XMASS experiment

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Very High Energy Phenomena in the Universe

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for XMASS collaboration

- Introduction: Liquid xenon for DM search
- XMASS experiment
- Result from XMASS commissioning run term
- Refurbishment of XMASS and future project
- Summary
Introduction : Liquid xenon for DM search
Characteristic of liquid xenon

-100°C liquid: easy to liquefy and use.

High density (~3g/cm³) can make compact detector (~2m diameter for 10ton scale)

Large z (=54): self shielding for external BG.

A. Aprile and T. Doke
Rev. Mod. Phys. 82, 2053
• Large photon yield: low threshold can be achieved.

• Scintillation wavelength \( \sim 175\text{nm} \):
  – Detected directly by PMTs.

• Purification: absorption material for example water and oxygen can be purified by Zr getter.
Direct Detection Principle

WIMPs elastically scatter off nuclei in targets, producing nuclear recoils.

- From the density of dark matter in the galaxy:
- Every liter of space: 10-100 WIMPs,
- Moving at $\frac{1}{1000}$ the speed of light
Event rate and cross section

\[ \frac{dR}{dE_R} = \frac{R_0 F^2(F_{ER})}{E_0 r} \frac{k_0}{k} \frac{1}{2\pi v_0} \int_{v_{\min}}^{v_{\max}} \frac{1}{u} f(V, V_E) d^3V \]

- \( R_0 \): Event rate
- \( F \): Form Factor should be calculated in each nucleus
- Maxwellian distribution for DM velocity is assumed.
- \( v_0 \): dispersion
- \( V \): velocity onto target,
- \( V_E \): Earth’s motion around the Sun

\[ R_0 = \frac{377}{M_\chi M_N} \left( \frac{\sigma_0}{1 \text{pb}} \right) \left( \frac{\rho_D}{0.3 \text{GeV}c^{-2}\text{cm}^{-3}} \right) \left( \frac{v_0}{230 \text{km s}^{-1}} \right) \text{kg d}^{-1} \]

Spin independent case:

\[ \sigma_0 = A^2 \frac{\mu_T^2}{\mu_p^2} \sigma_{\chi-p} \]

Larger A is higher event rate
Xenon is one of the best target for event rate.
Mechanism of DM detection

• Single phase:
  – DM signal are identified by fiducial volume analysis.
  – Also PSD may reduce background.
    • Scintillation decaytime difference btw nuclear (DM) recoil and electron recoil can be used.

• Double phase:
  – DM signal are identified by fiducial volume and ionization (S2)/scintillation (S1) ratio.

V.Chepel and H.Araujo arXiv:1207.2292
Current dark matter experiment by liquid xenon

**Xenon100/1t**
- 161kg xenon
- 50kg FV
- Continue data taking 2014
- DM search run planned:
  - Phase1a: 25kgFV x 60days
  - Phase1b: 300kgFV x 180days

**LUX**
- 350kg xenon
- 118kg FV
- First result:
  - arXiv:1310.8214v2
- Using Apr-Aug 2013

**PANDA-X**
- 118kg FV
- DM search run planned:
  - Phase1a: 25kgFV x 60days
  - Phase1b: 300kgFV x 180days

**XMASS**
- XMASS-I is ongoing since 2010
- 835kg xenon
- 100kgFV
XMASS experiment

Dark Matter Search
XMASS Collaborator

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10 institutes

~40 physicists

June 2014
XMASS experiment

XMASS-I
- 835kg, 100kg FV
- 80cm φ
- 2010Nov
- DM search

XMASS-1.5
- 5ton, 1ton FV
- (x10 of XMASS-I)
- 2.5m φ, ~1800 PMTs
- DM search

XMASS-II
- 25ton, 10ton FV
- 25m φ
- Multi purpose
- DM search
- pp solar neutrino
- 0ν2β decay

Y. Suzuki, hep-ph/0008296
Structure of XMASS detector

- **Detector**
  - Single phase (scintillation only) liquid Xenon detector
  - Operated at -100°C and ~0.065MPa
  - 100 kg fid. mass, [835 kg inner mass (0.8 mφ)]
  - Pentakis-dodecahedron
    - $\leftrightarrow$ 12 pentagonal pyramids: Each pyramid $\leftrightarrow$ 5 triangle
  - 630 hexagonal & 12 round PMTs with 28-39% Q.E.
  - photocathode coverage: > 62% inner surface

1.2m diameter
Characteristics of XMASS

- **XMASS**: single phase detector
  - Large volume and simple structure, operation.
    - 1 ton scale xenon detector, 100kg for fiducial volume.
  - Background reduction technique:
    - Self shielding
    - Reconstruction by hit pattern of PMTs
  - High light yields & Large photon coverage (15 pe/keV)
    - Low energy threshold (< 5 keVee ~ 25 keVNR) for fiducial volume
    - Lower energy threshold: 0.3 keV for whole volume
  - Large Scalability, simple to construct.
Low background technique

(1) BG from detector materials

- 642 PMTs: We developed new ultra low RI PMT with Hamamatsu.
- OFHC copper: Bring in the mine < 1 month after electrorefining (Mitsubishi Material Co.).
- Other materials: All the components were selected with HPGe and ICP-MS. (>250 samples were measured) The total RI level is much lower than PMT BG.

(2) External BG

- Gamma and n from rock are sufficiently reduced by a >4m thickness pure water tank: \( \gamma < \gamma \) from PMT, \( n << 10^{-4} / \text{day/kg} \)
- 72 20” PMTs for active veto for CR \( \mu \)
(3) Internal BG (in Xenon)

- **Radon**: Our goal ($<10^{-5}$ /day/keV/kg) => $222\text{Rn} < 0.6 \text{ mBq/detector}$
  - Radon emanation from detector material was measured with material selection. $<15\text{mBq/detector}$ was estimated.
  - Radon concentration in XMASS by Bi-Po coincidence analysis : $8.2^{+/-}0.5\text{mBq}$.
  - The radon removal system from xenon gas are prepared.
    
    *K. Abe et al. for XMASS collab., NIMA661, 50-57 (2012)*

- **Kr**: Our goal ($<10^{-5}$ /day/keV/kg) => 1ppt
  - 5 order of magnitude reduction with 4.7kg/hr processing time was achieved by distillation system.
    
    *K. Abe et al. for XMASS collab., Astropart. Phys. 31 (2009) 290*
  - $<2.7\text{ppt}$ (API-MS measurement of sample gas) was achieved.

- **Water, H2, O2 etc** :
  - Worse the optical property of xenon.
  - Xenon gas was passed to hot and room temperature getter to remove these.
History of XMASS-I

- Sep. 2010: Detector construction completed.
Result from XMASS commissioning run term
Detector response for a point-like source (\(~\text{WIMPs}\)~)

- $^{57}\text{Co}$ source @ center gives a typical response of the detector.
- $14.7 \text{p.e./keV}_{ee}$ (\(\cong 2.2\) for S1 in XENON100)
- The pe dist. well as vertex dist. were reproduced by a simulation well.
- Signals would be $<150\text{p.e. exp shape}$. 

RI source with rod 

reconstructed vertex
Low mass WIMPs search

- Threshold is 0.3 keV and Full volume analysis.
- Spectrum shows that observed data and MC WIMPs signal with best fit per WIMPs mass.
- Sensitive to the allowed region of DAMA/CoGeNT.
- Some part of the allowed regions can be excluded.
- After refurbishment, sensitivity will be improved ~ 2 order.

![Graph showing XMASS observed energy vs. WIMP cross section on nucleon (cm$^2$) and GeV](image)
Solar axion search in XMASS

- Axion is a hypothetical particle to solve the strong CP problem.
- Produced in the Sun and detected in our detector. (like photo-electric effect)
- Our detector is suitable to see its signal, especially because of a large mass and low background.

Analyzed data:
- No indication of signals. Bound in \( g_{\text{aee}} \) vs. mass.
- Better than any constraint in 10-40keV.
- Better than any experimental constraint <1keV

129Xe inelastic scattering in 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 $^{129}\text{Xe}$: 26.4%

Signal MC for 50GeV WIMP

(1) = pre-selection
(2) = (1) & radius cut
(3) = (2) & timing cut
(4) = (3) & band cut

Observed data (165.9 days)

Achieved $\sim 3 \times 10^{-4}$ dru @ a few 10’s keV

Published in PTEP 063C01 (2014)

Red line: XAMSS 90% C.L. upper limit

Pink band: XAMSS 90% C.L. upper limit w/ systematic

Red point: XMASS 90% C.L. upper limit
Bosonic super-WIMPs search

- Candidate for lighter dark matter
- 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

Limits on pseudoscalar boson coupling are also obtained.

arXiv:1406.0502
Unexpected BG in XMASS commissioning run:

- BG was 2 order larger than PMT gamma BG which was assumed as main BG.
- The origin of BG for >5keV were confirmed. BG from PMT Al seal (238U-230Th and 210Pb-206Pb).
- BG origin from “detector surface” is dominant. Leakage event in FV region is introduced by worse of PMT response. Need to remove these.
Energy spectrum of XMASS commissioning run with other DM search exp.

![Energy spectrum graph](image)

E. Aprile, 2010 Princeton
Refurbishment of XMASS and future project (XMASS 1.5)
XMASS refurbishment for background reduction

- PMT Al seal are covered by copper ring and plate.
  - Cu ring: reduce the beta and X-ray which are dominant background origin in <100keV.
  - Cu Plate: make a simple and flat surface to reduce the mimic of inside event.
Copper plate

Ring mounting

Copper ring

PMT

Before refurbishment

After refurbishment

+ Copper plate
Current status (1): spectrum

- Nov.2013: re-start data taking.
- Already accumulated 126 days data for WIMP search till June.2014.
- Quick check of energy spectrum indicates one order reduction of background from commissioning run data.
Current status (2) maxpe/totPE

- The event in small Maxpe (maximum NPE for one PMT)/totalPE region are reduced rapidly.
- It suggests that the event near of “blind of PMT” are reduced and mimic of inside event are reduced.
- Dark matter search with fiducial volume analysis is ongoing.
XMASS-1.5

• Full: 5ton, FV 1ton xenon
• New PMT:
  – More clean material (include Al seal) will be selected.
  – New PMTs being developed help to identify surface events.
• BG will be controlled by techniques of Refurbishment.
• Sensitivity for DM search:
  – $\sigma_{SI} < 10^{-46}\text{cm}^2 (\text{>5keV})$ for fiducialization.

Red arrows: track of scintillation photons

Dotted line = photo cathode

PMTs for XMASS-1
High probability to miss catching the photons from the surface.

PMTs for XMASS-1.5
Scintillation light from the surface can be detected.
Summary:

- Liquid xenon is encouraging target for dark matter search.
- The XMASS experiment are summarized

- Physics results from commissioning data
  - Light WIMPs
  - Solar axions
  - \(^{129}\text{Xe}\) inelastic scattering by WIMPs
  - Bosonic super-WIMPs

- Current status
  - Results will come in near future.

- Future
  - Designing of XMASS-1.5 is on-going.