# Four-dimensional Calorimeter to Discriminate Gammas from Neutrons for the KOTO Experiment

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@Calorimetry for the High Energy Frontier (CHEF2019)

# Introduction

# KOTO Experiment

**Search for $K_L \to \pi^0 \nu\bar{\nu}$ at J-PARC**

CP violating decay

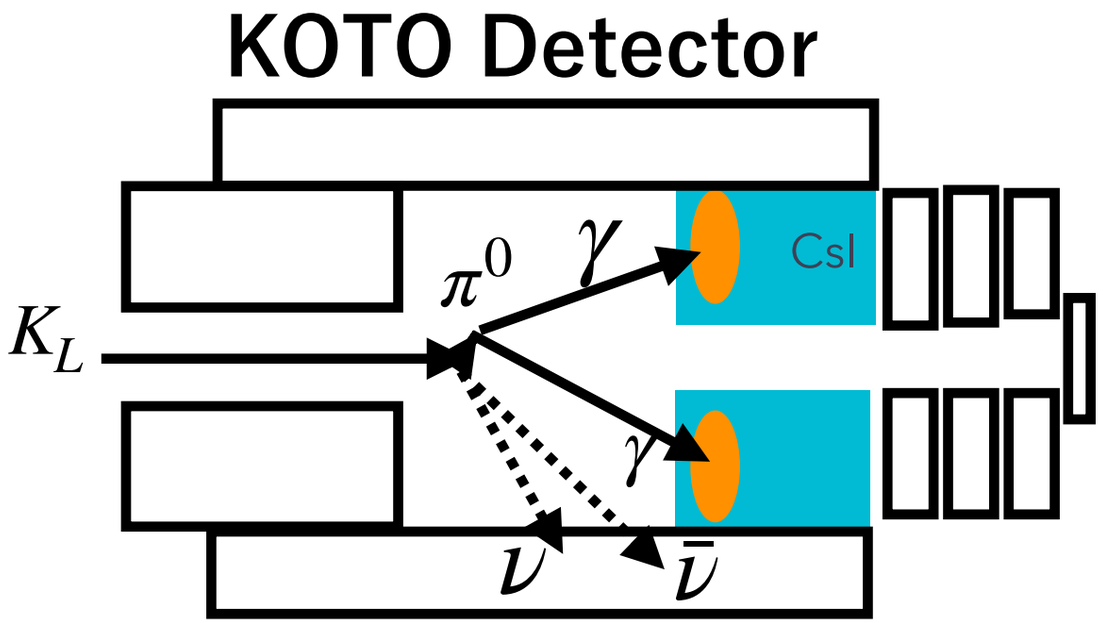
Highly suppressed in SM (BR : 3.0 $\times$ $10^{-11}$) ➡ **Sensitive** to **new physics**

Small theoretical uncertainties (2%)

**Signal**

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

**nothing** : @ other detectors



# CsI Calorimeter

- **CsI Crystals**

  **undoped CsI** (50cm)

  # of crystals = 2716

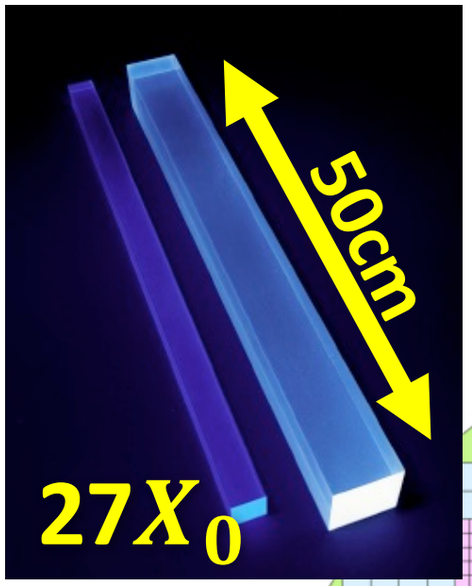
  2240 small ($25 \times 25 mm^2$) inner

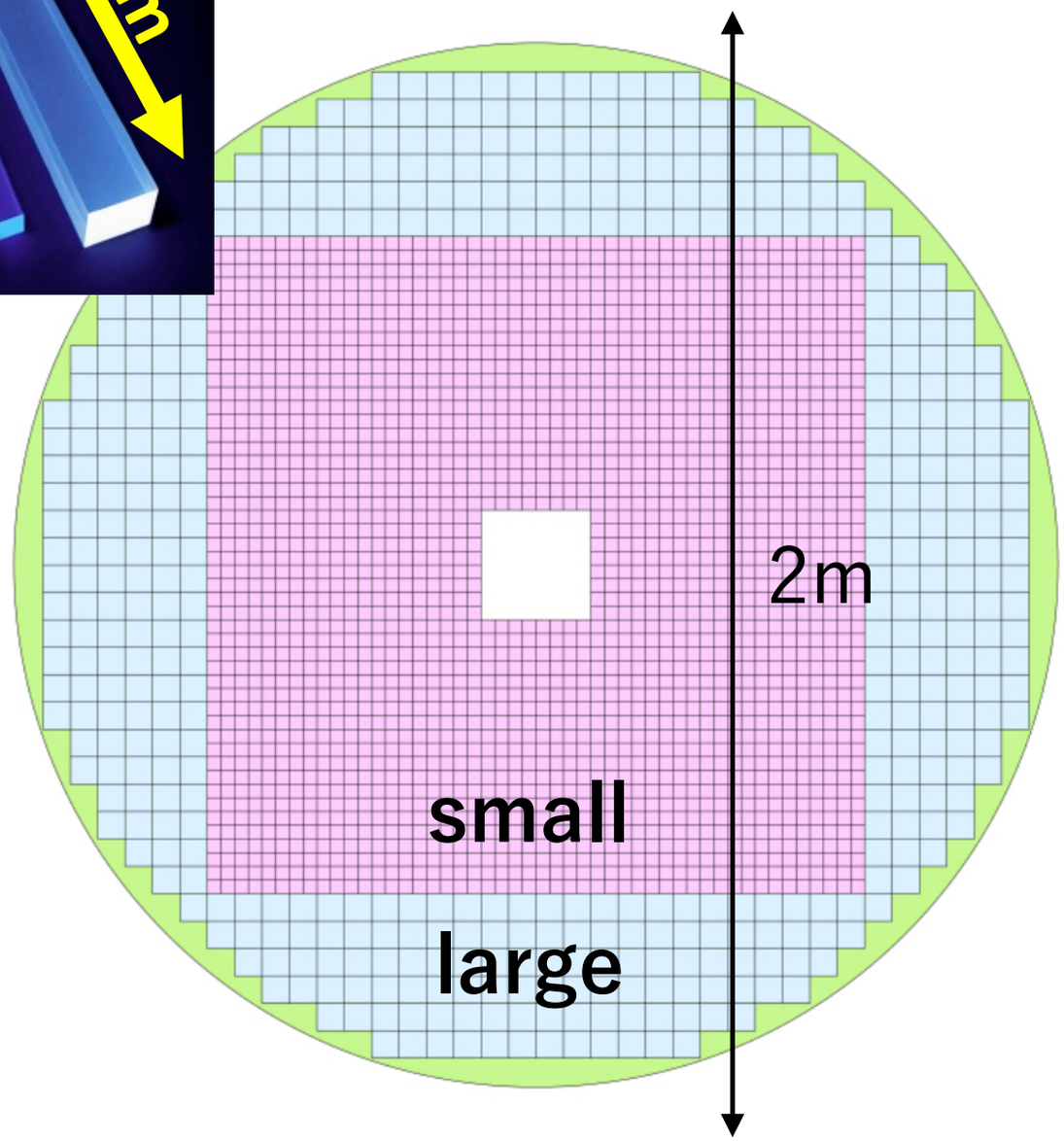
  476 large ($50 \times 50 mm^2$) outer

- **Excellent energy resolution**

  $$\sigma_E/E = 0.99\% + 1.74\,\%/\sqrt{E[\mathrm{GeV}]}$$

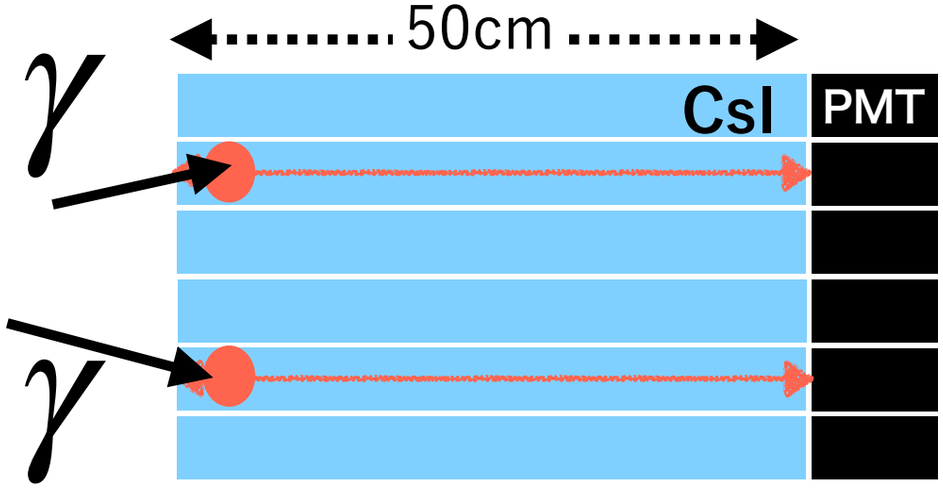
- **Readout with a PMT** (rear side)



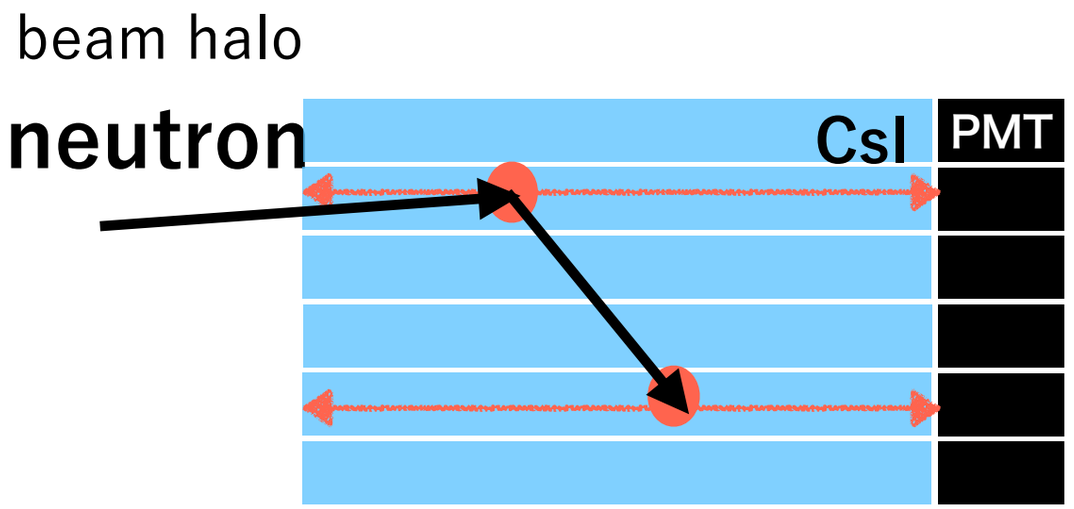
# Hadron-cluster Background

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




radiation length ~ 2cm

## Hadron-cluster Background




interaction length ~ 40cm

| | Single event sensitivity | # of Hadron-cluster BG |
|---|---|---|
| 2015 run | $1.3 \times 10^{-9}$ | 0.24 |
| 2016~2018 run | $6.9 \times 10^{-10}$ | 0.02 |
| SM sensitivity | $3 \times 10^{-11}$ | 0.5 |

improving the existing cut

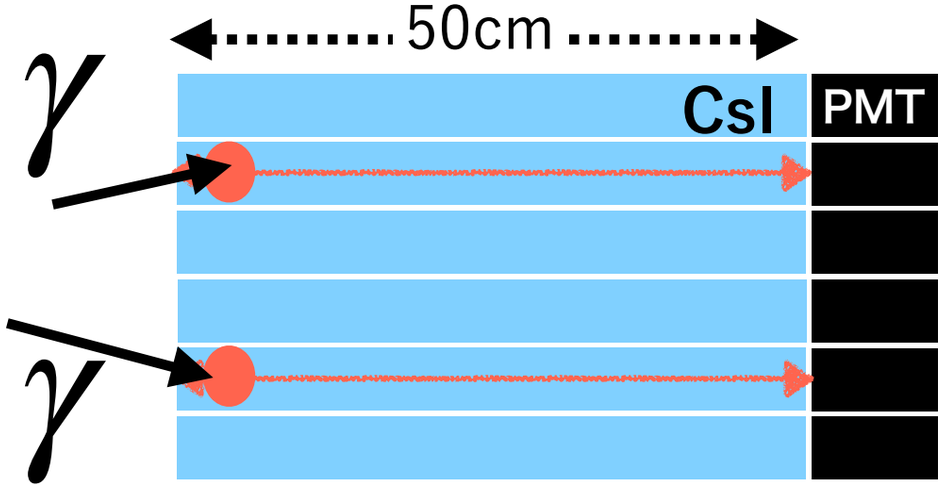
To reach the **SM** sensitivity,

we would suppress the background events further by **a factor of 10**

by the CsI calorimeter upgrade

# Hadron-cluster Background

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

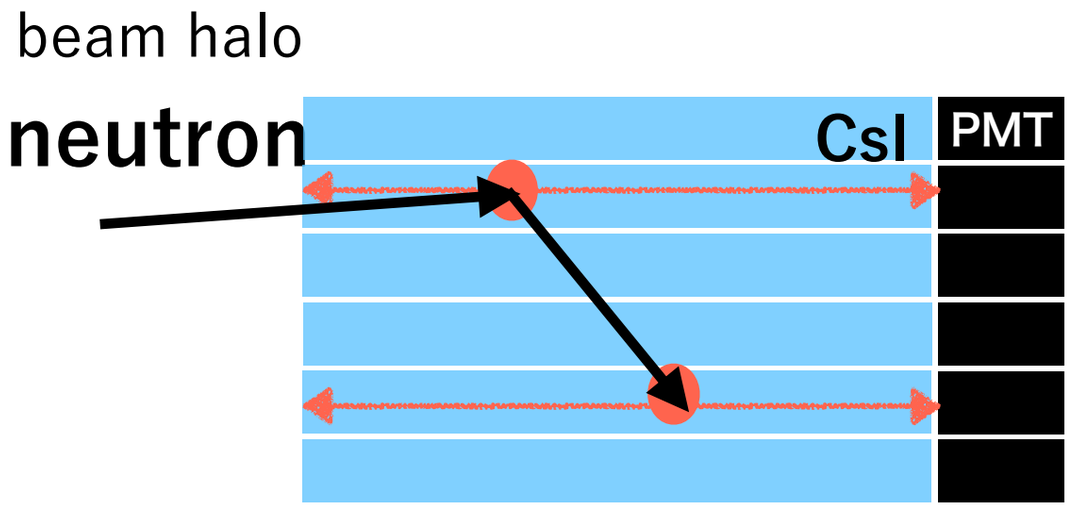



radiation length ~ 2cm

**Upstream**

**shallow** distribution

## Hadron-cluster Background




interaction length ~ 40cm

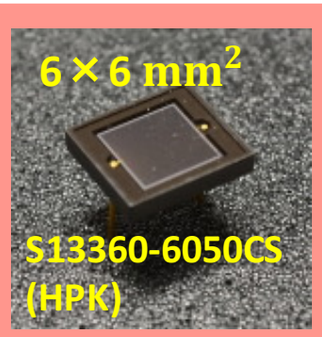
**Downstream**

**wide** distribution

Distinguishable

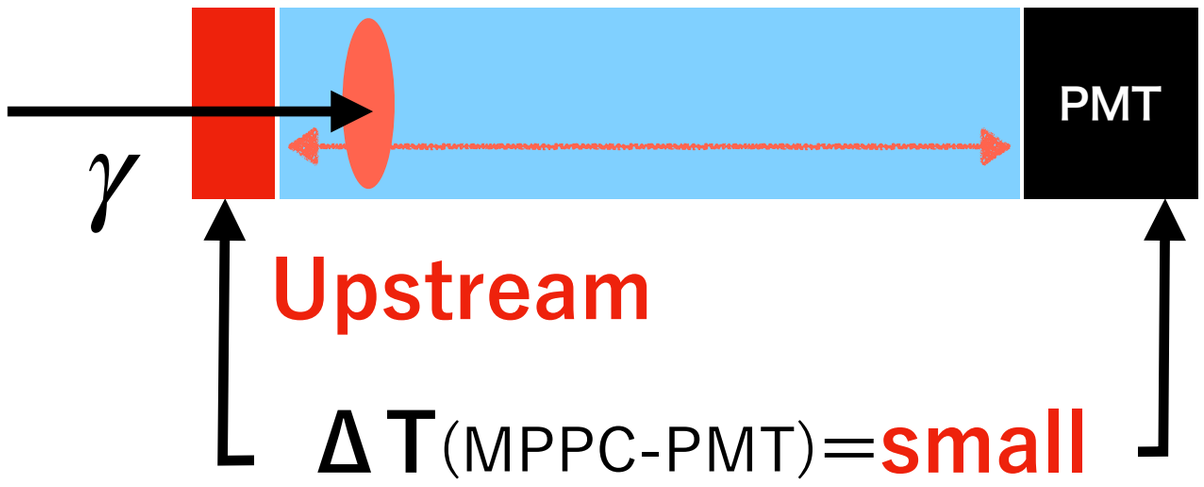
using the **depth** of the interaction

# Both-end Readout



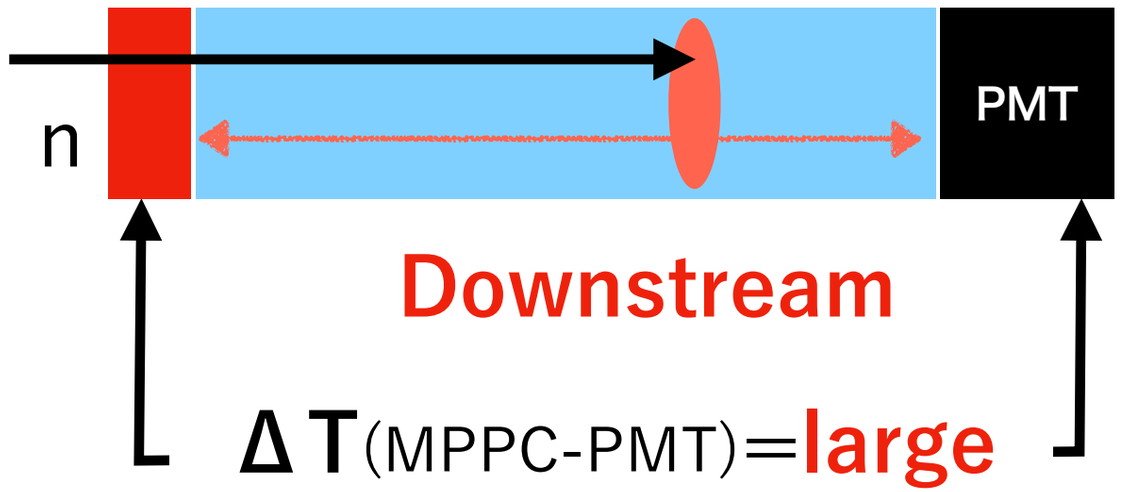

$$K_L \to \pi^0 \nu \bar{\nu}$$

MPPC




## Hadron-cluster Background

MPPC

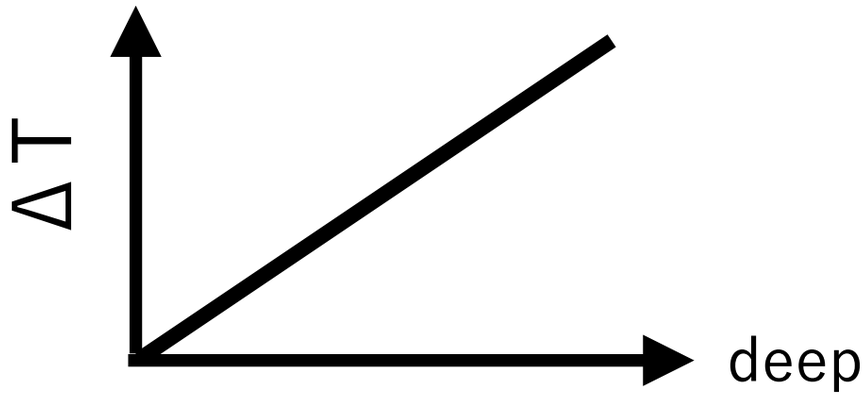



- **ΔT → reflect the depth of the interaction**
- Obtain **four-dimensional** information

  x, y → hit position on the CsI calorimeter

  z → ΔT(MPPC-PMT)

  time → timing of the PMT



# Both-end Readout Upgrade

# Readout

- Attached 4080 MPPCs
- To reduce # of the readout channels

4080

↓

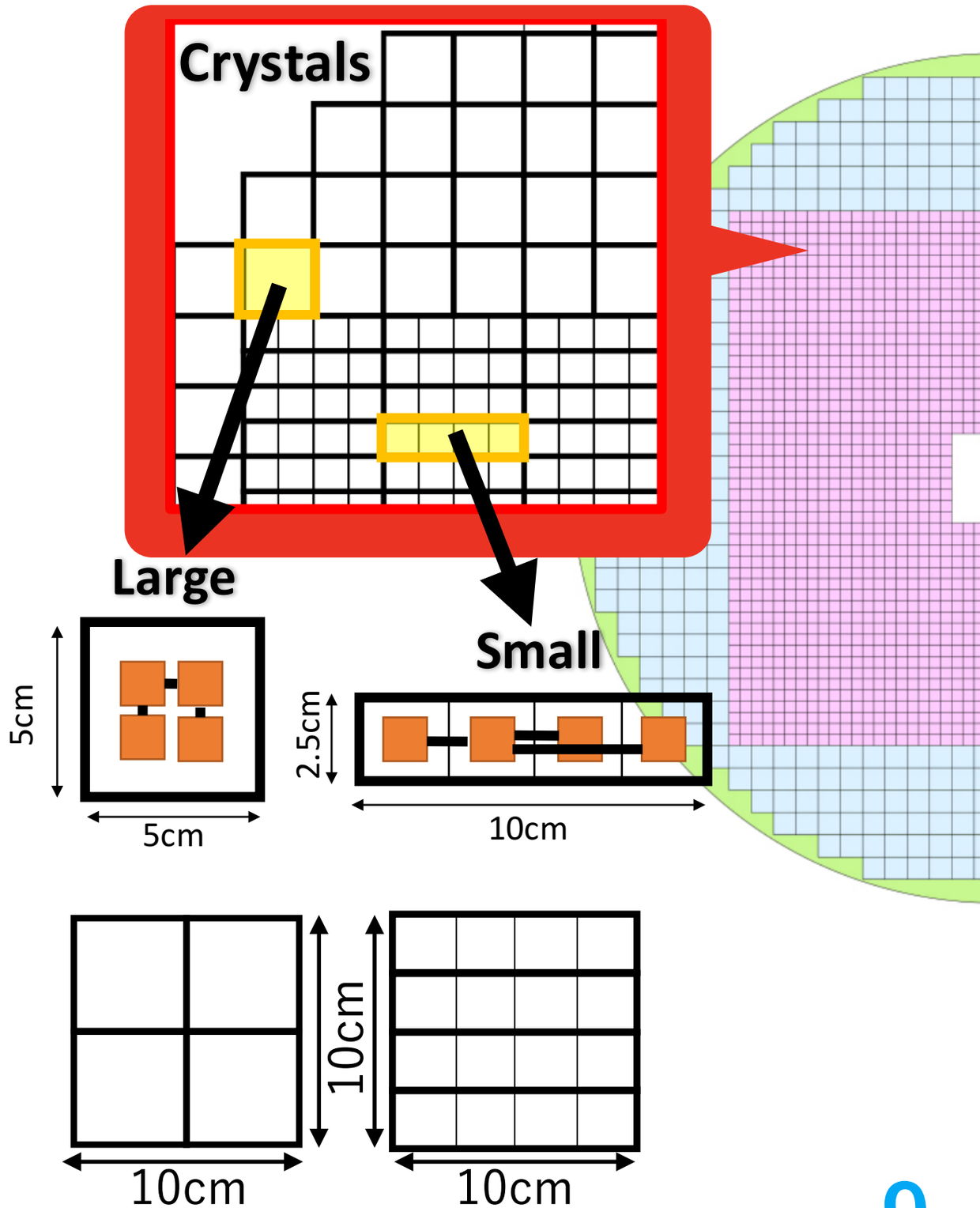
4 MPPCs are connected (1020)

↓

4 readout are summed (256ch)

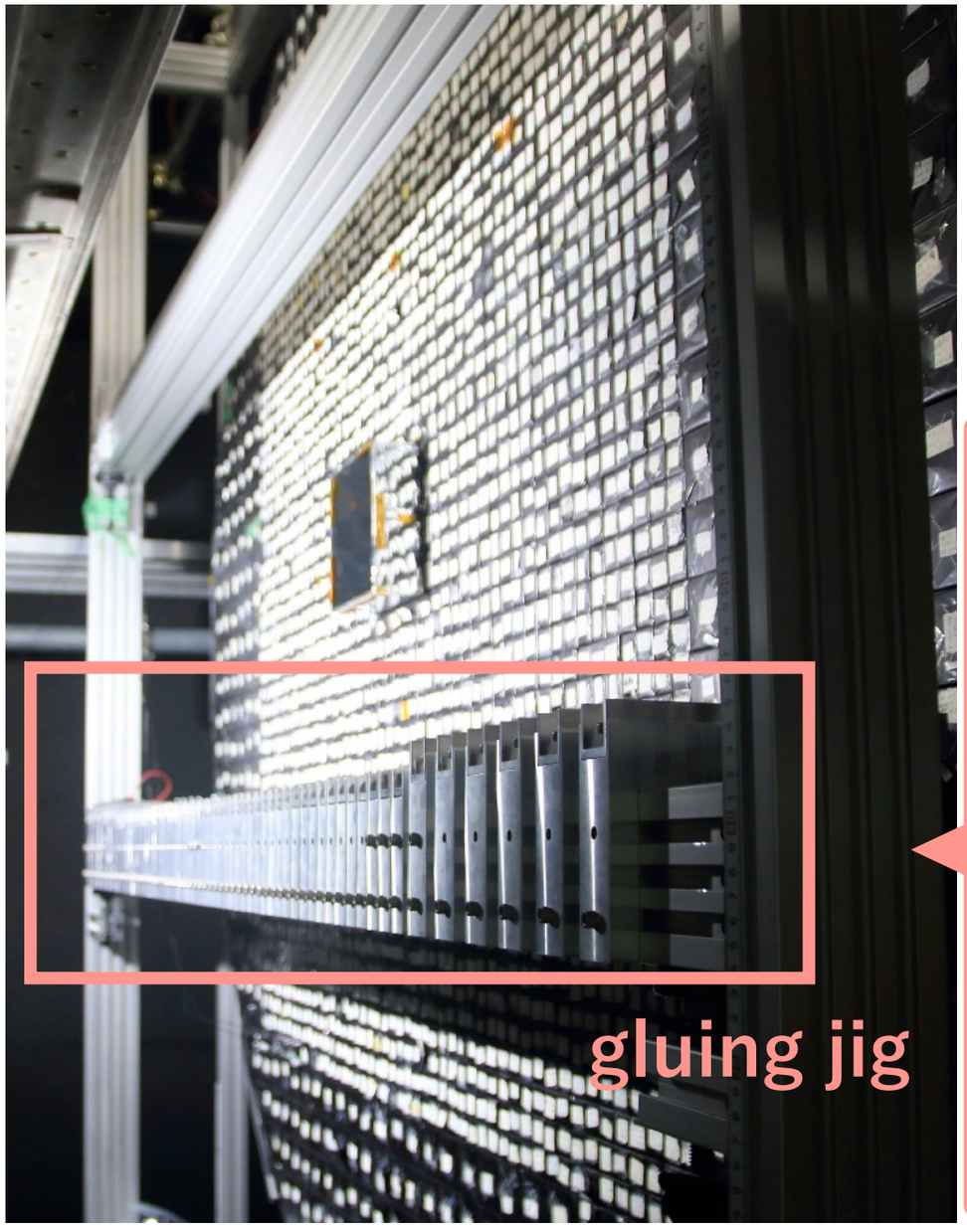
(10cm × 10cm region

~ EM shower size)



# MPPC Installation

CsI from upstream

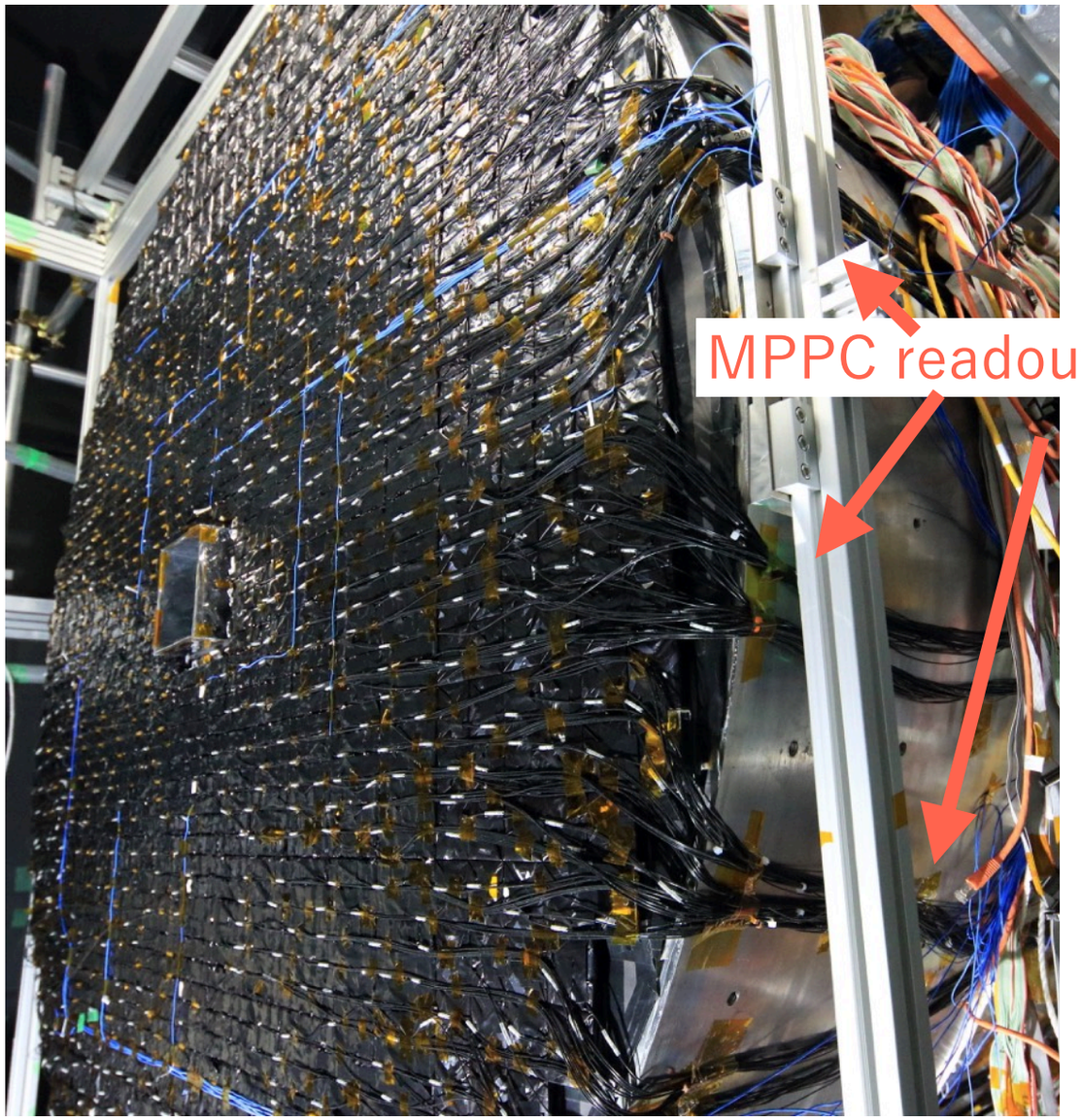



- **Glued MPPCs on two rows in a day.**
  (1 row : 12 ~ 60 crystals)
- **Finished installation as scheduled.**
  (2018 Oct. 1st ~ Nov. 15th)

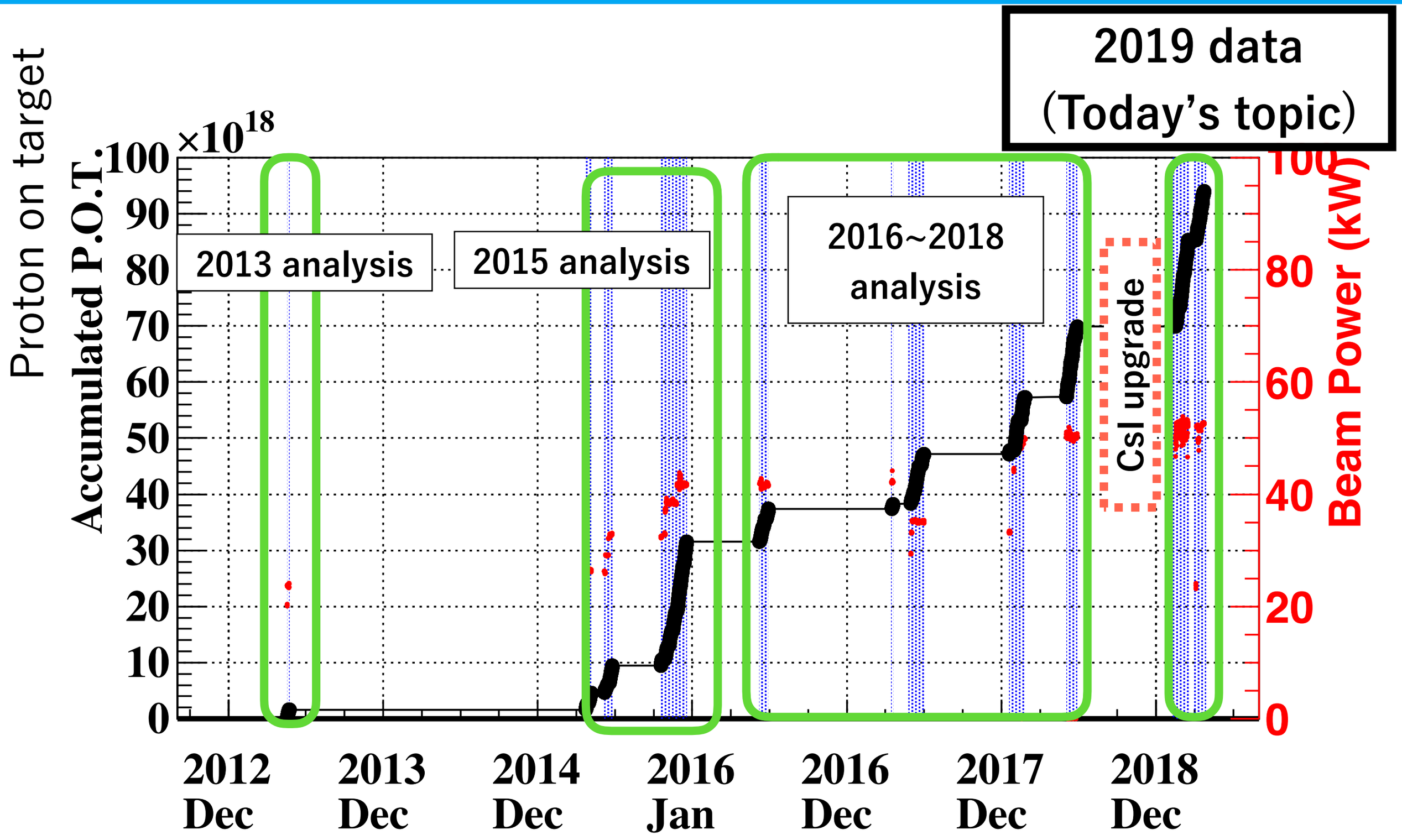
# MPPC Installation

## ~2018

## 2019~



# Data Taking

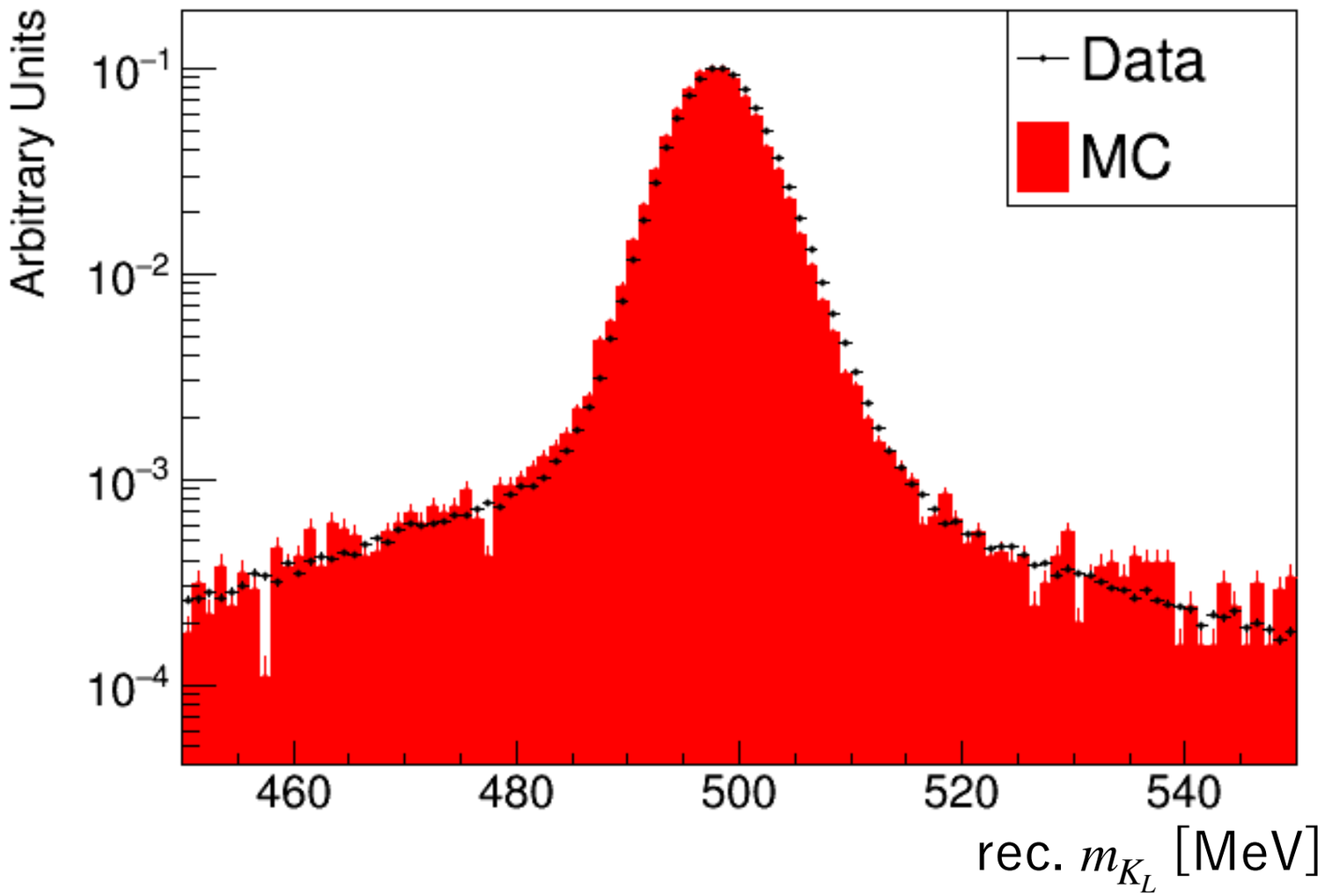

2019 data
(Today's topic)
2013 analysis
2015 analysis
2016~2018
analysis
CsI upgrade
Proton on target
Accumulated P.O.T.
×10^18
100
90
80
70
60
50
40
30
20
10
0
Beam Power (kW)
100
80
60
40
20
0
2012
Dec
2013
Dec
2014
Dec
2016
Jan
2016
Dec
2017
Dec
2018
Dec

# Analysis

# Gamma Sample

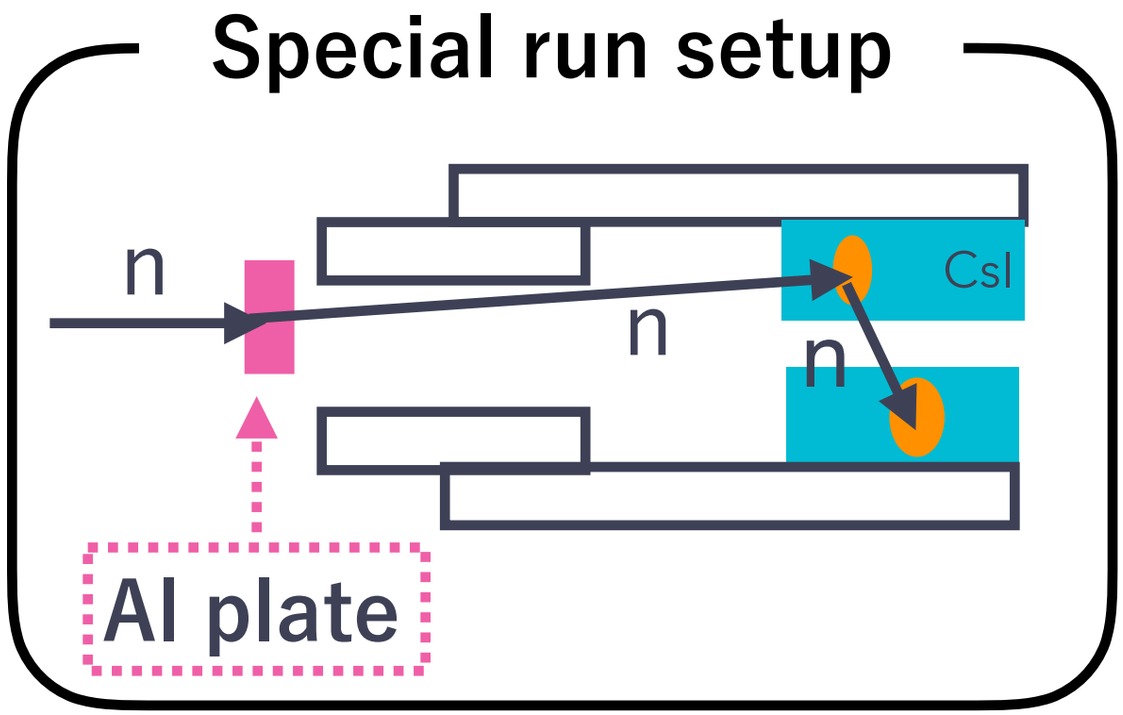
- $K_L \to 3\pi^0$ decay
- A pair of gammas from a $\pi^0$ is used for the control sample

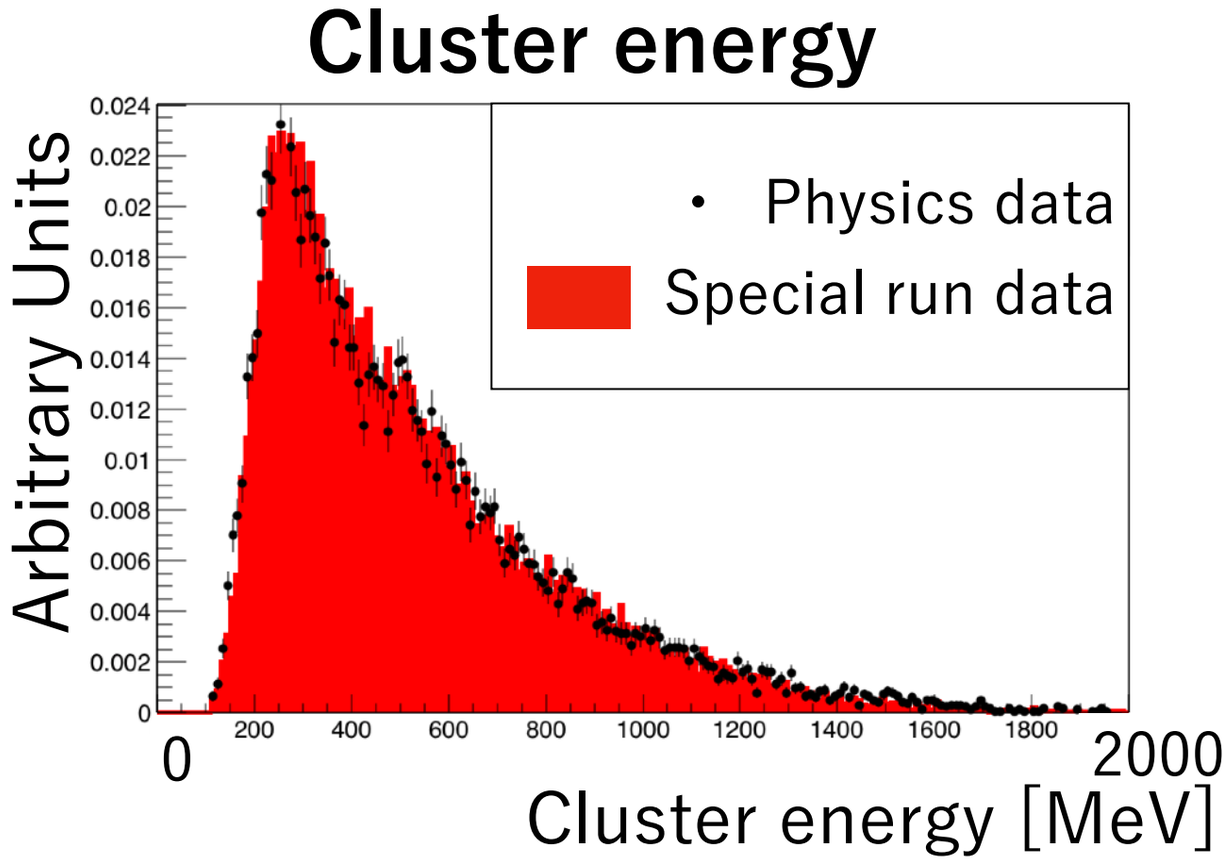
reconstructed $m_{K_L}$ distribution



# Hadron-cluster Control Sample

- Used special run data as a neutron samples
  → **Enhance the scattered neutron events by placing Al plate**

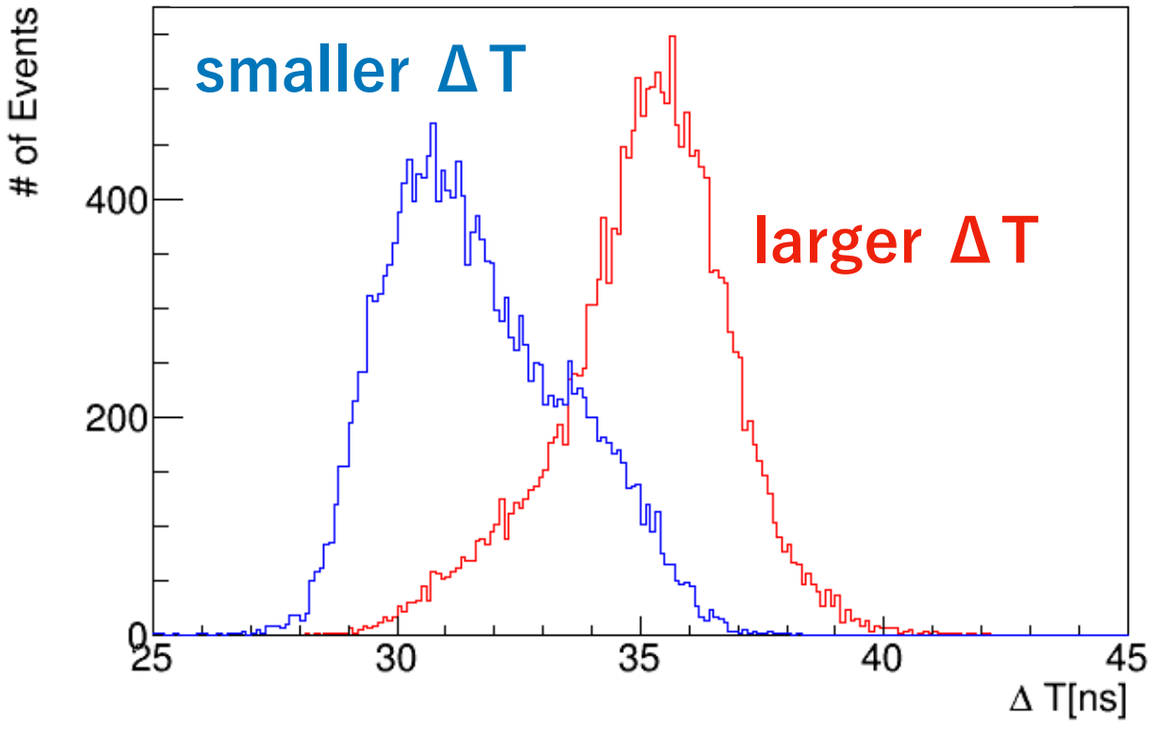


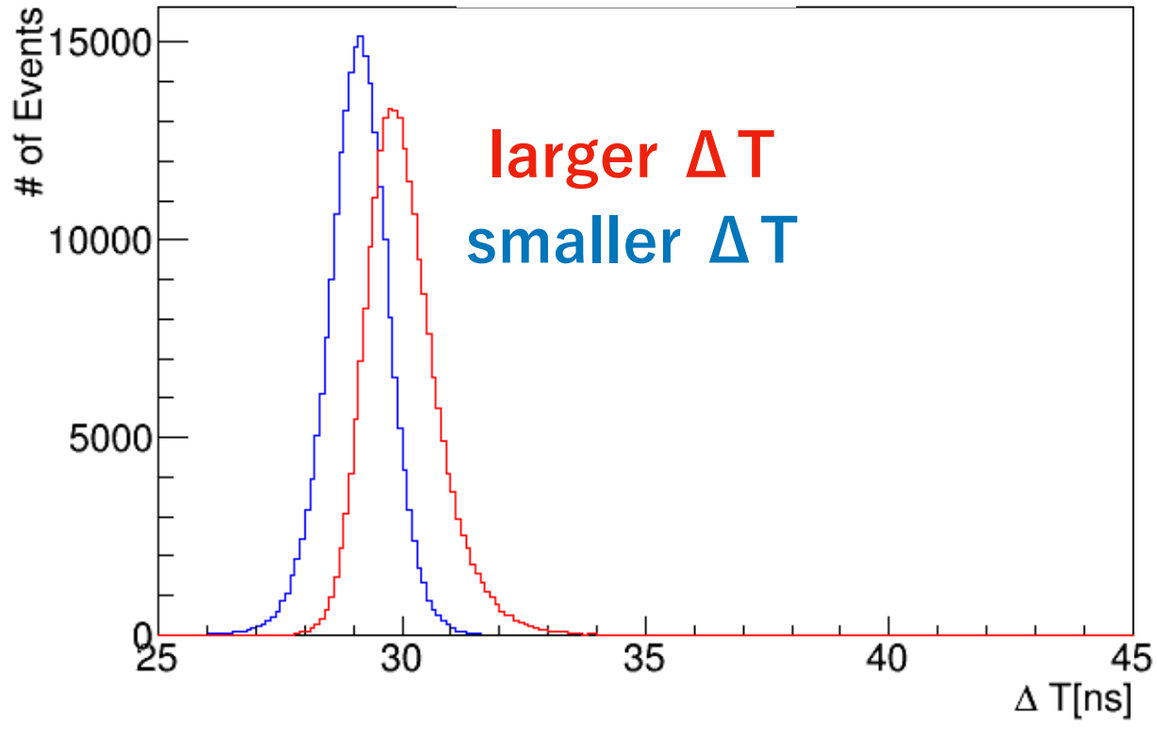
# ΔT Distribution

## ΔT distribution of two clusters

Hadron-cluster control sample



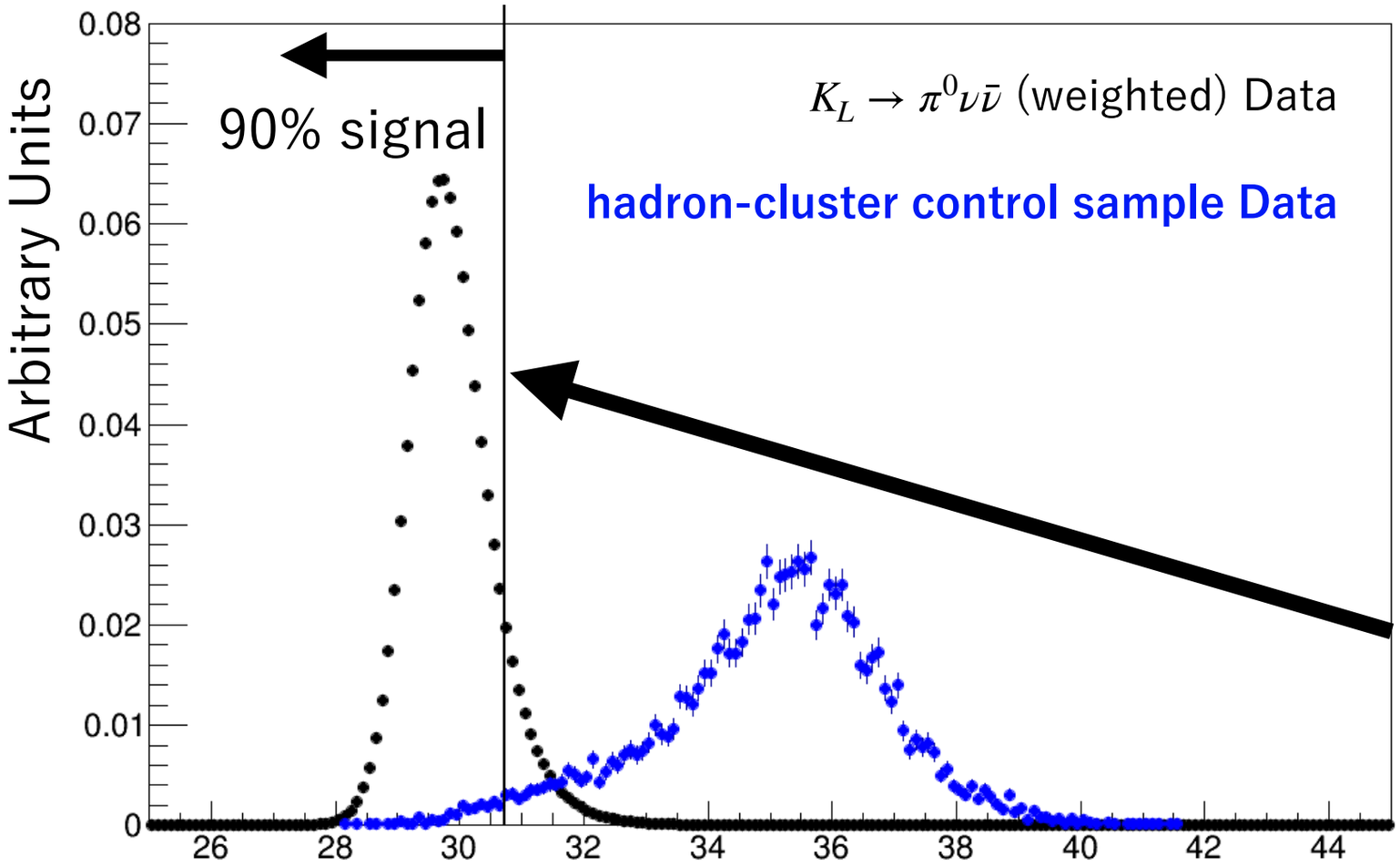

$K_L \to 3\pi^0$



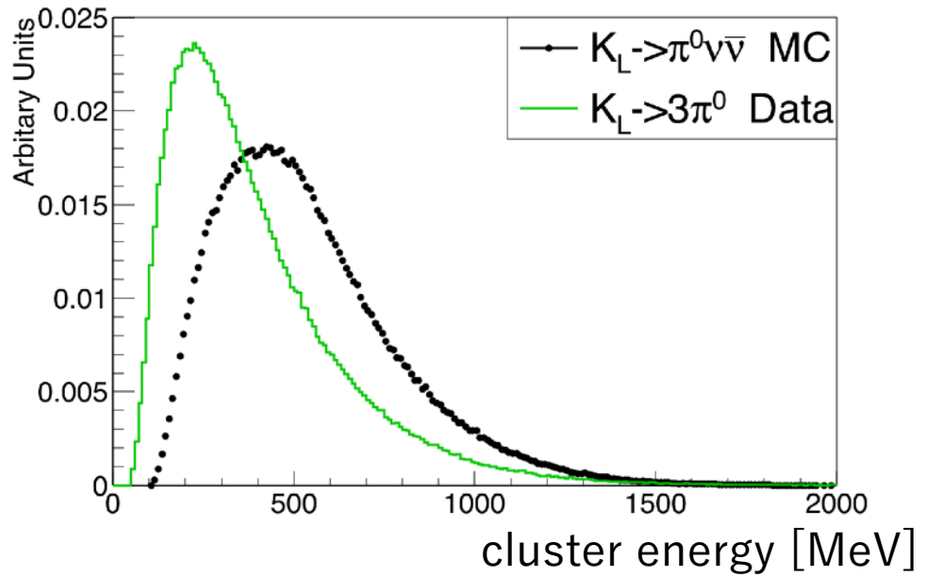

- For the $K_L \to 3\pi^0$ decay, a pair of gammas from a $\pi^0$ is filled.
- Both gammas interact at upstream
  The secondary neutron tends to interact at downstream
- Use the **<u>larger ΔT value</u>** out of two clusters to suppress the hadron-cluster background.

# ΔT Distribution

Larger ΔT distribution out of two clusters




cluster energy distribution




The ΔT distribution of the $K_L \to \pi^0\nu\bar{\nu}$

→ weighed the ΔT distribution of $K_L \to 3\pi^0$

according to the cluster energy

The hadron cluster background is suppressed to **1/45** with 90% signal efficiency

# Summary

- We succeeded in the CsI calorimeter upgrade
- We evaluated the neutron rejection performance using the data taken in 2019
- **The hadron-cluster background is suppressed down to 1/45 with 90%  signal efficiency.**