XMASS experiment

S. Moriyama, spokesperson of XMASS experiment

May 15, 2019 @ external review committee, ICRR

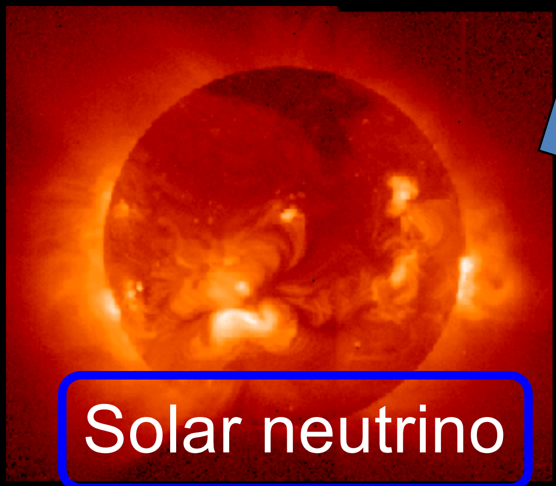
XMASS experiment

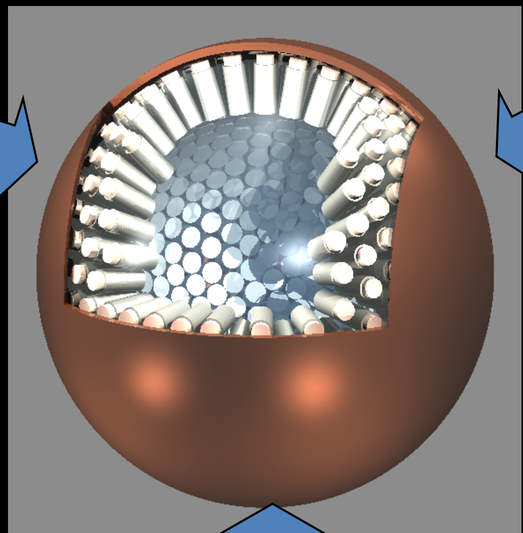
● XMASS

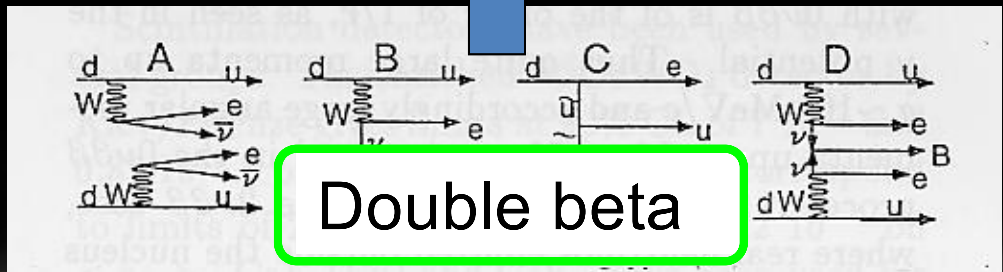
◎ **Xenon MASSive detector for Solar neutrino (pp/^{7}Be)**

◎ **Xenon neutrino MASS detector (double beta decay)**

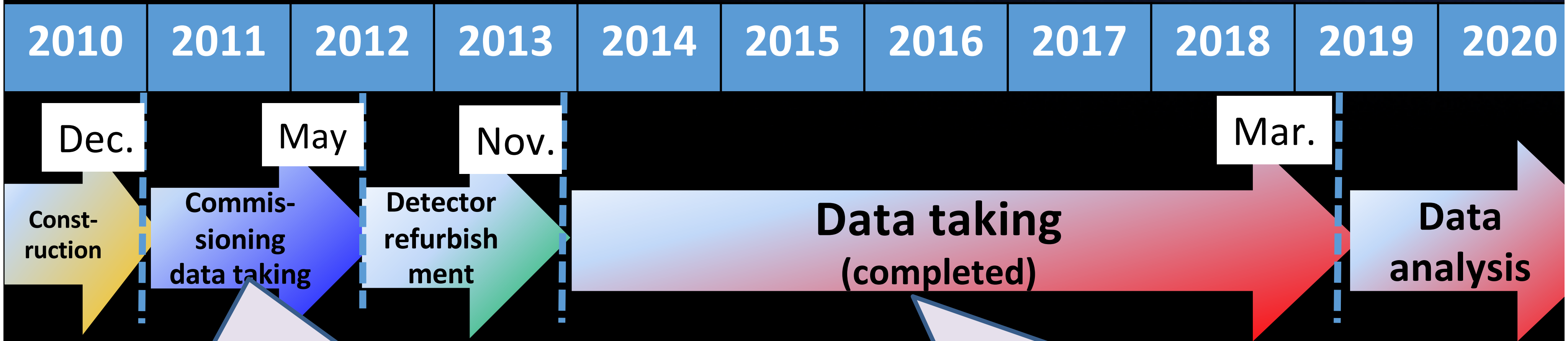
◎ **Xenon detector for Weakly Interacting MASSive Particles (DM)**







History of XMASS-I



- Light WIMPs
- WIMP-^{129}Xe inelastic scattering
- Bosonic super-WIMPs
- Solar axion
- ^{124}Xe 2ν double electron capture

- Annual modulation
- Hidden photons/ALPs DM
- ^{124}Xe 2ν double electron capture
- Solar Kaluza-Klein axion
- WIMPs search by fiducialization

With 1.5 yrs commissioning data and 5 yrs data, searches for various types of dark matter and unobserved phenomena in nuclear physics and astrophysics were conducted. After the completion of data taking, data analysis is continuing.

The XMASS collaboration

Kamioka Observatory, ICRR, Univ. of Tokyo:
M. Nakahata, S. Moriyama, M. Yamashita,
A. Takeda, K. Abe, H. Sekiya, K. Kobayashi, K. Hiraide
K. Ichimura, S. Tasaka, T. Suzuki, N. Kato, S. Imaizumi, Y. Chen
IPMU, University of Tokyo: Y. Suzuki, K. Martens, A. Mason
Kobe University: Y. Takeuchi, K. Miuchi
Tokai University: K. Nishijima
Yokohama National University: S. Nakamura
Miyagi University of Education: Y. Fukuda
ISEE, Nagoya University: Y. Itow, K. Sato
Tokushima University: K. Fushimi
Nihon University: H. Ogawa
Tohoku University: Y. Kishimoto
KRISS: M.K.Lee, K.B. Lee,
CUP, IBS: Y.D. Kim, Y.N. Kim, Y.H.Kim
CAP, IBS: B.S.Yang, **Tsinghua University:** B.D. Xu

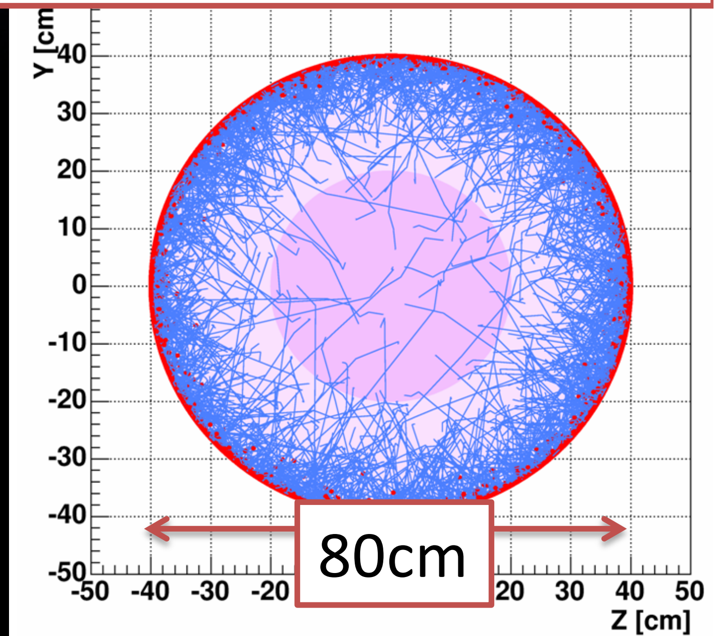
34 collaborators,
14 institutes

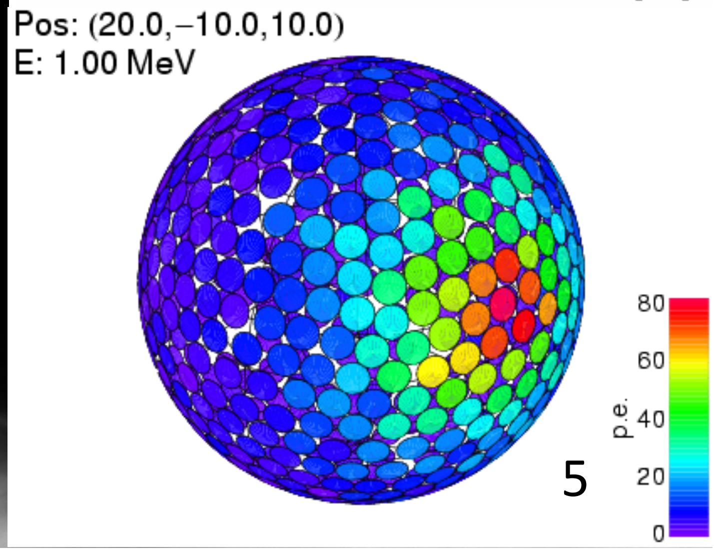
Spokesperson:
S. Moriyama
from Dec. 2016
Y. Suzuki
till Dec. 2016

XMASS-I: single-phase LXe detector

- BG red. by fiducial volume (FV) cut
  - Very large photoelectron yield
    ~ 14.7 p.e./keV ⇔ Super-K ~6 hits/MeV
  - Event reconstruction based on observed hit pattern ~ a few keV.
  - 832 kg in total, 100 kg in r<20 cm FV.
  - Target of a WIMP search ~ $2 \times 10^{-45} cm^2$.
  - Good to search for e/γ events as well.
- Larger det. has better performance.
  - T info useful (scintil. const. 30-40 ns)
  - Better self-shielding for e/γ/n
  - Attenuation >10 m for scintillation light

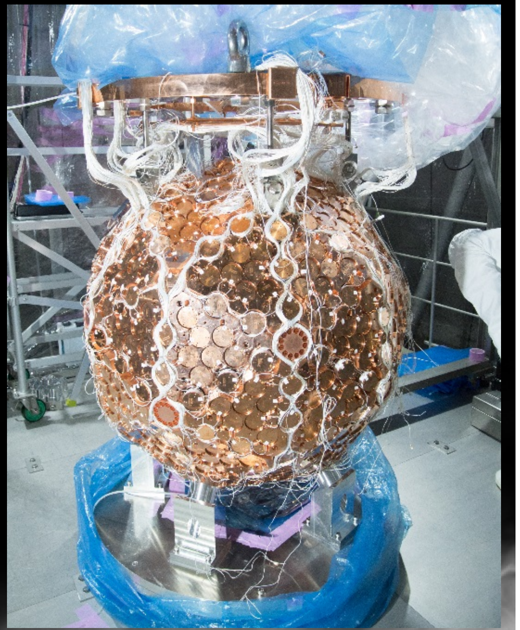
Self shielding for γ injection (XMASS-I)





Refurbishment work

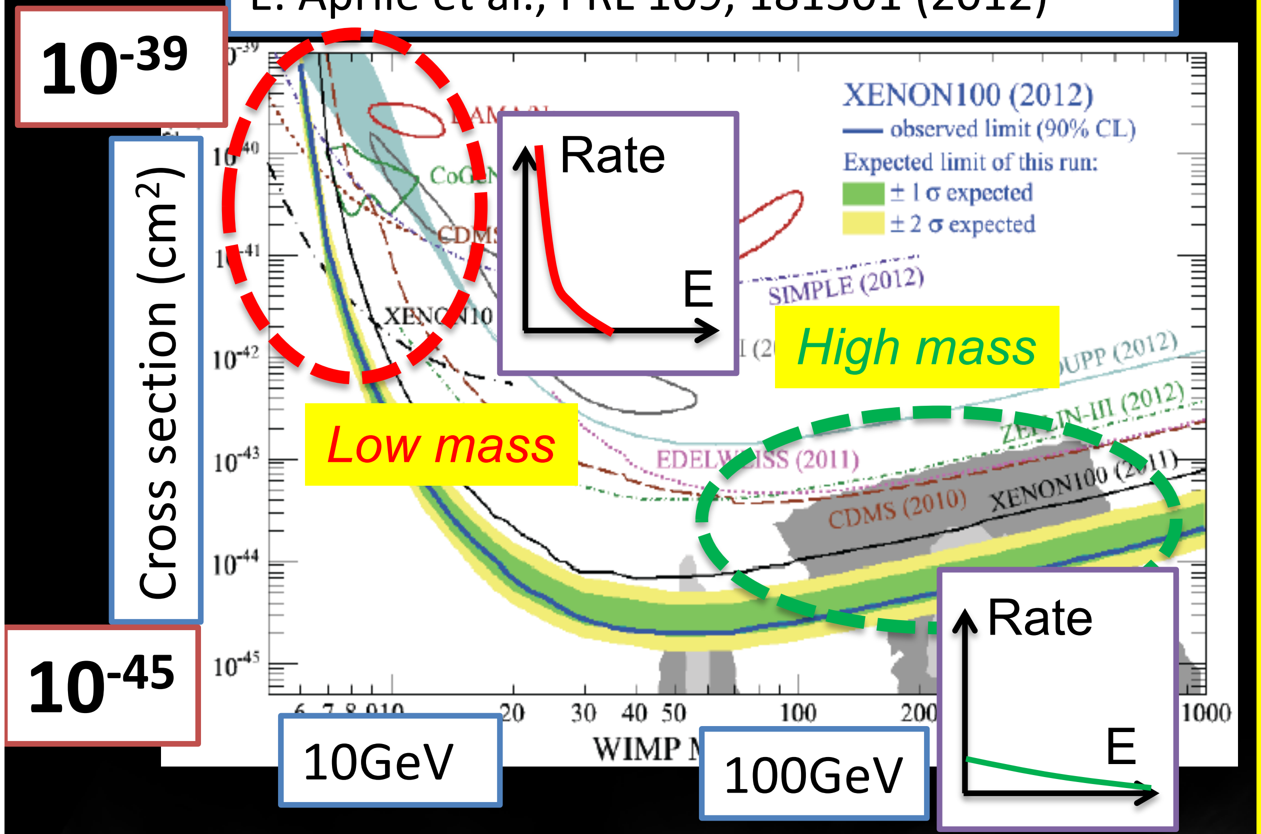
- Radioactivity inside the PMTs’ aluminum seal between quartz window and metal body caused background.
- Copper plates covering that seal were installed.
- Achieved ~1/10 BG reduction in all volume, ~1/100 in FV.



DM search in XMASS-I

- In the past six years, our experimental reach was extended to low mass, high mass, and non- WIMPs.

E. Aprile et al., PRL 109, 181301 (2012)



Non WIMPs

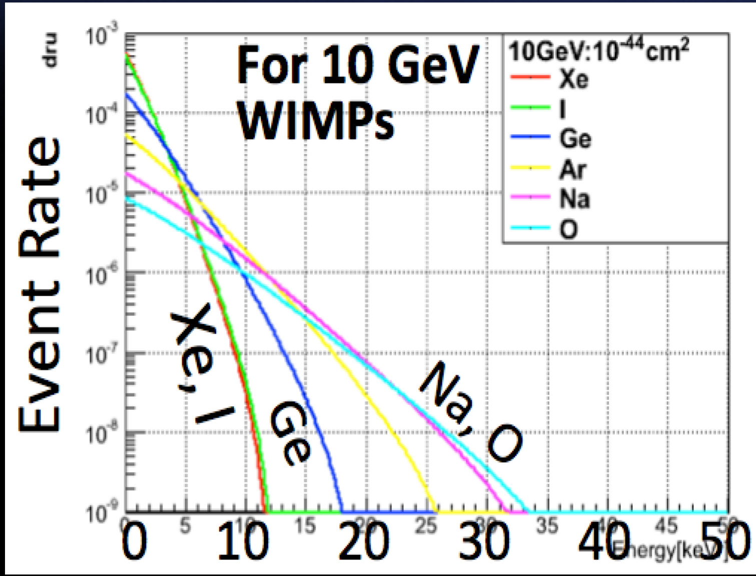
1. Low mass WIMPs
- DAMA/LIBRA indication
  - Annual modulation
- Low E threshold required
  - w/o reconstruction
- Bremsstrahlung/Migdal effect

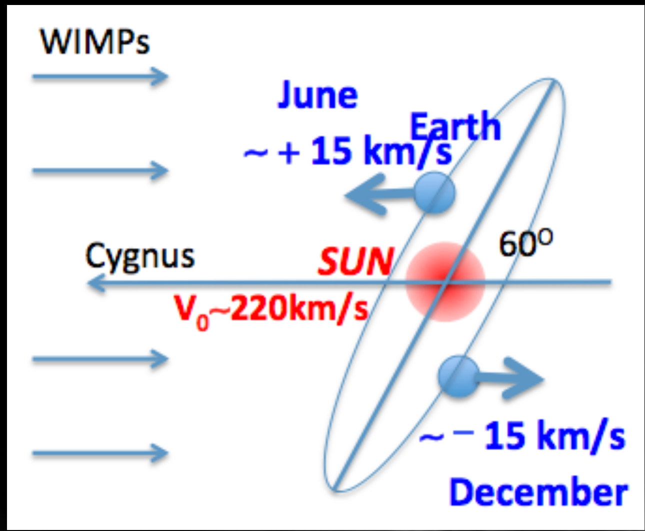
2. High mass WIMPs
- Low background required
  - Reconstruction = fiducialization useful
- Understanding BG necessary

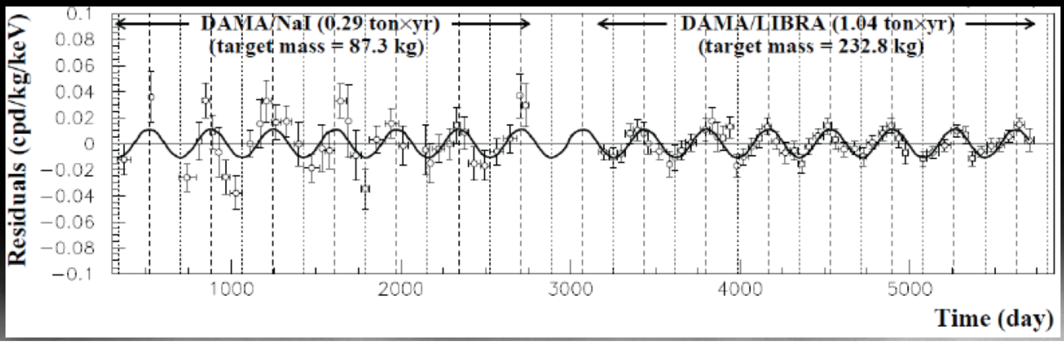
3. Non WIMPs: we pioneered!
- Dark Photon, axion-like particles: kinetic mixing, axioelectric effect.

1. Low mass: annual modulation

- In isothermal halo models, v_{DM}~200-300 km/s and WIMP nuclear recoils have ~ a few keV, low E.
- We are moving relative to their rest frame, the galaxy.
- Stable observation of a WIMP signal over many years should trace this variation.
- Direct check of DAMA/LIBRA “results”

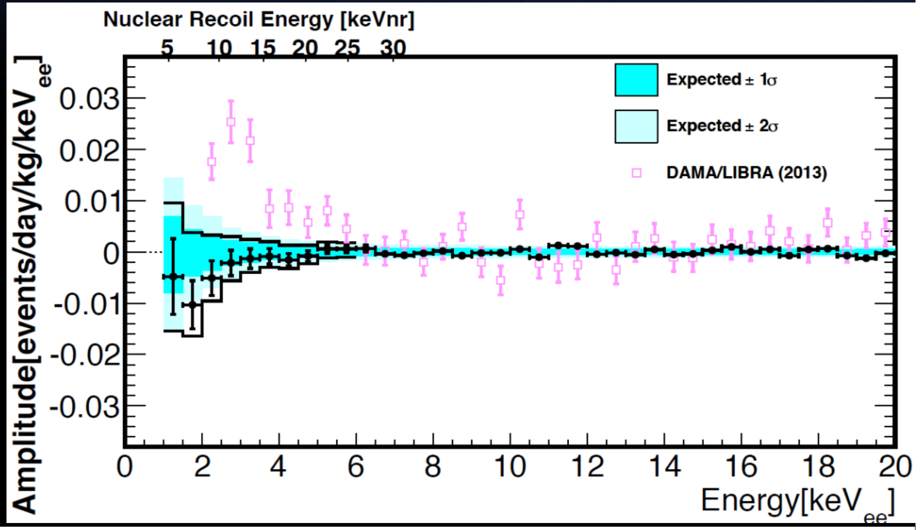


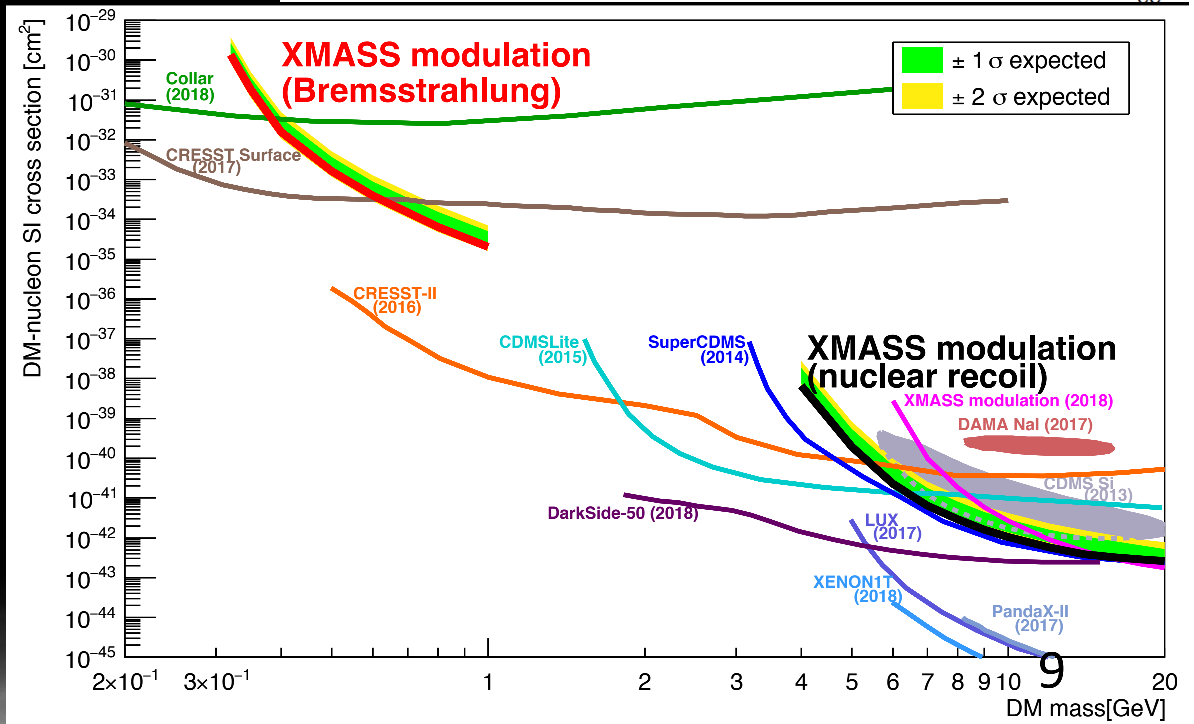




1. Low mass: annual modulation

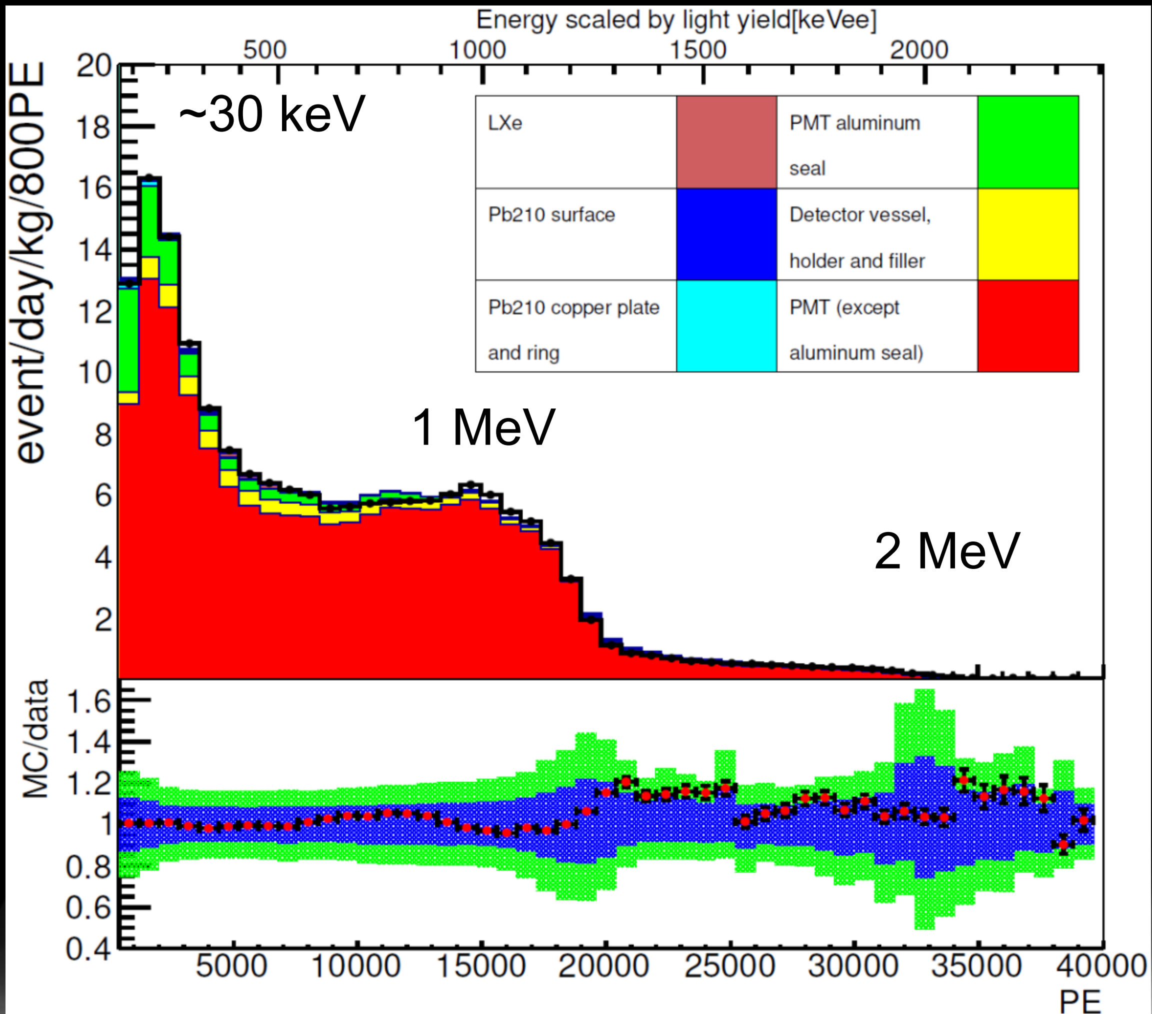
- By looking at modulation amplitudes in individual energy bins, XMASS would see this modulation regardless of the nature of the recoil (nuclear/electron).
- 1.82 ton y (XMASS) ⇔ 1.33 ton y (DAMA)
- Brems. Effect: search for sub-GeV WIMPs
- First direct check using the modulation effect.





2. High mass: fiducialization

- Understanding background is most crucial.
- Background in the whole 832 kg mass & calib data.



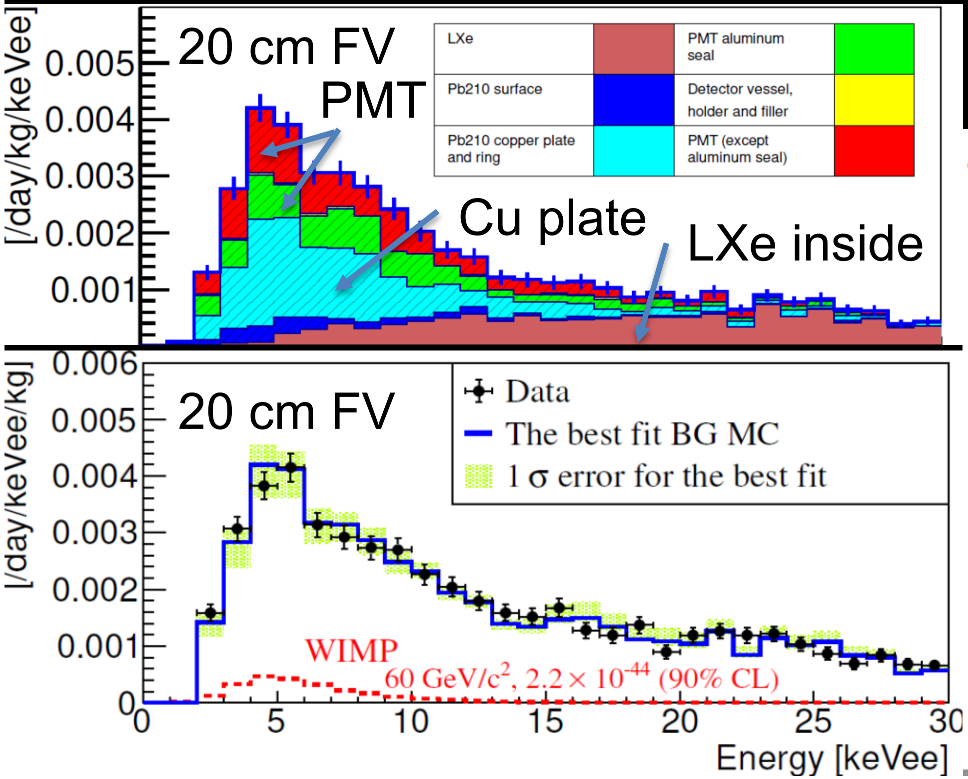
Detailed background modeling & calibration based on

- Ex-situ measurements of detector parts (Ge, ICPMS)
- In-situ measurements of surface activity (α rays, Rn, etc.)
- Inner calibration sources.

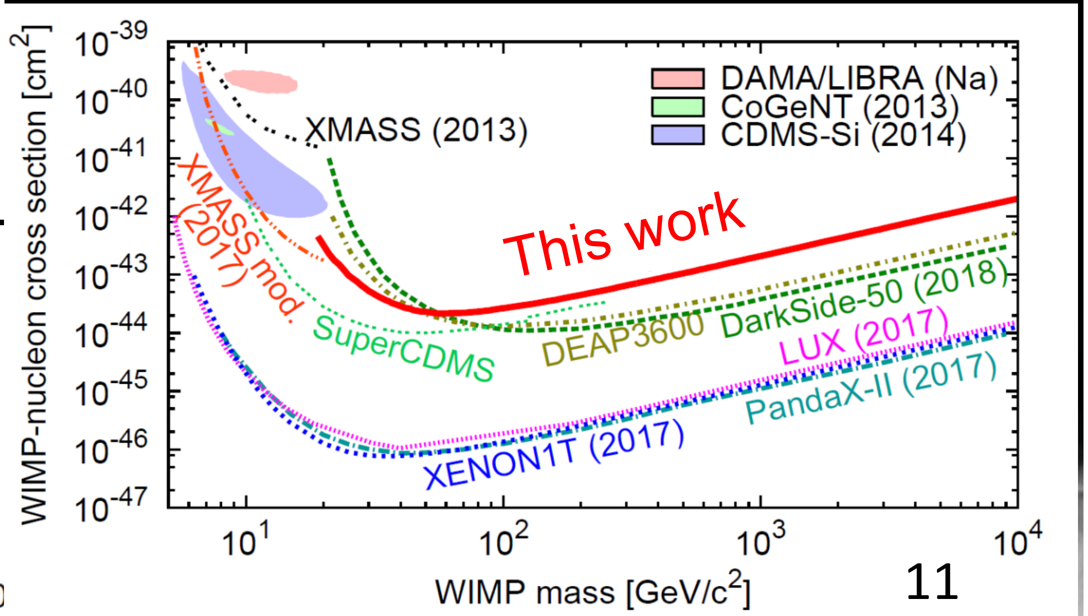
Modeling >30 keV (no DM signal expected) succeeded by fitting energy spectrum including systematic errors on individual activity etc.

2. High mass: fiducialization

- Fiducial mass 97 kg and 706 days data was used to search for an excess above the background energy spectrum.
- Observed energy spectrum was consistent with expected background within systematic errors. Upper limit on cross section: < 2.2×10^{-44} cm^2 @60 GeV (90% C.L.)

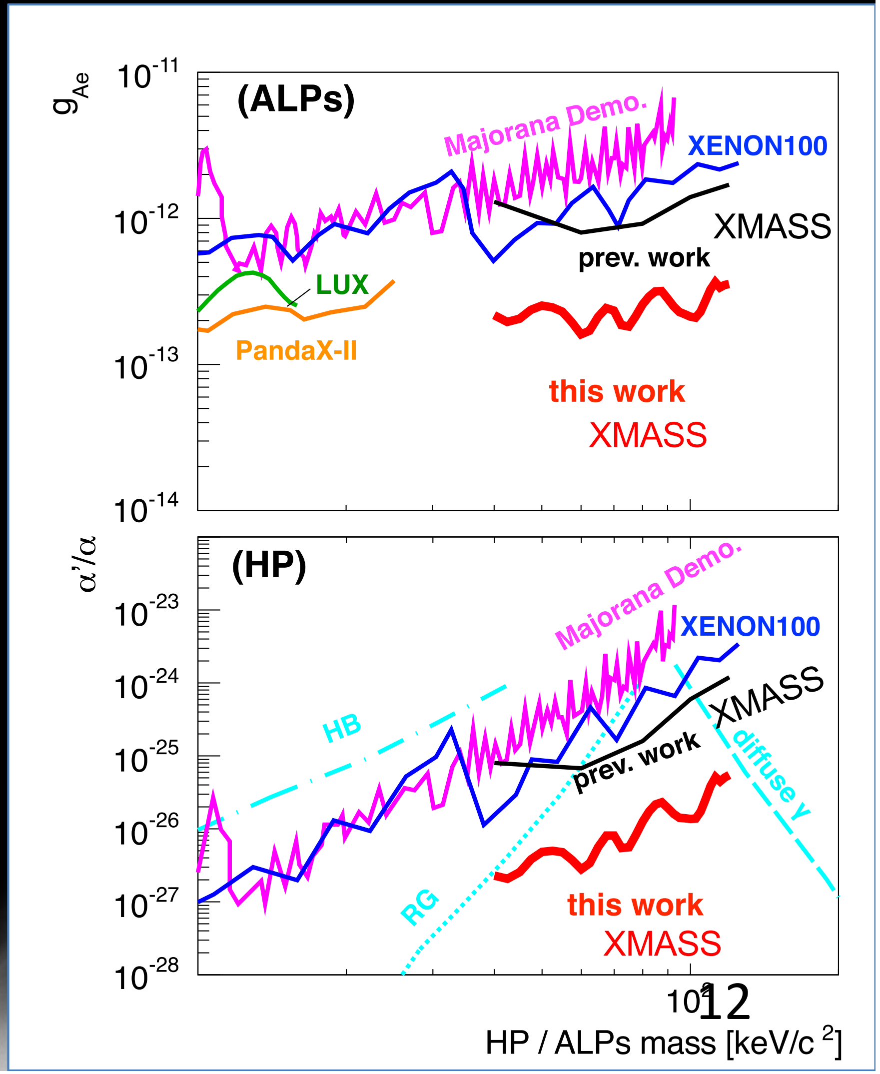


Most stringent limit among results from single-phase liquid xenon detectors.



3. Non WIMPs: Bosonic Super-WIMPs

- WIMP candidates have not been observed in accelerators.
- Cold DM has some issues.
- Lighter DM particles with much weaker int. are good candidates.
- Dark photon, axion like particles are leading candidates.
- Astrophysical constraints weak.
- A peak in E spec@m_{DM} expected.
- Our PRL paper got Editors' Suggestion.

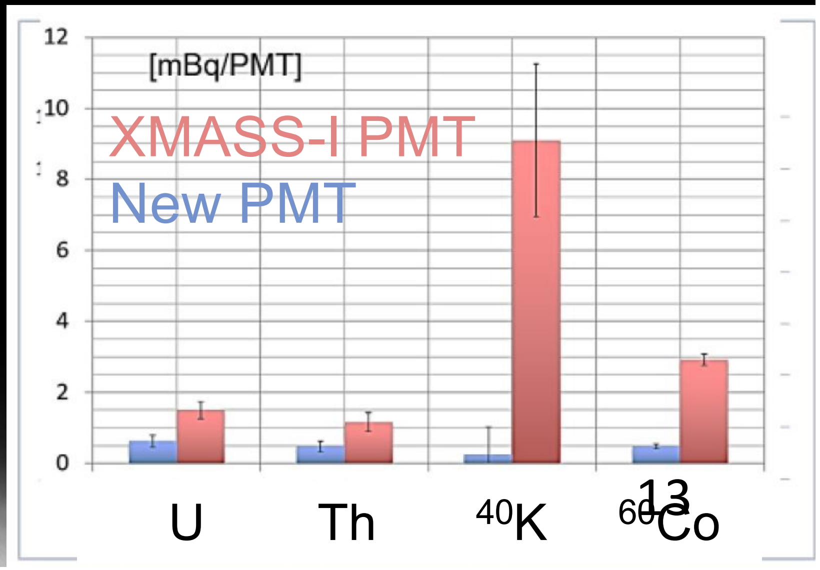


Development of low BG techniques

- Surface alpha ray counter: world best
  - Surface contamination (Rn daughters) are common BG source among DM detectors.

First time to operate underground
~ 1x10^{-5} α/cm^2/hr achieved w/ our efforts ⇔
Common α-ray counter: ~1x10^{-3} α/cm^2/hr
Even bulk contamination can be measured.

- New low BG photosensors: future applications
  - Lower RI
  - Better shape to catch photons



Publications (DM, Nucl. Phys., Tech.)

"Distillation of Liquid Xenon to Remove Krypton," Astopart. Phys. 31 (2009) 290.

"Scintillation-only Based Pulse Shape Discrimination for Nuclear and Electron Recoils in Liquid Xenon," Nucl. Instrum. Meth. A659 (2011) 161.

"Radon removal from gaseous xenon with activated charcoal," Nucl. Instrum. Meth. A661 (2012) 50.

"Light WIMP search in XMASS," Phys. Lett. B719 (2013) 78.

"Search for solar axions in XMASS, a large liquid-xenon detector," Phys. Lett. B724 (2013) 46.

"XMASS detector," Nucl. Instrum. Meth. A716 (2013) 78.

"Search for inelastic WIMP nucleus scattering on ^{129}Xe in data from the XMASS-I experiment," PTEP 2014 (2014) 063C01.

"Search for bosonic superweakly interacting massive dark matter particles with the XMASS-I detector," Phys. Rev. Lett. 113 (2014) 121301.

"Micro-source development for XMASS experiment," Nucl. Instrum. Meth. A784 (2015) 499.

"Search for two-neutrino double electron capture on ^{124}Xe with the XMASS-I detector," Phys. Lett. B759 (2016) 64.

"Direct dark matter search by annual modulation in XMASS-I," Phys. Lett. B759 (2016) 272.

"A measurement of the time profile of scintillation induced by low energy gamma-rays in liquid xenon with the XMASS-I detector," Nucl. Instrum. Meth. A834 (2016) 192.

"Detectability of galactic supernova neutrinos coherently scattered on xenon nuclei in XMASS," Astropart. Phys. 89 (2017) 51.

"Search for solar Kaluza-Klein axion by annual modulation with the XMASS-I detector," PTEP 2017 (2017) 103C01.

"Identification of ^{210}Pb and ^{210}Po in the bulk of copper samples with a low-background alpha particle counter," Nucl. Instrum. Meth. A884 (2018) 157.

"Improved search for two-neutrino double electron capture on ^{124}Xe and ^{126}Xe using particle identification in XMASS-I," PTEP 2018 (2018) 053D03.

"Direct dark matter search by annual modulation with 2.7 years of XMASS-I data," Phys. Rev. D97 (2018) 102006.

"A direct dark matter search in XMASS-I," arXiv:1804.02180 [astro-ph.CO], accepted for publication in Phys. Lett. B.

"Search for dark matter in the form of hidden photons and axion-like particles in the XMASS detector," Phys. Lett. B787 (2018) 153.

"Development of low radioactivity photomultiplier tubes for the XMASS-I detector," arXiv:1808.03617 [physics.ins-det].

"Search for sub-GeV dark matter by annual modulation using XMASS-I detector," arXiv:1808.06177 [astro-ph.CO].

"Search for WIMP-^{129}Xe inelastic scattering with particle identification in XMASS-I," arXiv:1809.05358 [astro-ph.CO].

22 papers published so far.
Still increasing.

Activity towards a future direct DM search

- We planned to construct a larger detector, XMASS-1.5. However, we concluded that it was not competitive anymore.
  - The primary reason was that the background due to e scattering by low E solar ν is difficult to distinguish from a WIMP signal.
  - Dual phase detectors were already approved for construction.
- We aim for a future, more sensitive, third generation detector (G3) and in the meantime to collaborate with a competitor building a multi-ton G2 detector.
- This plan was submitted to the future project committee in ICRR.
- The committee agreed that XMASS-1.5 was not competitive with other contemporary projects and accepted this change of our plan for the future. It also recognized participation in one of the G2 experiments, in particular the XENONnT experiment, as appropriate.

Summary of the past six years

- We have completed XMASS-I data taking.
- Using >5 yrs data, various types of DM candidates were searched for. Heavy WIMPs $\sigma_{SI} < 2.2 \times 10^{-44} cm^2$.
- Nuclear physics, axions, and neutrino physics were studied using the XMASS-I dark matter detector.
- Cutting edge low BG tech. development continues.
- New activity towards a discovery of dark matter particles was initiated and is ongoing.
- XMASS data analysis continues. Hints of new physics are waiting to be discovered.