The XMASS experiment

Kamioka observatory,
ICRR, University of Tokyo
Byeongsu Yang

Oct. 6th, 2014 DBD2014 at Hawaii

Contents

- Introduction to the XMASS
- Results from XMASS commissioning run
  - Low mass WIMPs search
  - Solar axion search
  - Bosonic super-WIMPs search
  - Inelastic WIMP nucleus scattering search
- Refurbishment, current status and future project
- summary

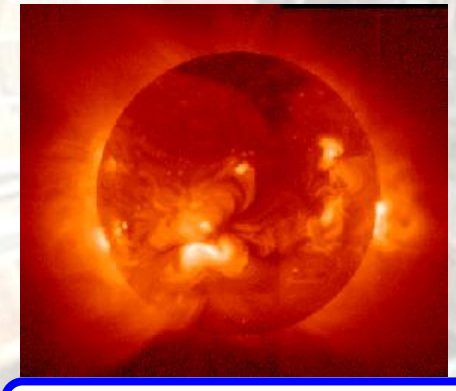
Introduction to the XMASS

XMASS experiment

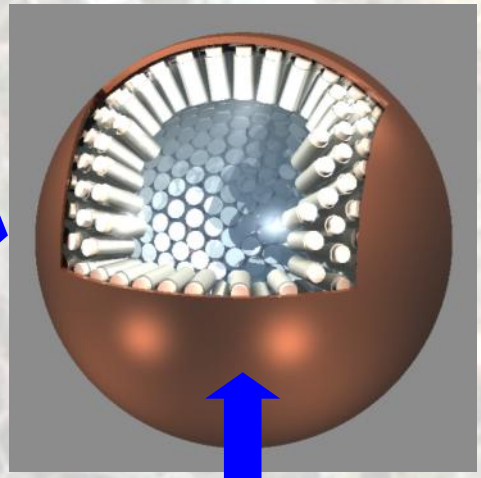
- What is XMASS?

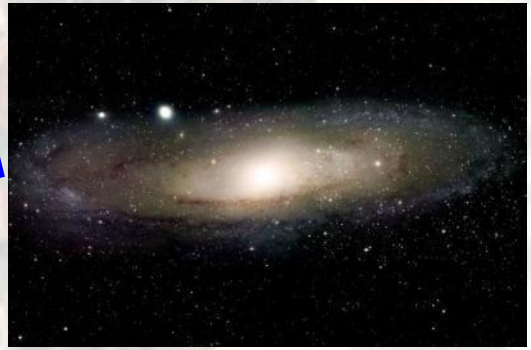
  Multi purpose, low-background and low-energy threshold experiment with large volume of liquid Xenon

- **X**enon detector for Weakly Interacting **MASS**ive Particles (**DM search**)
- **X**enon **MASS**ive detector for solar neutrino (**pp/^{7}Be**)
- **X**enon neutrino **MASS** detector (**ββ decay**)

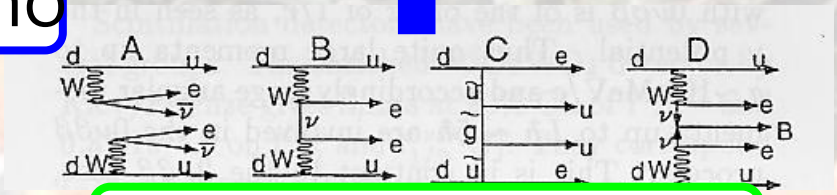


Solar neutrino





Dark Matter

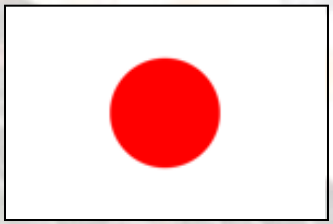


Double beta decay

+axion, etc

XMASS Collaborator

11 institutes
~40 physicists



Kamioka Observatory, ICRR, the University of Tokyo: K. Abe, K. Hiraide, K. Ichimura, Y. Kishimoto, K. Kobayashi, M. Kobayashi, S. Moriyama, M. Nakahata, T. Norita, H. Ogawa, H. Sekiya, O. Takachio, A. Takeda, M. Yamashita, B. Yang

Kavli IPMU, the University of Tokyo: J.Liu, K.Martens, Y. Suzuki

Kobe University: R. Fujita, K. Hosokawa, K. Miuchi, Y. Ohnishi, N. Oka, Y. Takeuchi

Tokai University: K. Nishijima

Gifu University: S. Tasaka

Yokohama National University: S. Nakamura

Miyagi University of Education: Y. Fukuda

STEL, Nagoya University: Y. Itow, R. Kegasa, K. Kobayashi, K. Masuda, H. Takiya

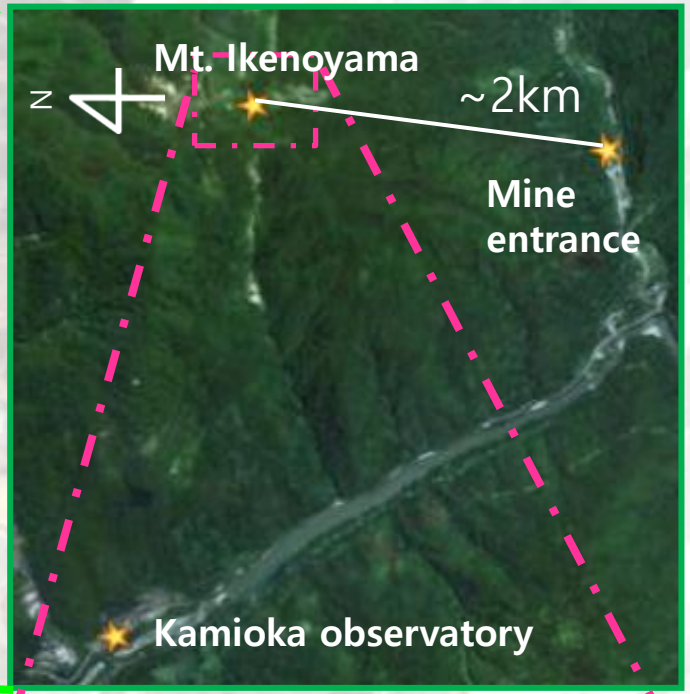
Sejong University: N. Y. Kim, Y. D. Kim

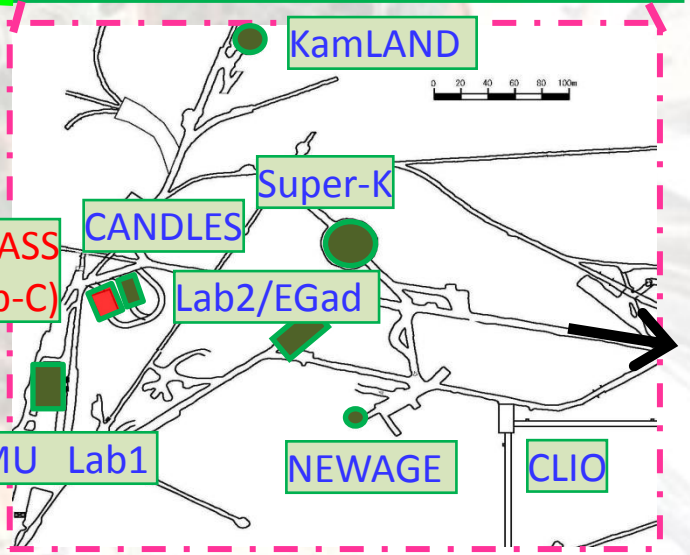
KRISS: Y. H. Kim, M. K. Lee, K. B. Lee, J. S. Lee

Tokushima University : K. Fushimi

Collaboration meeting at Kobe Univ. in June 2014

XMASS detector : site



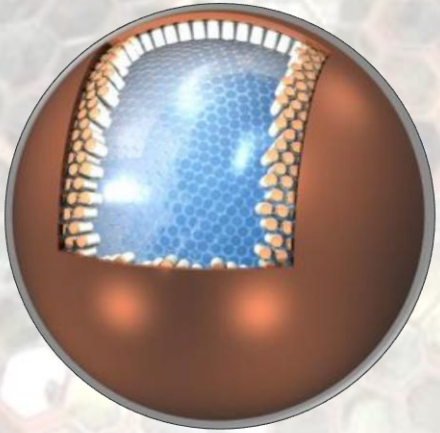


XMASS experiment

XMASS-I

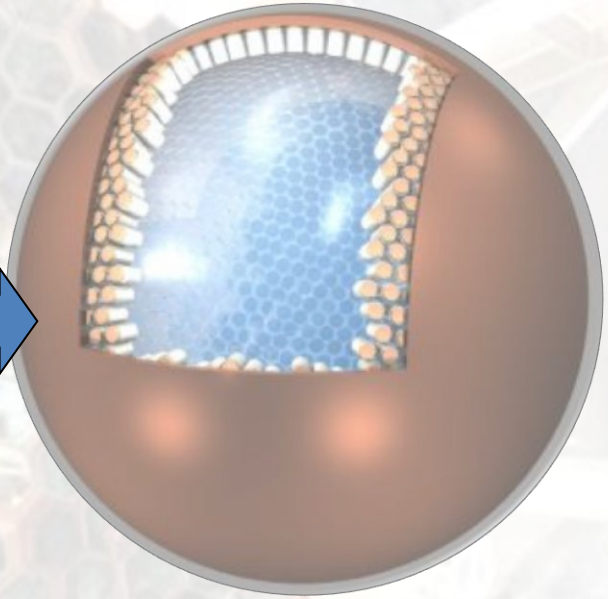
835kg,
100kg FV
80cmϕ
2010Nov
DM search

XMASS-1.5



5ton,**1ton FV**
(x 10 of XMASS-I)
1.5mϕ, ~1800 PMTs
DM search

XMASS-II

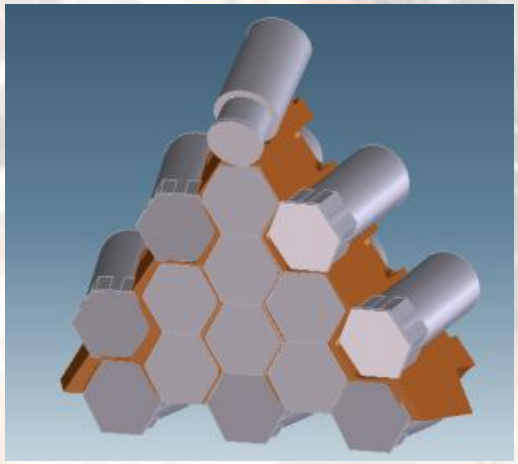


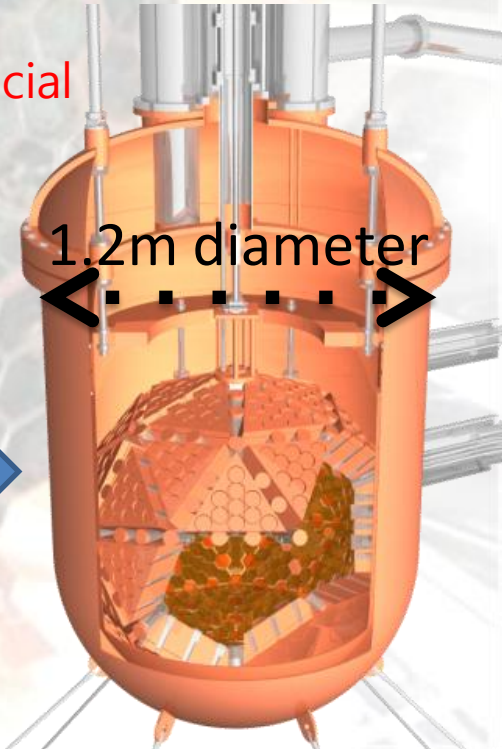
25ton, **10ton FV**
2.5mϕ
Multi purpose
DM search
pp solar neutrino
$0\nu2\beta$ decay

Y. Suzuki, hep-ph/0008296

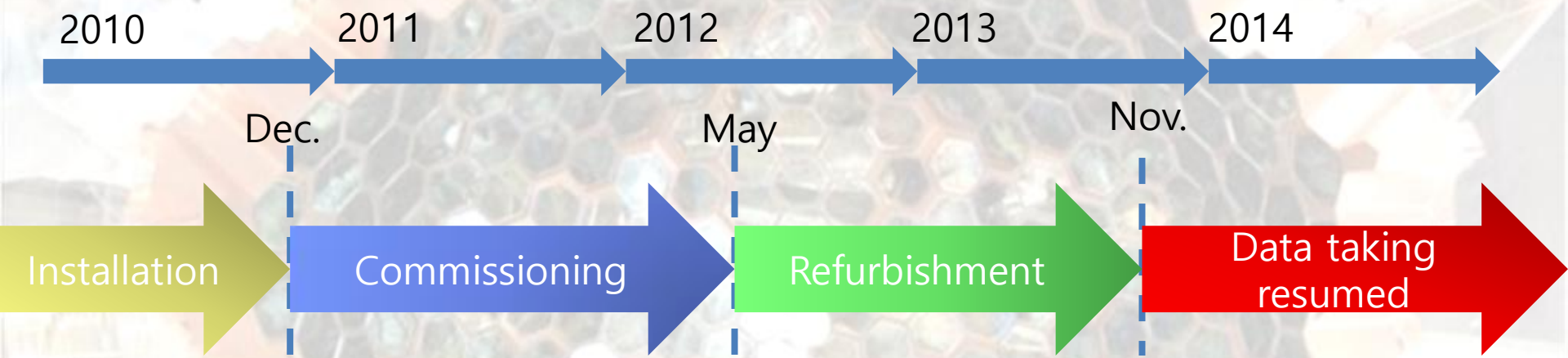
XMASS-I detector

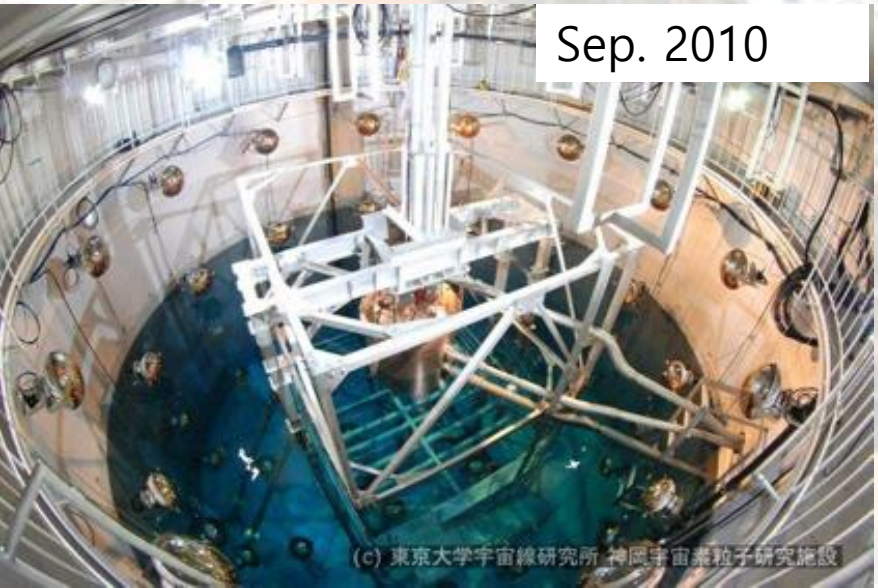
- Single phase (scintillation only) liquid Xenon detector : sensitive to e/γ events with very low backgrounds as well as nuclear recoil events
- Operated at -100°C and ~0.065MPa
- Large 100 kg fid. mass, [835 kg inner mass (0.8 mϕ)]
- Pentakis-dodecahedron ← 12 pentagonal pyramids: Each pyramid ← 5 triangle
- 630 hexagonal & 12 round PMTs with 28-39% Q.E.
- High light yields(13.9 pe/keV) & Large photon coverage
  - photocathode coverage: > 62% inner surface
  - Low energy threshold : < 5 keV_{ee} (~ 25 keV_{NR}) for fiducial volume and 0.3 keV_{ee} for full volume





History of XMASS-I



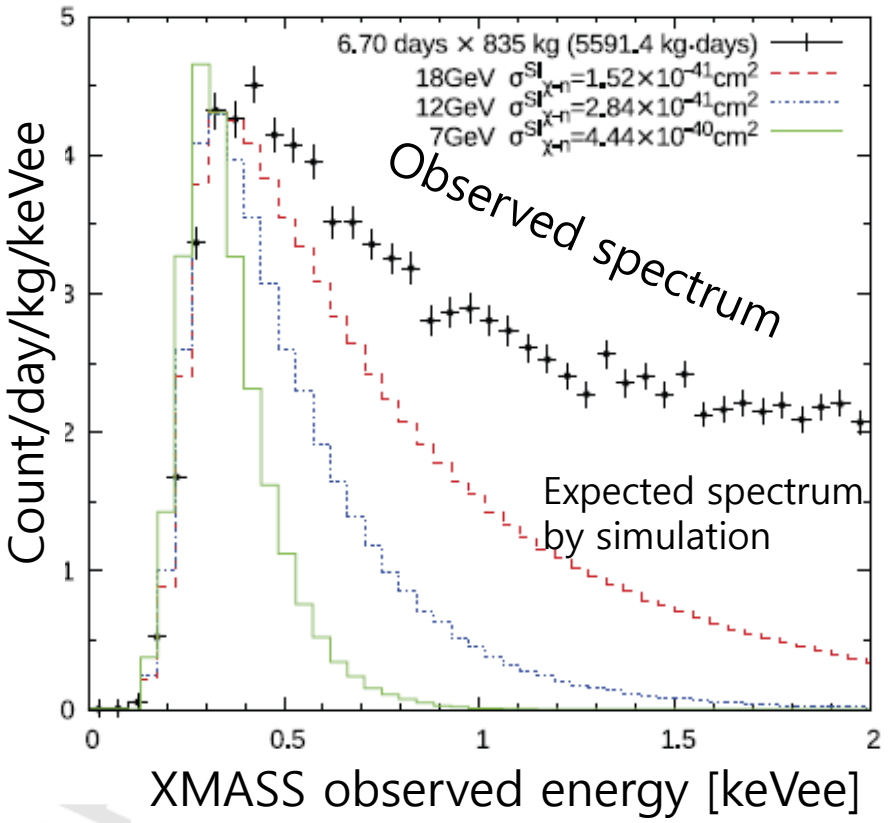


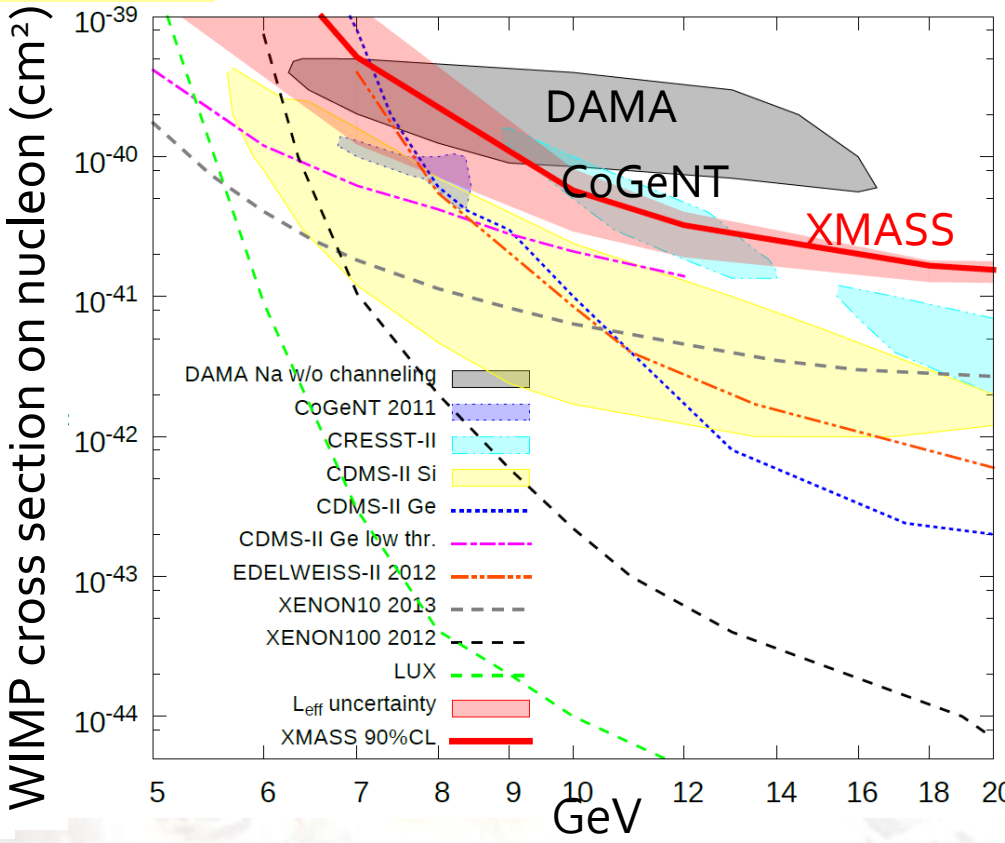
Results from XMASS commissioning run

Low mass WIMPs search

- Search for elastic WIMP nucleus scattering without discriminating between nuclear-recoil and electron events
- Threshold is 0.3keVee and Full volume analysis.
- Set absolute maxima of the cross section.
- With just 6.70 days × 835kg data, excluded most of the parameter space favored by DAMA.

PLB 719 (2013) 78





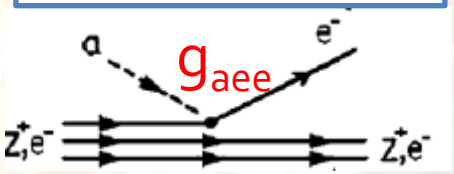
Solar axion search

- Axions can be produced in the sun by bremsstrahlung or Compton effect, and detected by axio-electric effect in XMASS.
- Our detector is suitable to see these events, especially because of a large mass, low background, and sensitivity to electron recoil.

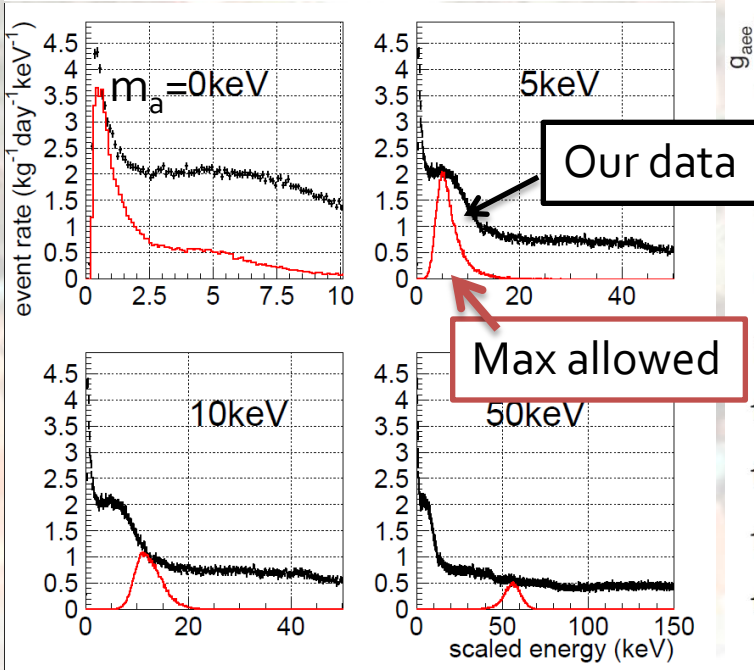
- The same data set as the low mass WIMPs search.
- No indication of signals. Set maximum of g_{aee} for each mass.
- In 10-40keV, stringent constraint

Bremsstrahlung and Compton effect

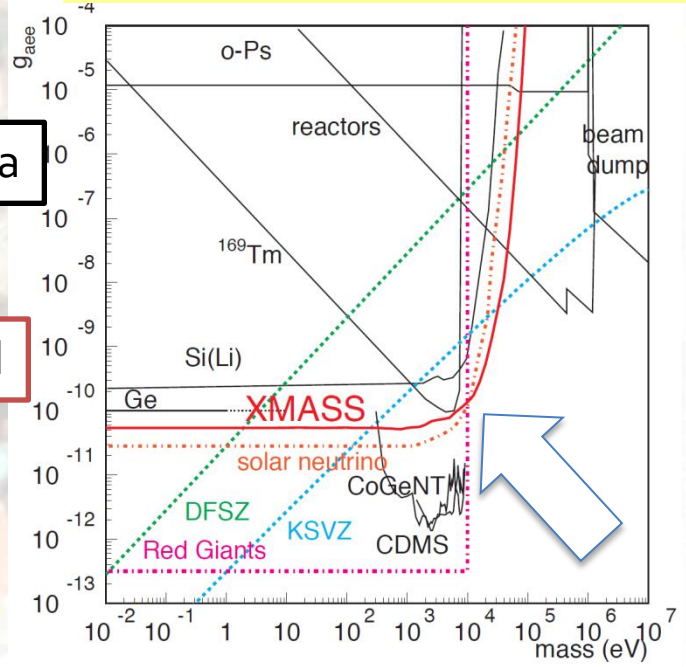
Axio-electric effect (like photo-electric)



Observed and expected energy spectrum.



Phys. Lett. B 724 46 (2013)



Bosonic super-WIMPs search(1)

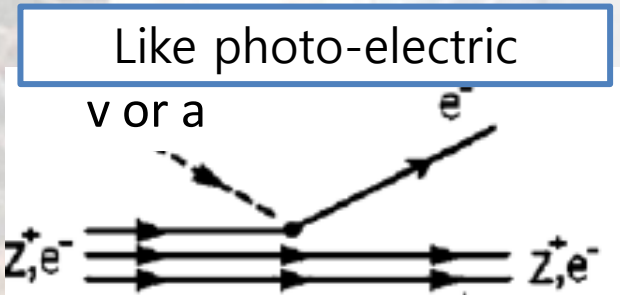
- The latest results in XMASS (Published in PRL 113, 121301(2014), in Sep. 18, 2014)
- Due to the followings, search for lighter and more weakly interacting particles is attracting attention.
  - Expectation on the structure on galactic scales of the CDM scenario is richer than observed.
  - So far no evidence of supersymmetric particles at the LHC.
  - LUX excluded parameter space $\sigma_{SI}<10^{-45}cm^2$ around 30GeV, also low mass WIMP regions.
- Bosonic super-WIMPs search
  - A lukewarm dark matter candidate, and lighter and more weakly interacting particles than WIMPs
  - Experimentally interesting since their absorption in a target material would deposit an energy essentially equivalent to the super-WIMP's rest mass.
  - Search for pseudoscalar and vector boson (sometimes called as dark, para, or hidden photon)
  - For vector boson, there is only astrophysical constraint.

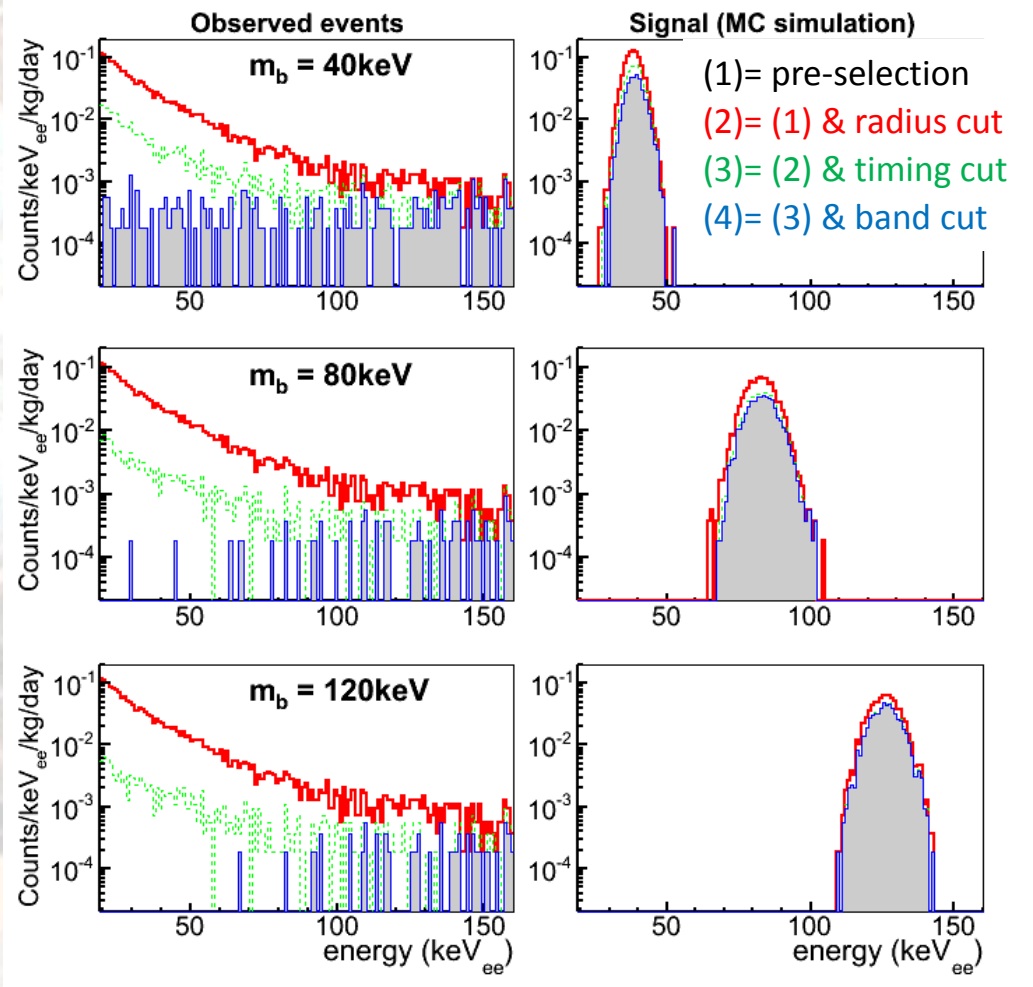
    ➡ Need experimental search

Bosonic super-WIMPs search(2)

D.C. Malling's thesis (2014)

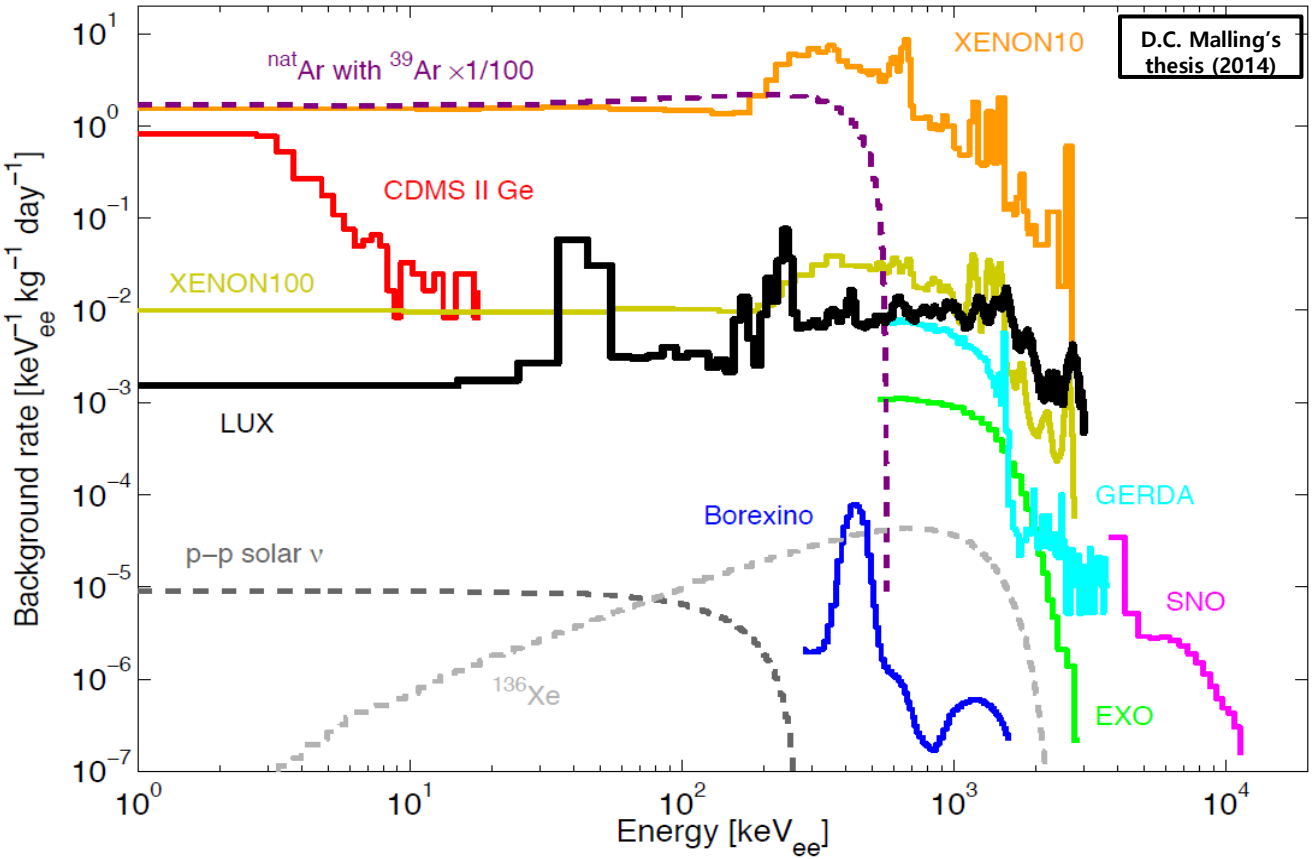
- Can be detected by absorption of the particle, which is similar to the photoelectric effect.
  - Pospelov et, al. Phys. Rev. D 78 115012 (2008)
- Search for mono-energetic peak at m_b (the rest mass of a bosonic super-WIMP)
- optimized cut for each m_b
- The remaining event rate ($O(10^{-4})$/day/kg/keV_{ee}), the lowest ever achieved, is in good agreement w/ expected BG from 214Pb w/ keeping > 50% signal efficiency

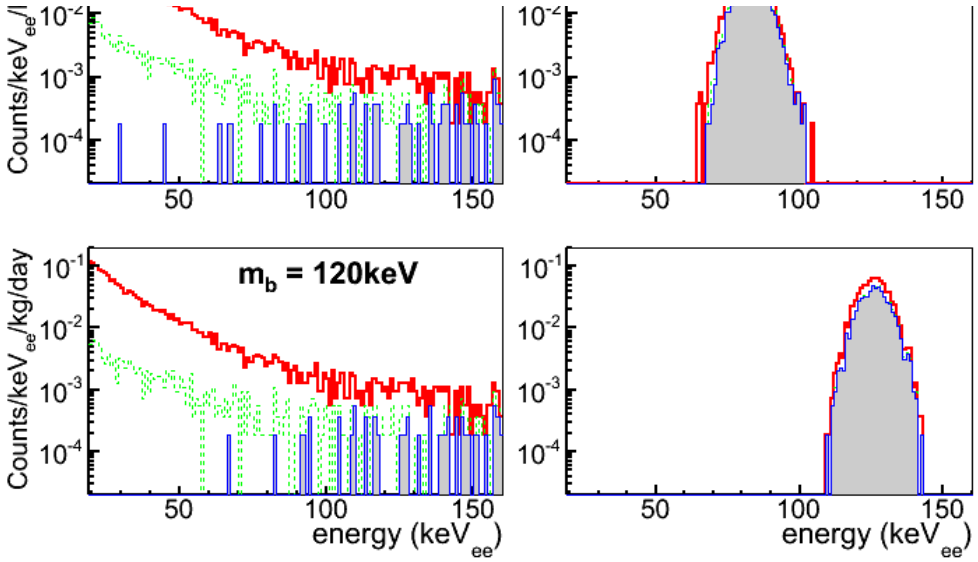




Bosonic

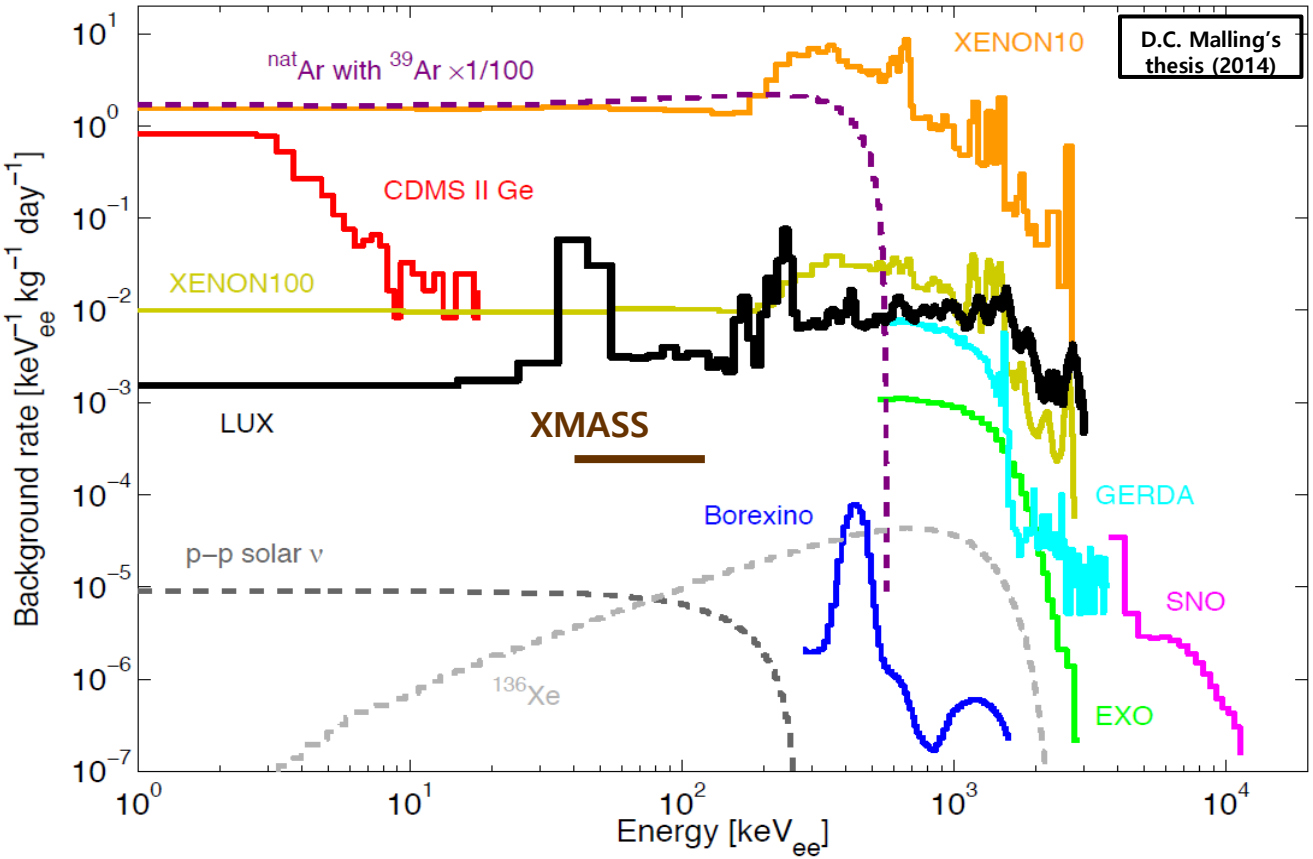
- Can be detected b
  of the particle, whi
  to the photoelectri
  - Pospelov et, al.
    D 78 115012 (2
- Search for mono-e
  peak at m_b (the res
  a bosonic super-W
- optimized cut for e
- The remaining event rate ($O(10^{-4})$/day/kg/keV_{ee}), the lowest ever achieved, is in good agreement w/ expected BG from 214Pb w/ keeping > 50% signal efficiency

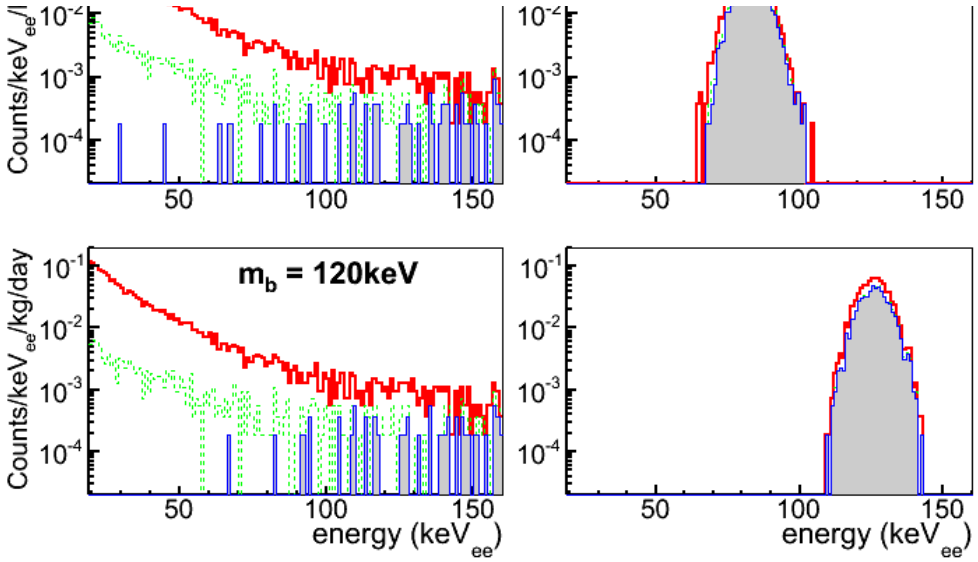




Bosonic

- Can be detected b
  of the particle, whi
  to the photoelectri
  - Pospelov et, al.
    D 78 115012 (2
- Search for mono-e
  peak at m_b (the res
  a bosonic super-W
- optimized cut for e
- The remaining event rate ($O(10^{-4})$/day/kg/keV$_{ee}$), the lowest ever achieved, is in good agreement w/ expected BG from 214Pb w/ keeping > 50% signal efficiency





Bosonic super-WIMPs search(3)

- The counting rate in the detector becomes :

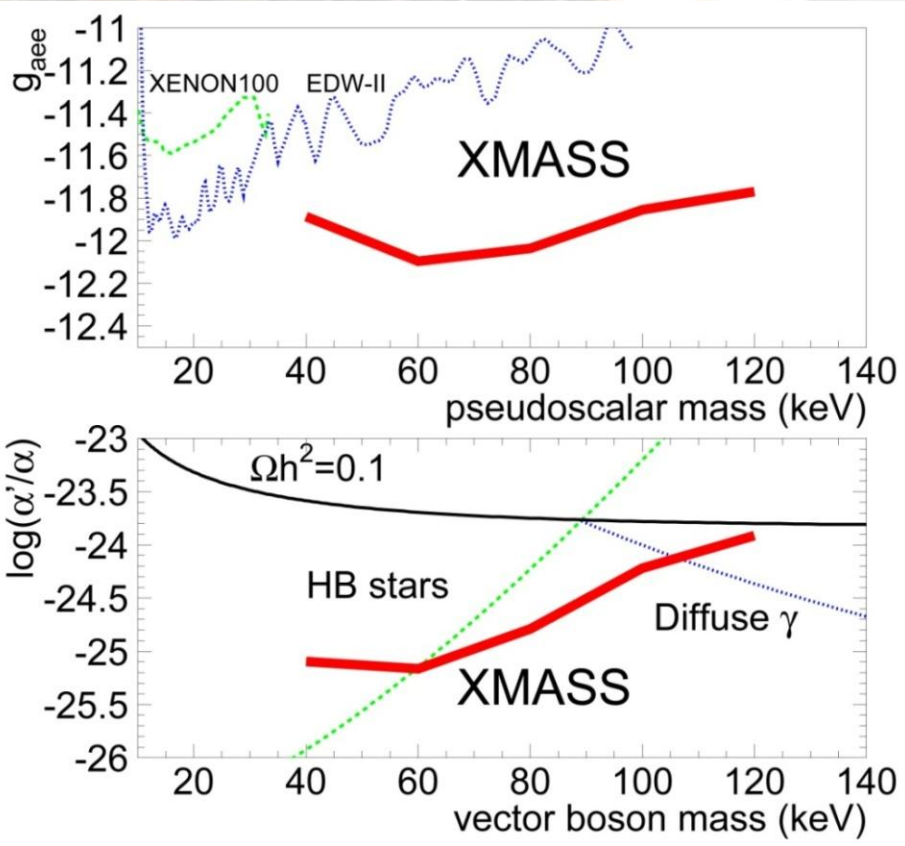
$$S_a \approx \frac{1.2\times10^{19}}{A} g_{aee}^2 \left(\frac{m_a}{\mathrm{keV}}\right)\left(\frac{\sigma_{\mathrm{photo}}}{\mathrm{barn}}\right)\ \mathrm{kg}^{-1}\,\mathrm{day}^{-1}$$

$$S_v \approx \frac{4\times10^{23}}{A}\frac{\alpha'}{\alpha}\left(\frac{\mathrm{keV}}{m_V}\right)\left(\frac{\sigma_{\mathrm{photo}}}{\mathrm{barn}}\right)\ \mathrm{kg}^{-1}\,\mathrm{day}^{-1}$$

where, α′ is the vector boson analogue to the fine structure constant.

- For vector bosonic super-WIMPs, the first direct search in the 40-120keV range. The limit excludes the possibility that such particles constitute all of dark matter. The most stringent direct constraint on g_{aee}, because of the low background in this energy range.

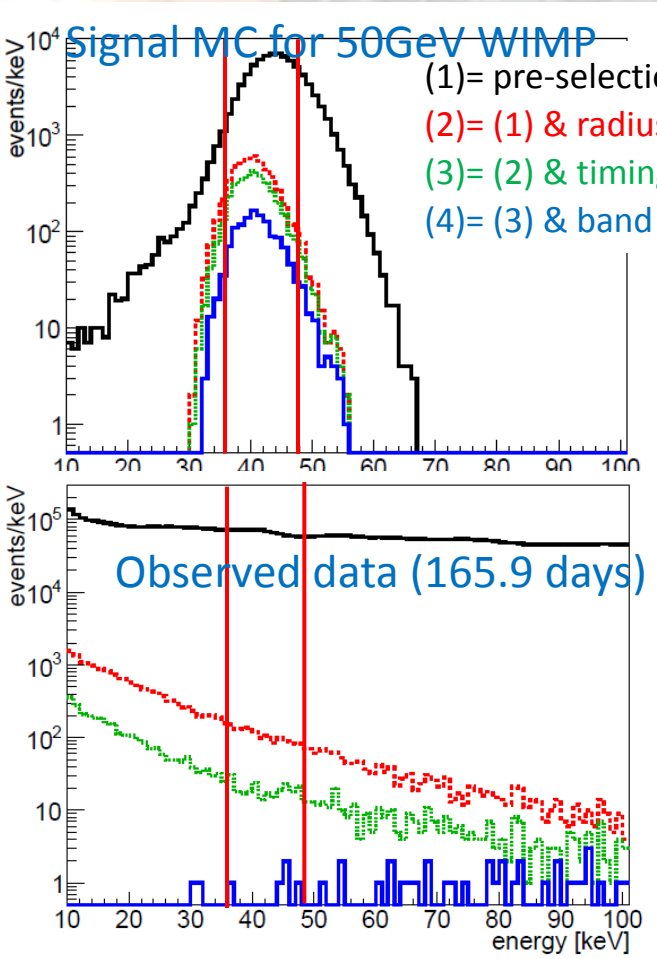
PRL 113, 121301(2014)

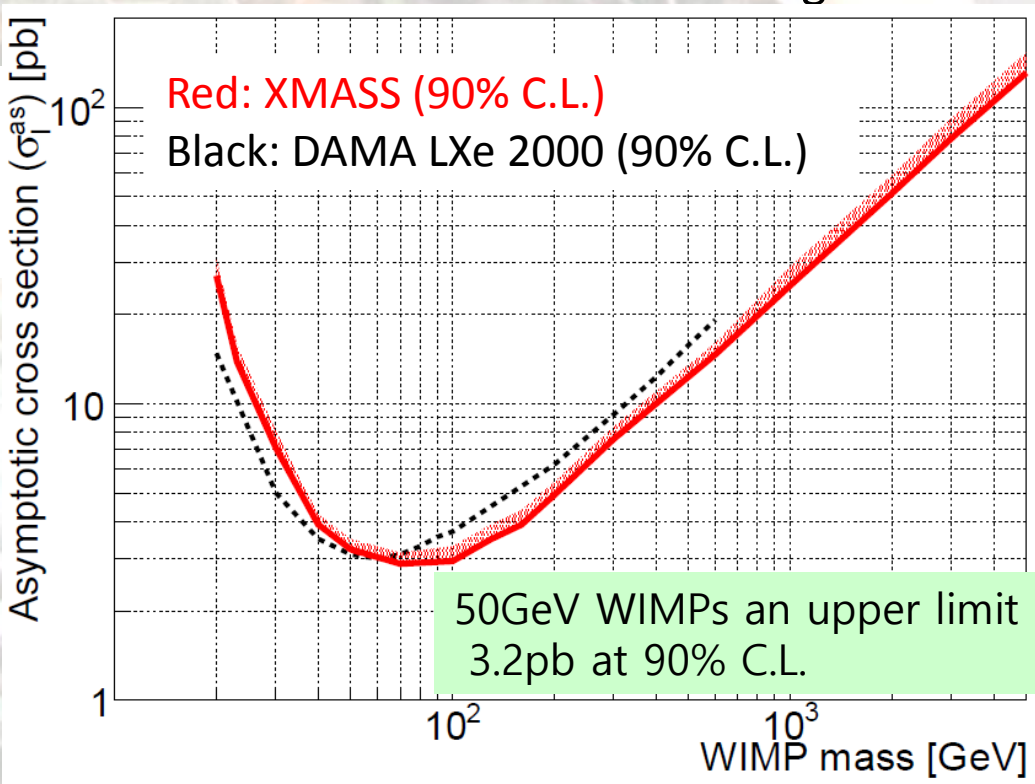


Inelastic WIMP nucleus scattering search

- $\chi + {}^{129}Xe \rightarrow \chi + {}^{129}Xe^*$ (Natural abundance of ^{129}Xe: 26.4%)

  ${}^{129}Xe^* \rightarrow {}^{129}Xe + \gamma$ (39.6keV) (Nuclear recoil with γ-ray emission)
- The same data set as the bosonic super-WIMPs search was used.
- Cuts are optimized to have best S/N in 30-80keV using calibration data
- Achieved without explicit background subtraction because of low background.





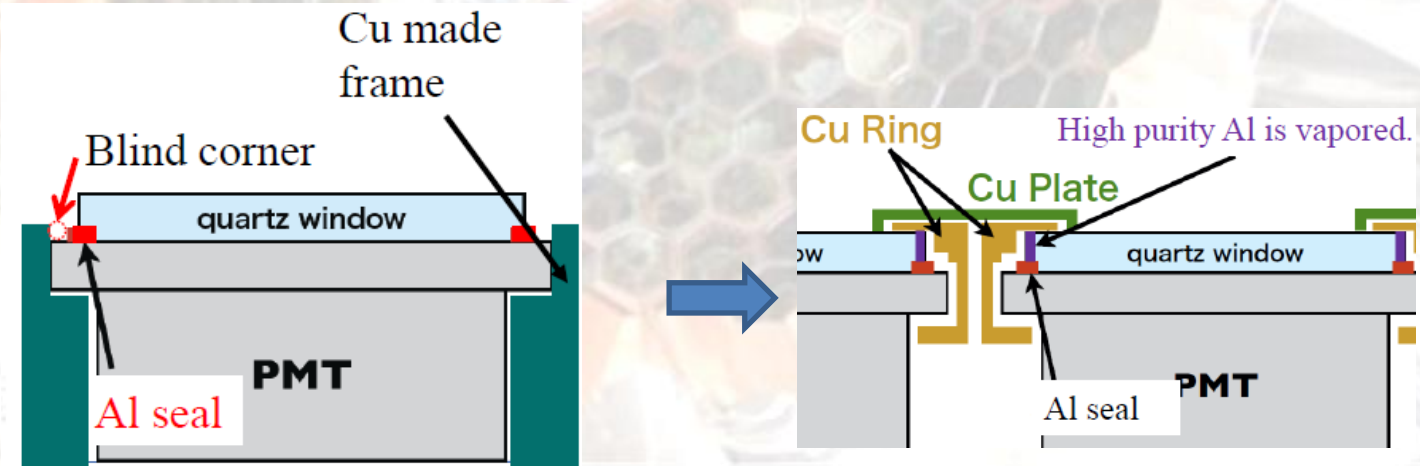
Achieved ~3x10^{-4} dru @ a few 10's keV

Published in PTEP 063C01 (2014)

Refurbishment, current status and future project

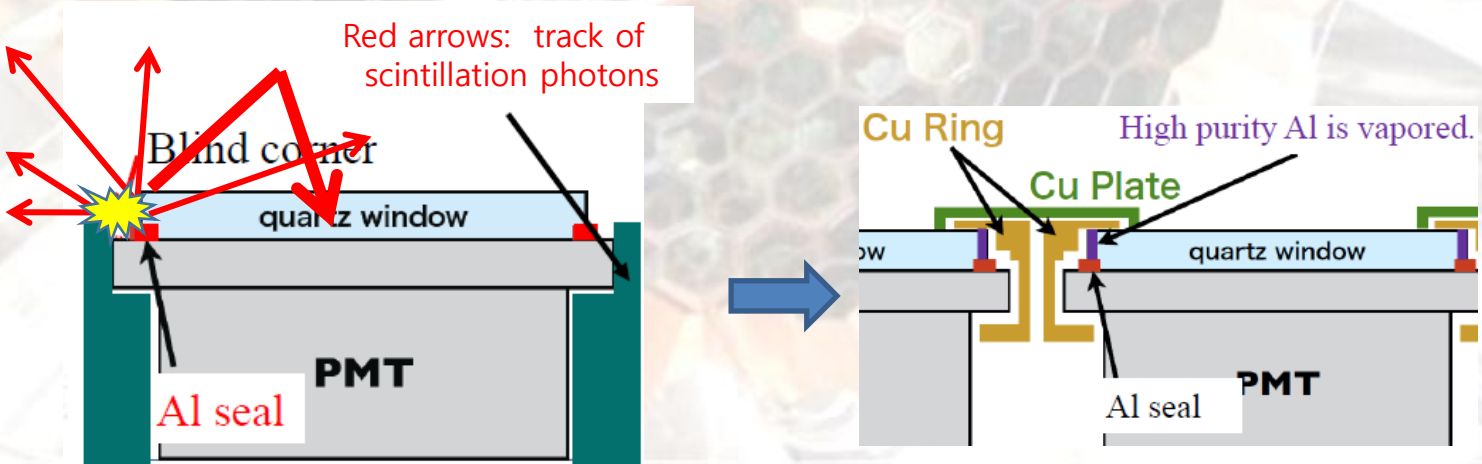
Refurbishment

- BG in the commissioning run originated from “detector surface” is dominant.
  - RI in PMT Al seal and on surface of PMT and PMT holder
  - Such events are likely to be leakage, because photons are hardly detected in neighboring PMTs.
- Refurbishment from May 2012 to Nov. 2013
  - PMT Al seal are covered by copper ring and plate, to reduce the beta and X-ray and make a simple and flat surface to reduce the mimic of inside event.
  - Also those rings, plates & PMT holders were electropolished.

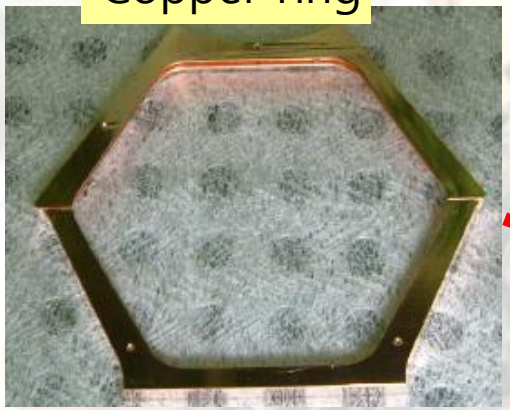


Refurbishment

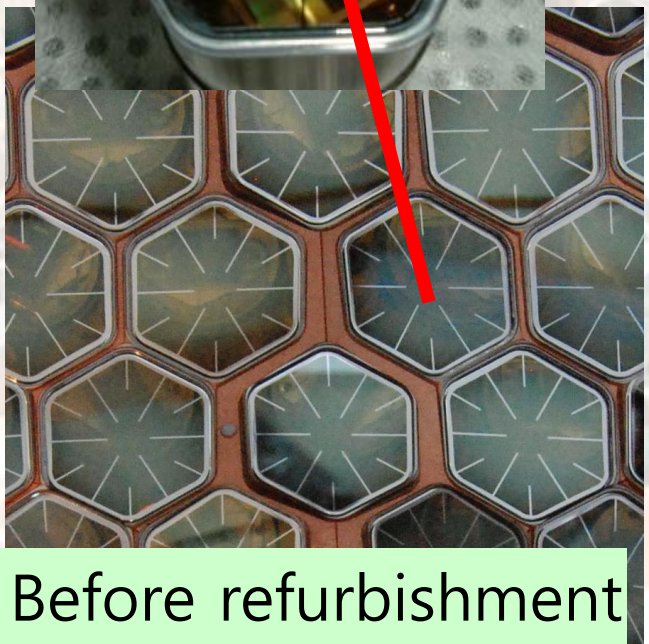
- BG in the commissioning run originated from “detector surface” is dominant.
  - RI in PMT Al seal and on surface of PMT and PMT holder
  - Such events are likely to be leakage, because photons are hardly detected in neighboring PMTs.
- Refurbishment from May 2012 to Nov. 2013
  - PMT Al seal are covered by copper ring and plate, to reduce the beta and X-ray and make a simple and flat surface to reduce the mimic of inside event.
  - Also those rings, plates & PMT holders were electropolished.



Copper ring

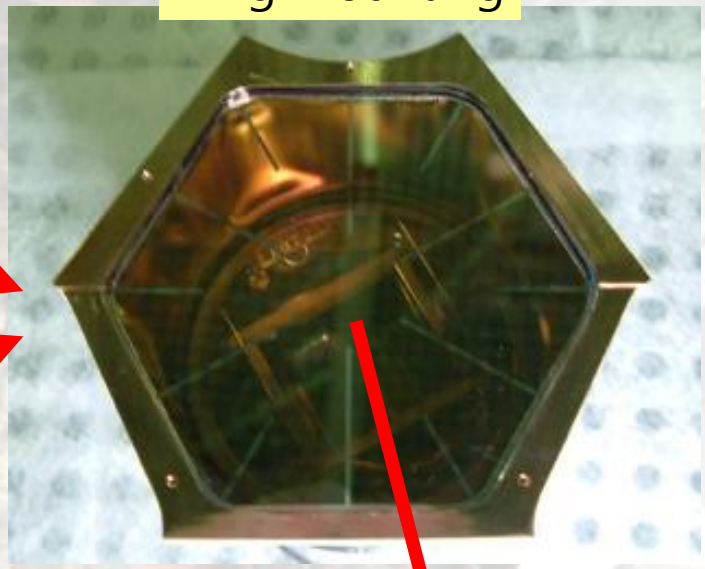


PMT

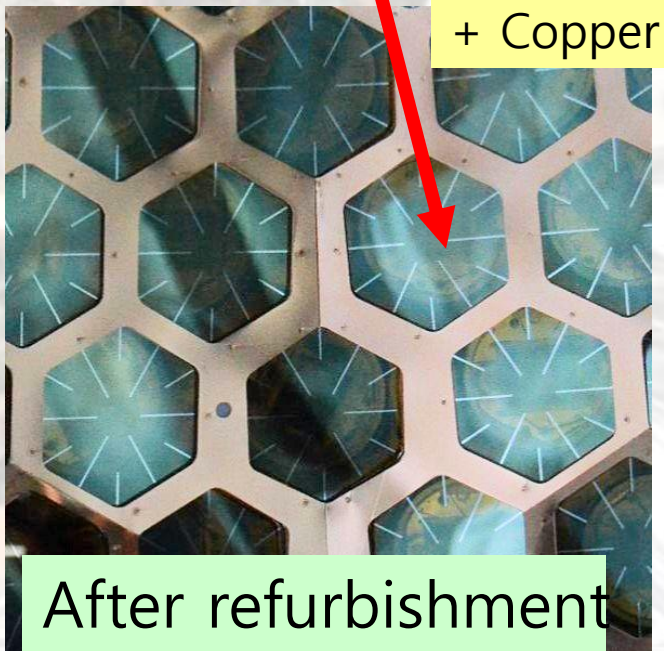


Before refurbishment

Ring mounting



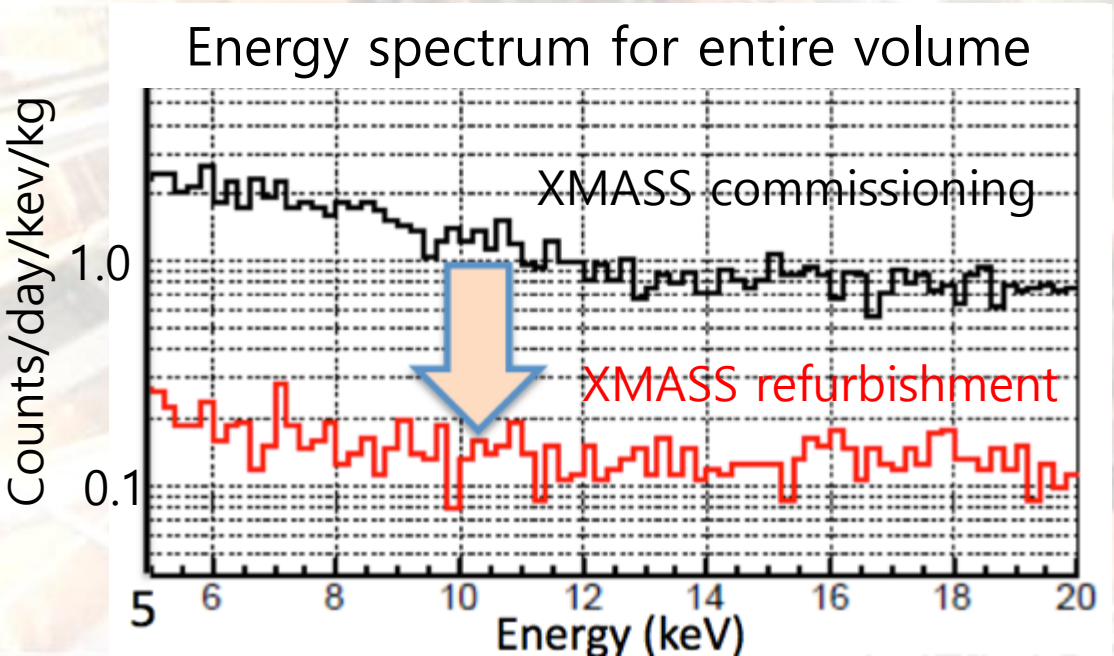
+ Copper plate

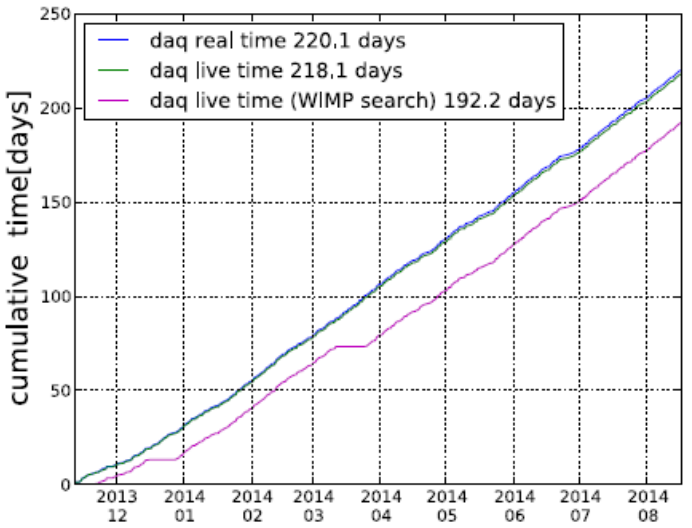


After refurbishment

Current status(1)

- Restarted data taking from Nov. 2013
- Quick check of energy spectrum indicates one order reduction of background from commissioning run data.
- Already accumulated 192.2 days data for WIMP search till Sep. 2014.
- Using this data, physics analyses including WIMP search with fiducialization and annual modulation are on-going.

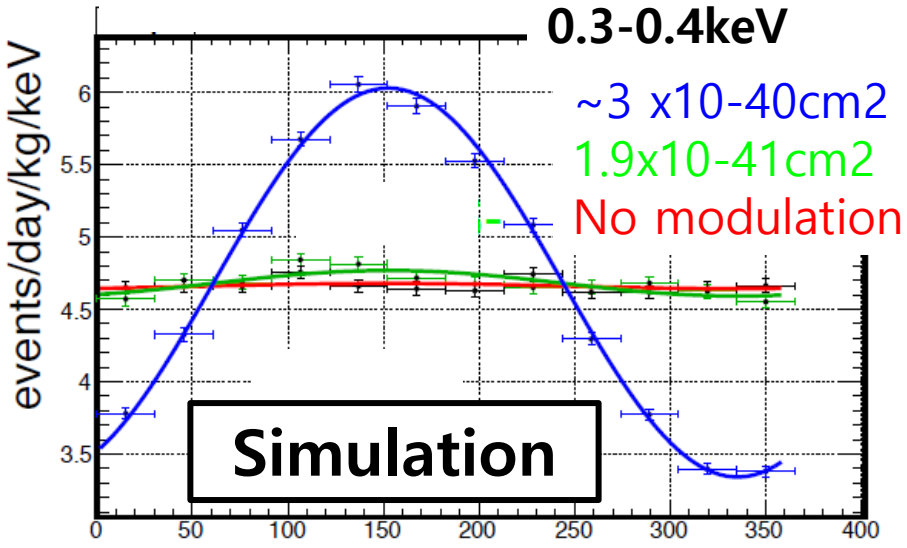




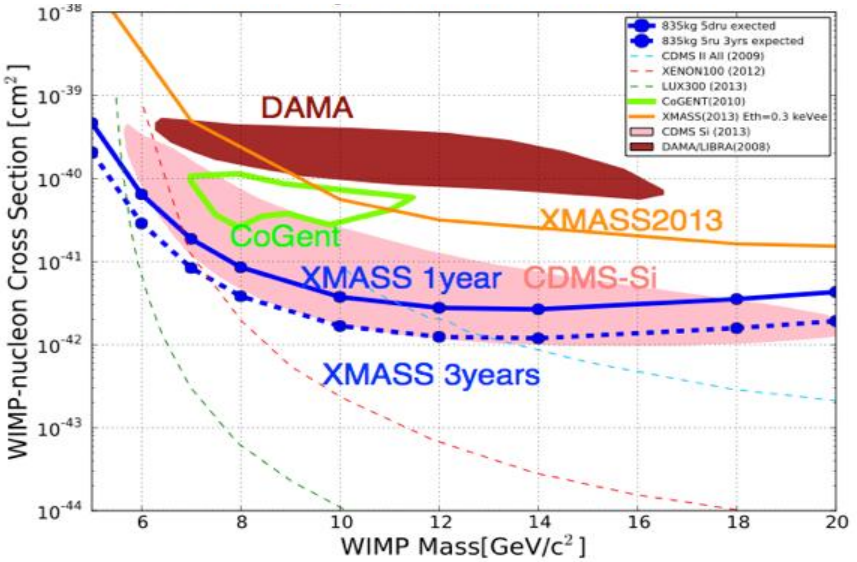
Current status (2)

- Annual modulation analysis after the refurbishment
  - For full volume
    - World's largest mass : 1 yr data of XMASS ~ 14yrs data of DAMA/LIBRA
      0.8 ton*year ~ 1.33 ton*year
      Current statistics is ~ half of DAMA/LIBRA data
    - Low energy threshold : 0.3keVee
    - Select events with simple cut w/o reconstruction
    - For several physics (DM, axion,..) w/o PID.
    - The results for 1yr data will come in near future.
  - To be analyzed for fiducial volume in near future.

Expected modulation in XMASS for 8GeV WIMP

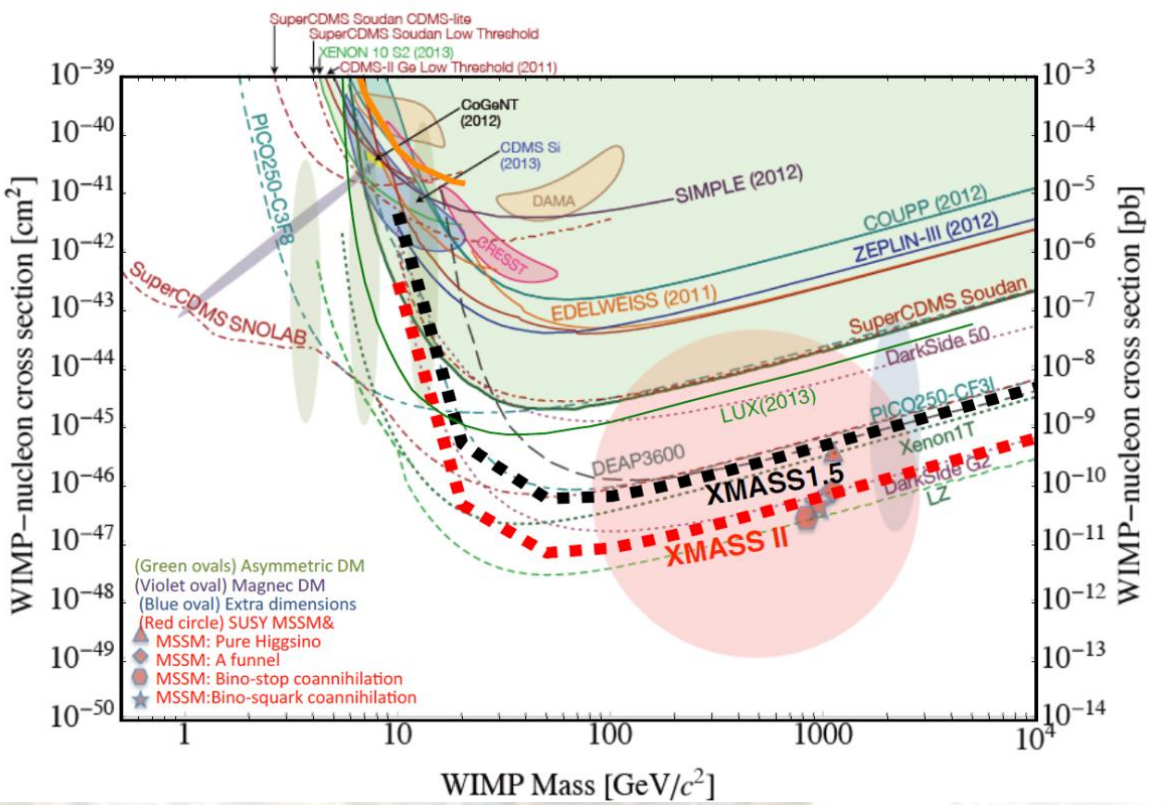


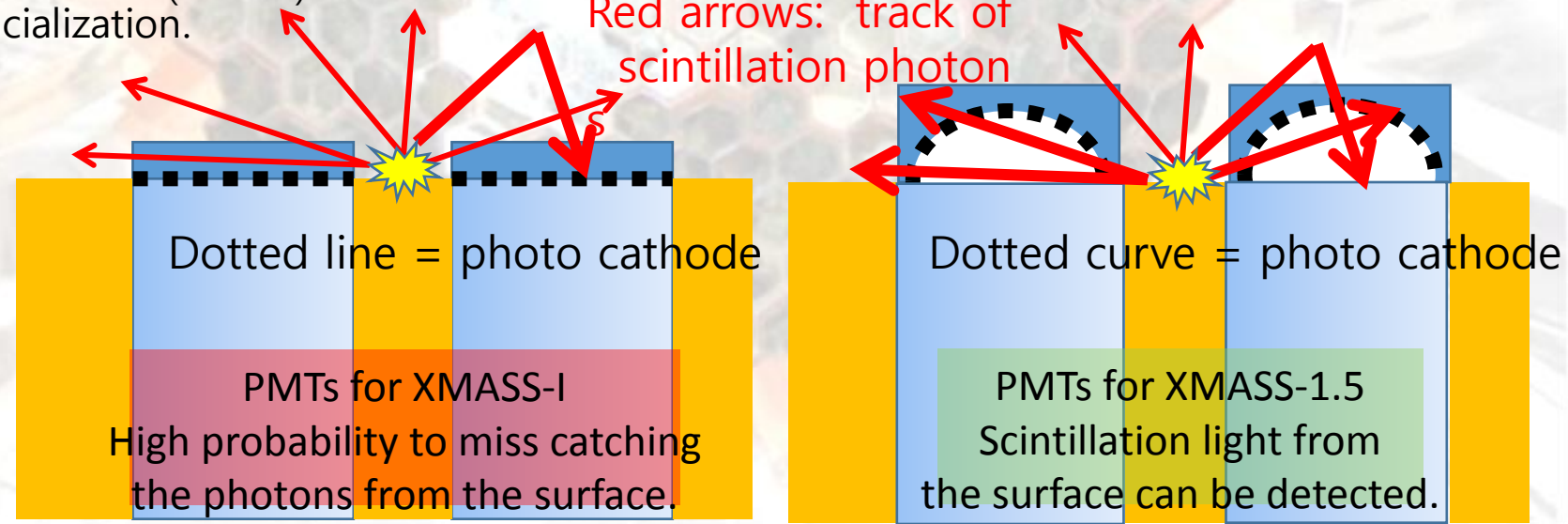
Prospects after refurbishment for full volume



Future project

- XMASS-1.5 : FV 1ton, Full 5tons 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:
  - σ_{SI}<10^{-46}cm2(>5keV) for fiducialization.





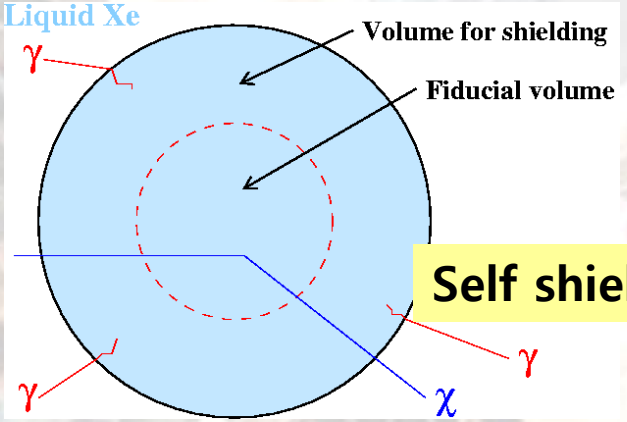
Summary

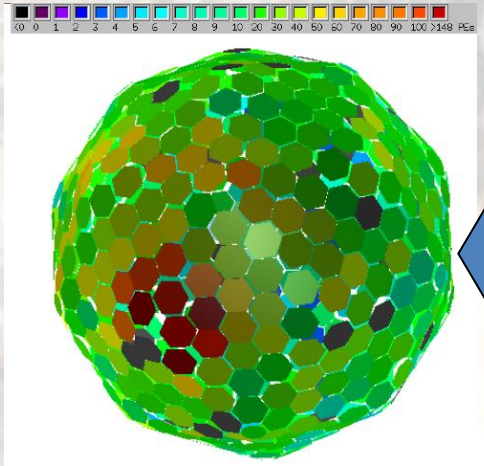
- Physics results from commissioning data
  - Taking the full advantage of sensitivity to e/γ events as well as nuclear recoil, large volume, low threshold and low background at a few 10's keV at a level of 10^{-4}/day/kg/keV$_{ee}$
    - Low mass WIMPs : with just 6.70 days(×835kg) data, excluded most of the parameter space favored by DAMA. (Phys. Lett. B 719 78 (2013))
    - Solar axions : In 10-40keV, stringent constraint for g_{aee} (Phys. Lett. B 724 46 (2013))
    - New — Bosonic super-WIMPs : For vector boson, the first direct search in the 40-120keV range. The limit excludes the possibility that such particles constitute all of dark matter. For pseudoscalar, the most stringent direct constraint on g_{aee}. (Phys. Rev. Lett. 113, 121301(2014))
    - Inelastic WIMP nucleus scattering : Achieved the limint without explicit background subtraction (PTEP 063C01 (2014))
- Current status
  - The refurbishment of detector completed and data-taking resumed in Nov. 2013.
  - Succeeded one order reduction of background from commissioning run data. Using these data, physics analyses including WIMP search with fiducialization and annual modulation are on-going. Its results will come in near future.
- Future
  - Designing of XMASS-1.5 is on-going.
  - Aim to $\sigma_{SI}<10^{-46}$cm2(>5keV) for fiducialization.

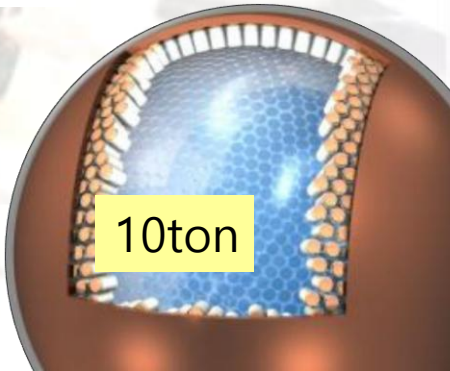
Backup

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. (1/100 of ordinary one).

●OFHC copper: Bring in the mine < 1month 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.

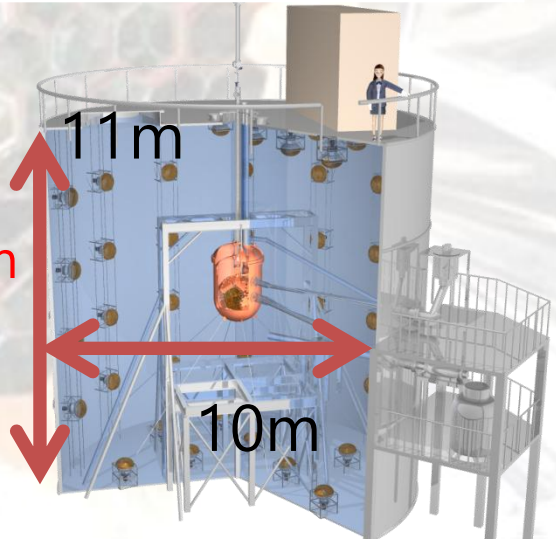
PMT HPGe meas. result

RI in PMT	Activity per 1PMT(mBq/PMT)
238U-chain	0.70+/-0.28
232Th-chain	1.51+/-0.31
40K-chain	9.10+/-2.15
60Co-chain	2.92+/-0.16

(2) External BG

● gamma and n from rock are sufficiently reduced by a >4m thickness pure water tank : $\gamma < \gamma$ from PMT, $n << 10^{-4}$ /day/kg

●72 20" PMTs for active veto for CR μ

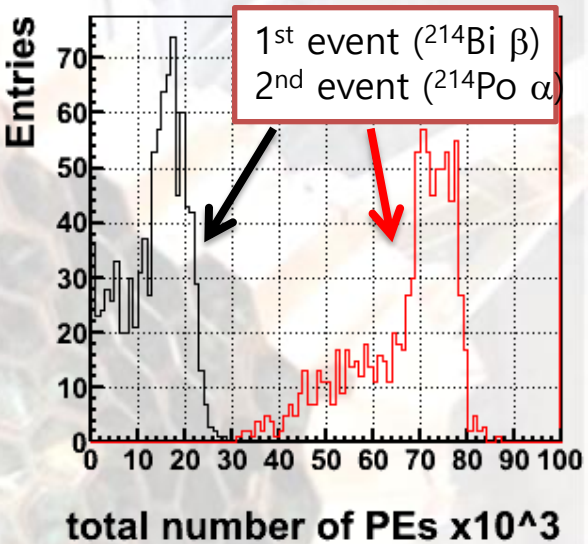


(3) Internal BG (in Xenon)

- Radon : Our goal (<10-5 /day/keV/kg)=> 222Rn < 0.6 mBq/detector
  - Radon emanation from detector material was measured with material selection. <15mBq/detector was estimated.
  - Radon concentration in XMASS by Bi-Po coincidence analysis : 8.2+/-0.5mBq.
  - The radon removal system from xenon gas are prepared.

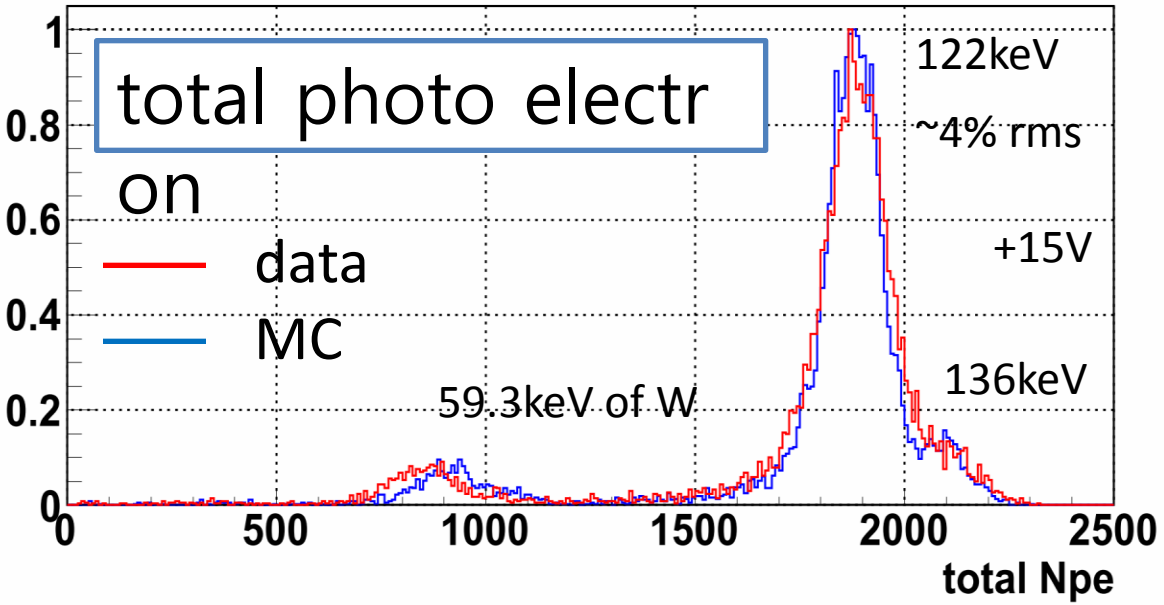
    K. Abe et al. for XMASS collab., NIMA661, 50-57 (2012)
- Kr : Our goal (<10-5 /day/keV/kg)=> 1ppt
  - 5 order of magnitude reduction with 4.7kg/hr processing time was achieved by distillation system.

    K. Abe et al. for XMASS collab., Astropart. Phys. 31 (2009) 290
  - <2.7ppt (API-MS measurement of sample gas) was achieved.
- Water, H2, O2 etc :
  - Worse the optical property of xenon and probability of BG (3T)
  - Xenon gas was passed to hot and room temperature getter to remove these.

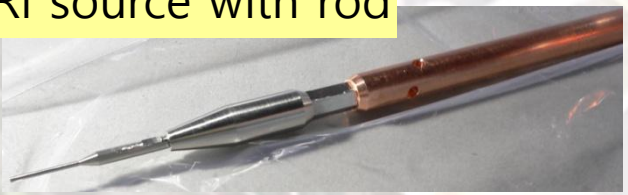


Distillation tower

Detector response for a point-like source (~WIMPs)

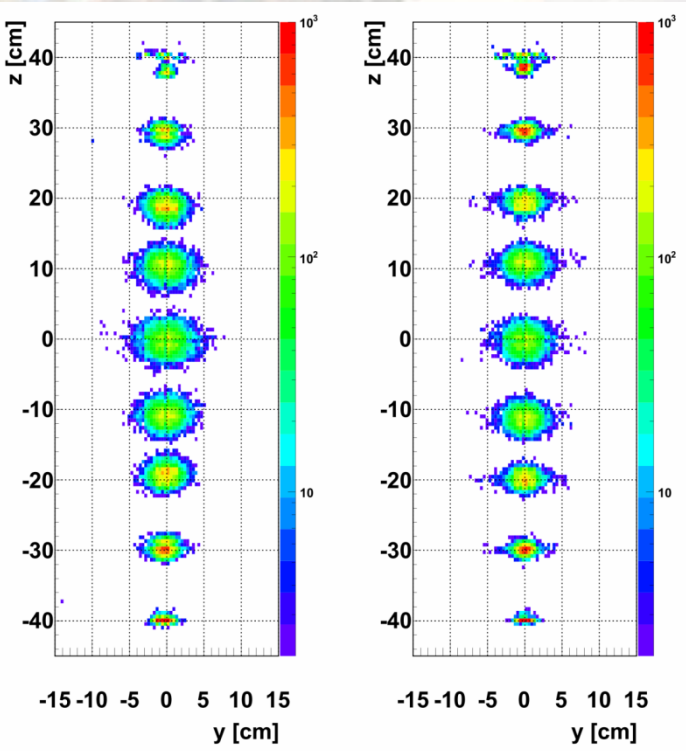


RI source with rod

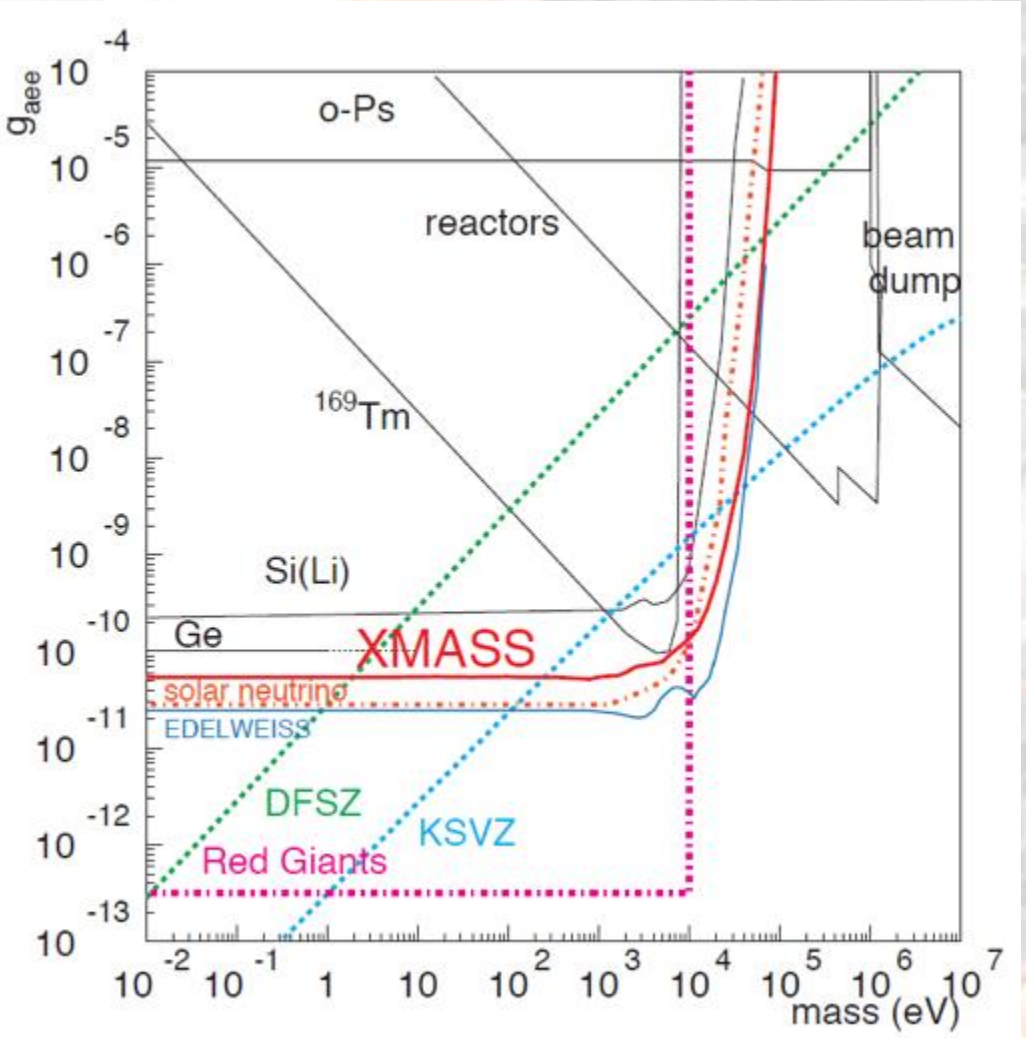


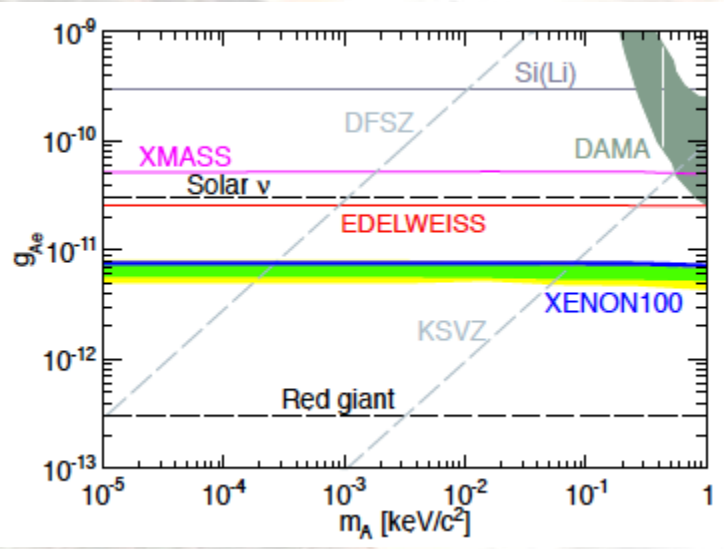
reconstructed vert
ex

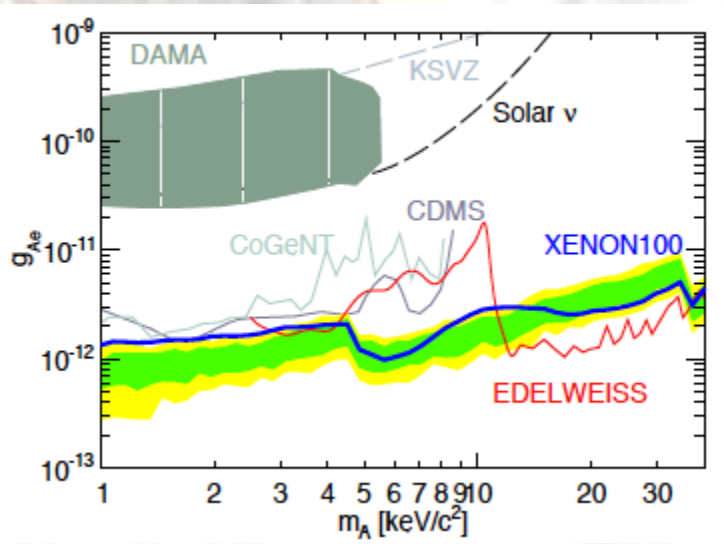
data MC



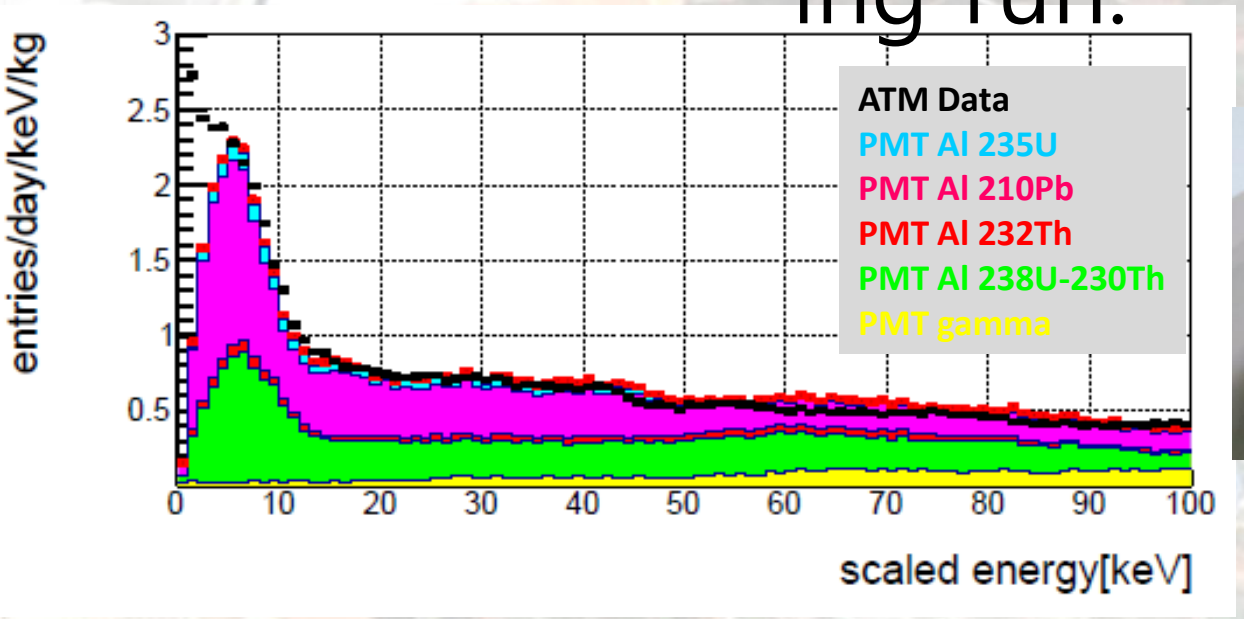
- ^{57}Co source @ center gives a typical res ponse of the detector.
- 14.7p.e./keV$_{ee}$ (⇔ 2.2 for S1 in XENON10 0)
- The pe dist. well as vertex dist. were repr oduced by a simulation well.
- Signals would be <150p.e. exp shape.

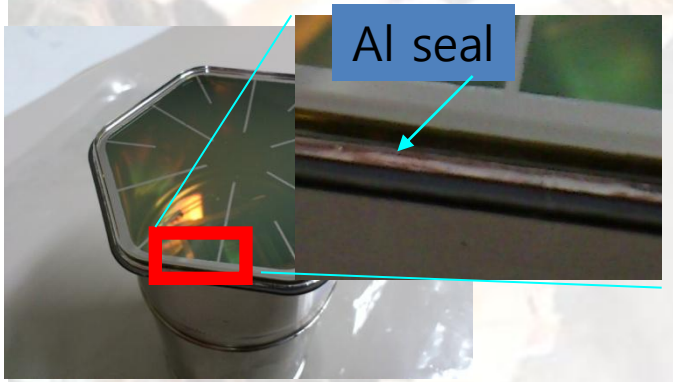

g_{aee}
o-Ps
reactors
beam dump
^{169}Tm
Si(Li)
Ge
XMASS
solar neutrino
EDELWEISS
DFSZ
KSVZ
Red Giants
mass (eV)


g_{Ae}
Si(Li)
DFSZ
DAMA
XMASS
Solar ν
EDELWEISS
XENON100
KSVZ
Red giant
m_A [keV/c^2]

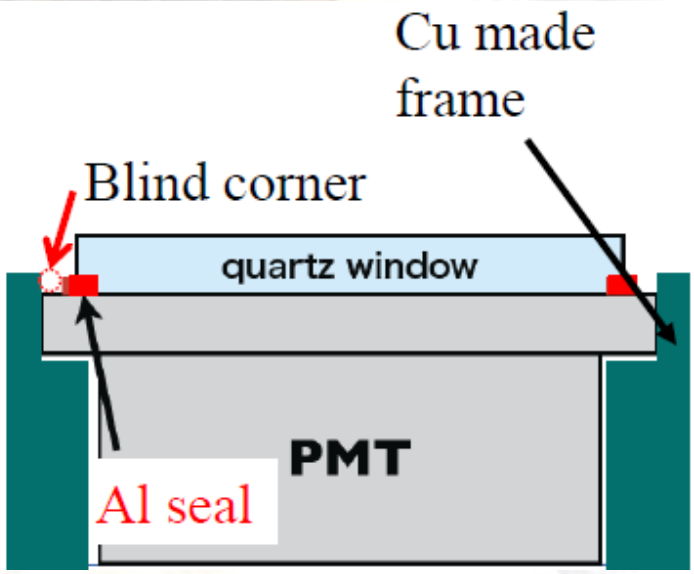

g_{Ae}
DAMA
KSVZ
Solar ν
CDMS
CoGeNT
XENON100
EDELWEISS
m_A [keV/c^2]

Unexpected BG in XMASS commissioning run:



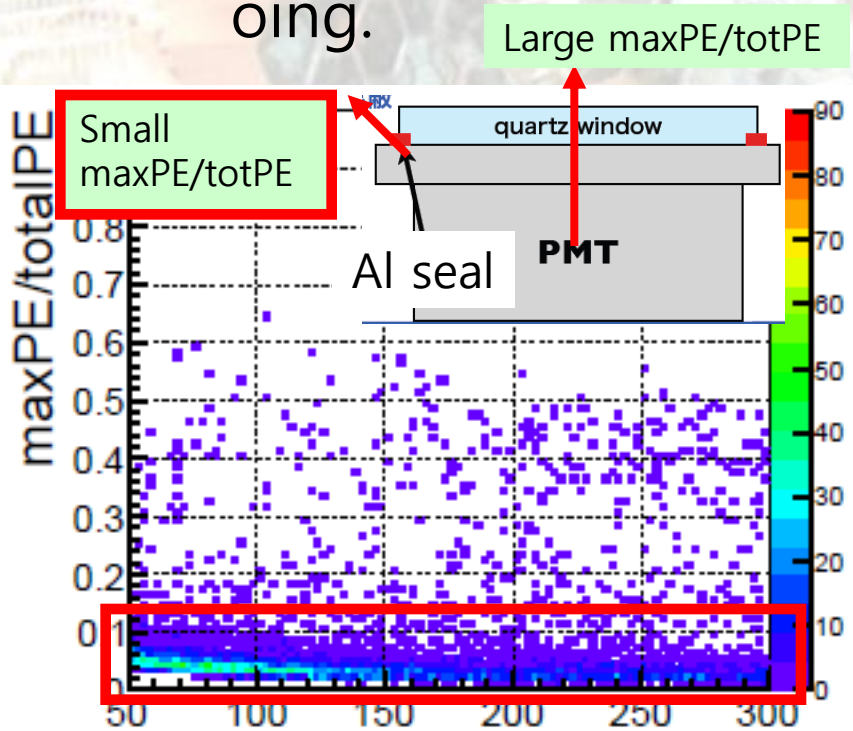


- BG was 2 order larger than PMT gamma BG which was assumed as main BG.
- (BG level is nearly with DAMA and CoGent.)
- The origin of BG for >5keV were confirmed. (1) BG from PMT Al seal (238U-230Th and 210Pb-206Pb). (2) 210Pb-206Pb in Copper surface.
- BG origin from "detector surface" is dominant. Leakage event in FV region is introduced by worse of PMT response. Need to remove these.

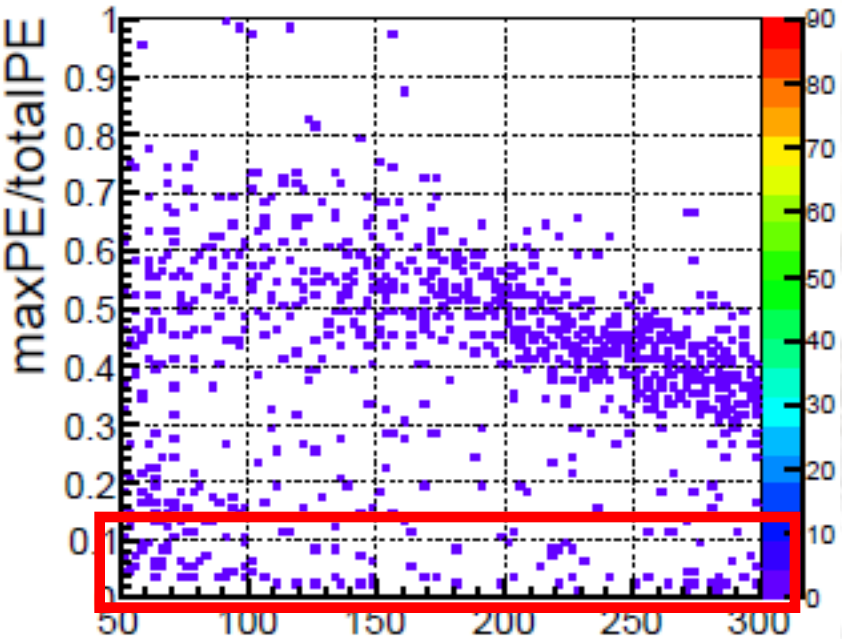


Current status (2) maxpe/totPE

- The event in small Maxpe (maximum NPE for one PM T)/totalPE region are reduced rapidly.
- It suggest that the event near of "blind of PMT" are re duced and mimic of inside event are reduced.
- Dark matter search with fiducial volume analysis is ong oing.



Commissioning run



Aft refurbishment run