XMASS experiment

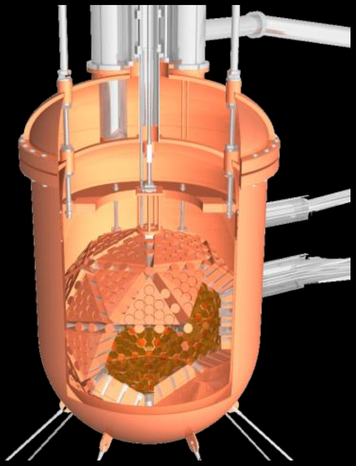
S. Moriyama

January 17, 2013 @ external review, ICRR

XMASS experiment

Multi-purpose experiment using liquid xenon (-100C)

XMASS-I

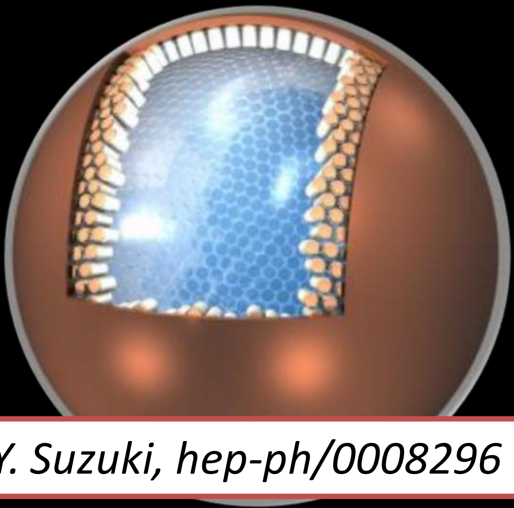


Phase I: 100kg fiducial volume (Total 835kg)

Direct detection of Dark Matter

χ+Xe → χ+Xe

XMASS-II Multi-purpose



Y. Suzuki, hep-ph/0008296

Final goal: 10ton fiducial volume (total 25ton)

Direct detection of Dark Matter χ+Xe → χ+Xe

pp-^{7}Be-solar neutrino ν+e → ν+e

Double beta decay ^{136}Xe → ^{136}Ba + 2e^{-}

The XMASS collaboration

Kamioka Observatory, ICRR, Univ. of Tokyo:
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Miyagi University of Education: Y. Fukuda

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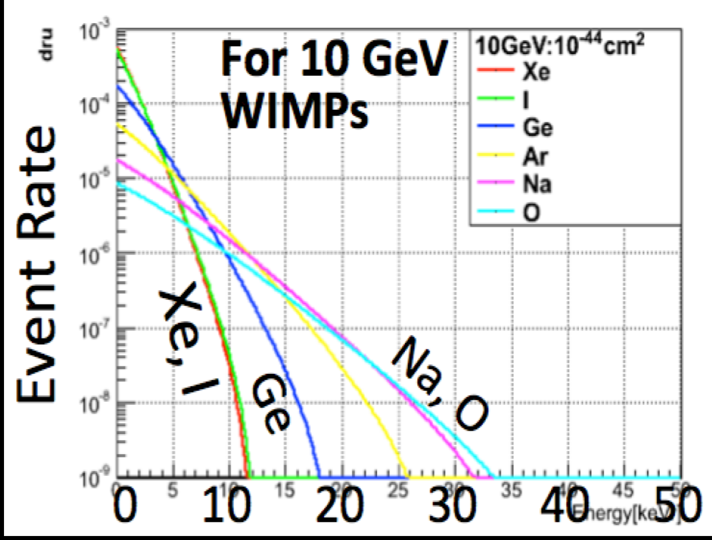
KRISS: Y.H. Kim, M.K. Lee, K. B. Lee, J.S. Lee

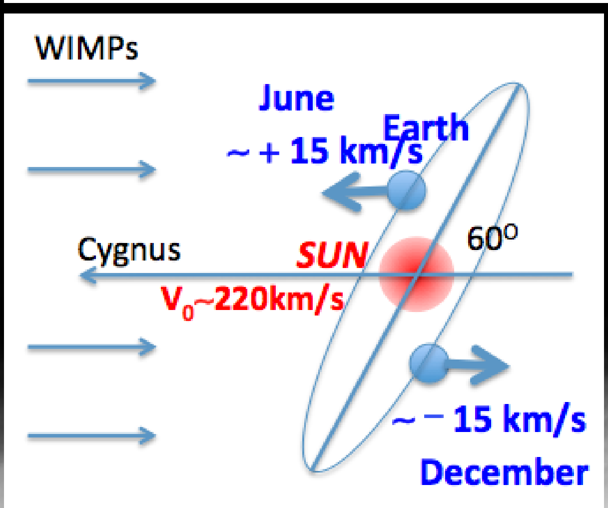
42 collaborators,
10 institutes

Physics in XMASS

- Solar neutrino, pp & ^{7}Be (XMASS-II)
  - 14ev/d pp-ν, 6ev/d ^{7}Be ν (10 ton)
  - ~1/10 of expected BG of phase I
- Double beta decay (XMASS-II)
  - High light yield and good E res.
- Dark Matter search
  - Isothermal halo model, v~10^{-3}
  - ~ 0.1 ev/day/100kg-Xe

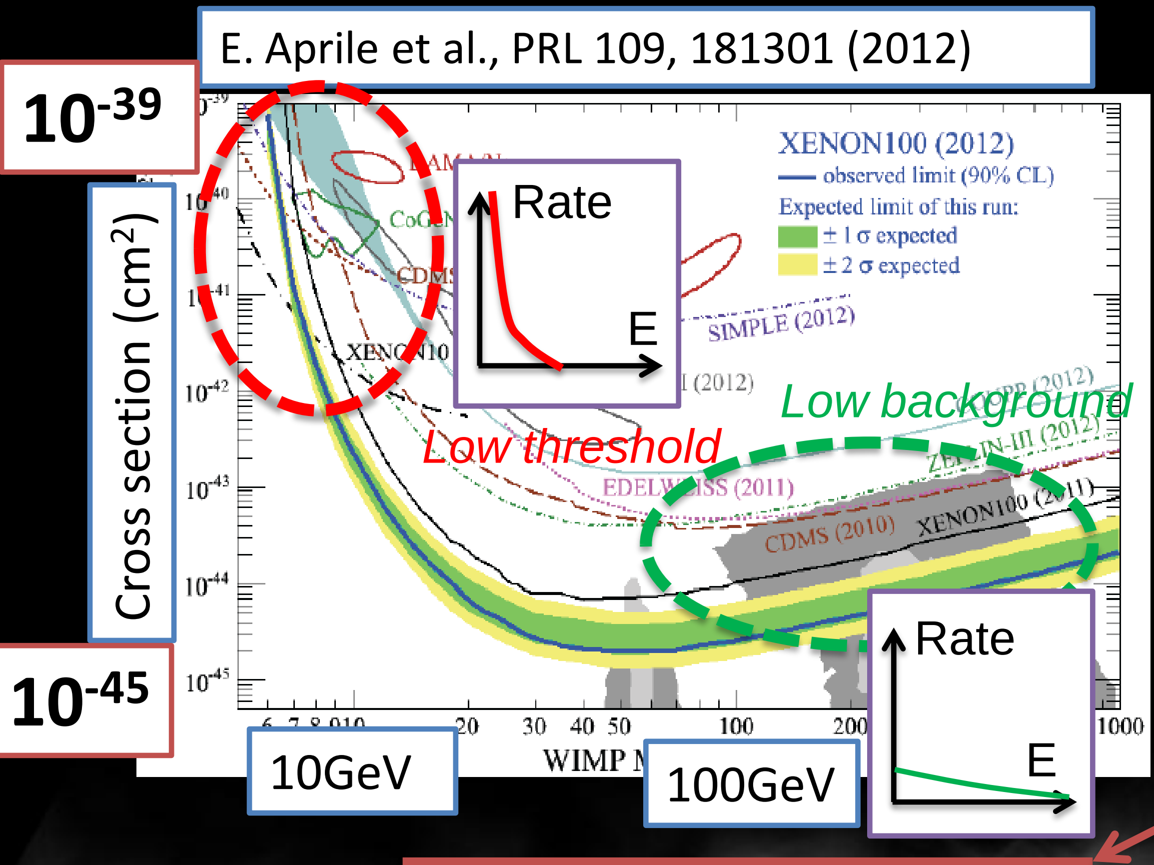
  (m_χ = 50 GeV and $\sigma_{SI}=10^{-44}$ cm^2)
  - Annual modulation <10%





Physics in XMASS

– Light mass WIMPs (low energy threshold)
– Heavy mass WIMPs (low background)



- Phase I
  - Sensitivity

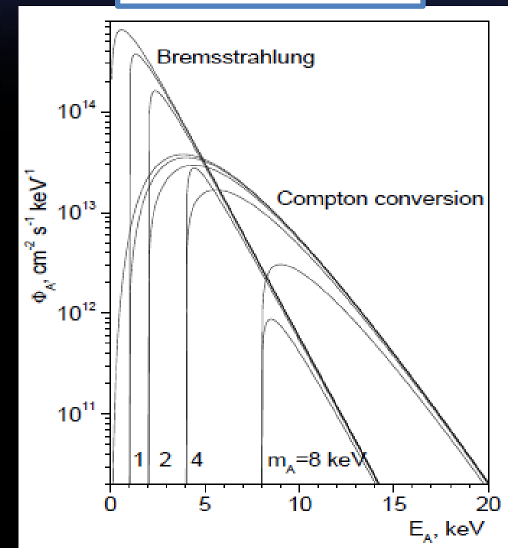
    σ_{SI} ~ a few x 10^{-45} cm^2
  - BG 10^{-4} /day/kg/keV
- Final goal (XMASS-II)

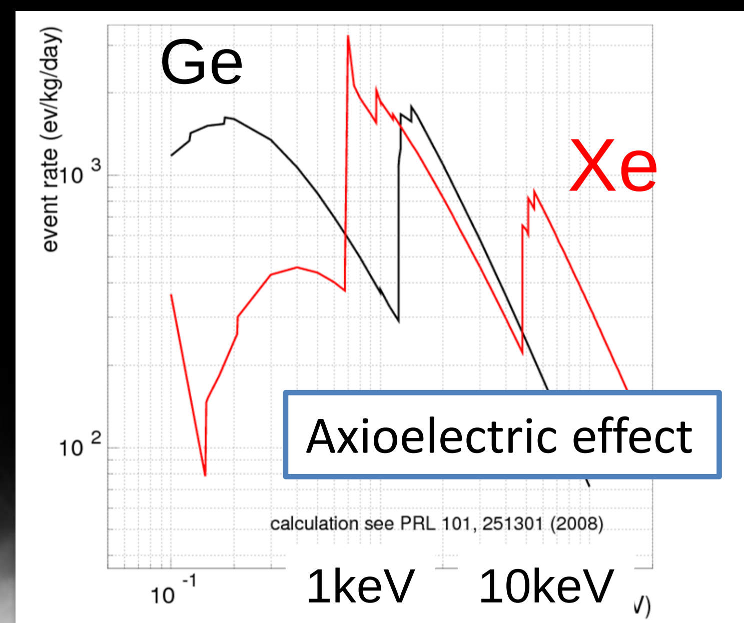
  $\sigma_{SI} \sim 10^{-47}$ cm^2

Physics in XMASS

- Search for e/γ signals
  - Large mass: ~>O(ton)
  - Low energy threshold <<1keV
  - Low background <<1/kg/keV/day
- Ex. 1) Axion and its relatives
  - DM axion: 10^{-6}-10^{-3}eV: Invisible
  - Solar axions
  - Axion Like Particles
- Ex. 2) Bosonic super-WIMPs as DM (0.3-100keV)

Solar axions

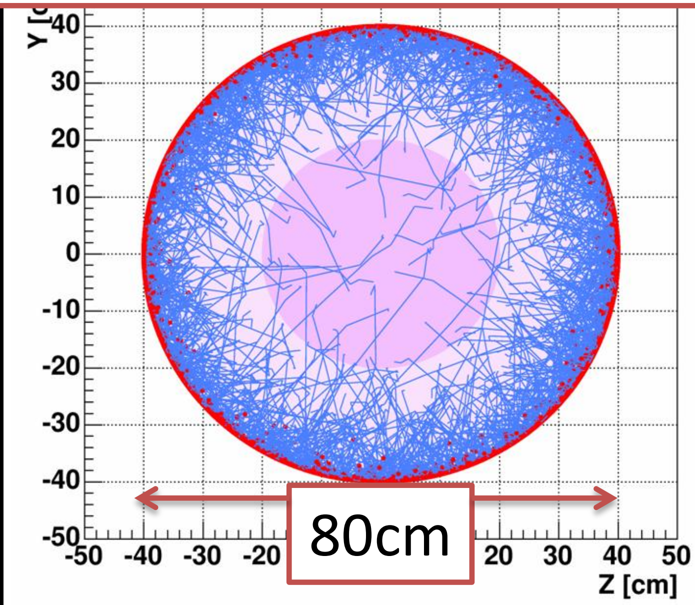




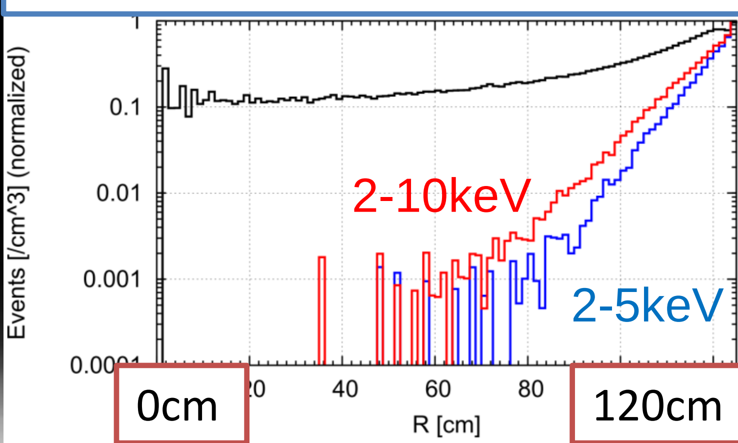
Single-phase LXe detector

- BG red. by fiducial volume (FV) cut
  - Good to search for e/γ events
- Larger det. has better performance.
  - Timing information start to be major info. (scintillation group velocity ~ 11cm/ns ⇔ scintillation τ=30-40ns)
  - Attenuation ~6m for scintillation light
    ⇔2phase: charge attenuation <1m
  - Better self-shielding eff. for e/γ/n
    ⇔2phase: e/γ rej. only ~ 10^{-2}–10^{-3}
    ⇔2phase: High voltage is a potential problem (XENON100: 30kV (16kV achieved), XENON1t: 100kV)

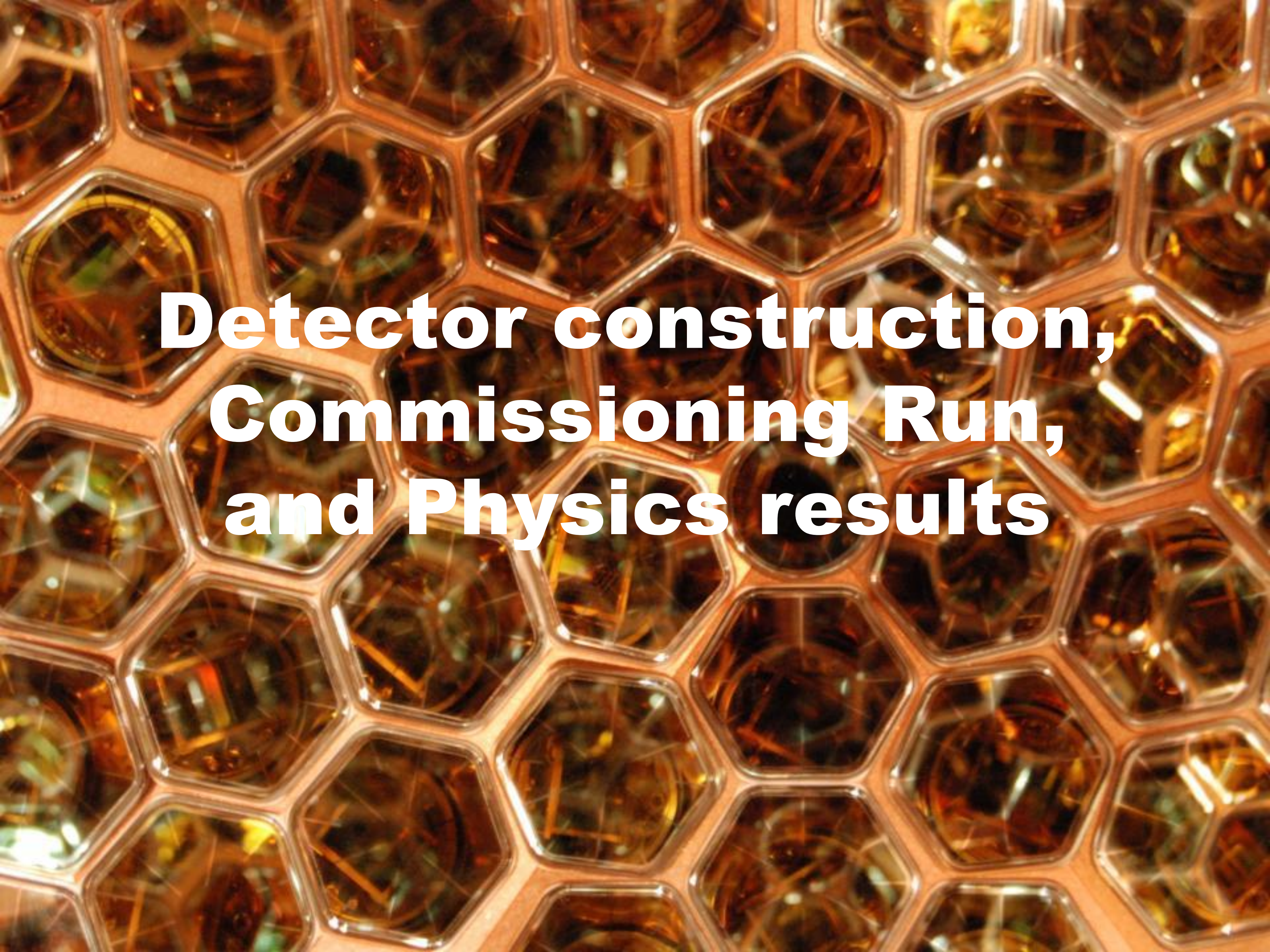
Self shielding for γ injection (XMASSI)



10MeV neutron injection (XMASSII)

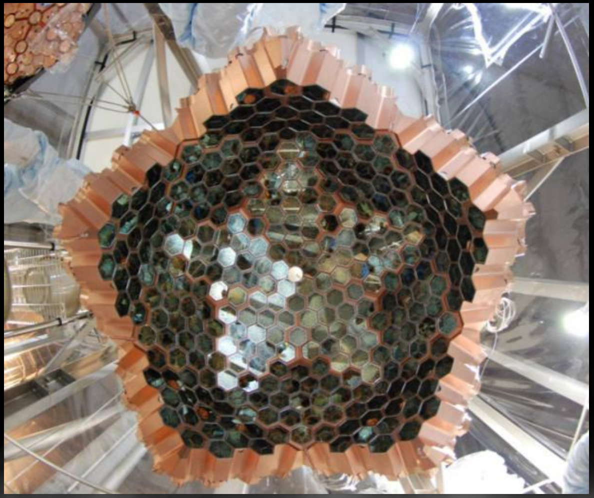


Detector construction, Commissioning Run, and Physics results

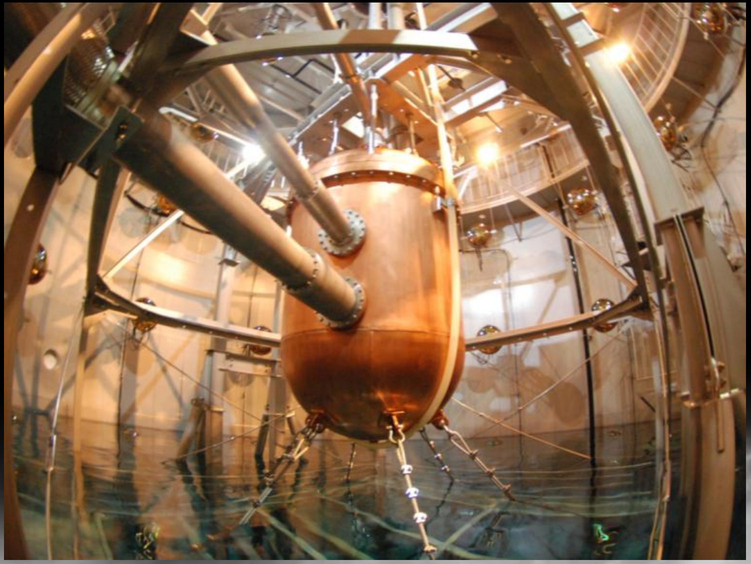


Detector construction

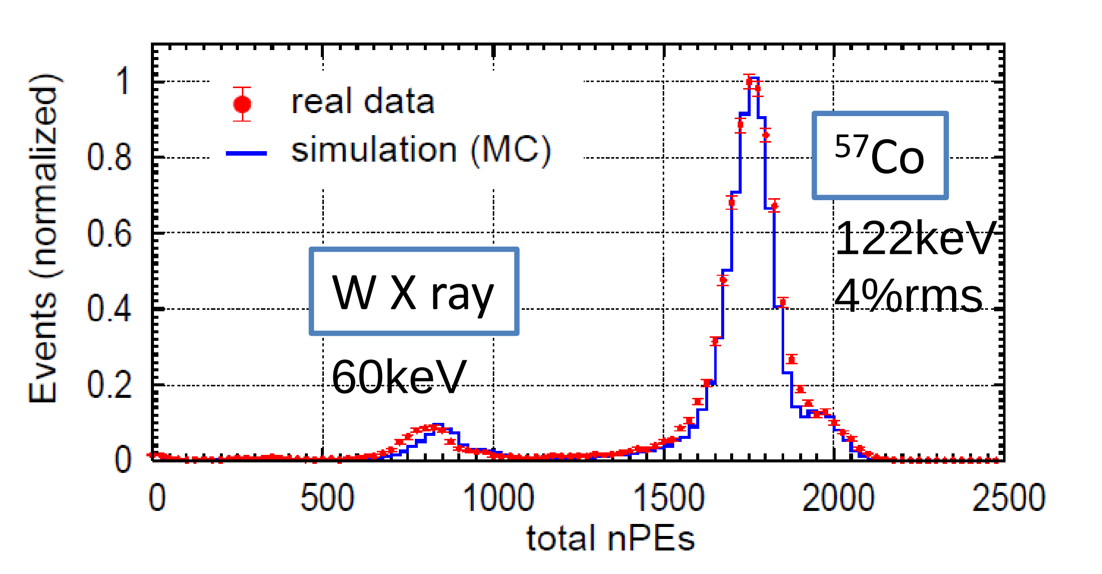
- 2009.11: PMT holder and PMT installation



- 2010.09: Construction Completed

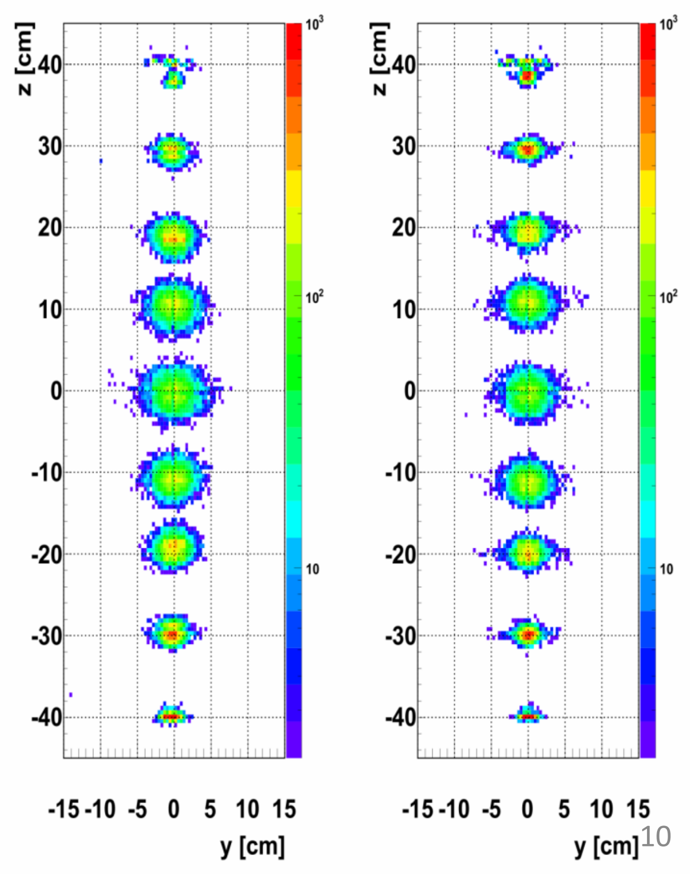


Demonstration of the detector performance



Reconstructed position

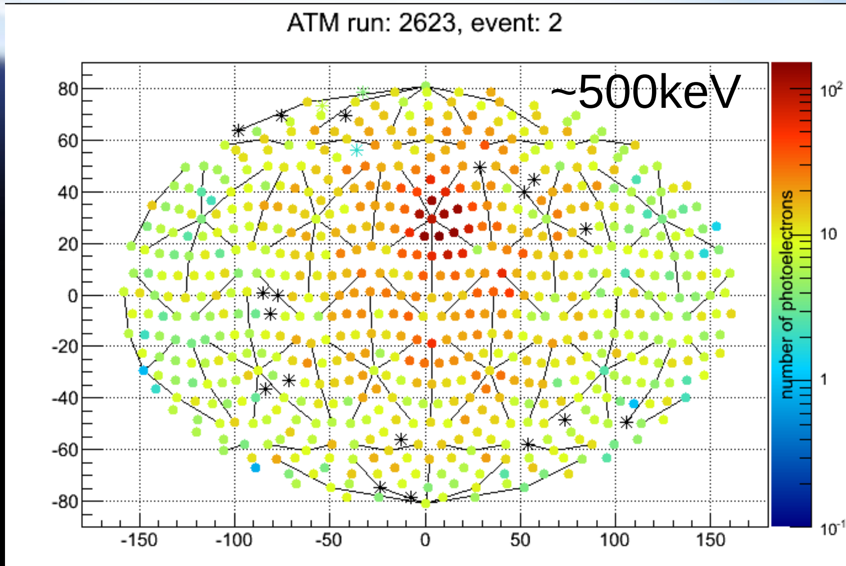
Real Data Simulation

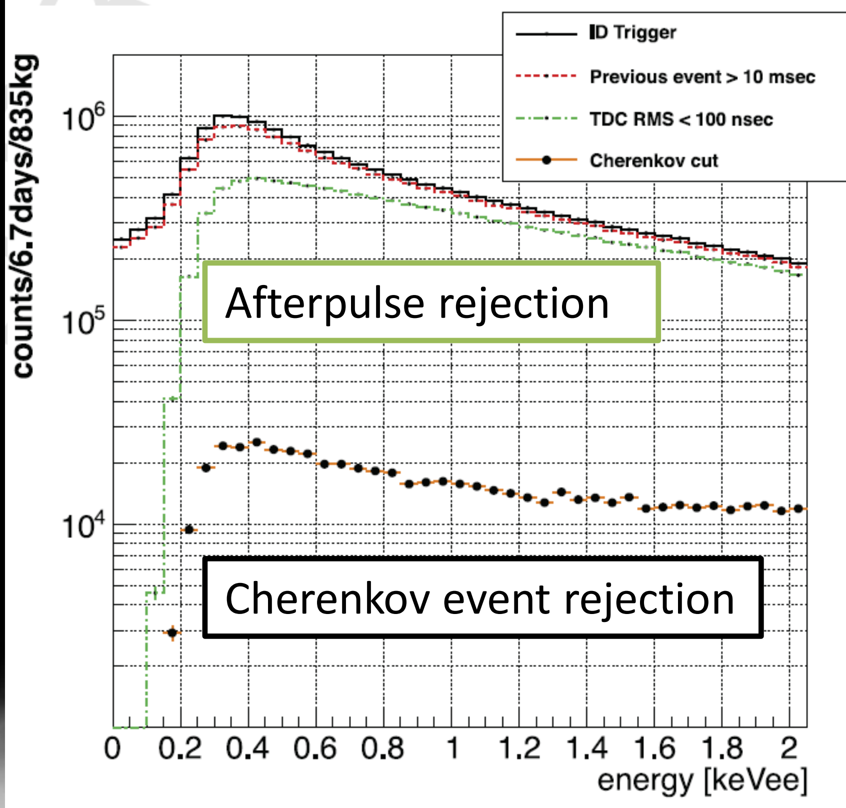


- The detector gave high photo-electron yield ~14.7p.e./keV thanks to efforts. Largest among DM detectors (2p.e./keV XENON100)
- Detailed description of the detector: arXiv:1301.2815

Normal run data

- From the first “dark” on Oct. 24 2010, we continued commissioning by May 2012.
- DAQ is triggered based on # of hit PMT within 200ns window.
- Right figure shows the energy spectrum for each reduction step.

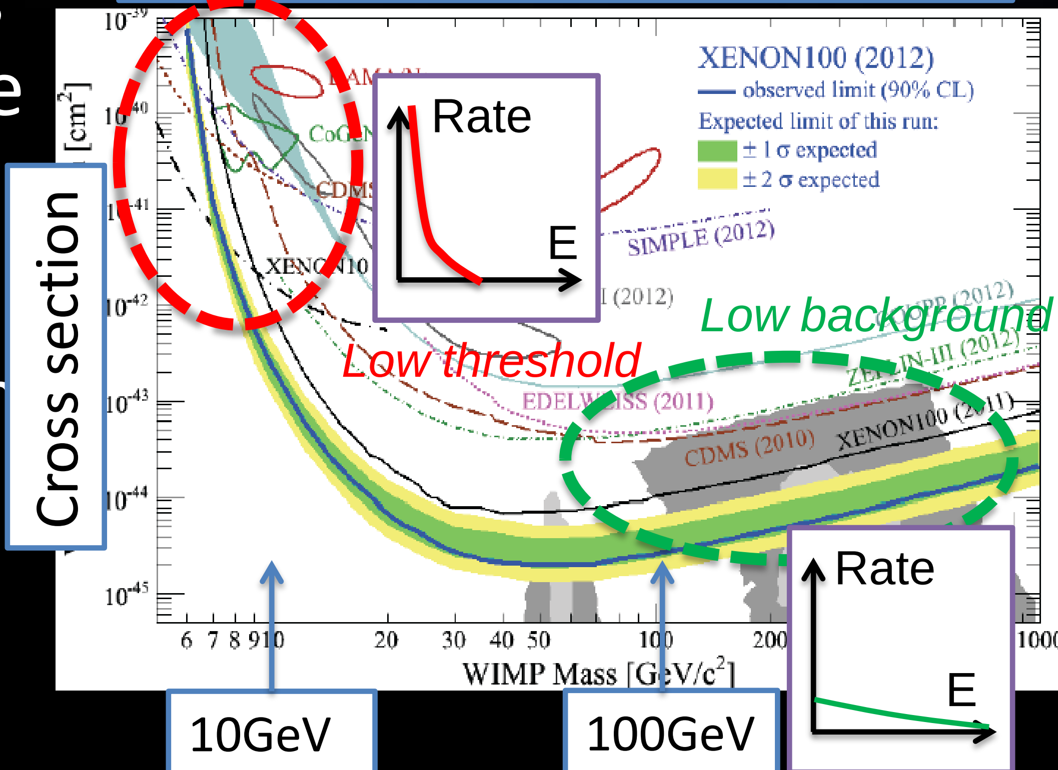




(1) Low mass WIMPs search

- One of the interesting parameter space to be studied.
  - DAMA and CoGeNT saw signal/modulation
  - Fermi?
- Energy deposition is smaller for them.

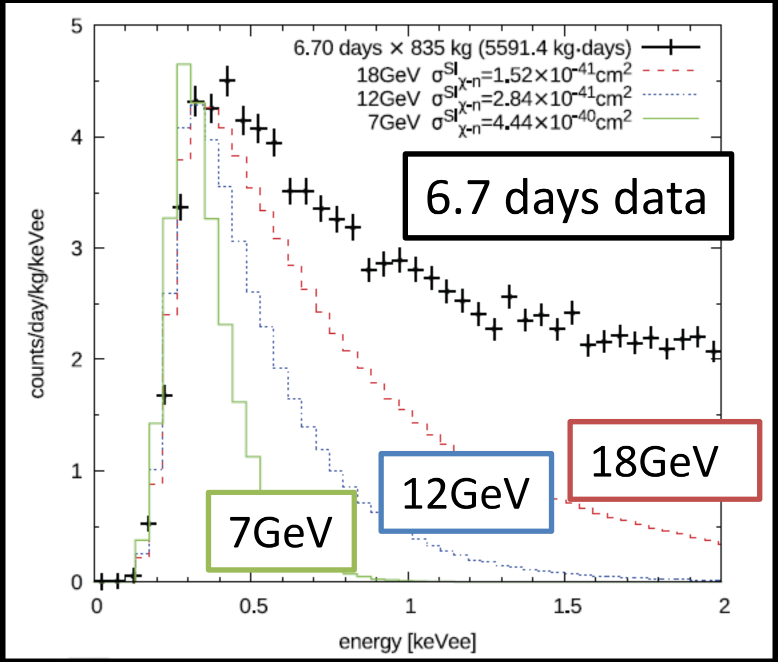
E. Aprile et al., PRL 109, 181301 (2012)

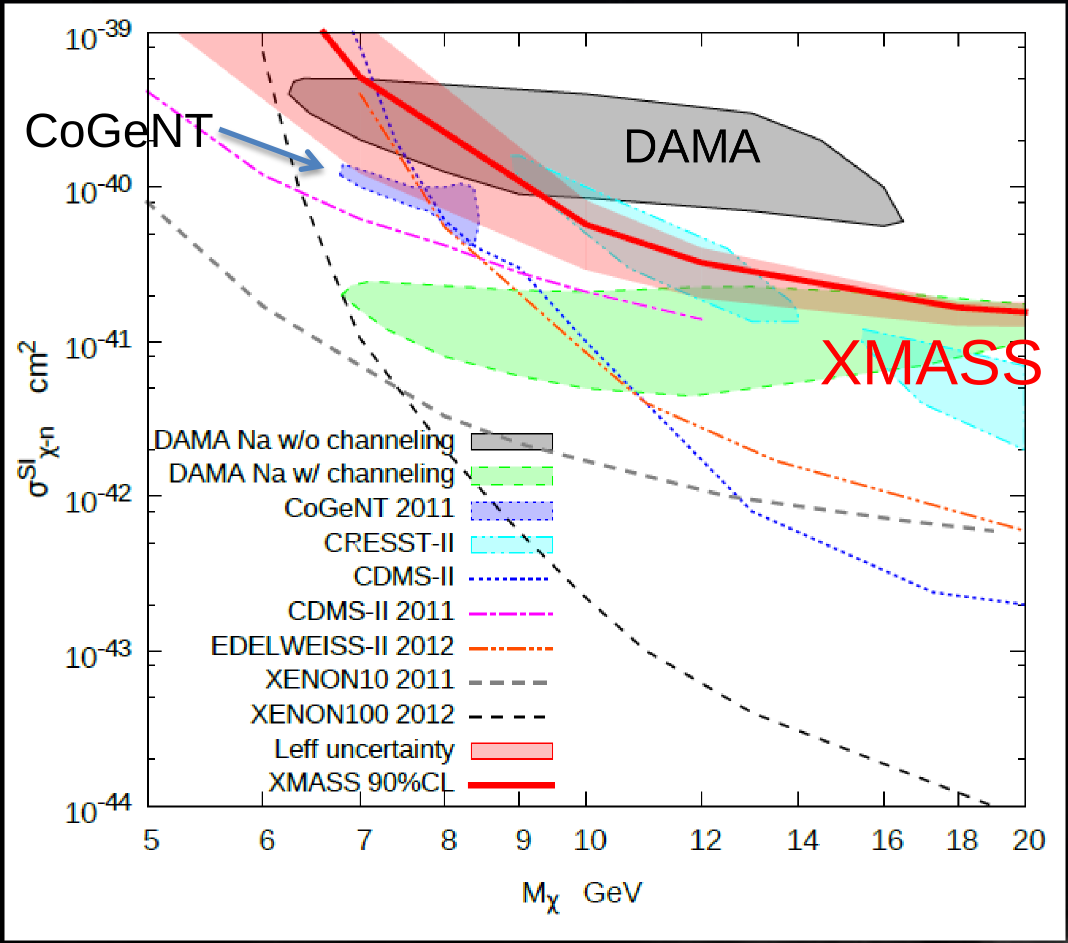


- Our low-energy threshold (0.3keV ⇔ 0.5keV for CoGeNT, 2keV for DAMA) is suitable for the study since the low mass WIMPs can give smaller energy.

Exclusion with current data set

- 0.3 keV threshold enables us to search for low mass WIMPs.



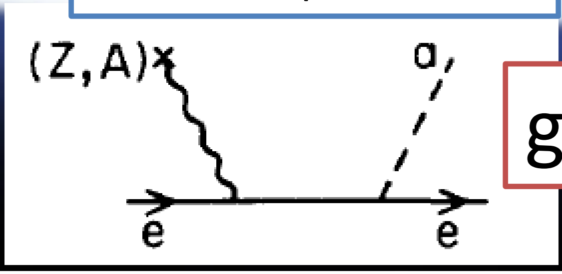


Will be published in PLB (online already available)
http://dx.doi.org/10.1016/j.physletb.2013.01.001

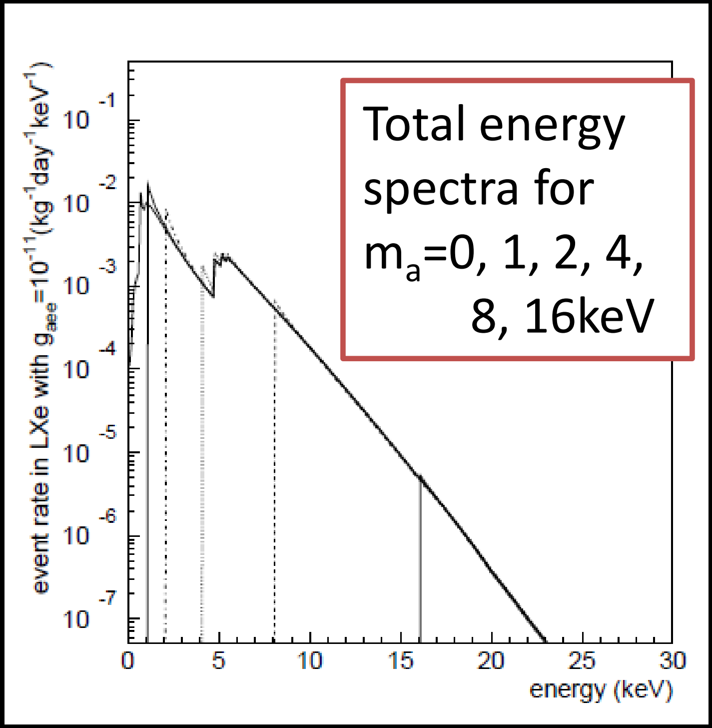
(2) Solar axion search

- Axion is a hypothetical particle to solve the strong *CP* problem.
- Produced in the Sun and detected in our detector. (like photo-electric effect)
- Our detector is suitable to see its signal, especially because of a large mass and low background.

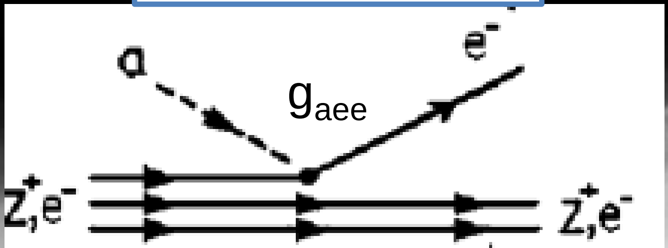
Bremsstrahlung and Compton effect



g_{aee}

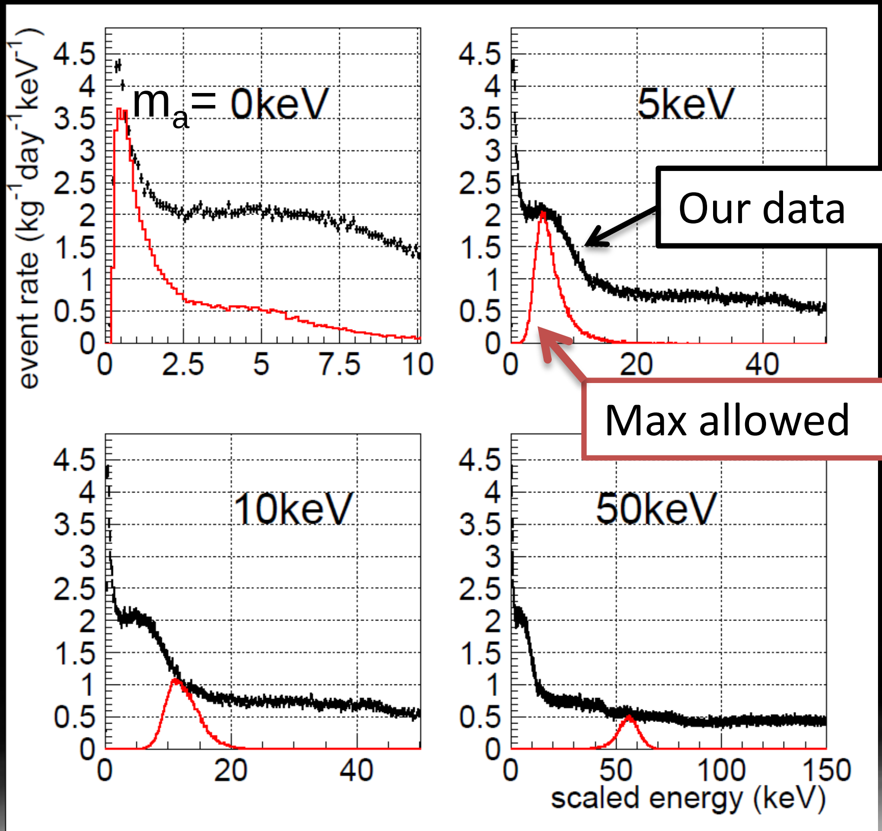


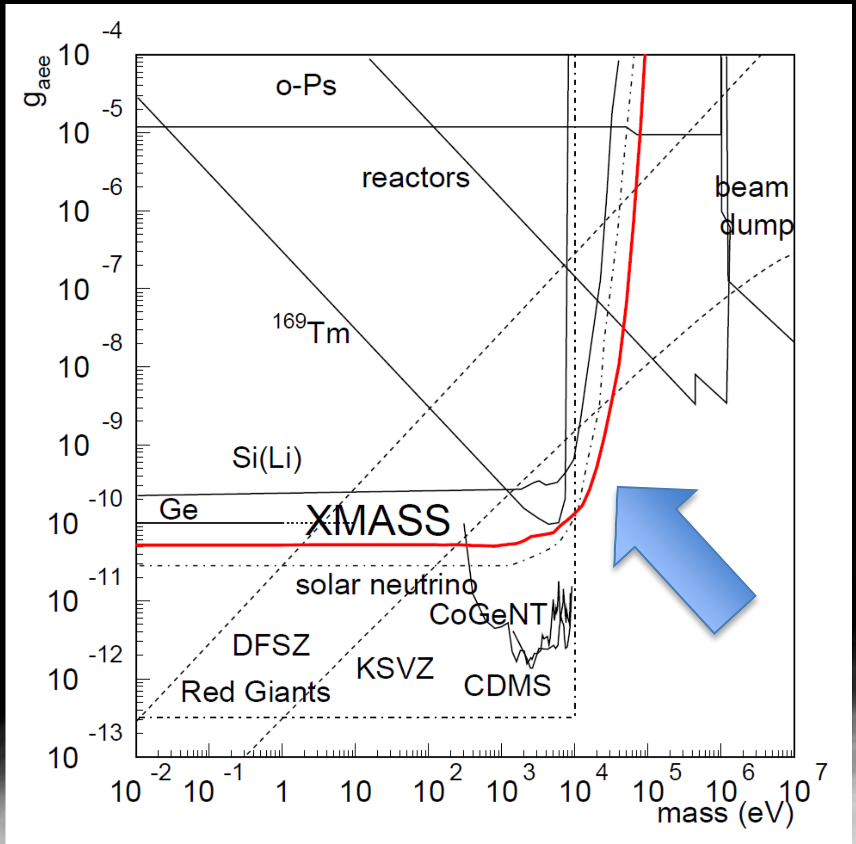
Axio-electric effect



Our experimental search

- No indication of signals. Bound in g_{aee} vs. mass.
- Better than any constraint in 10-40keV.
- Better than any experimental constraint <1keV





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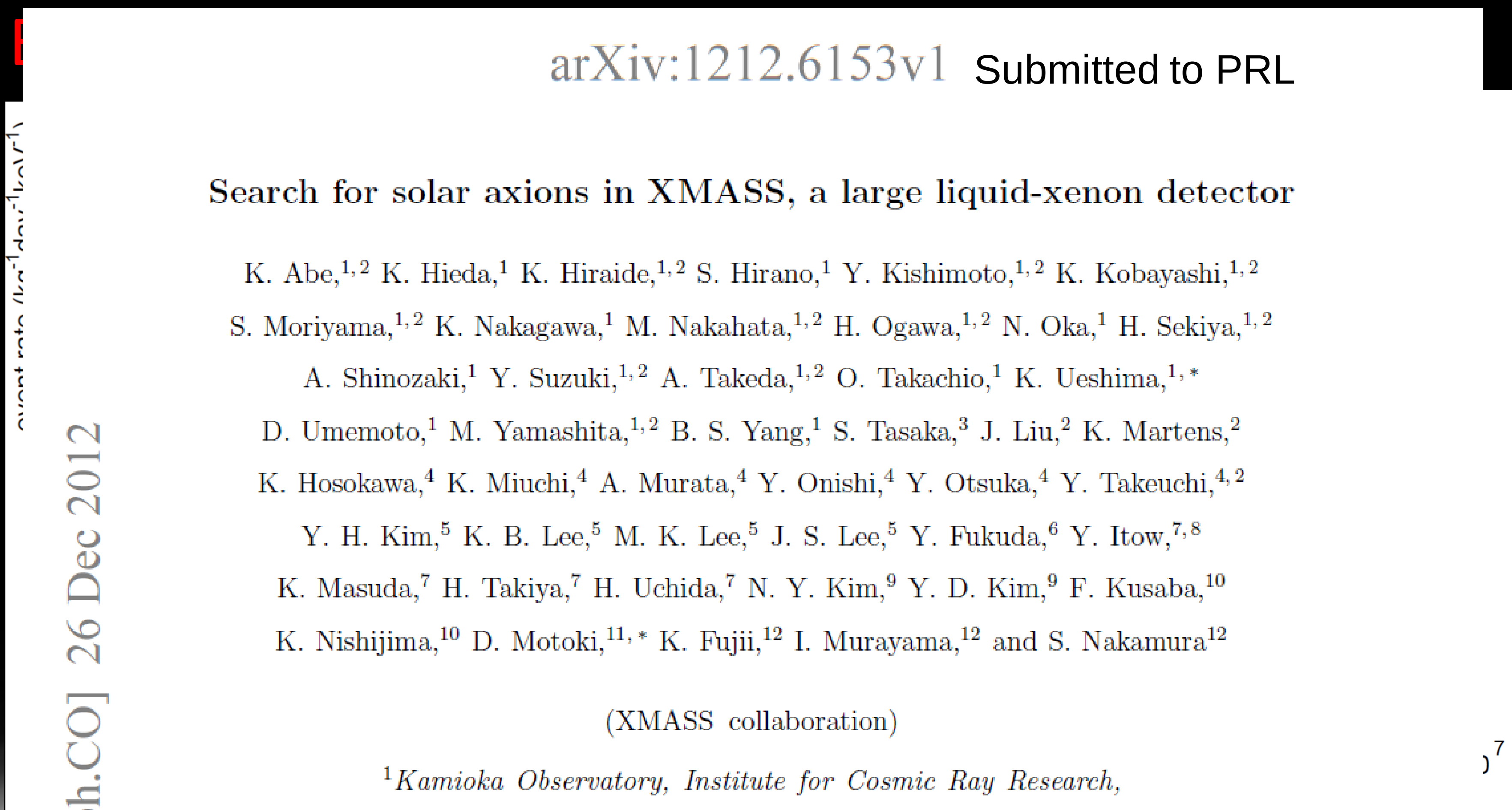

arXiv:1212.6153v1 [astro-ph.CO] 26 Dec 2012

Submitted to PRL

Search for solar axions in XMASS, a large liquid-xenon detector

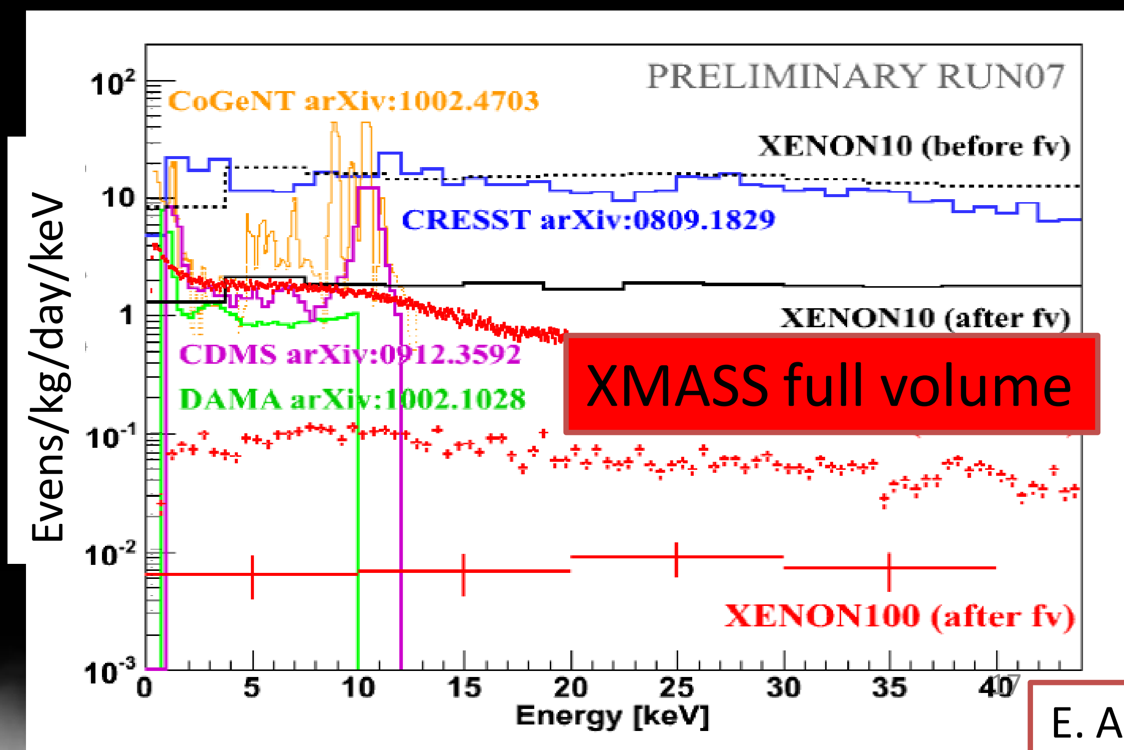
K. Abe,[1,2] K. Hieda,[1] K. Hiraide,[1,2] S. Hirano,[1] Y. Kishimoto,[1,2] K. Kobayashi,[1,2] S. Moriyama,[1,2] K. Nakagawa,[1] M. Nakahata,[1,2] H. Ogawa,[1,2] N. Oka,[1] H. Sekiya,[1,2] A. Shinozaki,[1] Y. Suzuki,[1,2] A. Takeda,[1,2] O. Takachio,[1] K. Ueshima,[1,*] D. Umemoto,[1] M. Yamashita,[1,2] B. S. Yang,[1] S. Tasaka,[3] J. Liu,[2] K. Martens,[2] K. Hosokawa,[4] K. Miuchi,[4] A. Murata,[4] Y. Onishi,[4] Y. Otsuka,[4] Y. Takeuchi,[4,2] Y. H. Kim,[5] K. B. Lee,[5] M. K. Lee,[5] J. S. Lee,[5] Y. Fukuda,[6] Y. Itow,[7,8] K. Masuda,[7] H. Takiya,[7] H. Uchida,[7] N. Y. Kim,[9] Y. D. Kim,[9] F. Kusaba,[10] K. Nishijima,[10] D. Motoki,[11,*] K. Fujii,[12] I. Murayama,[12] and S. Nakamura[12]

(XMASS collaboration)

[1] *Kamioka Observatory, Institute for Cosmic Ray Research,*

(3) Understanding BG

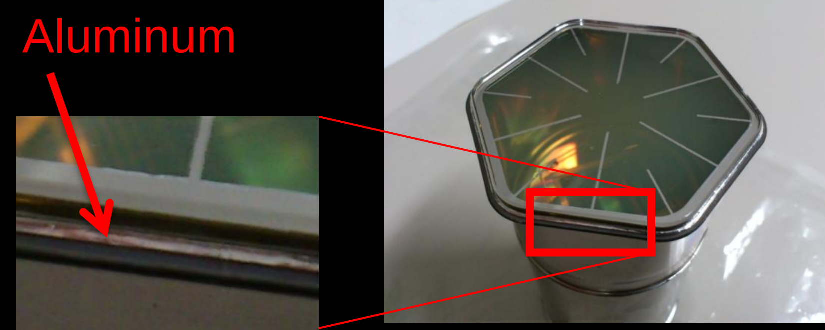
- Background of our detector is low, but not as low as we expected.
- Lower than CRESST, comparable to CoGeNT, DAMA, CDMS and XENON10 before particle ID.

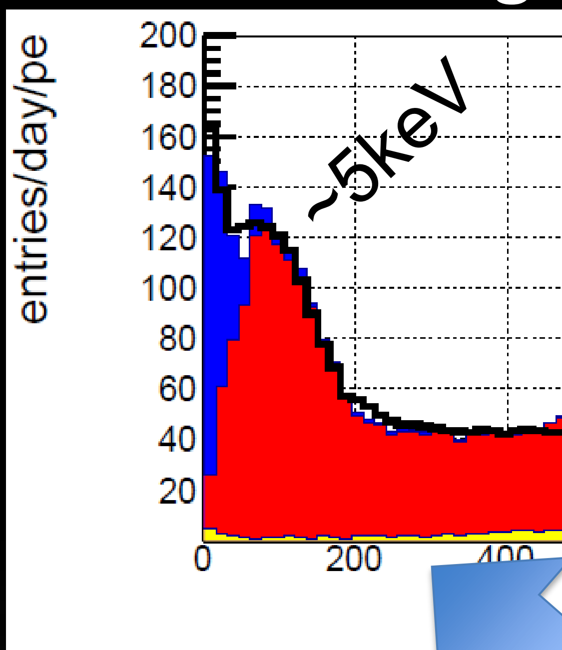


E. Aprile, 2010 Princeton

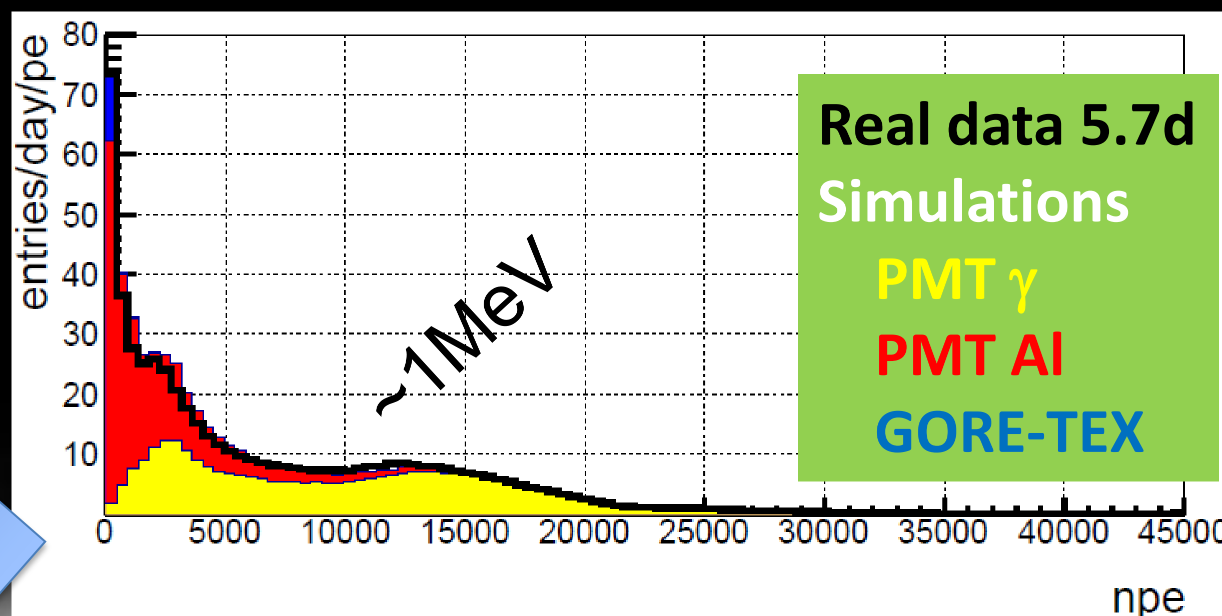
Origin of unexpected BG

- Found aluminum seal parts contain ^{238}U and ^{210}Pb.
- Simulation reproduces >5keV: reduction possible
- <5keV not yet convinced.
- ~100 times larger than exp.





Low energy

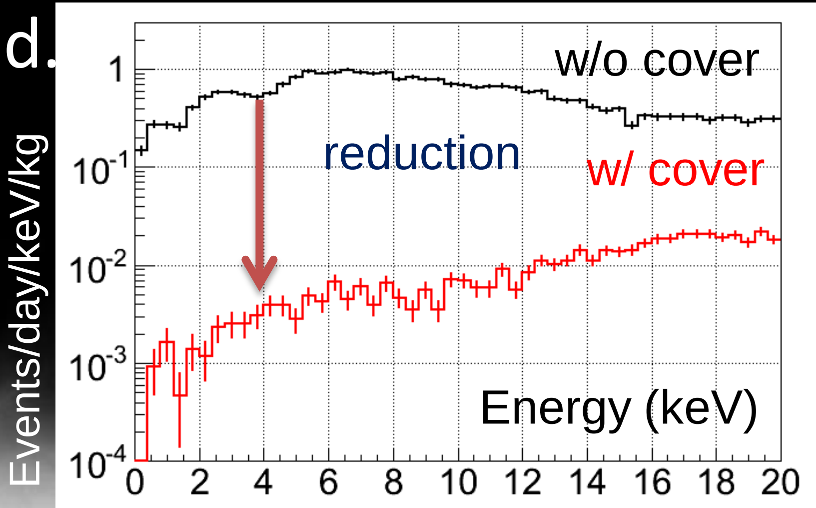


Refurbishment for reducing BG

- Most of BG is caused by α/β rays from aluminum. Can be shielded by metal covers.
- It's not perfect since small branch γ rays (~60, 90keV) cannot be shielded completely but good for a short-term improvement.
- The detector already disassembled. Resume data taking by summer.

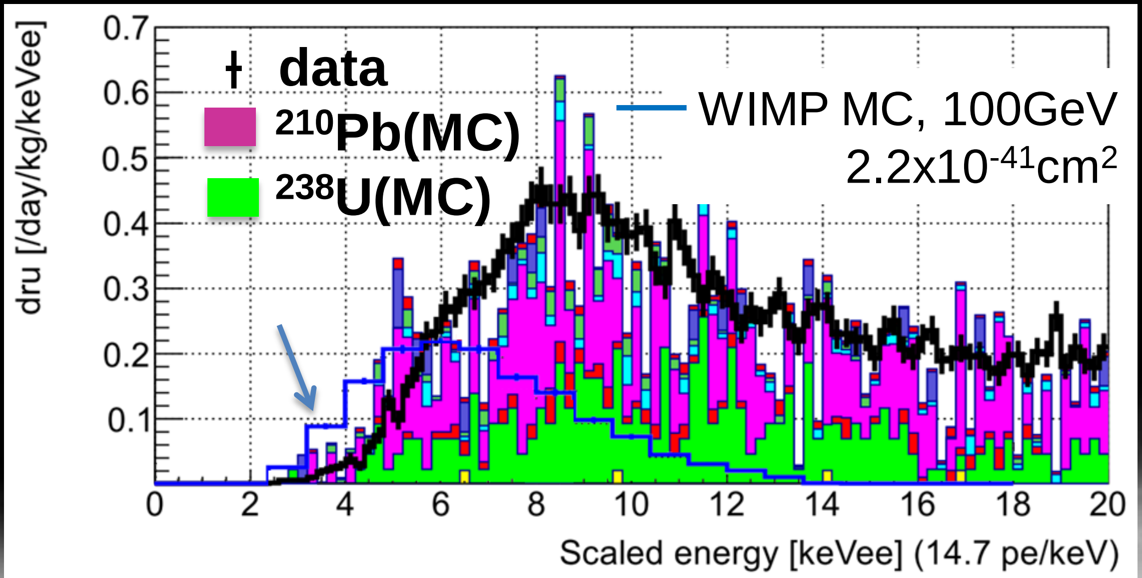
➔ Large gain in physics analyses

➔ Establish surface treatment



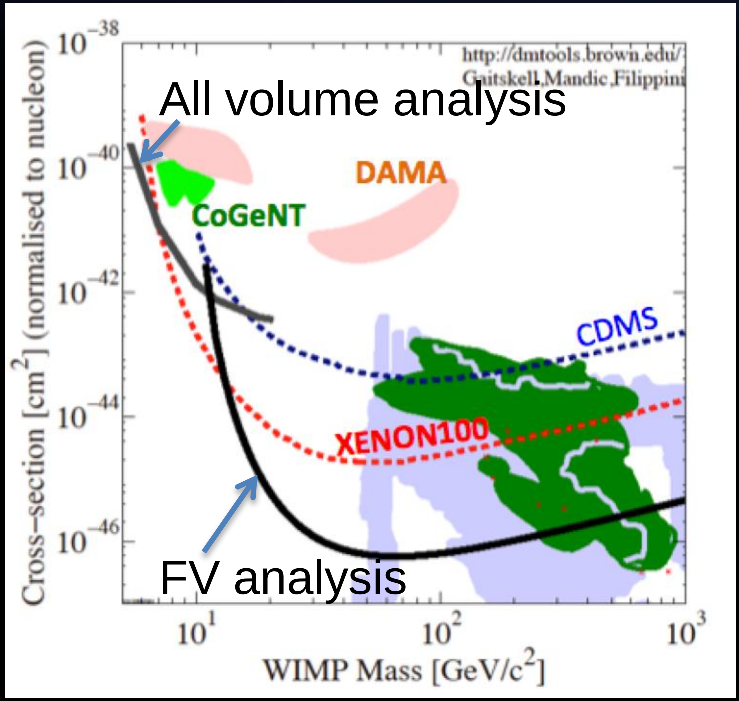
(4) FV cut study

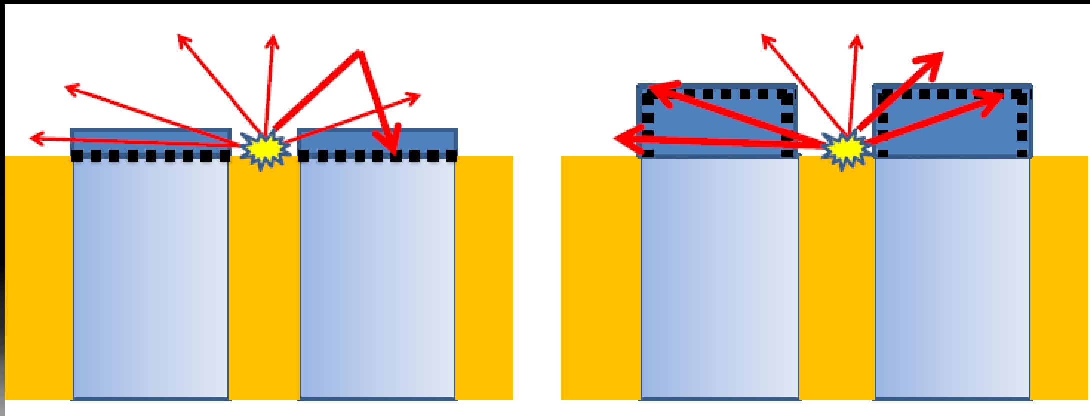
- FV cut by vertex reconstruction. Surface BG leaks into FV. Surface BG explain the observed data within +/-30% range.
- Fit with signals (blue) and BG prediction requires syst. error evaluation of BG prediction. Examining MC dependence.
- A topological cut and timing cut is expected to reduce BG and examine ~10^{-43}-10^{-44}cm^2. Under study.
- Improvements after the refurbishment are expected.



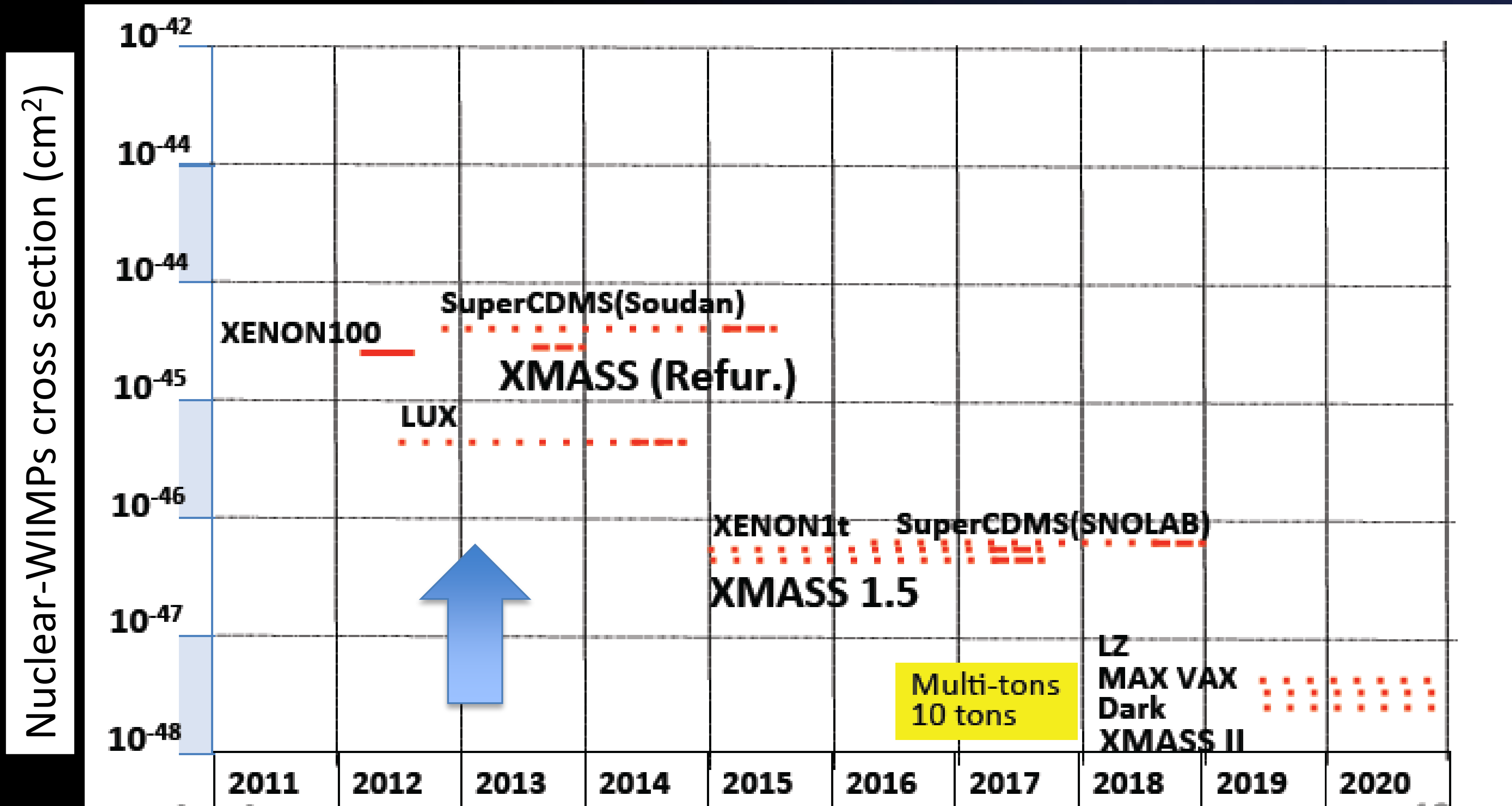
XMASS 1.5 as a next step

- Larger detectors have many advantages. 1t FV (5t total).
- We can use U-free Al in hand.
- Surface BG must be controlled.
- New PMTs being developed help to identify surface events.





Sensitivities of experiments



- Only XMASS has sensitivity both on e and nuclear recoils in a few years. It also has advantages for the scalability.

Summary

- Phase I
  - Successful construction/operation of the largest liquid-xenon detector (835kg). P.E. yield is the best (14.7p.e/keV) among low-background detectors and energy threshold is low (0.3keV).
  - Low mass WIMPs, solar axions, and super-WIMPs were searched for. Richer physics targets than expected.
  - Expecting to have significant improvements of BG by hardware/software improvements at this summer.
- Phase 1.5 & II
  - Larger detectors with higher sensitivity is projected.