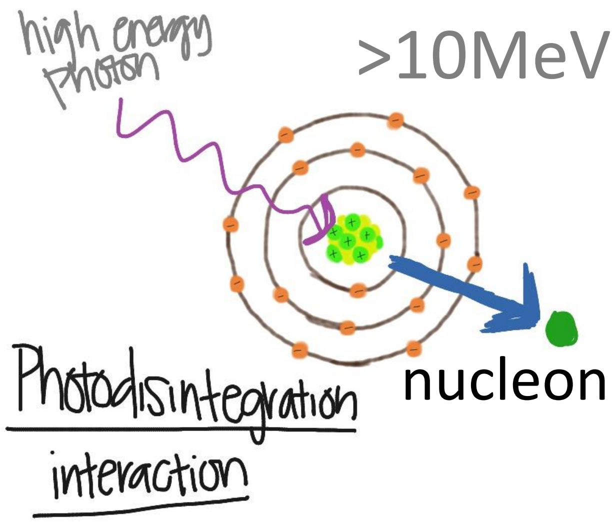
24th IEEE Real Time conference
@ ICISE - Quy Nhon – Vietnam
2024, April 22nd – 26th

Evaluation Of Timing And Pulse Shape Analysis Method For The Measurement Of Photoneutron Energy Distribution Using Commercially Available Digitizer

Tran Kim Tuyet[1], Toshiya Sanami[1], Bui Tuan Khai[2]
[1]KEK/SOKENDAI, [2]QUP-KEK, Japan

IEEE NPSS
NUCLEAR & PLASMA SCIENCES SOCIETY

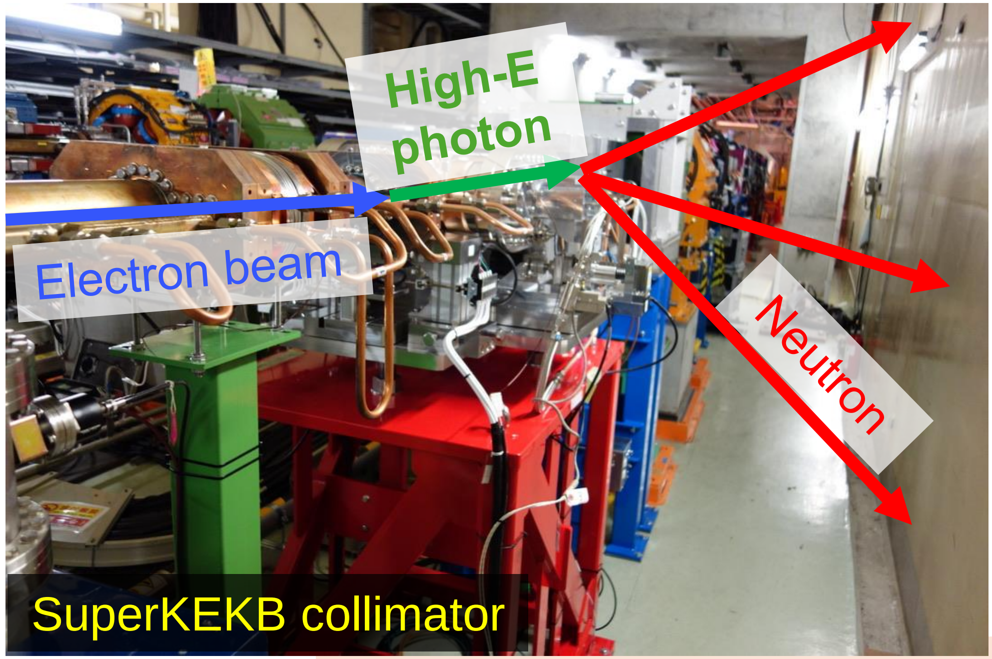
Photonuclear reaction & Photoneutron



- High energy photons can react with nuclei

⇒**Photonuclear reaction**

⇒Nucleon(s) is emitted (photoneutron, photoproton)



- In Electron accelerator,
  - Electron beam dumps on materials, produce high energy photons.
  - The photons produce neutron through **photonuclear reaction**

⇒ The neutrons: very ***difficult to shield***, can ***activate materials and induce additional exposure***

Energy and angular distribution of photoneutron are important to: **estimate activity**, and **shielding design**

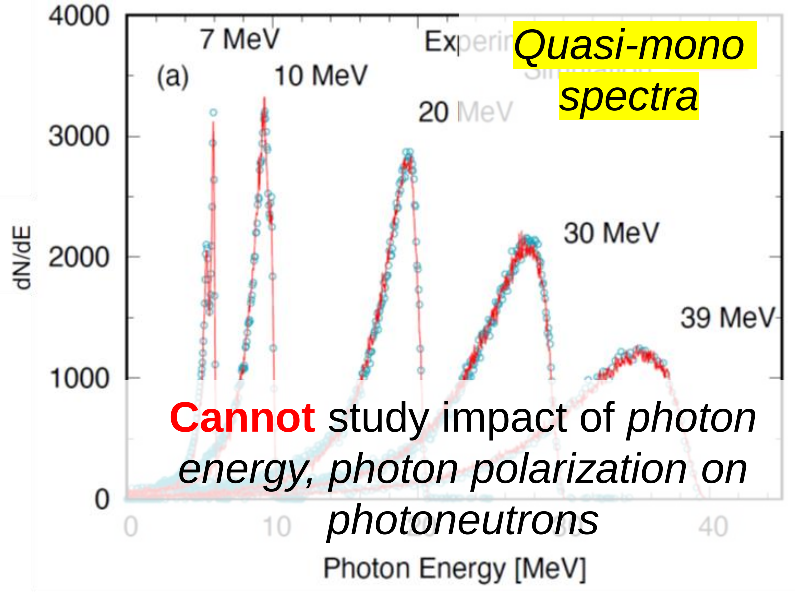
Studies on **photoneutron** production

- Experimental data on photoneutron (g,xn) production are important resources for theoretical studies and modeling.

⇒ There are many challenges for experimental studies:

1. How to generate high-E photon source

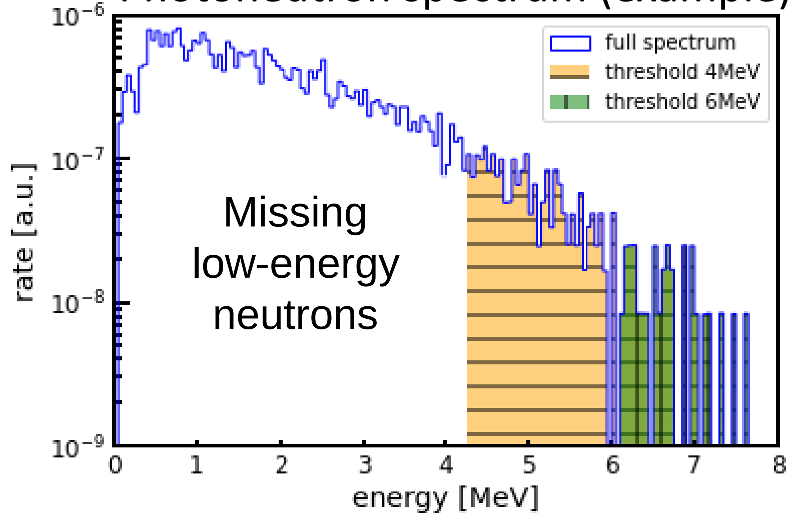
⇒Mostly bremsstrahlung or quasi mono-energetic



2. Neutron detection technique

⇒ Detector based on nuclear reaction, requires high energy threshold (4–6MeV), ***cannot see low-energy spectra***

Photoneutron spectrum (example)



3. Data analysis

⇒No data on energy and angular distribution of photoneutrons

Studies on **photoneutron** production

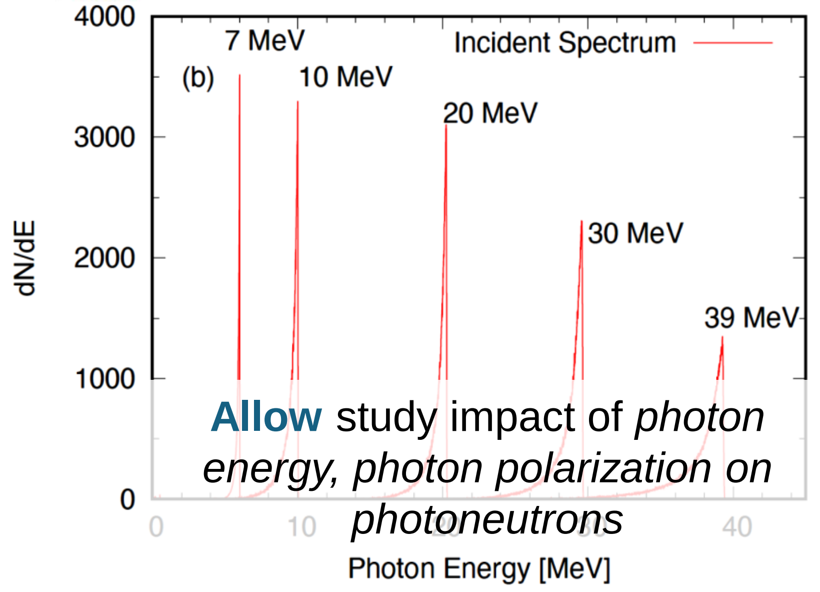
- Experimental data on photoneutron (g,xn) production are important resources for theoretical studies and modeling.

⇒ There are many challenges for experimental studies:

1. How to generate high-E photon source

⇒Mostly bremsstrahlung or quasi mono-energetic

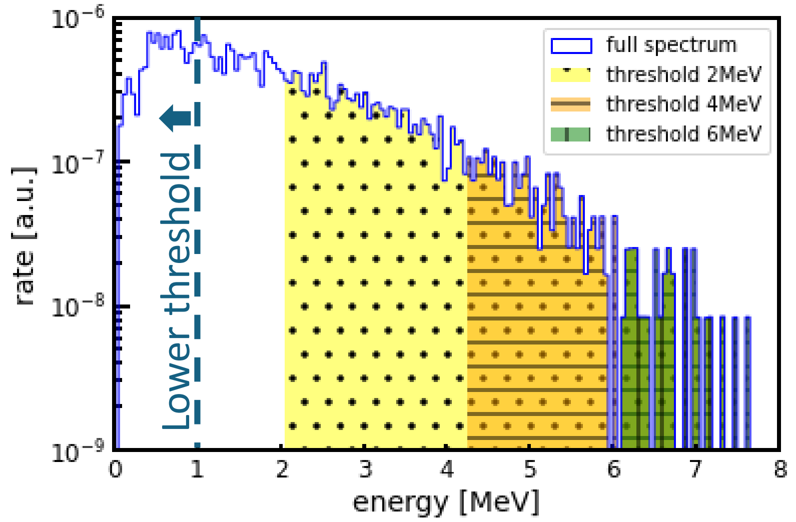
⇒In our study, used laser Compton scattering: mono-energy + linearly-polarized photons (LCS photon) for study photoneutrons.



2. Neutron detection technique

⇒ Detector based on nuclear reaction, requires high energy threshold (4–6MeV), ***cannot see low-energy spectra***

⇒ Time-of-flight technique for a lower energy threshold (2MeV)

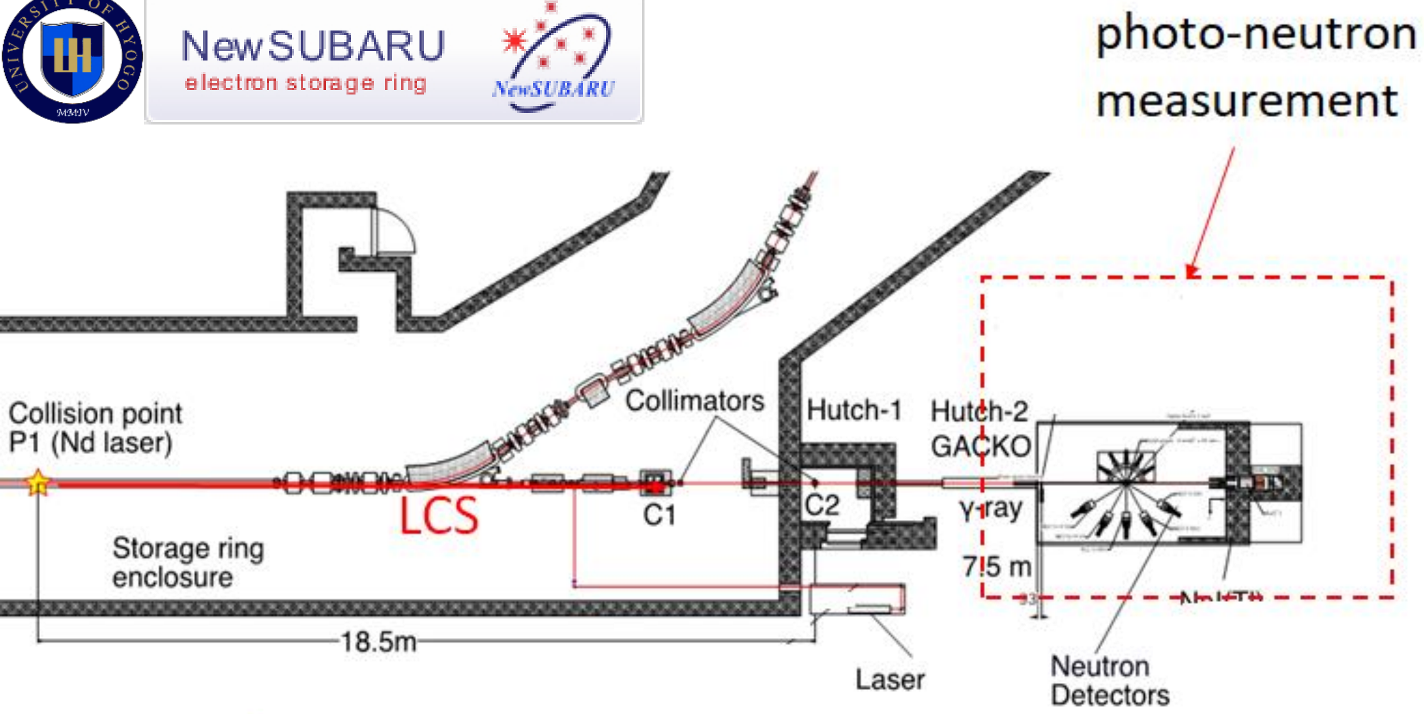


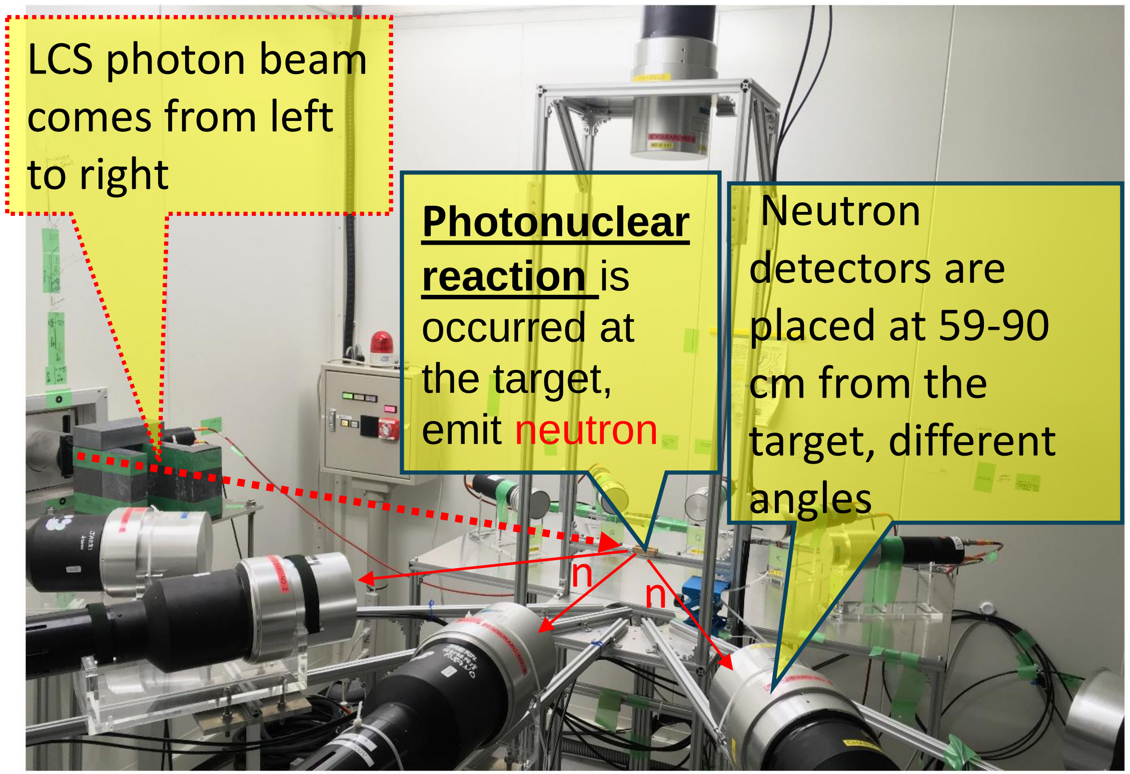
3. Data analysis

⇒No data on energy and angular distributions of neutrons

⇒Aim for: energy & angular distribution of photoneutrons

Our study on photoneutron





$$E_\gamma = \frac{4E_L\gamma^2/(1+R)}{1+\gamma^2\theta^2/(1+R)}, \qquad R = \frac{4E_L\gamma}{mc^2}$$

E_L laser photon energy

$\gamma = E_e / mc^2$;

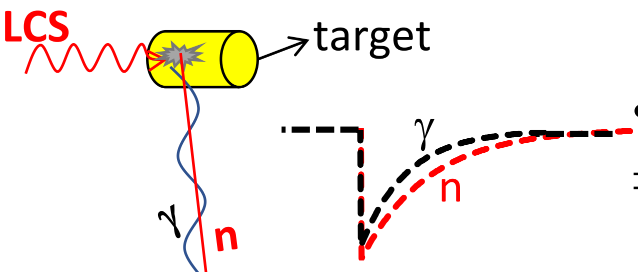
θ is an angle of scattered photon

- Performed experiment at NewSUBARU, Japan

$\Rightarrow$ Make use of laser Compton scattering to produce photons

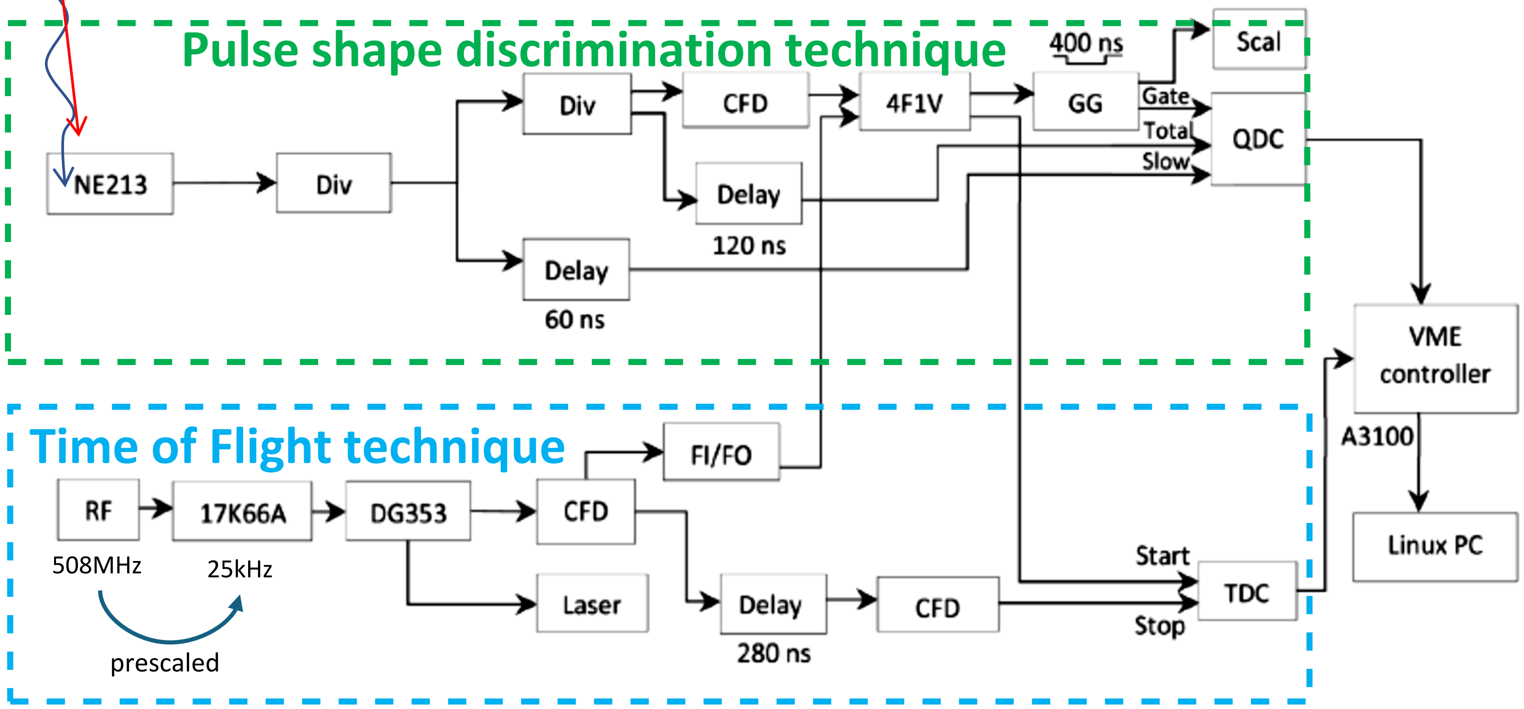
- Incident photon energies can be calculated by E_e and E_L
- Neutron detector: NE213 liquid scintillator at different angle
- RF from storage ring triggers DAQ system

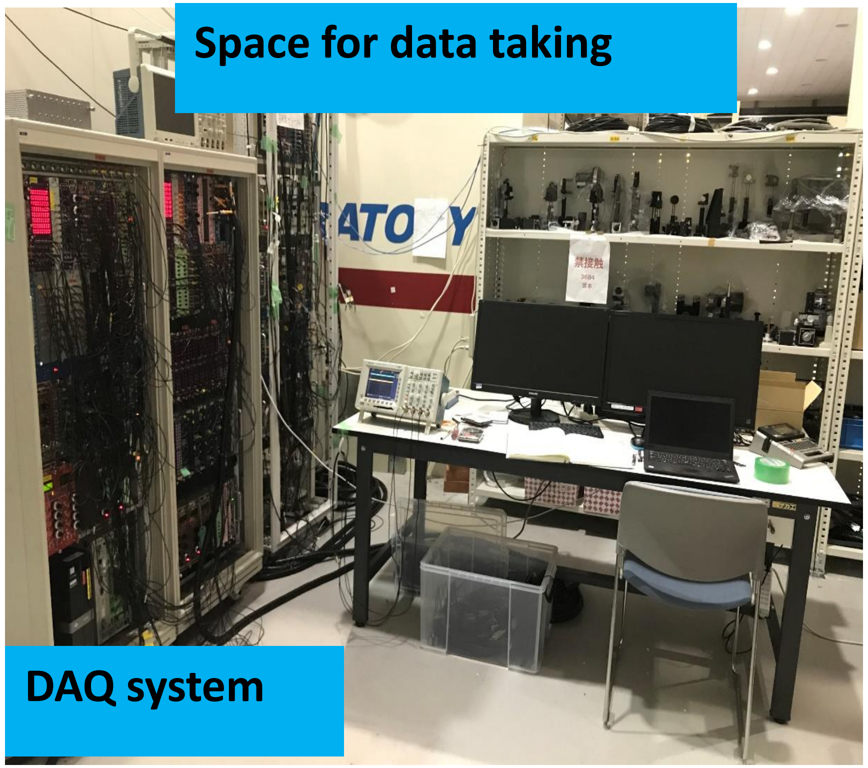
Data Acquisition System (DAQ)



- This figure presents the schematic diagram of the electronics circuit for neutron detectors.
- To seperate **n** and **g**

⇒Use **pulse shape discrimination technique**



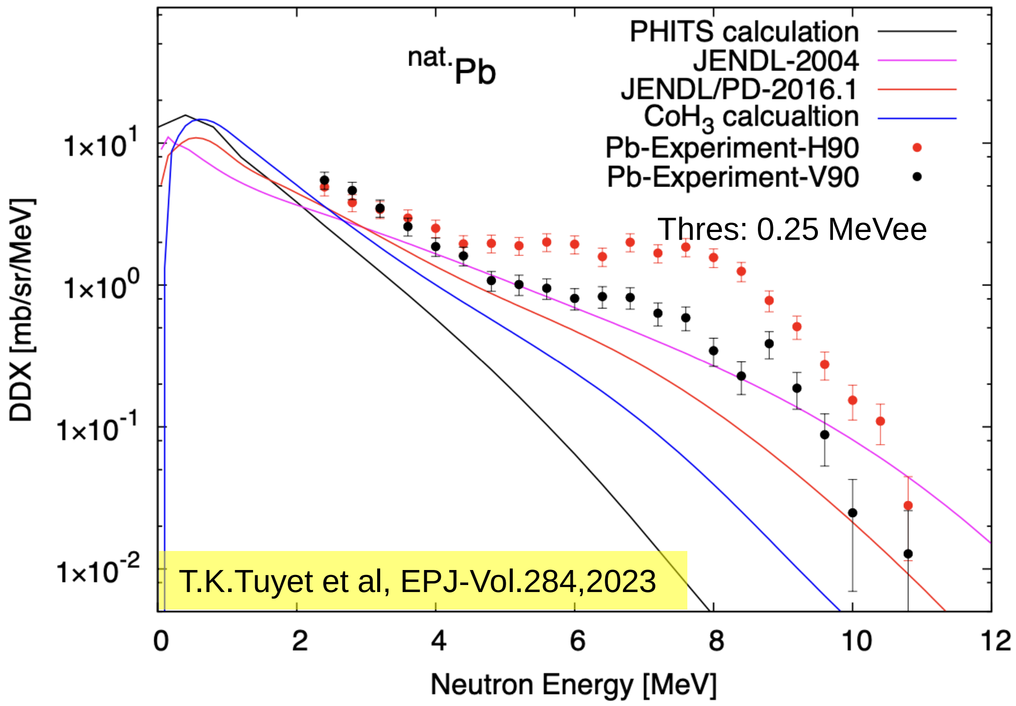


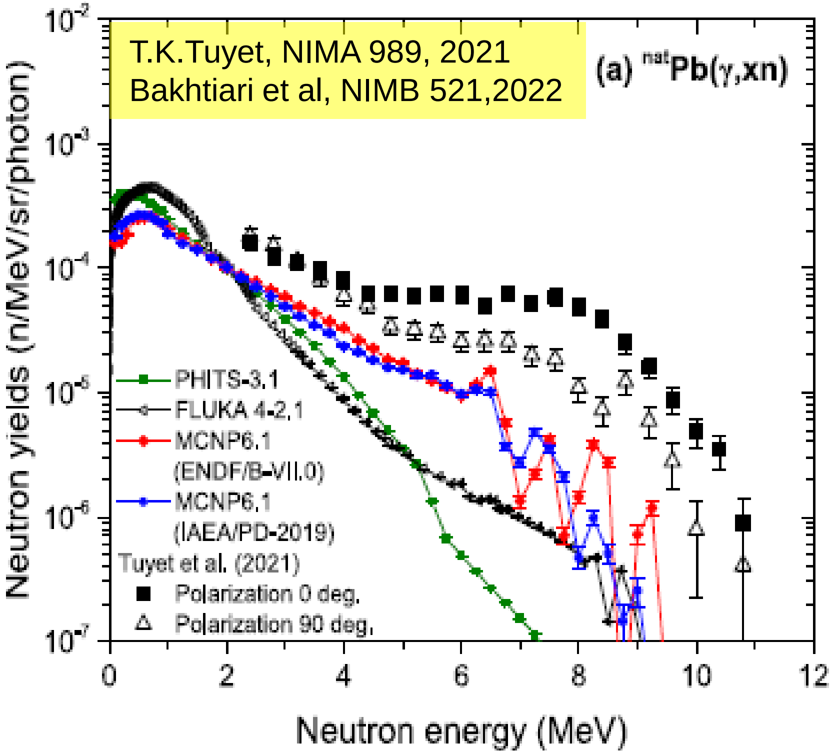
It takes time for neutron emitted from the target to "flight" to NE213 detector

⇒**Time of flight corresponds to neutron's energy**

Our experimental data and theory calculation

- Double differential cross section (DDX) of photoneutrons reported as first data [NIMA 989 2021].
- Compared with calculation program (nuclear data library, PHITS, FLUKA, MCNP)
  - Bakhtiari et al, NIMB 521,2022, T.K.Tuyet et al, EPJ-Vol.284,2023





➔ Inconsistency between calculated and experiment spectrum

➔ Calculated data are ***always lower*** than the experimental data

➔ Experimental data shows Photoneutron in low energy are missed in our experiment.

➔ We want to obtain the data set from lower energy (around 0.5 MeV) to high energy (around 12 MeV)

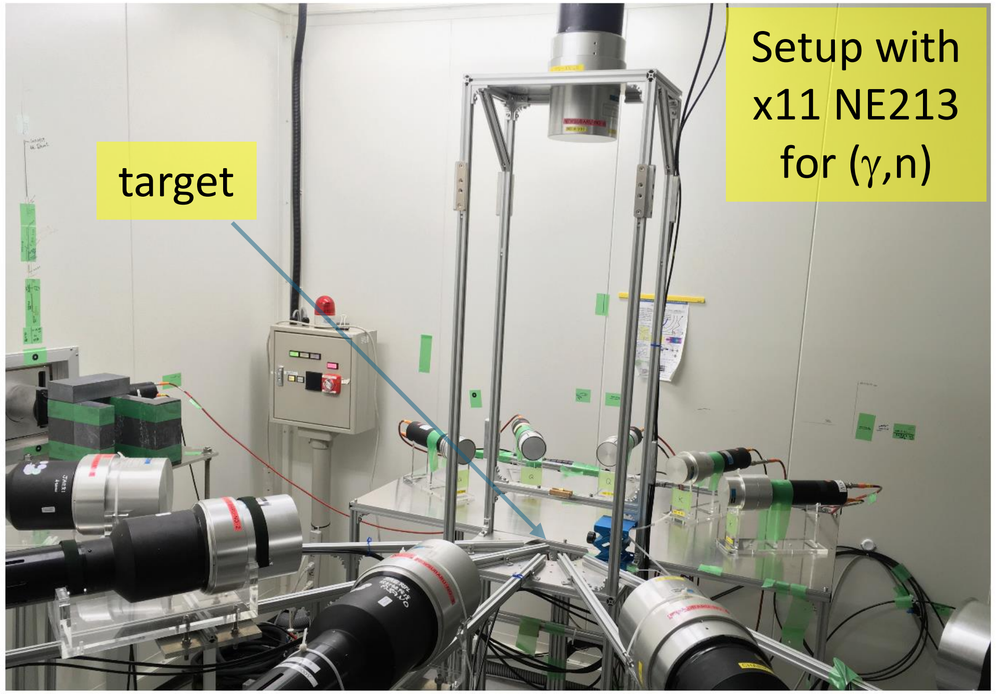
→ This data set is necessary to improve theory calculation

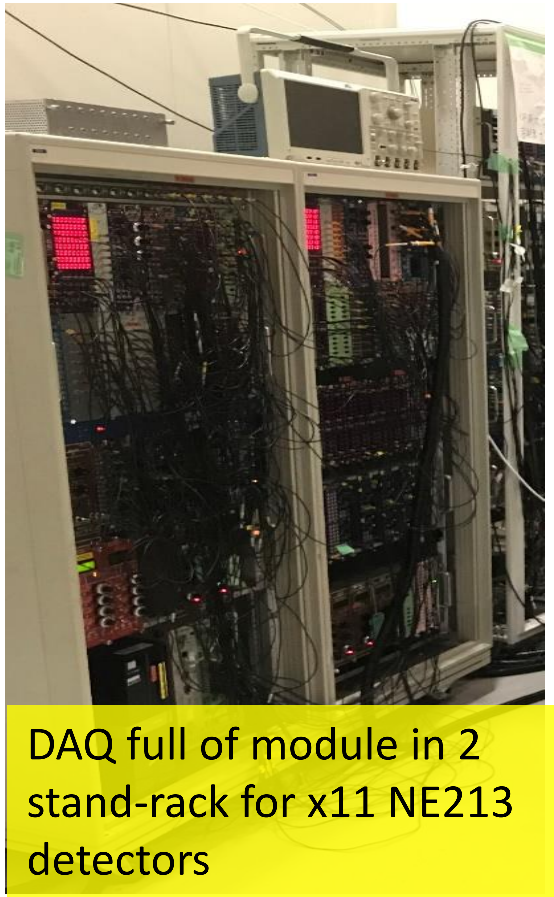
Previous DAQ system

- Numerous NIM and VME modules for x11 NE213 detectors

⇒ More detectors for deeper angular distribution study, DAQ will be expanded to huge size.

- Photoneutrons <2MeV cannot be obtained.





Previous DAQ system ⇨ Digitizers

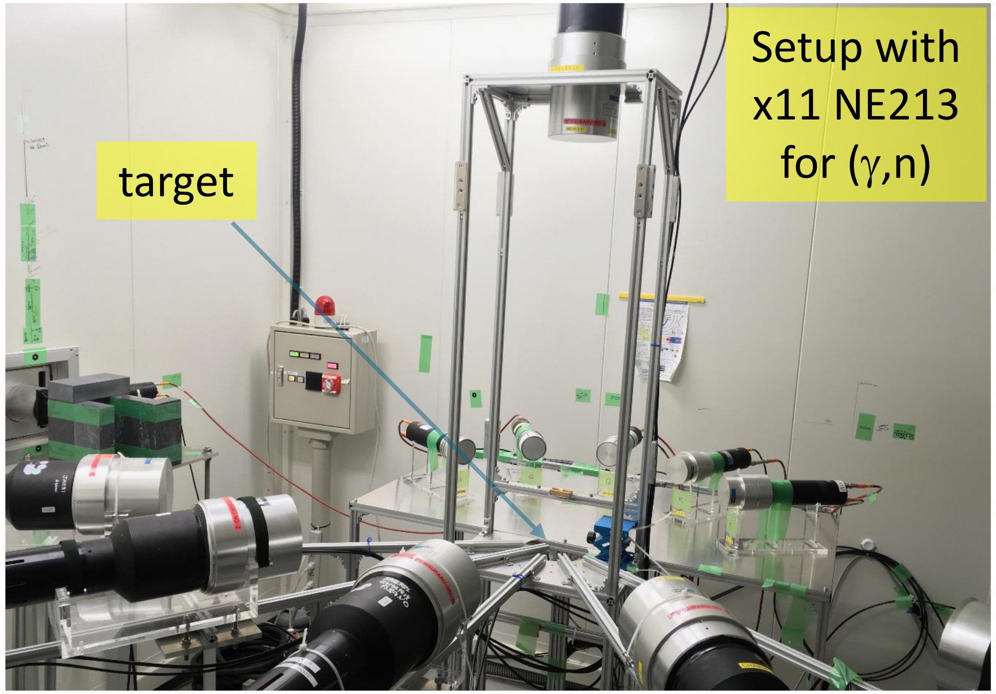
- Numerous NIM and VME modules for x11 NE213 detectors

⇒ More detectors for deeper angular distribution study, DAQ will be expanded to huge size.

- Photoneutrons <2MeV cannot be obtained.

upgrade

- Make DAQ with digitizers
- Raw waveforms are recorded
- Low energy photoneutrons can be measured using fast digitizer and high resolution



Can these 3 little guys solve the problem?

APV8104
TechNo Co.
4 Channels
1GSa/s

APV digitizer

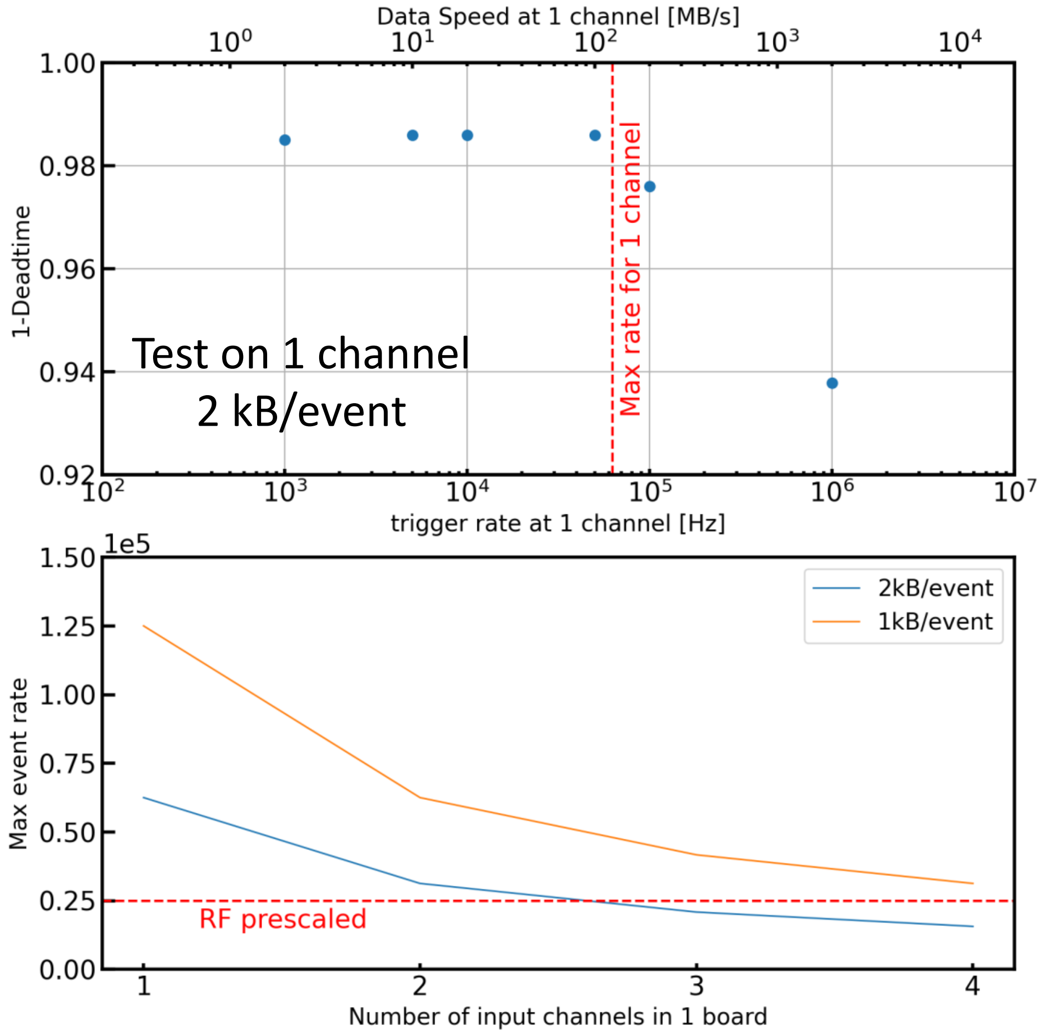
- Produced by Techno AP Co.
- 1 GSa/s,14-bit resolution

⇒Good for recording waveform from fast scintillator

- 4 channels; Input ±1 Volt

⇒ 3 modules: up to 12 detectors

- 4000points/channel/event

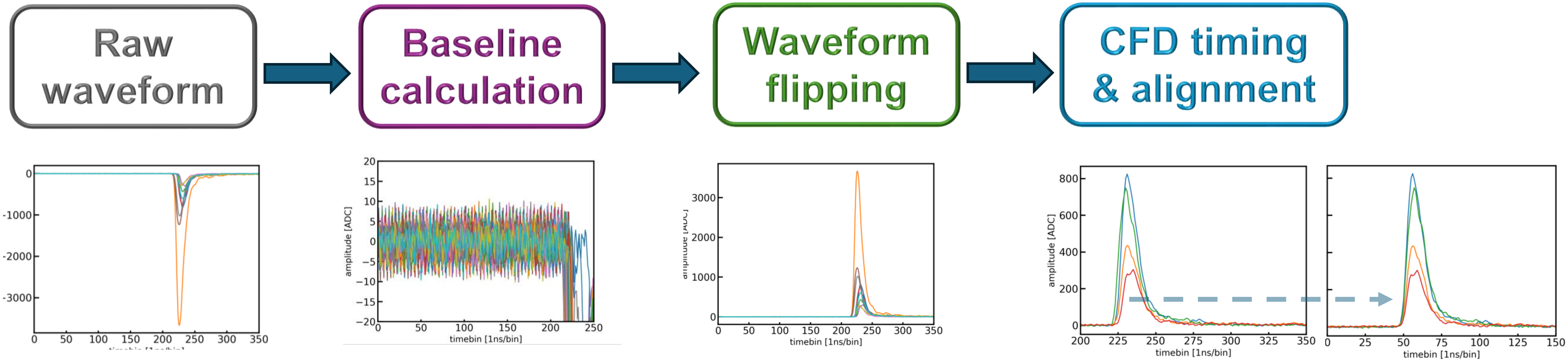


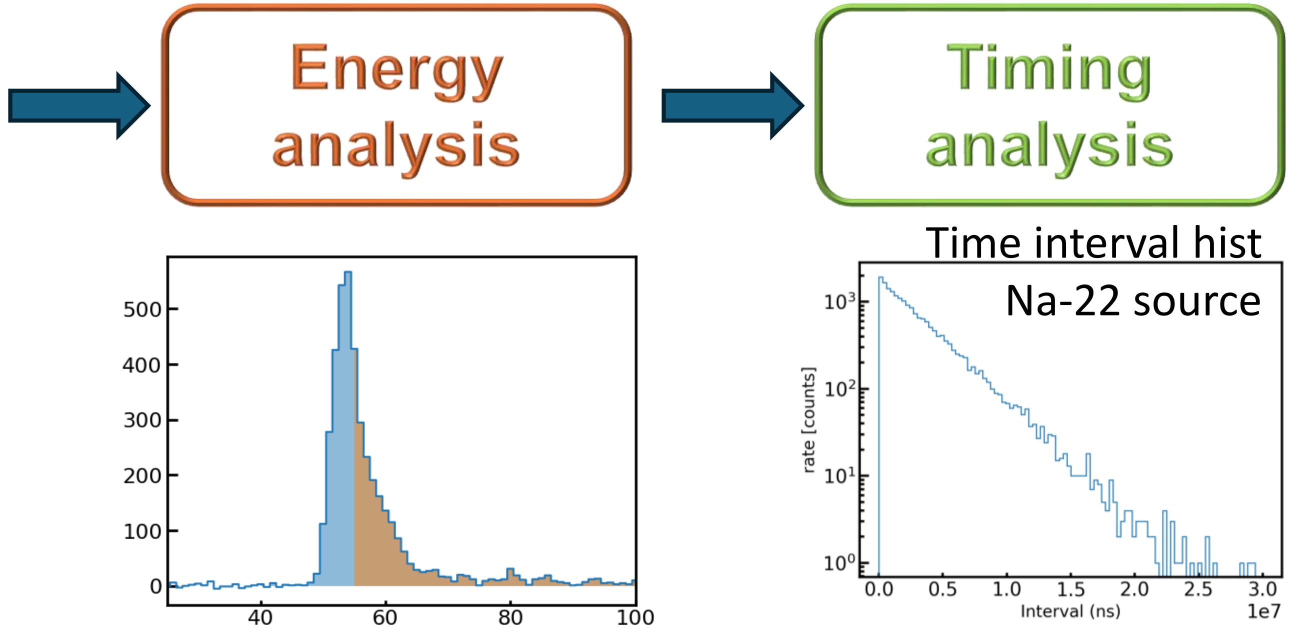
Data rate

- In previous DAQ, the RF signal from storage ring is coincidence with NE213 for triggering
- RF signal was prescaled to 25kHz.
- For APV8104, max event rate for 4 channels: 15kHz (2kB/event) or 30kHz (1kB/event).

⇒ Good enough for measurements.

Proceeessing waveforms





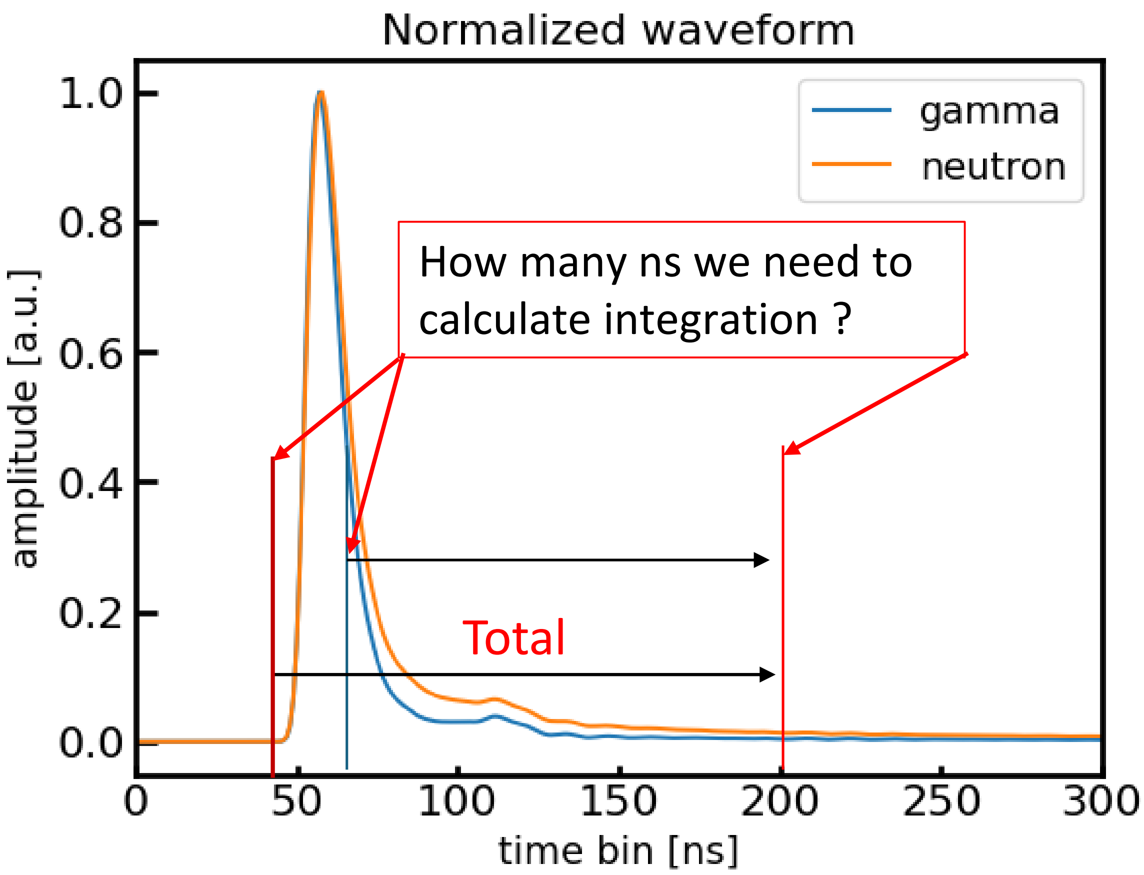
- Waveform analysis are performed from raw data.
- Multiple outputs: energy, timing, pulse shape analyses,...

Pusle shape discrimination method

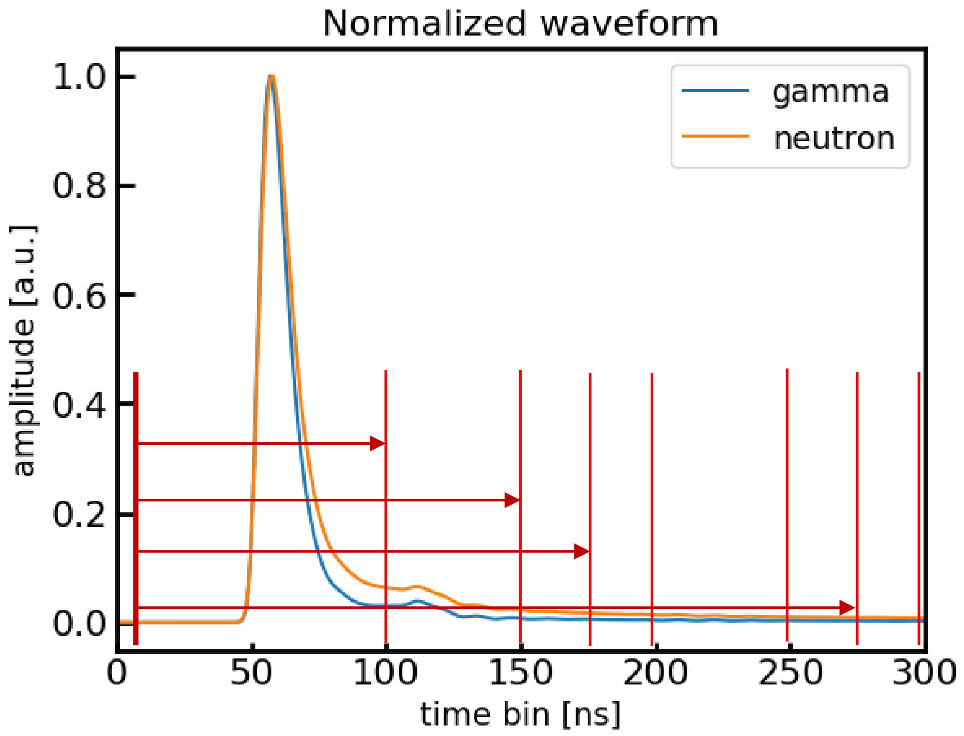
- Charge integration method
  - Ratio of charge in tail to total
  - PSD = $\frac{\int_{tail\_start}^{tail\_end} Q.dt}{\int_{total\_start}^{total\_end} Q.dt}$

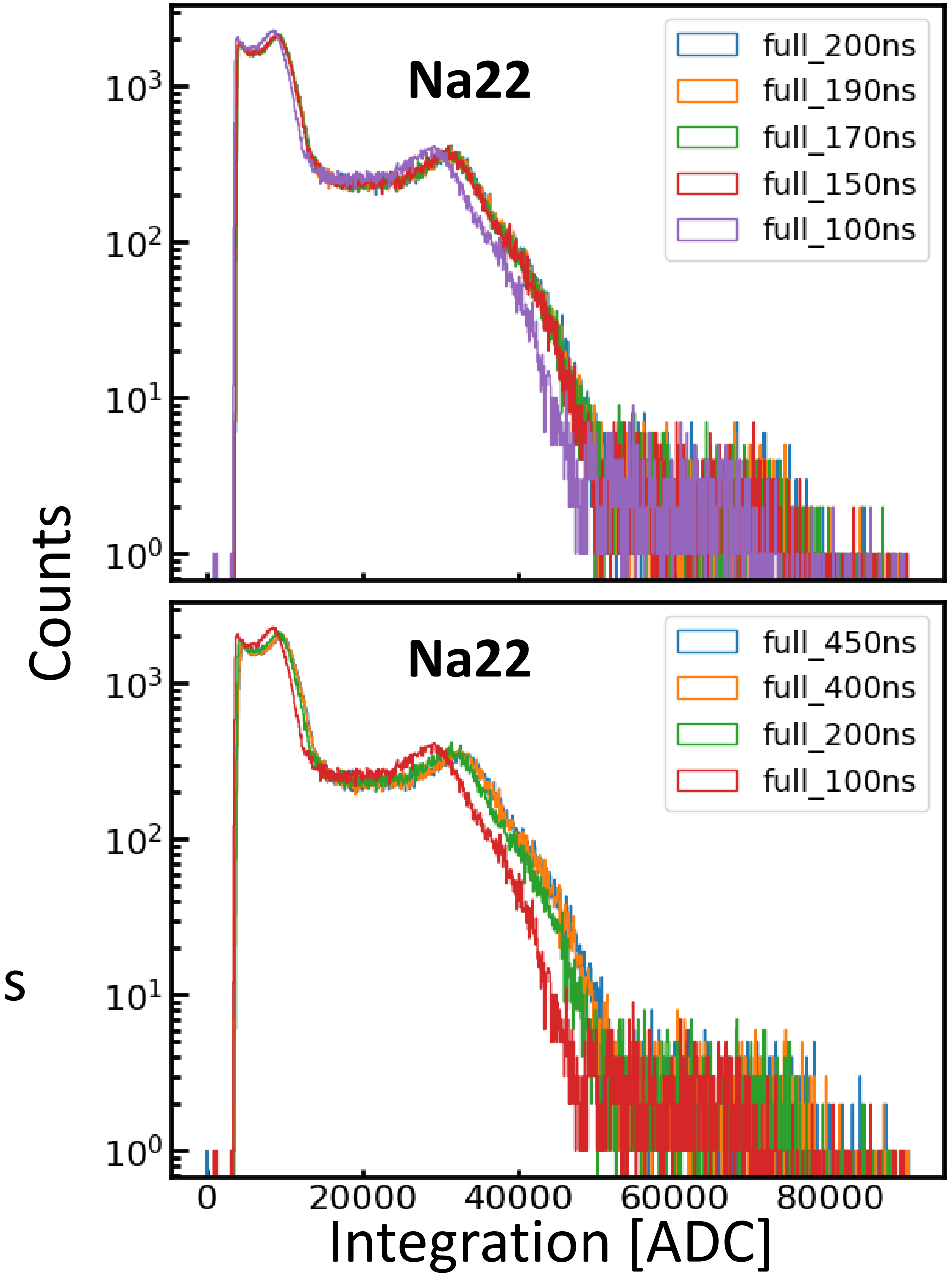
→ We need to determine:

- ➢ time window to calculate total and tail of charge
- ➢ Figure of merit (FOM) to evaluate the separation performance of the PSD technique



Determine time window (in ns) to calculate total integration

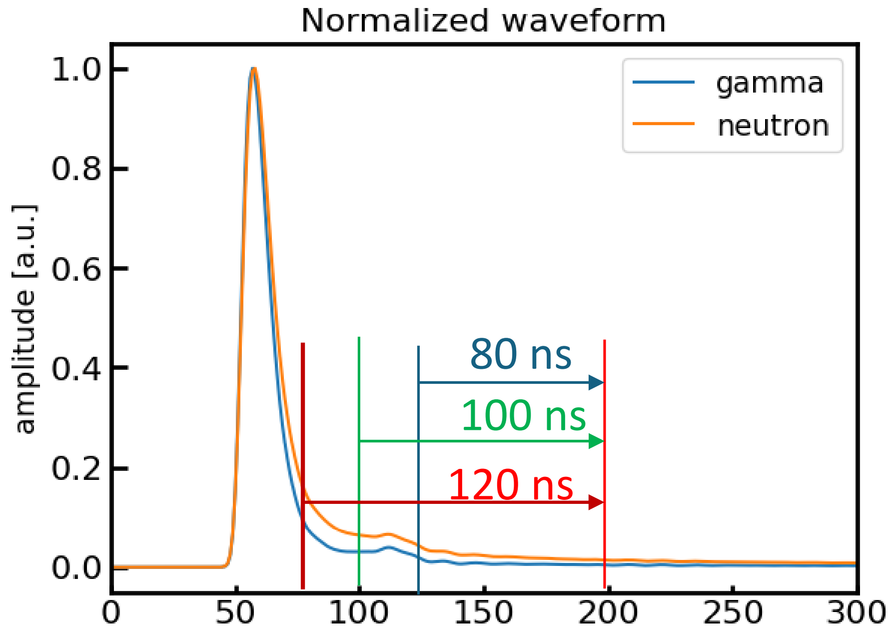


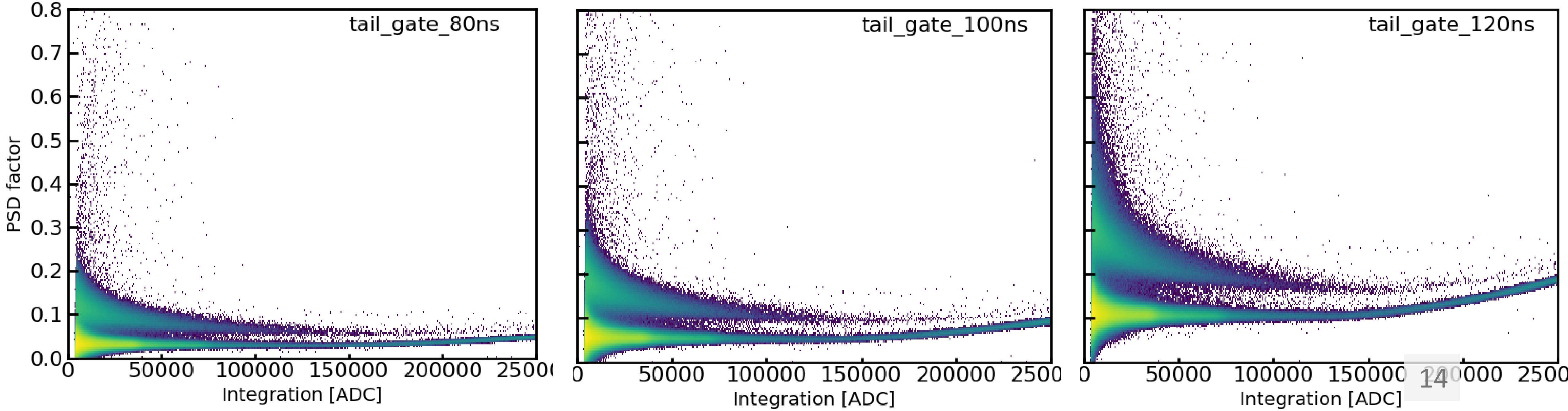


- Use gamma source: Na22
- These pectra calulcated by integrating ADC with changing time window
- Integration spectra in 150 ns, 200 ns to 400ns are almost similar.
- Calculate “total integration” in gate of 200ns

Determine time window (in ns) to calculate tail integration

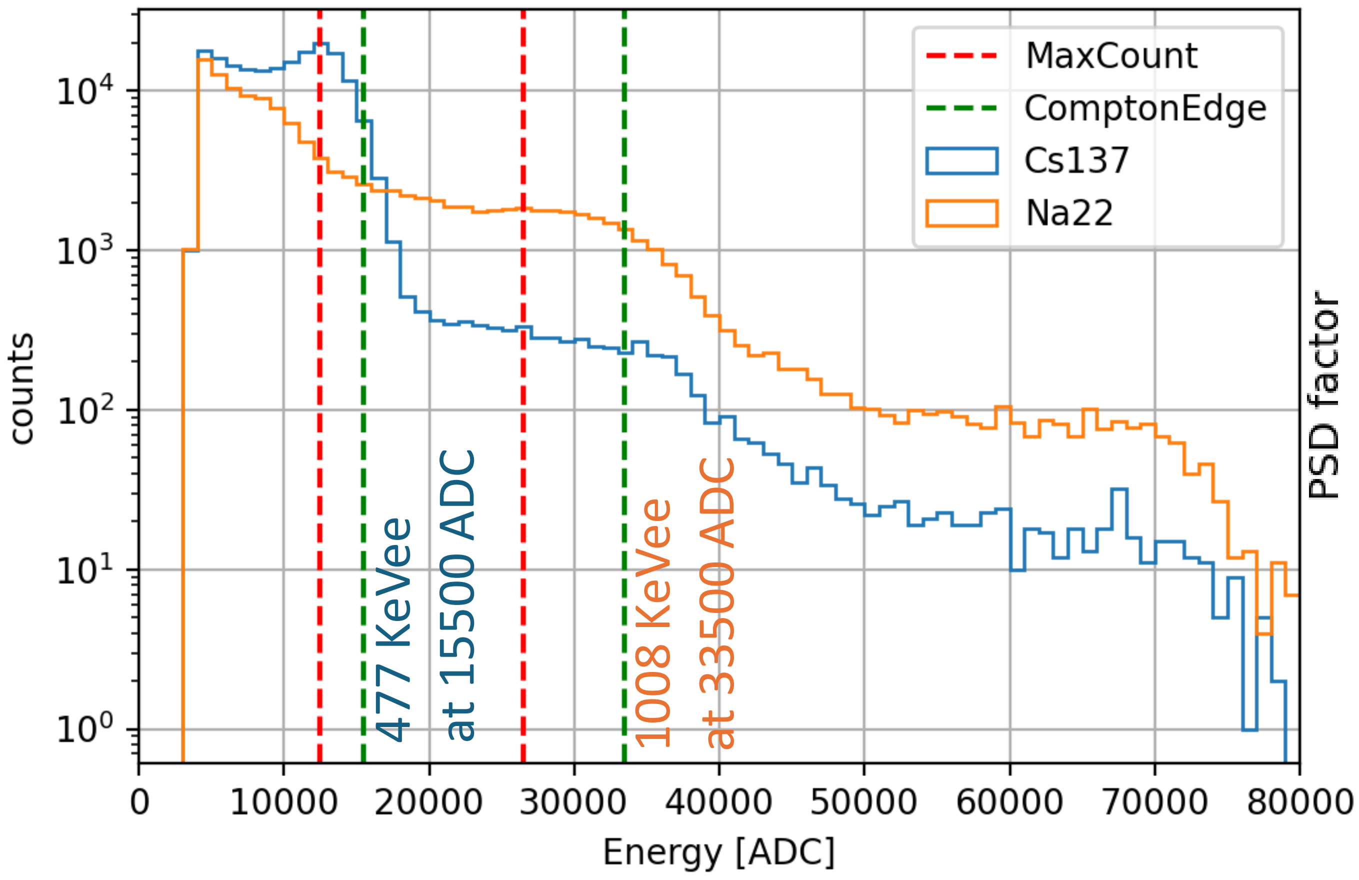
- Data for Cf252
- PSD factor = $\frac{\text{tail integration}}{\text{total integration}}$
- Tail_integration calculated in 80 ns, 100ns and 120ns.
- Integration values is as function with PSD factor
- Tail_gate in 120ns shows a good seperation.



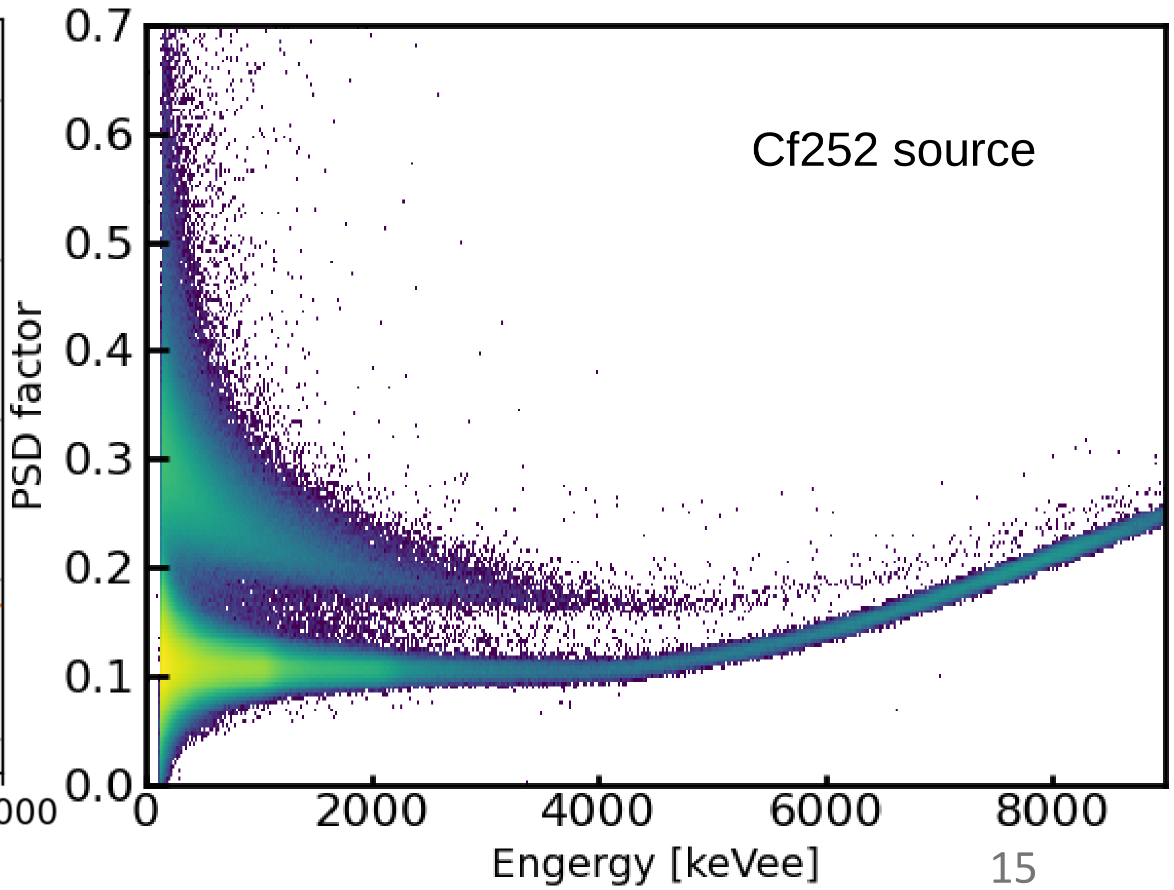


Energy calibration

- Gamma sources: Na22 and Cs137
- Energy [keVee] = ADC*0.0295 +19.75

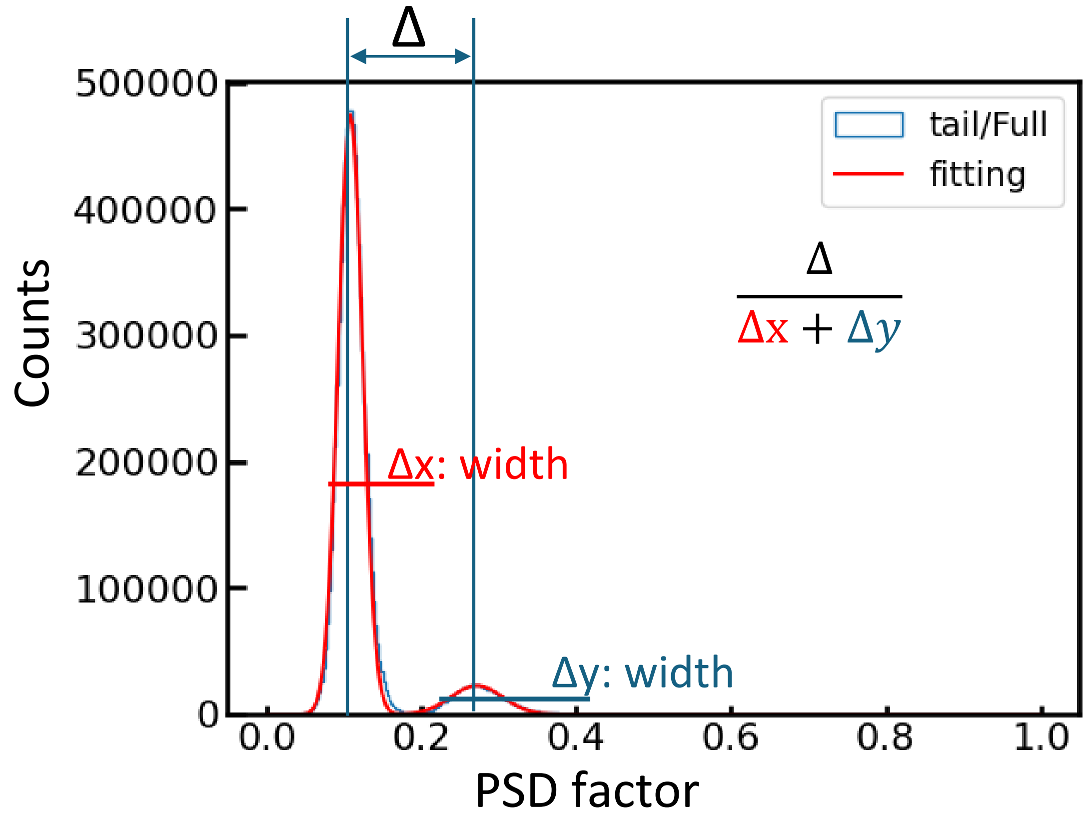


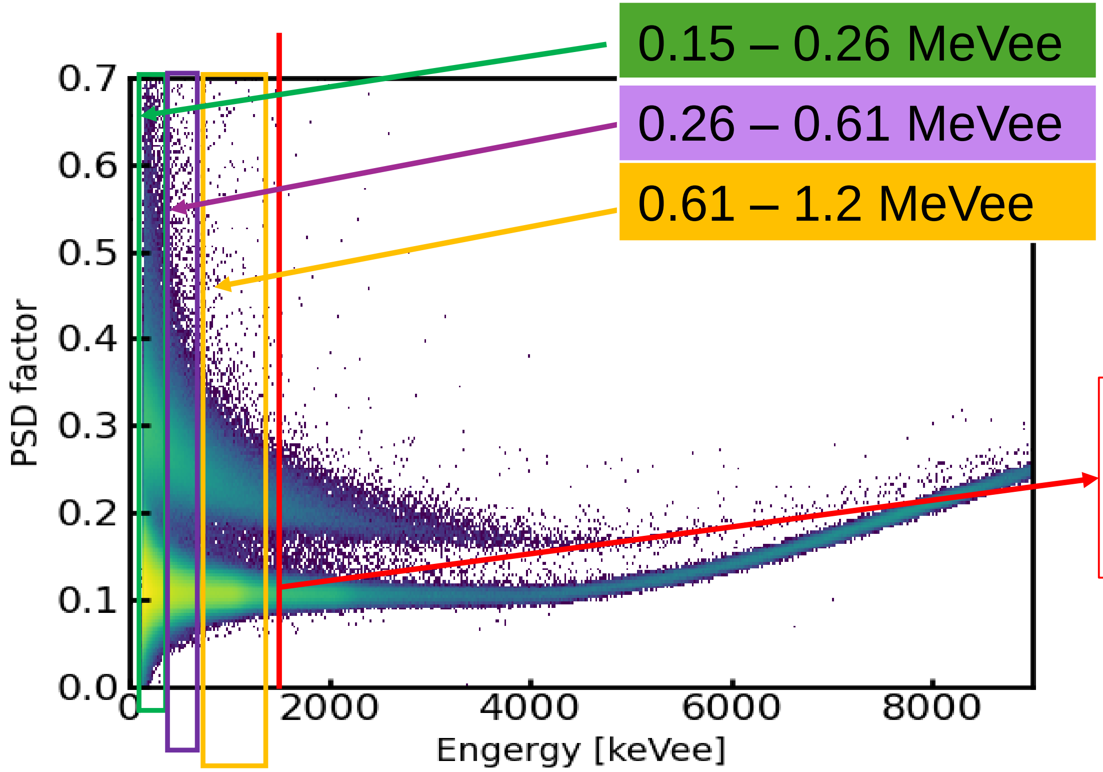
- Data for Cf252
- X-axis: Convert ADC to energy in keVee



Calculate Figure of Merit (FOM)

- FOM can evaluate the separation performance of the PSD technique
- FOM calculated by this formular $\frac{\Delta}{\Delta x + \Delta y}$
- These parameters are determined by fitting Gaussian distribution





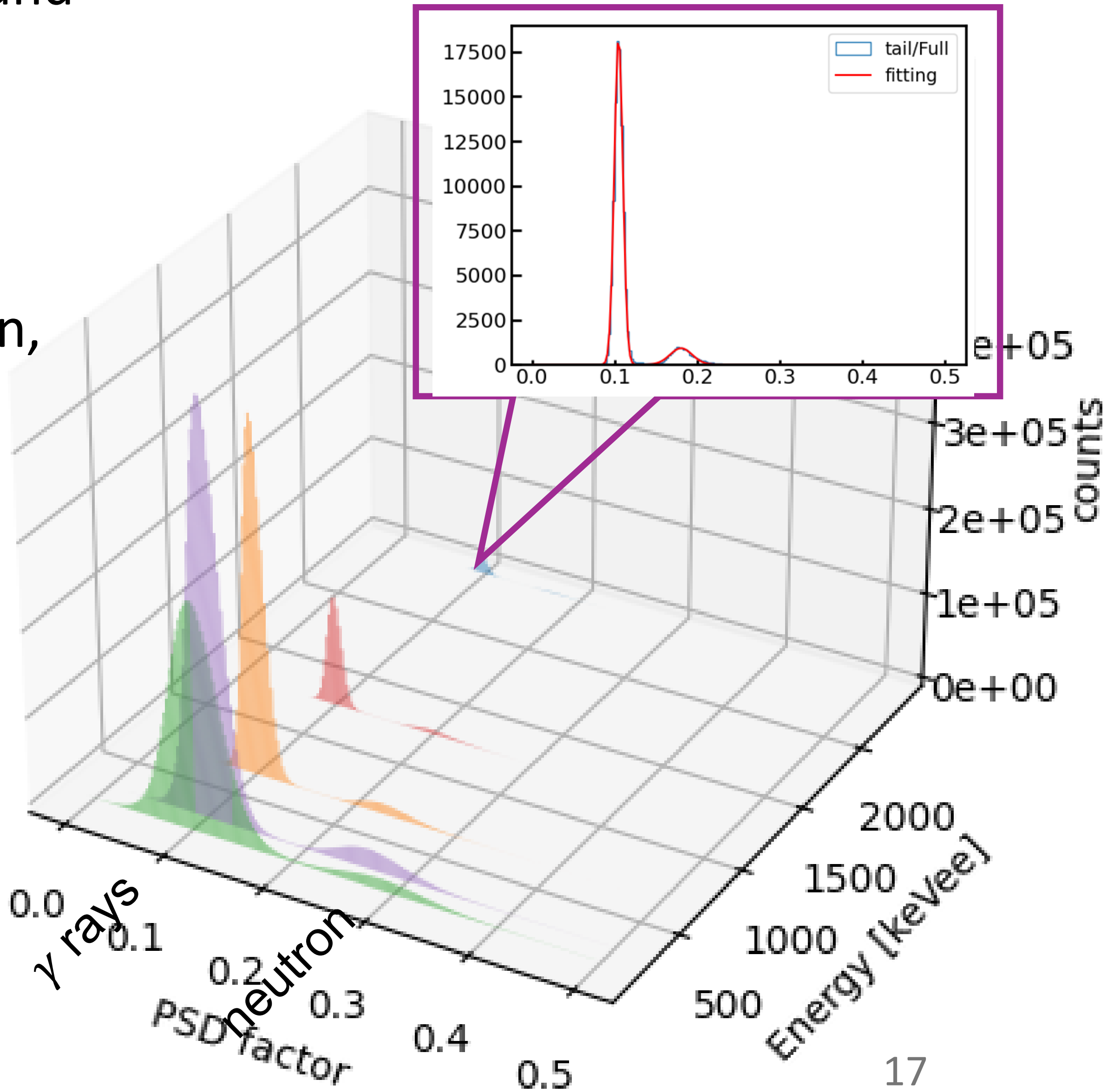
Neutron, gamma discriminated well in energy range higher than 1.5 MeV

Calculate FOM

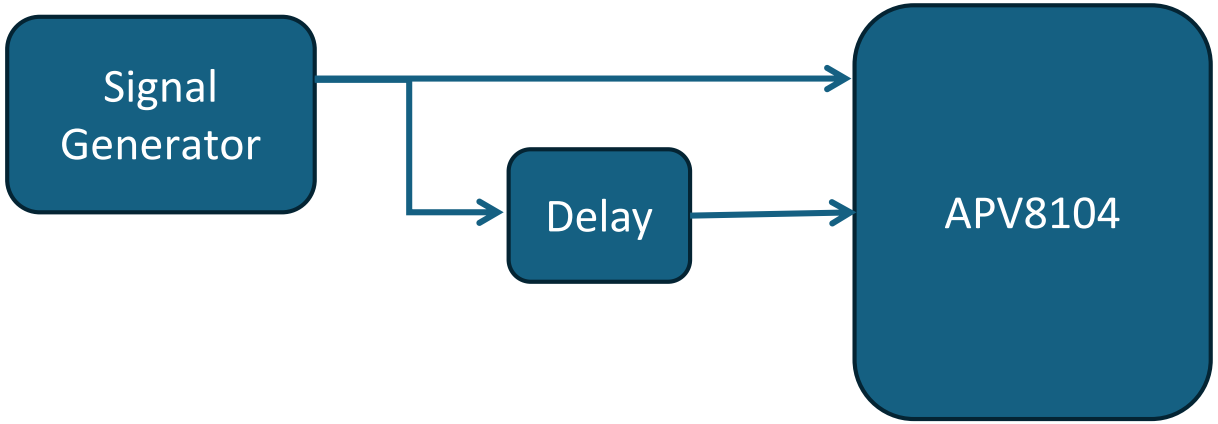
- PSD factors of gamma are almost similar (around 0.1~)
- Neutron-gamma can be separated well with threshold higher than **0.15 MeVee**

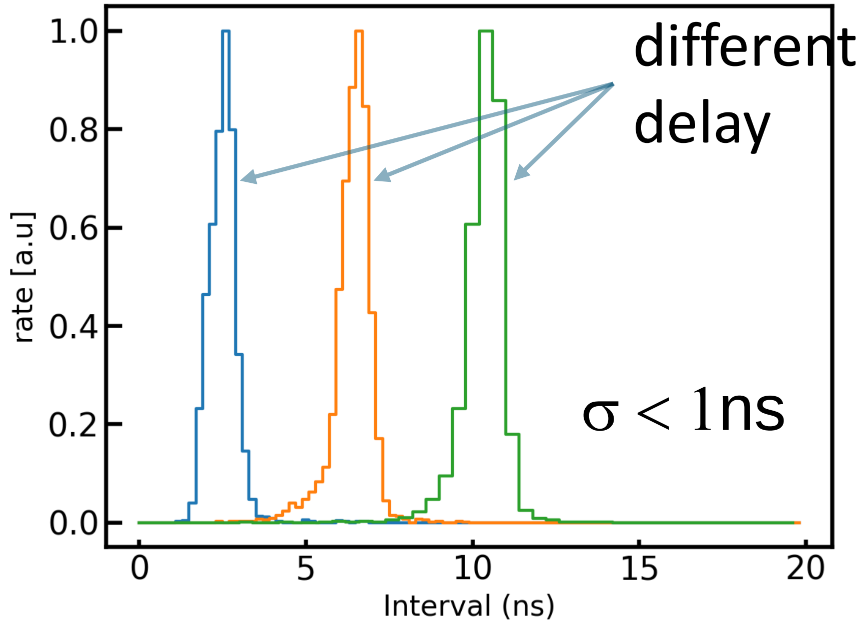
⇒ Lower threshold in neutron-gamma separation, compared to previous DAQ (0.25 MeVee).

Engergy range [MeVee]	FOM
0.15 – 0.26	2.25
0.26 – 0.61	3.33
0.61 – 1.2	3.79
1.2 – 2.38	3.92
2.38 – 4.44	4.09



Time-of-Flight capability





- Travel time of neutron at specific energy and distance can be determined bv

$$E_n(x) = M_o c^2\left(\frac{1}{\sqrt{1-\beta^2}} - 1\right), \quad \beta = \frac{V_n(x)}{c} = \frac{L}{c.T_n(x)},$$

- In our photo-neutron measurement, ToF of neutron is 10-25ns with distance ~0.5m.
- APV8104 provides timestamp with picosecond precision for timing measurement

- Timing calibration with signal generator and delay module.

⇒ Good timing capability,

⇒ σ is less than 1ns.

⇒ As good as the previous DAQ

Conclusion

- Plan to upgrade DAQ for the photoneutron measurement at NewSUBARU, Hyogo, Japan.
  - $\Rightarrow$ Waveform recording for more complex analysis
  - $\Rightarrow$ Digitizer APV8104 (1GHz 14-bit) is a good resolution
- Test different capabilities of digitizer:
  - $\Rightarrow$ n-γ PSD: good ability to separate down to 150 keVee (lower than previous DAQ, threshold in n-g of 250 keVee)
  - $\Rightarrow$ Timing measurement: timestamp of each input channels allow ToF measurement. Timing resolution <1ns (similar to prev. DAQ)
  - $\Rightarrow$ Can operate at high input rate: up to 30kHz for 4channels

Future plan

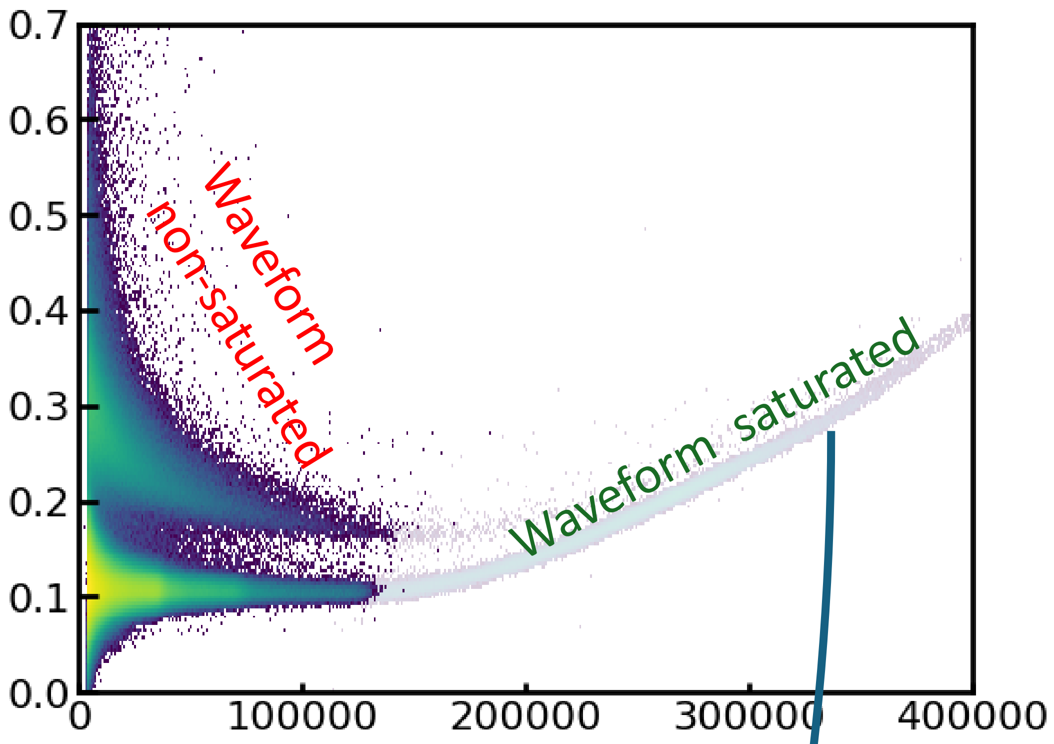
- Determine PSD with fitting pulse

  Many saturated events observed cannot be used

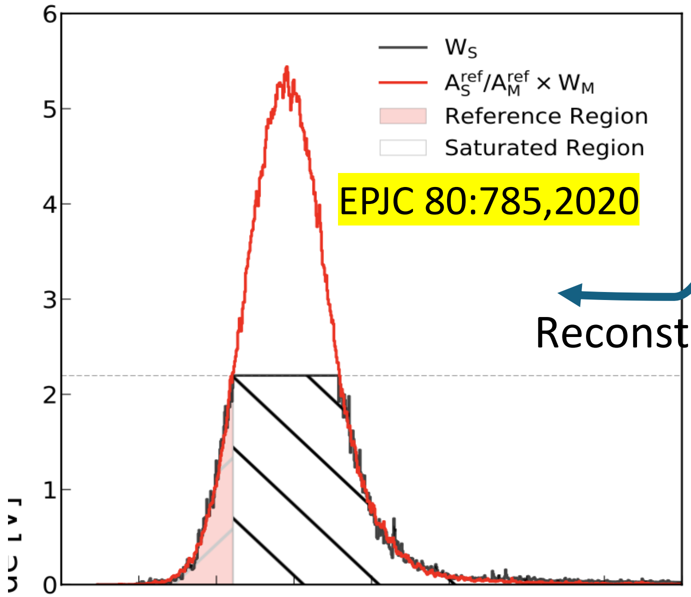
  ⇒ Reconstruct waveform of the saturated events, expand the dynamic range.

- Measure energy of neutron source by time of flight

- Perform experiments with Laser Compton Scattering using digitizer



Reconstruction?

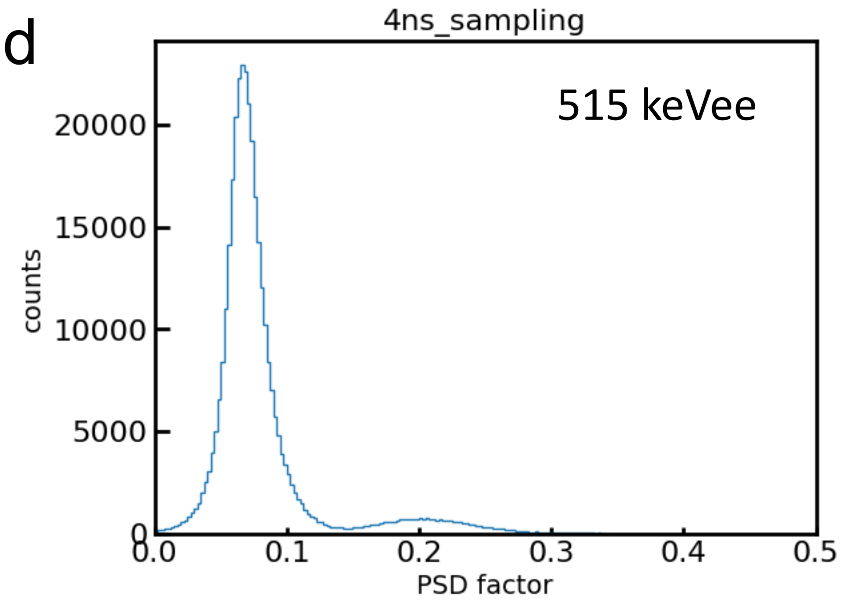


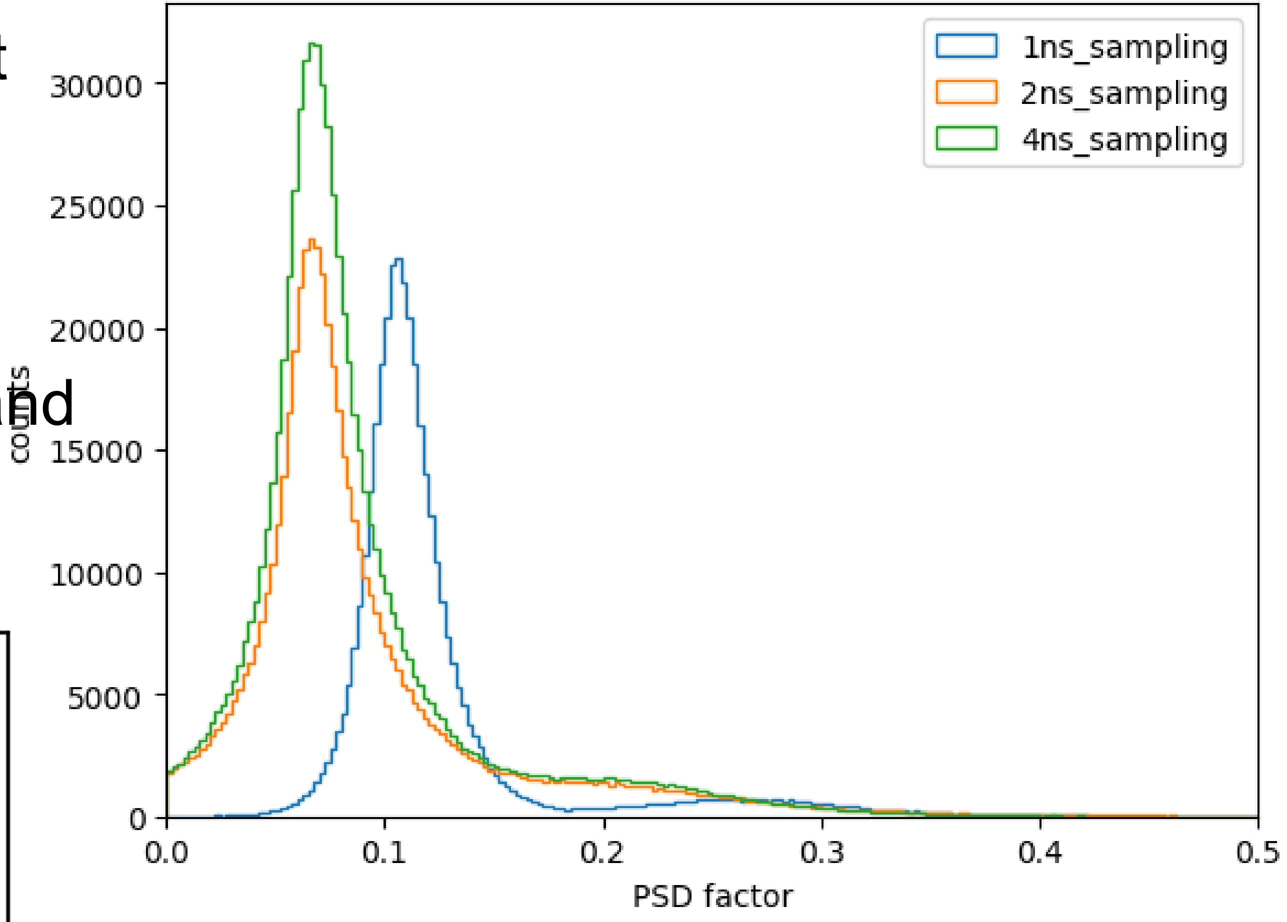
Thank you for your attention

Backup slides

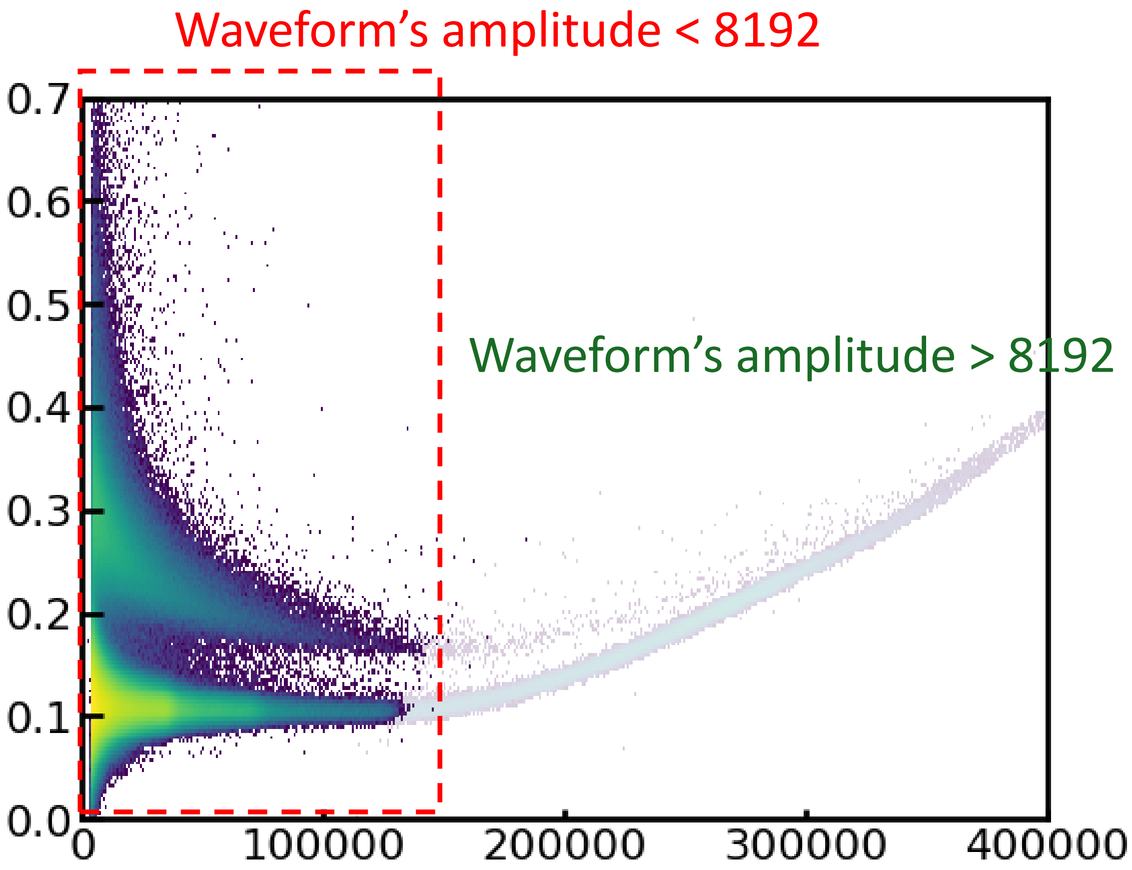
Comparing different sampling rates

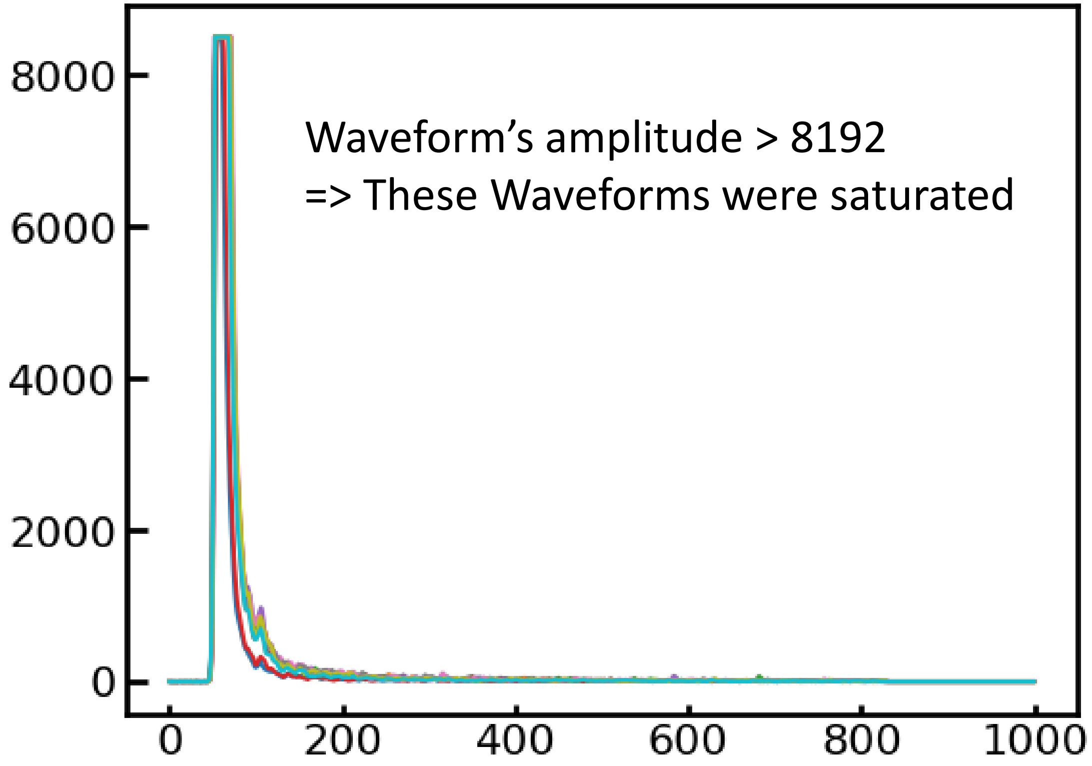
- PSD factors are calculated with different sampling rate
  - ⇒ Using 150 keVee threshold
  - ⇒ n-g cannot be separated using 2ns and 4ns sampling rate with 150 keVee threshold





- Two figures with same data set but different condition to plot:
  - All data
  - Waveform’s amplitude < 8192





- 1ns sampling PSD