Results from the annual modulation analysis of the XMASS-I dark matter data

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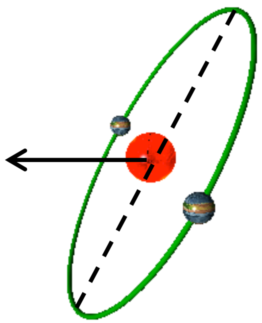
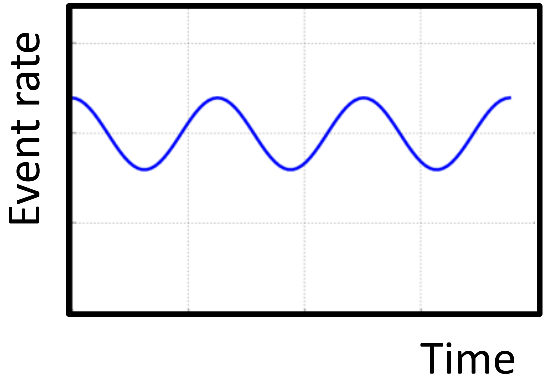
ICRC2015 CONFERENCE

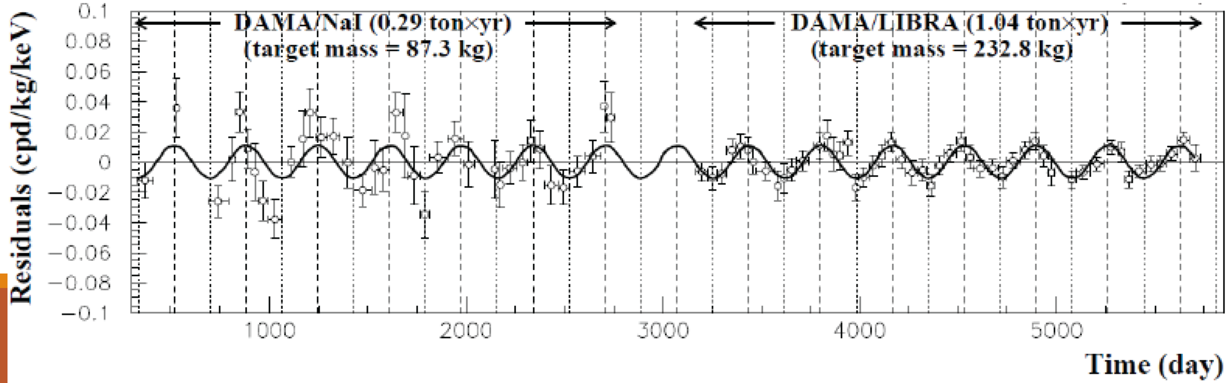
Introduction

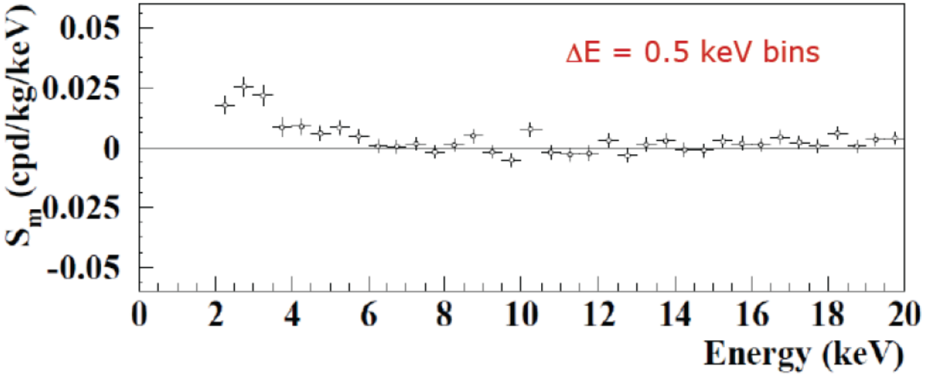
- Event rate of dark matter signal is expected to modulate annually due to relative motion of the Earth around the Sun.
  ➔ It would be a strong signature of dark matter.





- Annual modulation claimed by the DAMA group
  - Total exposure: 1.33 ton*year (14 cycles)
  - 9.3σ significance
  - Modulation amplitude: (0.0112+/-0.0012) cpd/kg/keV for 2-6 keV

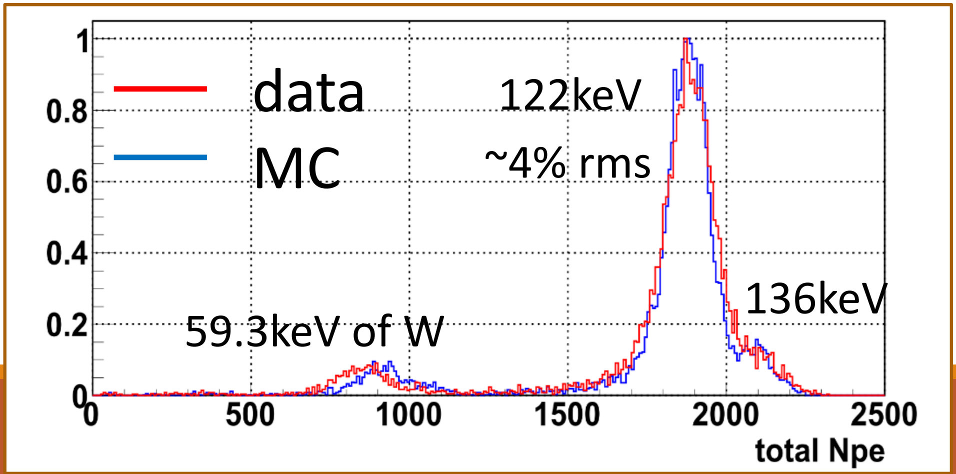


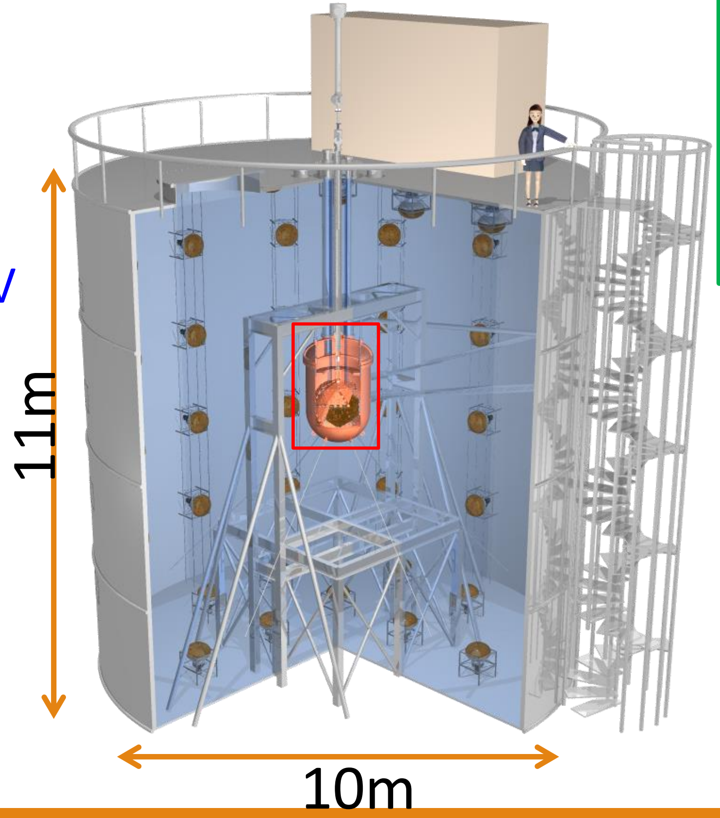


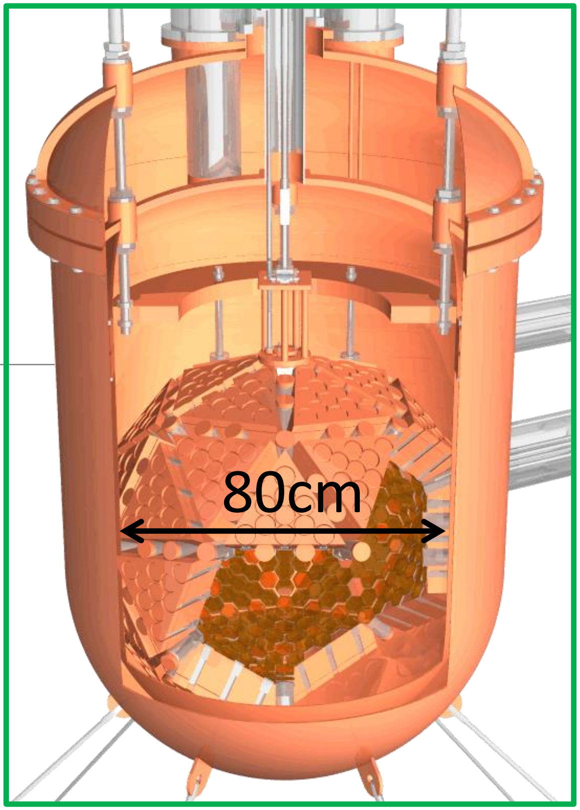
The XMASS-1 detector

- Located in the Kamioka mine in Japan (~2,700m water equivalent)
- A single-phase detector with ~830kg LXe surrounded by an active water shield

- Energy scale calibration by ^{57}Co 122keV γ-ray
  - In this presentation, we denote that "keVee" = (the observed PE)/(PE for ^{57}Co) x122keV
  - Energy non-linearity is taken into account in the Monte Carlo simulation.

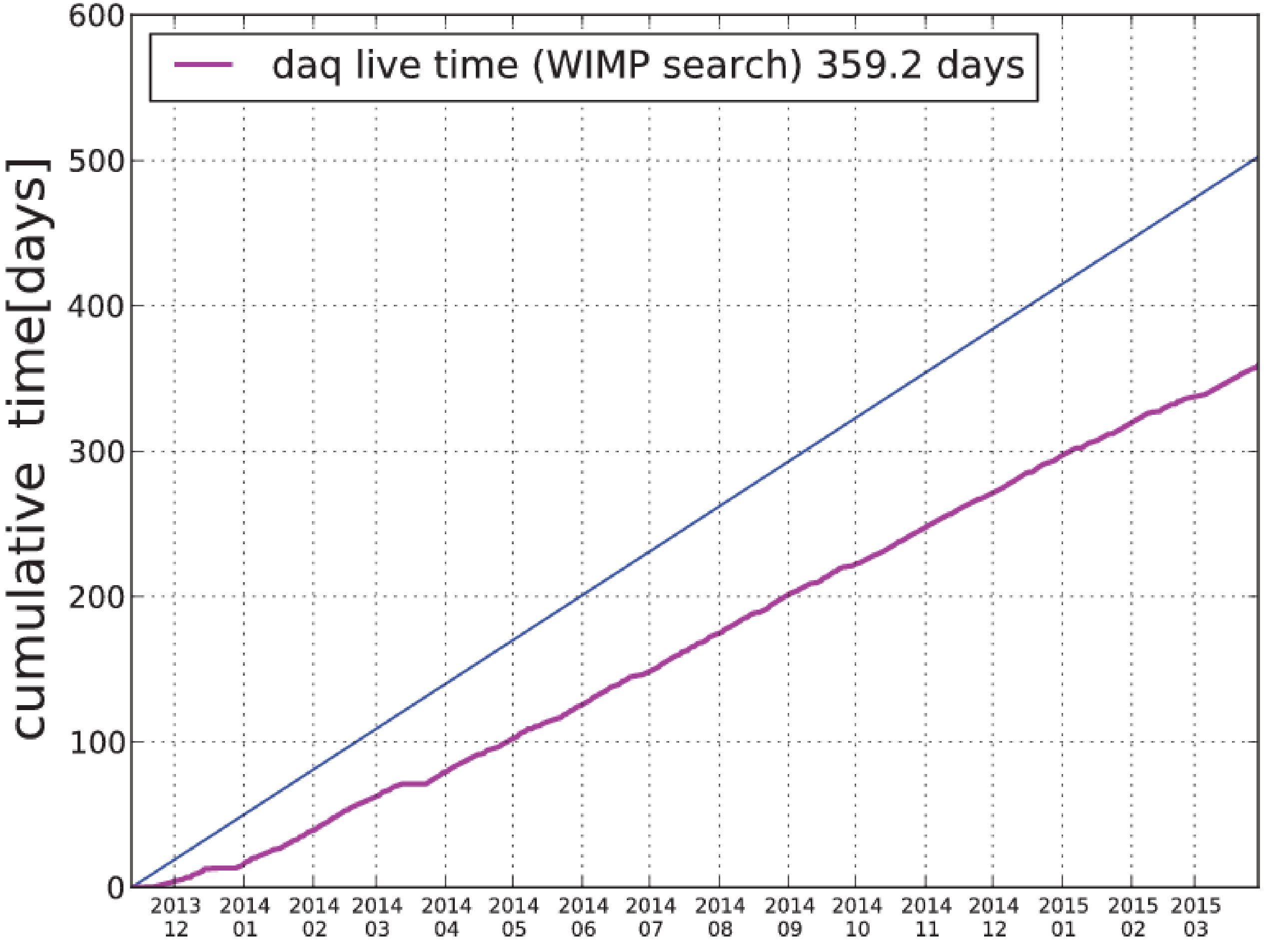






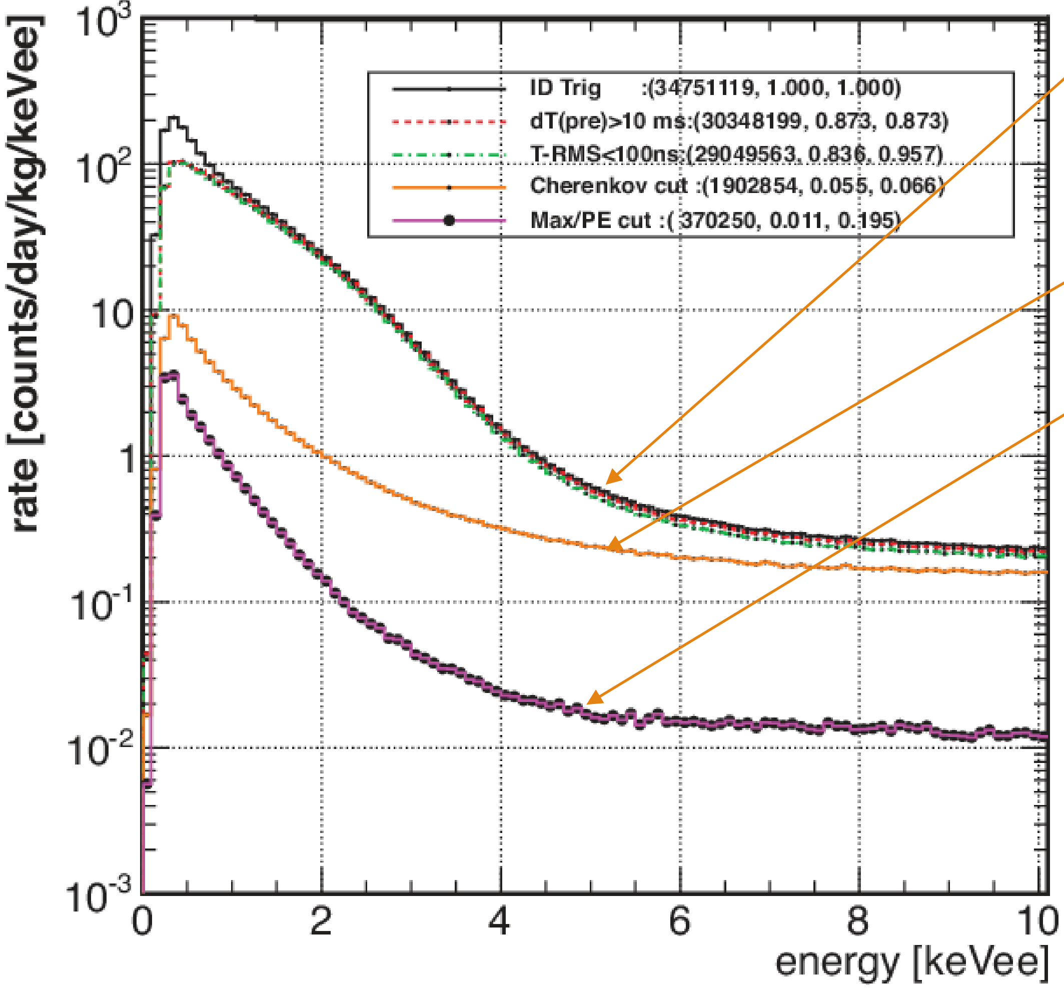
Data set

- November 20, 2013 - March 29, 2015
  - 504.2 calendar days
  - 359.2 live days (71%) for analysis
  - 0.82 ton*year exposure (cf. DAMA 1.33 ton*year)
- Trigger: >=4 hits
- Analysis threshold: 0.5 keVee
- No particle identification
  - Both nuclear recoil and *e*/γ events are retained



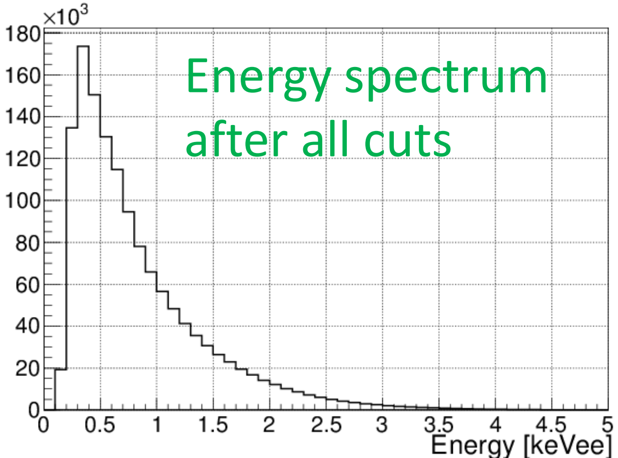
Event selection

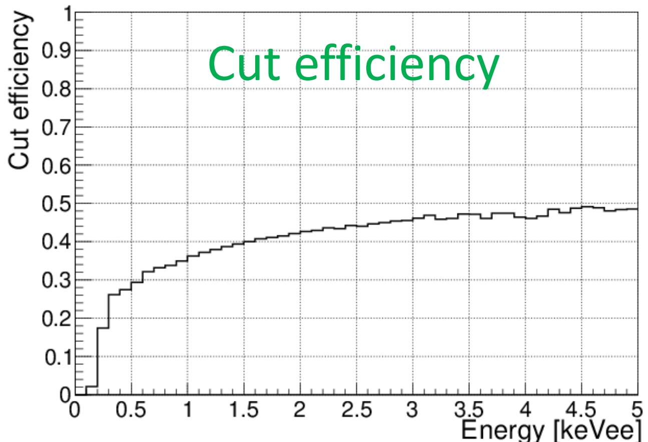
Our observed data (359.2 live days)



- Select events triggered only by LXe detector
- Simple noise reduction
  - Veto 10 ms after the events
  - RMS of hits' timing < 100 ns
- Remove Cherenkov events occurred in PMT glass (^{40}K)
  - # of hits in earlier 20 ns >60% of total hits
- Remove events in front of PMT
  - Larger MaxPE/TotalPE ratio

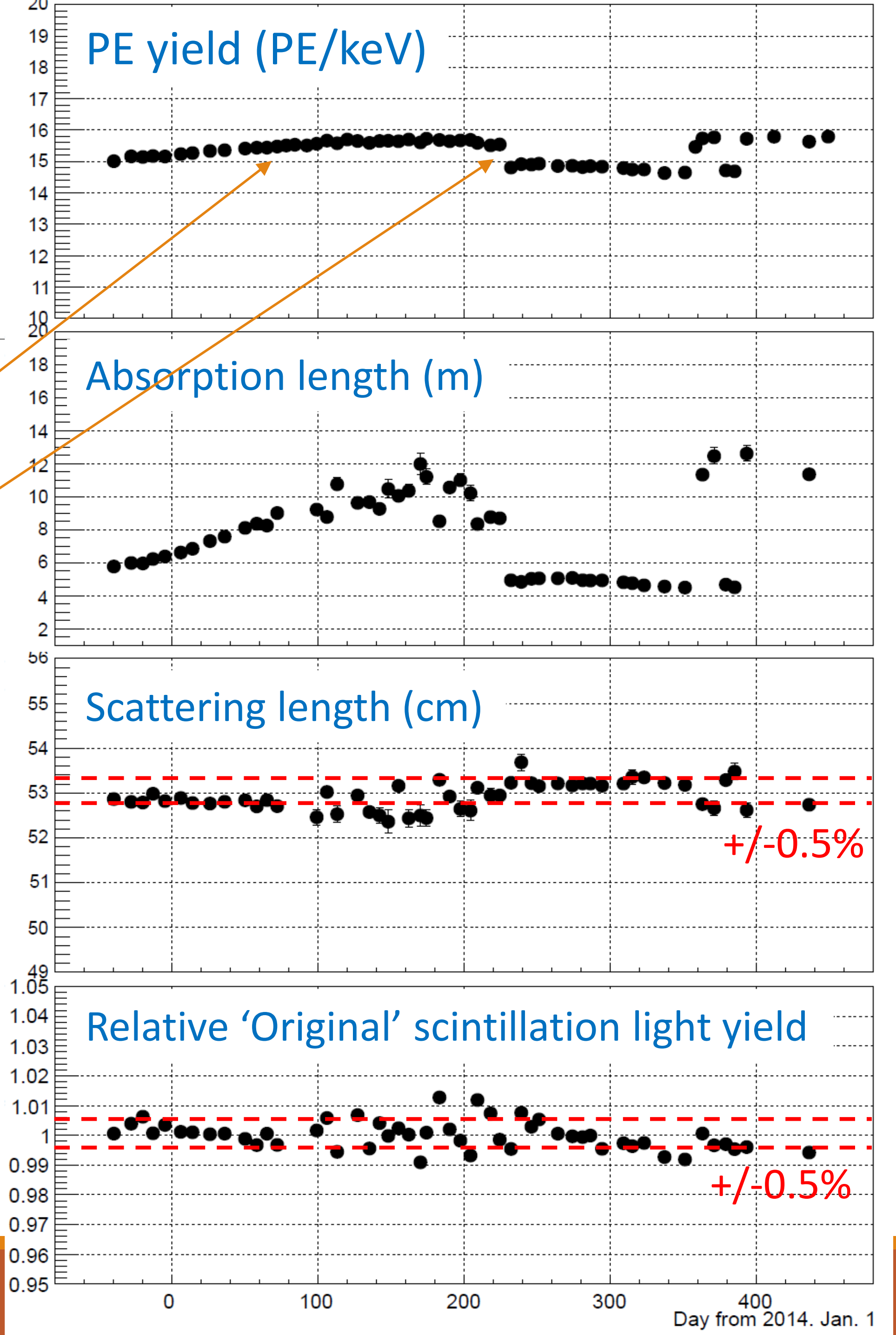
MC simulation (20GeV WIMP)





Detector stability

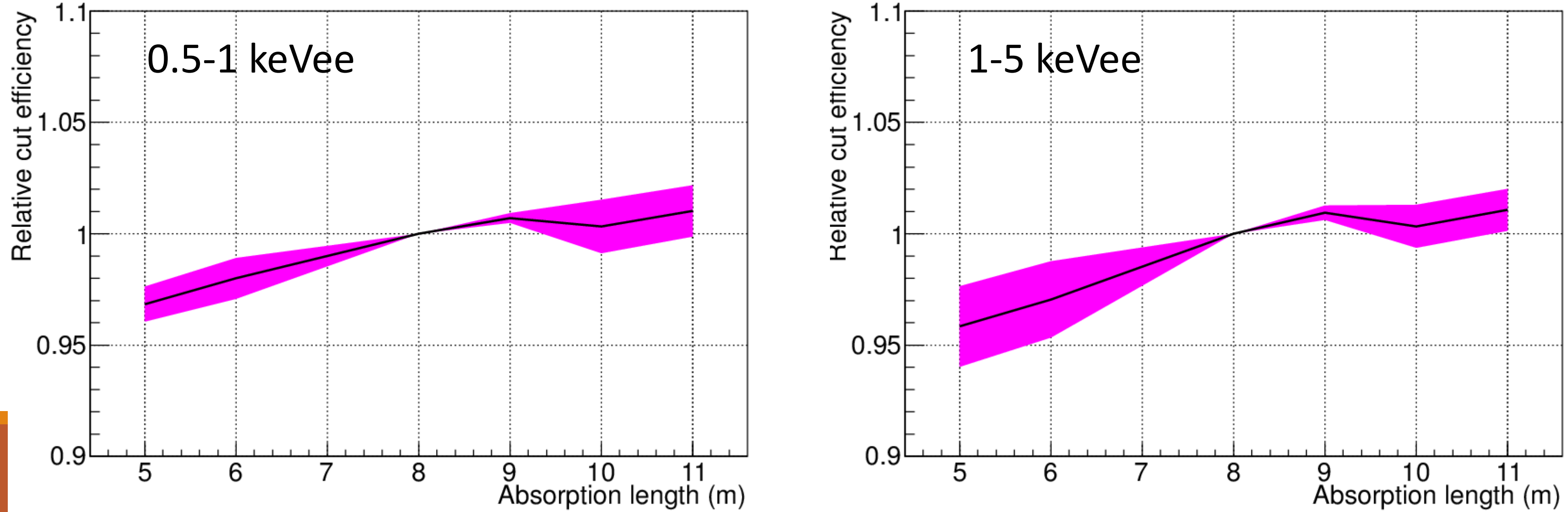
- Calibration by a ^{57}Co source every week to monitor
  - Photo-electron (PE) yield
  - Optical properties of liquid xenon
- The observed PE yields experienced
  - Gradual change from the beginning
  - Sudden drop at power failure (~5%)
- These PE yield changes can be explained by the change of the absorption length in liquid xenon
  - Scattering length: stable within +/-0.5%
  - The 'original' light yield extracted: stable within +/-0.5%
- Uncertainties due to this instability is taken into account



Relative efficiency correction

- The change of absorption length affects cut efficiency
- The relative change of cut efficiency is evaluated using Monte Carlo simulation and data is corrected for.
- Its uncertainty band is estimated to cover the position dependence of detector response and is taken into account as systematic error. ➔ A dominant systematic error for this analysis

Relative efficiency correction (14GeV WIMP)



Modulation analysis (1)

- Binned chi-square method
  - Data set is divided into 10 days time bins and 0.1 keVee energy bins.
  - All energy and time bins are fitted simultaneously.

- Two independent analyses for systematic error treatment

R^{obs}: observed event rate
R^{pred}: predicted event rate

Analysis 1: With a nuisance parameter α

$$\chi^2 = \sum_{i}^{E-\mathrm{bins}} \left(\sum_{j}^{t-\mathrm{bins}} \frac{(R_{i,j}^{\mathrm{obs}} - R_{i,j}^{\mathrm{pred}} - \alpha_i K_{ij})^2}{\sigma(\mathrm{stat})_{i,j}^2} + \alpha_i^2 \right)$$

Analysis 2: With a covariance matrix

$$\chi^2 = \sum_{i,j}^{Et-\mathrm{bins}} (R_i^{\mathrm{obs}} - R_i^{\mathrm{pred}})(V_{\mathrm{stat}} + V_{\mathrm{sys}})_{ij}^{-1}(R_j^{\mathrm{obs}} - R_j^{\mathrm{pred}})$$

Systematic errors

K_{ij} or $(V_{sys})_{ij}$ represents 1σ systematic error

Modulation analysis (2)

- Model independent modulation search

$$\mathrm{R}^{\mathrm{pred}}(E_i, t_j) = C_i + A_i \cos 2\pi(t_j - t_0)/T$$

→ ***A_i*** (modulation amplitudes at each energy bin) and
C_i (unmodulated rates at each energy bin) are parameters to be fitted.

- Modulation search assuming WIMP dark matter

$$\mathrm{R}^{\mathrm{pred}}(E_i, t_j) = C_i + \sigma \times A(m_\chi, E_i) \cos 2\pi(t_j - t_0)/T$$

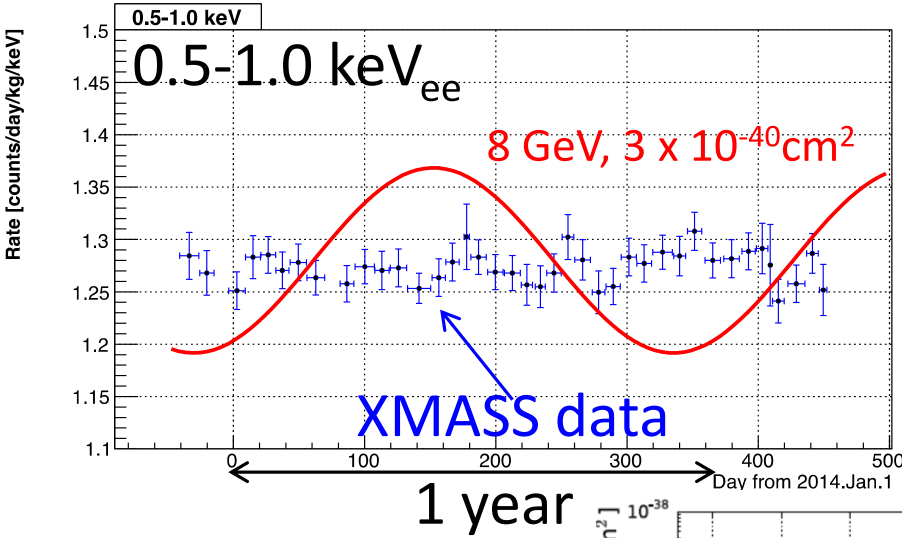
→ ***C_i*** (unmodulated rates), **σ** (WIMP cross section) and **m_χ** (WIMP mass) are parameters.

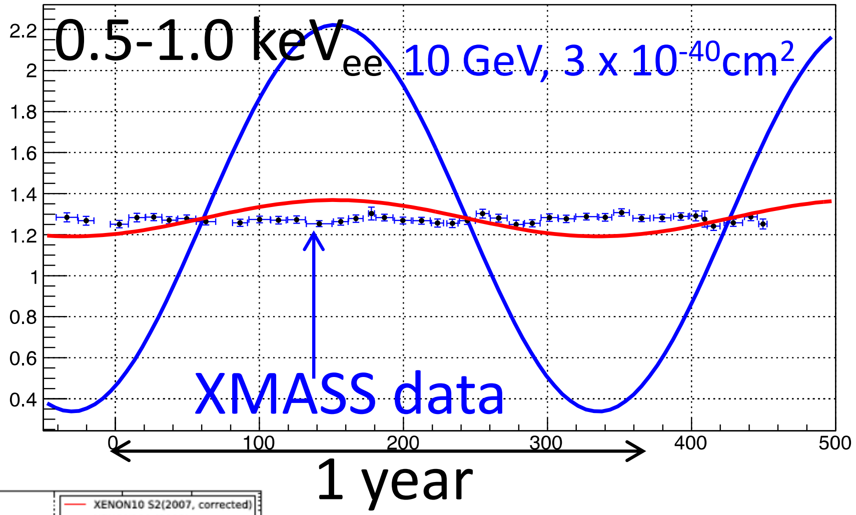
Today's topic

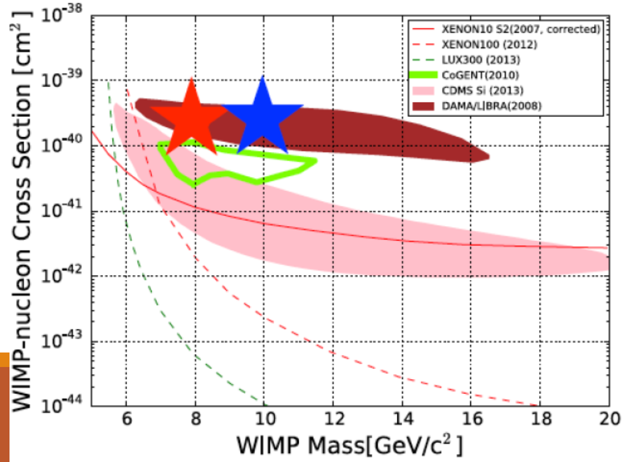
In both cases, modulation period and phase are fixed to T=365 days and t_0=152.5 days, respectively.

Sensitivity to annual modulation

XMASS ‘real’ data (359 days); 0.5 -1.0 keVee (4.8 – 8.0 keVr) w/o syst.



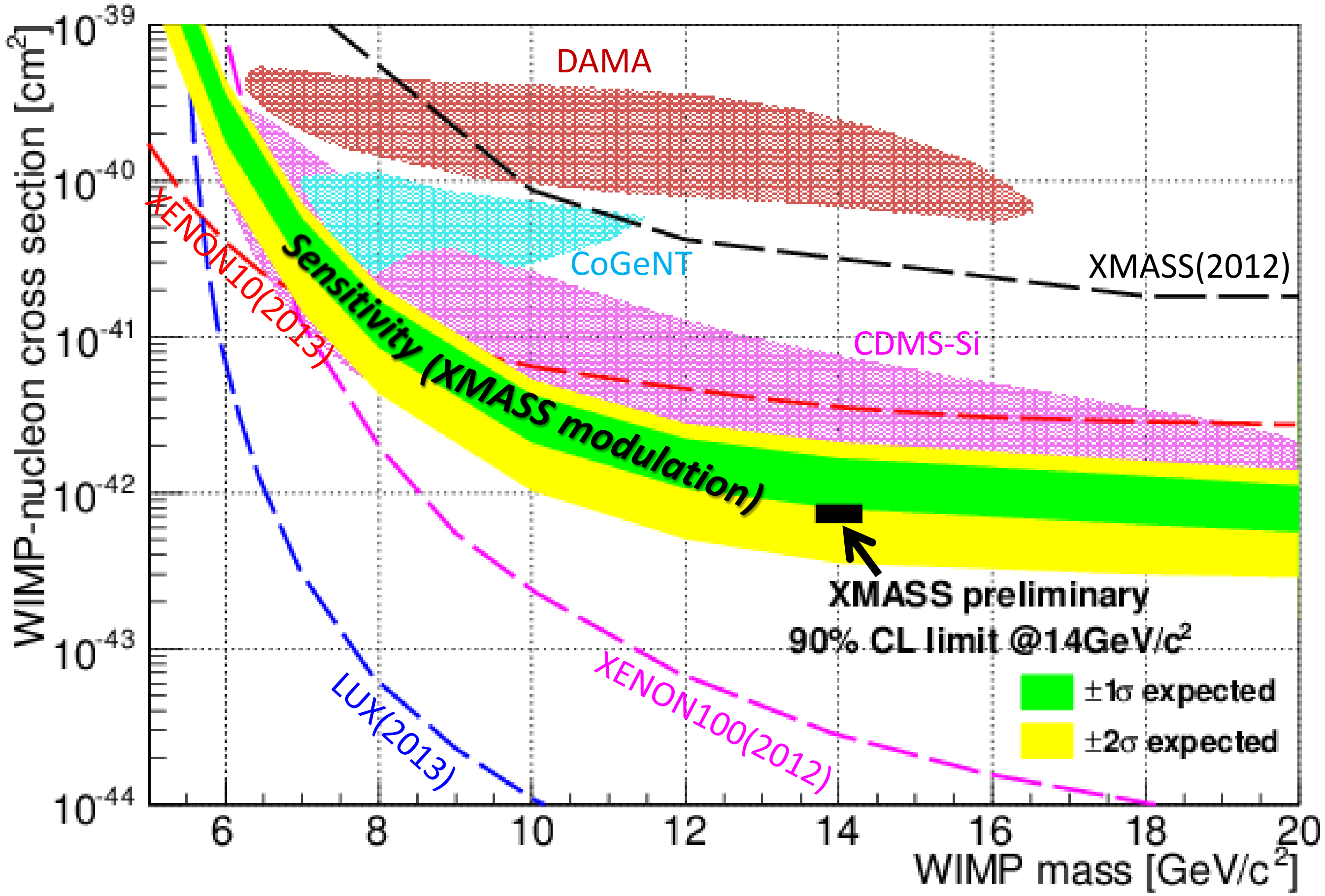




- High sensitivity to modulation
  - Largest mass (832 kg)
  - Low threshold (0.5 keVee)
- Sensitive both nuclear recoil and *e*/γ signals
  - Same as DAMA
  - If nuclear recoil
    - Direct comparison is possible (lines)
  - If e/γ signal
    - Need models to compare

Preliminary results on WIMP dark matter

- Astrophysical parameters assumed
  - v_0=220 km/s, v_{esc}= 650 km/s, ρ=0.3 GeV/cm^3
- We show the expected sensitivity from **our annual modulation analysis.**
  - Covers DAMA's allowed region
- Our preliminary 90% CL upper limits for 14 GeV/c^2 WIMP is also shown.
- We are finalizing systematic error evaluation and final results will come soon.



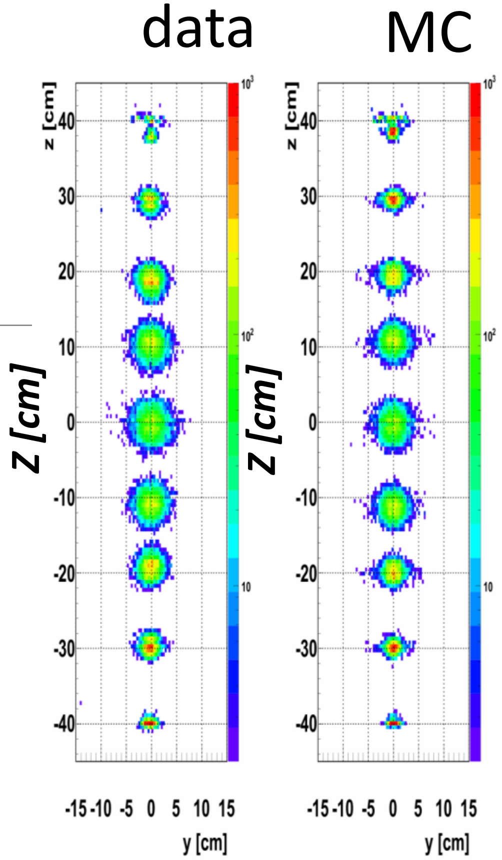
Conclusions

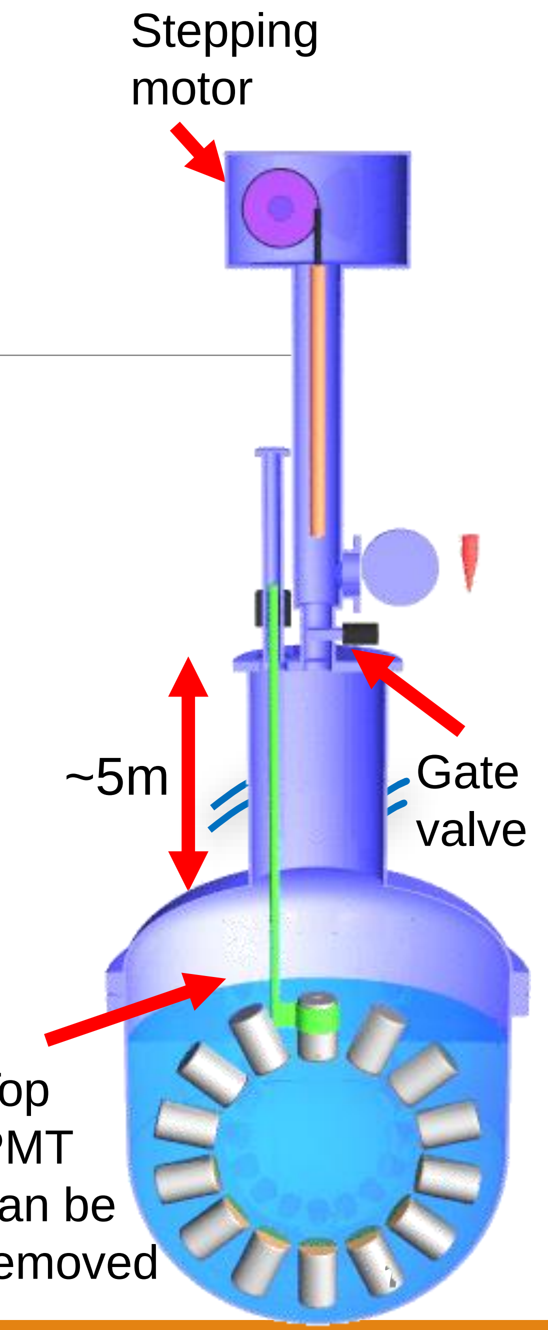
- Annual modulation of event rate in the direct dark matter detection experiments would be a strong signature of dark matter.
- We performed an annual modulation analysis using our 359.2 live days of dark matter data.
- The expected sensitivity of our modulation analysis covers DAMA's allowed region.
- We are finalizing systematic evaluation and final results will come soon.

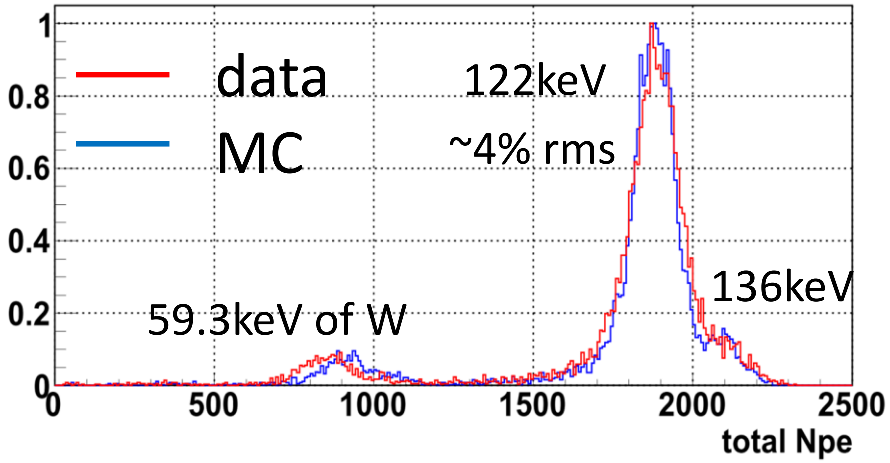
Backup slides

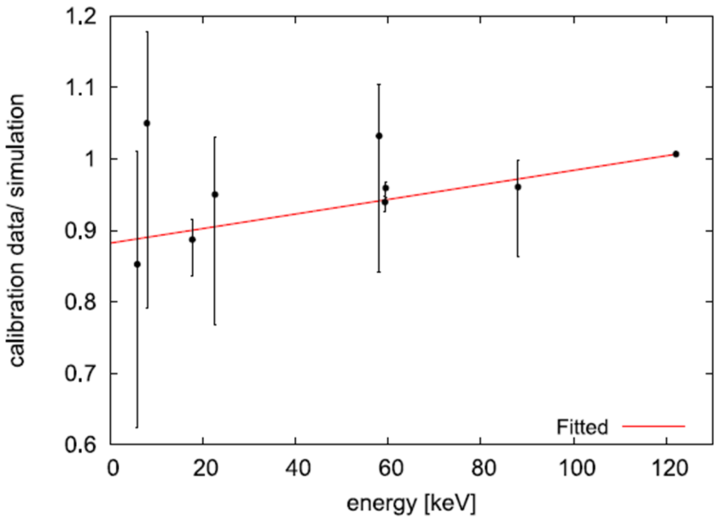
XMASS Inner Calibration

- Calibration sources: ^{55}Fe, ^{109}Cd, ^{241}Am, ^{57}Co, ^{137}Cs
- Light Yields, Optical parameters, position reconstruction









NEST simulation