Status of KIMS experiment

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For KIMS collaboration

KIMS (Korea Invisible Mass Search) collaboration

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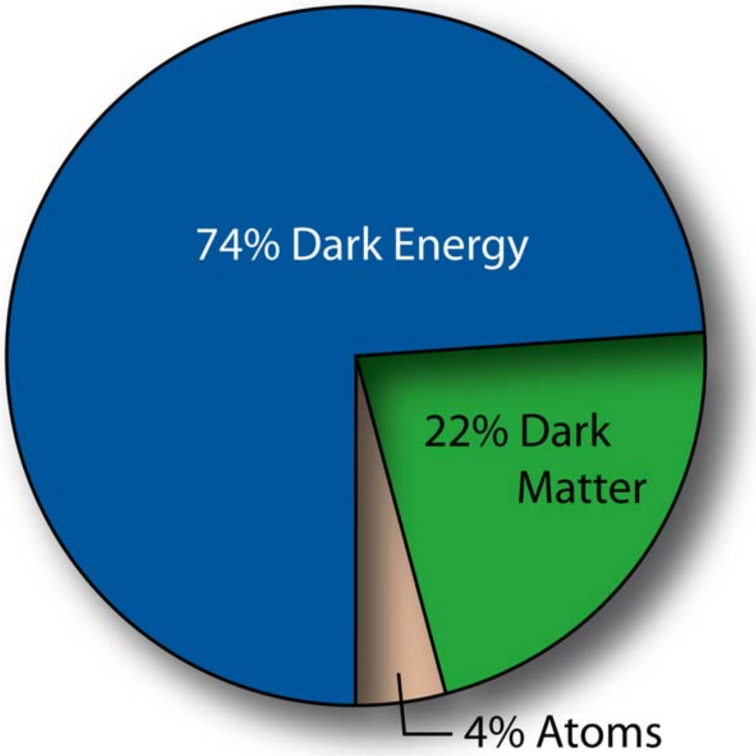
Dark matter ?



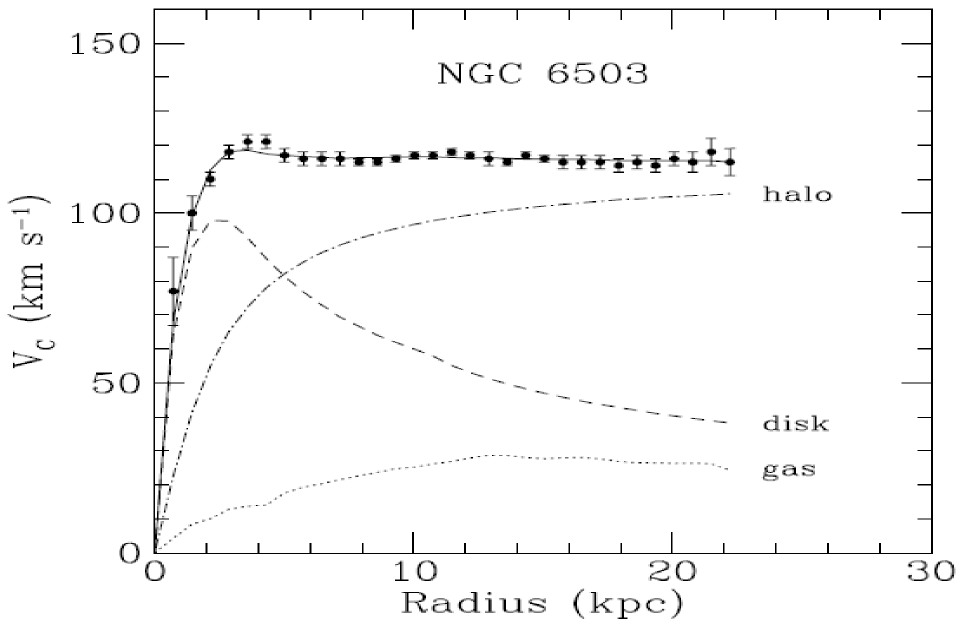
From WMAP website

Most matter of the universe is unknown.

=> It doesn't emit the light.

It rarely interacts.

But, its gravitational effect is evident.



Rotation curve for Galaxy NGC6503

Dark matter ?

Ordinary matter like atoms, or other known particles can't explain these unknown matter effect.

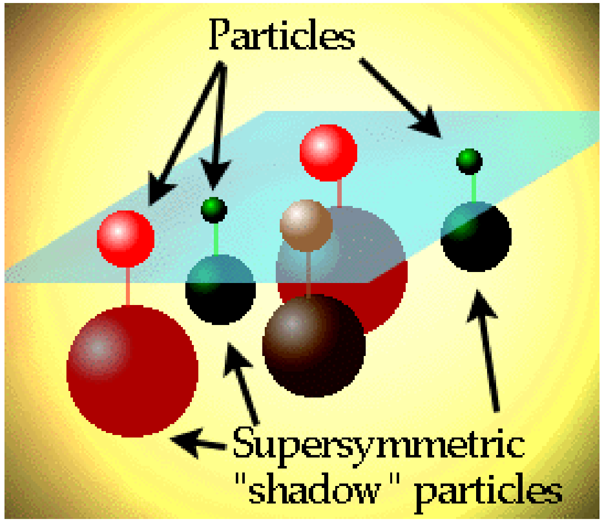
The existence of exotic dark matter is supported more than before by recent observations like bullet clusters.

From NASA website

WIMP(Weakly Interacting Massive Particle)?

One of strong candidates of the dark matter

Introduced naturally from the supersymmetry theory



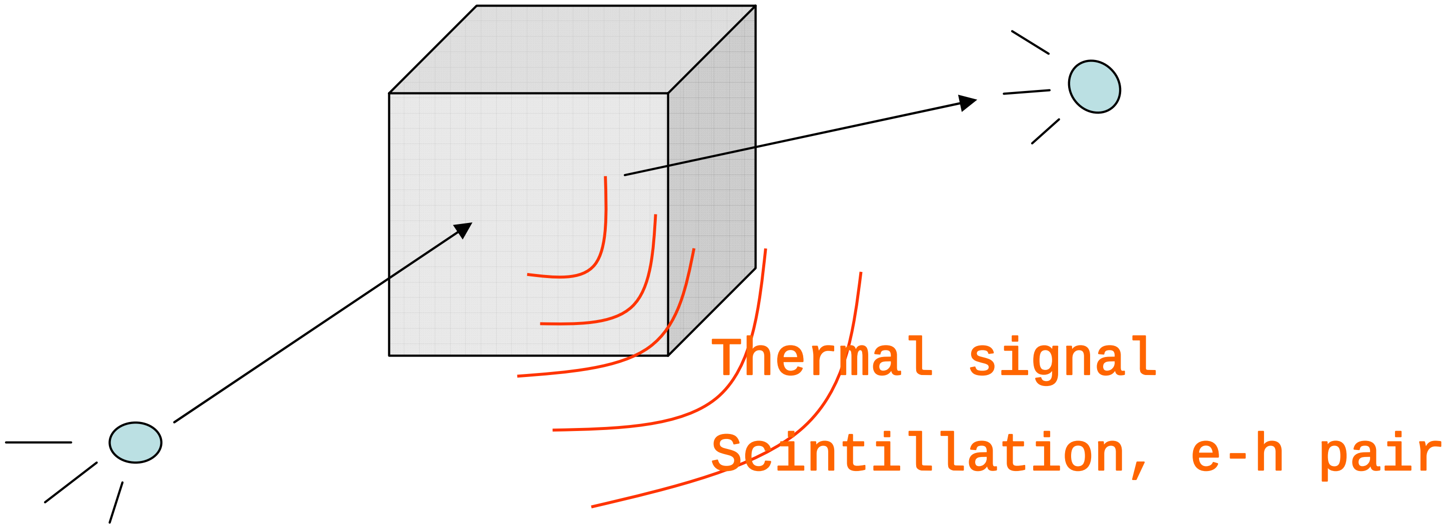
By R parity conservation, lightest supersymmetric particle(LSP) can be the stable weakly interacting massive particle.

With non-relativistic (i.e,cold or Massive) & Weakly interacting particle,
Relic dark matter density for large scale structure of the universe can be explained .

How to sense WIMP?

WIMP recoils nucleus.

It is expected to deposit around a few tens keV.



Since it interacts rarely,

Background event from radioisotope impurity or cosmic shower must be reduced seriously.

⇒Selection of Radioisotope free material

⇒Location at Underground laboratory

KIMS(Korea Invisible Mass Search)

KIMS is the research project to search WIMP using CsI(Tl) crystal scintillator.

CsI crystal?

High light yield:~60000/MeV

Slight hygroscopicity

Pulse Shape Discrimination

Easy to get large mass with an affordable cost

Decay constant:~1050ns

KIMS’ main detector: CsI(Tl) scintillator

CsI crystal?

Sensitive to both SD and SI WIMP interactions

Isotope	J	Abun	<Sp>	<Sn>
^{133}Cs	7/2	100%	-0.370	0.003
^{127}I	5/2	100%	0.309	0.075
^{73}Ge	9/2	7.8%	0.03	0.38
^{129}Xe	1/2	26%	0.028	0.359
^{131}Xe	3/2	21%	-0.009	-0.227
^{19}F	1/2	100%	0.441	-0.109

Internal radioisotope background

-> Cs^{137}, Cs^{134}, Rb^{87}…

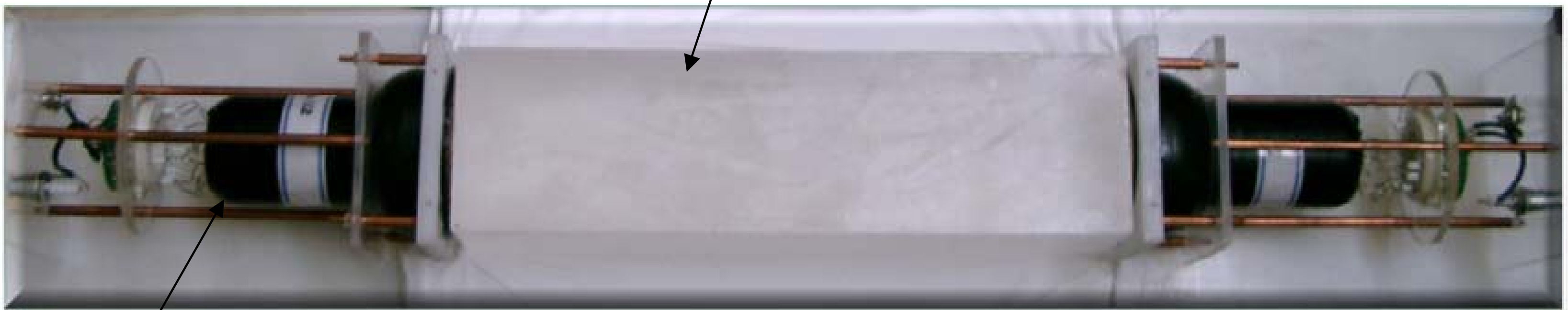
-> Now, we can obtain ~2cpd CsI powder using “ultra” pure water in processing the powder.

-> Still, there’s a room for improvement to <1cpd through recrystallization method

CsI(Tl) crystal detectors

One detector module : one CsI Crystal + 2 PMTs

Crystal size: 8x8x30 cm3 (8.7 kg)
(Beijing Hamamatsu Photon Techniques Inc.)



PMT : 3” PMT (9269QA, Electron tube Inc),

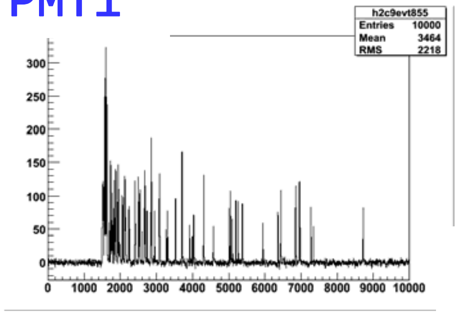
Quartz window,

RbCs photo cathode (Green enhanced)

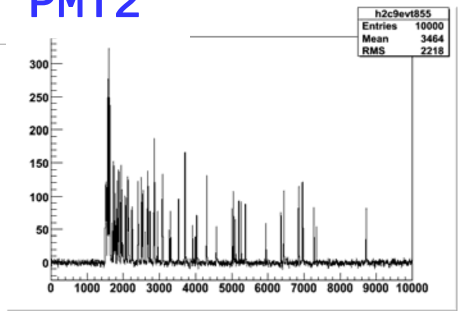
~5 photon/keV

CsI(Tl) crystal detectors

PMT1



PMT2

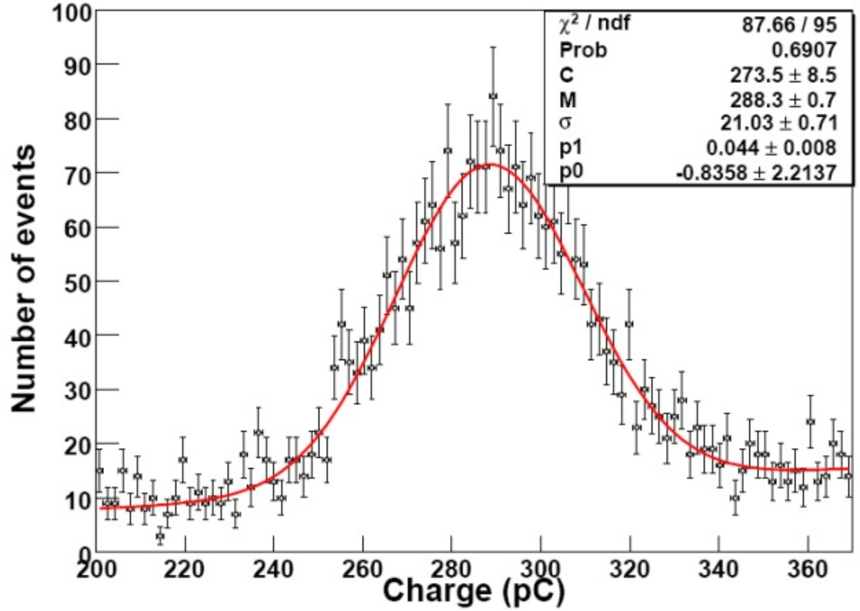


Trigger condition:

In 2us, 2 more photons in each PMT + high energy event

Event window is 32μs.

(Now, 40μs)



calibration for Am^{241}

Resolution @ 59.5 keV : 7.3%

8ms dead time is applied after high energy event.

->Efficiency > 99.6%

Digitized with 500MHz FADC
(Now, 400MHz FADC)

Experimental site: Yangyang underground lab

(Upper Dam)

Located in Yangyang Pumped Storage Power Plant
(Korea Middleland Power Co.)

Minimum depth from the ground : 700m

Water equivalent depth : 2000m

Access tunnel:~ 2km, accessible by car

Ground Lab

(Power Plant)

(Lower Dam)

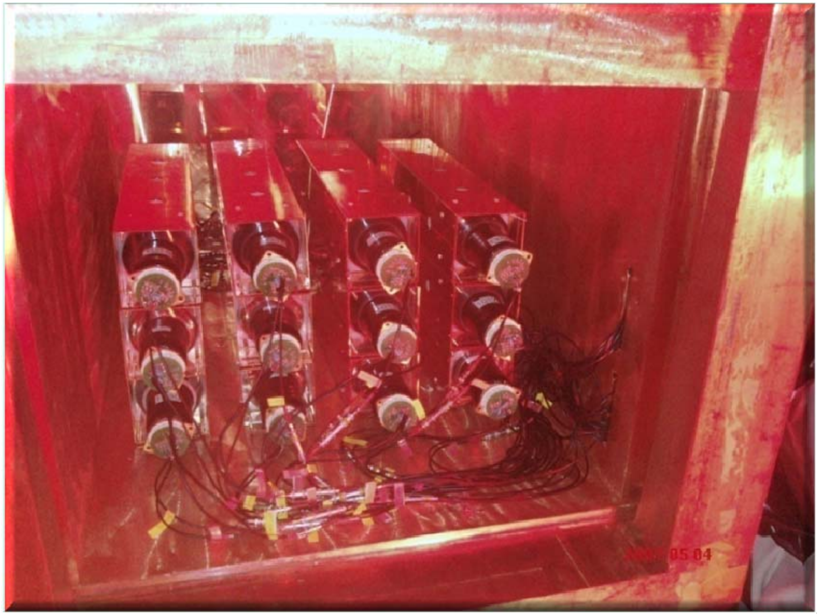
양양양수발전소 Underground Lab

KIMS Detector system

CsI(Tl) crystal scintillators

Muon coincidence checked

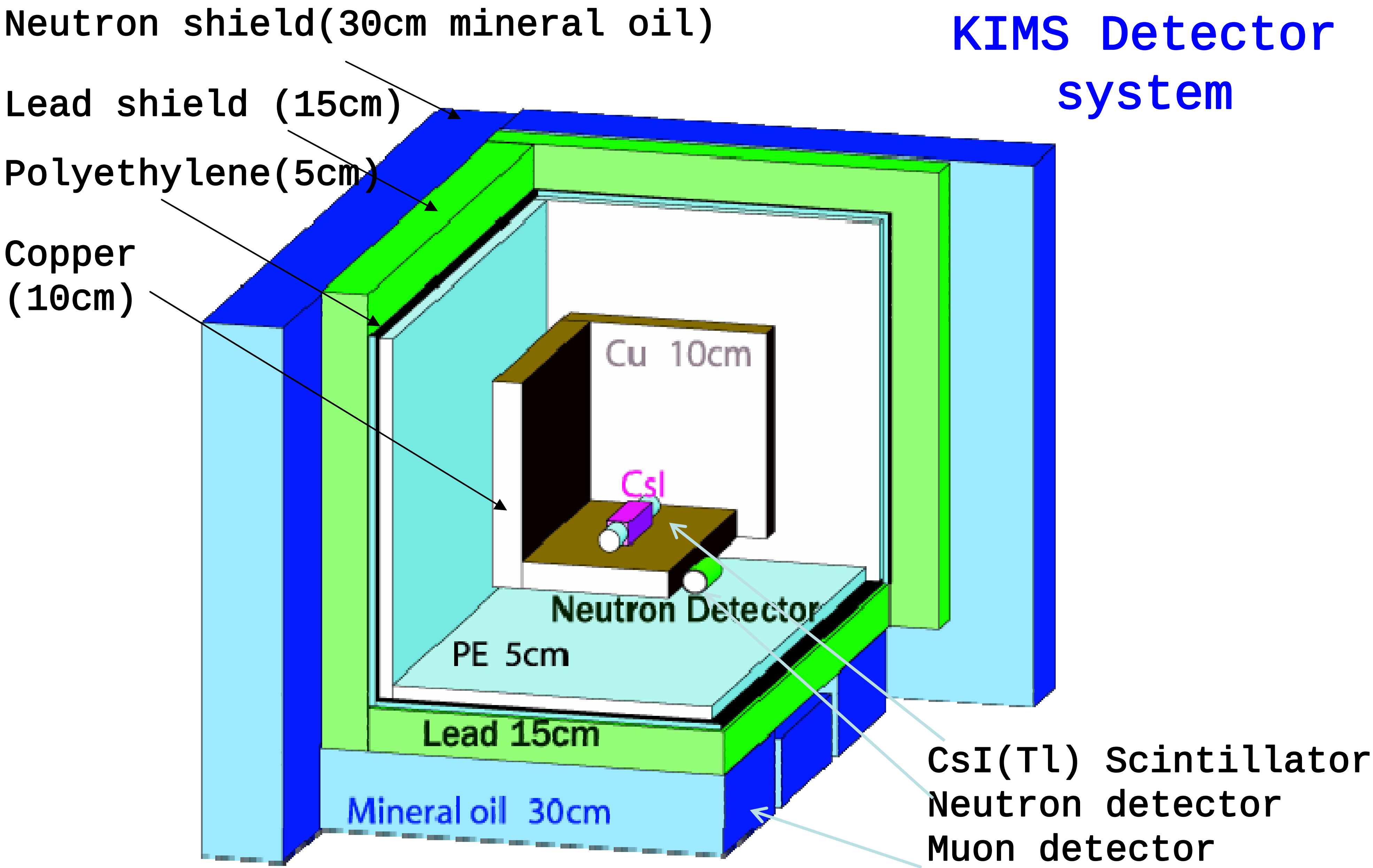
Neutron flux monitored



Inside of the Full Detector System

Outside of the Full Detector System

KIMS Detector system



N_2 gas flow inside the Cu shield

Two issues in this talk

Latest WIMP search analysis results
->PRL 99,091301(2007)

Background event study other than WIMP

Latest WIMP search analysis results

Total exposure used for the analysis

=> 4 detectors used.

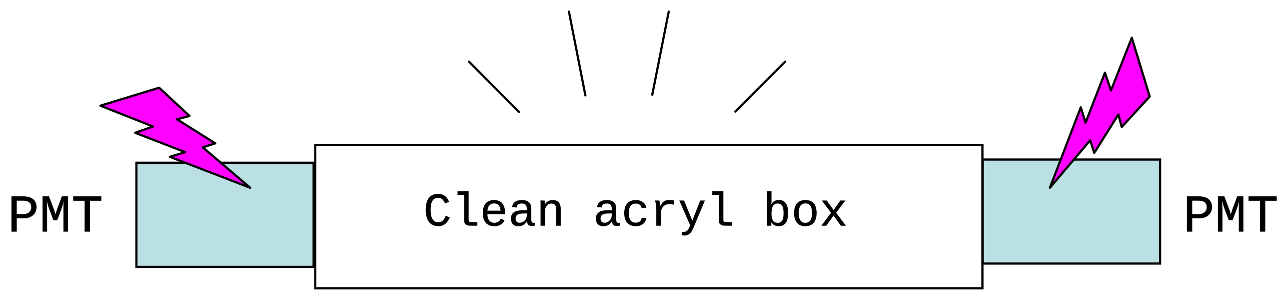
Crystal	p.e./keV	Mass (kg)	Data (kg·days)
S0501A	4.6	8.7	1147
S0501B	4.5	8.7	1030
B0510A	5.9	8.7	616
B0510B	5.9	8.7	616
Total		34.8	3409

Latest WIMP search analysis results

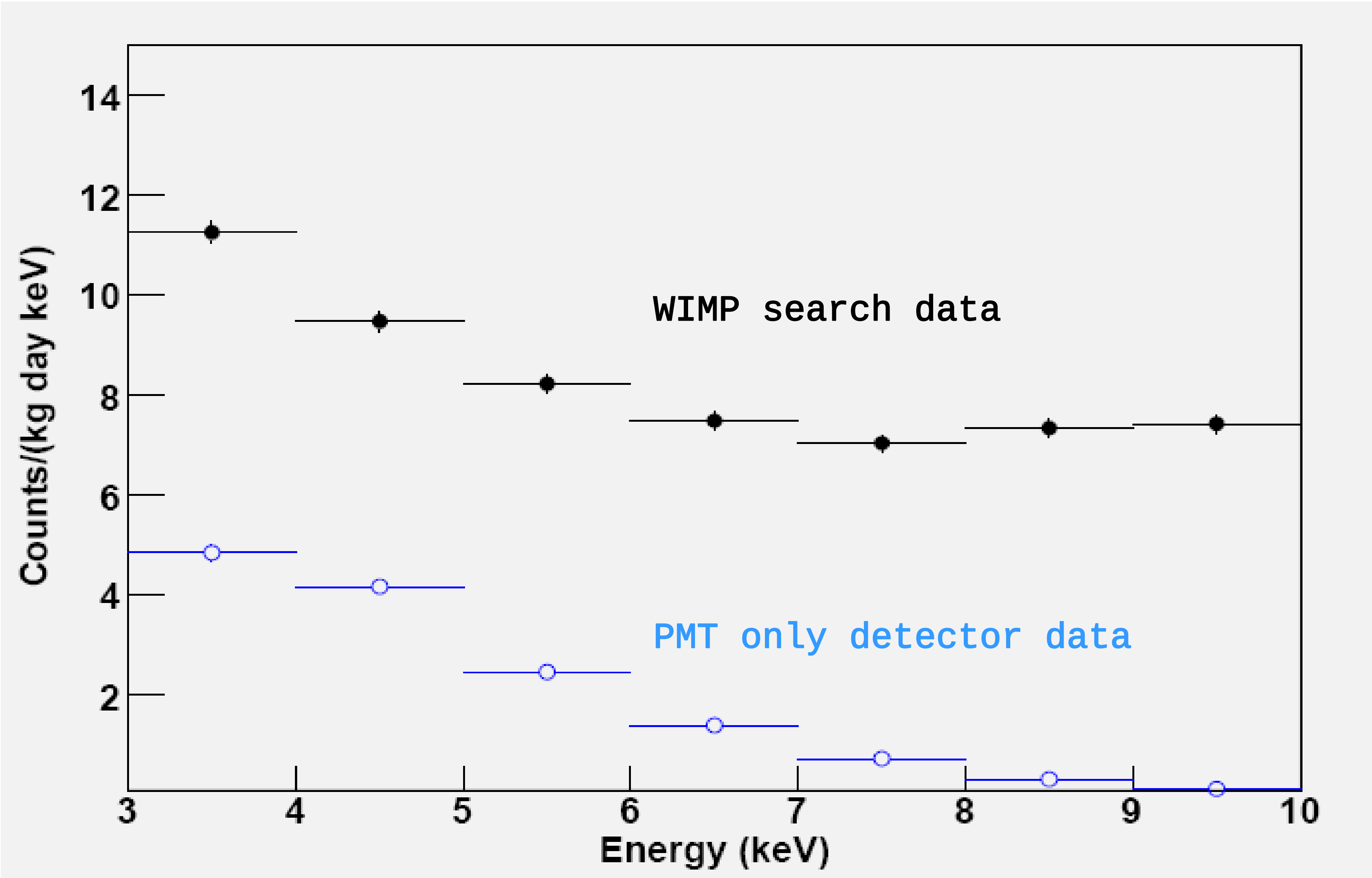
PMT only detector data

PMT noise(dark current) significantly limits the sensitivity at the energy range of interest for WIMP search.

~350 kg days of PMT only detector data taken for each crystal with the PMTs used for each crystal to understand the PMT noise event
=> Determine event selection criteria



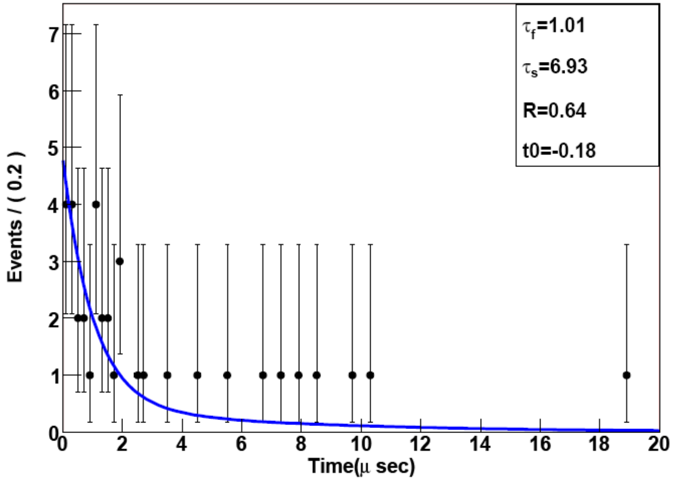
PMT only detector event rate



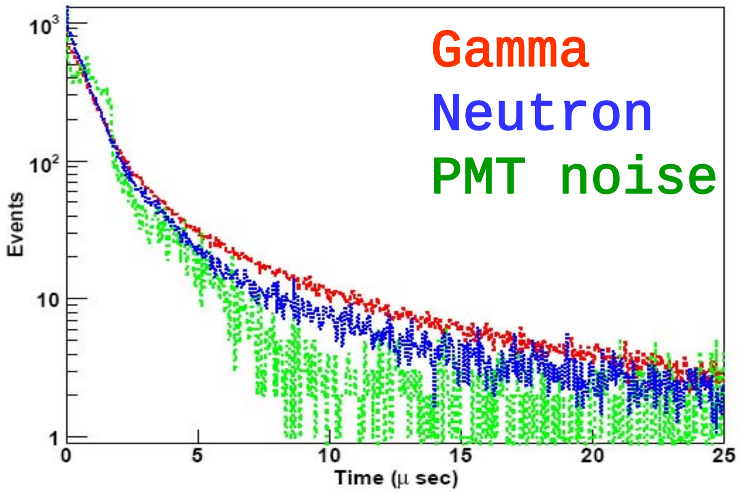
Event selection

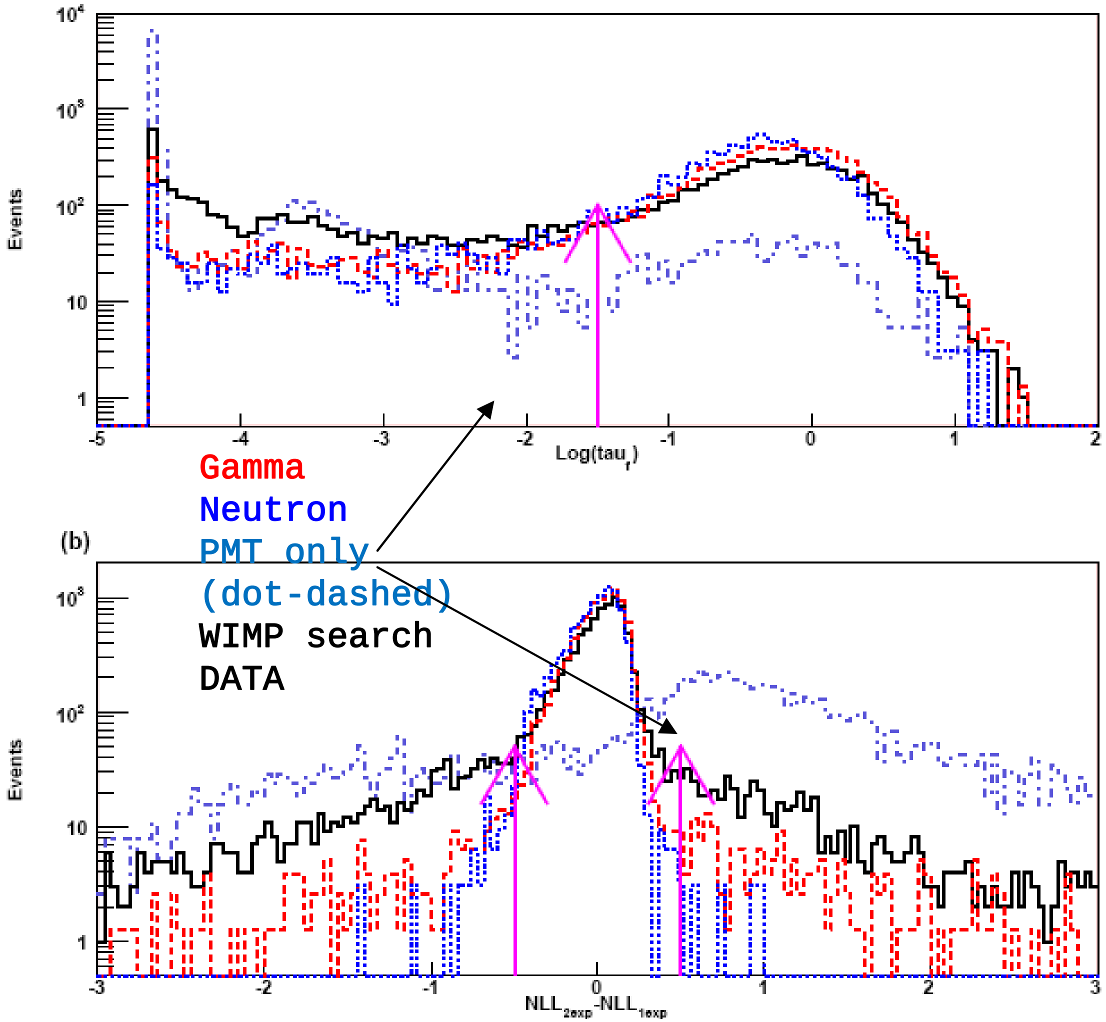
Likelihood fit with

$F(t) = 1/\tau_f \exp(-(t-t_0)/\tau_f) + r/\tau_s \exp(-(t-t_0)/\tau_s)$



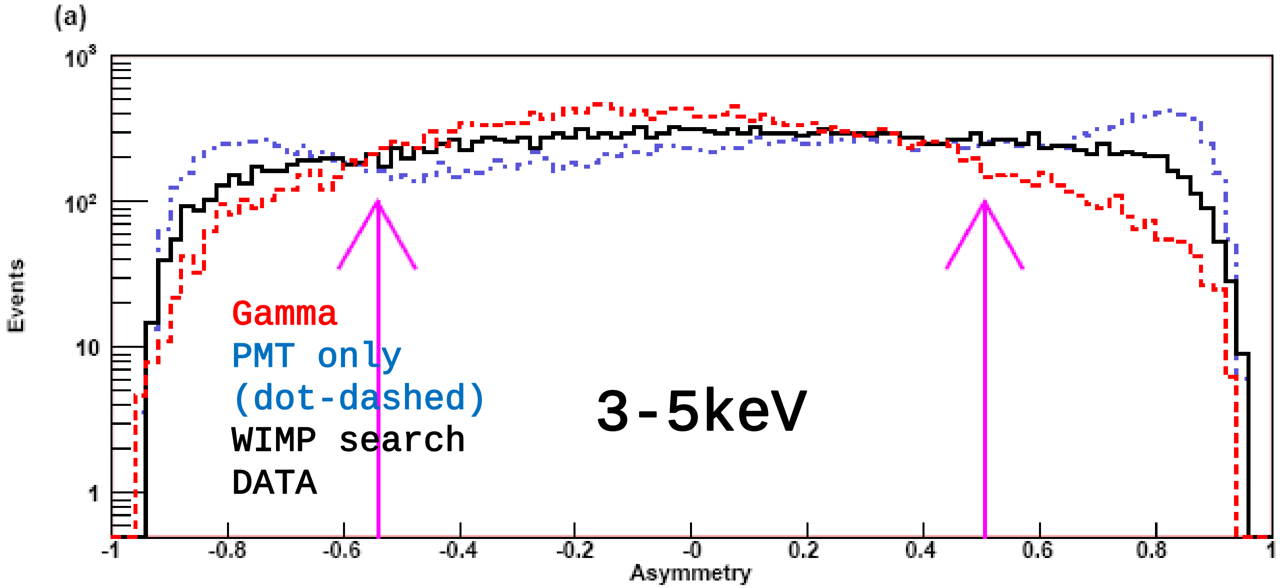
Fit result of time distribution of one event



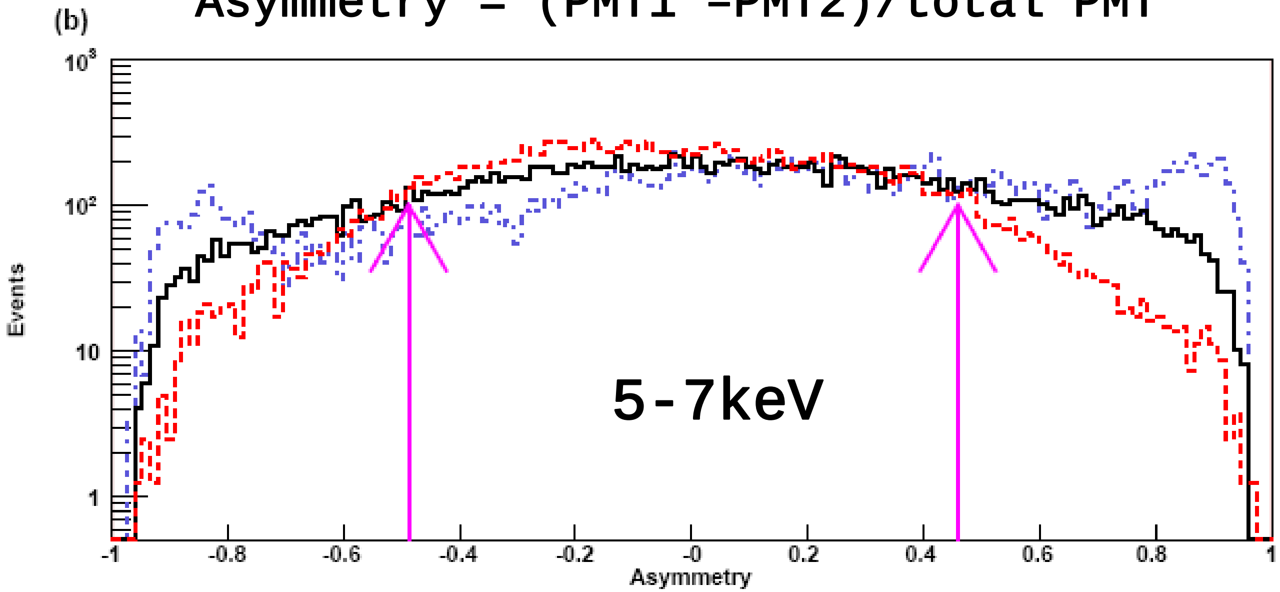


Cut developed from time distribution fit

Event selection

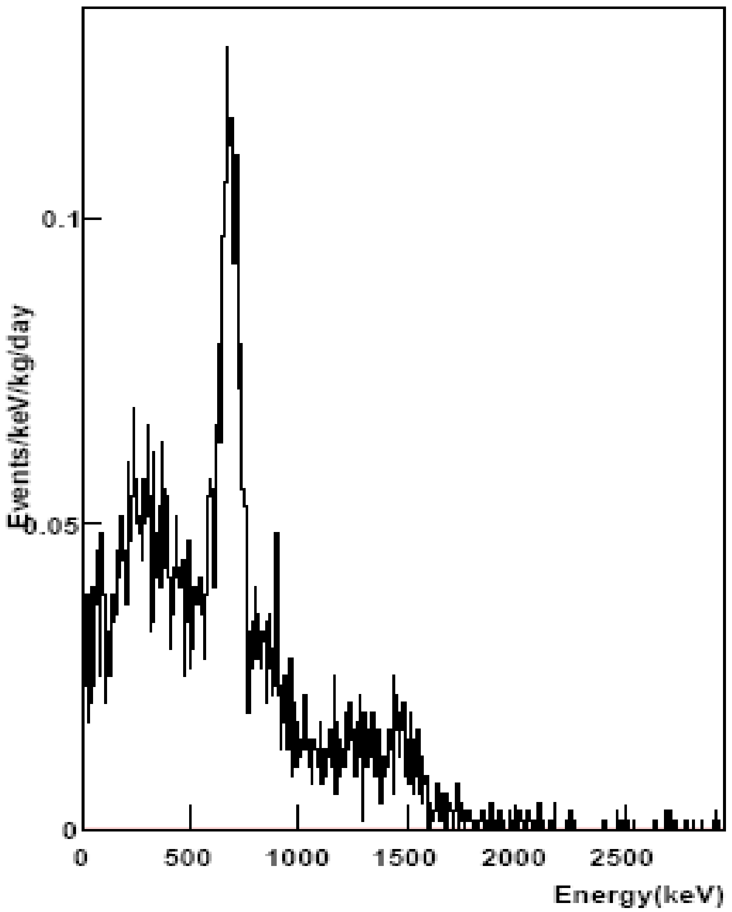


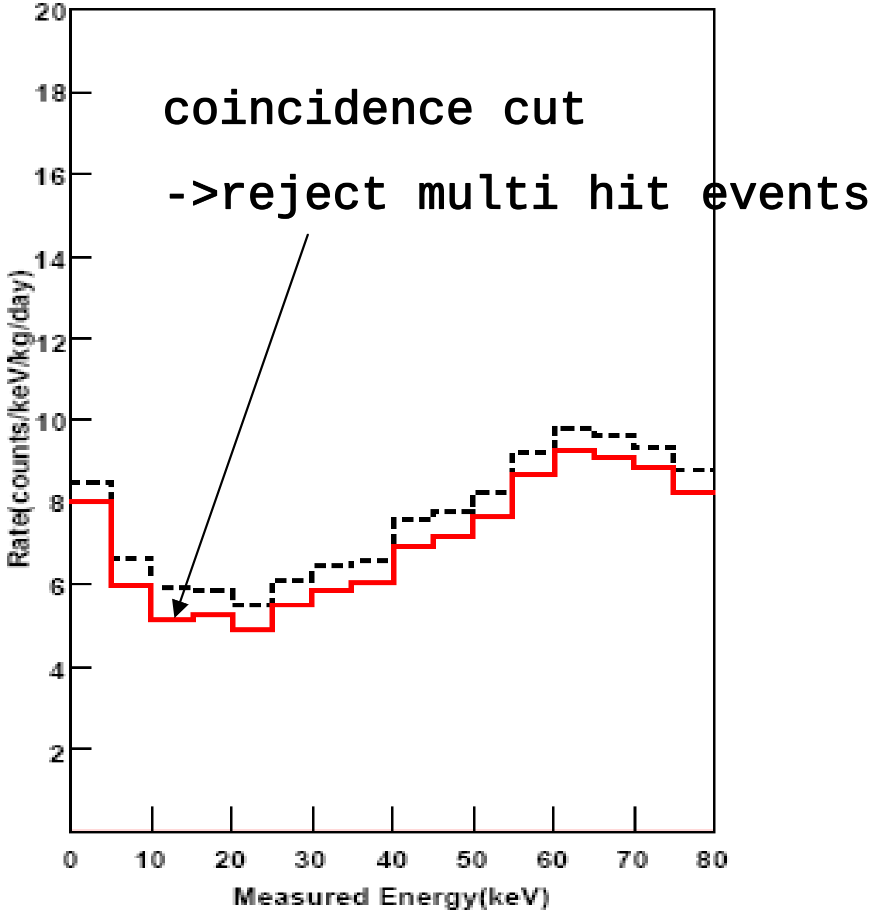
Asymmetry = (PMT1 –PMT2)/total PMT



Asymmetry cut along two PMTs(85% of calibration)

Event selection

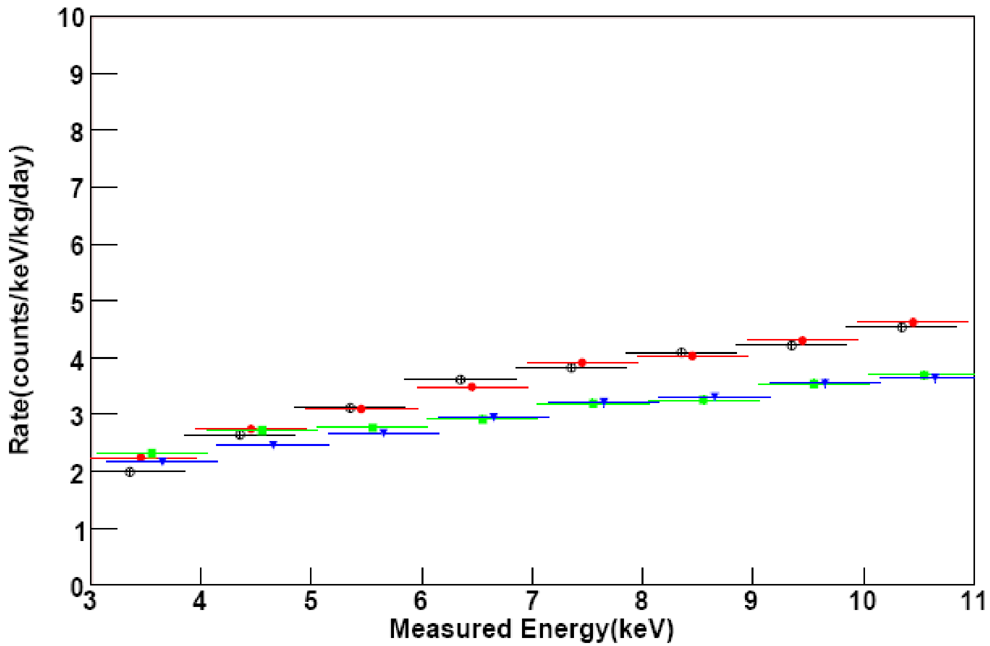




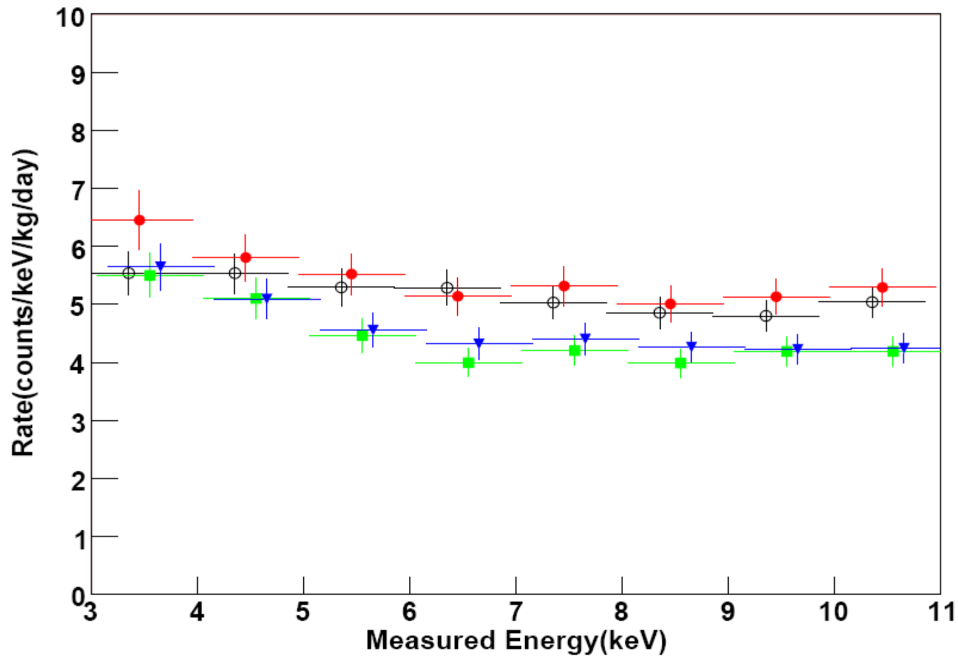
spectrum of the sum of energy of
all the crystals

Latest WIMP search analysis results

Event rate of 4 detectors



WIMP search Data after cut



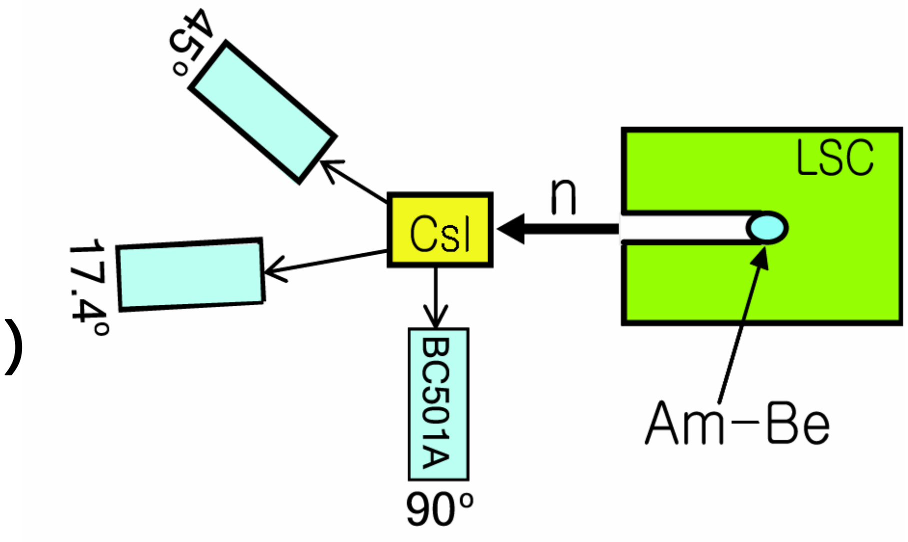
WIMP search Data

after cut efficiency correction

Neutron calibration for Pulse shape discrimination

300 mCi Am/Be source

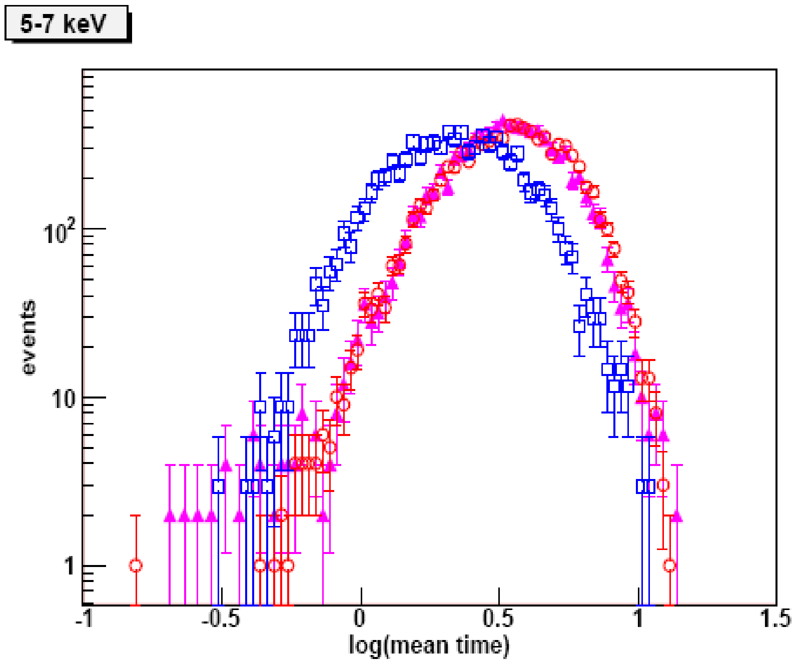
a few 100 neutrons/sec hit
3cm × 3cm × 3cm crystal(sample)

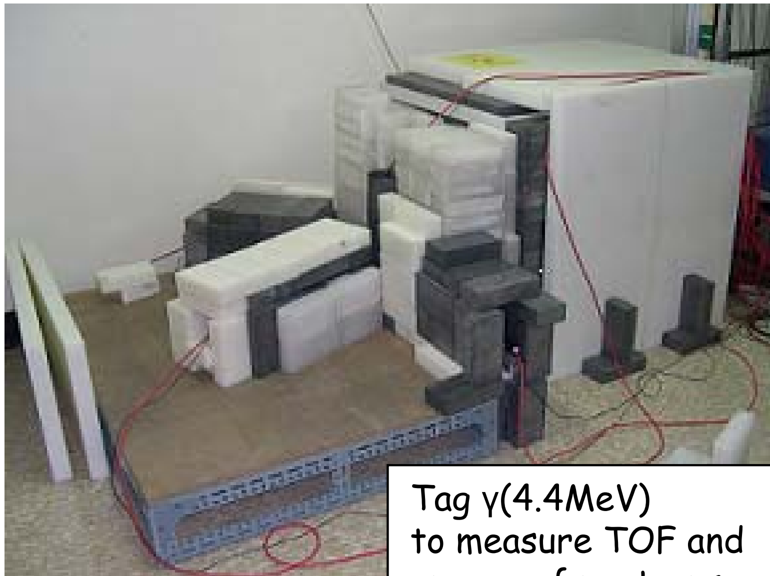


Neutron sample

Gamma Full size

Gamma sample



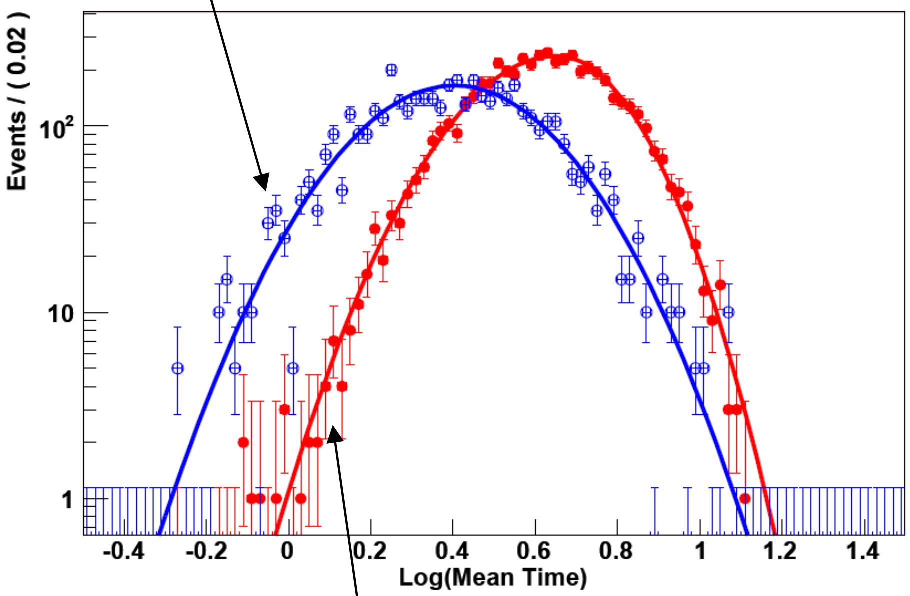


Tag γ(4.4MeV) to measure TOF and energy of neutrons

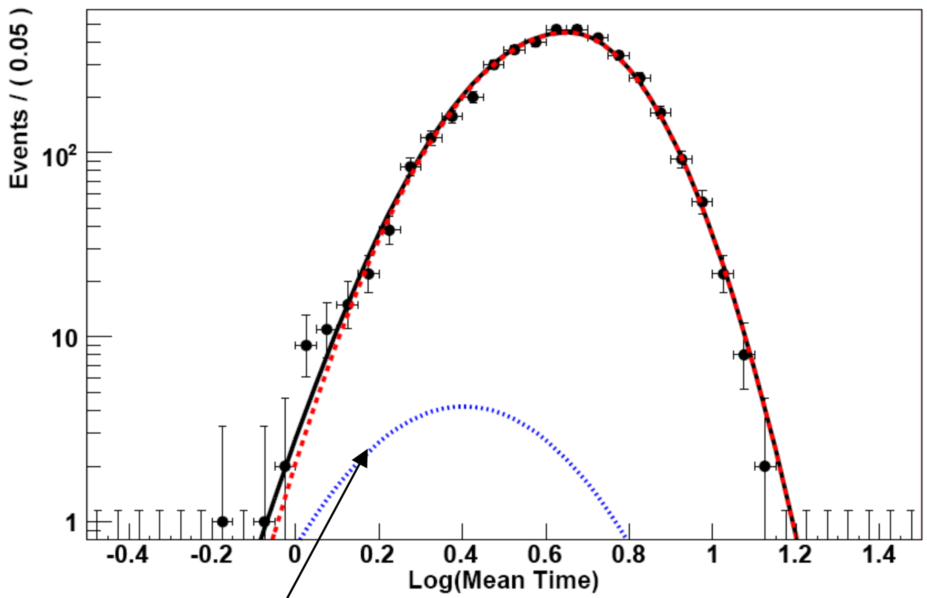
Latest WIMP search analysis results

Extraction of Nuclear Recoil event

Neutron calibration



gamma calibration



Fit the WIMP search data with PDF function from gamma and neutron calibration data

→ extract NR events rate

Uncertainty in nuclear recoil event rate estimation

Statistical error depends on event numbers.

Factors for systematic error

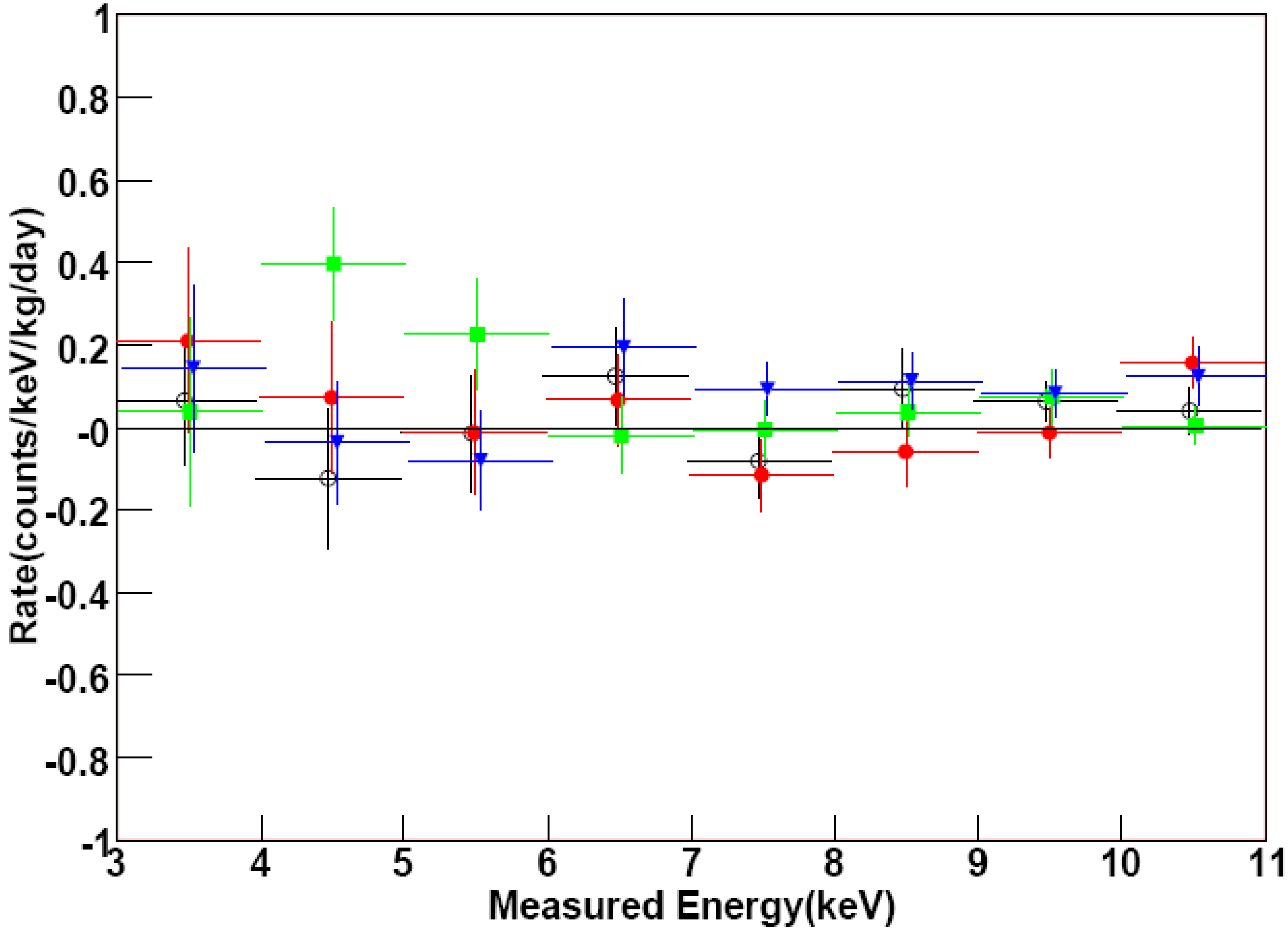
-> uncertainty in mean time calibration of nuclear recoil and gamma recoil

-> variation according to different crystal & different temperature condition

Energy	NR	Statistical	Fit Systematic			
			total	γ	neutron	different crystal
3-4 keV	26.6	64.2	16.3	15.7	2.6	3.9
4-5 keV	-62.0	85.6	33.0	26.5	1.6	19.5
5-6 keV	-8.7	83.2	15.9	14.6	4.7	4.2
6-7 keV	79.3	73.8	15.5	14.0	5.7	3.7
7-8 keV	-55.4	59.8	11.5	4.5	0.9	10.6
8-9 keV	64.5	63.6	9.0	3.6	8.2	0.4
9-10 keV	45.3	32.6	4.9	4.5	0.6	1.7
10-11 keV	30.3	40.5	8.3	6.5	4.4	2.9

Estimated Nuclear Recoil(NR) event with errors for S0501A crystal

Latest WIMP search analysis results



Estimated nuclear recoil rates

Latest WIMP search analysis results

WIMP Nucleus Cross section

Assuming

WIMP forms a spherical halo around our galaxy.

WIMP has a Maxwellian velocity distribution.

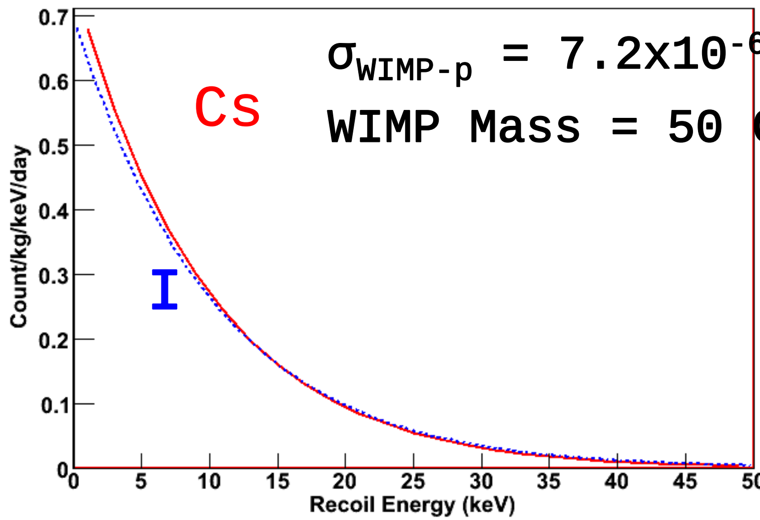
-> Interaction rate of WIMP with the target nucleus
(according to WIMP mass & Cross-section)

WIMP density
ρ_D=0.3 GeV/c²/cm³

Earth's velocity
v_0=220km/s

Local galactic escape velocity
v_{esc}=650km/s

Interaction type: SI,SD

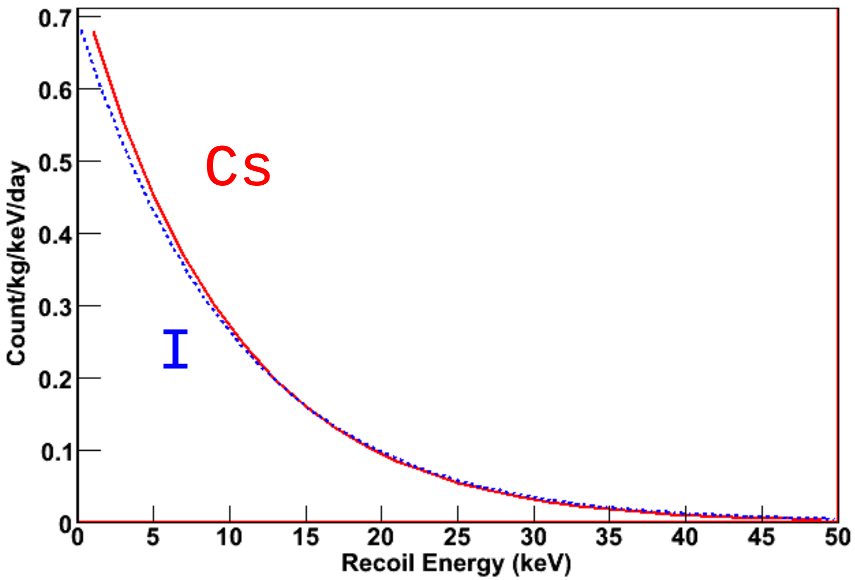


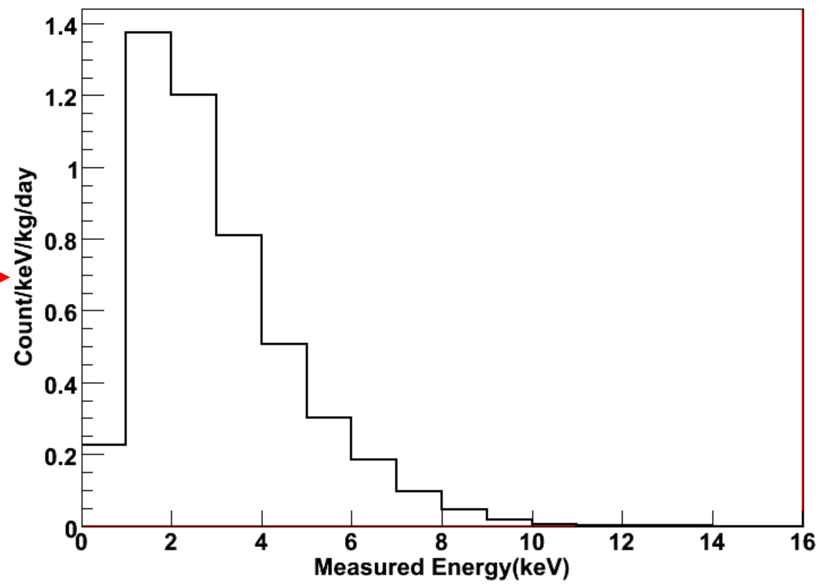
σ_{WIMP-p} = 7.2x10^{-6}pb
WIMP Mass = 50 GeV

Latest WIMP search analysis results

Simulation of expected energy spectrum

Fix σ_{WIMP-p} = 7.2x10^{-6}pb, WIMP Mass = 50 GeV

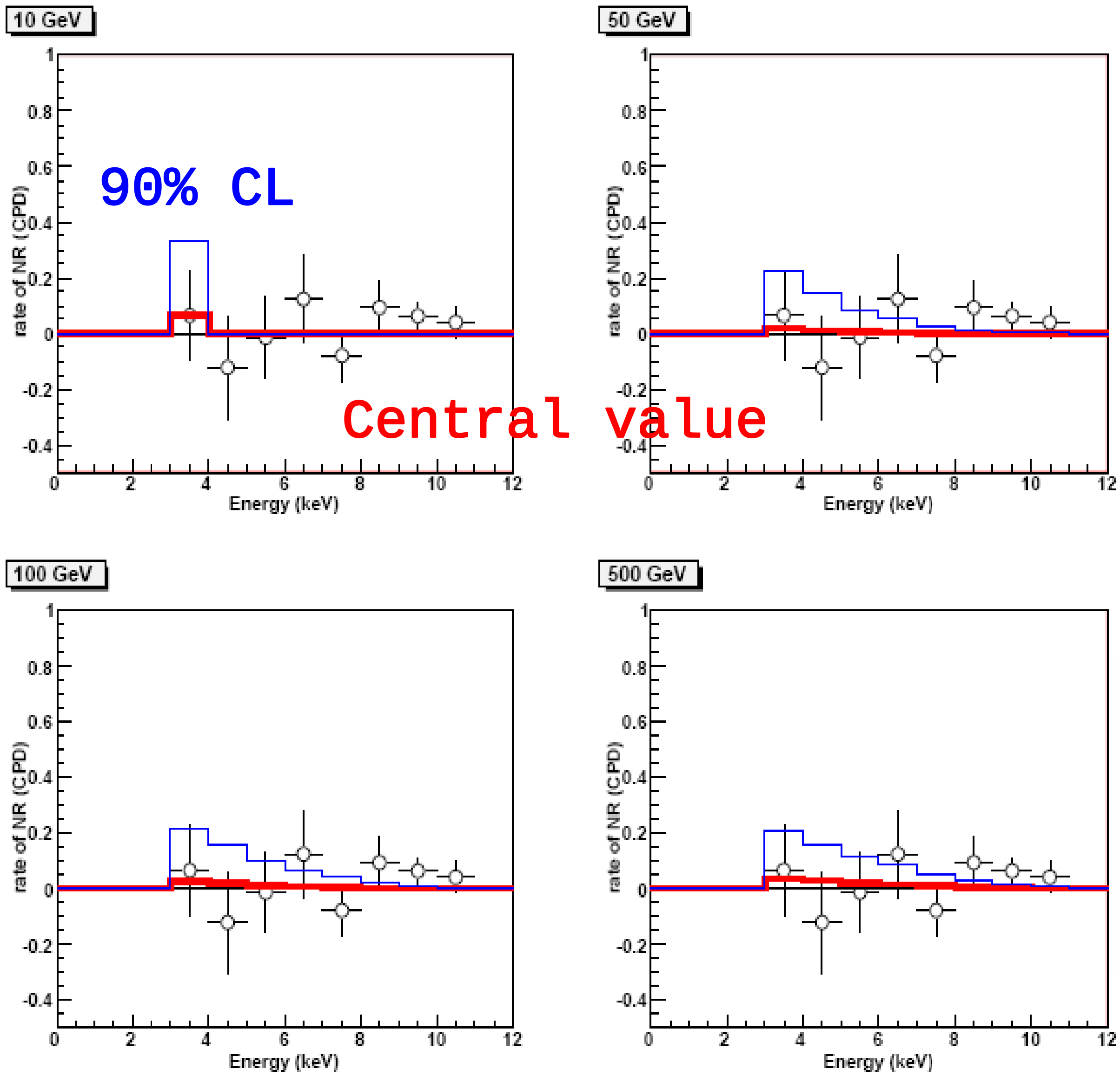




GEANT4 Simulation considering Quenching factor, Energy resolution, form factor, detector character

Latest WIMP search analysis results

Limit on WIMP nucleus cross section



Fitting the data with the simulation,

$\Rightarrow$ Find the best fit value σ_{WA} according to WIMP mass

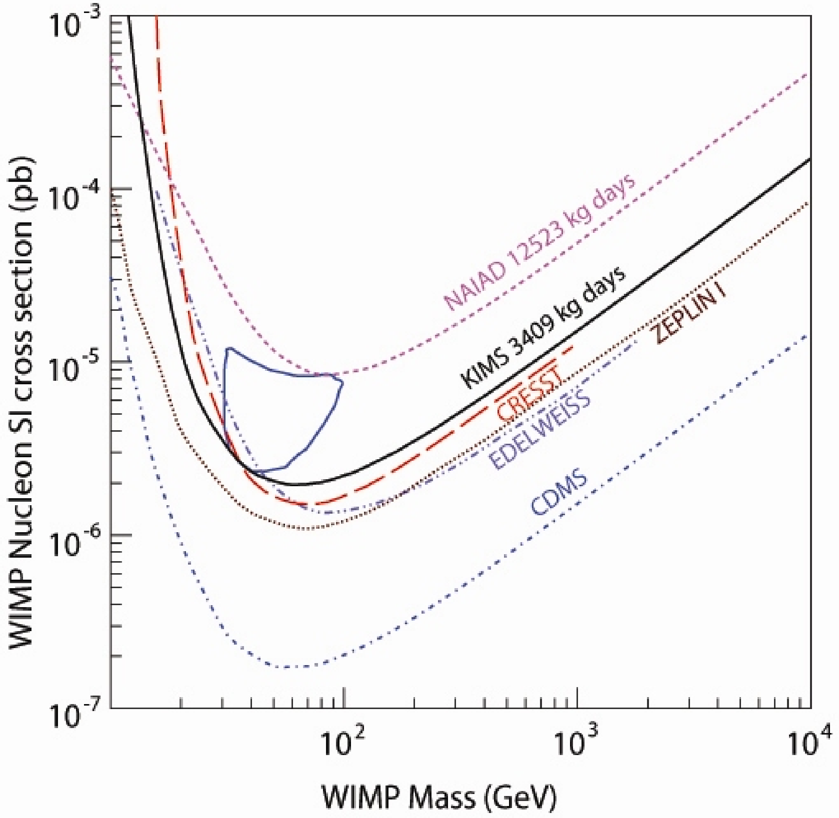
$$\sigma^{SI}_{W-n} = \sigma_{W-A} \frac{\mu_n^2}{\mu_A^2} \frac{1}{A^2},$$

$$\sigma^{SD}_{W-n,p} = \sigma_{W-A} \frac{\mu_{n,p}^2}{\mu_A^2} \frac{3}{4} \frac{J}{(J+1)} \frac{1}{\langle S_{n,p} \rangle^2}$$

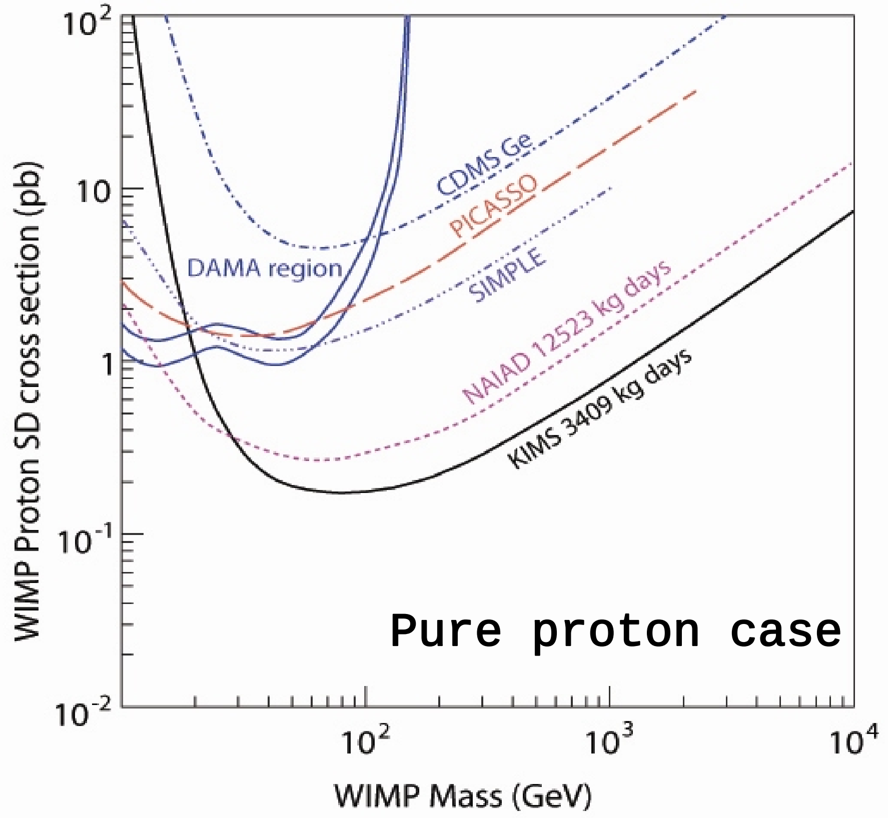
:WIMP Nucleon cross section

Latest WIMP search analysis results

Spin independent limits



Spin dependent limits



PRL 99, 091301 (2007)

Background event study which mimics WIMP

Neutron signal is similar to WIMP signal.

Neutron background at a deep underground

->spontaneous fission of ^{238}U

->(α,n) reactions

->cosmic ray muons

Neutron from natural radioactivity can be blocked by proper passive shield sufficiently.

Background event study which mimics WIMP

High Energy muon can produce the neutron inside the shield structure of the detector.

High Energy muon event has long tail, so this tail event can be detected as the low energy signal.

To understand these contribution,

Neutron Monitoring Detectors (NMD) are installed besides CsI main detectors and outside of the detector shield.

Outmost layer of the Shield is designed as the Muon detector(MD) for muon veto.

Neutron Flux monitoring

Neutron Monitoring Detector

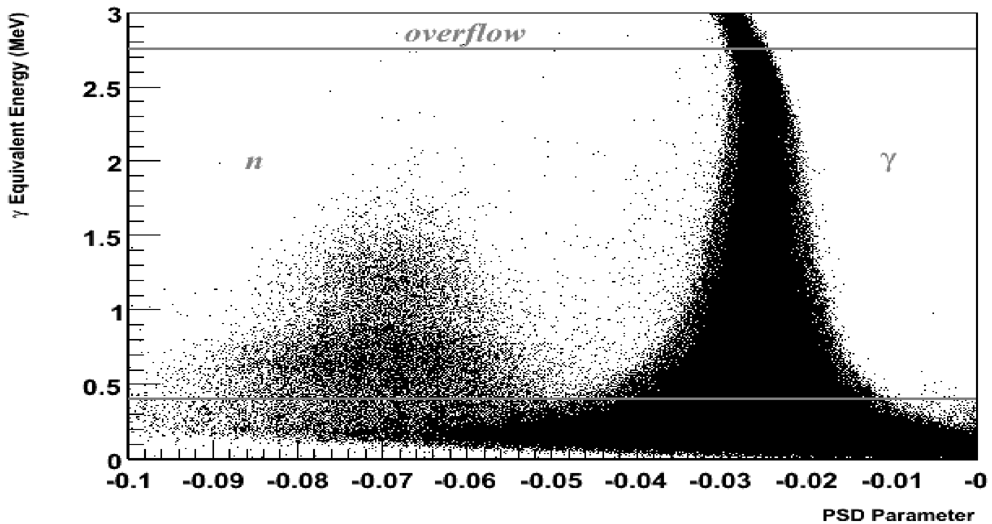
Neutron Monitoring Detector(NMD)

->BC501A Scintillator

->Good n/gamma separation capability

Neutron flux outside the detector shield

->$8 \times 10^{-7}/cm^2/s$(1.5MeV<E<6MeV)



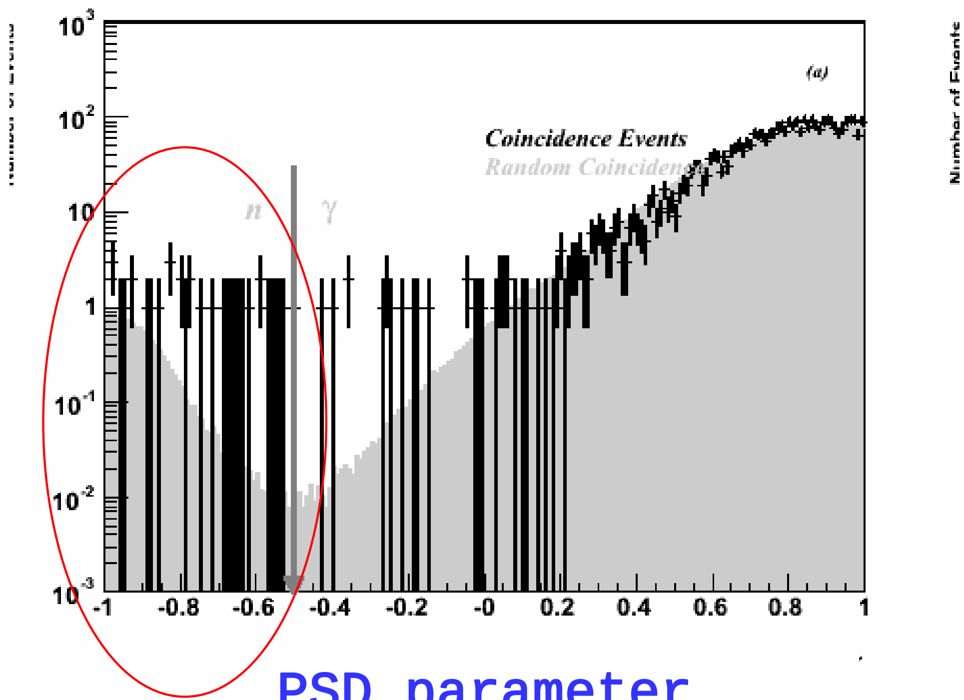
PSD parameter

Neutron Flux monitoring

From the coincidence between muon detector and NMD inside the detector shield, we can measure the muon induced neutron rate inside the shield.

-> $(3.8 \pm 0.7)\times10^{-2}$ counts/day/ℓ measured in 0.4MeV<E<2.75MeV

-> $(2.0\pm0.2)\times10^{-2}$ counts/day/ℓ by GEANT4 MC



PSD parameter

Muon coincidence signal

Muon Detector (MD)

The outermost shielding layer acts as a MD.

MD is filled with 95 % mineral oil as moderator and 5 % homemade liquid scintillator (Pseudocumene +PPO+POPOP).

56 PMTs to cover 4 π

Measured Muon flux
->2.7×10^{-7} /cm^2/s

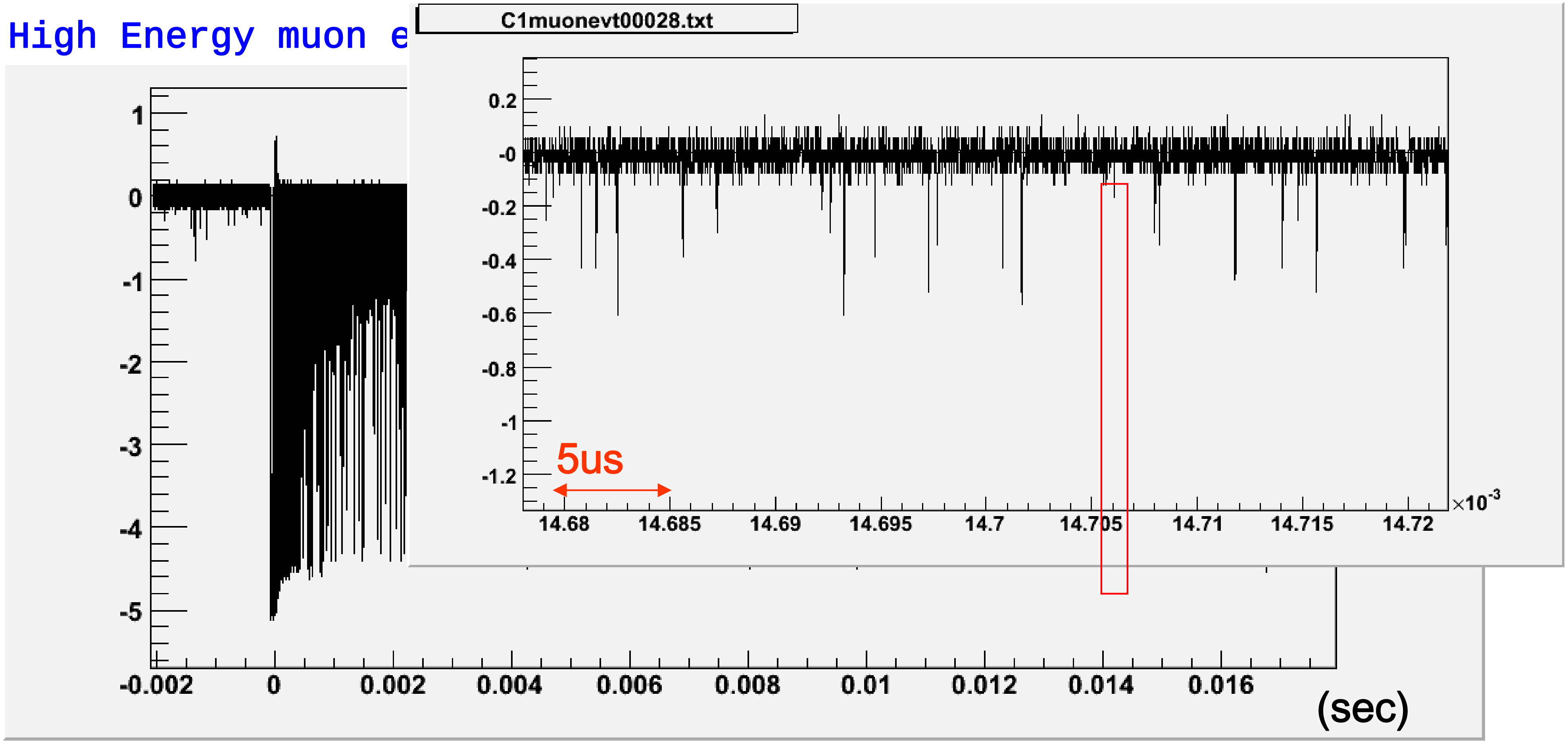
Muon Coincidence signal

Muon coincidence event rate: ~6evt/hr for 12 detectors

Muon coincidence event is very high energy event and triggers multicrystals.

It requires a few tens ms for scintillation to disappear.

High Energy muon e

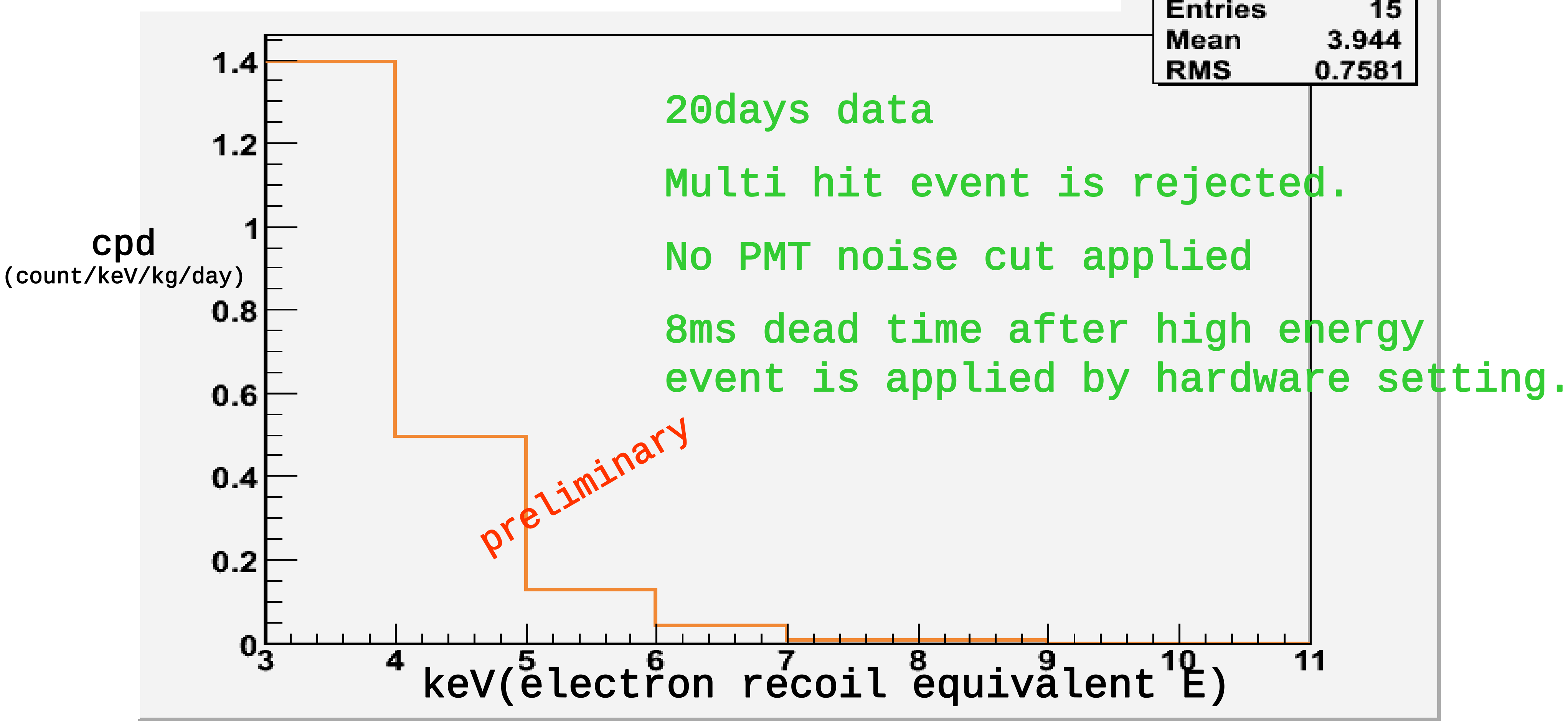


Muon Coincidence signal

Event rate of muon tail event

-> muon tail event is defined as the event which shows up in 30ms from the start of Muon coincidence event.

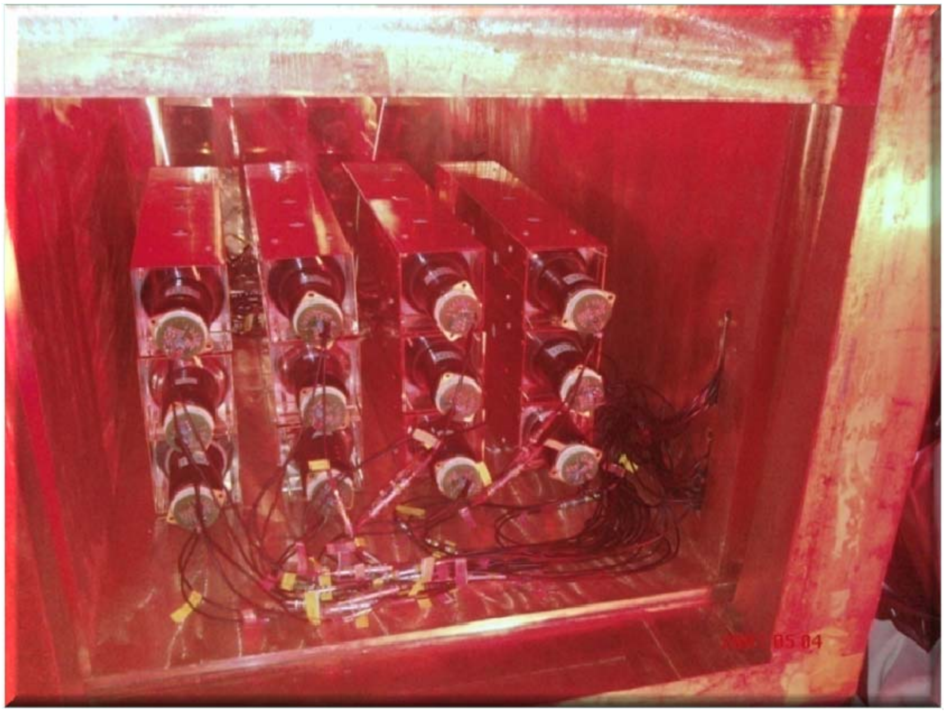
Event rate of muon tail event of det0

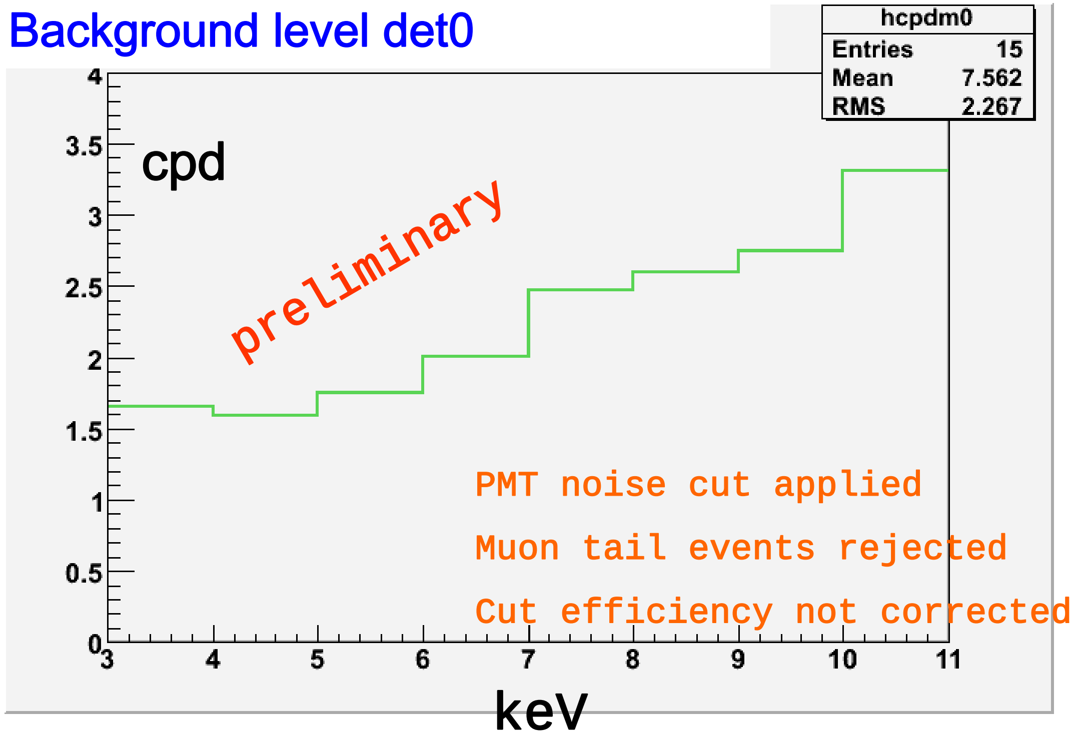


Current status

12 crystals(104.4kg) installed.

Optimization was finished
& Now, running in good condition!!





Short remarks on Annual Modulation Study in KIMS

Have been taking data with 100 kg array for ~7 months

AM study without applying PSD can be done

<u>With 100kg CsI(Tl), ~3 cpd background level</u>

if no AM:

one-year-run -> upper limit on AM amplitude

< 0.01 cpd/keV/kg level with 90% CL

if AM amplitude ~ 0.02 cpd (as observed by DAMA):

two years data is required to confirm

with more than 3σ significance

We'll also analyze AM of muon tail events.