Position-sensitive diamond detector prototype for the Super-FRS

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Contents

- **Particle identification (PID)**
  - requirements & developments needed for the Super-FRS

    ToF detectors

- **Progress on the Super-FRS diamond project**
  - results of 2014 experiments

    direct comparison ToF diamond vs standard FRS
  - future experiments

PID at the Super-FRS

- **Increasing intensity of radioactive beams** requires detecting system with high-rate capability and remote handling/control

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

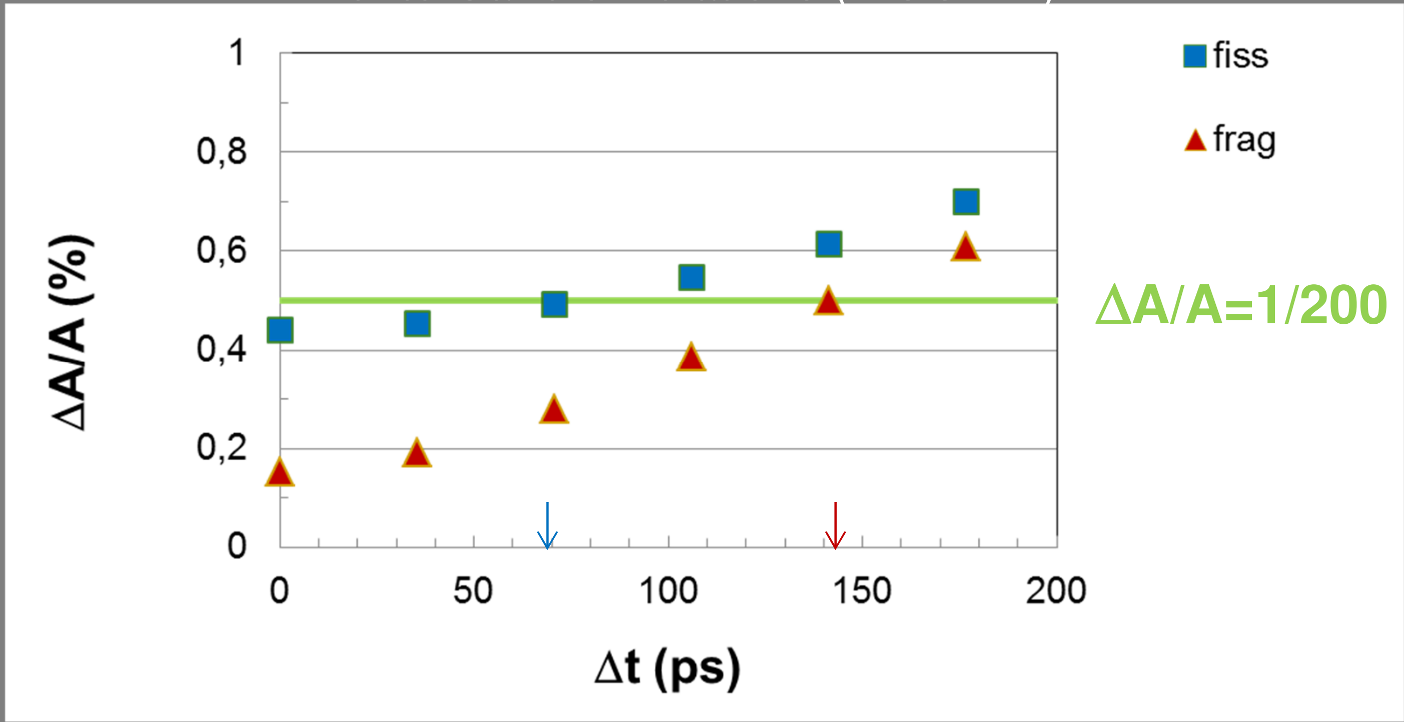
  $\rightarrow$ momentum tagging $\Delta x \sim 1mm$

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

Nowadays, tracking detectors reach resolution of some tens of mm, thus the velocity resolution at the separator is limited by the performance of the time measurement.

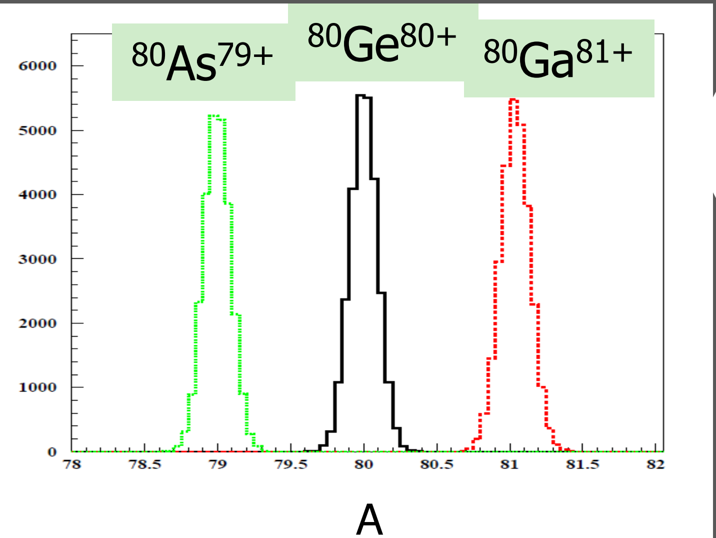
Resolution

Monte Carlo simulations (MOCADI)



C. Nociforo, 2014 *JINST* 9 C01022

Isotope identification

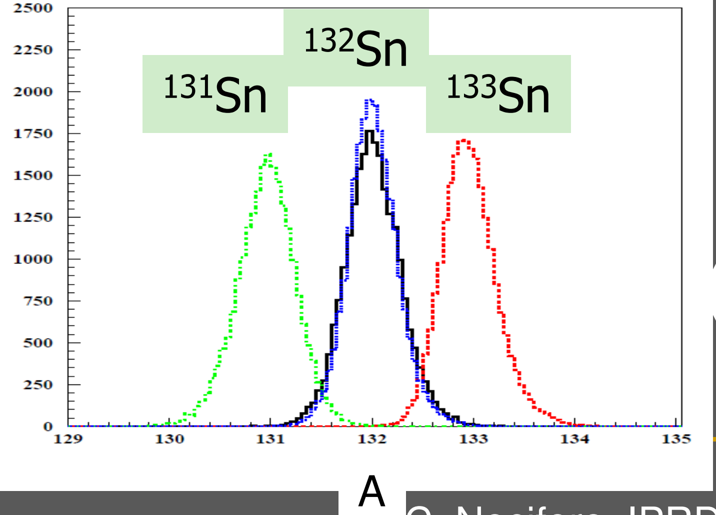


fragmentation $^{86}Kr + C \rightarrow\ ^{80}Ge$

Monte Carlo simulations

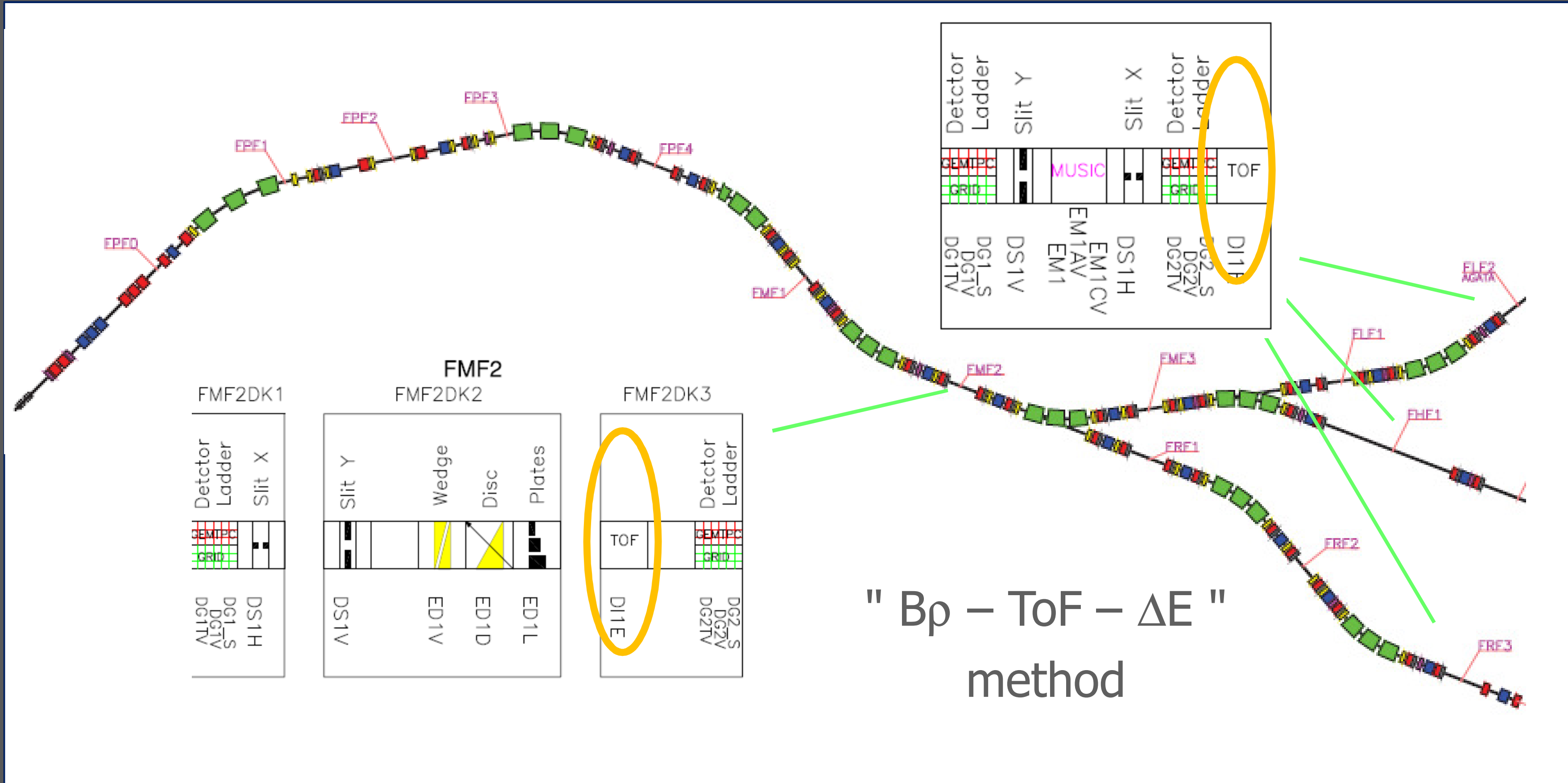
(Yields not scaled)

σ_t= 30ps, σ_x= 0.5mm



fission $^{238}U + C \rightarrow\ ^{132}Sn$

Layout of the Super-FRS beam line

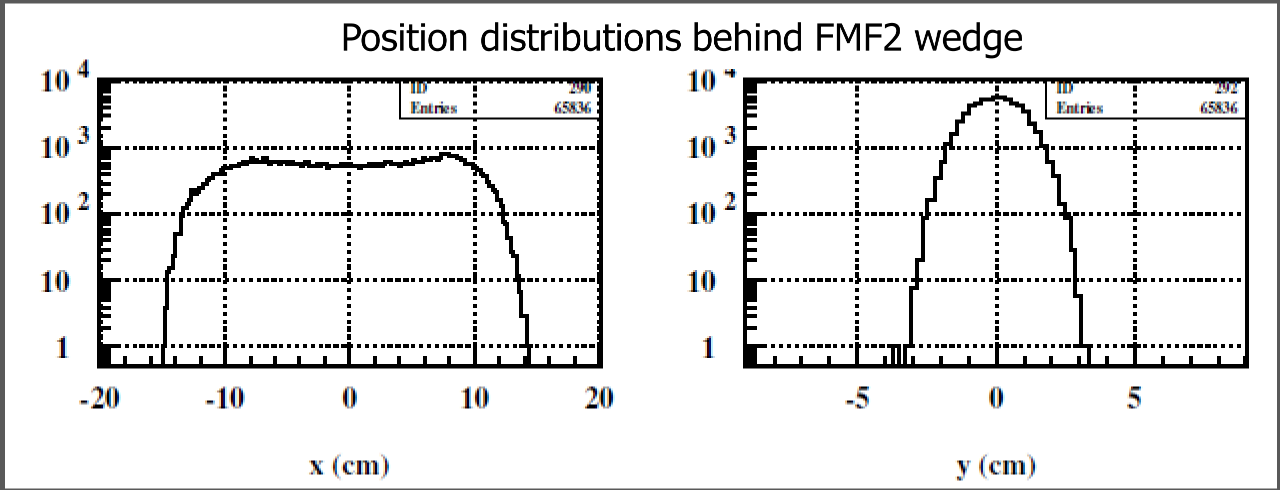


Intensity	10^{12} /s	$<10^{10}$ /s	$<10^{9}$ /s	$<10^{7}$ /s	$<10^{5}$ /s

ToF requirements

- **Radiation-hard solid state detector** (e.g. diamond, silicon)
  - 4 units working in vacuum
  - active area 380/200mm x 50mm
  - max rate 500 Hz/mm^2

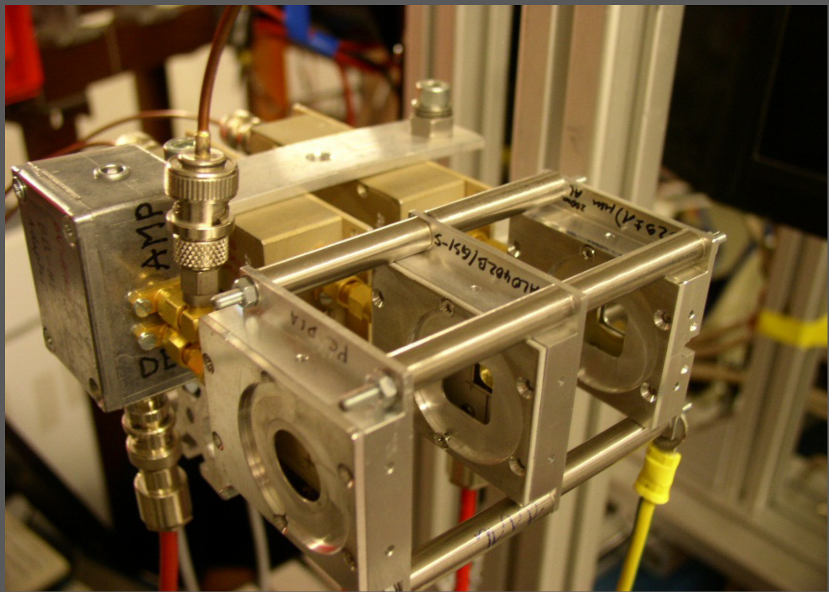
U fission fragment
MOCADI simulation



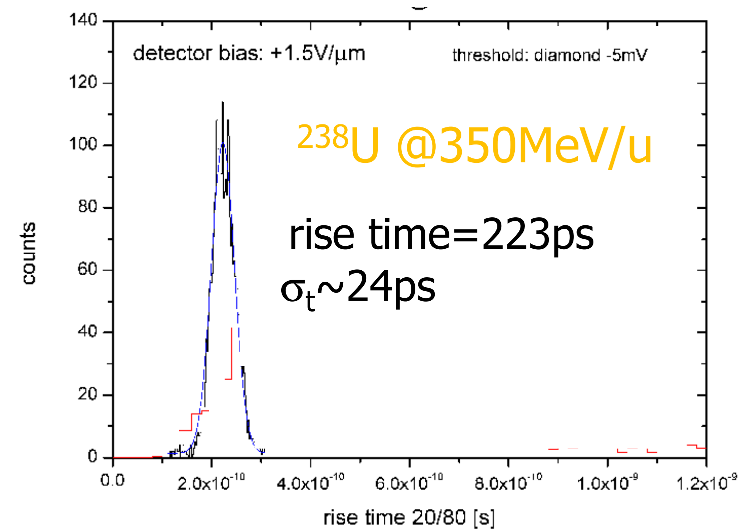
- **Multi-channel fast readout board** (NINO, PADI, ...)

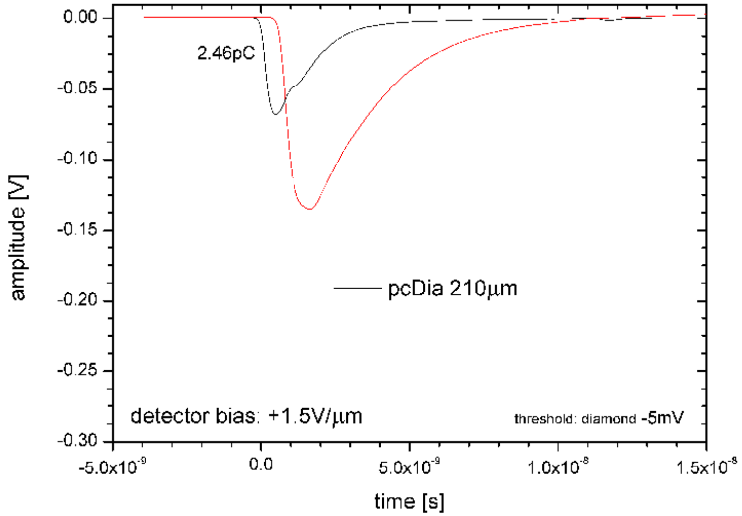
Diamond time properties

pcCVD -DD **10x10x0.2 1 mm^3**



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

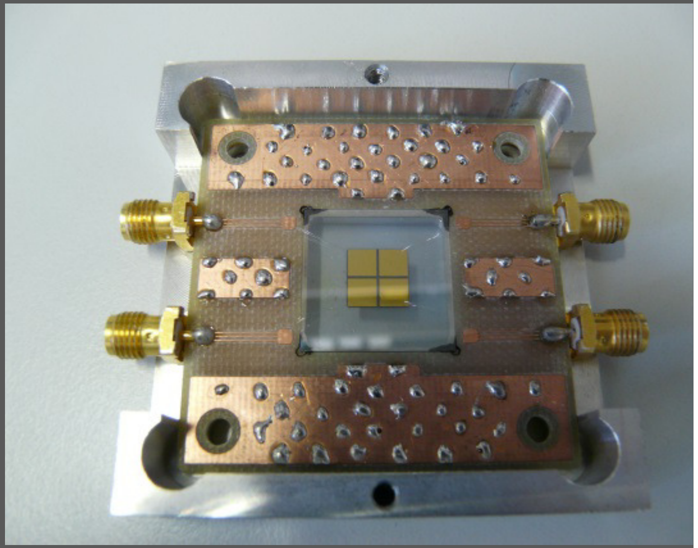




GSI-DL
GSI-FRS

Irradiation test in Dubna

Performed at ACCULINNA separator with 40.5 MeV/u Ar beam, detectors operated in vacuum.

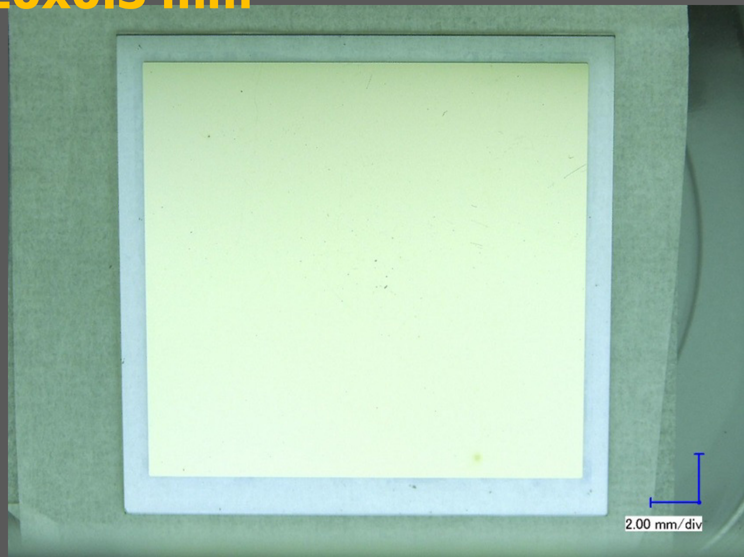


Diamond (Q)

- new sample (E6) pcCVD-DD(20x20x0.3) mm^3 with 4 Al contacts
- $\Delta E \sim 20\text{-}600$ MeV (DBA amp, $V_{in} < 50$ mV)
- 10^{11} ions/cm^2 (at least a factor 10^3 more to see any effect)
- no change in the leakage current observed during the irradiation
- ToF resolution 80ps (σ) with pcCVD-DD (10x10x0.6) mm^3 measured by VFTX .

Prototype design

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

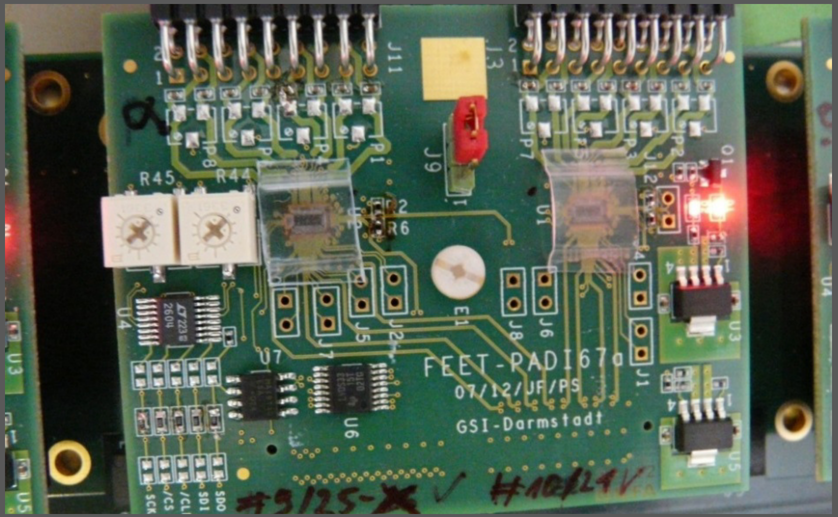


Detector processing:

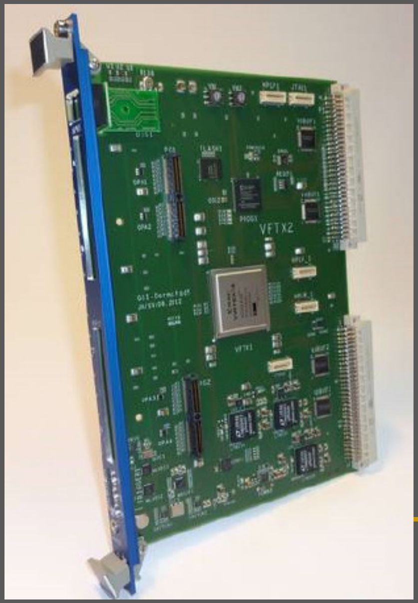
- electrode metallization with Cr/Au with thickness 50/100 nm made in-house
- photolithography by laser followed by etching made in-house
- 8 strips (1 mm) + 16 strips (0.5 mm) – gap 60 μm
- annealing of the device at 500º in Ar
- 1 year R&D

Electronics with ToT capability

- **PADI** ASIC 0.18 μm CMOS
  - rise time < 500 ps
  - 30 fC <Q< 2000 fC
  - σ < 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)
  - σ < 10 ps

GSI-DL
GSI-EE

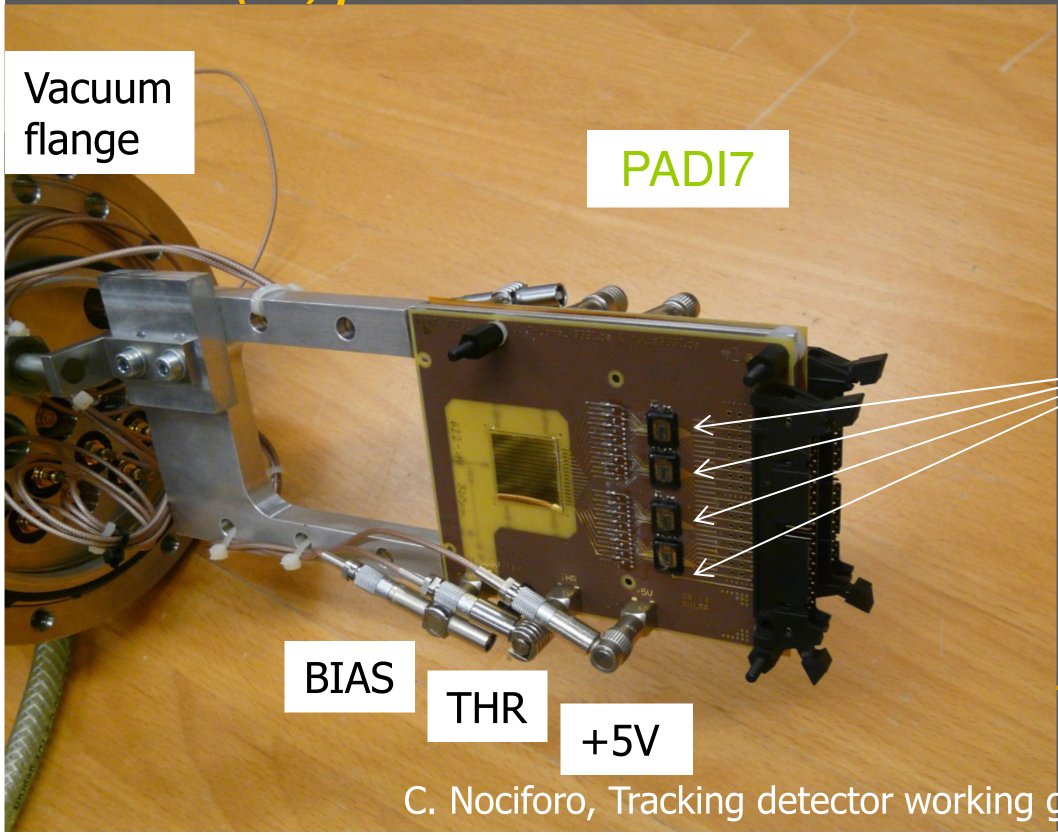
(https://www.gsi.de/fileadmin/EE/Module/Dokumente/vftx1_8.pdf)

ToF tests at FRS

Comparison of ToF (Dia S2-S4) with the standard ToF (SCI21-41) with 1GeV/u ^{197}Au primary beam.

Diamond (Strip)

2 x (E6) pcCVD -DD 20x20x0.3 mm^3



Layout

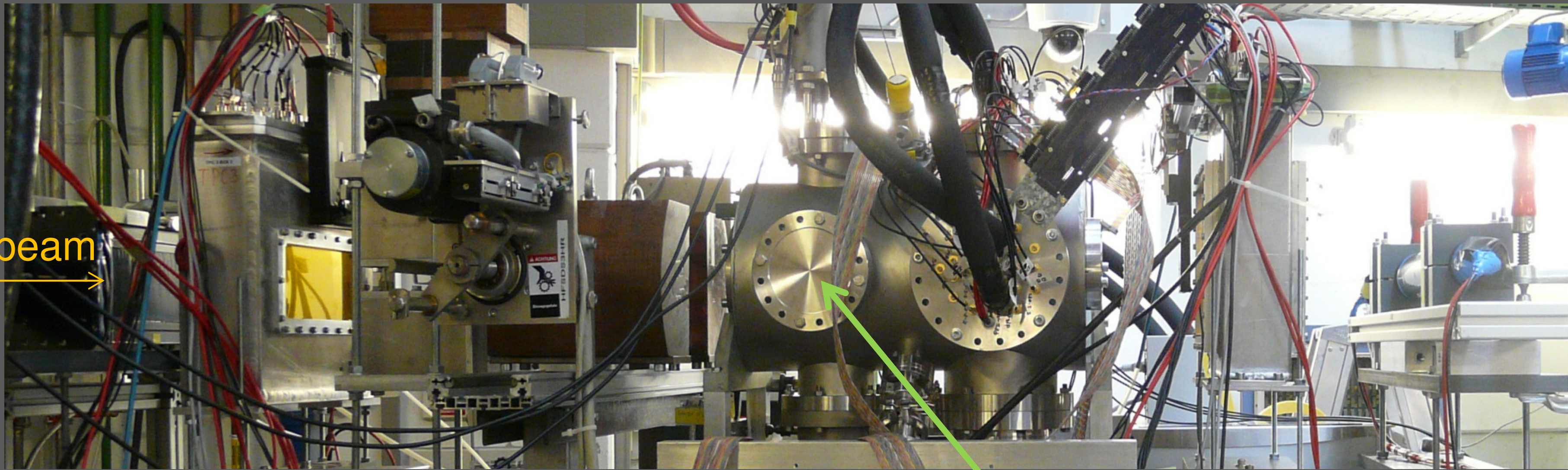
- 16 vertical strips: (1x18)mm^2 each (0.15 mm gap), C = 4.3 pF/strip

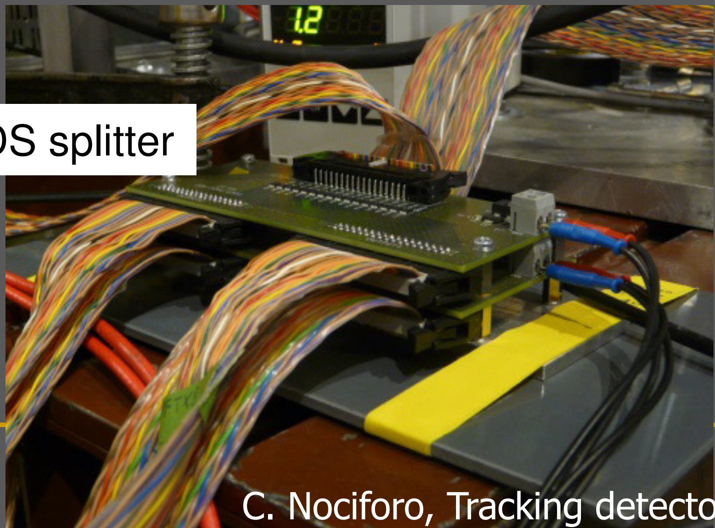
Board

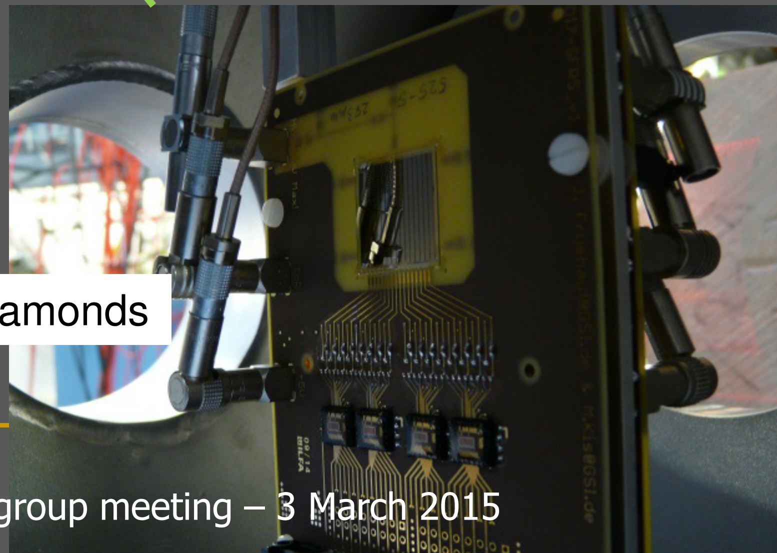
- PADI7
  gain~250, LVDS digital outputs, ToT capability

Measured PADI/VFTX time resolution σ_j = 15 ps.

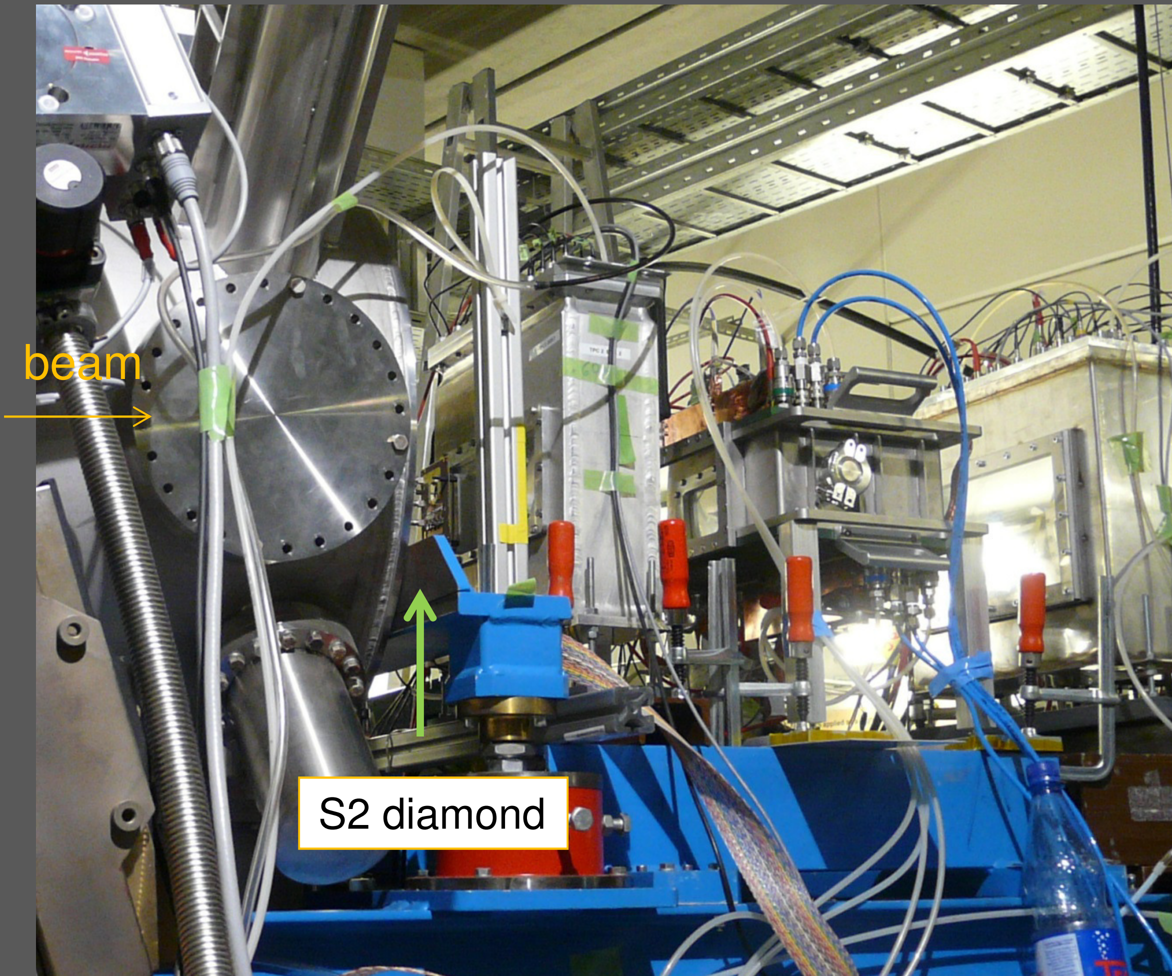
S4-FRS experimental setup







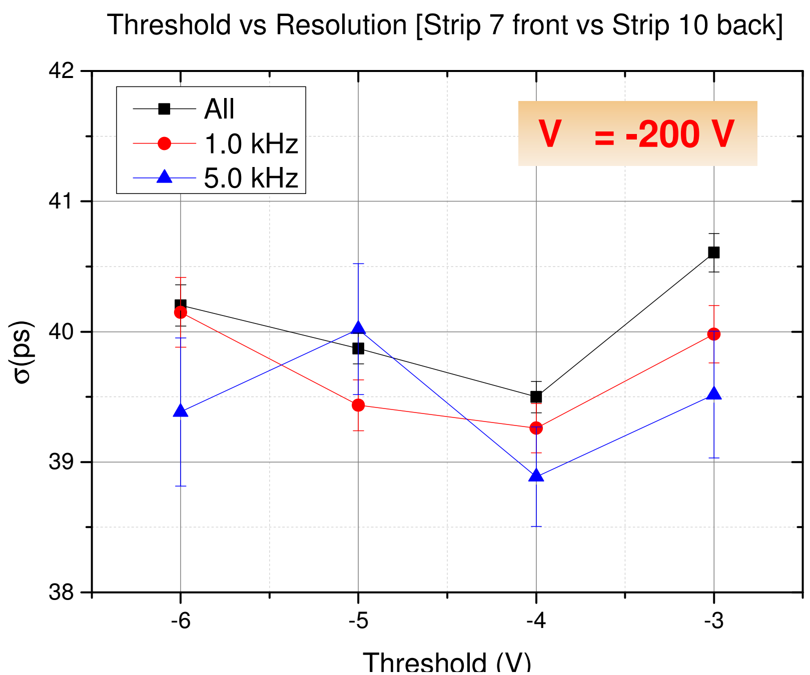
S2-FRS experimental setup



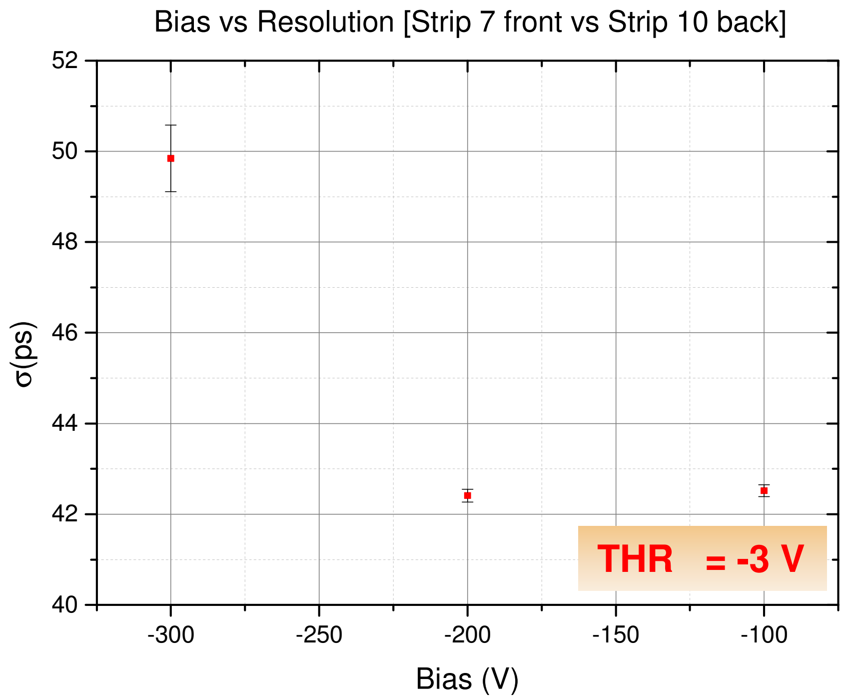
Detector characterization

^{197}Au @900MeV/u

Threshold dependence

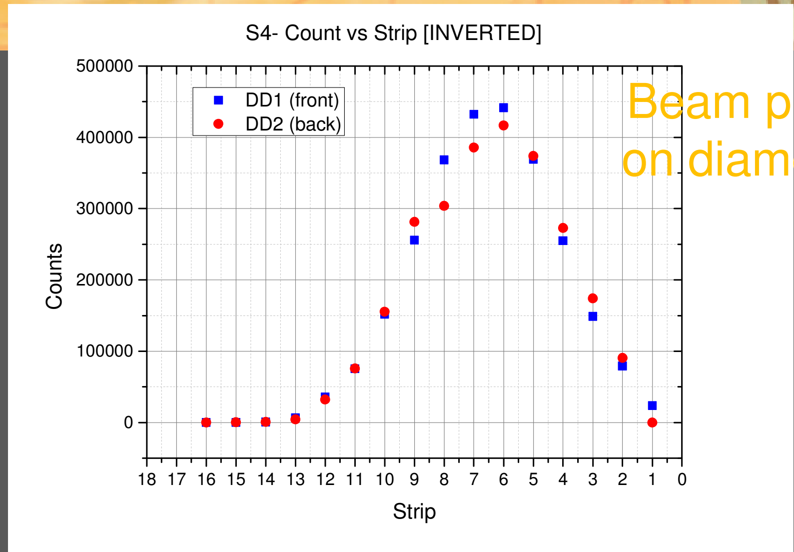


Bias dependence



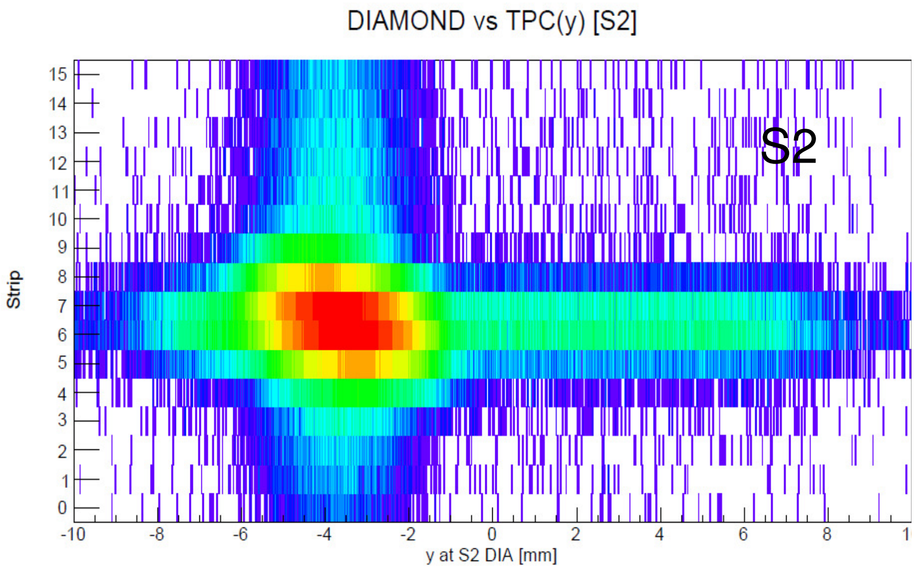
Beam spot size

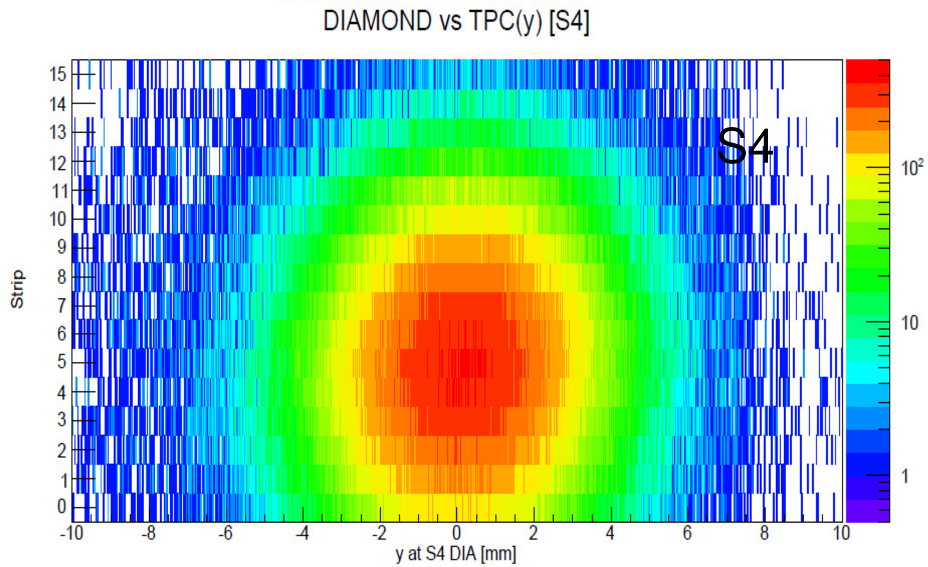
^{197}Au@900MeV/u



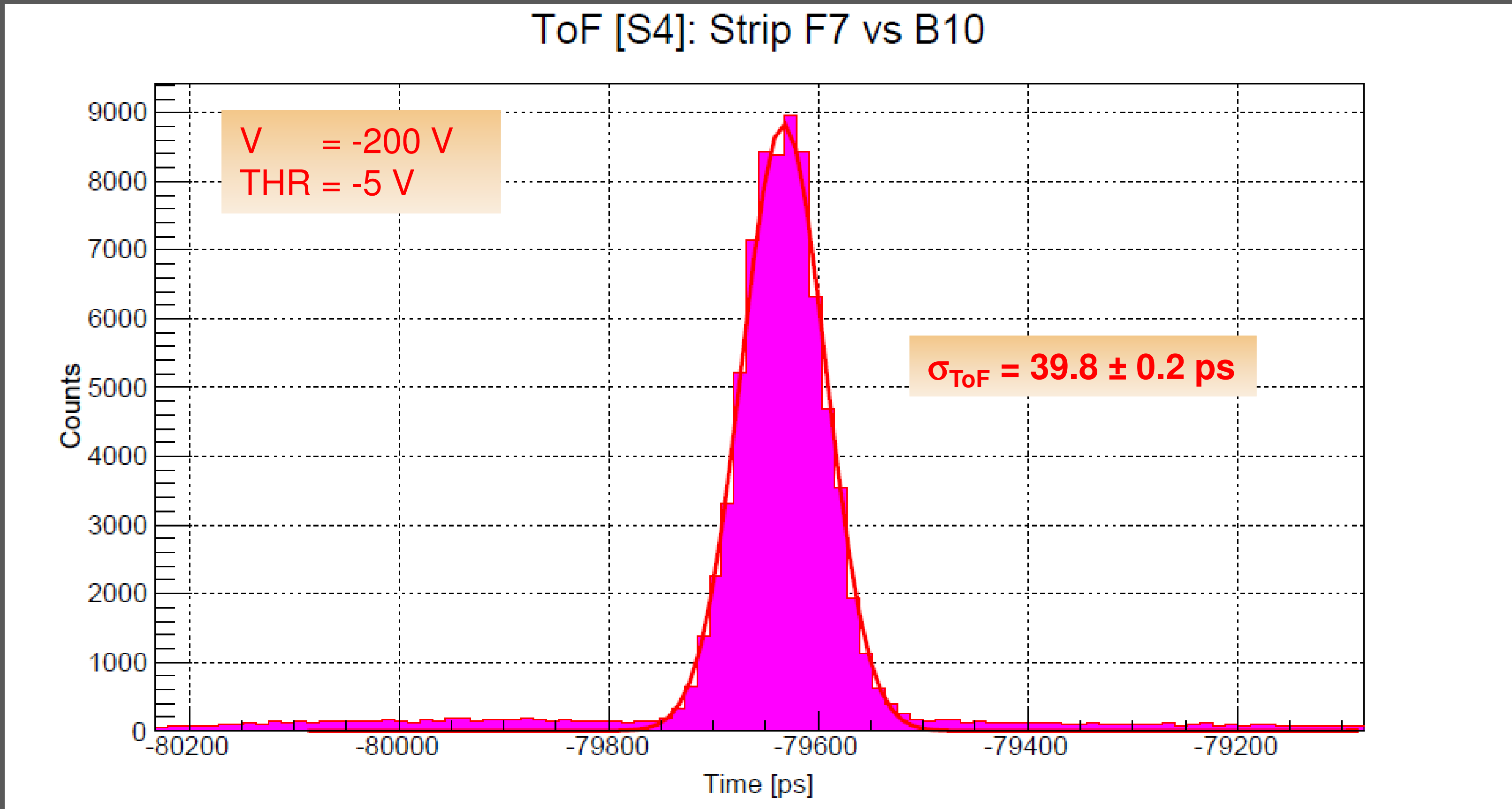
Beam profile on diamonds

Diamond data correlated to FRS detectors



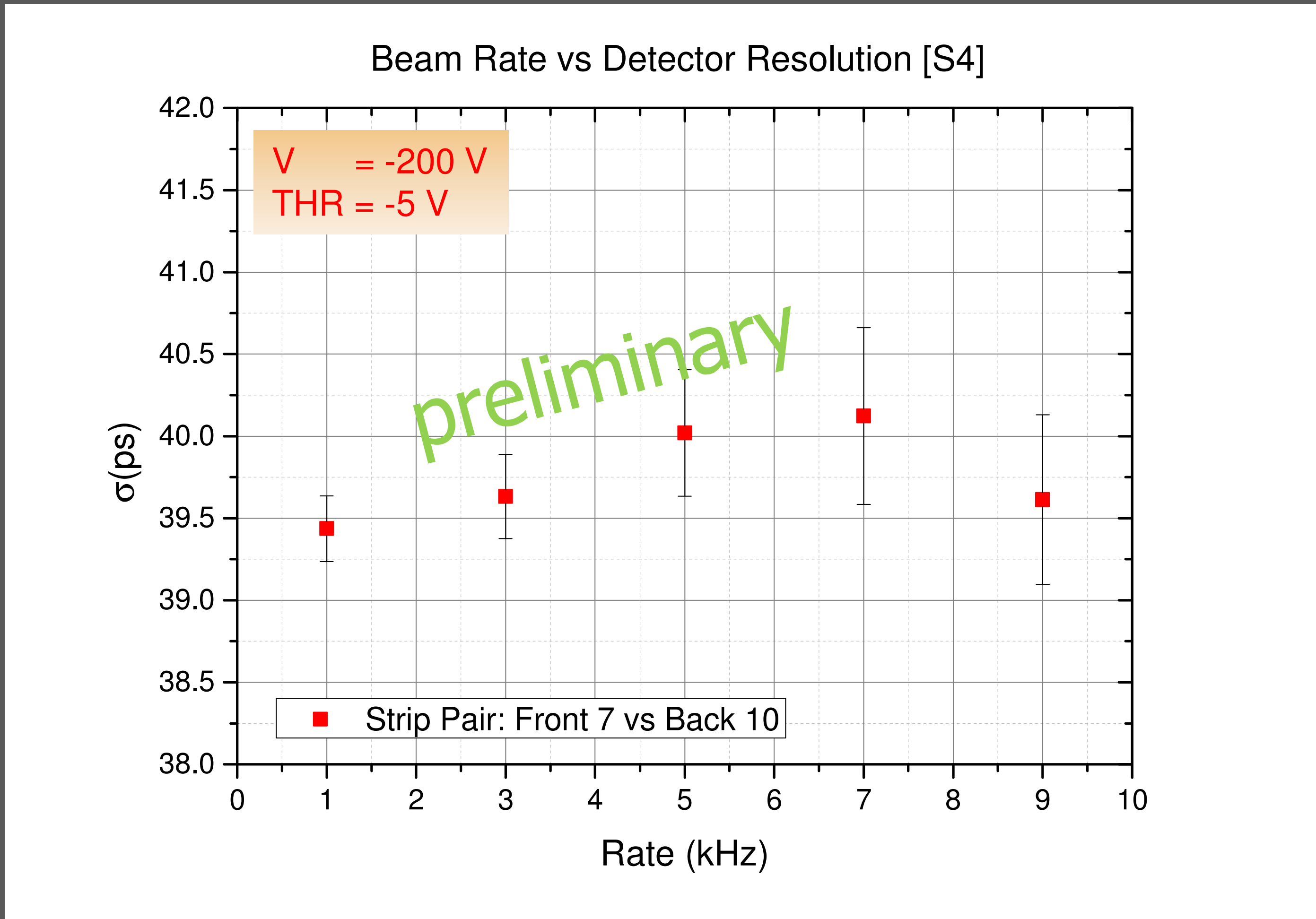


Diamond ToF (no corr)



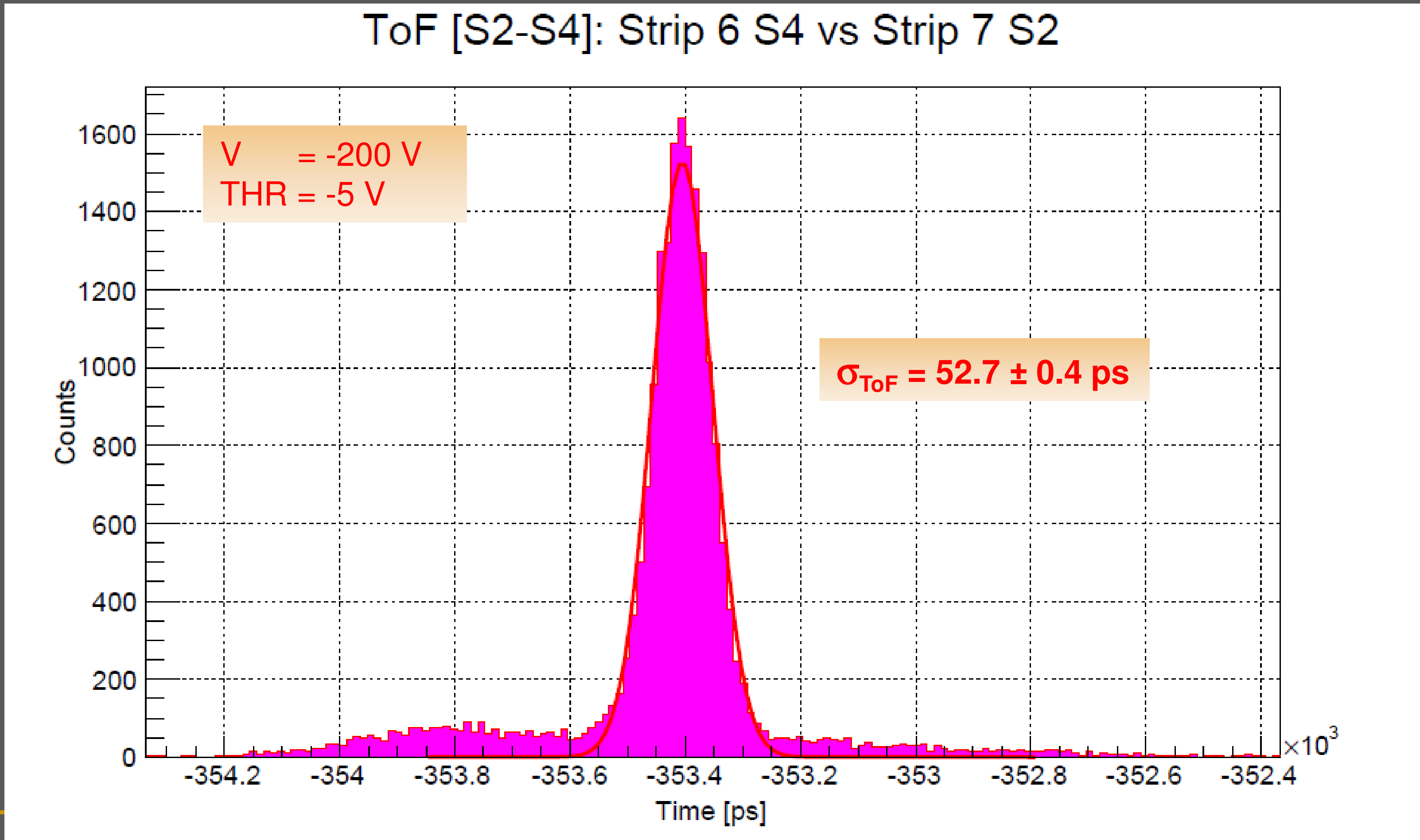
$$\sigma_{intr} = \sigma_{ToF}/\sqrt{2} = \sqrt{\left((\sigma_{start}^2 + \sigma_{stop}^2) /2\right)}$$

Diamond rate dependence

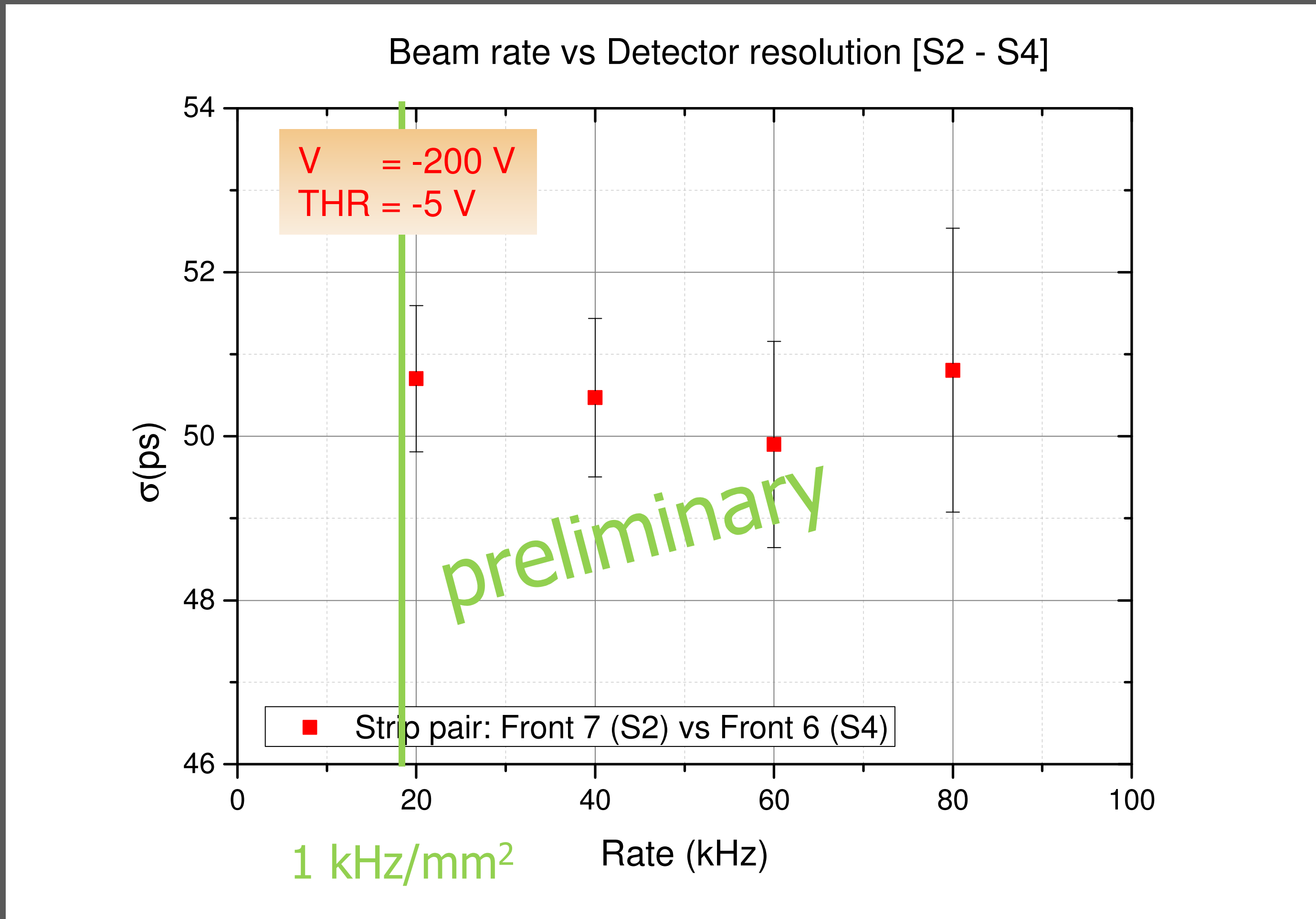


Diamond ToF S2-S4 (no corr)

Synchronization made by 200 MHz clock distributed over 40 m.

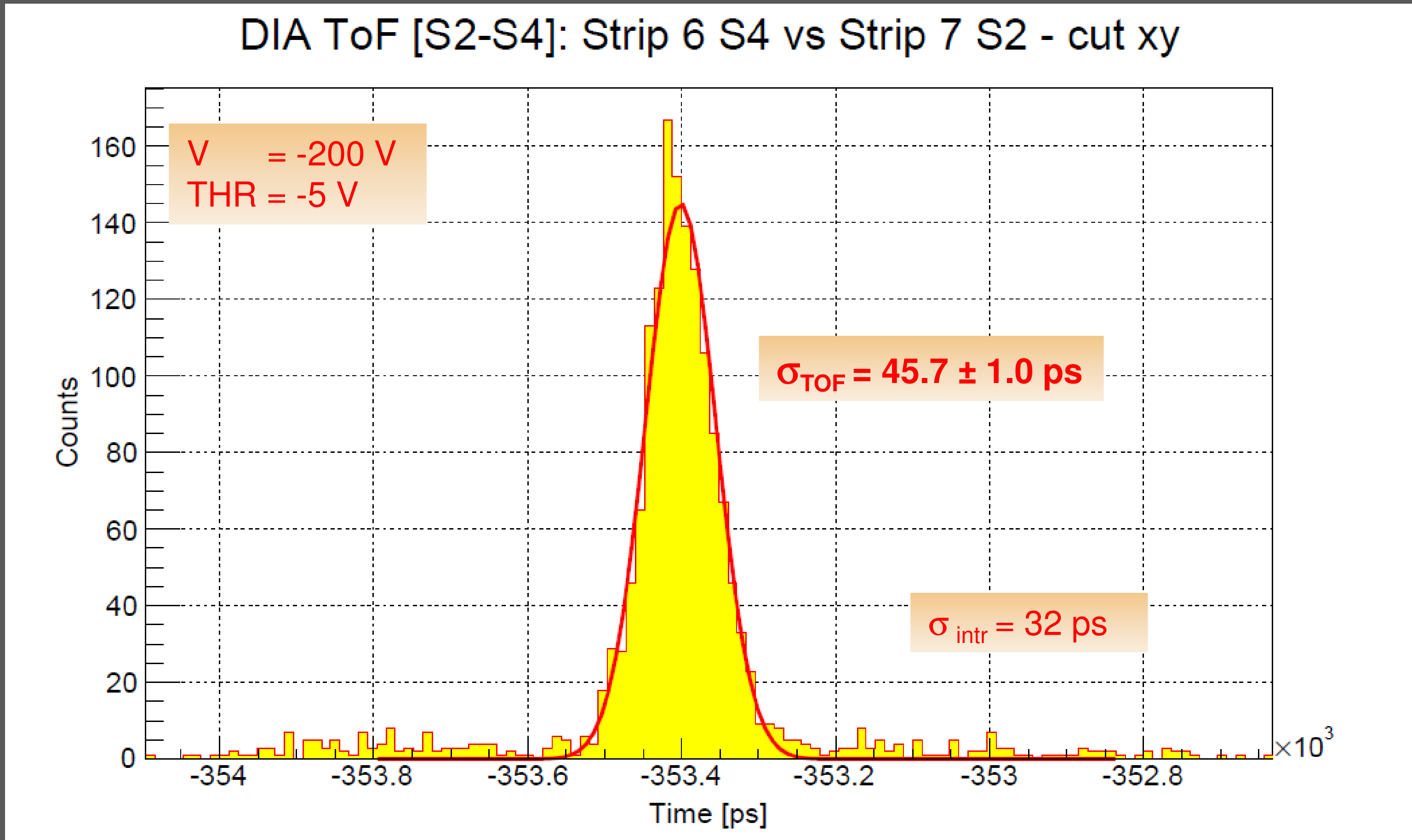


Diamond rate dependence

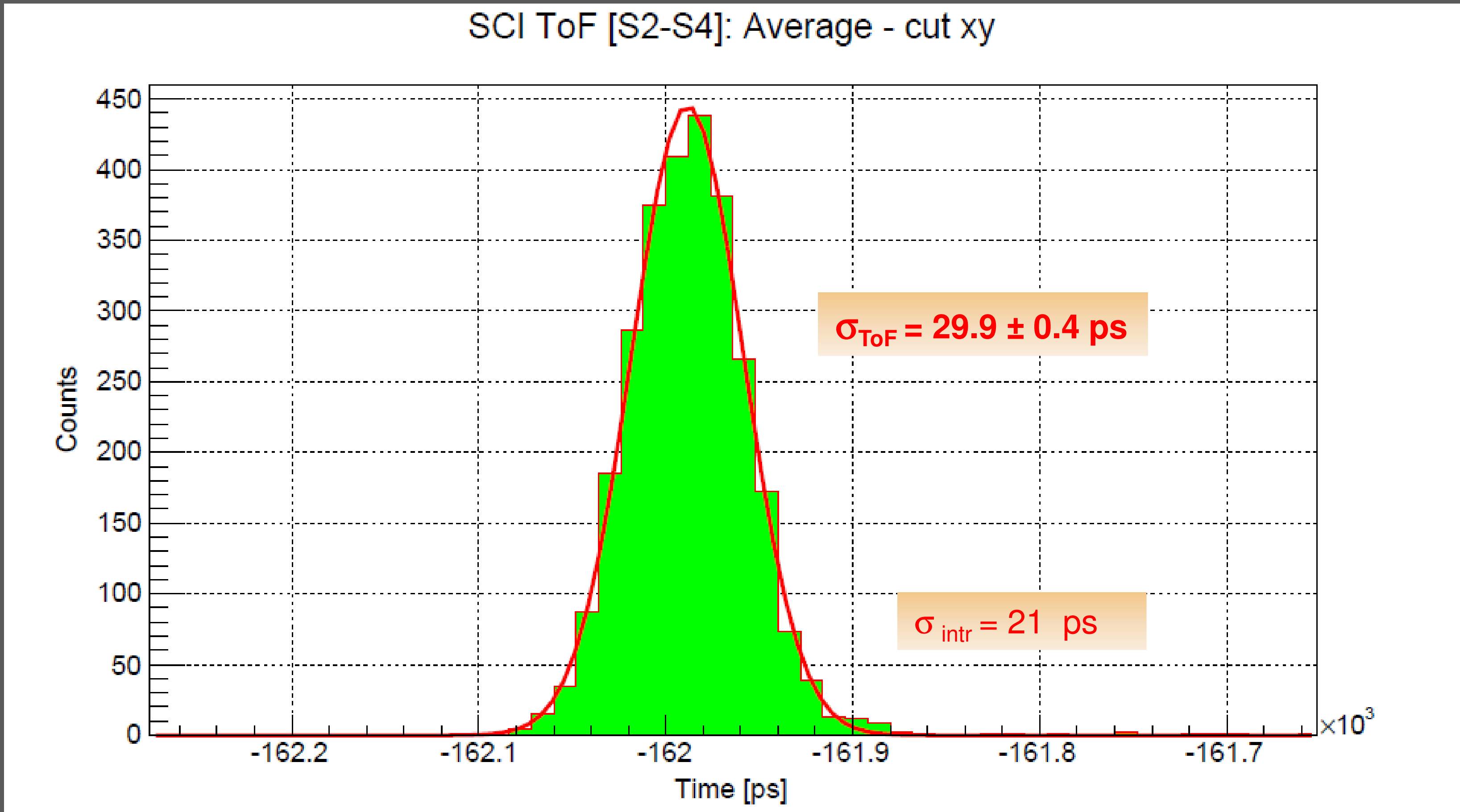


Diamond ToF distribution (pos corr)

Cut: [S4: 0.4<x<1.0 , -1.0<y<1.0], [S2: 5.9<x<6.4 , -4.0<y<-3.0] (mm)



Standard ToF distribution



ToF = 0.5 * [(SCI41L-SCI21L)+(SCI41R-SCI21R)]

σ_{intr} contribution

Diamond	Scintillator	σ (ps)	±Δσ (ps)
DIA(S4) Front Strip 7	SCI41L (S4)	35.3	0.8
DIA(S4) Back Strip 10	SCI41L (S4)	50.7	1.3
Being everything connected to the same crate, electronic noise (15 ps for 32 ch VFTX) is the same for both diamond sensors.			

The back diamond strip detector shows worse performances, later moved to S2.

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 ps

$\sigma_{intr,DD2}$=35 ps

Comparison ToF DIA vs SCI

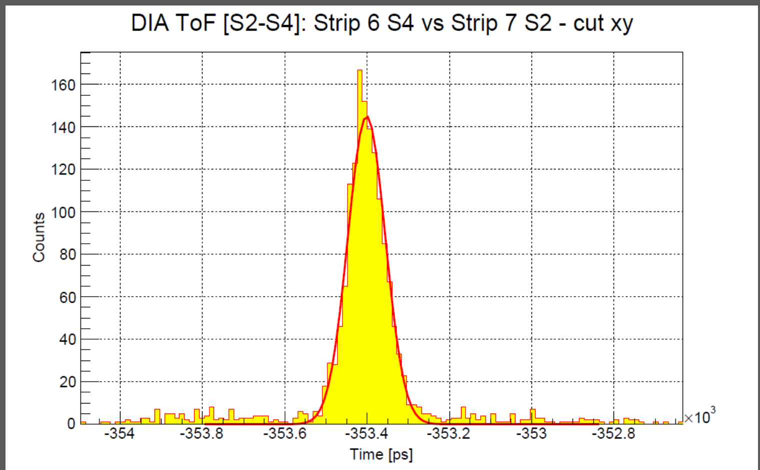
	Distance (m)	σ_{ToF} (ps)	Note
DIA (S4)*	-	≈40	strip-strip time difference
SCI	-	18	L-R time difference
DIA (S4)-DIA (S2)*	34	≈50	strip-strip time difference
SCI	34	36	gated on strip position
DIA (S4)-DIA (S2)*	34	≈45**	after x,y cut by TPC
SCI	34	30	after x,y cut by TPC

* One detector shows better performances
** Time resolution can be improved with ToT correction

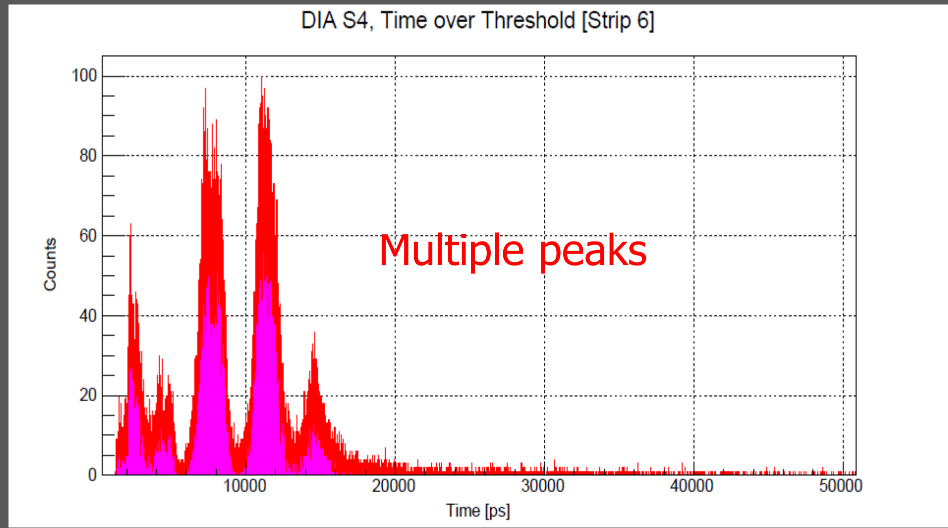
To do

- recovery of interstrip events and multiple hits (in progress)

- presence of background due to the electronics (not well understood)



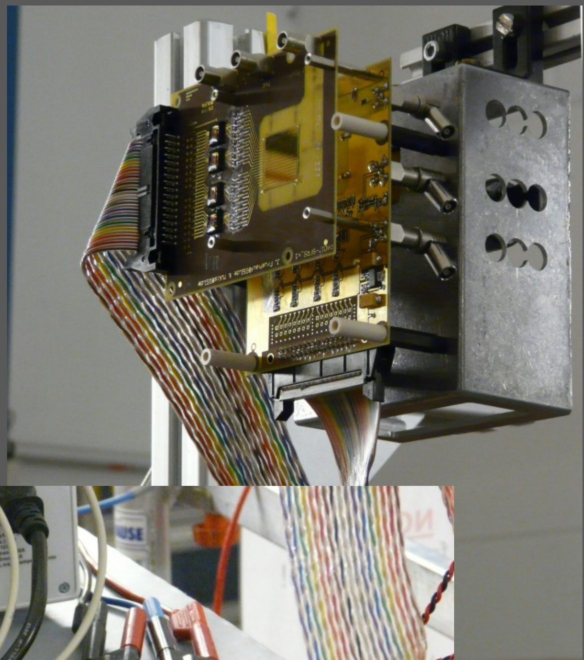
- A/q reconstruction (in progress)



- ToT corrections

The presence of multiple ToT peaks did not allow to perform a correlation between rise and trailing time.
ToT allows corrections for the energy deposited and may lead to marked improvements on σ_{ToF}

Diamond test in HADES cave

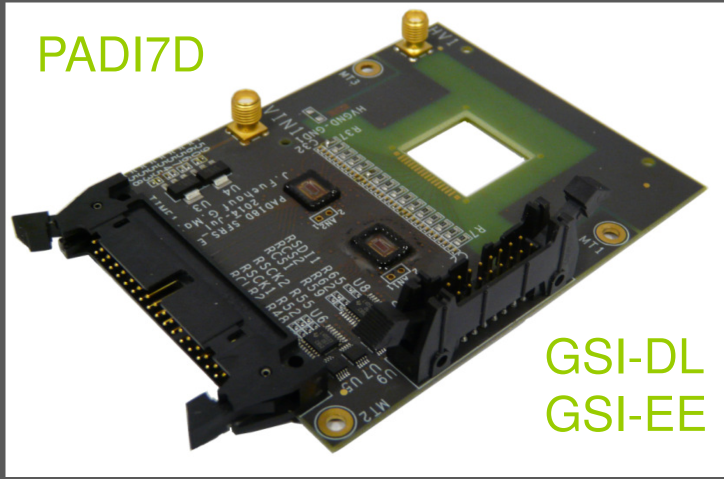


<u>Same</u> strip diamonds tested few weeks later during CBM detector test with 1.1 GeV/u Sm beam

- Front detector rotated by 90° (position cut 1mm^2)
- Signals read out (CBM DAQ) with two different FPGA TDCs and optical data transfer
- Preliminary measured time resolution ~ 25 ps (σ), confirmation of the FRS results.

Future experiments

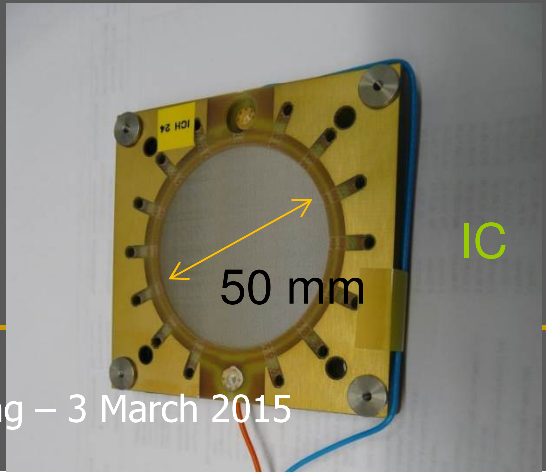
- **Test of new PADI board at CERN**
  - new chip PADI7D (distance reduced)
  - 8 channels
  - new threshold control



- **Irradiation test at LNS-INFN with ^{12}C @62 MeV/u**

Series of irradiation at intensity $2x10^8$ $^{12}C/mm^2$ s followed by data taking at low rate to monitor the CCE and the time resolution of the diamond material
Goal: $7.9x10^7$ Gy total absorbed dose

Integrated beam current measured by IC built at GSI-DL.



Summary

- **Solid state radiation hard material represents a real possibility to obtain a clean PID at the Super-FRS, especially of the fission fragments**

- **Strip diamond detectors can be successfully processed in house**

- **Results of in beam tests performed with diamonds in condition similar to that of the Super-FRS show that a ToF resolution below 100 ps (FWHM) is achievable**

Outlooks: new electronics and sensors have being prepared in view of 2015 beam time.

Acknowledgment

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I-V characteristics