XMASS

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Physics Objectives of XMASS

Multi-purpose liq. Xenon detector  

• Final Goal: 10 ton fiducial mass, 25 ton total (2.5mφ)
  – pp-solar neutrinos: $\nu + e \rightarrow \nu + e$
  – Double beta decay $^{136}\text{Xe} \rightarrow ^{136}\text{Ba} + 2e^-$
  – Dark Matter: $\chi + \text{Xe} \rightarrow \chi + \text{Xe}$

$\Rightarrow$ Phase-I (100 kg fid.): dedicated to a search for WIMPs dark matter
  – Search down to $\sigma_{SI} \sim \text{a few } 10^{-45} \text{ cm}^2$
  – BG level in the fiducial volume: $\sim 10^{-4} /\text{kg/keV/day}$

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The phase-I XMASS detector

• Detector
  – Single phase (scintillation only) liquid Xenon detector
  – 100 kg fid. mass, [835 kg inner mass (0.8 mφ)]
  – 630 hexagonal & 12 round PMTs with 28-39% Q.E.
  – photocathode coverage: > 62% inner surface: : 14.7±1.2 pe/keV
    • Can achieve low energy threshold
  – Sensitive also to electron/γ events
Detector Construction

• 2009.11: PMT holder and PMT installation

• 2010.09: Construction Completed
Commissioning run

- **Calibration**
  - Source Rod (57Co, 241Am, 137Cs, 109Cd, 55Fe)
  - External sources: 60Co, 137Cs, 232Th, Neutron
- **Normal Data taking (physics runs)**
- **Development of Software**
- **Change of the physical condition of Xenon.**
  - High/Low pressure runs, O2 runs to change absorption length, etc.
- **Xe Gas run** Important to identify the BG
- **RI measurement of the detector parts (attach materials at the end of the calibration rod)**

CM runs ended because the calibration rod fell off and stuck
Energy and vertex reconstruction

For $^{57}$Co (122keV, $\gamma$-rays)

- Energy resolution: $\sim$4% rms
- High p.e. yield: $14.7\pm1.2$ pe/keV
- Position Resolution:
  - 1.4 cm rms (0cm: center)
  - 1 cm rms ($\pm$20cm)
We anticipated that the most backgrounds come from PMT $\gamma$ (measured by Ge detector) (shown by yellow).

But we found unexpected BG which dominates below 100–200 keV.

In the signal region below 10 keVee, it amounts 2 order of magnitude larger than PMT BG.
• Suspected detector parts were examined again, and found

Aluminum seal used between quartz window and metal body of the PMTs contains $^{238}\text{U}$ (upper chain) and $^{210}\text{Pb}$, $^{210}\text{Pb}$ on Cu surface (as usual)
• BG below 5 keV: not explained by Al-seal and surface 210Pb

• GORE-TEX: between PMT and holder used for a light seal contains up to \( \sim 6 \pm 3\% \) of modern carbon

• GORE-TEX might explain
  – But parameters (ex. transparency of light inside of GORE-TEX) are not well known

• There may be unidentified sources of BG or something else.

• We will remove GORE-TEX in future detector refurbishment

\[ m_{DM} = 18 \text{ GeV} \]
\[ \sigma_{SI} = 1.6 \times 10^{-41} \text{ cm}^2 \]
Internal BG

- $^{222}\text{Rn}: \text{214Bi} \rightarrow \text{214Po}(164\mu s) \rightarrow \text{210Pb}$
  - $8.2\pm0.5\text{mBq}$ in the entire inner volume (835kg)
- $^{220}\text{Rn}: \text{220Rn} \rightarrow \text{216Po}(0.14\text{s}) \rightarrow \text{212Pb}$
  - Upper limit $<0.28\text{mBq}$ (90% C.L.)
Background level

- Our BG level (whole volume) after removing Cherenkov events is still ‘low’ even with the unexpected surface backgrounds.
Physics analysis

Analysis with different volumes and thresholds

- Whole Volume Analysis (Large target mass of 835 kg, low energy threshold, (large BG), no reconstruction)
  1) lowest threshold analysis (> 0.3 keVee) (Low mass DM search)
  2) 2keVee threshold annual modulation (e/γ/NR)
  3) keV Axion DM (ex. super-WIMPs) (e/γ)
  4) Solar Axions (e/γ)
  ➔ Light WIMPs & ALP

- Fiducial Volume analysis (low BG)
  1) Standard WIMPs search (> 2~5 keV)
  ➔ Event reconstruction/reduction program
Whole Volume Analysis with lowest threshold

We took data with 4 hits threshold and analyze the events above > 0.3 keVee for entire volume

6.64 days in Feb
- Clean up
- Cut: Cherenkov rejection
  - 40K decay in photo cathodes to create Cherenkov in the window of PMT
  - Most BG in this energy region

Sciellon: ≈0.5, Cherenkov:0.9~1

(# of hits in 20ns window)/(total # of hits) > 0.6

For 7 GeV DM
30% @0.25 keV
> 50% @0.30 keV

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• Compare Dark Matter MC to the data
• Obtain the maximum cross section (upper limits) of the spectrum not to exceed the observed data points.
• Current XMASS is close to the allowed regions of DAMA/CoGeNT/CRESST.

We will reduce the backgrounds in near future
Annual modulation (Sensitivity test)

- Use all the available data from commissioning runs: 165 days; divided into 11 periods
- Same event reduction for low energy whole volume analysis
- Energy scale based on 57Co data (±3%)
- Scale factor re-adjustment by 60Co in each periods (0.1 ~ 0.6 %)
- Count number of events
- Check for 2 - 6 keVee DAMA modulation

*Good test for electron/γ events (ex. Luminous DM) [not a test for NR]*

- $\chi^2$
  - 22.2 for flat
  - 31.6 for ‘DAMA modulation’

Parameters:

A=0.0098 /keV/kg/day
T=365 days, peak=159.2 days
Nuclear Recoil

Test for Nuclear Recoil:

• QF(Na) \sim 0.25, \text{ Leff(Xe)} \sim 0.15
• 2\sim 6\text{keVee}(\text{Na}) \Rightarrow 8\sim 24\text{keV}_{\text{NR}} \Rightarrow 1\sim 4\text{keVee}(\text{Xe})
  – but 1/30 sensitivity \Leftarrow recoil shape, A^2 dependence,....
  – Current XMASS does not have a sensitivity
• $\chi^2$: 10.8 for flat, 23.8 for ‘the DAMA modulation’

1\sim 4\text{keVee}(\text{Xe}) \Leftrightarrow 2\sim 6\text{keVee (Na)}

• 2\sim 6\text{keVee (I)} \Rightarrow 3.5\sim 13\text{ keV keVee(Xe): under study}
DM Axions

- Event Rate for the axion dark matter (through axio-electric effect)
  \[ R[kg^{-1}d^{-1}] = 1.2 \times 10^{19} A^{-1} g_{ae}^2 m_a \sigma_{pe} \]
- \( g_{ae} \): strength of the coupling constant, \( m_a \): axion mass in keV, \( \sigma_{pe} \): photo-electric cross section in barns/atom.
DM Axions

• Results show that XMASS have similar sensitivity to the current experiments.
• The fitting the signal with backgrounds above 5 keV, where we know the background very well, will increase the sensitivity by factor of 5 (in future)

![Graph showing axion mass vs. gaee with different experiment results](image)

- DAMA allowed
- XMASS
- CoGeNT 2011
- CDMS 2009

XMASS fitting result > 5 keV (sensitivity study)
Solar Axions

• Production: Various mechanism
  
  1. Bremsstrahlung and Compton scattering ($g_{aee}$)
  2. Primakoff effect ($g_{a\gamma\gamma}$)
  3. Nuclear de-excitation (57Fe) ($g_{aN}$)
     - Line signal @14.4 keV

• Observation through axio electric effect ($g_{aee}$)
Solar Axions

Bremsstrahlung and Compton scattering ($g_{aee}$)

- Limits from absolute maximum: $g_{aee} = 4.5 \times 10^{-11}$
- Allowed mass for particular models:
  - $< 200$ eV for KSVZ
  - $< 2$ eV for DFSZ

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Solar Axions

Primakoff: $g_{\gamma\gamma}$ & $g_{\text{ee}}$
- Black body spectrum with $\sim 4$ keV peak
- $g_{\gamma\gamma}$ & $g_{\text{ee}} < 1.1 \times 10^{-1}$

Nuclear de-excitation: : $g_{aN}$ & $g_{\text{ee}}$
- due to the temperature of the sun low energy excited state is highly populated
- $^{57}\text{Fe}$ is the best candidate of the source of axions.

Non linear energy response causes the shift of the energy of the 14.4 keV signal.
Refurbishment

- PMT Al-seal
  - Difficult to remove
  - Installation of Cu ring around the PMT quartz window

- Place a Cu-cover between PMTs

- Remove GORE-TEX

- Clean up surface

  → 1/100 reduction of BG

- Dis-assemble of the detector has started in July

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Time schedule

|----------|----------|----------|----------|----------|

**XMASS-I refurbishment**

**XMASS-I Physics run**

**XMASS-1.5**

5 ton (1 ton fiducial) detector, BG $\sim 10^{-5}$/keV/kg/day

Sensitivity: $s_{\text{Si}} < 10^{-46}$ cm$^2$ (higher mass), $<10^{-42}$ cm$^2$ (low mass DM)

DM Axions, Solar Axions

**Design, R&D construction**

**Physics run**

**XENON1t**

commissioning

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Summary

• Around 5 keV region, we have more than 2 orders of magnitude larger BG than originally estimated.
  – They are from PMT Al seal and Cu surface 210Pb.
• Below 5 keV, there may be a contribution from 14C contaminated in GORE-TEX, but not confirmed yet. There may be unknown BGs or something else.
• For the whole volume analysis, we have obtained similar/better sensitivities to/than other current experiments.
  – Low mass dark matter search, Annual variations, Axion dark matter and Solar axions
  – Thanks to the XMASS large total mass, low threshold, sensitivity to the electro-magnetic events as well as nuclear recoils
• Fiducial volume analysis is under evaluation.
• Refurbishment to remove those backgrounds will be done in next several months and we will expect one to two orders of magnitude improvements.
• XMASS 1.5 design work will start soon, hope to start to take data in 2015 (not funded yet).