The XMASS experiment

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for XMASS collaboration

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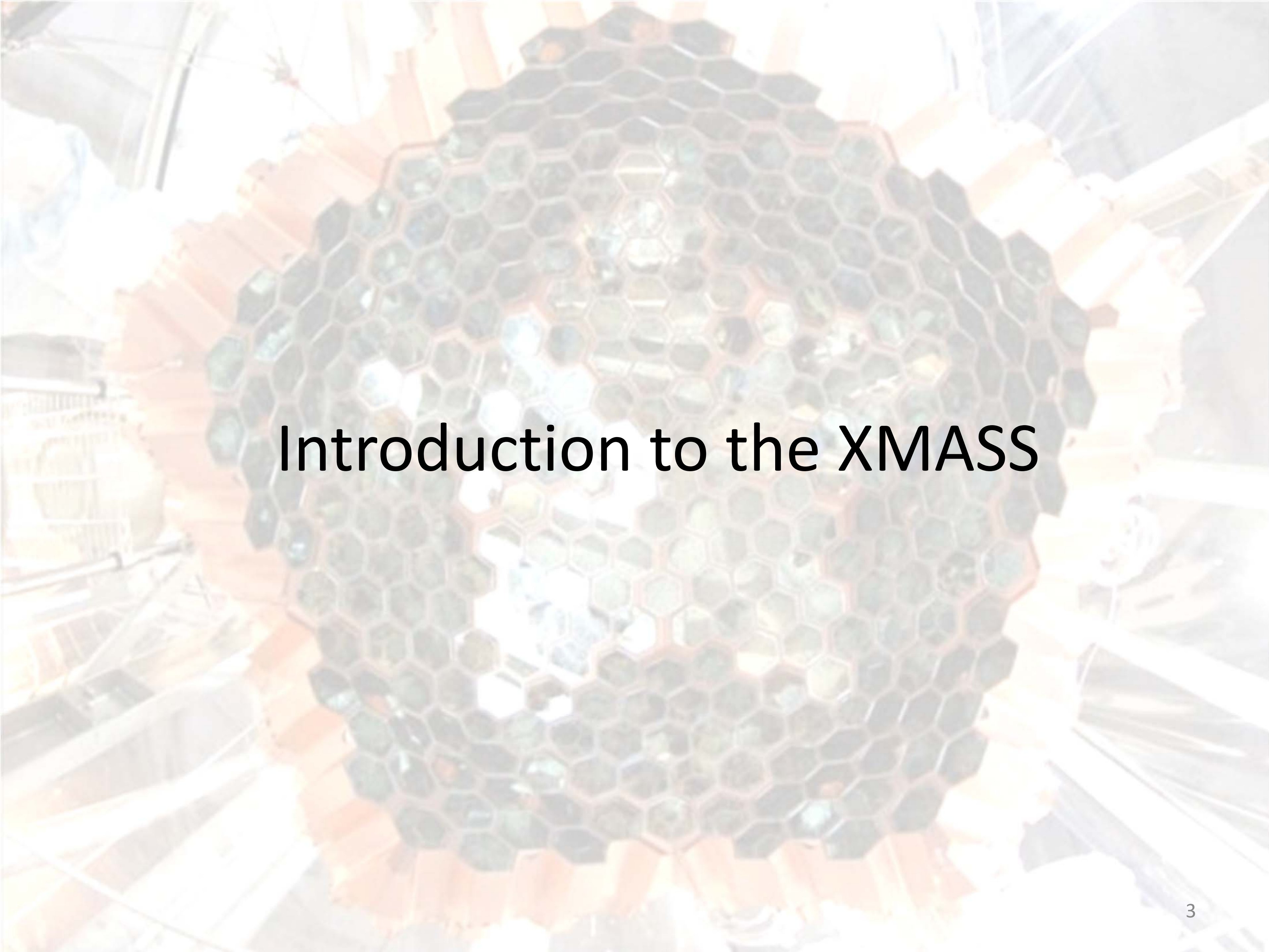
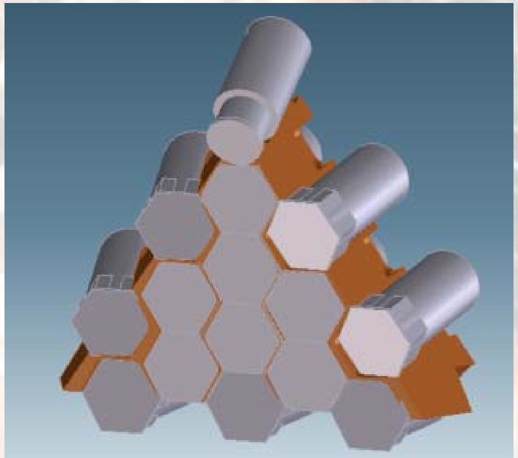
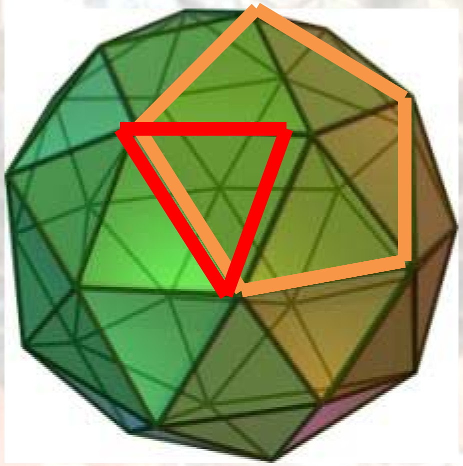


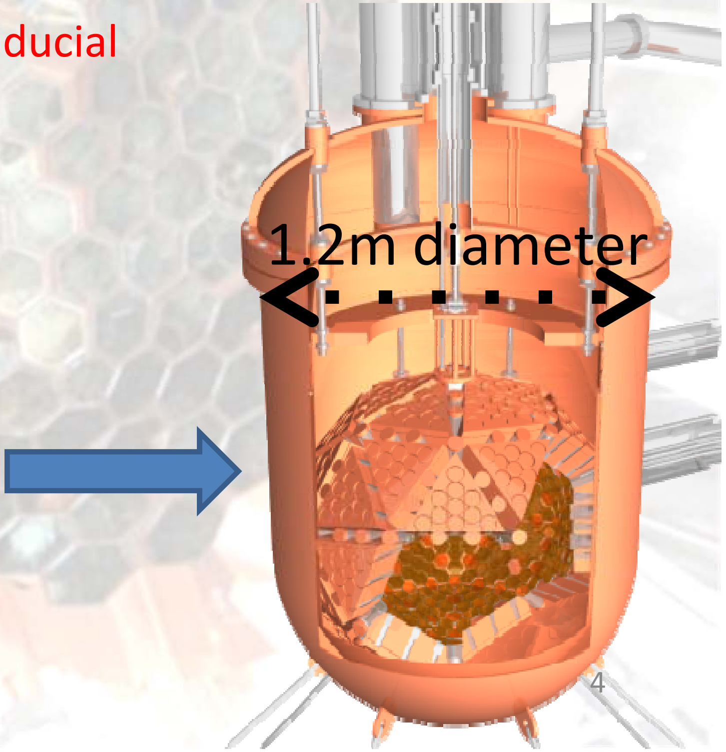
Introduction to the XMASS

XMASS experiment

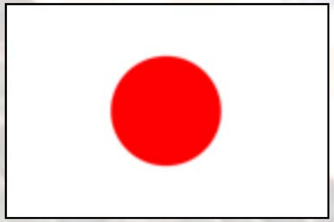
- Single phase (scintillation only) liquid Xenon detector : sensitive to e/γ events with very low backgrounds as well as nuclear recoil events
- Large 100 kg fid. mass & 835 kg inner mass (0.8 mϕ)
- Pentakis-dodecahedron ← 12 pentagonal pyramids: Each pyramid ← 5 triangle
- 630 hexagonal & 12 round PMTs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







XMASS Collaborator



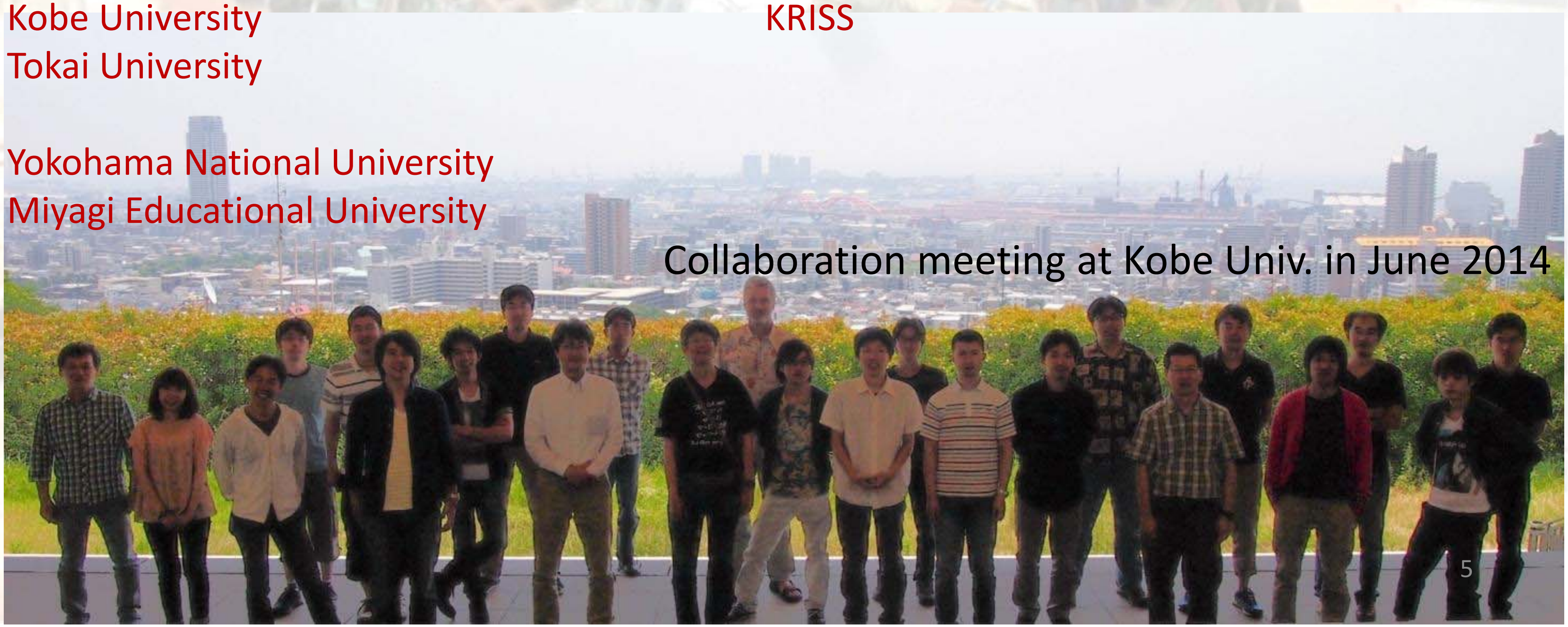
11 institutes
~40 physicists

Institute for Cosmic Ray Research, the University of Tokyo
Kavli Institute for the Physics and Mathematics of the Universe, the University of Tokyo
Kobe University
Tokai University

Yokohama National University
Miyagi Educational University

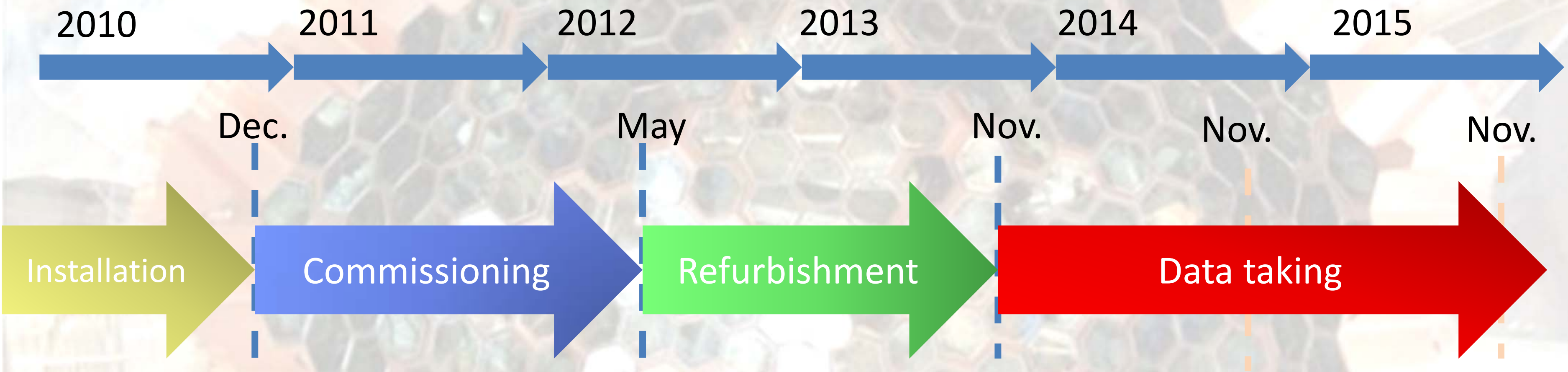
STE lab., Nagoya University
Tokushima University

Center for Underground Physics, Institute for Basic Science
KRISS



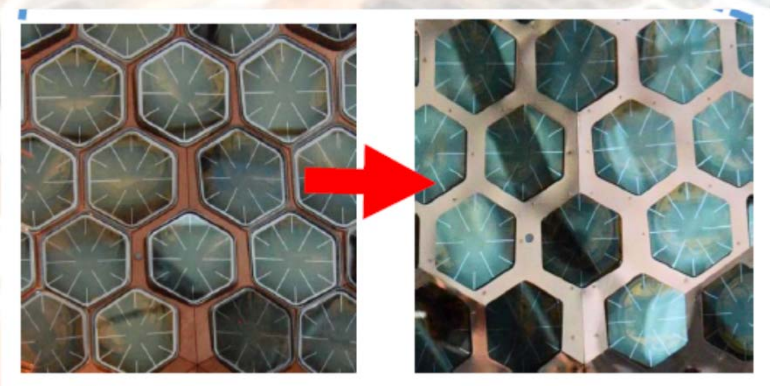
Collaboration meeting at Kobe Univ. in June 2014

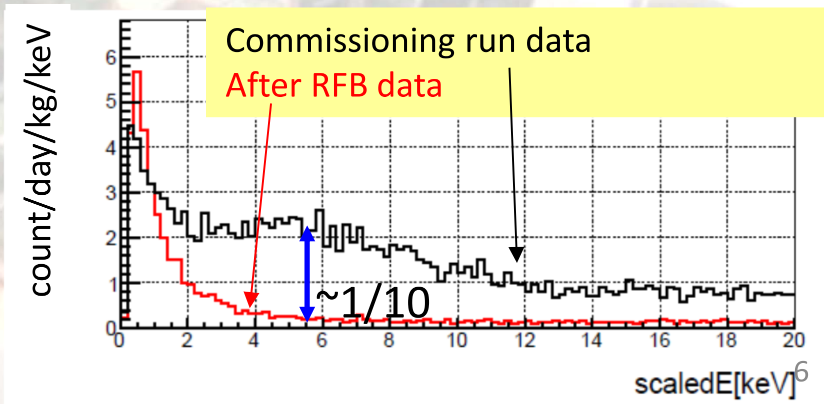
History of XMASS-I



PMT Al seal were covered by copper ring and plate to reduce BG as detector refurbishment. After refurbishment, event ~ 5keV is reduced to ~1/10.

Now, the 3rd year continuity operation is ongoing. The longest running time among LXe detectors!





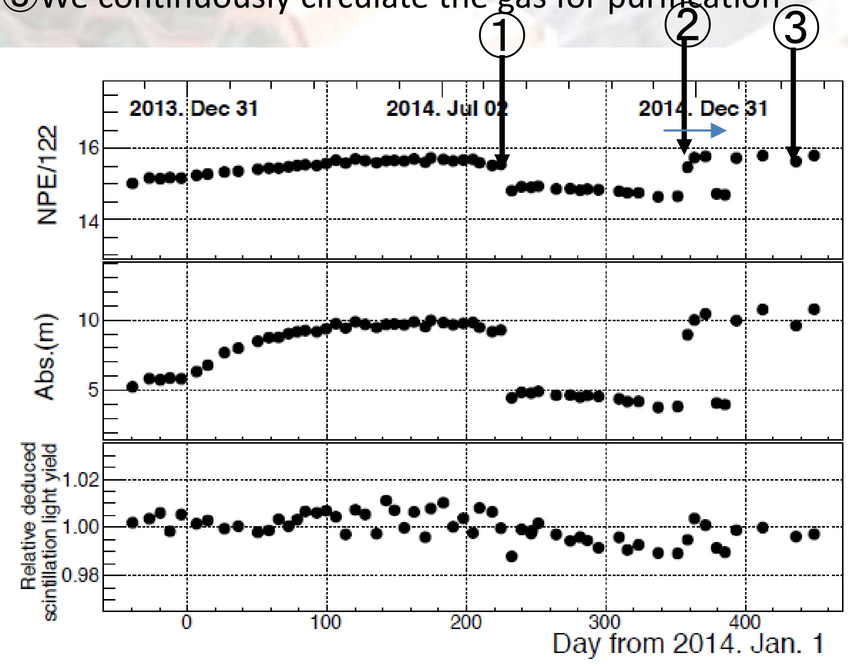
This year's physics results

- So far
  - Low mass WIMPs search (PLB 719 (2013) 78)
  - Solar axion search (PLB 724 (2013) 46)
  - Bosonic super-WIMPs search (PRL 113, 121301 (2014))
  - Inelastic WIMP nucleus scattering search (PTEP 063C01 (2014))
- This year
  - Search for annual modulation (arXiv: 1511.04807)
  - Search for double electron capture on ^{124}Xe (arXiv: 1510.00754)

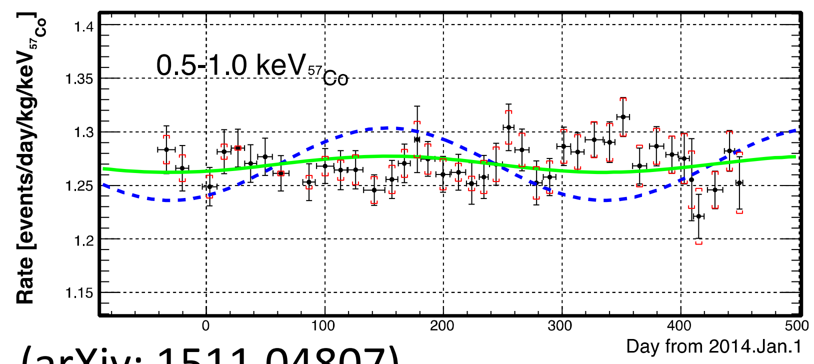
Search for annual modulation (1)

- Event rate of dark matter signal is expected to modulate annually due to relative motion of the Earth around the Sun. It would be a strong signature of dark matter.
- The dataset after refurbishment (Nov 2013-Mar 2015) was analyzed.
  - Rejection of noise, Cherenkov and front of PMT event.
  - No e/n separation
- Detector stability was monitored by Co57 calibration. The change of efficiency by the change of light yield was evaluated with the systematic error.
- The observed count rate as function of time was estimated in each energy bin.
- Two kind of analysis was done.
  - Model independent analysis
  - Standard WIMPs search

①Sudden drop at the power failure
②purification work
③We continuously circulate the gas for purification



7GeV/c² WIMPs
8GeV/c² WIMPs
Cross section of 2 × 10^{-40}cm²



(arXiv: 1511.04807)

Search for annual modulation (2)

(arXiv: 1511.04807)

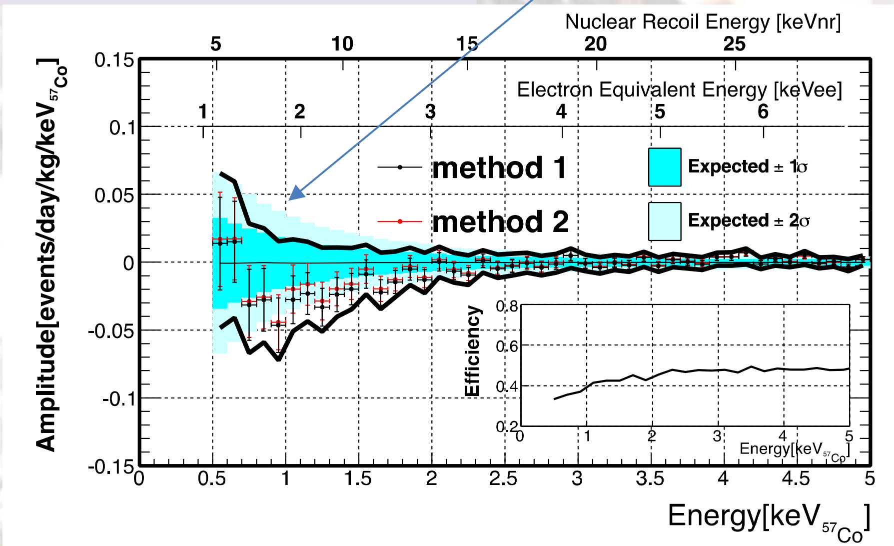
- Model independent analysis :
  - ✓ Annual modulation signal is searched for without any model assumption.
  - ✓ 1.1keVee (5keVr) analysis threshold is taken.
  - ✓ Phase t0=152.5days, period T=365.25days , Ai (modulated amplitude) and Ci (unmodulated amplitude) are fitted by :

$$R^{\mathrm{ex}}_{i,j} = \int_{-\frac{1}{2}\Delta t_j}^{\frac{1}{2}\Delta t_j} (C_i + A_i \cos 2\pi (t_j - t_0)/T) dt_j$$

  - ✓ The difference of two methods are used for analysis. Difference is small.
  - ✓ No significant modulated signal has been observed.

Amplitude as function of energy (before efficiency correction)

dummy sample as no modulation case



Method 1 (pull term)

$$\chi^2 = \sum_i^{R\text{-bins}} \left(\sum_j^{t\text{-bins}} \frac{(R_j^{obs} - R_{i,j}^{Pred} - \alpha K_{i,j})^2}{\sigma(\mathrm{stat})_j^2} \right) + \alpha^2$$

Method 2 (covariance matrix)

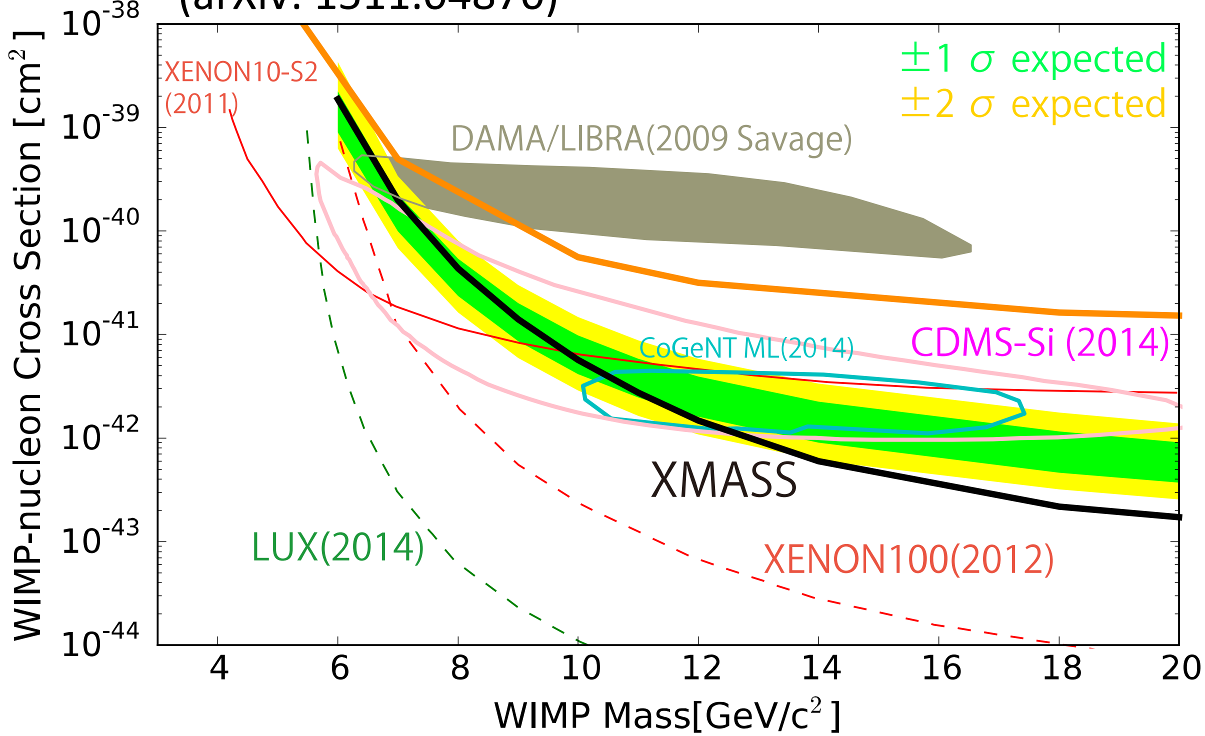
$$\chi^2 = \sum_{i,j}^{Et-\mathrm{bins}} (R_i^{obs} - R_i^{pred})(V_{stat} + V_{sys})^{-1}_{ij} (R_j^{obs} - R_j^{pred})$$

Search for annual modulation (3)

- Standard WIMPs search :
  - ✓ Assuming standard WIMP, data is fitted with the following equation:

$$R^{\text{pred}}(E_i, t_j) = C_i + \sigma \times A(m_\chi, E_i) \cos 2\pi (t_j - t_0)/T$$

(arXiv: 1511.04870)



- Leff uncertainty is taken into account.
- Figure is drawn by Method 1. The difference between two methods are within 30%.
- DAMA/LIBRA region is mostly excluded by our measurement.

Model assumption

V_0: 220.0 km/s

V_{esc}: 650.0 km/s

ρ_{dm}: 0.3 GeV/cm^3

Lewin, Smith (1996)

The first extensive search against the DAMA region, including electron recoils.

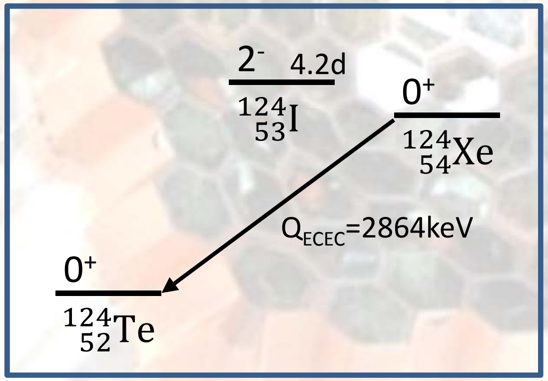
Search for double electron capture on ^{124}Xe (1)

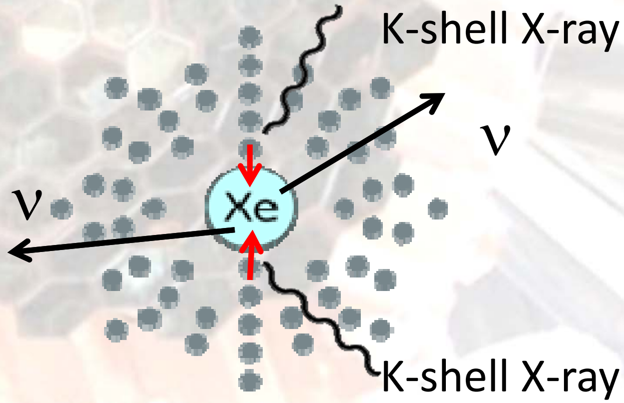
Isotope	^{124}Xe	^{126}Xe	^{128}Xe	^{129}Xe	^{130}Xe	^{131}Xe	^{132}Xe	^{134}Xe	^{136}Xe
Natural abundance	0.095%	0.089%	1.9%	26.4%	4.1%	21.2%	26.9%	10.4%	8.9%

- Natural xenon contains double electron capture nuclei as well as double beta decay nuclei
- ^{124}Xe 2ν double electron capture (ECEC)

$$^{124}\mathrm{Xe}\ (\mathrm{g.s.},\ 0^+) + 2e^- \rightarrow {}^{124}\mathrm{Te}\ (\mathrm{g.s.},\ 0^+) + 2\nu_e + 2864\mathrm{keV}$$

  - In the case of 2K-capture, signal is total energy deposition of 63.6keV from atomic X-rays and Auger electrons.
- ^{126}Xe can also undergo 2ν ECEC, but this reaction is much slower. (Q=896keV)

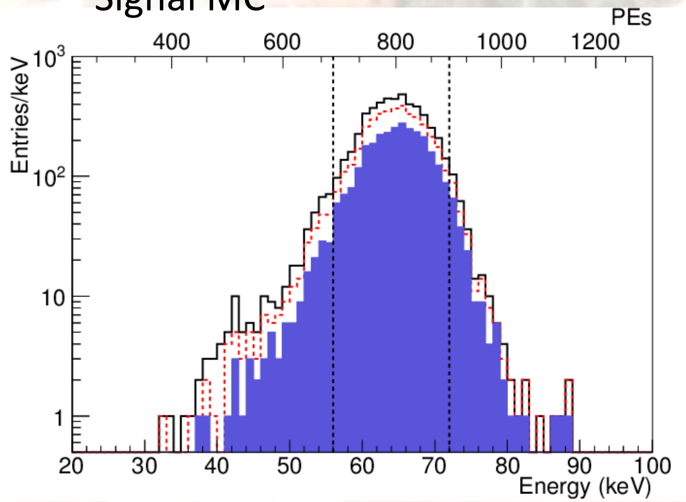




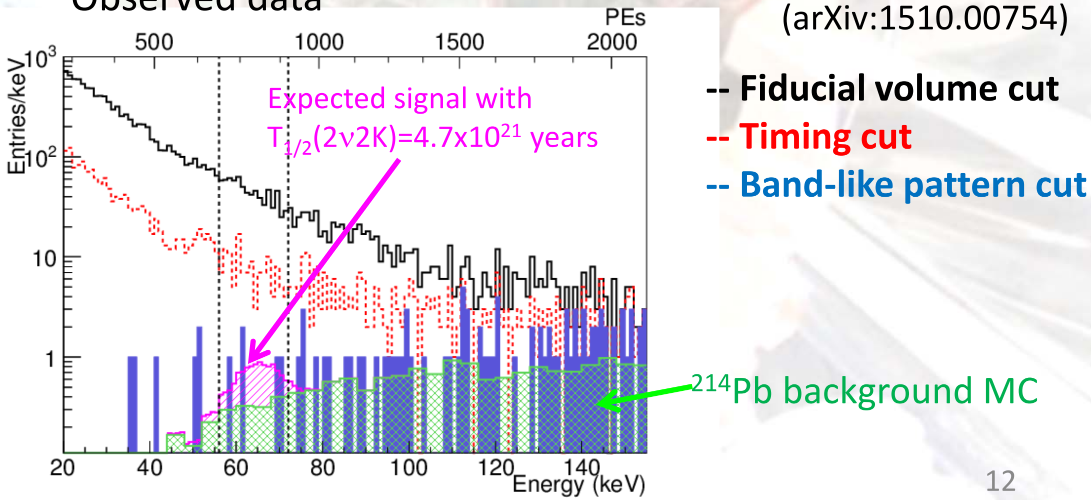
Search for double electron capture on ^{124}Xe (2)

- Signal MC
  - X-rays and Auger electrons after 2ν 2K-capture are simulated.
  - The energy window (56-72keV) is determined so that it contains 90% of the simulated signal.
  - Efficiency for signal is 59.7%.
- Observed data
  - Commissioning run data were analyzed.
  - Effective live time is 132.0 days, and fiducial mass of natural xenon is 41kg (It contains 39g of ^{124}Xe).
  - 5 events remained in the signal region. Main background in this energy region is ^{214}Pb (daughter of ^{222}Rn) in the detector, and expected number of 214Pb BG events in the signal region is 5.3+/-0.5. No significant excess above background was observed.
- Set the world best lower limit of half-life : $T_{1/2}>4.7\times10^{21}$ years (90%CL).

Signal MC



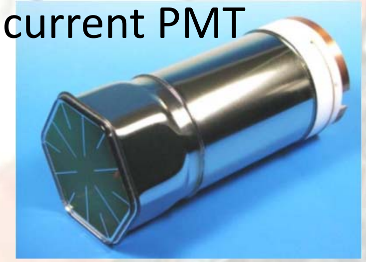
Observed data



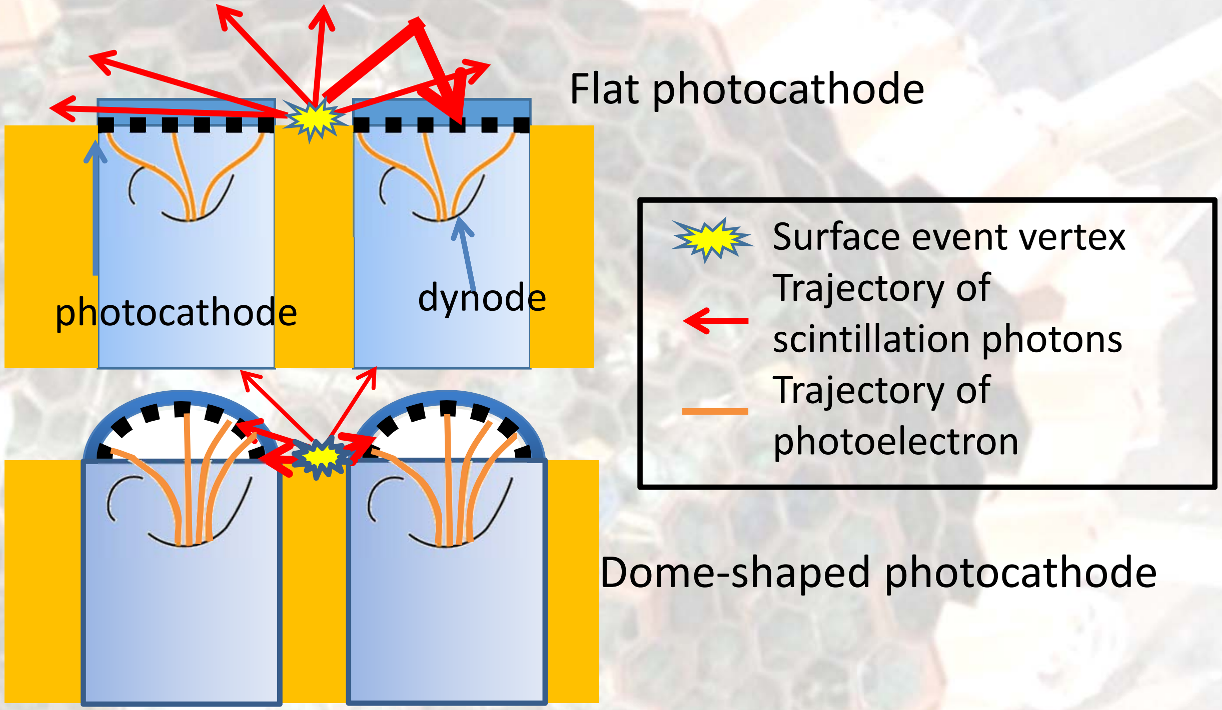
Future of XMASS

New PMTs for future XMASS

2inch hex shape
current PMT

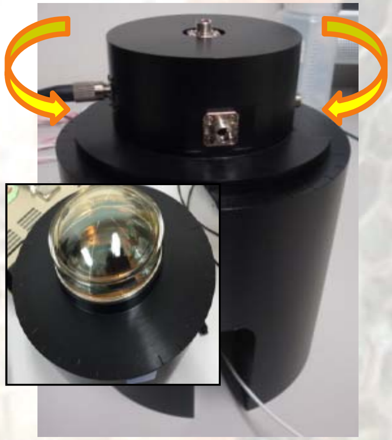


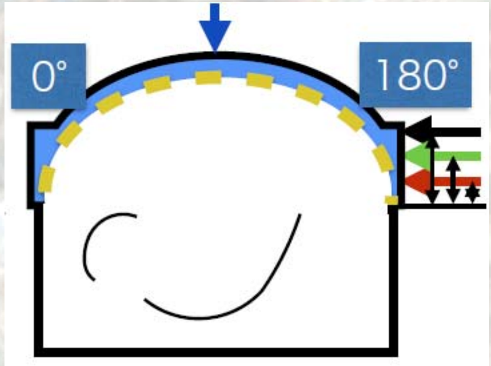
3inch dome shape
new PMT



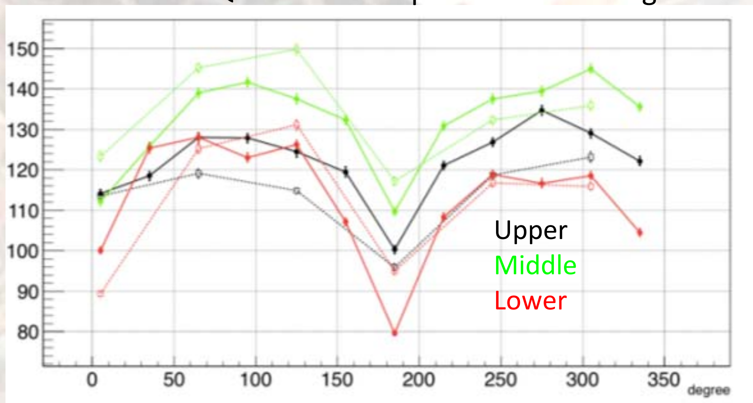
- Surface events can be identified and rejected very effectively by new dome-shaped PMTs.
- TTS(Transit Time Spread) of the new PMT will be improved, and it will result in improvement of Cherenkov BG rejection and position reconstruction using timing.
- Performance test was carried out using the first batch of the new PMTs.
- Reduction of radioactivity in PMT parts was done.

PMT Performance test(1)





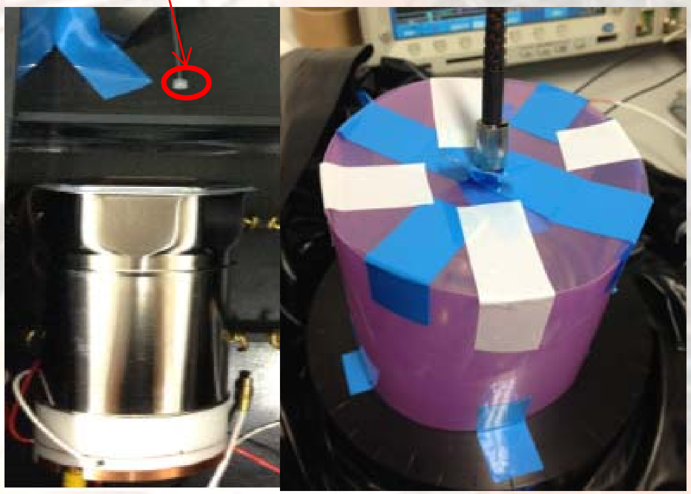
The relative CE*QE to that at top VS azimuthal angle

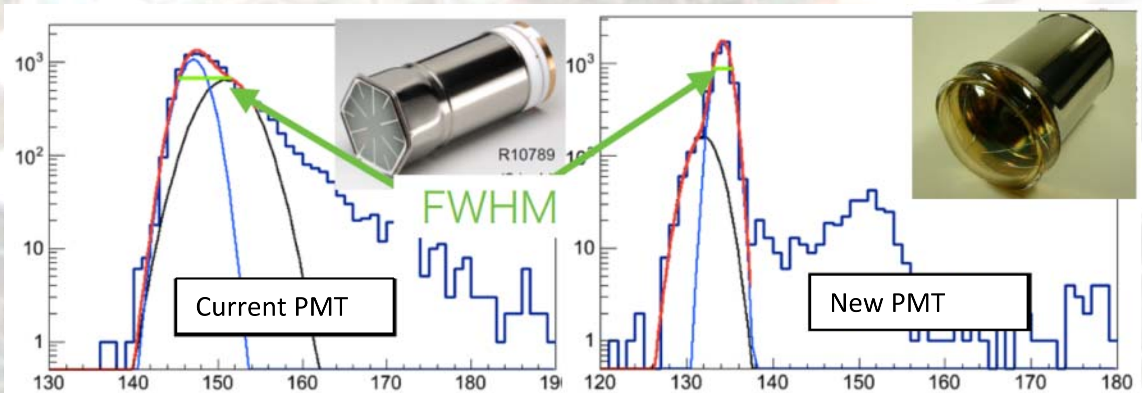


- Sensitivity at the side of photocathode was measured as the relative CE(collective efficiency) including QE(quantum efficiency).
  - Put a PMT in the instrument of the figure.
  - Inject laser through a hole out of 4 holes on the cap, which can be turned.
  - Even the worst CE is 80% of CE at top. It may be sufficient for surface BG rejection.
  - The performance of surface BG rejection in future XMASS detectors will be checked using MC.

PMT Performance test (2)

- Measurement of transit time spread
  - Entire photocathode was irradiated by laser through a diffuser.
  - Measured time difference between laser clock and 1pe PMT signal. Compared with current PMT, improved.
  - The performance of Cherenkov BG rejection and position reconstruction using timing in future XMASS detectors will be checked using MC.



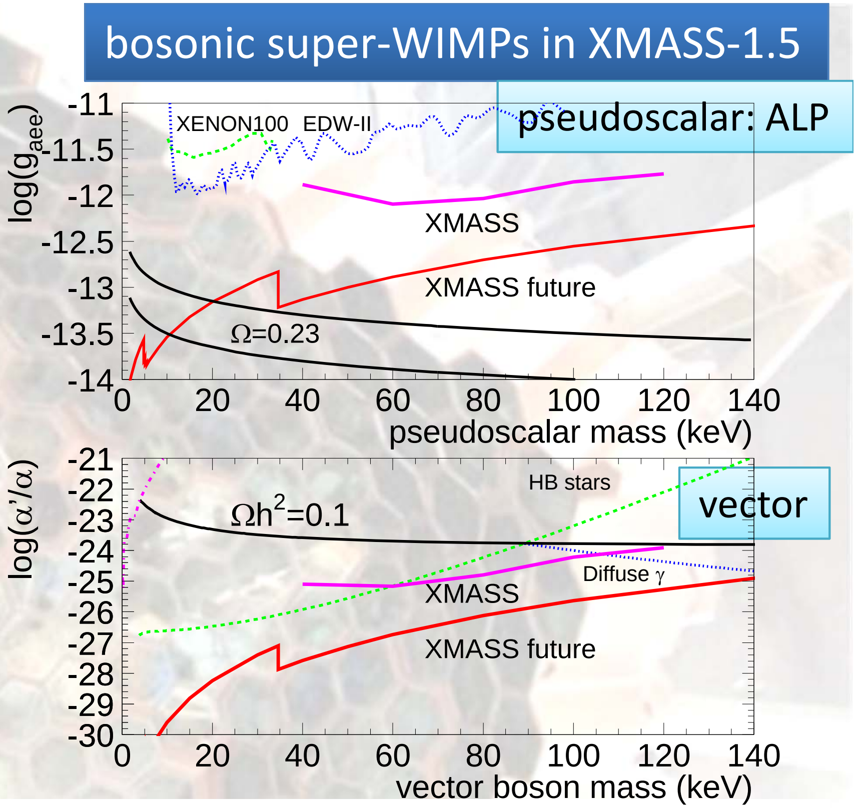


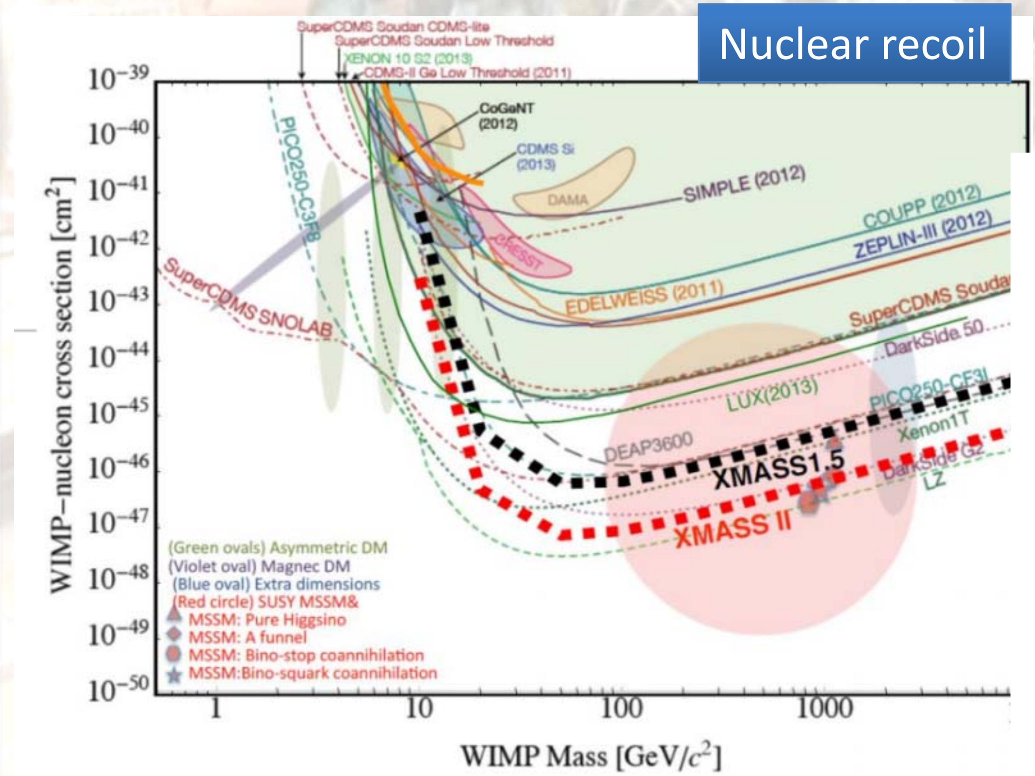
	New1	New2	New3	Current
TTS(ns)	1.93	2.42	1.98	6.87

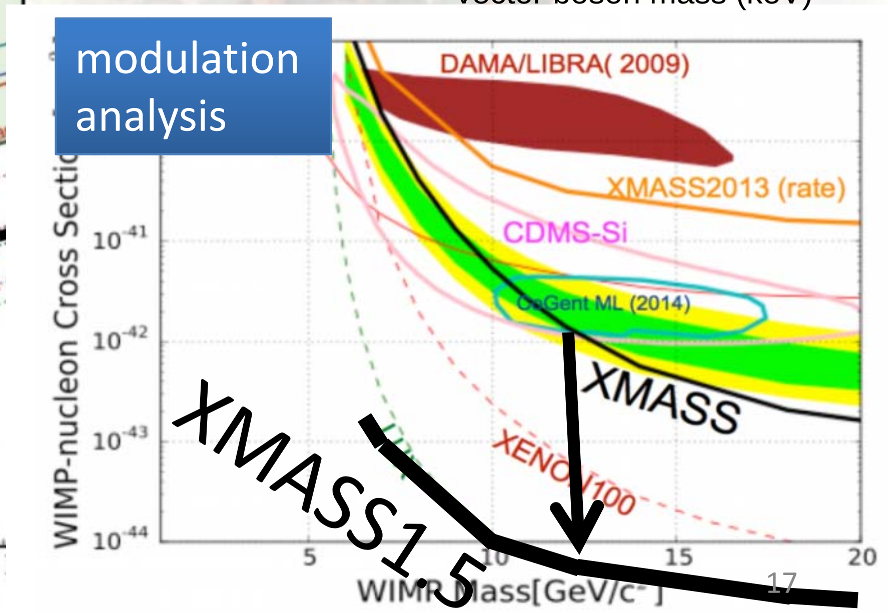
Future XMASS

- XMASS-1.5 : Total 5ton/fiducial 1ton
- XMASS-II : Total 25ton/fiducial 10ton
- 9×10^{-47}cm^2 & 2×10^{-47} cm^2 @100GeV
- ~1×10^{-5}/keV/kg/d (~1 x pp solar n)

Realize ultimate sensitivity for *e* recoil.



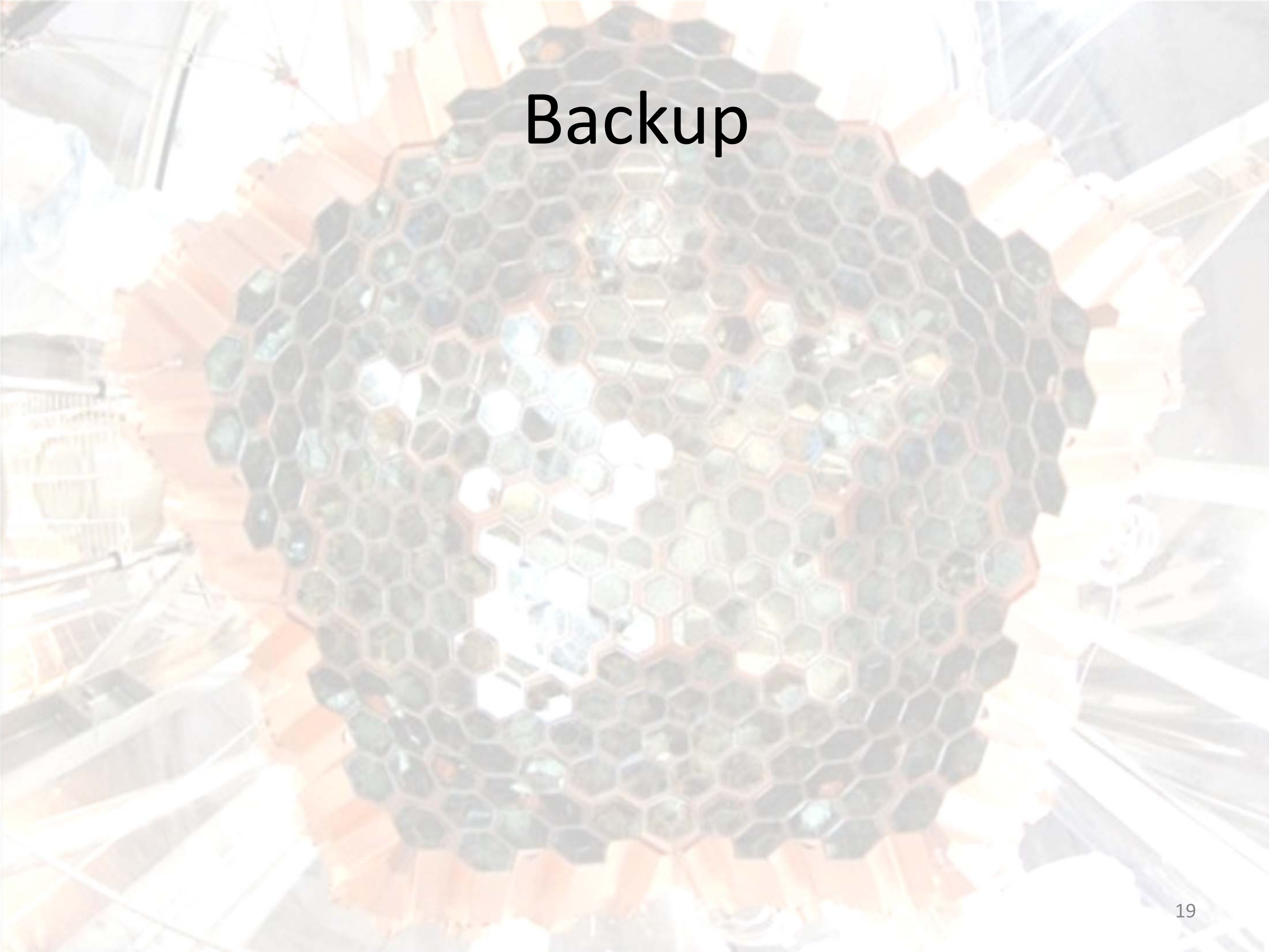




Summary

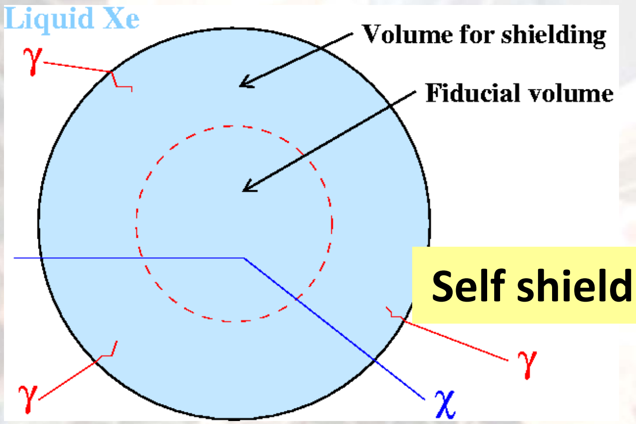
- Current status
  - After refurbishment, event rate around ~5keV is reduced by ~1/10. Now, the 3rd year continuity operation is ongoing. The longest running time among LXe detectors.
- This year's physics result
  - Dark matter search by means of annual modulation due to relative motion of the Earth around the Sun
    - In the model independent analysis, no significant modulated signal has been observed.
    - In the standard WIMP search, DAMA/LIBRA region is mostly excluded by our measurement. It's the first extensive search against the DAMA region, including electron recoils.
  - Search for double electron capture on ^{124}Xe
    - No significant excess above background was observed.
    - We set the world best lower limit $T_{1/2}(2\nu 2K) > 4.7 \times 10^{21}$ years (90% CL).
- Future of XMASS
  - Performance test of the new PMT for future XMASS was done using the first batch of the PMTs successfully.
  - Reduction of radioactivity in PMT parts done.
  - Aim to $\sigma_{SI} < 10^{-46}$cm2(>5keV) for fiducialization.

Backup

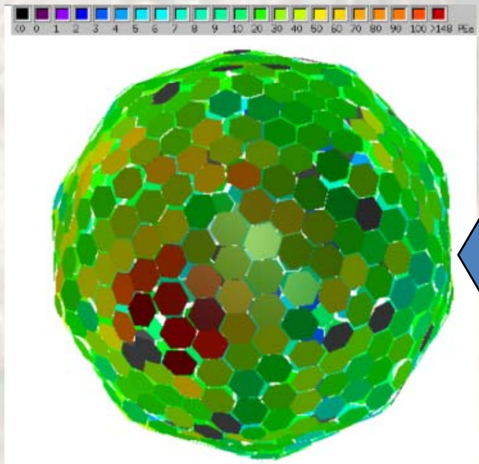


Characteristics of XMASS

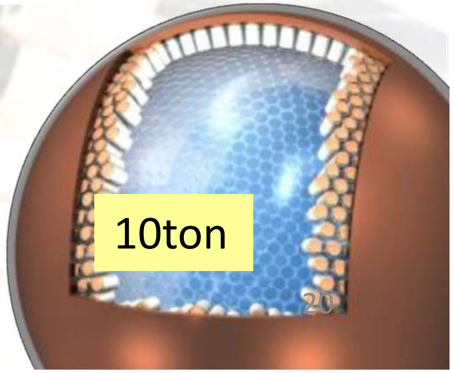
- XMASS : single phase detector
  - Large volume and simple structure, operation.
    - 1 ton scale xenon detector, 100kg for fiducial volume.
  - Background reduction technique :
    - Self shielding
    - Reconstruction by hit pattern of PMTs
  - High light yields & Large photon coverage (15 pe/keV)
    - Low energy threshold (< 5 keVee ~ 25 keVNR) for fiducial volume
    - Lower energy threshold: 0.3 keV for whole volume
  - Large Scalability, simple to construct.



Self shielding



1ton



10ton

Low background technique

(1) BG from detector materials

- 642 PMTs: We developed new ultra low RI PMT with Hamamatsu. (1/100 of ordinary one).

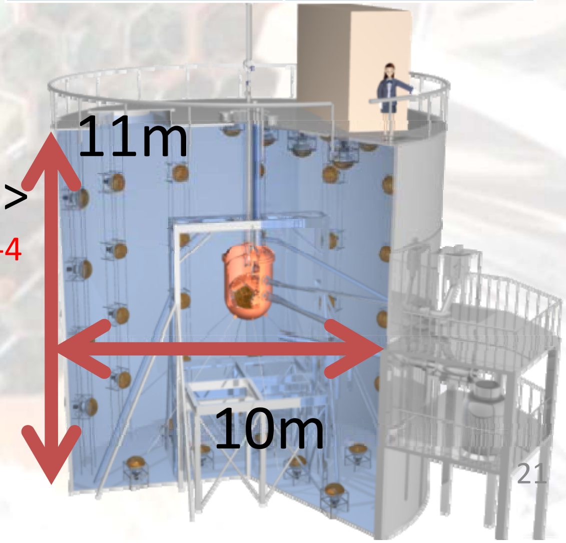
●OFHC copper: Bring in the mine < 1month after electrorefining (Mitsubishi Material Co.)
●Other materials: All the components were selected with HPGe and ICP-MS. (>250 samples were measured)
The total RI level is much lower than PMT BG.

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)

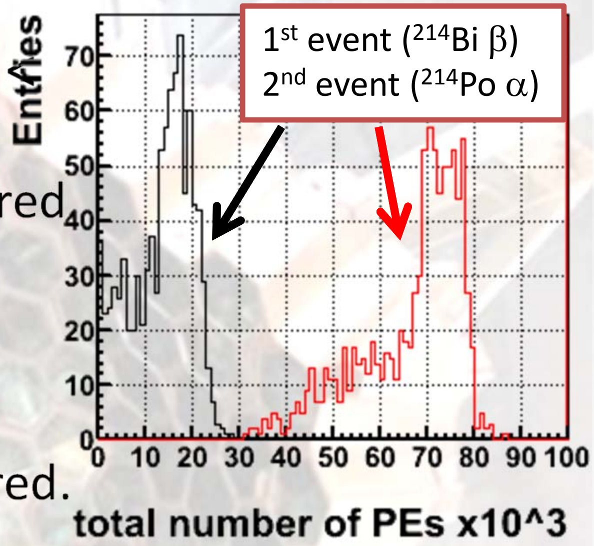
- Radon : Our goal (<10-5 /day/keV/kg)=> 222Rn 0.6 mBq/detector
  – Radon emanation from detector material was measured with material selection. <15mBq/detector was estimated.
  – Radon concentration in XMASS by Bi-Po coincidence analysis : 8.2+/-0.5mBq.
  – The radon removal system from xenon gas are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

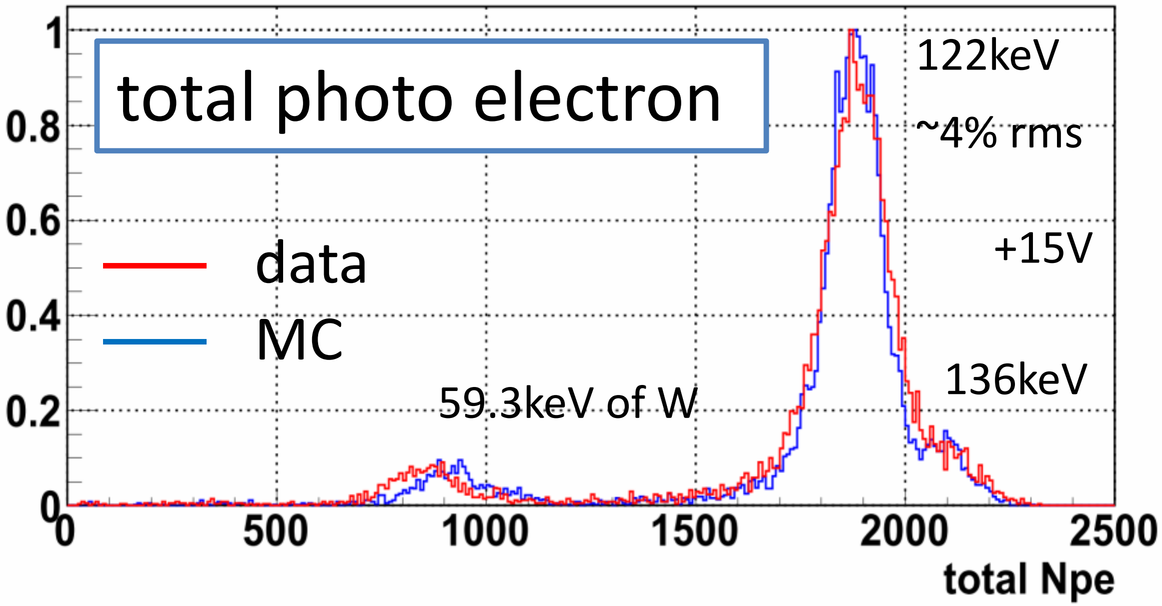
K. Abe et al. for XMASS collab., Astropart. Phys. 31 (2009) 290

  – <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.

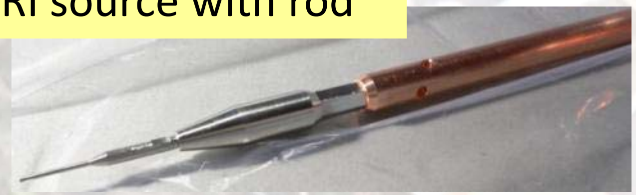


Distillation tower

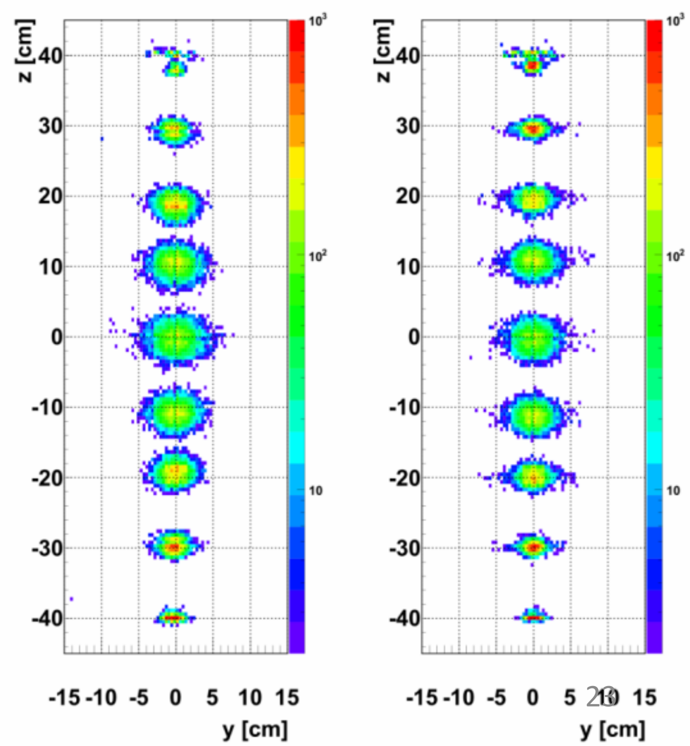
Detector response for a point-like source (~WIMPs)



RI source with rod

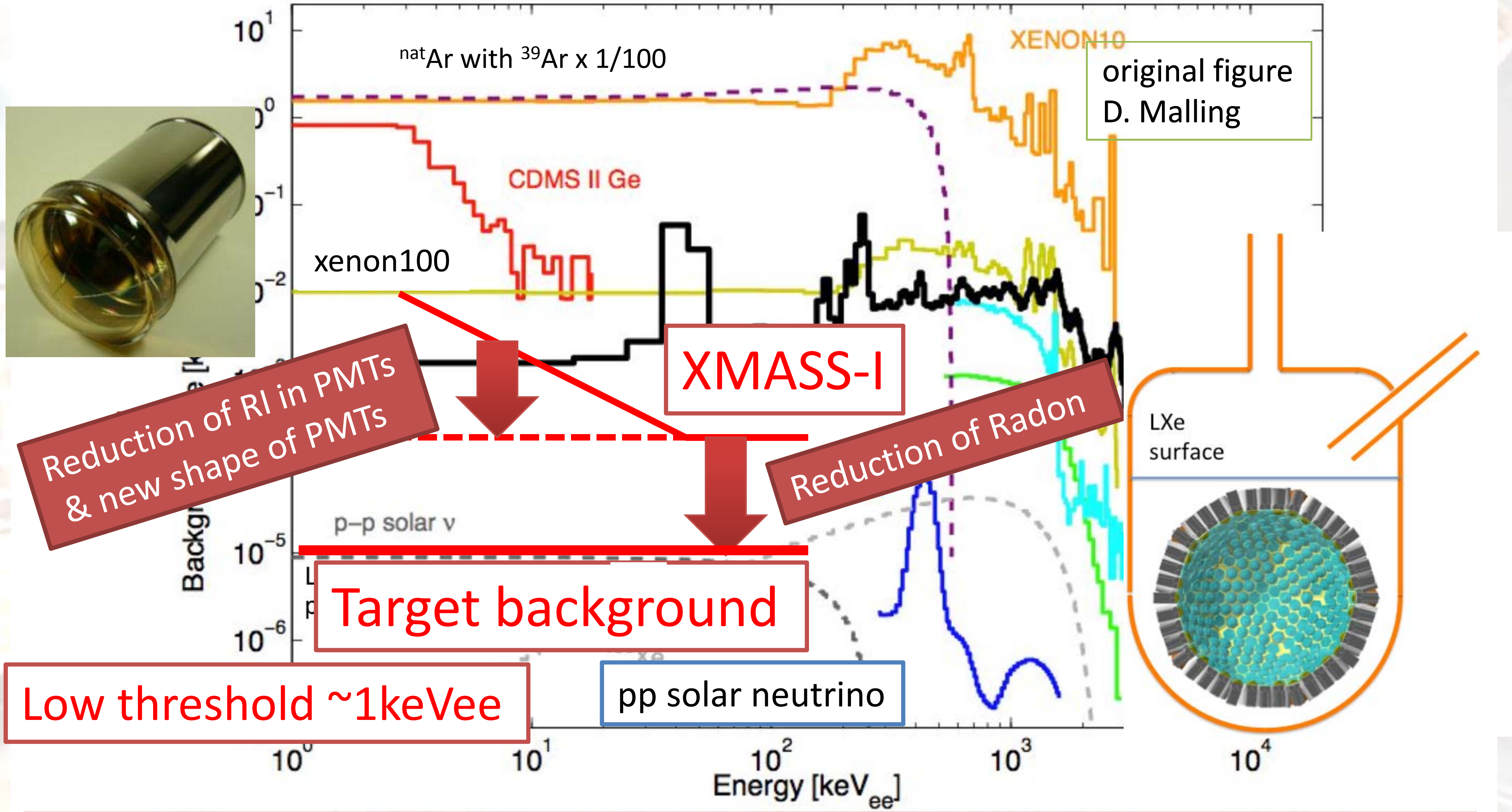


reconstructed vertex



- ^{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.

The world best background of electron recoils in fiducial volume and reduction for future XMASS



By achieving the ultimate BG caused by pp ν BG and utilizing the low threshold, an extensive search for DM signal must be done!