Development of an imaging detector to reduce the long-lived spallation background in the KamLAND2-Zen experiment

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Research purpose

Developing new detector for PID with **Imaging** and reducing long-lived spallation backgrounds by 90% on KamLAND2-Zen

Goal Designing imaging detector and evaluating performance for PID by simulation

1, Backgrounds & Physics target

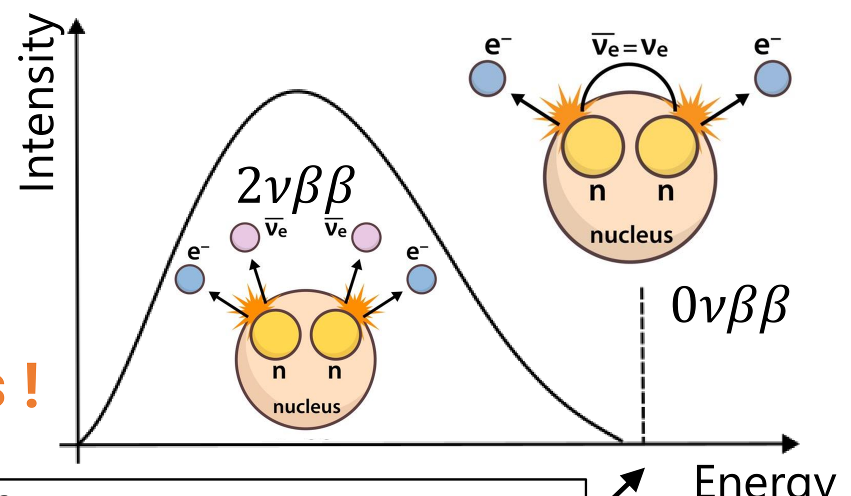
0νββ decay

- Predicted by Majorana ν
- Undiscovered
- Very rare event

If we discover 0νββ, we can resolve physics problems !

- Tiny neutrino mass
- Matter dominant universe

Energy spectrum of ββ decay

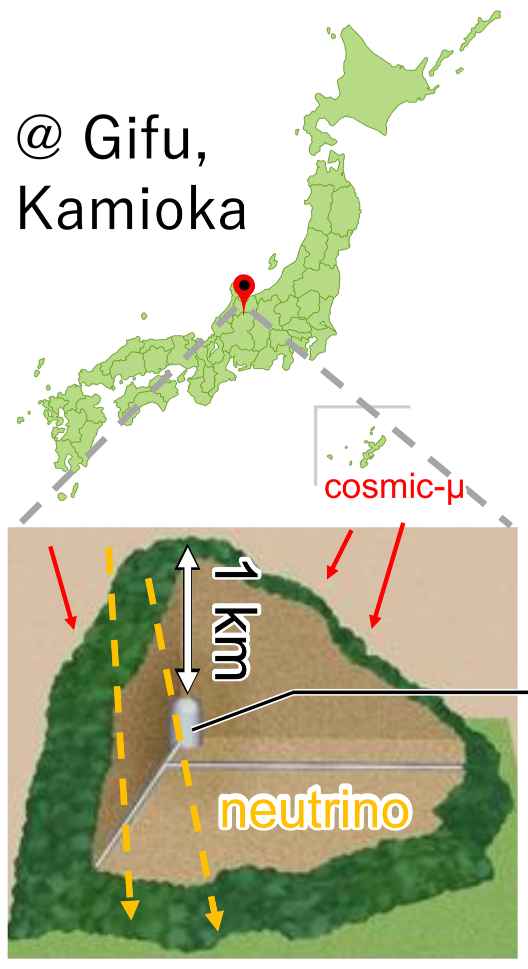


If 0νββ exists, it appears as mono peak on Q value.

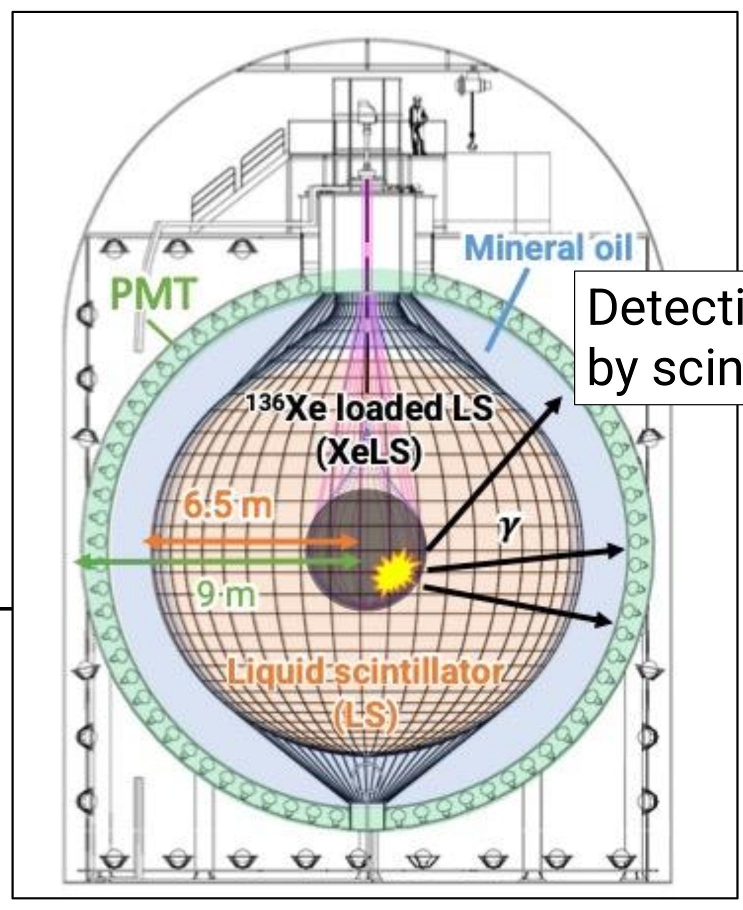
KamLAND-Zen

Observation for 0νββ decay from ^{136}Xe ββ decay

@ Gifu, Kamioka



KamLAND side view



ββ decay of ^{136}Xe :
$^{136}Xe \rightarrow {}^{136}Ba + 2e^-$
$Q_{\beta\beta} = 2.46$ MeV

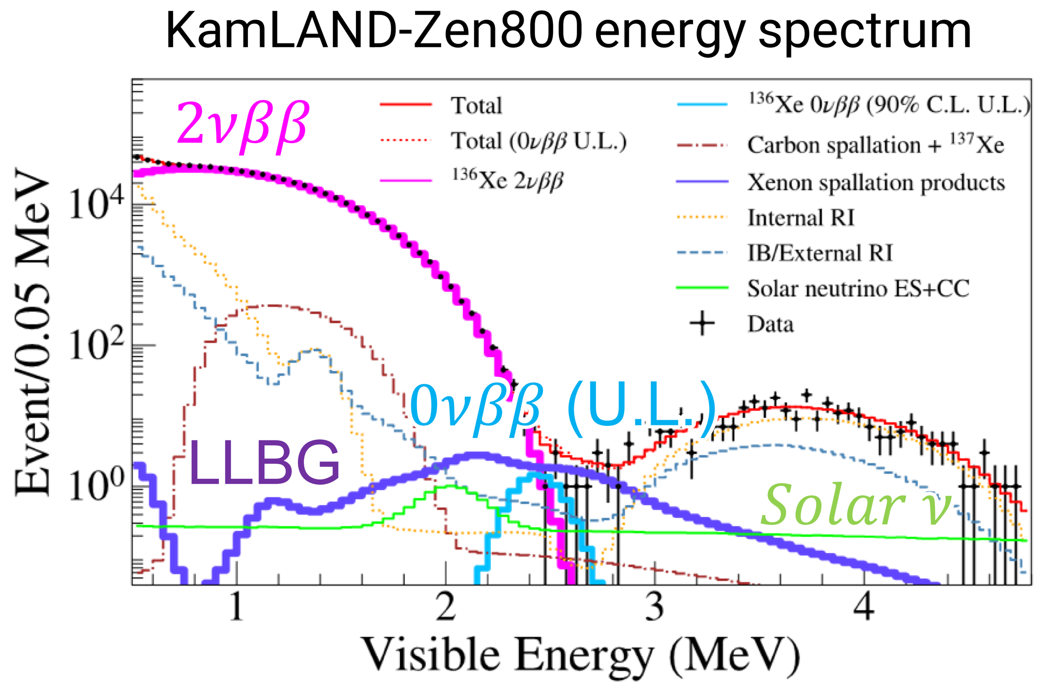
Detecting event by scintillation

Latest result

- 0νββ is still undiscovered
- but half life is limited !

$T_{1/2}^{0\nu} > 2.29 \times 10^{26}$ [yr] (90%C. L.) World Record

KamLAND-Zen800 energy spectrum



KamLAND2-Zen *Now going !*

Modifying KamLAND to improve sensitivity for 0νββ

- High QE PMT
- Winstone cone
- Brighter LS

▶ Improving resolutions
- Energy, Position

- New electronics
- Scintillation balloon

▶ Reducing RI

Long-lived spallation background (LLBG)[1]

- Xe spallation product by cosmic-μ
- Long half-life
- ▶ Delayed coincidence isn't effective
- Generated naturally
- ▶ Can't removed by LS distillation

New reducing method is needed !

Ex. of LLBG (ROI : 2.35~2.7 MeV) estimated by FLUKA & Geant4

Nuclides	Rate [day^{-1}kton^{-1}]
^{124}I (EC/β^+ γ)	0.18
^{130}I (β^- γ)	0.17
^{122}I (EC/β^+ γ)	0.11
Total (32 species)	1.06

2, LLBG reduction by Imaging

Spread of scintillation points

- It depends on emitted particles from event
- ▶ may be able to use identifying events

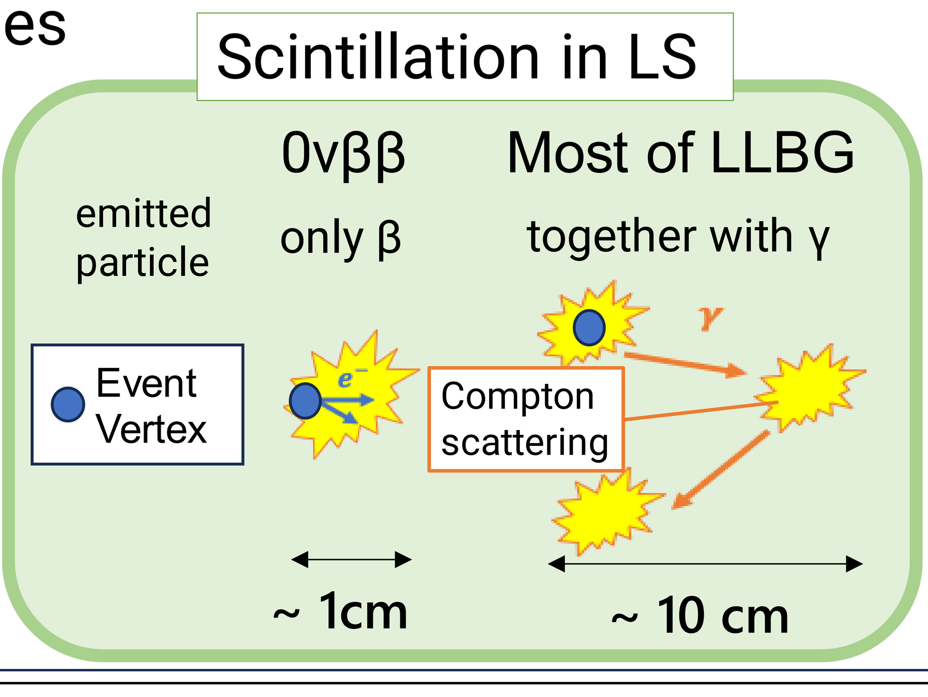
How to detect the spread ?

▼

By imaging events

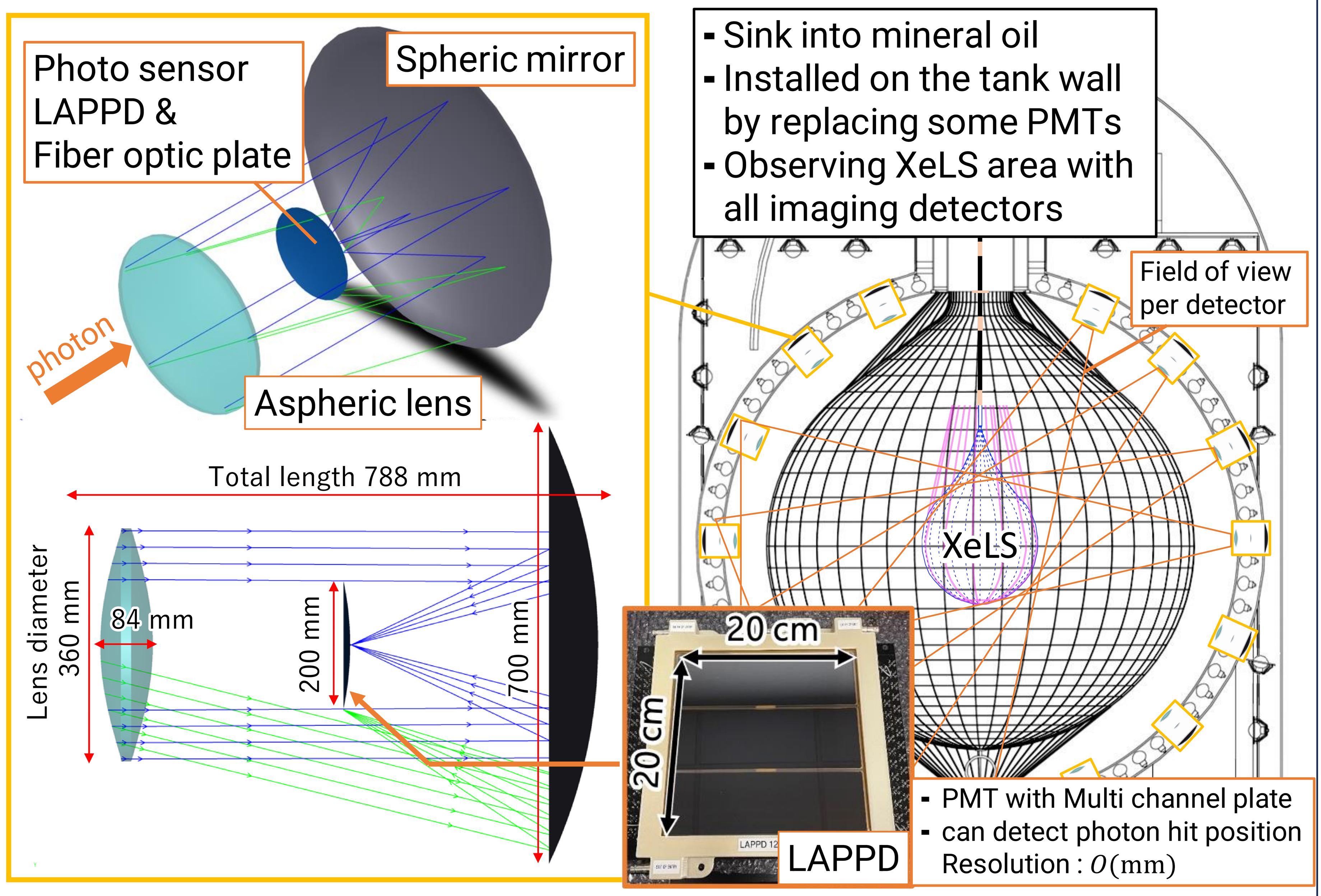
Goal LLBG 90% reduction
Same as solar ν level

Scintillation in LS



Ref [1] S. Abe et al, 2023, PhysRevC, 107(5), 054612

3, Imaging detector design



- Sink into mineral oil
- Installed on the tank wall by replacing some PMTs
- Observing XeLS area with all imaging detectors

- PMT with Multi channel plate
- can detect photon hit position
Resolution : O(mm)

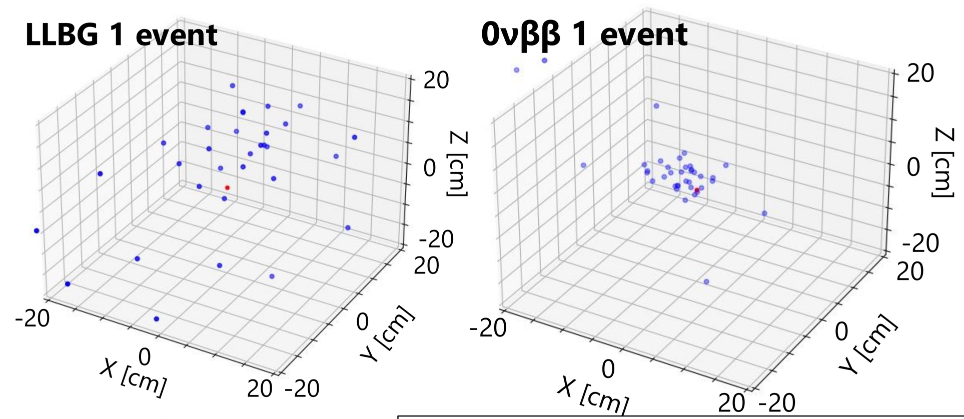
4, Method for LLBG reduction

Scintillation points reconstruction

- Pseudo scintillation points are estimated by image of event & PMT information
- Reconstructing one by one for all photons detected by the imaging detector

▼

Ex. of reconstructed scintillation points (from simulation)

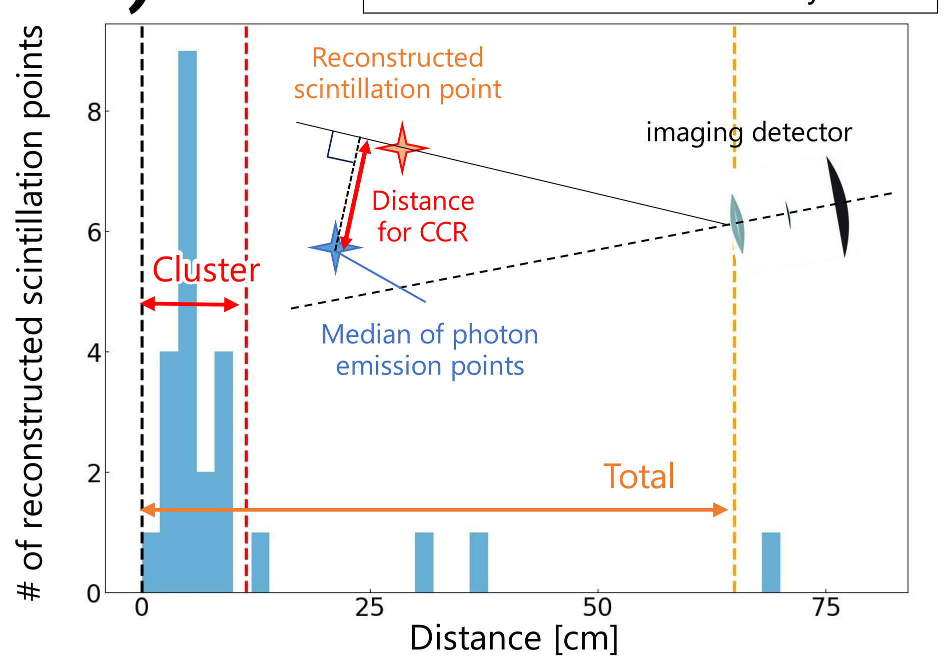


Blue : reconstructed scintillation points
Red : Event vertex estimated by PMTs

Cluster charge ratio (CCR)

- Grouping scintillation points by the distance
- Calculating the ratio of # of each group

definition $CCR = \frac{N_{Cluster}}{N_{Total}}$



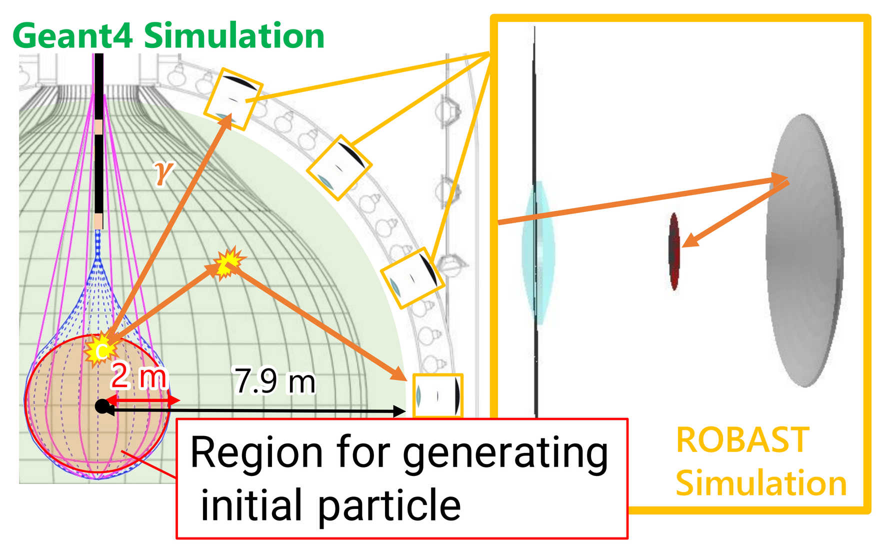
Identifying events type by CCR

5, Performance

Simulation

Tracking photons from 0νββ & LLBG events ▶ **Evaluating CCR**

- Assumptions
  - # of imaging detector : 180
  - KamLAND2-Zen environment

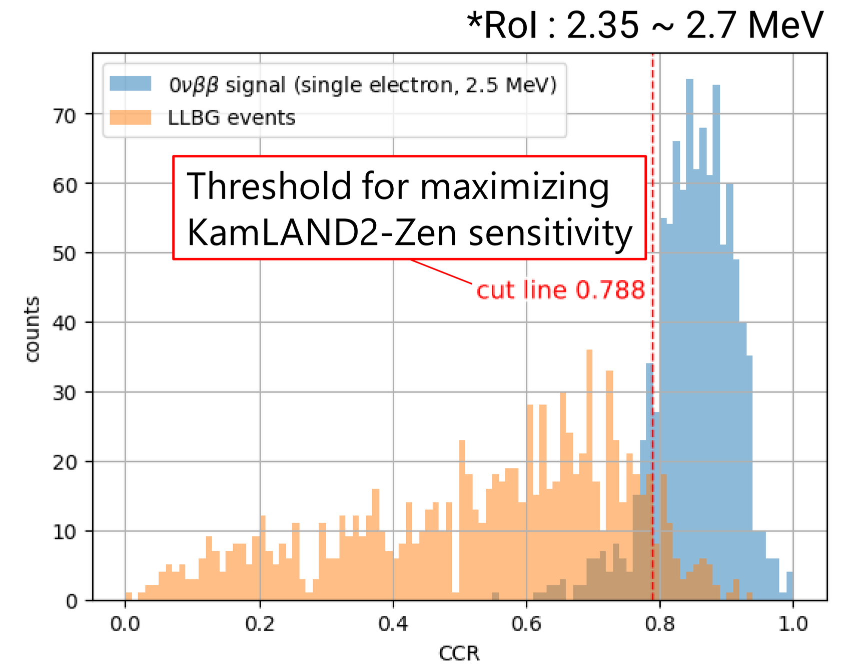


Result

- Comparing CCR distribution of 0νββ & LLBG (1,000 events)

Efficiency	Value
$0\nu\beta\beta$ detection	88.0 %
LLBG reduction	**92.3 %**

*RoI : 2.35 ~ 2.7 MeV



Summary

- To detect 0νββ decay on KamLAND2-Zen, new way to reduce LLBG is needed. I'm developing reduction method with Imaging.
- I made design of imaging detector + identification method, They can reduce LLBG by more than 90%.