STATUS OF KIMS EXPERIMENT

2012.11. 6 Juhee Lee and KIMS Collaboration for PPC2012 @ KIAS

Contents

- Introduction to KIMS
- The latest publication - Astropart. Phys. 35 (2012) 781
  PRL 108 181301(2012)
- Recent results - Background study,
  Annual Modulation, Channeling effect
- Future Plans - Upgrade of PMTs and NaI(Tl)
- Summary

Introduction to KIMS

1. The location of Y2L for WIMP search
   - The Muon flux in the detector room : 2.7×10^{-3} /m²/s

Introduction to KIMS

2. Detector

- 12 CsI(Tl) crystals, each 8 * 8 * 30 cm^3 (8.7kg), w/ 3" PMTs (9269QA)

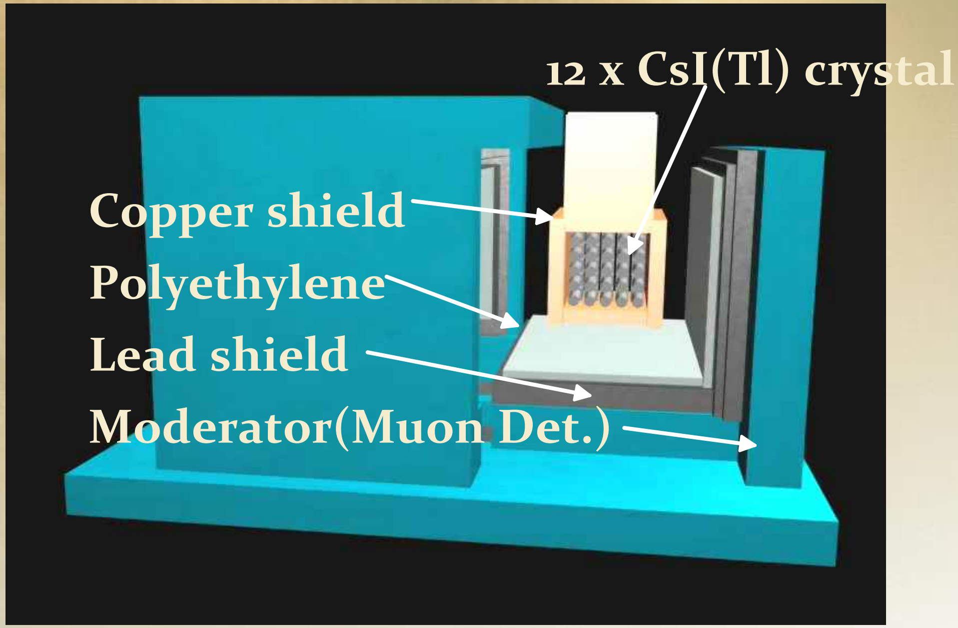
- Measured light yields for gammas: ~ 5 p.e./ keV
- SI + SD interaction search for the WIMP-nucleon scattering

Isotope	J	Abun	<Sp>	<Sn>
^{133}Cs	7/2	100%	-0.370	0.003
^{127}I	5/2	100%	0.309	0.075

- Background level : 2~ 3 cpd/kg/keV : slide #12
- Pulse shape discrimination(PSD) : slide #8

Introduction to KIMS

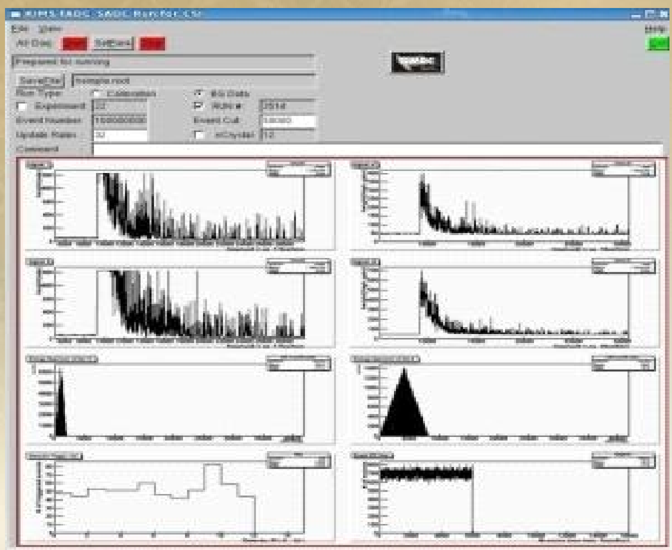
3. The shielding setup
   - External gammas (<< internal BG) : HPGe measurement
   - Neutrons (~ zero) : ~100 days Bc501A measurement w/ the time anaylsis
   - N2 gas flow inside the setup

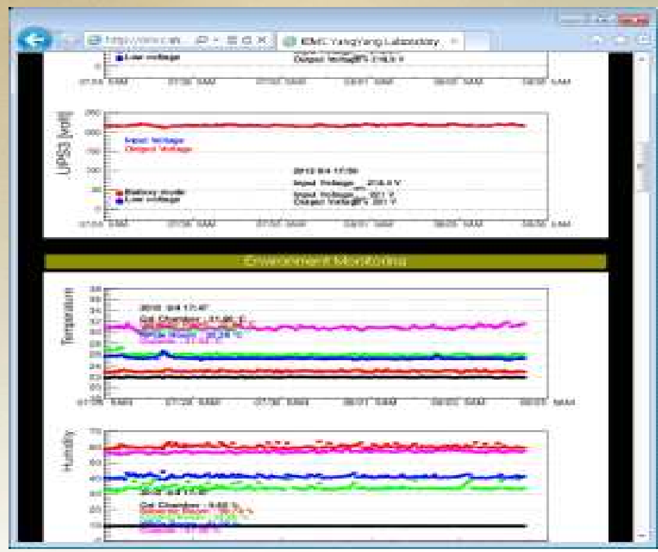


- Muon Det. : supply the veto signals to CsI(Tl) (6~7 counts /hr)

Introduction to KIMS

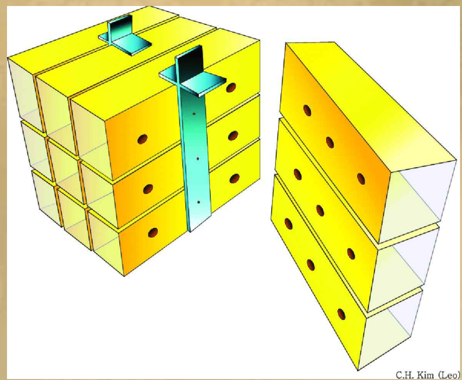
4. DAQ
   - Trigger condition : 4 p.e. for two PMTs
   - DAQ rate : < 6 Hz.
   - 400 MHz FADC (10 bit) w/ x 100 preAmp.
     & 64 MHz SADC (12 bit) w/ x 10 preAmp.
   - Stability check - By monitoring of temperature, electric power etc.
   - CsI(Tl) temp. : 20~21.6 (depending on the positions) ± 0.2 ℃

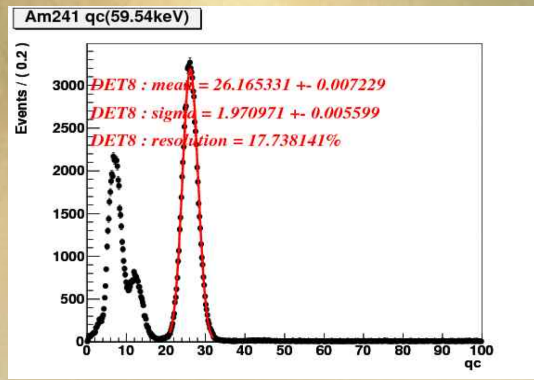




Introduction to KIMS

5. Calibration
   - Electron recoil energy calibration w/ bar type sources of ^{241}Am (59.54 keV γ)





and low energy efficiency check w/ ^{55}Fe (5.9 keV x-ray)

   - Nuclear recoil energy calibration (in Seoul National University)
     - For small sample crystals of each detector in Y2L
     - $^{241}Am/^{9}Be$ 300 mCi, 2.4 MeV neutron beam (in progress)
     - **Nuclear recoil event sample - PDF as a function of LMT10 (the PSD value) for each E_{meas} (F_{NR})**

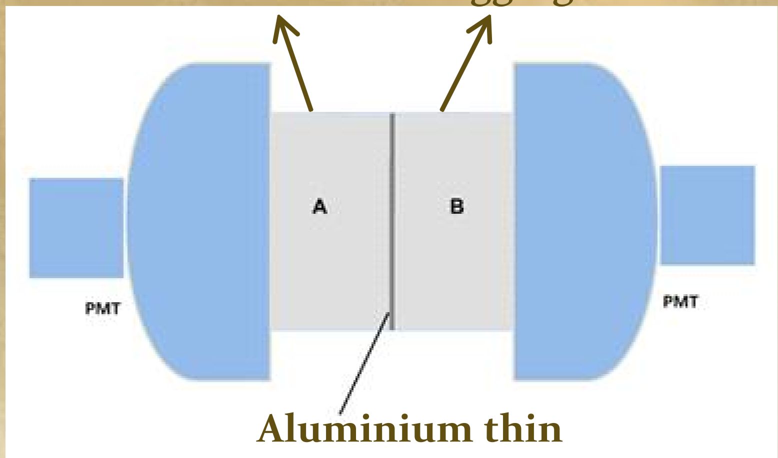
$$<t> = \frac{\sum_{i_{t0}}^{n_{10\mu s}} A_i t_i}{\sum_{i_{t0}}^{n_{10\mu s}} A_i}, \; LMT10 = \log <t>$$

The latest publication

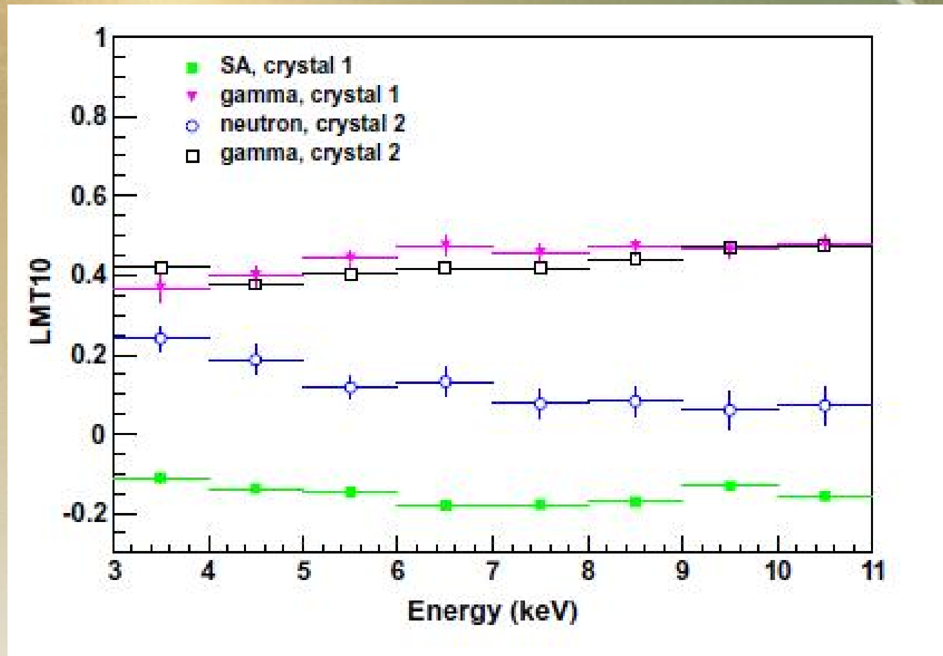
- Astropart. Phys. 35 (2012) 781 by S. C. Kim et. al.
  - Surface alphas (SA)- main backgrounds from Rn progenies.
  - W/ Radon double detector (A & B)

CsI(Tl) A : Rn progenies contaminated one

CsI(Tl) B : Alpha tagging detector



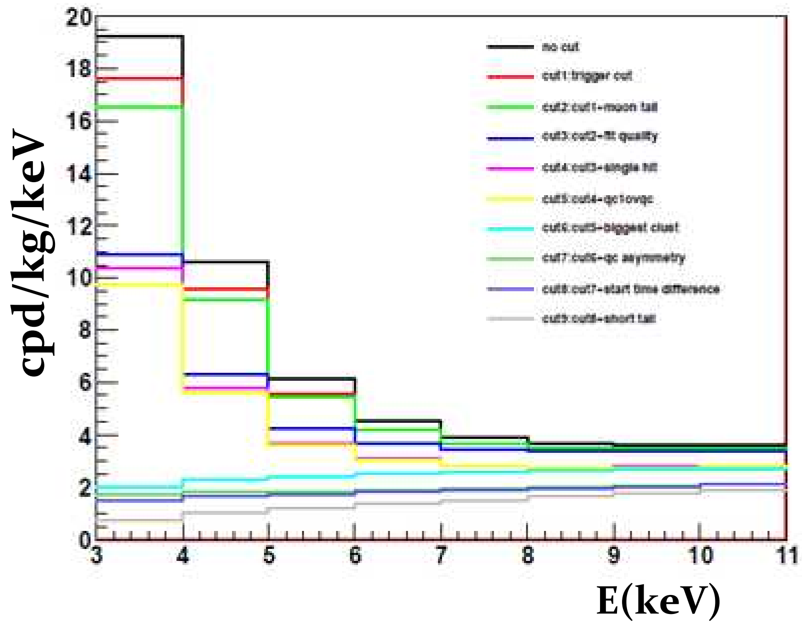
Aluminium thin foil 6 µm



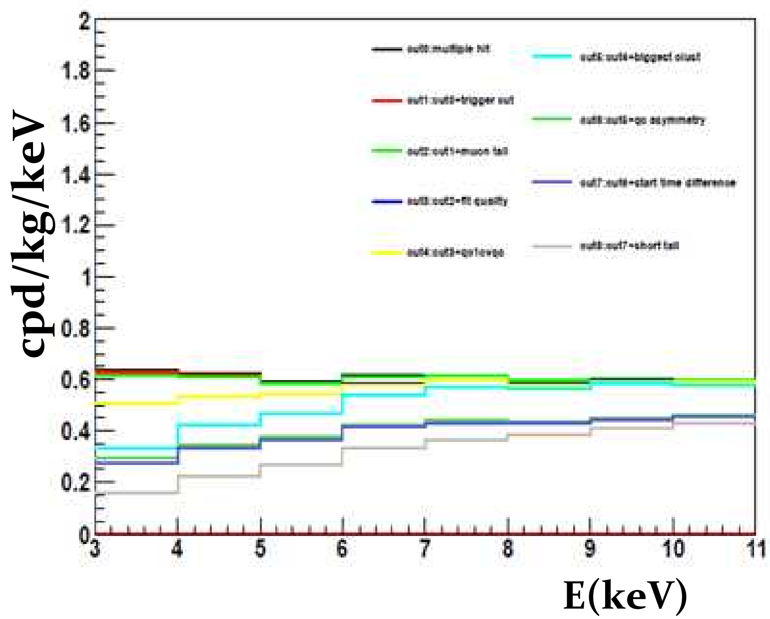
  - From SA sample events - PDF of LMT10 (F_{SA})

The latest publication

- Phys. Rev. Lett. 108 181301(2012) by S. C. Kim et. al.
  - **1 year of data (Sep. 2009 – Aug. 2010)**
  - PMT noise rejection cuts
    - Reference data : from the PMT dummy detector
    - Different characteristics from multiple hit events(Compton scattering events) and nuclear recoil events



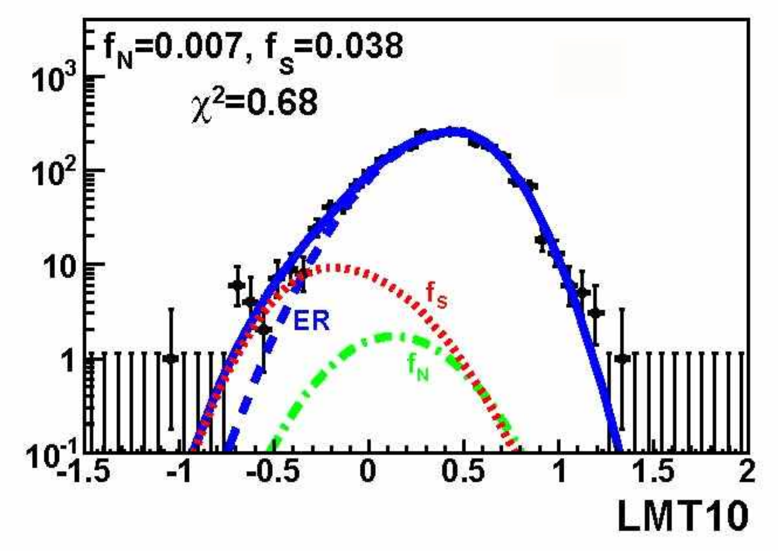
[Single hit events]



[Multiple hit events]

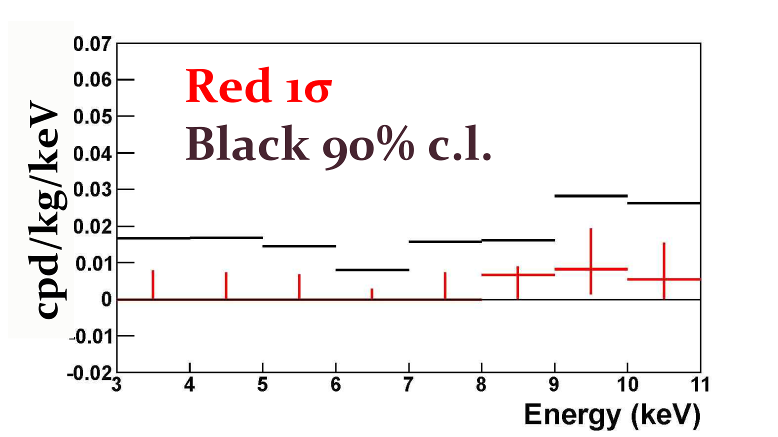
The latest publication

- Phys. Rev. Lett. 108 181301(2012)
  - By Bayesian Analysis Tool
    - The most probable ratios for F_{NR}, F_{SA} and F_{gamma} for each E_{meas}
    - Efficiency corrections for the nuclear recoil event limits



$$F = f_N F_{NR} + f_S F_{SA} + (1 - f_N - f_S) F_\gamma$$

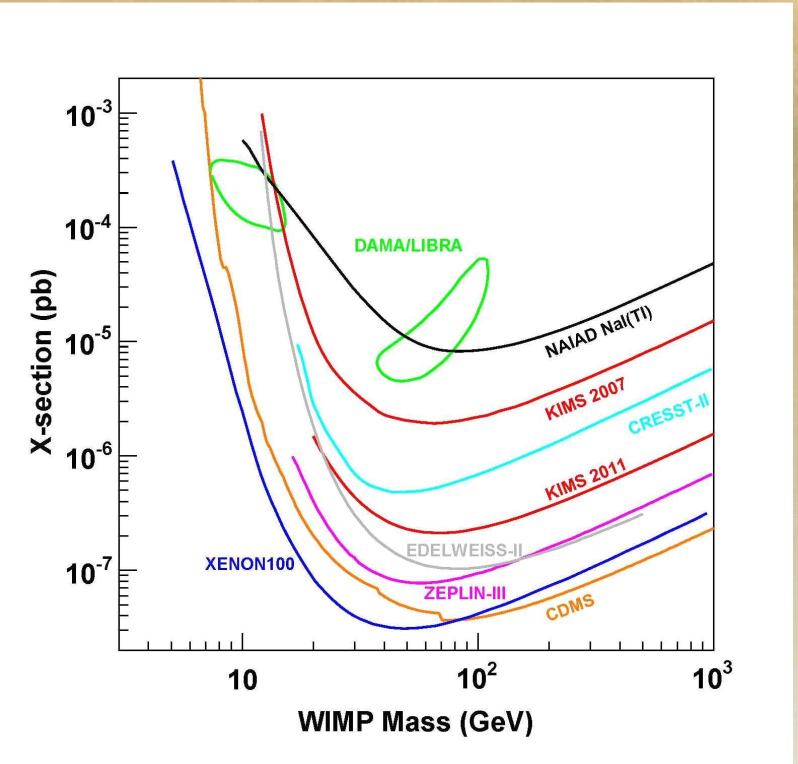
(for 6 keV bin of Det 9)



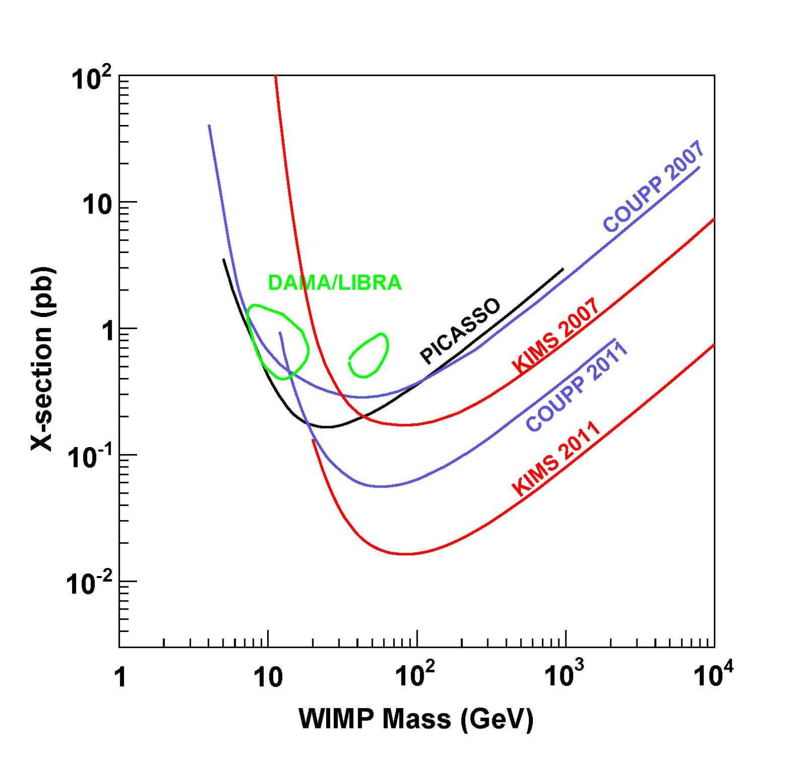
3.6-5.8 keV (2-4 keV in DAMA)
90% c.l. is 0.0098 cpd/kg/keV
< 0.0183 cpd/kg/keV modulation signal of DAMA

The latest publication

- Phys. Rev. Lett. 108 181301(2012)



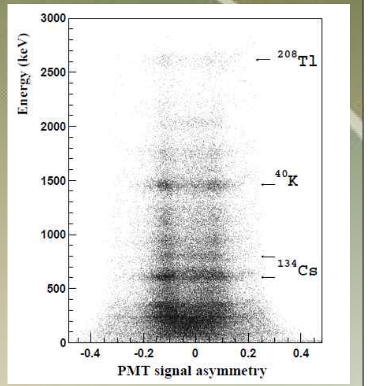
[SI cross section limit]

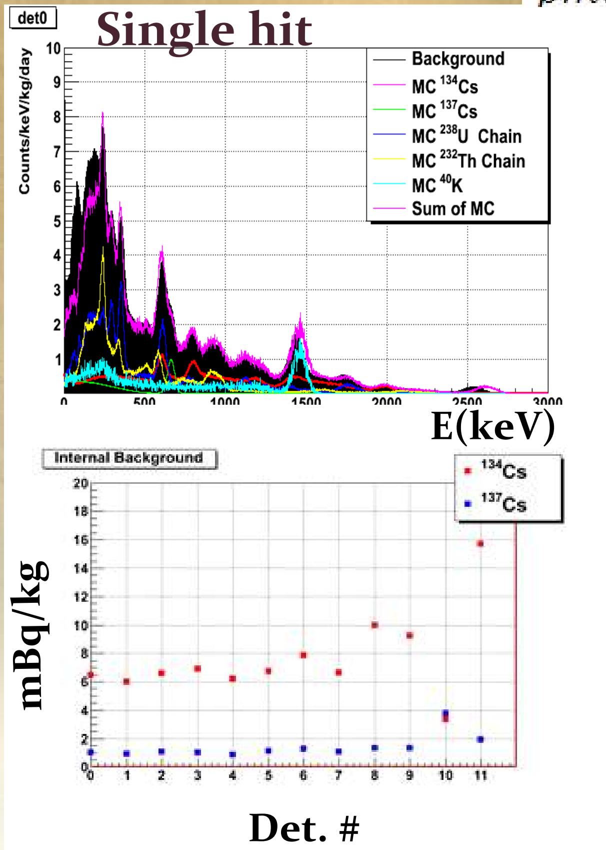


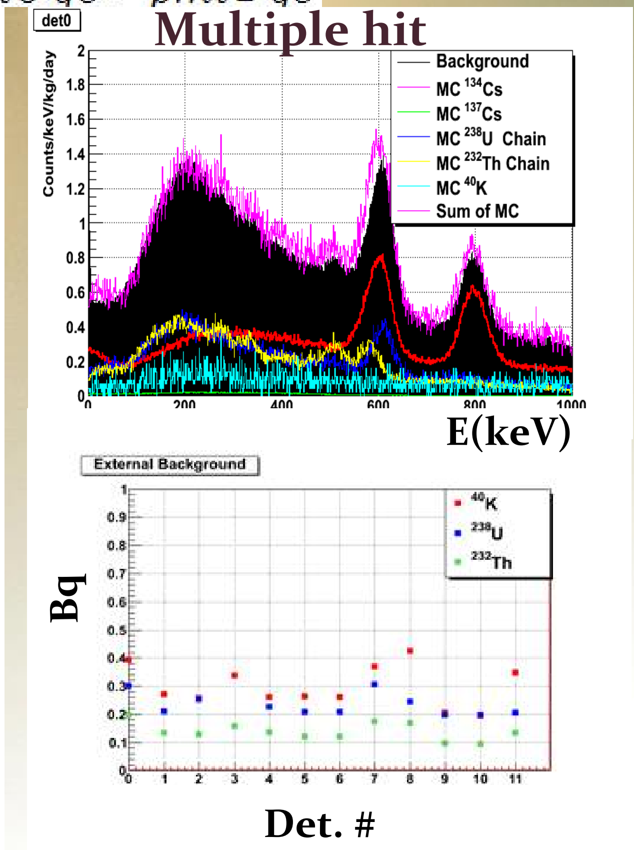
[SD cross section limit]

Recent Results

1. Background study by using e/γ events (by J. K. Lee in preparation)
   - ^{134}Cs/ ^{137}Cs - in CsI(Tl), $^{238}U/^{232}Th/^{40}K$ - in PMT glue
     - For data - Energy calibration w/ 59.54 (^{241}Am), 605, 796 keV(^{134}Cs)
       Charge asymmetry($\frac{pmt0.qc - pmt1.qc}{pmt0.qc + pmt1.qc}$)correction →

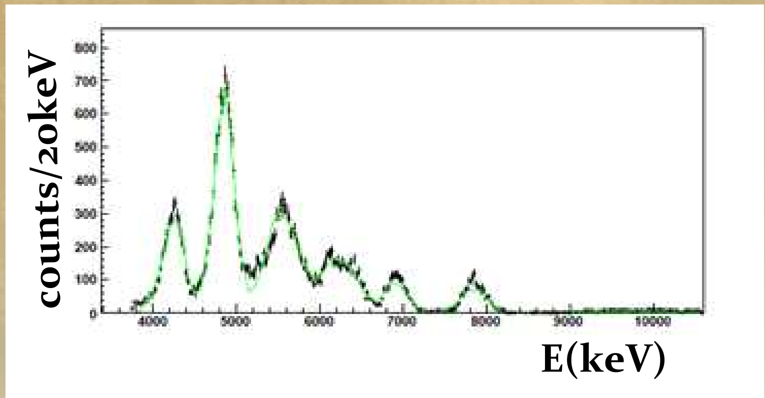






Recent Results

1. Background study by using α events (by S. S. Myung submit to NIMA)
   - $^{238}U/^{232}Th$ - in CsI(Tl)
     - Better energy resolution w/ two corrections of the charge asymmetry and the saturation
     - Quenching factor measurement
     - Fit data w/ MC events generated by ***f***



     - Bkg. level ~ 0.008 cpd/ kg/keV
     - Time analysis can underestimate U/Th activity.

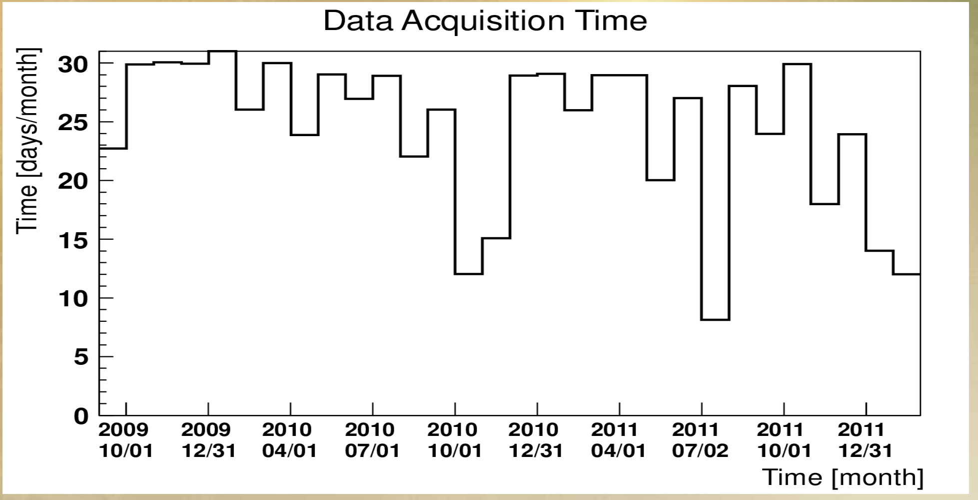
$$f = P0(^{238}U + ... + ^{210}Po) + P1(^{232}Th + ... + ^{212}Po) + P2(^{238}U) + P3(^{234}U + ^{230}Th + ^{226}Ra) + P4(^{232}Th) + P5(^{228}Th + ^{224}Ra) + P6(^{210}Po).$$

detector	Activity of Nuclide (μBq/kg) ^{238}U	$^{234}U^{a}$	$^{222}Rn^{b}$	^{210}Po	^{232}Th	$^{228}Th^{c}$	$^{220}Rn^{d}$
0	109.05	246.36	7.89	75.37	23.51	25.61	7.89
1	84.79	220.59	11.91	16.82	34.77	33.21	11.73
2	101.96	226.11	7.58	27.11	29.63	36.37	9.61
3	15.32	45.29	5.34	23.21	7.11	17.72	6.15
4	33.19	97.12	4.18	2.35	17.23	9.43	4.71
5	14.99	44.68	3.05	8.05	6.53	7.40	3.70
6	22.60	65.86	11.15	2.83	9.62	22.65	9.62
7	73.64	165.87	7.98	1.81	11.63	21.57	8.73
8	14.03	35.07	5.22	11.72	7.97	14.73	6.03
9	2.11	19.60	2.11	5.79	7.26	7.25	3.63
10	6.42	22.64	6.42	271.30	3.53	6.95	3.48
11	7.83	19.30	0.97	28.81	4.49	3.84	1.92

[a] $^{234}U + ^{230}Th + ^{226}Ra$. [b] ^{222}Rn and its alpha decay progenies.
[c] $^{228}Th + ^{224}Ra$. [d] ^{220}Rn and its alpha decay progenies.

Recent Results

2. Annual Modulation (by J. H. Choi in preparation)
   - **2.5 year of data (Sep. 2009 – Feb. 2012) , 75.53 ton·days**

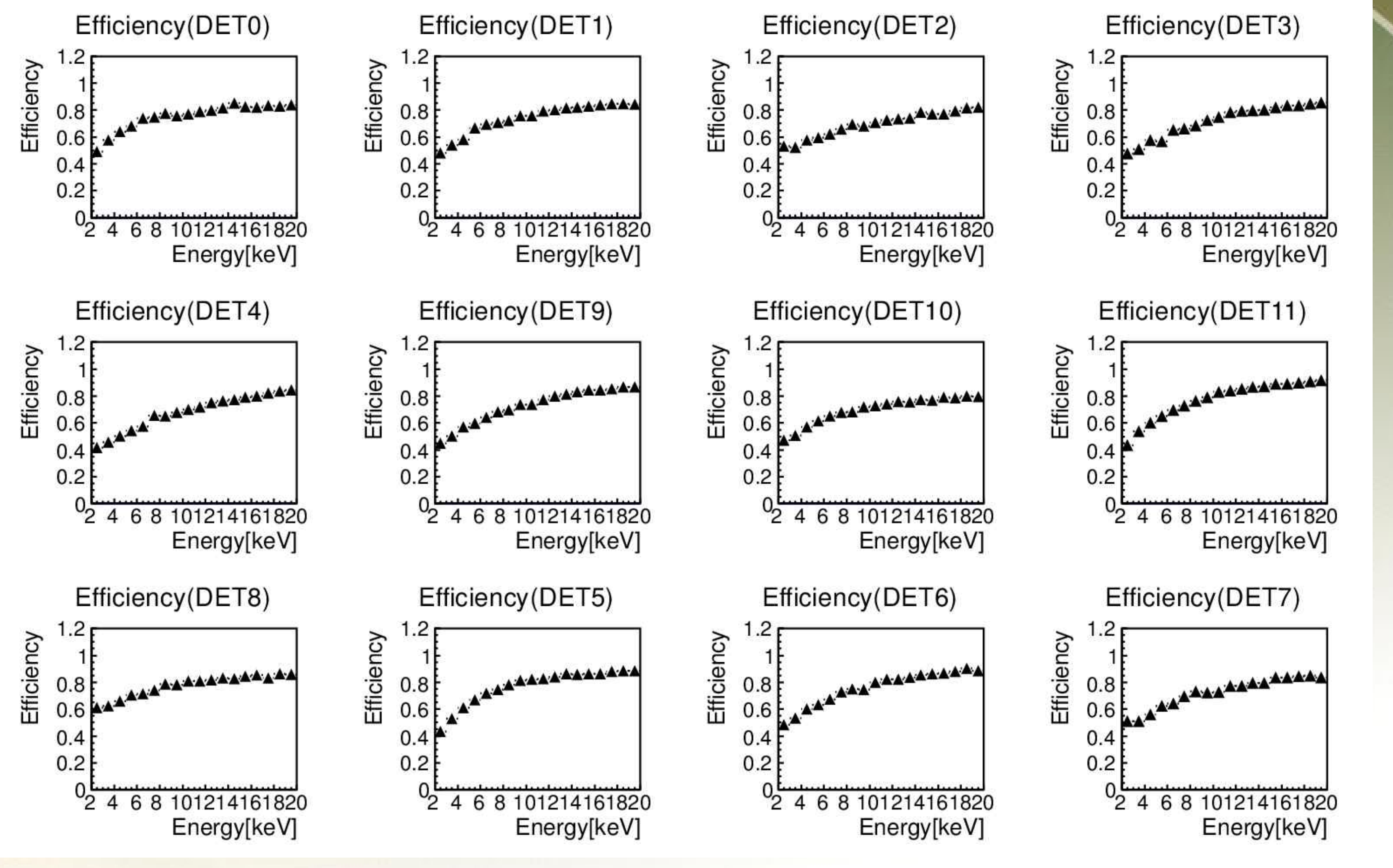


     - Due to an outage of electricity or an abnormal termination of computers, sometimes not a full month data

   - **For data - PMT noise cuts and the efficiency correction (w/ multiple hit events, in next slide), No PSD**

Recent Results

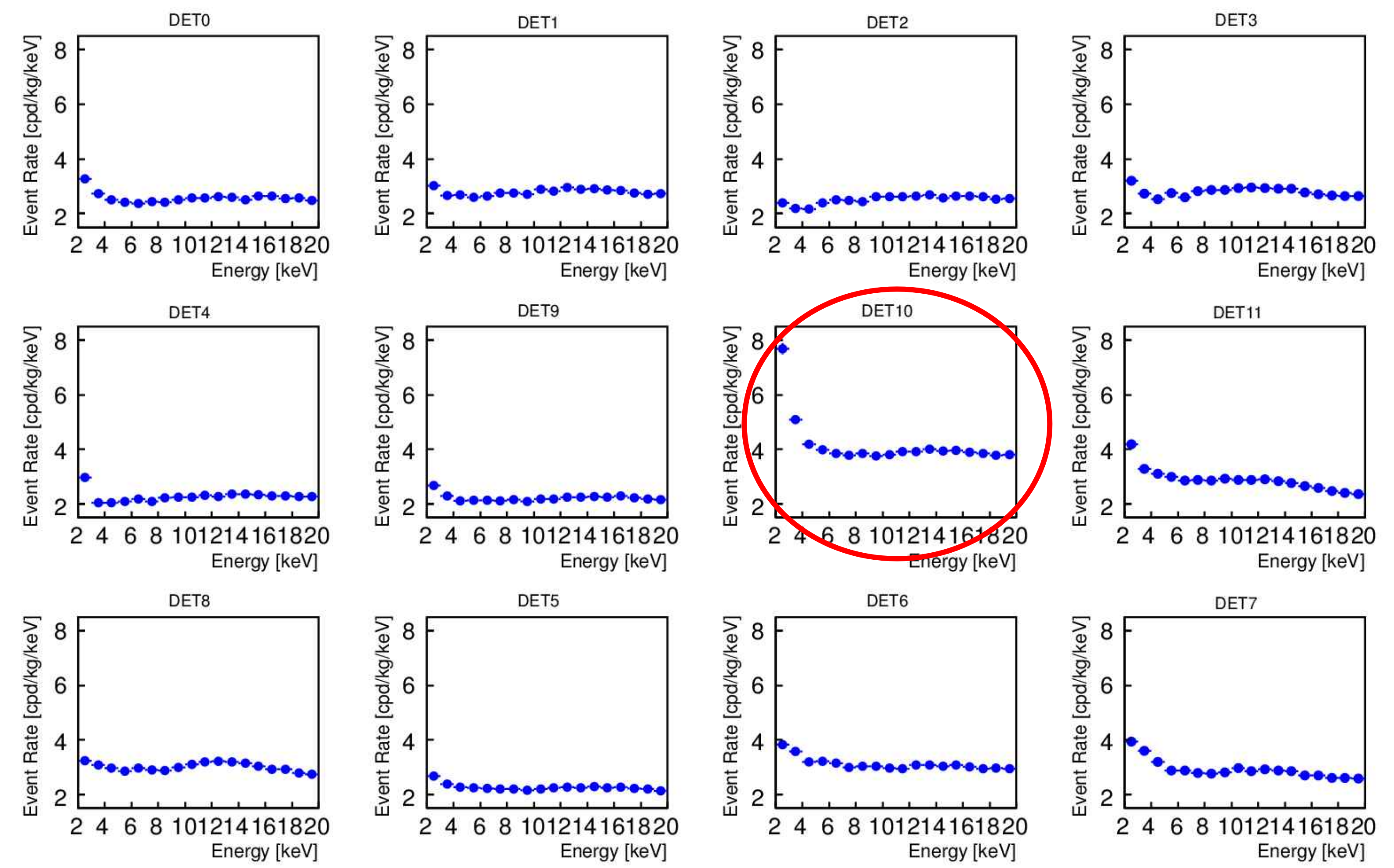
2. Annual Modulation
   - Cut efficiency from multiple hit data



Recent Results

2. Annual Modulation

- Single hit events after all cuts and efficiency correction (except Det10 for its high background rate)



Recent Results

2. Annual Modulation

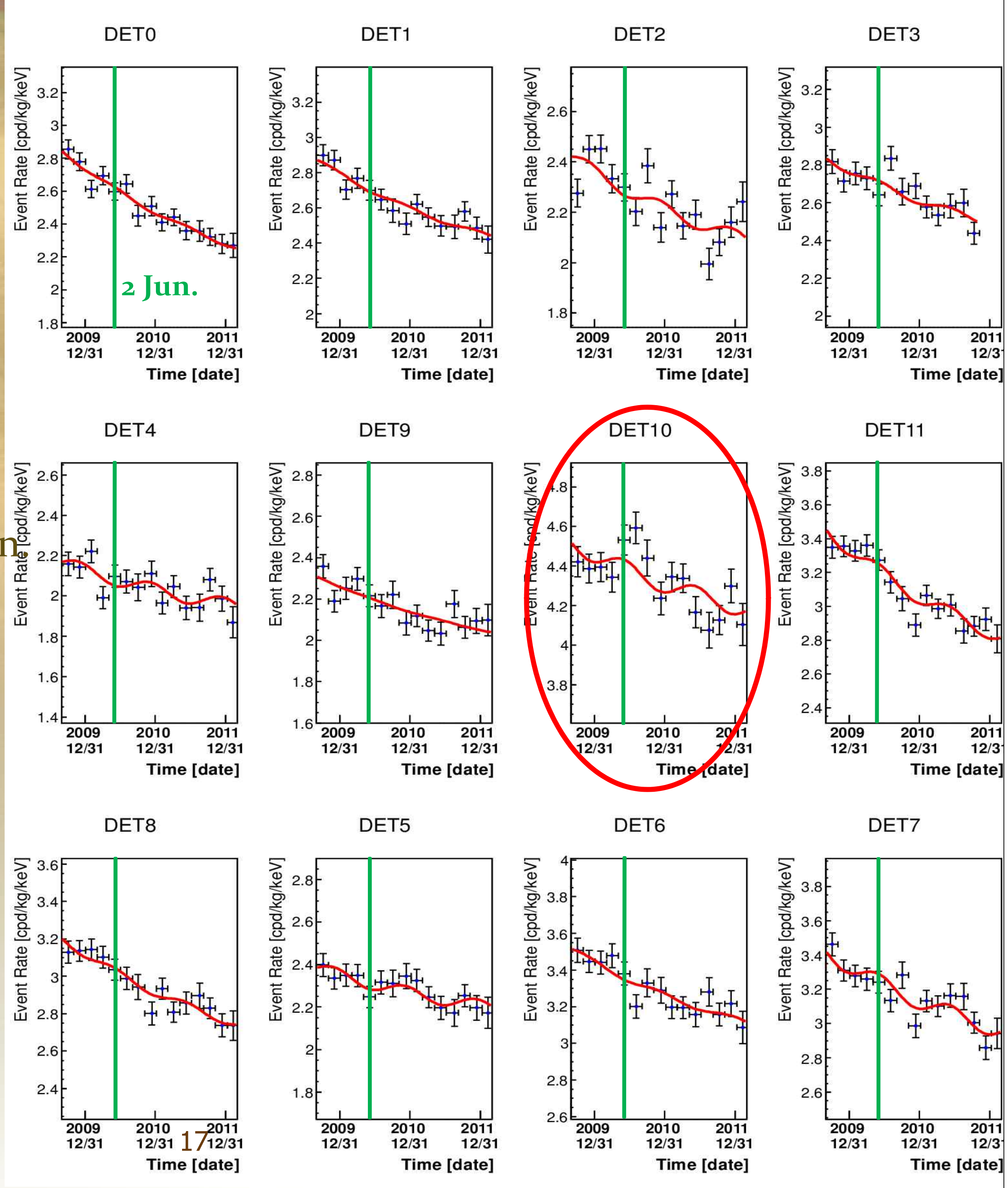
3-6 keV

- Similar E_{meas} bin w/ DAMA's 2-4 keV bin from quenching factor correction.

- After fitting data w/ ***R***, A_{mod} can be extracted.

$$R = A_{decay} e^{-\frac{t-t_0}{\tau}} + bkg. + A_{mod} \cos \frac{2\pi}{365}(t - t_{peak})$$

(t_o : 1. sep. 2009, τ : 2.98 y. t_{peak} : 153 d. (2. Jun.))

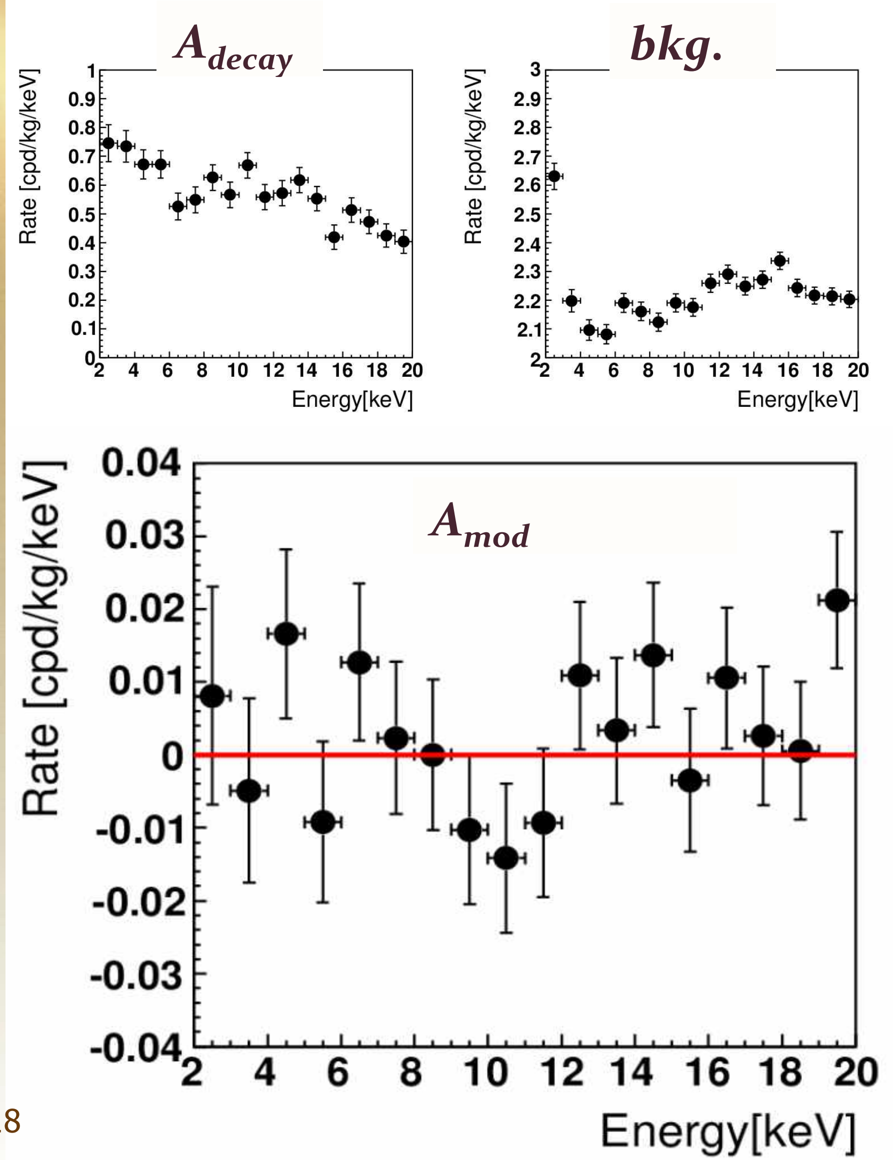


Recent Results

2. Annual Modulation
   3-6 keV

- A_{decay} has the same decay time as ^{134}Cs. (τ : 2.98 y)
- The *bkg.* level of 2 keV bin is higher than other energy bin.
  More bkg. reduction is needed.
- A_{mod}
  - 1σ : 0.0008±0.0068 cpd/kg/keV
  - 90 % c. l : 0.0119 cpd/kg/keV

  Inconsistent with DAMA's modulation signal independent of halo model.

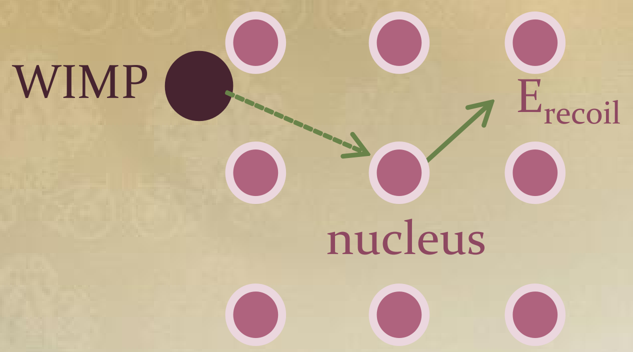


Recent Results

3. Channeling effect

IEEE TNS. 59. 5 (2012) 2346 (by J. H. Lee et. al.) and in preparation

- R. Bernabei et. al. (Eur. Phys. J. C. 53 (2008) 205)
  - KIMS PSD method might lose some nuclear recoil events relevant to the channeling effect.
- Channeling effect : When recoil ions go through the symmetry axes/planes



From the ion cascades after the recoil

$E_{recoil} \Rightarrow E_{phonon} + E_{ionization} + E_{damage}$

Enhanced light yield
due to the enhanced
Eionization

However, gamma like events?
(cf. alpha events)
Stopping power may be the
more important thing.

Recent Results

3. Channeling effect

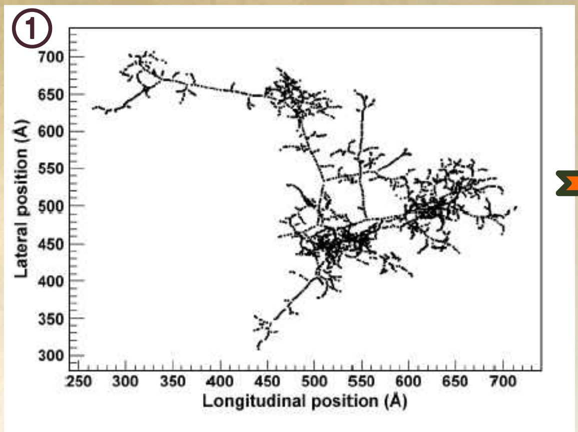
- E_{meas} reproduction for a E_{recoil} in the monocrystalline CsI(Tl)

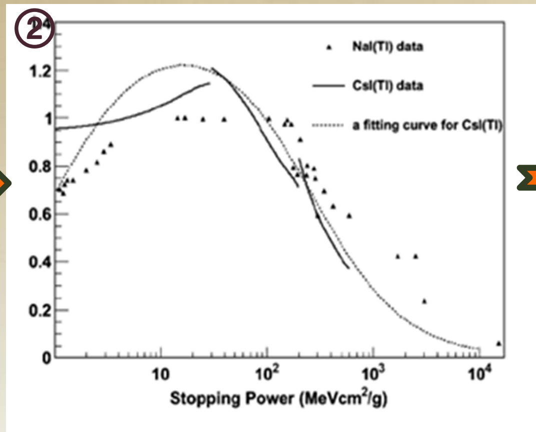
  - To know the channeling effect on E_{meas}

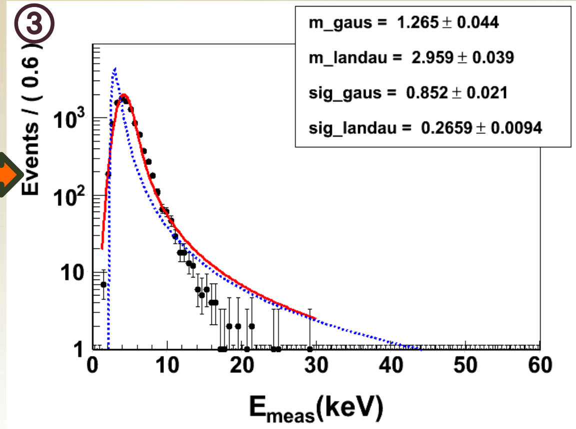
  ① By simulation (TRIM/MARLOWE) : $E_{ionisation}$ distribution

  ② Scintillation efficiency model based on Birk's formula : Conversion to E_{meas}

  ③ PDF of E_{meas} spectrum (Landau-Gaussian funtion) for amorphous and monocrystalline cases

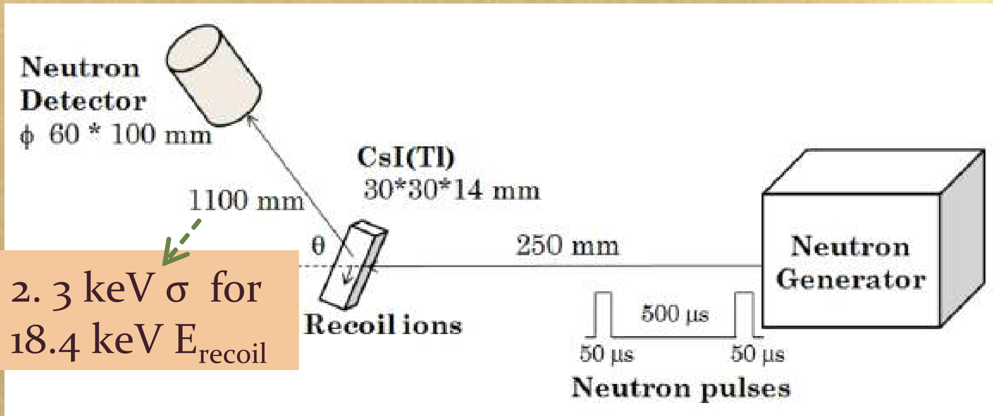






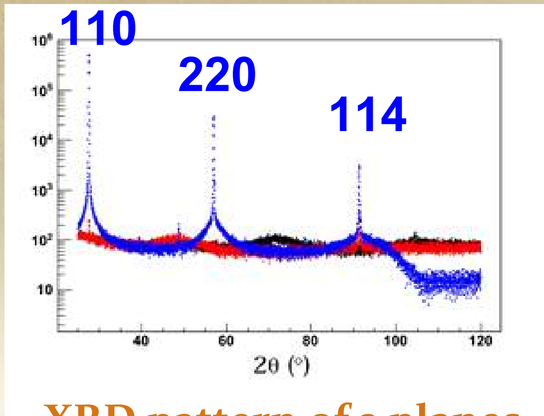
Recent Results

3. Channeling effect
   - Exp. setup

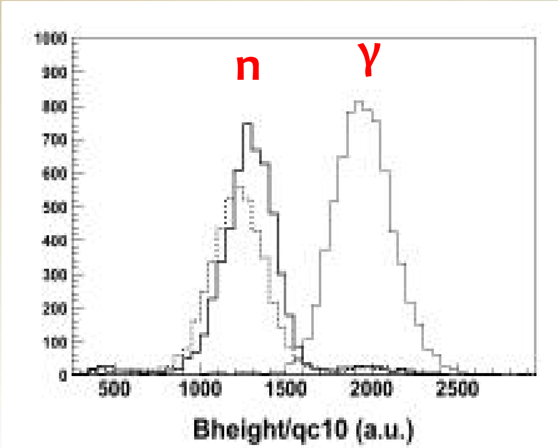


2. 3 keV σ for 18.4 keV E_{recoil}

θ = 45° : E_{recoil} = 10.8 keV
60° : 18.4 keV
90° : 36.6 keV



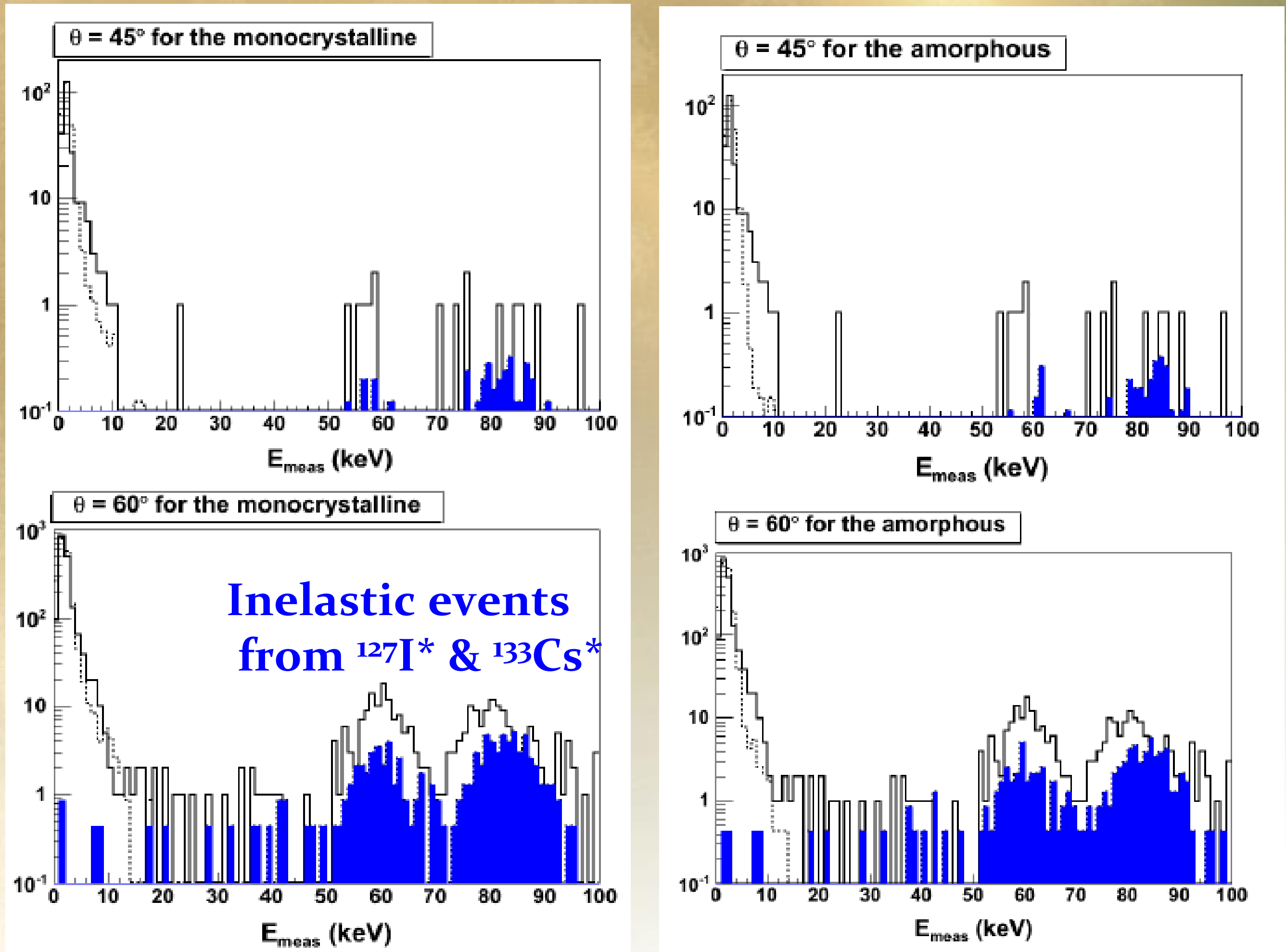
XRD pattern of 3 planes on the CsI(Tl)



PSD power of a neutron detector

Recent Results

3. Channeling effect
   - E_{meas} spectrum for E_{recoil} w/ a small deviation
     - **Normalized by # of events below 10 keV**



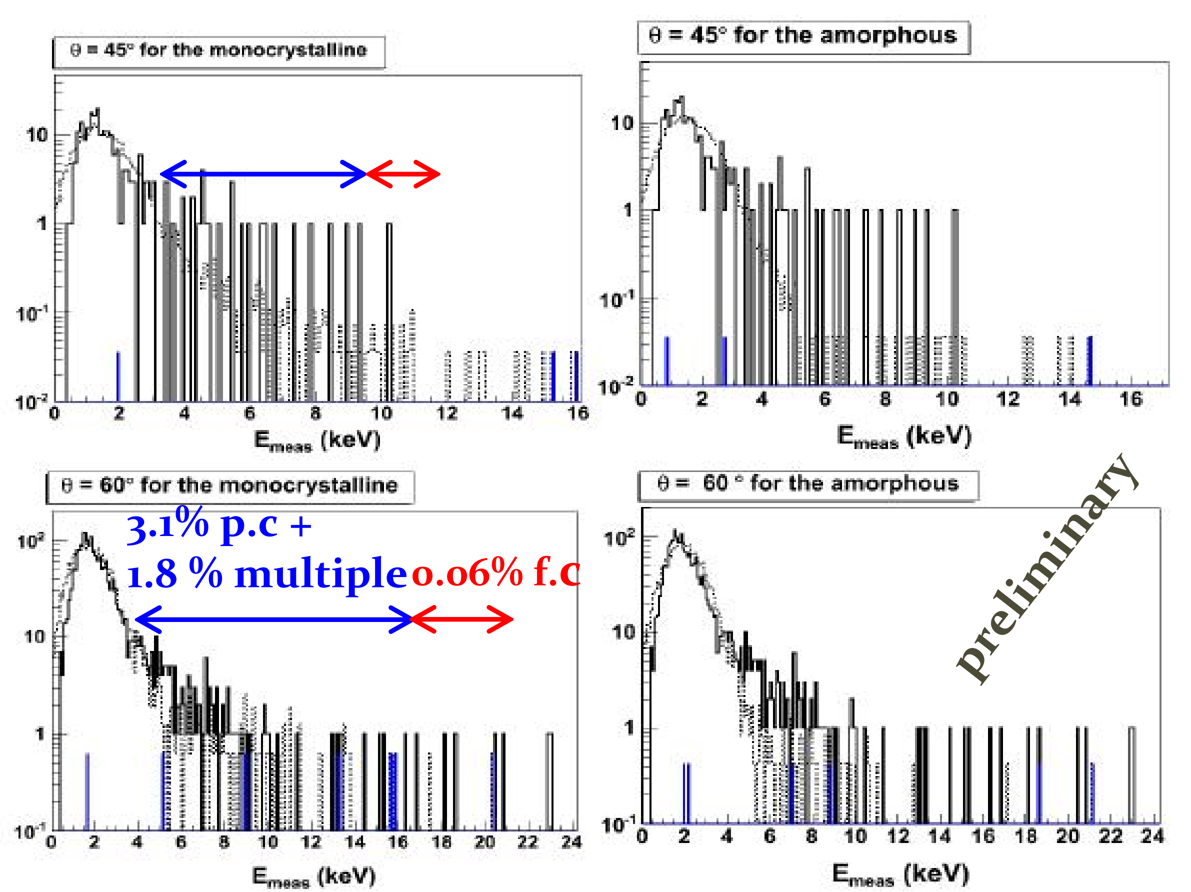
Solid - Measured total evts.

Dashed - Reproduced total evts.

Blue - Reproduced gamma contaminated evts.

Recent Results

3. Channeling effect
   - Zoom in below E_{recoil}
     - To consider symmetry axes and planes in CsI(Tl) represents data well.



Criteria of the range selection

Blue : partial channeling

$<E_{meas}>_{normal} + 3\sigma_{normal} < E_{meas} < E_{recoil} - 2\sigma_{recoil}$

Red : full channeling

$E_{recoil} - 2\sigma_{recoil} < E_{meas} < E_{recoil} + 2\sigma_{recoil}$

- Channeling effect is ~3 % in partial.
- PSD cut seems to be reasonable.

Future Plans

1. Upgrade of PMTs (tested by K. W. Kim)

Unit: mBq/PMT

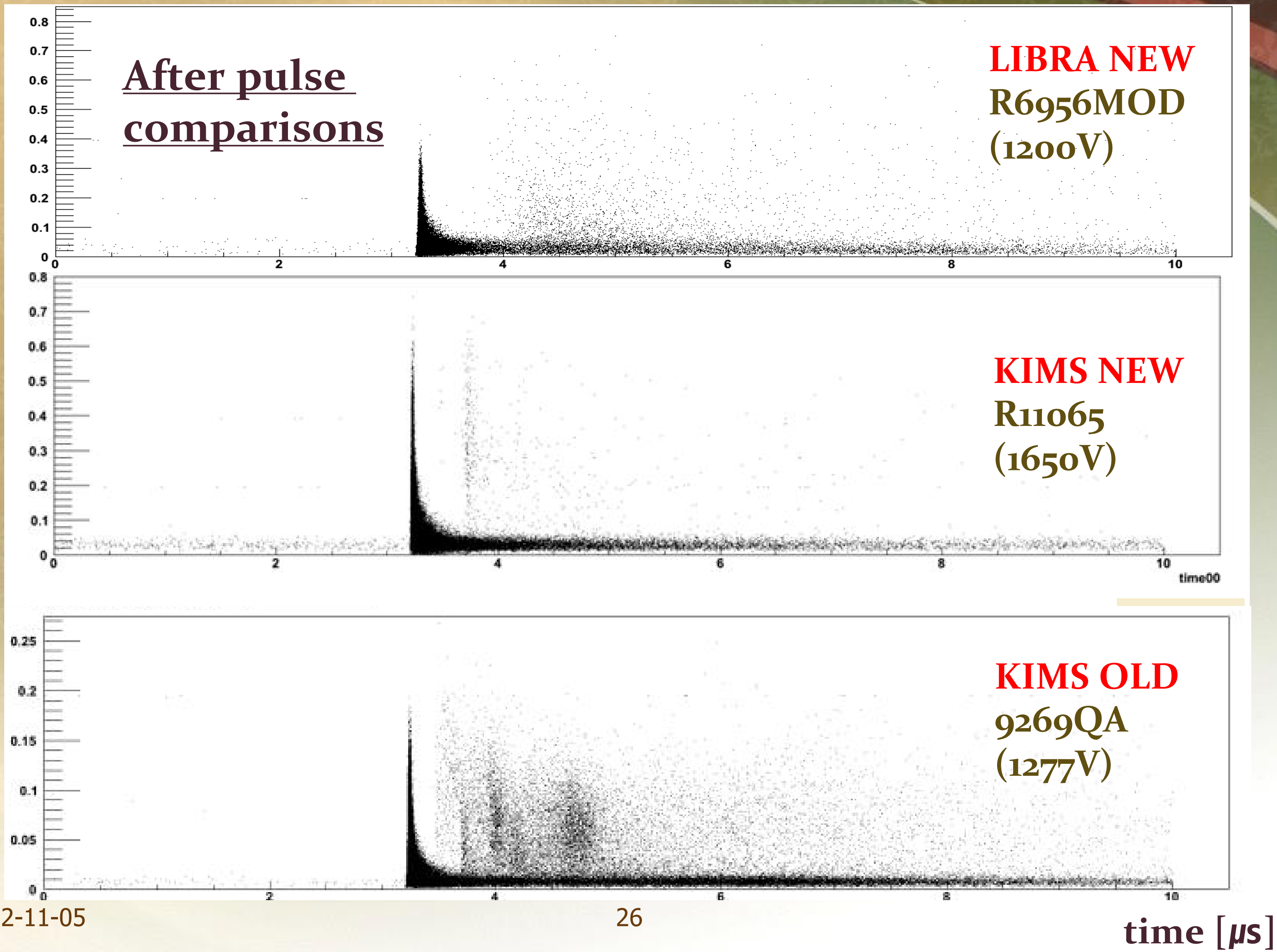
(from company)	U	Th	K
Present (9269QA)	83	48	1866
Plan (R11065)	33	1.9	32

- High K content : at the coupling of Quartz and Borosilicate glasses at the center of PMT body.
- The Cherenkov light from ^{40}K decay in the glass or weak glass scintillation may be the origin of the PMT noise.
- With new PMT and suface alpha reduction from the polishing , ***we can reduce by ~ 1cpd/kg/keV***
- With this lower bkg level, low mass WIMP search is possible.

Future Plans

PMT comparisons	R6956MOD (R6233MOD)	R11065	9269QA
	LIBRA NEW	KIMS NEW	KIMS OLD
Photocathode	SBA	Bialkali	RbCs
Window	Borosil	Quartz	Quartz
Effective Dia.	70	64	
Body	Borosil	Metal	Quartz+ Borosil
QE(500,550,600)	20,7.5,2.3	22,11,5	18,11,3
Gain	$1X10^6$	$5X10^6$	$1X10^6$
U (mBq/PMT)	128	33	83
Th(mBq/PMT)	20	1.9	48
K (mBq/PMT)	97	32	1866
Dark counts (kHz)	0.5	3	0.6
Afterpulse (x 10^{-3})	~5.0	0.4	~10
# of pe/keV	7.7	8.8	6.1

Future Plans



Future Plans

2. Pure NaI(Tl)

Crystal	Exp.	U (ppt)	Th (ppt)	K (ppb)	Background Level (/keV kg day)
NaI	DAMA	2-10	1-6	~ 20	
	LIBRA	0.7-10	0.5-7.5	13	
	ANAIS			400	>10
CsI	KIMS	0.75	0.38	<10	~3

- It is possible to add several NaI(Tl) crystals to KIMS.
- We are developing low background NaI(Tl) crystals from scratch in collaboration with Signa-Aldrich company & DM-ICE group.
- Sigma-Aldrich company made first low-K NaI powder in June 2012.
- Normal NaI powder (crystal grade) ~300ppb vs.

  New one (astro grade) ~4ppb (Claimed by Sigma-Aldrich)
- We are confirming their results now.

SUMMARY

- 1 year data with 100 kg CsI(Tl) data analyzed with PSD method. DAMA Iodine region is inconsistent with KIMS NR rate limit.
- Stringent limit of spin-dependent proton cross section is given.
- Background levels of 12 detectors are well understood.
- 2.5 year data is analyzed without PSD for the annual modulation → null modulation limit inconsistent with the level of DAMA's modulation amplitude : final numbers are underway.
- Channeling & quenching factor studies produced first data.
- Planned upgrades will reduce the background further.