Status of the SIRIUS detector array

R. CHAKMA
On behalf of the SIRIUS collaboration

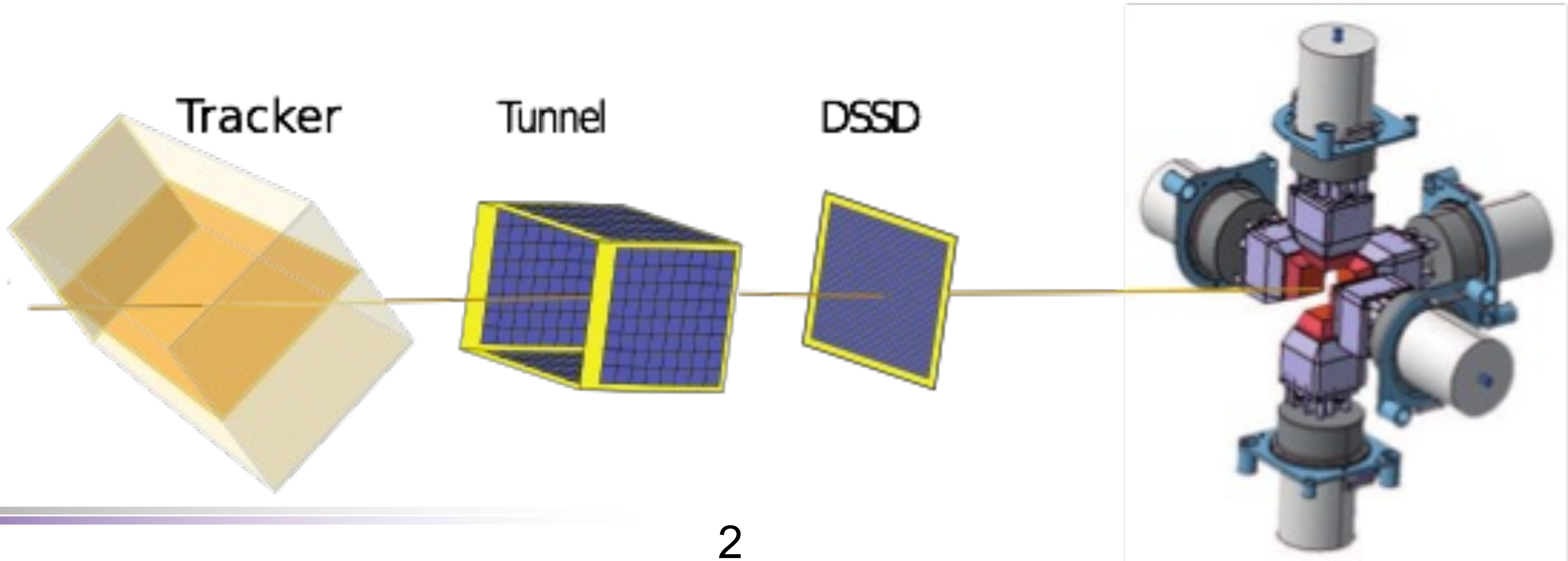
S3 has been funded by the French Research Ministry, National Research Agency (ANR), through the EQUIPEX (EQUIPment of EXcellence) reference ANR-10EQPX- 46, the FEDER (Fonds Européen de Développement Economique et Régional), the CPER (Contrat Plan Etat Région), and supported by the U.S. Department of 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

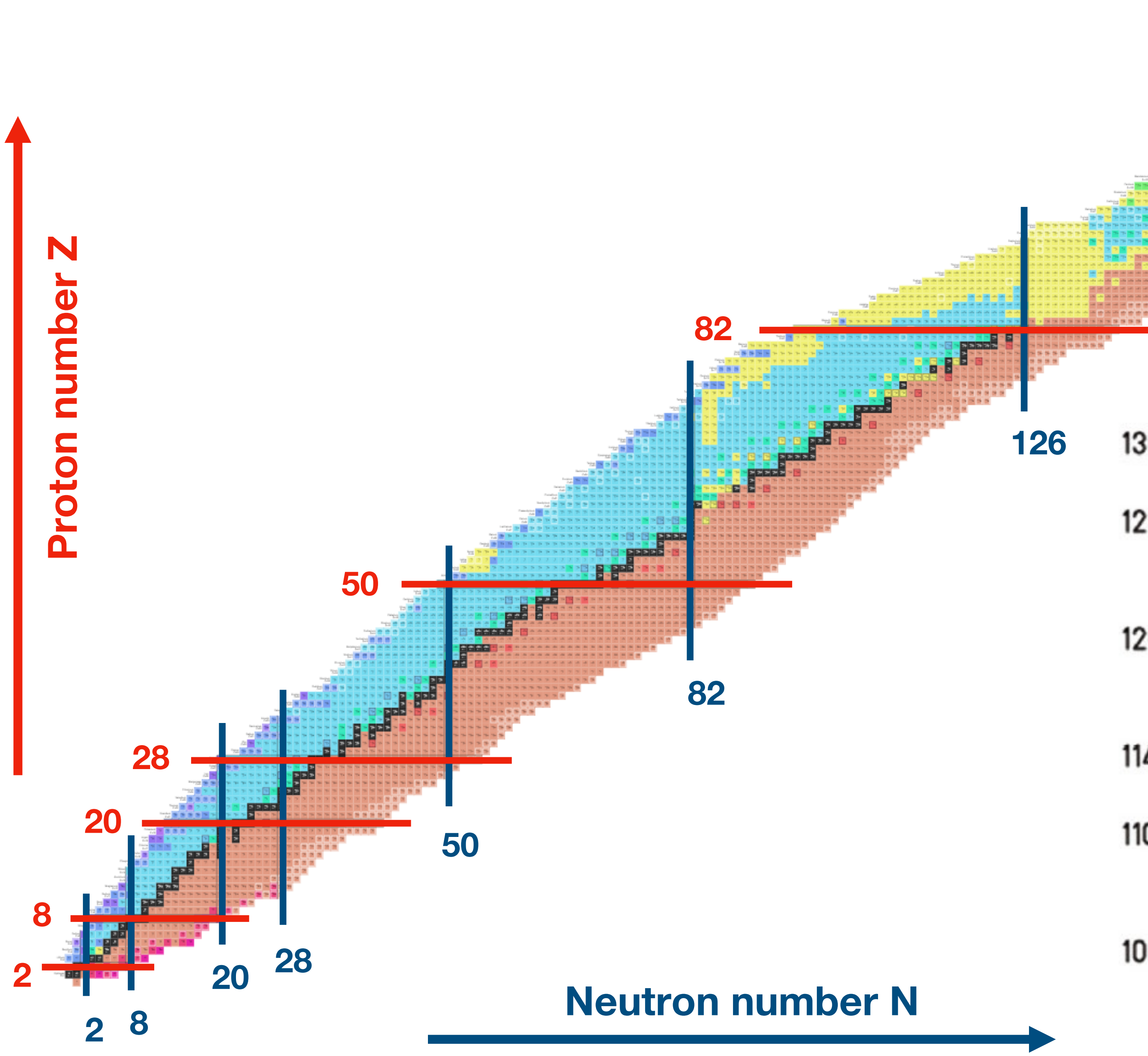
- Motivation
- Overview of SIRIUS
- Characteristics and performance:
    1. DSSD
    2. Tunnel
    3. Tracker
- Conclusions and prospective



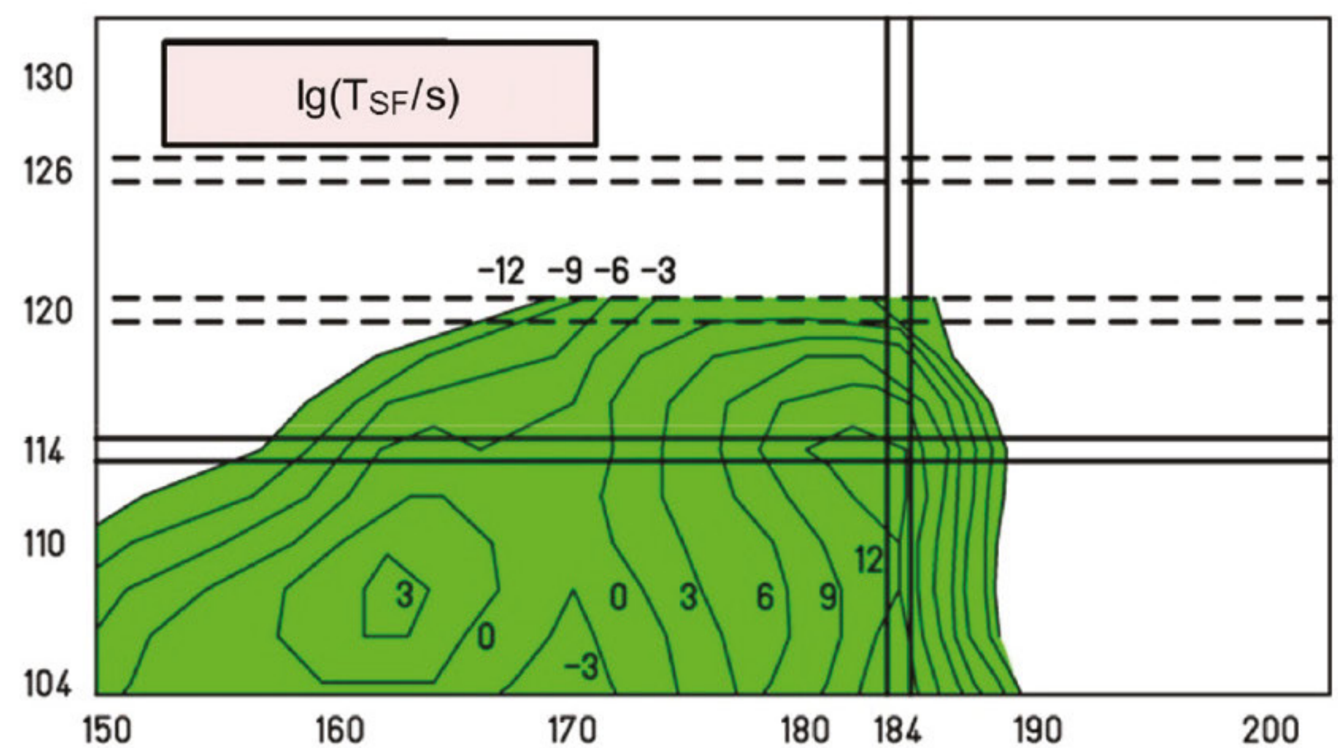
Motivation

Explore:
- **Nuclear structure of exotic nuclei**
- **Nature of the Nuclear interactions at large Z and A**
- **The limits of nuclear stability**
- **...**

using decay spectroscopy



An island of stability - the next magic numbers beyond Z = 82 and N = 126



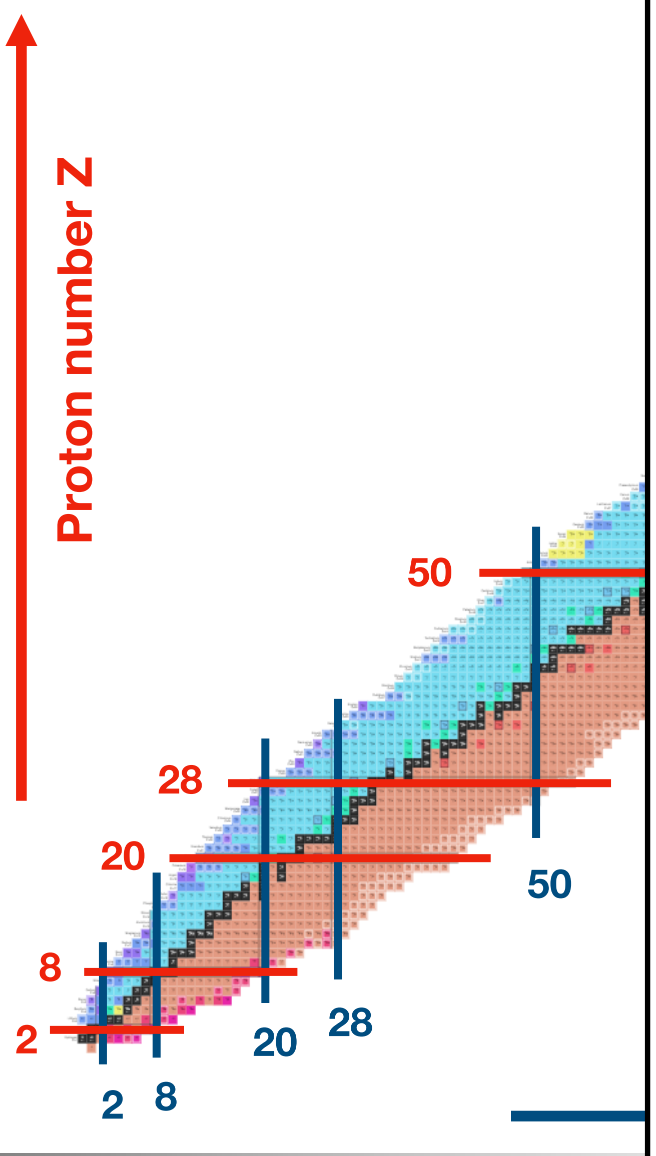
S. Hofmann et al., *Pure and Applied Chemistry*, **90**, no. 11, 2018, pp. 1773-1832

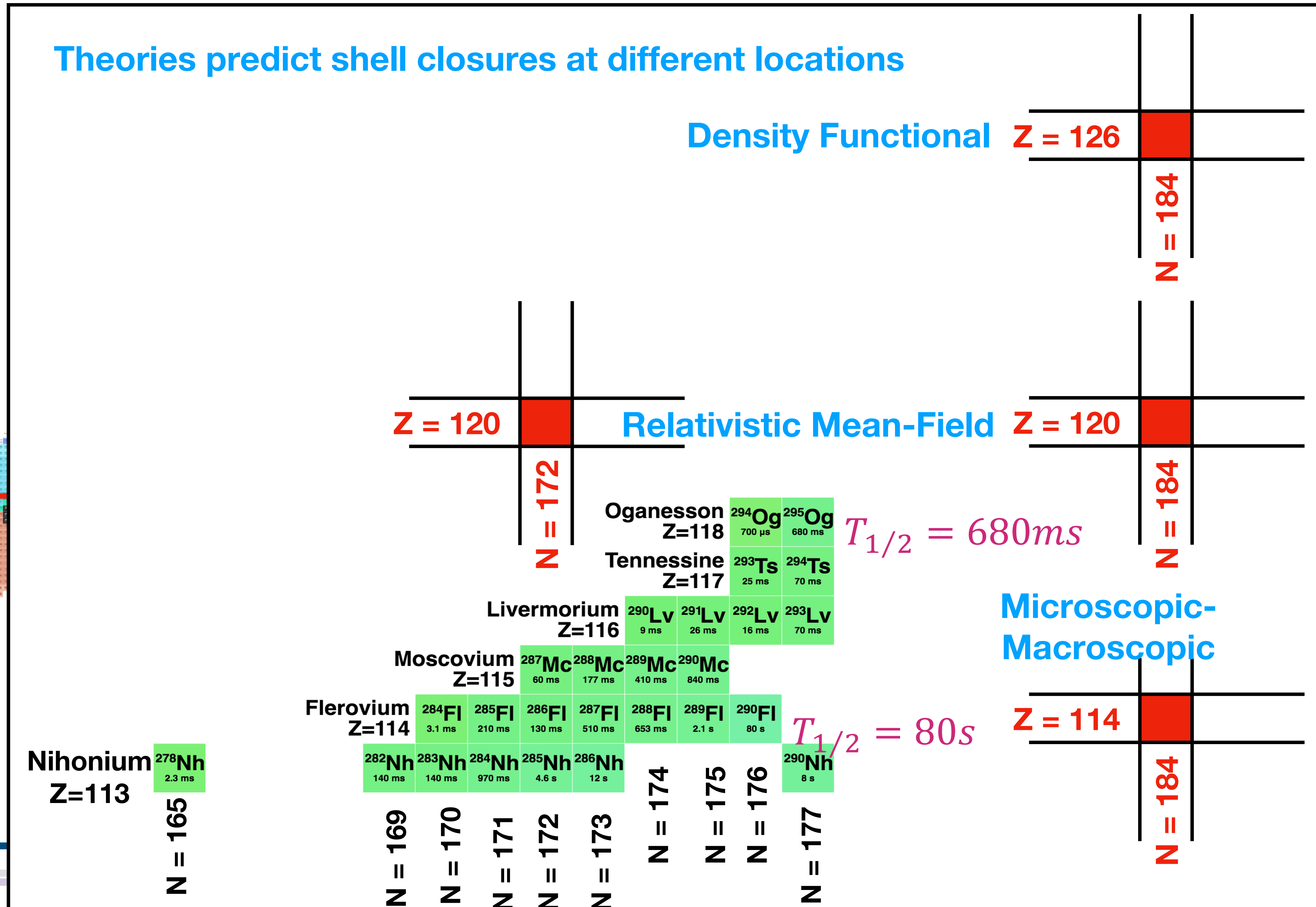
Motivation

Explore:

- **Nuclear structure of exotic nuclei**
- **Nature of the Nuclear interactions at large Z and A**
- **The limits of nuclear stability**
- **...**

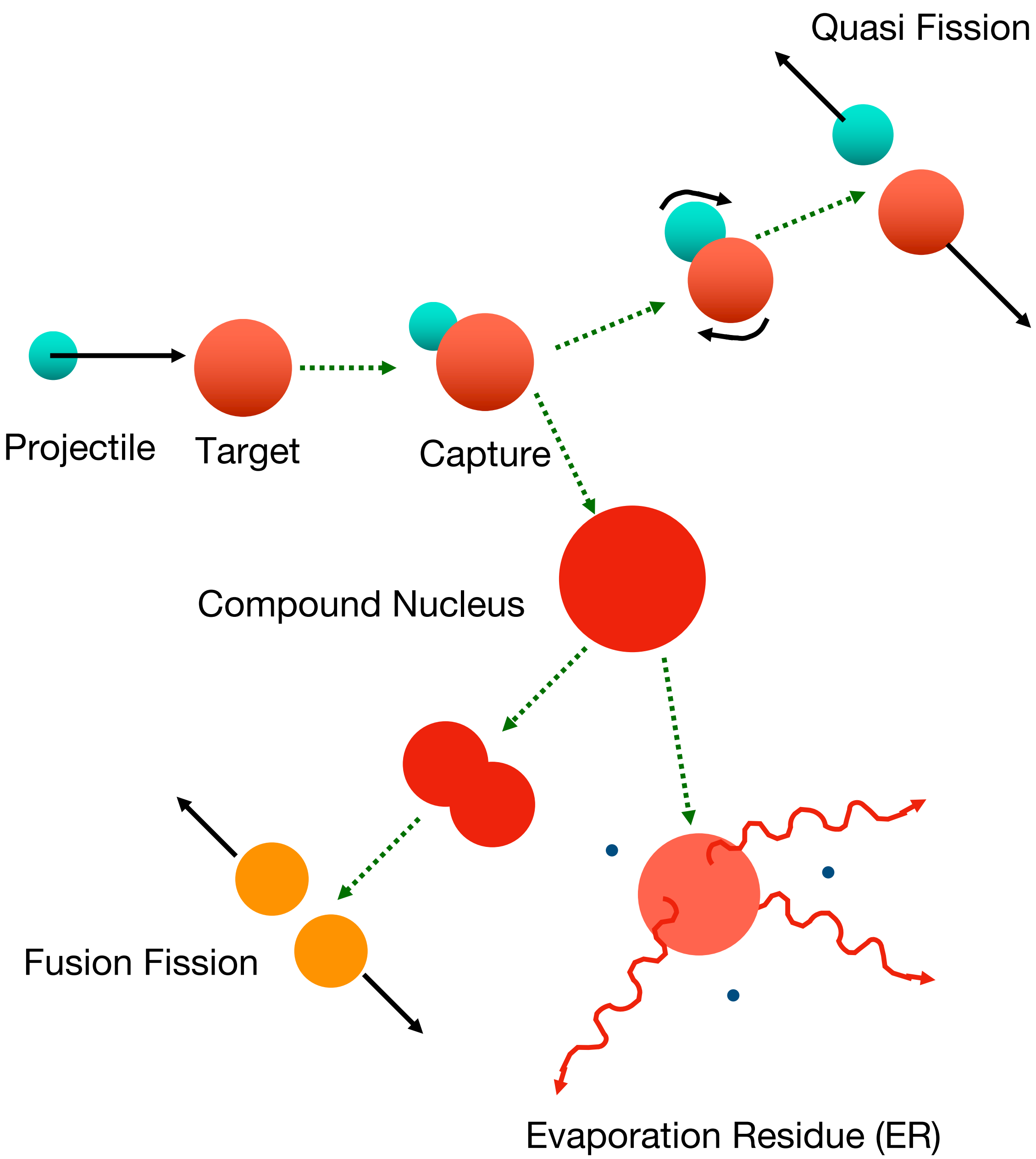
using decay spectroscopy





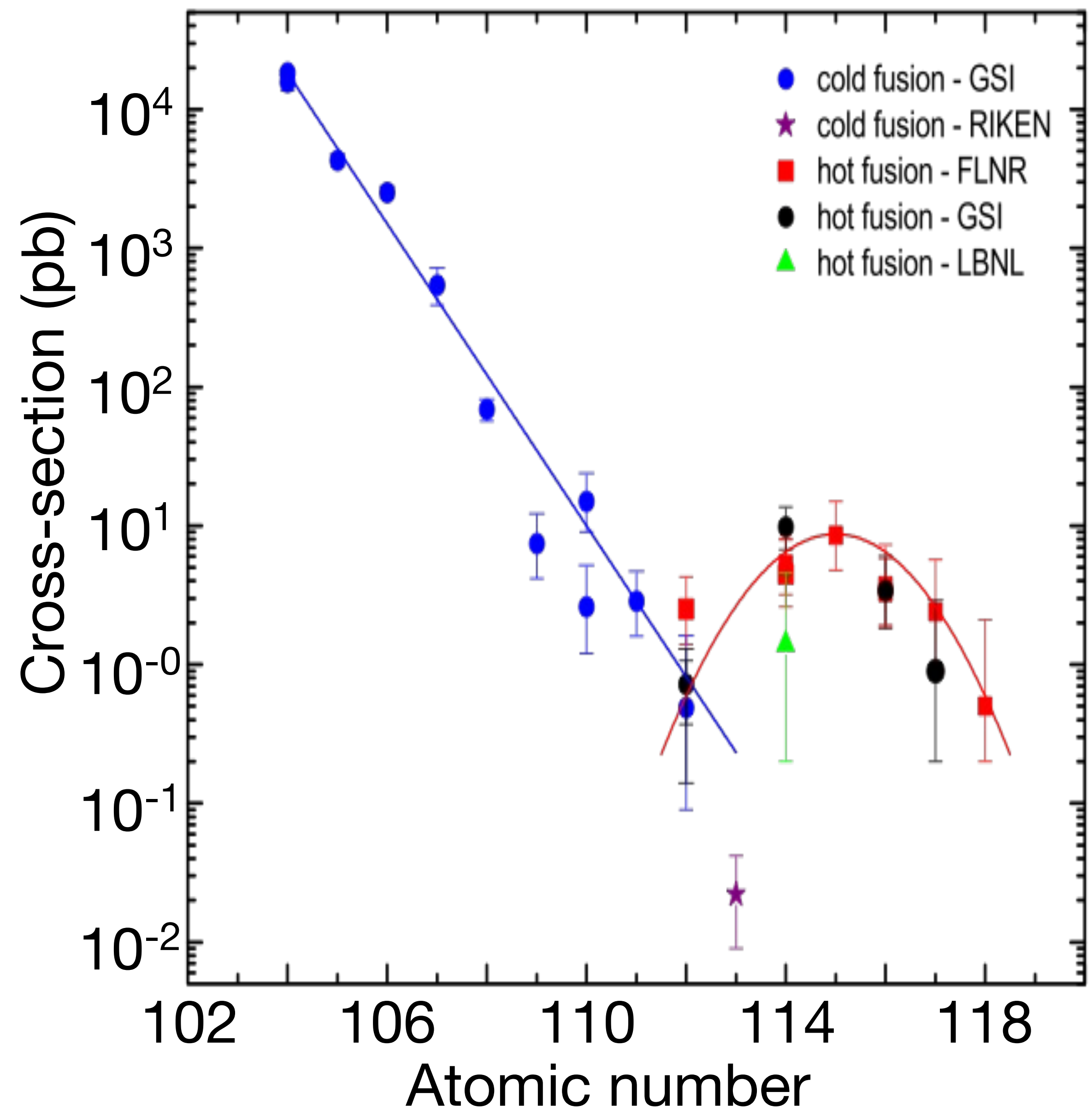
Challenge: Production of SHN

Superheavy nuclei are produced in
Fusion Evaporation Reactions



$$\sigma(ER) \approx \underbrace{\sigma(Fission)}_{1\ b} \times 10^{-12} b$$

D. Ackermann and Ch Theisen, Phys. Scr. 92 (2017) 083002



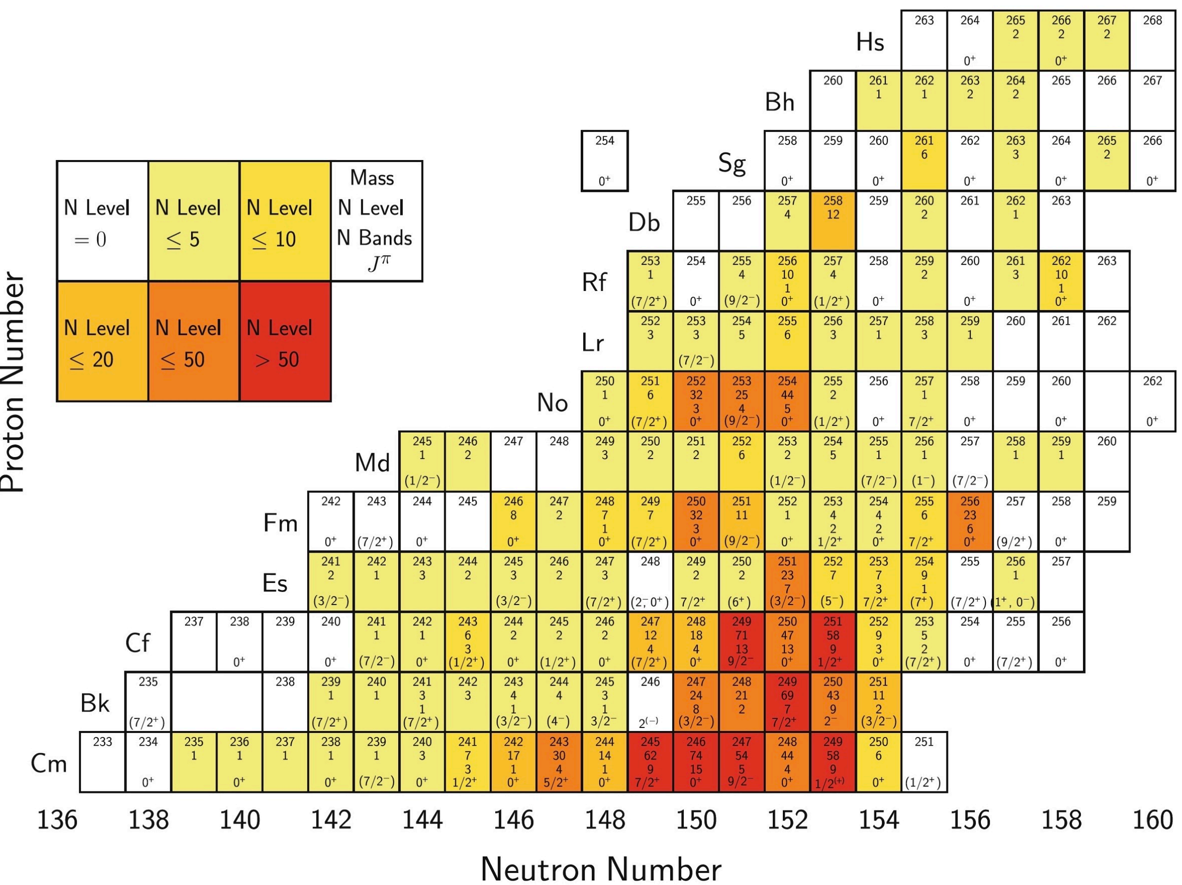
Rate

Beam Intensity
1 pμA
Target thickness
150 μg/cm^2

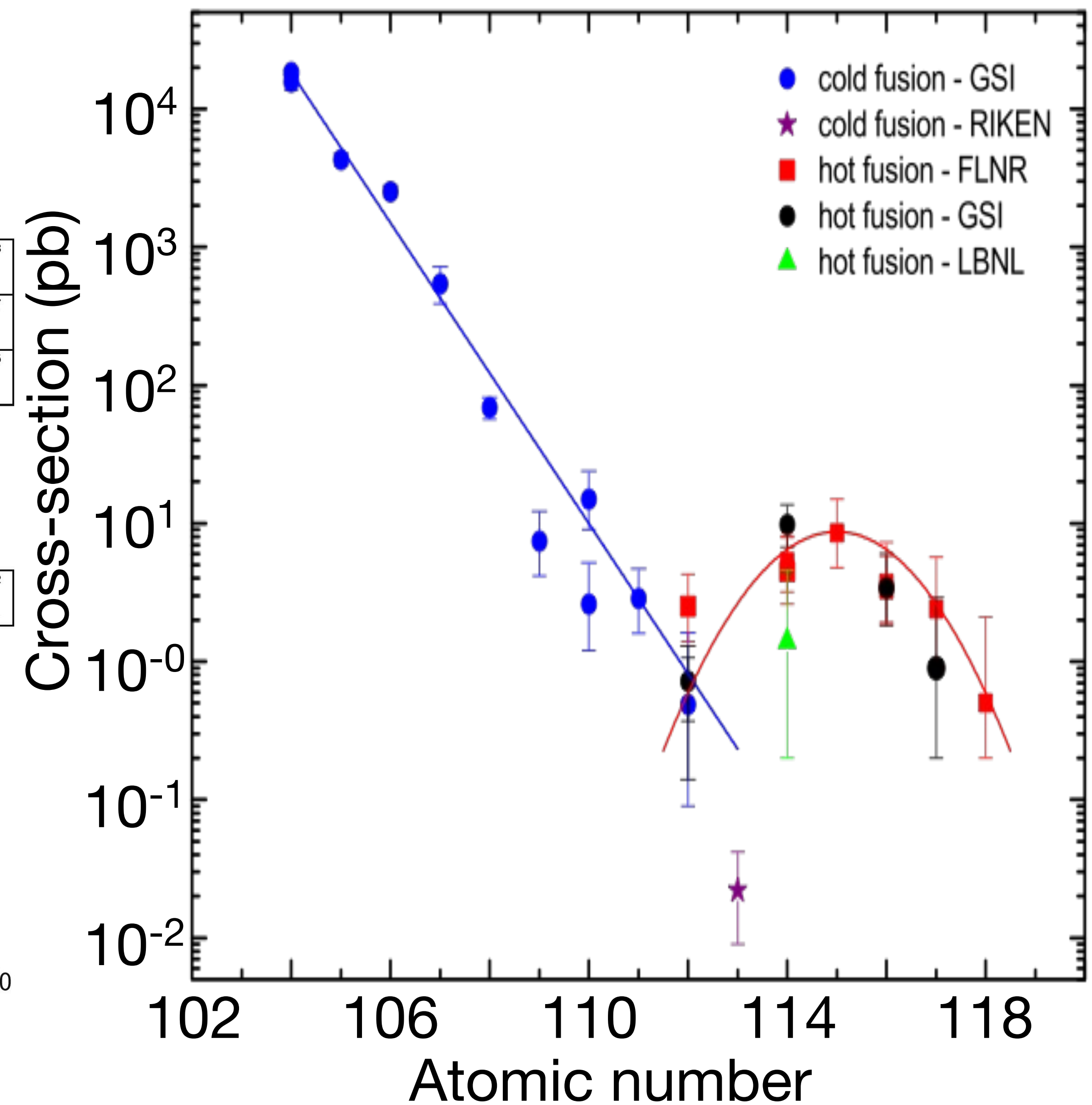
1 nb	**10 /hr**
1 pb	**1 /week**
10 fb	**1 /year**

Challenge: Production of SHN

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



D. Ackermann and Ch Theisen, Phys. Scr. 92 (2017) 083002



Rate

Beam Intensity
1 pμA
Target thickness
150 μg/cm^2

1 nb **10 /hr**

1 pb **1 /week**

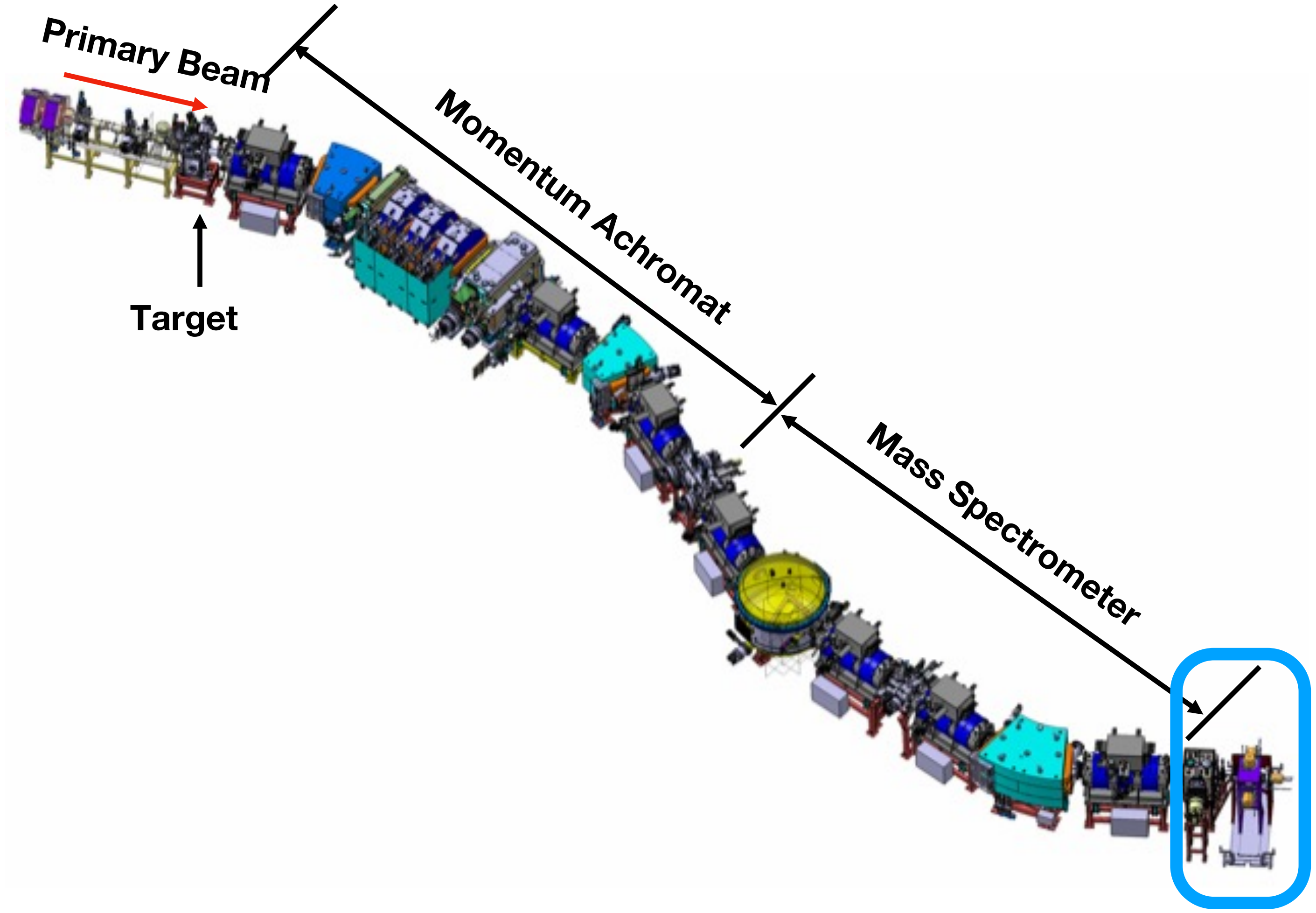
10 fb **1 /year**

$$N_{produced} = I_{beam} \times duration \times \sigma \times \Delta x_{target} \times N_A / M_{target}$$

Requirements:
- **High beam intensity**
- **Efficient setup + Spectrometer**

Challenge: Detection of SHN

SPIRAL2-LINAC



S3 Collaboration., Déchery, F., Drouart, A. *et al., Eur. Phys. J. A* **51**, 66 (2015).

S^3 (Super Separator Spectrometer)

Large Acceptance : $> \pm 50\, mrad$

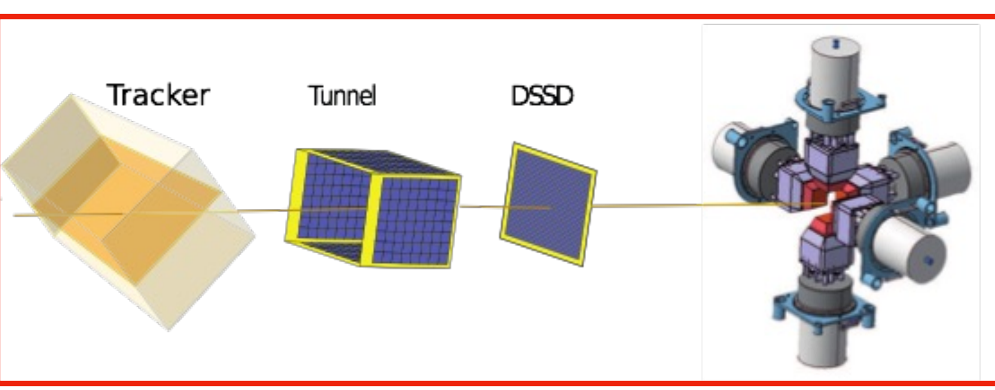
High Transmission:

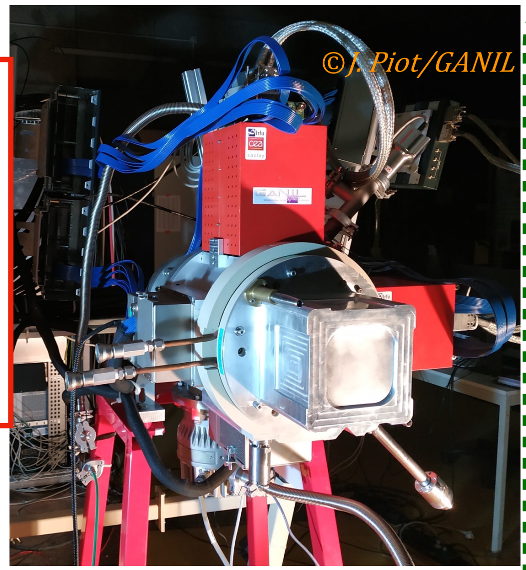
$\approx 50\%\, asymmetric\ reactions\ (Ca + Pb)$

$\approx 20\%\, very\ asymmetric\ reactions\ (Ne + U)$

Good Mass Separation: $\Delta M/M \approx 1/500$

Designed to perform experiments using fusion evaporation reaction with very low cross-sections



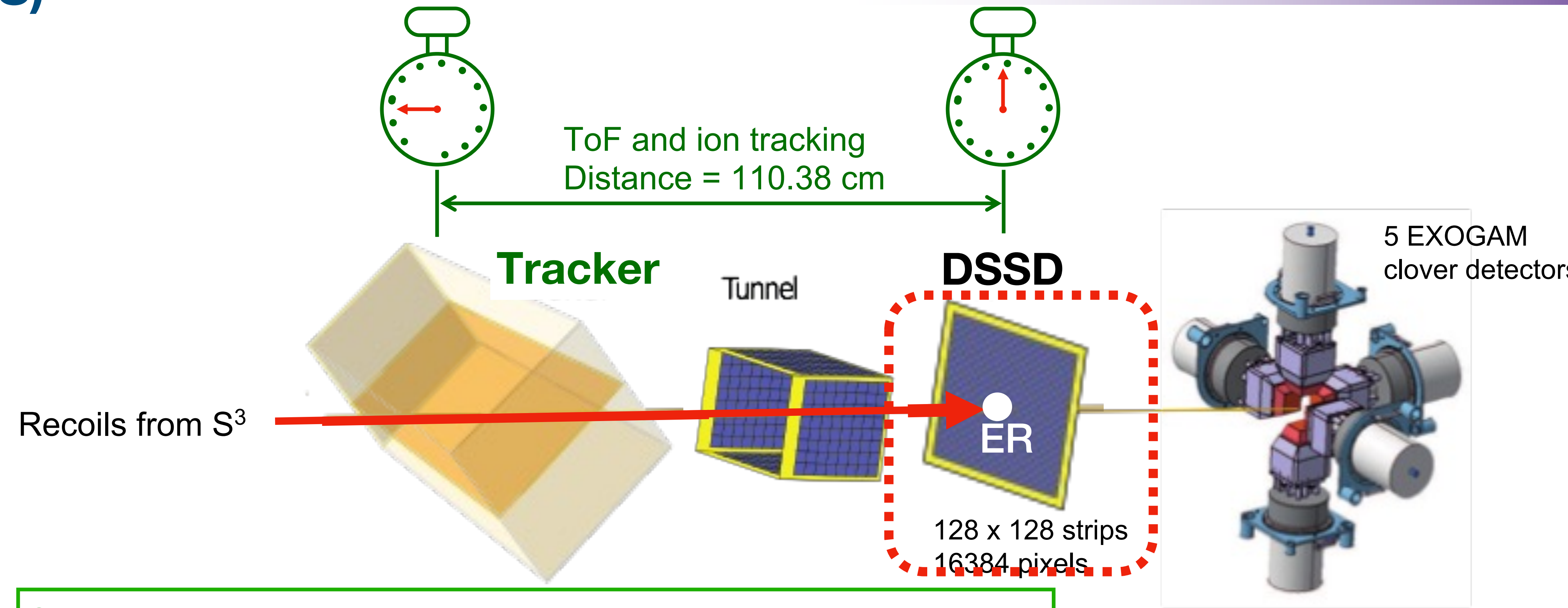


SIRIUS (Spectroscopy and Identification of Rare Isotopes Using S^3)

The focal plane detection system of S^3

Designed to detect heavy ions and their subsequent decays (α, β, γ, internal conversion e-, X rays and Fission Fragments)

Spectroscopy and Identification of Rare Isotopes Using S^3 (SIRIUS)

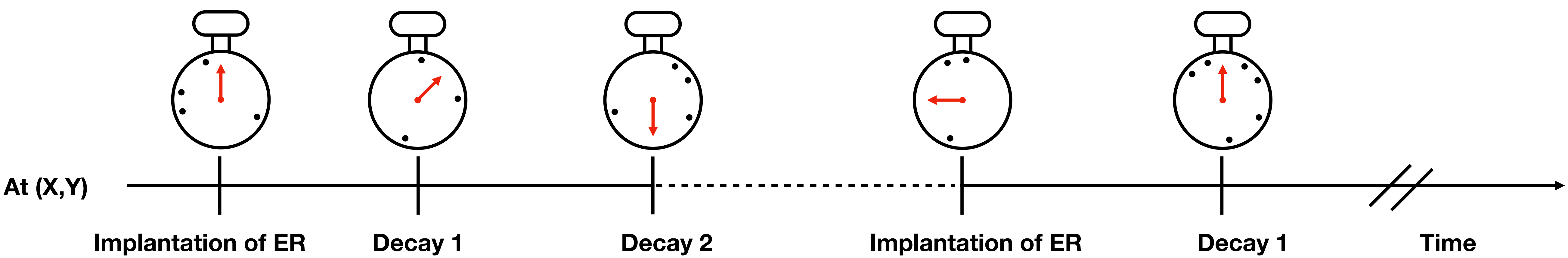


Serve as a marker to identify the recoil events from the decay events

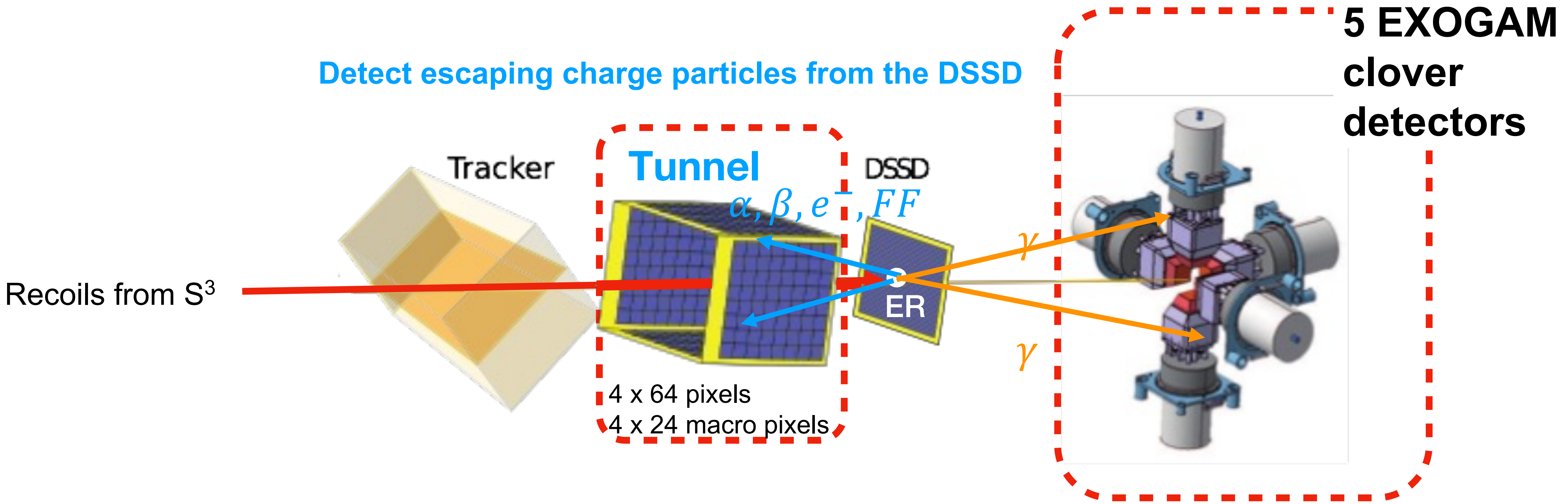
Measurement of :

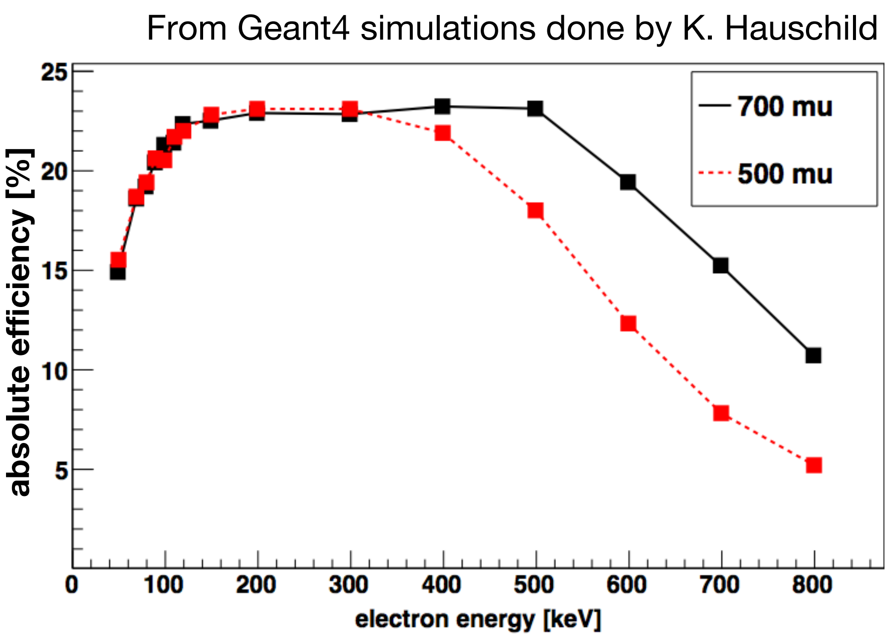
- Lifetimes
- Energies
- Decay modes

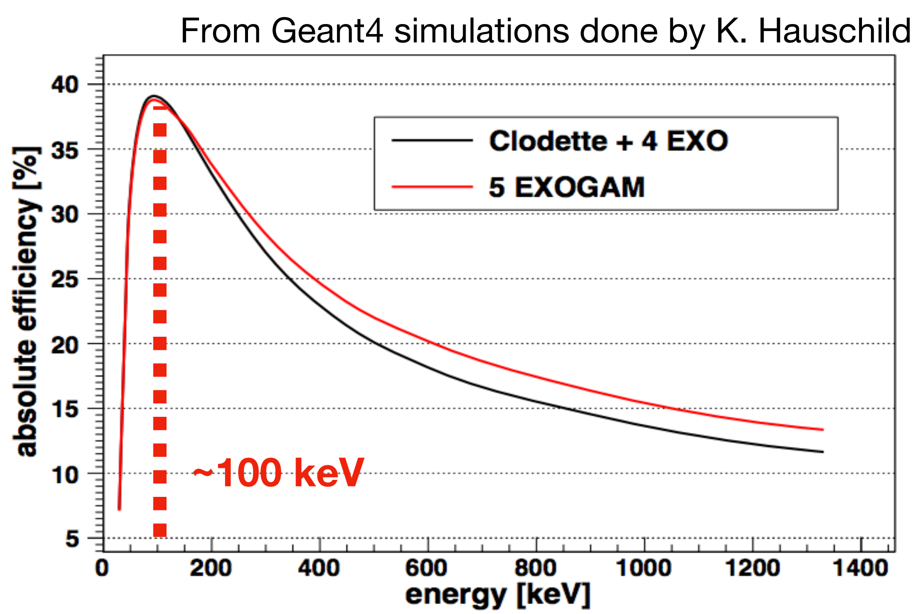
At the focal plane (Position-sensitive) detector:
recoil-decay, decay-decay correlations



Spectroscopy and Identification of Rare Isotopes Using S^3 (SIRIUS)







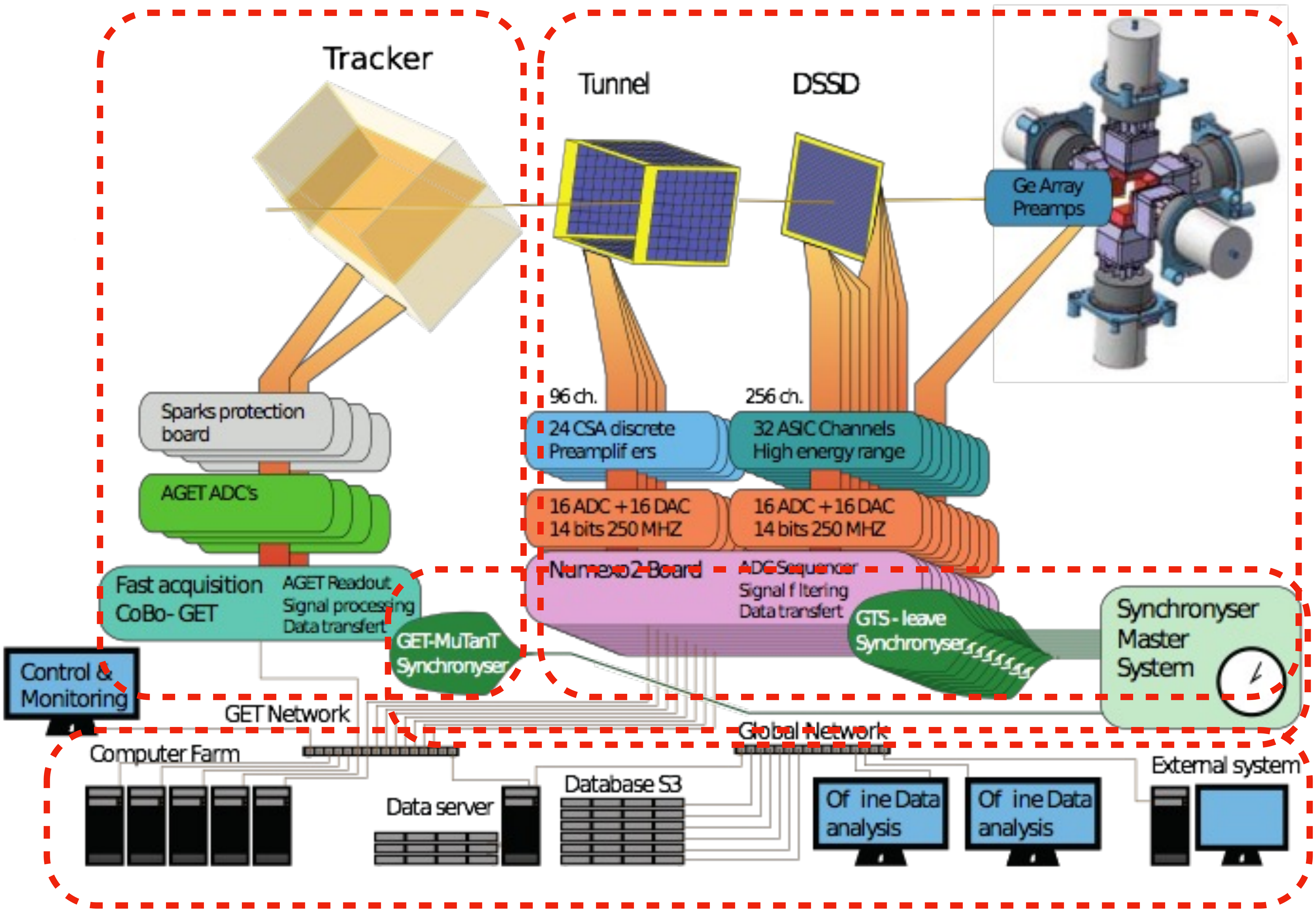
Identify different transitions from :

- Alpha-electron correlation
- Alpha-gamma correlation
- Electron-gamma correlation
- …

Measurement of :

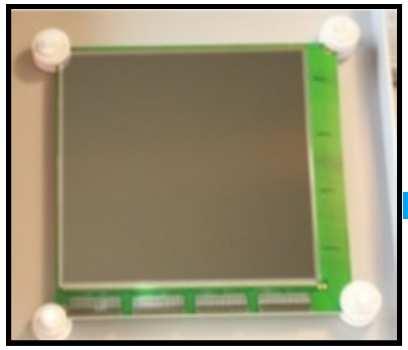
- Lifetimes
- Excitation energies
- Multipolarity of the transitions

Schematic of the SIRIUS Acquisition system

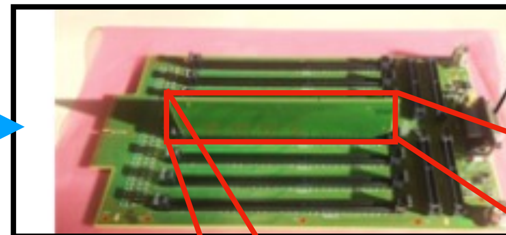


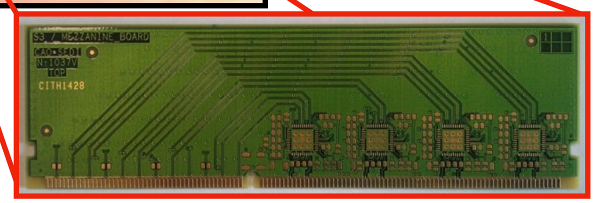
DSSD

DSSD in vacuum



Floating Points Charge Sensitive Amplifiers





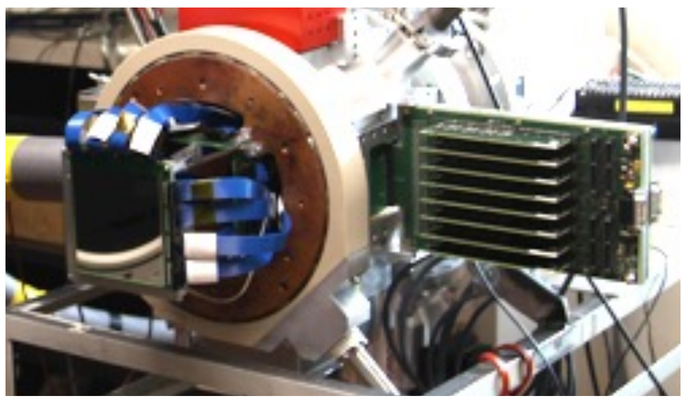
Adaptation board

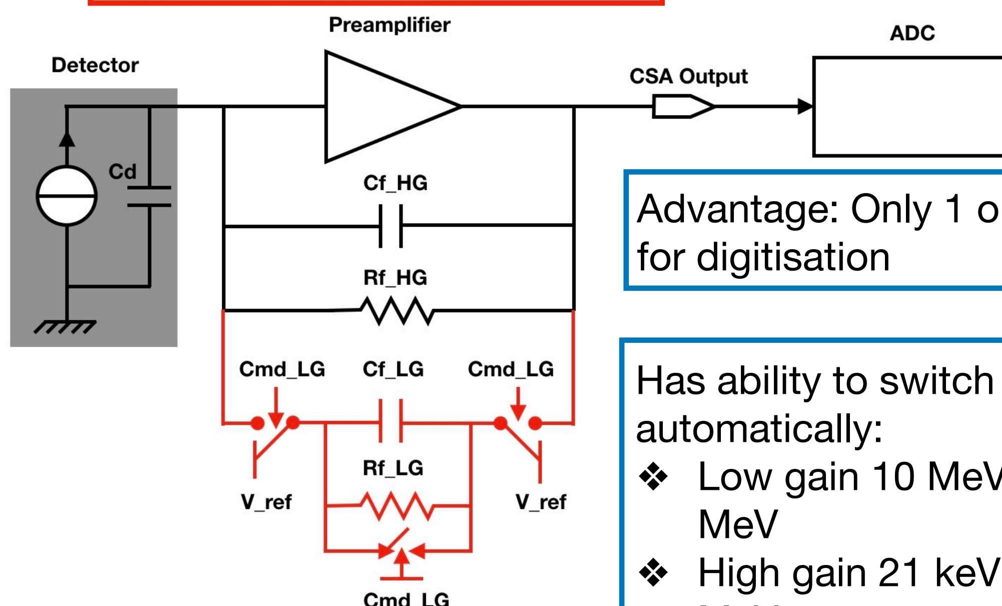
HDMI cable

Numexo2
200 MHz digitisation

GRU
C++ code

Traces saved in a disk

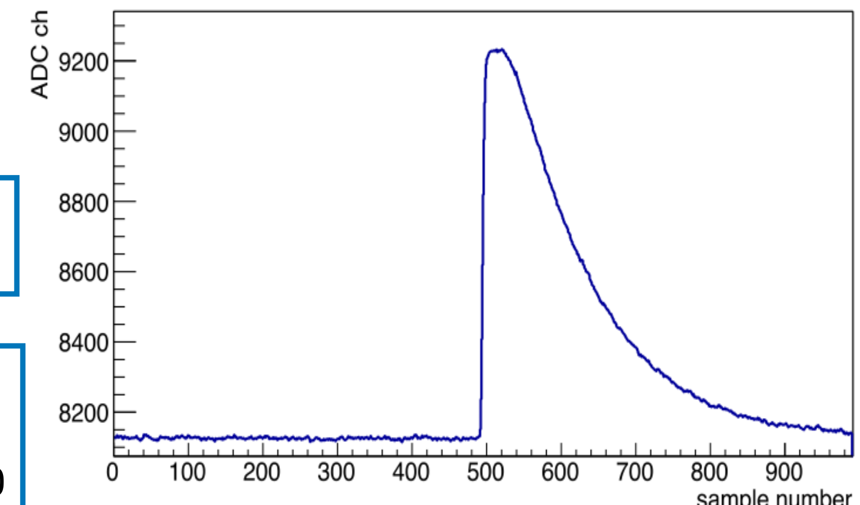




Advantage: Only 1 output for digitisation

Has ability to switch gain automatically:

- ❖ Low gain 10 MeV - 500 MeV
- ❖ High gain 21 keV - 40 MeV



- ➢ remove pile-up
- ➢ detection of short-lived decays

Detector Characteristics

Active area: $\approx 10\times10 cm^2$

Thickness: $\approx 300\mu m$

Dead layer: $\sim 50nm$

128 x 128 Strips

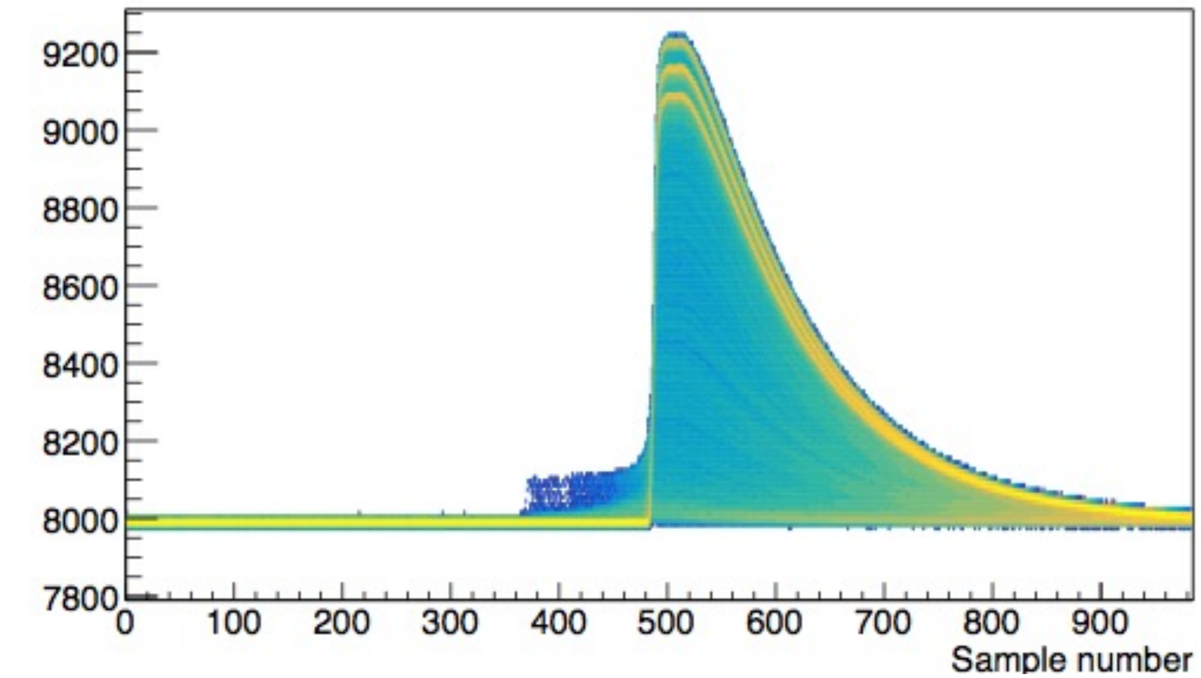
Detect alpha, e-, fission fragments and beam

Whole DSSD has been instrumented with all 16 Numexo2 boards

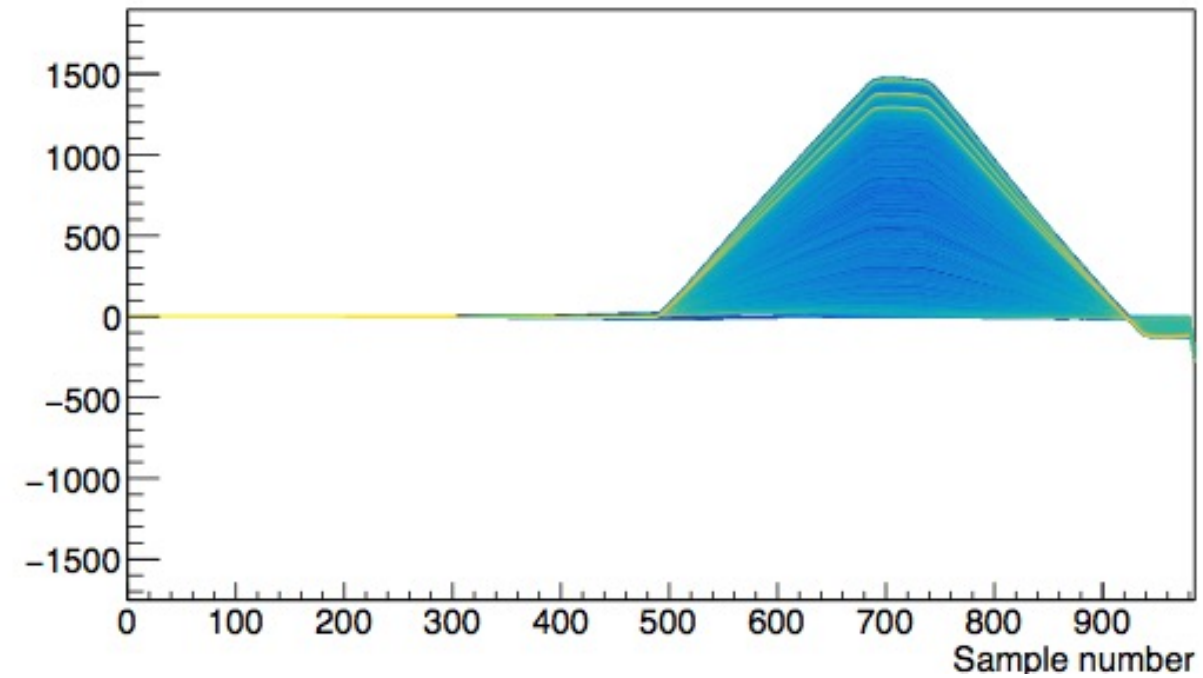
Performance of the DSSD in high gain mode with 3-alpha source

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

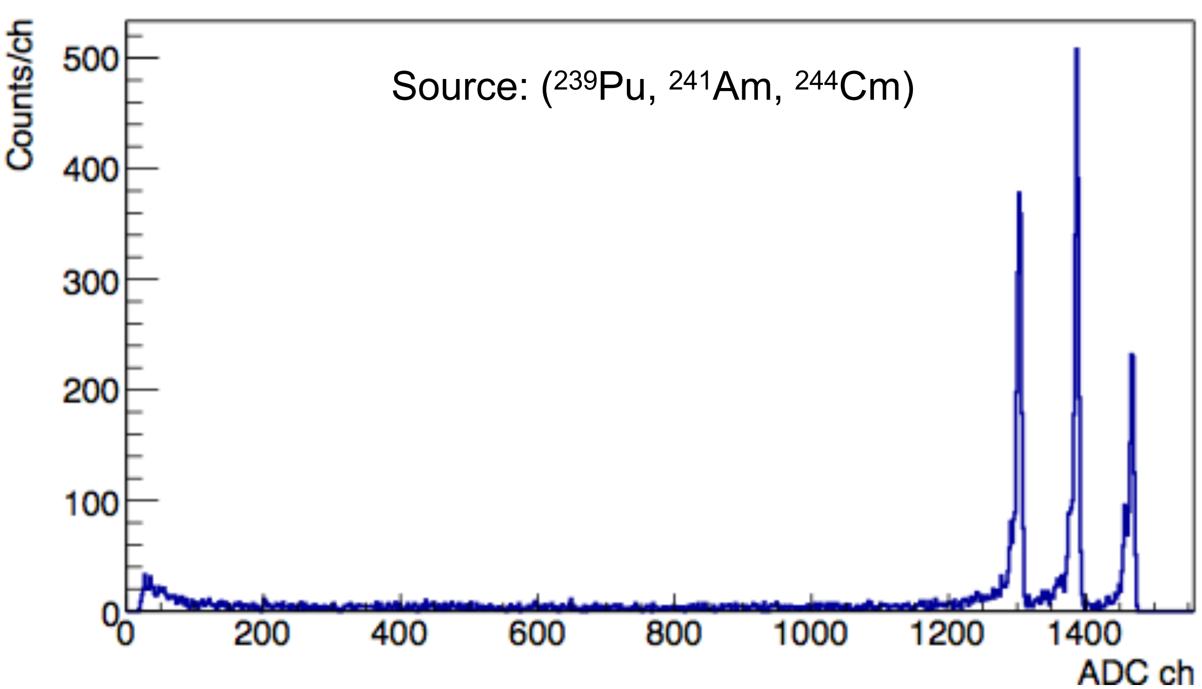
Traces from 1 DSSD strip



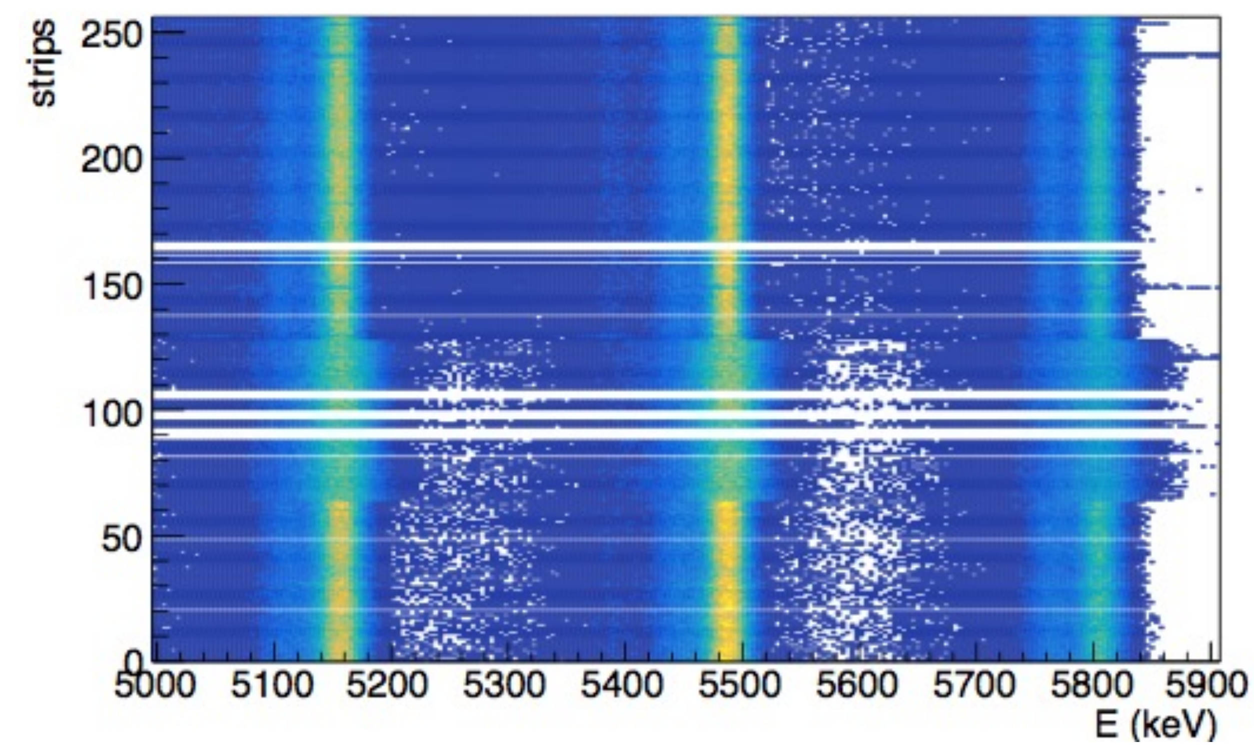
Trapezoidal filter



Raw spectrum

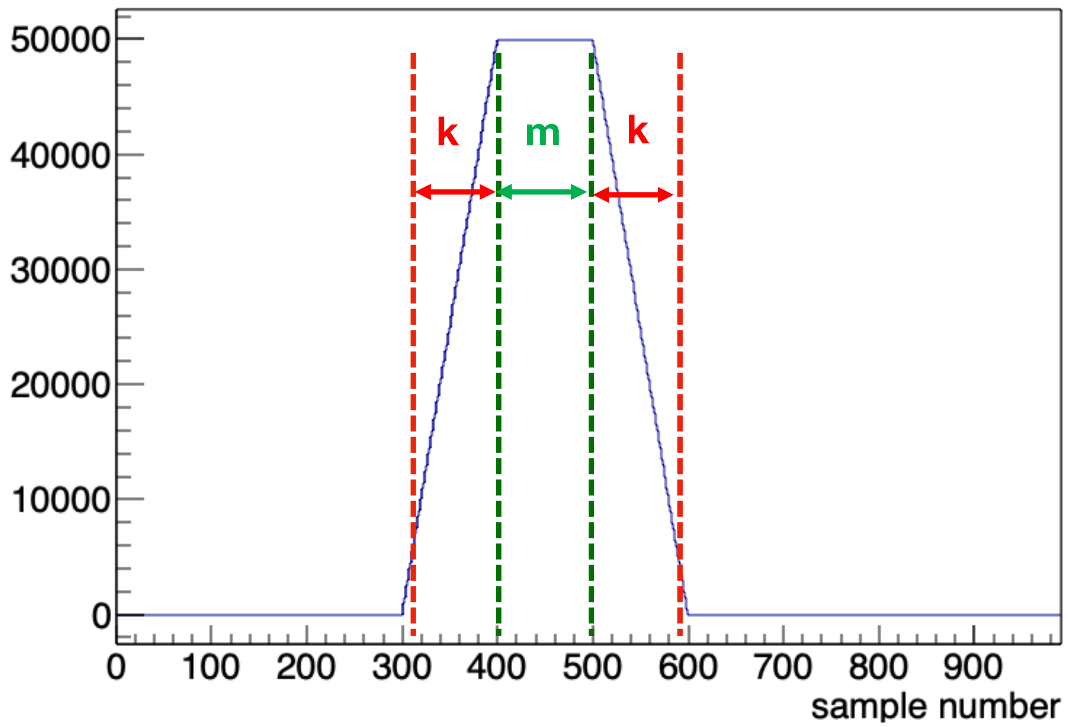


Calibration of 256 strips



Performance of the DSSD in high gain mode with 3-alpha source

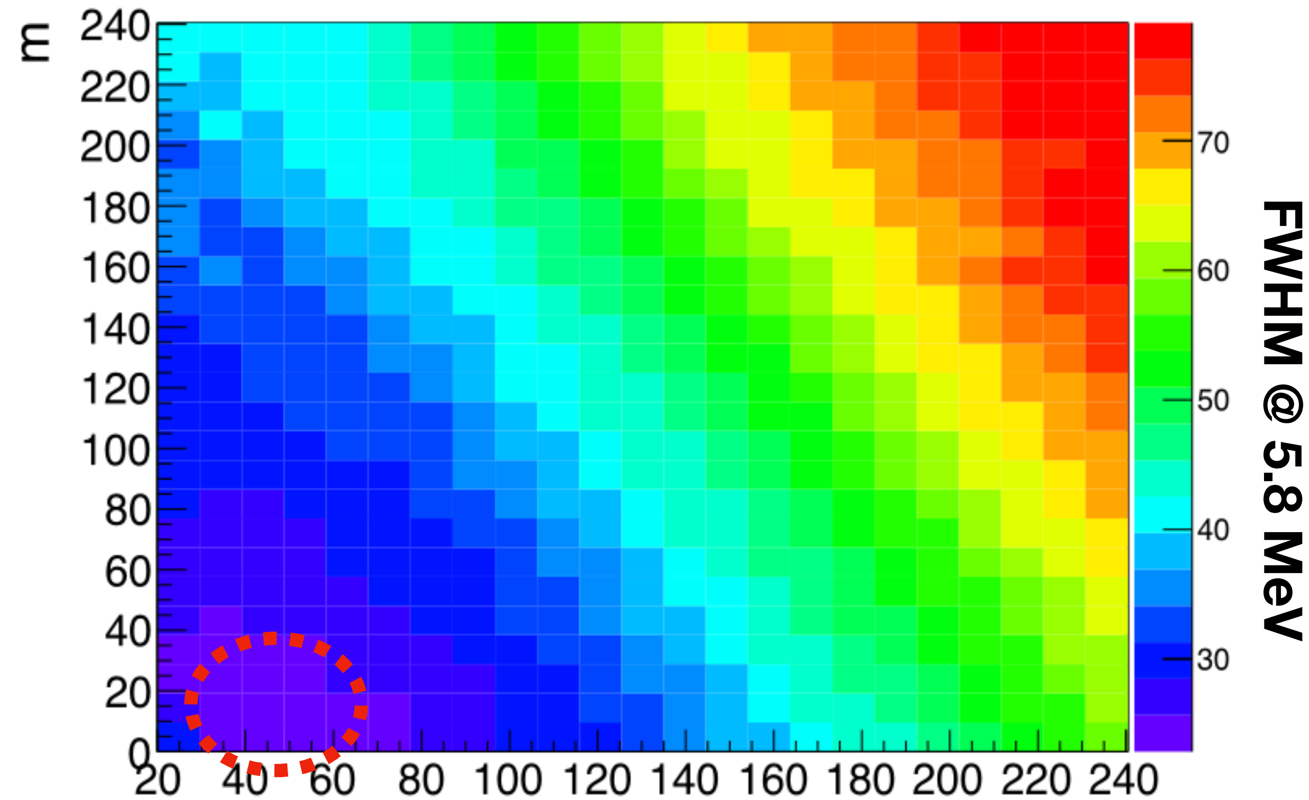
Optimisation of the trapezoidal filter parameters

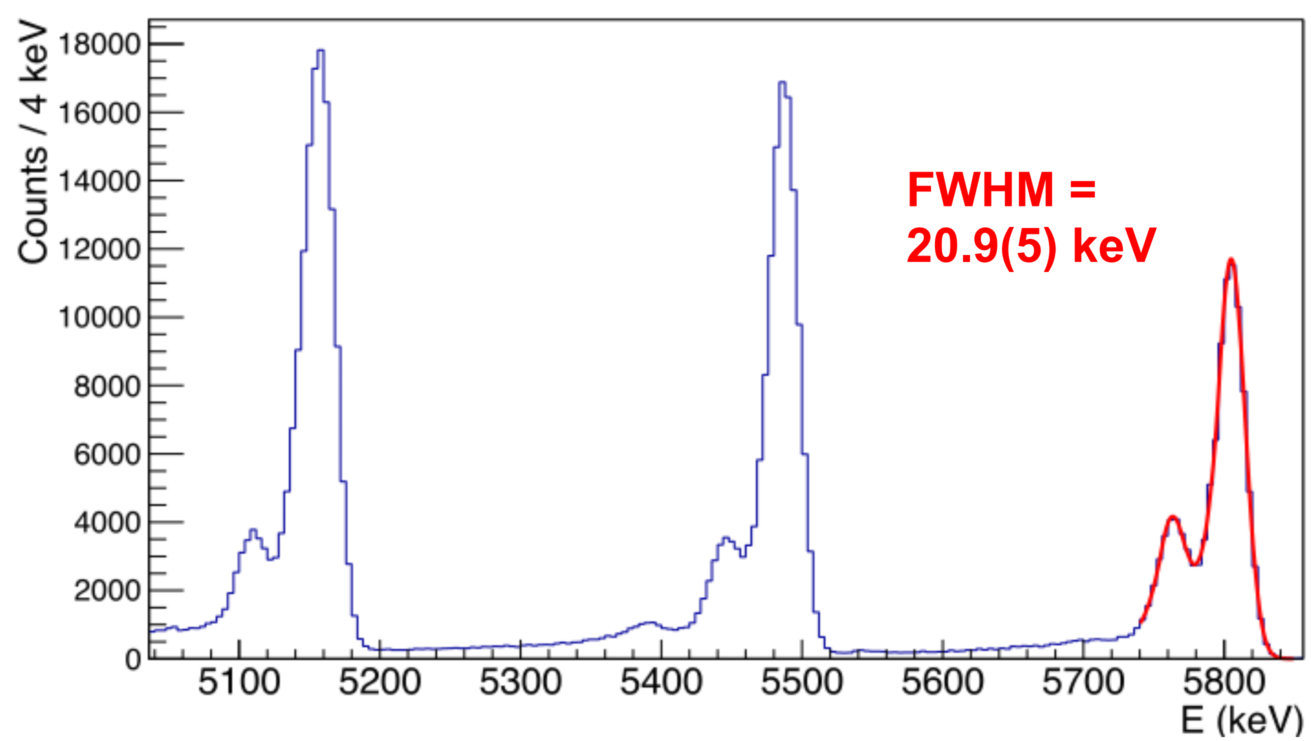


K =50 and m = 10 Samples

Optimisation performed for all the 256 strips of the DSSD

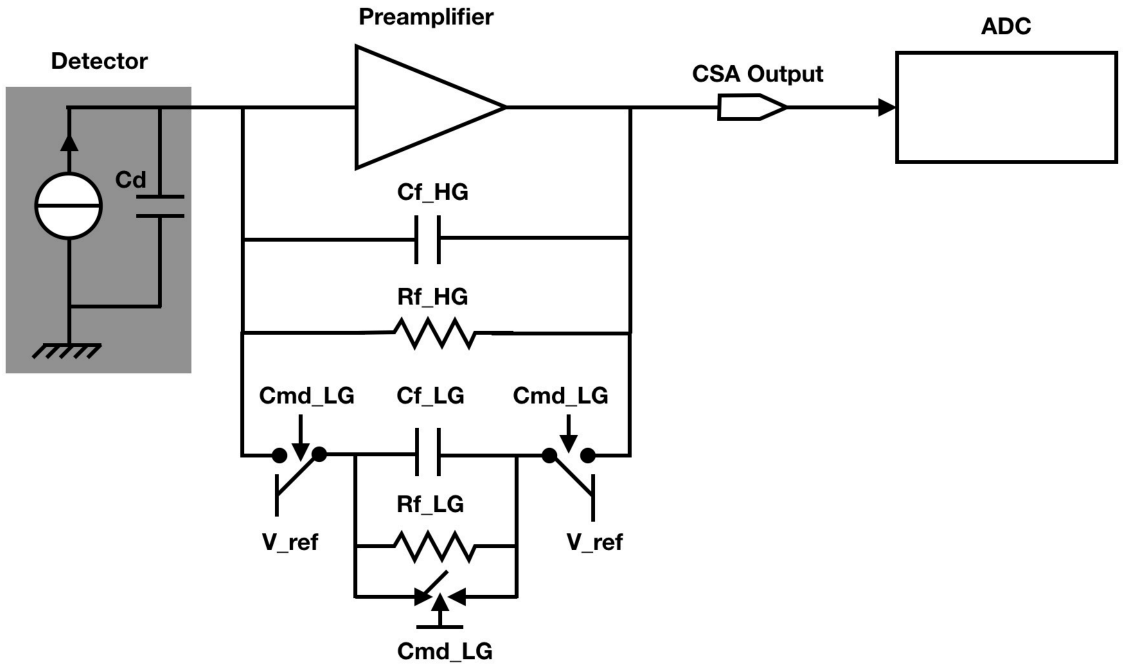
FWHM of a single strip as a function of k and m

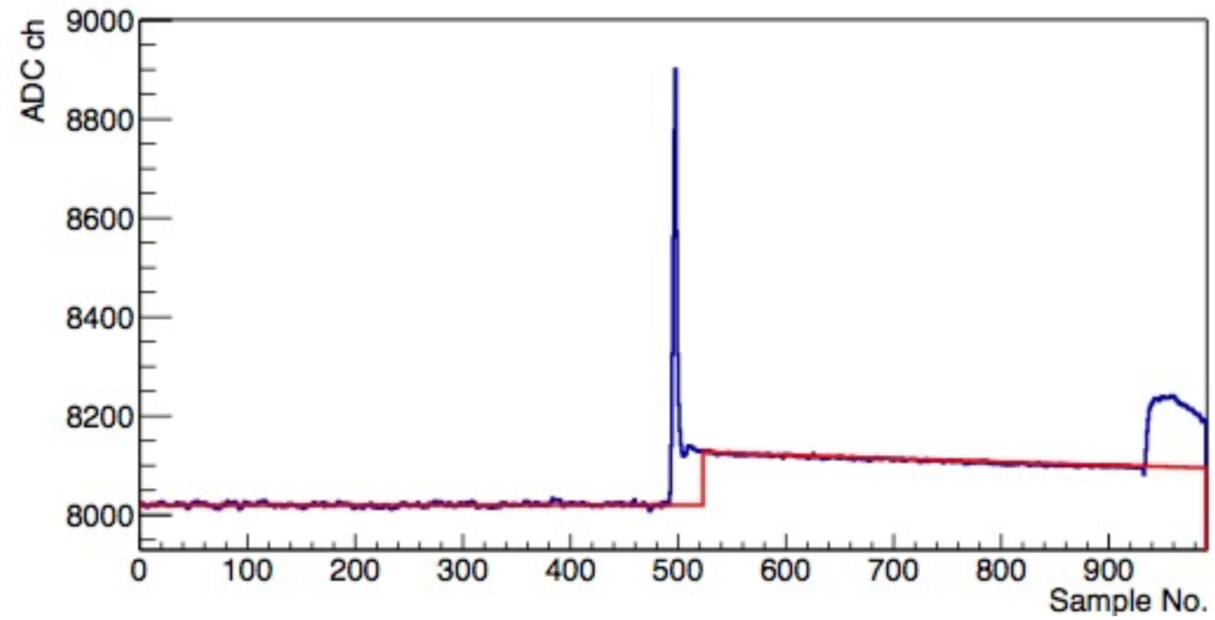




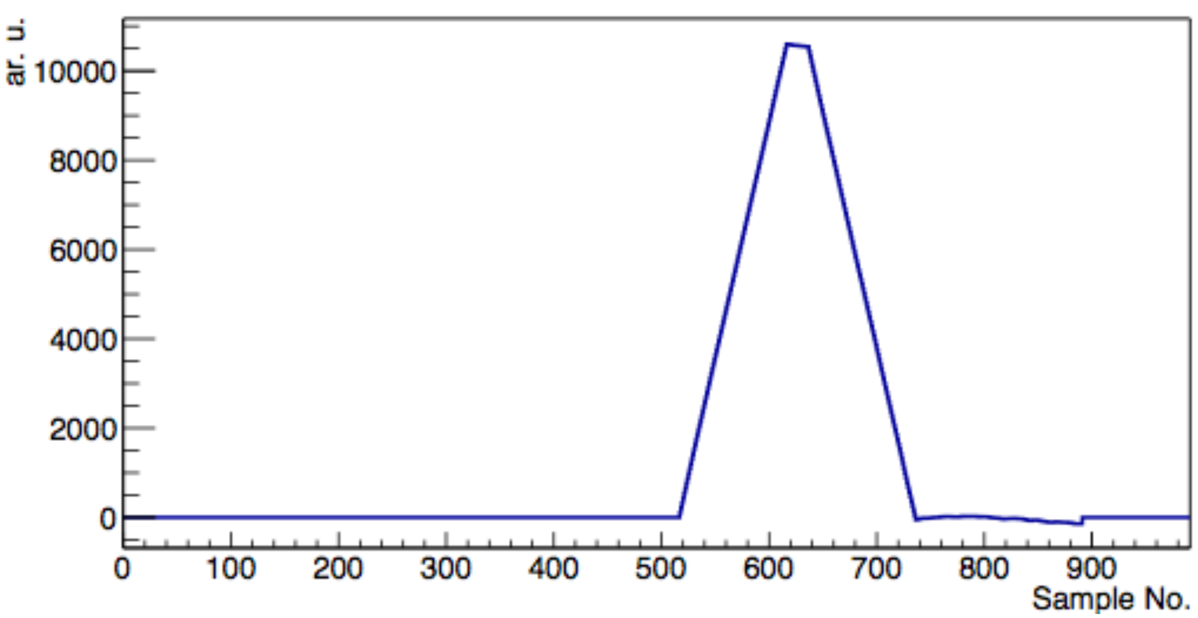
DSSD: Auto Gain

Floating Point Charge Sensitive Amplifier (FPCSA)

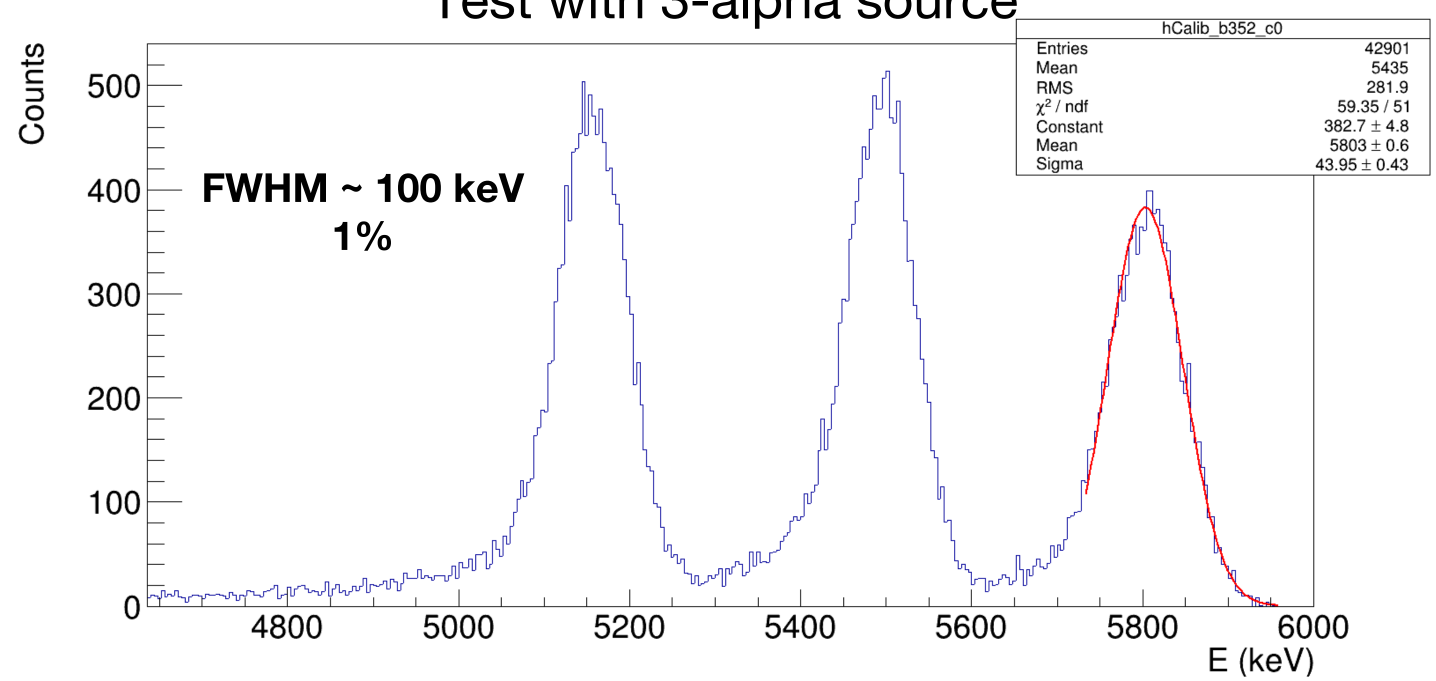




Switching feedback capacitor to
change gain as a function of output signal level

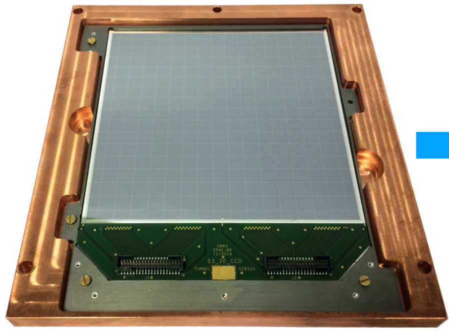


Test with 3-alpha source

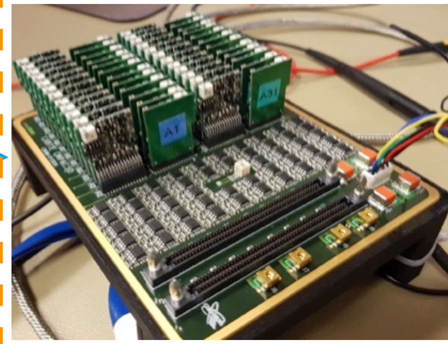


Tunnel

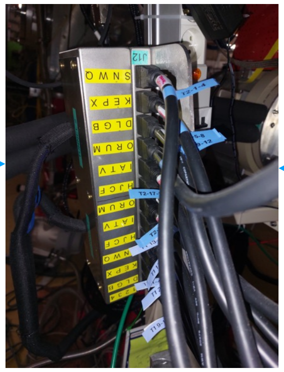
4 Strippy pad
silicon detector



2 x 48 Digital FeedBack
Charge Sensitive Preamplifiers

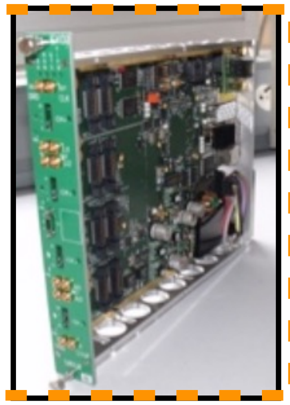


Adaptation box



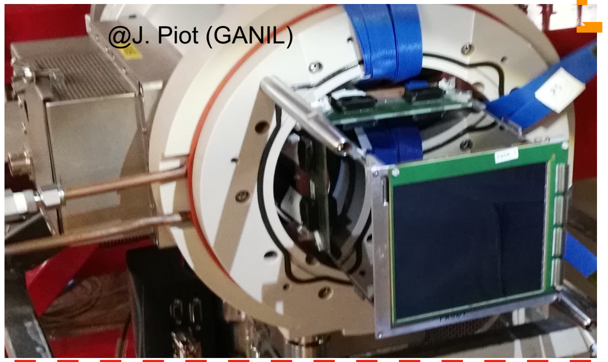
HDMI Cables

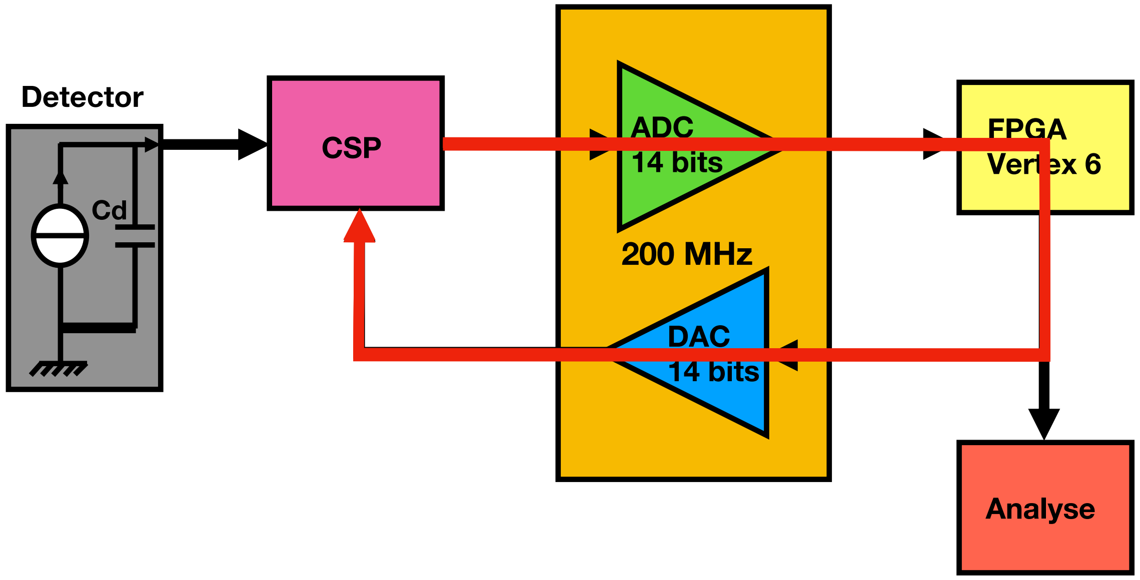
Numexo2

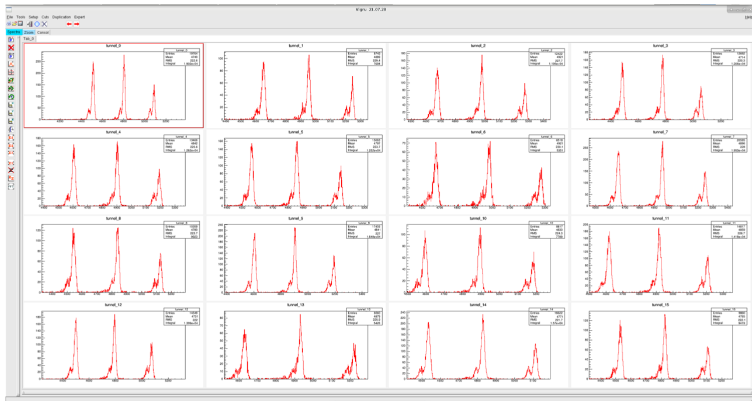


GRU
C++ code

Traces **NOT** saved
in a disk
Processed online







Detector Characteristics

Active area: $\approx 10\times10cm^2$

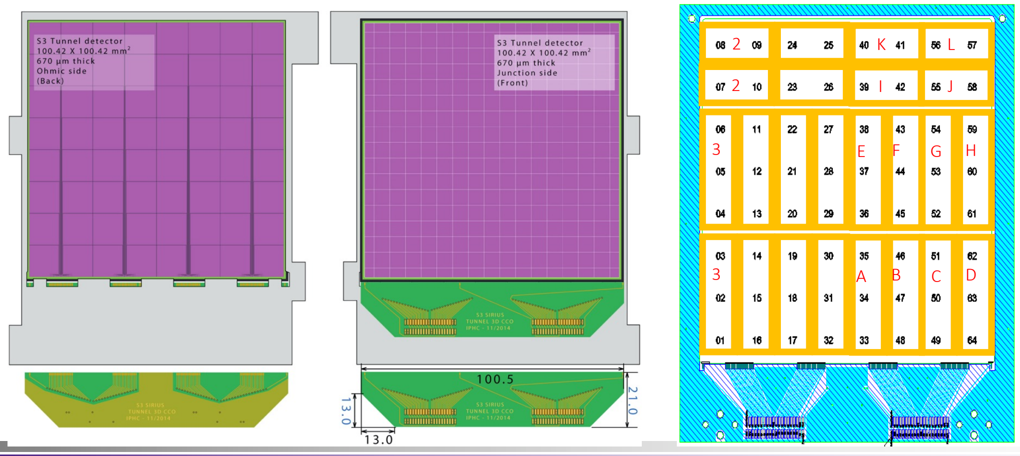
Thickness: $\approx 500\mu m$

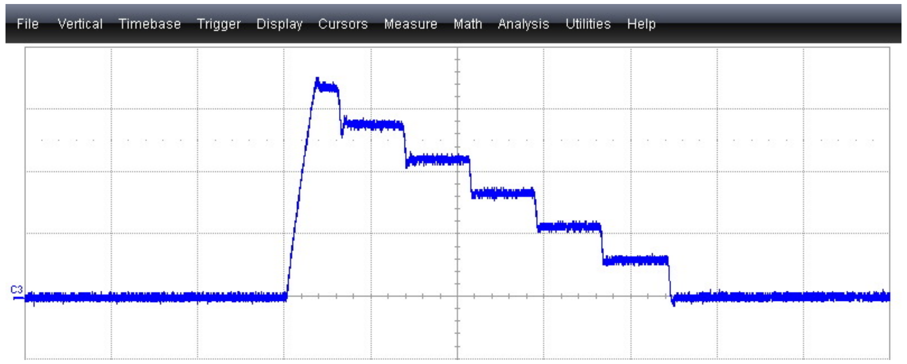
Dead layer: $\sim 30nm$ *(Windowless)*

64 pixels

24 Macro pixels

P. Brionnet et al. Nucl. Inst. Meth., A 1015 (2021) 165770



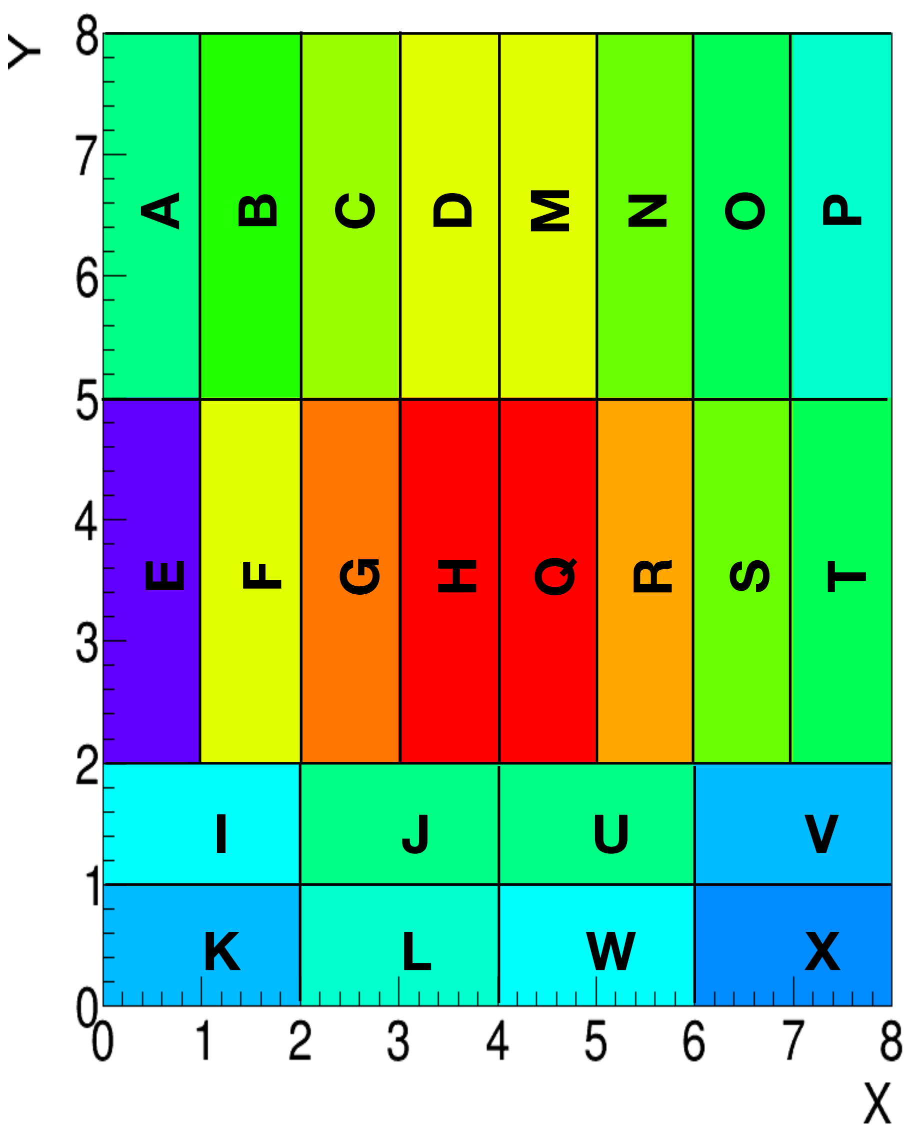


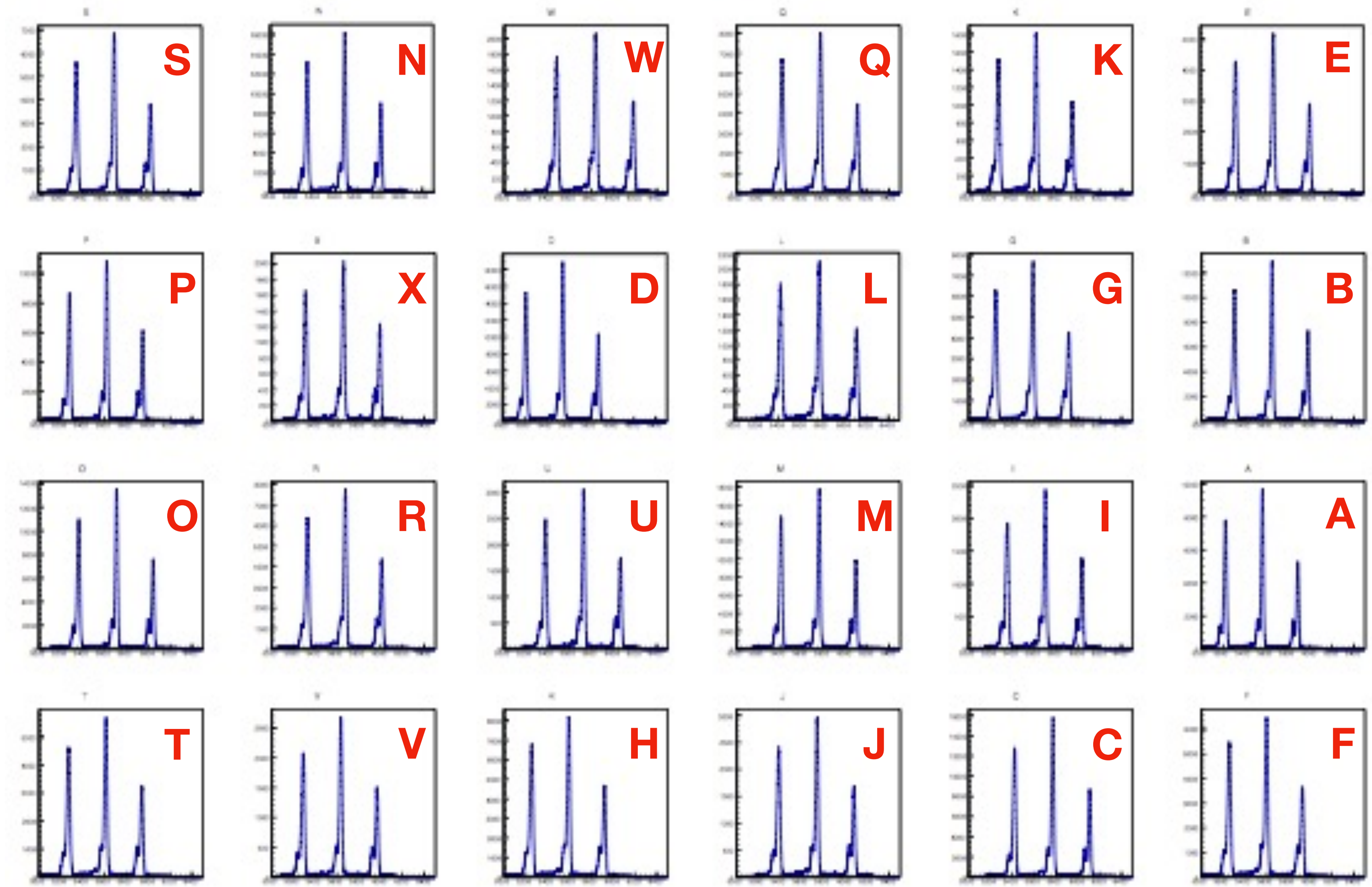
FEE Specifications

High Energy resolution using DFCSP From 20 to 150 MeV	< 0,03 %
Linearity on overall range	< 1.5%
Dead time	< 5 µs
High gain resolution @ 6 MeV	13,5 keV
Linearity	< 0,8 %
Dead time using MWD	< 8 µs

All 4 tunnel detector has been instrumented
With all 6 Numexo2 boards

Tunnel detectors

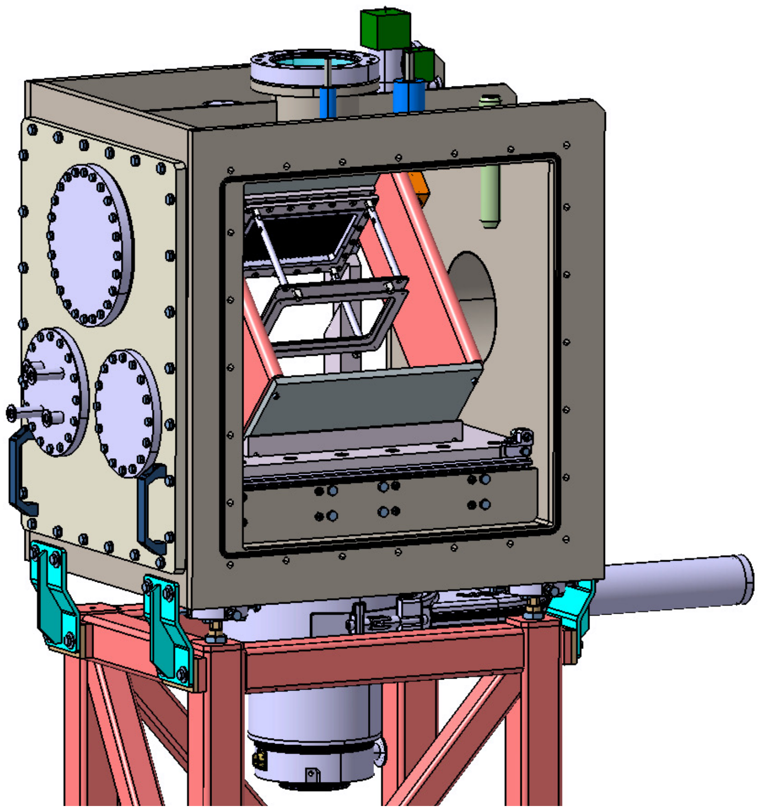


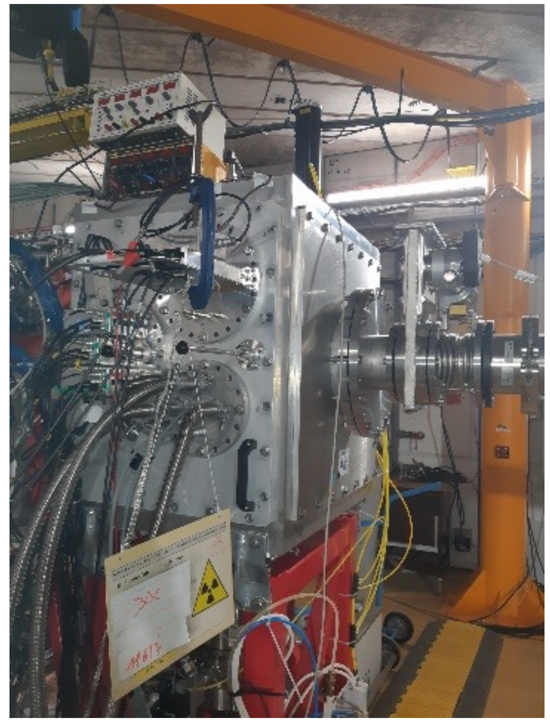


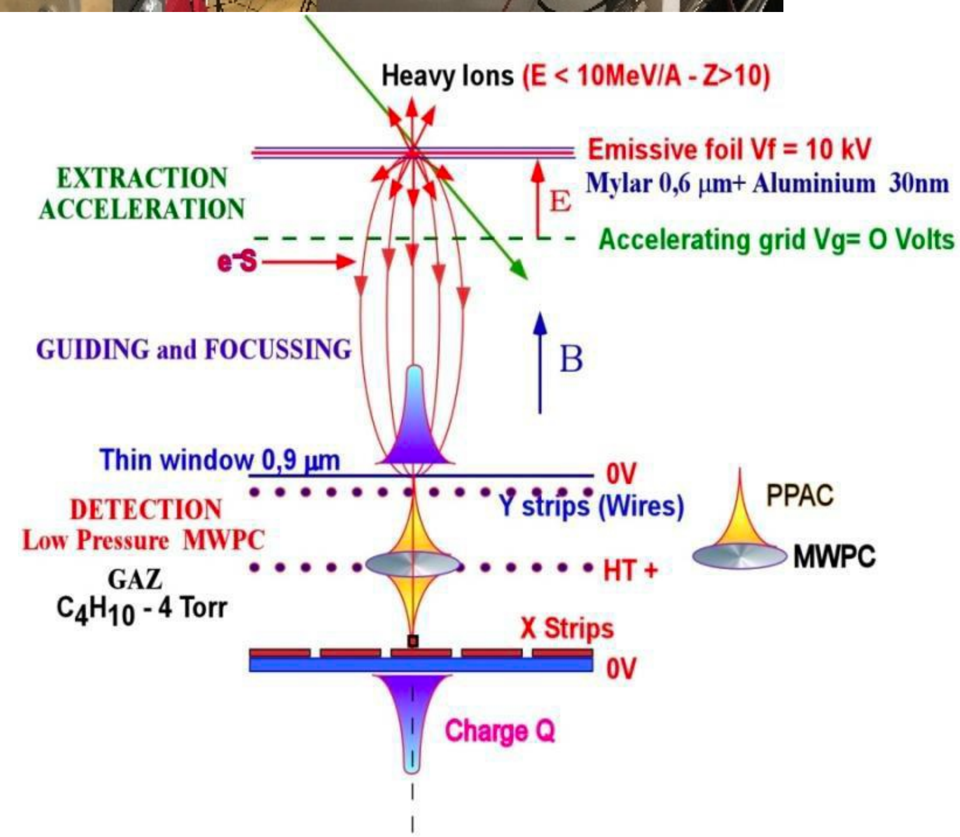
FWHM @ 5.8 MeV
with Bias Voltage 70 V and Temp = -20 C

Detector	FWHM (keV)
1	21.3(2)
2	21.9(2)
3	20.4(1)

Tracker







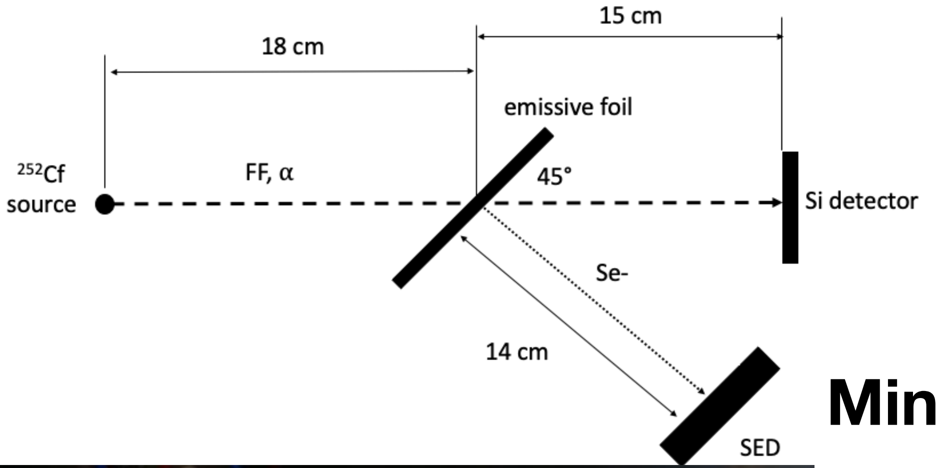
Detector Characteristics

Active area (in beam): $\approx 20\times10cm^2$

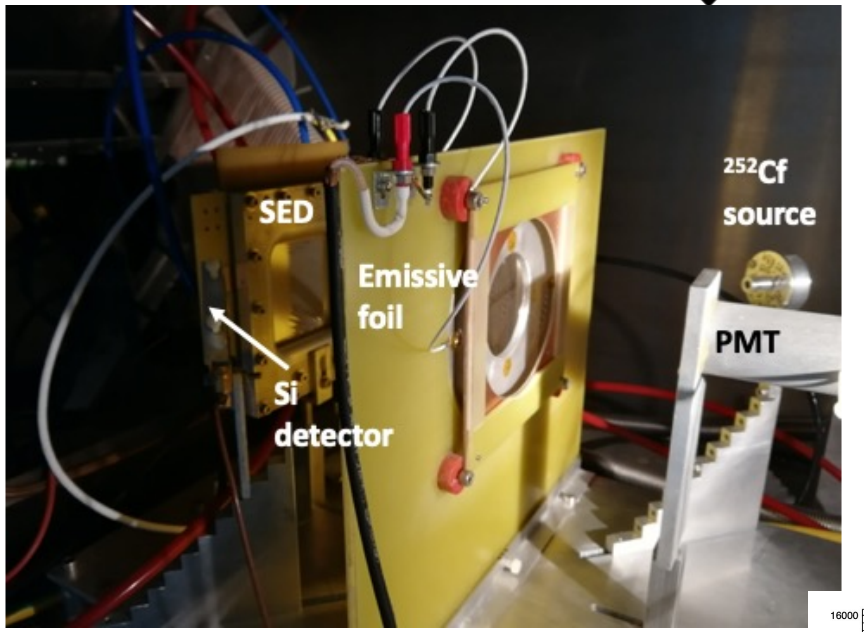
Mylar foil Thickness: $\approx 0.9\mu m$

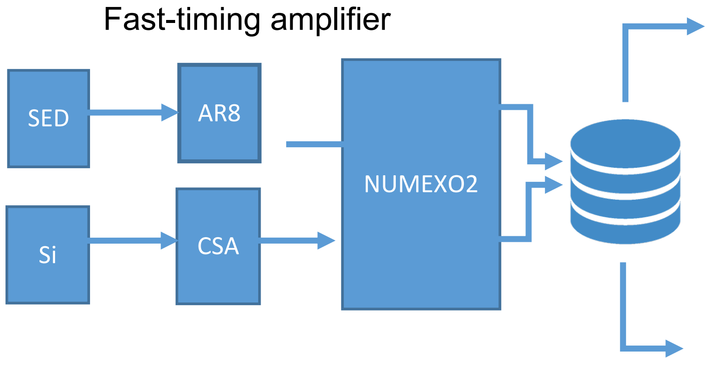
Gas(isobutane) pressure: $\approx 6-7mbar$

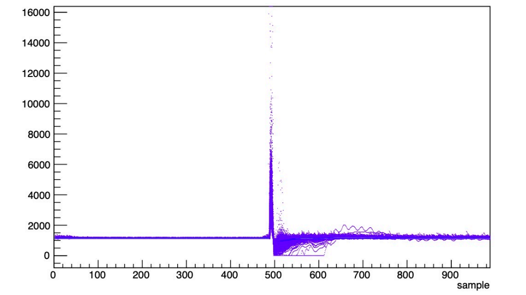
Time of Flight test using a ^{252}Cf source

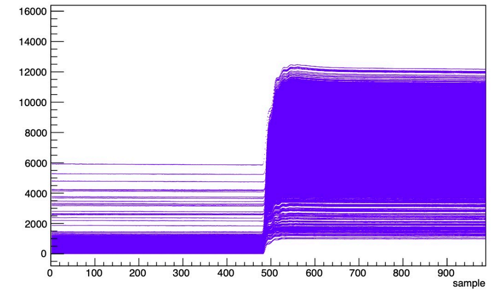


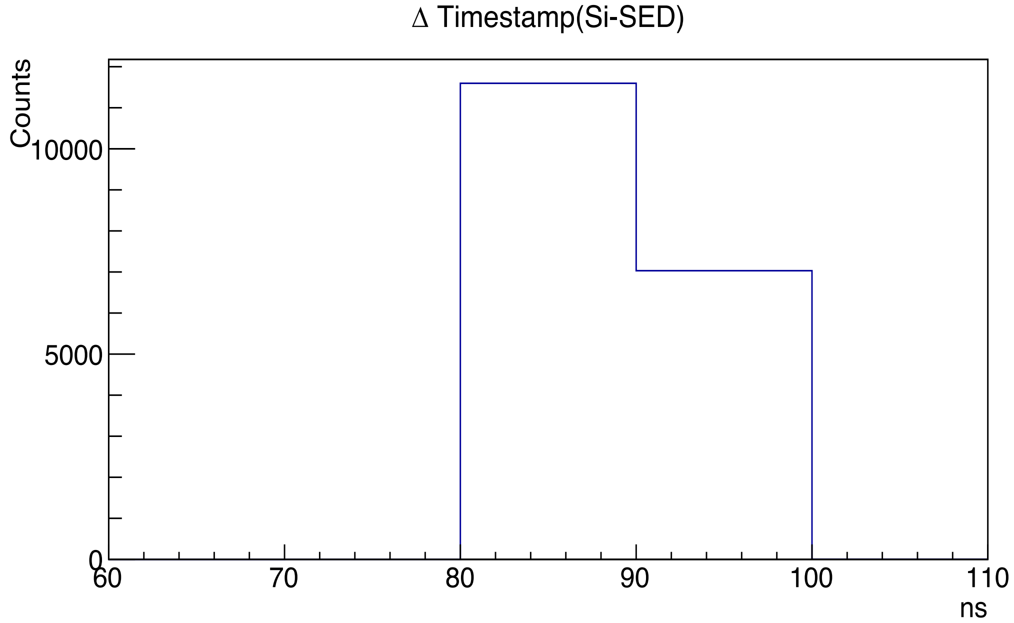
Mini SeD





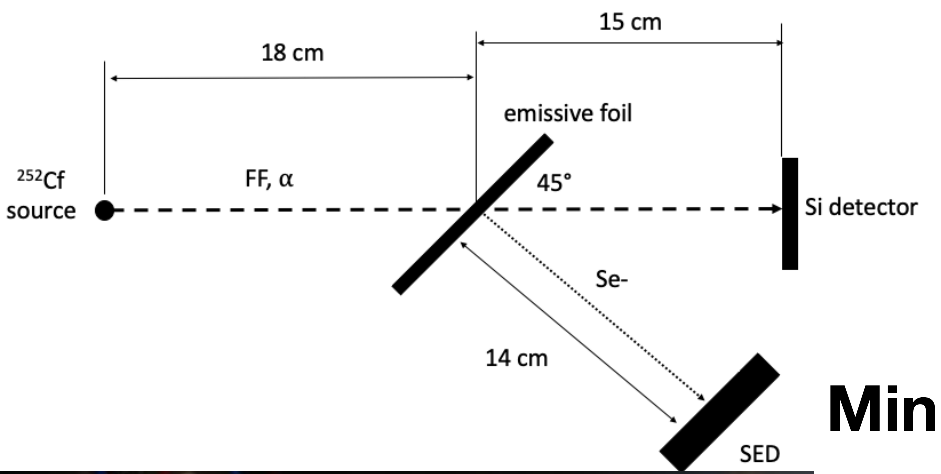




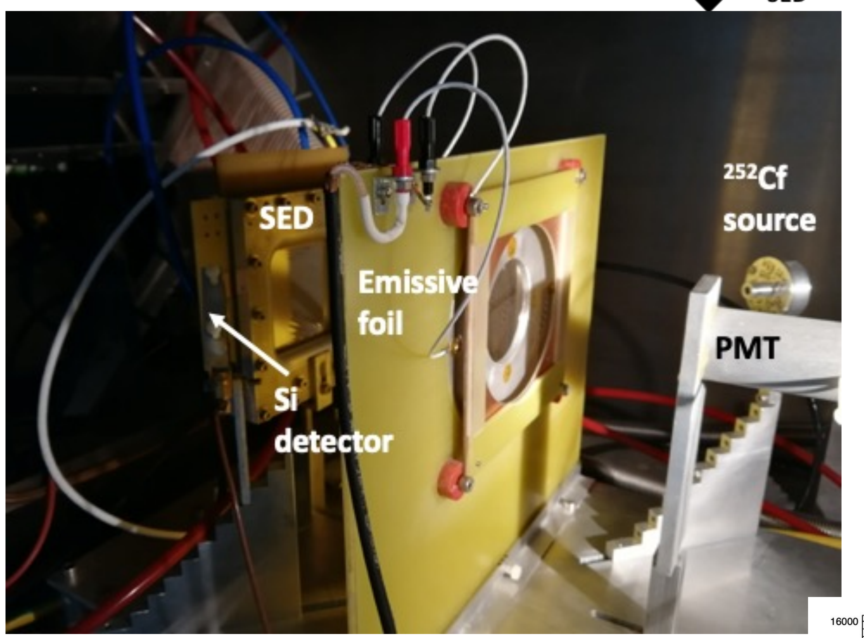


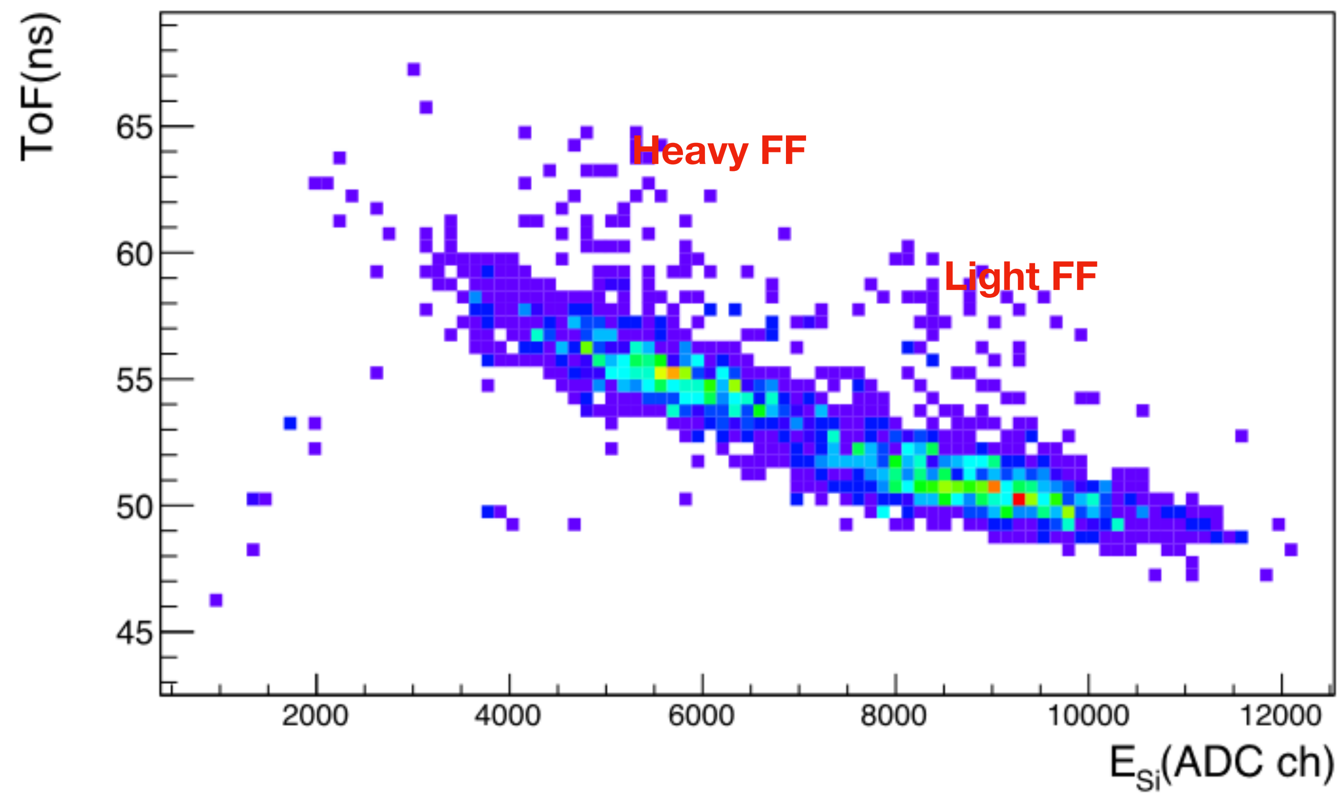
Timestamp difference between Si and SED signals

Time of Flight test using a ^{252}Cf source

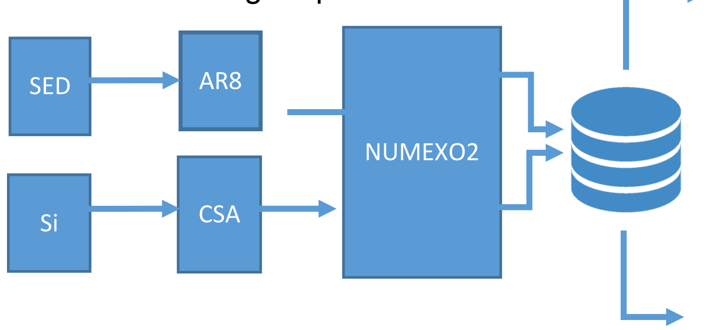


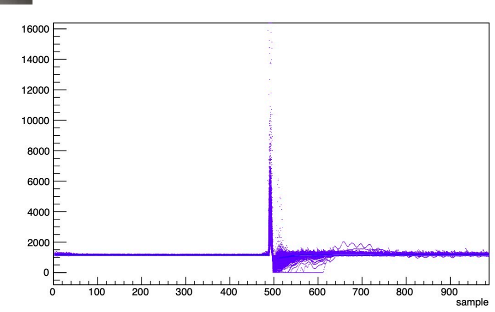
Mini SeD

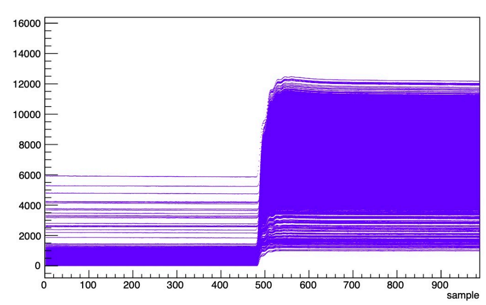




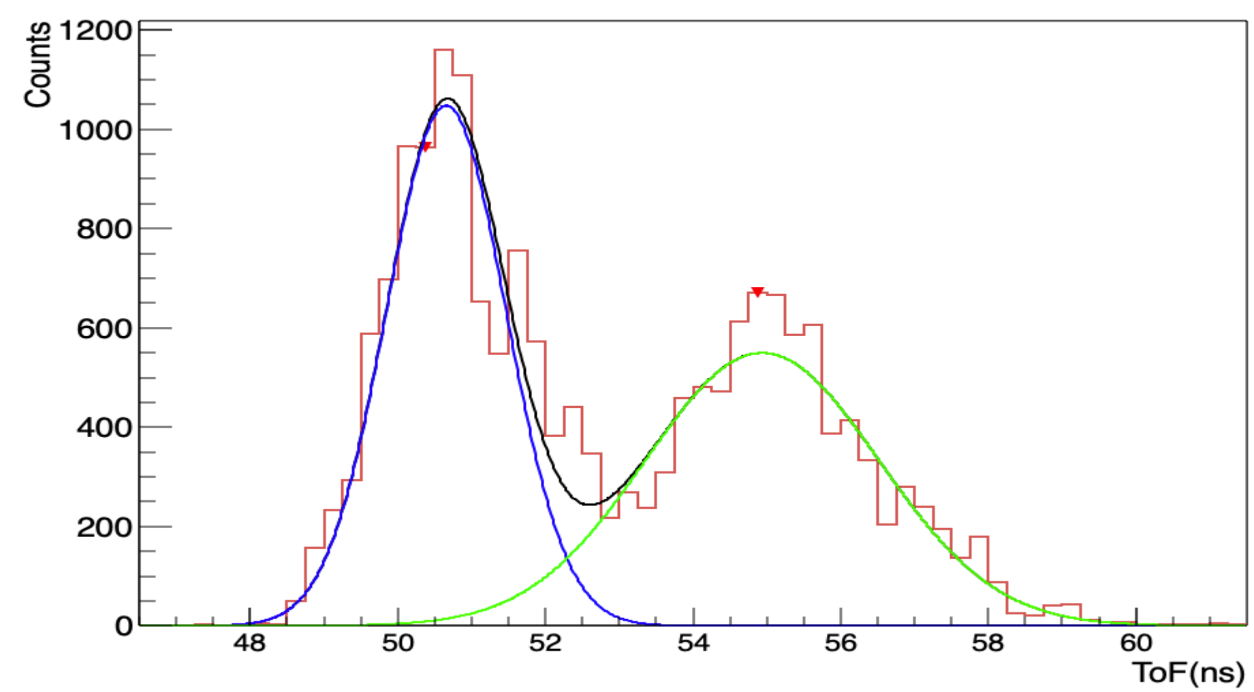
Fast-timing amplifier



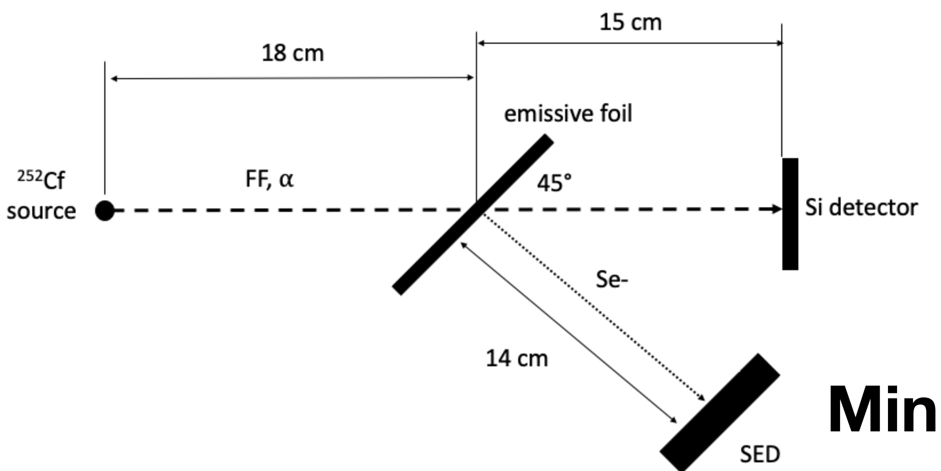




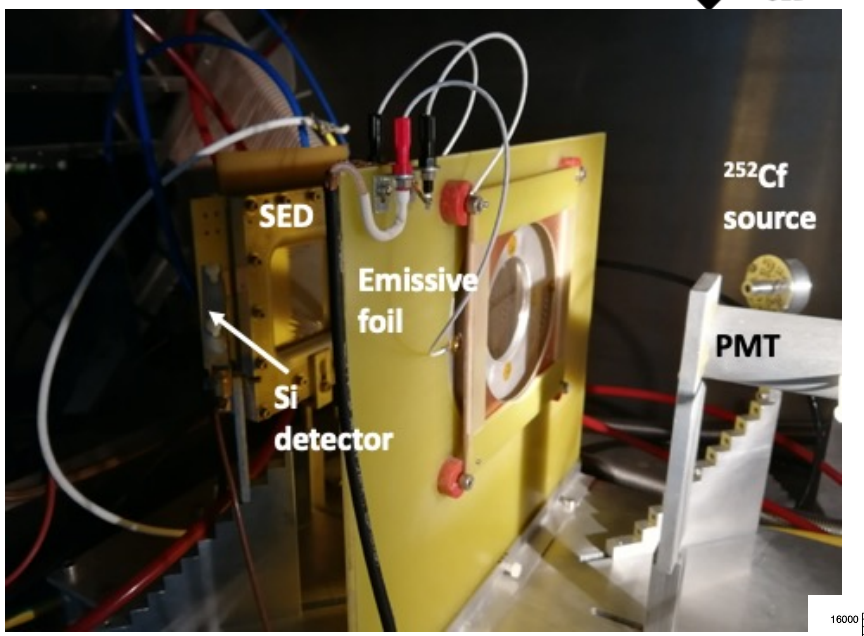
Δ T(Si-SED) Sed:d=10ns, f= 35%, Si:d=10ns, f=30%

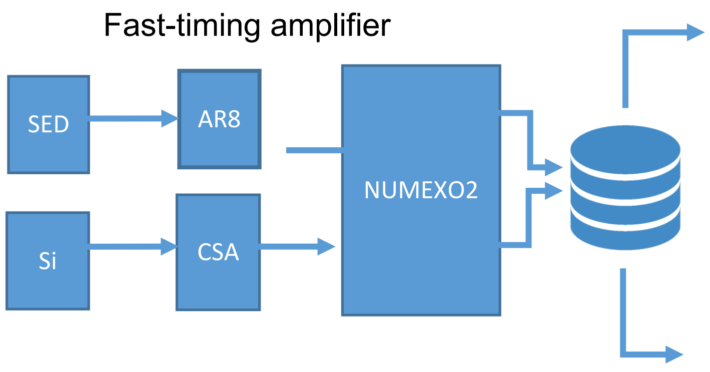


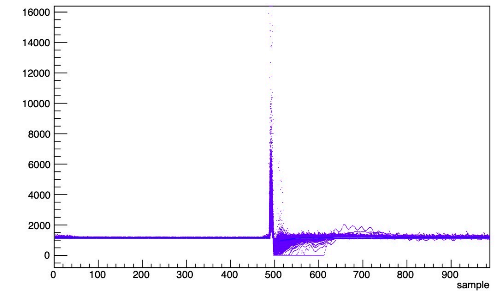
Time of Flight test using a ^{252}Cf source

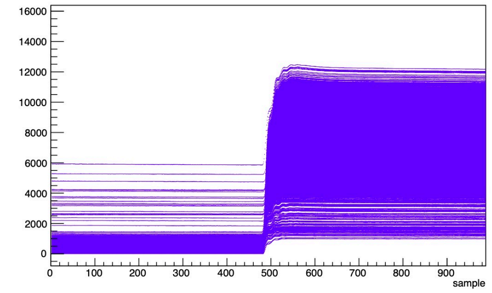


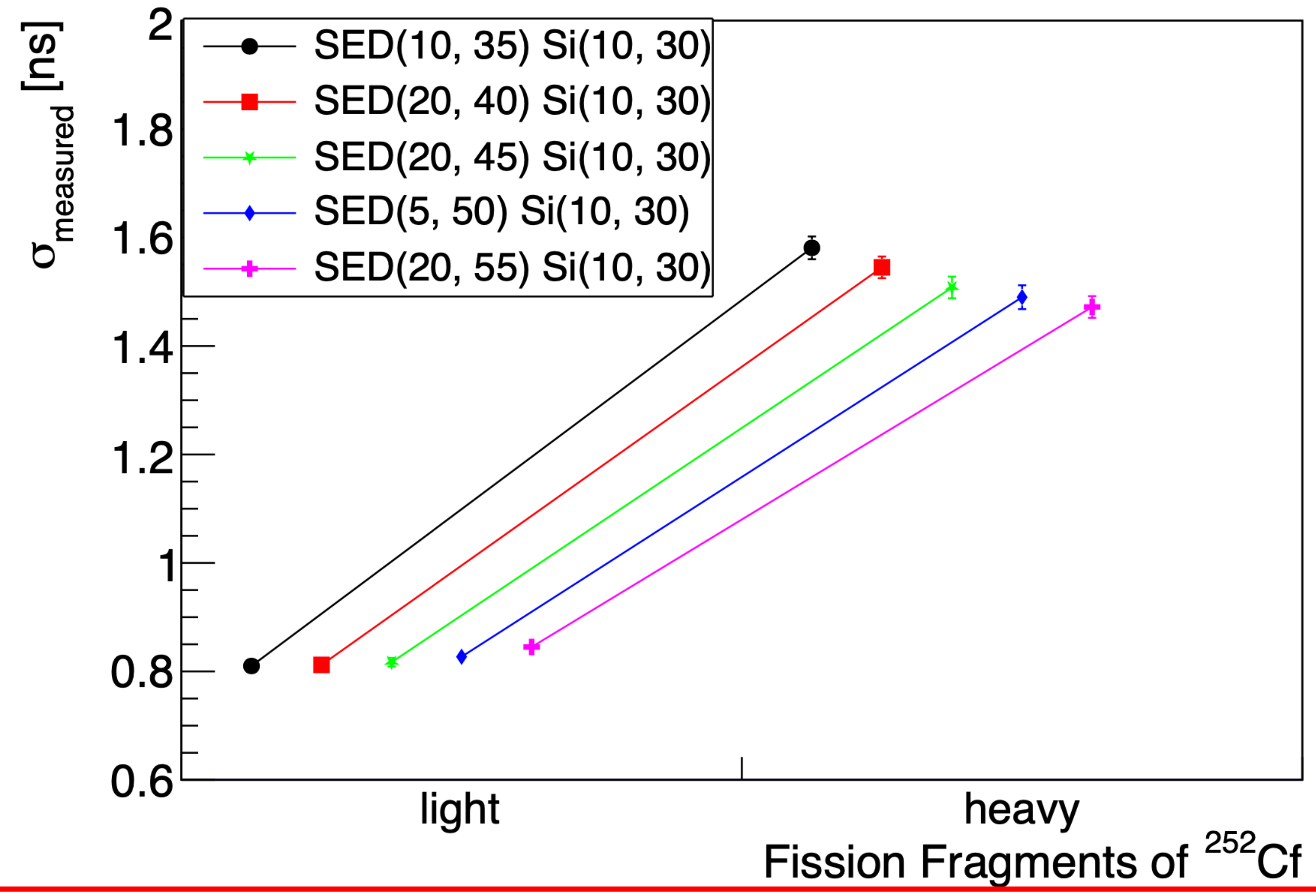
Mini SeD



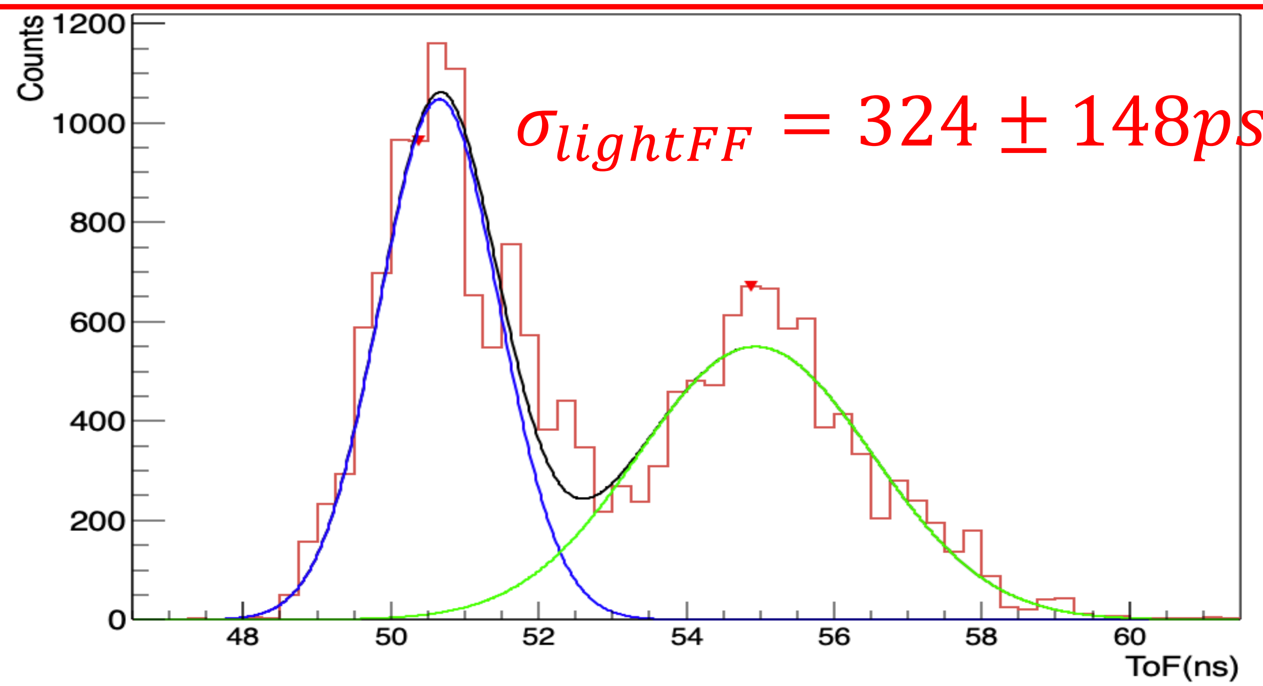




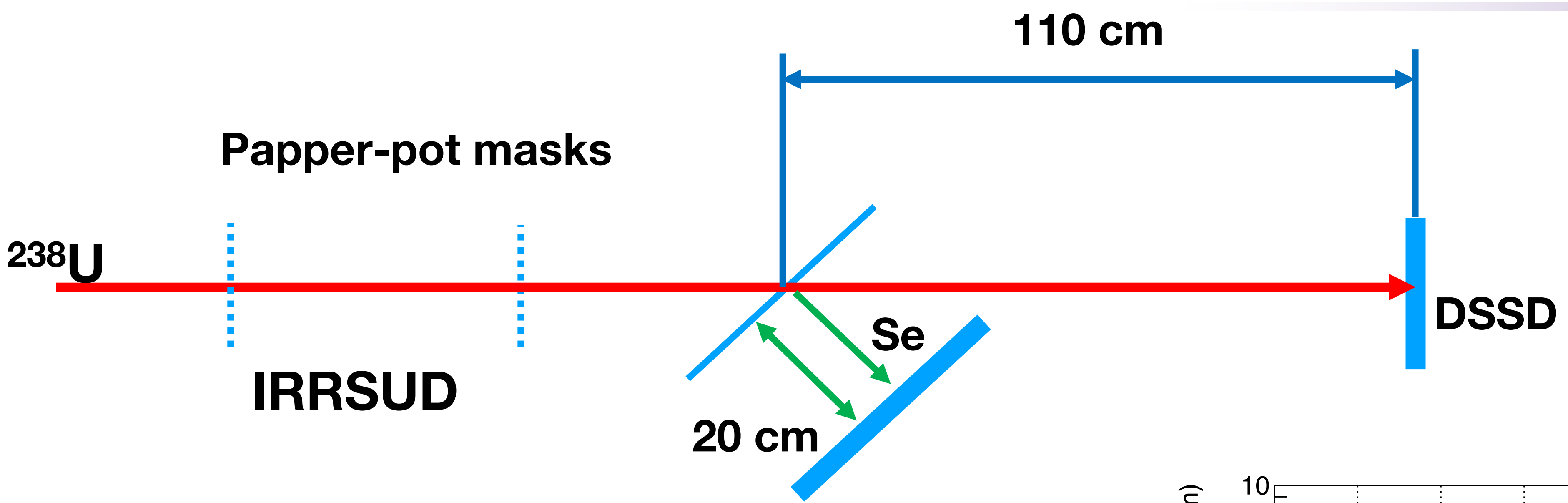


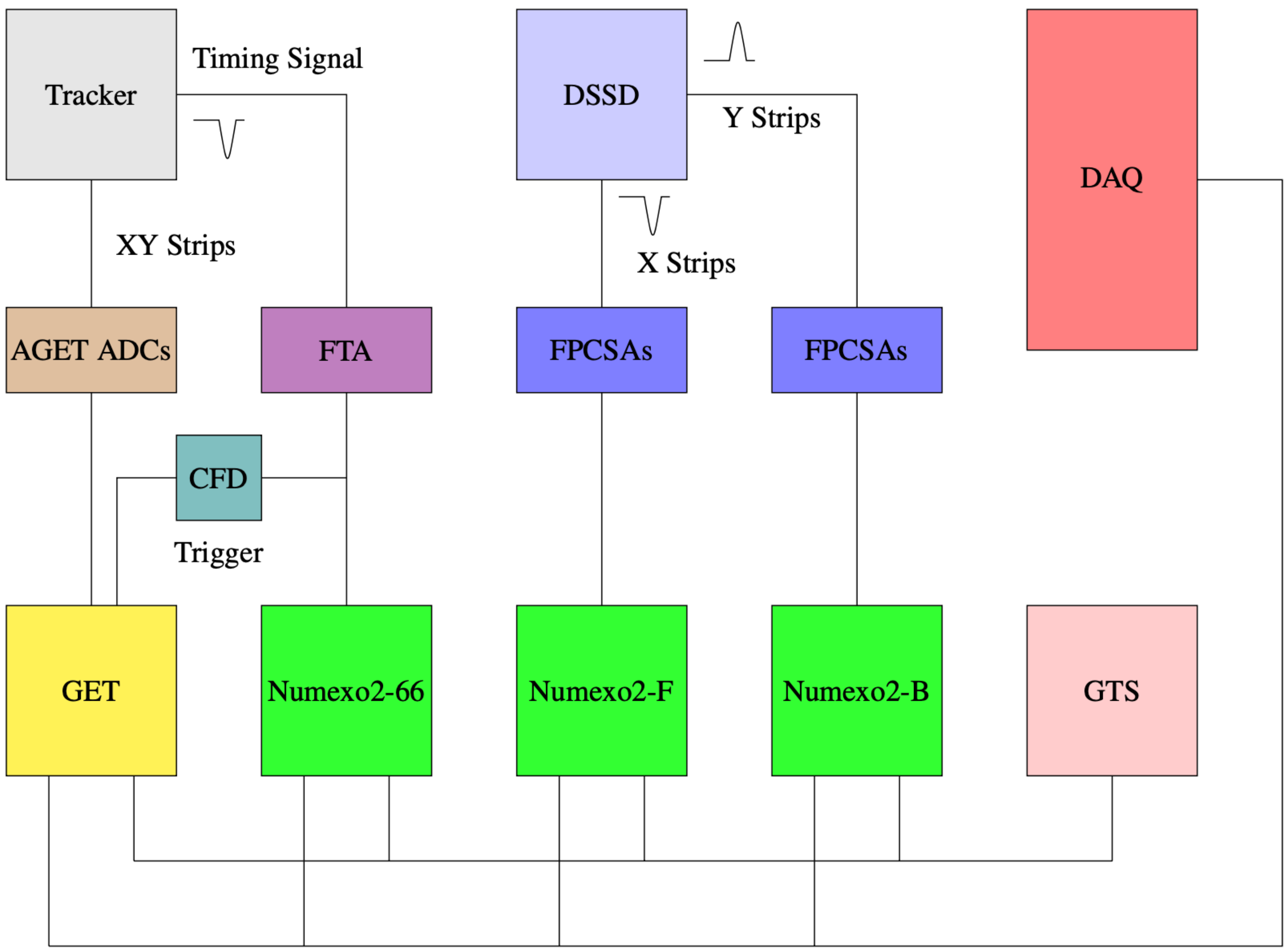


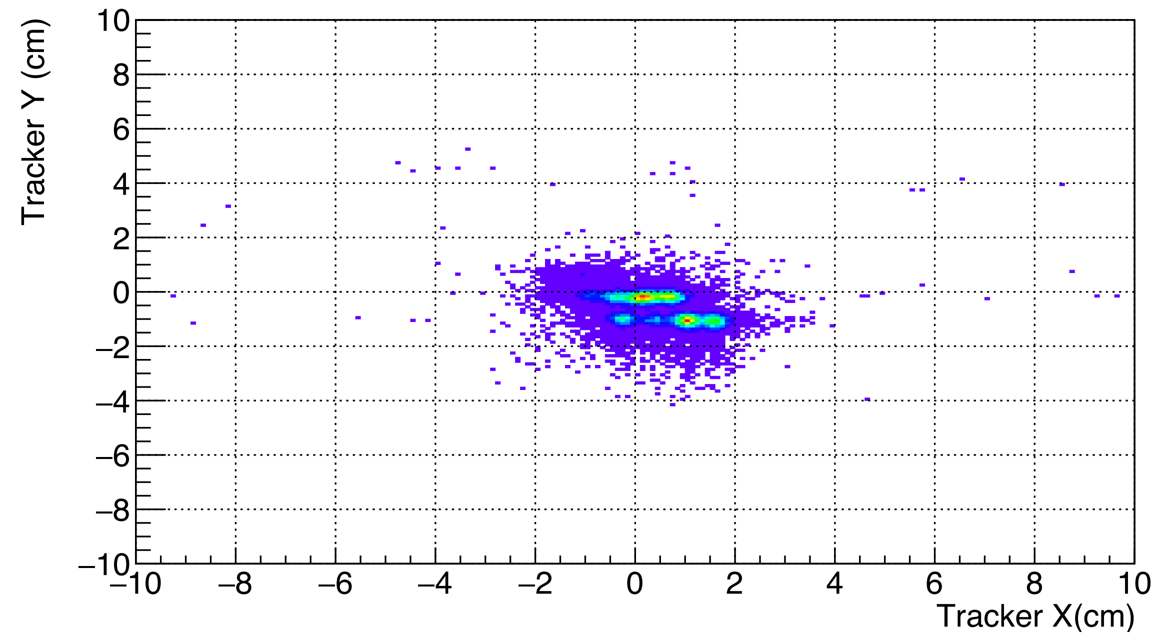
$$\sigma_{Si-SED} = \sqrt{\sigma^2_{measured} - \sigma^2_{electronic} - \sigma^2_{intrinsic} - \sigma^2_{geometry}}$$

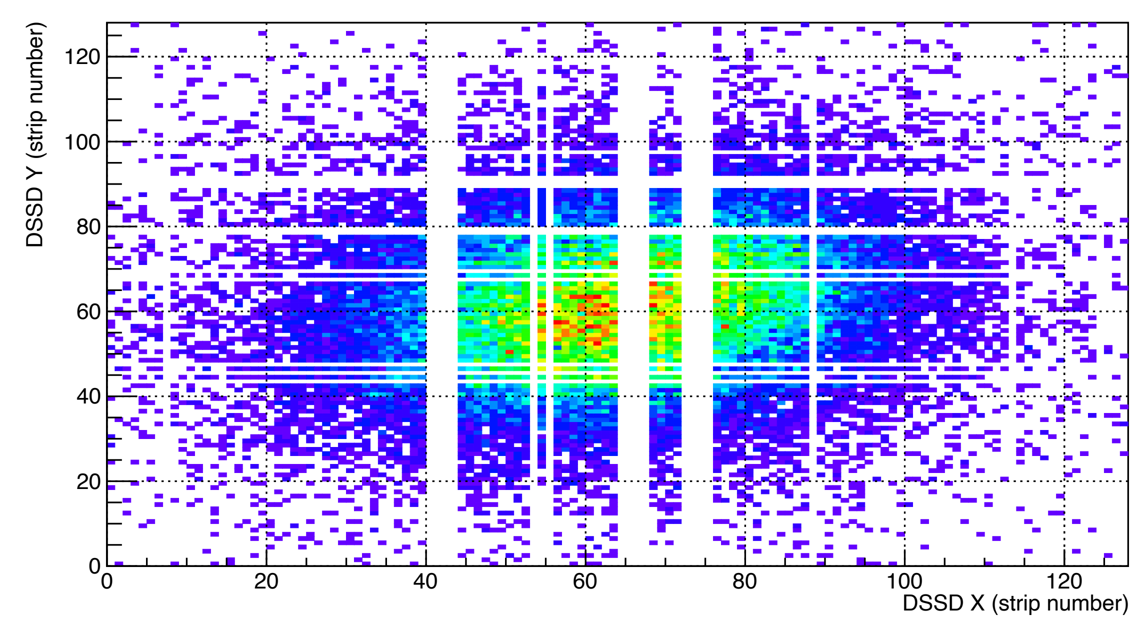


Beam tracking with SIRIUS

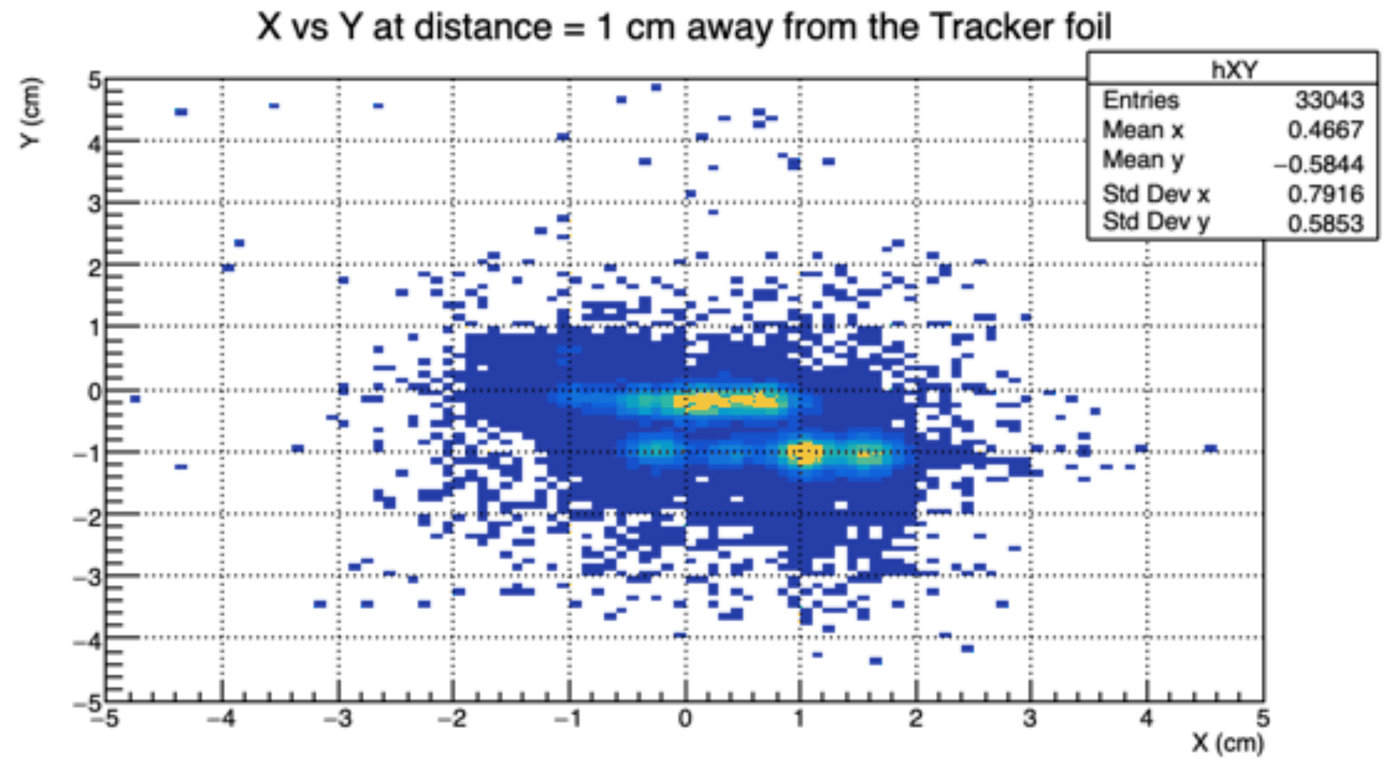




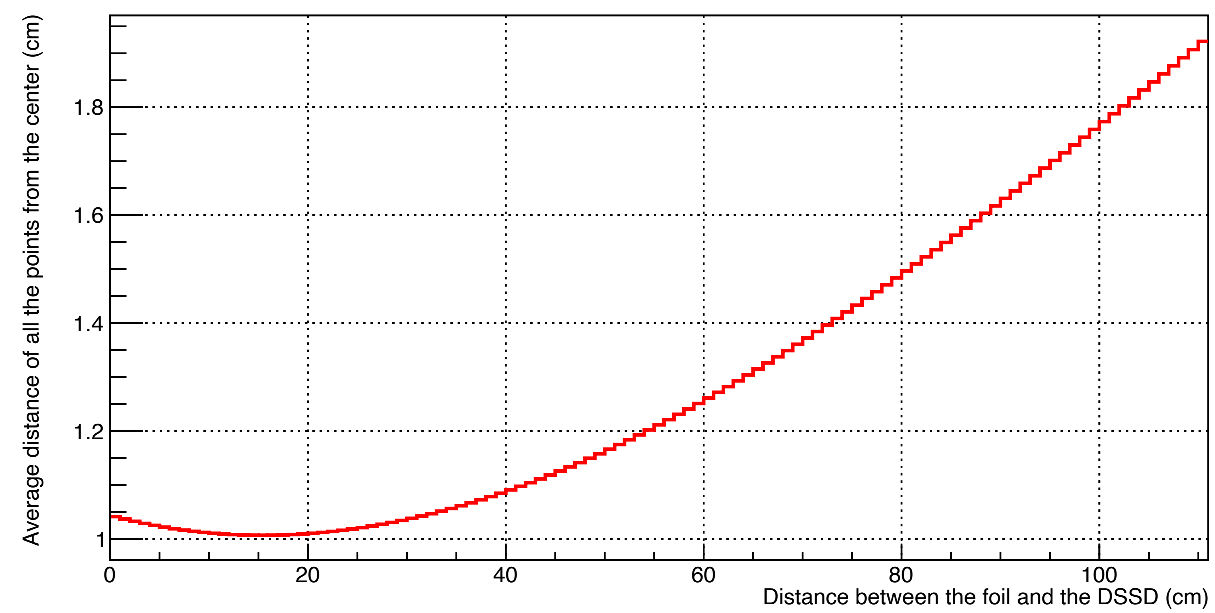


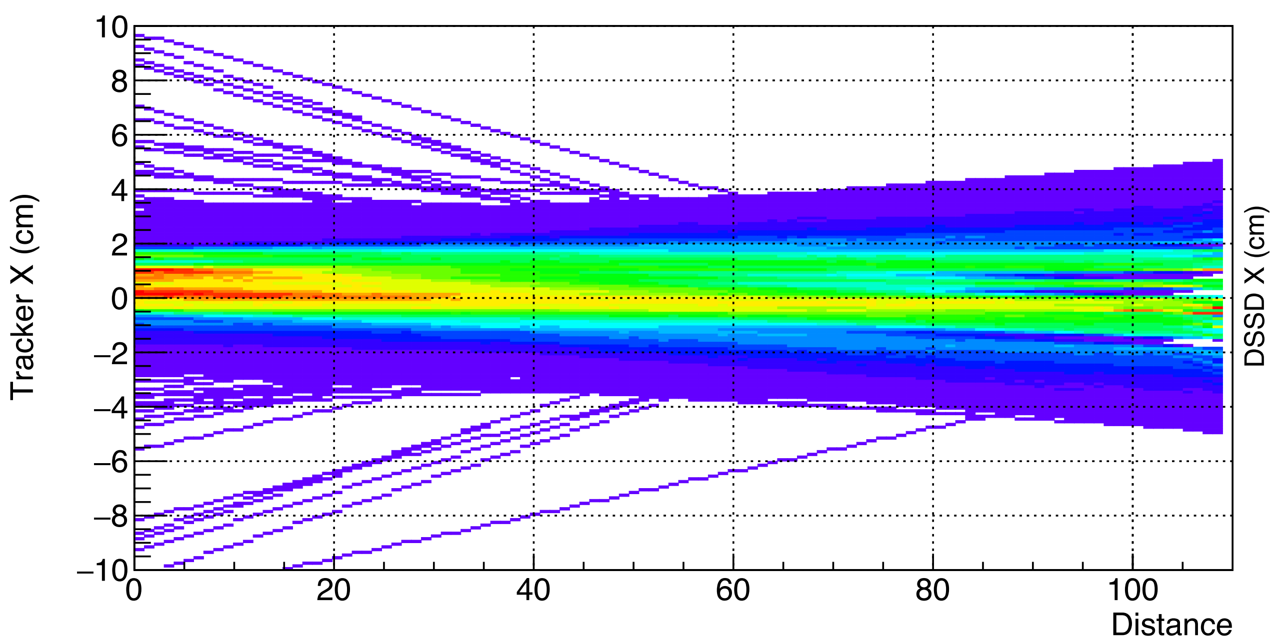


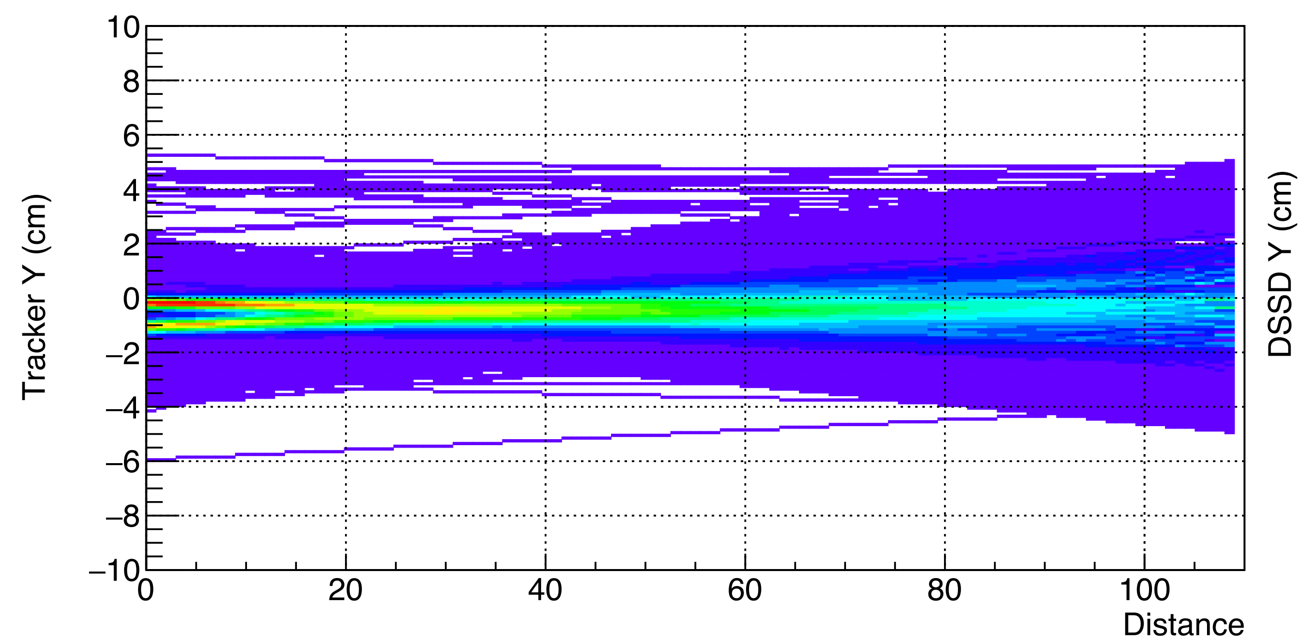
Beam tracking with SIRIUS



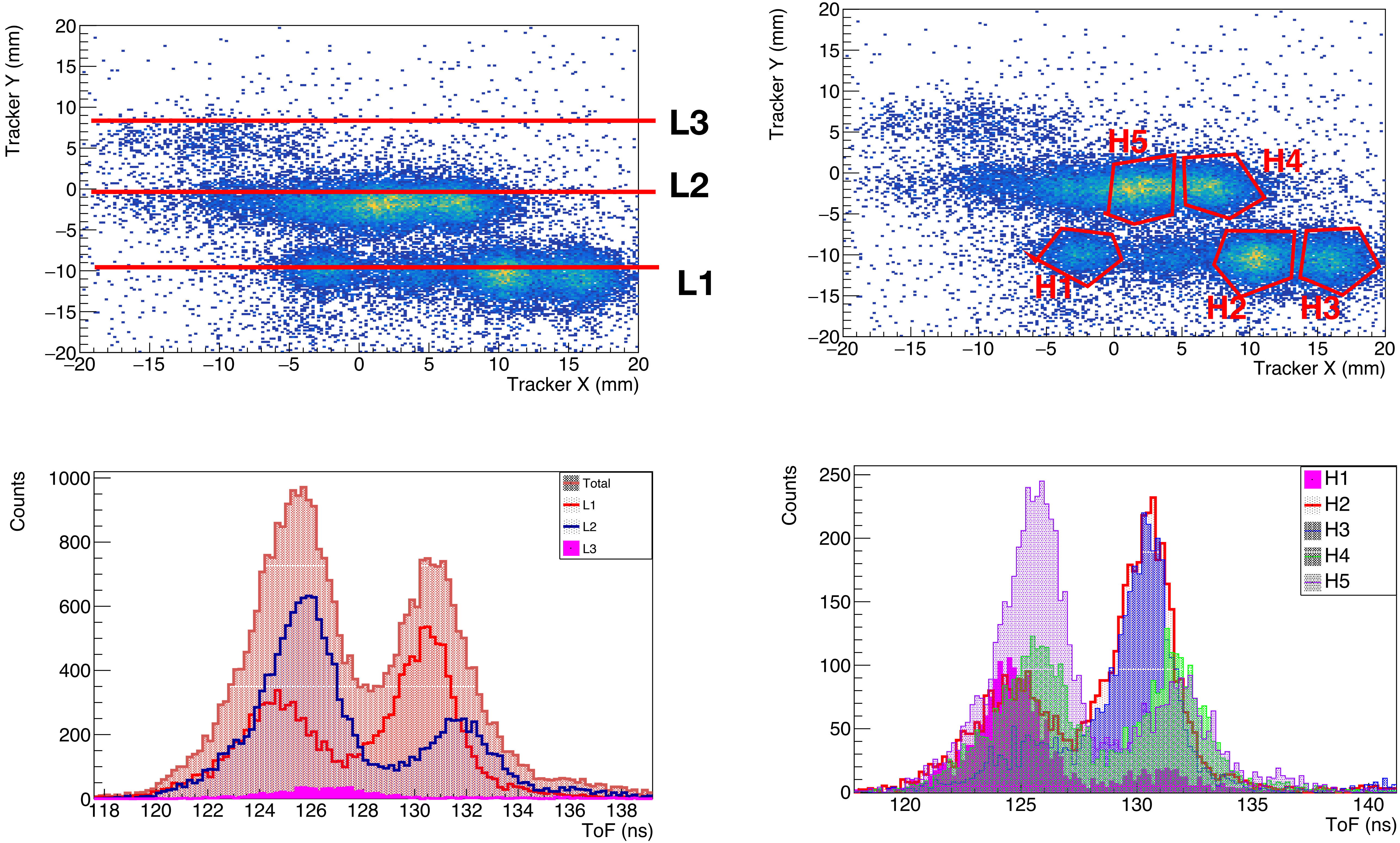
Beam focussing





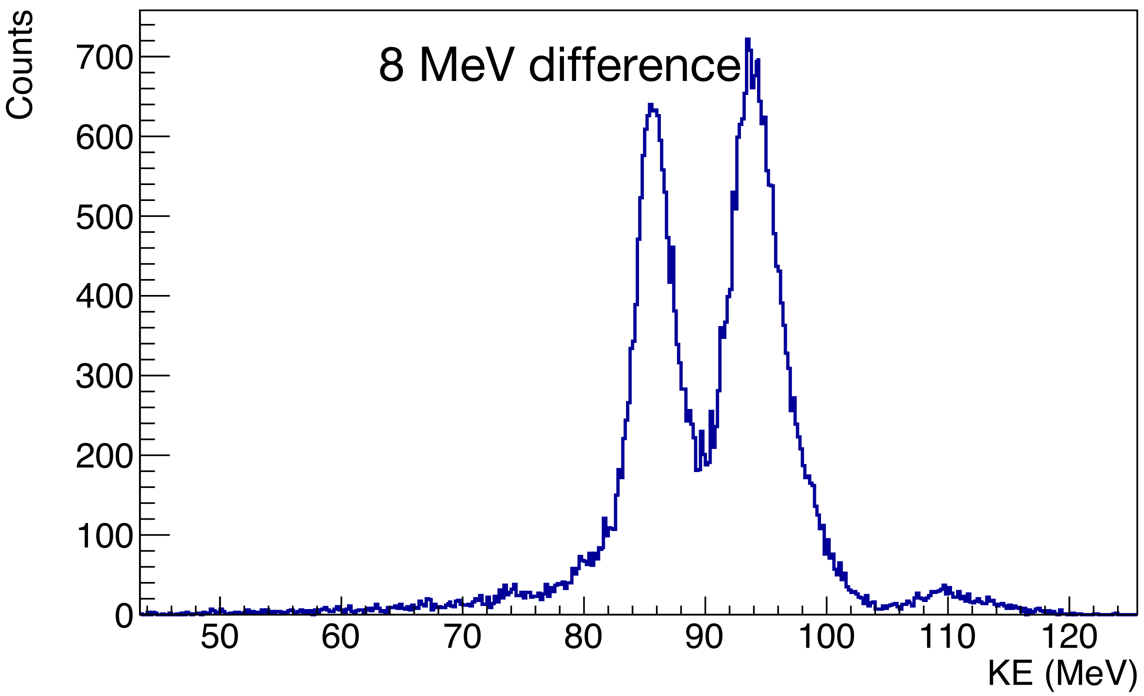


ToF decomposition

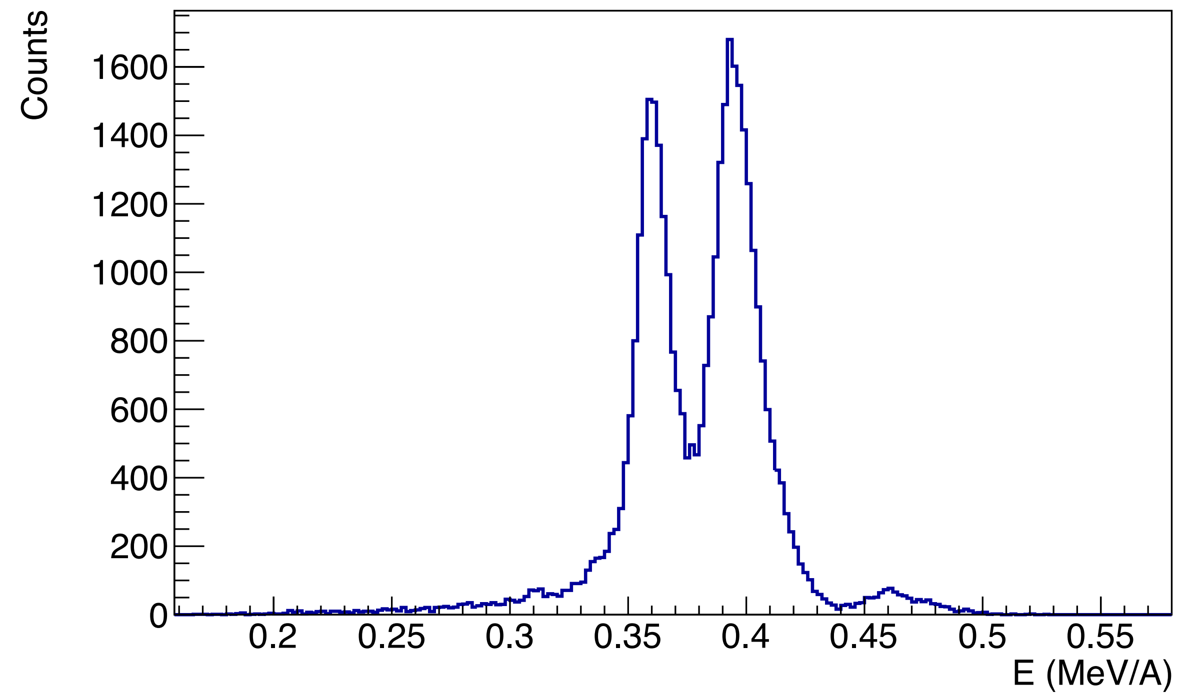


Possible reason for 2 peaks in the ToF spectrum

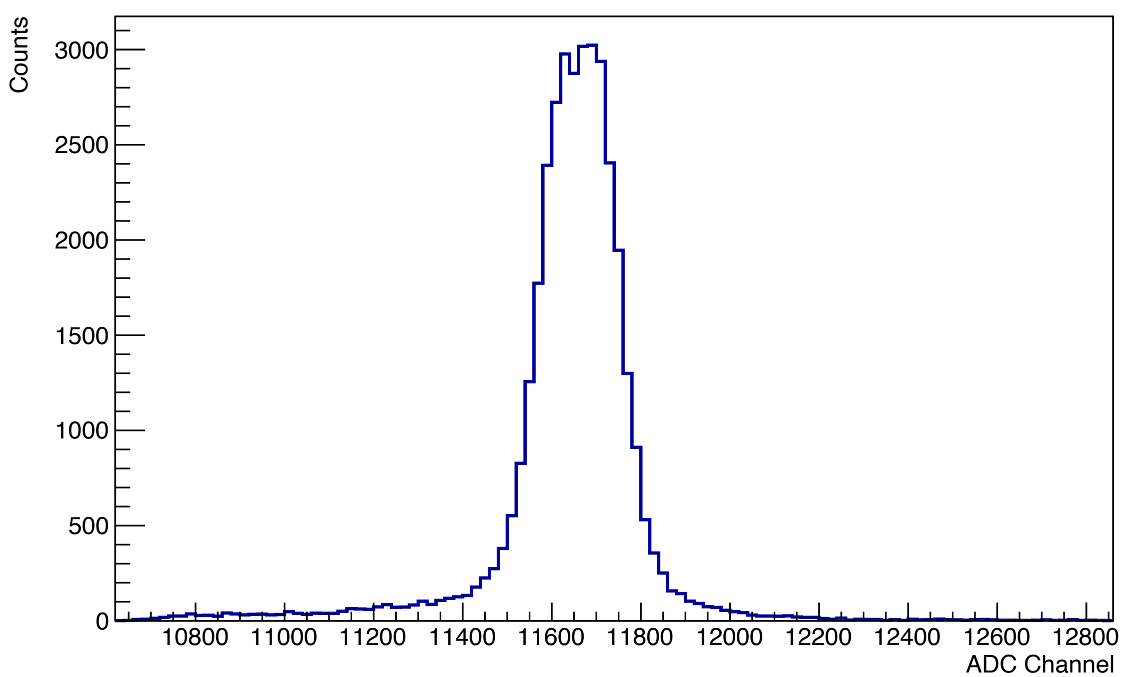
Beam E

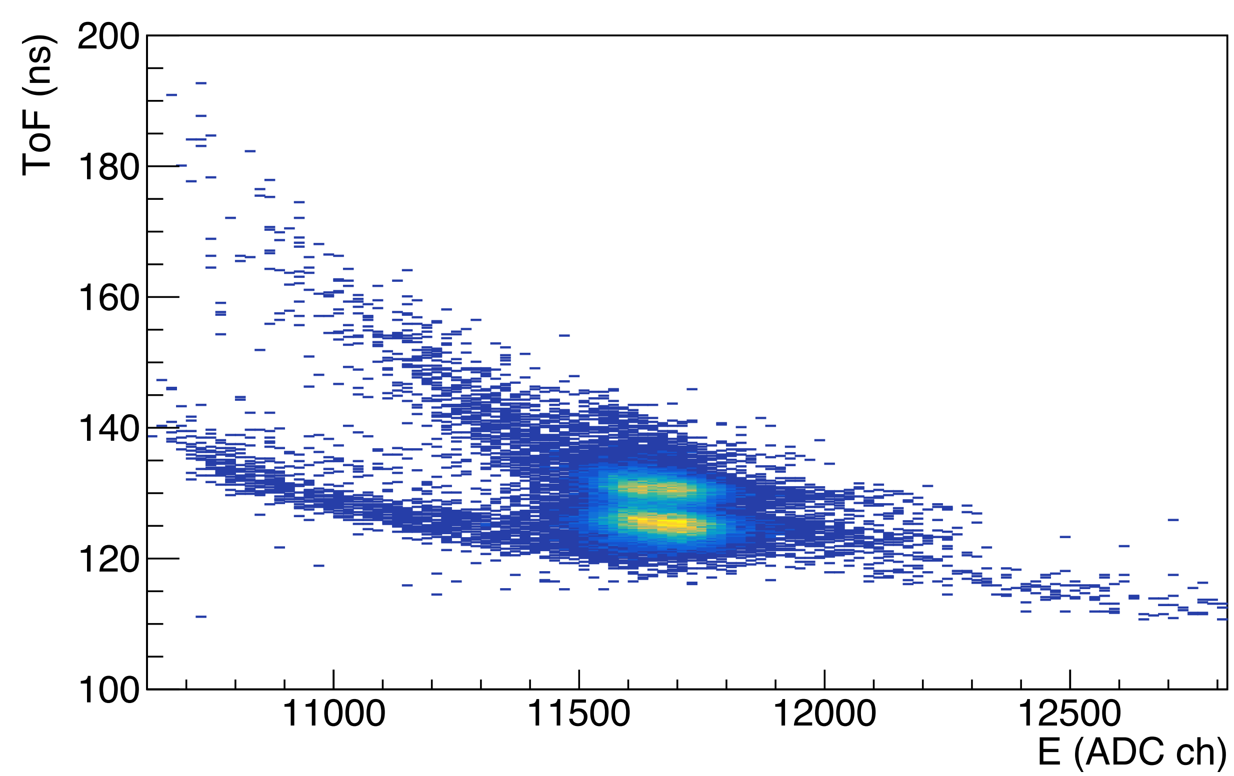


Beam E/A

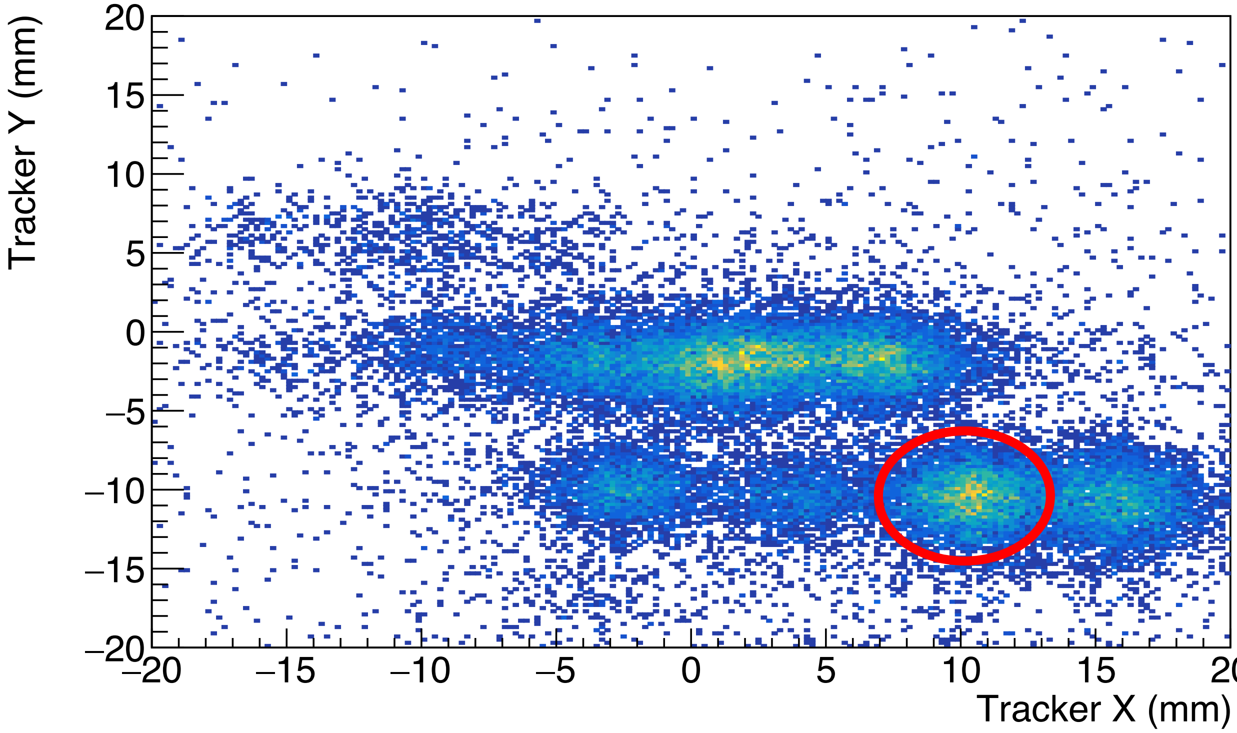


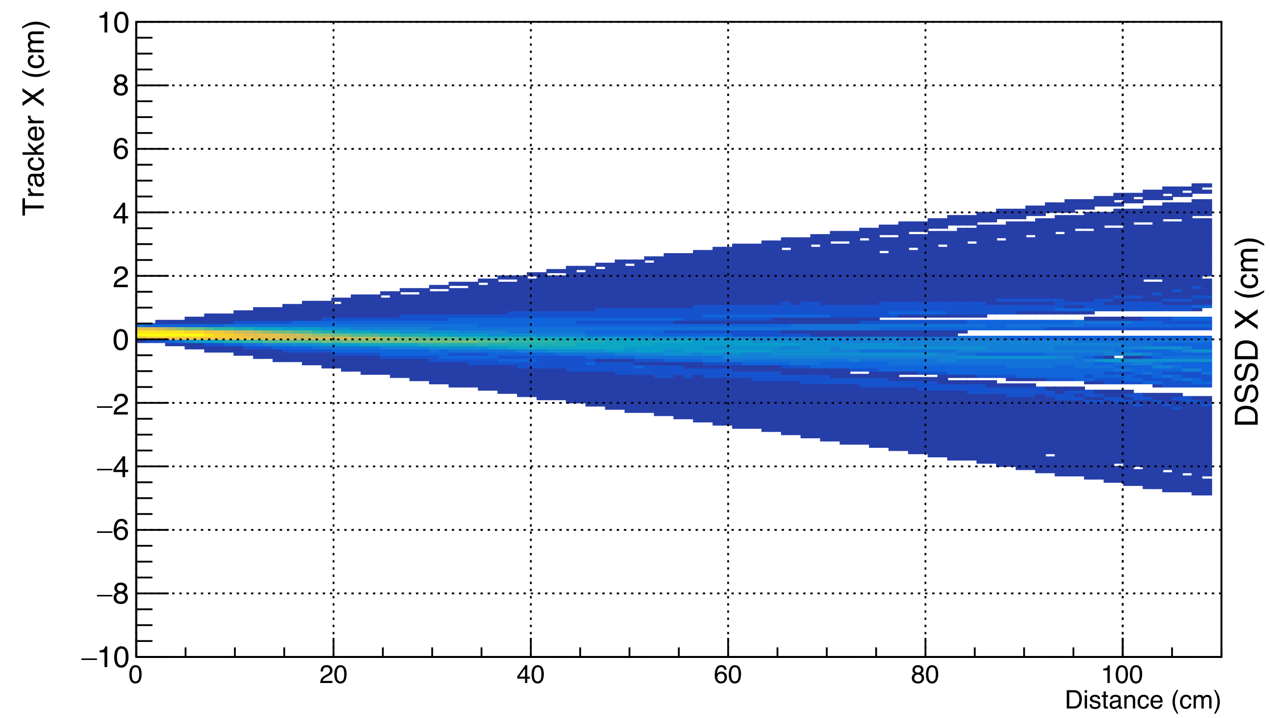
E in the DSSD

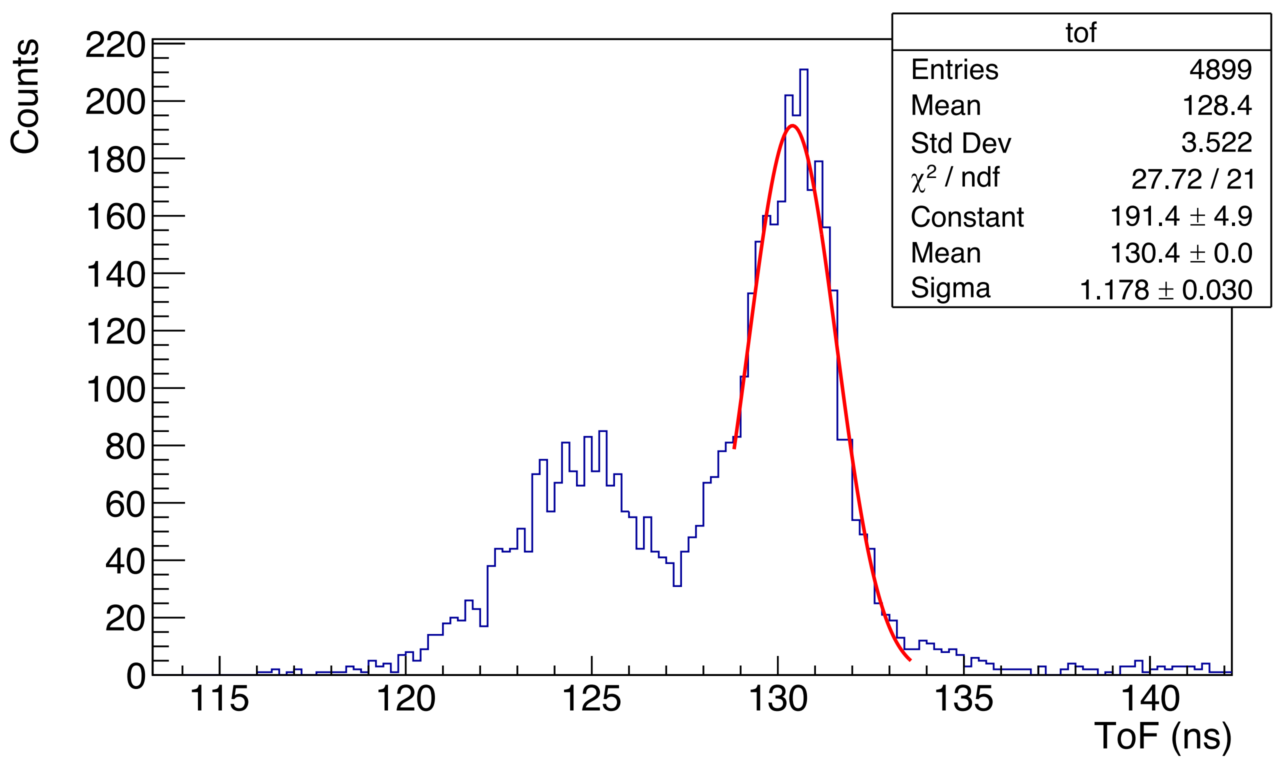


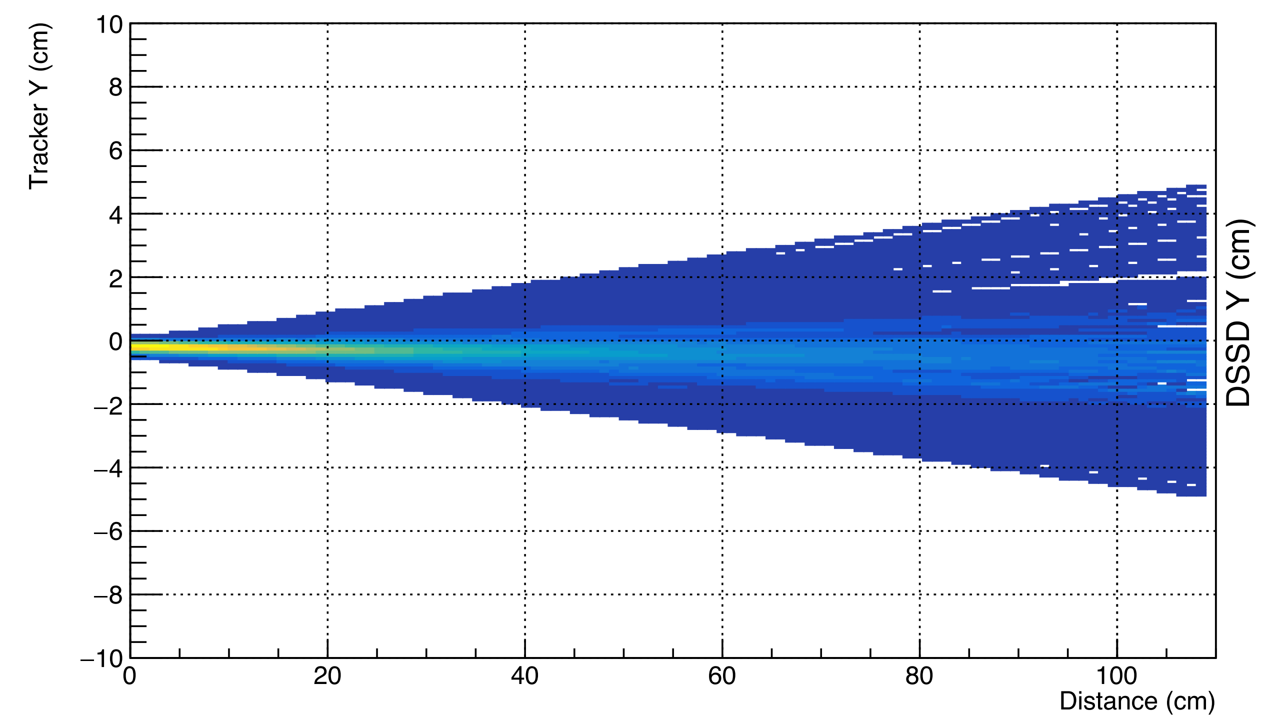


Time resolution

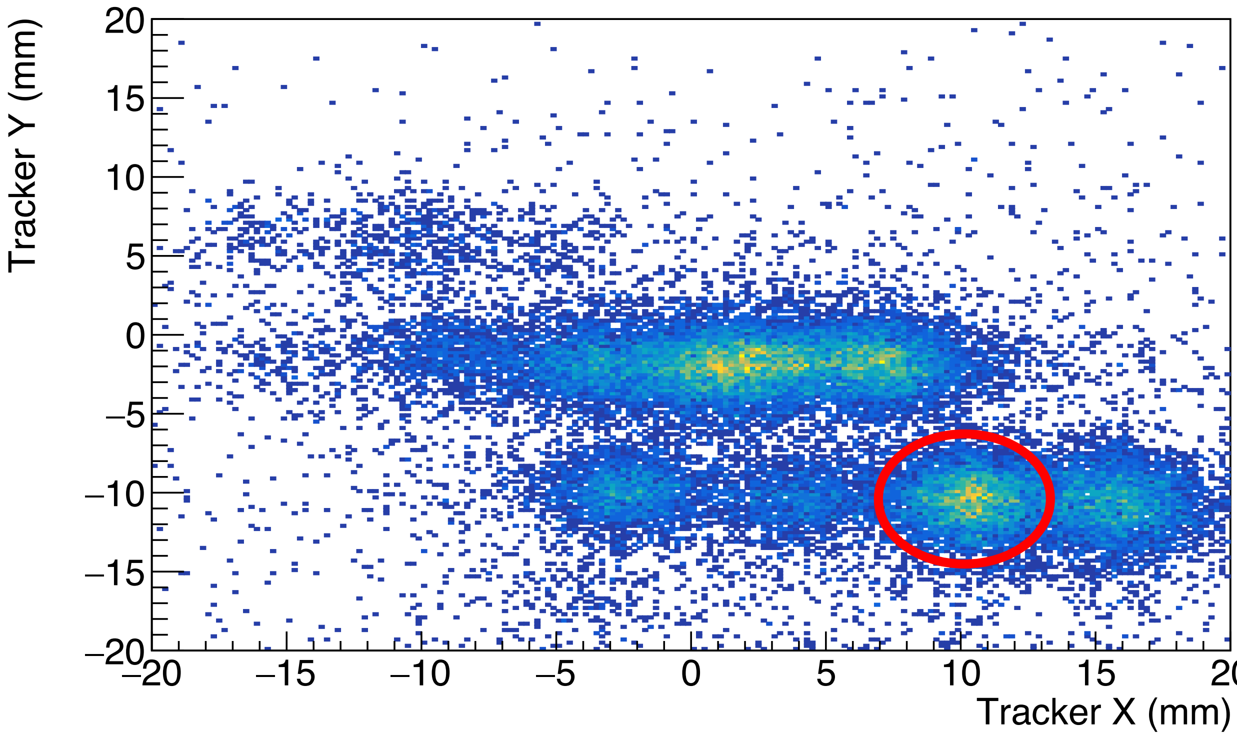


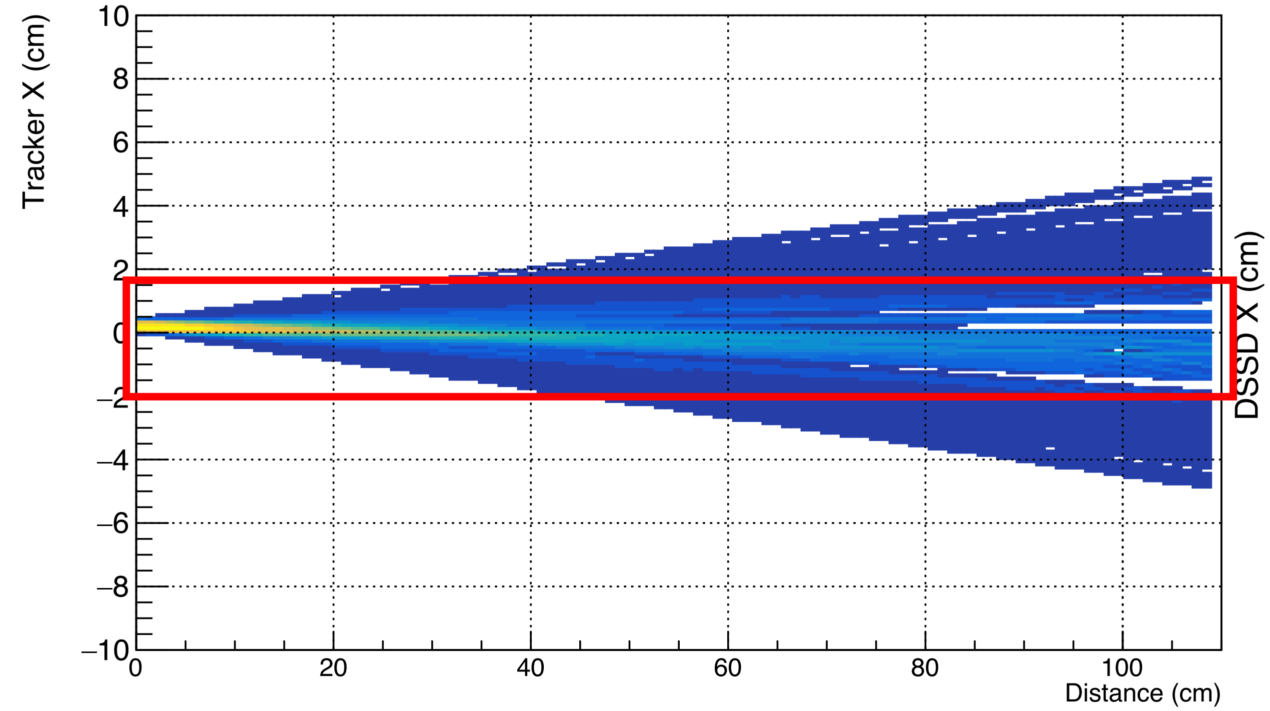


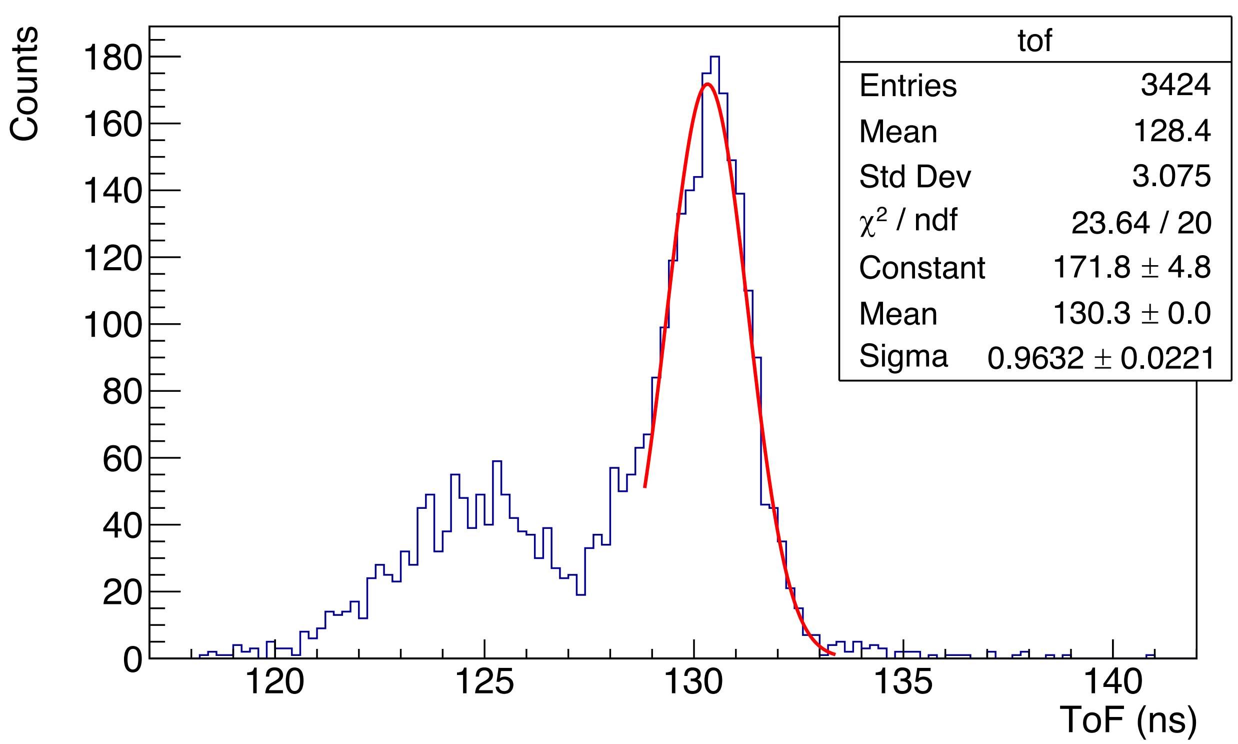


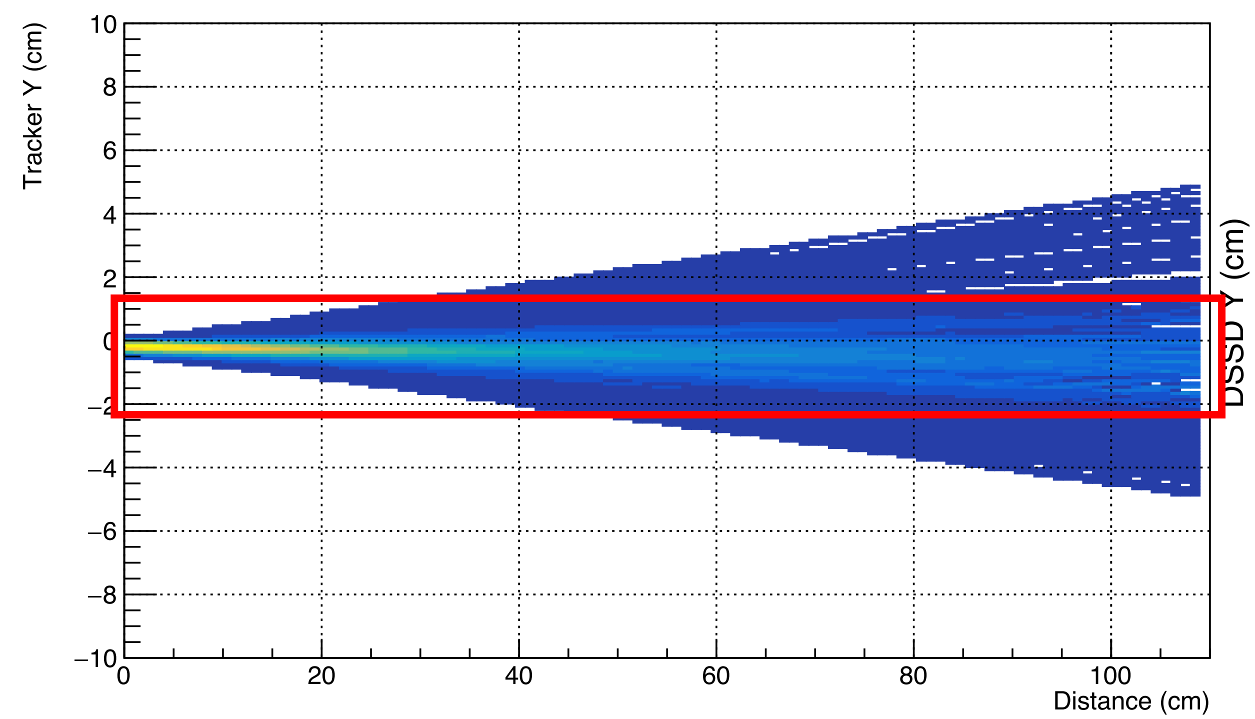


Time resolution









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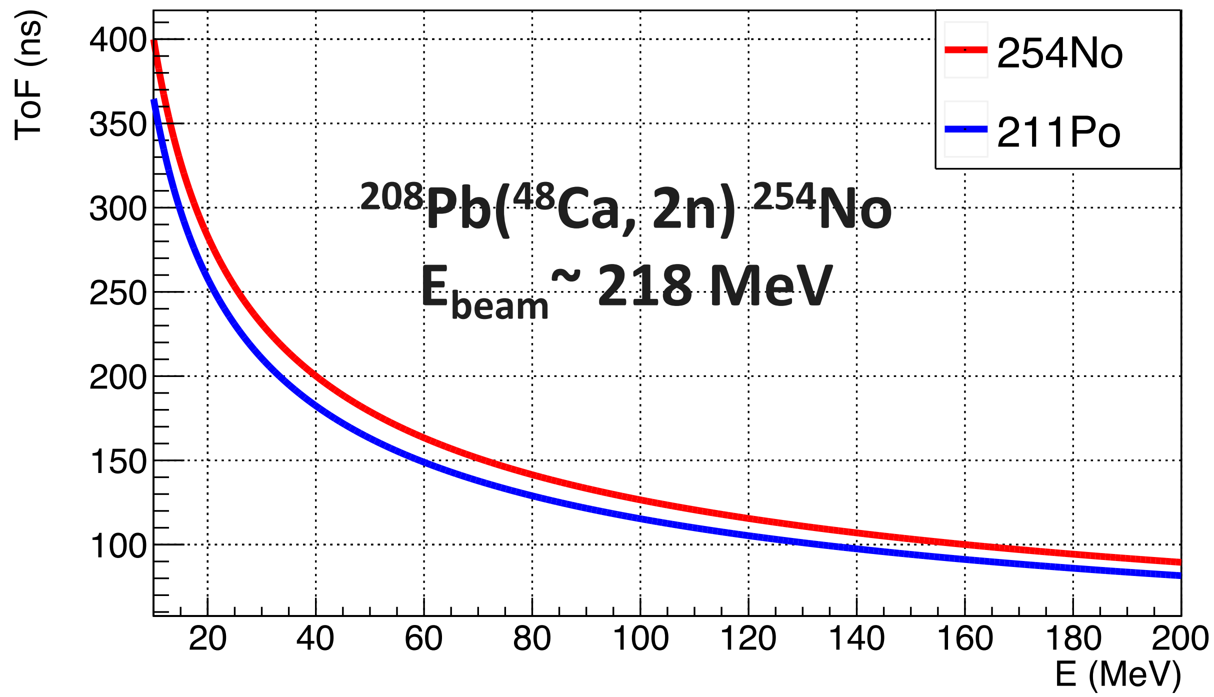
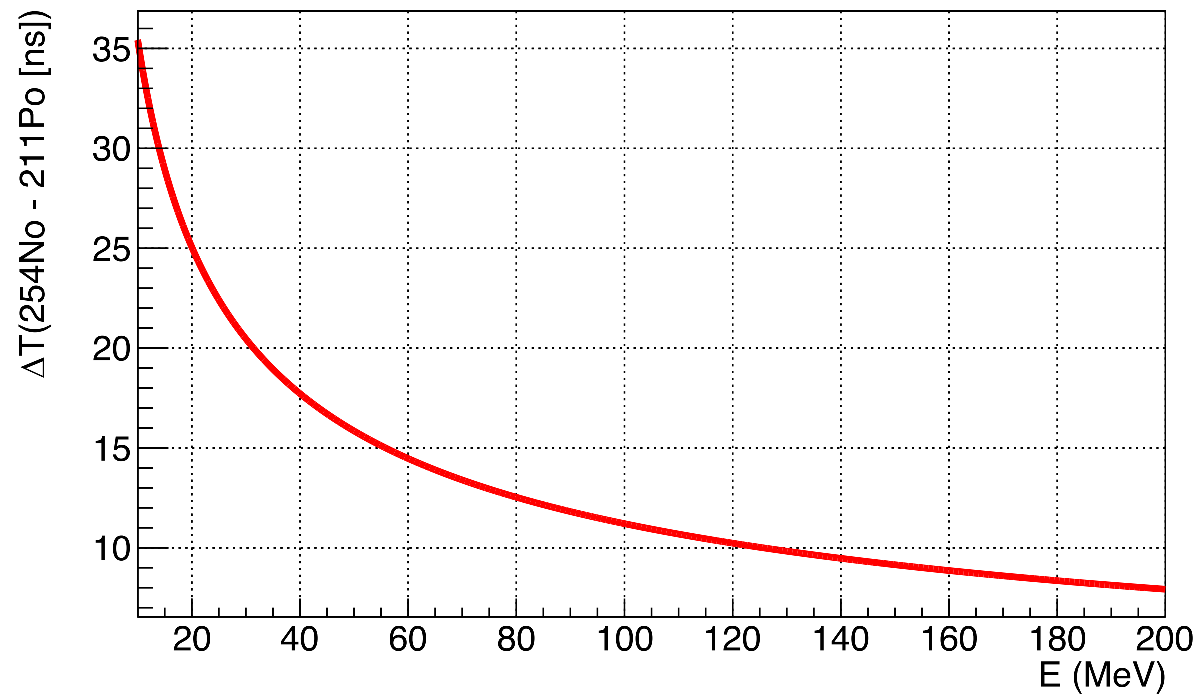
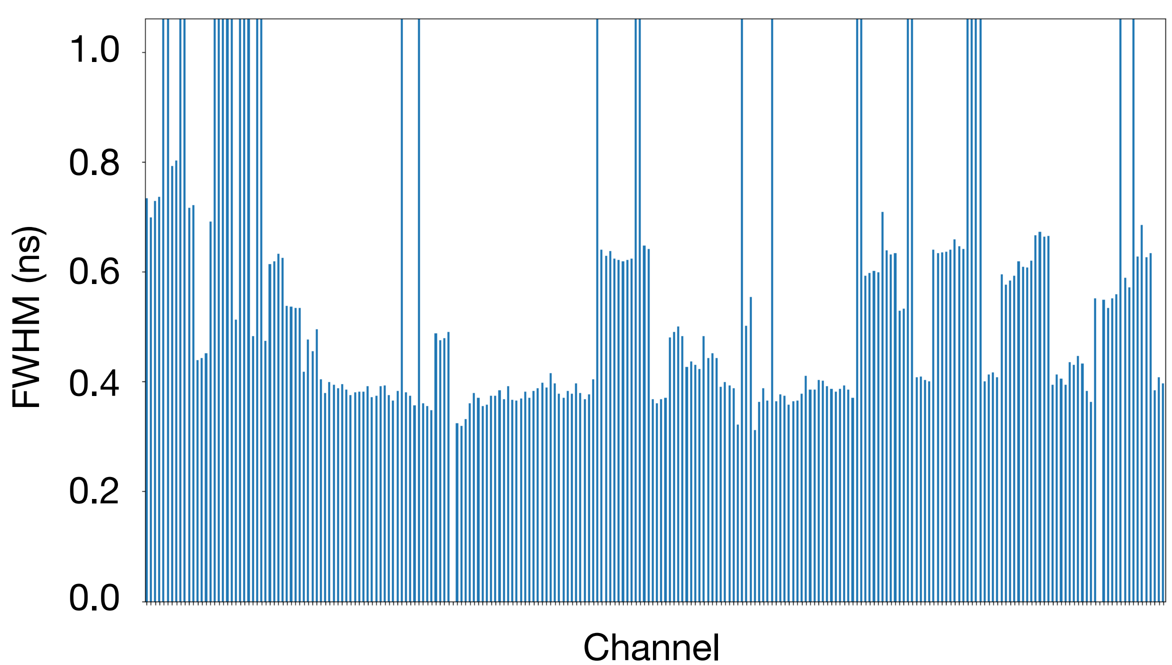
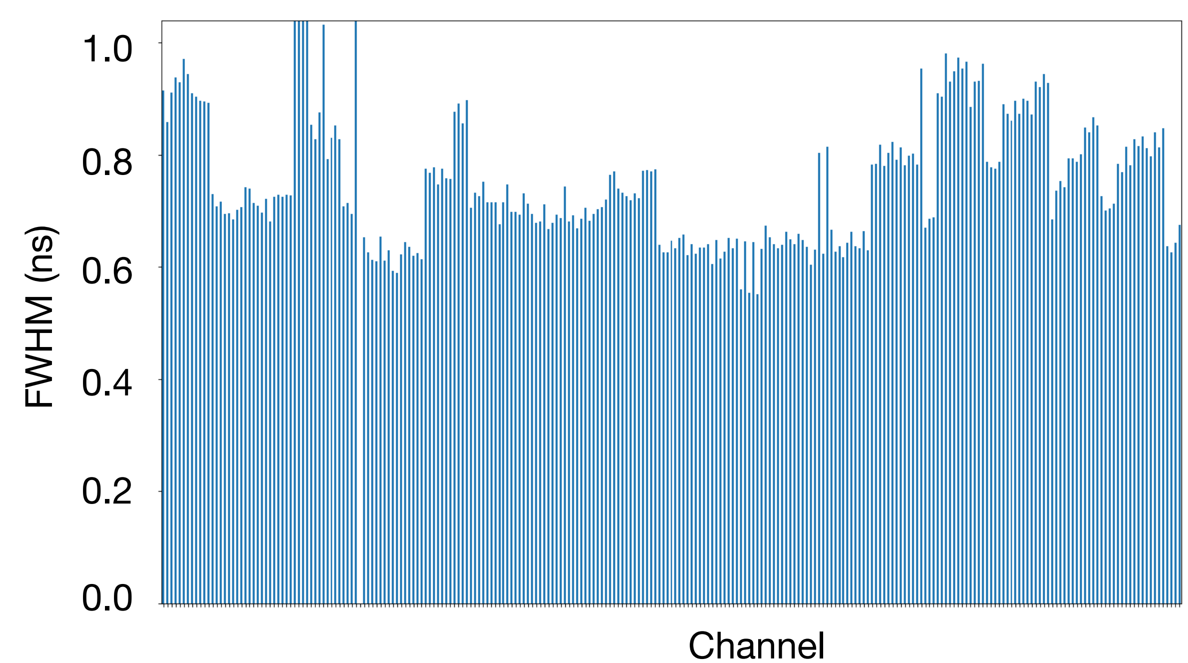




With the New firmware

With the Previous firmware





Time resolution is expected to improve with the new firmware

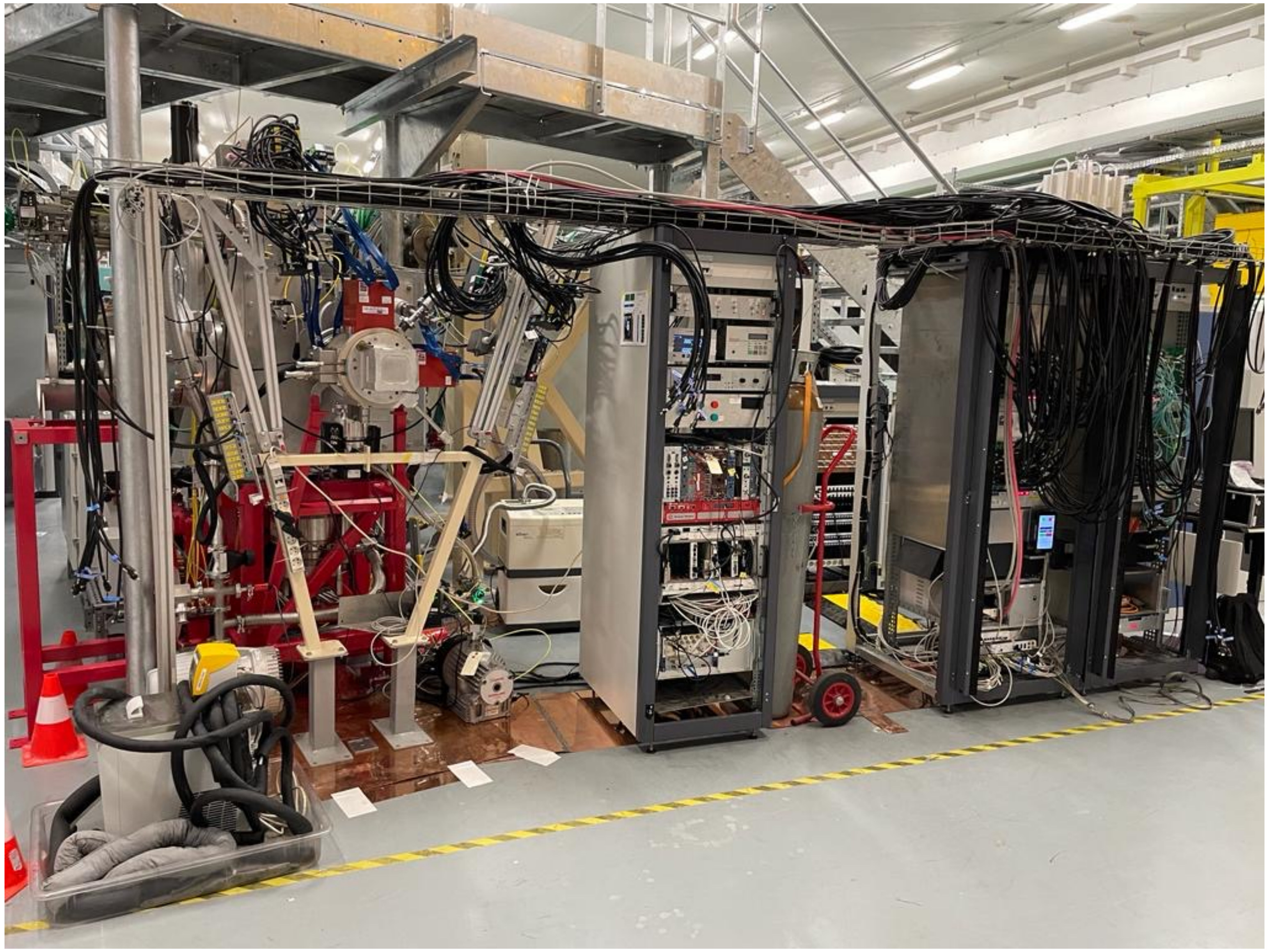
Conclusions and outlook

The DSSD, the tunnel detectors and the Tracker detector have been fully instrumented

Their performance has been tested

The stability of the acquisition system has been tested

Data analysis software are ready for the users



Next Steps:

- Test the new DSSD firmware
- Integrate the EXOGAM Ge detectors
- Continue testing with sources/pulse generators

Make SIRIUS ready for experiments at S^3

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.

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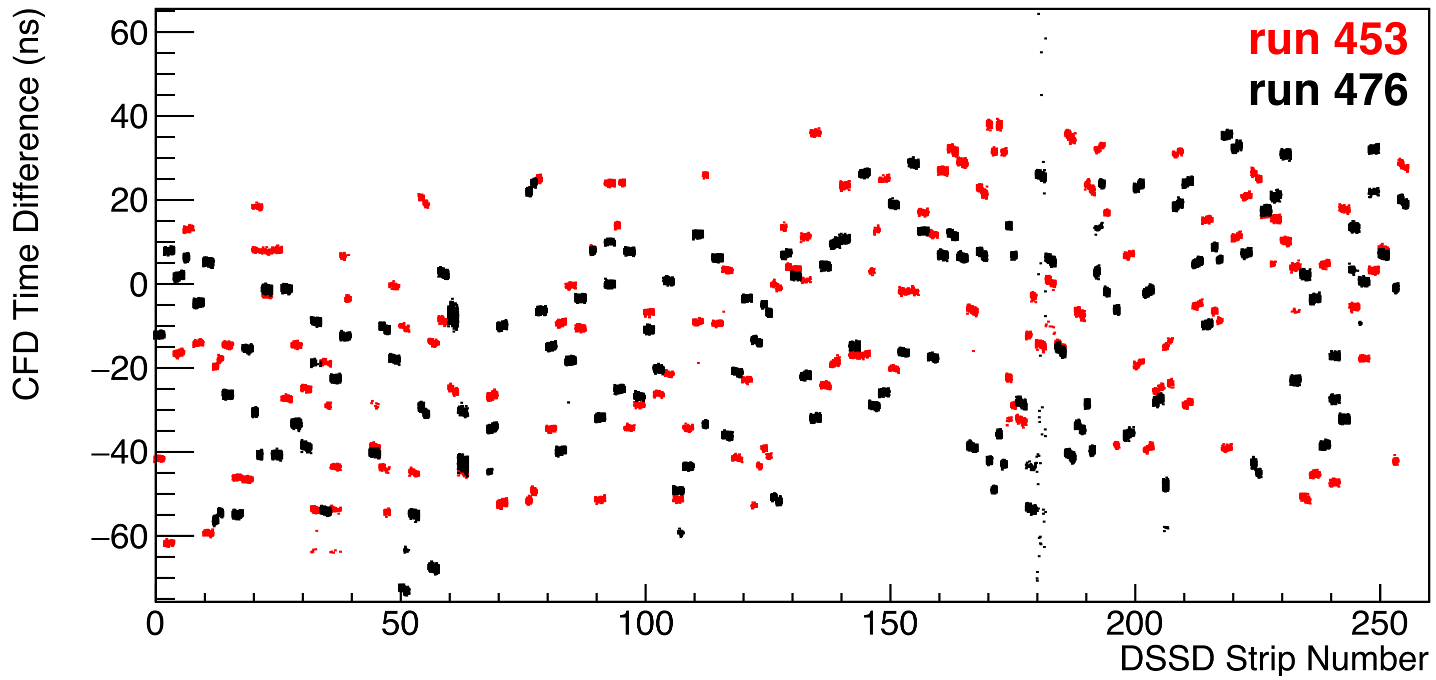
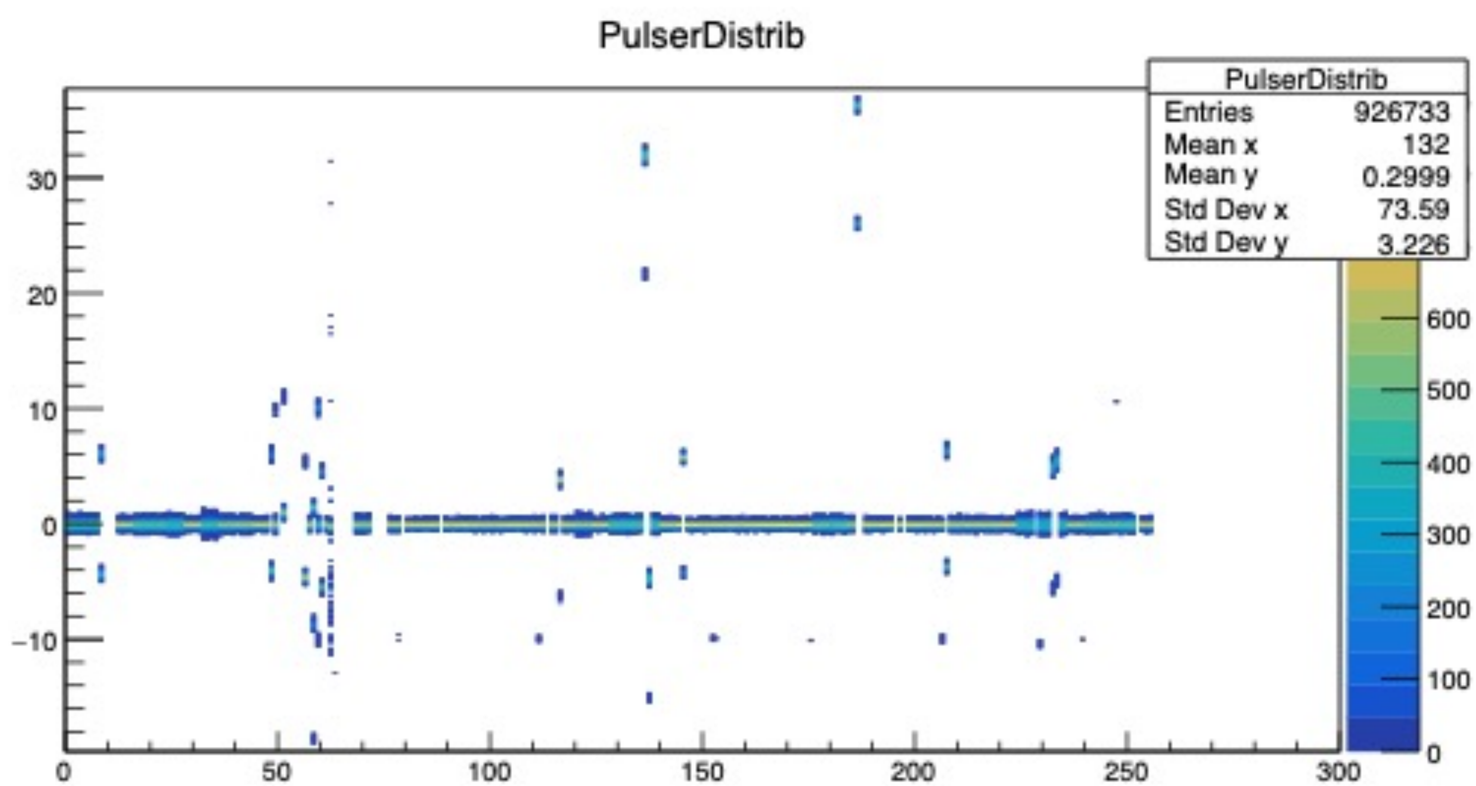
SIRIUS has been funded by the CPIER (Contrat Plan Etat Inter Régional)

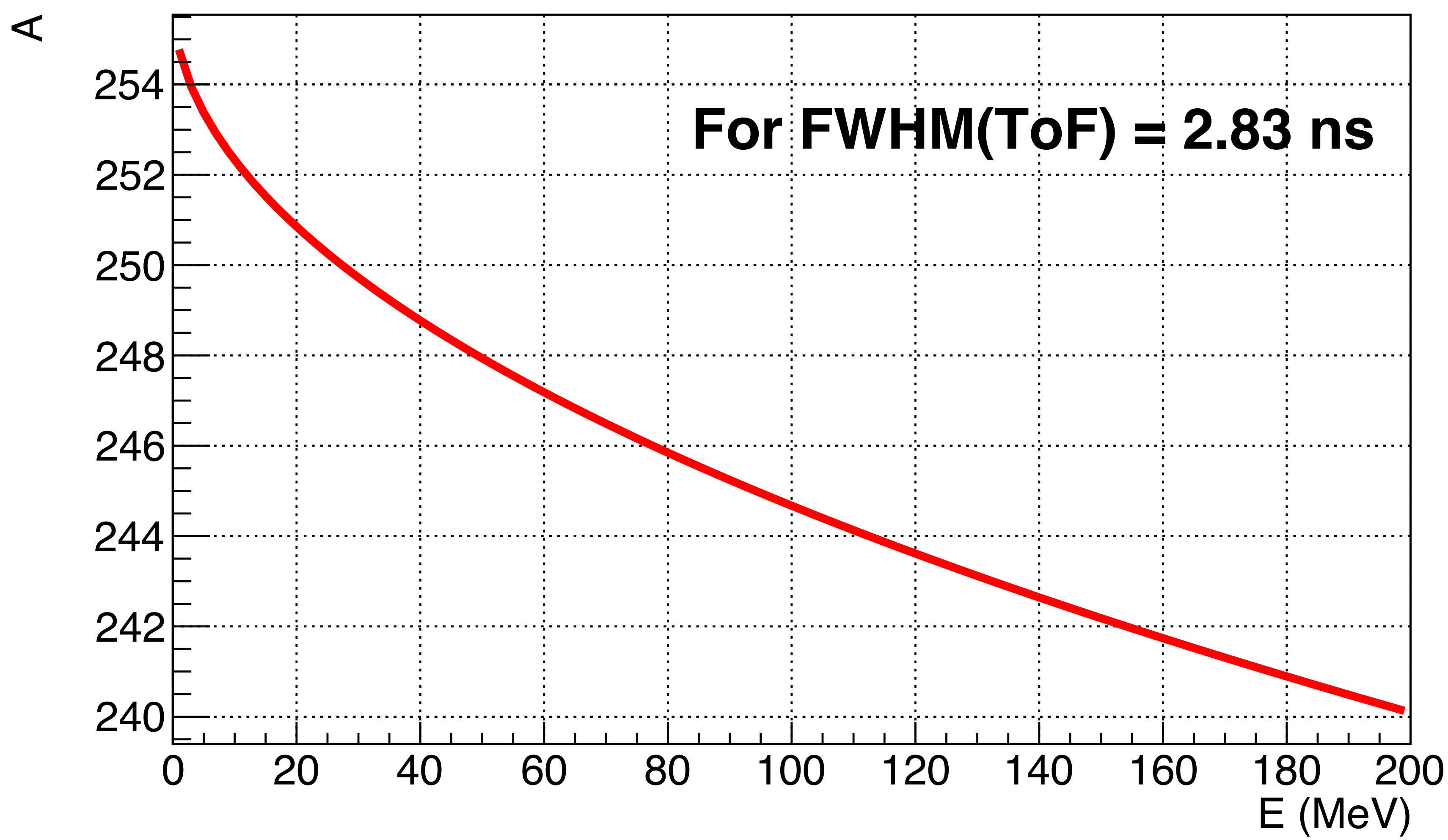
Rikel Chakma's contact is funded by the Région Normadie & FEDER through the SoSIRIUS RIN tremplin Grant

Time Alignment





Mass separability from the ToF spectrum



Developments for the users

laboratoire commun CEA/DSM CNRS/IN2P3

Required libraries

- ✦ GRU SIRIUS
  - ✦ Online
  - ✦ Offline (VIGRU)
- GRU VIGRU
- ✦ Offline analysis program
- SIRIUS User Lib
- ✦ Convert to ROOT (TTree) file
- MFM, ROOT
- ✦ Calibration and digital parameter optimisation

✦ Data analysis programs

For Ganil users

For External users

✦ A Graphical User Interface