CANDLES for the study for Double Beta Decay of ^{48}Ca

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CANDLES collaboration

Osaka University, University of Fukui, University of Tokushima,
Hiroshima University, Saga University,
Kyoto San-gyo University

^{48}Ca Enrichment

Tokyo Institute of Technology,
Sophia University

Outline

- Double beta decay of ^{48}Ca
- ELEGANT VI system (previous system)

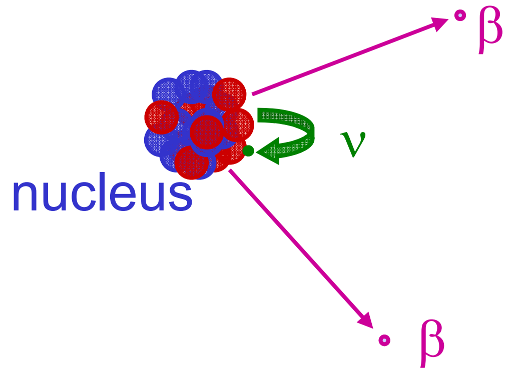
  = CaF_2(Eu) scintillators + CsI(Tl) scintillators system
- CANDLES System

  = CaF_2(pure) scintillators + Liquid scintillator system
  - CANDLES III system at Kamioka underground lab.
    - Pre-measurement for performance test
- R&D
- Summary

Double Beta Decay

- Double Beta Decay
  - Neutrino-less double beta decay
    - Very rare decay $T_{1/2} > (\sim 10^{25}$years)
    - If observed
      - Neutrino → Majorana particle
      - Lepton number violation
      - Decay rate $T_{1/2} \propto 1/m_\nu^2$
  - We have studied double beta decay of ^{48}Ca

Neutrino-less double beta decay



Double Beta Decay of ^{48}Ca

- Why ^{48}Ca?
  - Higher $Q_{\beta\beta}$-value(4.27MeV) . . .

    ^{76}Ge(2.0MeV), ^{100}Mo(3.0MeV), ^{130}Te(2.5MeV)

    →Low background

    because $Q_{\beta\beta}$-value is higher than BG

    E_{max}=2.6MeV(^{208}Tl, γ-ray)

    3.3MeV(^{214}Bi, β-ray)

We have developed the detector system for no background measurement

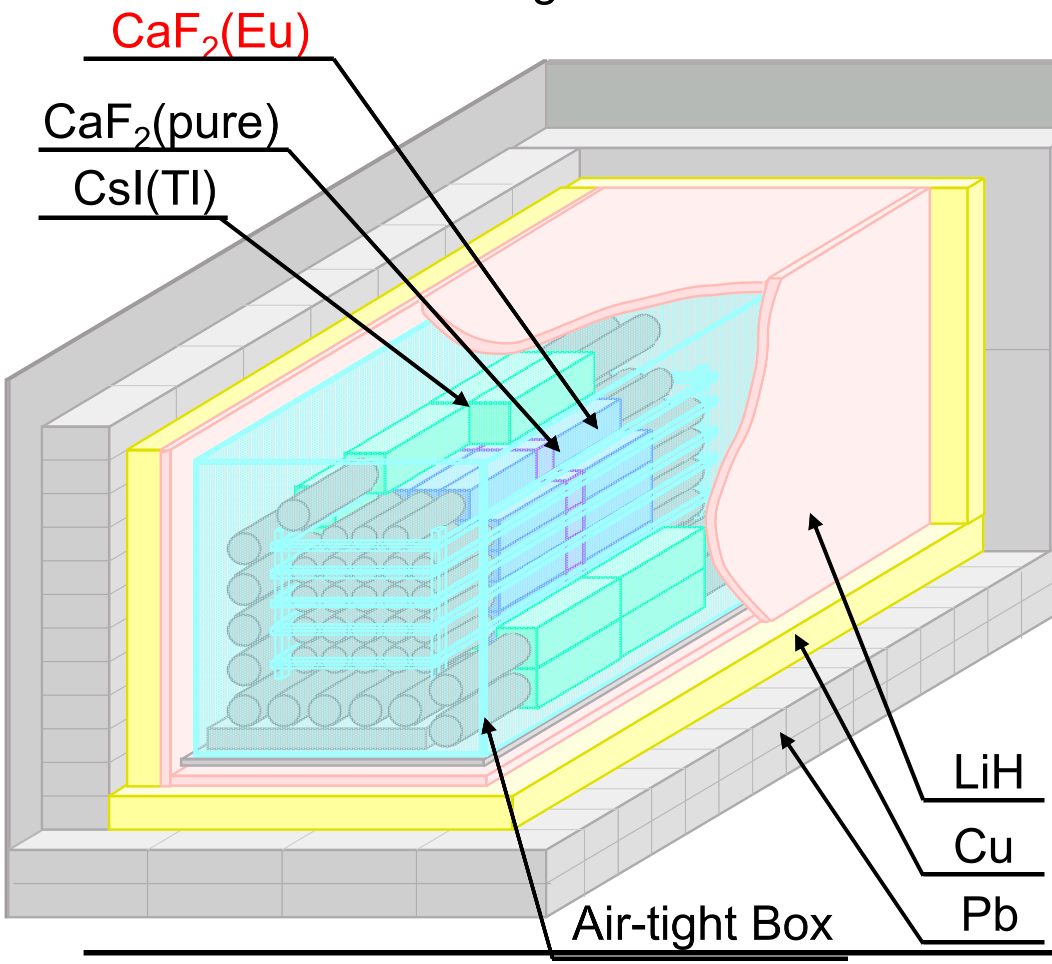
- Double beta decay of ^{48}Ca by CaF_2 scintillators
  - ELEGANT VI system

    Scale up
  - CANDLES series

ELEGANT VI

ELEGANT VI
ELEctron Gamma-ray Neutrino Telescope

- Schematic drawing of ELEGANT VI

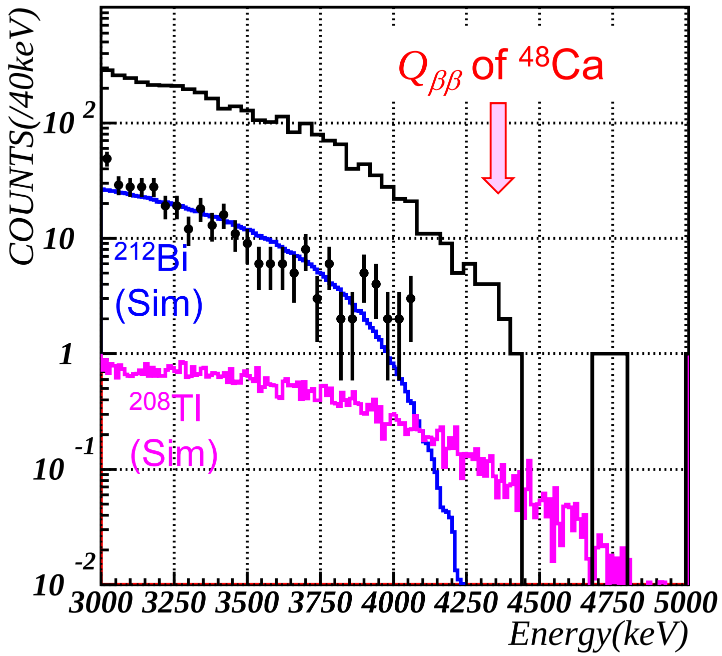


- CaF$_2$ Scintillator (CaF$_2$(Eu))
  - 23 Crystals(45×45×45cm^3:290g)
  - Source of ββ Decay : ^{48}Ca
    ($Q_{\beta\beta}$=4.27MeV)
- veto counters
  - 46 CaF$_2$(pure)
  - 38 CsI(Tl)
  - → 4π Active Shield
- Passive shields
  - for γ-ray
    - Cu : 5cm,Pb : 10cm
  - for Neutron
    - LiH+Paraffin :15mm
    - Cd sheet : 0.6mm
    - H_3BO_3 loaded water

Result of ELEGANT VI

Obtained Result

Energy Spectra(Jan2003-)



Run summary (Measurement for 4 years)

Date	Number of Event	Expected BG (^{212}Bi, ^{214}Bi, ^{208}Tl)	Live Time kg・day
Jun1998-	0	1.30	1553
Jan2003-	0	0.27	3394

No events in 0νββ Energy Window

0νββ Half-Life of ^{48}Ca : > 5.8×10^{22} year (90% C.L.)

$\langle m_\nu \rangle$ < (3.5-22) eV

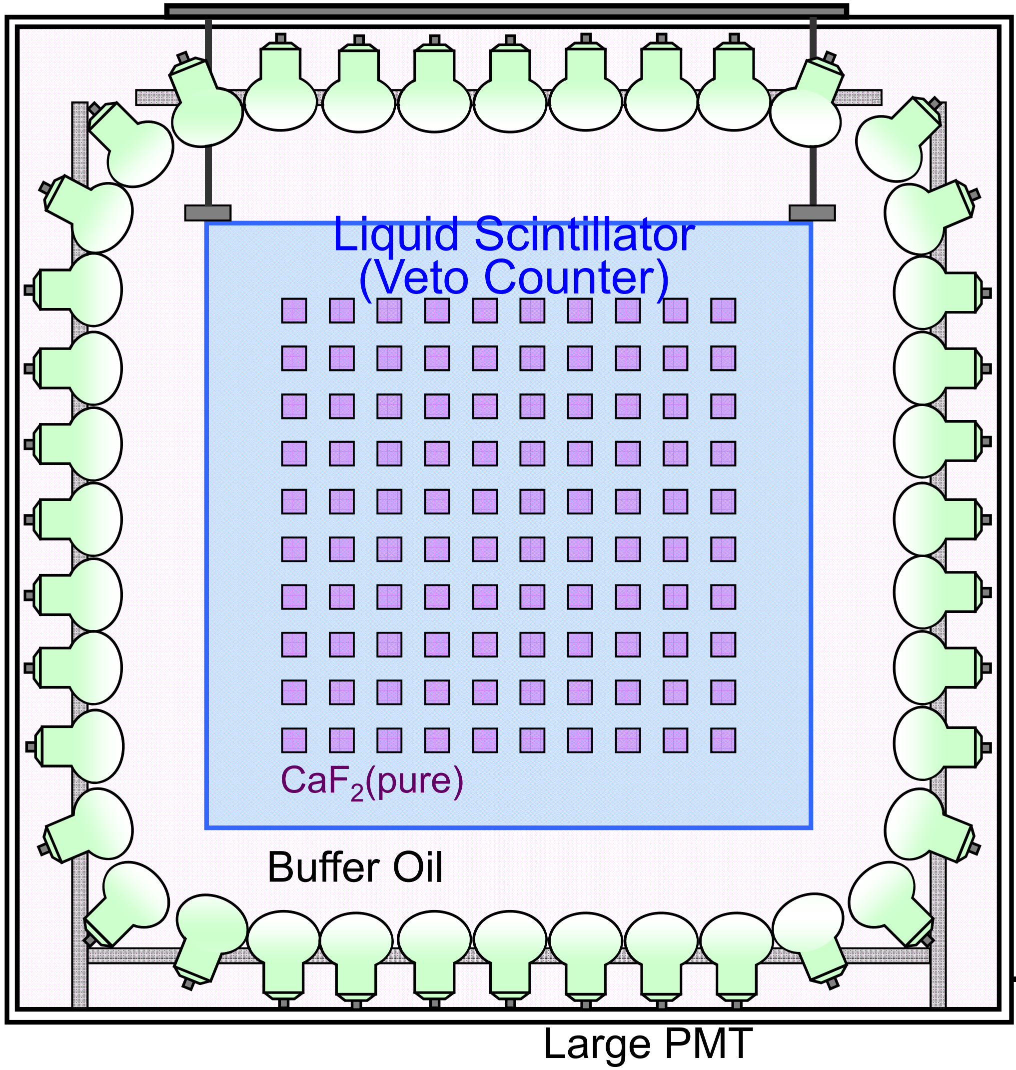
- 4π active shield is effective for background free measurement.
- Expected backgrounds are ^{212}Bi and ^{208}Tl

For higher sensitivity, we need a large amount of ^{48}Ca.

Design Concepts of CANDLES

CANDLES

CAlcium fluoride for studies of Neutrino and Dark matrters
by Low Energy Spectrometer



- CaF_2(pure) scintillator
  - Long attenuation length (>10m@350nm)
  - Double beta decay source
  - ^{48}Ca (Q_{bb}=4.27MeV)
- Liquid scintillator
  - 4 π Active Shield
- Large photomultiplier tube
  - Signals from both scintillators are detected simultaneously

⇩

- **Active Shielding Technique**

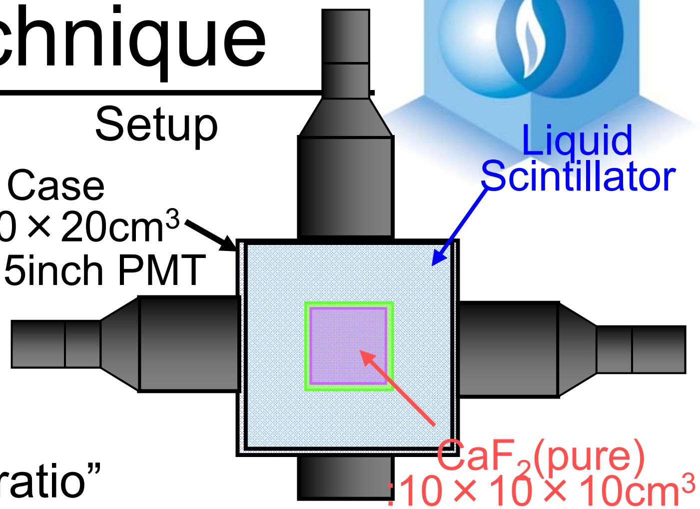
Different time constants

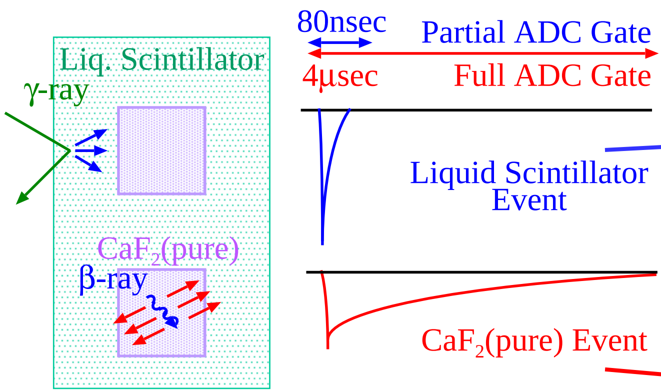
CaF_2(pure)	: ～1μsec
Liquid scintillator	: a few 10 nsec

Active Shielding Technique

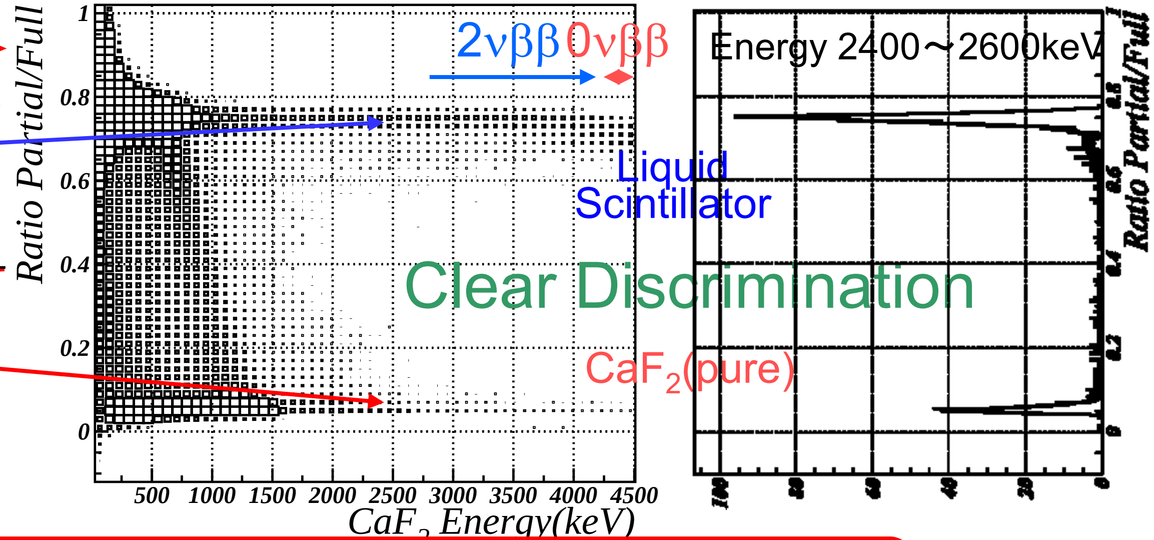
Concept of 4π Active Shield and Performance Test

- PSD between CaF_2 and Liquid Scintillators





Distribution of "charge ratio"



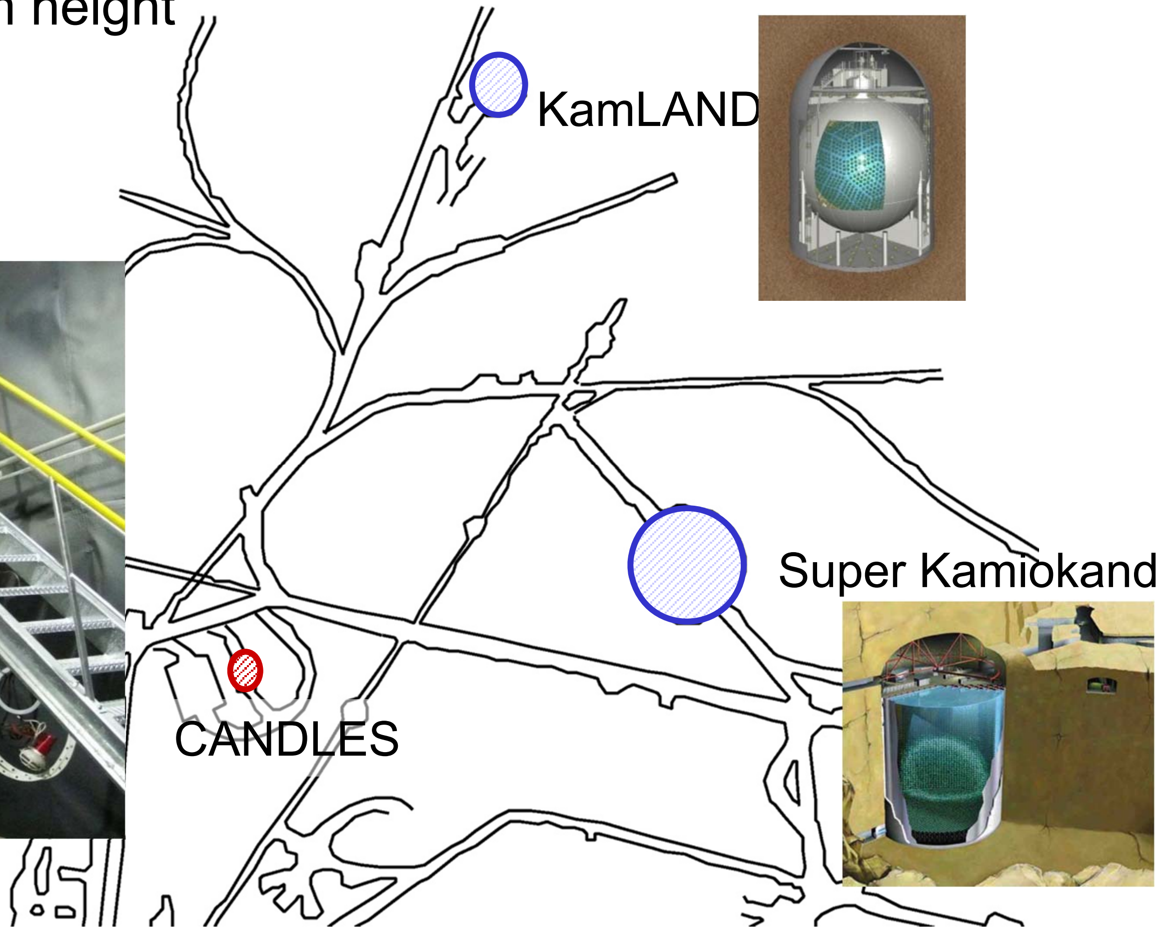
Clear Discrimination between CaF_2 and Liquid Scintillators
. . .Well Act as Veto Counter

CANDLES III at Kamioka Lab.

- CANDLES at Kamioka underground Lab.
  - CANDLES III
    - 3m diameter × 4m height (water tank)

CANDLES III

Kamioka Lab. Map



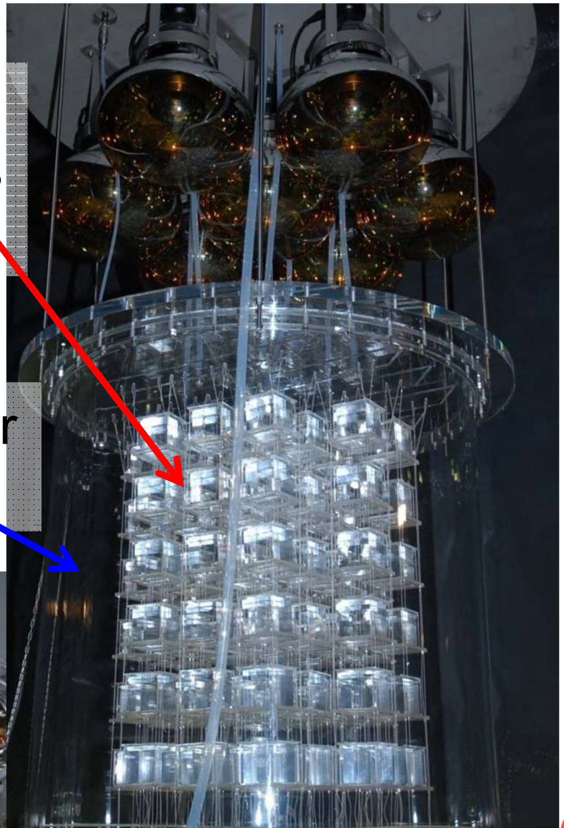
CANDLES III

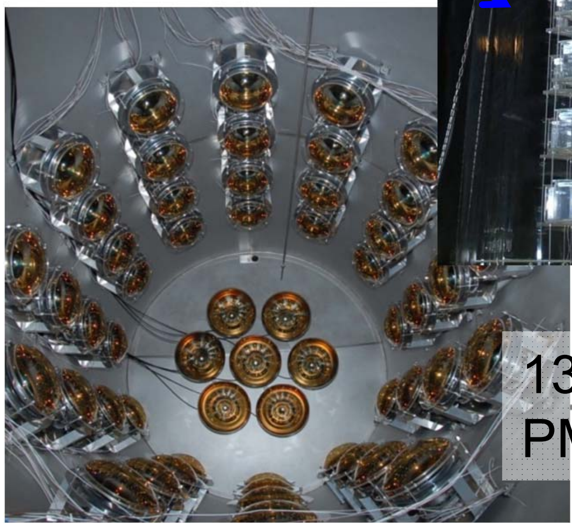
CANDLES at Kamioka underground laboratory

CANDLES III

Main detector
CaF_2 Scintillators
(305kg)

Liquid Scintillator
Tank(2m^3)





13inch and 20inch
PMTs

- CaF$_2$ scintillator (CaF$_2$(pure))
  305 kg (96 modules × 3.2kg)
  τ ~ 1μsec

- Liquid scintillator (LS)
  4 π Active Shield
  Volume:2m^3
  τ ~ a few ten nsec

- Large photomultiplier tube
  13inch PMT × 48
  20inch PMT × 14

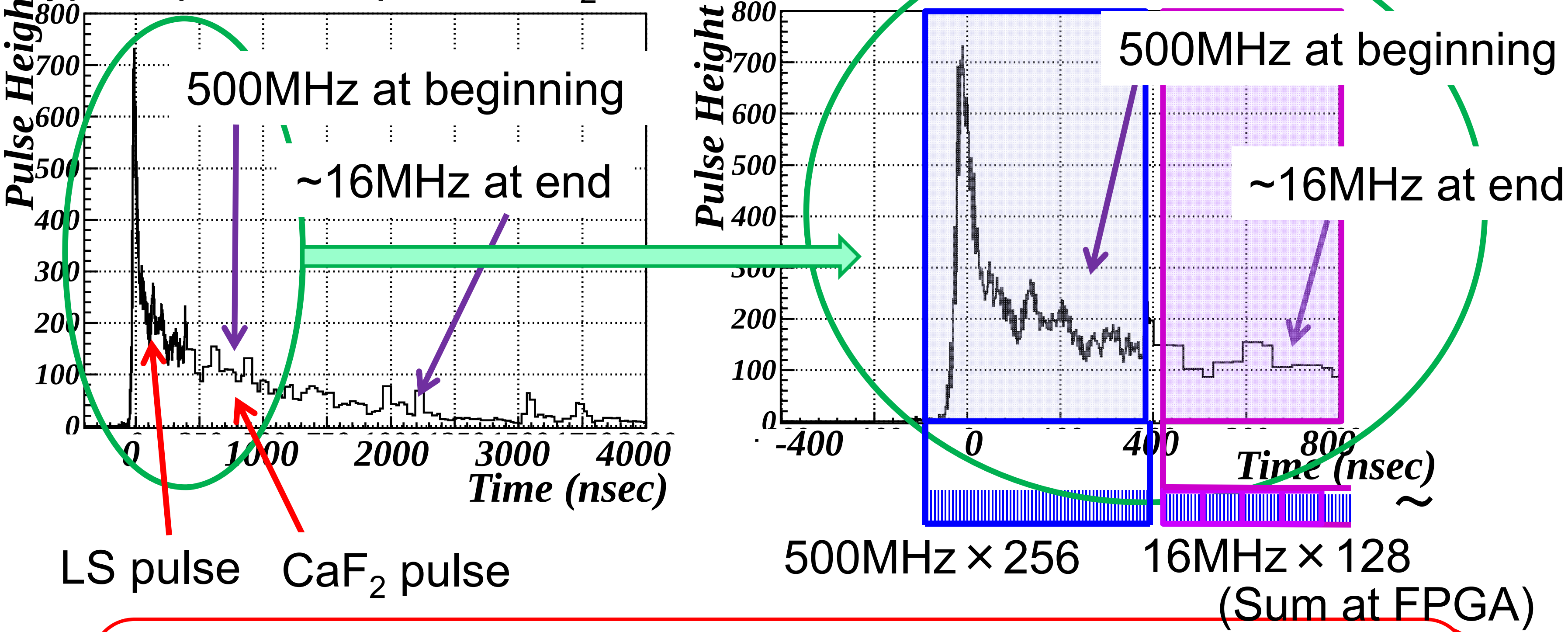
for CANDLES III system

- Characteristic FADC
  for CaF$_2$ (long)
  and LS(short) signals
- Selective trigger for CaF$_2$

FADC for CANDLES

- For CaF_2 and LS signals . . . And data suppression
  - High sampling rate at the beginning, Low sampling at the ending

Typical pulse shape of CaF_2+LS



Clear Discrimination between CaF_2 and Liquid scintillators

・Details of PSD will be presented in a poster session by G. Ito

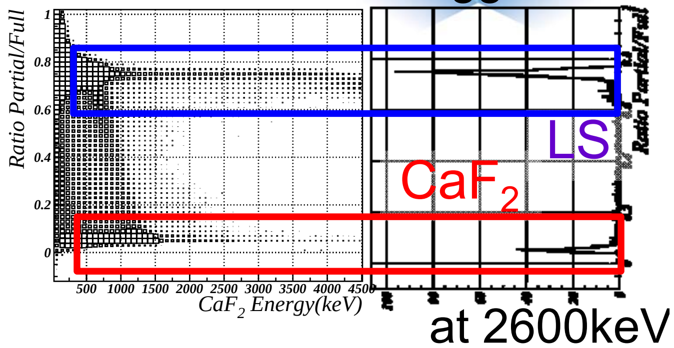
Data size is small.

・500MHz×2048data → 500MHz×256data + 16MHz×128data

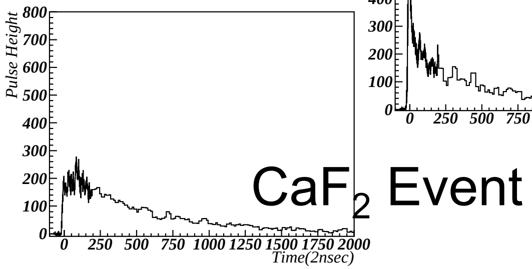
Selective Trigger

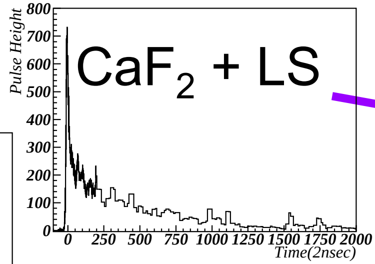
- Selective trigger for CaF_2
  - by using “threshold for integrated signal”
    in poster session by M. Saka

with normal trigger

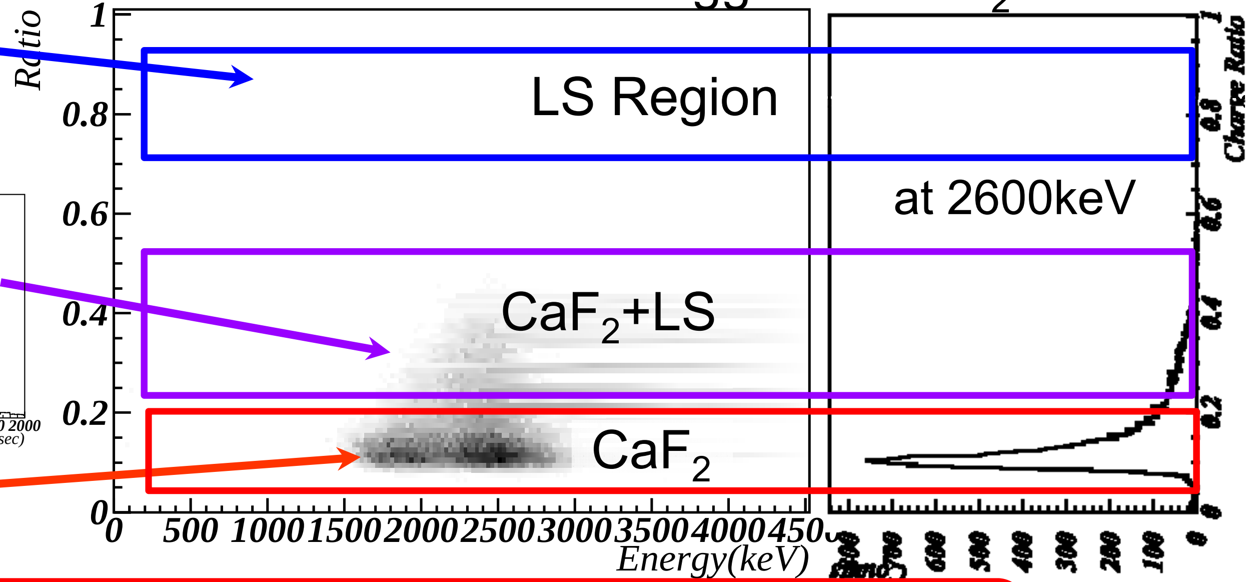


No LS Events
Threshold
for integrated signal
well works.





Event Distribution with Trigger for CaF_2

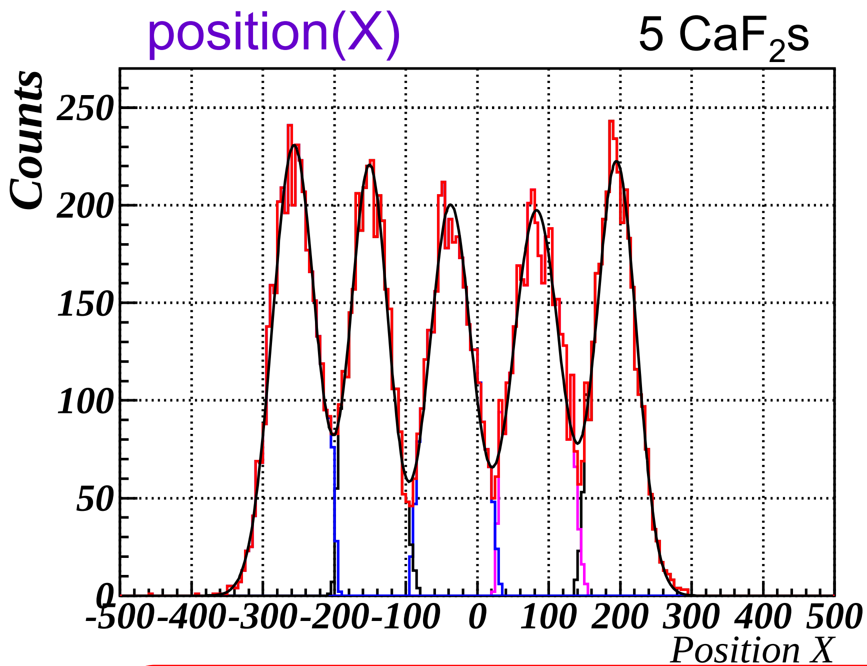


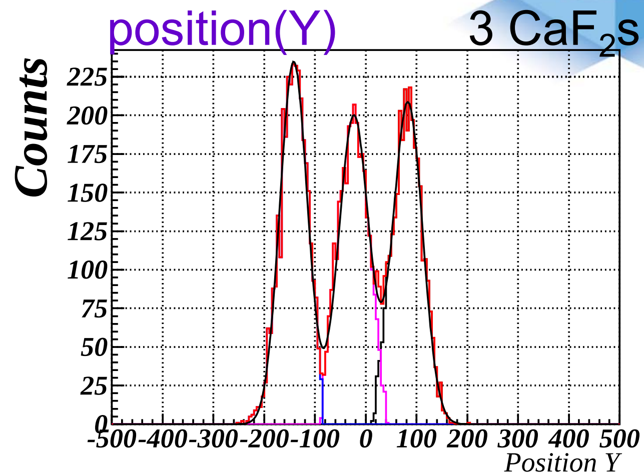
We obtained . . .
- High efficiency for CaF_2 Scintillator, Low efficiency for LS

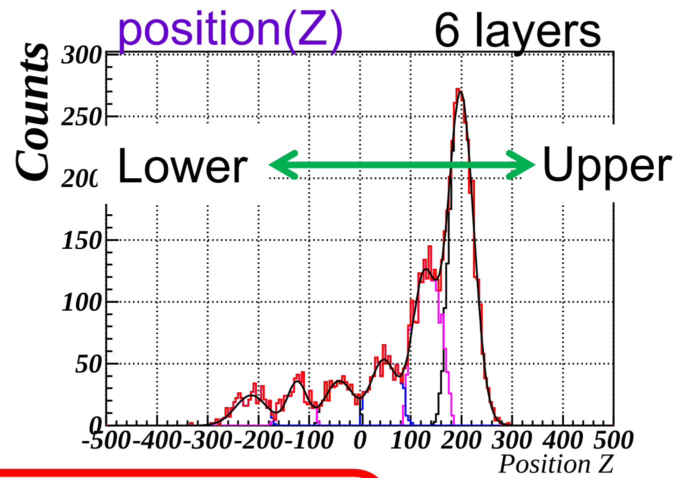
Position Reconstruction

Position Reconstruction

- for events with CaF_2 pulse shapes
- for identification of CaF_2 position







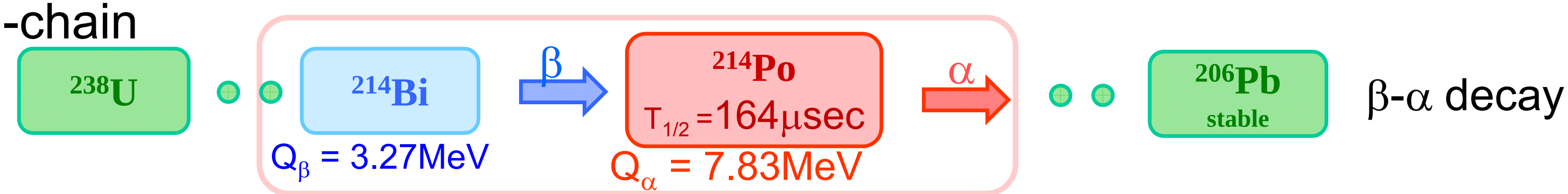
We can identify each CaF_2 position.

in a poster session by K. Yasuda

Pre-measurement

- For performance test
  - by standard γ source
    in a poster presentation by H. Kakubata
  - by radioactive contaminations within a reference CaF_2
    - Delayed α analyses
      - $^{214}Bi \rightarrow ^{214}Po$ (U-chain)
      - $^{219}Rn \rightarrow ^{215}Po$ (Ac-chain)
      - $^{220}Rn \rightarrow ^{216}Po$ (Th-chain)

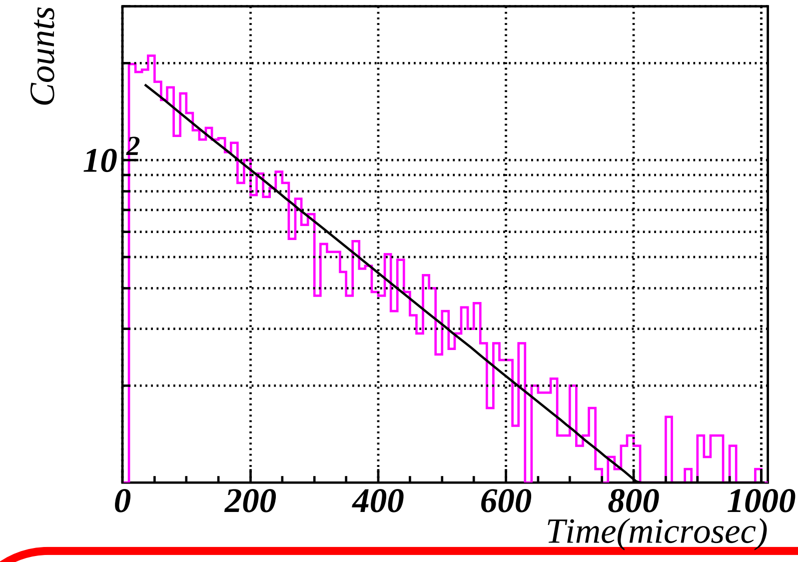
U-chain



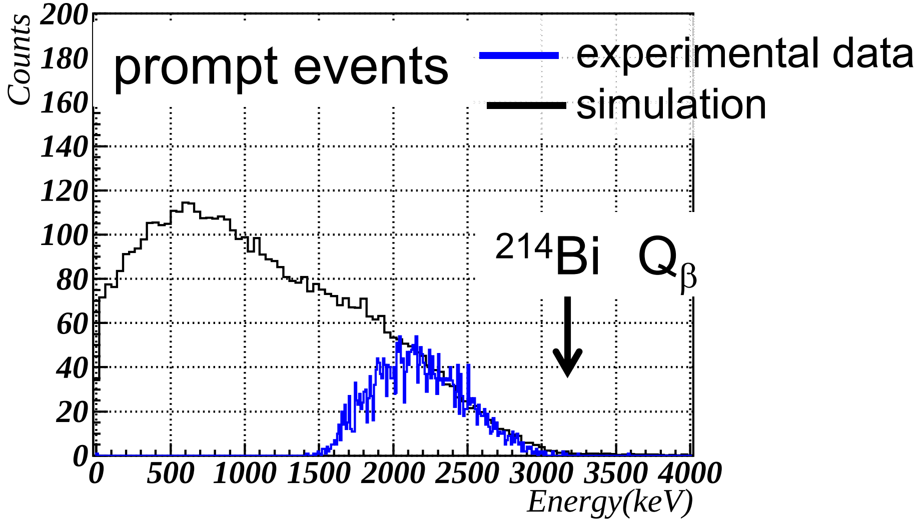
Delayed α analysis

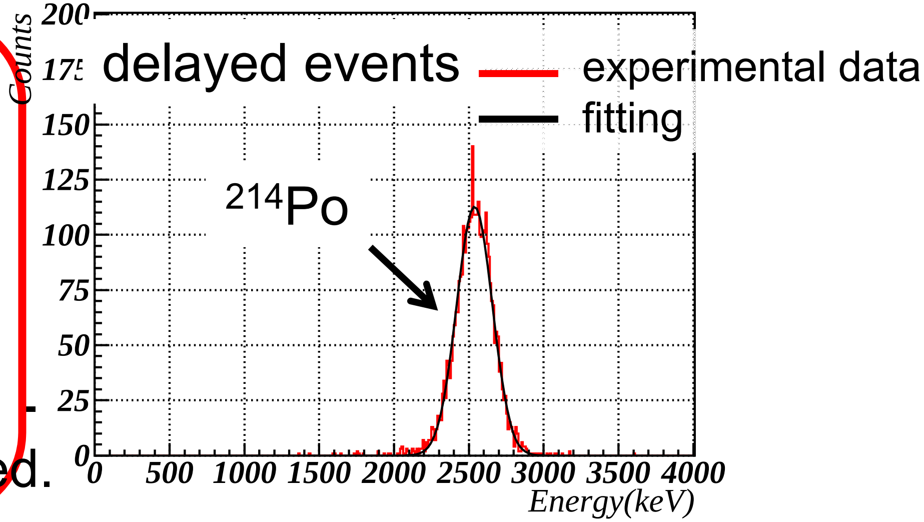
$^{214}Bi \rightarrow {}^{214}Po \rightarrow {}^{210}Pb$ decay ($\beta \rightarrow \alpha$ decay in U-chain)

Δt distribution



Energy Spectra(Δt <300μsec)





Half-life: 175±10μsec (164μsec)

energy resolution : σ=4.3%

radioactivity: 61±9(syst.)mBq/kg

(previous measurement:65mBq/kg)

Expected performances
with current CANDLES III were obtained.

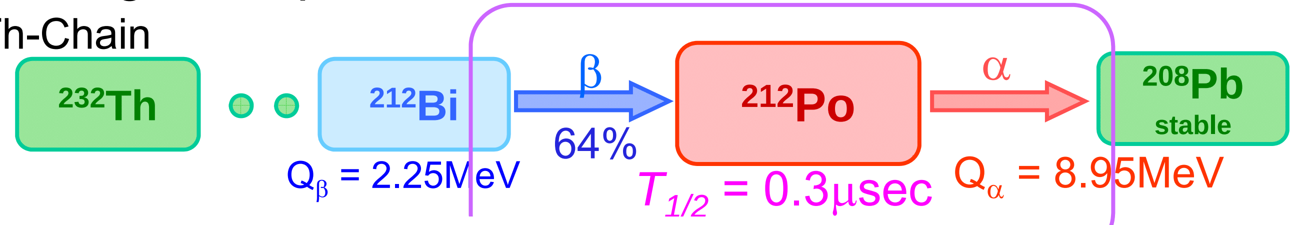
Expected Background

Background Event in CANDLES System

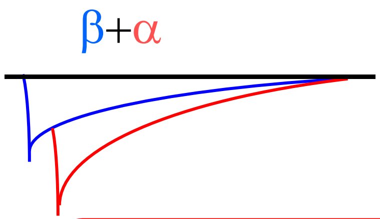
Radioactive Contamination within CaF_2(pure)

Background process

Th-Chain



Pile-up event
(Sequential event)



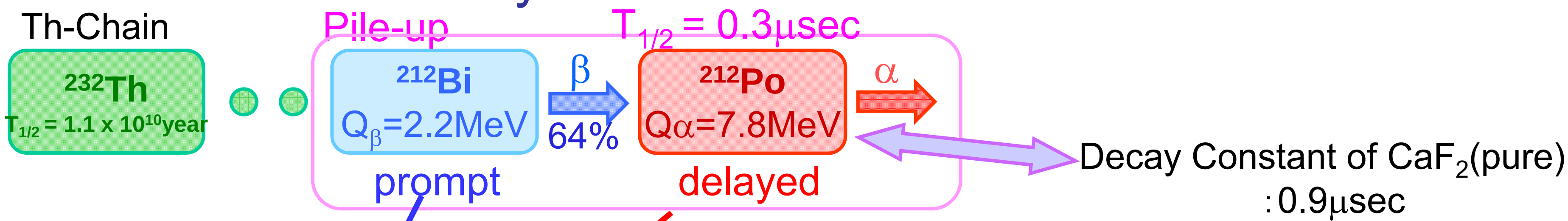
because . . .
CaF_2(pure) :
time constant ~1μs

E_{max} = 5.3MeV
($Q_{\beta\beta}$ = 4.27MeV)

To reject as the sequential event (background event)
- identify the "pile-up" shape
- α–γ rays particle identification

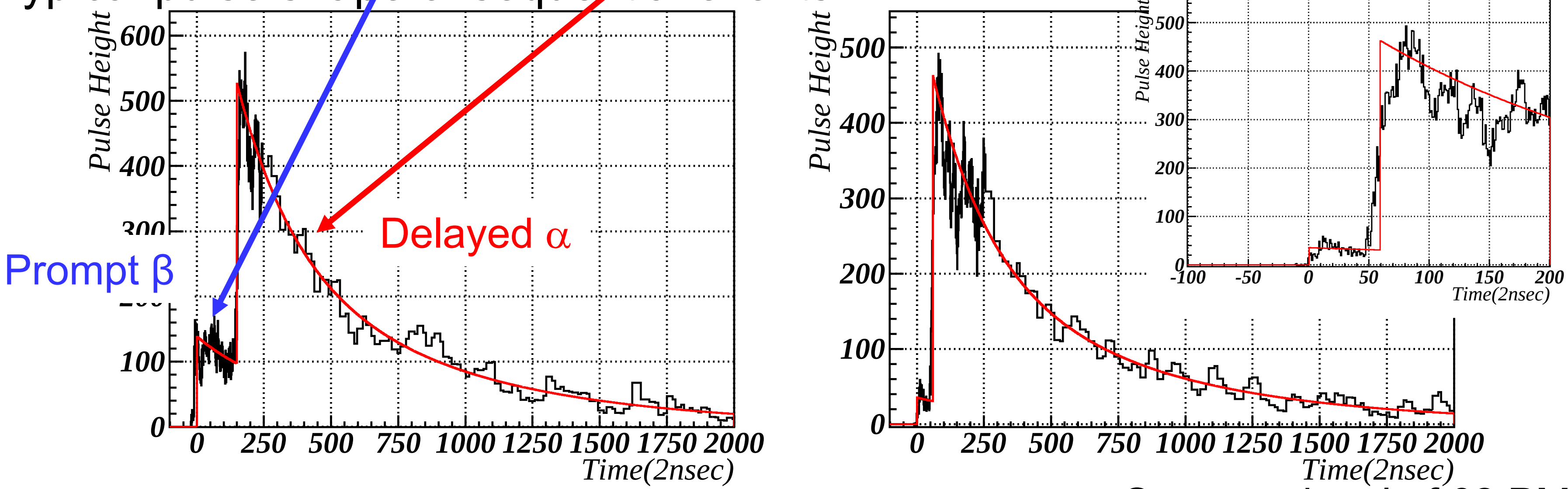
Sequential Events

$^{212}Bi \rightarrow ^{212}Po$ decay



Typical pulse shape of sequential events

with small Δ t



Sum-up signal of 62 PMT

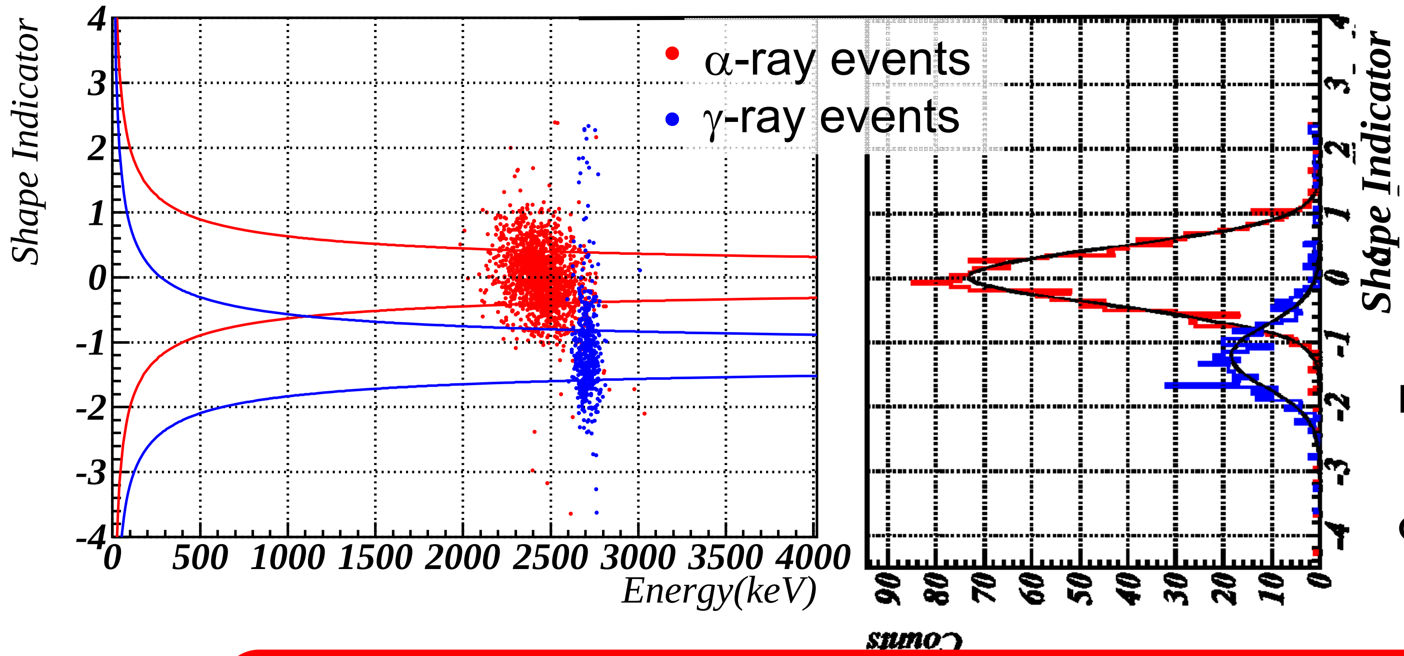
We can identify the sequential events.
Rejection efficiency > 90%

Pulse Shape Discrimination

Particle Identification between α and γ rays

α-ray : ^{214}Po 7.6MeV(E_e=2.5MeV)
γ-ray : ^{208}Tl 2.6MeV

ref : Shape Indicator (PRC67(2003) 014310)



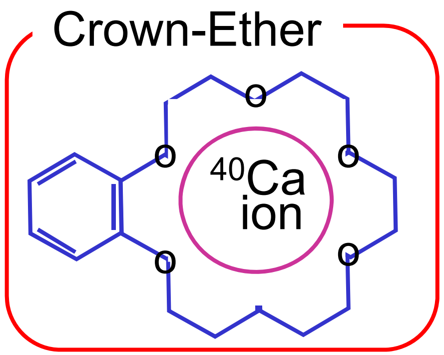
mean : 0 (α-ray)
-1.2 (γ-ray)
σ : 0.42

- 97 % rejection efficiency at 2.6MeV (γ ray:85%)
  →95% (β+α) at 4.27MeV (γ:85%)

R&D : Enrichment of ^{48}Ca

Enrichment by crown-ether

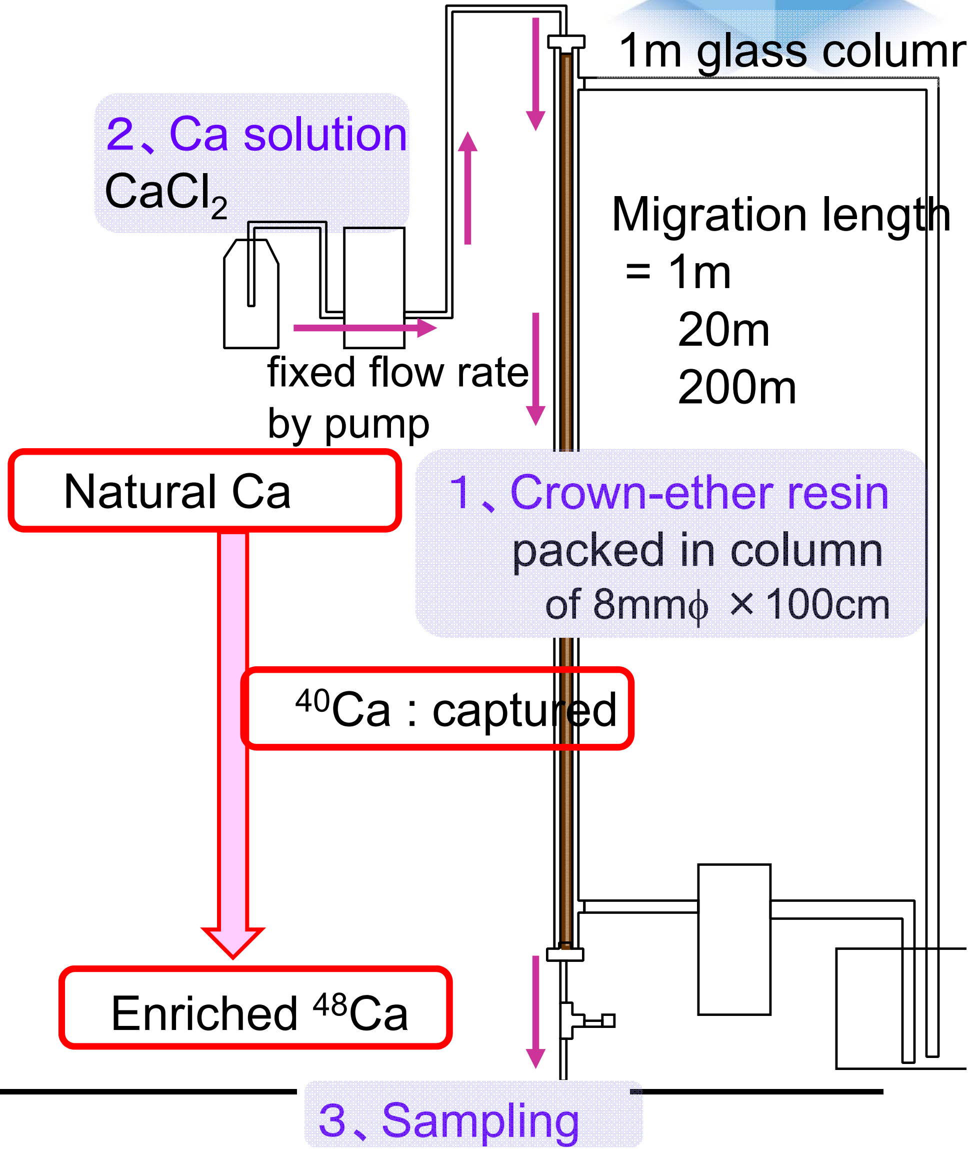
- Crown-ether rings adsorb Calcium ions
- For calcium, ^{40}Ca adsorption in crown-ether is slightly prior



Experimental setup

Chromatography : Breakthrough method

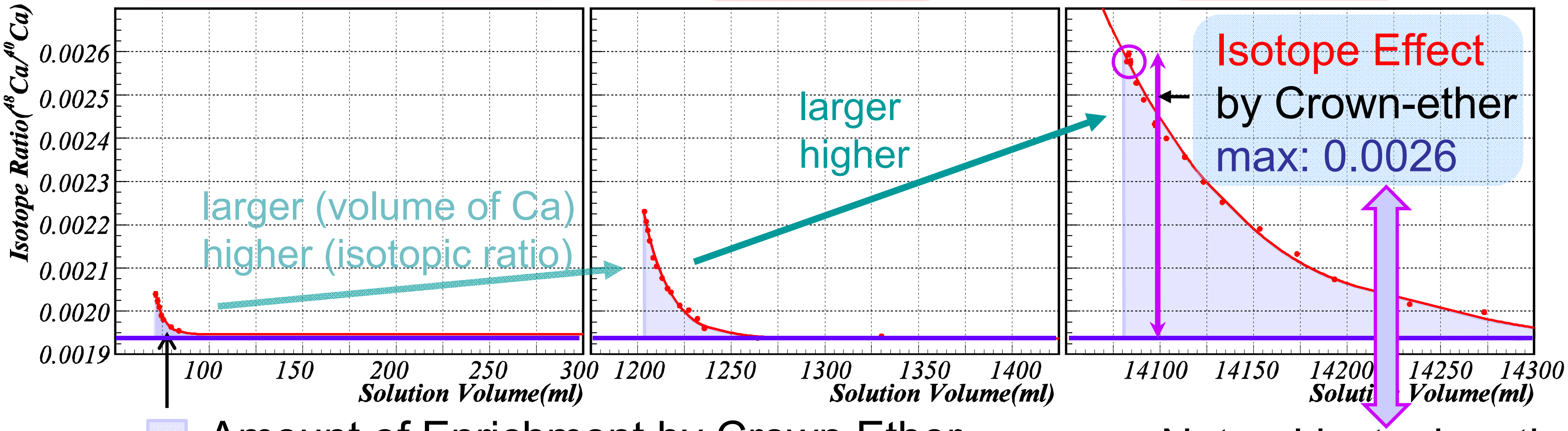
= Migration of Ca solution in resin area



Result of Enrichment

Isotope Enrichment with Longer Migration Time (Length)

~7hours 1m migration length → longer → ~70hours 20m → longer → ~250hours 200m



Isotope Effect (Enrichment Effect)

- The longer migration time(length) = the larger volume and the higher isotopic ratio
- ^{48}Ca enrichment → next CANDLE system

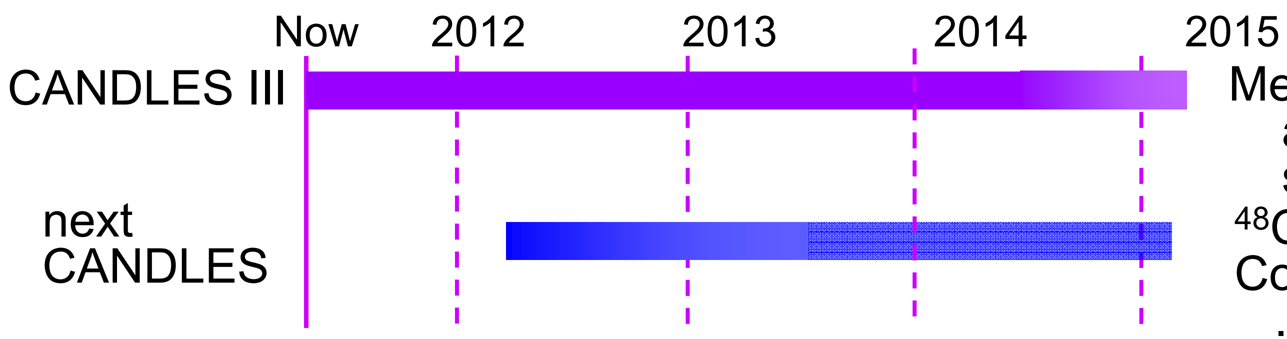
Sensitivity of CANDLES Series

CANDLES series

	CANDLES III	Next CANDLES
Crystal	3.2kg × 96 crystals	
Total Mass	305kg	2 ton
Energy Resolution	4.0%(Req.)	2.8%(Req.)
$2\nu\beta\beta$	0.01	<0.2
^{212}Bi, ^{208}Tl	0.26	~0.1
Expected BG	0.27/year	<0.3 /year
$\langle m_\nu \rangle$	0.5 eV	0.05

2% ^{48}Ca
and cooling system for CaF_2
in a poster presentation
by K. Takubo

Schedule



Measurement
at Kamioka Lab.
sensitivity 0.5eV

^{48}Ca enrichment
Cooling system for CaF_2
. . . not funded yet

Summary

- ELEGANT VI at Oto Cosmo Obs.
  - 7kg of CaF_2(Eu) Scintillators
  - $T_{1/2} > 5.8 \times 10^{22}$ years (< 3.5-22 eV)

- CANDLES III at Kamioka Lab.
  - 300kg of CaF_2(pure) scintillators
  - Pre-measurement for performance test
  - Expected sensitivity : 0.5 eV for $<m_\nu>$

Current status

We started the measurement in 2011.

- R&D (for next CANDLES)
  - Enriched $^{48}CaF_2$(pure) scintillators
    + Cooling system for CaF_2(pure)
  - Sensitivity : ~0.2 eV~0.05eV