The DCBA Double Beta Decay experiment

11 June, 2012

Hidekazu Kakuno
Tokyo Metropolitan University
ββ experiments in the world

Scintillation/Calorimetry

- Ionization: COBRA ($^{130}$Te, $^{116}$Cd, etc.), Majorana ($^{76}$Ge), GERDA ($^{76}$Ge)
- Scintillation: CANDLES ($^{48}$Ca), MOON ($^{100}$Mo), KamLAND-Zen ($^{136}$Xe), SNO+ ($^{150}$Nd)
- Bolometry: CUORE ($^{130}$Te)

Combination

- NEMO3 ($^{100}$Mo, $^{82}$Se, $^{150}$Nd, etc.)
- Super NEMO ($^{82}$Se, $^{150}$Nd, etc.)

Tracking (momentum reco.)

- DCBA ($^{100}$Mo, $^{150}$Nd, etc.)
(Dis-)Advantages of Tracking method

Advantages:

- Insensitive to the neutral background (e.g. $\gamma$-ray)
- More information than other methods:
  - Full 4-momentum and charges of two $\beta$-rays
  - Decay vertex position
- Good background rejection:
- More information (E-spectrum of single $\beta$, angular correlation) to constrain New Physics beyond the SM (if $0\nu\beta\beta$ observed)

Disadvantage:

For better resolution:
Need to have **less material** inside of the tracking volume

For better statistics:
Need to have **more source** inside of the tracking volume

hard to increase source weight
DCBA: method

- have source plate(s) inside of the tracking volume
  Source plate: $^{100}$Mo ($^{150}$Nd in future)
- emitted two electrons make helical trajectories inside of the tracking volume
- reconstruct momenta of two electrons

Source plate is put parallel the B-field
→ electrons having large angle to the source plate, travel across the B-field
DCBA: track reconstruction method

Reconstruction of position information
X: drift time
Y: hit position of the anode wire
Z: hit position of the pickup wire

Kinetic energy
\[ T = \sqrt{p_t^2 + p_z^2 + m_e^2 - m_e} \]
\[ = \sqrt{(0.3B\rho)^2(1 + \tan^2\lambda) + m_e^2 - m_e} \]
\[ = \sqrt{(0.3B\rho)^2 / \cos^2\lambda + m_e^2 - m_e} \]
Display of $\beta\beta$ candidate

- Left: $\beta^- 0.82$ MeV
- Right: $\beta^- 0.67$ MeV

Vertex point
Event displays

Signal candidate (left-top) and backgrounds (others)

$\#\text{signal candidate}/\#\text{background} \sim 1/10000$

DCBA can separate signals and backgrounds event-by-event by looking at their hit pattern.
DCBA experiment

DCBA experiment is performed at Fuji-experimental hall @ KEK
<table>
<thead>
<tr>
<th>Year</th>
<th>DCBA/T2/T2.5/T3/T3.5</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>2005 DCBA</td>
<td>charge dividing</td>
<td>6 mm pitch wires (xy + xz)</td>
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</table>
| 2007 DCBA-T2 | $^{100}$Mo source (natural Mo 30g) | 0.6 - 0.8 kG magnetic field  
|          | Normal conducting magnet: 9h/day operation (Mon.-Fri) | |
| 2011 DCBA-T2.5 | 6 mm pitch wires (xy + xz) | $^{100}$Mo source (natural Mo 30g)  
|          | 0.8 kG magnetic field  | super-conducting magnet: 24h nonstop operation |
| 2013 DCTA-T3 | 3 mm pitch wires (xy + xz)*8 | $^{150}$Nd (5.6% in natural Nd$_2$O$_3$)  
|          | $^{82}$Se $^{150}$Nd(condensed) | B=3 kG at the maximum |
| 2017 MTD (tentative name) | several 10 kg | |

DCBA-T2 Chamber installed into the DCBA-T3 SC-Magnet
DCBA-T2

2005 DCBA

- charge dividing
- 6 mm pitch wires (xy + xz)

2007 DCBA-T2

- $^{100}$Mo source (natural Mo 30g)
- 0.6 - 0.8 kG magnetic field
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2017 MTD (tentative name)

- $^{82}$Se $^{150}$Nd (condensed) several 10 kg

DCBA-T2 Chamber installed into the DCBA-T3 SC-Magnet
**DCBA-T2: Detector**

- Normal condcting manget: \( B = 0.6 \sim 0.8 \text{kGauss} \)
- Natural Mo source plate:
  - Size: 280mm x 130mm x 50\( \mu \text{m} \)
  - Thickness: 45mg/cm\(^2\)
  - Total: 30g
  - \(^{100}\text{Mo}: 9.6\% \) in the plate (0.03 mol)
Energy resolution of DCBA-T2

Electron energy:
0.48 MeV (1.5%) 0.56 MeV (0.6%),
0.98 MeV (7.0%) 1.05 MeV (2.4%)

Energy resolution: ~0.15 MeV (FWHM)
This result is also valid for DCBA-T2.5
DCBA-T2.5

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- 6 mm pitch wires (xy + xz)

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- $^{150}\text{Nd}$ (5.6% in natural Nd$_2$O$_3$)
- $B=3$ kG at the maximum

2017 MTD
(tentative name)
- $^{82}\text{Se}$ $^{150}\text{Nd}$(condensed)
- several 10 kg

DCBA-T2 Chamber installed into the DCBA-T3 SC-Magnet
DCBA-T2.5

DCBA-T2 chamber is in the DCBA-T3 magnet

DCBA T2 Chamber

DCBA-T3 Magnet:
Super-Conducting solenoid
24 hour operation
DCBA-T2.5 data

Data taking started at July, 2011
Stably taking data (plot is up to Mar. but taking data after Mar.)

Integrated number of triggers

Triggers / day

Zoom
DCBA-T2.5 analyzed events

- about 1 signal candidate / 1 day running
- Most of data is not analyzed yet, stay tuned
Three distributions are measured:
- Total energy \((E_{\beta_1} + E_{\beta_2})\) distribution
- Single \(\beta\) energy \((E_{\beta_1\&\beta_2})\) distribution
- Angular correlation b/w two \(\beta\)s

(Only a part of T2.5 data is included)
Toward DCBA-T3

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• charge dividing
• 6 mm pitch wires (xy + xz)

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• 3 mm pitch wires (xy + xz)*8
• $^{150}$Nd (5.6% in natural $\text{Nd}_2\text{O}_3$)
• $B=3$ kG at the maximum

2017 MTD
(tentative name)
• $^{82}\text{Se} \quad ^{150}\text{Nd}$(condensed) several 10 kg
Development of DCBA-T3 Chamber

One of 8 layers is being assembled for test

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<th>T3</th>
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<tr>
<td># of wires</td>
<td>40</td>
<td>160</td>
</tr>
<tr>
<td>Wire pitch</td>
<td>6mm</td>
<td>3mm</td>
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32ch Preamp & FADC
- 5 modules for anode
- 5 modules for pickup

Amplification & A/D conversion at the chamber side

Expected momentum resolution: <100keV by fine pitch (6mm → 3mm) readout
# Next generation experiment: MTD

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| 2013 | DCTA-T3    | - 3 mm pitch wires (xy + xz)*8  
          - $^{150}$Nd (5.6% in natural Nd$_2$O$_3$)  
          - B=3 kG at the maximum |
| 2017 | MTD        | - $^{82}$Se $^{150}$Nd (condensed)  
          - Several 10 kg |

DCBA-T2 Chamber installed into the DCBA-T3 SC-Magnet
Future plan: MTD

Magnetic Tracking Detector (tentative name)

Chamber cell: the same as DCBA-T3, Source plate: 80 m²/module
Thickness: 40 mg/cm², Source weight: 32 kg/module, 27 source plates

Expected Energy Resolution:

\[
\text{FWHM}(E_{\text{sum}}) = \sqrt{2 \times 80\text{ keV}} \approx 3.4\%
\]

Geant4
2.4 kG
He+CO₂ (10%)
Nd₂O₃
40 mg/cm²

Energy (MeV)

80 keV
FWHM @ 1.7 MeV
Summary

DCBA is track-based ββ-decay experiment:
- reconstruct full 4-momentum of two β-rays
  more information, less background

DCBA-T2.5 is now running:
- 24 hour operation with Super Conducting solenoid magnet
- 20000 triggers/day, 1 signal candidate/day from $^{100}$Mo source

DCBA-T3 is under development:
- Momentum resolution: < 100keV with 3mm pitch
- Eight layers

Future plan: MTD
- Aim to observe 0νββ from $^{150}$Nd and/or $^{82}$Se source
- If 0νββ is found, provide information (E-spectrum of single β,
  angular correlation b/w two βs) to constrain NP beyond the SM