Search for neutrino-less double beta decay of ^{48}Ca - CANDLES -

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for CANDLES collaboration

Outline

- Double beta decay of ^{48}Ca
- CANDLES system
  =CaF_2(pure) scintillators + Liquid scintillator
  - CANDLES III system at Kamioka underground lab.
    - Shielding system for background reduction
  - Low background measurement
- for future CANDLES
  - Enrichment of ^{48}Ca
  - CaF_2 scintillating bolometer
- Summary

Double beta decay of ^{48}Ca

- Why ^{48}Ca ? : advantage of ^{48}Ca
  - higher $Q_{\beta\beta}$ value (4.27MeV) . . .

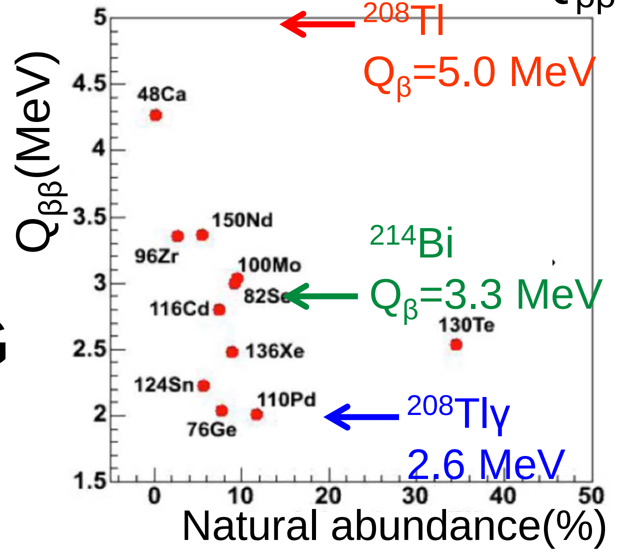
    →low background

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

    E_{max}=2.6MeV(^{208}Tl, γ-ray)

    3.3MeV(^{214}Bi,β-ray)
  - But small natural abundance 0.19%
- Double beta decay of ^{48}Ca by using CaF_2
  - CANDLES system
    - large scale detector : CANDLES III
    - Future : Enrichment + scintillating bolometer

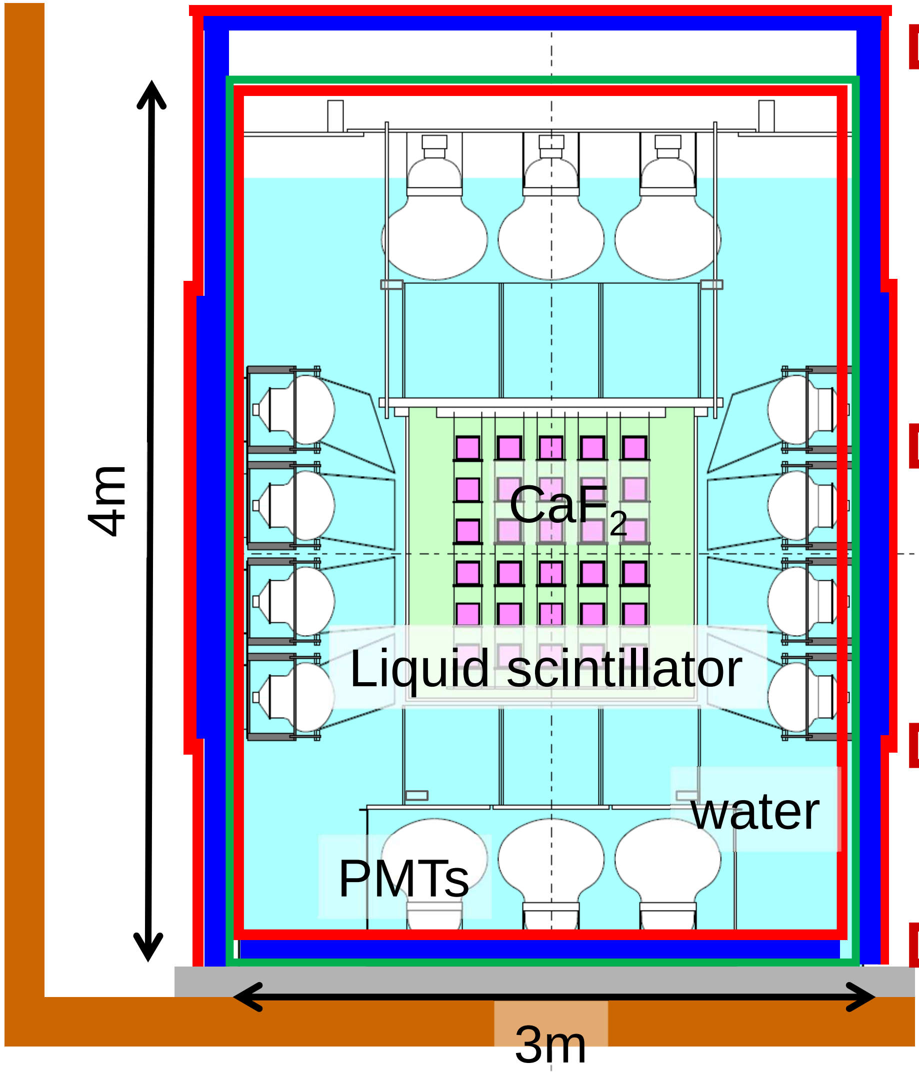
Natural abundance vs $Q_{\beta\beta}$




CANDLES
@Kamioka Observatory

CANDLES III

- CANDLES III at Kamioka underground laboratory



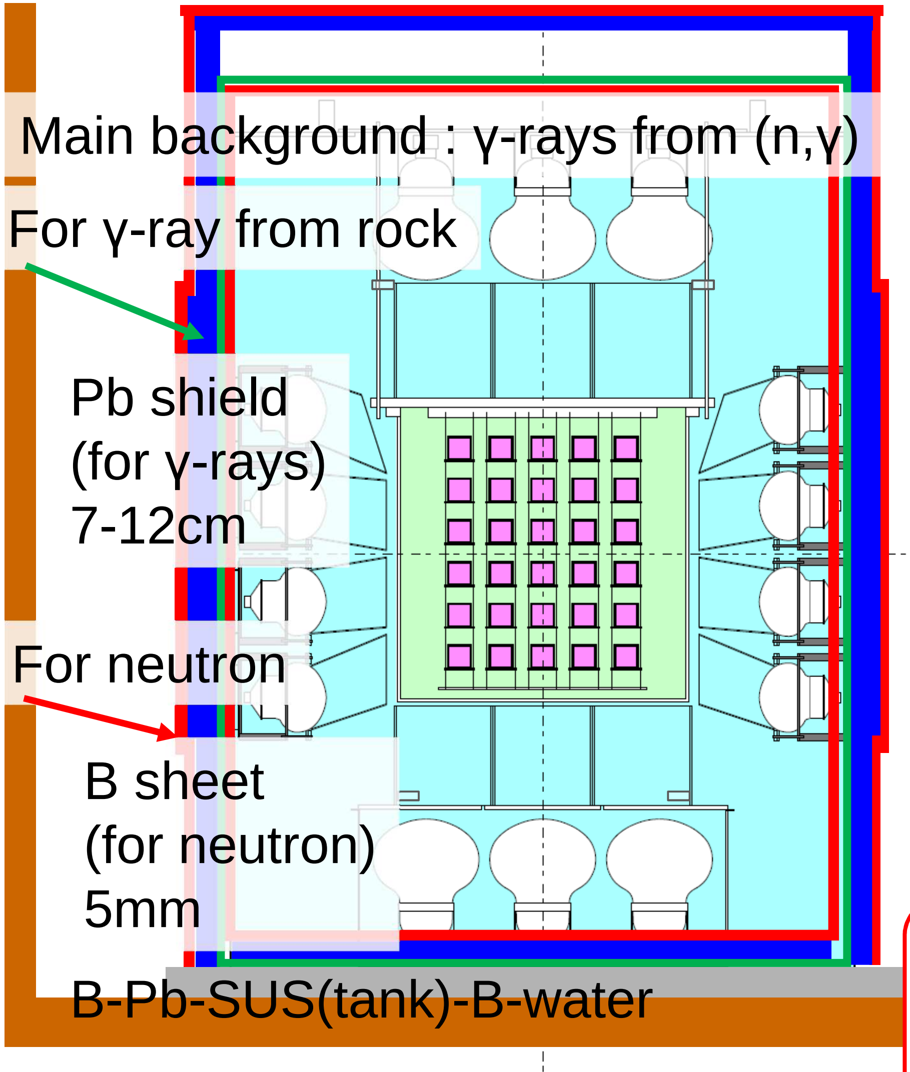
- CaF_2 scintillator (CaF_2 (pure))
  - 305kg (96modules × 3.2kg)
  - ^{48}Ca : 350g
  - time constant:~ 1μsec
- Liquid scintillator (LS)
  - 4π active shield($2m^3$)
  - time constant :a few 10nsec
- 62 Large photomultiplier tube

↓

- realize 4π active shield
  - by pulse shape analysis

Shielding system

☐ Toward “background free measurement” : neutron



CANDLES tank(stainless steel)
Pb（γ-ray shield）
B sheet（neutron shield）

☐ Shielding system：BG ~1/100

Pb bricks (7-12 cm in thickness)
- reduce γ-ray BG from (n,γ) reaction
- BG γ-rays from rock decrease
  by factor of ~1/120

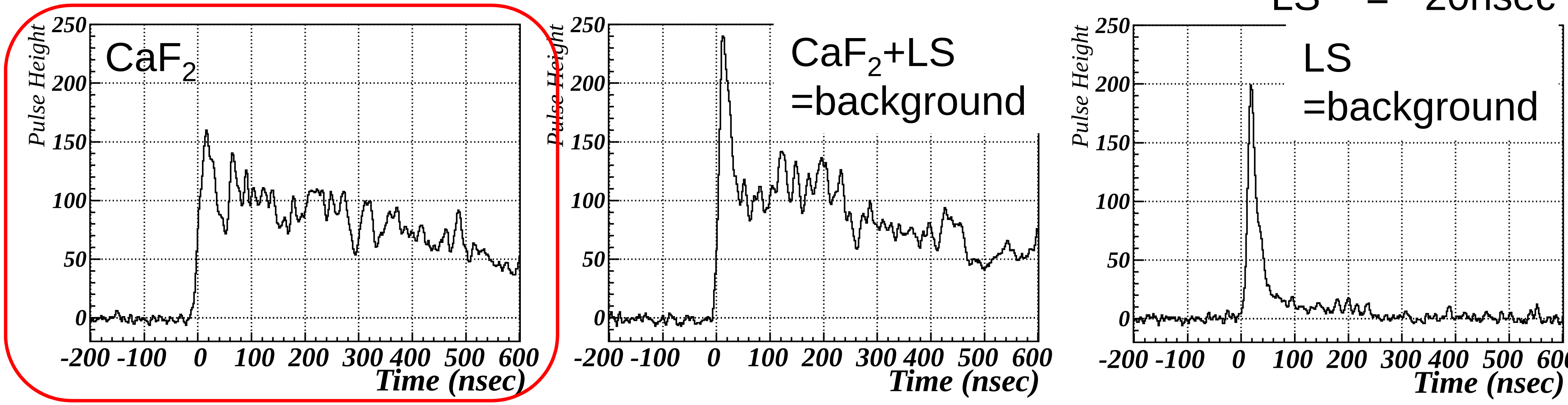
B sheet (5mm in thickness)
- reduce thermal neutron
  → reduce BG from (n,γ) in main tank.
- n-capture events decrease
  by factor of ~1/30

Construction of the shielding system
- Shieldings inside/outside the tank
- BG rate : ~ 1/100

Background rejection by liquid scintillator

- Rejection of external γ-ray backgrounds by pulse shape discrimination
- Typical pulse shape in CANDLES III

τ of CaF_2 = ~1000nsec
LS = ~20nsec



- In CANDLES system . . .
  - Difference of pulse shape
    - short（LS scintillator=a few 10ns）and long（CaF_2=~4μsec）
  - CaF_2 selection by using pulse shape information

→realized 4π active shield

Result

- Result of measurement for 131days

	results
0νββ efficiency	0.39±0.06
Num. of eve.(exp)	0
Expected BG	~1.2
Half life of ^{48}Ca	$>6.2\times10^{22}$year
Sensitivity	3.6×10^{22}year

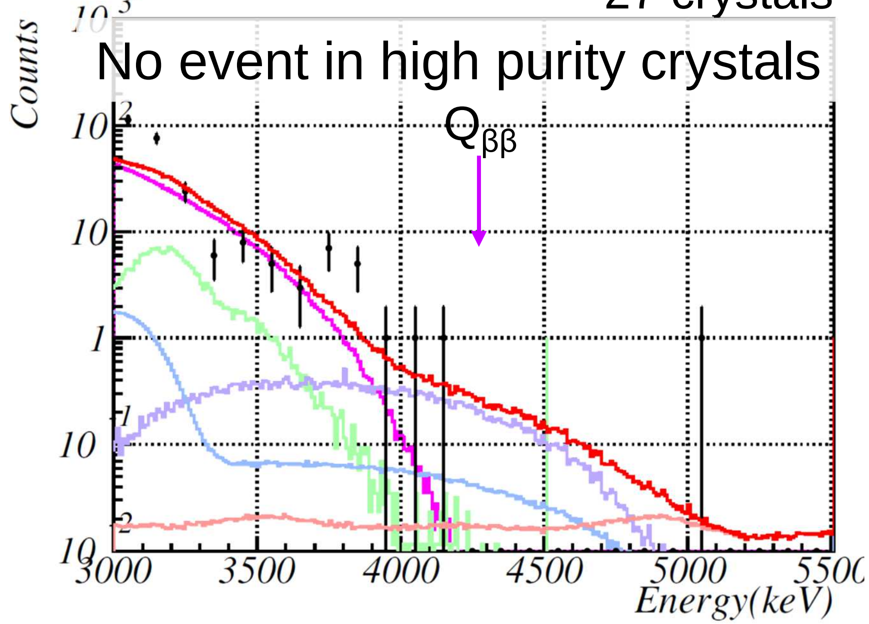
＊ELEGANT VI
measurement time：4947kg・day(2 years <)
half life limit　：5.8×10^{22} year

● experimental data
simulation(total)
γ-ray from N capture
contamination：^{208}Tl
2νββ
other BG

Energy spectrum and BG simulation

27 crystals

No event in high purity crystals

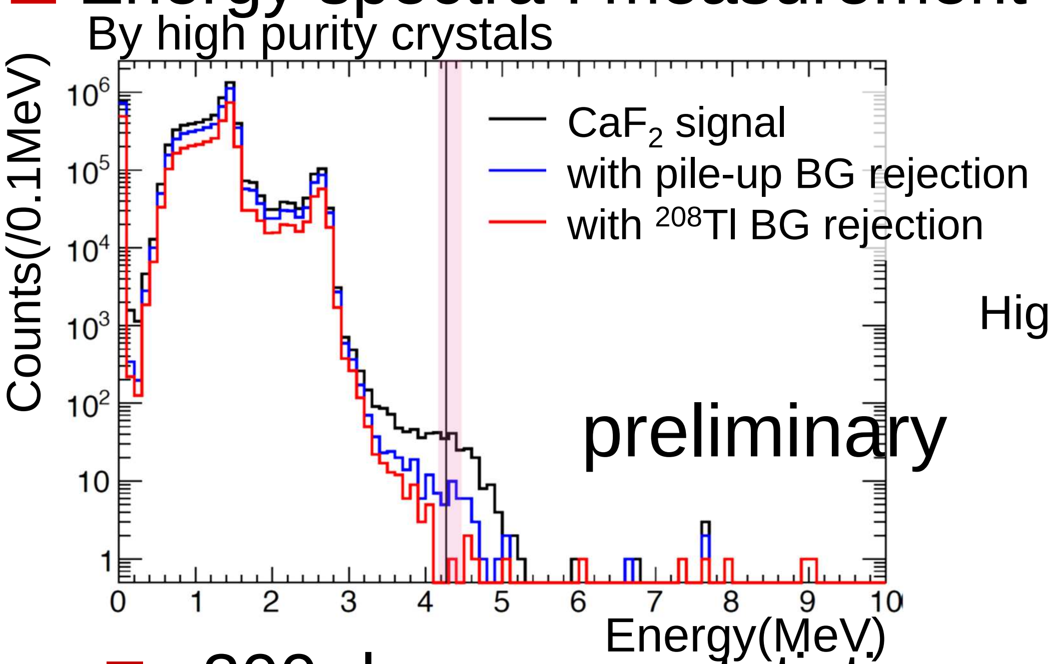


CANDLES is giving the best half-life limit of ^{48}Ca
・further data taking
・development for future CANDLES

Further measurement : update

Preliminary

- Energy spectra : measurement time 504 days

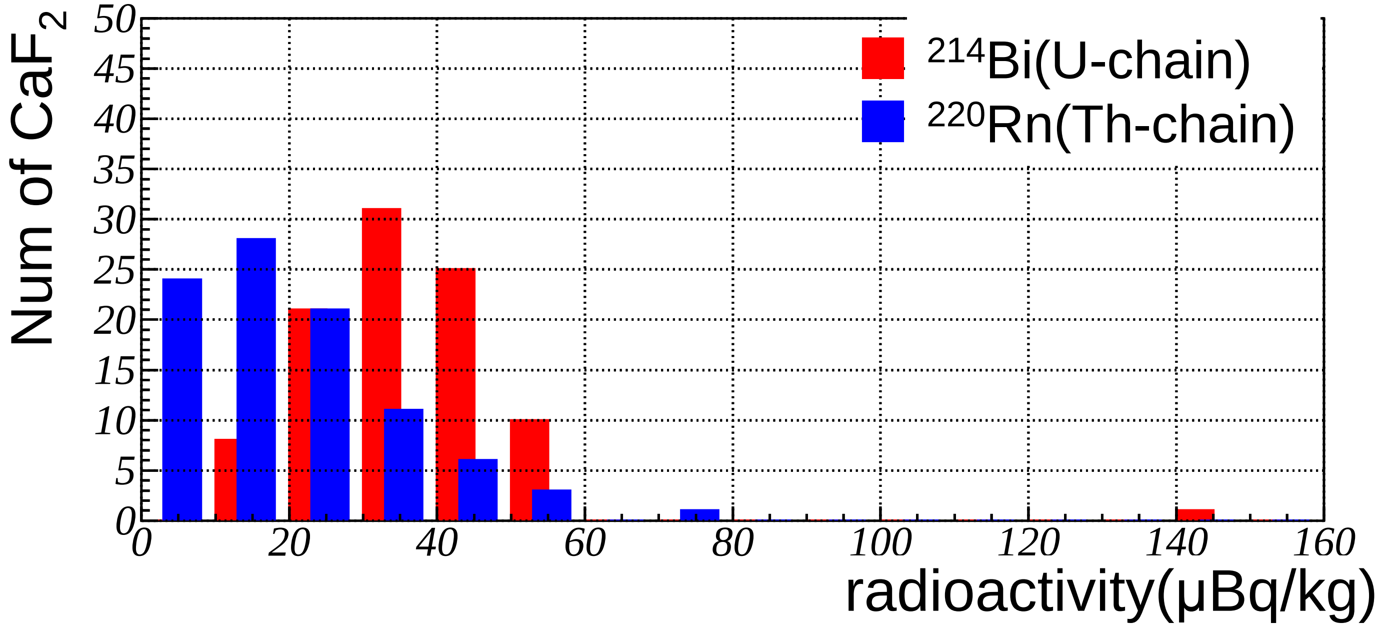


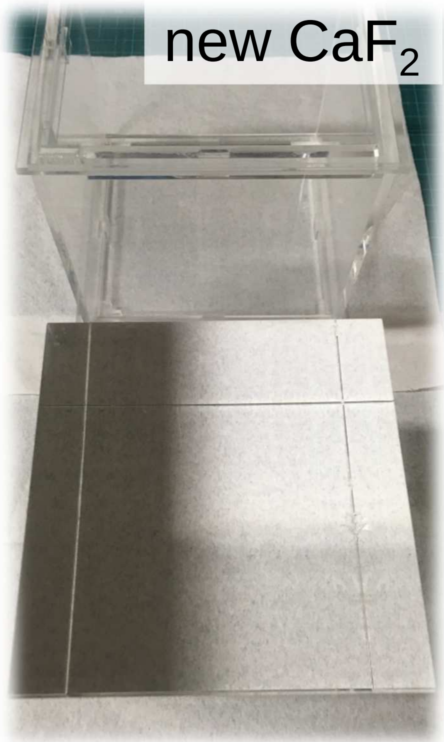
High purity crystals < 10μBq/kg(^{232}Th)

- ~300 days more statistics
  - not yet finished analysis (not optimized analysis)
- Obtained spectra : as expected from BG estimation
- We will update the half-life limit of ^{48}Ca

Upgrade for CANDLES III

- Main background : Th contamination in CaF_2
  - Radioactivity of 96 CaF_2 crystals & replacement





Replacement to high purity(Th) CaF_2

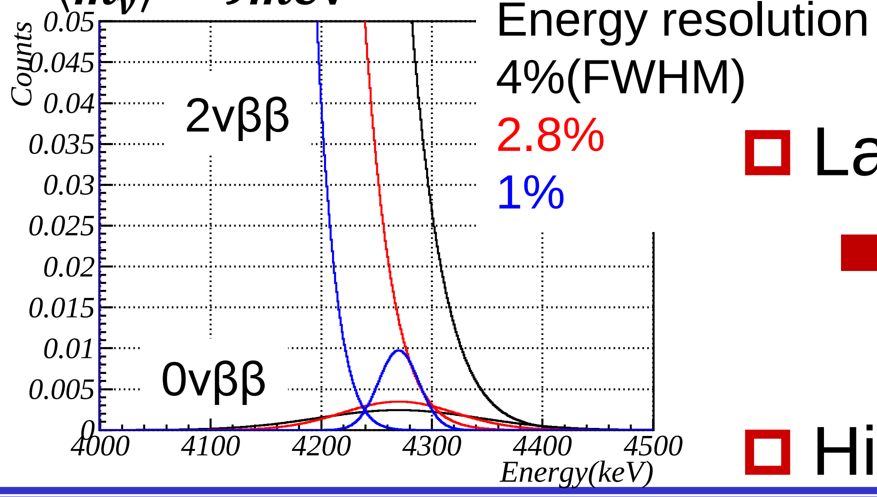
- We will restart the measurement in this autumn after CaF_2 replacement.

Future CANDLES

- Next step of double beta decay measurement

	CANDLES III	Next detector system
^{48}Ca Abundance	0.187%	50%
^{48}Ca Weight	0.35 kg	600 kg ~
Energy Resolution	6%	1.0% (required)
$\langle m_\nu \rangle$ sensitivity	500meV	~9 meV
Feature	Cooling CaF_2 Low BG	Massive ^{48}Ca & high energy resolution IH ⇒ NH

$\langle m_\nu \rangle = 9meV$



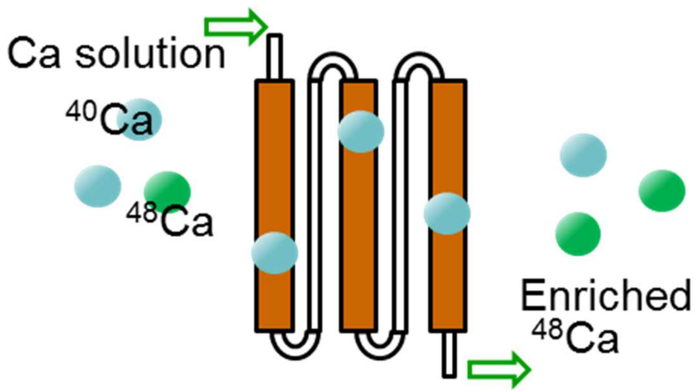
- Large amount of ^{48}Ca
  - Current CANDLES limited by mass of ^{48}Ca
- Higher energy resolution

Next detector system：enrichment

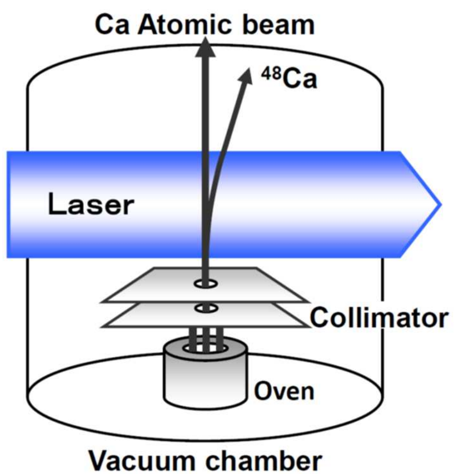
- ^{48}Ca
  - Natural abundance is low：0.19%

    →We can improve the detector sensitivity by enrichment
  - But enrichment of ^{48}Ca is difficult
- New enrichment techniques
  - Crown-ether, laser enrichment, Electrophoresis

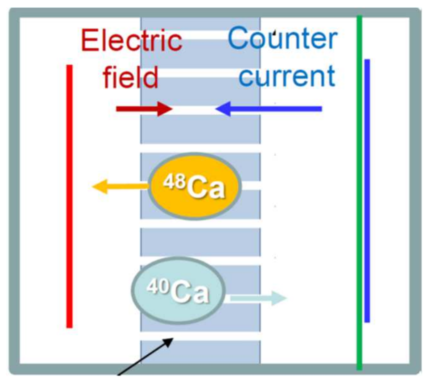
Chemical enrichment by crown-ether



Laser enrichment



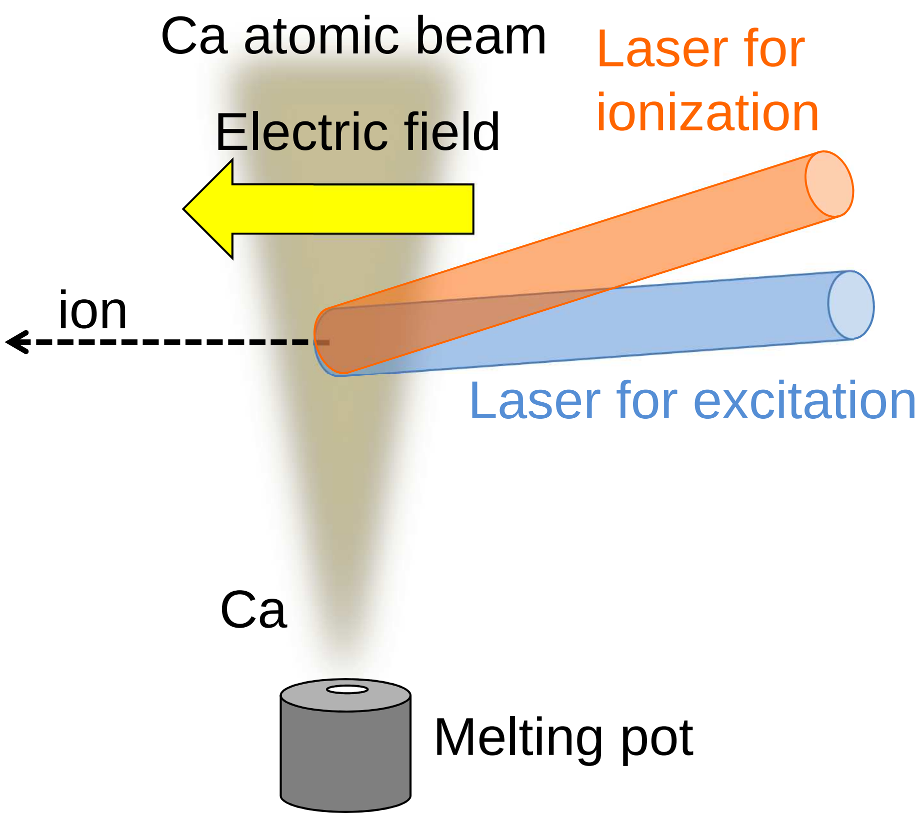
Electrophoresis

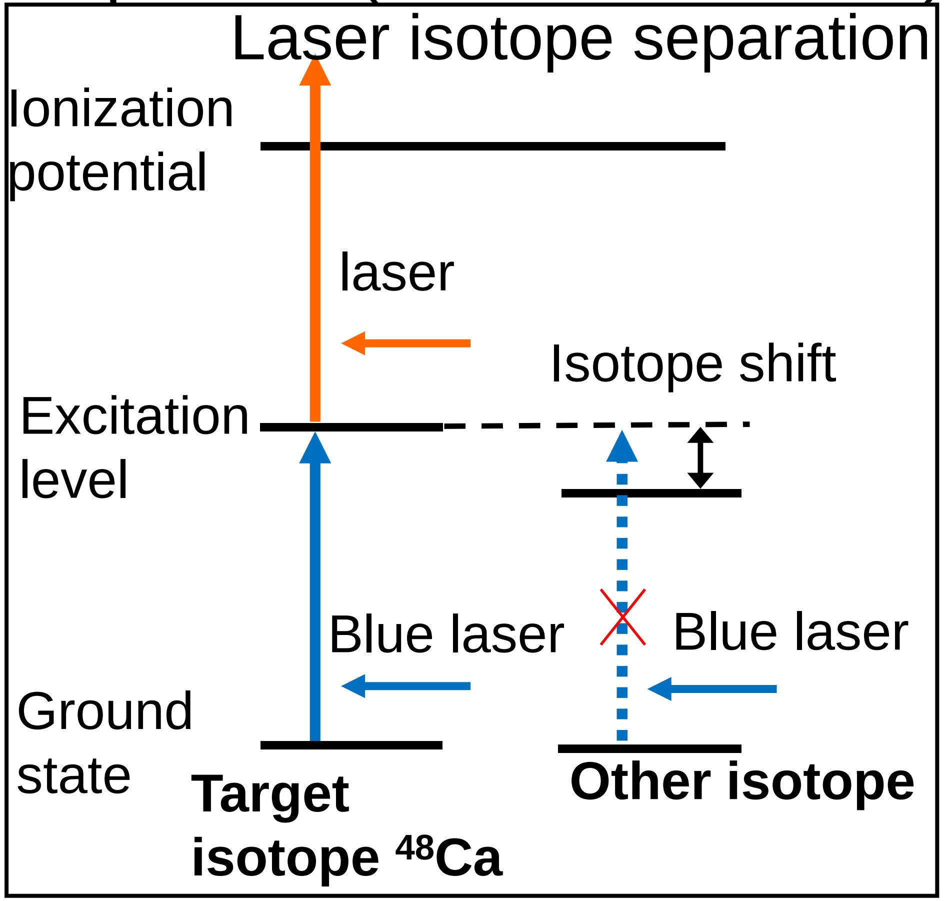


Laser isotope separation

Niki-group, Fukui Univ.

- Today's topic : laser isotope separation(ionization method)





lasers

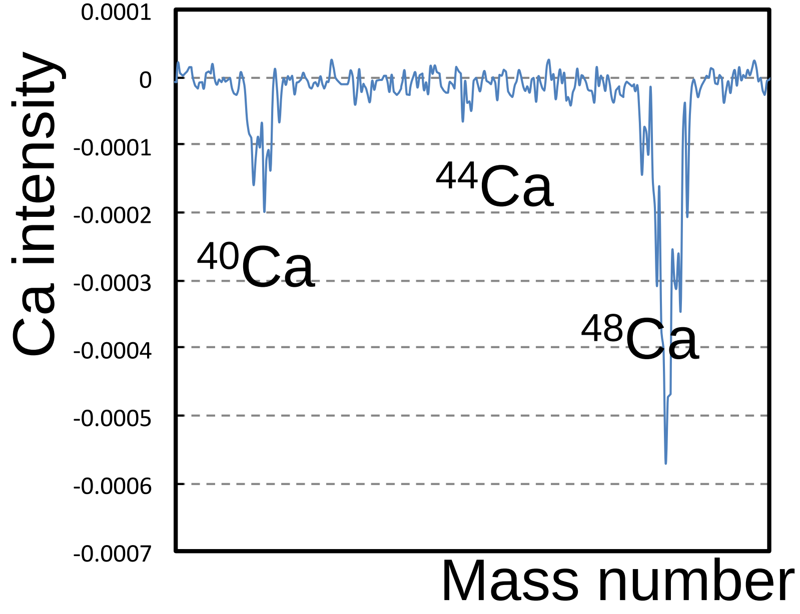
blue laser for excitation with controlled wavelength

laser for ionization

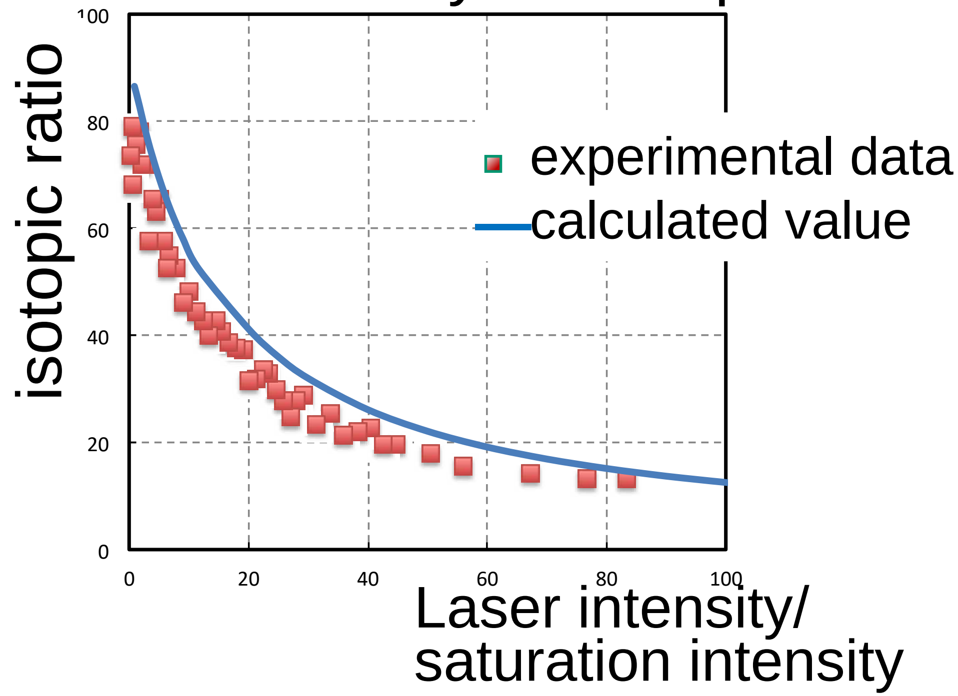
Laser isotope separation

Niki-group, Fukui Univ.

Mass spectrum



Laser intensity vs isotopic ratio



Maximum isotopic ratio：78%
~ NA × 400

Simulation represented exp. data

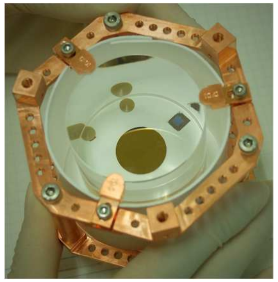
principle experiment : OK(ionization method, deflection method)

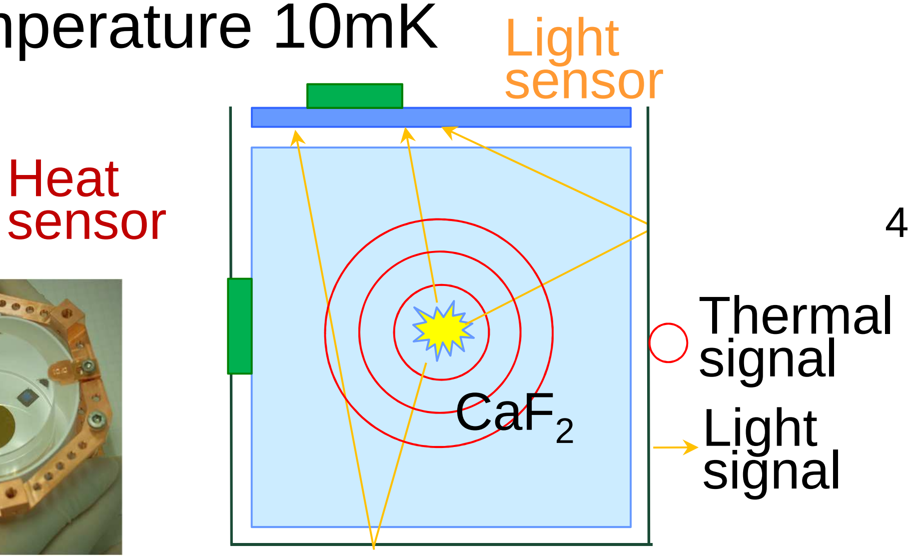
But small amount → Now on stage of mass production

High-output blue laser with high-resolution wave length

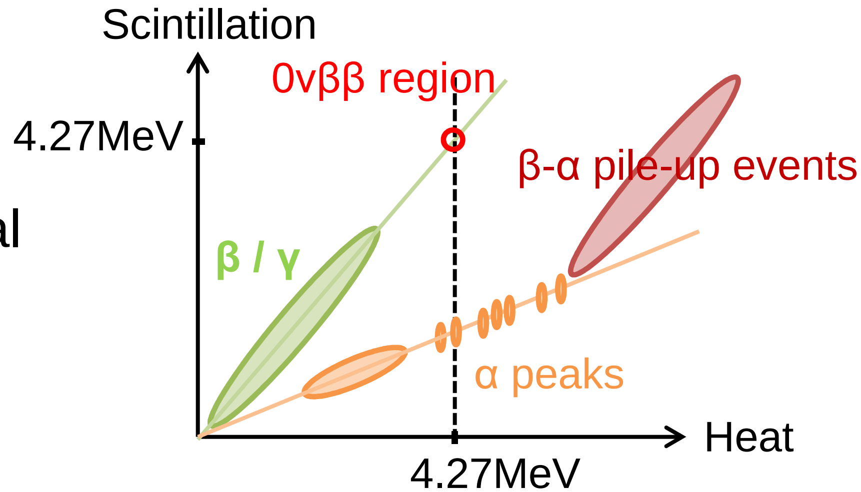
Next detector system：scintillating bolometer

Scintillating bolometer at low temperature 10mK





Particle identification by scintillating bolometer

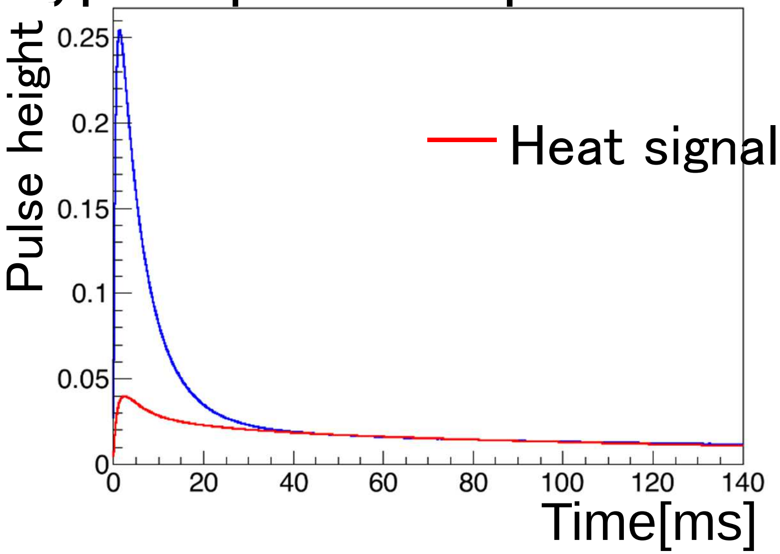


- Expected BG： 2νββ events, α-rays
- bolometer：good energy resolution
  - For reduction of BG affects from 2νββ events
- Scintillating bolometer：good particle identification ability
  - For reduction of BG affects from α-ray

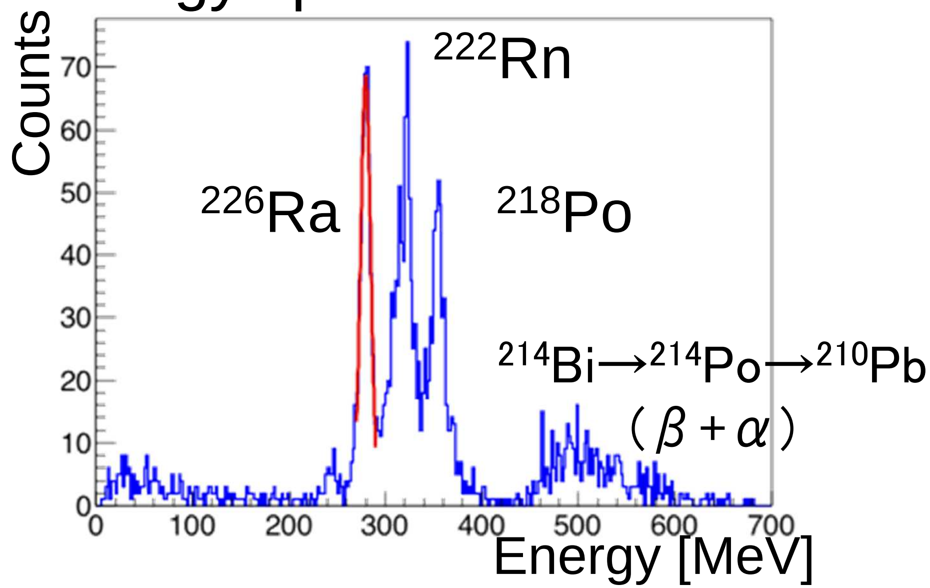
Scintillating bolometer

with Kim Yong-Hamb-group, Korea

Typical pulse shape



Energy spectrum of α-events



- First result of CaF_2(pure) scintillating bolometer
  - We achieved simultaneous measurement of heat & scintillation signals
  - Energy resolution(σ): 1.86±0.11%
- We aim to improve energy resolution

Summary

- CANDLES
  - Measurement of ^{48}Ca double beta decay
  - We installed the shielding system.
    - BG from neutron capture is reduced by ~1/100
  - Obtained half-life limit：>6.2×10^{22}年
    - new half-life limit of ^{48}Ca.
    - We will update half-life by further data & upgrade.
- Future
  - We will apply :
    - Enrichment of ^{48}Ca :$^{48}CaF_2$
      - Now on stage of “cost effective” mass production
    - CaF_2 scintillating bolometer