The XMASS 800kg Experiment

平成23年度共同利用研究成果発表会

Jing LIU

IPMU, Univ. of Tokyo

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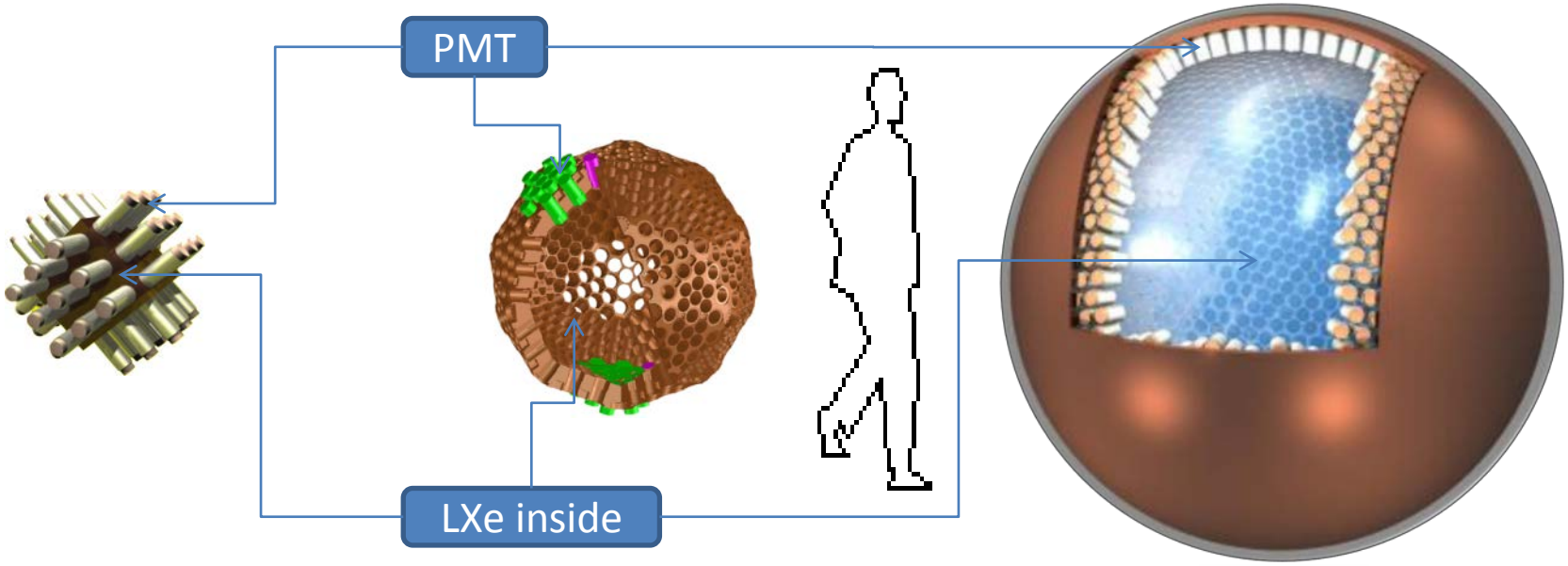
The XMASS Experiment

Xenon MASSive detector for Solar neutrino (pp/^{7}Be)
Xenon neutrino MASS detector (double beta decay)
Xenon detector for weakly interacting MASSive Particles



~100 kg LXe
prototype

~800 kg LXe
direct dark matter search

~26 ton LXe
Multi-purpose

LXe (Liquid Xenon) surrounded by PMTs (Photomultiplier Tubes) recording scintillation lights generated by nuclear or electronic recoils in LXe

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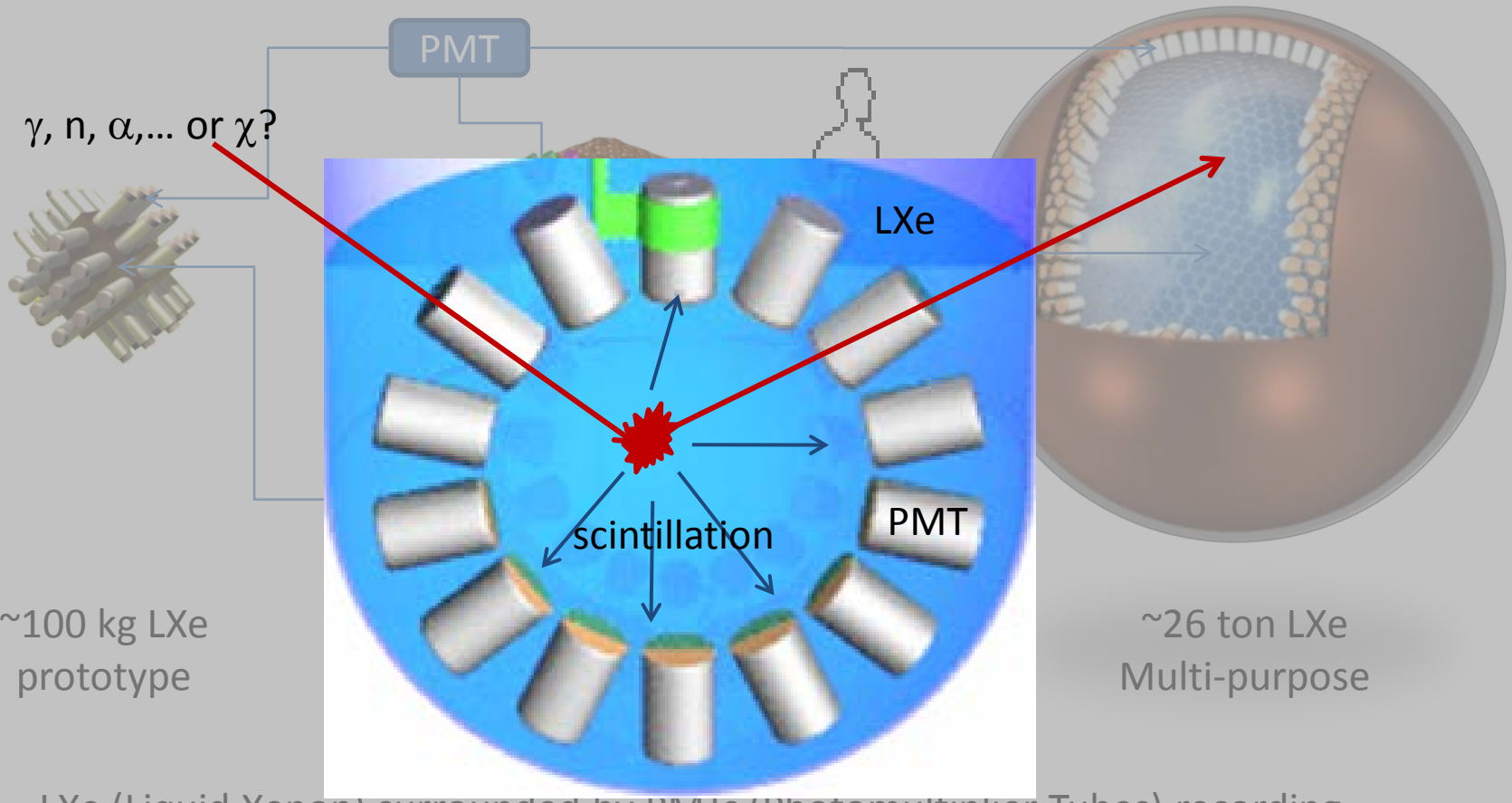

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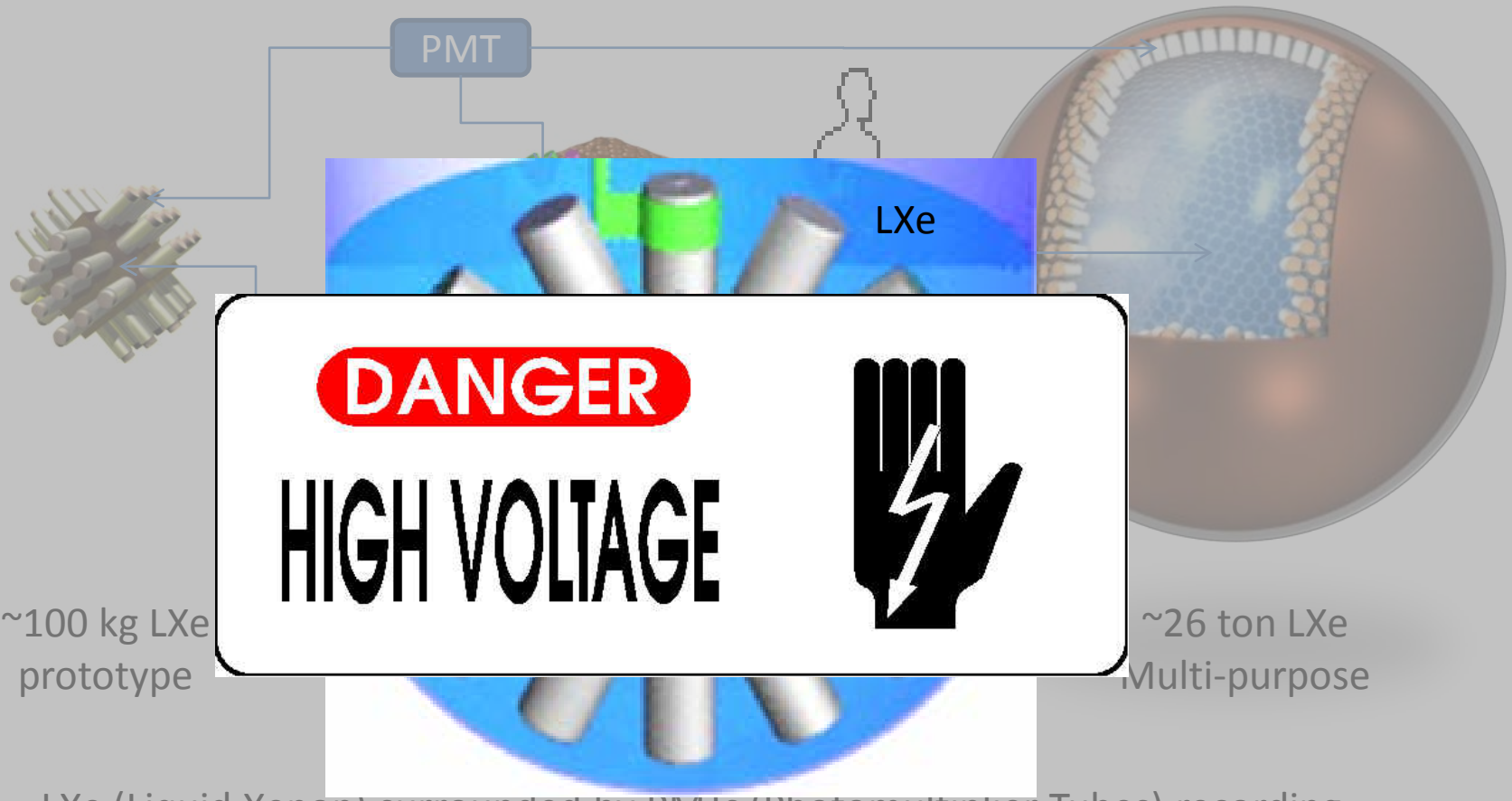

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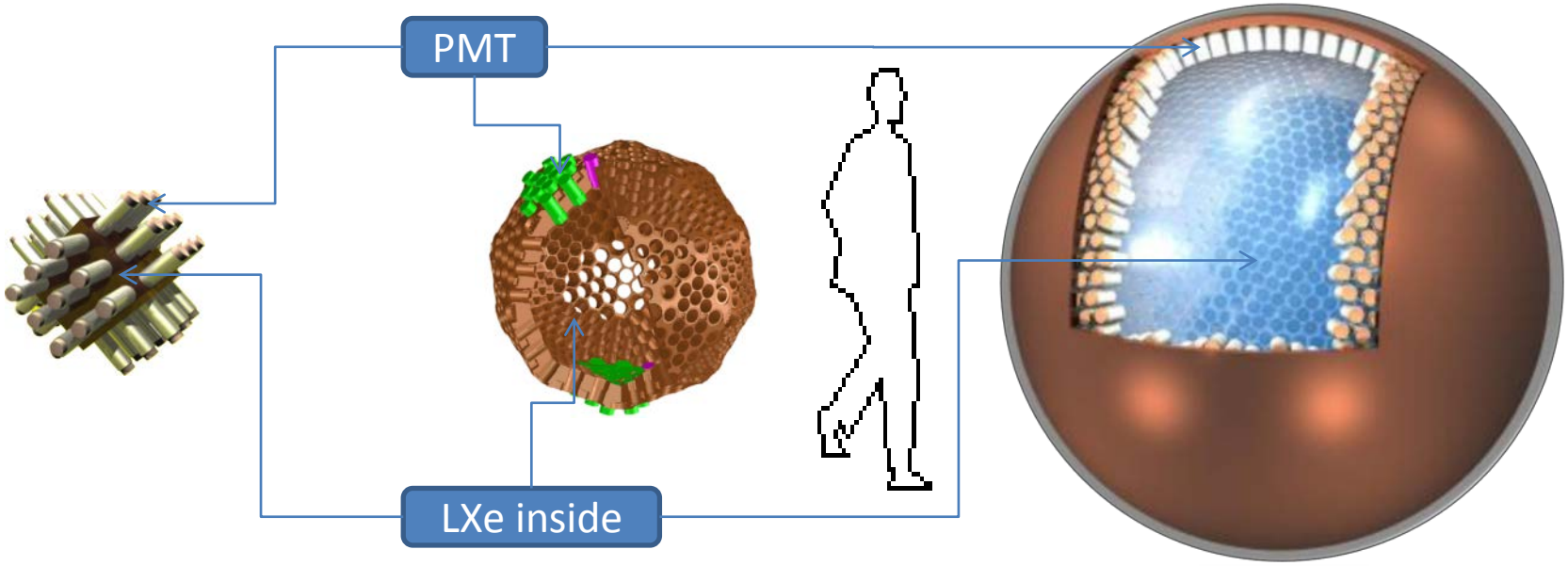

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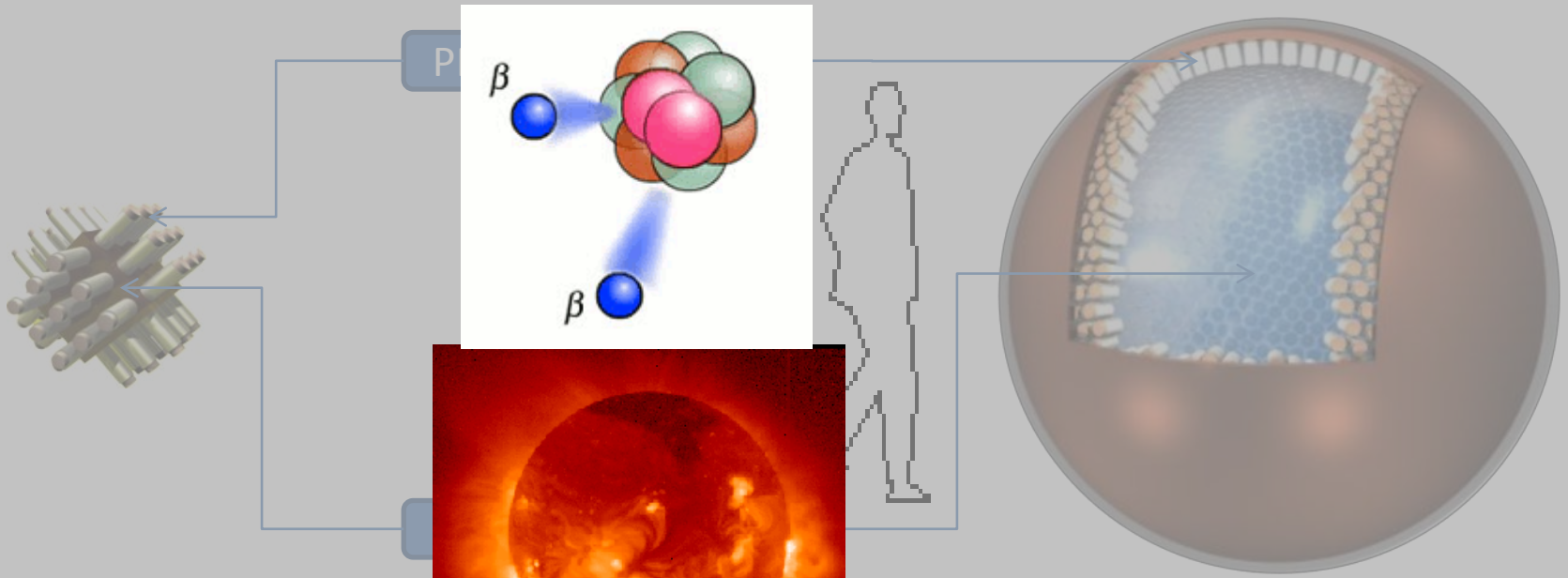

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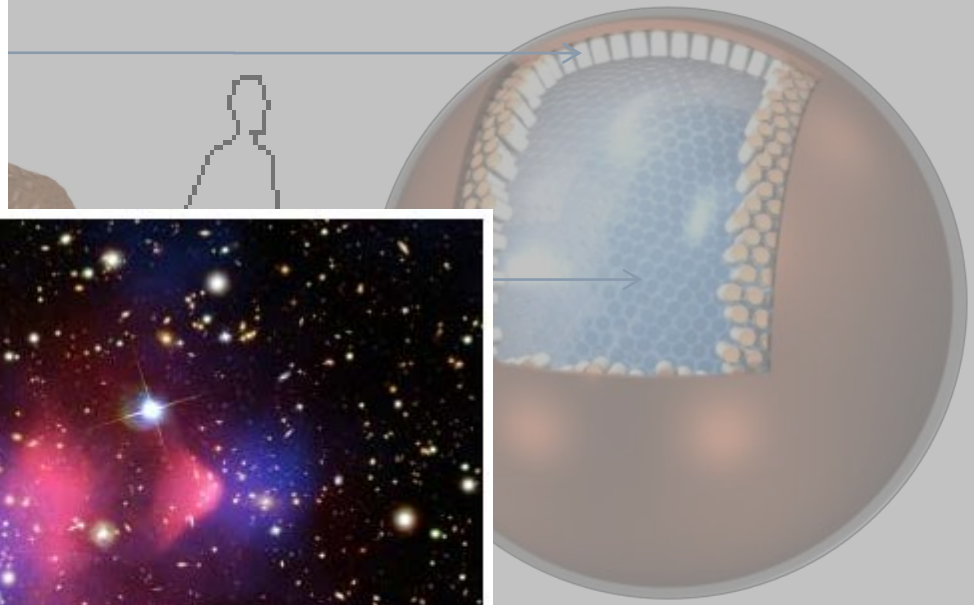

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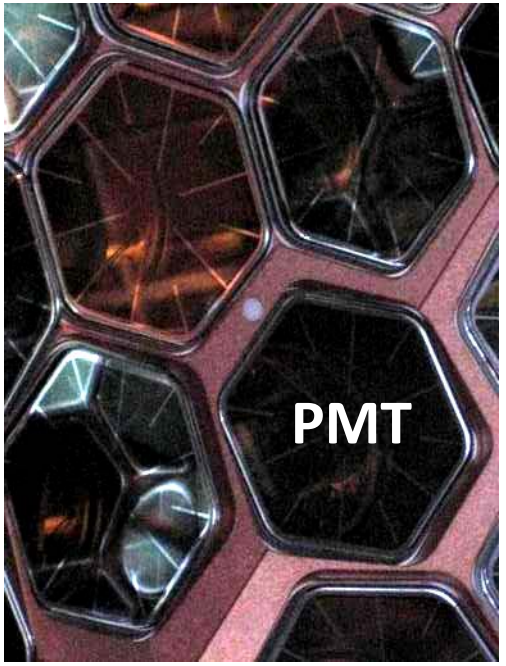
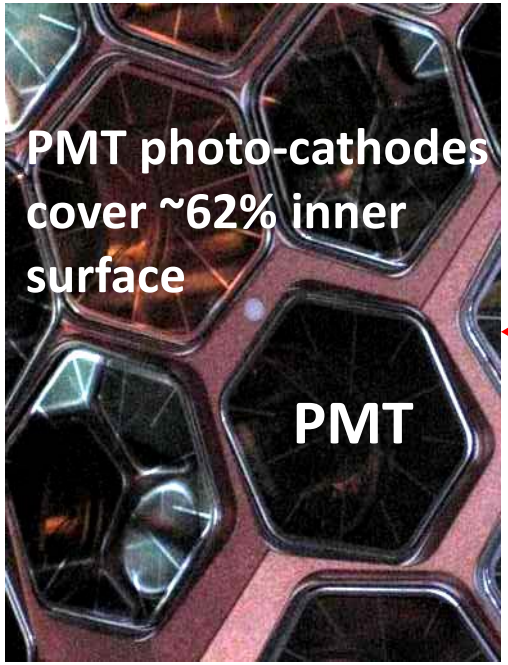
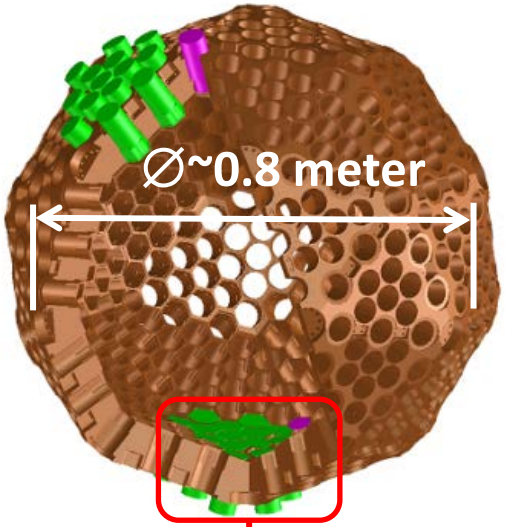
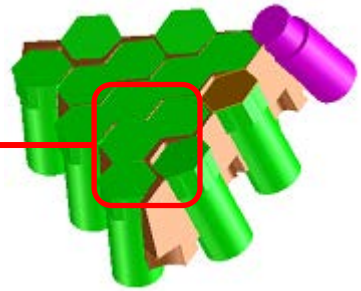
Structure of XMASS 800kg detector



Structure of XMASS 800kg detector





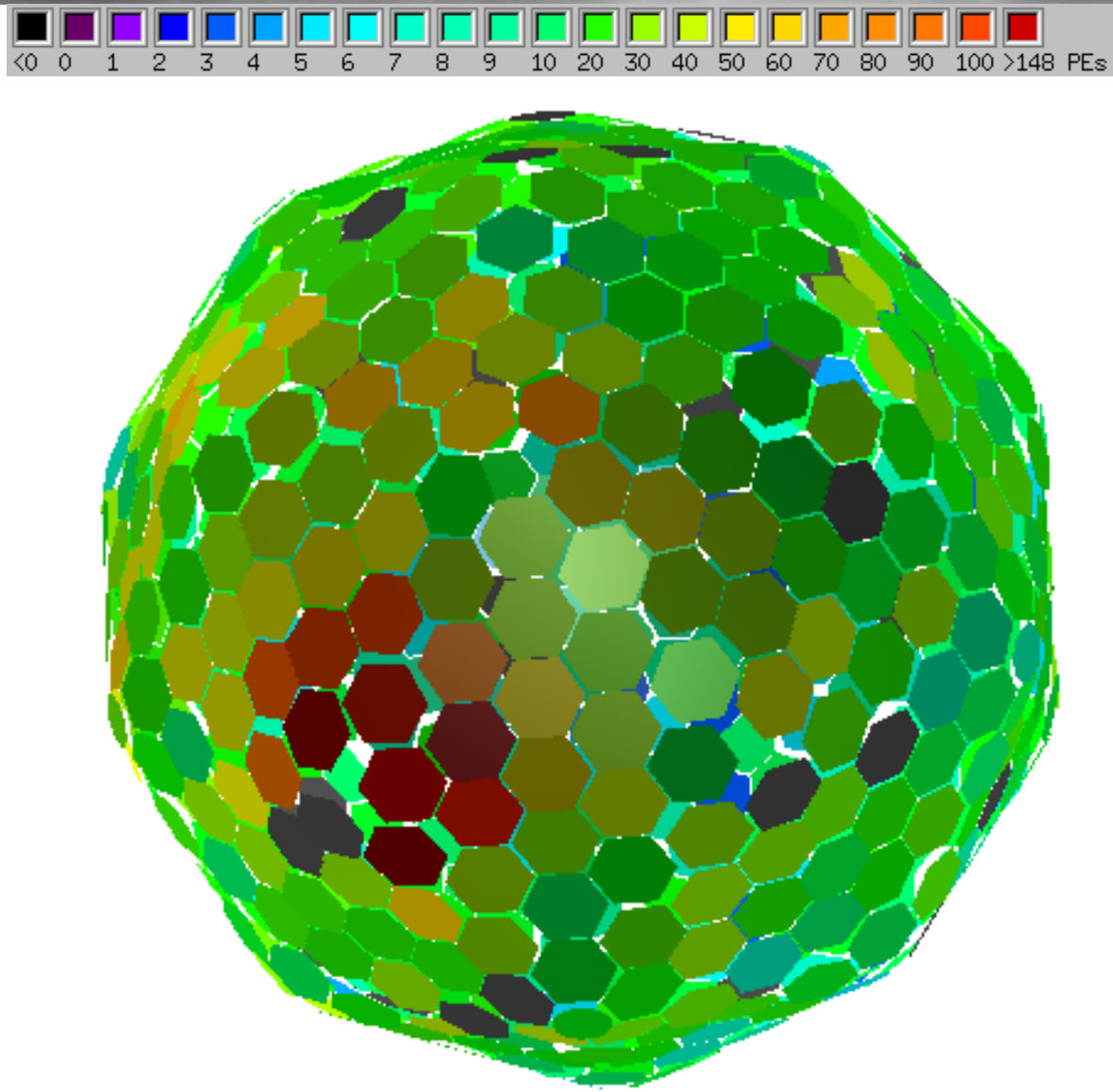


~10 PMTs in one triangle
642 PMTs in total

Reconstruct interaction point from PMT hit pattern

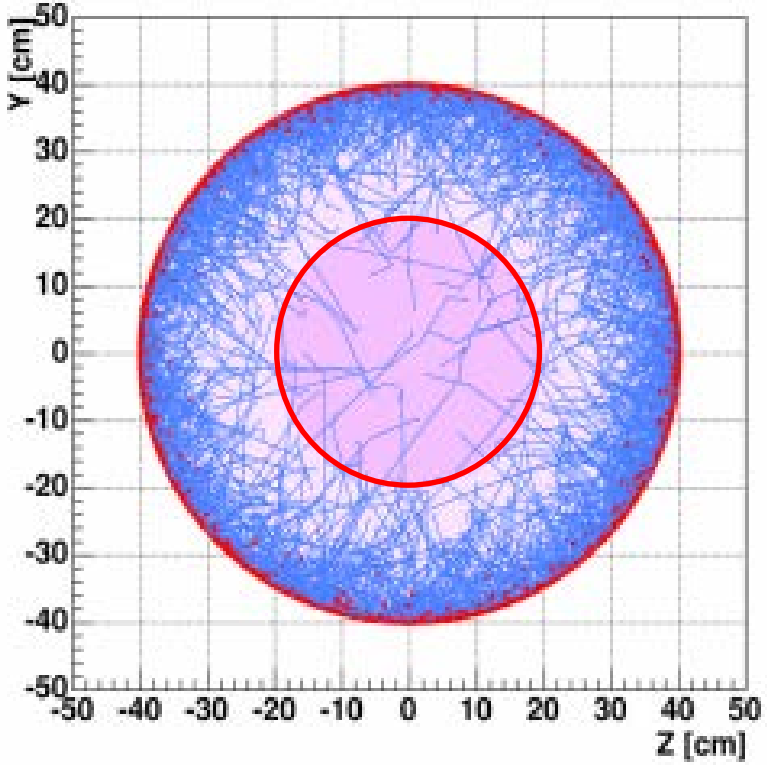
Colored photo cathodes indicating number of p.e. (photoelectrons) recorded by PMTs

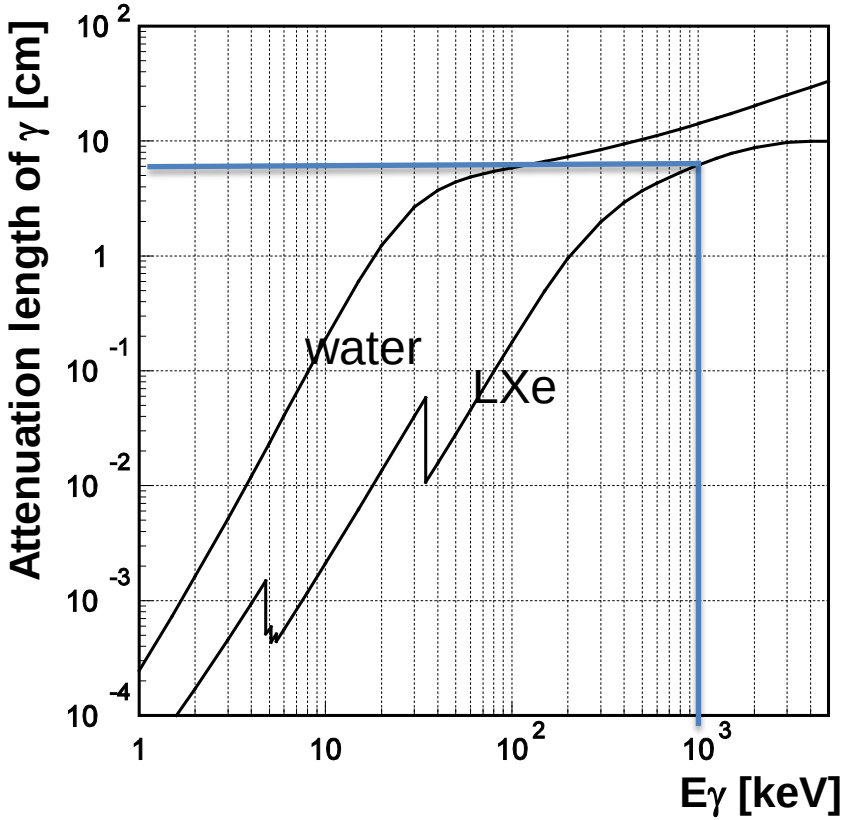
Interaction point (vertex) can be reconstructed from the PMT hit pattern.



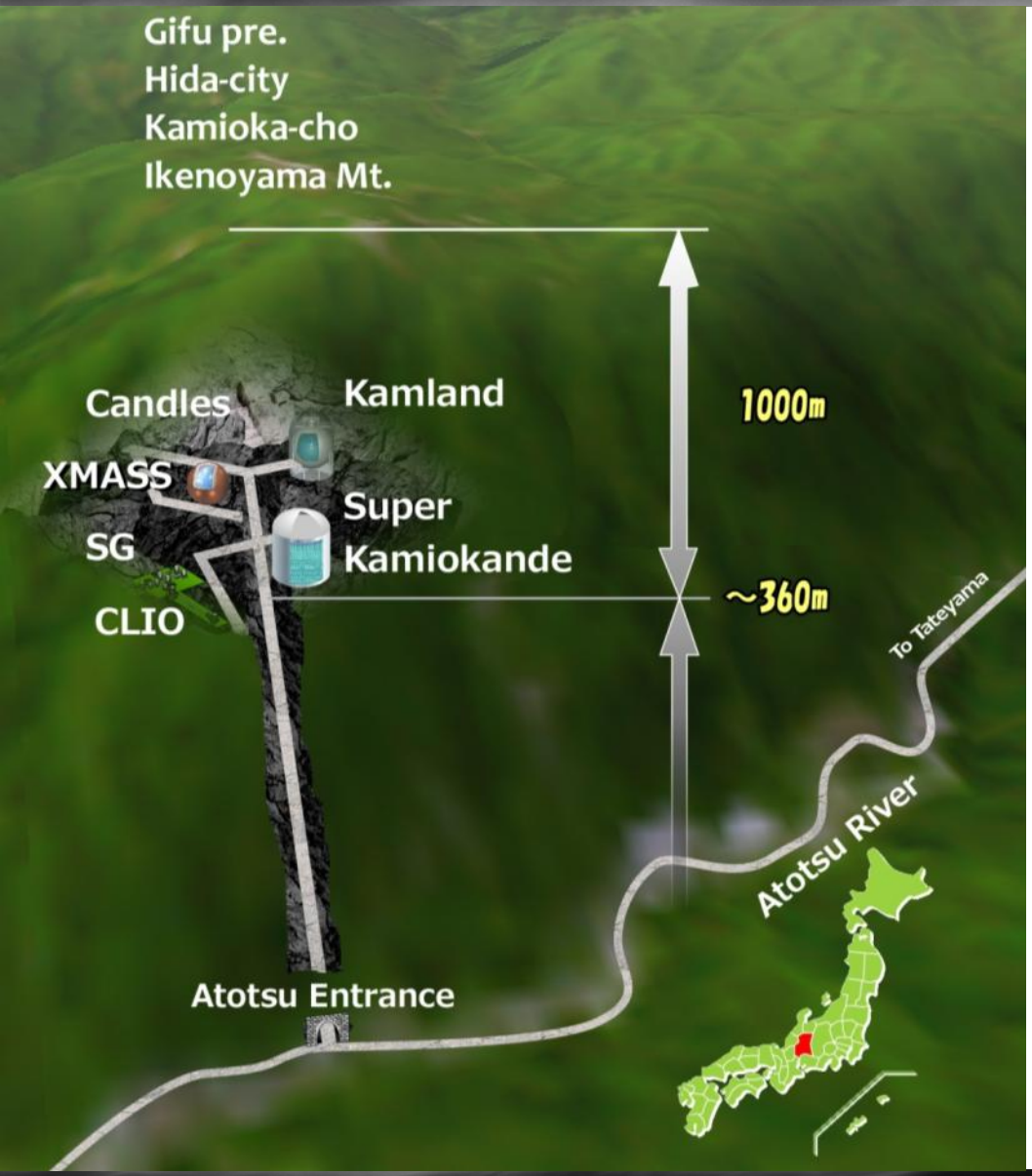
LXe self-shielding

Simulation: γ into LXe





Where is it?

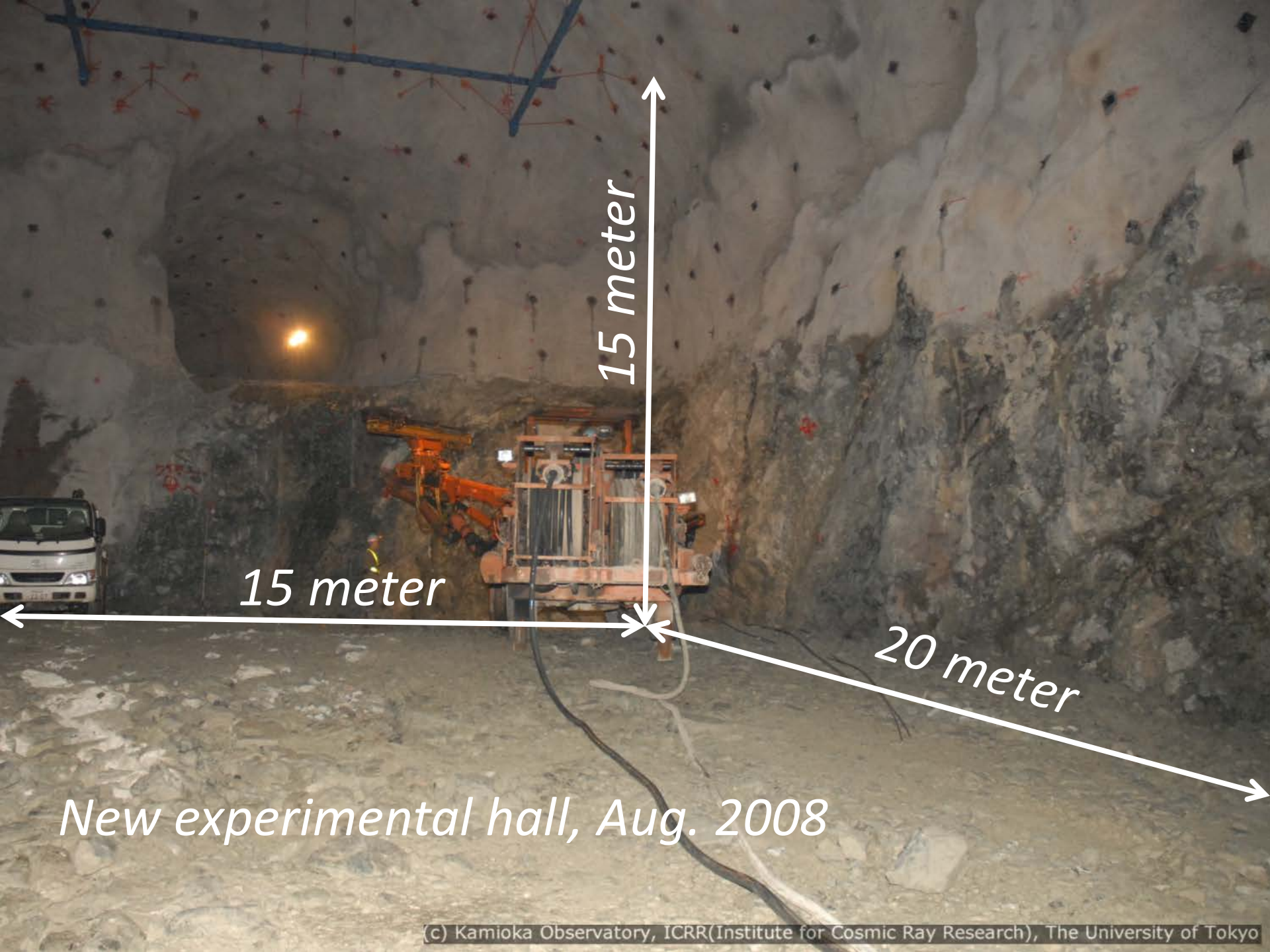


Kamioka underground observatory

1000 m rock overburden
(2700 m water equiv.):
Muon: 6.0×10^{-8} /cm^{-2}/s/sr
Neutron: 1.2×10^{-6}/cm^{-2}/s

360m above the sea

Lab-C, muon rate is measured to be consistent with SK result



New experimental hall, Aug. 2008


water tank, Nov. 2008
10 m x 10 m
(c) Kamioka Observatory, ICRR(Institute for Cosmic Ray Research), The University of Tokyo


Frame of clean room in water tank, Mar. 2008
(c) Kamioka Observatory, ICRR(Institute for Cosmic Ray Research), The University of Tokyo


PMT mounting in clean room, Dec. 2009
(c) Kamioka Observatory, ICRR(Institute for Cosmic Ray Research), The University of Tokyo

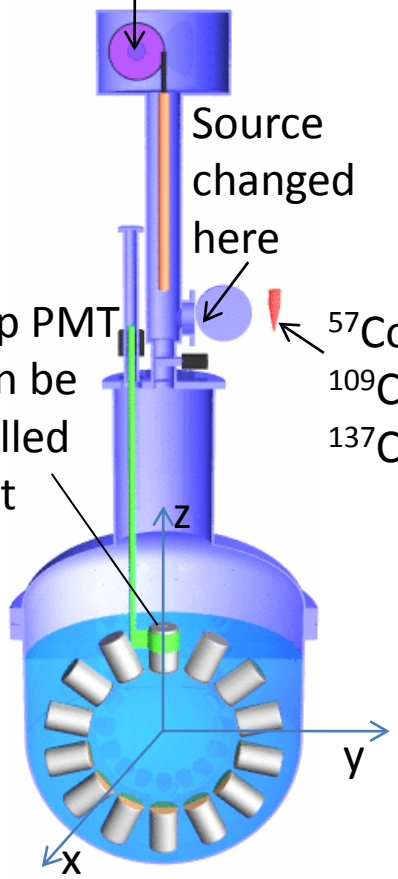

PMT mounting finished, Feb. 2010
(c) Kamioka Observatory, ICRR(Institute for Cosmic Ray Research), The University of Tokyo


Water filling, Sep. 2010
(c) Kamioka Observatory, ICRR(Institute for Cosmic Ray Research), The University of Tokyo


Commissioning started, Nov. 2010
(c) Kamioka Observatory, ICRR(Institute for Cosmic Ray Research), The University of Tokyo

Scintillation light yield :: calibration system

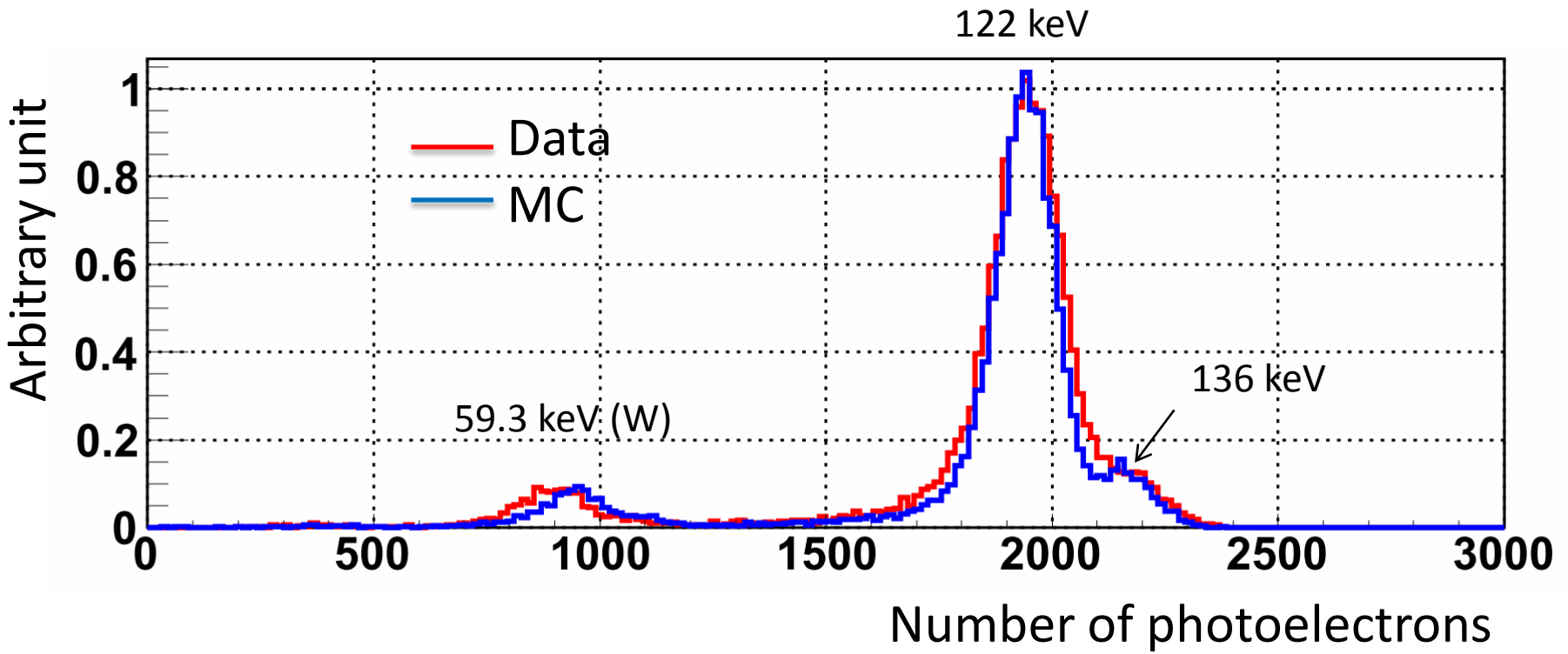
Z position of source is controlled by
a motor on top at <1 mm accuracy



Φ~4mm

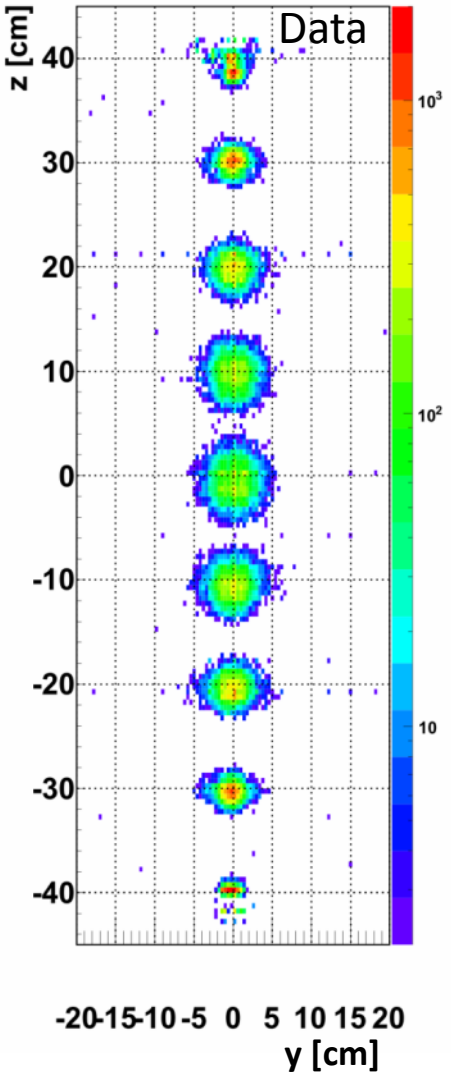
Φ~0.15mm for ^{57}Co

Scintillation light yield: 15.9 ± 1.2 p.e./keV (^{57}Co at center)



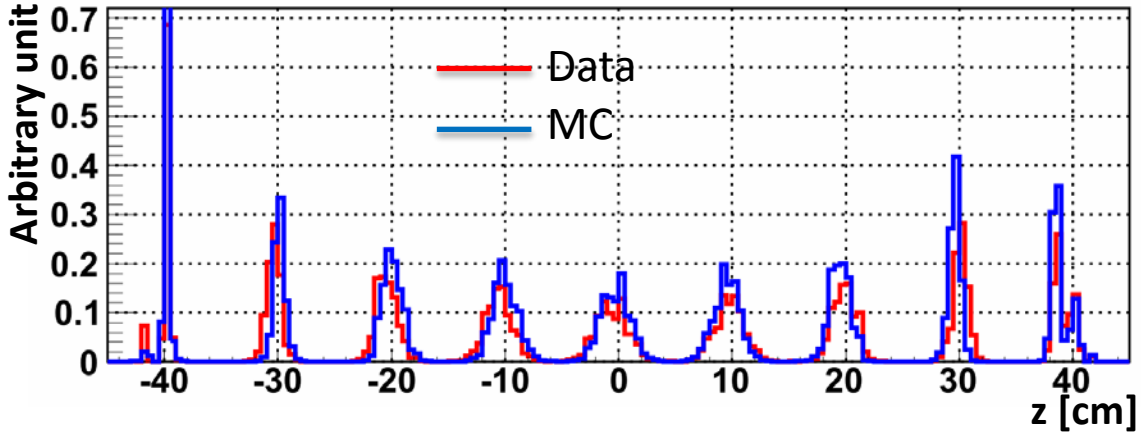
Position & energy resolution (122keV γ from ^{57}Co)

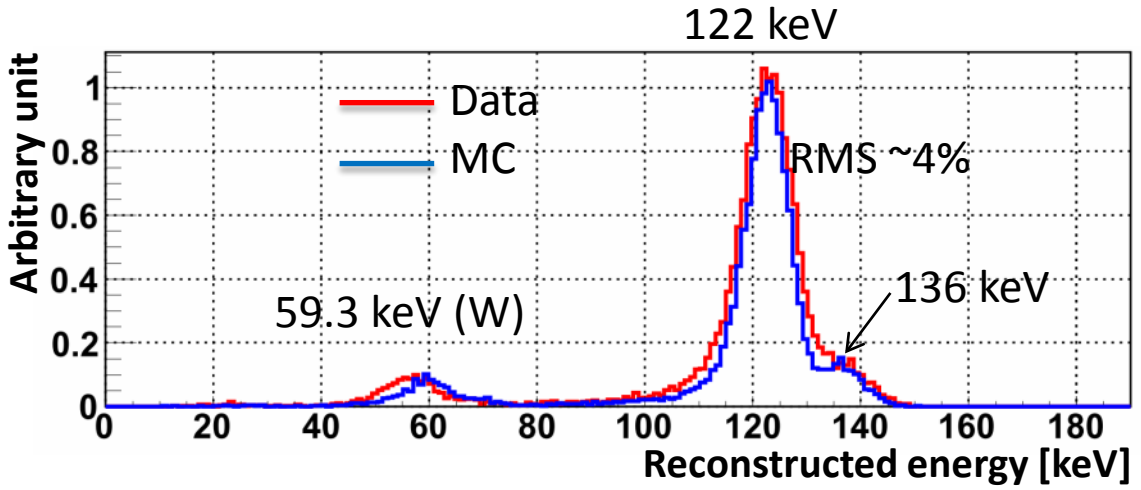
Reconstructed vertices for various source positions



Position resolution (RMS):

- 1.4 cm @ z = 0 cm
- 1.0 cm @ z = ±20 cm





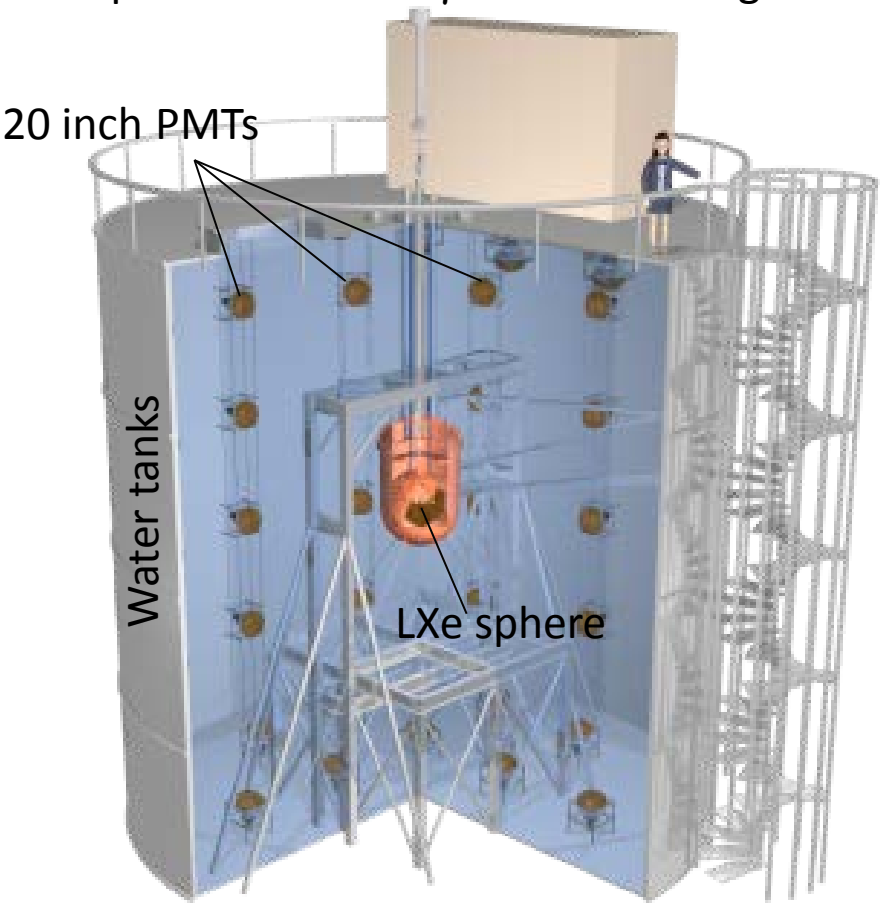
Background under control?

- External
  - Comic ray: underground, muon veto
  - Ambient gamma & neutron: water shielding
  - PMT radiation: LXe self-shielding
- Internal
  - Rn: material screening, clean room filled with Rn free air
  - Kr: distillation

Ambient γ and n: pure water tank, ∅~10 meter

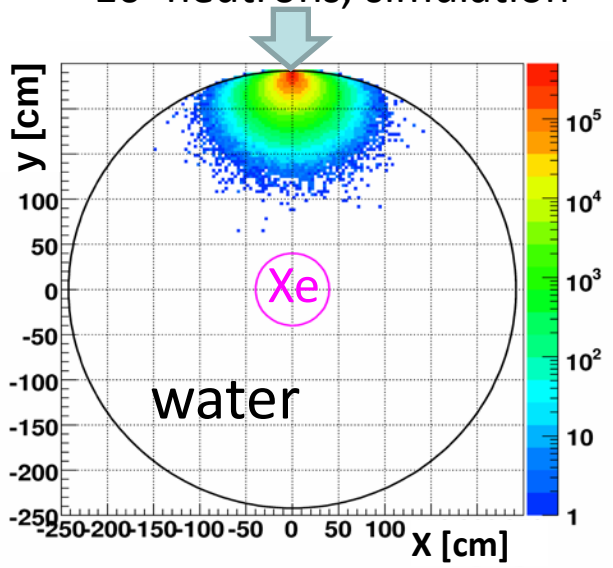
Pure water tank (large enough for 26 ton LXe) equipped with 20 inch PMTs on the wall as

- active muon veto and
- passive ambient γ and n shielding

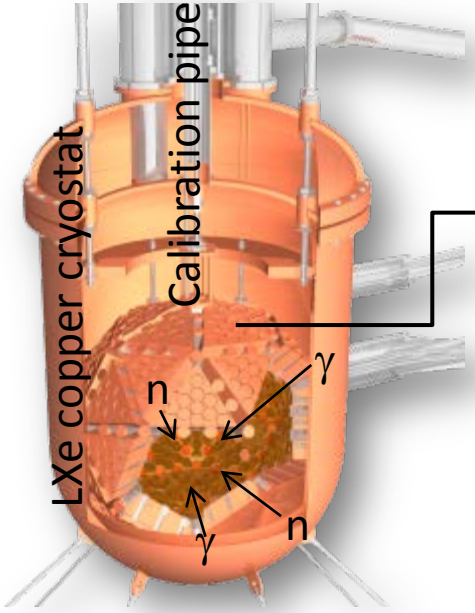


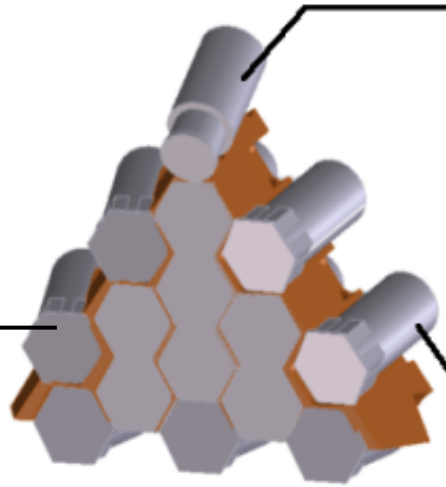
γ << γ from PMT, n<<10^{-4}/d/kg

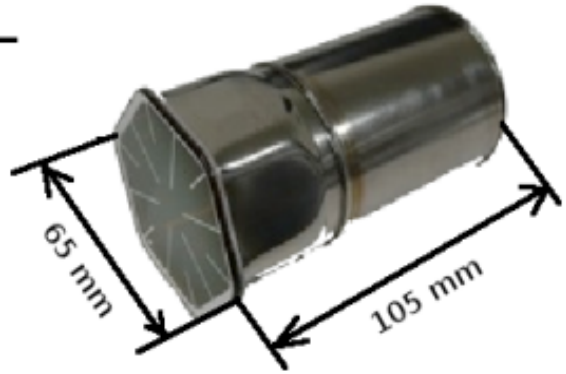
10^7 neutrons, simulation



PMT radiation: Ultra low background PMTs



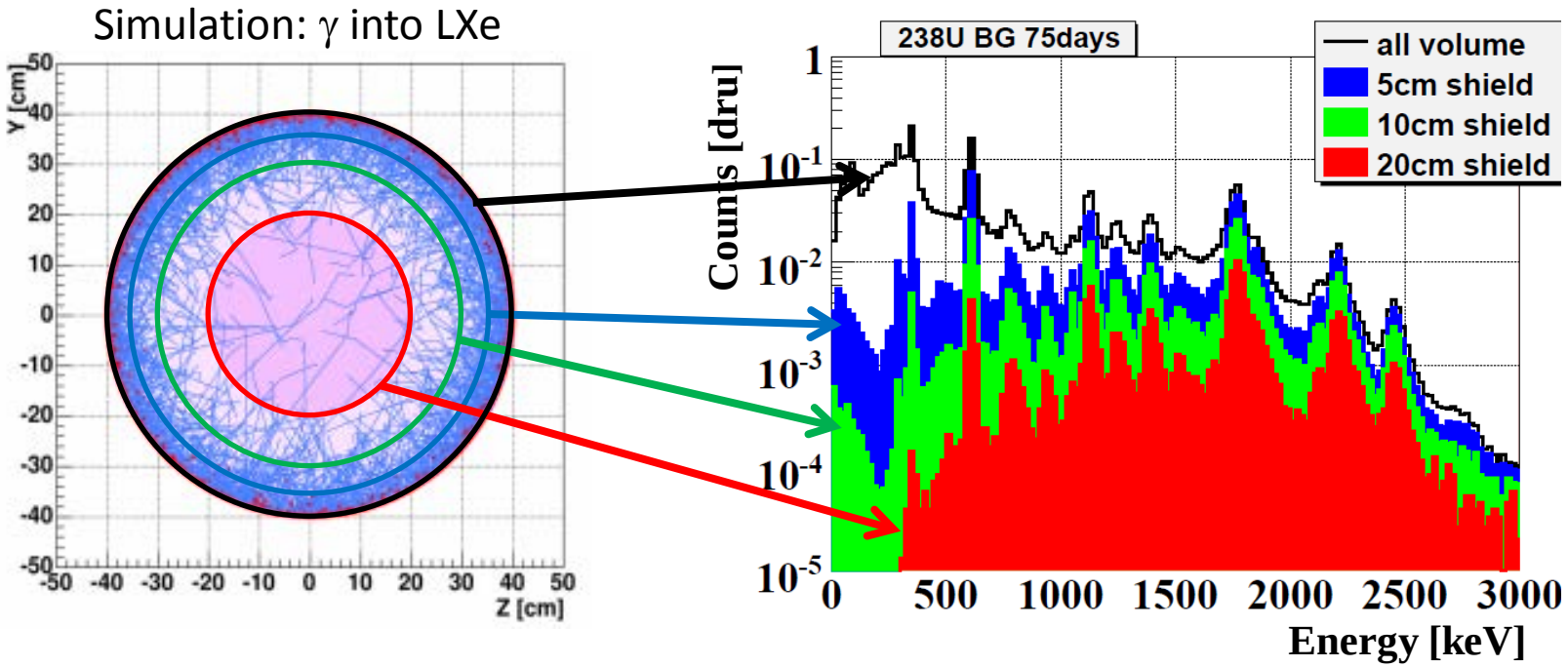




PMT

Q.E.: 27~39%
Time resolution: ~4 ns
238U: 0.70 +/- 0.28 mBq/PMT
232Th: 1.51 +/- 0.31 mBq/PMT
40K: <5.1 mBq/PMT
60Co: 2.92 +/- 1.61 mBq/PMT
Neutron: <1.2x10^{-5} dru @5-10 keV

PMT & PMT holder radiation: LXe self-shielding



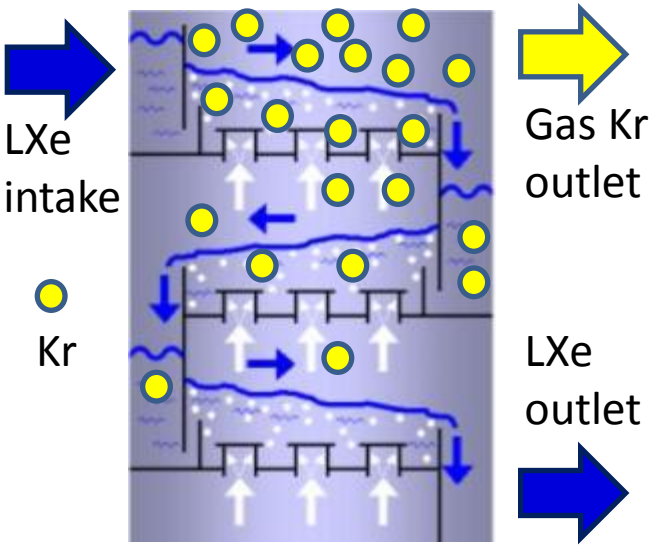
	BG/PMT [mBq]
U chain	0.70 ± 0.28
Th chain	1.51 ± 0.31
^{40}K	< 5.10
^{60}Co	2.92 ± 0.16

fiducial volume: r<20cm, 100 kg LXe

^{85}Kr (Q_β=687keV) : distillation

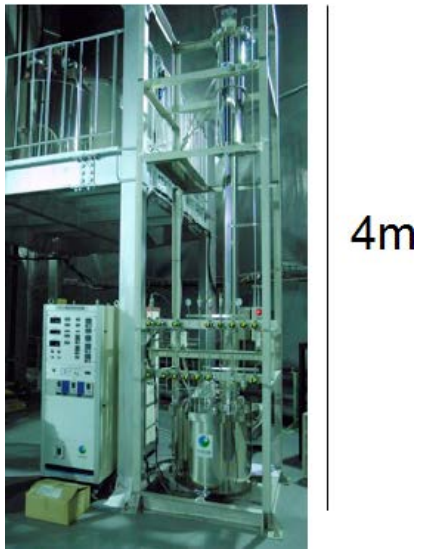
K. Abe *et al*. for XMASS collab., Astropart. Phys. 31 (2009) 290

Kr can be boiled out from LXe



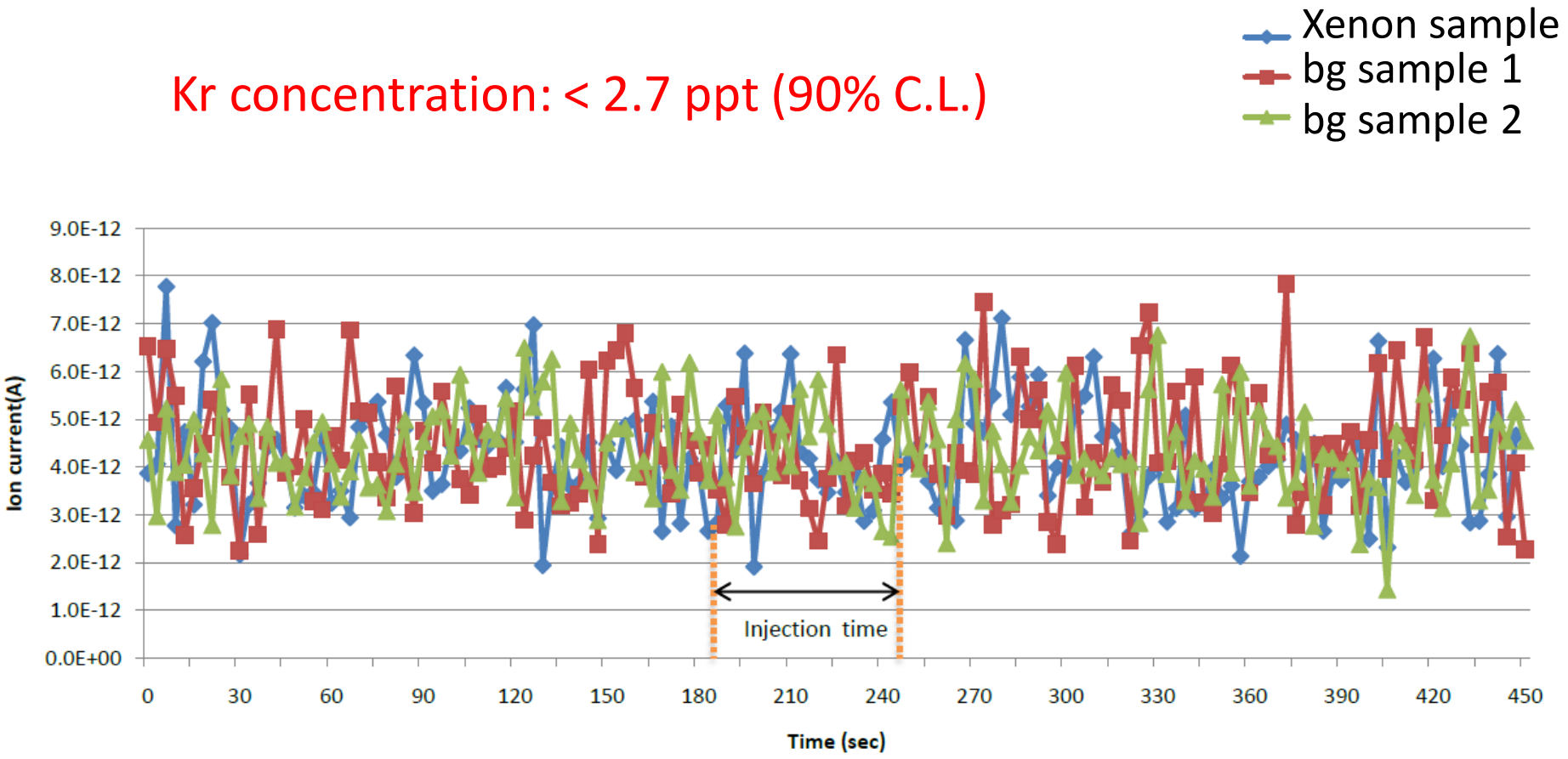
	Boiling point (@0.2MPa)
Xe	178 K
Kr	140~150 K

0.1 ppm → ~1ppt (~1 ton in 10 days)



Kr concentration

Kr concentration: < 2.7 ppt (90% C.L.)



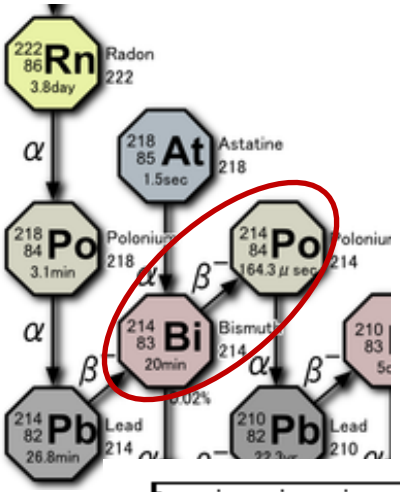
Measured by gas chromatography + API mass spectrometer

^{222}Rn

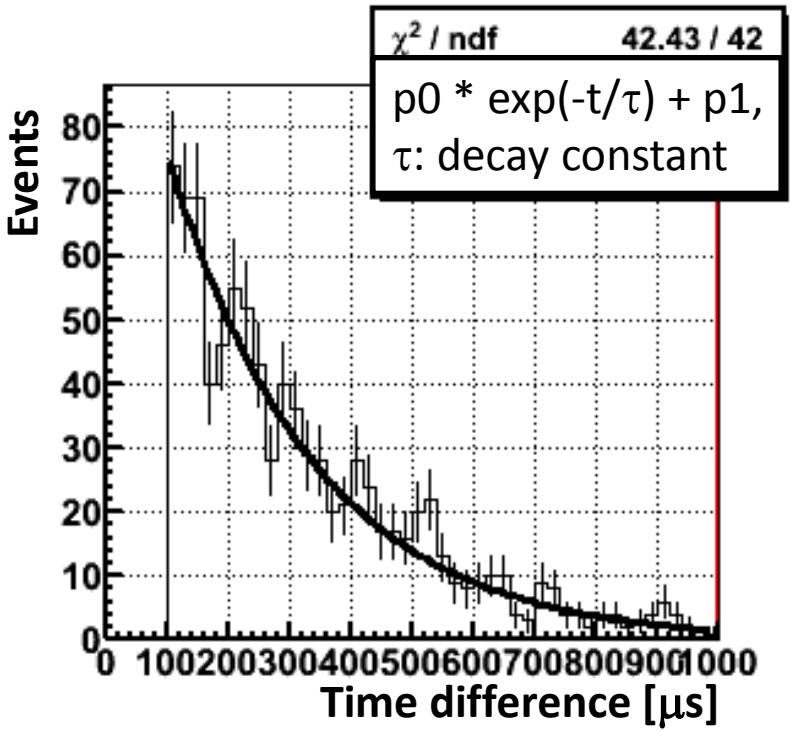
^{214}Po decays with 164 μs half life.

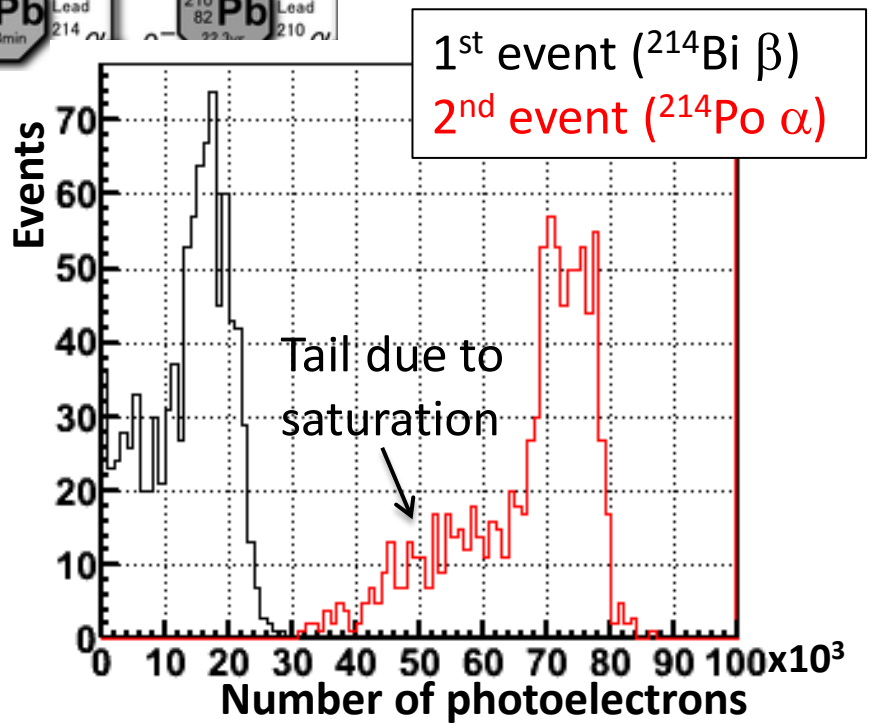
It can be identified by time coincidence between two consecutive events:

1. ^{214}Bi β decays into ^{214}Po
2. ^{214}Po α decays into ^{210}Pb



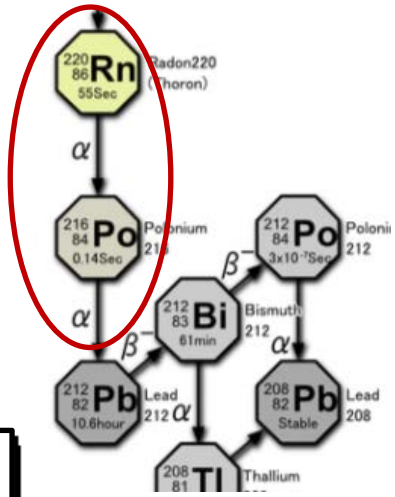
8.2±0.5 μBq/kg



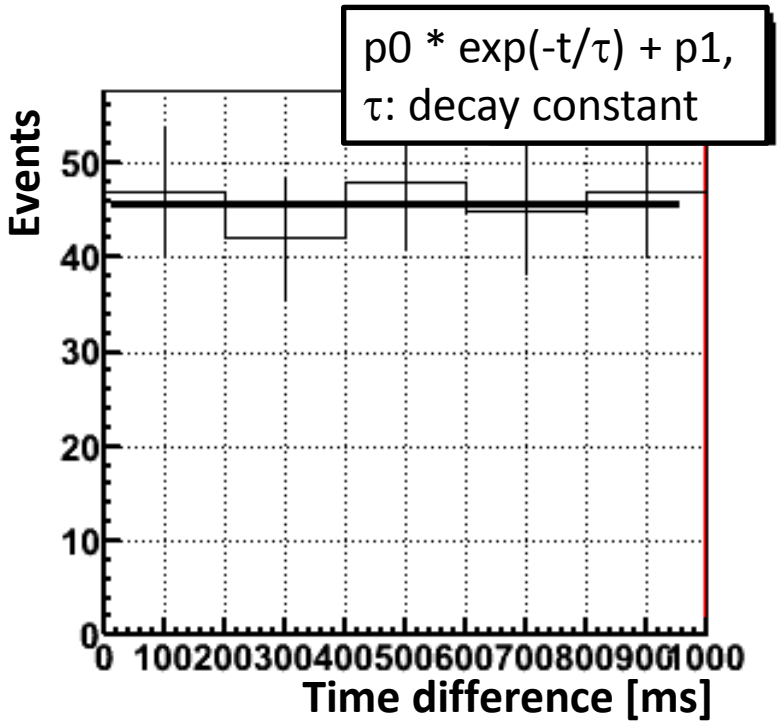


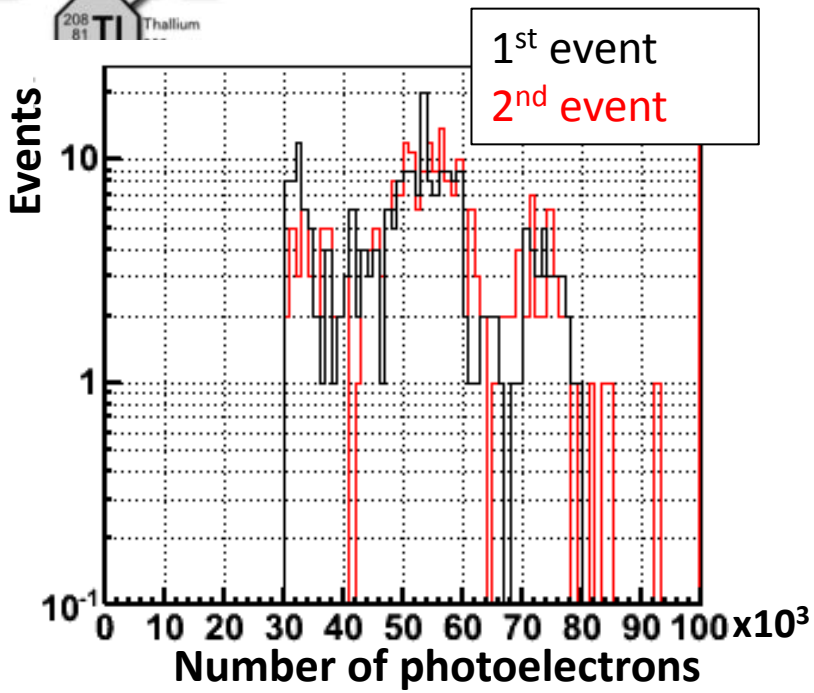
^{220}Rn

^{216}Po decays with
140 ms half life

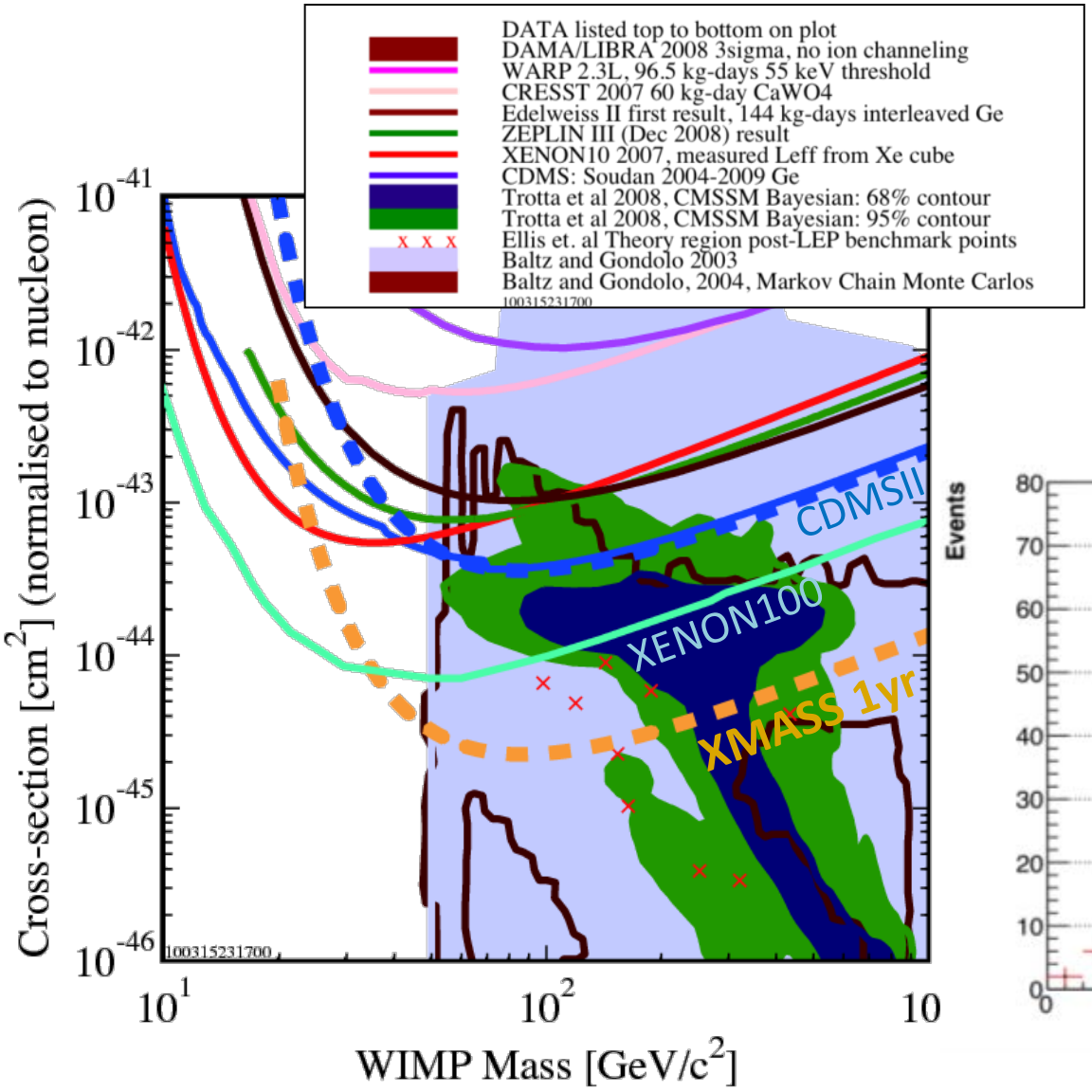


<0.28 μBq/kg (90%C.L.)



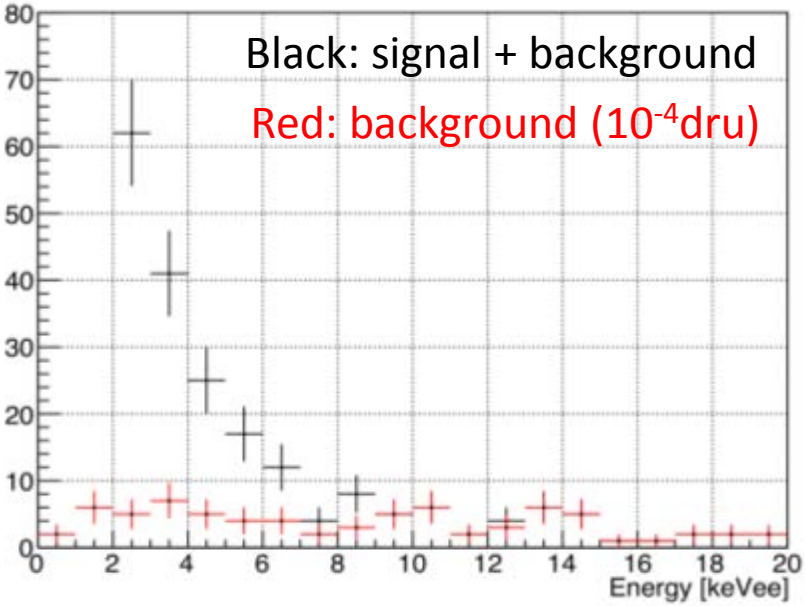


Target sensitivity of WIMP-nucleon XS (spin independent)



Expected energy spectrum assuming

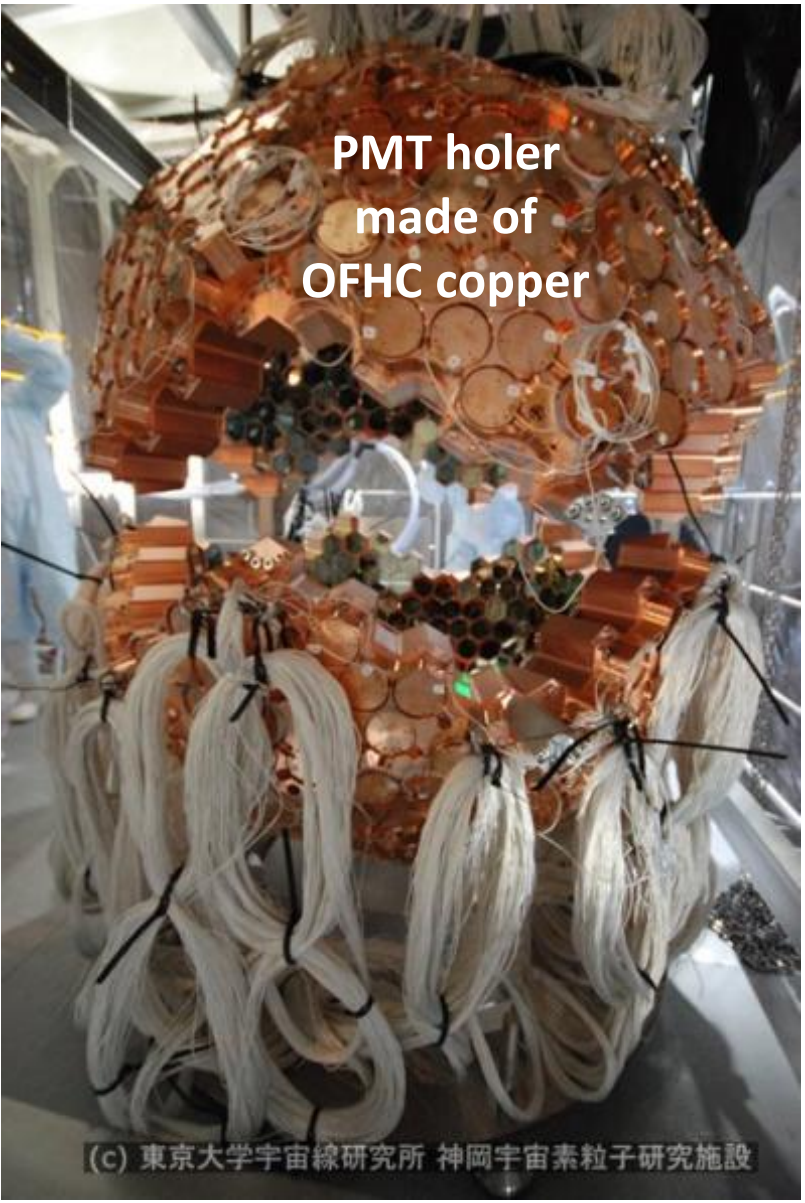
- 1 year exposure
- flat background (10^{-4} dru)
- $\sigma_\chi = 10^{-44}$ cm^2
- $M_{WIMP} = 50$ GeV
- $L_{eff} = 0.2$



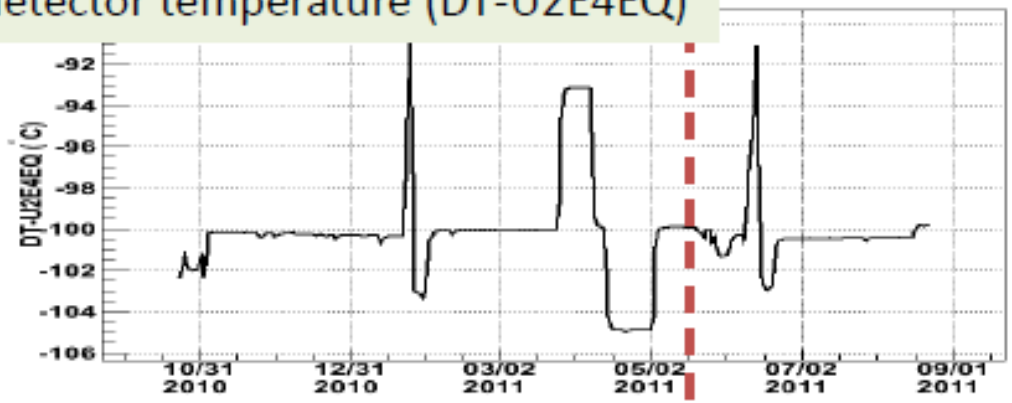
Conclusion

- The XMASS 800kg detector is a single phase LXe scintillation detector
- Construction of the 800kg detector finished last winter
- Commissioning runs are on going to confirm the detector performance and low background properties
  - High light yeild
  - Energy resolution and vertex resolution were as expected. ~1cm position resolution and ~4% energy resolution for 122 keV γ.
  - Radon and Kr background are close to the target values.
- The physics results are on the way

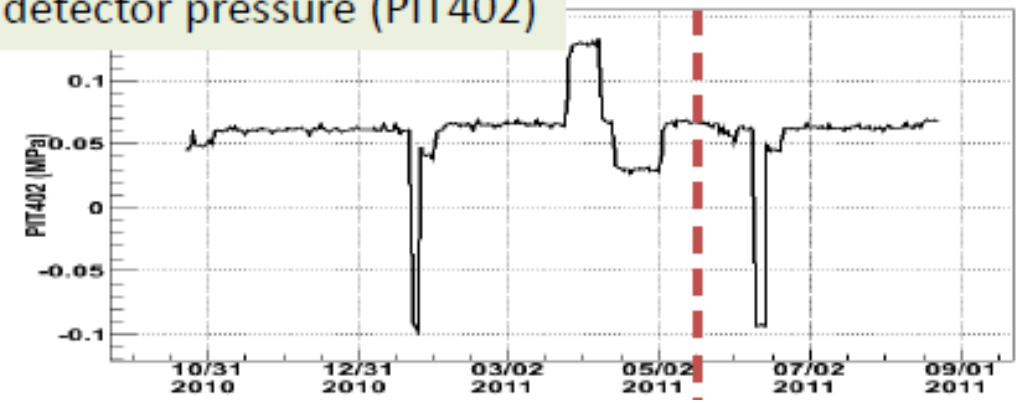

Thanks!



detector temperature (DT-U2E4EQ)



detector pressure (PIT402)



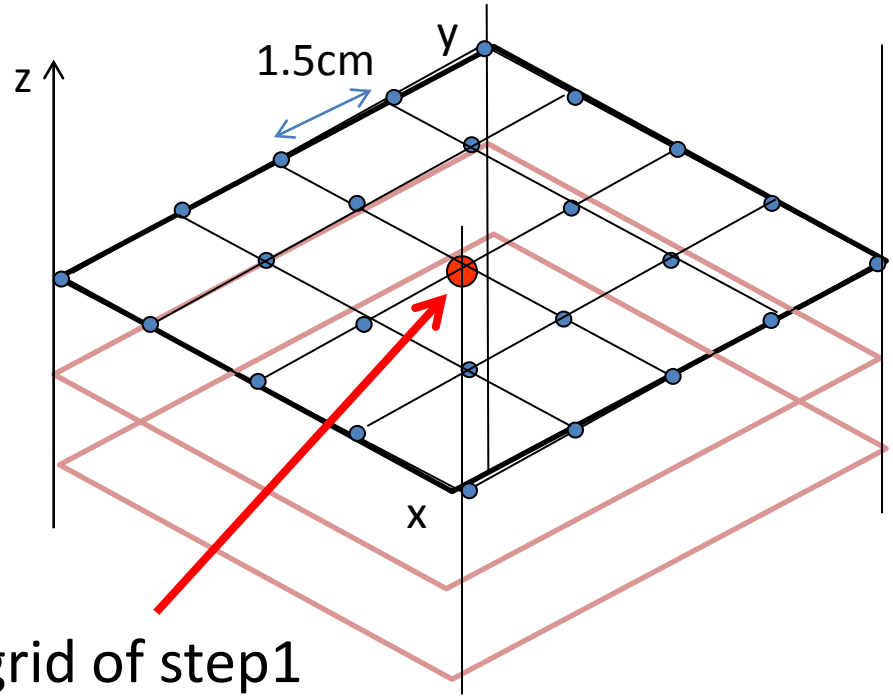
3 Steps in reconstruction

- Step1
  - Search the map grid where likelihood becomes smallest.
- Step2
  - By linear interpolation, calculate likelihood at finer “interpolated grid” in Cartesian coordinate.
  - 1.5cm interval, 5x5x5 finer grid points are evaluated.

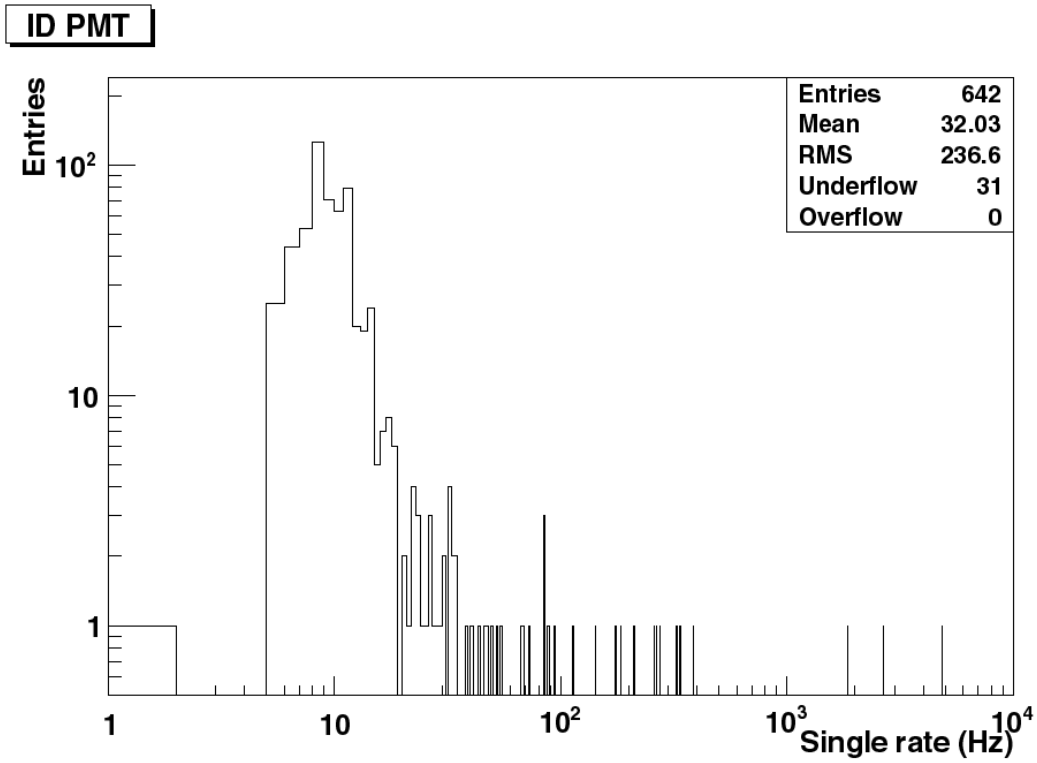
- Ln likelihood is calculated from the expected pe and observed pe. Using gamma distribution.

$$\mathrm{Log}(L) = \sum_{PMT} \mathrm{Log}\left(\frac{\exp(-\mu)\mu^{pe}}{\Gamma(pe+1)}\right)$$

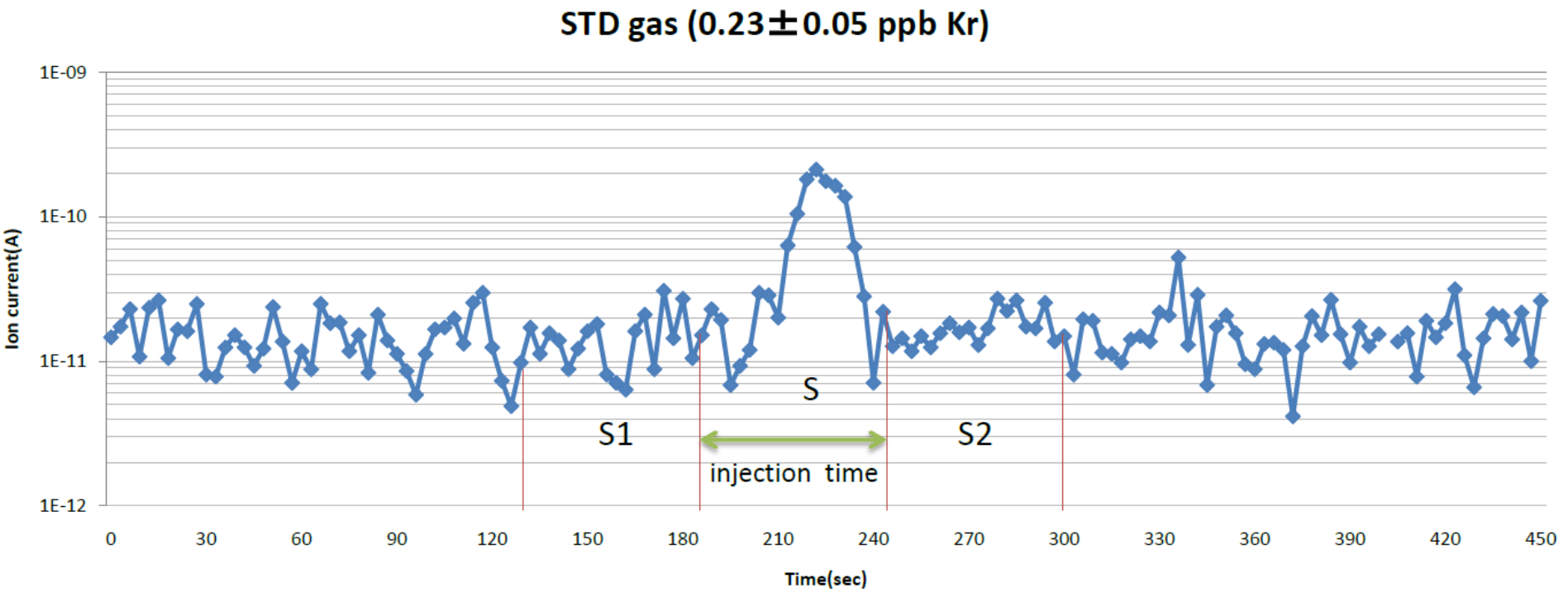
- Treatment of saturated PMT, cumulative probability of gamma distribution.



Result grid of step1


ID PMT
Entries
642
Mean
32.03
RMS
236.6
Underflow
31
Overflow
0
Entries
10^2
10
1
1
10
10^2
10^3
10^4
Single rate (Hz)

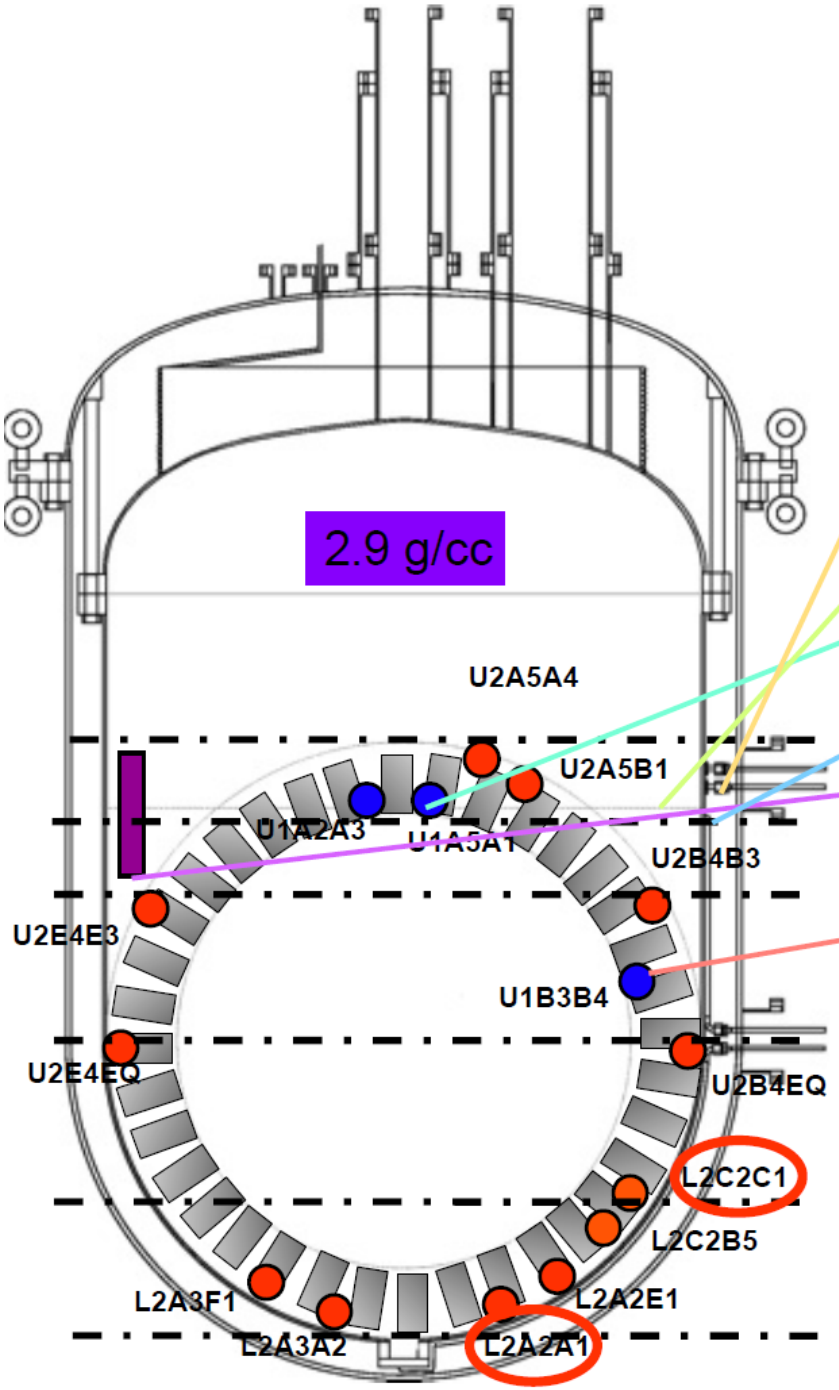
Calculation of Kr in STD gas ②



	Time[s]	Area[C]
S1	132~189	8.44E-10
S	189~246	3.90E-09
S2	246~303	9.73E-10

$$\text{peak area} = S - \frac{(S1 + S2)}{2} = 2.99E-9[C]$$

Thermometer and level meter position

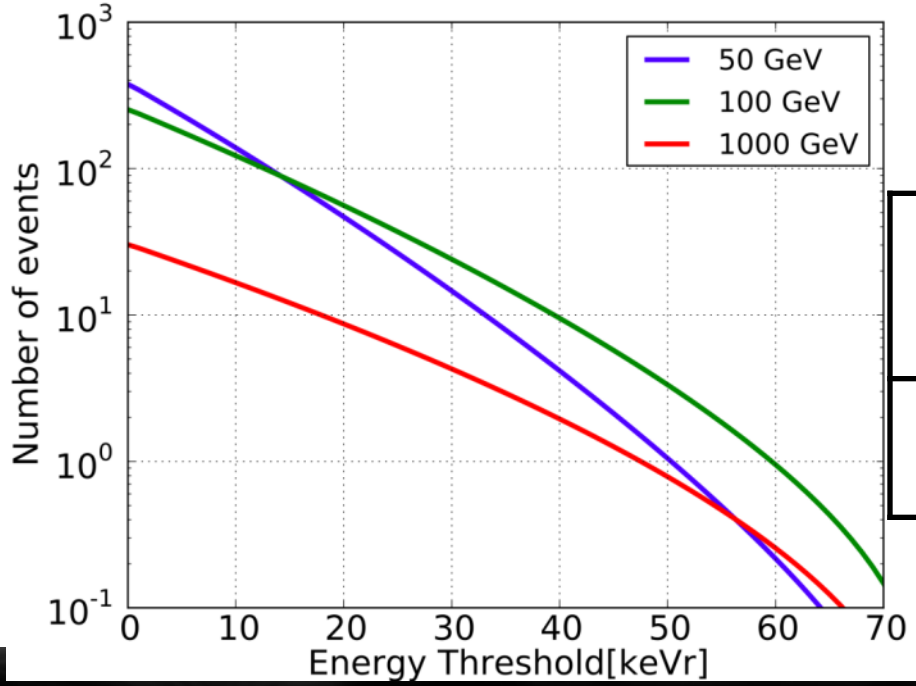


calc.		LXe amount	LXe +GXe amount	(wei.res)
• From IVC bottom				
• U2A5A4 1104mm				
• U2A5B1 1104mm				
• Liq. pipe 1095mm				
• Stop filling 1015mm	394L	1081.2 kg	1088.9 kg	(684kg)
• Liquid level 1005 mm with circulation	366.6L	1063.2 kg	1070.6kg	(702kg)
• Liquid level 996mm (Filler top)	362.0L	1046.2 kg	1054kg	(719kg)
• U1A2A3 991mm	361.9L	1042.2 kg	1050kg	(723kg)
• U1A5A1 991mm	361.9L	1042.2 kg	1050kg	(723kg)
• H-Line 953.5mm upper(IVC-C3,IVC-C4 will react)	359L	1028.2 kg	1036kg	(737kg)
• Cont. LV 835.5mm	329L	937.7 kg	946 kg	(827kg)
• U2B4B3 743mm	274L			
• U2E4E3 743mm	274L			
• U1B3B4 661mm	244L	697.6kg	707 kg	(1066kg)
• (Center 560mm	172L)			
• U2B4EQ 525mm	151L			
• U2E4EQ 525mm	151L			
• L2C2C1 271mm	26.8L			
• L2C2B5 167mm	3.67L			
• L2A2E1 92mm	1.11L			
• L2A3F1 92mm	1.11L			
• L2A2A1 15mm	0.17L			
• L2A3A2 15mm	0.17L			

Error for estimation
is 3L for 342 L.(Abe-san)

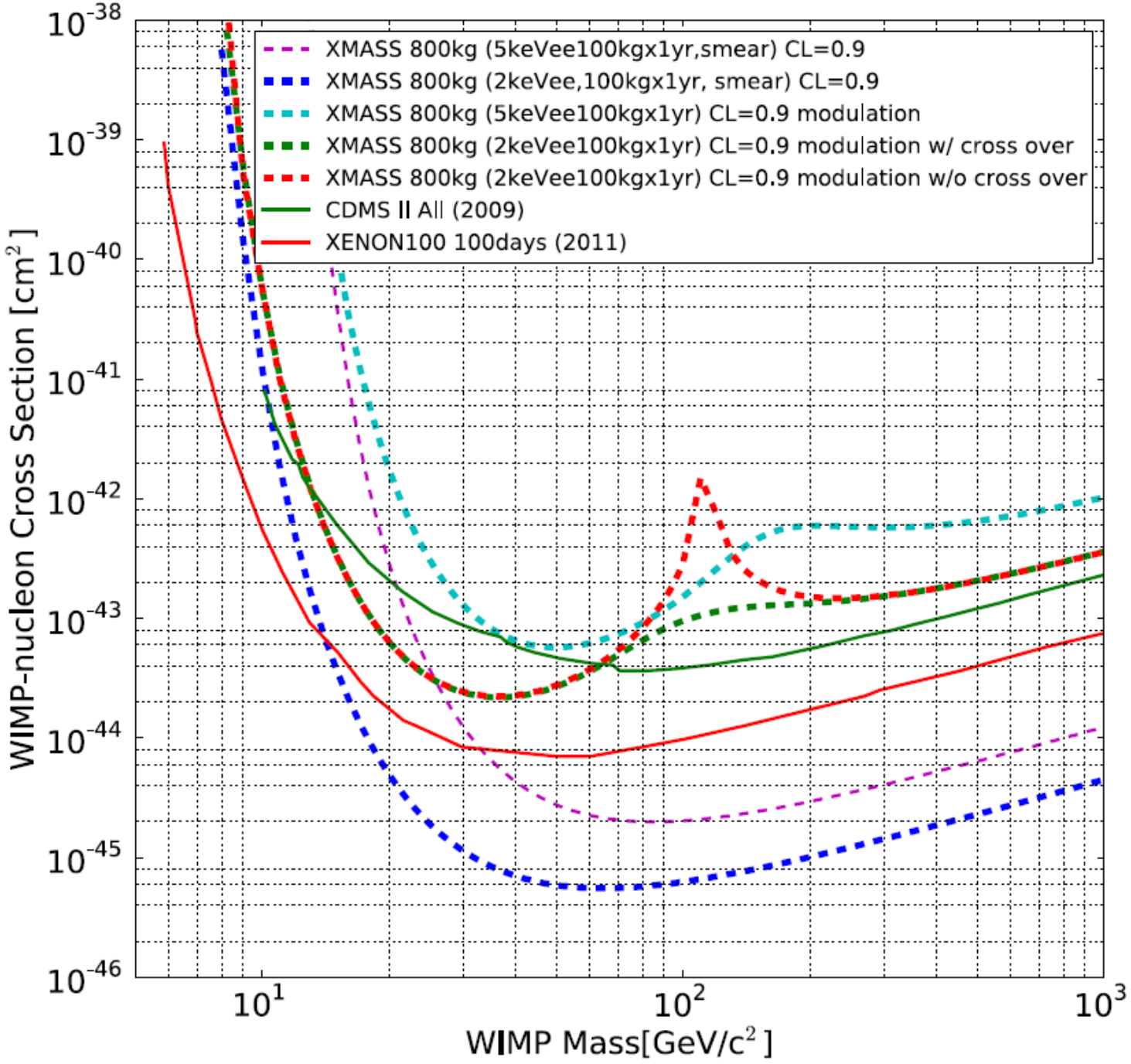
Integral spectrum

Assumption
1x10^-44 cm^2
100 kg X 1 year exposure

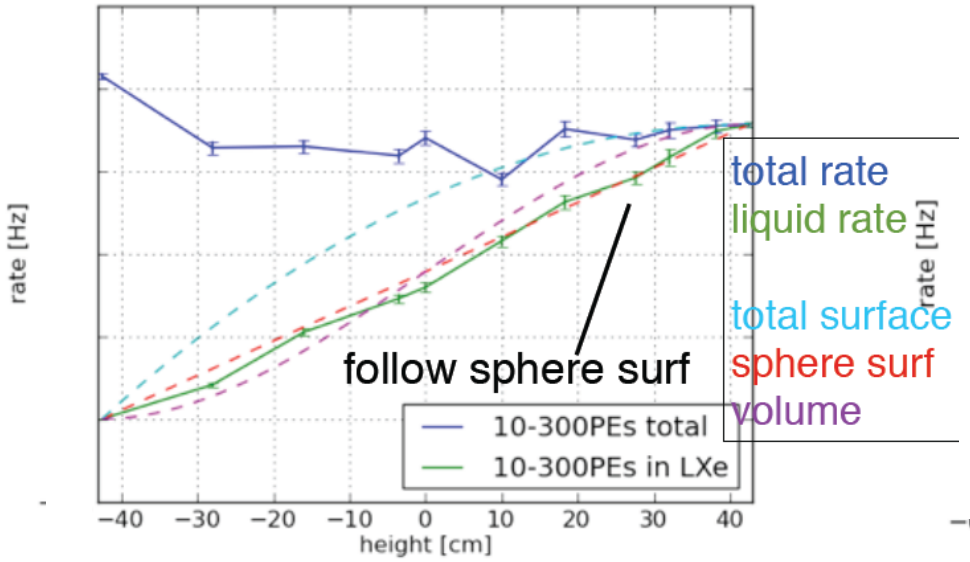


25 keVr(5keVee) energy threshold
100kg x 1 year

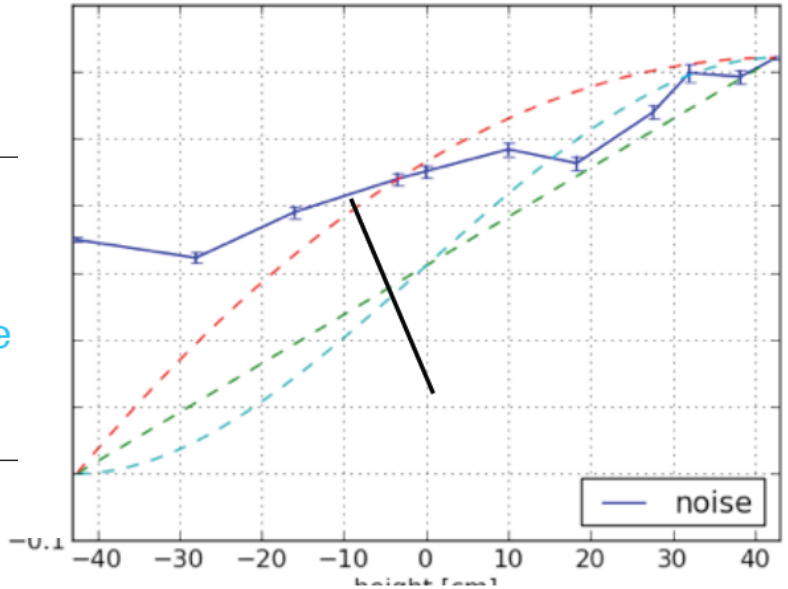
	WIMP Mass [GeV]		
	50	100	1000
No. of Events	26	37	6


XMASS 800kg (5keVee100kgx1yr,smear) CL=0.9
XMASS 800kg (2keVee,100kgx1yr, smear) CL=0.9
XMASS 800kg (5keVee100kgx1yr) CL=0.9 modulation
XMASS 800kg (2keVee100kgx1yr) CL=0.9 modulation w/ cross over
XMASS 800kg (2keVee100kgx1yr) CL=0.9 modulation w/o cross over
CDMS II All (2009)
XENON100 100days (2011)
WIMP-nucleon Cross Section [cm^2]
WIMP Mass[GeV/c^2]
10^{-38}
10^{-39}
10^{-40}
10^{-41}
10^{-42}
10^{-43}
10^{-44}
10^{-45}
10^{-46}
10^{1}
10^{2}
10^{3}

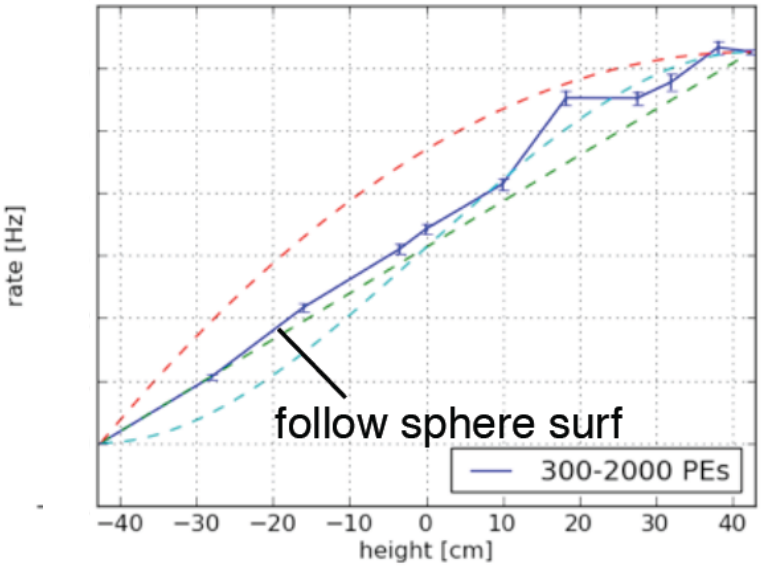
10-300 nPE (after basic +noise cut)
(~2keV - 20 keV)



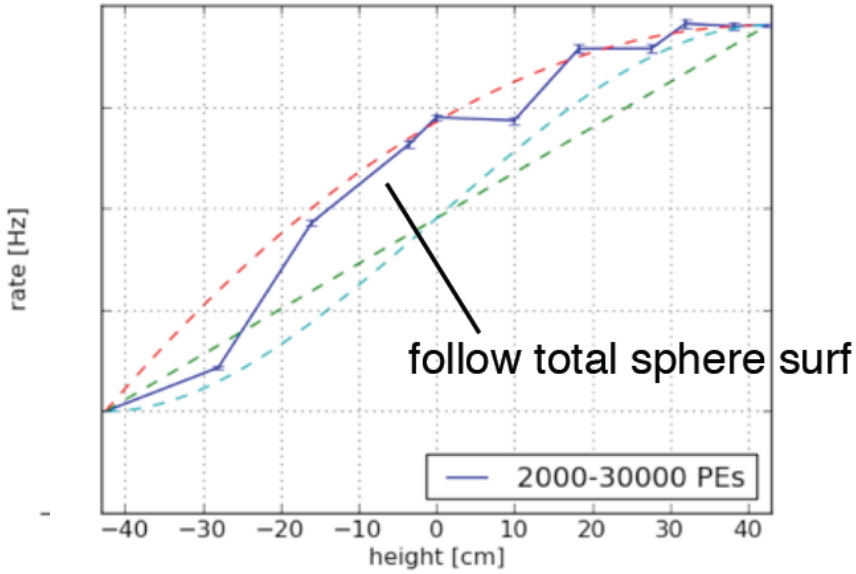
noise events(Cerenkov)

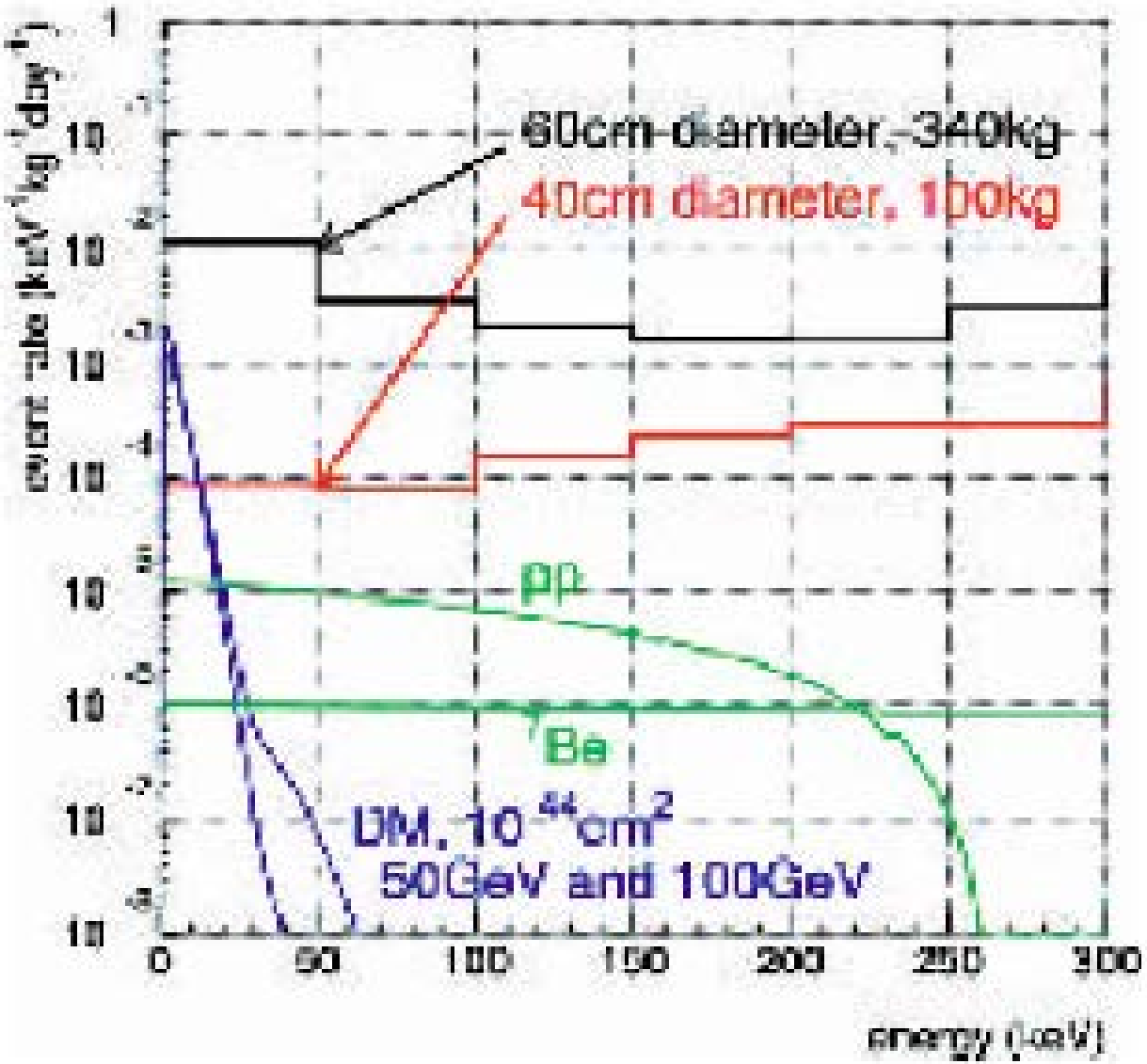


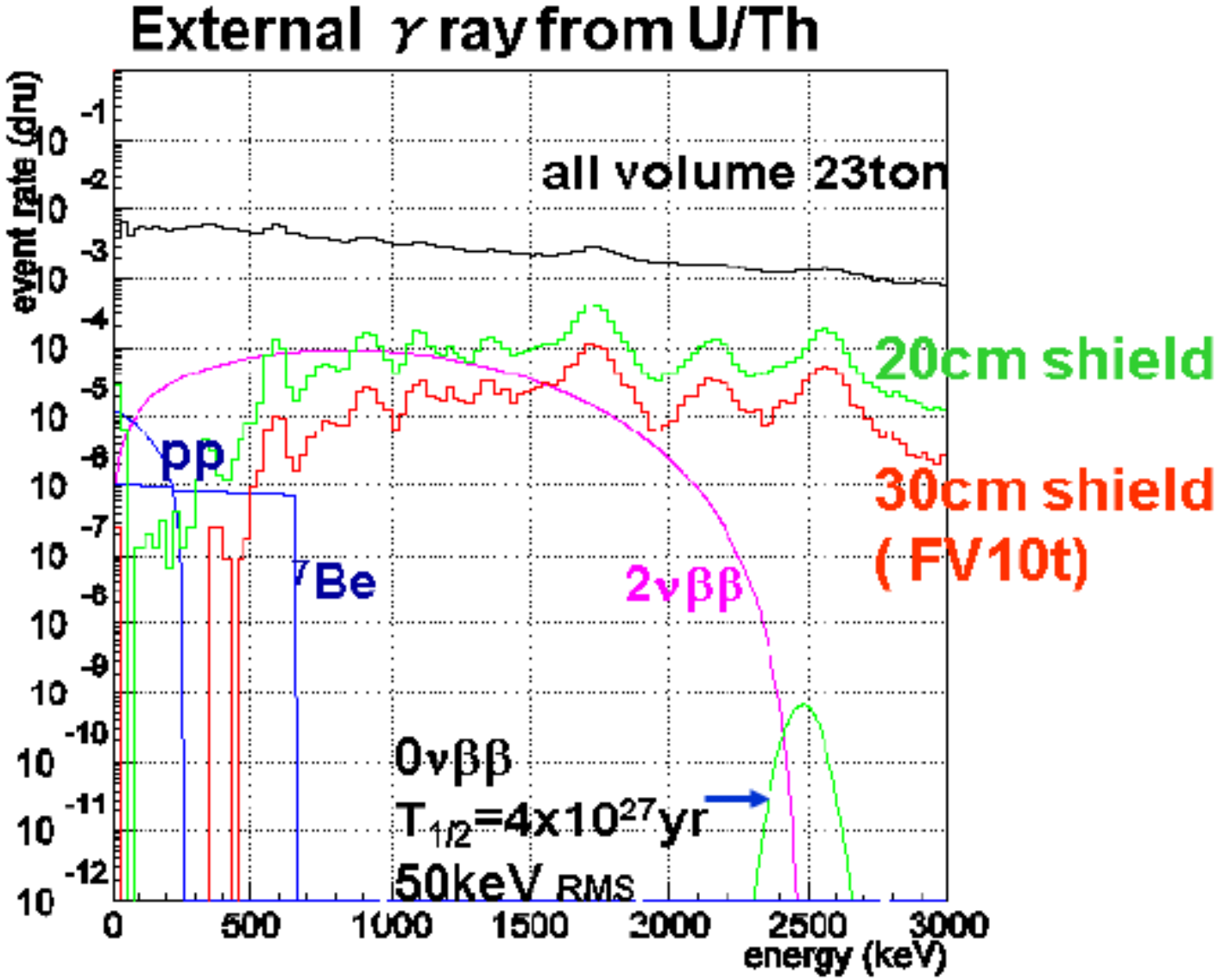
300-2000(~ 20-100keVee)

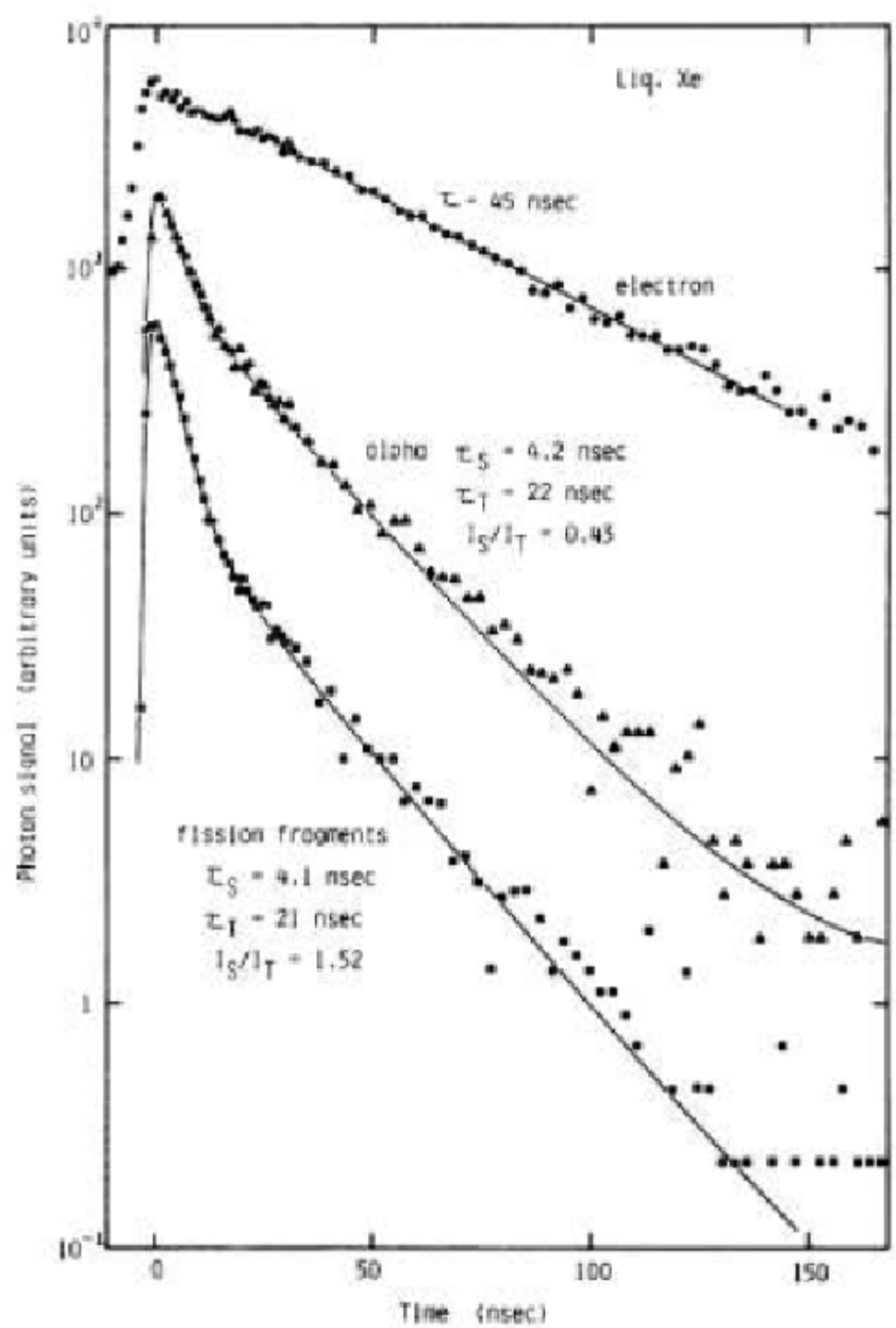


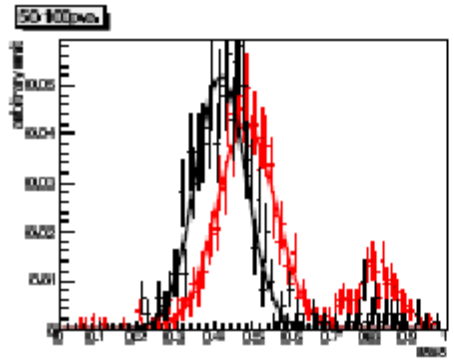
2000-30000 (~100keV -2000keV)

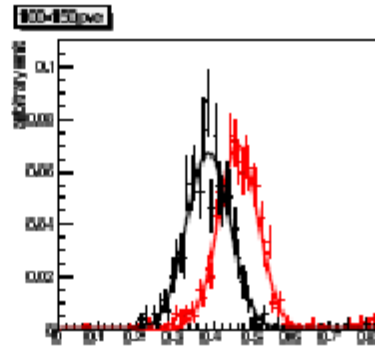


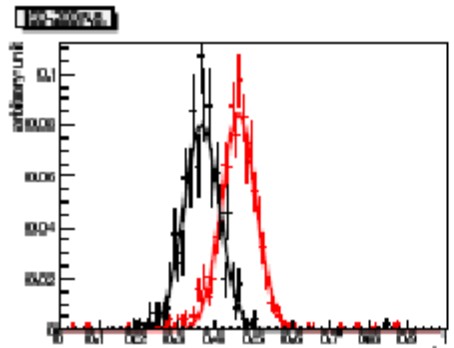

60cm diameter, 340kg
40cm diameter, 100kg
pp
⁷Be
DM, 10⁻⁴⁴cm²
50GeV and 100GeV
0
50
100
150
200
250
300
energy (keV)

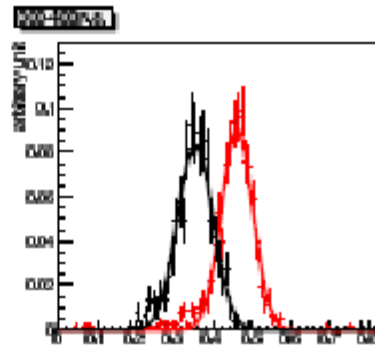

External γ ray from U/Th
event rate (dru)
all volume 23ton
20cm shield
30cm shield
(FV10t)
pp
7Be
2νββ
0νββ
T1/2=4x10^27yr
50keV RMS
energy (keV)
0
500
1000
1500
2000
2500
3000

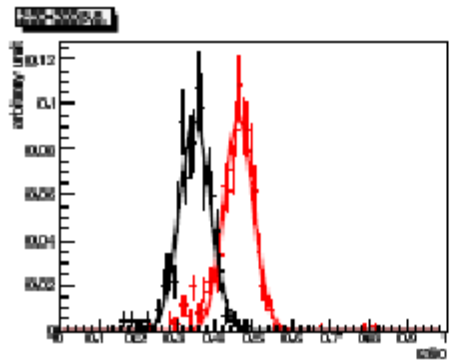

Liq. Xe
τ ~ 45 nsec
electron
alpha τS = 4.2 nsec
τT = 22 nsec
IS/IT = 0.43
fission fragments
τS = 4.1 nsec
τT = 21 nsec
IS/IT = 1.52
Photon signal (arbitrary units)
Time (nsec)
0
50
100
150

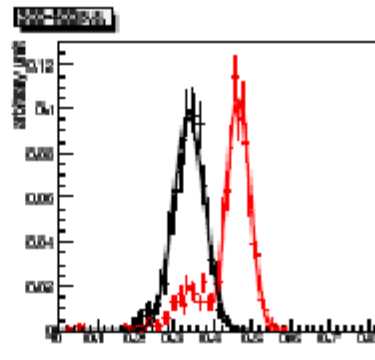


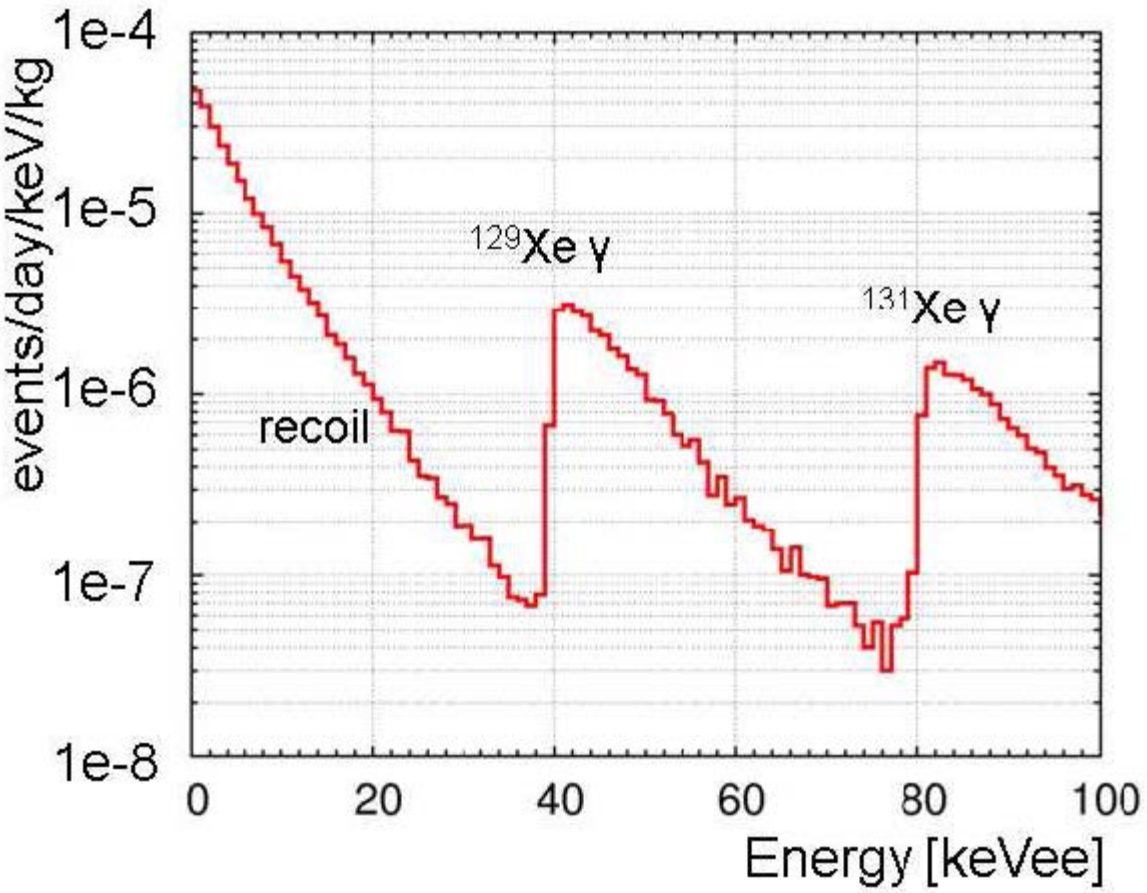


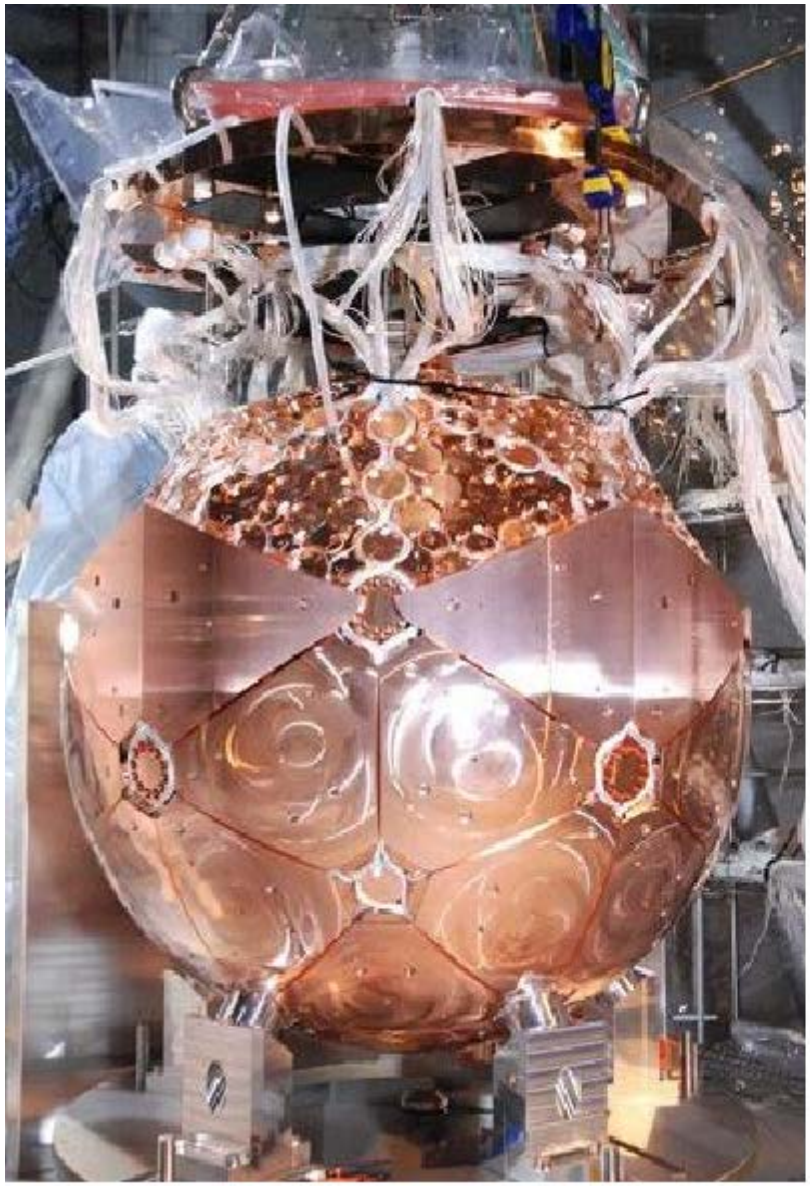


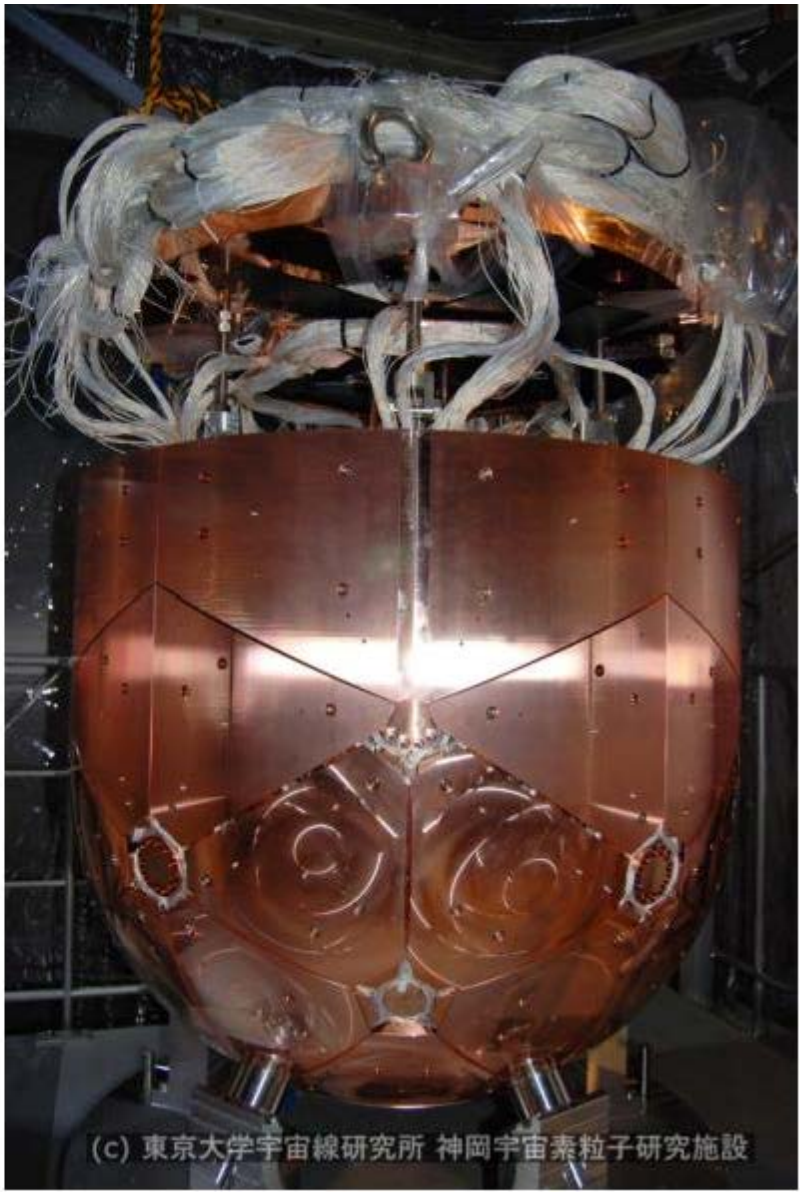







1e-4
1e-5
1e-6
1e-7
1e-8
events/day/keV/kg
recoil
129Xe γ
131Xe γ
0
20
40
60
80
100
Energy [keVee]




(c) 東京大学宇宙線研究所 神岡宇宙素粒子研究施設

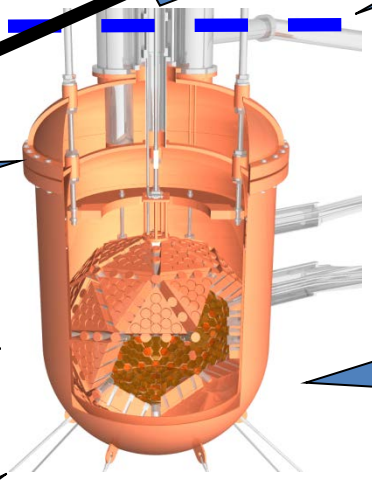
Xenon purification

Kr <1ppt
Distillation

H2O <1ppb(target)
baking
Molecular sieves
Getter
Xenon draining

Particle <mg/all(target)
Particle filter
Xenon draining

Radon
<1.2mBq/all(target)
Charcoal



Light absorption background
Target transparency >>m

N2,O2,CO2, CO etc
<1ppb(target)
MS, getter

H2 <0.16ppbw
Room temp.Getter

U/Th <10^{-14}g/g(target)
Getter
evaporation

RI background

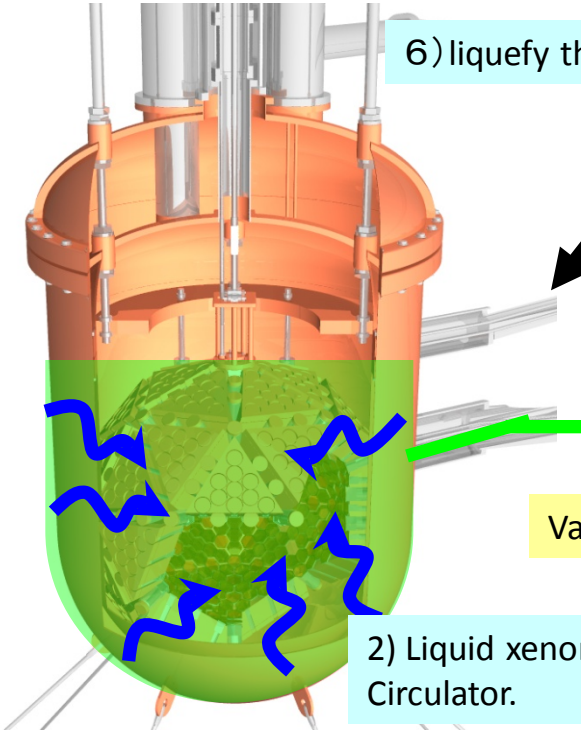
※device has been already worked

※All values are our target value

Detector cleaning : Drain the xenon from detector

10/24 & 10/31
Xenon filled in detector with 1136kg

10/19- & 10/26-
Start xenon filling from storage to detector
~9kg/hr



6）liquefy the xenon

5)Make gas and passing getter

getter

Xenon condence

Valve station

circulator

Liquid xenon storage tank

Filter housing

2F

2) Liquid xenon transfer using Circulator.

1）impurity take to xenon

3）take dust by all SUS particle filter

4）xenon collects to liq.xenon tank

10/25,2010 : liquid xenon was drained to storage ~300kg/hr

By this work, light yield increased about 16% (form 57Co source data)