DM direct searches in JAPAN

Keishi Hosokawa, Kentaro Miuchi

THANKS
Japanese Experimental Dark matter Investigators

ANKOK GROUP  PICO-LON  Emulsion
Xenon Kamioka
Argon surface (Waseda)
NaI surface (Tokushima)
Emulsion surface (Nagoya)
Gas TPC Kamioka
The XMASS experiment

- Proposed as a multi purpose experiment with liquid Xenon
  - Xenon detector for Weakly Interacting MASSive Particles (dark matter)
  - Xenon MASSive detector for solar neutrino ($pp/^{7}\text{Be}$ solar neutrino)
  - Xenon neutrino MASS detector (double beta decay)

- Low energy threshold
- Sensitive to $e/\gamma$ events as well as nuclear recoil
  - WIMPs (by elastic and $^{129}\text{Xe}$ inelastic scattering),
  - Solar axions, Bosonic super-WIMPs,
  - Supernova neutrino burst, double electron capture, ...

- Large target mass and its scalability
The XMASS collaboration

Kavli IPMU, the University of Tokyo: J. Liu, K. Martens, Y. Suzuki
Kobe University: R. Fujita, K. Hosokawa, K. Miuchi, Y. Ohnishi, N. Oka, Y. Takeuchi
Tokai University: K. Nishijima
Gifu University: S. Tasaka
Yokohama National University: S. Nakamura
Miyagi University of Education: Y. Fukuda
STEL, Nagoya University: Y. Itow, R. Kegasa, K. Kobayashi, K. Masuda, H. Takiya
Sejong University: N. Y. Kim, Y. D. Kim
KRISS: Y. H. Kim, M. K. Lee, K. B. Lee, J. S. Lee

10 institutes
~40 physicists

June 2014
The XMASS-1 detector

- Located in the Kamioka mine in Japan (~2,700m water equivalent)
- A single-phase detector employing ~830kg of liquid xenon
- Equipped with 642 PMTs
- Active water shield
History of XMASS-1

- Sep. 2010: Detector construction completed.
**XMASS Commissioning Run**

* Search for $^{129}$Xe inelastic scattering *(PTEP 063C01(2014))*
* Search for bosonic super-WIMPs *(Accepted by PRL on Aug. 20th)*

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

**Graphical Data**

- Red: XMASS (90% C.L. stat. only)
- Pink band: XMASS (w/ sys. error)
- Black: DAMA LXe 2000 (90% C.L.)
Detector refurbishment

- Found RIs (210Pb, 238U) in the Aluminum seal of PMT.
- BG events at the blind corner of PMT are often misidentified as events in the fiducial volume.
- To reduce this background, new structures to cover this Al seal were installed.
Current status

- Understanding of detector response
- Understanding of reconstruction performance
- Understanding of BG
  ➔ They are on-going

- Quick check of BG in entire volume
  One order of magnitude reduction above 5 keVee for entire volume achieved.

- Results will come in near future

Energy spectra in entire volume
(without position reconstruction)
Future: XMASS-1.5

- Total 5 tons of liquid xenon (with fiducial mass of 1 ton)
- Target sensitivity for $\sigma_{\text{SI}} < 10^{-46} \text{ cm}^2$ for 100 GeV WIMPs
- Design of the detector is on-going

Red arrows: track of scintillation photons

Dotted line = photo cathode

High probability to miss catching the photons from the surface.

Dotted curve = photo cathode

PMTs for XMASS-1.5

Scintillation light from the surface can be detected.

WIMP-nucleon cross section [cm$^2$]

DAMA

EoGeNT

CDMS-Si

XMASS1.5 Annual Variation

XMASS1.5
ANKOK
Double phase argon detector

- Density: 1.39 g/cm³
- Boiling point: −186°C
- Scintillation
  - ~128nm (VUV)
  - Will be converted to visible light by WLS
  - ~50 photons/keV (S1)
- Low-priced!! (same as water or cheap wine.)
- $^{39}$Ar β-ray background
BG reduction techniques

- WIMP signal:
  - Nuclear Recoil (NR)
- Gamma · β (include $^{39}$Ar):
  - Electron Recoil (ER)
    1. PSD (Pulse Shape Discrimination)
      - Slow/total (Ar merit)
    2. S2/S1 ratio
- $\alpha$: higher energy + vertex
- $\mu$: veto (+ go underground)
- Neutron: (NR)
  - Shield
    - + multiple interaction (+ go underground)

2014/08/23 K. Yorita
Target of ANKOK

- Need to detect $\sim 20$ keVnr nuclear recoil signal.
  - Aim
    1. High sensitivity (Highest photo yield)
    2. BG reduction power
Maximizing light yield

- Light yield test with a 1-phase liquid argon detector.
  - Optimize method to soak WLS on PMT and reflector surface (evacuation) and amount of soaking WLS.
  - Reduce impurities in LAr.

Consists of LAr, 2 PMT, reflector and WLS

The second in the world!!

2014/08/23 K.Yorita
Surface run for test stand

- Temperature
- Pressure
- Ar liquid level
- Ar gas flow rate

2014/08/23 K.Yorita
Typical events

☆$^{60}$Co ER event

☆$^{252}$Cf NR event

Event Selection:

S2 exists ($>\sim 1$p.e.)

Multiple Event Veto

Drift time (= z−fiducial) cut

S1 light yield (100 $\sim 500$ p.e.)

e tc.

S1 fast : $t=0 \sim 100$ ns
S1 slow : $t=100$ ns $\sim 5\mu$s
S2 : $t=5\mu$s $\sim 80\mu$s

2014/08/23 K.Yorita
Whole gamma events was rejected in this $^{60}$Co data.

- Detail analysis is ongoing.
  - Energy dependence study, quantitative study on rejection power and so on.

2014/08/23 K.Yorita
ANKOK experiment is a direct WIMP search experiment using a 2-phase Ar detector.

They constructed a stable detector system. A surface run is ongoing.

Whole gamma events was separated from neutron event region by “S2/S1” & “PSD” analysis in $^{60}\text{Co}$ data.
- Detail analysis is ongoing.
POCO-LON
KamLAND-PICO
Dark Matter Search Project

Ken-Ichi Fushimi
for
KamLAND-PICO
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

\[ \gamma \text{(INELASTIC)} \]

X-ray

RECOIL

S1

S2

\[ \gamma \text{(INELASTIC)} \]
PICO-LON single layer module
R&D for pure NaI(Tl) production

- developed by I.S.C. Lab.
- pod selection
- NaI(Tl) powder selection
- lab status

- 3.0”φX3.0” NaI(Tl)
- Improvement step by step
Ingot 23 results (26 days live time)

Count

$^{226}\text{Ra}$  $^{222}\text{Rn}$  $^{218}\text{Po}$

$^{216}\text{Po}$

$^{214}\text{Po}$

Alpha_Particle_Energy (keV)
## Present result

<table>
<thead>
<tr>
<th></th>
<th>DAMA</th>
<th>DM-Ice</th>
<th>Ingot 23</th>
<th>Goal of PICO-LON</th>
</tr>
</thead>
<tbody>
<tr>
<td>nat$^7$K (ppb)</td>
<td>&lt;20</td>
<td>660</td>
<td>Not yet</td>
<td>&lt;20</td>
</tr>
<tr>
<td>$^{232}$Th (ppt)</td>
<td>0.5-0.7</td>
<td>2.5</td>
<td>3.3 ± 2.0</td>
<td>&lt;1</td>
</tr>
<tr>
<td>$^{238}$U (ppt)</td>
<td>0.7-10</td>
<td>1.4</td>
<td>5.4 ± 0.9</td>
<td>&lt;1</td>
</tr>
<tr>
<td>$^{210}$Pb (μBq/kg)</td>
<td>5-30</td>
<td>1470</td>
<td>58 ± 26</td>
<td>&lt;100</td>
</tr>
</tbody>
</table>

- U-chain: 1 ppt = 12.3 μBq/kg
- Th-chain: 1 ppt = 4.0 μBq/kg
- $^{210}$Pb: 1 ppt = 2.5 kBq/kg
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
  - Low background study for NaI(Tl) with $4\pi$ active shield.
- Detector performance OK
- Impurity of NaI(Tl) OK
EMULSION
Nuclear Emulsion Technology and Directional Dark Matter Study

Tatsuhiro NAKA
KMI / IAR, Nagoya University

KMI2013 @ Nagoya University, Dec. 12th (11-13), 2013
Directional Dark Matter Search

Direction sensitive detector

Emulsion detector
Current Collaboration

Nagoya University

Chiba University
K. Kuge

University of Napoli
G. de Lellis, A. Di Crescenzo, A. Sheshukov, A. Aleksandrov, V. Tioukov

University of Padova
C. Sirignano

Laboratori Nazionale de Grann Sasso (LNGS)
N. D’Ambrossio, N. Di Marco, F. Pupilli

Technical Support
- SPring-8
- DarkSIDE group at LNGS
- retired FUJI FILM engineer etc.
Emulsion mass ~ 30 ton

Why is it capable of detection of tau neutrino?

It has extremely high spatial resolution.
(tau decay length ~ 100 µm)

Why does it have such high spatial resolution?
Nuclear Emulsion Detector

- Charged Particle
- Silver halide crystal (AgBr)
- Polymer (C, (N,O))
- Development treatment

Ionized electrons concentrated on the electron trap to form the latent image specks in a crystal

\[ \text{Ag}^+ + e^- \rightarrow \text{Ag}_1 \cdots \text{Ag}_n \]

- Silver grains
  - size: several 10 nm ~ 1 \( \mu \text{m} \)
Key technology

Devise self-production

Emulsion production facility @ Nagoya U.

Readout system

- High precision and speed stage
- Wide FOV optical system

HTS

- Computer GPU board

Track of MIP

100μm

~ 100 kg order /year
Emulsion Self-Production at Nagoya University

Production scale ~ 1 kg detector/week

\[ \text{AgNO}_3 + \text{KBr} \rightarrow \text{AgBr} + \text{NO}_3^- + \text{K}^+ \]
Neutron (14 MeV) recoil track under optical microscopy

Almost Br recoil (170 - 600 keV) because of low sensitivity tuning.
Direction Sensitivity

Ion implant system

$\Rightarrow 80, 100, 125, 150, 200 \text{ keV C ion}$

(realistic C ion demonstration)

$\Delta E/E < \sim 1\%$

Angular distribution of 100 keV C ion

- : data
- : MC simulation

Angular resolution of C ion due to Ion implant

[Crytal size : 44.6 $\pm$ 0.4 nm]
Near Future plan

2013
- Proposal to LNGS
- Detector R&D for low backgrounds
- Evaluation of background rejection power and detection efficiency
- Intrinsic background estimation @ LNGS

2014
- R&D phase

2015
- 1~10 g scale commissioning
- Background study

2016
- ~ g scale commissioning

2017
- 100g scale Run
- aim to DAMA 100 GeV/c² region

Underground neutron measurement
underground neutron flux > 1 MeV
NEWAGE
NEWAGE
Direction-sensitive dark matter search

Kiseki Nakamura (Kyoto univ.)


(1) Kyoto university department of physics
(2) Kobe university department of physics
(3) ICRR

- NEWAGE detector
- Result of underground measurement
- Background study
- Summary
NEWAGE-0.3b’ detector

• Aim \( \geq 10 \) improvement from previous measurement (PLB2010)
  • Large size: \( \sim 2 \) (23 \times 27 \times 31cm^3 \Rightarrow 30 \times 30 \times 41cm^3) 
  • Low pressure (low threshold): 0.2 \Rightarrow 0.1 \text{ atm} \ (100 \Rightarrow 50 \text{ keV})
  • Upgrade tracking algorithm (DAQ upgrade)
  • Gas circulation system with cooled charcoal
GEM (8-segmented)
- pitch: 140 μm
- hole: 70 μm
- thickness: 100 μm
- gain: ~5

μ-PIC (30.72x30.72 cm²)
(z = -20.9 cm)
- pitch: 400 μm
- gain: ~1000

Drift plane (z = +20.5 cm)

B plate (2x2 cm²)
(-5, 0, -12) cm

Cathode
Anode
RUN14
- period: 2013/7/20-8/11, 10/19-11/12
- live time: 31.6 days
- fiducial volume: 28x24x41 cm³
- mass: 10.36 g
- exposure: 0.327 kg·days

**Energy spectrum**
- Threshold: 100 => 50 keV
- BG rate: 1/10 @ 100 keV

**Skymap, cosθ distribution**
- Set limit by significant difference in 2-binned measured cosθ and DM-wind simulated cosθ
Obtained limit: \[557 \text{pb} \at 200\text{GeV}\]
(Best direction-sensitive limit)
Improved one order of magnitude from previous RUN5
Background understanding

1. Estimate from high energy spectrum.
2. Estimate from gamma assay by Ge spectrometer.

Both indicate
Dominant BG is found to be alphas from $\mu$-PIC
Xenon Kamioka
Argon surface (Waseda)
NaI surface (Tokushima)
Emulsion surface (Nagoya)
Gas TPC Kamioka