

Waveform analysis with WAS3ABi for measurements of ion implantation and charged-particle decays

Marco Tik Tsun Yeung^{1,2}, Shunji Nishimura², Vi Ho Phong²

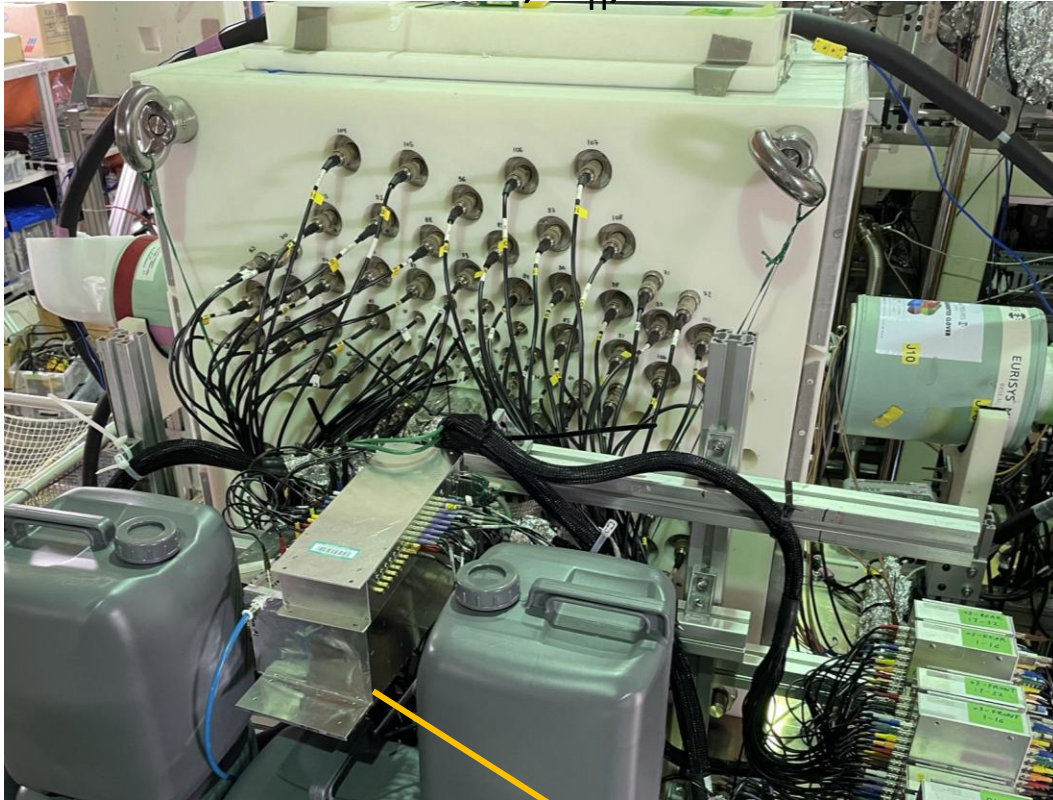
¹ The University of Tokyo

² RIKEN Nishina Center

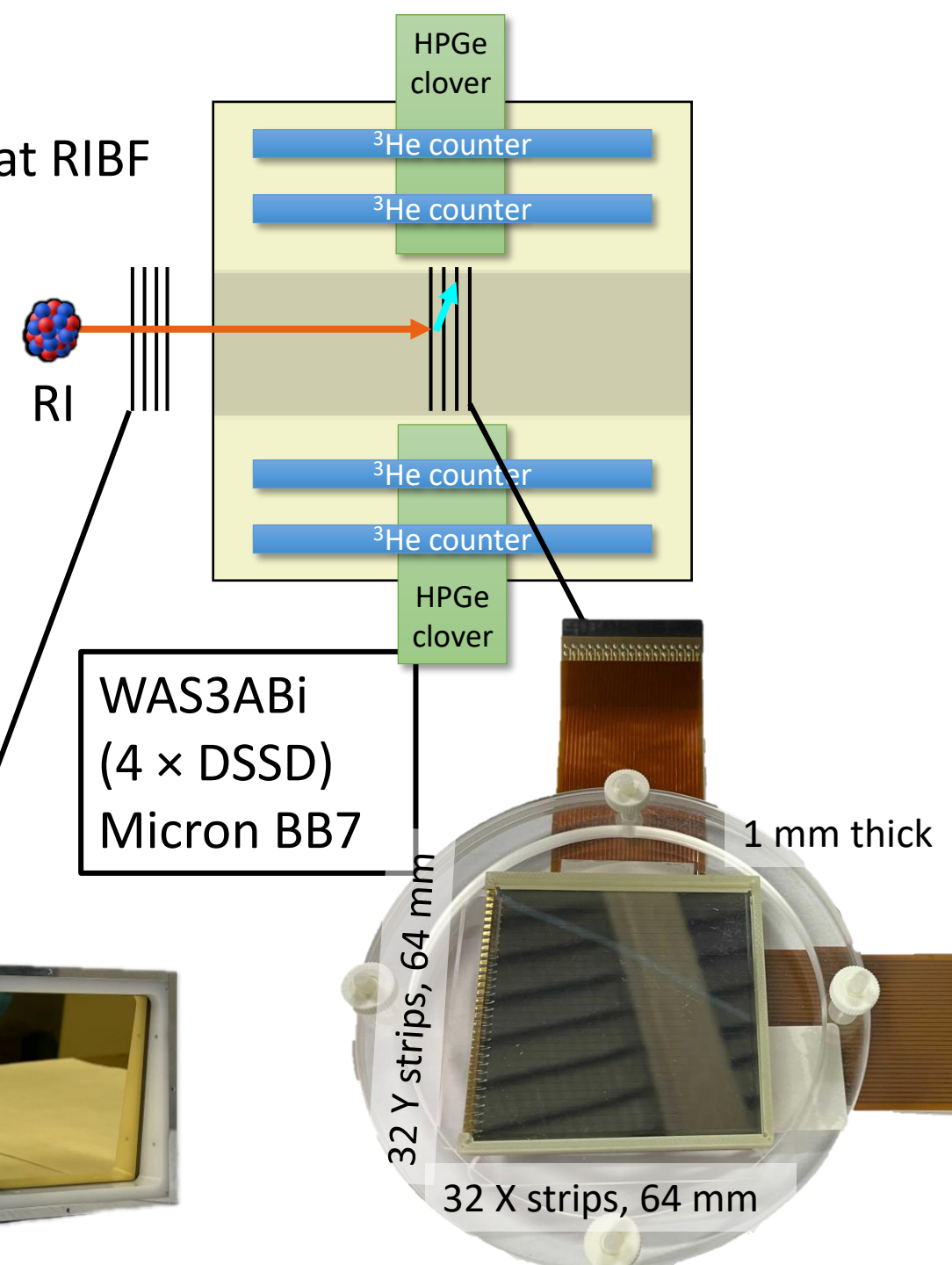


BRIKEN

- First physics experiment for neutron-rich $N=126$ at RIBF
- Measure half-life, P_n , isomer

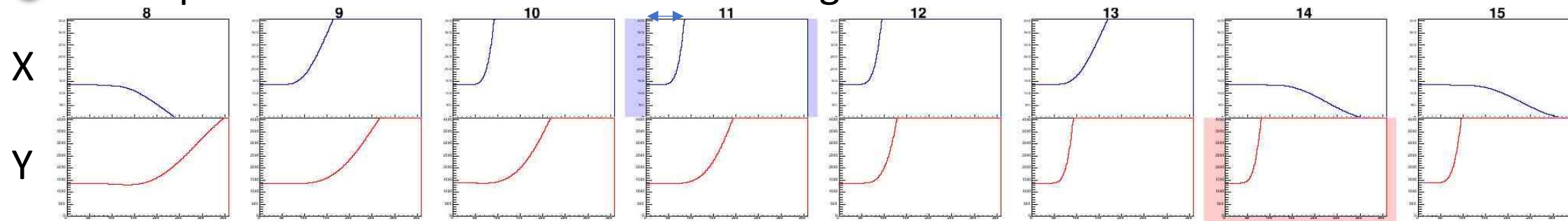


Silicon dE telescope
(4 × 600- μm Si)

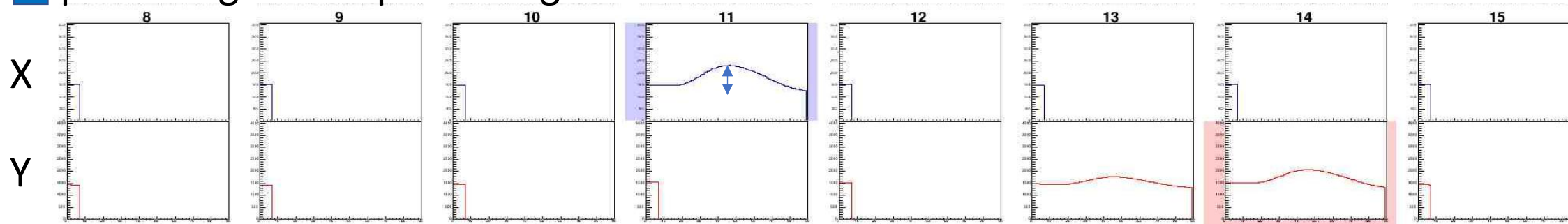


Position determination

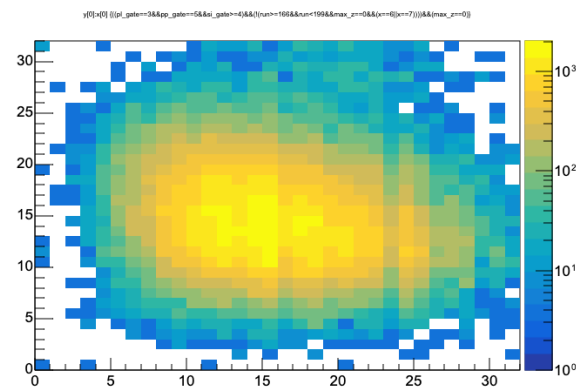
- Ion implantation: earliest saturation timing



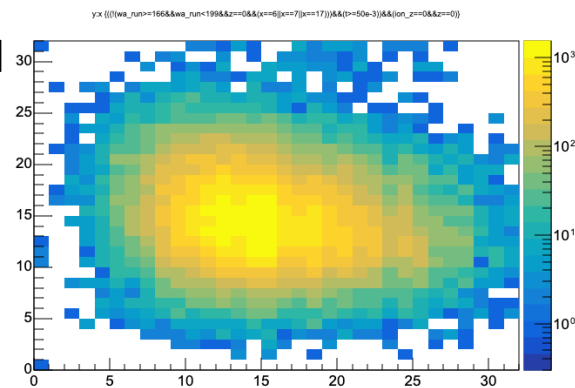
■ β event: greatest pulse height



- Ion implantation



■ RI-correlated β decay

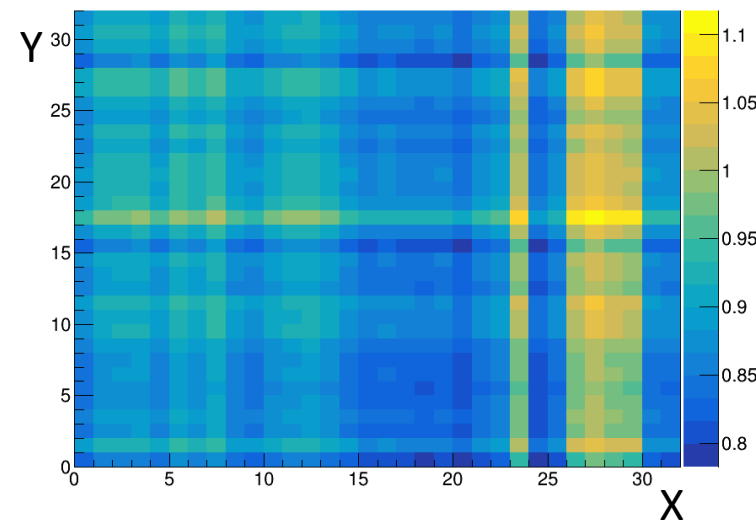
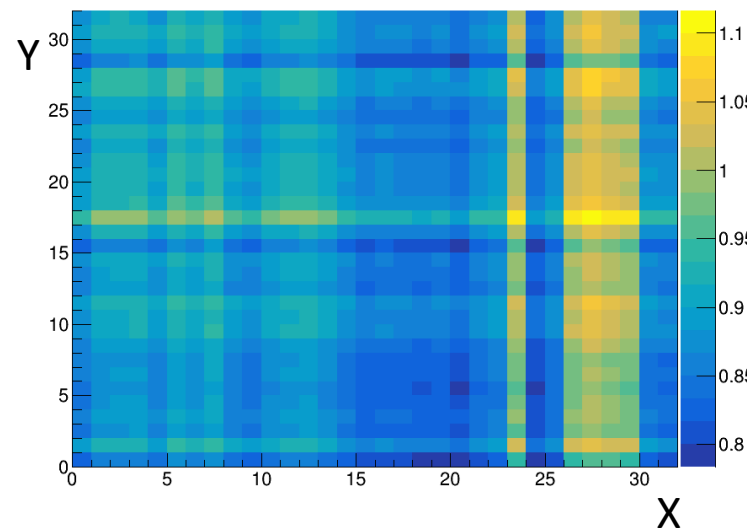
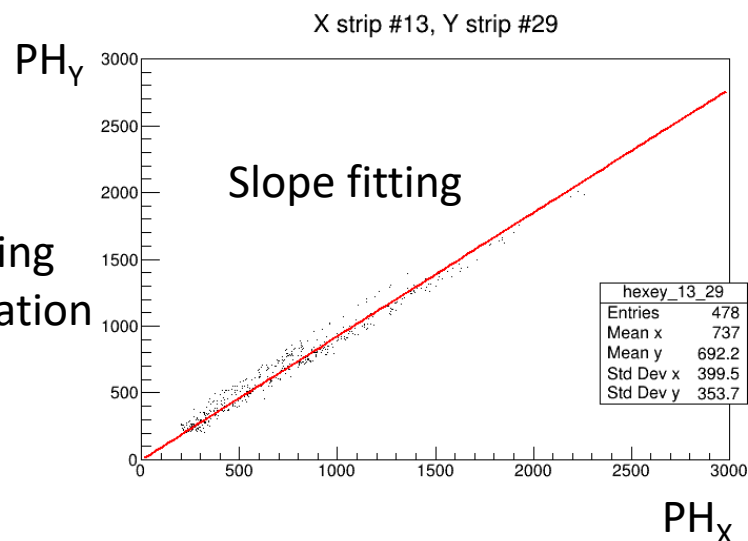


Energy calibration

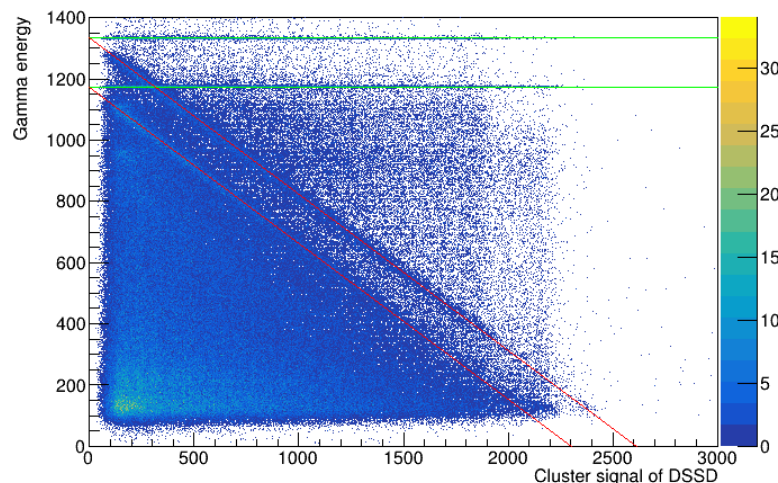
M. Reese et al., Nucl. Instrum. Methods Phys. Res., 779, 63-68 (2015)

Experimental slope

Reconstructed slope

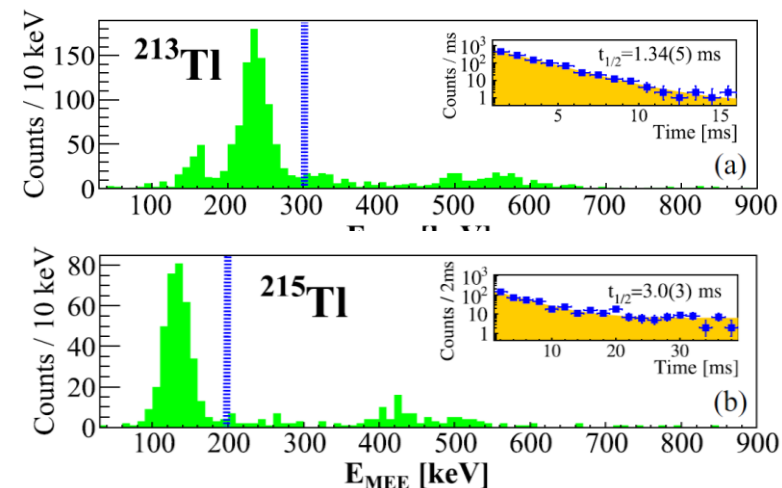


Compton scattering
(35 keV @ 282 keV)

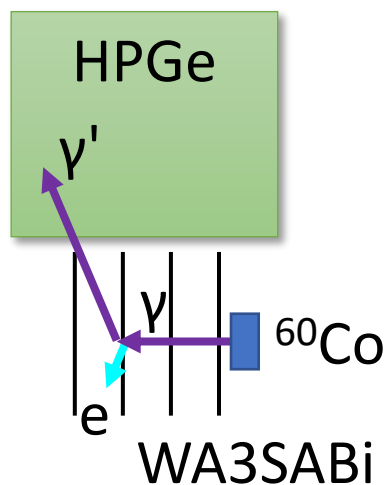


Energy threshold > 50 keV

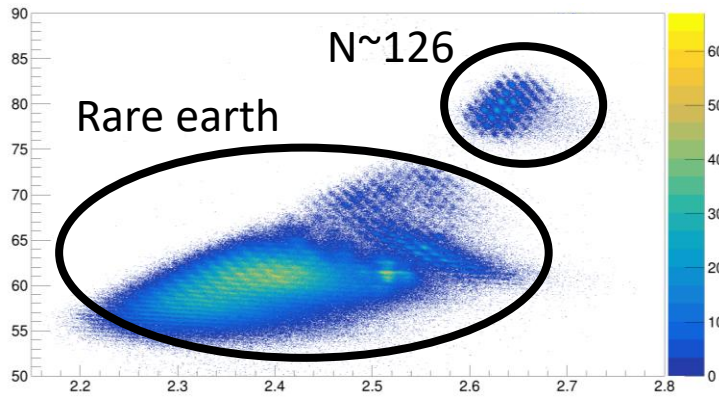
Conversion electron
(36.5 keV @ 236 keV)



T. T. Yeung et al., Phys. Rev. Lett. **133**, 072501 (2024)



Challenges



Unwanted RI &
light particle

Noise

Long half-life

Waveform filter

Limited dynamic range
(High gain: 1.5 MeV)
(Low gain: 15 MeV)

α decay
(8 MeV)

Implantation
(10 GeV)

Energy reconstruction
from waveform

Why waveform?

Extract more information!

Waveform analysis (flash ADC)

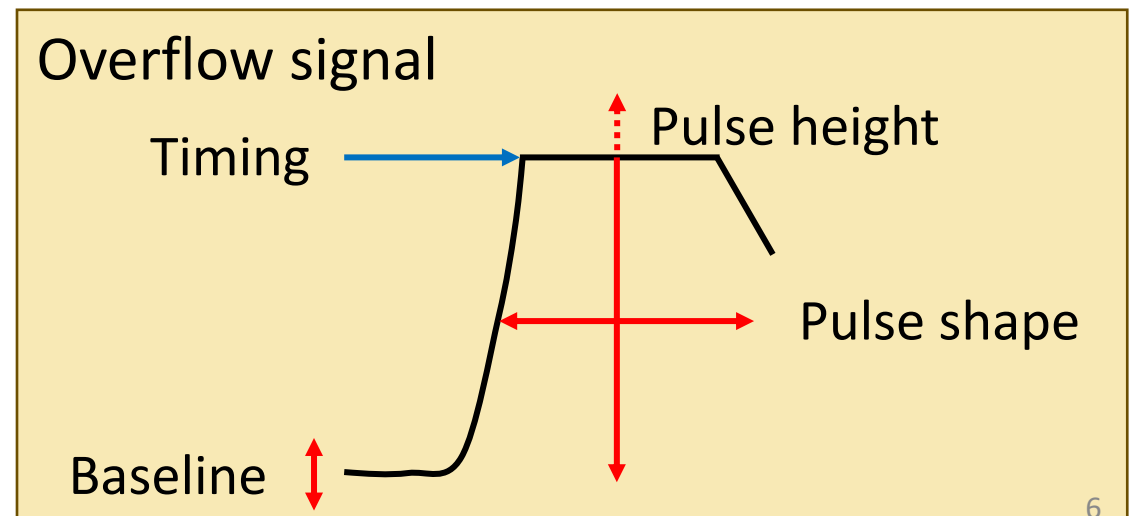
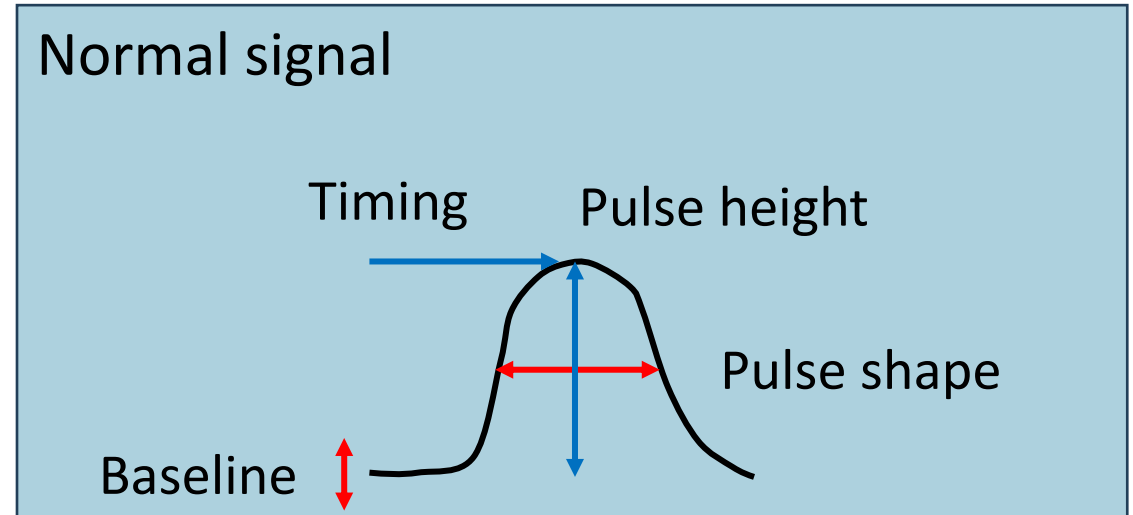
Conventional readout

Output data:

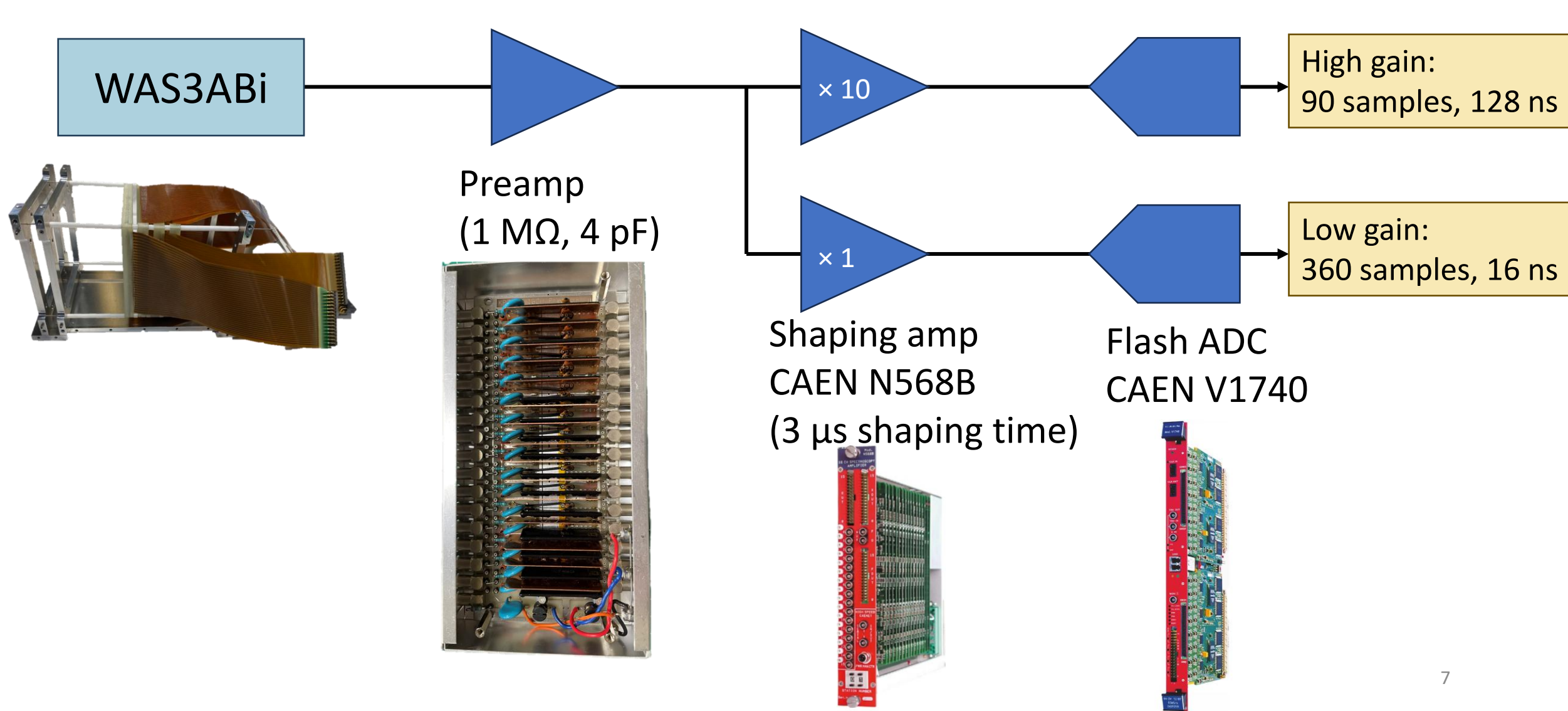
- Pulse height (ADC)
- Timing (TDC)

Output data:

- ~~Pulse height (ADC)~~
- Timing (TDC)

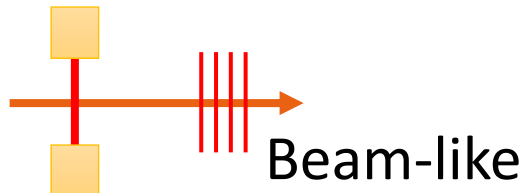
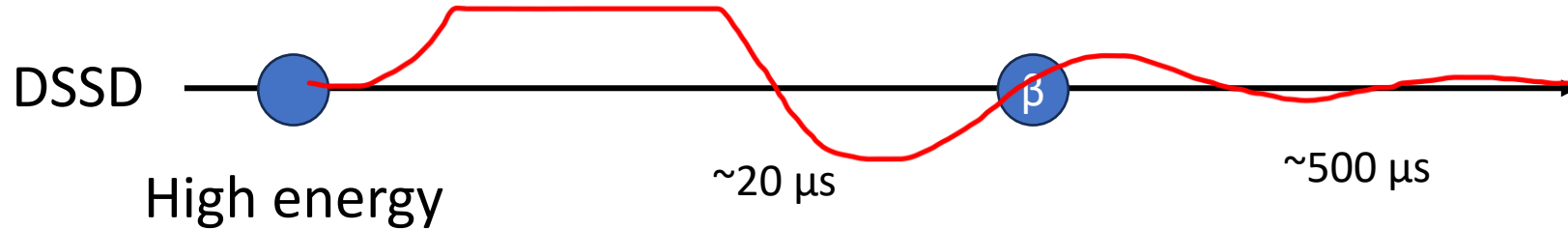
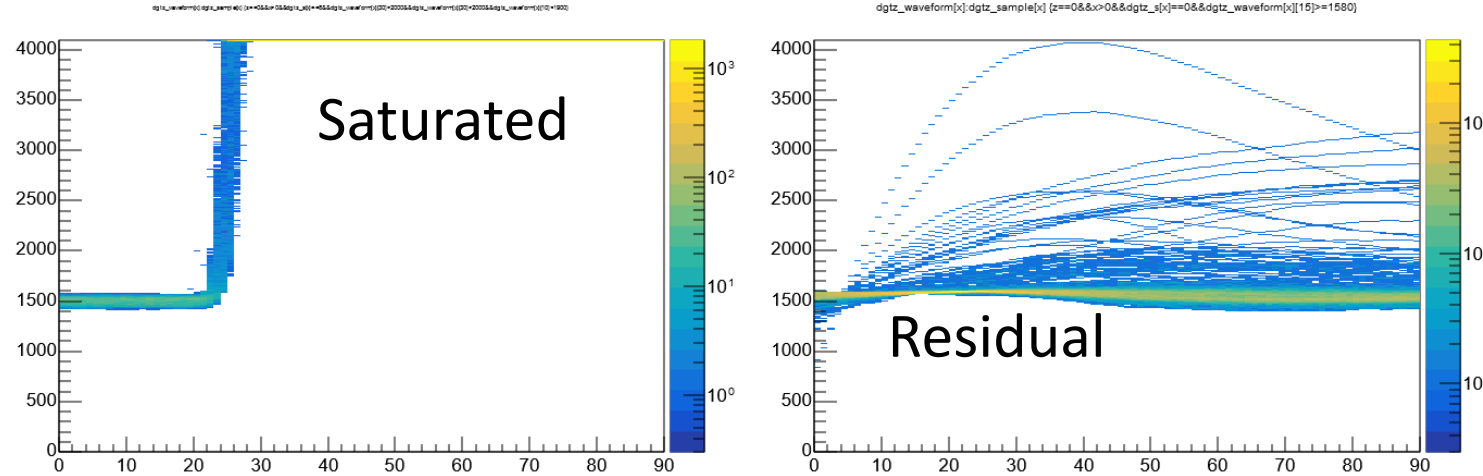


Waveform recording

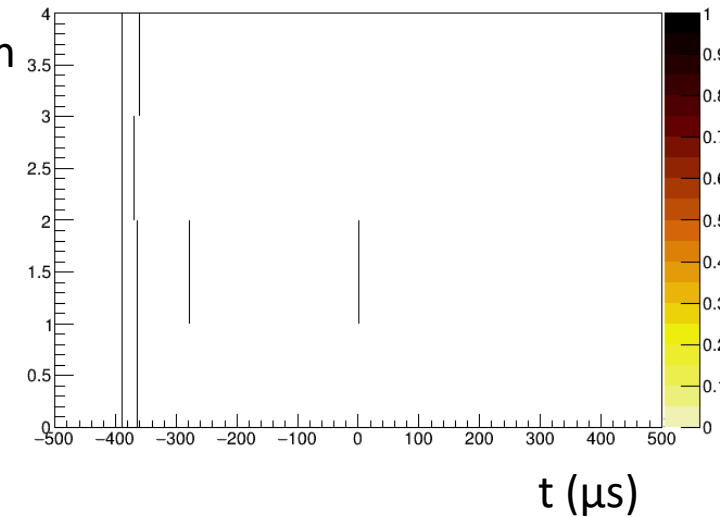


Noise reduction

Residual pulse in DSSD

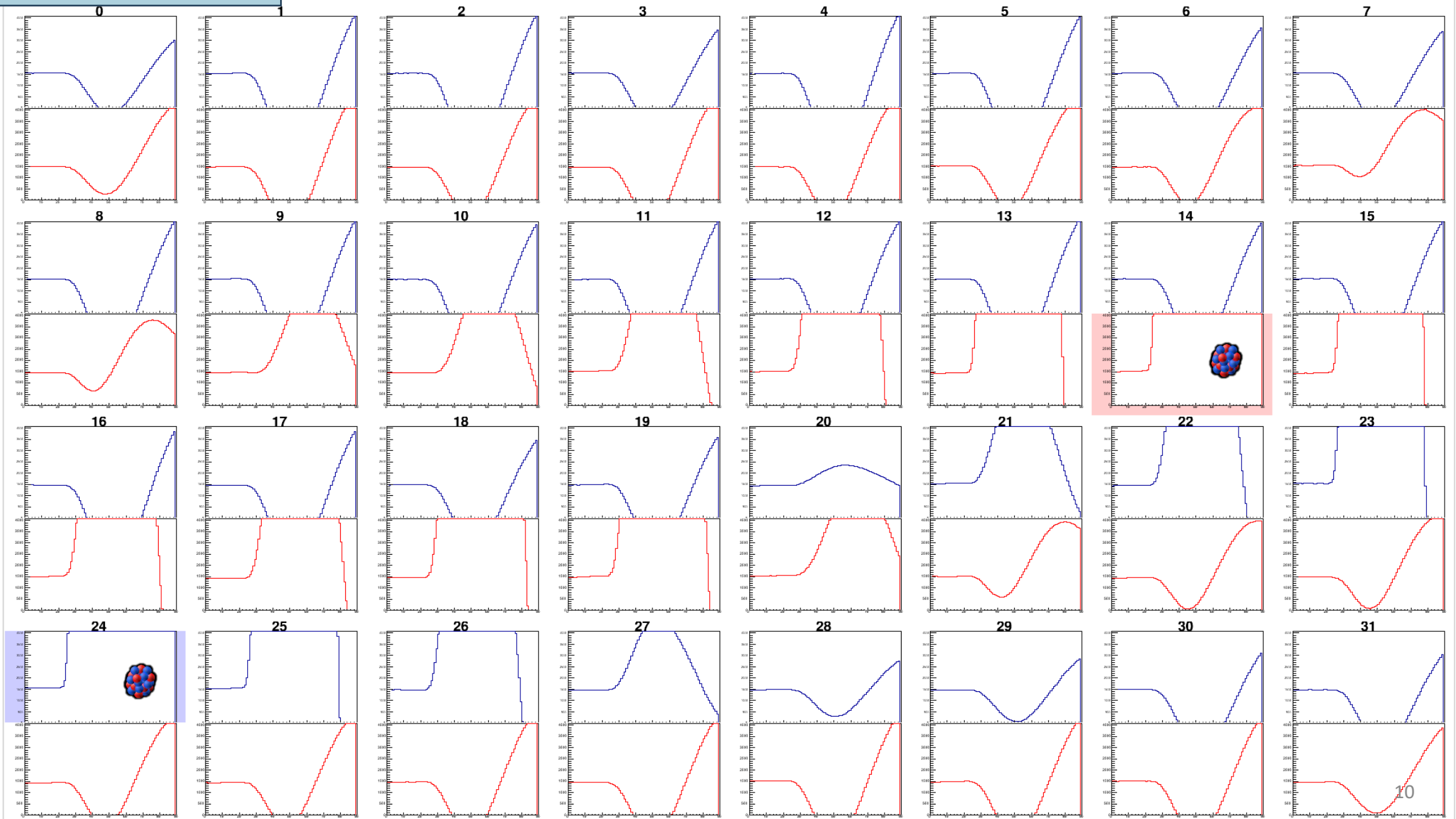


Example:



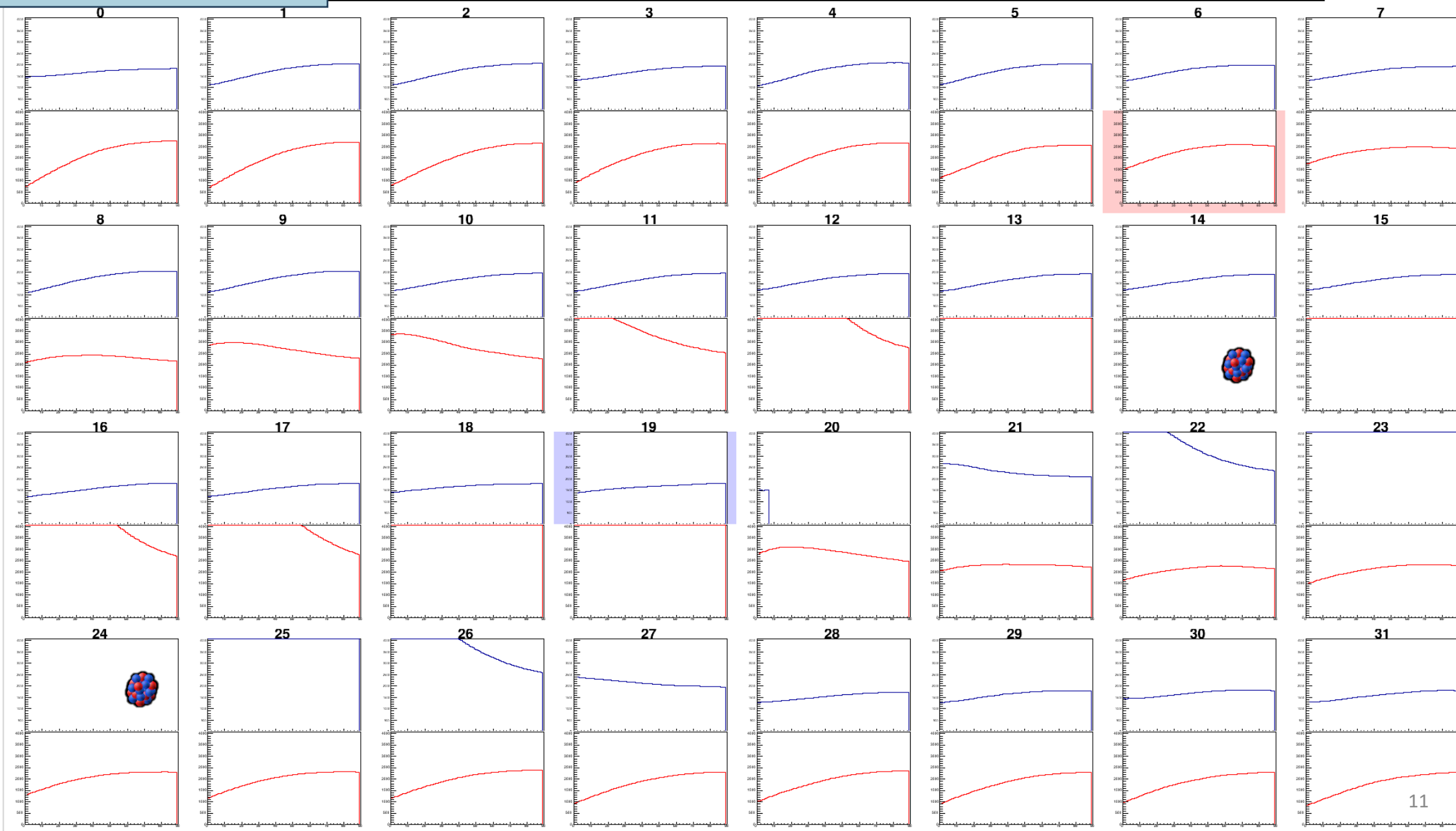
$t = 0$ (beam-like)

run=285, ientry=9917, x=24, y=14, z=1, ts=146821643988096, dts1=-40, dts2=4070656



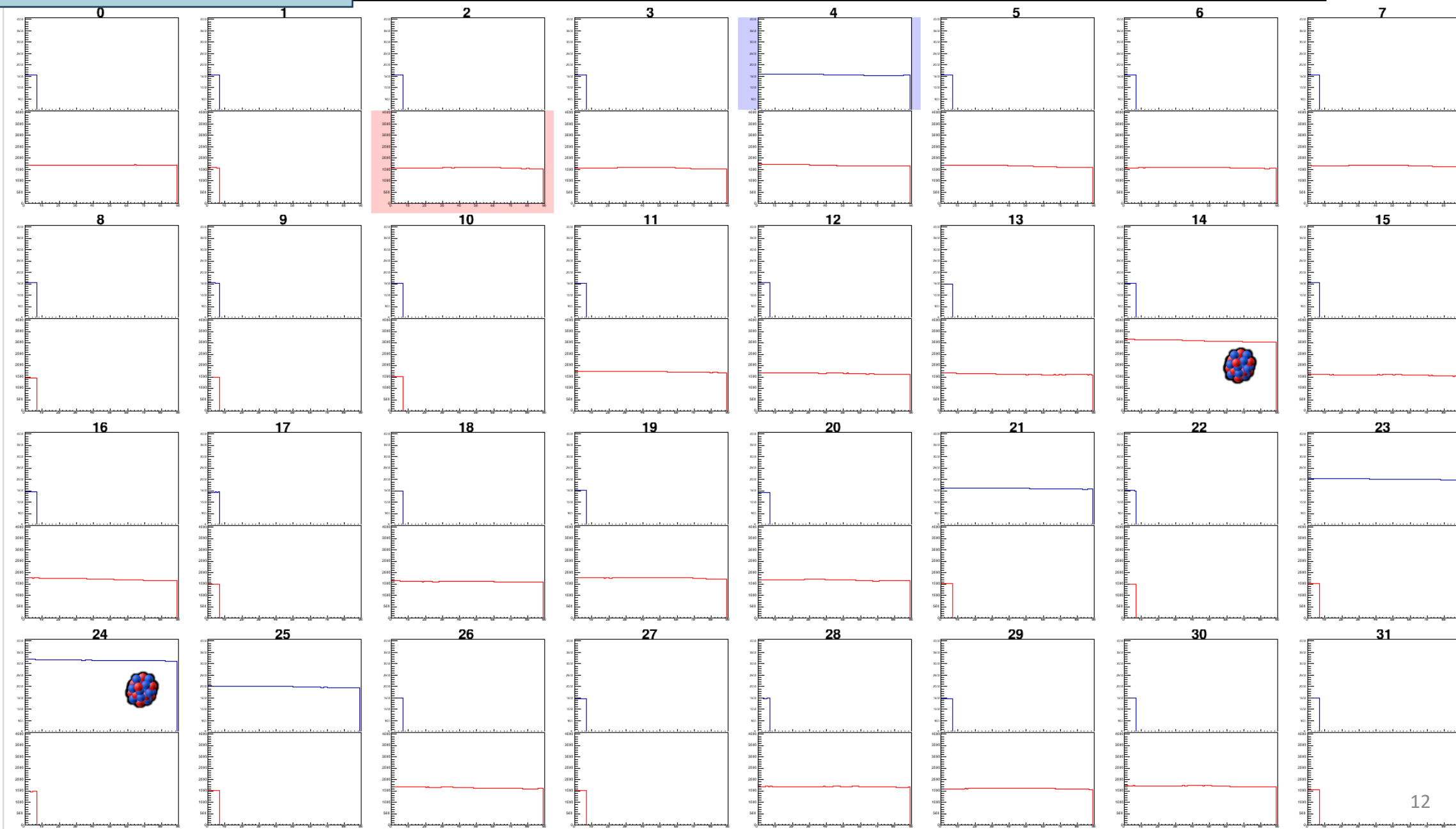
$t = 20 \mu\text{s}$ (residual)

un=285, ientry=9919, x=19, y=6, z=1, ts=146821644012416, dts1=472, dts2=24320



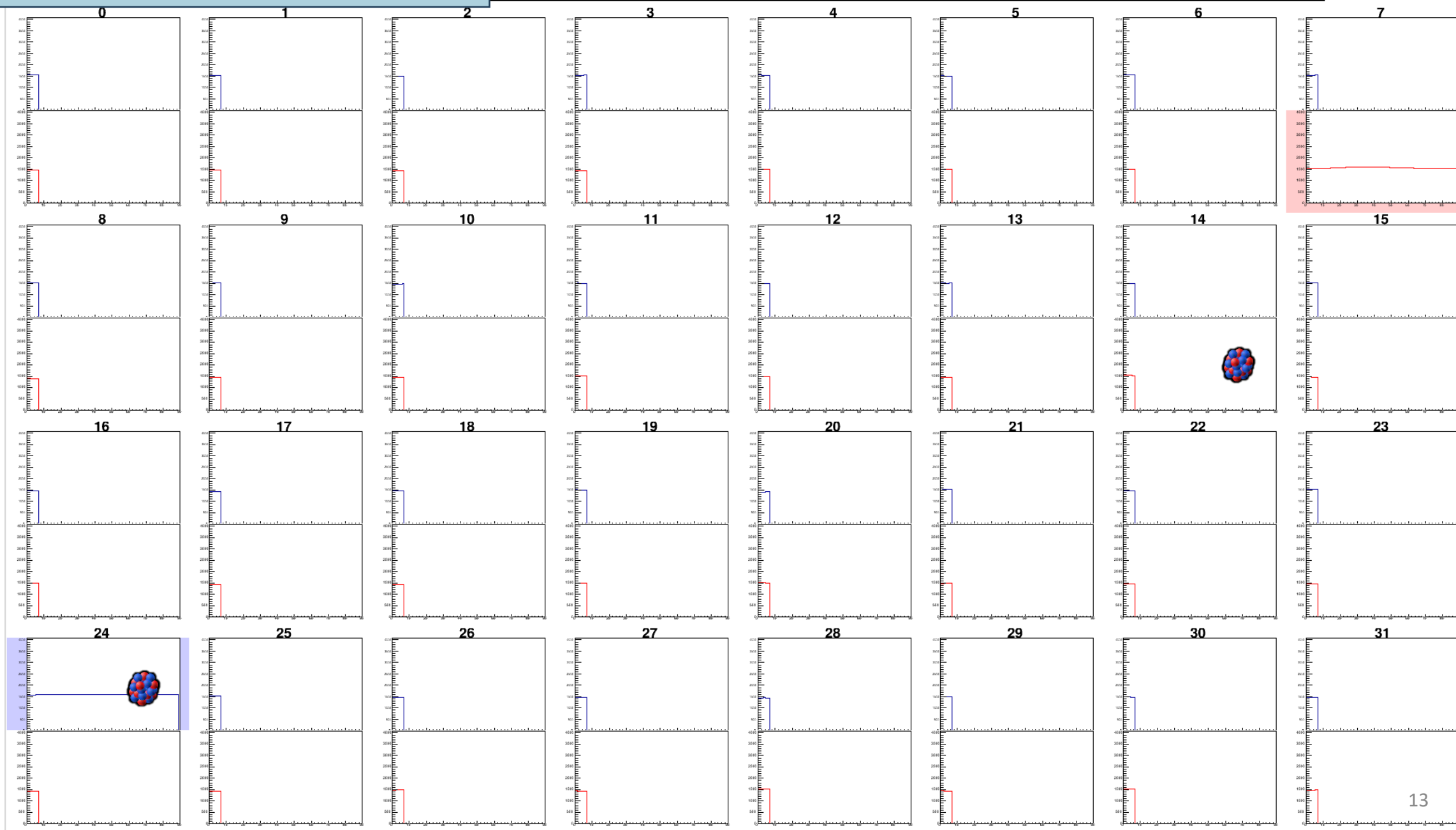
$t = 100 \mu\text{s}$ (residual)

285, ientry=9920, x=4, y=2, z=1, ts=146821644097664, dts1=-60840, dts2=17280

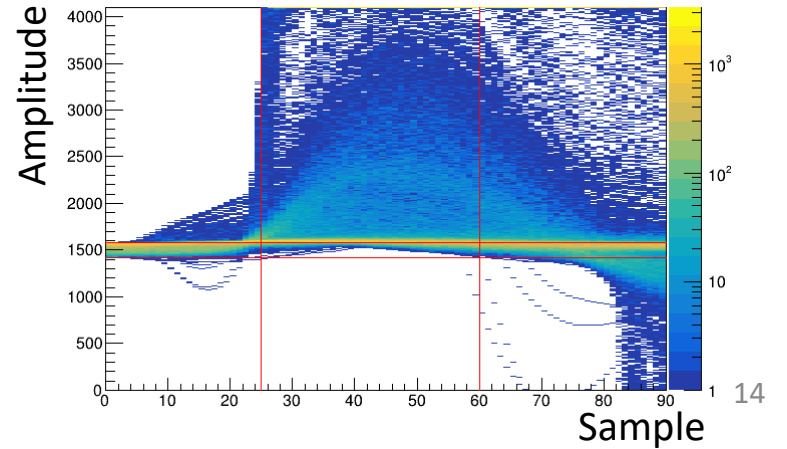
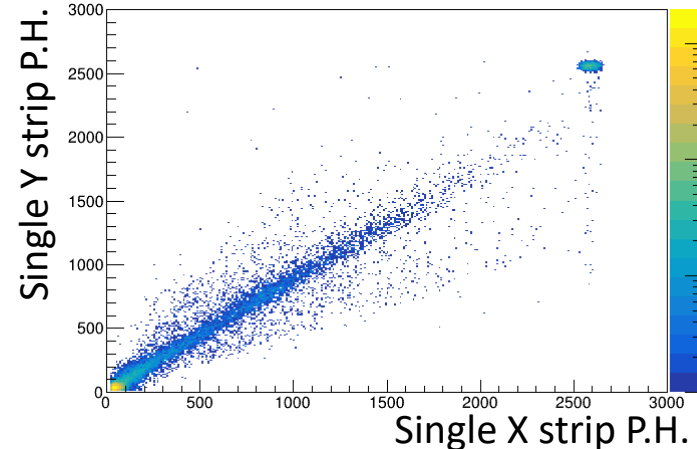
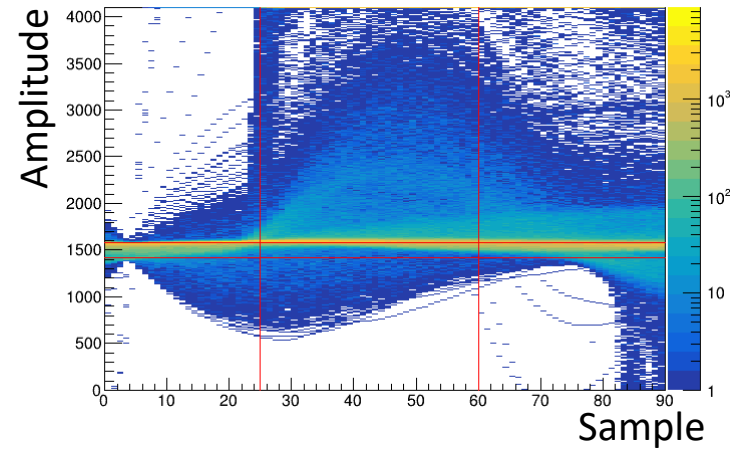
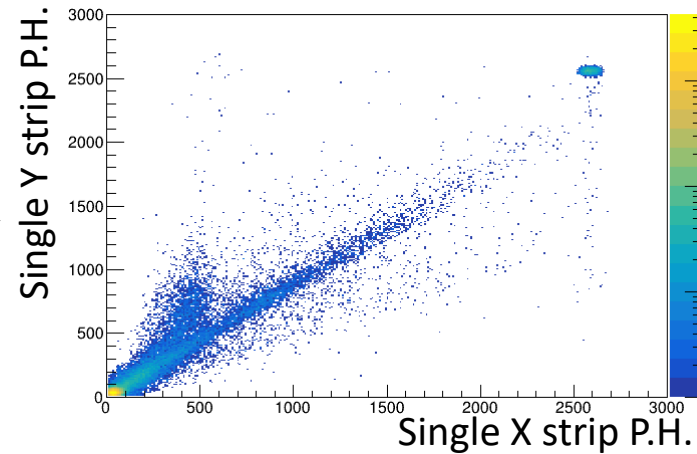
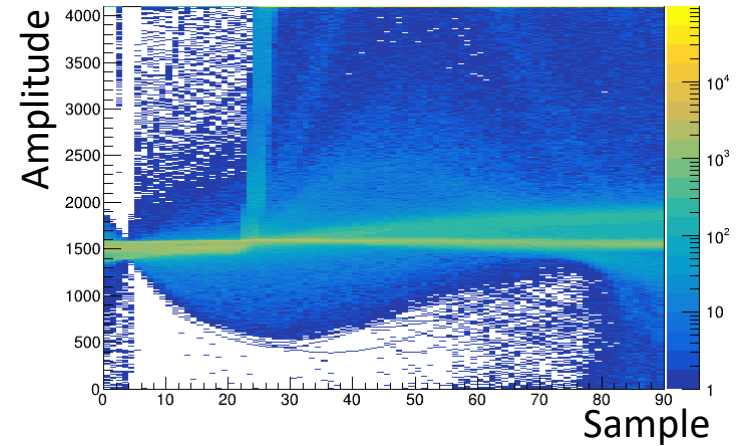
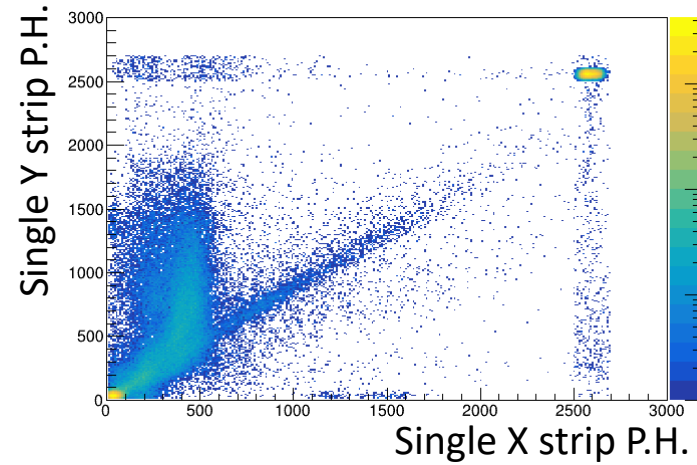
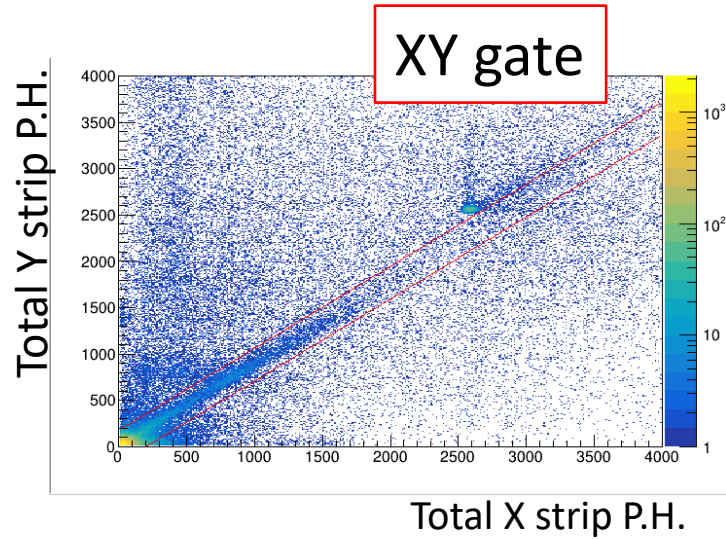


$t = 400 \mu\text{s}$ (residual/ β -like)

921, x=24, y=7, z=1, ts=146821644376448, dts1=20608, dts2=20608



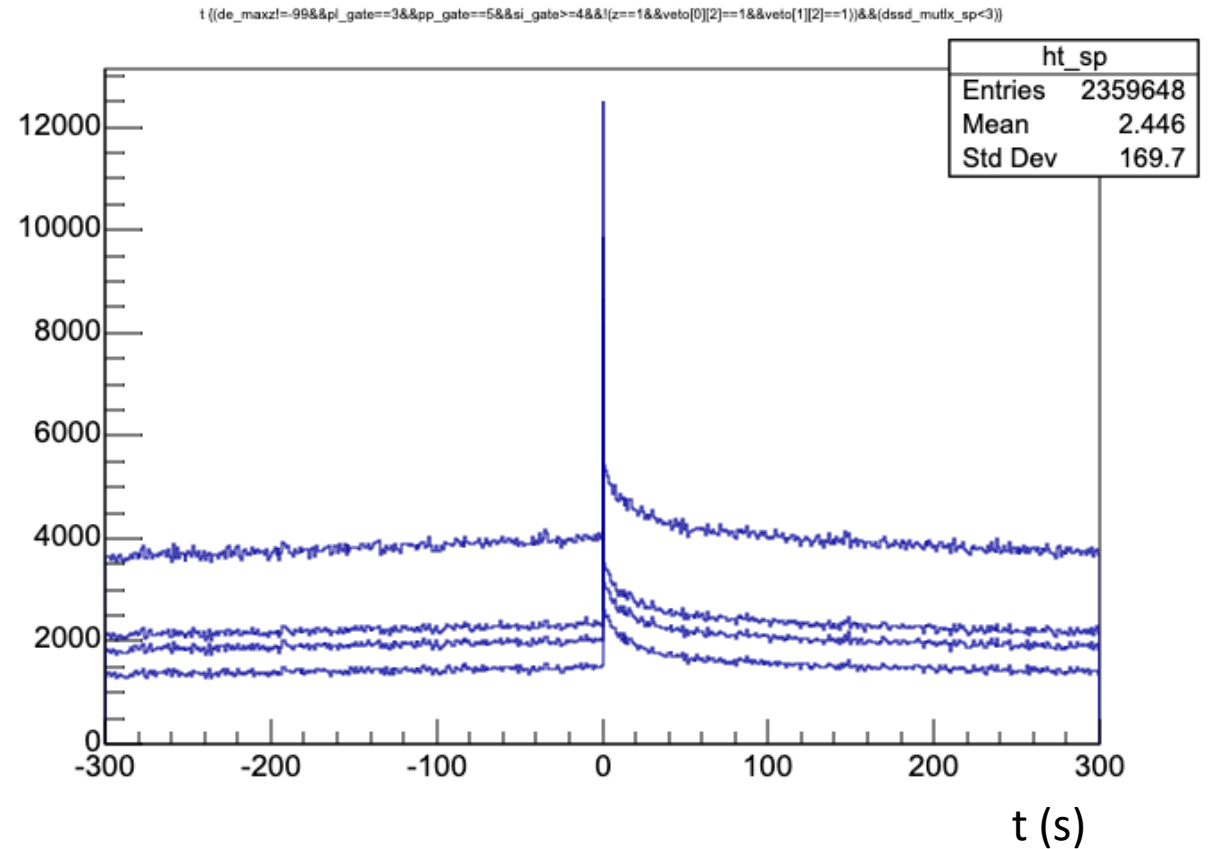
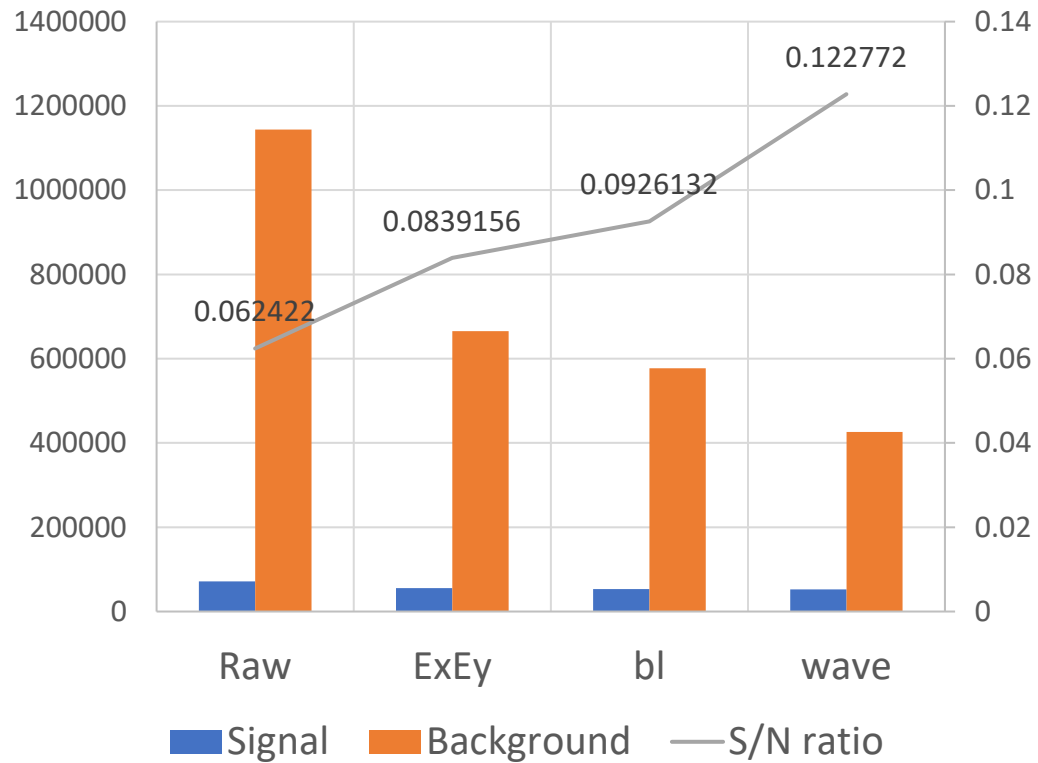
Noise reduction



Waveform gate

- Reject negative pulse
- Peak/ overflow time in certain range
- Small baseline fluctuation/ deviation

Performance of waveform gate



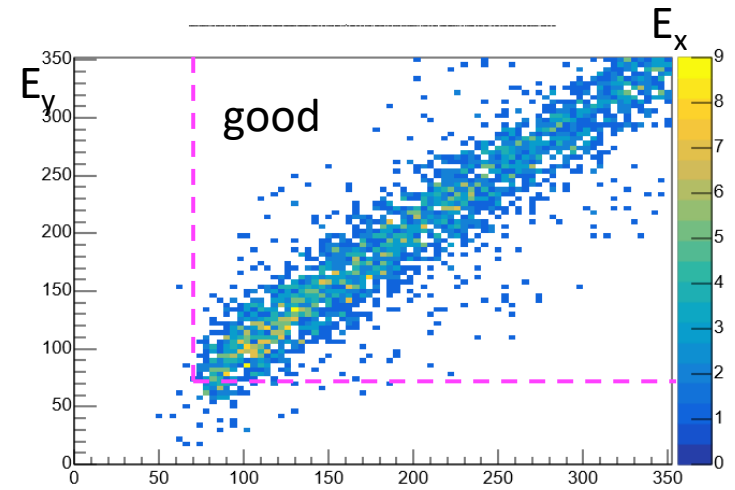
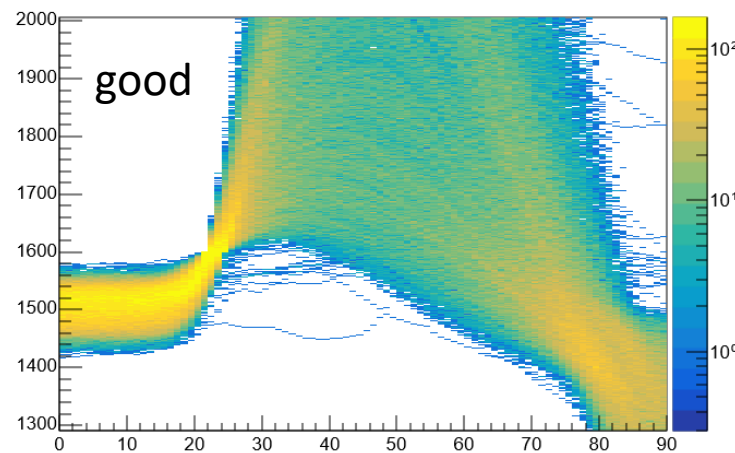
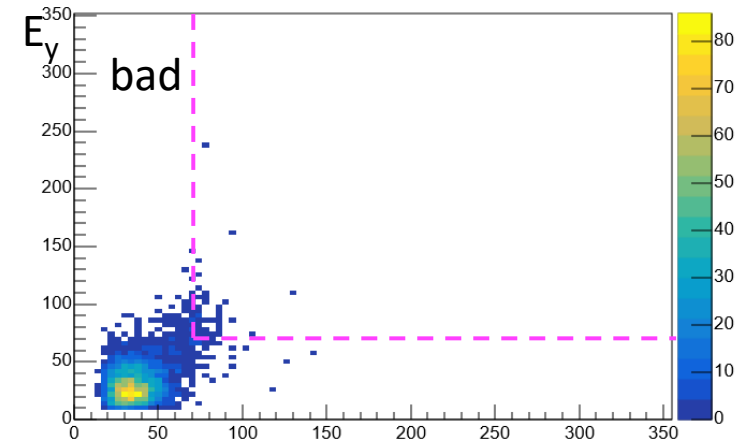
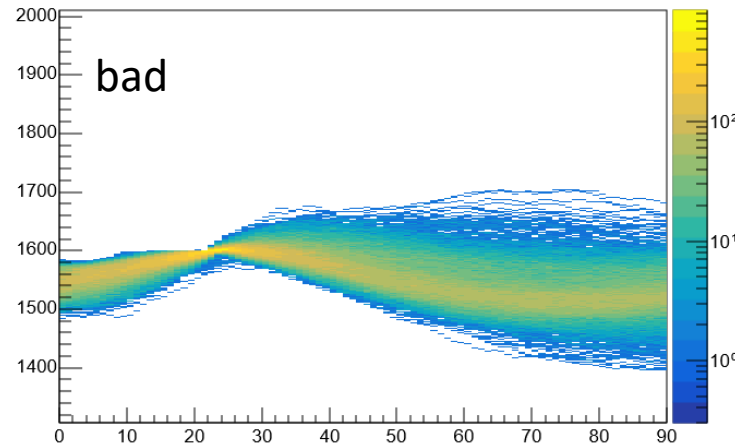
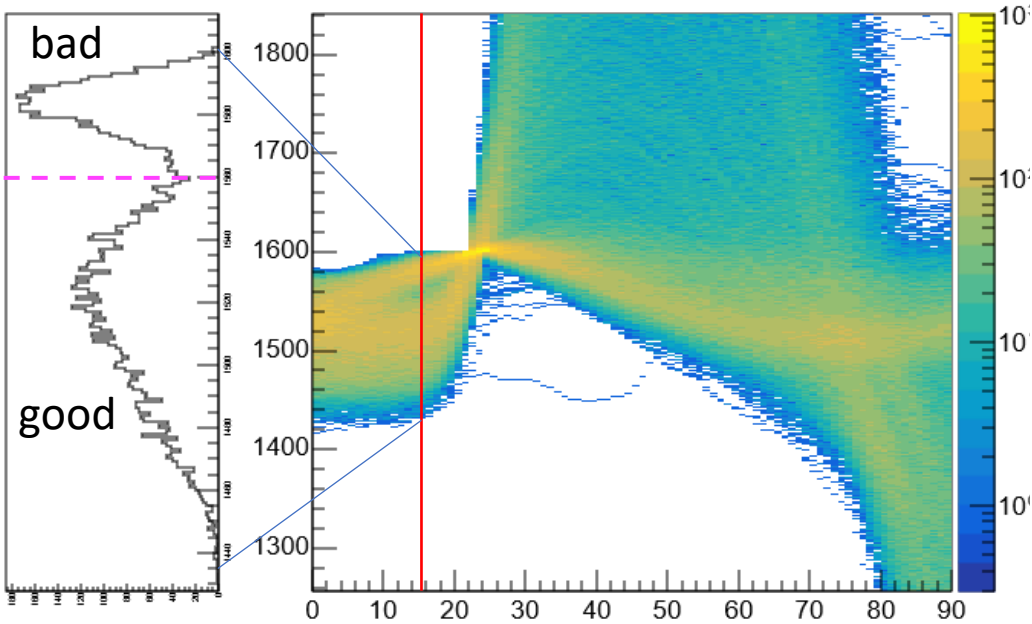
- 50 % improvement in S/N ratio

Low-energy residual

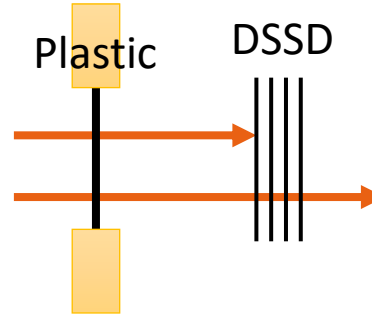
Waveform indicator

Energy threshold: 70 keV

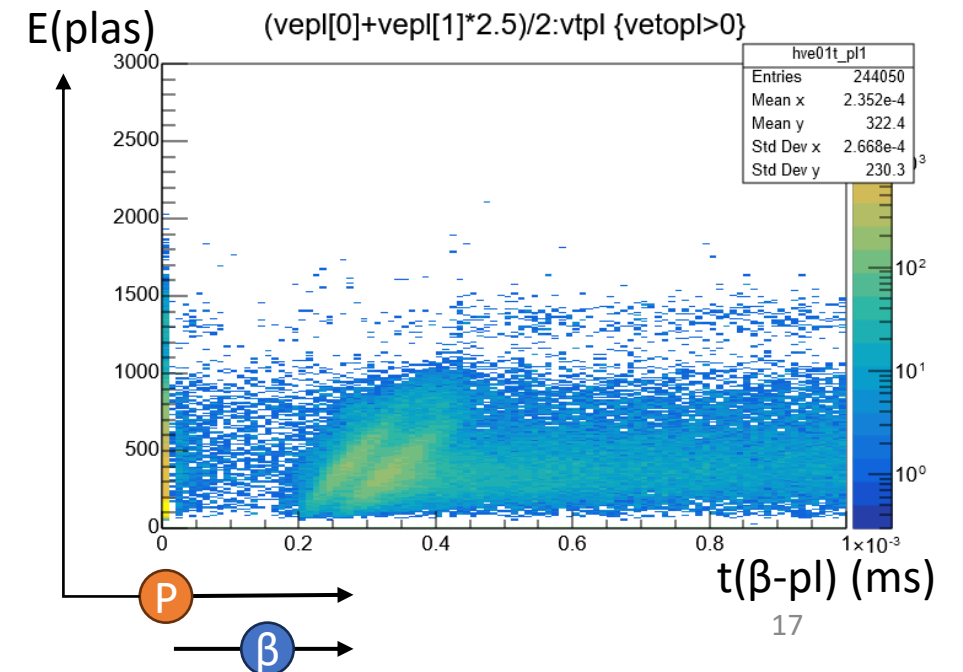
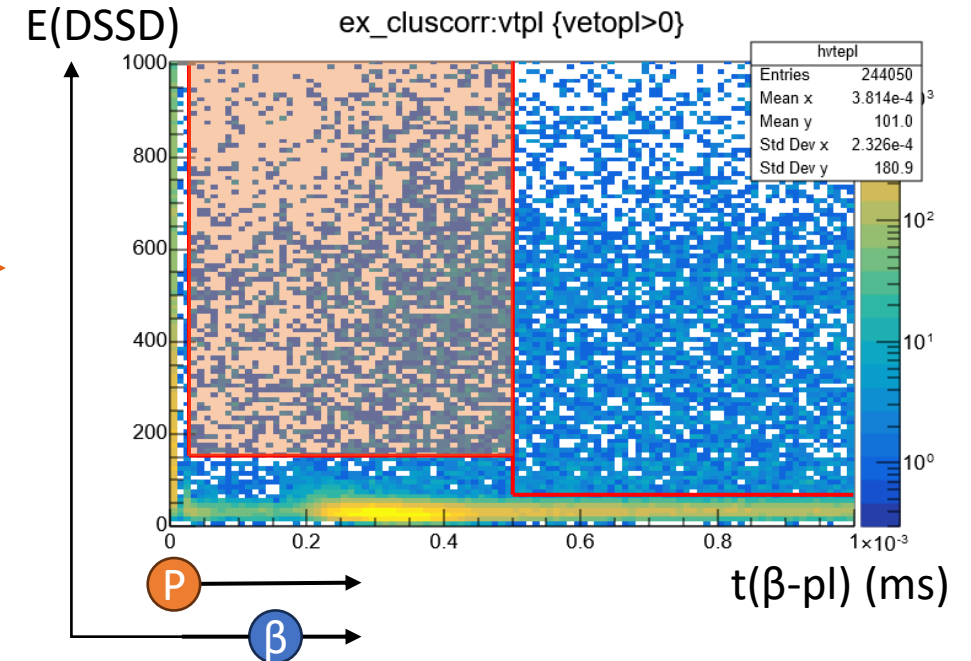
Y projection



Veto by F11 plastic



- Prompt
 - High-energy RI signal
 - DSSD & plas same timing $\rightarrow$ beam-like event
- Delayed
 - Low-energy residual
 - $\uparrow E(\text{plas})$, later t for residual pulse
- Recovery time
 - 500 μs
 - Partially recover events before 500 μs ?

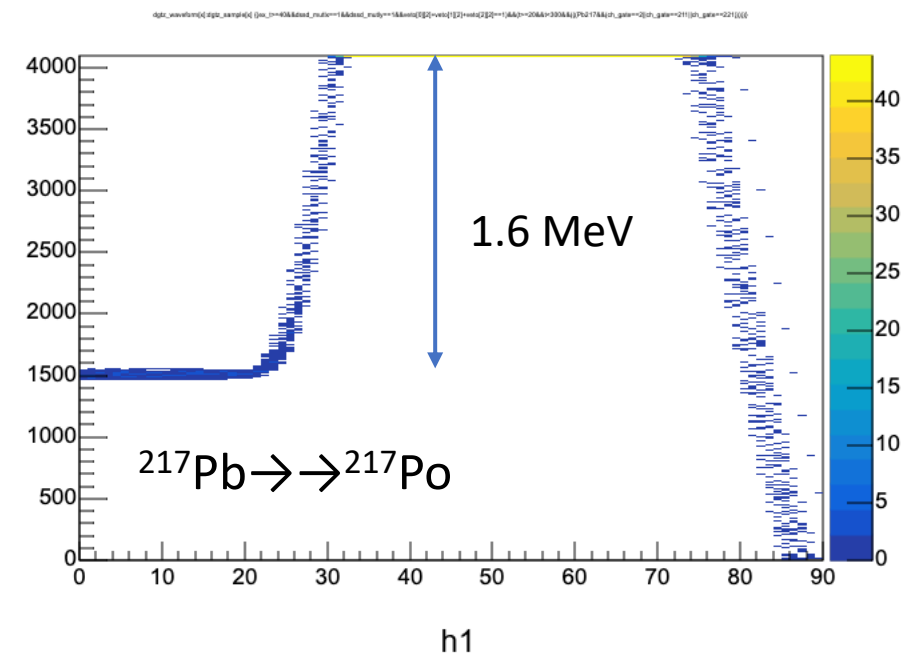
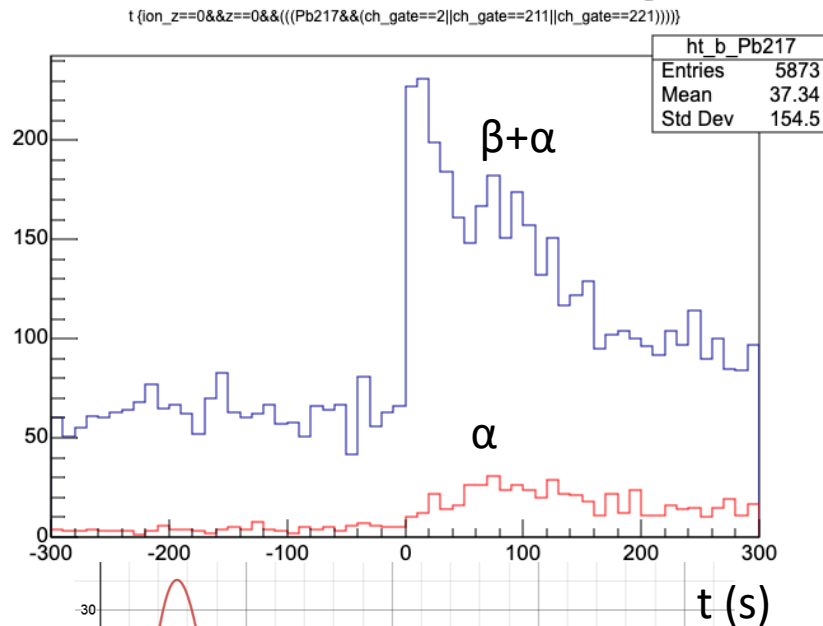


Reconstruction of α energy

α decay & waveform fitting

215Po 1.781 ms $\alpha=99.999\%$ $\beta^-=2.3e-4\%$	216Po 144 ms $\alpha=100\%$	217Po 1.53 s $\alpha=97.5\%$ $\beta^-=2.5\%$	218Po 3.097 min $\alpha=99.978\%$ $\beta^-=0.022\%$	219Po 10.33 min $\beta^-=71.8\%$ $\alpha=28.2\%$
214Bi 19.71 min $\beta^-=99.979\%$ $\alpha=0.021\%$	215Bi 7.6 min $\beta^-=100\%$	216Bi 2.25 min $\beta^-=100\%$	217Bi 98.5 s $\beta^-=100\%$	218Bi 33 s $\beta^-=100\%$
213Pb 10.2 min $\beta^-=100\%$	214Pb 27.06 min $\beta^-=100\%$	215Pb 142 s $\beta^-=100\%$	216Pb 99.4 s $\beta^-=100\%$	217Pb 19.9 s $\beta^-=100\%$

6539(4) keV



$$p_0 + Ap_1x_0^{p_4-1}\exp(-x_0)(p_4 - x_0)$$

where $x_0 = \frac{x-p_2}{p_3}$

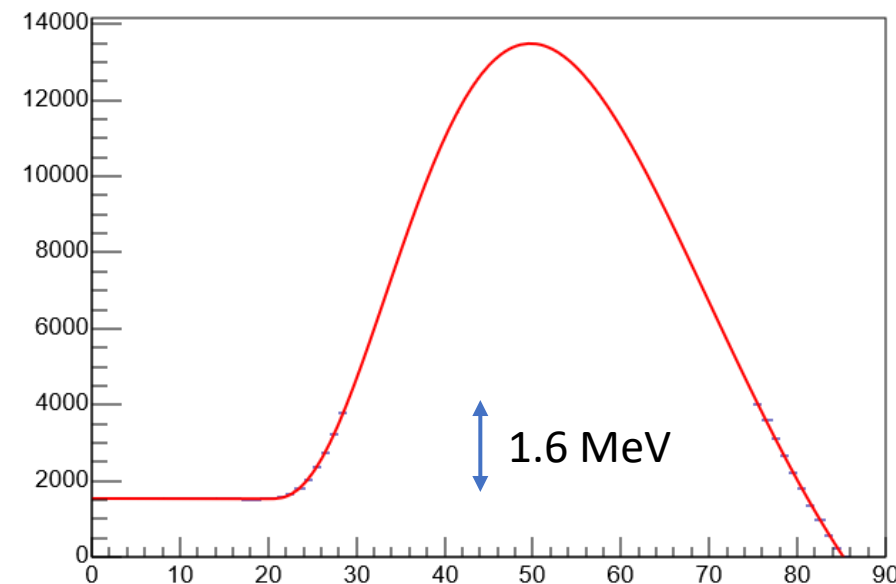
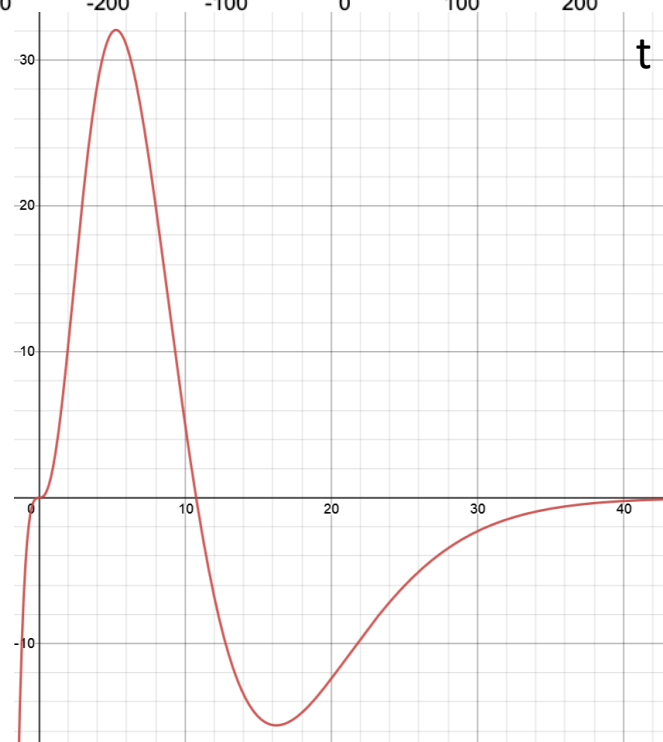
p_0 : Background offset

p_1 : Pulse height

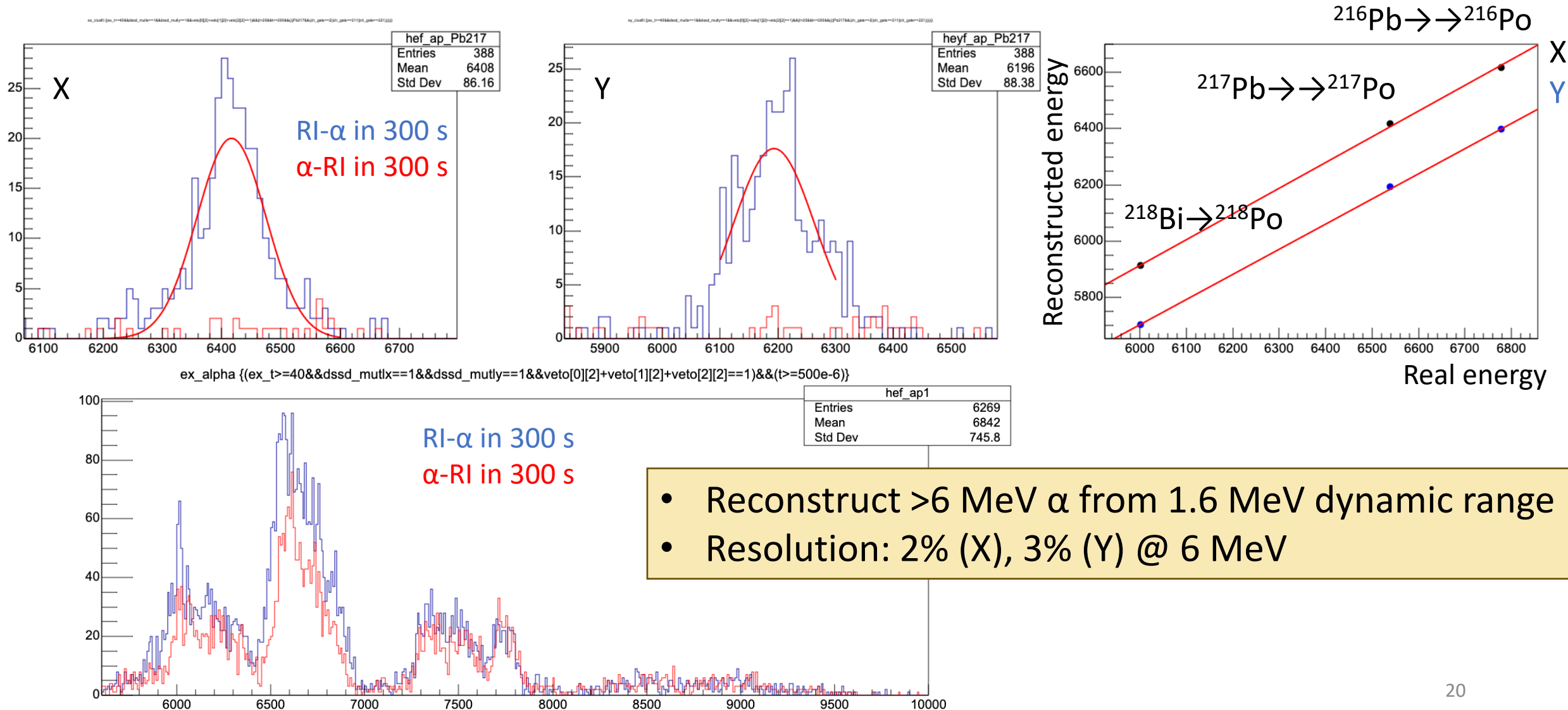
p_2 : Time offset

p_3 : Width

p_4 : Power



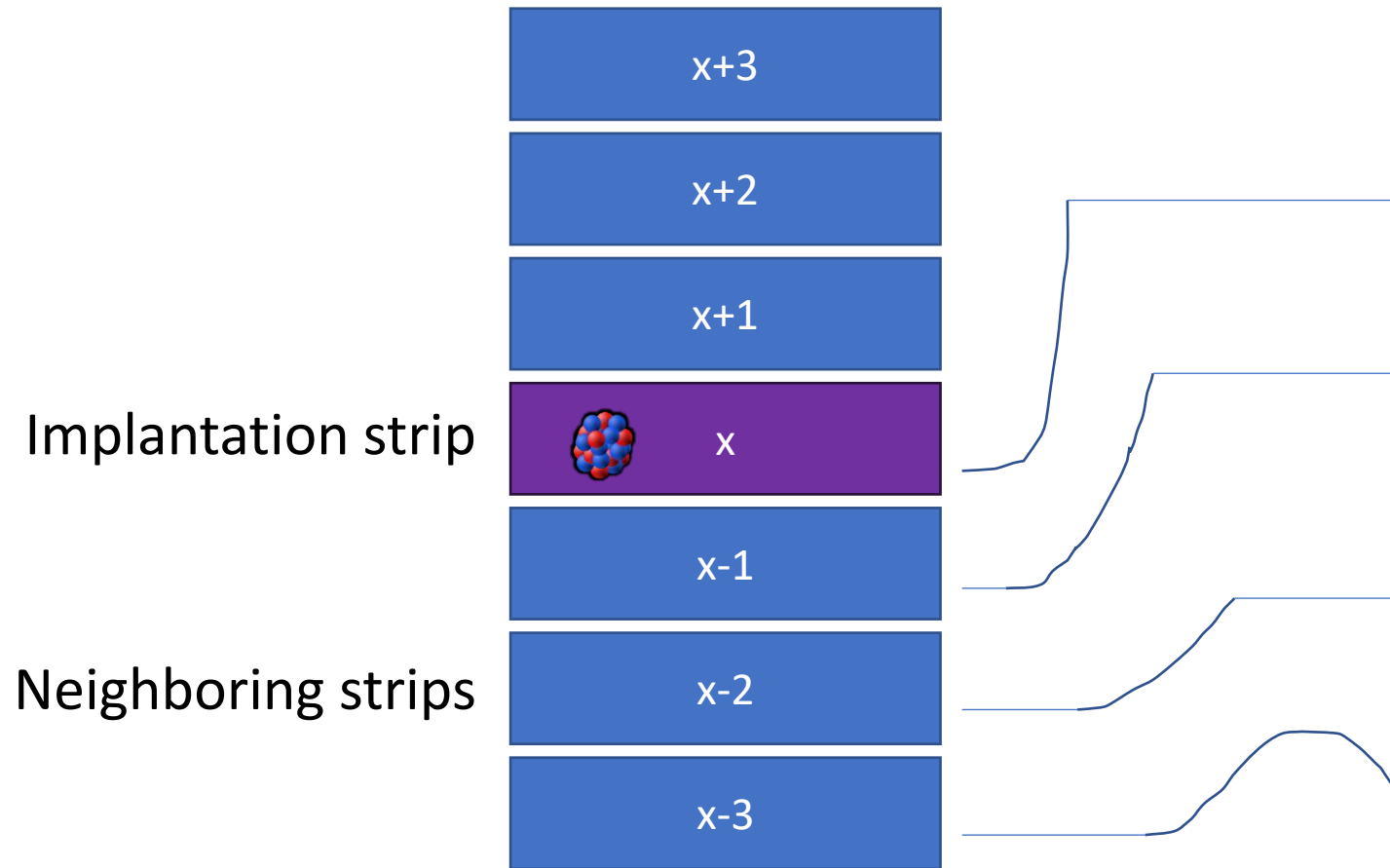
α energy calibration



- Reconstruct >6 MeV α from 1.6 MeV dynamic range
- Resolution: 2% (X), 3% (Y) @ 6 MeV

Reconstruction of implant energy

Crosstalk in DSSD



Possible sources:

- DSSD (interstrip capacitance)
- Preamplifier

Very saturated $\rightarrow$ no info

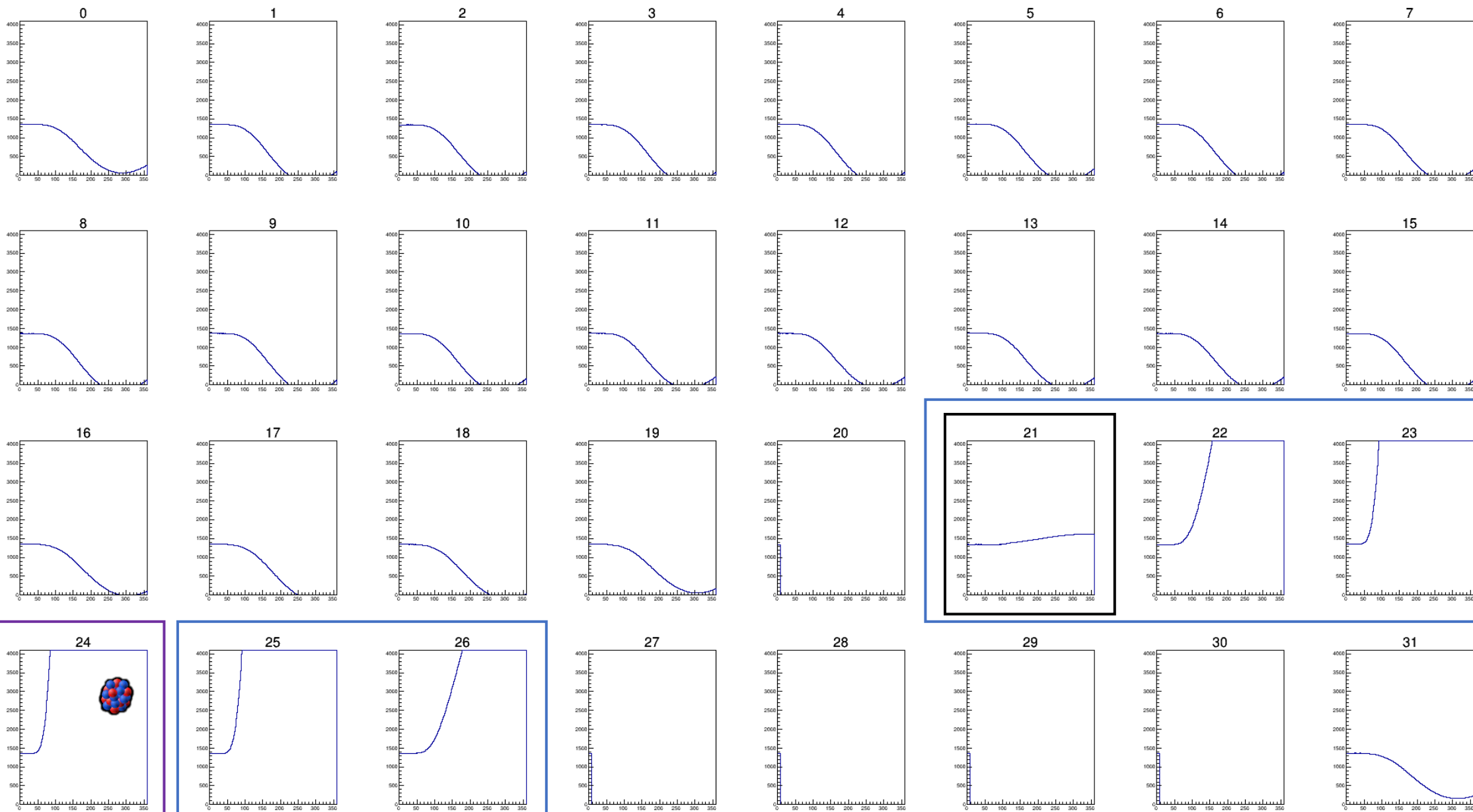
- 10 GeV in 15 MeV dynamic range

$\times 10$ attenuation (1 GeV)

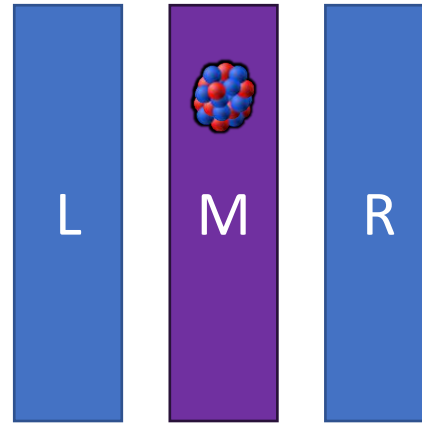
$\times 100$ attenuation (100 MeV)

$\times 1000$ attenuation (10 MeV)

entry=89, max=24



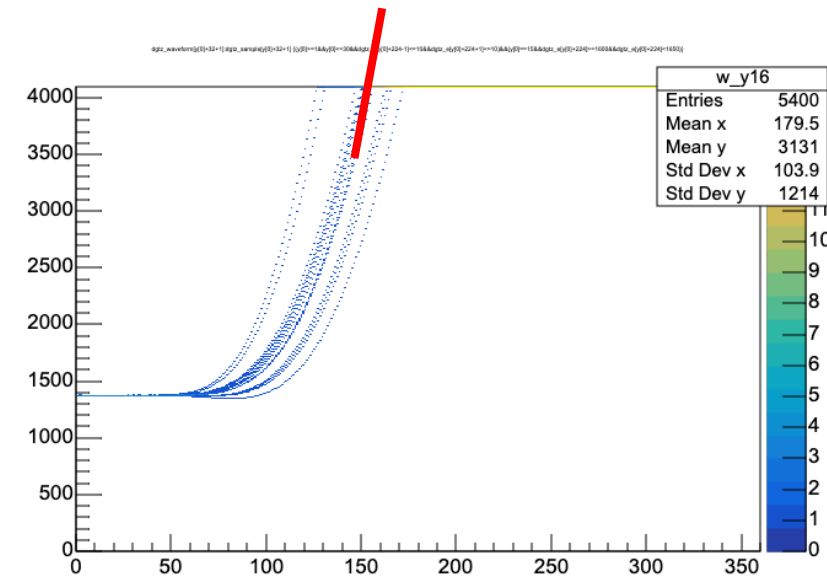
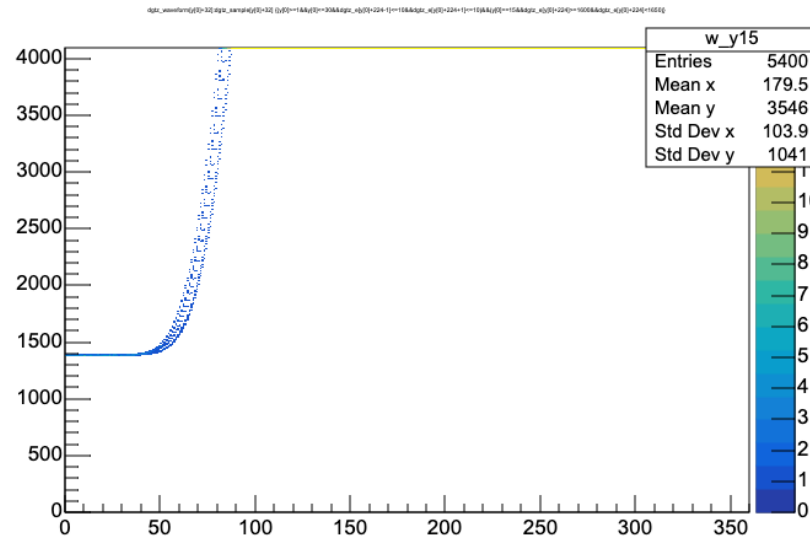
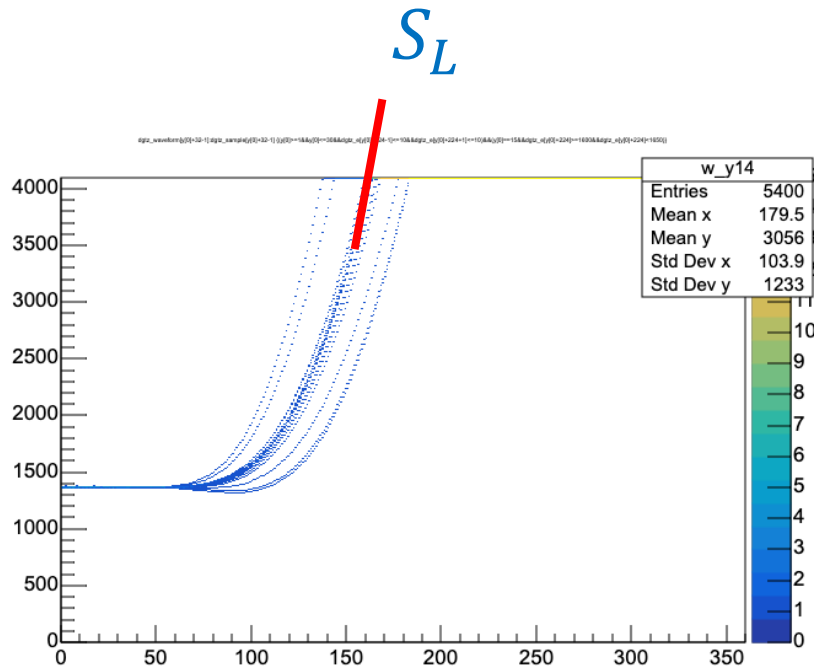
Neighboring strip + slope method



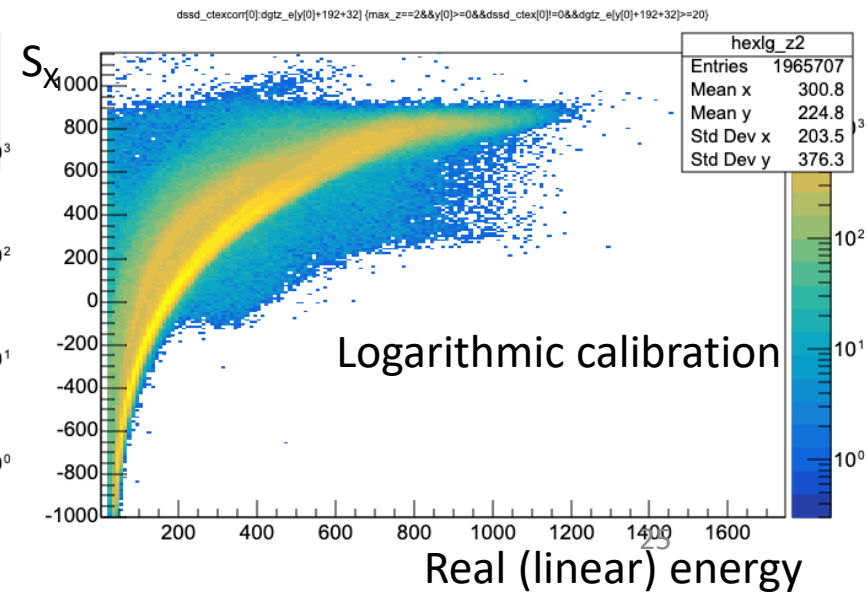
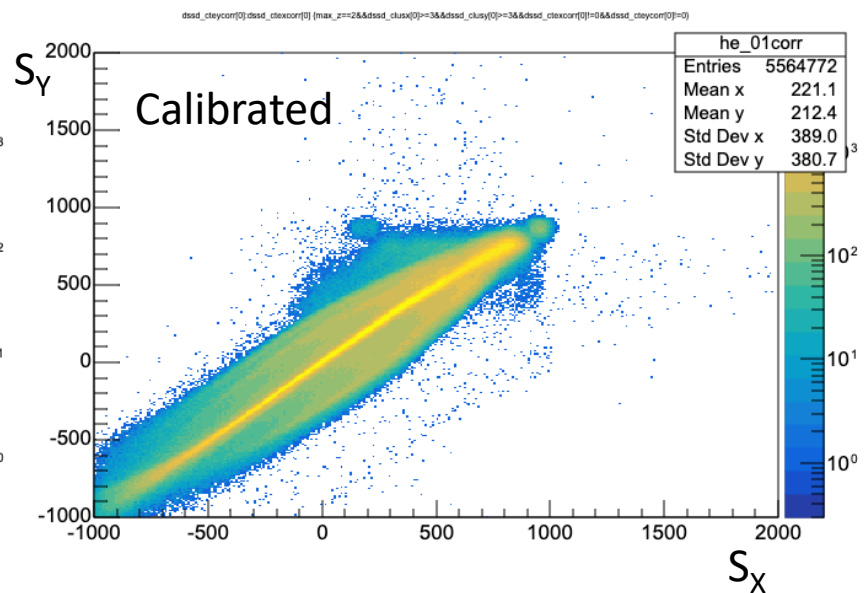
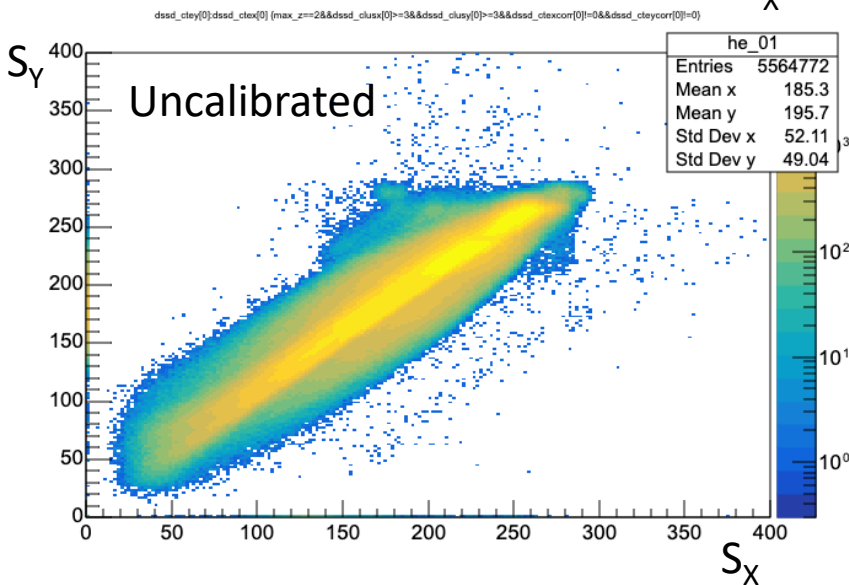
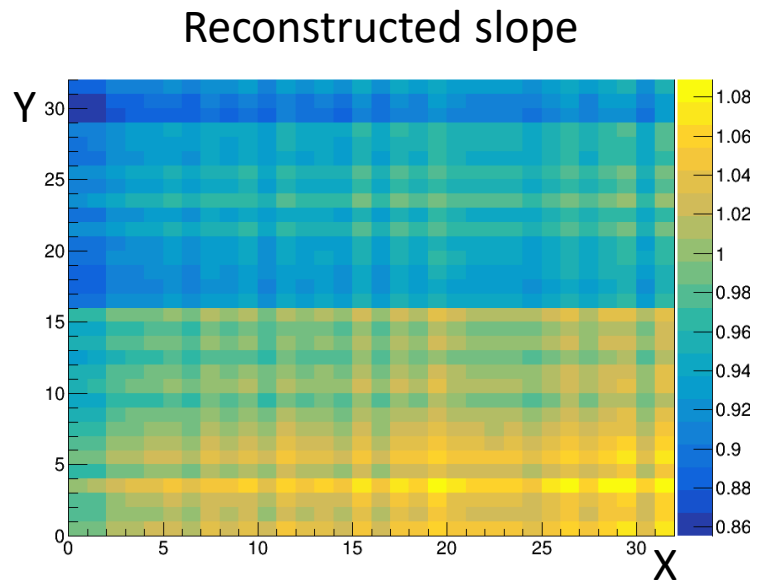
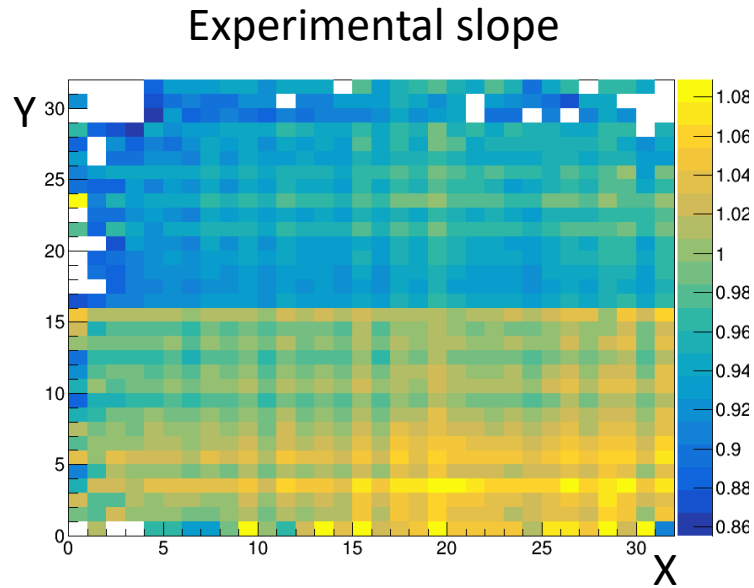
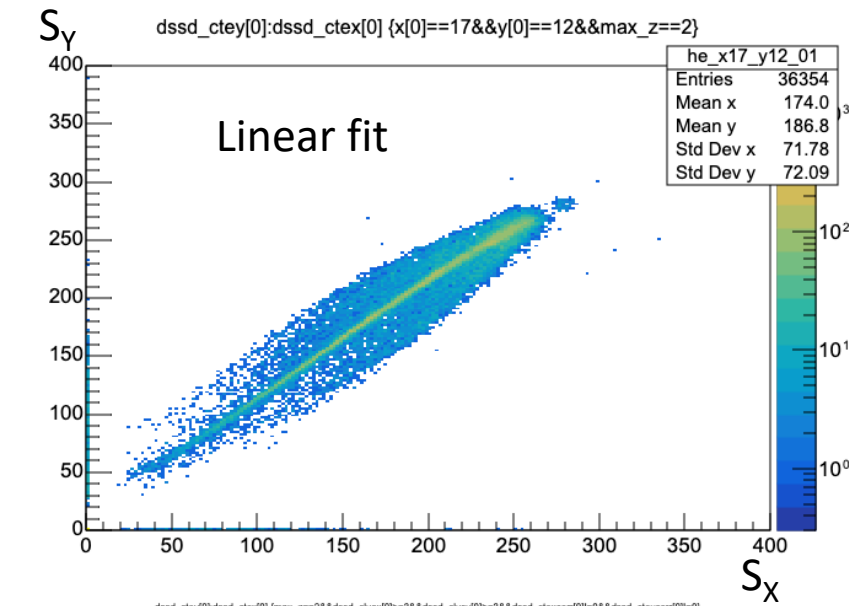
$$E_M \propto E_L + E_R$$

$$\uparrow \qquad \uparrow$$

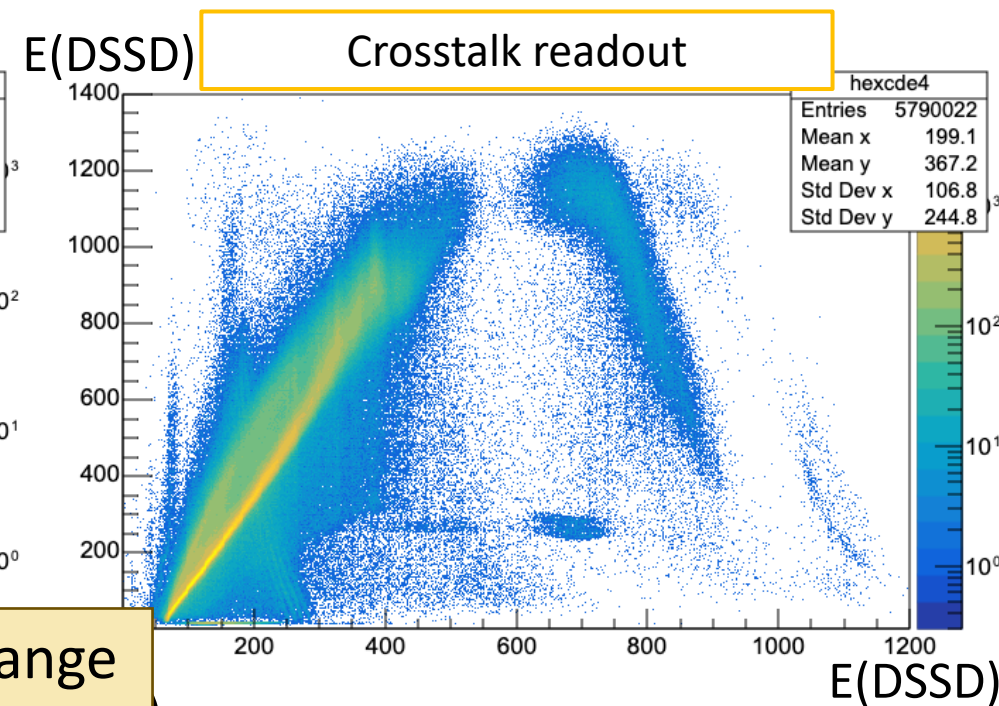
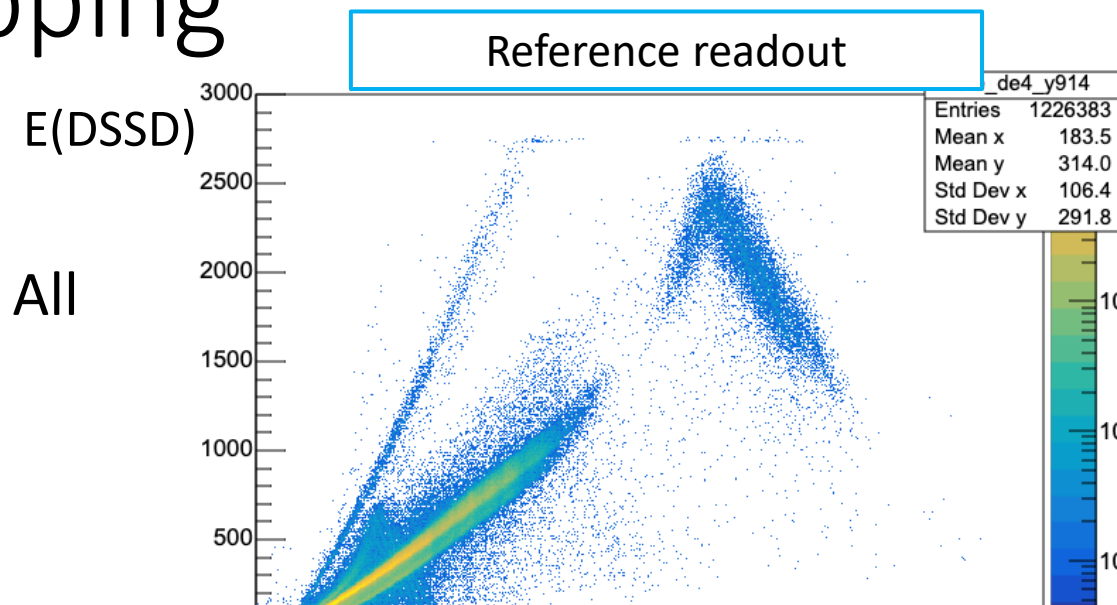
$$\sim S_L + S_R \equiv S$$



Implant energy calibration

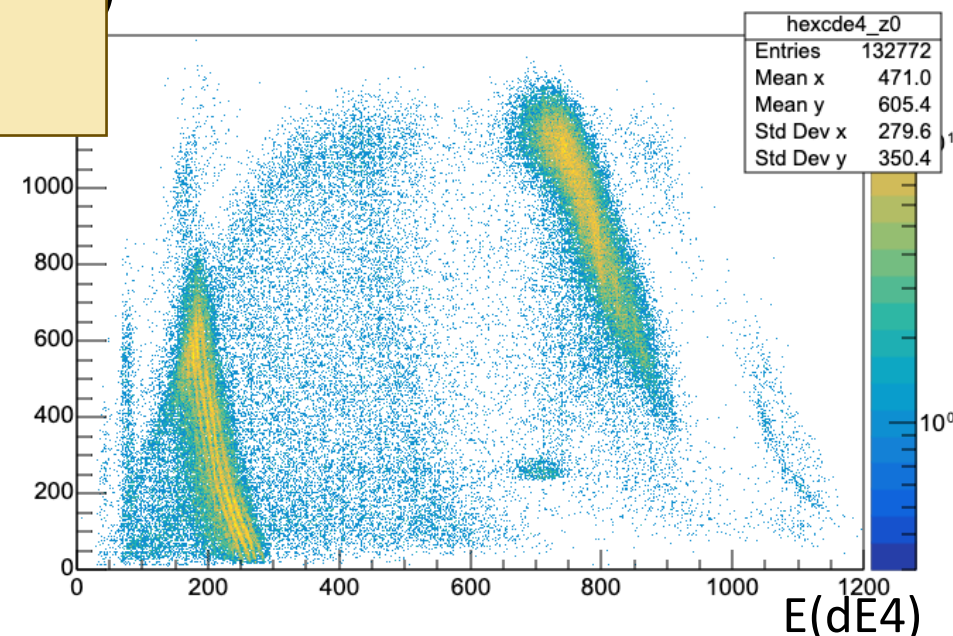
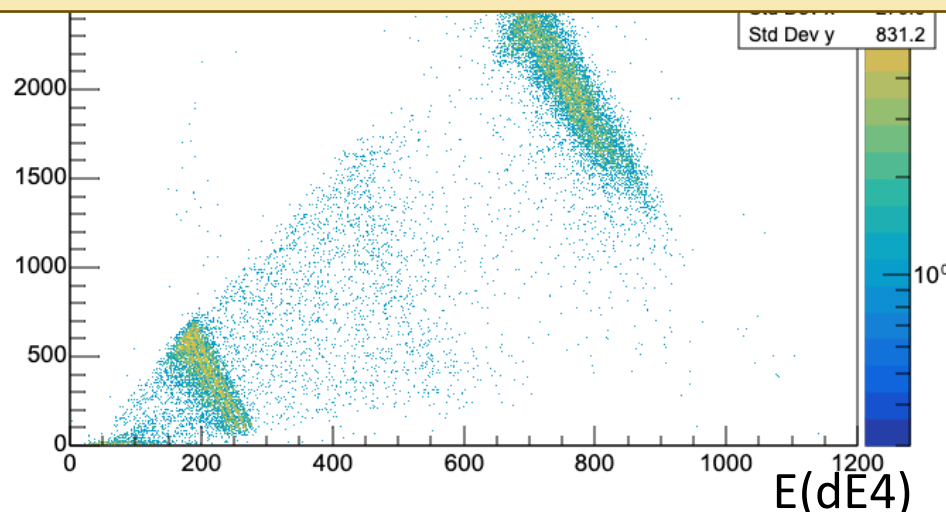


Ion stopping



- Reconstruct 10 GeV implant from 15 MeV dynamic range
- Sensitive to Z & depth
- Resolution (?), Linearity (?)

Stop at 1st DSSD



Conclusion

- Waveform can recover information
 - Distinguish signal/ noise
 - Reconstruct energy
- WAS3ABi is versatile
 - R_I , β , conversion electron, α
- Power of software
 - Go beyond hardware limitations
 - Keep a simple hardware