「XMASS実験の現状と展望」

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2012年7月19日

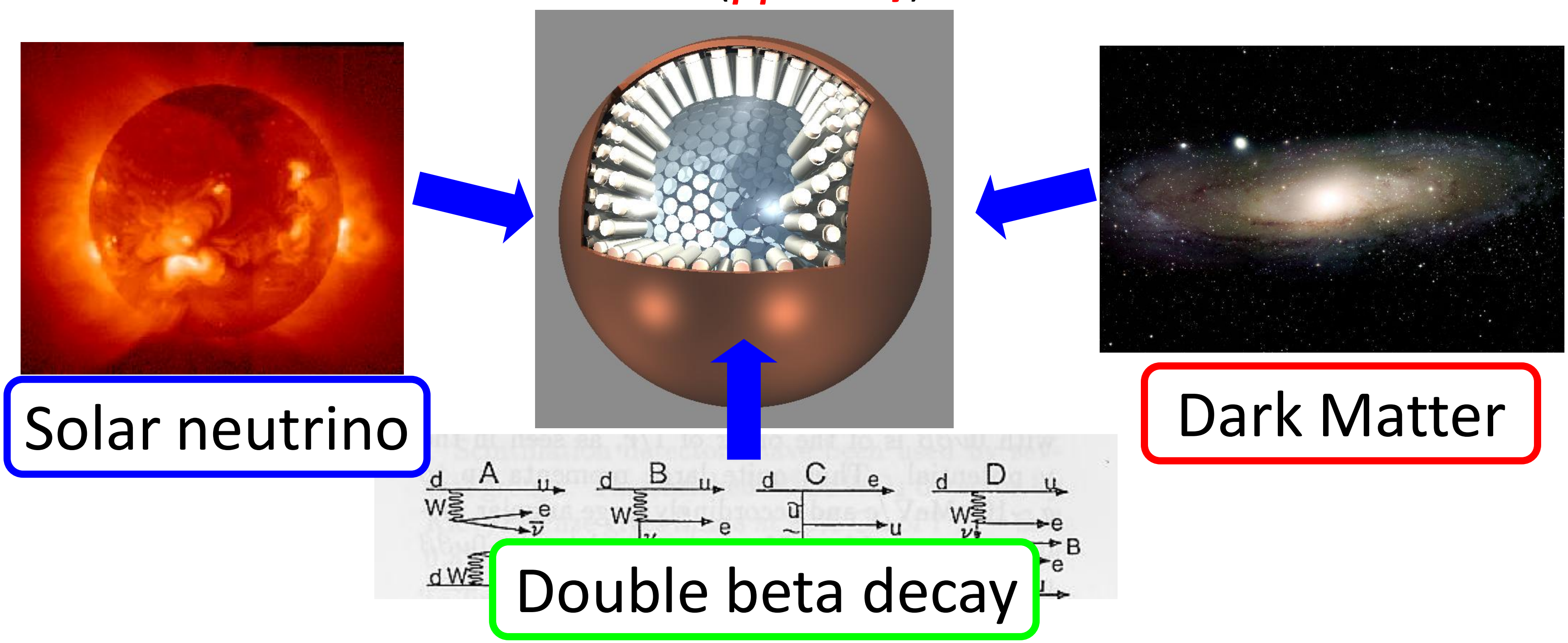
PPP2012, 京都大学基礎物理学研究所

XMASS experiment

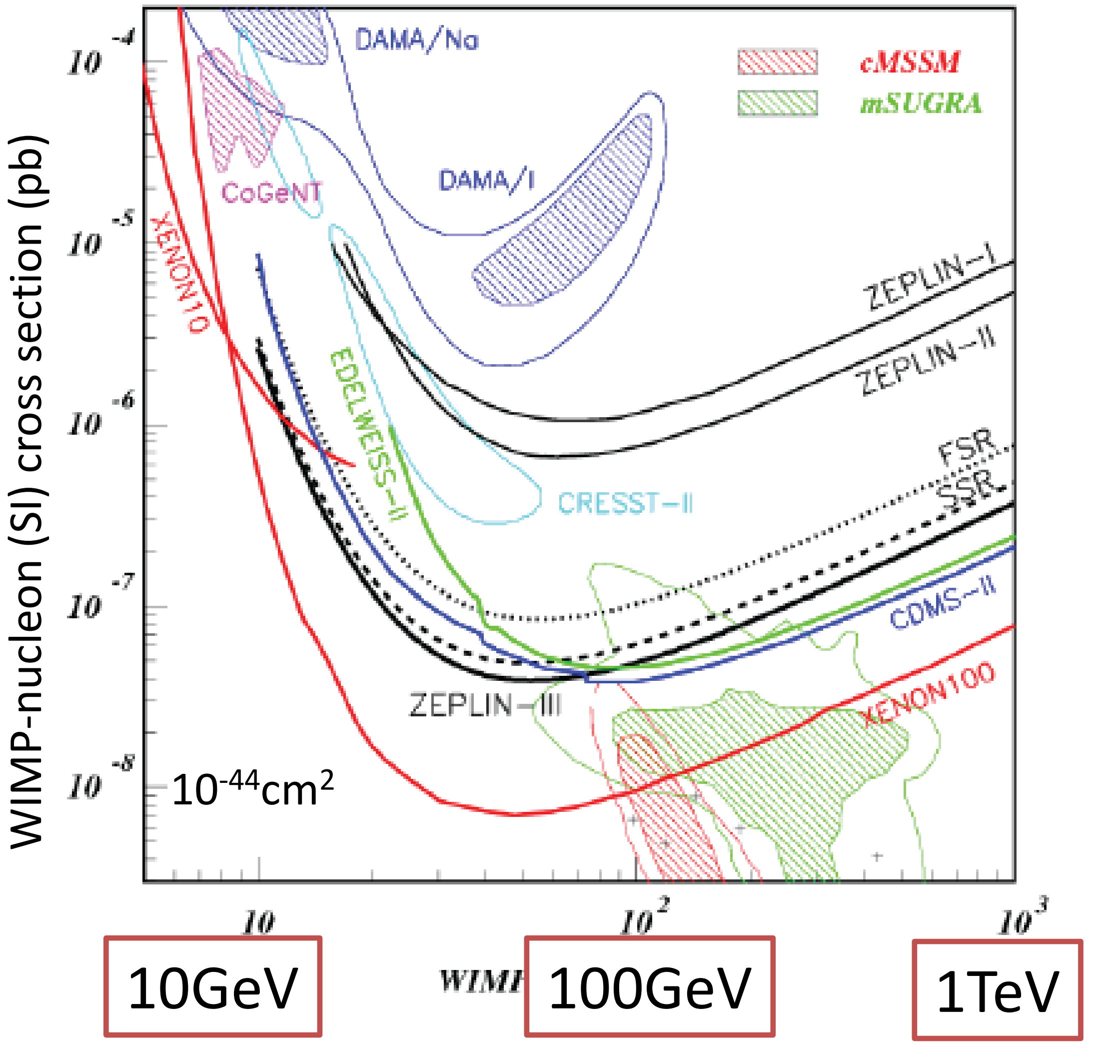
- What is XMASS?

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

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

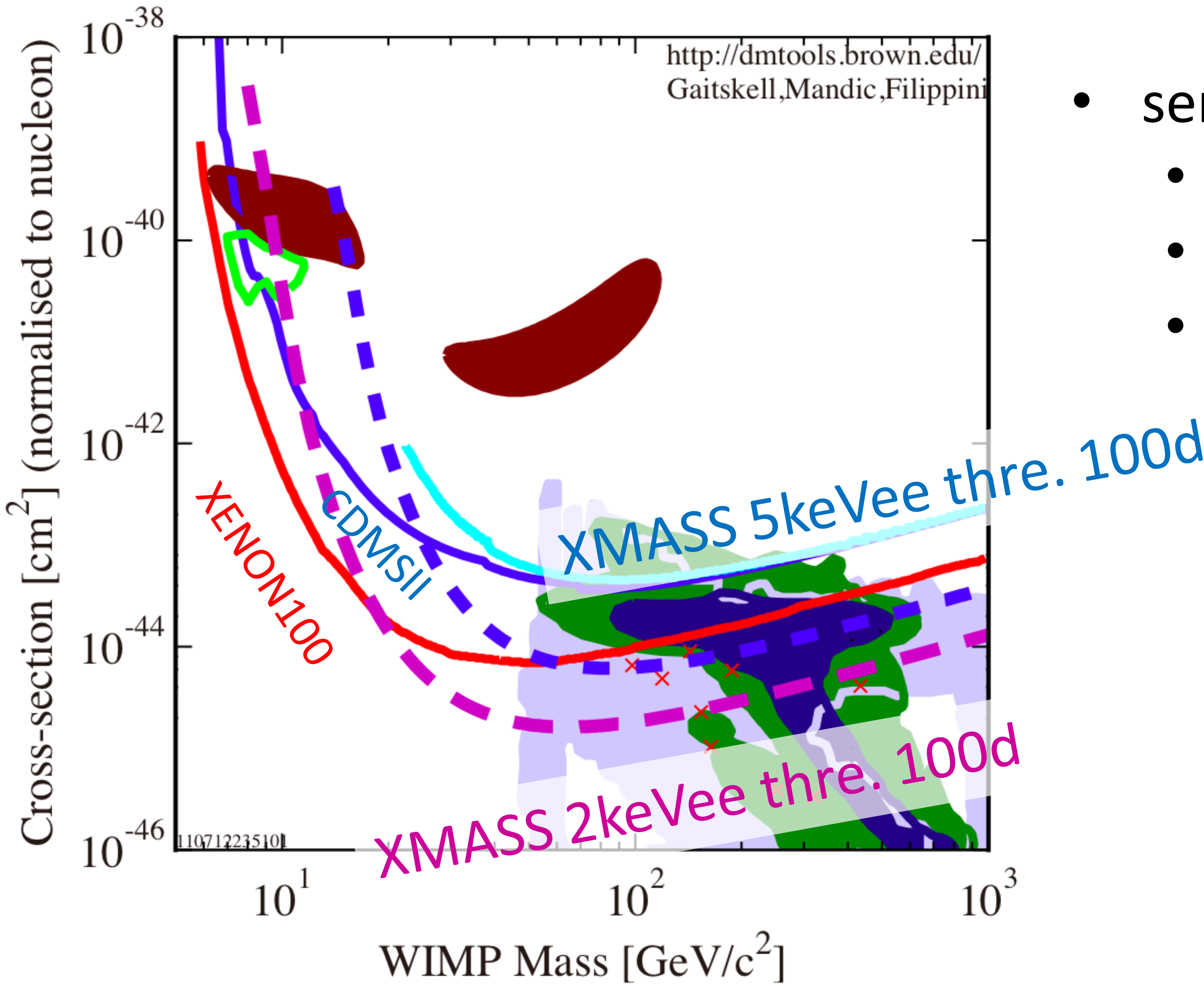


Current status of WIMP dark matter search



R. Gatitskell@dm2012

goal of XMASS-I



- sensitivity: $\sigma_{SI}<2*10^{-45}cm^2$
  - 5years measurement
  - 100kg fiducial mass
  - $E_{threshold}$=5keV

XMASS collaboration

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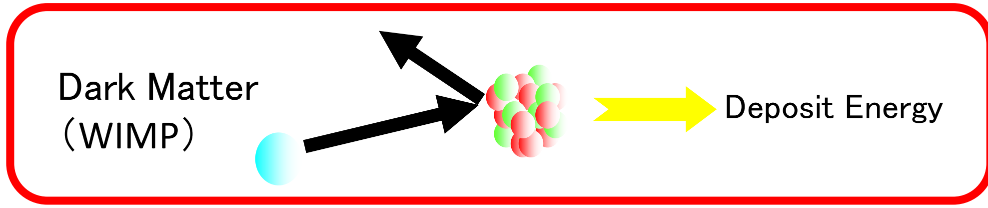
Direct Detection Principle

WIMPs elastically scatter off nuclei in targets, producing nuclear recoils.

- **From the density of dark matter in the galaxy:**
- **Every liter of space: 10-100 WIMPs,**
- **moving at 1/1000 the speed of light**
- **Less than 1 WIMP/week will collide with an atom in 1kg material**

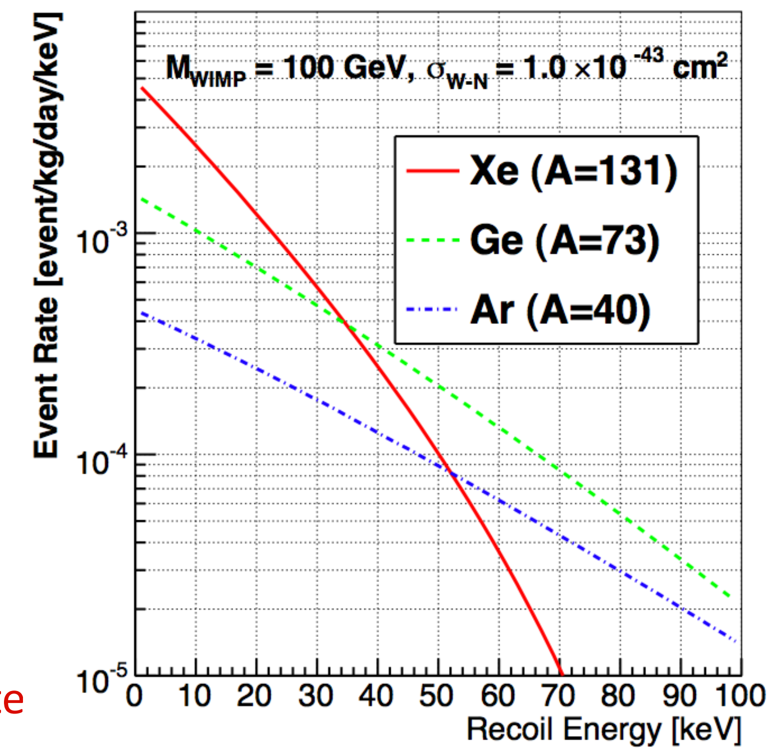


$$\frac{dR}{dE_R} = \frac{R_0 F^2(E_R)}{E_0 r} \frac{k_0}{k} \frac{1}{2\pi v_0} \int_{v_{min}}^{v_{max}} \frac{1}{v} f(\mathbf{v}, \mathbf{v_E}) d^3\mathbf{v}$$

R_0: Event rate
F: Form Factor
should be calculated in each nuclei

Maxwellian distribution for DM velocity is assumed.
v_0:dispersion
V :velocity onto target,
V_E: Earth's motion around the Sun

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



Spin independent case:

$$\sigma_0 = A^2 \frac{\mu_T^2}{\mu_p^2} \sigma_{\chi-p}$$

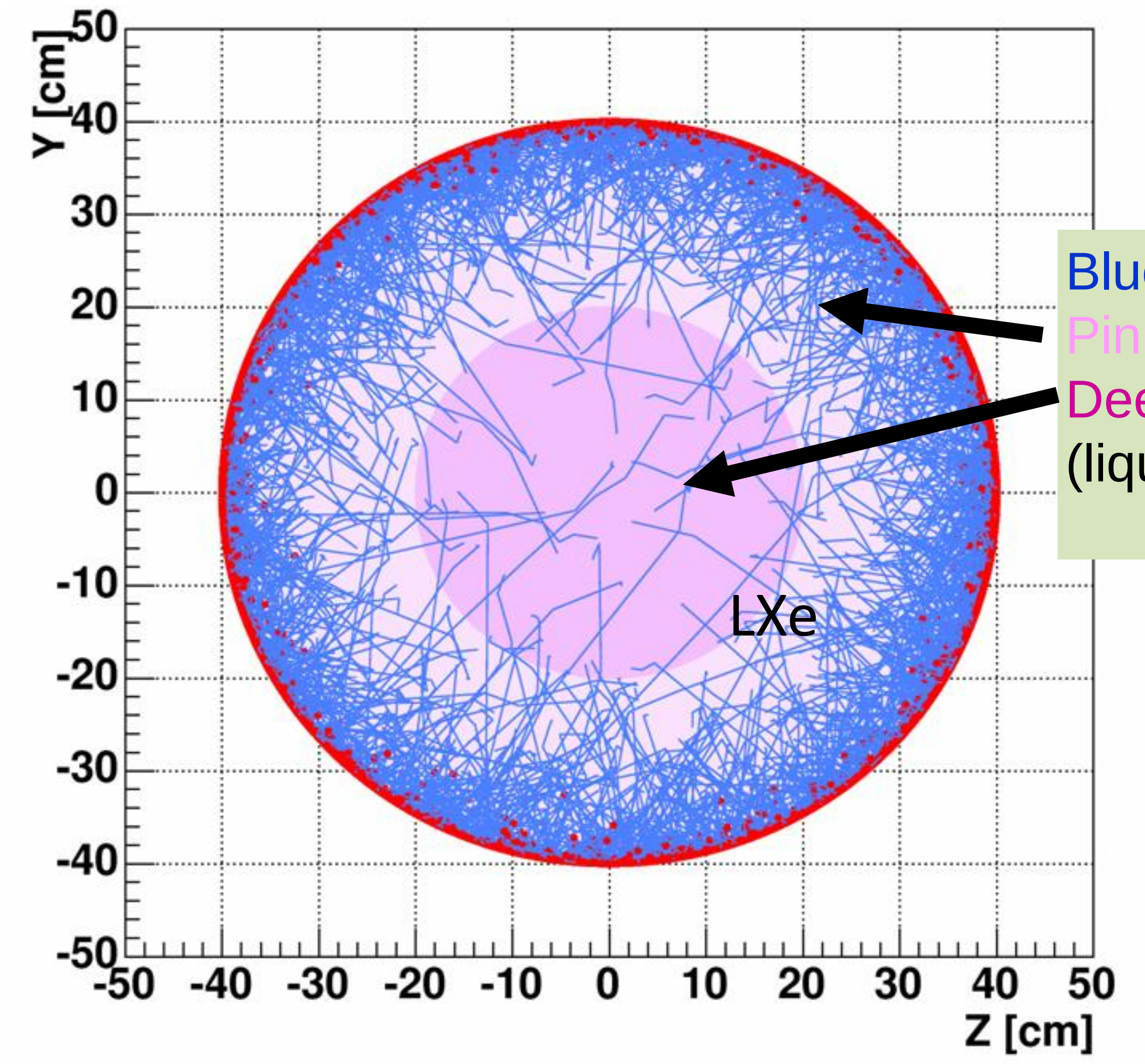
Larger A is higher event rate

Xe (A=131) is one of the best target.

Why Liquid Xenon ?

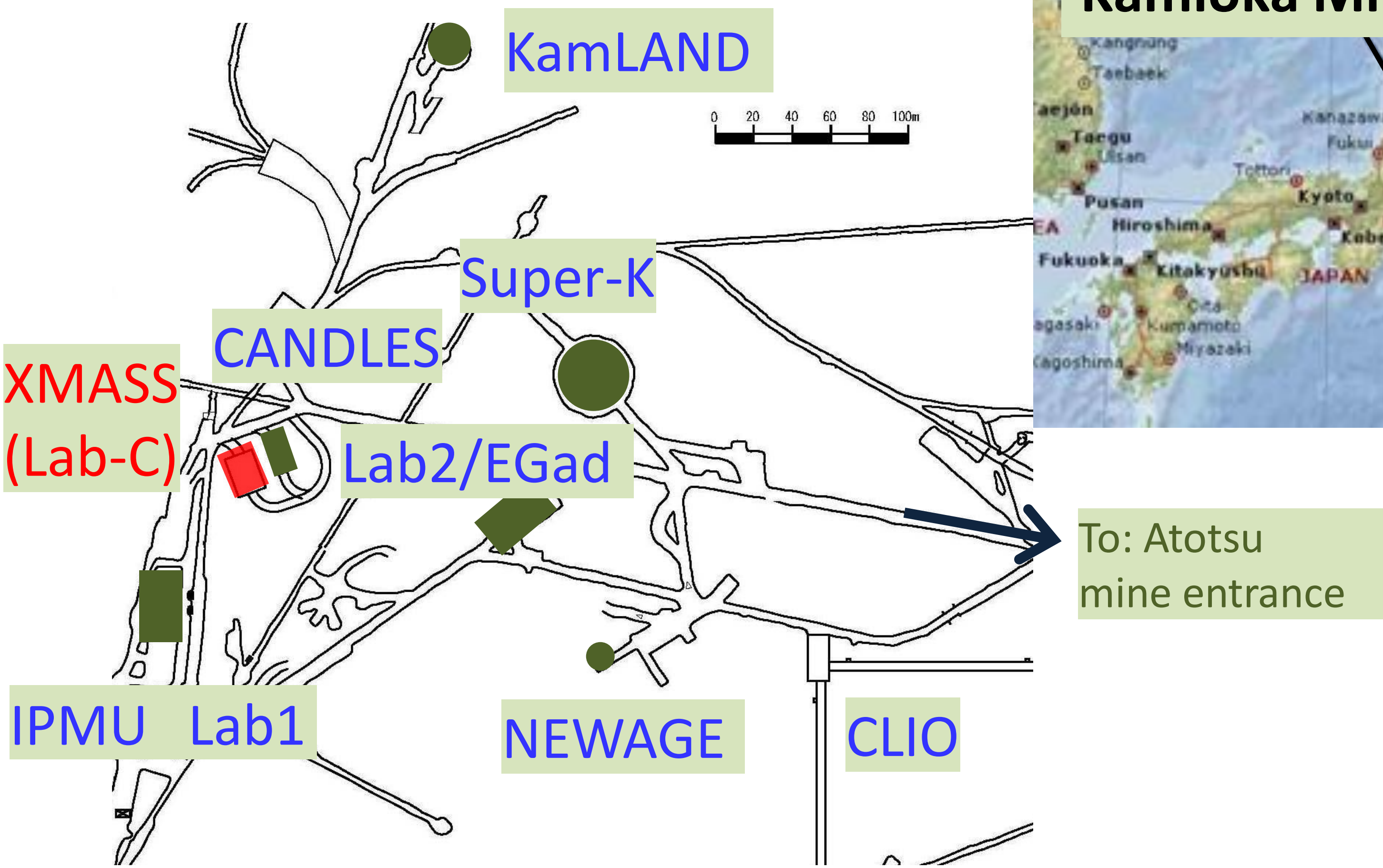
- High Atomic mass Xe (A~131)
  - good for SI case (cross section $\propto$ A^2)
- Odd Isotope (Nat. abun: 48%, 129,131) with large SD enhancement factors
- High atomic number (Z=54) and density (ρ=3g/cm^3)
  - compact, flexible and large mass detector.
- High photon yield (~ 42 UV photons/keV at zero field)
- No long life radioactive isotope
- Easy to purify for both electro-negative and radioactive purity
  - by circulating Xe with getter for electro-negative
  - Distillation for Kr removal

External gamma-ray MC



Blue : track
Pink : self-shield (liquid xenon)
Deep pink : fiducial volume (liquid xenon)

Kamioka mine



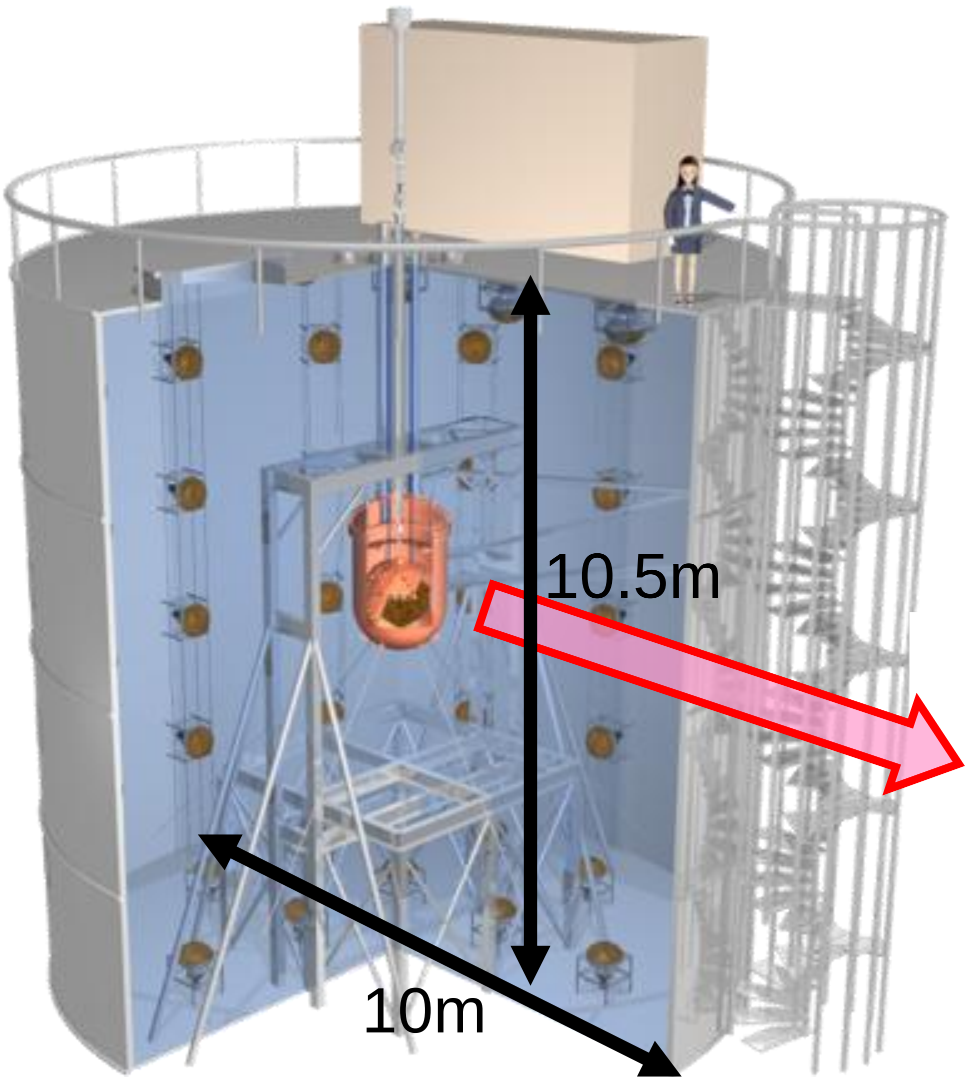
Lab-C

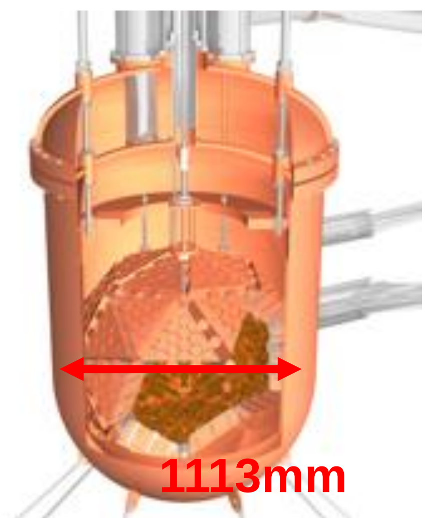
In Mar. 2008, excavation is finished.

- Hall-C facility was completed in Mar. 2009.
- urethane resin for radon shield on the wall and floor.
- air from the outside the mine ($8m^3$/min, ~$20Bq/m^3$)
- Water tank construction is completed in Mar. 2009.

detector

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

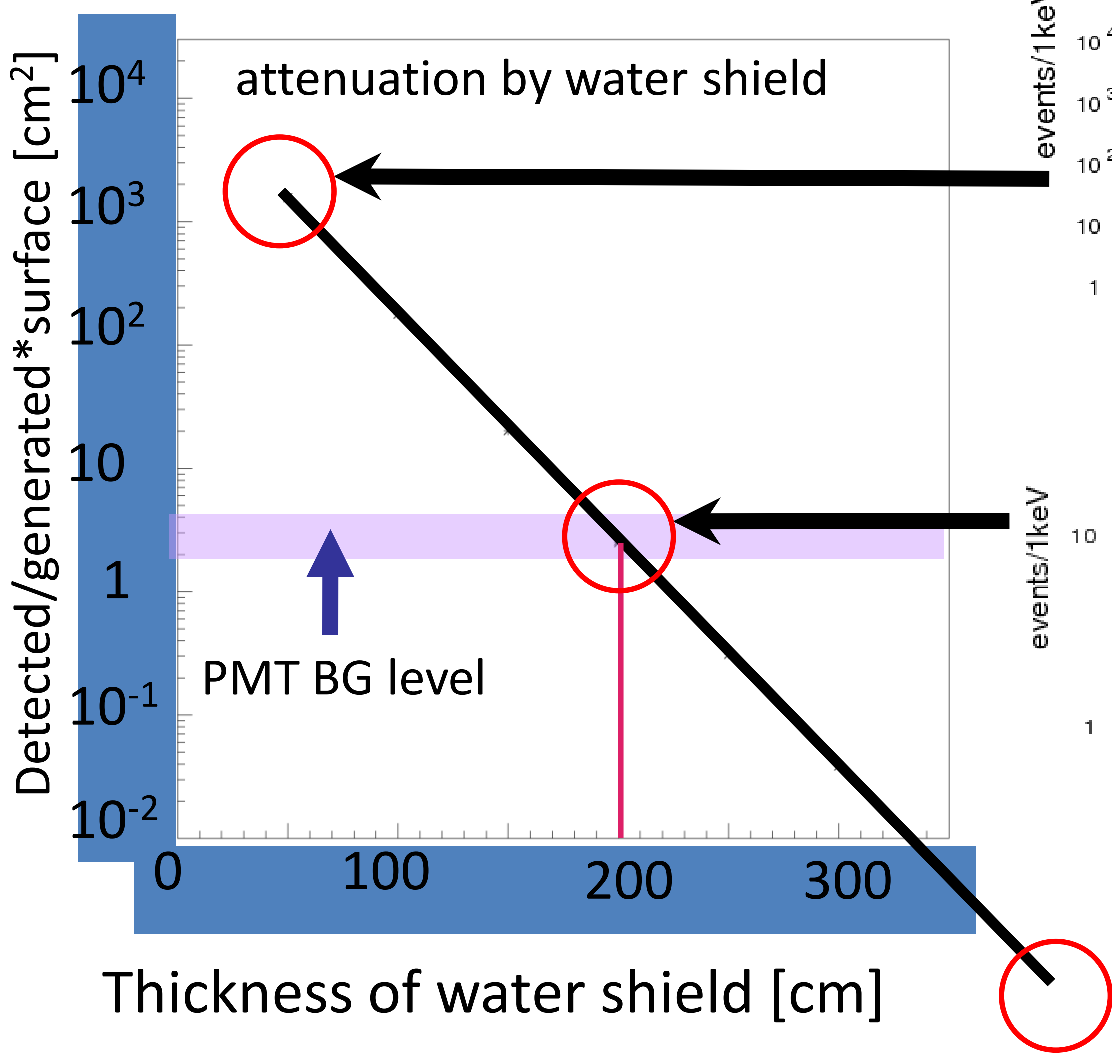




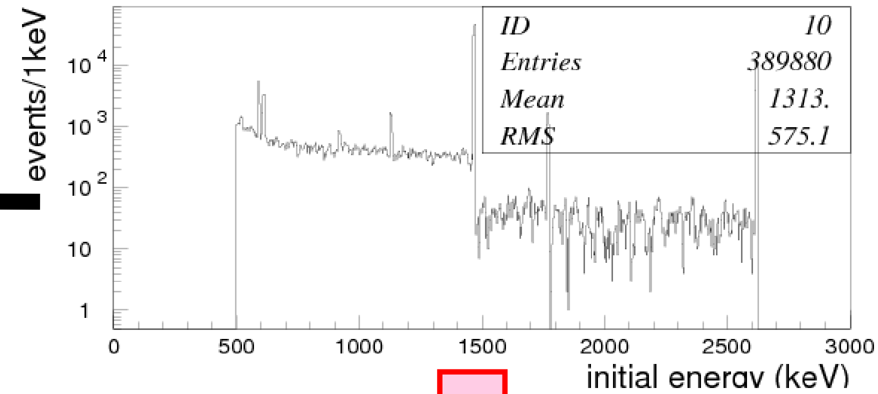
OVC

IVC

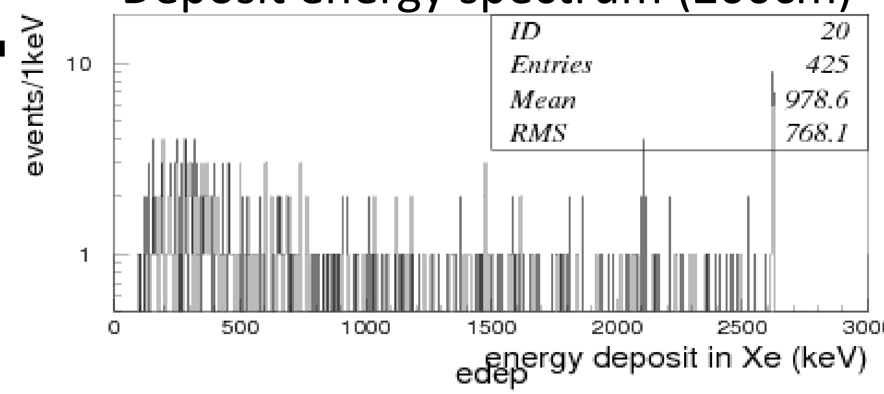
Water shield for gamma-ray background



Initial energy spectrum from the rock



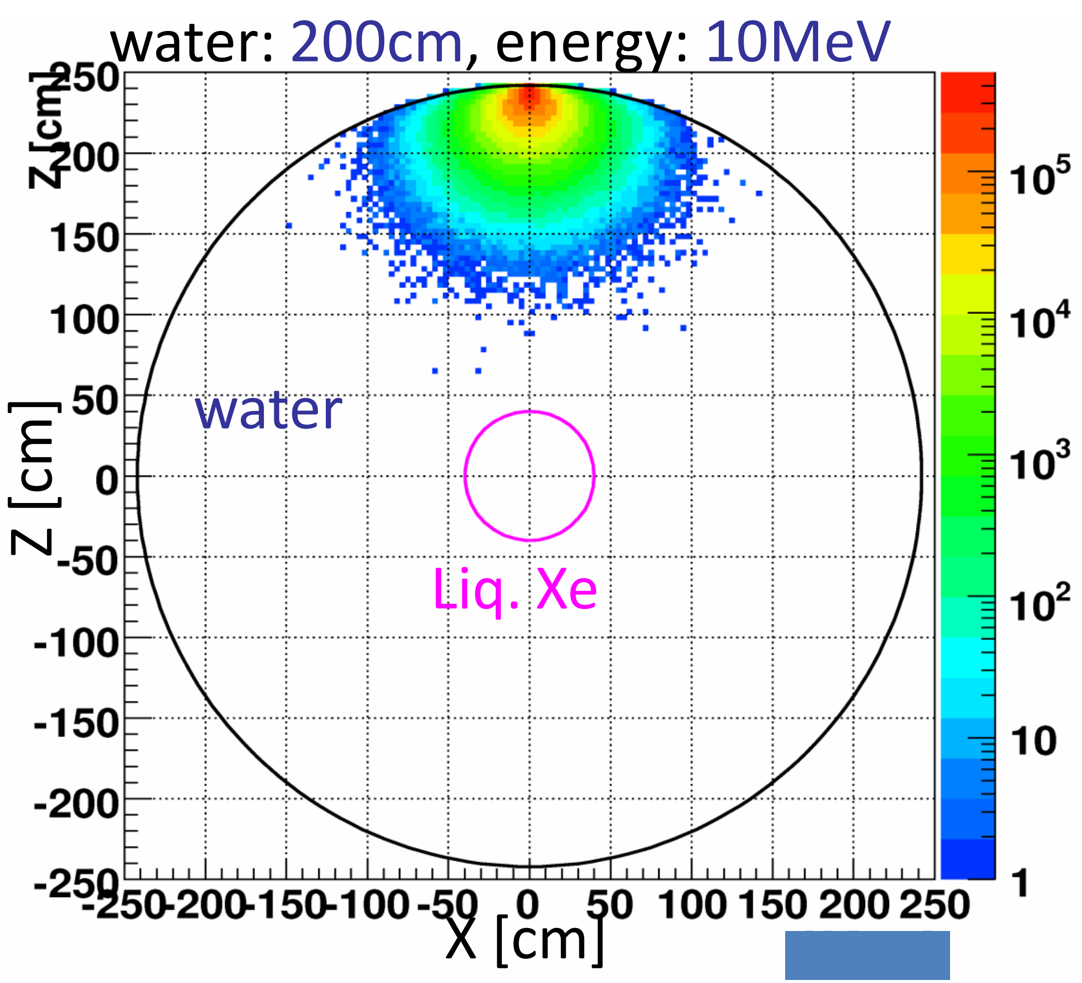
Deposit energy spectrum (200cm)



More than 200cm water is needed to reduce the BG to the PMT BG level

Water Shield for fast neutron background

- Fast n flux @Kamioka mine: (1.15±0.12) x10^{-5} /cm^2/sec



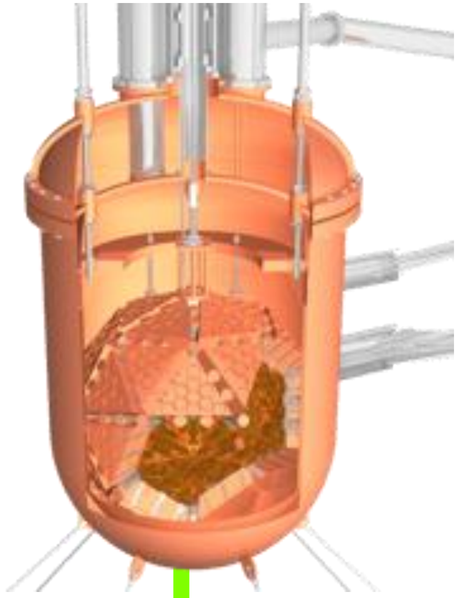
- Assuming all neutron's energies are 10 MeV very conservatively

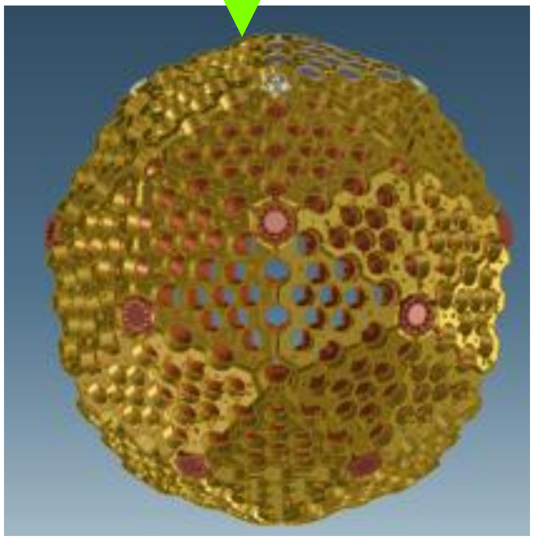
Generat:10^7 MC events, no event in Liquid Xe volume

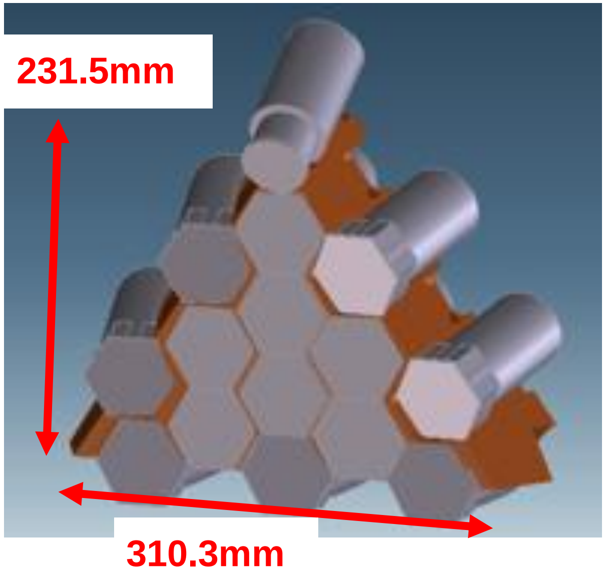
< 2 x 10^{-4} counts/day/kg

200cm of water is enough to reduce the fast neutron

Detector design detail

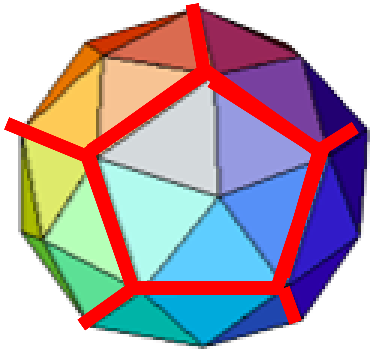






pentakisdodecahedron

Hexagonal PMT
Hamamatsu R10789



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

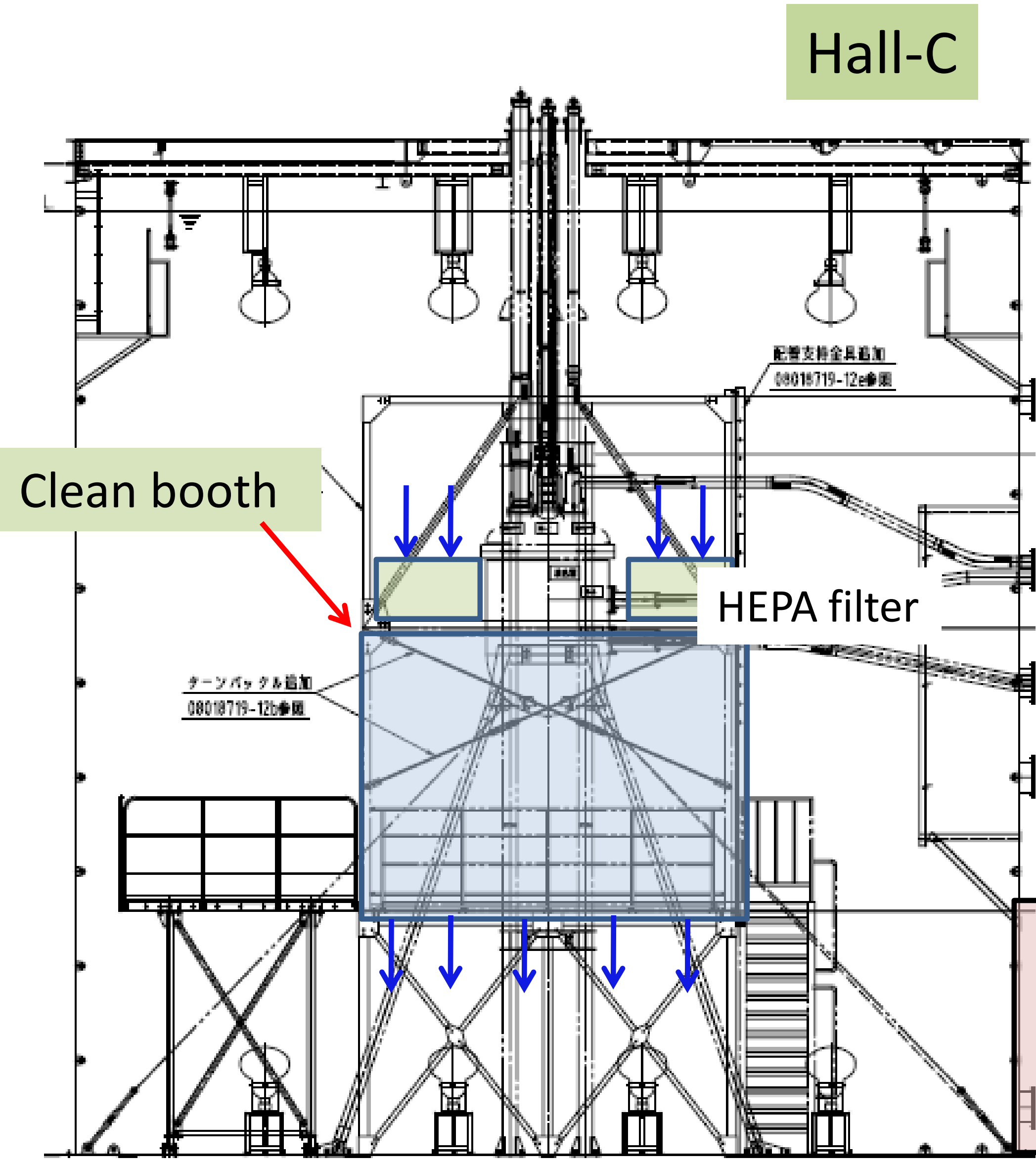
PMT history

YEAR	2000	2002	2009
Model	Prototype	R8778	R10789
			
Material:Body	glass	Kovar	Kovar
QE	25%	25%	27-39%
RI:			
U [mBq/PMT]	*50*	*18±2*	*0.7 ± 0.28*
Th [mBq/PMT]	*13*	*6.9±1.3*	*1.5 ± 0.31*
^{40}K [mBq/PMT]	*610*	*140±20*	*<5.1*
^{60}Co [mBq/PMT]	*<1.8*	*5.5±0.9*	*2.9 ± 0.16*

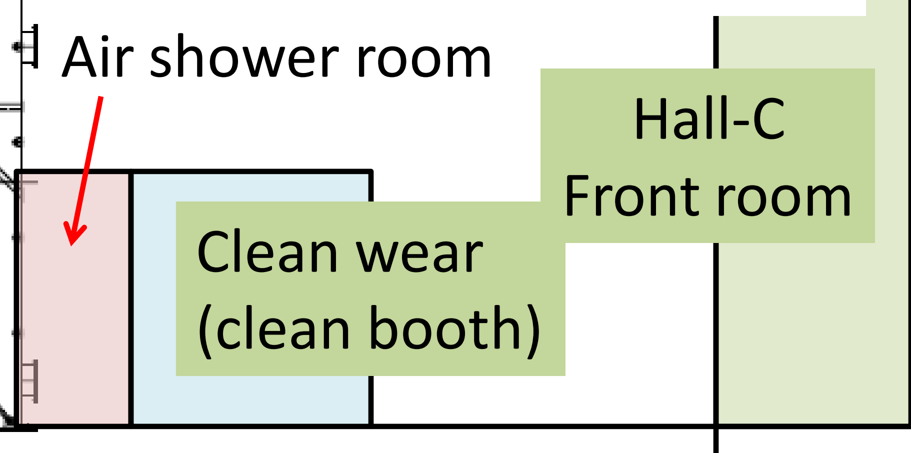
With base

- Developed with Hamamatsu Photonics K.K.
- Mass production of the PMTs was completed in Oct. 2009.

PMT, holder, and filler installation



- Dust and radon in the air could be background source.
- Dust from mine is shielded by two shutters.
- Water tank is closed and is filled with radon-free air.
- Clean booth is made in the water tank for the installation.
- During the installation, radon concentration is ~200mBq/m^3.
- Dust level is <1000/ft^3.



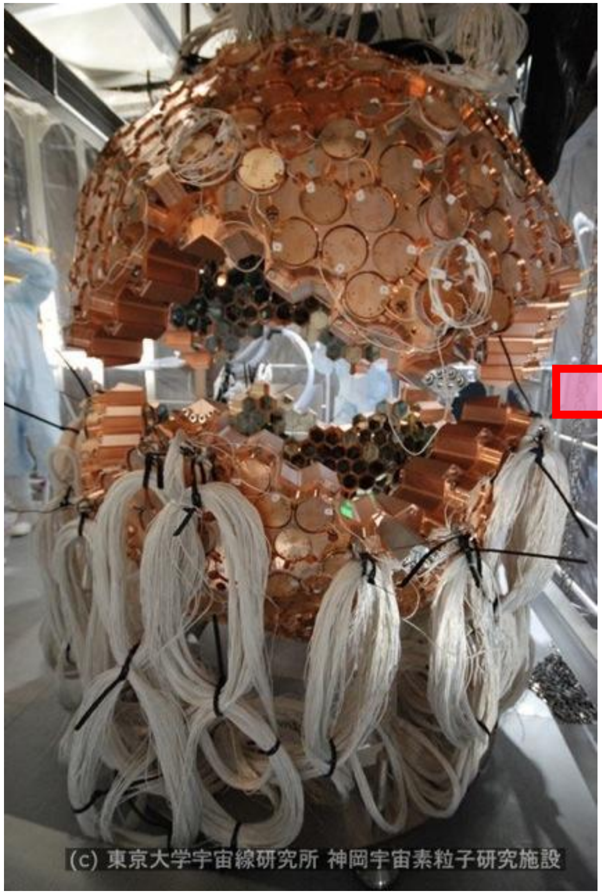
Clean booth in the water tank

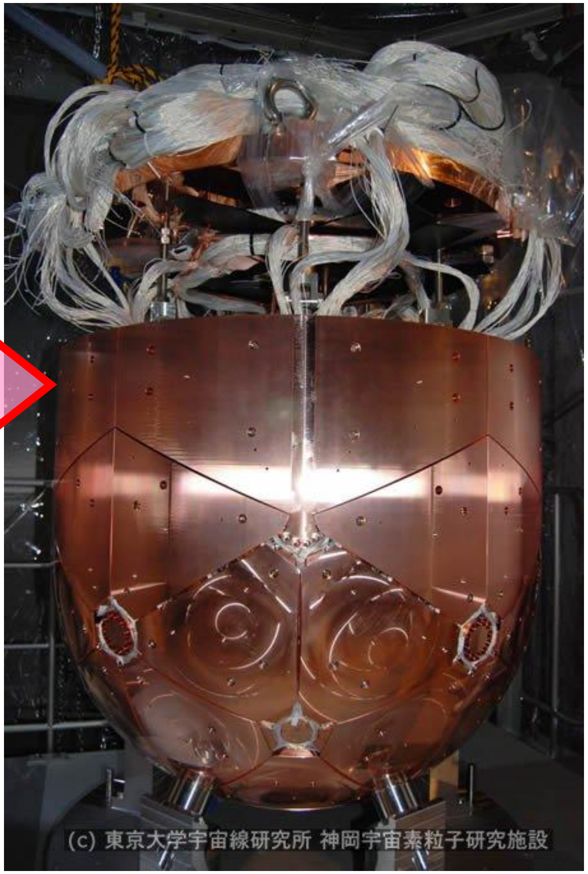
Base with clean booth
For the detector assembly

PMT/holder installation

PMT installation was done from Dec. 2009 to Feb. 2010.

PMT holder



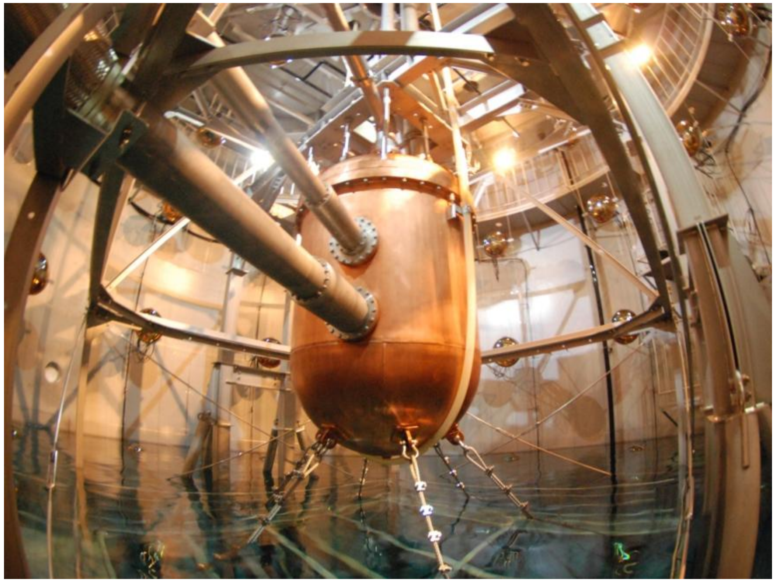


OFHC Filler to reduce the amount of liquid xenon

chamber, OD installation and water filing

IVC/OVC installation

OD PMT installation



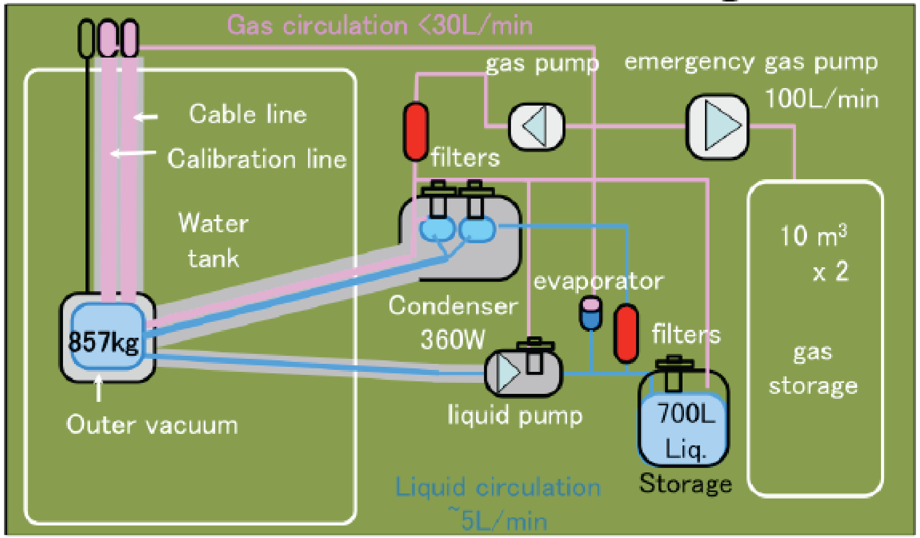
water filling

fall, 2010

Xe filling

- Evacuation and Baking
- 2010.10.16 Test filing 100kg
- 2010.10.16 Xe Collection
- 2010.10.24 1st Filling 1129kg
- 2010.10.26 Xe Collection
- 2010.10.31 2nd filling 1065kg

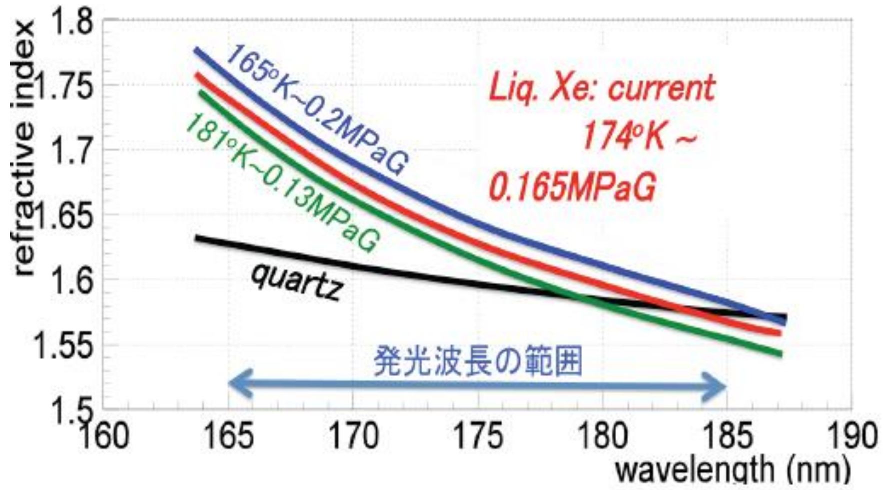
液体のまま回収することで、測定器内部をきれいにする。



- 2011.01.21 Xe Collection for the work to fix the stacked calibration rod
- 2011.01.31 3rd filling 1085kg

commissioning run

- calibration
  - source rod (57Co, 241Am, 137Cs, 109Cd, 55Fe)
  - external source (60Co, 137Cs, 232Th, neutron)
- normal run data taking
- develop software
- change of the xenon quality
  - hight/low pressure run
    (change of Xe refractive index)
  - O2 injected run
    (change of absorption length)
  - boiling run
    (make convection flow)
- Xe gas run
  - important to identify the surface background.
- measurement of the background candidate material
  - Al, goretex, Cu, Ni plate (measured at calibration source rod)



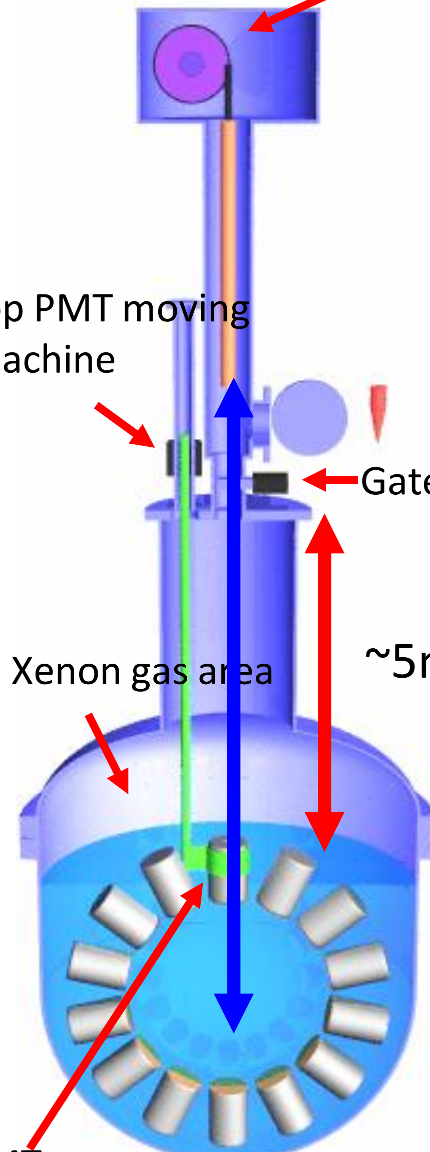
commissioning run history

Year	Month		special runs	electronics
2010	12			ATM (ADC+TDC, old SK elec.)
2011	01	3rd filling		
	02			+FADC (60ch, 10-11 PMTSUM)
	03		Low pressure run	
	04		High pressure run	
	05			
	06	Xe collection		
	07	4th filling	Gas run	
	08			
	09	add 1ppm O2	O2 run	
	10			
	11			
	12		Boiling run	
2012	01	Xe collection	remove O2 Gas run	+FADC (642 individual channels)
	02	5th filling		
	03			
	04			
	05			

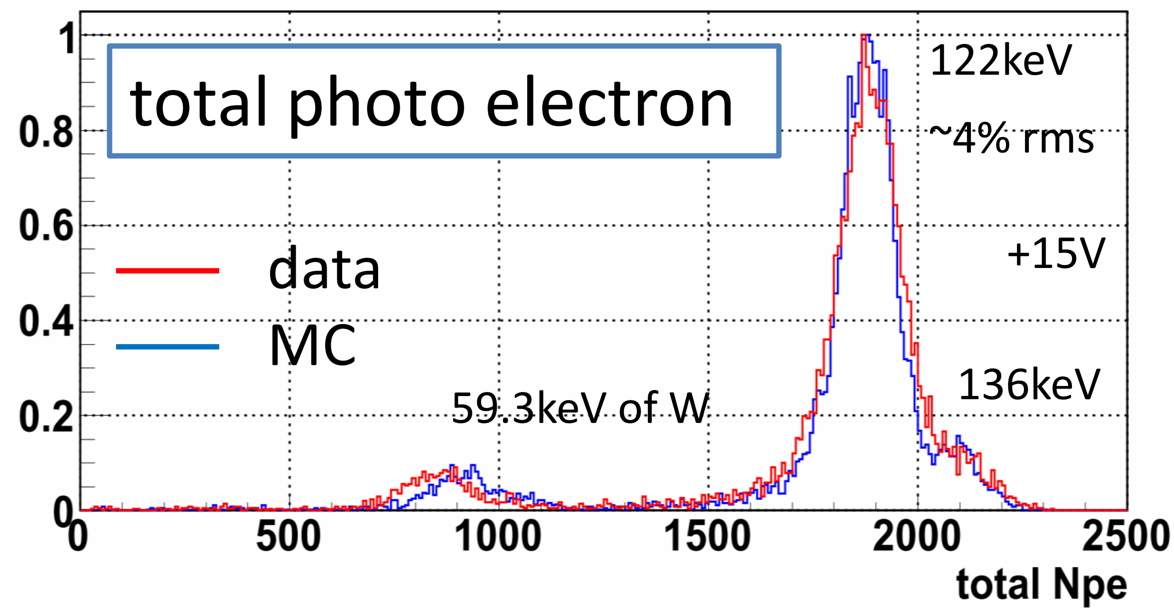
Calibration system

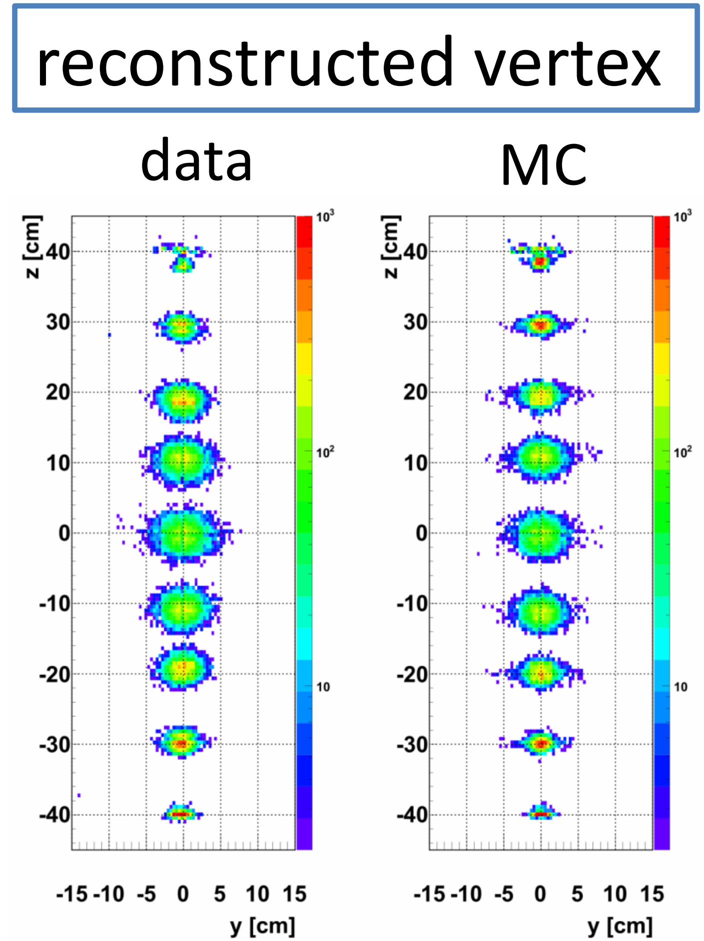
RI sources

	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)

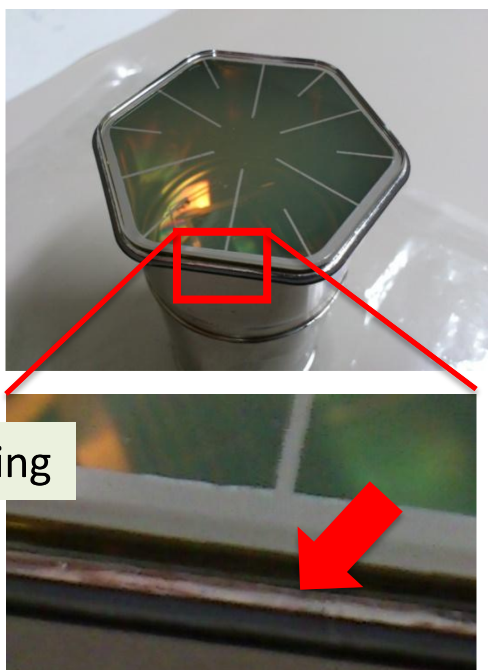




- ^{57}Co source @ center gives a typical response of the detector.
- 14.7p.e./keV_{ee} (⇔ 2.2 for S1 in XENON100)
- The pe dist. well as vertex dist. were reproduced by a simulation well.
- Signals would be <150p.e. exp shape.

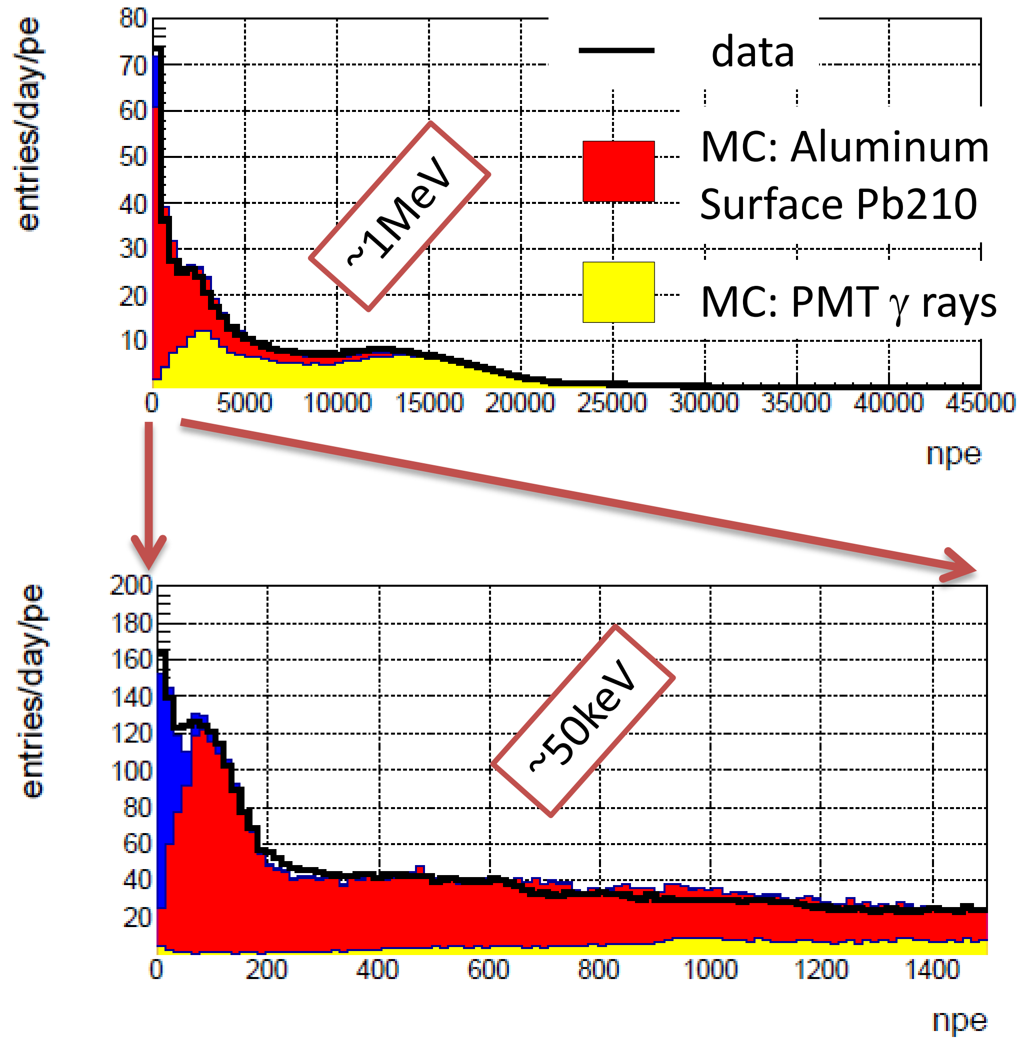
Background and its understanding

- Major origin of BG was considered to be γ 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

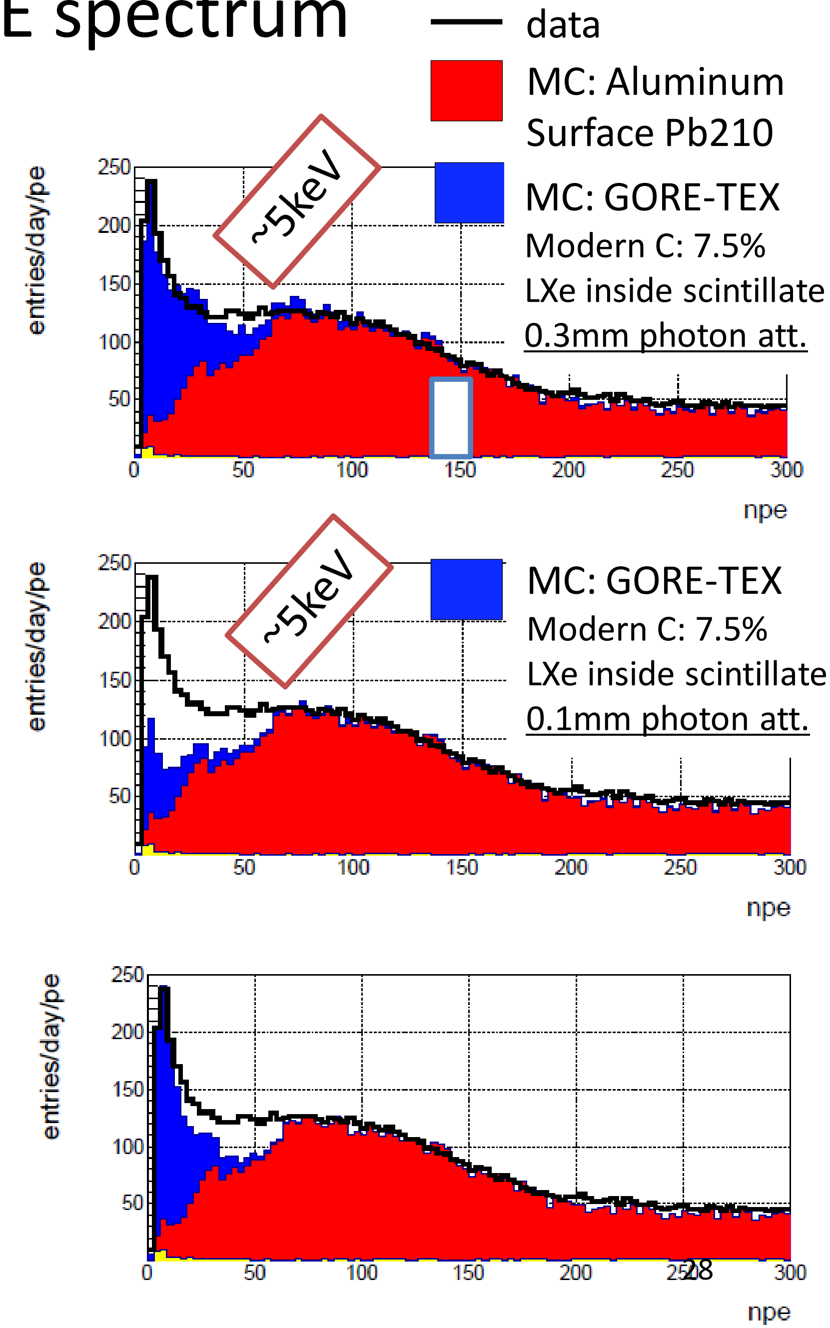
- Three contributions to the NPE spectrum
  1. High energy (0.1-3MeV): PMT γ rays: <u>Measured by Ge detectors and well understood.</u>
  2. Mid. energy (5keV-1MeV): Aluminum and radon daughters: <u>Measured by Ge det. and consistent with observed α-ray events</u> (61/64mcps in data/MC). Rn daughters on the inner wall identified by α events.



background contribution to NPE spectrum

3. Low energy (0-5keV): Under study.

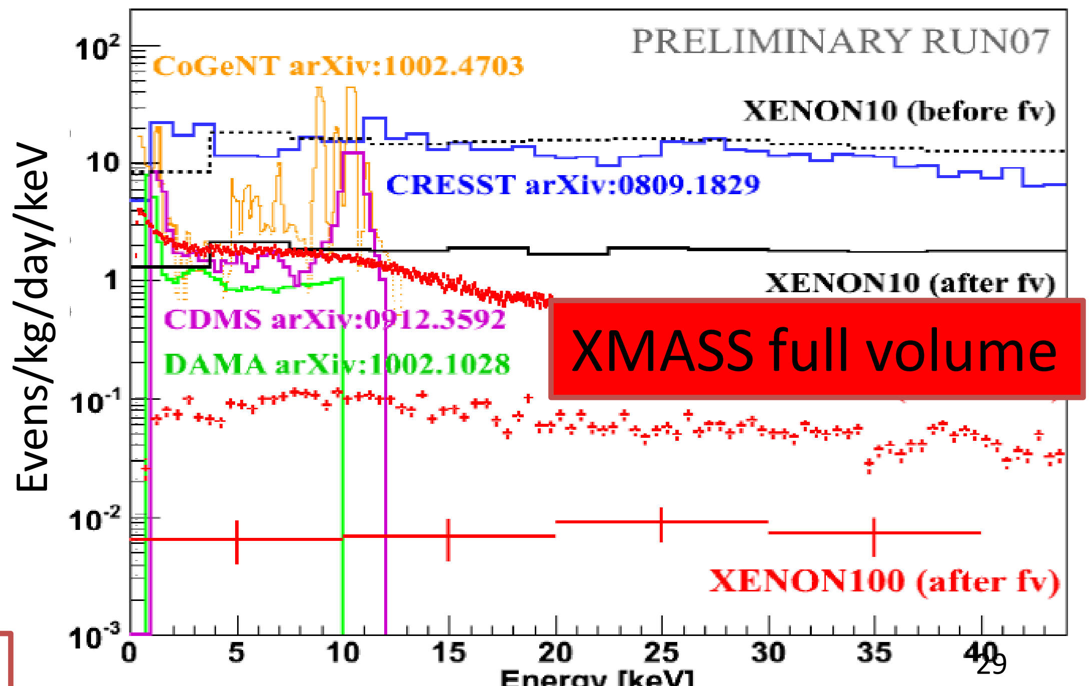
Prediction based on some assumptions on GORE-TEX gives a similar shape. But assumption dependent. Confirmation possible only by removing the GORE-TEX.



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!
- In principle, the surface BG can be eliminated by vertex reconstruction. Optimization of the reconstruction program is on going to minimize a possible leakage to the inner volume.
- Our sensitivity for the low mass WIMP signals at low energy without reconstruction will be shown.



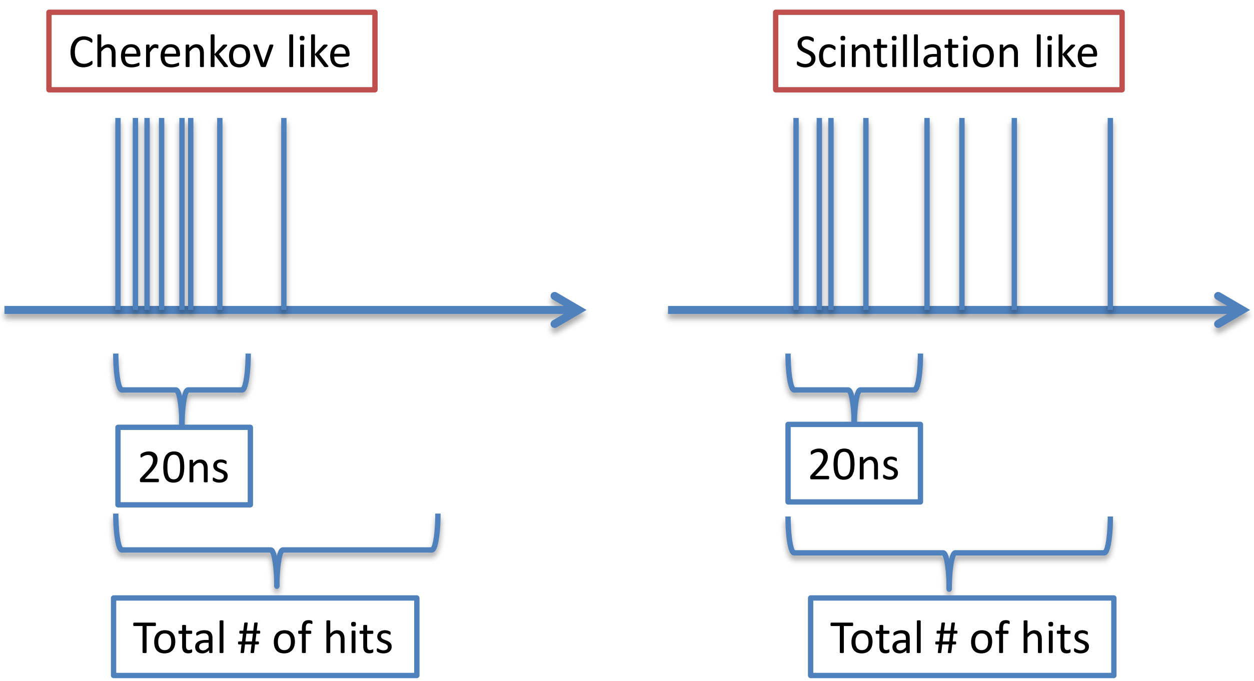
E. Aprile, 2010 Princeton

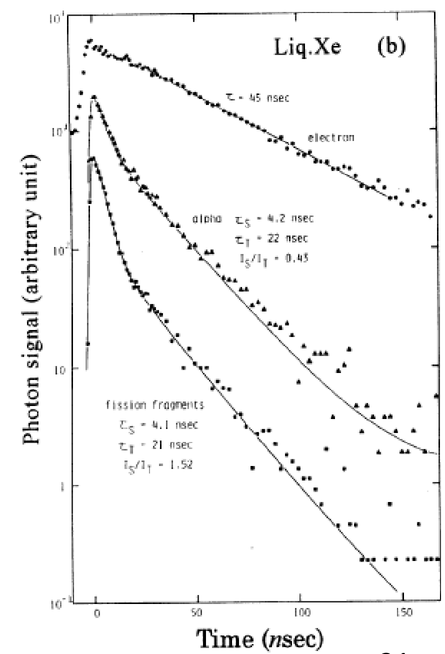
Low energy, full volume analysis for low mass WIMPs

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

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.

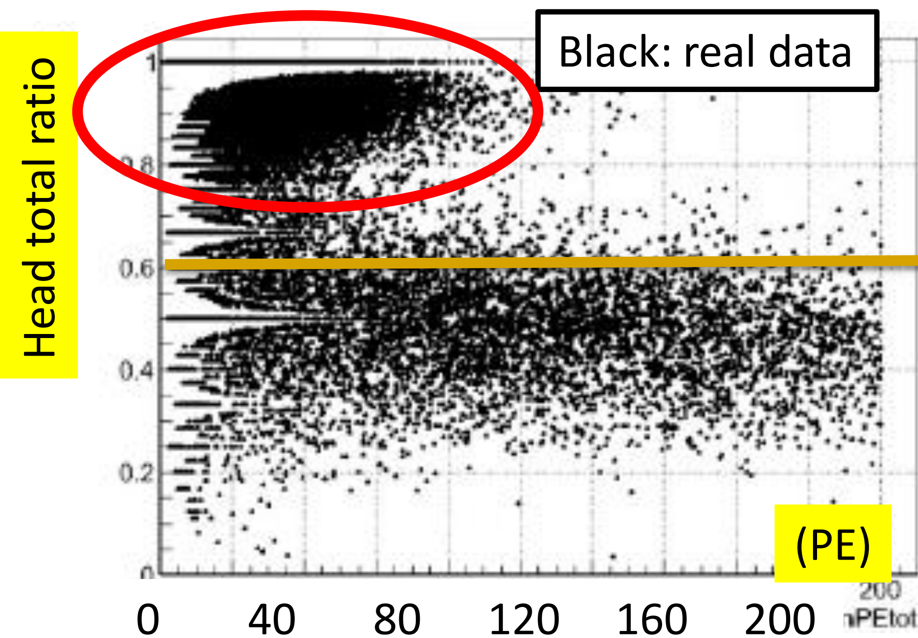


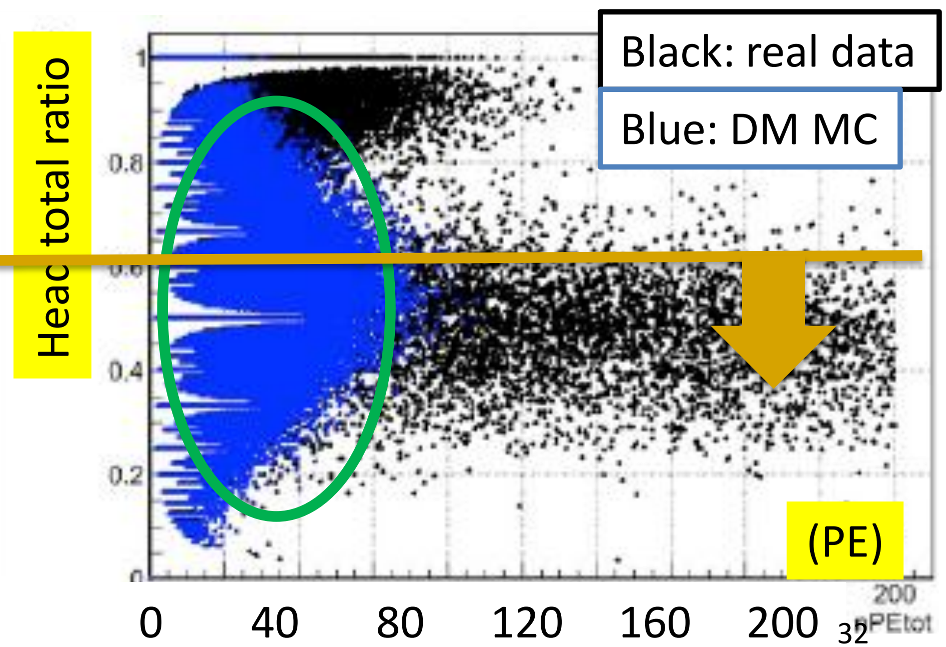


A. Hitachi et al., Phys. Rev. B 27 (1983) 5279.

“head total ratio” distribution

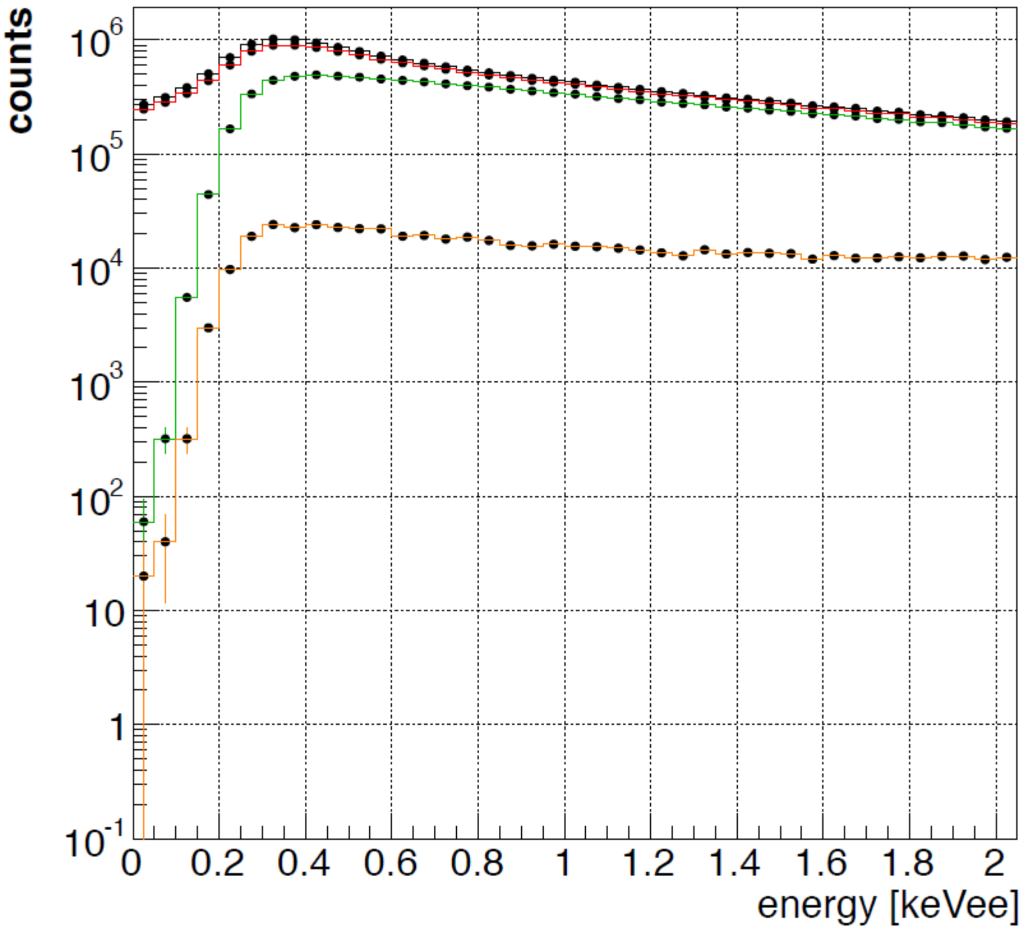
- Cherenkov events peaks around 1 ⇔ scintillation ~ 0.5
- Low energy events observed in Fe55 calibration source as well as DM simulation (t=25ns) show similar distributions.
- Efficiency ranges from 40% to 70% depending on the p.e. range.





p.e. distribution after each cut

- 6.64 days data
- The Cherenkov events are efficiently reduced by the cut.



cut0: trigId == 1 :932863

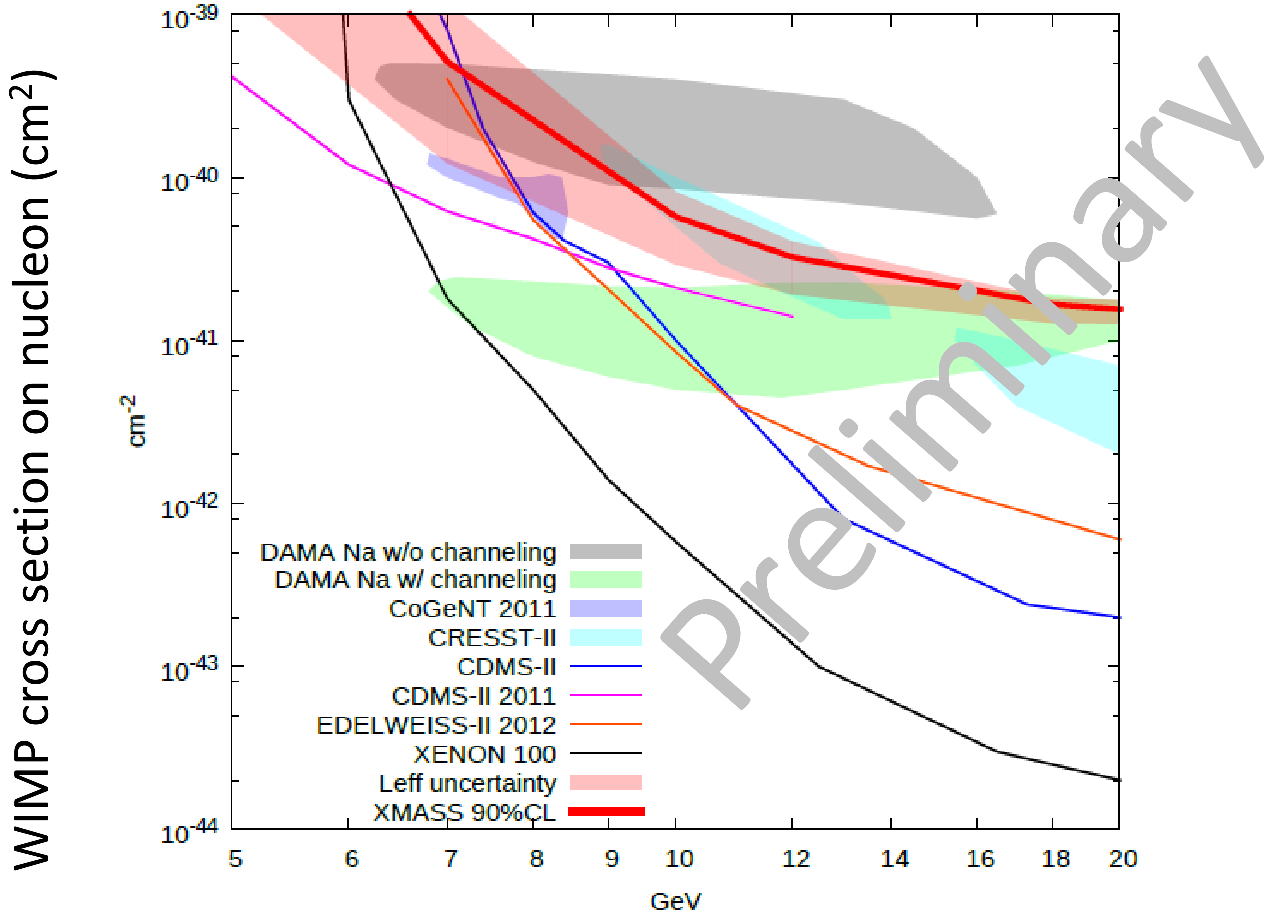
cut1: + dT_Pre(10msec) :866343

cut2: +tdcRMS<100 :570025

cut3: +Chrenkov :28863

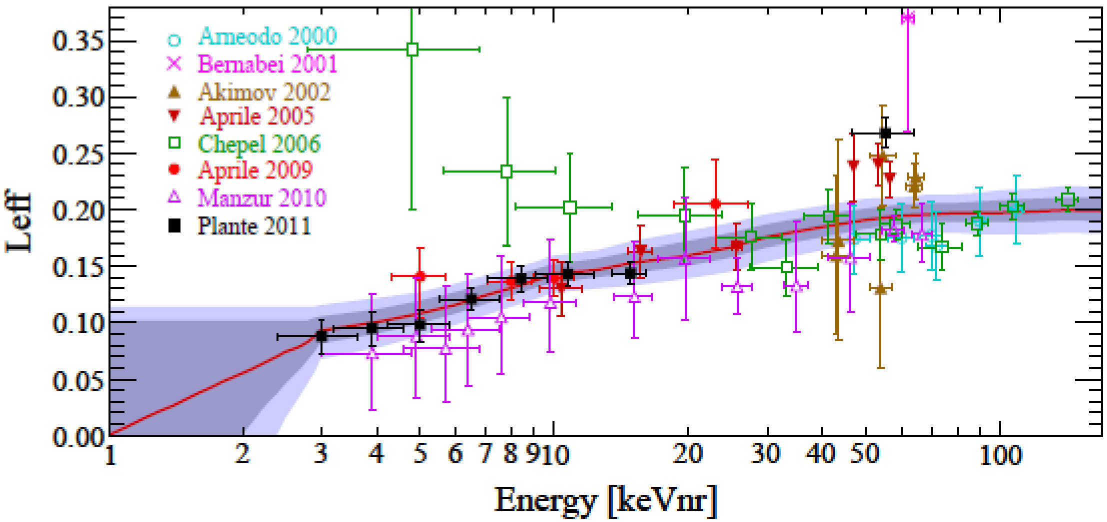
exclusion region

- Sensitive to the allowed region of DAMA/CoGeNT.
- Some part of the allowed regions can be excluded.



Uncertainties

- Major uncertainty is the scintillation efficiency of nuclear recoil in liquid xenon.
- Uncertainties of the trigger thre. (hard trig. 4hits), cut eff., and energy scale are also taken into account.

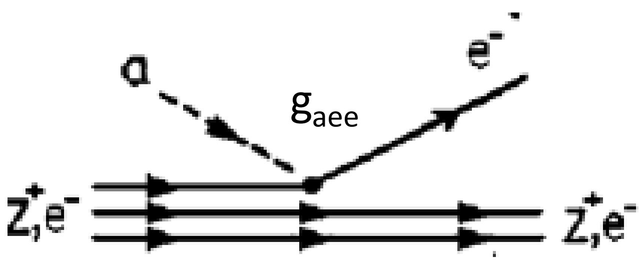


Scintillation efficiency as a function of energy
E. Aprile et al., PRL 105, 131302 (2010)

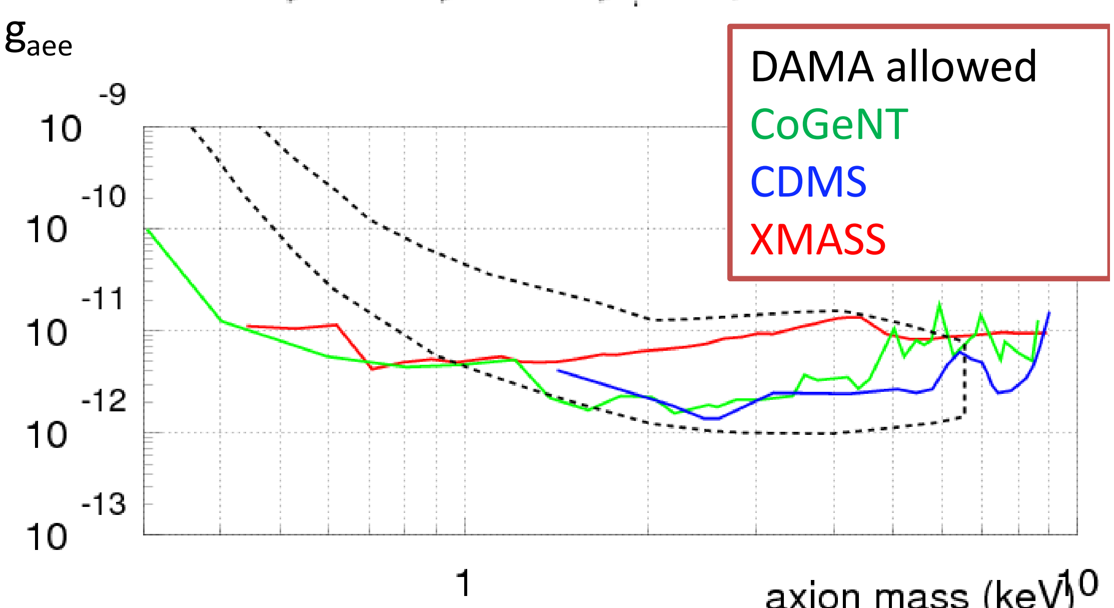
Note: our "energy" = keVnr * Leff

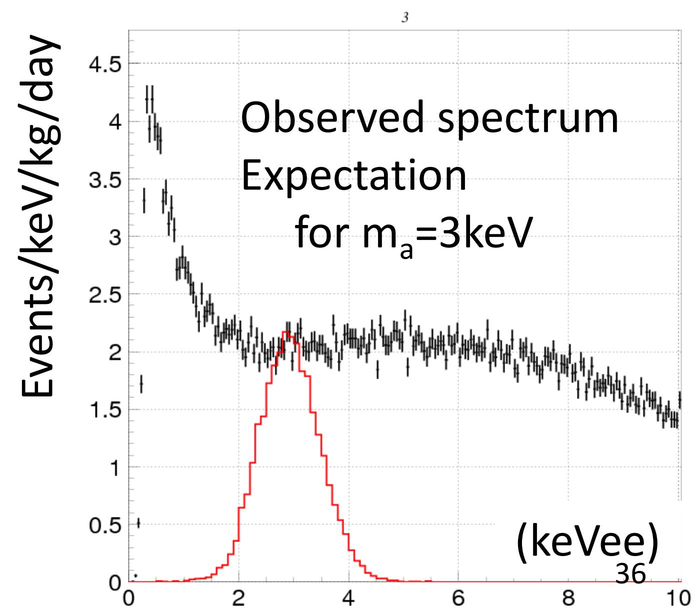
Sensitivity on the axio-electric dark matter coupling

- The DAMA signal may be due to electromagnetic interaction of WIMPs to the NaI detectors by such as a non-relativistic axion dark matter. See J. Collar, arXiv: 0903.5068



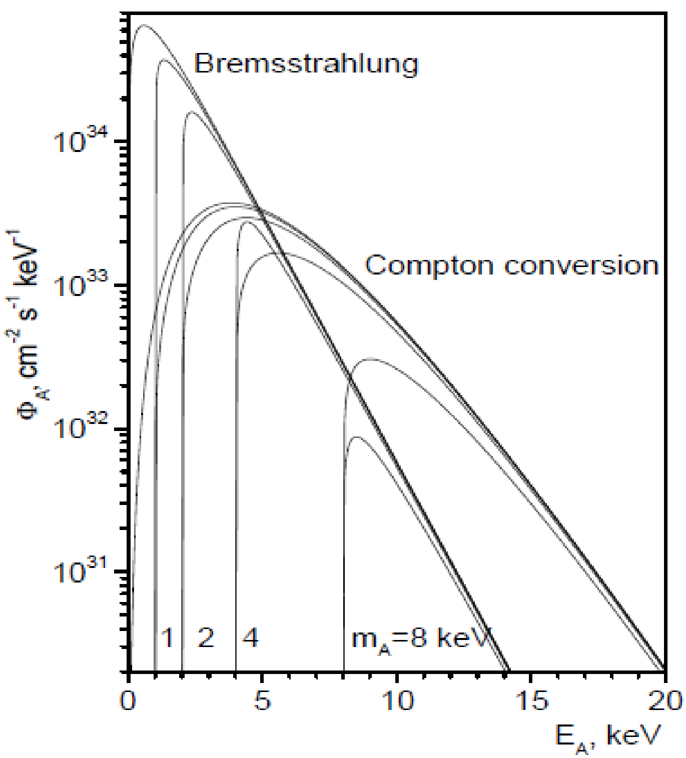
Non relativistic axion deposits its total energy similarly to the photo-eletcric effect.

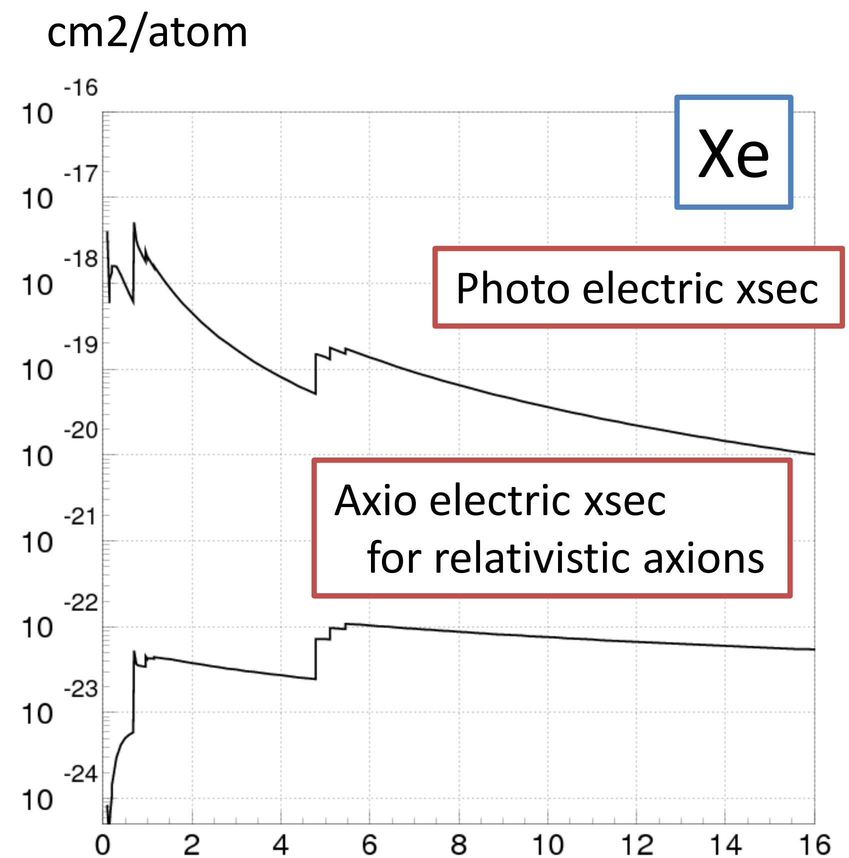




Solar axion search
Bremsstrahlung + Compton: gaee only

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

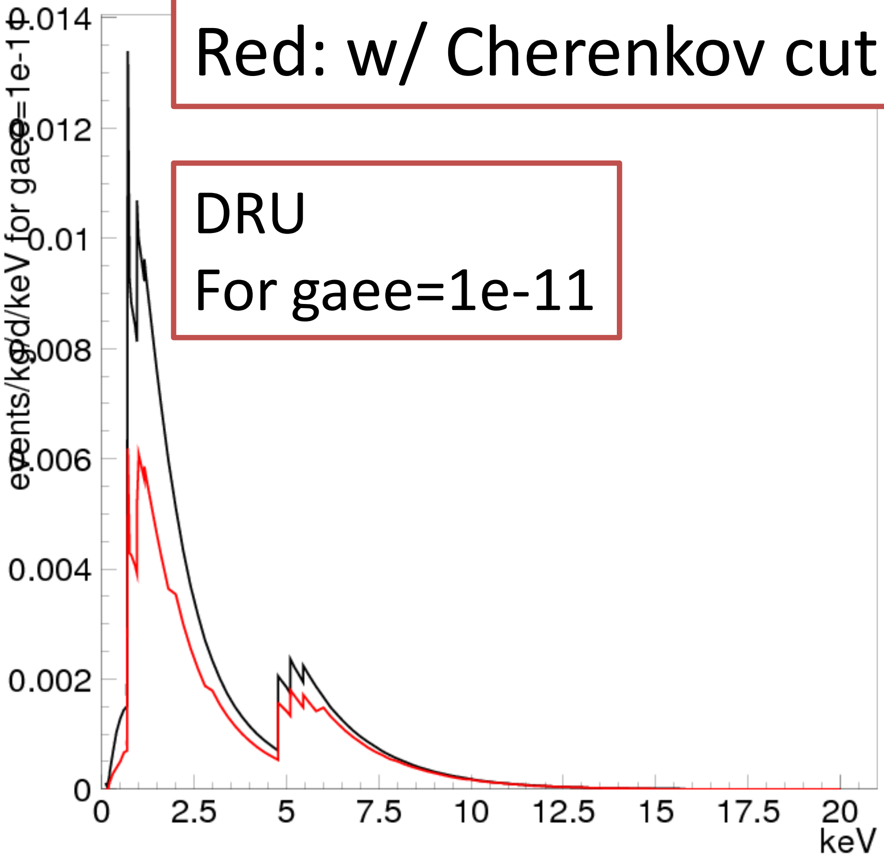


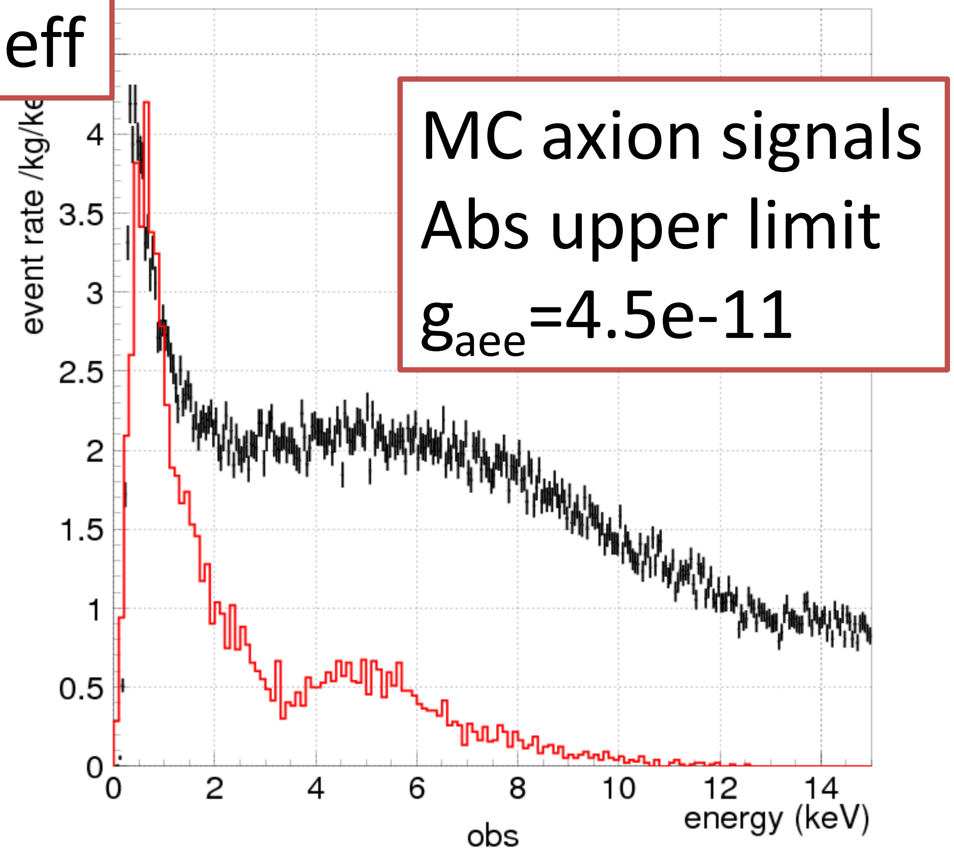


Expected signals and MC simulation

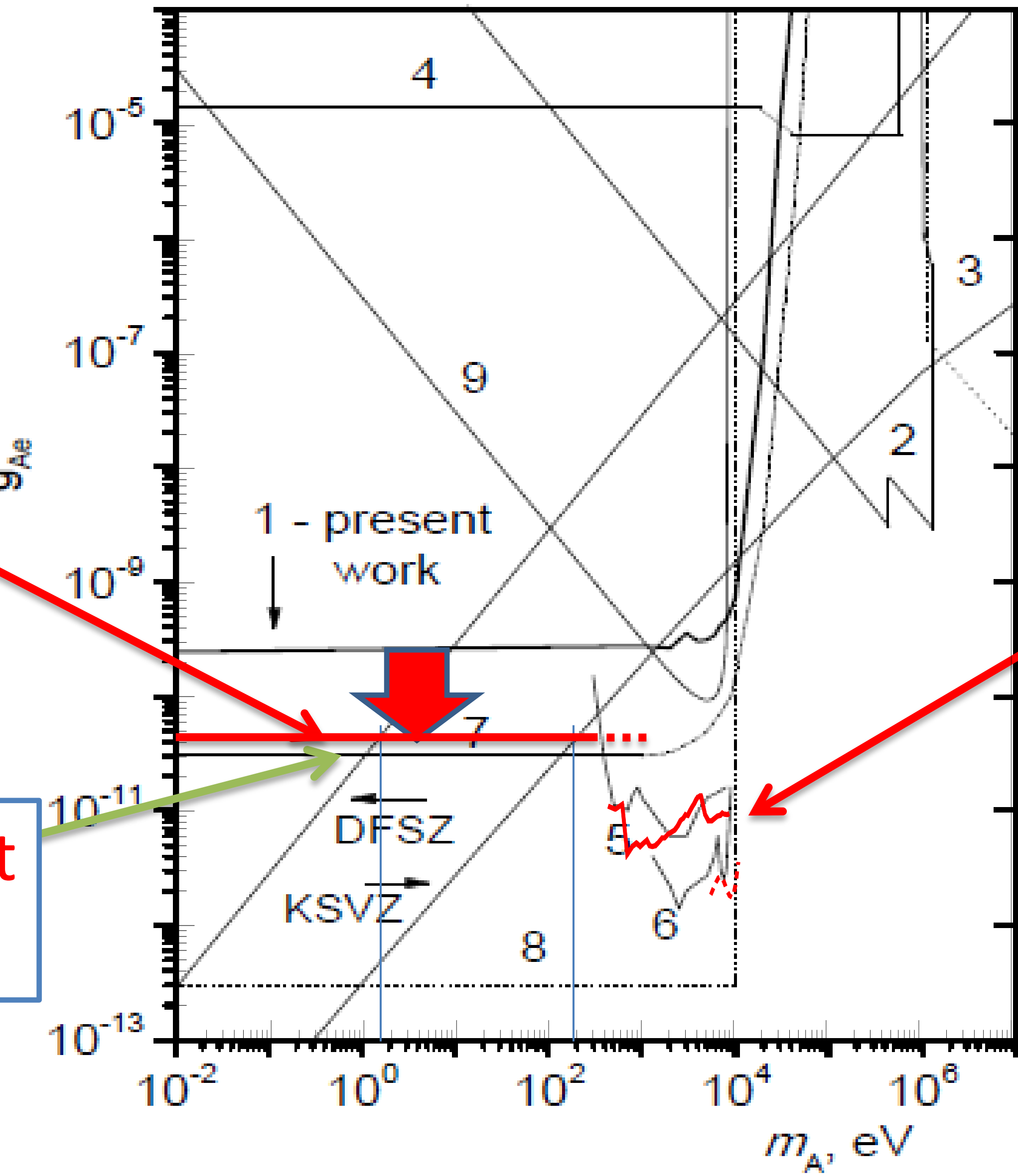
- Left: analytical spectrum
- Right: simulated spectrum overlaid with observed spectrum

Black: w/o efficency
Red: w/ Cherenkov cut eff





solar axion sensitivity



Original figure from Derbin, 1206.4142

XMASS Limit by solar axion 4.5e-11

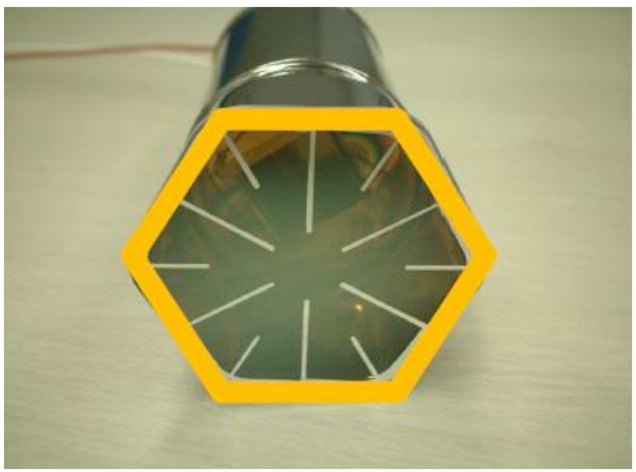
Solar limit 2.8e-11

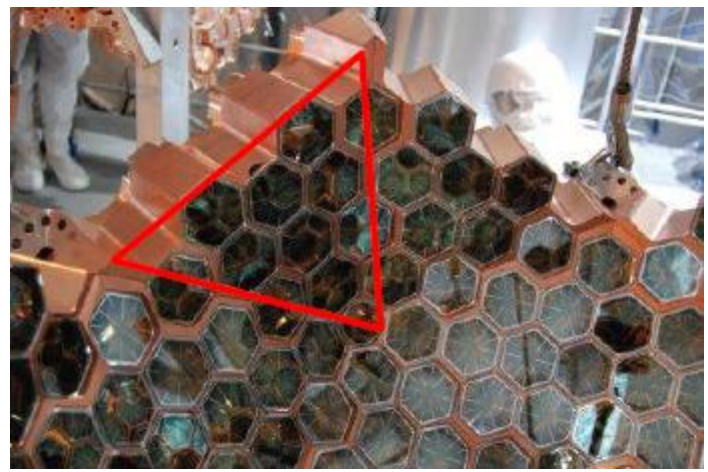
XMASS Limit by DM

Allowed mass
< 200eV for KSVZ
<2eV for DFSZ

Plan: Refurbishment work

- Tuning of reconstruction/reduction is on going but for better sensitivity, removing the origins of BG must be done.
- To reduce the BG caused by Aluminum, we are planning to cover the part and surfaces by copper rings and plates:

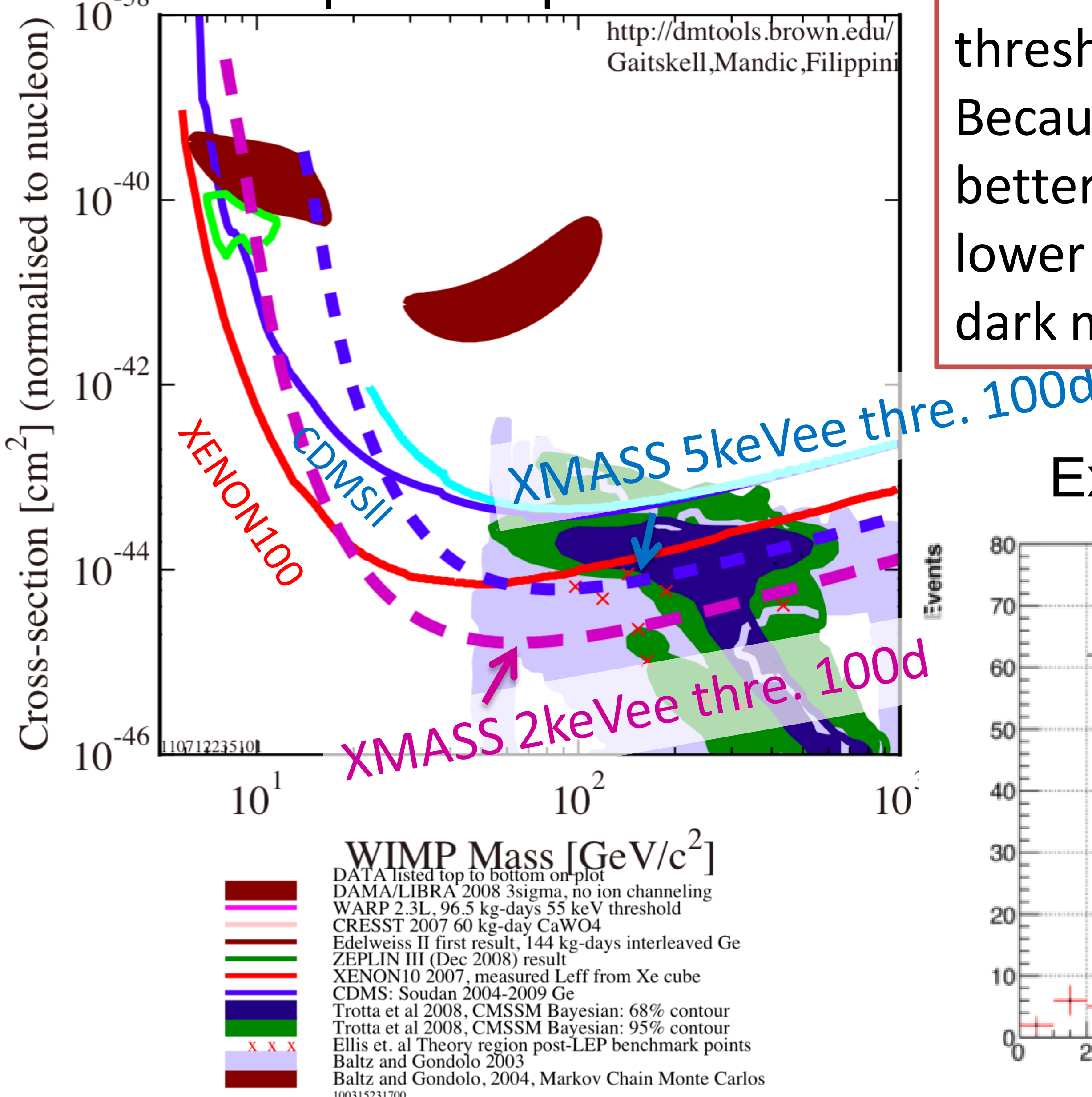




- BG > 5keV must be reduced significantly.
- Schedule: latter half of this fiscal year

Expected sensitivity with fiducialization

Spin Independent



Initial target of the energy threshold was ~5keVee. Because we have factor ~3 better photoelectron yield, lower threshold = smaller mass dark matter may be looked for.

Expected energy spec.