Status of the DCBA experiment

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Osaka University, JAPAN
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)

Ionization +scintillation
EXO($^{136}$Xe)
NEXT($^{136}$Xe)

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.)
Characteristics of Tracking method

Advantages:
- Insensitive to neutral background (e.g. γ-ray)
- More information than other methods:
  - Full 4-momentum and charges of two β-rays
  - Decay vertex position
- Good background rejection:
- More information (E-spectrum of single β, angular correlation) to constrain New Physics beyond the SM (if 0νββ 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 to the B-field
→ electrons having large angle to the source plate, travel across the B-field
DCBA: track reconstruction method

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

Reconstruct momentum:

\[ T = \sqrt{p_t^2 + p_z^2 + m_e^2} - m_e \]
\[ = \sqrt{(0.3B\rho)^2(1 + \tan^2\lambda) + m_e^2} - m_e \]
\[ = \sqrt{(0.3B\rho)^2/cos^2\lambda + m_e^2} - m_e \]

Gas: He(90%) + CO₂(10%)
Full kinematics of two $\beta$-rays are available:

1. electric charges of two $\beta$-rays
2. momenta of two $\beta$-rays
3. angle b/w the two $\beta$-rays
4. sum of kinetic energy of two $\beta$-rays
5. position of the decay vertex
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$E(\beta_1) = 0.354\text{MeV}$

$E(\beta_2) = 0.531\text{MeV}$

$E(\beta_1) + E(\beta_2) = 0.885\text{MeV}$
Information of an event

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$E(\beta_1) = 0.531\,\text{MeV}$

$\cos \theta = -0.661$

Vertex point

$\beta_1$ and $\beta_2$

$Y 183.0\,\text{mm} 183.9\,\text{mm}$

$Z 151.7\,\text{mm} 146.3\,\text{mm}$
Information of an event

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$E(\beta_1) = 0.531$ MeV
$E(\beta_2) = 0.354$ MeV

$E(\beta_1) + E(\beta_2) = 0.885$ MeV
DCBA experiment

DCBA experiment is performed at Fuji-experimental hall @ KEK

Fuji experimental hall is constructed for $e^+e^-$ collider experiment, and is **NOT** underground facility
History and Future Plan

2005 DCBA

2007 DCBA-T2 - R&D of the experimental Method
- Measurement of $2\nu\beta\beta$

2011 DCBA-T2.5 - Prototyping towards MTD
- Precise measurement of $2\nu\beta\beta$

now - Search for $0\nu\beta\beta$

2017 DCTA-T3

20XX MTD (tentative name) DCBA-T2 Chamber installed into the DCBA-T3 SC-Magnet
DCBA-T2.5

2005 DCBA

2007 DCBA-T2
- R&D of the experimental Method
- Measurement of $2\nu\beta\beta$

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2017 DCTA-T3
- Precise measurement of $2\nu\beta\beta$

20XX MTD (tentative name)
- Search for $0\nu\beta\beta$

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

DCBA-T2 chamber is installed in the DCBA-T3 magnet

**DCBA T2 Chamber**

**Natural Mo source plate:**
- 280mm x 130mm
- 50μm
- 45mg/cm²
- total 30g
- $^{100}$Mo: 9.6% in the plate (0.03 mol)

**DCBA-T3 Magnet:**
- Super-Conducting solenoid
- 24 hour operation
- B~0.6-0.8kGauss for T2.5
DCBA-T2.5: Data Taking

July 2011: Started data taking
July 2016: Finished data taking

Number of events / day: \( \sim 1 \times 10^4 \) 
(\( \gg 99\% \) of events are cosmic-ray background)
Total number of recorded events: \( \sim 8 \times 10^6 \)
Total number of analyzed events: \( \sim 1 \times 10^6 \)
← eye-scan based event selection
DCBA-T2.5: Distributions of signal candidate

**Sum of Kinetic energy**

- Count vs. MeV

**Kinetic energy of Single electron**

- Count vs. MeV

**Cosine of opening angle b/w electrons**

- Count vs. cos th

**Vertex position difference b/w electrons**

- Count vs. Y and Z

**Q-value of ^{100}\text{Mo}**

- Preliminary

**Y (anode)**

- Preliminary

**Z (pickup)**

- Preliminary

**Entries**

- 579

**Mean**

- 1.051

**RMS**

- 0.55

**Entries**

- 1158

**Mean**

- 0.5254

**RMS**

- 0.3793

**Entries**

- 579

**Mean**

- -0.5502

**RMS**

- 0.3621
**DCBA-T2.5:**
Distributions of signal candidate

- **Sum of Kinetic energy**
  - Entries: 579
  - Mean: 1.051
  - RMS: 0.55
  - Q-value of $^{100}$Mo

- **Duration:** $8.38 \times 10^6$ sec
- **Reconstruction efficiency:** 9.3%
- **Amount of $^{100}$Mo:** 0.03 mol

- **Expected number of signals:** 52 events


- $T_{1/2} = [7.41 \pm 0.02 \text{(stat.)} \pm 0.43 \text{(syst.)}] \times 10^{18}$ yrs

**Signal candidate:** 579 events

← contain many background events:

- Double Compton scattering
- Möller scattering
DCBA-T2.5: Improvement of Simulation & Analysis

Geant4 MC simulation

Automated track finding & fitting

Electron 1
$E_1 = 1.239\,[\text{MeV}]$

Electron 2
$E_2 = 1.261\,[\text{MeV}]$

2 Electrons Sum Energy
$E_1 + E_2 = 2.500\,[\text{MeV}]$

(Left Chamber) Electron 1
$E_1 = 1.213\,[\text{MeV}]$

(Left Chamber) Electron 2
$E_2 = 1.177\,[\text{MeV}]$

(Left Chamber) 2 Electrons Sum Energy
$E_1 + E_2 = 2.390\,[\text{MeV}]$

Development is in progress
DCBA-T3

2005 DCBA

2007 DCBA-T2
- R&D of the experimental Method
- Measurement of $2\nu\beta\beta$

2011 DCBA-T2.5
- Prototyping towards MTD
- Precise measurement of $2\nu\beta\beta$

2017 DCTA-T3
- Precise measurement of $2\nu\beta\beta$

20XX MTD
(tentative name)
- Search for $0\nu\beta\beta$

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

DCBA-T3 aim to improve energy resolution by fine pitch drift chambers and high B-field

<table>
<thead>
<tr>
<th></th>
<th>T2</th>
<th>T3</th>
</tr>
</thead>
<tbody>
<tr>
<td># of wires</td>
<td>40</td>
<td>160</td>
</tr>
<tr>
<td>Wire pitch</td>
<td>6mm</td>
<td>3mm</td>
</tr>
<tr>
<td>B-Field</td>
<td>0.8kG</td>
<td>3kG</td>
</tr>
</tbody>
</table>

- **Drift Chamber**: To be tested
- **Readout Electronics (Preamp+TDC+FADC)**
- **Gas Container**
- **SC-Magnet**: Is ready (already in use for DCBA-T2.5)

Test of the drift chamber using cosmic ray muon → To be started soon
Next generation experiment: MTD

- 2005 DCBA
- 2007 DCBA-T2
  - R&D of the experimental Method
  - Measurement of $2\nu\beta\beta$
- 2011 DCBA-T2.5
  - Prototyping towards MTD
  - Precise measurement of $2\nu\beta\beta$
- 2017 DCTA-T3
  - Search for $0\nu\beta\beta$
- 20XX MTD (tentative name)
R&D towards MTD

Magnetic Tracking Detector (tentative name):
- Search for $0\nu\beta\beta$ using $^{150}\text{Nd}$

Sensitivity for Neutrino mass @ 1 year operation:

<table>
<thead>
<tr>
<th>Thickness of a source plate</th>
<th>Natural Nd ($^{150}\text{Nd}$ 5.6%)</th>
<th>Condensed Nd ($^{150}\text{Nd}$ 60%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15mg/cm$^2$</td>
<td>0.8eV</td>
<td>0.2eV</td>
</tr>
<tr>
<td>40mg/cm$^2$</td>
<td>0.5eV</td>
<td>0.1eV</td>
</tr>
</tbody>
</table>

Chamber cell: the same as DCBA-T3, Source plate: 80 m$^2$/module
Thickess: 40 mg/cm$^2$, Source重量: 32 kg/module, 27 source plates

Expected Energy Resolution

$$\text{FWHM}(E_{\text{sym}}) = \sqrt{2 \times 80\text{keV}}$$

$$\frac{Q_{\text{Nd-150}}(3370\text{keV})}{3.4\%}$$
Summary

DCBA experiment is a unique double beta decay experiment:
- reconstruct momenta of two $\beta$-rays and the decay vertex
  → full information of the decay is available

DCBA-T2.5 experiment
- $^{100}$Mo (0.03mol) as source, non-stop operation using SC magnet
- Finished operation at July 2016 for DCBA-T3 upgrade
- Around 10% of data is analyzed
  → signal candidate is about 10 times as much as expected
  → understanding signal and background is in progress

DCBA-T3 experiment
- Assembling of drift chamber system is in progress
  → cosmic ray test will be started soon

R&D toward MTD
- R&D of large area drift chamber is in progress
backup
Energy resolution of DCBA-T2 (& T2.5)

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)

Energy spectra of internal conversion electrons from $^{207}$Bi

Including Backgrounds

FWHM $\approx 0.15$ MeV

Chamber conditions
He (90%) + CO$_2$ (10%) 1 atm
B = 0.8 kG
Wire pitch = 6 mm
Estimation of energy resolution by MC

$\sigma/E = 6.83 \pm 0.02\% \quad [0.8kG]$  
$\sigma/E = 8.72 \pm 0.02\% \quad [0.6kG]$
DCBA-T2.5: A $2
\nu\beta\beta$ Signal Candidate

Current analysis method:
Eye scan based analysis using graphical tools
Understand the event topology

E1=0.398MeV
E2=0.575MeV
E3=0.441MeV

$\cos\theta=0.233$

Vertex point

E1
E2

Y  206.5mm  205.5mm
Z  210.7mm  213.3mm
Another $2\nu\beta\beta$ signal candidate

Characteristics of the signal candidate:

1. Trajectory of the two tracks looks like inverse “S” shape
2. Vertex points of two tracks are consistent

Vertex point:

E1 = 0.531 MeV
E2 = 0.354 MeV
$\cos\theta = -0.661$

Y: 183.0 mm 183.9 mm
Z: 151.7 mm 146.3 mm
Yet another signal candidate

Characteristics of the signal candidate

1. trajectory of the two tracks looks like inverse “S” shape
2. vertex points of two tracks are consistent

- Trajectory of two tracks:
  - E1 = 1.221 MeV
  - E2 = 0.115 MeV
  - \( \cos \theta = -0.823 \)

- Vertex points:
  - Y: 127.4 mm, 131.8 mm
  - Z: 91.3 mm, 97.6 mm
A typical background event

1. Energy is too large
   
   \[
   (^{100}\text{Mo}\rightarrow^{100}\text{Ru}: \text{Q-value}=3.0\text{MeV})
   \]

2. Vertex point is inconsistent between two tracks

<table>
<thead>
<tr>
<th>E1</th>
<th>E2</th>
<th>Y</th>
<th>Z</th>
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<tbody>
<tr>
<td>2.739 MeV</td>
<td>3.40 MeV</td>
<td>205.9mm</td>
<td>77.4mm</td>
</tr>
<tr>
<td>111015-120_69</td>
<td></td>
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</table>

Background event of Double Compton scattering
DCBA-T3

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
- 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

2014 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 (tentative name)
- $^{82}$Se $^{150}$Nd (enriched)
- Several 10 kg

now

DCBA-T2 Chamber installed into the DCBA-T3 SC-Magnet
### Next generation experiment: MTD

<table>
<thead>
<tr>
<th>Year</th>
<th>Experiment</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>2005</td>
<td>DCBA</td>
<td>6 mm pitch wires (xy + xz)</td>
</tr>
<tr>
<td>2007</td>
<td>DCBA-T2</td>
<td>100(^{100})Mo source (natural Mo 30g)</td>
</tr>
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<td></td>
<td></td>
<td>150(^{150})Nd (5.6% in natural Nd(_2)O(_3))</td>
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<td></td>
<td>B=3 kG at the maximum</td>
</tr>
<tr>
<td>2017</td>
<td>MTD</td>
<td>82(^{82})Se 150(^{150})Nd(enriched) several 10 kg</td>
</tr>
</tbody>
</table>

Note: DCBA-T2 Chamber installed into the DCBA-T3 SC-Magnet
Design study of the mechanical structure has been started
MTD: R&D status (cont'd)

- Drawing of MTD chambers
- Production of a chamber frame mock-up
- Calculation of sag of the horizontal frame
- Measurement of sag
- Support fin of the Horizontal frame
- Digital height gauge

Design of MTD chamber w/ mock-up is ongoing