Xmass

Dark Matter Search

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ICRR, University of Tokyo
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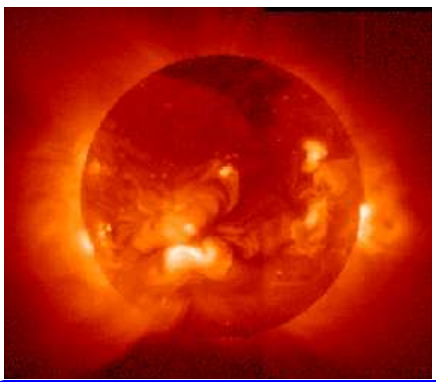
Feb. 14th, 2013 HPNP2013 at Toyama University

# XMASS experiment

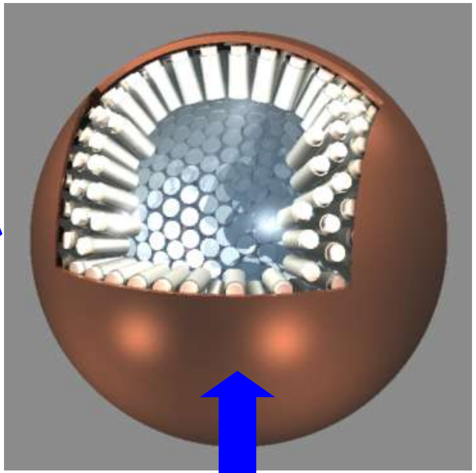
- What is XMASS?

  Multi purpose low-background and low-energy threshold experiment with liquid Xenon

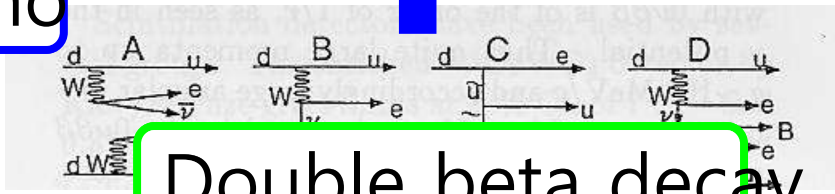
- **X**enon detector for Weakly Interacting **MASS**ive Particles (**DM (direct) search**)
- **X**enon **MASS**ive detector for solar neutrino (**pp/$^7$Be**)
- **X**enon neutrino **MASS** detector (**ββ decay**)



Solar neutrino



Dark Matter




Double beta decay

+axion, etc

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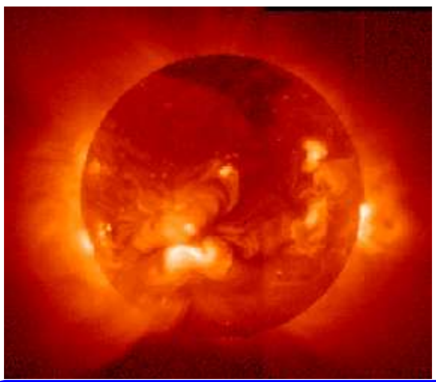
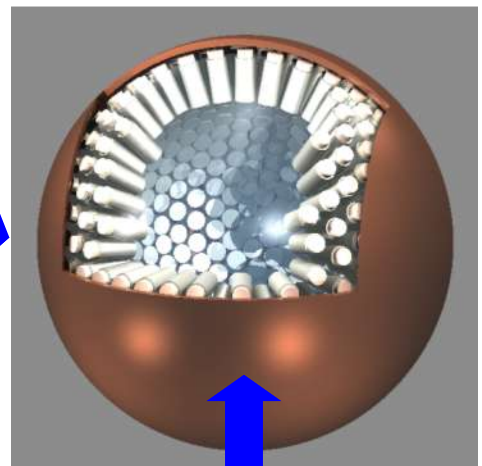
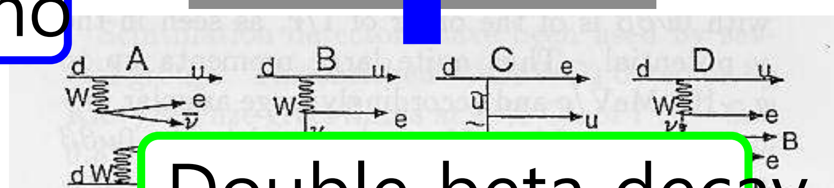
Main purpose of current phase



Solar neutrino



Dark Matter



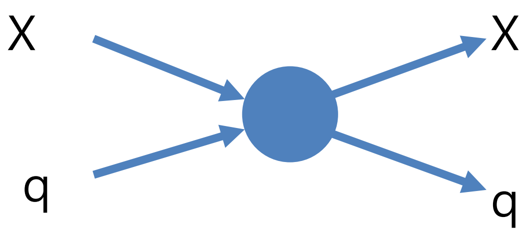

Double beta decay

+axion, etc

# Direct search

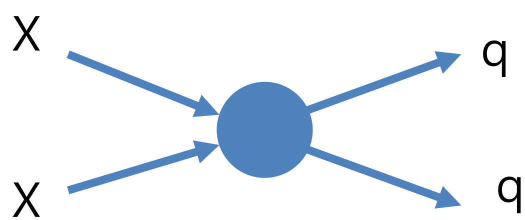
## One of the approaches to detection to WIMP

**Direct**



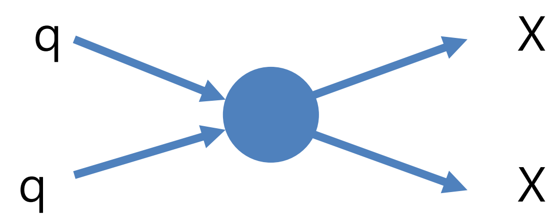

search for the scattering of dark matter particles off atomic nuclei within a detector

**Indirect**




search for the products of WIMP annihilation or decay

**Collider**




to produce WIMP in the lab

XMASS
XENON
CDMS
CoGeNT
DAMA
………

PAMELA
SK
ICECUBE
…

LHC, ILC

# Direct detection technique

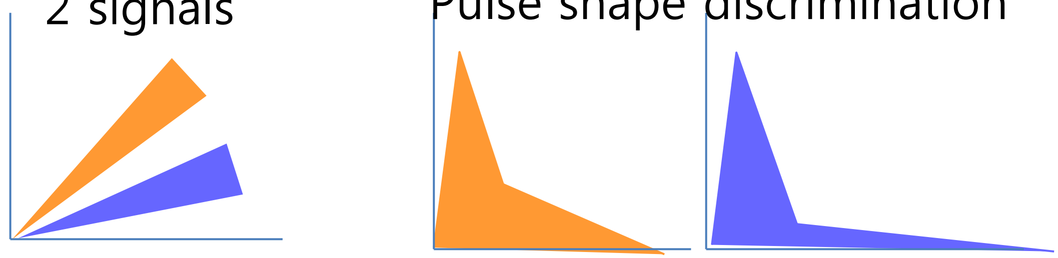
## Target material

Noble liquid/gas : Xe, Ar, Ne,..
Scintillating crystal : NaI, CsI
Solid state cryogenic : Ge, $CaWO_4$ …
Superheated liquid : $CF_3I$ …
….

## Particle ID : nuclear or electron/gamma recoil

2 signals

Pulse shape discrimination



## By the signal type of recoil E

Scintillation

Ionization

Phonons

Superheated liquid

DarkSide, LUX, PandaX, Xenon, ZEPLIN

XMASS, ANAIS, DAMA, DEAP/CLEAN, DM-Ice, KIMS

CRESST-II

CoGeNT, DM-TPC, DRIFT

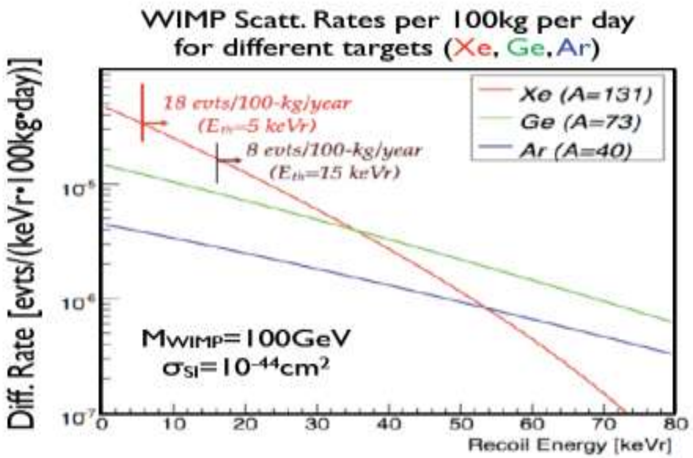
CDMS
EDELWEISS

CRESST-I

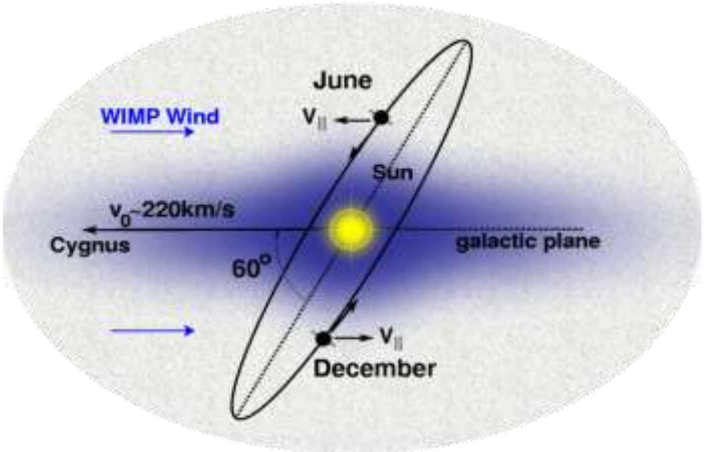
COUPP
PICASSO

# Observation and current status

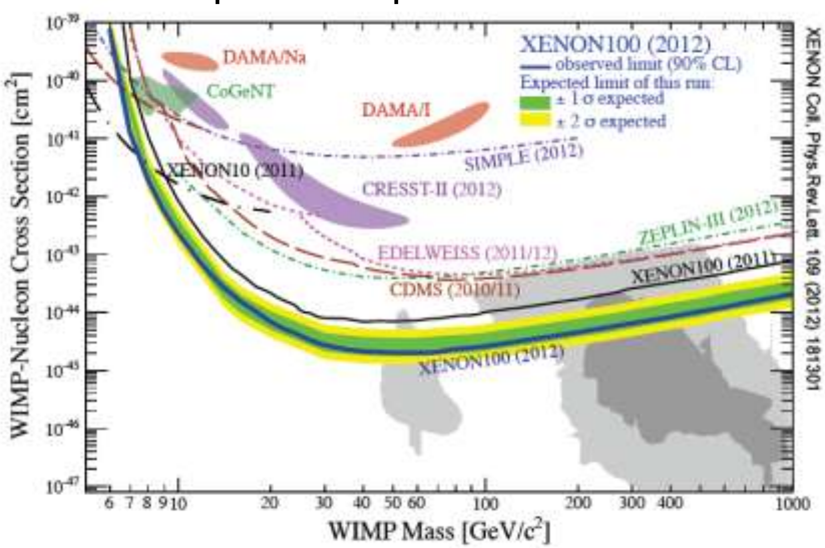
Energy spectrum :
depending on mass and cross section




Annual modulation :
due to Earth revolution




Spin independent

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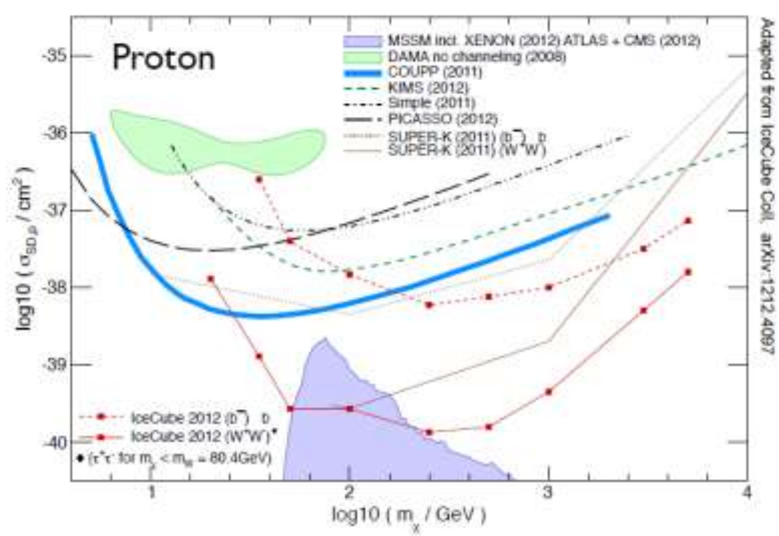
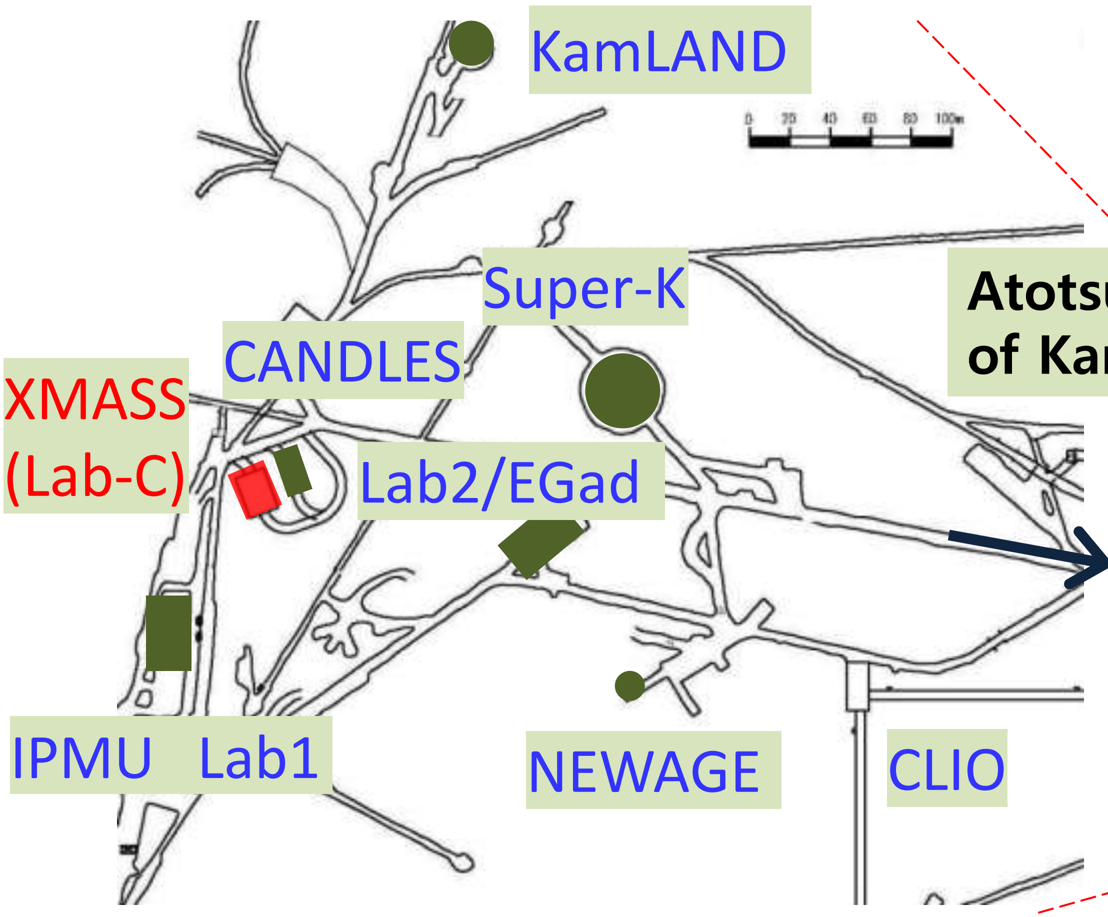
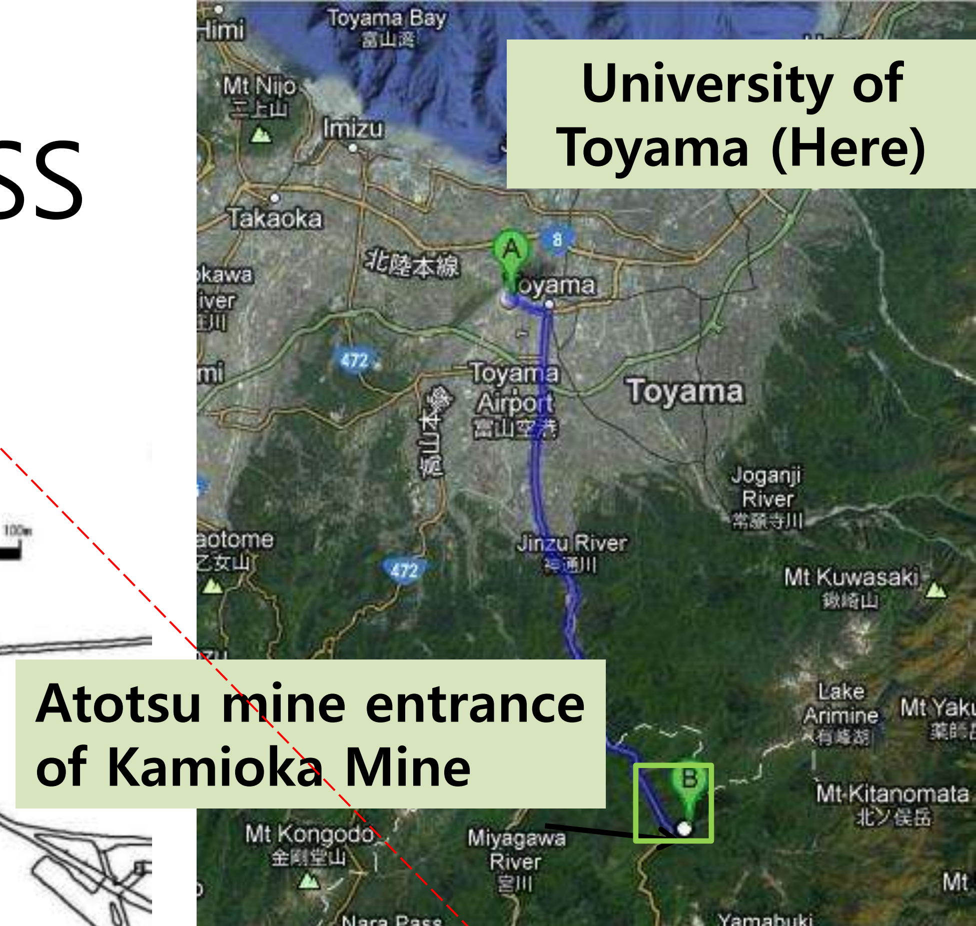
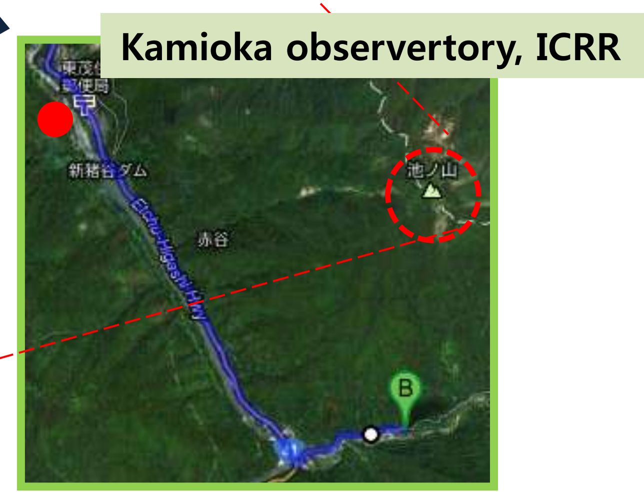


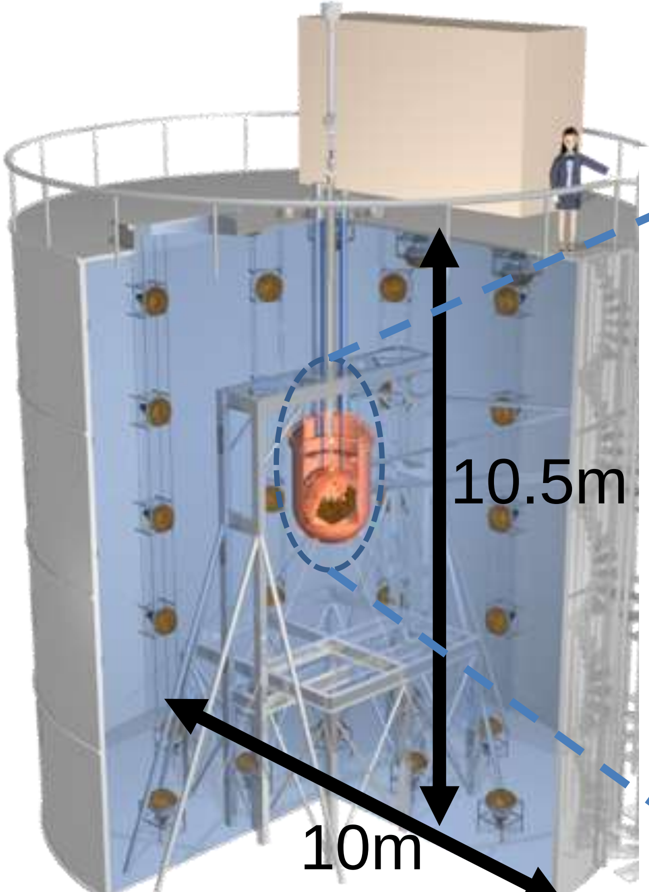
# Location of XMASS

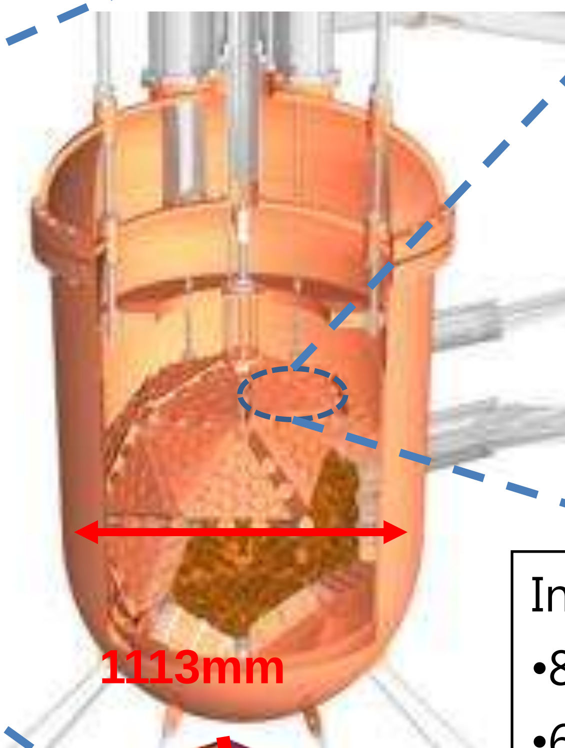


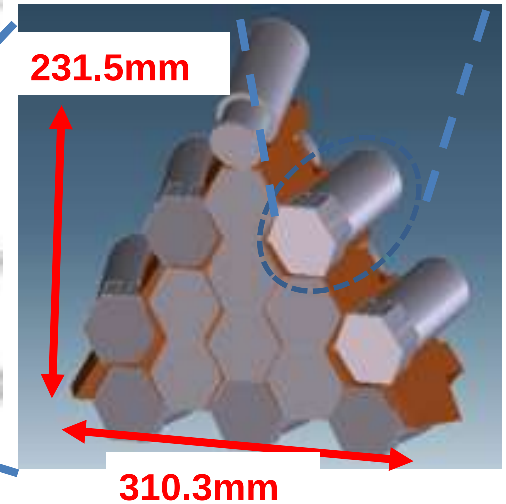



# Detector


Pentakisdodecahedron

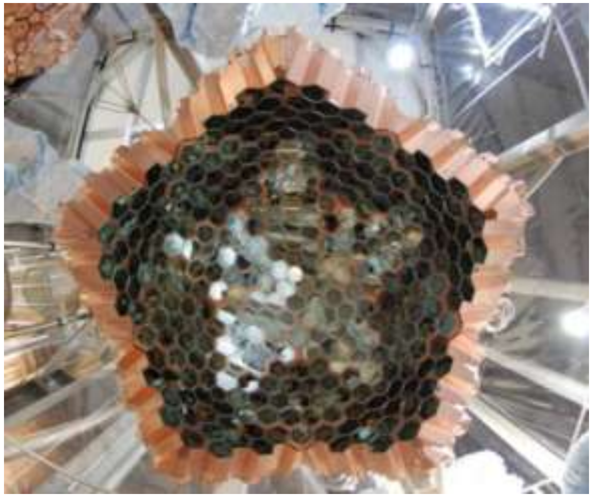
Outer detector
- Water tank
- 76 20-inch PMTs
- shield for gamma-ray and neutron
- cosmic ray muon veto

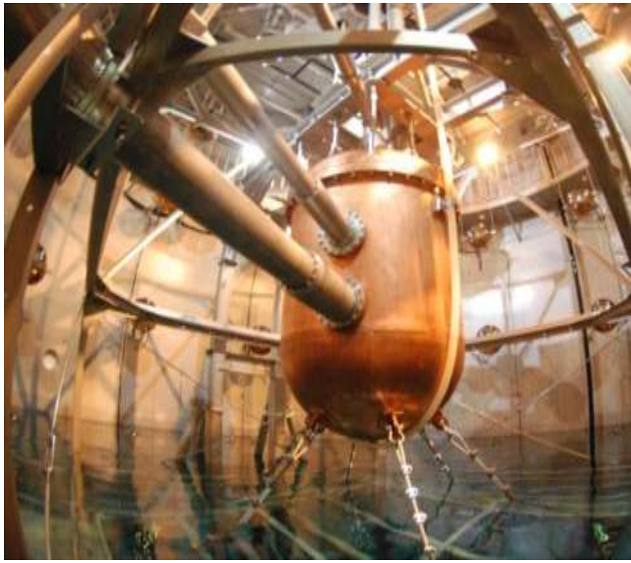
XMASS detector,
K. Abe et al, arXiv:1301.2815

Inner detector
- 835kg LXe
- 60 triangular PMT holders
- Total: 642PMTs
- Photo coverage: 62%
- Diameter: ~800mm
- 14.7p.e./$keV_{ee}$
(Best photon yield)

# Status

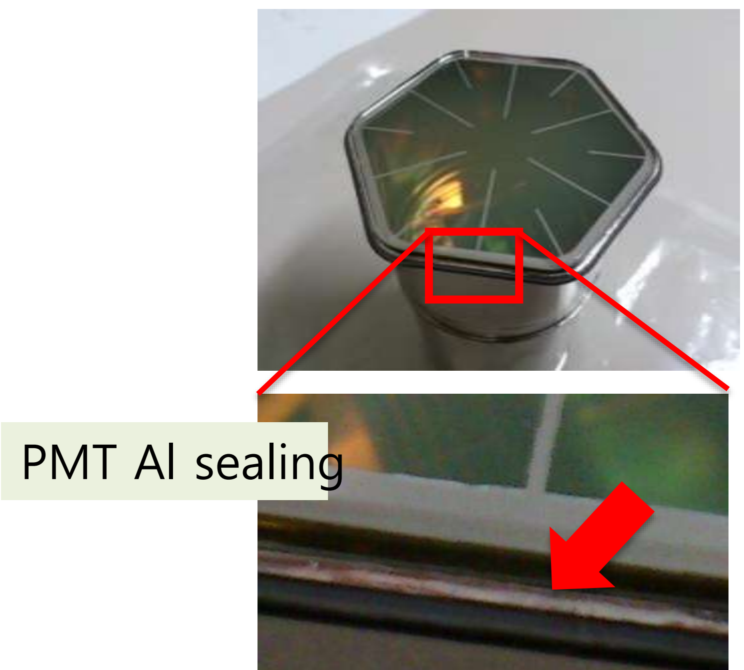
- Detector construction was completed at September 2010.
- Commissioning run was conducted from December 2010 until June 2012.
- Analyses are on-going.
- 1 physics paper(low mass WIMP search) was accepted.
- 1 physics paper(solar axion search) was submitted.

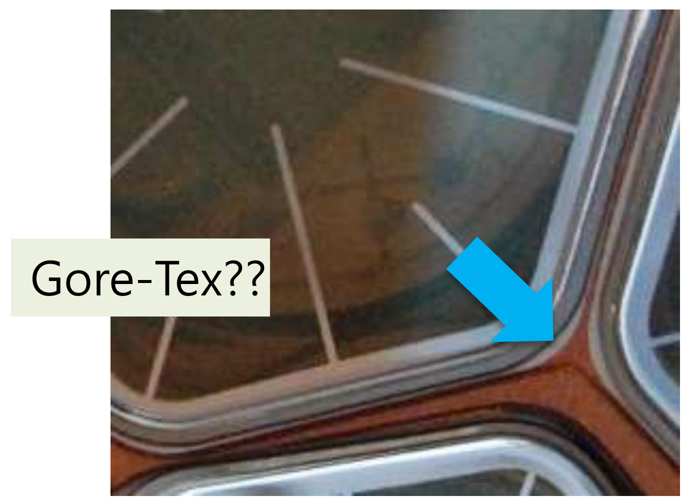


# Background and its understanding

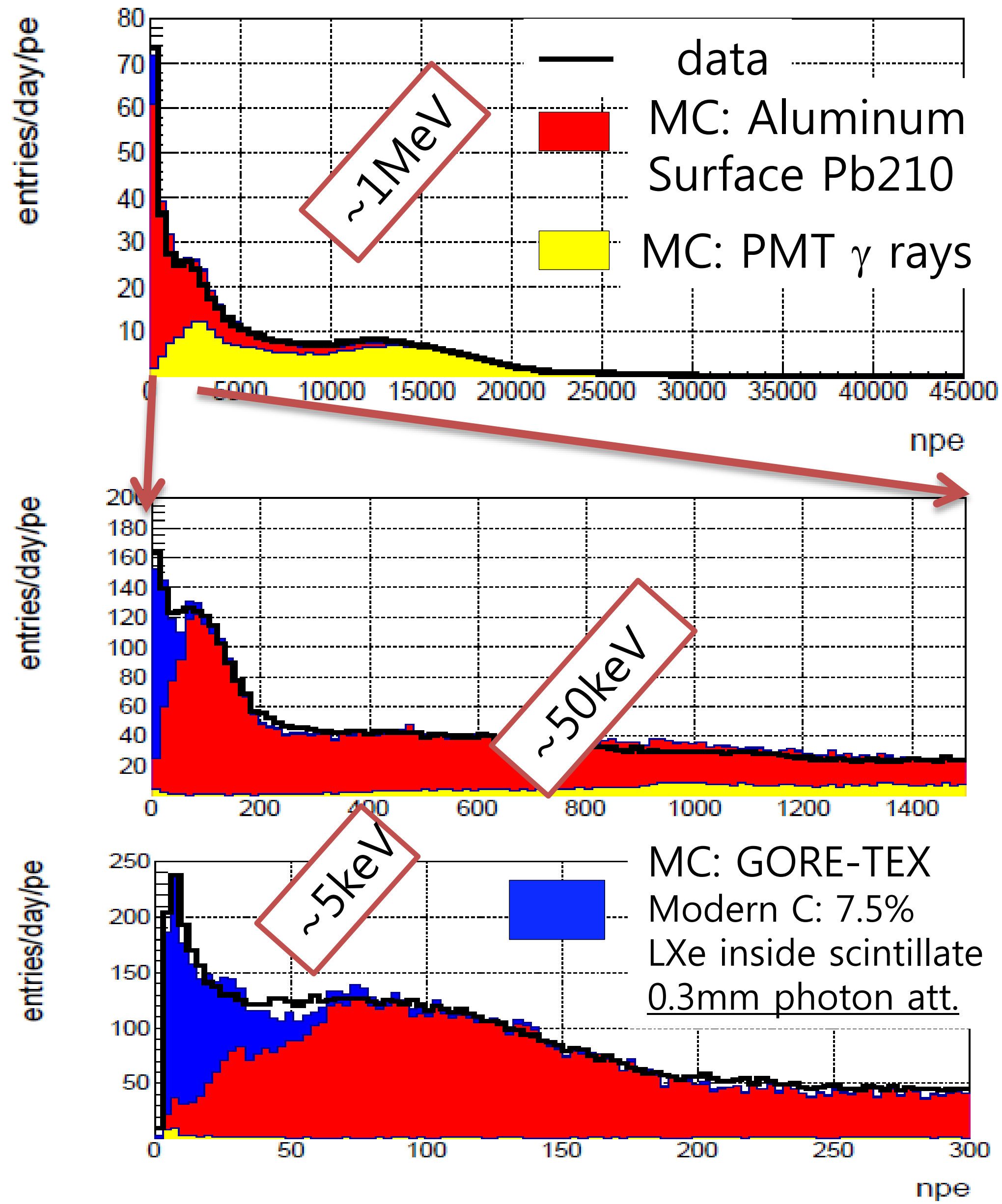
- Major origin of BG was considered to be $\gamma$ from PMTs. But the observed data seemed to have additional surface BG.
- Detector parts which touch liquid xenon were carefully evaluated again:
  - Aluminum sealing parts for the PMT (btw metal body and quartz glass) contains U238 and Pb210 (secular equiv. broken).
  - GORE-TEX between PMT and holder contains modern carbon (C14) 0~6+/-3%.



# Background contribution to NPE spectrum

- Three contributions to the NPE spectrum
  1. High energy (0.1-3MeV): PMT γ rays: <u>Measured by Ge detectors and well understood.</u>
  2. Mid. energy (5keV-1MeV): Aluminum and radon daughters: <u>Measured by Ge det. And consistent with observed α-ray events</u> (61/64mcps in data/MC). Rn daughters on the inner wall identified by α events.
  3. Low energy (0-5keV): Under study.
     - Prediction based on some assumptions on GORE-TEX gives a similar shape. But assumption dependent. Confirmation possible only by removing the GORE-TEX.



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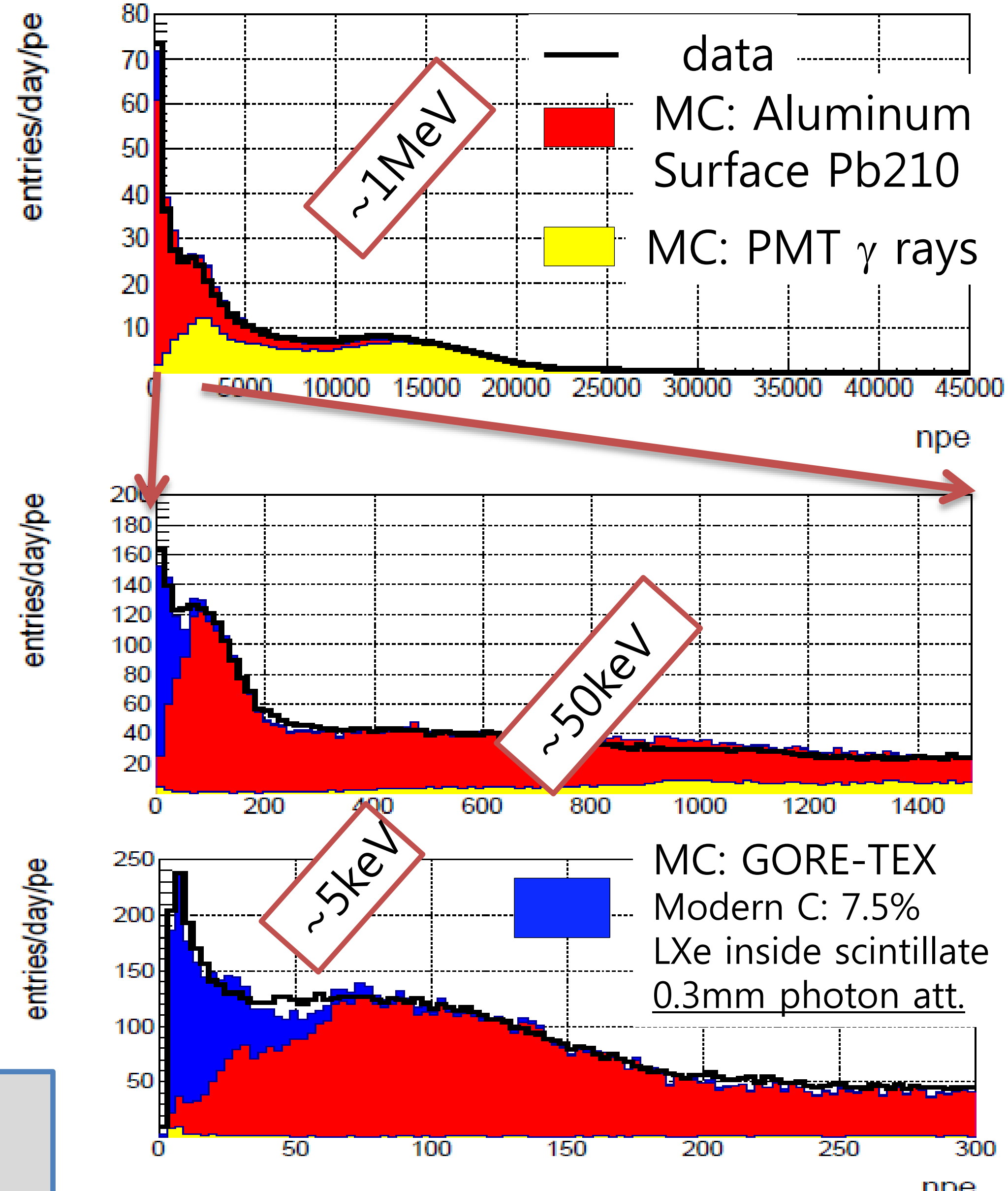
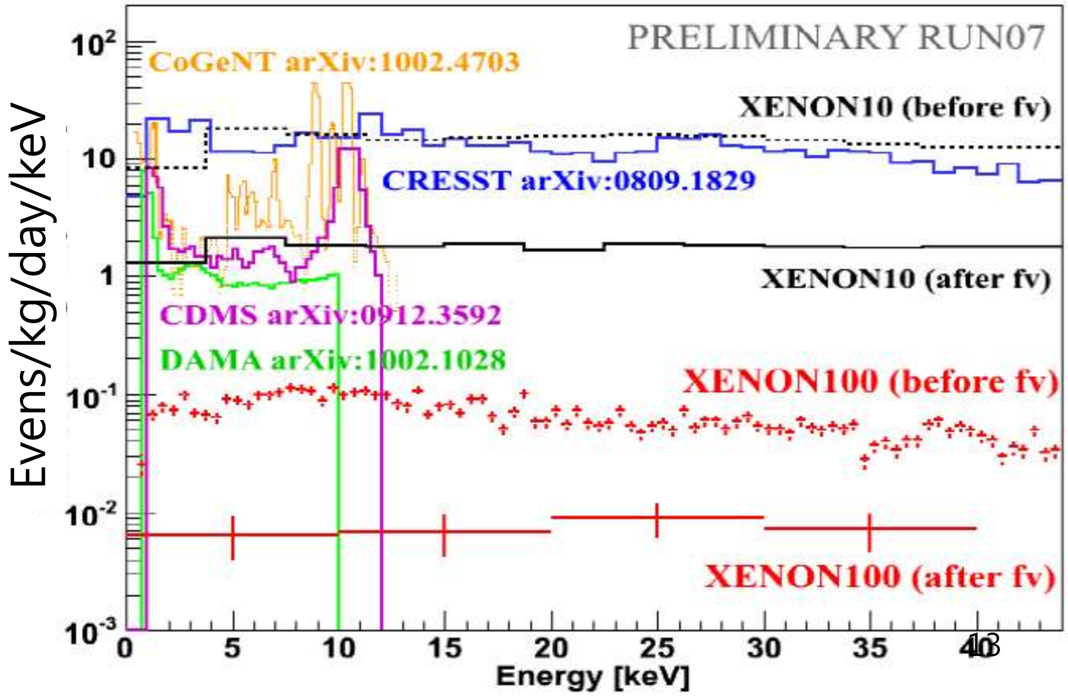
BG >5keV (the design energy thre.) is well understood!



# Low background even with the surface BG

- Our BG is still quite low, even with the extra surface BG!




E. Aprile, 2010 Princeton

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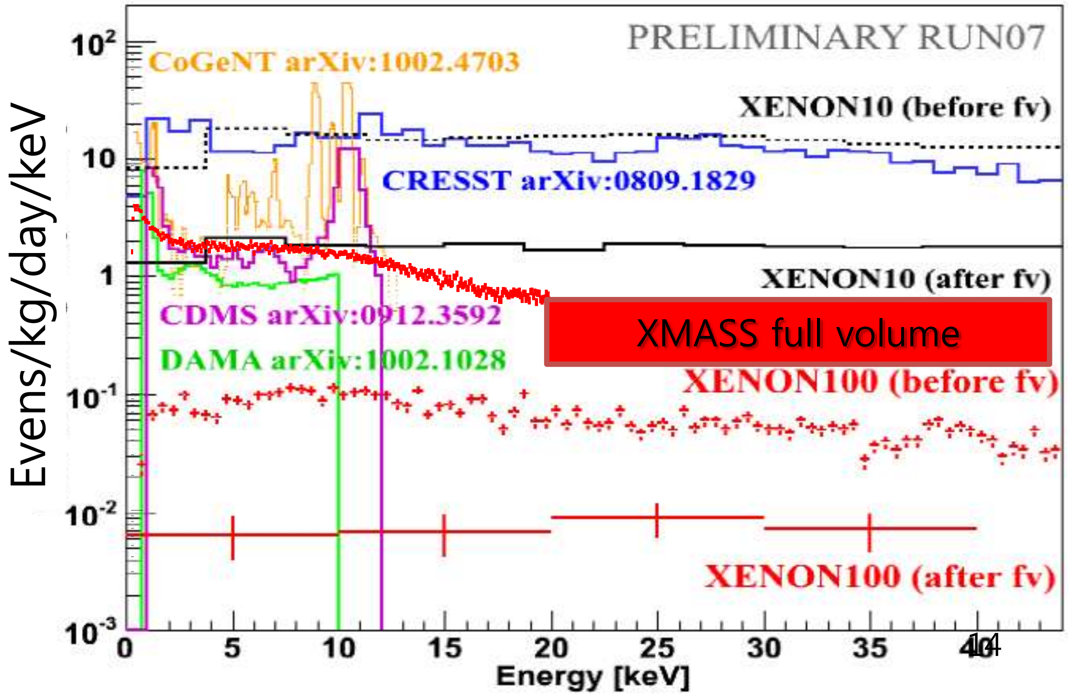


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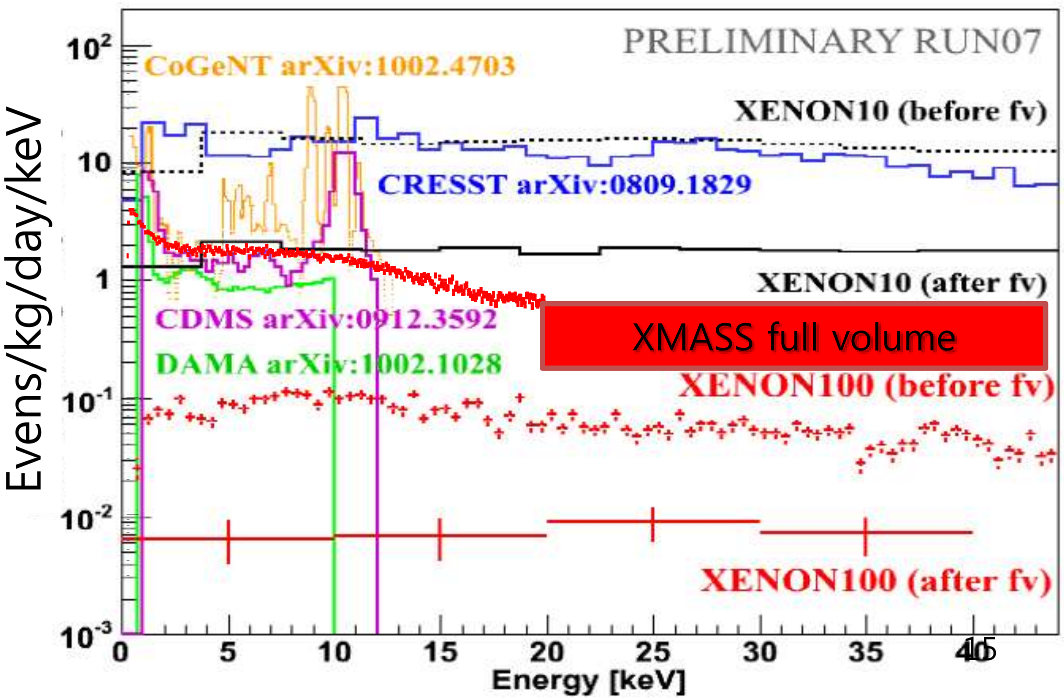
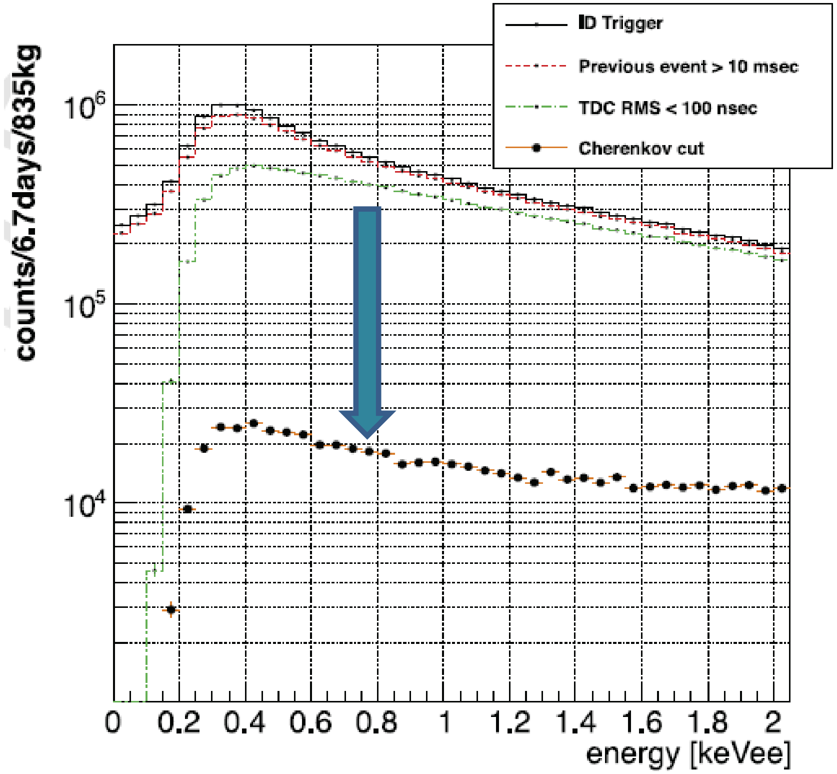
- Our sensitivity for the low mass WIMP signals at low energy without reconstruction will be shown.




E. Aprile, 2010 Princeton

# Low energy, full volume analysis for low mass WIMPs

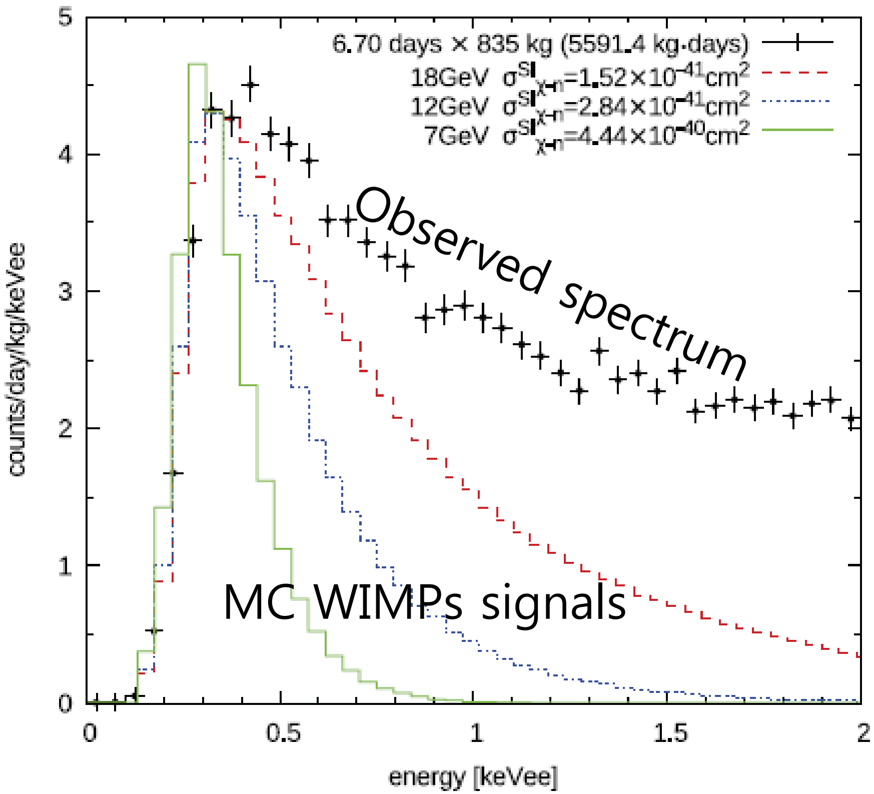
- 6.70 days data.
- The largest BG at the low energy end is the Cherenkov emission from $^{40}K$ in the photo cathodes.
- Selection criteria
  - Triggered by the inner detector only (no water tank trigger)
  - Time difference to the previous/next event >10ms
  - RMS of hit timing <100ns (rejection of after pulses of PMTs)
  - Cherenkov rejection
    - The Cherenkov events are efficiently reduced.

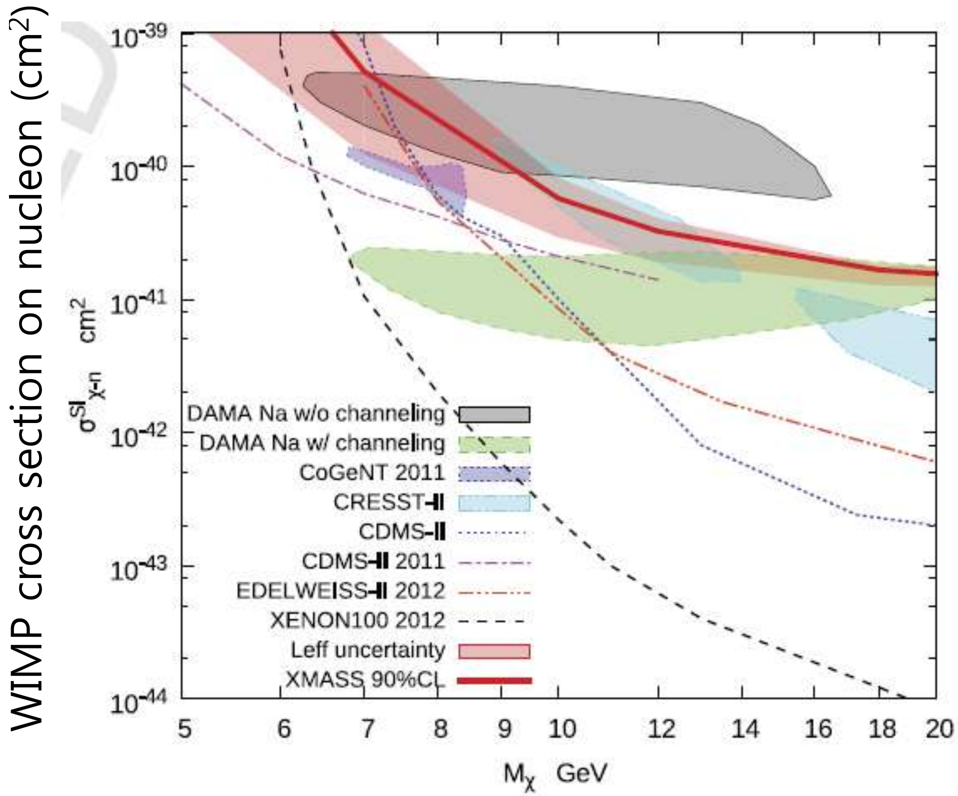



Light WIMP search in XMASS, K. Abe et al, accepted in Phys. Lett. B (2013), (arXiv:1211.5404)

# Low energy, full volume analysis for low mass WIMPs

- The dark matter signal rapidly increase toward low energy end. The large p.e. yield enables us to see light WIMPs.
- Try to set absolute maxima of the cross section (predicted spectrum must not exceed the observed spectrum).
- Sensitive to the allowed region of DAMA/CoGeNT.
- Some part of the allowed regions can be excluded.

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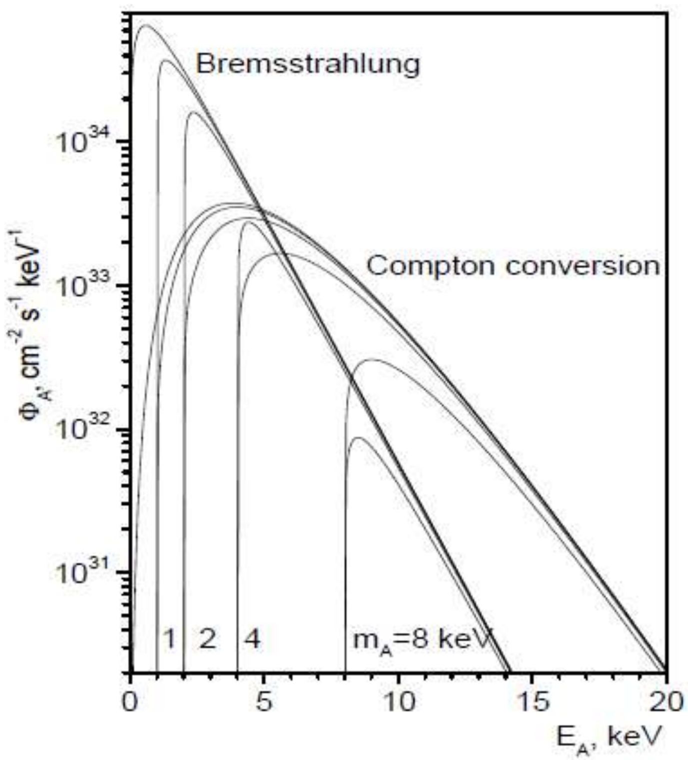
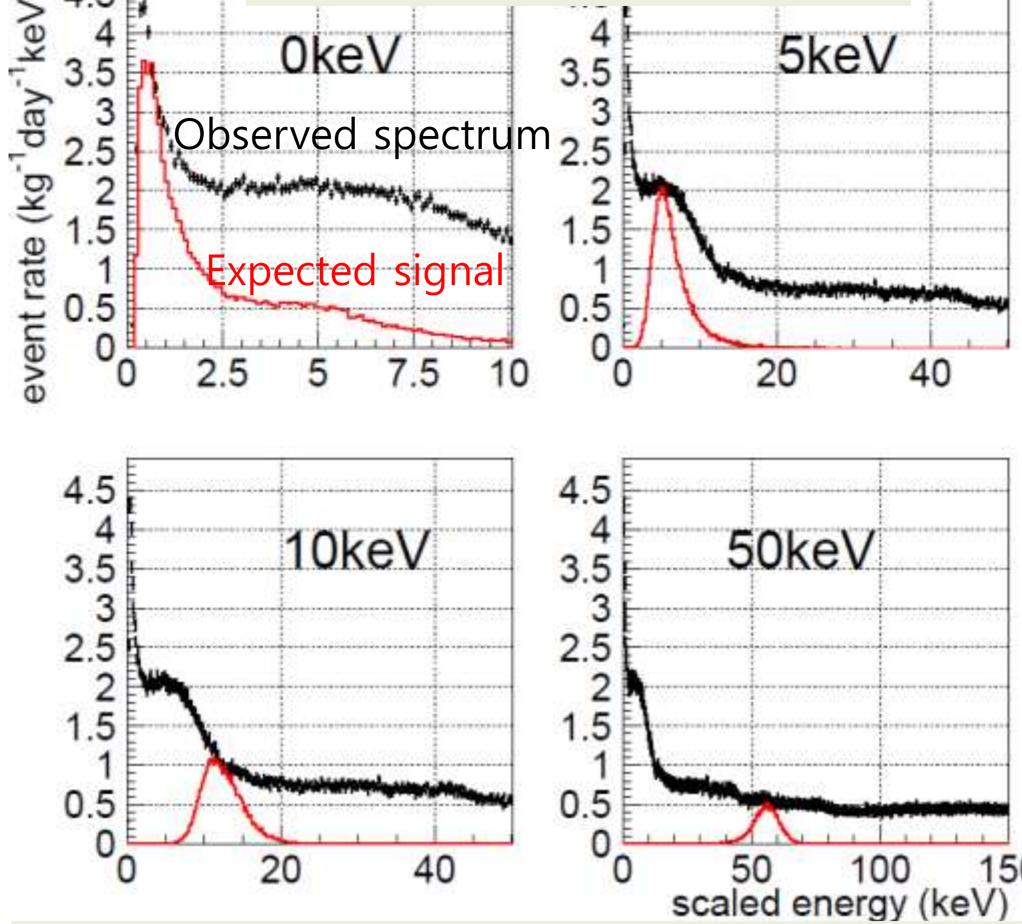
# Solar axion search
# Bremsstrahlung + Compton: $g_{aee}$ only

- Large flux can be expected for DFSZ axions.
- $m_A$=0 by Derbin $g_{aee}$=1
- Analytical expression for mA=0 is in PRD 83, 023505 (2011)

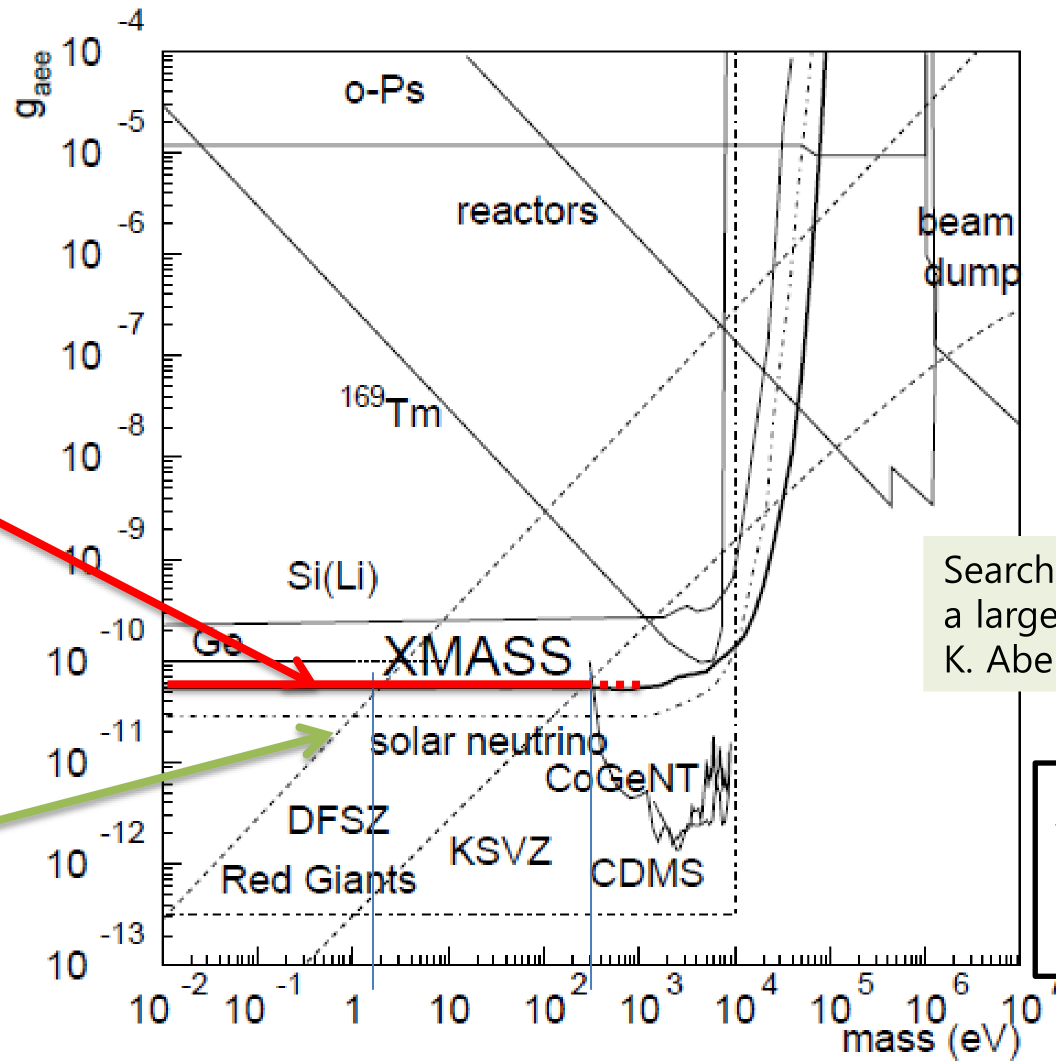



Expected signals and MC simulation




Search for solar axion in XMASS,
a large liquid-xenon detector, K. Abe et al, arXiv:1212.6153

# Constraint on axion-electron coupling




XMASS
Limit by solar axion
5.4e-11

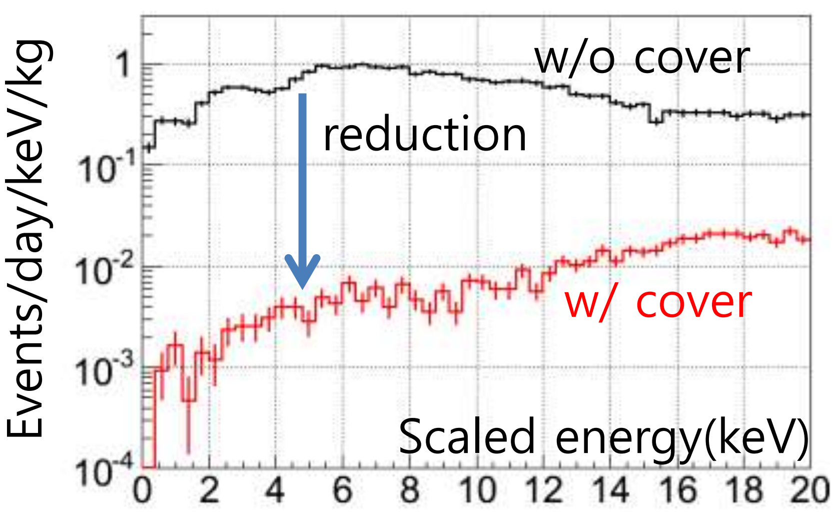
Solar limit
2.8e-11

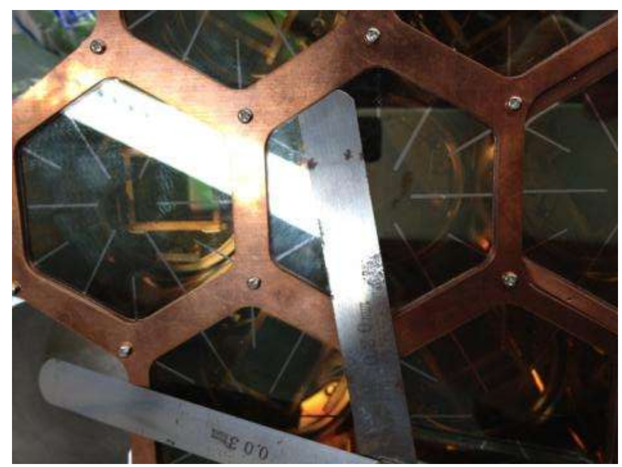
Search for solar axion in XMASS, a large liquid-xenon detector, K. Abe et al, arXiv:1212.6153

Allowed mass
< 250eV for KSVZ
<1.9eV for DFSZ

# Refurbishment work

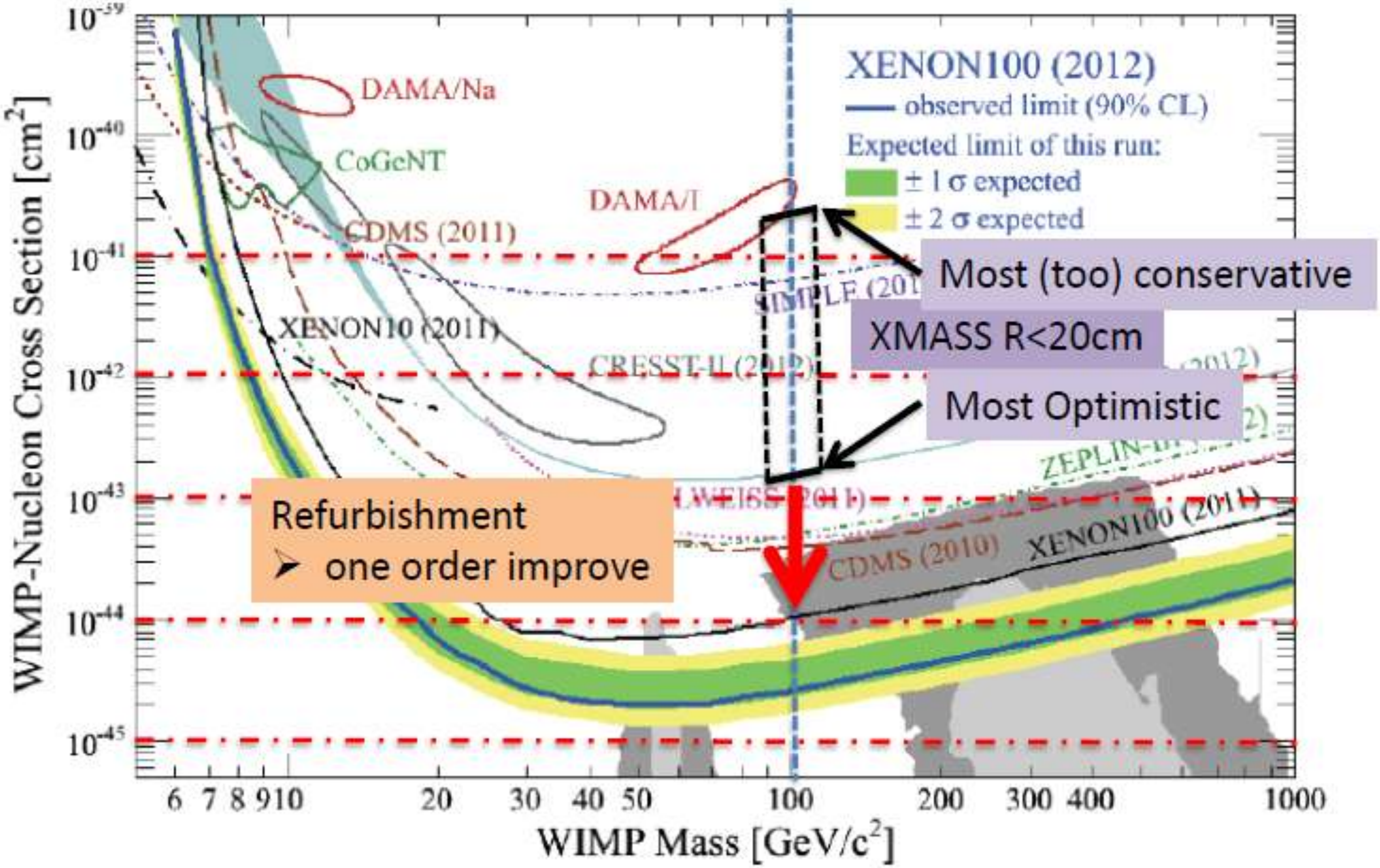
- PMT Al is covered by copper.
- To simplify the structure, copper cover will be made.
  ➡reduce background which mimic signals.
- Electronic polishing to remove copper surface RI.
- And so on.
- The next run will start in summer 2013.



# Expected sensitivity with fiducialization

Spin Independent



# Summary

- XMASS construction and operation is done with 835kg liquid xenon.
  - Best photon yield (14.7pe/keVee)
  - Low mass WIMP search/solar axion search are carried out.
  - Detector refurbishment and software improvement is ongoing. The next run will start in summer 2013.

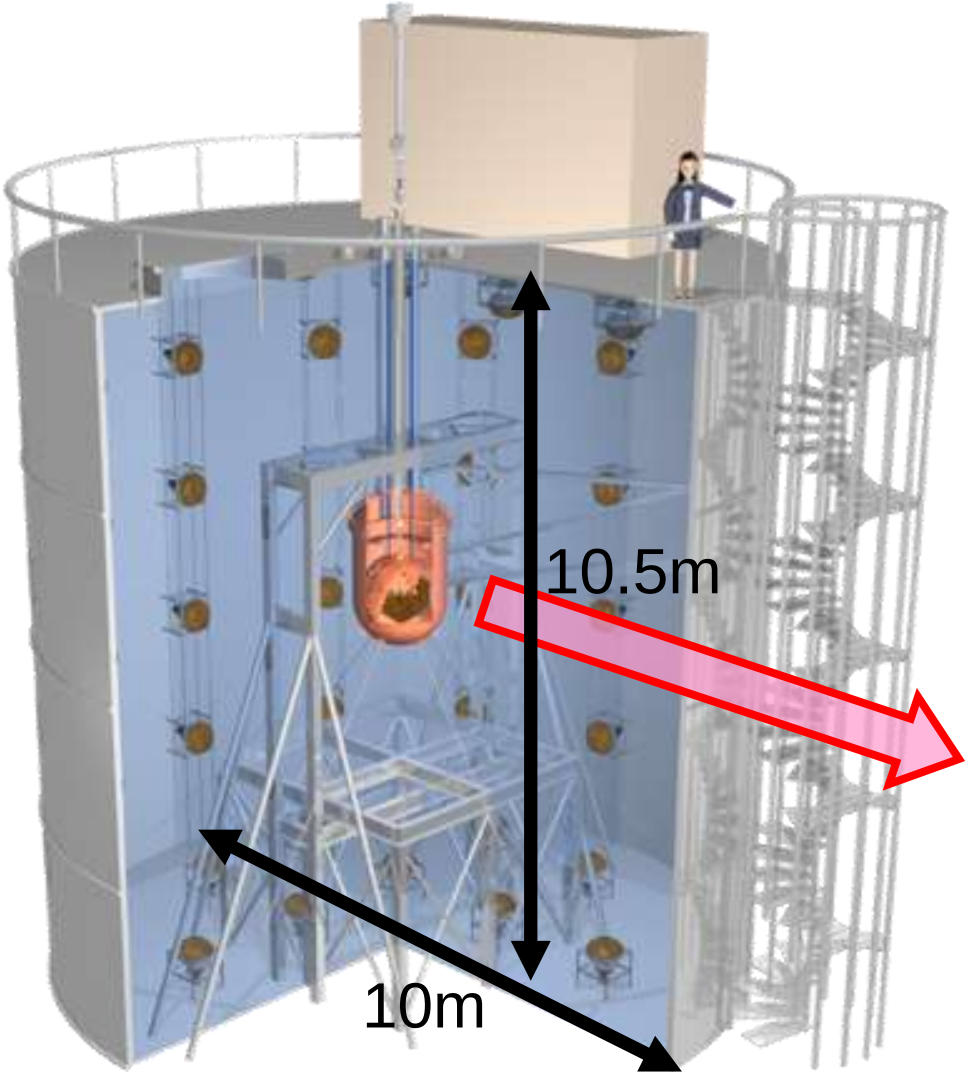
# Backup

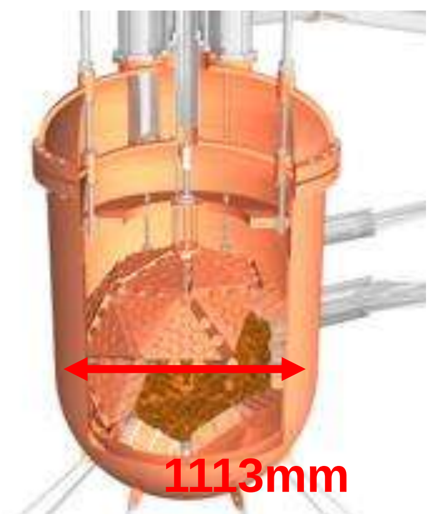
# XMASS collaboration

| | |
|---|---|
| **ICRR, University of Tokyo** | K. Abe, K. Hieda, K. Hiraide, Y. Kishimoto, K. Kobayashi, S. Moriyama, K. Nakagawa, M. Nakahata, N. Oka, H. Ogawa, H. Sekiya, A. Shinozaki, Y. Suzuki, O. Takachio, A. Takeda, D. Umemoto, M. Yamashita, B. Yang |
| **Kavli IPMU, University of Tokyo** | J. Liu, K. Martens |
| **Kobe University** | K. Hosokawa, K. Miuchi, A. Murata, Y. Ohnishi, Y. Takeuchi |
| **Tokai University** | F. Kusaba, K. Nishijima |
| **Gifu University** | S. Tasaka |
| **Yokohama National University** | K. Fujii, I. Murayama, S. Nakamura |
| **Miyagi University of Education** | Y. Fukuda |
| **STEL, Nagoya University** | Y. Itow, K. Masuda, H. Takiya, H. Uchida |
| **Sejong University** | N.Y. Kim, Y. D. Kim |
| **KRISS** | Y. H. Kim, M. K. Lee, K. B. Lee, J. S. Lee |

# Detector

- 72 20-inch PMTs : to veto cosmic-ray muon (<$10^{-6}$ for thr-mu, $10^{-4}$ for stop-mu).
- Water : active shield for muon induced neutron and also passive shield for gamma-ray and neutron from rock/wall.
- IVC and OVC : made of OFHC (Oxygen-free high thermal conductivity) copper



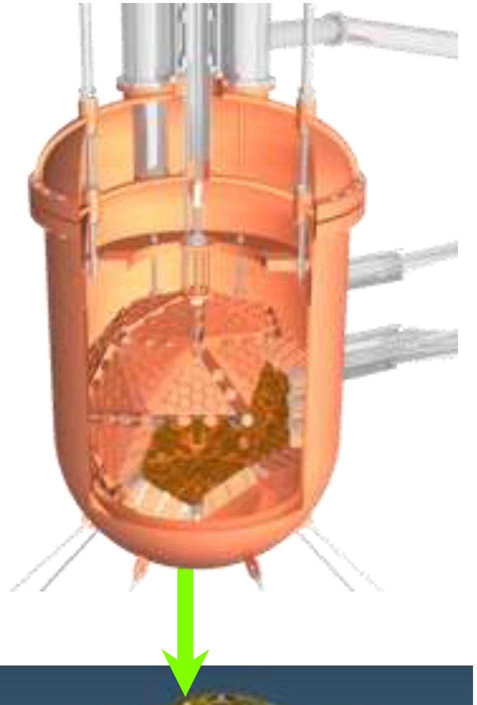



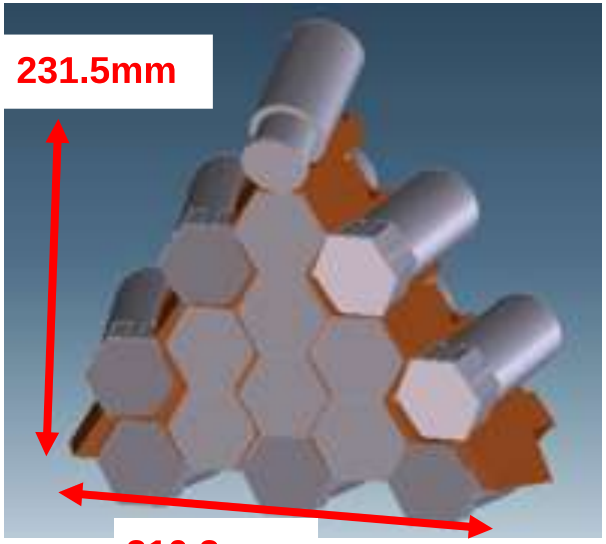


OVC
(Outer Vacuum Chamber)

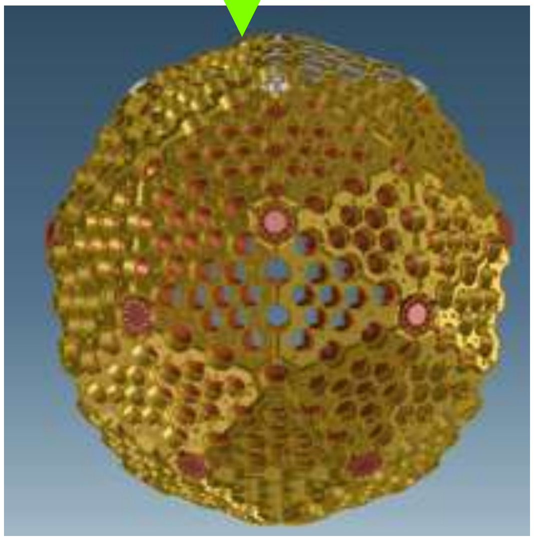

IVC
(Inner Vacuum Chamber)

# Detector design detail






pentakisdodecahedron



Hexagonal PMT
Hamamatsu R10789

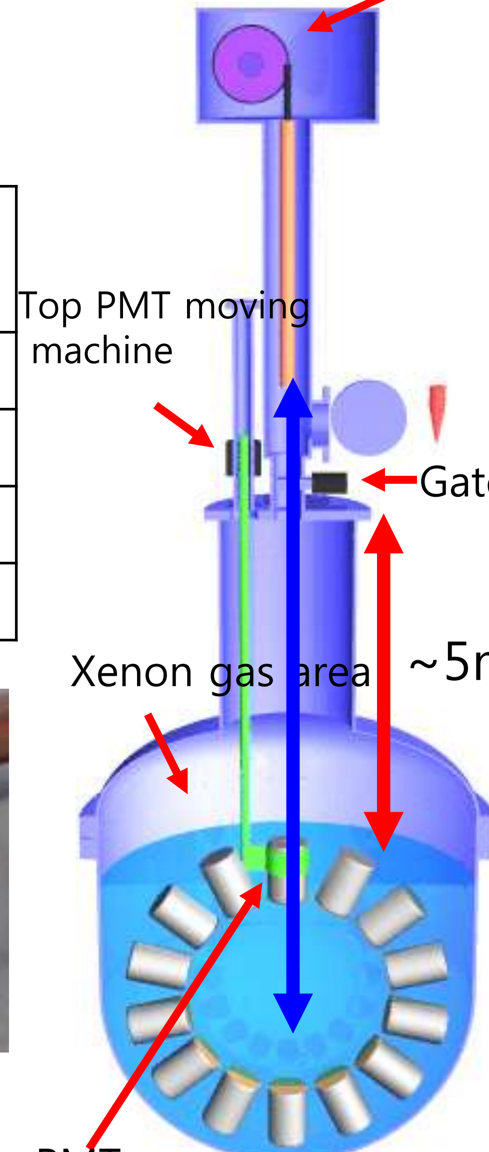
- 60 triangles
- Total: 642PMTs
- Photo coverage: 62%
- Diameter: ~800mm

XMASS detector,
K. Abe et al, arXiv:1301.2815

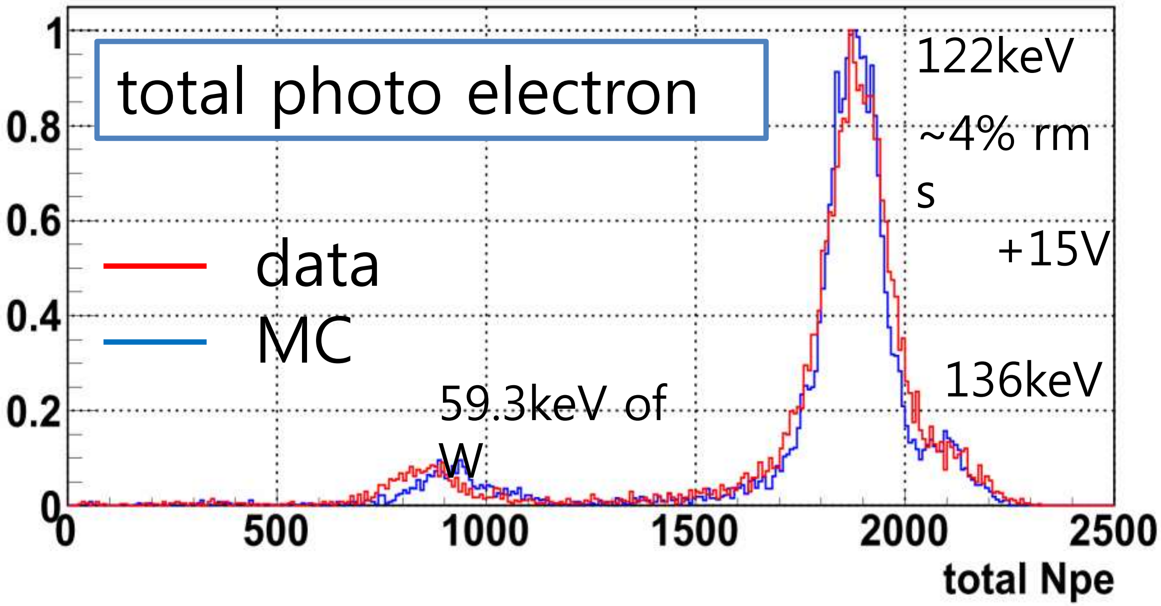
# Calibration system

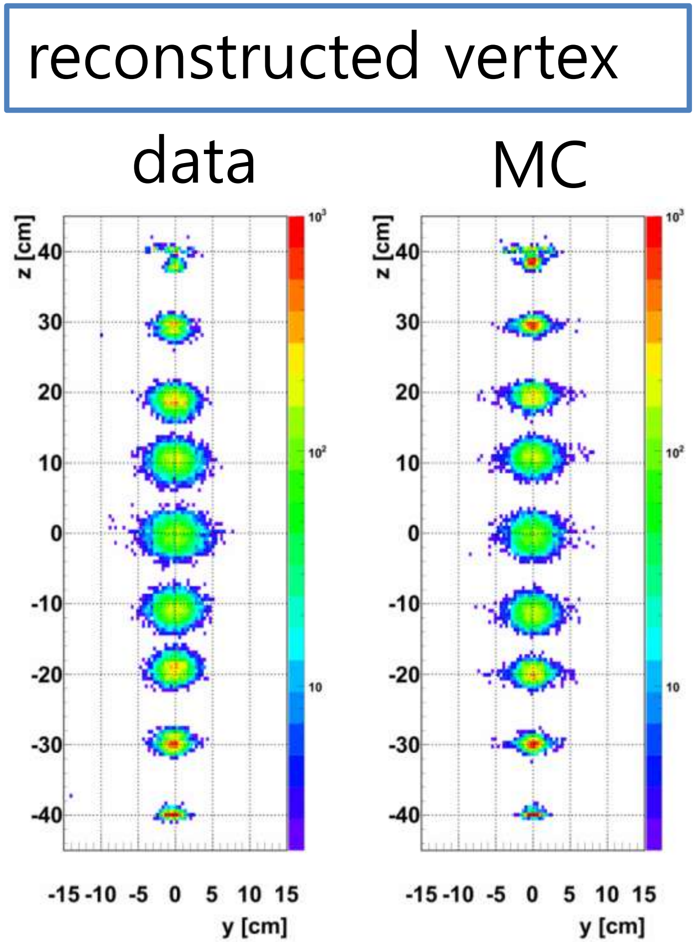
## RI sources

| | energy [keV] | RI | φ [mm] | package |
|---|---|---|---|---|
| (1) Fe-55 | 5.9 | 350 | 5 | brass |
| (2) Cd-109 | 22, 25, 88 | 800 | 5 | brass |
| (3) Am-241 | 59.5 | 485 | 0.15 | SUS |
| (4) Co-57 | 122 | 100 | 0.21 | SUS |

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



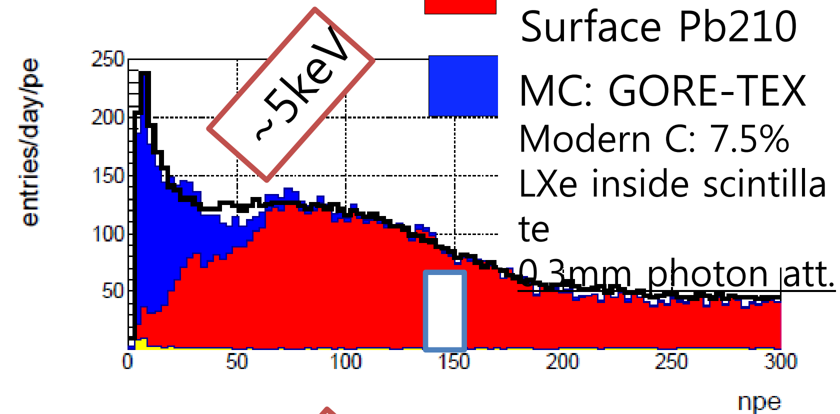



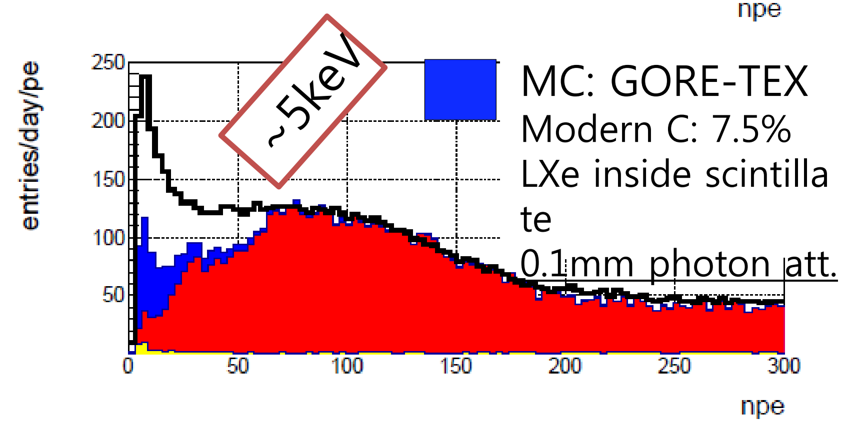

- $^{57}$Co source @ center gives a typical response of the detector.
- 14.7p.e./keV$_{ee}$ (⇔ 2.2 for S1 in XENON100)
- The pe dist. well as vertex dist. were reproduced by a simulation well.
- Signals would be <150p.e. exp shape.

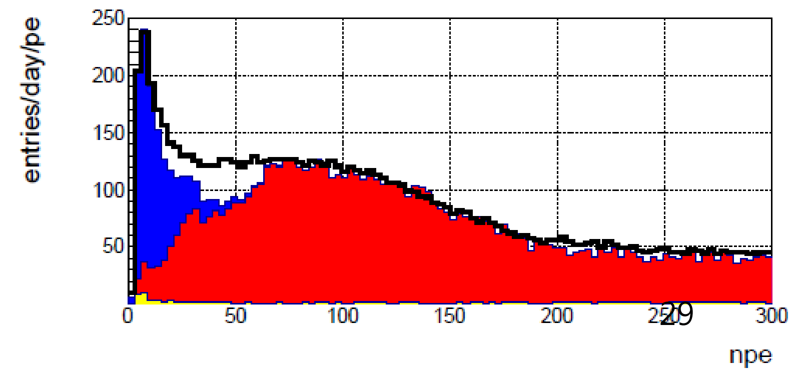
# background contribution to NPE spect

— data

MC: Aluminum Surface Pb210

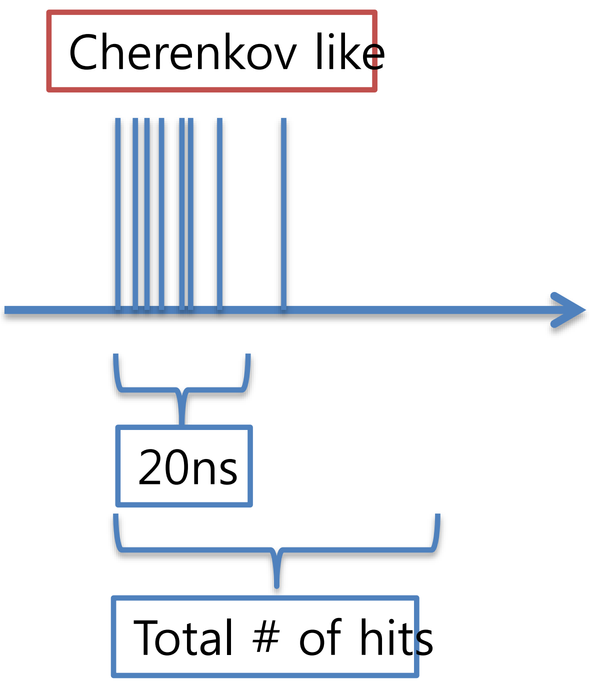


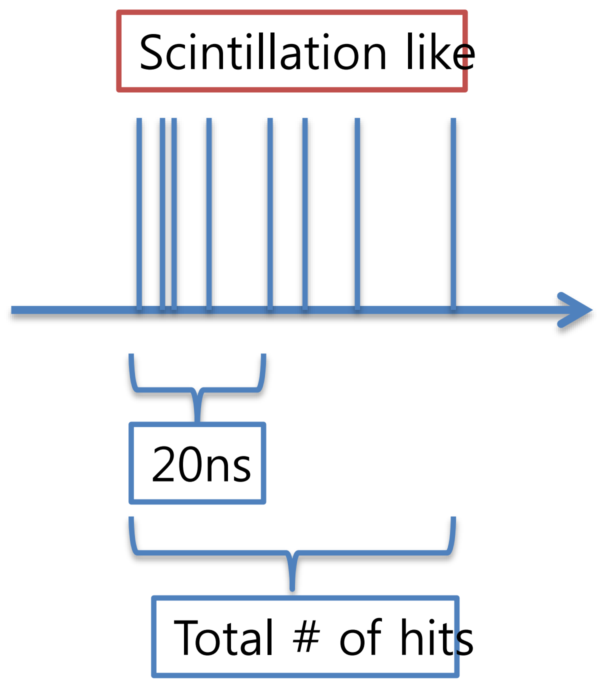



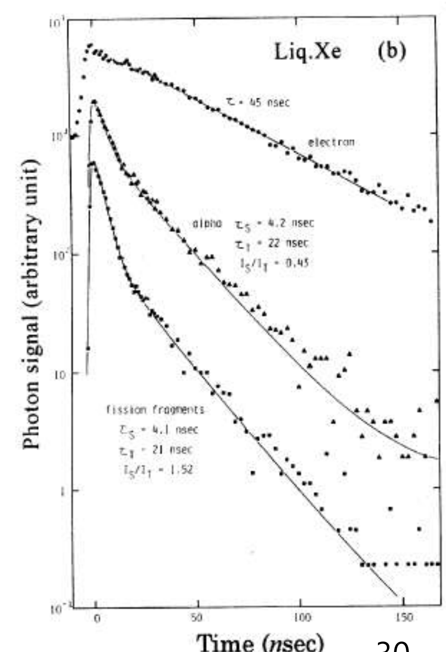



# Detail of the Cherenkov rejection

- Basically, separation between scintillation lights and Cherenkov lights can done using timing profile.
- (# of hits in 20ns window) / (total # of hits) = “head total ratio” is a good parameter for the separation.



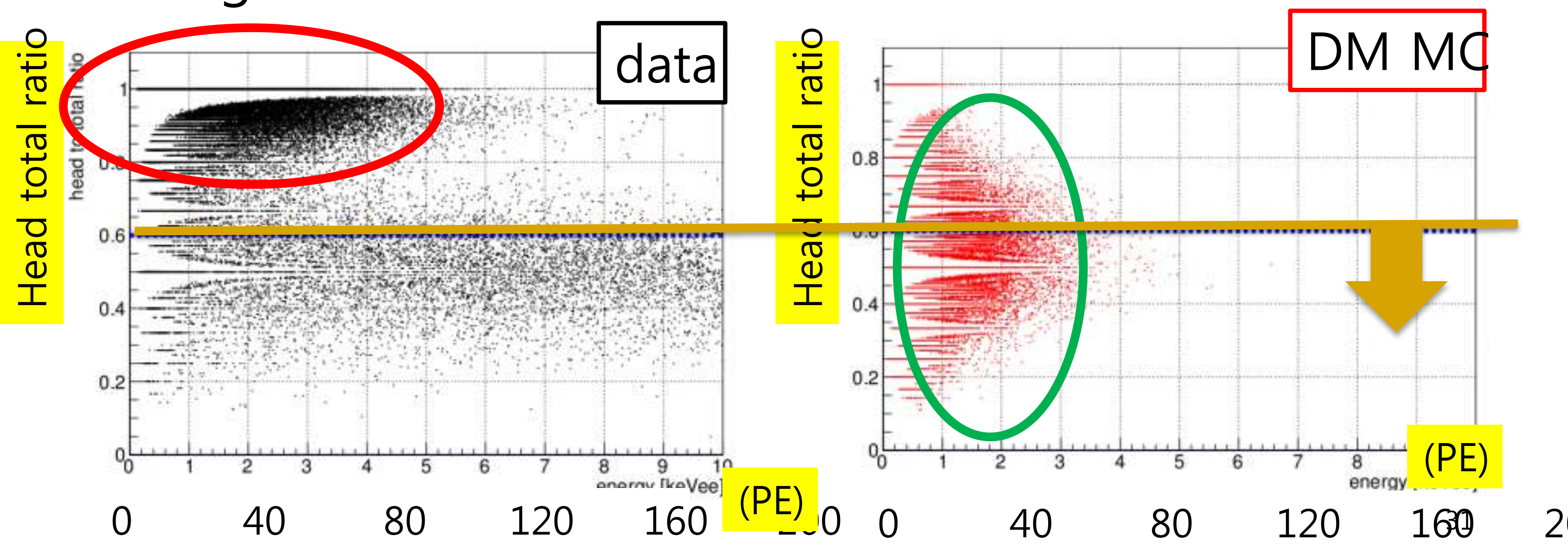






A. Hitachi et al., Phys. Rev. B 27 (1983) 5279.

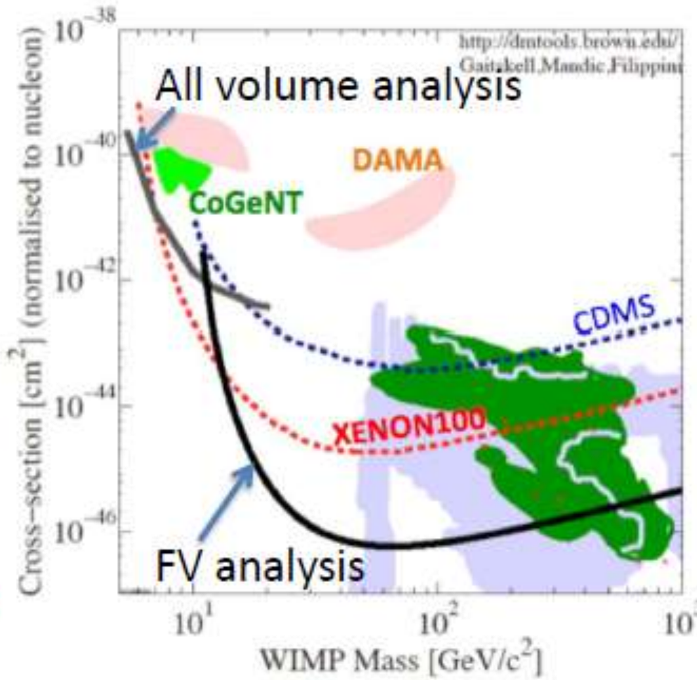
# "head total ratio" distribution

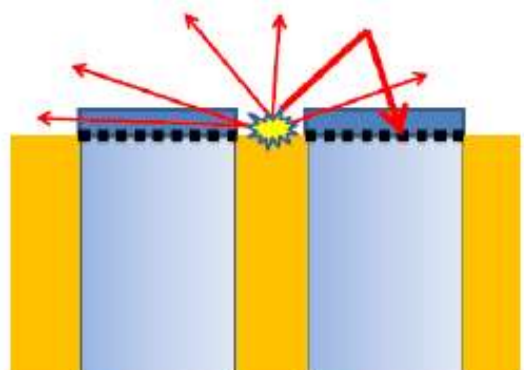
- Cherenkov events peaks around 1 ⇔ scintillation ~ 0.5
- Low energy events observed in Fe55 calibration source as well as DM simulation (t=25ns) show similar distributions.
- Efficiency ranges from 40% to 70% depending on the p.e. range.

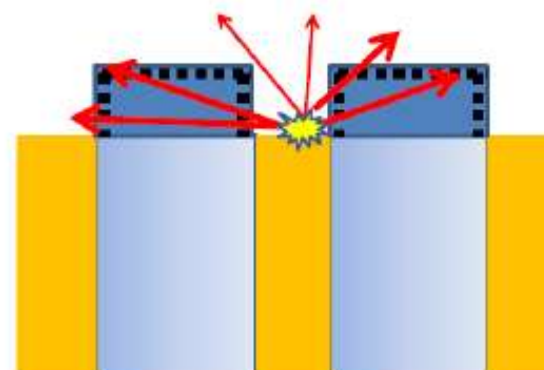


# XMASS 1.5 as a next step

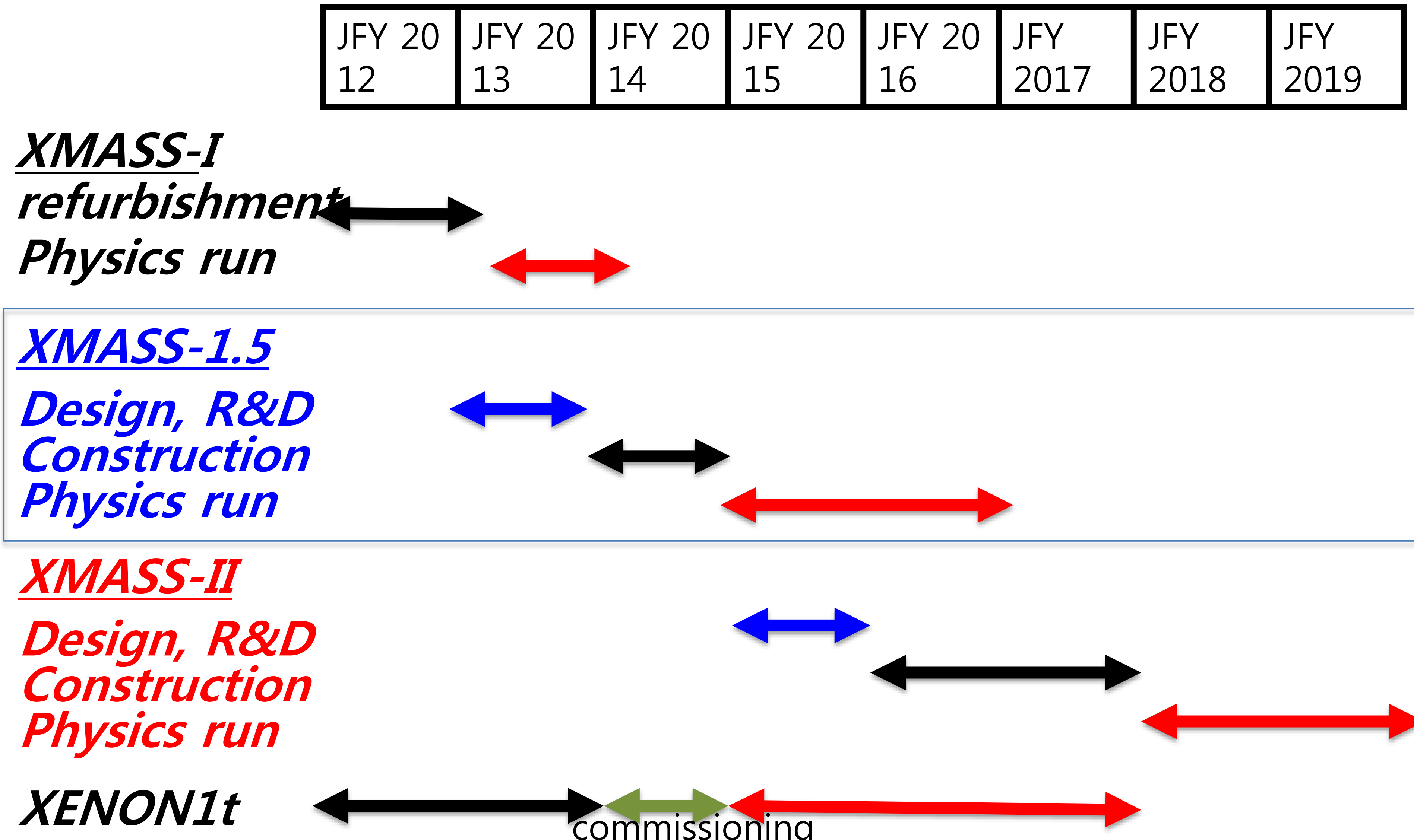
- Larger detectors have many advantages. 1t FV (5t total).
- We can use U-free Al in hand.
- Surface BG must be controlled.
- New PMTs being developed help to identify surface events.





# schedule


JFY 2012
JFY 2013
JFY 2014
JFY 2015
JFY 2016
JFY 2017
JFY 2018
JFY 2019
XMASS-I
refurbishment
Physics run
XMASS-1.5
Design, R&D
Construction
Physics run
XMASS-II
Design, R&D
Construction
Physics run
XENON1t
commissioning