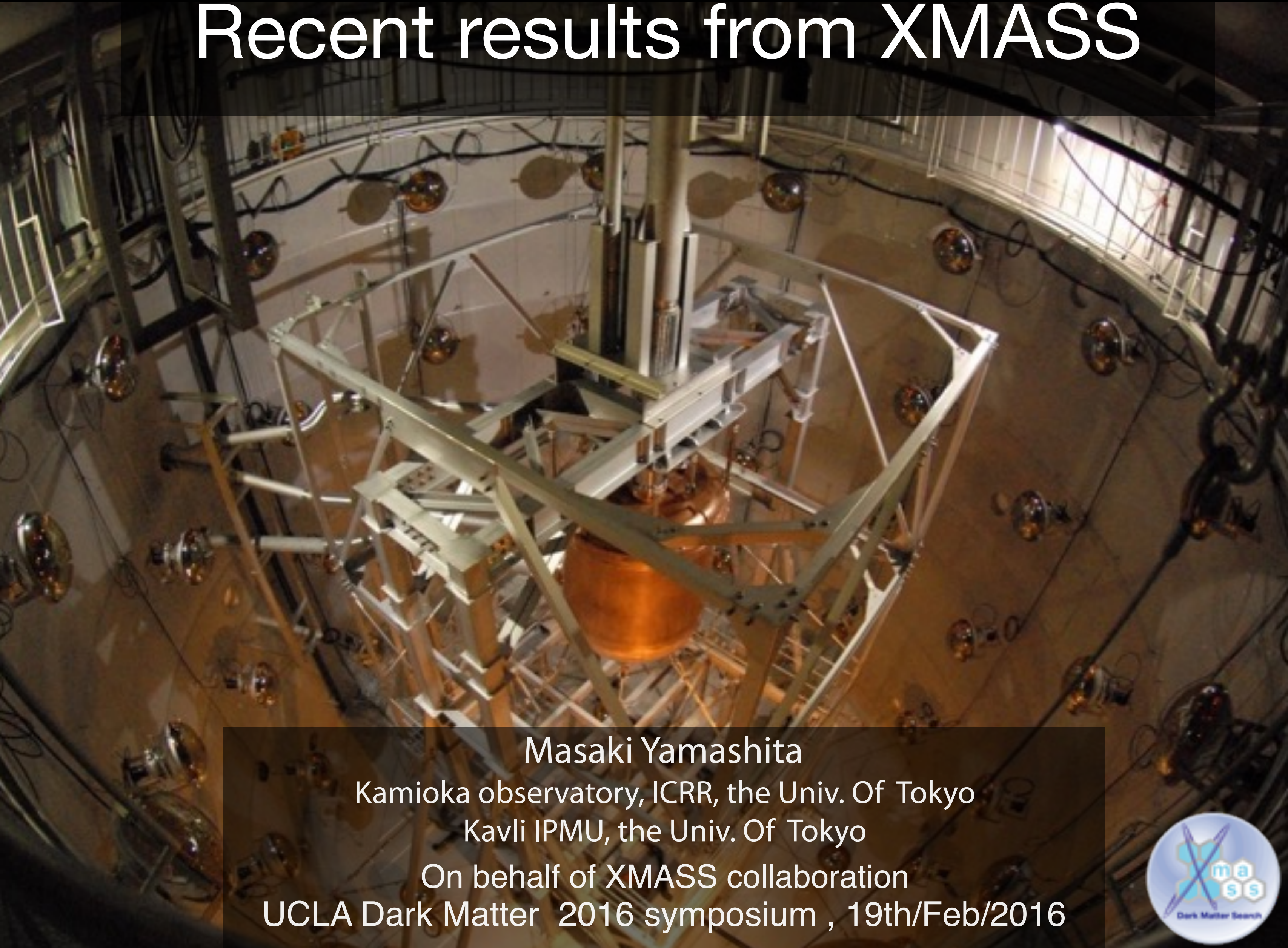
Recent results from XMASS



Masaki Yamashita
Kamioka observatory, ICRR, the Univ. Of Tokyo
Kavli IPMU, the Univ. Of Tokyo
On behalf of XMASS collaboration

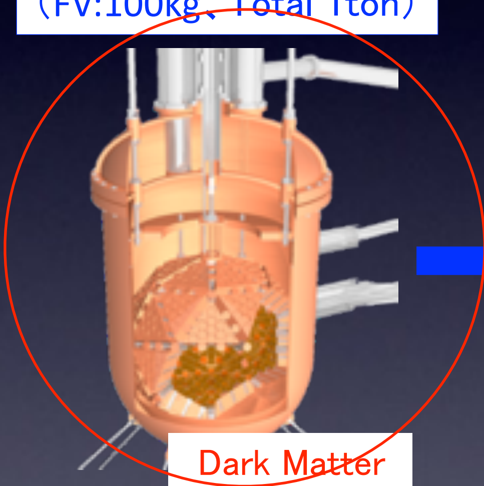
UCLA Dark Matter 2016 symposium , 19th/Feb/2016

XMASS Experiment

Multi purpose low-background experiment with single phase LXe.

- Xenon MASSive detector for Solar neutrino (pp/^{7}Be)
- Xenon neutrino MASS detector (double beta decay)
- Xenon detector for Weakly Interacting MASSive Particles (DM)

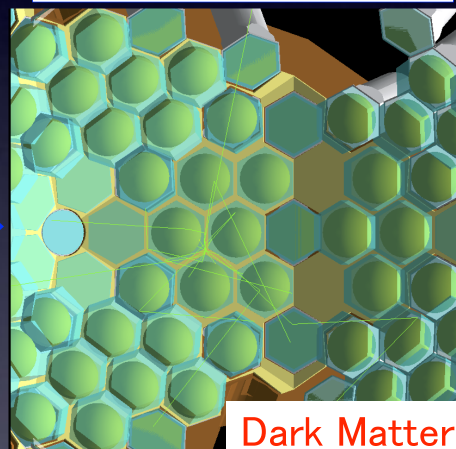
XMASS I
(FV:100kg、Total 1ton)



Dark Matter

2007: Project was funded.
2013〜: Data taking

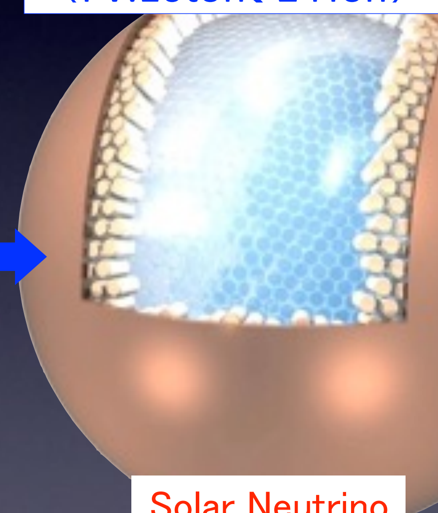
XMASS 1.5
(FV:3ton、Total 6ton)



Dark Matter

3inch dome shape PMT

XMASS II
(FV:10ton、24Ton)



Solar Neutrino
Dark Matter
DBB

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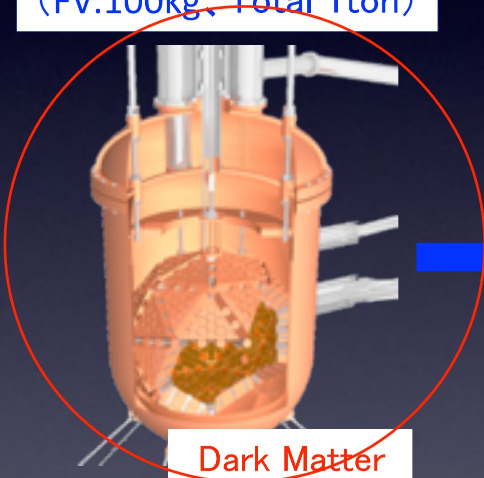
XMASS Experiment

Multi purpose low-background experiment with single phase LXe.

- **X**enon **MASS**ive detector for Solar neutrino (pp/^{7}Be)
- **X**enon neutrino **MASS** detector (double beta decay)
- **X**enon detector for Weakly Interacting **MASS**ive Particles (DM)

XMASS I
(FV:100kg、Total 1ton)



Dark Matter

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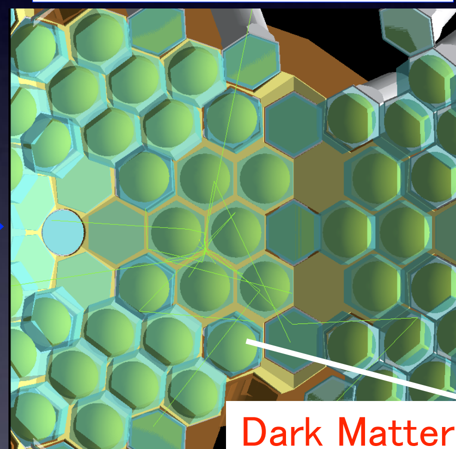
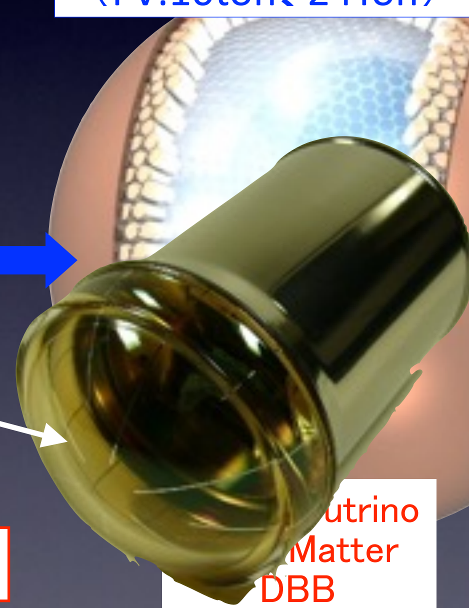


Dark Matter

3inch dome shape PMT

XMASS II
(FV:10ton、24Ton)



utrino
Matter
DBB

- 180° field view (FISHEYE PMT)
- R10789 5.6nsec →R13111 <3.5nsec
- goal is 1/10 of R10789 radioactivity

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The XMASS collaboration:

Kamioka Observatory, ICRR, the University of Tokyo:
K. Abe, K. Hiraide, K. Ichimura, Y. Kishimoto, K. Kobayashi, M. Kobayashi, S. Moriyama, M. Nakahata, T. Norita, H. Ogawa, H. Sekiya, S. Tasaka , O. Takachio, A. Takeda, M. Yamashita, B. Yang

Kavli IPMU, the University of Tokyo:
J.Liu, K.Martens, Y. Suzuki, X. Benda

Kobe University:
R. Fujita, K. Hosokawa, K. Miuchi, Y. Ohnishi, N. Oka, Y. Takeuchi

Tokai University:
K. Nishijima

Yokohama National University:
S. Nakamura

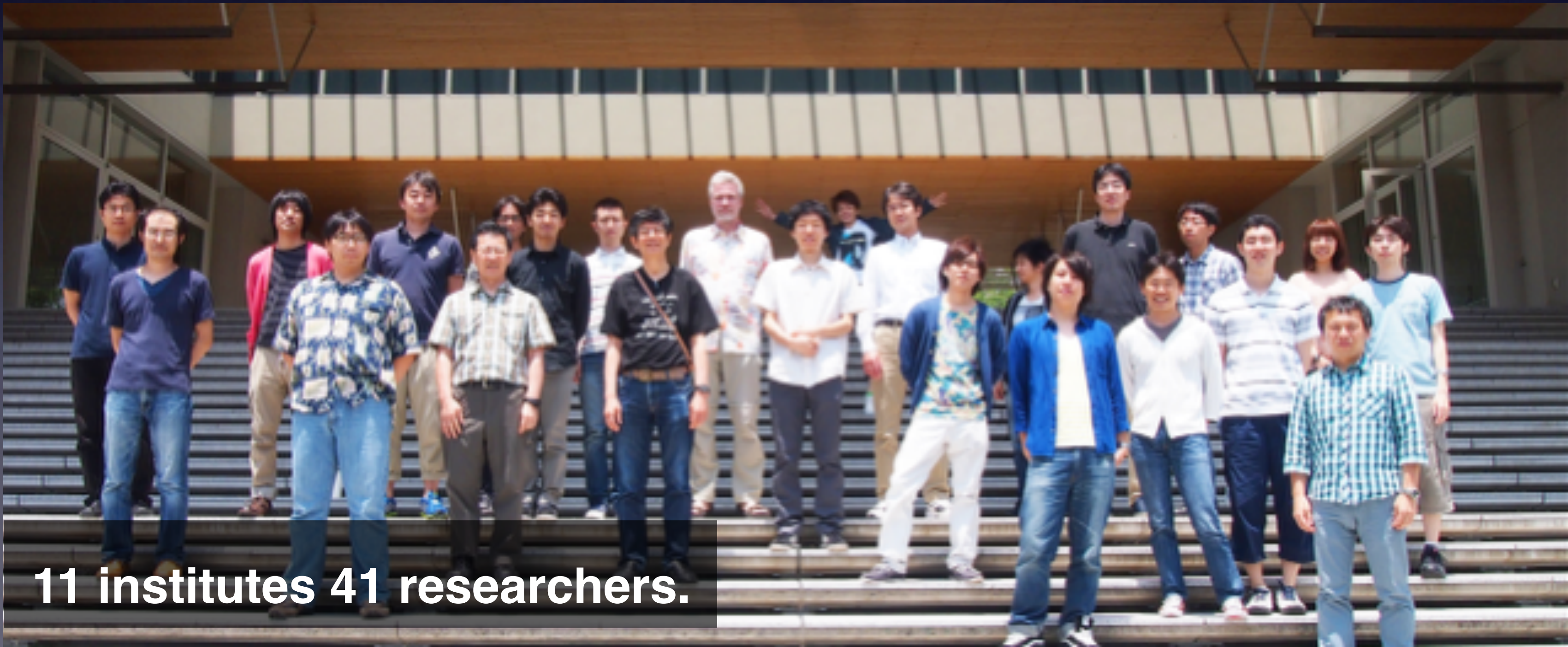
Miyagi University of Education:
Y. Fukuda

STEL, Nagoya University:
Y. Itow, R. Kegasa, K. Kobayashi, K. Masuda, H. Takiya

Sejong University:
N. Y. Kim, Y. D. Kim

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

Tokushima University:
K.Fushimi

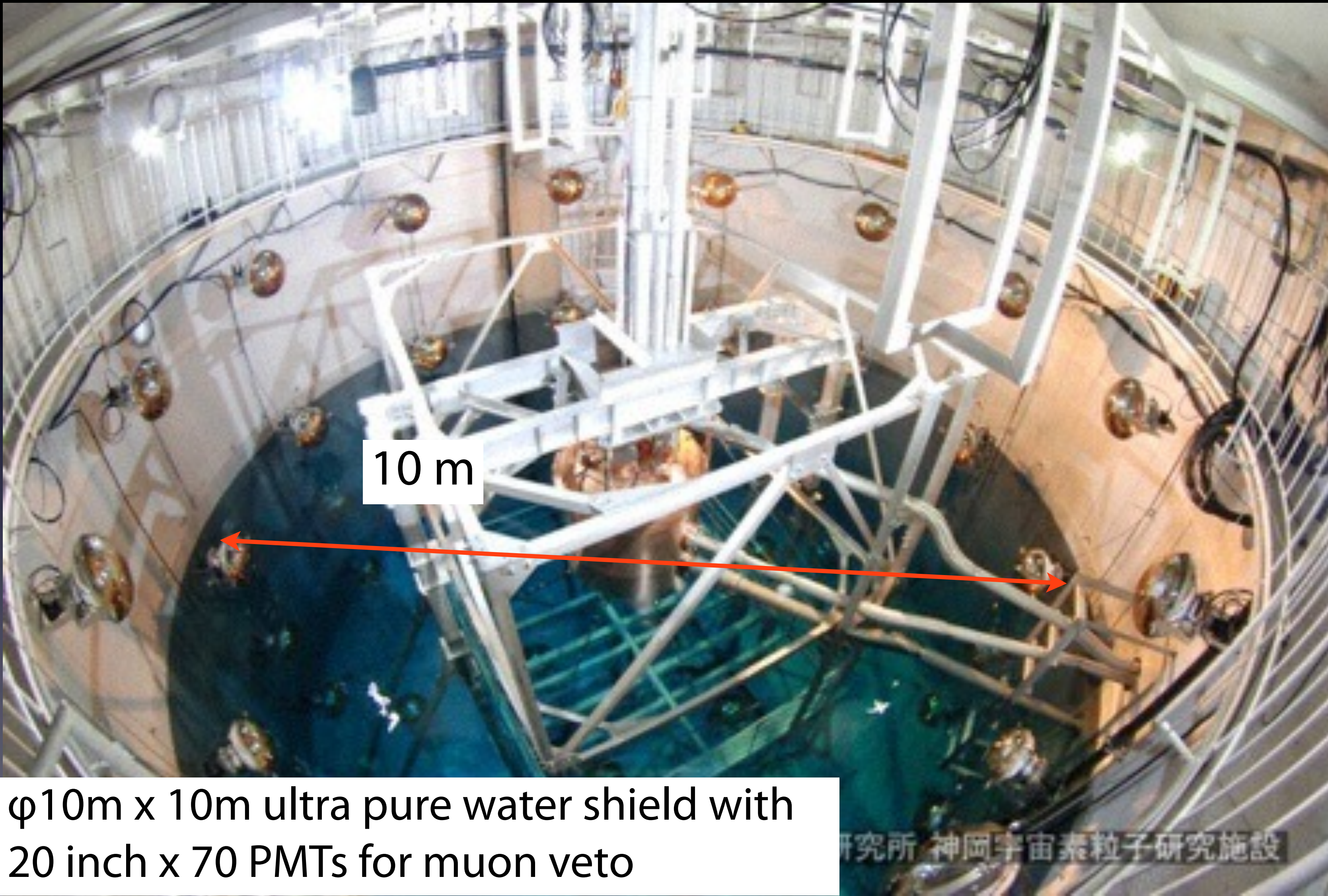


Kamioka mine

Gifu, Hida city, Ikenoyama

- 1000m under a mountain = 2700m water equiv.
- 360m above the sea
- Horizontal access
- Experiment
  - Super-K
  - KamLAND (Tohoku U.)
  - KAGRA
  - NEWAGE

Water Shield

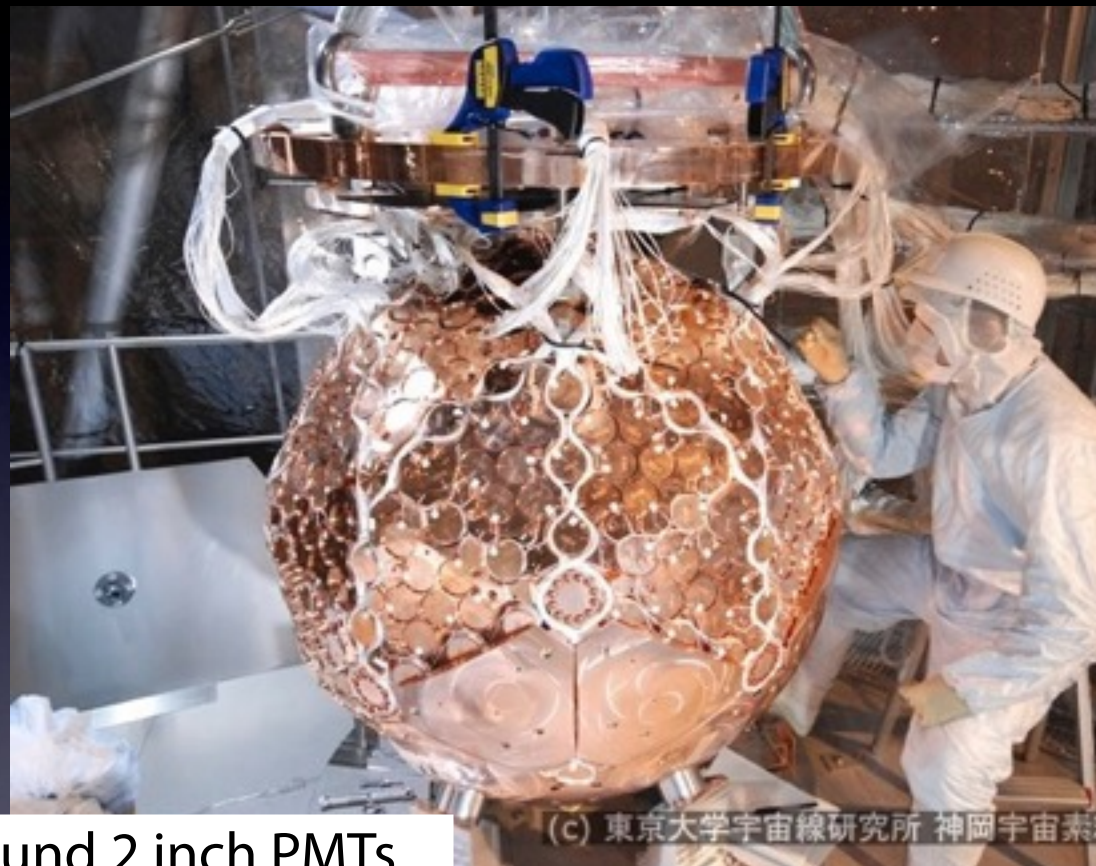


- φ10m x 10m ultra pure water shield with 20 inch x 70 PMTs for muon veto

XMASS Detector

R10789

RI in PMT	Activity per 1PMT(mBq/
238U-chain	0.70+/-0.28
232Th-chain	1.51+/-0.31
40K	<5.1
60Co	2.92+/-0.16



- 642 ultra low background 2 inch PMTs
- 62% photo coverage
- Largest detector: 832 kg of LXe for sensitive volume.

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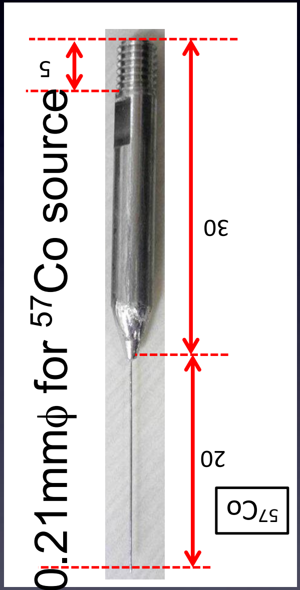
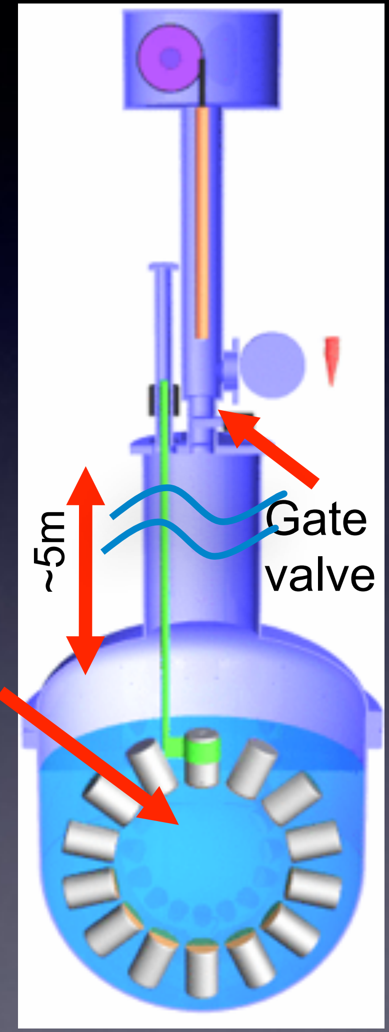
Detector calibration

-Inner calibration is for energy calibration.





Isotopes	Energy [keV]	Shape
^{55}Fe	5.9	cylinder
^{109}Cd	8(*1), 22, 58, 88	cylinder
^{241}Am	17.8, 59.5	thin cylinder
^{57}Co	59.3(*2), 122	thin cylinder
^{137}Cs	662	cylinder

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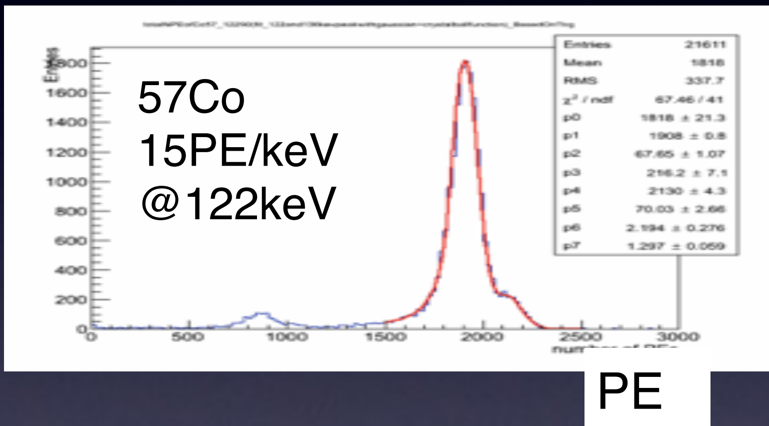
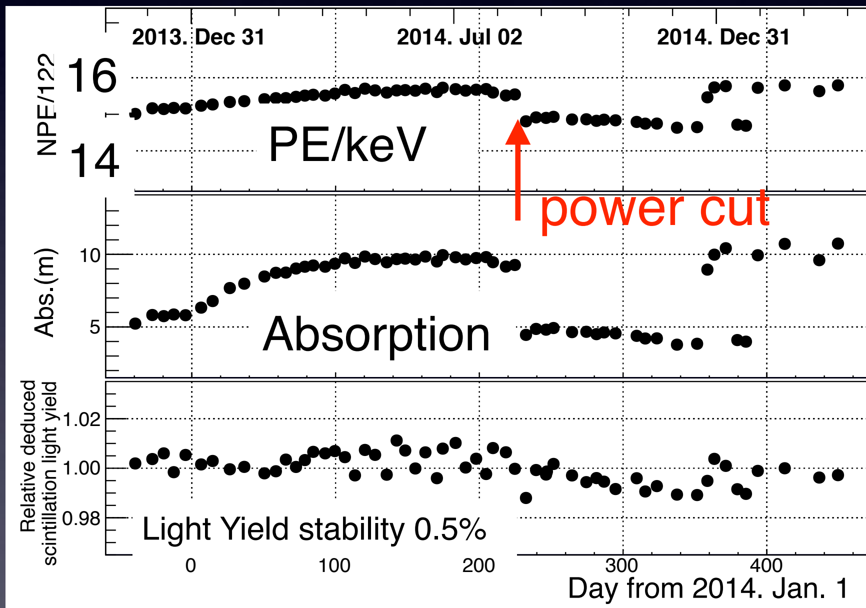
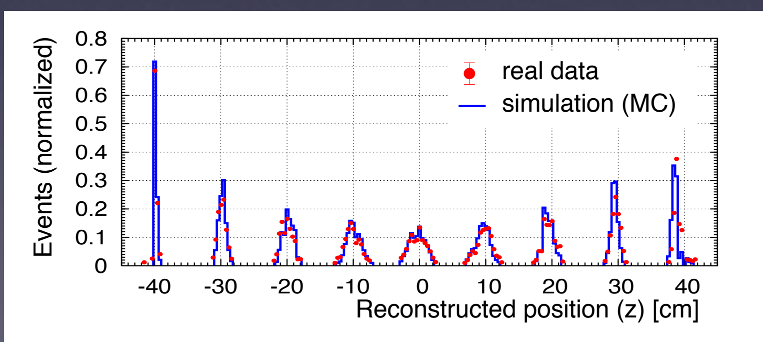
Energy calibration

-High Photoelectron Yield ~15 PE/keV
-Good agreement between data and.
(evaluated absorption length 4-11 m, scatter 52cm)



57Co source





~500 days

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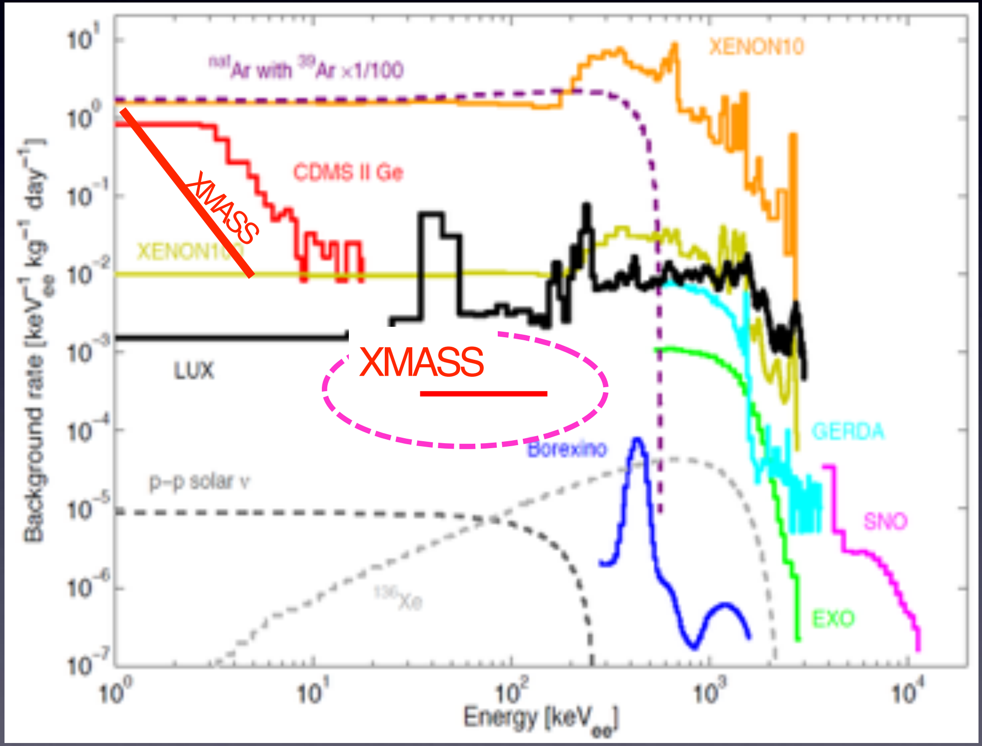
Comparison of background rate

- Background rate in the fiducial volume before separation of nuclear recoils from e/γ.
- XMASS achieved O(10^{-4}) event/day/kg/keVee at a few 10's keV.
- Even modest background at low energy, XMASS has good sensitivity with a large mass (832 kg) and low energy threshold. (~1keVee) by annual modulation search.



Added to D.C.Malling thesis (2014) Fig.

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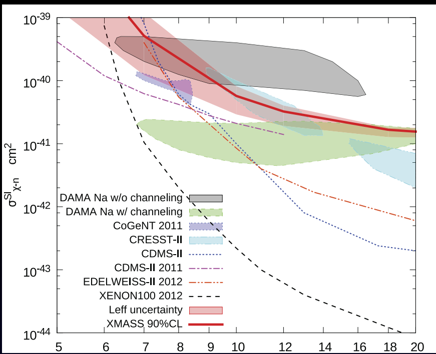
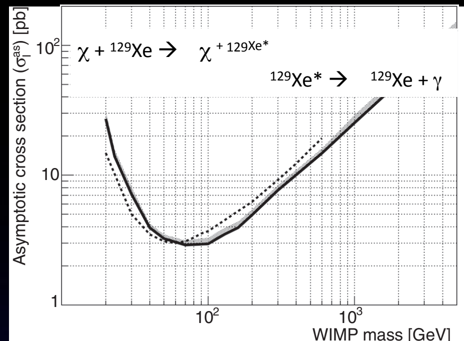
Search by XMASS



light mass WIMP

Phys. Lett. B 719 (2013) 78



Inelastic scattering

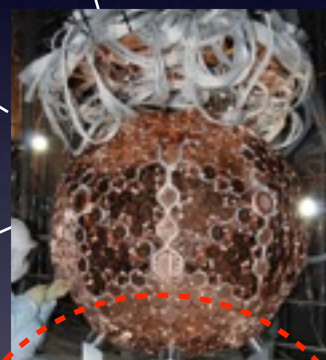
PTEP 2014, 063C01

Solar axion

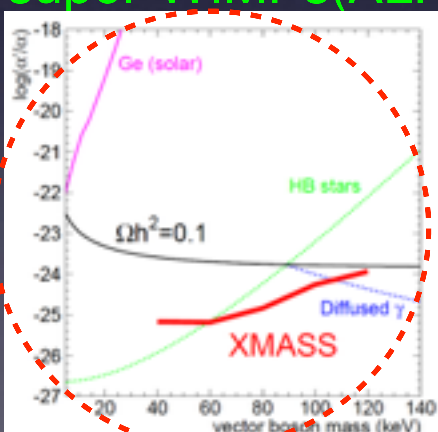
Phys. Lett. B 724 (2013) 46

coherent ν-n scattering

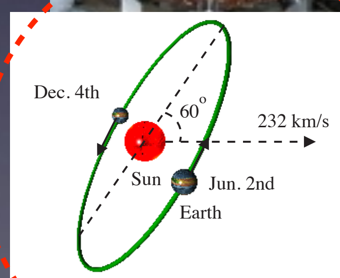
Supernova



super-WIMPs(ALPs)



Phys. Rev. Lett. 113 (2014) 121301

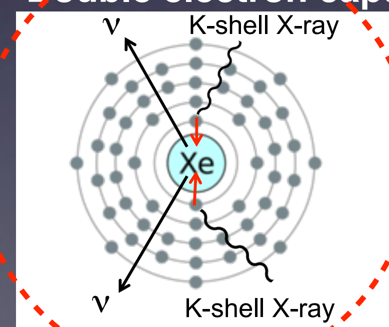


anual modulation

arXiv:1511.04807v1

Rare decay search

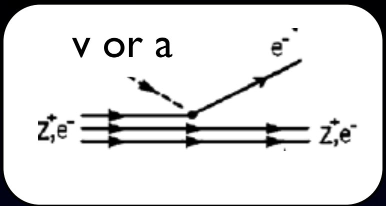
Double electron capture



arXiv:1510.00754

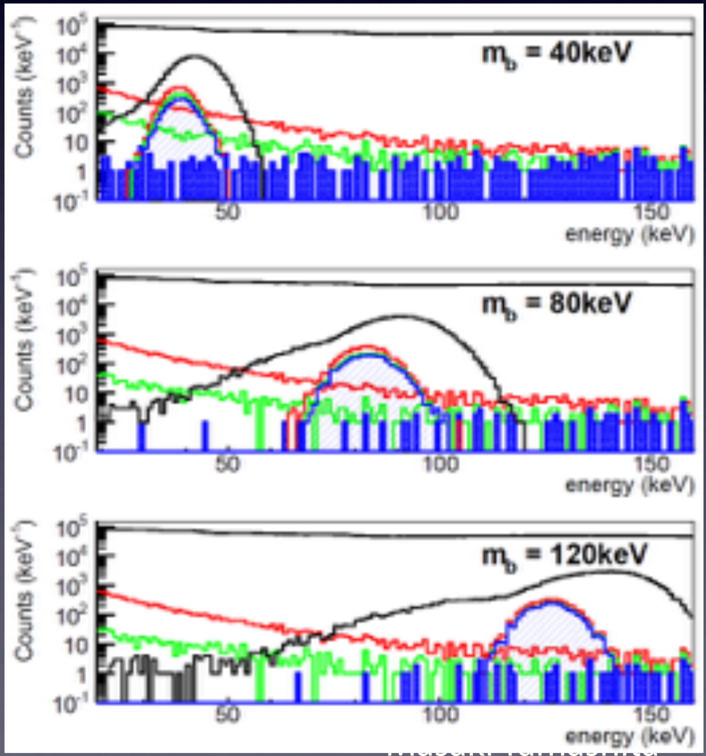
Search for Bosonic super-WIMPs

Phys. Rev. Lett. 113 (2014) 121301



- We should look for variety of candidate. Not only n-recoil signal. (NO SUSY so far.)
- Motivated by Warm Dark Matter
  - sterile neutrino, gravitino …
- However, it can be pseudoscaler or vector boson and in this case, it can be detected by absorption of the particle, which is similar to the photoelectric effect.
- Search for mono-energetic peak at the mass of the particle
- same data set as inelastic scattering
  41 kg fiducial volume cut ,
  2010/12/24-2013/05/10 165.9 days data.

Observed data + signal(MC)



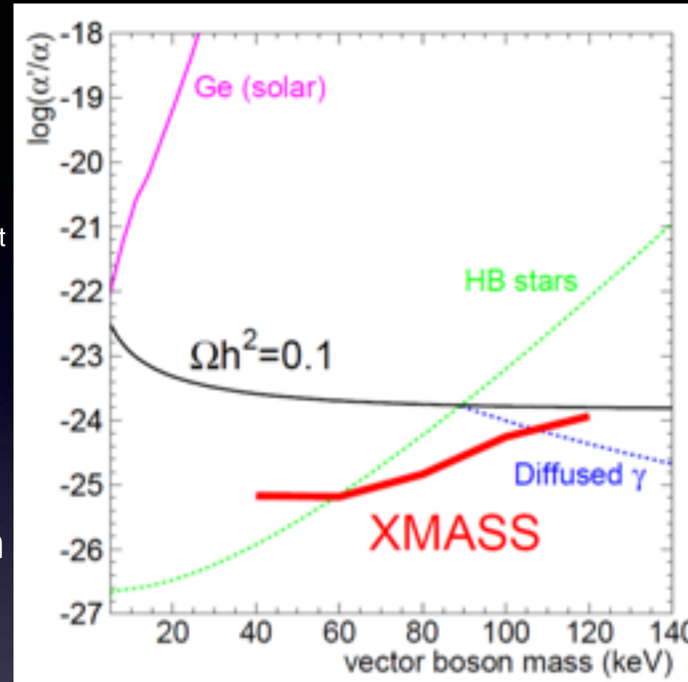
Bosonic super-WIMPs Search Results

- **For vector boson case**

Count rate

$$S_v \approx \frac{4\times 10^{23}}{A}\frac{\alpha'}{\alpha}\left(\frac{\mathrm{keV}}{m_V}\right)\left(\frac{\sigma_{\mathrm{photo}}}{\mathrm{barn}}\right)\ \mathrm{kg}^{-1}\ \mathrm{day}^{-1},$$

α: fine structure constant

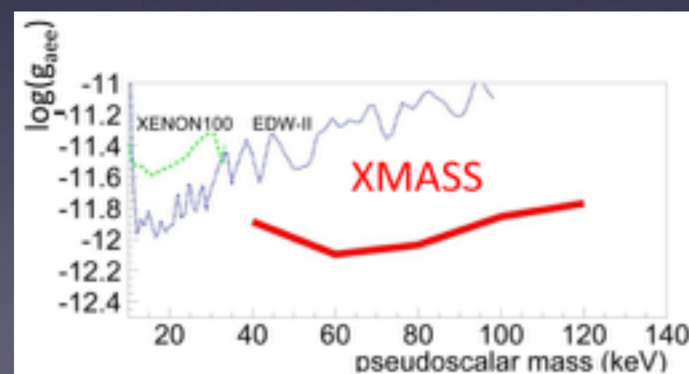


- the first direct search in the 40–120 keV range.
- Our limit excludes the possibility that such particles constitute all of dark matter.

- **For pseudoscaler case**

Count rate

$$S_a \approx \frac{1.2\times 10^{19}}{A} g_{aee}^2 \left(\frac{m_a}{\mathrm{keV}}\right)\left(\frac{\sigma_{\mathrm{photo}}}{\mathrm{barn}}\right)\ \mathrm{kg}^{-1}\ \mathrm{day}^{-1}.$$



- The most stringent direct constraint on gaee.

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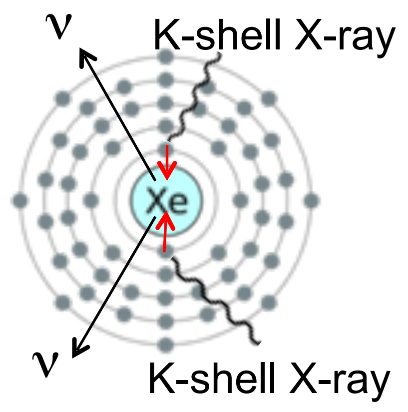
Double Electron Capture on ^{124}Xe and ^{126}Xe

arXiv:1510.00754

Double electron capture (ECEC) is a rare nuclear decay analogue to double beta decay.

Although $2\nu\beta^-\beta^-$ has been observed in more than ten isotopes, there exist only a few positive experimental results for 2νECEC so far. (138Ca, 78Kr)



^{124}Xe (g.s.) +2e^- → ^{124}Te (g.s.) + ($2\nu_e$) (Q_{ECEC}=2864 keV)

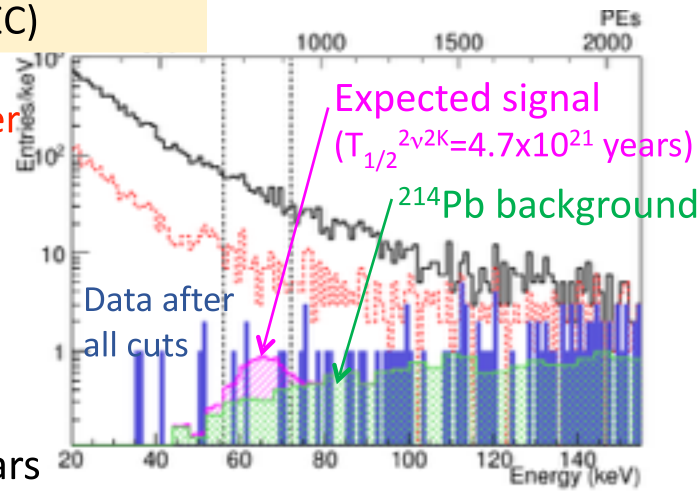
2ν mode : New reference for calculation of nuclear matrix element *from the proton-rich side of the mass parabola*

0ν mode : *Evidence for lepton number violation, Majorana neutrino*

Sensitive to right-handed weak current ($0\nu\beta^+$EC)

Searched for a peak at 64keV from two K-shell X-rays after 2νECEC

132 live days, 41kg of natural xenon (39g of ^{124}Xe)



$T_{1/2}^{2\nu 2K}$(^{124}Xe) >4.7x10^{21} years (90%CL)

$T_{1/2}^{2\nu 2K}$(^{126}Xe) >4.3x10^{21} years (90%CL)

Theoretical predictions: $T_{1/2}^{2\nu ECEC}$(^{124}Xe)= 10^{20}-10^{24} years

Annual Modulation search

-We carried out the analysis without particle ID for WIMP case and model independent case.

-Large mass (832 kg)

- Data set

2013/11/20 - 2015/03/29 (359.2 live days)

1 year data of XMASS (0.82 ton x year) vs. 14 years data of DAMA/LIBRA (1.33 ton x year)

=>Current statistics is already half of DAMA/LIBRA data.

-Low energy threshold: 0.5 keV by 122keV

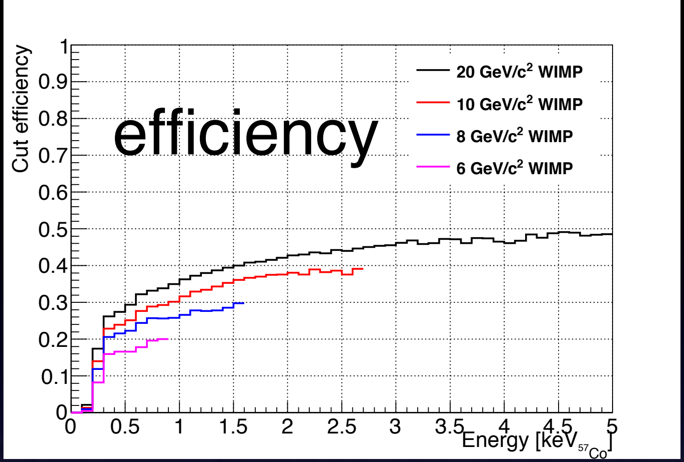
=> 4.8keVnr (estimated by Aprile et al. PRL(2011))

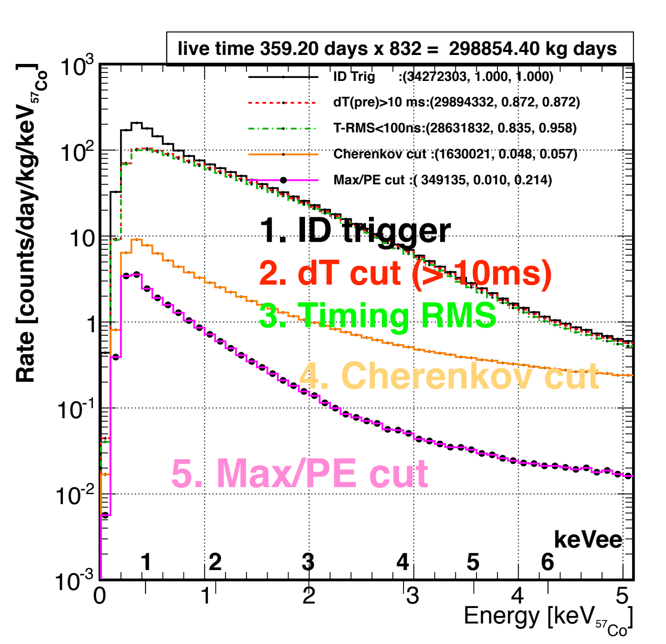
1.1 keVee (15% difference from NEST,

see also Baudis et al. PRD(2013)

-Systematic error due to time dependence of light yield (~ 10%) was treated by two method

(pull-term, covariance matrix) as a relative efficiency difference.





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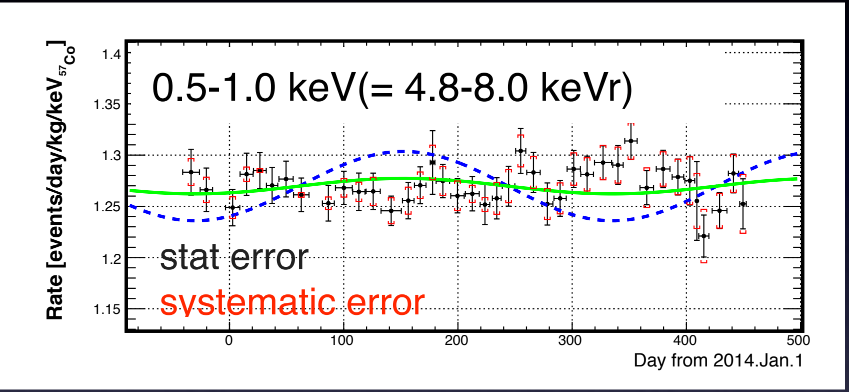
WIMP case

time variation data was fitted by

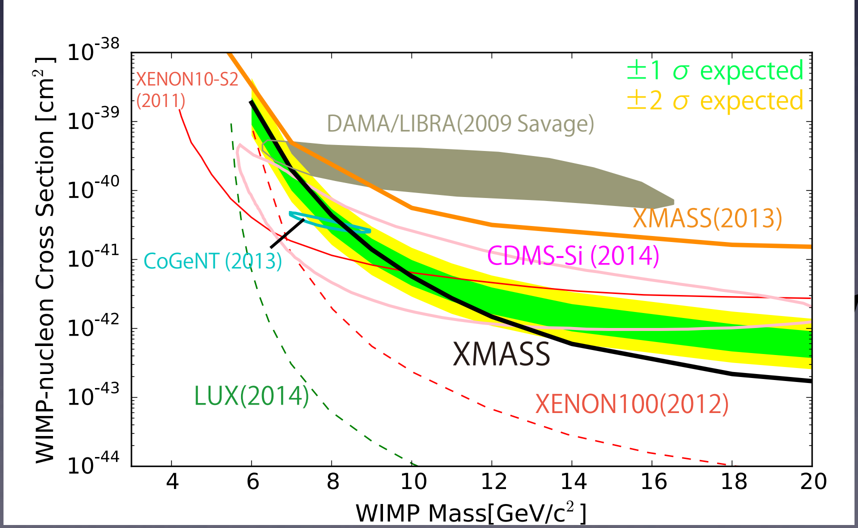
$$R_{i,j}^{\rm ex} = \int_{t_j - \frac{1}{2}\Delta t_j}^{t_j + \frac{1}{2}\Delta t_j} \left(C_i + \sigma_{\chi n} \cdot A_i(m_\chi) \cos 2\pi \frac{(t - t_0)}{T}\right) dt,$$

Ai: amplitude
Ci: constant
σ_χ: WIMP-nucleus cross section
m_χ: WIMP mass
t0: 152.5 day
T : 1 year



- assuming WIMP spectrum
- 2D fitting (time and energy bin)
- DAMA/LIBRA region is mostly excluded by annual modulation search.

  $<4.3 \times 10^{-41}$cm^2 (90% CL) @ 8GeV



V_0: 220.0 km/s
V_{esc}: 650.0 km/s
ρ_{dm}: 0.3 GeV/cm^3
*Vesc 544 km/s gives $<5.4 \times 10^{-41}$cm^2

Model Independent Case

time variation data was fitted by

$$R^{\mathrm{ex}}_{i,j} = \int_{t_j-\frac{1}{2}\Delta t_j}^{t_j+\frac{1}{2}\Delta t_j} \left(C_i + A_i \cos 2\pi \frac{(t-t_0)}{T} \right) dt$$

free in energy bin

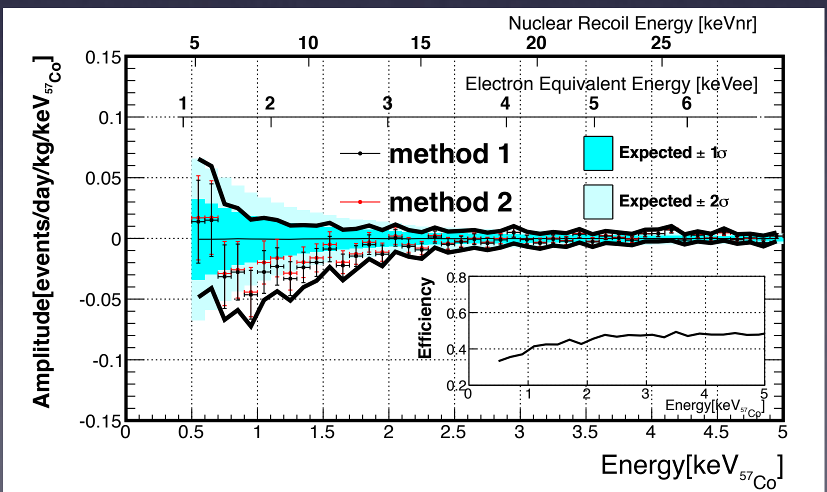
Method1 (pull tem)

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

Method2 (covariance matrix)

$$\chi^2 = \sum_{k,l}^{N_{\mathrm{bins}}} (R^{\mathrm{data}}_k - R^{\mathrm{ex}}_k)(V_{\mathrm{stat}} + V_{\mathrm{sys}})^{-1}_{kl}(R^{\mathrm{data}}_l - R^{\mathrm{ex}}_l),$$

R^{data}: observed data, R^{ex}: expected rate, Nbins:Ebins x tbins



Model independent analysis :

- Annual modulation signal is searched for without any model assumption.
- Ai and Ci are free parameter.
- They are fitted by the difference of two methods are used for analysis for consistency check.
- Slightly negative amplitude was observed.
- Significance was evaluated with test statistic (10,000 sample) and no significant modulated signal has been observed. (1.8σ, 1.4σ)
- < ~3x10^{-3} counts/day/kg/keVee in 2-6keVee (0.5keVee bin width). (90 CL, Bayesian) , (e.g. ~0.02 dru by DAMA/LIBRA, closed to XENON100 sensitivity)
- Another one year cycle with more stable data set is available soon.

Masaki Yamashita, ICRR, Univ of Tokyo

Summary

- Recent Result from XMASS
- bosonic Super WIMP
  - vector-boson warm dark matter was ruled out in the 40-80 keV.
- **Search for 2ν double electron capture**
  - **$T_{1/2}^{2\nu 2K}(^{124}Xe) > 4.7 \times 10^{21}$ years (90%CL)**
    $T_{1/2}^{2\nu 2K}(^{126}Xe) > 4.3 \times 10^{21}$ years (90%CL)
- Annual modulation
  - WIMP $<4.3 \times 10^{-41} cm^2$@8GeV
  - <~3e-3 counts/day/kg/keVee
    (2-6 keVee range, 0.5keVee bin width)
  - another one year cycle with more stable data will be ready soon.