Liquid Xe experiments for WIMP search

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Direct search for dark matter

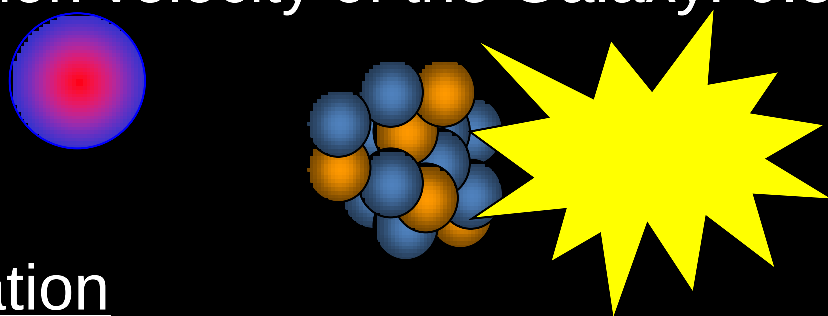
Long history from the 1930s: clusters, rotation of galaxies, large scale structures, the bullet cluster, non baryon by CMB!

➔ All of them are from astronomy, no detailed property known.

Confirm and study the particle nature.

Direct detection: weakly interacting massive particles (WIMPs)

From the rotation velocity of the Galaxy: 0.3GeV/cc, $\beta \sim 10^{-3}$



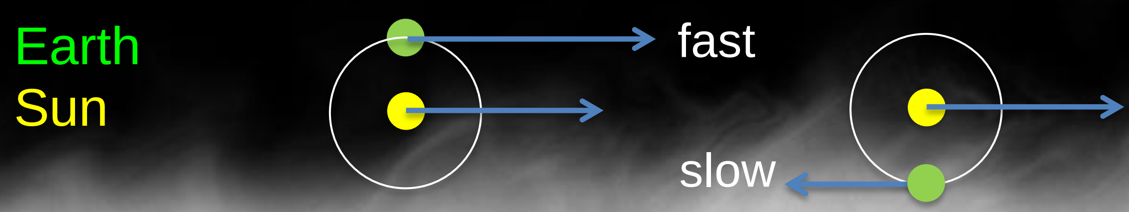
$m_{target}\beta^2/2 \sim 50keV$

for $m_{target} \sim 100GeV$

Annual modulation

The Sun rotates in the Galaxy, the Earth rotates around the Sun.

The relative speed of WIMPs changes in a sidereal year.

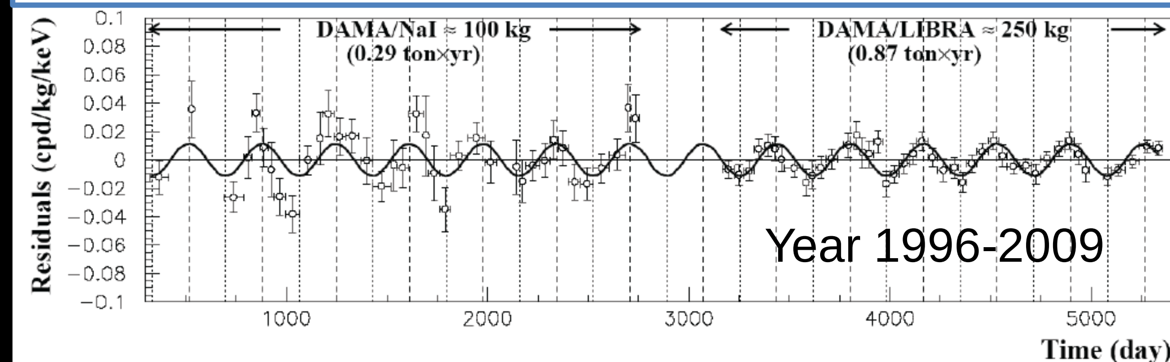


Existing indications of signals on WIMPs

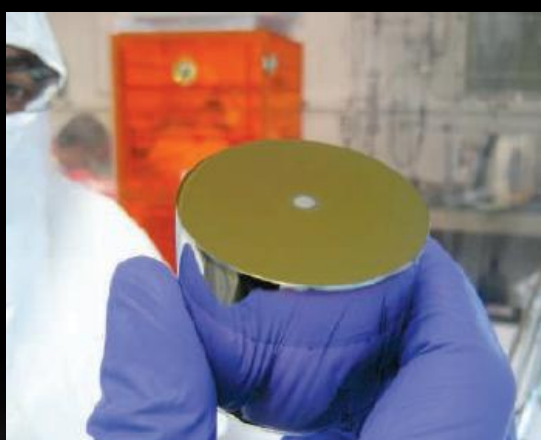
DAMA/LIBRA: 100kg NaI(Tl)

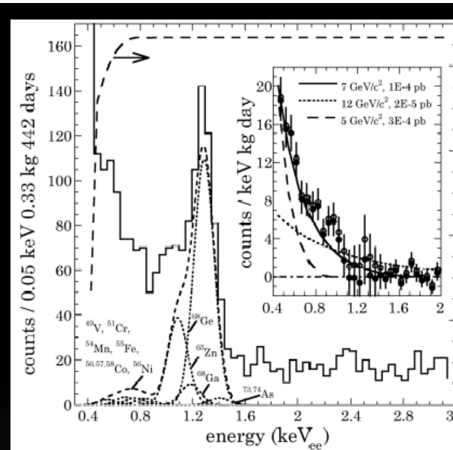
Are they from WIMPs?

Significant modulation (8.9σ, +/-2%) over 13 years!!



CoGeNT: Point Contact Ge detector (small C→ low thre.)





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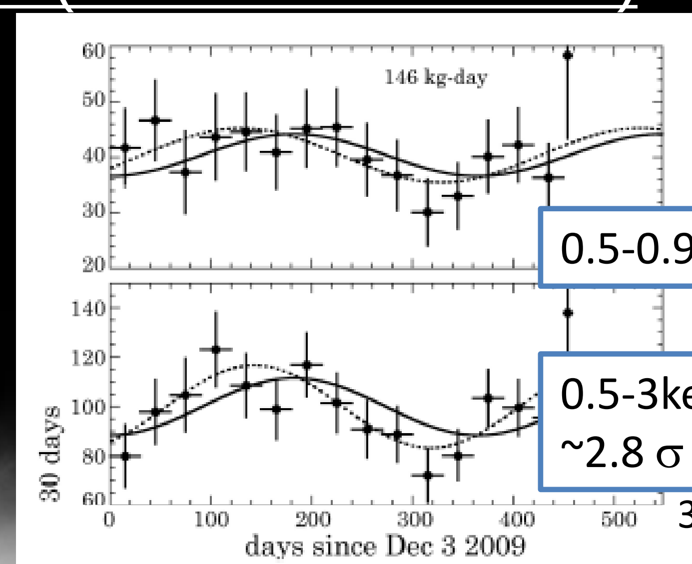
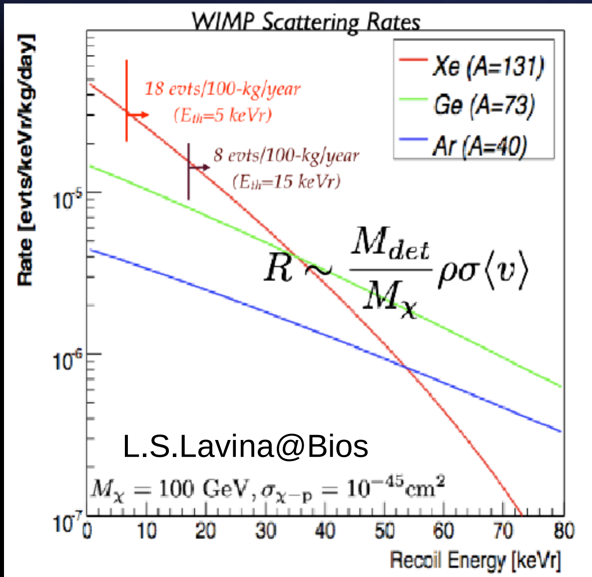
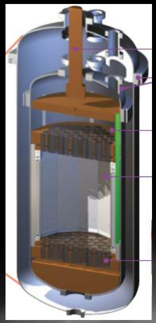


Liquid xenon and application to the WIMP search

- Advantages of liquid xenon
  - Large atom. #, Z=54: good for coh. scat.
  - High density, 3g/cc: compact detector
  - Scalability, easy handling: liq at -100C
  - Established purification: getter, distillation
  - Liquid TPC: scinti and Q collection OK

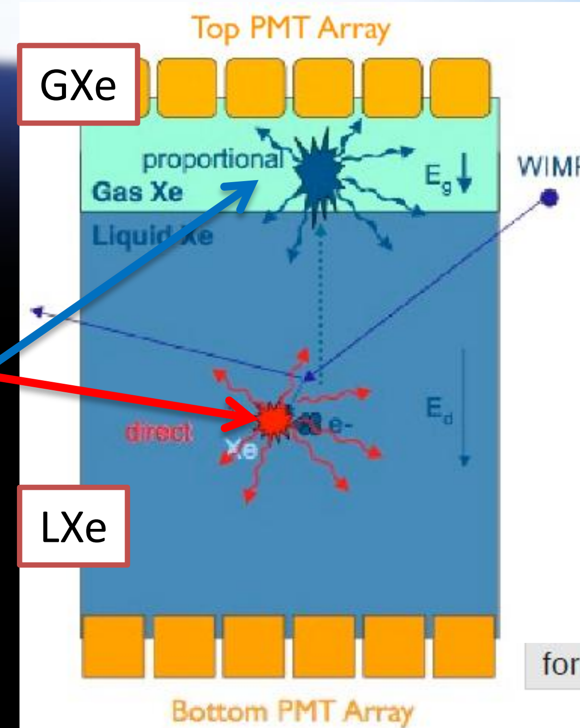


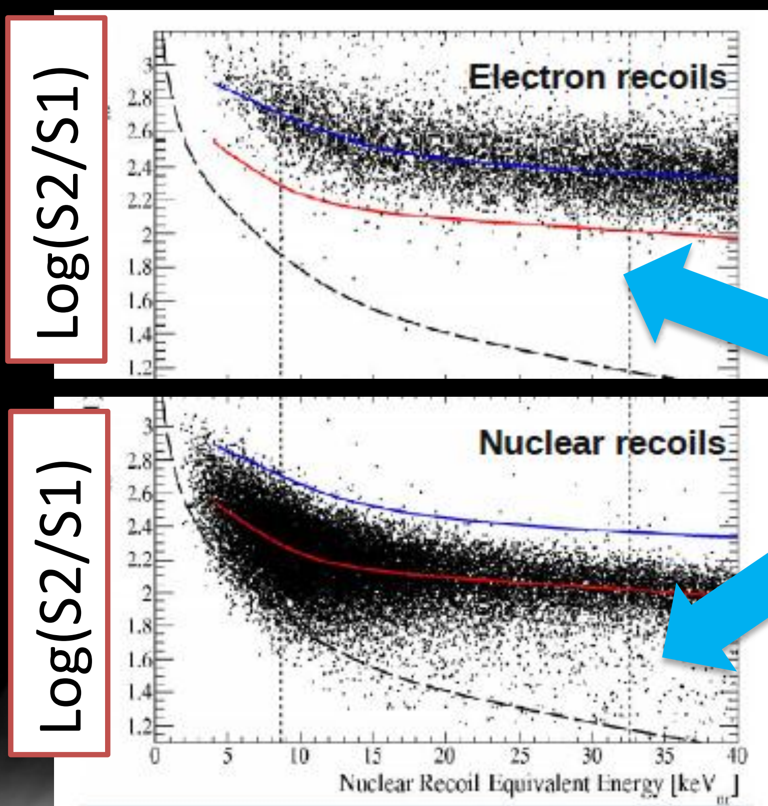
- Many experiments around the world
  - ZEPLIN-III (UK): finished
  - XENON100 (US): just finished
  - XMASS (Japan): commissioning
  - LUX (US): just installed underground
  - PANDA-X (China): preparation
- Future: XENON1t, XMASS1.5, LZ, DARWIN, MAX, …



Liquid xenon TPC

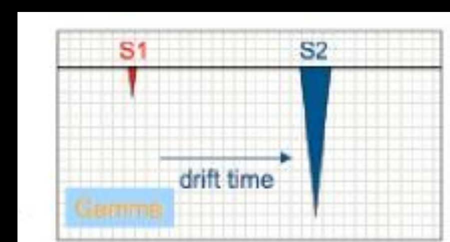
- LXe time projection chamber
- Prompt signal, scintillation S1
- Proportional scintillation: S2 (~2μs/mm)
- S2/S1 dep. on the particle type

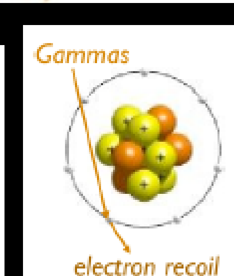


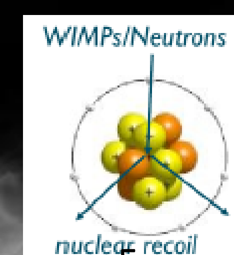


Electron recoils
~major BG

Nuclear recoils
~ WIMPs





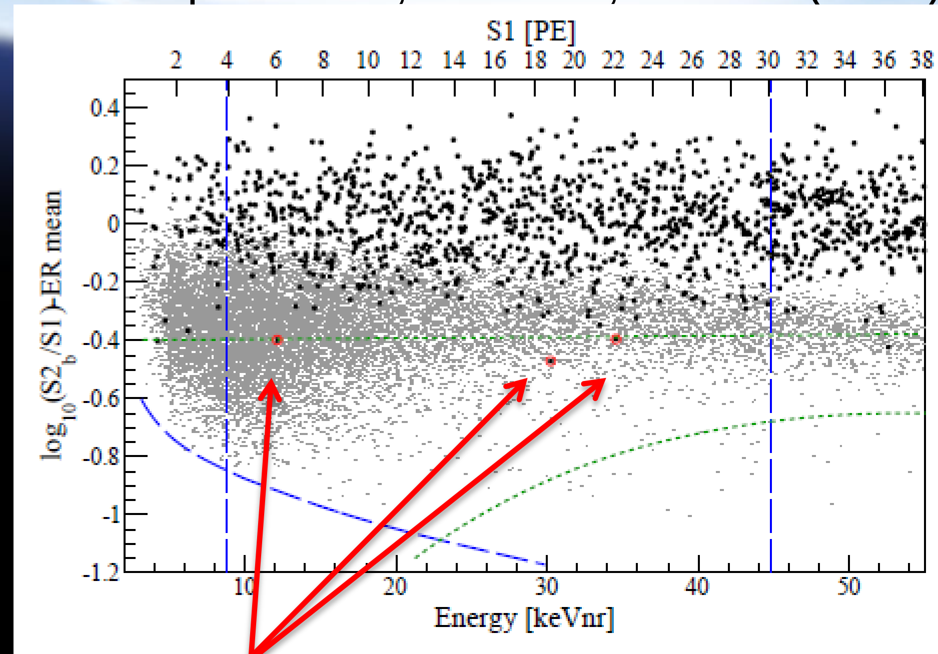


XENON100@Gran Sasso

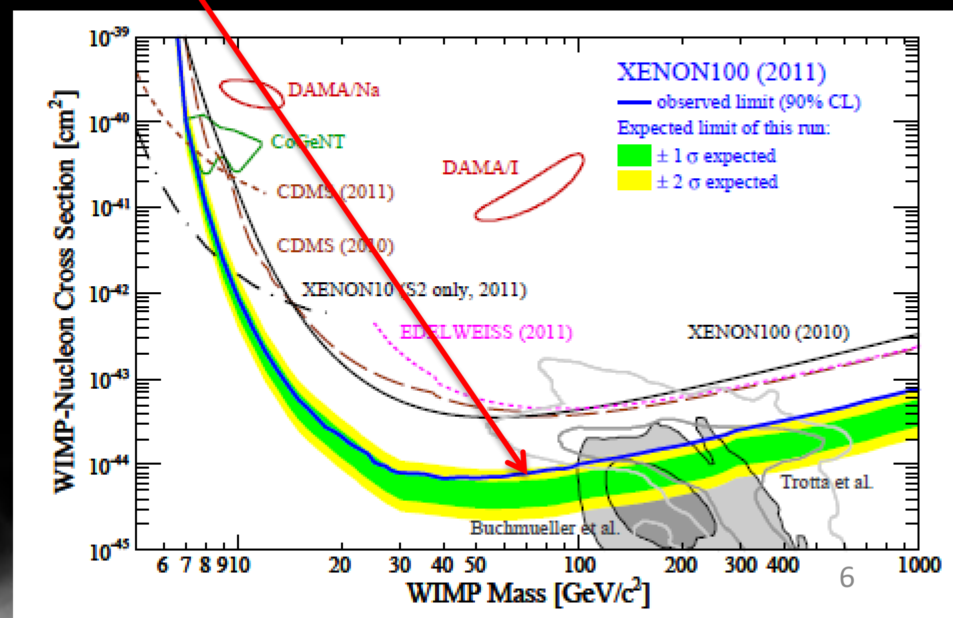
- 160kg, 48kg fiducial volume
- 2.2p.e./keV w/ electric field
- 7x10^{-45}cm^2 at 50GeV

- Kr reduction by distillation done after the 100days result.
- Terminated data taking
- Results with +200 days data in a few weeks.
- If Kr reduction succeeded, BG will be 1/3 than 100days data.
  ~2x10^{-45}cm^2 expected

E. Aprile et al., PRL 107, 131302 (2011)



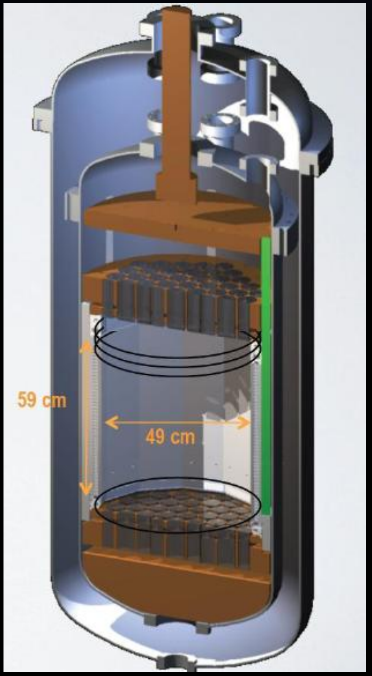
100days: 3 events ⇔ BG 1.8+/-0.6 ev exp.

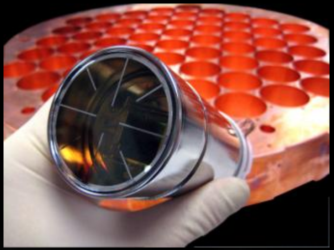


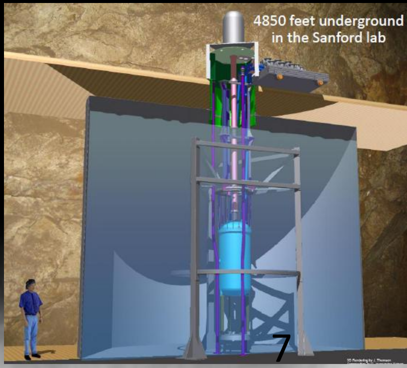
LUX@Homestake

Viveiros@Blois, E. Bernard@dm2012

- 350kg, 100kg fiducial volume
- 8p.e./keV w/o electric field
- Developed at a surface lab.
- Drift field limited by a feed-through
- Drift length: >12cm (Z=59cm)
- Started to install into Davis cavern last month, 4850ft, Sanford lab., SD
- Finish installation Sep. 2012
- First result in first quarter of 2013
- Goal: 300days, x30 improvement w/r to XENON100





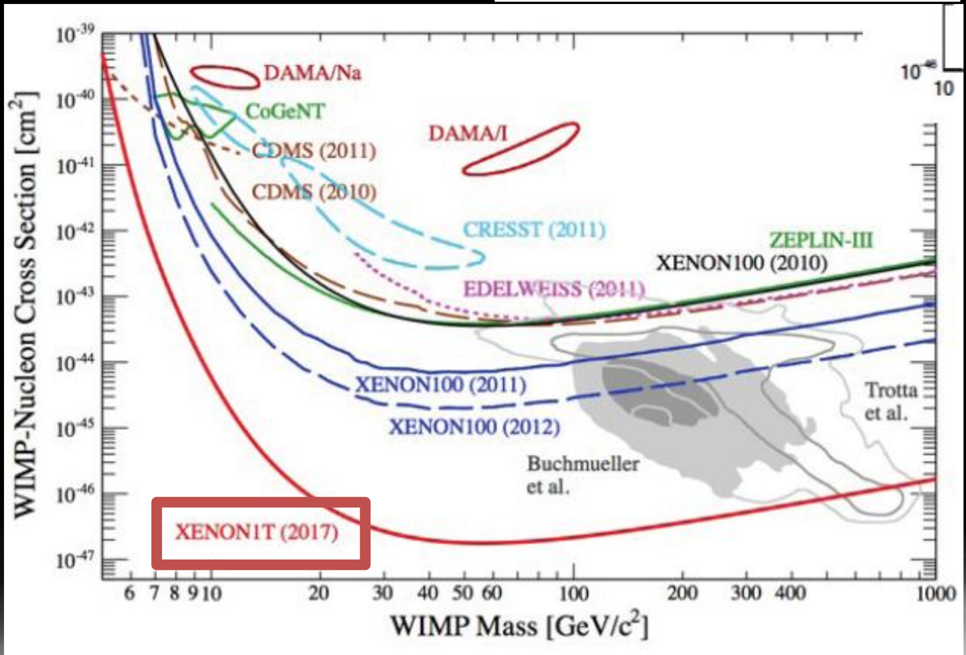


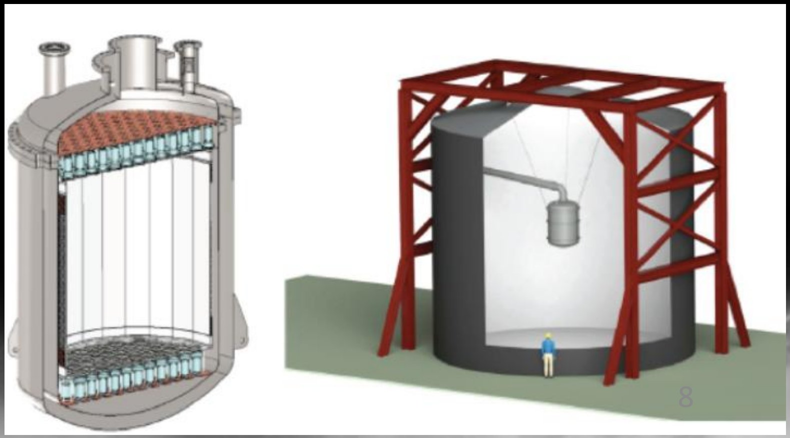
XENON1t@Gran Sasso

- <u>Construction expected to start this fall</u>
- Science run: 2015~
- 2.2t, 1.1t FV, 1m drift TPC. 10m Water Cherenkov veto
- <u>Goal: 2yr, x100 improvement w/r to XENON100</u>

?

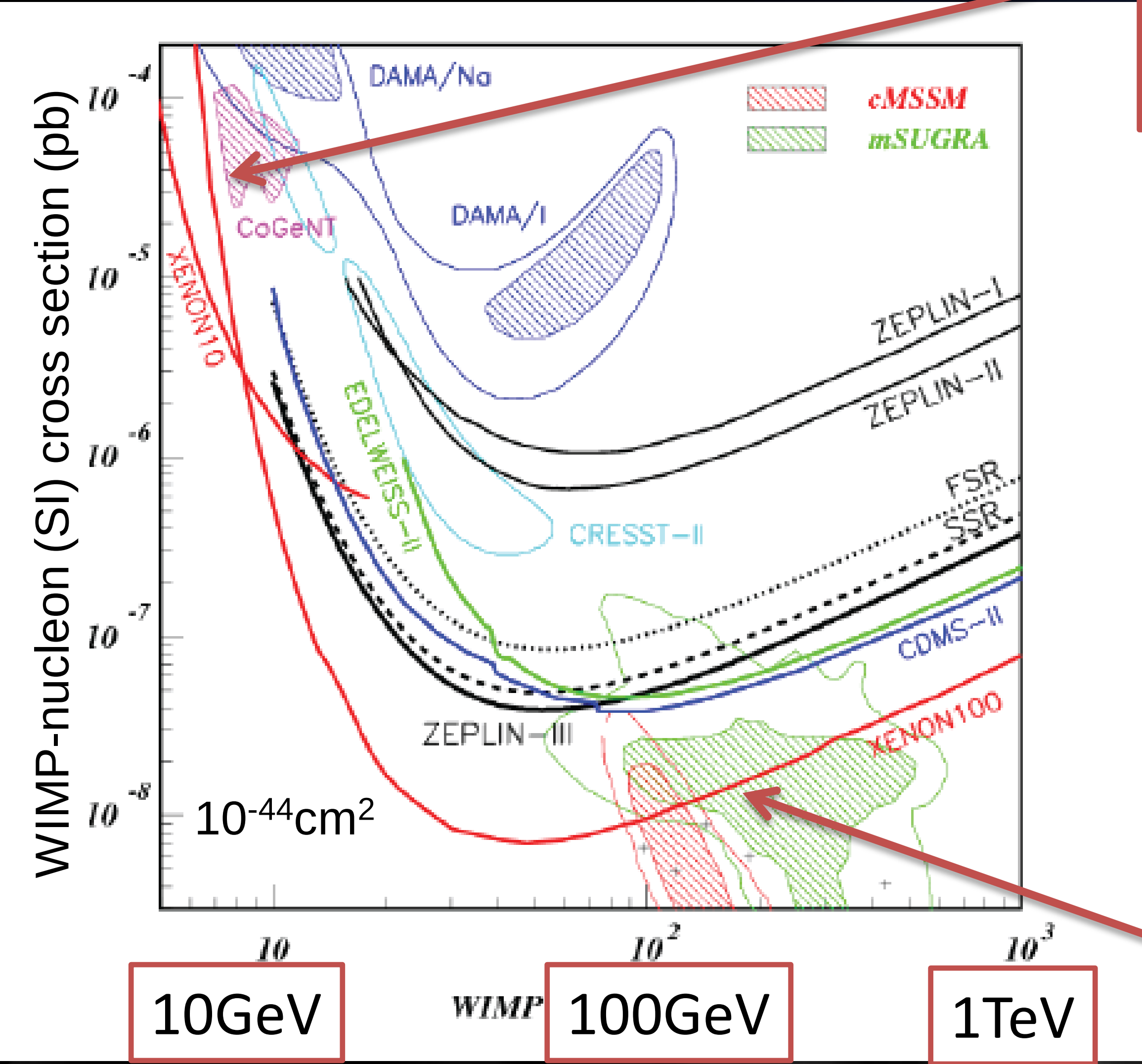
E. Aprile @ dm2012

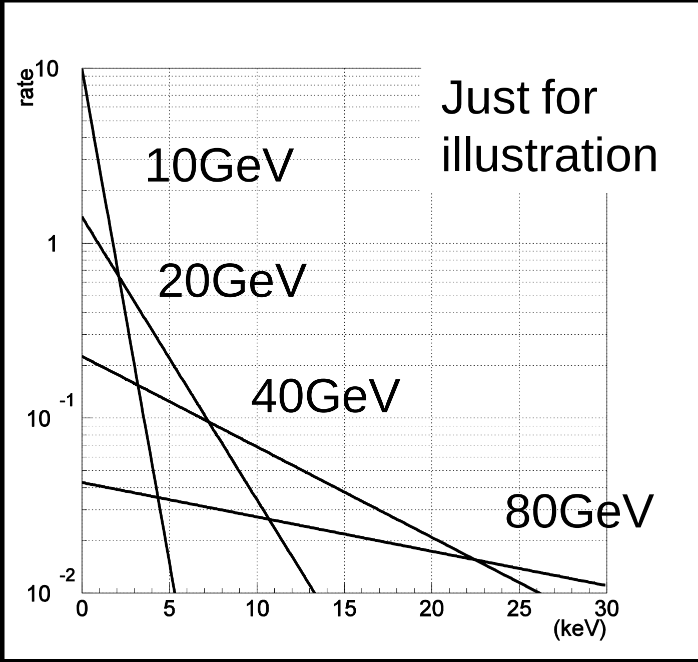




Current status

Light WIMPs:
Low thre (large p.e.) very important
BG, less important





Heavy WIMPs: Low BG important
Larger A preferable

R. Gatitskell@dm2012

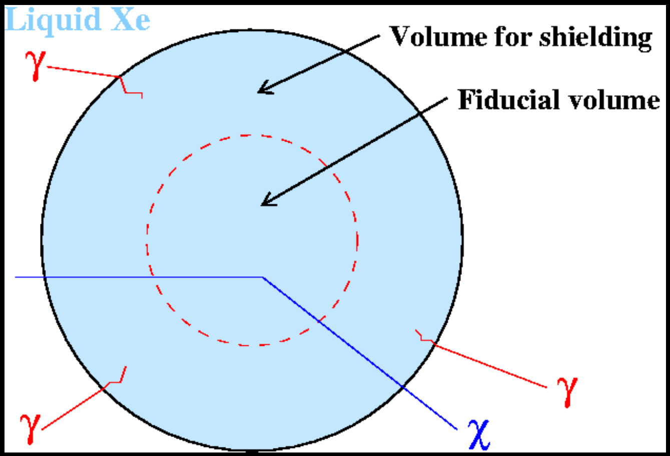
XMASS experiment

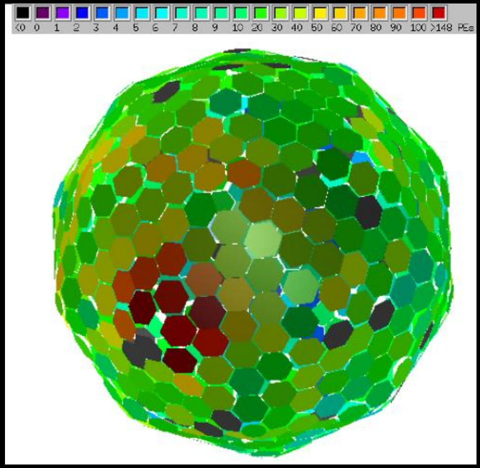
The XMASS experiment

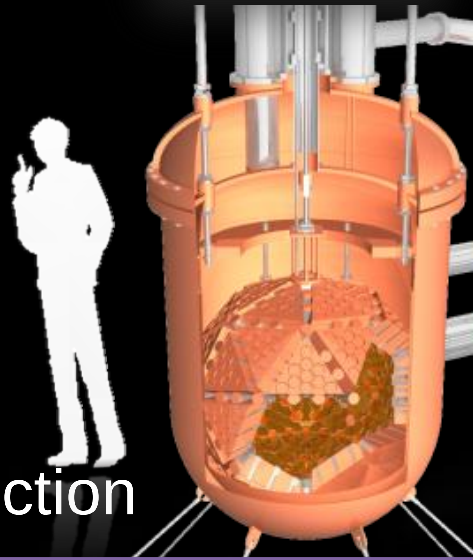
- Single-phase liquid xenon detector, goal: $2\times10^{-45}cm^2$
- 800kg LXe, 642 PMTs immersed in LXe to have max. light yield

- Background reduction w/ self-shielding effect

  Pattern-based vertex reconstruction, E thre >5keV





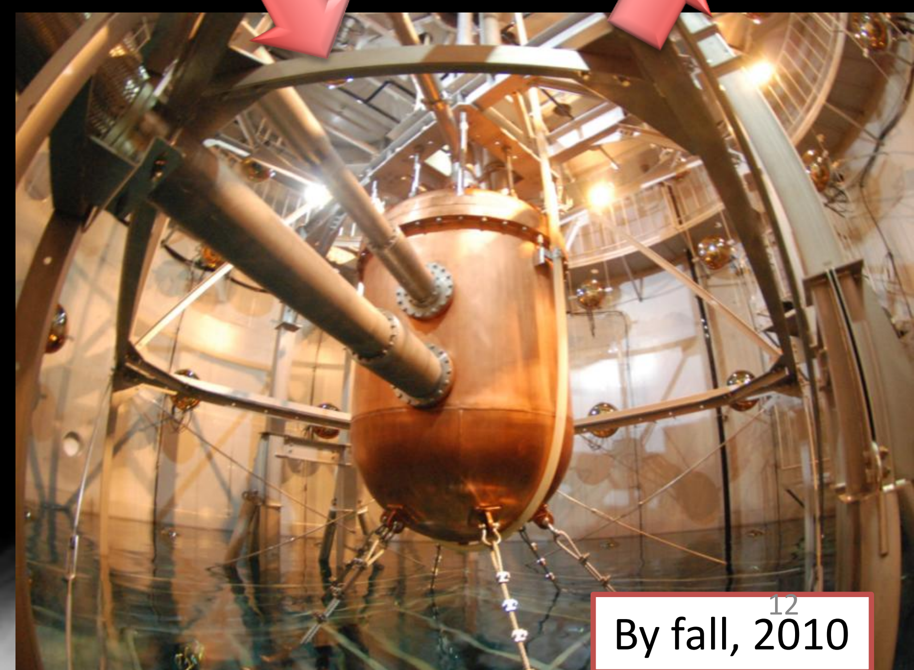


- Distillation for Kr reduction, charcoal for Rn reduction
- Detector construction completed on late 2010.
- Commissioning data taking now.

100kg FV (800kg)
~80cm diameter

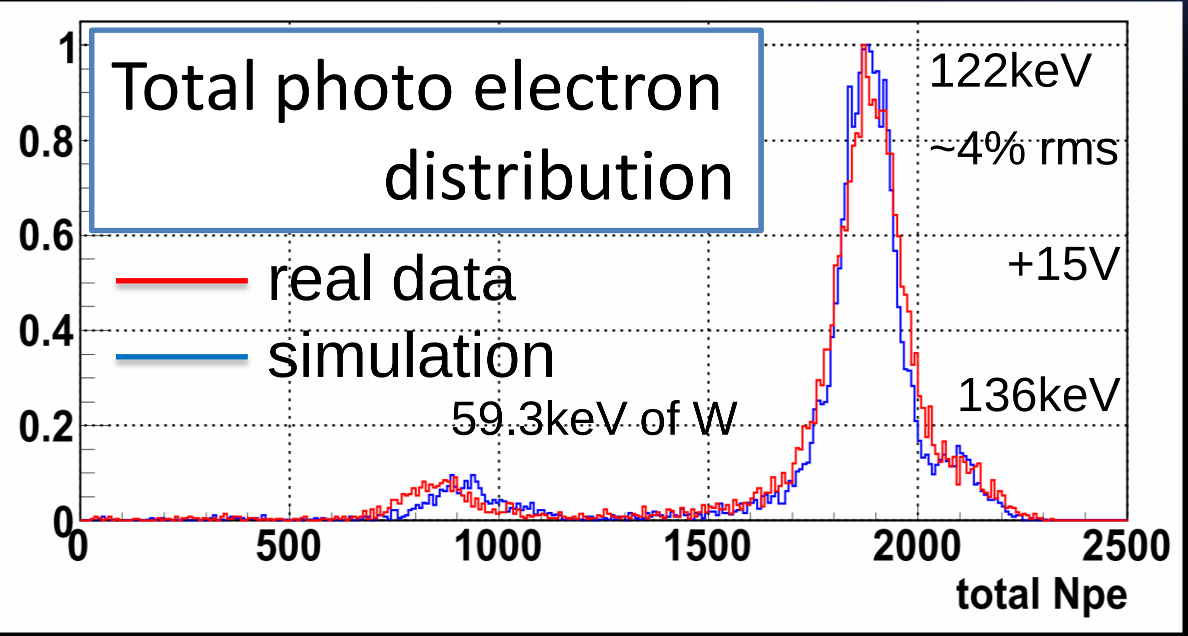
Detector construction

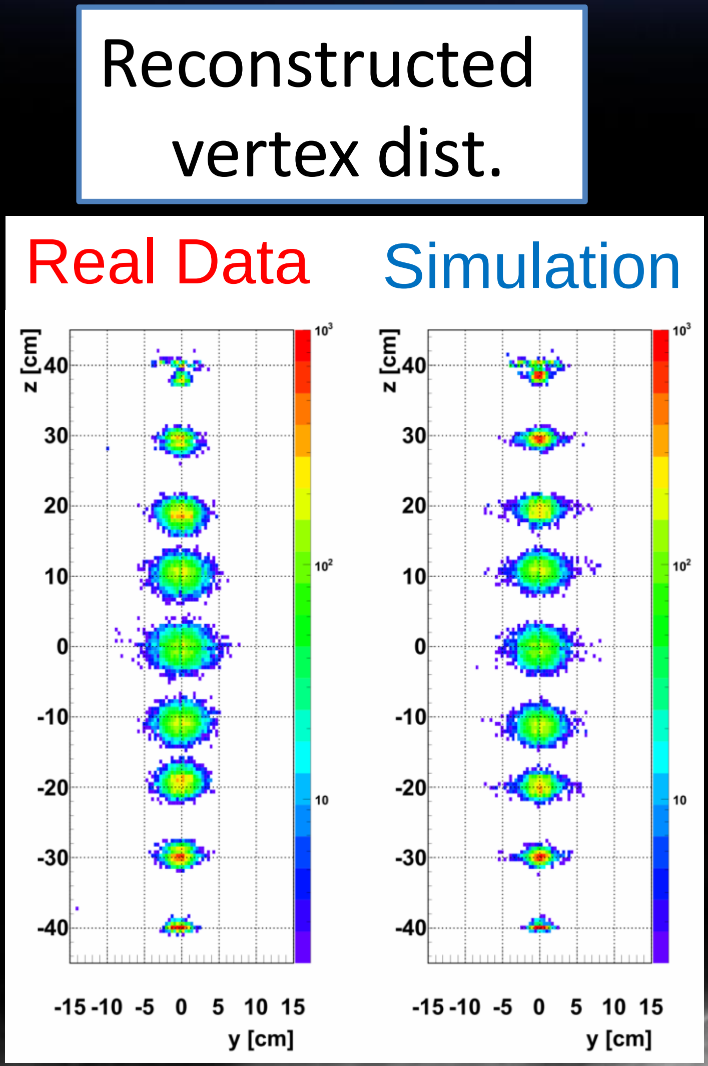
1st application of WC tank for WIMP search



By fall, 2010

Detector response for a point-like source (~WIMPs)

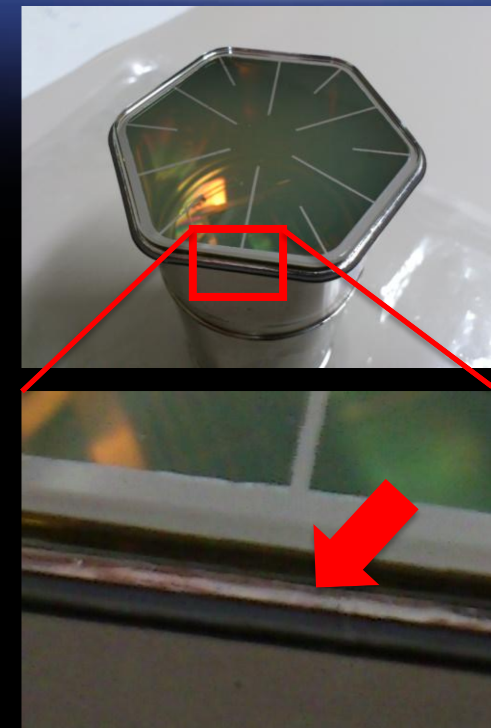




- ^{57}Co source @ center gives a typical response of the detector.
- 14.7p.e./keV_{ee} (⇔ 2.2 for S1 in XENON100)
- The pe dist. well as vertex dist. were reproduced by a simulation well.
- Signals would be <150p.e. exp shape.

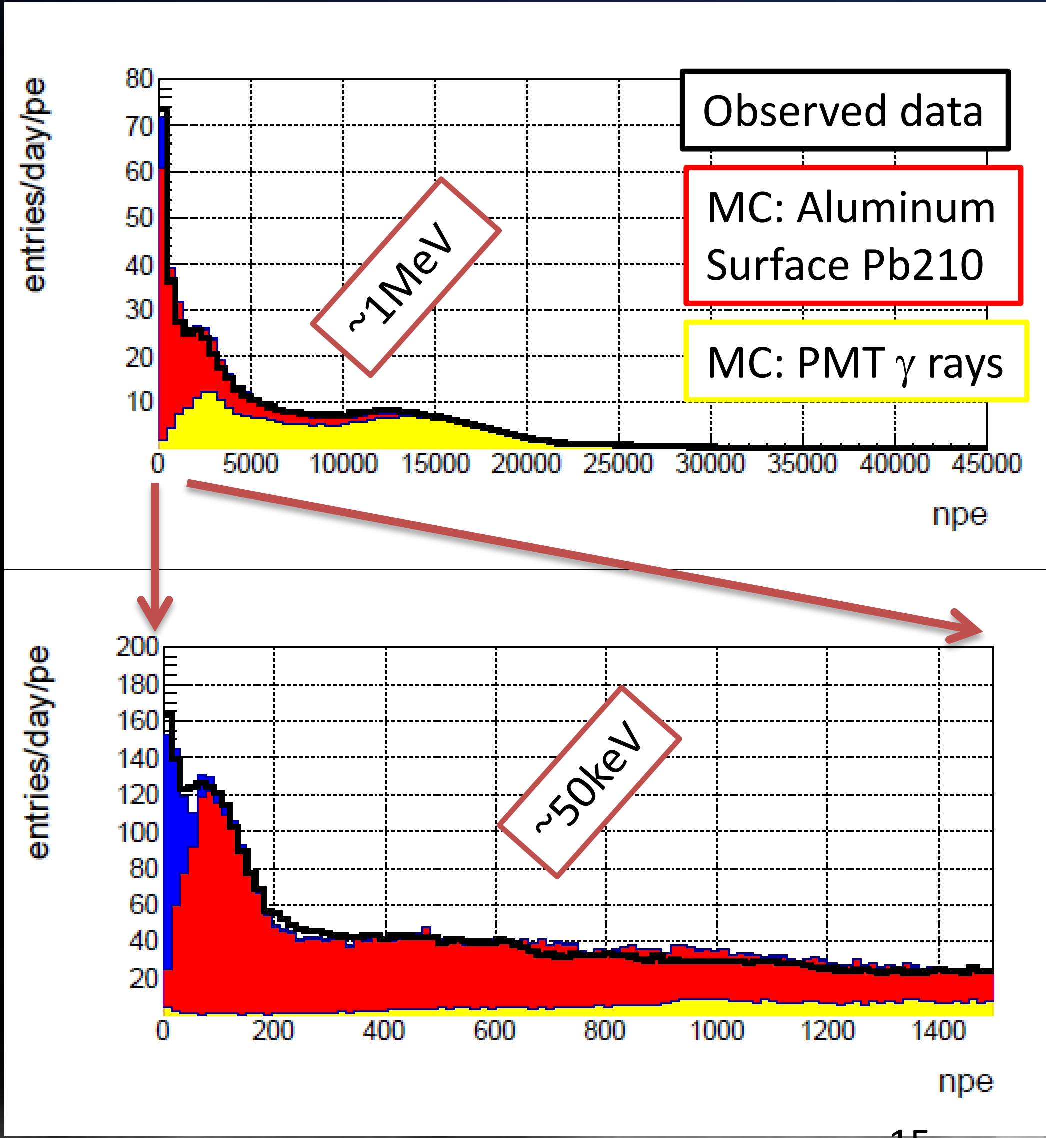
Background and its understanding

- Really important to understand BG to look for a positive evidence of signals.
- 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%.



Closer look at the observed spectrum

- Three contributions to the observed 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.



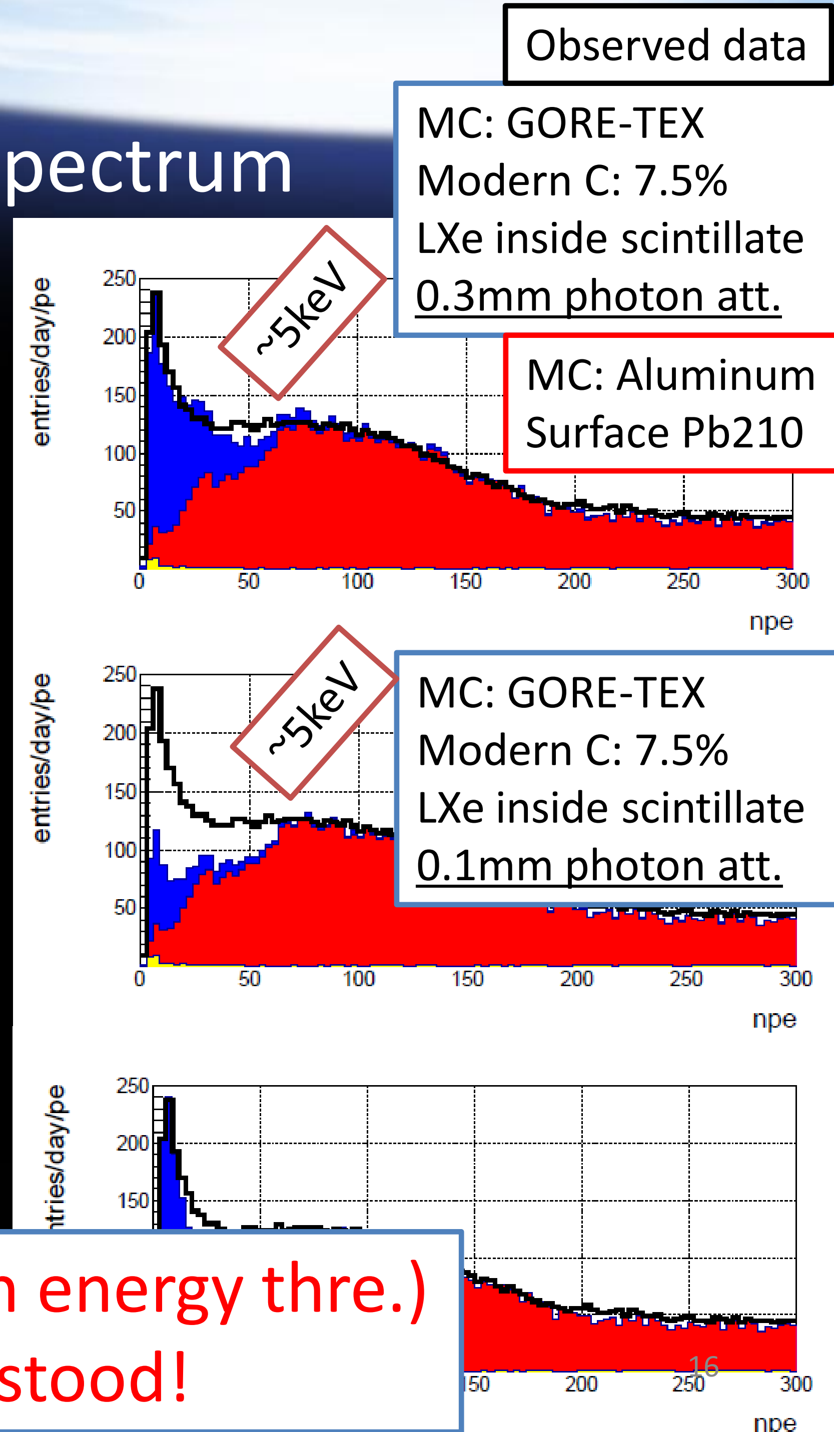
Closer look at the observed spectrum

- Three contributions to the observed 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.

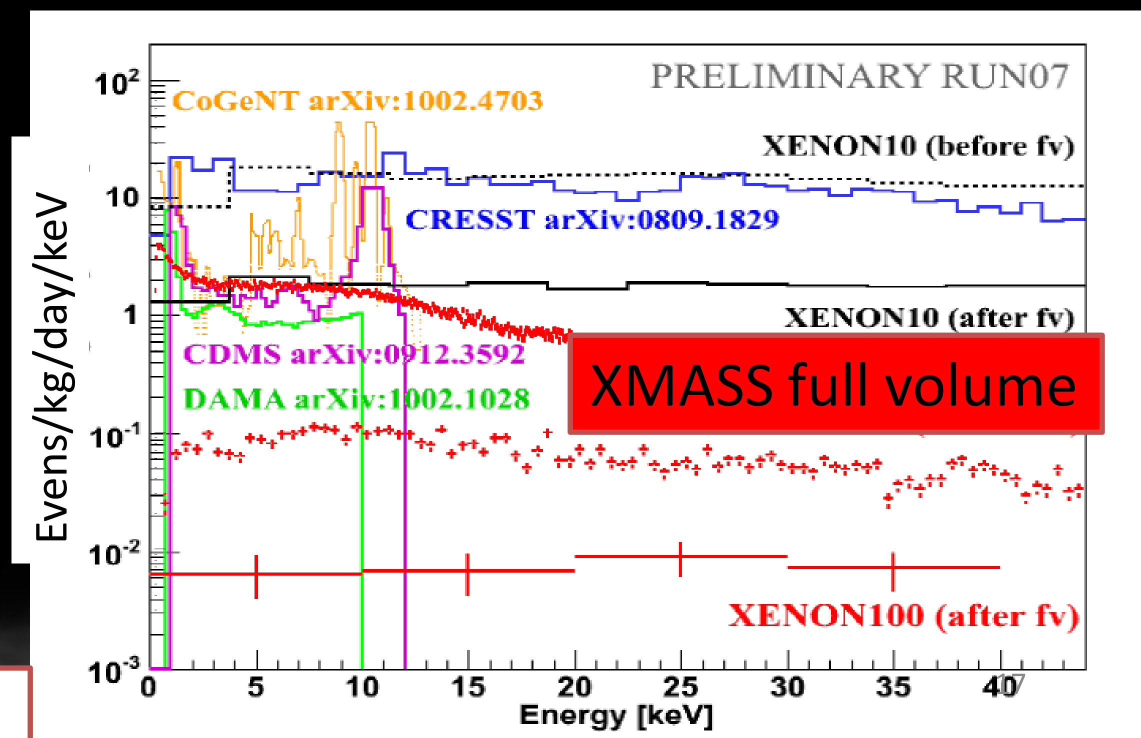
  No prejudice for the origin of these events must be held.



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.
- Today, our sensitivity for the low mass WIMP signals at low energy without reconstruction will be shown.



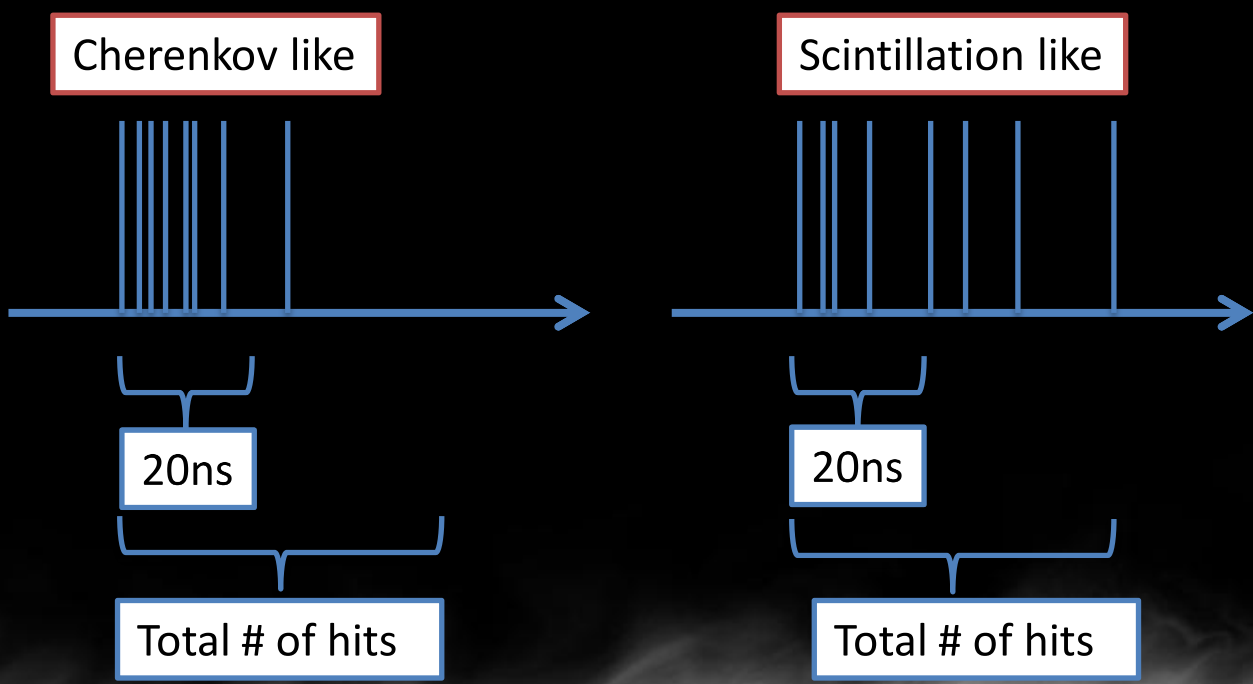
E. Aprile, 2010 Princeton

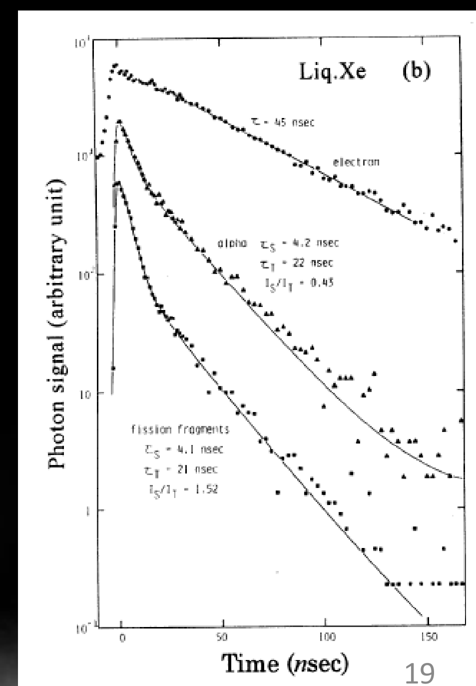
Low energy, full volume analysis for low mass WIMPs

- 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.

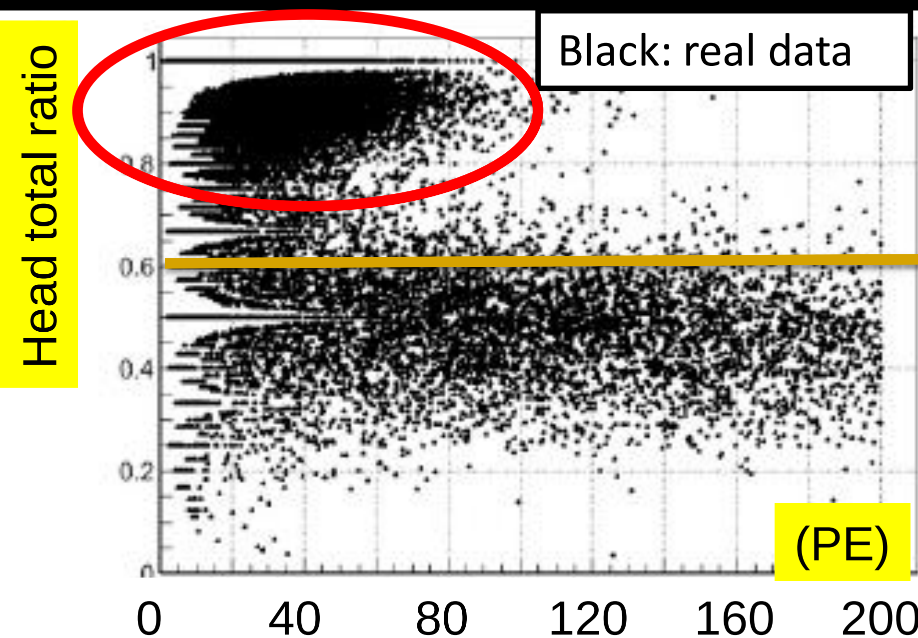


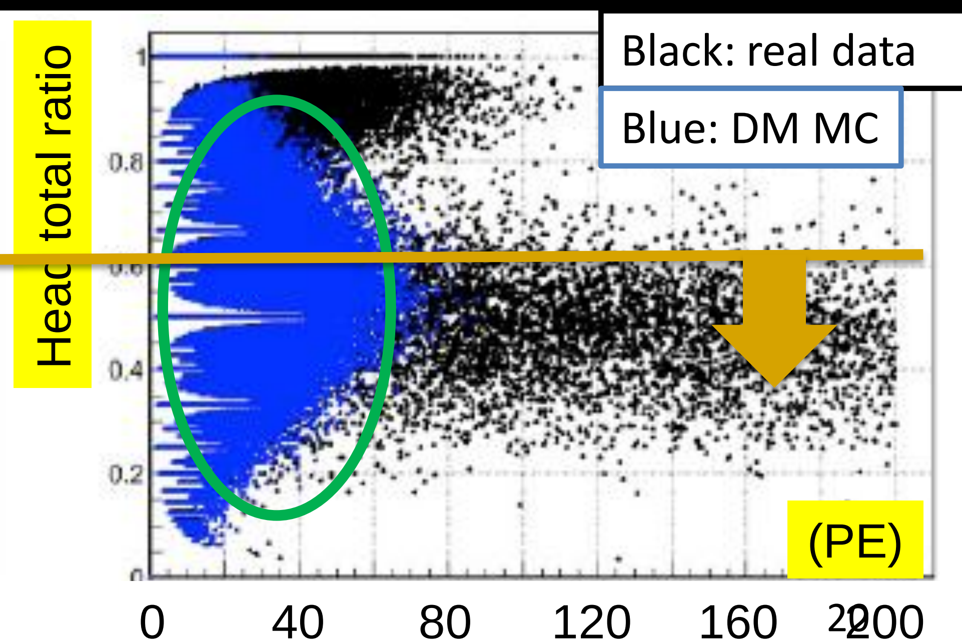


A. Hitachi et al., Phys. Rev. B 27 (1983) 5279.

"head total ratio" distribution

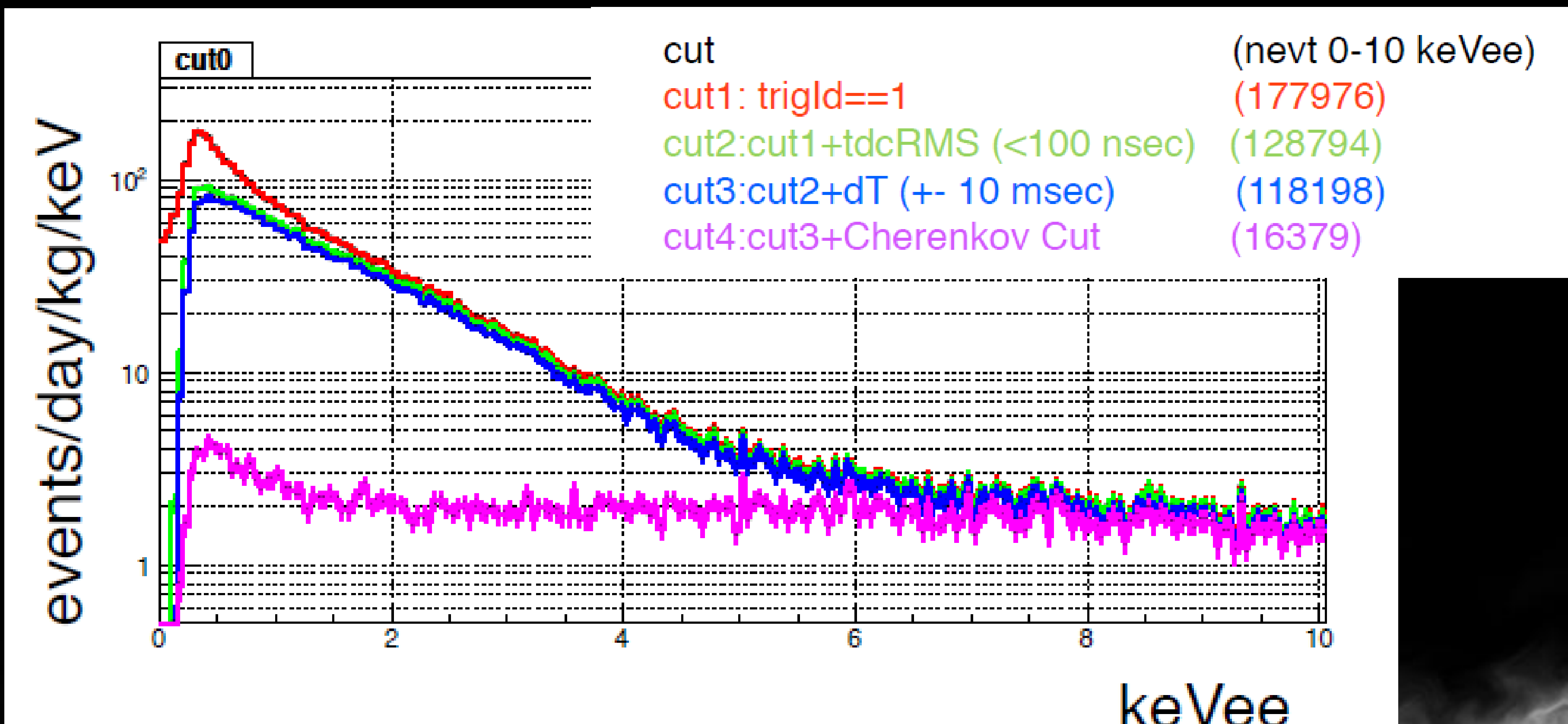
- Cherenkov events peaks around 1 ⇔ scintillation ~ 0.5
- Low energy events observed in Fe55 calibration source as well as DM simulation (t=25ns) show similar distributions.
- Efficiency ranges from 40% to 70% depending on the p.e. range.





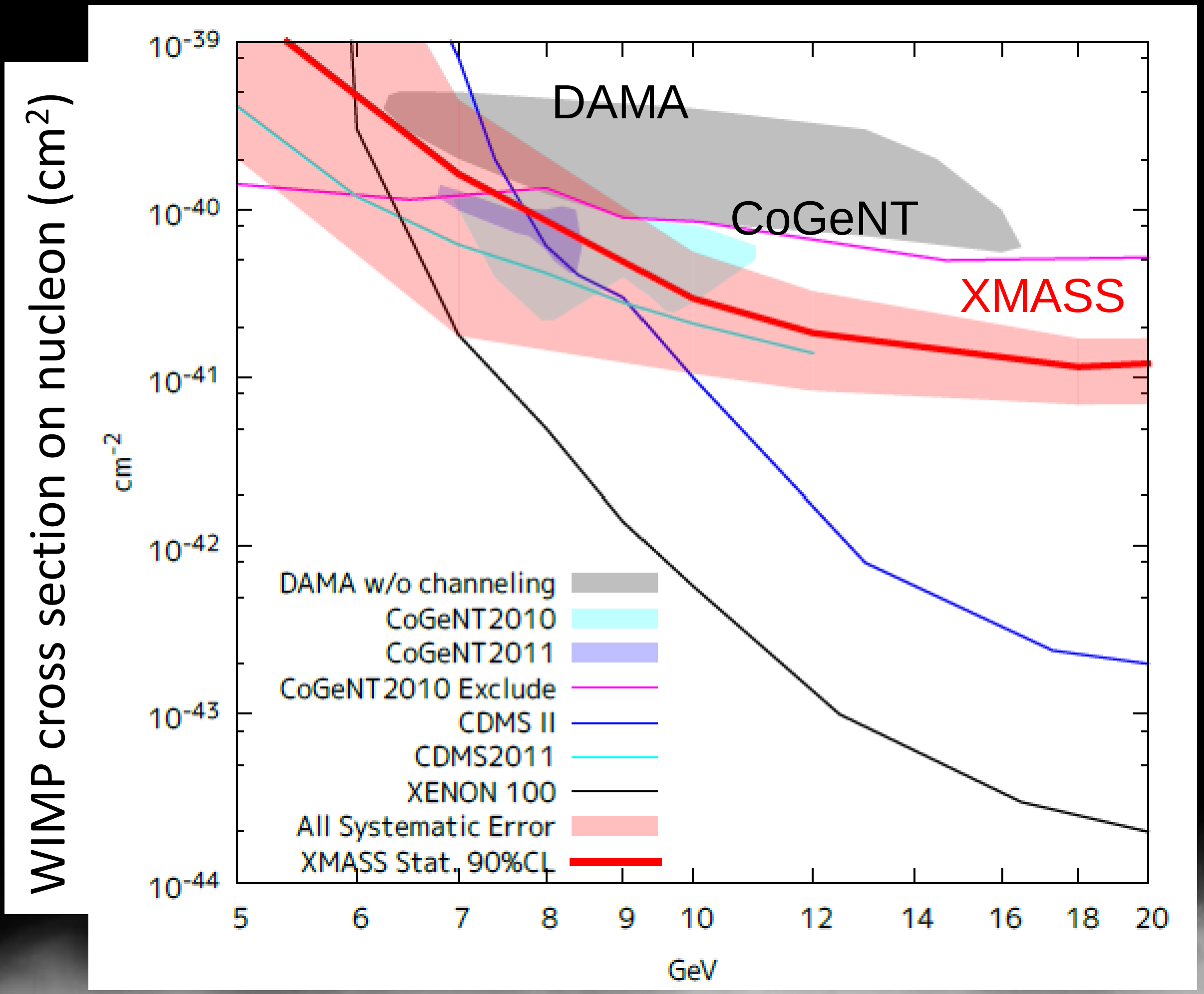
p.e. distribution after each cut

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



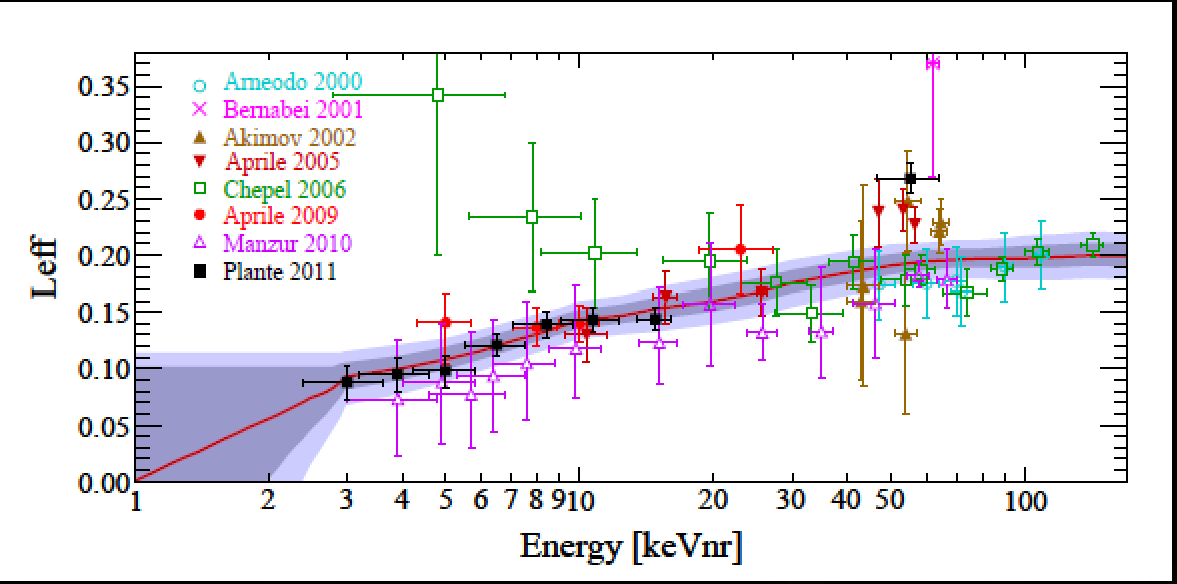
Sensitivity

- 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 properly taken into account.

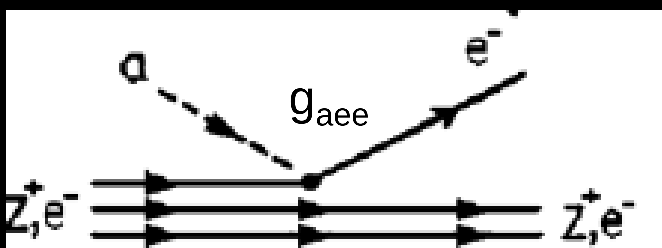


Scintillation efficiency as a function of energy
E. Aprile et al., PRL 105, 131302 (2010)

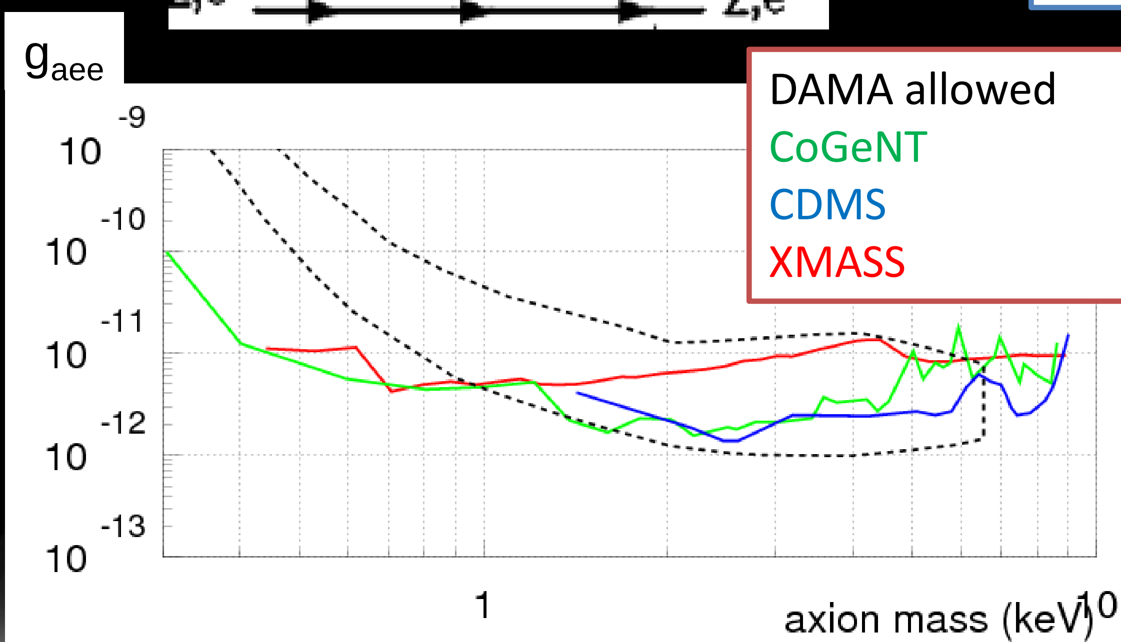
Note: our "energy" = keVnr * Leff

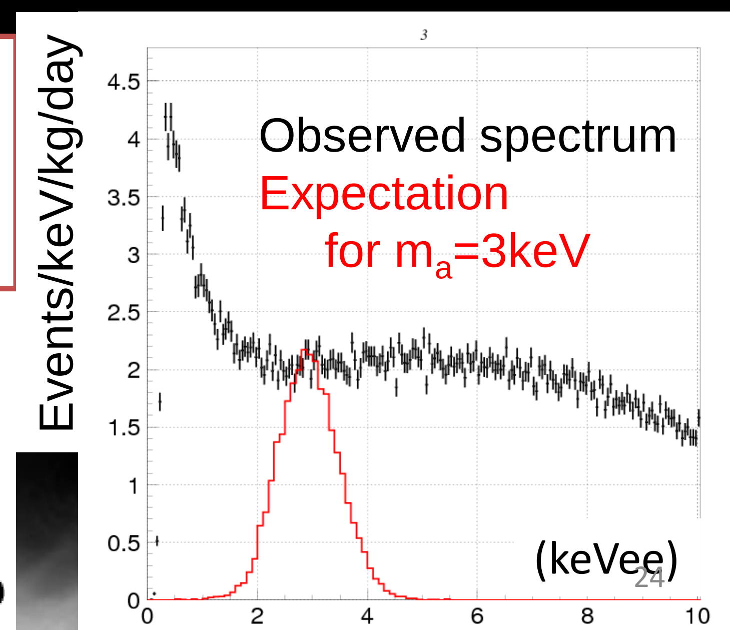
Sensitivity on the axio-electric dark matter coupling

- 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



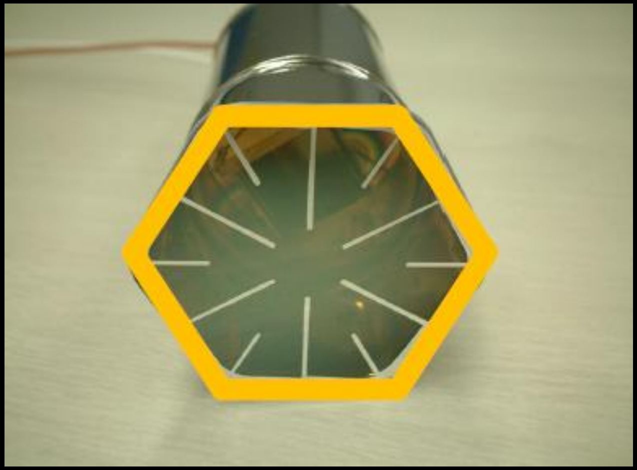
Non relativistic axion deposits its total energy similarly to the photo-eletcric effect.

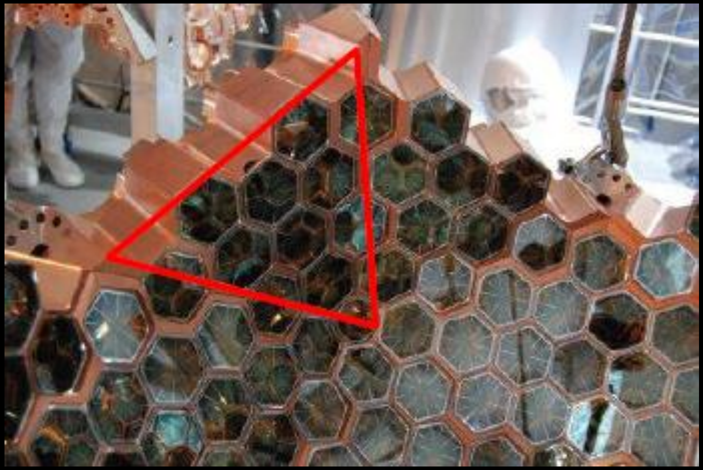




Plan: Refurbishment work

- 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:

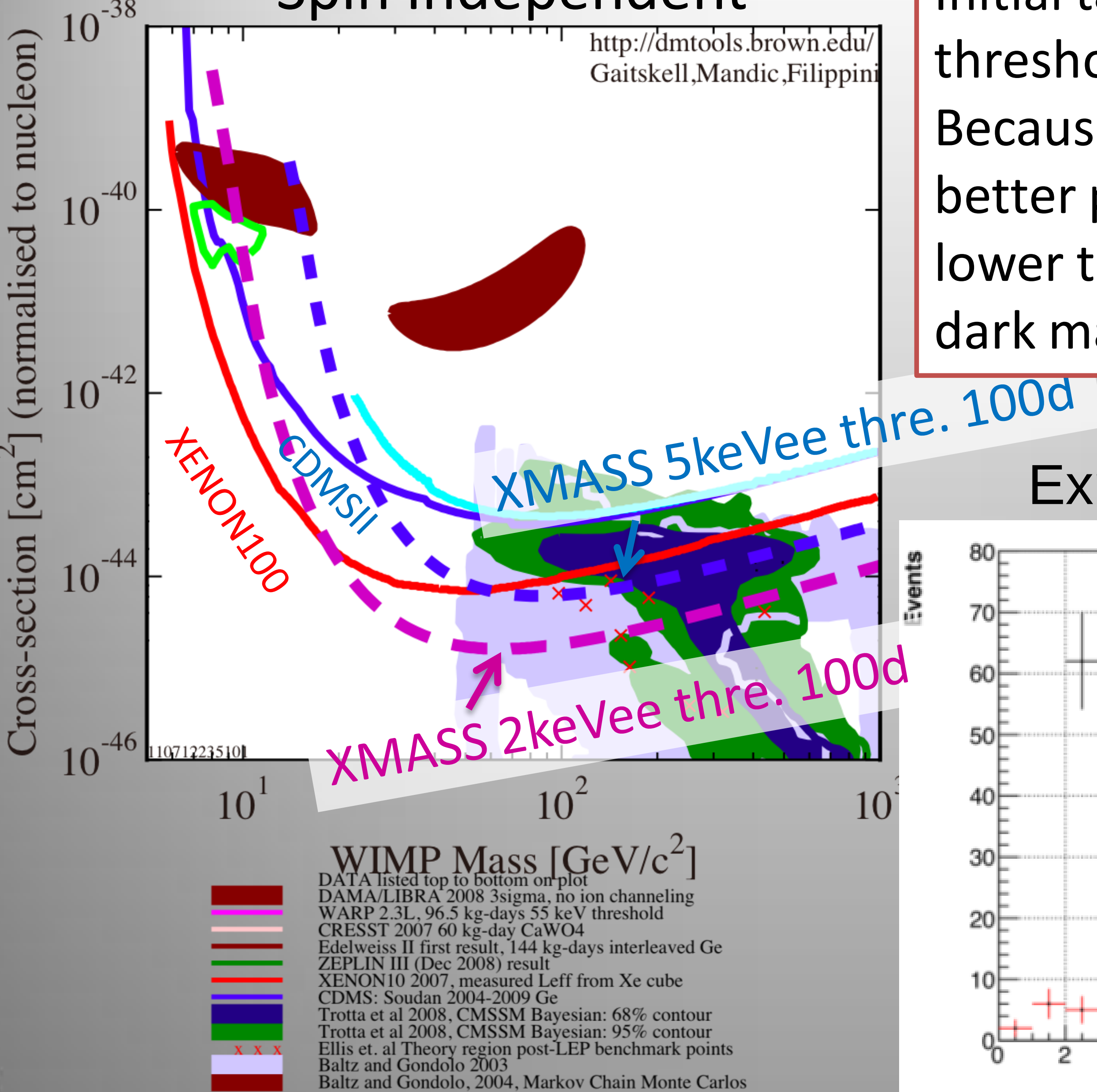




- BG > 5keV must be reduced significantly.
- Schedule: latter half of this year

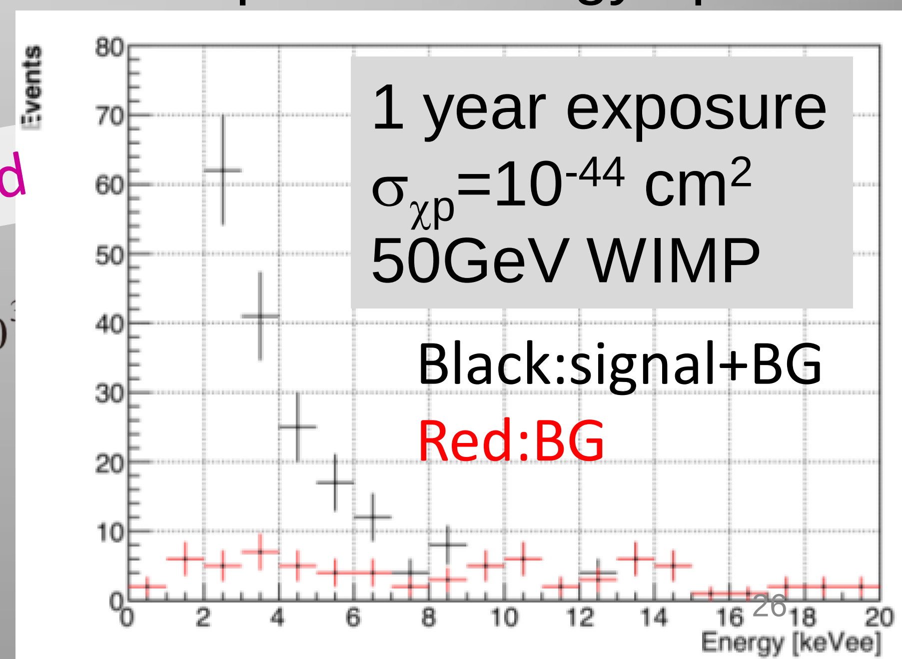
Expected sensitivity with fiducialization

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.



Summary

- LXe has advantages for WIMP search, and is widely used.
- Current best limit: $7 \times 10^{-45} cm^2$ (3 orders of mag./10yr!)
- DAMA/LIBRA and CoGeNT suggested low mass (~10GeV) WIMPs which are widely studied by many groups.
- XMASS started commissioning run. Low thr. with large light yield. World top class sensitivity for the low mass WIMPs even though it has surface BG. BG well understood >5keV.
- Detectors with larger size but lower BG for much better sensitivity on WIMPs are planned over the world.