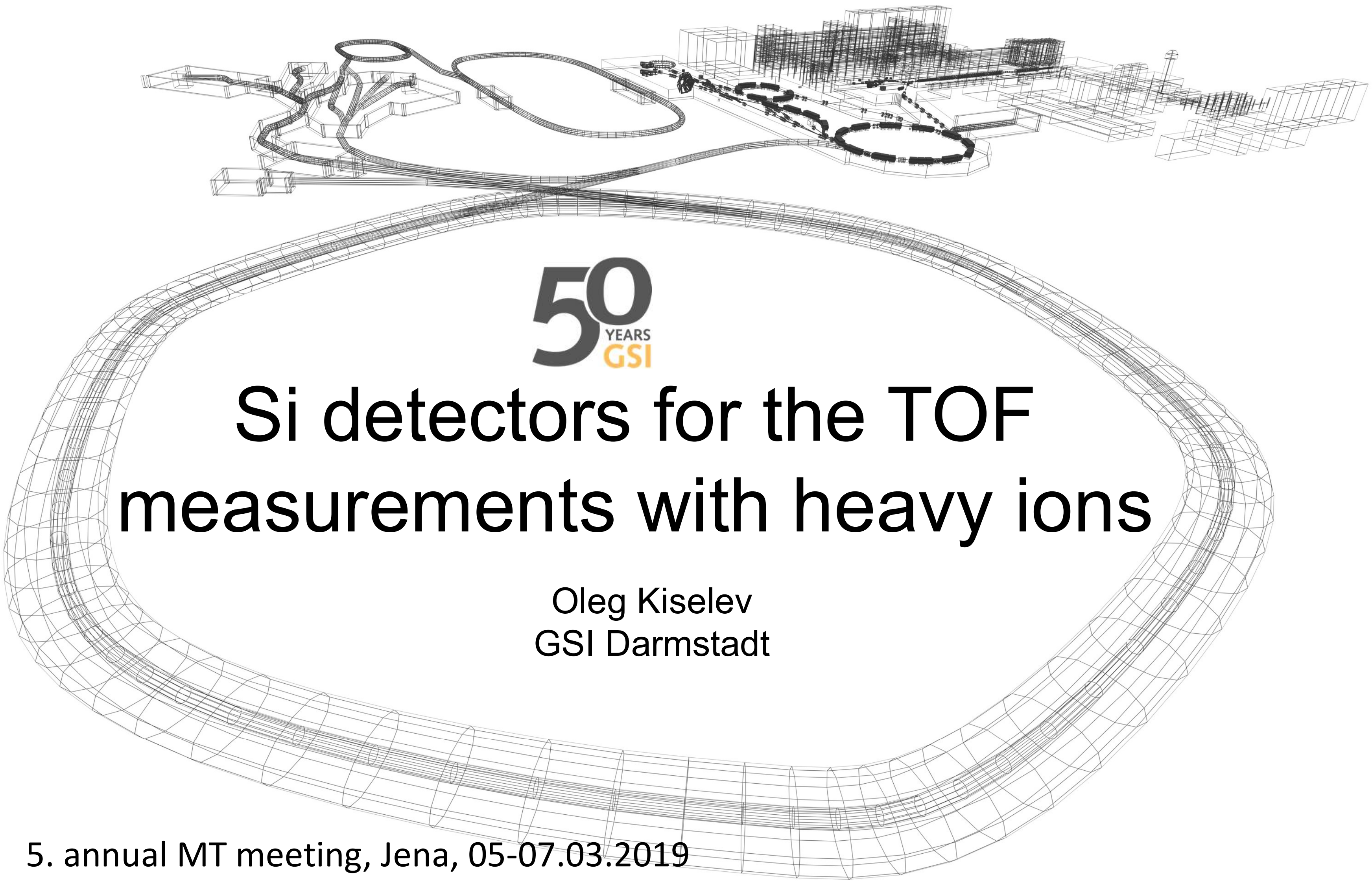
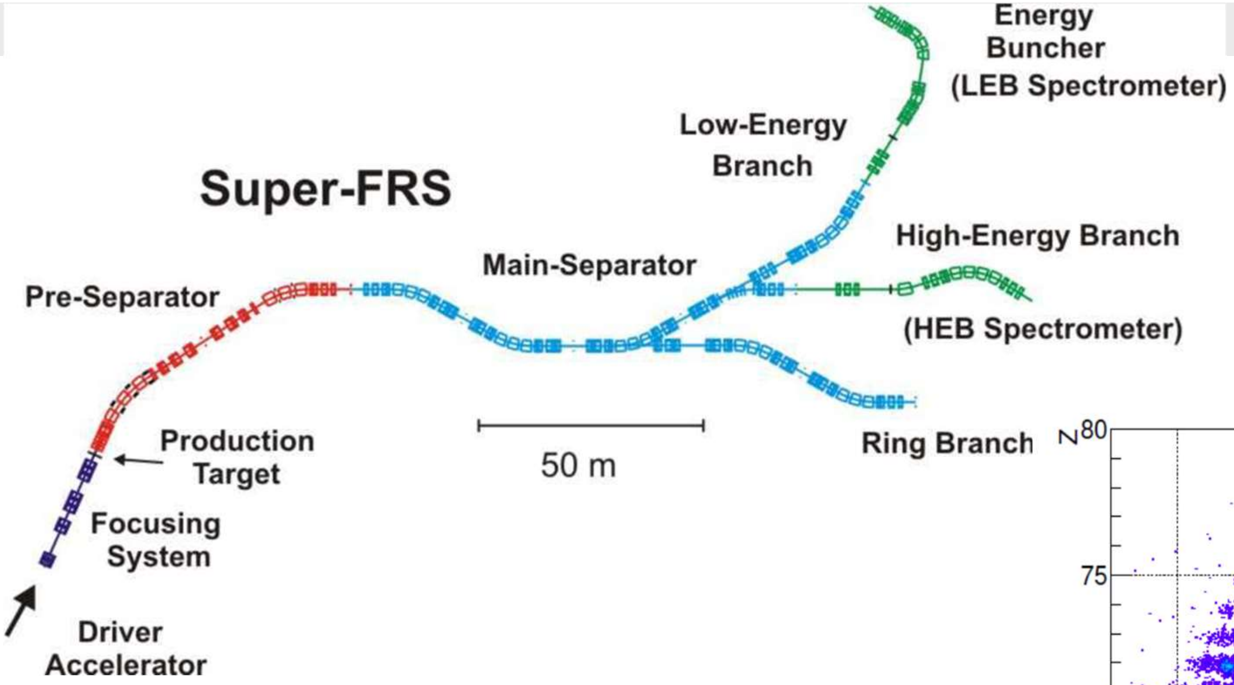


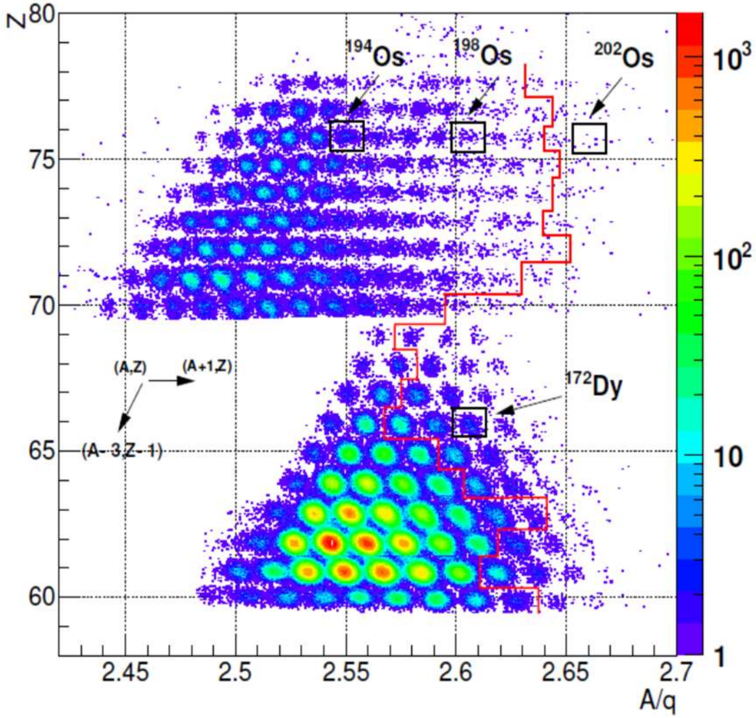
Si detectors for the TOF measurements with heavy ions

Oleg Kiselev
GSI Darmstadt

5. annual MT meeting, Jena, 05-07.03.2019

Particle identification @ SFRS FAIR





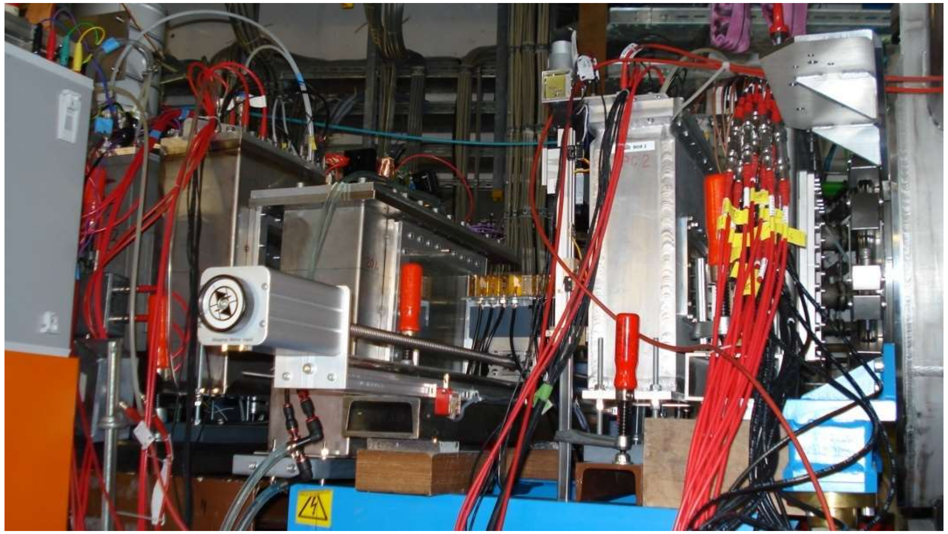
[F.Farinon, JLU Gießen, Diss., 2012]

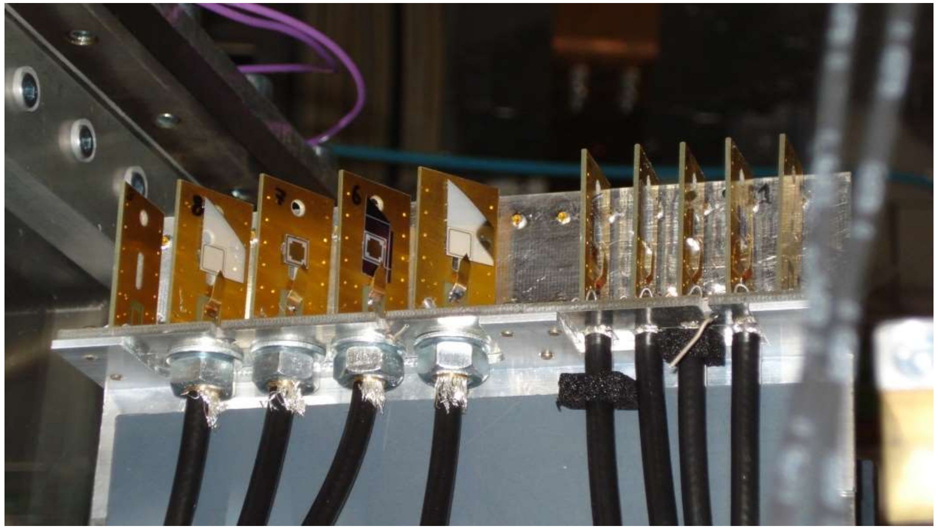
- Beam diagnostics –**ΔE –ToF** (Time of Flight) method
- The simultaneous measurements of the energy loss and the time of flight can **uniquely identify the particles**
- Rate from 10^{12} s^{-1} at pre-separator to 10^{5} s^{-1} at the end of main separator

Si detectors for TOF

- Si detectors typically used for energy measurements and tracking only – slow??
- Matter of proper detector topology and electronics
- Proposal to use Si strip detectors for TOF stations MF4, MF7, MF11
- Ion rate $<10^5\ s^{-1}$ per station
- Time resolution < 50 ps
- Position resolution – 0.1 – 1 mm
- Fast trigger for the rest of the diagnostic system
- Feasibility needs to be demonstrated

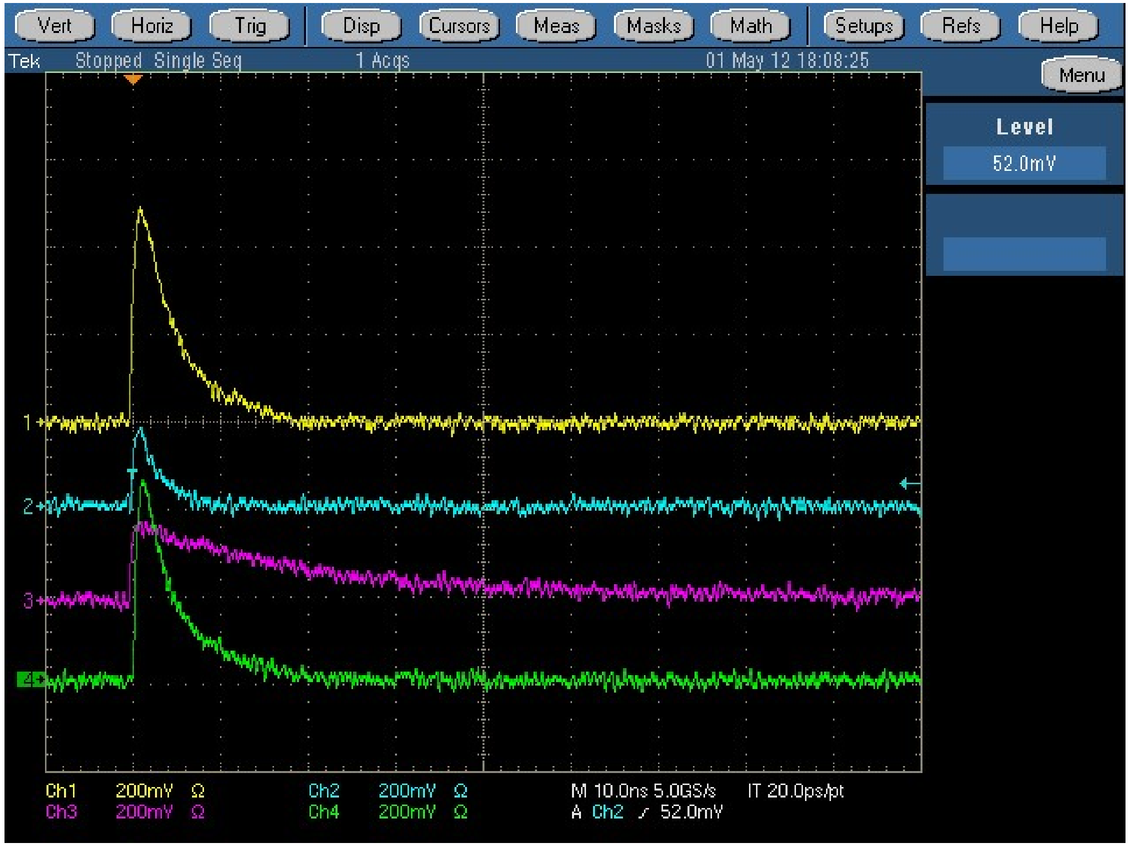
First test experiment at FRS





- Beam – ^{197}Au at 750 MeV/u
- S2 focal point of the FRS
- 8 Si detectors
- Size – 25 mm^2, matched to capacity to a typical size and capacity of one strip of large strip detector
- Readout directly from the detectors with a fast oscilloscope (4 GHz bandwidth, 8 bit, 10 GS/s)

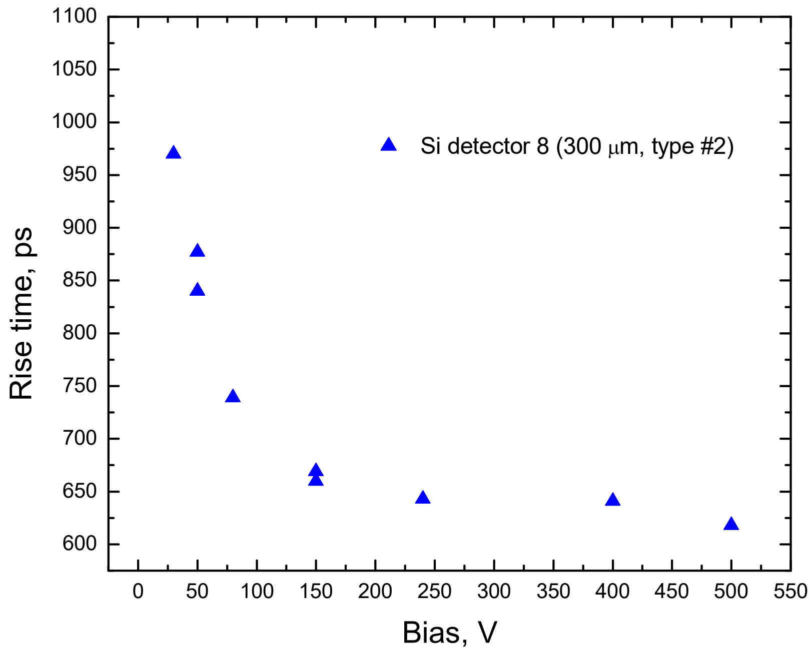
Example of the digitized signals



No amplification!

Waveforms saved and analysed offline
Waveform analysis software developed specially for the project
Amplitude, charge, rise time, time and charge correlations extracted

Rise time vs bias, detector #8

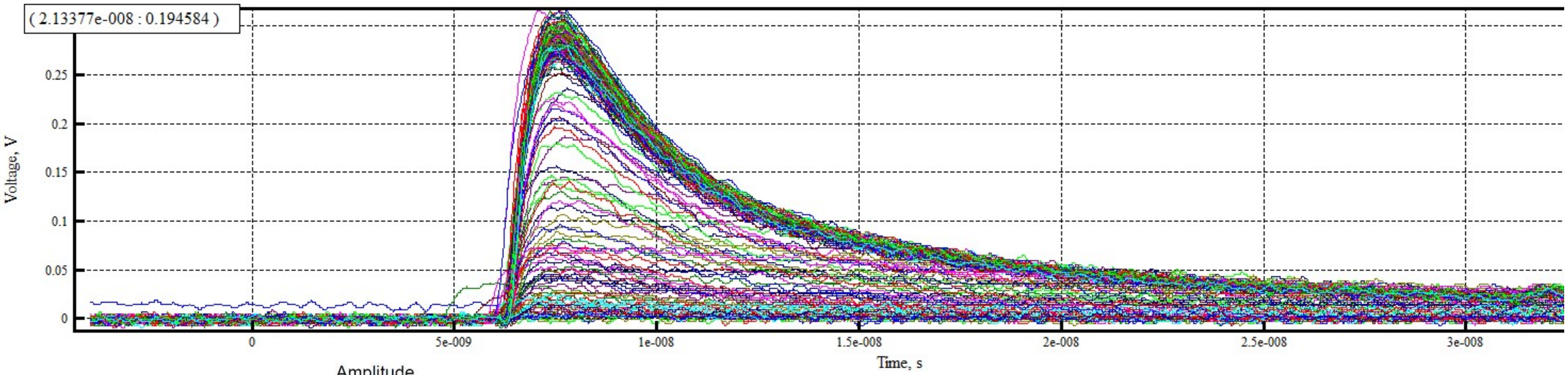


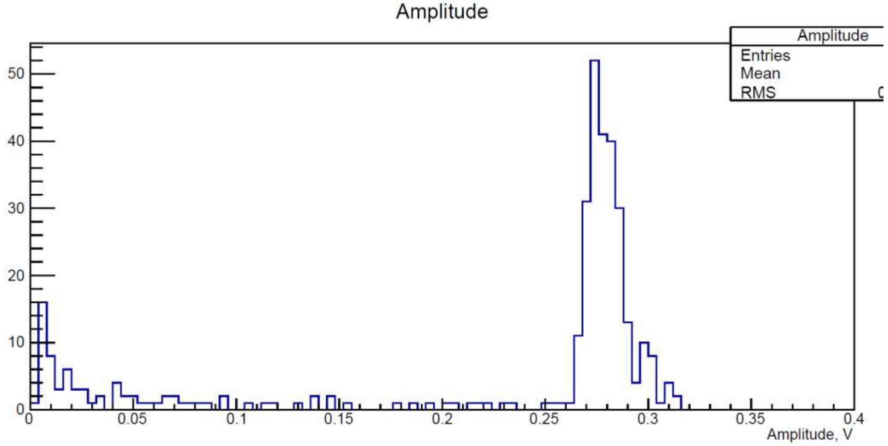
Time resolution in first order directly proportional to the slope of the signal and inverse proportional to the noise

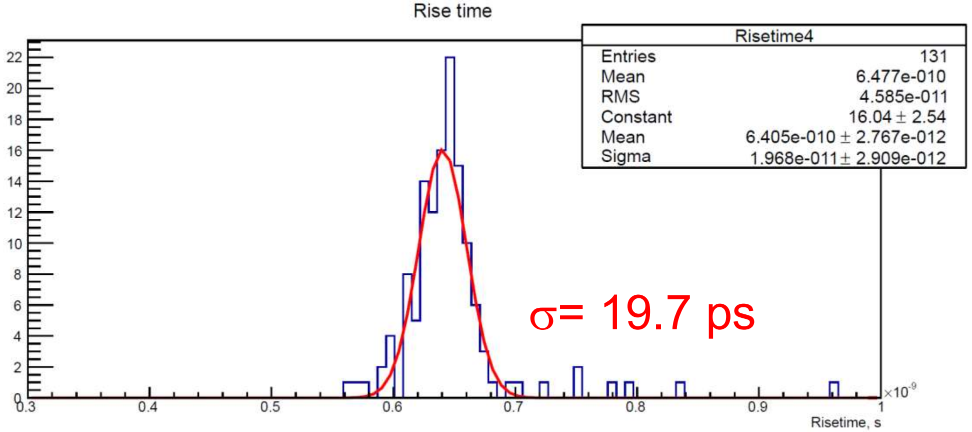
So – fast and strong signals are important

Thickness 300 μm, type #2
Rotated to 30° with respect to beam axis
Good resolution (20 ps) start from 150 V

Time jitter with pulse-shape analysis



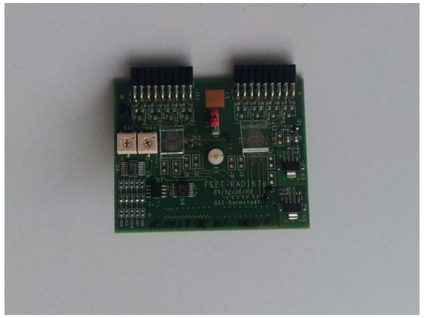




Time jitter obtained using leading-edge discriminator with amplitude correction

Using CFD might provide even better timing

PADI amplifier/discriminator + FPGA TDC



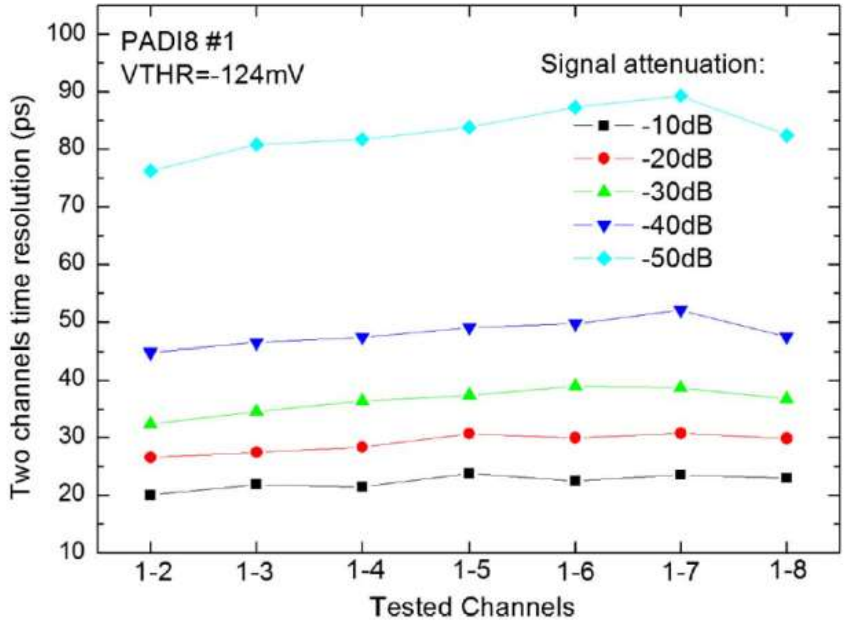


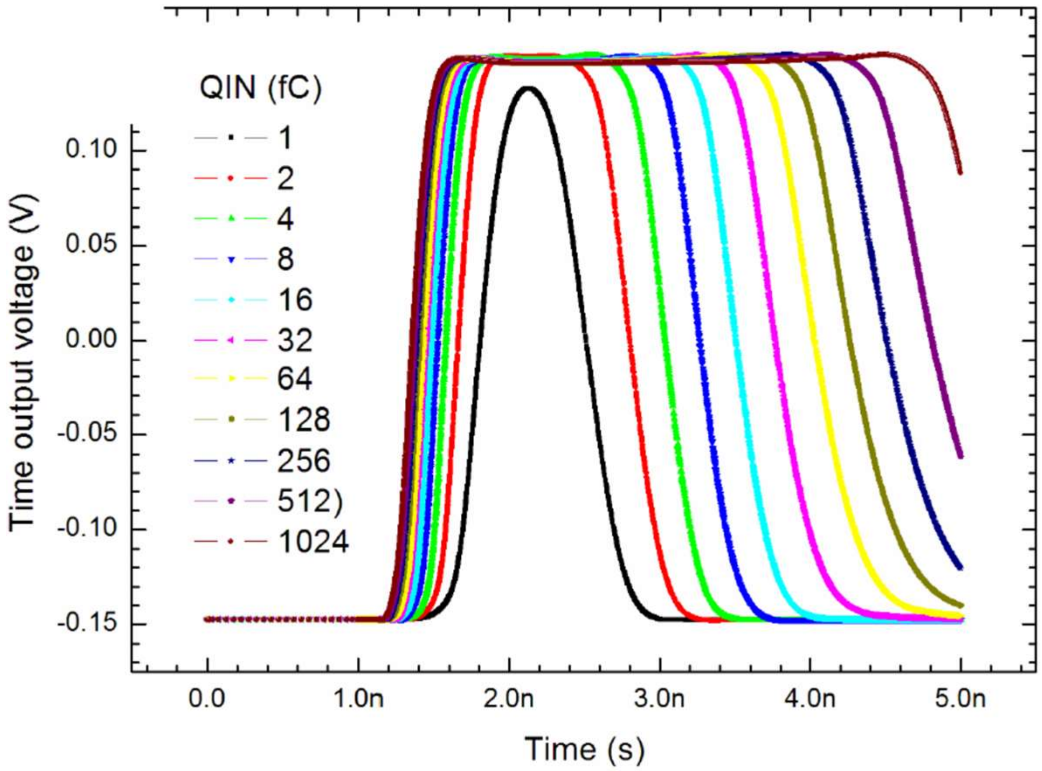
Fig. 19. Measured time resolution for different channel combinations on one chip (channel 1 against the others 7). The test pulse (0.25 V amplitude and 3 ns width) is attenuated by the specified values.

GSI DL and ExEl

- ASIC developed at for extremely fast signals and best possible time resolution
- 4/8 channels per chip – **current amplifier** (x100) and leading-edge discriminator, Time-over-Threshold, LVDS output
- VFTX2 FPGA TDC – 28 channels with 7 ps time resolution (GSI development)

PADI8 ASIC

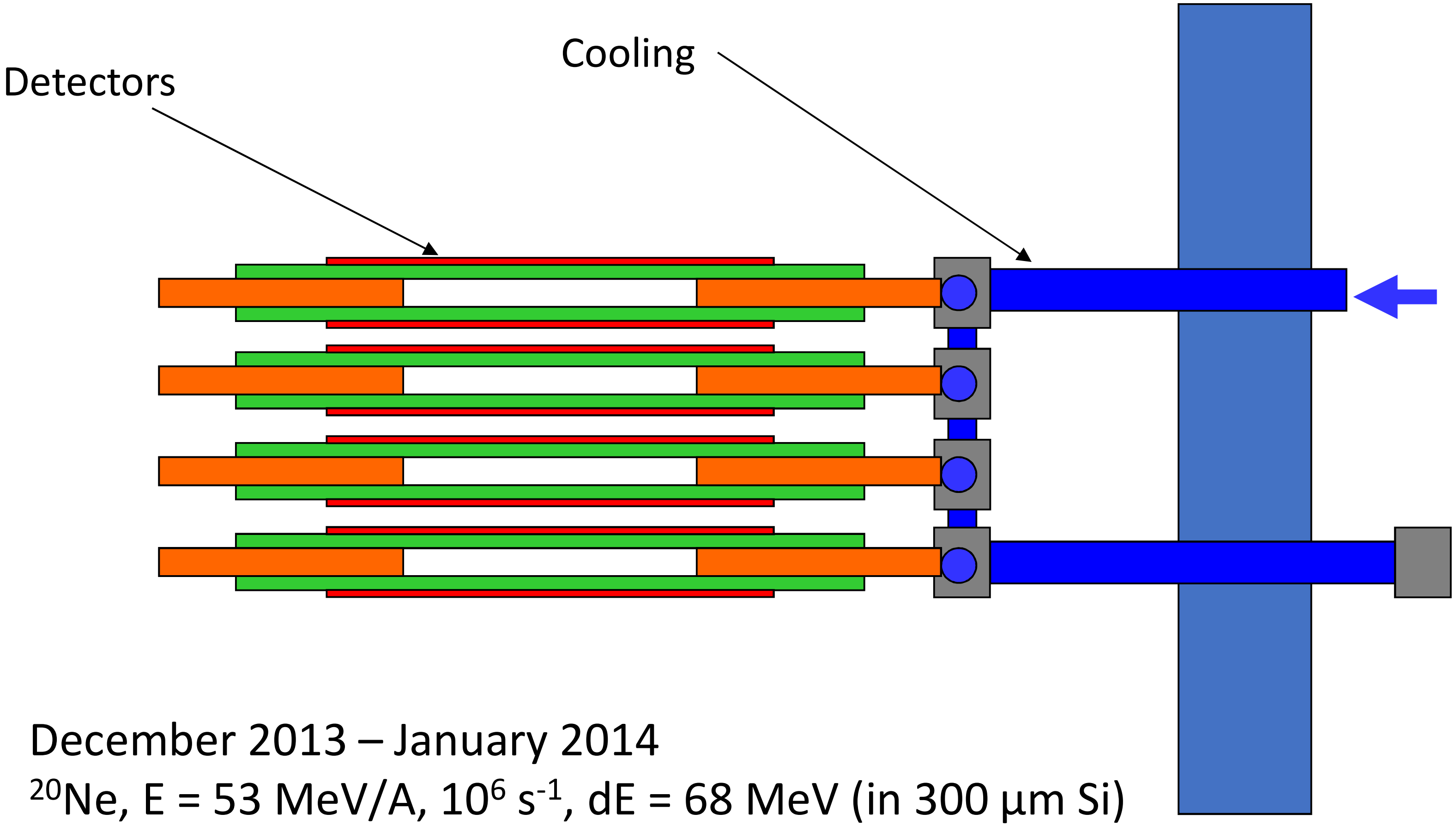
- UMC 180 nm
- 8 channels
- One threshold per channel
- Time and ToT
- Bandwidth 400 MHz
- Peaking time 1 ns
- Equivalent noise 1145 e^-
- Power consumption 17 mW/ch



GSI DL and ExEl

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

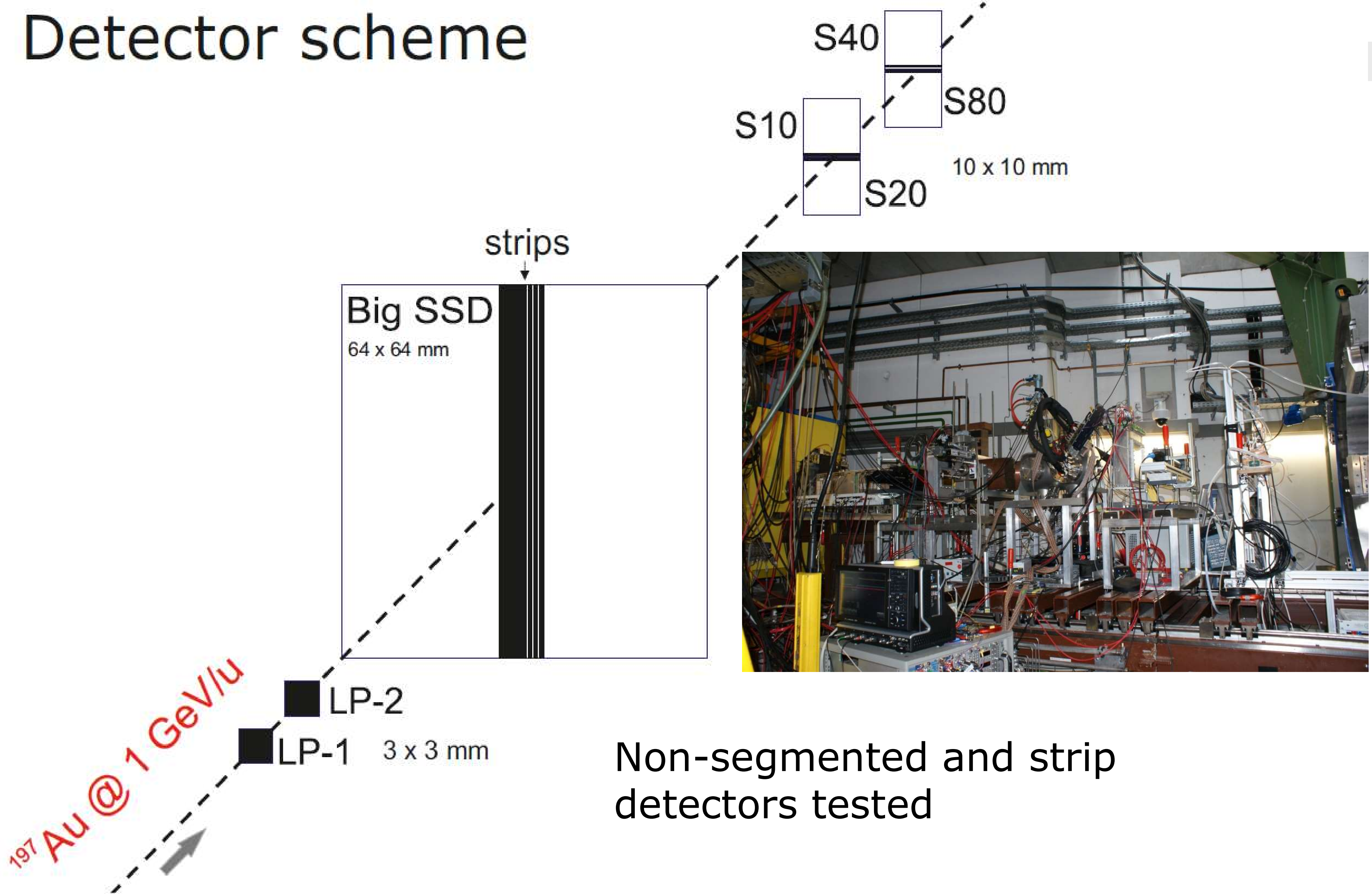
Detectors for the beam tests at JINR, Dubna



- December 2013 – January 2014
  ^{20}Ne, E = 53 MeV/A, 10^6 s^{-1}, dE = 68 MeV (in 300 µm Si)
  ^{11}B, E = 35 MeV/A, 10^6 s^{-1}, dE = 24 MeV (in 300 µm Si)
- Several detectors in stack, size – up to 64 x 64 mm
- Cooling up to -30°, in vacuum chamber

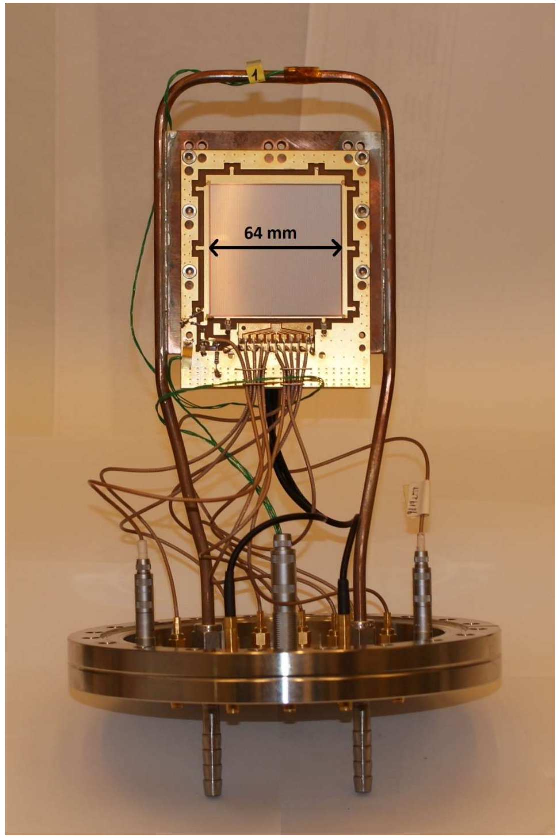
Test experiment Aug. 2014 @ FRS GSI

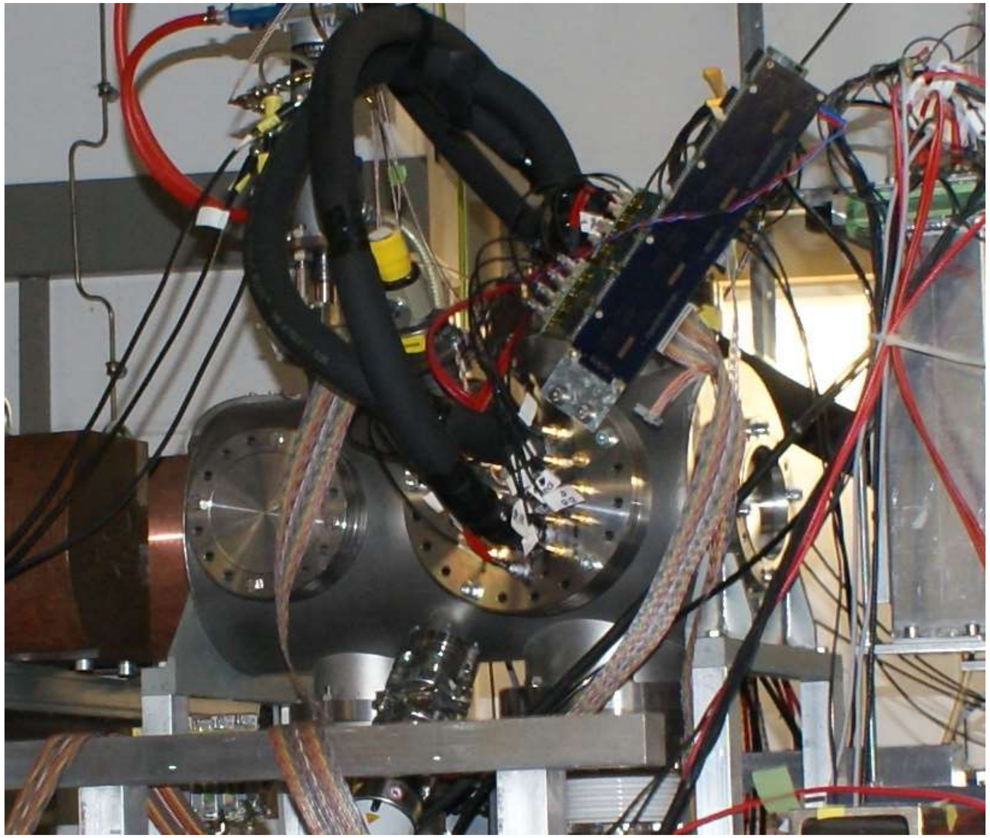
Detector scheme



Non-segmented and strip detectors tested

Cooled detectors in a vacuum chamber





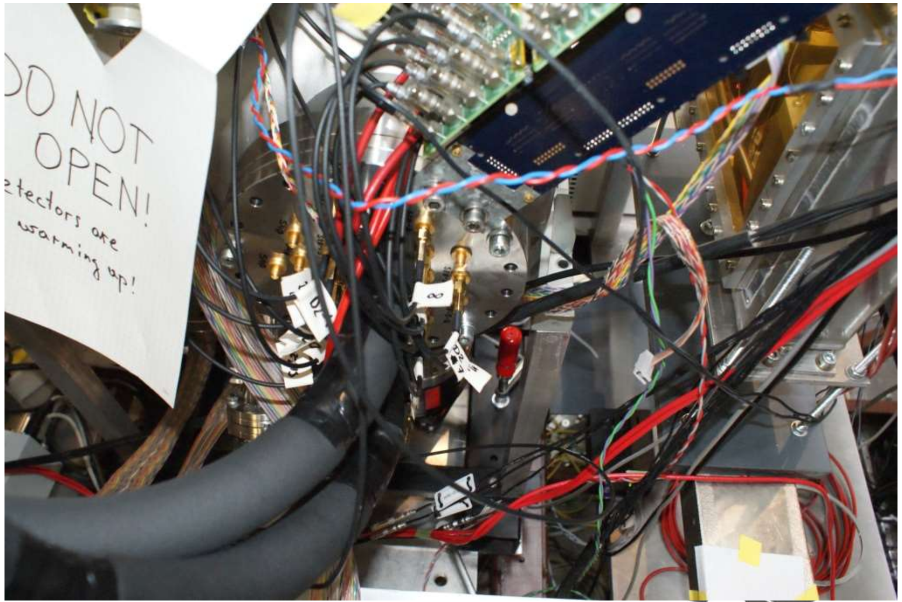
- The temperature of cooling tube –13° C, detectors +7° C
- Cooling of the detectors is reducing dark current and noise
- Vacuum about 10^{-4} mbar
- Diamond detectors in the same vacuum chamber

4 different versions of DAQ

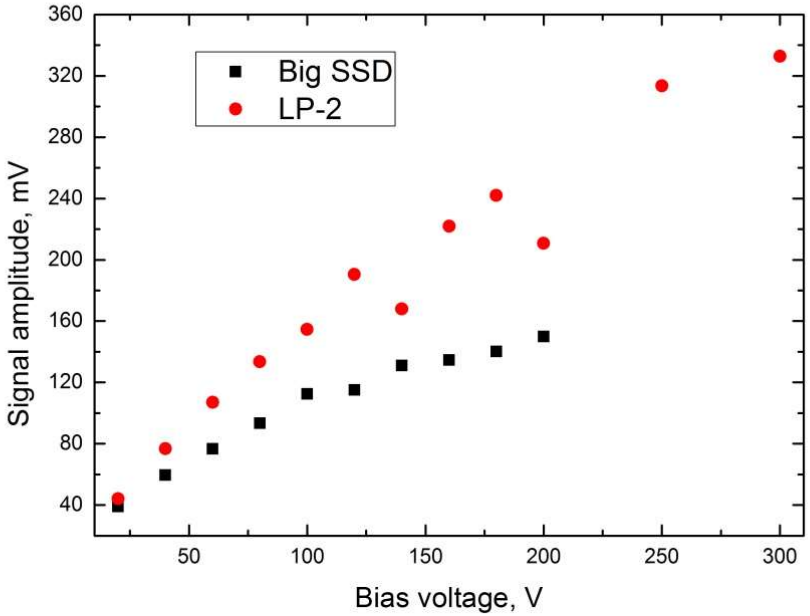
- Fast oscilloscope with 2 GHz analog bandwidth
- PADI preamplifier/discriminator + VFTX2 TDC
- CAEN FADC DT5742, sampling up to 5 Gs/s
- CAEN FADC DT5743, sampling up to 3.2 Gs/s, **beta-test of the device and the software (special deal with CAEN)**

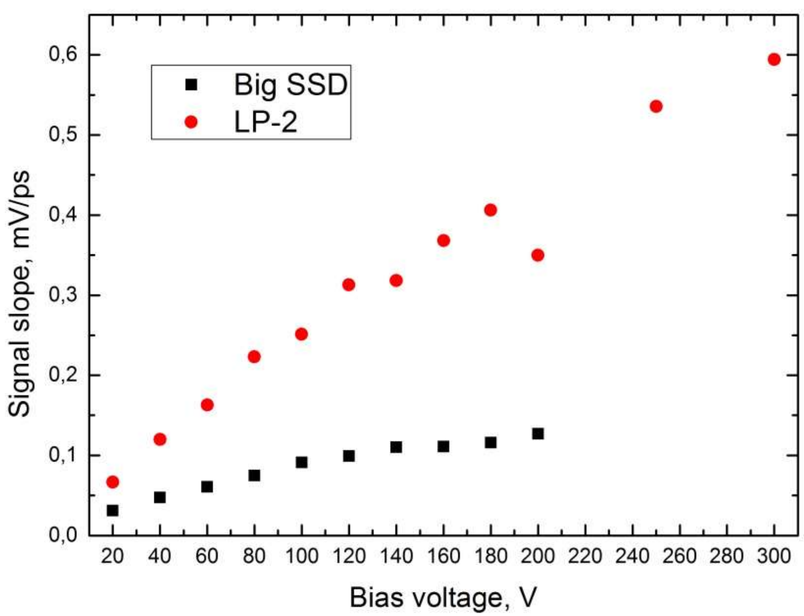
DT5743

DT5742



Signals vs bias

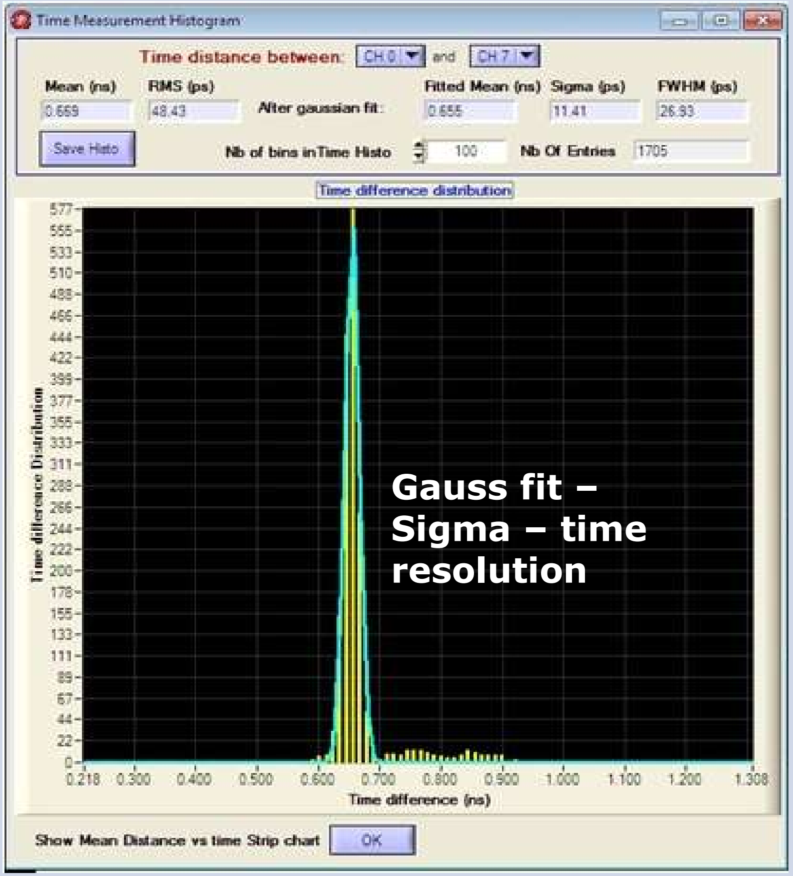


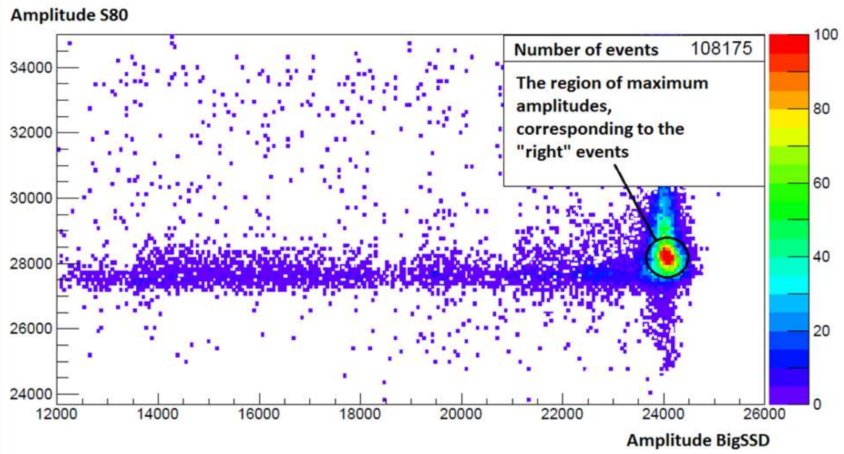


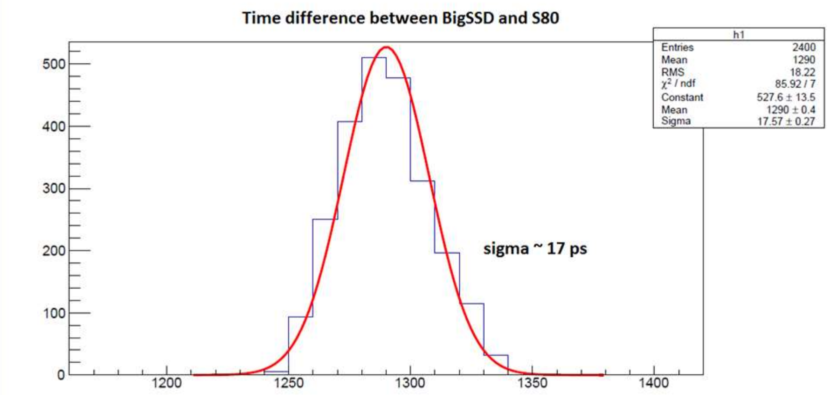
Optimum bias for all detectors found in this way
In order to get good timing, the detectors need to be overbiased
(and have low dark current)

Time resolution with FADC and PADI/VFTX

DT5743	PADI + VFTX
CAEN WaveCatcher, built-in CFD method	







Results of this test

Detector pair	PADI + VFTX2, σ (ps)	DT5743, σ (ps)
big SSD and S80	17	15
big SSD and S20	16	60

The results obtained with PADI + VFTX2 (sigma ~ 17 ps) look more stable for all combination of the detectors. This testifies **the perspectives of use** of the radiation hard silicon strip detectors for the beam diagnostics in the RIBs experiments.

There is the difference of time resolution for different detector pairs in case of DT5743 analysis. The low sampling frequency (bin 312.5 ps) or specific algorithm of smoothing procedure??

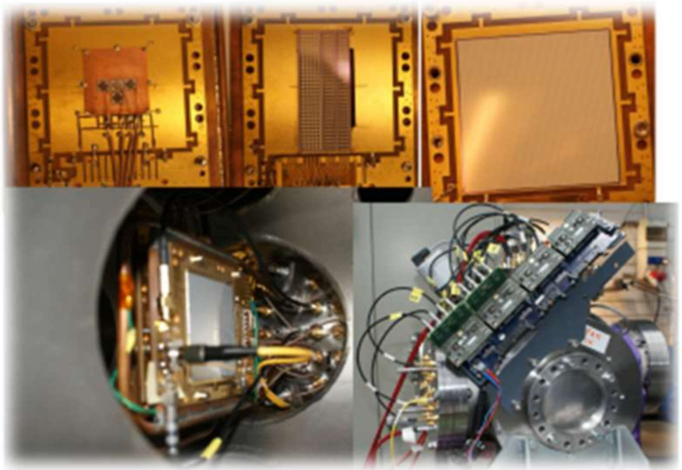
Test experiment June 2016, Cave C GSI

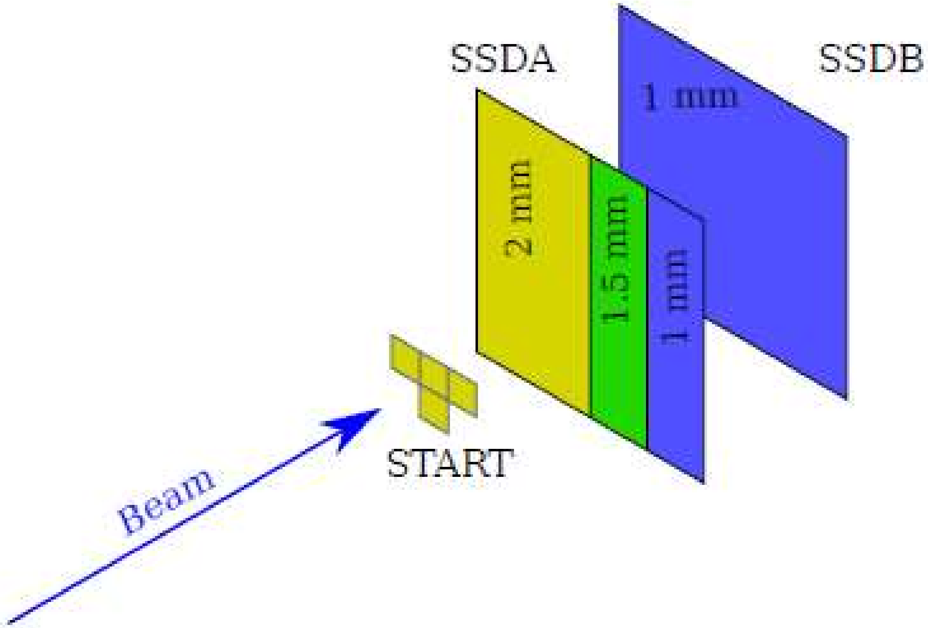
Detectors:

- 4 5x5 mm 300 µm non-segmented detectors
- 64x64 mm 300 µm strip-detector with different strip size (2, 1.5 and 1 mm)
- 64x64 mm 300 µm strip-detector with 1 mm strips

Readout systems:

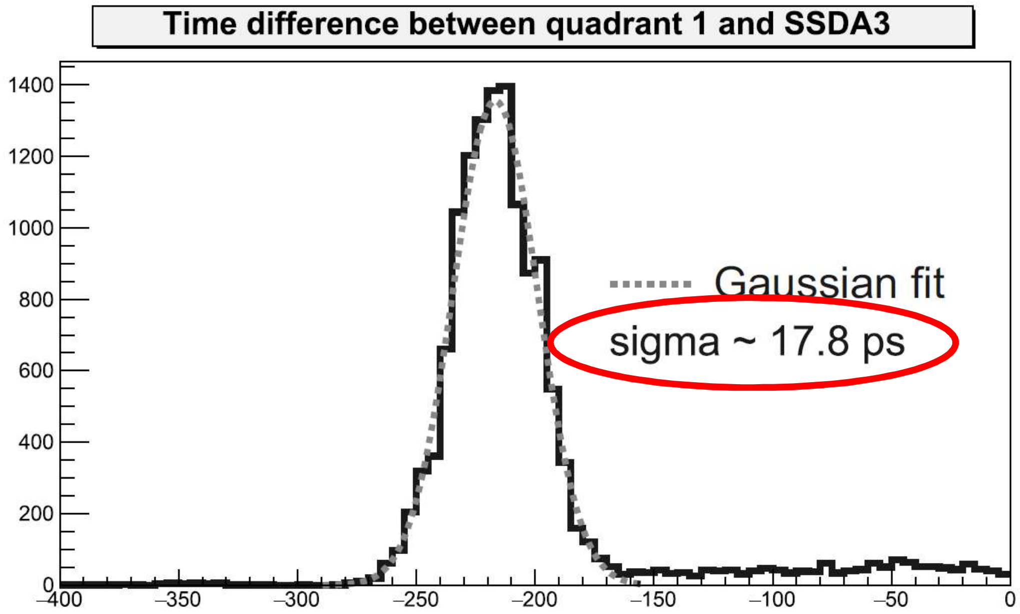
- PADI + VFTX2
- 32 ch Mesytec QDC

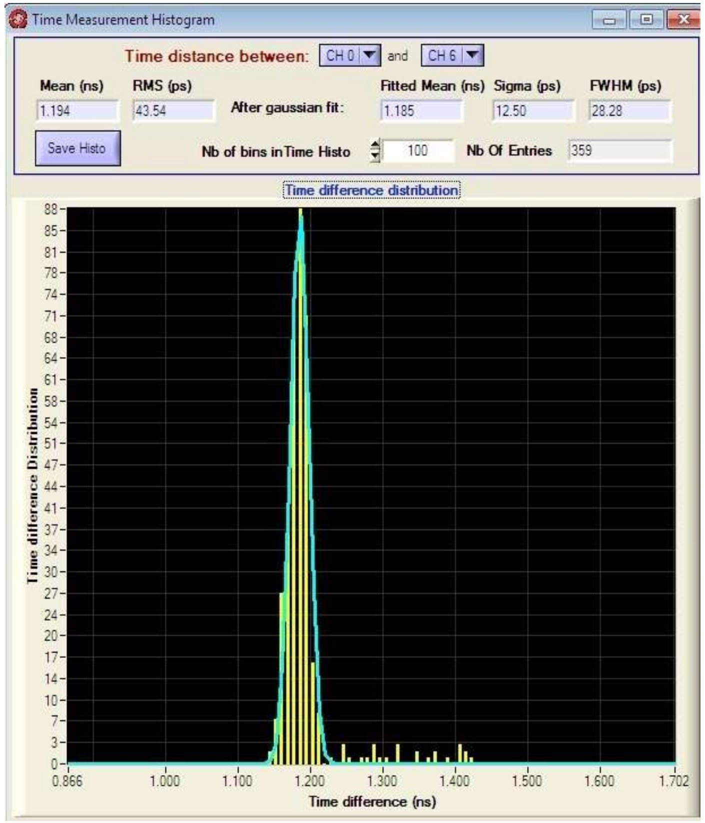




Time resolution, test experiment June 2016

- Xe beam 600 MeV/u

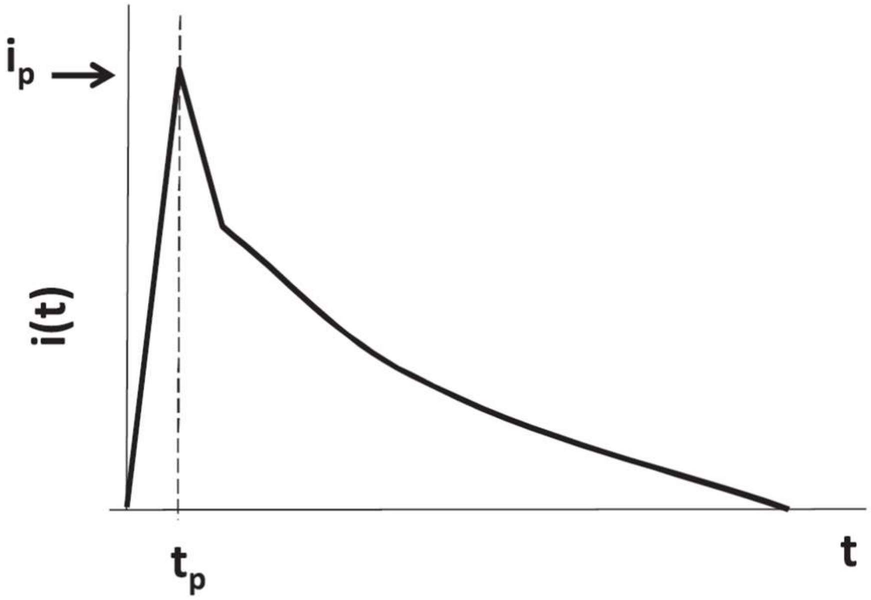


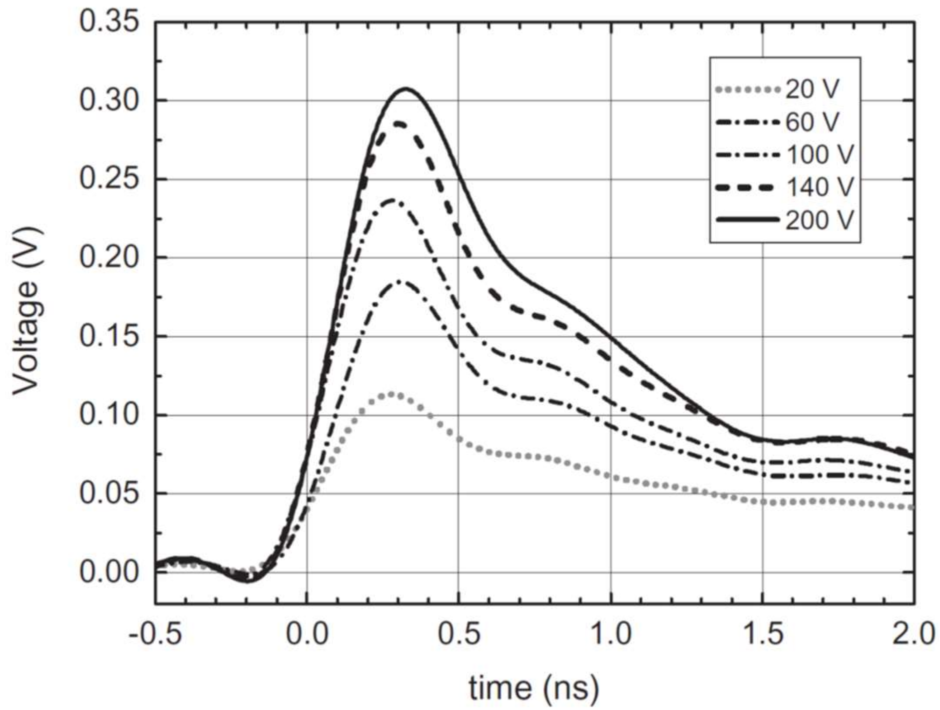


[V. Eremin et al. JINST 12 C030001 2017]

- Time resolution for C beam 600 MeV/u ~100 ps

Simulation of current response/timing





$T_p \sim$ 20 ps
Rise time of the real signal from the detector 200-1000 ps, defined by the RC and bandwidth of the amplifier/digitizer

V. Eremin, O. Kiselev et al., NIM A796 (2015) 158

Simulation of the signals produced by the heavy ions

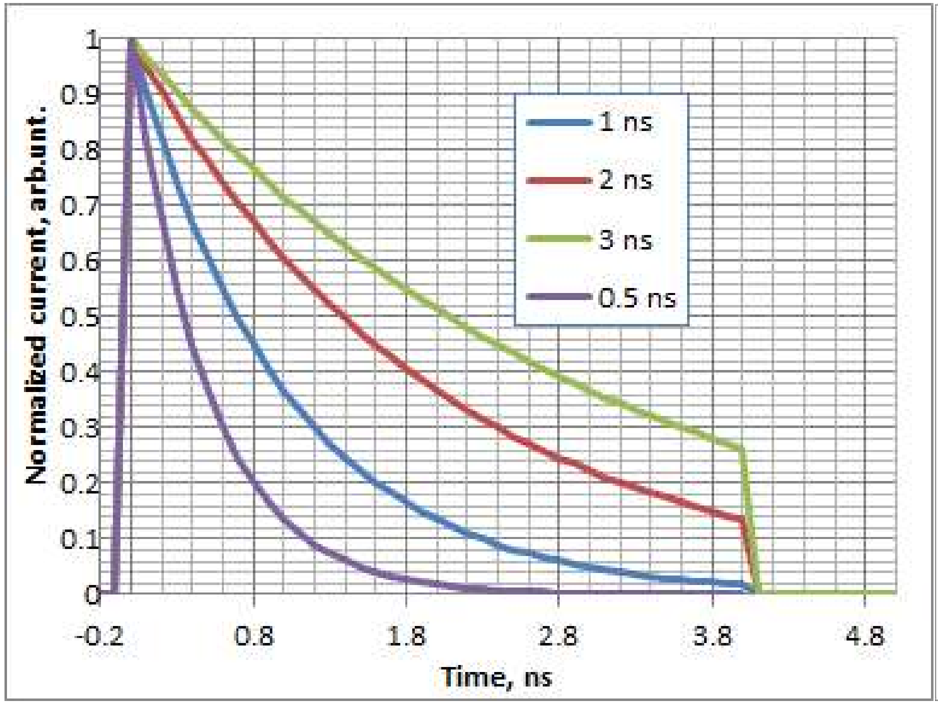
Simulated current pulses at different trapping time

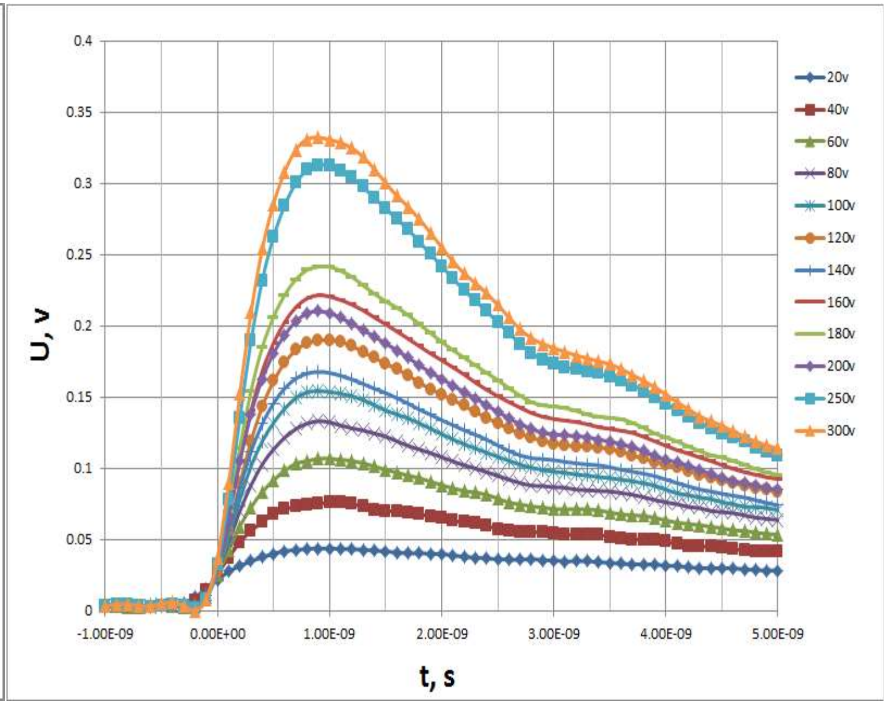
Rising edge of current pulses

^{197}Au, E = 920 MeV/u

Detector thickness - 300 um

Voltage range 20 – 300 V

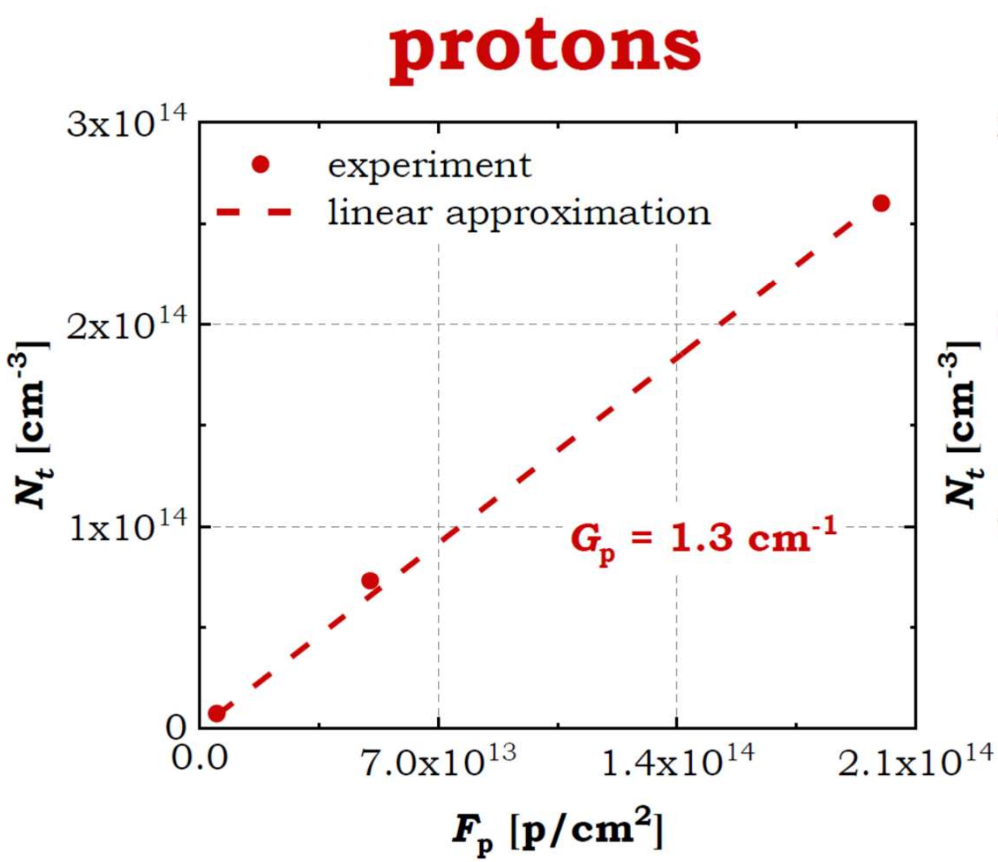


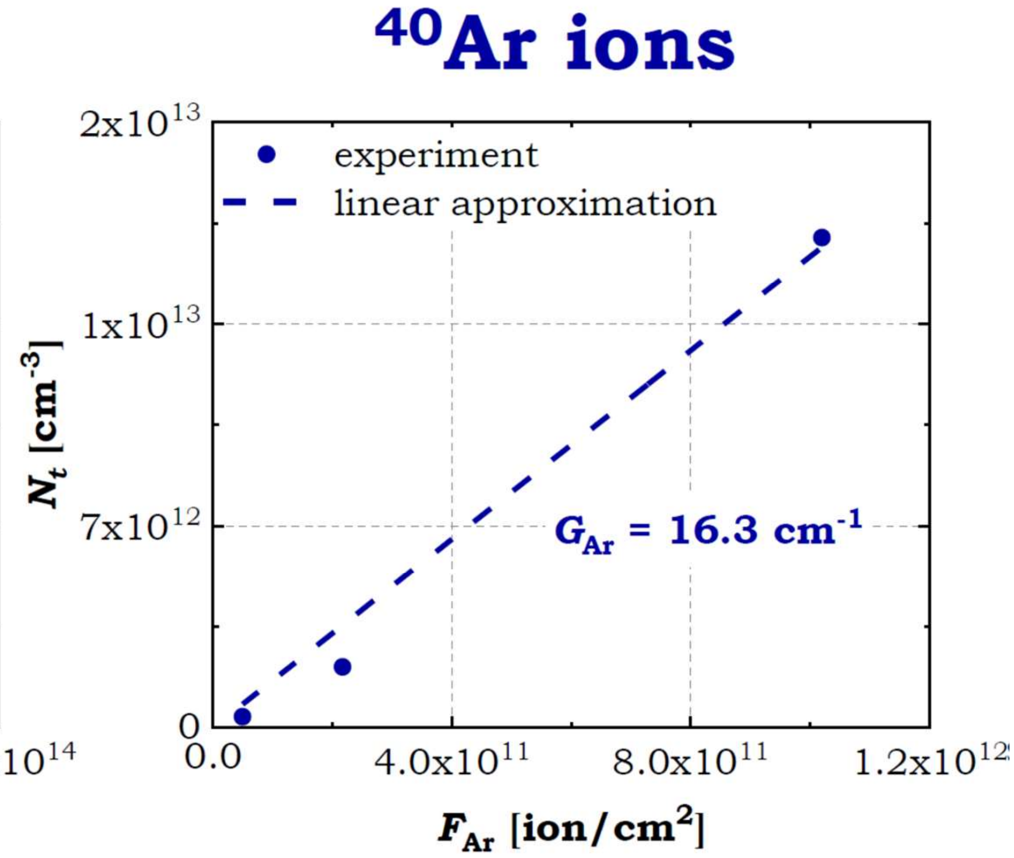


Amplitude of the peak current I_p

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

Radiation damage – introduction rate

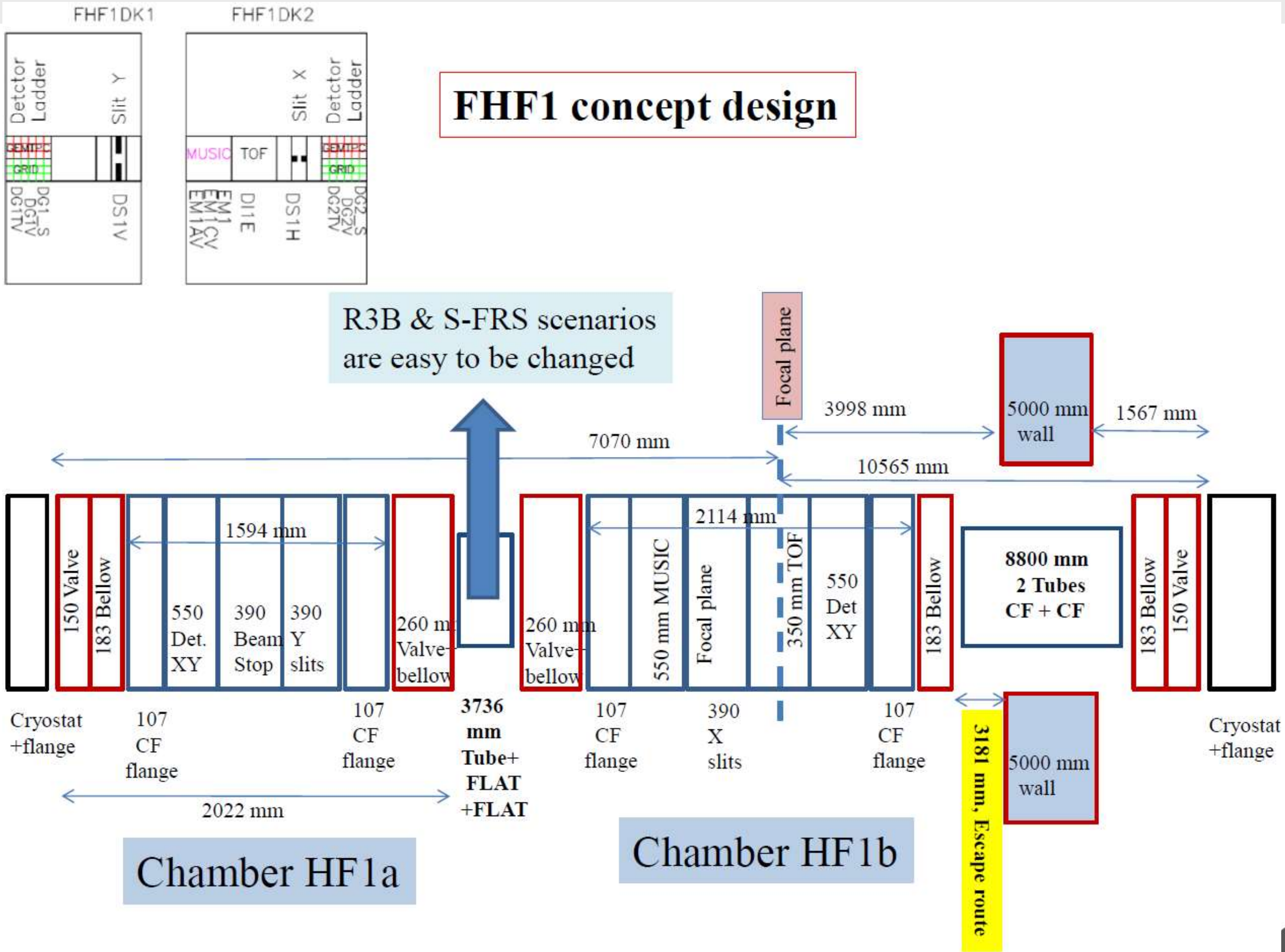




Ions/proton ratio ~11!

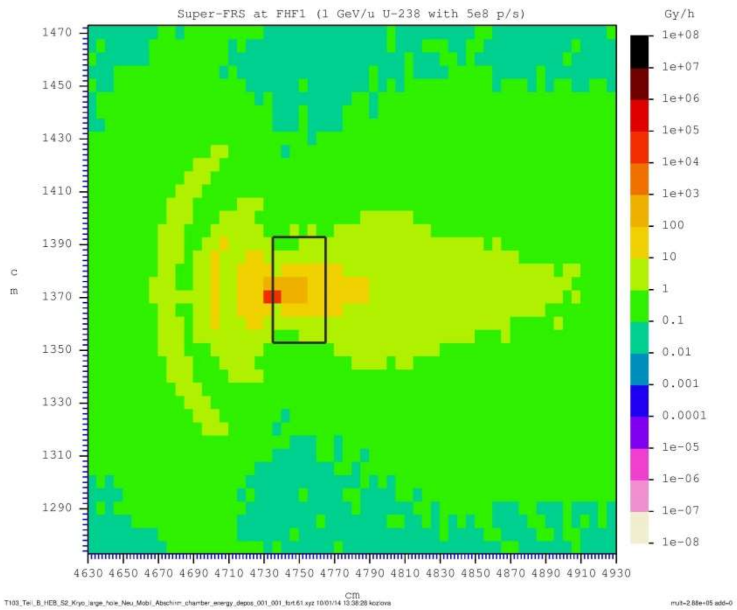
D. Mitina et al., 33 RD50 Workshop, CERN, Geneva, Nov 26-28, 2018

TOF detectors at SFRS (FHF1)



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

TOF detectors at SFRS – rad. dose



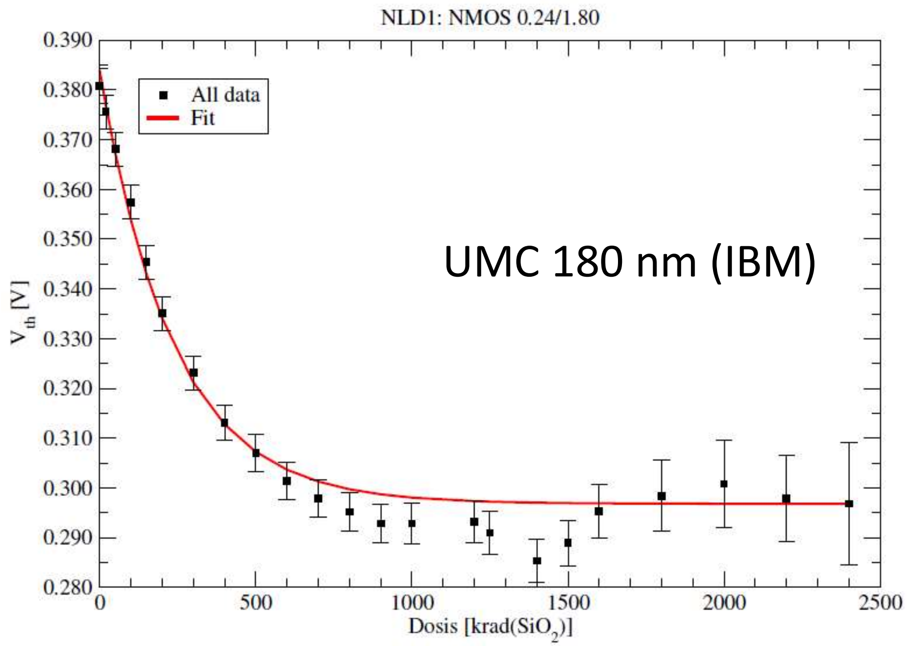


Fig. 5. Threshold voltage shift of a single NMOS transistor (0.24/1.80) for different dose levels.

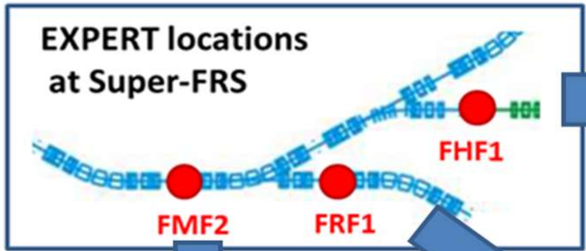
S. Löchner, Proceedings of European Conference on Radiation and Its Effects on Components and Systems (RADECS), IEEE, 2009

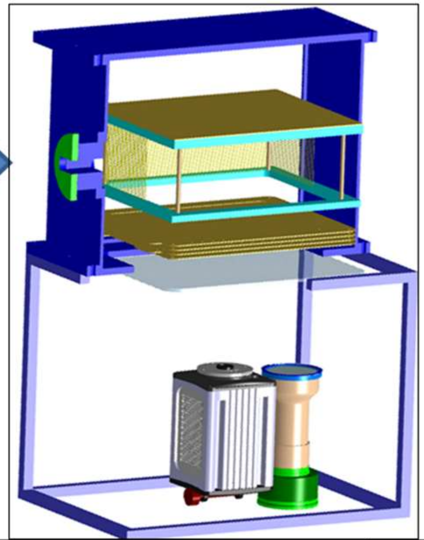
- 100 Rad/h at the position of FEE ⇒ Mrad/month (worse case)
- FEE should be rad. hard at Mrad level
- Location of FEE – better 10-20 cm from the beam if possible

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

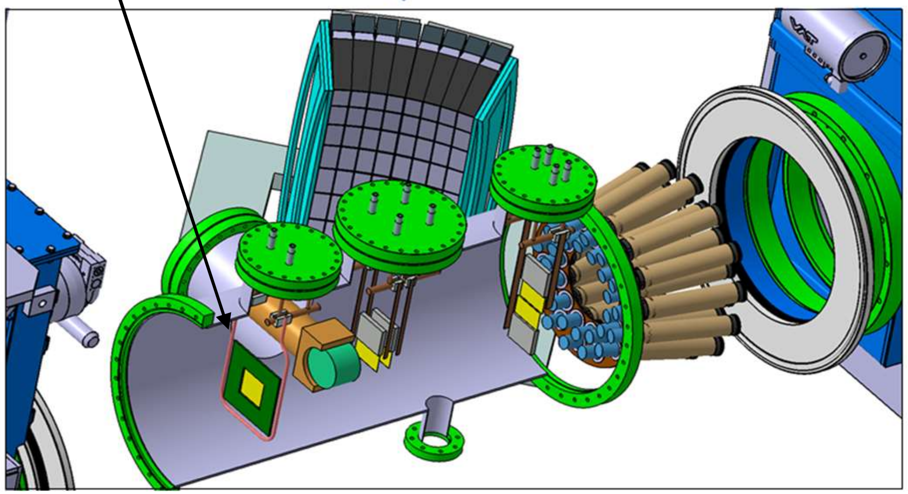
Detectors EXPERT at different locations

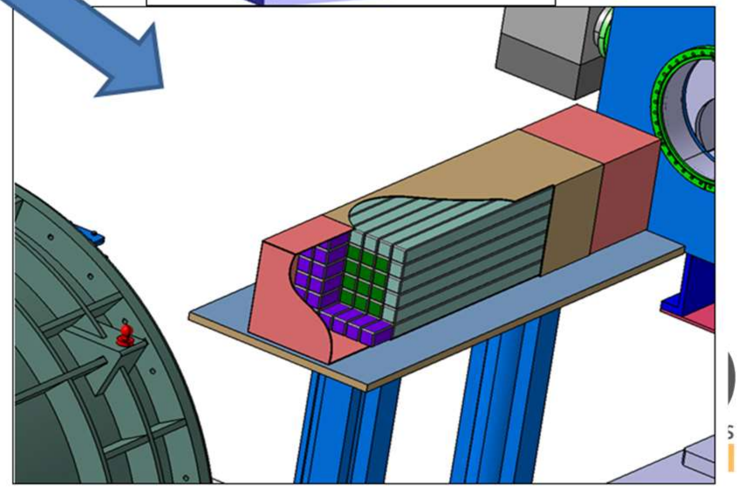
Super-FRS Experiment Collaboration



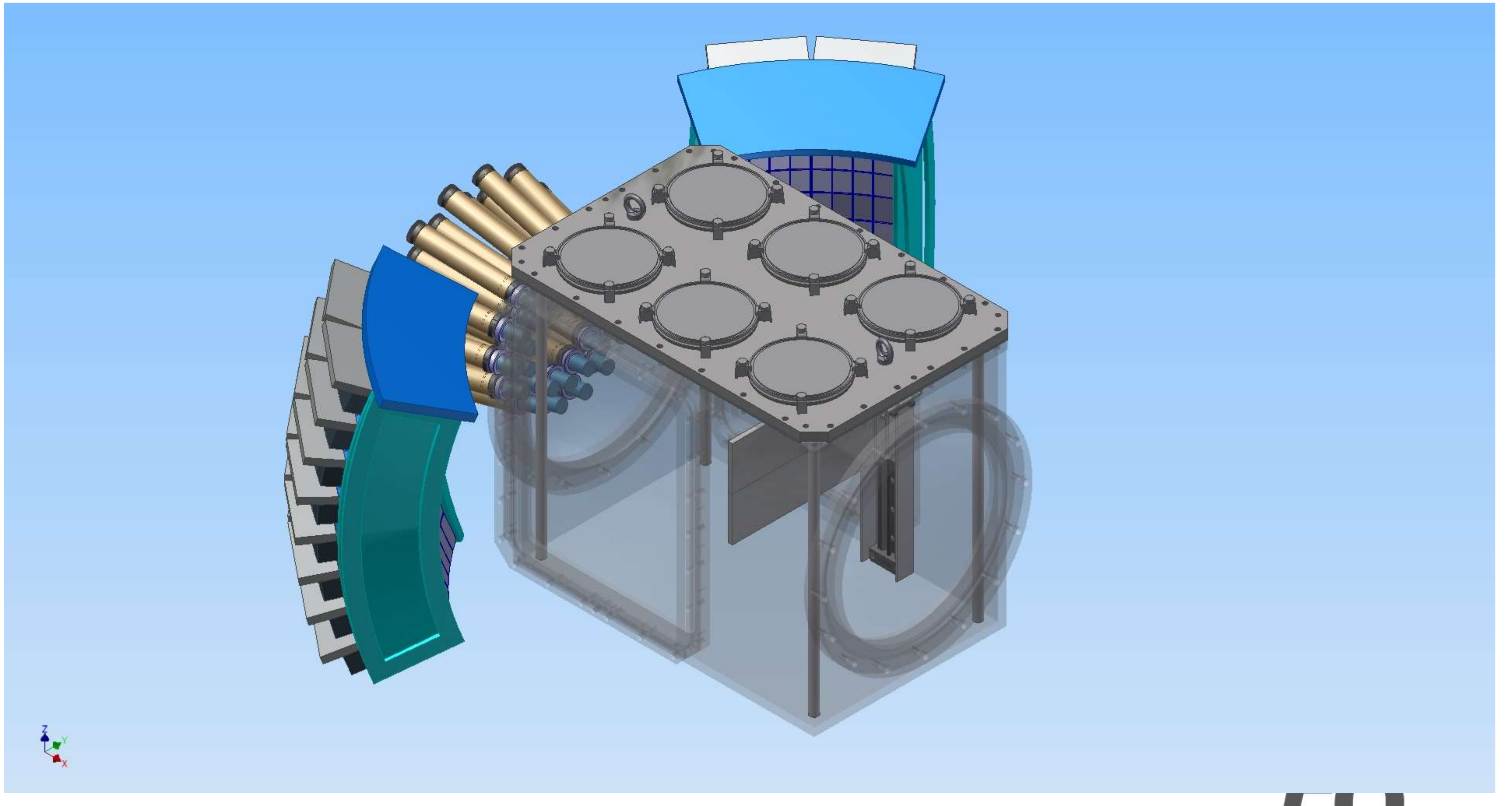


Si TOF detectors



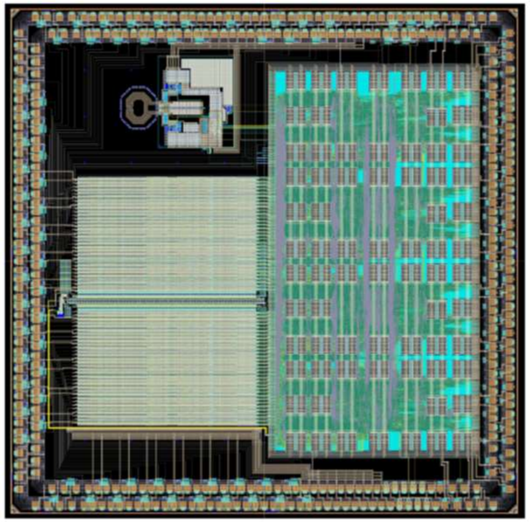


Vacuum chamber for the EXPERT detectors



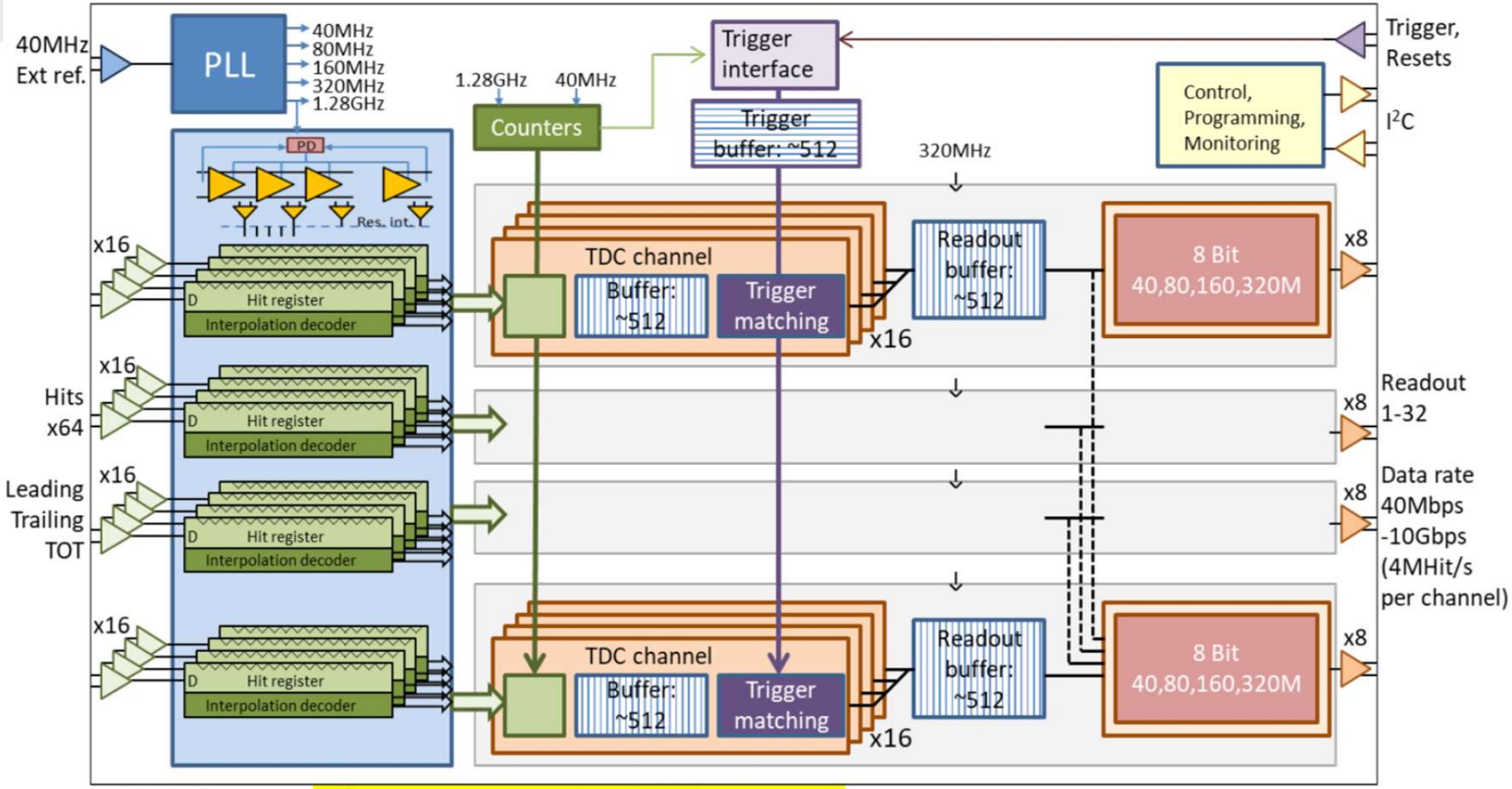
New TDC for Si TOF detectors

- PicoTDC: Pico-second TDC
- Based on the design of HPTDC/CERN
- Non-triggered or trigger with configurable latency and length, overlap possible
- **3 ps or 12 ps binning**
- **32 or 64 channels per ASIC**
- 100 µs full range
- 25 bit leading edge measurement
- Time-over-Threshold measurement



Jorgen Christiansen, Moritz Horstmann, et al. (CERN)

New TDC for Si TOF detectors



TDC Architecture (Change: separate trigger FIFO per group)

- Low power consumption – 1 W @ 3 ps/64 ch at event rate – up to 320 MHz/ch
- TSMC 65 nm production technology – rad. hard up to 100 Mrad
- **Cost – 1-2 CHF/ch**
- Limited production – 2018; testing of fist chips by the users – Q2-Q3 2019
- **Possible synergy with the other projects**

Conclusions

- Si detectors are rather universal – can measure energy, coordinates and time
- Detecors can work in different environment – vacuum (including UHV), air, room and low temperature
- As any of solid state detectors, Si detectors are sensitive to the radiation but this is measurable and predictable
- TOF resolution for the heavy ions can be as low as 15-20 ps (σ)
- Timing of the Si planar detectors can be explained and calculated $\rightarrow$ predicted
- Feasibility is demonstrated, large-size system can be made