The XMASS 800kg Experiment

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XMASS collaboration:

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Miyagi University of Education : Y. Fukuda

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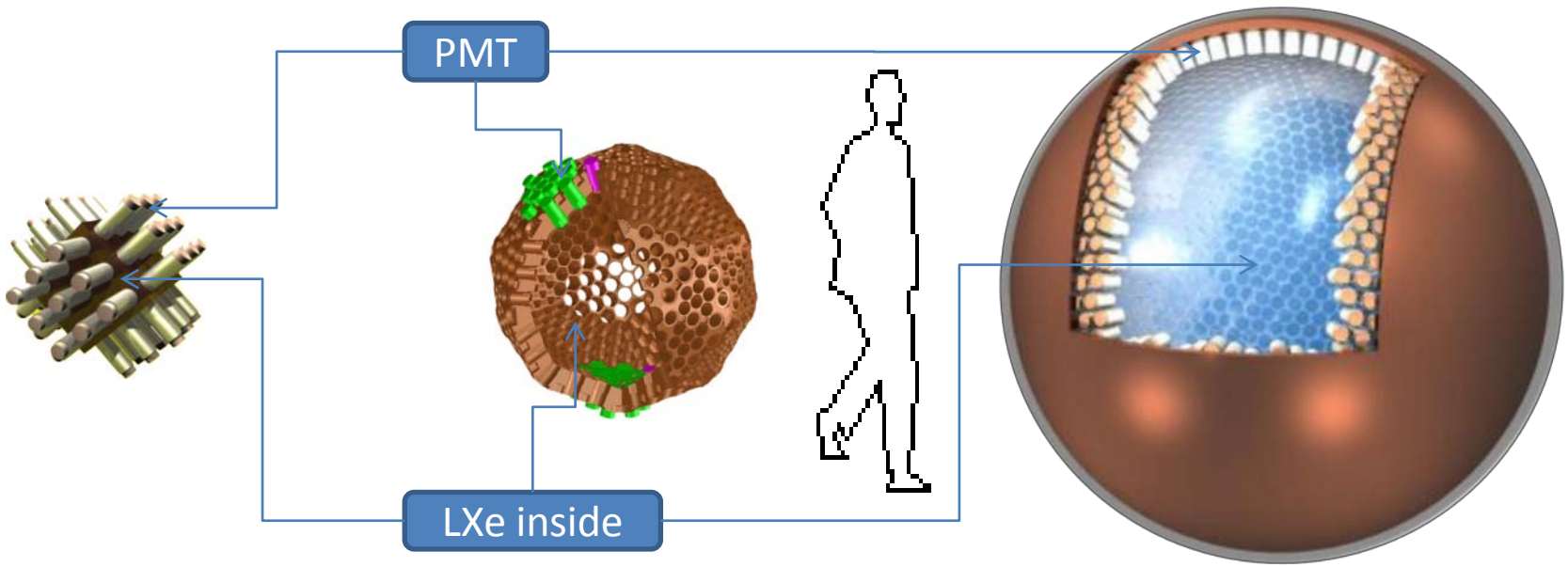
The XMASS Experiment

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

multi ton scale
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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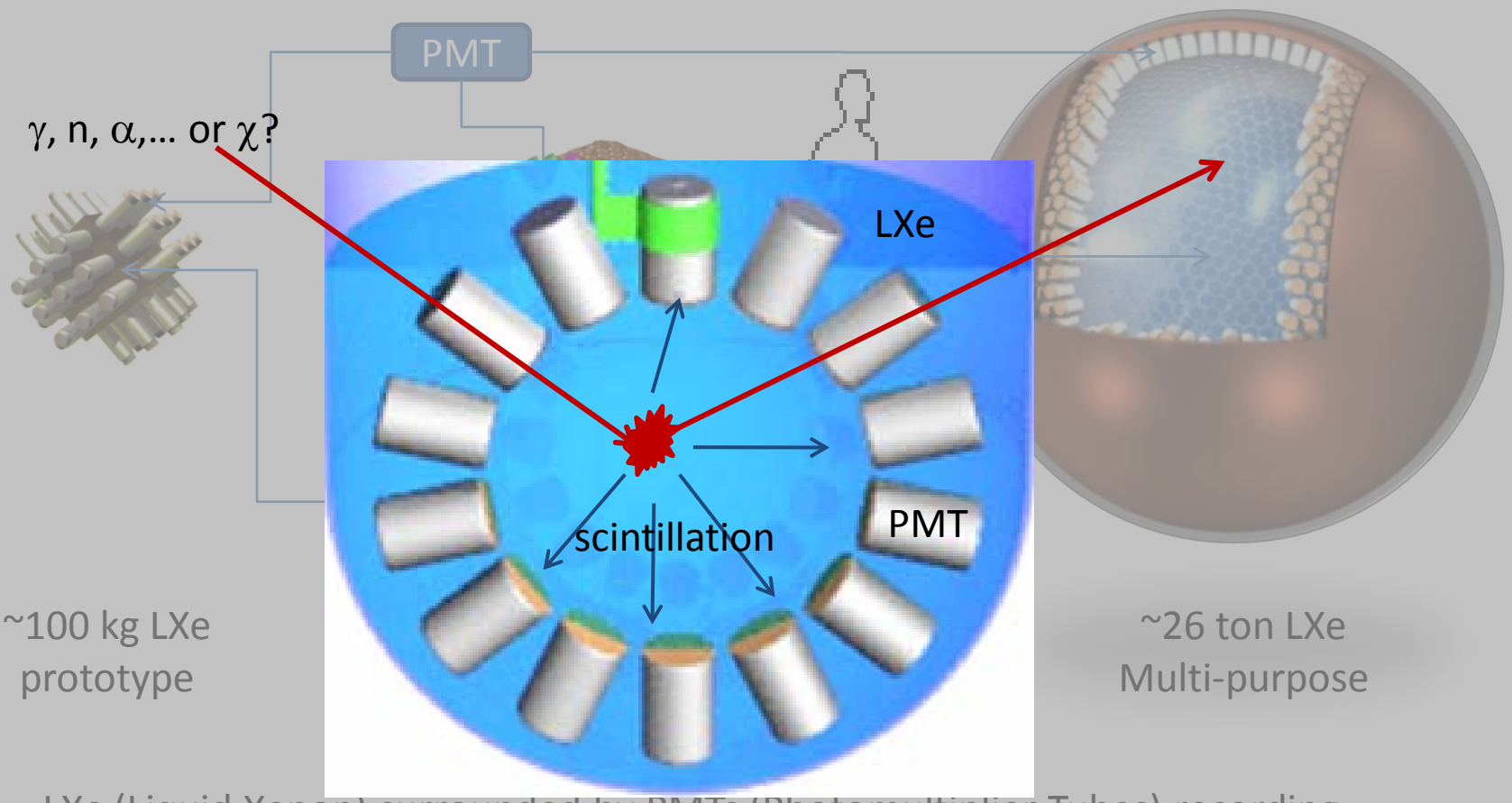

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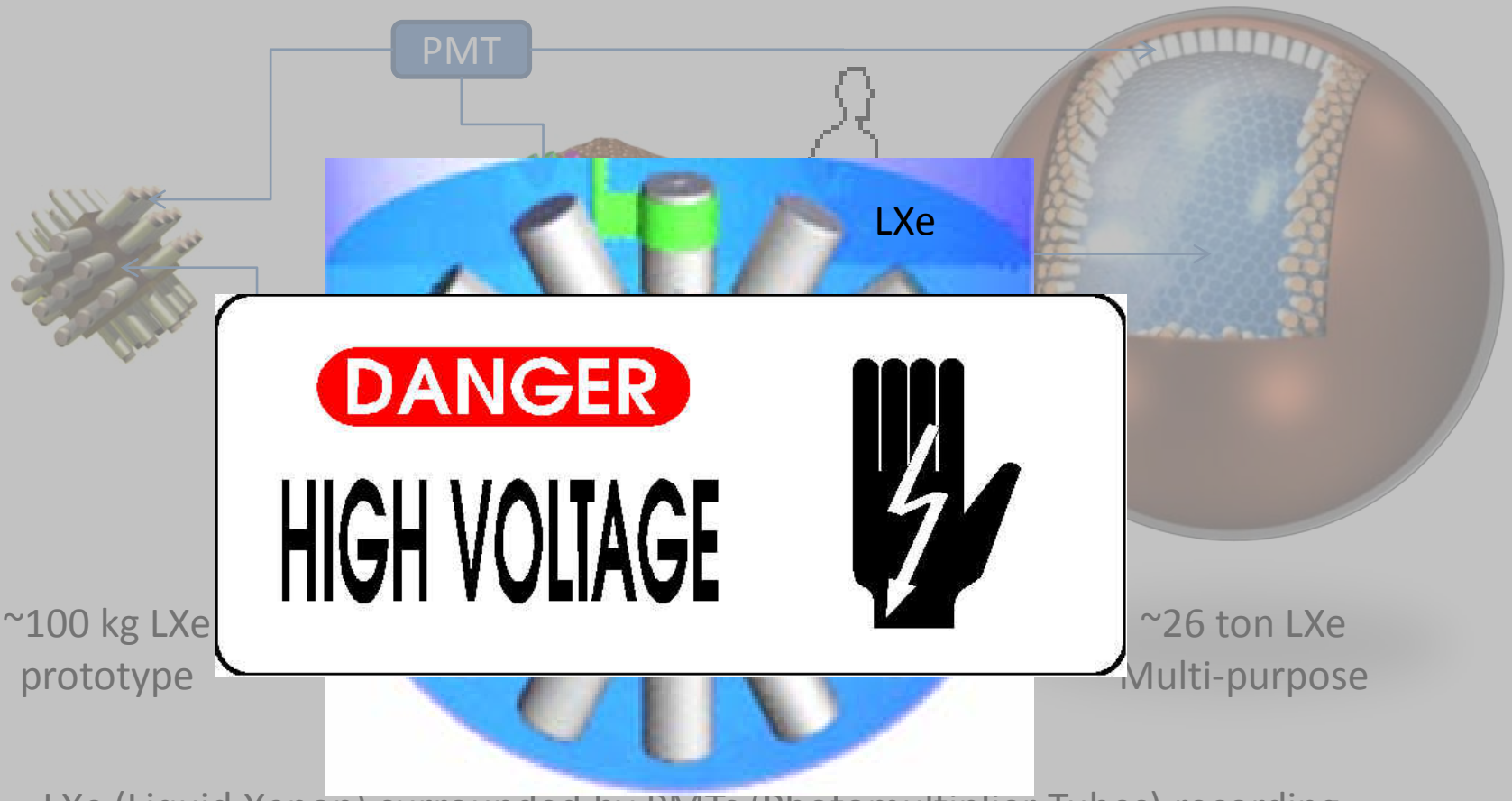

~100 kg LXe
prototype

~26 ton LXe
Multi-purpose

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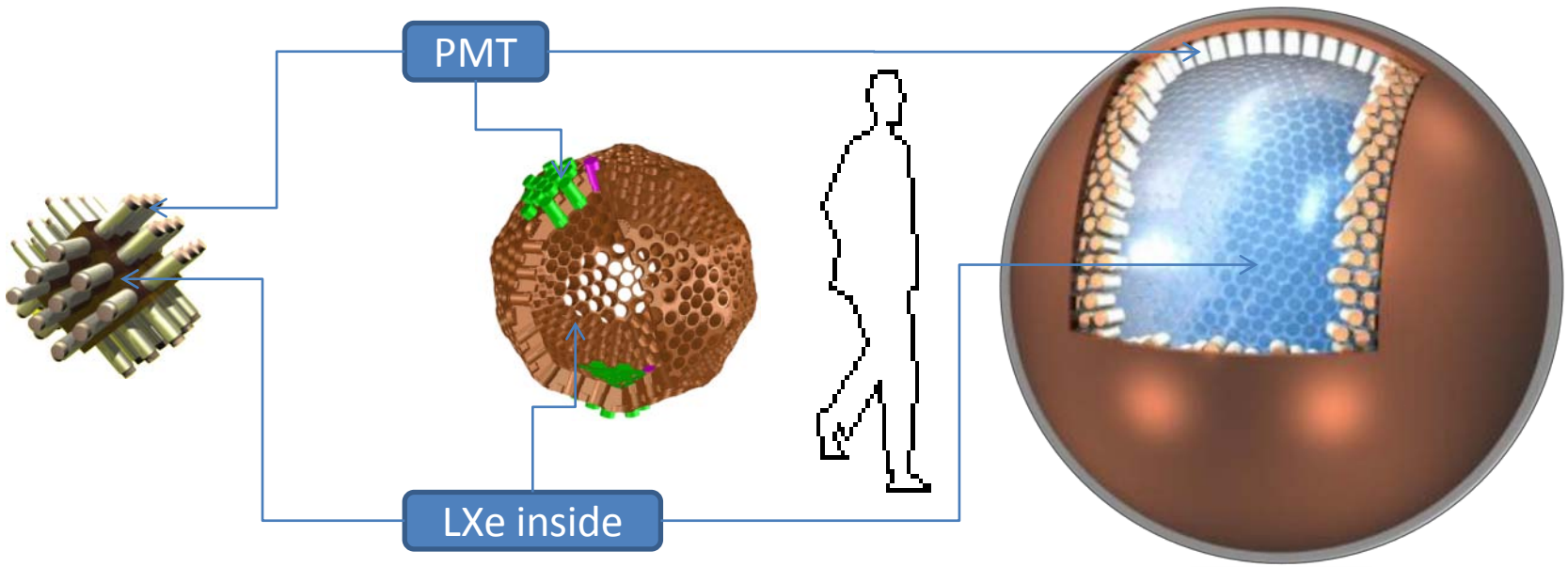

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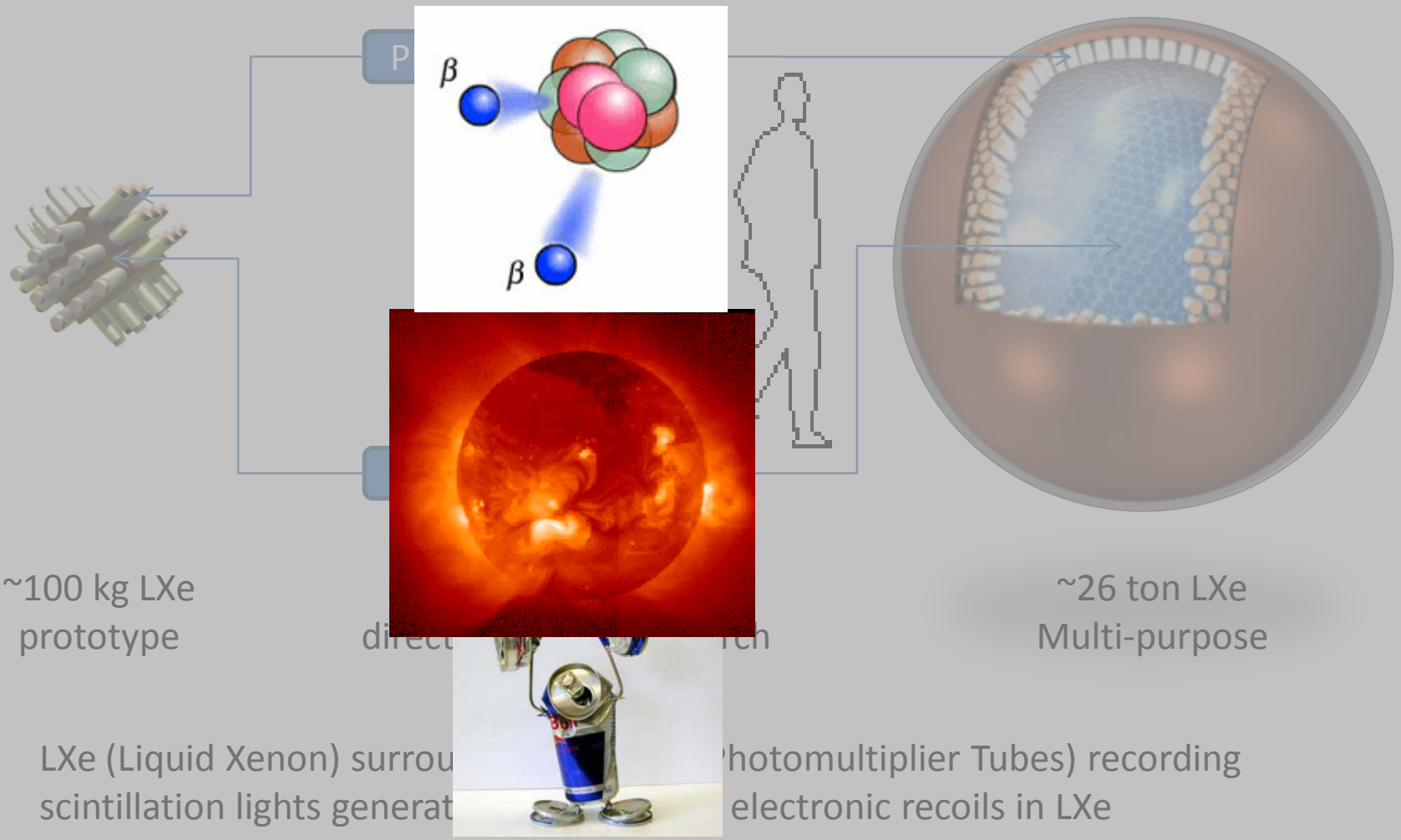

LXe (Liquid Xenon) surrou hotomultiplier Tubes) recording
scintillation lights generat electronic recoils in LXe

The XMASS Experiment

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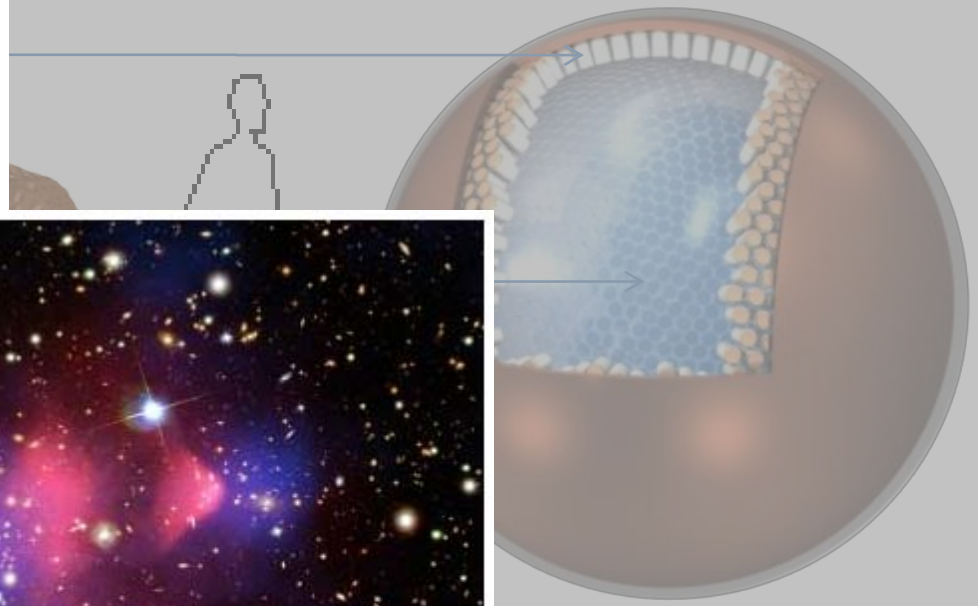

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prototype

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Multi-purpose

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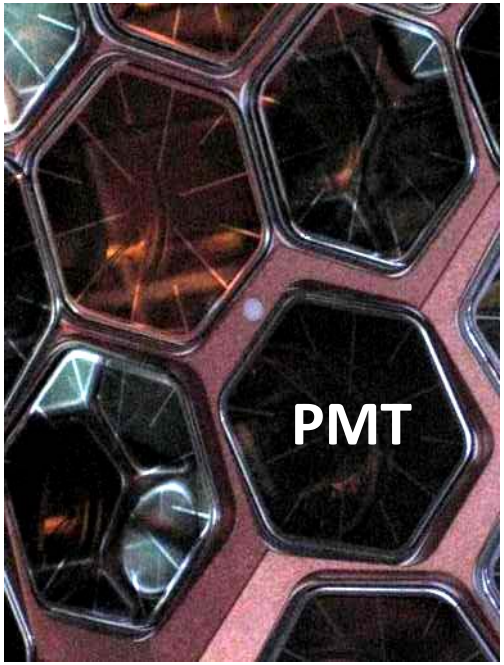
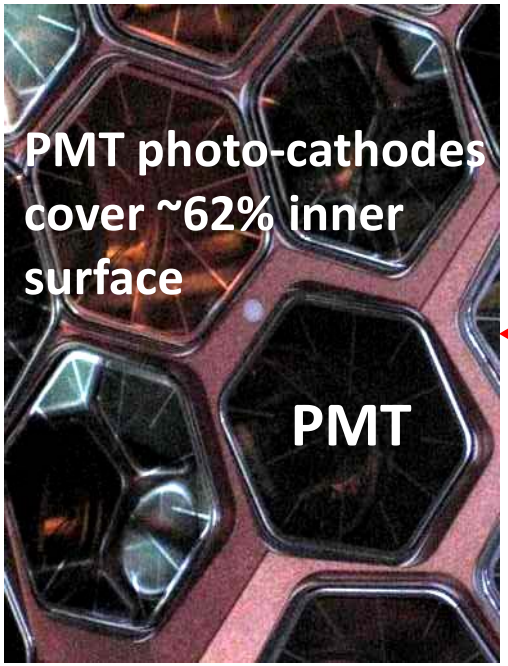
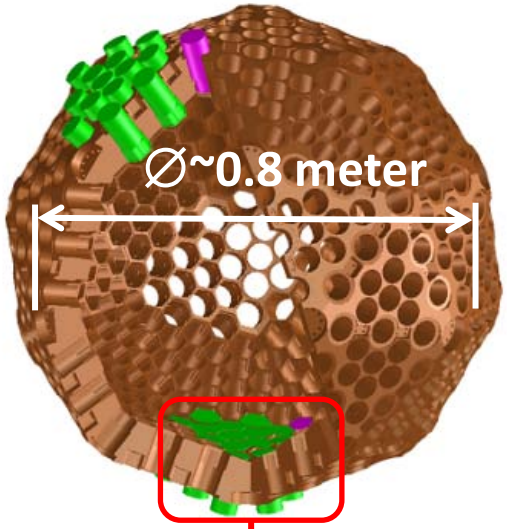
Detector

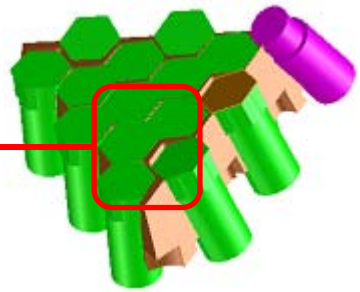
Structure of XMASS 800kg detector



Structure of XMASS 800kg detector





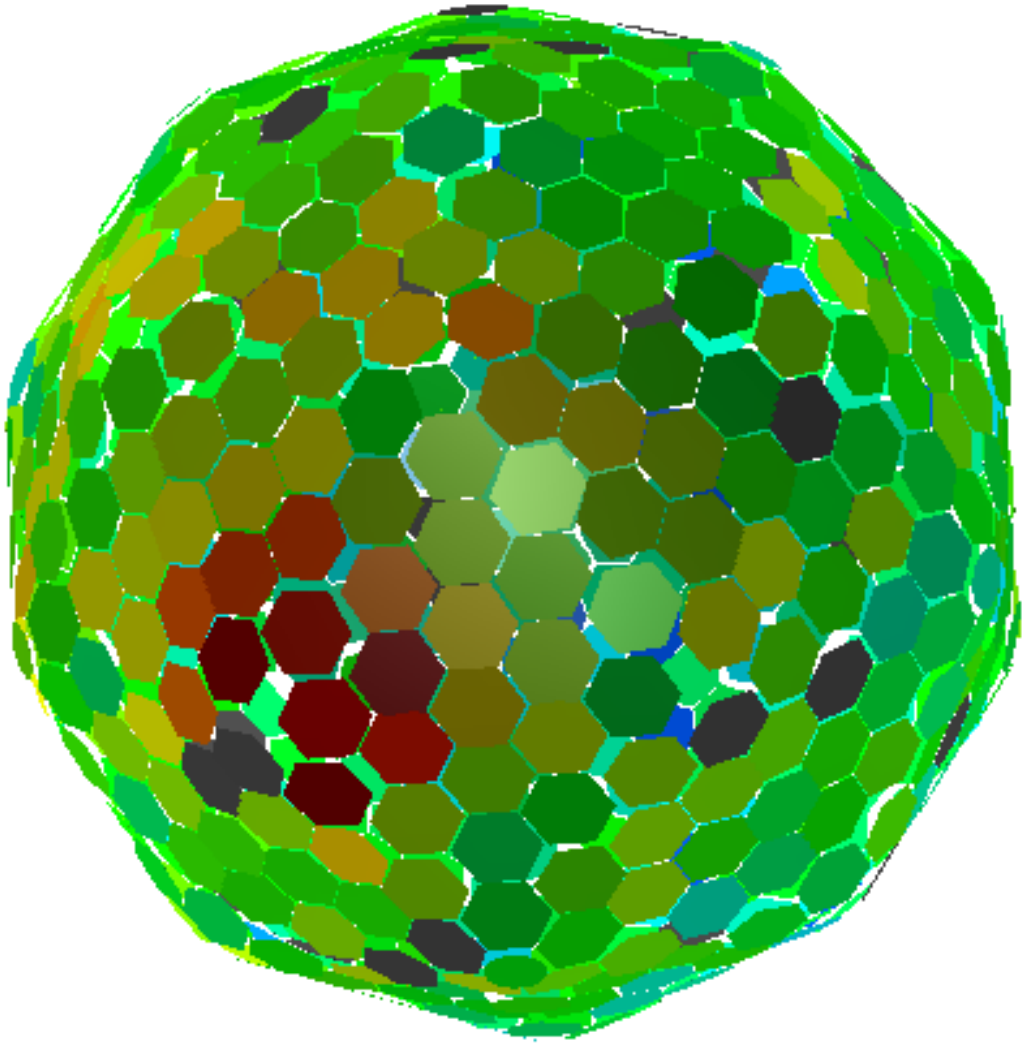


~10 PMTs in one triangle
642 PMTs in total

Reconstruct interaction point from PMT hit pattern

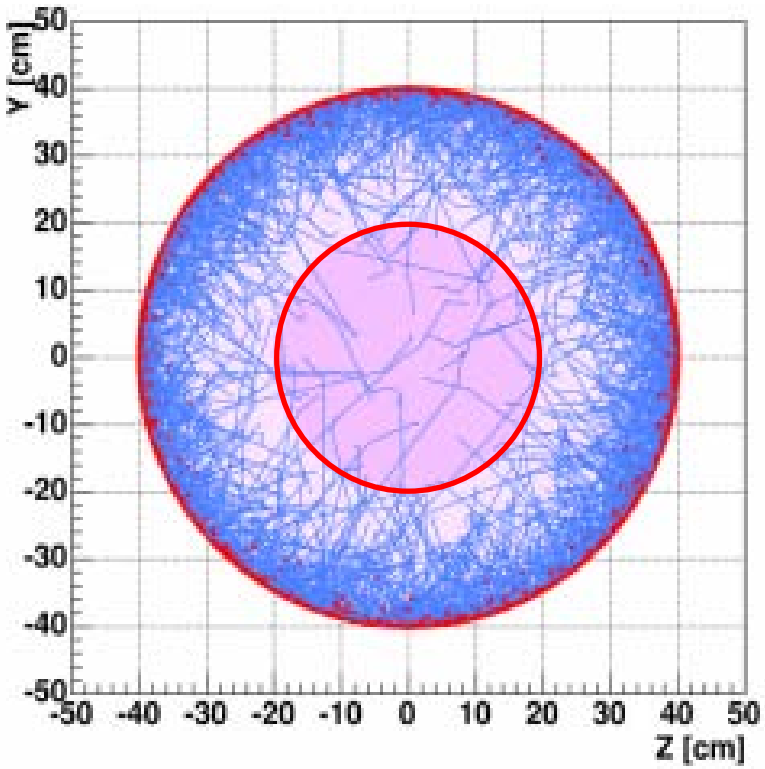
Colored photo cathodes indicating number of p.e. (photoelectrons) recorded by PMTs

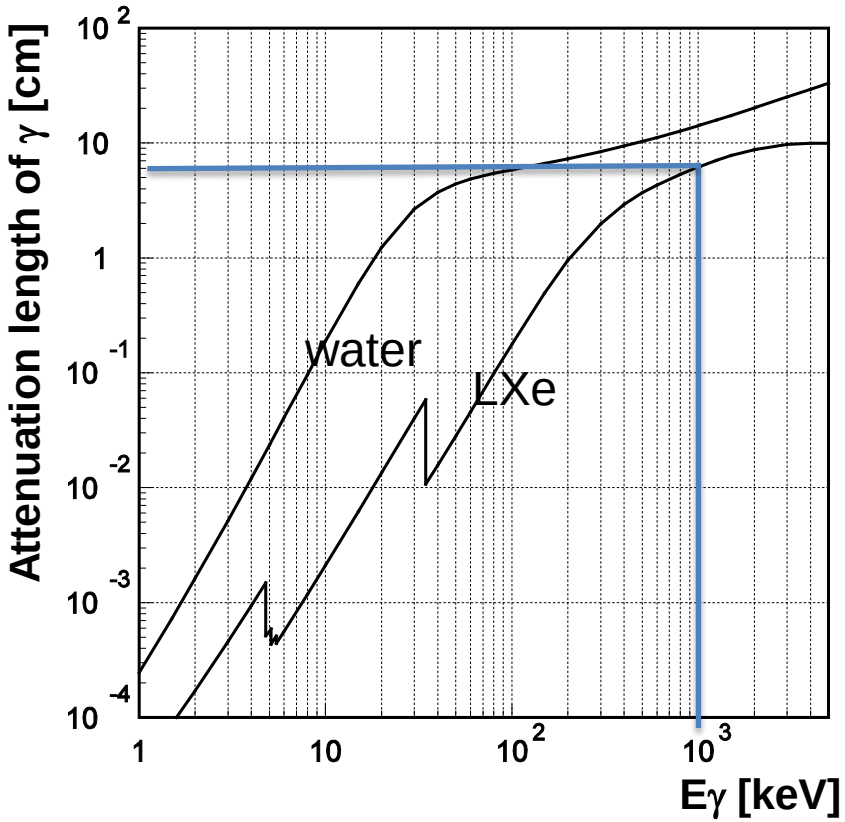
Interaction point (vertex) can be reconstructed from the PMT hit pattern.



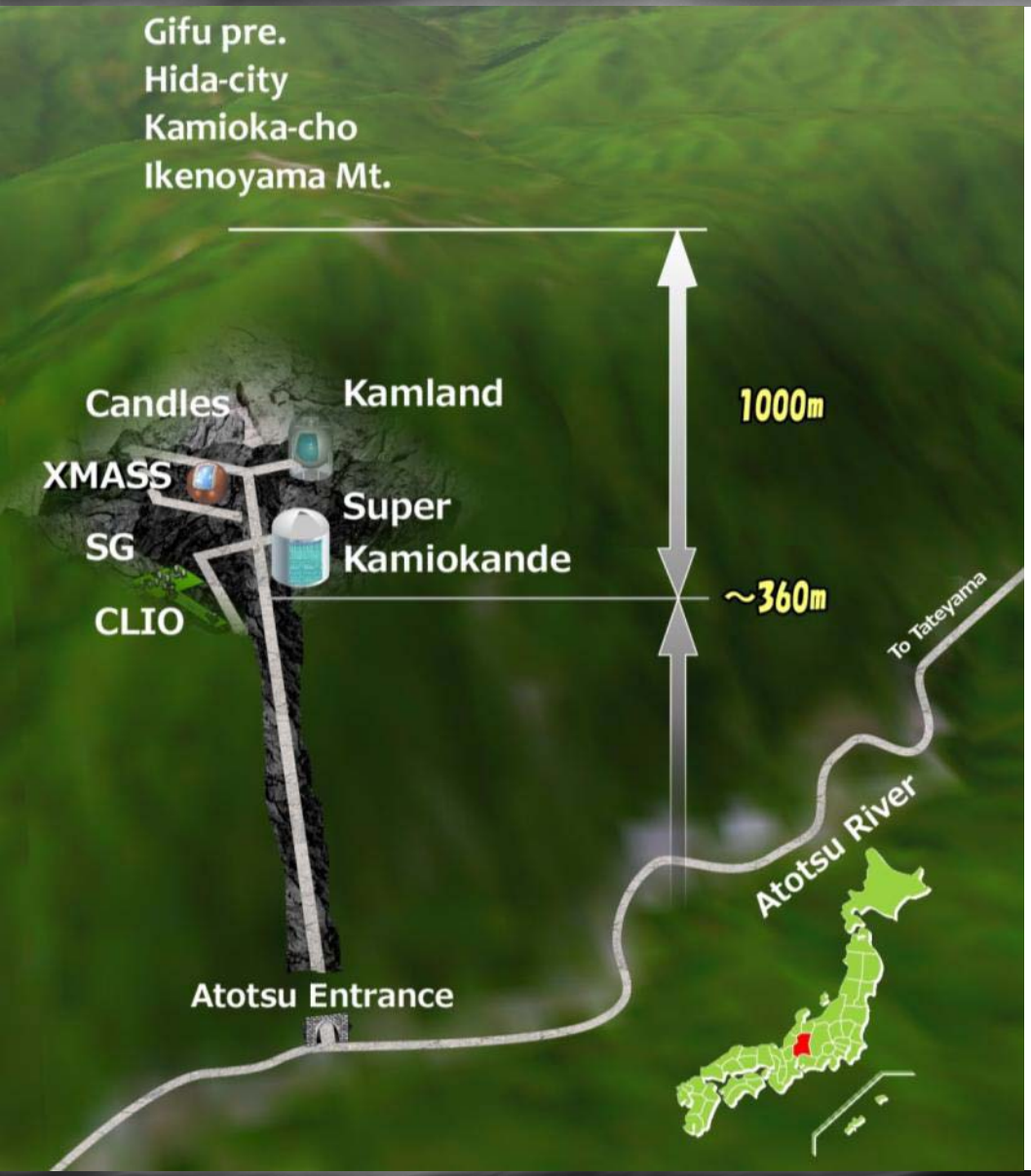
LXe self-shielding

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

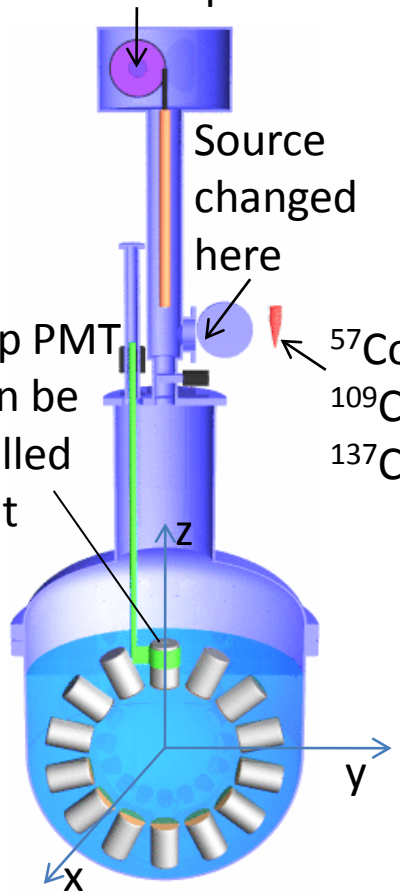
Horizontal access:
15 minutes drive from office, too easy to get in!
No excuse to avoid 24-hour shift ☹


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

Scintillation light yield :: calibration system

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



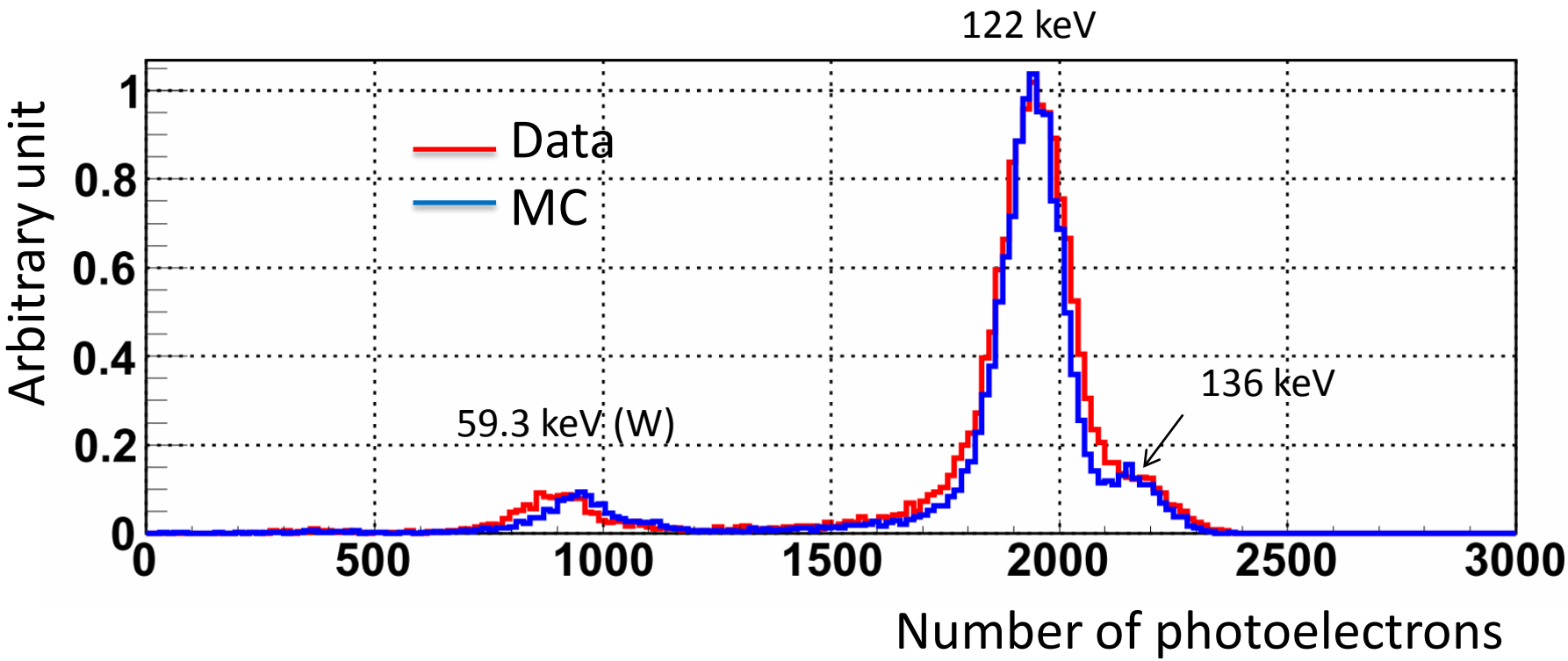
^{57}Co, ^{241}Am, ^{109}Cd, ^{55}Fe, ^{137}Cs

Φ~4mm

Φ~0.15mm for ^{57}Co

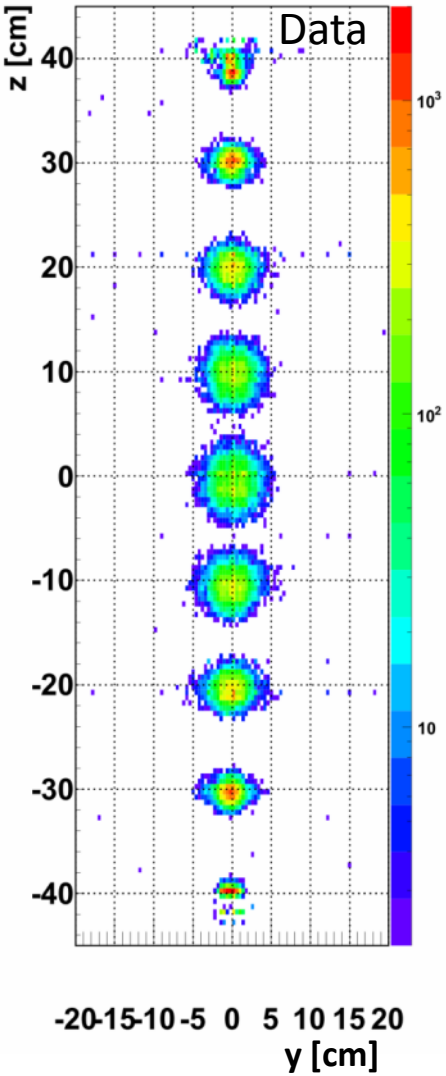
Scintillation light yield: 14.7 ± 1.2 p.e./keV (^{57}Co at center)

~ 2 p.e./keV in XENON100



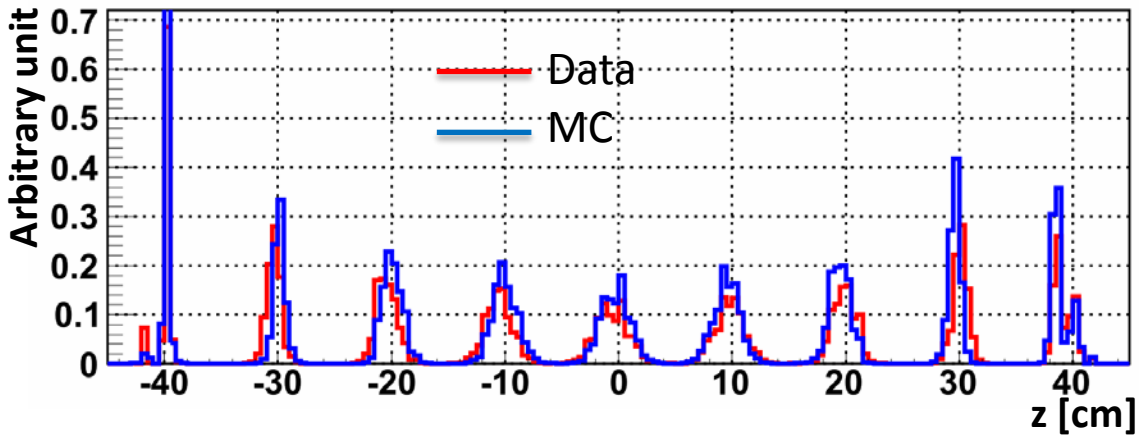
Position & energy resolution (122keV γ from ^{57}Co)

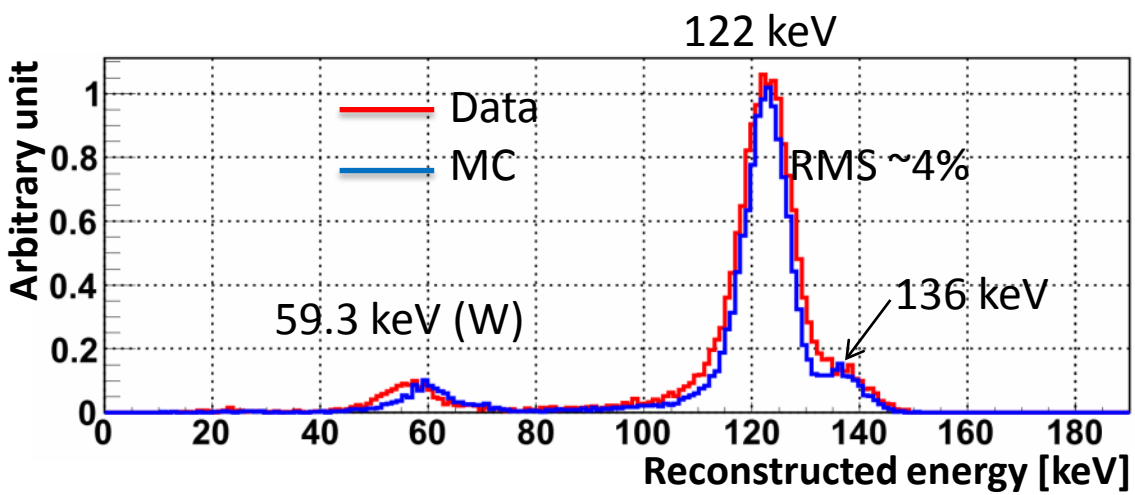
Reconstructed vertices for various source positions



Position resolution (RMS):

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



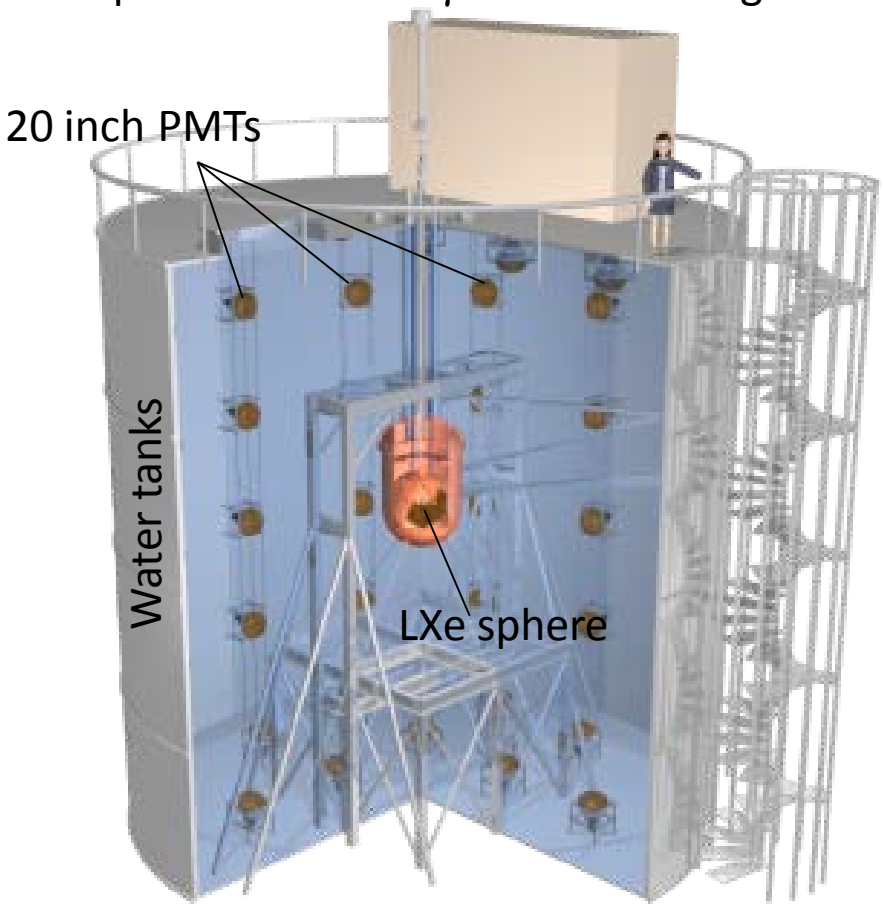


Background

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

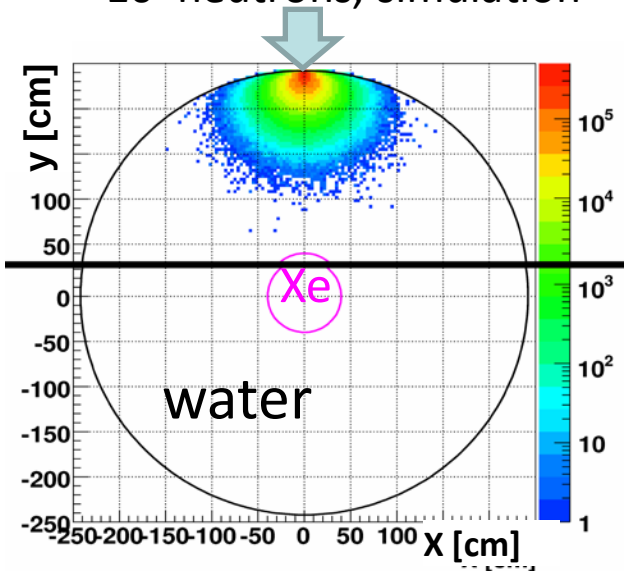
Pure water tank (large enough for multi ton LXe) equipped with 20 inch PMTs on the wall as

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

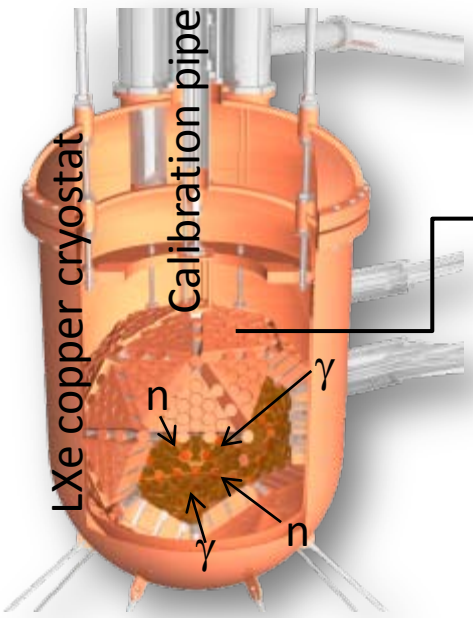


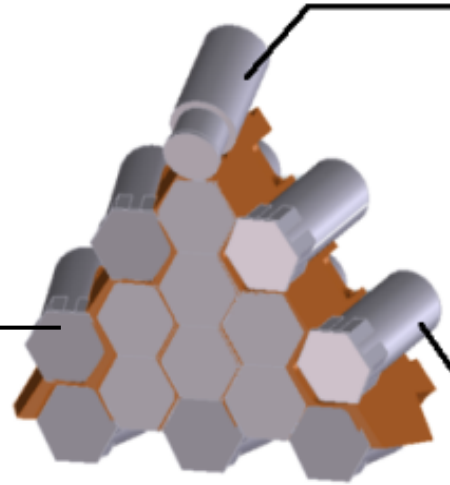
$\gamma \ll \gamma$ from PMT, $n \ll 10^{-4}$/d/kg

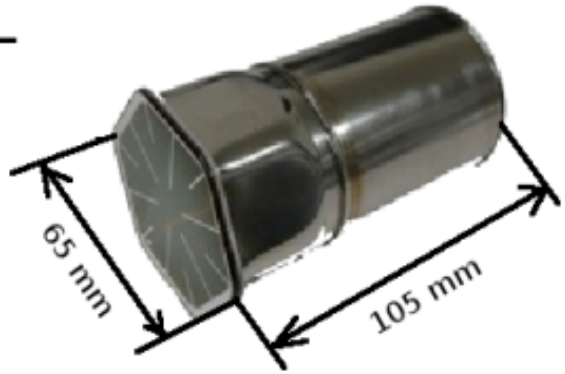
10^7 neutrons, simulation



PMT radiation: Ultra low background PMTs





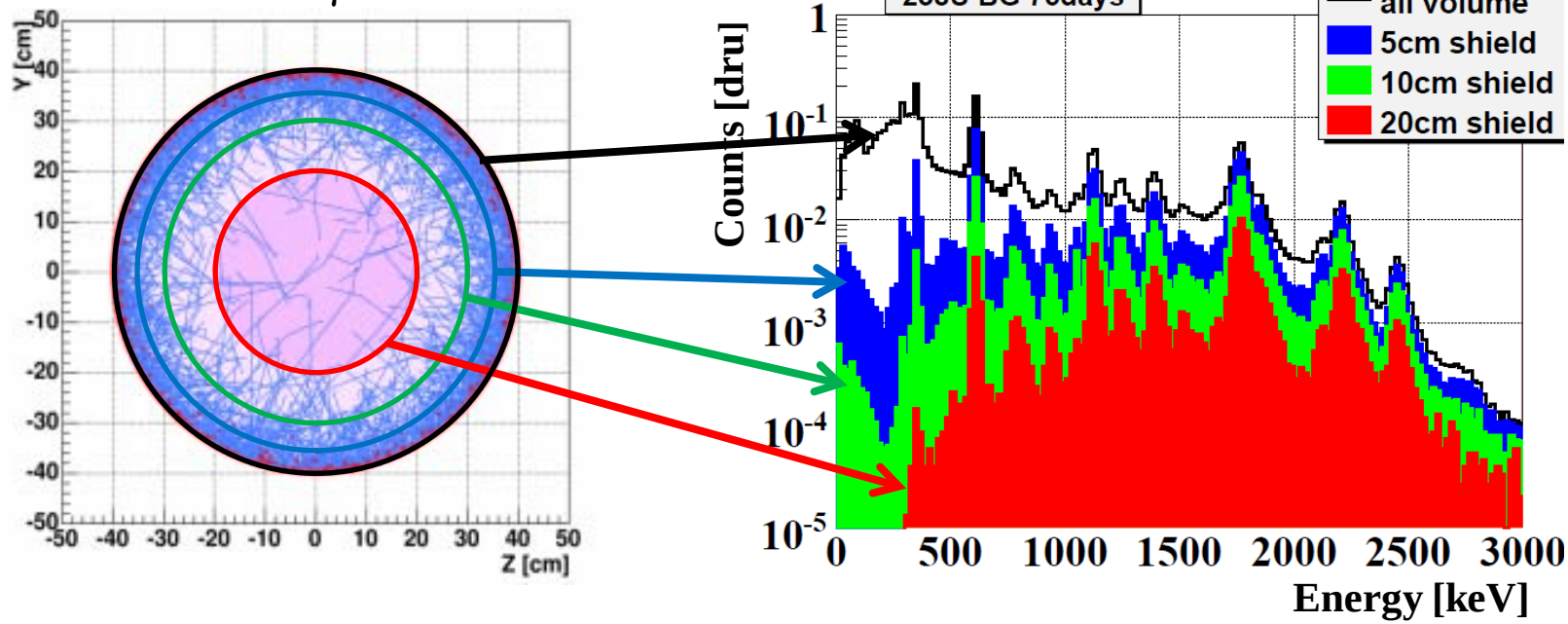


PMT

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

Simulation: γ into LXe



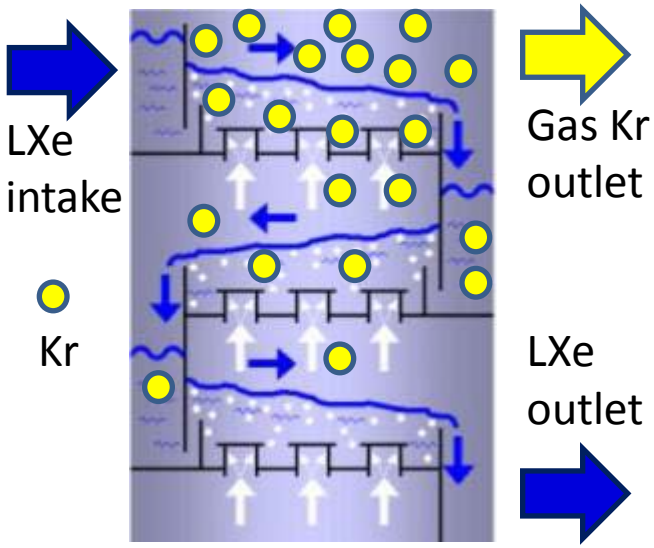
	BG/PMT [mBq]
U chain	0.70 ± 0.28
Th chain	1.51 ± 0.31
^{40}K	< 5.10
^{60}Co	2.92 ± 0.16

fiducial volume: r<20cm, 100 kg LXe

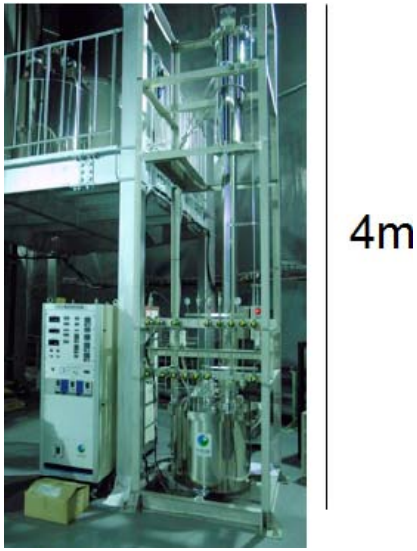
^{85}Kr (Q_β=687keV) : distillation

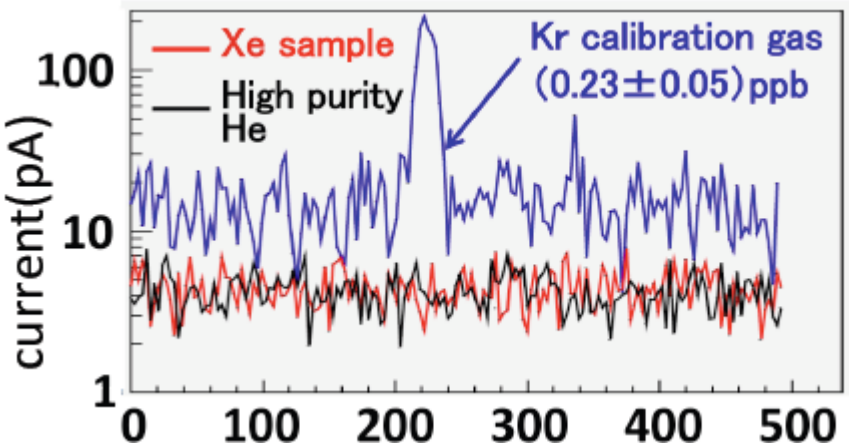
K. Abe *et al*. for XMASS collab., Astropart. Phys. 31 (2009) 290

Kr can be boiled out from LXe



0.1 ppm → ~1ppt (~1 ton in 10 days)





API-MS

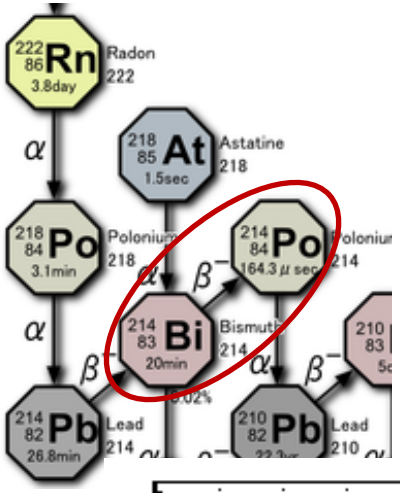
Kr concentration:
< 2.7 ppt (90% C.L.)
(Goal: 2 ppt)

^{222}Rn

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

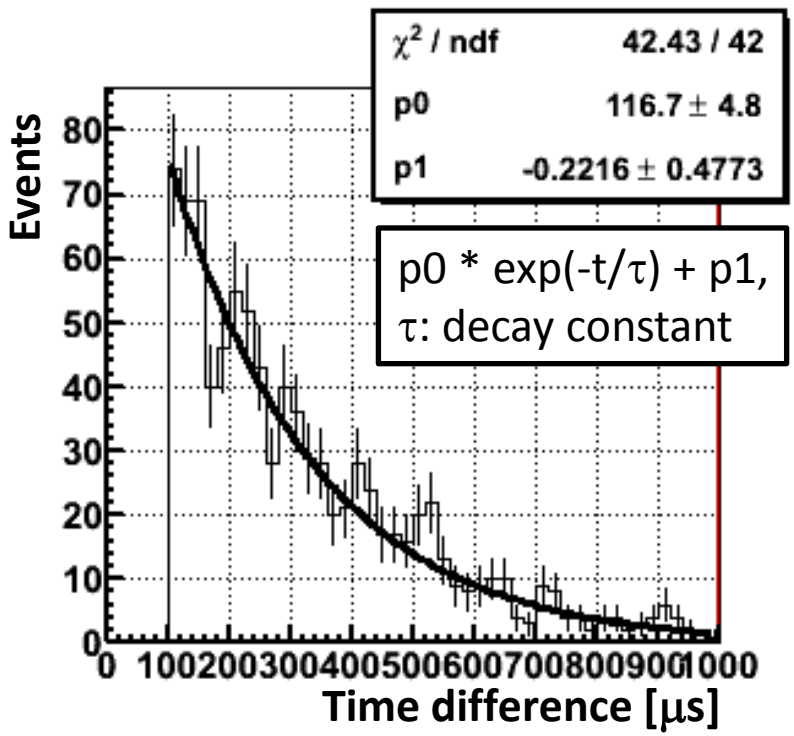
It can be identified by time coincidence between two consecutive events:

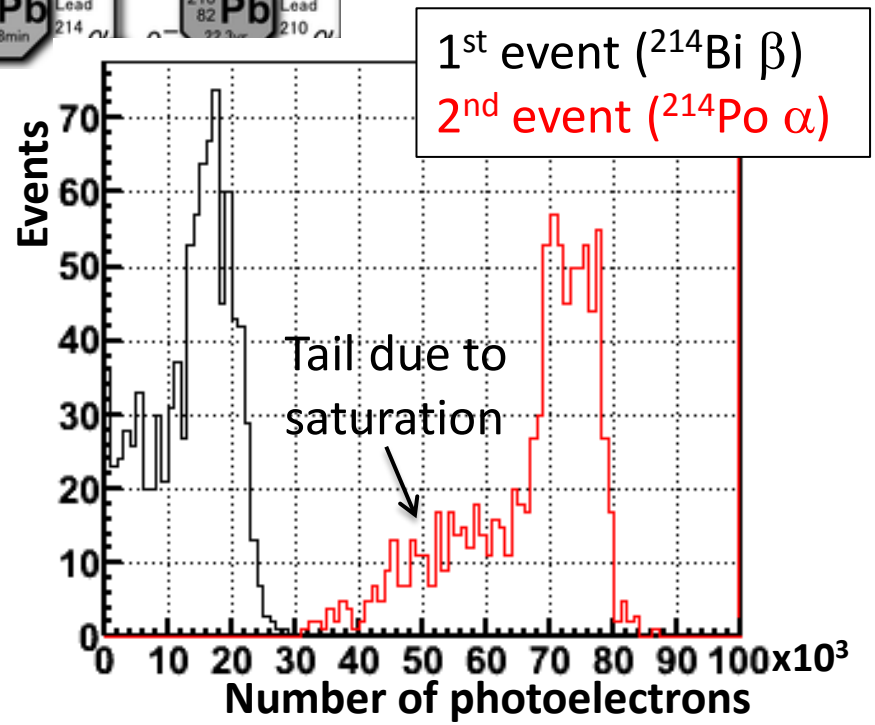
1. ^{214}Bi β decays into ^{214}Po
2. ^{214}Po α decays into ^{210}Pb



EXO200: 4.5 μBq/kg

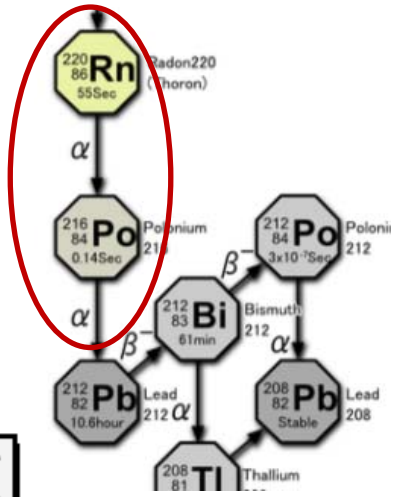
8.2±0.5 μBq/kg



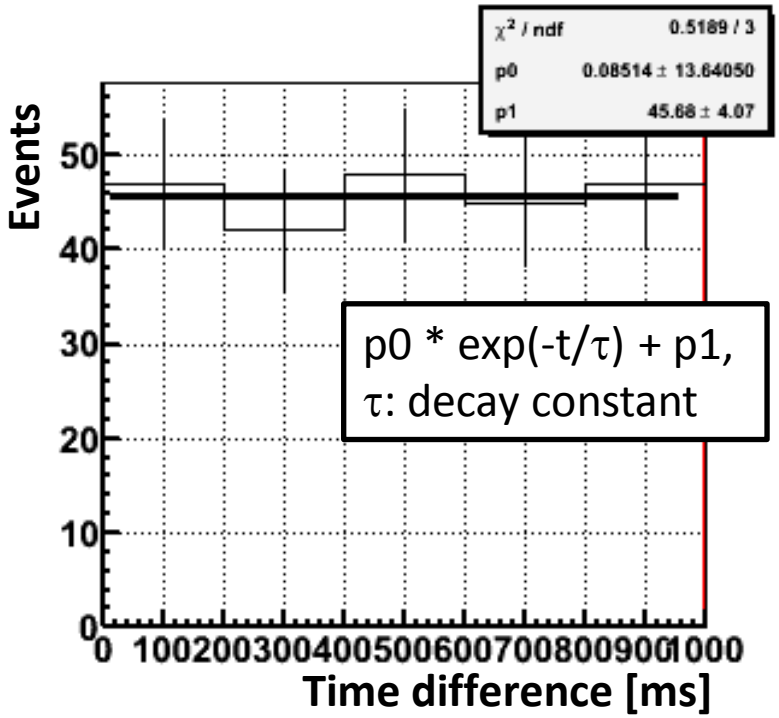


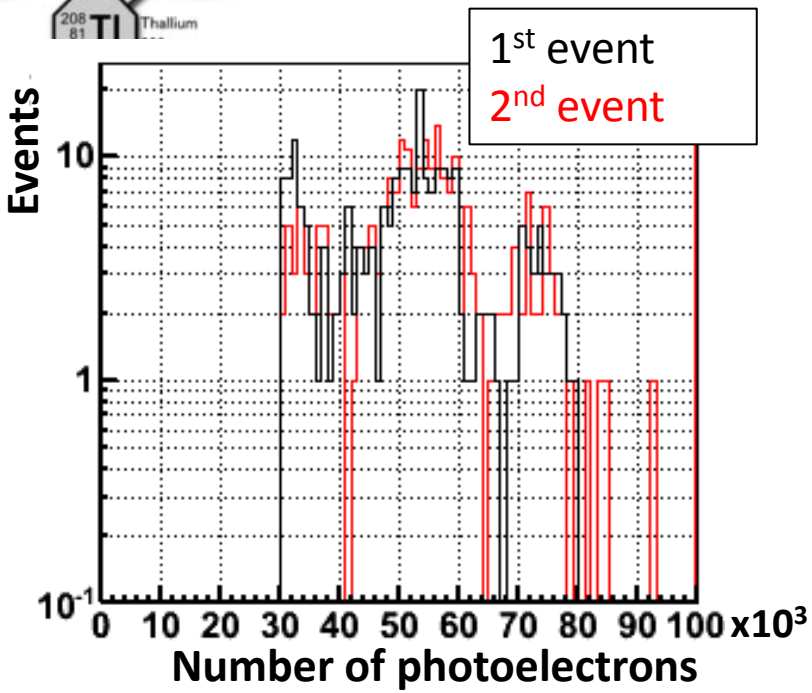
^{220}Rn

^{216}Po decays with
140 ms half life



<0.28 μBq/kg (90%C.L.)



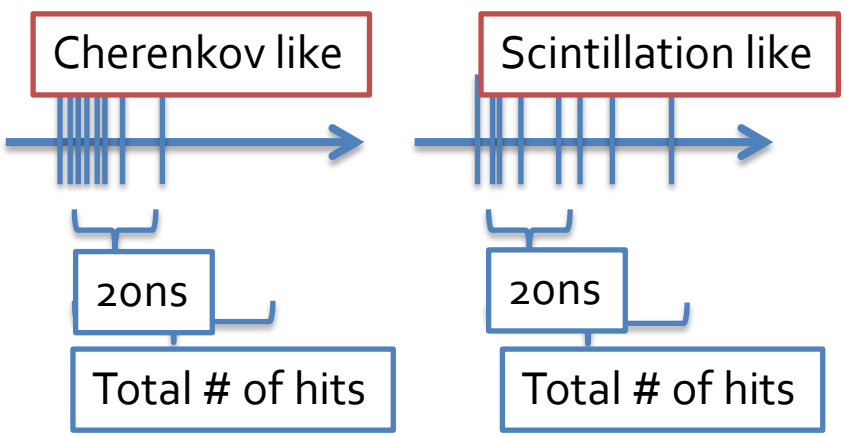


Cherenkov light from PMT window

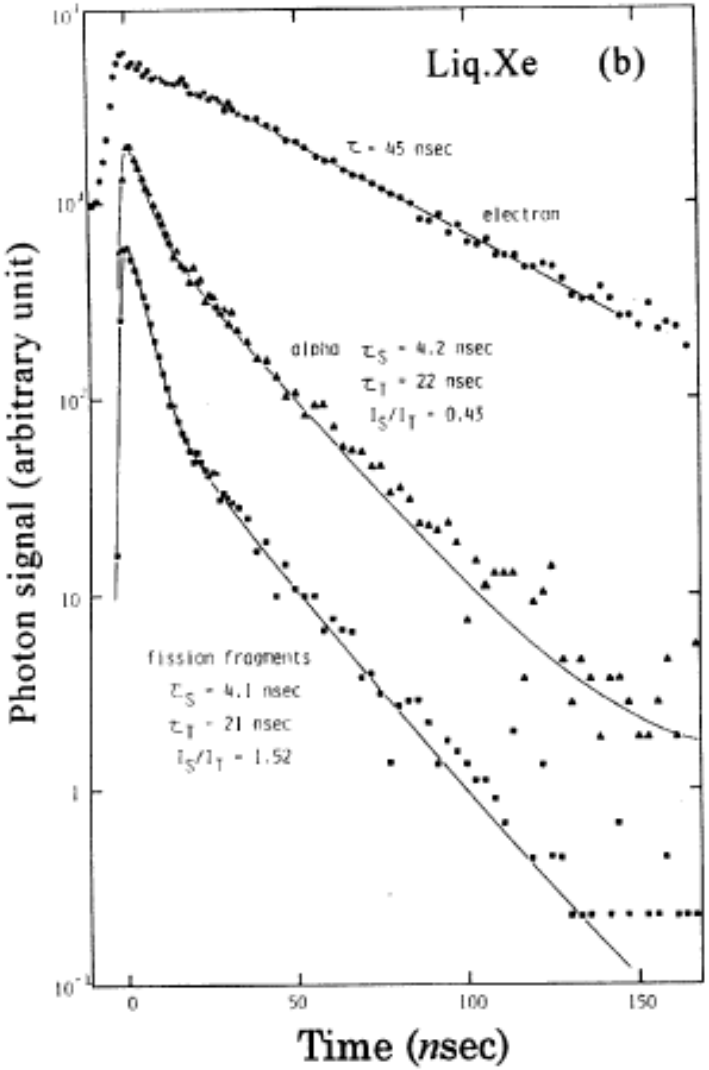
Electrons from ^{40}K in a PMT photo cathode create Cherenkov lights in PMT window
--- a major background at low energy

head-to-total ratio ≡
(# of hits in 1st 20ns window) / (total # of hits)

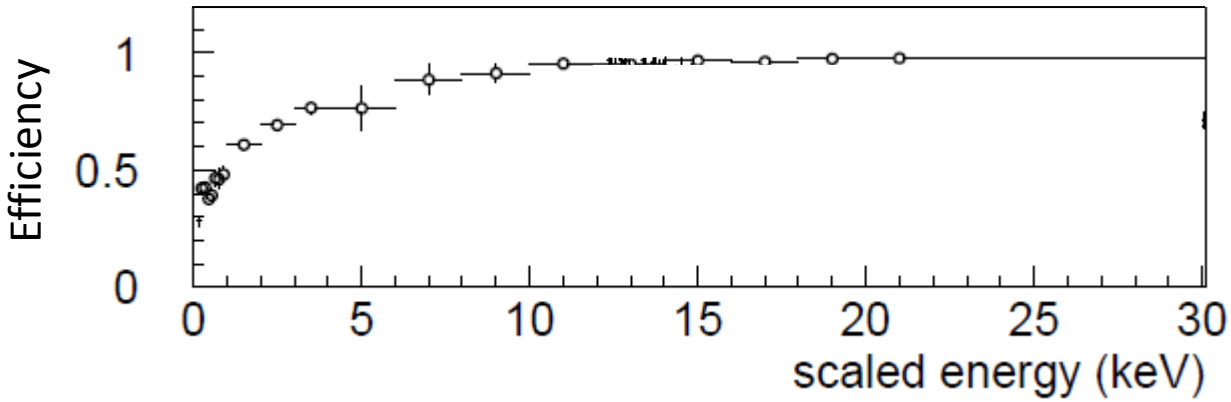
is used to reject Cherenkov events



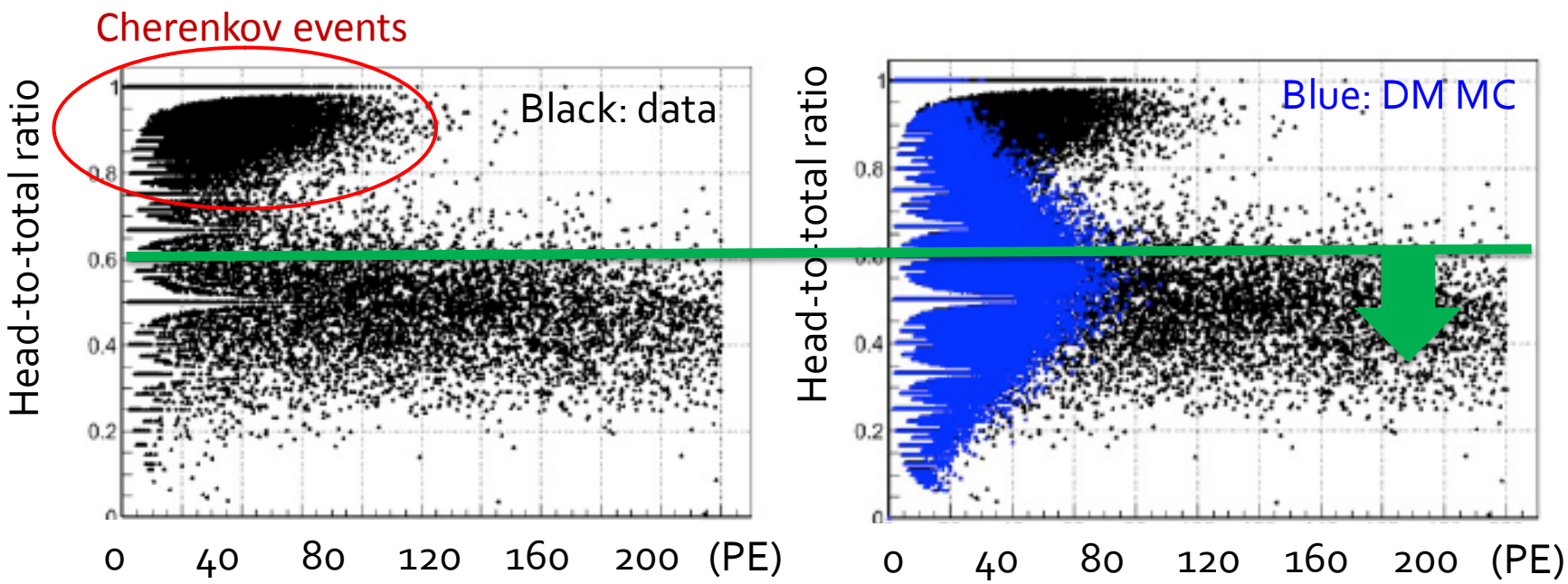
A. Hitachi et al., Phys. Rev. B 27 (1983) 5279.



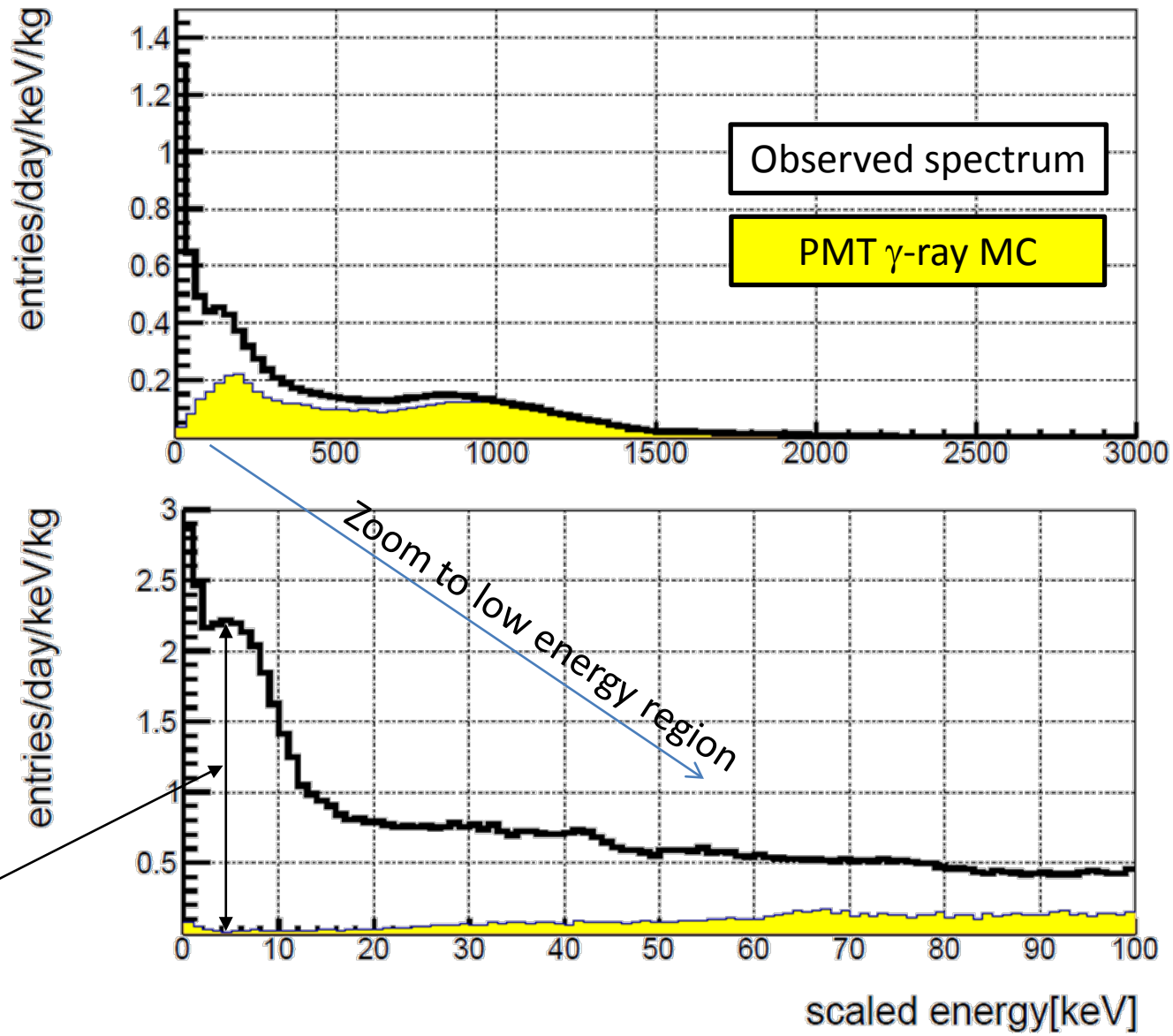
Cherenkov cut and efficiency



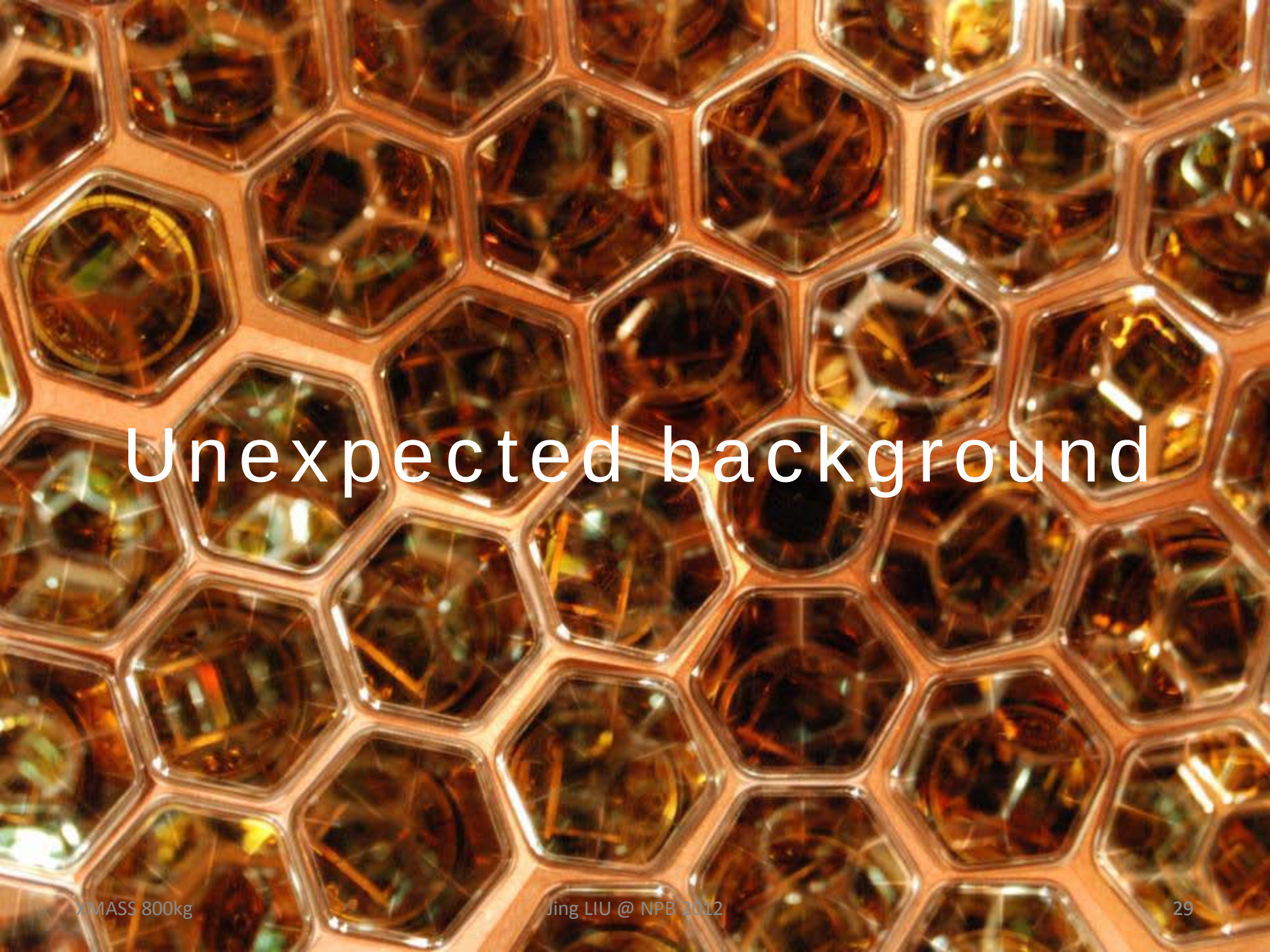
Low energy events from Fe55 calibration data show similar distribution as DM MC



Measured Spectrum after cleanup



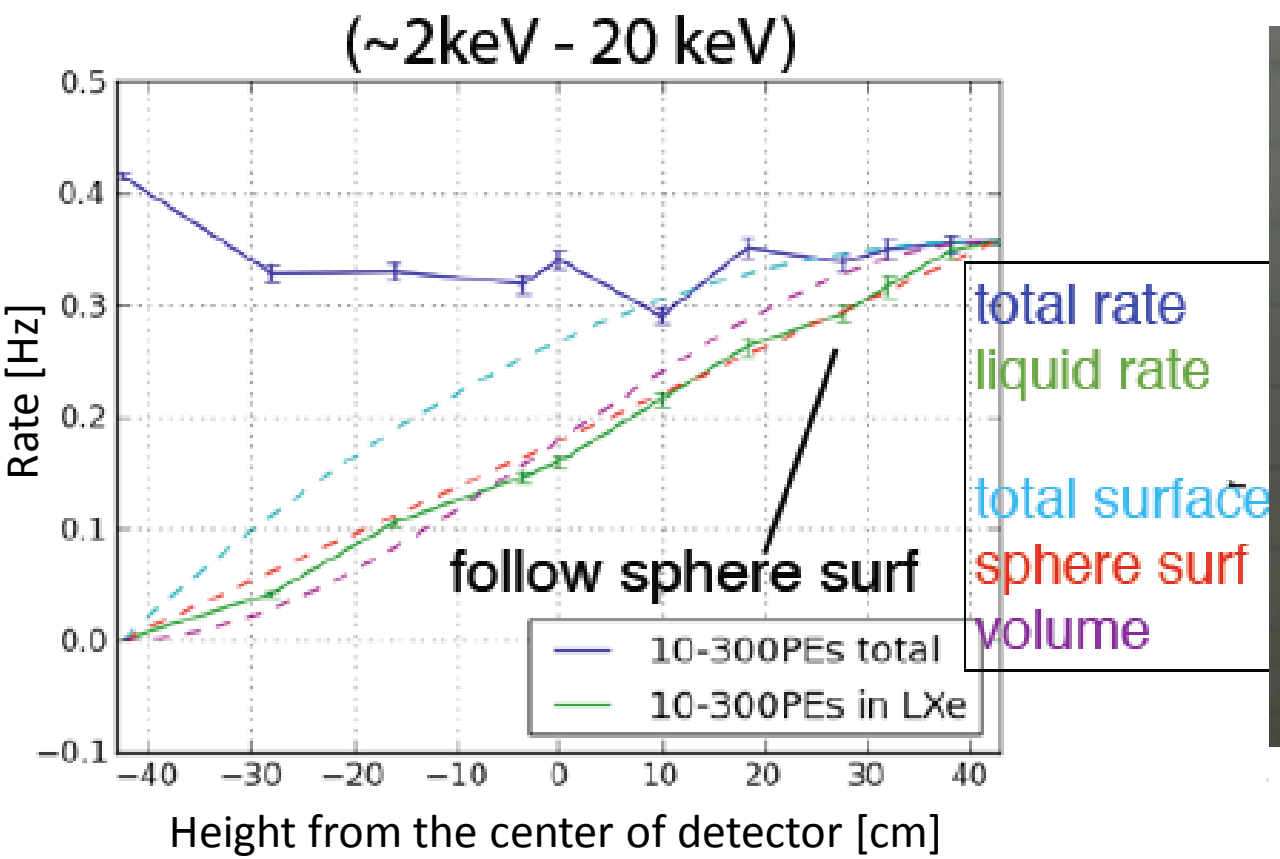
Background ~100 times higher than expectation

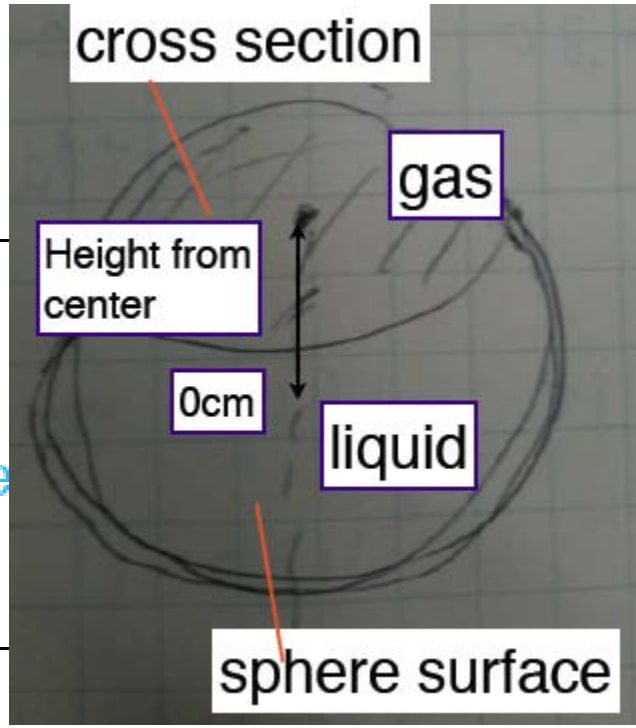


Unexpected background

External or internal?

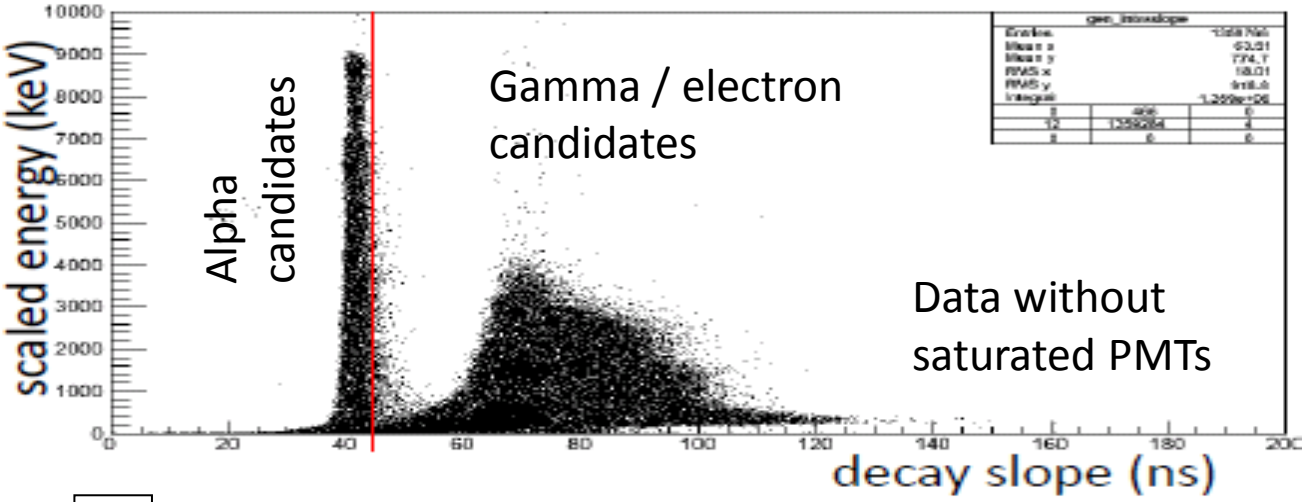
Taking data when lowering down the liquid xenon level



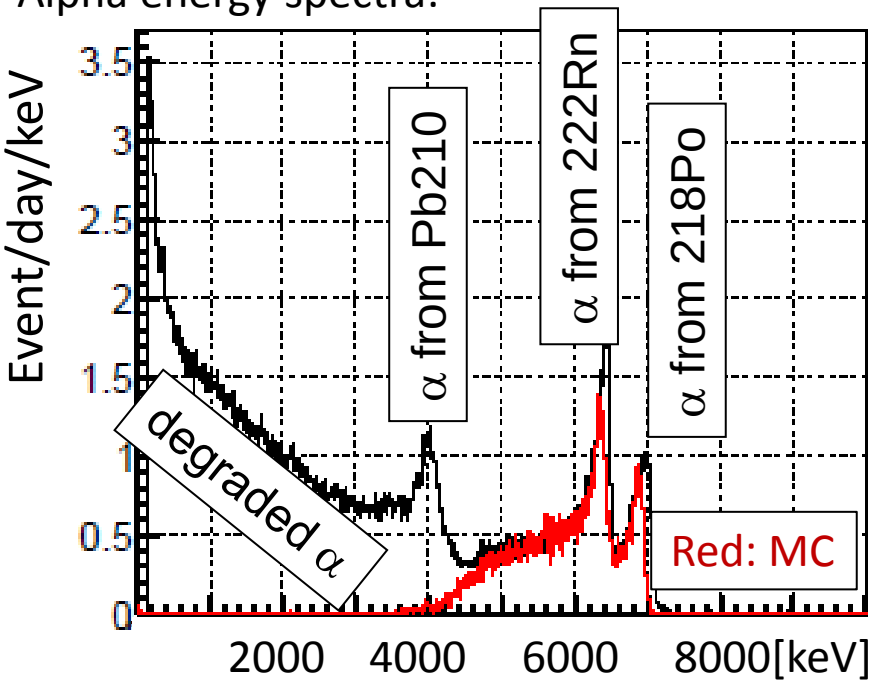


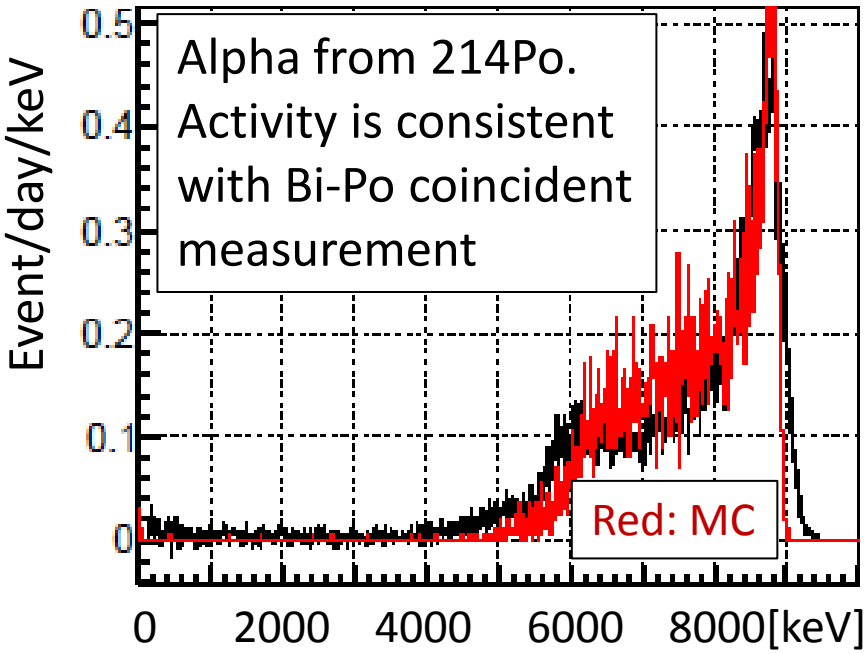
Particle identification

Data taken with ~50 channels of FADC allow us to fit the pulse shape to get the scintillation decay time



Alpha energy spectra:

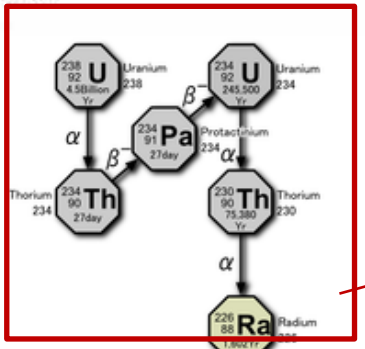




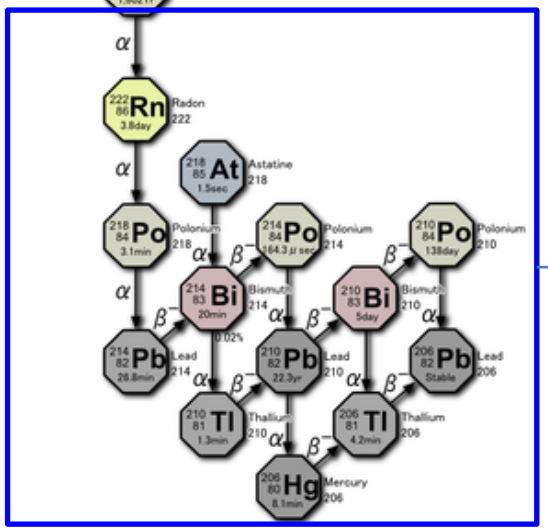
Hint from a low background workshop in SNOLAB

TABLE 3. Radioactivity levels in materials from direct γ-ray counting using the SNOLAB

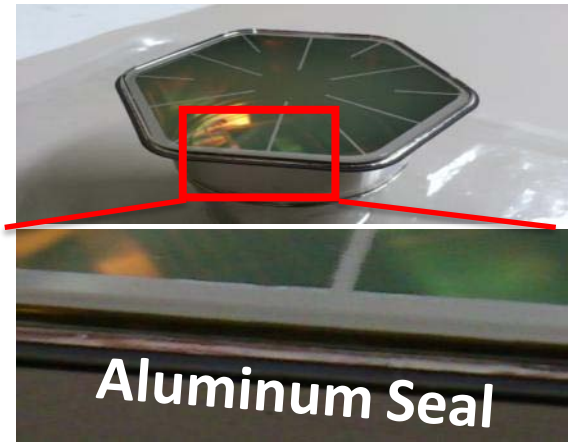
Sample Identifier	Manufacturer If Known	^{238}U via ^{226}Ra (mBq/kg)	^{238}U via ^{234m}Pa (mBq/kg)	^{235}U (mBq/kg)
Aluminium	Canada	42.17 ± 7.69	9408.4 ± 719.62	518.22 ± 30.96
Aluminium	Canada	7.07 ± 2.44	10826.09 ± 850.19	514.89 ± 41.97



high background from upper stream of U238



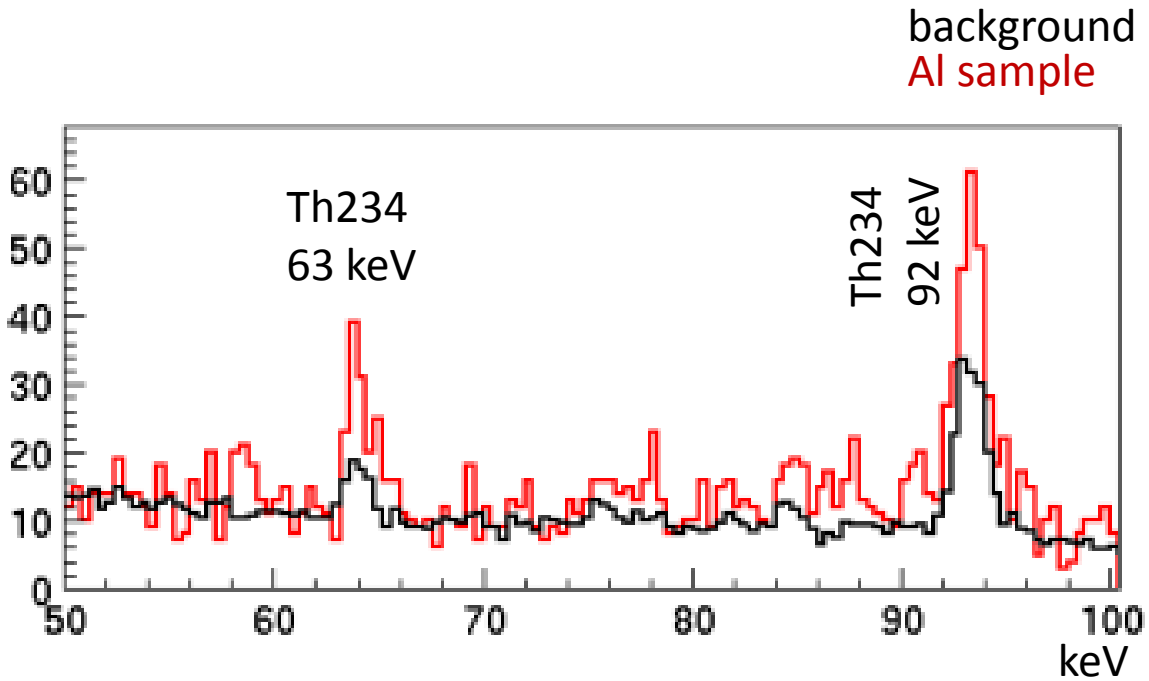
Low background from down stream (after Ra226) of U238 Chain



Re-measurement of aluminum activity

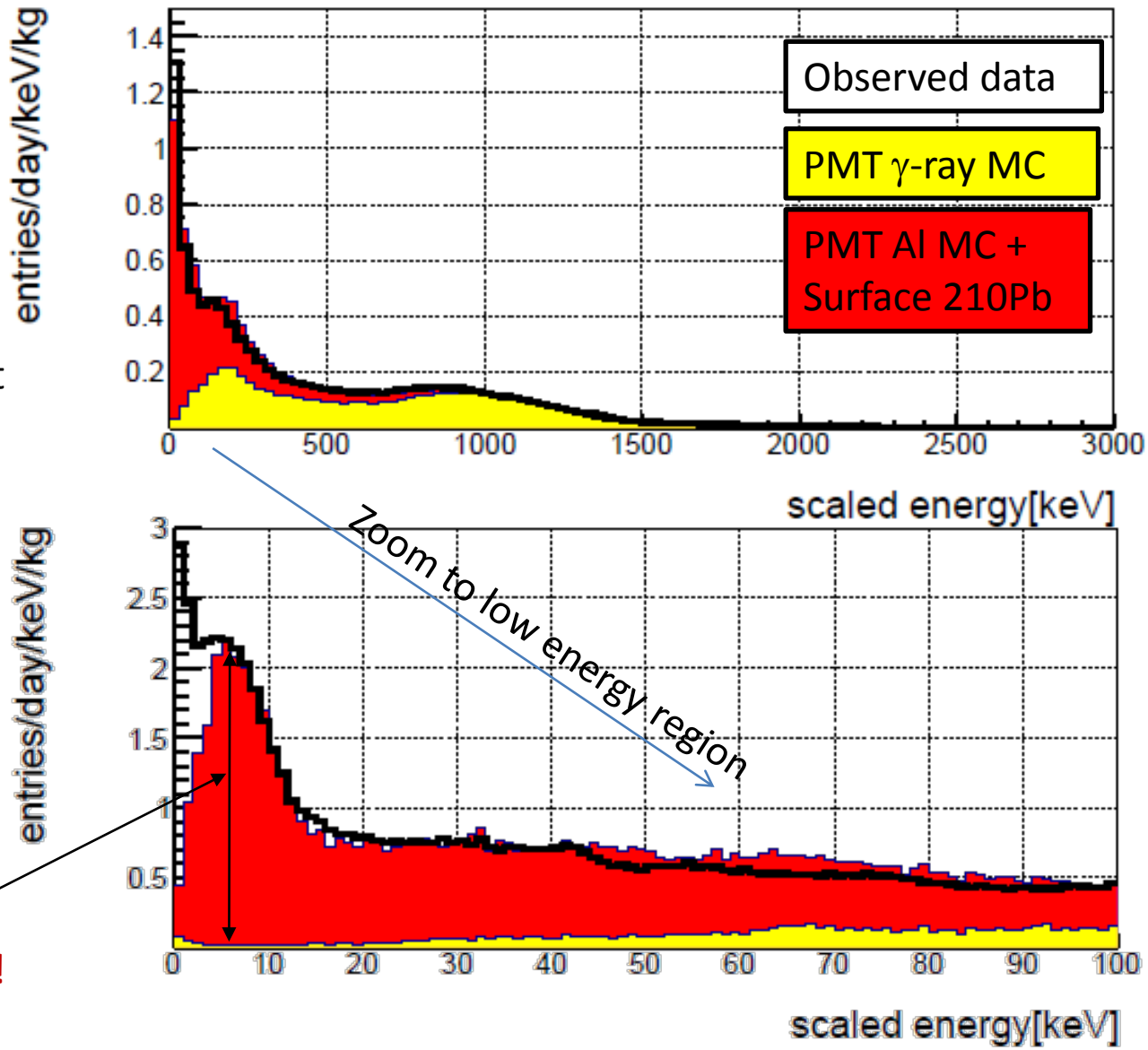
Old germanium result: consistent with 0

New germanium result
(pay special attention to U238 upper stream contamination):



Al MC simulation

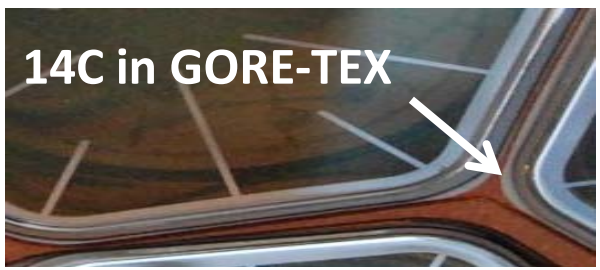
Also consistent with alpha measurement

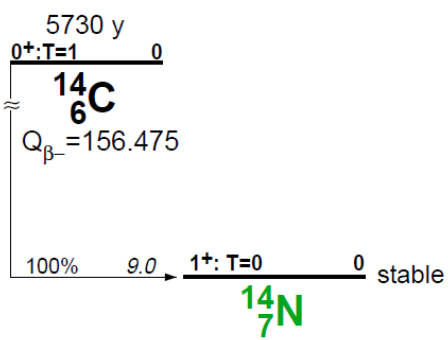


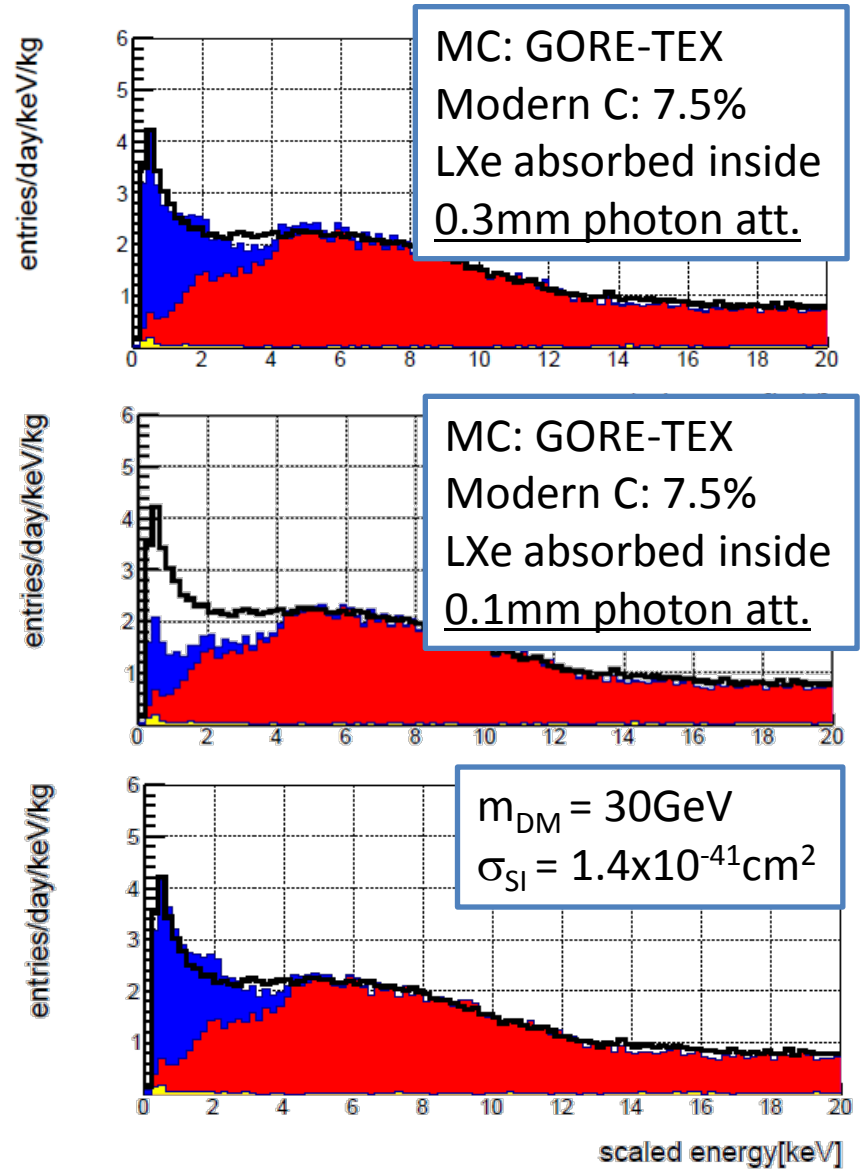
Background above 5 keV being explained!

A background candidate below 5 keVee

Gore-tex
- between PMT and holder
- preventing light leak
- 0~6±3% of modern carbon
- Transparency unknown



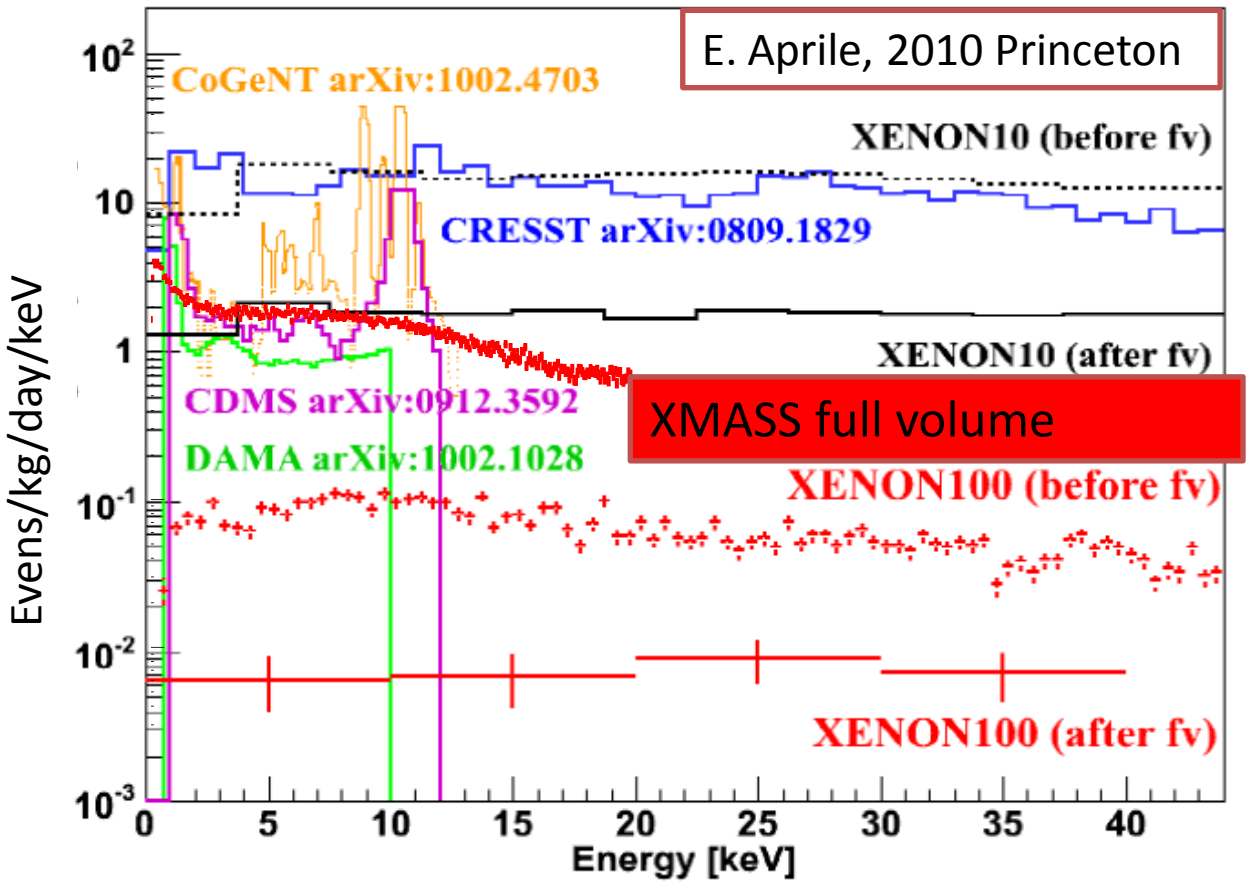


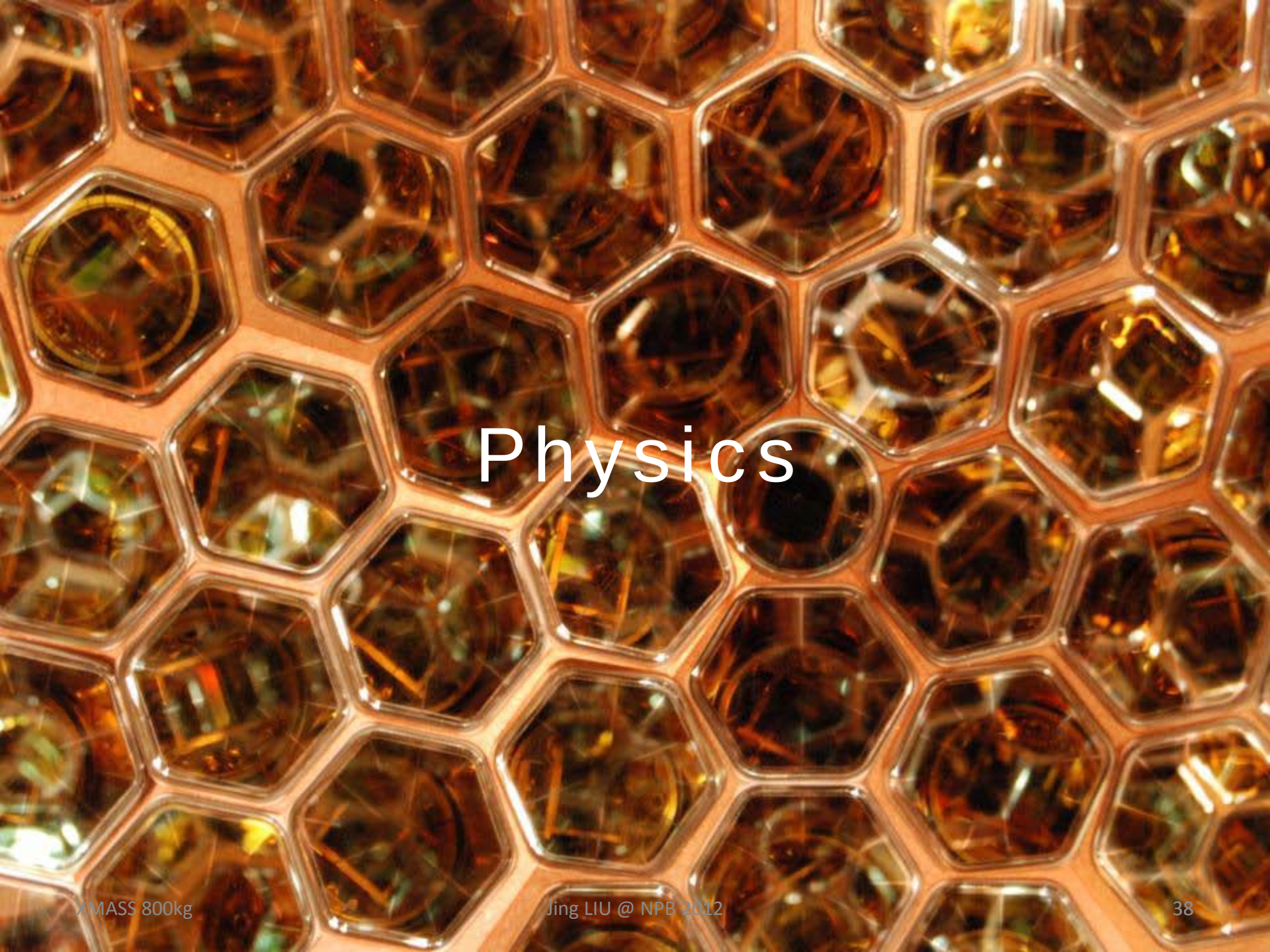


A full list of background

Material	Measured RI and activity	Methods of the measurements
PMTs (per PMT)	238U: 0.704 ± 0.282 mBq 232Th: 1.51 ± 0.31 mBq 60Co: 2.92 ± 0.16 mBq 40K: 9.10 ± 2.15 mBq	HPGe detector measurement for each parts and whole PMT
PMT aluminum (210g)	238U-230Th: 1.5 ± 0.4 Bq 210Pb: 5.6 ± 2.3 Bq 232Th: 96 ± 18 mBq 235U: ~67 mBq	HPGe detector measurement. → By calculation
Detector surface	210Pb: ~40 mBq	Alpha candidates using FADC data Surface: PMT window 59%, PMT Al 7.0% PMT rim 7.0%, GORETEX 3.7%, Cu 23.3% (surface 7.8%, wall 14.2%, bottom 1.3%)
GORE-TEX for PMTs (120g)	14C: 0.4 ± 0.2 Bq (6±3% of modern carbon) 210Pb: 26.5 ± 11.9 mBq	14C: modern carbon measurement. 210Pb: Ge measurement.
Internal RI in xenon	85Kr: <2.7 ppt 214Pb: 8.2 mBq	85Kr : API-MS measurement 214Pb : ~222Rn concentration in detector

A comparison to other experiments





Physics

Make full use of large target mass and high light yield

Advantages of current detector:

1. Largest target mass w/o fiducialization
2. High light yield -> low energy threshold

Disadvantages:

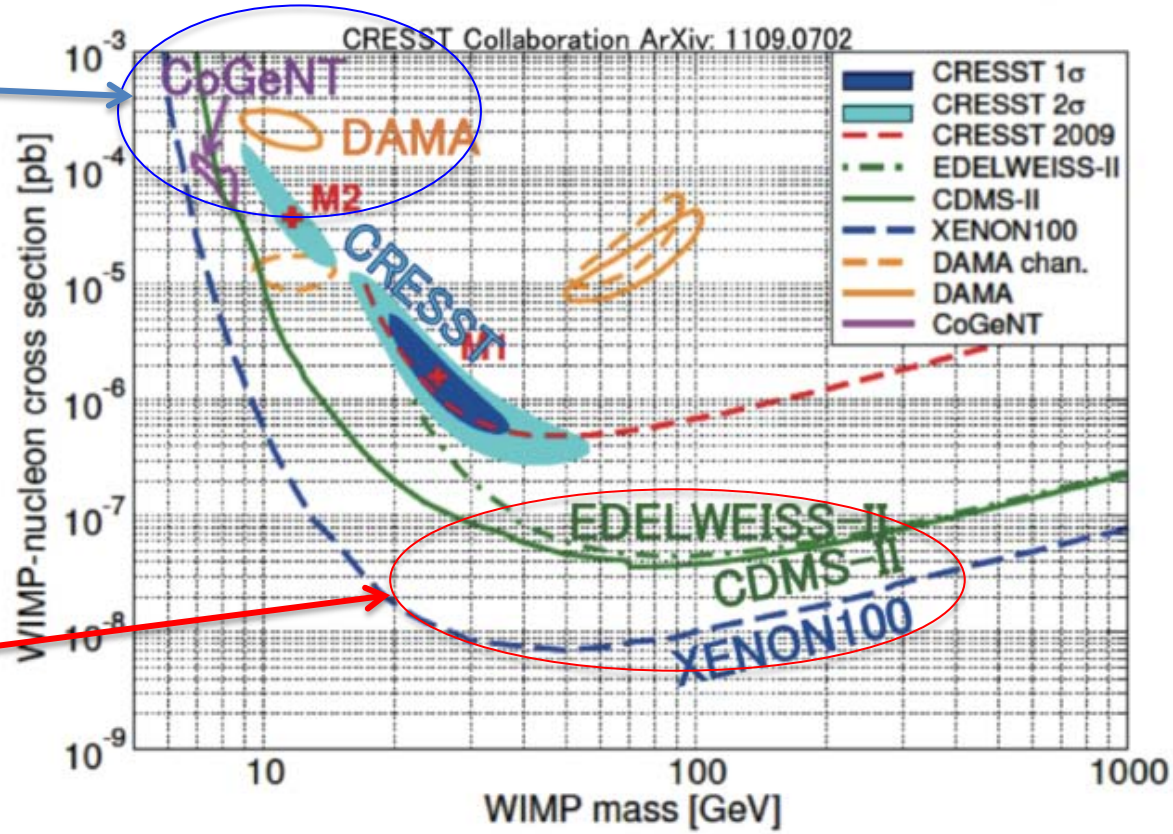
1. High background
2. Lack of bg rejection methods except fiducialization

Whole volume, low threshold analysis

- Threshold: 4 hits -> ~ 0.3 keVee
  - Light dark matter search
  - Axion-like particle search
- Threshold: 10 hits -> ~ 0.7 keVee
  - Annual modulation

Fiducial volume, High threshold analysis

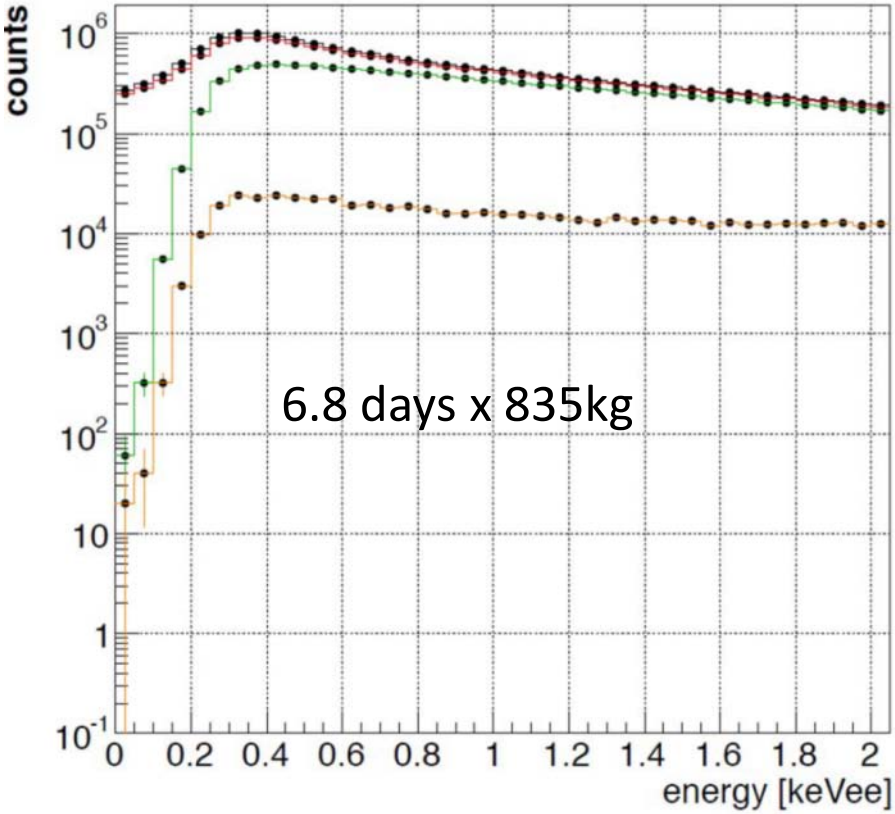
- threshold: > 5 keVee
  - Standard WIMPs search

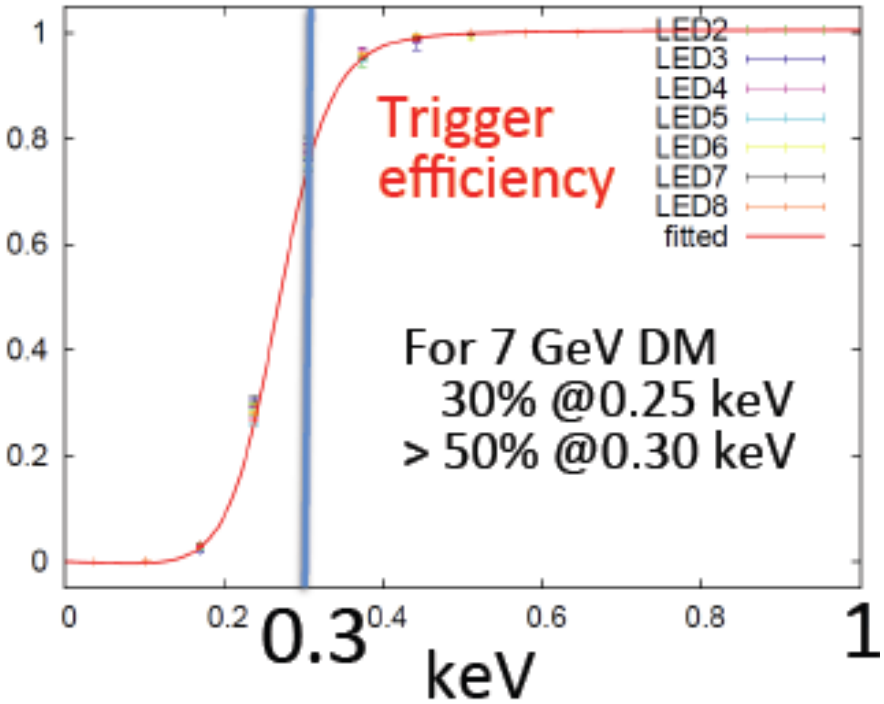


Energy spectra after each cut

Data selection:

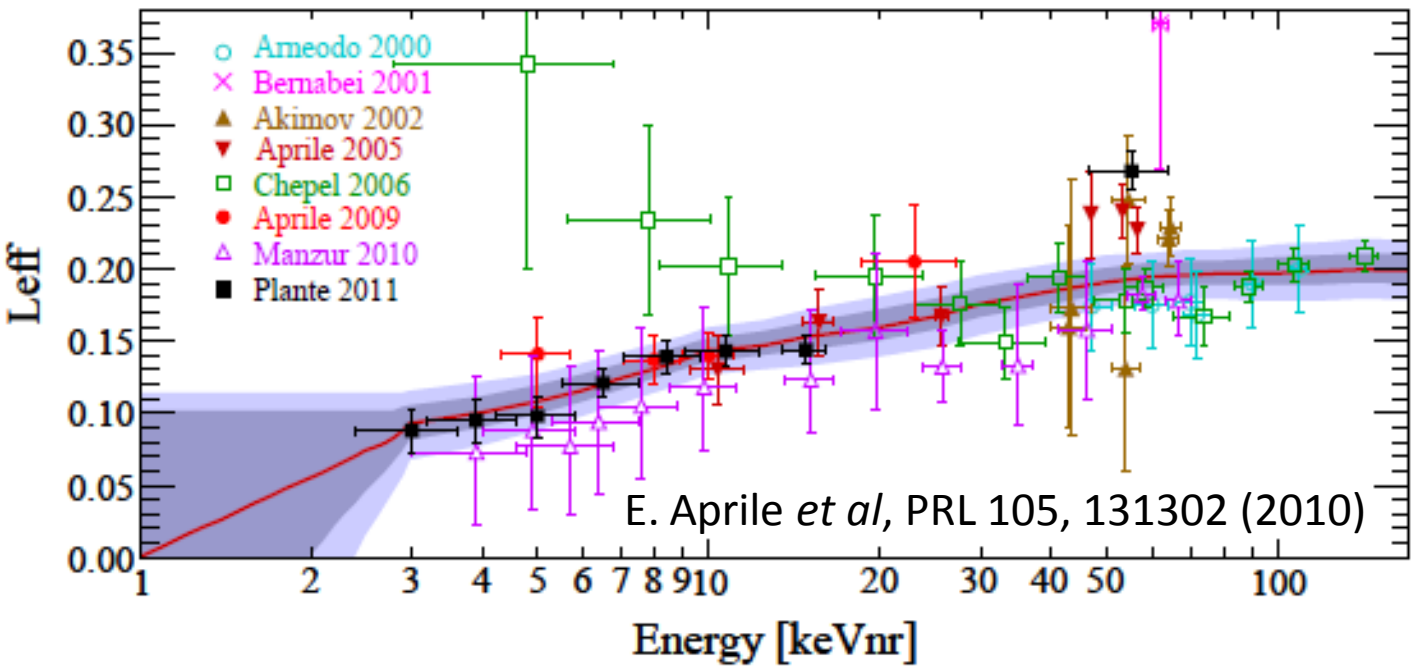
- Triggered by the inner detector only (no water tank trigger)
- Time difference to the previous/next event >10ms
- RMS of hit timing <100ns (rejection of after pulses of PMTs)
- Cherenkov cut





Uncertainties

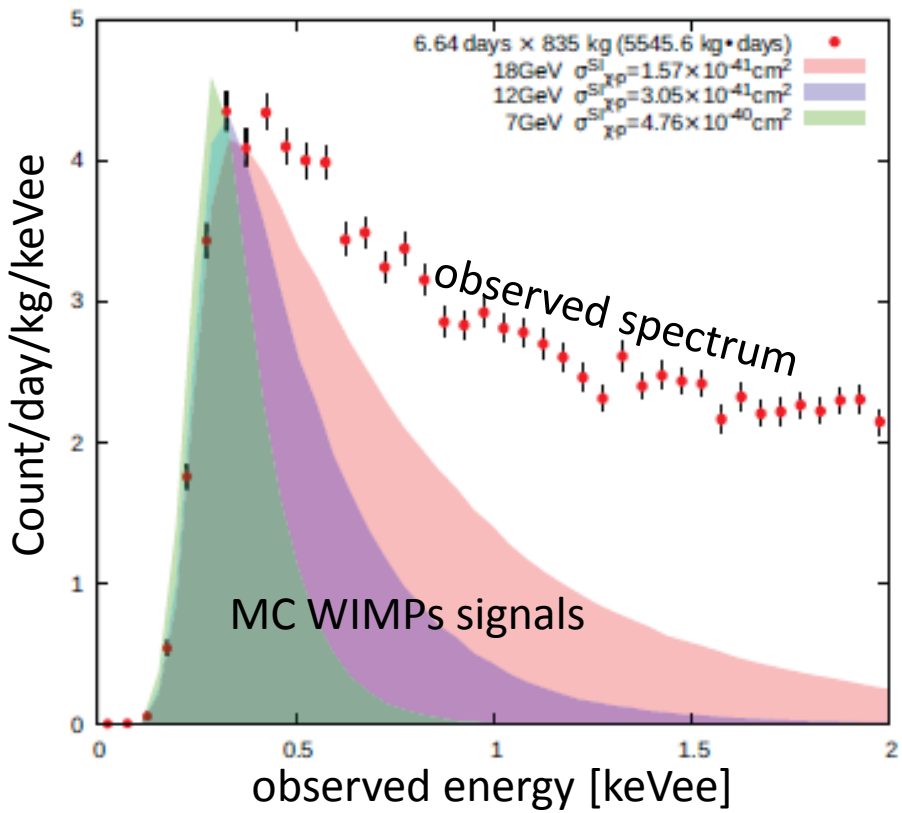
- Major uncertainty is the scintillation efficiency of nuclear recoil in liquid xenon
- Uncertainties of the trigger threshold, cut efficiencies and energy scale are much smaller, but also properly taken into account

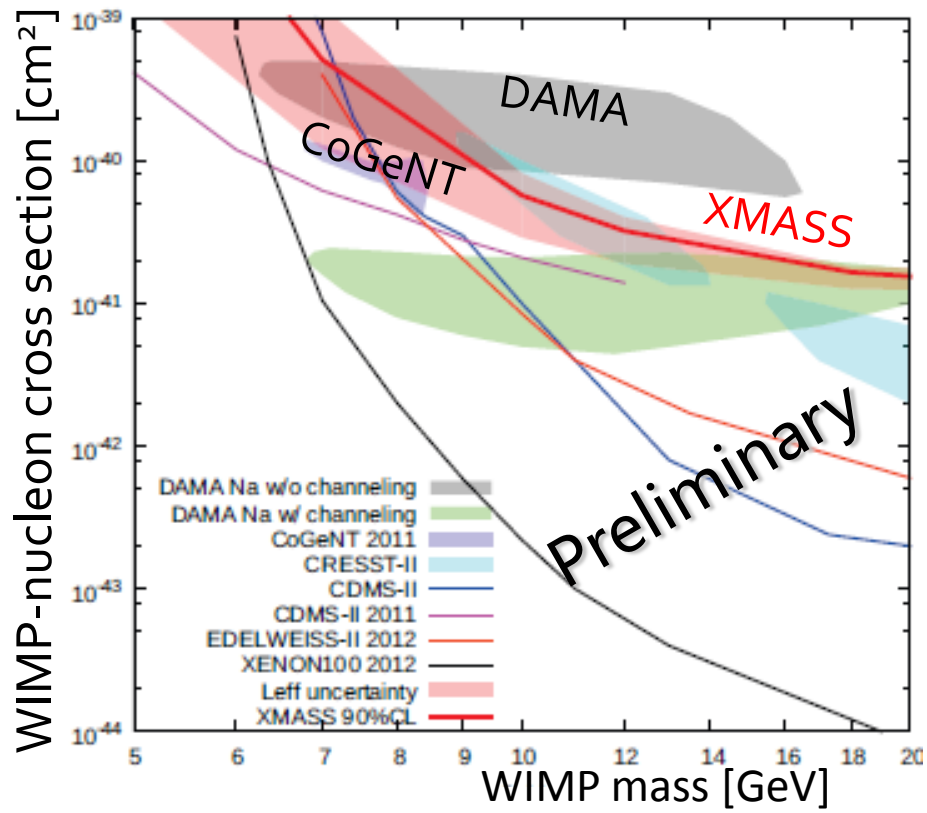


E. Aprile *et al*, PRL 105, 131302 (2010)

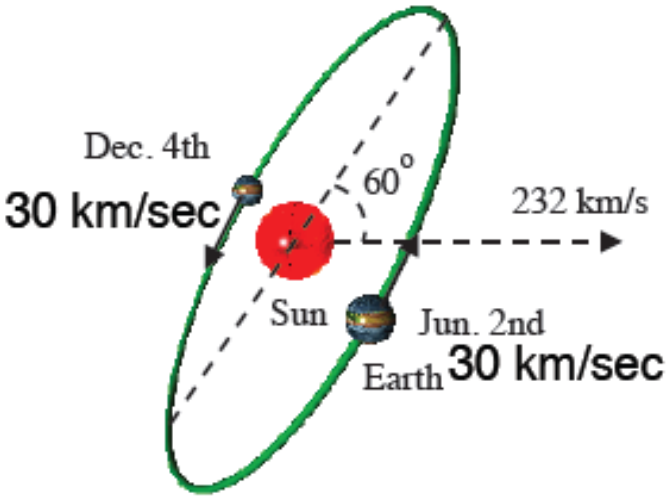
Spectrum and Sensitivity

Uncertainty band is mainly contributed by that of Leff





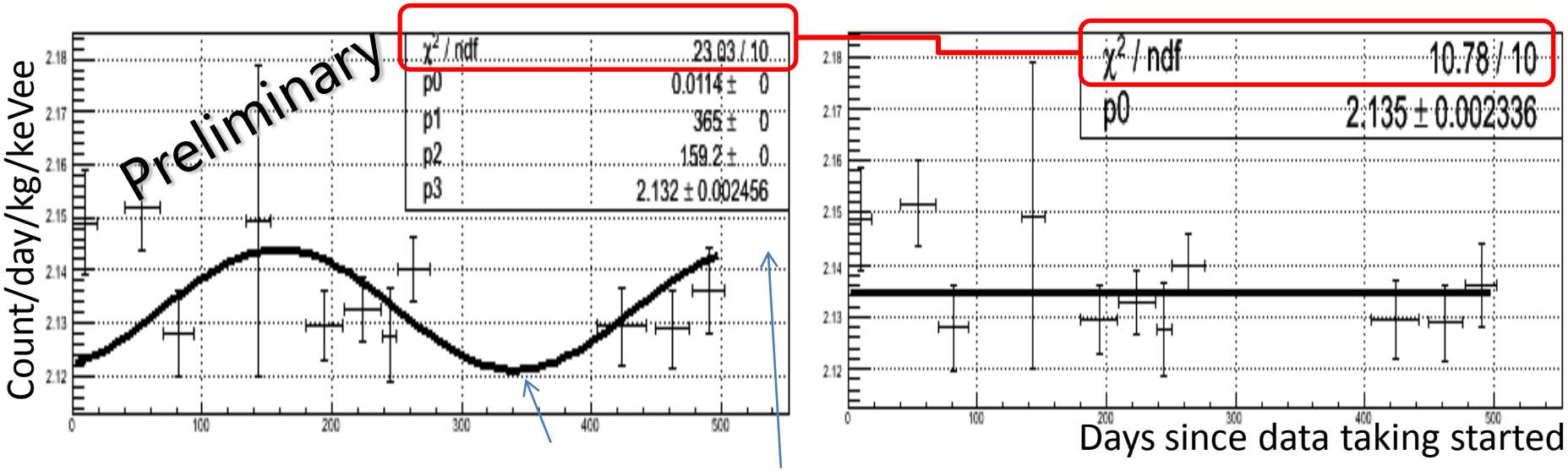
Annual modulation analysis



Check DAMA modulation signal:

- QF(Na)~0.25, Leff(Xe)~0.15 ➔ 2~6keVee(Na) ➔ 8~24 keV$_{NR}$ ➔ 1~4keVee(Xe)
- Recoil shape, A^2 ➔ 1/30 sensitivity

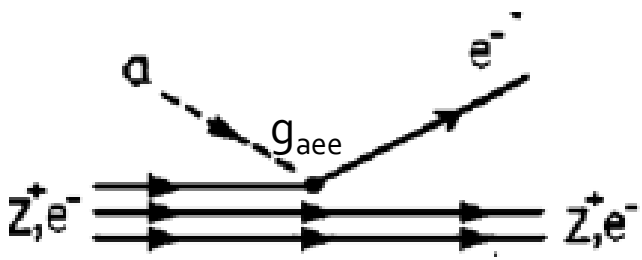
Energy range: 1-4 keVee



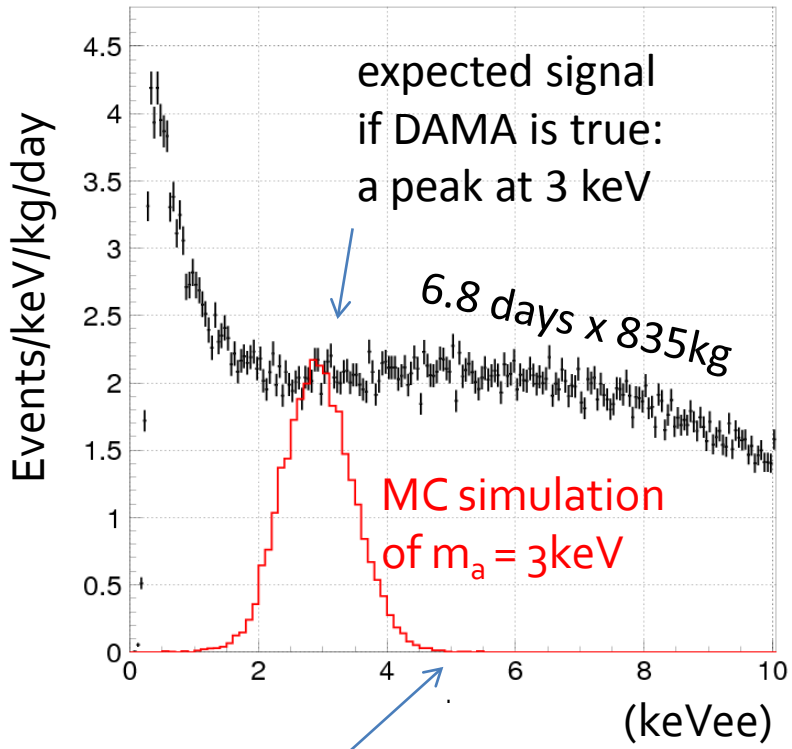
Expected maximum and minimum will be covered in the future

Axion-like dark matter search

Non-relativistic axion like dark pseudo scalars being explanation of DAMA annual modulation
[R. Bernabei et al., Int. J. Mod. Phys. A 21, 1445 (2006)]

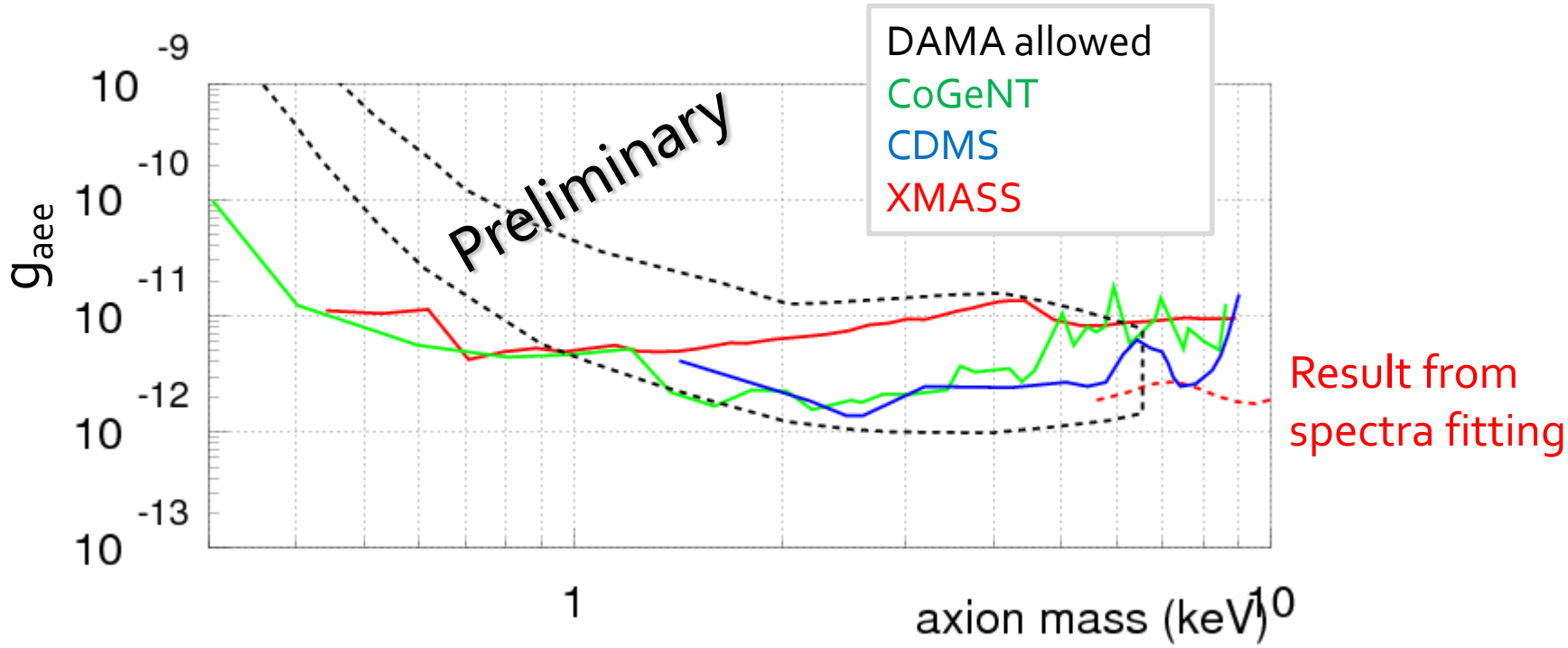


Axio-electric effect
similar to photo-electric effect



It can be further improved above 5 keV by fitting signal + background MC to the observed spectrum

Limit on the axio-electric coupling

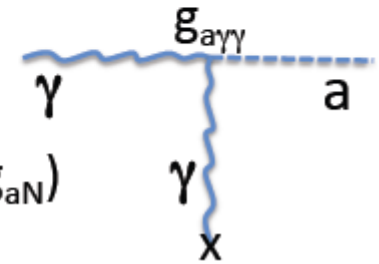


Solar axion search

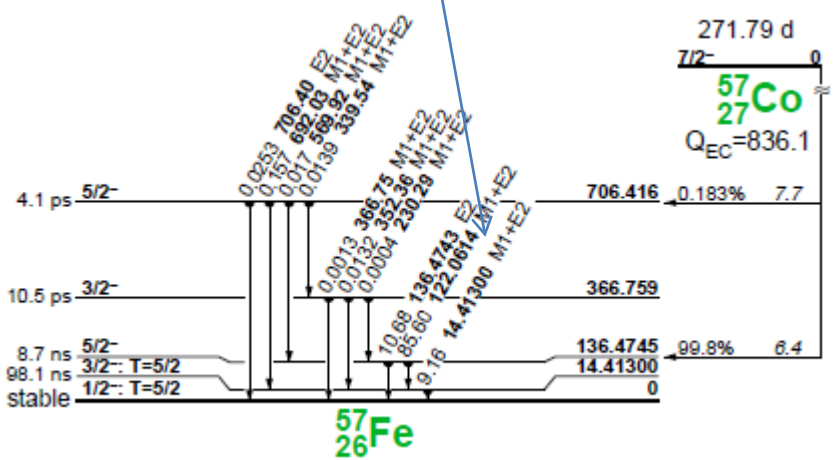
Production: Various mechanism

1. Bremsstrahlung and Compton scattering (g_{aee})

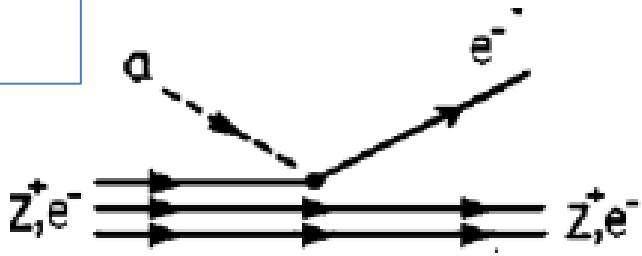
2. Primakoff effect ($g_{a\gamma\gamma}$)



3. Nuclear de-excitation (57Fe) (g_{aN})
   - Line signal @14.4 keV

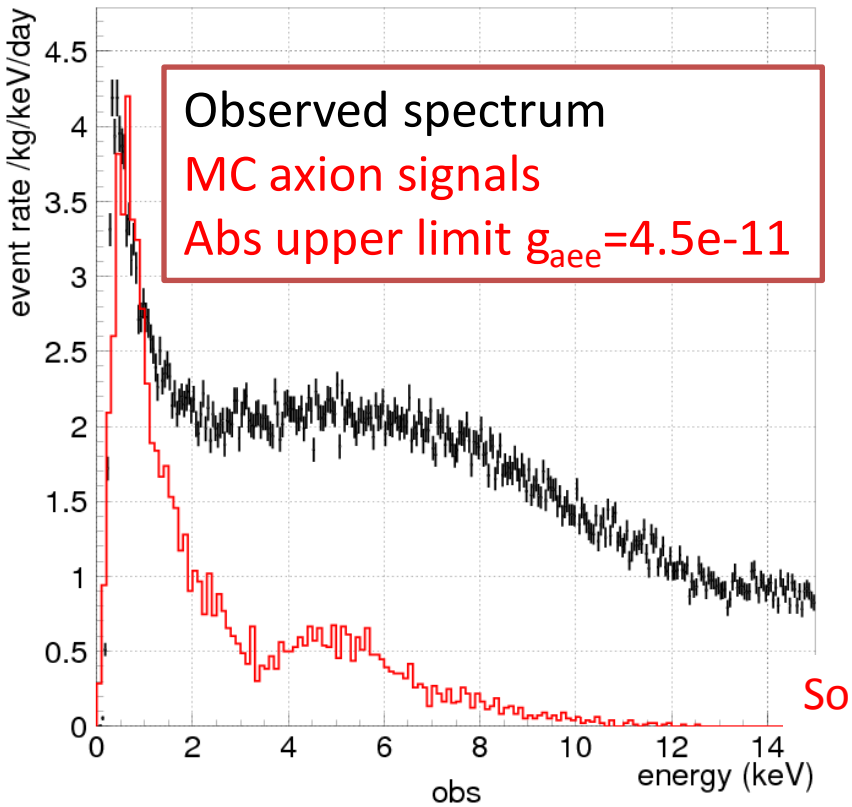


Observation:

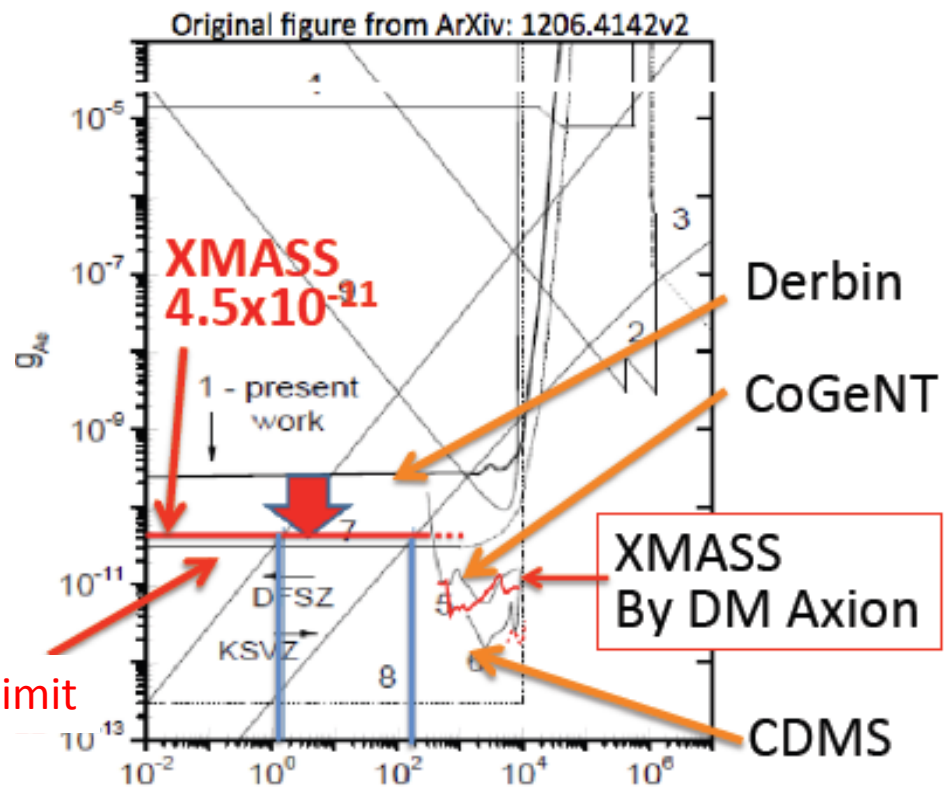


Axio-electric effect
analog to photo-electric effect

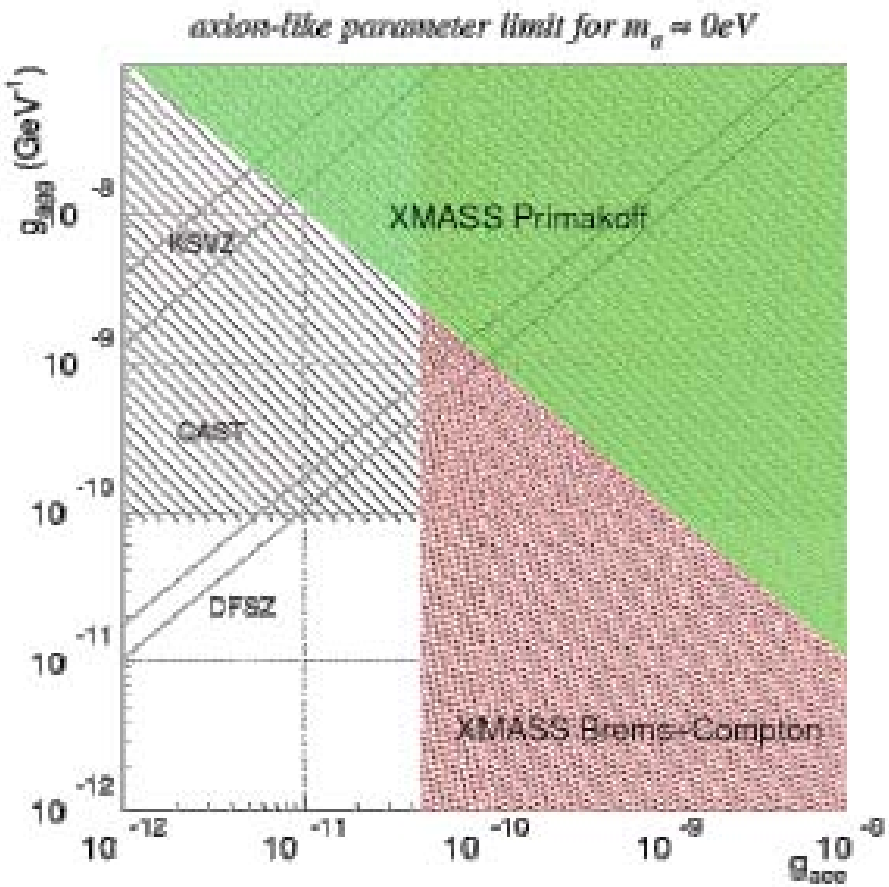
Produced through gaee, detected through gaee

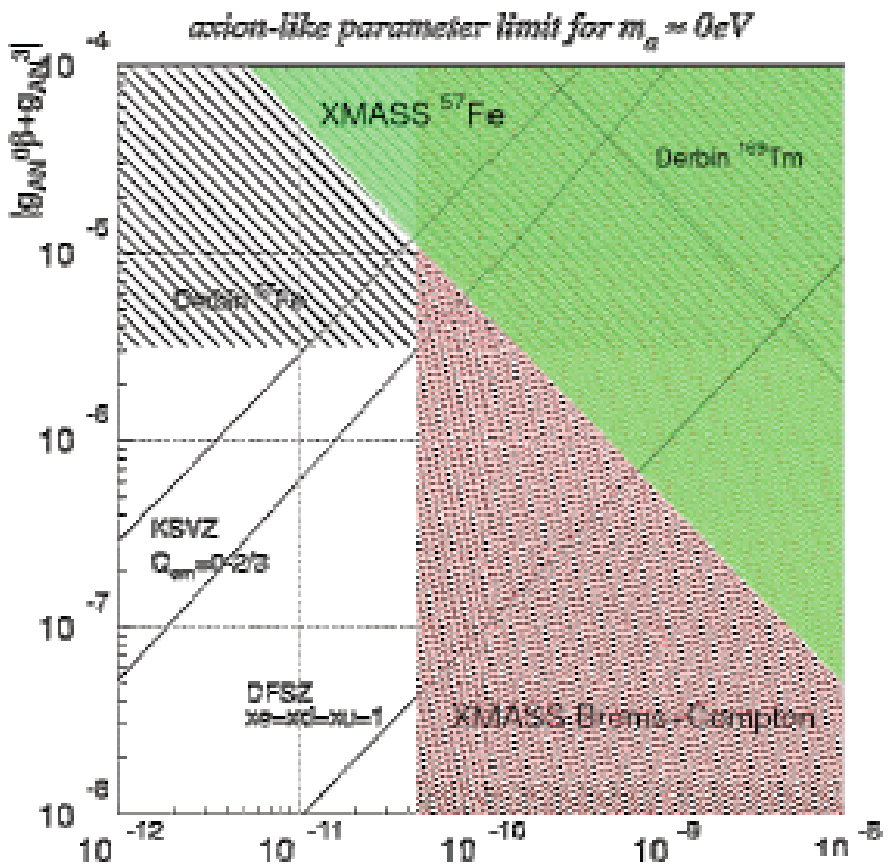


Solar limit

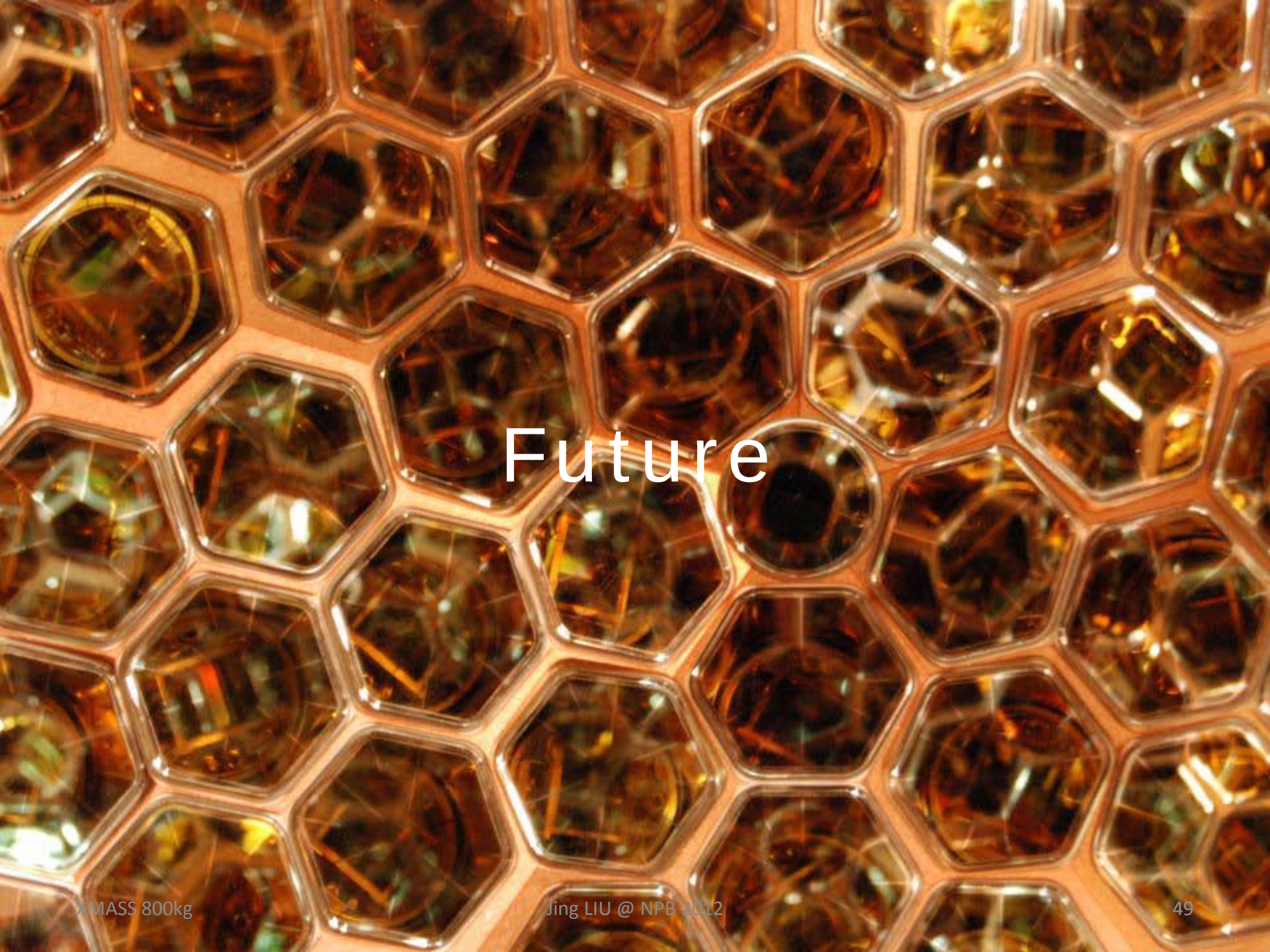


Produced through gaγγ, gaN, detected by gaee



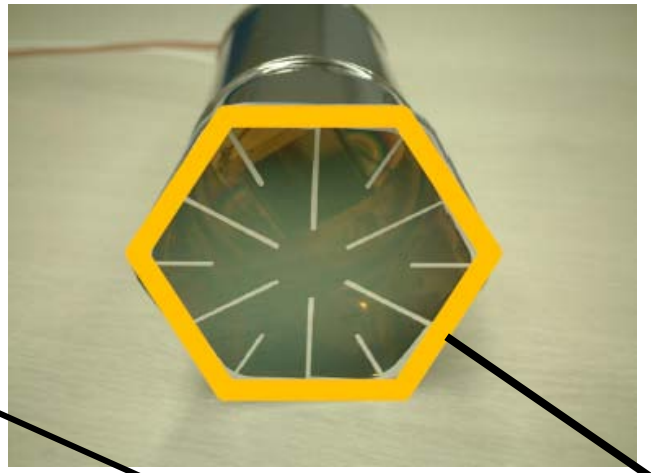


gaee



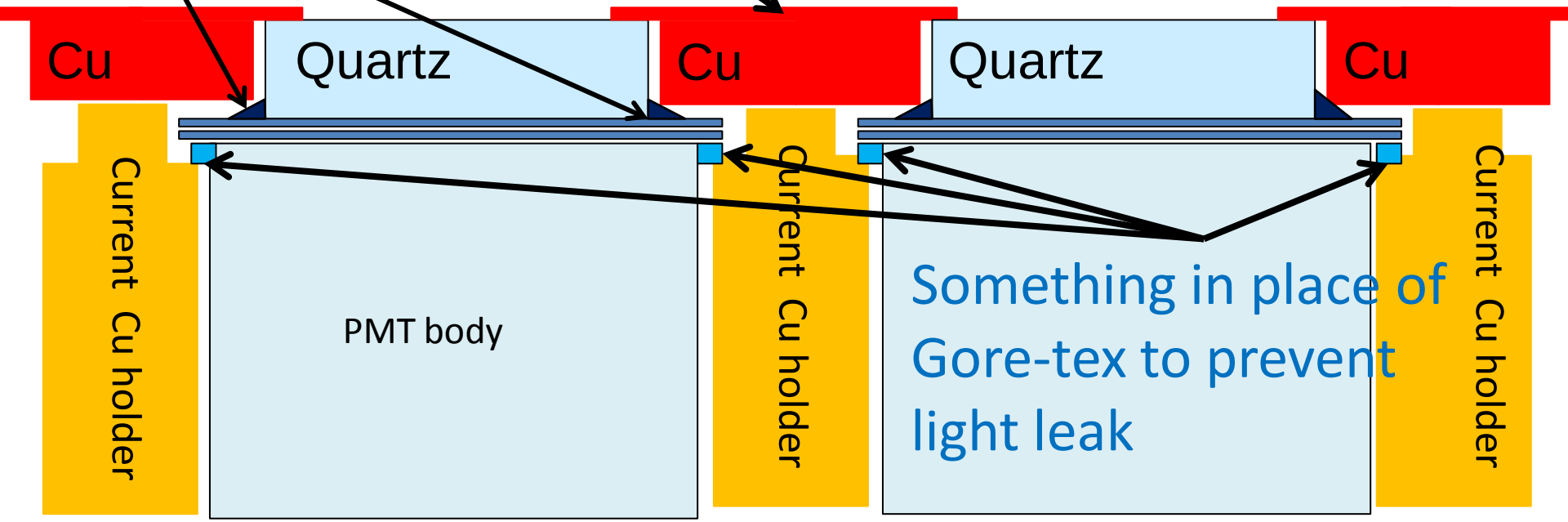
Future

Refurbishment

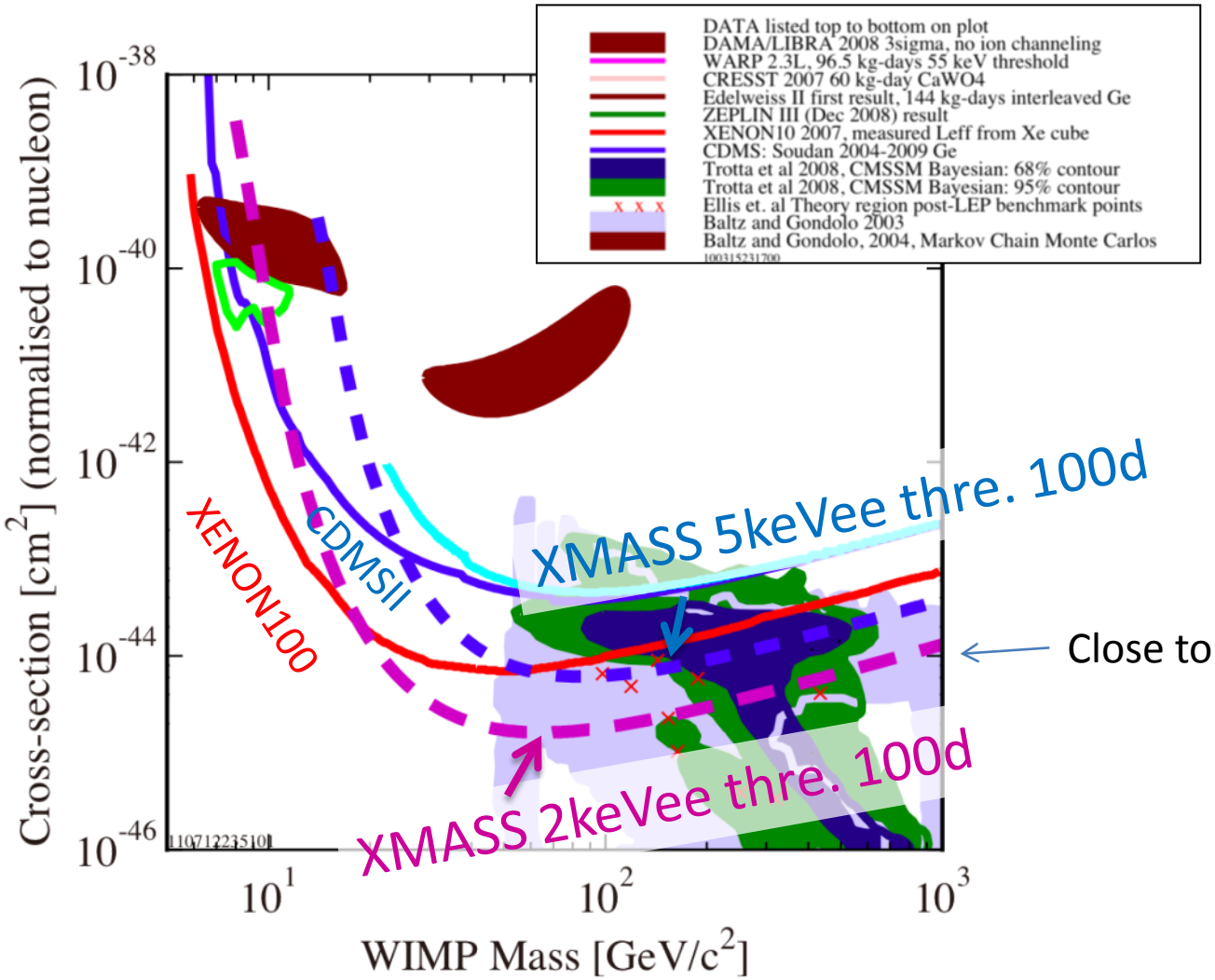


Expect more than 1 order of magnitude reduction of background

Dirty Al



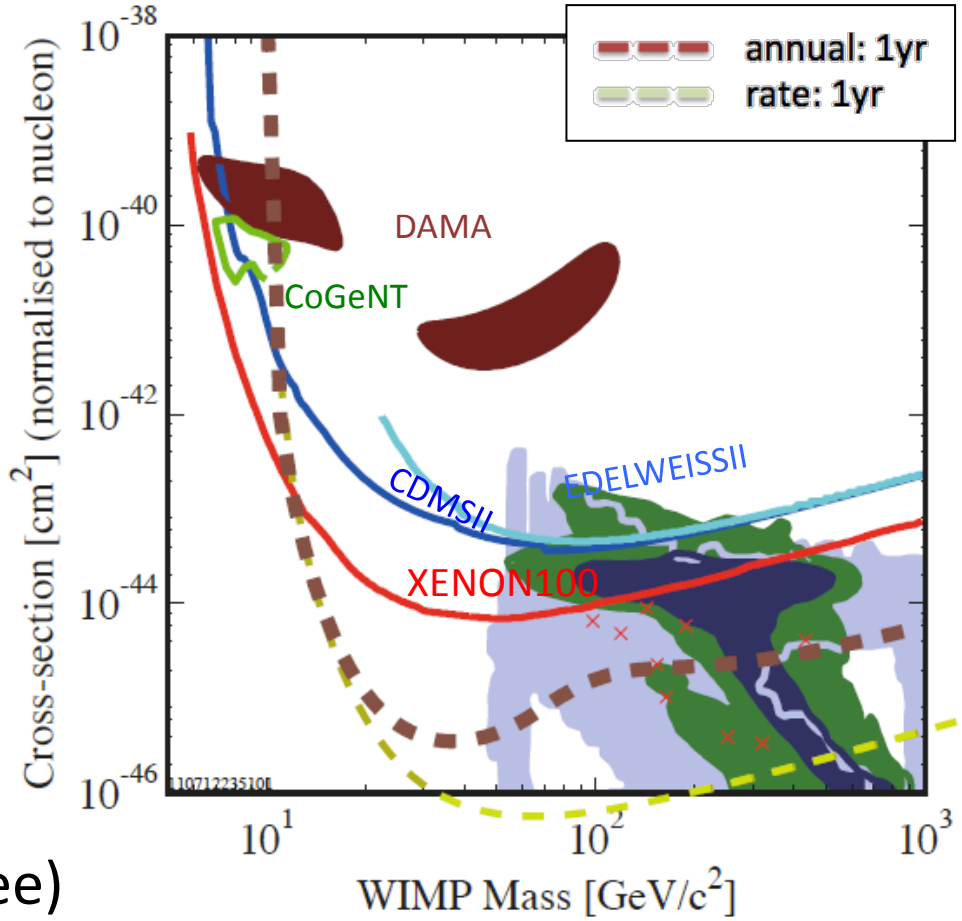
Spin independent sensitivity after refurbishment



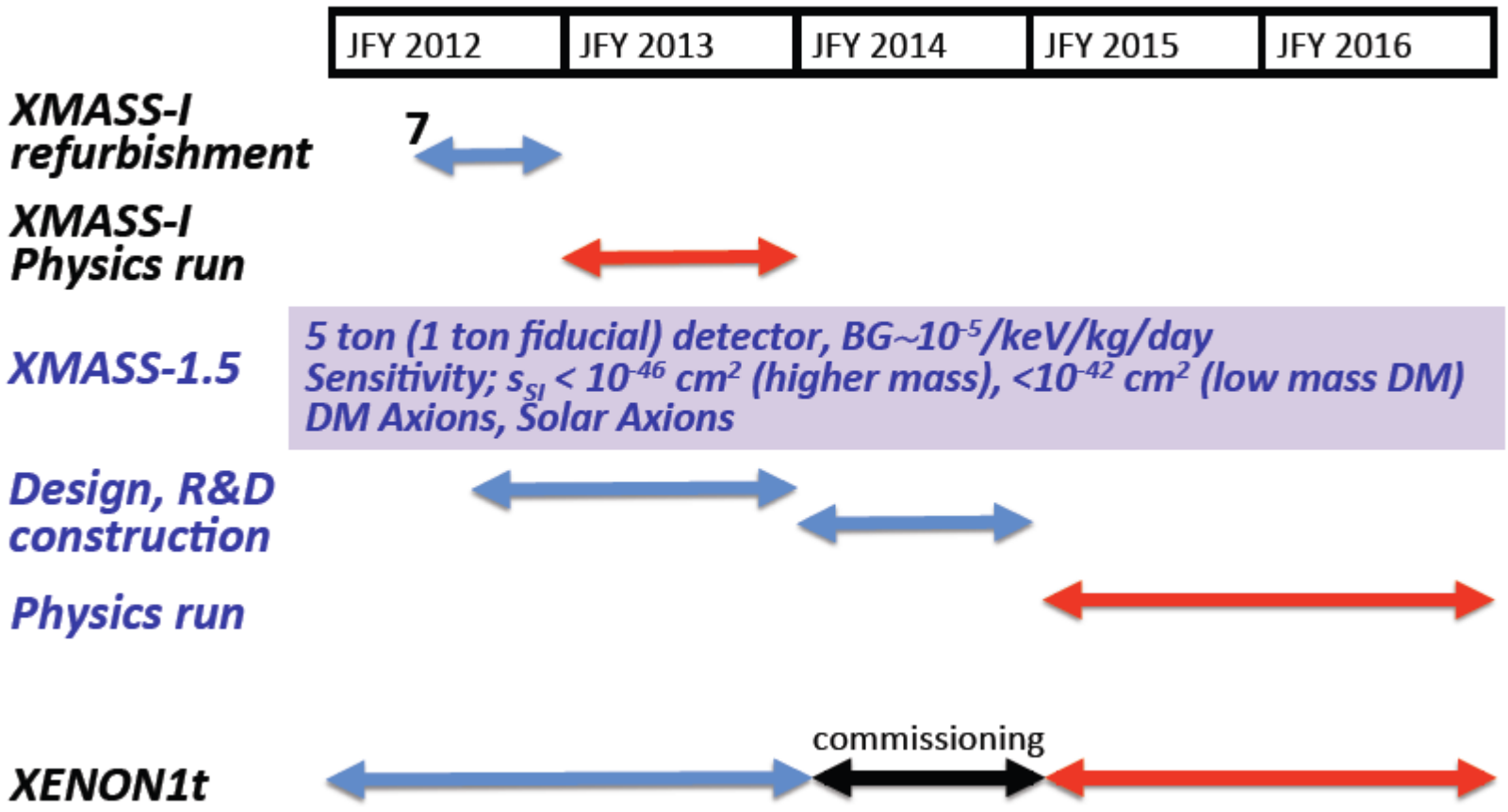
Close to latest XENON100 result

XMASS phase 1.5

- Half step to XMASS phase 2
  - Hence named 1.5
- Total mass 5 tons
  - Fiducial mass 1 ton
- Background
  - New PMTs
  - No Gore-tex
  - Less surface ^{210}Pb
  - Expect 10^{-5} dru
- Sensitivity
  - $s_{SI} < 10^{-46}$ cm^2 (> 5 keVee)
  - a few x 10^{-42} cm^2 (>0.3 keVee)



Schedule


JFY 2012
JFY 2013
JFY 2014
JFY 2015
JFY 2016
XMASS-I refurbishment
7
XMASS-I Physics run
XMASS-1.5
5 ton (1 ton fiducial) detector, BG~10^{-5}/keV/kg/day
Sensitivity; s_{SI} < 10^{-46} cm^2 (higher mass), <10^{-42} cm^2 (low mass DM)
DM Axions, Solar Axions
Design, R&D construction
Physics run
commissioning
XENON1t

Summary

- Detector
  - was constructed and started commissioning late 2010
  - high light yield, low threshold
  - large target mass
- Background
  - not as low as originally expected
  - but composition is well understood above 5keV
- Physics
  - preliminary results on light dark matter
  - and axion-like particle searches
- Future
  - improving reconstruction/BG reduction
  - refurbishing hardware
  - aiming at the original sensitivity
  - XMASS1.5 is planed to run in 2015