading edge method with amplitude correction
- ΔT (TOF) ≥30 ps (σ)
- Only possible method for high event rates

Time resolution vs topology

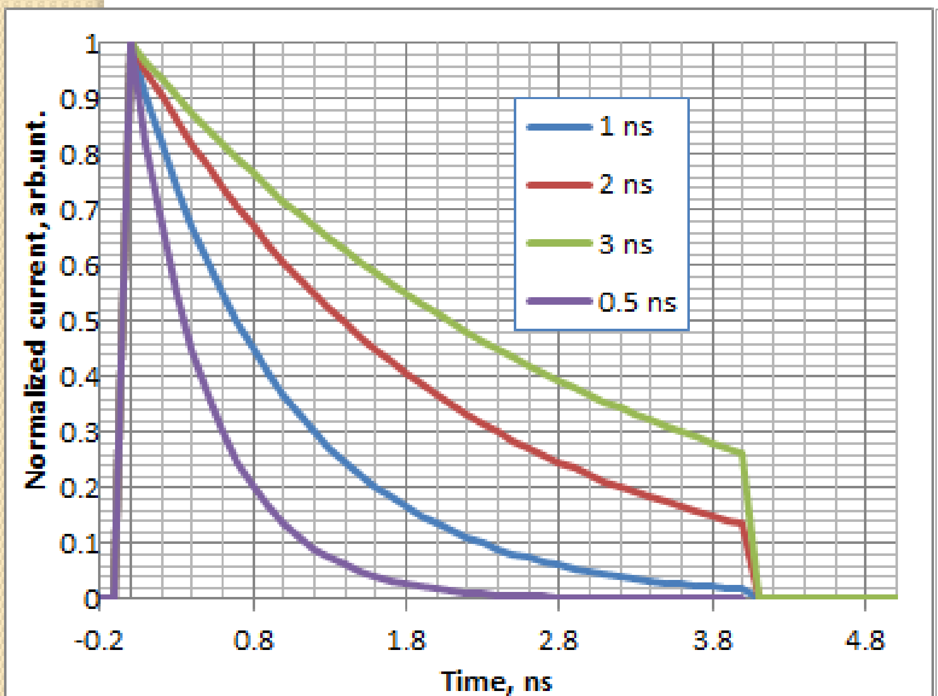
Detectors	Strip width (μm)	σ (ps)
big SSD vs small PIN-diode LP-1	900	17.8
big SSD vs small PIN-diode LP-2	900	16.4
big SSD vs small strip detector S80	900 - 80	15.2
big SSD vs small strip detector S20	900 - 20	59.6
small PIN-diode S80 vs LP-1	80	29.8
small PIN-diode S80 vs LP-2	80	37.4
small PIN-diode S20 vs LP-2	20	51.0
small PIN-diode S10 vs LP-1	10	55.7
small PIN-diode S10 vs LP-2	10	97.2

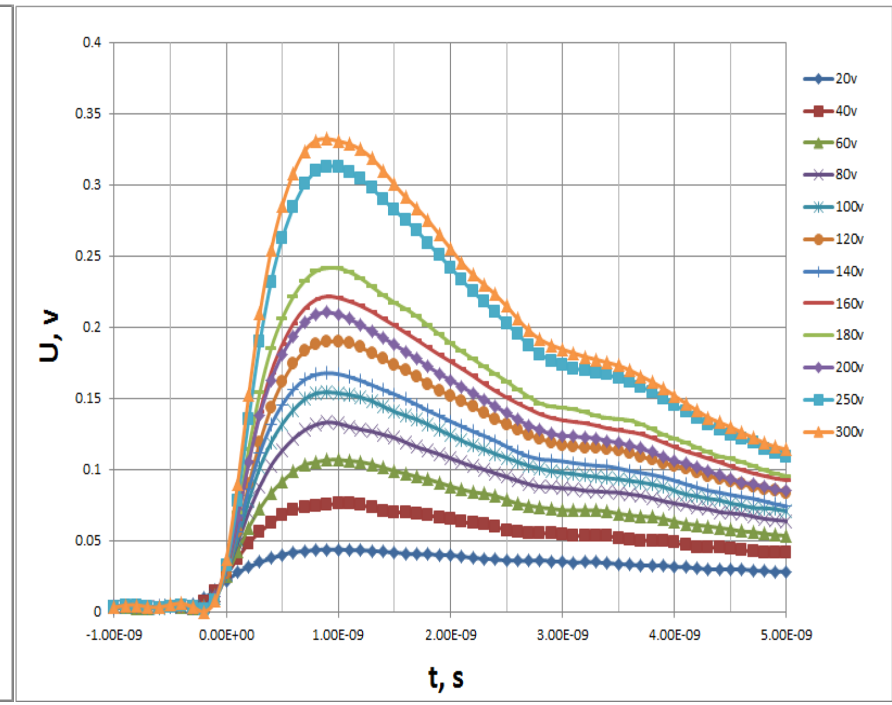
- *Very small strips are not good for timing, large (~900 μm) are OK*
- *Strip size (probably 900 μm) for the final detectors will be chosen according to occupancy*

Simulation of the signals produced by the heavy ions

Simulated current pulses at different trapping time

Rising edge of current pulses
^{197}Au, E = 920 MeV/u
Detector thickness - 300 um
Voltage range 20 – 300 V



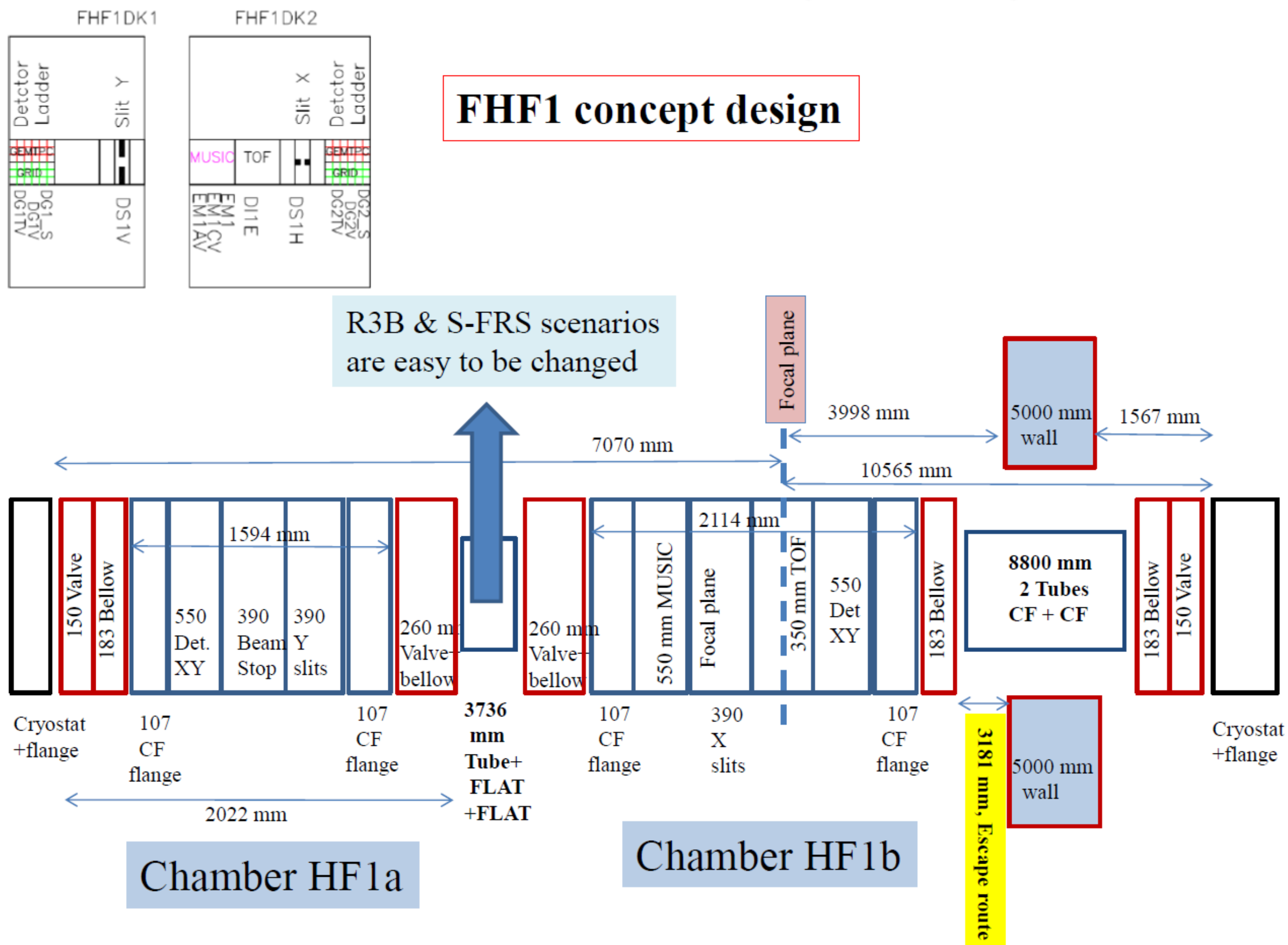


Amplitude of the peak current I_p
I_p at 1e^{12} ions/cm^2 = 1 - Tr/Ttr = 1 - 1ns/5ns = 0.8
(1ns – time of reaching maximum)

After 2.2*10^{11} ions/cm^2
10% degradation – reasonable agreement

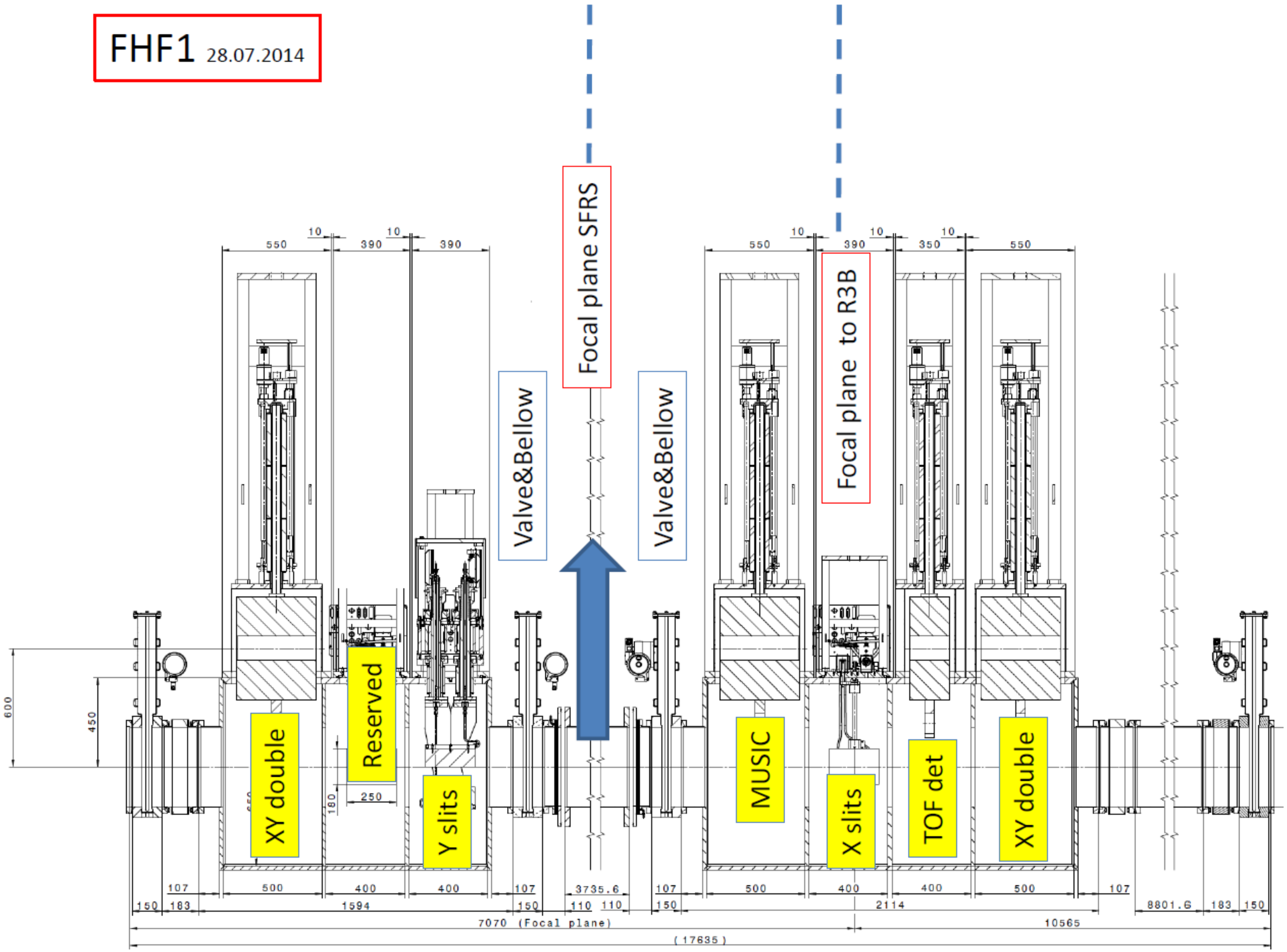
Detailed FLUKA simulations of the track creation inside the detector started

TOF detectors at SFRS (FHF1)

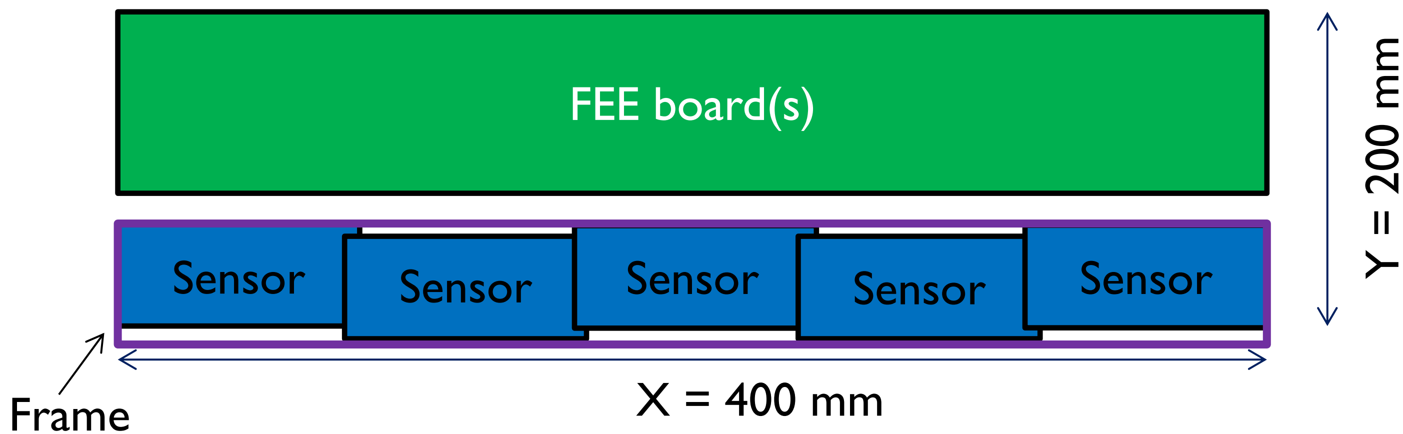


- Limited space, vacuum, active cooling
- Mounting on a movable ladder

TOF detectors at SFRS (FHF1)

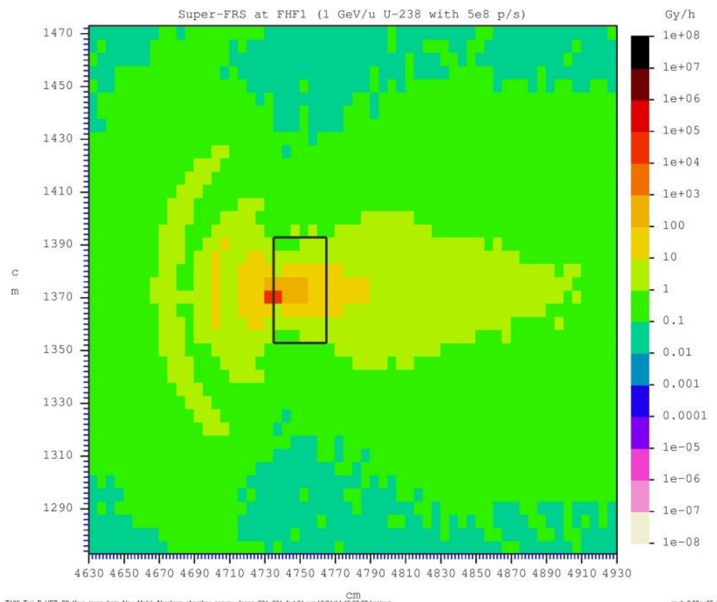


TOF detectors arrangement



- Sensor – 60 x 90 mm
- No dead zones
- Minimum overlap zones
- Light frame without elements in the active area
- Active cooling of FEE and the sensors

TOF detectors at SFRS – rad. dose



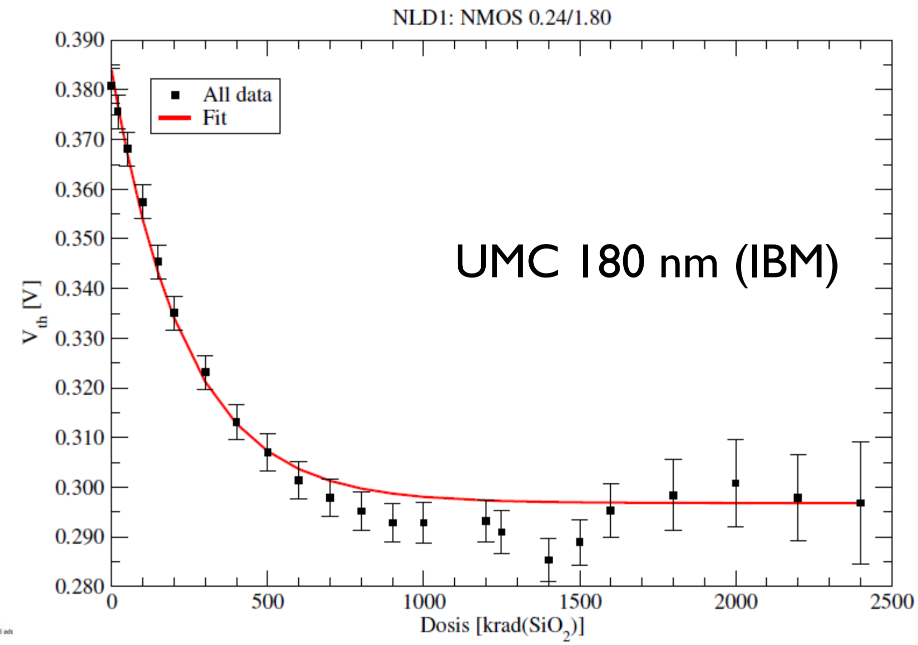


Fig. 5. Threshold voltage shift of a single NMOS transistor (0.24/1.80) for different dose levels.

S. Löchner, Proceedings of European Conference on Radiation and Its Effects on Components and Systems (RADECS), IEEE, 2009

- 100 Rad/h at the position of FEE ⇒ Mrad/month (worse case)
- FEE should be rad. hard at Mrad level
- Location of FEE is better not very close to the sensors, 10-20 cm if possible
- All options of FEE should be tested on rad. hardness

Published data - 130 nm BiCMOS and CMOS are rad. hard up to several MRad

PADI8 ASIC

- UMC 180 nm
- 8 channels
- One threshold per channel
- Time and ToT
- Bandwidth 400 MHz
- Peaking time 1 ns
- Equivalent noise 1145 e^-
- Power consumption 17 mW/ch

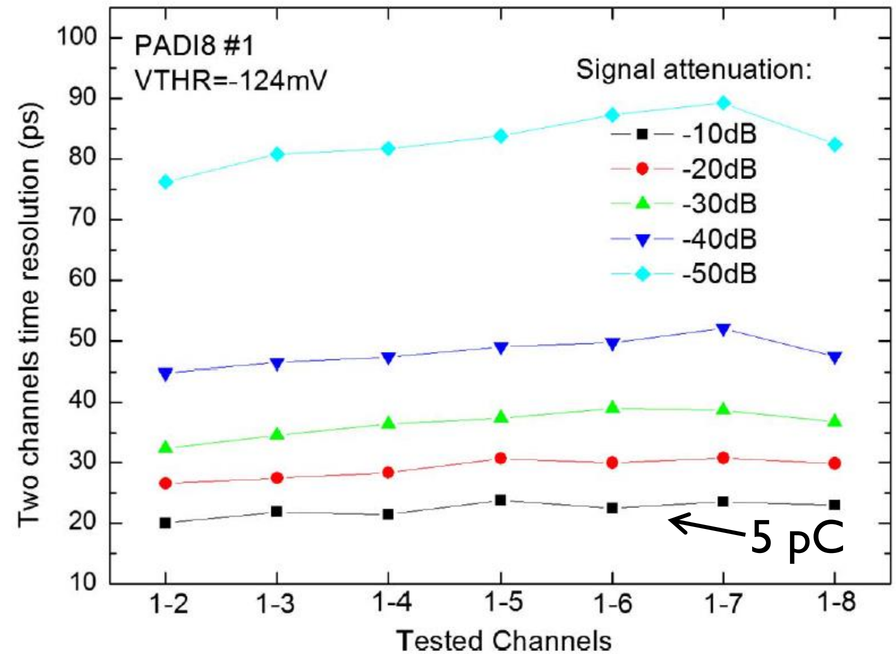


Fig. 19. Measured time resolution for different channel combinations on one chip (channel 1 against the others 7). The test pulse (0.25 V amplitude and 3 ns width) is attenuated by the specified values.

M. Ciobanu et al., IEEE Transaction on Nuclear Science, V 61, N 2 (2014) 1015

Space for the FEE inside the SFRS tube is limited, 400 x 100(200) mm
Up to 400 LVDS lines to outside per TOF station – connectors with 800 pins
Distance to the TDC < 2 m (?)
Difficult to keep the performance

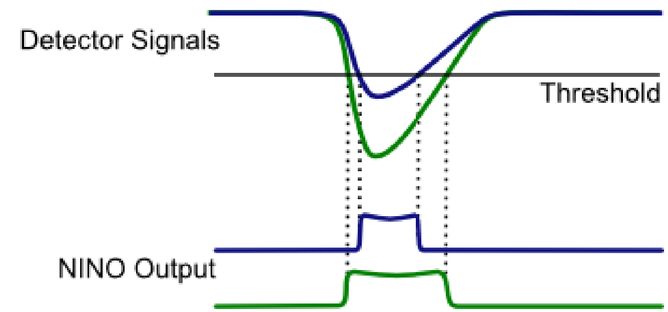
Analogue Front End – NINO32

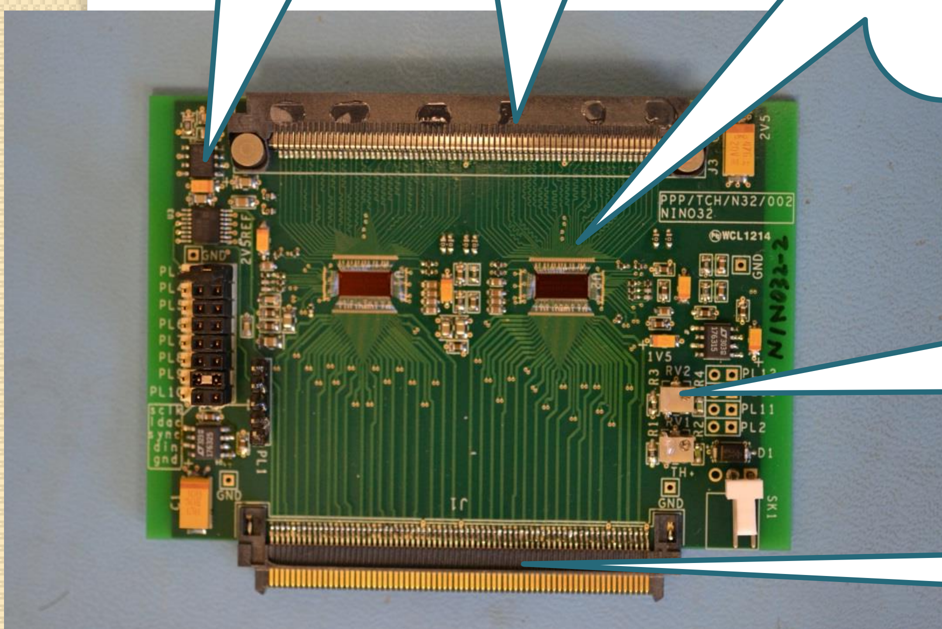
Time resolution 32 ps (NINO + HPTDC)

DAC – Setting threshold

Input – negative phase only

2 x **NINO** - Time Over Threshold Measurement, 64-ch board





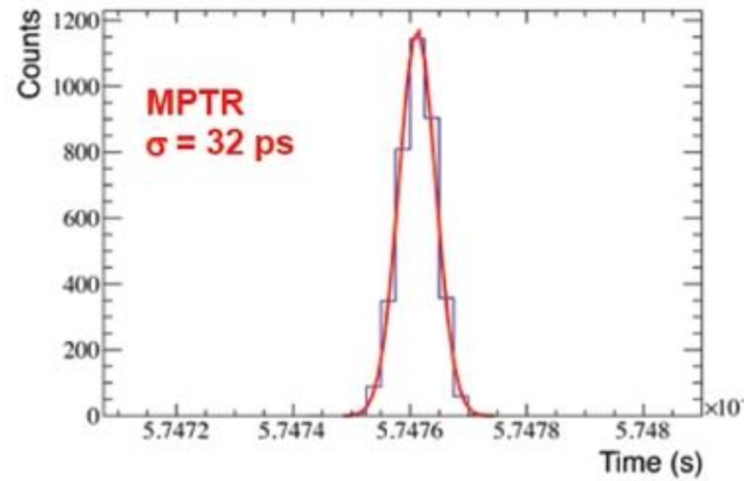
Potentiometer – threshold quick settings

LVDS output, DAC control and **power**

LHCb, CERN

PET SYS TOF ASIC v1

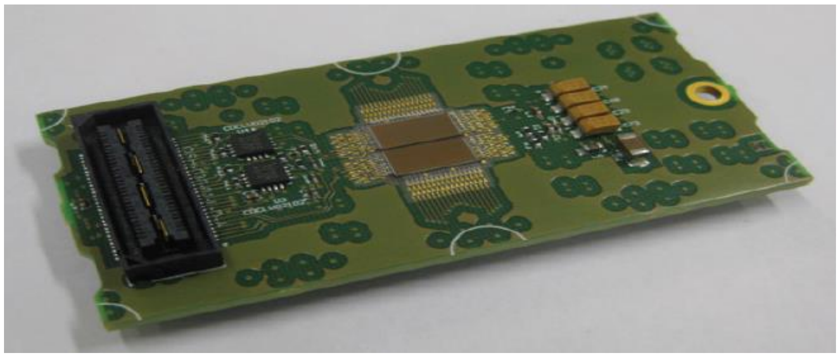
- Preamplifier, discriminator and TDC in the same chip
- Banwidth 250 MHz (PADI and NINO chips ~300 MHz)
- Free-running, time-based readout
- Timestamp
- Energy measurement via Time-over-Threshold
- Double-threshold discriminator
- Event rate – 160 kHz/ch
- On-Chip calibration system with precise pulser (6-bit amplitude setting)
- CMOS 130 nm (IBM) technology



Input capacitance : up to 300 pF
Input charge: 50 fC – 300 pC
Number of channels: 64
Power consumption: 8-11 mW/ch
Clock frequency: 160 MHz
Electronic time resolution: 25 ps rms
Radiation hardness: 0.5 MRad (???)
Peaking time: 1 ns

Company PETsys Electronics SA

PET SYS TOF System



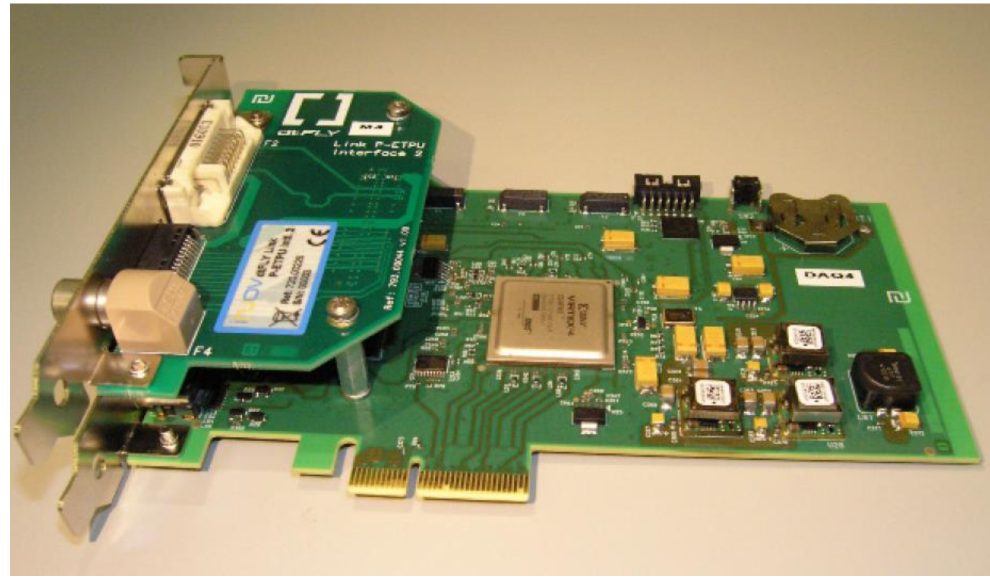
- Standard FEE board with 2 ASICs – 128 channels
- Customisation possible
- Gain setting – 1, ½, ¼
- Only 4 LVDS data links to the carrier board
- Data rate – up to 1.2 Gb/s

Company PETsys Electronics SA

- Carrier board for up to 8 FEE boards (1024 channels)
- Direct connection or flex kapton cables
- Electrical (up to 1.2 Gbit/s) or two optical (2x6.4 Gbit/s) links to a reciever card
- XILINX Kintex 7 FPGA
- Low and high voltages for all FEE boards and detectors

PET SYS TOF System

- Receiver board (PCIe)
- Electrical or optical lines (up to 4 Gbit/s)
- Up to 10^4 readout channels
- Coincidence triggers
- XILINX Virtex4 FPGA

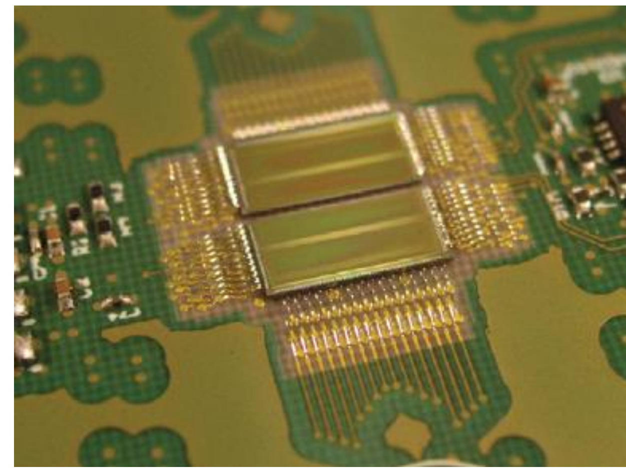


Very compact, fully integrated solution
Support from the company, readiness to make adaptations
Time resolution with detector (MPPC) and laser – 32 ps rms
PANDA TOF (Cherenkov detector) has this solution as an option, tested in lab (Uni Giessen), beam test at CERN in May 2015

Company PETsys Electronics SA

PET SYS TOF ASIC v2

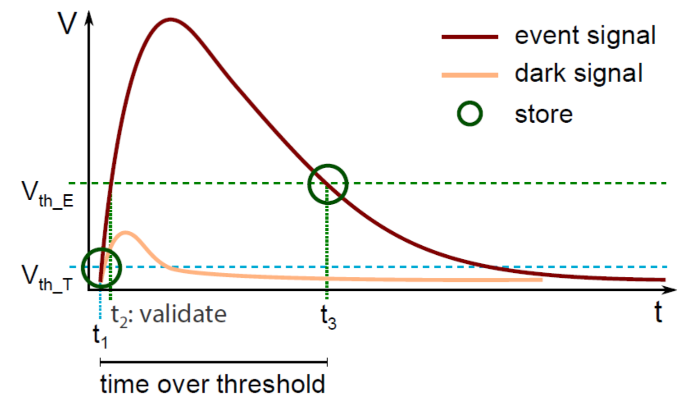
- Latest development (February 2015) based on the success of ASIC v1
- Event rate – 600 kHz/ch
- Linear preamplifier up to 1500 pC
- Linear charge measurement up to 1500 pC
- Improved time measurement
- Gain setting – 1, 1/2, 1/4, 1/8
- Power consumption: 5-8 mW/ch
- Data rate – up to 3.2 Gb/s
- Clock frequency: 200 MHz
- Improved calibration



Company PETsys Electronics SA

Panda STrip ASIC (PASTA)

- Free-running, time-based readout
- Timestamp
- Time-over-Threshold
- Double-threshold discriminator
- Time and energy measurement
- Event rate – 100 kHz/ch
- First prototype is cooming soon

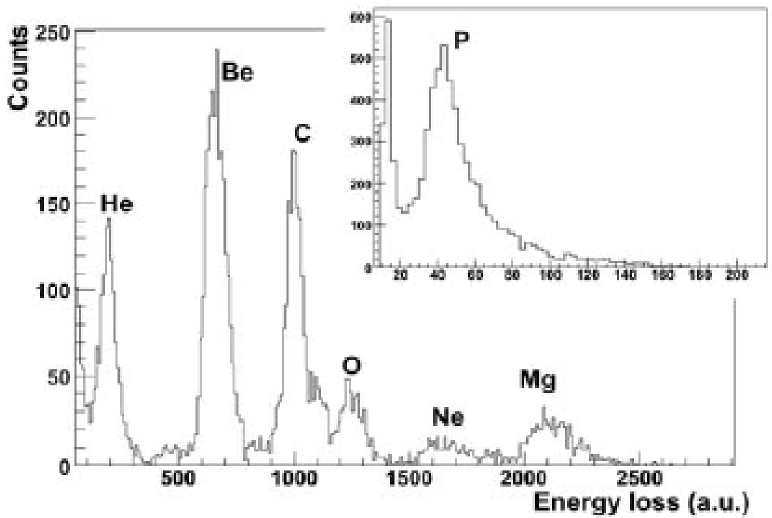


Input capacitance : 10 - 35 pF
Input charge: < 38 fC
Number of channels: 64
Power consumption: < 4 mW/ch
Clock frequency: 160 MHz
Time binning: 50 ps (the actual time resolution need to be verified)
Radiation hardness:100 kGy
Peaking time: 50 ns (can be 3-4 ns)

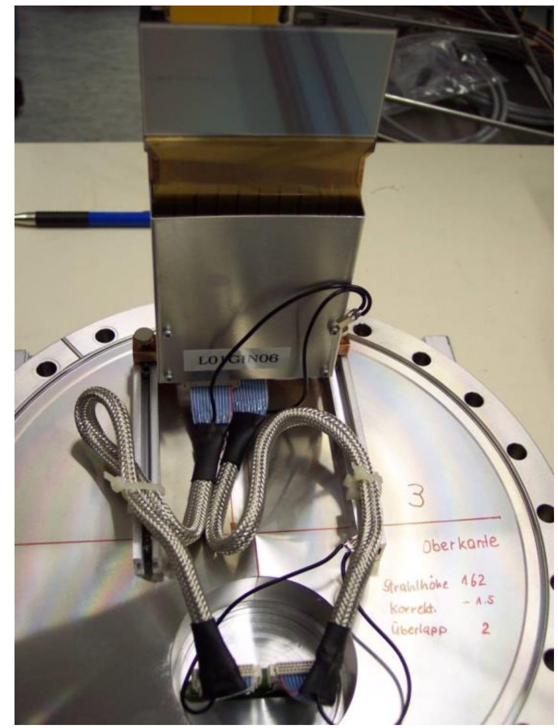
Decision of FAIR IKRB and FAIR Council

- ***The IKRB recommends to the Council to agree (and Council agreed) to the collaboration between FAIR GmbH and the Ioffe Physical-Technical Institute of the Russian Academy of Sciences, St. Petersburg, for the listed components of beam diagnostics equipment for the Super-FRS:***
- ***CVD-DD (diamond detectors, calibration)***
- ***CVD-DD (diamond detectors, calibration)***
- ***ToF detectors, ToF Diamond***
- ***ToF detectors, ToF Silicon***
- ***CVD-DD readout***
- ***Technical specifications until the end of 2015***
- ***Contract is expected at the beginning of 2016***

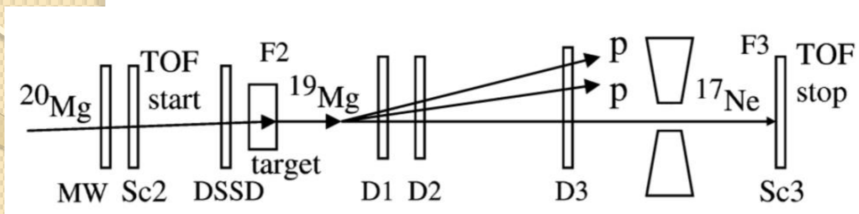
Si microstrip detectors for tracking of the fast ions and protons



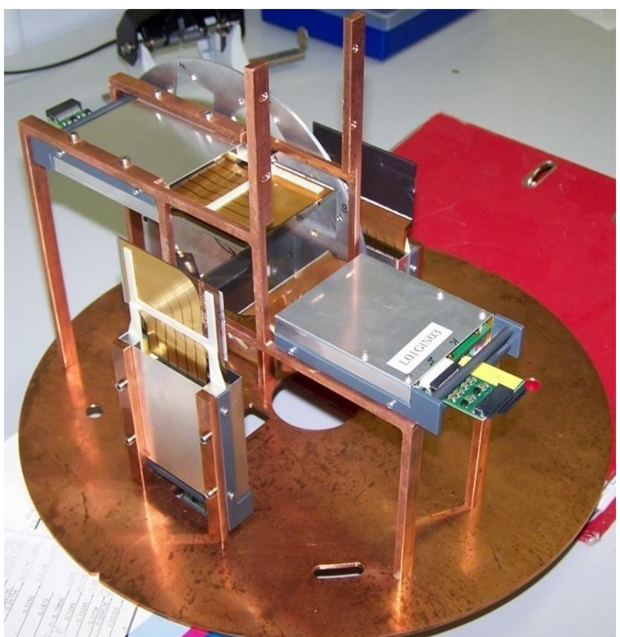
- DSSDs, area 28 cm^2, 300 μm, 100 μm strip pitch (X & Y)
- Energy resolution ~ 50 keV (for 5.5 MeV α-particles)
- Dynamic range – from p to Fe
- Low energy dissipation - work in vacuum without active cooling
- Used in several experiments at GSI

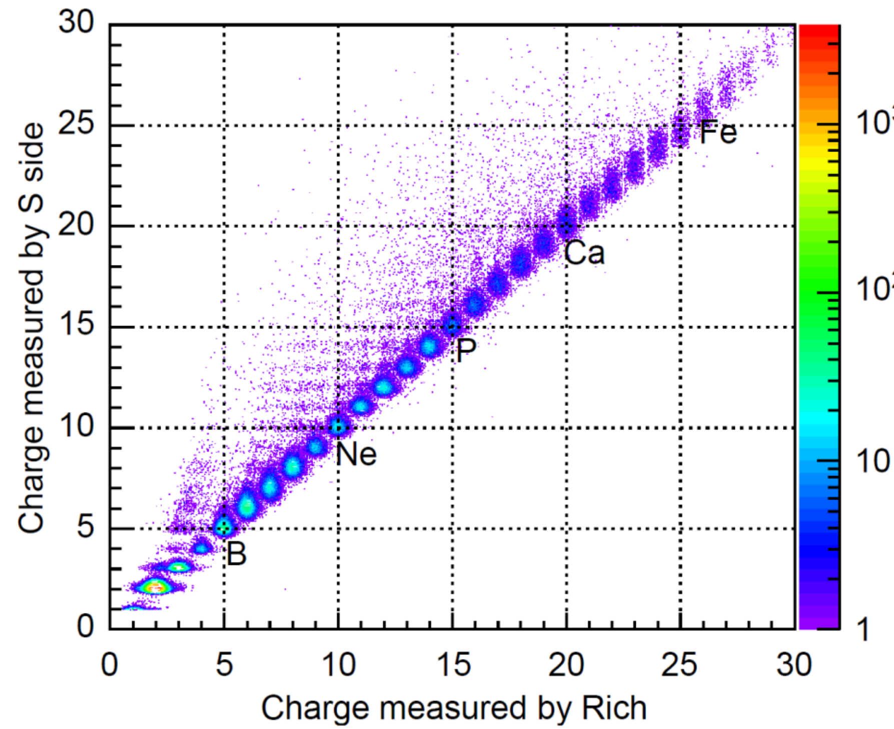


Precise tracking + spectroscopy



S271, S388 experiments at FRS, tracking of ions + protons
I. Mukha et al., PRL 99, 182501 (2007)

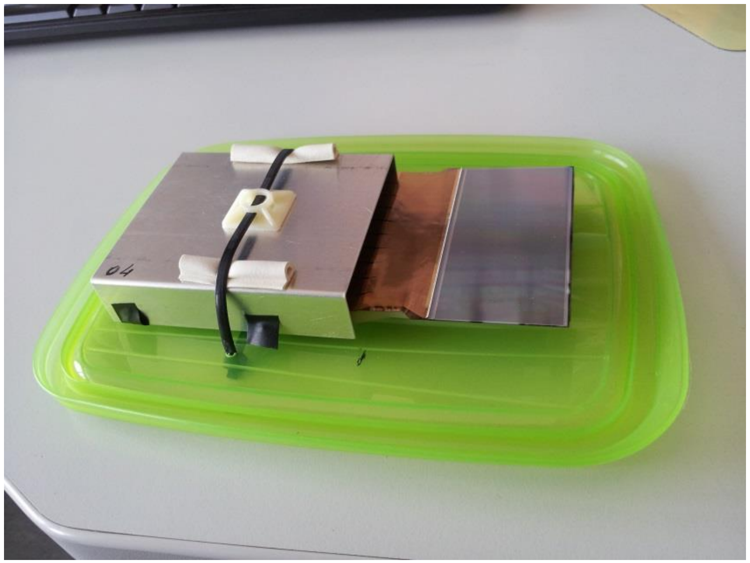




Si – RICH correllation (AMS data)

- C, P, Ne + protons tracking (<70 μm) and identification
- ***Key to success*** of two-proton radioactivity and QFS experiments

New tracking detectors



- Same sensors as before
- New FEE chips – VA140 instead of VA64hdr
- Lower power consumption - 0.3 mW/ch vs 0.8 mW/ch
- Lower noise - ≤ 100 e$^-$ vs ≤ 200 e$^-$
- Higher radiation tolerance
- 2 times better linearity (2% for negative signals, 5% for positive
- 2 times higher range (now ±200 fC)

- 6 new detectors with readout electronics are available
- Modification of the biasing scheme is required (Dubna)
- ***Will be tested with ^{40}Ar beam at CERN, 18 – 30 march 2015 – collaboration with DAMPE project***
- ***Position and charge resolution for Z = 1-18***

Detectors will be used: RIKEN (2015-2016), GSI FRS (2017-2018), FAIR SFRS (2021?)
Part of EXPERT project of SFRS Physics Collaboration

Conclusions and Plans

- After full analysis of irradiated samples the choice of Si matherial will be done
- Choice of detector topology will be done soon
- 60x60 mm test/preproduction prototypes will be produced (fall 2015)
- Preparations for 90x60 mm prototypes will be made (end of 2015)
- Follow or take part in PET TOF tests by PANDA collaboration
- PCBs with FEE (PADI8, PET TOF, may be NINO32) – fall 2015
- Beam test – Dubna, fall 2015
- Test of the radiation hardness of the FEE

- Characterisation of all tracking microstrip detectors (march 2015)
- Repare of the damaged detectors (spring 2015)
- Optimization of the readout with SIDEREM modules (fall 2015)
- Using of the detectors in the experiments at RIKEN (2015-2016), Dubna ACCULINNA2 (2016?), GSI FRS (2017-2018), FAIR SFRS (2021?)

TOF detectors Tracking detectors