Dark matter search at XMASS

2013 Shanghai Particle Physics and Cosmology Symposium (SPCS2013)
Shanghai, China, June 3–5, 2013
5th of Jun. 2013
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XMASS project

XMASS-I
- 835 kg, 100 kg Fiducial volume (FV)
- φ80 cm, 642 PMTs
- Since 2010 Nov.
- Refurbishment work is ongoing
  - Dark matter search

XMASS-1.5
- 5 ton, 1 ton FV
- φ1.5 m, ~1000 PMTs
  - Dark matter search

XMASS-II
- 25 ton, 10 ton FV
- φ2.5 m
  - Multi purpose
    - Dark matter
    - pp solar neutrino
    - 0ν2β decay

Y. Suzuki, hep-ph/0008296
XMASS detector

- Single phase detector using ultra pure liquid xenon
  - Simple and good scalability
  - No need for complicate structure like an HV
- BG reduction by self-shielding
  - Effective even for neutron BG
- High light yield & low energy threshold
- Sensitive for e/γ events

![Graph showing events against radius with color coding: Black: all events, Blue: 2 < E(keVee) < 5 keV, Red: 2 < E(keVee) < 10 keV, Green: F.V. (30cm from wall)]
2. Status of XMASS-I

Performance

- Detail: *NIMA 716 (2013) 78*
- Using 835 kg ultra pure liquid xenon,
  - *World largest*
  - *Lowest threshold (0.3keVee)*
    detector for dark matter search
- Commissioning runs were conducted (2010/10–2012/5)

Results

- Low mass WIMPs search: *PLB 719 (2013) 78*
- Solar Axion search: *arXiv:1212.6153 (to be published in PLB)*
- Seasonal modulation for DM search (being analyzed)
- Inelastic scattering DM search (being analyzed)
Detector configuration

@ Laboratory C in Kamioka observatory (2700 mwe)

Water tank

Elec. hut

Refrigerator

Reservoir

OFHC copper vessel

835kg liq. xenon

642 PMTs

72 20inch PMTs (veto)
Detector calibration

<table>
<thead>
<tr>
<th>RI</th>
<th>Energy [keV]</th>
<th>[Hz]</th>
<th>dia. [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Fe-55</td>
<td>5.9</td>
<td>350</td>
<td>5</td>
</tr>
<tr>
<td>(2) Cd-109</td>
<td>8(*1), 22, 25, 88</td>
<td>800</td>
<td>5</td>
</tr>
<tr>
<td>(3) Am-241</td>
<td>17.8, 59.5</td>
<td>485</td>
<td>0.21</td>
</tr>
<tr>
<td>(4) Co-57</td>
<td>59.3(*2), 122</td>
<td>40</td>
<td>0.21</td>
</tr>
<tr>
<td>(5) Cs-137</td>
<td>662</td>
<td>200</td>
<td>5</td>
</tr>
</tbody>
</table>

(*1) Kα X-rays from the copper used for housing.
(*2) Kα X-rays from the tungsten used for housing.
Low mass WIMPs search

- Full volume (835 kg) analysis
- 6.80 days in 2012 Feb.
- 5591.4 kg day exposure
- 0.3 keVee threshold

![Energy vs Counts/day/kg/keVee](chart)

![Graphical comparison of cross-sections](graph)
Solar Axion search

*arXiv: 1212.6153, to be published in PLB*

- Axion is a hypothetical particle to solve the strong CP problem
- Produced in the Sun and detected in the detector
- XMASS is suitable to search because of a large mass and low BG

Bremsstrahlung and Compton effect

Axio-electric effect

Bremsstrahlung and Compton effect

Axio-electric effect

Our data

Max allowed
Seasonal modulation for DM search

- 160 days × 835 kg exposure (Preliminary)
- In commissioning run, several kinds of data with different conditions were taken to understand the detector response. Currently, data with same condition were used for analysis.
- $\chi^2 : 23.03$ DAMA modulation ($A=0.014, T=365, \text{Phase}=159.2$)
- $\chi^2 : 10.8$ for flat
Inelastic scattering DM search

\[ E_{\text{true}} = E_{40\text{keV}} + E_{\text{recoil}} \]

- Sensitivity is as good as the DAMA’s world best limit
  \((NJP \text{ vol.2, 15 (2000), R. Bernabei, et al})\) even before optimization of
  BG reduction.
- Now, optimization of reduction and evaluation of systematic error
  are on-going. The result will be shown soon.
Remaining background in XMASS-I

- BG level was 2 order of magnitude larger than expectation
- It was same level with DAMA and CoGeNT
- The origin of BG for \( \geq 5 \) keV were confirmed (lower figure)
- Also for < 5 keV, likeliest candidate (Gore-Tex) was identified
- “Surface events” are dominant in both energy regions
- To reduce these surface events, refurbishment is in progress.

![Graph showing background rates and components](image)

- Black line: Real data
- Colored histogram: BG (MC)
  - Surface Cu 210Pb
  - PMT Al 235U-231Pa
  - 210Pb
  - 232Th
  - 238U-230Th
  - PMT gamma
  - Gore-Tex 210Pb
  - Gore-Tex 14C
Origin of BG in XMASS-I

- **Main BG source (≥ 5keV)**
  - In refurbishment, Al seal will be covered by copper rings and GORE-TEX will be removed
  - In XMASS-1.5, Al seal will be replaced with ultra pure one

- **BG candidate (< 5keV)**
Fiducial volume analysis in XMASS-I

- BG reduction by fiducial volume cut using position reconstruction.
- It was confirmed that position reconstruction worked well using calibration data.

- “Leakage events” that “surface events” were miss-reconstructed into the fiducial volume are serious problem.
  → ”Surface events” itself should be reduced.
- Structure around PMT also resulted in “leakage events.”
  → Refurbishment of structure is also needed.

For fiducial volume analysis, refurbishment work is needed.
3. XMASS Refurbishment work

- **Purpose of Refurbishment:**
  - Confirmation of BG reduction by shielding of scintillation light originated from PMT Al
  - Also reducing $^{210}$Pb (2nd largest component in BG) with electro-polishing and special clean environment.

- **Expected BG level:**
  Al and surface BG are reduced to same level as PMT gamma BG. ($\sim 10^{-44} \text{ cm}^2$ for 100 GeV WIMP with fiducialization)

- In next step (XMASS-1.5), it will be replaced with new PMT.
XMASS-1.5

- Total 5 ton (FV 1 ton)
- BG reduction:
  - No dirty aluminum
  - No GORETEX
  - Less surface $^{210}\text{Pb} (< 1/100)$
- New PMT with round shape window to identify surface event is being developed. MC study for evaluation of miss-reconstruction rate is on-going.

**Diagram: XMASS-1.5 sensitivity**

**Round shape window**

**XMASS-1.5 full volume**

**WIMPs mass [GeV/c$^2$]**

**XMASS-1.5, 2keV threshold, 1yr**
Less surface $^{210}\text{Pb} (<1/100)$

- Environment controlling during machining of detector
  1. All the works should be done under Rn free air with Rn concentration of $\sim 10\text{mBq}/\text{m}^3$ (usually $20\text{Bq}/\text{m}^3$)
  2. All the surfaces should be cleaned by electro-polishing (EP)

- Controlling of Rn exposure after EP
  1. Minimization during machining: Optimization of all process
  2. Minimization during storage:
     Packed with Rn barrier sheet (EVOH) and conductive bag.
  3. Less Rn environment during assembling ($<10\text{mBq}/\text{m}^3$):
     Rn removing device with electro-static collection is being developed.
     (Rn decay products (especially, $^{218}\text{Po}$) tend to have positive charge and collected with high voltage)
PMT with round shape window

- Mass-production is OK
- Optimization of shape and cost-cutting are being concerned
- Less radio-active impurities
- MC study of miss-reconstruction rate is being evaluated:
  Reduction rate of $< 10^{-5}$ at 2.5keV was obtained for events occurred in the side of window.

- 3 PMTs around event vertex detect 48% of pe.
- Cut criteria:
  Fraction of pe in 3 PMTs $> 10\%$
Schedule

- 2013 autumn: Complete XMASS Refurbishment and start data taking
- 2014: Start XMASS-1.5 construction
- 2015: Complete XMASS-1.5 construction and start commissioning run
- 2016–2018: XMASS-1.5 physics run
- 2018: Complete XMASS-2 construction and start commissioning run
Summary

- XMASS-I is the world largest (835kg) and lowest threshold (0.3keVee) detector for dark matter search.
  - Low mass WIMP search (PLB 719(2013)78)
  - Solar Axion search (to be published in PLB)
  - Seasonal modulation for DM search
  - Inelastic scattering DM search

- BG level in XMASS-I is not as low as original expectation. However, origins of BG are mostly identified and possible to be reduced.

- The refurbishment of XMASS-I is on-going. Data taking will resume in first of autumn 2013

- XMASS-1.5 is also planned.