Status of XMASS experiment

CYGNUS 2013@Toyama

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Nagoya univ. Hiroyoshi Uchida
for XMASS collaboration

XMASS project

XMASS-I

XMASS-1.5

XMASS-II

835 kg,
100 kg Fiducial volume (FV)
φ80 cm, 642 PMTs

- Dark matter search
- Axion like particle search

5 ton, **1 ton FV**
φ1.5 m, ~1000 PMTs

25 ton, **10 ton FV**
φ2.5 m

- Dark matter
- pp solar neutrino
- 0ν2β decay

Y. Suzuki, hep-ph/0008296

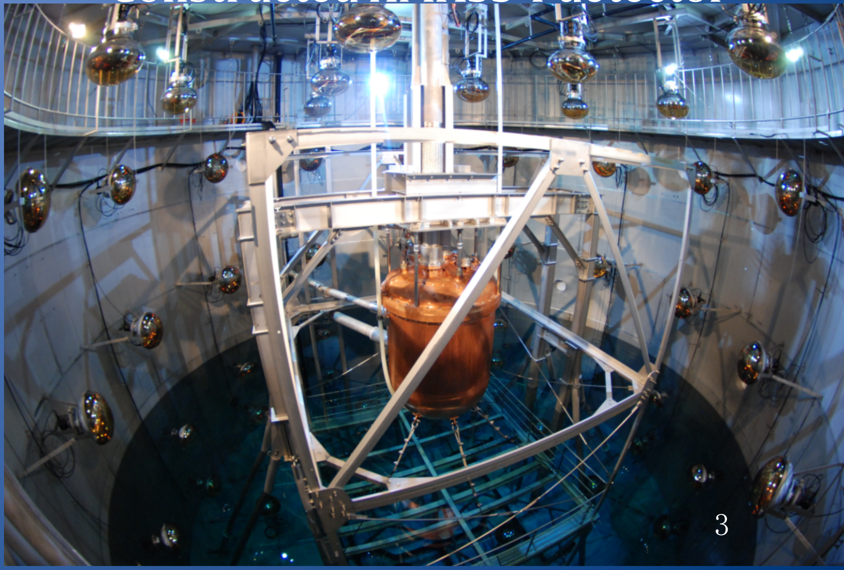
- In this slide, I'd like to explain our XMASS project at Kamioka observatory in Japan.
- Our final goal, a ten ton scale detector of XMASS-2 will cover multiple purposes such as dark matter, pp solar neutrino and 0ν2β decay.
- Refurbishment of XMASS-I will be completed in this autumn and XMASS-1.5 is planed to start in 2015. They are mainly for dark matter search.
- Commissioning data of XMASS-I was taken from Nov. 2010 to May. 2012.

XMASS-I detector

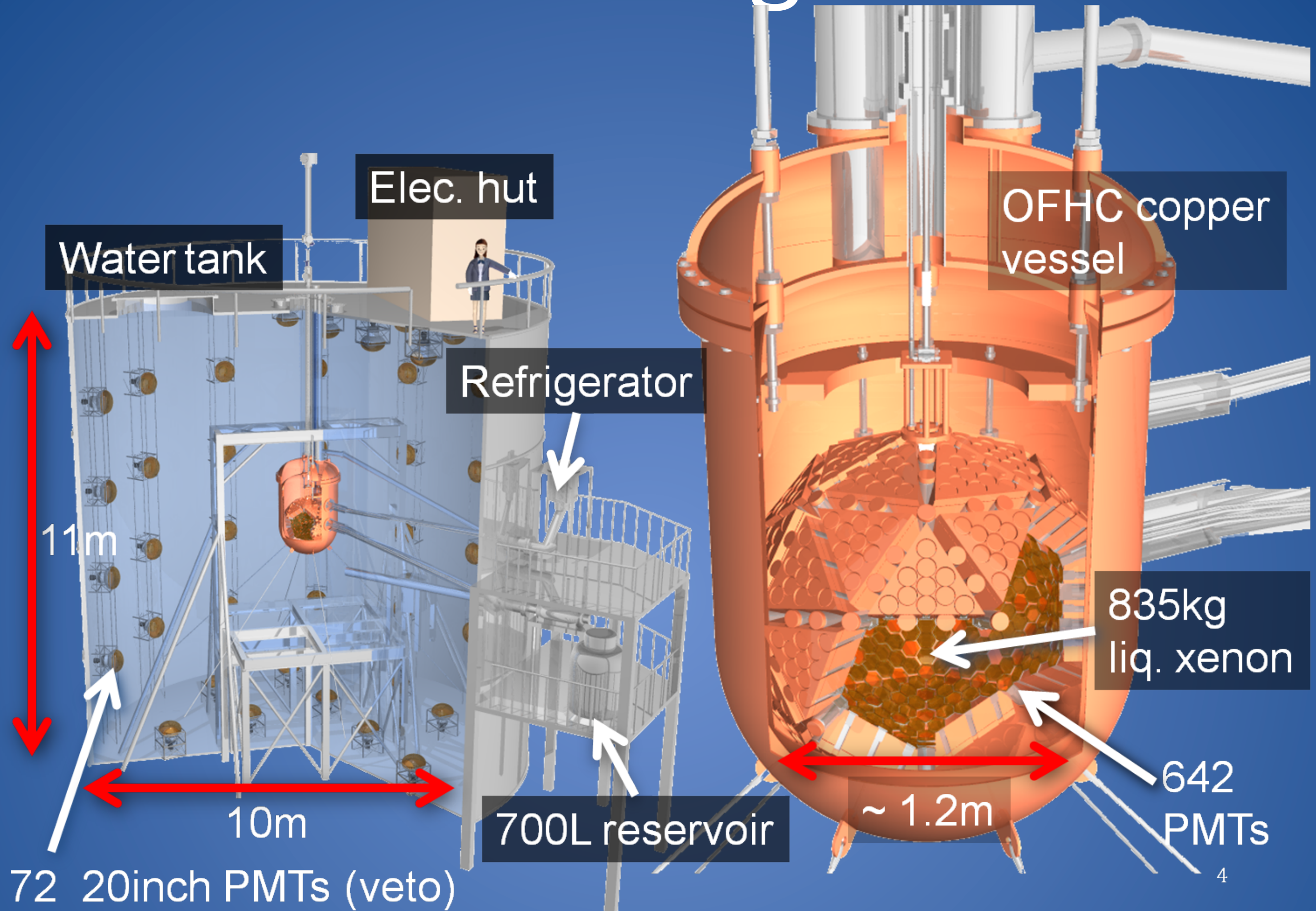
- XMASS-I is a single phase detector using 835kg of liquid xenon.
- External backgrounds are reduced by self-shielding of liquid xenon.
- The detector has high light yields (~14p.e./keV) & a low energy threshold (~0.3keVee).
- It is designed to have low background without particle ID, which enable us to make a sensitive search for nuclear recoils as well as exotic electromagnetic signals.

OFHC copper PMT holder and PMTs

Constructed XMASS-I detector



Detector configuration



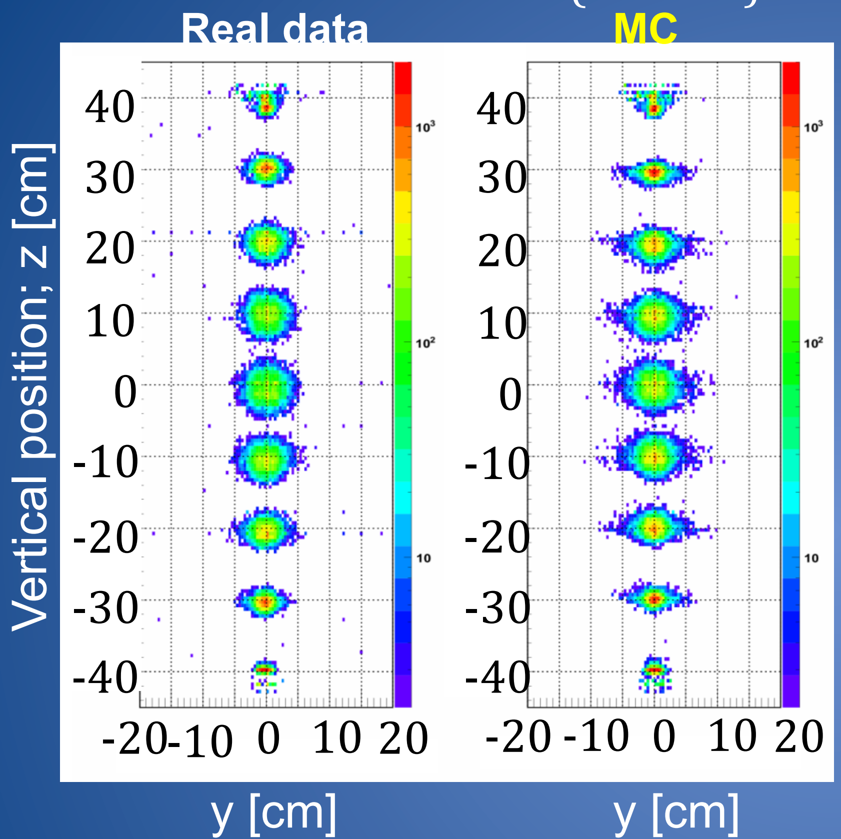
•The XMASS detector uses a water tank as a radiation shield, which is also used for an active muon veto.

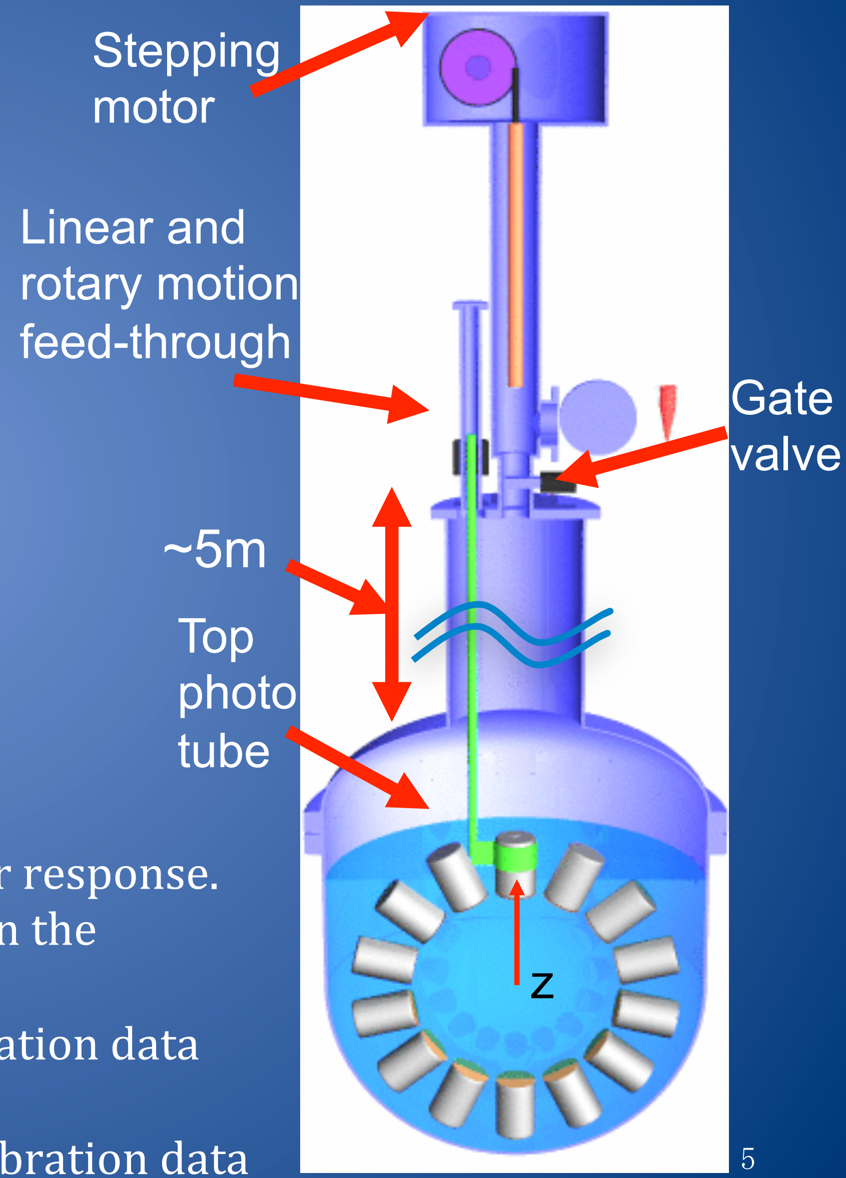
•The size of water tank is 10 m in diameter and 11m in height.

•The detector vessel and PMT holder are made of oxygen free high-conductivity copper equipped with 642 PMTs.

Calibration data

^{57}Co calibration data (122keV)

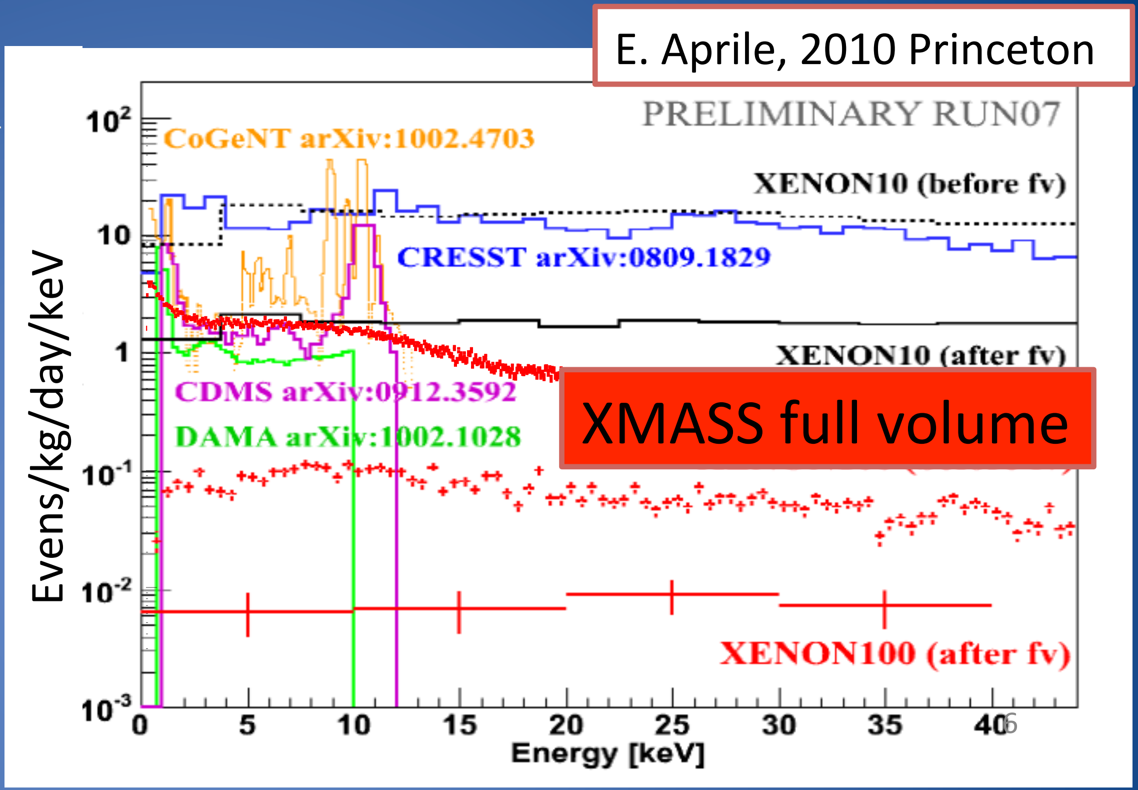




- Calibration sources are used for checking detector response.
- The sources can be moved along the vertical axis in the detector.
- Right hand animation shows a procedure of calibration data taking.
- The reconstructed vertex distributions of the calibration data are well reproduced by the simulation

Observed data and physics analyses

- The background level of entire volume of XMASS-I is comparable with other experiments.



- By using the commissioning data, following analyses were conducted:

Whole volume analysis without fiducial volume cut

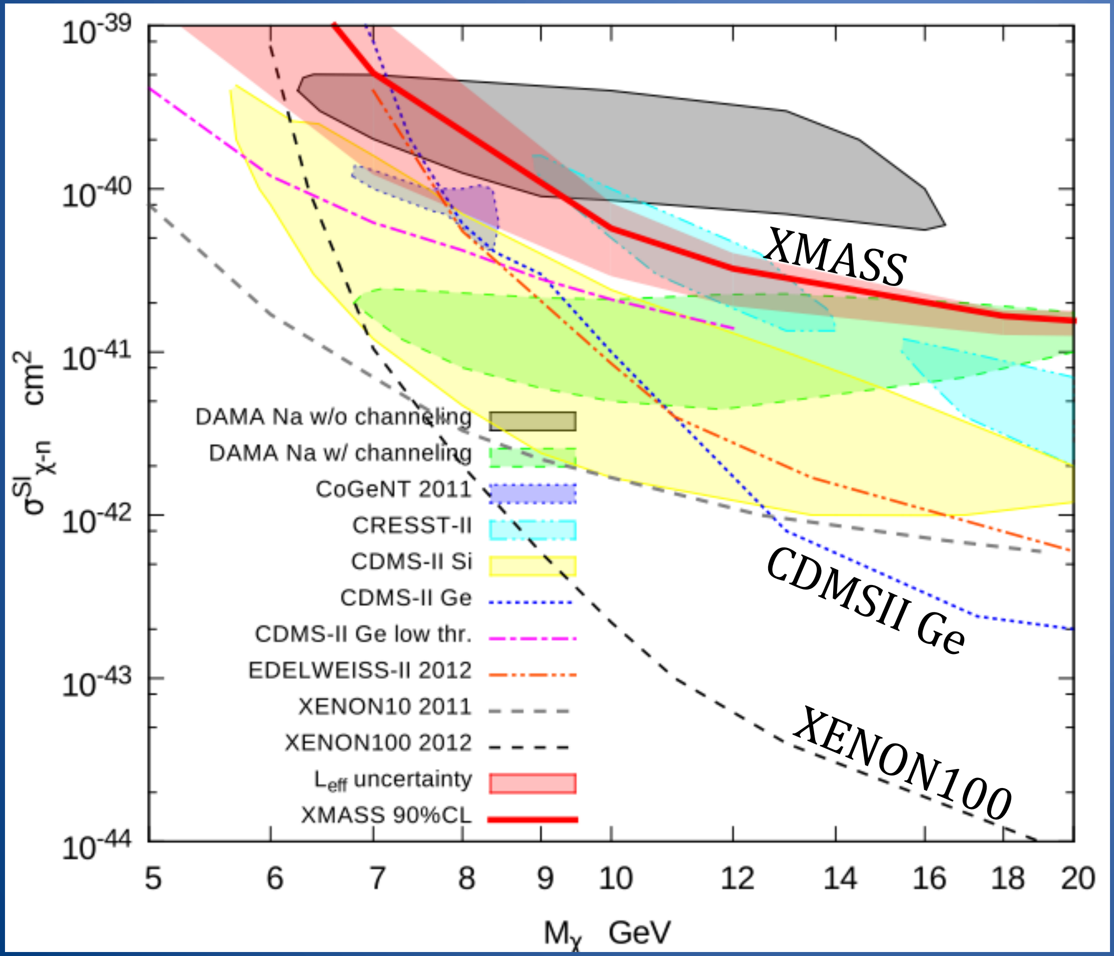
- Low threshold (0.3keVee) analysis: light mass WIMP search
- Searches for axion-like particles

Inelastic scattering of ^{129}Xe by WIMPs: I will explain this analysis in detail.

Recent physics result

Light mass WIMP search

- Light mass WIMP search analysis is conducted using full volume data.
- The exposure of the detector is 835 kg LXe times 6.70 days of live time.
- We have a good sensitivity for light mass WIMPs since the photoelectron yield is exceptionally high ~14 pe/keV and the energy threshold is low ~0.3 keVee.



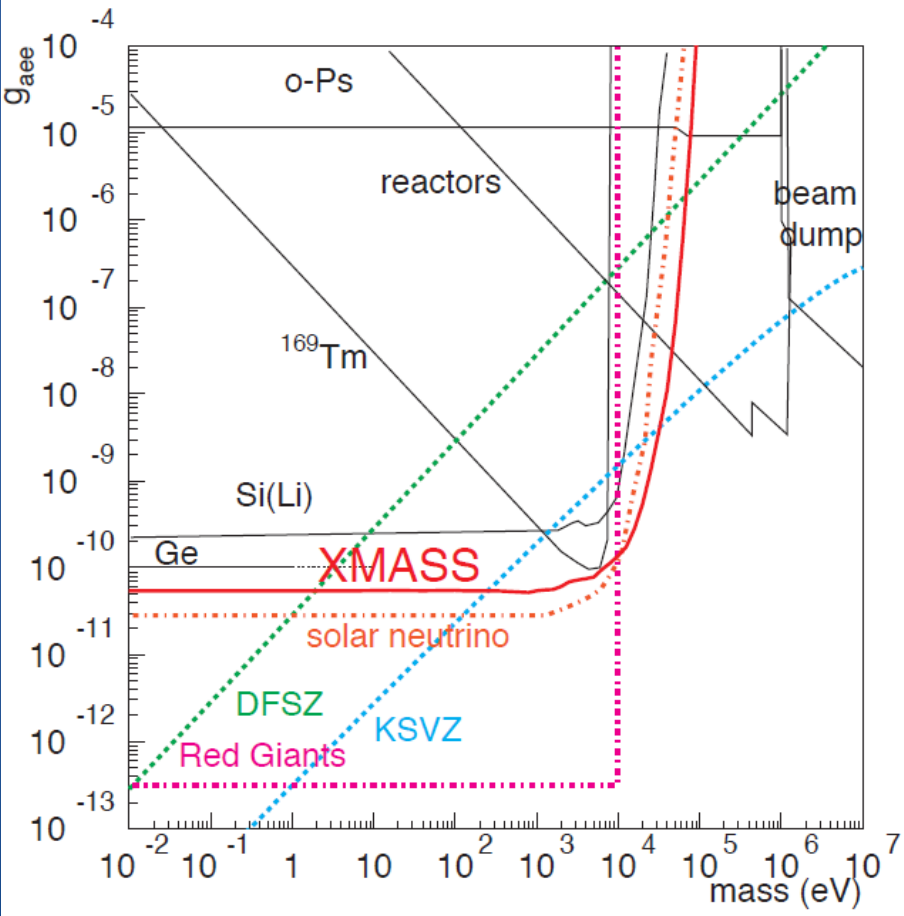
- This result excludes a part of the parameter space favored by other measurements.

- After the refurbishment, we will expect 1 to 2 orders of magnitude improvement.

Published in
PLB 719 (2013) 78-82

Solar Axion search

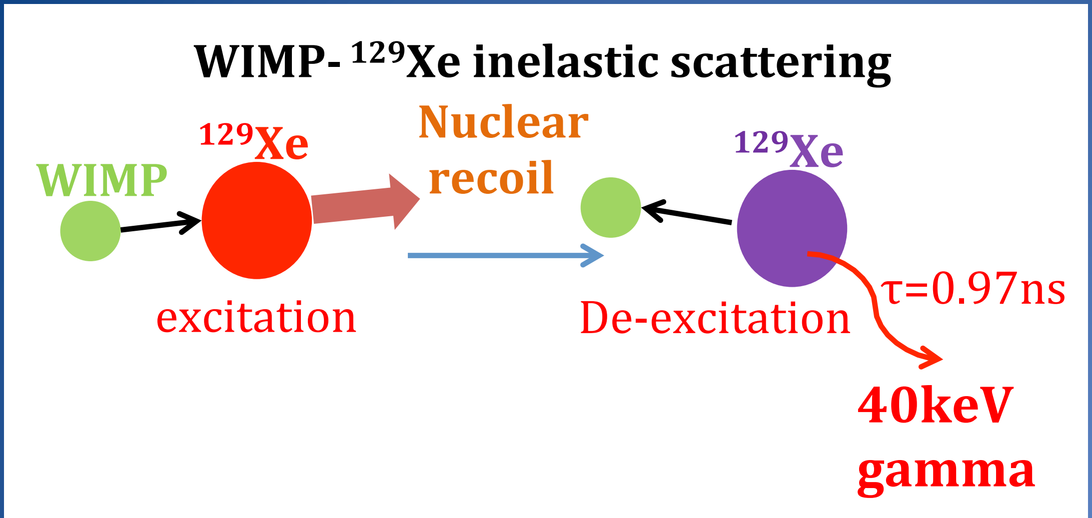
- Axion is a hypothetical particle to solve the strong *CP* problem.
- Similar particles (axion like particles) might be produced inside the Sun and would be detected.
- XMASS is suitable detector because of a large mass and low background.



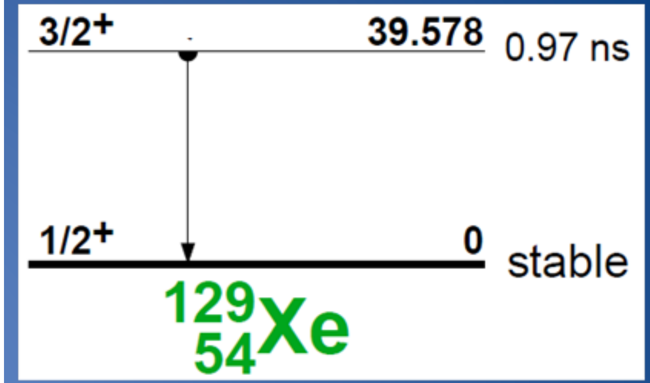
•We have obtained the best limit for g_{aee} among the terrestrial experiments.

Reference:
arXiv:1212.6153
Accepted for publication in PLB.

WIMP- ^{129}Xe inelastic scattering



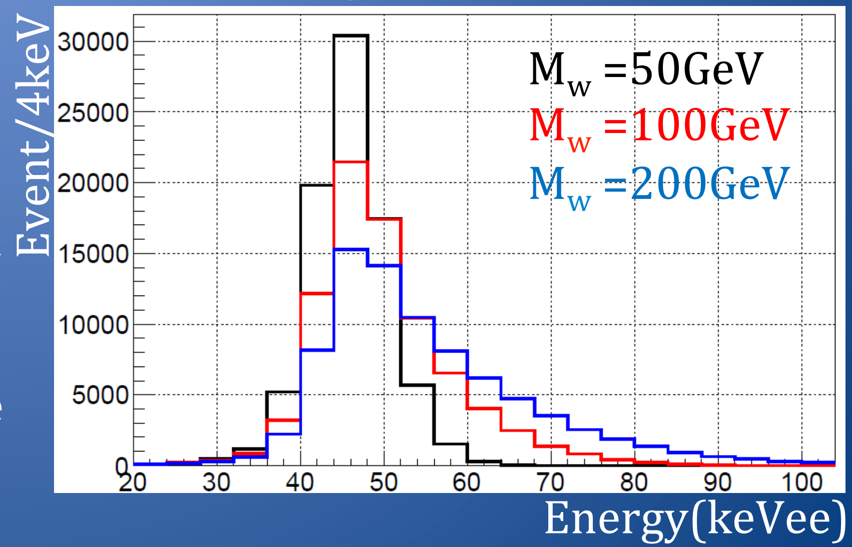
level of ^{129}Xe nuclei



- There is a possibility to have an excitation of ^{129}Xe nuclei when a WIMP scatters off the nuclei.
- A 40keV gamma ray due to de-excitation is immediately emitted after the interaction.
- These interaction would cause a peak in an observed energy spectrum as shown in the right figure.
- The shape of the peak depends on the mass of WIMPs because of different nuclear recoil energies.

$$E_{expected} = E_{40keV\gamma} + E_{recoil} \times Leff$$

Expected energy distribution in XMASS

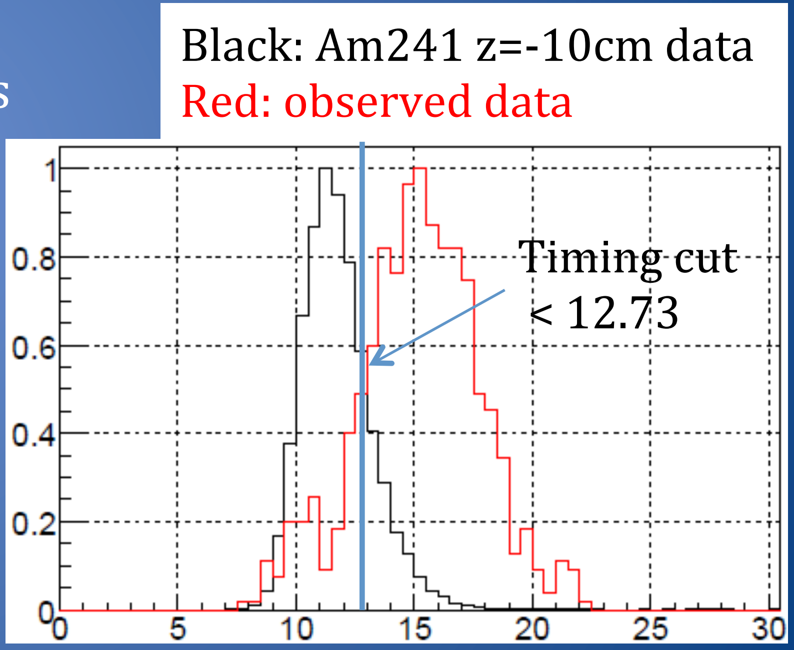


Reduction of surface background 1

We found that majority of backgrounds comes from ^{238}U and ^{210}Pb contaminated in the aluminum seal used for PMTs.

We use three cuts to reduce those backgrounds.

- Radius cut
  - Observed p.e. pattern was used to reconstruct event vertex.
  - Those events with reconstructed radius less than 15cm are used for this analysis.
- Timing cut
  - Even after the radius cuts, some surface events remain due to leakage of reconstruction tail.
  - Timing information helps to reduce those remaining surface backgrounds further.
  - Basically, it uses timing difference between the early hits and average of hit timing of other PMTs. Larger timing difference suggests surface events.



Timing cut parameter

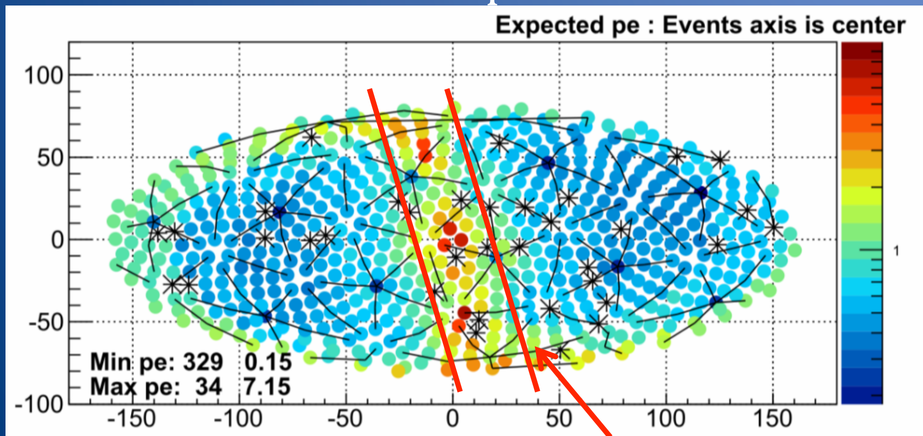
Reduction of surface background 2

- Band cut
  - There are grooves and gaps between PMTs.
  - Scintillation light caused by events in the grooves must have characteristic pattern as shown in the figure below. This is because direction of scintillation light is confined by the grooves.
  - This characteristic pe pattern (band structure) can be identified. Events with this pattern can be eliminated by the band cut.

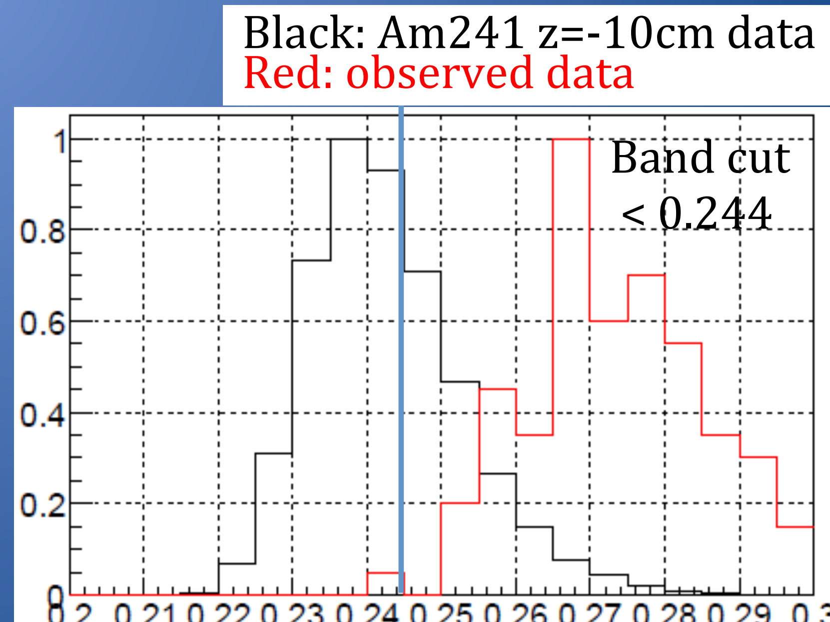
$$\text{Band cut parameter} = \frac{\text{Maximum pe in the 15cm width band}}{\text{Total pe}}$$

  - The 15cm width band is moved around to maximizing the pe inside.

PMT hit pattern



Band structure by grooves in the hit pattern

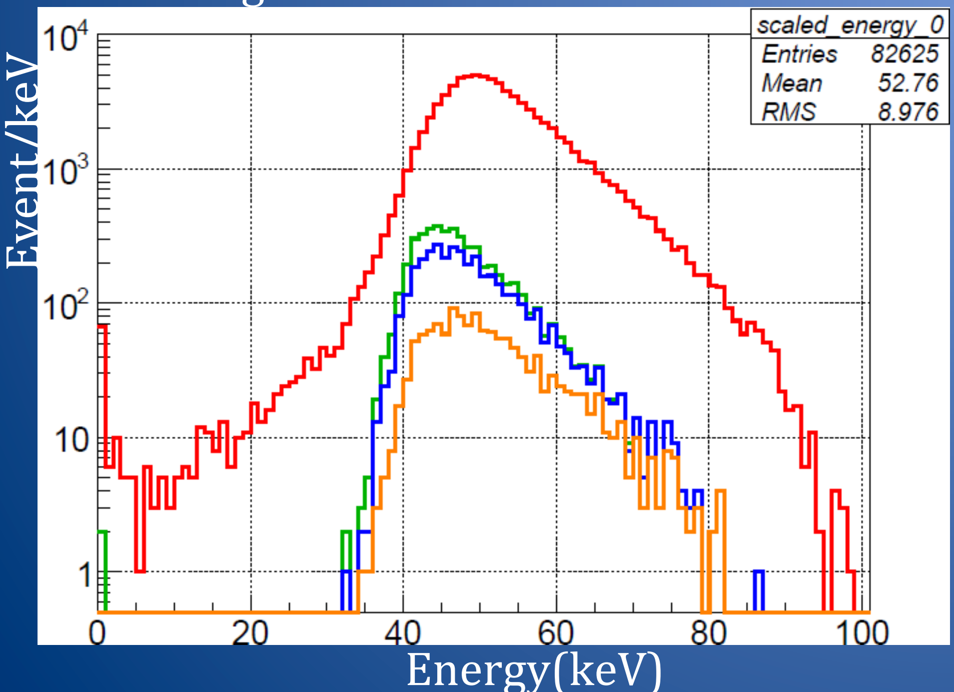


Band cut parameter

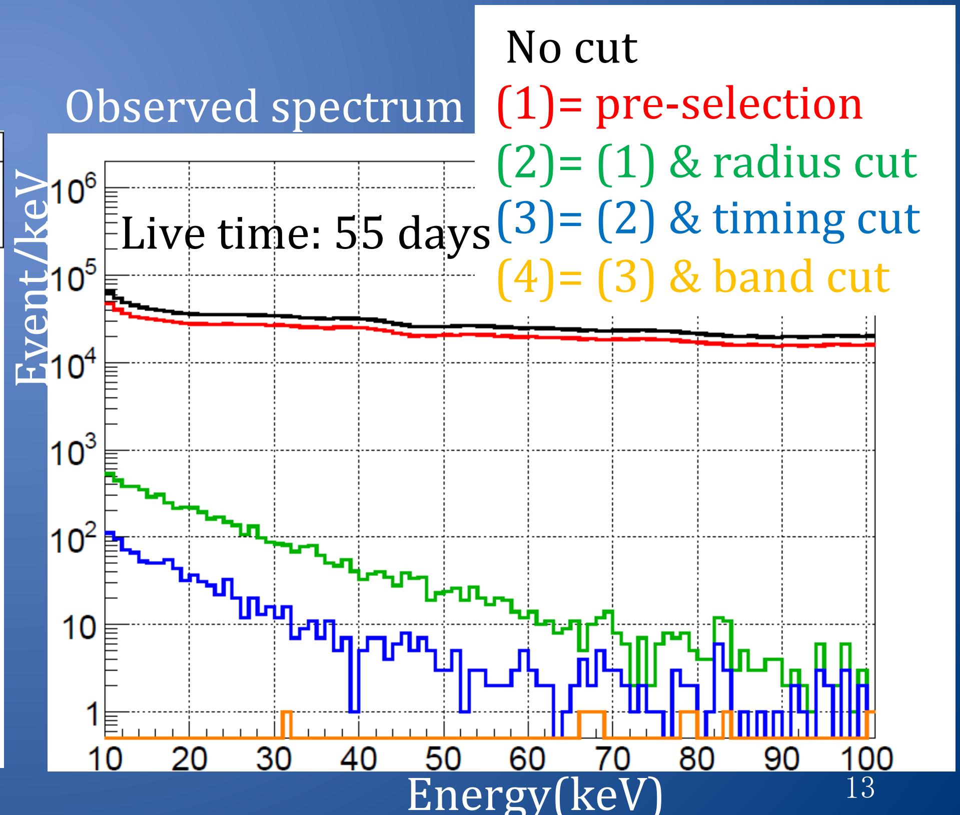
Optimization of the cut parameters

- To achieve the best S/N ratio, radius, timing, and band cut positions are optimized using side band data (10-30keV, 80-100keV.)
- Left hand figure is a signal MC after each cut. Right figure is the observed spectrum after each cut.
- 99.6% of observed events are rejected by timing and band cut after 15cm radius cut (effective mass).
- Signal acceptance for 100GeV WIMP signal MC is 22% with effective mass.

Signal MC for 100GeV WIMP



Observed spectrum



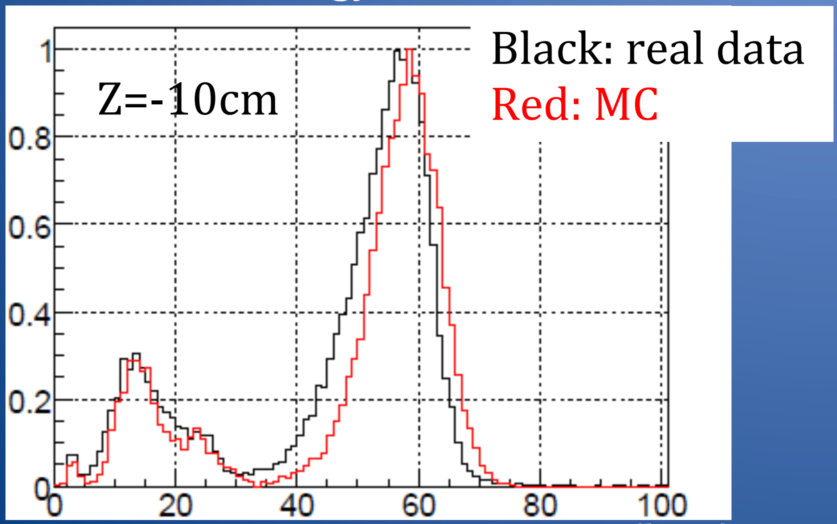
Systematic error

By comparing calibration data (60keV peak in ^{241}Am data) and corresponding MC samples, we have evaluated systematic errors on the cross section of inelastic scattering caused by following uncertainties:

- Energy resolution: <1%
- Energy scale: 10% (with 100GeV signal MC)
- Reconstructed radius cut: 5%
- Timing and band cut: 24%

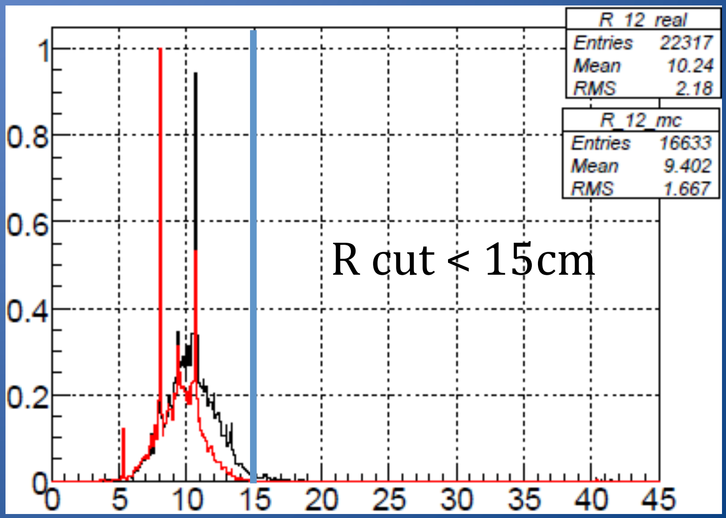
Total systematic error is 27%.

^{241}Am energy distribution



Energy(keV)

Radius cut parameter distribution



Reconstructed radius (cm)

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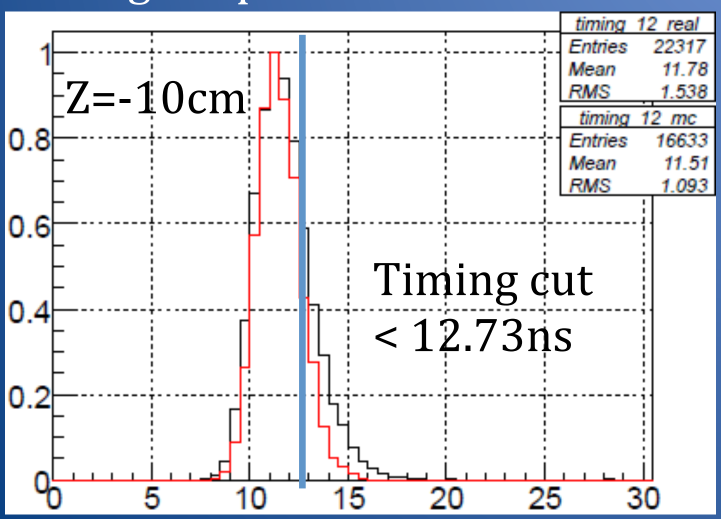
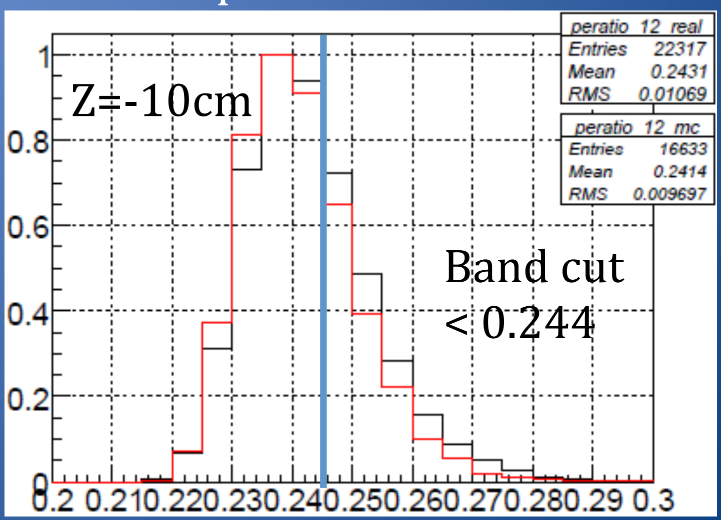
Timing cut parameter distribution



Timing cut parameter

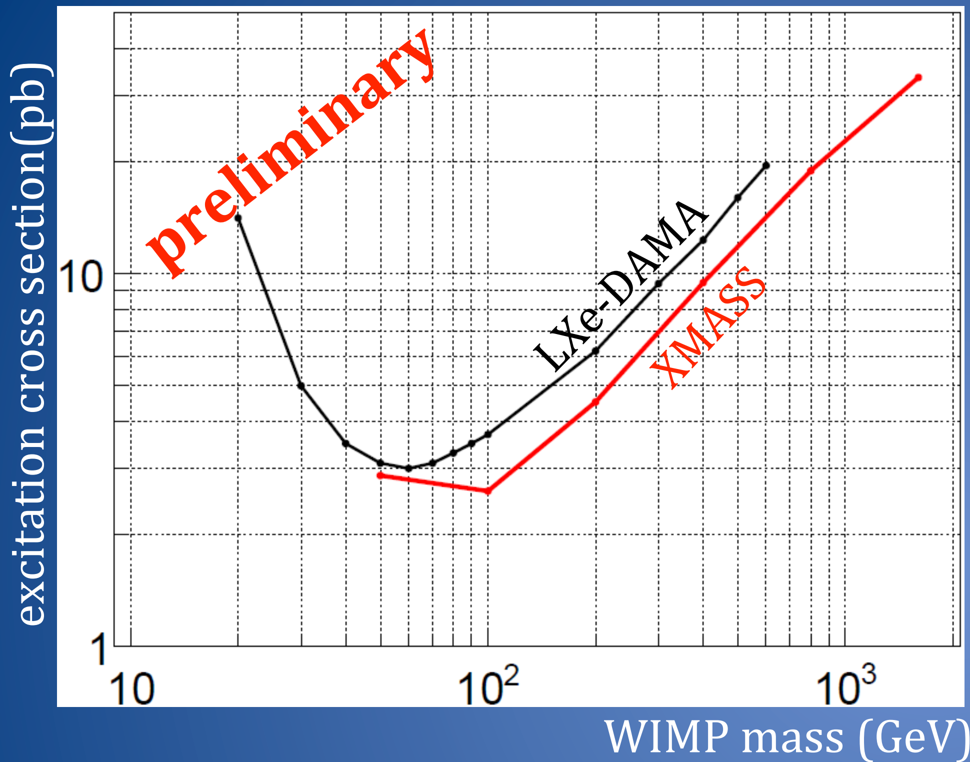
Band cut parameter distribution



Band cut parameter

Upper limit for the inelastic cross section

Excitation cross section



Black: LXe-DAMA 2000(90%C.L.)
Ref: NJP vol.2, 15 (2000), R Bernabei, et al

Red dot: XMASS upper limit
(90%C.L. statistical error only)

cut (Signal region: 37-50keV)

- R cut < 15cm
- Timing cut < 12.73ns
- Band cut < 0.244

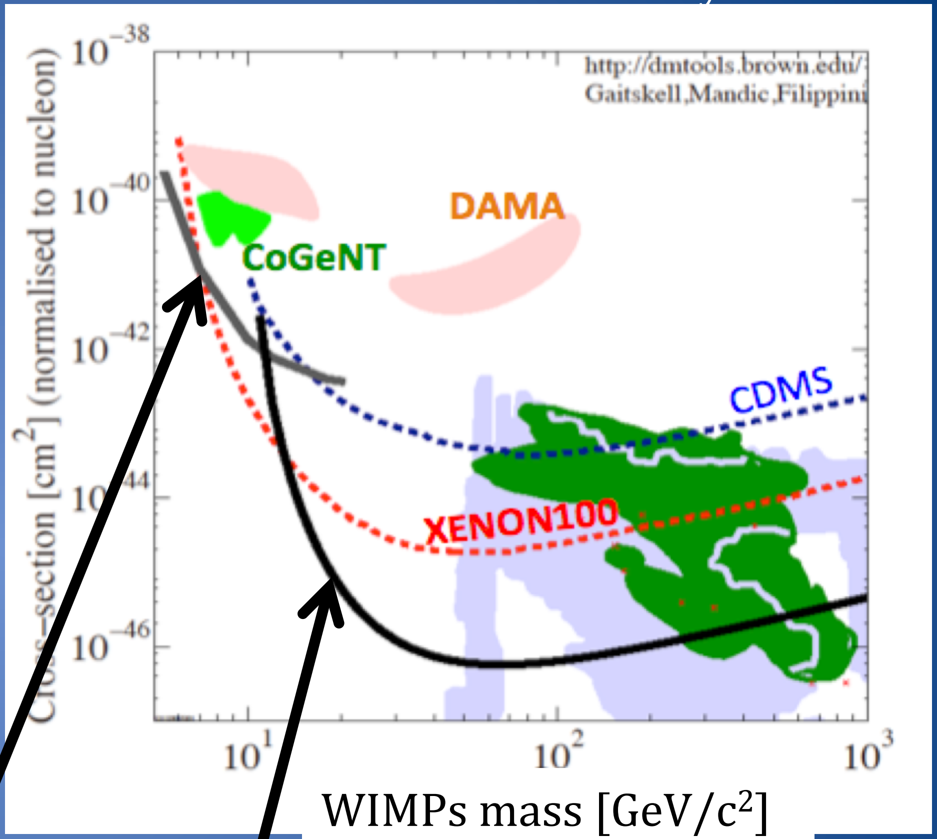
- Red points in this figure show the 90% C.L. upper limit we obtained by this analysis.
- The points do not include systematic errors but it is evaluated as 27% for 100GeV WIMPs.
- Black points show LXe-DAMA experiment result which used 6.5 kg of 99.5% ^{129}Xe enriched Xe.
- We will finalize our result by taking into account the systematic errors.

Next stage of XMASS

XMASS-1.5

- XMASS-1.5 uses five ton liquid xenon and fiducial volume will be one ton.
- New PMT will be developed without dirty aluminum.
- Surface ^{210}Pb will be less than 1/100 by its cleaning and improving an environment of detector construction.
- Sensitivity for SI cross section will be 10^{-46} cm^2 at 100GeV WIMPs.

XMASS-1.5 sensitivity



XMASS-1.5 full volume

XMASS-1.5, 2keV threshold , 1yr

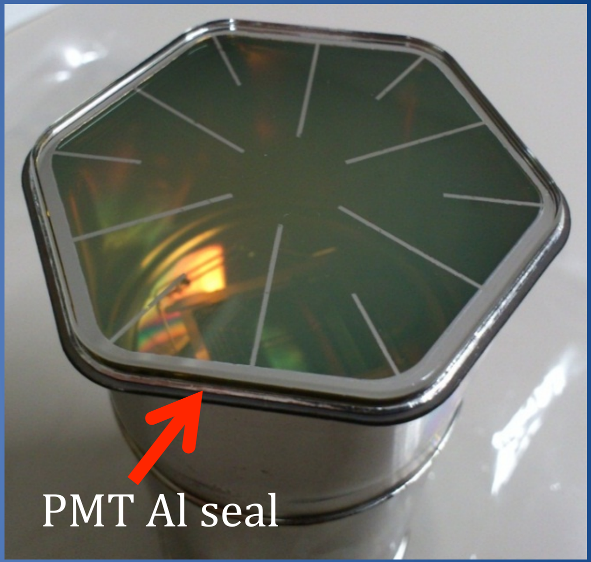
Round shape window

- New PMT with round shape window to identify surface event is being developed.

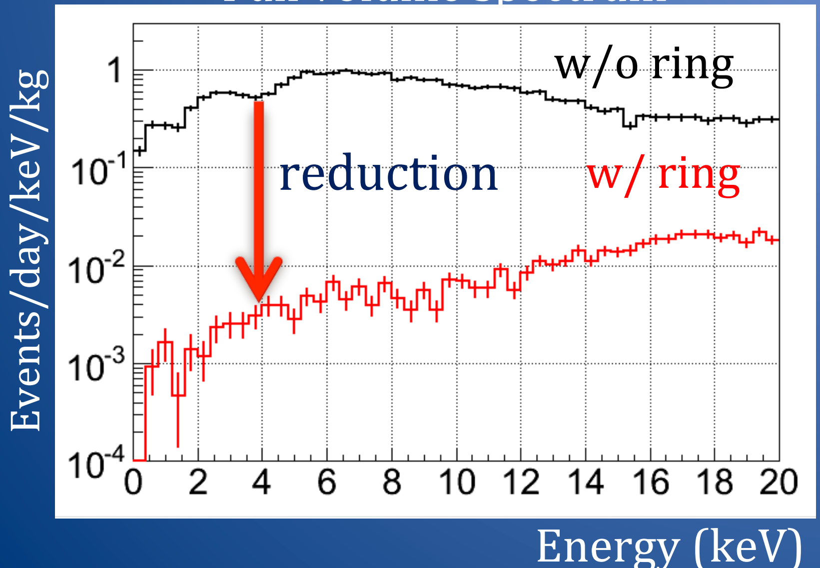
Refurbishment for XMASS-I

- Purposes of Refurbishment are:
  - Confirmation of background reduction by shielding of scintillation light originated from PMT aluminum by copper ring. (Right hand figure)
  - Also to demonstrate the reduction of ^{210}Pb (2nd largest component in background) with electro-polishing and special clean environment
- Expected background level:
  - Aluminum background is expected to be reduced by 1 to 2 orders of magnitude lower by placing the copper rings around PMTs.

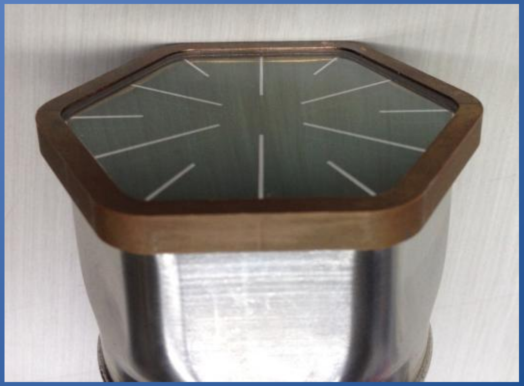
Before installation of ring



Full volume spectrum



After installation of ring



Summary

- XMASS-I is the world's largest (835kg) and lowest threshold (0.3keVee) detector for dark matter search. We have demonstrated high performance of our detector by following physics results:
  - Light mass WIMP search (PLB 719(2013)78)
  - Solar Axion search (to be published in PLB)
  - Inelastic scattering DM search.
- XMASS-1.5 is being designed and will be expected to start in 2015.
- The refurbishment of XMASS-I will be completed in autumn 2013.