Status of the **DCBA** Experiment

**DCBA:** Drift Chamber Beta-ray Analyzer

Nobu ISHIHARA (KEK)
for the DCBA collaboration

Contents

1. Introduction to DCBA
2. DCBA-T2 in engineering run
3. DCBA-T3 under construction
4. Future prospect of DCBA/MTD
Introduction to DCBA

Momentum analyzers to study
♦ Majorana nature by searching for $0\nu\beta\beta$
♦ Effective neutrino mass by measuring $T_{1/2}^{0\nu}$

Advantage of DCBA
♦ Background elimination by particle ID
♦ Characteristic pattern of $\beta\beta$ in a magnetic field
♦ Decay vertex determination
♦ Energy measurement of individual $\beta$ ($e^{-}$)
♦ Angular correlation between $\beta\beta$

Disadvantage
♦ Energy resolution (FWHM≈100 keV) worse than Ge and Te calorimeter
♦ Low detection efficiency (≈30%)
♦ Large space for decay source installation
Principle of electron detection in DCBA

PICKUP WIRE

ANODE WIRE

SOURCE PLATES

FADC

CATHODE WIRE

Gas: He(90%) + CO₂(10%)

Momentum Acceptance

\[ p(\text{MeV/c}) = 0.3 r(\text{cm}) B(\text{kG}) \]

\[ B \approx 2 \text{ kG} \]

\[ 2 \text{ cm} < r < 5 \text{ cm} \]

\[ \downarrow \]

\[ 1.2 \text{ MeV/c} < p < 3 \text{ MeV/c} \]

Energy Acceptance for e⁻

\[ 0.8 \text{ MeV} < T < 2.5 \text{ MeV} \]

α is automatically rejected

\[ T = 1 \text{ MeV} \rightarrow p \approx 87 \text{ MeV/c} \]
DCBA-T2 drift chamber

Sensitive vol. : 18(x) × 24(y) × 24(z) [cm³]

Gas : He (90%) + CO₂(10%)

Magnet : solenoid magnet 0.6 - 0.8 [kG]
Straight track of a cosmic ray
Position resolution of DCBA-T2

σ_x: 1.00 mm

σ_y: 0.21 mm

σ_z: 0.17 mm
Energy measurement of an I. C. electron from $^{207}$Bi

Energy = 1073 keV

Oct. 10-13, 2009

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Energy resolution of DCBA-T2

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

Including Backgrounds

FWHM $\approx 0.15$ MeV

Expected $\Delta E/E$ at $Q = 6.3\%$ (FWHM) for $^{150}$Nd

Chamber conditions
He(90%) + CO$_2$(10%) 1 atm
B=0.8 kG
Wire pitch=6 mm

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Other BGD events (1)

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\[ \text{Alpha-ray} \]

\[ \text{pair creation} \]
Double Buffer FADC against Background Events

2e⁻ Background

\[
\begin{align*}
\frac{214}{83} \text{Bi} & \rightarrow \frac{214}{84} \text{Po} + \beta^- + \bar{\nu} \\
(Q=3.28\text{MeV}) & \rightarrow \text{conv. } e^- \\
& \rightarrow \frac{210}{82} \text{Pb} + \alpha \\
(T_{1/2} = 164 \mu\text{sec}) & 
\end{align*}
\]

Double buffer FADC

Test pulse input

160 \mu\text{s}

Memory 1

Memory 2

160 \mu\text{s}

40 \mu\text{s}

40 \mu\text{s}

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Engineering run of DCBA-T2 using Natural Mo source plate of 45 mg/cm² thick
DCBA-T2 after installing Mo
Detection Efficiency for $2\nu\beta\beta$ in DCBA-T2

Nat. Mo (10% $^{100}$Mo)
45 mg/cm$^2$

B=0.6 kG
Back-to-back

$\varepsilon = 9.5\%$
Back-to-back event of DCBA-T2
(Candidate of $2\nu\beta\beta$)

- Time gap
- 0.6 MeV
- 0.3 MeV
- 10% $^{100}$Mo plate
- Wire pitch = 6 mm
- B = 0.8 kG

- Helical Radius: $r$
- Azimuth Angle: $\varphi$
- Pitch Angle: $\lambda$
- Opening angle $\theta \approx 120$ deg
- $\cos \theta = -0.5$

- Natural Mo plate (45 mg/cm²)

- FADC counts/10 ns
- 090505-39_12
- $10 \mu$sec $\approx 5$ cm
- Pickup wire

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Back-to-back event probably coming from $^{214}\text{Bi}$

$^{214}\text{Bi}$ (Uranium decay series)

$\beta_{\text{max}} = 1.85 \text{ MeV}$

(e1 = 0.342 MeV)

$\cos \lambda_1 = 0.839$

$\cos \lambda_2 = 0.452$

$e_1 = 0.342 \text{ MeV}$

$r_1 = 23.9 \text{ mm}$

$r_2 = 34.1 \text{ mm}$

$e_2 = 1.369 \text{ MeV}$

$3.27 \text{ MeV}$

1.42 MeV

conv. elec.

(e2 = 1.369 MeV)

$0^+$

$0^+$

$^{214}\text{Po}$

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Background Event / Double Compton?

LY(-614, 28, Z)  
T=0.32 MeV  
r=26.3 mm

RY(621, 30, Z)  
T=1.14 MeV  
r=21.1 mm

X-Y plane

LZ(-626, Y, 20)  
\cos \lambda = 0.321

RZ1(623, Y, 18)  
\cos \lambda = 0.963

X-Z plane

RZ2(636, Y, 21)

10FADC counts \approx 0.5 mm

090505-52_14
**DCBA-T3 (under construction)**

- **Magnetic Flux Return Yoke**
- **Drift Chambers**
- **Source Plates**
- **SC-Magnet**

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**Oct. 10-13, 2009**

**N. Ishihara at DBD09, Hawaii**

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**976 keV**

- \( \varepsilon \approx 52\% \)

**1500 keV**

- \( \varepsilon \approx 60\% \)

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**Geant4**

**Nd_2O_3**

- **40 mg/cm^2**

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**Refrigerator**

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**SC-magnet**

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**Geant4**

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**Entries**: 525

**Mean**: 0.9111

**RMS**: 0.07605

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**Entries**: 597

**Mean**: 1.421

**RMS**: 0.112
# Differences between DCBA-T3 and T2

- Drift chamber: Mini-jet chambers with multi-particle separation capability

<table>
<thead>
<tr>
<th></th>
<th>DCBA-T3</th>
<th>DCBA-T2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Source</strong></td>
<td>Nd$_2$O$_3$ (40 mg/cm$^2 \times$13,760 cm$^2$) = 550 g :$^{150}$Nd = 0.18 mol</td>
<td>Nd$_2$O$_3$</td>
</tr>
<tr>
<td>Sensitive vol.</td>
<td>$8 \times (4(X) \times 44(Y) \times 44(Z))$ cm$^3$</td>
<td>$9(X) \times 26(Y) \times 26(Z)$ cm$^3$</td>
</tr>
<tr>
<td>Anode pitch</td>
<td>3 mm</td>
<td>6 mm</td>
</tr>
<tr>
<td>Pickup pitch</td>
<td>3 mm</td>
<td>6 mm</td>
</tr>
<tr>
<td>Signal readout</td>
<td>Flash ADC</td>
<td>Flash ADC</td>
</tr>
<tr>
<td>X-position</td>
<td>Drift vel. $\times$ time : $\sigma_X \approx 0.5$ mm</td>
<td>$\sigma_X \approx 1$ mm</td>
</tr>
<tr>
<td>Y-position</td>
<td>Anode position : $\sigma_Y \approx 0.2$ mm</td>
<td>$\sigma_Y \approx 0.2$ mm</td>
</tr>
<tr>
<td>Z-position</td>
<td>Pickup position : $\sigma_Z \approx 0.2$ mm</td>
<td>$\sigma_Z \approx 0.2$ mm</td>
</tr>
<tr>
<td><strong>Magnet</strong></td>
<td>SC-solenoid + F.R.Y.</td>
<td>Normal-sol.+ F.R.Y.</td>
</tr>
<tr>
<td>Magnetic field</td>
<td>3.0 kG (Max.)</td>
<td>0.8 kG (Max.)</td>
</tr>
<tr>
<td>Uniform Vol.</td>
<td>80 dia. x 60 cm$^3$ $\delta B/B_0 &lt; 1%$</td>
<td>40 dia. x 60 cm$^3$ $\delta B/B_0 &lt; 1%$</td>
</tr>
<tr>
<td>$\Delta E/E$ expected at Q</td>
<td>&lt; 5% (FWHM)</td>
<td>6.3% (FWHM)</td>
</tr>
<tr>
<td>Power consumption</td>
<td>1 kW (refri.)+10 W (power supply)</td>
<td>9 kW (Power supply)</td>
</tr>
</tbody>
</table>

Natul. Mo:32g
$^{100}$Mo=0.03 mol
DCBA-T3
Electronics and DAQ

Chamber 4 Layers 1,280ch (1st stage)
Serial LVDS cable (Digital transfer)

32ch Pre-Amp & FADC module
FPGA with Memory

DCBA-T3
Pickup
Anode

Start/Stop
Trigger Board
CPU Board
DAQ Board

EVENT
MEMORY
FPGA
Anode / 160ch
Pickup / 160ch

CompactPCI

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MTD (Magnetic Tracking Detector: temporary name) module after DCBA

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

Expected Energy Resolution

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

\[ Q_{\text{Nd-150}}(3370 \text{keV}) \approx 3.4\% \]
Expected event rate in MTD

Conditions
- Assumed effective mass $<m_{rr}>$ is 50 meV.
- Used $T_{1/2}^{0\nu}$ are from Faessler et al. presented at TAUP2009 and A. Staudt et al. in Europhys. Lett. 13 (1) (1990) 31.
- 50 modules of MTD are operated.
- Source thickness is 40 mg/cm$^2$: thus 30 kg/mod $\times$ 50 mod = 1500 kg.
- Event rate is obtained by $n = \varepsilon N_0 \ln 2 / T_{1/2}^{0\nu}$ where $\varepsilon$ is the detection efficiency (=0.3) and $N_0$ the number of nuclei.

<table>
<thead>
<tr>
<th>Item</th>
<th>Source</th>
<th>Natural Nd (5.6%$^{150}$Nd)</th>
<th>$^{150}$Nd (60% enr.)</th>
<th>$^{100}$Mo (90% enr.)</th>
<th>$^{82}$Se (90% enr.)</th>
<th>$^{76}$Ge (90% enr.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amount (mol)</td>
<td>560</td>
<td>6000</td>
<td>13500</td>
<td>16460</td>
<td>17760</td>
<td></td>
</tr>
</tbody>
</table>

\begin{align*}
\text{Faessler } T_{1/2}^{0\nu} (y) & = 3.55 \times 10^{25} & 3.55 \times 10^{25} & 3.33 \times 10^{26} & 3.50 \times 10^{26} & 1.10 \times 10^{27} \\
\text{Event rate (y}^{-1}) & = 2 & 21 & 5 & 8 & 2 \\
\text{Staudt } T_{1/2}^{0\nu} (y) & = 1.35 \times 10^{25} & 1.35 \times 10^{25} & 5.08 \times 10^{26} & 2.41 \times 10^{26} & 9.32 \times 10^{26} \\
\text{Event rate (y}^{-1}) & = 5 & 55 & 3 & 9 & 2
\end{align*}
**DCBA collaboration**

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(26 persons from 11 Institutes)
Conclusions

1. DCBA is momentum analyzers for studying neutrinoless double beta decay.

2. DCBA-T2 has taken DBD candidates from natural Mo source plates of 45 mg/cm² thickness, which include 10% $^{100}$Mo.

3. DCBA-T3 is now under construction at KEK, being expected to have the energy resolution of less than 100 keV (FWHM) for each electron in the energy range of 1 – 2 MeV.

4. Magnetic Tracking Detector (MTD: named temporarily) is the future project based on DCBA. The energy resolution of MTD is expected to be less than 4% (FWHM) at the Q-value of $^{150}$Nd (3.37 MeV). MTD of 50 modules will make it possible to investigate the effective neutrino mass down to 50 meV.