Study on ^{10}C Tagging Efficiency for KamLAND2-Zen

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GP-PU QE1

Outline

1.Background of this study

- KamLAND-Zen Experiment
- Future Plan : KamLAND2-Zen Experiment

2.Problem in KamLAND2-Zen

- ^{10}C background
- How to handle the problem

3.Tag efficiency of neutron and ^{10}C

- neutron tag efficiency
- ^{10}C tag efficiency

4.Summary

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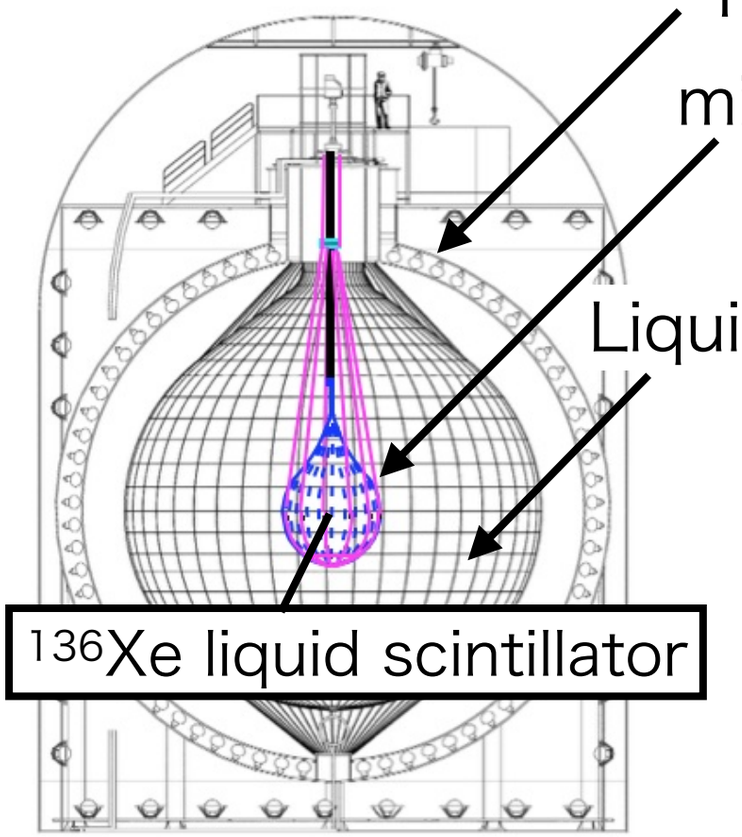
KamLAND-Zen Experiment

KamLAND-Zen Experiment

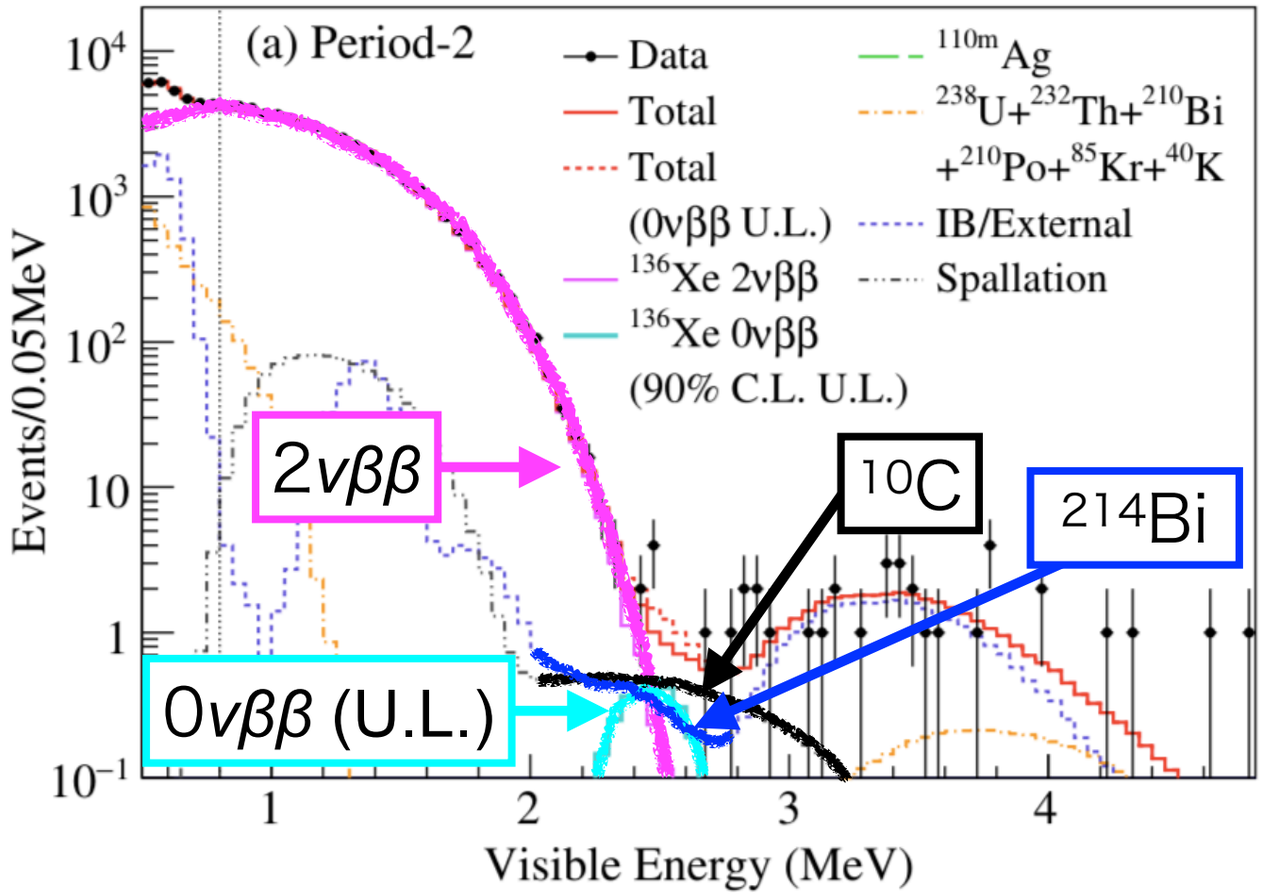
= Neutrino-less double beta decay ($0\nu\beta\beta$) search of ^{136}Xe



$T_{1/2}^{0\nu} > 1.06 \times 10^{26}$ [yr] (90% C.L.)

$\langle m_{\beta\beta} \rangle < 61$ -165 [meV] (90% C.L.)

Spectrum of KamLAND-Zen 400



Need to improve <u>energy resolution</u> → KamLAND2-Zen Experiment

KamLAND2-Zen Experiment

- **High Quantum Efficiency PMT(HQE-PMT)**

  light yields × 1.9

- **Light collection mirror**

  light yields × 1.8

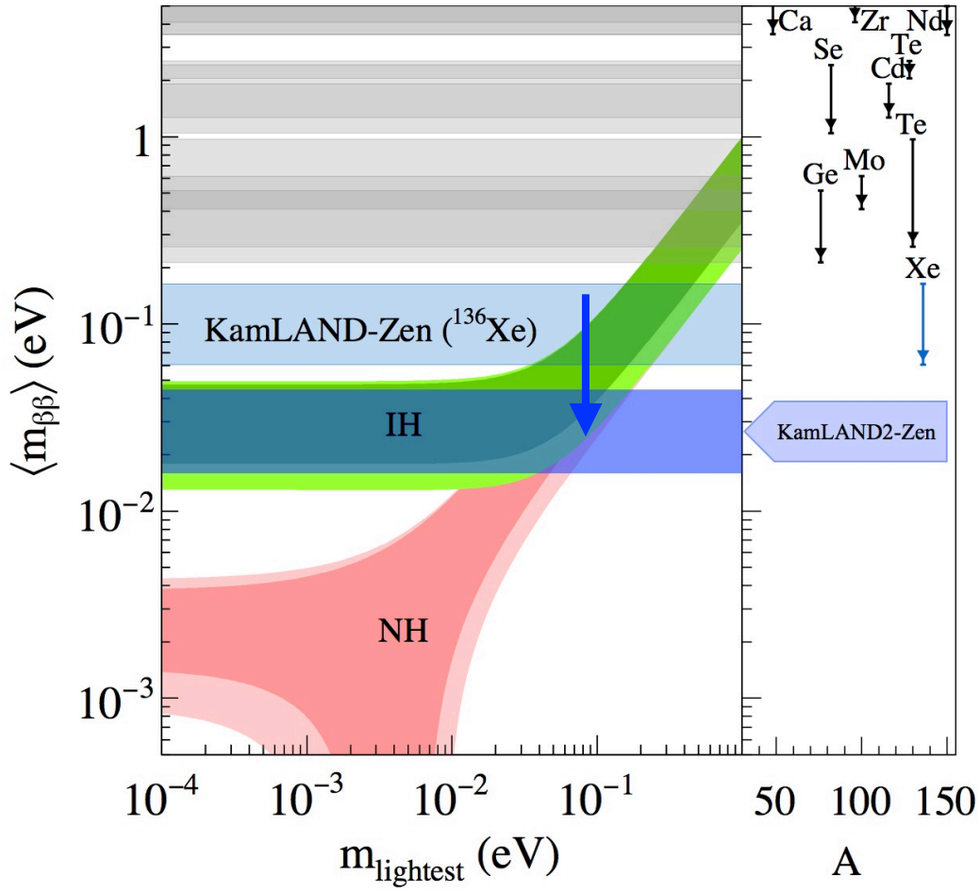
- **New liquid scintillator**

  light yield × 1.4

Total light yields × 5

☑ Energy resolution(σ) : 4.2% → ~ 2% @ Q-value

☑ $2\nu\beta\beta$ background : ~1/100



Others

- Scintillation mini-balloon for ^{214}Bi tag
- New data acquirement circuit(MoGURA2)

Aim to $\langle m_{\beta\beta} \rangle$ ~ 20 [meV] w/ 1000 kg Xenon in 5 yr

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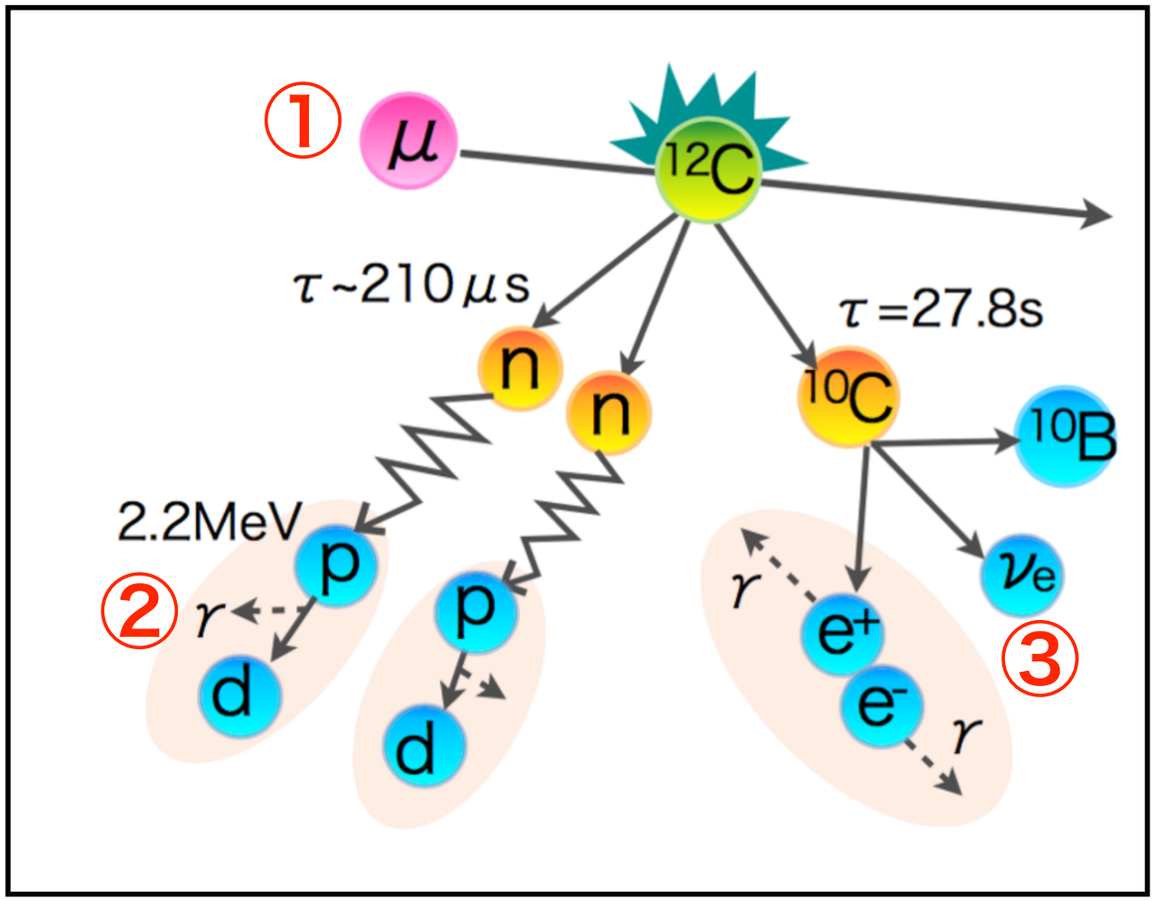
^{10}C Tag

- improvement of energy resolution($2\nu\beta\beta$↘)
- Scintillation mini-balloon(^{214}Bi can be tagged)

→ **Main background of KamLAND2-Zen = ^{10}C**

^{10}C ⋯ Cosmic ray muon spallation product



① Muon

② Neutron capture

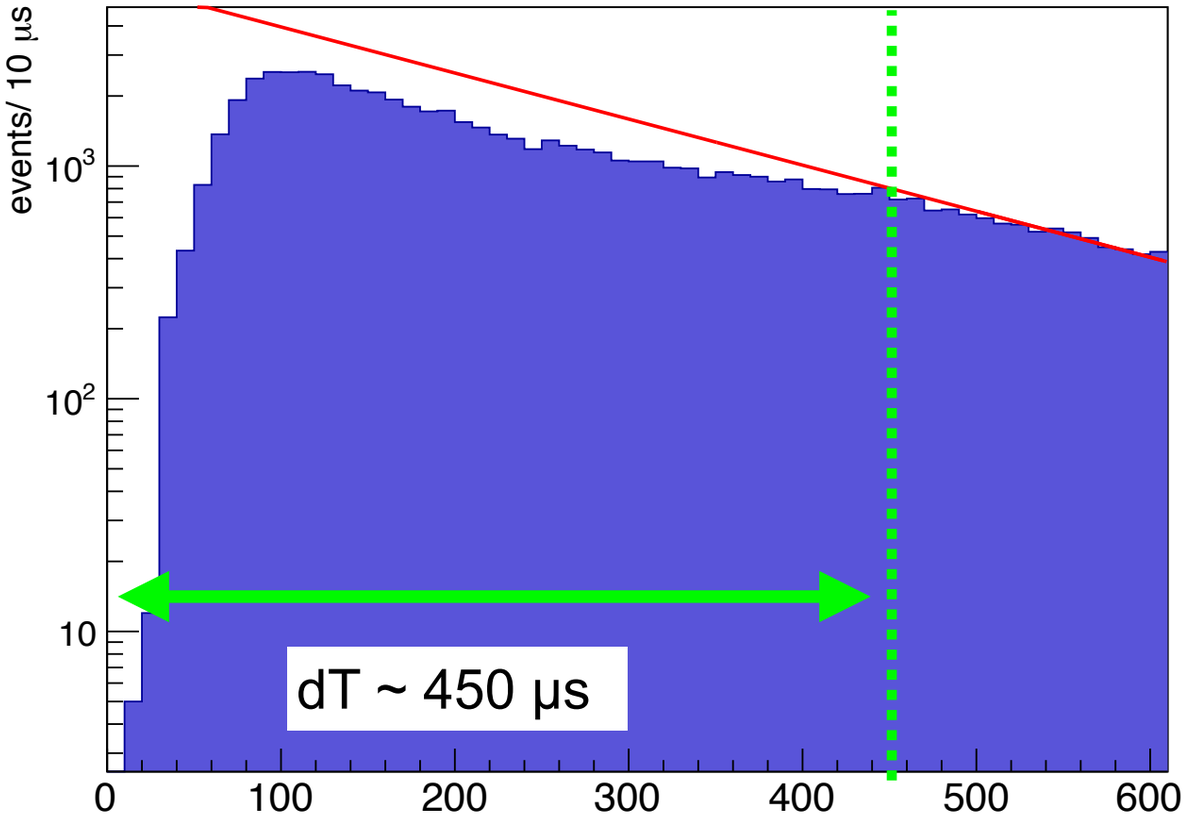
③ β+ decay of ^{10}C

Tag w/ triple delayed coincidence

Tag efficiency : 64±4%

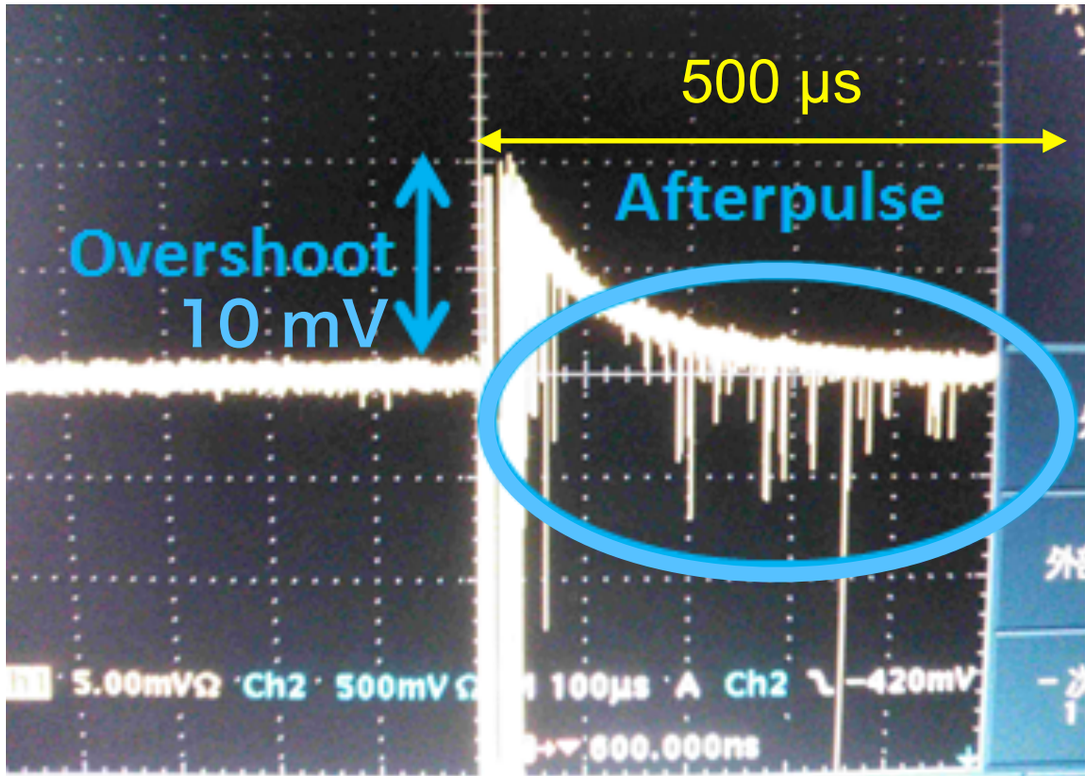
Miss of neutron events

of neutron detection after muon



- Tag efficiency : ~54%

Cause of neutron missing



- Discriminator does not work
- Data acquirement stuck

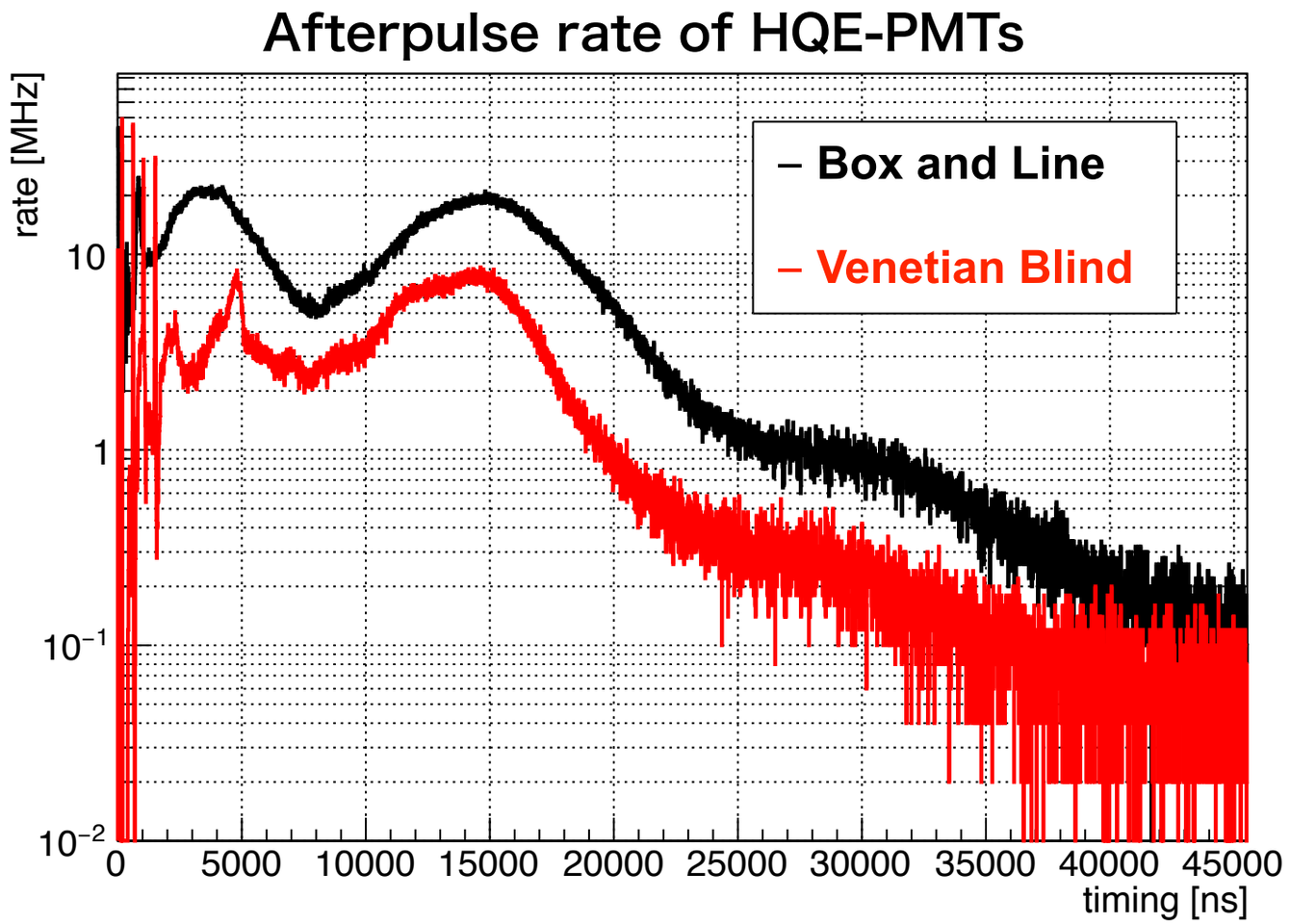
Neutron detection will be more difficult in KamLAND2 (light yield ↗)

→ **Need prevention of overshoot and afterpulse**

Using Venetian Blind PMT

Candidate PMT = 20”Box and Line type(R12860 HQE) :

- Good time and light collection property
- <u>High afterpulse rate</u>



R3600 HQE : 20”Venetian Blind type PMT
(Used in Outer detector of KamLAND / Super-Kamiokande)

Venetian Blind PMT is **superior in terms of neutron detection**

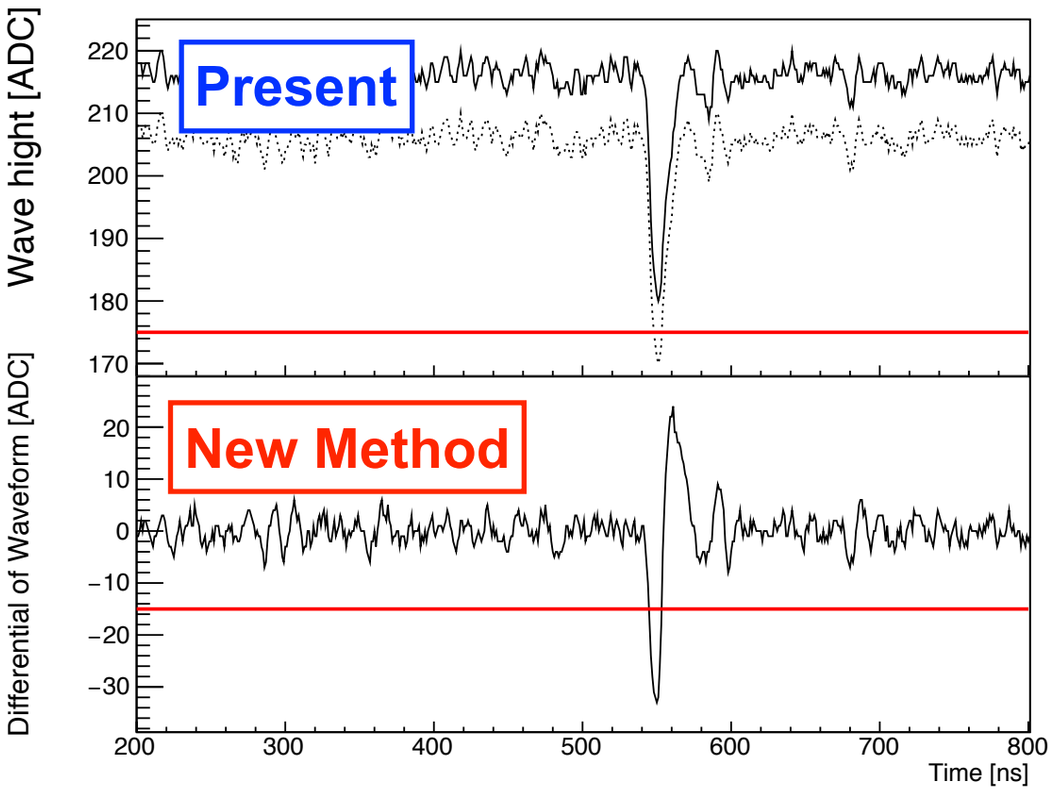
New trigger mode

- Mount trigger mode dedicated to neutron detection (Only after muon)

  → **Differential hit + Local hit trigger scheme**

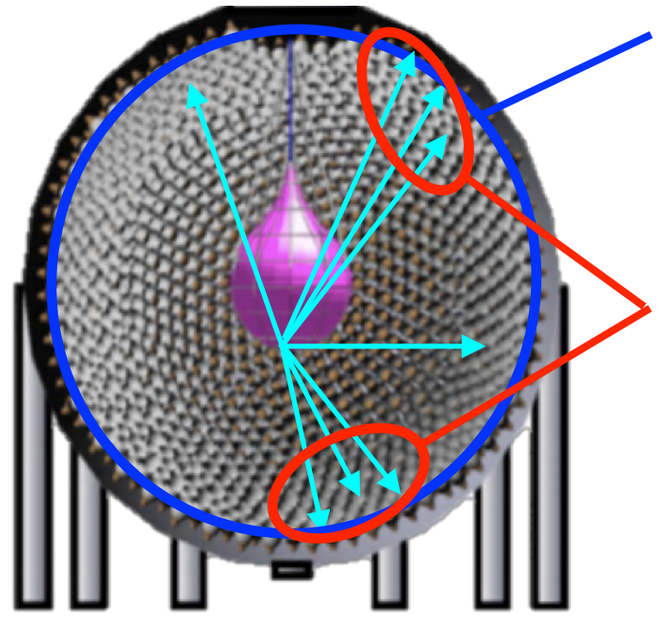
Differential hit detection

Threshold is set in terms of <u>differential</u>



Can detect signals under baseline shift

New trigger scheme : Local hit scheme



By setting threshold in terms of the # of local hit (determined w/ the # of hit PMTs **<u>in local area</u>**), time window for hit detection can be shorter.

→ influence of afterpulse become smaller

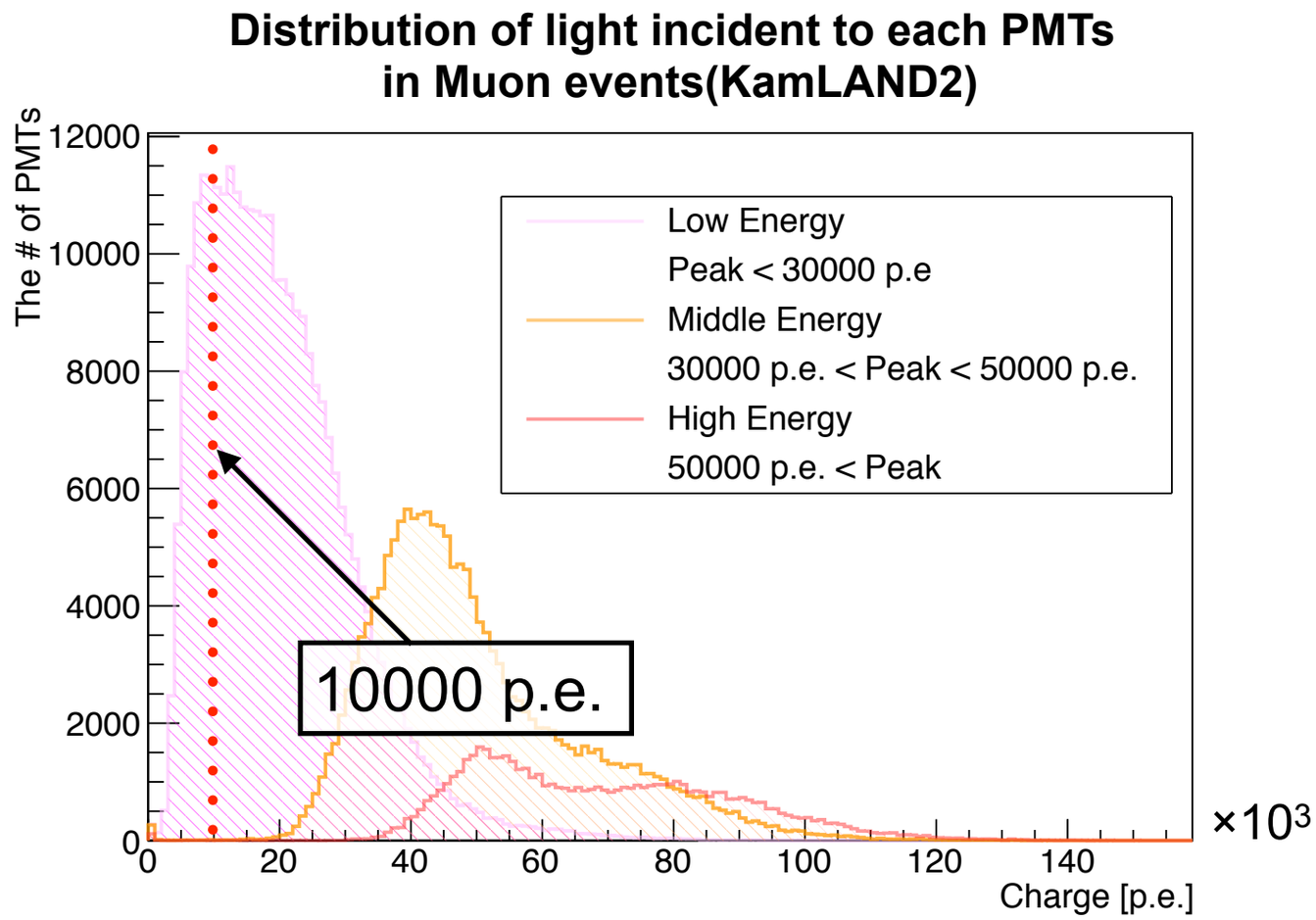
Optimized parameters in previous study (assumption : <u>10000 p.e. incident</u>)

- Threshold for local hit = 14 ch/16ch in local area
- Threshold for data acquirement = 65 local hit/118 local hit

ref.) Y.Honda master thesis, Tohoku (2017)

Muon events in KamLAND2

Light incident to PMTs in muon event in KamLAND2 will be **more than 10000 p.e.**



- More influence of overshoot and afterpulse to neutron detection than expected in previous study
- Afterpulse might disturb event reconstruction

Neutron tag efficiency = Neutron detection efficiency × Neutron reconstruction efficiency

Need more study of new trigger scheme

Purpose

To evaluate new trigger mode

・to investigate neutron tag efficiency

(Neutron tag efficiency = Neutron detection efficiency × Neutron reconstruction efficiency)

- Consider more than 10000 p.e. incident

- Consider influence of afterpulse to event reconstruction

- Check the case that 30% of PMTs are Venetian Blind type

∵ T.T.S. and light collection efficiency are inferior to those of Box and Line type

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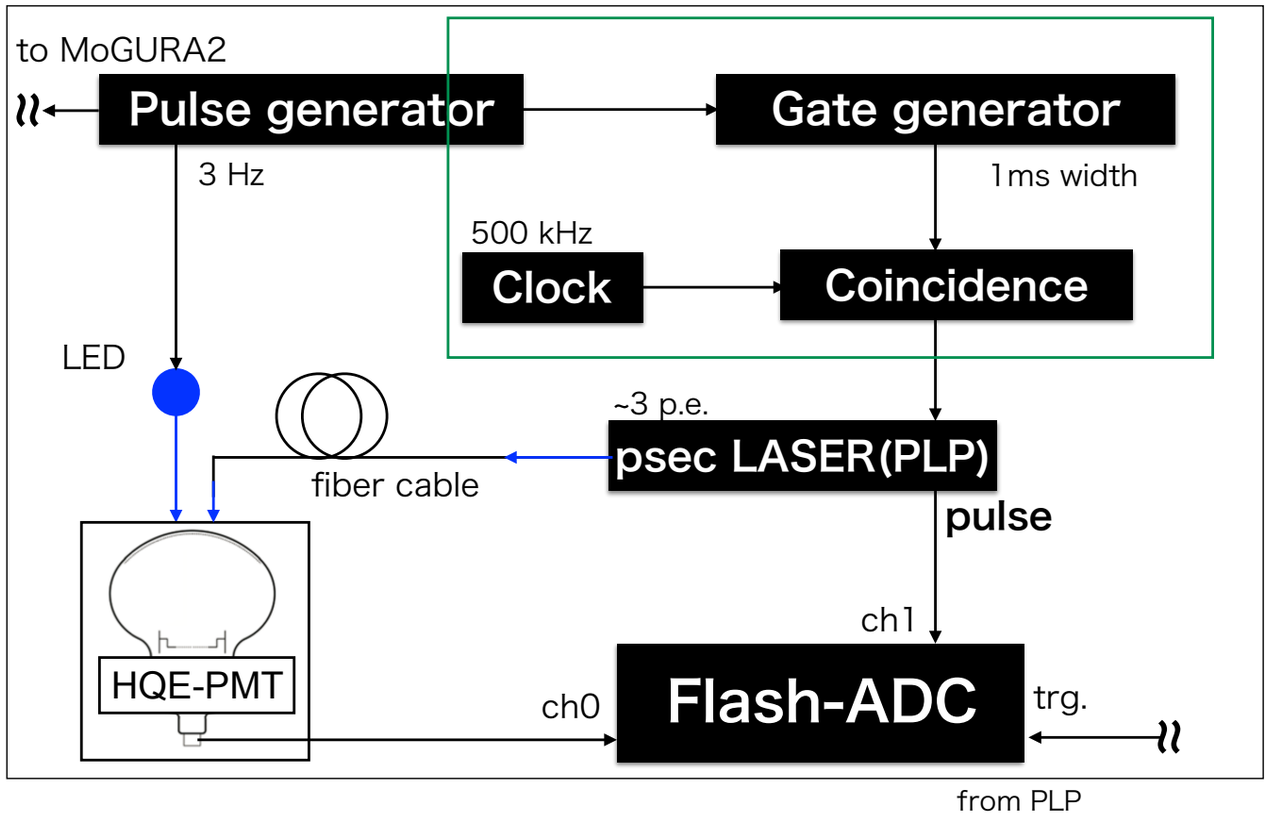
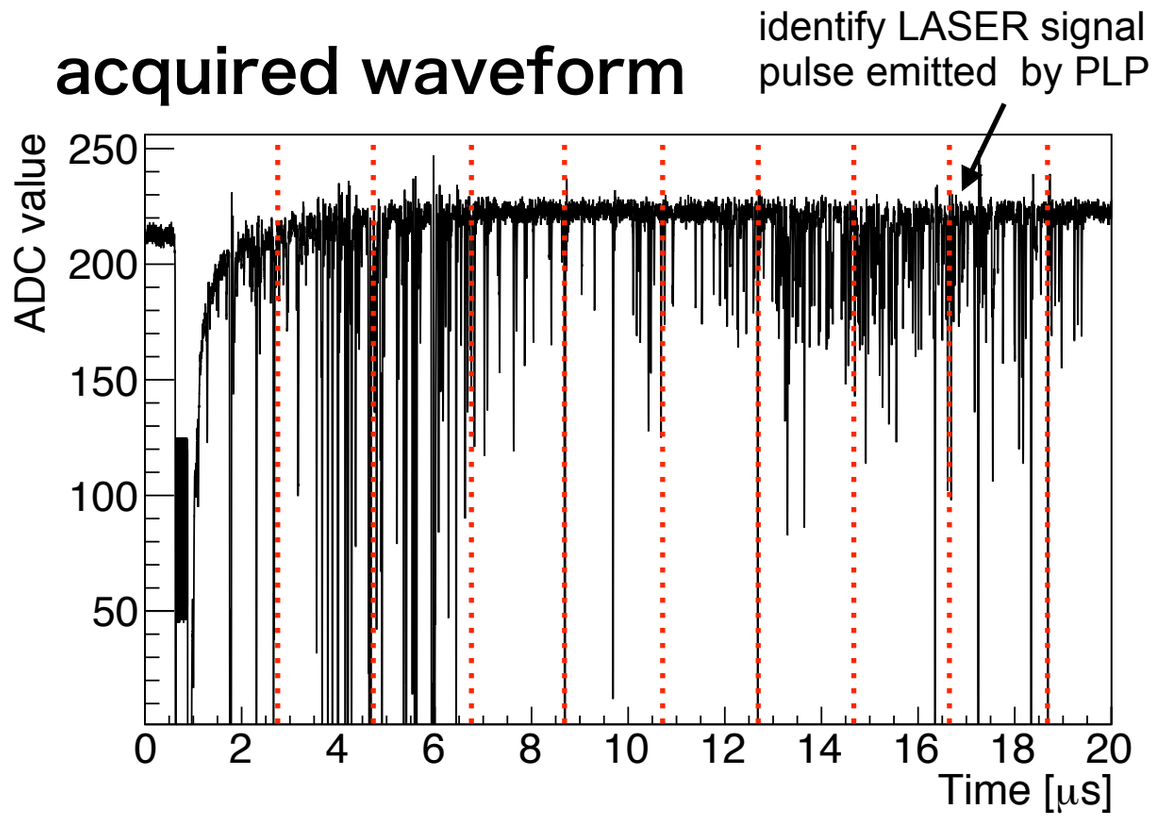
Neutron detection efficiency

Simulation of local hit probability with real HQE-PMTs waveform

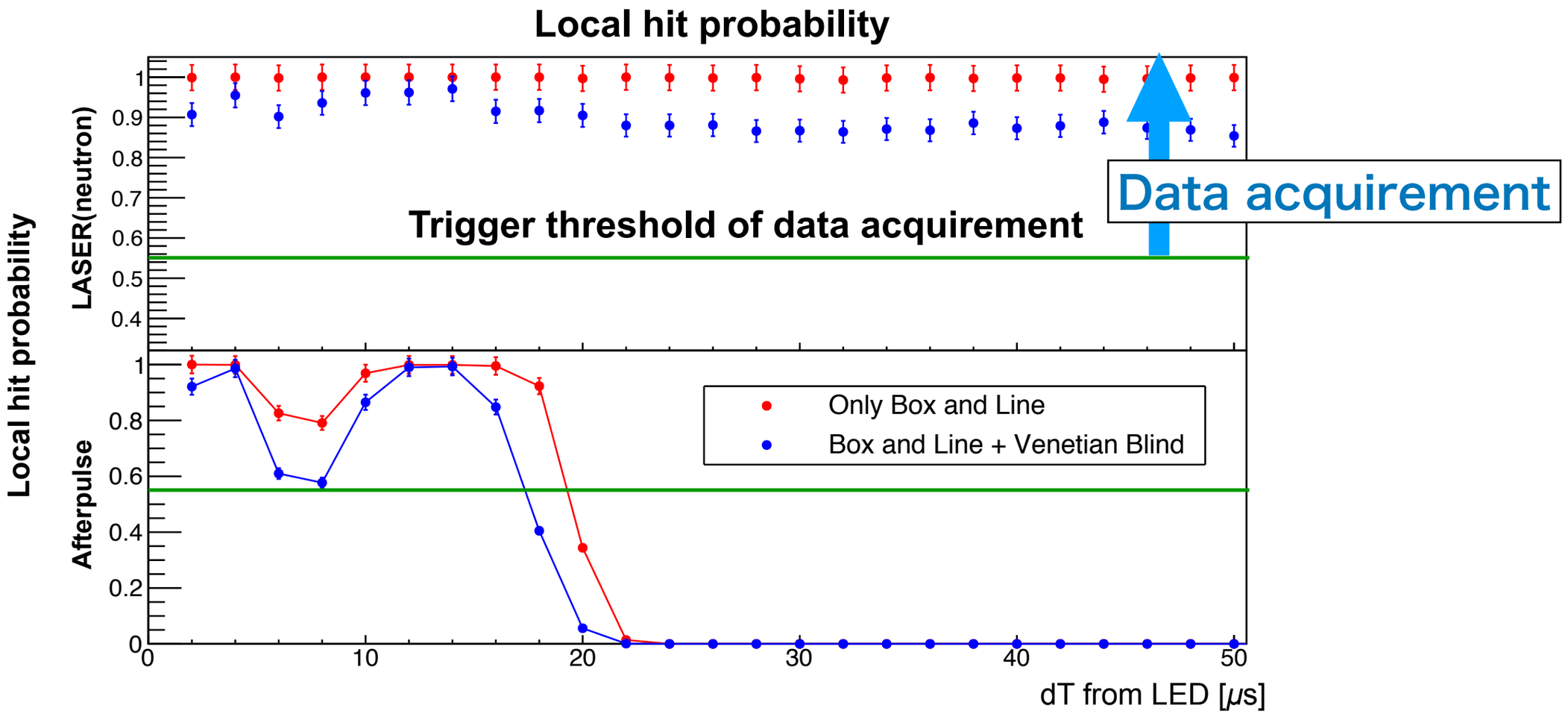




- LED : 1×10^4, 2×10^4, 3×10^4, 4×10^4, 5×10^4, 7×10^4, 9×10^4, p.e.
- PLP : ~ 3 p.e.

- Checked two cases
  - 100% Box and Line PMT
  - 30% Venetian Blind + 70% Box and Line

Trigger on neutron/afterpulse



- Trigger issues on neutron events
- Trigger on afterpulse converges within about 20 μs (not data acquirement stuck)

All neutron events data is recorded

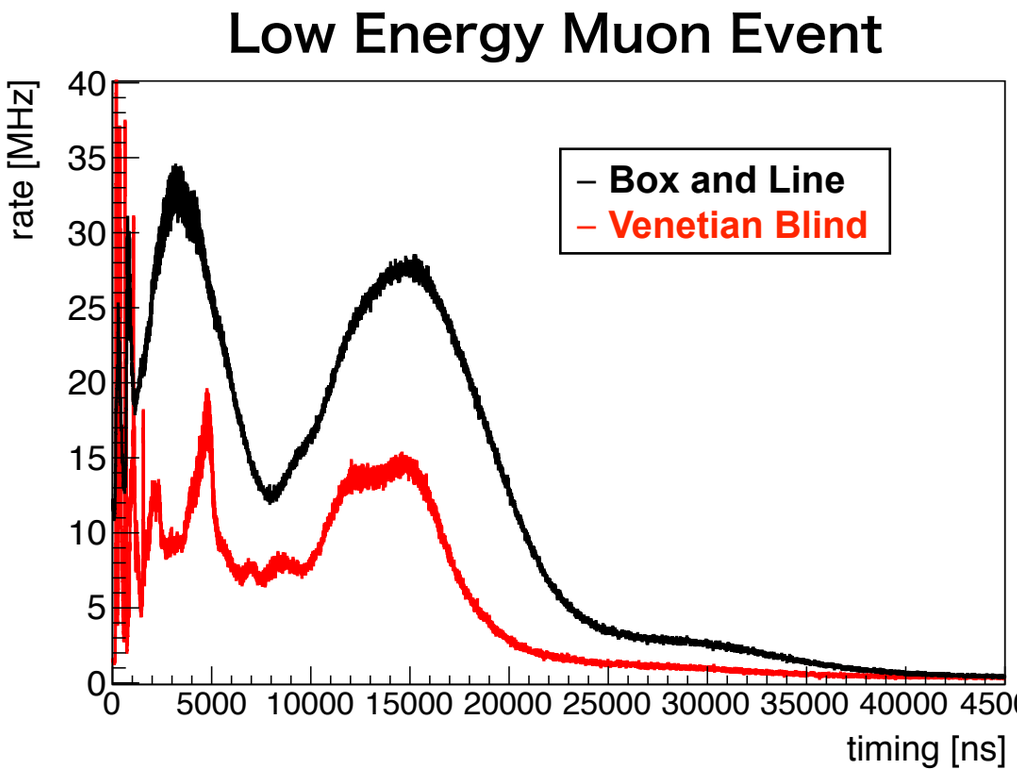
Neutron tag efficiency = Neutron detection efficiency × Neutron reconstruction efficiency

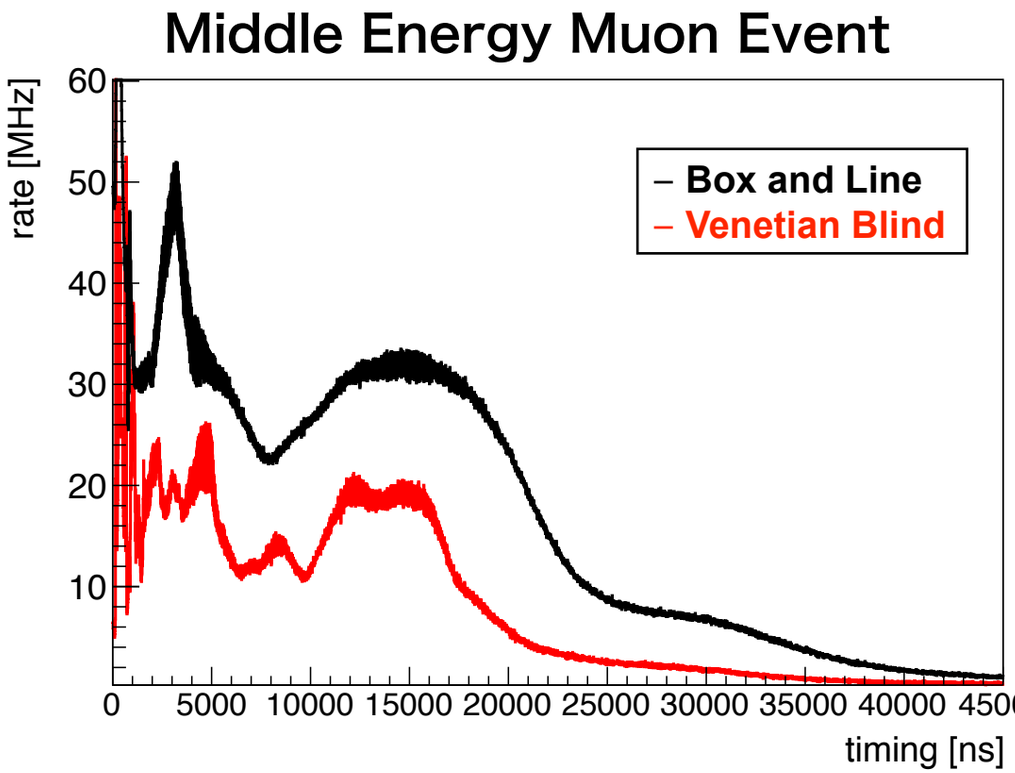
→ **Neutron tag efficiency is determined by reconstruction efficiency**

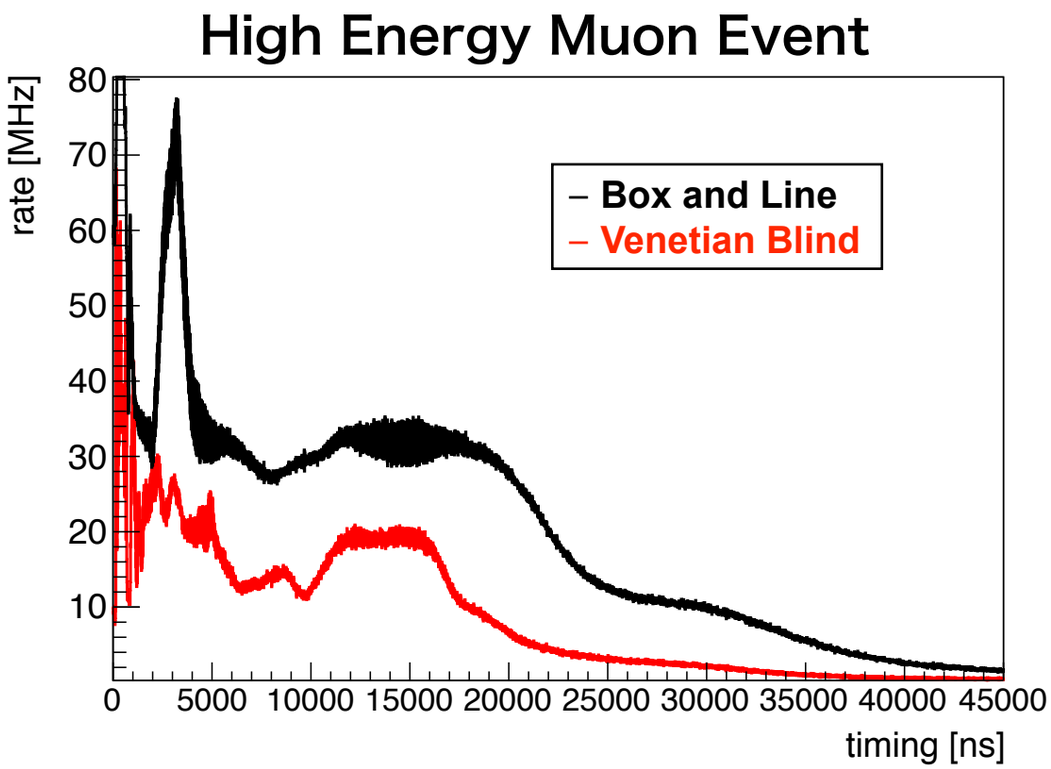
Simulation of reconstruction considering afterpulse rate is needed.

Rate of afterpulse following muon event

- Checked afterpulse rate in non-LASER region of acquired waveform







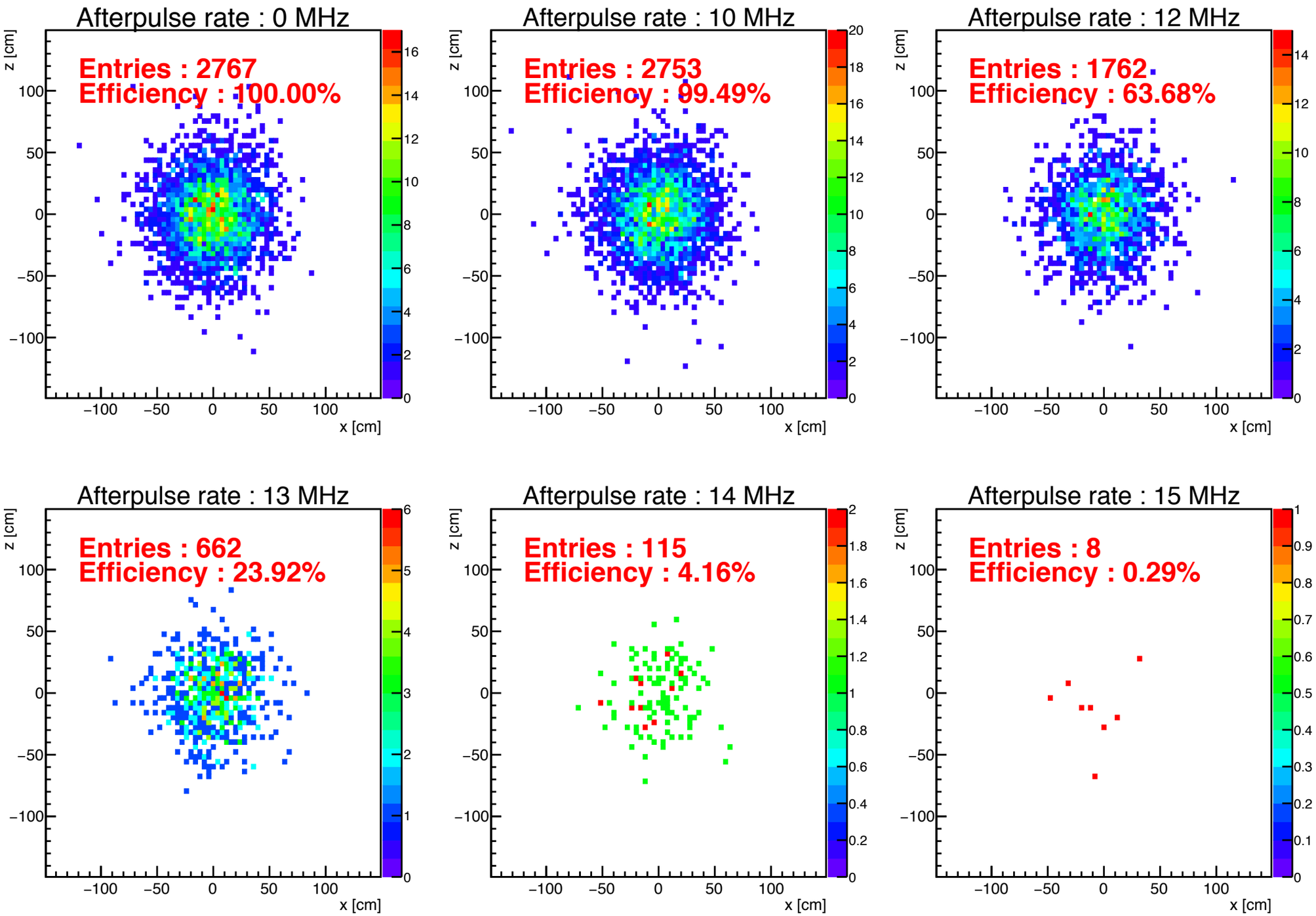
Venetian Blind PMT : Lower afterpulse assuming reconstruct

- Box and Line case
  → w/ Box and Line PMT
- Box and Line + Venetian Blind case
  → only w/ Venetian Blind PMT

Event reconstruction efficiency(Box and Line)

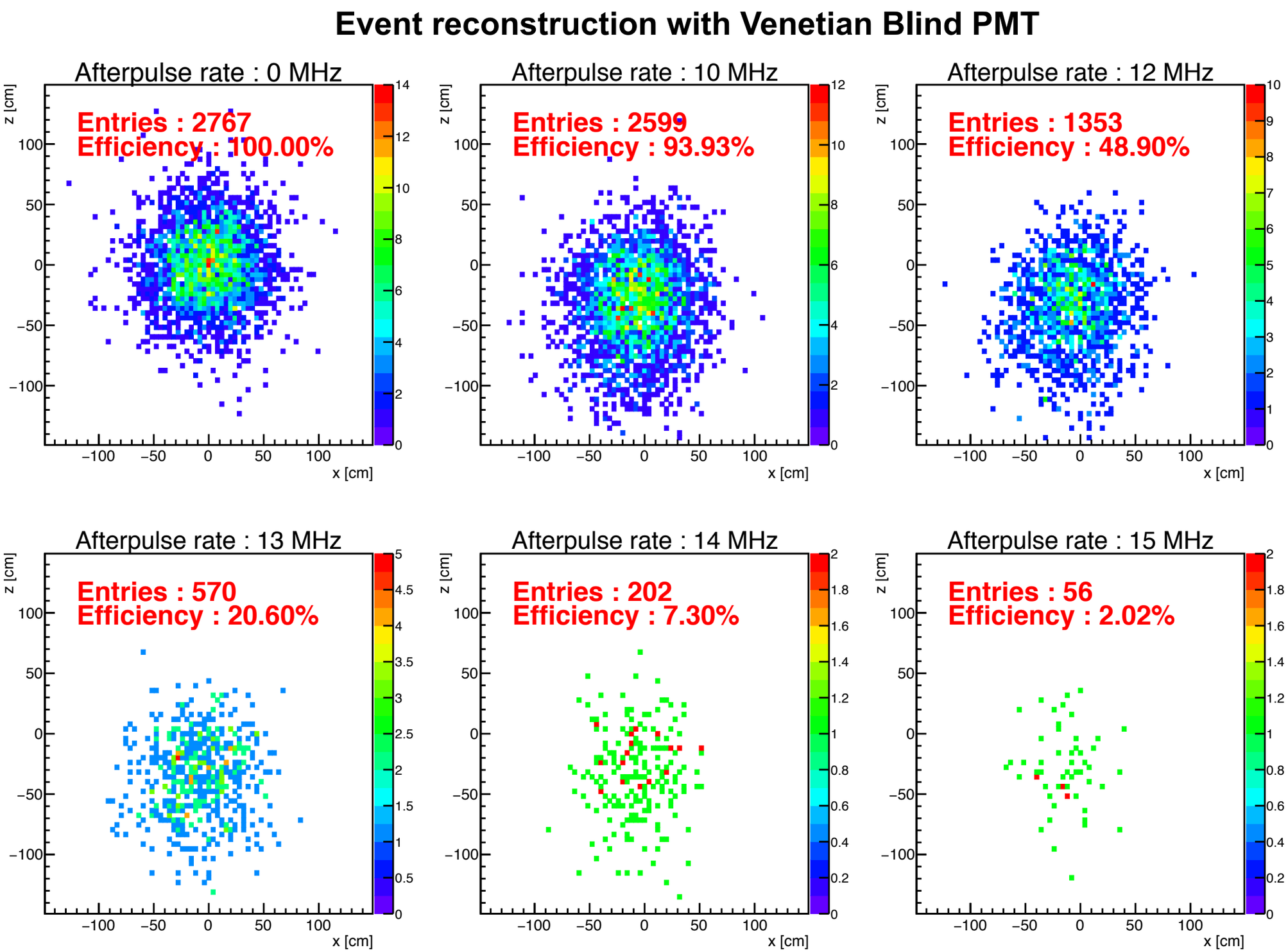
- Imitiated hit data of neutron events in KamLAND2 with data of ^{60}Co at center of KamLAND
- Checked reconstruction efficiency after adding hit data of fake signal artificially

Event reconstruction with Box and Line PMT



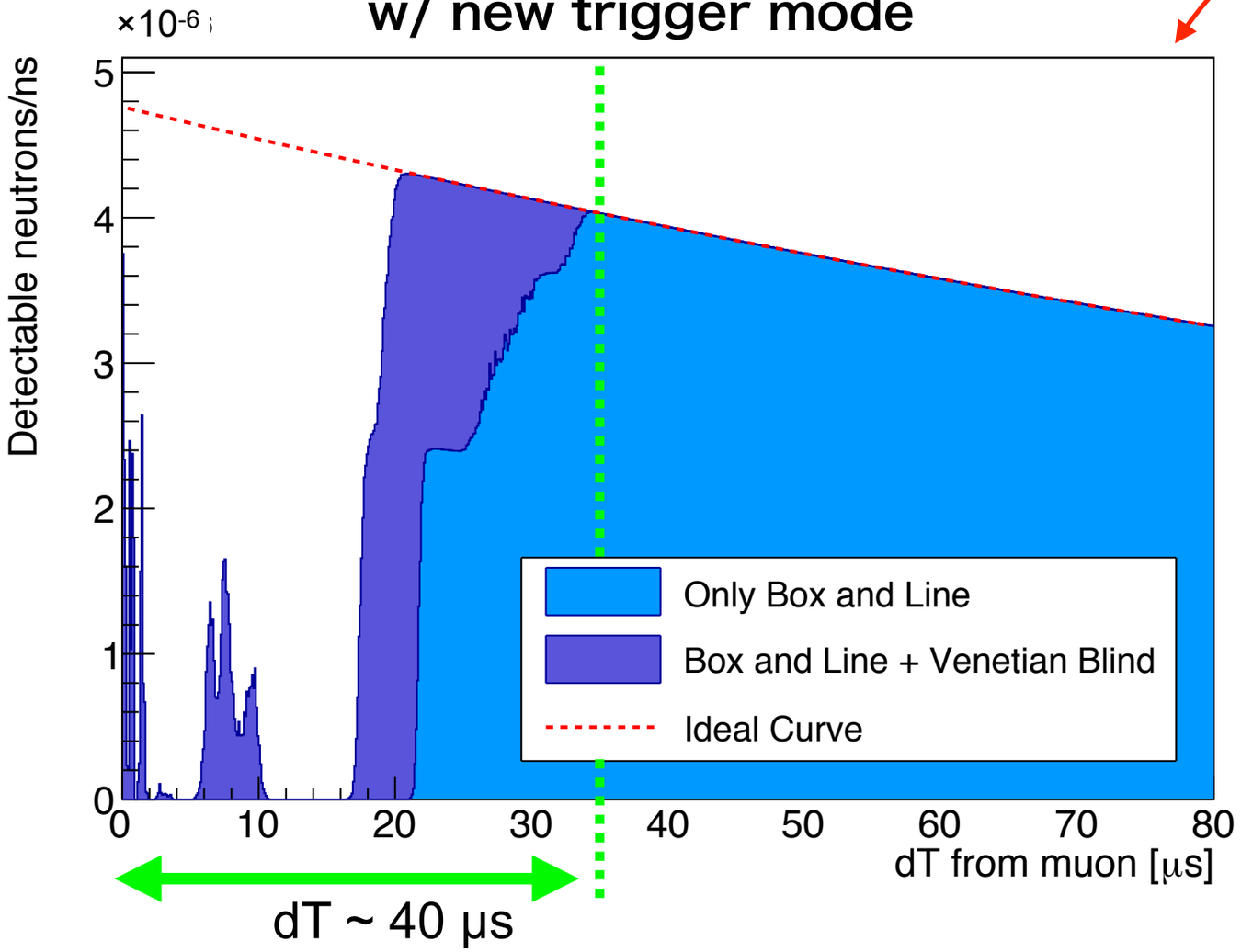
Event reconstruction efficiency(Venetian Blind)

- light collection and T.T.S. are considered

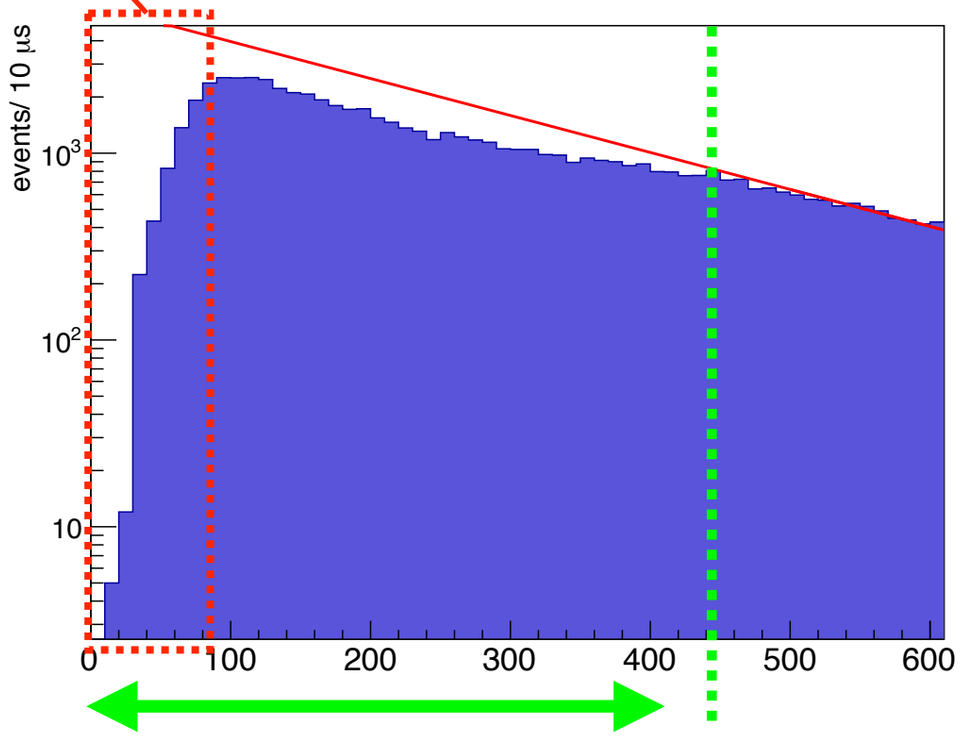


Neutron tag

of neutron tagging after muon w/ new trigger mode



of detected neutron after muon



All the neutrons can be tagged within dT ~ 40 μs even after muons which produce ^{10}C

Neutron tag efficiency

Neutron tag efficiency p_E

・Present : p_E = 54%

⬇ ・new data acquirement system

p_E = 88.80 ± 2.00% (only Box and Line PMT)

⬇ ・new data acquirement system + Venetian Blind PMT

p_E = 92.28 ± 1.83% (Box and Line + Venetian Blind PMT)

- **Neutron detection efficiency will be improved by new data acquirement system**
- **Efficiency will be enhanced with Venetian Blind PMT**

^{10}C Tag efficiency P

present : P = 64% →
- P = 98.75 ± 0.03% (only Box and Line)
- P = 98.82 ± 0.02% (Box and Line + Venetian Blind)

Backgrounds in 5years measurement

KamLAND-Zen
(calculated by result of KamLAND-Zen 400)

BG	events[/5 yr]
$2\nu\beta\beta$	36.9
^{10}C	20.8

- energy resolution : 4% → 2%
- analysis : r < 1 m → 2 m
- shower tag method for ^{10}C
  (total tag efficiency : 87.0%)

KamLAND2-Zen
(w/o new data acquirement system)

BG	events[/5 yr]
$2\nu\beta\beta$	2.77
^{10}C	18.6

energy region : -2σ ~ $+2\sigma$

Considering new data acquirement system

Box and Line

BG	events[/5 yr]
$2\nu\beta\beta$	2.77
^{10}C	1.79

70% Box and Line + 30% Venetian Blind

BG	events[/ 5yr]
$2\nu\beta\beta$	3.41 ←increase because of less light collection
^{10}C	1.69

Due to new data acquirement system,
^{10}C BG will decrease dramatically

(Using only Box and Line type is better in terms of total background amount)

In 5 years measurement …

- ^{214}Bi can be tagged
- ^{8}B solar ν

- Limit on half-life of 0vbb : $T_{1/2}^{0\nu} > 1.89 \times 10^{27}$ [yr] (90% C.L.)
- Limit on Majorana effective mass : $\langle m_{\beta\beta} \rangle < 14.5 - 39.0$ [meV] (90% C.L.)

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Summary

- KamLAND2-Zen = Futeure plan for KamLAND-Zen($0\nu\beta\beta$ search)
  - It is concerned that detection efficiency of neutron and ^{10}C tag efficiency will become worse
- Property of Venetian Blind PMT(R3600 HQE) was studied under intense light incident
  - Revealed that V.B. PMT is effective to improve neutron detection efficiency
- New trigger scheme for neutron detection was studied
  - Incident in KamLAND2 was reprodeuced
  - Influence of fake signals to event reconstruction was considered
  - Effectiveness of Venetian Blind PMT was also investigated

  - neutron tag : 54% → 88.80 ± 2.00%(B&L), 92.28 ± 1.83%(B&L+VB)
  - ^{10}C tag : 64% → 98.75 ± 0.03%(B&L), 98.82 ± 0.02%(B&L+VB)