Search for Neutrino-less Double Beta Decay with CANDLES

UMEHARA Saori

umehara@rcnp.osaka-u.ac.jp

T. Kishimoto, M.Nomachi, S. Ajimura, S.Yoshida, K.Matsuoka, N. Nakatani,
K. Ichimura, G.Ito, K.Yasuda, H.Kakubata, M. Saka, K. Takubo, K. Seki, W. Wang,
Y.Tamagawa, I.Ogawa, K.Fushimi, R.Hazama, H. Ohsumi, K.Okada
CANDLES collaboration
Osaka University, University of Fukui, University of Tokushima,
Hiroshima University, Saga University,
Kyoto San-gyo University

Y. Fujii, Y. Sakuma, M. Nomura, T. Suzuki, T. Kaneshiki, S. Nemoto
Tokyo Institute of Technology,
Sophia University

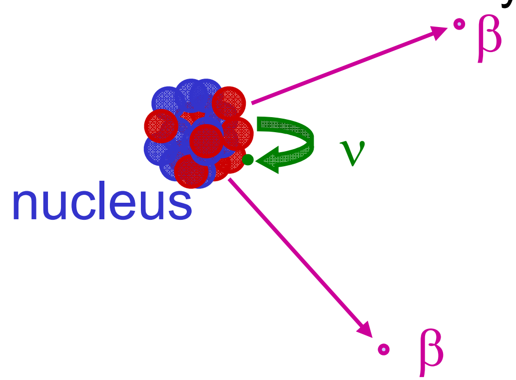
Outline

- Double Beta Decay of ^{48}Ca
- ELEGANT VI System (previous system)
  - = CaF_2(Eu) scintillators + CsI(Tl) scintillators system
  - Result
- CANDLES System (next system)
  - = CaF_2(pure) scintillators + Liquid scintillator system
  - CANDLES III system (at Kamioka Underground Lab.)
    - Pre-measurement (without liquid scintillator)
- R&D
  - ^{48}Ca enrichment
- Summary

Double Beta Decay

- Double Beta Decay
  - Two neutrino double beta decay
    - within Standard model
      →already observed
  - Neutrino-less double beta decay
    - not obserbed $T_{1/2}$ > (~10^{25}years)
      cf. H.V. Klapdor-Kleingrothaus et al.
    - If observed
      - Neutrino → Majorana particle
      - Lepton number violation
      - Decay rate $T_{1/2} \propto 1/m_{\nu}^2$

Neutrino-less
double beta decay



Double Beta Decay

- Experimental study for double beta decay

  because double beta decay = rare decay

  - Large amount of double beta nuclei

    a few kg ~ a few ton

  - Low background condition

    $1/m_\nu^2 \propto T_{1/2} \propto M_{detector}$ if no background

    $1/m_\nu^2 \propto T_{1/2} \propto M_{detector}^{1/2}$ if background limited

  - Nuclei and measurement of double beta decay

    for example . . .

    - ^{76}Ge : Klapdor et al., IGEX, MAJOANA, GERDA
    - ^{100}Mo : NEMO3→SuperNEMO, ELE V→MOON
    - ^{130}Te : Cuoricino→CUORE
    - ^{136}Xe : EXO, NEXT,
    - ^{48}Ca : Our group(ELEGANT VI→CANDLES)

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

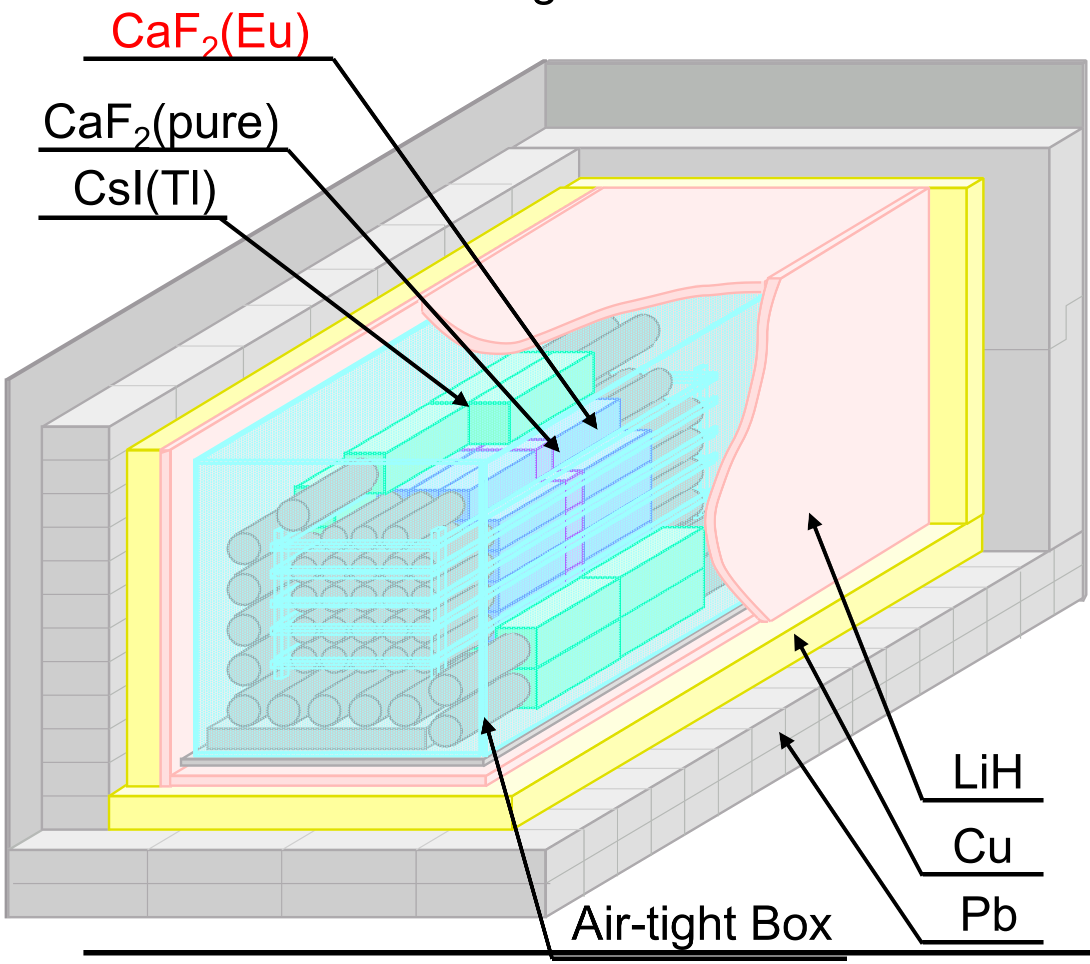
- Double Beta Decay of ^{48}Ca by CaF_2 Scintillators
  - ELEGANT VI system

    ↓ 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 $\beta\beta$ Decay : ^{48}Ca
  ($Q_{\beta\beta}$=4.27MeV)

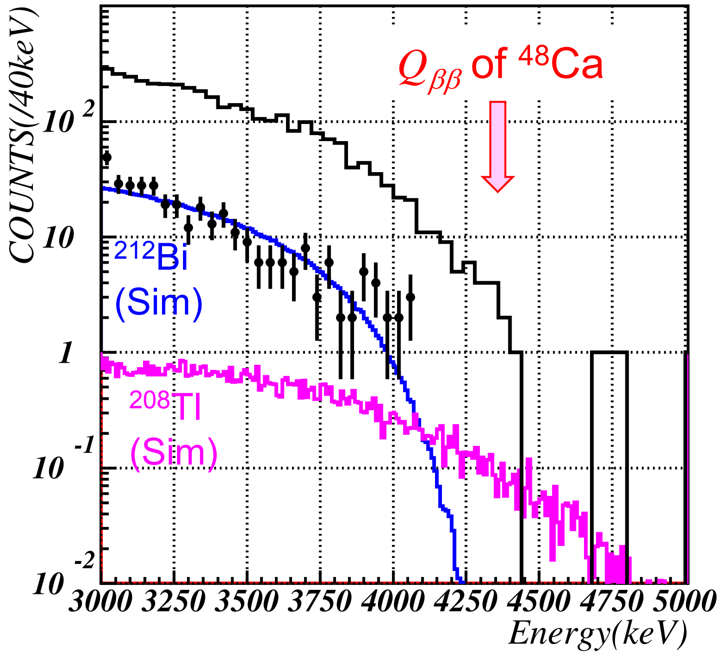
- veto counters
  46 CaF_2(pure)
  38 CsI(Tl)
  → 4π Active Shield

- 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

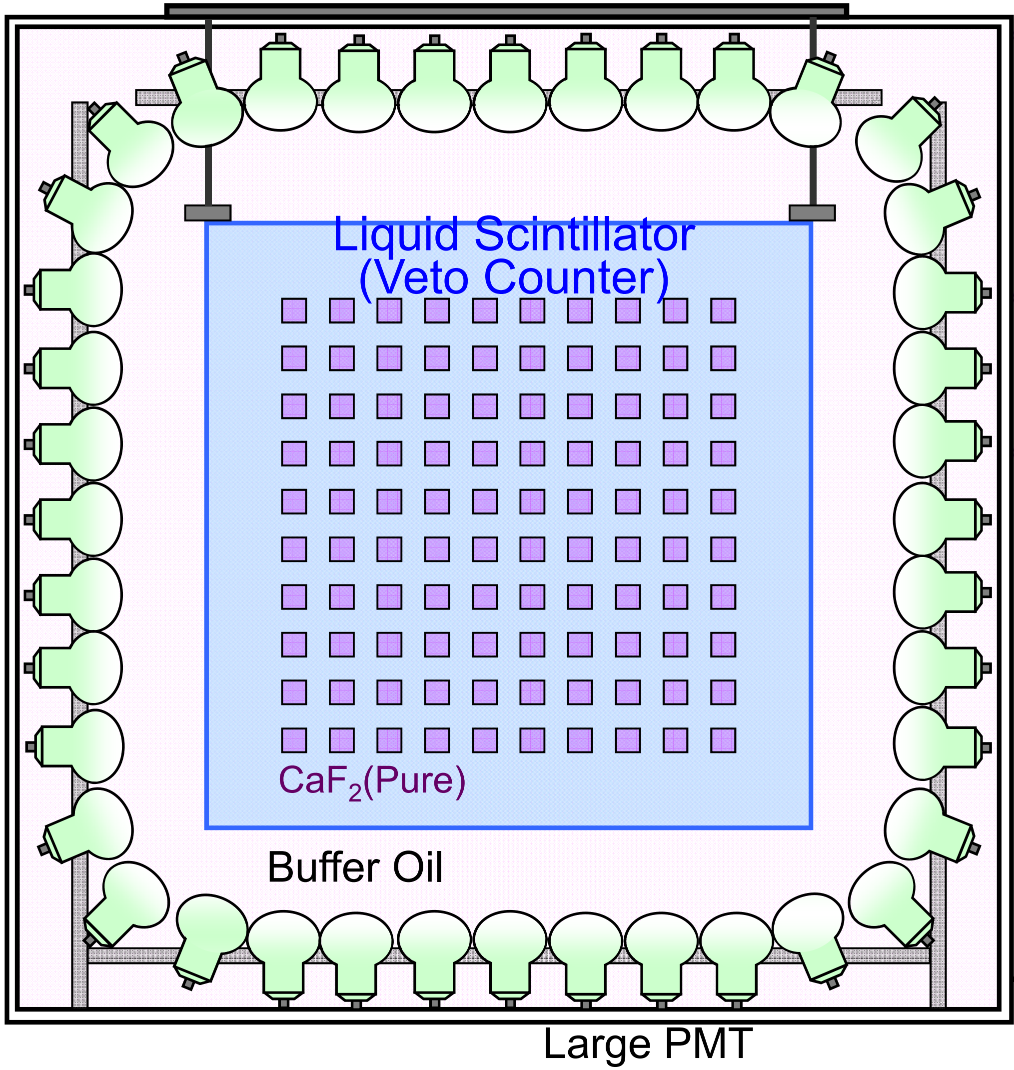
0νββ Half-Life of ^{48}Ca : > 5.8×10^{22} year (90% C.L.)

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

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



- Undoped CaF_2 scintillator (CaF_2(Pure))
  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

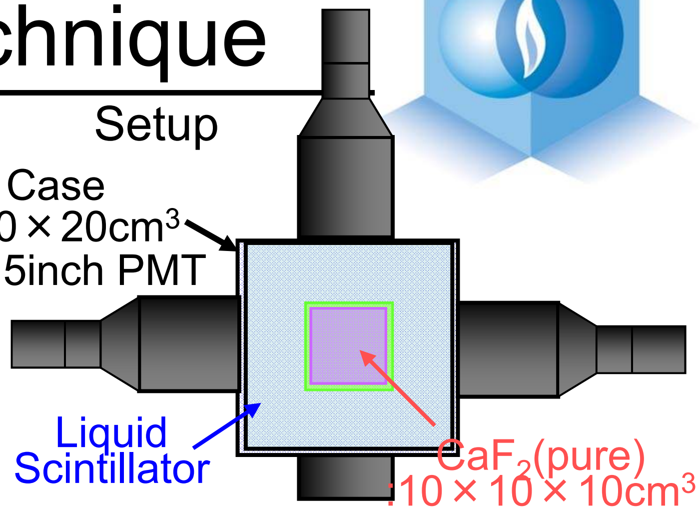
⇩

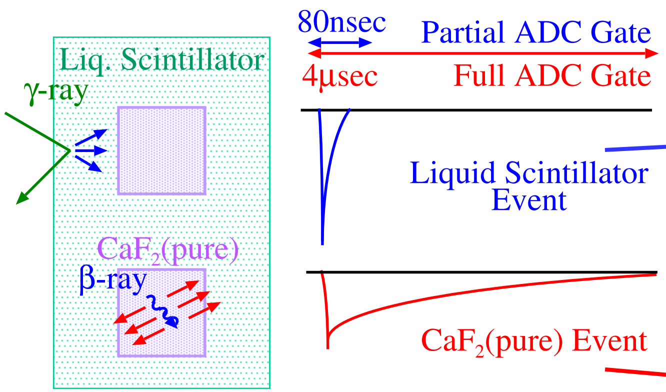
- Active Shielding Technique
  Different time constants
  CaF_2(pure) : ～1μsec
  Liquid scintillator : a few 10 nsec

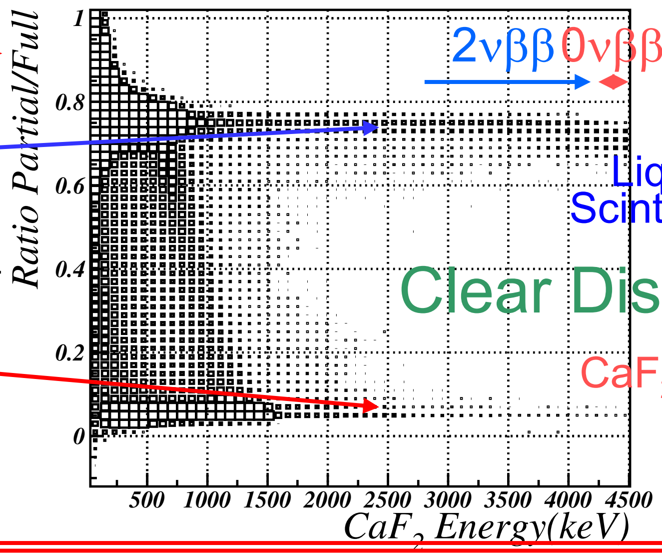
Active Shielding Technique

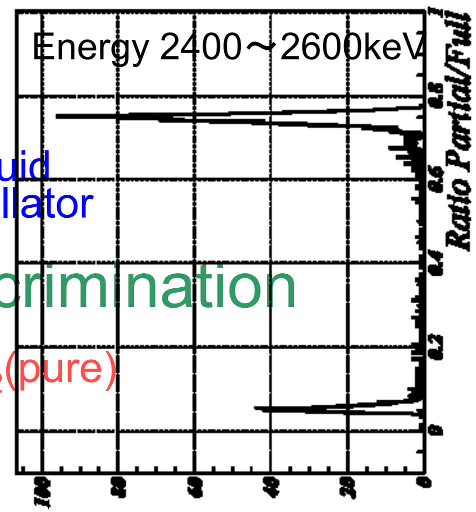
Concept of 4π Active Shield and Performance Test

- PSD between CaF_2 and Liquid Scintillators









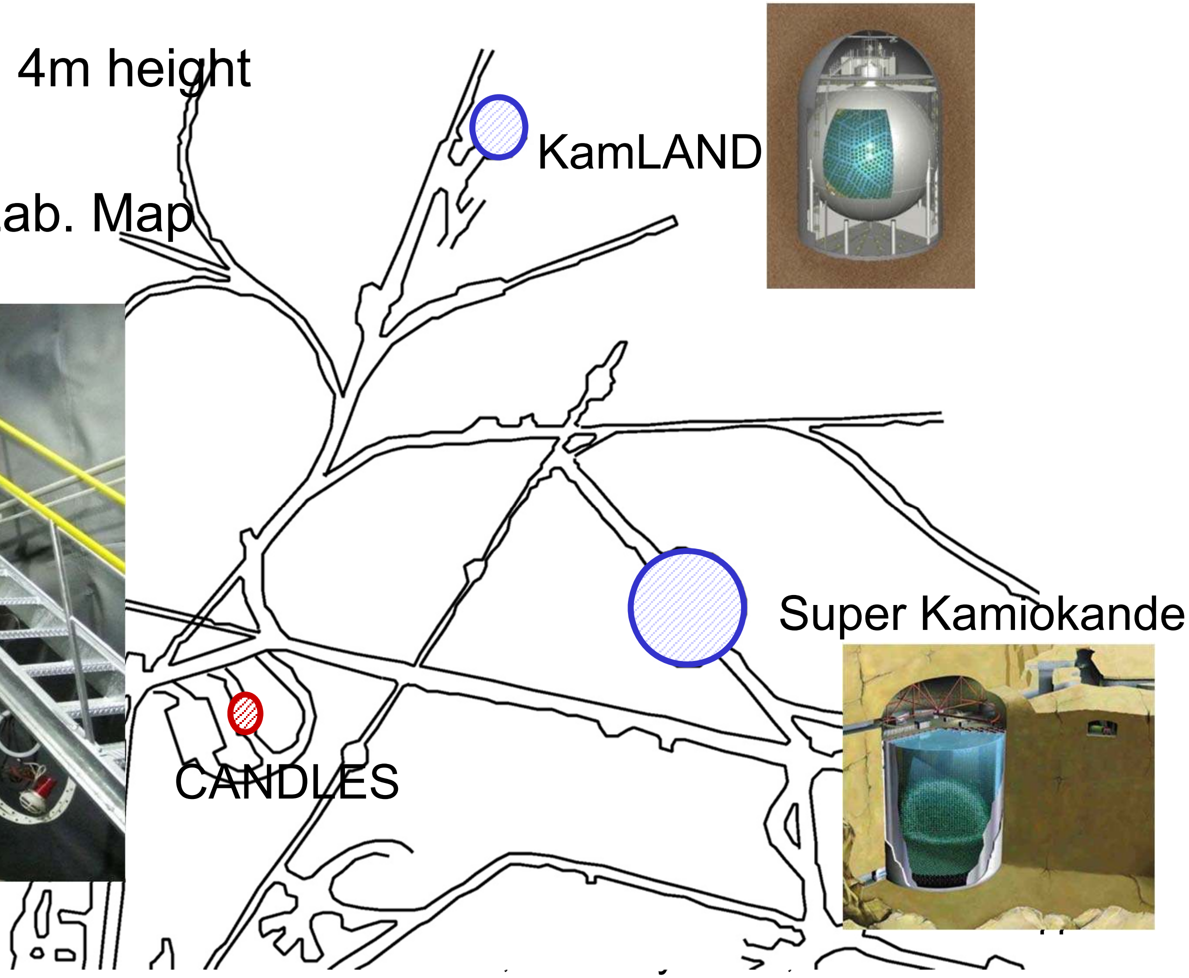
Clear Discrimination between CaF_2 and Liquid Scintillators
. . .Well Act as Veto Counter

CANDLES III at Kamioka Lab.

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

Kamioka Lab. Map

CANDLES III

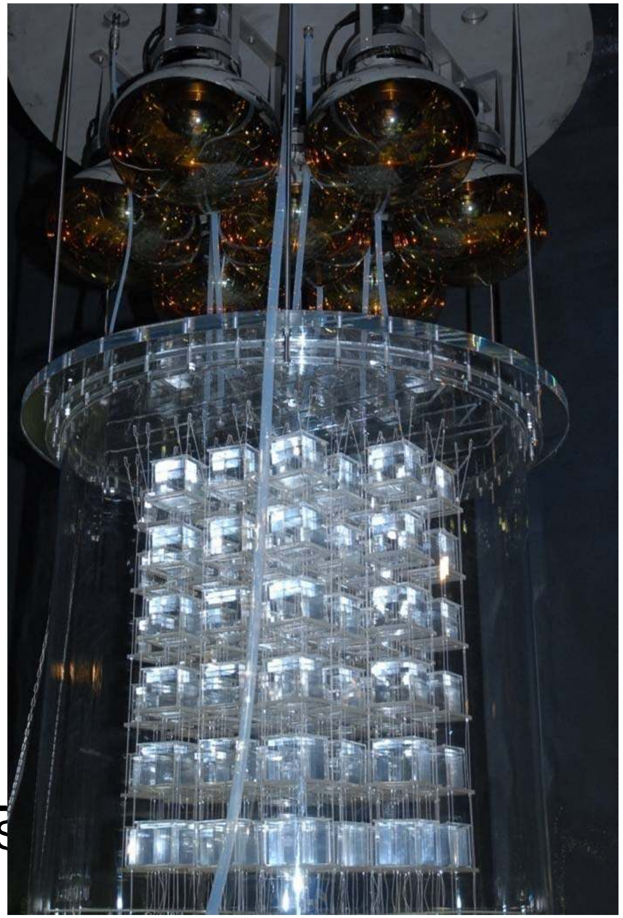


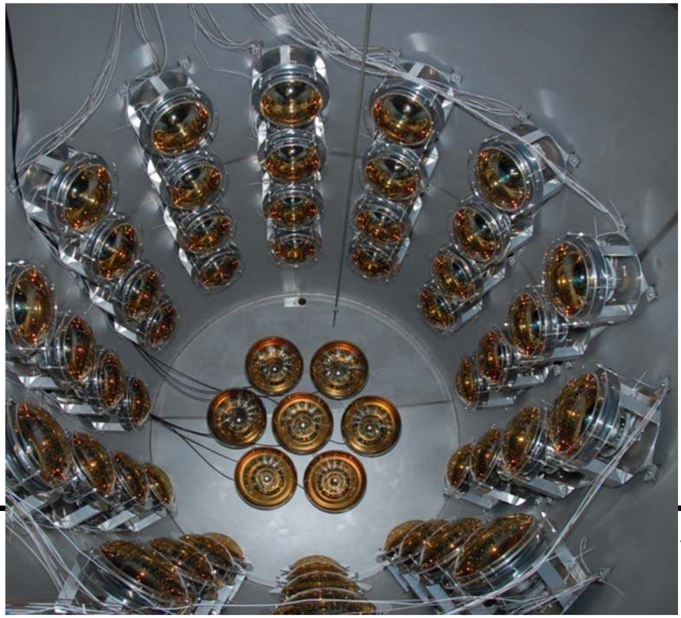
CANDLES III at Kamioka Lab.

- CANDLES III
  - 62 PMTs
  - 96 CaF_2(pure) Scintillators (~300kg)

First measurement
: without LS and water
for check of CaF_2 pulse shape
(without LS pulse)

Inside Modules
(CaF_2 Scintillators)



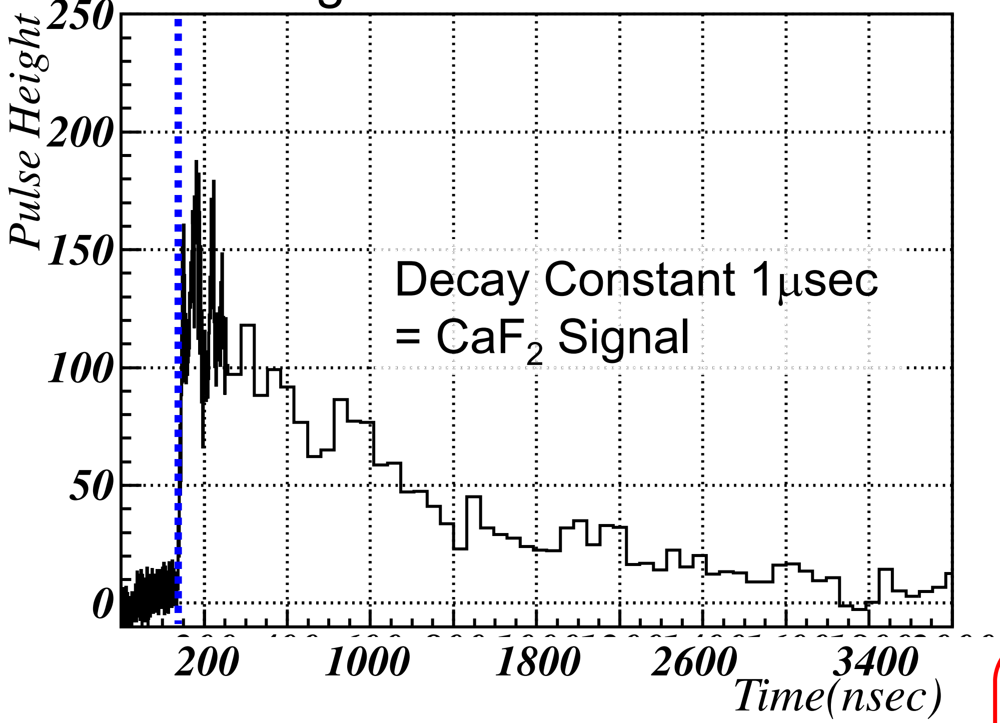


Inside View
of Water Tank

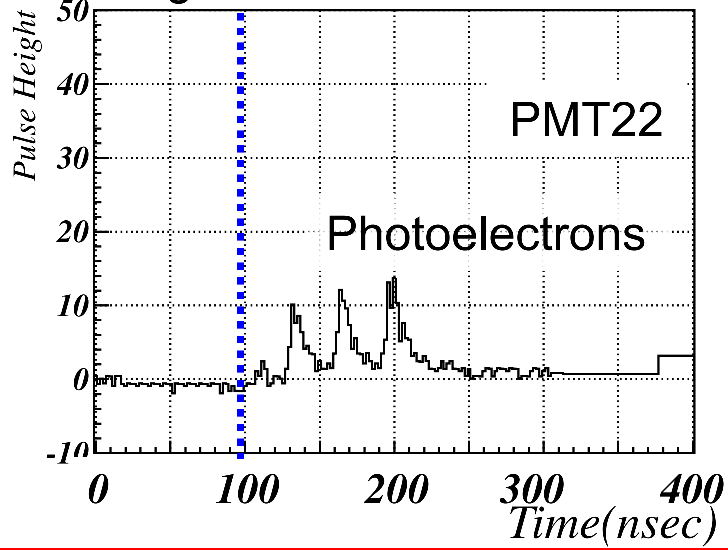
Measurement without LS and Water

Typical Pulse Shape

Sum Signal from 62 PMTs



Signal from each PMT



FADC for CANDLES system

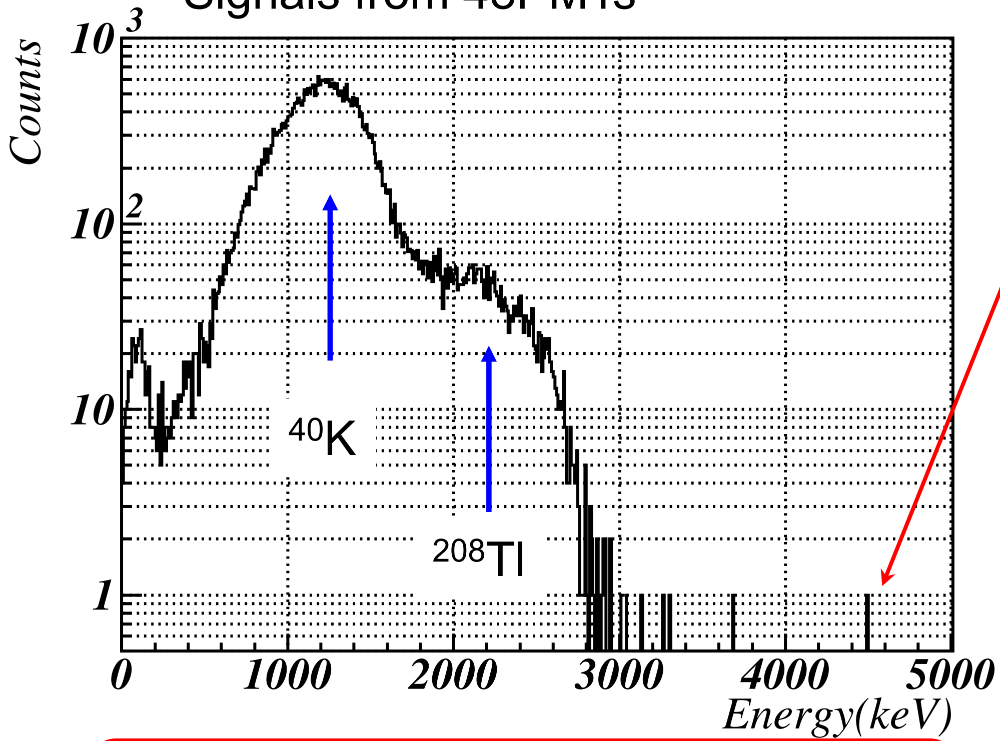
- Beginning of pulse : 500MHz FADC
- Late of pulse : 16MHz FADC

for Data suppression

Measurement without LS and water

Energy Spectrum

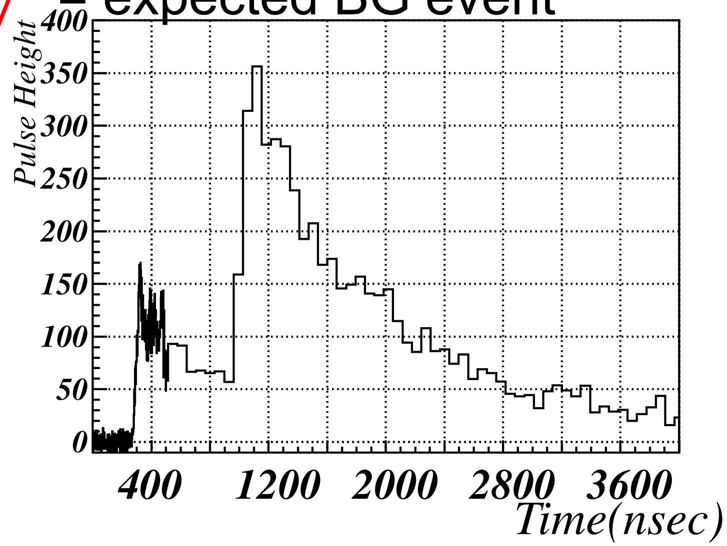
Signals from 48PMTs



- ^{40}K、^{208}Tl can be observed.
  →Reference pulse for CaF_2 signal

Pile-up event

Event at 4.5 MeV
= expected BG event



In this measurement . . .
・A high contaminated crystal as reference crystal (～30mBq/kg)

We can reject by FADC

June 2011 . . .
We started the measurement with LS and water.

R&D: Enrichment of ^{48}Ca

for Study of $0\nu\beta\beta$ by CANDLES

It needs a large amount of ^{48}Ca(~10kg)

→1^{st} Step : Large scale detector : CaF_2 of 300kg ~ a few ton

→2^{nd} Step :^{48}Ca enrichment（~2%⇔natural abundance 0.187%）

Technologies for ^{48}Ca Enrichment

Gas diffusion	､､､	×
Gas centrifuge	､､､	×
Chemical process	､､､	○

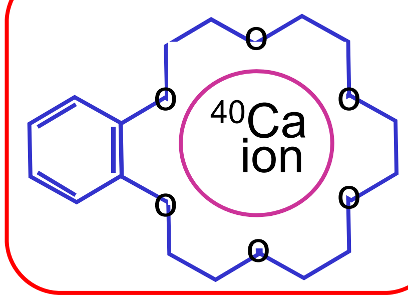
⇐ Calcium = No Gaseous Compound

⇩

Isotope enrichment by Crown-Ether

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

Crown-Ether



Setup for Enrichment Test

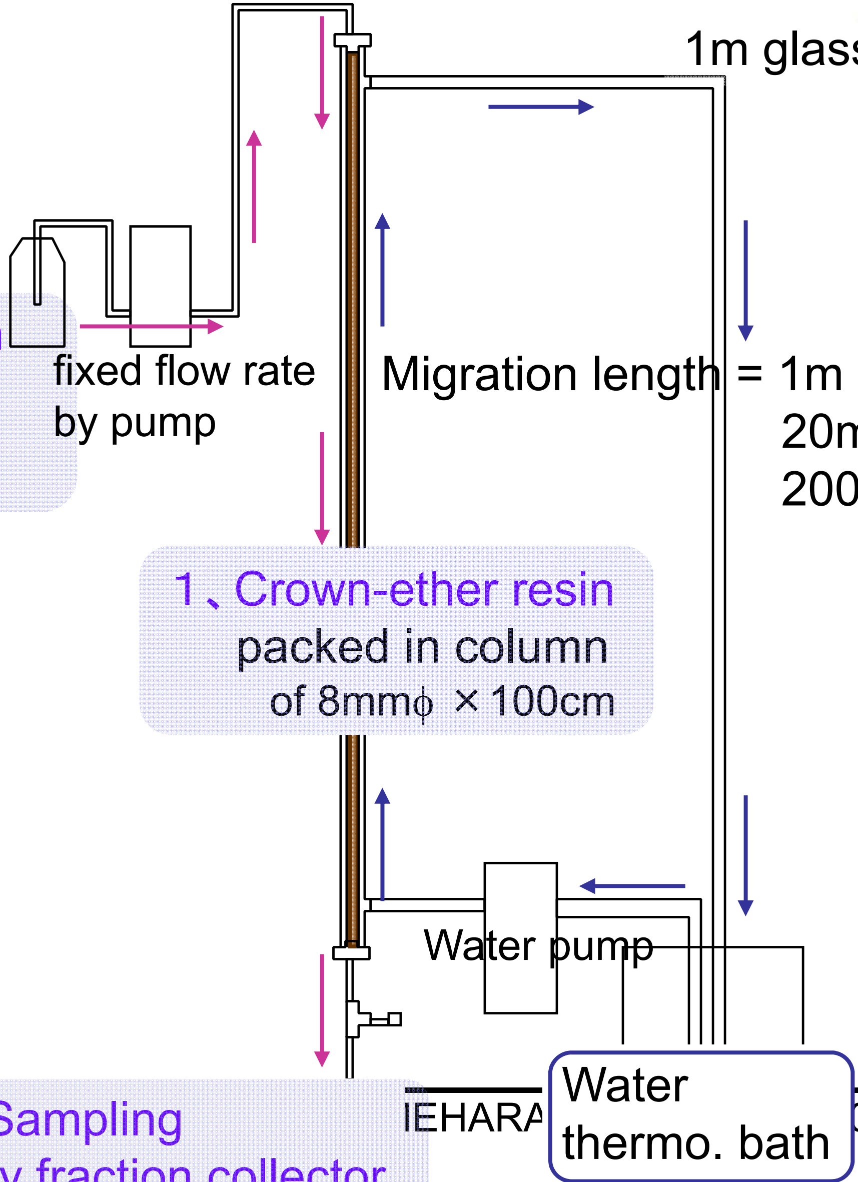
Experimental system

Chromatography:

Breakthrough method

= Migration of Ca solution in resin area

2、Ca solution
$CaCl_2$
+Conc. HCl



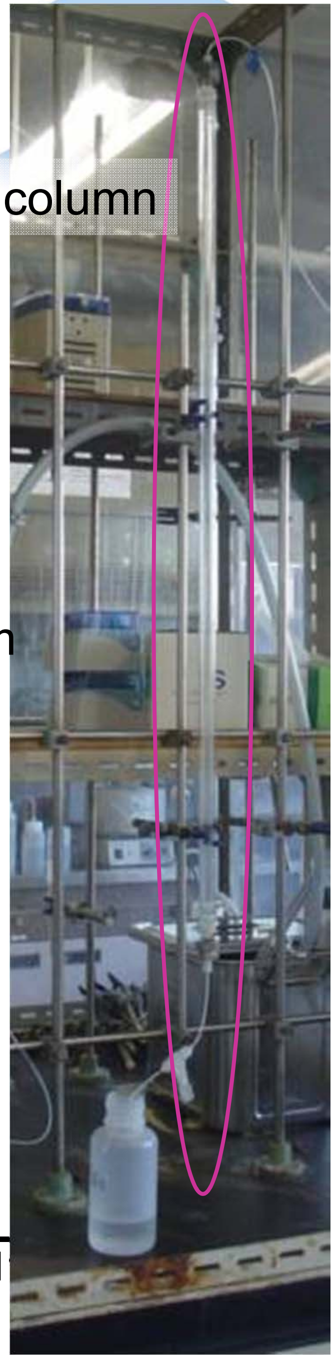
1、Crown-ether resin
packed in column
of 8mmϕ × 100cm

5、Measurement of isotopic ratio

4、Measurement of Ca concentration

Fraction collector

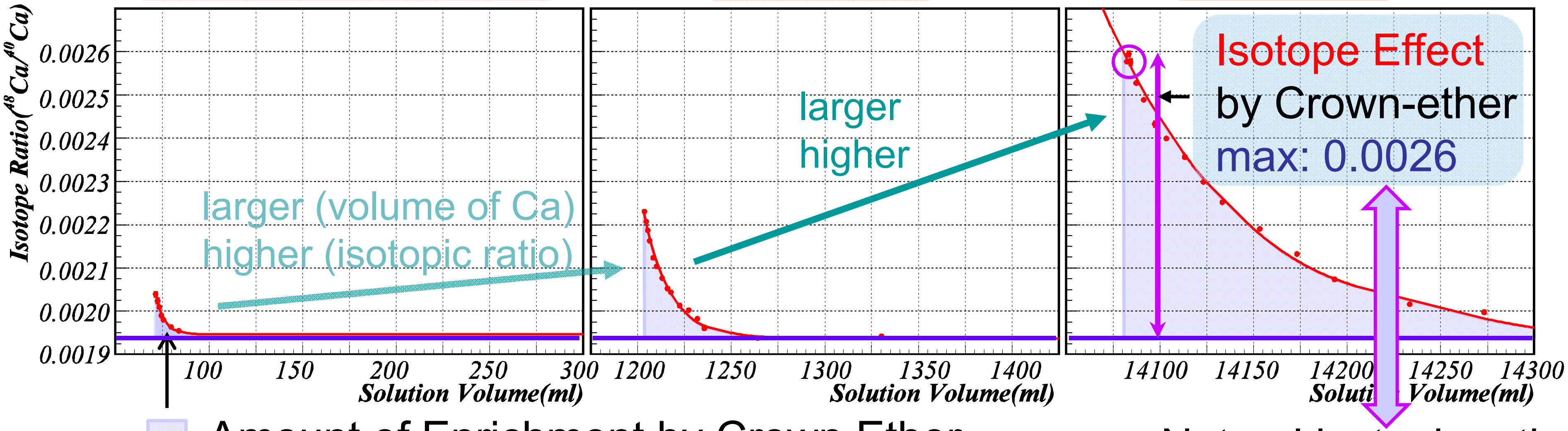
3、Sampling by fraction collector



Result of Enrichment

Isotope Enrichment with Longer Migration Time (Length)

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



Amount of Enrichment by Crown Ether

Natural isotopic ratio
= 0.0019

Isotope Effect (Enrichment Effect)

- The longer migration time(length) =
  the larger volume and the higher isotopic ratio
- We continue to study ^{48}Ca enrichment.

Current Rough Estimation

- for 2%^{48}Ca、200kg Calcium
  - Migration time : ~5~ years

- for improvement
  - Kind of crown-ether
    - Now:Benzo-18-crown-6-ether
    - Candidate : for example. . .

      Dibenzo-18-crown-6-ether → inexpensive (~1/10)
  - Optimization of migration parameter
    - Solvent : (now) HCl → (Candidate) Organic solvent (methanol. . .)
      - Good adsorptive rate
    - Migration speed : (now)0.3ml/min,1ml/min→3ml/min. . .

      time effective

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
  - Expected sensitivity : 0.5 eV for $<m_\nu>$

Current status

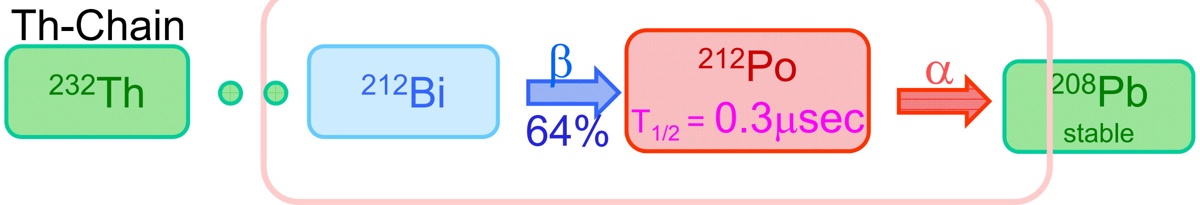
We started the measurement in June.

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

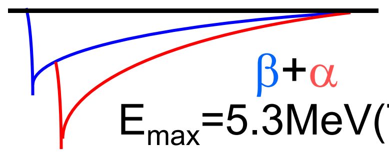
Backgrounds

Radioactive Contaminations in CaF_2 Crystals

Pile-up Events

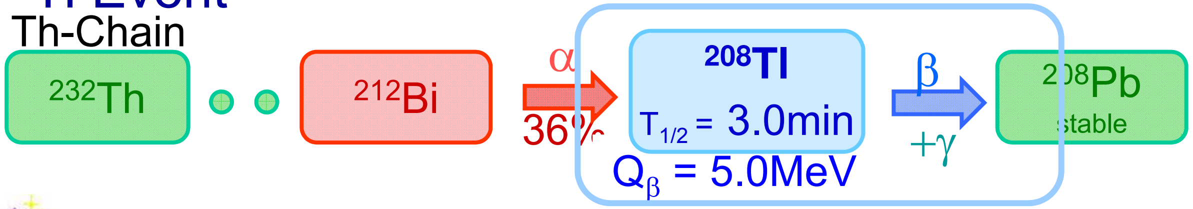


Pile-up because of τ of CaF_2 signal = 1μsec



E_{max}=5.3MeV(Th-chain)
5.8MeV(U-chain)

^{208}Tl Event



E_{max}=5.0MeV
^{212}Bi and ^{208}Tl($T_{1/2}$=3min) . . .
Space-Time Correlation Cut

2νββ Events

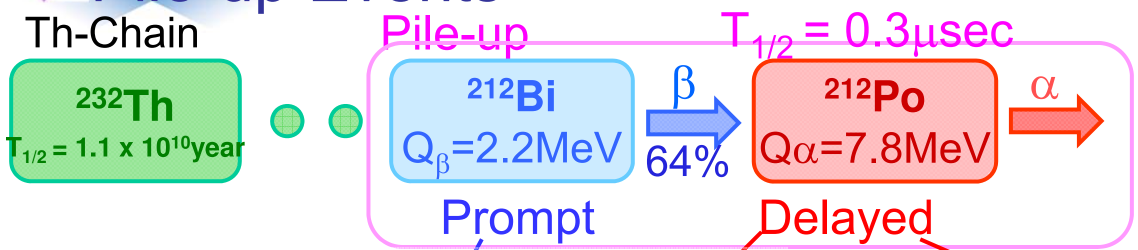
Possible to reduce by good energy resolution
. . . negligible in CANDLES III (expected resolution = ~4% at 4.27MeV)

Background Rejection

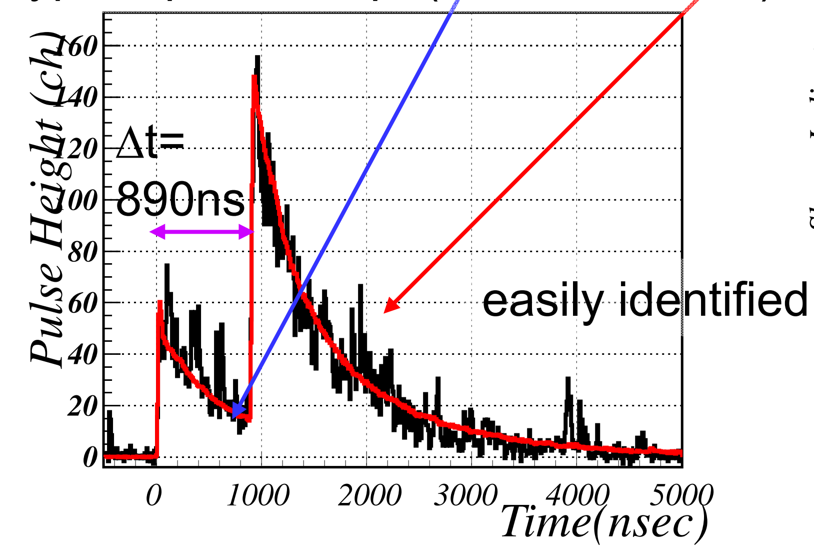
Pile-up Events . . . Pulse Shape Analysis by using FADC

Rejection of Pile-up Events

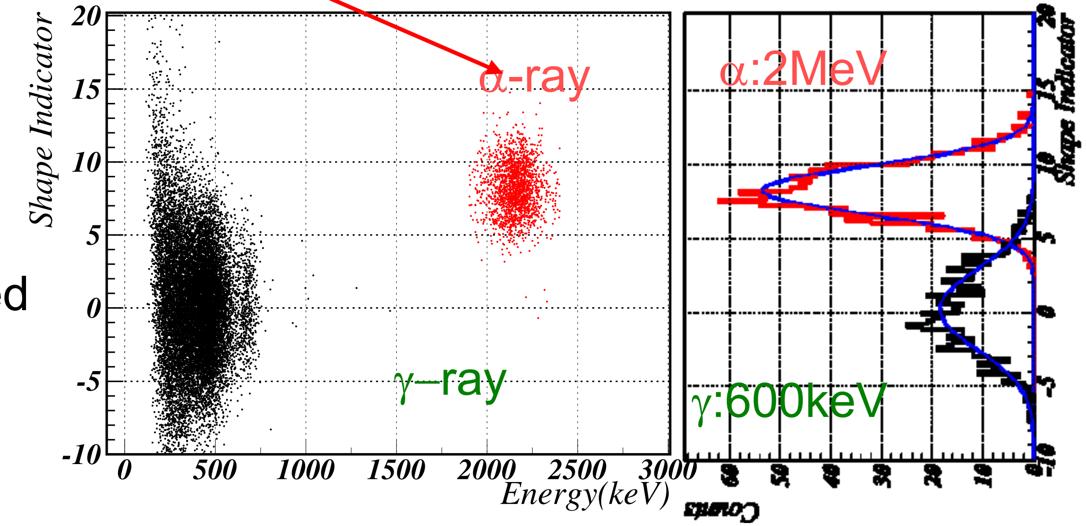
Pile-up Events



Typical pulse shape(500MHz FADC)



Particle discrimination between α and γ-rays



Pile-up event rejection ~99%

Clear discrimination for Δt > 5nsec

Rejection by particle discrimination ~ 99%

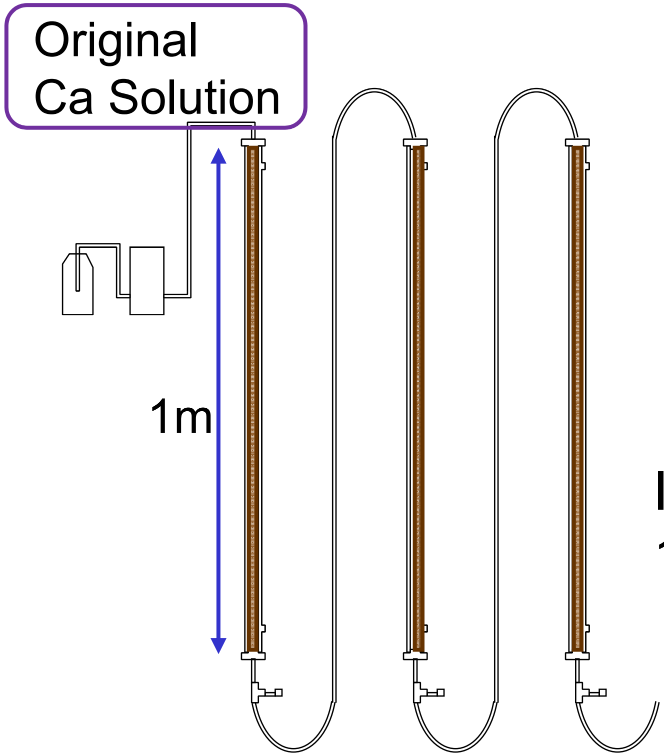
→Improvement with 4 order of magnitude

Setup for Long Migration

- Setup for Long Migration Experiment (200m migration)

  for high enriched Ca

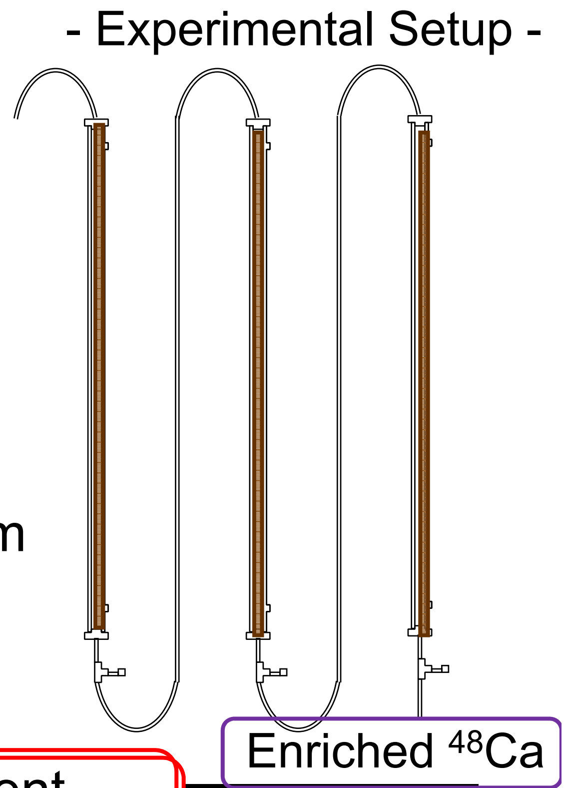
  - Regeneration & Reuse of Resin (by removing Ca ion)



1m × 200 columns

○ ○ ○ ○ ○ ○ ○ ○ ○

In this experiment,
18 times 12 columns = ~200m



Study for possibility of high enrichment
by long migration length

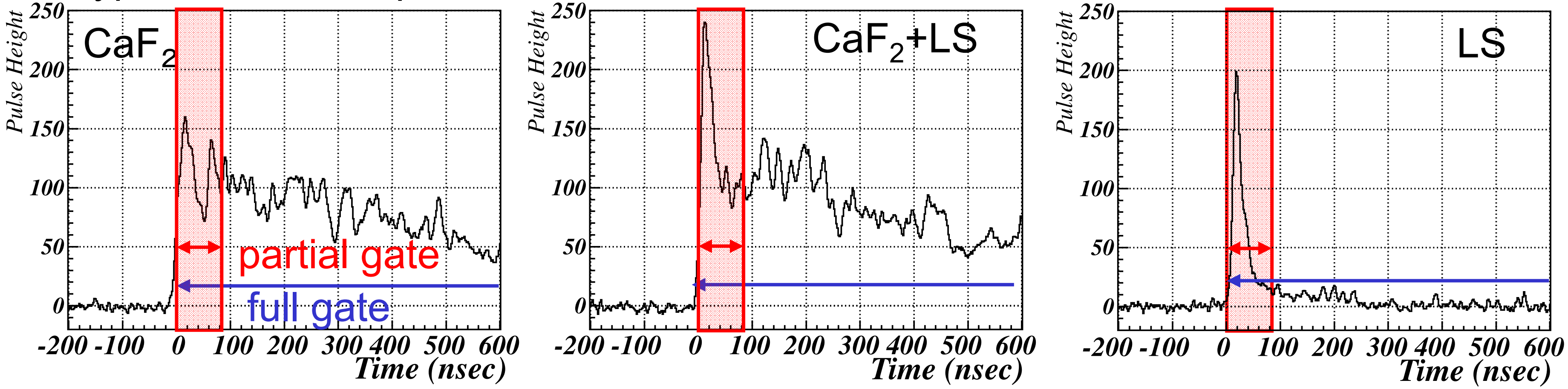
Rejection of LS Signals

Rejection by using FADC Data

3 Types of Pulse Shapes

τ of CaF_2 = 900nsec
LS = ~20nsec

Typical Pulse Shapes



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

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

We can clearly discriminate between CaF_2 and others