THE XMASS EXPERIMENT

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On behalf of XMASS collaboration

10th PATRAS Workshop on Axions, WIMPs and WISPs

29th June - 4th July 2014 CERN Geneva, Switzerland

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★ Introduction to the XMASS experiment

★ Results from XMASS commissioning run

- Light mass WIMPs
- Solar axions
- ^{129}Xe inelastic scattering by WIMPs
- Bosonic super-WIMPs

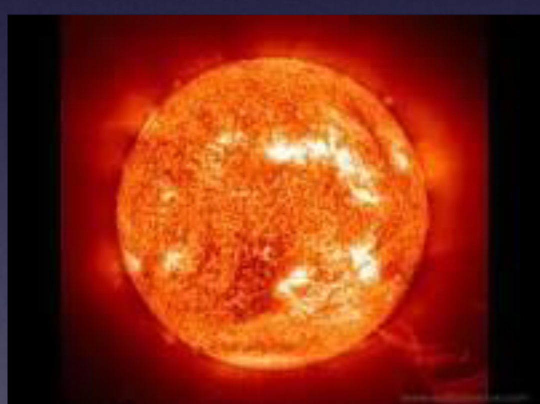
★ Refurbishment of XMASS and current status

The XMASS experiment

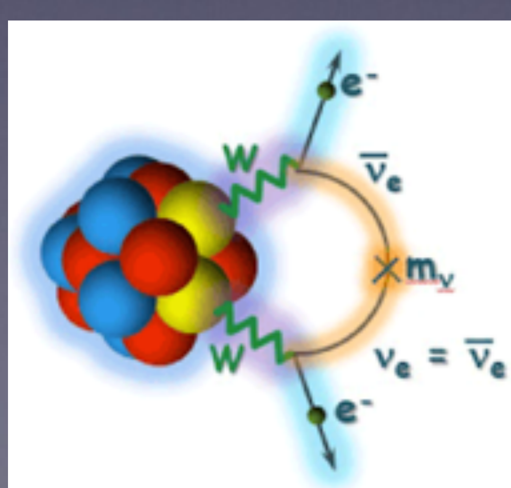
★ Multi purpose low-background experiment with LXe

- Xenon MASSive detector for solar neutrino (pp/^{7}Be neutrino)
- Xenon neutrino MASS detector ($\beta\beta$ decay)
- Xenon detector for Weakly Interacting MASSive Particles (DM)

solar neutrino



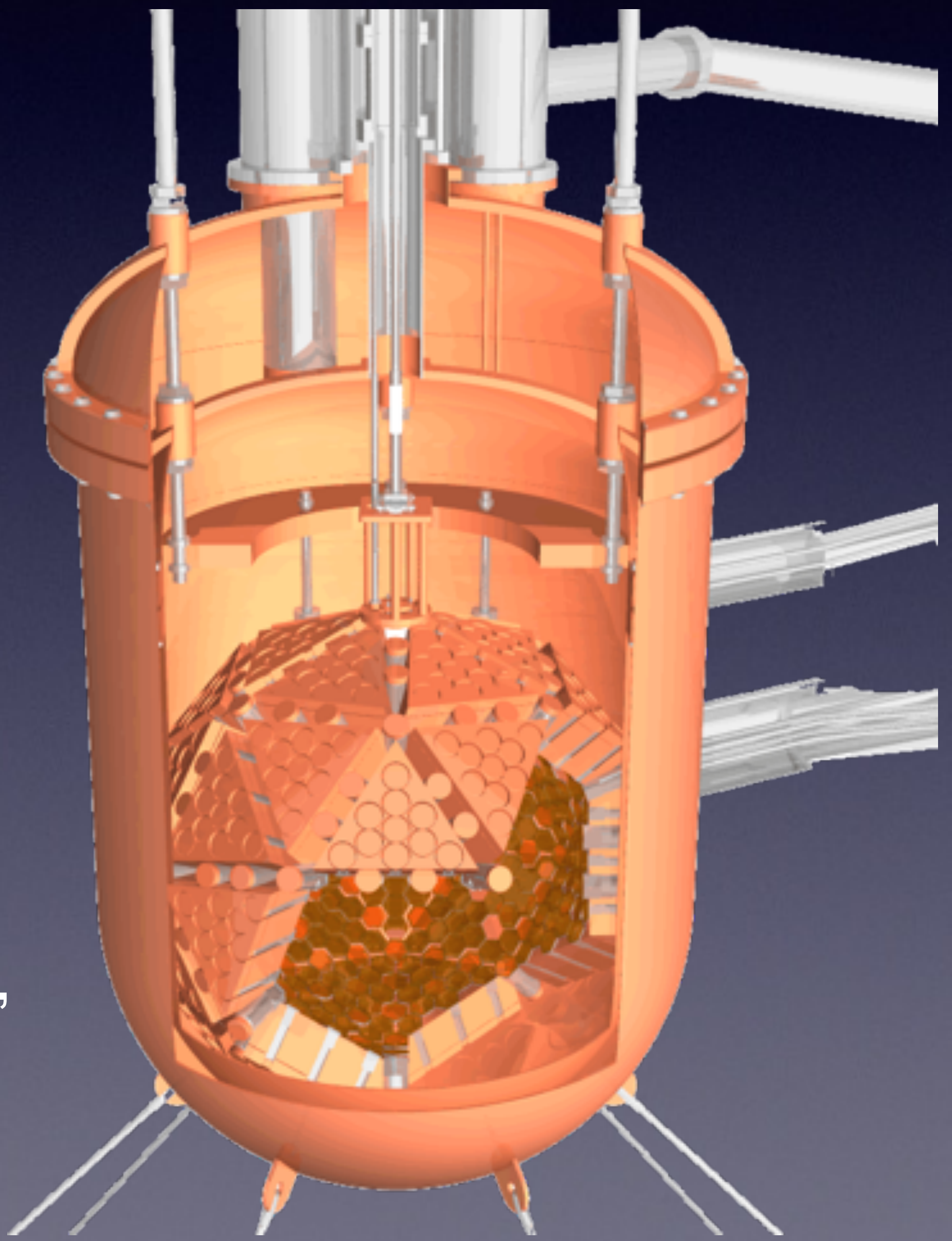
$0\nu\beta\beta$



Dark Matter

Detector and feature

- ★ Located in the Kamioka mine in Japan (~2,700m.w.e.)
- ★ A single-phase detector
- ★ an active target of 835 kg of LXe
- ★ 642 PMTs



feature

- ★ Low energy threshold. (13.9 p.e./keV_{ee})
- ★ Sensitive to e/γ events
  - sensitive to axions,Bosonic super-WIMPs, inelastic scattering and so on, as well as “Standard” WIMPs
- ★ Large target mass and its scalability

The XMASS collaboration

- Kamioka Observatory, ICCC, 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 and B.Yang
- Kavli IPMU, the University of Tokyo : J.Liu, K.Martens and Y.Suzuki
- Kobe University : R.Fujita, K.Hosokawa, K.Miuchi, Y.Onishi, N.Oka and 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.Matsuda and T.Takiya
- Sejong University : N.Y.Kim and Y.D.Kim
- KRISS : Y.H.Kim, M.K.Lee, K.B.Lee and J.S.Lee

39 collaborators
10 institutes

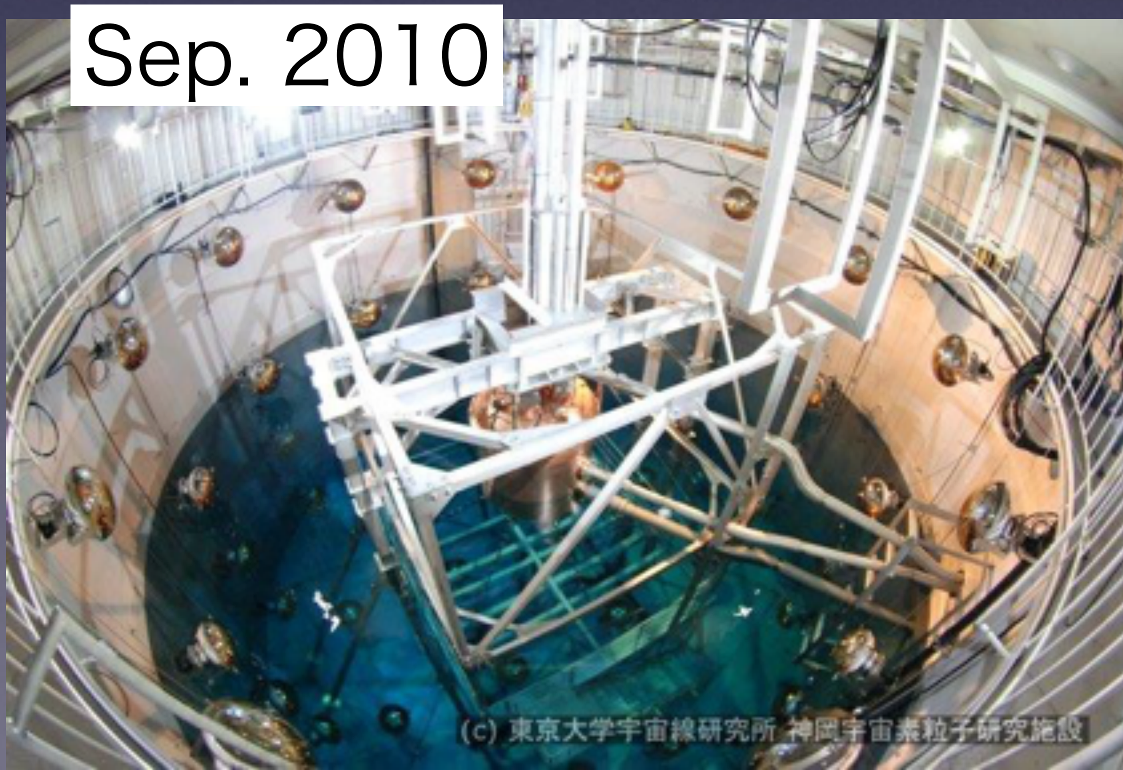
The XMASS I history

2010 → 2011 → 2012 → 2013 → 2014

Dec. | May | Nov.

Installation → commissioning run → Refurbishment → data taking resumed

Sep. 2010

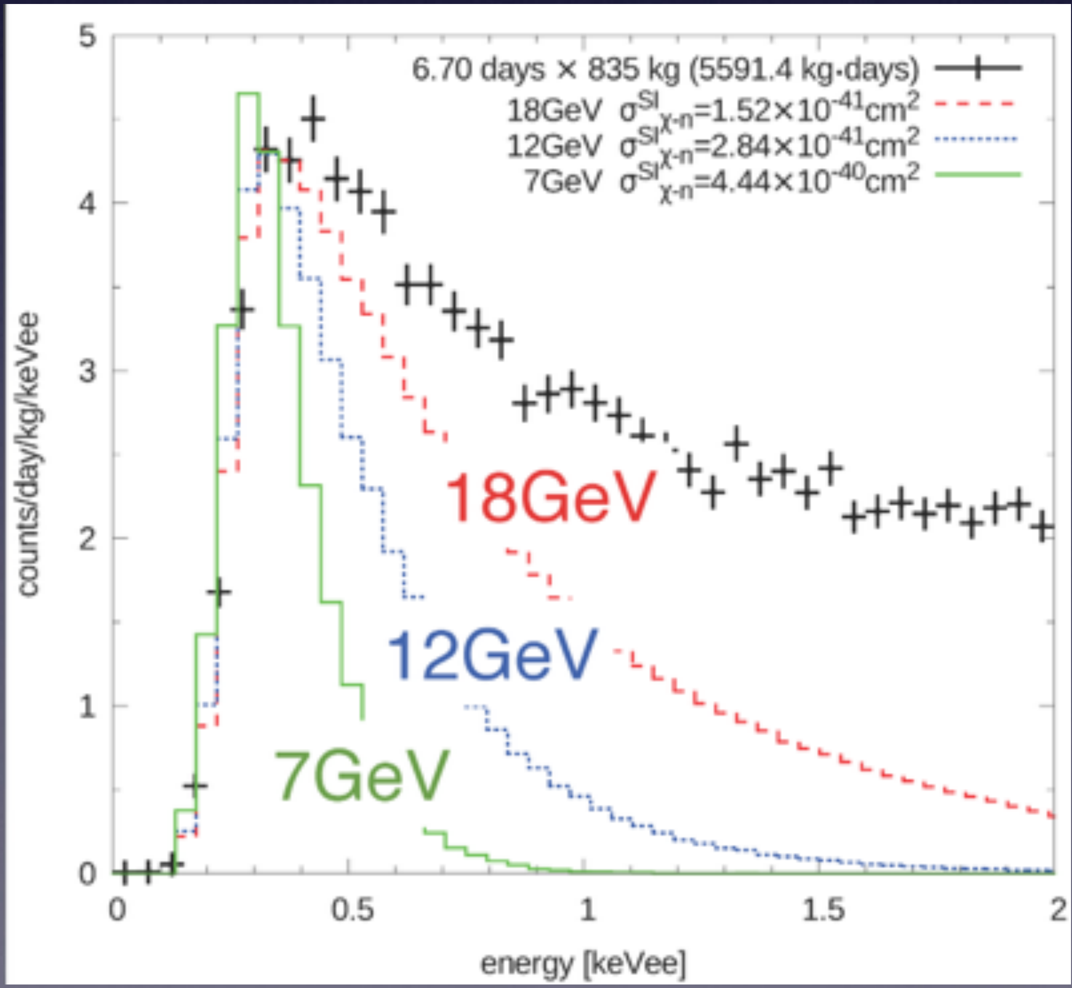


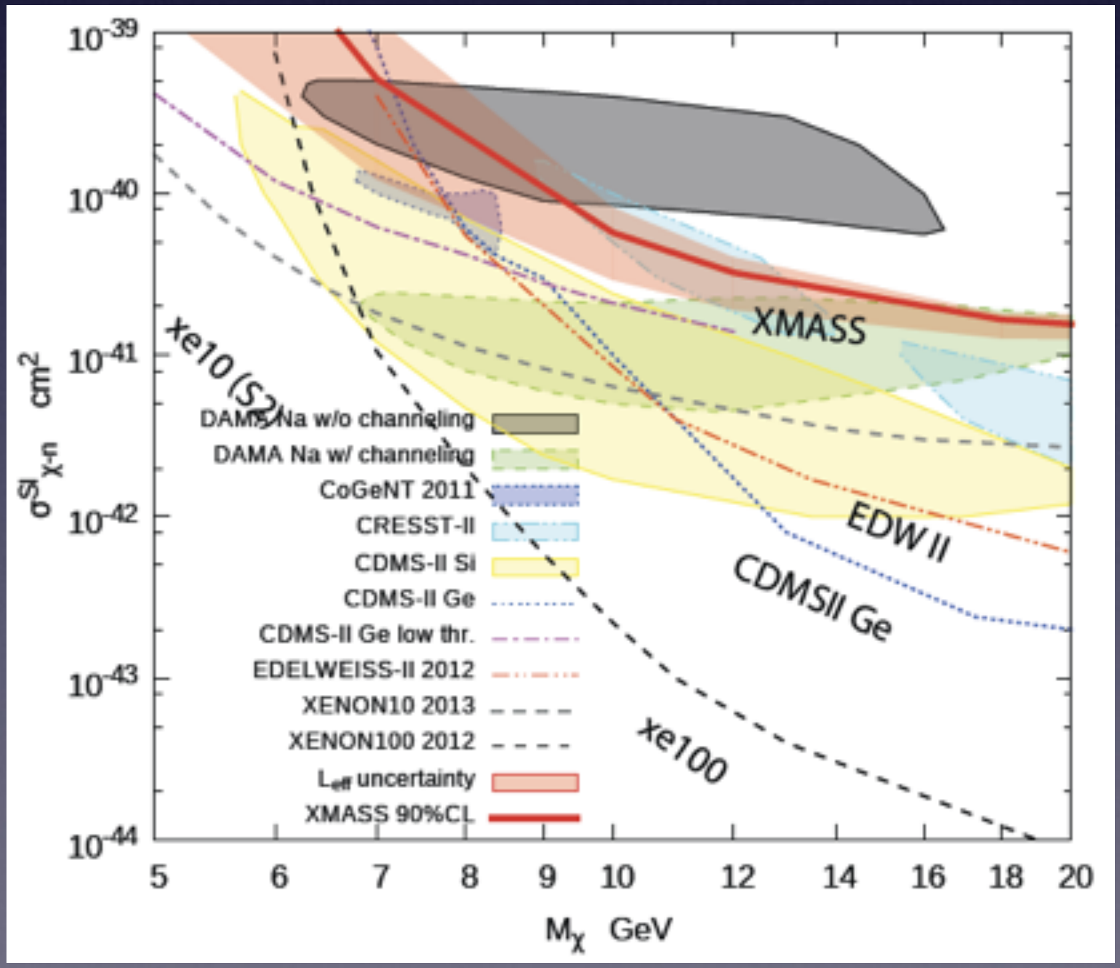
Aug. 2013

Result from XMASS commissioning run

Light mass WIMPs search

- ★ Data : 835kg x 6.7 days
- ★ Full volume analysis , w/o fiducial cut
- ★ Light Yield : 14.7 p.e./keV
- ★ Threshold : 0.3 keV_{ee} (scaled by 122 keV)
- ★ Scintillation Efficiency (L_{eff}) from XENON (Phys.Rev.Lett. 107 (2011) 131302)



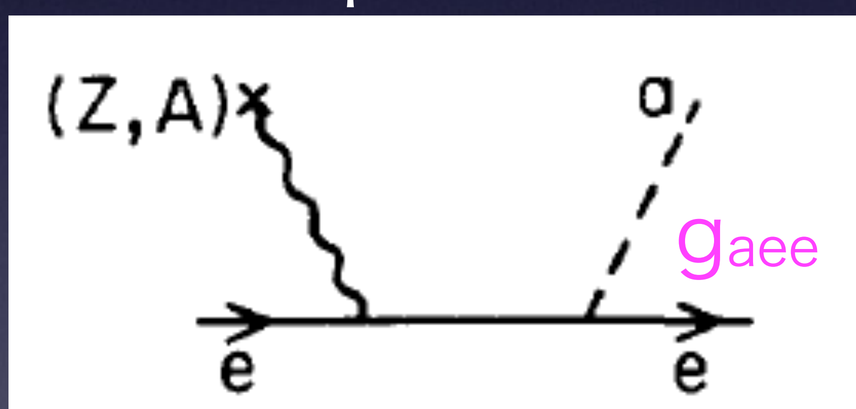


Published in Physics Letters B 719 78 (2013)

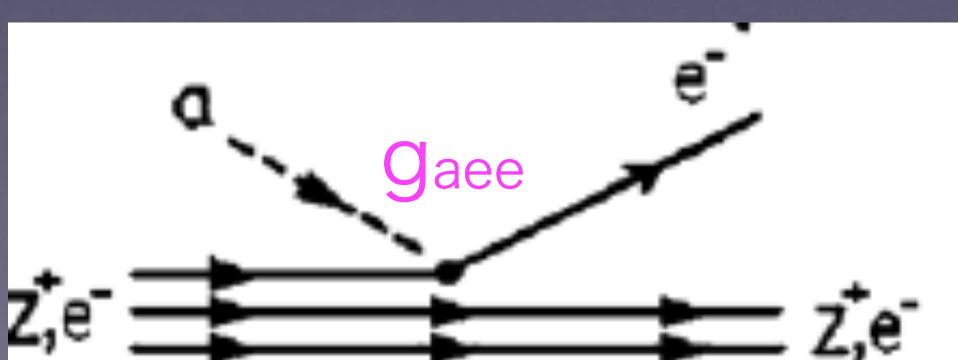
Solar axions

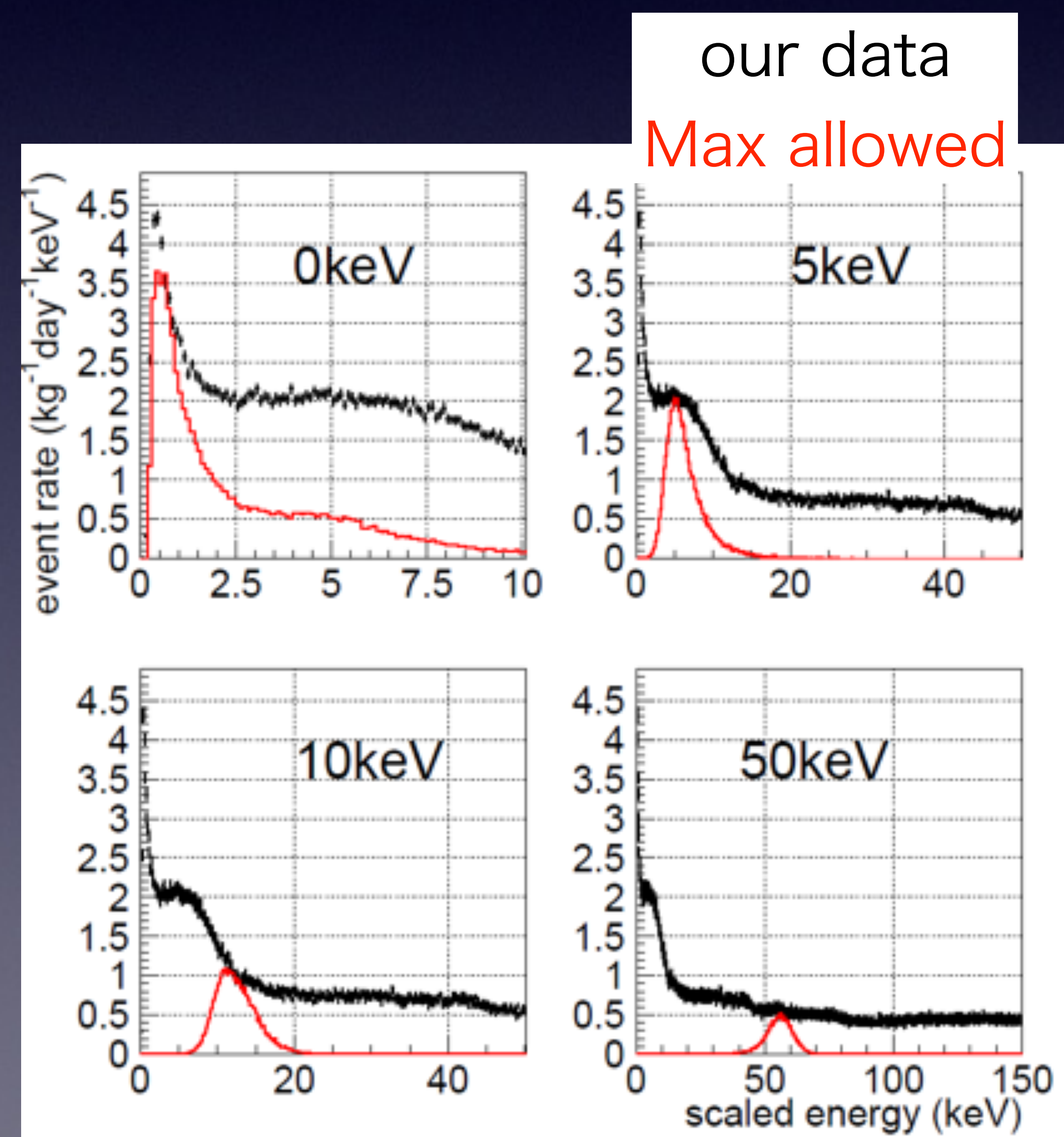
- ★ Axions can be produced in the sun by bremsstrahlung and Compton effect, and detected by axio-electric effect in XMASS
- ★ The same data set as the light mass WIMP search is used

Bremsstrahlung and Compton effect

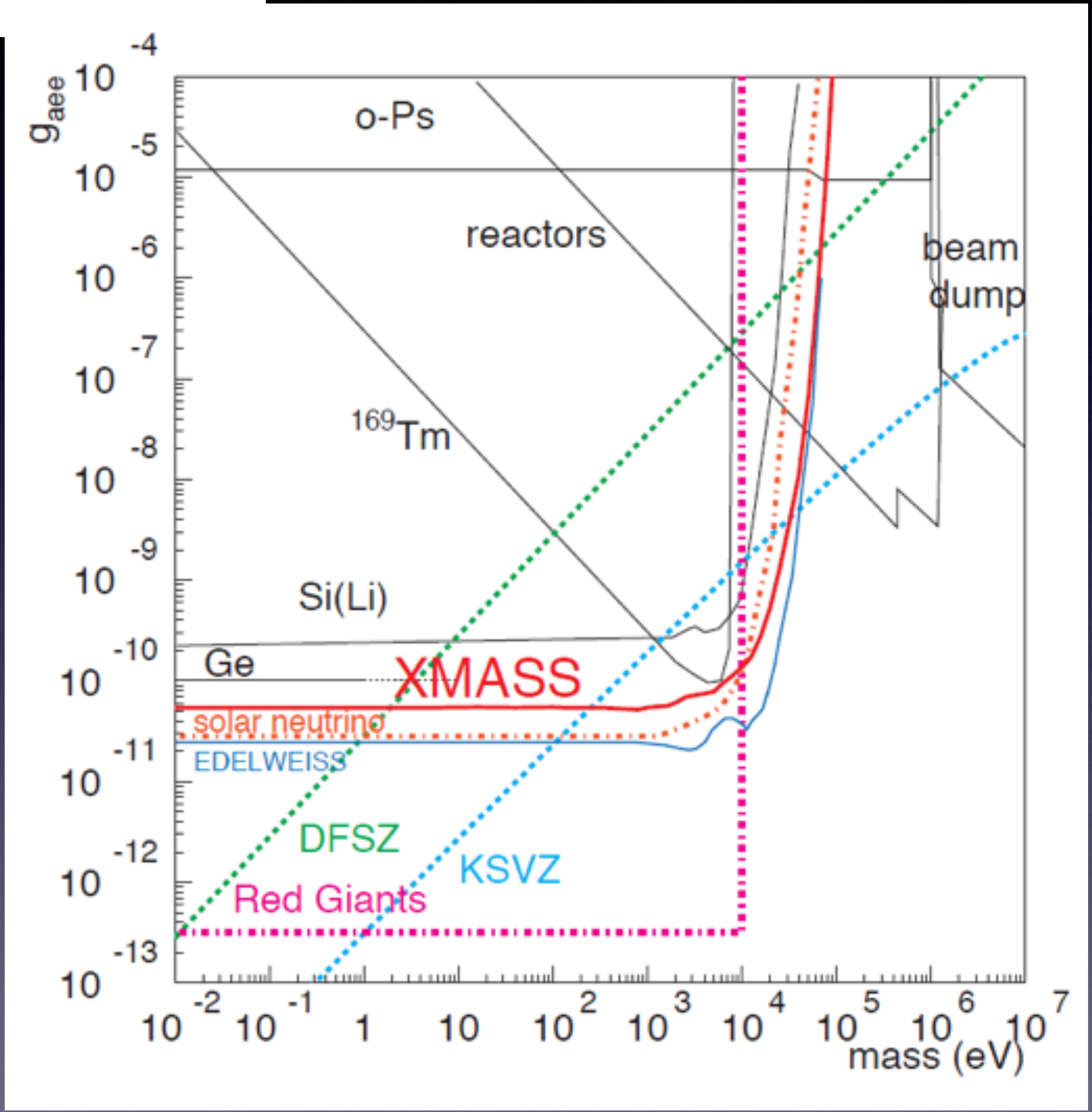


axio-electric effect

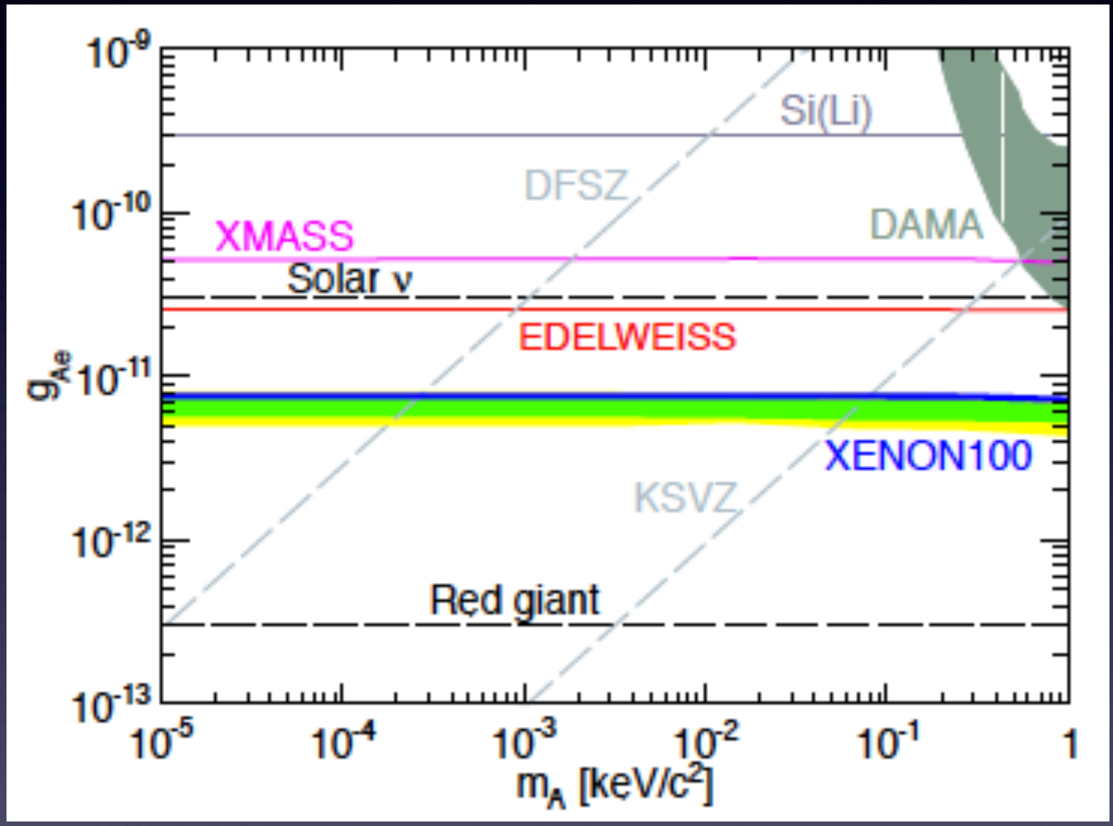




Solar axions



arXiv:1404.1455



Published in Physics Letters B 724 46 (2013)

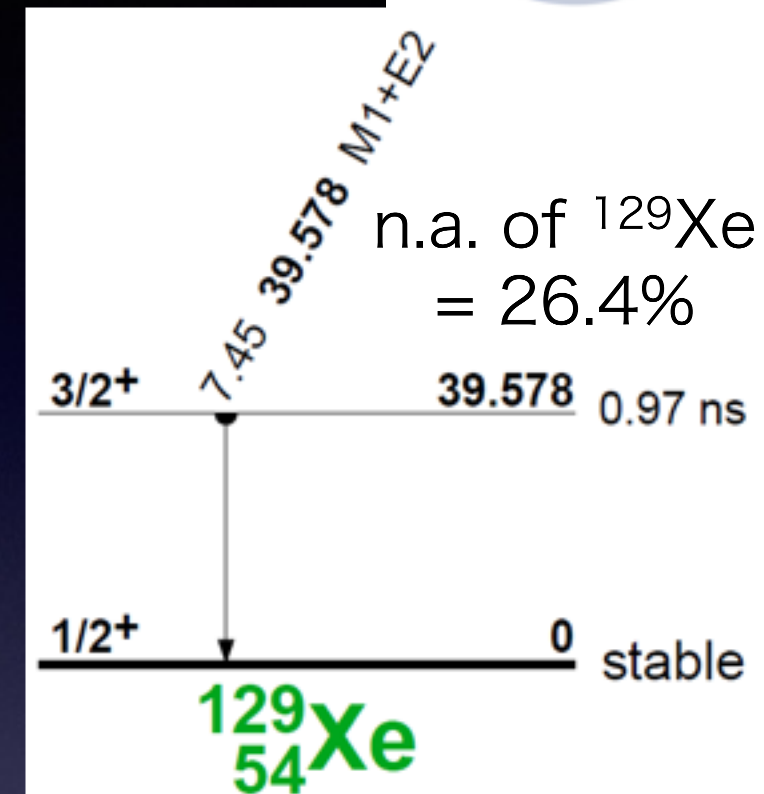
^{129}Xe inelastic scattering by WIMPs

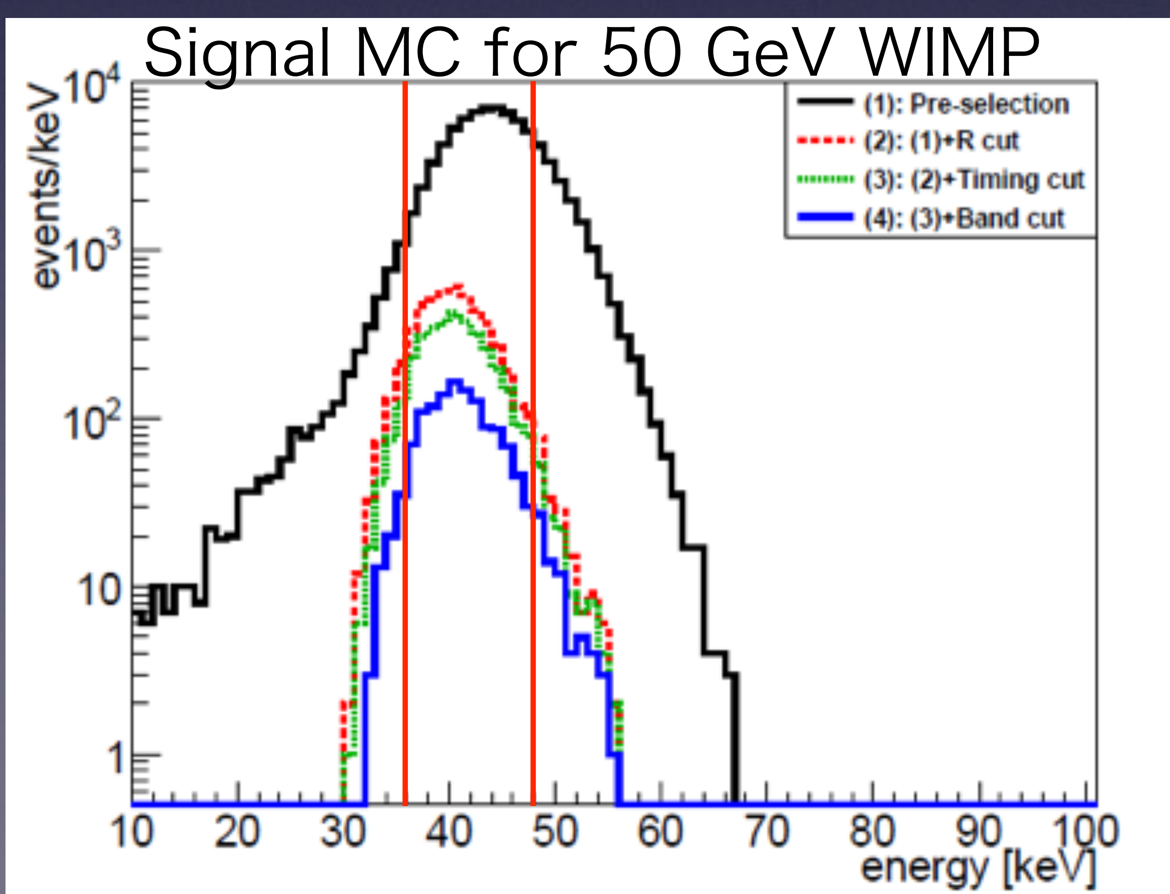
★ $\chi + {}^{129}\text{Xe} \rightarrow \chi + {}^{129}\text{Xe}^*$

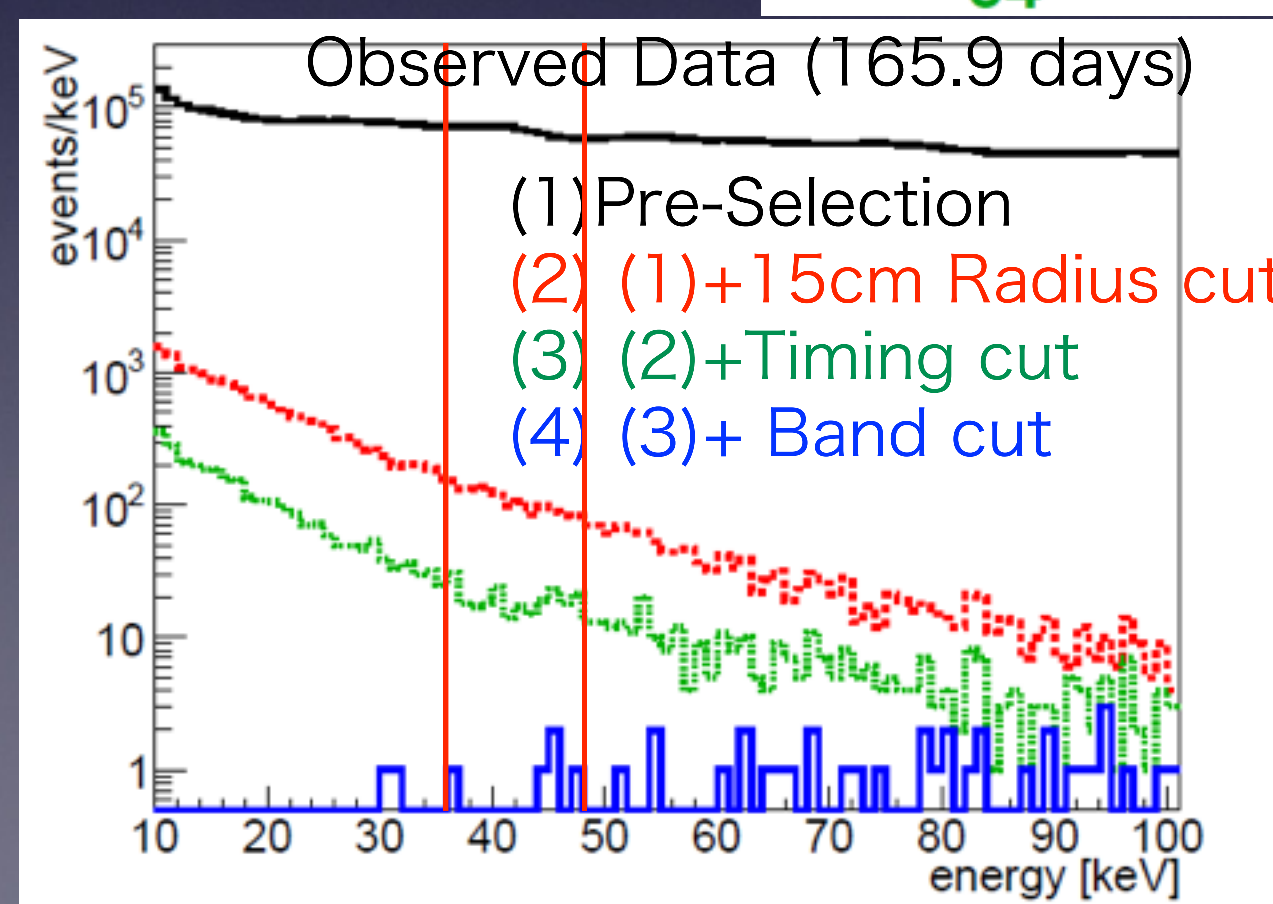
$\rightarrow \chi + {}^{129}\text{Xe} + \gamma$ (39.6keV, $\tau \sim 1.0$ns)

(Not $\chi + \text{N} \rightarrow \chi^* + \text{N}$)

★Intrinsic BG of XMASS I : $O(10^{-4})$/day/kg/keV$_{ee}$ at 40 keV, dominated by ^{214}Pb, w/o PID

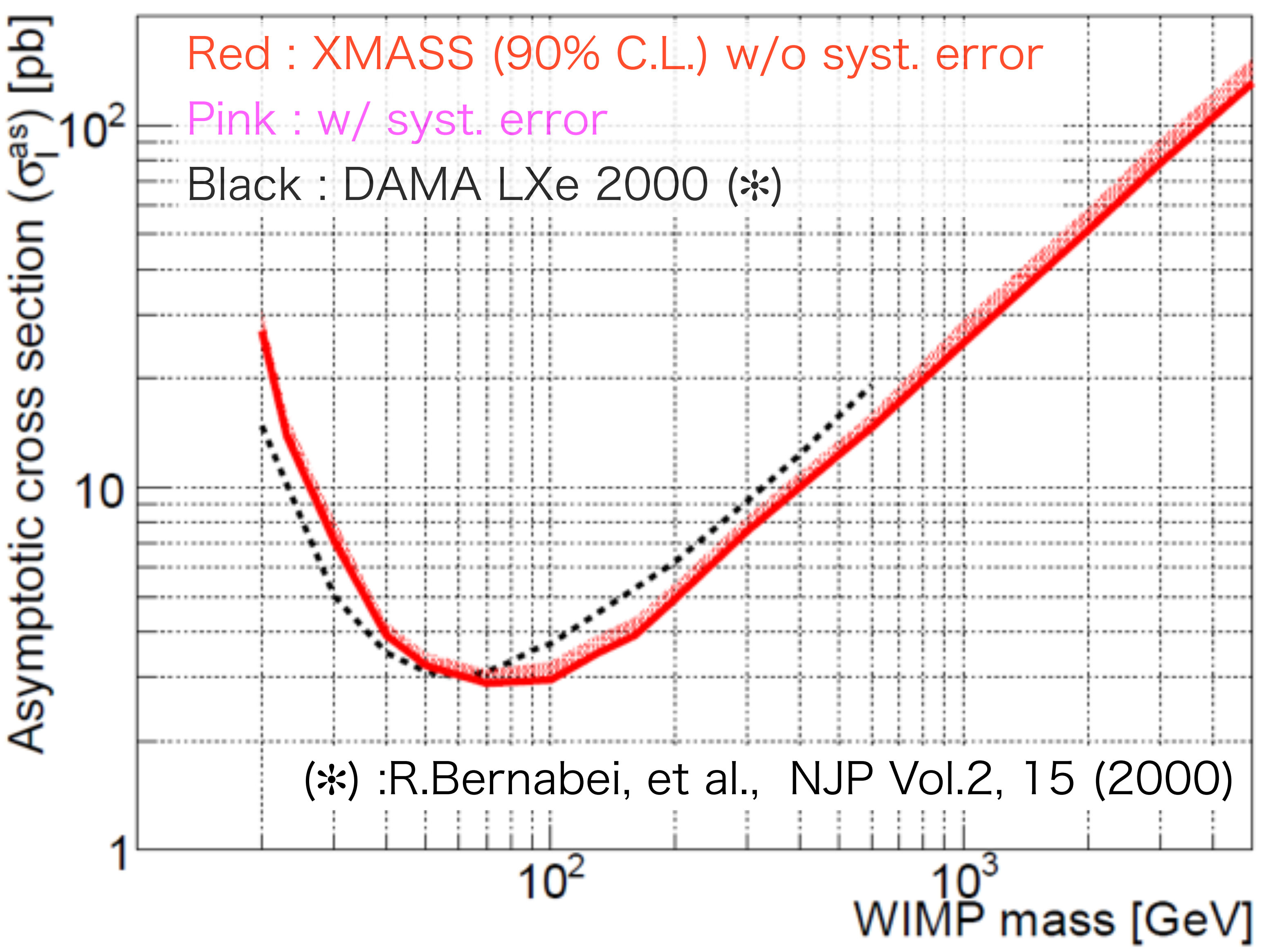






^{129}Xe inelastic scattering by WIMPs

- ★ We first choose the form factor which is the one used by DAMA group, to allow for comparison with this, the only other inelastic scattering result for ^{129}Xe
- ★ asymptotic cross section for inelastic scattering on ^{129}Xe using the same form factors as DAMA was obtained.
- ★ Our low BG allows us to derive this limit w/o BG subtraction
- ★ 3.2pb at 50 GeV WIMPs



Published in PTEP 2014, 063C01

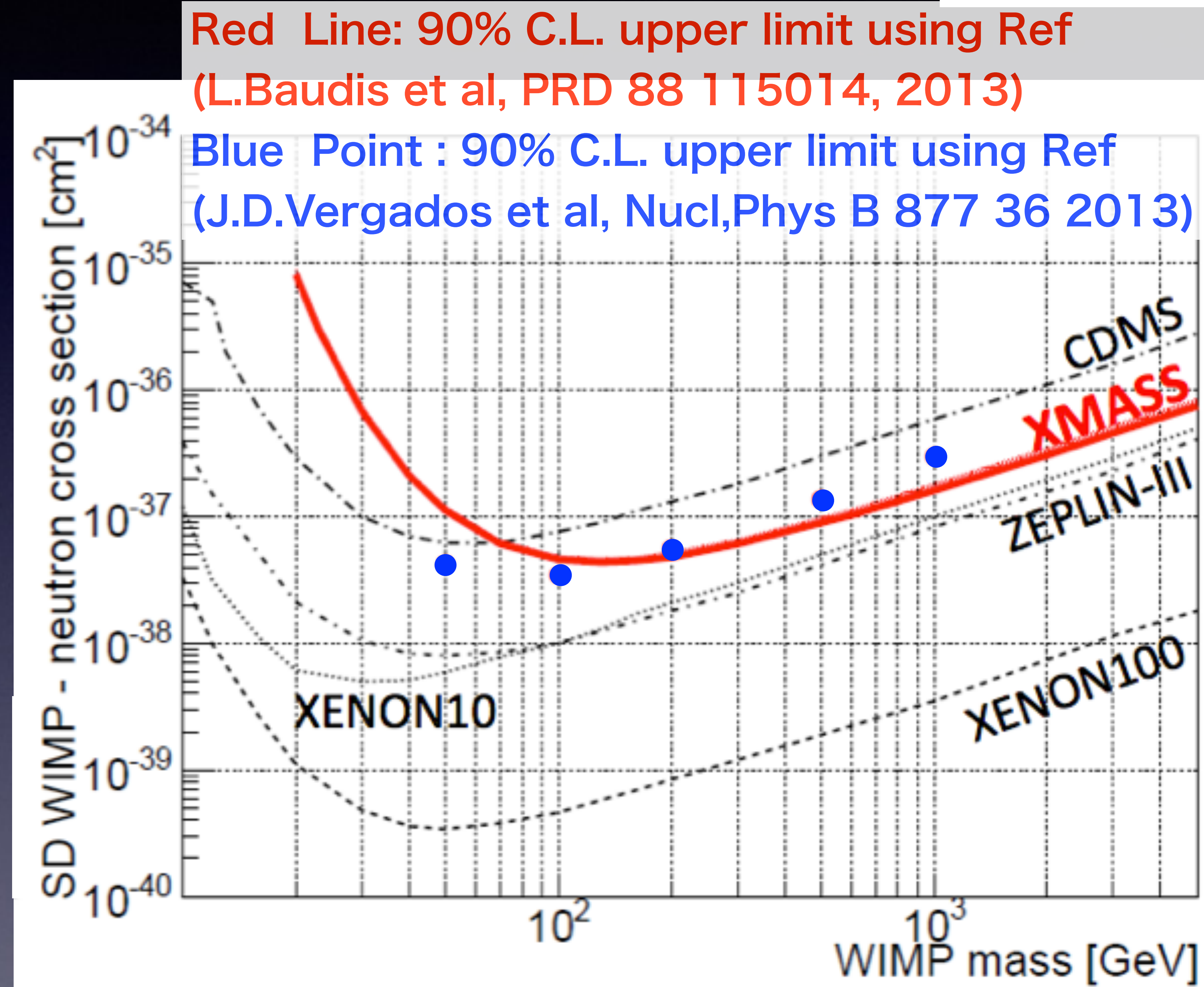
^{129}Xe inelastic scattering by WIMPs

★ Next we use the most recent calculations for interpreting our results in terms of a constraint on SD WIMP-neutron cross section.

★ Results are based on the inelastic structure factors in Ref(✻)

★ Our own limit is the first derived exclusively from data on inelastic scattering

★ 110 fb or 42 fb at 50 GeV, depends on form factor model calculation.



Published in PTEP 2014, 063C01

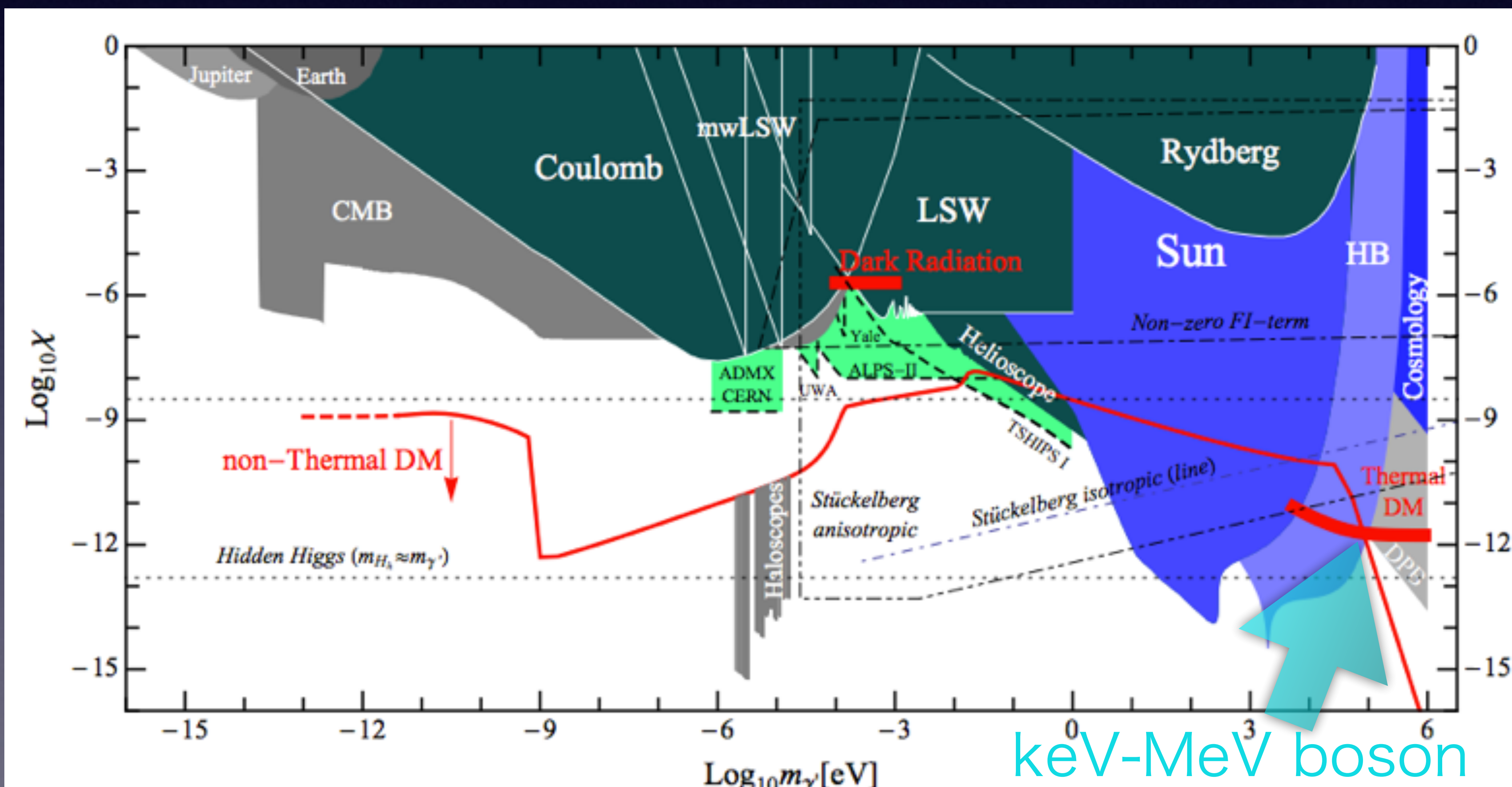
Ref(✻) : L.Baudis et al, Phys.Rev. D 88 115014(2013)

Bosonic Super-WIMPs

★ Candidate for lukewarm Dark Matter

- Search for Pseudoscalar, vector boson

★ For vector boson case, it is called dark, para, hidden photon



Andreas Ringwald

Physics of the dark universe

Vol. 1 p116-135(2012)

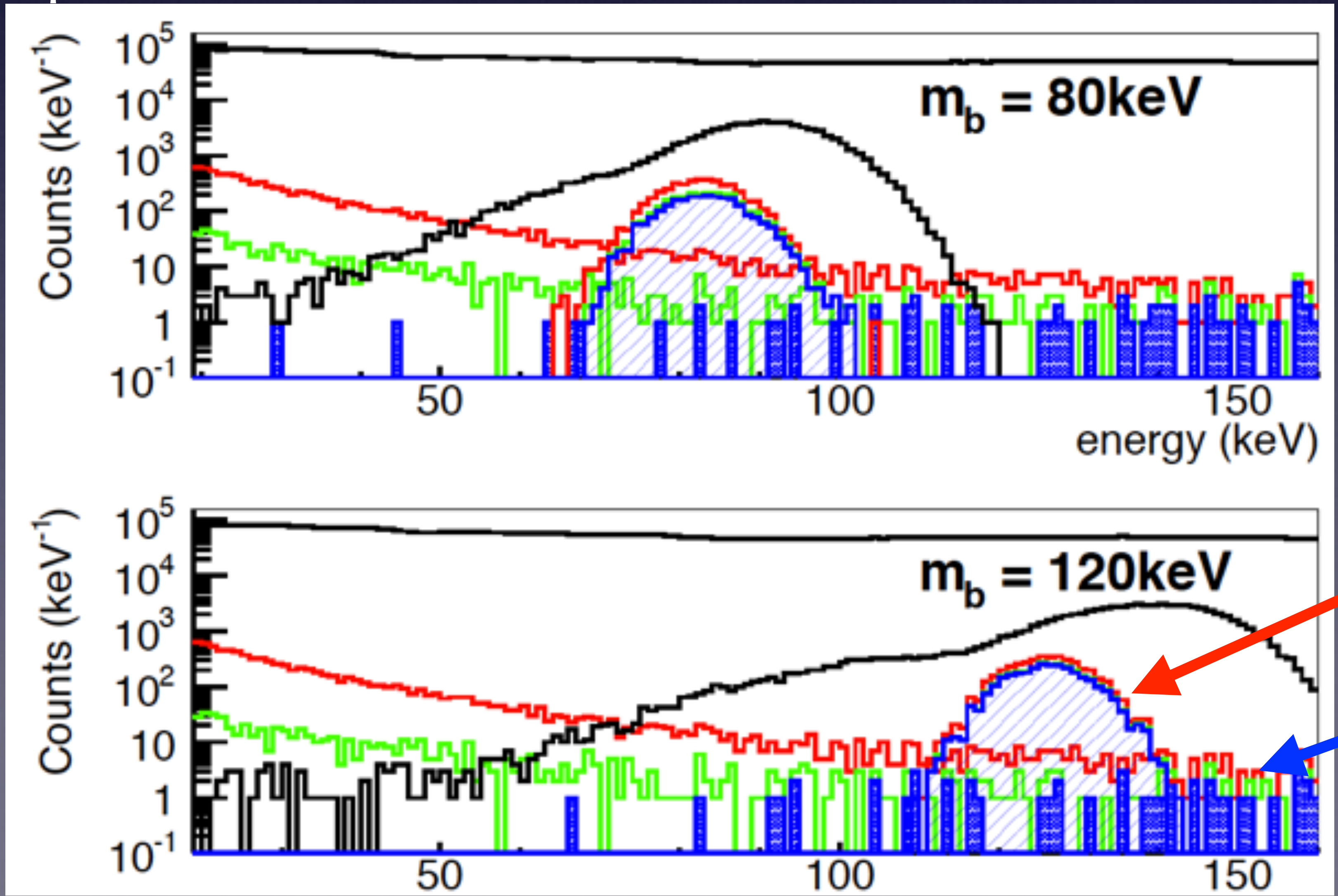
★ For thermal DM, there is only astrophysical constraint.

➡ Need experimental search

Bosonic Super-WIMPs

- ★ mono-energetic peak at the mass of particle like photoelectric interaction
  - Pospelov et, al. Phys. Rev. D 78 115012 (2008)
- ★ Used the same data set as the ^{129}Xe inelastic scattering by WIMPs
- ★ optimized cut for each m_b

Photoelectric-like interaction



(1)Pre-Selection
(2) (1)+15cm Radius cut
(3) (2)+Timing cut
(4) (3)+ Band cut

oblique hatched MC

dark hatched data

Bosonic Super-WIMPs

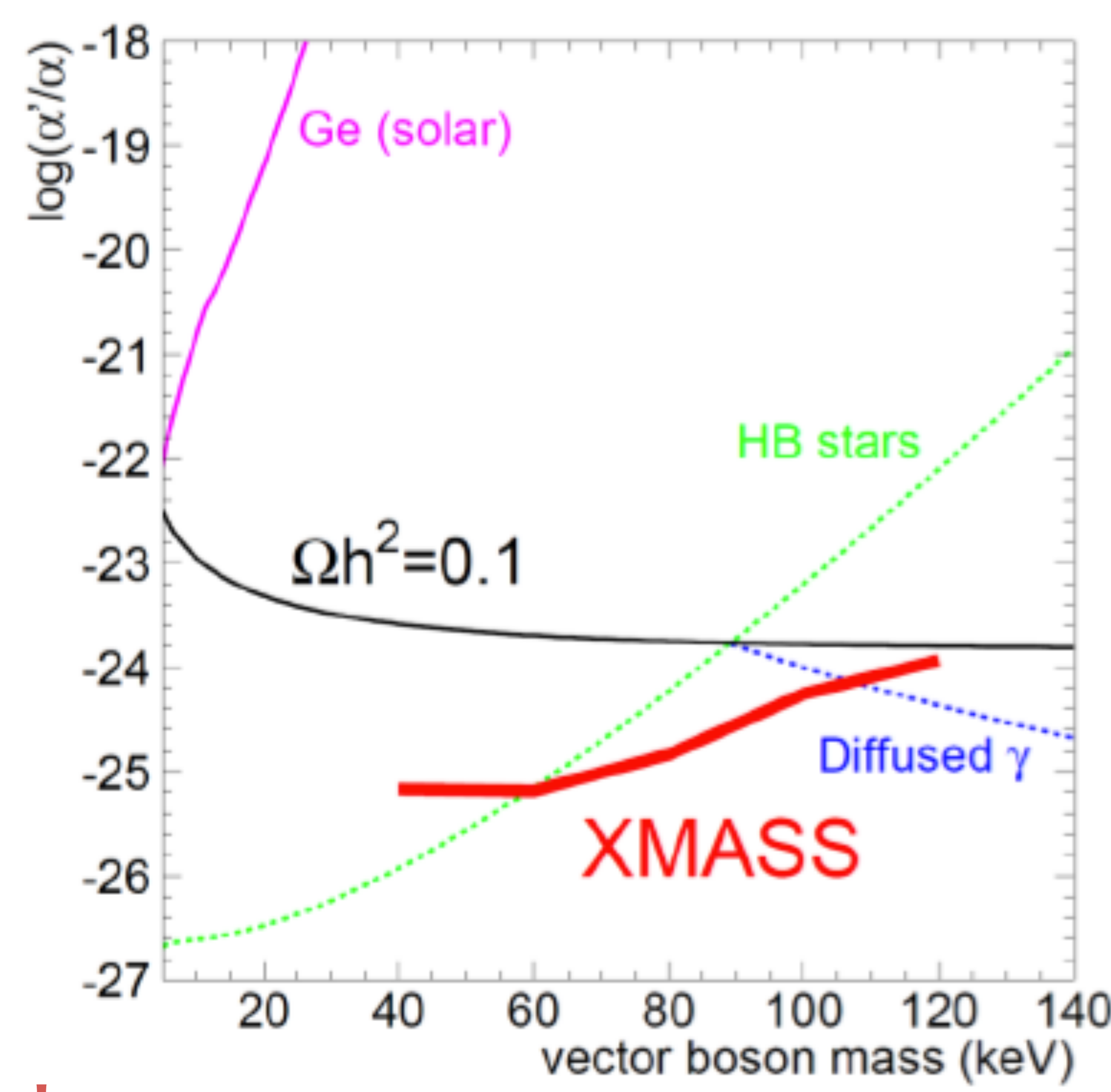
arXiv:1406.0502

- ★ The counting rate in the detector becomes :

$$R \approx \frac{4\times 10^{23}}{A}\frac{\alpha'}{\alpha}\left(\frac{\mathrm{keV}}{m_V}\right)\left(\frac{\sigma_{\mathrm{photon}}}{\mathrm{barn}}\right)\mathrm{kg}^{-1}\mathrm{day}^{-1},$$

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

- ★ event rate ($O(10^{-4})$/day/kg/keV_{ee}) is in good agreement w/ expected BG from ^{214}Pb w/ keeping > 50% signal efficiency



★ **First constraint from experiment**

Ref : R.Horvat D. Kekez, M. Krˇcmar, Z. Kreˇcak, A. Ljubiˇci´ Phys. Lett. B 721, 220 (2013)
M.Pospelov, A. Ritz, and M. Voloshin,et, al. Phys.Rev.D 78, 2008
J.Redondo M. Postma. JCAP 02, 005(2009)

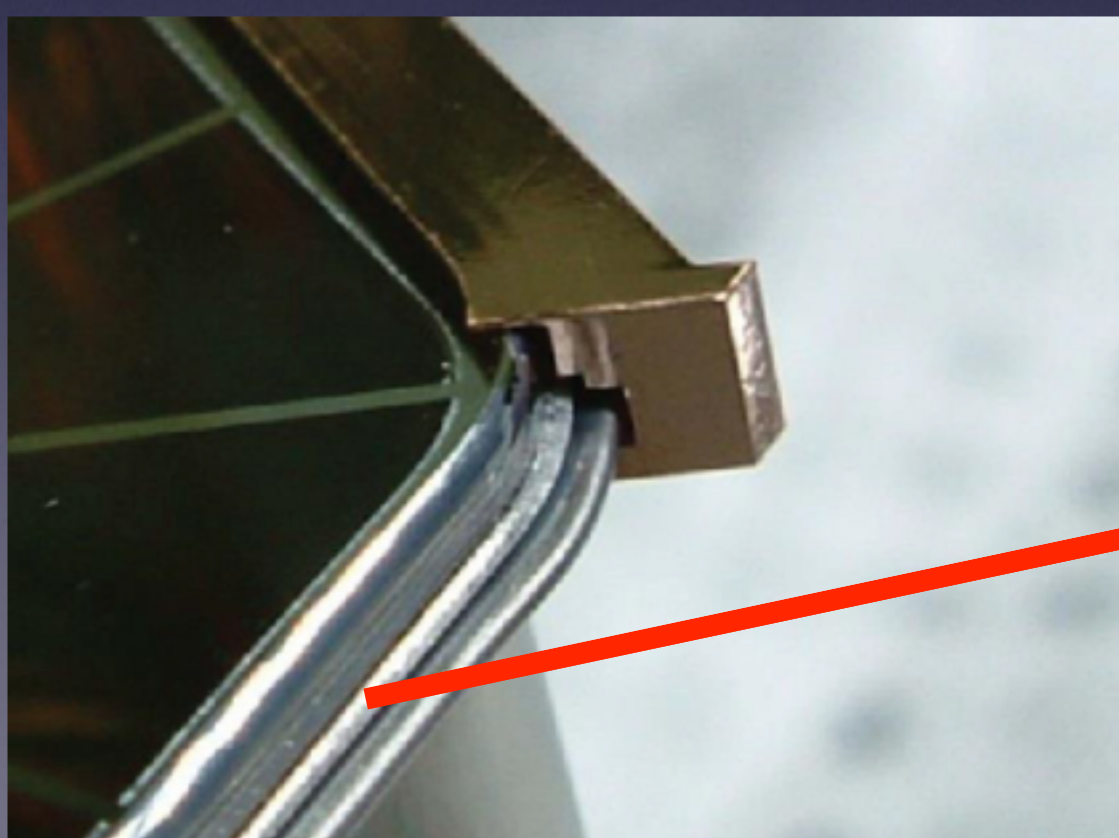
Refurbishment of XMASS and current status

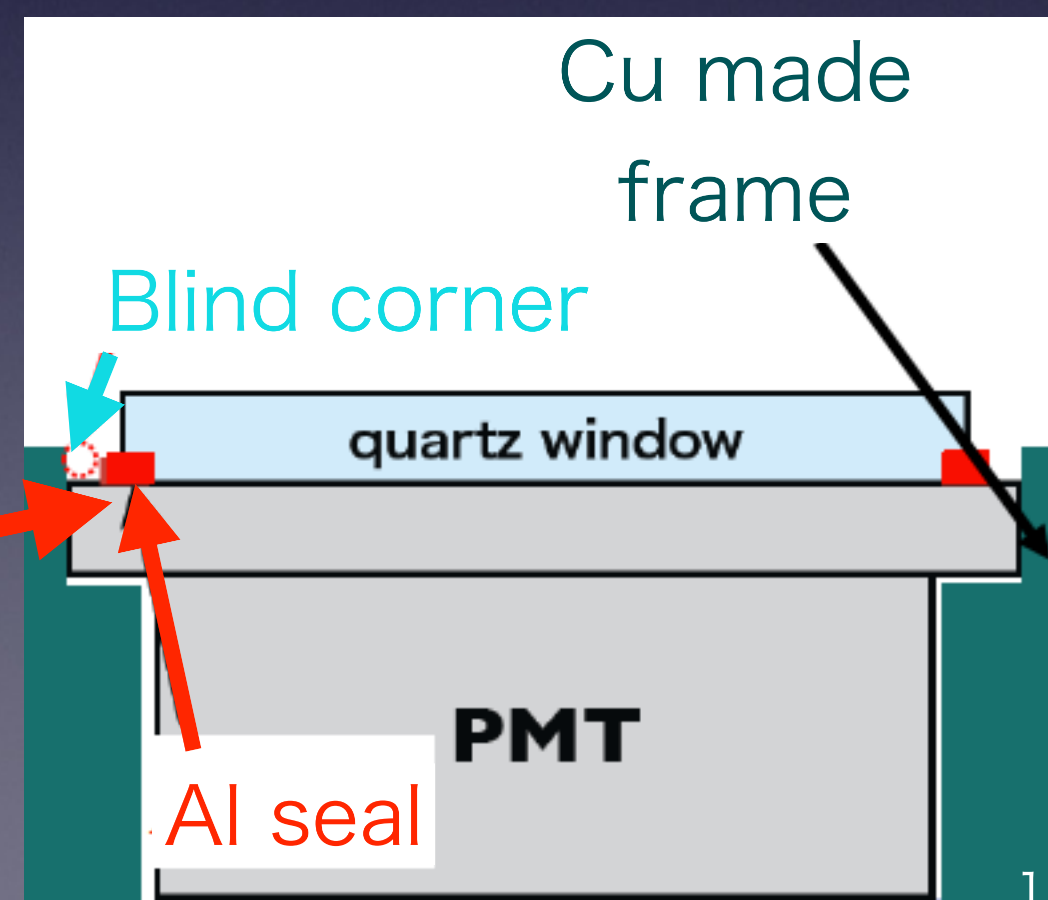
Refurbishment

★ For deeper understanding of BGs, better sensitivities

★ The issues in the commissioning run are :

- RIs (^{210}Pb, ^{238}U) in Aluminium seal of PMTs
- BG events at blind corners of PMTs are frequently mimic events within the fiducial volume





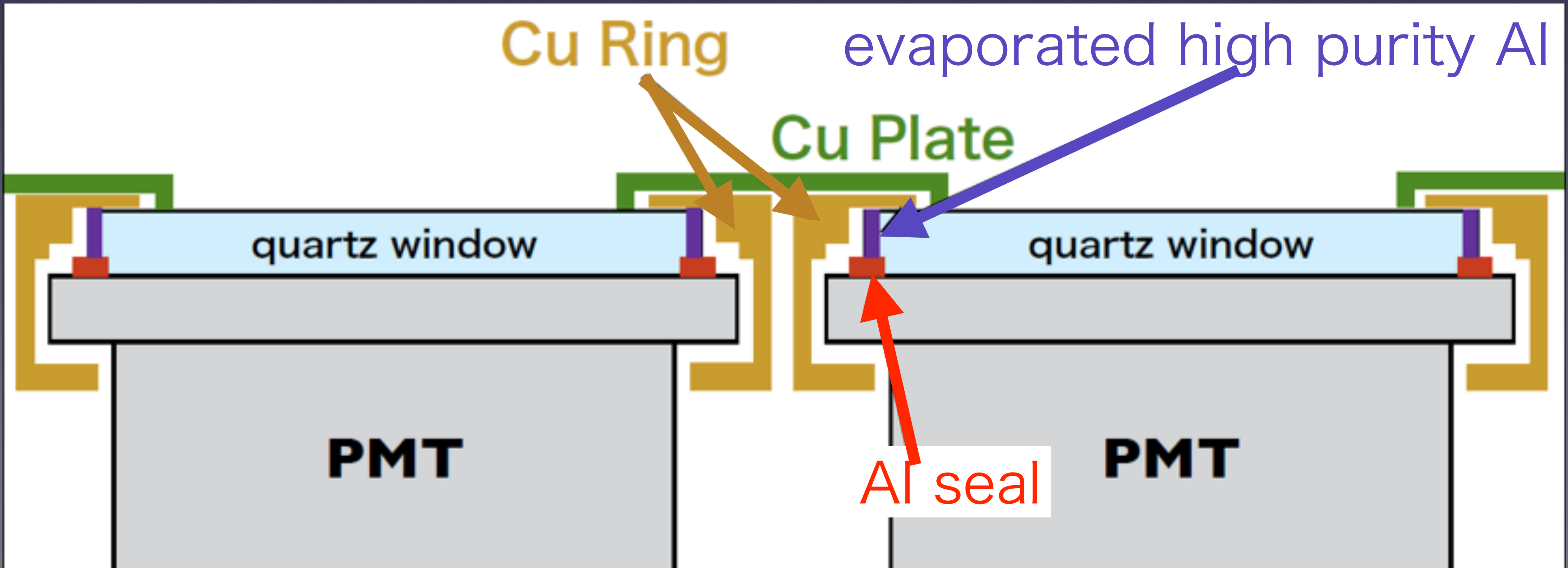
Refurbishment

★ Cu ring over PMT-Al

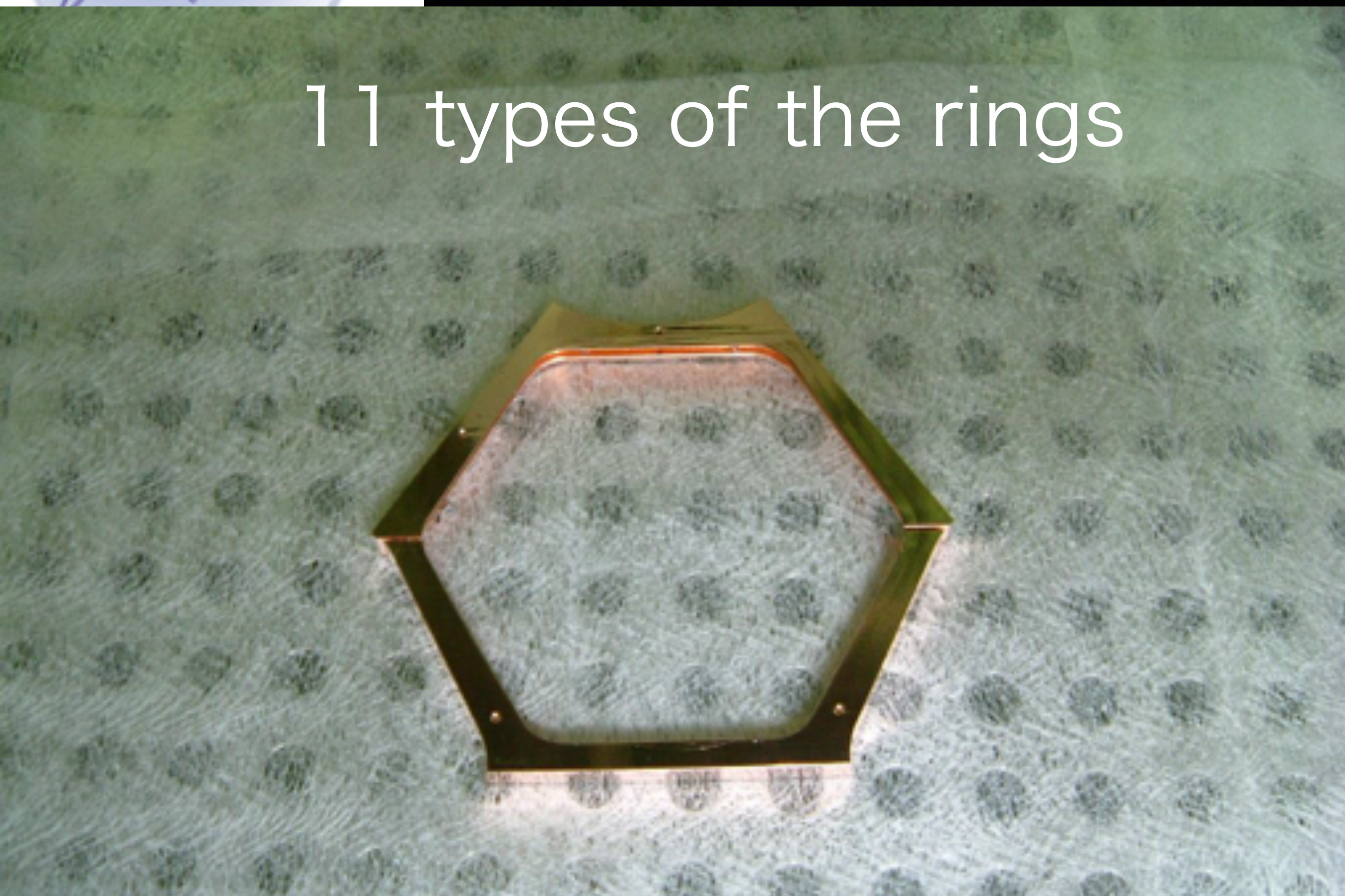
- To minimize scintillation lights from the Al together with the Al deposition at the side of quartz.

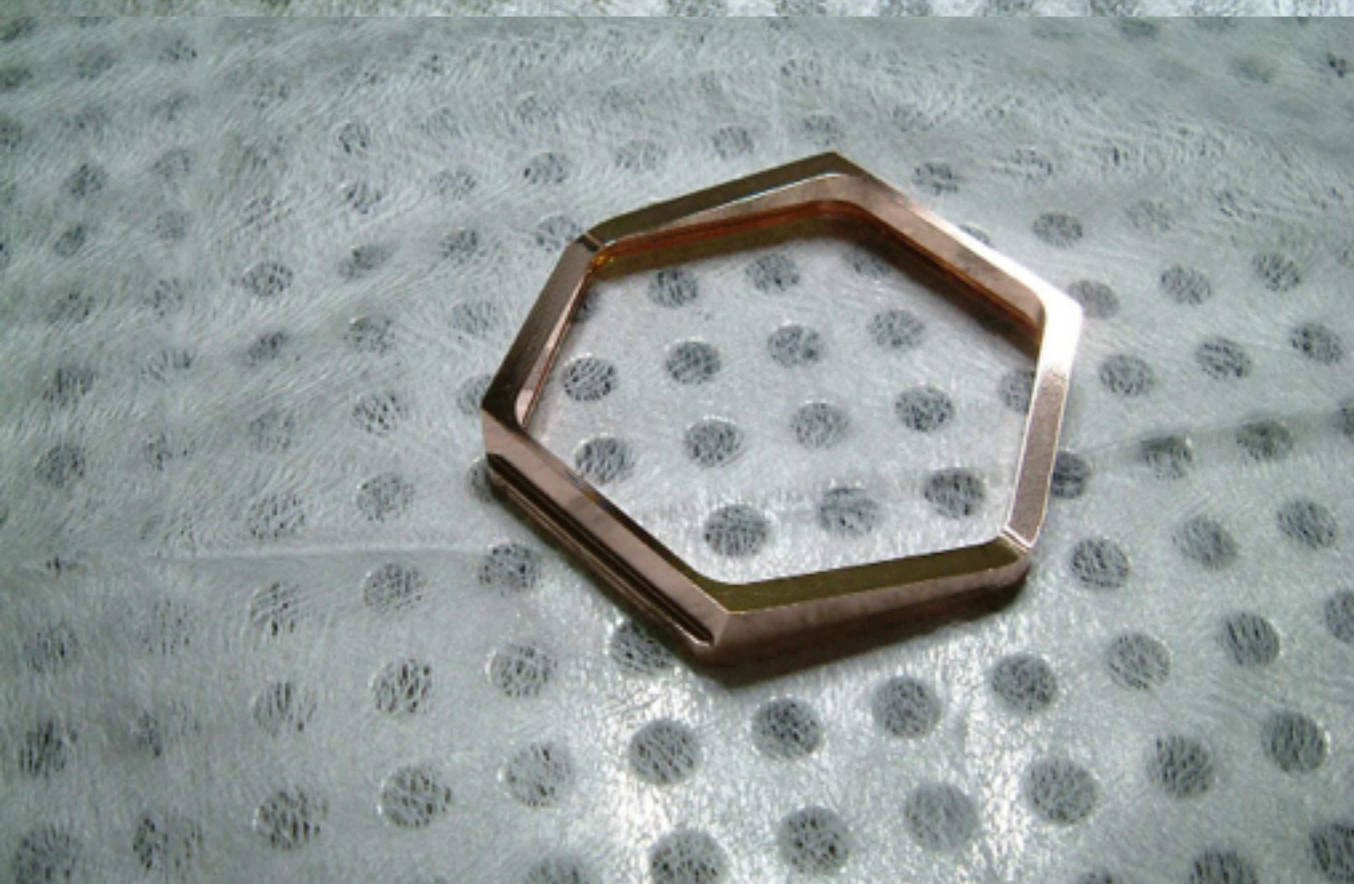
★ Thin Cu Plate

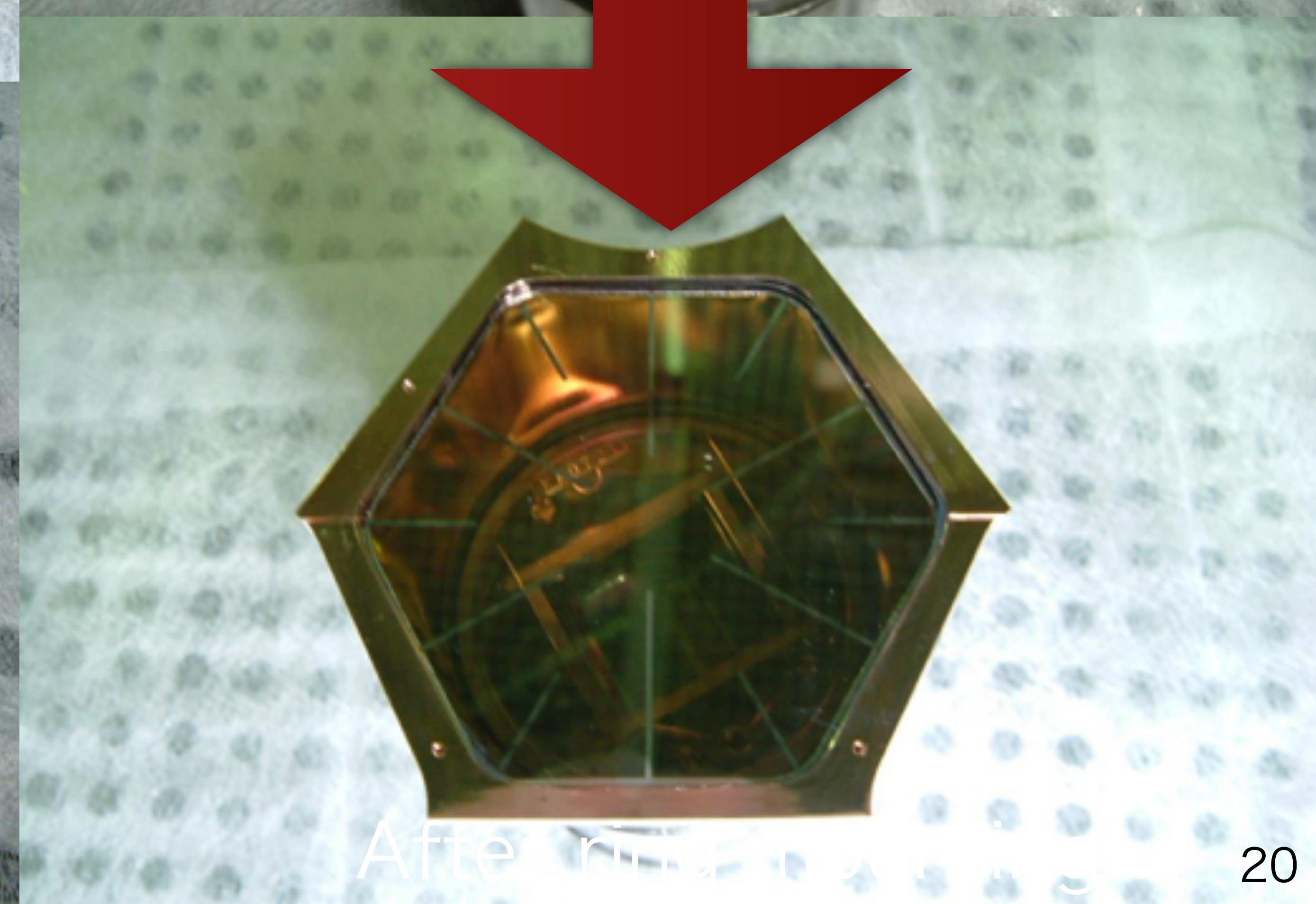
- To minimize the gaps between the PMT rings, which are blind corner of PMTs



Photos of the RFB(1)



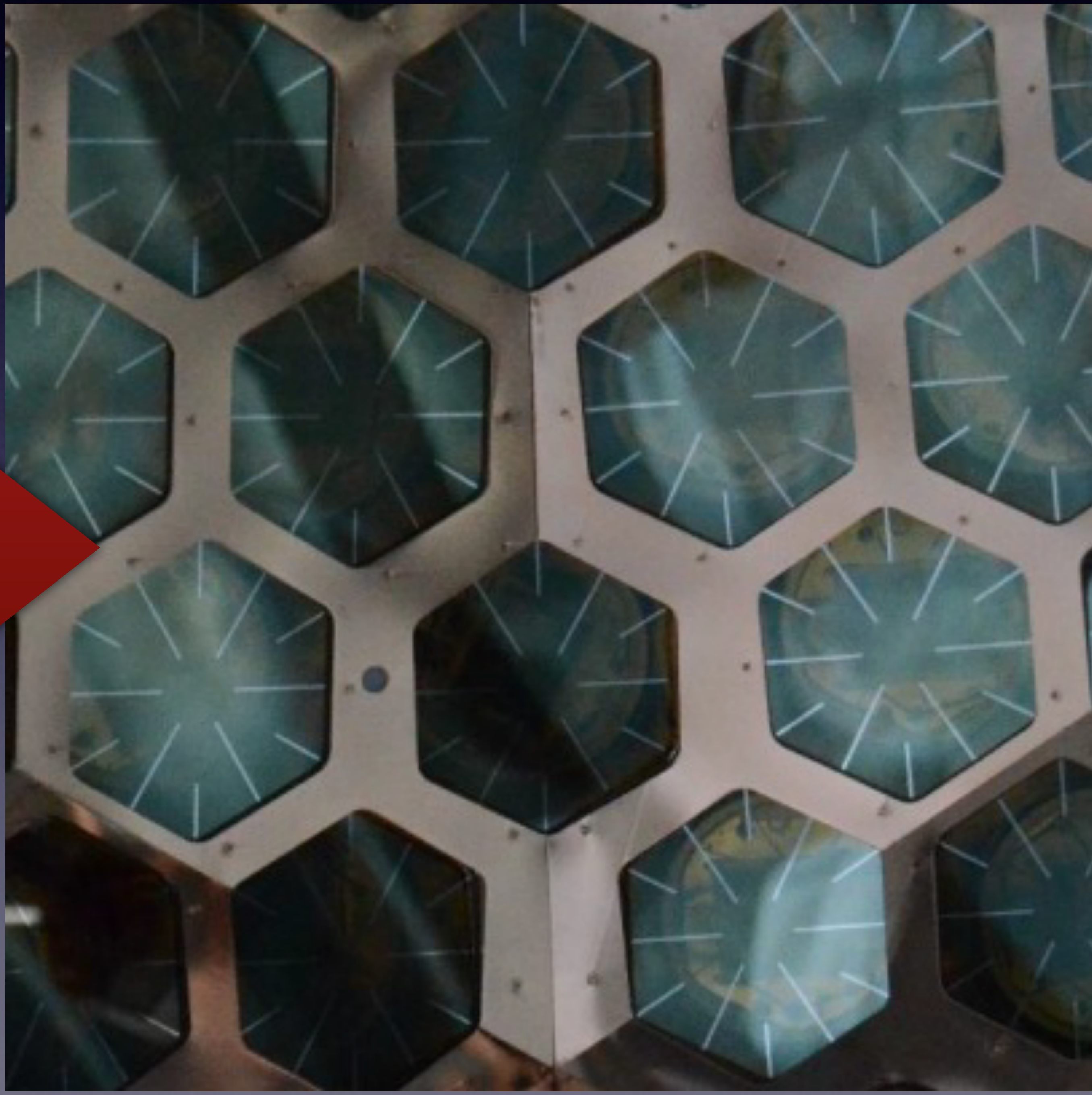




Photos of the RFB(2)

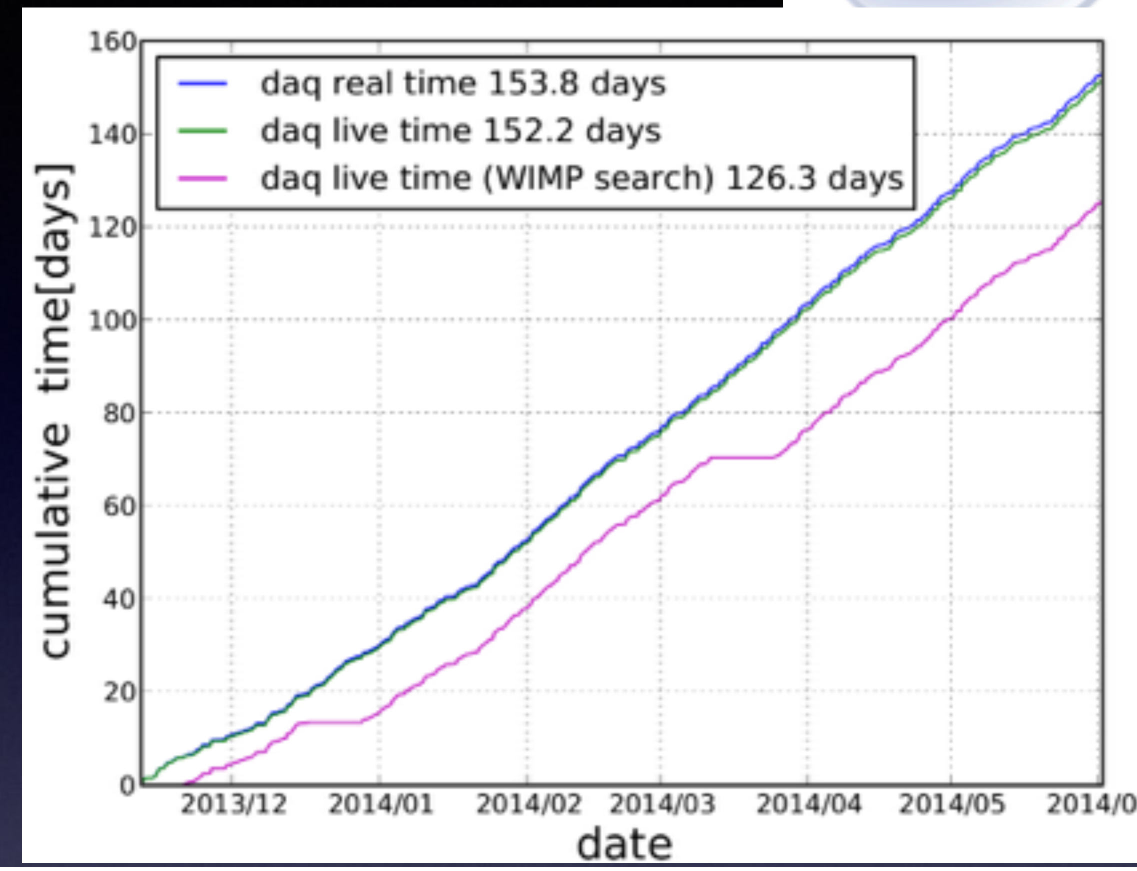
Before

After

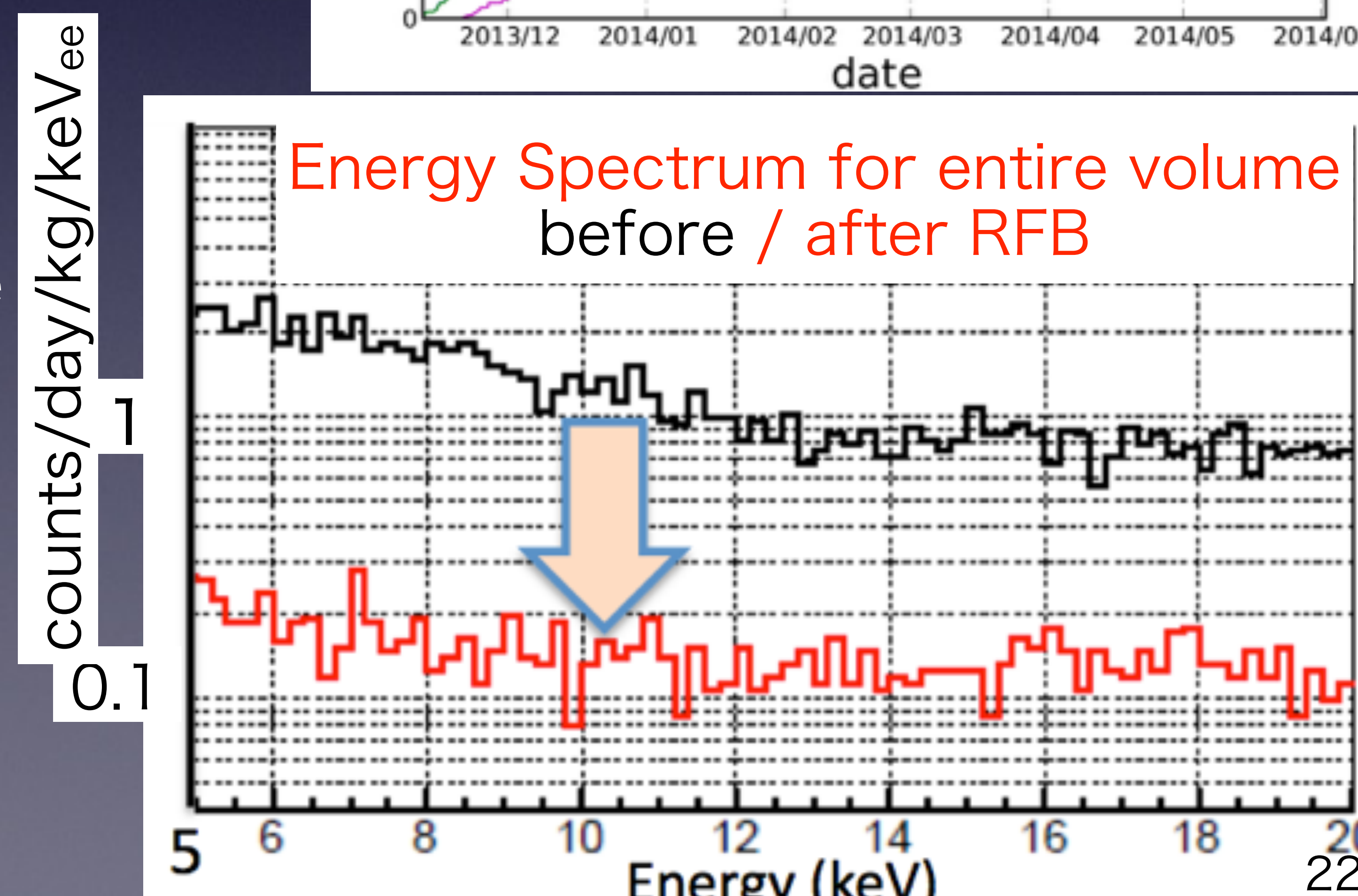


Current status

- ★ Resumed data-taking in Nov. 2013
- ★ Already accumulated 126 days data.
- ★ Changed from ATM-based analysis to FADC-based analysis
  - 1 GS/s FADCs are used for recording waveforms from all 642 PMTs



- ★ One order of magnitude reduction above 5 keV for entire volume is achieved.
- ★ Now we deepen understanding of the detector response, remained BG and reconstruction performance



Summary

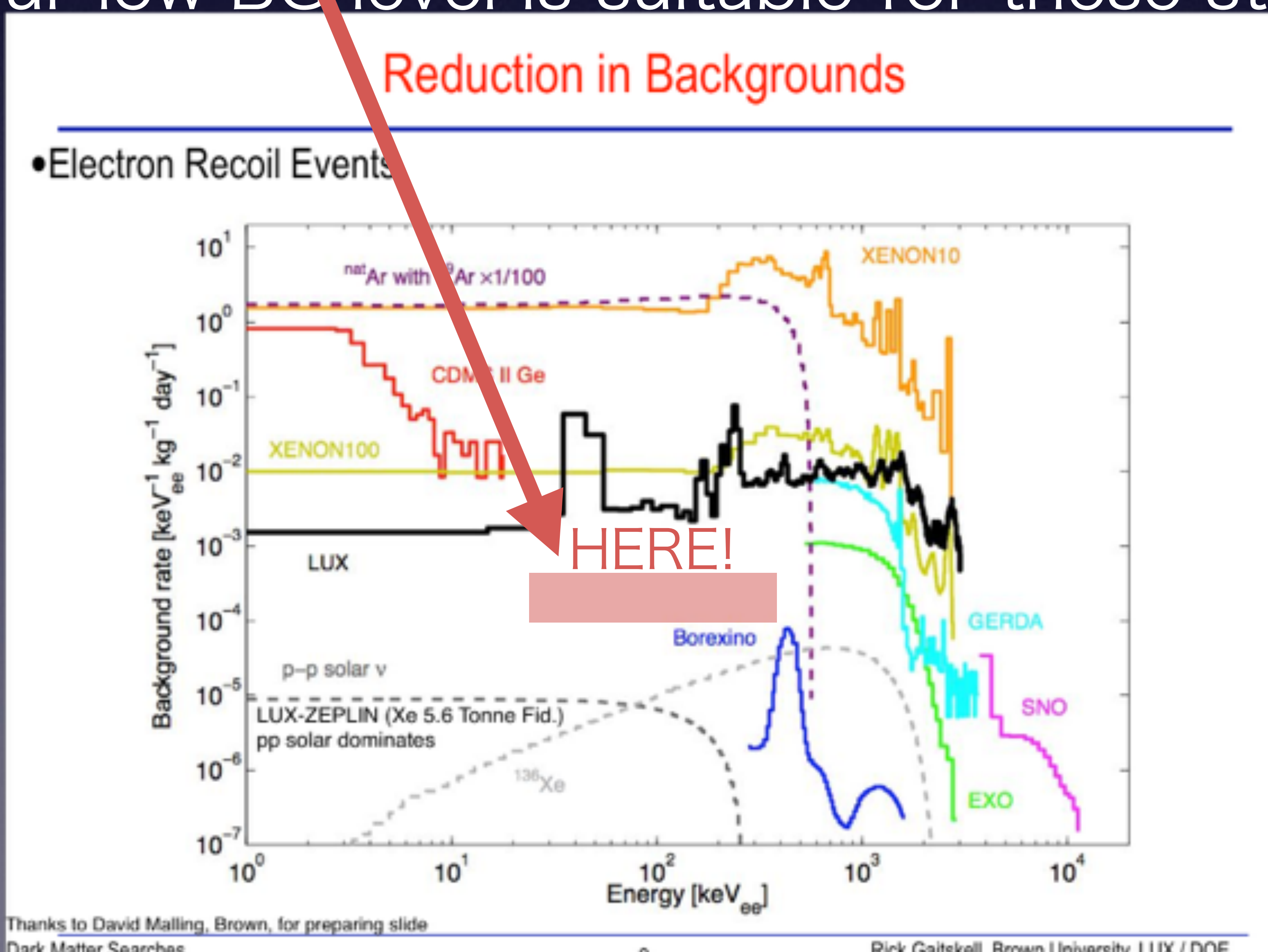
★ We obtained following physics result from commissioning run :

- Light mass WIMPs (Phys. Lett. B 719 78 (2013))
- Solar axions (Phys. Lett. B 724 46 (2013))
- Our low Energy threshold is suitable for these studies

Summary

★ We obtained following physics result from commissioning run :

- ^{129}Xe inelastic scattering by WIMPs (PTEP 063C01 (2014))
- Bosonic super-WIMPs (arXiv : 1406.0502)
- Our low BG level is suitable for these studies



Slide from Rick Gaitskell, TeVPA/IDM2014

Summary

★ We obtained following physics result from commissioning run :

- Light mass WIMPs (Phys. Lett. B 719 78 (2013))
- Solar axions (Phys. Lett. B 724 46 (2013))
- ^{129}Xe inelastic scattering by WIMPs (PTEP 063C01 (2014))
- Bosonic super-WIMPs (arXiv : 1406.0502)

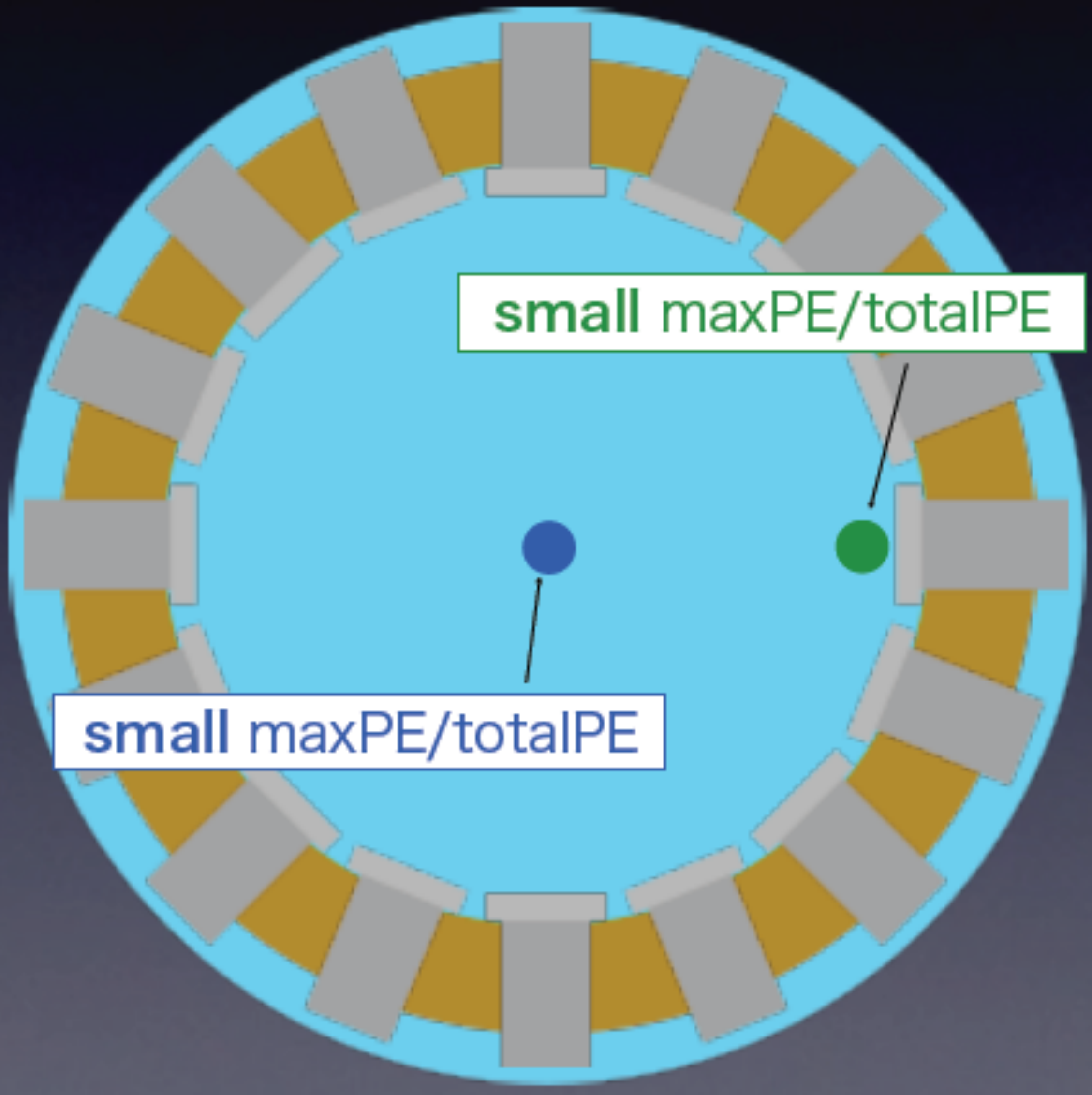
★ Refurbishment of the detector has been completed and we resumed data taking

Backup

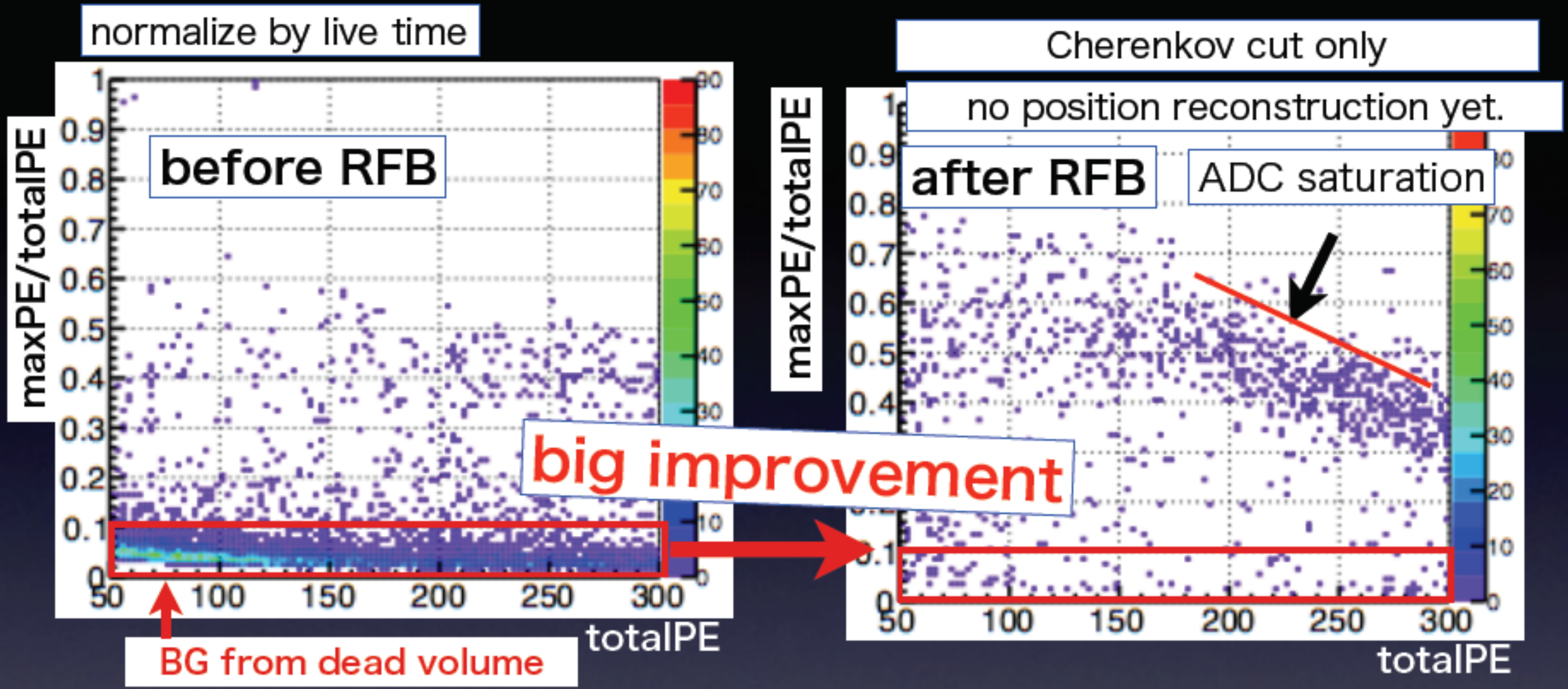
RFB improve ?

$$\text{maxPE/totalPE} = \frac{\text{maximum PE in one PMT}}{\text{Total PEs}}$$

- ✓ Quick look by using simple parameter maxPE/totalPE to see the how the events distributed in the detector.
- ✓ maxPE/totalPE is getting bigger if the event R is larger. (except dead volume like between PMTs.)



We did it.

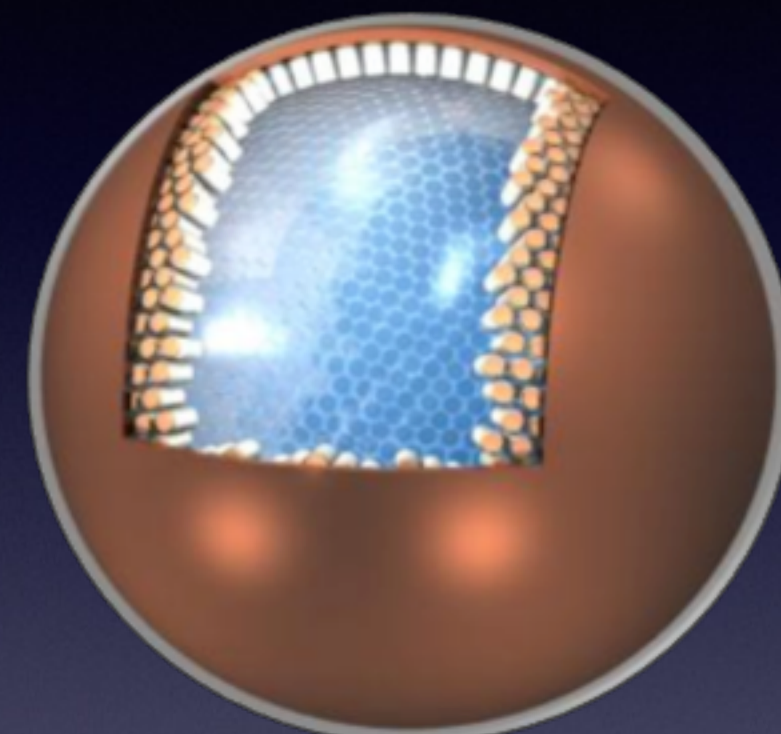


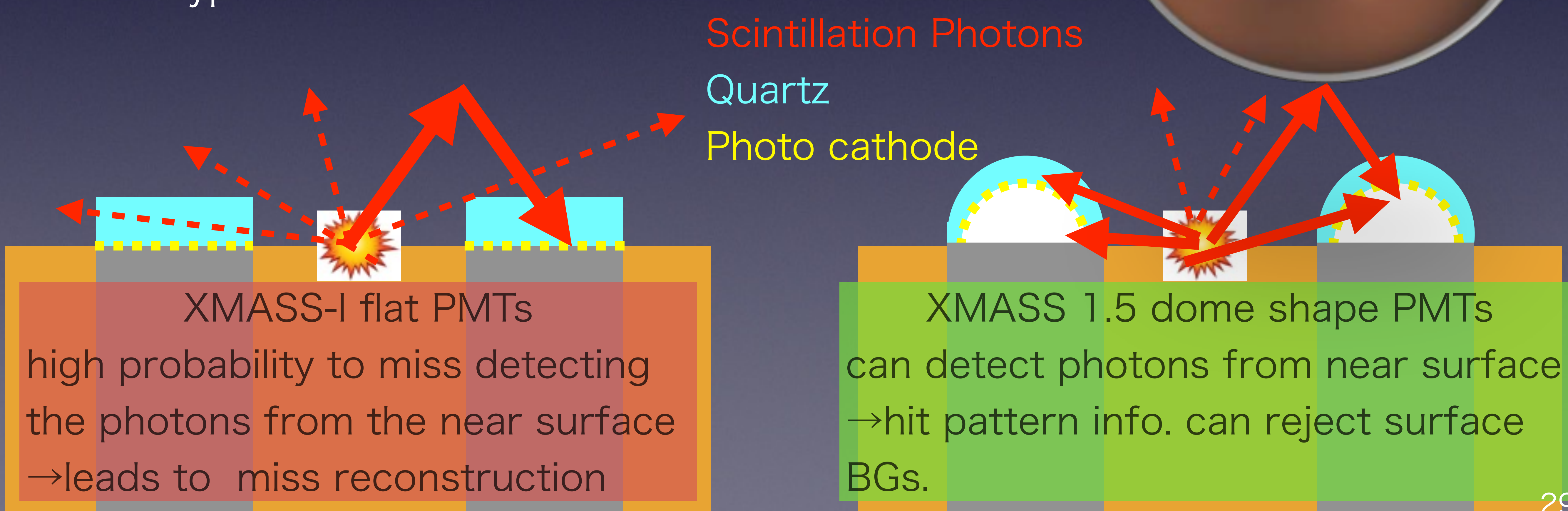
- ✓ Obviously, the background from
  - ~ 1/10 background reduction by this RFB work. (50~100p.e.)
  - Those events easily recognized by max/Total PE distribution and more than one order of magnitude reduction can be achieved even by this simple cut.
- ✓ Position reconstruction based on PE and Timing will improve the situation.

Future prospect : XMASS 1.5

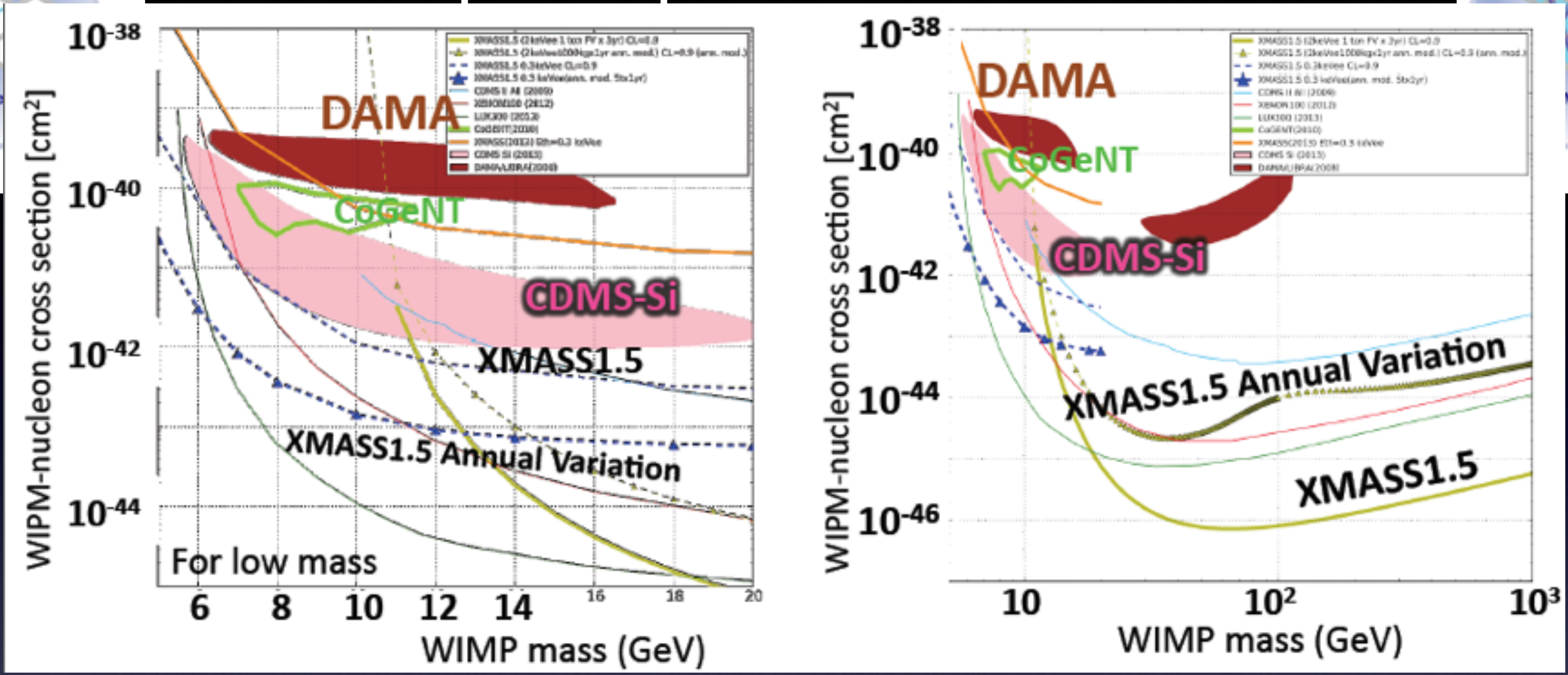
- ★ Aim to best sensitivity for ‘standard’ WIMPs, and other kinds of dark matter which can be detected though e/γ events
- ★ To identify the surface BG with simple method, dome shape PMT is effective.
- ★ Prototype PMTs will be delivered.

XMASS 1.5 (5 ton LXe)





Future prospect : XMASS 1.5



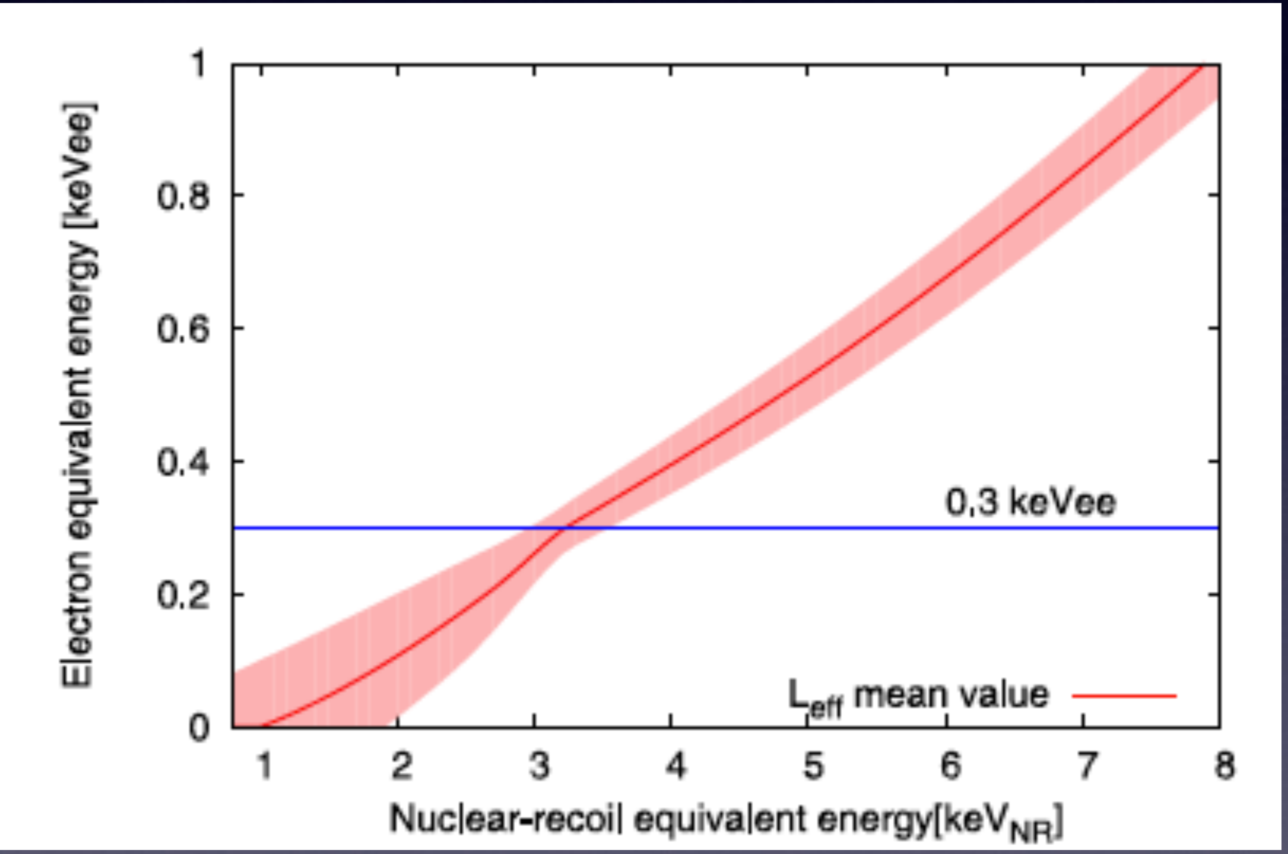
★ Whole volume and ~0.3 keV threshold

- BG assumption : 1/50 of XMASS-1
- By the 1 years operation : CoGent,CDMS-Si region will be covered.
- The sensitivity of the seasonal variation is better by ~ one order

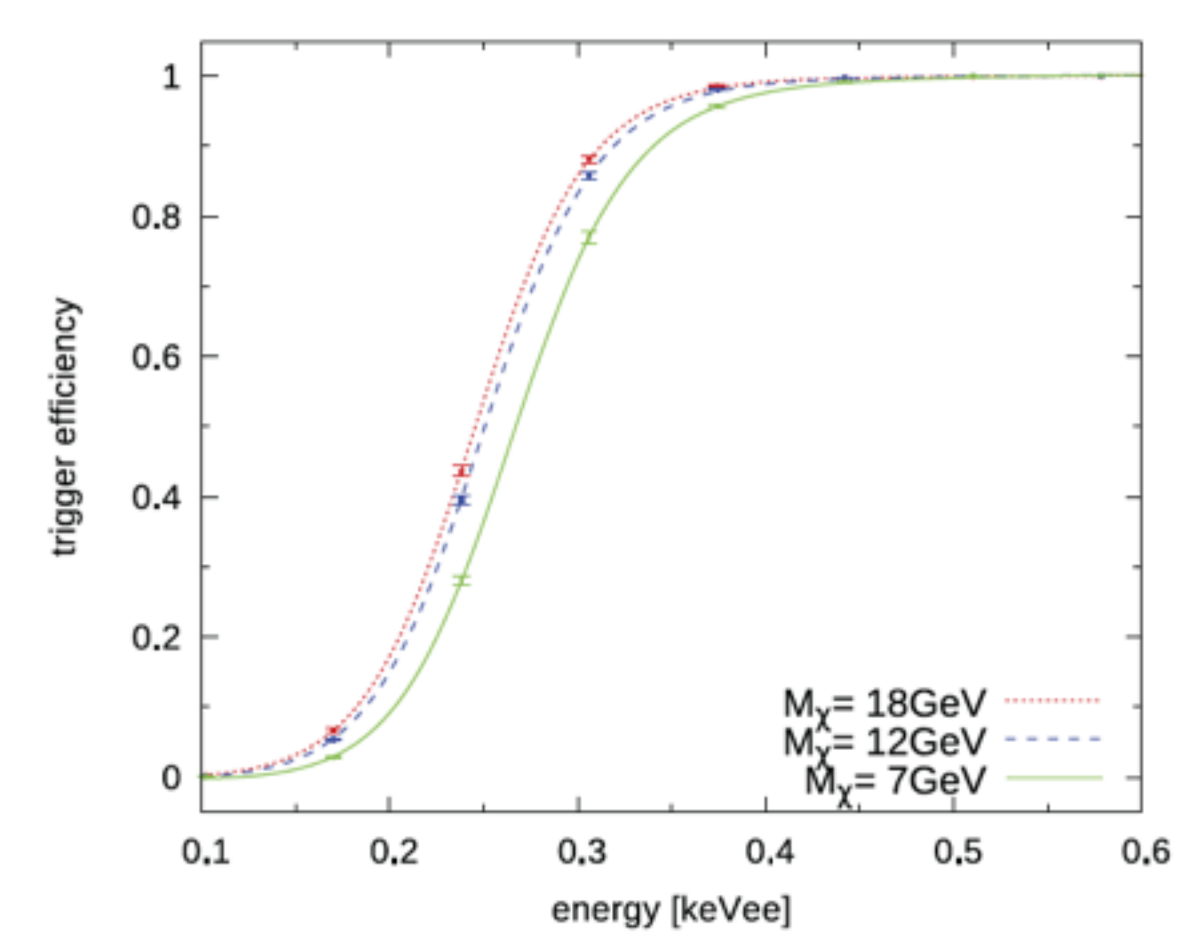
★ Fiducial Volume and ~2 keV threshold

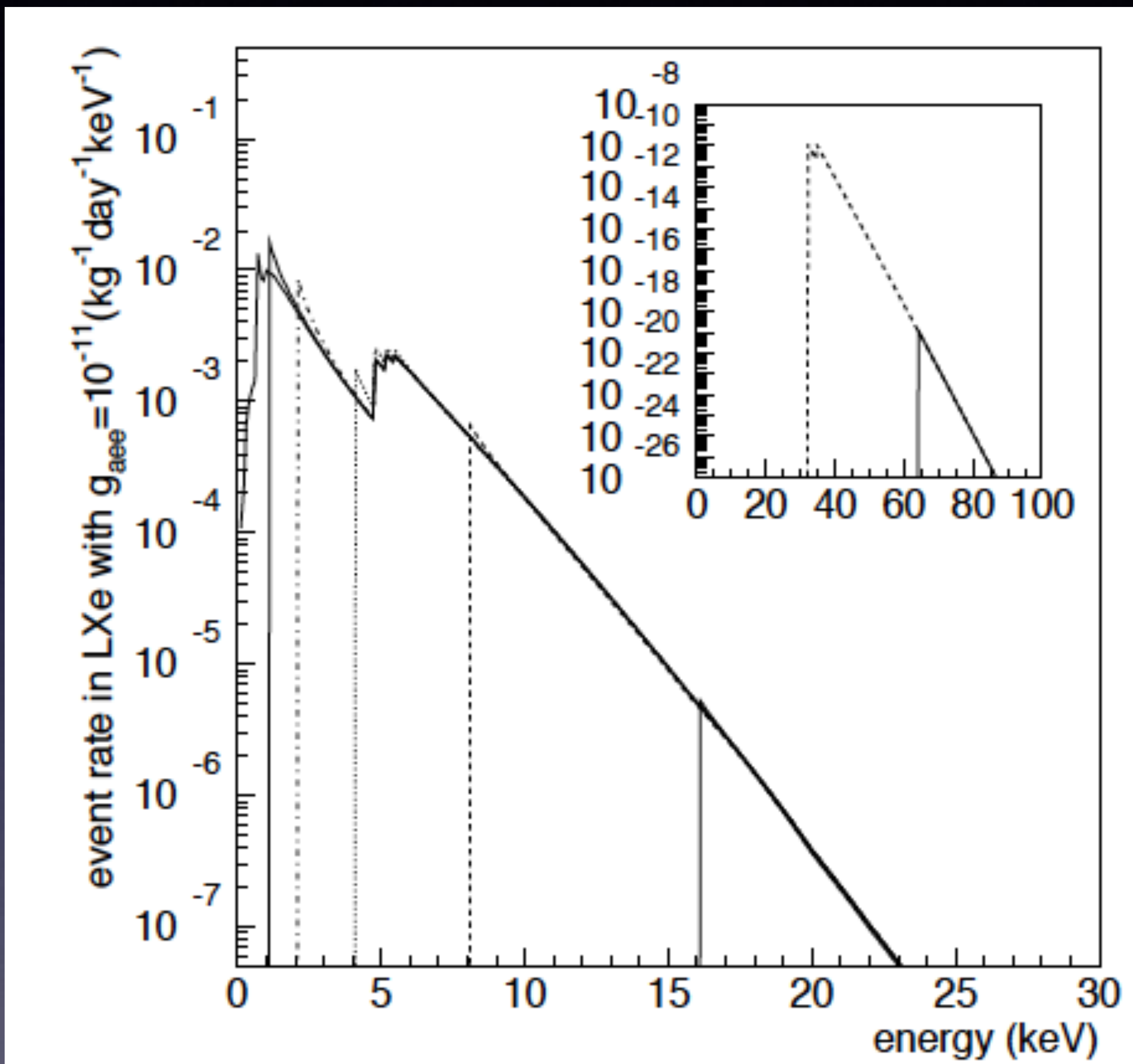
- BG assumption:10^{-5}counts/day/kg/keV_{ee}
- Effective 3 years measurements
- Effective masses 1tons
- Sensitivity will be ≦ 10^{-46} cm^2 for 100 GeV WIMPs

Leff



Trigger Efficiency from LED data





Calibration

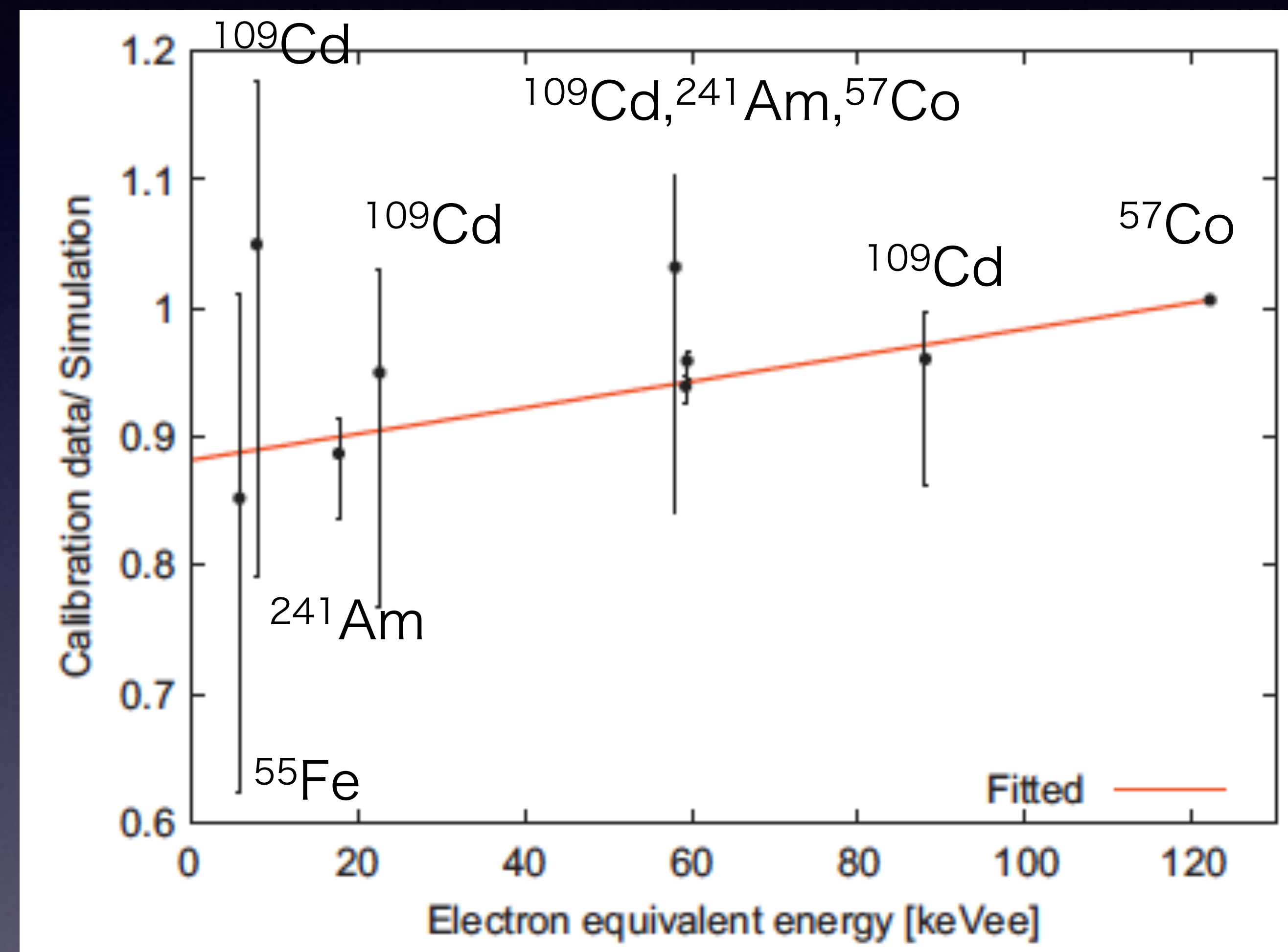
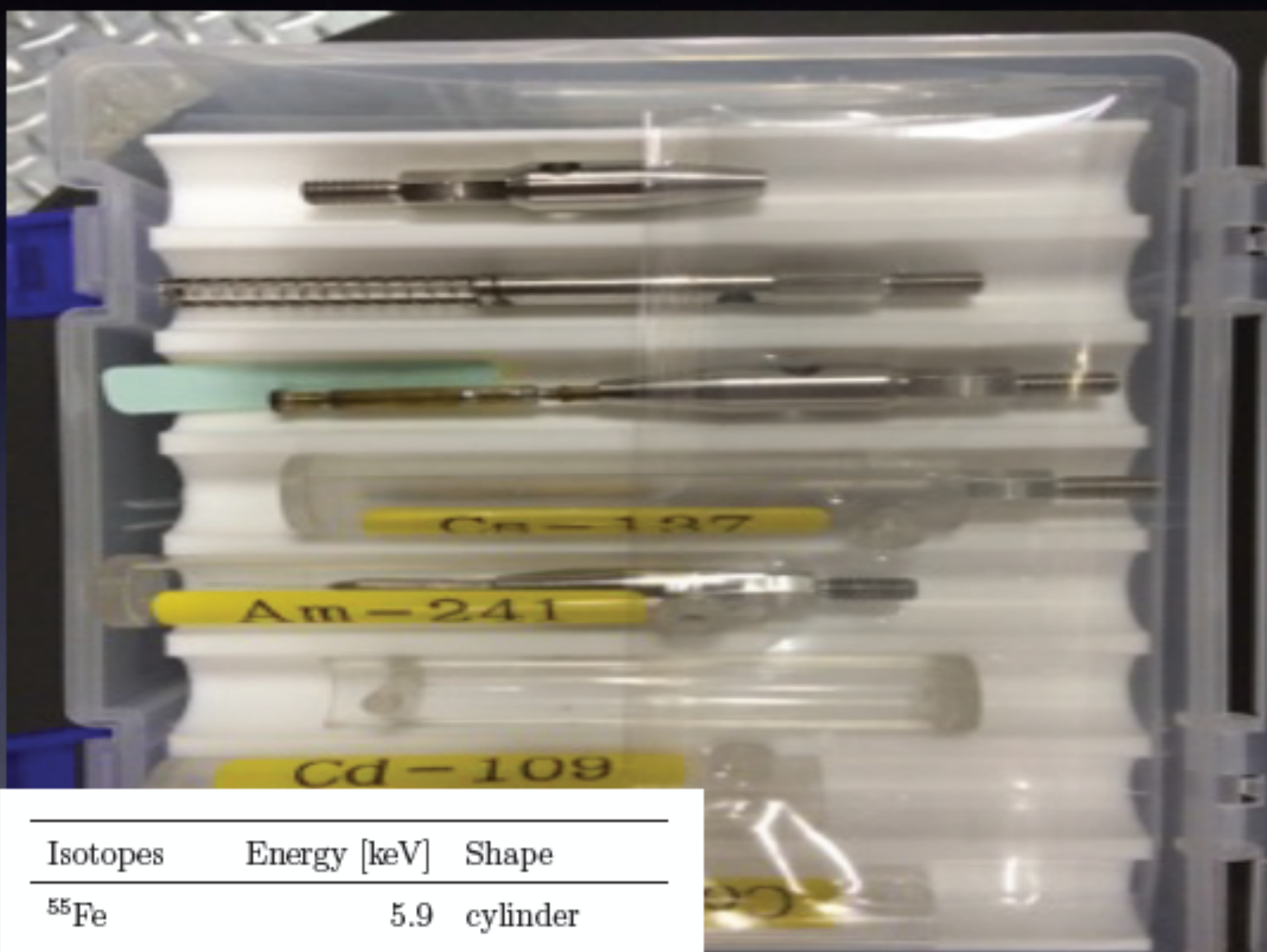


Figure 1: Expected energy spectra of events observed using the liquid-xenon detector. No resolution effects are included. Different curves are for axion masses with 0, 1, 2, 4, 8, and 16 keV. The inset shows spectra of axion masses with 32 and 64 keV. Due to a cross section enhancement for nonrelativistic axions, an increase at $E \sim m_a$ can be seen. The step around 5 keV corresponds to the L-shell absorption edge of the axioelectric effect.

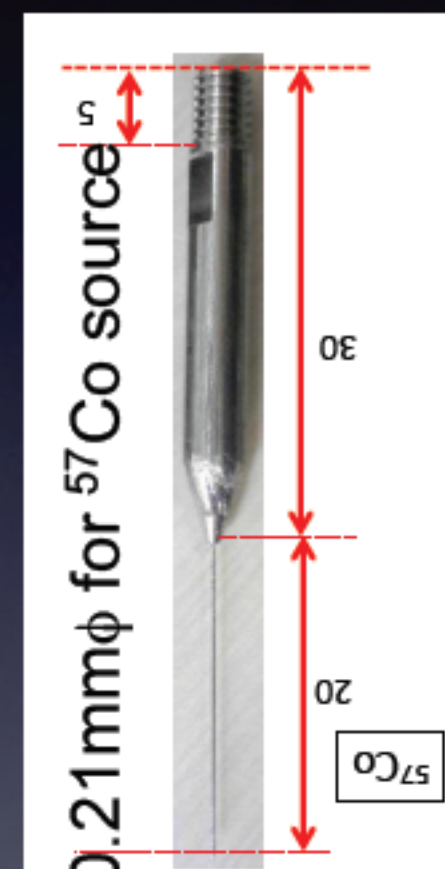
Detector calibration

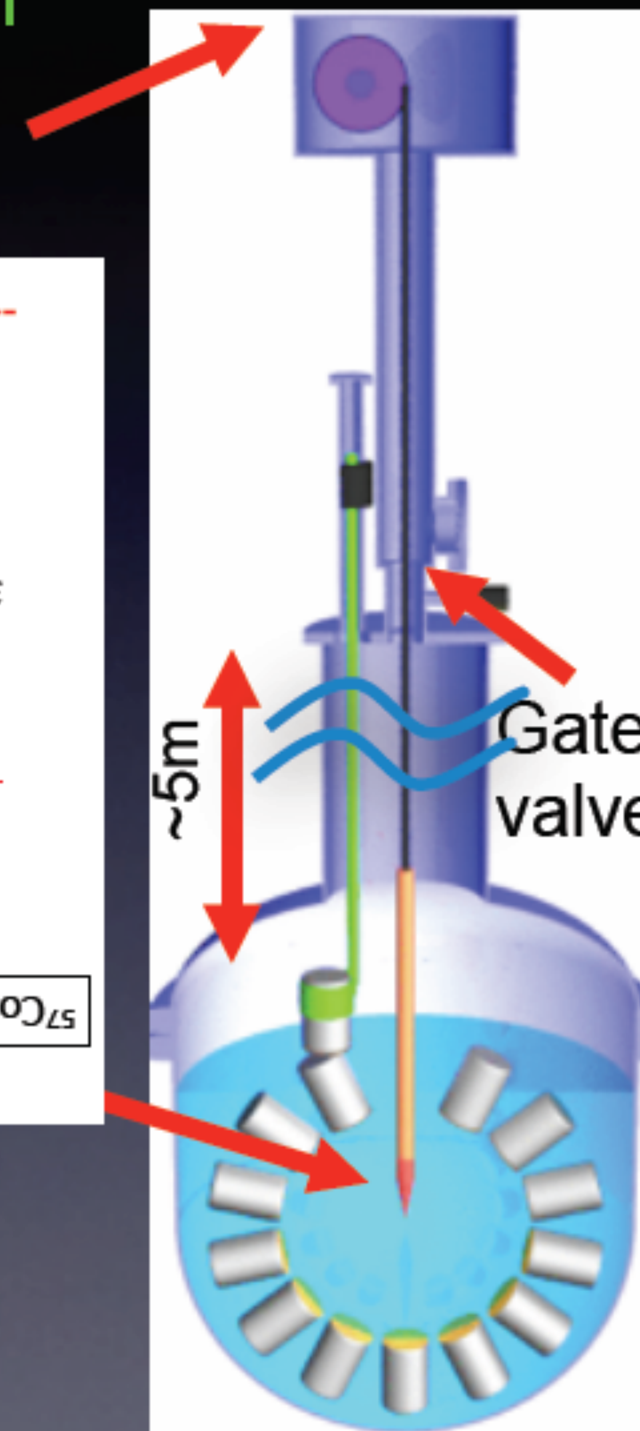
(KRISS, Sejong University)

-Inner calibration is very important for position reconstruction.



Isotopes	Energy [keV]	Shape
^{55}Fe	5.9	cylinder
^{109}Cd	8(*1), 22, 58, 88	cylinder
^{241}Am	17.8, 59.5	thin cylinder
^{57}Co	59.3(*2), 122	thin cylinder
^{137}Cs	662	cylinder



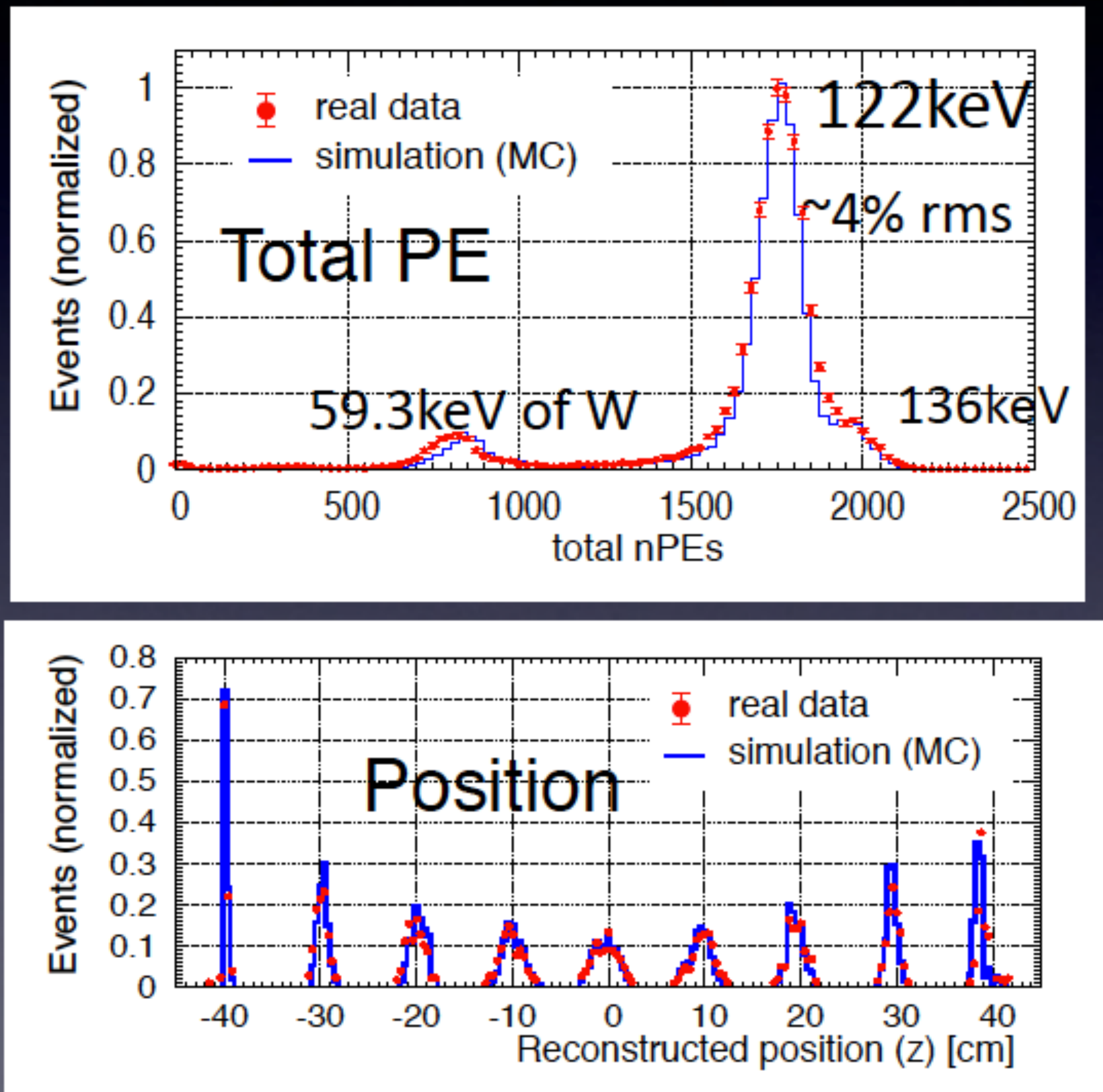


Masaki Yamashita

Detector calibration

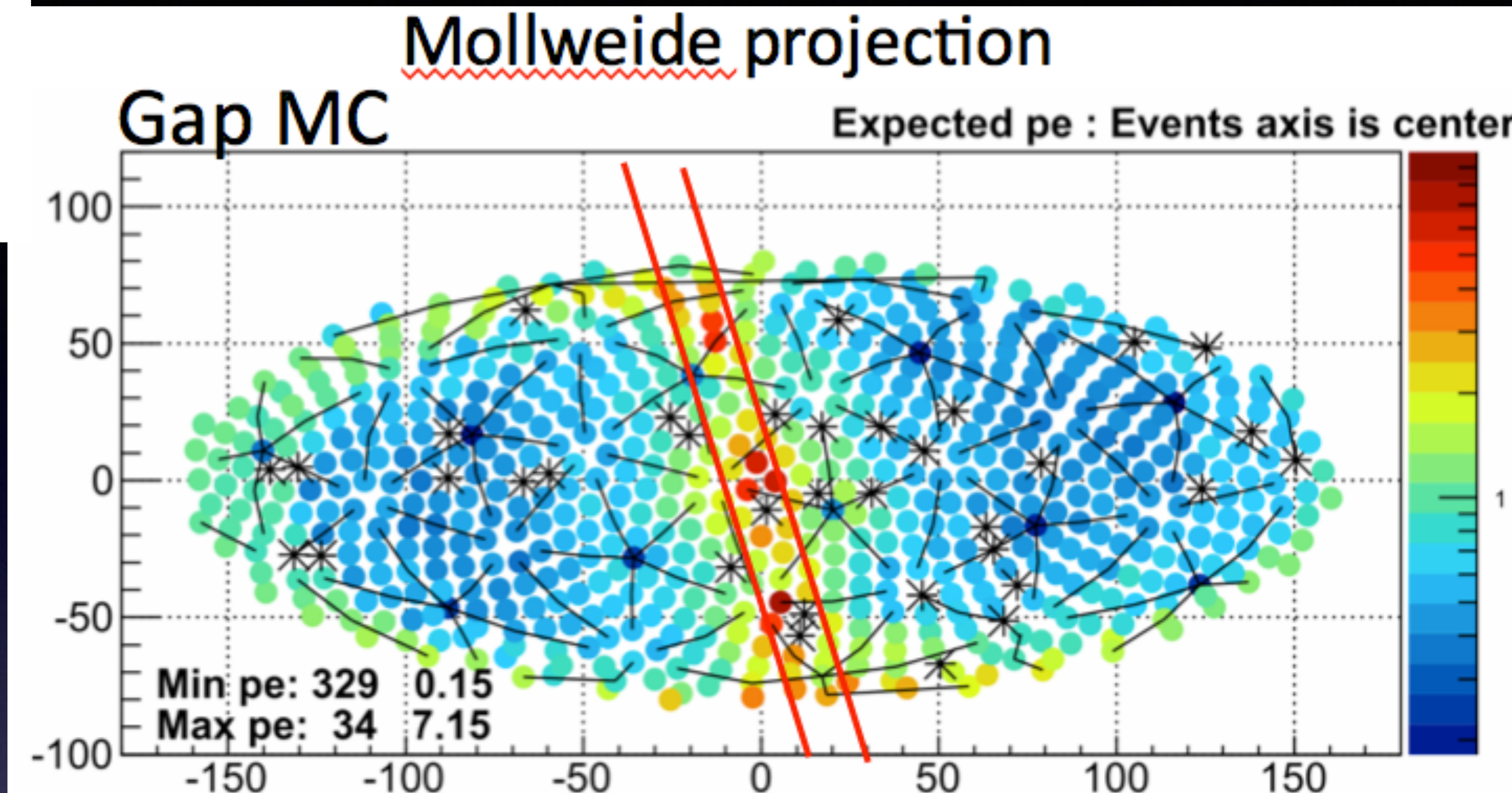
-Highest Light Yield 14.7 PE/keV

-Good agreement between data and.



Masaki Yamashita

Band cut Parameter



- ★ Grooves and gaps exist between PMTs.
- ★ Scintillation light caused by events inside these grooves projects onto the inner surface of the XMASS detector in a characteristic band pattern
- ★ This pattern emerges because the propagation of scintillation light from within a straight groove is constrained by the rims of that groove acting as a slit

- ★ Timing cut :
  - ★ timing difference between the first hit in an event and a mean timing of hater hits.
  - ★ Surface events has larger timing difference than inside events

Table for SuperWIMPs

8.2±0.5 mBq

m_b (keV)	R (cm)	δT_m (ns)	F_B	E	eff. (%)	obs.	^{214}Pb expected	α'/α	g_{aee}
40	15	12.62	0.258	23.7–53.7	51±13	48	7.9 ± 0.7	8.0×10^{-26}	1.3×10^{-12}
60	15	12.54	0.248	46.9–76.9	63±16	12	11.6 ± 1.0	6.8×10^{-26}	8.0×10^{-13}
80	15	11.51	0.246	68.1–98.1	59±18	8	9.6 ± 0.8	1.6×10^{-25}	9.2×10^{-13}
100	15	11.14	0.244	89–119	65±20	15	11.4 ± 1.0	6.0×10^{-25}	1.4×10^{-12}
120	15	11.11	0.244	111–141	74±23	18	14.4 ± 1.1	1.2×10^{-24}	1.7×10^{-12}

Pseudoscaler case

$$R \approx \frac{1.2 \times 10^{19}}{A} g_{aee}^2 \left(\frac{m_a}{\mathrm{keV}}\right) \left(\frac{\sigma_{\mathrm{photon}}}{\mathrm{barn}}\right) \mathrm{kg}^{-1}\mathrm{day}^{-1},$$