The development of multi-channel photon detector for Liquid Argon Time Projection Chamber

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29 Sep 2023

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NanoGRAMS

… Proof-of-concept study of small Compton camera using liquid argon

➢ We use **Liquid Argon Time Projection Chamber** (LArTPC)

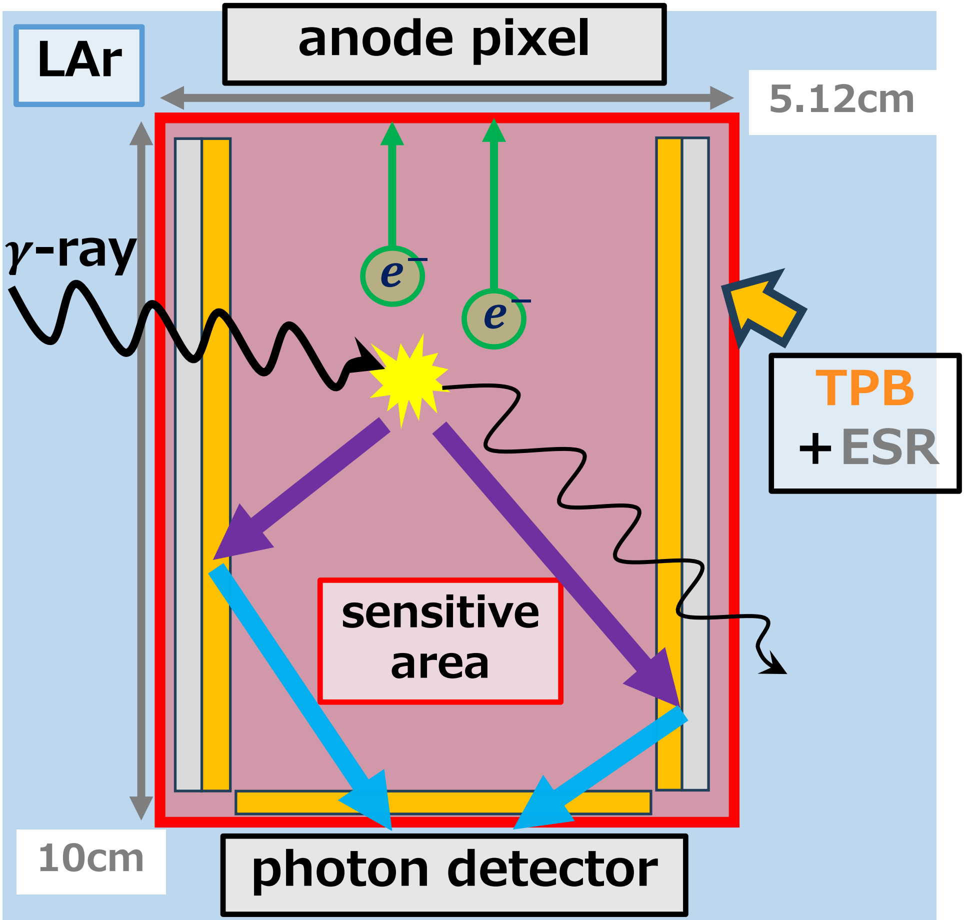
① ・Compton scattering $\xrightarrow{\text{hit}}$ ionized electron
・photoelectric absorption

② Interaction with argons
→ **ionized electrons**, **scintillation light**

③ Detection after **electron drift in E-field**, **wavelength conversion**

→ **XY position of hit ＋Energy deposit**

→ **Time stamp(Z pos)＋Energy deposit**

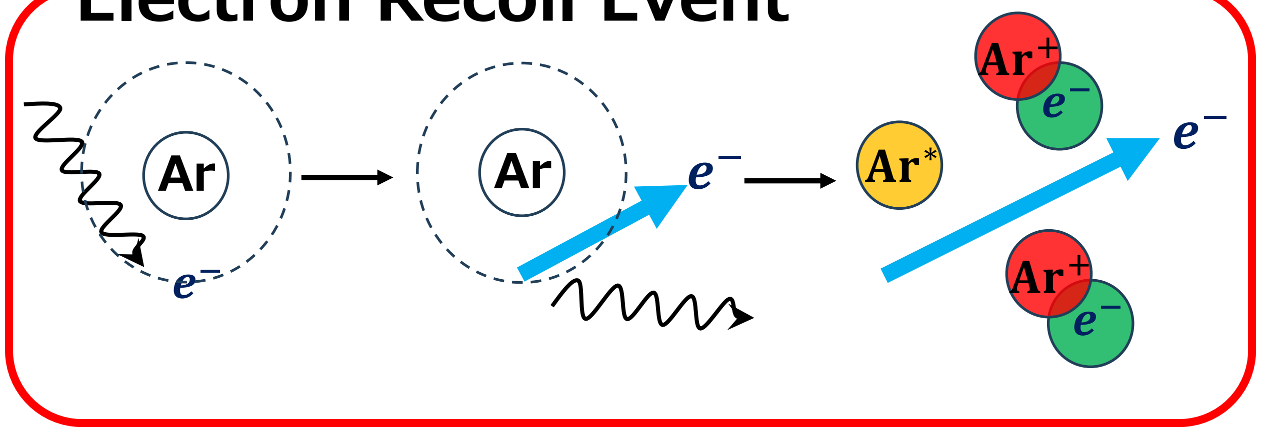


Atmospheric background

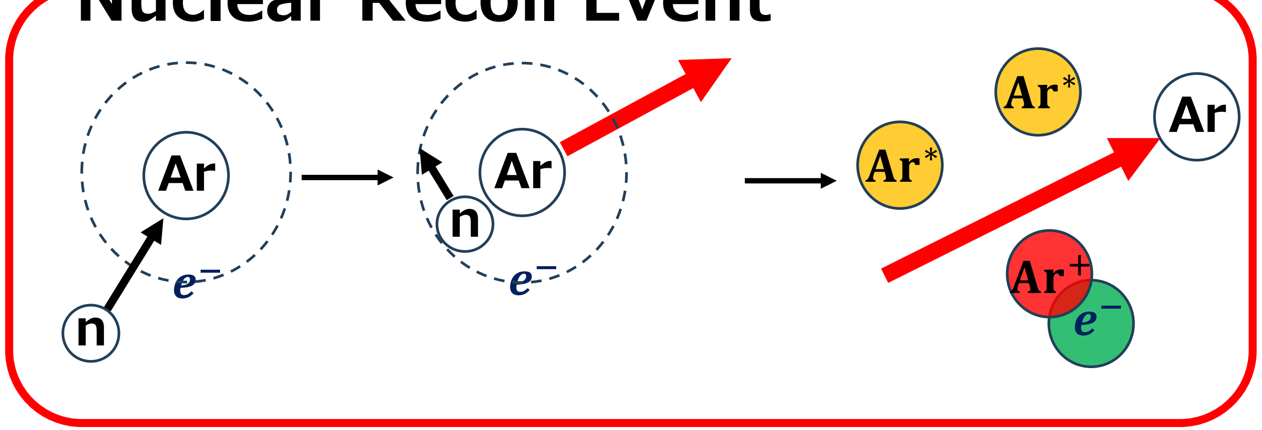
Neutrons make background events in observation

● : excited Ar ● : ionized Ar

Electron Recoil Event



Nuclear Recoil Event

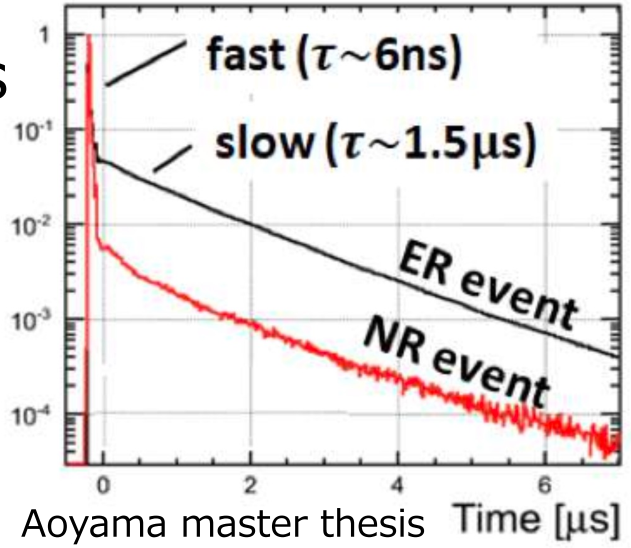


- ✓ S_{fast}/S_{slow} from Ar* , Ar+ are different
- ✓ $N_{\mathrm{Ar\_ionized}}/N_{\mathrm{Ar\_excited}}$ depends on energy deposition process

Slow component fraction { **high** (ER event) / **low** (NR event)

Difference of the slow-to-fast ratio discriminates background events

scintillation light waveform

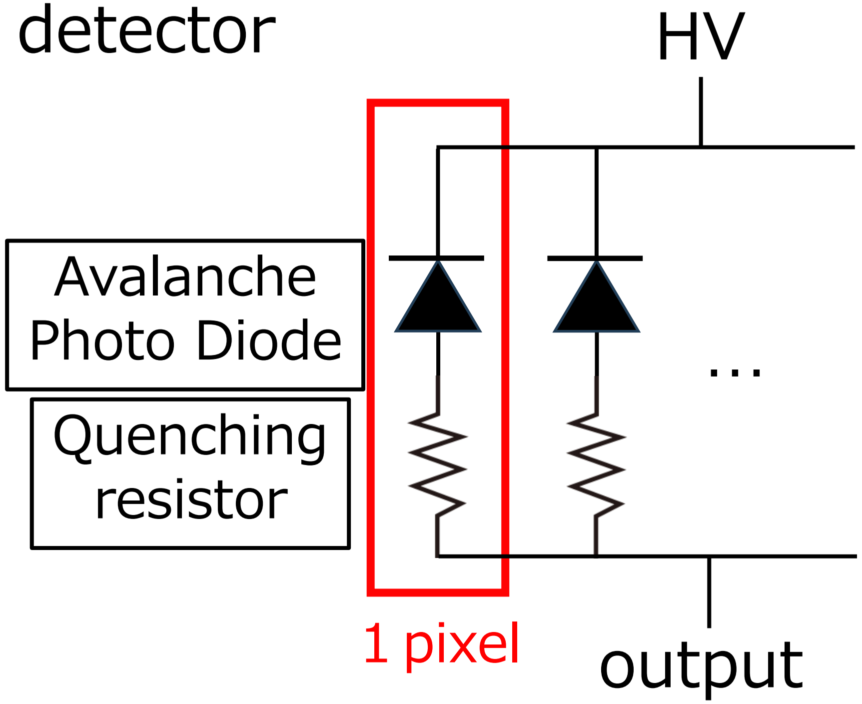


Aoyama master thesis (waseda 2019)

Photon detector and important parameters

✓ **MPPC (Multi Pixel Photon Counter)** as photon detector

- photon counting capability
- high quantum efficiency
- flexible design for a compact detector



Important parameters of MPPC

gain : Contributes to **energy resolution**

□ APD goes into Geiger mode

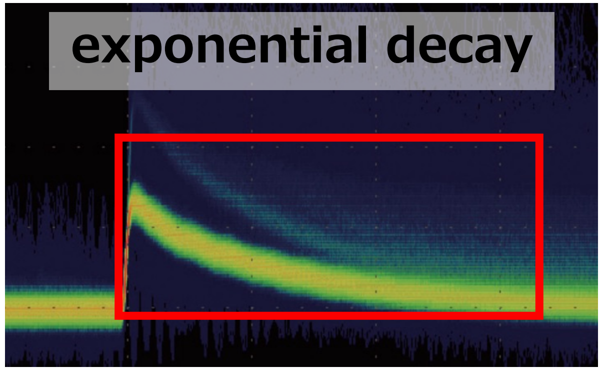
- Avalanche amplification factor of excited electrons

decay time : Contributes to **discrimination performance**

<250ns@100 photons

□ Geiger mode is cancelled by voltage drop in the resistor

- Decay time of exponential decay when recharging

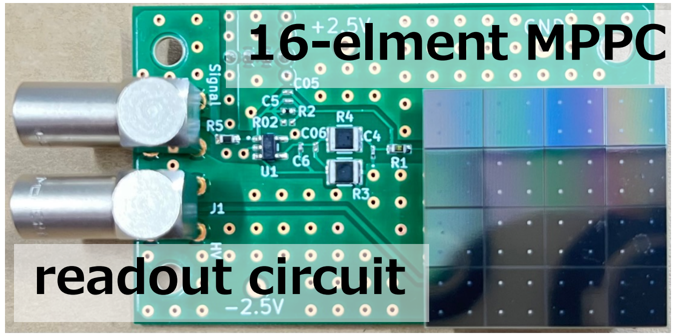


typical waveform from MPPC

16-element array of MPPC

We developed a low noise and fast response readout circuit working at LAr temp

- transimpedance preamplifier (I-V conversion)
- feedback resistor is 3.2kΩ

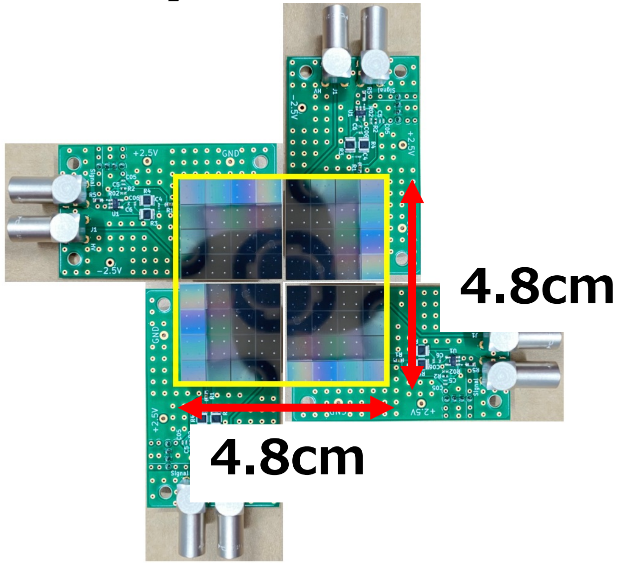


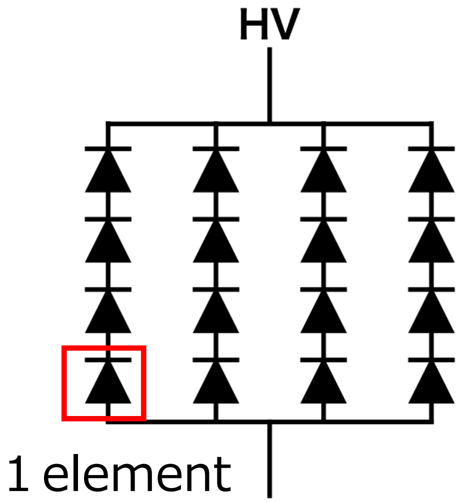
✓ The bottom of the sensitive volume is covered by MPPCs

→ 64 MPPCs and readout required

Combines all the output of the 16 MPPCs into one channel

Sufficient coverage with only 4ch readout





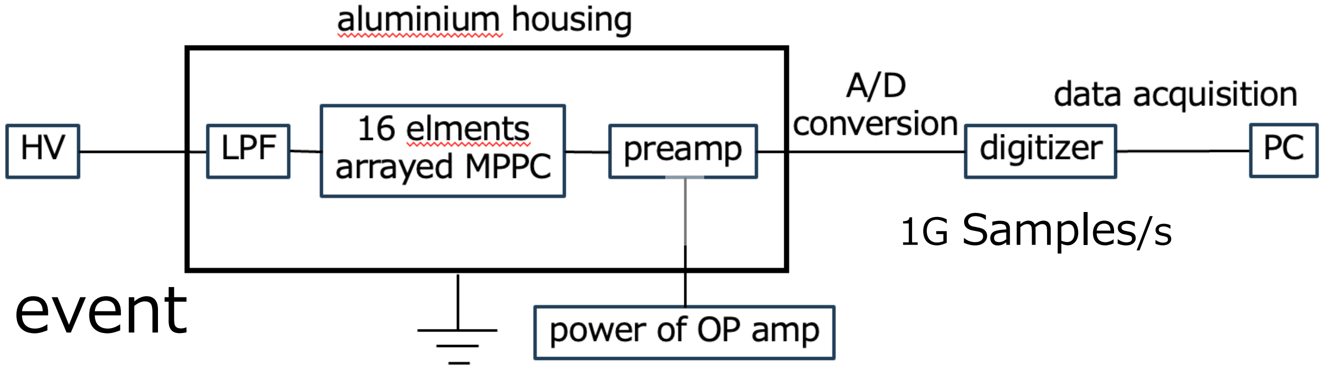
Both series and parallel connection have pros and cons

→ We choose **4 series** × **4 parallel**

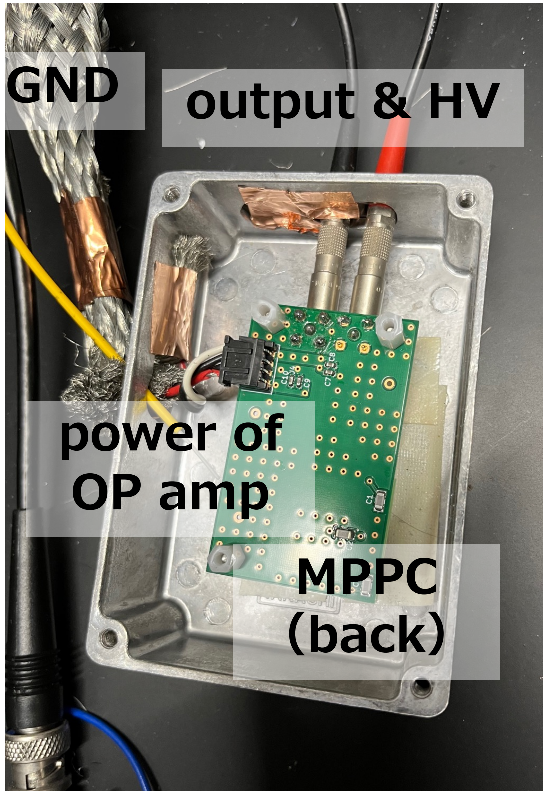
Evaluate performance changes

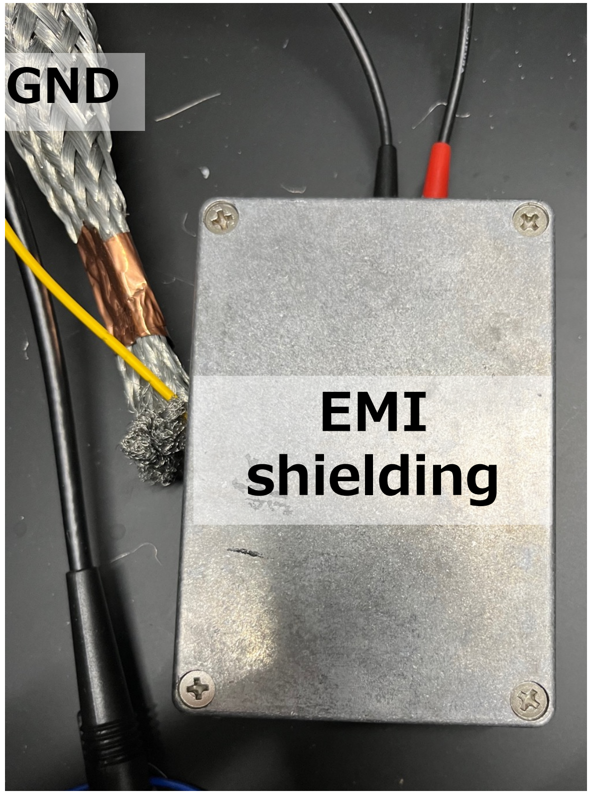
Experimental setup

- Liquid nitrogen temp(-196℃)
  - ➢ Physical conditions are close to LAr

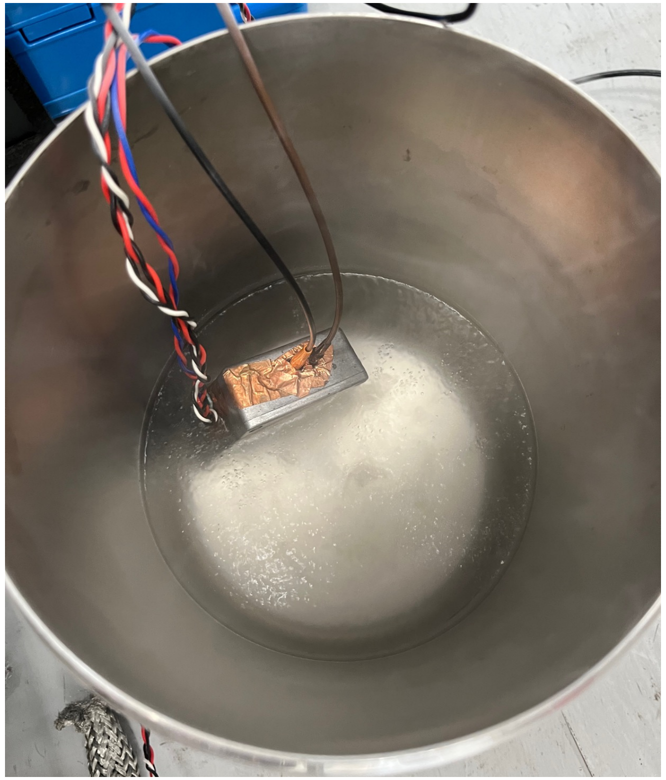


- Get data equivalent to a few photon event
  - ➢ Shading by blackout curtain



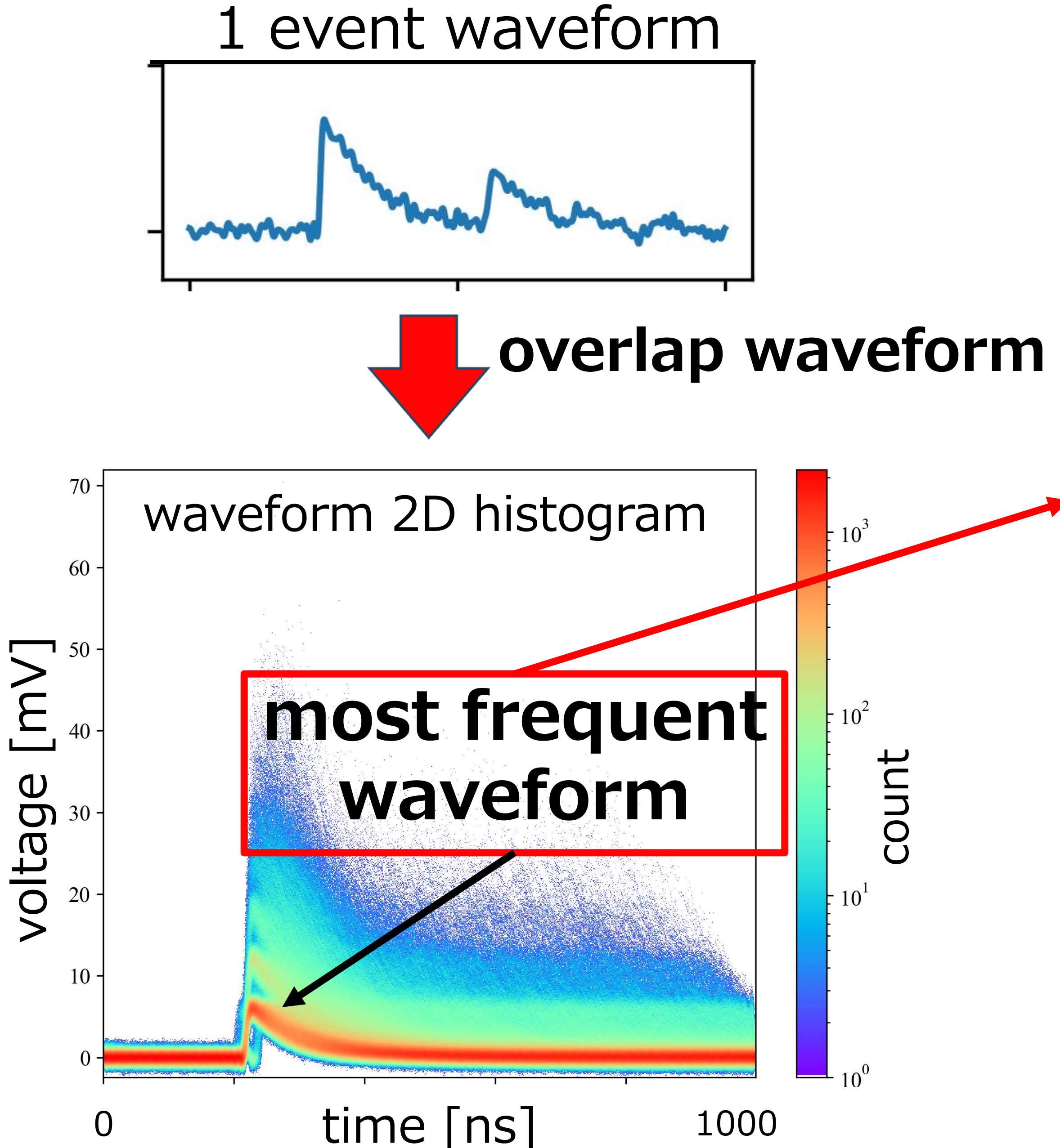


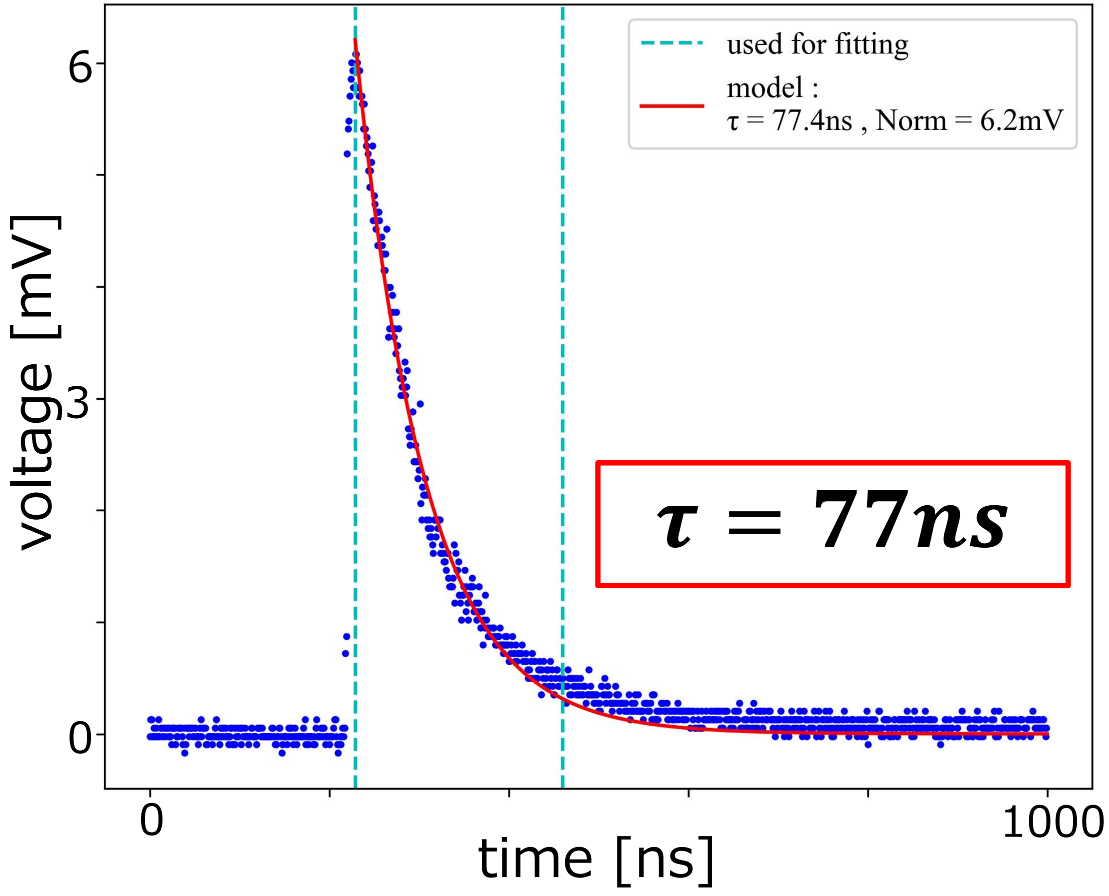
Immerse directly in liquid nitrogen



Put a black curtain over the top

MPPC array performance test ①

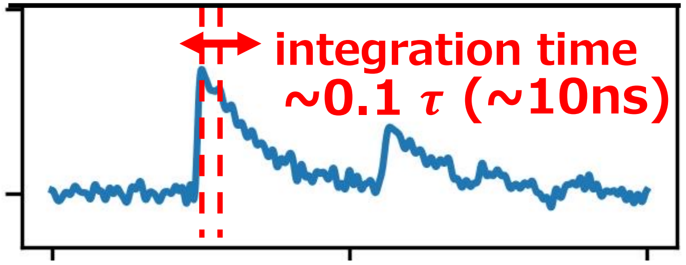




- Extract most frequent waveform
- Fitting with $f(t) = A\exp(-t/\tau)$

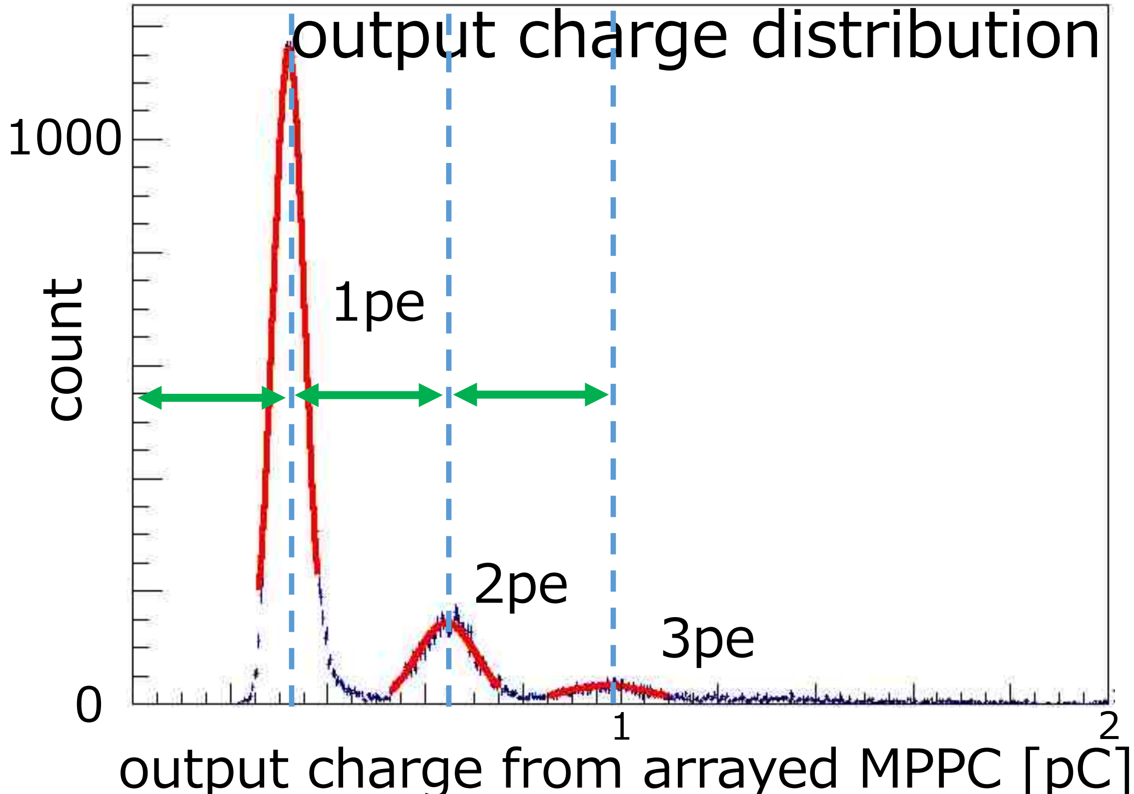
MPPC array performance test ②

1 event waveform

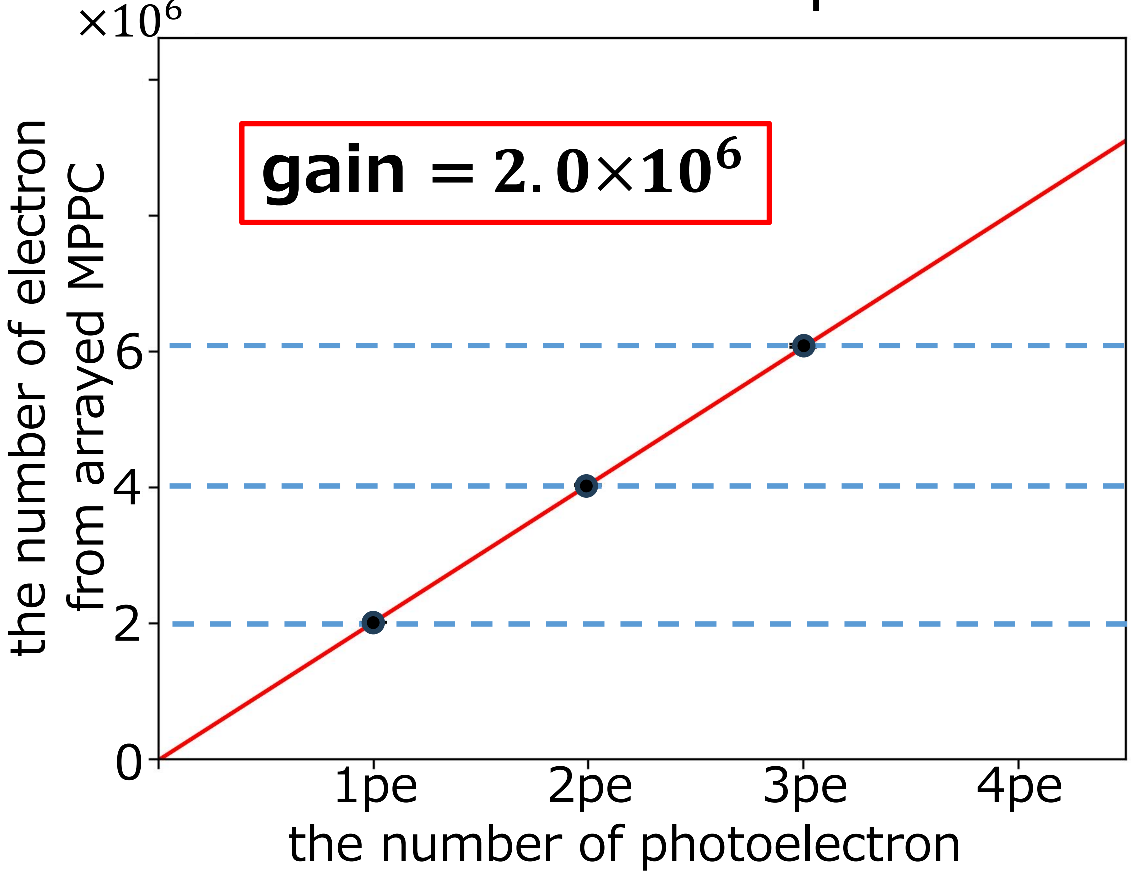


$$\begin{cases} I = \dfrac{V}{R_f} \\ Q = \int I\,dt \end{cases}$$

converted to output charge from MPPC

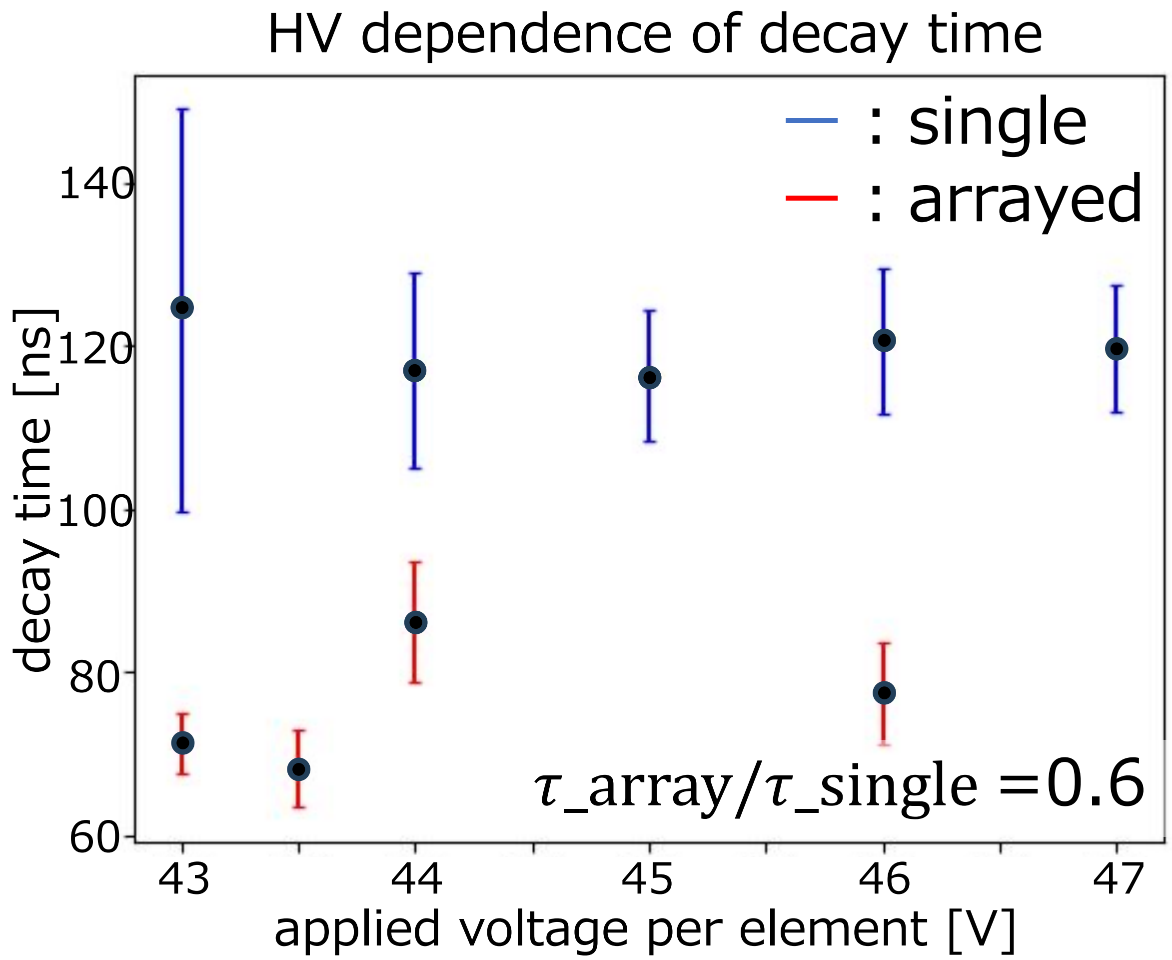


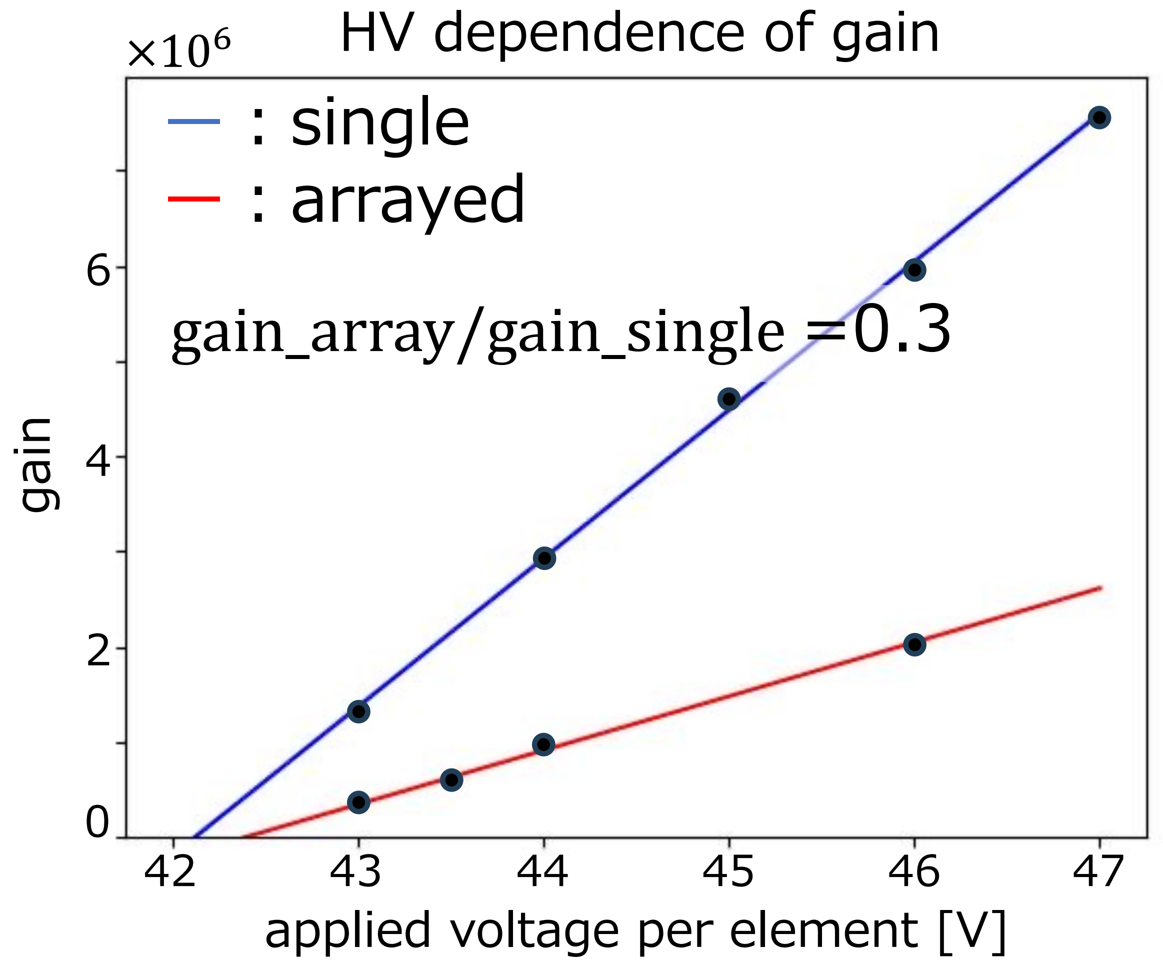
the number of electron before and after amplification



- Discrete output charge from MPPC
- Output charge from
  1 photoelectron(pe), 2 pe,⋯

HV dependence of arrayed & single MPPC



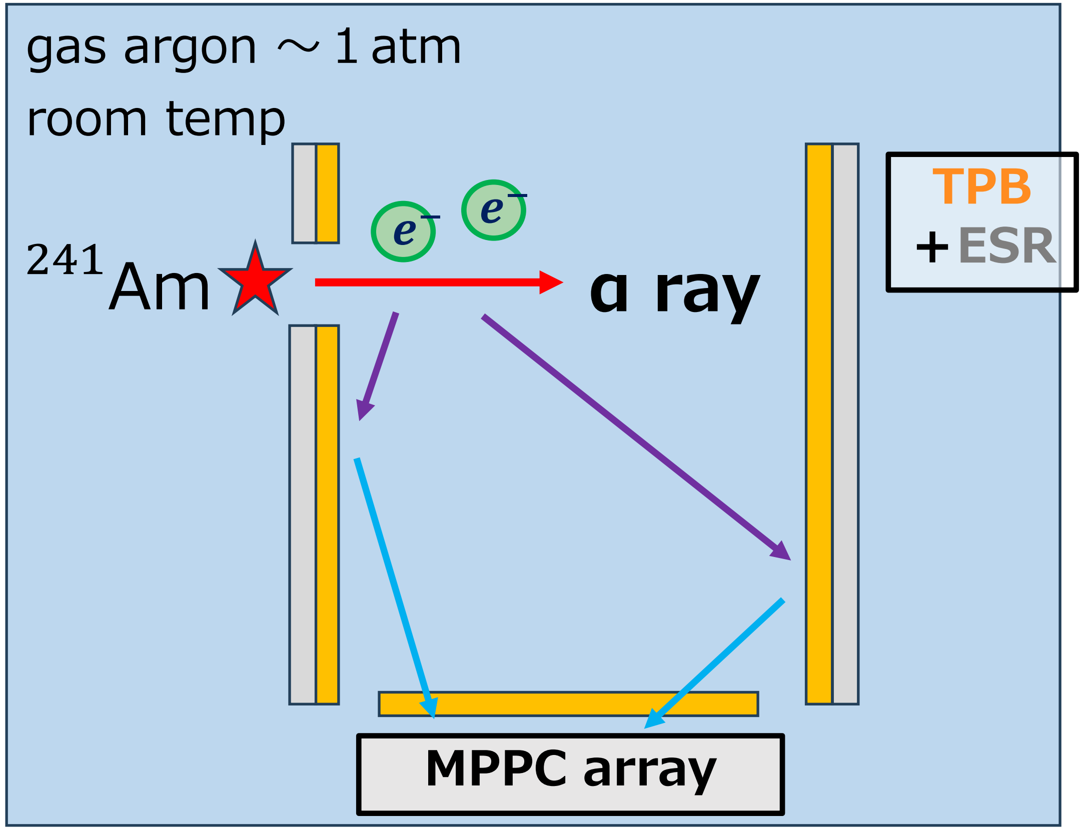


- Sufficiently fast timing response for background discrimination(<250ns)
- Sufficiently high gain for photon counting

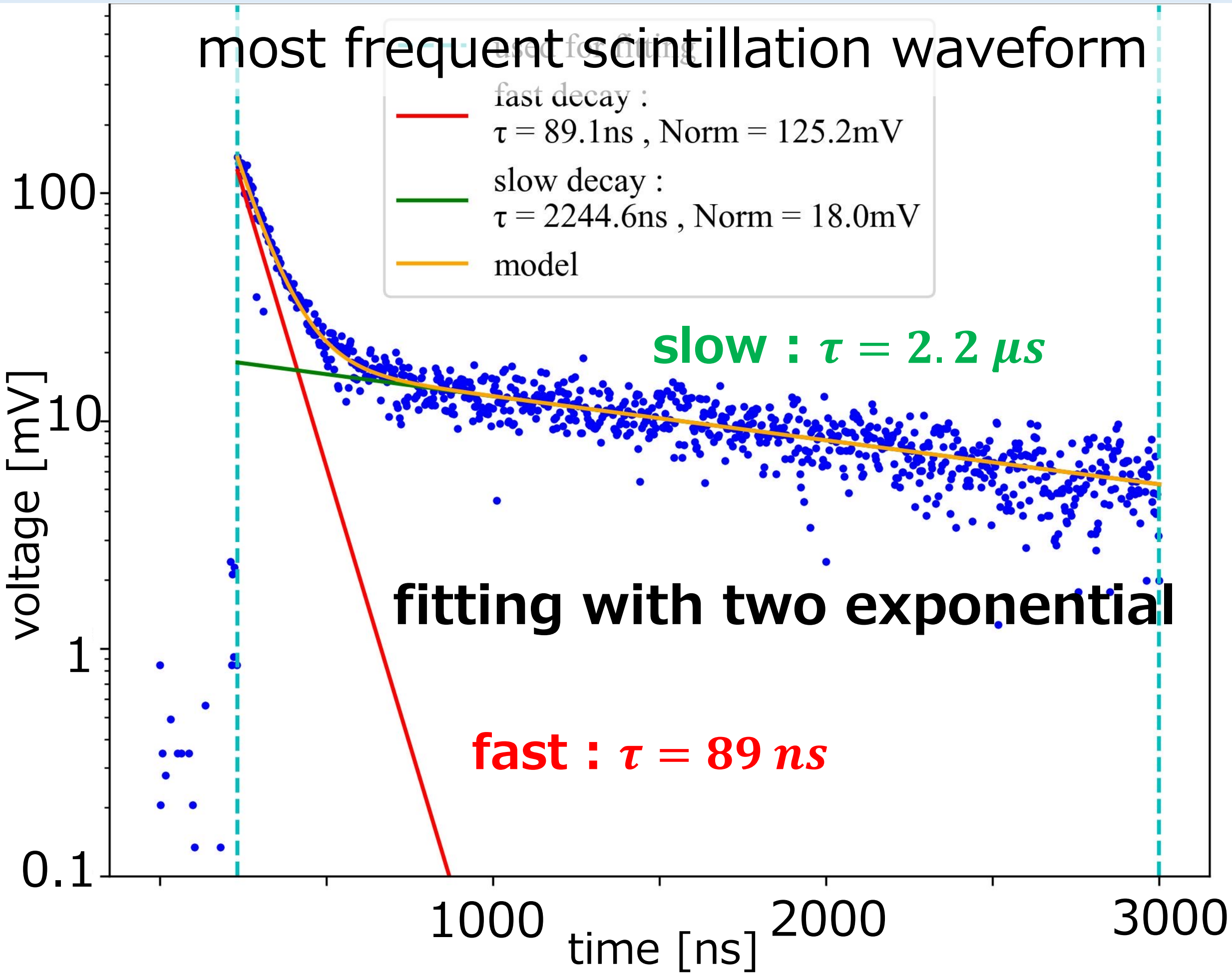
Sufficient performance as photon detecter of LArTPC

Scintillation light caused by α rays

Experimental setup



- TPC is filled with gas argon
- α ray source is installed nearby TPC
- Set a trigger level above dark event voltage
- Count rate is 1.64Hz



We can see slow component necessary for background event discrimination

This discrimination is applicable to each event

Summary and future

- **We are developing the first Compton camera using liquid argon**

- **We evaluate the performance of LArTPC photon detector**

- **We developed a low noise and fast response readout circuit working at LAr temp for MPPC array**

- **We determine the value of gain and decay time of 4 series $\times$ 4 parallel arrayed MPPC**

  future : Optimize amplifier gain to match liquid argon signal

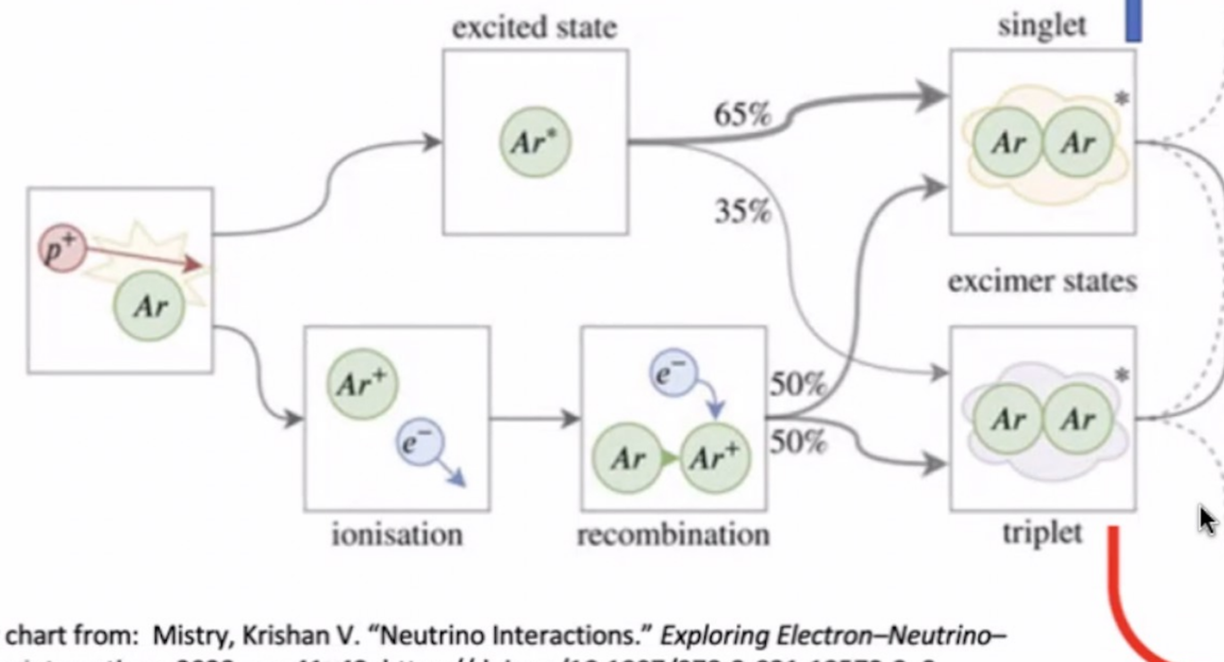
- **We successfully measure a slow component necessary for discrimination of background events from α ray events**

  future : Perform discrimination test using γ and neutron sources

Appendix

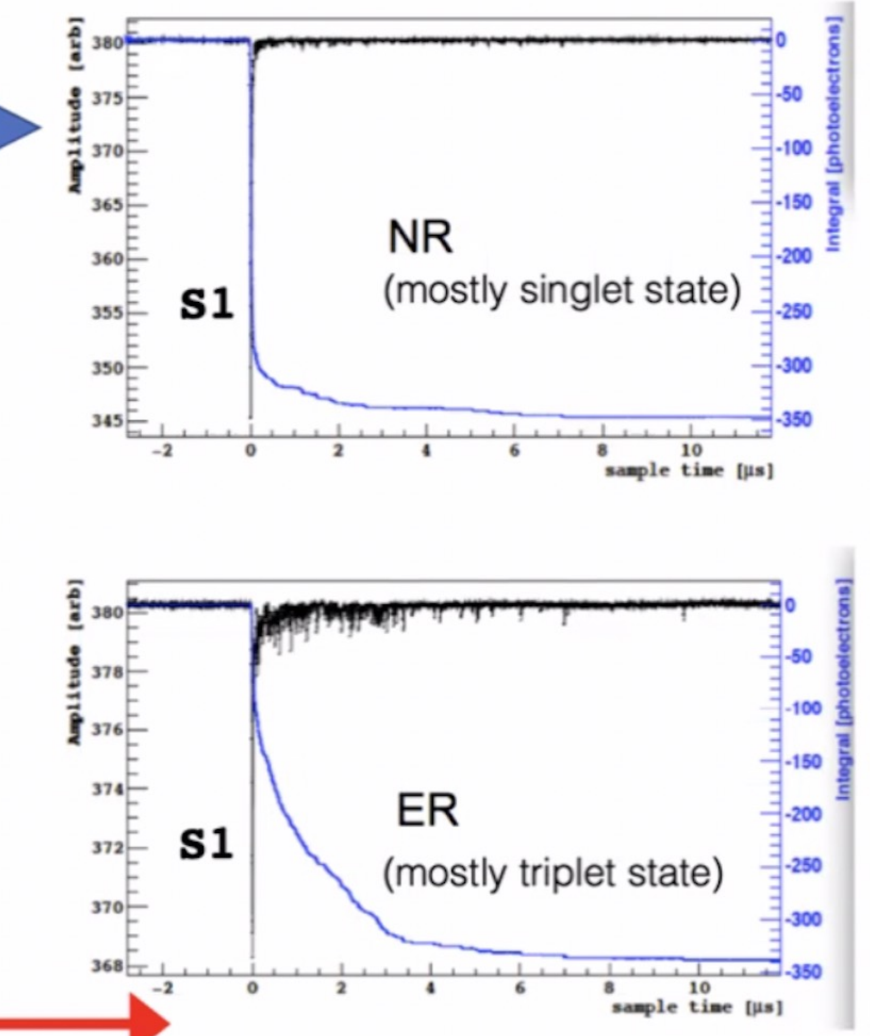
Physical process of argon scintillation light

- **Self-trapped exciton luminescence**
  - Argon excimer is produced directly from interaction
  - De-excitation of these ‘molecules’ emits S1 scintillation photon
- **Electron-ion recombination**
  - Argon is ionized which can lead to the production of the same excimers (but with different statistics)
  - Ionization electrons that escape recombination are drifted by E-field to anode tile of TPC detector



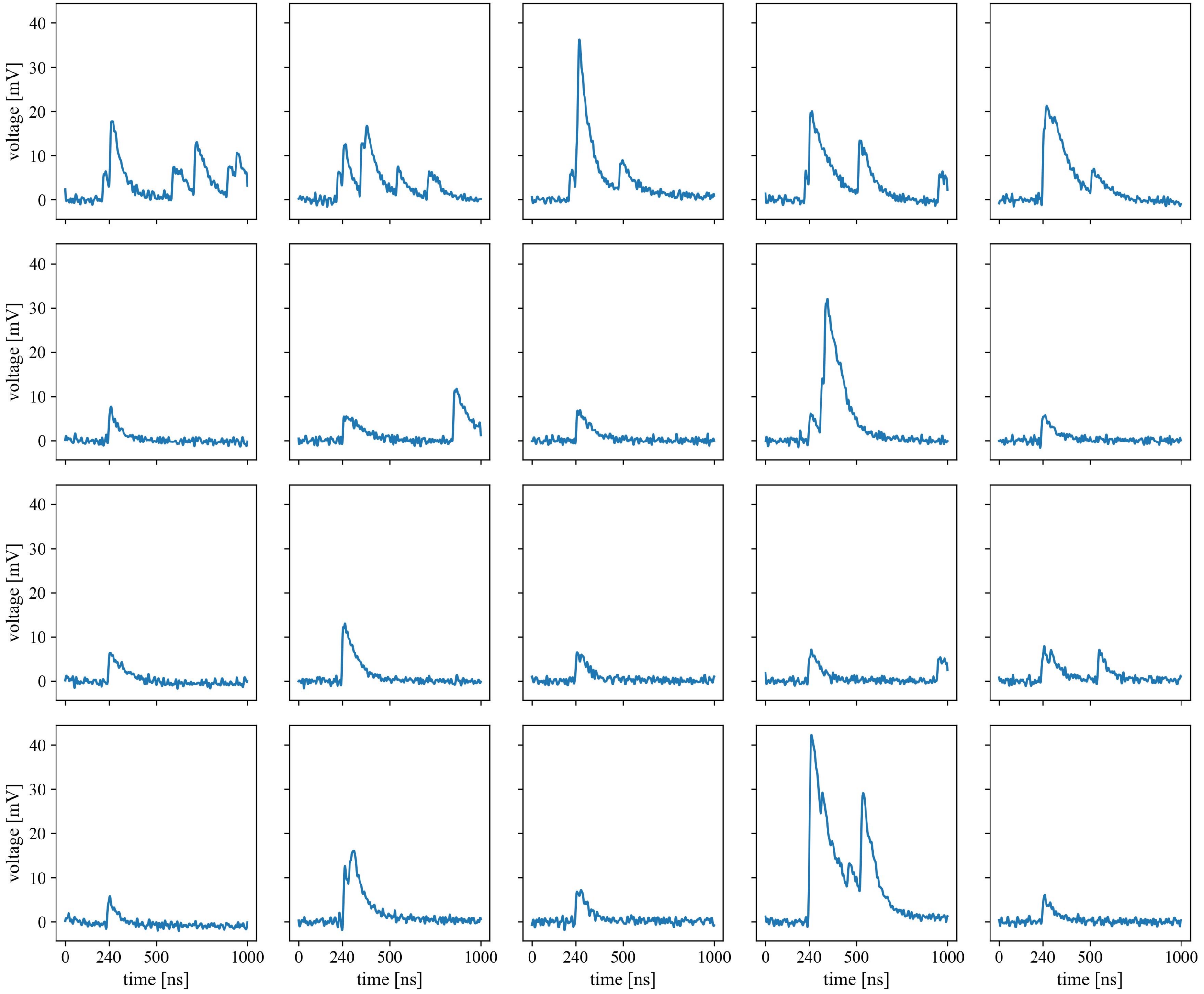
Flow chart from: Mistry, Krishan V. “Neutrino Interactions.” *Exploring Electron–Neutrino–Argon Interactions*, 2023, pp. 41–42, https://doi.org/10.1007/978-3-031-19572-3_3.

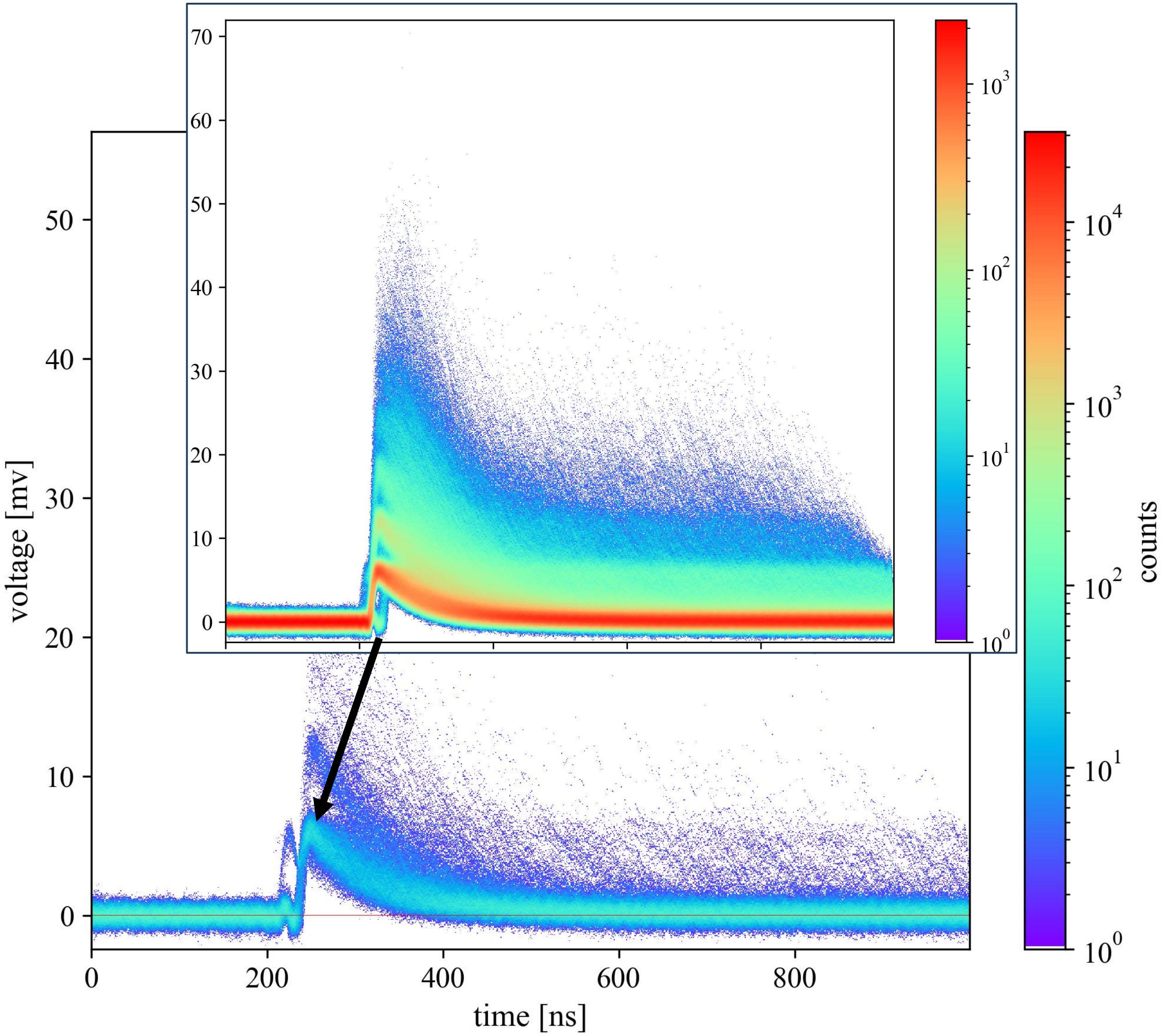
Typical NR vs. ER waveforms seen by light collection system:



slide from Jiancheng Zeng@Northeastern University

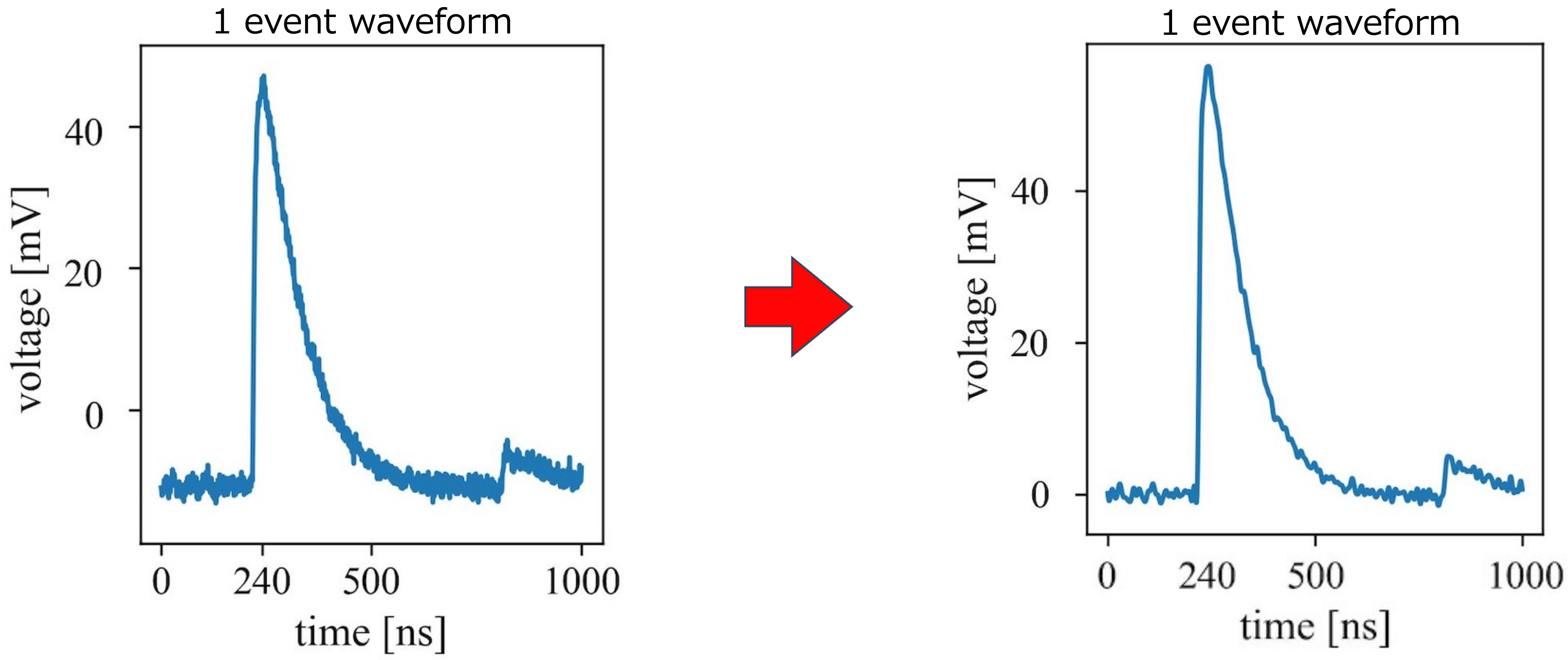
construction around trigger timing





trigger timing is off ?

waveform processing



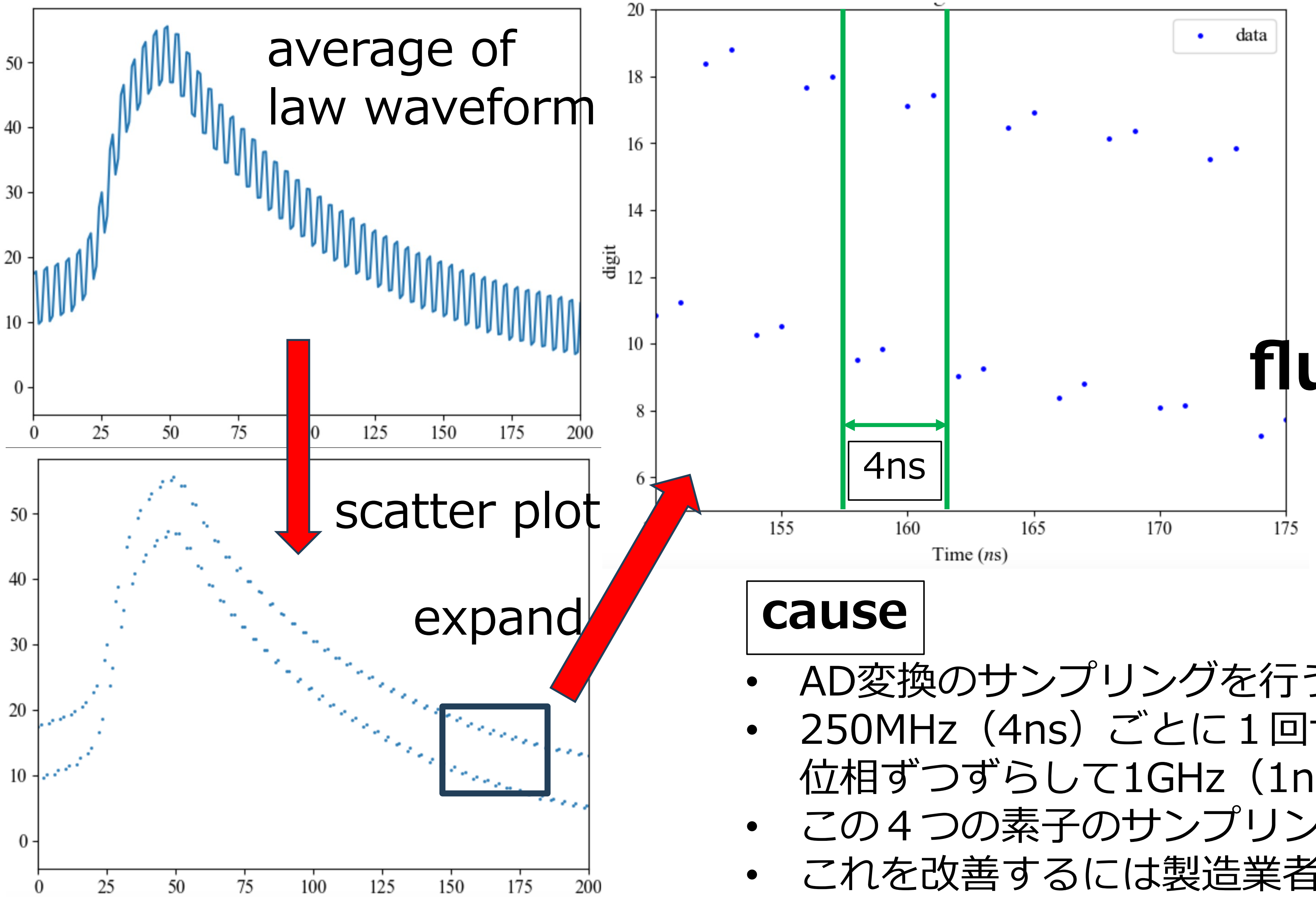
① cyclic offset correction caused by digitizer

② removal of high frequency components by FFT

③ baseline correction

④ elimination of bad events by voltage threshold

cyclic offset caused by digitizer

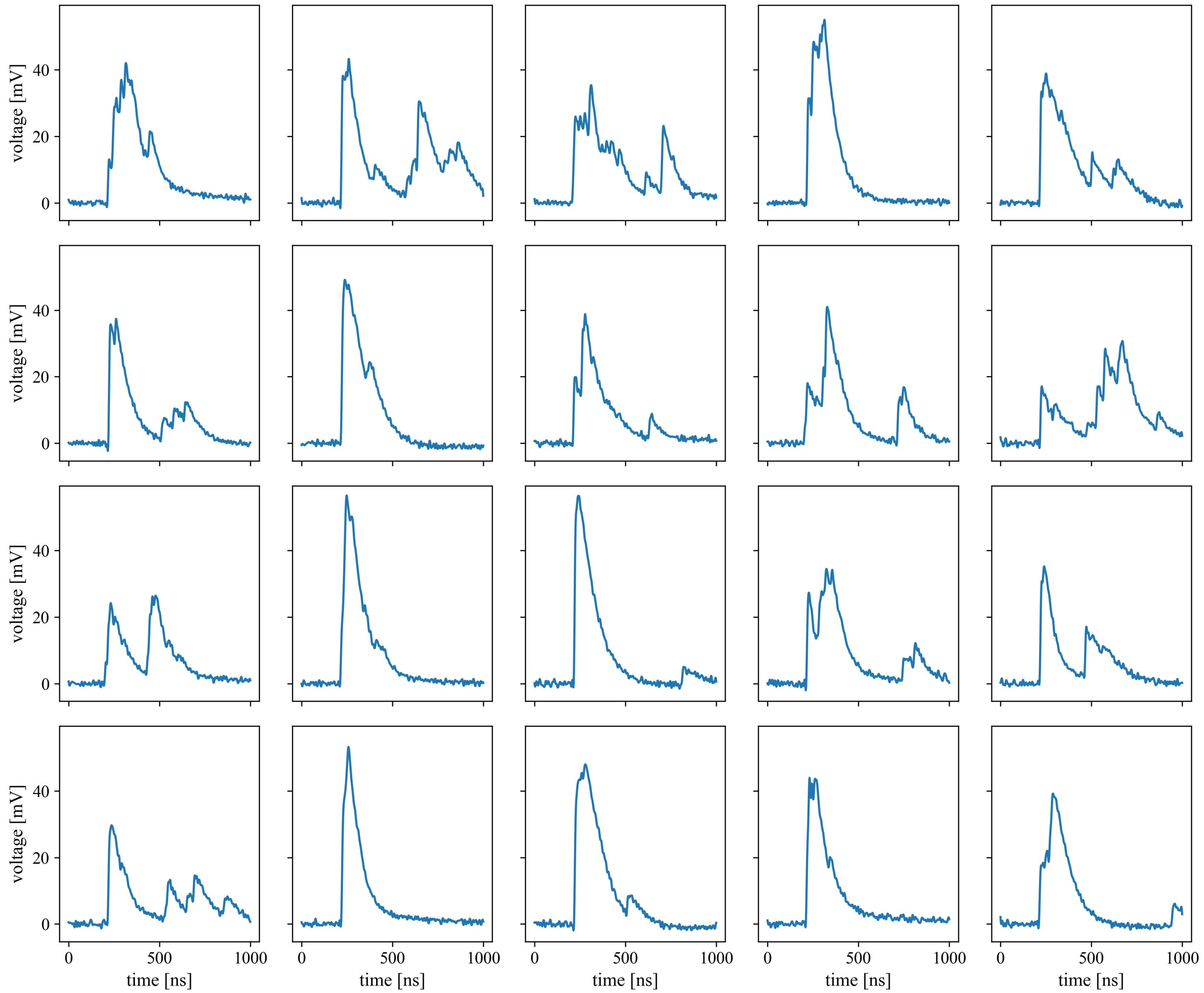


periodic fluctuation of 4ns

cause

- AD変換のサンプリングを行う素子が４種類
- 250MHz（4ns）ごとに１回サンプリングする素子を1/4位相ずつずらして1GHz（1ns）のサンプリングを実行
- この４つの素子のサンプリングのオフセットによる構造
- これを改善するには製造業者に頼むしかない

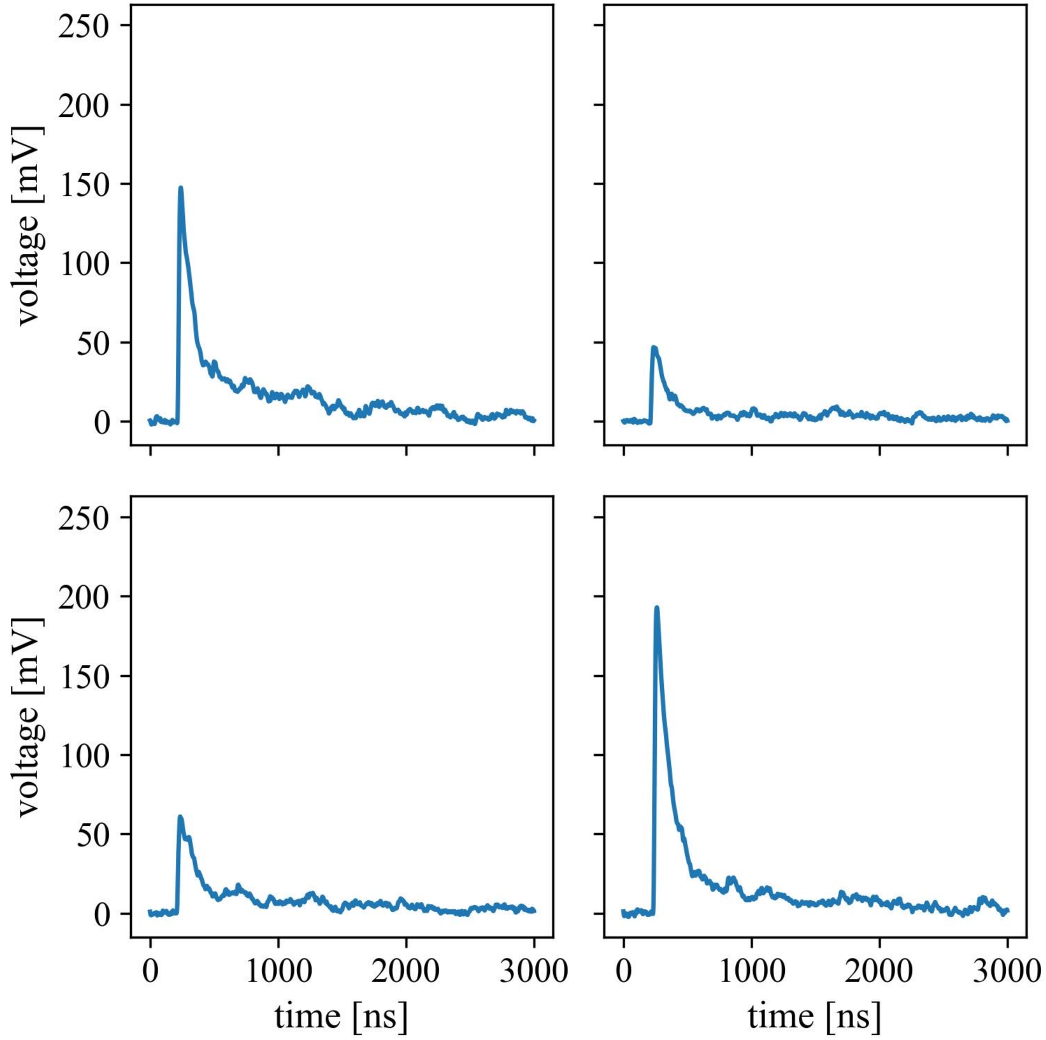
good event waveform



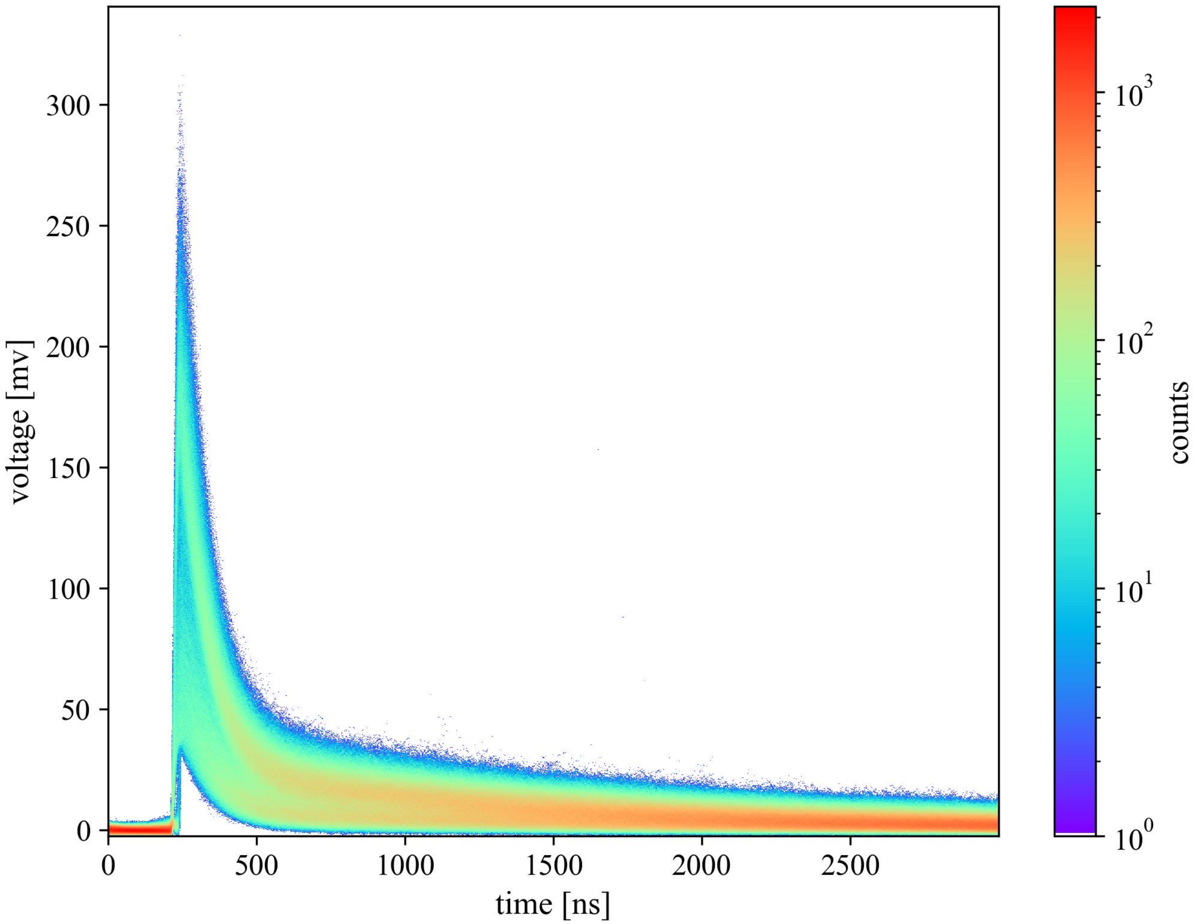
many of the pileup event

extract average waveform
from most frequent waveform

scintillation light caused by α rays

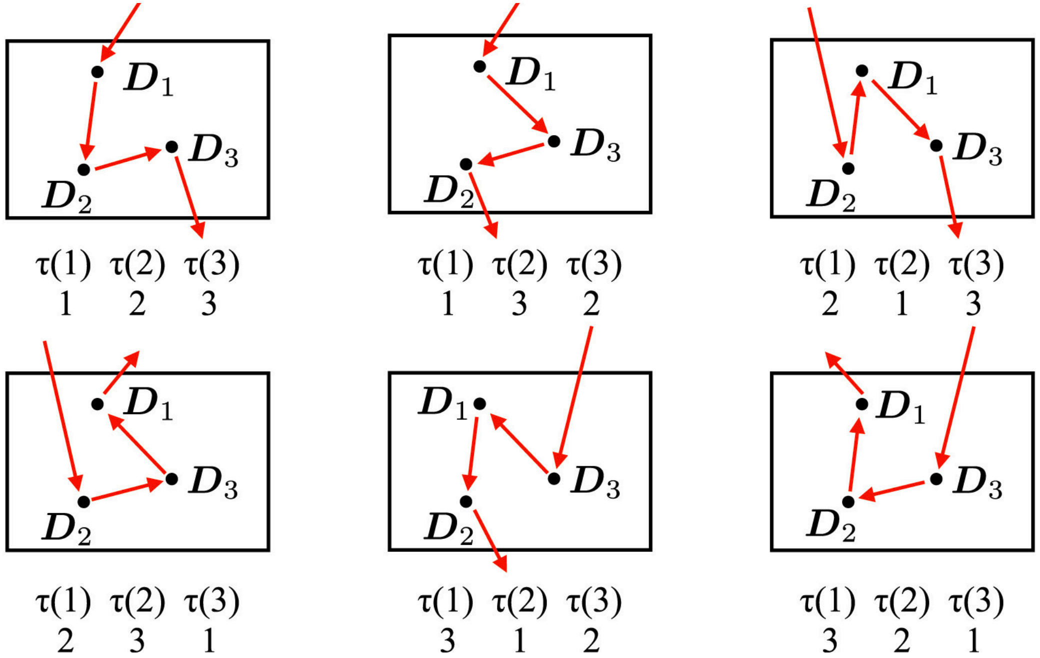


overlap

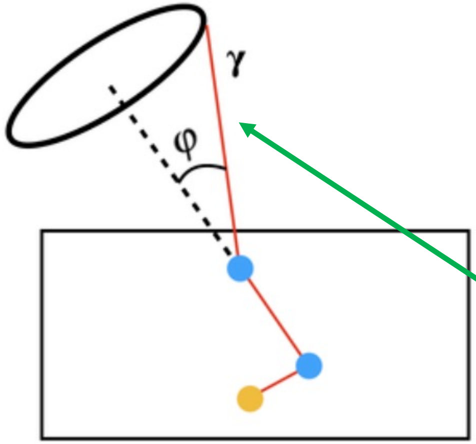


ガンマ線イメージ再構成

ヒットの位置とエネルギー損失の情報から散乱の順番(N!通り)を推定



Yoneda et al 2022

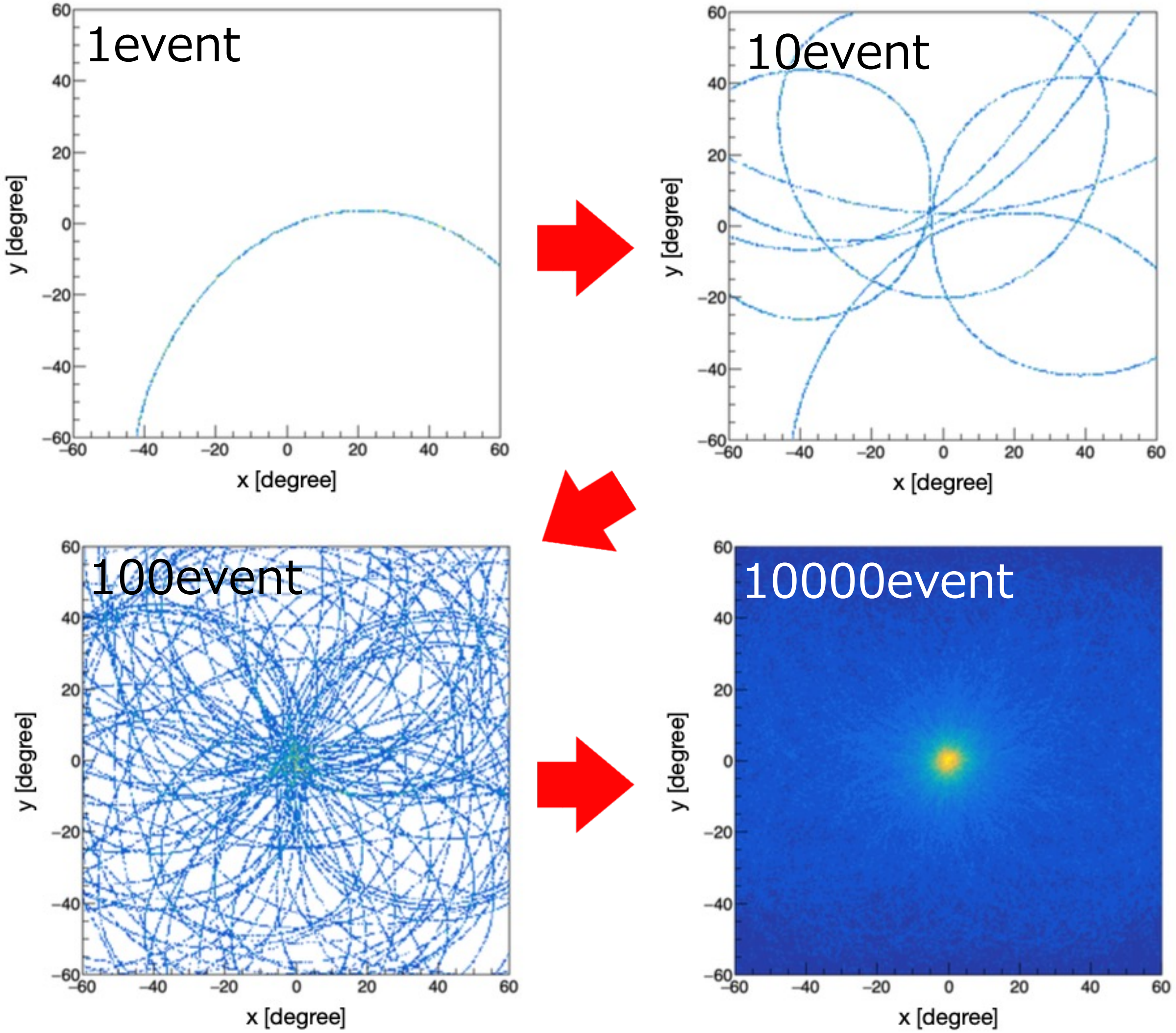


Kierans et al 2022

ヒットの順番が分かると
入射ガンマ線の到来方向は
compton cone上に制限

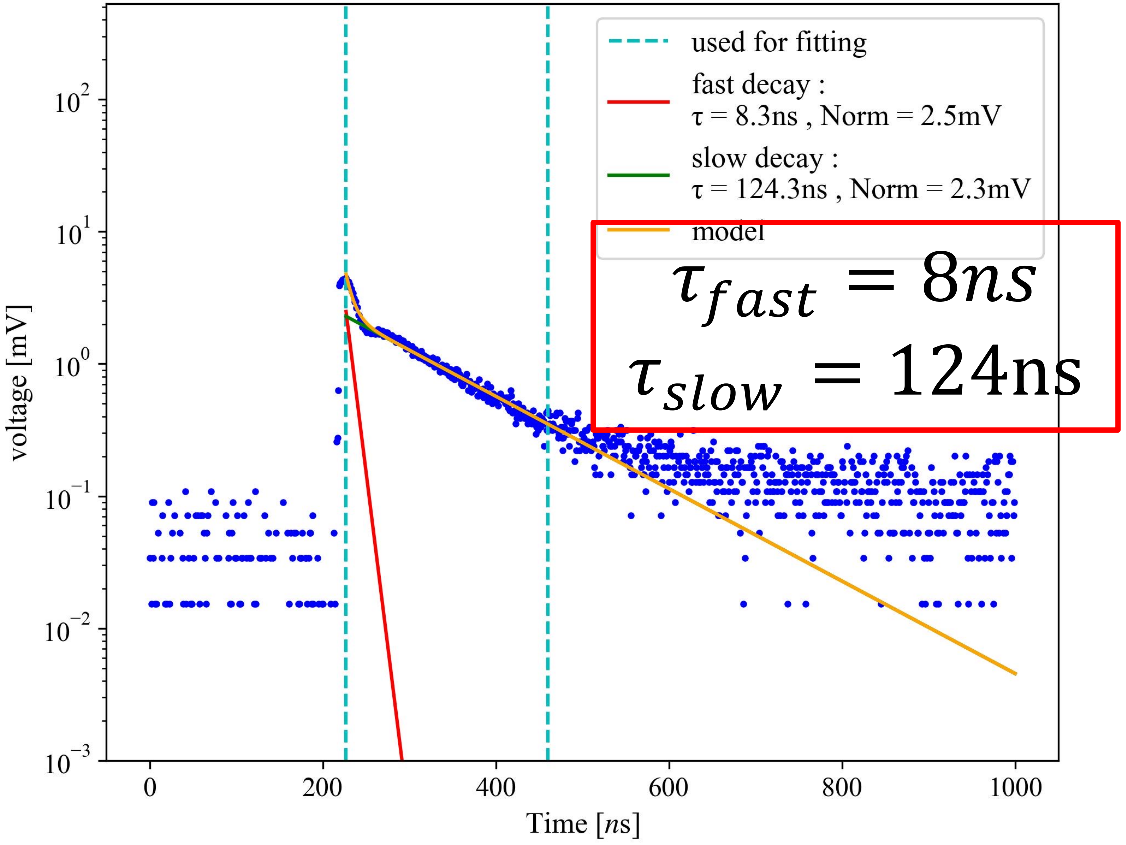
compton coneを重ねていくと…

小高さん資料



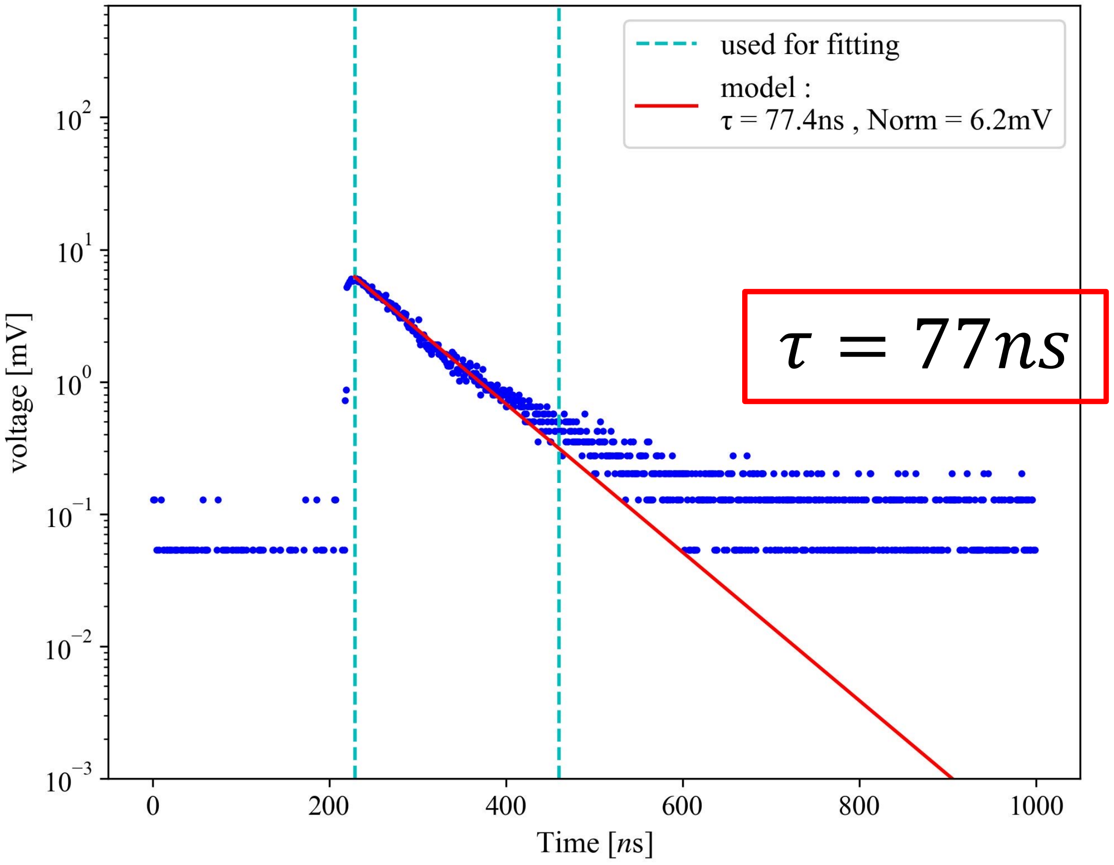
単素子との比較

単素子



二つの指数関数でモデル化

16素子アレイ



一つの指数関数でモデル化