



TASCA 23

20th Workshop on Recoil Separator for
Superheavy Element Chemistry & Physics

Status of the SIRIUS detector array

Rikel CHAKMA
On behalf of S³ collaboration



S3 has been funded by the French Research Ministry, National Research Agency (ANR), through the EQUIPEX (EQUIPment of EXcellence) reference ANR-10-EQPX-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.

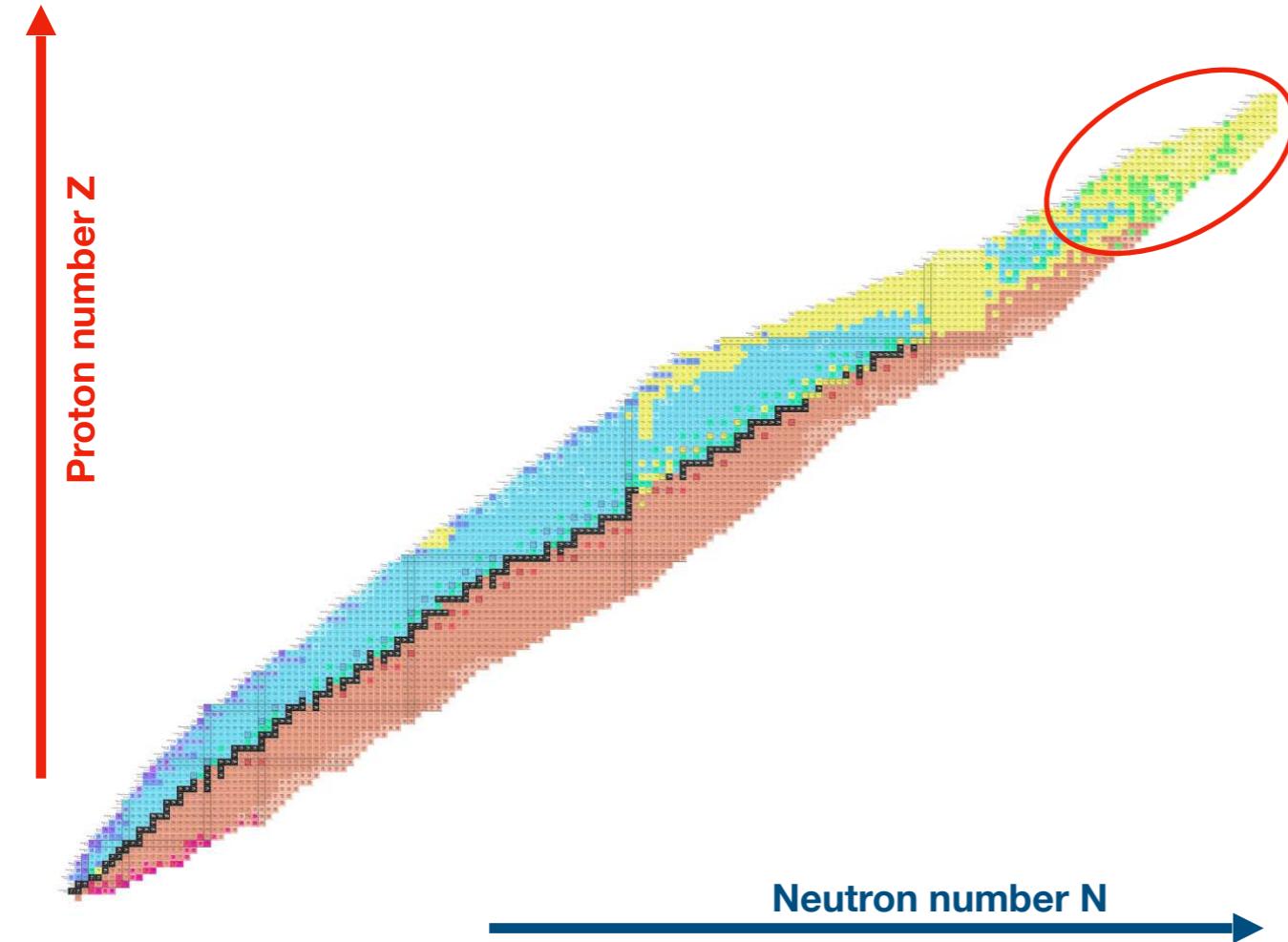
SIRIUS has been funded by the CPIER (Contrat Plan Etat Inter Régional)

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

Outline

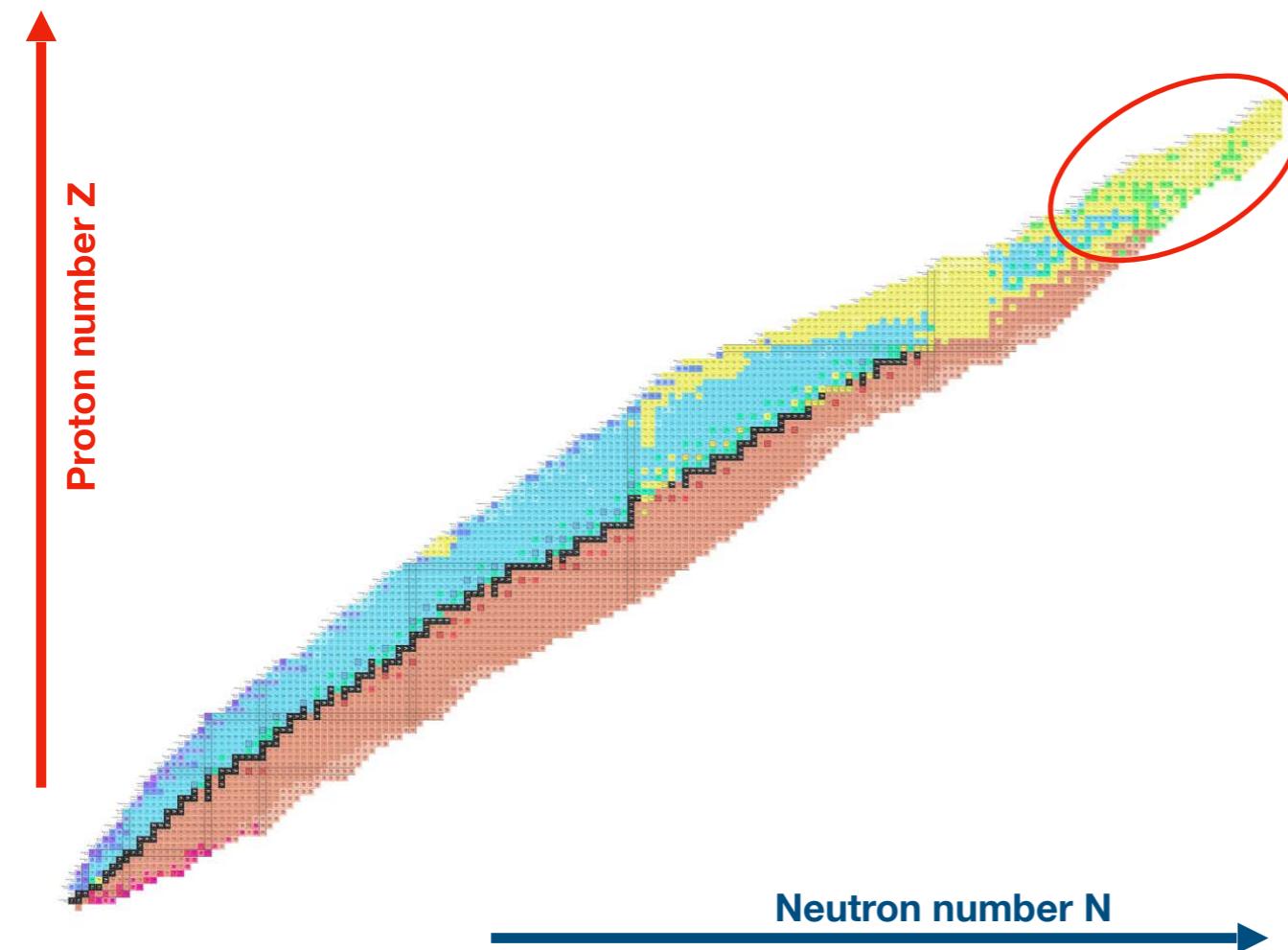
- Motivation : nuclear structure of superheavy nuclei
- Overview of SIRIUS
- Characteristics and performance:
 1. DSSD
 2. Tunnel
 3. Tracker
- Ongoing test on the DSSD + Tracker for ToF and ion tracking
- Developments for the users
- Conclusions and outlook

What are Superheavy nuclei?



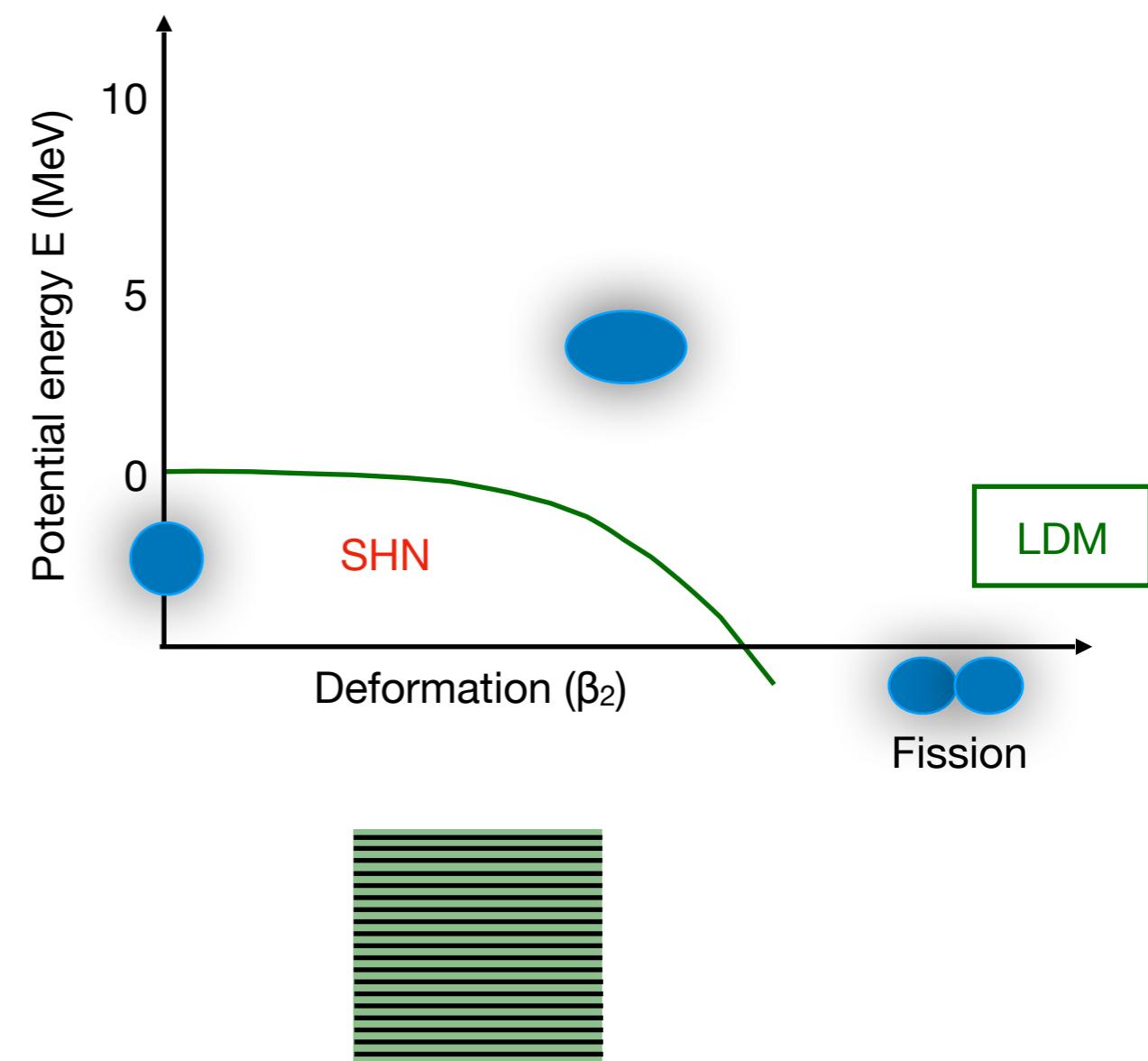
**Superheavy nuclei (SHN) are nuclei
with atomic number $Z \geq 100$**

What are Superheavy nuclei?



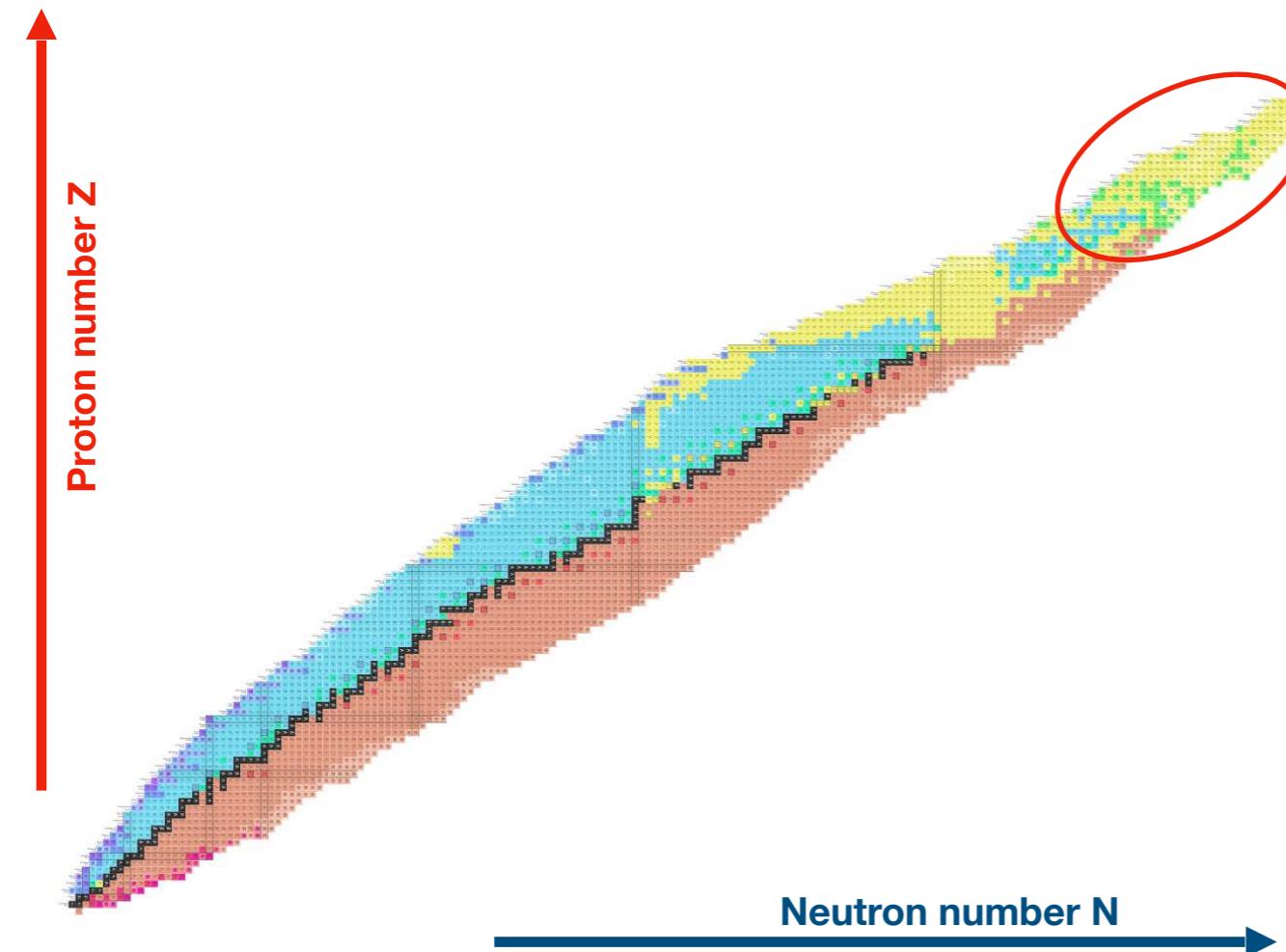
Superheavy nuclei (SHN) are nuclei with atomic number $Z \geq 100$

Characterised by zero fission barrier in the Liquid Drop Model (LDM)



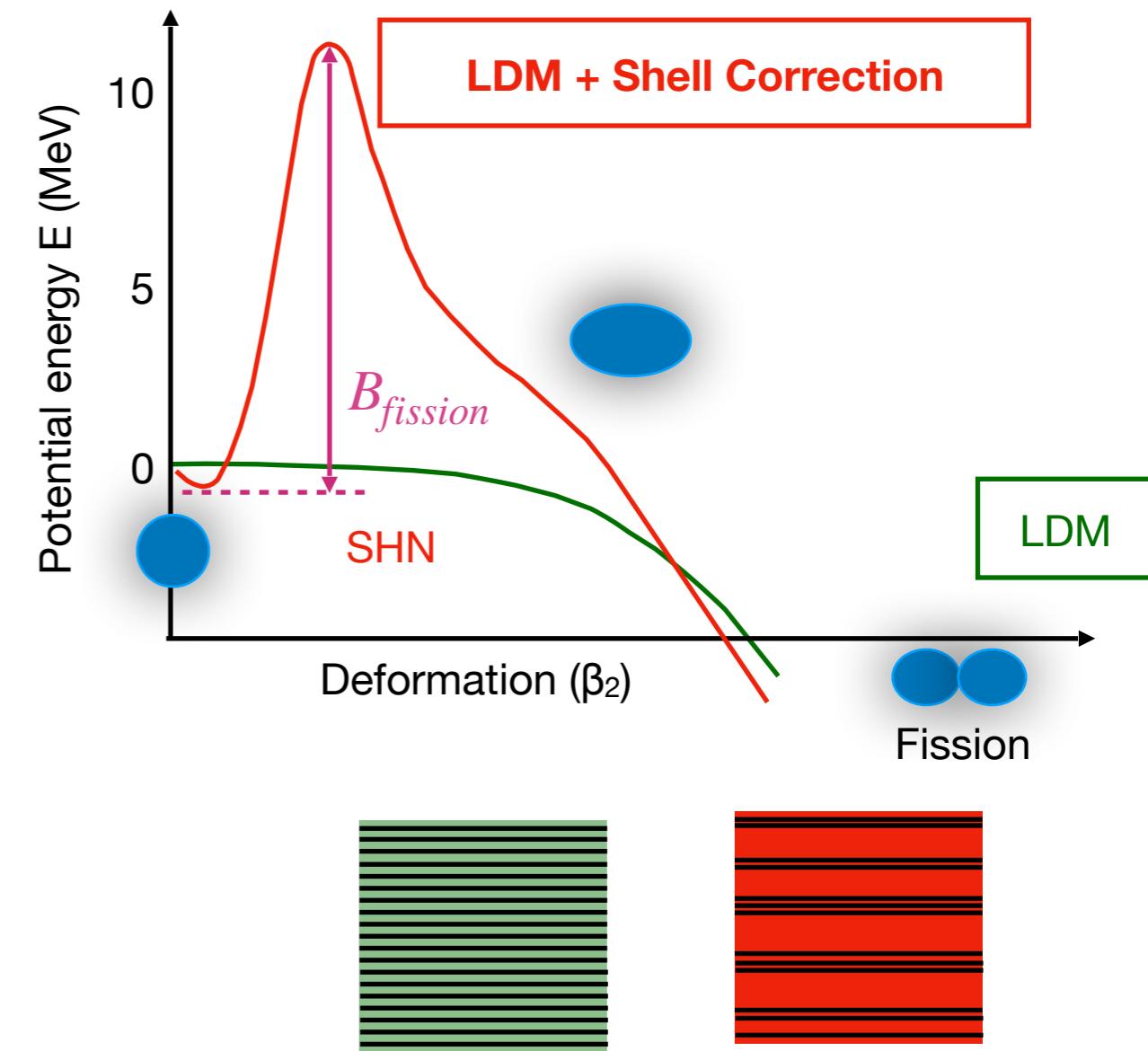
$$E(Z, N, \beta_\lambda) = E_{LDM}(Z, N, \beta_\lambda)$$

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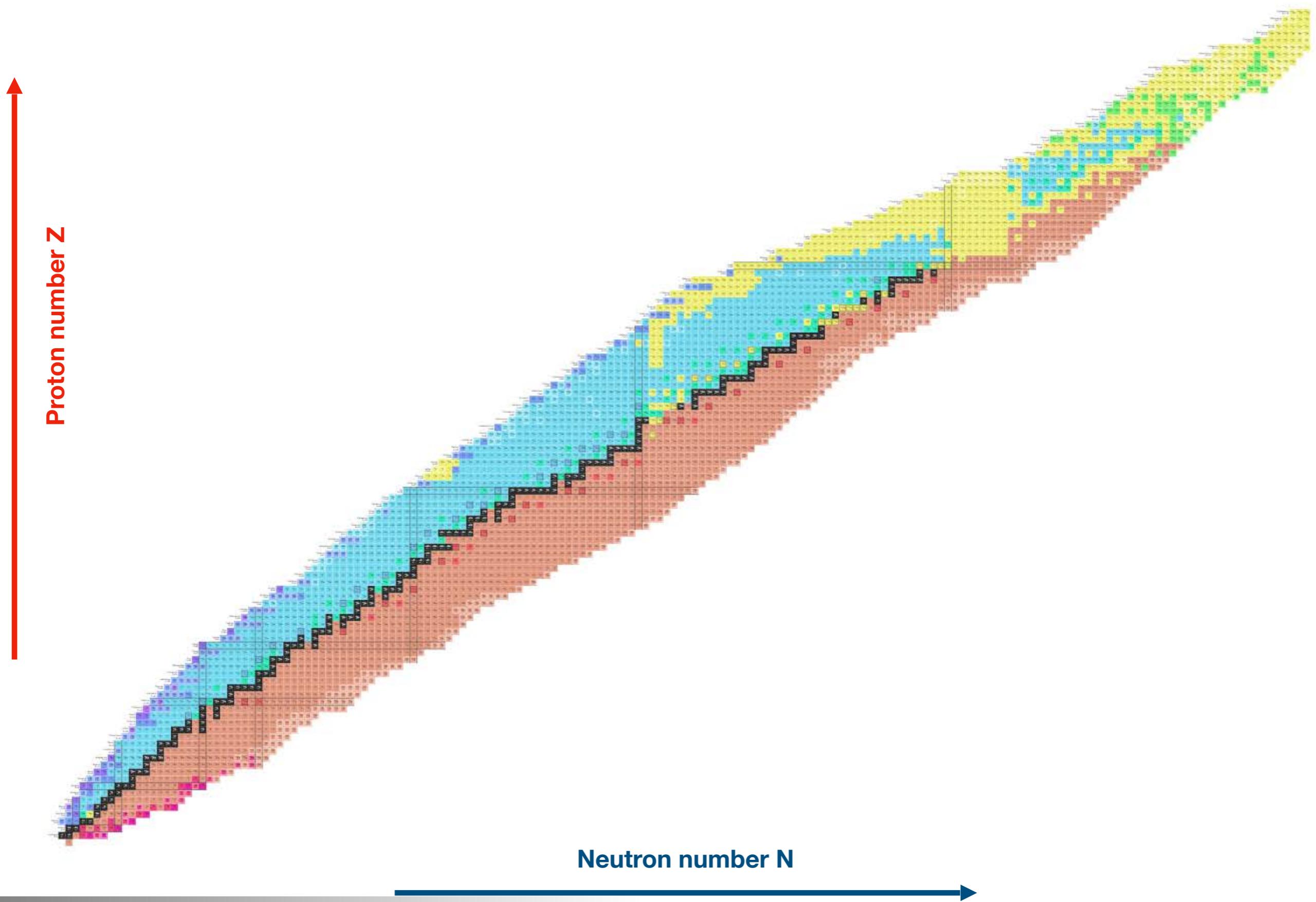


$$E(Z, N, \beta_\lambda) = E_{LDM}(Z, N, \beta_\lambda) + E_{Shell}(Z, N, \beta_\lambda)$$

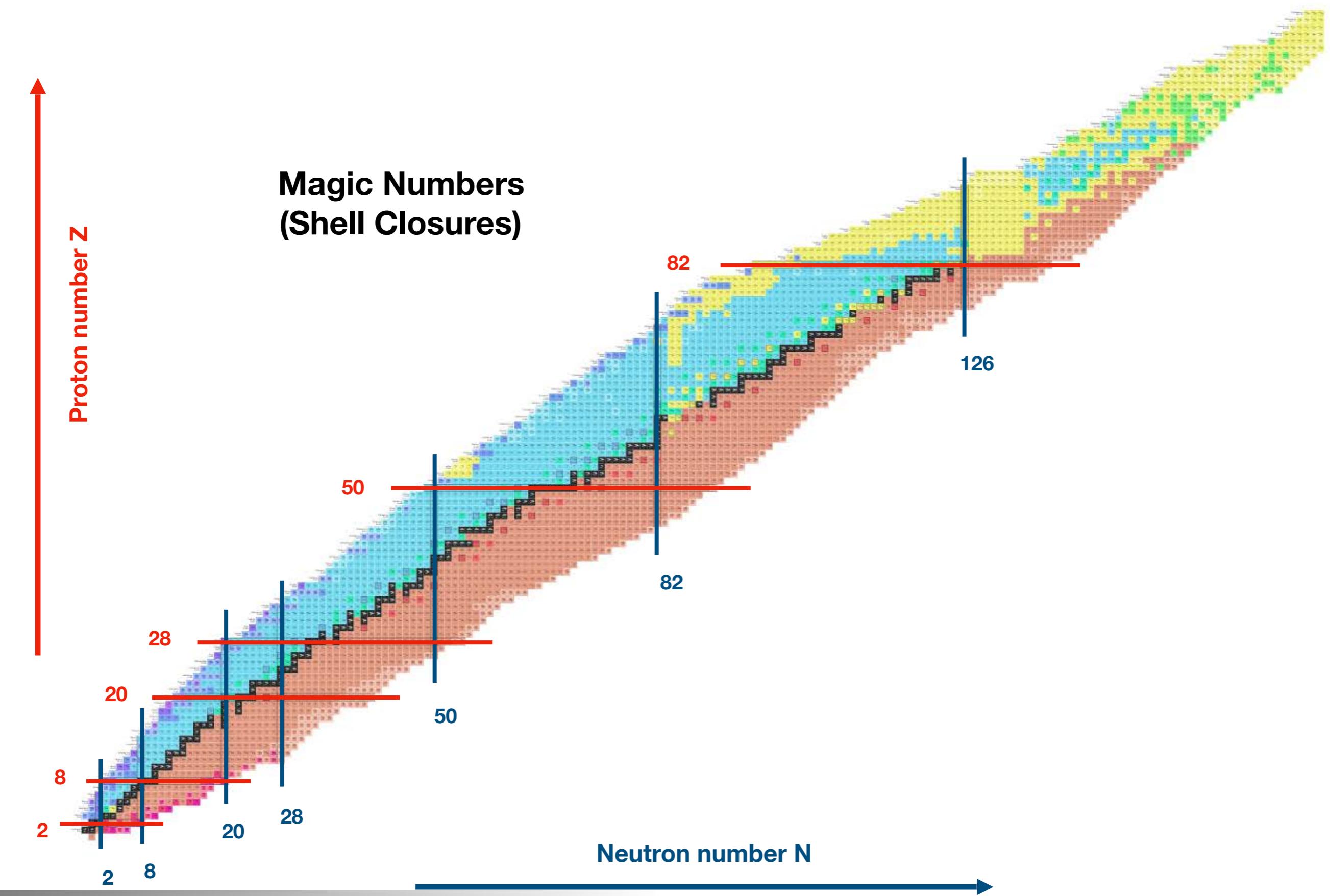
V. M. Strutinsky, Nucl. Phys. A 95, 420 (1967)

Superheavy nuclei exist because of the stabilising effects of the quantum shells

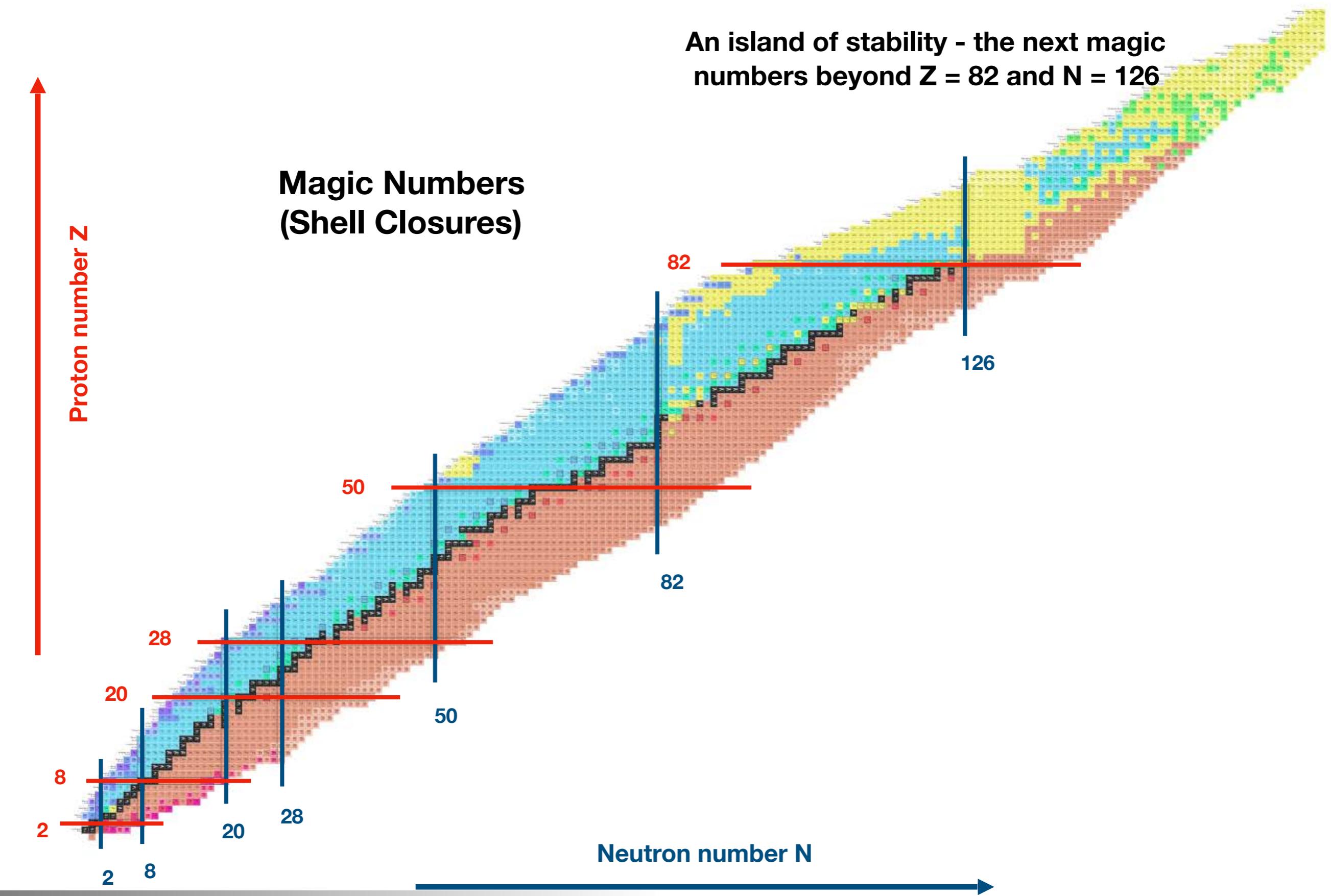
Shell effects - “Island of stability”



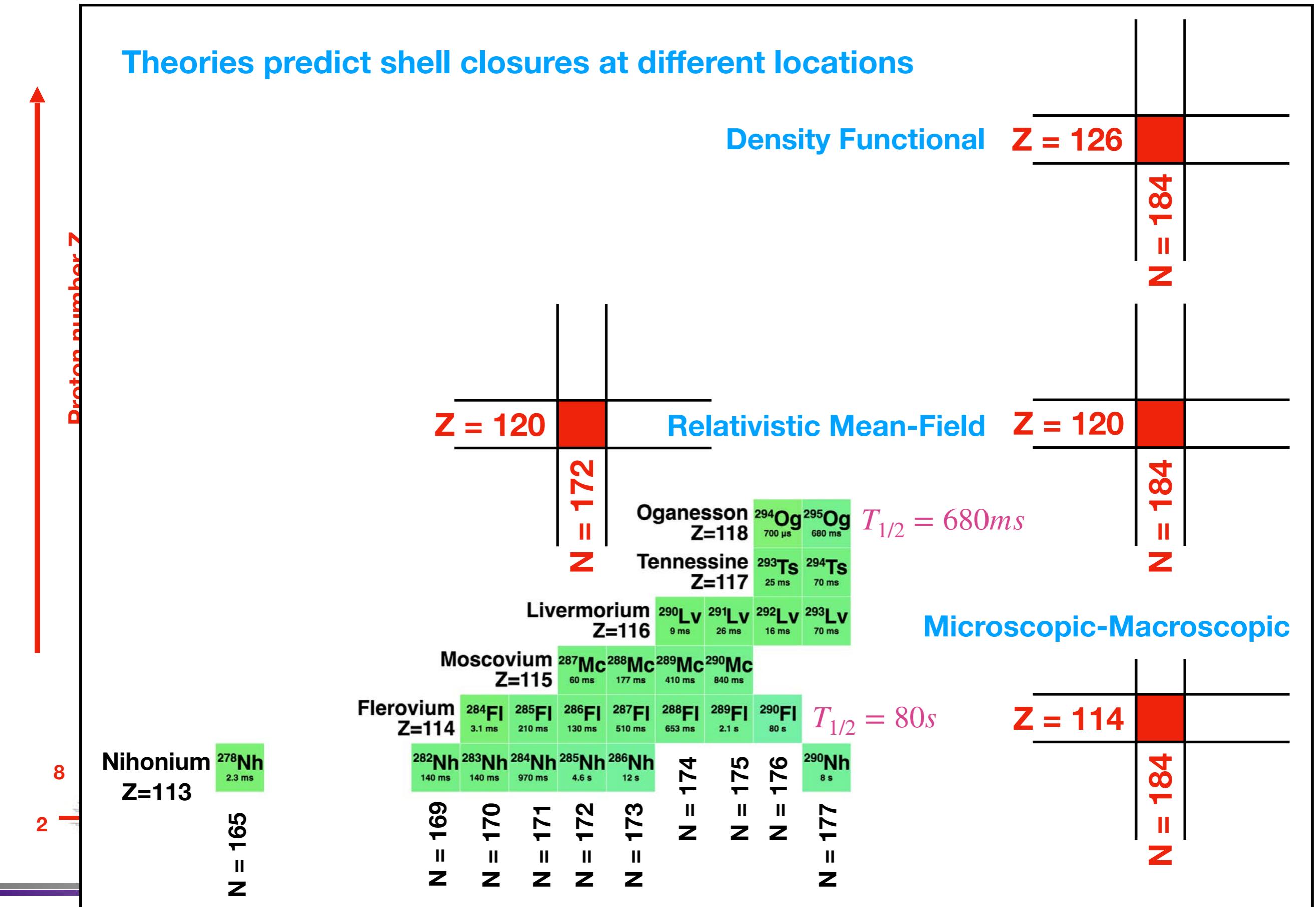
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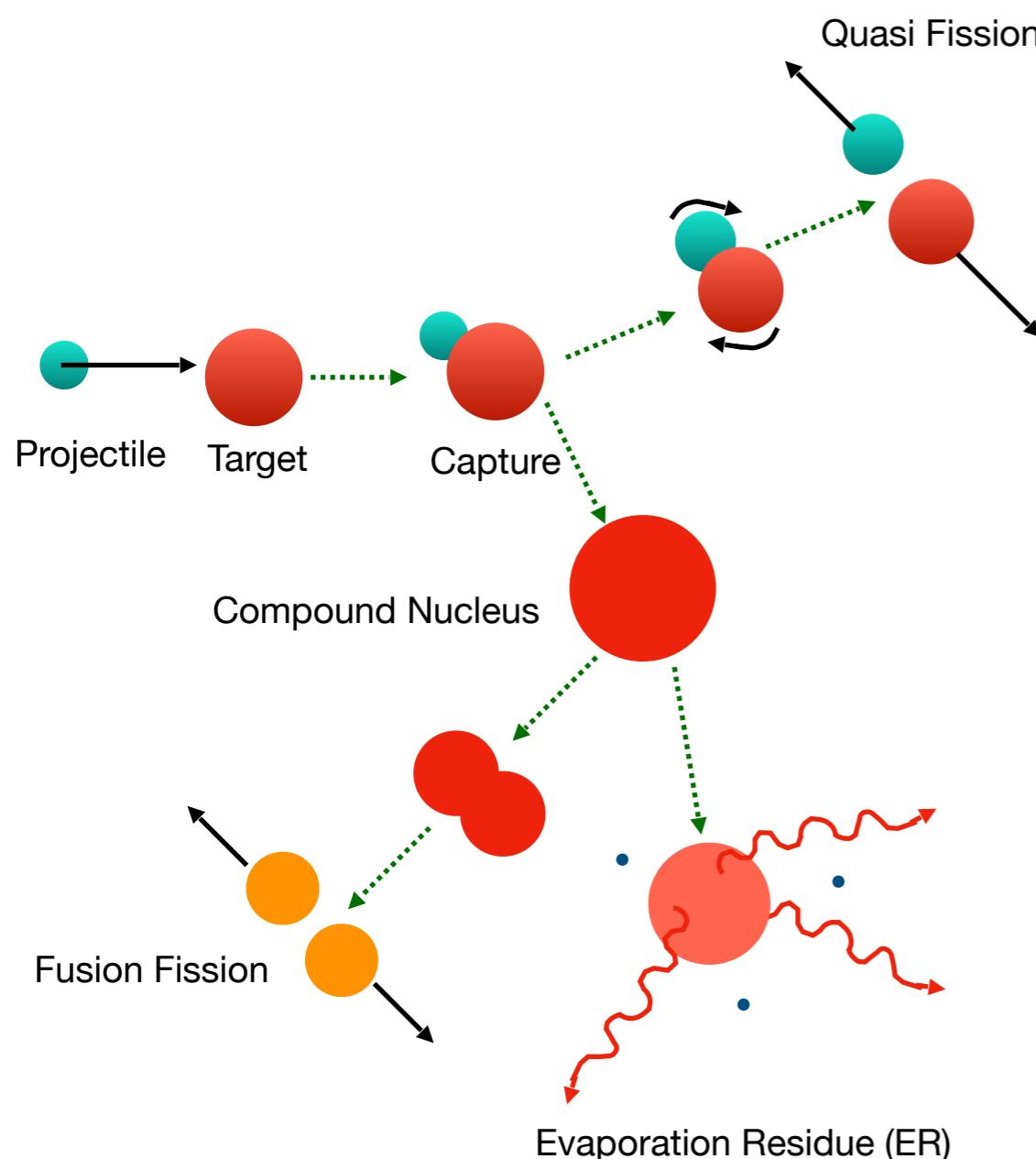


Shell effects - “Island of stability”



Production of SHN: Challenges

Superheavy nuclei are produced in
Fusion Evaporation Reactions

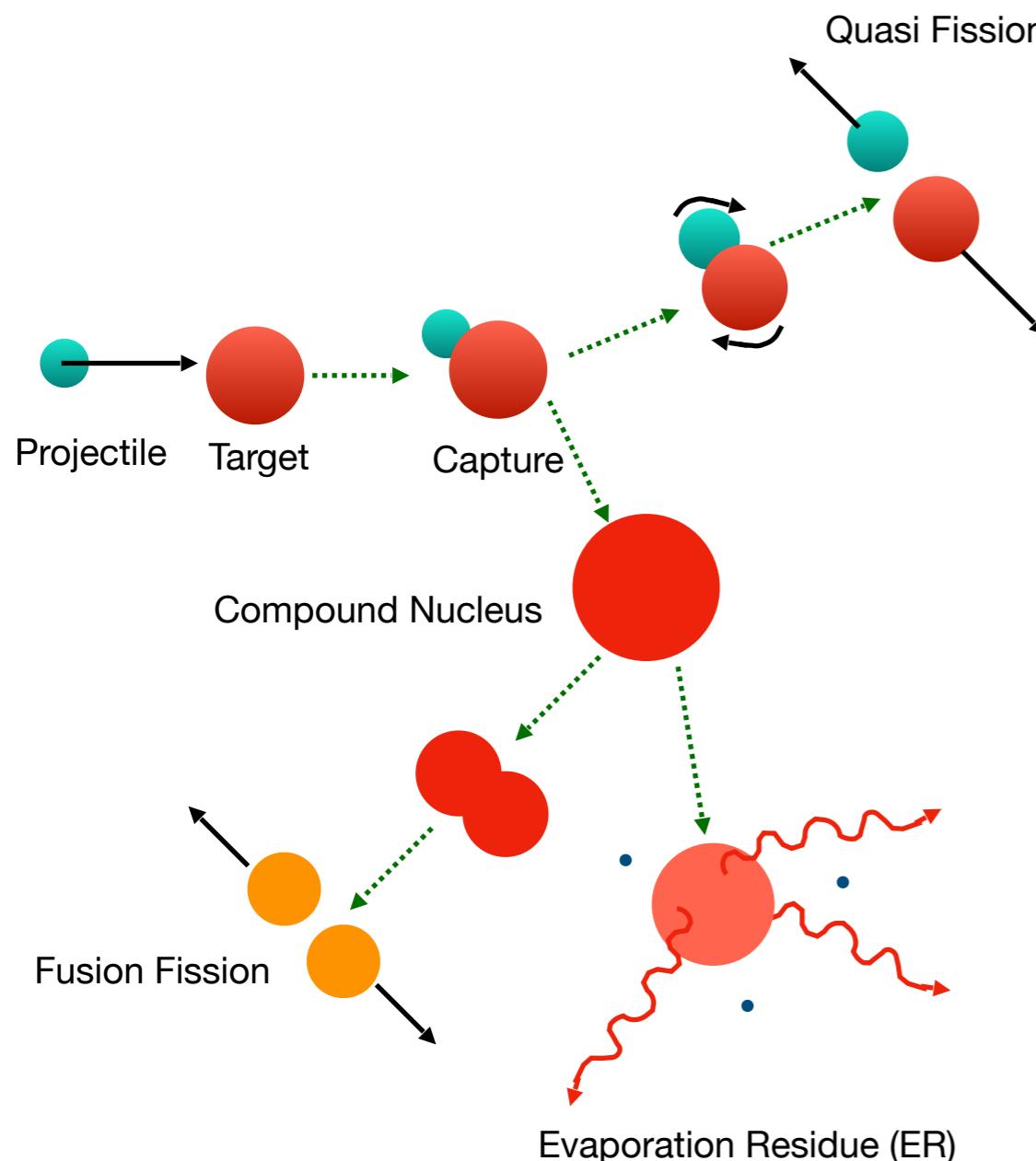


$$\sigma(ER) \approx \sigma(Fission) \times 10^{-13} mb$$

$$10^3 mb$$

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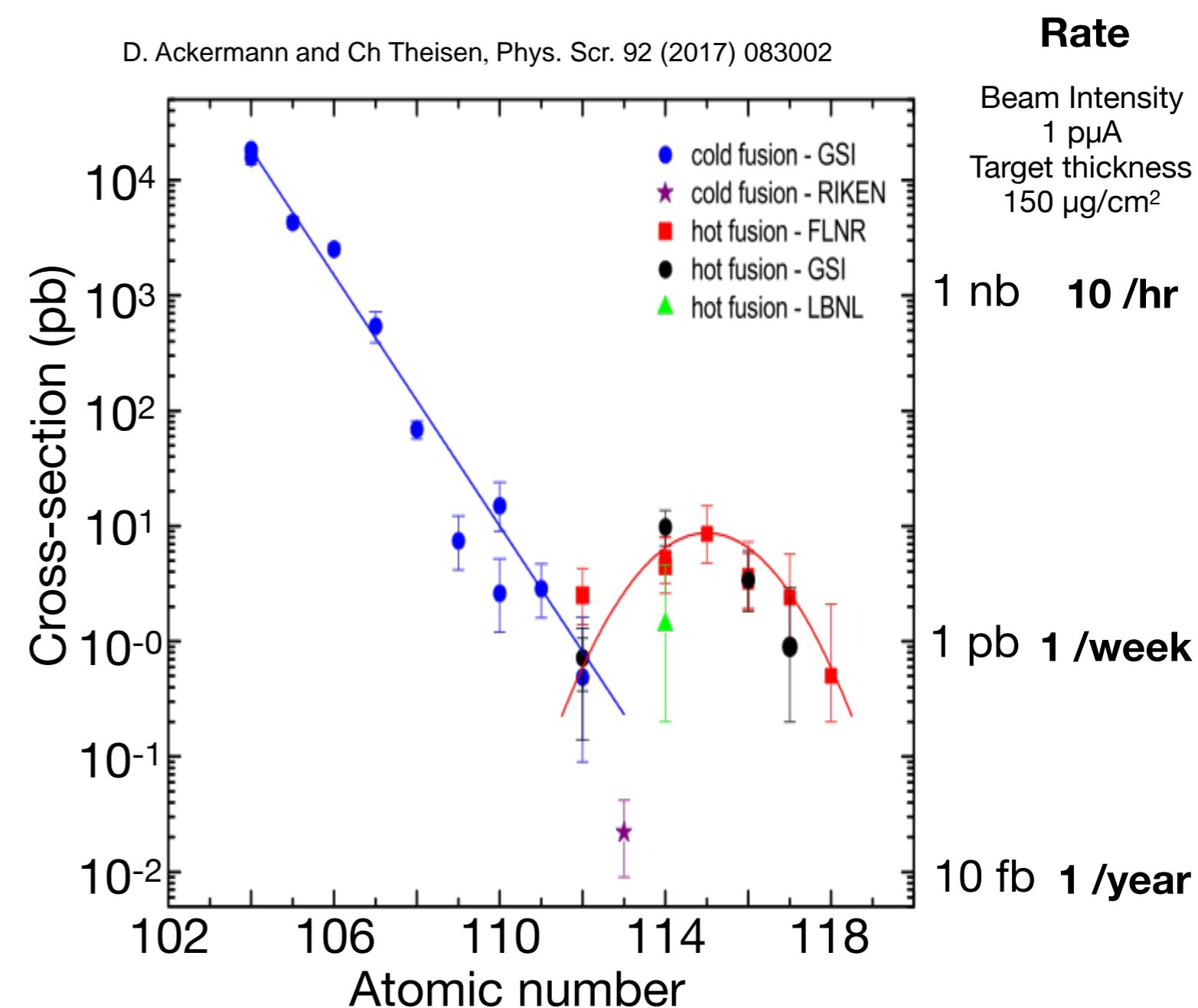
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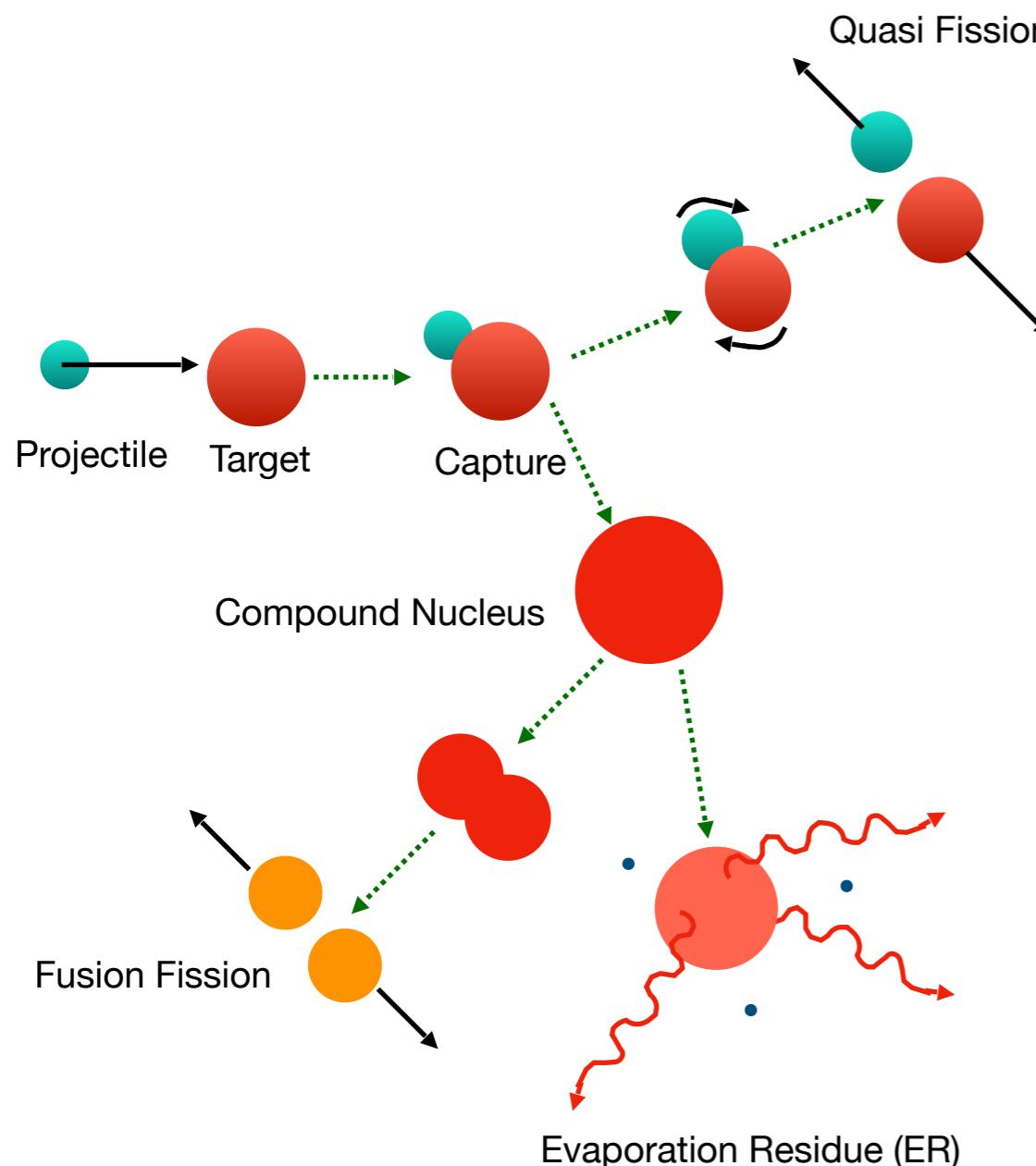
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D. Ackermann and Ch Theisen, Phys. Scr. 92 (2017) 083002



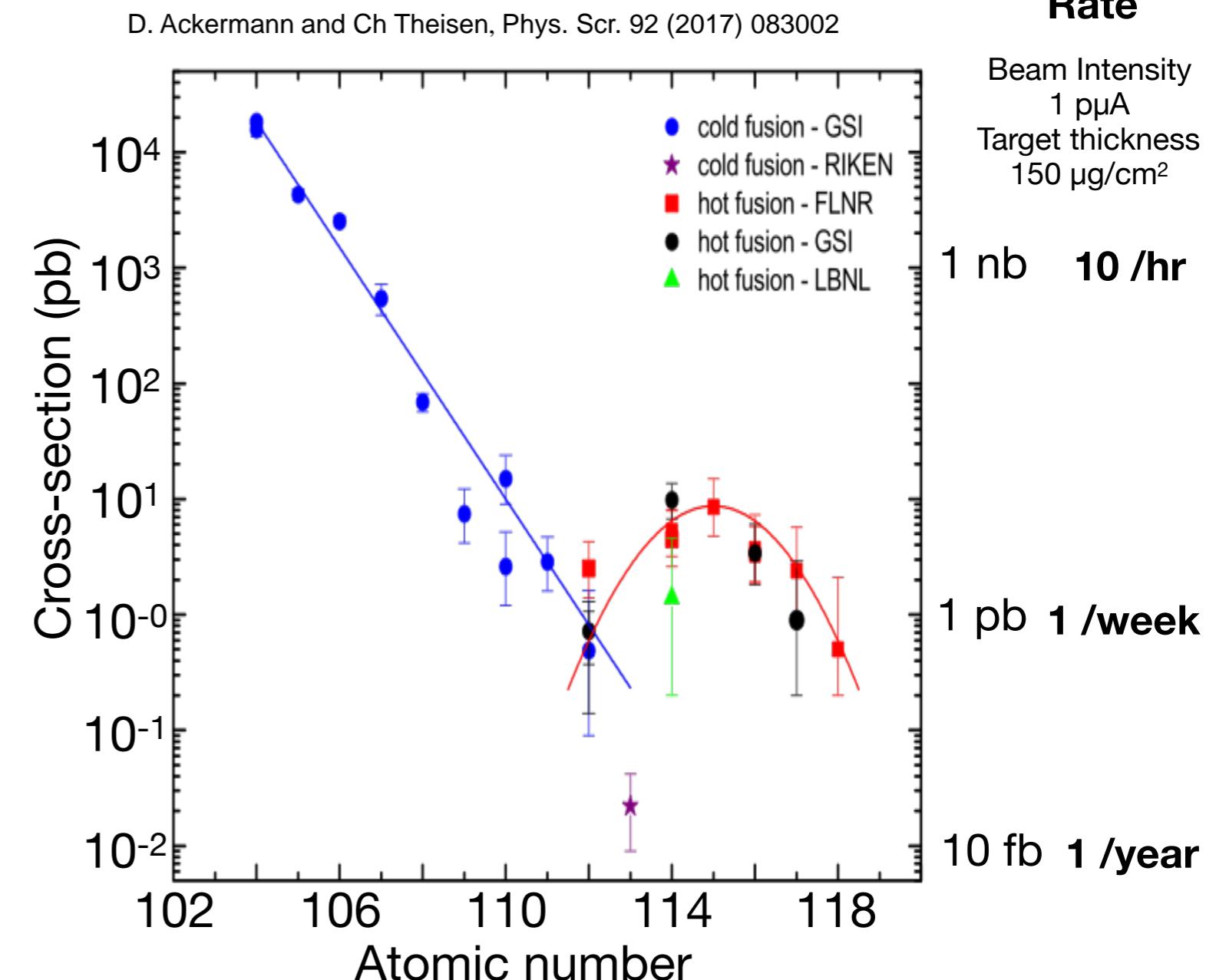
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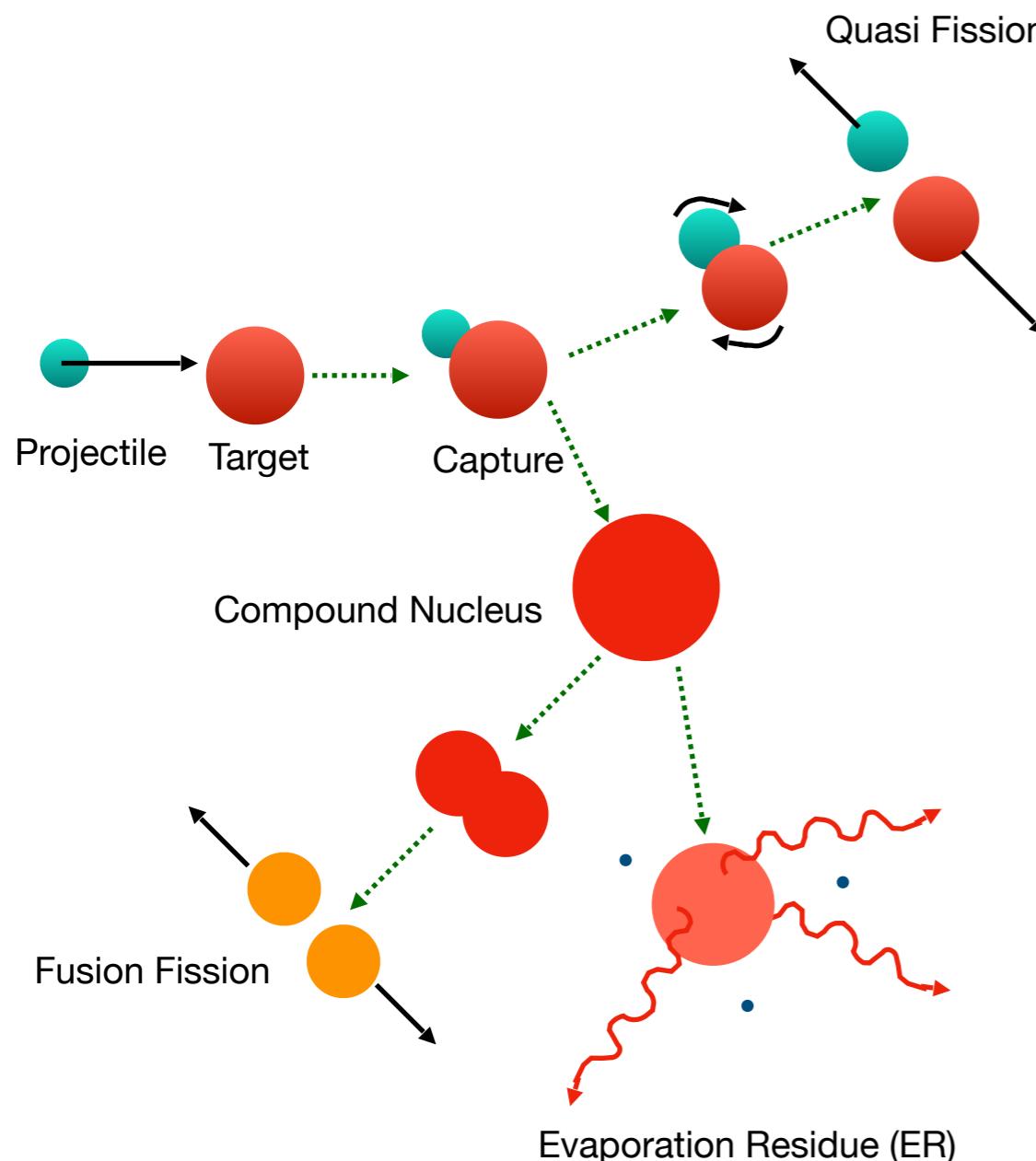
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$$N_{produced} = I_{beam} \times duration \times \sigma \times \Delta x_{target} \times N_A / M_{target}$$

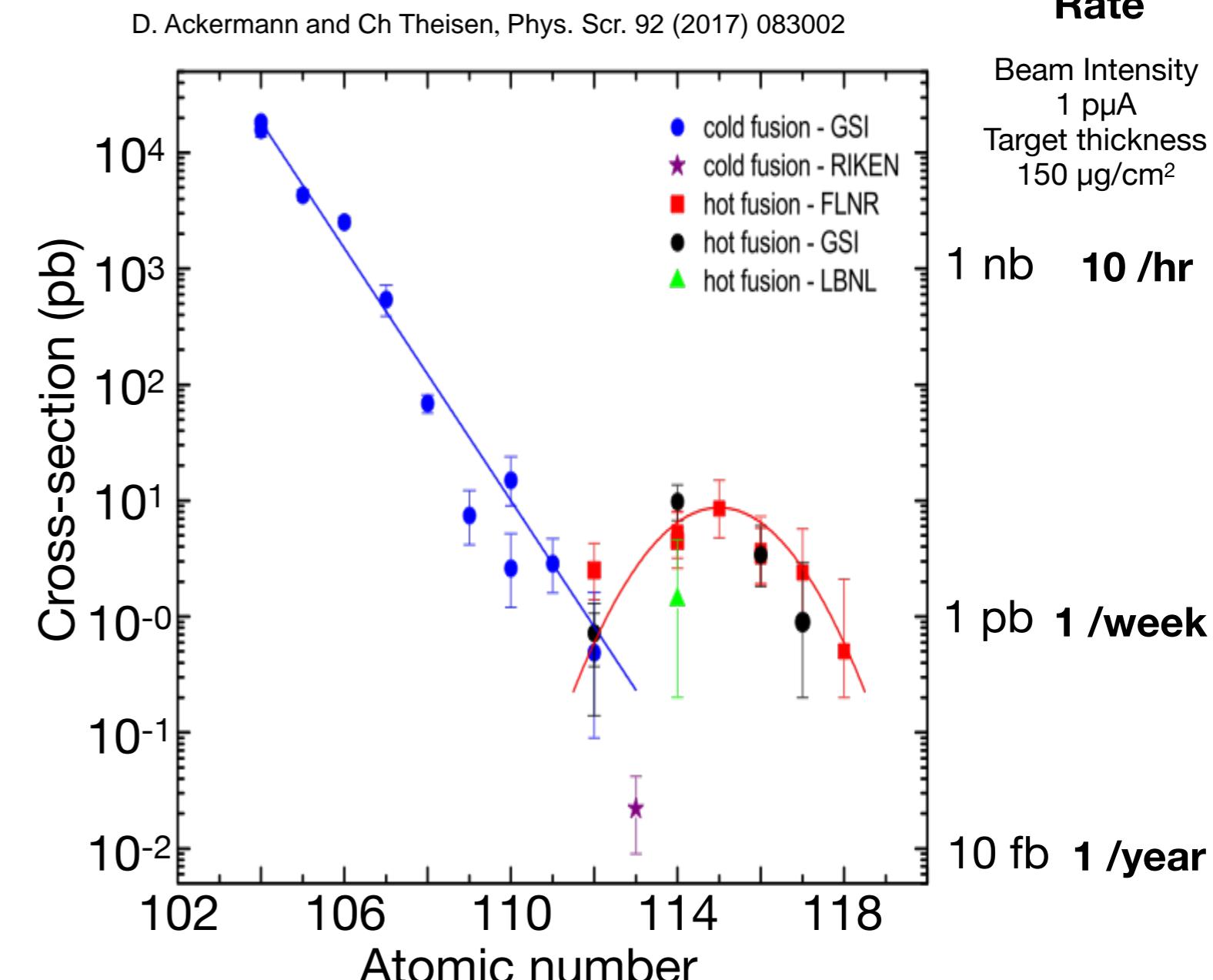
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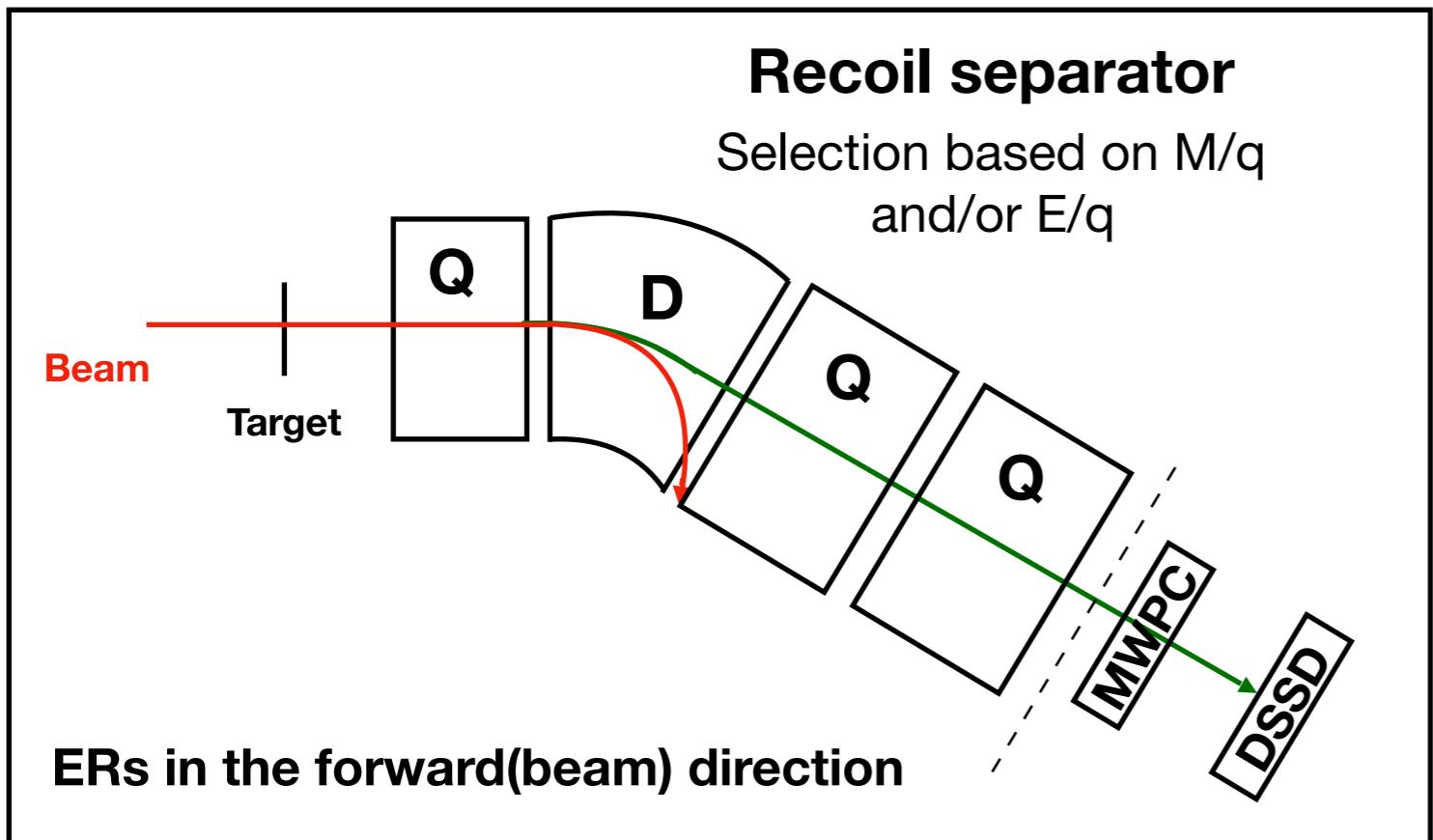


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Requirements:

- High beam intensity
- Efficient setup + Spectrometer

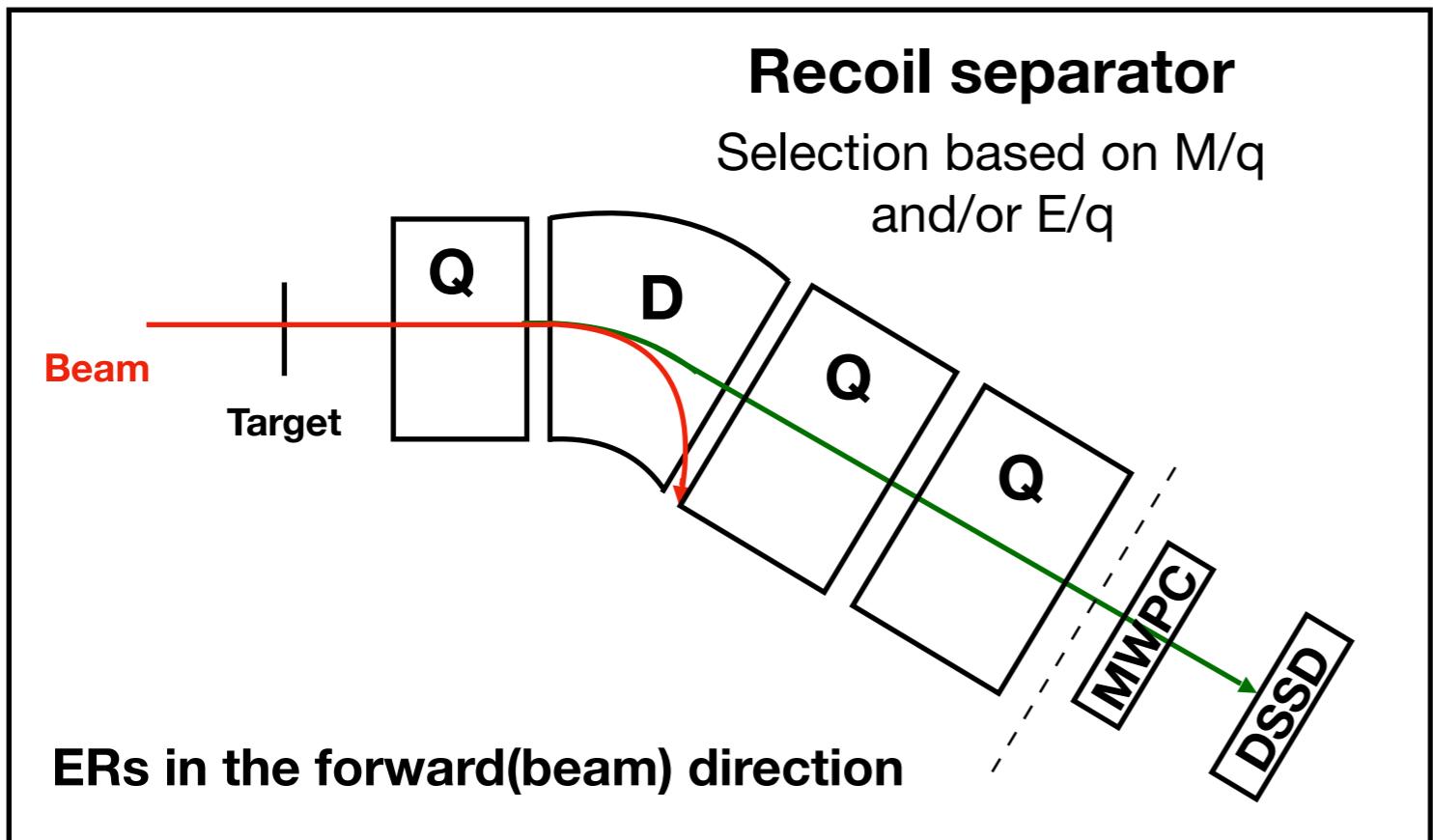
Detection of SHN: Challenges



Require a good recoil separator:

- **High Rejection**
- **High transmission**
- **Large acceptance**

Detection of SHN: Challenges



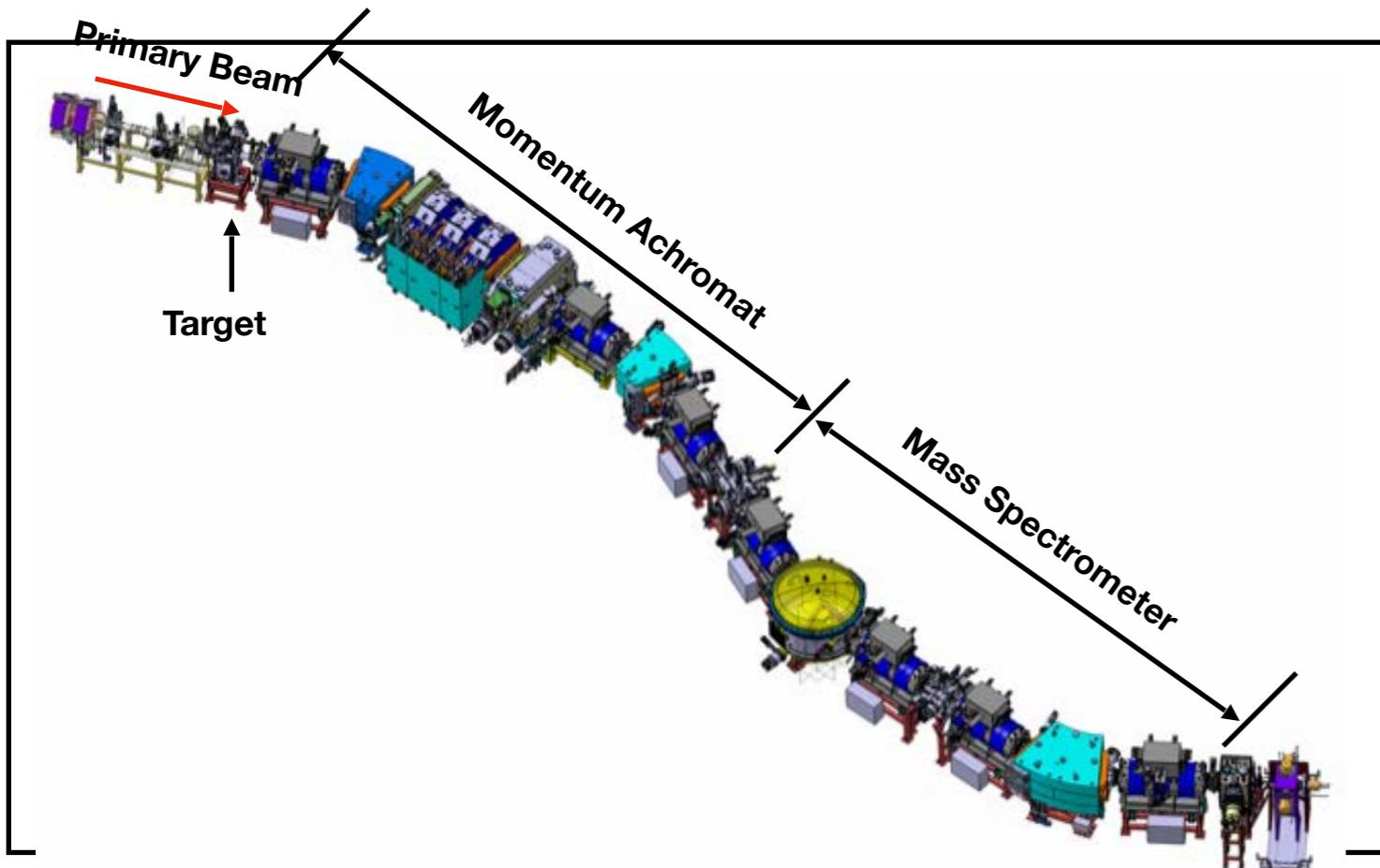
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Require an efficient detection system:

- High detection efficiency
- Position sensitive detectors (large pixelization)
- Good energy and time resolution (~ 20 keV, ~ 500 ps)
- Good acquisition system (negligible dead time)

Detection of SHN: Challenges



S³ (Super Separator Spectrometer)

Large Acceptance : $> \pm 50\text{mrad}$

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

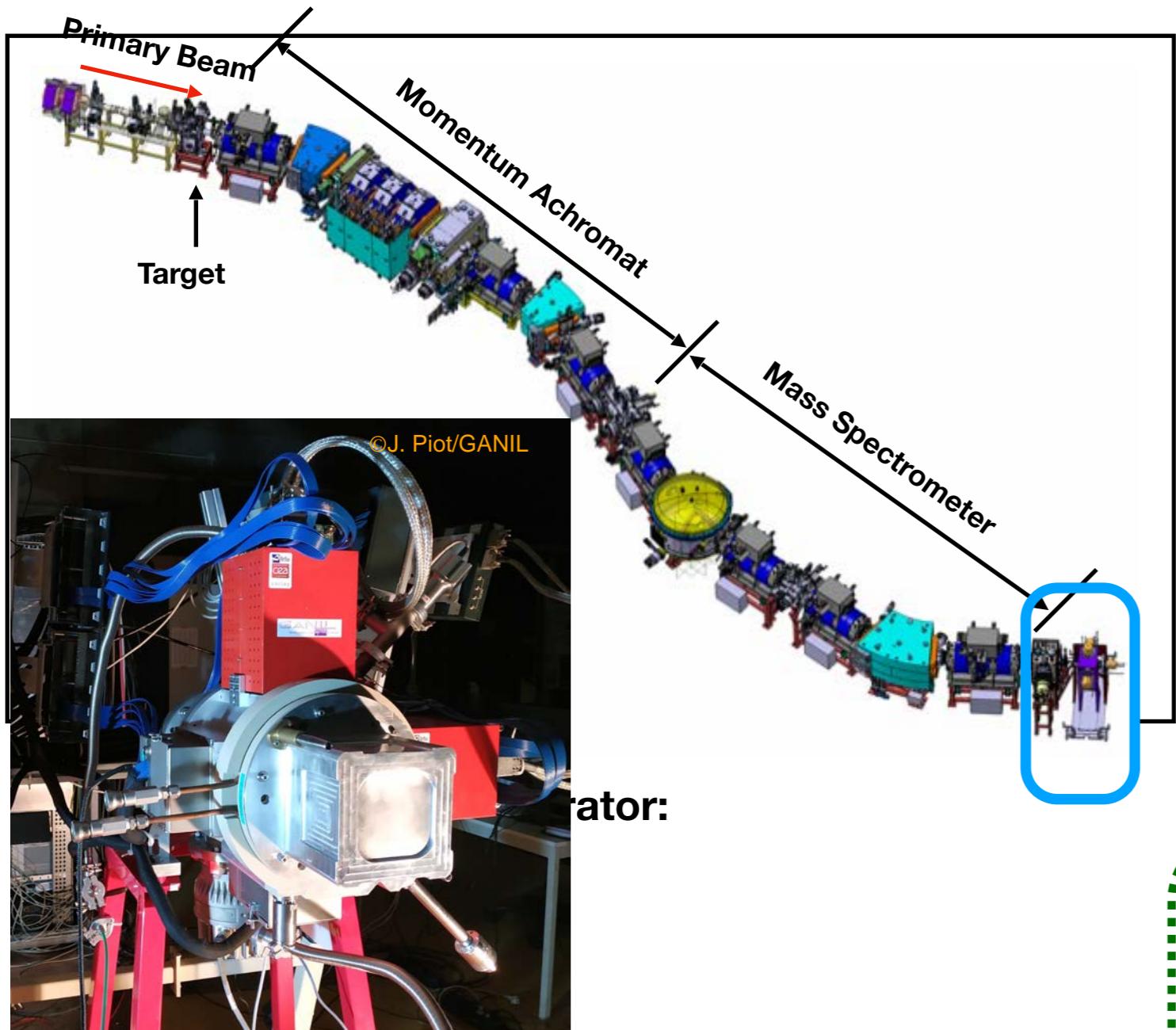
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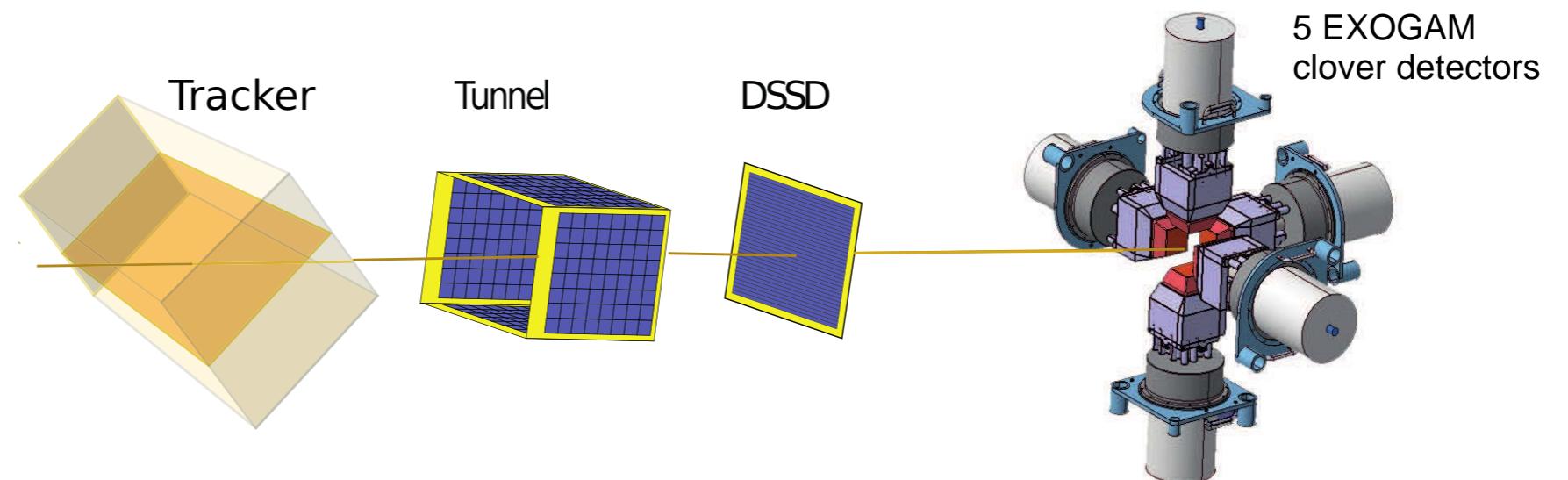
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SIRIUS (Spectroscopy and Identification of Rare Isotopes Using S³)

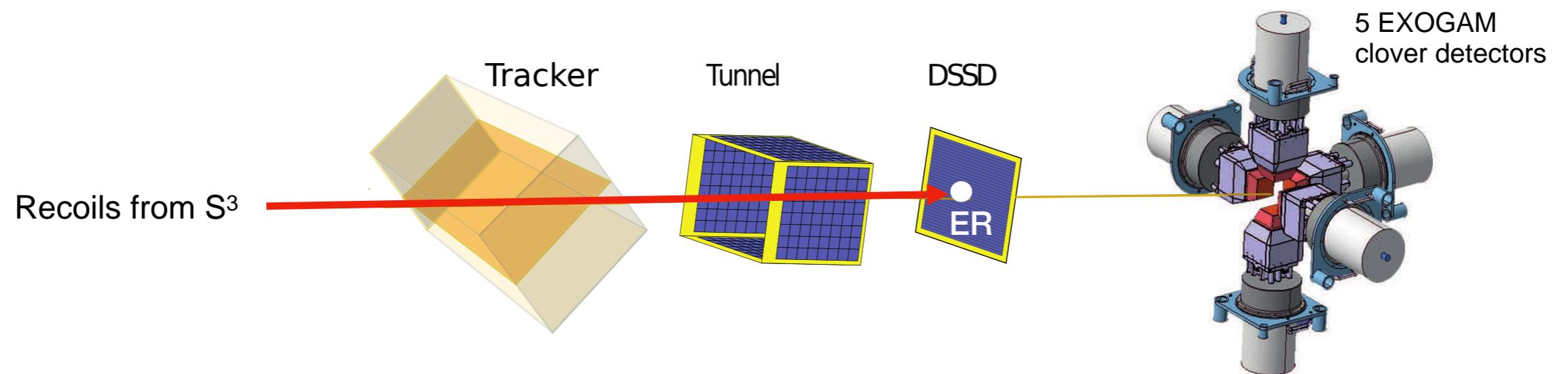
The focal plane detection system of S³

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

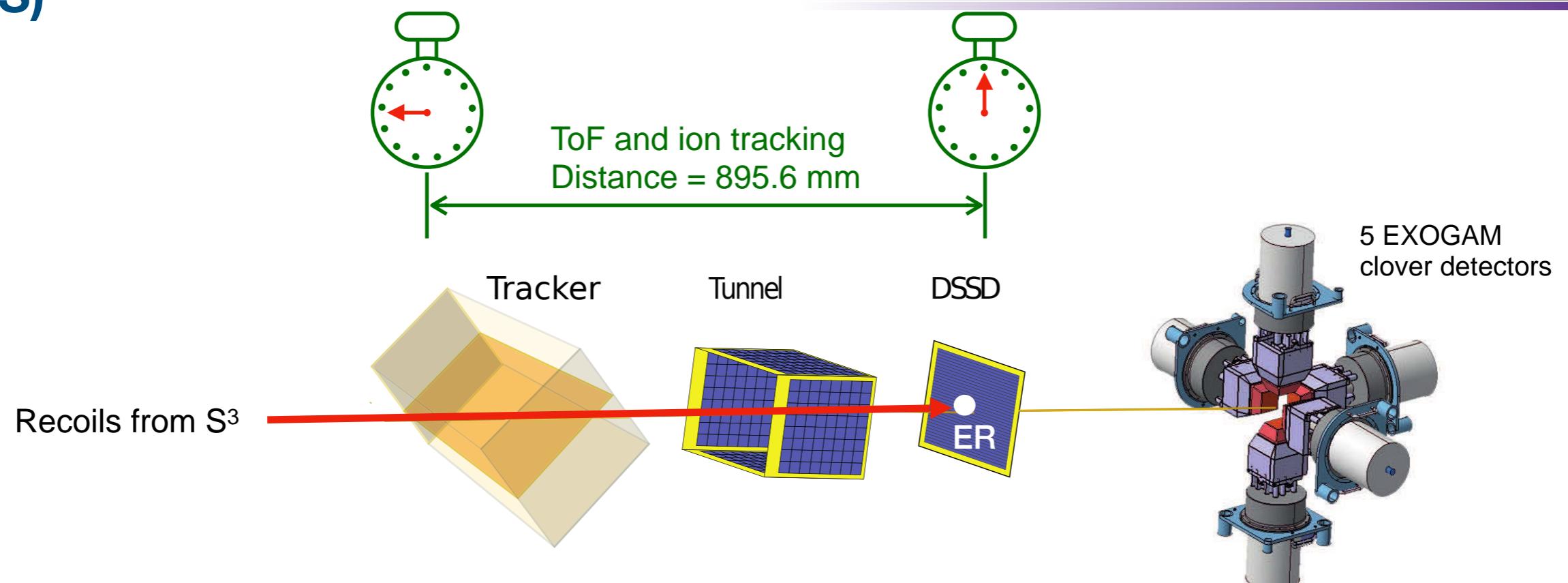
Spectroscopy and Identification of Rare Isotopes Using S³ (SIRIUS)



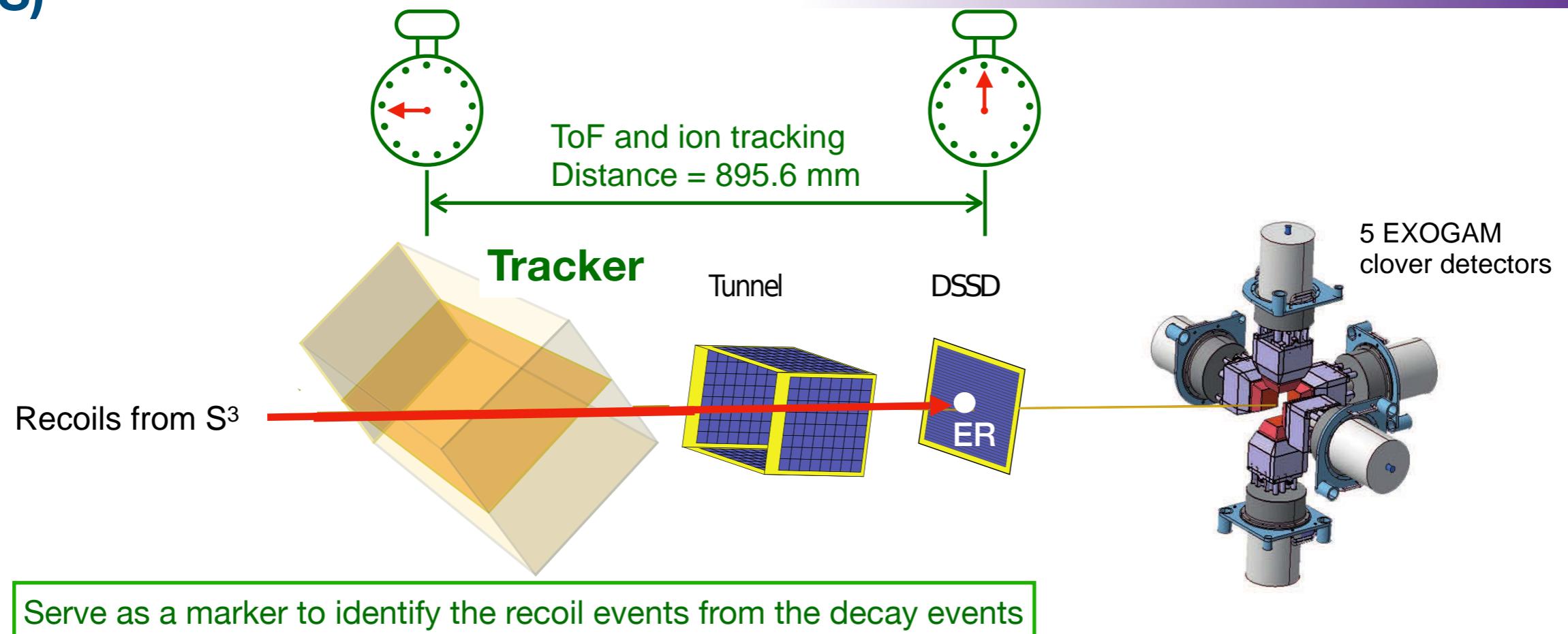
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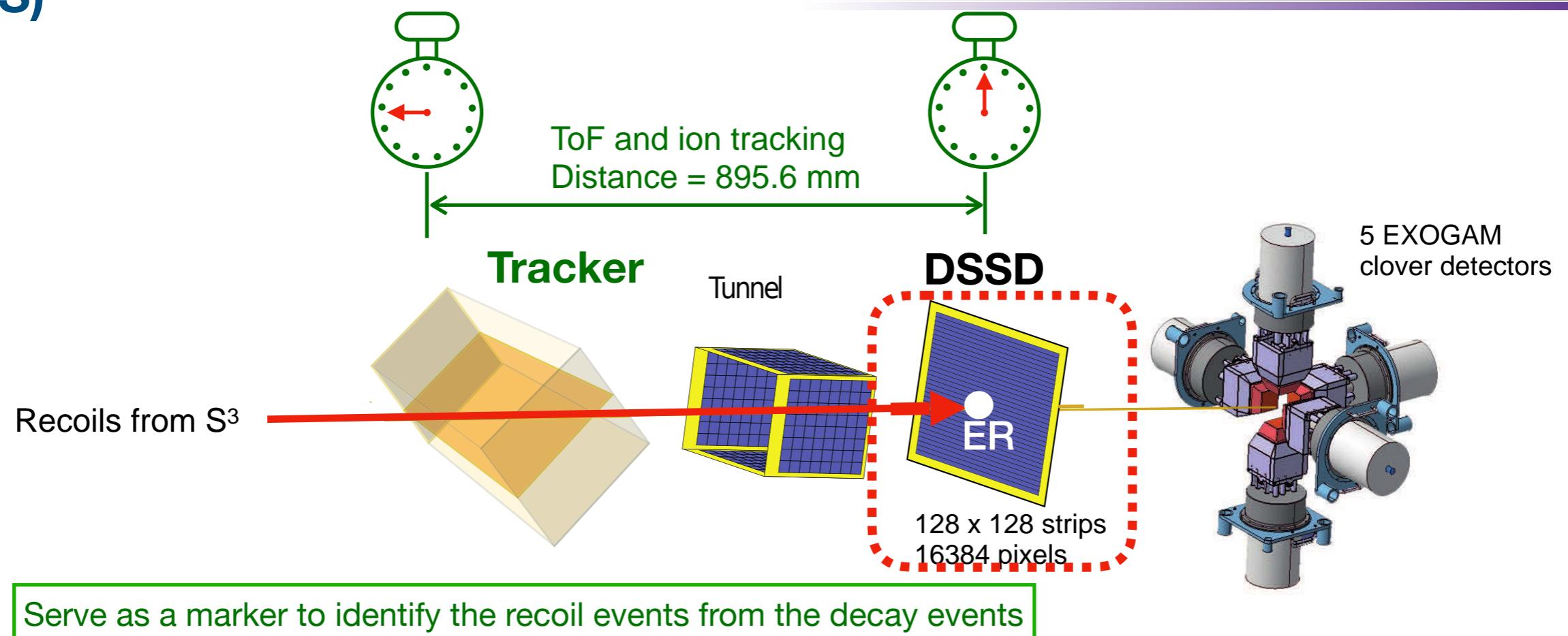
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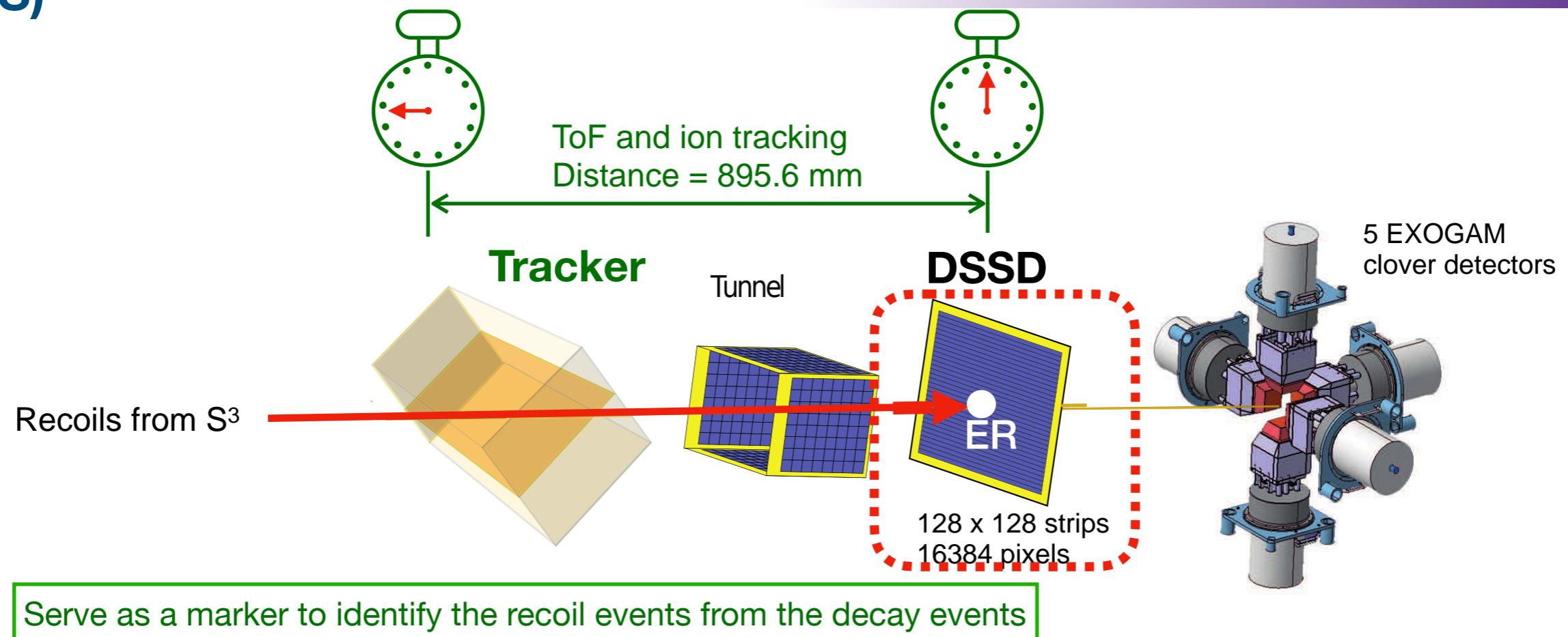
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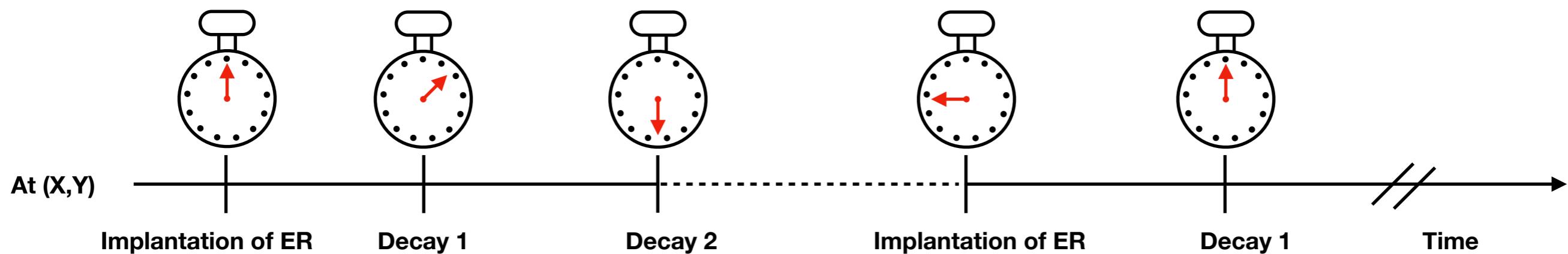
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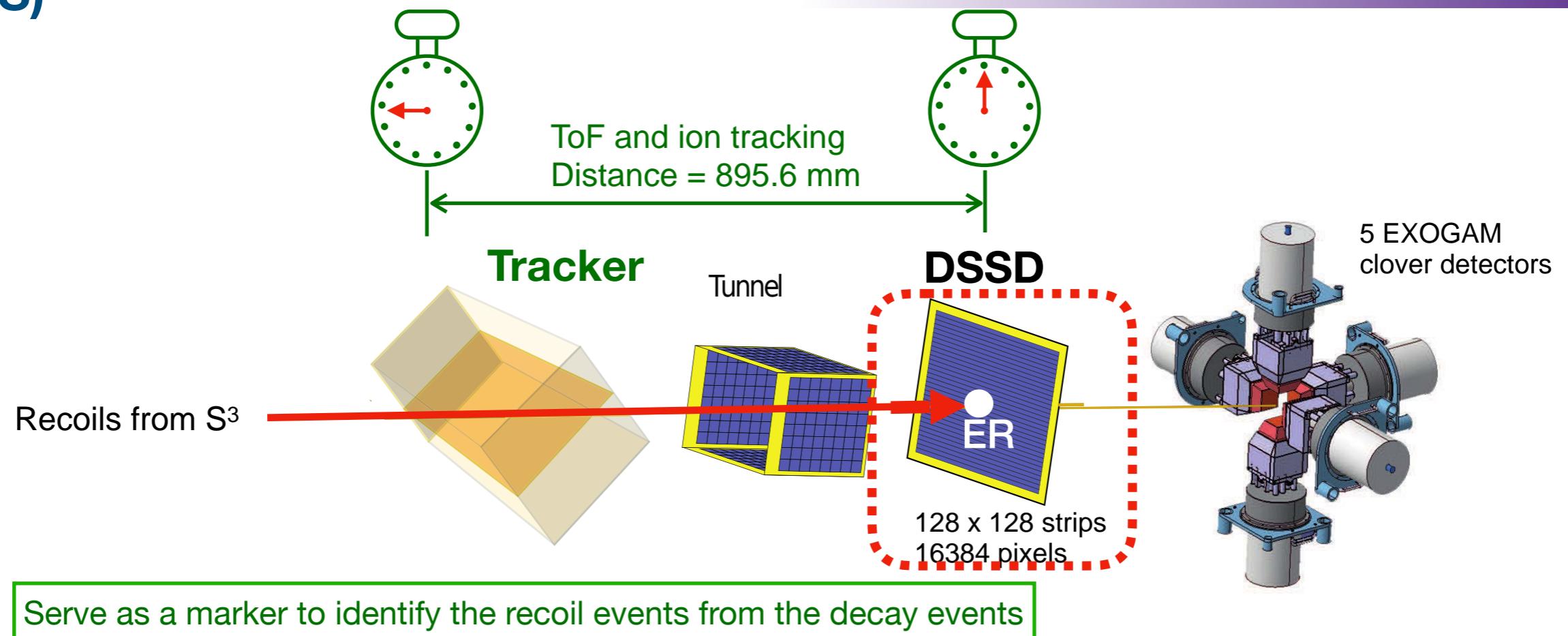
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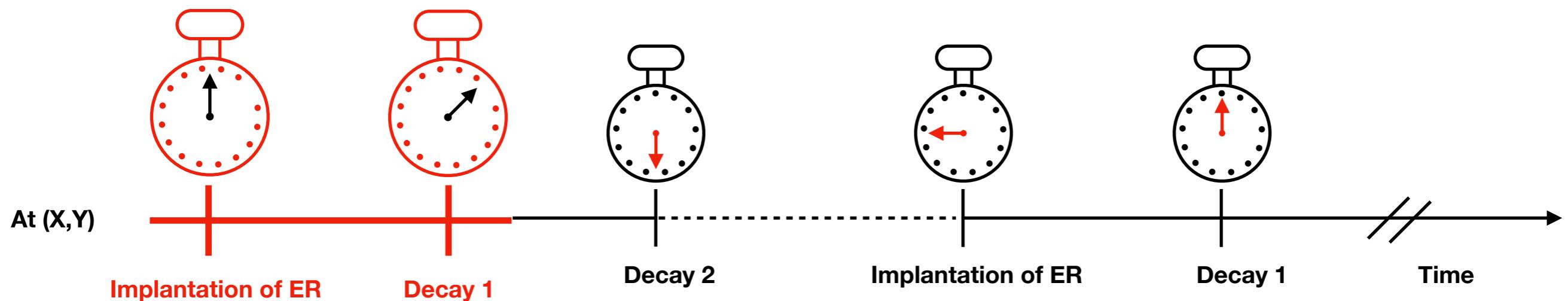
**At the focal plane (Position-sensitive) detector:
recoil-decay, decay-decay correlations**



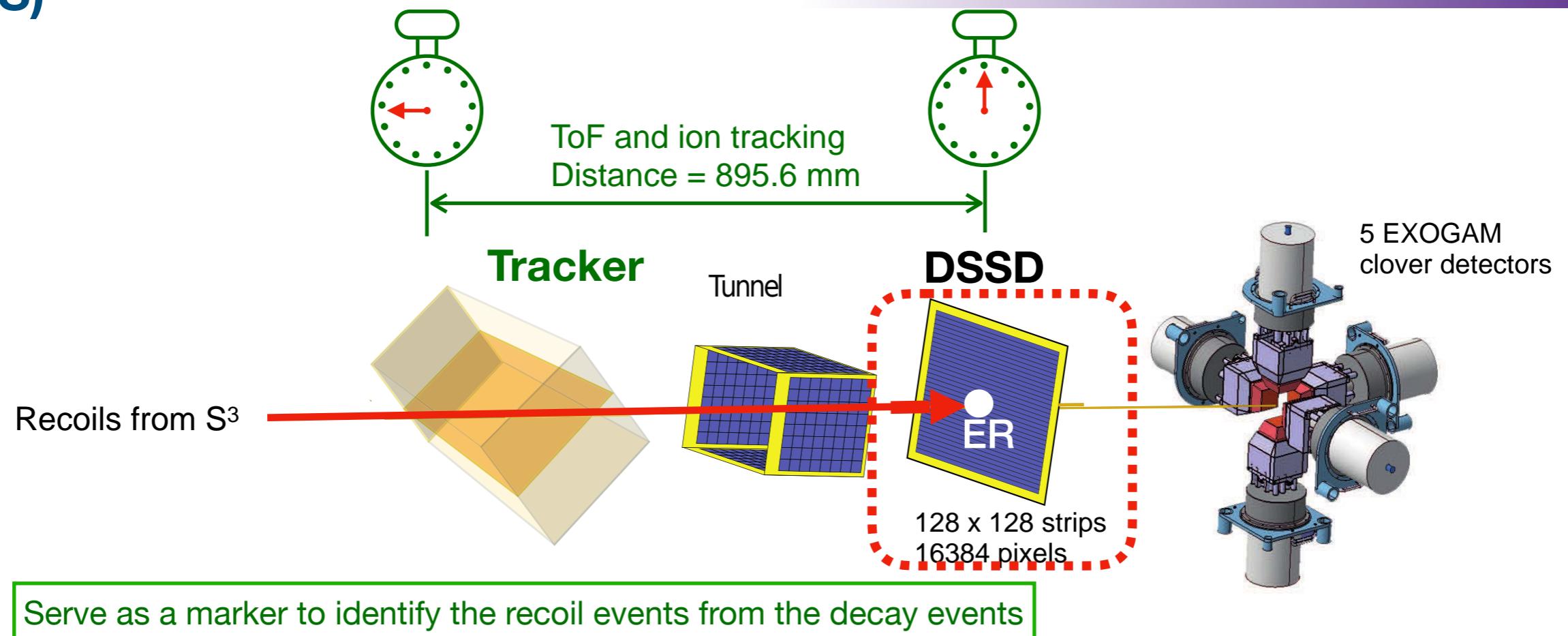
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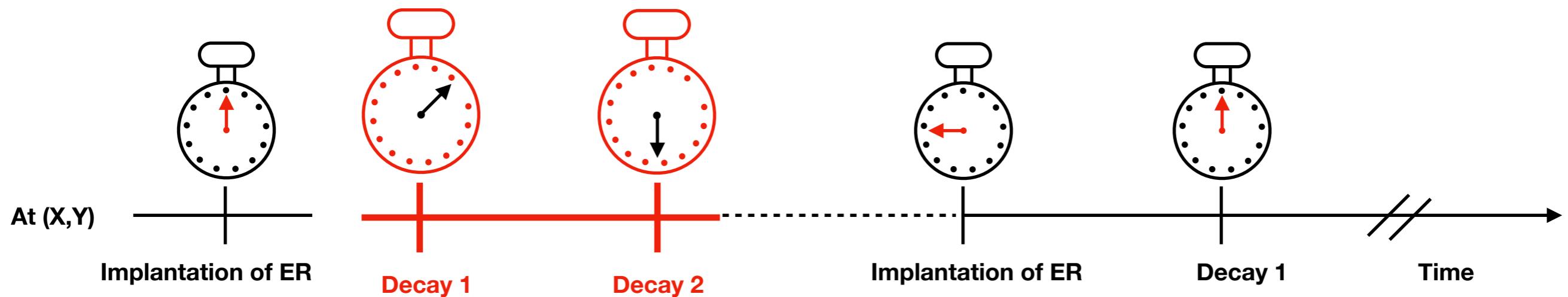
At the focal plane (Position-sensitive) detector:
recoil-decay correlations relations



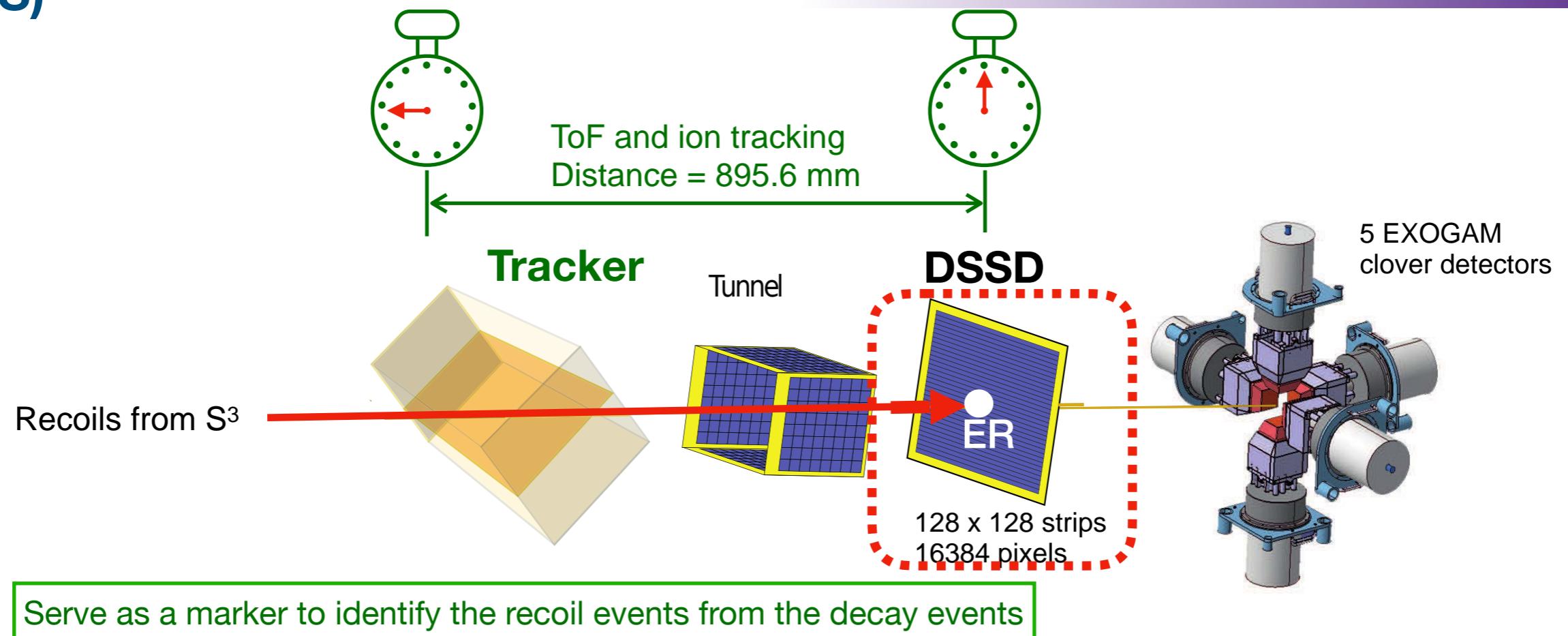
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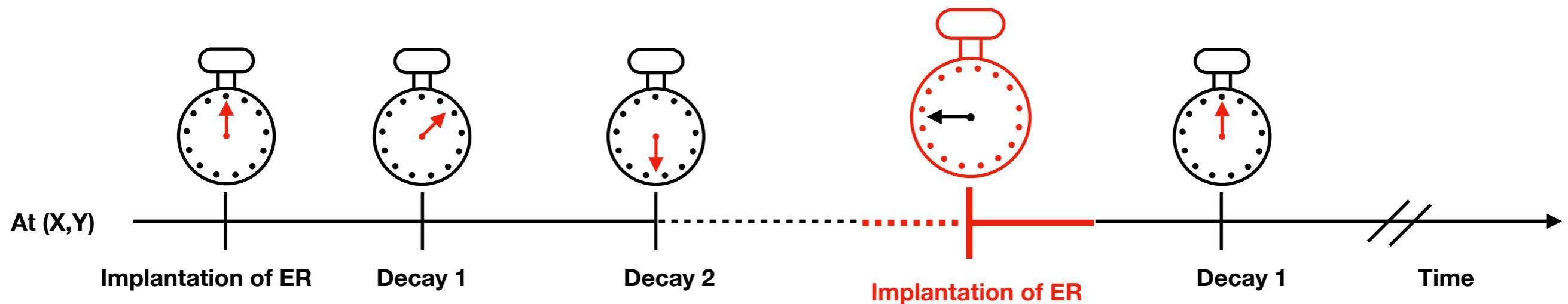
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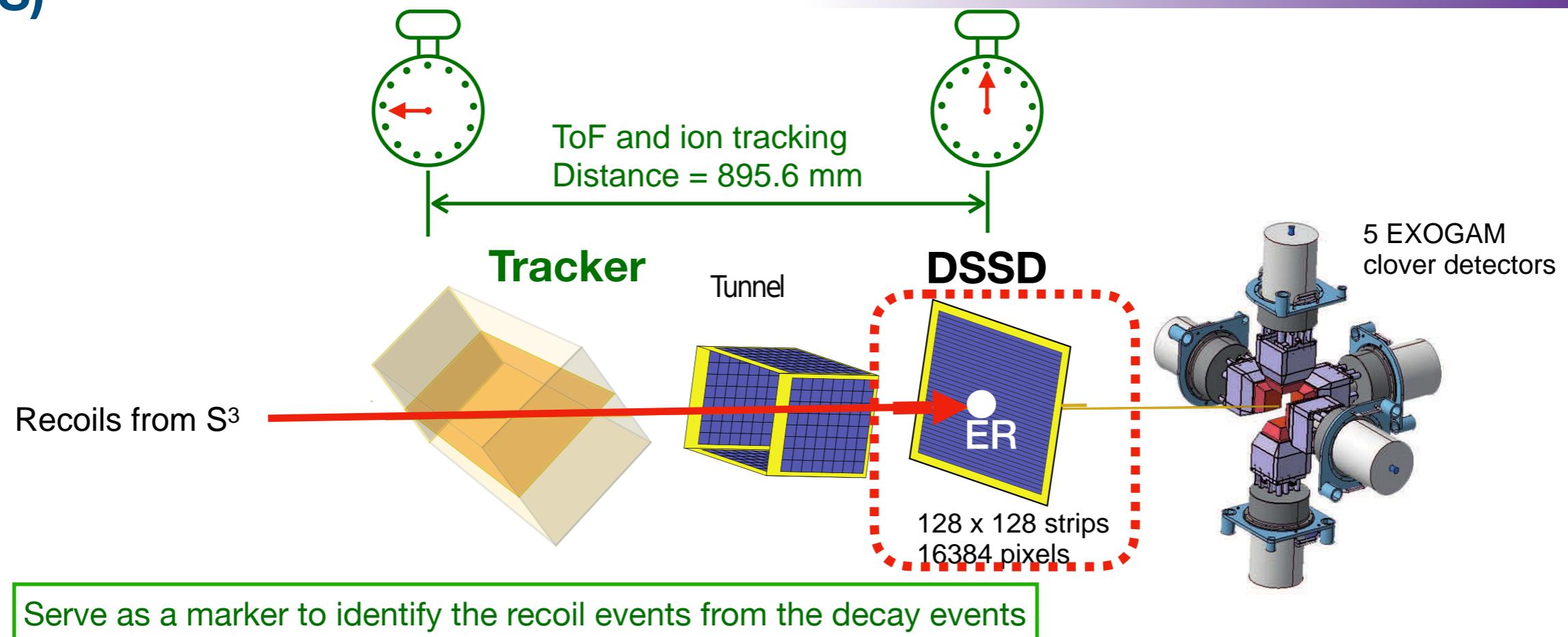
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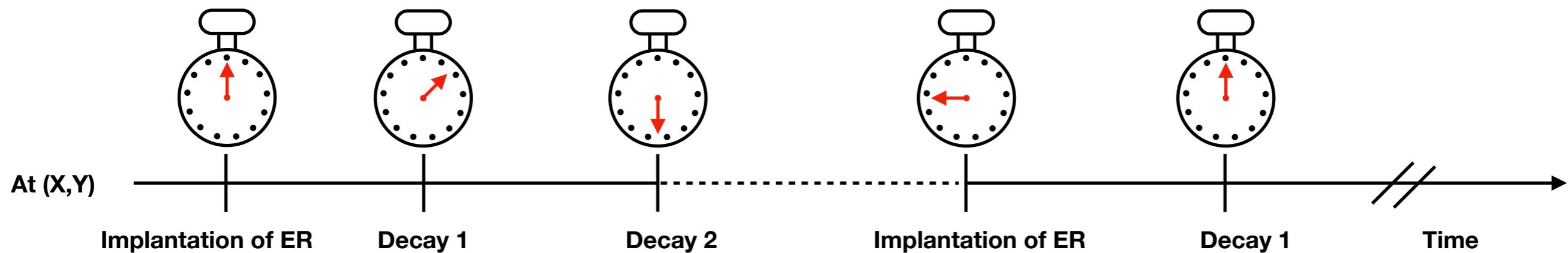
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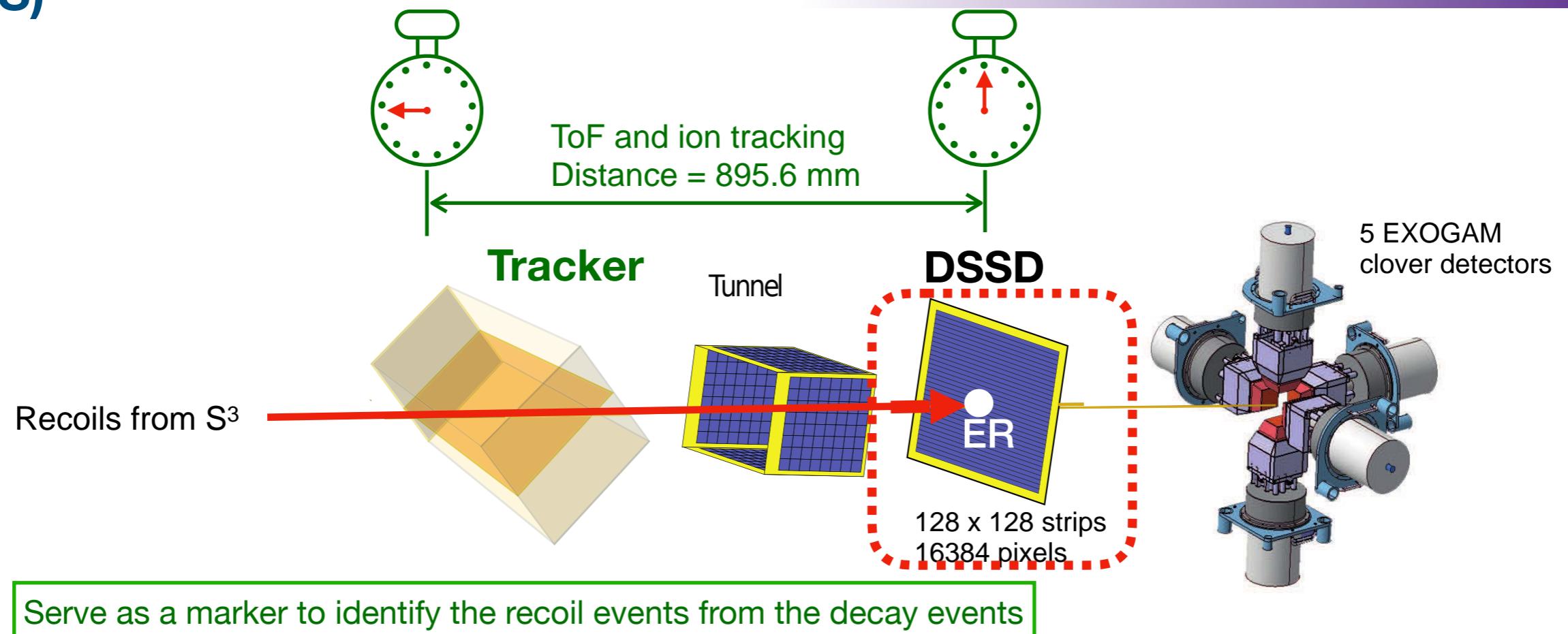
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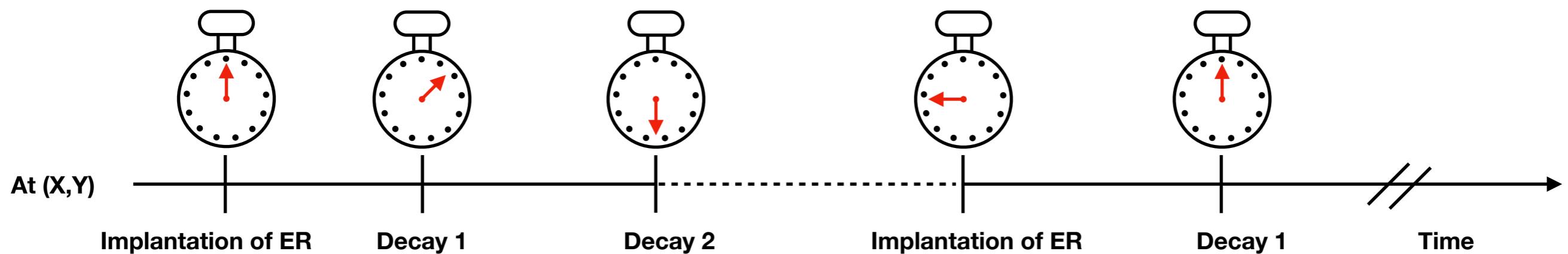
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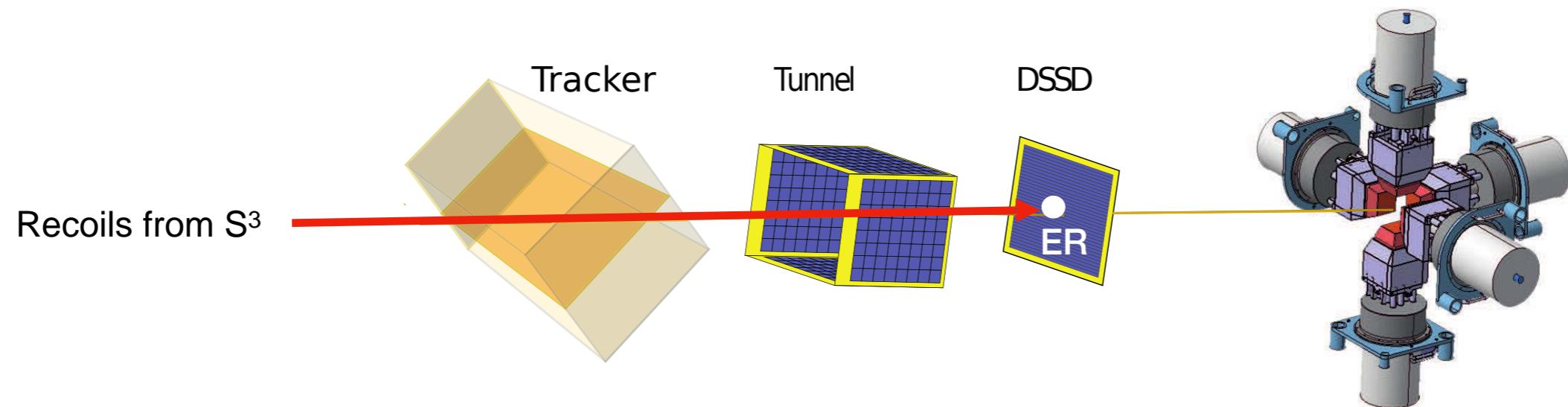
**At the focal plane (Position-sensitive) detector:
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Determination of :

- ▶ Lifetimes
- ▶ Energies
- ▶ Decay modes

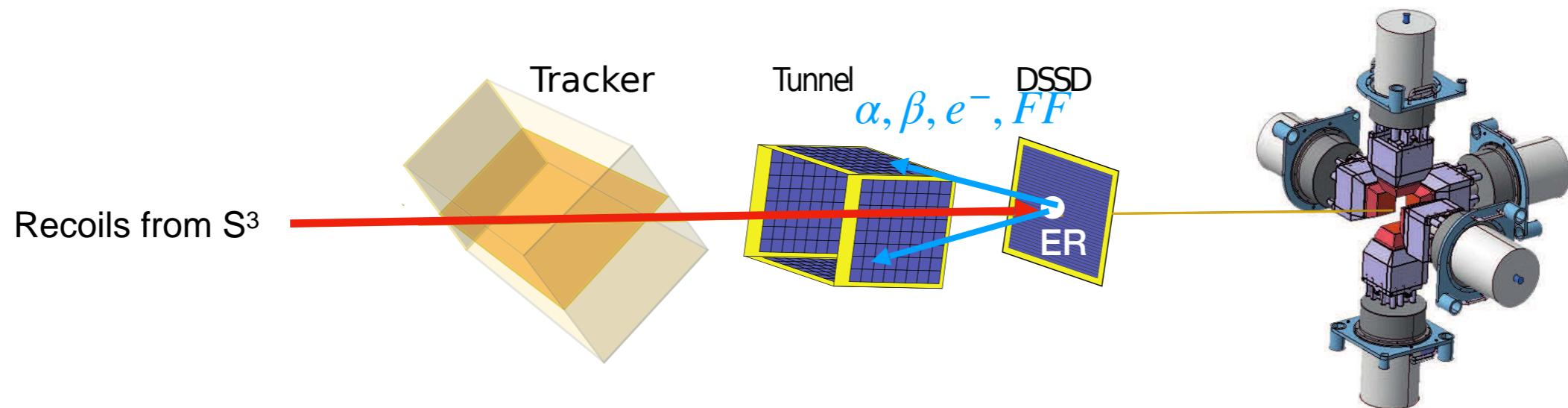


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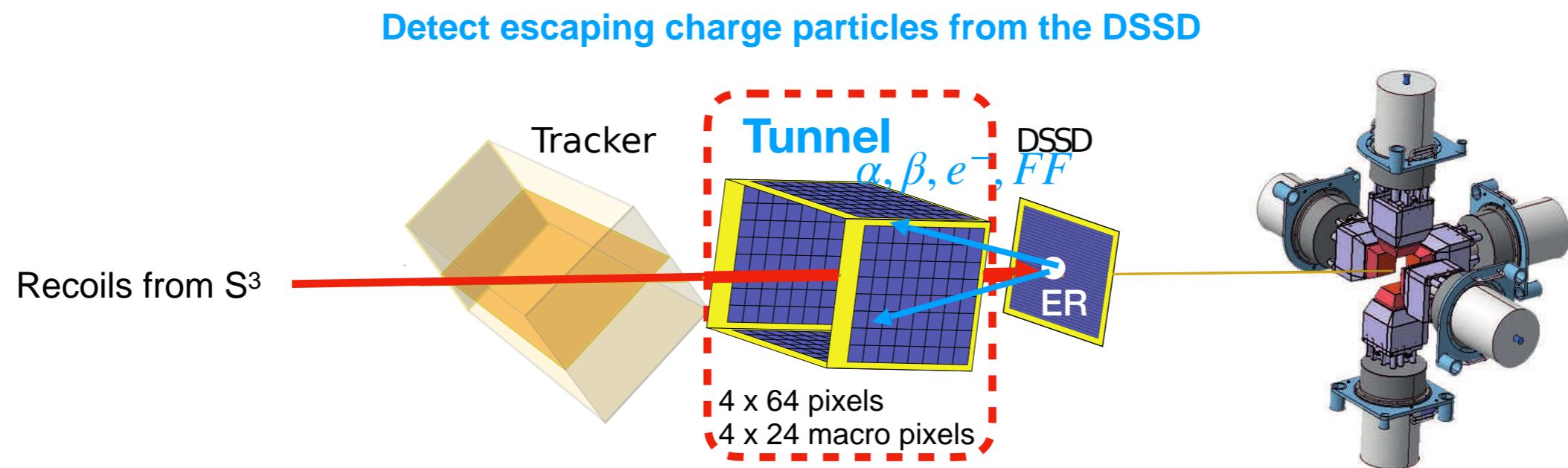


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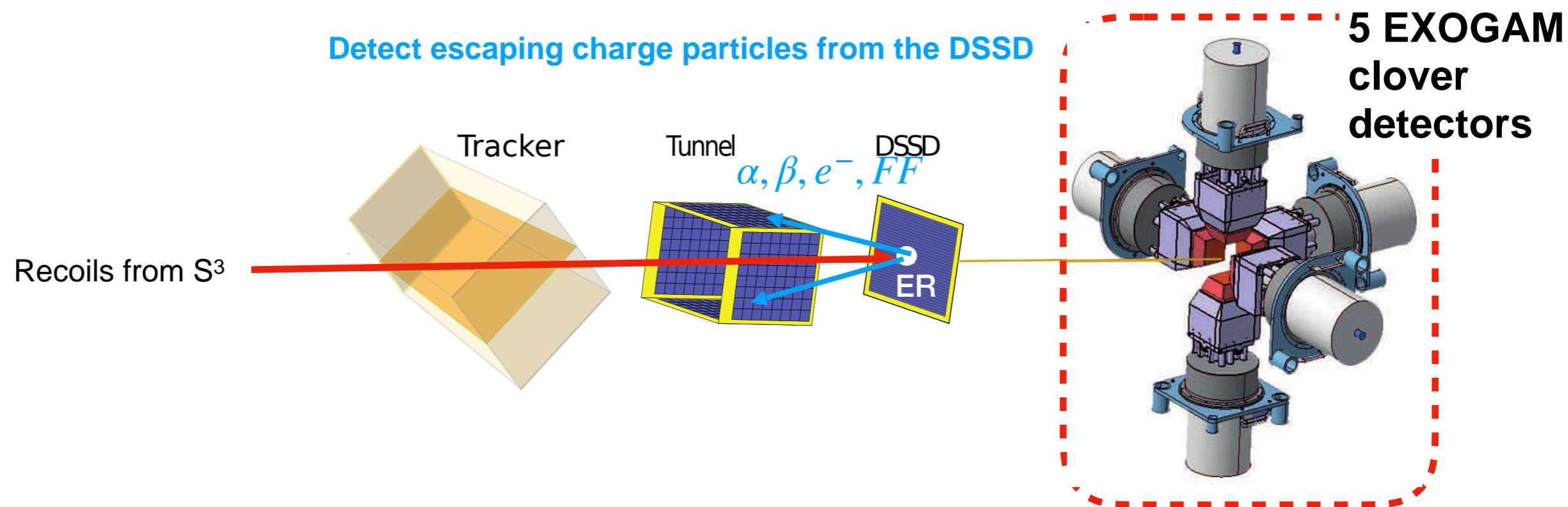
Detect escaping charge particles from the DSSD



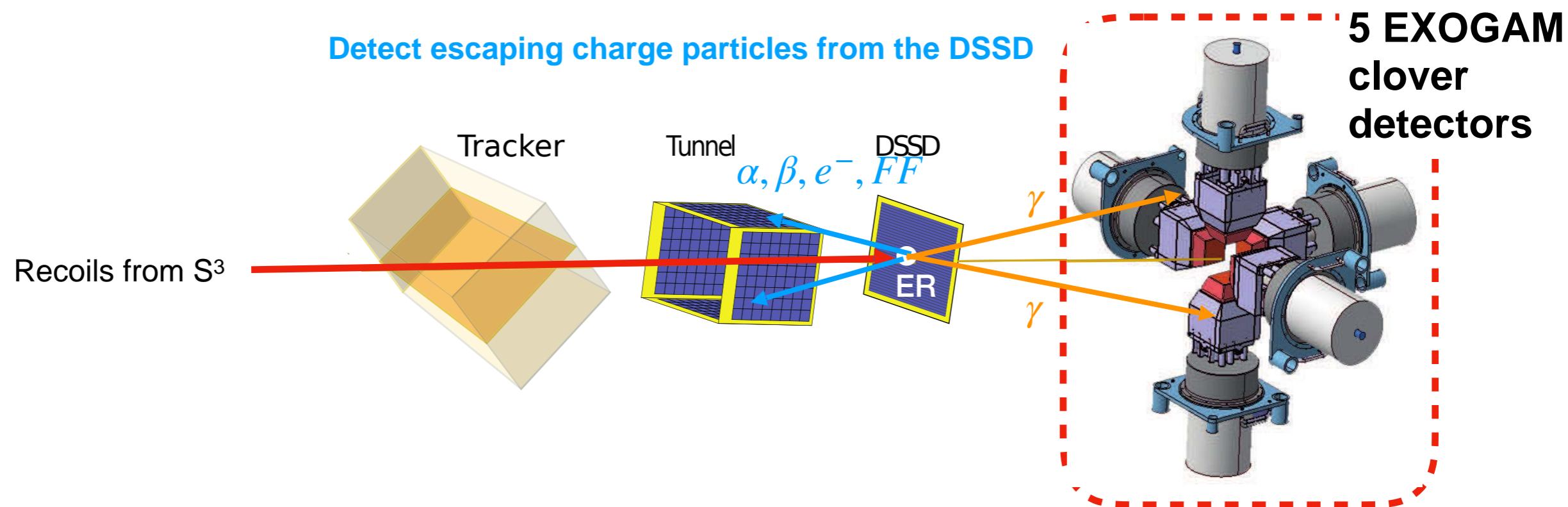
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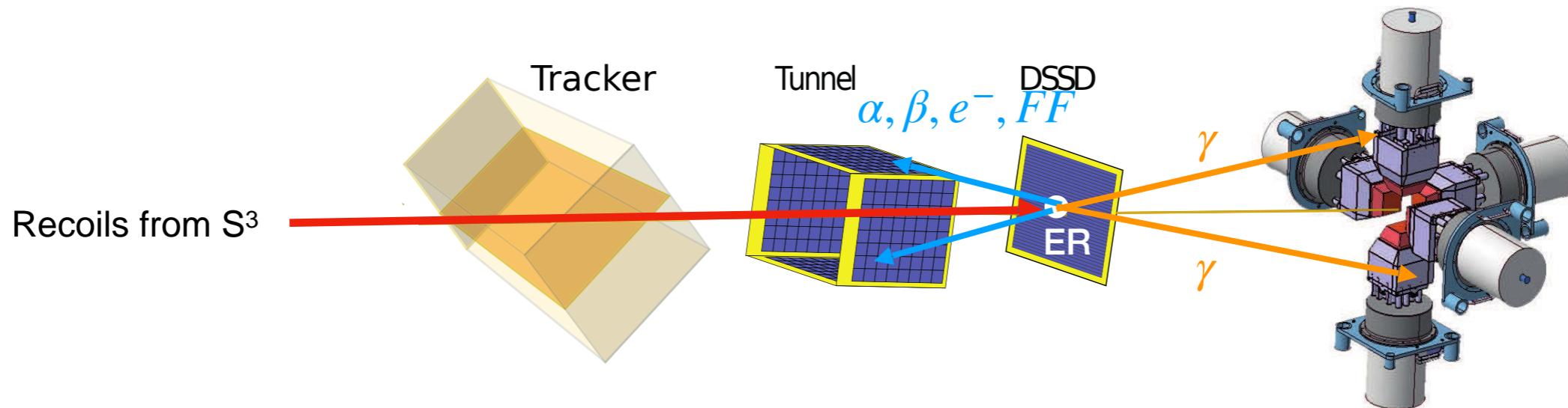


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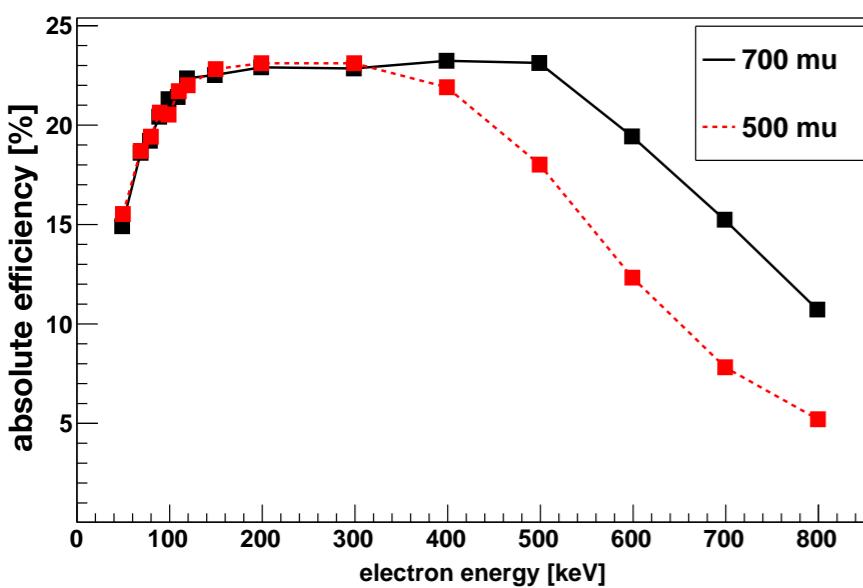


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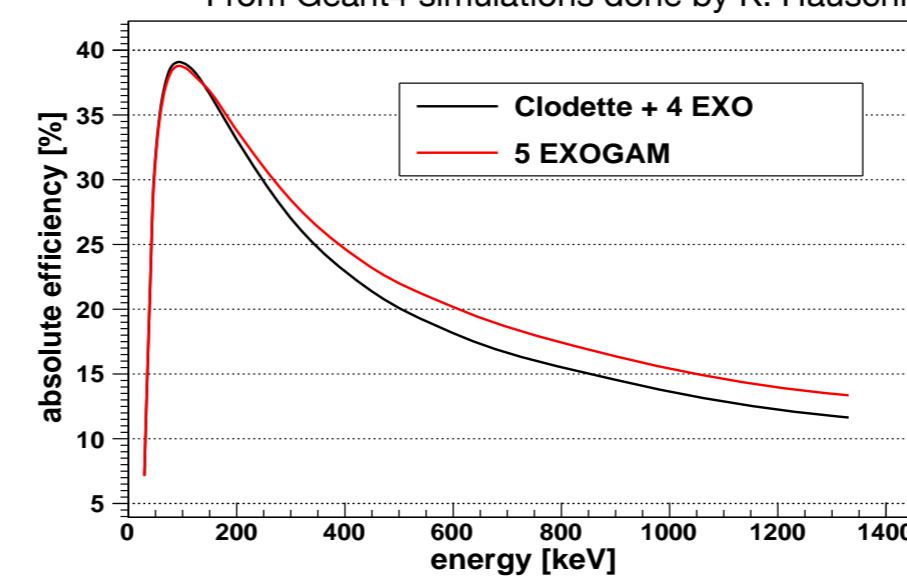
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From Geant4 simulations done by K. Hauschild

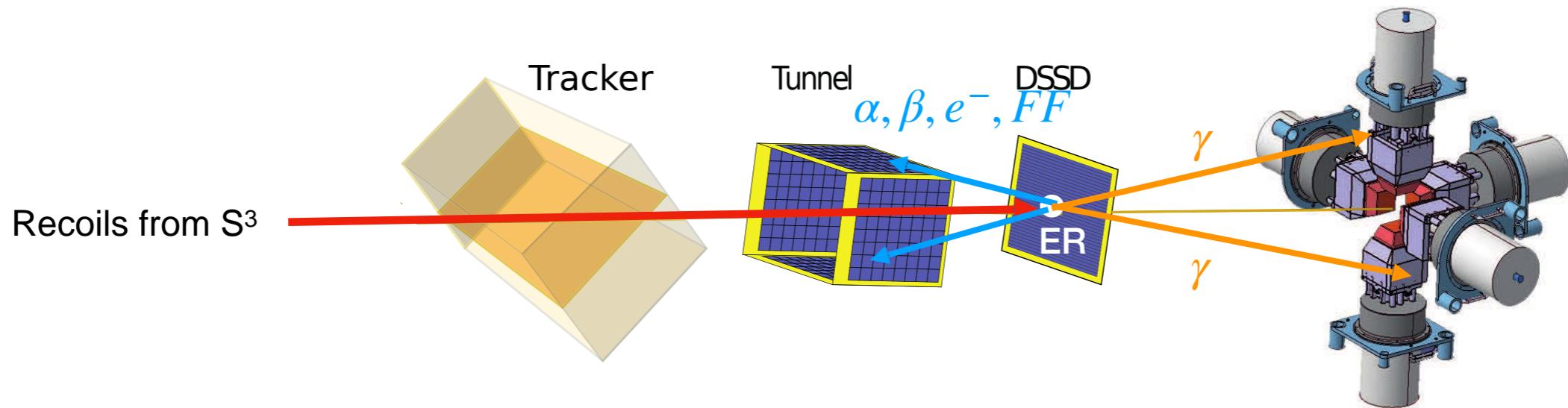


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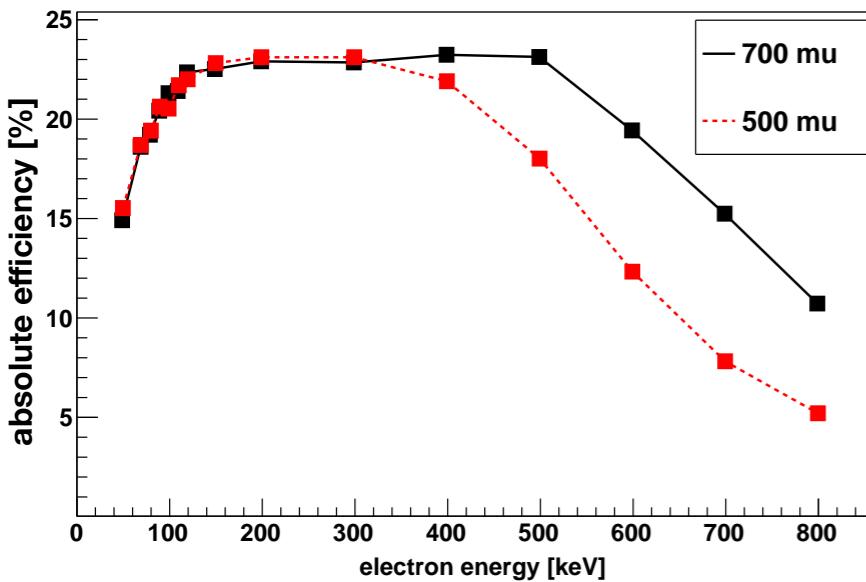


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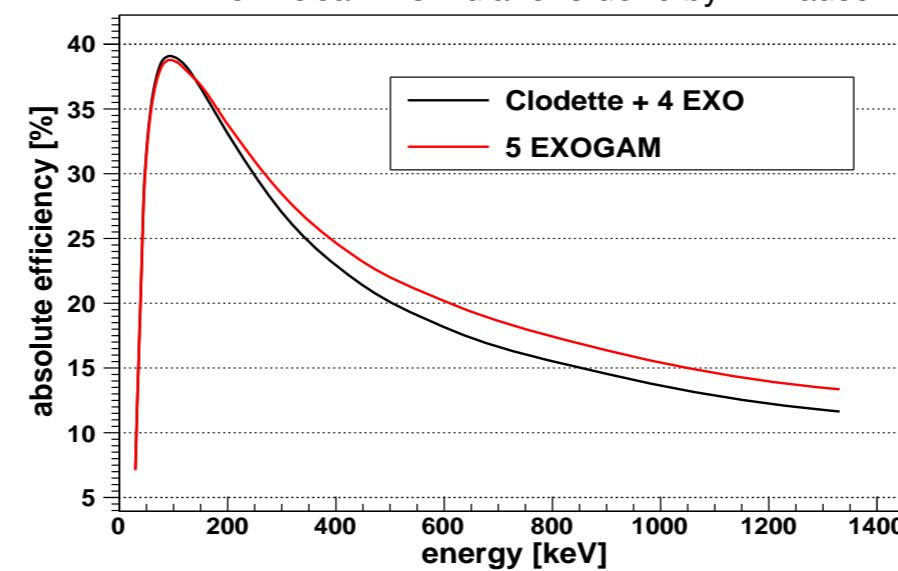
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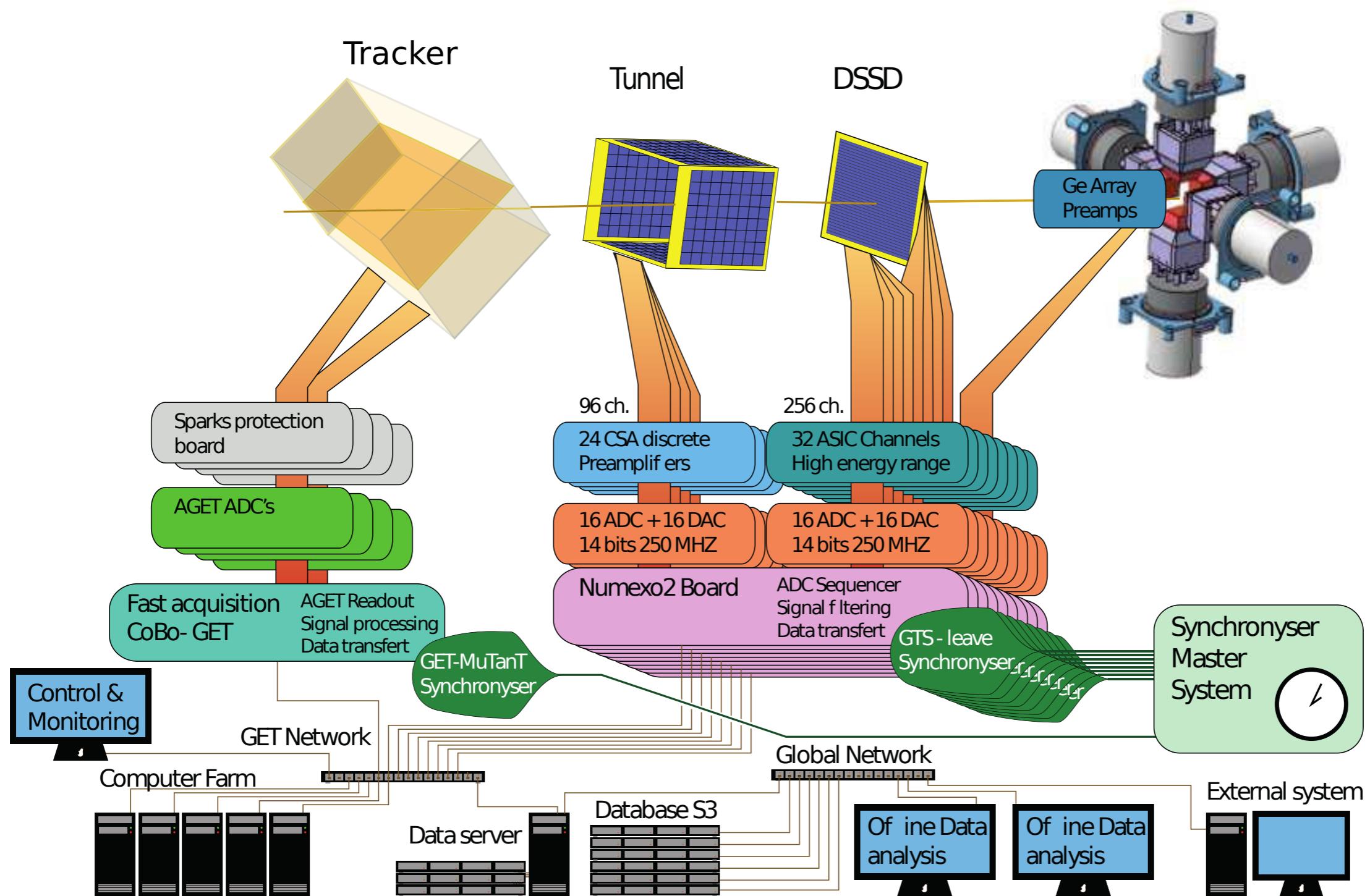
Perform:

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

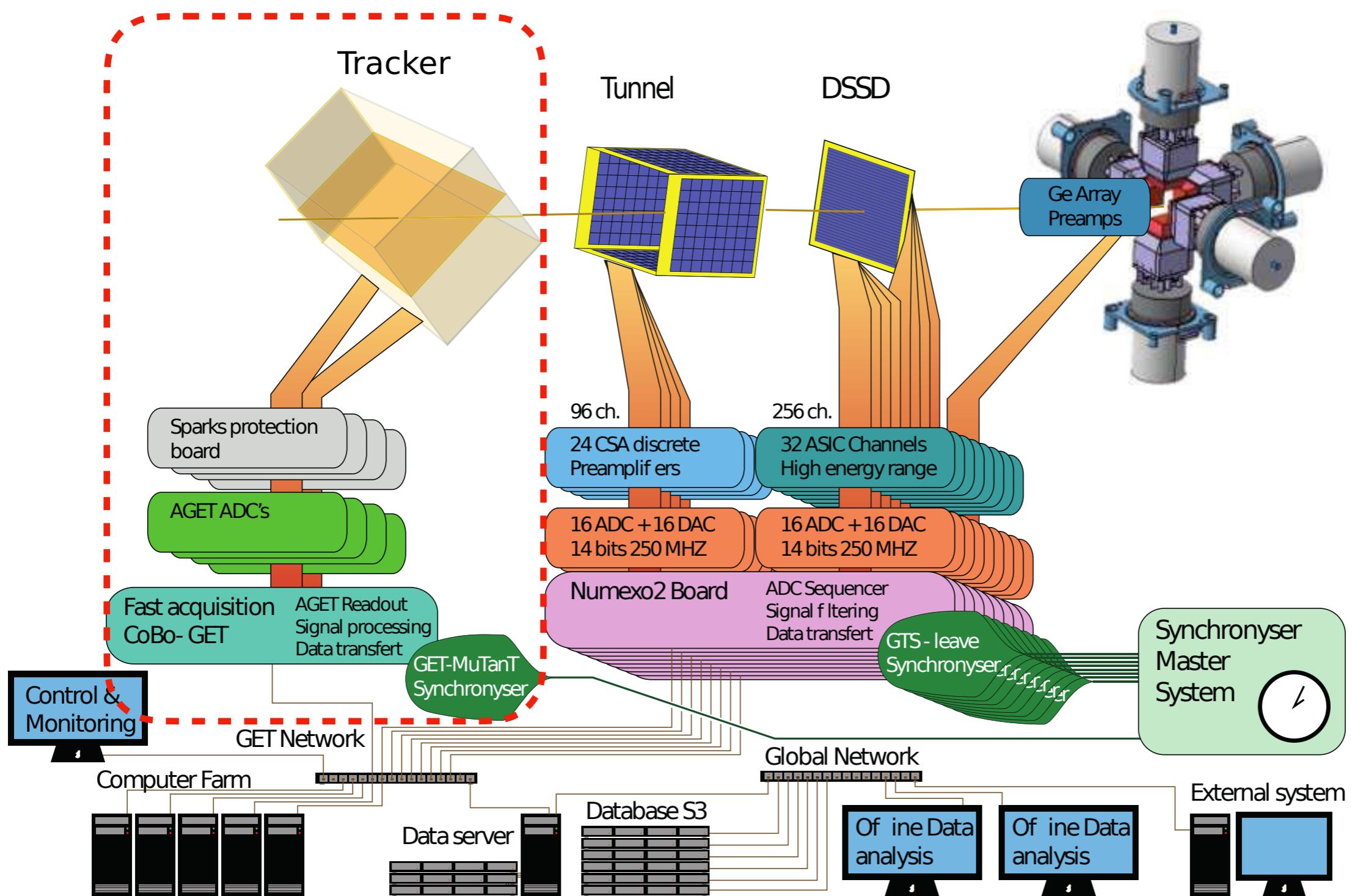
Determination of :

- Lifetimes
- Excitation energies
- Multipolarity of the transitions

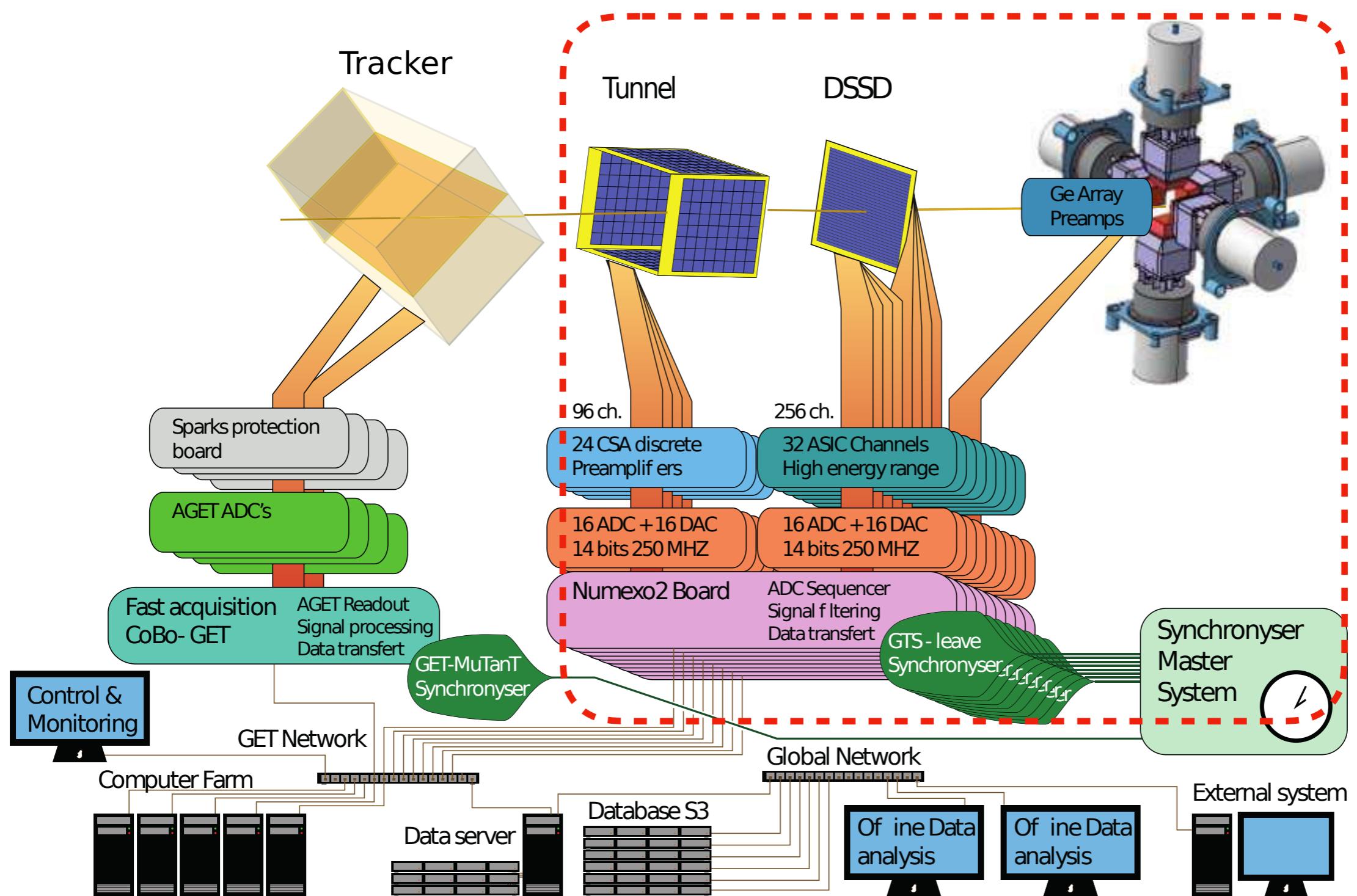
Schematic of the SIRIUS Acquisition system



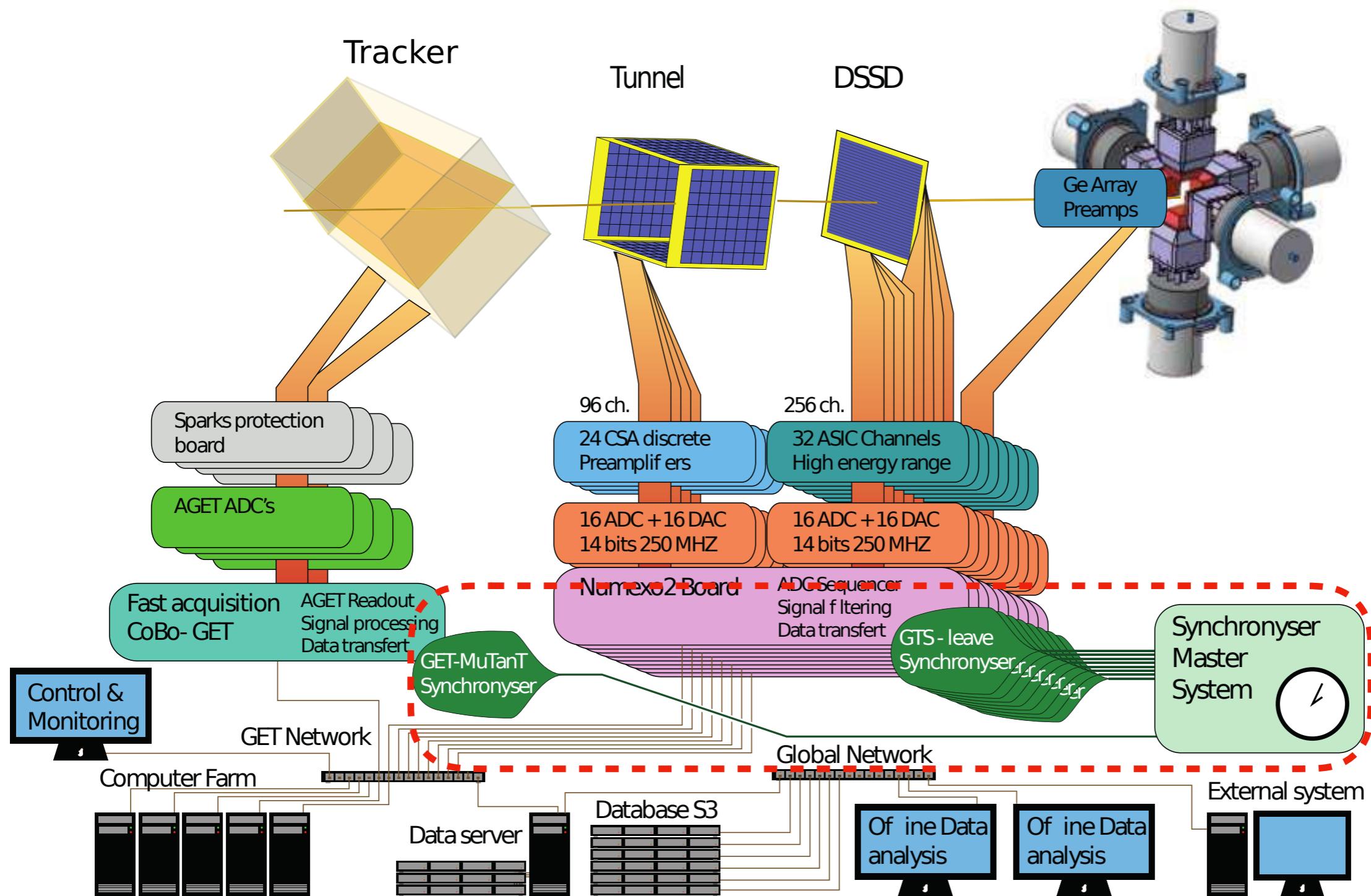
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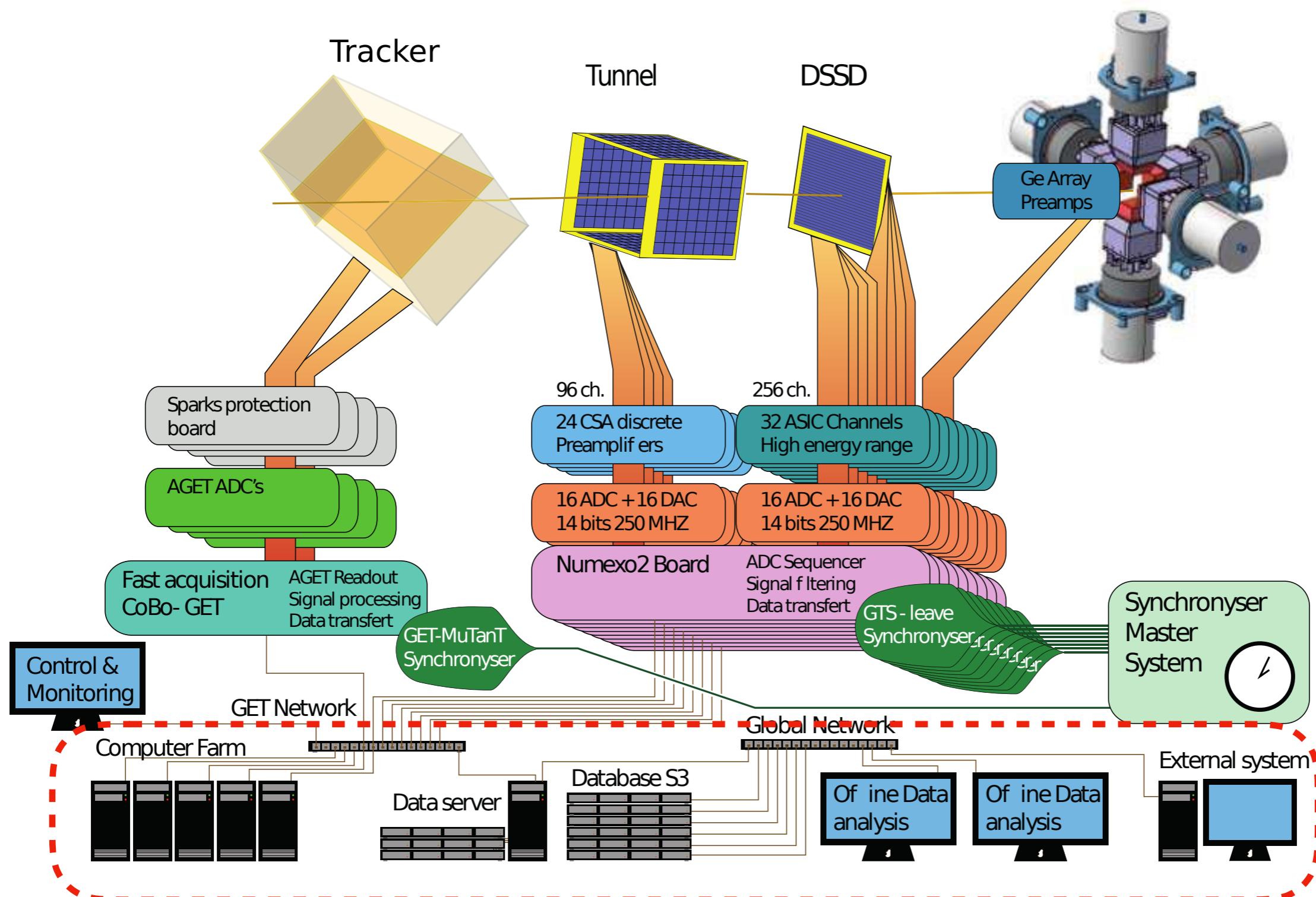
Schematic of the SIRIUS Acquisition system



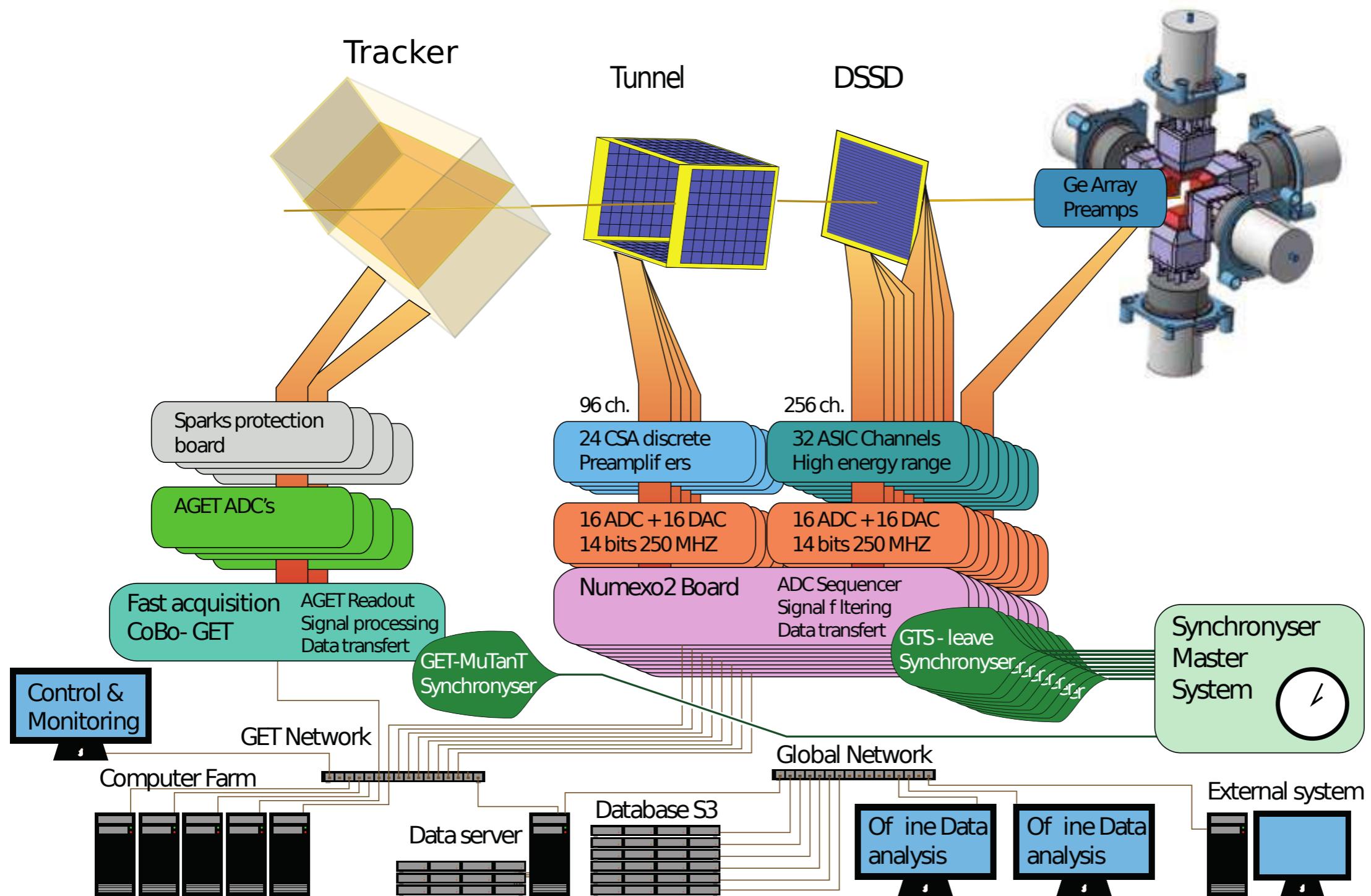
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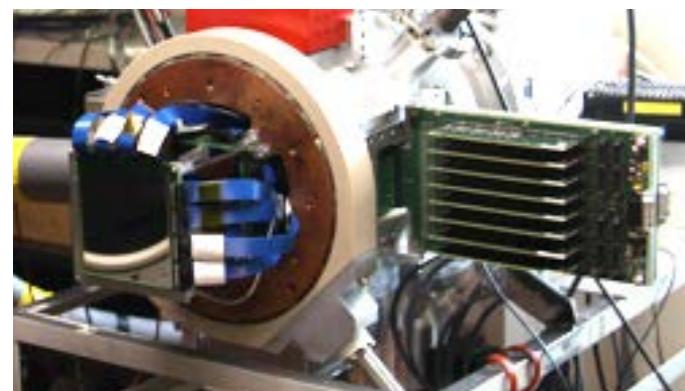
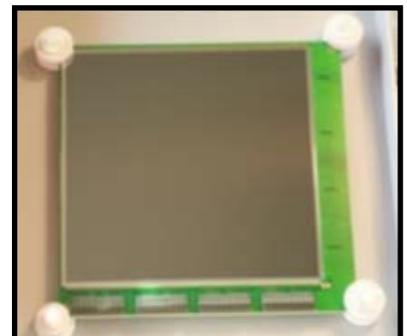
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Schematic of the SIRIUS Acquisition system



DSSD in vacuum



Detector Characteristics

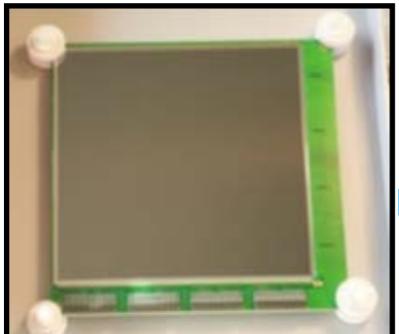
Active area: $\approx 10 \times 10 \text{ cm}^2$

Thickness: $\approx 300 \mu\text{m}$

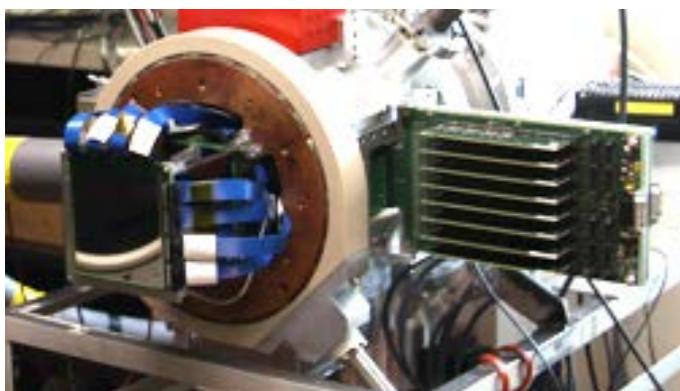
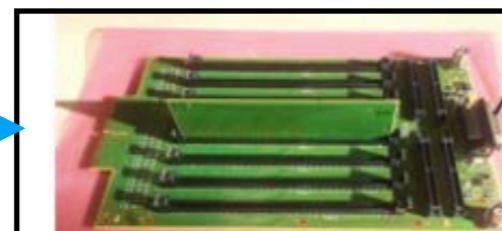
Dead layer: $\sim 50 \text{ nm}$

128 x 128 Strips

DSSD in vacuum



Floating Points Charge
Sensitive Amplifiers



Detector Characteristics

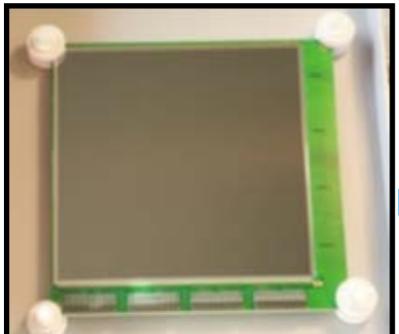
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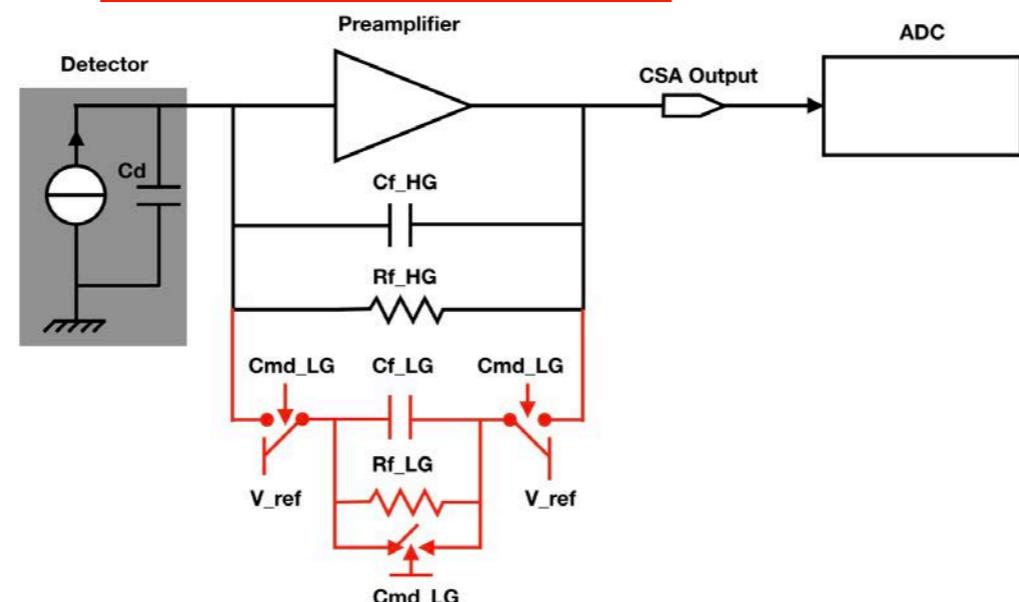
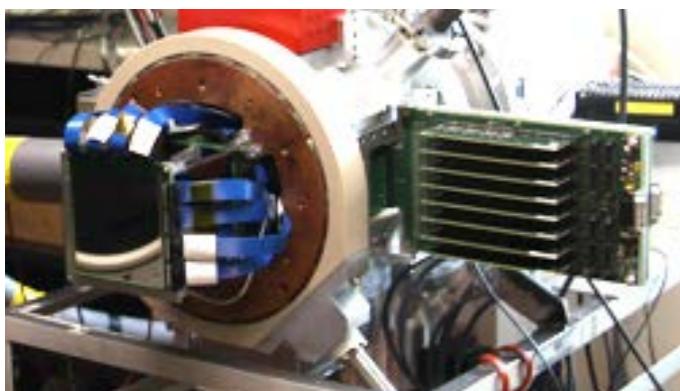
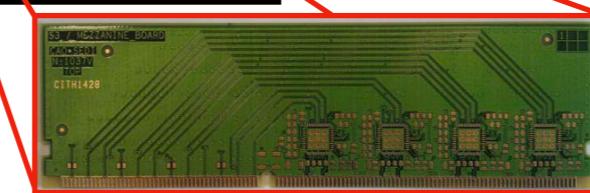
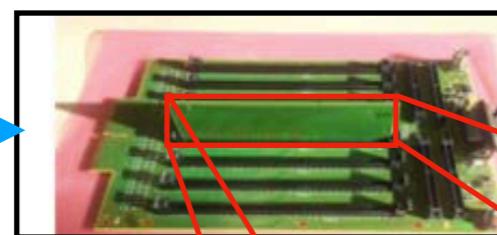
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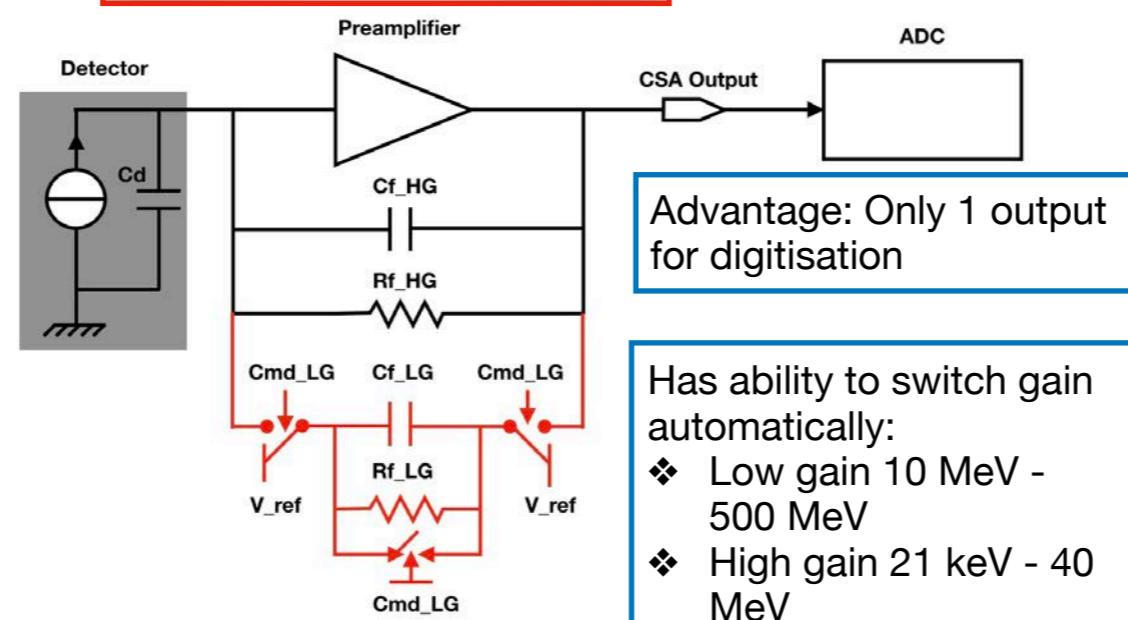
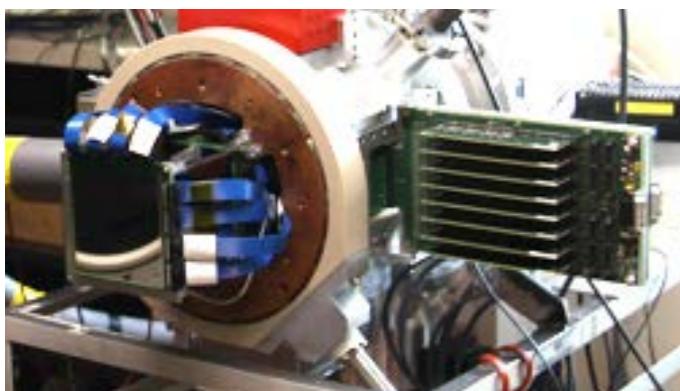
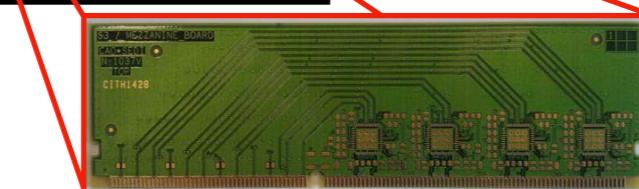
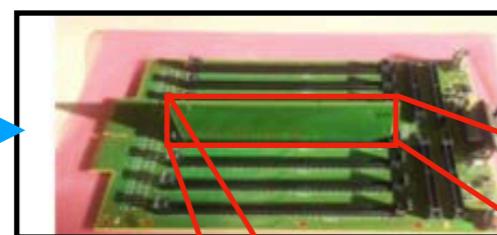
Dead layer: $\sim 50 \text{ nm}$

128 x 128 Strips

DSSD in vacuum



Floating Points Charge
Sensitive Amplifiers



Detector Characteristics

Active area: $\approx 10 \times 10 \text{ cm}^2$

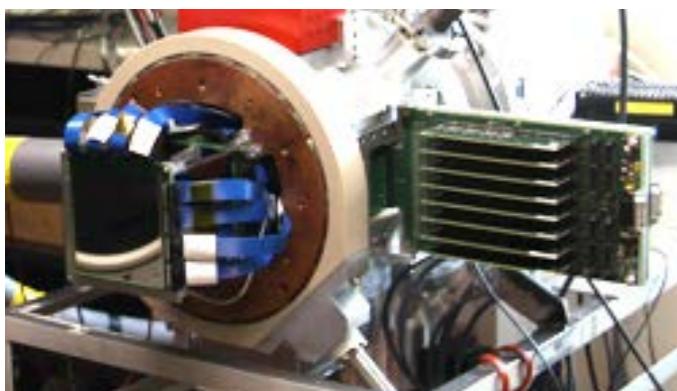
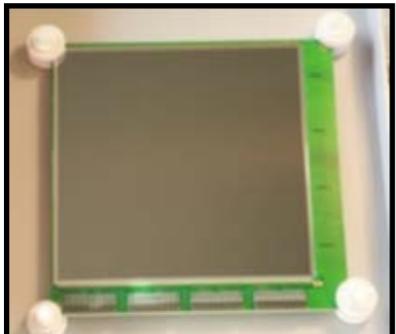
Thickness: $\approx 300 \mu\text{m}$

Dead layer: $\sim 50 \text{ nm}$

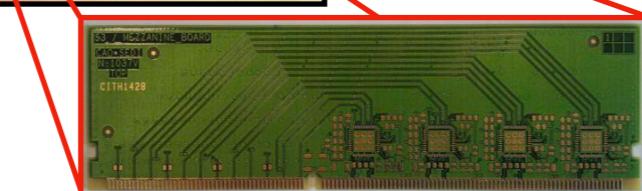
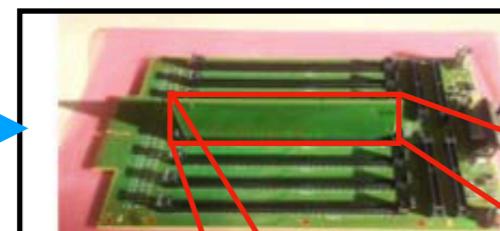
128 x 128 Strips

Detect alpha, e-, fission fragments and beam

DSSD in vacuum



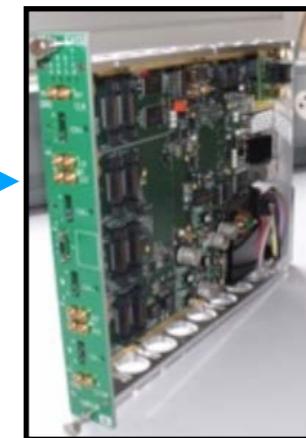
Floating Points Charge Sensitive Amplifiers



Adaptation board



Numexo2
200 MHz digitisation



HDMI cable

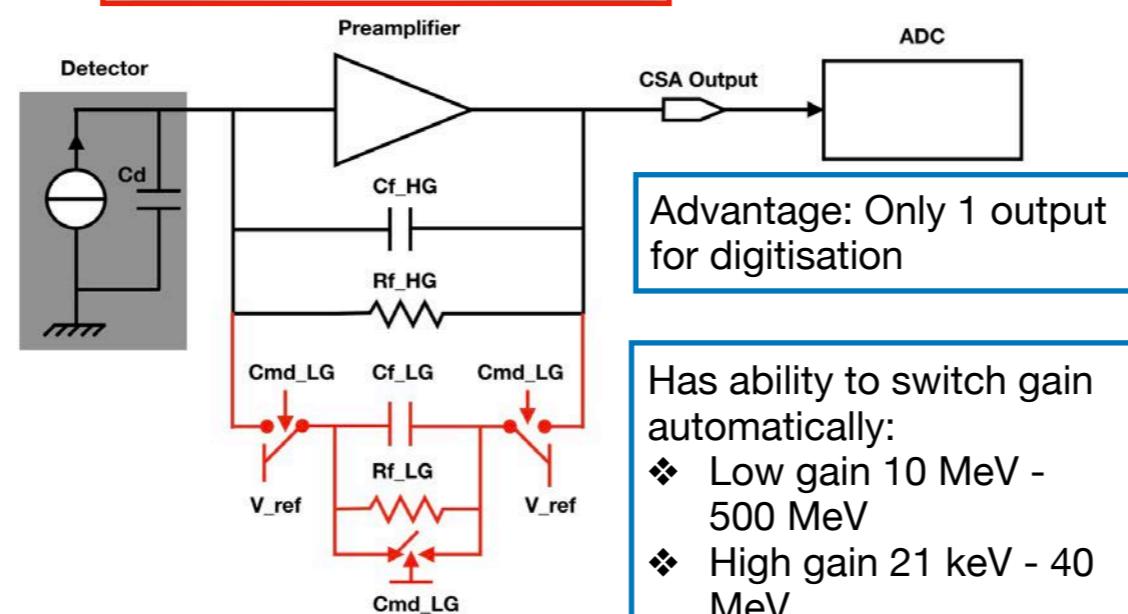
Detector Characteristics

Active area: $\approx 10 \times 10 \text{ cm}^2$

Thickness: $\approx 300 \mu\text{m}$

Dead layer: $\sim 50 \text{ nm}$

128 x 128 Strips

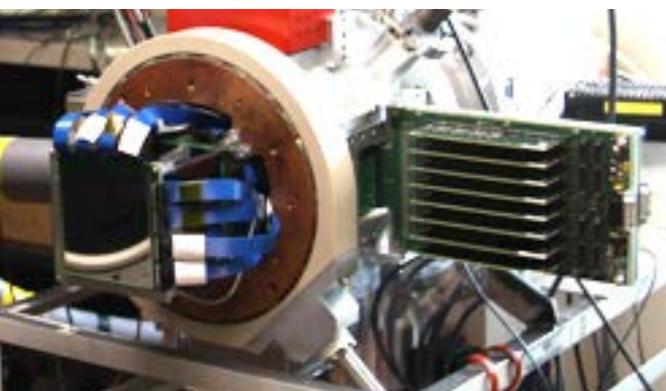


Advantage: Only 1 output for digitisation

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

Detect alpha, e-, fission fragments and beam

DSSD in vacuum



Detector Characteristics

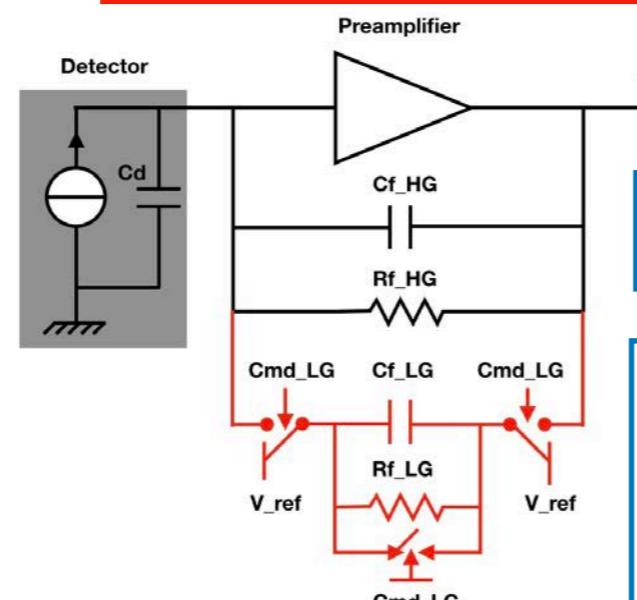
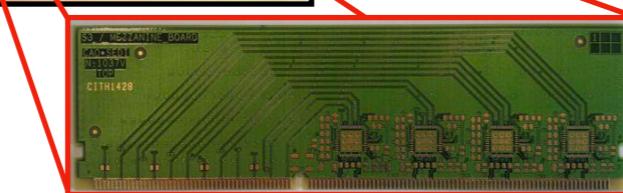
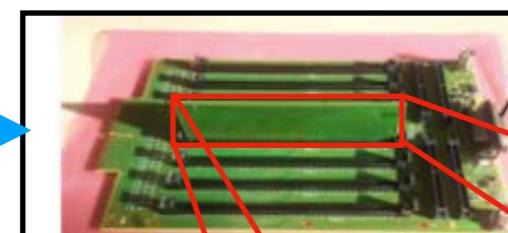
Active area: $\approx 10 \times 10 \text{ cm}^2$

Thickness: $\approx 300 \mu\text{m}$

Dead layer: $\sim 50 \text{ nm}$

128 x 128 Strips

Floating Points Charge Sensitive Amplifiers

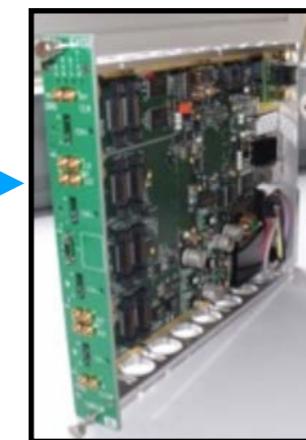


Detect alpha, e-, fission fragments and beam

Adaptation board



Numexo2
200 MHz digitisation

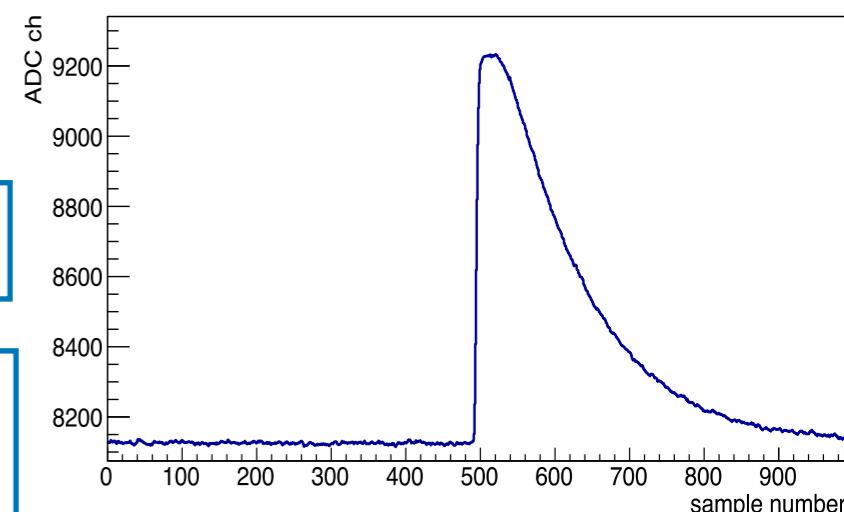


HDMI cable

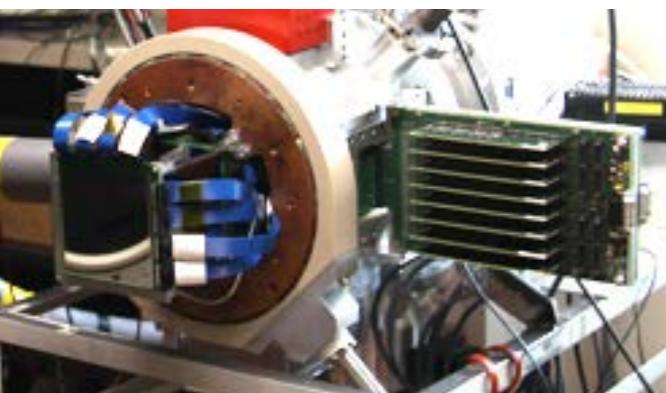
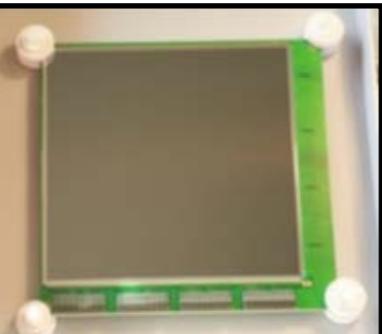
GRU
C++ code



Traces saved in a disk



DSSD in vacuum



Detector Characteristics

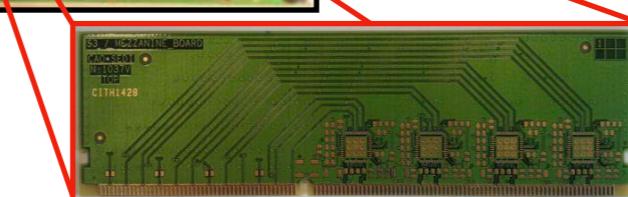
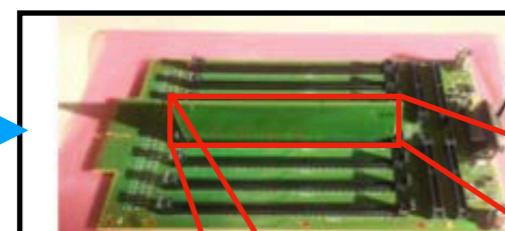
Active area: $\approx 10 \times 10 \text{ cm}^2$

Thickness: $\approx 300 \mu\text{m}$

Dead layer: $\sim 50 \text{ nm}$

128 x 128 Strips

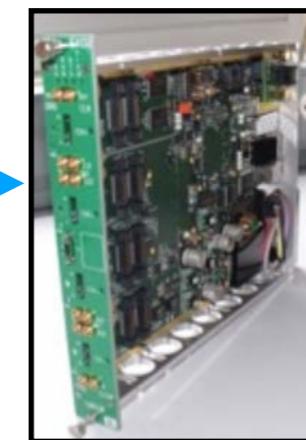
Floating Points Charge Sensitive Amplifiers



Adaptation board



Numexo2
200 MHz digitisation

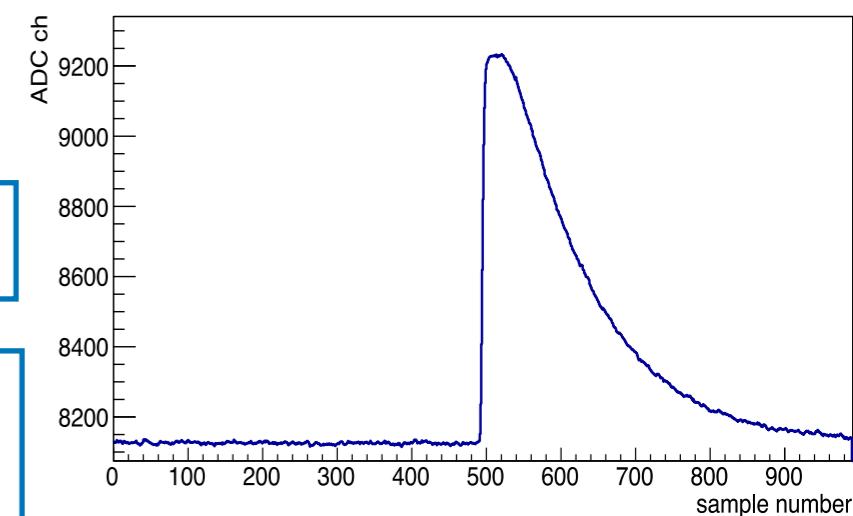
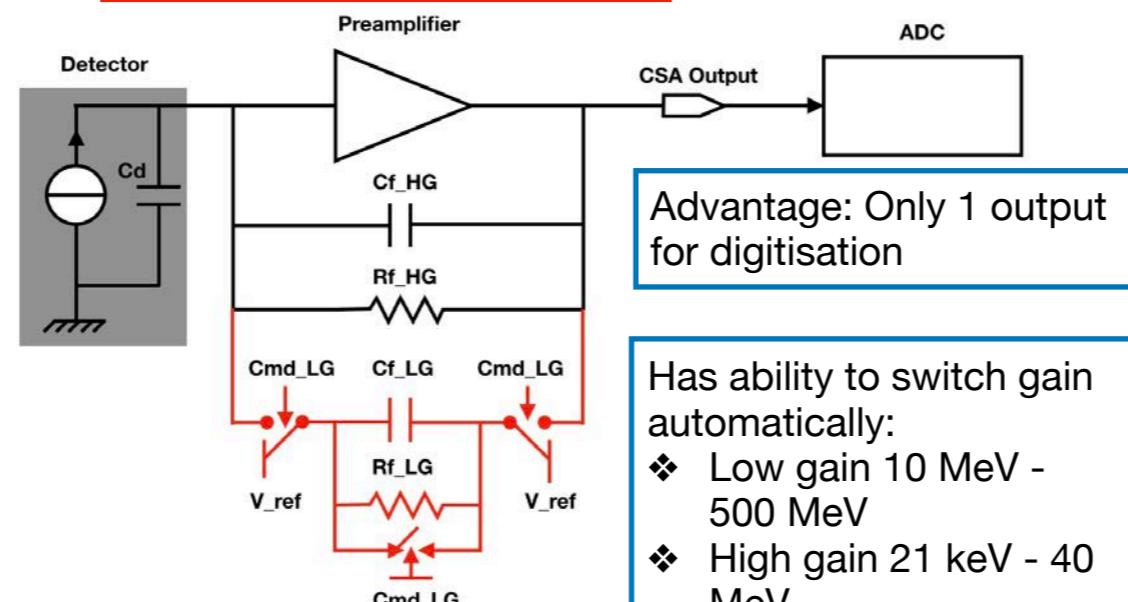


HDMI cable

GRU
C++ code



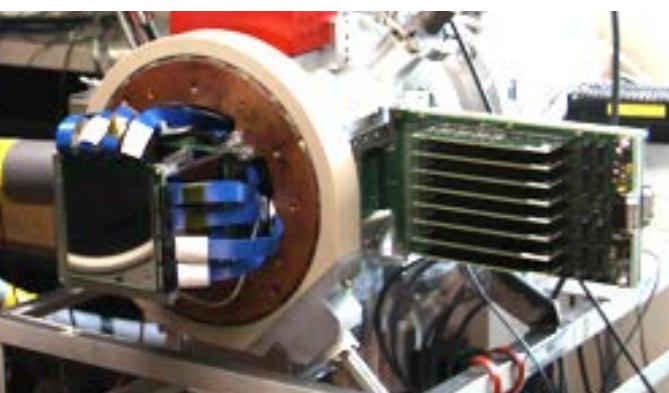
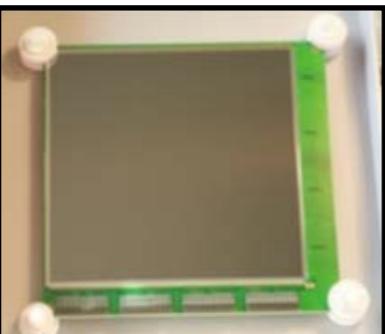
Traces saved in a disk



Detect alpha, e-, fission fragments and beam

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

DSSD in vacuum



Detector Characteristics

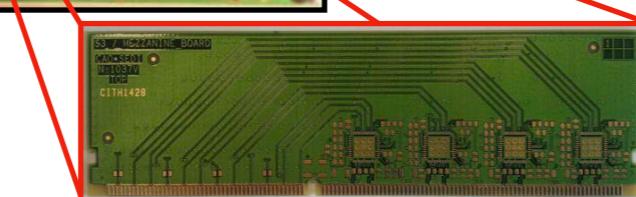
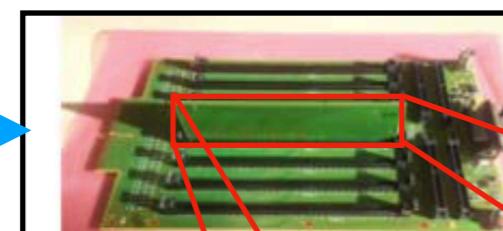
Active area: $\approx 10 \times 10 \text{ cm}^2$

Thickness: $\approx 300 \mu\text{m}$

Dead layer: $\sim 50 \text{ nm}$

128 x 128 Strips

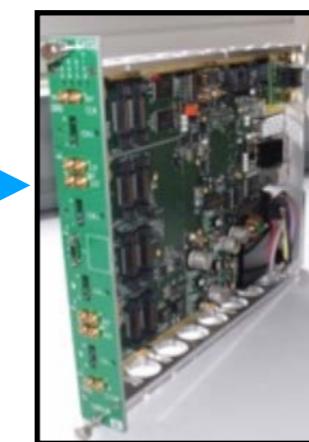
Floating Points Charge Sensitive Amplifiers



Adaptation board



Numexo2
200 MHz digitisation

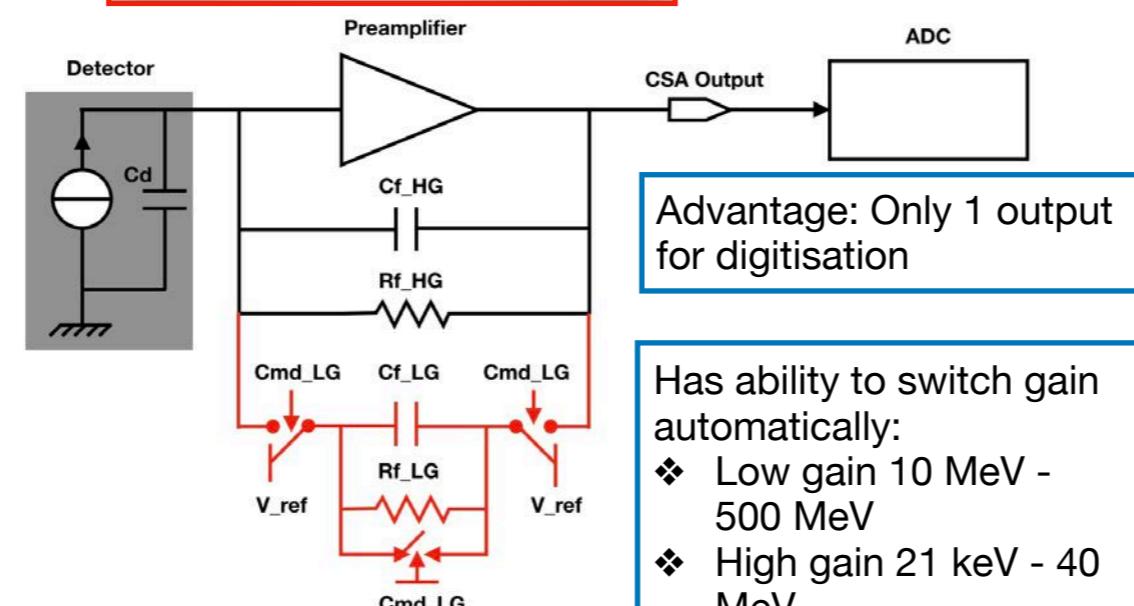


HDMI cable

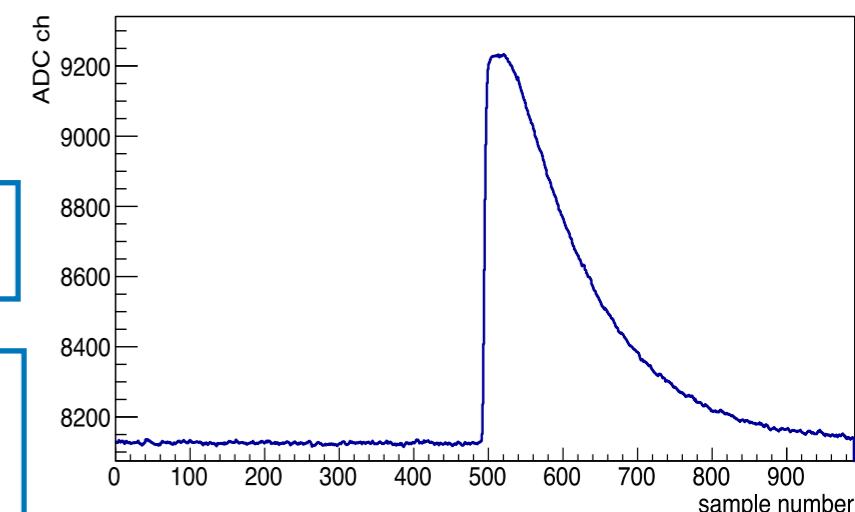
GRU
C++ code



Traces saved in a disk



Detect alpha, e-, fission fragments and beam

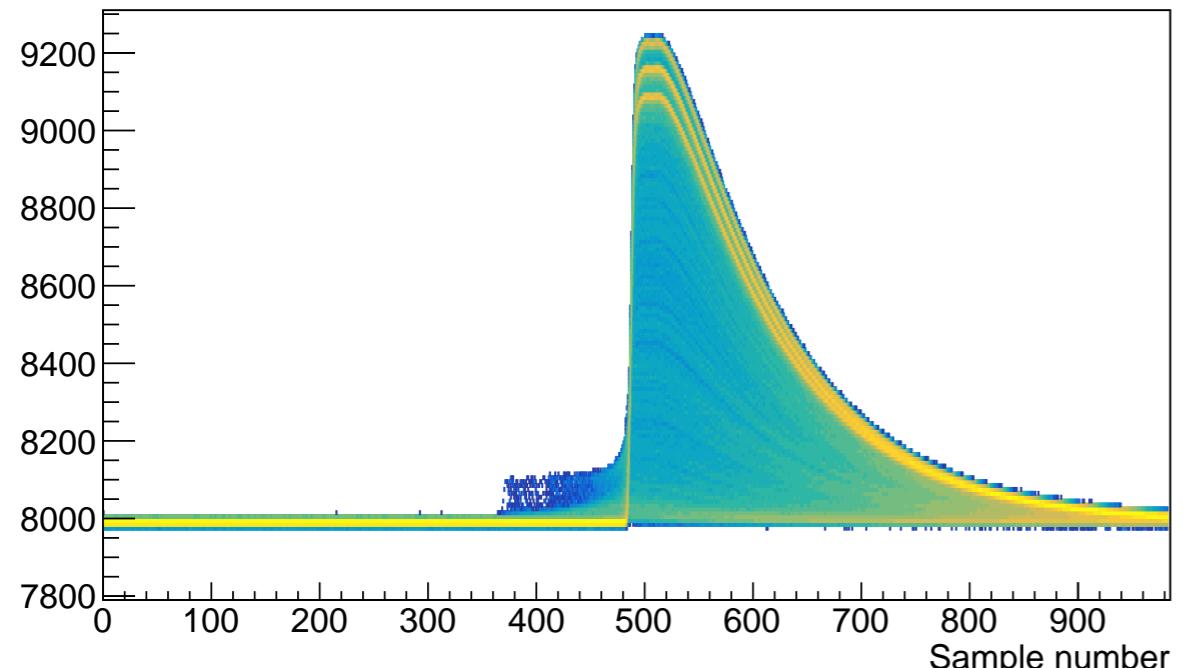


- remove pile-up
- detection of short-lived decays

Whole DSSD has been instrumented with all 16 Numexo2 boards

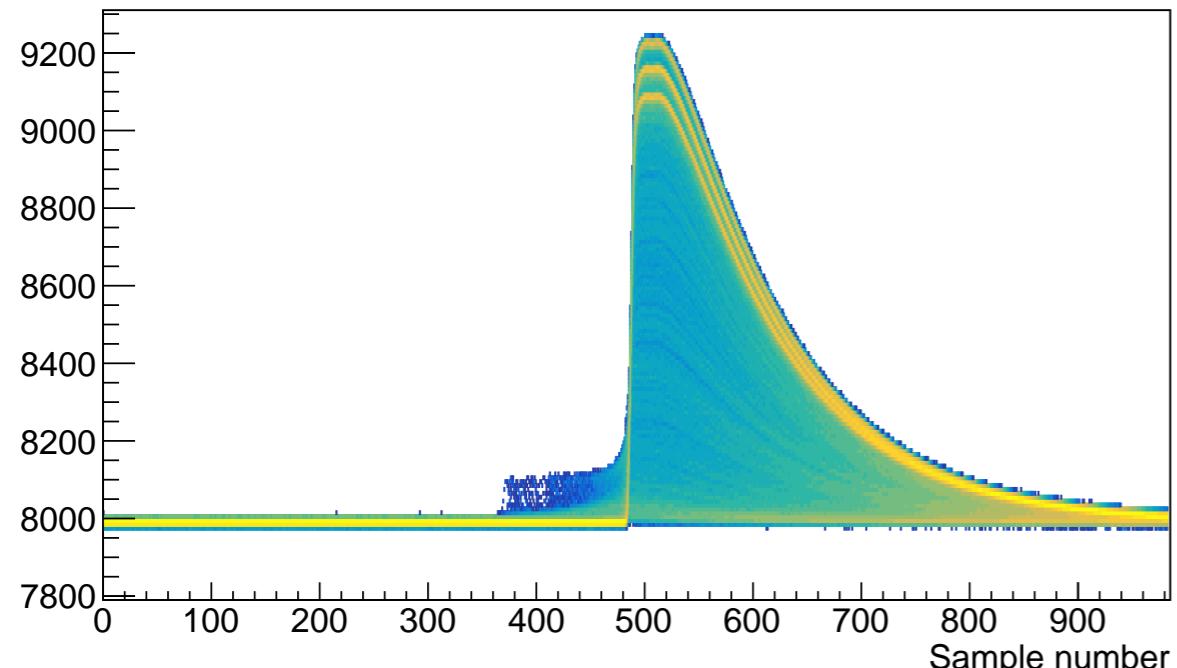
Performance of the DSSD in high gain mode with a 3-alpha source

Traces from 1 DSSD strip

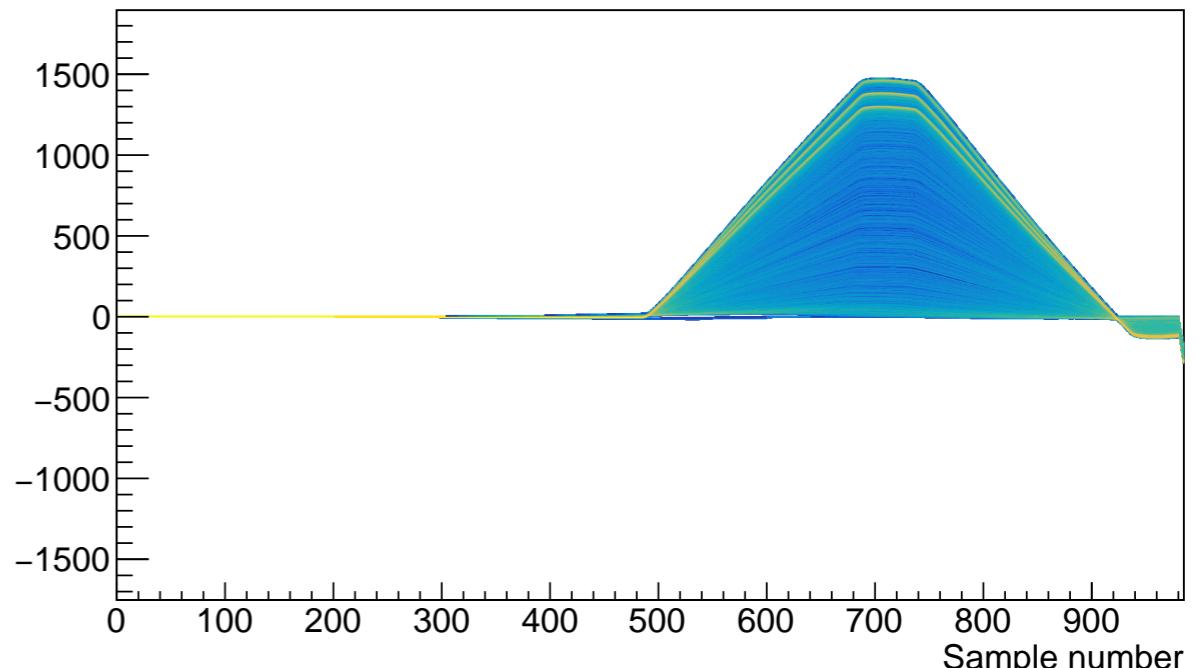


Performance of the DSSD in high gain mode with a 3-alpha source

Traces from 1 DSSD strip

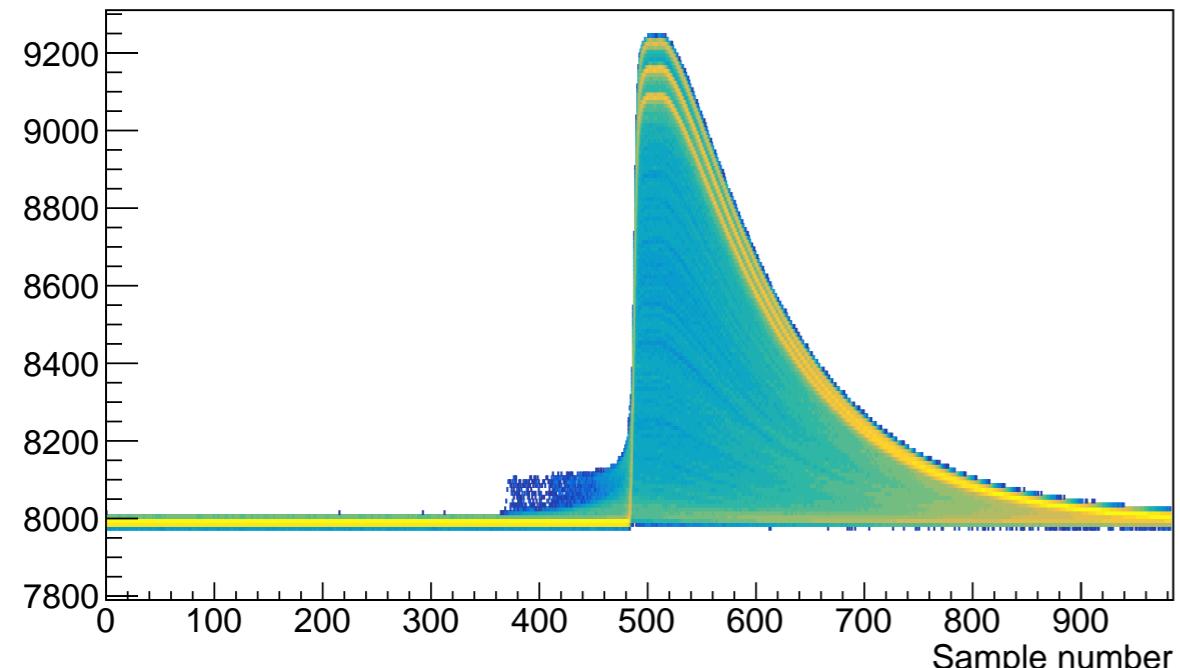


Trapezoidal filter

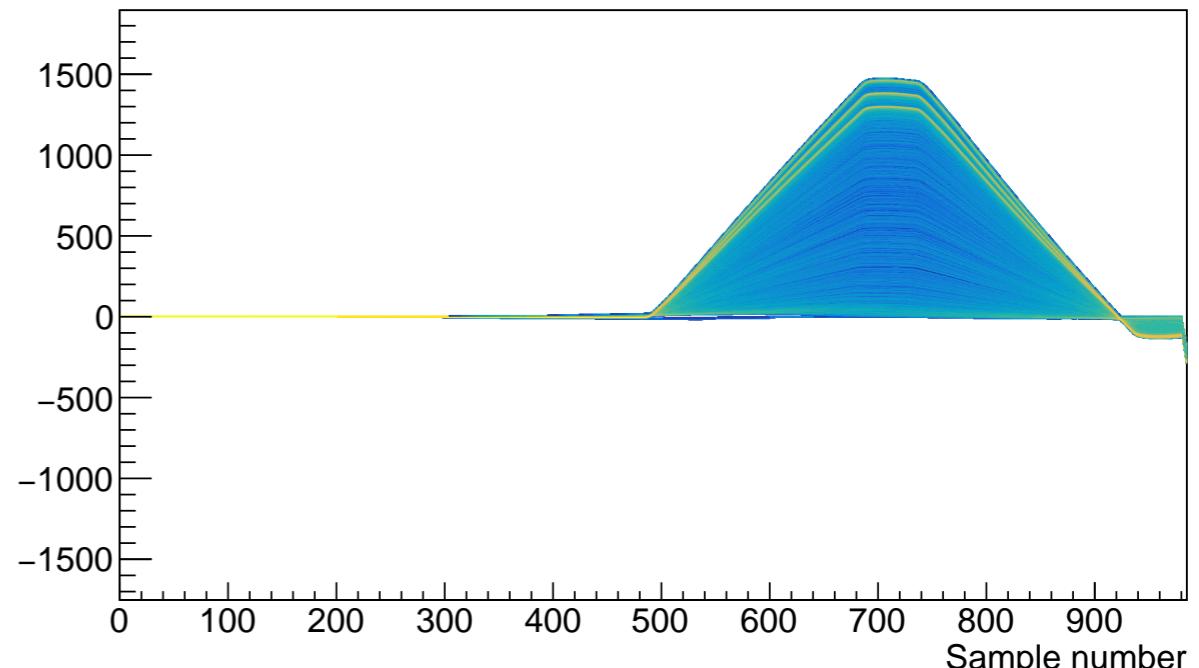


Performance of the DSSD in high gain mode with a 3-alpha source

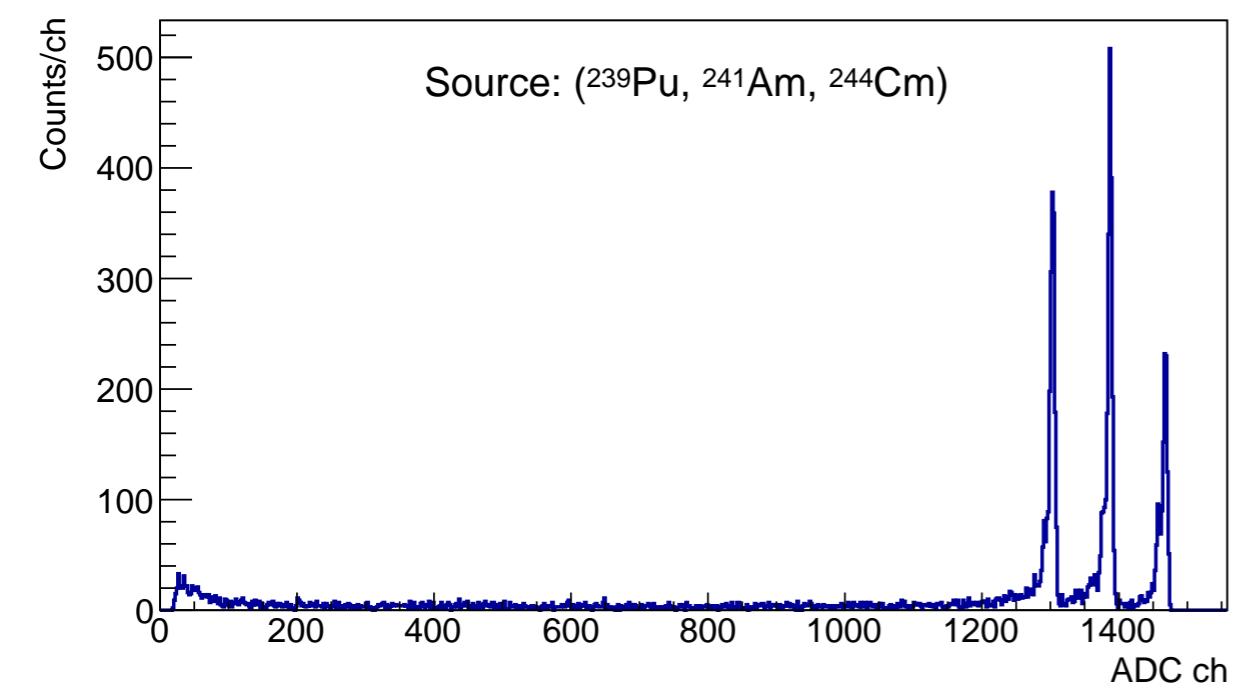
Traces from 1 DSSD strip



Trapezoidal filter



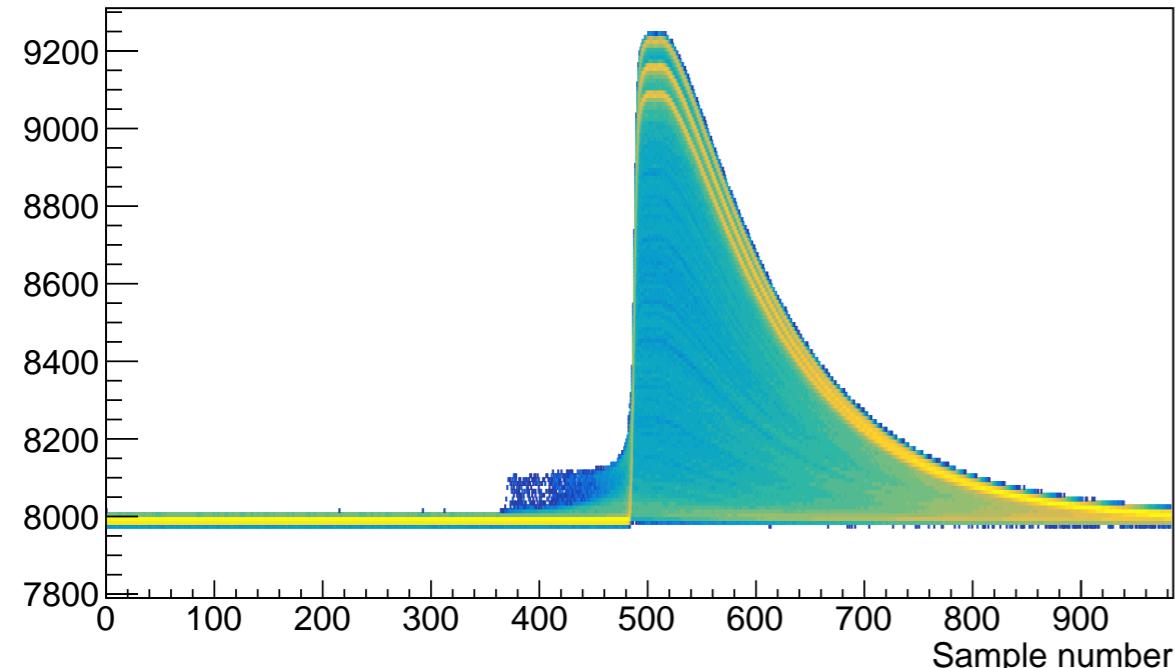
Raw spectrum



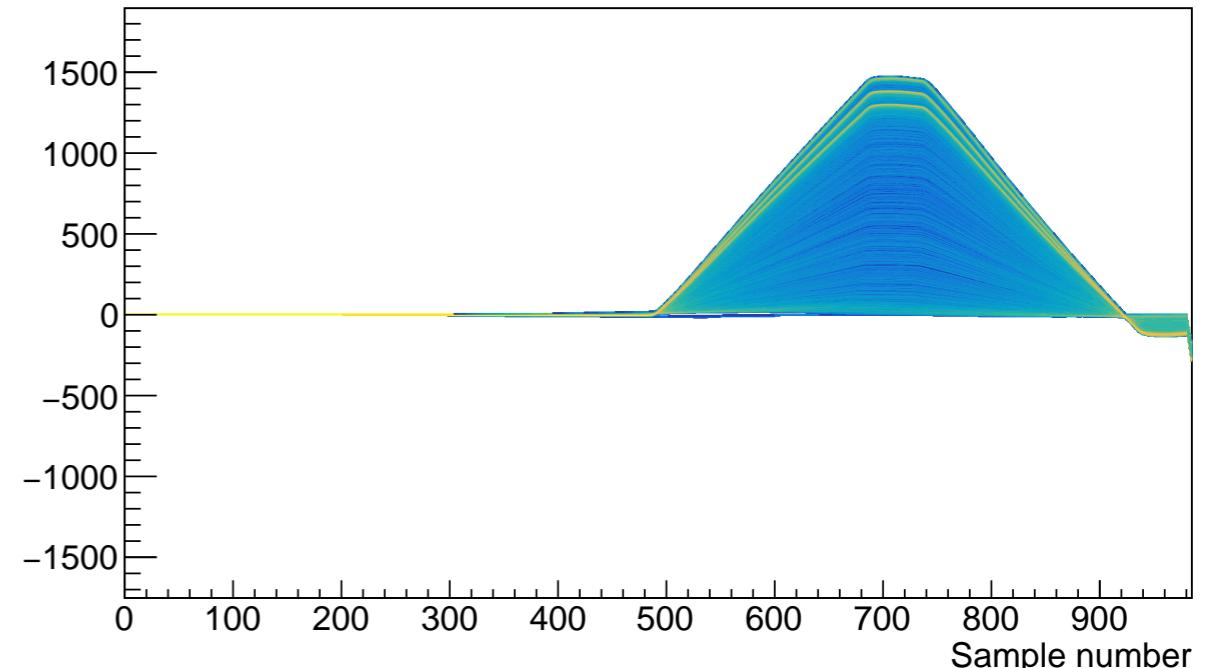
Performance of the DSSD in high gain mode with a 3-alpha source

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

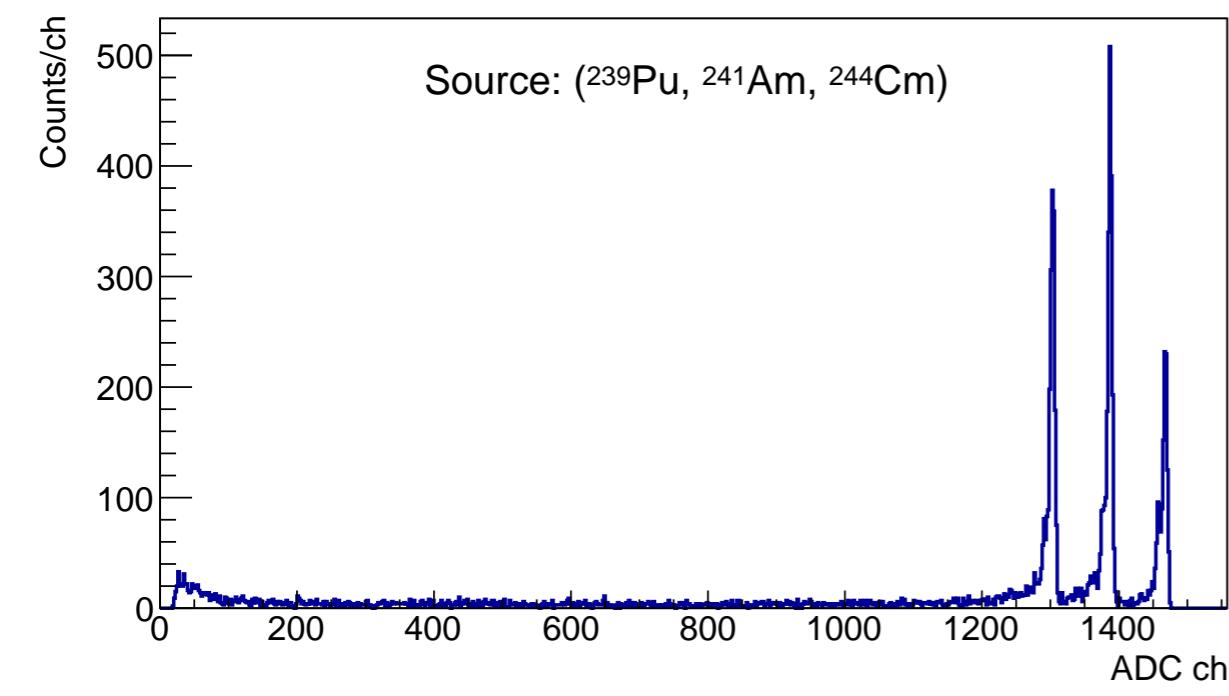
Traces from 1 DSSD strip



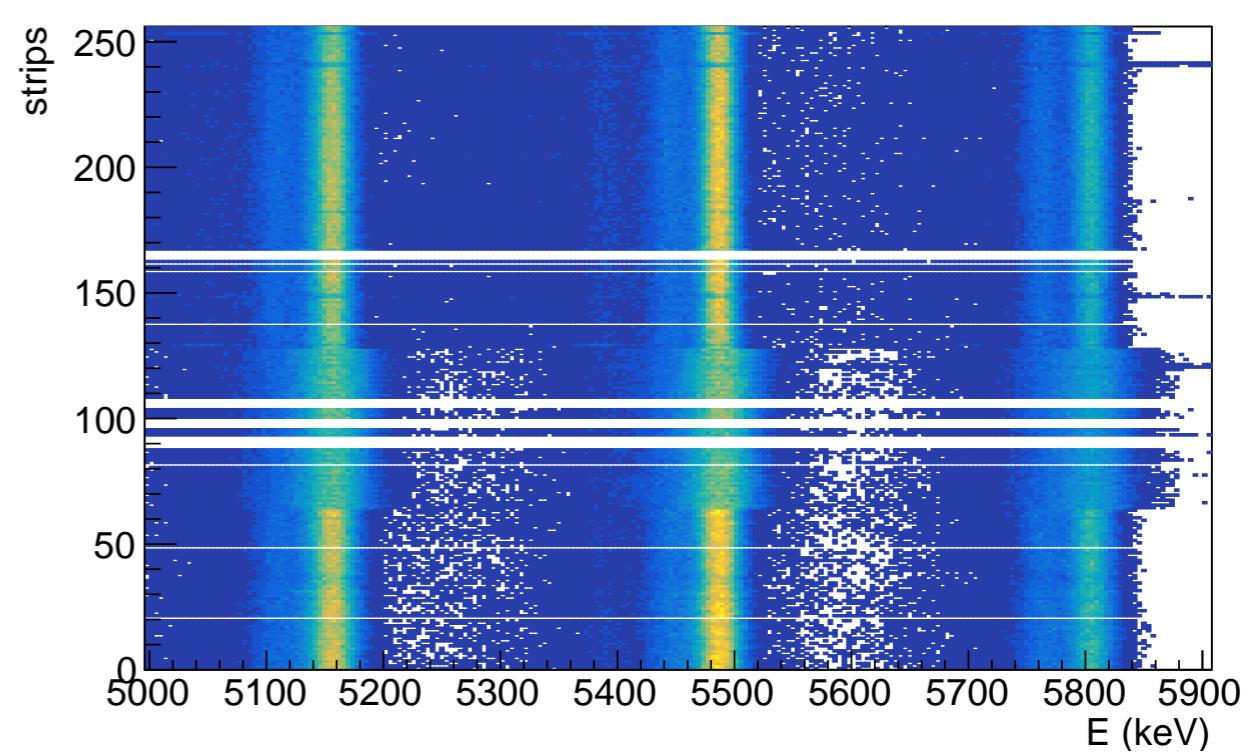
Trapezoidal filter



Raw spectrum



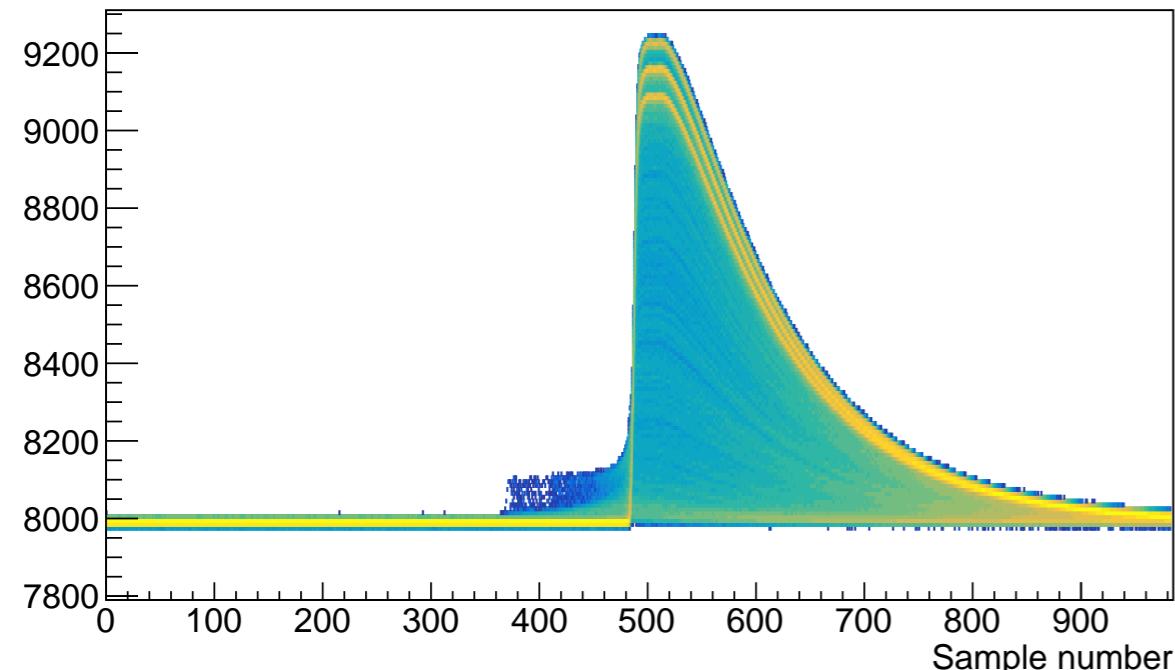
Calibration of 256 strips



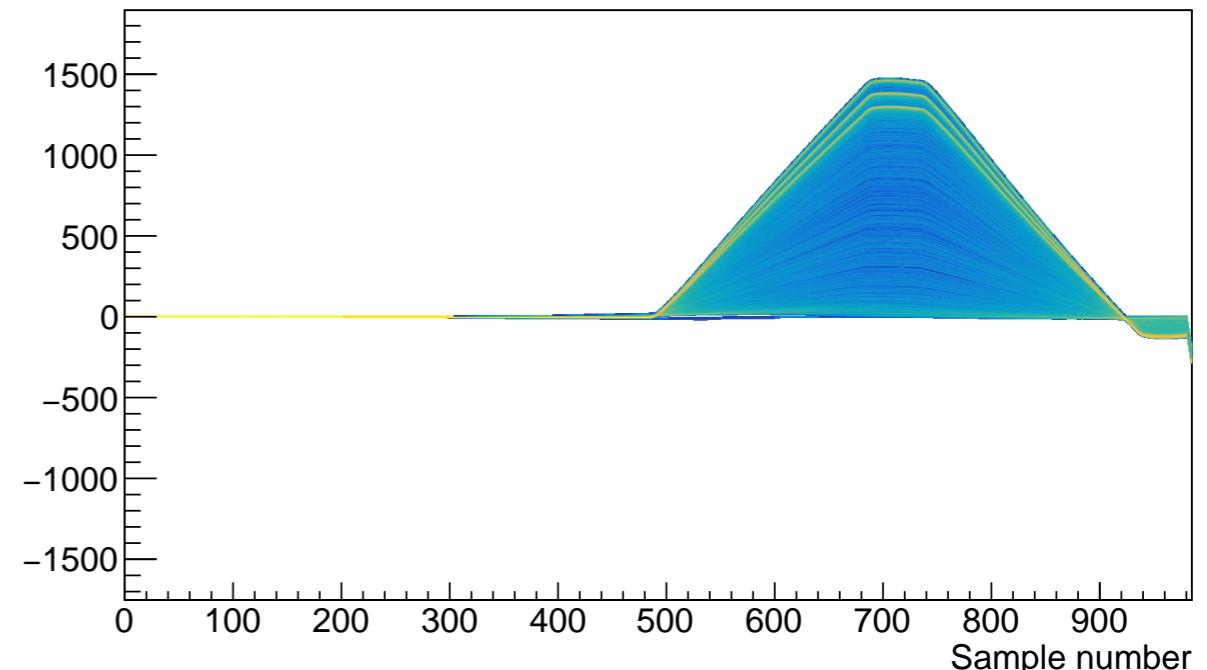
Performance of the DSSD in high gain mode with a 3-alpha source

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

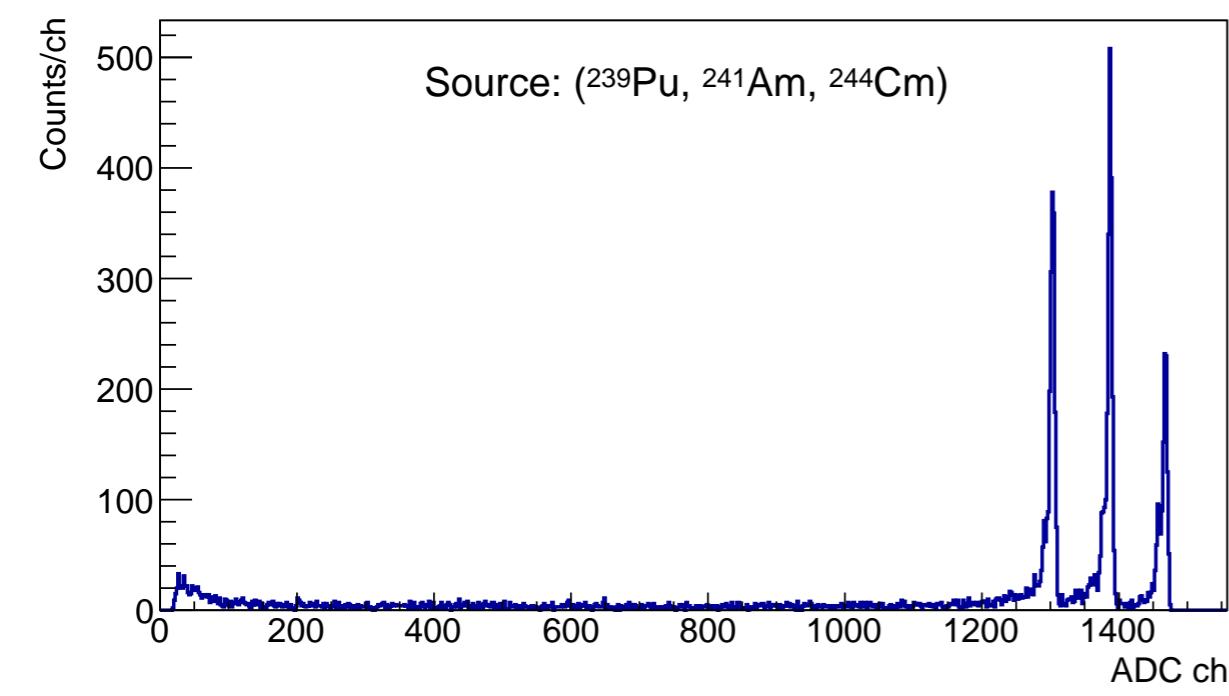
Traces from 1 DSSD strip



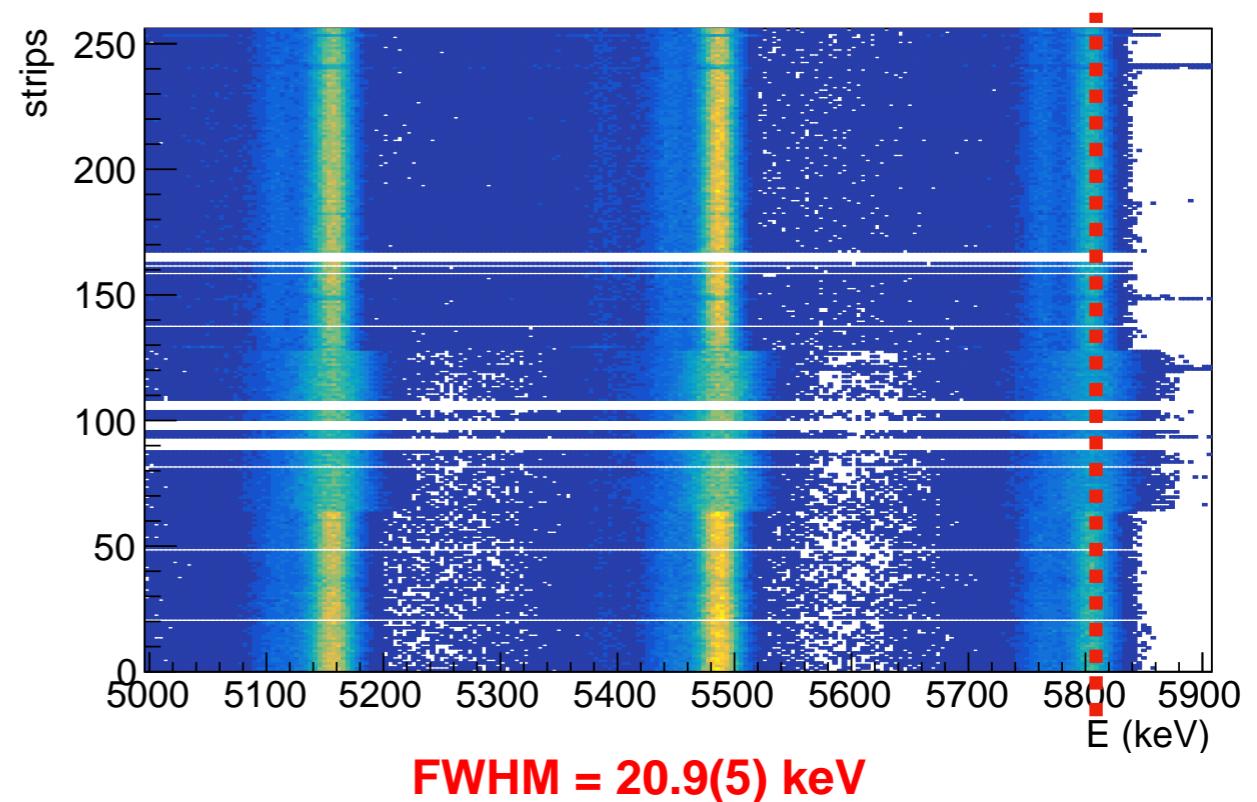
Trapezoidal filter



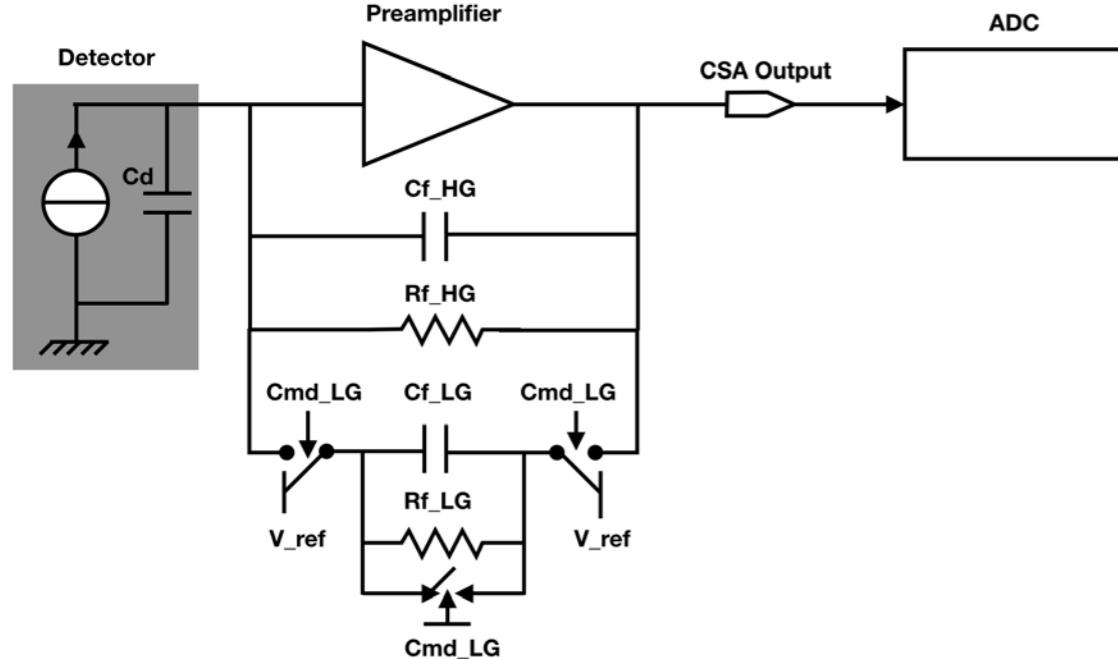
Raw spectrum



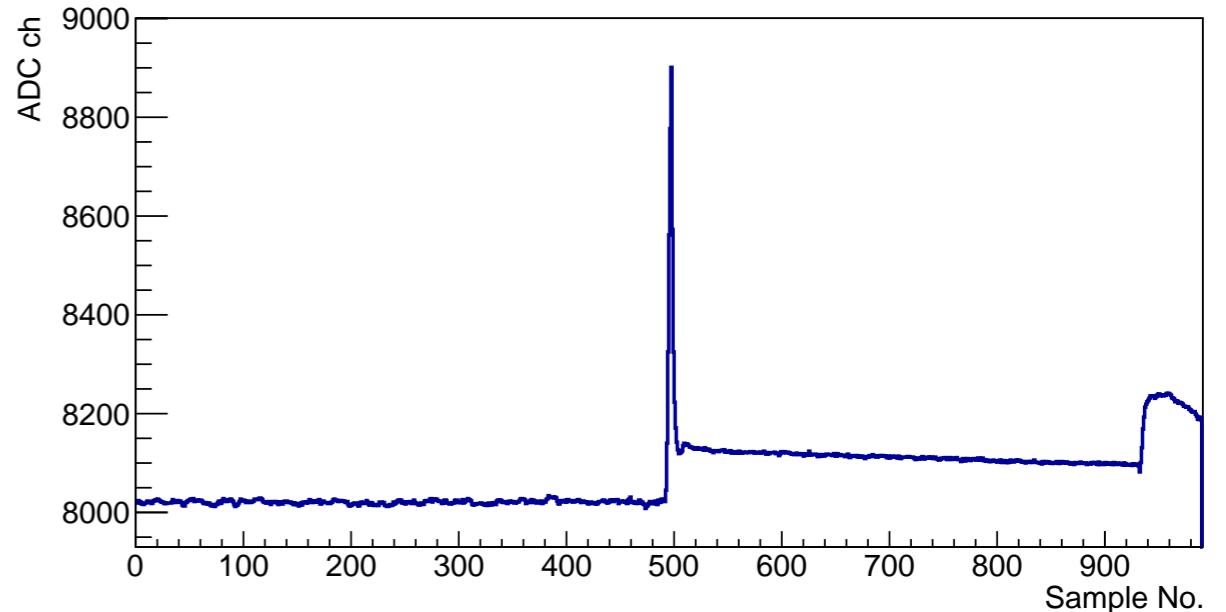
Calibration of 256 strips



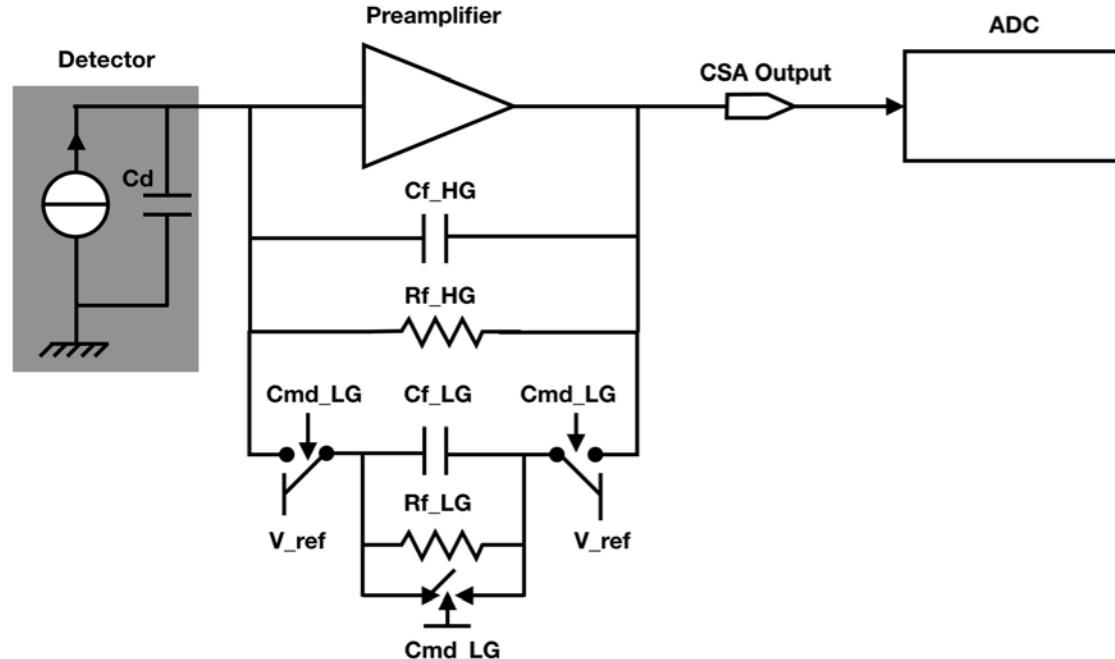
DSSD: Auto Gain Floating Point Charge Sensitive Amplifier (FPCSA)



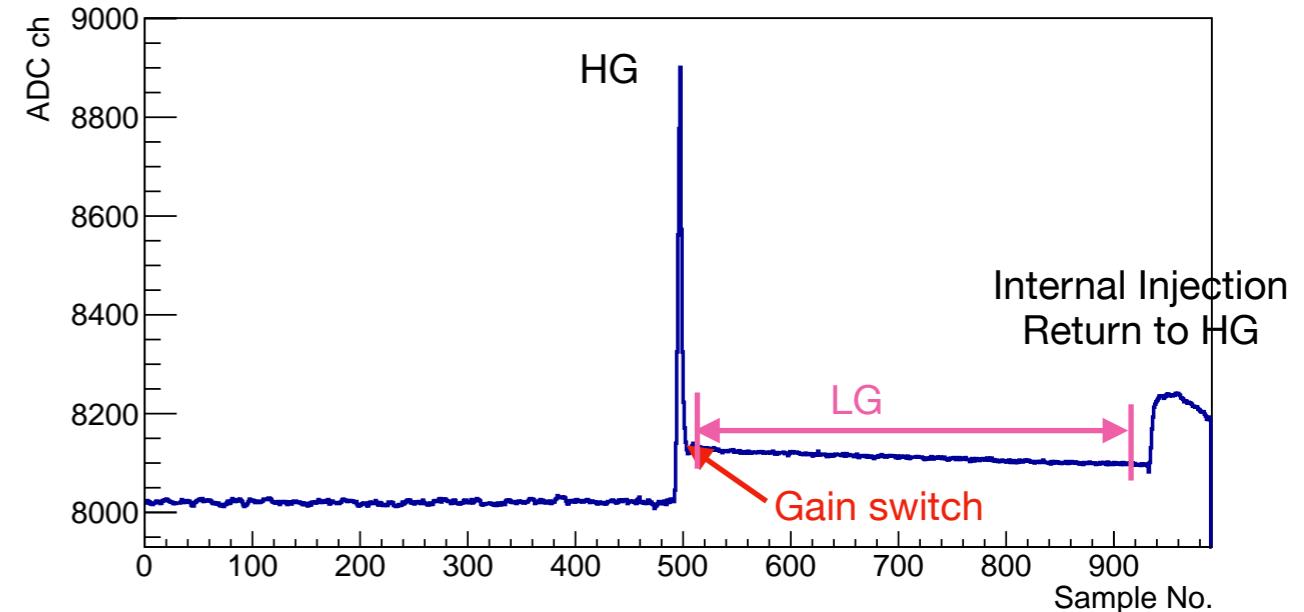
Switching feedback capacitor to change gain as a function of output signal level



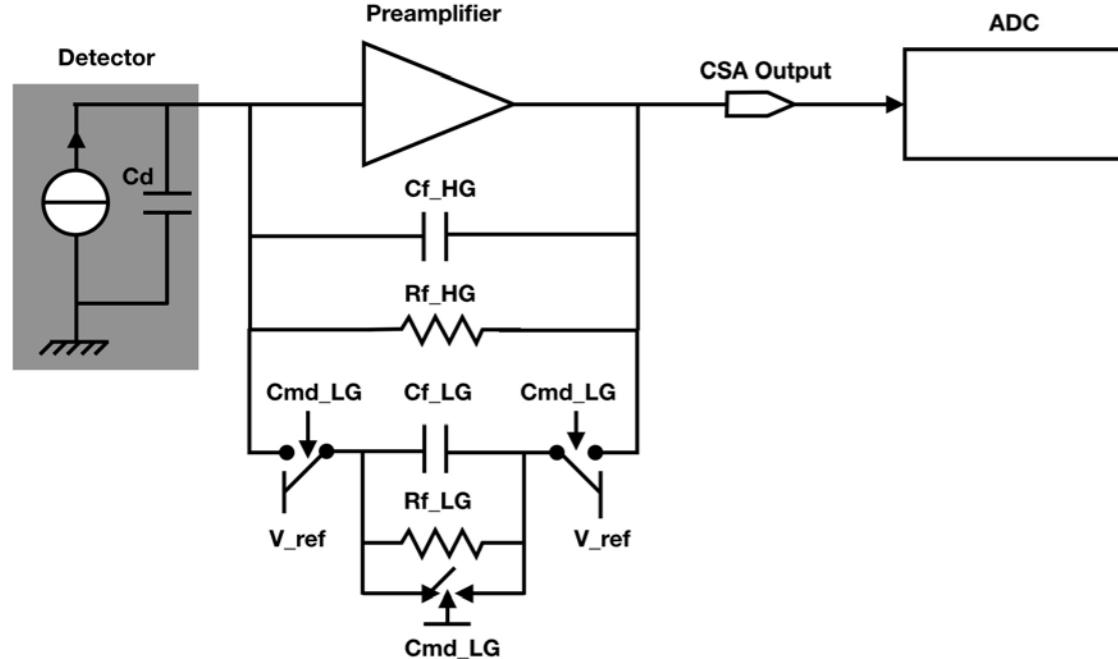
DSSD: Auto Gain Floating Point Charge Sensitive Amplifier (FPCSA)



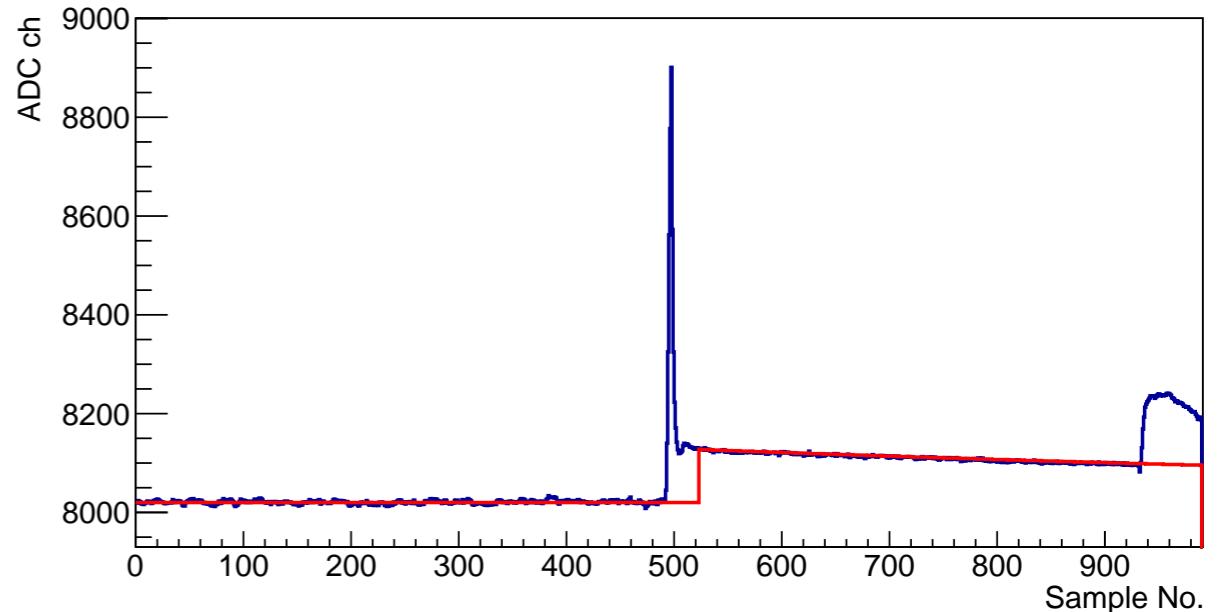
Switching feedback capacitor to change gain as a function of output signal level



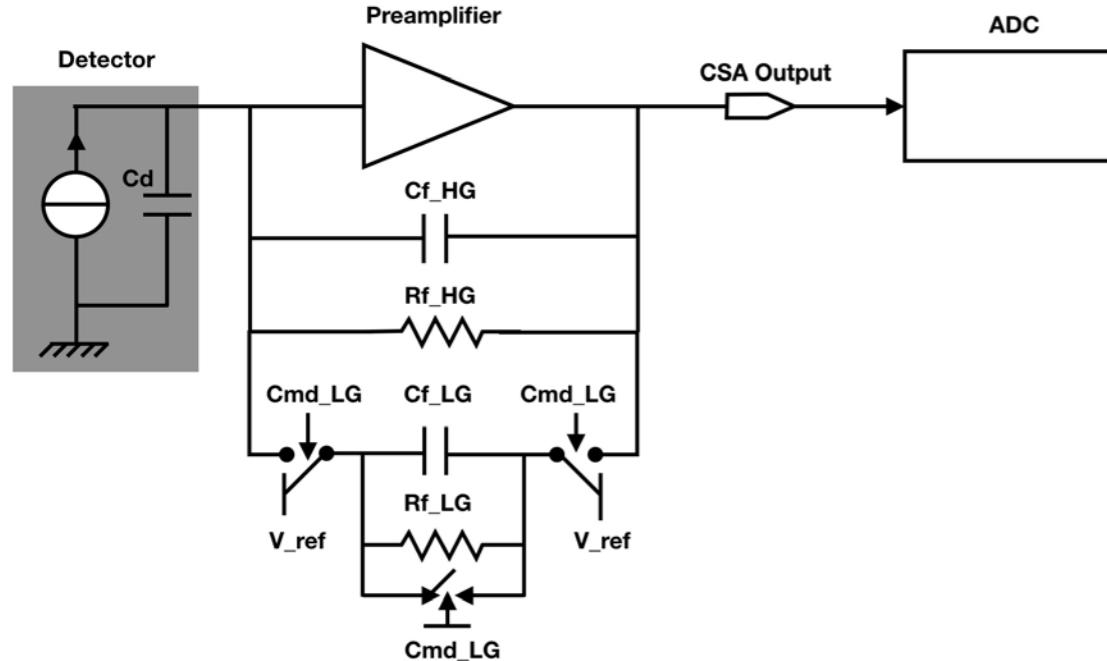
DSSD: Auto Gain Floating Point Charge Sensitive Amplifier (FPCSA)



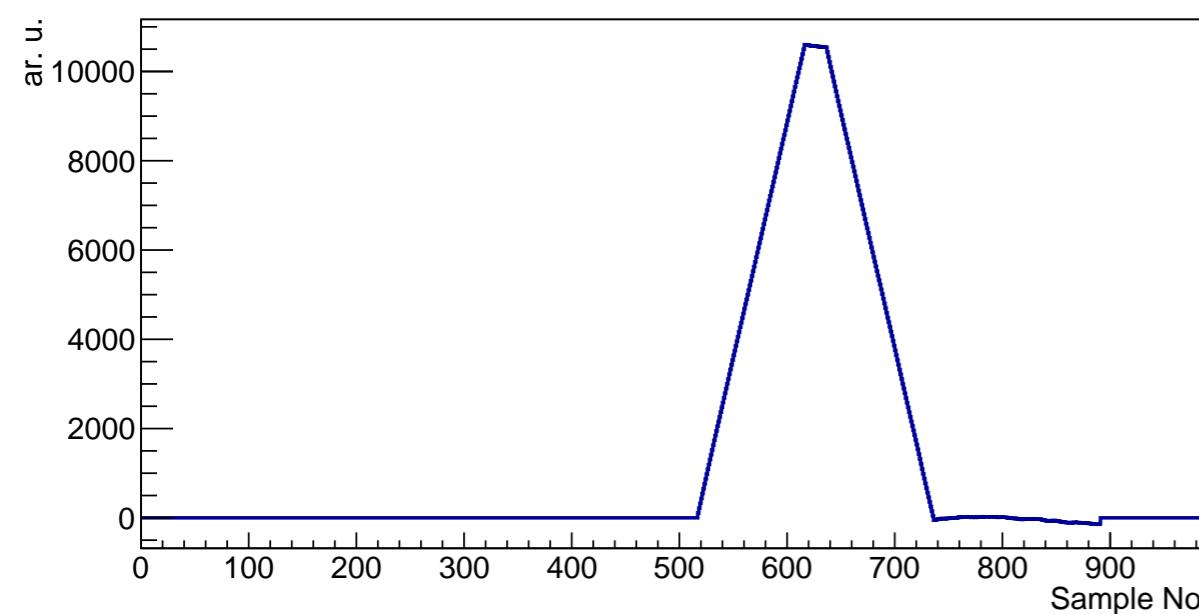
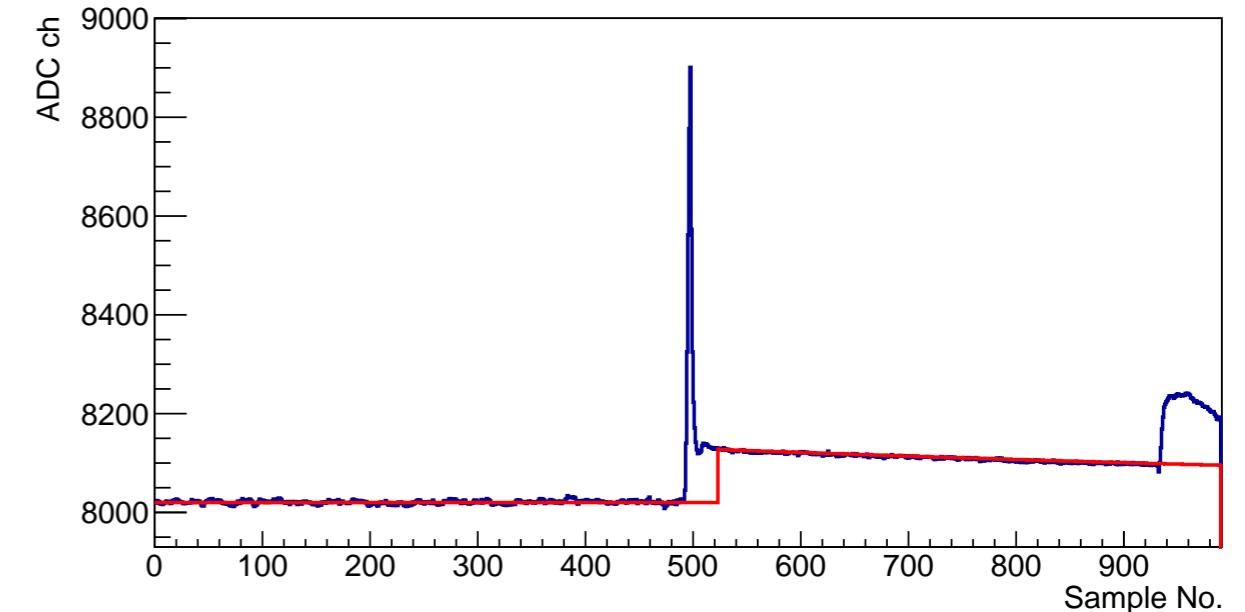
Switching feedback capacitor to change gain as a function of output signal level



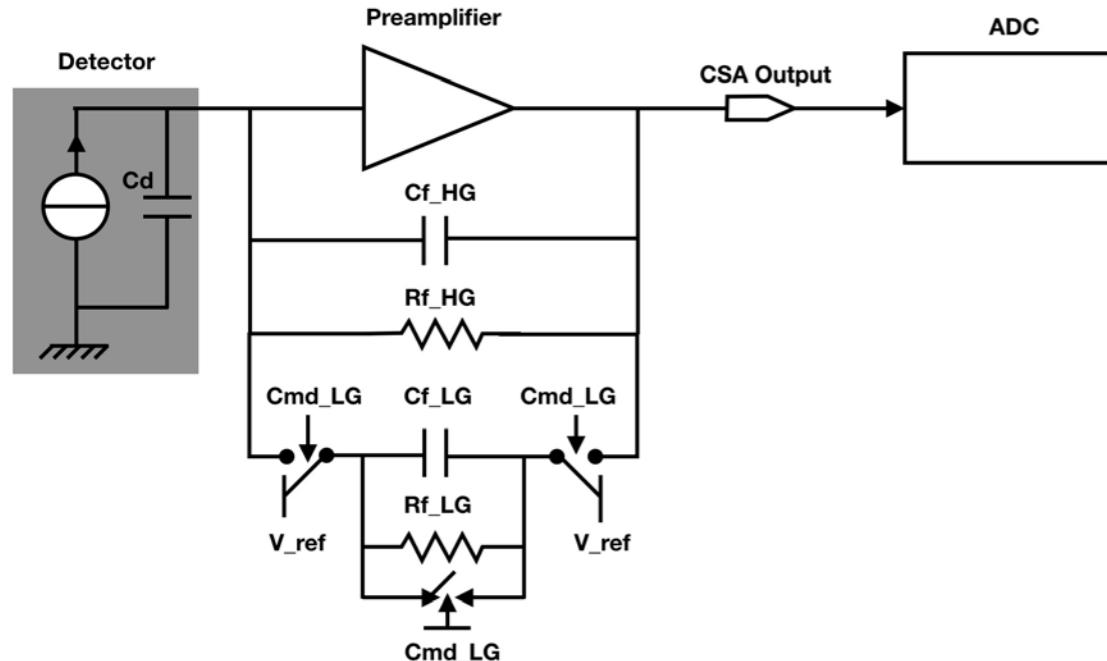
DSSD: Auto Gain Floating Point Charge Sensitive Amplifier (FPCSA)



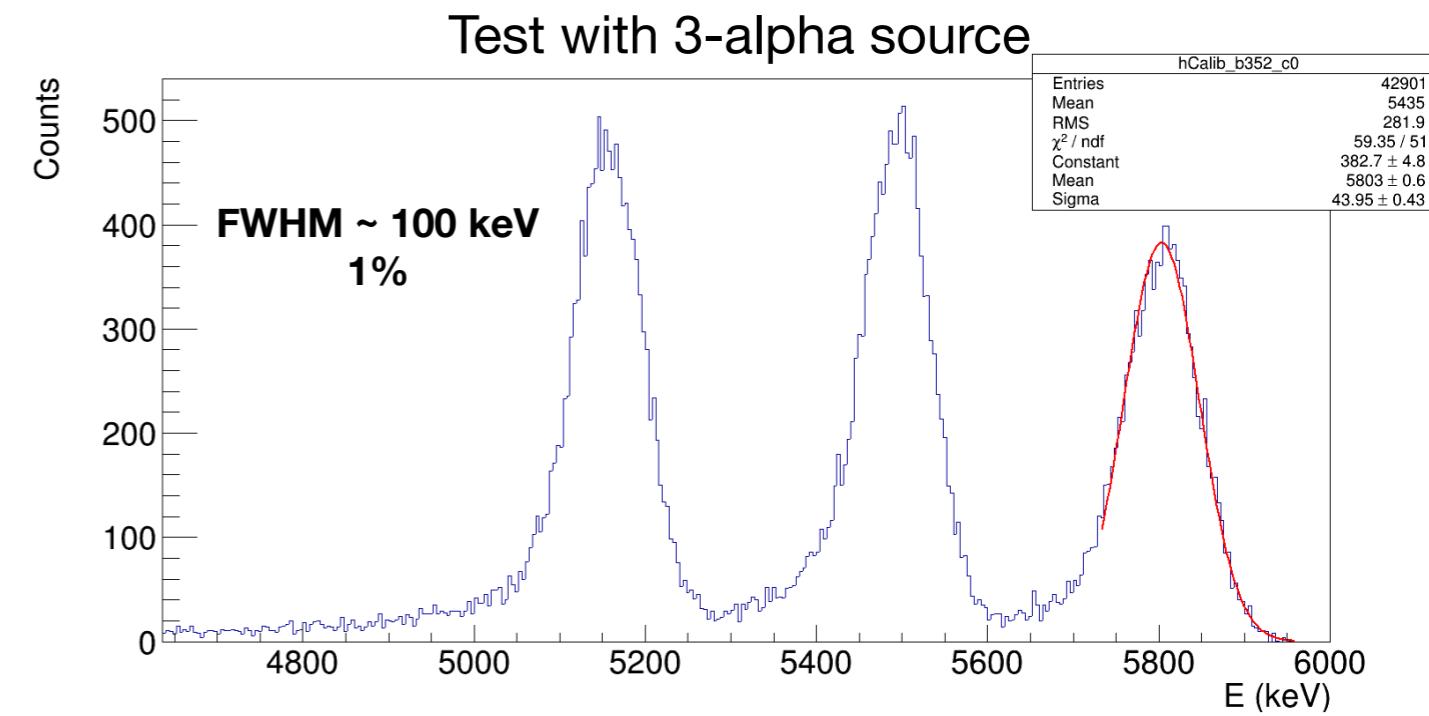
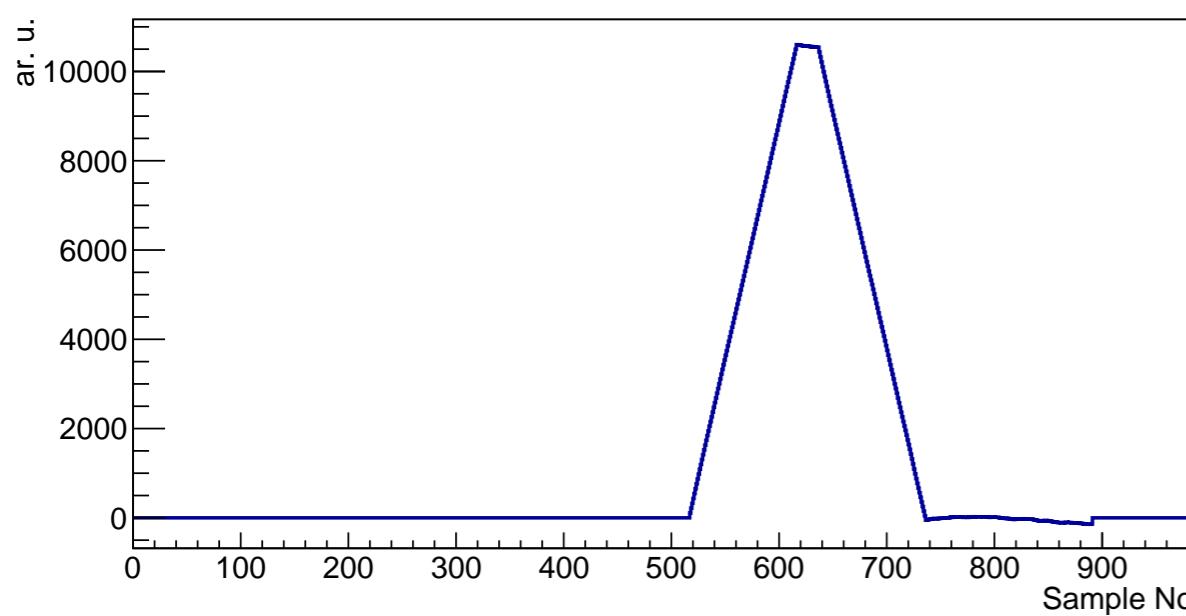
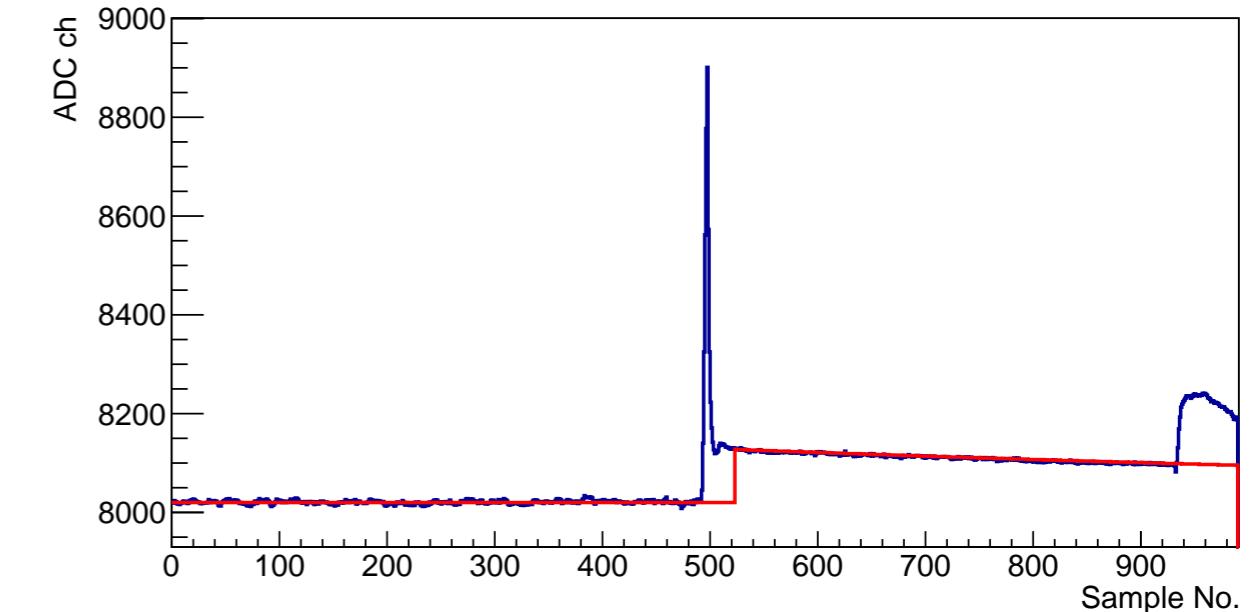
Switching feedback capacitor to change gain as a function of output signal level



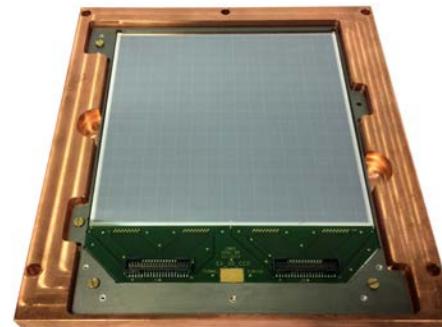
DSSD: Auto Gain Floating Point Charge Sensitive Amplifier (FPCSA)



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



4 Strippy pad
silicon detector



Detector Characteristics

Active area: $\approx 10 \times 10 \text{ cm}^2$

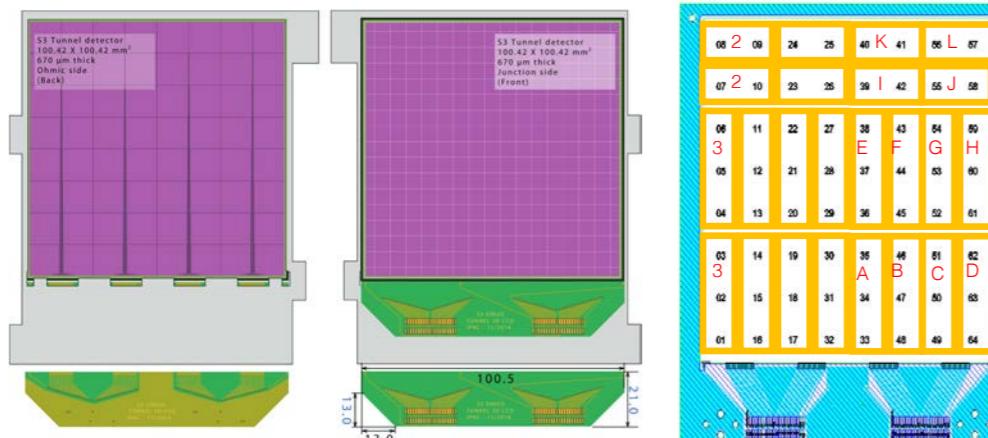
Thickness: $\approx 500 \mu\text{m}$

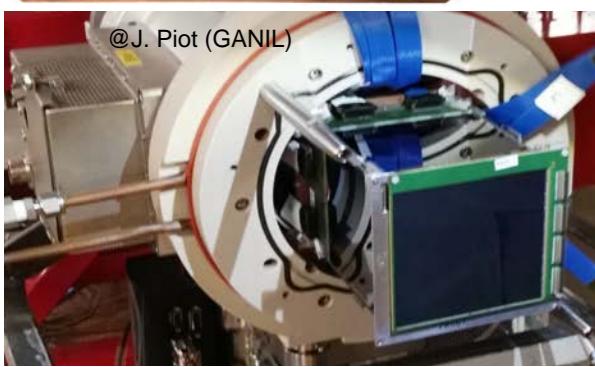
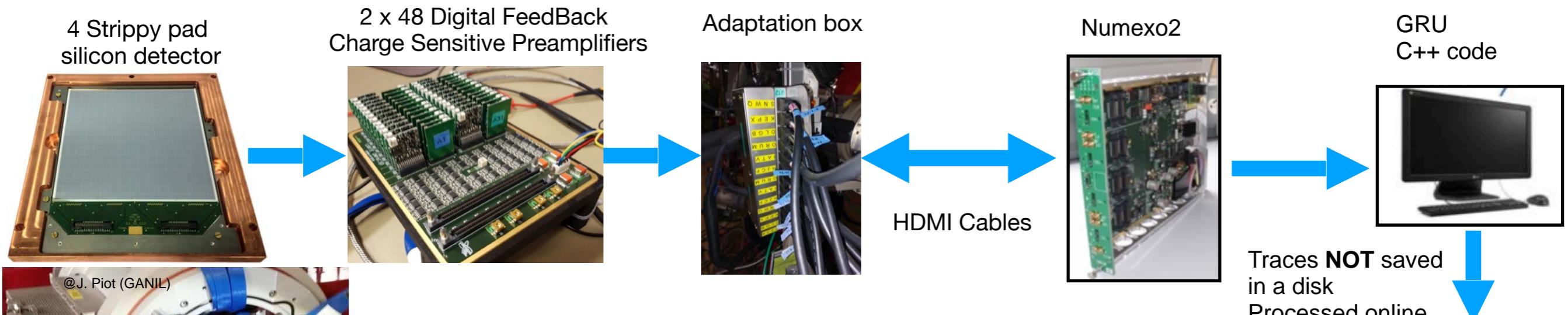
Dead layer: $\sim 30 \text{ nm}$ (**Windowless**)

64 pixels

24 Macro pixels

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





Detector Characteristics

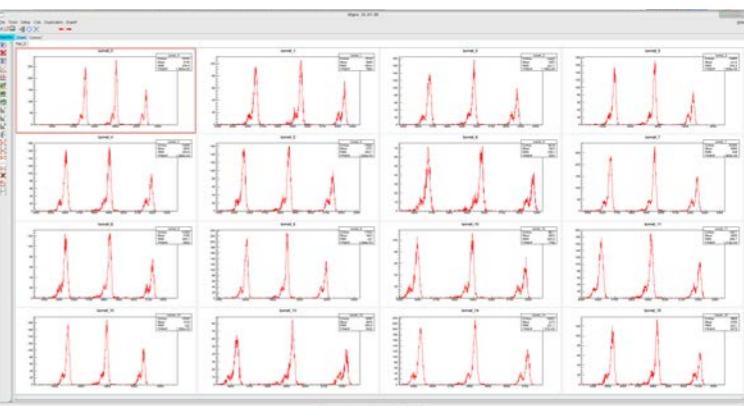
Active area: $\approx 10 \times 10 \text{ cm}^2$

Thickness: $\approx 500 \mu\text{m}$

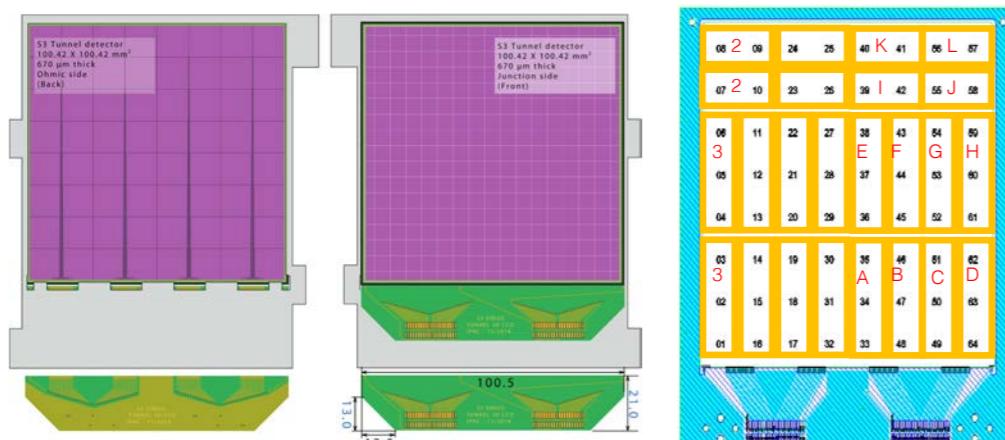
Dead layer: $\sim 30 \text{ nm}$ (**Windowless**)

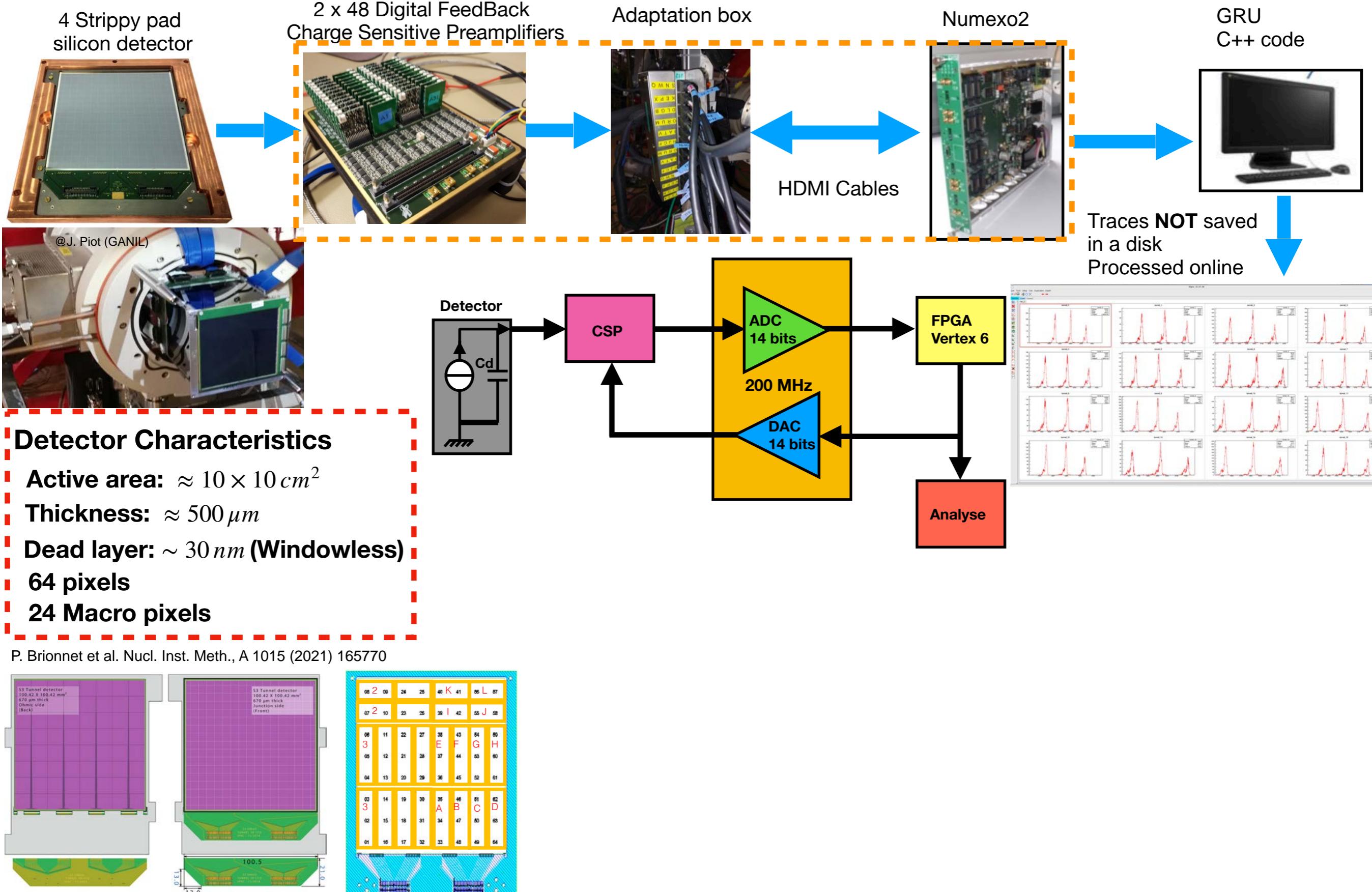
64 pixels

24 Macro pixels

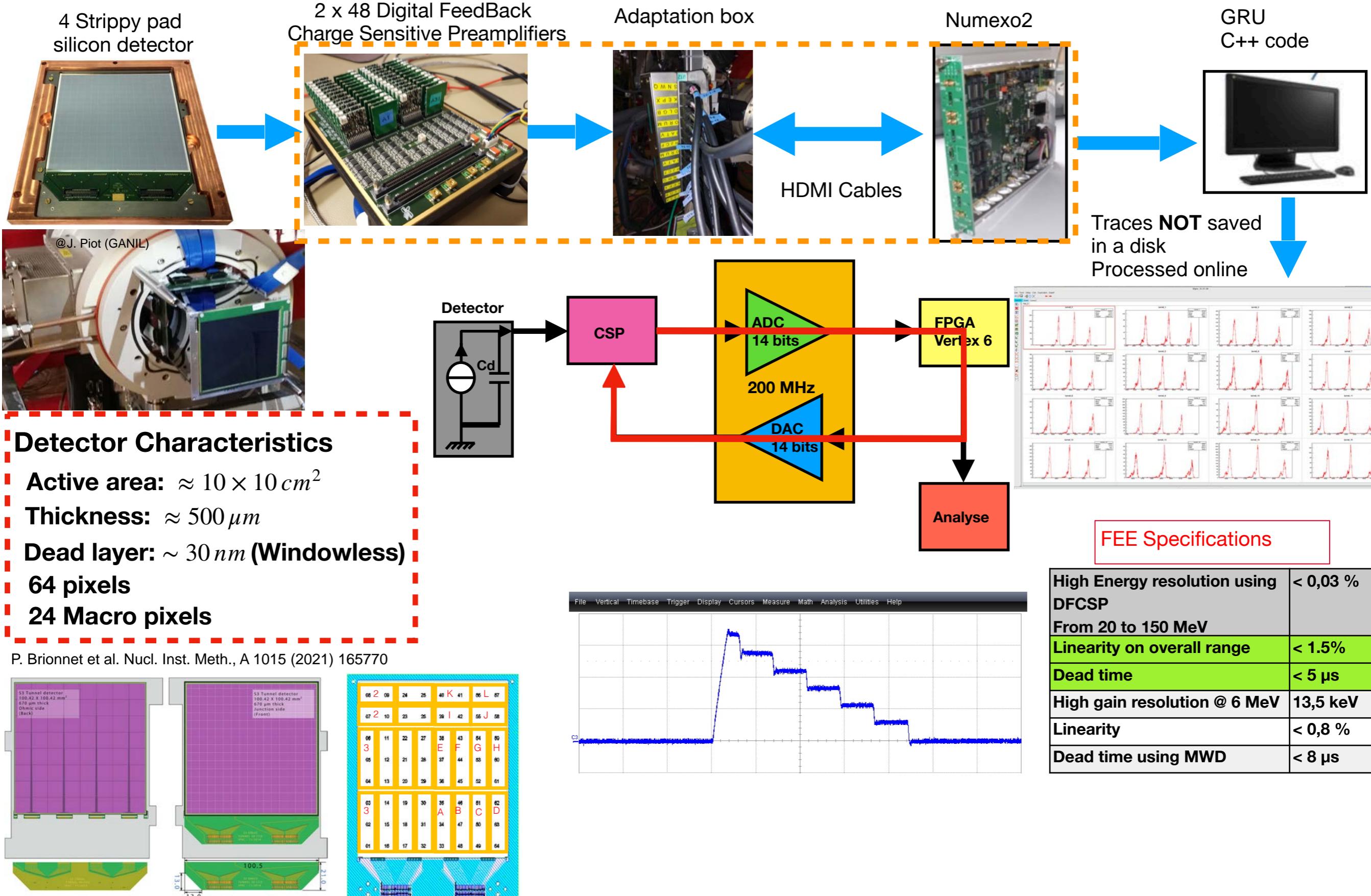


P. Brionnet et al. Nucl. Inst. Meth., A 1015 (2021) 165770

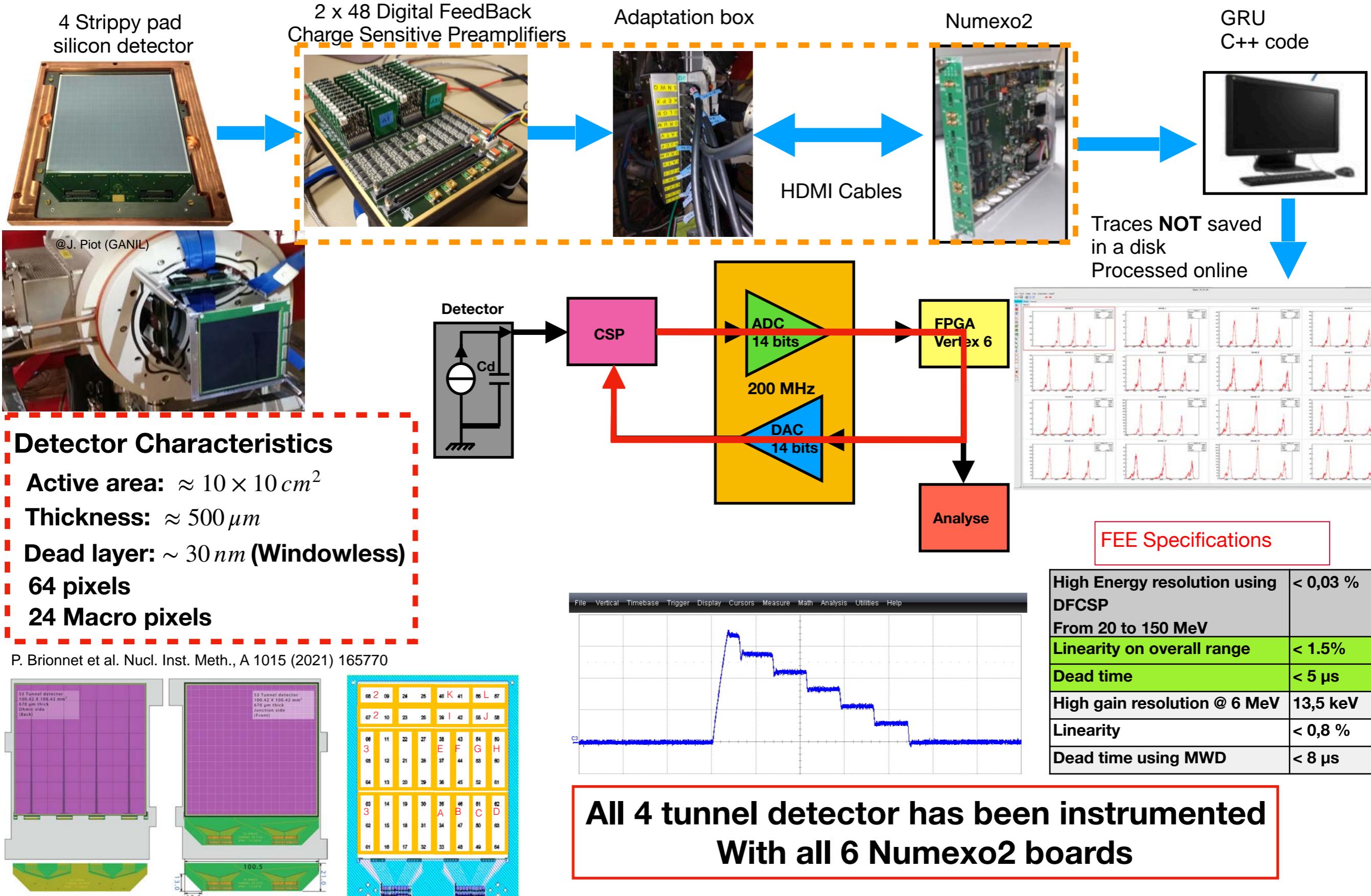




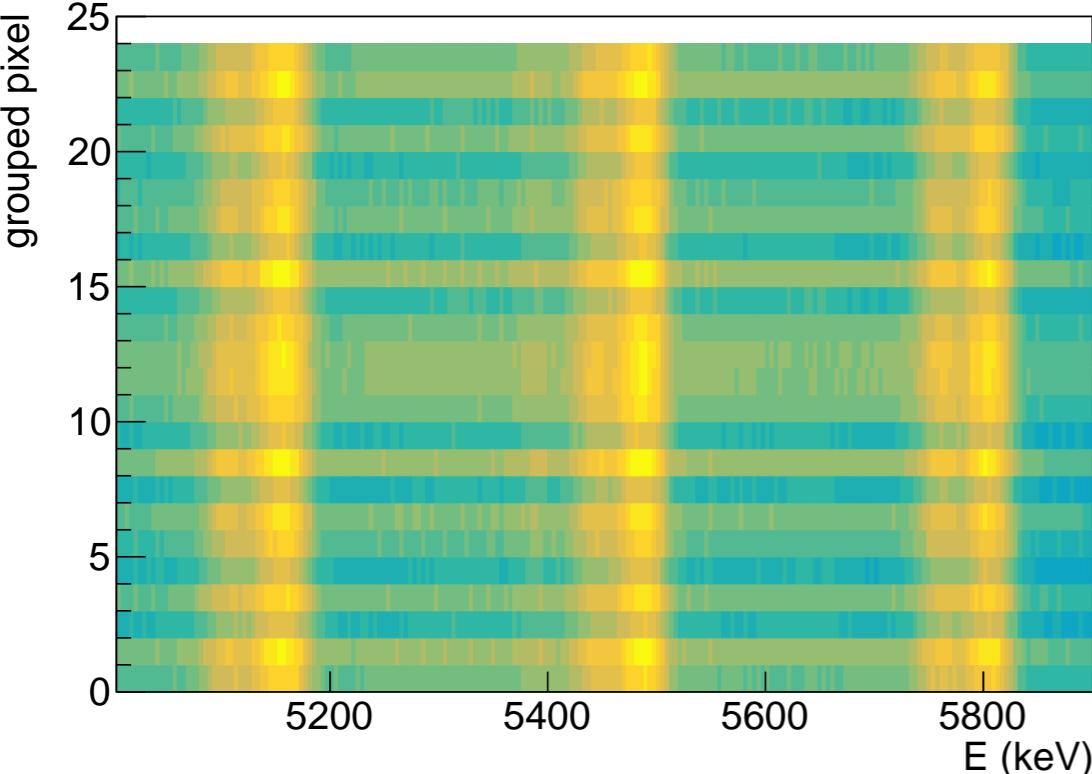
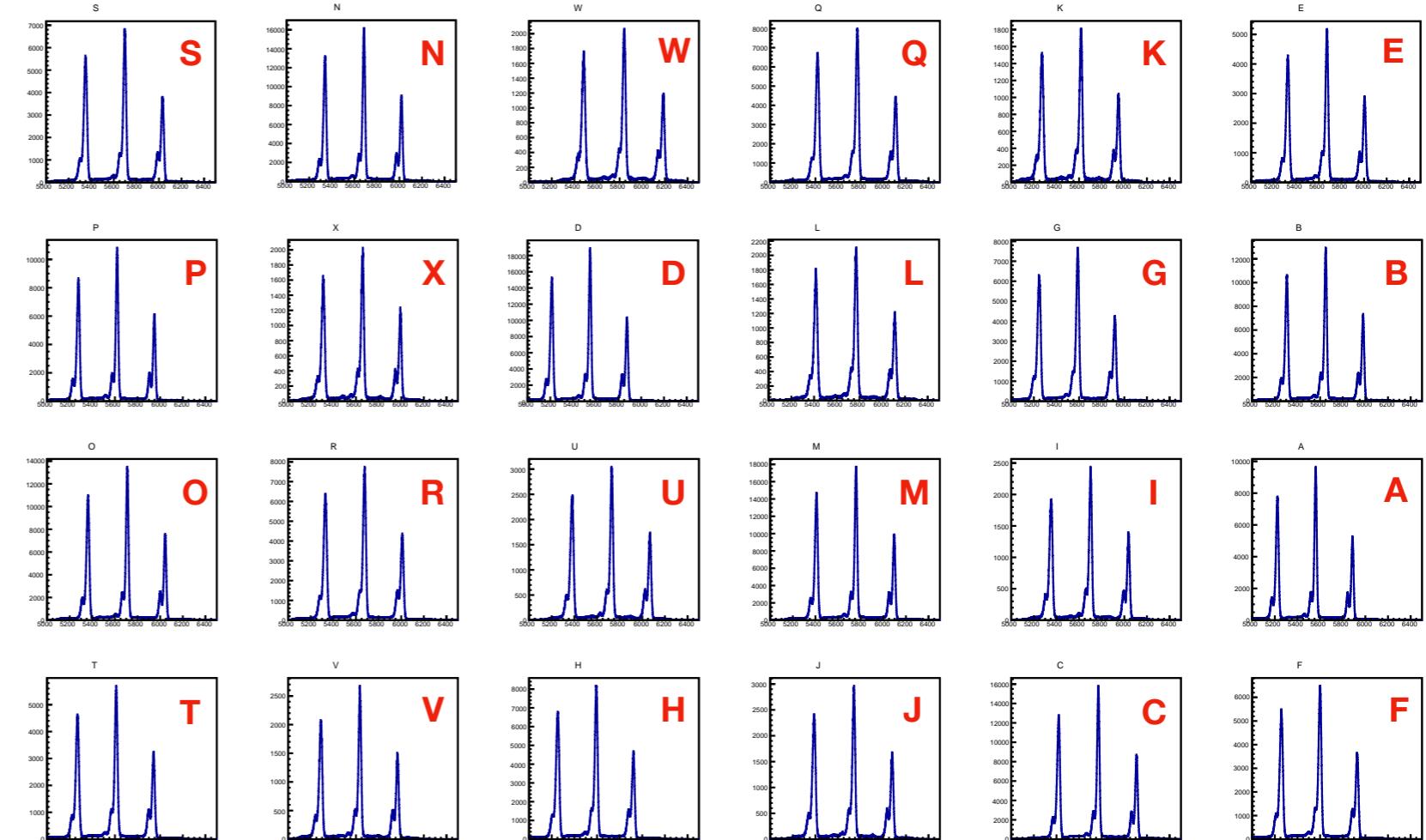
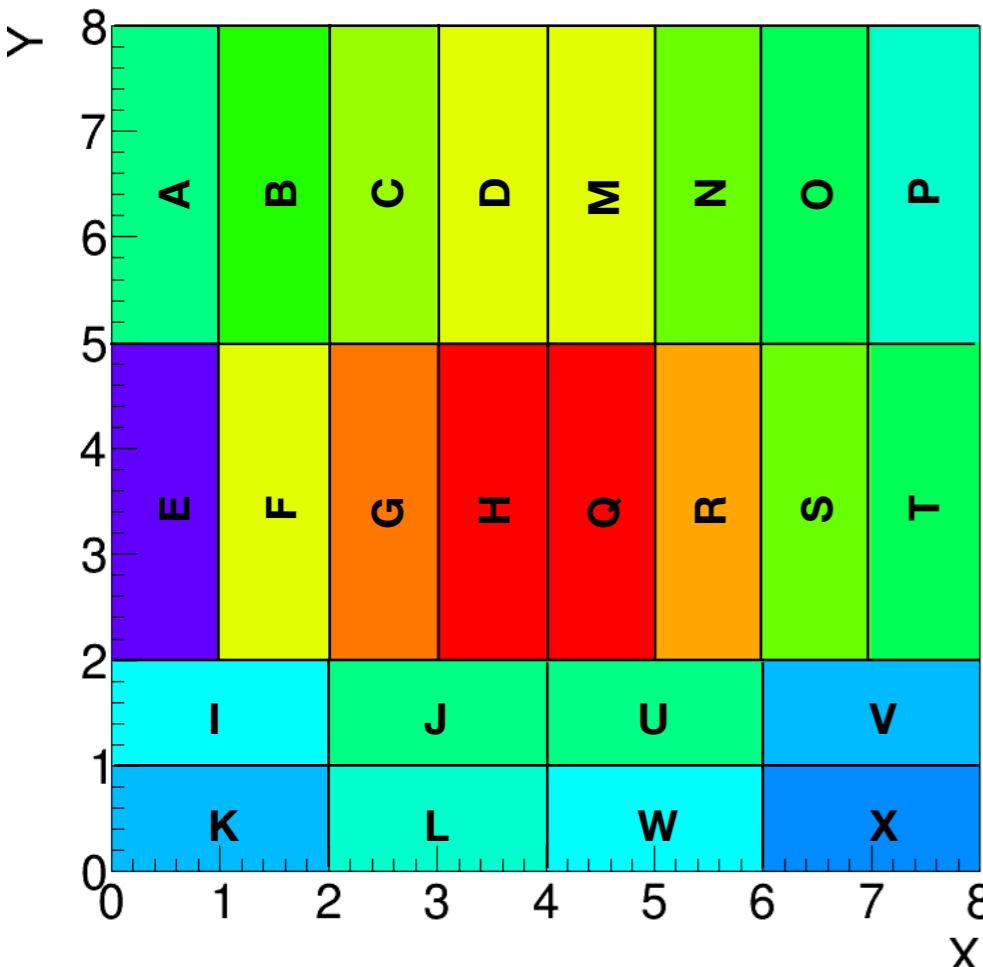
Tunnel



Tunnel



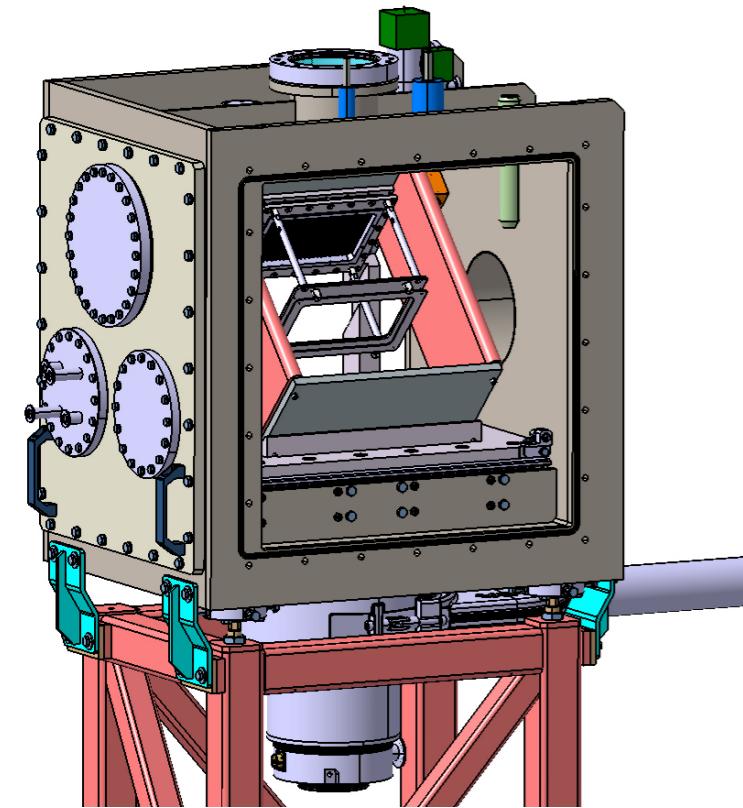
Performance of the Tunnel detectors



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

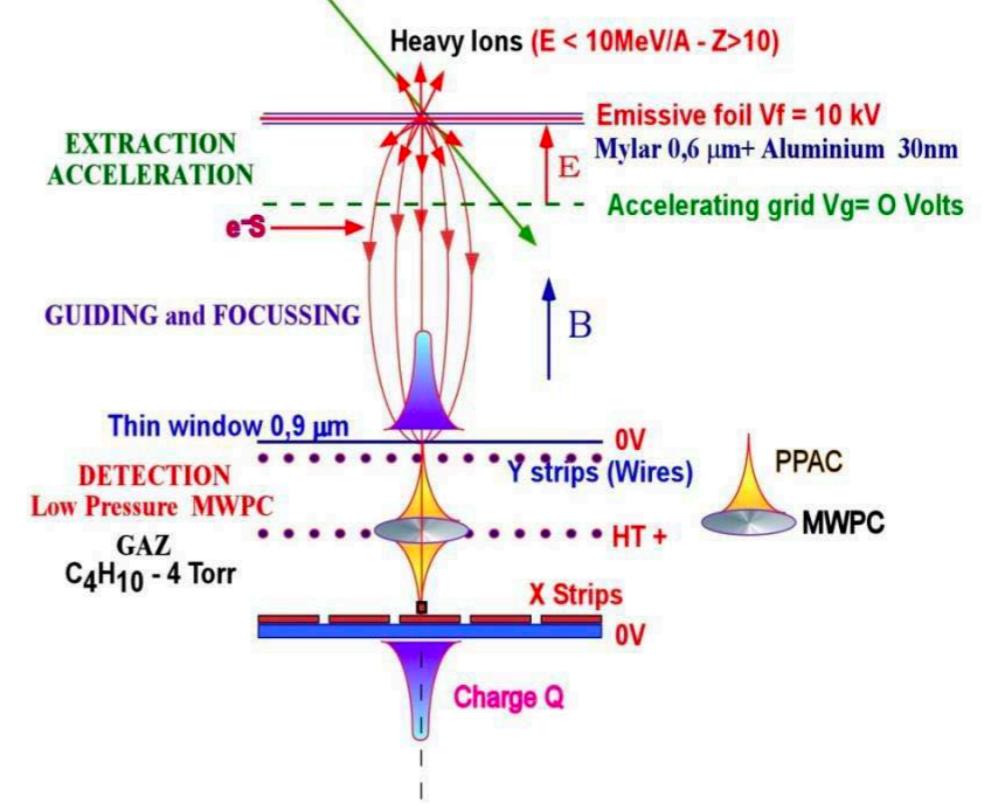
FWHM = 18.3(2) keV

Tracker

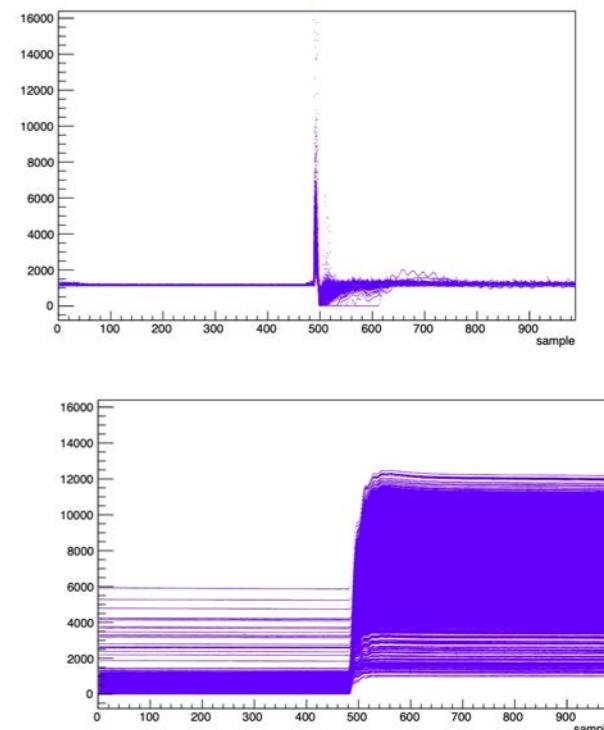
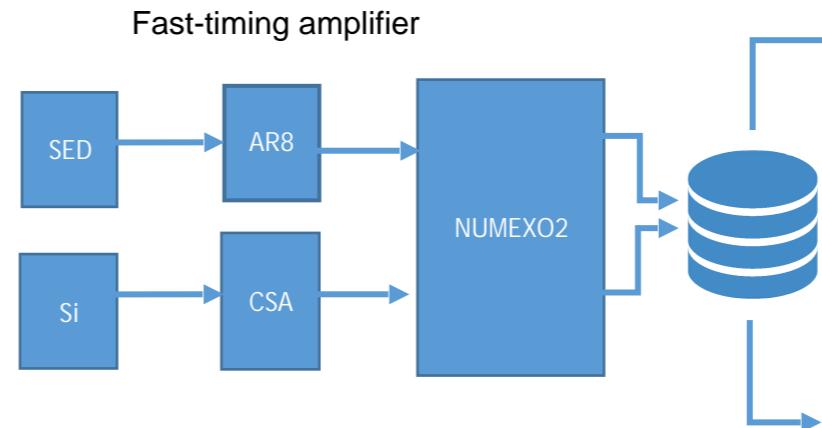
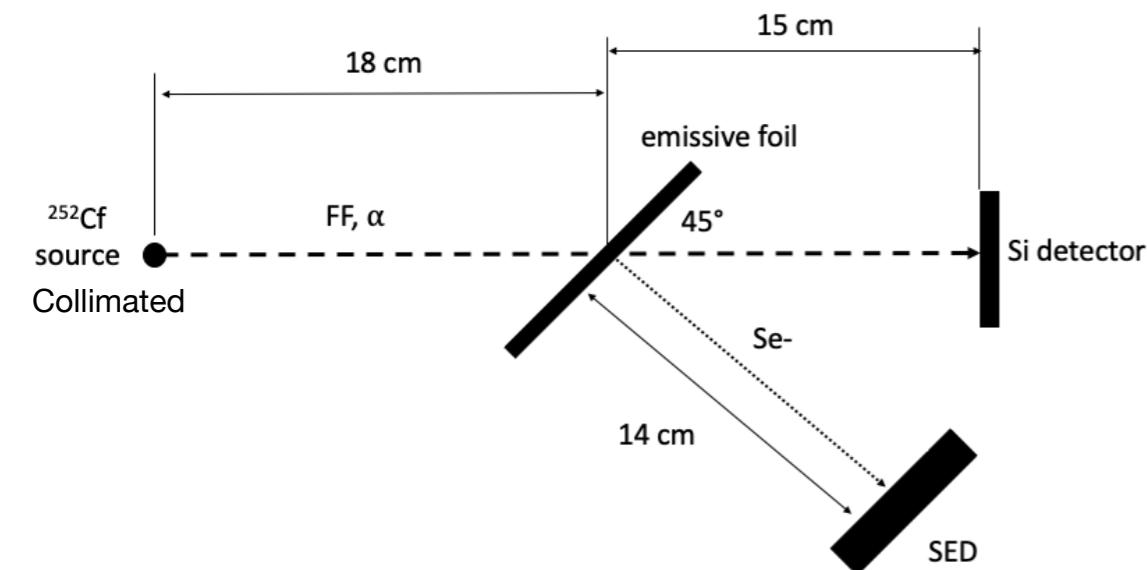


Detector Characteristics

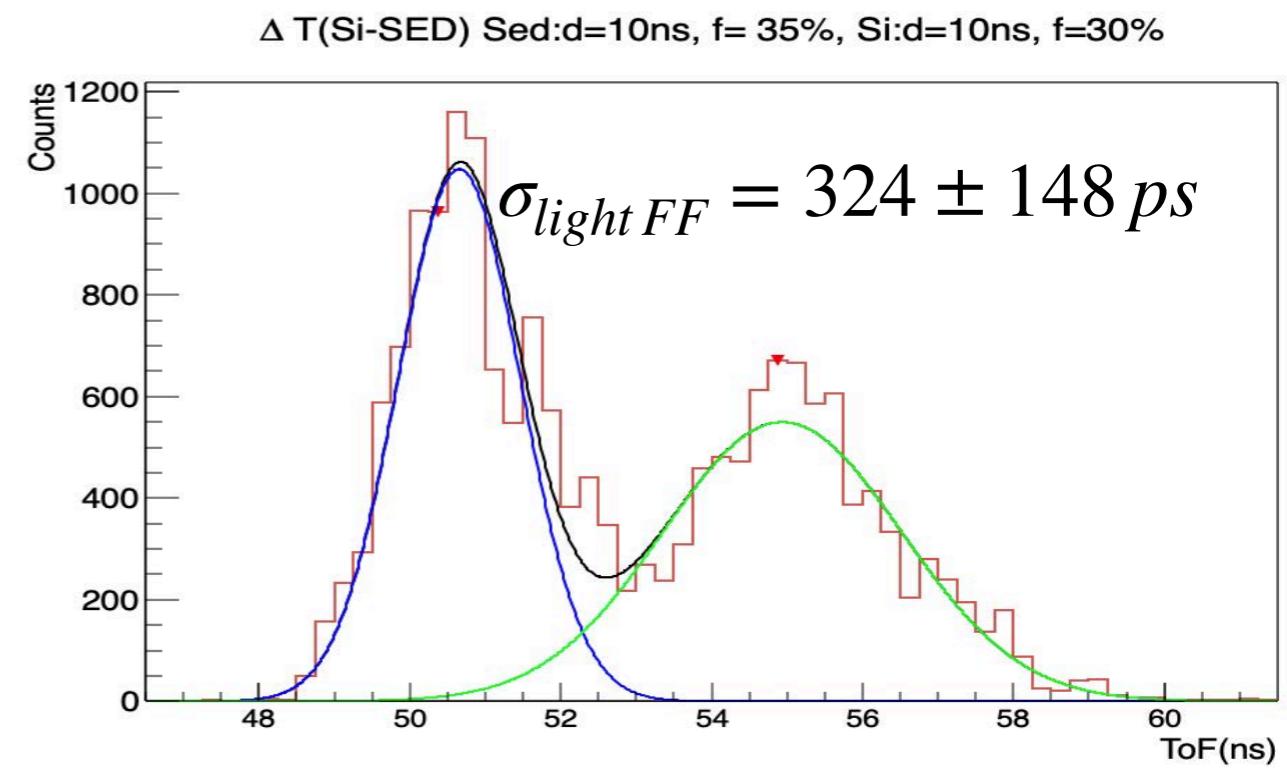
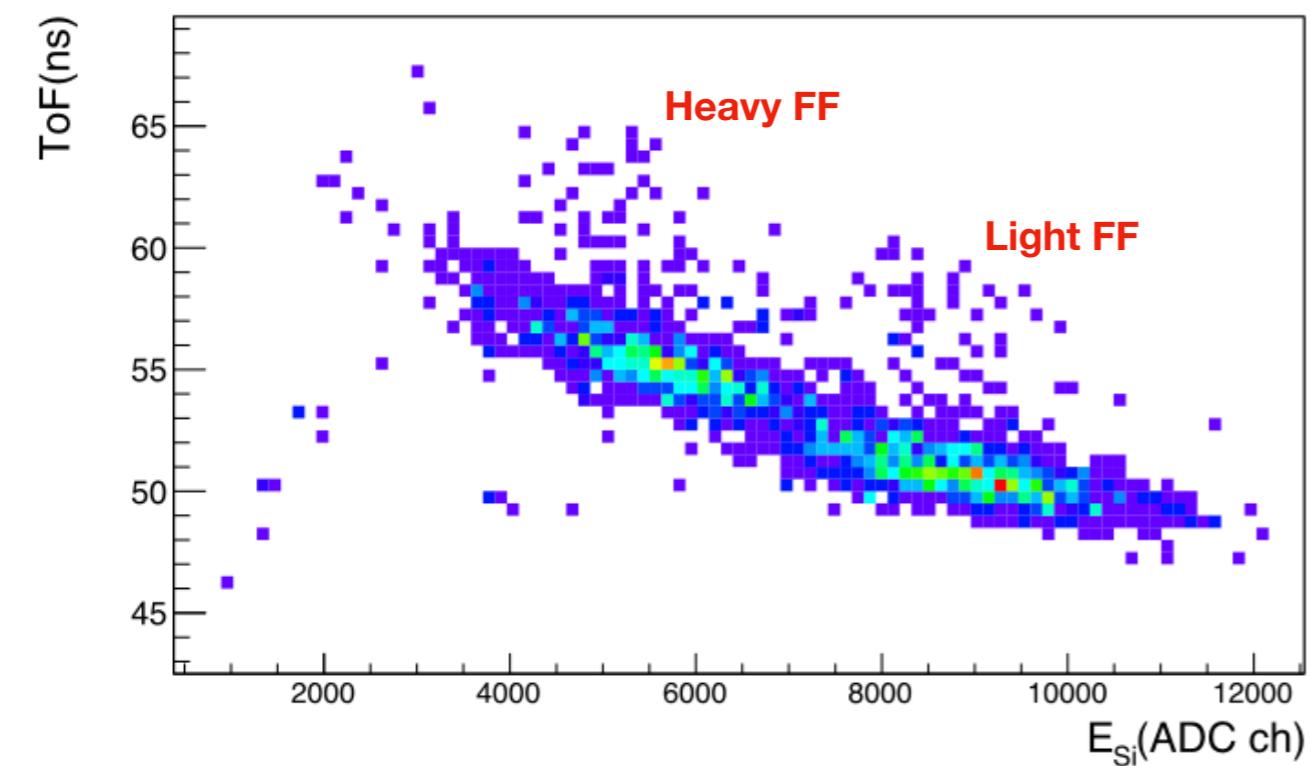
- Active area (in beam):** $\approx 20 \times 10 \text{ cm}^2$
- Mylar foil Thickness:** $\approx 0.9 \mu\text{m}$
- Gas(isobutane) pressure:** $\approx 6 - 7 \text{ mbar}$
- 10 kV polarisation**
- Distance from the DSSD 895.6 mm**
- strips : 87 in X and 63 in Y**
- good time resolution ($\sim 100 \text{ ps}$) and**
- position resolutions ($\sim 0.5 \text{ mm}$)**



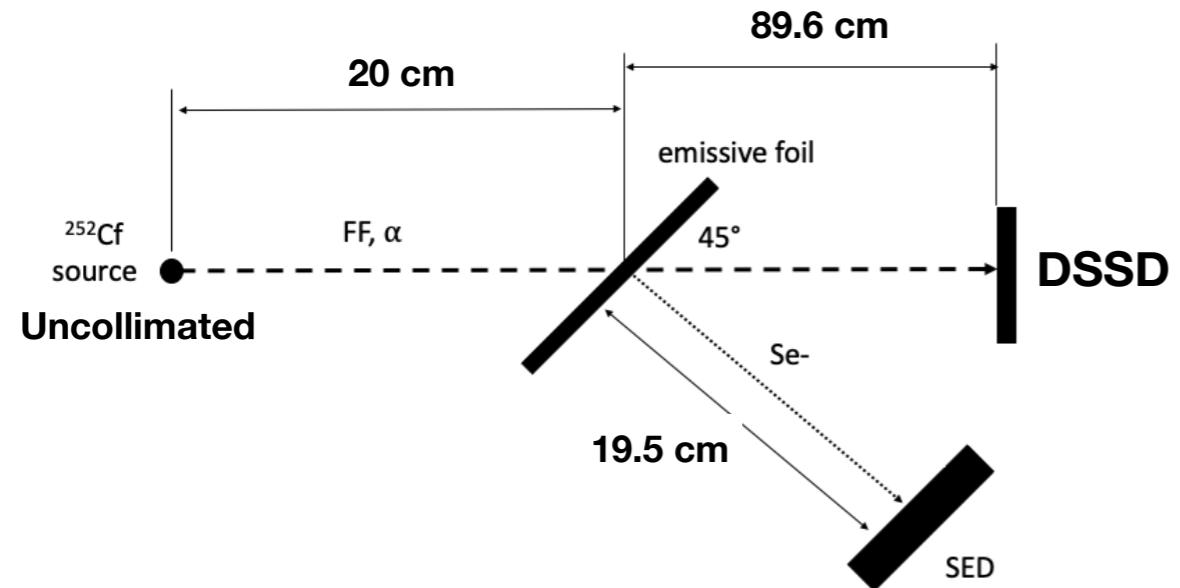
Time of Flight test using a ^{252}Cf source



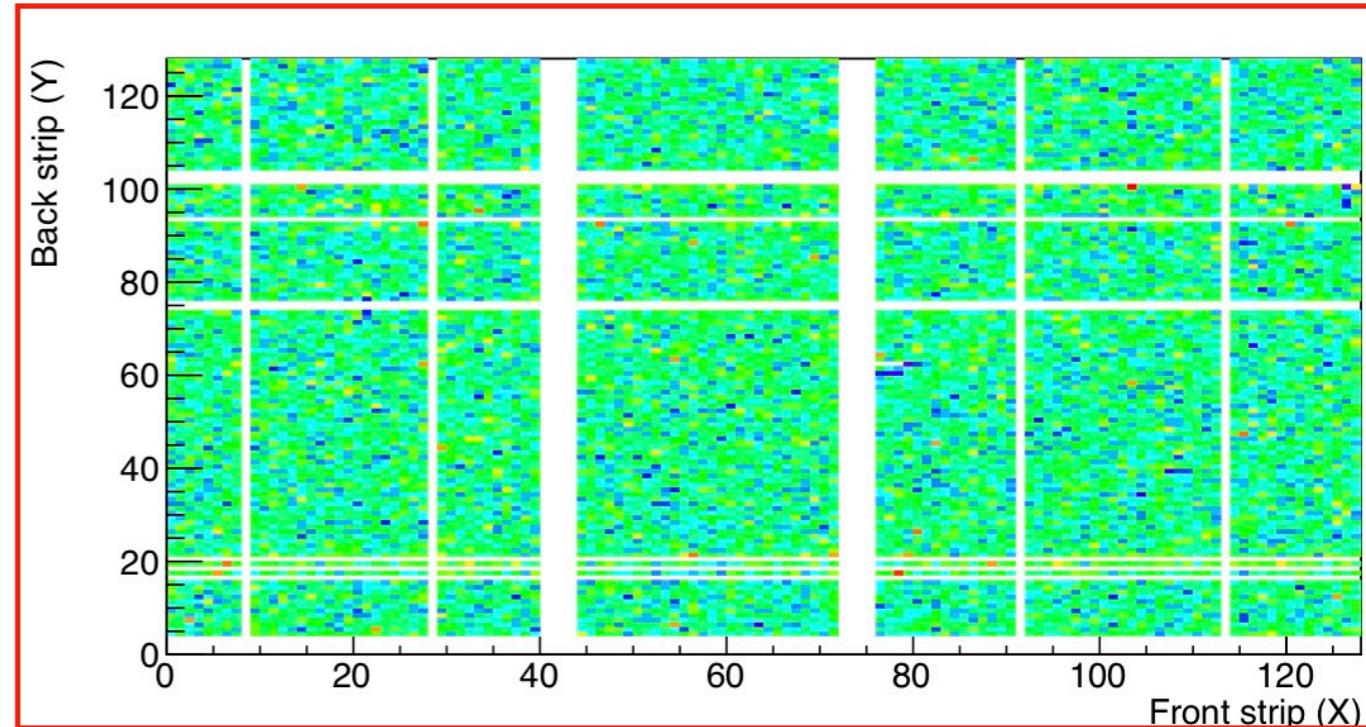
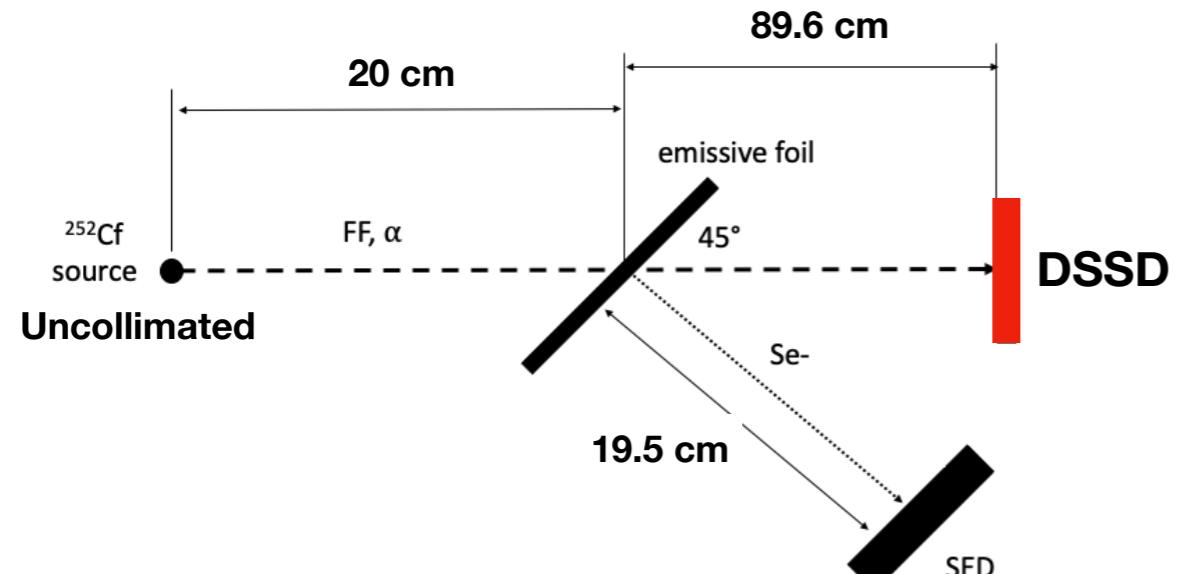
Using digital CFD



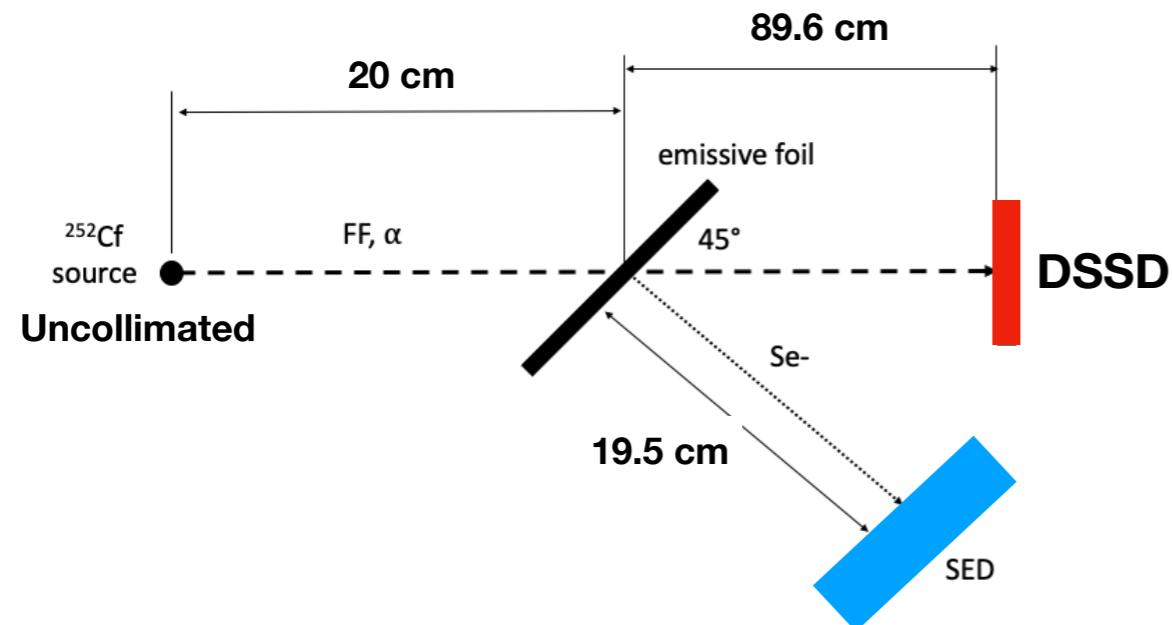
Time of Flight test using a ^{252}Cf source



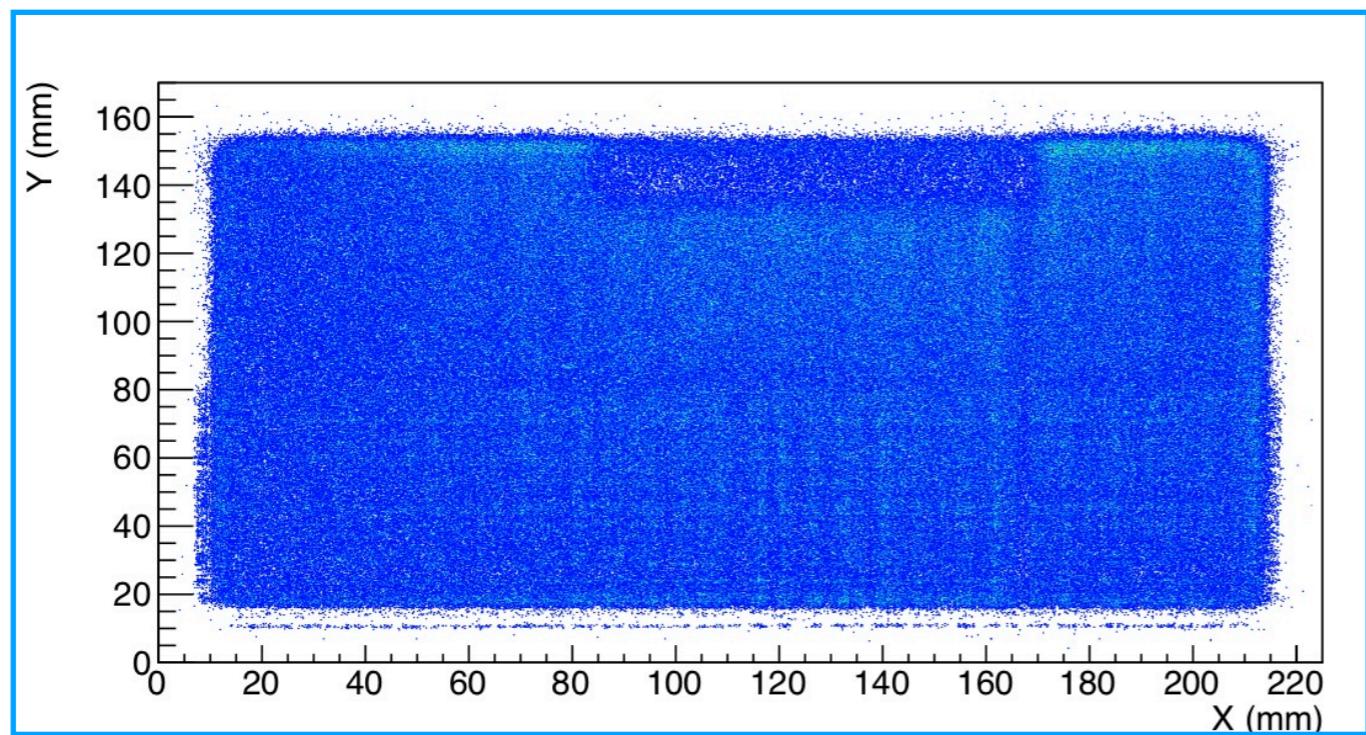
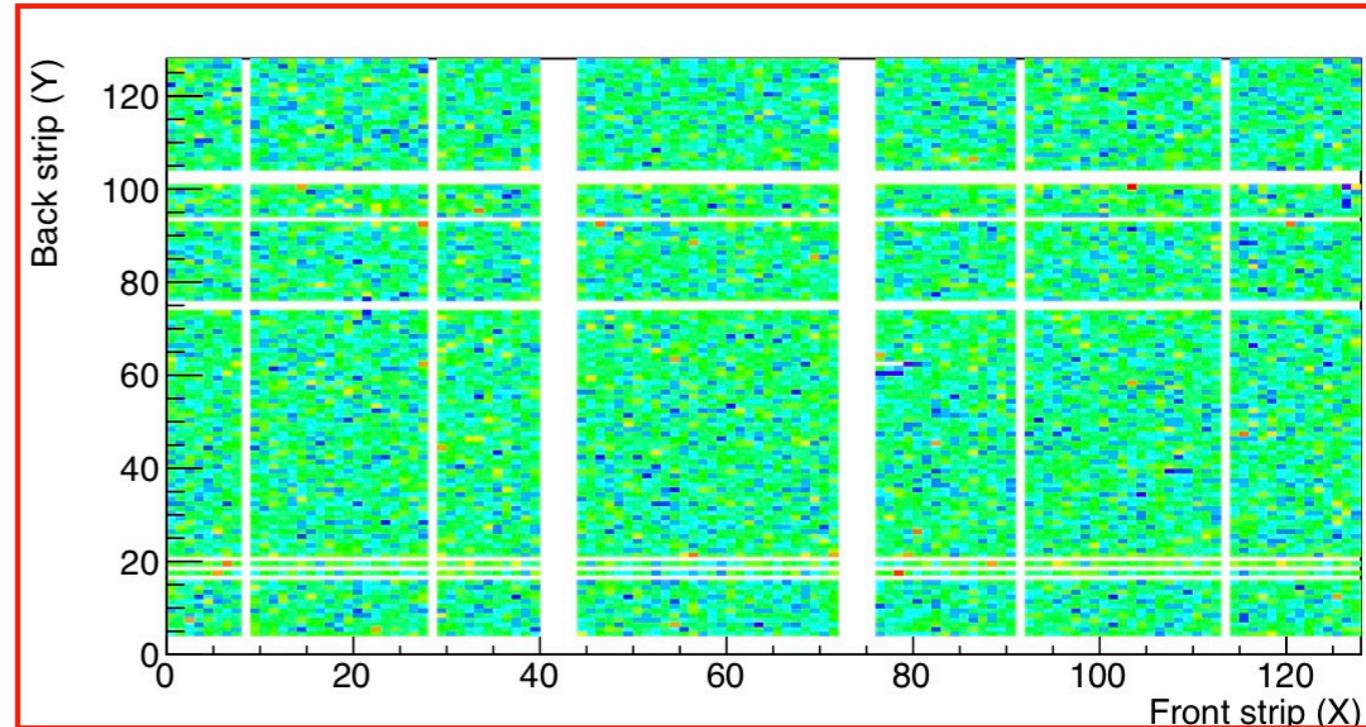
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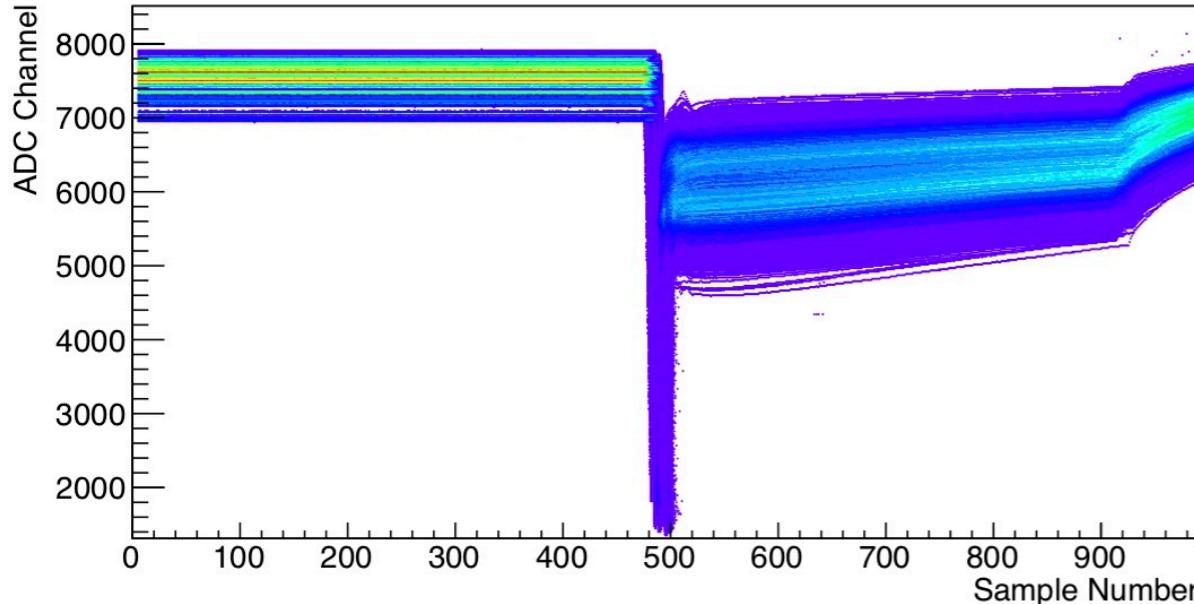
Uncollimated



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

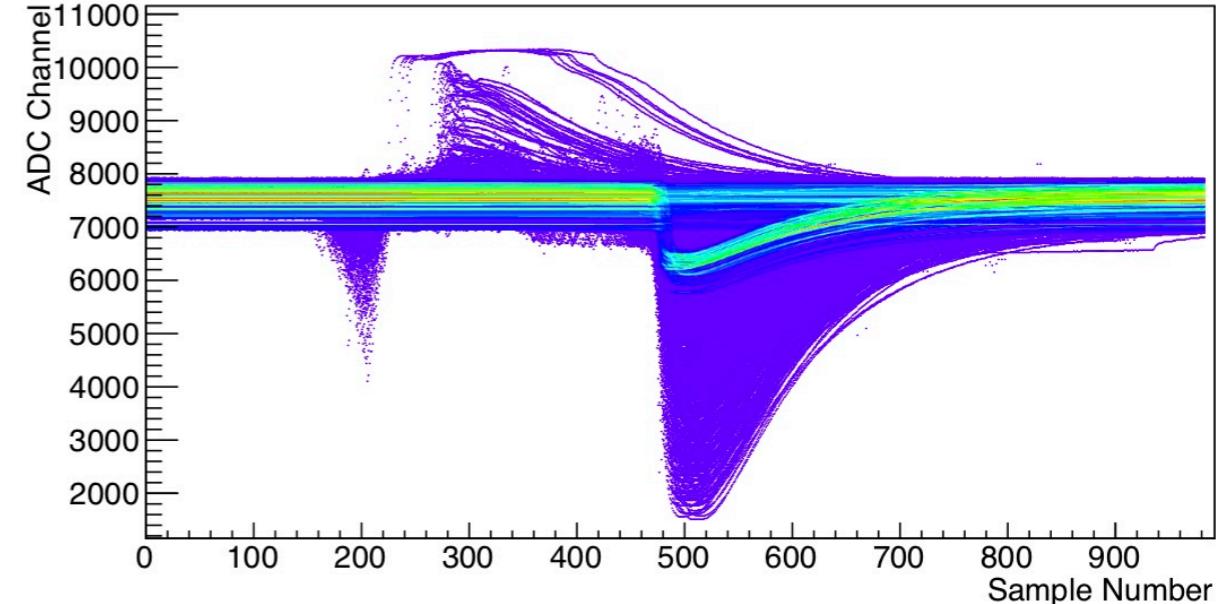
Fission fragments

Front strips' traces: Gain switched

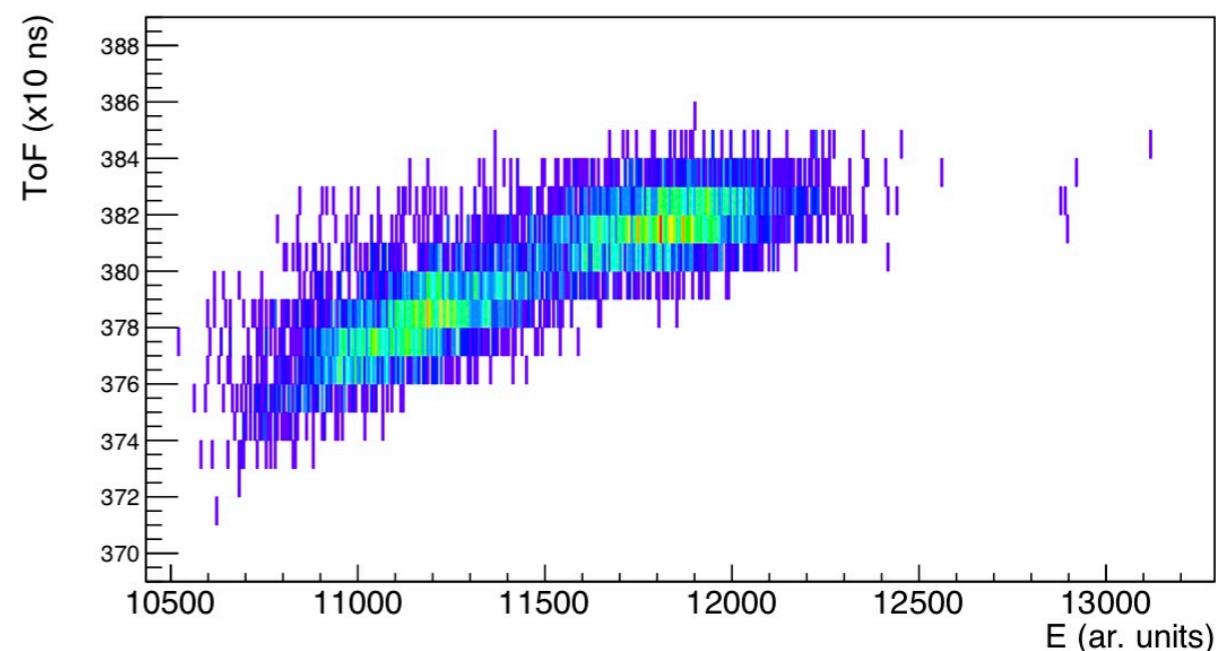
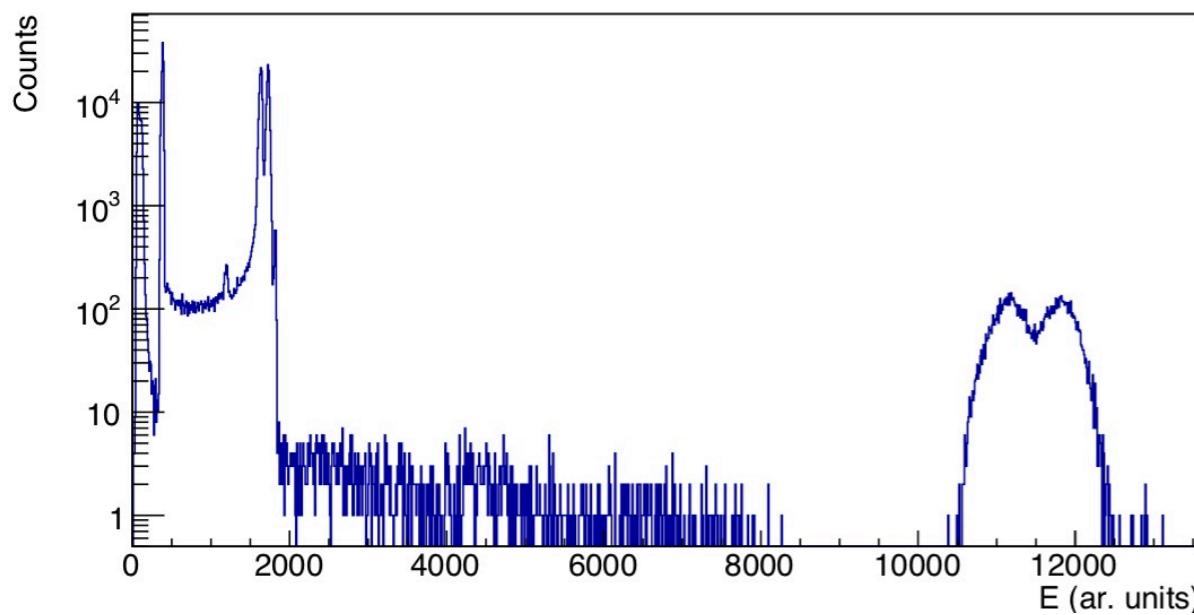


E (Front Strips)

Front strips' traces: Gain not switched



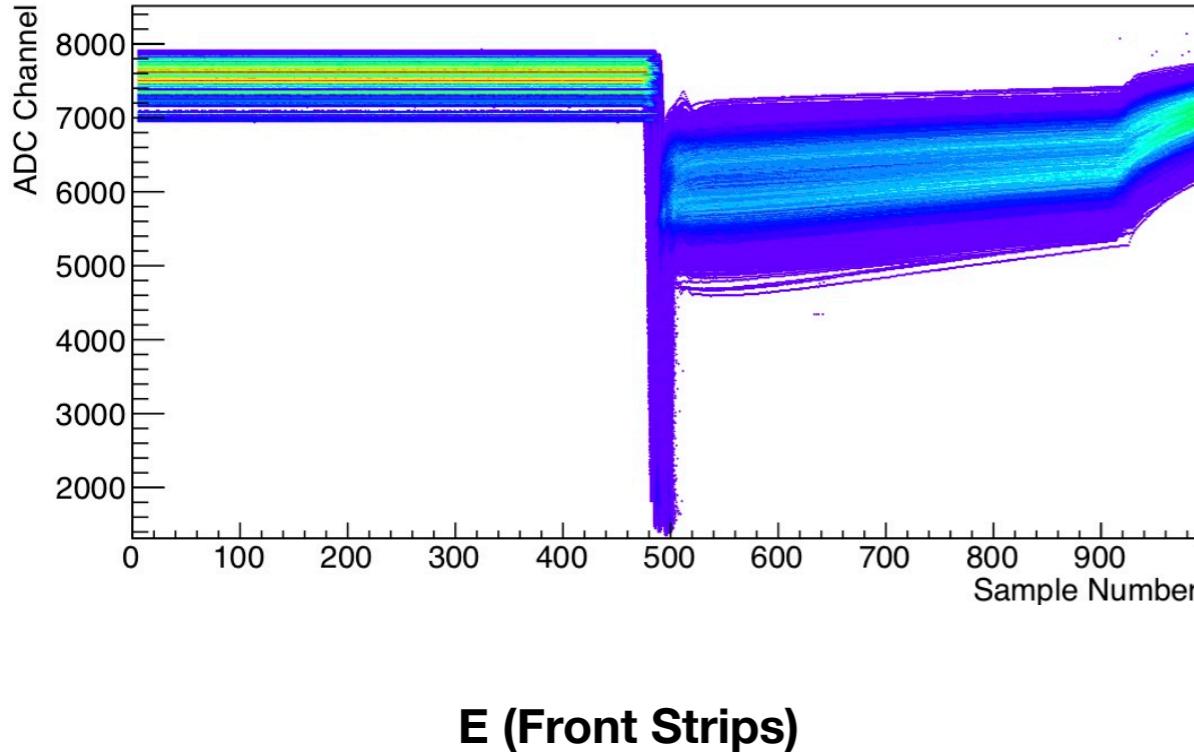
Time of flight from the DSSD and tracker timestamps



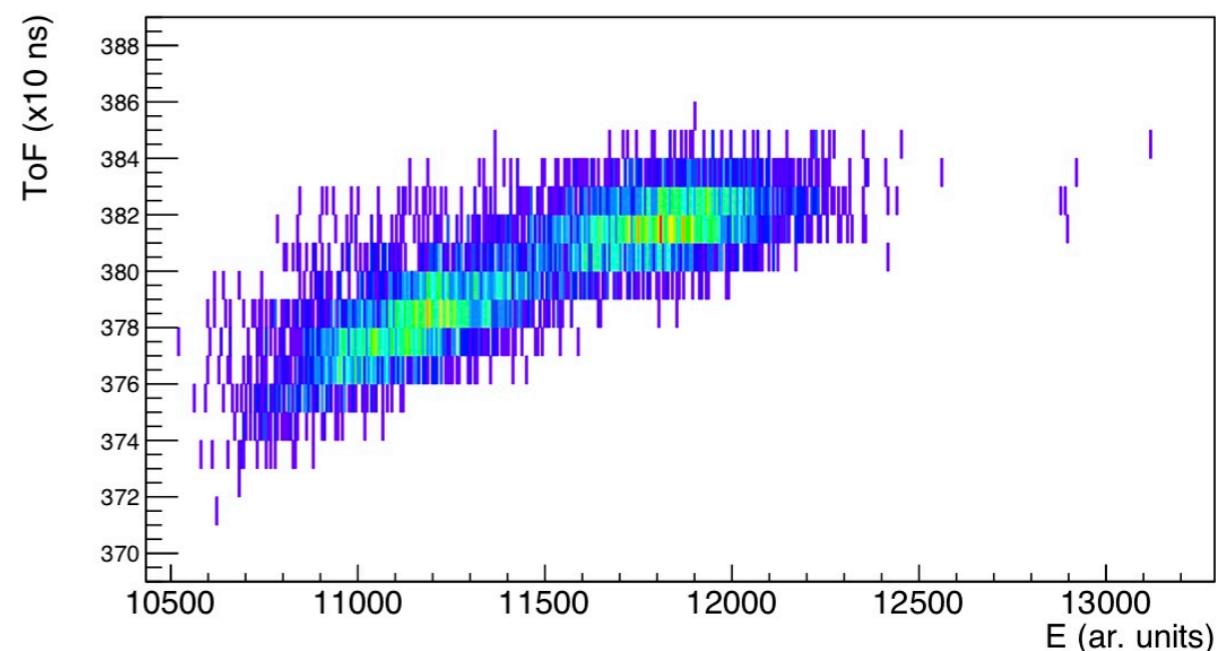
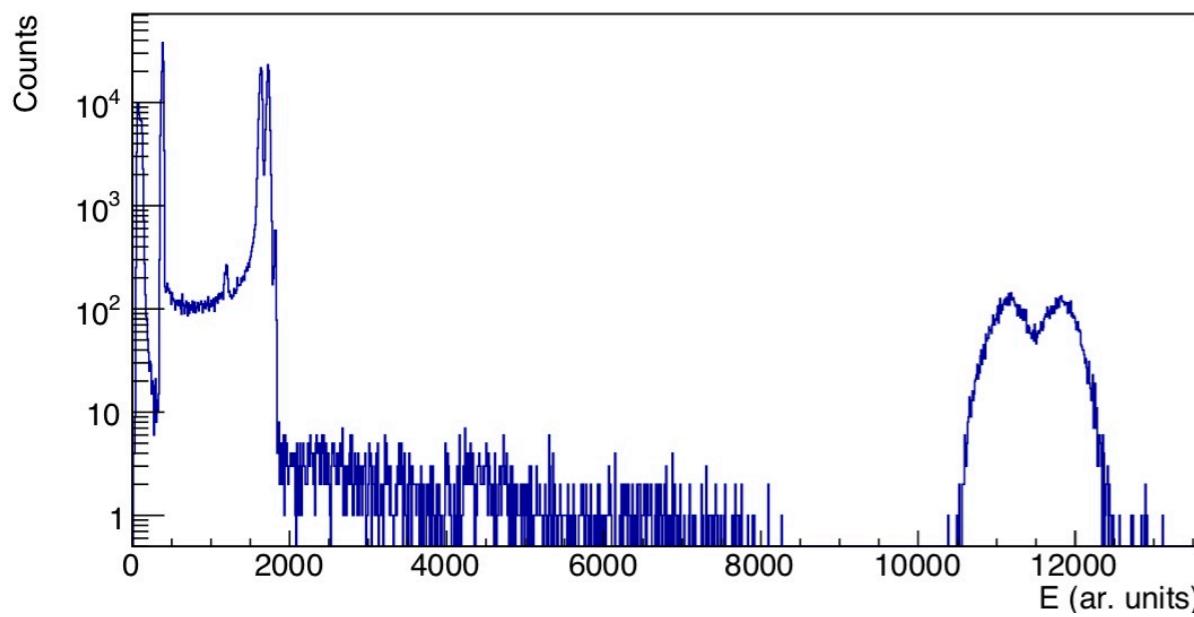
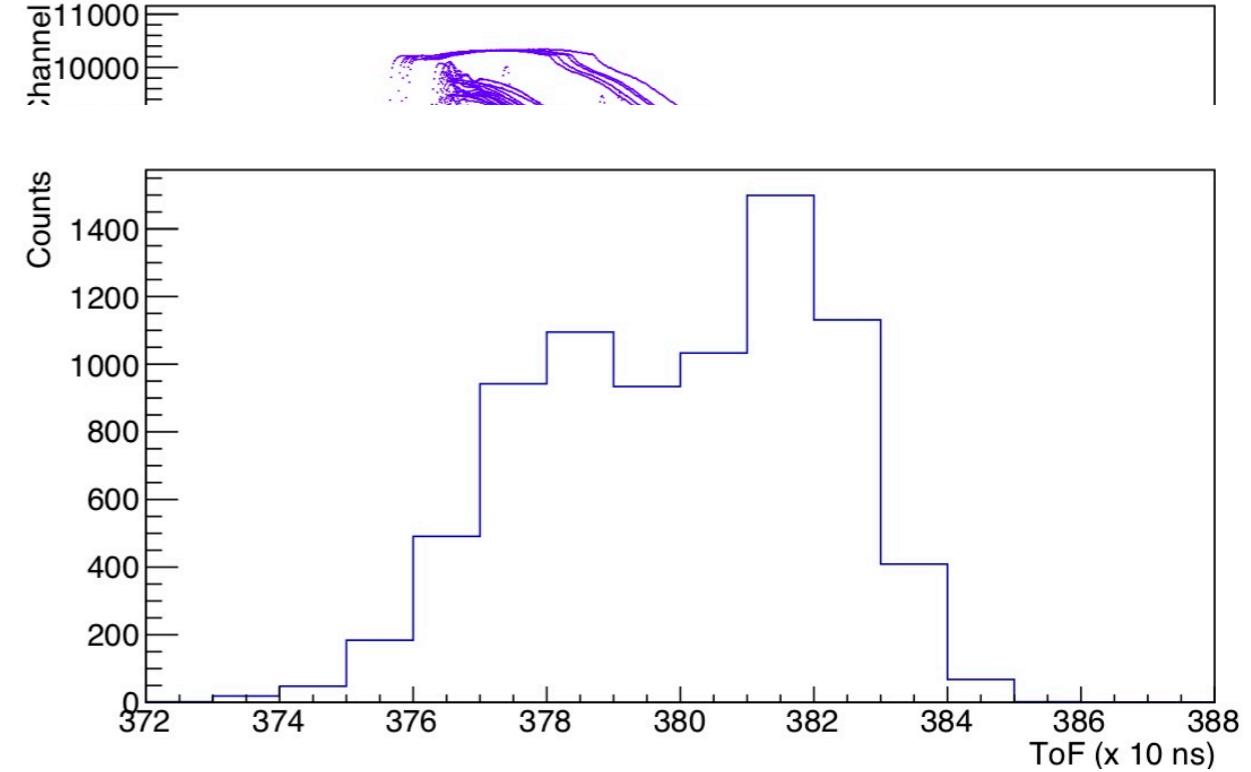
Time of Flight test using a ^{252}Cf source

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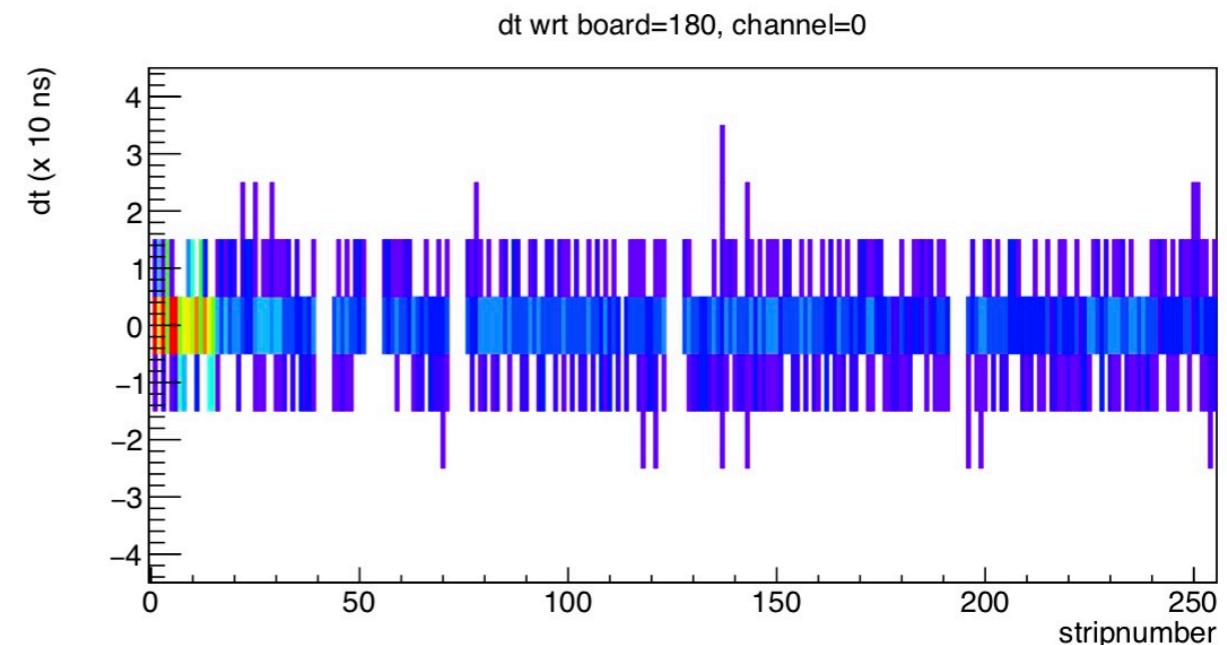
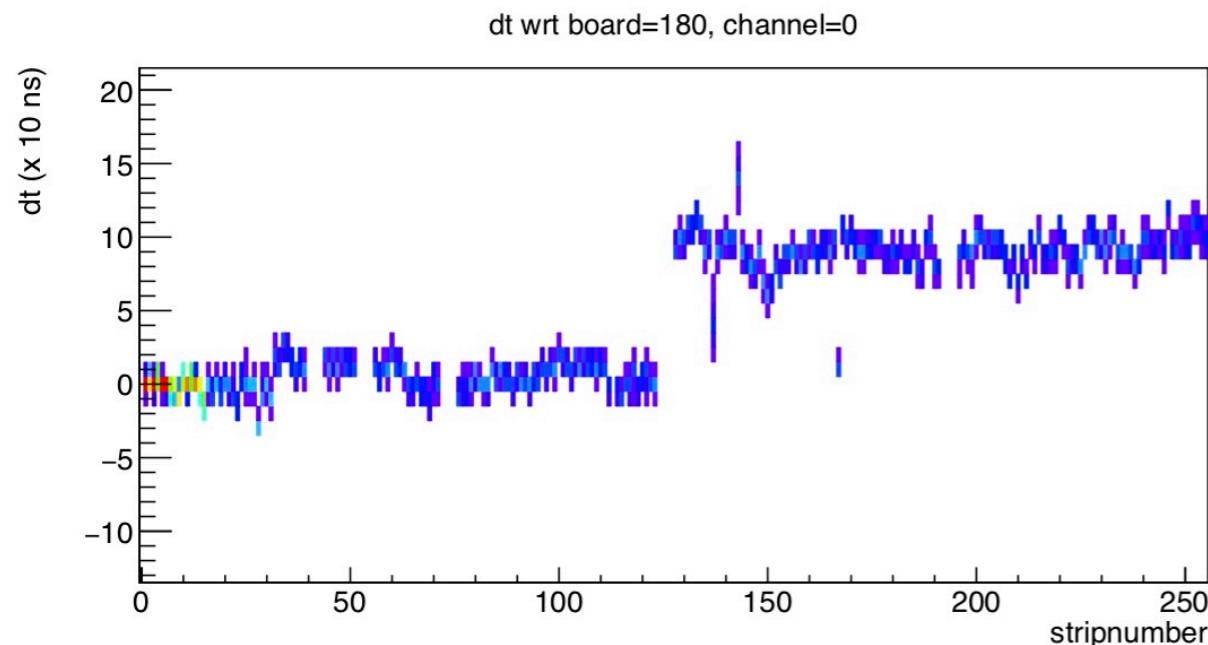
Time of Flight test using a ^{252}Cf source

Analysis still ongoing to extract the time resolution using the CFD method

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

Analysis still ongoing to extract the time resolution using the CFD method

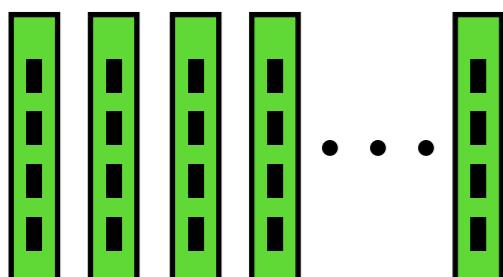
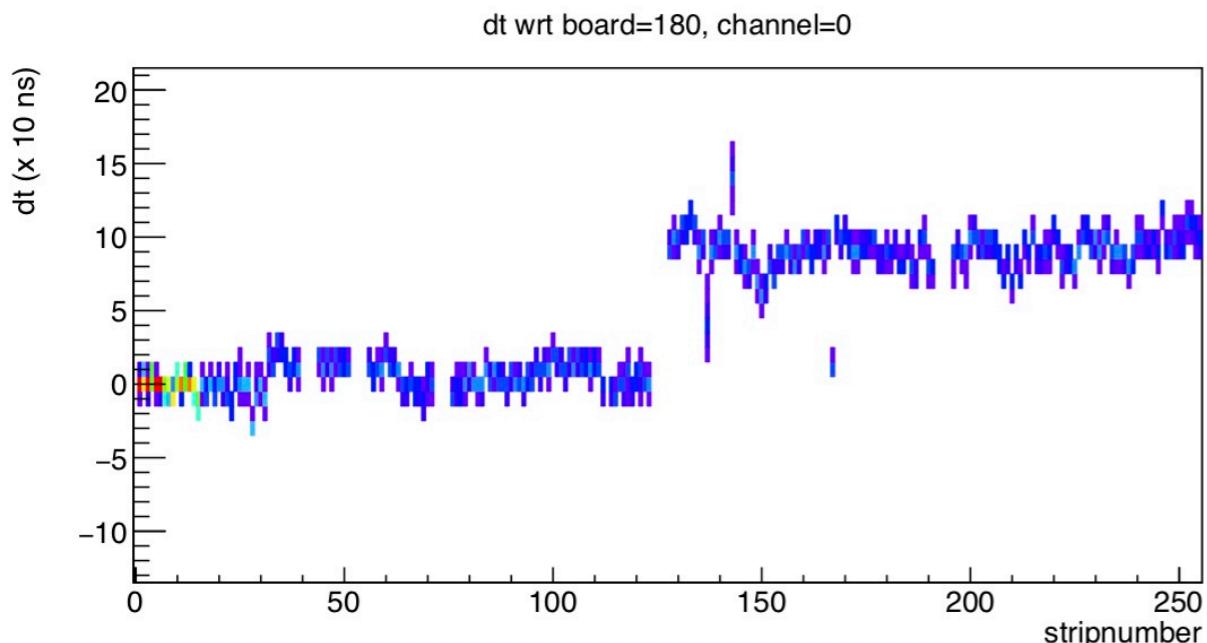
Timestamp alignment



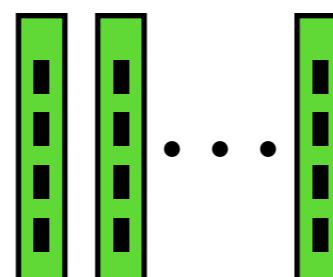
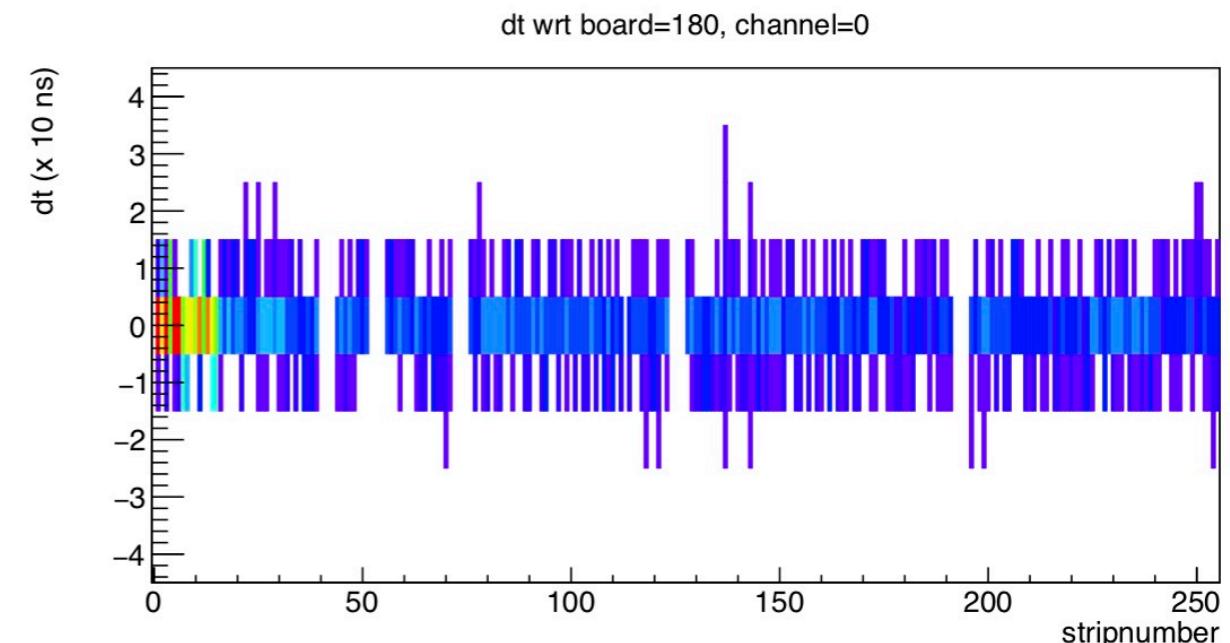
Time of Flight test using a ^{252}Cf source

Analysis still ongoing to extract the time resolution using the CFD method

Timestamp alignment



16 Numexo2 modules for the DSSD



6 Numexo2 modules for the tunnel detectors



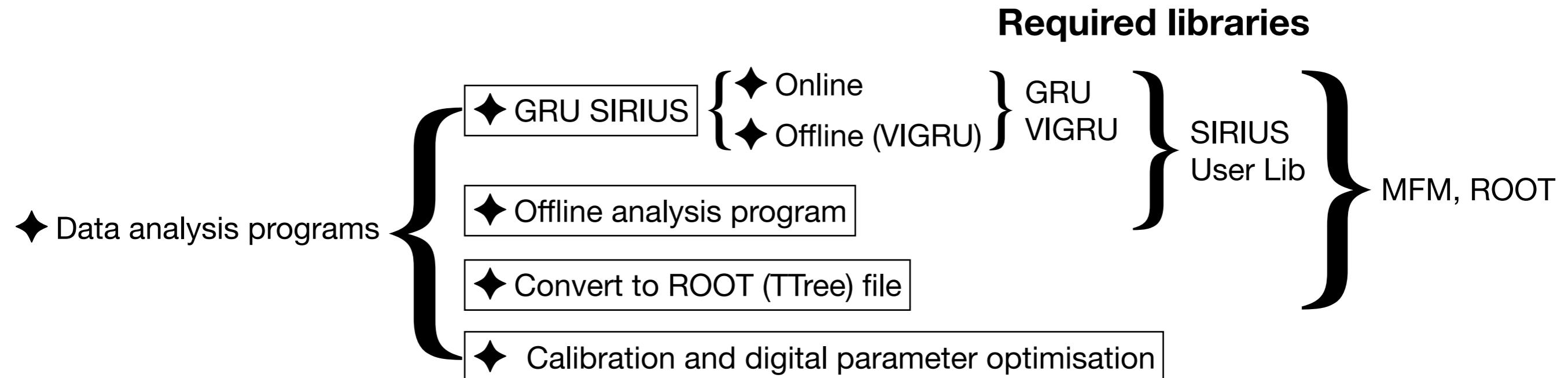
1 Numexo2 module for the tracker time signal



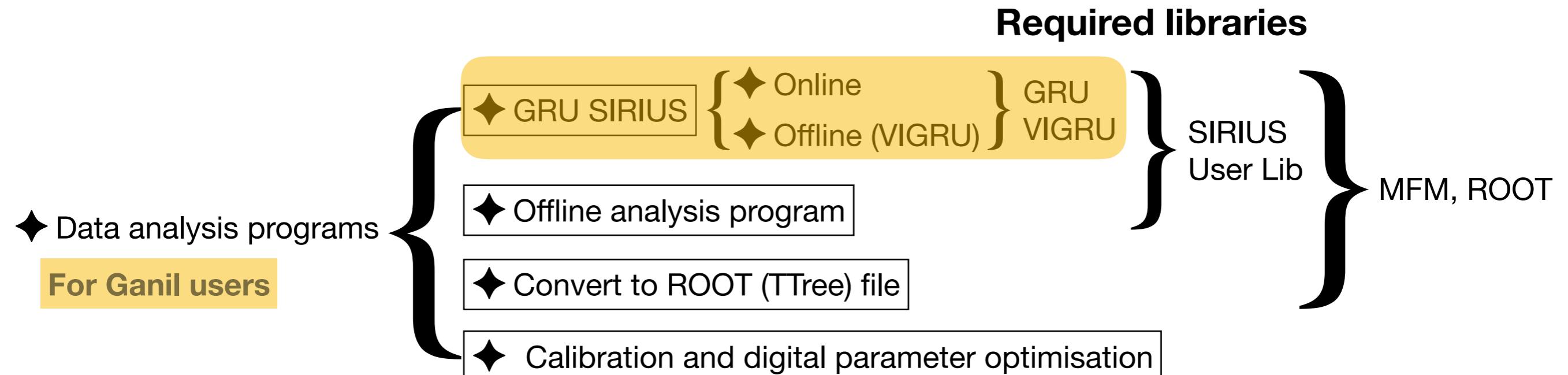
For the tracker Time and position information

Merging of data for highly asymmetric data flow from various modules is being prepared for both online and offline analysis

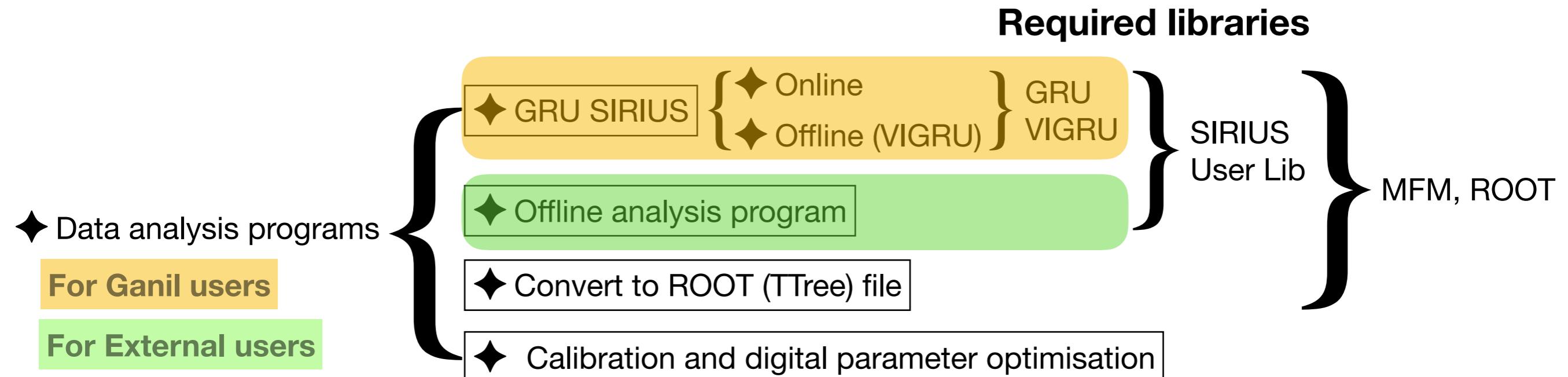
Developments for the users



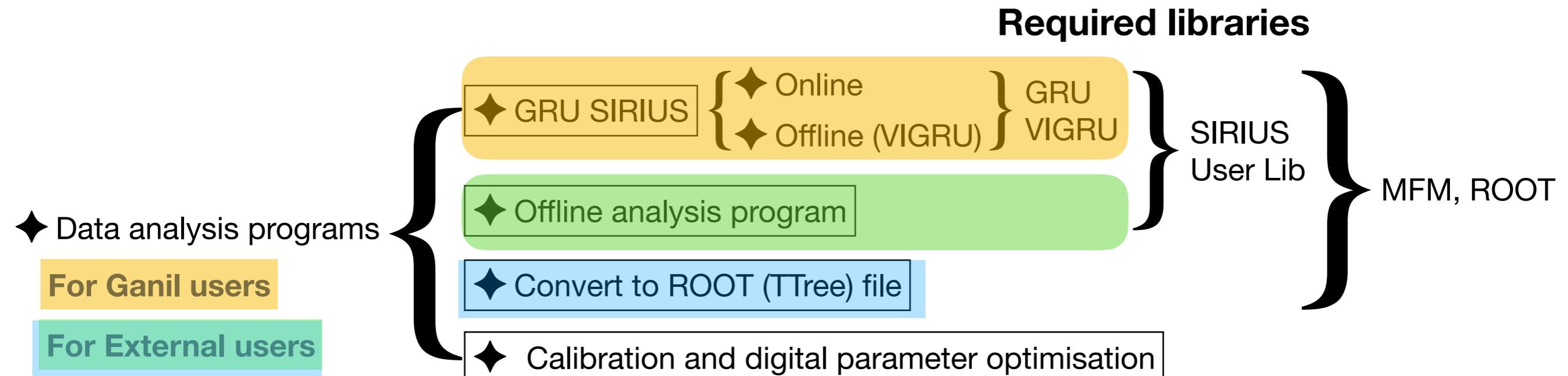
Developments for the users



Developments for the users



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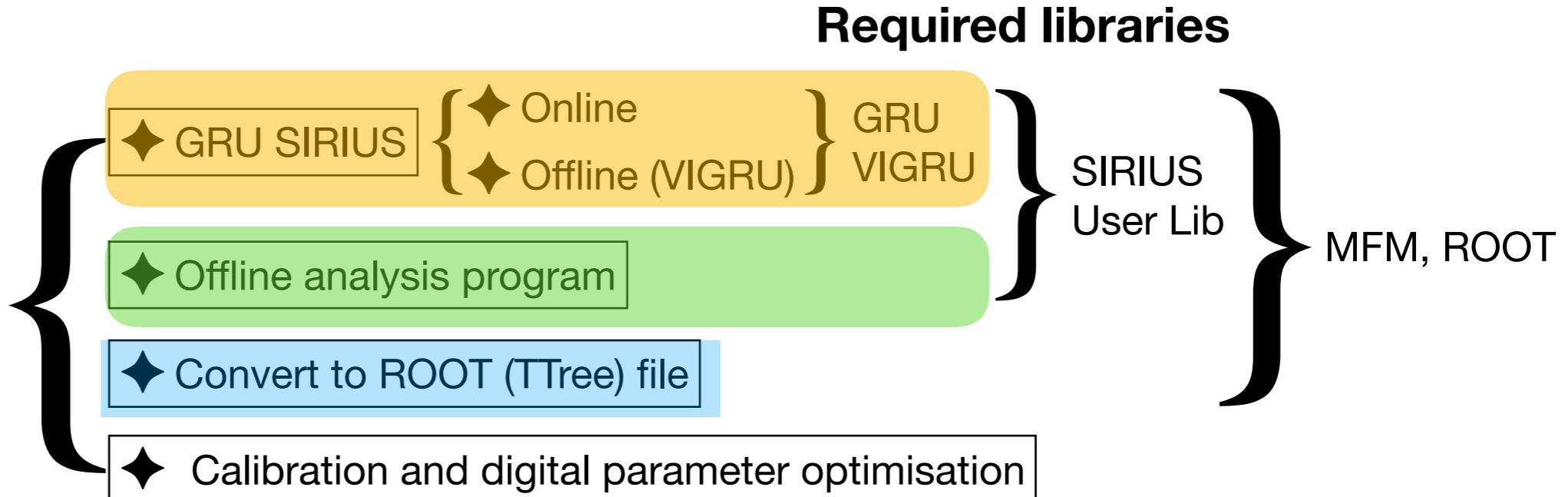


Developments for the users

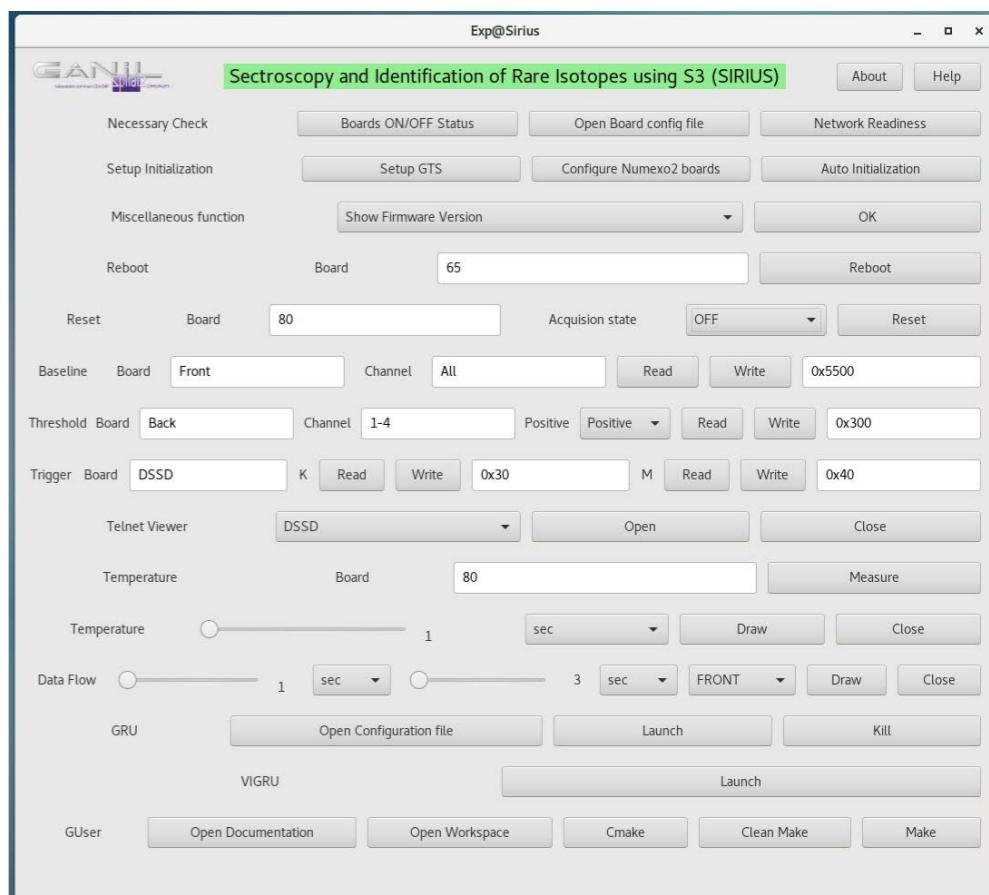
◆ Data analysis programs

For Ganil users

For External users



◆ A Graphical User Interface

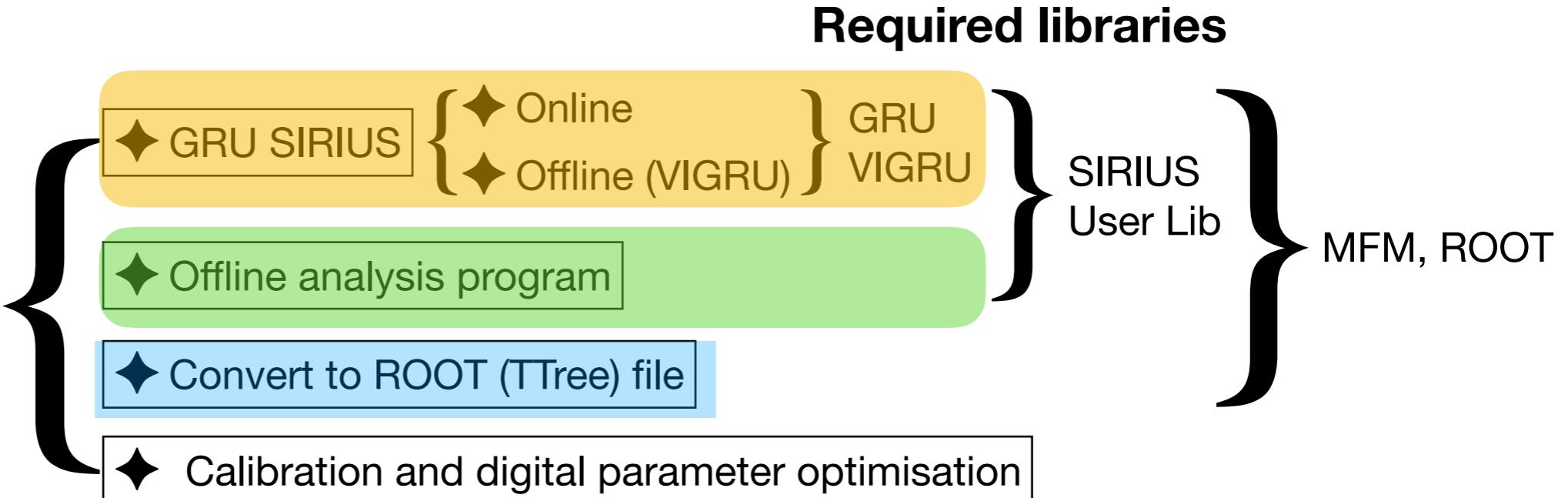


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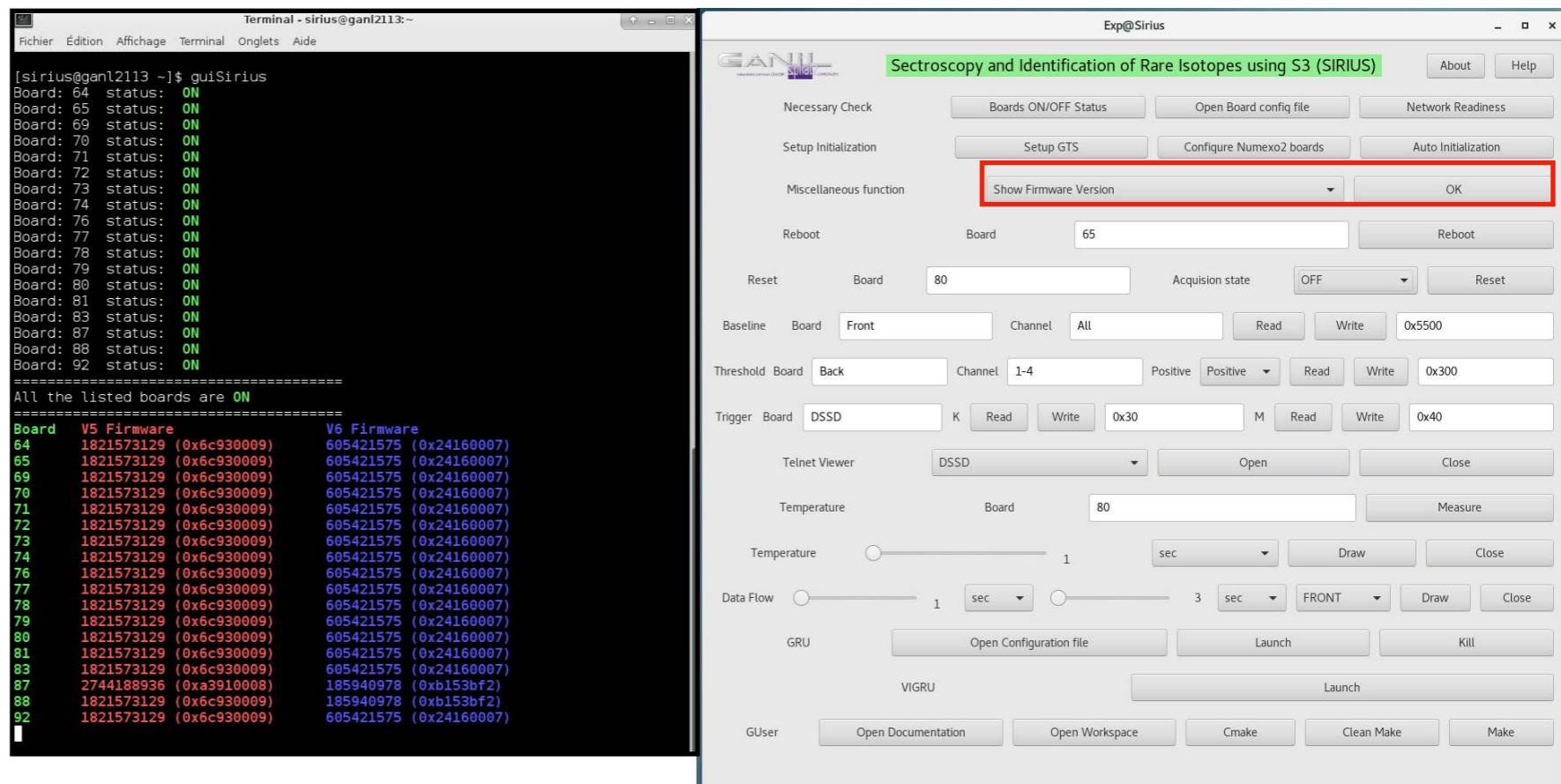
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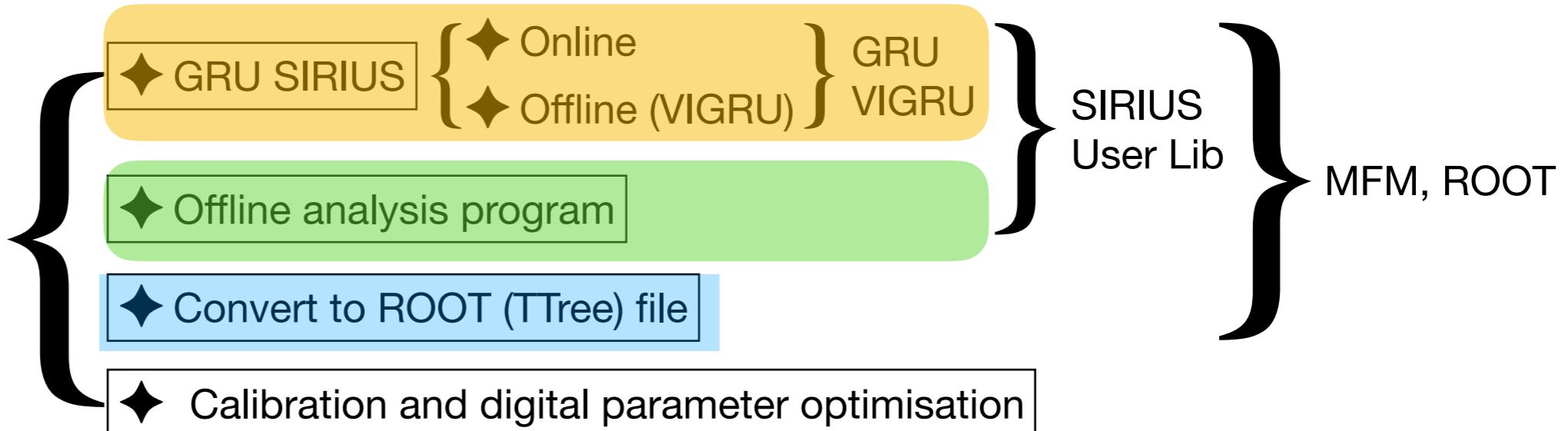
Developments for the users

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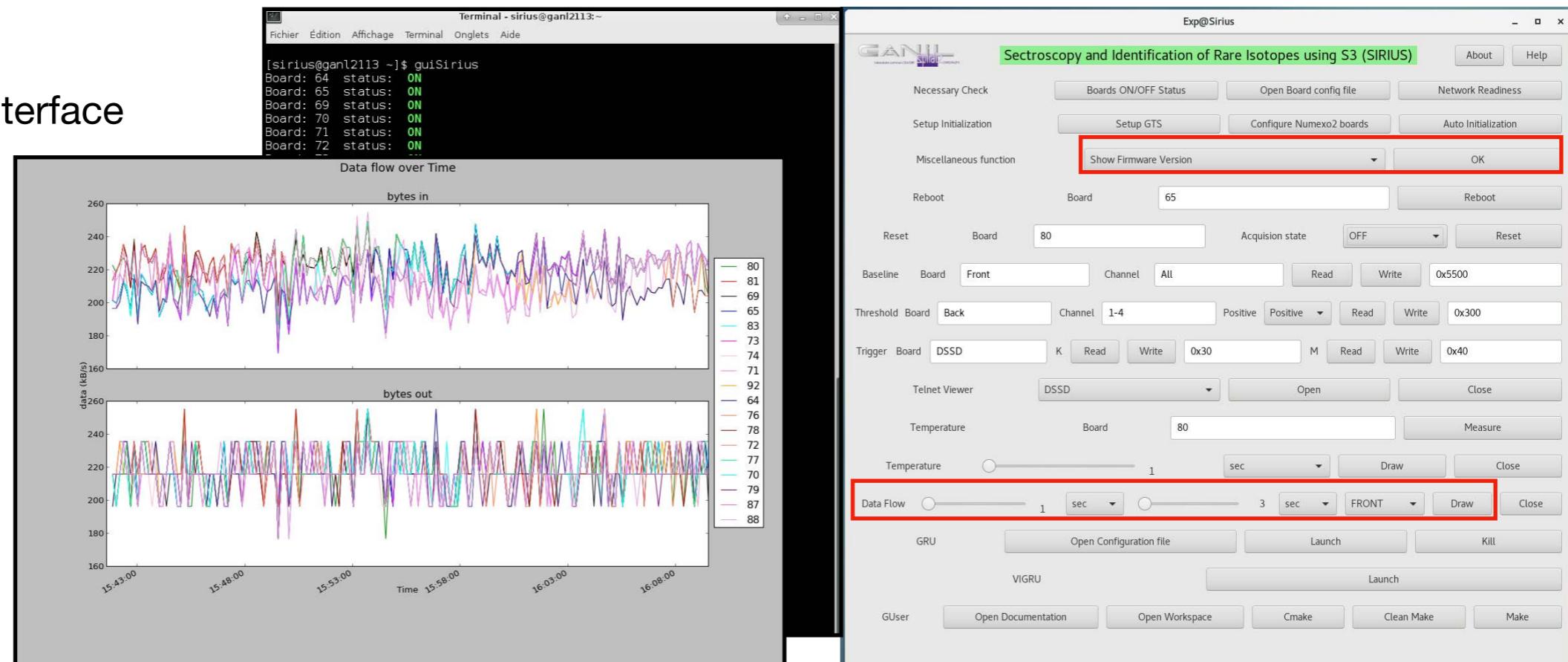
For Ganil users

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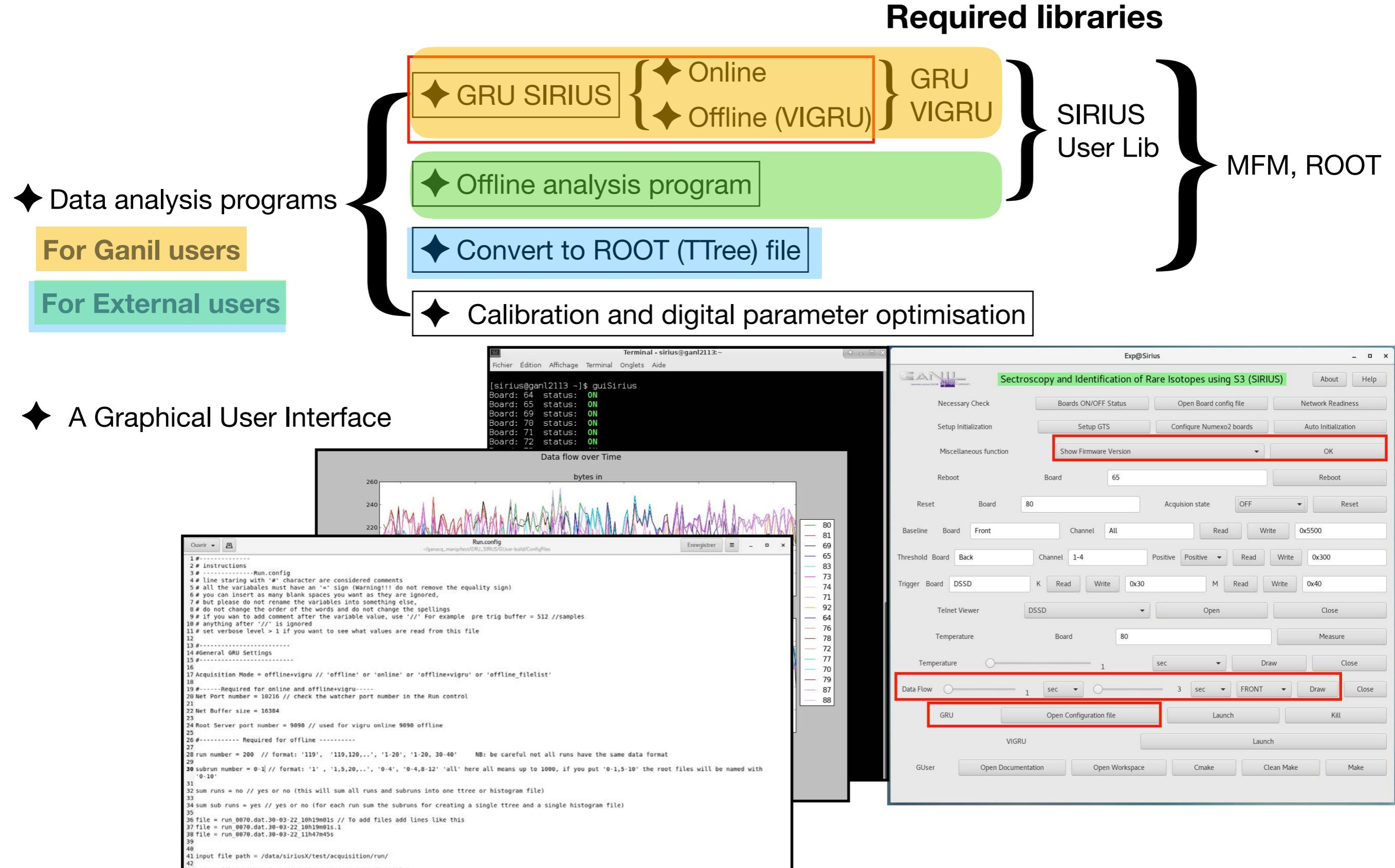
Required libraries



◆ A Graphical User Interface



Developments for the users

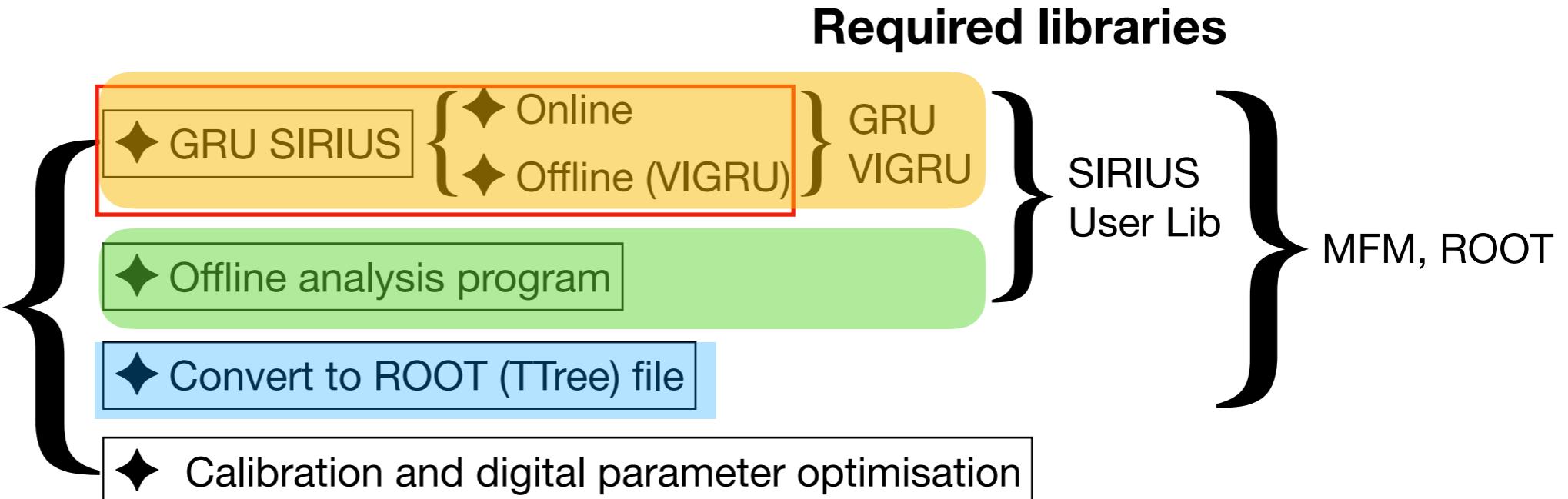


Developments for the users

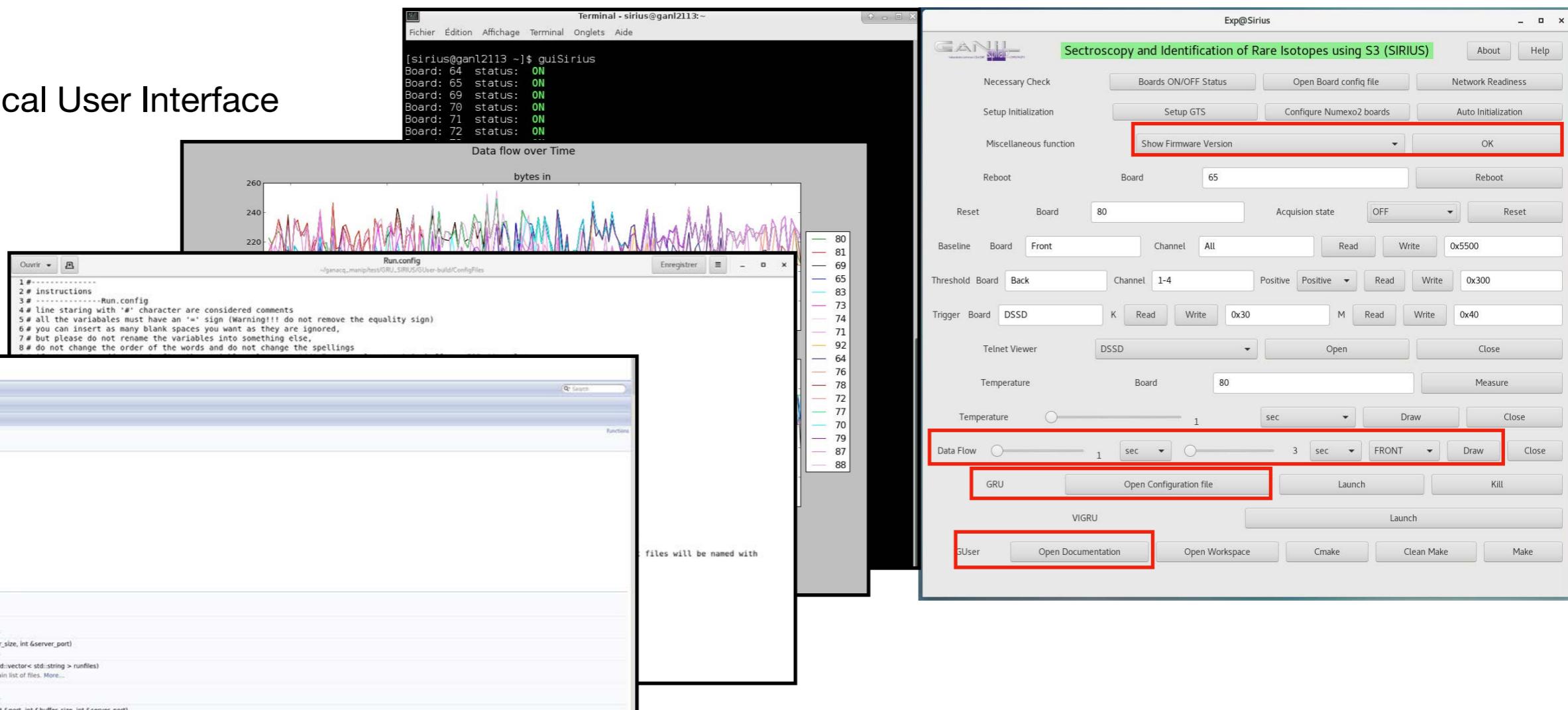
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Conclusions and outlook

- The DSSD and the tunnel detectors have been fully instrumented
- Their performance has been tested
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SIRIUS will be ready by the end of this year

Thank you for your attention

SIRIUS Collaboration

- ❖ GANIL : R. Chakma, J. Piot, D. Ackermann, M. Blaizot, A. Boujrad, L. Cáceres, E. Clément, S. Coudert, J. Goupil, S. Herlant, G. Lebertre, F. Lutton, C. Maugeais, J. Pancin, F. Saillant, H. Savajols, G. Wittwer, C. Houarner
- ❖ 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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