XMASS Projects

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for the XMASS Collaboration

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- Recent physics results
  - From 2012 commissioning run
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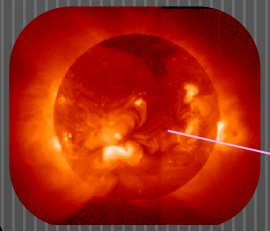
  - XMASS-1.5

XMASS Projects…

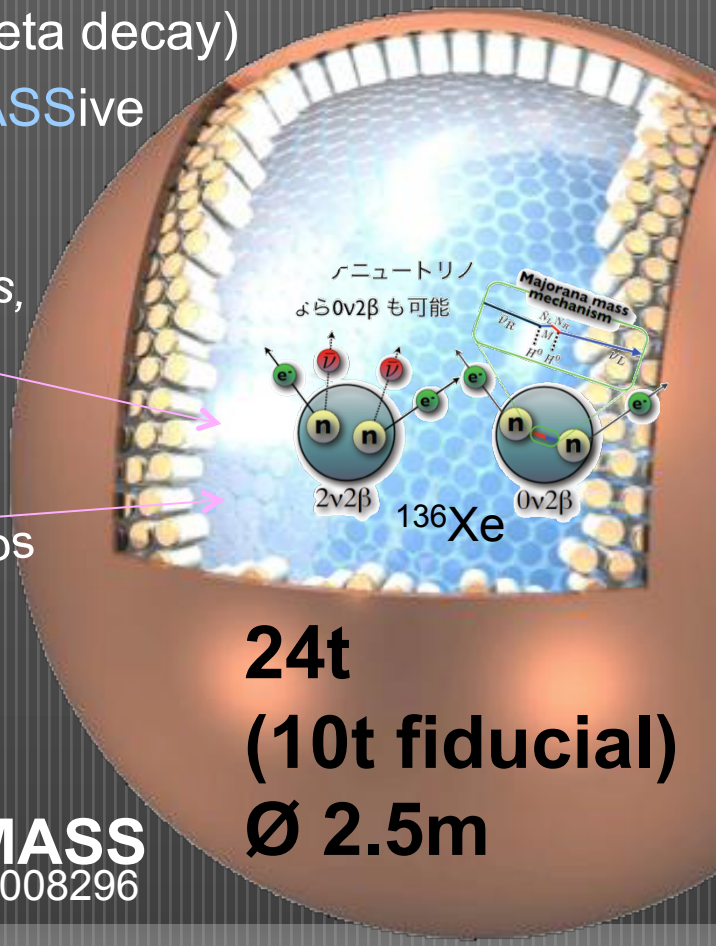
Multipurpose low BG experiment with single phase (liquid) Xe

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



neutrinos, axions

dark matters, neutrinos



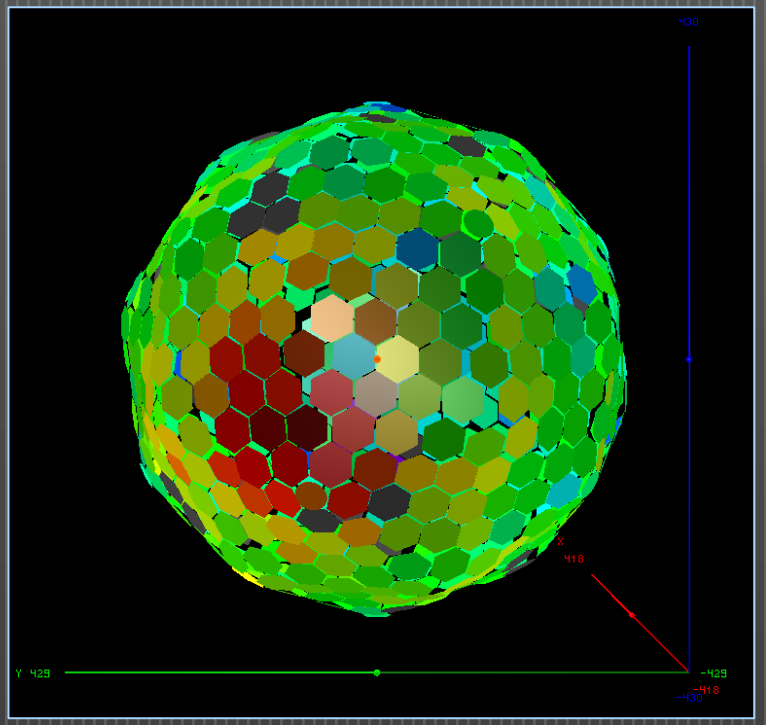
24t
(10t fiducial)
Ø 2.5m

The ultimate XMASS
Y. Suzuki, hep-ph/0008296

XMASS-1

- 835kg LXe detector for Dark Matter search

80cm



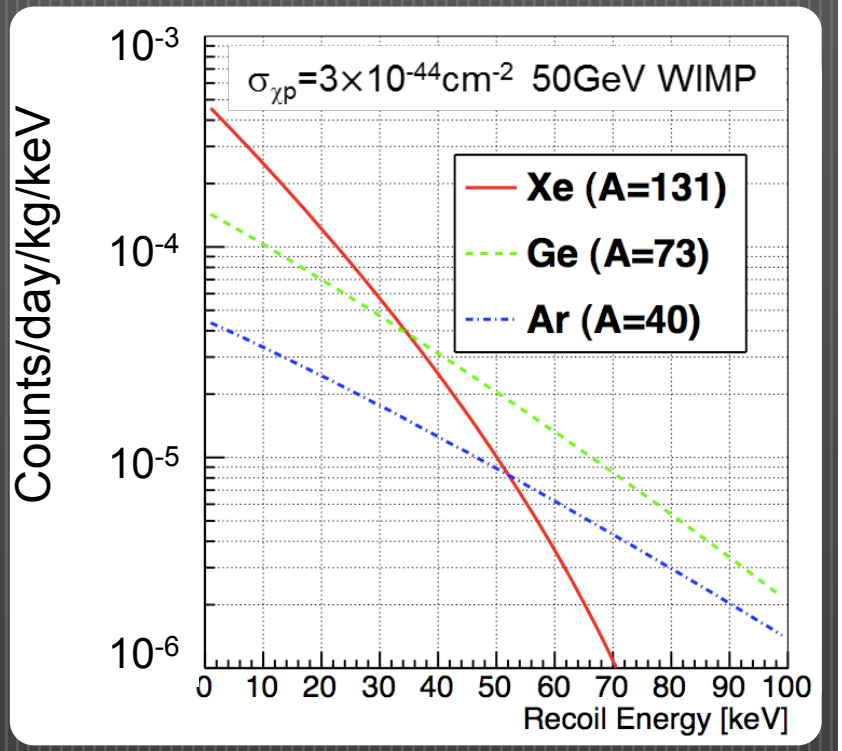
Why Single Phase Xe?
Simple and Clean for Large Scalability

Simplicity
- Single phase LXe scintillator
- Simple structure like Super-K

Cleanliness
- Made of pure materials
  - Development of low BG PMTs
- Xe purification technologies
  - distillation system

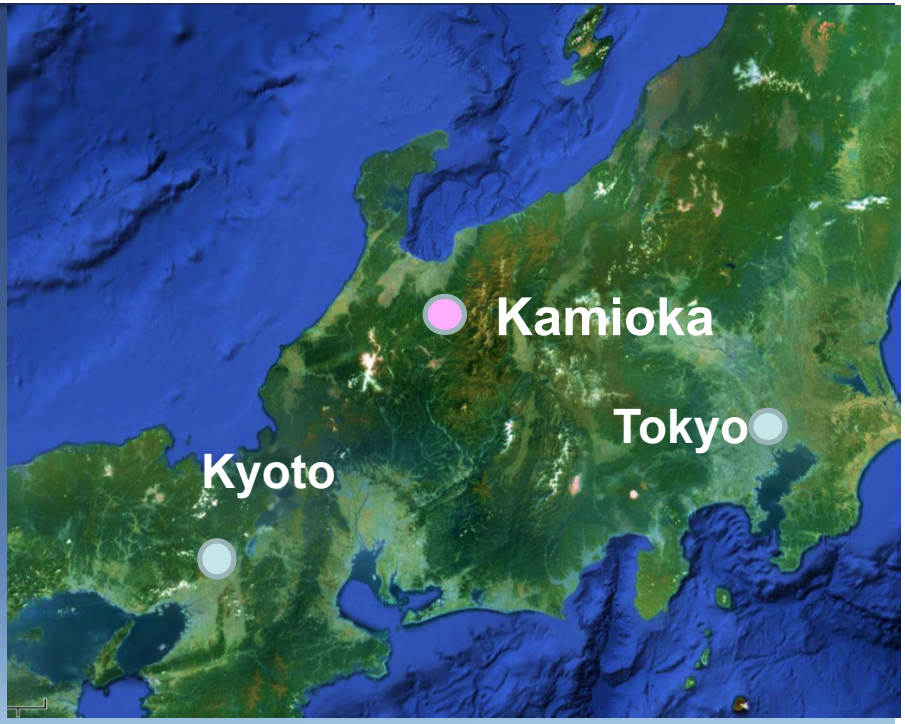
Xe has the advantage for Spin Independent interacting WIMPs

Expected WIMP spectrum



Kamioka Observatory

- Located underground in Mozumi zinc mine at a 2700 m.w.e. depth.
- 2km horizontal access by cars



Mt. Ikenoyama
(1369m)

1000m

Surface Lab.

Entrance

1800m

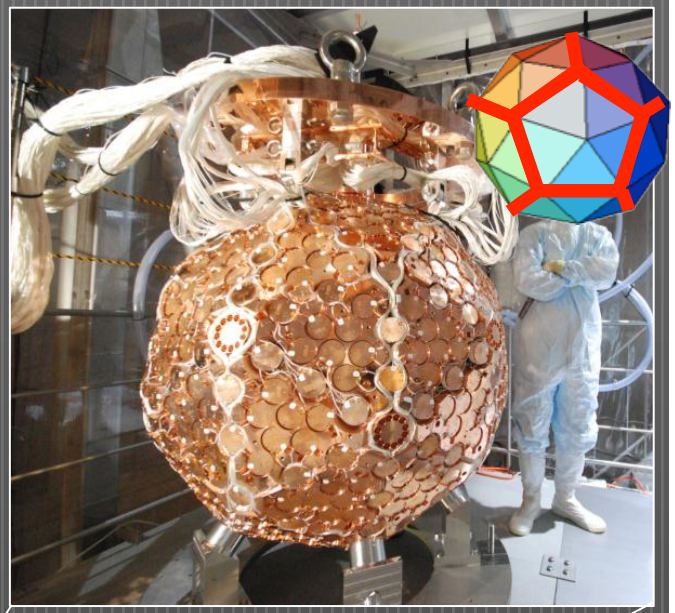
Underground
Lab.s

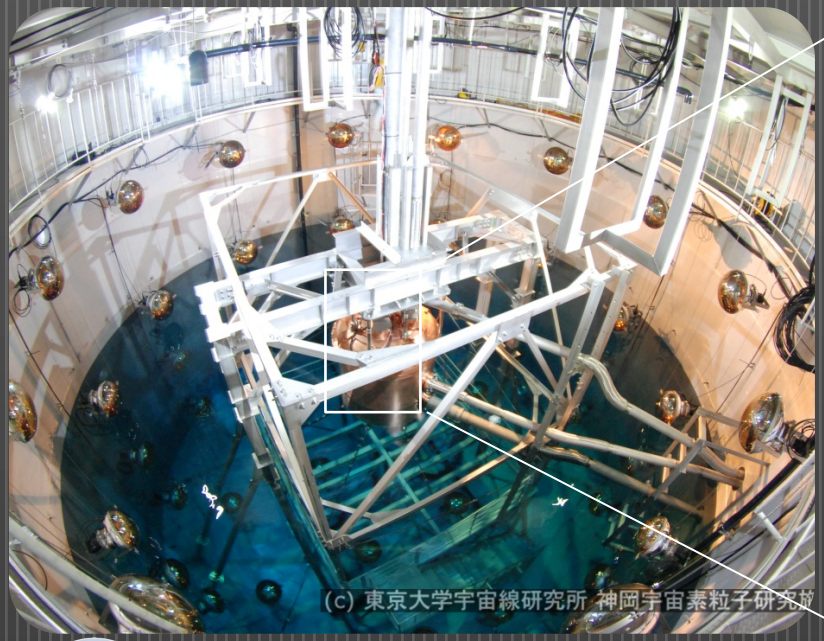
Image © 2010 DigitalGlobe
Image © 2010 Digital Earth Technology
© 2010 Cnes/Spot Image
Data © 2010 MIRC/JHA

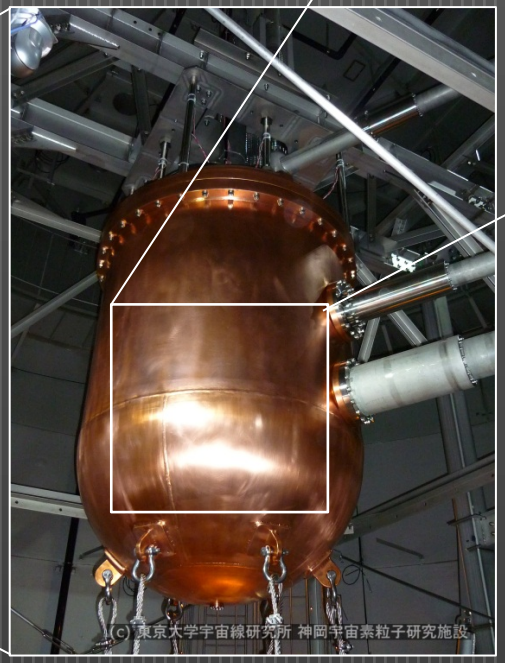
©2009 Google

XMASS-1 Detector

- 10m x ϕ10m water shield for external BG
- 1050 kg Liquid Xe within the chamber.
  - Largest mass among DM detectors
- 642 hexagonal PMTs on
  80cm pentakisdodecahedron







Construction was completed in Oct 2010

Inside of the pentakisdodecahedron

- Photo coverage is 62.4%

Clean PMT

HAMAMATSU

XMASS PMT HISTORY

YEAR	2000	2002	2009
Model	Prototype	R8778	R10789
Material:Body	glass	Kovar	Kovar
QE	25%	25%	**27-39%**
RI:			w/ PMT base
U [mBq/PMT]	*50*	*18±2*	*0.70±0.28*
Th [mBq/PMT]	*13*	*6.9±1.3*	*1.51±0.31*
^{40}K [mBq/PMT]	*610*	*140±20*	*9.10±2.15*
^{60}Co [mBq/PMT]	*<1.8*	*5.5±0.9*	*2.92±1.61*

- Clean PMT Base has also been developed.

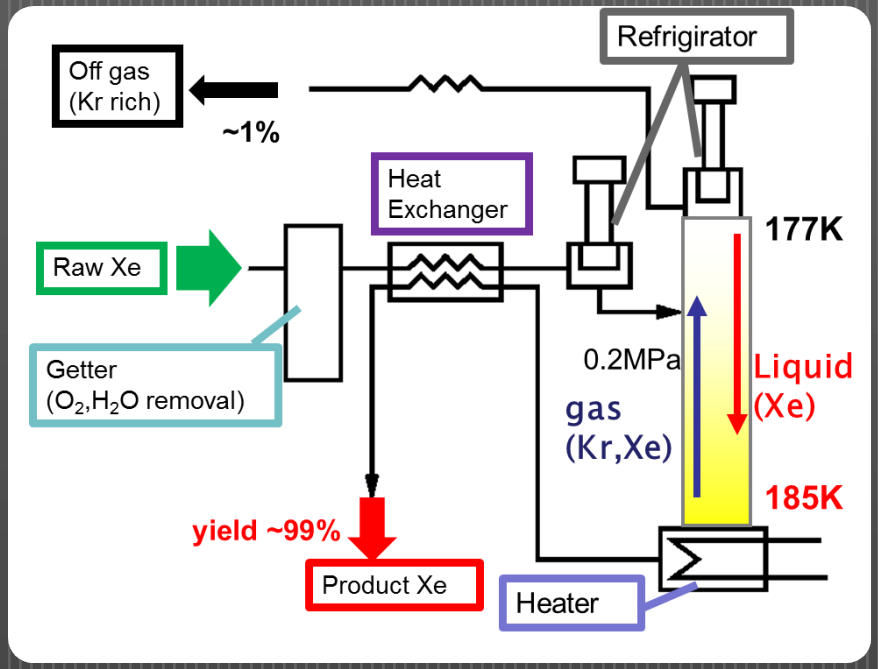
Astoparticle Physics 31, (2009) 290

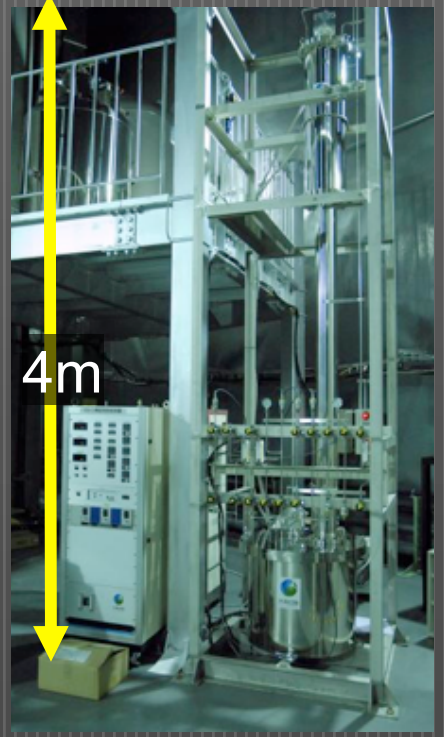
Xe Distillation System

- Commercial "pure Xe" contains ~0.1ppm Kr
  - ^{85}K / K = 1.2×10^{-11} τ =10.8 year, Q_β = 687keV
  - 5 order reduction was indispensable.

	Boiling point (@0.2MPa)
Xe	178K
Kr	140K~150K

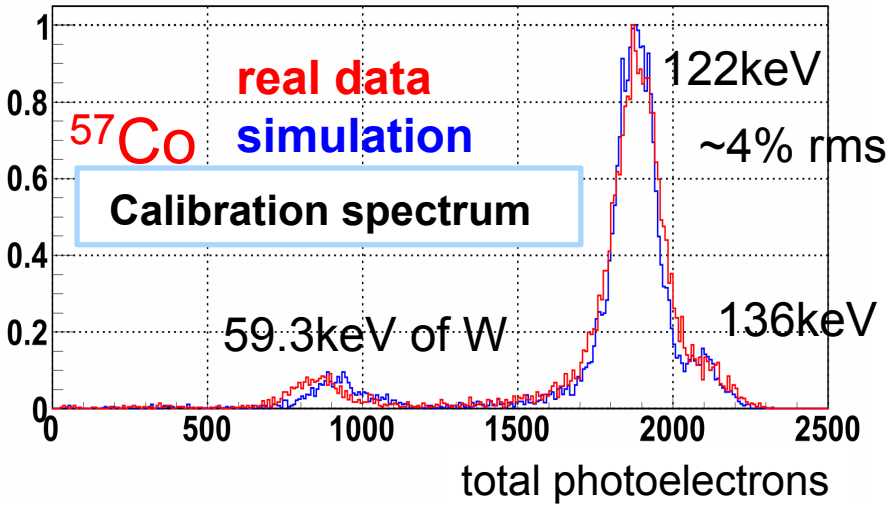
We established Xe purifiaction by distillation

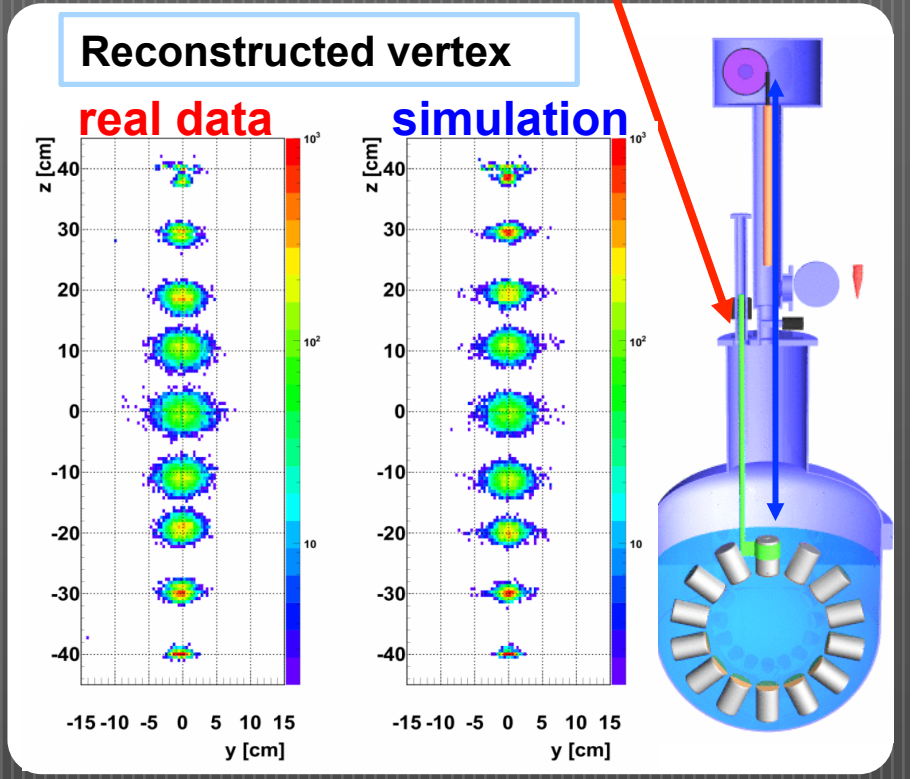


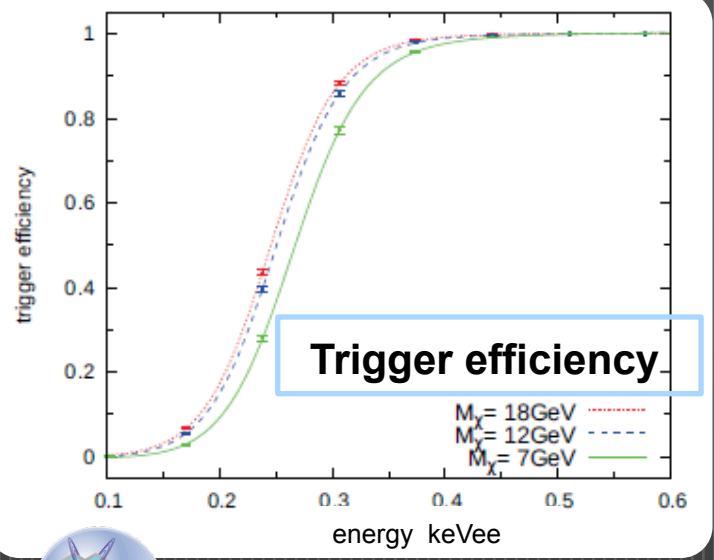


- 1 ton LXe = 170 m^3 gas Xe Process speed: 4.7kg/hr → 10 days
- Confirmed Kr < 2.7ppt by API-MS

Detector Response



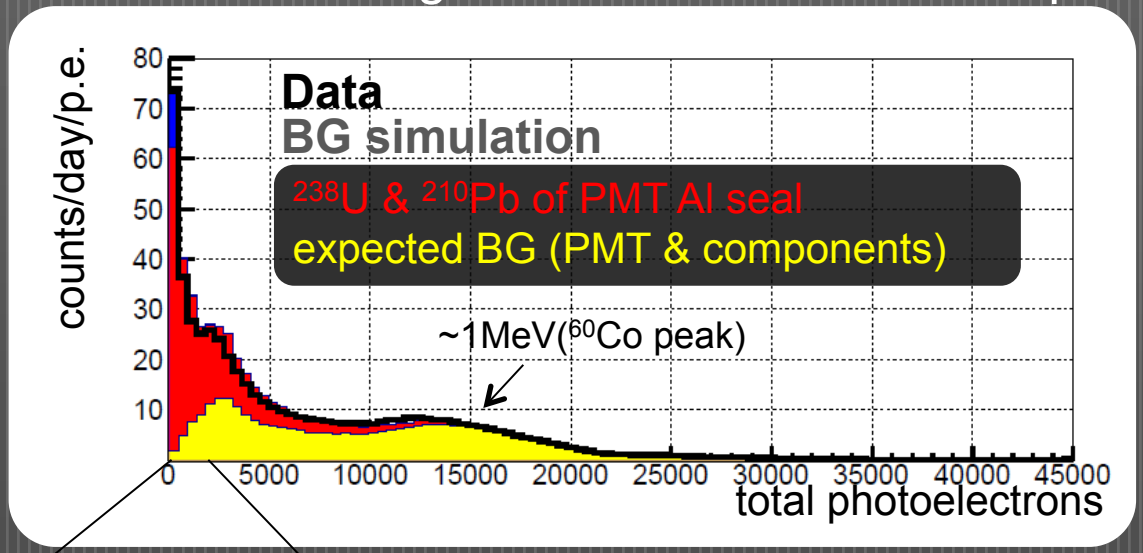


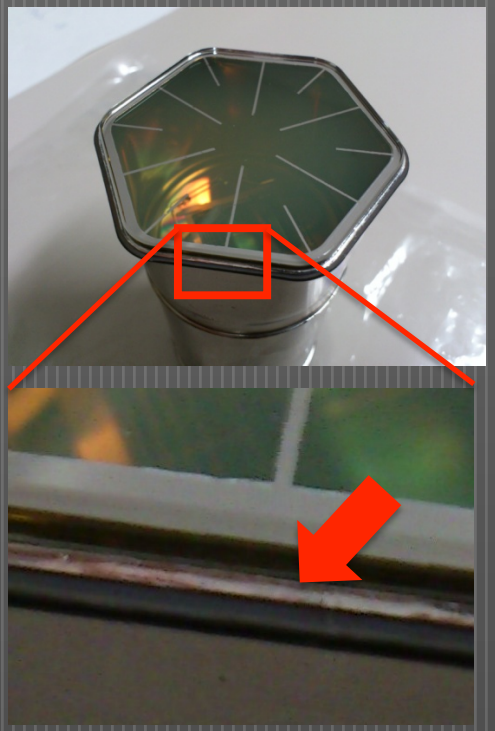


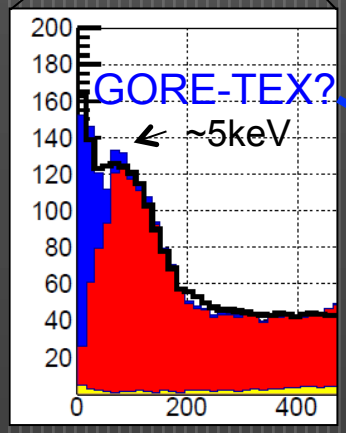
- Highest LXe scintillation yields: 14.7p.e./keVee
- Lowest threshold: 4hits→0.3keVee

Unexpected BG

- BG is 2 order higher than that had been expected.



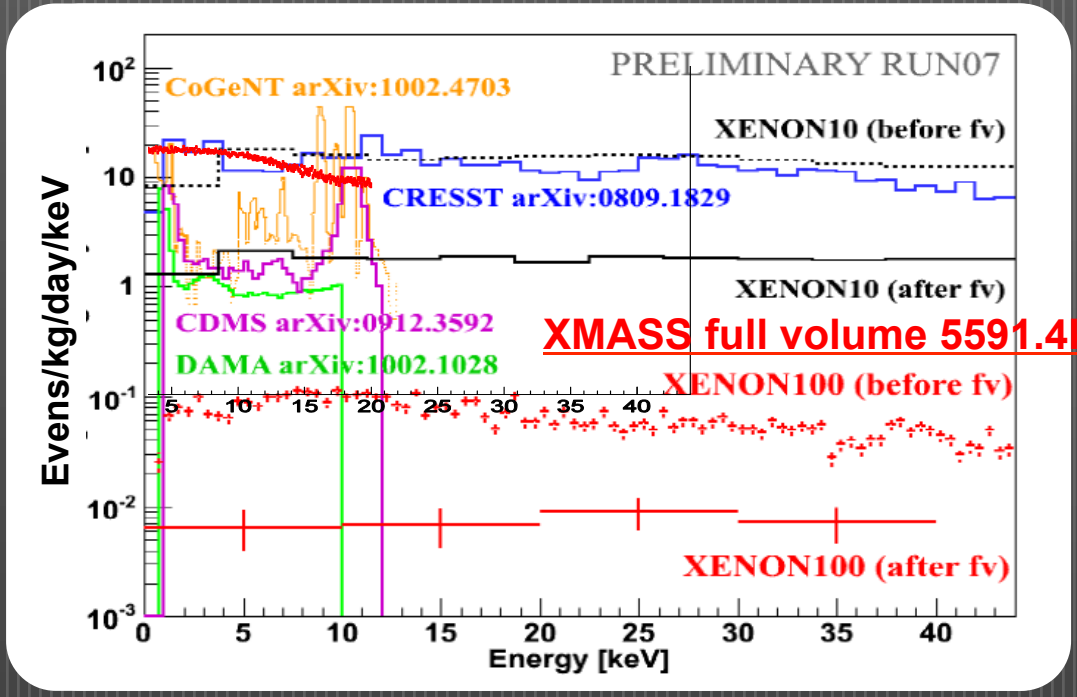




- Major origin of BG was considered to be γ from PMTs, but the observed data seemed to have additional surface contamination.
  - Aluminum sealing parts for the PMT (btw metal body and quartz glass) contains ^{238}U and ^{210}Pb (>5keV)
  - GORE-TEX between PMT and holder is suspicious below 5keV.

XMASS Full Volume: Low BG w/o PID

- Although extra BG sources were found, XMASS BG level is still competitive w/o rejecting electronic events.
  - XMASS has a competitive sensitivity to Light WIMPs & Axions



E. Aprile, 2010 Princeton

- Fiducial volume analyses are on-going and will be released.

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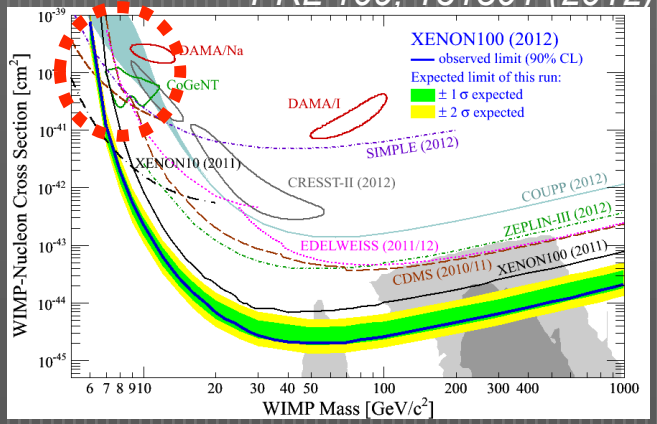
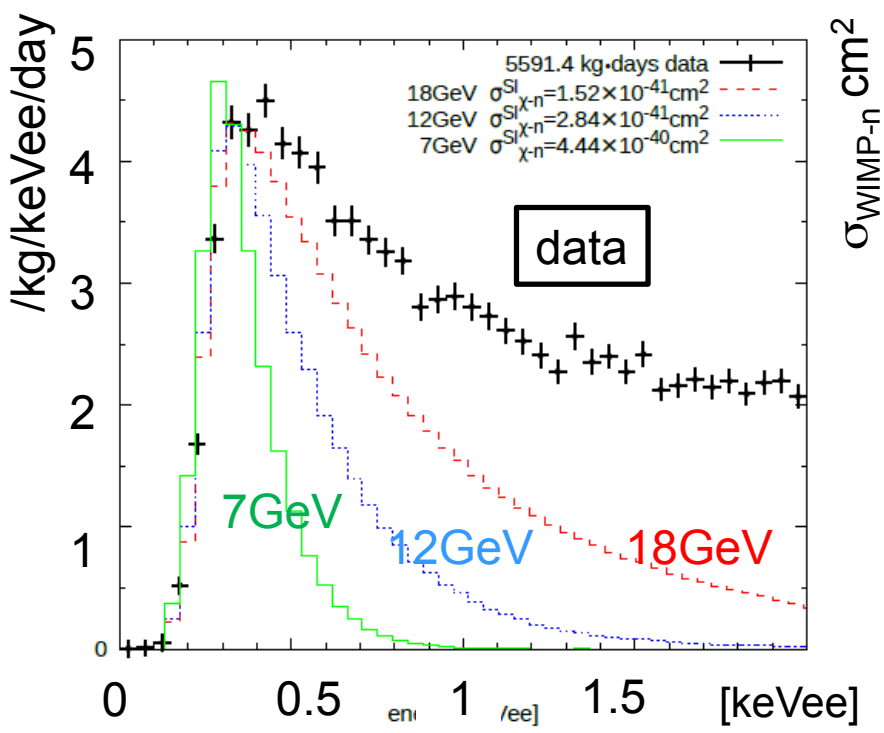
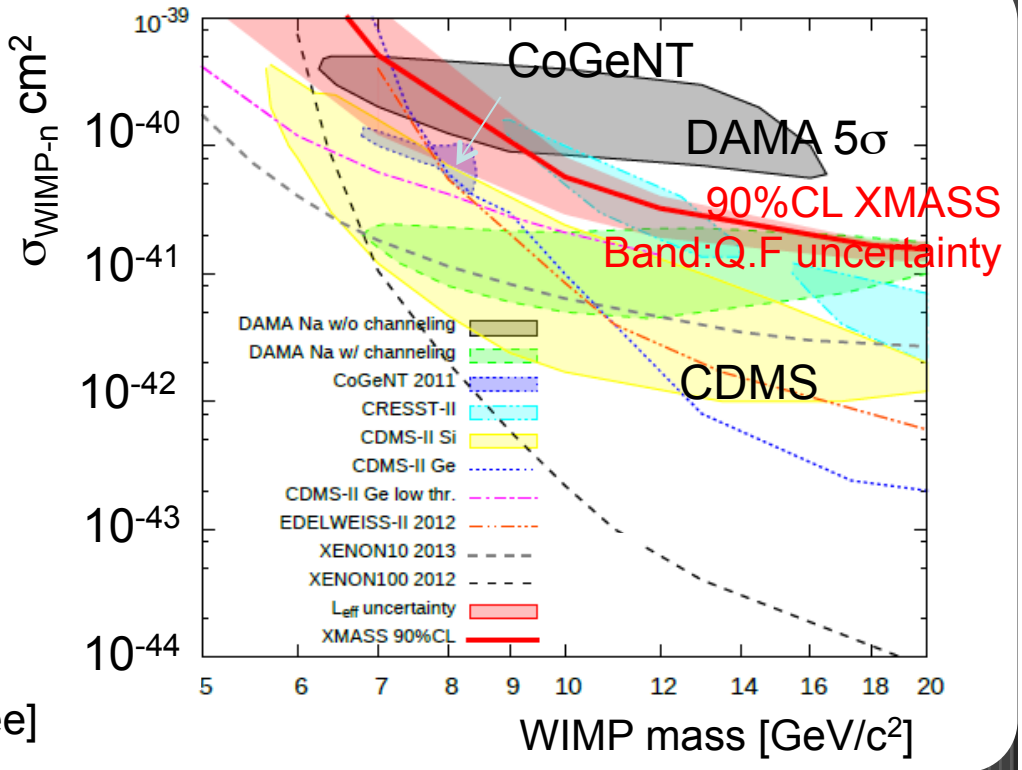
PRL 109, 181301 (2012)

Light WIMPs

- Set an upper limit on the WIMP-nucleon cross section for WIMPs with masses below 20GeV w/o PID and excludes part of the parameter space allowed by DAMA



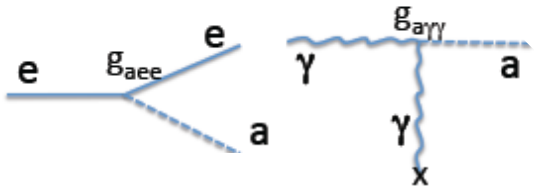


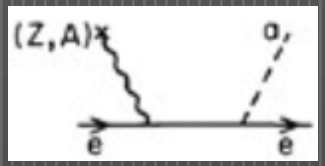


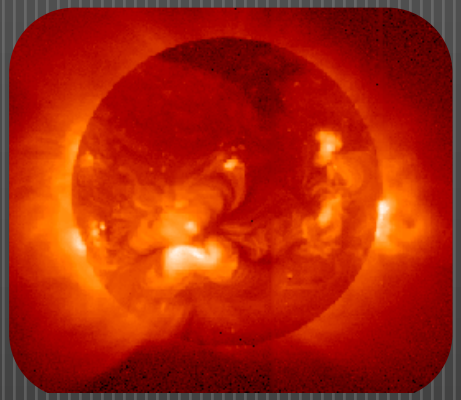
Solar Axions

JETP Lett., 95, 379 (2012)
A. V. Derbin et al.,arXiv:1206.4142

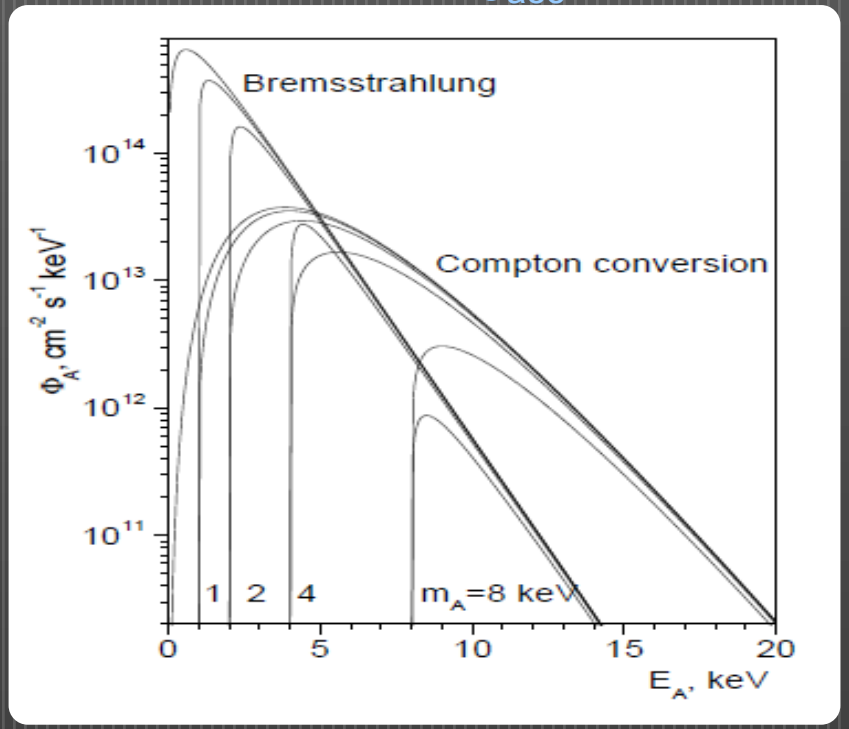
- XMASS has also sensitivity to solar axions that would be produced by Bremsstrahlung and Compton effects (g_{aee}) in the Sun through the axio-electric effect in Xe
  N.B. Not $g_{a\gamma\gamma}$ through Primakoff effect







Expected flux $g_{aee}=10^{-10}$.



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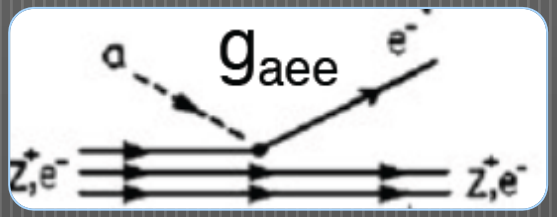
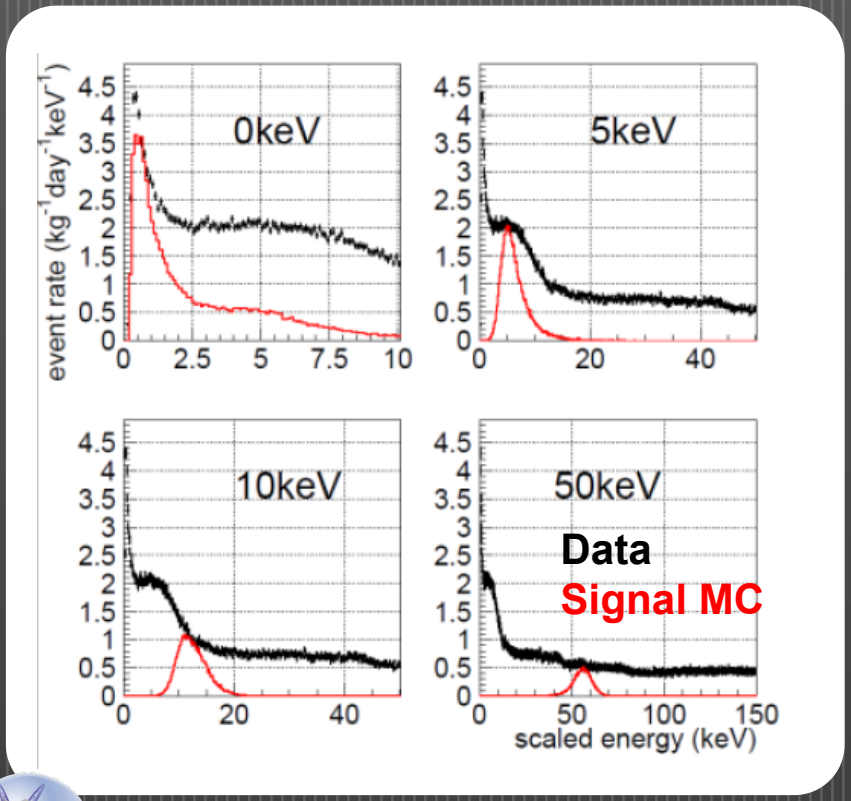
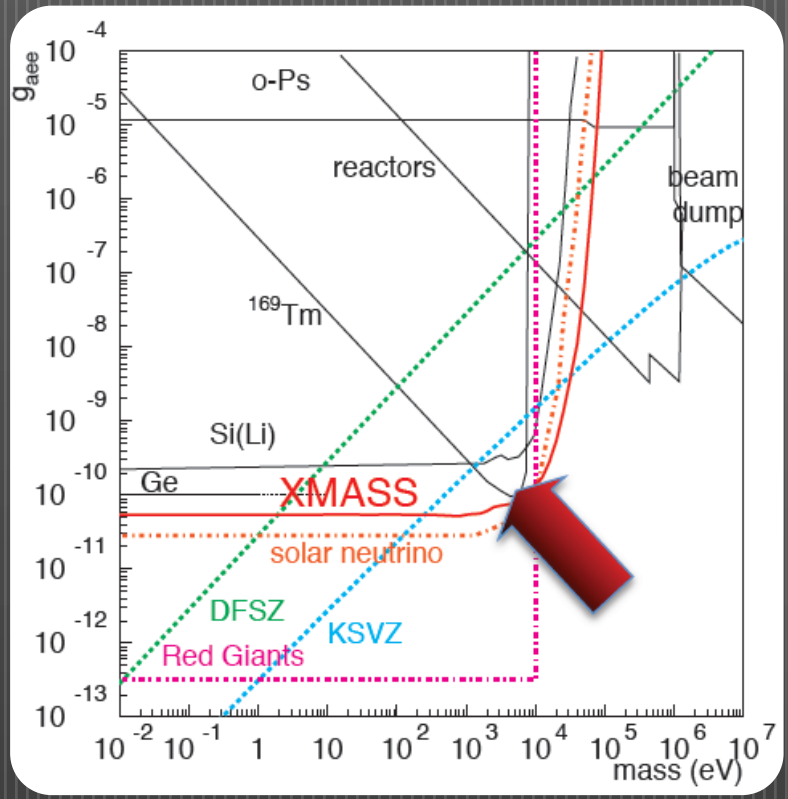
Solar Axions

- Same data set as Light WIMP search
- No indication of signals. Bound in gaee vs. mass.
- Better than any other constraint in 10-40keV.
- Better than any other experimental constraint

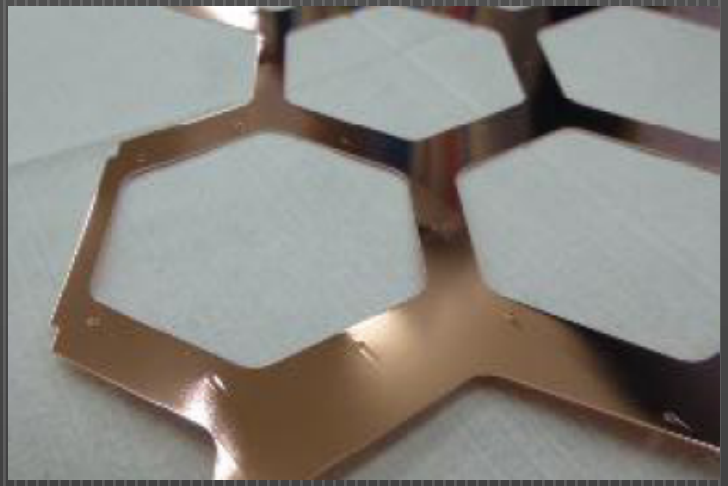






XMASS-1 Refurbishment
for Background reduction

- Countermeasures
  - PMT+Cu surface cleanup
  - Remove GORE-TEX
  - Cover PMT Aluminum seal
    - Cu ring around aluminum seal
    - Electropolished Cu cover above Cu rings



After Cu ring attachment

After thin Cu plate attachment

Almost finished

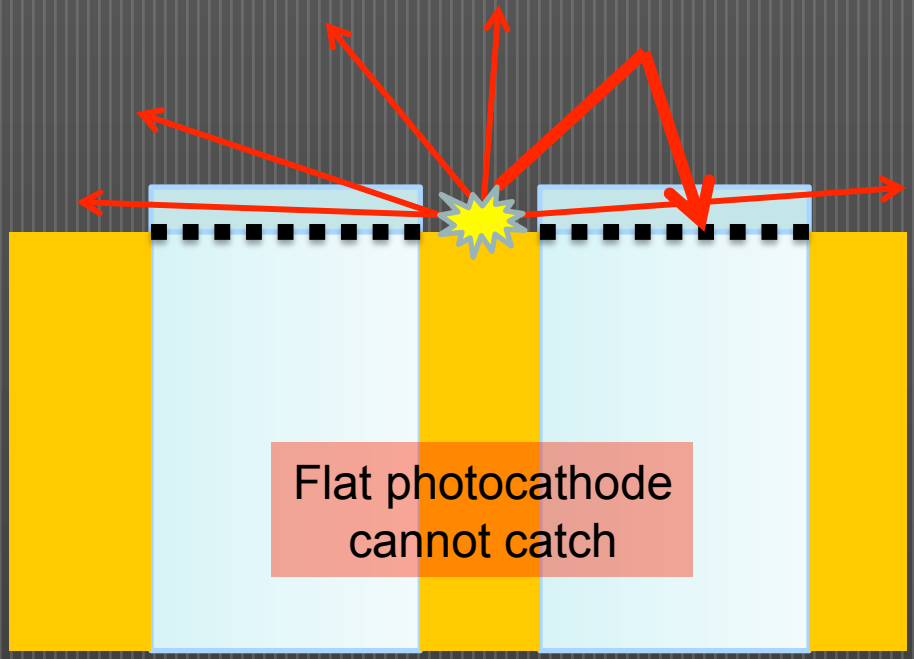
- Will resume data taking in this autumn.

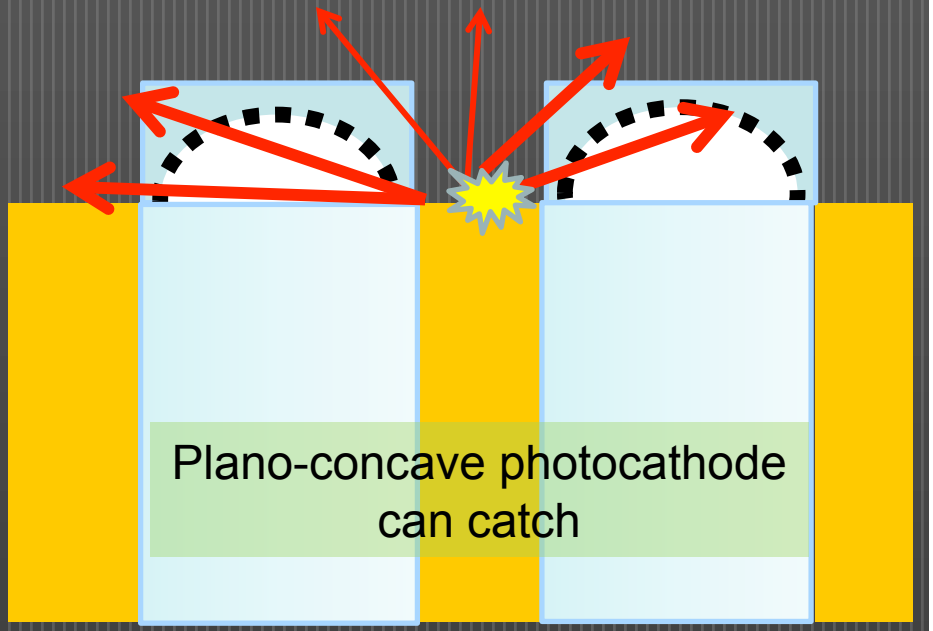
Next step: XMASS-1.5

- Inner Ø: 1.5 m
  - contains 5 tons of LXe
  - fiducial mass 1 ton
- Lessons from XMASS-1

Still Dark matter detector

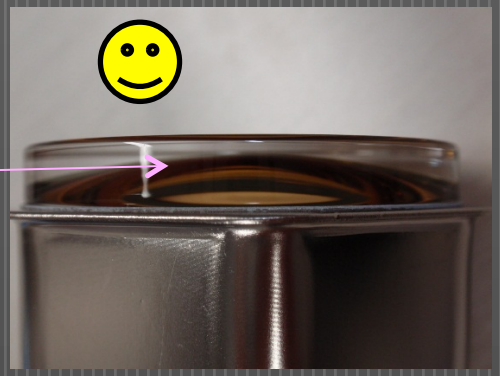
New PMT



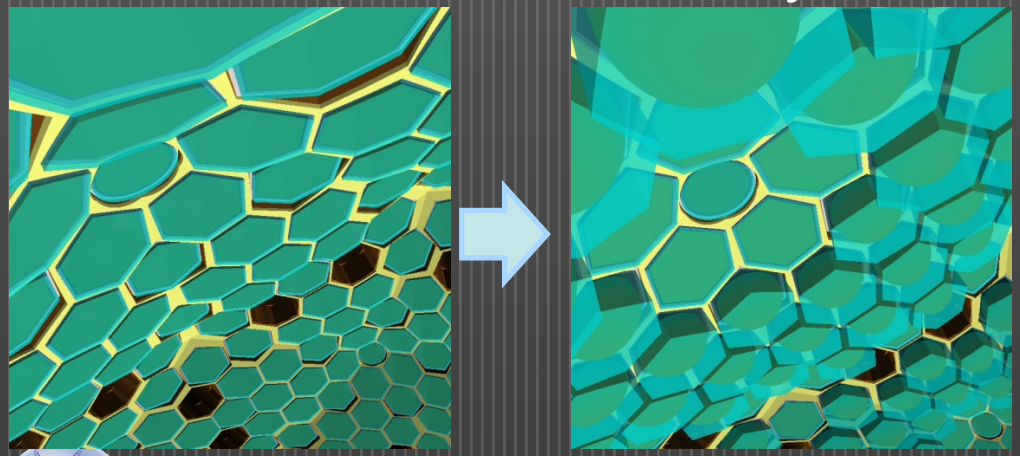


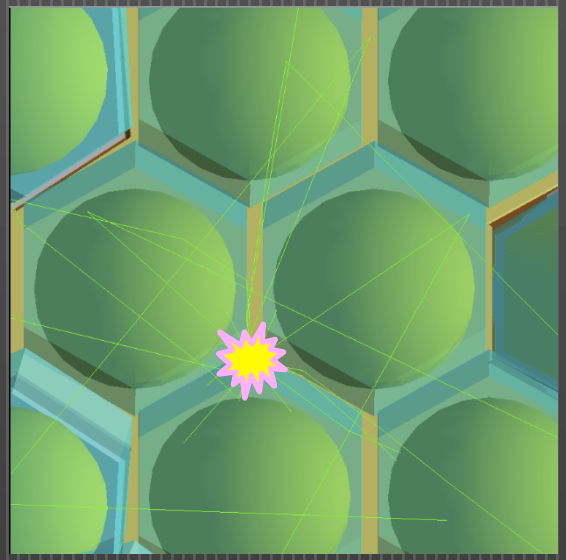
XMASS-1.5

- Actively being developed w/ Hamamatsu



- Effectiveness is verified by MC



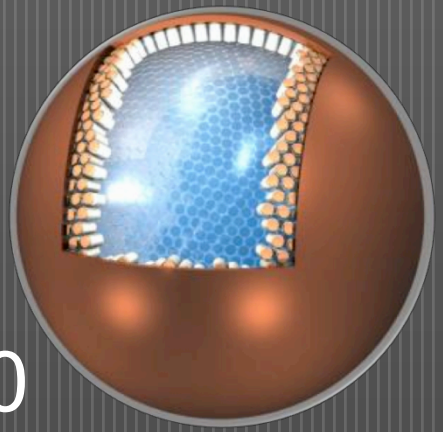


XMASS projects and timeline

XMASS-1-RFB

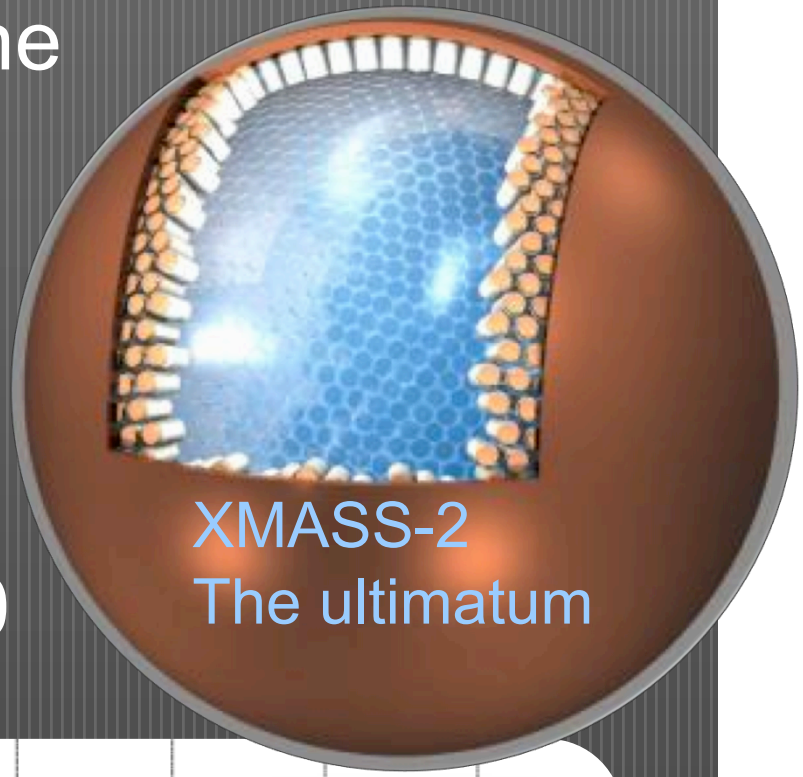
x10

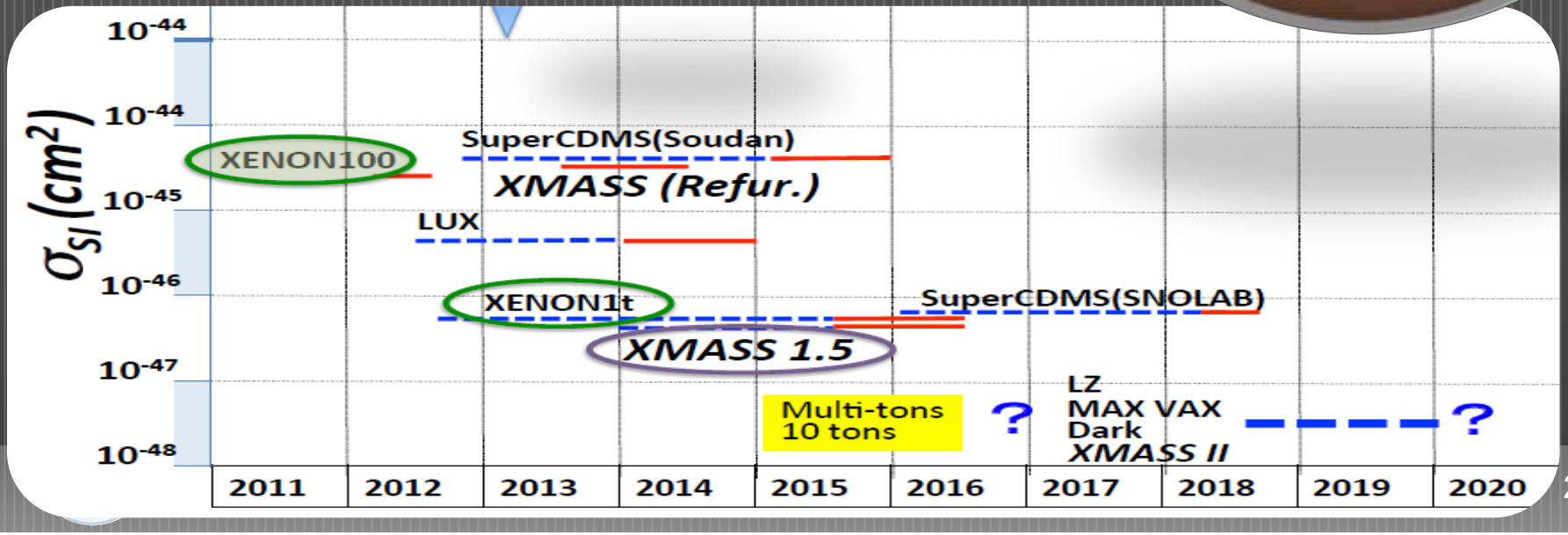
XMASS-1.5



x10

XMASS-2
The ultimatum





Conclusion

- XMASS-1 obtained light WIMP and solar axion result by using 835kg of LXe with very low threshold (0.3keVee)

  Phys. Lett B 719(2013)78, Phys. Lett B 724 (2013) 46

- Initial contamination problems are understood and being addressed.
  - The refurbishment of XMASS-1 is on-going and data taking will resume soon.
- XMASS-1.5 is planned and the projects move on.

Extra slides

XMASS Collaboration

- Kamioka Observatory, ICRR, Univ. of Tokyo: Y. Suzuki (Spokesperson), M. Nakahata, S. Moriyama, M. Yamashita, Y. Kishimoto, A. Takeda, K. Abe, H. Sekiya, H. Ogawa, K. Kobayashi, K. Hiraide, B. Yang, A. Shinozaki, k. Hieda, O. Takachio, D. Umemoto, N. Oka, K. Nakagawa
- Kavli-IPMU, University of Tokyo: K. Martens, J.Liu
- Tokai University: K. Nishijima, F. Kusaba
- Gifu University: S. Tasaka
- Yokohama National University: S. Nakamura, I. Murayama, K. Fujii
- Miyagi University of Education: Y. Fukuda
- STEL, Nagoya University: Y. Itow, K. Masuda, H. Uchida, Y. Nishitani, H. Takiya
- Kobe University: Y. Takeuchi, K. Miuchi, O. Yosuke, K. Hosokawa, A. Murata
- Sejong University : Y.D. Kim, N.Y.Kim
- Korea Research Institute of Standards and Science (KRISS): Y. H. Kim, M. K. Lee, K. B. Lee, J. S. Lee

42 researchers form 10 institutes

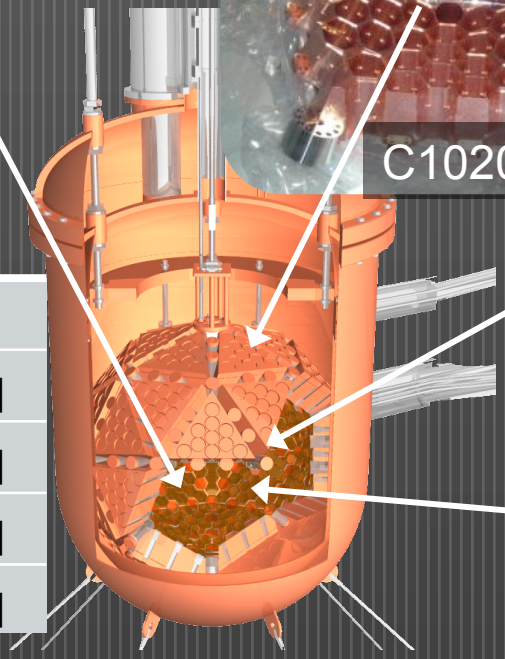
Pure components

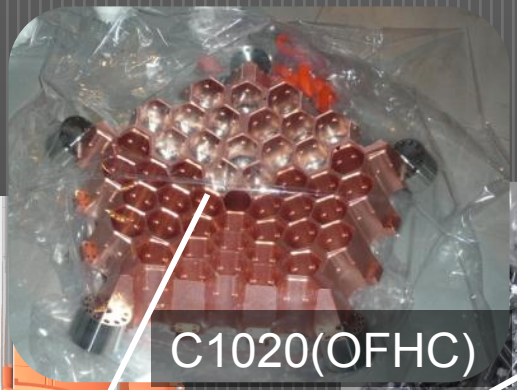
- More than 250 components

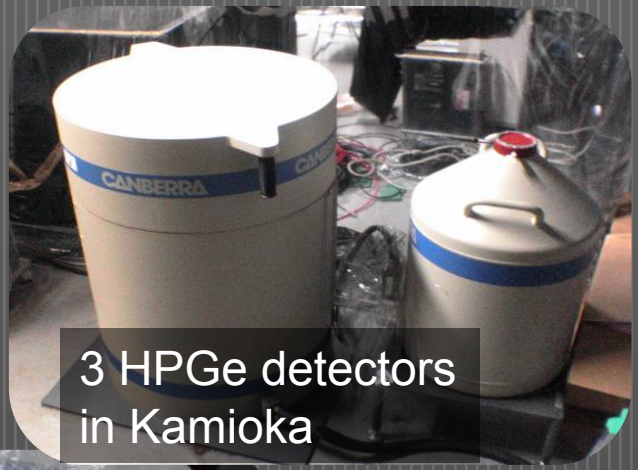
  RIs of all the components were measured with HPGe and low RI materials were selected.

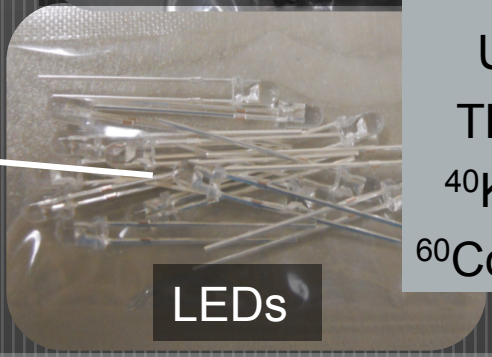
PMT(R10789)

RI:	/one PMT
U	*0.70±0.28* mBq
Th	*1.51±0.31* mBq
^{40}K	*9.10±2.15* mBq
^{60}Co	*2.92±1.61* mBq









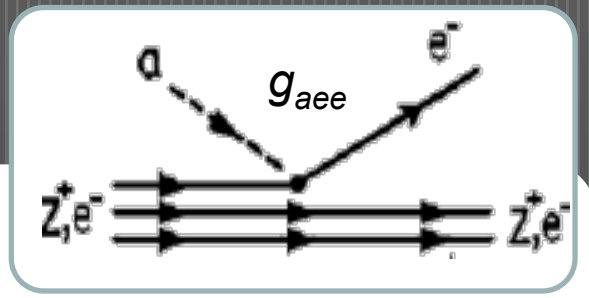
Sum of other components	
RI:	Compared w/ 642 PMTs
U	<35%
Th	<35%
^{40}K	<20%
^{60}Co	<20%

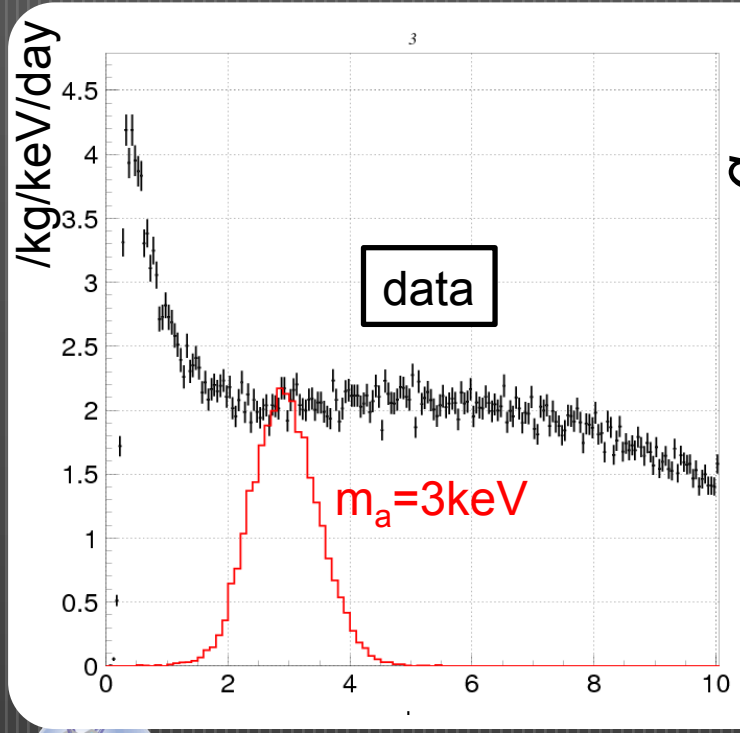
Dark Matter Axion

- DAMA signal can be explained by electromagnetic interactions of non-relativistic Axions and NaI.

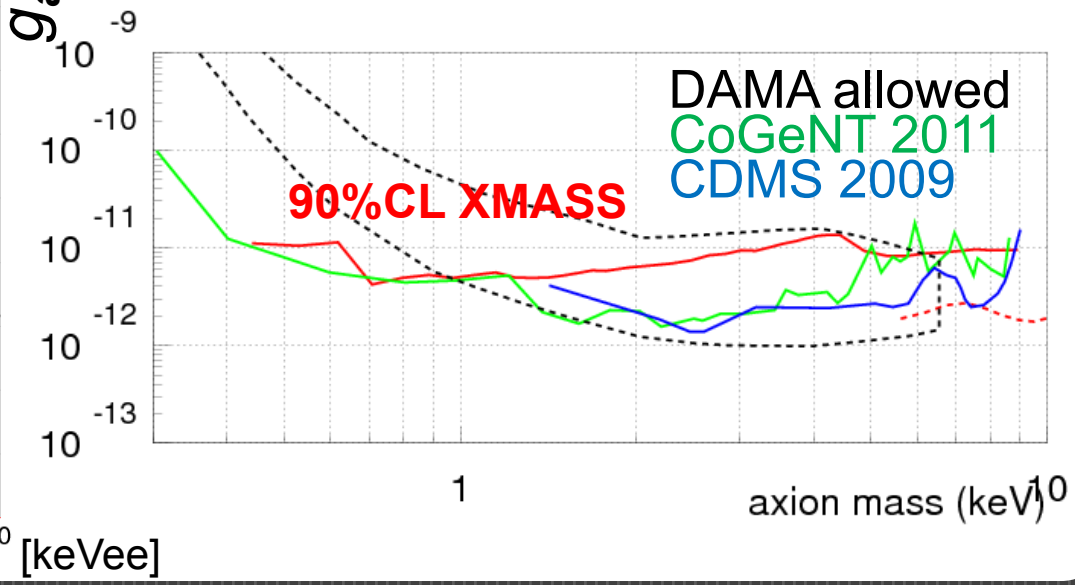
  [J. Collar, arXiv: 0903.5068]

- XMASS has sensitivity to dark matter Axion through Axio-electric effect.



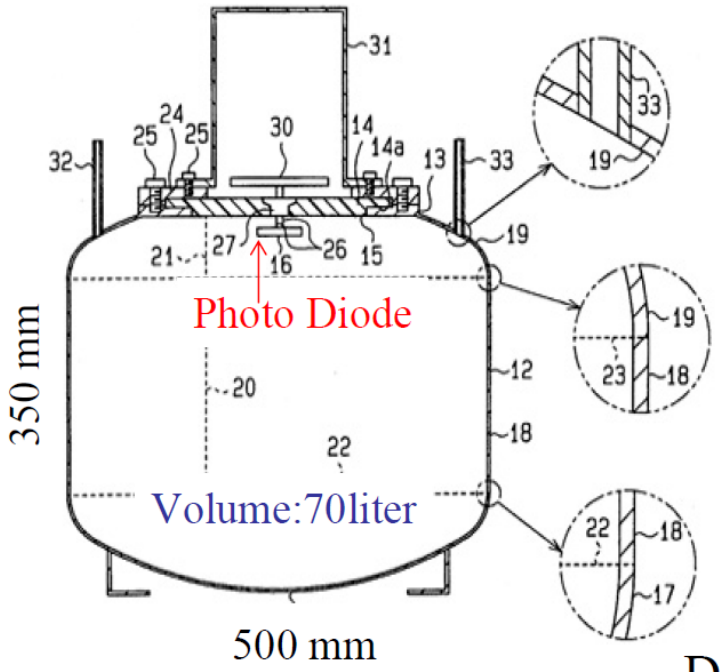


Limits on g_{aee}



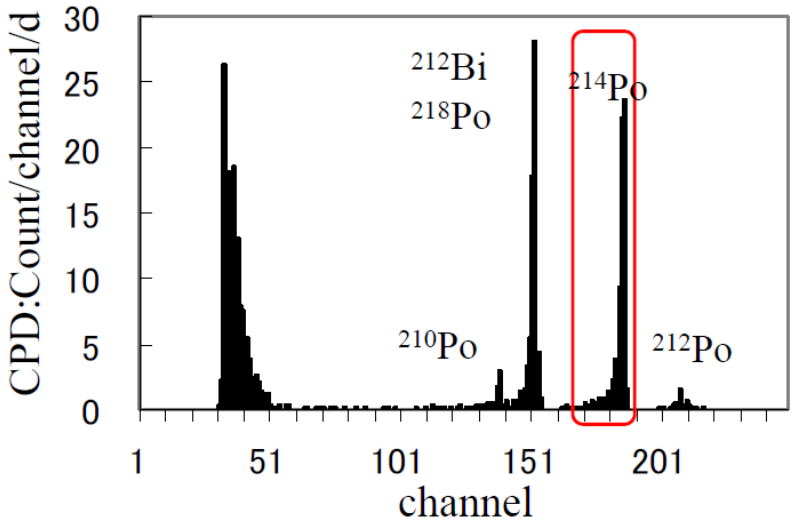
Rn

Electrostatic collection Radon Detector



- Sensor : PIN Photo-Diode
  α-rays energy separation
- Electro-polished stainless steel
- Electrostatic Voltage -2kV
- Detection Limits 5(mBq/m^3)

Typical Pulse high distribution
2009/11/30-2009/12/11



Detector Calibration by Source
^{226}Ra(PYLON 78.3Bq)
CF=1.93±0.01[CPD/(mBq/m^3)]
Absolute Humidity=0.011(g/m^3)
CF=2.03-1.08*SQRT(AH), AH<1.6g/m^3

Quenching Factor/Leff uncertainty

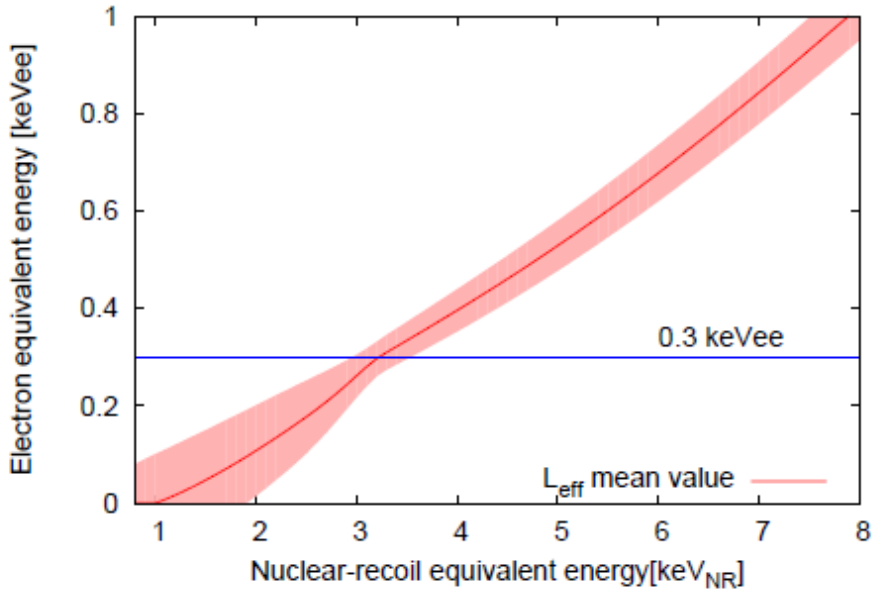
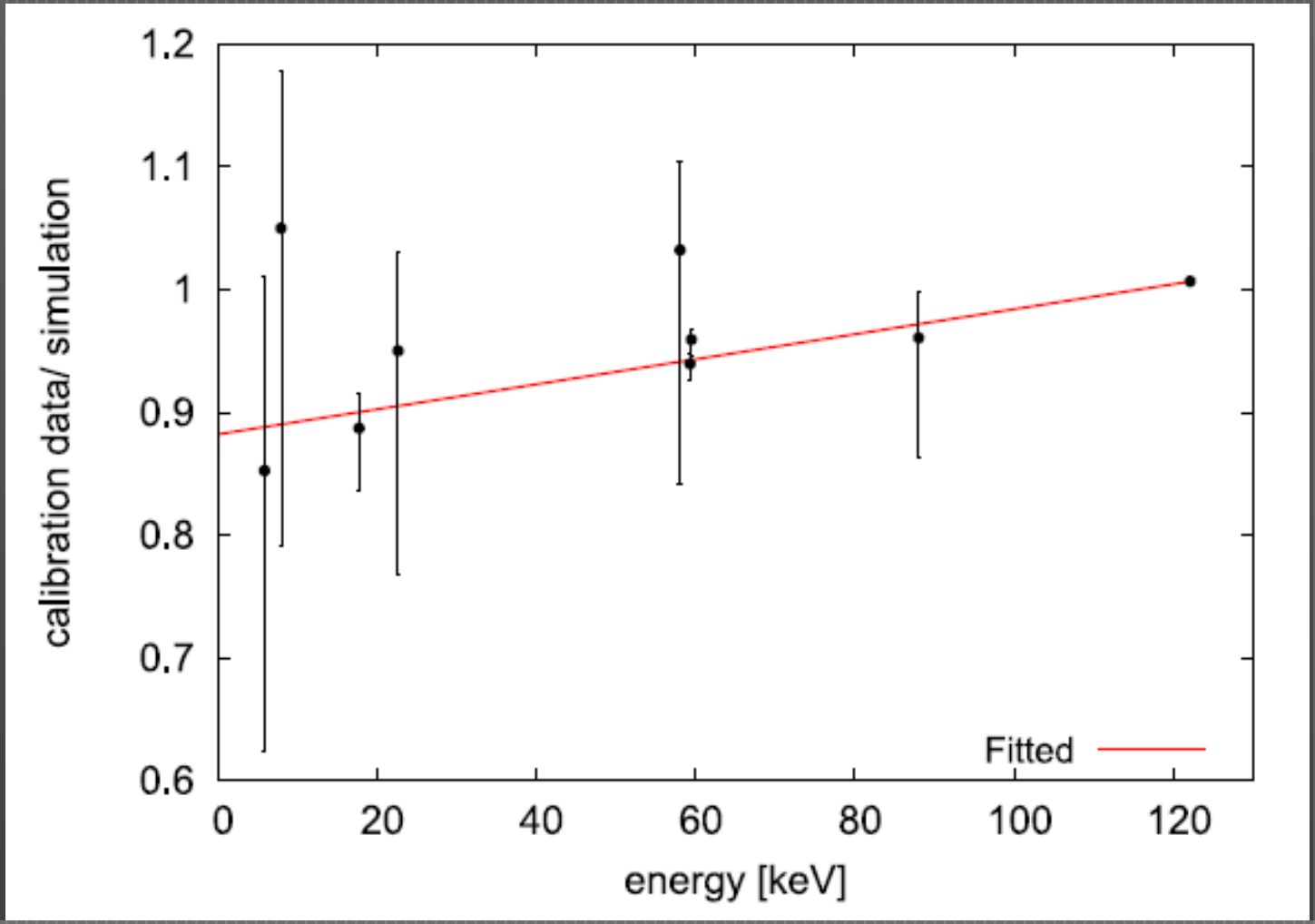


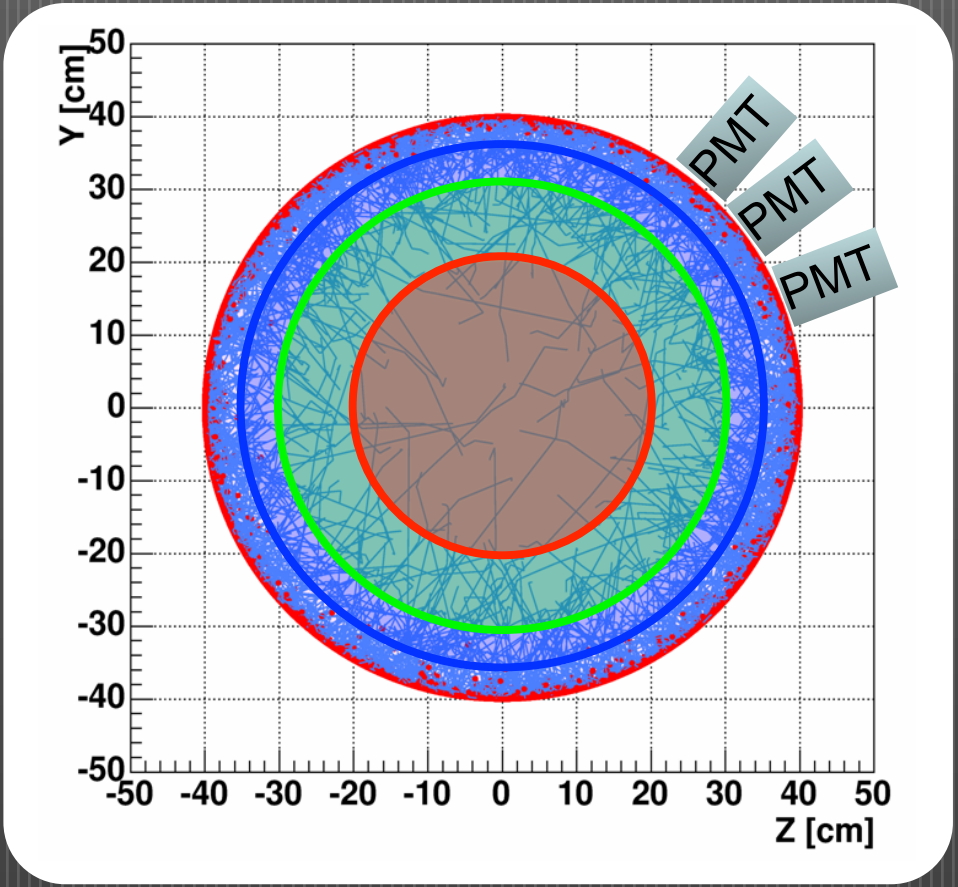
Figure 1: The relationship between the electron equivalent energy and the nuclear-recoil equivalent energy based on the $\mathcal{L}_{\text{eff}}$ method of Ref. [14]. The one-σ uncertainty and the 0.3 keVee analysis threshold are also shown.

Energy scale calibration



Self-shielding for detector material BG

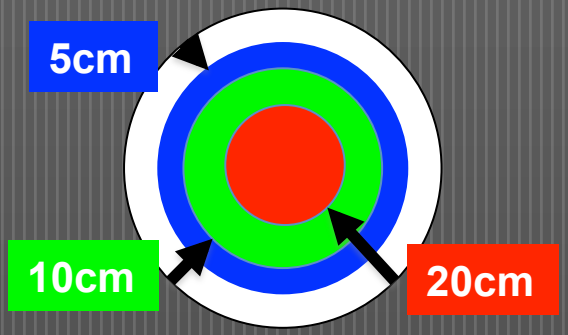
- High density Xe itself is the shield for γ,n from PMT/OFHC/…



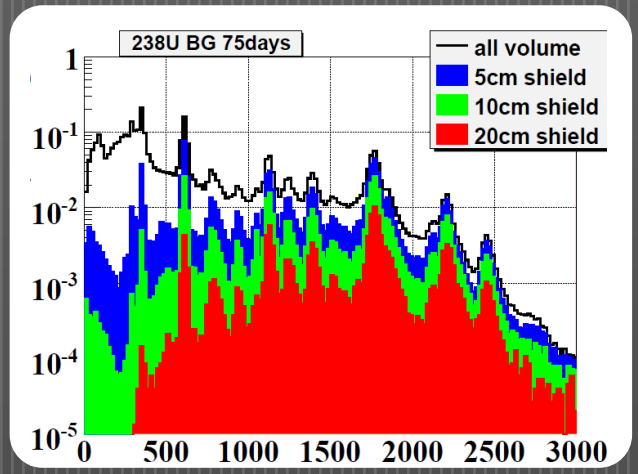
Thicker shield makes lower BG region in center

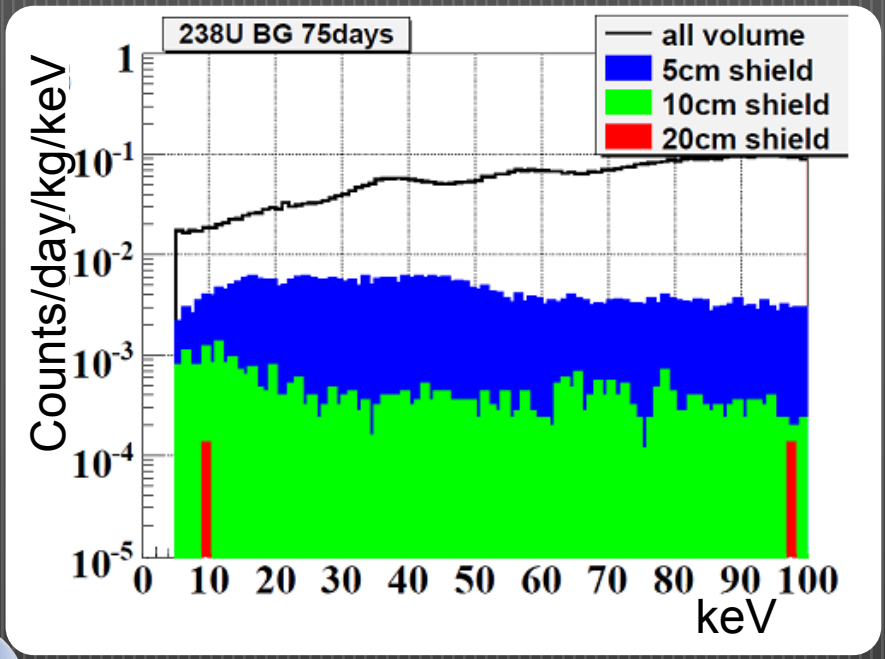
Original expectation

Ex.) Most dirty component : PMT ^{238}U Chain 1.8mBq/PMT



Full MC,
assuming abs.
100cm, scat. 30cm
for photon tracking





20cm Xe is used for shield
Fiducail Volume is 100kg
(Full Volume is 857kg)

gammas < 10^{-5} counts/day/kg/keV
neutrons < 10^{-6} counts/day/kg/keV

Xe circulation system

4 x 180W refrigerator
PTR developed by KEK

Gas circulation 30L/min

gas pump

emergency gas pump
100L/min

Cable line

Calibration line

filters

Water tank

Condenser
360W

evaporator

filters

10 m^3
x 2

gas storage

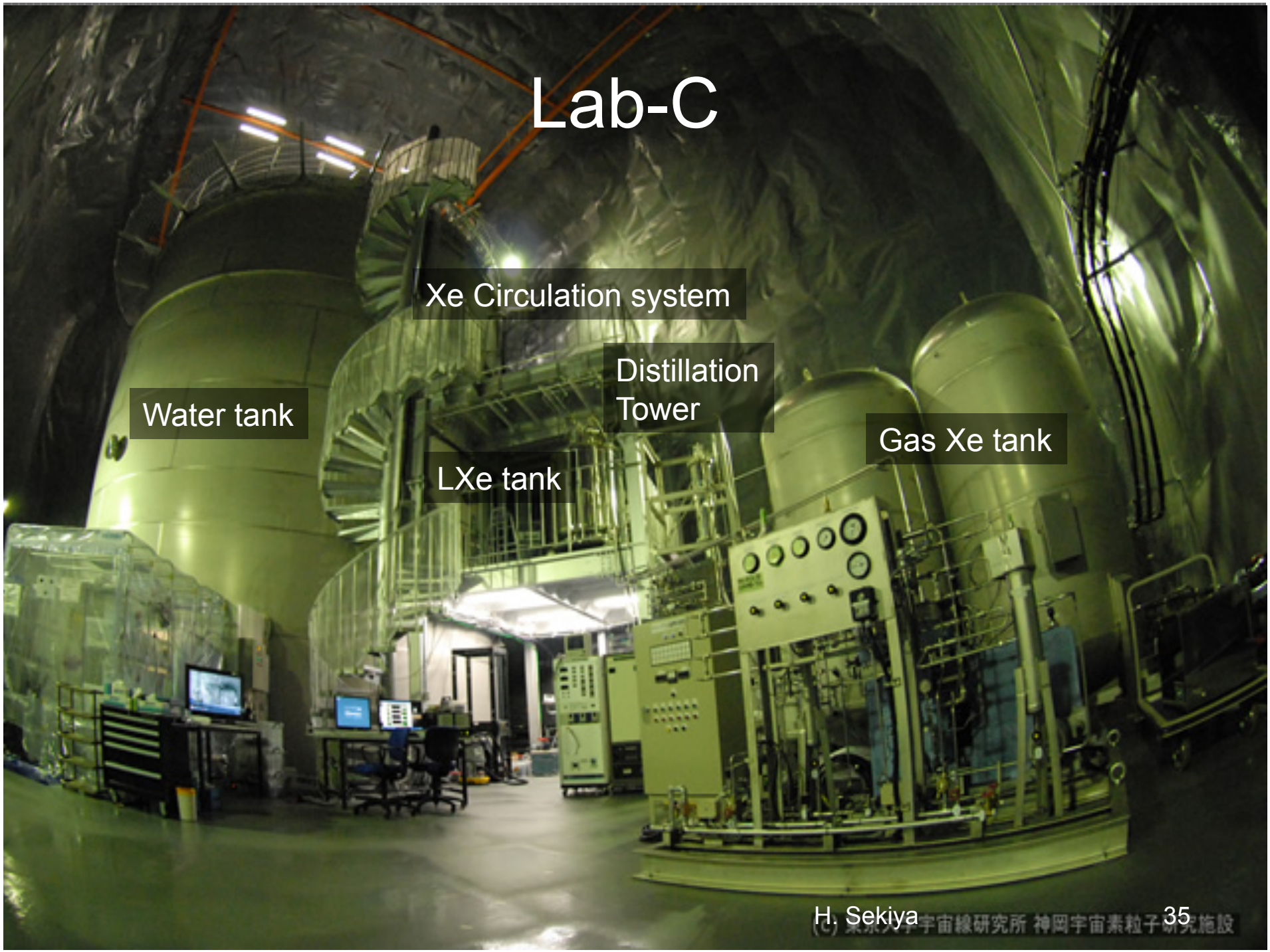
1050kg

Outer vacuum

liquid pump

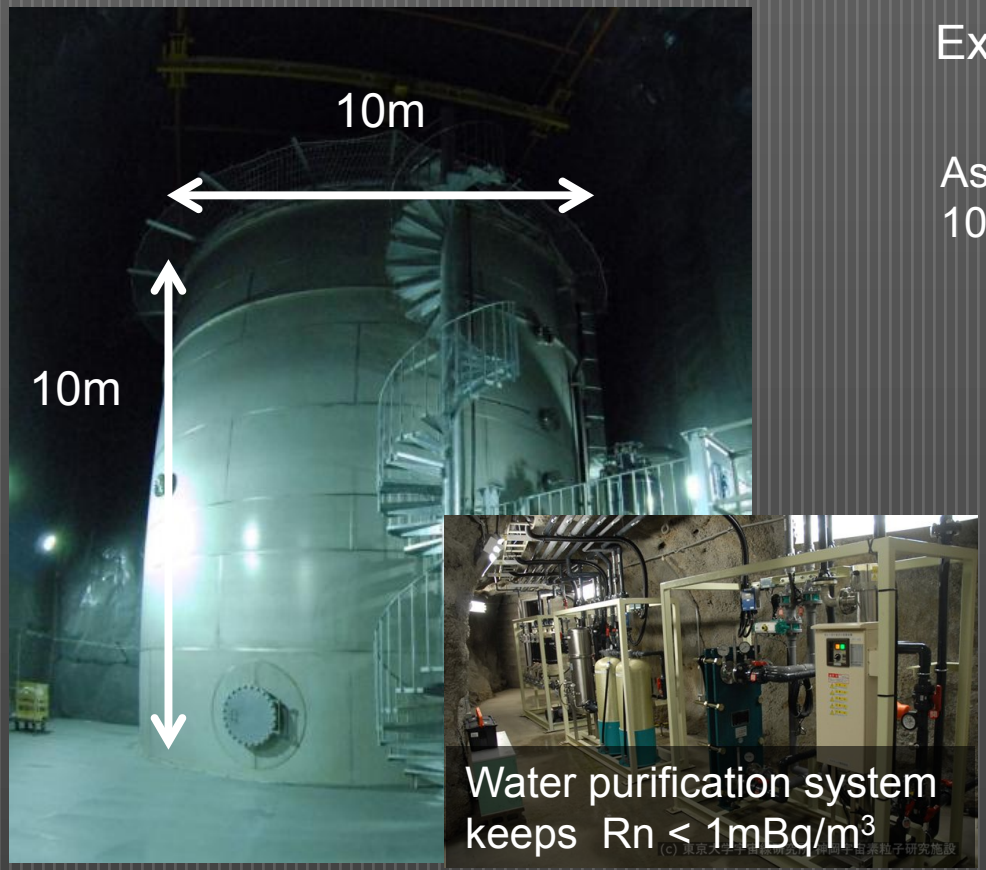
Liquid circulation 5L/min

700L
Liq.
Storage


Lab-C
Xe Circulation system
Distillation Tower
Water tank
Gas Xe tank
LXe tank
(C) 東京大学宇宙線研究所 神岡宇宙素粒子研究施設

Water shields for external BG

- Active for μ, passive for γ,n

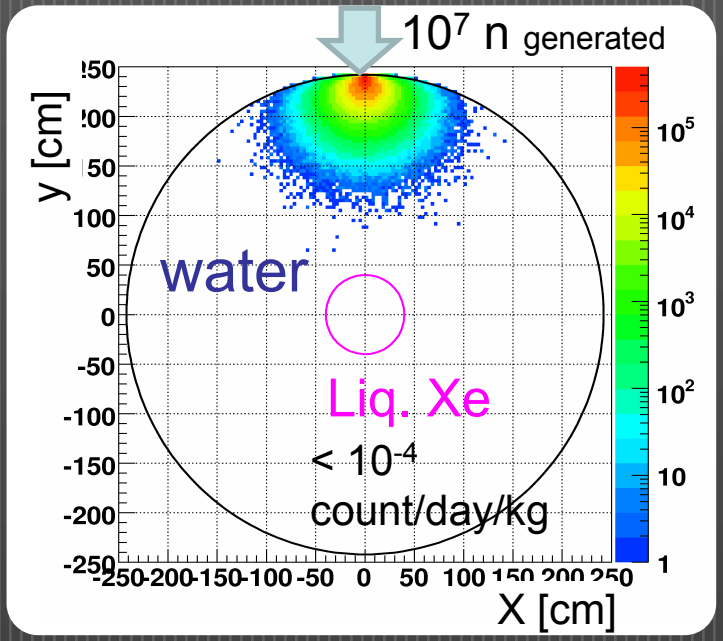


Water purification system keeps Rn < 1mBq/m^3

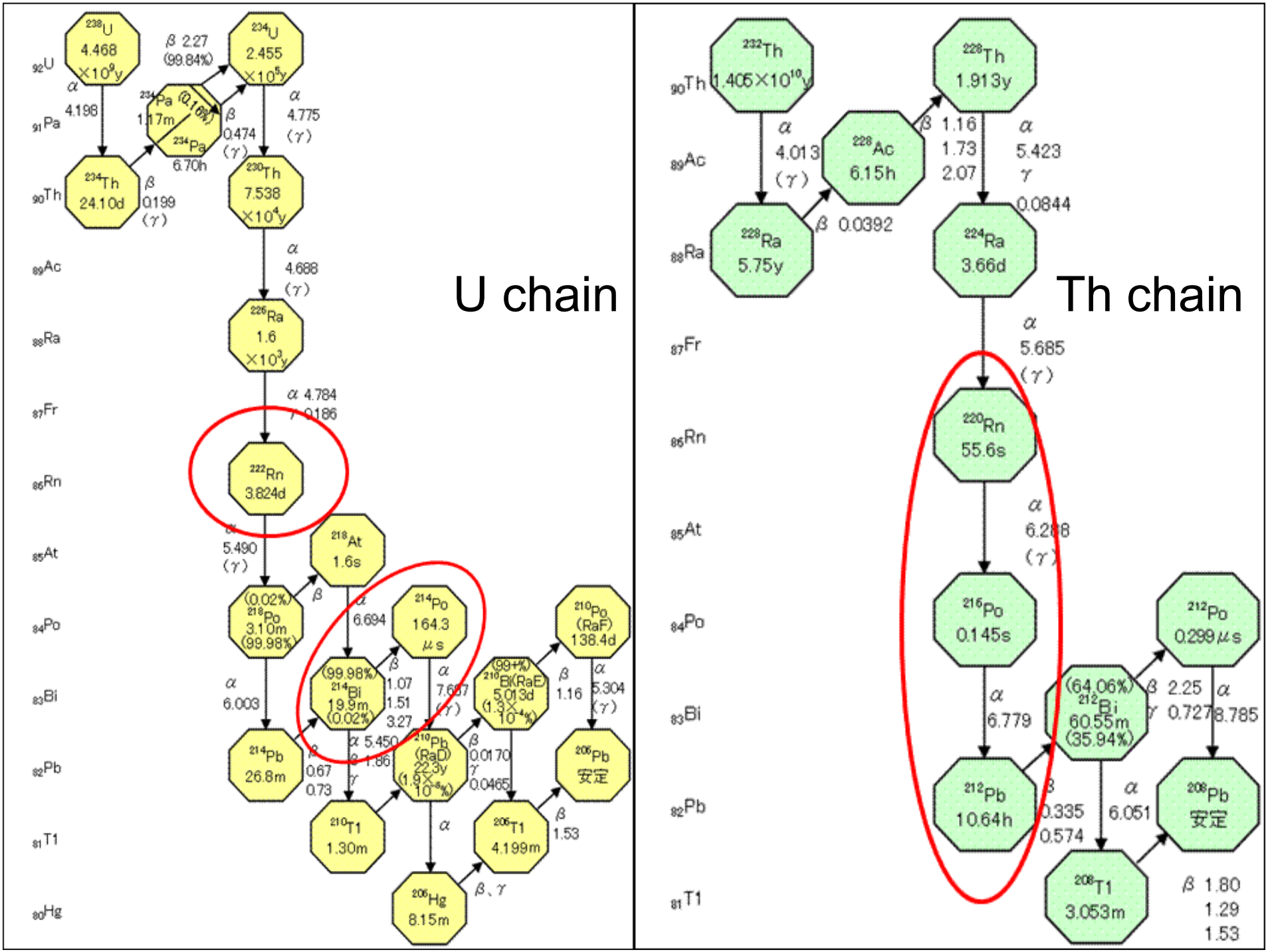
with 70 PMTs (20 inch) to detect Cerenkov light

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

Assuming all neutron's energies are 10 MeV very conservatively



5m tank is enough large to shield n and γ


U chain
Th chain
92U
91Pa
90Th
89Ac
88Ra
87Fr
86Rn
85At
84Po
83Bi
82Pb
81T1
80Hg
238U 4.468 ×10^9y
234U 2.455 ×10^5y
234Th 24.10d
234Pa 1.17m
234Pa 6.70h
230Th 7.538 ×10^4y
226Ra 1.6 ×10^3y
222Rn 3.824d
218At 1.6s
218Po 3.10m (99.98%)
214Pb 26.8m
214Bi 19.9m (0.02%)
214Po 164.3 μs
210Tl 1.30m
210Pb (RaD) 22.3y
210Bi (RaE) 5.013d
210Po (RaF) 138.4d
206Tl 4.199m
206Pb 安定
205Hg 8.15m
232Th 1.405×10^10y
228Ra 5.75y
228Ac 6.15h
228Th 1.913y
224Ra 3.66d
220Rn 55.6s
216Po 0.145s
212Pb 10.64h
212Bi 60.55m (35.94%)
212Po 0.299 μs
208Tl 3.053m
208Pb 安定

Calibration System

- Calibration source rod

- Source list

Isotopes	Energy [keV]	intensity [Hz]	diameter [mm]
(1) Fe-55	5.9	350	1.42
(2) Cd-109	22, 25, 88	800	1.42
(3) Am-241	59.5	485	0.15
(4) Co-57	122	100	0.21