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

Umehara, Saori
Research Center for Nuclear Physics, Osaka University
umehara@rcnp.osaka-u.ac.jp

for CANDLES collaboration
Outline

- Double beta decay of $^{48}$Ca
- CANDLES system
  - $\text{CaF}_2$(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
  - $\text{CaF}_2$ 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
    - $E_{\text{max}}=2.6\text{MeV}(^{208}\text{Tl, }\gamma\text{-ray})$
    - 3.3MeV($^{214}\text{Bi, }\beta\text{-ray}$)
  - 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
CANDLES III

CANDLES III at Kamioka underground laboratory

- CaF$_2$ scintillator (CaF$_2$ (pure))
  - 305kg (96 modules × 3.2kg)
  - $^{48}$Ca: 350g
  - time constant: ~ 1 μsec

- Liquid scintillator (LS)
  - 4$\pi$ active shield (2m$^3$)
  - time constant: a few 10 nsec

- 62 Large photomultiplier tube

- realize 4$\pi$ active shield
  - by pulse shape analysis
**Shielding system**

- Toward “background free measurement” : neutron

  - Main background : γ-rays from (n,γ)
  - For γ-ray from rock:
    - Pb shield (for γ-rays) 7-12cm
  - For neutron:
    - B sheet (for neutron) 5mm

  - 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 $\gamma$-ray backgrounds by pulse shape discrimination

- Typical pulse shape in CANDLES III

\[ \tau_{\text{CaF}_2} = \sim 1000 \text{nsec} \]
\[ \tau_{\text{LS}} = \sim 20 \text{nsec} \]

- In CANDLES system . . .
  - Difference of pulse shape
    - short ($\text{LS scintillator} = \text{a few 10ns}$) and long ($\text{CaF}_2 = \sim 4 \mu\text{sec}$)
  - $\text{CaF}_2$ selection by using pulse shape information
    $\rightarrow$ realized 4$\pi$ active shield
Result

Result of measurement for 131days

<table>
<thead>
<tr>
<th></th>
<th>results</th>
</tr>
</thead>
<tbody>
<tr>
<td>0νββ efficiency</td>
<td>0.39±0.06</td>
</tr>
<tr>
<td>Num. of eve.(exp)</td>
<td>0</td>
</tr>
<tr>
<td>Expected BG</td>
<td>~1.2</td>
</tr>
<tr>
<td>Half life of $^{48}$Ca</td>
<td>$&gt;6.2 \times 10^{22}$ year</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>$3.6 \times 10^{22}$ year</td>
</tr>
</tbody>
</table>

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

No event in high purity crystals

Energy spectrum and BG simulation

CANDLES is giving the best half-life limit of $^{48}$Ca
  • further data taking
  • development for future CANDLES
Further measurement : update

- Energy spectra : measurement time 504 days
  By high purity crystals
  
  ![Energy spectrum graph]

  - CaF$_2$ signal
  - with pile-up BG rejection
  - with $^{208}$Tl BG rejection

  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**

<table>
<thead>
<tr>
<th></th>
<th>CANDLES III</th>
<th>Next detector system</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{48}$Ca Abundance</td>
<td>0.187%</td>
<td>50%</td>
</tr>
<tr>
<td>$^{48}$Ca Weight</td>
<td>0.35 kg</td>
<td>600 kg ~</td>
</tr>
<tr>
<td>Energy Resolution</td>
<td>6%</td>
<td>1.0% (required)</td>
</tr>
<tr>
<td>$\langle m_\nu \rangle$ sensitivity</td>
<td>500meV</td>
<td>~9 meV</td>
</tr>
<tr>
<td>Feature</td>
<td>Cooling CaF$_2$ Low BG</td>
<td>Massive $^{48}$Ca &amp; high energy resolution IH $\Rightarrow$ NH</td>
</tr>
</tbody>
</table>

- **Energy resolution**

  - $2\nu\beta$: 2.8%
  - $0\nu\beta$: 1%
  - 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%
  - $\rightarrow$ 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
Today’s topic: laser isotope separation (ionization method)

Laser for ionization

Laser for excitation

Isotope shift

Ground state

Excitation level

Ionization potential

Target isotope $^{48}\text{Ca}$

Other isotope

Blue laser

Laser isotope separation

Niki-group, Fukui Univ.

Ca atomic beam

Electric field

Melting pot

Lasers

blue laser for excitation with controlled wavelength

laser for ionization

Laser isotope separation

Mass spectrum

Laser intensity vs isotopic ratio

Maximum isotopic ratio: 78% ~ \( \text{NA} \times 400 \)

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**
  - ![Diagram](image)
  - **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

- First result of CaF$_2$(pure) scintillating bolometer
  - We achieved simultaneous measurement of heat & scintillation signals
  - Energy resolution(\(\sigma\)) : 1.86 ± 0.11%
- We aim to improve energy resolution
Summary

- CANDLES
  - Measurement of $^{48}\text{Ca}$ double beta decay
  - We installed the shielding system.
    - BG from neutron capture is reduced by $\sim 1/100$
  - Obtained half-life limit: $>6.2 \times 10^{22}$ 年
    - new half-life limit of $^{48}\text{Ca}$.
    - We will update half-life by further data & upgrade.

- Future
  - We will apply:
    - Enrichment of $^{48}\text{Ca} : ^{48}\text{CaF}_2$
      - Now on stage of “cost effective” mass production
    - CaF$_2$ scintillating bolometer