XMASS
A Dark Matter Search Experiment with Liquid Xenon

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Kurume City Plaza

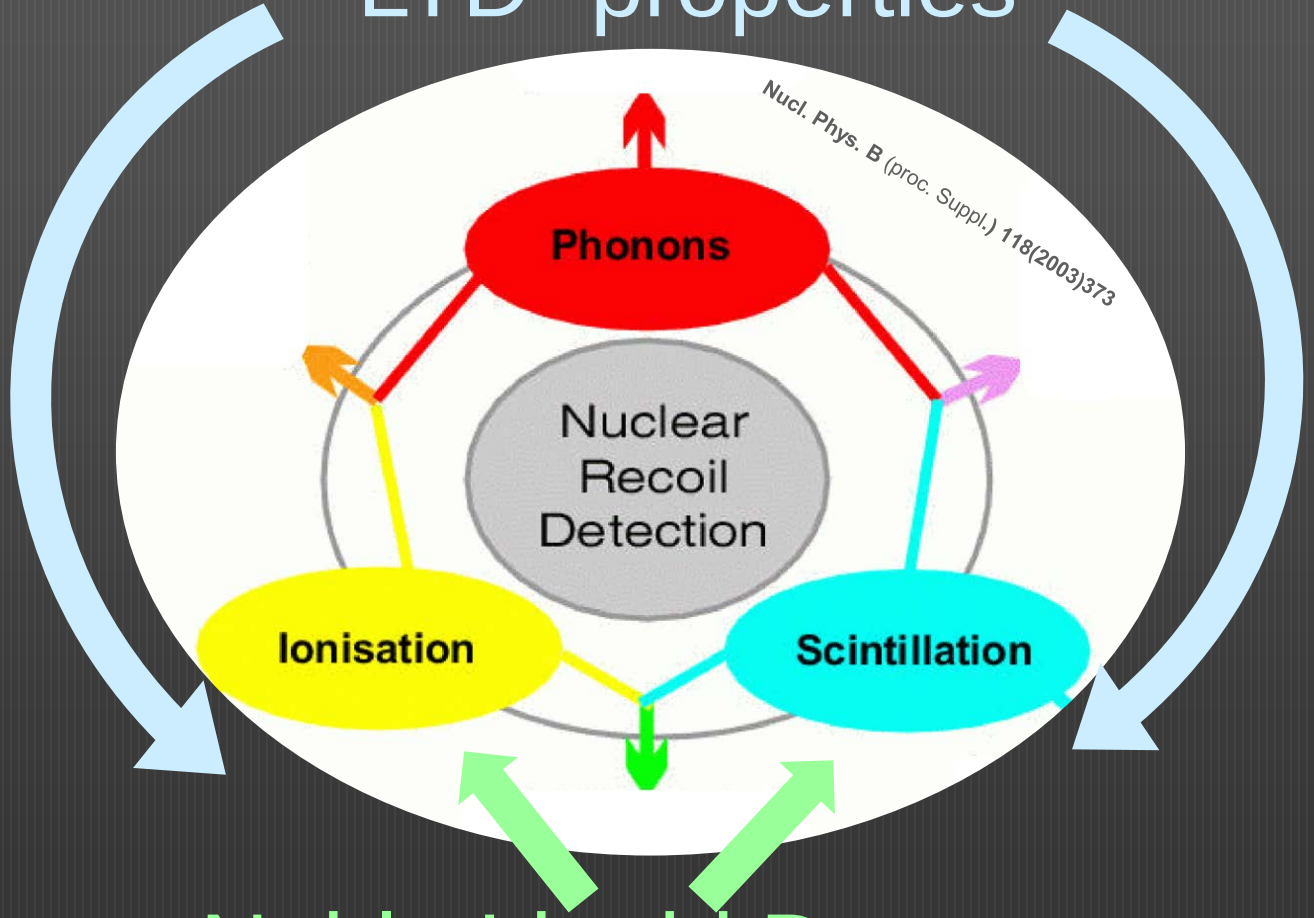
LTD17

Contents

- NLD?
- The XMASS experiment
- Recent dark matter results
  - WIMPs search by fiducialization **New results !**
  - Annual modulation search **New results !**
- Summary

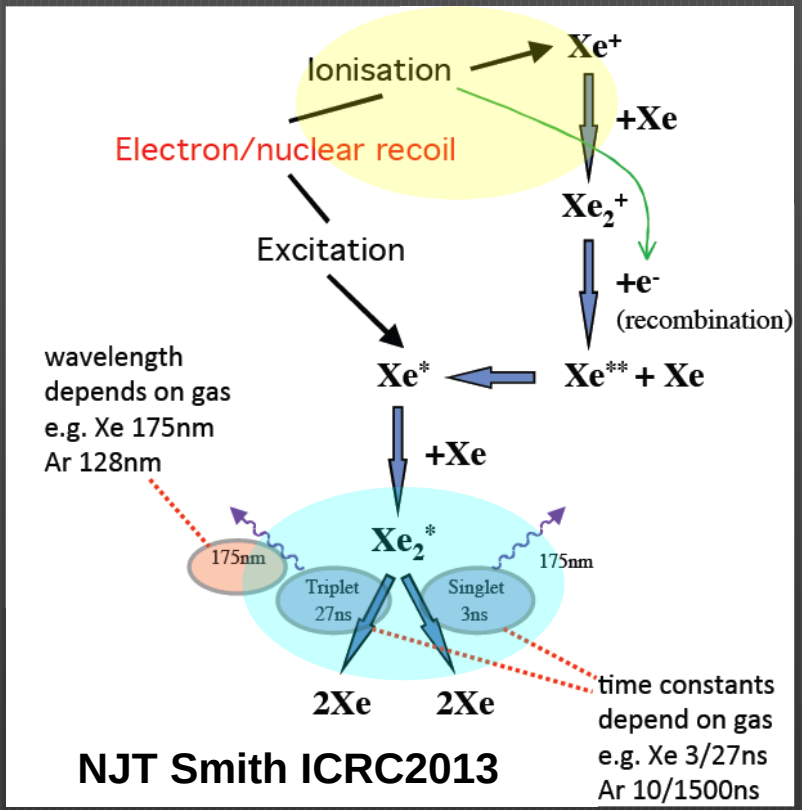
Not “LTD”, it’s “NLD” Relatively low temperature detector…

“LTD” properties



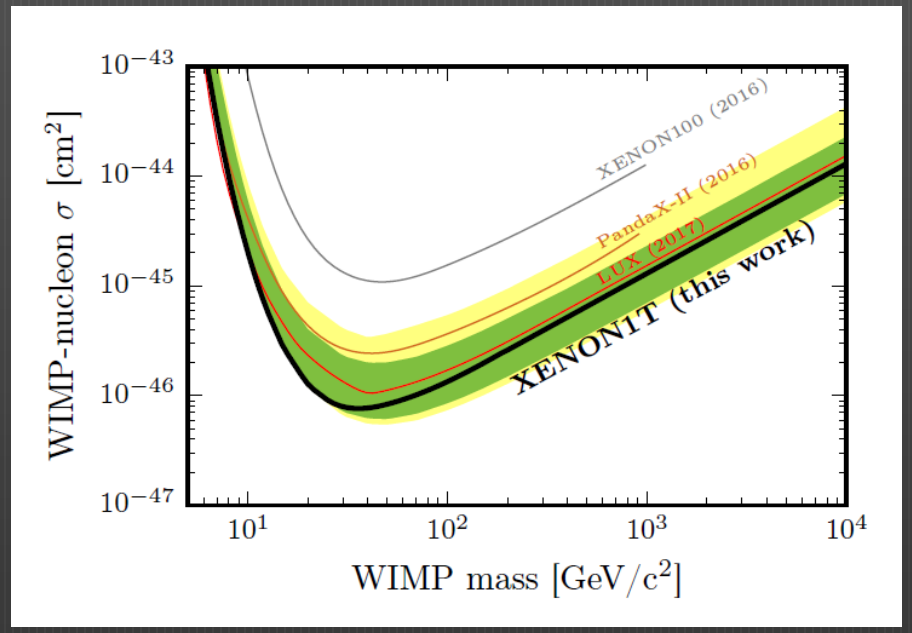
Noble Liquid Detectors

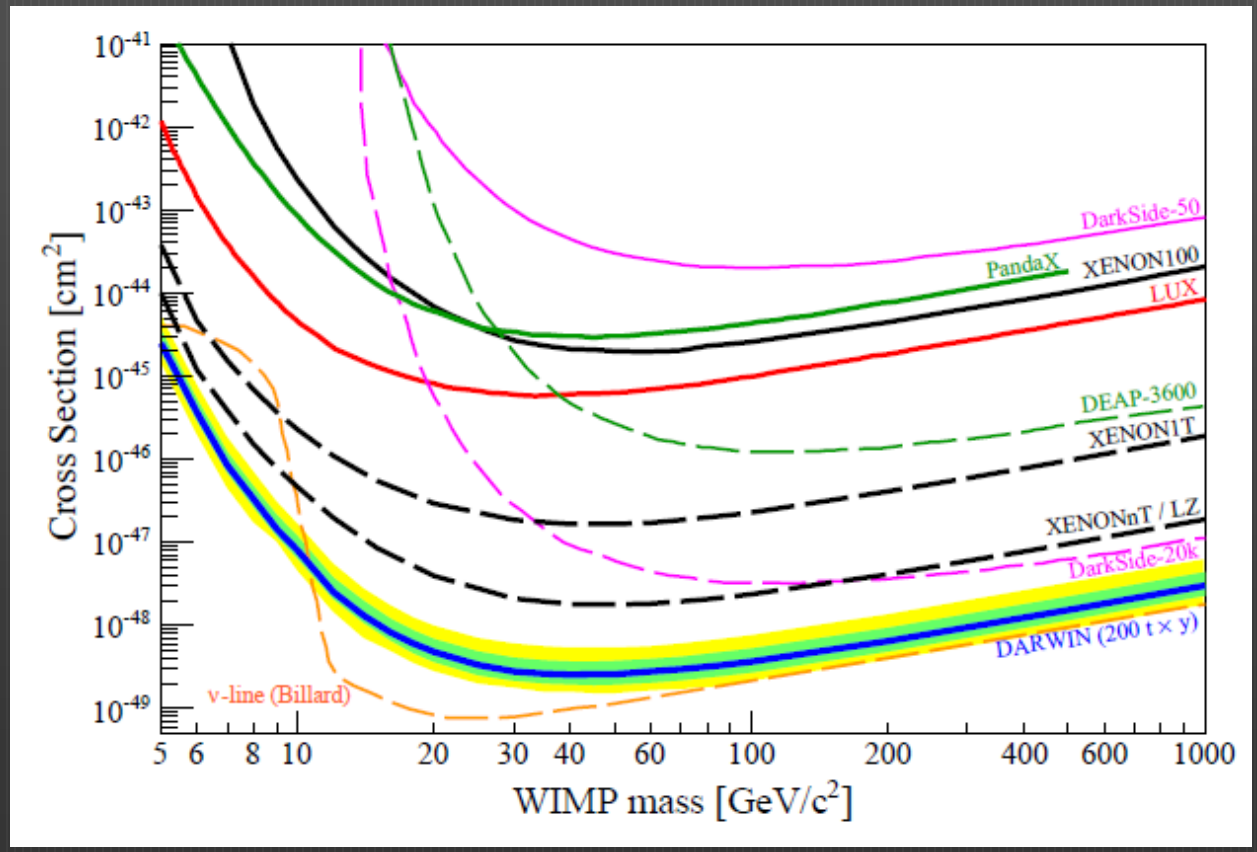
Noble gas interaction process



Current Status and future of Direct Dark Matter Search

- XENON1T
  - LUX, PandaX-II
- DARWIN, DarkSide-20k, XENONnT LZ





All of them are "NLD"

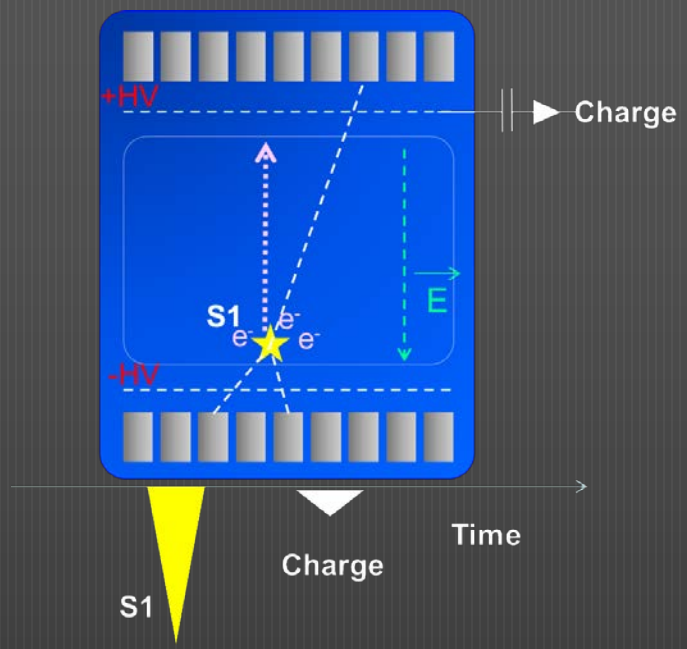
Why are noble liquids good for DM searches?

- Both scintillation and ionization signals are detectable.
  - Excitation/ionization ratio provides electron/nuclear recoil separation

  →Active BG rejection

- Large mass/scalability
- Large mass number (Xe)
- →Passive BG rejection: self shielding by fiducialization
- In situ purification → lower BG

How to use noble liquids; 3 concepts

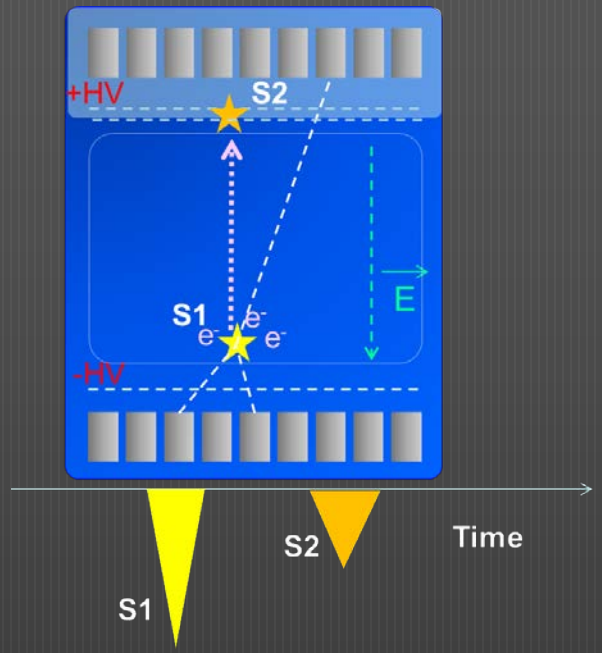


1 phase(L) TPC

Original concept of NLD

High E application w/ Ar

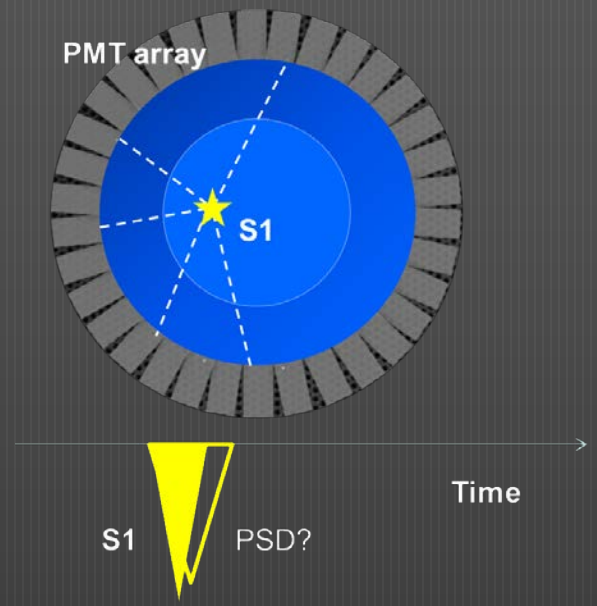
ICARUS/DUNE



2 phase(L+G) TPC

Low E application w/ Xe

The most successful DM detector so far



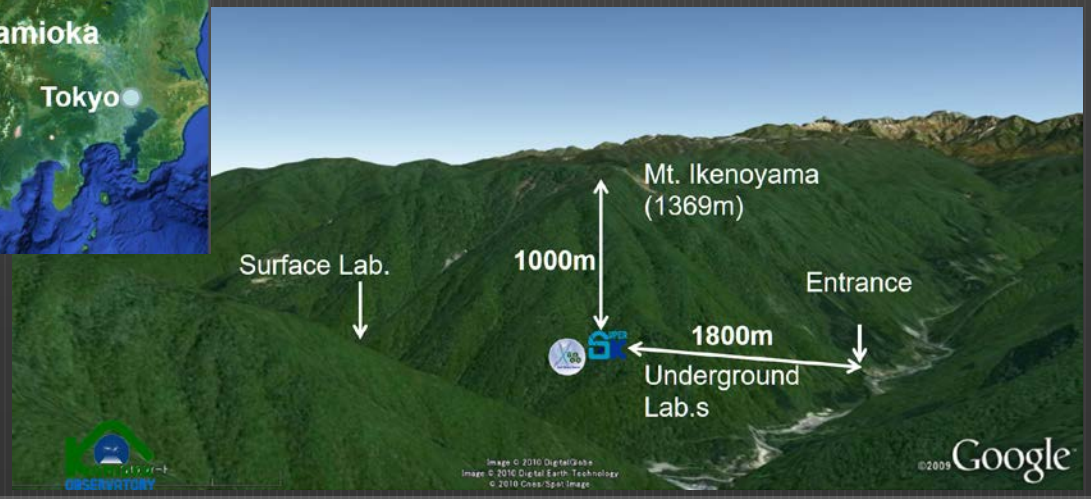
1 phase(L) Scintillator

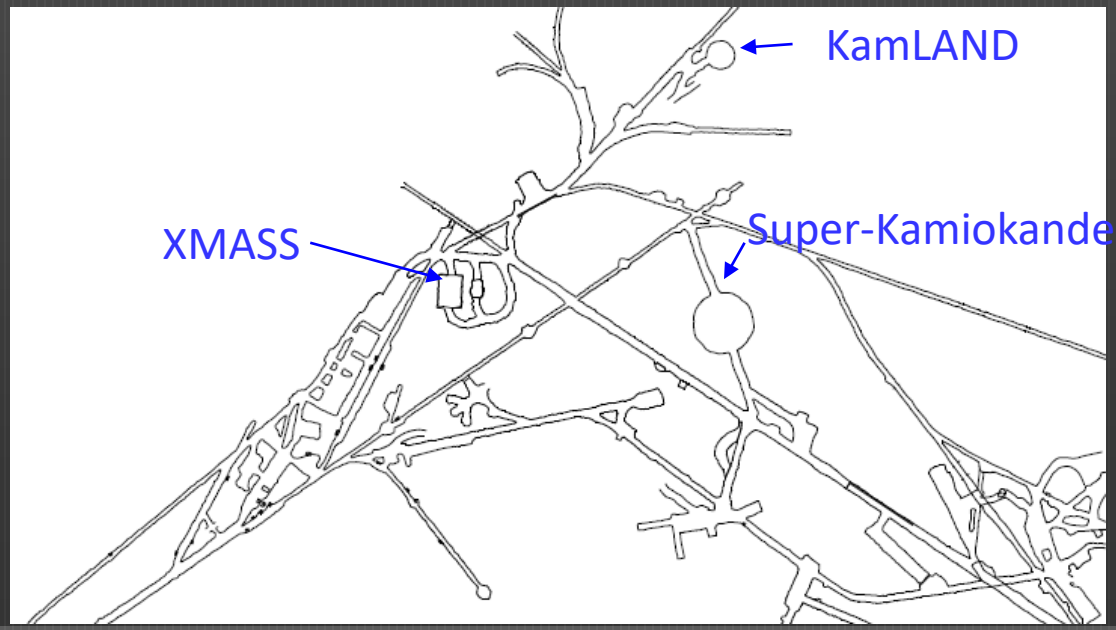
Simplest for scalability

Also sensitive to ionization, in a sense, through the recombination process

The XMASS project

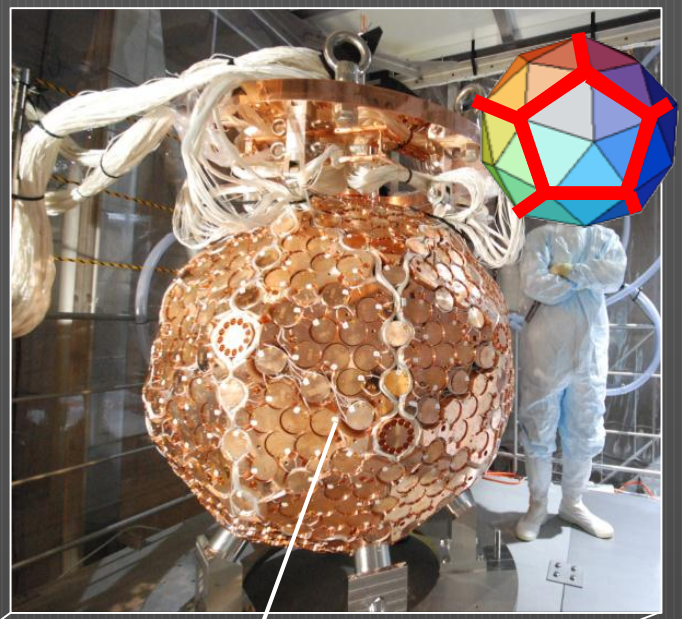
- Multipurpose low BG experiment with single phase (liquid) Xe
  - Xenon MASSive detector for Solar neutrino (pp/^{7}Be)
  - Xenon neutrino MASS detector (double beta decay)
  - Xenon detector for Weakly Interacting MASSive Particles(DM)
- Located underground in Kamioka mine at a 2700 m.w.e. depth.

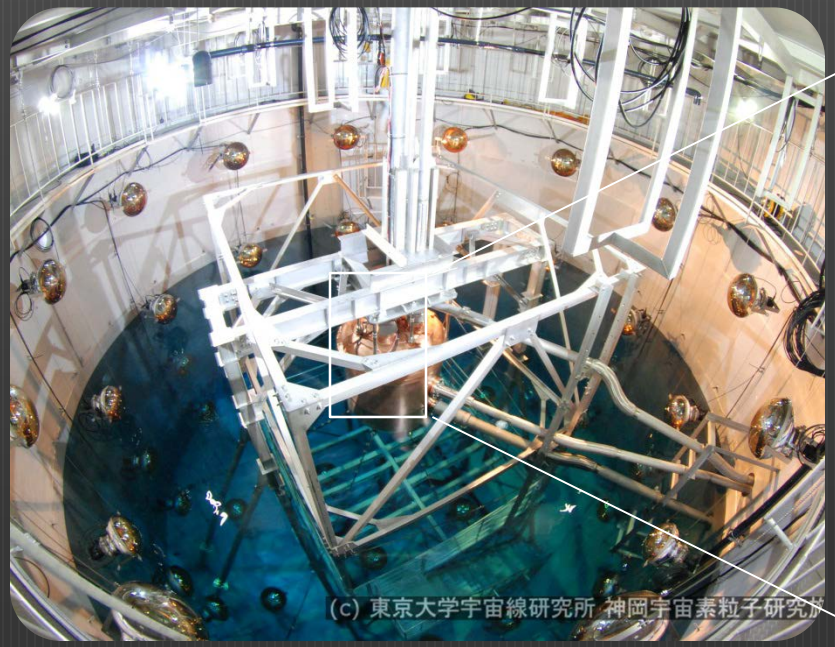


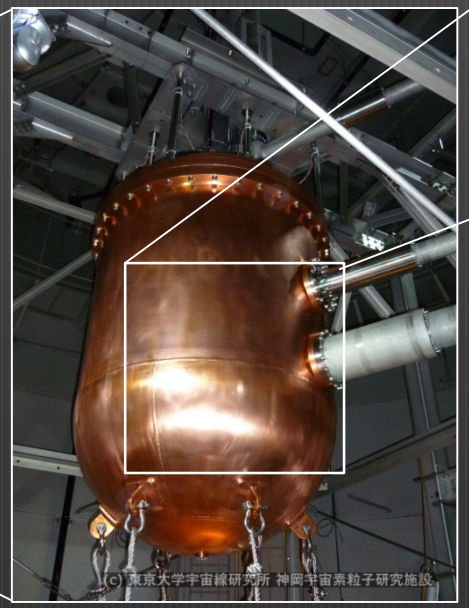


XMASS detector

- 832 kg of liquid xenon (-100 ºC) target
  - Total 1050kg
- 642 2-inch hexagonal PMTs on 80cm pentakisdodecahedron
  - Photocathode coverage 62.4%
- 10m x ϕ10m water shield for external BG
  - 72 20-inch PMTs







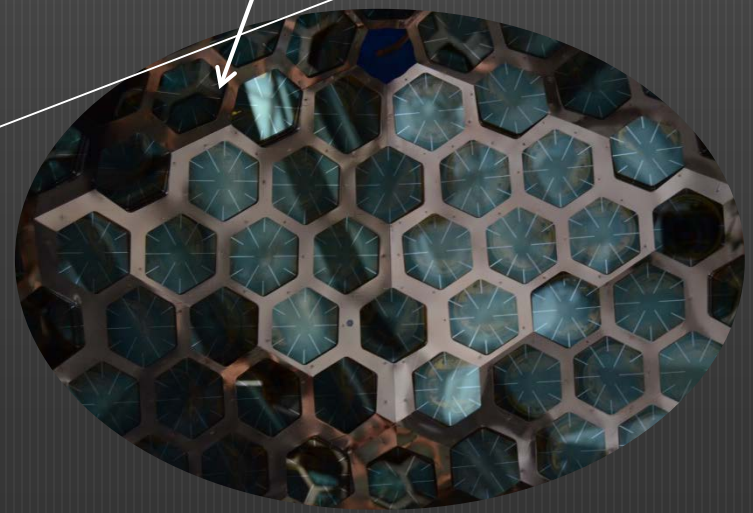
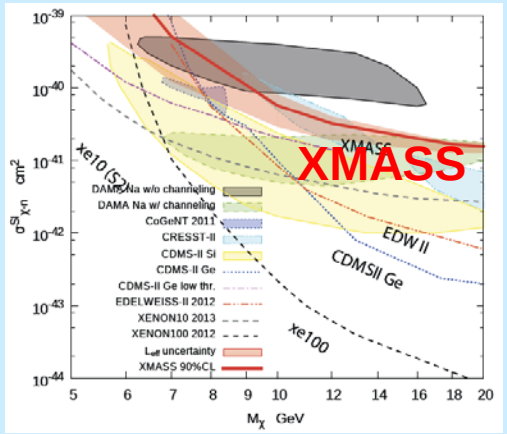


Photo coverage 62.4%

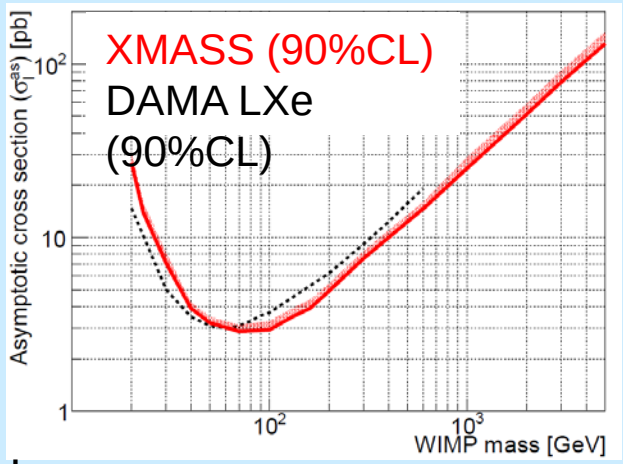
XMASS physics results Not only DM

Dark matter searches

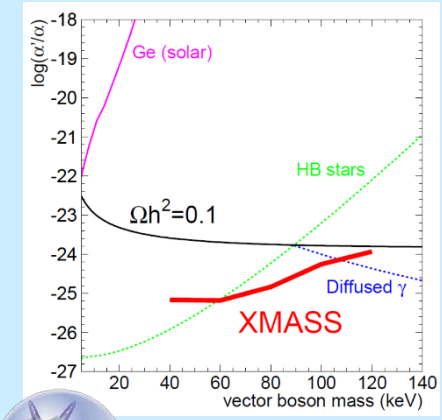
Low mass WIMP search
Phys. Lett. B719 (2013) 78



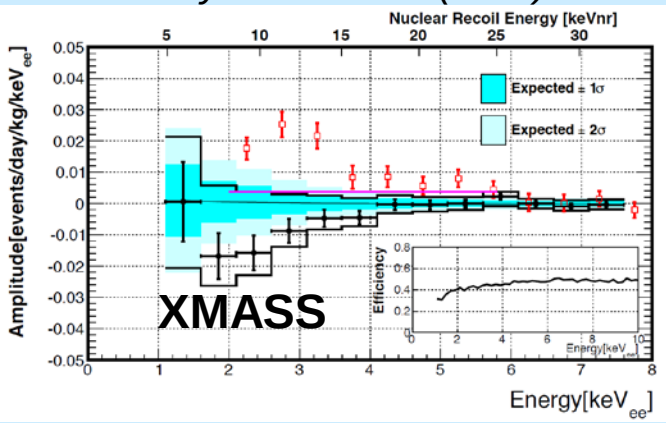
WIMP-^{129}Xe inelastic scattering
PTEP (2014) 063C01



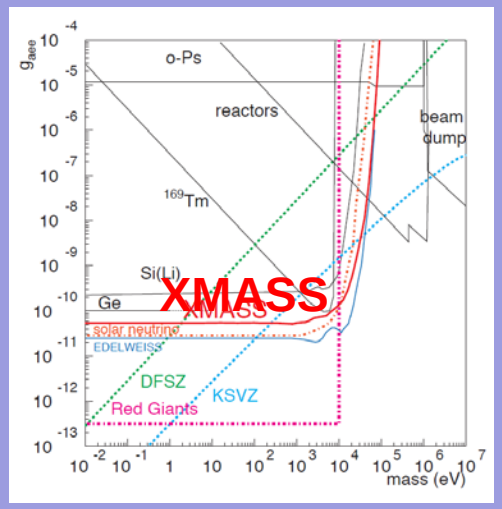
Bosonic super-WIMPs search
Phys. Rev. Lett. 113 (2014) 121301



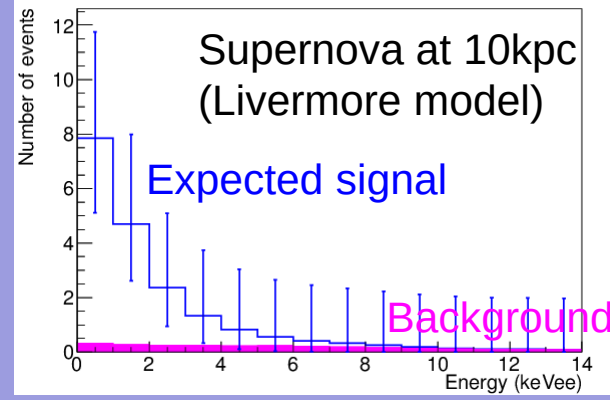
Annual modulation search
Phys. Lett. B759 (2016) 272



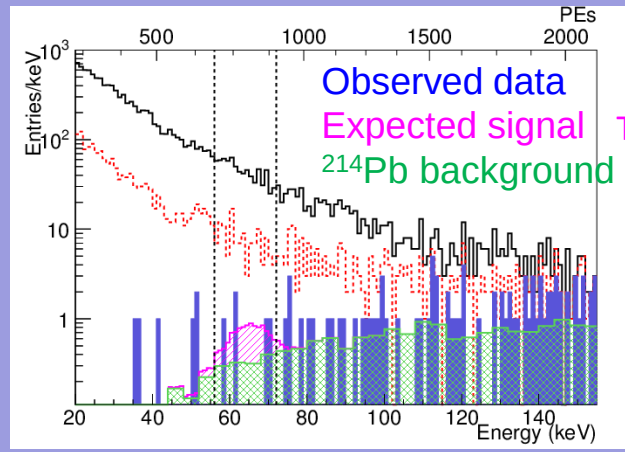
Solar Axion search
Phys. Lett. B724 (2013) 46



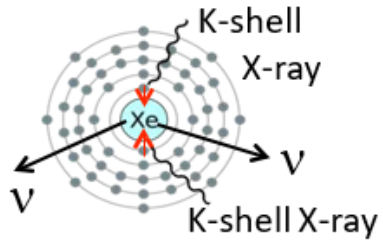
Supernova neutrino detection via coherent scattering
Astropart. Phys. 89 (2017) 51



Search for 2ν double electron capture on ^{124}Xe, ^{126}Xe
Phys. Lett. B759 (2016) 64



$T_{1/2}(2\nu 2K)=4.7\times10^{21}$ years

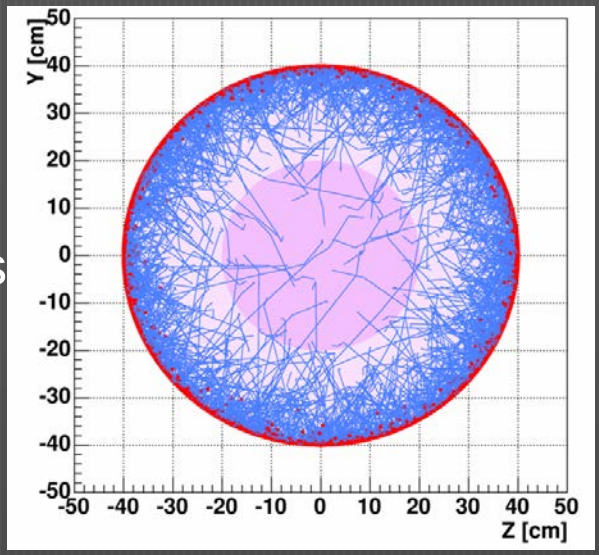


β/γ sensitive, but can be cut by fiducialization

- Self-shielding:

  high atomic number (Z=54) and high density (2.9g/cm3)

  ➡ Fiducial volume R<20cm (97kg)

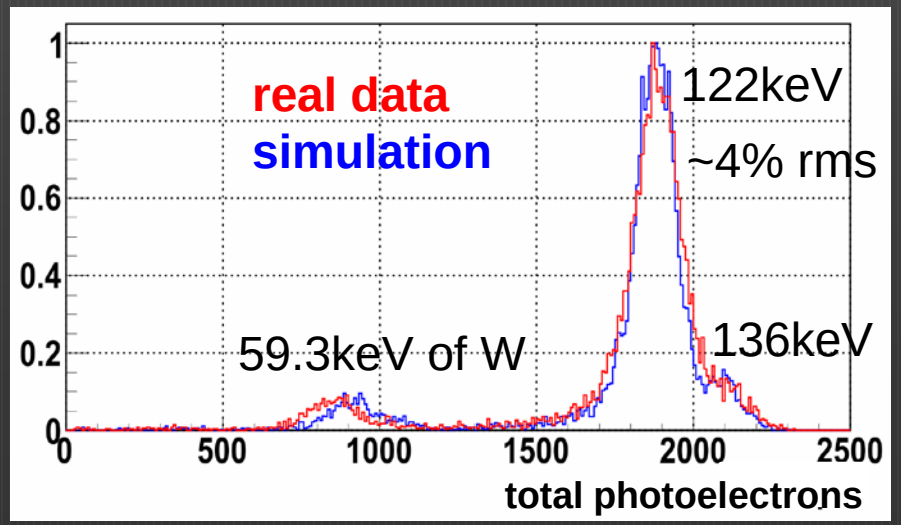


Traces of γ-rays from PMTs

- Event vertex position and energy are reconstructed using number of PE in each PMT

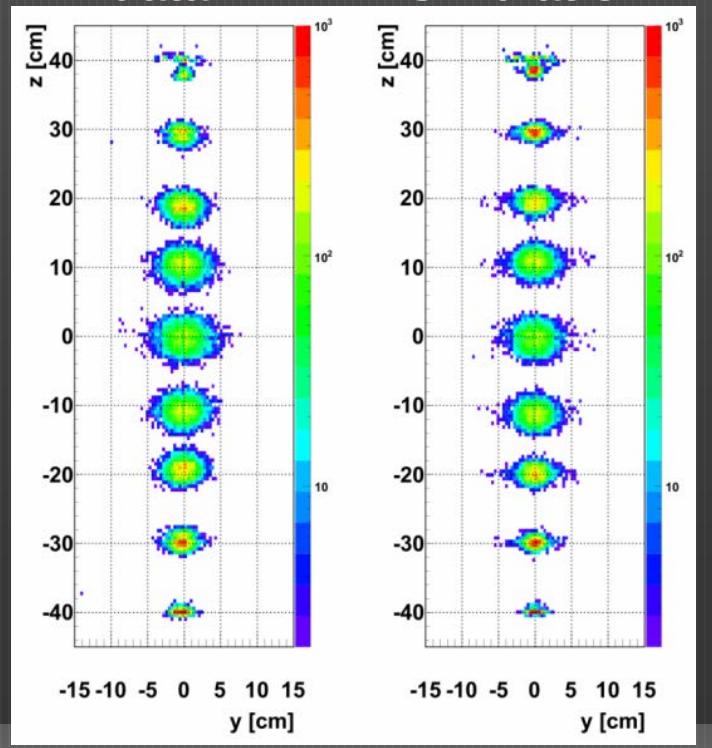
$$L(\mathbf{x}) = \prod_{i=1}^{642} p_i(n_i)$$

P_i (n) : probability that the i-th PMT detects n PE



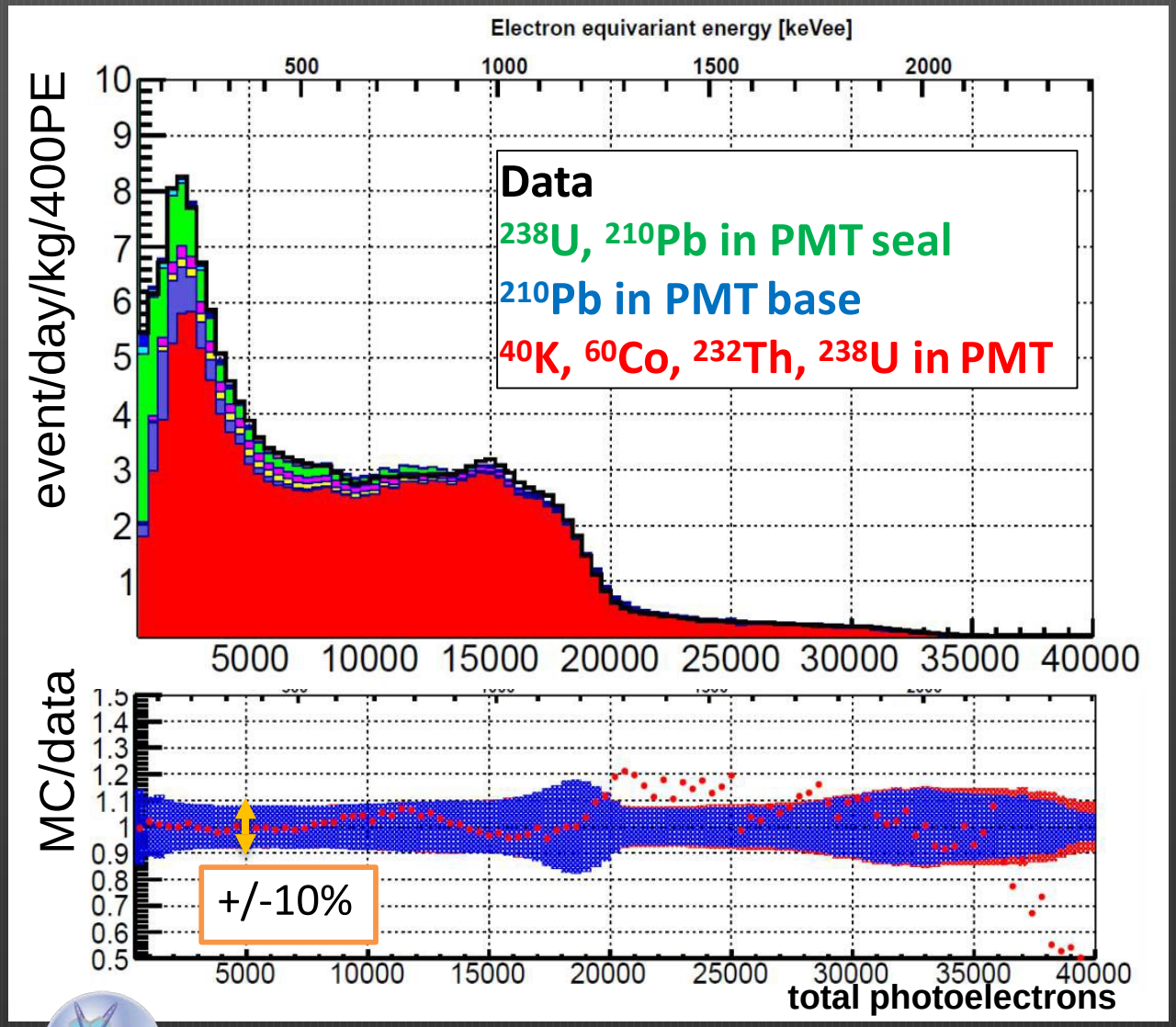
^{57}Co calibration
Calibration spectrum

Light Yield:
~15 photoelectron/keV



^{57}Co calibration
Vertex reconstruction

Background understanding w/o fiducialization

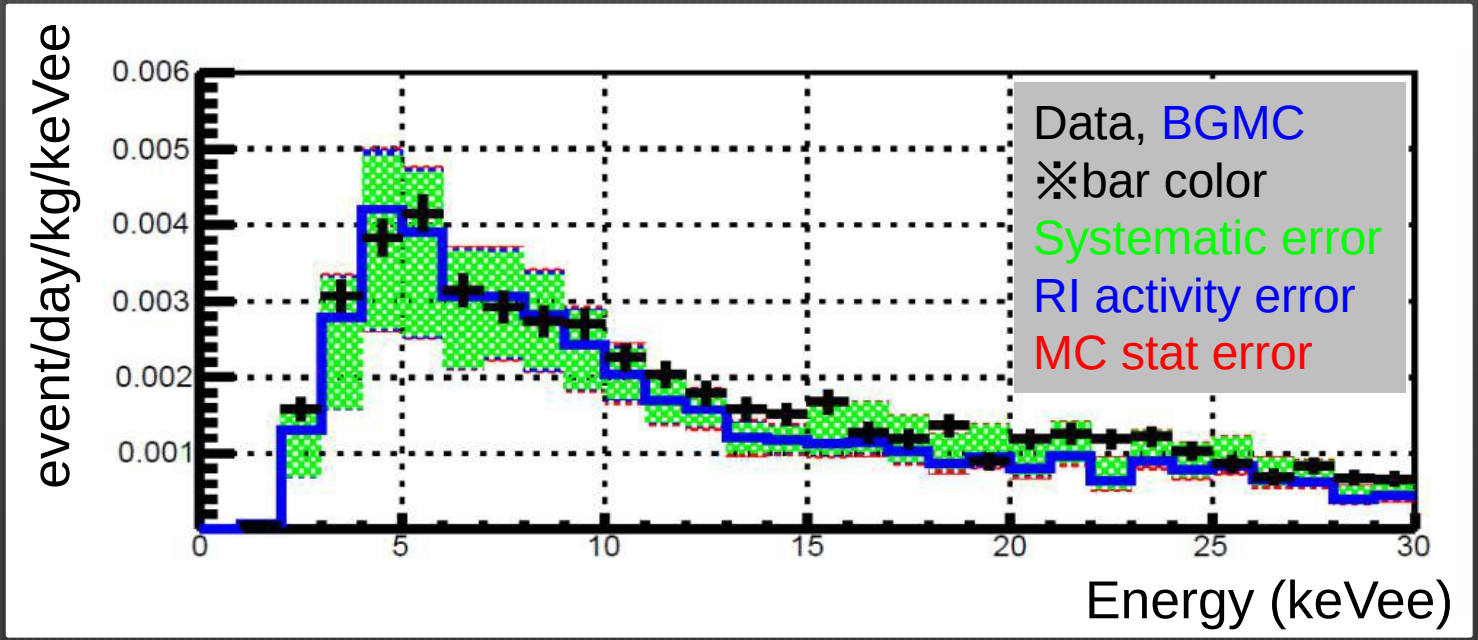


- The energy spectrum above 30 keVee was fitted with MC under the constraints by other direct RI measurements.
  - All the detector material were measured by Ge detectors before installation.
  - α events were selected using scintillation decay time. → ^{210}Pb in PMT/copper
  - ^{210}Pb (~20 mBq/kg) in the bulk of oxygen-free copper was identified by the low background alpha-particle counter (XIA Ultra-Lo-1800)
- Understood the BG within 10% error!
  - Most of the BG are from PMTs

Energy spectrum (<30keV) after fiducialization

- 706 live days taken in Nov. 2013 – Mar. 2016
- Fiducial mass 97kg (R<20cm)

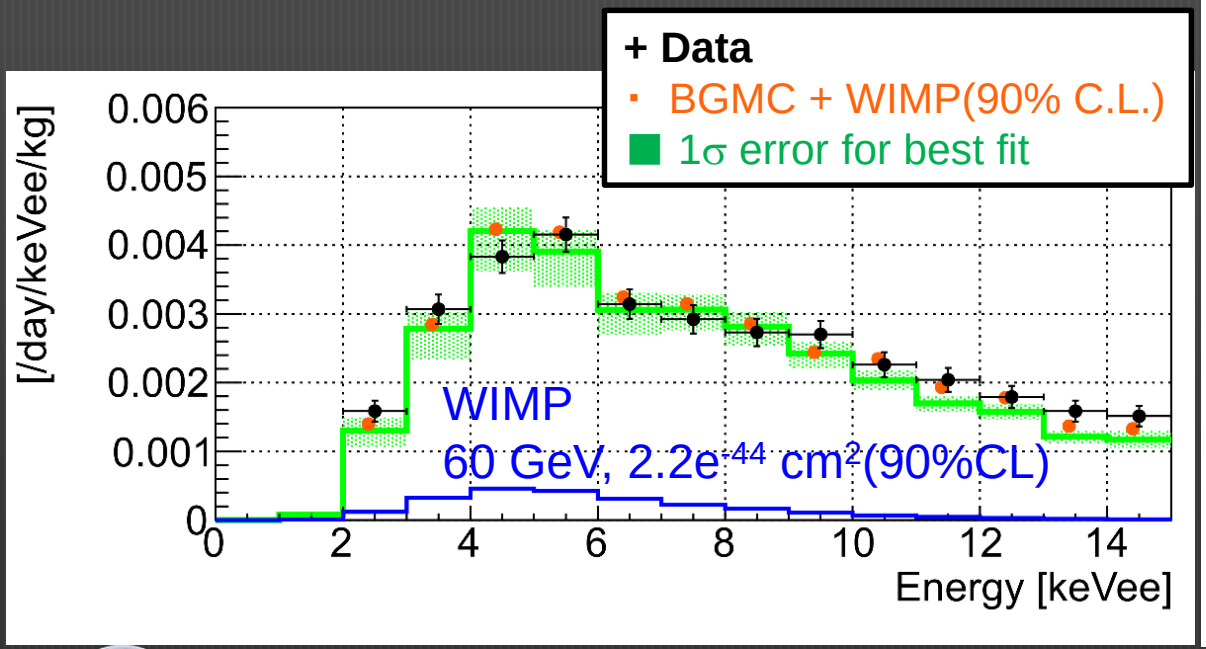
WIMP search region (2-15keVee)

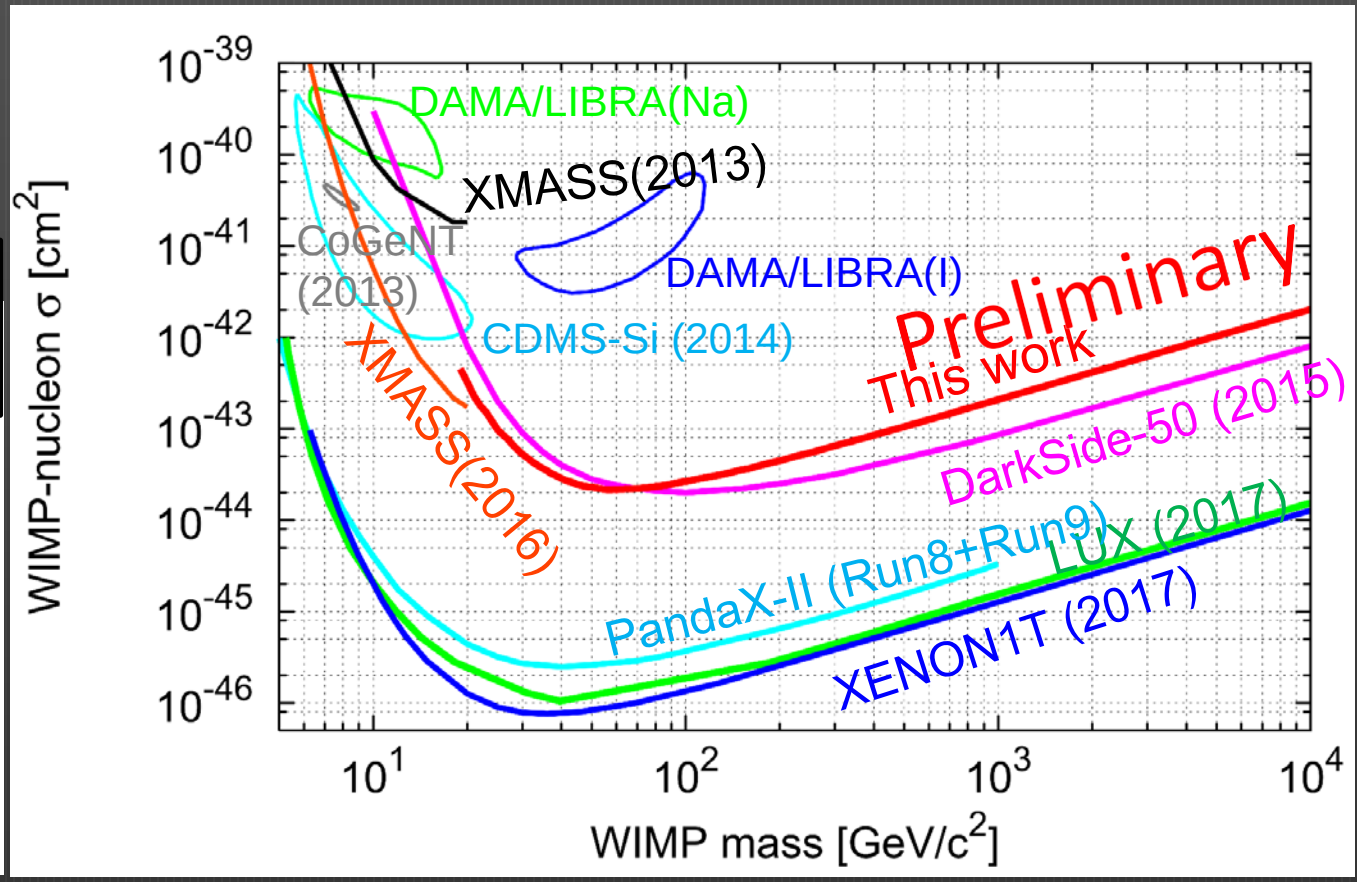


- Main BG <15keVee
  - Misreconstructed surface events
  - ^{210}Pb in the copper bulk
  - γ-rays from PMTs
- Internal RIs dominate >15keVee
  - Rn, Kr, etc …
  - Neutrons, alpha-rays are negligible
- Dominant systematic uncertainty
  - Condition of detector inner surface (gap size, surface roughness)

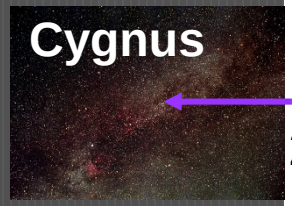
2013-2016 Dark Matter search results

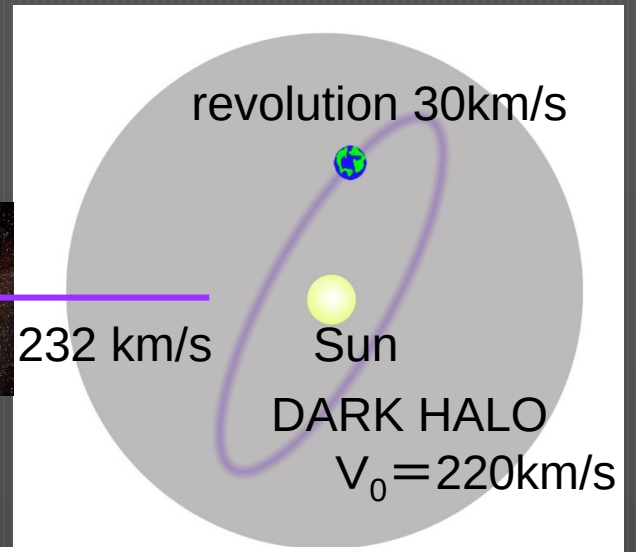
- The energy spectrum at 2-15 keVee is fitted with signal + BG
- Systematic uncertainties are taken into account as nuisance parameters.
- 90% CL upper limit on spin-independent WIMP-nucleon cross section is derived.



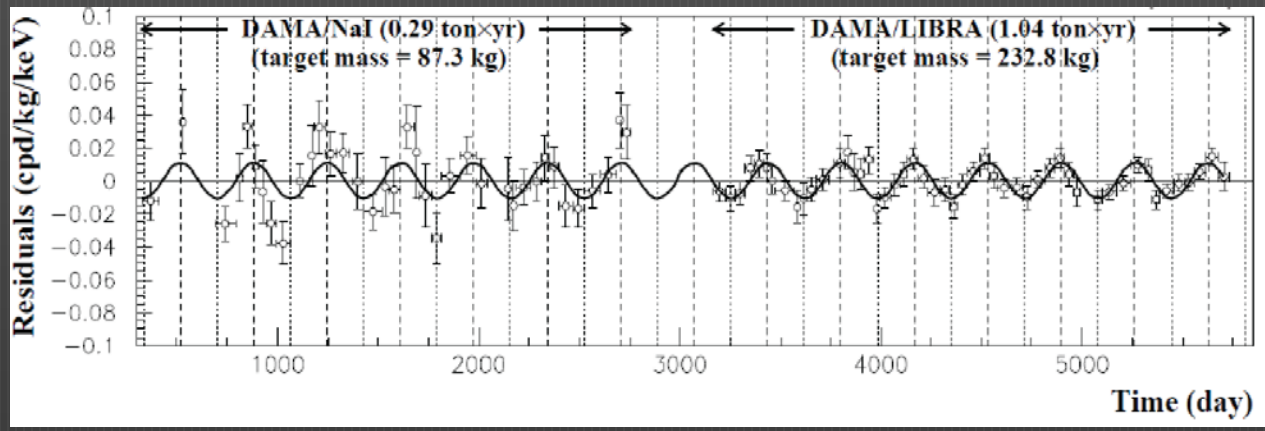


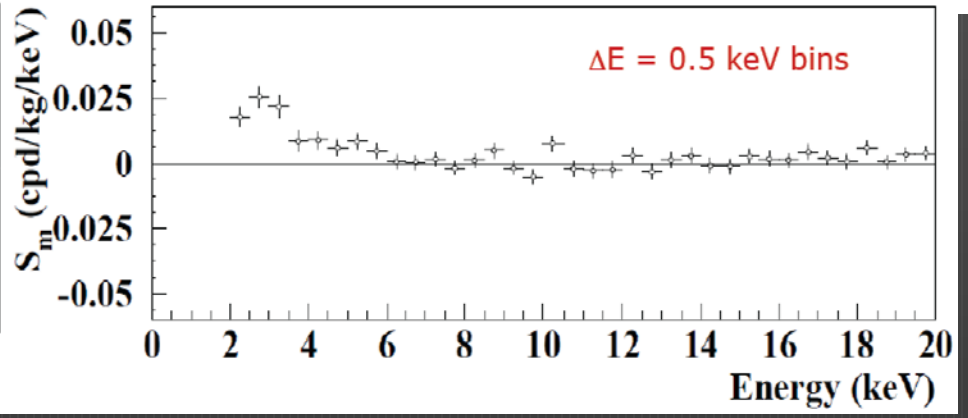
Search for annual modulation





- DAMA/LIBRA claims modulation at 9.3σ
  - Total exposure of 1.33 ton year (14 cycles)
  - Modulation amplitude of (0.0112+/-0.0012) cpd/kg/keV for 2-6 keV

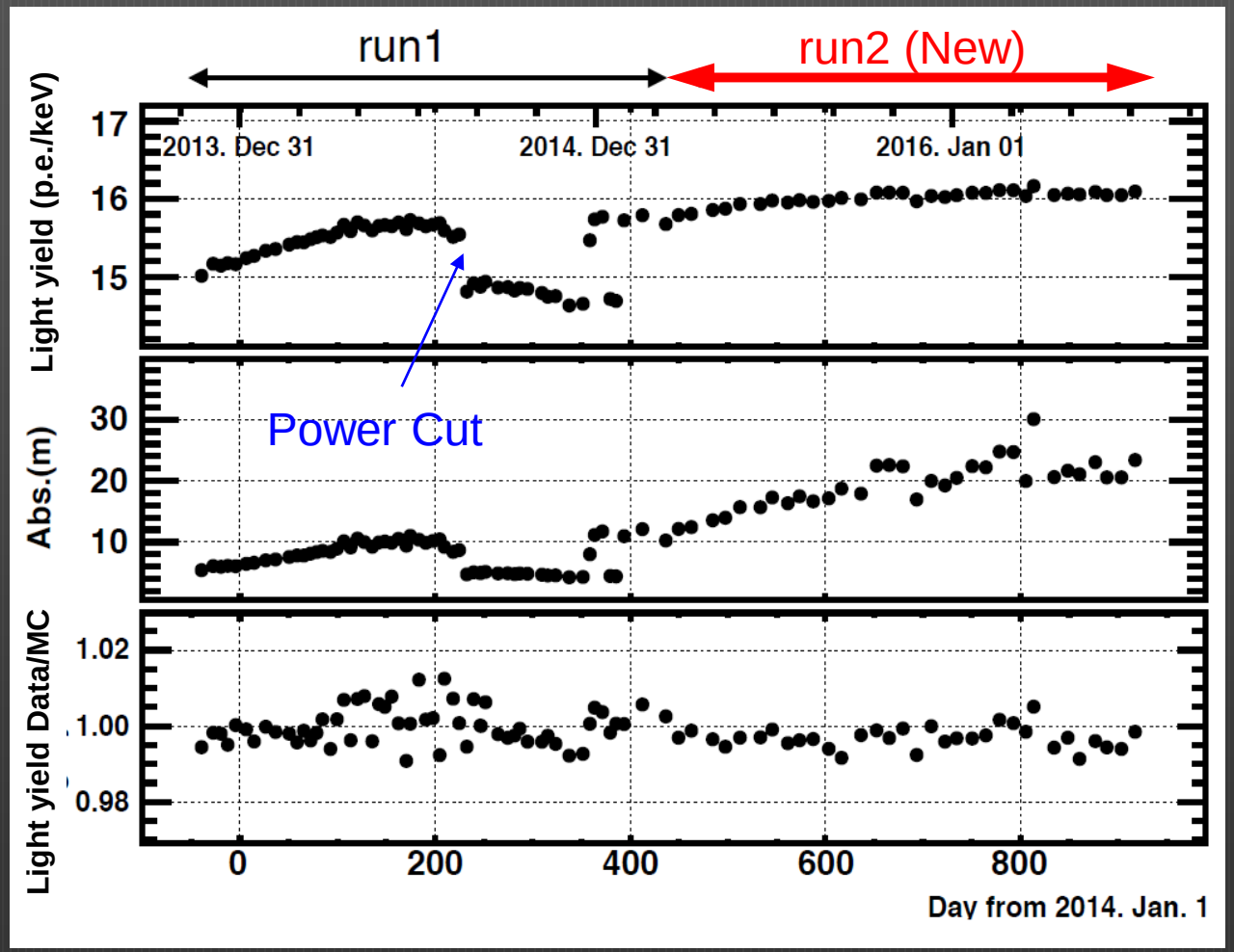




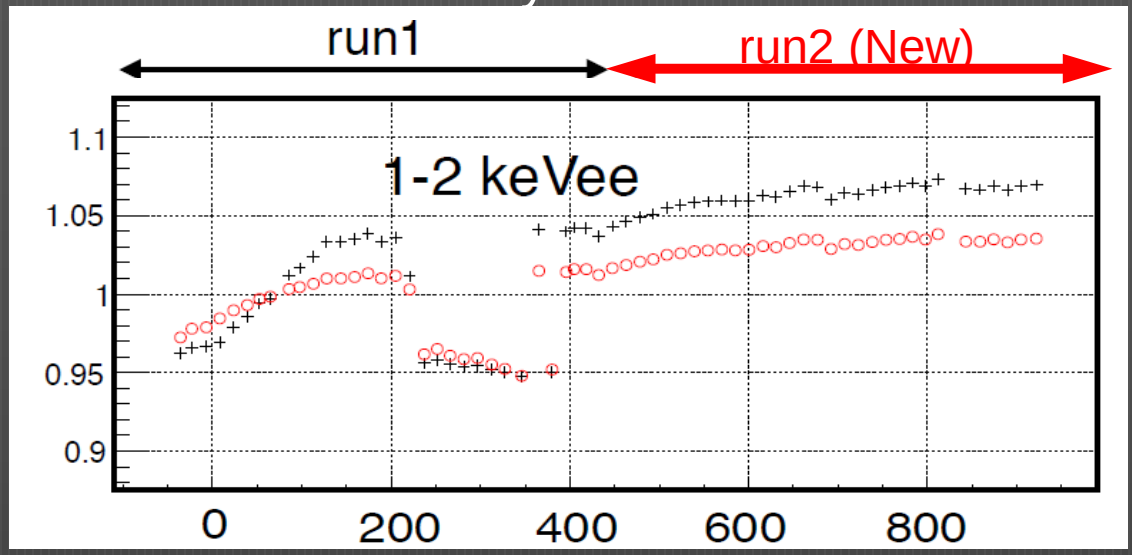
- Updated annual modulation search in XMASS
  - 800 live days x 832 kg =1.82 ton year (3 cycle)
  - Trigger threshold 0.6 keVee
  - Look for event rate modulation not only for nuclear recoil but also for e/γ events

Detector stability; New run2 period

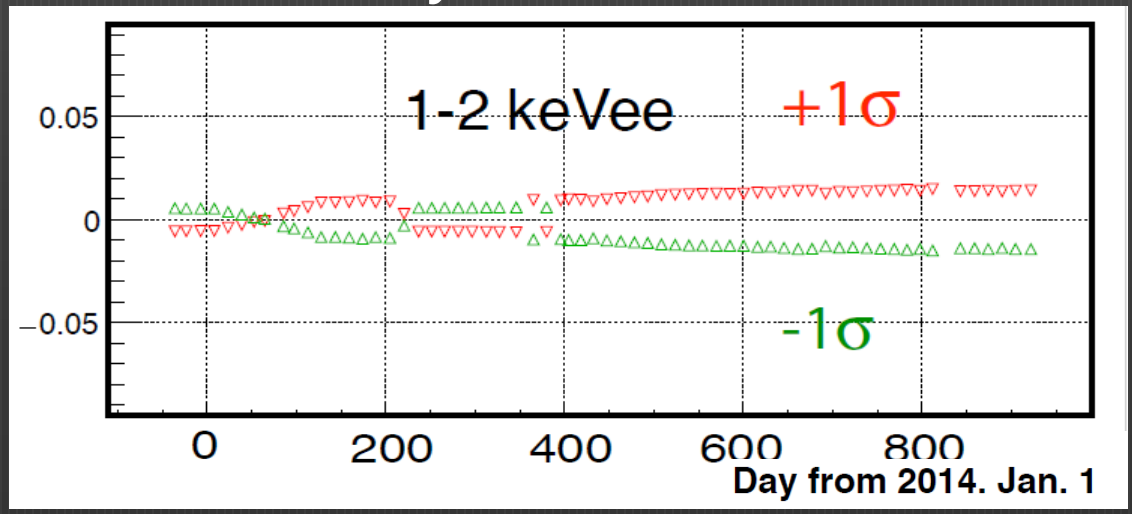
- Weekly ^{57}Co 122keV calibration



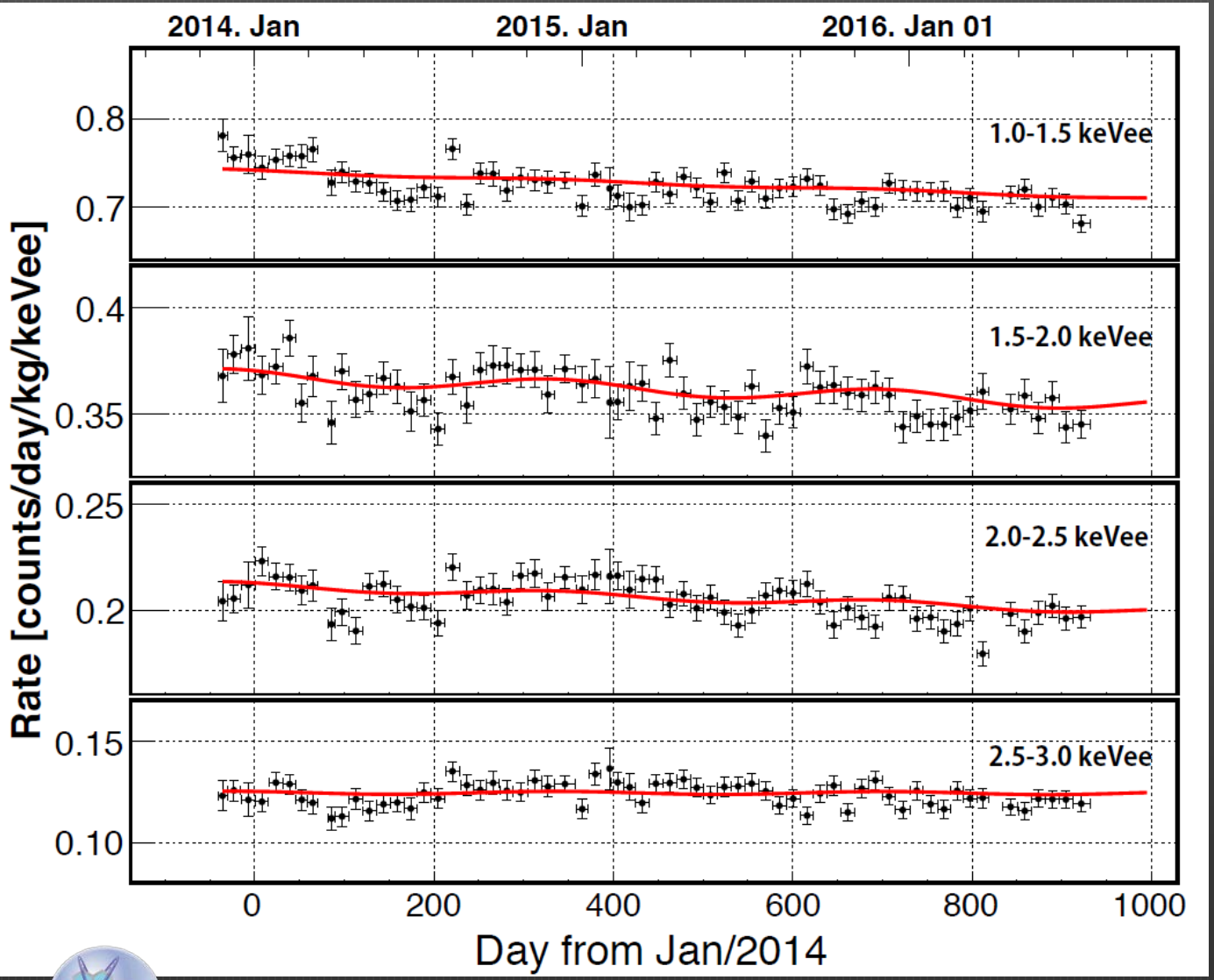
- Stability correction factor
  - Relative efficiency to Abs.= 8m



- Total size of systematic error



Model independent analysis

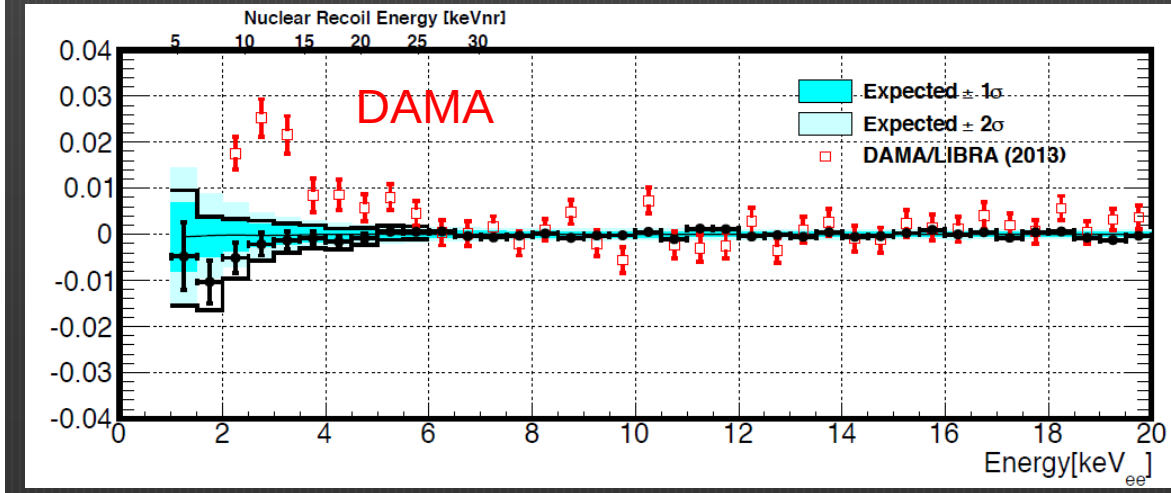


$$\chi^2 = \sum_i^{E_{bins}} \sum_j^{t_{bins}} \left(\frac{(R_{i,j}^{\text{data}} - R_{i,j}^{\text{ex}})^2}{\sigma(\text{stat})_{i,j}^2 + \sigma(\text{sys})_{i,j}^2} \right) + \alpha^2,$$

$$R_{i,j}^{\text{ex}} = \int_{t_j - \frac{1}{2}\Delta t_j}^{t_j + \frac{1}{2}\Delta t_j} \left(\varepsilon_i^s A_i \cos 2\pi \tfrac{(t-t_0)}{T} + \varepsilon_i^b(\alpha)(B_i t + C_i^b) \right) dt,$$

t_0: June 2nd *Bi,Ci* unmodulated components

- Modulation Amplitude *Ai*



WIMP assumed analysis

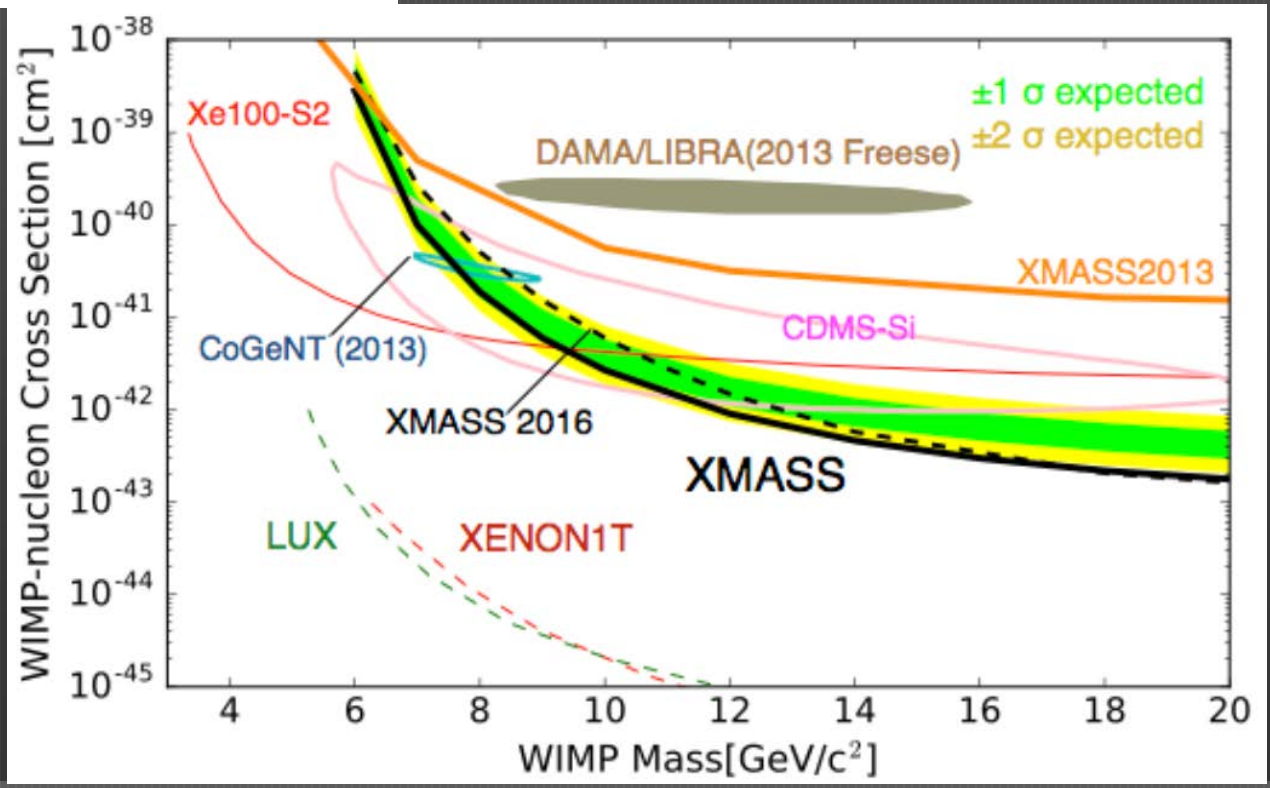
$$\chi^2 = \sum_i^{E_{bins}} \sum_j^{t_{bins}} \left(\frac{(R_{i,j}^{\mathrm{data}} - R_{i,j}^{\mathrm{ex}}(\alpha,\beta))^2}{\sigma(\mathrm{stat})_{i,j}^2 + \sigma(\mathrm{sys})_{i,j}^2} \right) + \alpha^2 + \sum^{Nsys} \beta_i^2,$$

$$R_{i,j}^{\mathrm{ex}} = \int_{t_j - \frac{1}{2}\Delta t_j}^{t_j + \frac{1}{2}\Delta t_j} \left(\varepsilon_i^b(\alpha) \cdot (B_i t + C_i^b) + \sigma_{\chi n} \cdot \varepsilon_i^s(\alpha) \cdot \left(C_i^s(\beta) + A_i^s(\beta) \cos 2\pi \frac{(t-t_0)}{T} \right) \right) dt$$

WIMP-nucleon cross section

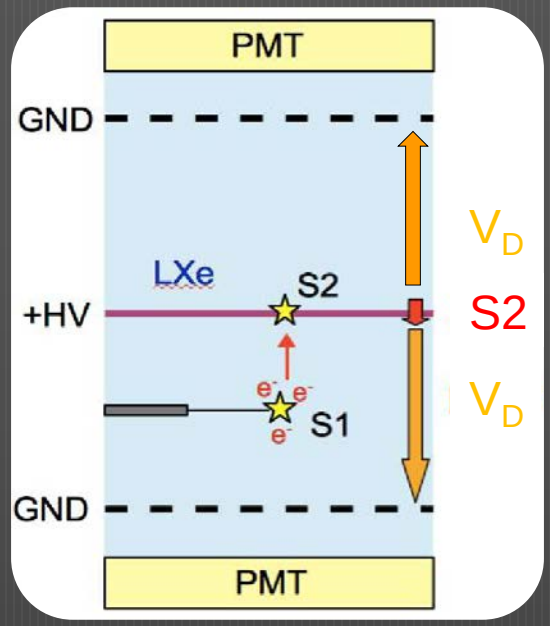
a function of the WIMP mass $A_i(m_\chi)$

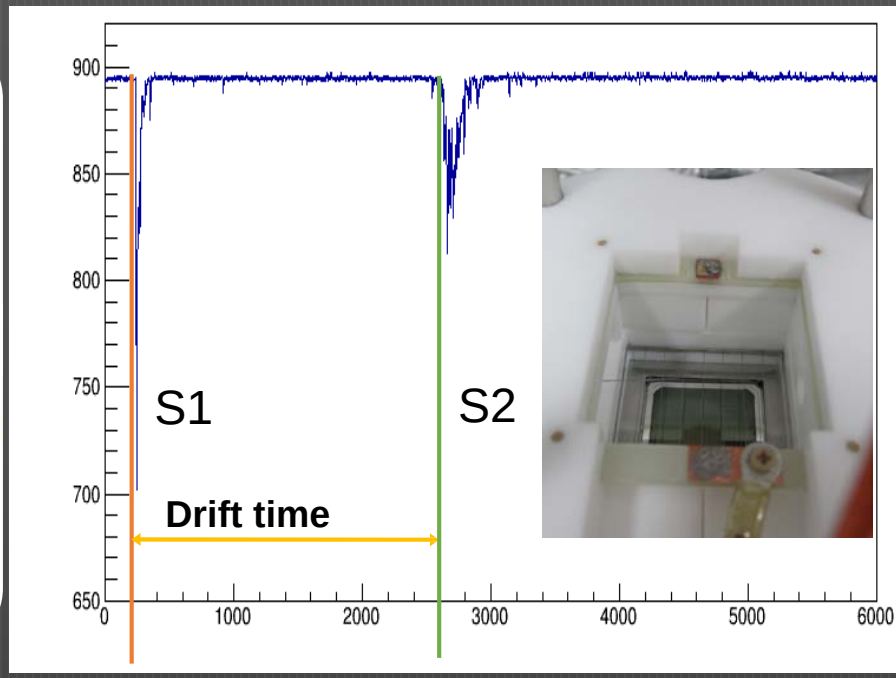
- DAMA region is excluded



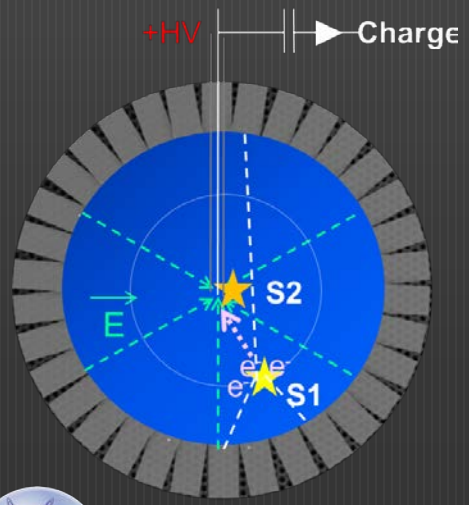
R&D for Future-TPCs

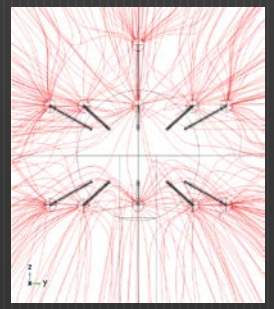
- Single phase TPC
  - Charge amplification in Liq.
  - For beyond 2 phase det.
    - Multiple drift region(for larger)
    - No level control(for more stable)

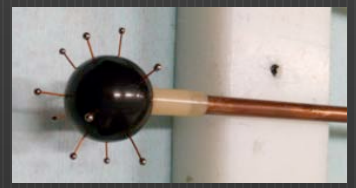




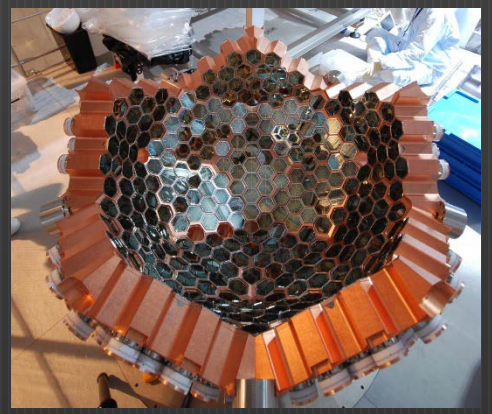
- Spherical TPC
  - Trying to put multi-ball electrode in XMASS
    - To produce higher drift field







Collaboration
with I.Giomataris/NEWS-G



- 2 phase TPC
  - New concepts

Summary

- XMASS is a multi-purpose experiment using single phase NLD technology
  - Lowest β/γ BG detector without PID
- WIMP search by fiducialization
  - 706 live days x 97 kg fiducial mass
  - Limit on SI WIMP-nucleon cross section $\sigma<2.2\times10^{-44}$ cm^2 for 60 GeV/c^2
- Annual modulation search
  - With 3-years of data, no significant modulation was observed.
  - $\sigma<1.9\times10^{-41}$ cm^2 for 8GeV/c^2 , excluded DAMA region
- For future of XMASS
  - R&Ds for TPC are ongoing.

Also please visit poster PE-38

- JinA Jeon “Directionality study of phonon-scintillation signals from a zinc tungstate crystal”
  - Direction sensitive Dark Matter LTD with MMC readout