Status and background considerations of XMASS experiment

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Outline

1. Various signal rates in large LXe detector
2. 800kg detector design
3. Gamma backgrounds in 800 kg detector
4. Neutron backgrounds
5. Possible calibration sources
Signals expected with natural LXe

WIMP (SI: $10^{-7}$ pb, $M_W=100$ GeV)

$^5\text{Be}$ pp

Solar $\nu$

$^{7}\text{Be}$

Event rates (counts keV$^{-1}$ kg$^{-1}$ day$^{-1}$)

Energy (keV)

Energy resolution is not applied.

$^5\text{Cr} \nu$ Source

(1MCi) @ 1-2m distant

$\mu_\nu = 1 \times 10^{-10} \mu_B$

Current direct limit

$\mu_\nu = 0$

$2\nu\beta$, $T_{1/2} > 2.4 \times 10^{21}$ yr

Recently, $T_{1/2} > 1.0 \times 10^{22}$ yr

NANP05 YDKim
XMASS: homogeneous single phase LXe detector.
Confining FV→self shielding effect for low energy events

\[ \gamma \text{ tracking MC from external to Xenon} \]

Blue: \( \gamma \) tracking
Pink: whole liquid xenon
Deep pink: fiducial volume
Total 800kg, 100kg FV

External \( \gamma \) ray from U/Th-chain

All volume (23ton)
20cm wall cut
30cm wall cut (10ton FV)

Large self-shield effect

Background are widely reduced in < 500keV low energy region
Status of 800 kg detector

- **Basic performances have been confirmed by 100 kg prototype detector.**
  - Vertex and energy reconstruction by likelihood fitting
  - Self shielding power.
  - BG level (~$10^{-2}$ dru @ 100 keV, consistent with MC).

- **Detector design is under progress using MC**
  - Structure and PMT arrangement (812 PMTs)
  - Event reconstruction
  - BG estimation

- **New experimental hall will be prepared.**
  - Necessary size of shielding around the chamber
Structure of 800 kg detector

- tried to optimize the photocathode coverage.
- tried to minimize the wall effect.

12 pentagons / 60 triangles pentakisdodecahedron

5 triangles make pentagon

10 PMTs / triangle surface

31 cm

34 cm

31 cm
- Total **812** hexagonal PMTs immersed into liq. Xe
- **~70%** photo-coverage
- Radius to inner face **~44cm**

Each rim of a PMT overlaps to maximize coverage
Event reconstruction (Simulation)

- Position resolution

Generated
R = 31 cm
E = 10 keV

σ = 2.3 cm

Boundary of fiducial volume

- 10 keV ~ 3.2 cm
- 5 keV ~ 5.3 cm

Fiducial volume

Distance from the center [cm]

Reconstructed position [cm]

σ (reconstructed) [cm]

Events
• Up to $\sim$40cm, events are well reconstructed with position resolution of $\sim$2~3cm
• Out of 42cm, grid whose most similar distribution is selected because of no grid data
• In the 40cm~44cm region, reconstructed events are concentrated around 42cm, but they are not mistaken for those occurred in the center
• No wall effect

$5\text{keV} \sim 1\text{MeV}$

- Vertex reconstructed
800kg BG study

Achieved (prototype detector)  Goal (800kg detector)

- $\gamma$ ray from PMTs $\sim 10^{-2}$ cpd/kg/keV → $10^{-4}$ cpd/kg/keV
  - Increase volume for self shielding
  - Decrease radioactive impurities in PMTs (~1/10)

- Liquid Xenon
  - $^{238}\text{U} = (33\pm7)\times10^{-14}$ g/g → Remove by filter
    - $1/33$ → $1\times10^{-14}$ g/g
  - $^{232}\text{Th} < 23\times10^{-14}$ g/g (90% C.L.) → Remove by filter (Only upper limit)
    - $1/12$ → $2\times10^{-14}$ g/g
  - $\text{Kr} = 3.3\pm1.1$ ppt → Achieve by 2 purification pass
    - $1/3$ → 1 ppt
Estimation of $\gamma$ BG from PMTs

- Inside PMT, put vacuum space, and ceramic board.
- Decays of $^{238}$U at ceramic board is simulated.
- assumed 10 times lower background than present R8778 pmt. $\rightarrow$ $1.26 \times 10^5$ decays/day
- Used Geant4 for all sequential decays.

\begin{align*}
R8778\ PMT & \\
^{238}\text{U} & : \ 1.8 \times 10^{-2} \ \text{Bq/PMT} \\
^{232}\text{Th} & : \ 6.9 \times 10^{-3} \ \text{Bq/PMT} \\
^{40}\text{K} & : \ 1.4 \times 10^{-1} \ \text{Bq/PMT}
\end{align*}
**Result of $^{238}$U background**

Statistics: 2.1 days

No event is found below 100keV after fiducial cut (R<24.5cm)

$< 1 \times 10^{-4}$ cpd/kg/keV can be achieved

(Now, more statistics is accumulating)
Shielding size should be estimated to fix the size of the new hall.

**A proposal of shielding for 800kg detector**
- Water shield for both ambient gammas and fast neutrons.
- Simple, not expensive, good for neutrons

**Configuration for simple estimation**
- Put 80cm diameter liquid Xe ball
- Assume several size of water shield of 50 – 300cm thickness.
- Assume copper vessel (2cm thickness) for liquid Xe.
- Actual shape may be cylinder, but assumed as sphere for simplicity of MC.

There are technical issues to be solved.
(1) $\gamma$ attenuation

Initial energy spectrum from the rock

Total # of gammas
$E>500\text{keV}$
$\sim 0.7/\text{cm}^2/\text{sec}$
More than 200cm water is Needed to reduce the BG to the PMT BG level

- Sum up the total histogram = 4.65
- $4.65 \times 50(keV/bin) \times 804(kg) / 86400(\text{sec/day}) \rightarrow 2.2Hz$
(2) Fast neutron attenuation

10^5 neutrons (=0.14 days) generated.

water: 200 cm, n: 10 MeV

- Fast n flux @ Kamioka mine: (1.15±0.12) ×10^{-5} /cm^2/sec
- Assuming all the energies are 10 MeV conservatively

< 2×10^{-2} counts/day/kg

~200 cm water is enough to reduce the BG to the PMT BG level

BG caused by thermal neutron is now under estimation
Calibration Issues for homogeneous detector.

- to define fiducial volume for low energy events, we need to confirm the position resolution with definite source.
- **Attenuation length of 20 keV gammas in LXe ~ 50 micrometer.** → source size should be small.

- For lower energy and position calibration, need X-ray source.
- Electro deposition of I-125 on 20 micrometer metal wire is planned.
- Locate the wire source in many positions in LXe.
\(^{220}\text{Rn}(\text{Thoron})\) source for position calibration

Beta–alpha coincidence events can be used to check the position resolution of low energy beta events since we know the position of alpha events accurately.

Since the chamber volume is small, most of the Rn gas will enter to Lxe chamber before decay.

\[ ^{228}\text{Th} \rightarrow ^{224}\text{Ra} \rightarrow ^{220}\text{Rn} \rightarrow ^{216}\text{Po} \rightarrow ^{212}\text{Pb} \]

\[ ^{212}\text{Bi} \rightarrow ^{208}\text{Tl} \rightarrow ^{208}\text{Pb} \]

\[ ^{212}\text{Po} \rightarrow ^{208}\text{Pb} \]

\[ Q = 2.25\text{MeV} \]

\[ \left| \frac{\Gamma}{V(\beta)} - \frac{\Gamma}{V(\alpha)} \right| \]

will give the position resolution of beta events.
• For $10^5$ beta-alpha coincidence events below $E(\text{beta})<100$ keV with 10 hours data taking, the activity of $^{228}\text{Th}$ should be ~ 20 kBq.
• Whole volume of LXe can be studied.
• Is there any background left over? → should be checked.

G4 simulation

Beta energy spectrum
New experimental hall will be made in Kamioka mine for XMASS and other similar scale experiments.

※ Tentative design

800kg chamber
Water shield tank
Experiment area excavation
>250cm water shield
- fast neutron: 1/10000 for 2m shield
- <500keV $\gamma$: 1/10 for 50cm shield

Other similar scale experiments such as CANDLES(DBD) can be housed.
Summary

- Multi-purpose ultra low background experiment with large mass liquid Xe (ton scale)

- 800 kg detector:
  mainly for dark matter search.
  \textit{10^2 improvement of sensitivity} above existing experiments is expected.

- Designing 800 kg detector is under progress.
  - BG estimation is done.
  - schematic shielding is studied.
  - New excavation is planned.
  - Hamamatsu PMT will be fixed, detail design is going on.