Rejection Power for the Hadron-cluster Background with the upgraded KOTO CsI calorimeter

2019/12/23

Osugi Mayu @ Year End Presentation

Contents

- **Introduction**
  KOTO Experiment
  Hadron-cluster background & both-end readout
- **Data samples**
- **Timing Calculation**
- **Performance of both-end readout**
- **Summary**

KOTO Experiment

Search for $K_L \to \pi^0 \nu\bar{\nu}$

CP violating decay

Highly suppressed in SM (BR : 3.0 $\times$ 10^{-11})

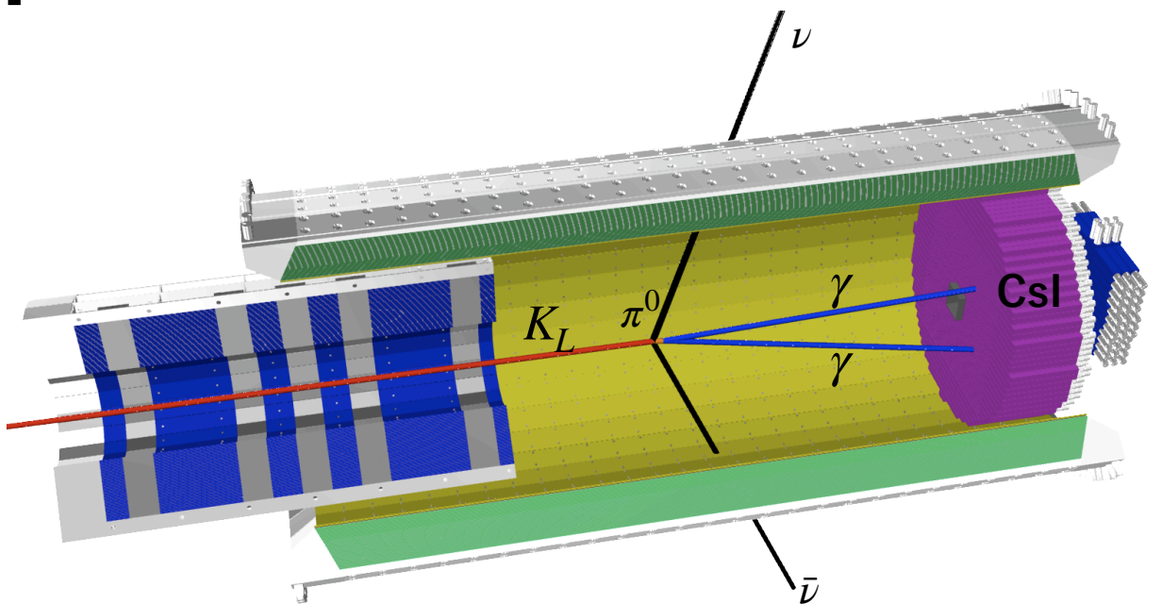
Small theoretical uncertainties (2%)

➡ **Sensitive** to **new physics**

Signal

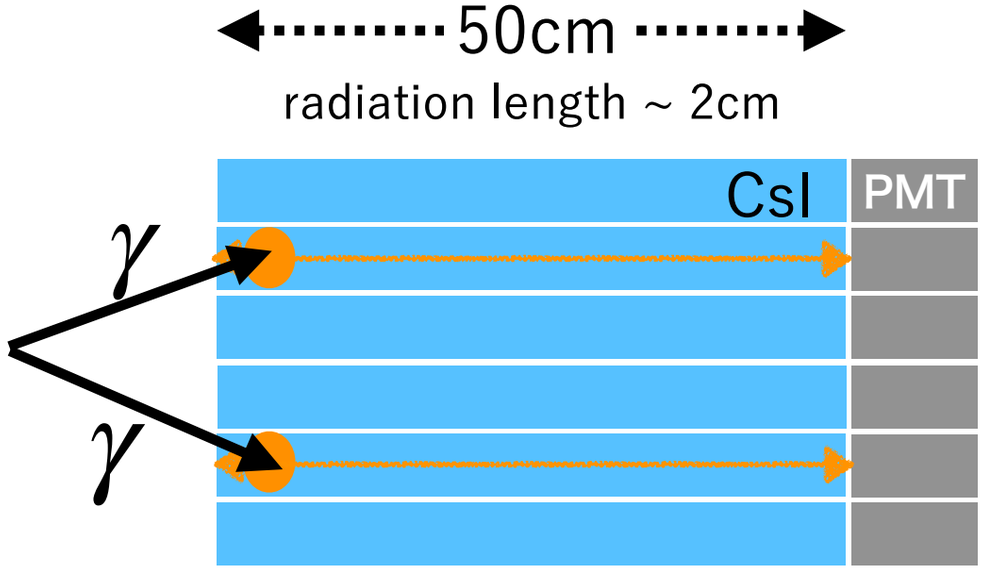
$\pi^0 \to 2\gamma$: @ CsI caloriemeter

nothing : @ other detectors



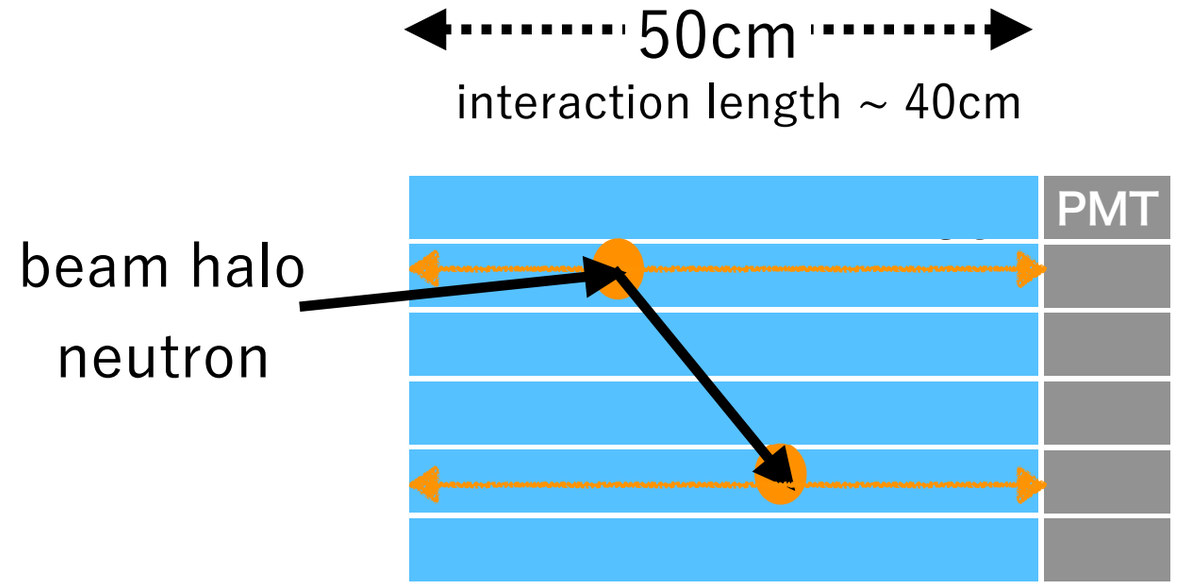
Hadron-cluster background

$K_L \to \pi^0 \nu\bar{\nu}$



Upstream

Hadron-cluster Background



Downstream

Background estimation (2015 data)

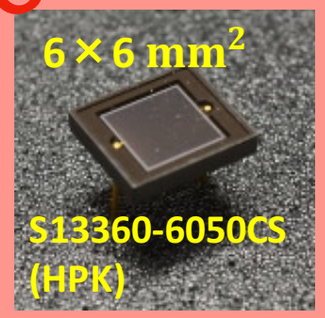
Background source	# of events
hadron-cluster background	0.24 ± 0.17
$K_L \to \pi^+\pi^-\pi^0$	0.05 ± 0.02
$K_L \to 2\pi^0$	0.02 ± 0.02
other source	0.11 ± 0.04
Total	**0.42 ± 0.18**

Largest contribution

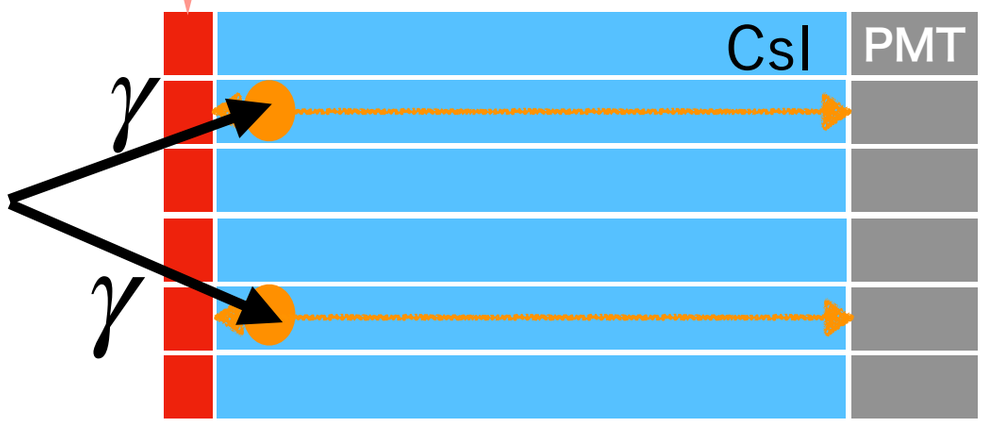
Should be suppressed

Hadron-cluster background

MPPC



$K_L \to \pi^0 \nu \bar{\nu}$

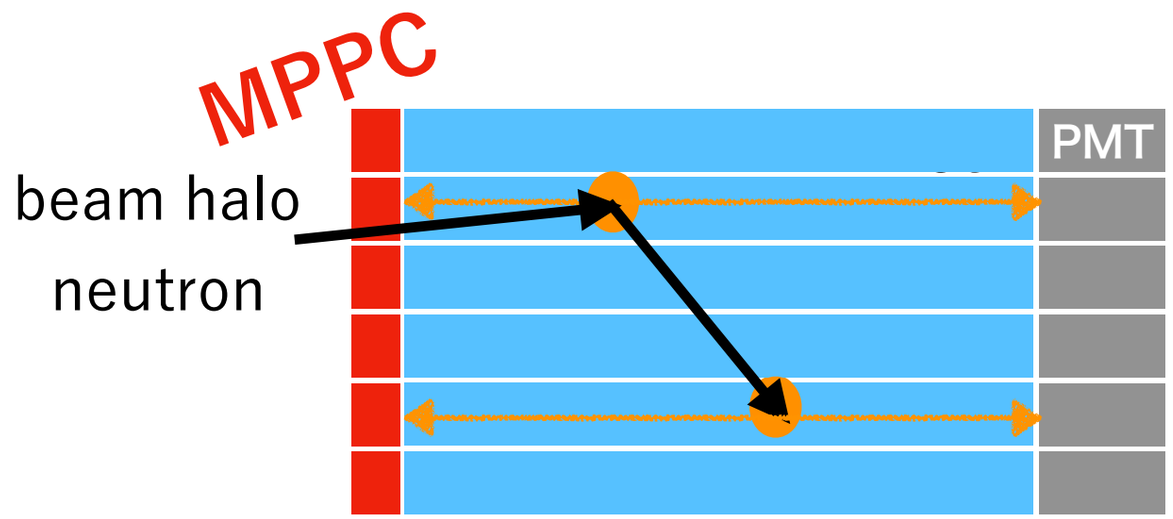


Upstream

ΔT(MPPC-PMT)=**small**

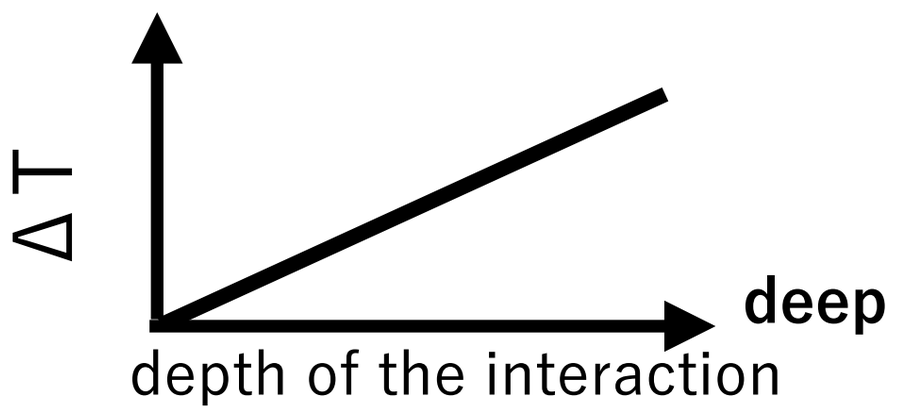
Hadron-cluster Background

MPPC



Downstream

ΔT(MPPC-PMT)=**large**



Data Samples

Used data taken in 2019 run

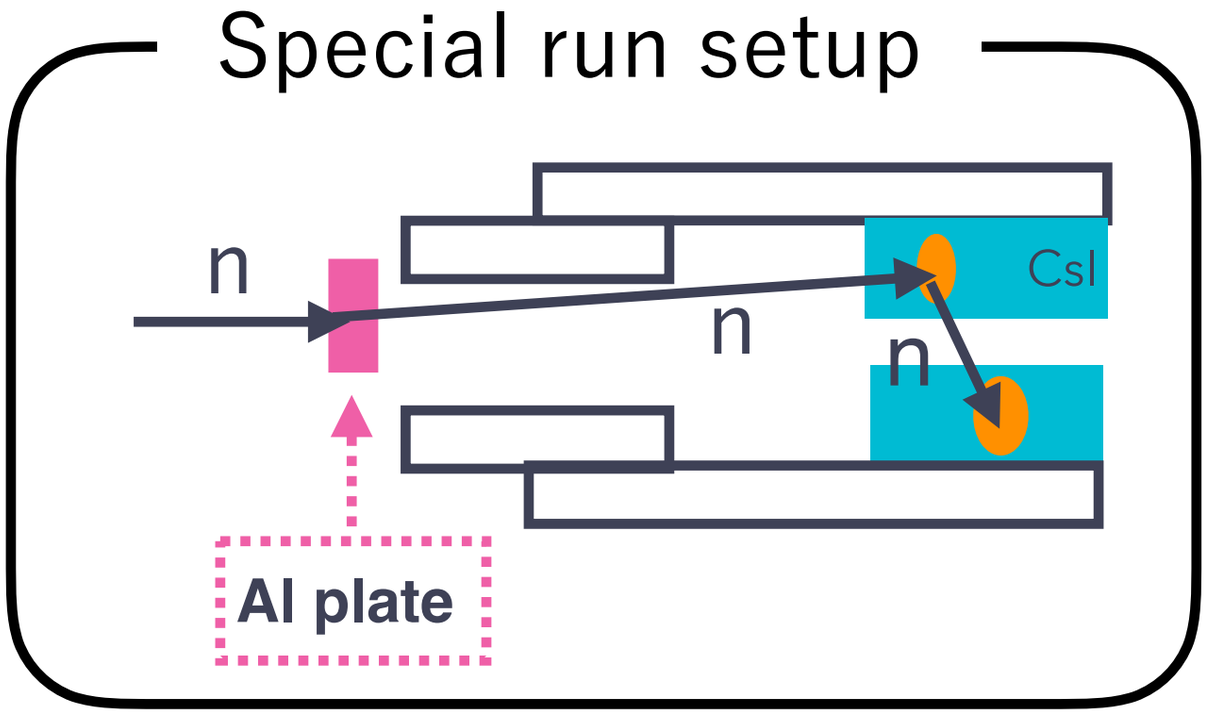
Gamma Sample

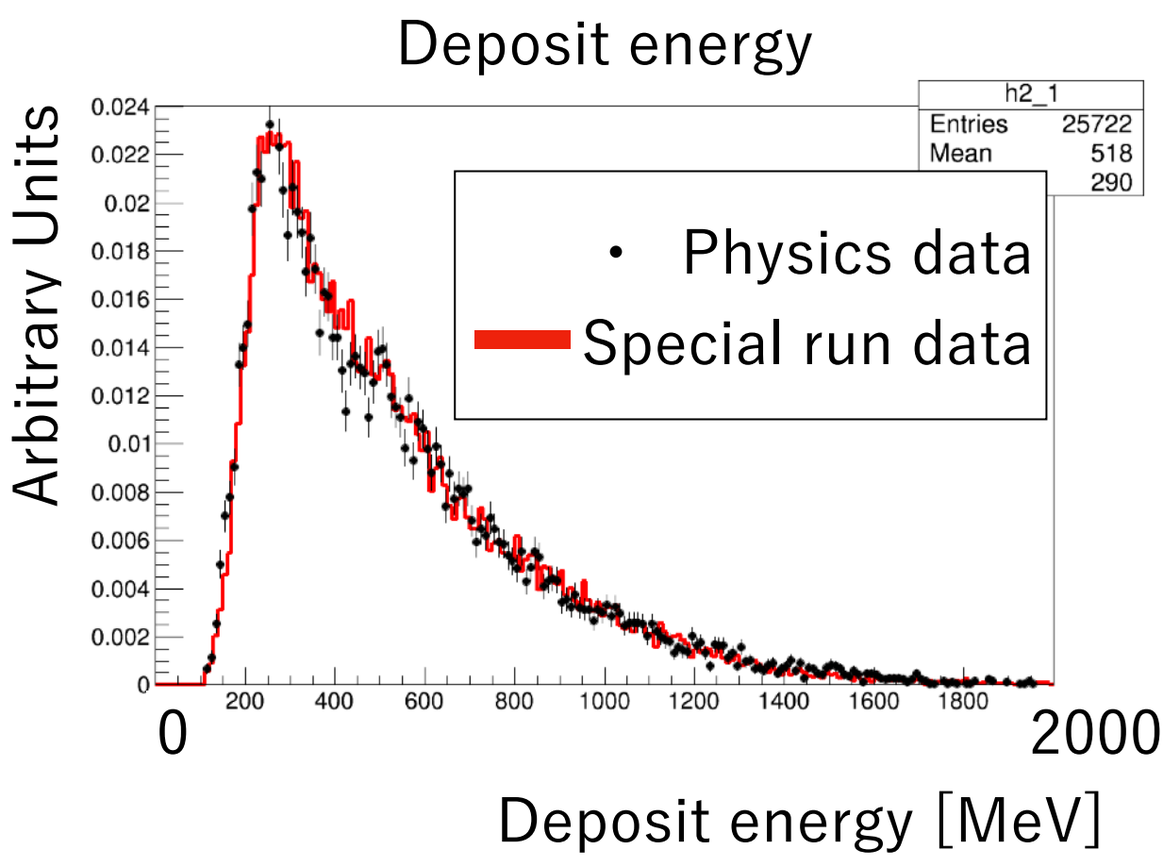
- Used $K_L \to 3\pi^0$ decay (BR: 19.52%)

Neutron Sample

- Used special run data as a neutron samples

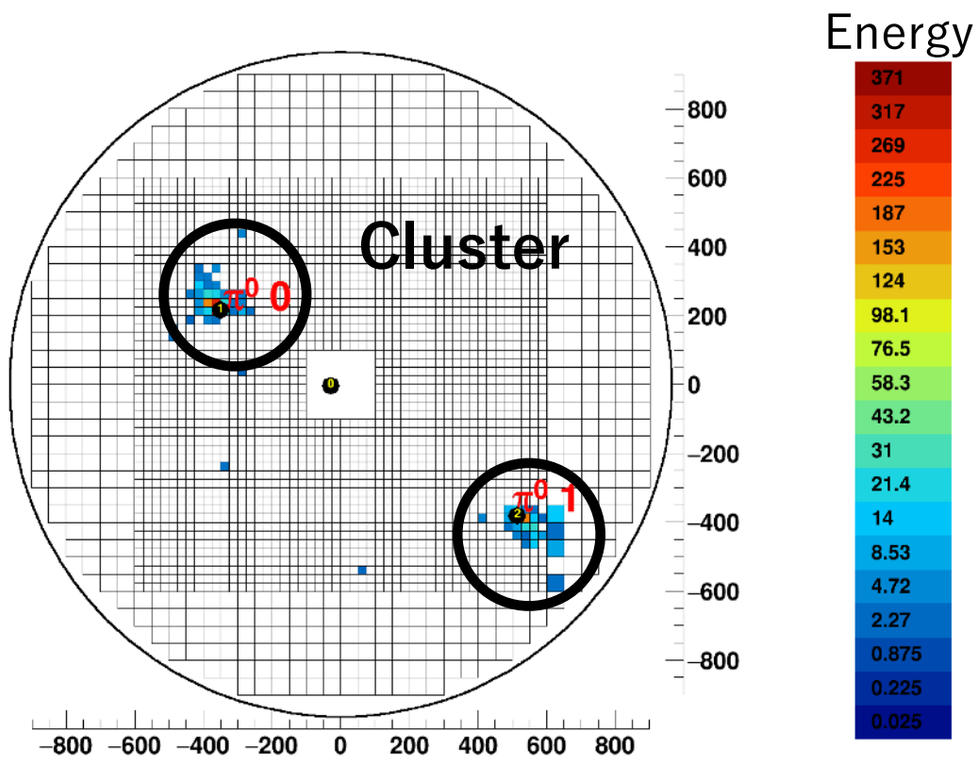
→ **Enhance the neutron events by placing Al plate**





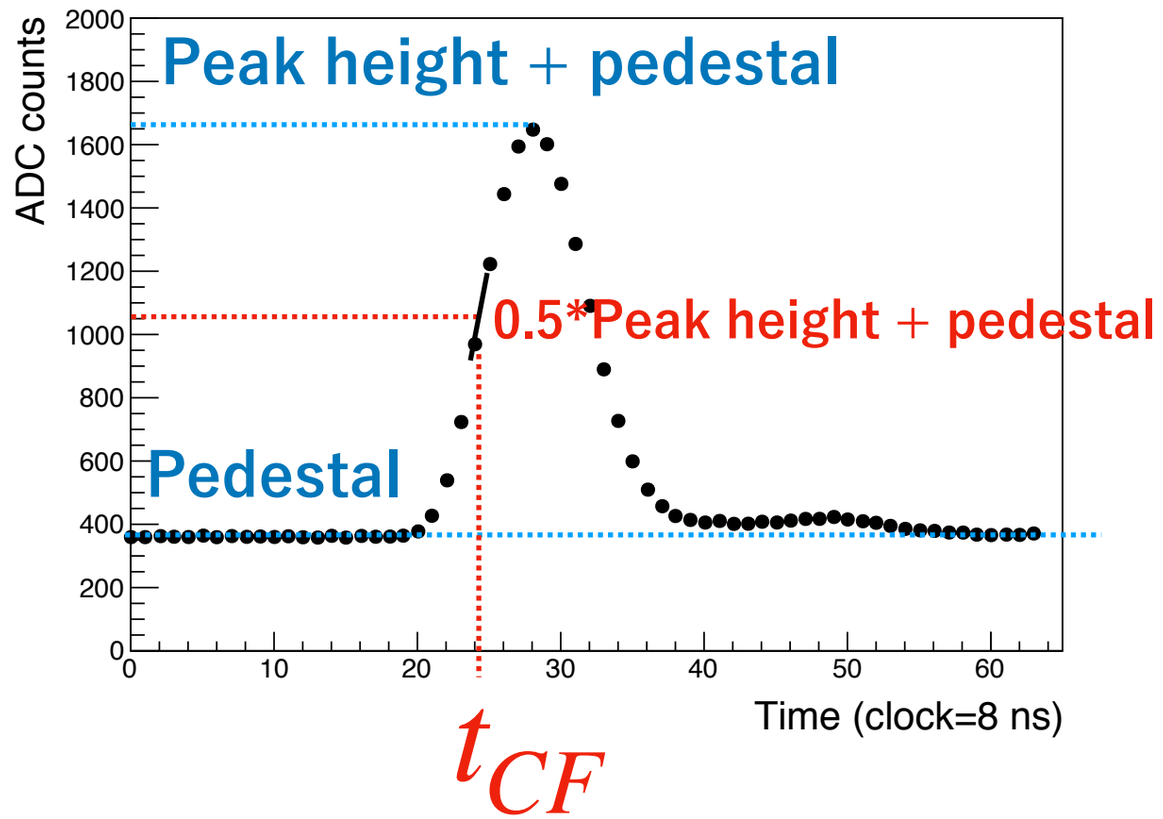
Timing Calculation (1)

Event Display of the CsI calorimeter



Channel Timing

→ Constant Friction Time (t_{CF})



Calculate **channel timing**

↓

Calculate **cluster timing** (used in analysis)

Timing Calculation (2)

Cluster Timing (MPPC)

Used 2 methods

➡ **Max energy channel timing** ($T^{\text{Max Energy}}_{\text{MPPC}}$)

➡ **Energy weighted timing** ($T^{\text{Energy Weighted}}_{\text{MPPC}}$)

(only for E>10 MeV channels)

Cluster Timing (PMT)

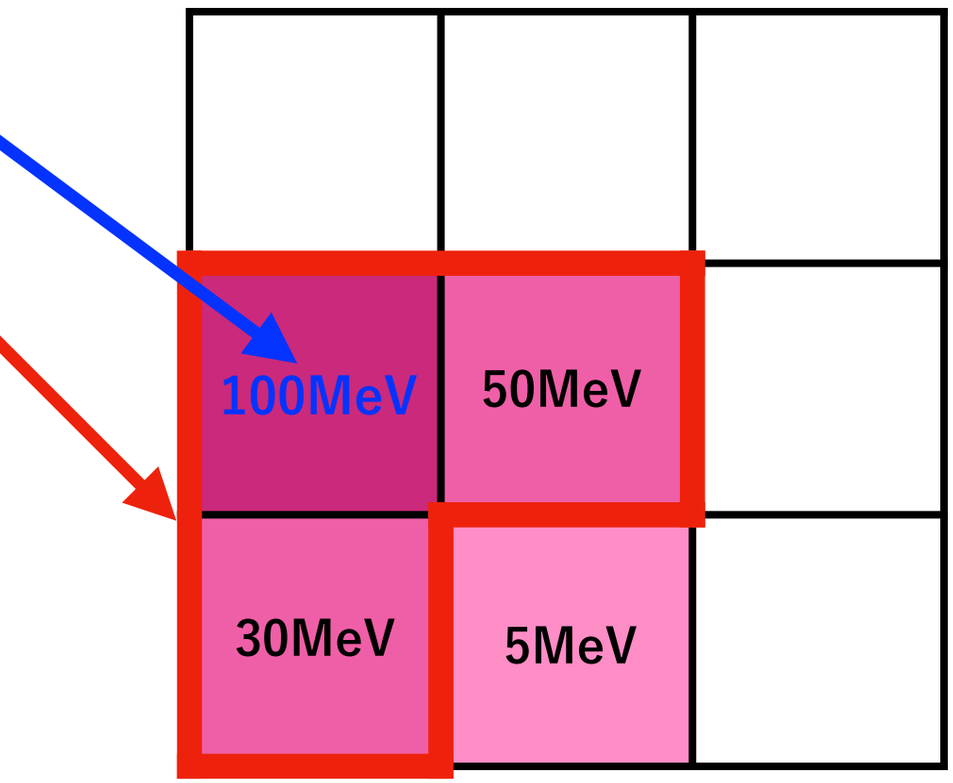
➡ Energy Weighted Timing

ΔT

➡ $\Delta T_{\text{M.E.}} = T^{\text{Max Energy}}_{\text{MPPC}} - T_{\text{PMT}}$

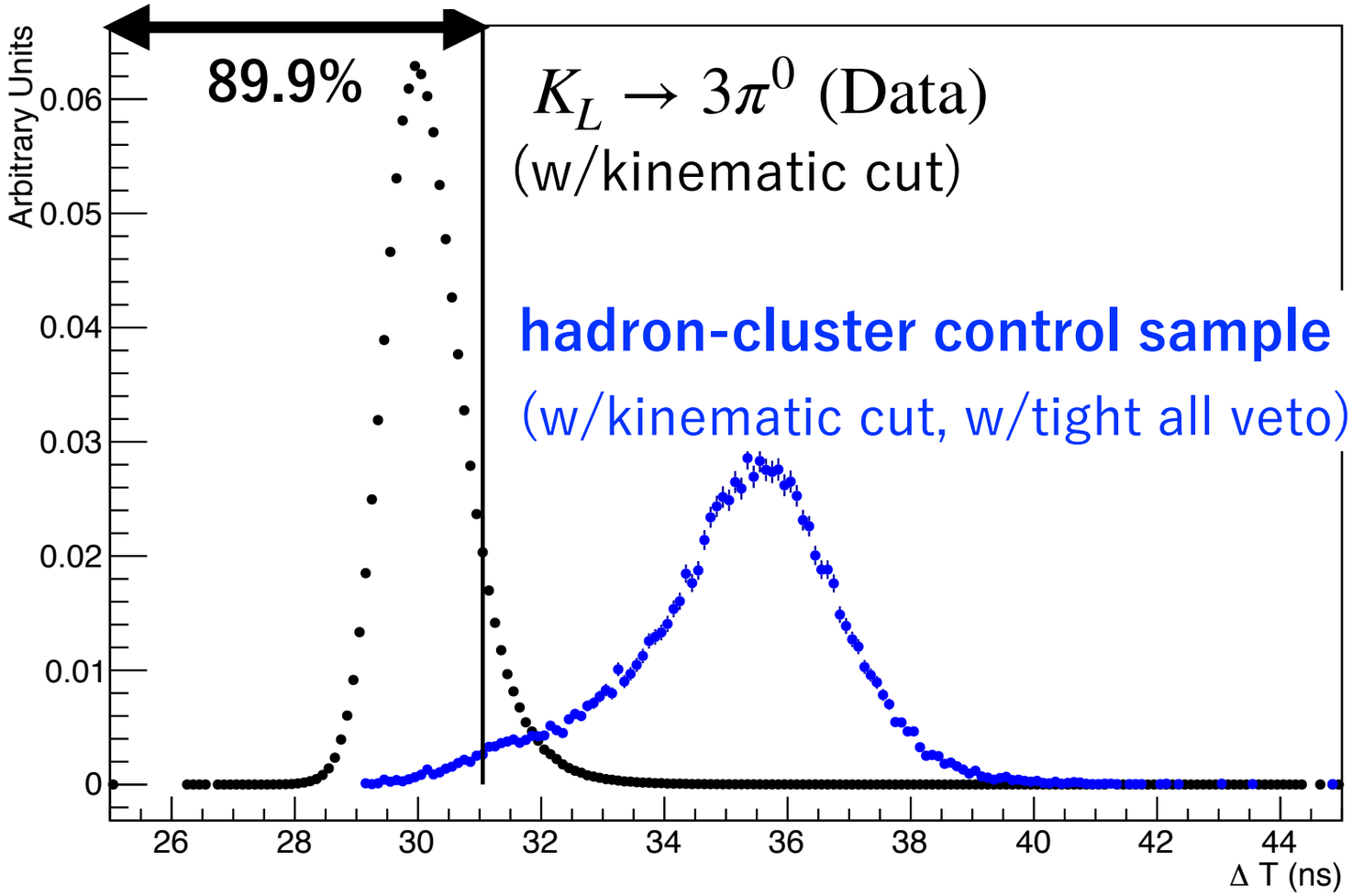
➡ $\Delta T_{\text{E.W.}} = T^{\text{Enegy Weighted}}_{\text{MPPC}} - T_{\text{PMT}}$

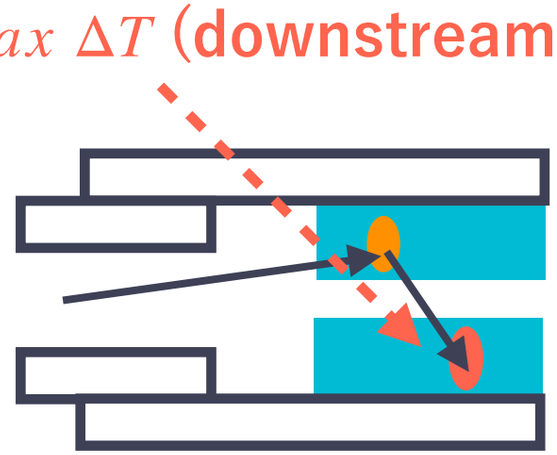
Event Display of the CsI calorimeter



Performance of ΔT Cut

Max $\Delta T_{\mathrm{E.W.}}$ distribution($\Delta T_{\mathrm{E.W.}} = T_{\mathrm{MPPC}}^{\text{Energy Weighted}} - T_{\mathrm{PMT}}$)





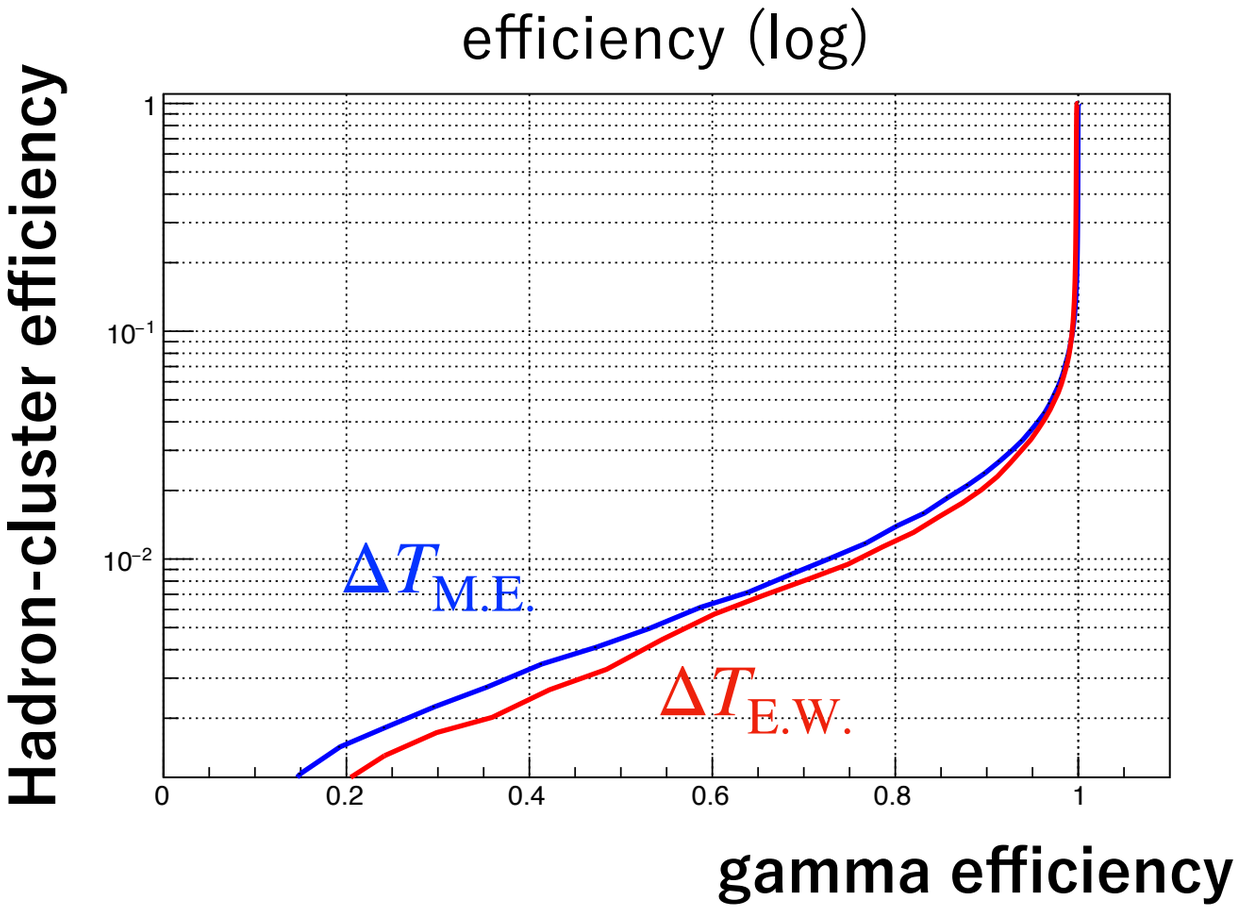
ΔT range : ΔT : 25 ns < ΔT < 31.05 ns

gamma efficiency = 89.9%

hadron-cluster background is suppressed to (2.1±0.1)%

Efficiency of ΔT cut

By changing the higher threshold of ΔT, efficiency (γ, hadron-cluster) are calculated



$$\Delta T_{\mathrm{M.E.}} = T_{\mathrm{MPPC}}^{\text{Max Energy}} - T_{\mathrm{PMT}}$$

$$\Delta T_{\mathrm{E.W.}} = T_{\mathrm{MPPC}}^{\text{Enegy Weighted}} - T_{\mathrm{PMT}}$$

Energy weighted timing($\Delta T_{\mathrm{E.W.}}$) has better performance

than maximum energy channel timing

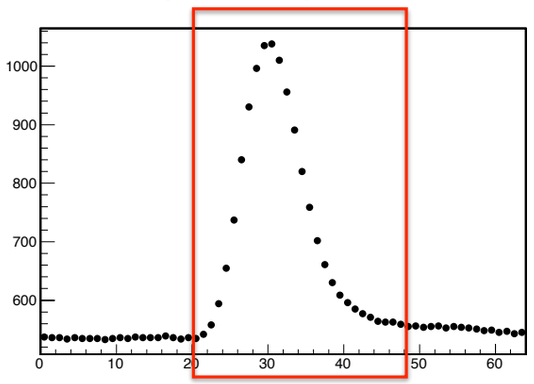
Correlation (Pulse Shape Related Cut)

Correlation btw. ΔT cut and other neutron cut

Pulse Shape Cut : Fourier Pulse Shape Discriminator (FPSD)

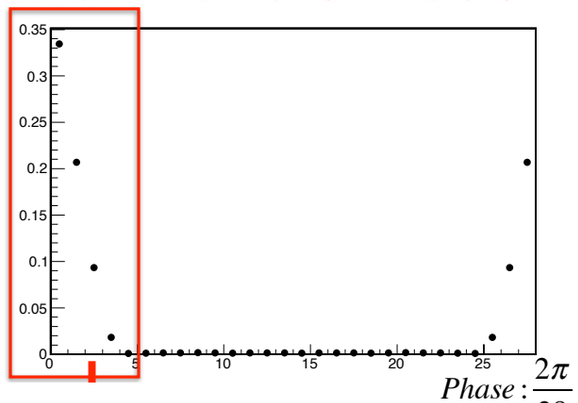
Waveform

[peak-10, peak+17]

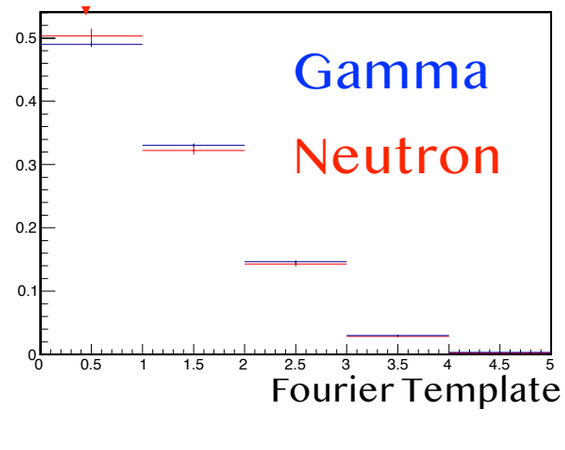


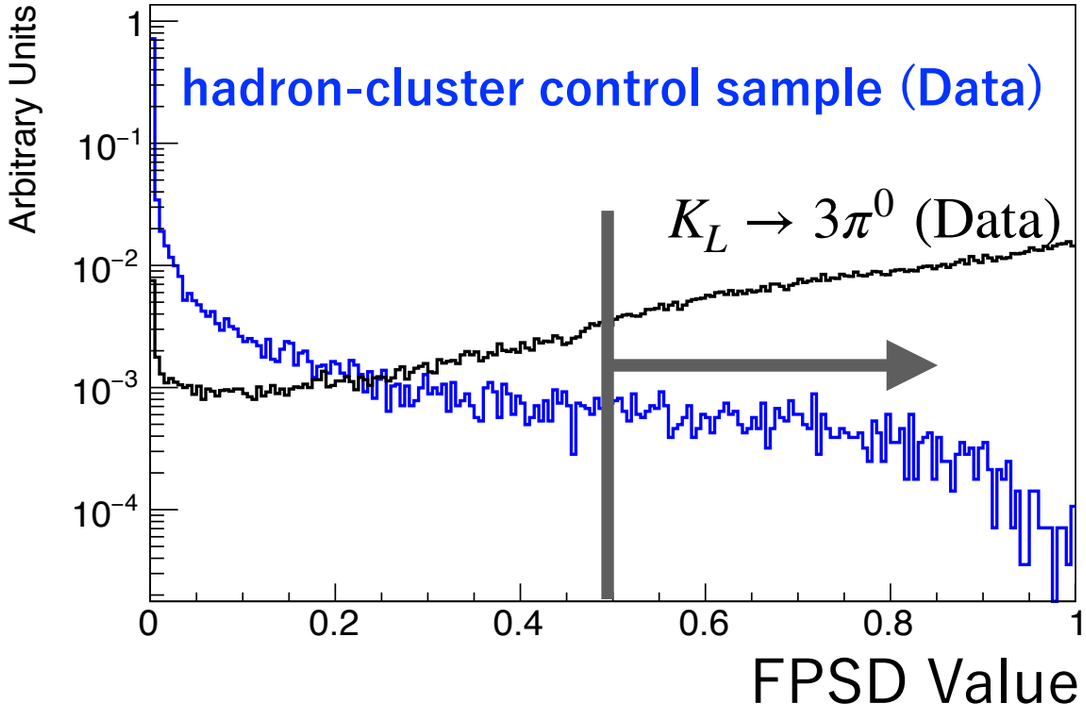
$$X_k = \sum_{n=0}^{N-1} x_n e^{-\frac{2\pi i}{N} kn}$$

Fourier Transformation



Template γ and neutron





Neutron Like ⟷ Gamma Like

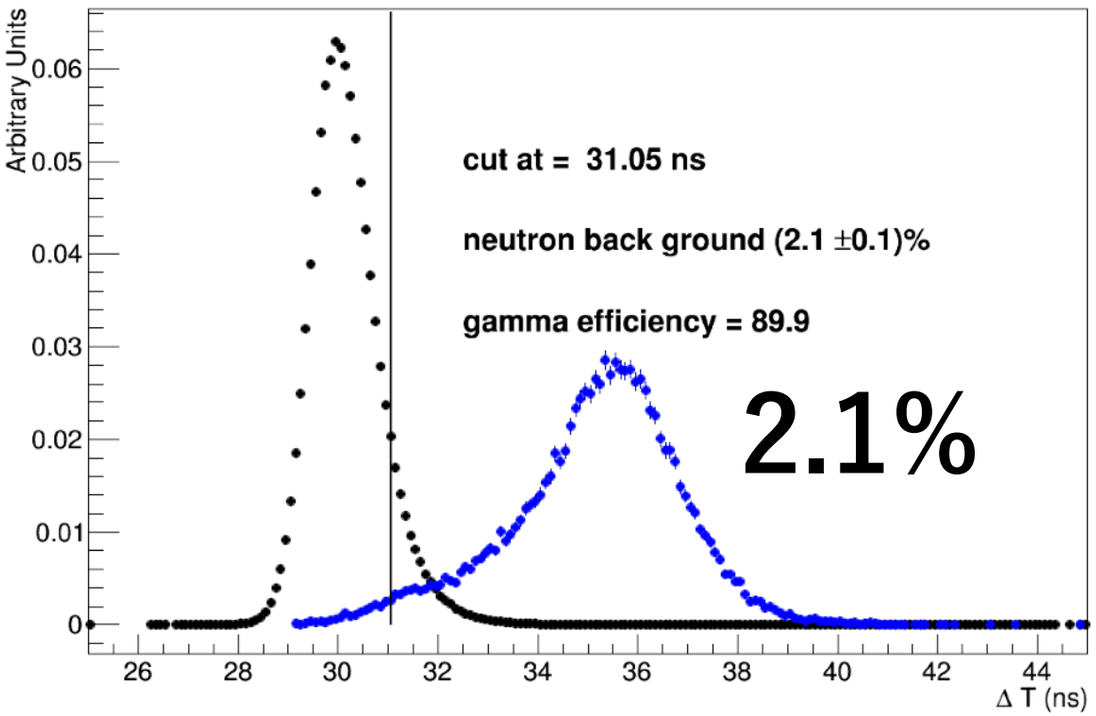
Neutron background is suppress to ~4%
(w/ 90% signal efficiency)

Correlation (FPSD vs ΔT)

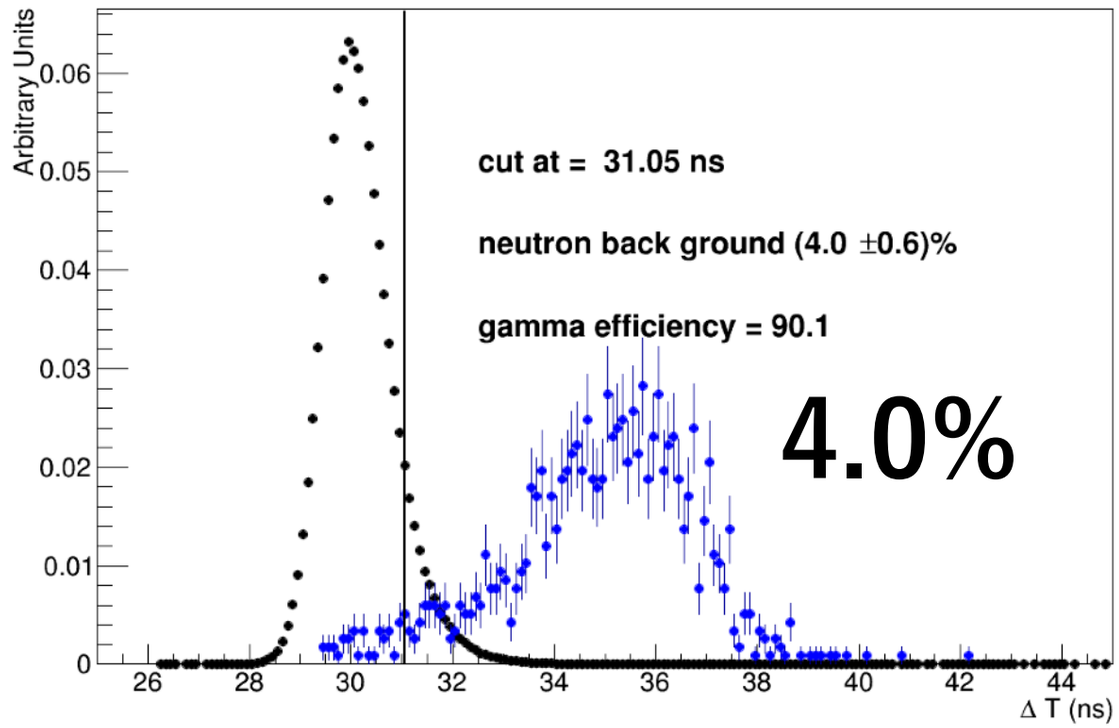
Any correlation btw. FPSD vs ΔT ?

Apply FPSD cut

ΔT (w/o FPSD cut)



ΔT (w/ FPSD cut)



Small correlation but

<u>hadron-cluster BG is suppress to 4%</u>

Summary

- **Performance of ΔT**

  Hadron-cluster background is suppressed to 2.1%
  (w/90% gamma efficiency)

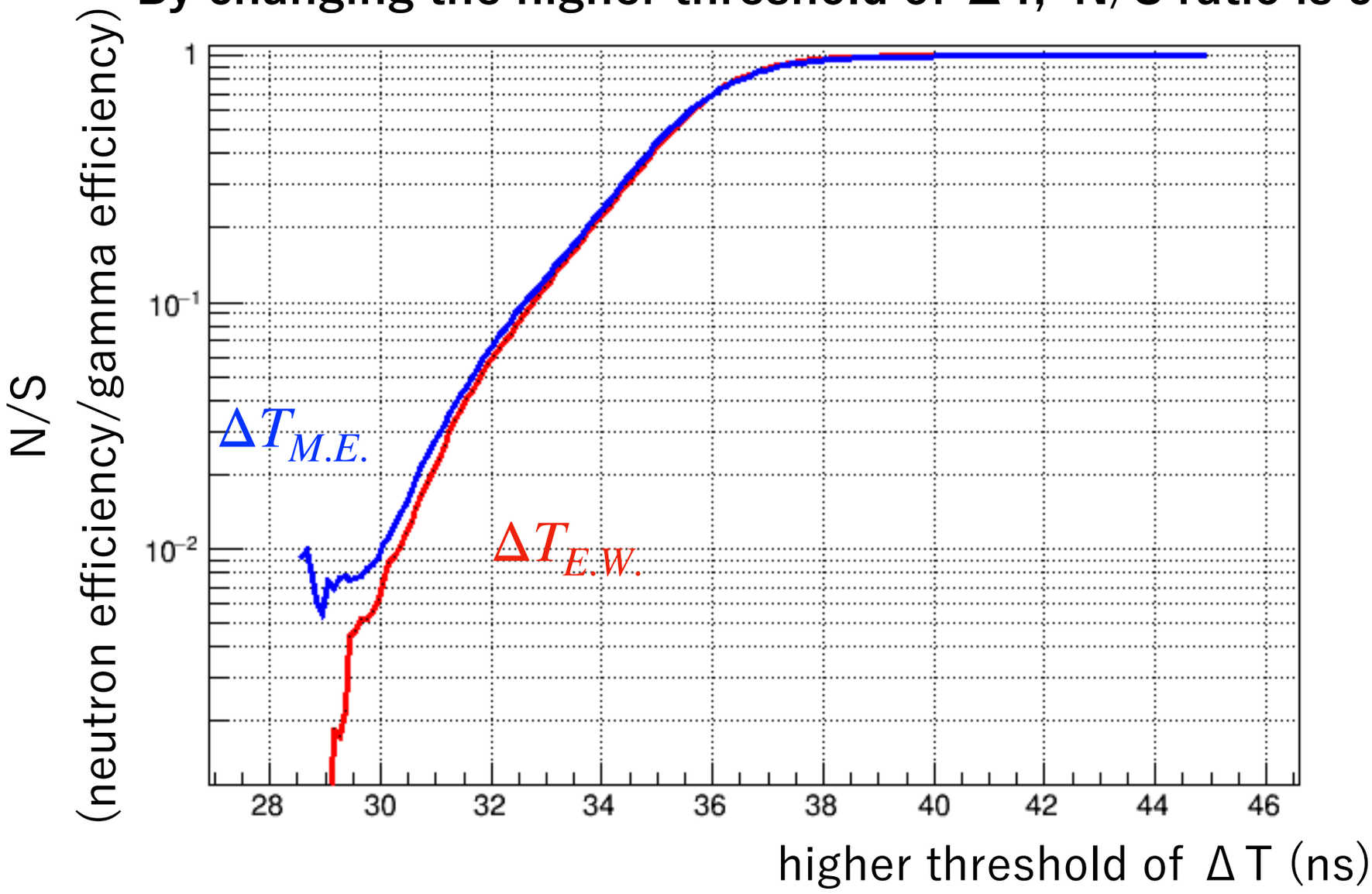
  Energy weighted timing has better performance than maximum energy channel timing.

- Correlation btw. **pulse shape cut vs ΔT**

  Correlation can be seen but enough small.

N/S Ratio

By changing the higher threshold of ΔT, N/S ratio is calculated.



$$\Delta T_{M.E.} = T_{MPPC\ Maximum\ Energy} - T_{PMT}$$

$$\Delta T_{E.W.} = T_{MPPC\ Enegy\ Weighted} - T_{PMT}\ (\text{MPPC channel energy} > 10\text{MeV})$$