Annual Modulation Of Dark Matter

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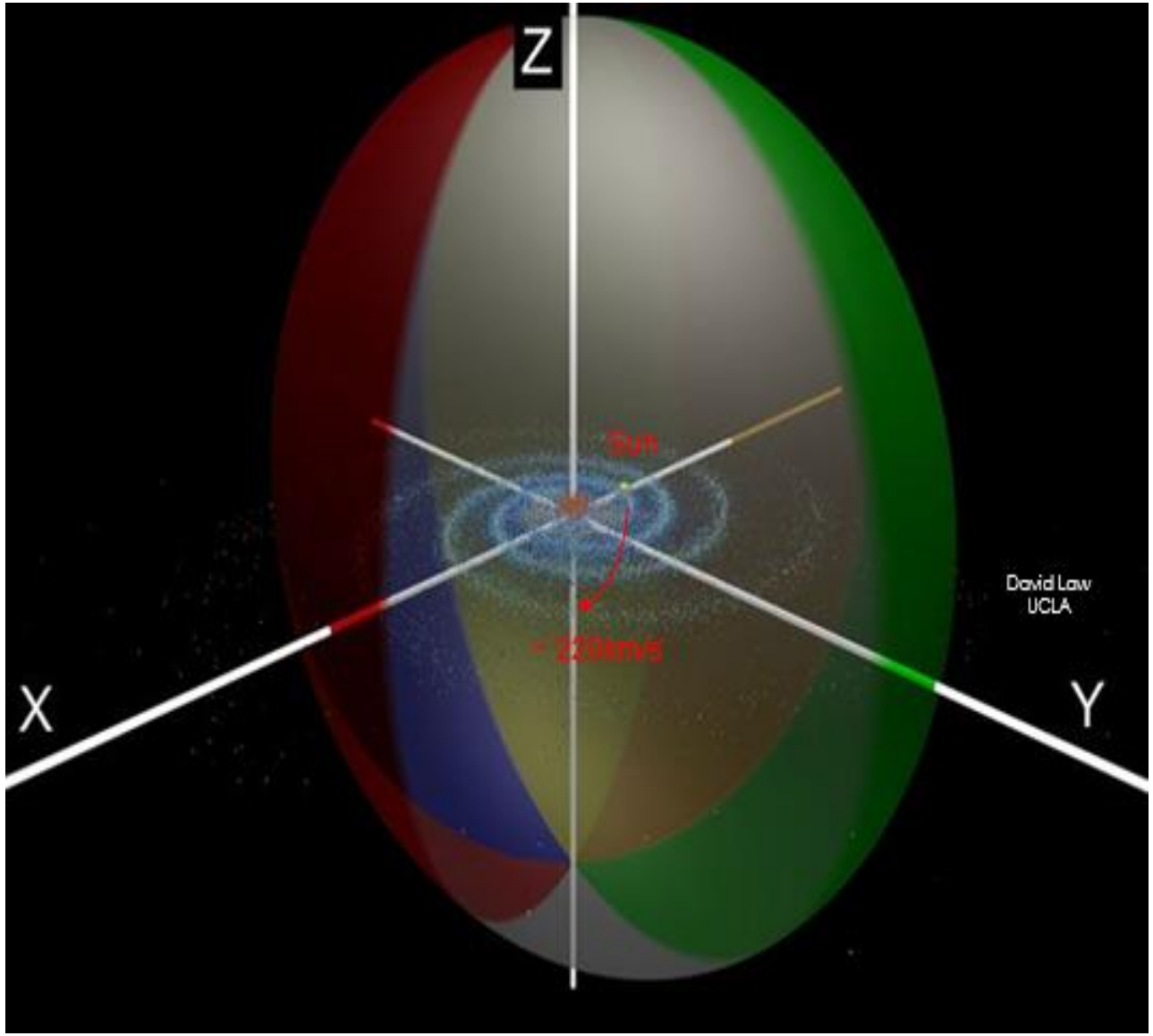
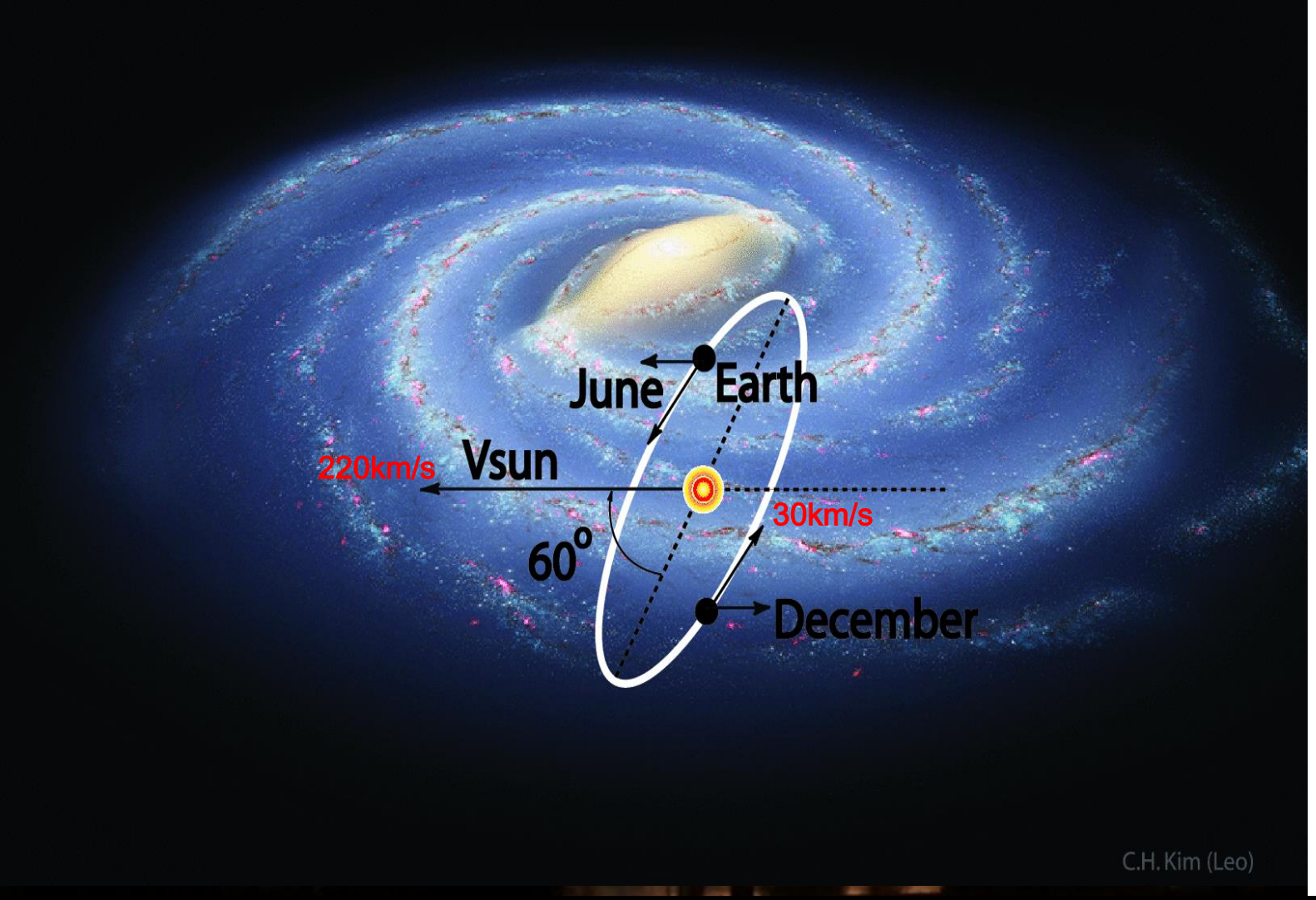
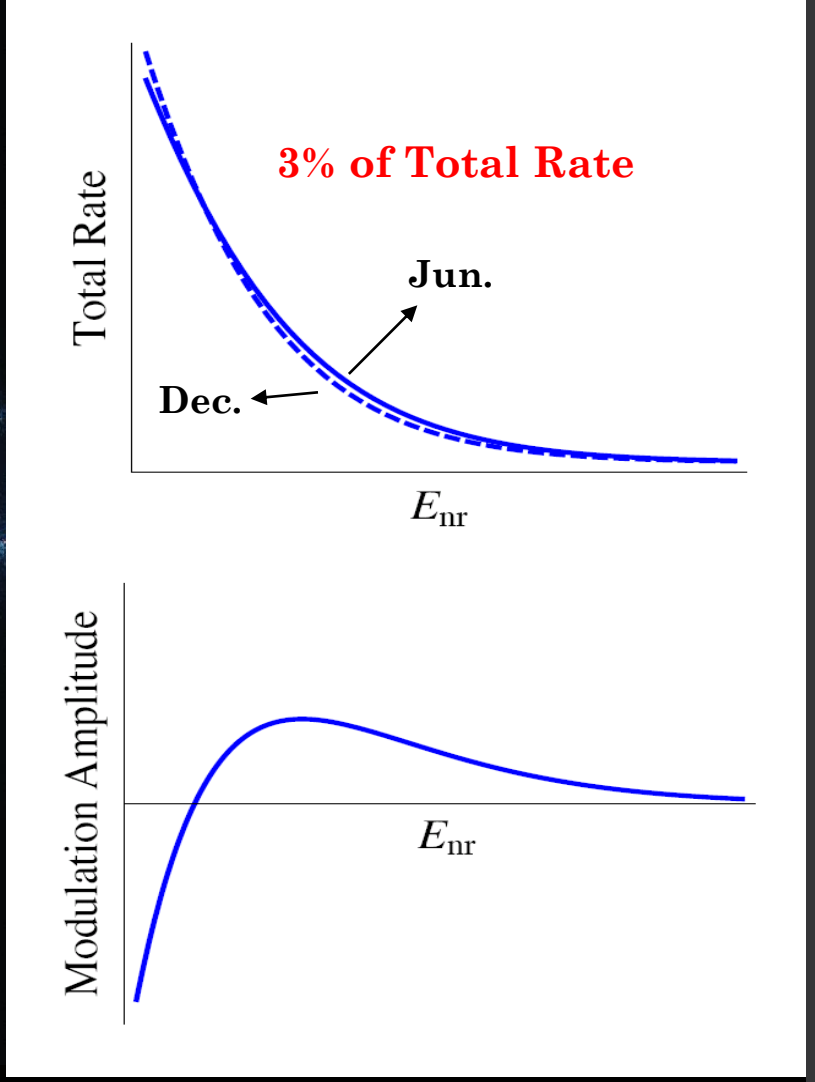
9th Patras Workshop on Axions, WIMPs and WISPs

The Milky Way With Dark Matter

- **Λ-CDM**
- WIMPs - relic abundance
- **Standard Halo Model (SHM)**
- Smooth and virialized halo
- Decoupled with ordinary matter
- Maxwellian velocity distribution but truncated with ~ 650 km/s (v_{esc})
- Mass - a few GeV to tens of TeV
- Density - ~ 0.3 GeV/cm^3 (ρ_χ)





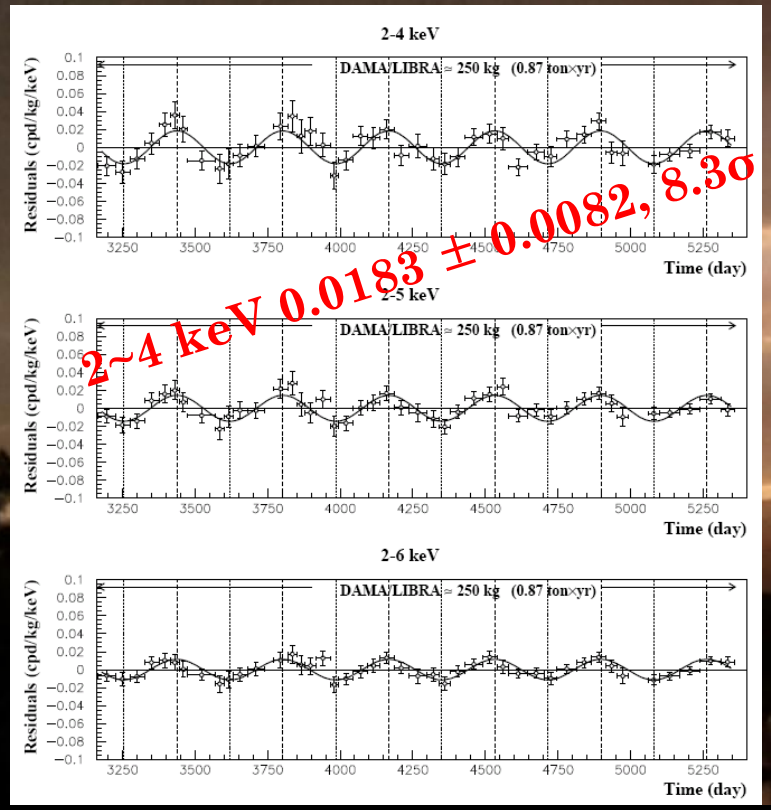


Annual Modulation Derived From The Earth's Orbit

$$v_E(t) \approx 220 + 15\cos\left(2\pi\frac{t-152.5}{365.25}\right) km/s$$

DAMA

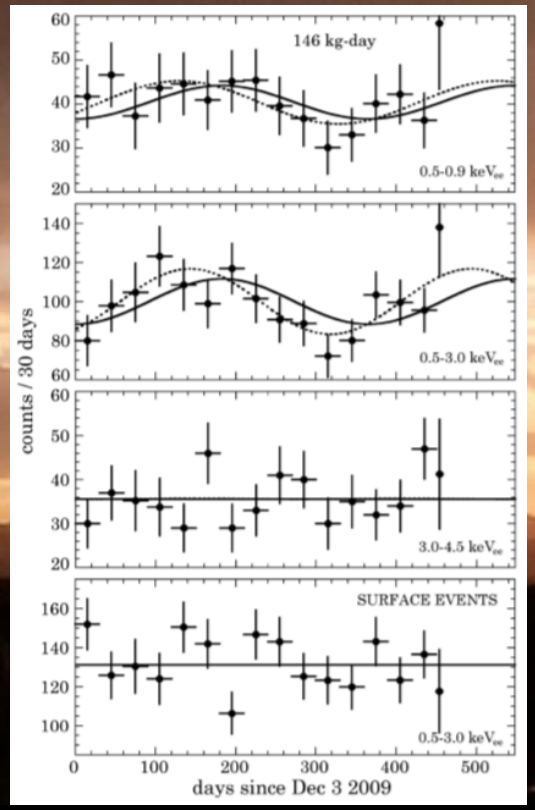
Eur. Phys. J. C 67 (2010) 39



2~4 keV 0.0183 ± 0.0082, 8.3σ

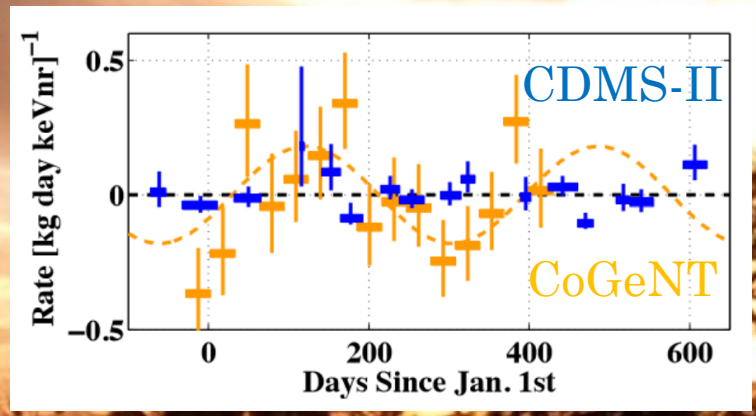
CoGeNT

PRL 107 (2011) 141301



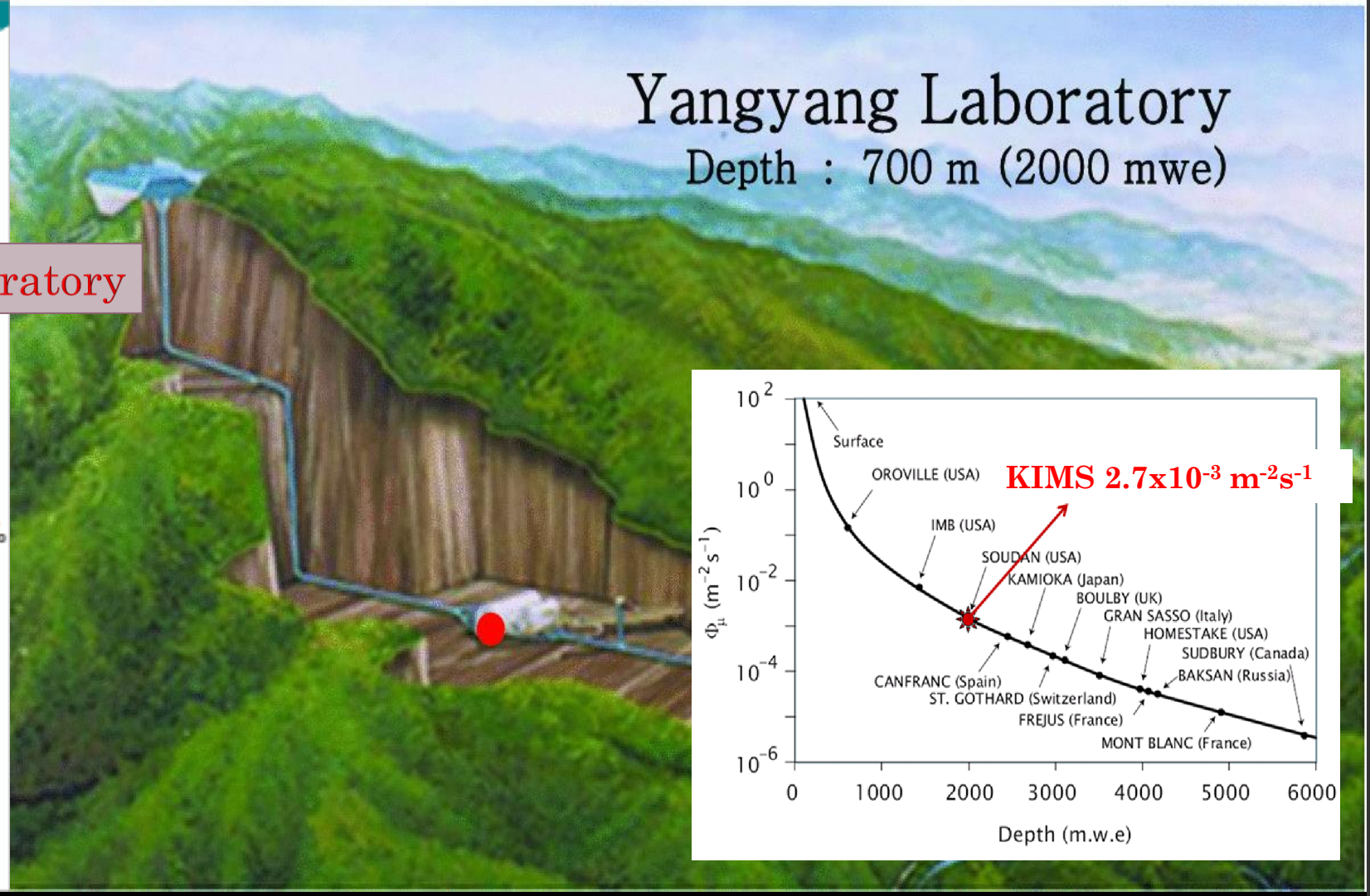
CDMS-II

arXiv:1203.1309v2



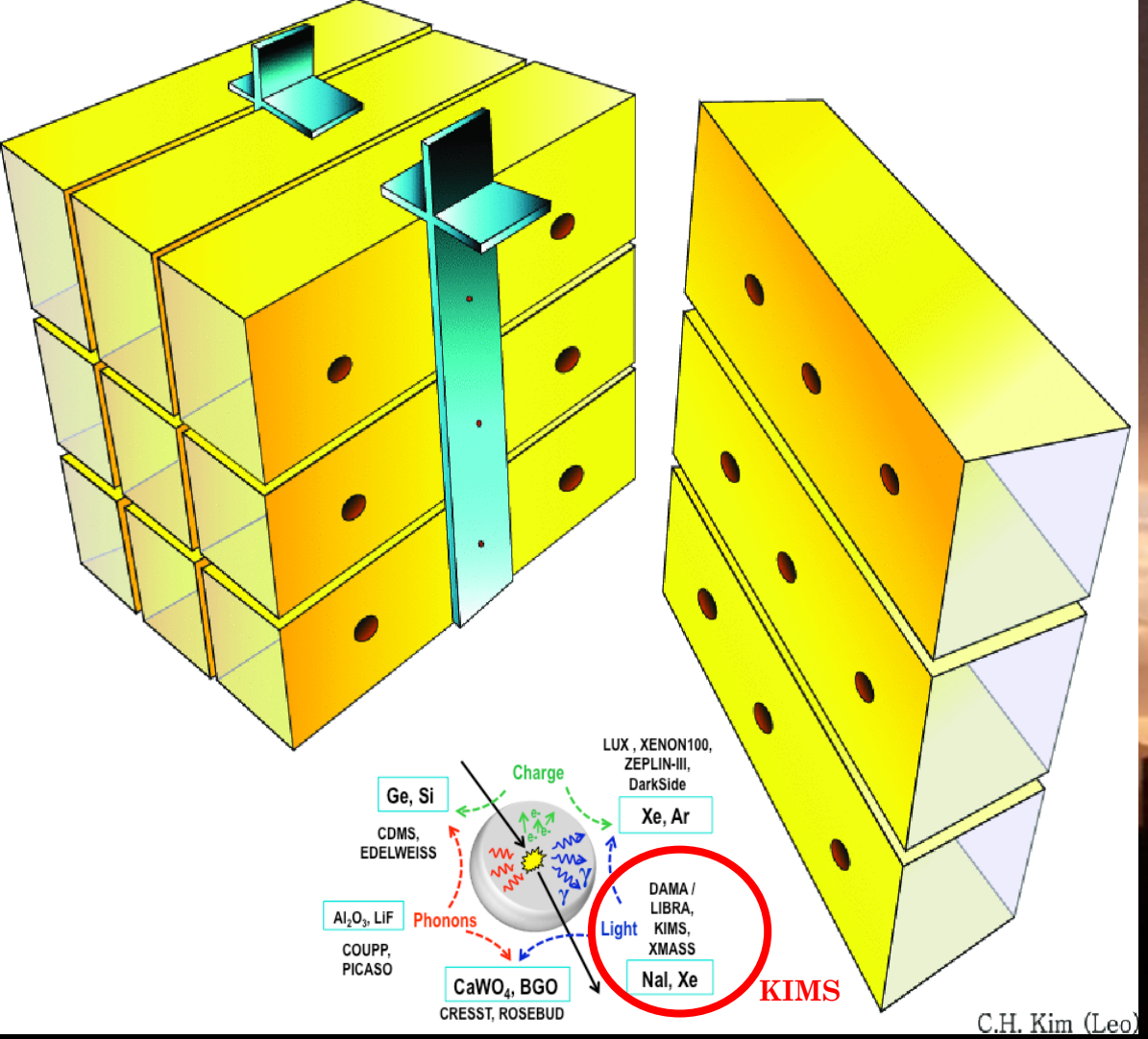
Annual Modulation Study

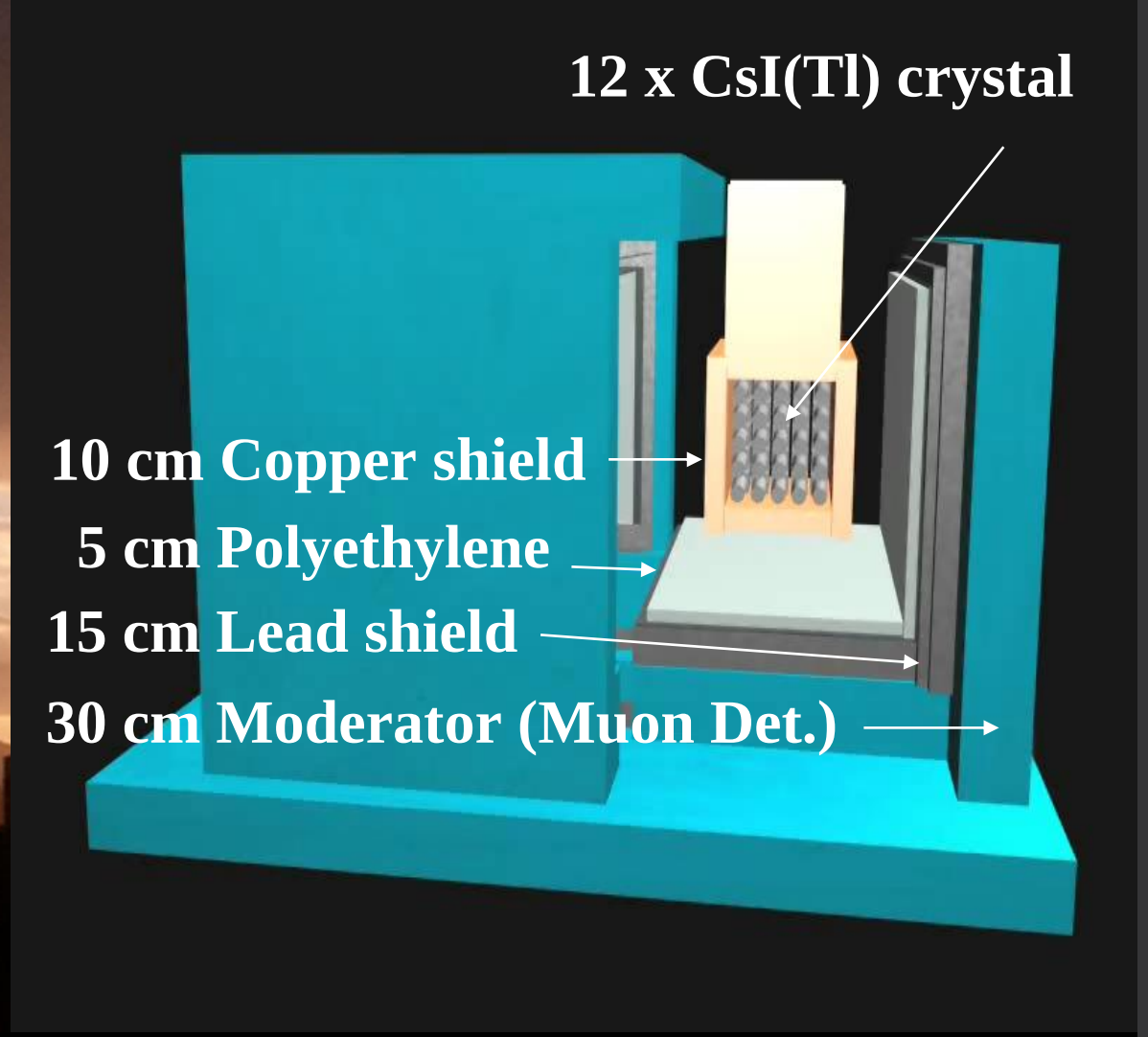
DAMA : 2~4 keV : 0.0183±0.0082, 8.3σ



KIMS Experiment

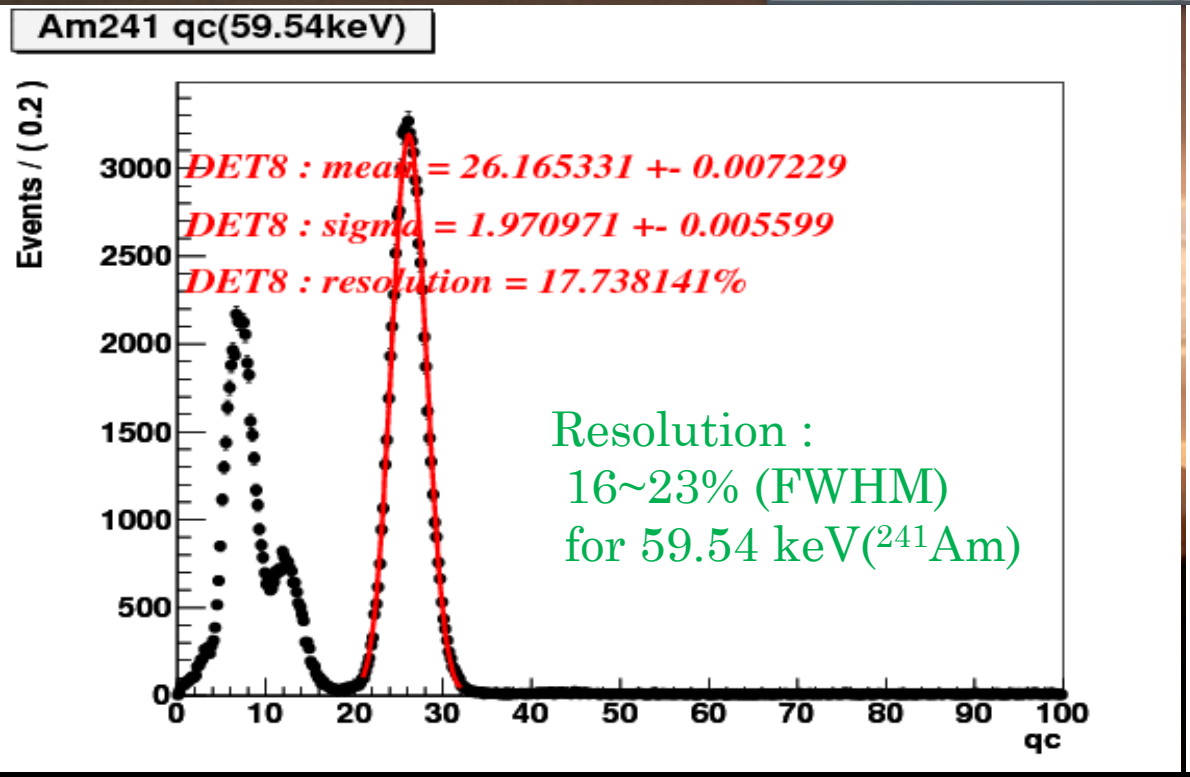
Underground Laboratory (2000 mwe), Muon flux : 2.7×10^{-3} $m^{-2}s^{-1}$



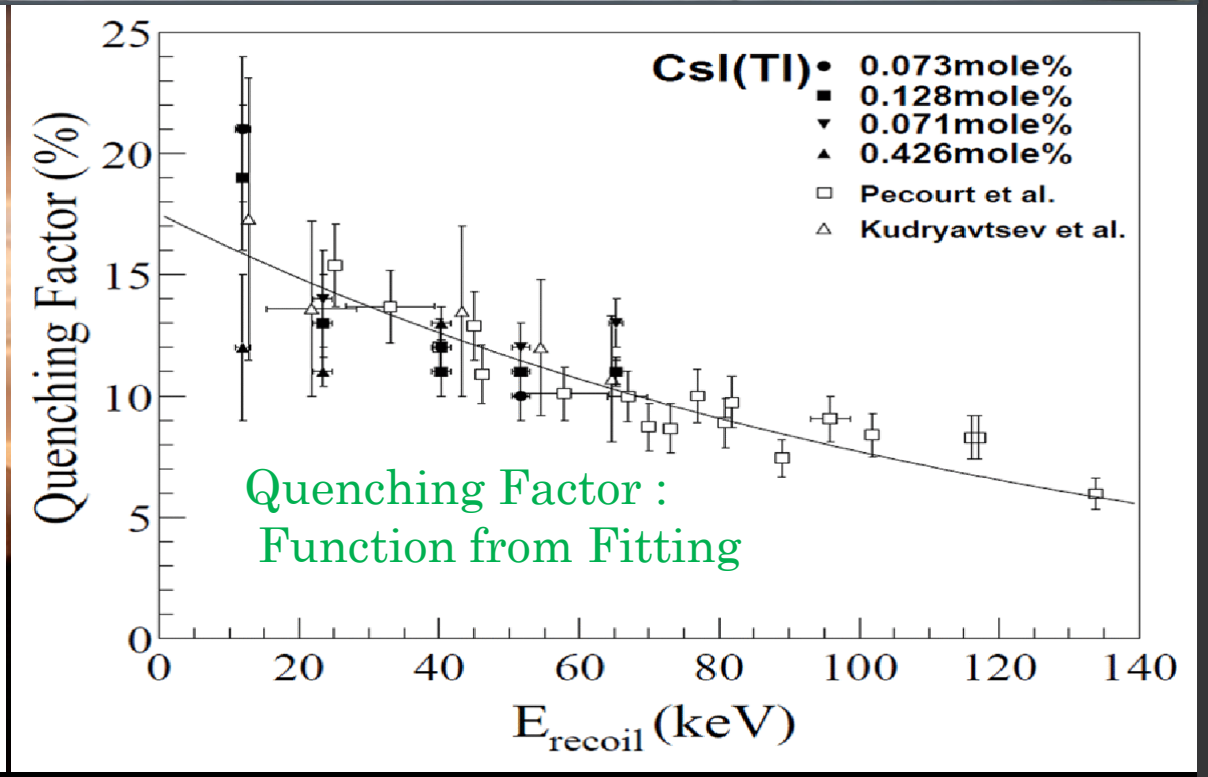


Detector & Shielding Structure

12 CsI(Tℓ) Crystals (103.4 kg)



Resolution :
16~23% (FWHM)
for 59.54 keV(^{241}Am)



Quenching Factor :
Function from Fitting

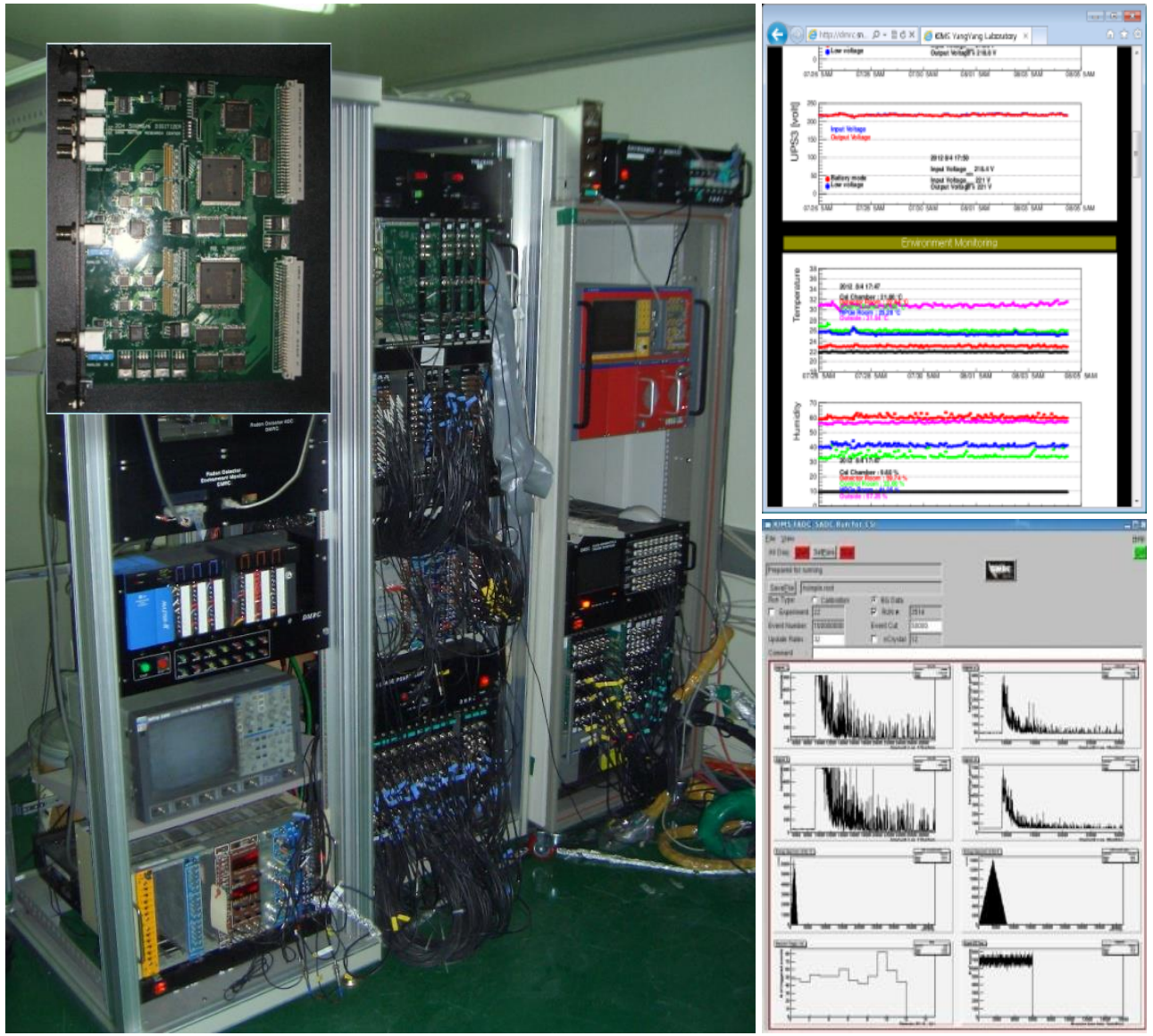
Detector Property

Density : 4.53 g/cm^3, Decay constant : ~1 μs, Peak emission : 550 nm, Light yield : ~60000 photons/MeV

Both ^{133}Cs, ^{127}I are sensitive to SD interaction

Electronics & Stabilities

- **Electronics**
- 400MHz FADC (10bit dynamic range, 40.96μs window)
- ROOT Based Linux System
- **Trigger Condition**
- 2 SPEs from 2 PMTs within 2 μs
- 300 ns width for big signal
- **Monitoring System Stabilities**
- Crystal's surface temperature
- High voltage, Gain, ……

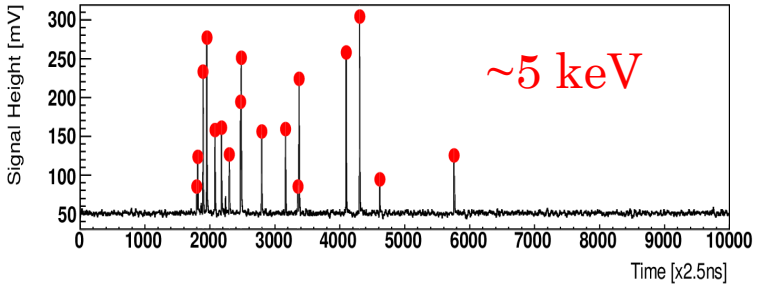


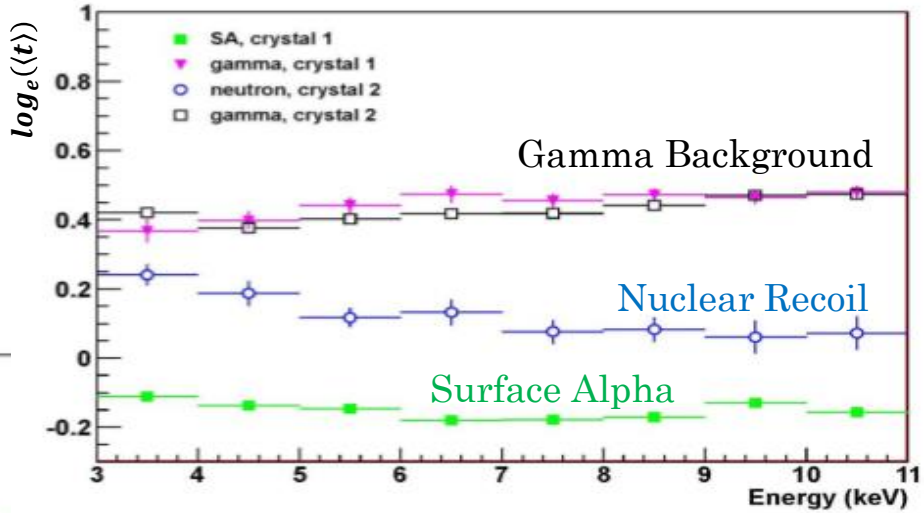
Signal

- **Signal**
  - Single Photoelectron(SPE) level
  - 4~6 SPEs/keV
- **Pulse Shape Discrimination (PSD)**
  - Calculate Mean time of signal and take logarithm of it

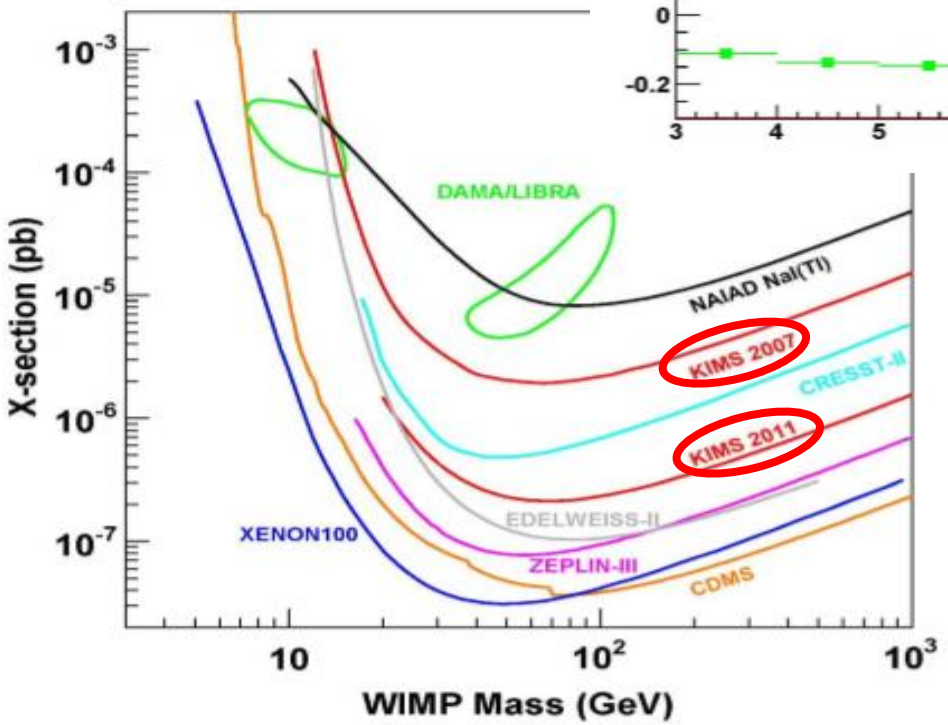
$$\langle t \rangle = \frac{\sum A_i t_i}{\sum A_i}, \; log_e(\langle t \rangle)$$

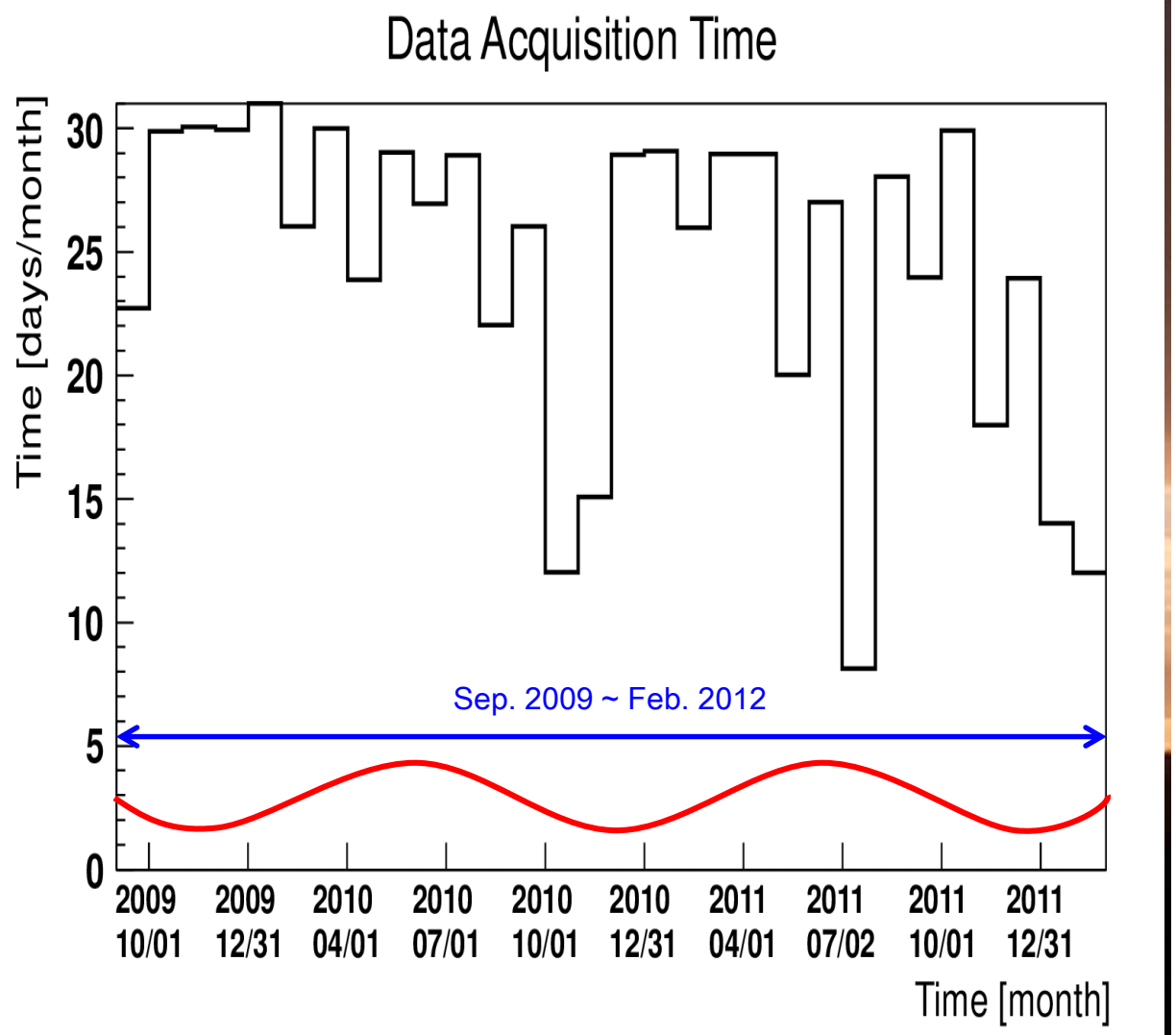
- **Annual Modulation Study**
  - KIMS may lose some nuclear recoil events by PSD cut - Eur. Phys. J. C. 53, 205 (2008)

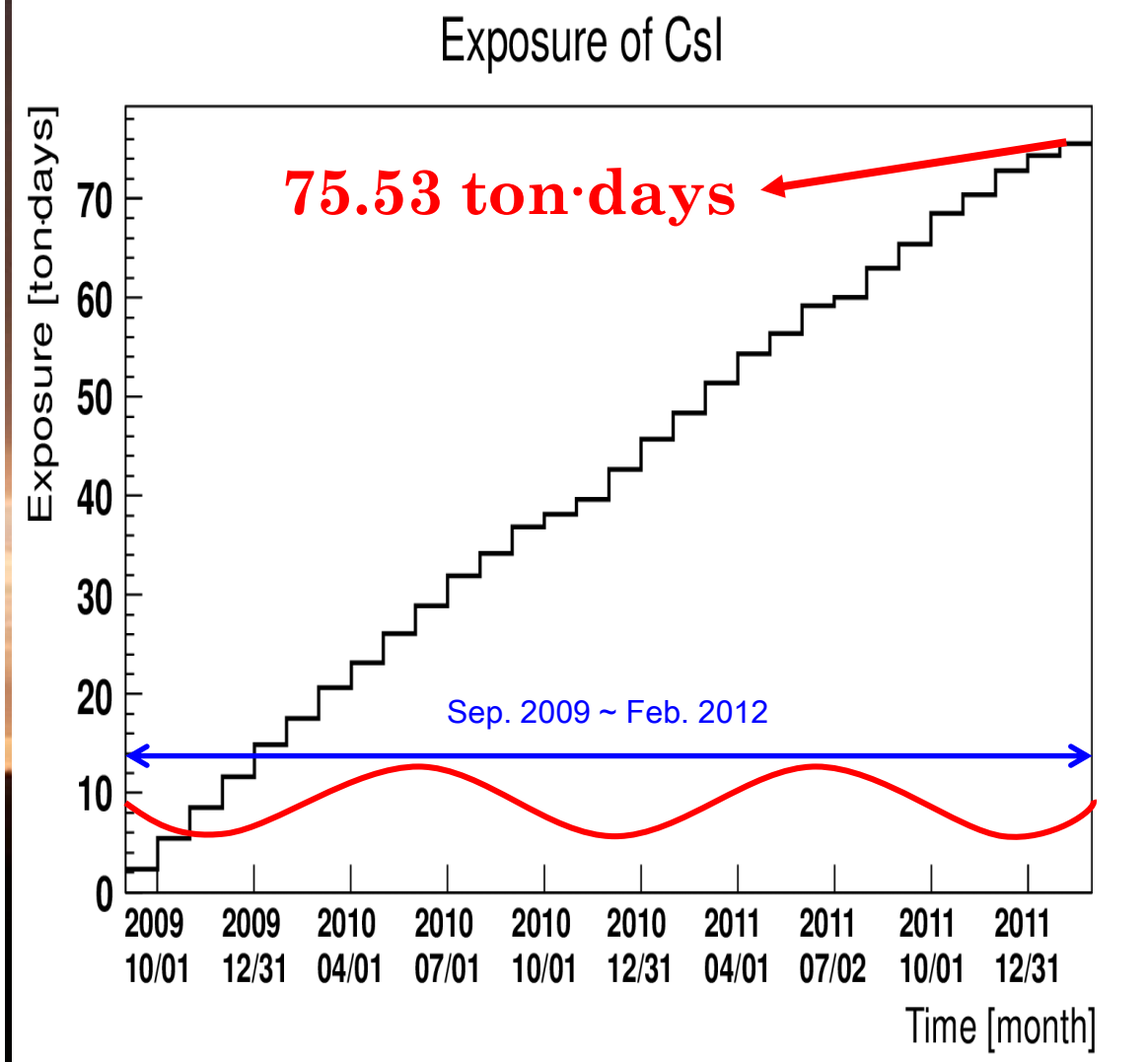




S.C. Kim et al., PRL 108 181301 (2012)



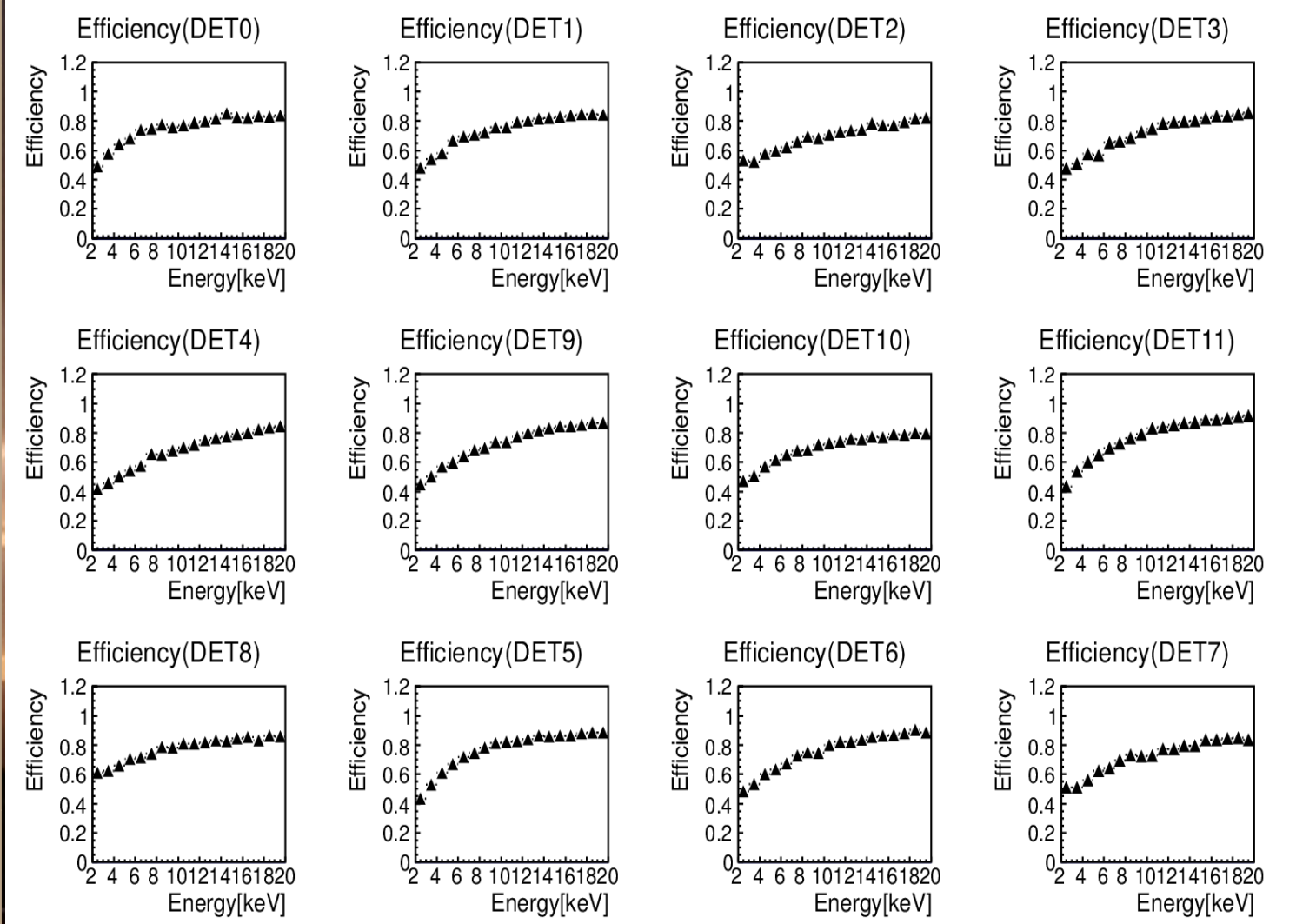




Data Taking

75.53 ton·days during 2.5 years

Cut	Target
Electronics Noise	electronics noise, …
Partial Charge	PMT afterpulse, pile-up signal, …
Spark Cut	PMT thermionic electron, spark, …
Charge Asymmetry	PMT scintillation or Cherenkov, …
Signal Start Time	PMT dark current, …
Time Asymmetry	PMT dark current, …
Fit Quality	Cosmic signal's tail, …

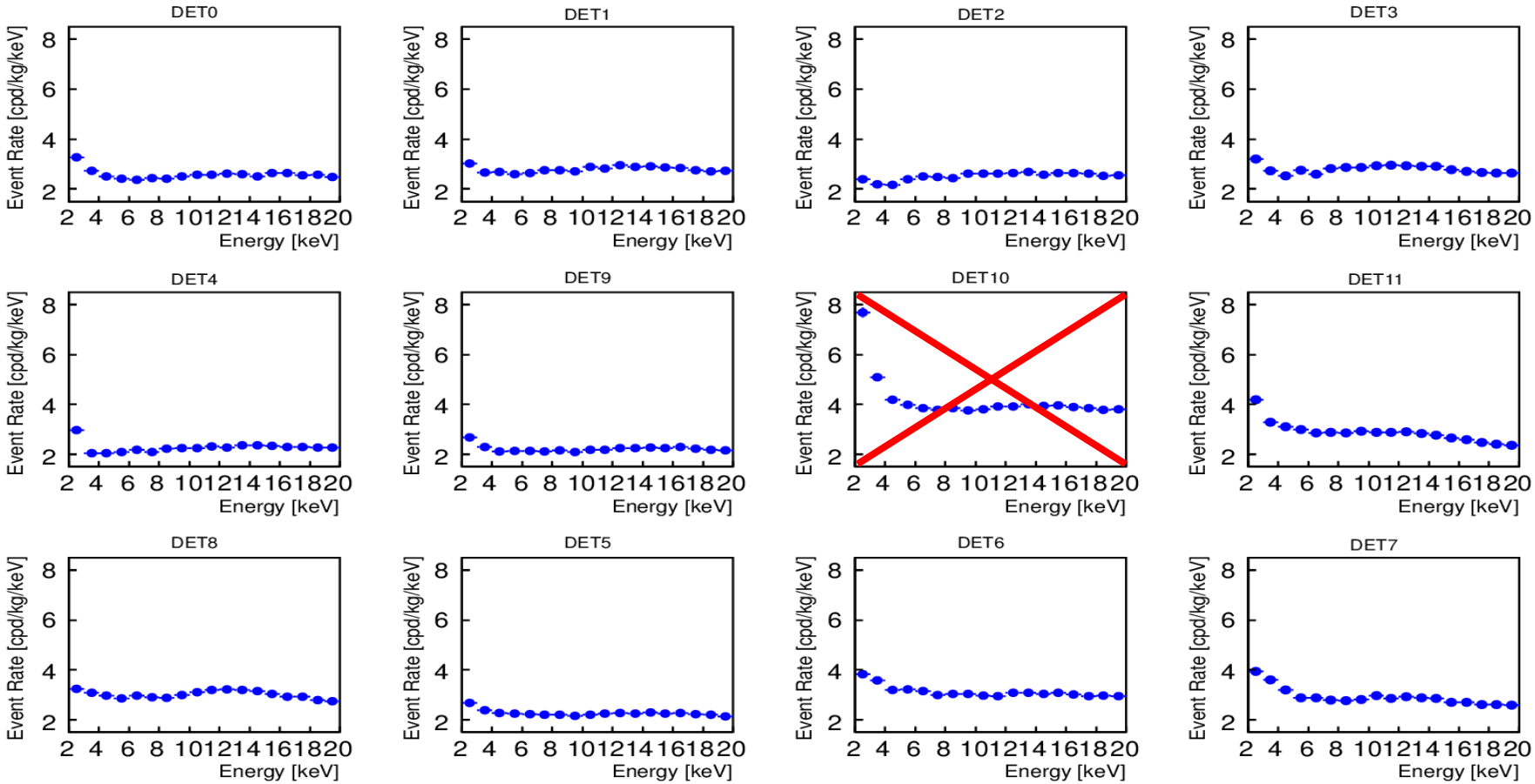


Events Selection

7 selection conditions are applied

Energy Spectrum

2~4 cpd/kg/keV



Annual Modulation Fitting

$$f(t) = A_{decay}\, e^{-\frac{(t-t_0)}{\tau}} + Bkg + A\cos\frac{2\pi}{\omega}(t-t_1)$$

Decay Constant Modulation

A_{decay} : Initial level (^{134}Cs)

t_0 : Initial time – fixed to 1 Sep. 2009

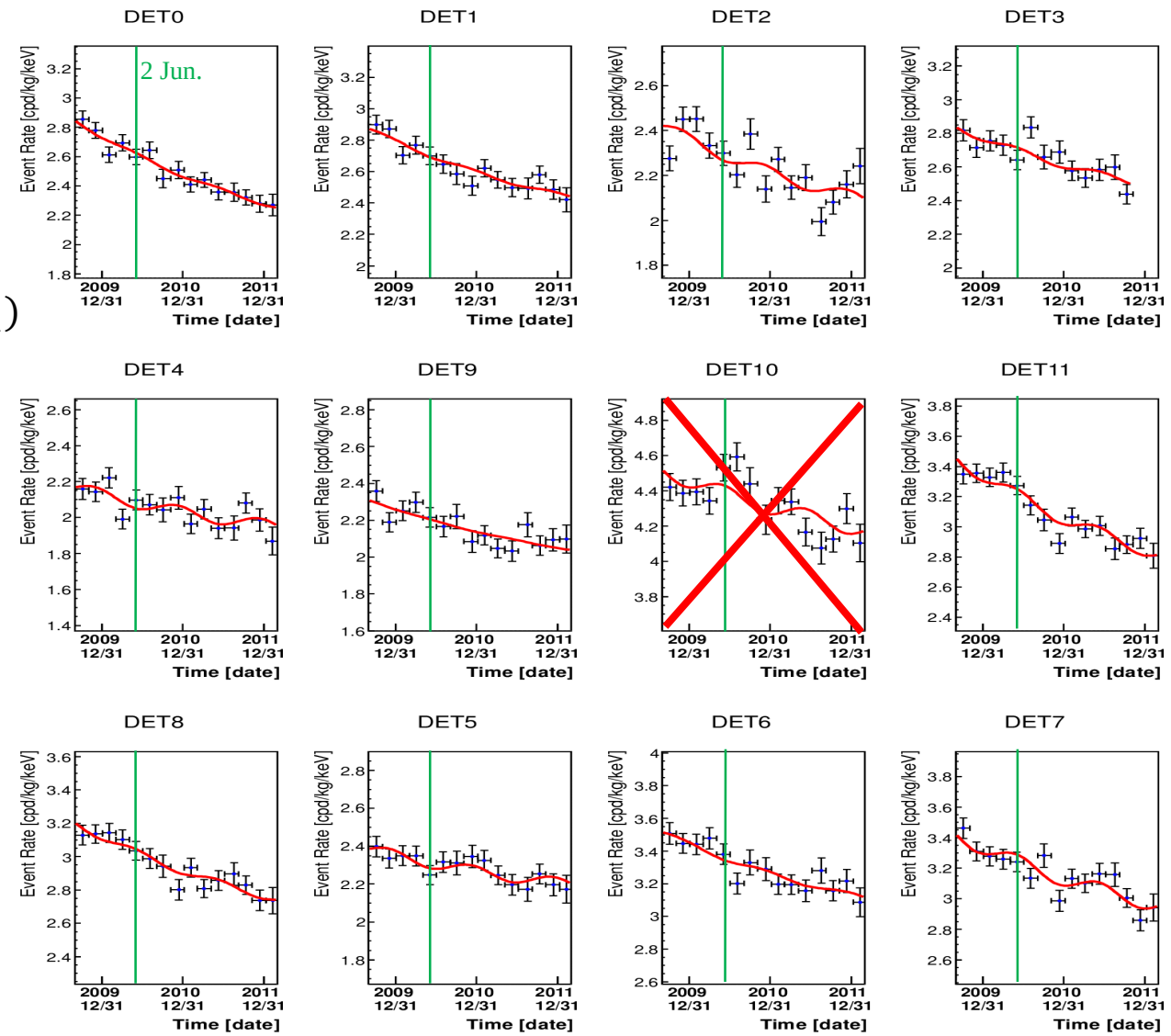
τ : Decay constant (^{134}Cs) – fixed to $T_{1/2}$=2.065 y

Bkg : Constant background level

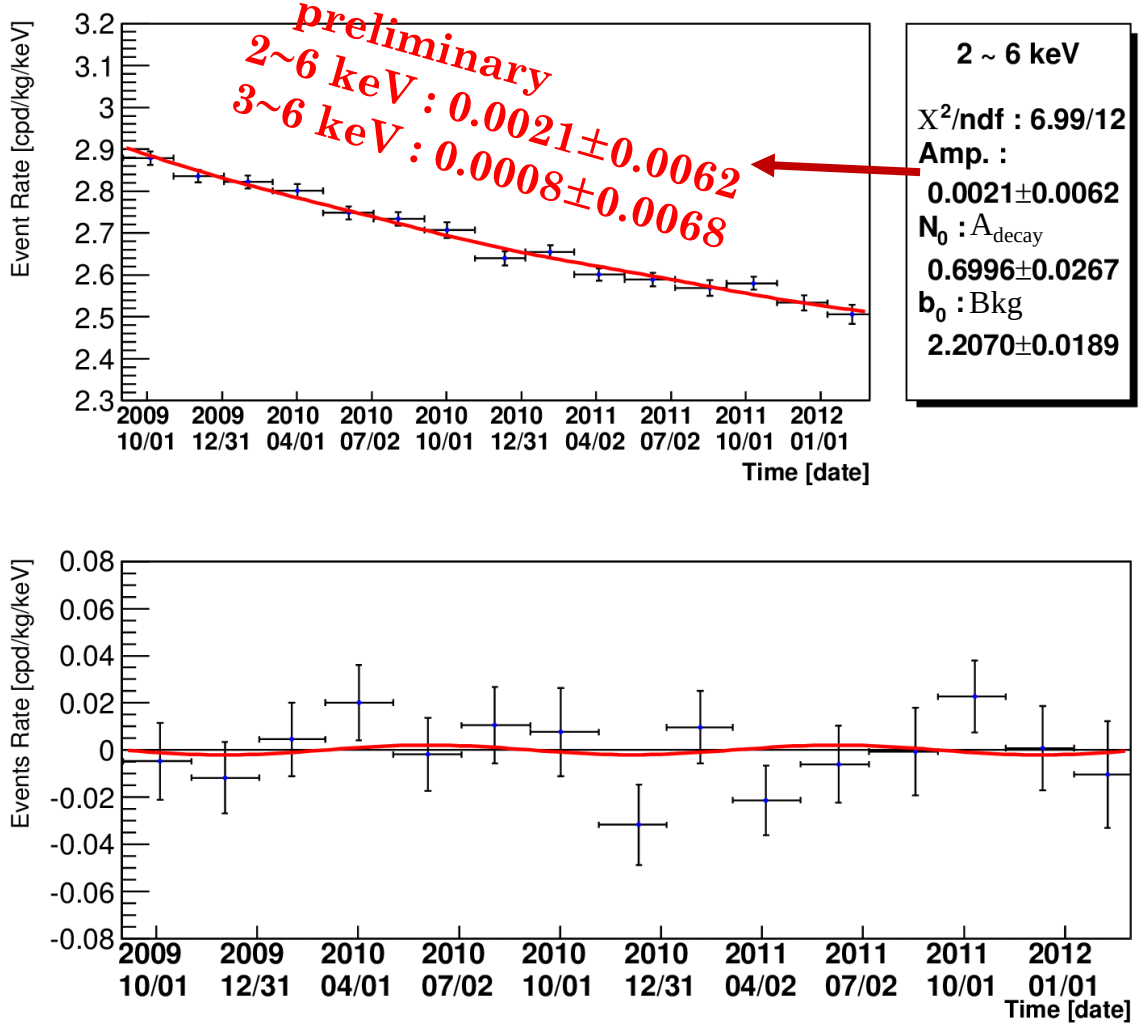
A : Annual Modulation Amplitude

ω : Period – fixed to 1 year=365.25 d

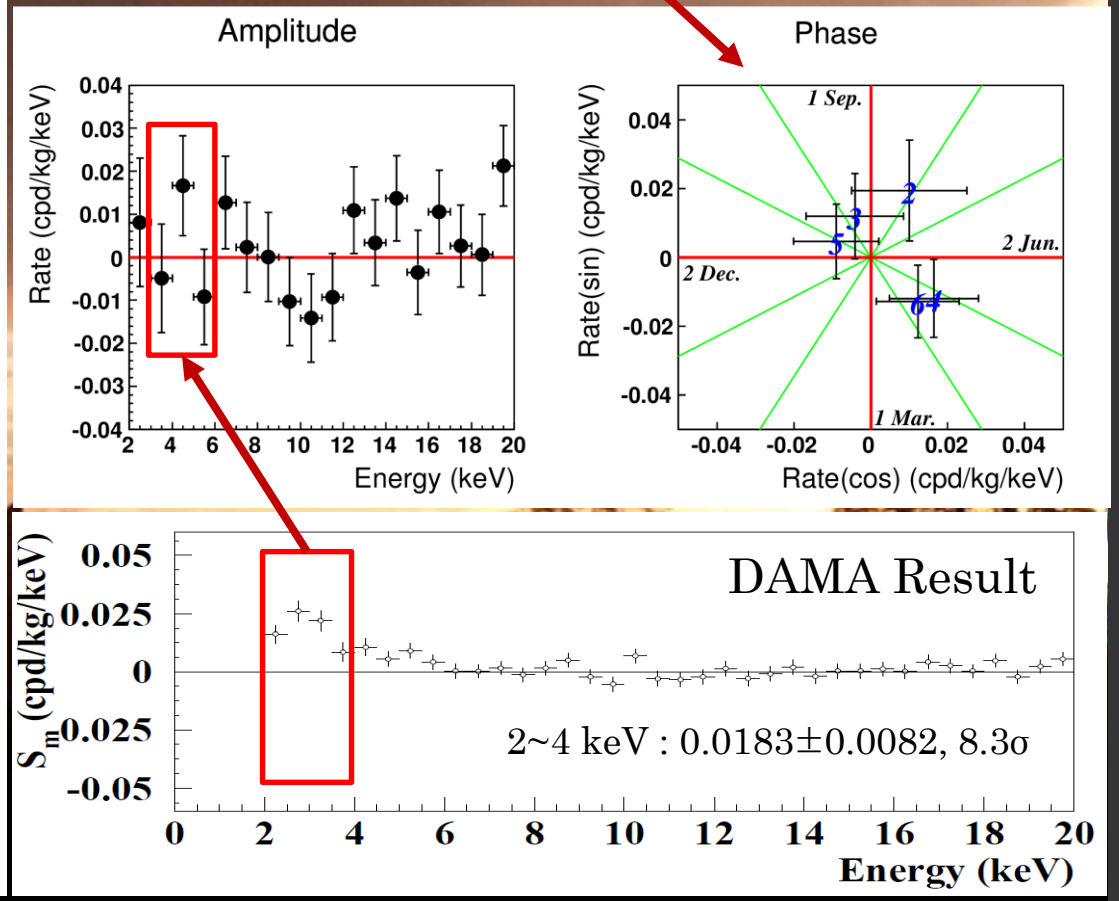
t_1 : Annual Modulation Peak – fix to 2 June



One Of Sample (3~4 keV)



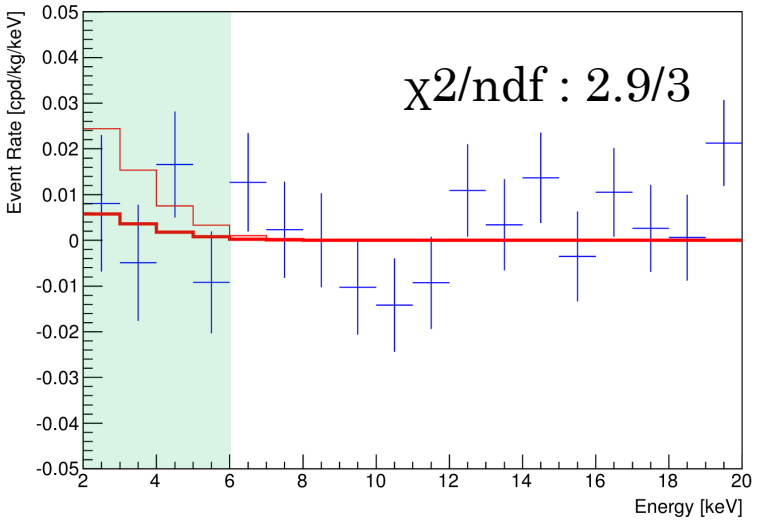
$$f(t) = A_{decay}e^{-\frac{t-t_0}{\tau}} + Bkg + A\cos\frac{2\pi}{\omega}(t - t_{1\,free})$$
$$= A_{decay}e^{-\frac{t-t_0}{\tau}} + Bkg + A\cos\frac{2\pi}{\omega}(t - t_{1\,fixed}) + B\sin\frac{2\pi}{\omega}(t - t_{1\,fixed})$$



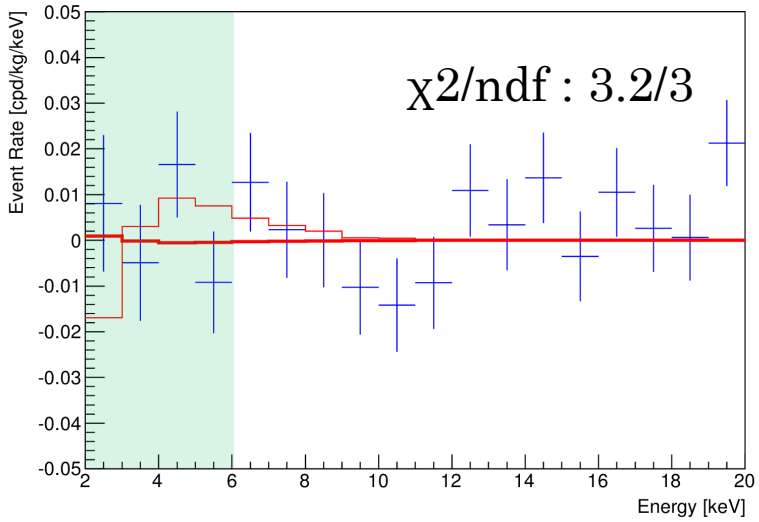
Model Independent Result

2~6 keV : 0.0021±0.0062 (0.0122 90% CL Positive Limit), 3~6 keV : 0.0008±0.0068 (0.0119 90% CL Positive Limit)

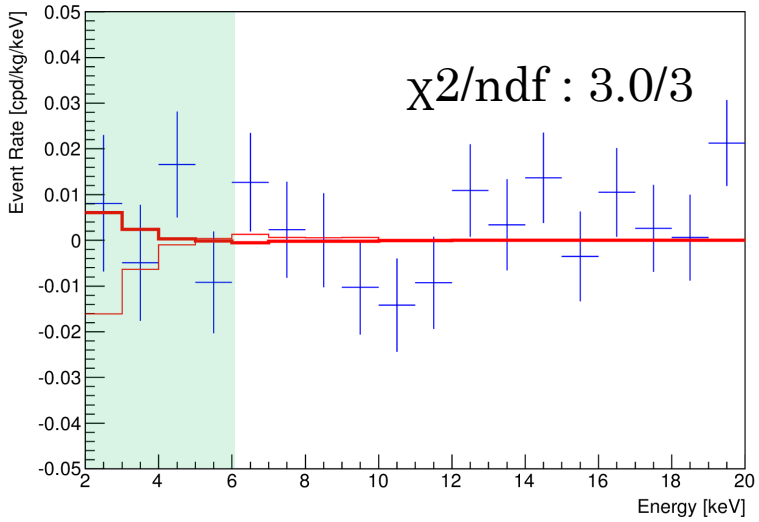
30 GeV/c^2 WIMP

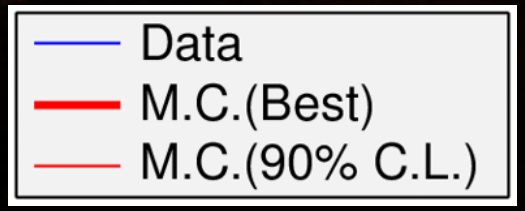


100 GeV/c^2 WIMP



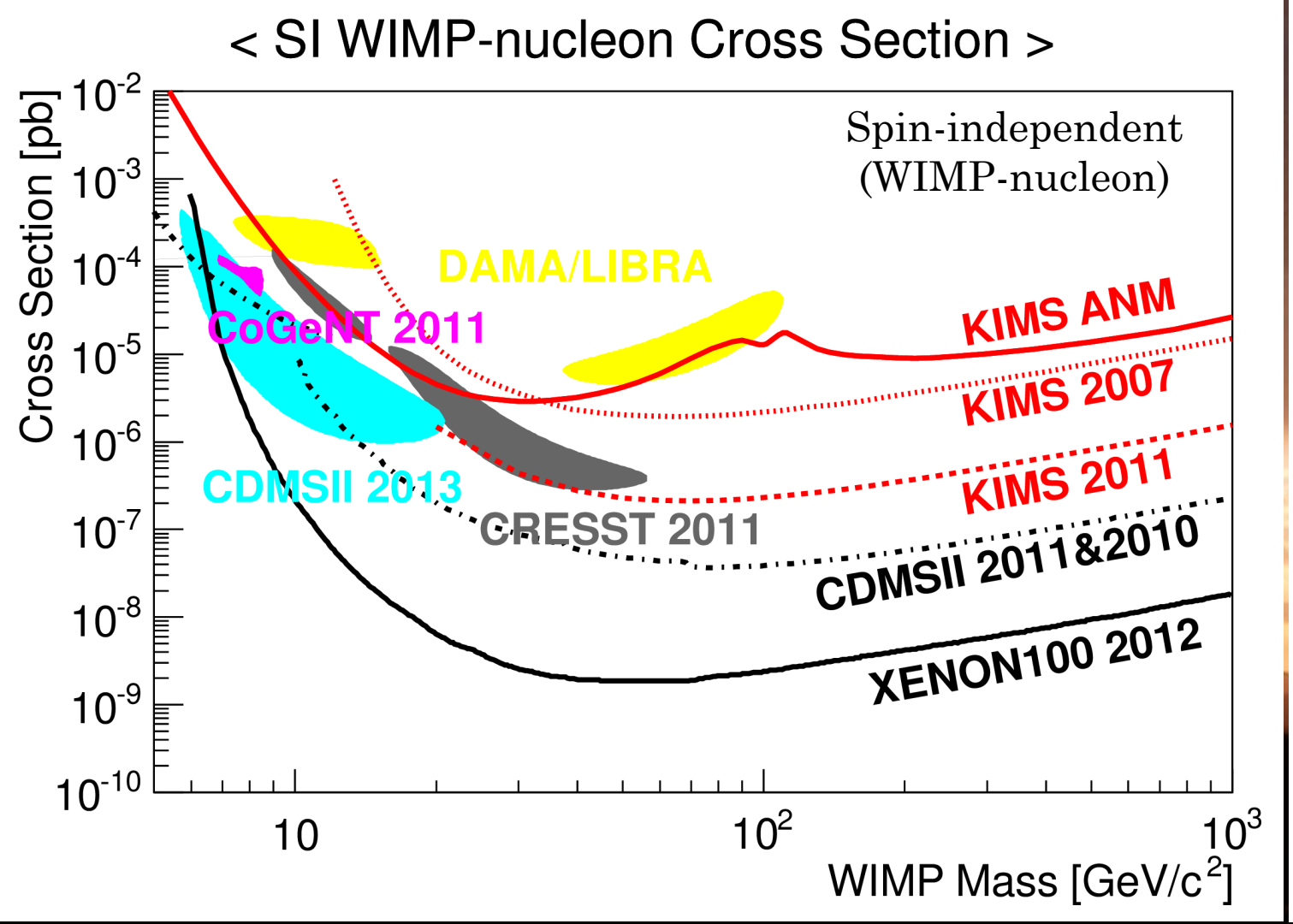
150 GeV/c^2 WIMP

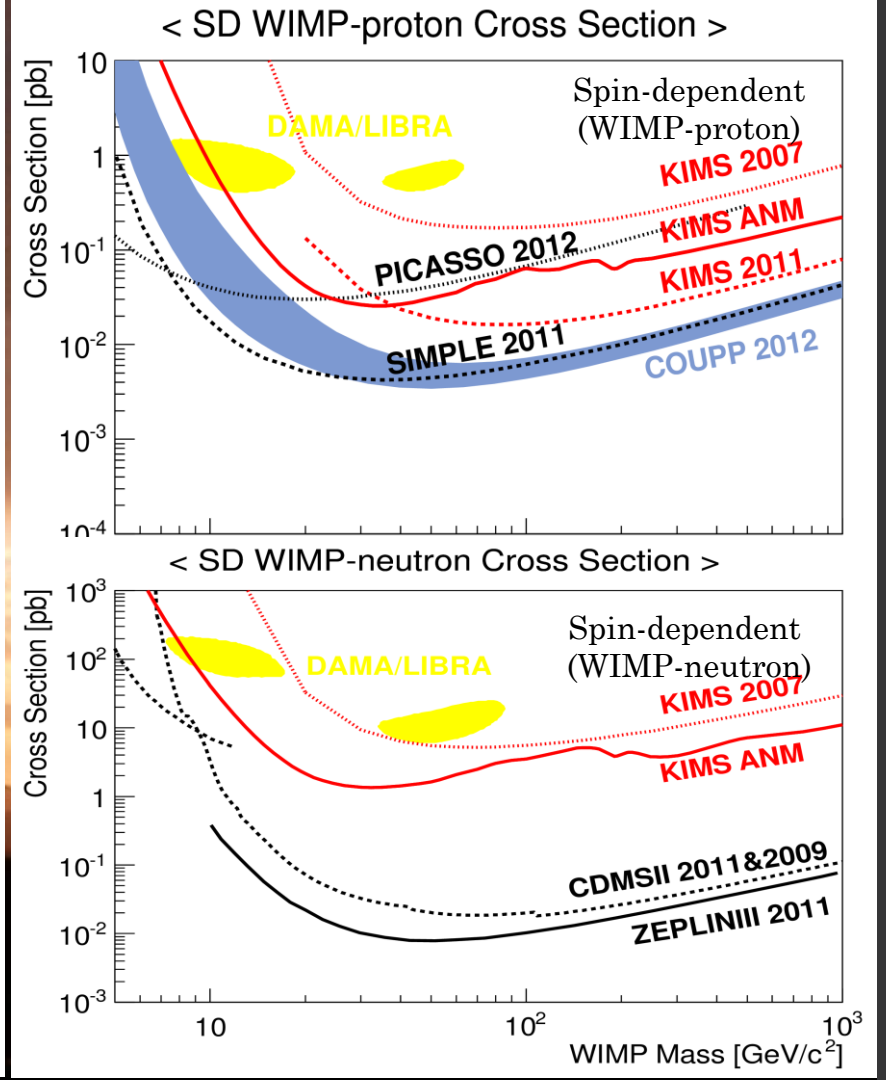




M.C. Simulation

$$R(t) = \int_{E_{nr1}/Q}^{E_{nr2}/Q} dE_{nr}\epsilon(QE_{nr})\frac{\rho_\chi}{2m_\chi\mu^2}\boldsymbol{\sigma_0}F^2(q)\int_{v>v_{min}} d^3v\frac{f(\mathbf{v},t)}{v}$$, Standard Halo Model





preliminary

Cross Section Limit

Spin-independent : $\sigma^{SI}_{W-n} = \sigma_0 \frac{\mu_n^2}{\mu_A^2} \frac{1}{A^2}$, Spin-dependent : $\sigma^{SD}_{W-n,p} = \sigma_0 \frac{\mu_{n,p}^2}{\mu_A^2} \frac{3}{4} \frac{J}{(J+1)} \frac{1}{<S_{n,p}>^2}$

Summary & Plan

- The analysis was done with 2.5 years data of 75.53 ton•days using CsI(*Tl*) cryatals
- The background level of single hit events is under 2~4 cpd/kg/keV passing 7 event selection conditions
- The amplitudes of annual modulation are 0.0021±0.0062 cpd/kg/keV (2~6 keV) and 0.0008±0.0068 cpd/kg/keV (3~6 keV) in KIMS experiment, which are consistent with zero amplitudes within errors.
- SI limit of annual modulation study can't exclude DAMA's iodine region fully but SD limits exclude DAMA's iodine region
- New PMTs will be installed to lower threshold
- KIMS will install NaI(*Tl*) crystals (~ 20 kg) to test next month
- We are trying to find new underground laboratory (minimum depth 1000 m)
- We are testing the prototype of low temperature detector, which is using TES.

Thank You

Very Much!