17+3 minutes

XMASS
The Direct Dark Matter detection experiment

Outline

1.INTRODUCTION

2.Results from 1st phase XMASS (100kg fid. [835kg total])

3.Refurbishment of XMASS-I

4.XMASS1.5 (next phase: 1t fid. [5t total])

5.Conclusion

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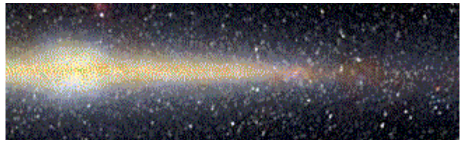
Direct detection of Dark Matter

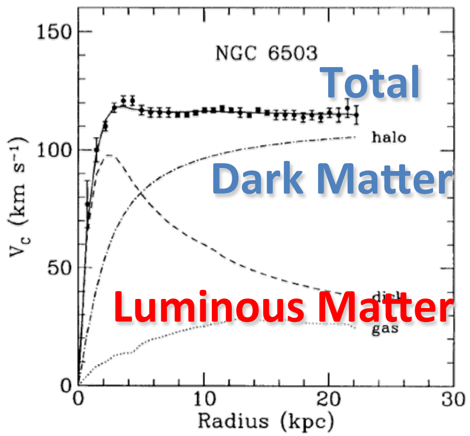
- Dark Matter:

  One of the most important subjects for astrophysics and particle physics
- Many evidence for the existence
  - Mass of the clusters of the galaxies, Gravitational lensing, Rotation curves of Galaxies, Large scale structure of the Universe, ...

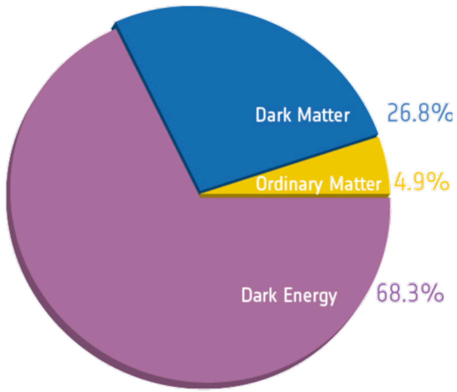
➔ Dark Matter must exist
  - One quarter of the energy-matter of the Universe (26.8% [Planck])
- But we do not know what they are (Neutral, Weakly Interacting, Cold, non-Baryonic, ...)
  - WIMPS, AXION,...
- **Direct detection**

  ➔ Unveils the true nature of dark matter





Rotation velocity



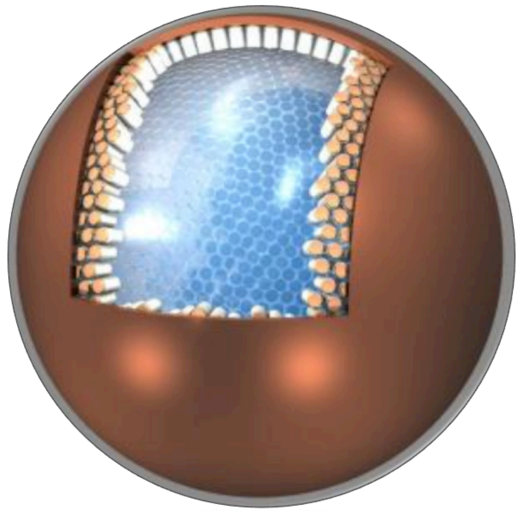
XMASS

Multi-purpose liq. Xenon detector

- Final Goal: 10 ton fiducial mass, 25 ton total (2.5mϕ)
  - pp-solar neutrinos: ν+e → ν+e
  - Double beta decay $^{136}Xe \rightarrow {}^{136}Ba + 2e^-$
  - Dark Matter: WIMPs, Axions, Axion Like Particles
- Single phase detector (scintillation only)
  - Simple, Scalable, …
  - BG reduction by self-shielding
  - Challenge
    - Need low radio-active background
- Staging Approach

Y. Suzuki, hep-ph/0008296

XMASS-II
Multi-purpose
10 ton /25 ton

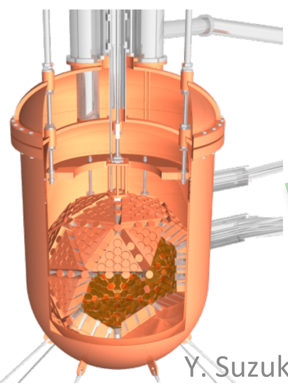


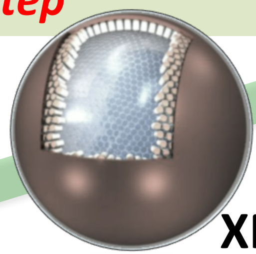
Need Intermediate size
Next Step

XMASS-I

100kg/835kg

Dark Matter





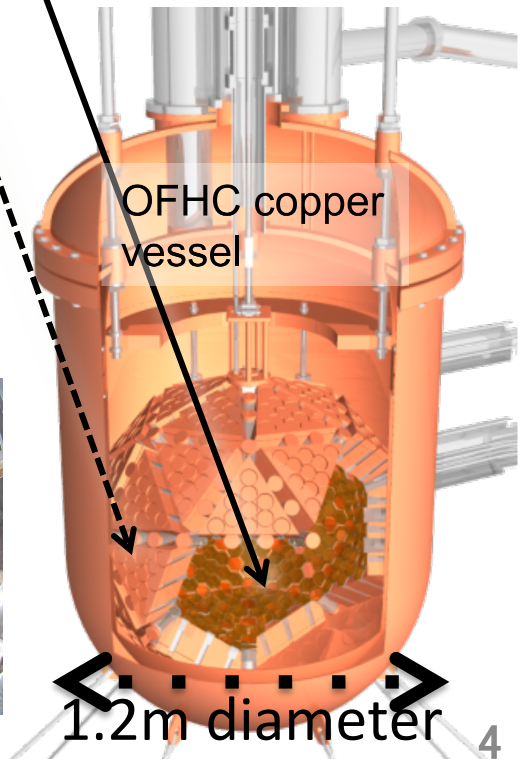
XMASS-1.5
1 ton /5 ton
Dark Matter

The phase-I XMASS

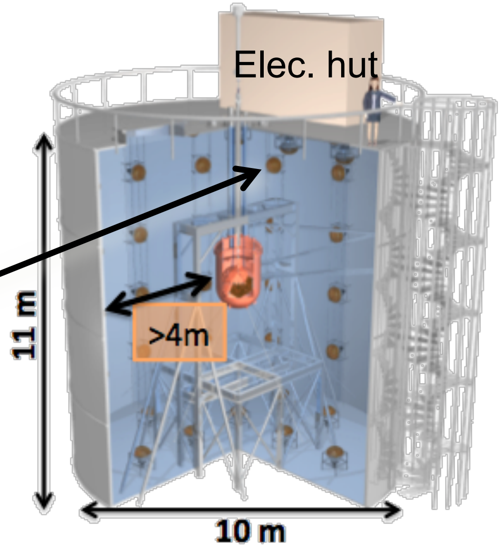
- 100 kg fid. mass, [835 kg inner mass (0.8 mϕ)]
- 630 hexagonal & 12 round PMTs with 28-39% Q.E.
- Sensitive also to electron/γ events

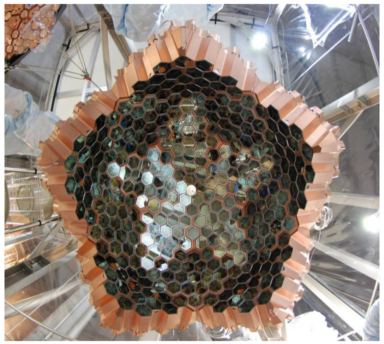
What we have learnt

- photocathode coverage: > 62% inner surface: **14.7±1.2 pe/keV (largest)**
- Threshold achieved: **0.3 keVee w/o reconstruction (lowest)**, and 5 keVee w/ reconstruction

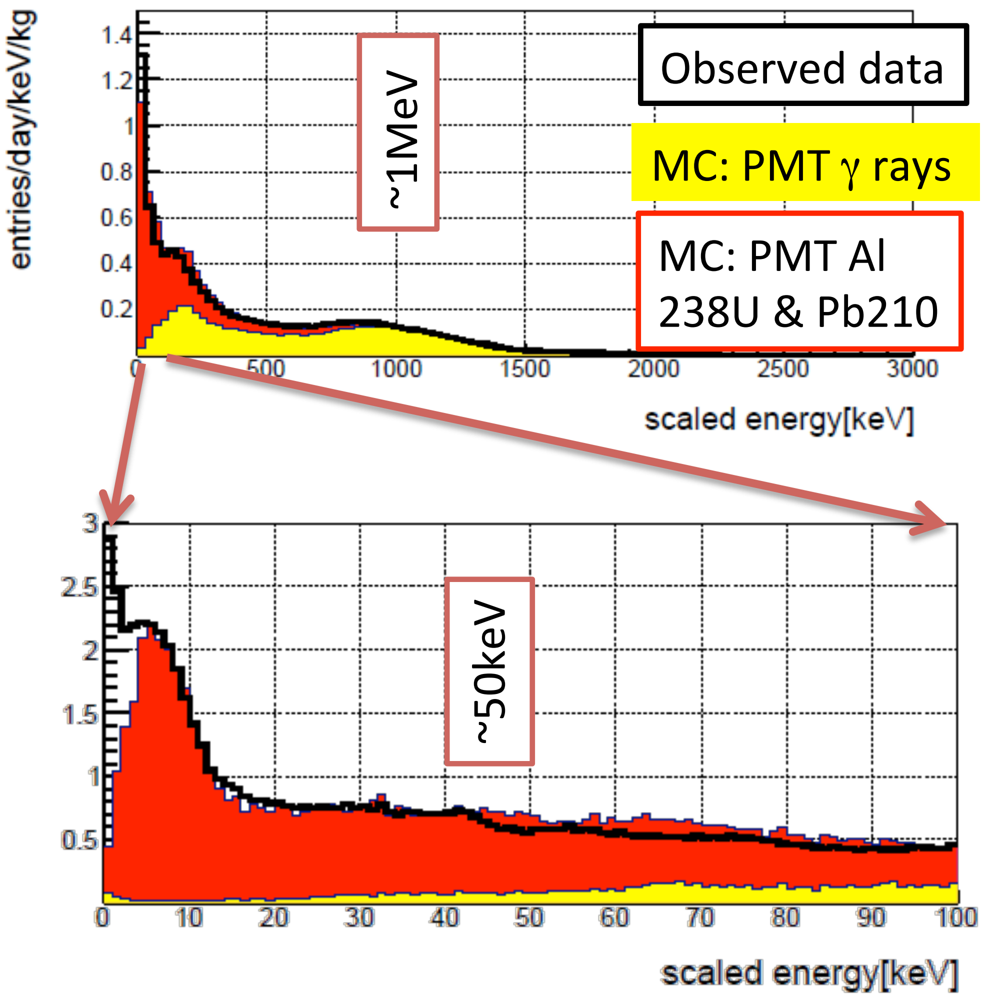


72 20inch PMTs (veto)



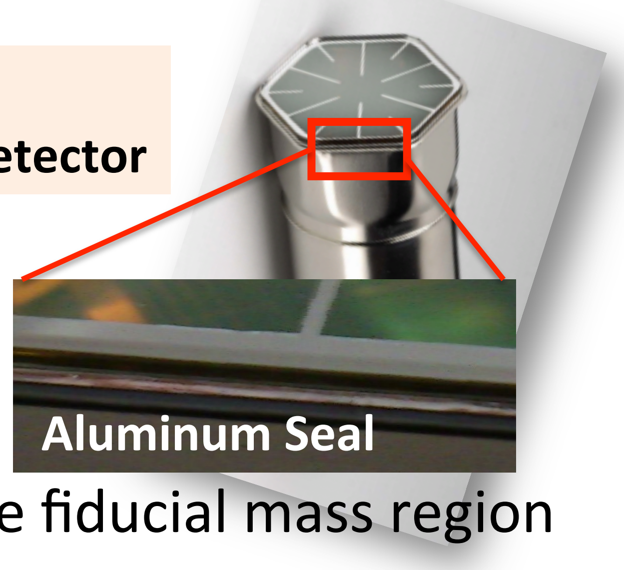


Unexpected backgrounds



- Suspected detector parts were examined again, and found that
  - Aluminum seal used between quarts window and metal body of the PMTs contains ^{238}U (upper chain) and ^{210}Pb

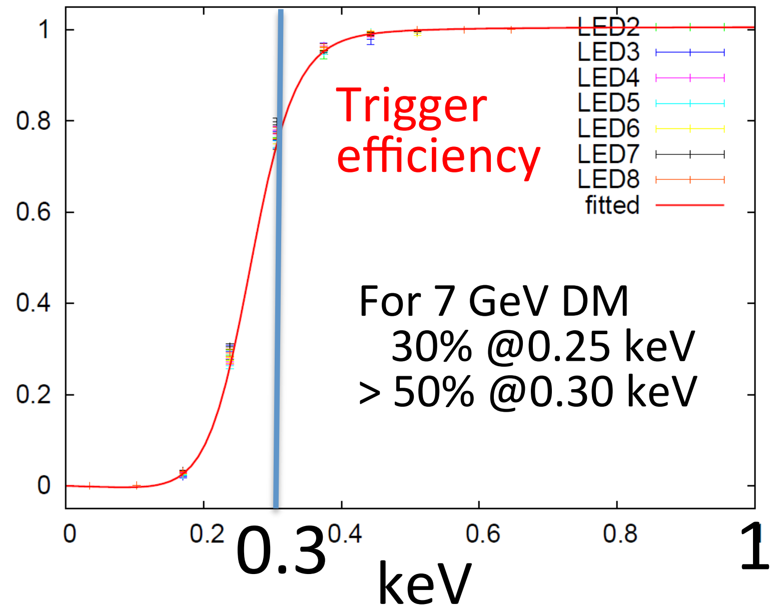
~40mBq /entire detector

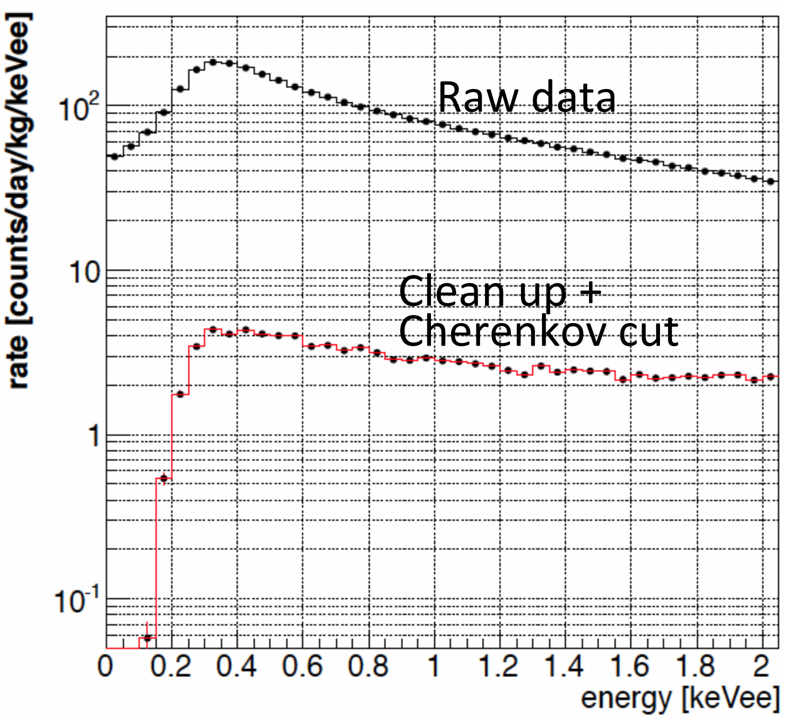


- A fraction of those surface BGs leaks into the fiducial mass region by the vertex reconstruction
- Need to replace all the PMT for the next phase, XMASS1.5

Whole Volume Analysis
with lowest threshold data

- We took data with 4 hits threshold and analyze the events above **> 0.3 keVee** for entire volume
- Advantage of **the high light yields**





6.64 days in Feb.,2012

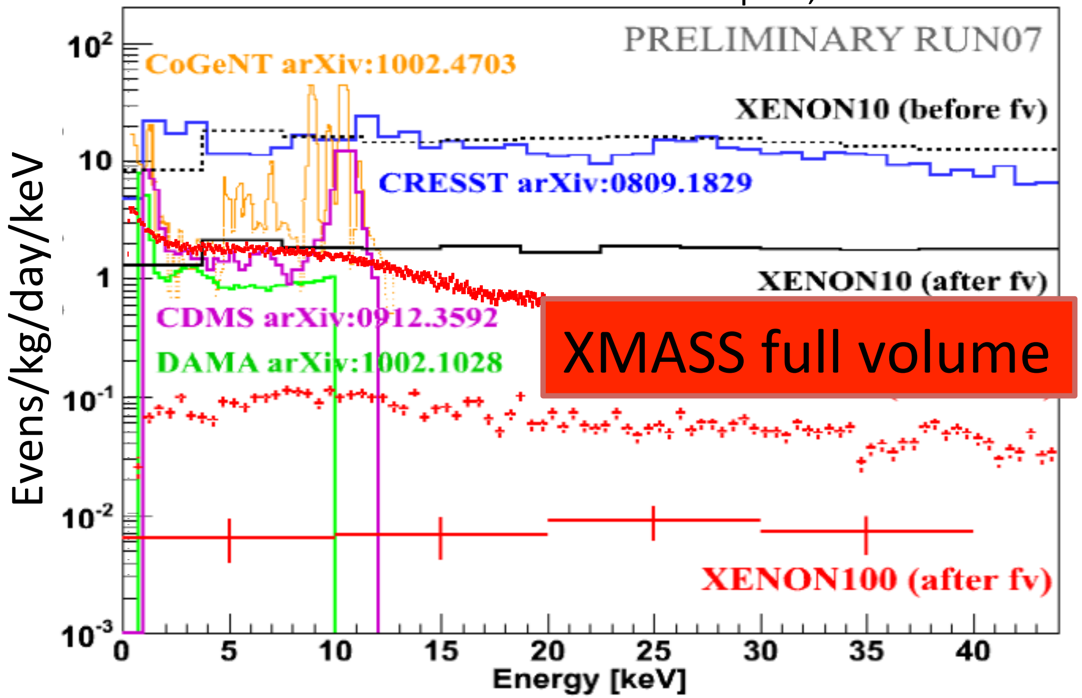
- Clean up
- Cut: Cherenkov event rejection
  - ^{40}K decay in photo cathodes to create Cherenkov in the window of PMT
  - Most BG in this energy region

(# of hits in 20ns window)/(total # of hits) > 0.6
Scintillation: ~0.5, Cherenkov:0.9~1

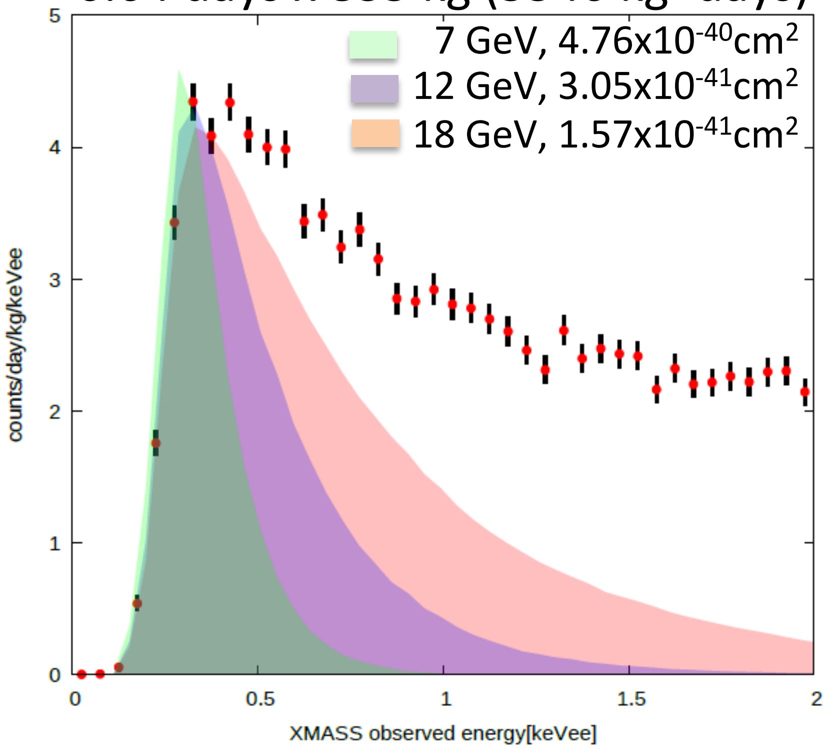
Background level

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

E. Aprile, 2010 Princeton



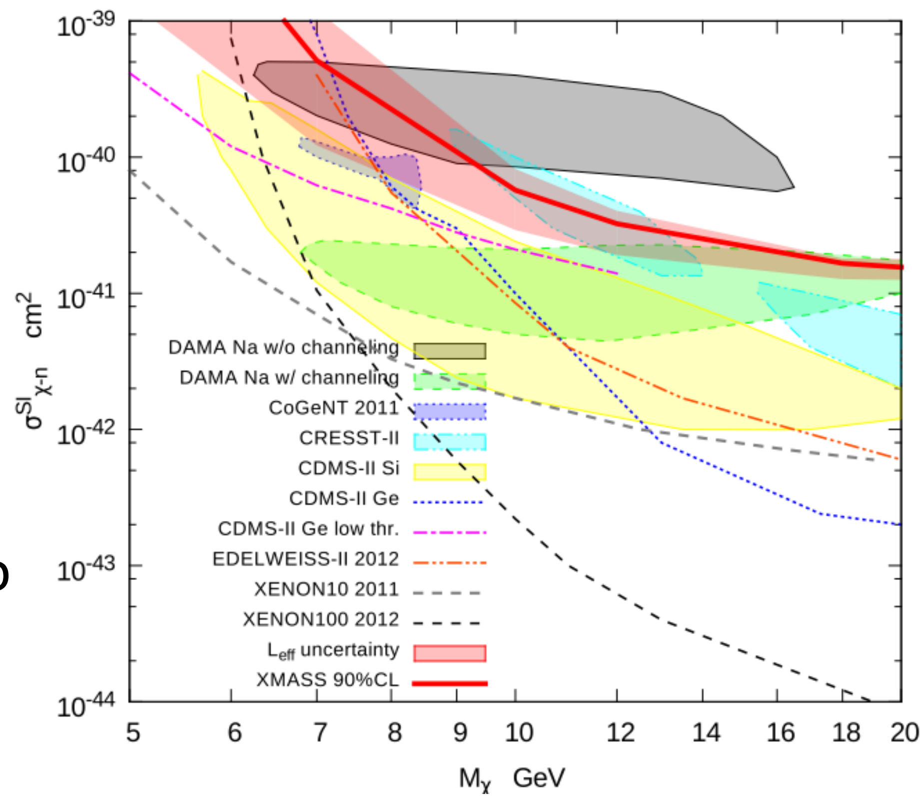
Results on low mass dark matter



PLB 719 (2013) 78

XMASS: stat.+syst. (90% lower bound)

← Leff uncertainty band

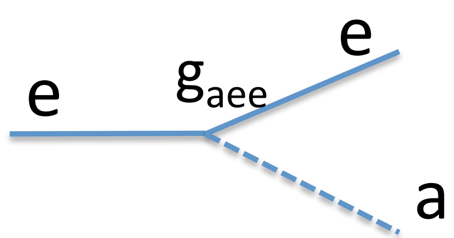


- Compare Dark Matter MC to the data
- Obtain the maximum cross section (upper limits) of the spectrum not to exceed the observed data points.
- Current XMASS is close to the allowed regions of DAMA/CoGeNT/CRESST/CDMSII-Si.

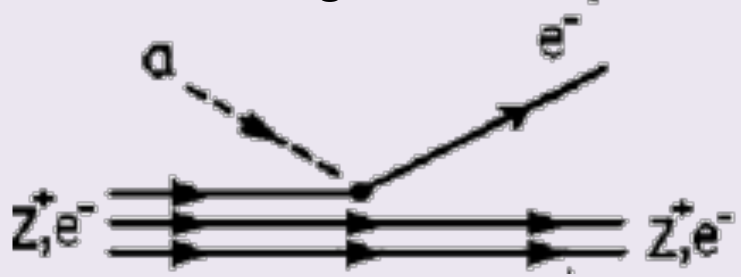
We will reduce the backgrounds in very near future

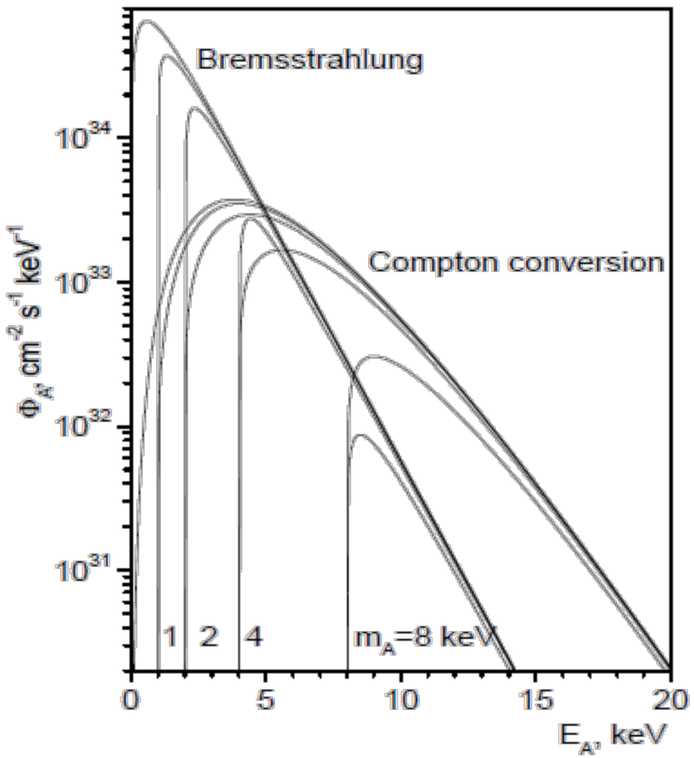
Solar Axions
Bremsstrahlung and Compton scattering (g_{aee})

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



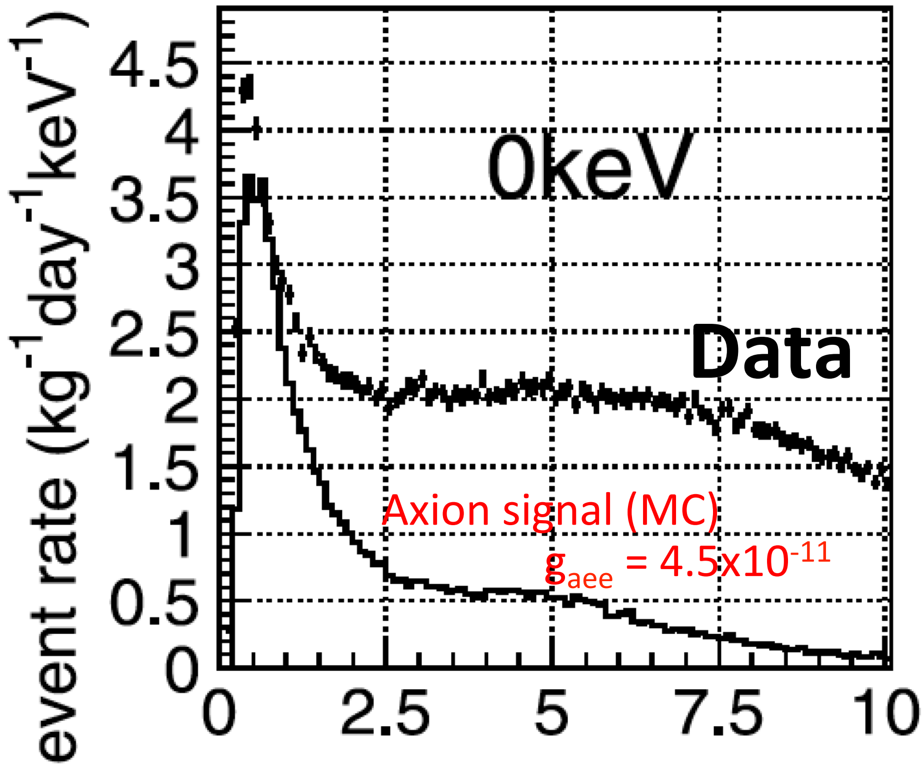
Observation: through axio-electric effect (g_{aee})

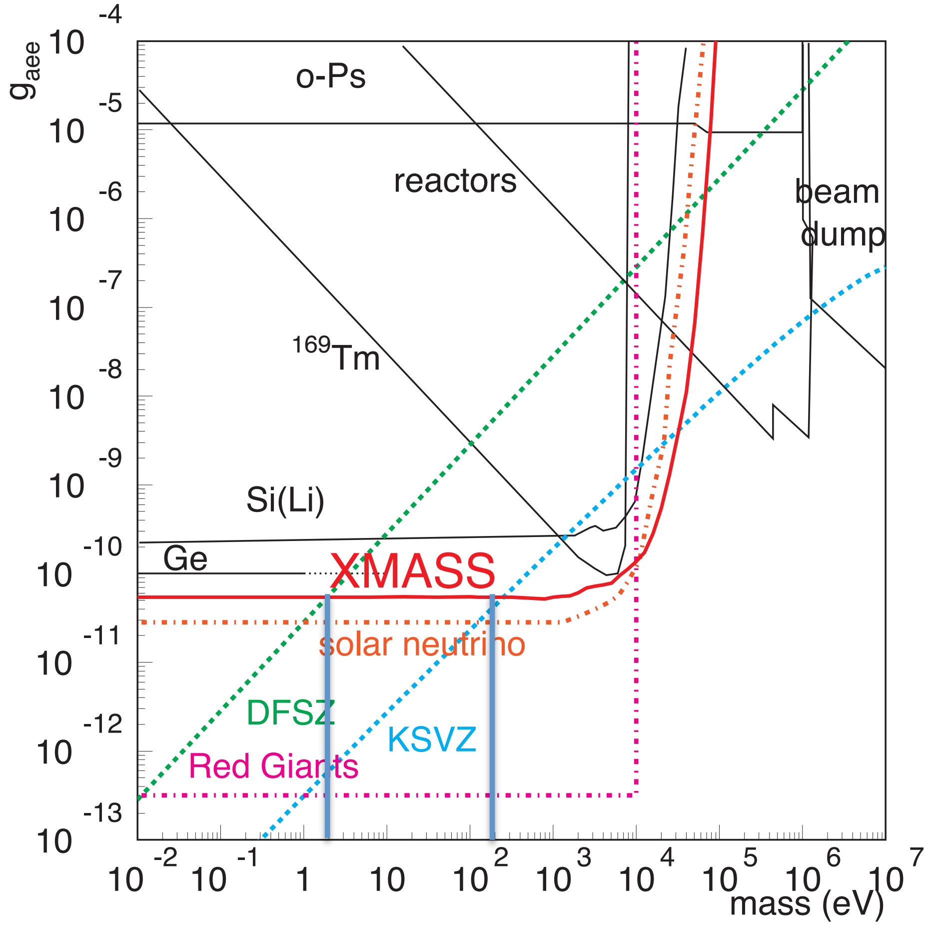




Solar Axions
Bremsstrahlung and Compton scattering (g_{aee})

Solar Axion Search, PLB 724 (2013) 46





- Limits from absolute maximum: g_{aee} = 4.5x10^{-11}
- Allowed mass for particular models:

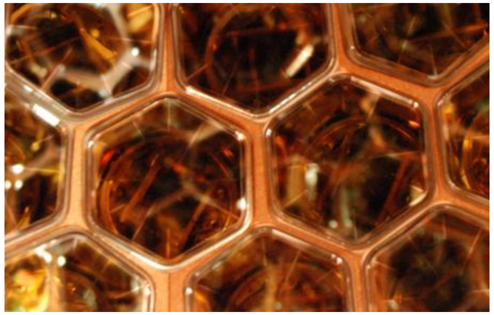
  < 200 eV for KSVZ; < 2 eV for DFSZ

Refurbishment of XMASS-I

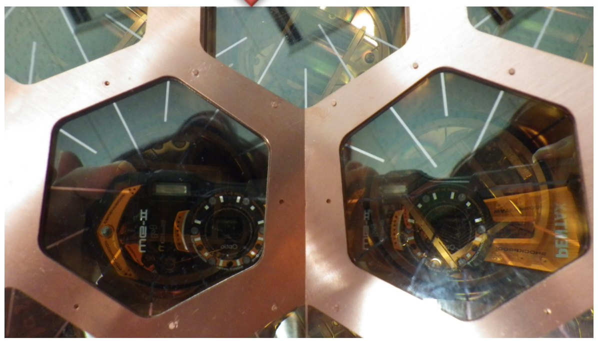
- Immediate imporovement
- We also understand the backgrounds further
- Establish the methods how to reduce those backgrounds.

1) PMT Al-seal (Source of the most BG)

  - Difficult to remove
  - Shield scintillation light originating from the PMT Al (α, β)
    - Installation of Cu ring around the PMT around the PMT Al-seal
    - Place a Cu-plate over the gaps between PMT Rings
  - But cannot stop γ BG



After installation of ring

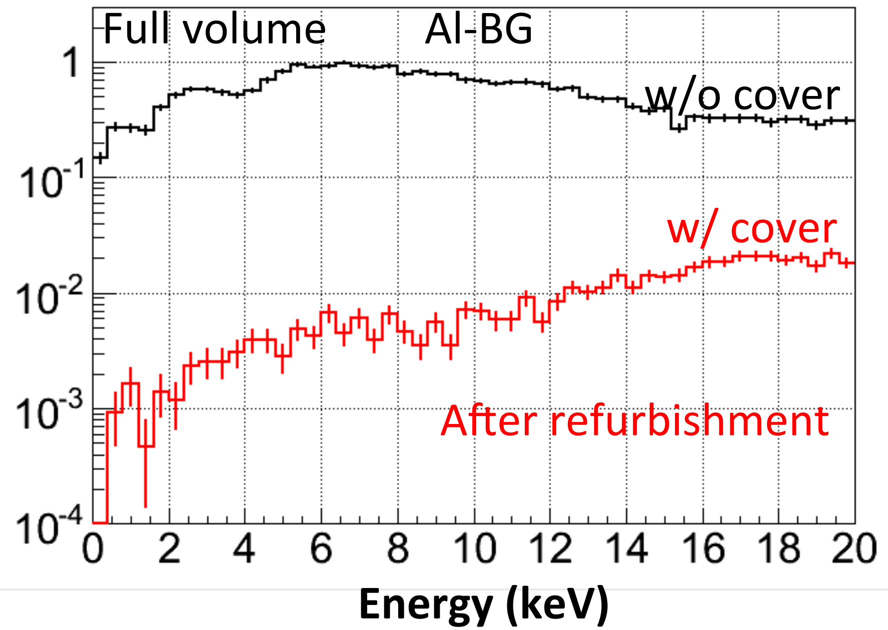


After installation of the plates

Refurbishment

2) Reduce the BG (^{210}Pb, ^{210}Po) on Cu surface (2nd largest component in the remaining BG)

- Clean up surface ^{210}Pb
  - Rn daughters, O(< μm) below the surface
  - Grind and electro-polishing
- Work in the low Rn environment (<10mBq/m^3)
- Test for XMASS1.5



- Expect 1/100 reduction of BG
- Refurbish work has already started in July and will be completed in early October
  - Limited modifications: not sufficient to get the satisfactory sensitivity

➔ need XMASS1.5

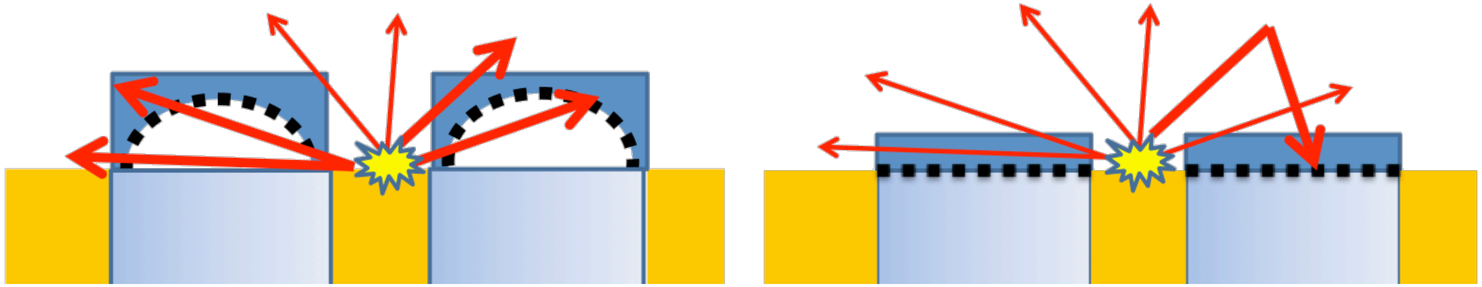
XMASS1.5

- Next step: XMASS1.5
  - 5 ton total mass and 1 ton fiducial mass. ⇔ comparable sensitivity to XENON1t

Improvement (learnt from XMASS-I)

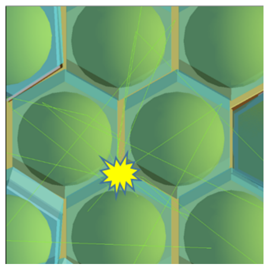
- Reduce surface backgrounds
  - Follow the low background technology established in the refurbishment of XMASS-I
  - No dirty material (Al, …)
- Use new PMTs, not only w/o dirty Al, but..

New PMTs for XMASS1.5



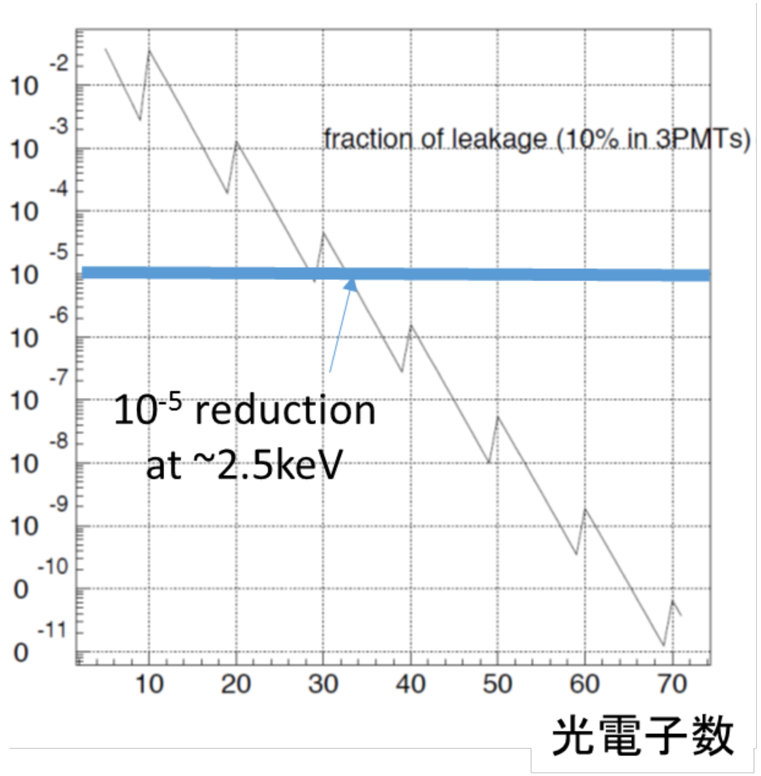
- Convex type round PMTs: Better identification of surface events (BG) by using the adjacent ones
- Sum of the detected photons of 3 PMTs surrounding the vertex of the surface events:

48% detection
for this configuration



  - At 2.5 keV, if > 10%, then only 10^{-5} of surface BG (O(1)) will leak into the fiducial volume

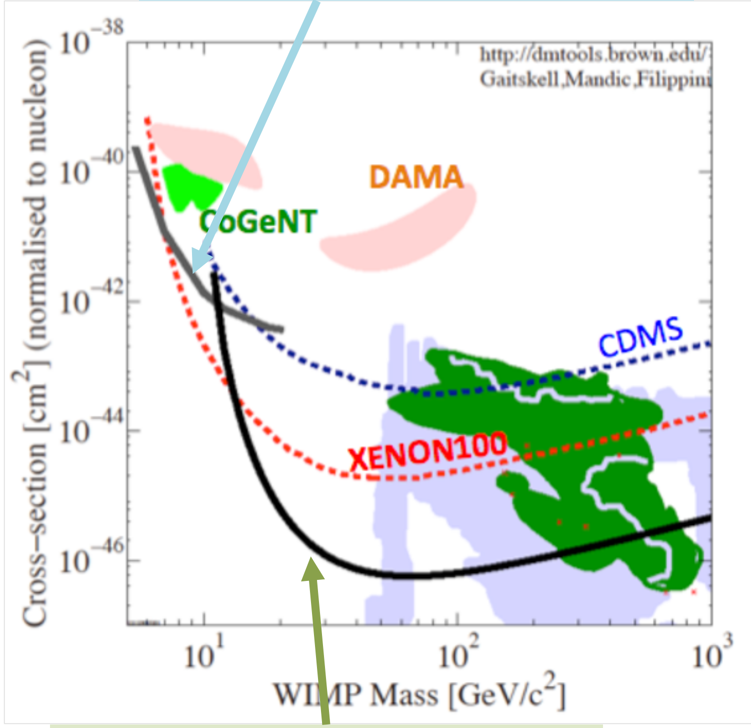
XMASS1.5 ➔ 10^{-4}/kg/d/keV



Sensitivity of XMASS1.5

- Sensitivity
  - Fid volume cut analysis (1 ton, >2keVee)
    - **$\sigma_{SI} < 10^{-46}$ cm^2 ⇔ XENON1t**
  - Whole volume analysis (5 ton, >0.3 keVee) [14.73 photo-electrons/keV]
    - **$\sigma_{SI} < \sim$ a few x10^{-42} cm^2 for low mass dark matter**
- Time schedule
  - 2014 - 15: Construction
  - 2016: Start data taking

Low energy analysis (>0.3 keVee): Effective for low mass WIMPS, Axion Like Particles,.....



Fiducial mass analysis (> 2keVee): Effective for higher mass WIMPs

Summary

- From XMASS-I, we have leant that
  - High light yield (14.7 pe /keVee); Low threshold (0.3 keVee)
  - But surface BGs are most crucial issue for single phase detectors
  - Demonstration of the advantage of the low threshold and e/γ detectability
    - Low Mass WIMP search (PLB 719(2013)78)
    - Solar Axion Search (PLB 724 (2013) 46)
- XMASS1.5
  - New PMTs
    - Suppression of the surface BG into fid. volume: 10^{-5}
  - Search for $\sigma_{SI}=10^{-46}$ cm^2 region: Highest sensitivity
  - Start data taking in 2016
- Refurbishment of XMASS-I is on going
  - Place covers around PMT-Al-Seal, not complete, γ-exist
  - To demonstrate the handling of BG
  - Data taking in October, 2013.

Time schedule

	JFY 2013	JFY 2014	JFY 2015	JFY 2016

XMASS-I refurbishment

XMASS-I-Ref Physics run

XMASS-1.5

5 ton (1 ton fiducial) detector, BG~10^{-5}/keV/kg/day
Sensitivity; s_{SI} < 10^{-46} cm^2 (higher mass), <10^{-42} cm^2 (low mass DM)
DM Axions, Solar Axions

Design, R&D construction

Physics run