XMASS experiment

K. Abe
Kamioka Observatory, the University of Tokyo
On behalf of XMASS collaboration
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content

• XMASS experiment
  – Single phase liquid xenon detector.
• Recent result from XMASS-I commissioning run.
• Refurbishment of detector to reduce BG.
• Result to come soon, modulation analysis.
• XMASS-1.5 for future.
XMASS single phase liquid xenon detector for Dark matter search

**Single phase:**
- Only liquid phase, only scintillation signal.
- DM signal (uniformly distributed) are identified by fiducial volume analysis.
  - BG events are stopped outside volume.
- Also PSD may reduce background.
  - Scintillation decay time difference between nuclear recoil (DM) and electron recoil can be used.

**Two phase:**
- Liquid phase and gas phase, scintillation signal(S1) and ionization signal(s2).
- DM signal (nuclear recoil) are identified by fiducial volume and S2/S1 ratio.
The XMASS collaboration:

- Institute for Cosmic Ray Research, the University of Tokyo
- Kavli Institute for the Physics and Mathematics of the Universe, the University of Tokyo
- Kobe University
- Tokai University
- Gifu University
- Yokohama National University
- Miyagi Educational University
- STE lab., Nagoya University
- Tokushima University
- Center for Underground Physics, Institute for Basic Science
- KRISS

11 institutes 41 researchers.
Kamioka Mine is located in Kamioka, Japan, approximately 1000m underneath Mt. Ikenoyama (2700 m.w.e.).

Sites include:
- KamLAND
- Super-K
- XMASS (Lab-C)
- CANDLES
- EGADS
- NEWAGE

Kamioka mine Lab-C
XMASS project

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

**XMASS-1.5**
- 5 ton,
- **1 ton** FV
- (x 10 of XMASS-I)
- 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 I detector

- 835kg of liquid xenon, 642 PMTs, 80 cm diameter.
- 10m x 10m water tank with 70 PMTs (20 inch) for muon veto.
- 62% inner surface is covered with photocathode area
  - High light yield (14.7 pe/keV)
  - Low threshold (0.3keVee)
- Sensitive to e/γ events as well as nuclear recoil
XMASS Inner Calibration

- Calibration sources: $^{55}\text{Fe}$, $^{109}\text{Cd}$, $^{241}\text{Am}$, $^{57}\text{Co}$, $^{137}\text{Cs}$
- Calibrate every week
- Light Yields, Optical parameters, position reconstruction

Calibration sources:
- $^{55}\text{Fe}$
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Calibrate every week.

Light Yields, Optical parameters, position reconstruction.

**Graphs**
- Data and MC comparison
- Peak at 122 keV and 136 keV
- ~4% rms
- 59.3 keV of W

**Images**
- Stepping motor
- Top photo Tube can be removed
- Gate valve
- ~5 m
- Source rod: $\Phi 0.21 \text{ mm}$ for $^{57}\text{Co}$ source
Comparison of background rate

- Background rate in the fiducial volume before separation of nuclear recoils from e/γ
- XMASS achieved $O(10^{-4})$ event/day/kg/keVee at a few 10’s keV.
History of XMASS-I

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<th>Event</th>
<th>Details</th>
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<td>2010</td>
<td>Construction</td>
<td>Several physics results.</td>
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<td>2010</td>
<td>Commissioning Run</td>
<td>Main BG source was identified, and it was covered with copper ring and plate.</td>
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<td>2011</td>
<td>Data taking</td>
<td>Stable and long term data taking is ongoing.</td>
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**Sep. 2010**
Main BG source was identified, and it was covered with copper ring and plate.
Physics results of XMASS-I

Published

  → Chosen as Editors’ suggestion
- Inelastic scattering on $^{129}$Xe, *PTEP* 2014, 063C01

Commissioning data

- Seasonal modulation with full volume of LXe
- Fiducial volume analysis for heavy WIMPs
- Double electron capture of $^{124}$Xe

Results to come soon
Search for $^{129}$Xe inelastic scattering by WIMPs

\[ \chi + ^{129}\text{Xe} \rightarrow \chi + ^{129}\text{Xe}^* \]
\[ ^{129}\text{Xe}^* \rightarrow ^{129}\text{Xe} + \gamma \ (39.6 \text{keV}) \]

Natural abundance of $^{129}$Xe: 26.4%

Published in PTEP 063C01 (2014)
Search for bosonic super-WIMPs (1/2)

- Lighter and more weekly interacting than WIMPs
- Candidate for lukewarm dark matter
- It can be pseudoscaler or vector boson.
- For vector boson, no experimental constraint so far.

- It can be detected by absorption of the particle, which is similar to the photoelectric effect.
- Search for mono-energetic peak at the mass of the particle

Published in Phys. Rev. Lett. 113, 121301 (2014)
Search for bosonic super-WIMPs (2/2)

- For vector boson case
  - the first direct search in the 40–120 keV range.
  - The limit excludes the possibility that such particles constitute all of dark matter.

- For pseudoscaler case
  - The most stringent direct constraint on $g_{aee}$.

![Diagram showing vector boson and pseudoscalar mass vs. $\log(g_{aee})$]
Refurbishment of Detector.

• In commissioning run, we found background source.
  – PMT’s Al seal. (210Pb, 238U)
  – Al seal placed area is the one of the most difficult area to look from that PMT. Al makes shadow.
  – These makes “leakage event”, misidentified as center region events.
• To reduce this background and confirm our understanding of BG.
  – As refurbishment, we put new structure to cover completely this Al seal.
XMASS Refurbishment

Before

After

+ Copper plate

Copper ring mounting
After refurbishment

- Restarted data taking from Nov. 2013.
- ATM (charge and timing) $\rightarrow$ FADC analysis.
- Energy threshold is reduced from 1keV to 0.3 keV.
- Already accumulated 359 days data for WIMP search till Mar. 2015.
- Using this data, physics analyses including WIMP search with fiducialization and seasonal modulation are on-going.
Modulation analysis

Data set
- November-20, 2013 to March-29, 2015
  - 504.2 calendar days,
  - 359.2 effective days (71%) for analysis
  - 0.82 ton · yr exposure
- Basically no PID
  - Both NR and e/γ events are retained
- Trigger: 4 hits (no outer detector hits)

Cuts
- Simple noise reduction
  - Veto 10ms after the events
  - RMS of time hits < 100 ns
- Remove Cherenkov events (orig. in quartz)
  - # hits in earlier 20 ns > 60% of total hits
- Remove events in front of PMT
  - Higher maxpe/totalpe event are rejected.
Detector Stability

- $^{57}$Co calibration: every week
- Observed photo-electron yields
  - gradually drift
  - Sudden jump due to the power failure (~5%)
- Those photo-electron change can be explained by the change of the absorption length.
  - Scattering length: stable < 0.5%
  - the ‘original’ light yields fitted: stable < 0.5%
- Uncertainty due to this instability is taken into account and currently finalizing.
Sensitivity to modulation

**XMASS ‘real’ data (359 days); 0.5 - 1.0 keVee (4.8 – 8.0 keVr) w/o syst.**

- **XMASS has high sensitivity to modulation**
  - Largest mass (835kg)
  - Low threshold (0.5 keVee)
- **No PID**
  - Same as DAMA
  - If NR
    - Direct comparison is possible (lines)
  - If e/γ signal
    - Need models to compare
XMASS1.5

- Total 5 tons of liquid xenon (fiducial mass of 1 ton)
- Target sensitivity for $\sigma_{SI} < 10^{-46}$ cm$^2$ for 100 GeV WIMPs
- Design of the detector is on-going
- New PMT with dome-shape window is developed.
  - No dirty aluminum is used
  - Pure Al seal (> 3 order magnitude lower U)
Dome shape window 3 inch PMT

• Dome shape window.
  – Large detection efficiency for “wall event”.
  – Reduce miss reconstruction probability of wall event.

• Diameter 2 inch -> 3 inch
  – Same number of PMT can realize factor 1.5 larger size detector. We can use similar structure of current XMASS-I.
  – Accumulated knowledge and technique can be used for more larger BG reduction.
Development of the PMT

- Large modification of dynode structure and voltage distribution, to realize
  - Large area of side part, tall dome height. ~30mm height.
  - High and Uniform collection efficiency for whole area. Lowest correction efficiency is ~80%. (QE ~30%)
  - Shorter TTS, higher timing resolution increase reduction of Cherenkov events. 5.6nsec -> 2.9nsec

- Shorter total length. 101.5mm/2inch -> 87.5mm/3inch
  - Thinner PMT holder, reduce weight and size of whole detector.
Summary

• XMASS-I is the world largest (~835kg) and low energy-threshold (0.3keVee) detector for direct dark matter search.
  - Sensitivity to e/\(\gamma\) events as well as nuclear recoil
  - Low BG at a few 10’s keV at a level of 10^{-4} /day/kg/keVee

• Refurbishment of detector and result to come soon.
  - Refurbishment was completed and data-taking resumed in Nov. 2013.
  - One order reduction of BG from commissioning run was achieved.
  - Results from seasonal modulation and fiducial volume analyses will come soon.

• XMASS-1.5
  - Designing is ongoing.
  - 3 inch dome shape PMT.
  - Target is \(\sigma_{SI}<10^{-46}\) cm\(^2\) for 100 GeV WIMPs