XMASS

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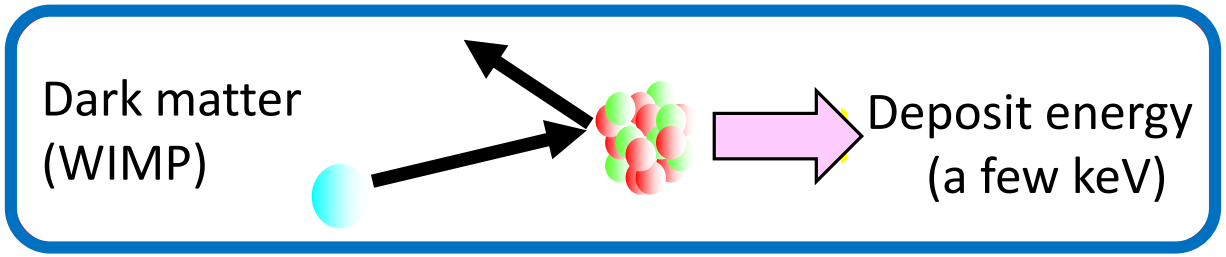
HPNP2015

Outline

- Introduction
  - Introduction of direct detection of dark matter
  - Current status of direct searches
- The XMASS project
  - Results from XMASS-I commissioning data-taking
  - Refurbishment of the XMASS-I detector and current status
  - Next step: XMASS-1.5
- Summary

Direct detection of dark matter (1/2)

Weekly Interacting Massive Particles (WIMPs) elastically scatter off nuclei in target material, producing nuclear recoils.



Event rate

$$\frac{dR}{dE_R} = \frac{R_0 F^2(E_R)}{E_0 r} \frac{k_0}{k} \frac{1}{2\pi v_0} \int_{v_{min}}^{v_{max}} \frac{1}{v} f(\mathbf{v}, \mathbf{v_E}) d^3\mathbf{v}$$

$$R_0 = \frac{377}{M_\chi M_N} \left(\frac{\sigma_0}{1\text{pb}}\right) \left(\frac{\rho_D}{0.3\text{GeVc}^{-2}\text{cm}^{-3}}\right) \left(\frac{v_0}{230\text{km s}^{-1}}\right) \text{kg d}^{-1}$$

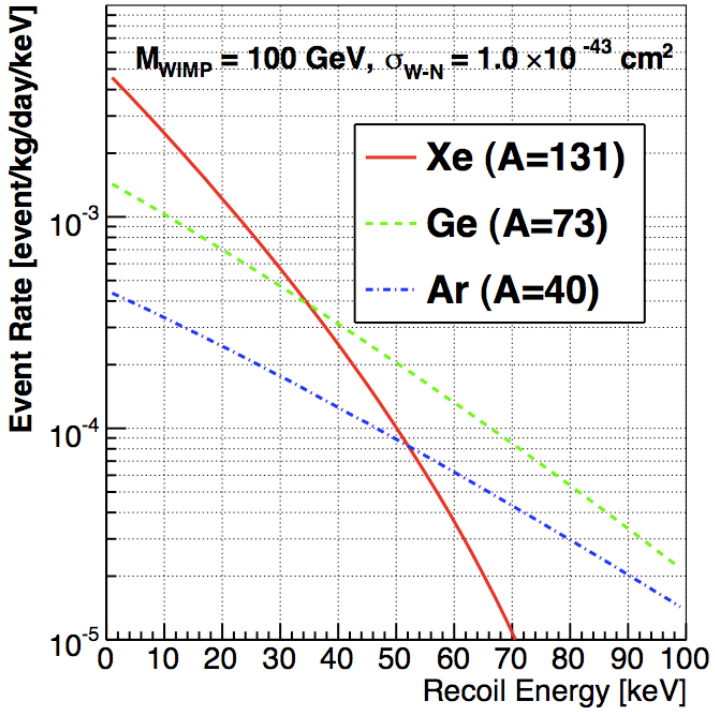
Assume Maxwellian distribution for DM velocity
- v_0 : dispersion
- v: velocity onto target
- v_E: Earth's motion around the Sun

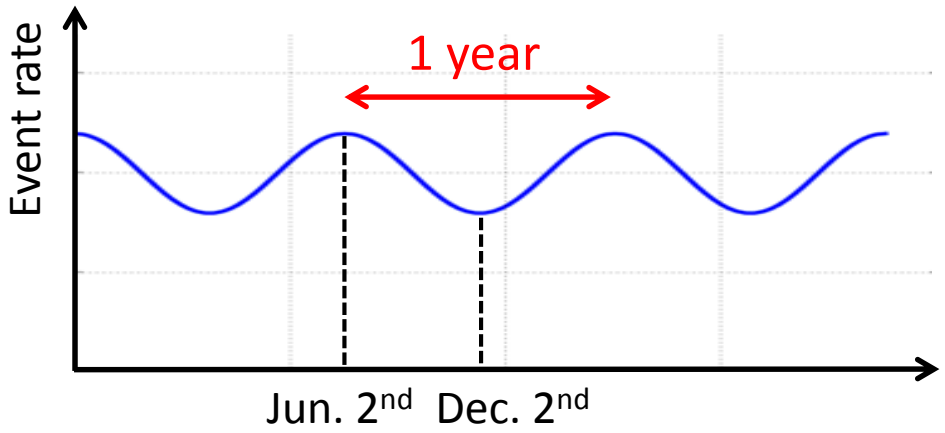
Spin independent case: $\sigma_0 = A^2 \frac{\mu_T^2}{\mu_p^2} \sigma_{\chi-p}$ → Larger A gives higher event rate.

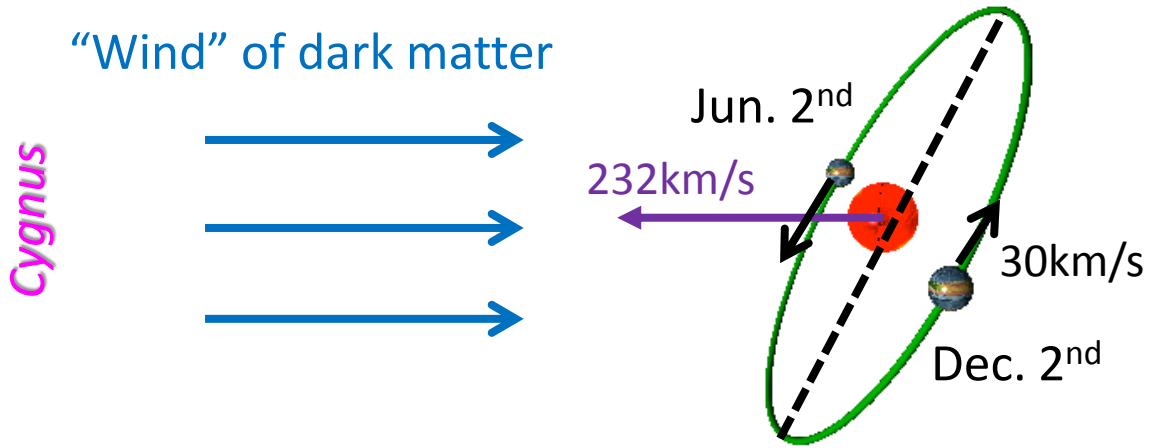
Direct detection of dark matter (2/2)

Experimental signature of dark matter

- Energy spectrum (number of events)
- Seasonal modulation of event rate
- Direction of dark matter “wind”

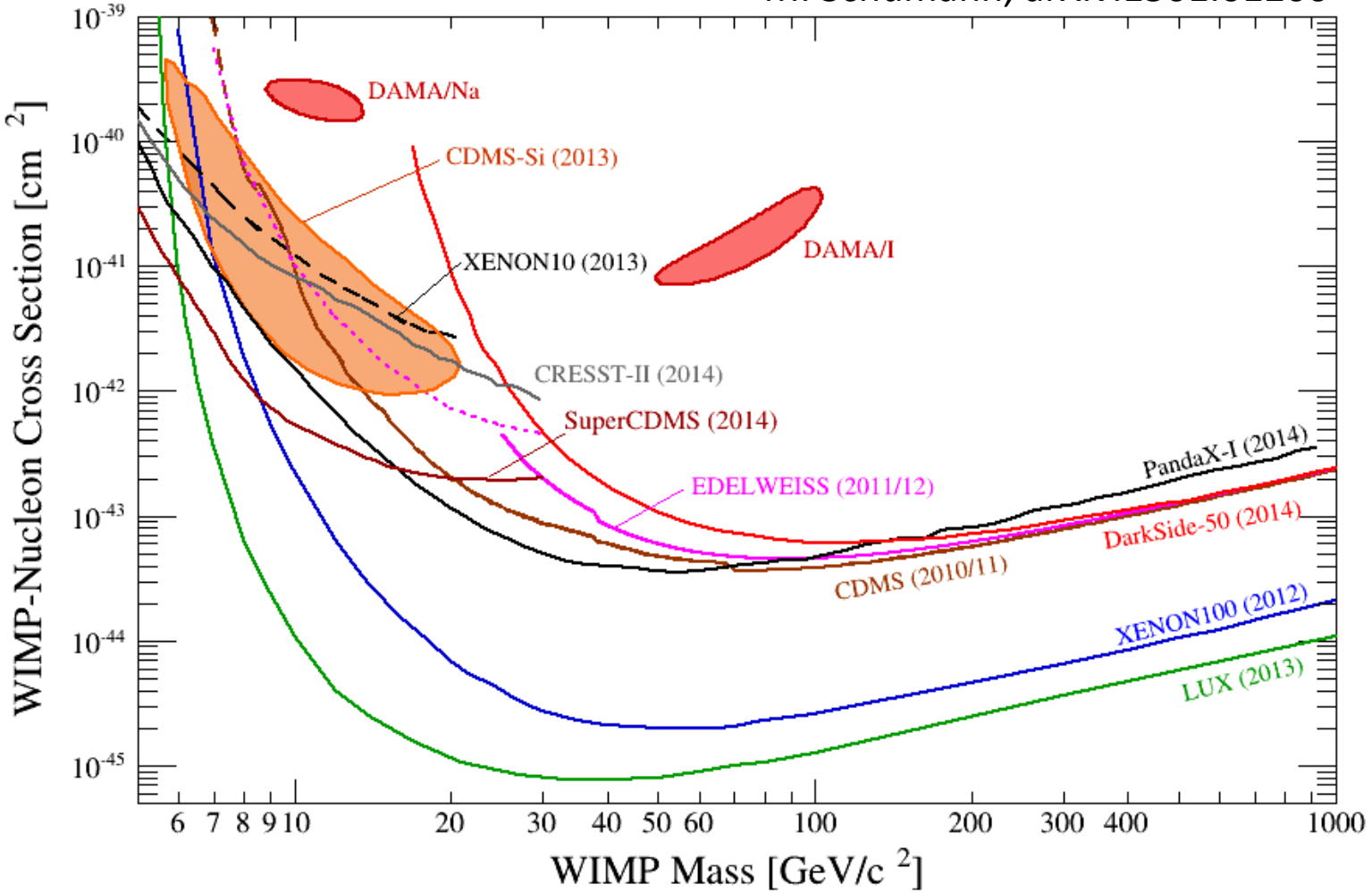






Current status of direct searches

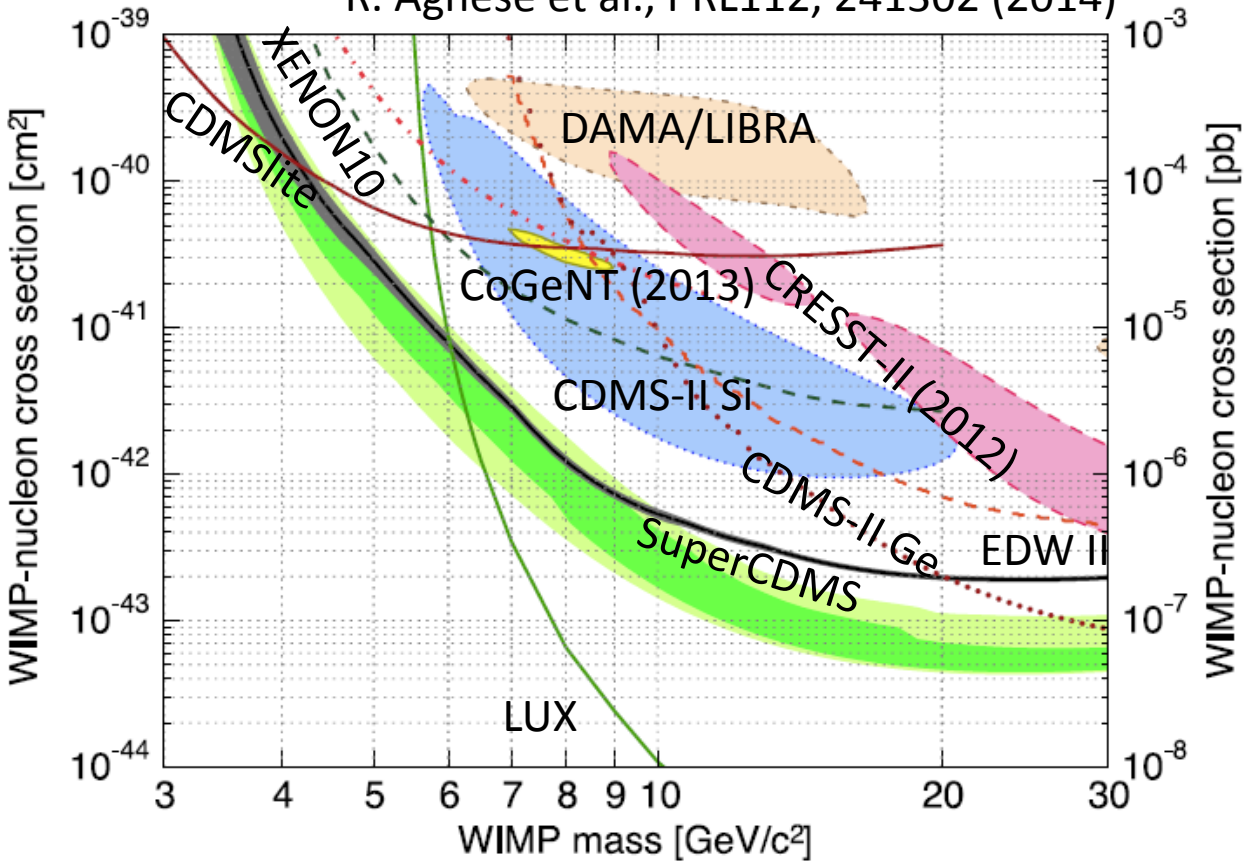
M. Schumann, arXiv:1501.01200



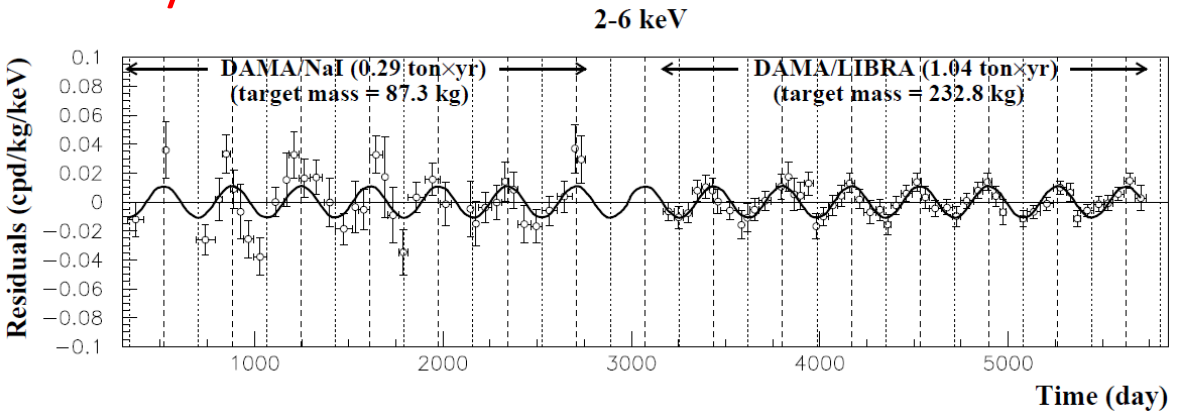
- Results on spin-independent WIMP-nucleon interactions
- The best limit above 6GeV was achieved by the LUX experiment.

Low mass WIMPs

R. Agnese et al., PRL112, 241302 (2014)



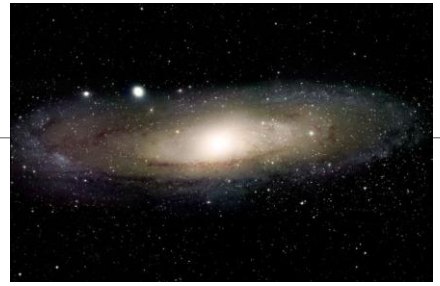
DAMA/LIBRA

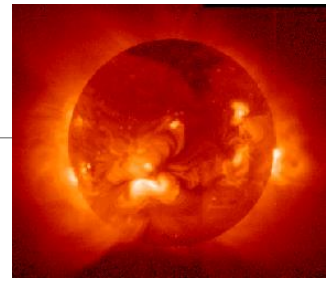


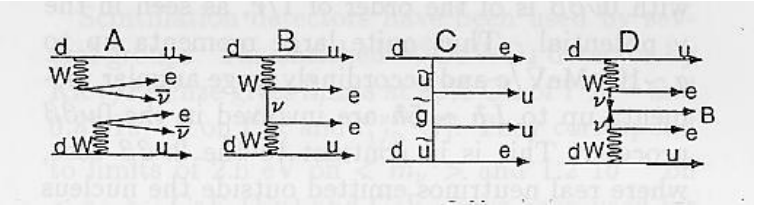
- A new result from CRESST-II doesn't confirm their previously reported excess.
  - G.Angloher et al., Eur. Phys. J. C 74, 3184 (2014).
- The significance of CoGeNT excess becomes <2σ level with the maximum likelihood analysis.
  - C.E. Aalseth et al., arXiv:1401.6234
- DAMA/LIBRA and CDMS-II Si allowed regions remain.

The XMASS project

The XMASS experiment







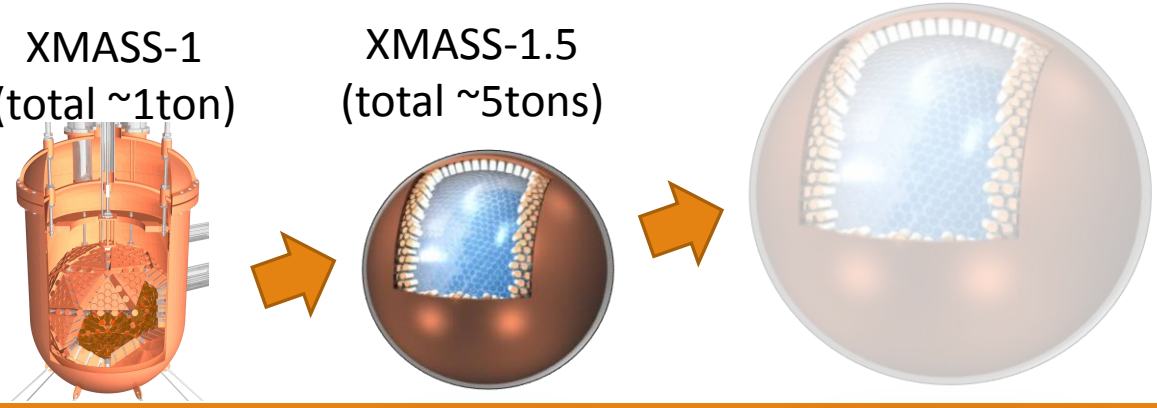
- Proposed as a multi purpose experiment with liquid Xenon
  - **X**enon detector for Weakly Interacting **MASS**ive Particles (**dark matter**)
  - **X**enon **MASS**ive detector for solar neutrino (**pp/^{7}Be solar neutrino**)
  - **X**enon neutrino **MASS** detector (**double beta decay**)
- Low energy threshold
- Sensitive to e/γ events as well as nuclear recoil

  WIMPs (by elastic and ^{129}Xe inelastic scattering),
  Solar axions, Bosonic super-WIMPs,
  Supernova neutrino burst, double electron capture, …
- Large target mass and its scalability

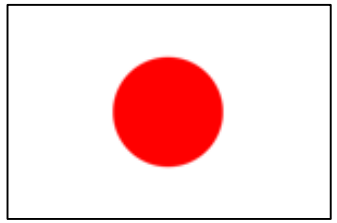
XMASS-1
(total ~1ton)

XMASS-1.5
(total ~5tons)

XMASS-2
(total ~24tons)



The XMASS collaboration



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

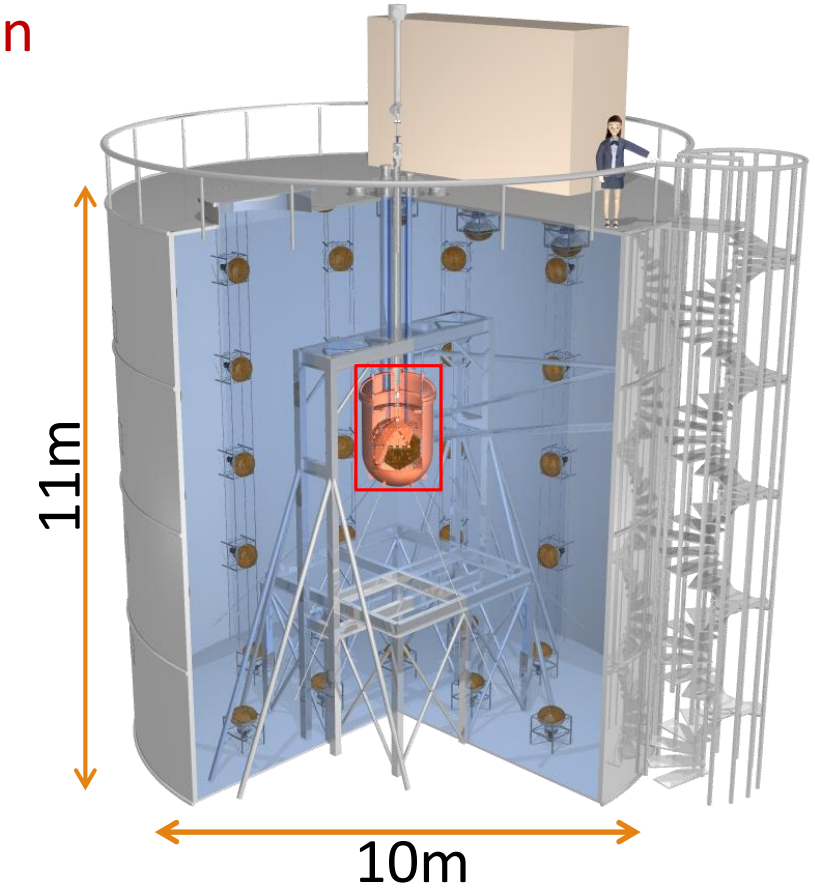
Tokushima University: K.Fushimi

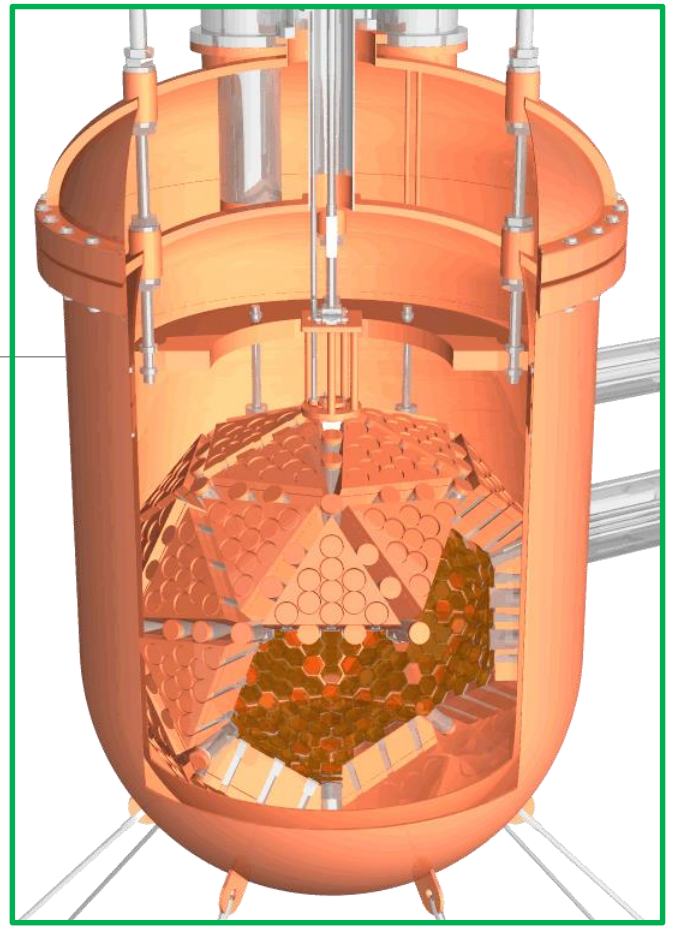
11 institutes

~40 physicists

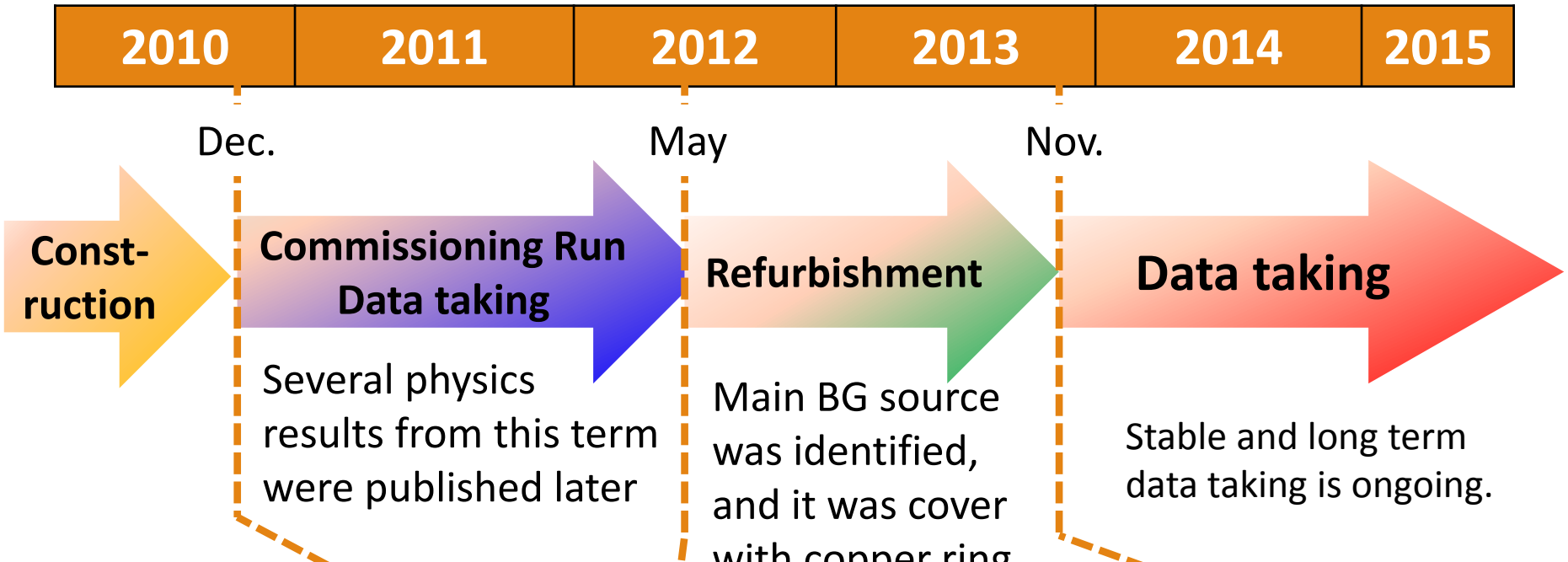
The XMASS-1 detector

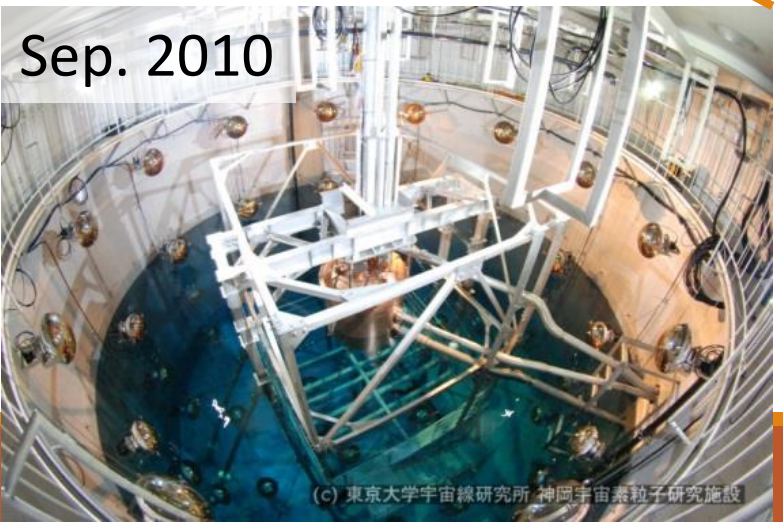
- Located in the Kamioka mine in Japan (~2,700m water equivalent)
- A single-phase detector employing ~830kg of liquid xenon
- Equipped with 642 PMTs
- Active water shield

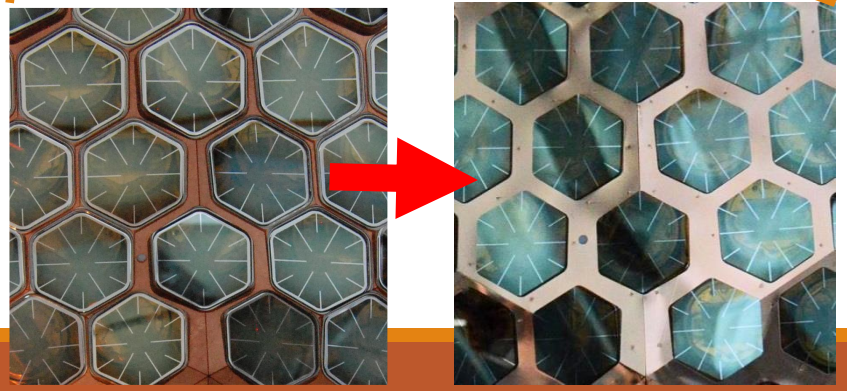




History of XMASS-I







Physics results of XMASS-I

Published

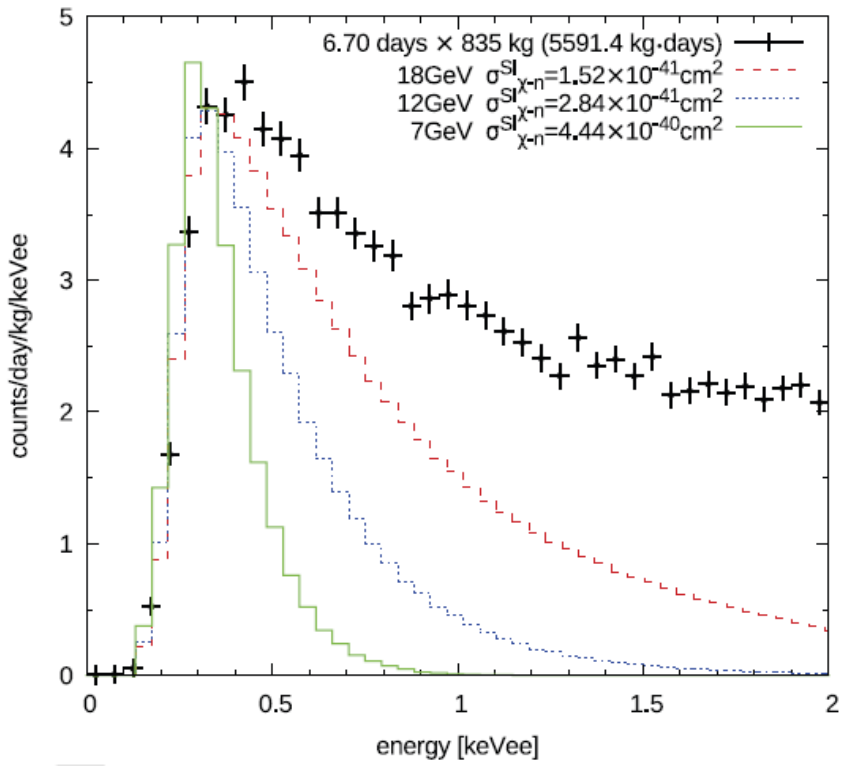
- Light WIMP search, ***Phys. Lett. B 719 (2013) 78***
- Solar axion search, ***Phys. Lett. B 724 (2013) 46***
- Bosonic Super-WIMPs, ***Phys. Rev. Lett. 113 (2014) 121301***
  → Chosen as Editor's suggestion
- Inelastic scattering on ^{129}Xe, ***PTEP 2014, 063C01***

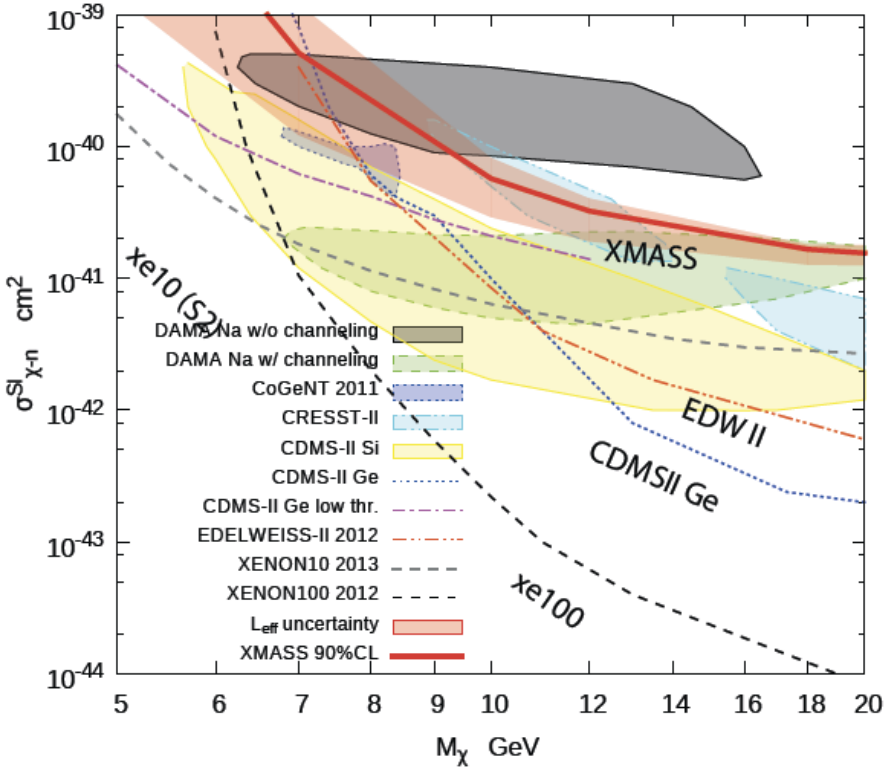
Results to come soon

- Double electron capture of ^{124}Xe
- Seasonal modulation with full volume of LXe
- Fiducial volume analysis for heavy WIMPs

Search for light WIMPs

- Use full volume of LXe
- 6.7 days x 835 kg
- 0.3 keVee threshold





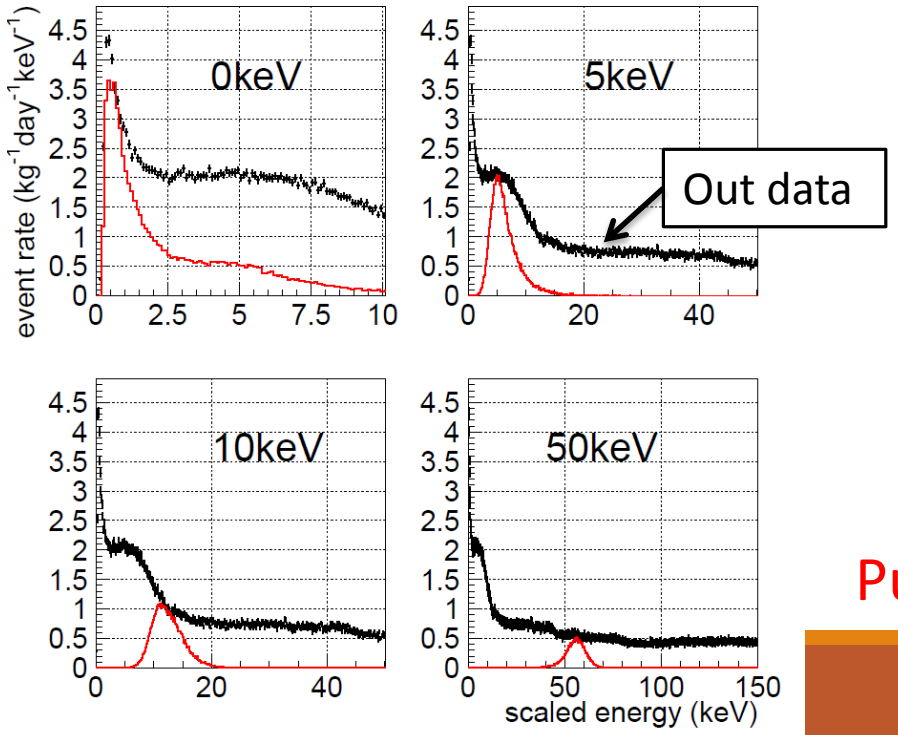
Published in Phys. Lett. B 719 78 (2013)

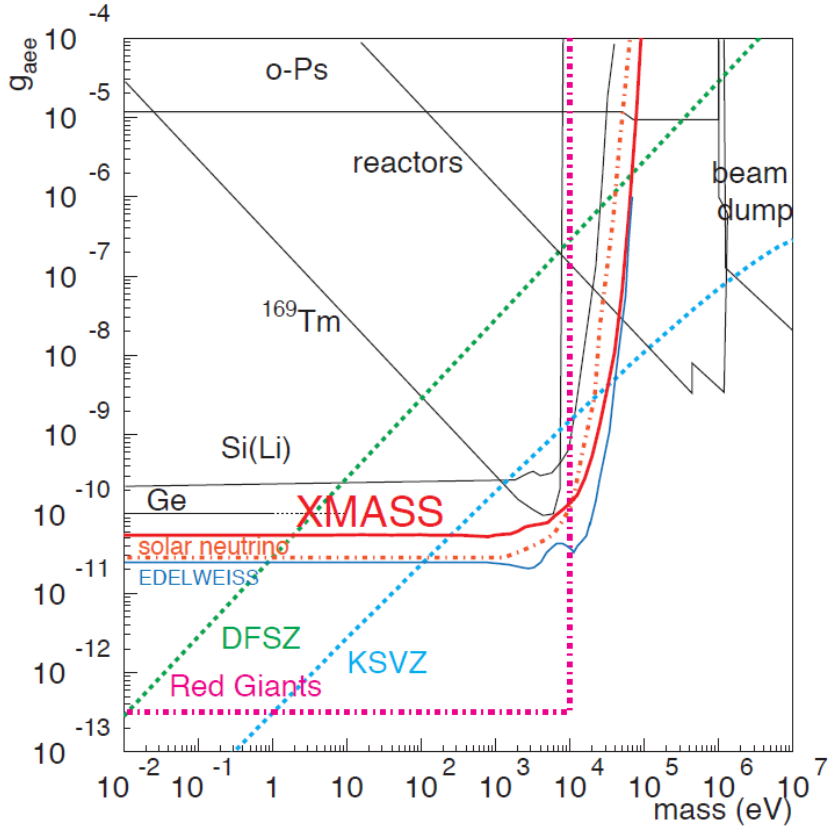
Search for solar axions

- Axions can be produced in the sun by bremsstrahlung and Compton effect, and detected by axio-electric effect in XMASS.
- Used the same data set as the light WIMPs search.

Bremsstrahlung and Compton effect

Axio-electric effect



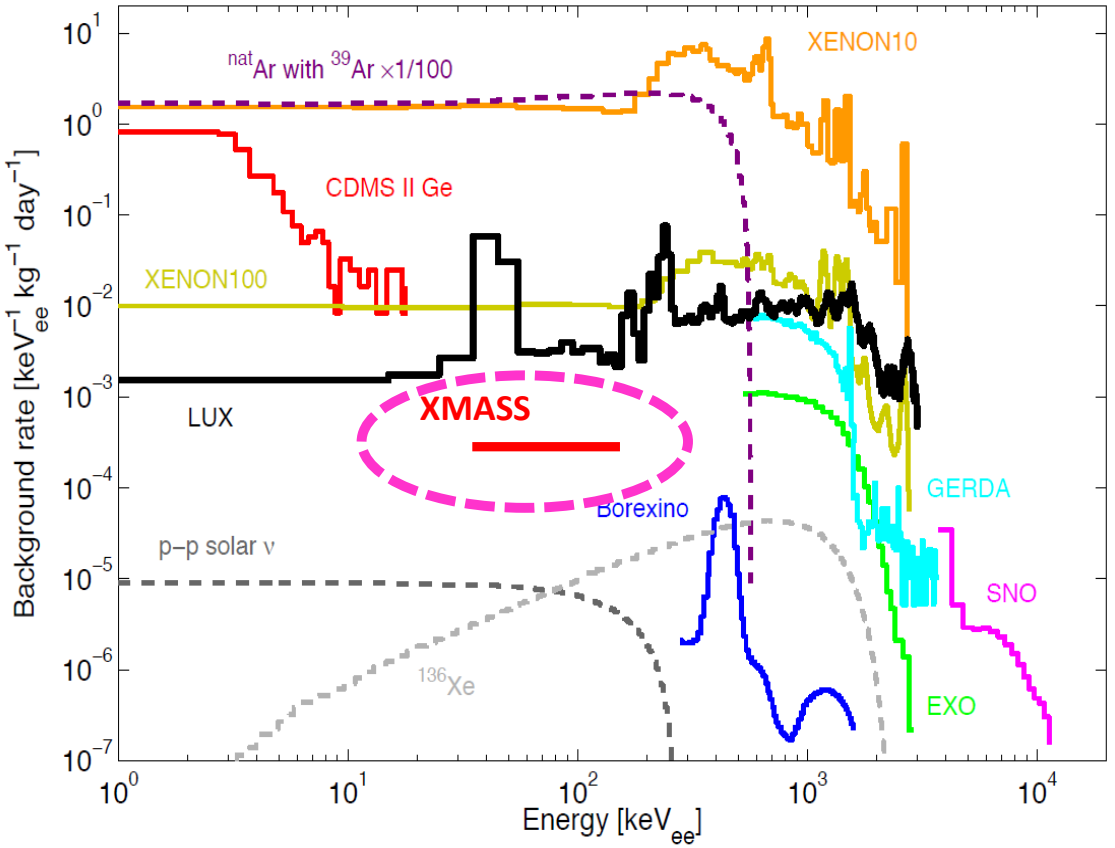


Published in Phys. Lett. B 724 46 (2013)

Comparison of background rate

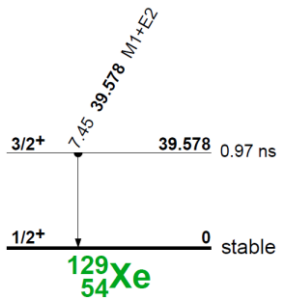
- Background rate in the fiducial volume before separation of nuclear recoils from e/γ
- XMASS achieved O(10^{-4}) event/day/kg/keVee at a few 10's keV.

Added to D.C.Malling thesis (2014) Fig.1.5

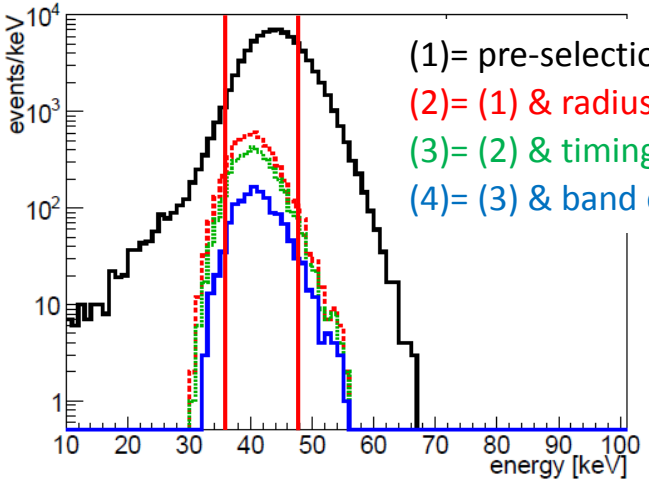


Search for ^{129}Xe inelastic scattering by WIMPs

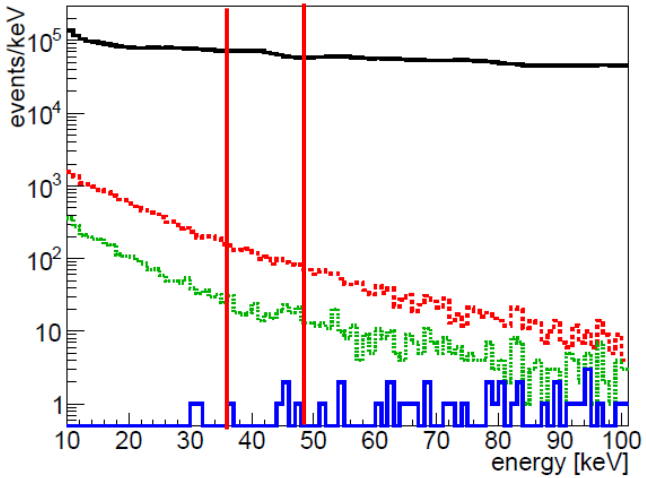
- $\chi + {}^{129}\mathrm{Xe} \rightarrow \chi + {}^{129}\mathrm{Xe}^*$
  ${}^{129}\mathrm{Xe}^* \rightarrow {}^{129}\mathrm{Xe} + \gamma$ (39.6keV)
- Natural abundance of ^{129}Xe: 26.4%

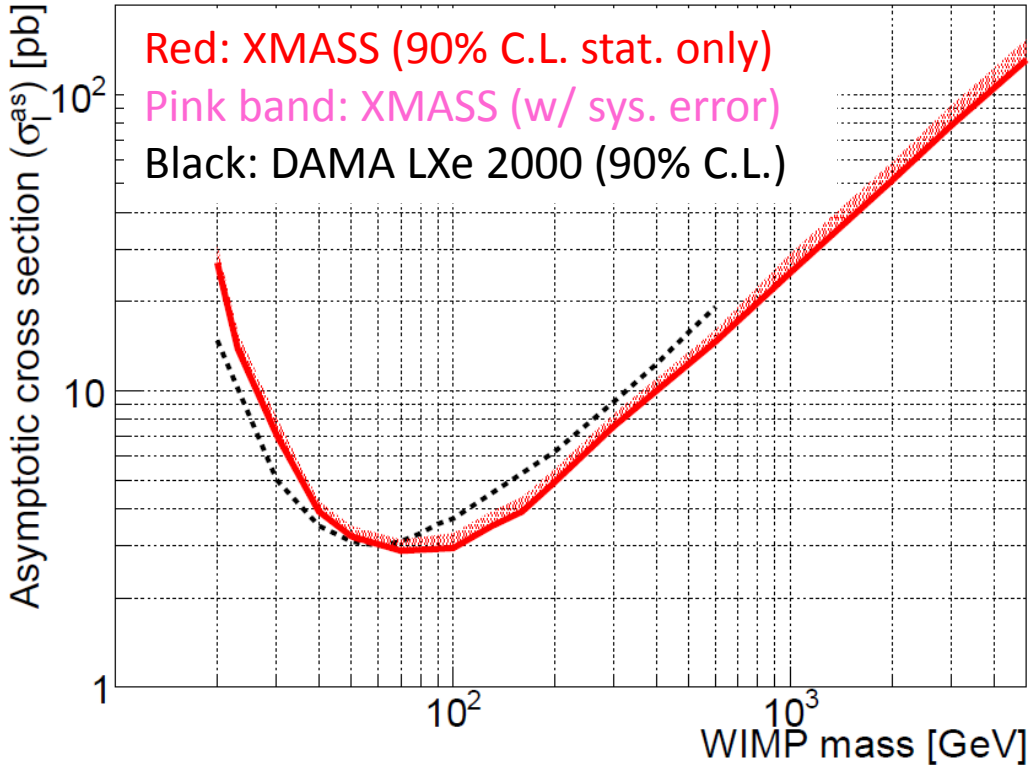


Signal MC for 50GeV WIMP



Observed data (165.9 days)



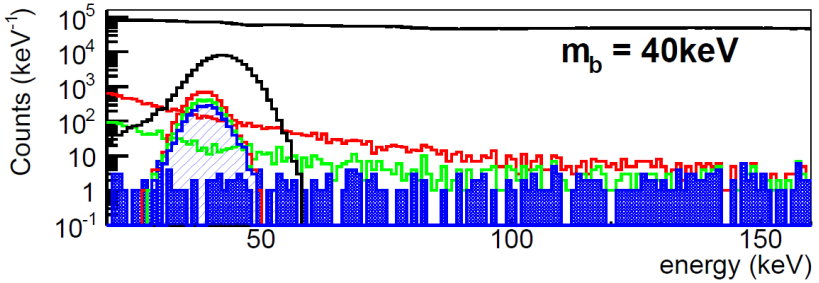


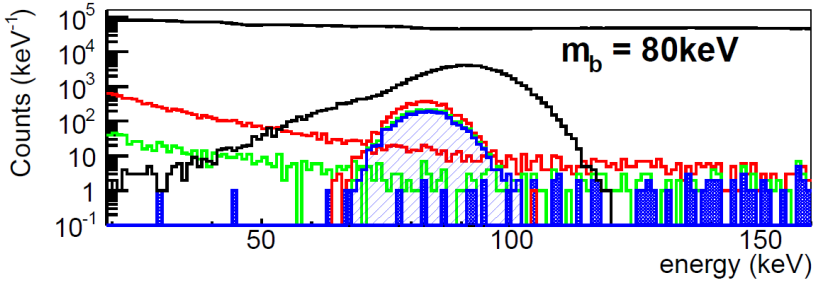
Published in PTEP 063C01 (2014)

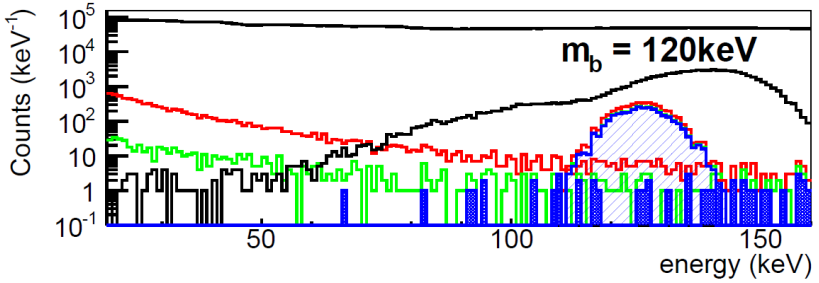
Search for bosonic super-WIMPs (1/2)

- Lighter and more weekly interacting than WIMPs
- Candidate for lukewarm dark matter
- It can be pseudoscaler or vector boson.
- For vector boson, no experimental constraint so far.

- It can be detected by absorption of the particle, which is similar to the photoelectric effect.
- Search for mono-energetic peak at the mass of the particle



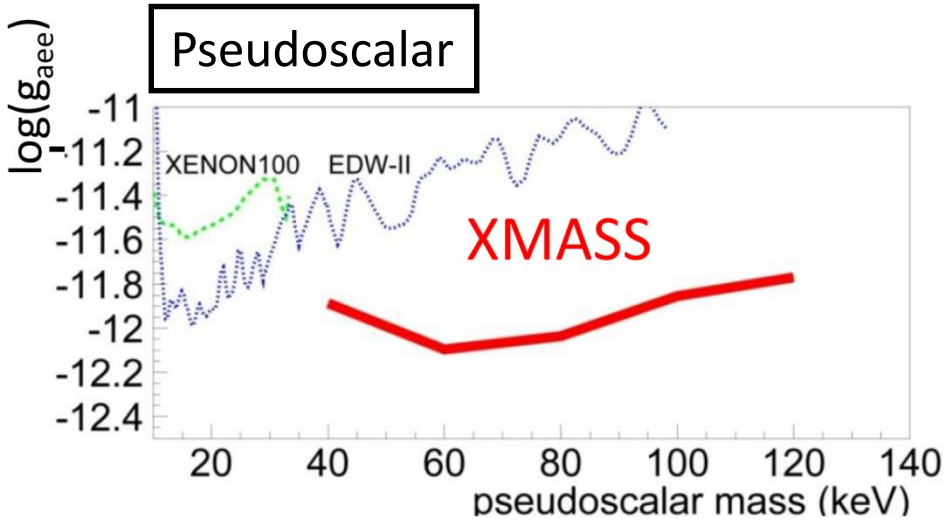


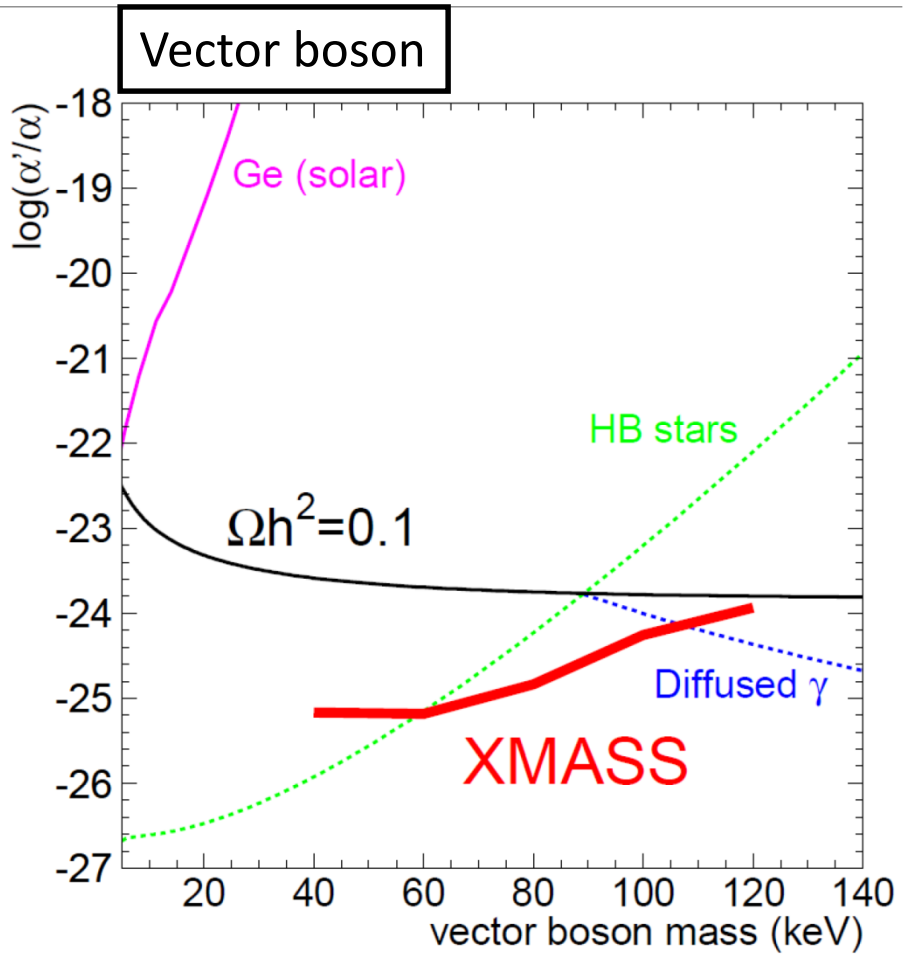


Published in Phys. Rev. Lett. 113, 121301 (2014)

Search for bosonic super-WIMPs (2/2)

- For vector boson case
  - the first direct search in the 40–120 keV range.
  - The limit excludes the possibility that such particles constitute all of dark matter.
- For pseudoscaler case
  - The most stringent direct constraint on gaee.





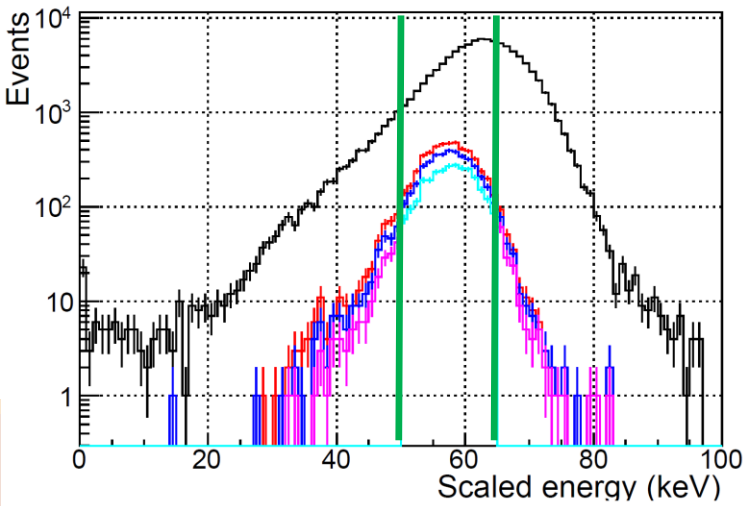
Search for double electron capture of ^{124}Xe

- Double electron capture can be occurred in analogy with double beta decay.
- Natural xenon has ^{124}Xe isotope (abundance 0.095%) which is one of candidate nuclei.

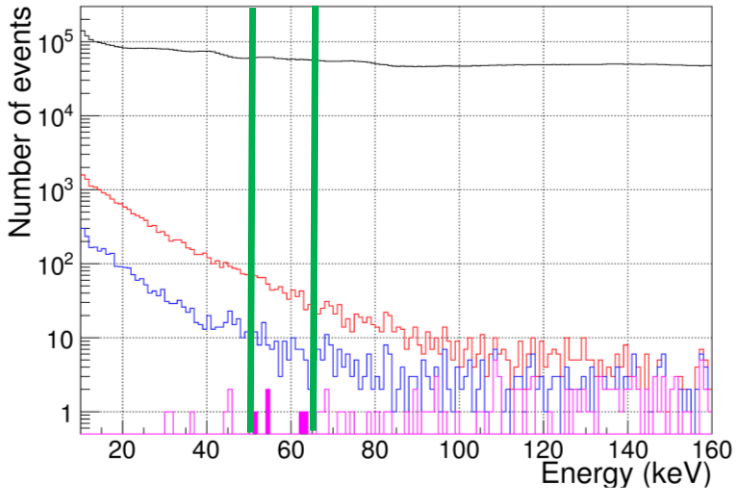
$$^{124}\mathrm{Xe}\ (\mathrm{g.s.},\ 0^+) + 2e^- \rightarrow {}^{124}\mathrm{Te}\ (\mathrm{g.s.},\ 0^+) + 2\nu + 2.866\mathrm{MeV}$$

- Theoretical calculations predict $T_{1/2}$ ~ 10^{20}~10^{24} years.
- The best experimental limit so far was $T_{1/2}(2\nu\ 2K) > 1.66\times10^{21}$ years (90%CL) [D.-M. Mei et al., PRC89, 014608(2014)]

Signal MC for double electron capture



Observed data (165.9 days)



5 events remain in the signal region, consistent with BG expectation (5.3+/-0.5)

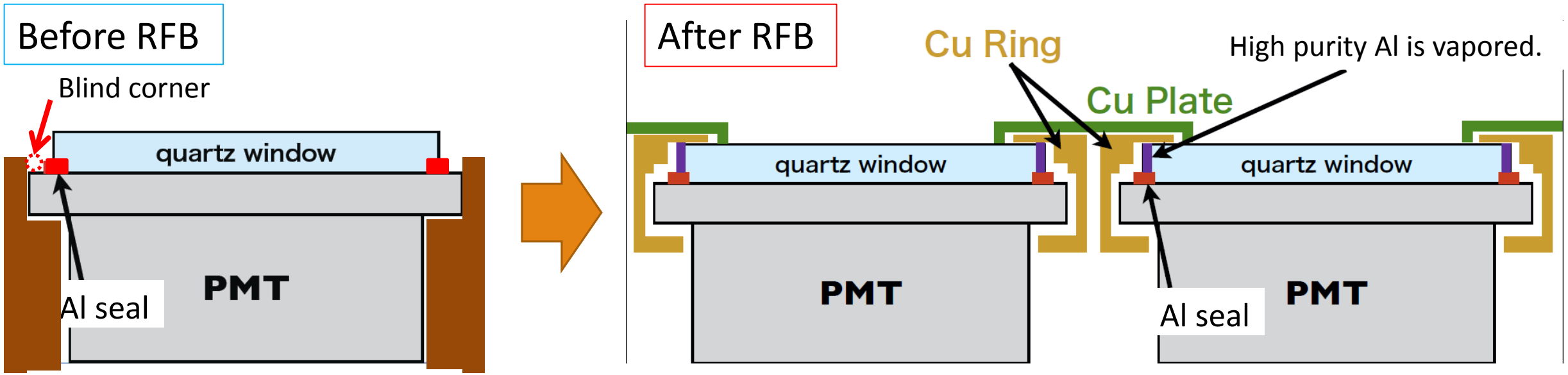
We set a limit on half life w/ BG subtraction

$T_{1/2}(2\nu\ 2K) > 4.9\times10^{21}$ years (90%CL)

Preliminary

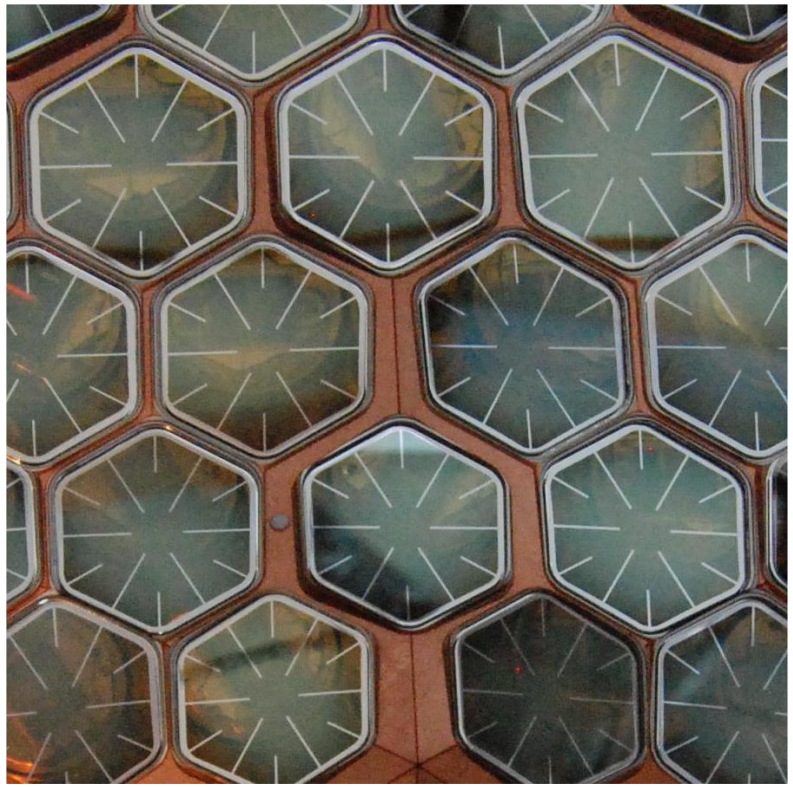
Detector refurbishment

- Found RIs (210Pb, 238U) in the Aluminum seal of PMT.
- BG events at the blind corner of PMT are often misidentified as events in the fiducial volume.
- To reduce this background, new structures to cover this Al seal were installed.

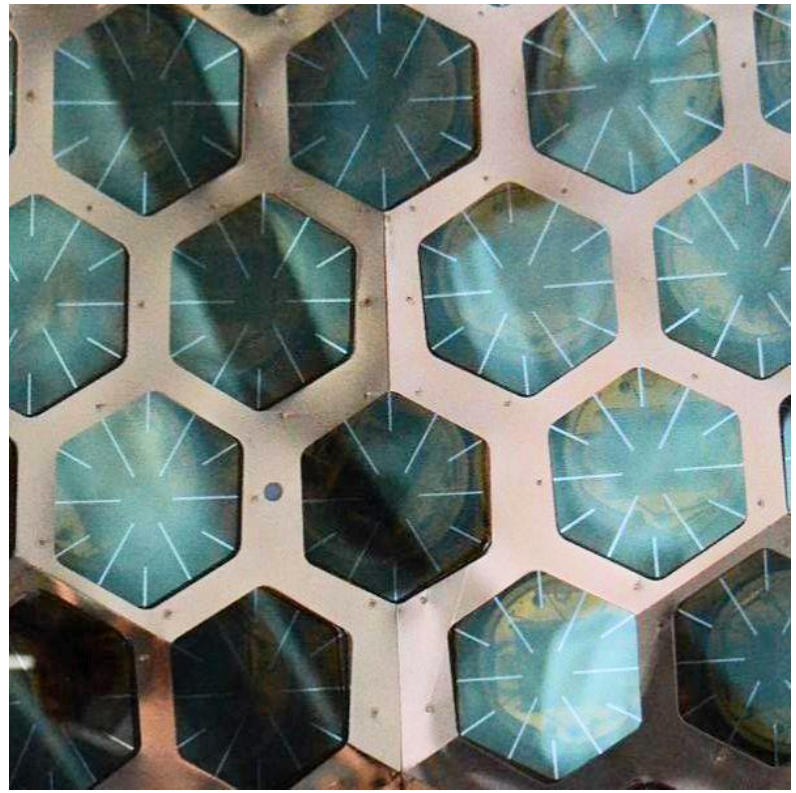


Photos of detector inner surface

Before refurbishment



After refurbishment

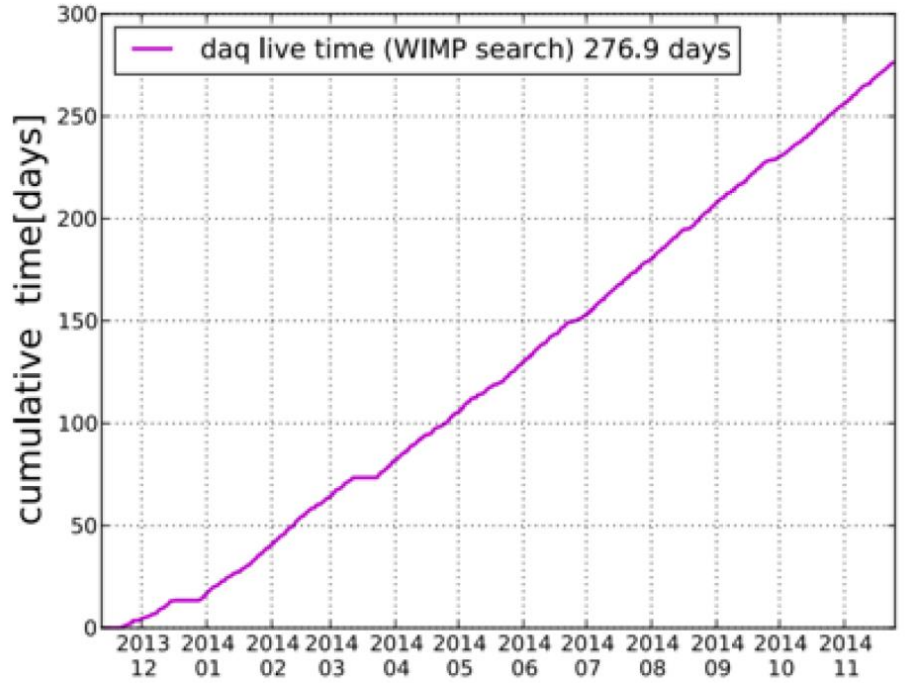


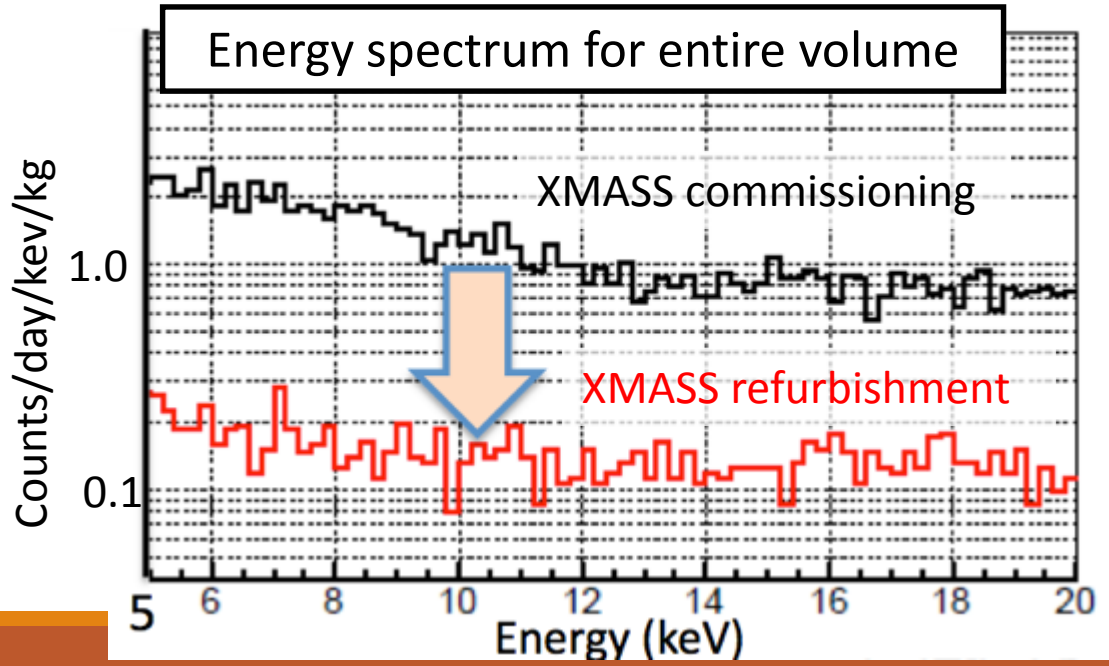
Data-taking after refurbishment

- Resumed data-taking in Nov. 2013.
- Energy threshold is reduced from 1keV to 0.3 keV.
- Start to use waveform data recorded by flash-ADCs.

- Quick check of energy spectrum indicates one order reduction of BG at 5-20 keV from commissioning run data.

- Already accumulated 277 days data till Dec. 2014.
- Physics analyses using these data are on-going.

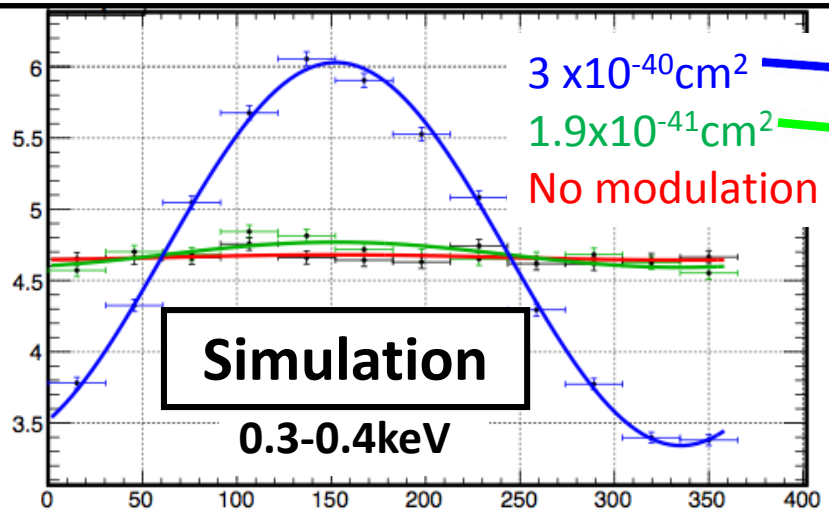




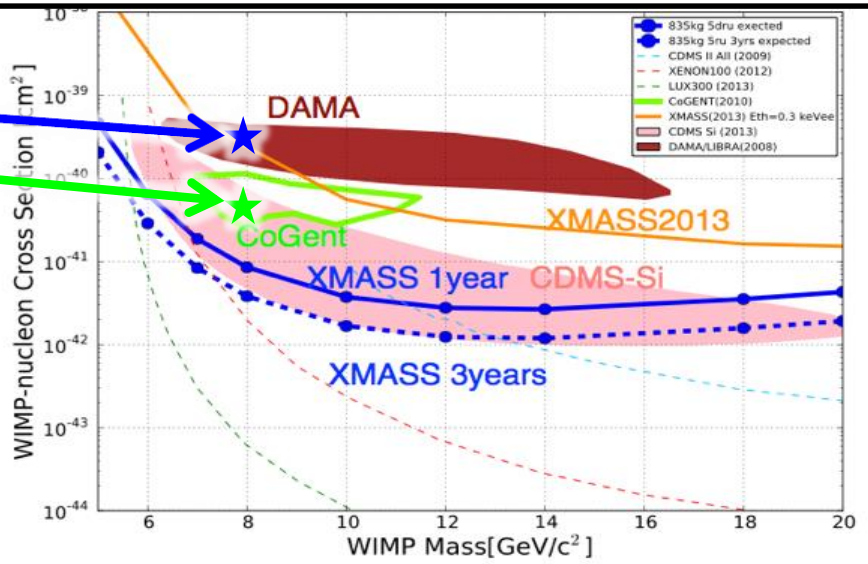
Current status: seasonal modulation analysis

- World's largest mass (832 kg after refurbishment):
  - ➢ **1 year data of XMASS (0.8 ton*year) vs. 14 years data of DAMA/LIBRA (1.33 ton*year)**
    → **Current statistics is already half of DAMA/LIBRA data.**
- Low energy threshold: 0.3 keVee.
- For several physics (DM, axion) without particle ID.
- The results for 1 year data will come soon.

Expected modulation in XMASS for 8 GeV WIMP



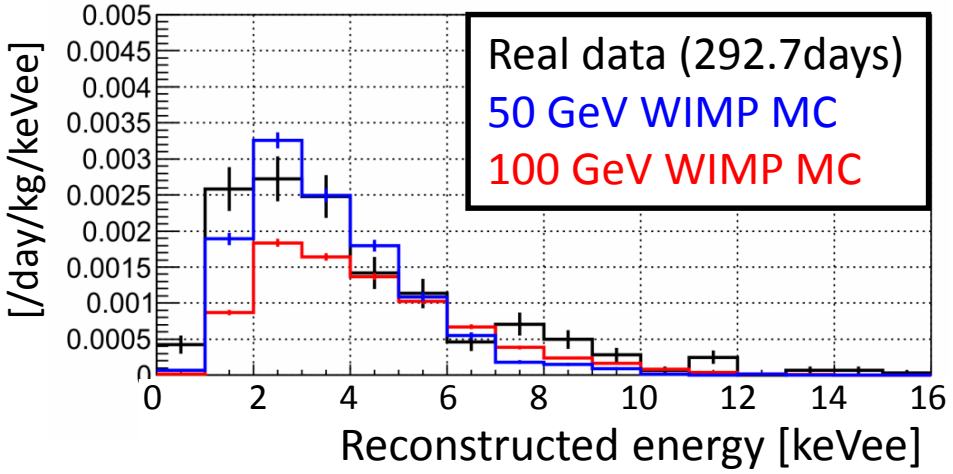
Prospects after refurbishment for full volume

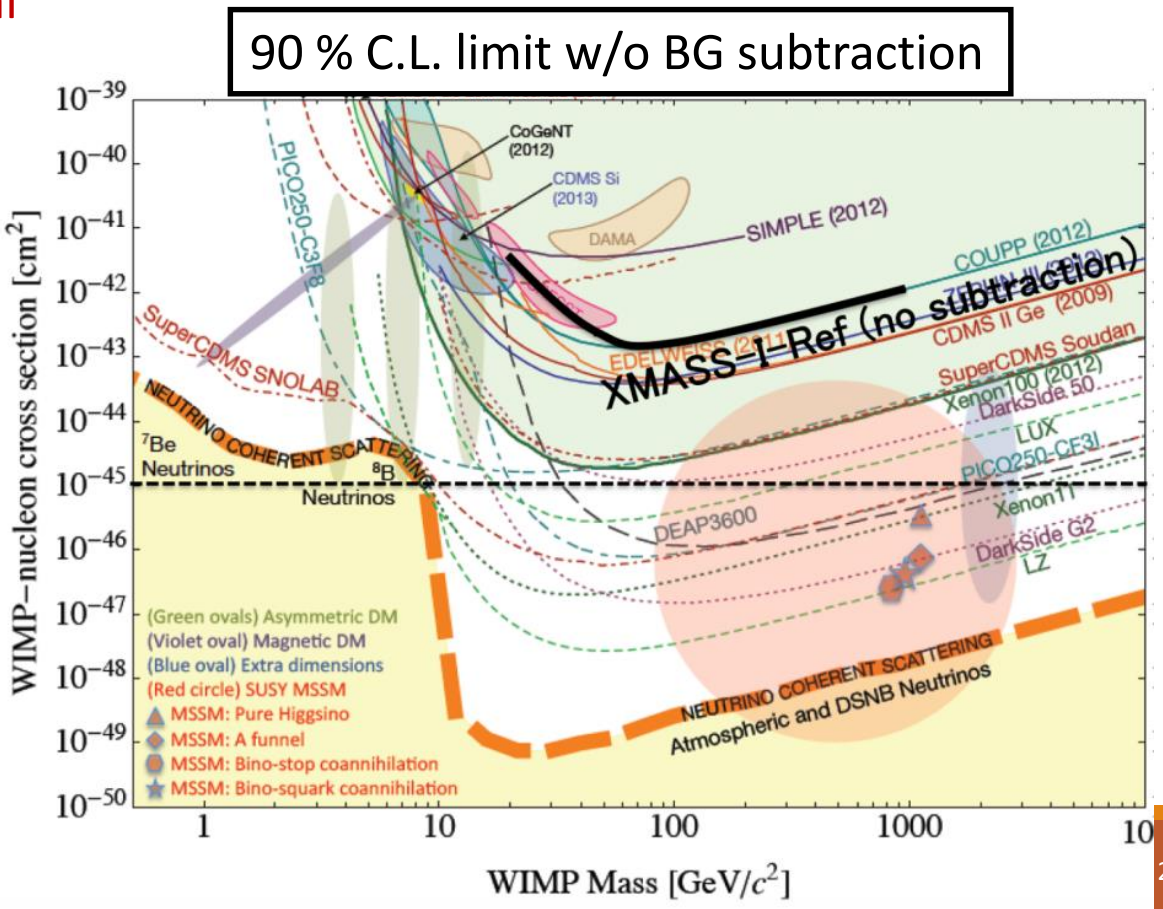


Current status: fiducial volume analysis for heavy WIMPs

- Conservative limit is derived assuming all remaining events are WIMPs signal
  $\sigma_{SI} < 2.7 \times 10^{-43}$ cm^2 (50GeV WIMPs)

- Remaining BG sources are identified. (Surface events sometimes mis-reconstructed)
- Results with BG subtraction being prepared.

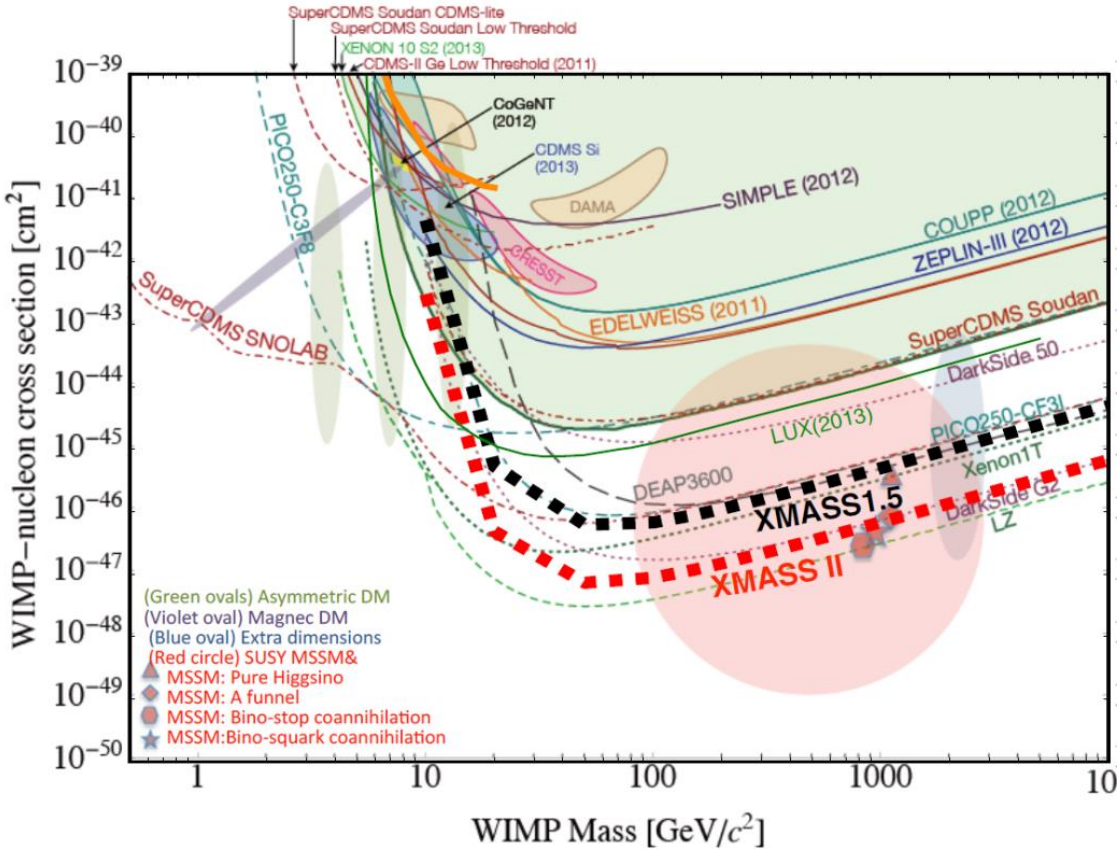


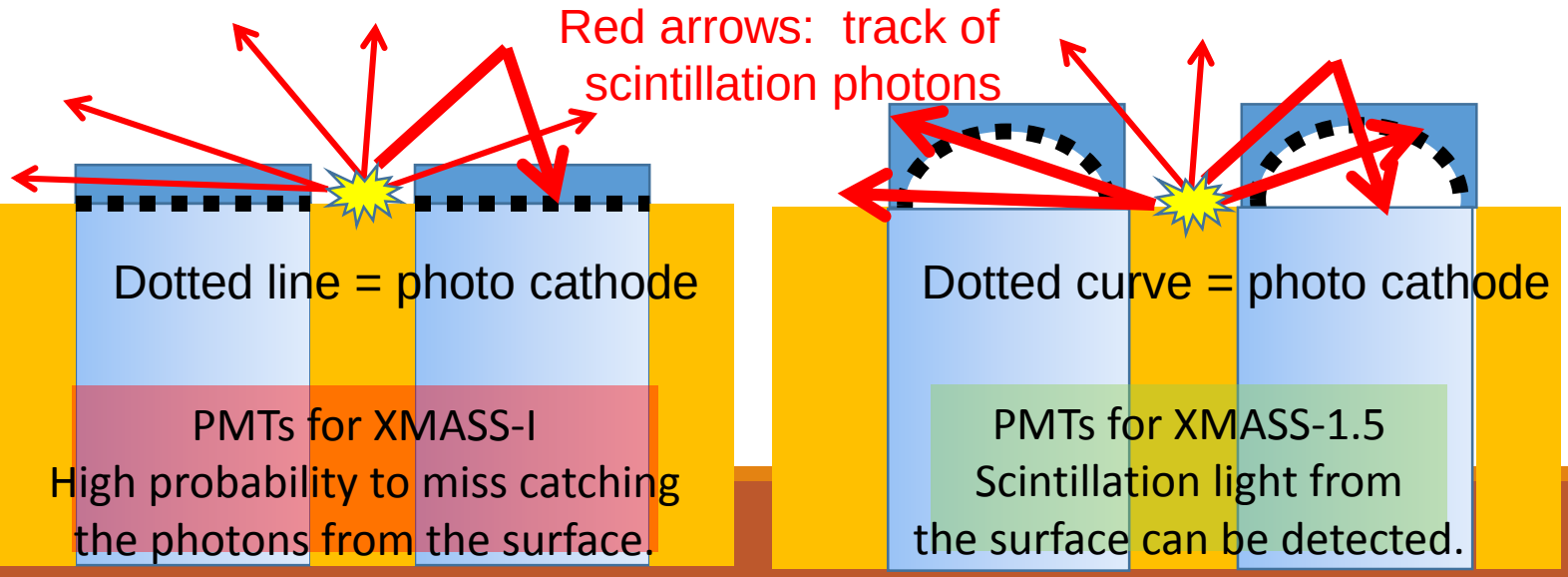


Next step: XMASS-1.5

- Total 5 tons of liquid xenon (fiducial mass of 1 ton)
- New PMT with round-shape window
  - No dirty aluminum is used
  - Identify surface events

- Target sensitivity for σ_{SI} <10^{-46} cm^2 for 100 GeV WIMPs
- Design of the detector is on-going





New PMT for XMASS-1.5

Summary

- XMASS-I is the world largest (~835kg) and low energy-threshold (0.3keVee) detector for direct dark matter search.
- Physics results from commissioning data with the full advantage of
  - Sensitivity to e/γ events as well as nuclear recoil
  - Low BG at a few 10's keV at a level of 10^{-4} /day/kg/keVee
- Current status
  - Detector refurbishment was completed and data-taking resumed in Nov. 2013.
  - One order reduction of BG from commissioning run was achieved.
  - Results from seasonal modulation and fiducial volume analyses will come soon.
- Next step
  - Designing of XMASS-1.5 is ongoing.
  - Aiming to σ_{SI} <10^{-46} cm^2 for 100 GeV WIMPs