PICO-LON
DARK MATTER SEARCH

KamLAND-PICO Collaboration

1. Aim of PICO-LON
2. PICO-LON Concept
3. Performance of PICO-LON Module
4. KamLAND-PICO Project
WIMPs search by NaI(Tl)

- Annual modulation
- Complementary work for directional measurement
- Limited work using NaI(Tl)
- DAMA, DM-Ice and PICO-LON

- PICO-LON in northern hemisphere
- However ...
  - Highly radiopure NaI(Tl) is needed.
  - Who makes the best NaI(Tl) in the world?
  - In Japan, we restarted to make the best NaI(Tl)
### Previous result by Japanese NaI(Tl) maker

<table>
<thead>
<tr>
<th></th>
<th>DAMA</th>
<th>DM-Ice</th>
<th>Horiba</th>
<th>Goal of PICO-LON</th>
</tr>
</thead>
<tbody>
<tr>
<td>natK</td>
<td>&lt;20ppb</td>
<td>500ppb</td>
<td>&lt;200ppb</td>
<td>&lt;20ppb</td>
</tr>
<tr>
<td>$^{232}$Th</td>
<td>0.5-0.7ppt</td>
<td>50ppt</td>
<td>0.6ppt</td>
<td>&lt;1ppt</td>
</tr>
<tr>
<td>$^{238}$U</td>
<td>0.7-10ppt</td>
<td>7.5ppt</td>
<td>1.07ppt</td>
<td>&lt;1ppt</td>
</tr>
<tr>
<td>$^{210}$Pb</td>
<td>5-30µBq/kg</td>
<td>2mBq/kg</td>
<td>6mBq/kg</td>
<td>&lt;100µBq/kg</td>
</tr>
</tbody>
</table>

- U-chain: 1ppt = 12.3µBq/kg
- Th-chain: 1ppt = 4.0µBq/kg
- $^{210}$Pb: 1ppt = 2.5kBq/kg
PICO-LON for WIMPs search

• Planar
• Inorganic
• Crystal
• Observatory for
• Low-background
• Neutr(al)ino

• High selectivity
• Background reduction
• Sensitive to
• Elastic scattering (SI+SD)
• Inelastic scattering (SD)
• Study the interaction type of WIMPs
Concept of PICO-LON detector
Background reduction

Segmented detector → Remove Compton scattering
Design of PICO-LON

- Requirements
  - Coincidence measurement of $^{127}$I gamma ray
    - Thin NaI(Tl) crystal 0.1cm
  - Low energy threshold
    - Low energy WIMPs signal $E_{ee} < 5$keV
  - Good energy resolution
    - Background by $^{210}$Pb at 46.5keV $\Delta E_{ee} = 12$keV
  - Large acceptance
    - Wide area crystal 10cm square ~ 18cm square
    - Pile up modular detectors
PICO-LON single layer module
$^{241}\text{Am source}$

$\Delta E/E = 24\%$ at 60keV
R&D for pure NaI(Tl) production

- Crucible selection
- Raw material of NaI selection
- Surroundings of a plant
- 3.0″φ×3.0″ NaI(Tl)
- Three different conditions
Pulse shape discrimination for alpha/beta selection

Small difference of pulse shape

<table>
<thead>
<tr>
<th>Partial</th>
<th>Full</th>
</tr>
</thead>
</table>

Gate 1000ns

200ns

Decay time

\[ \alpha \quad 190\text{ns} \]

\[ \beta/\gamma \quad 230\text{ns} \]
Ingot 16
NaI(Tl) ingot #20  Live time 28 days

ELECTRON EQUIVALENT ENERGY [keV]  
COUNTS

238U  
232Th  
226Ra  

234U  
230Th  
228Th  
222Rn  

210Po  
218Po  
212Bi  
216Po  

216Po  

Th chain  
U chain  

ELECTRON EQUIVALENT ENERGY [keV]
### Preliminary Result (µBq/kg)

<table>
<thead>
<tr>
<th>α source</th>
<th>Ingot 16</th>
<th>Ingot 18</th>
<th>Ingot 20 (Preliminary)</th>
</tr>
</thead>
<tbody>
<tr>
<td>U chain</td>
<td>²¹⁰Po</td>
<td>9600±100</td>
<td>1825±45</td>
</tr>
<tr>
<td></td>
<td>²²⁶Ra</td>
<td>4510±60</td>
<td>308±26</td>
</tr>
<tr>
<td></td>
<td>²³⁴U +²³⁰Th</td>
<td>520±73</td>
<td>1161±38</td>
</tr>
<tr>
<td>Th chain</td>
<td>²²⁸Th</td>
<td>243±11</td>
<td>255±12</td>
</tr>
</tbody>
</table>

Contamination depends on the purity of crucible.

Low density for ²¹⁰Pb = 300µBq/kg
Results for performance

• Good energy threshold
  • Lower than \(2\text{keV electron equivalent}\).

• NaI purification
  • R&D in progress
  • \(^{210}\text{Pb}\) was effectively reduced
**KamLAND-PICO**

- Install PICO-LON detector into KamLAND
- KamLAND is an ideal active shield.
BG Simulation of KamLAND-PICO

- Pure water
- Buffer oil
- Isoparaffin and dodecane
- Liquid scintillator
  - Dodecane, Pseudocumene, PPO
- PMT
- NaI(Tl)
Low energy region $^{214}\text{Bi}$ in NaI(Tl)

Energy threshold of KamLAND

100keV 180keV 400keV
## 6. Estimated Background (Preliminary!!)

<table>
<thead>
<tr>
<th></th>
<th>Events/kg/day/keV</th>
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<tbody>
<tr>
<td>$^{40}$K PMT glass</td>
<td>$5.3 \times 10^{-5}$</td>
</tr>
<tr>
<td>$^{232}$Th PMT glass</td>
<td>$2.7 \times 10^{-4}$</td>
</tr>
<tr>
<td>$^{40}$K PMT case</td>
<td>$2.7 \times 10^{-4}$</td>
</tr>
<tr>
<td>$^{210}$Pb NaI(Tl)</td>
<td>$6 \times 10^{-2}$</td>
</tr>
<tr>
<td>$^{212}$Pb NaI(Tl)</td>
<td>$1 \times 10^{-4}$</td>
</tr>
<tr>
<td>$^{40}$K NaI(Tl)</td>
<td>$3 \times 10^{-1}$</td>
</tr>
<tr>
<td>$^{40}$K light guide</td>
<td>$9 \times 10^{-2}$</td>
</tr>
<tr>
<td>$^{232}$Th light guide</td>
<td>$2.7 \times 10^{-7}$</td>
</tr>
<tr>
<td>$^{40}$K reinforcement</td>
<td>$5 \times 10^{-2}$</td>
</tr>
<tr>
<td>$^{232}$Th reinforcement</td>
<td>$5.5 \times 10^{-7}$</td>
</tr>
</tbody>
</table>

**DAMA**

BG $\sim 1$/kg/day/keV

**KamLAND-PICO** ($E_{th} = 100$keV)

BG $\sim 0.5$/kg/day/keV
Summary

- PICO-LON for WIMPs search
- High sensitivity to all the types of interaction.
  - Elastic scattering for SD+SI
  - Inelastic scattering for SD
- Good performance for WIMPs search
- KamLAND-PICO has been funded.
  - 15Myen/4year
  - Low background study for NaI(Tl) with $4\pi$ active shield.
Expected sensitivity (Elastic, 1ton*yr) 0.5/day/kg/keV Eth=2keV