Search for neutrino-less double beta decay with CANDLES

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CANDLES collaboration

Candles

Outline

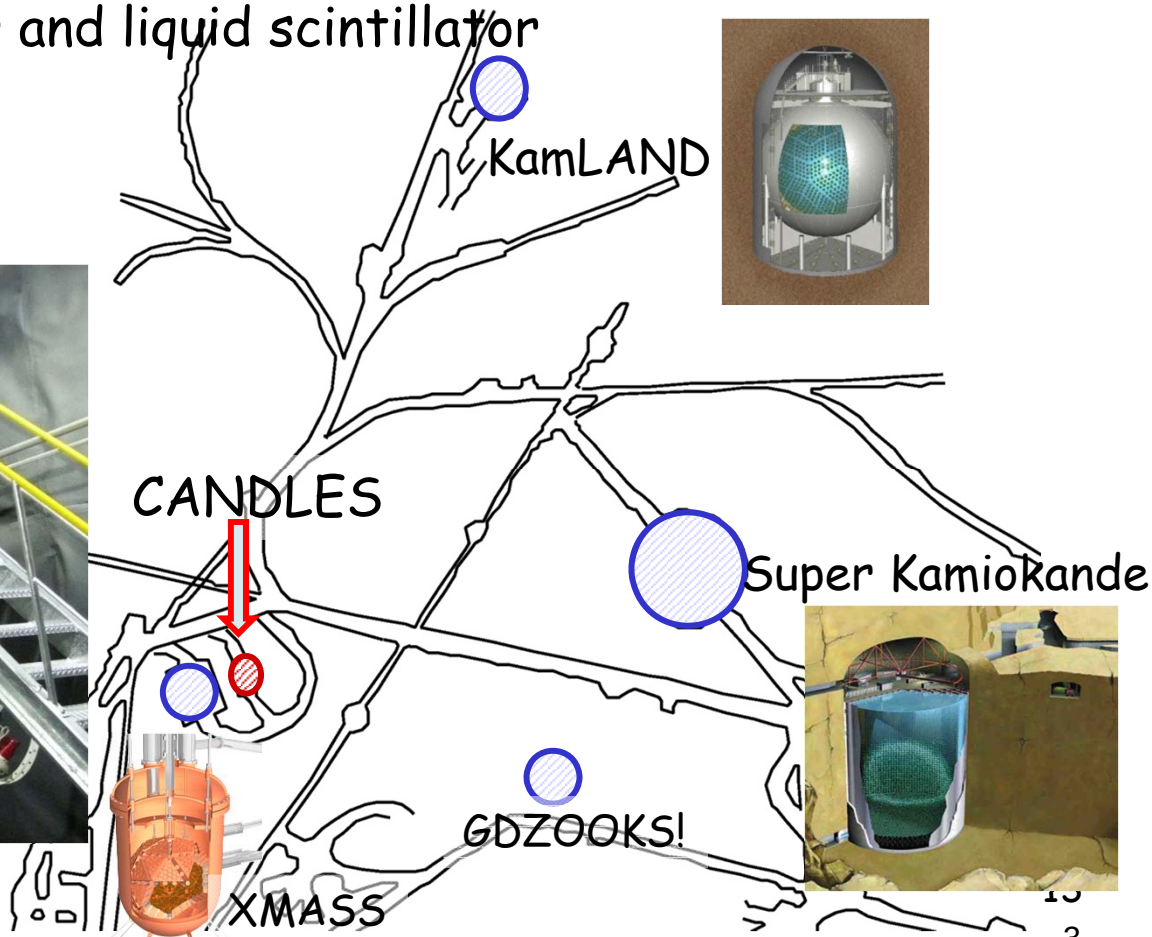
- CANDLES System
  = CaF_2(pure) scintillators + Liquid scintillator
  - CANDLES III system at Kamioka underground lab.
  - About CANDLES system
    - Background candidates and Background rejection
- R&D
- Summary

CANDLES III at Kamioka Lab.

- CANDLES at Kamioka underground Lab.
  - For ^{48}Ca $0\nu\beta\beta$ measurement
    - CaF_2 scintillator and liquid scintillator

CANDLES III

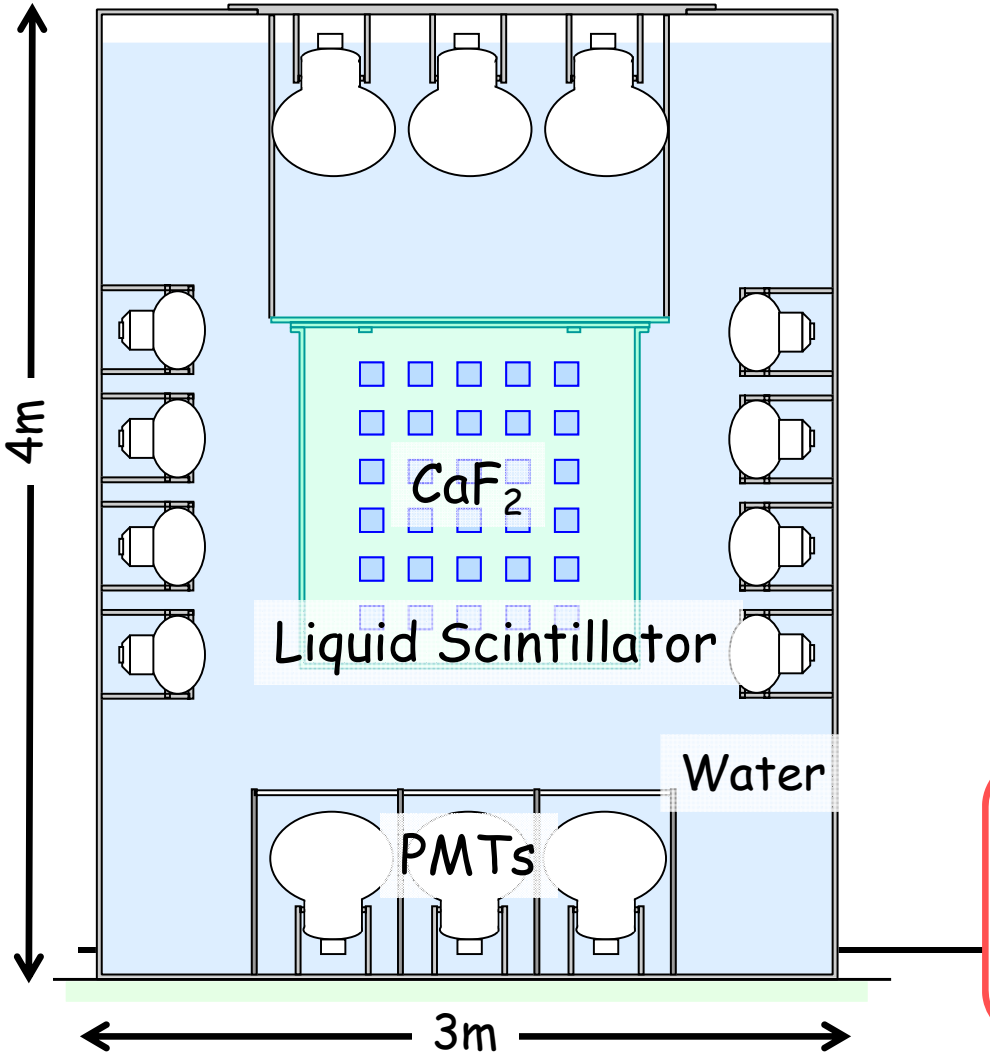
Kamioka Lab. Map



CANDLES III

CANDLES at Kamioka underground laboratory

CANDLES III



- 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

Active Shielding Technique by FADC

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

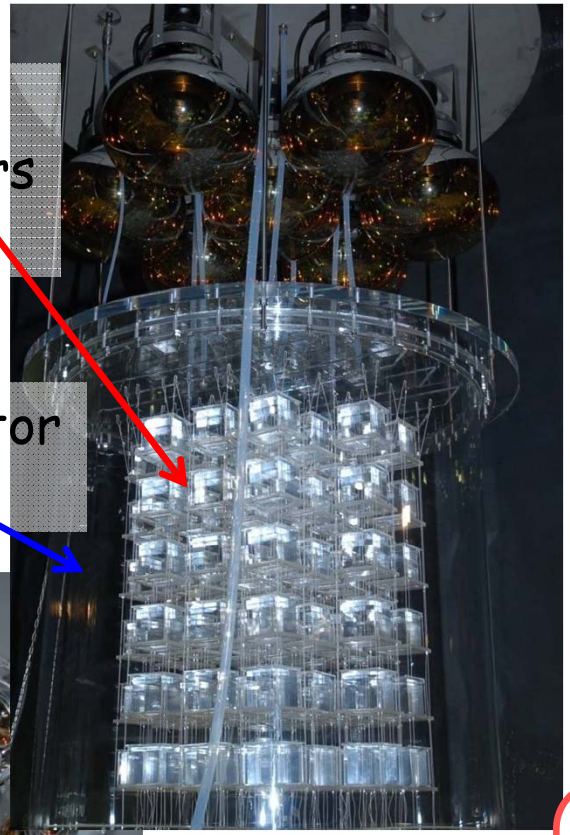
CANDLES III

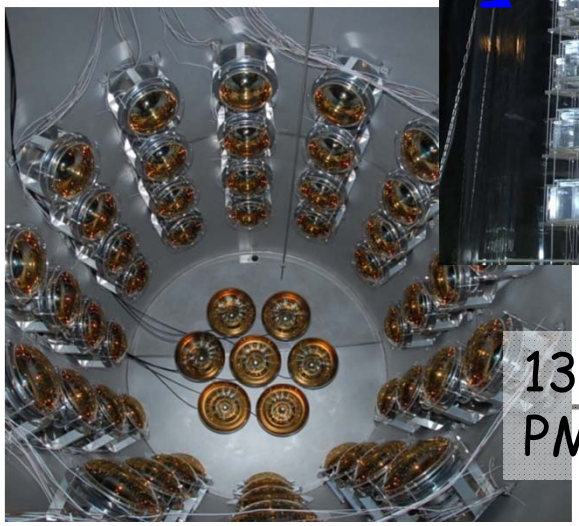
CANDLES at Kamioka underground laboratory

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:$2m^3$
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  13inch PMT × 48
  20inch PMT × 14

Active Shielding Technique by FADC

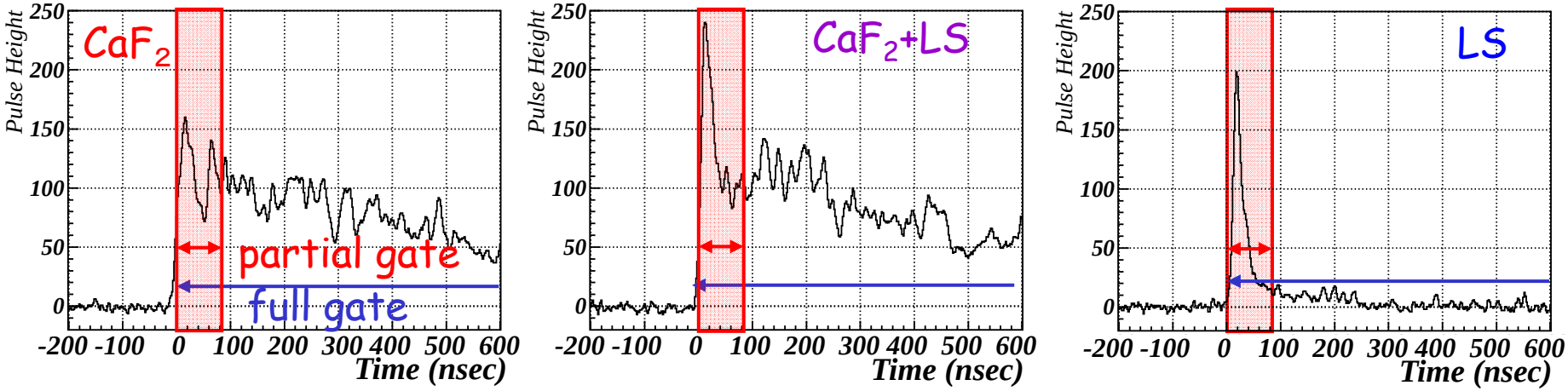
Different time constants
CaF_2(pure) : ~1μsec
Liquid scintillator : a few 10 nsec

Pulse Shape from CANDLES

Rejection by using pulse shape information

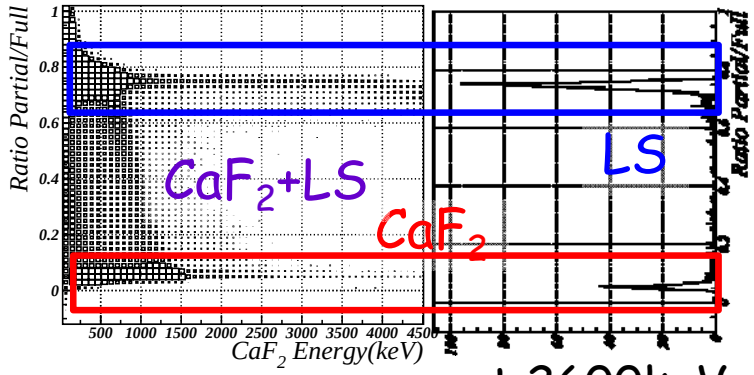
τ of CaF_2 = 1000nsec
LS = ~20nsec

3 Types of Pulse Shapes



Charge in partial gate = small ⟷ Charge in partial gate = large

Event Distribution



at 2600keV

$$\text{Charge-Ratio} = \frac{\text{charge in partial gate}}{\text{charge in full gate}}$$

We can clearly discriminate between CaF_2 and others

Backgrounds in CANDLES

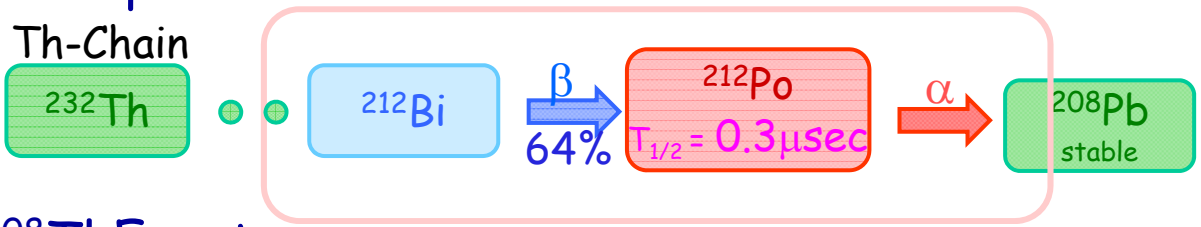
$2\nu\beta\beta$ Events

Possible to reduce by good energy resolution (~4% at 4.27MeV)

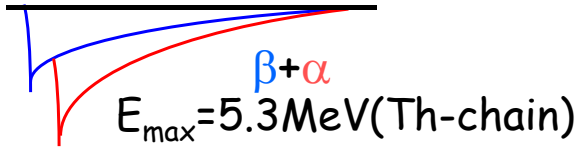
Radioactive Contaminations in CaF_2 Crystals

Pile-up Events

Th-Chain

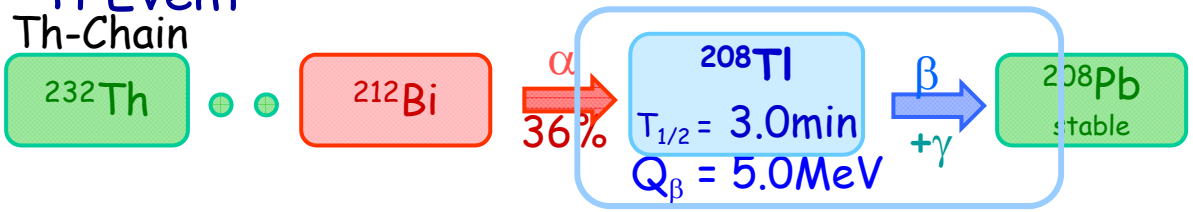


Pile-up because of τ of CaF_2 signal = 1μsec



^{208}Tl Event

Th-Chain



E_{max}=5.0MeV

^{212}Bi and ^{208}Tl($T_{1/2}$=3min) . . .

Space-Time Correlation Cut

α–γ Particle Identification

To reject these BG events

$2\nu\beta\beta$:good light collection efficiency (good energy resolution)

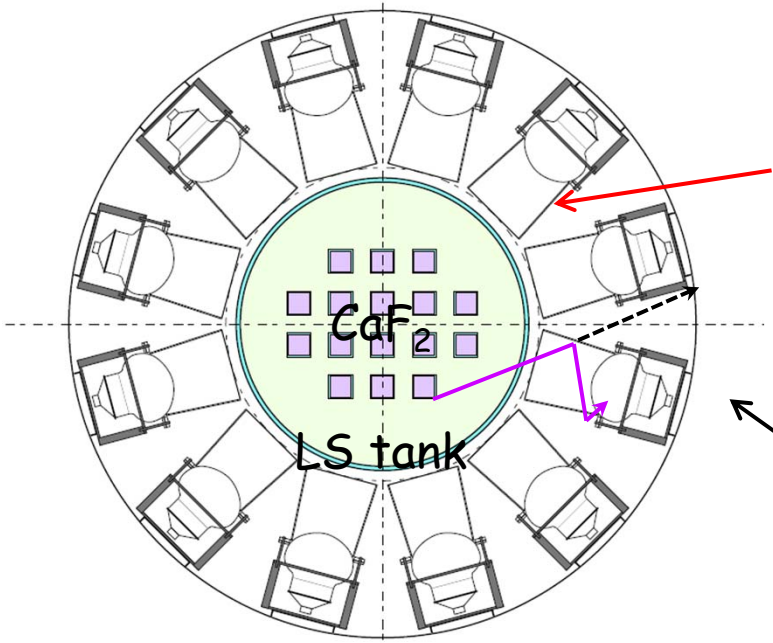
Pile-up event : identify the "pile-up" shape

^{208}Tl event : α-γ rays particle identification (for prompt ^{212}Bi)

2νββ reduction
-Instruction of Light Pipe System-

- To improve energy resolution
  - Guide scintillation light to PMTs
  - Reflector Film :
    reflectivity ~93% @ 420nm

Top View of CANDLES



Light Pipe (Side)

PMT (13 inch,Side)

Light Pipe System =
acrylic box with reflector films

UN

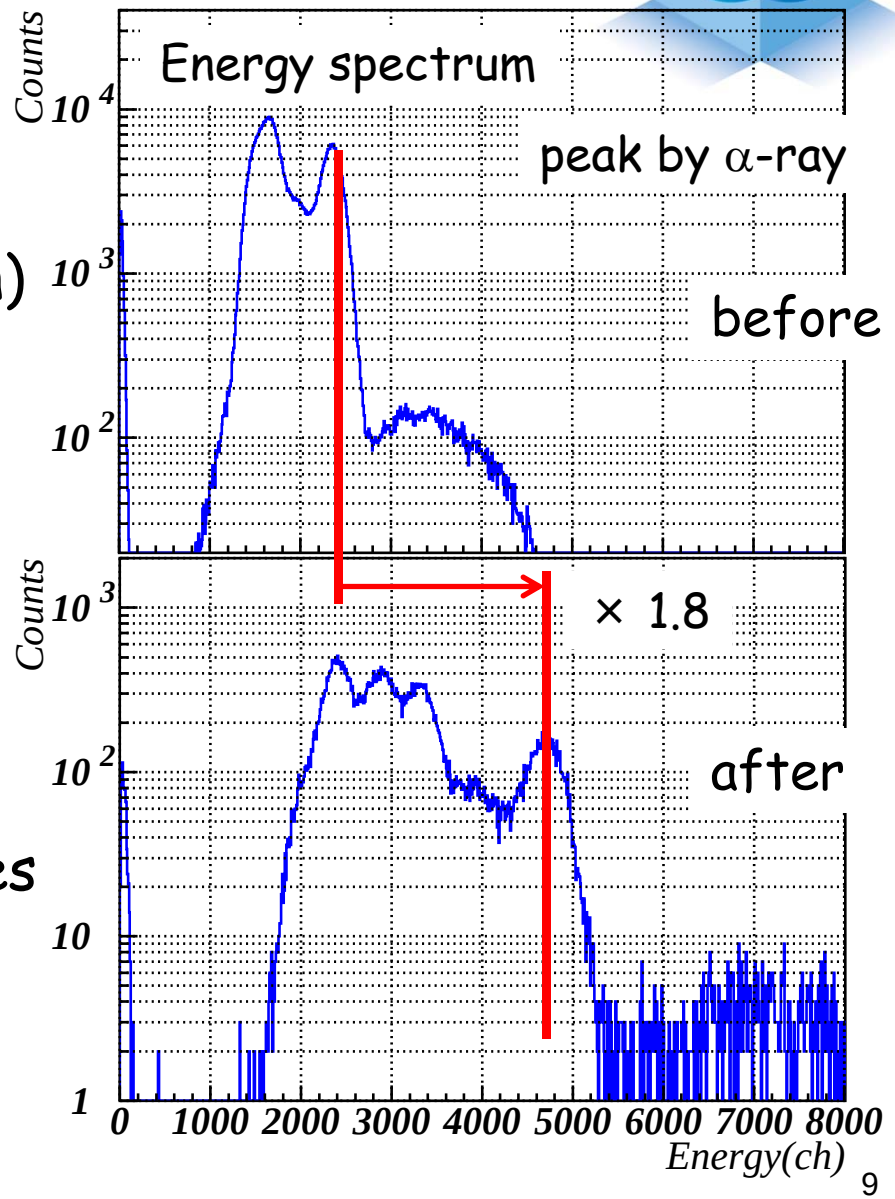
Light Pipe System

Light collection

- peak position of a-ray
  2500ch (before instruction)
  ⇩ ×1.8
  4600ch (after instruction)

Number of photo-electron
=0.9p.e./keV
~ 1 p.e./keV
=Req. for CANDLES series

Light Correction :
1.8 times as large as one of before



Rejection of pile-up events

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

Th-Chain

^{232}Th
$T_{1/2} = 1.1 \times 10^{10}$year

Pile-up

^{212}Bi
Q_β=2.2MeV
prompt

β
64%

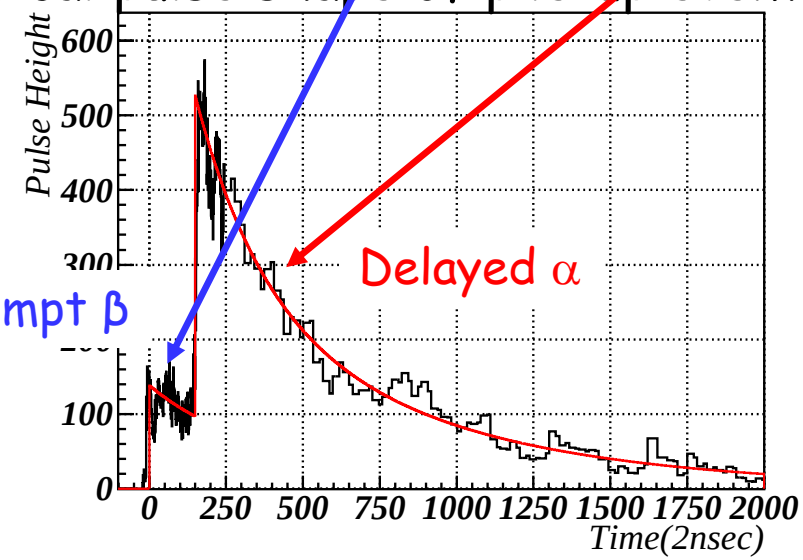
$T_{1/2}$ = 0.3μsec

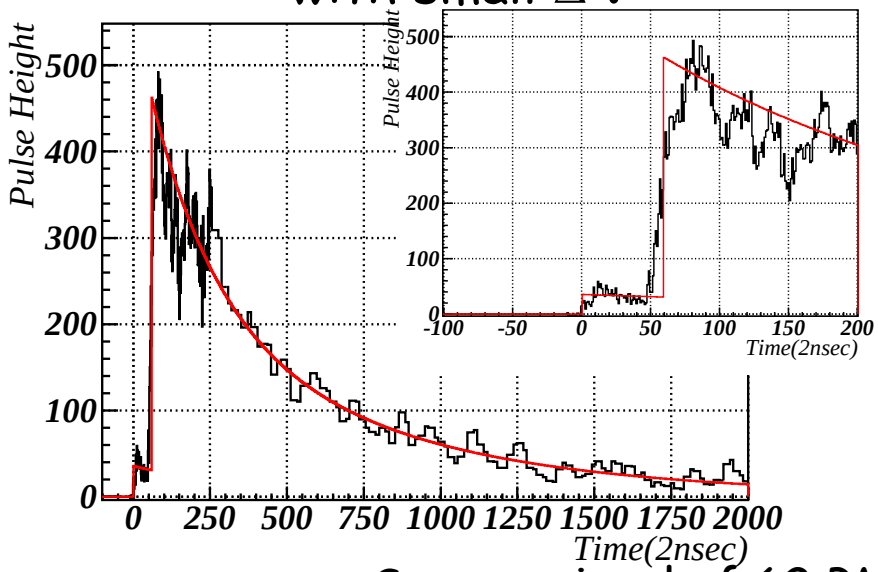
^{212}Po
Qα=7.8MeV
delayed

α

Decay Constant of CaF_2(pure)
: 1μsec
with small Δ τ

Typical pulse shape of pile-up events





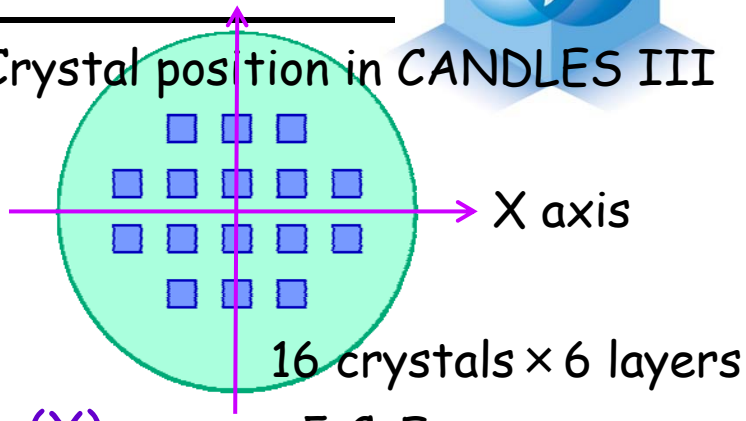
Sum-up signal of 62 PMT

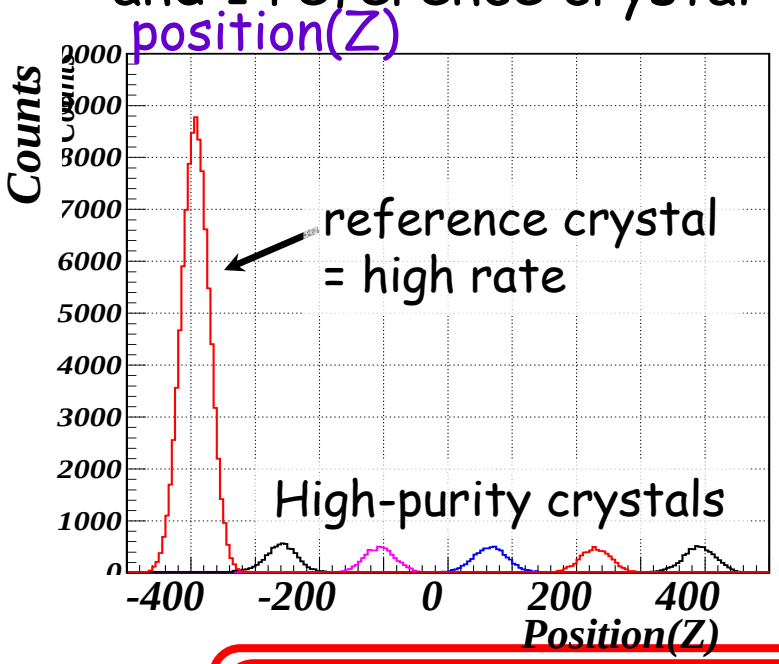
We can identify the pile-up events.
current rejection efficiency > 95%

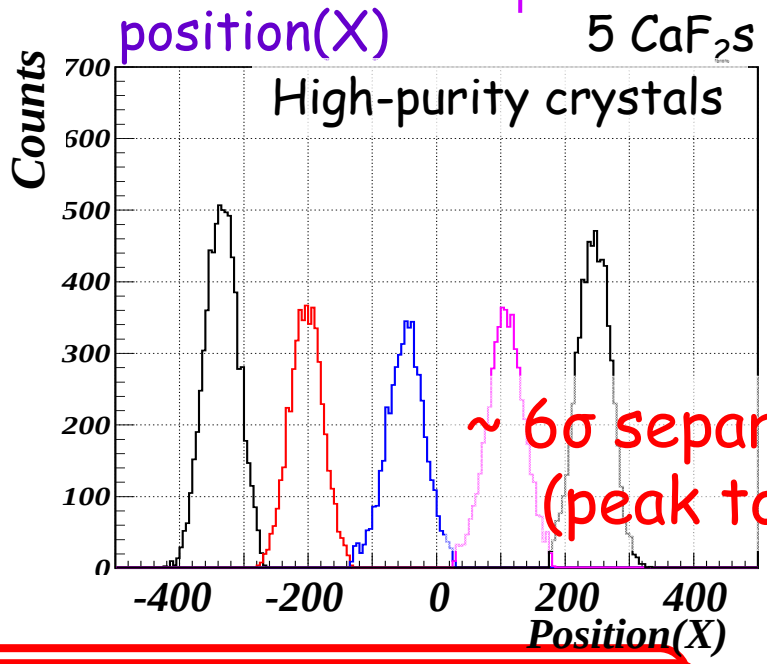
^{208}Tl rejection
Position Reconstruction

Position Reconstruction

- for events with CaF_2 pulse shapes
- for identification of CaF_2 position
- 95 high-purity crystals and 1 reference crystal







~ 6σ separation
(peak to peak)

Position reconstruction : OK for CANDLES III
Single-site & multi-site events of γ-rays : R&D

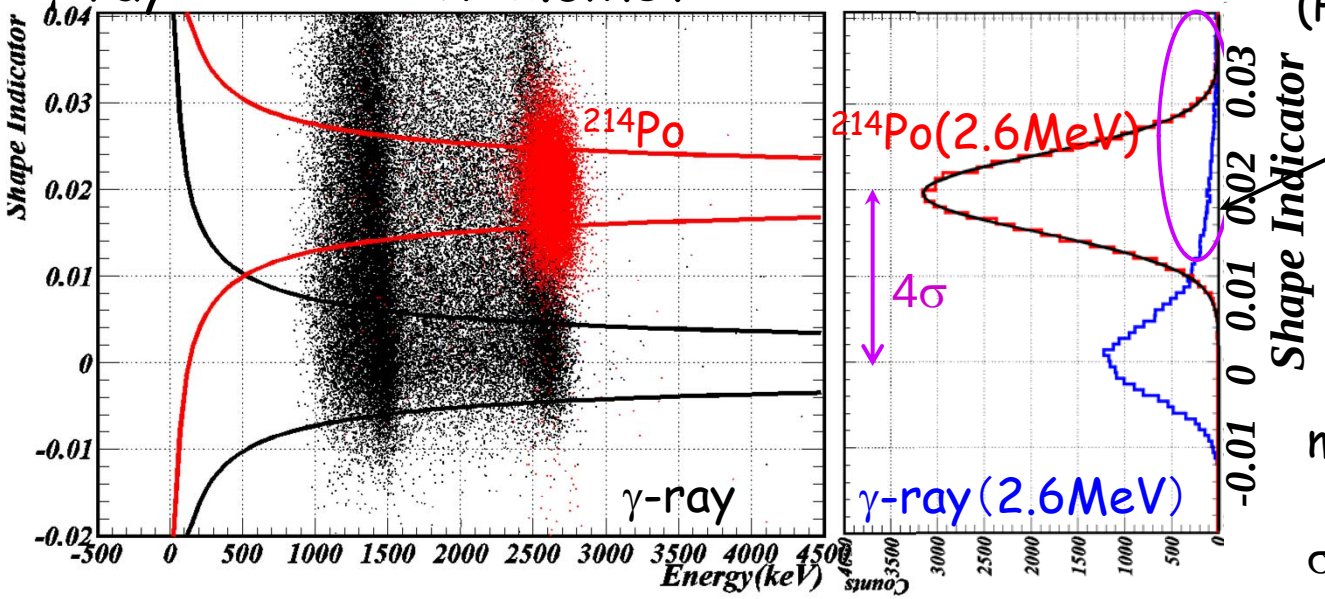
Pulse Shape Discrimination -pile-up event and ^{208}Tl-

Particle identification between α and γ rays

α-ray : ^{214}Po 7.6MeV(E_e=2.6MeV)

γ-ray : ^{208}Tl 2.6MeV

ref : Shape Indicator (PRC67(2003) 014310)



CaF_2 γ +small LS signal

mean :0.0000(γ-ray)
:0.0196(α-ray)

σ :0.0046(α-ray)

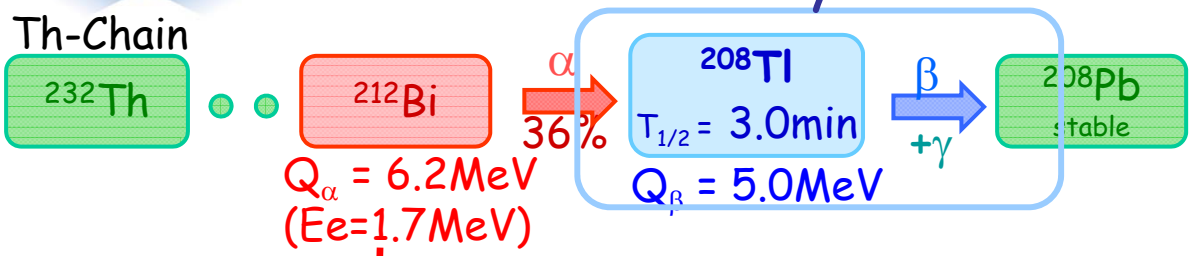
We applied not only "Shape Indicator" but also "χ^2 fitting" for PI.

97 % rejection efficiency at 2.6MeV(γ ray:3%)
→97% (β+α) at 4.27MeV(γ:3%)
・rejection of β–α pile-up events
・identification of prompt ^{212}Bi event

^{208}Tl rejection

^{212}Bi → ^{208}Tl → ^{208}Pb decay

Th-Chain

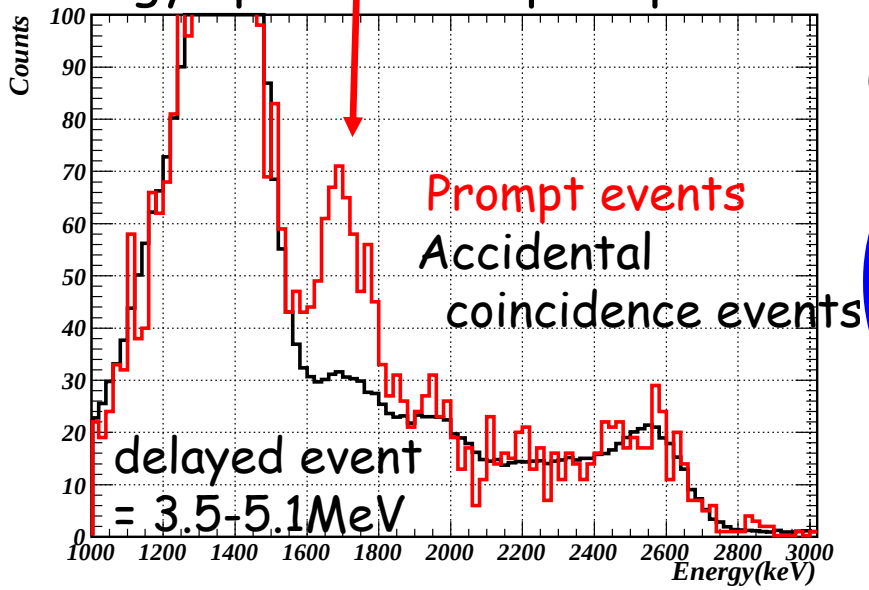


E_{max}=5.0MeV

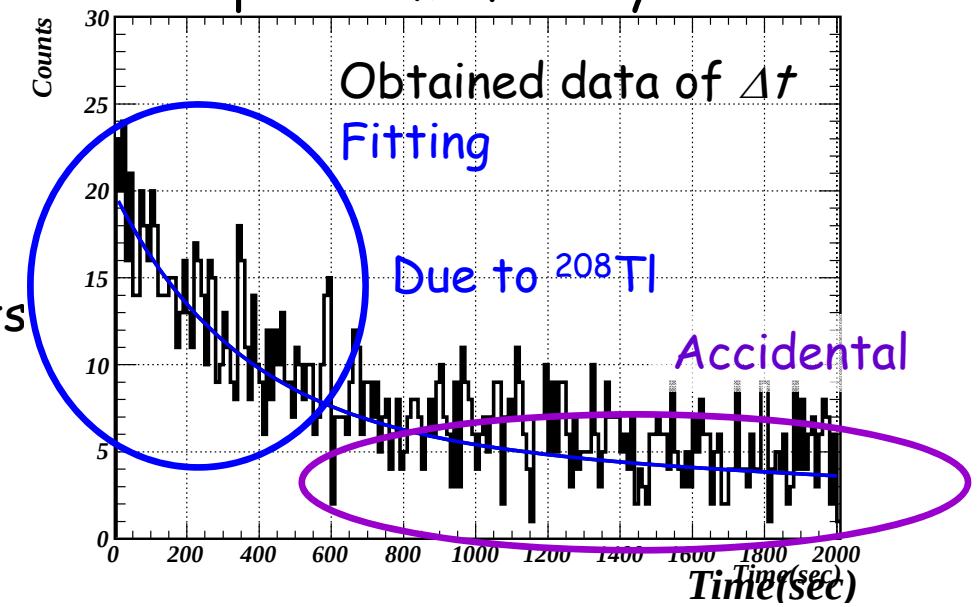
^{212}Bi and ^{208}Tl($T_{1/2}$=3min) . . .

Space-Time Correlation Cut

Energy spectrum of prompt ^{212}Bi



Δt spectrum of delayed ^{208}Tl



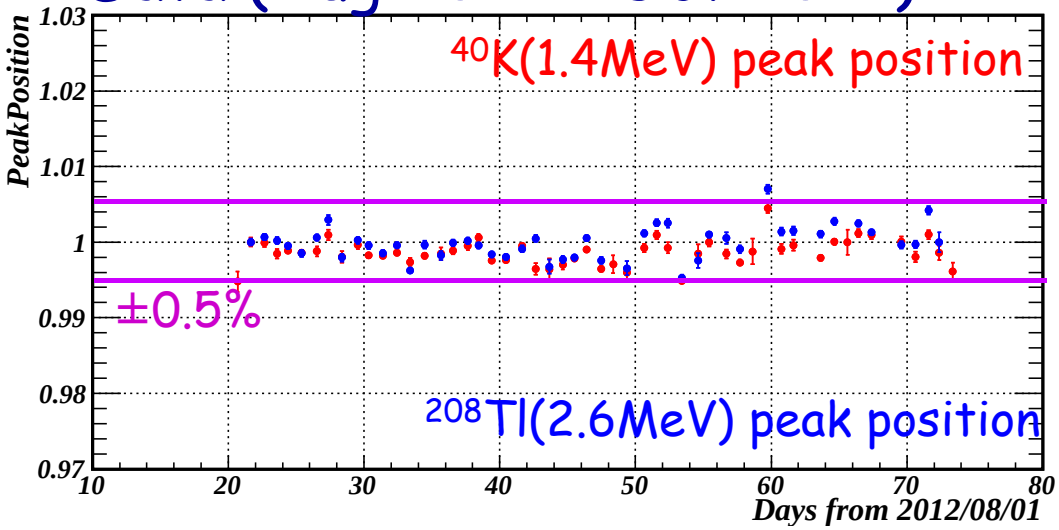
Obtained half-life
= 241±46sec

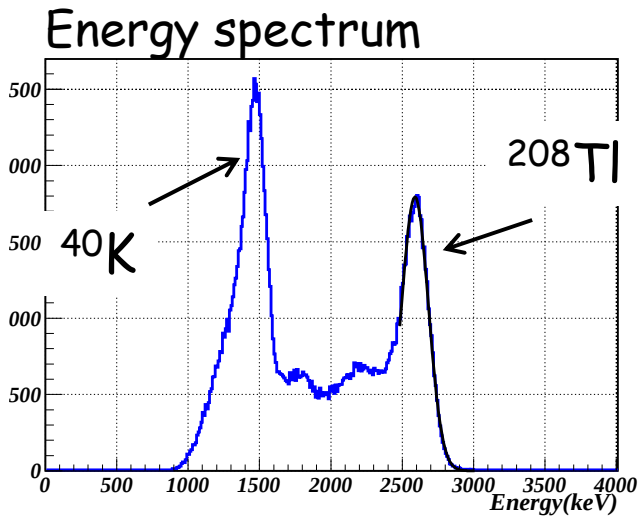
- We can identify the prompt ^{212}Bi
  Now : rejection efficiency = 55%, acceptance = 90%
- We will improve these efficiencies by DAQ upgrade etc.

p. 2013, TAUP2013

Measurement

- Measurement
  - Aug. 2012 - Nov. 2012 : measurement
  - Nov. 2012 - May. 2013 : detector improvement
  - May. 2013 : restart of measurement
- Data (Aug 2012 – Oct 2012)



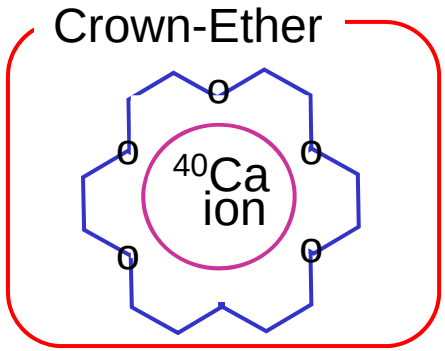


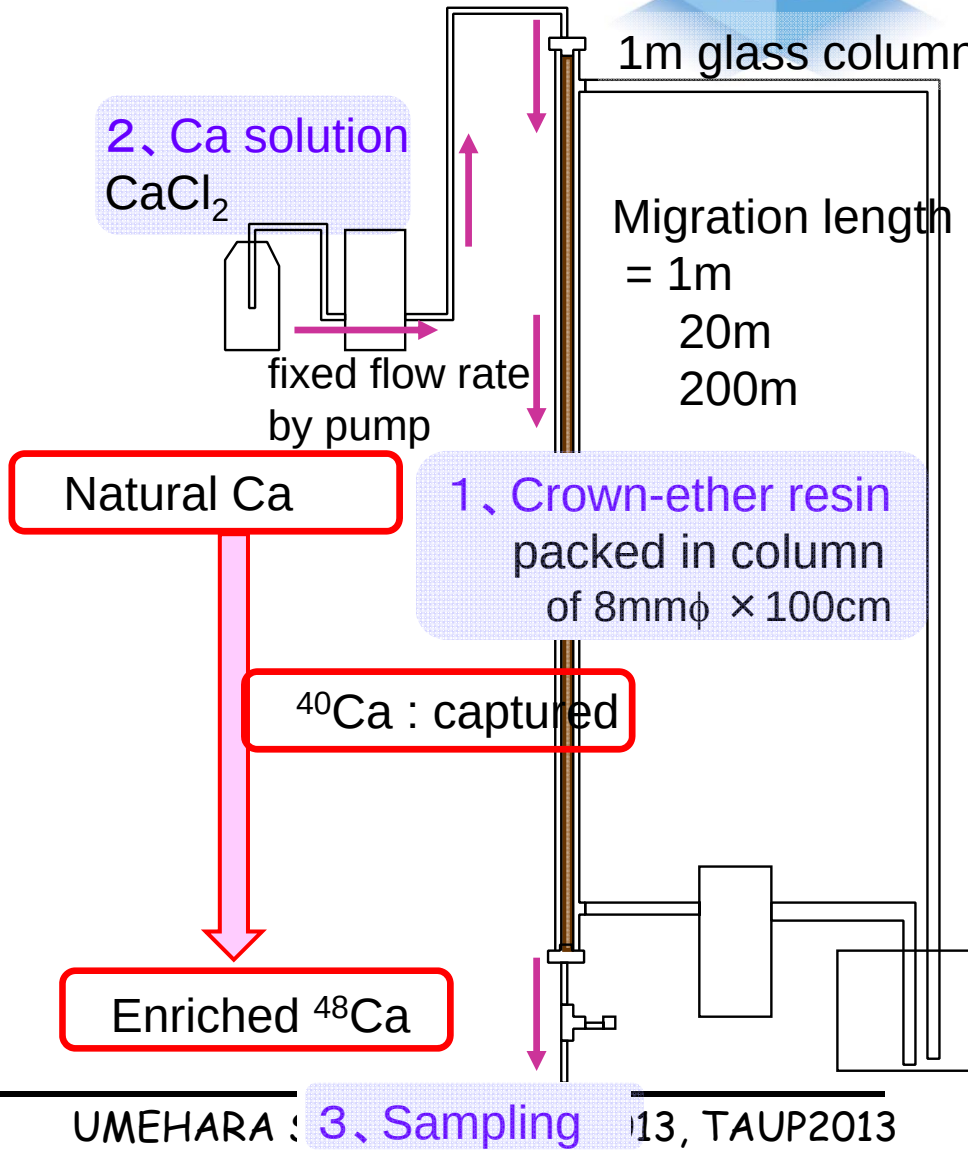
- Data Stability : OK
- Now in analyses for BG study and ββ measurement

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

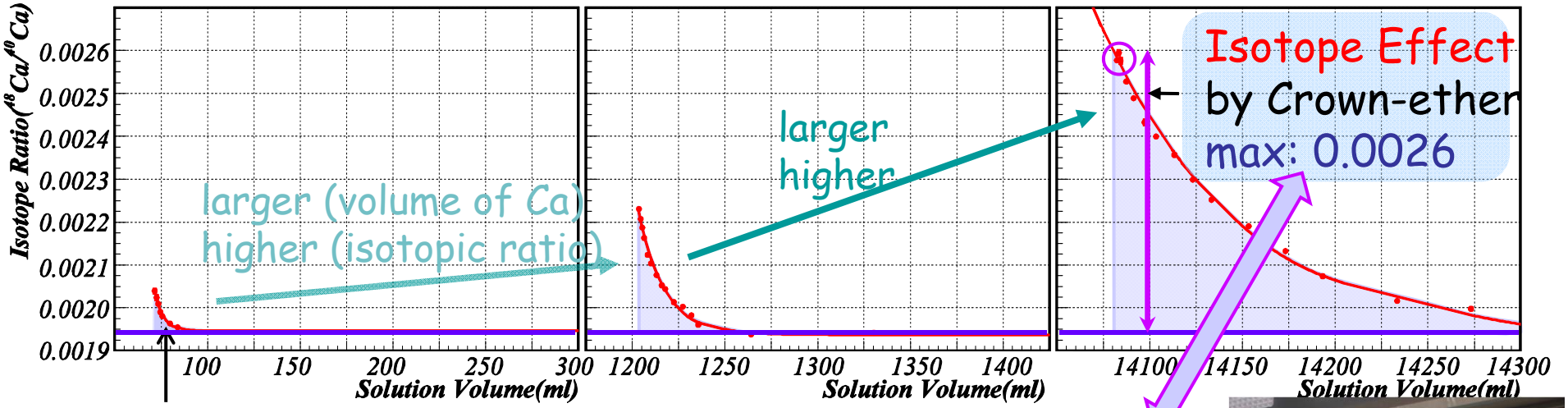
Chromatography：
Breakthrough method
= Migration of Ca solution in resin area

Result of Enrichment

Isotope Enrichment with Longer Migration Time (Length)

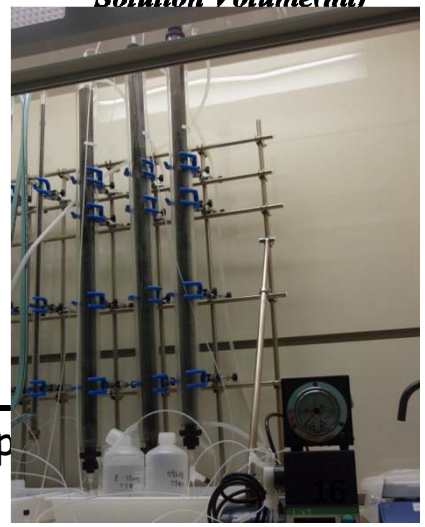
~7hours : 1m migration length → ~70hours:20m → ~250hours 200m

longer → longer



Amount of Enrichment

Natural isotopic ratio = 0.0019



Isotope Effect (Enrichment Effect)

- The longer migration time(length) = the larger volume and the higher isotopic ratio
- ^{48}Ca enrichment → next CANDLE system
  Now : R&D for mass production

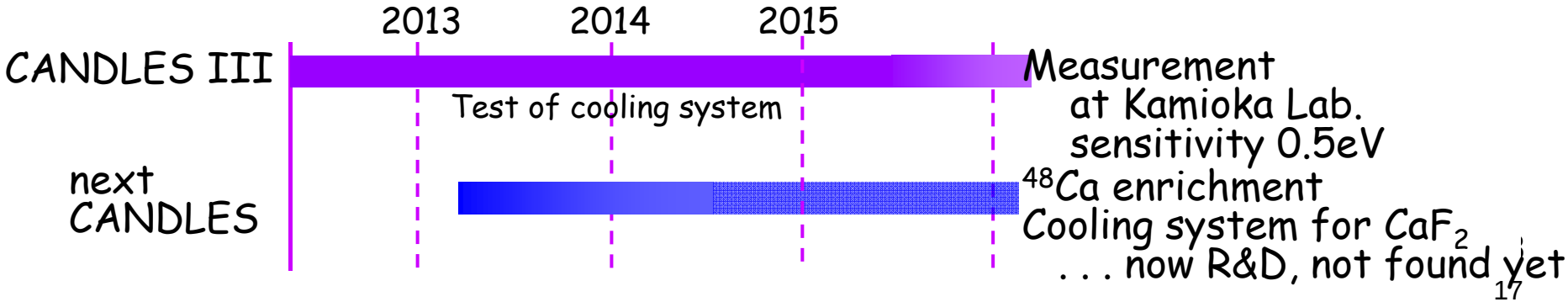
Sensitivity of CANDLES Series

CANDLES series

	CANDLES III	Next CANDLES
Crystal	3.2kg × 96 crystals	2% ^{48}Ca
Total Mass	305kg	2 ton
Energy Resolution	(4.0%)	2.8%(Req.)
$2\nu\beta\beta$	0.01	0.1
^{212}Bi, ^{208}Tl	0.26	~0.1
Expected BG	0.27/year	<0.7 /3year
$\langle m_\nu \rangle$	0.5 eV	0.08

~2% ^{48}Ca
and cooling system for CaF_2

Schedule



Summary

- Double beta decay measurement
- R&D for CANDLES system
  - Light pipe system
  - Analysis for background rejection
    - Pile-up event
    - ^{208}Tl event
- CANDLES III at Kamioka Lab.
  - Now : $\beta\beta$ measurement
  - Expected sensitivity : 0.5 eV for $\langle m_\nu \rangle$
- R&D (for next CANDLES)
  - Enriched $^{48}CaF_2$(pure) scintillators
    + Cooling system for CaF_2(pure)