SIRIUS commissioning at GANIL

SIRIUS, a detection system for decay spectroscopy @ S^3

Rikel CHAKMA on behalf of the SIRIUS collaboration

S3 has been funded by the French Research Ministry, National Research Agency (ANR), through the EQUIPEX (EQUIPment of EXcellence) reference ANR-10EQPX- 46, the FEDER (Fonds Européen de Développement Economique et Régional), the CPER (Contrat Plan Etat Région), and supported by the U.S. Department of Energy, Office of Nuclear Physics, under contract No. DE-AC02-06CH11357 and by the E.C.FP7-INFRASTRUCTURES 2007, SPIRAL2 Preparatory Phase, Grant agreement No.: 212692.

SIRIUS has been funded by the CPIER (Contrat Plan Etat Inter Régional)

Rikel Chakma's contact is funded by the Région Normadie & FEDER through the SoSIRIUS RIN tremplin Grant

Outline

Motivation

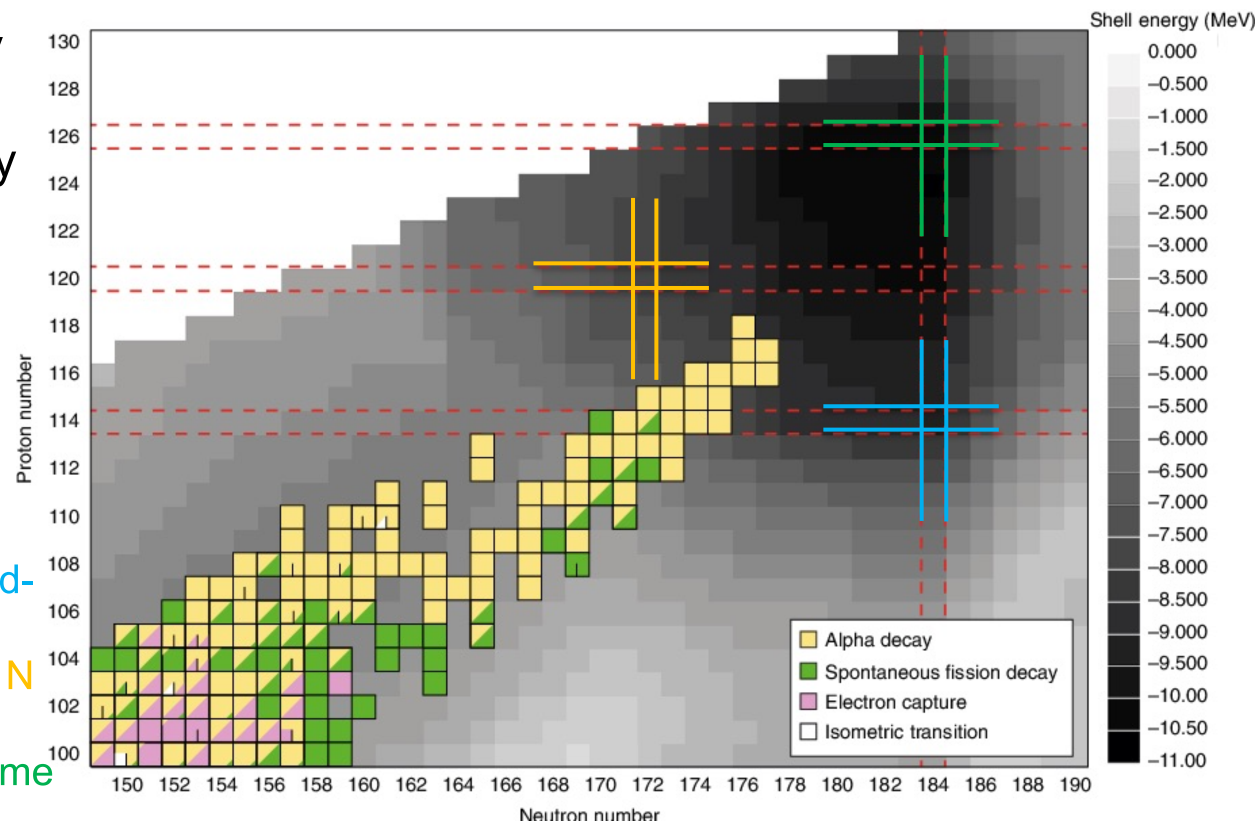
- Probe and understand nuclear structures of heavy and superheavy nuclei
- Locate the island of stability (Modern nuclear theories disagree on the next spherical shells beyond ^{208}Pb)

Location of the island of stability:

- Macroscopic-Microscopic (Folded-Yukawa): Z = 114, N = 184
- Relativistic mean-field: Z = 120, N = 172
- Density functional theories (Skyrme or Gogny interaction): Z= 126, N =184

M. Bender et al., Physical Review C, **60,** 034304

H. Haba, *Nature Chem* **11,** 10–13 (2019).



Motivation

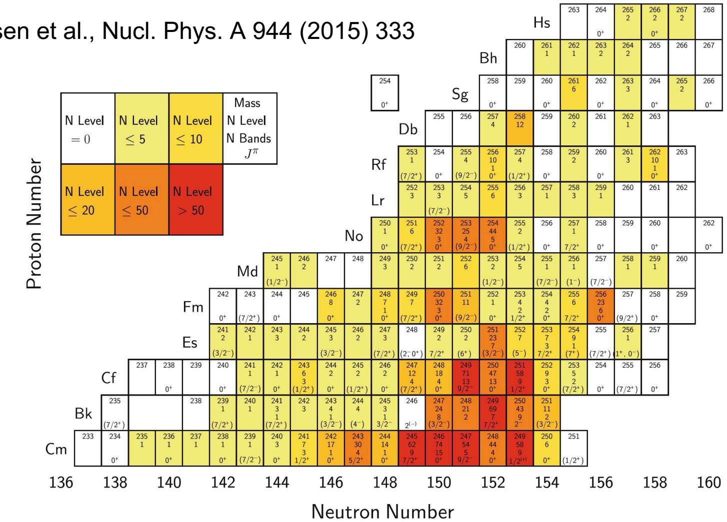
➢ A large body of experimental data (single-particle and collective states through prompt and decay spectroscopy) is required to guide the theories or identify which one is more realistic

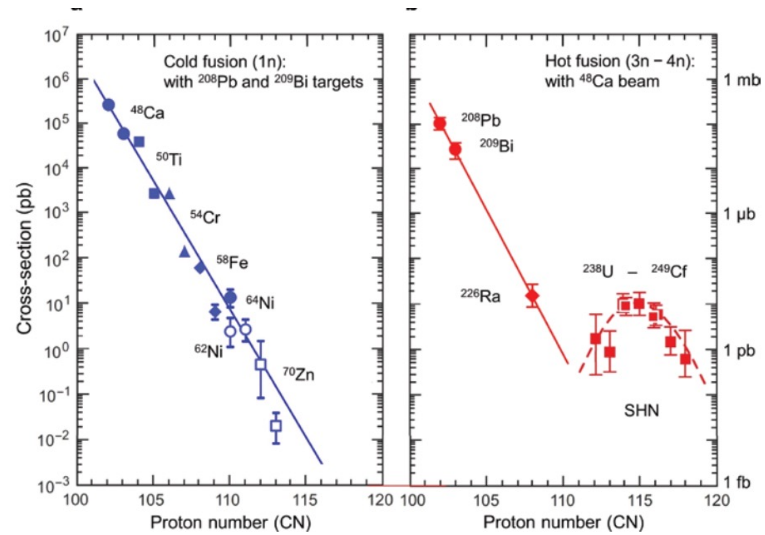
➢ The experimental data, however, in the heavy and superheavy region is scarce

➢ Production cross section drops significantly as atomic number increases

Low statistics is a big problem in data analysis and assignment of properties to observed transitions.

Ch. Theisen et al., Nucl. Phys. A 944 (2015) 333





S. Hofmann et al, Pure Appl. Chem. 2018; 90(11): 1773–1832

WHAT DO WE NEED

1. Very intense beams
2. High transmission and selectivity
3. High detection efficiency

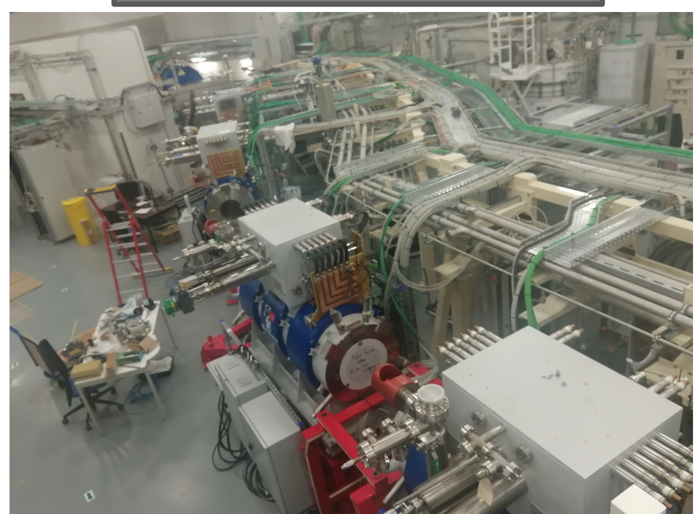
~10^{14} ions/s

60% for Ca + Pb
20% Ne + U

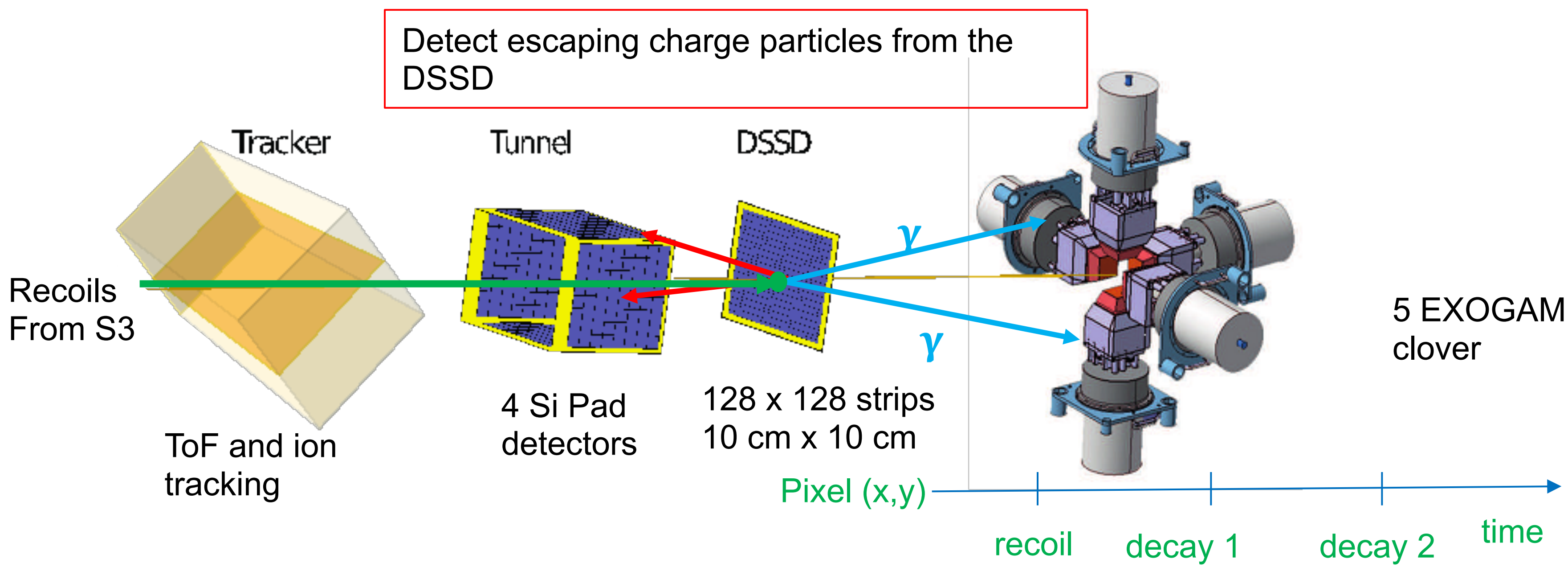
NEW GAIN A/Q = 3-7 → Superconducting linear accelerator of SPIRAL2

Injector 1 A/Q = 1-3 → Superconducting linear accelerator of SPIRAL2

Superconducting linear accelerator of SPIRAL2 → S3 → SIRIUS



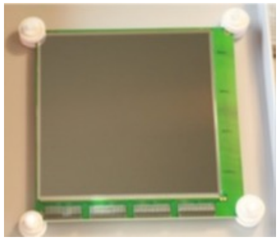
SIRIUS (Spectroscopy and Identification of Rare Isotopes Using S3)



- The DSSD and the front-end electronics were developed and tested at IRFU/CEA Saclay
- The Tunnel detectors were developed and tested at IPHC
- The front-end electronics of the tunnel detectors are being developed at IJCLab
- The Tracker was developed and is being tested at Ganil
- On 23rd March 2021, the setup was moved to Ganil

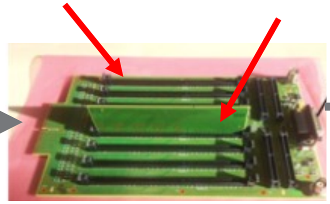
DSSD

DSSD in vacuum



Has a very Thin entrance window of 50 nm

4 Mother boards



64 Daughter boards
Each carry 4 Charge sensitive amplifiers

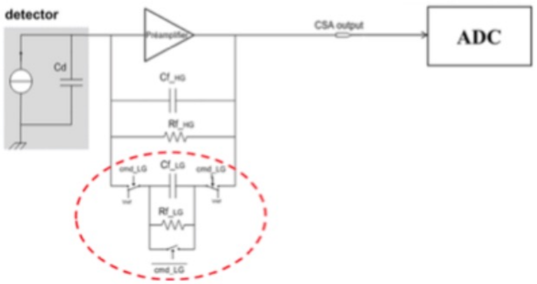
Adaptation board

HDMI cable

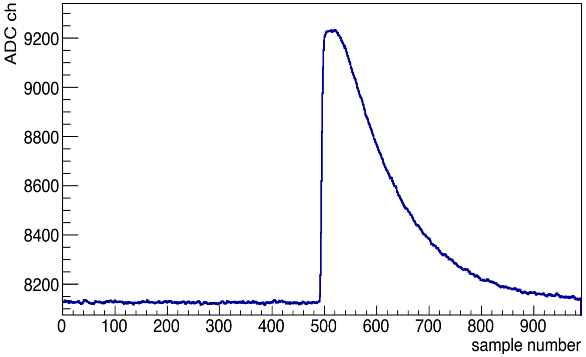
200 MHz digitization

Traces saved in a disk

GRU
C++ code



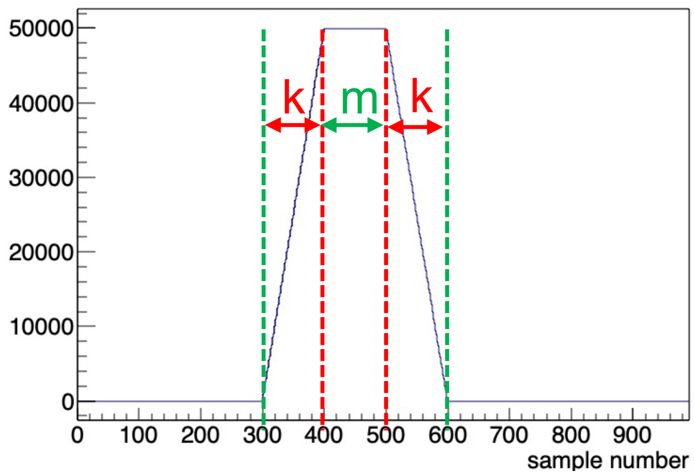
Has ability to switch gain automatically:
- ❖ Low gain 10 MeV - 500 MeV
- ❖ High gain 21 keV - 40 MeV



- ➢ remove pile-up
- ➢ pulse shape analysis ➡ detection of short lived isomers

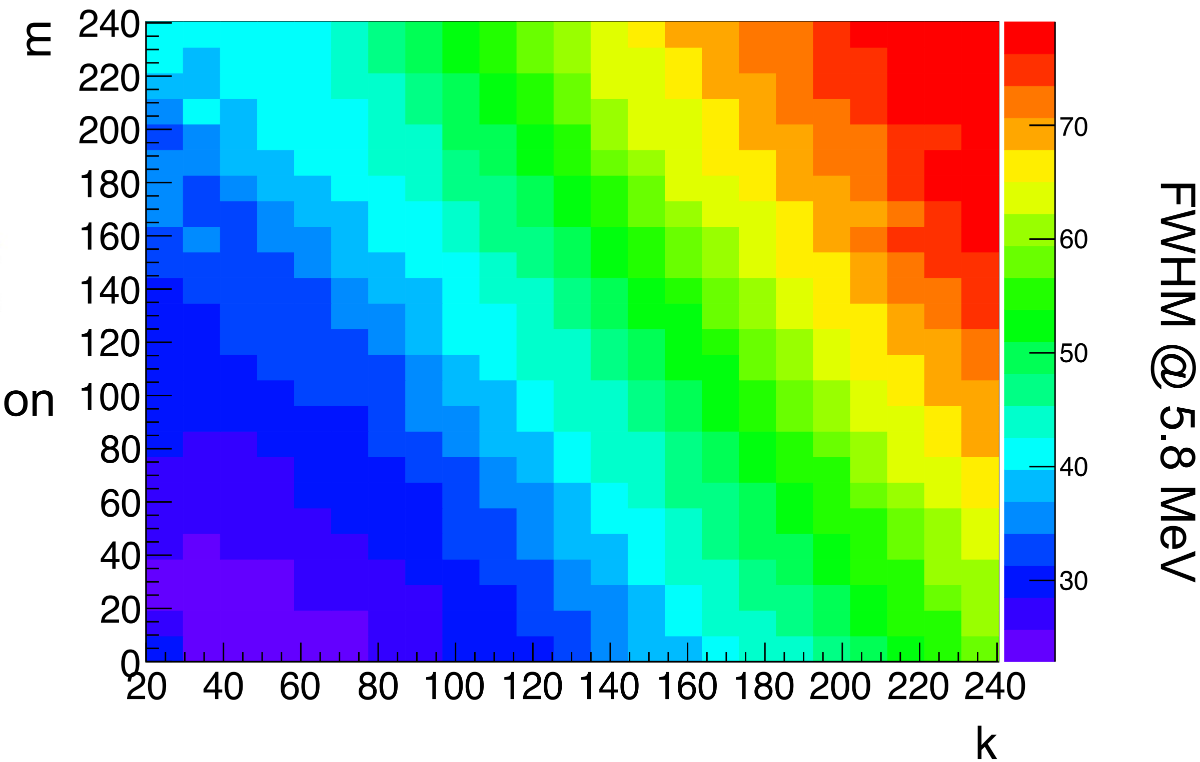
Optimization of k and m

V. T. Jordanov et al. NIMA,345(1994),337-345.



best parameters ≙ best resolution

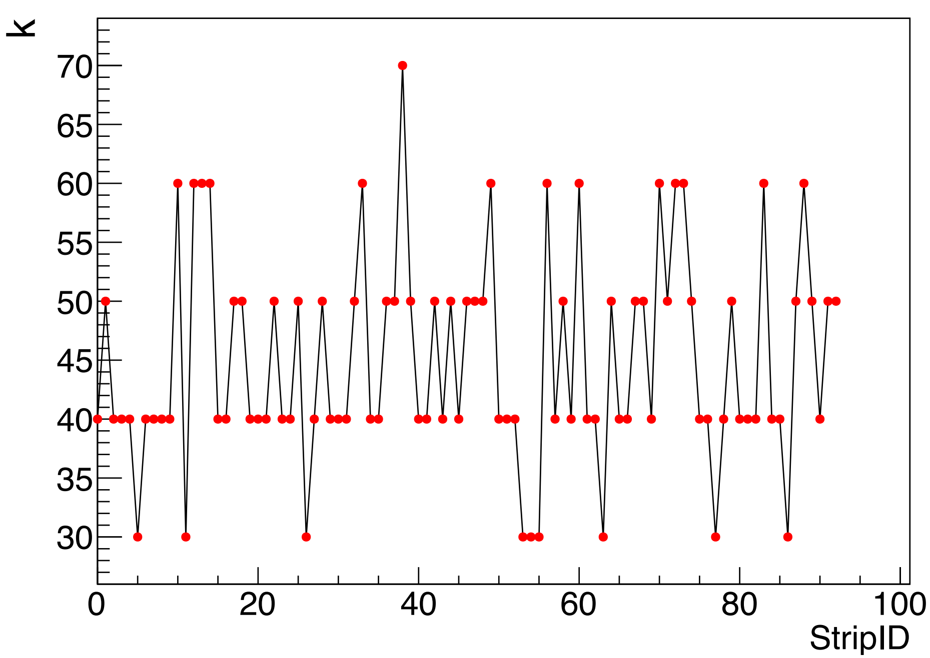
FWHM of a single strip as a function of k and m

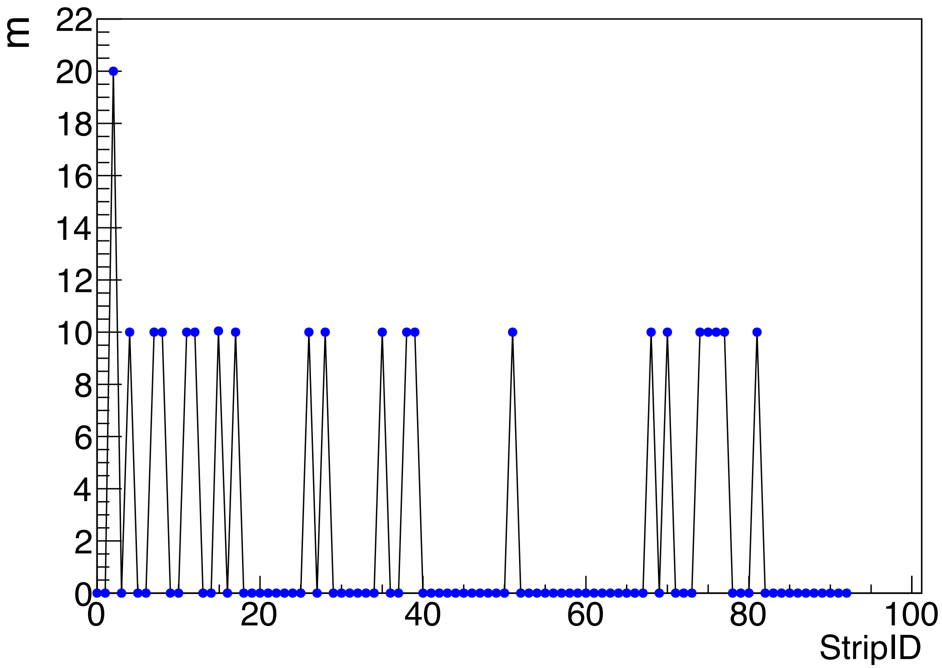


Experimental conditions:

- Source: (^{239}Pu, ^{241}Am, ^{244}Cm)
- Temperature: room (≥ 20 ℃)
- Pressure: 7.31×10^{-7} mbar
- Bias voltage: 55 keV
- Number of Back strips tested: 94

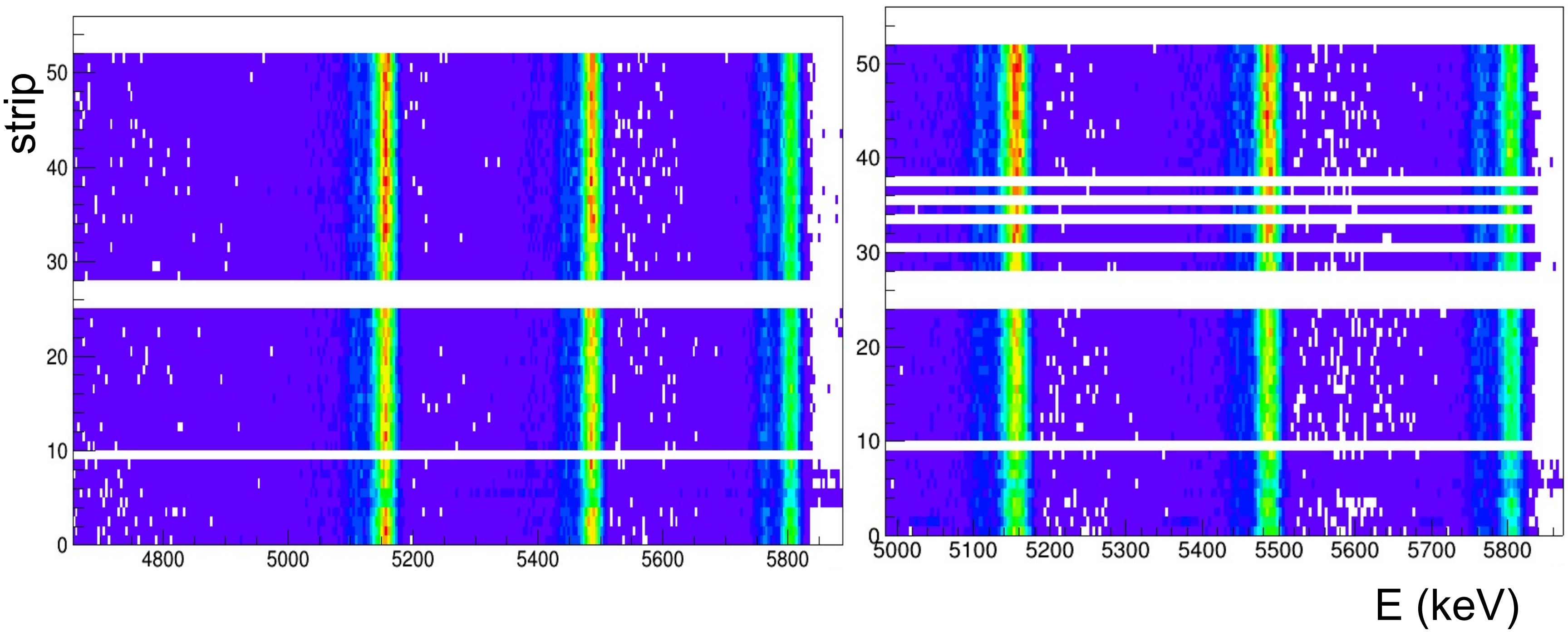
Optimized parameters





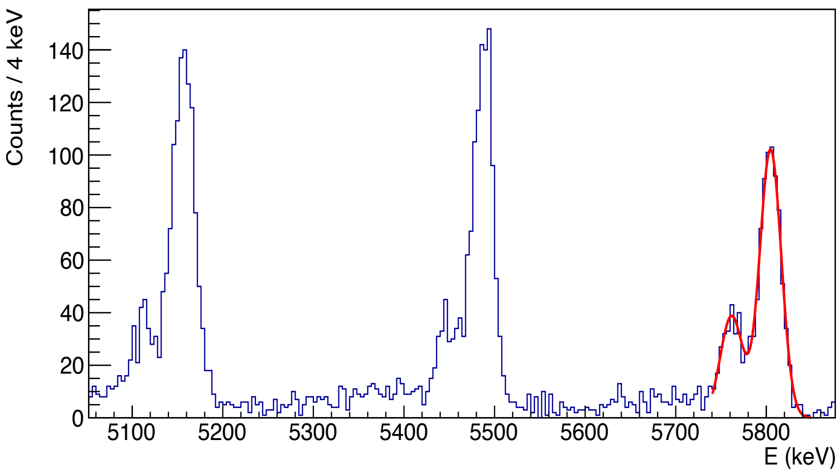
Using optimized parameters

MB3 MB4



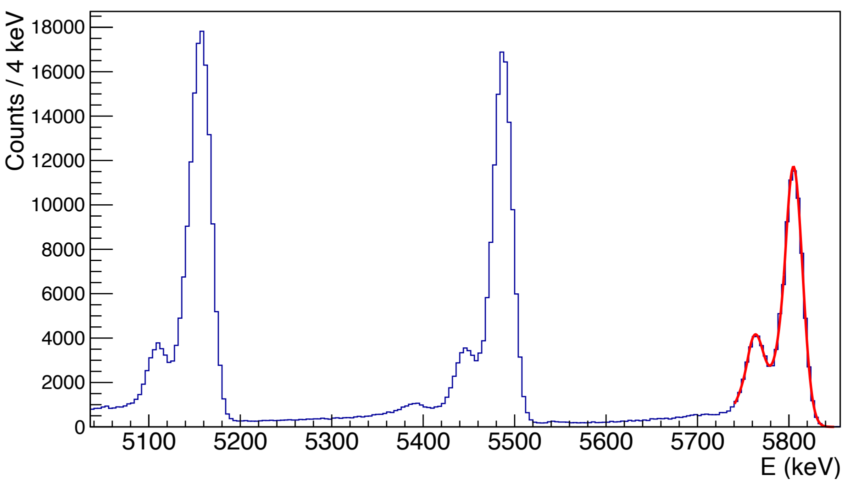
FWHM@ 5.8 MeV using the optimized parameters

Single strip



FWHM = 20.9(5) keV

Total strips



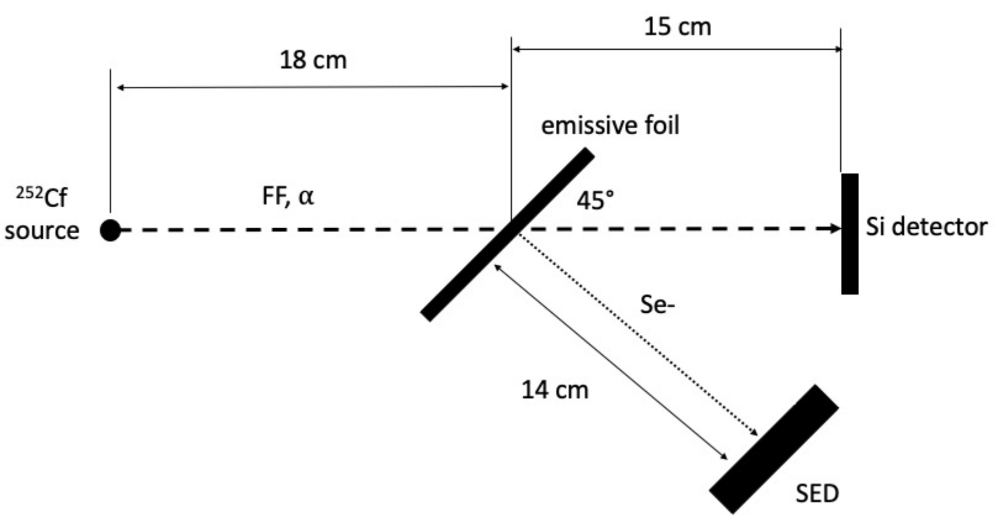
FWHM = 23.3(2) keV

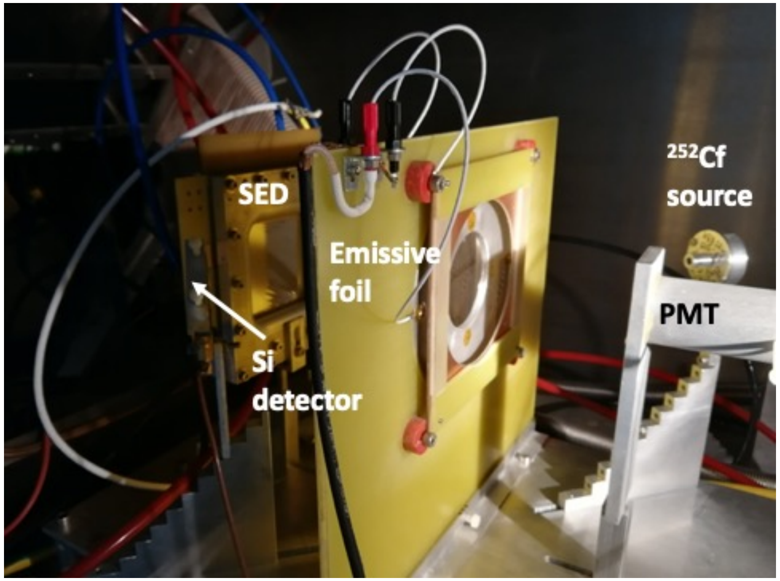
Test on the ToF using NUMEXO2

Objectives

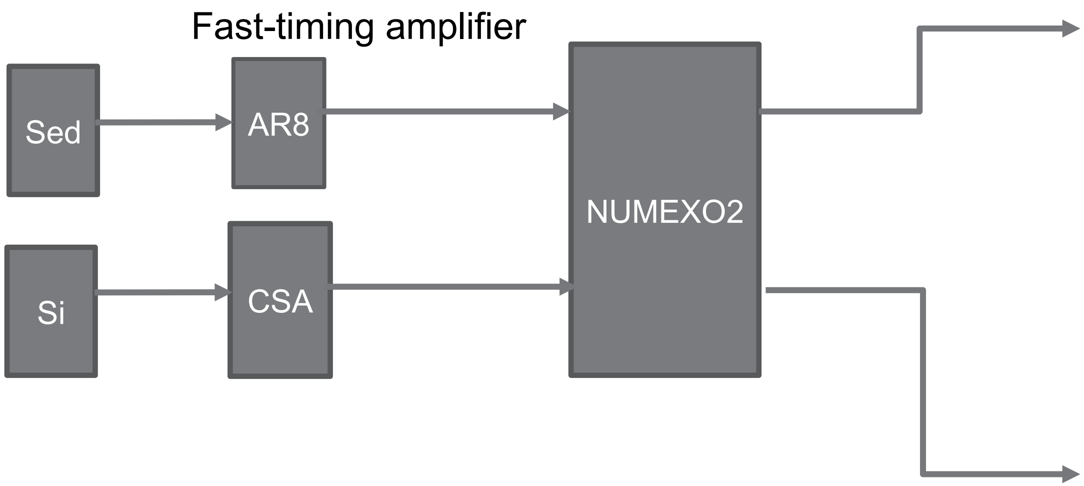
- Check the functionality of the ToF using NUMEXO2
- Check the proof of principle (Setup + Analysis technique)
- Obtain the time resolution of the setup

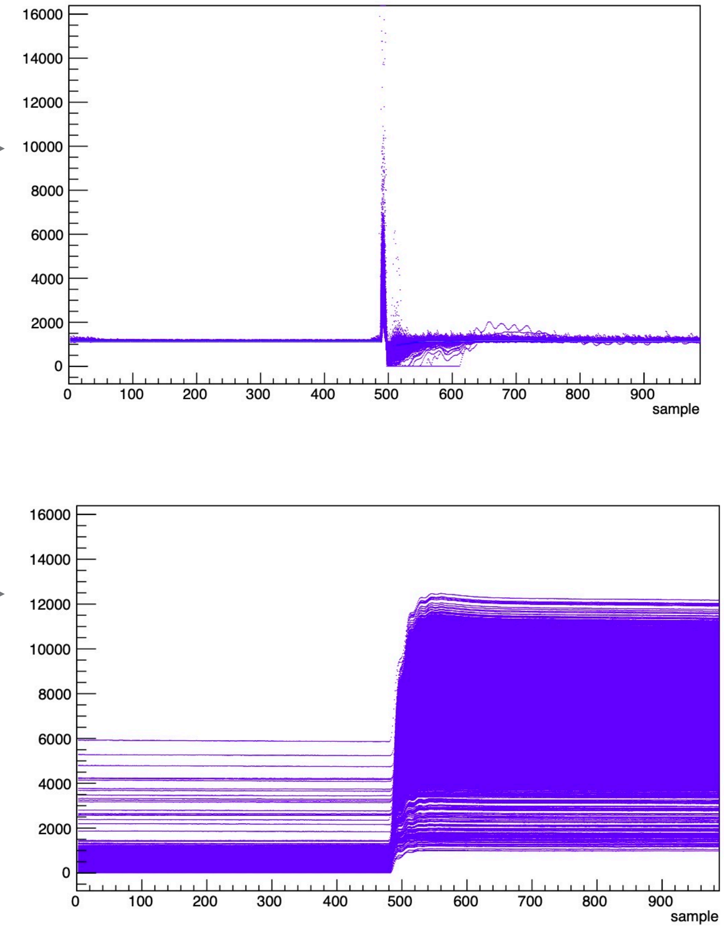
How do we measure ToF without timing signals from the DSSD





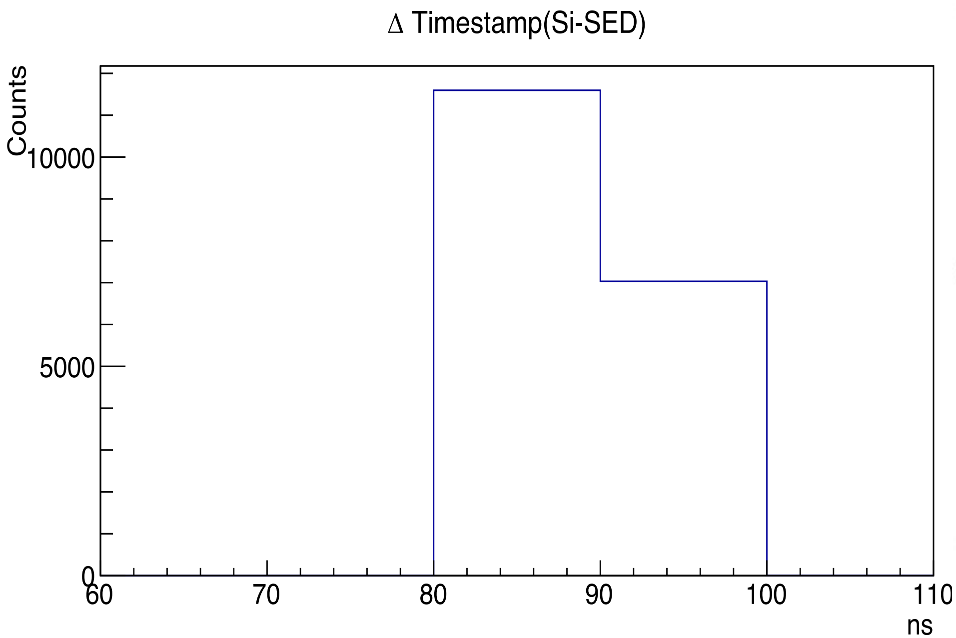
Electronics and Traces





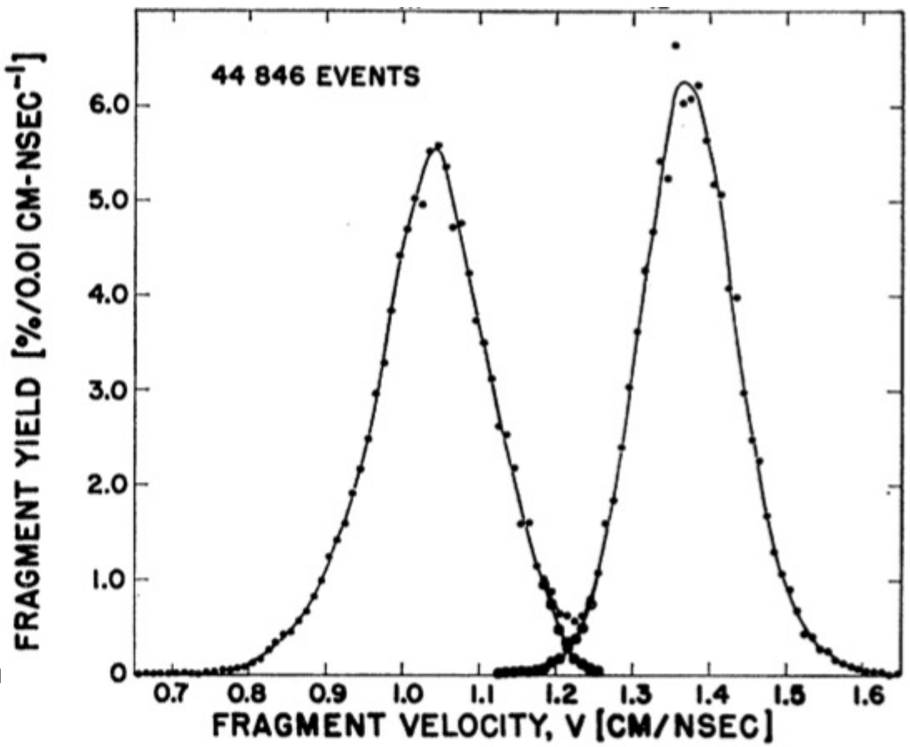
Timestamps of these signals are dependent on the trigger levels set for each detector

TOF?



Timestamp difference between Si and SED signals

S. L. Whetstone, Physical Review, 131, (1963), 1232-1243

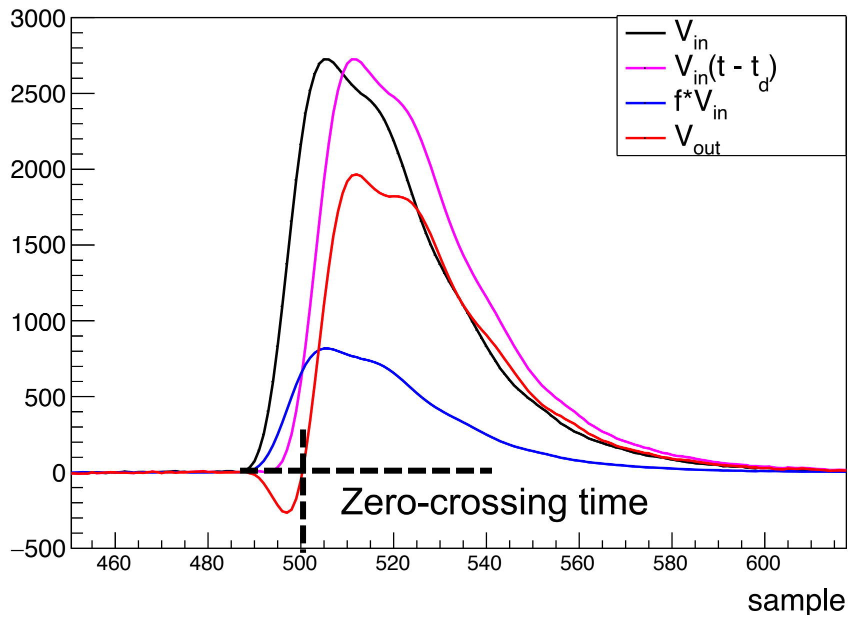


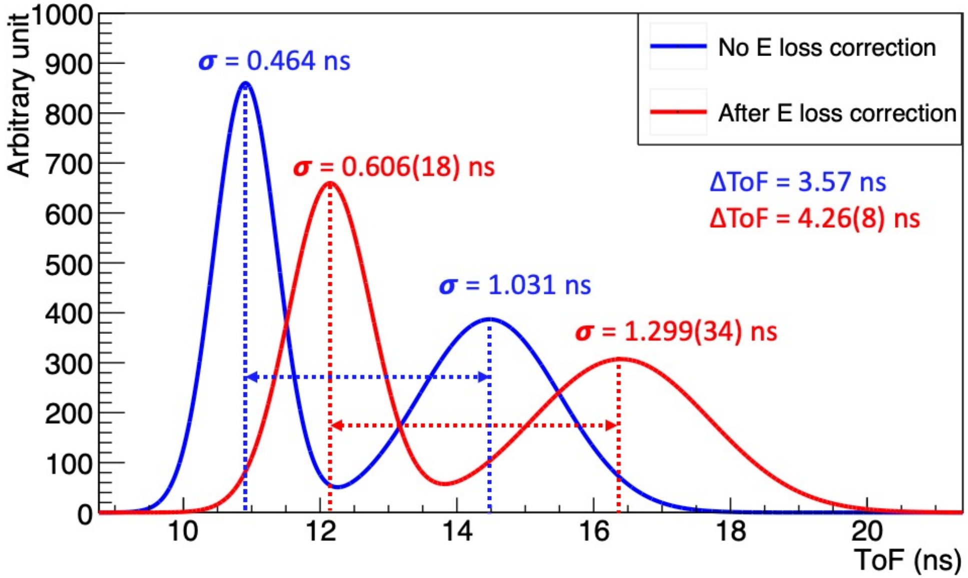
- Fission fragments from the ^{252}Cf source cannot be distinguished

Methodology

Use digital CFD to obtain more precise time information

S. L. Whetstone, Physical Review, 131, (1963), 1232-1243

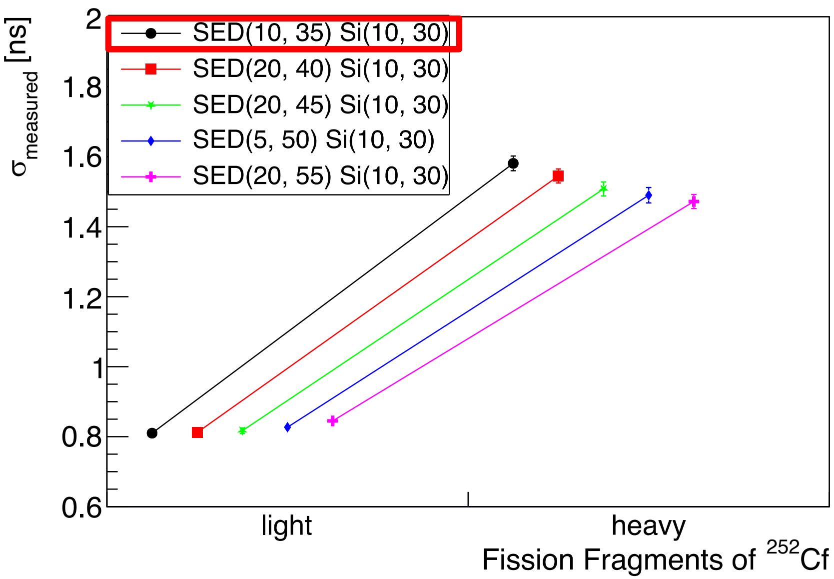


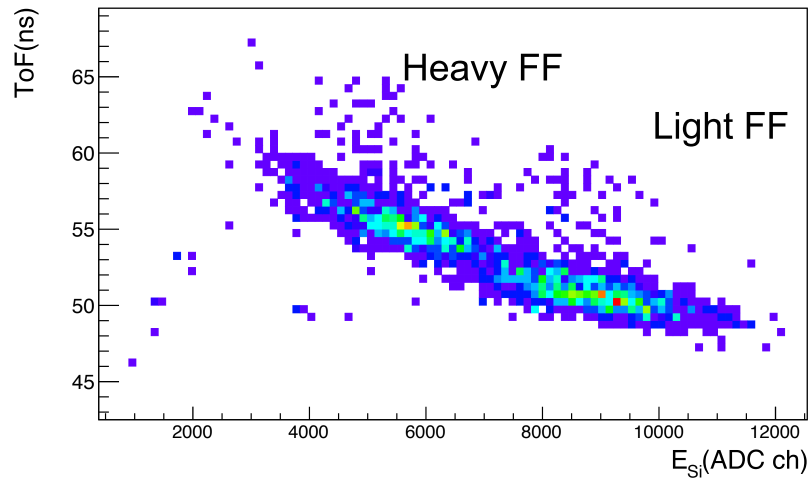


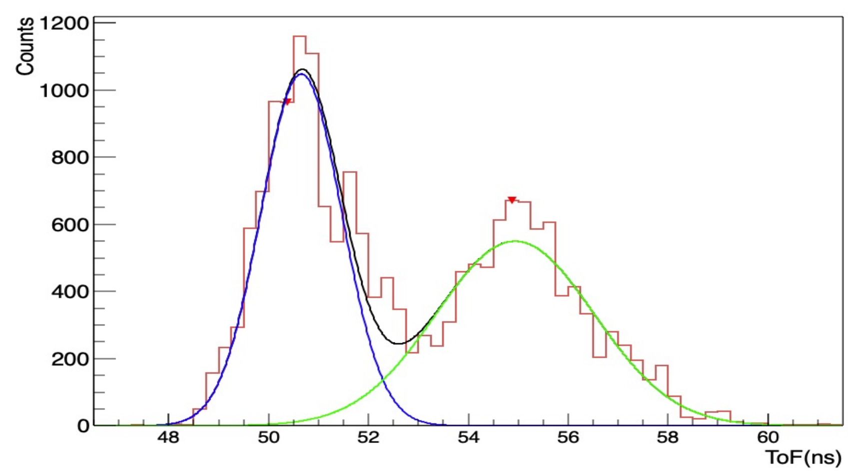
- The best set of parameters should give the best time resolution

Effect of energy losses (calculated using SRIM) by the fission fragments in the Mylar foils on their time of flights

Optimized parameters

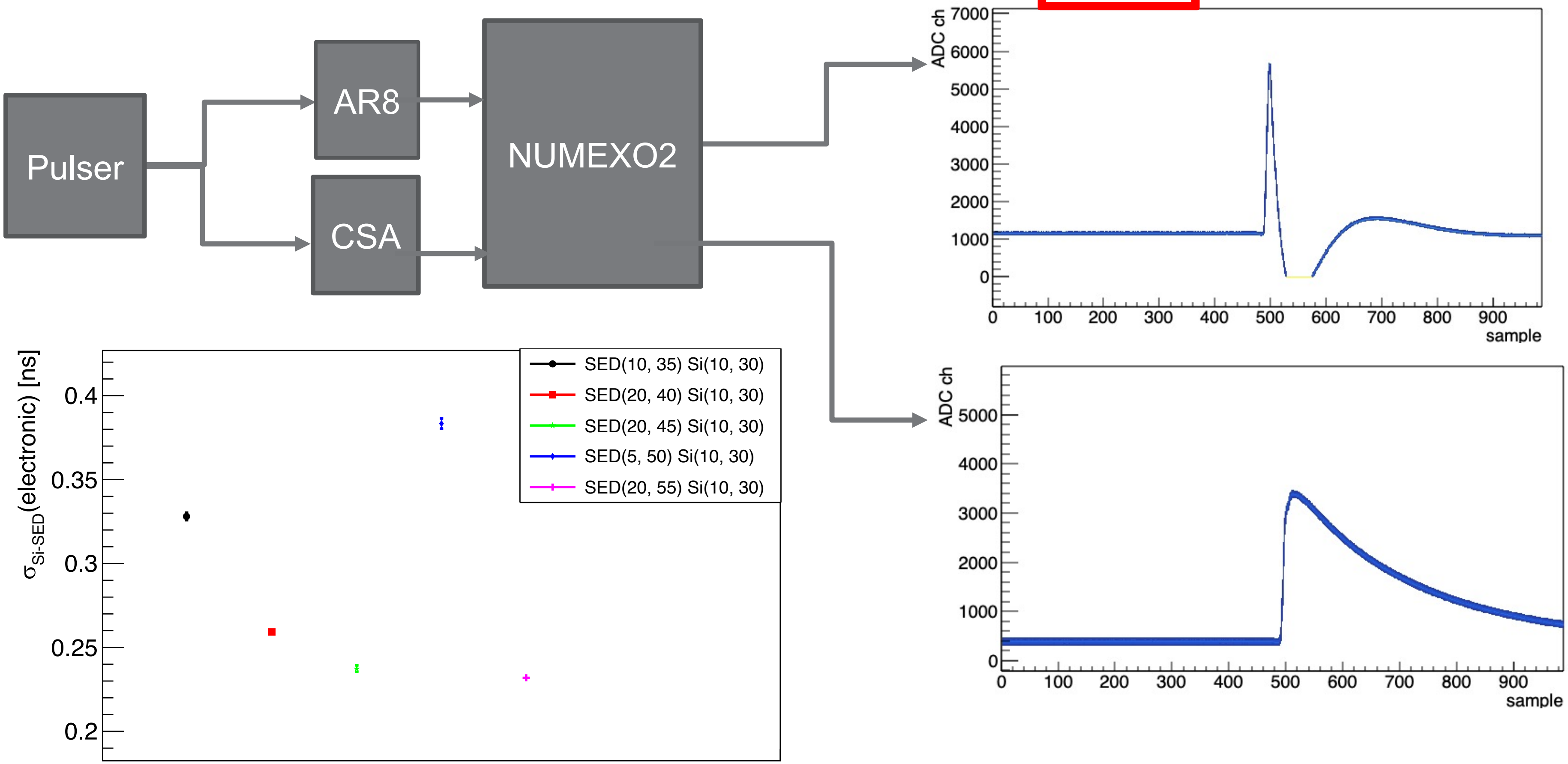






Resolution of our setup

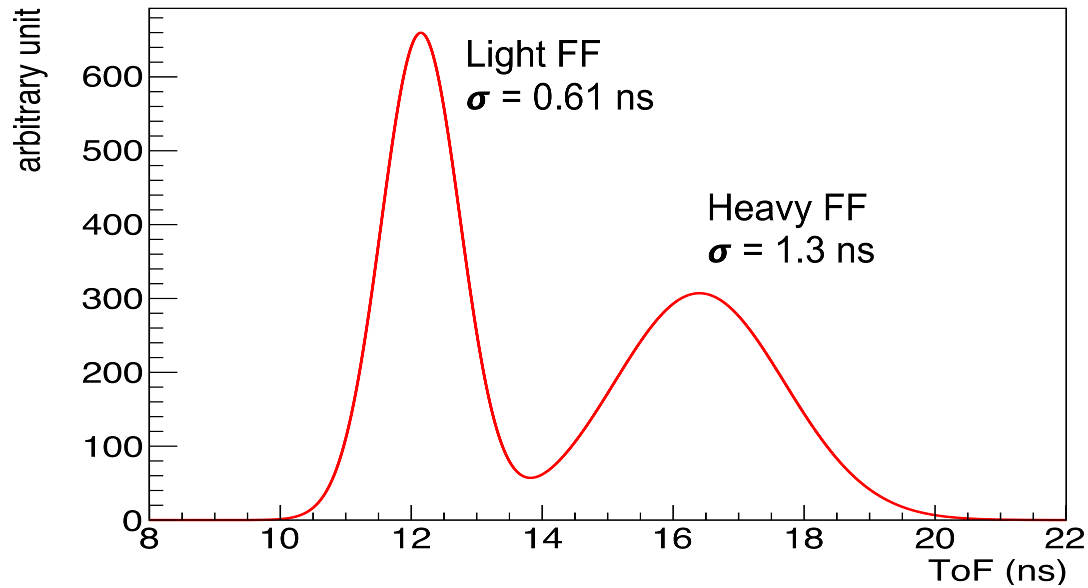
$$\sigma_{Si-SED} = \sqrt{\sigma^2_{measured} - \sigma^2_{electronic} - \sigma^2_{intrinsic} - \sigma^2_{geometry}}$$



Resolution of our setup

$$\sigma_{Si-SED} = \sqrt{\sigma^2_{measured} - \sigma^2_{electronic} - \sigma^2_{intrinsic} - \sigma^2_{geometry}}$$

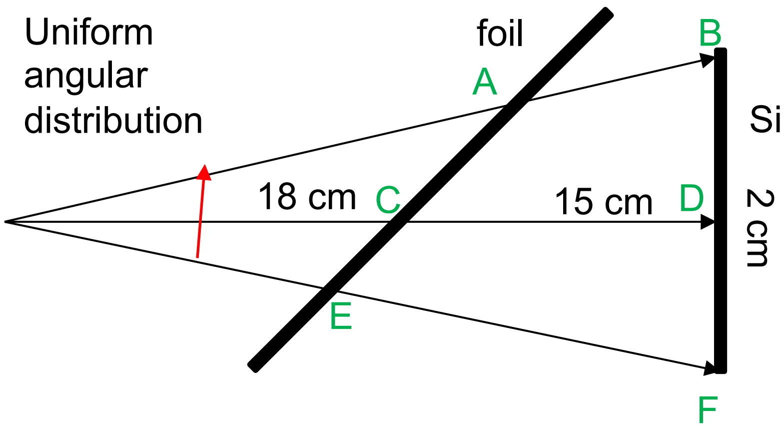
After E loss correction in the Mylar foils



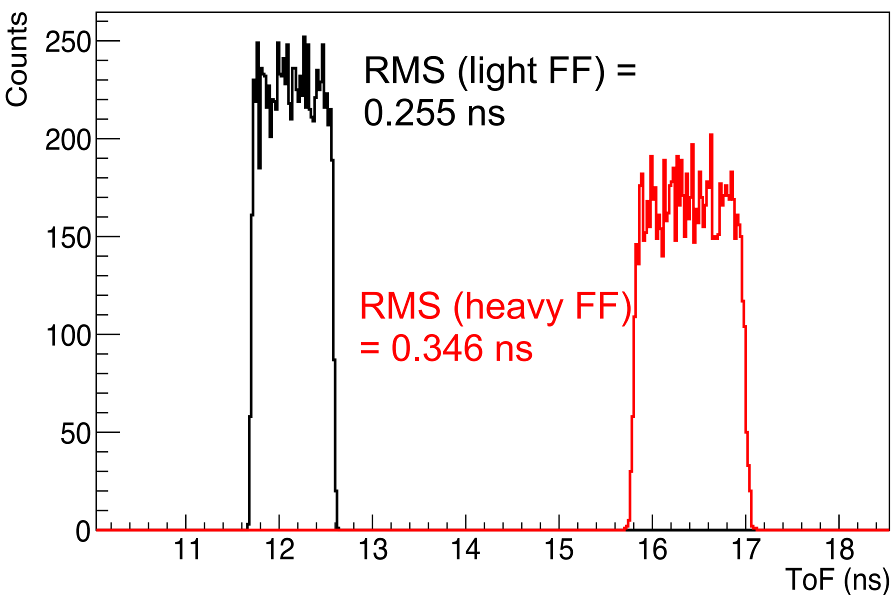
Resolution of our setup

$$\sigma_{Si-SED} = \sqrt{\sigma^2_{measured} - \sigma^2_{electronic} - \sigma^2_{intrinsic} - \sigma^2_{geometry}}$$

Monte Carlo method

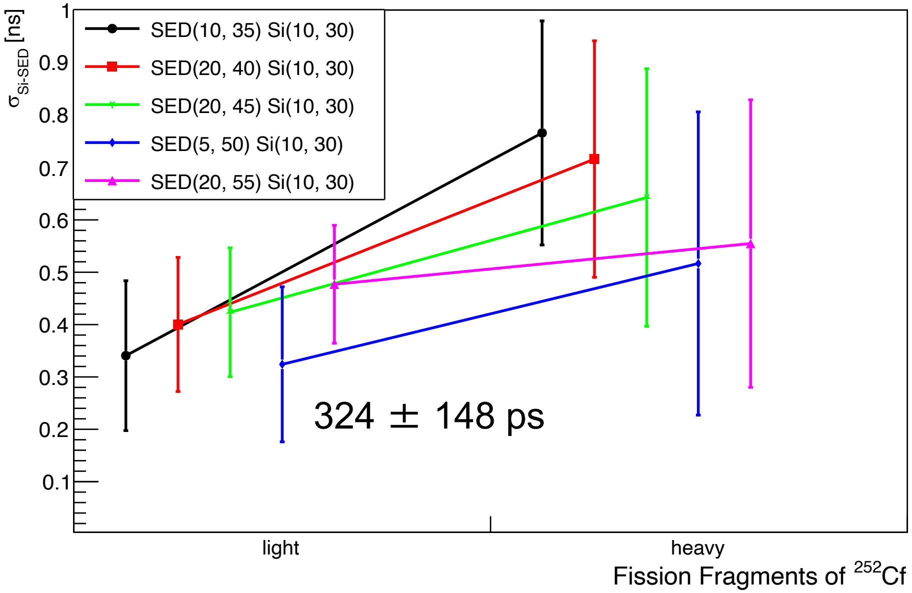


Trajectories of the fission fragments AB ≠ CD ≠ EF



Resolution of our setup

$$\sigma_{Si-SED} = \sqrt{\sigma^2_{measured} - \sigma^2_{electronic} - \sigma^2_{intrinsic} - \sigma^2_{geometry}}$$



Uncertainties		
Fission fragments	Light (ps)	Heavy (ps)
Measured (Average)	8	20
Electronic (Average)	2	2
SRIM (10% inaccuracy)	18	36
Neutron emission	98	132

S. L. Whetstone, Physical Review, 131, (1963), 1232-1243

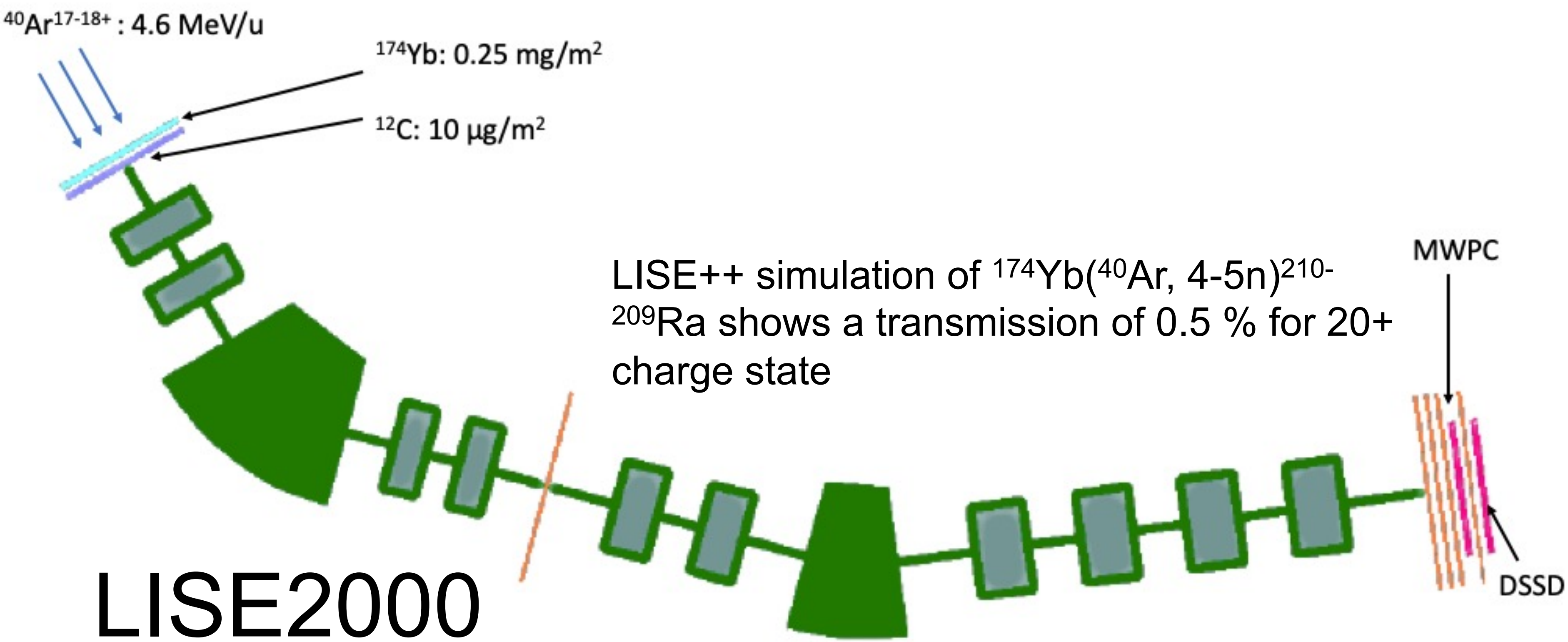
Previous measurement using different electronics ~ 300 ps

Online commissioning test

Objective:

Verify if LISE2000 is suitable for commissioning SIRIUS

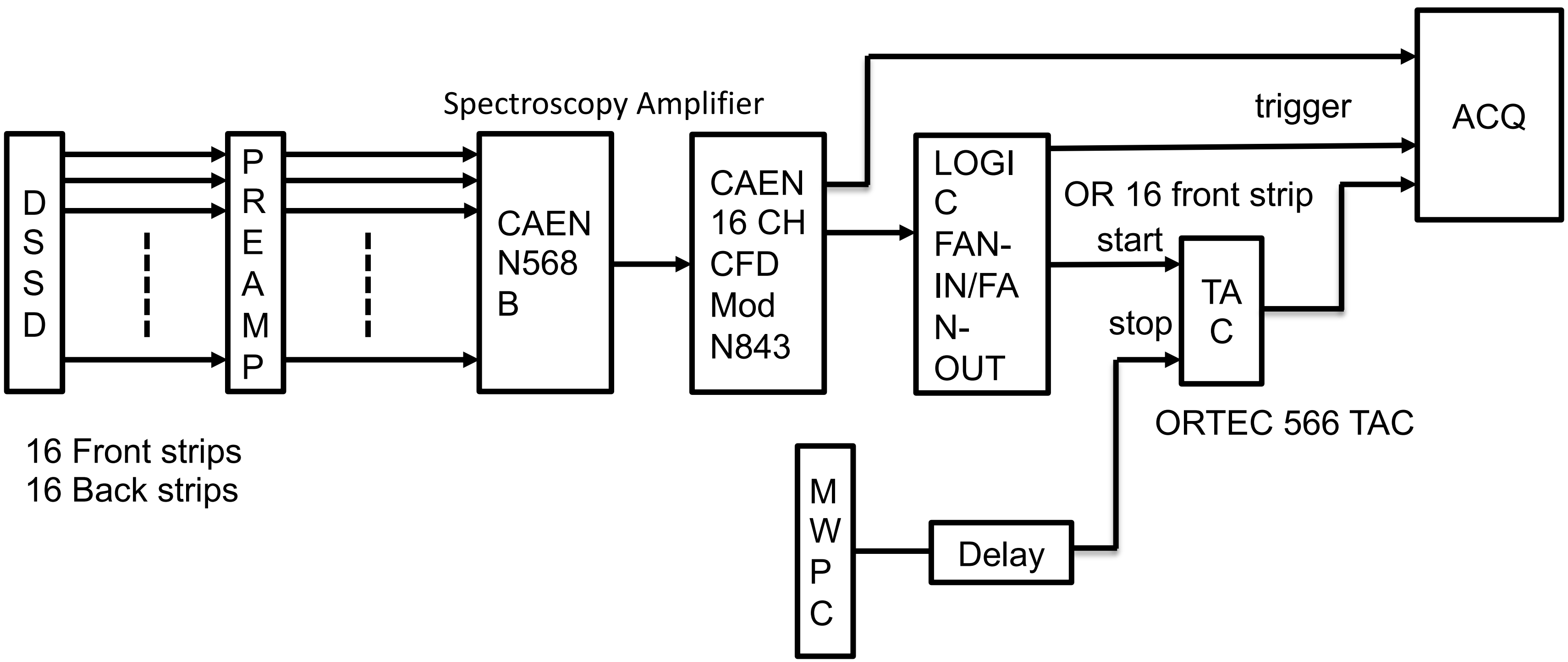
88 MHz



LISE++ simulation of $^{174}Yb(^{40}Ar, 4\text{-}5n)^{210-209}Ra$ shows a transmission of 0.5 % for 20+ charge state

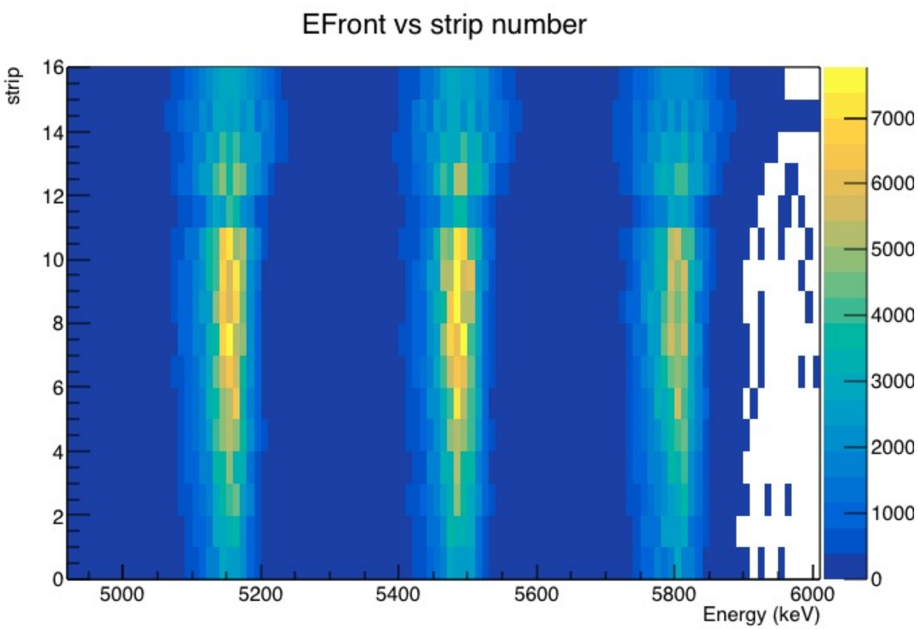
LISE2000

Electronic chain

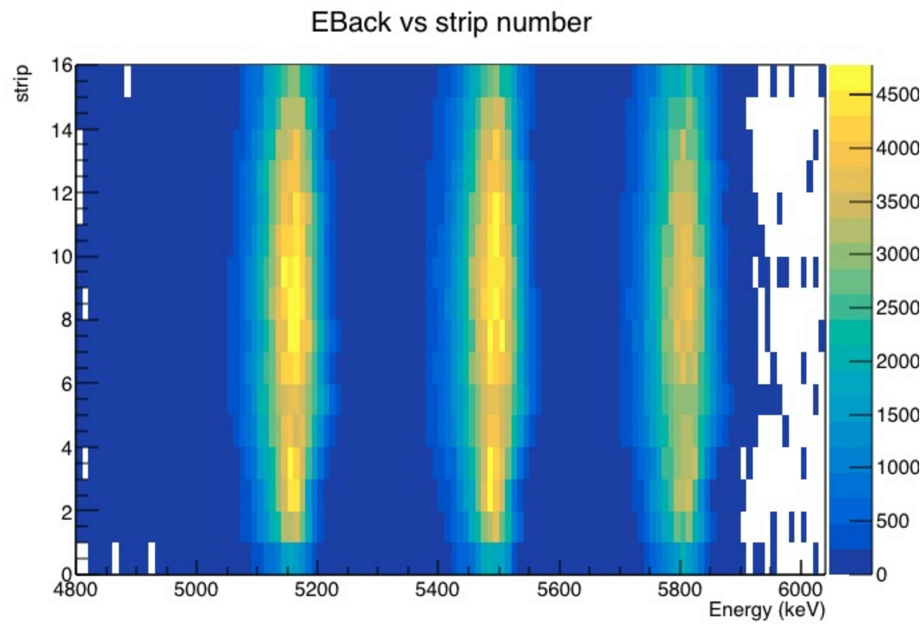


16 Front strips
16 Back strips

Calibration of the DSSD using a 3-α source

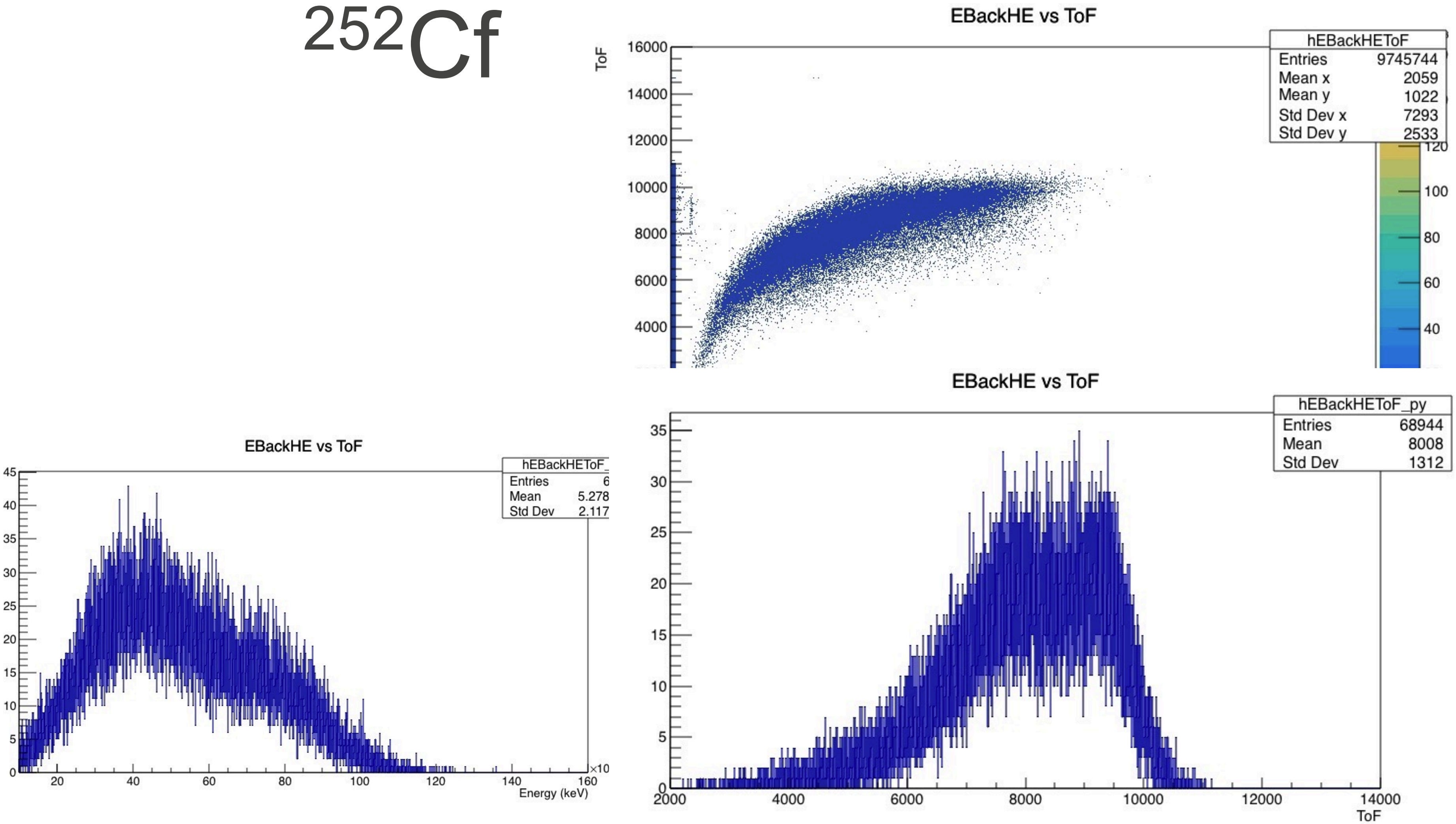


FWHM ≈ 66 keV @ 5.8 MeV



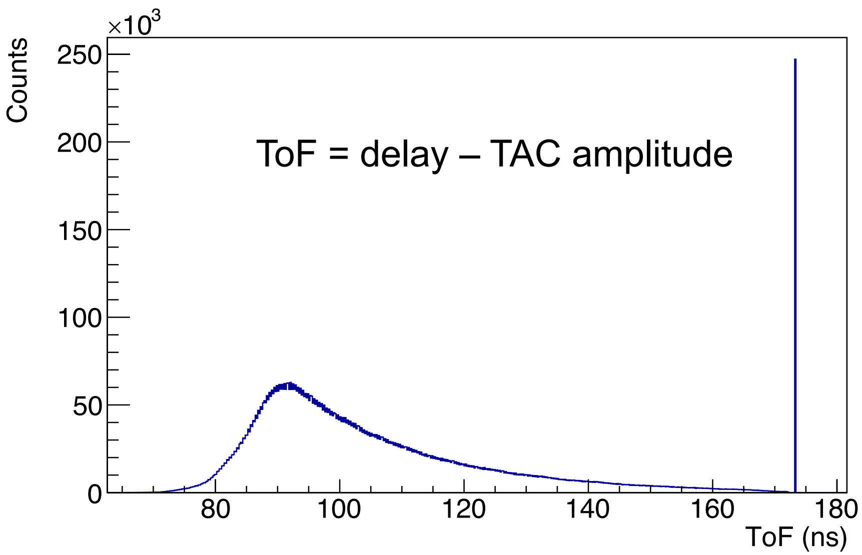
FWHM ≈ 75 keV @ 5.8 MeV

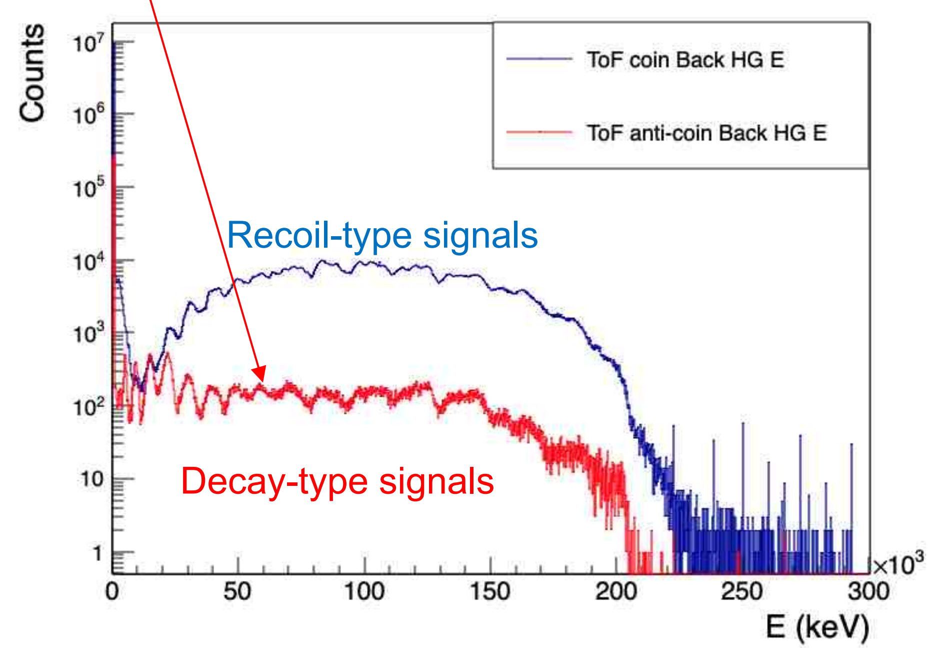
ToF study with a ^{252}Cf



Results

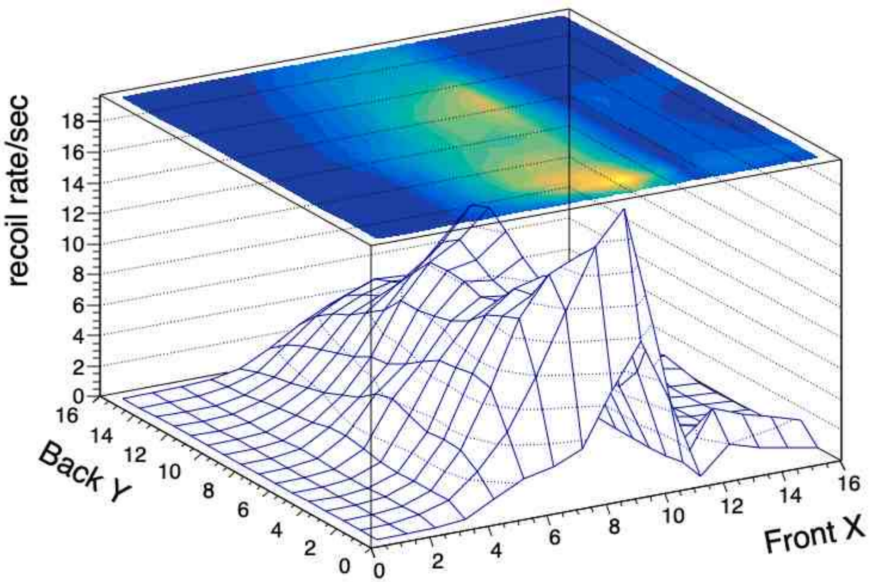
False decay signals: Light particles that did not trigger the MWPC

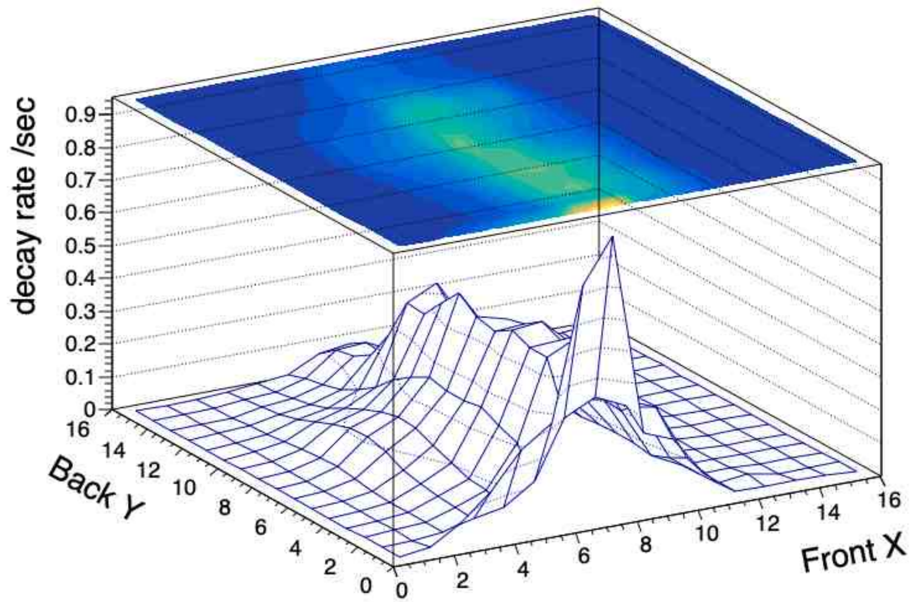




Recoil and Decay Rates in the DSSD

1 pnA on Target ≈1000 pps ➡ too many events in the DSSD

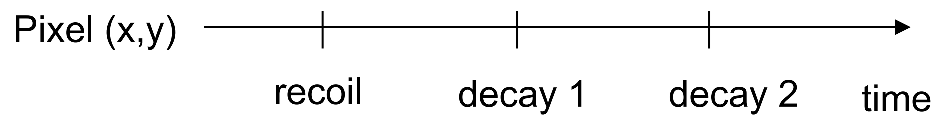




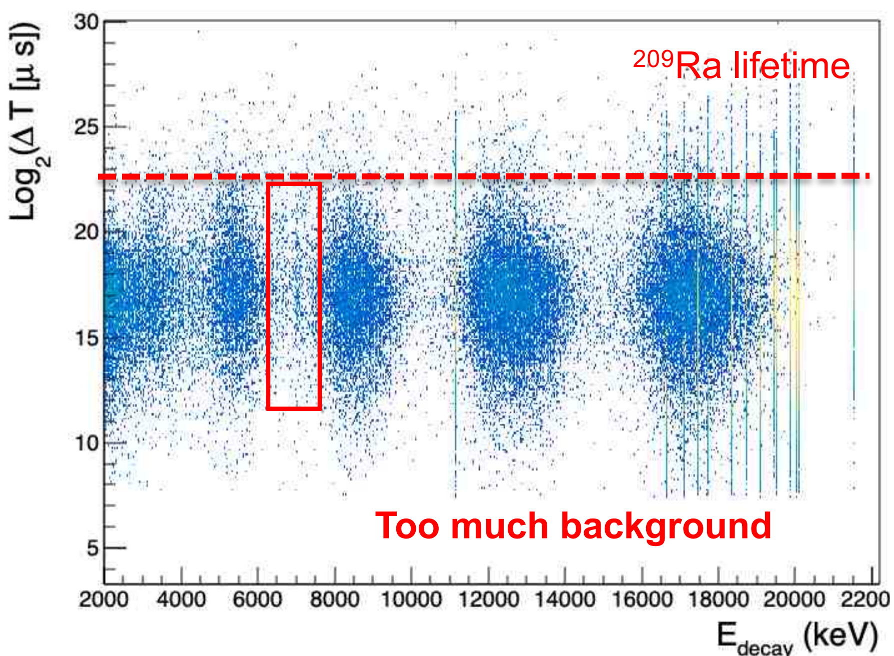
Rejection factor is not good enough

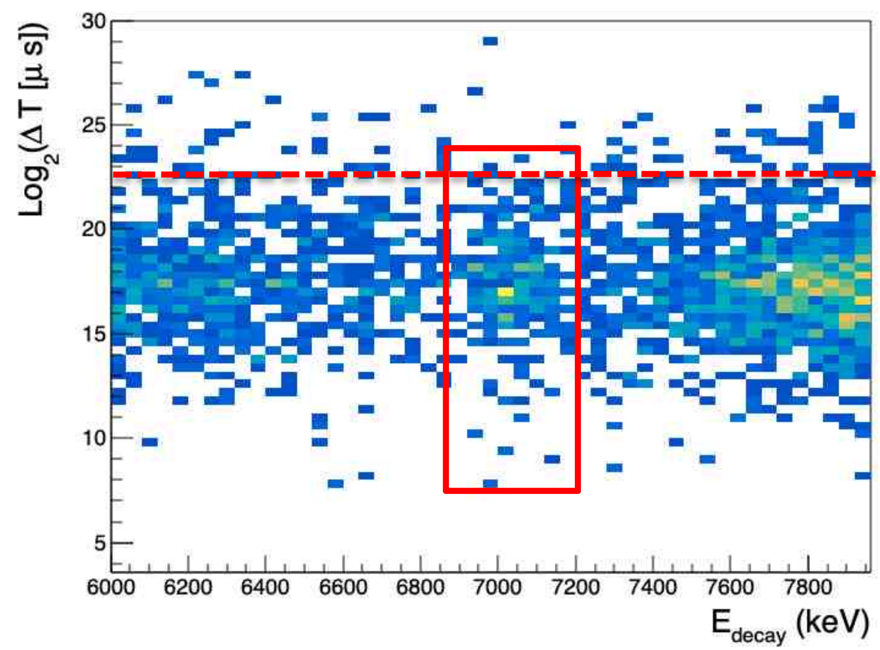
Charge state	18+	20+	21+
Rejection factor	7.8×10^7	8.5×10^6	1.13×10^7

Recoil-decay correlation



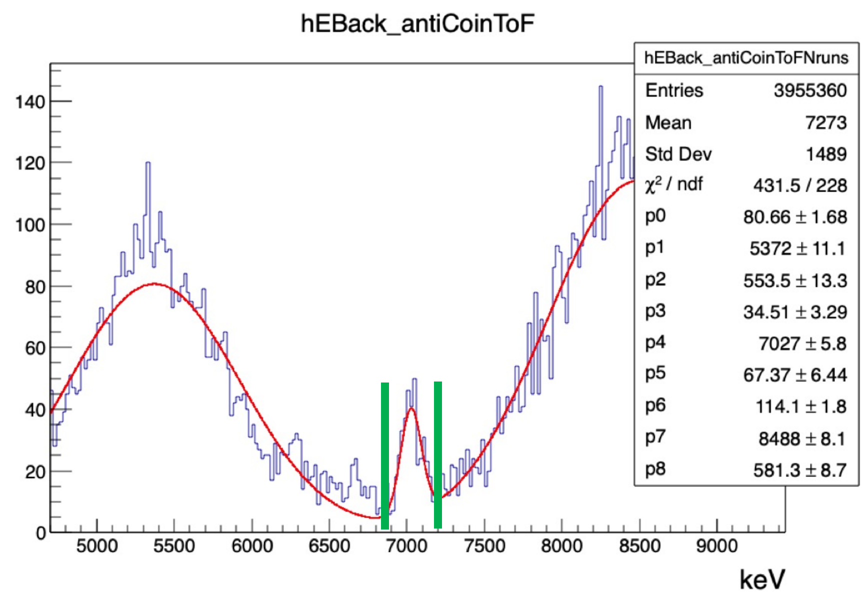
For the 20+ charge state of $^{209-210}Ra$

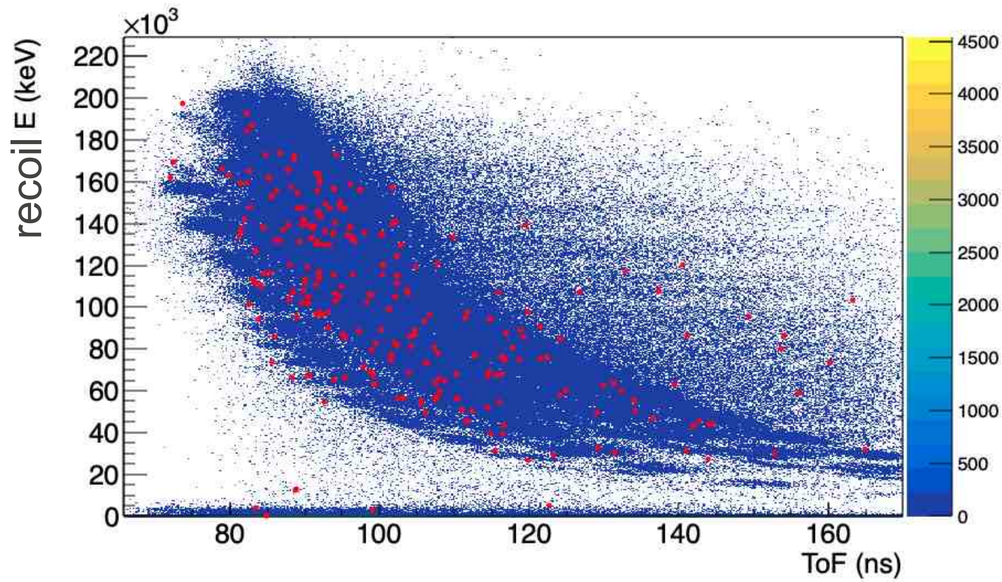




Charge state	18+	20+	21+
ToF efficiency (%)	96.3	97.3	98.03

Results





Charge state	18+	20+	21+
Transmission factor (%)	0.044(28)	0.61(12)	0.33(18)

Simulated ≅ 0.5%

Conclusions

- DSSD tests confirm the results from IRFU
- Optimization code is ready
- The time resolution of the ToF obtained in this test is compatible with the results reported previously
- LISE2000 is not suitable for commissioning of SIRIUS

Prospective milestones

- Test of new firmware
- Treatment of pile up events
- In-beam ToF measurement
- Test of the tunnel detectors
- Test of DSSD-Ge, Tunnel-Ge and DSSD-Tunnel coincidences

Thank you for your attention

SIRIUS Collaboration

- GANIL : R. Chakma, J. Piot, D. Ackermann, M. Blaizot, A. Boujrad, L. Càceres, E. Clément, S. Coudert, J. Goupil, S. Herlant, G. Lebertre, F. Lutton, C. Maugeais, J. Pancin, F. Saillant, H. Savajols, G. Wittwer
- IPHC : P. Brionnet, O. Dorvaux, H. Faure, B. Gall, Th. Goeltzenlichter, C. Mathieu
- IRFU : M. Authier, Th. Chaminade, A. Drouart, J. Kallunkathariyil, H. LeProvost, Z. Favier, B. Sulignano, Ch. Theisen
- IJClab : V. Alaphilipe, L. Gibelin, K. Hauschild, N. Karkour, X. Lafay, D. Linget, A. Lopez-Martens, F. Leblanc & 10 interns from MIT UL ESME universities.

S3 has been funded by the French Research Ministry, National Research Agency (ANR), through the EQUIPEX (EQUIPment of EXcellence) reference ANR-10EQPX- 46, the FEDER (Fonds Européen de Développement Economique et Régional), the CPER (Contrat Plan Etat Région), and supported by the U.S. Department of Energy, Office of Nuclear Physics, under contract No. DE-AC02-06CH11357 and by the E.C.FP7-INFRASTRUCTURES 2007, SPIRAL2 Preparatory Phase, Grant agreement No.: 212692.

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