KIMS : Dark Matter Search Experiment in Korea

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For the KIMS Collaboration

DSU2006, Madrid

KIMS

Korea Invisible Mass Search

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WIMP

SUSY model with R-parity conservation

Neutralino : stable LSP

weak interactions scale annihilation cross section

proper relic density for dark matter

$\Rightarrow$ Excellent CDM candidate

Neutralino:super-partner of neutral gauge and Higgs bosons

$$\tilde{\chi}_1^0 = N_{11}\tilde{B} + N_{12}\tilde{W} + N_{13}\tilde{H}_1^0 + N_{14}\tilde{H}_2^0$$

Direct WIMP Search

Signature : WIMP-nucleus elastic scattering

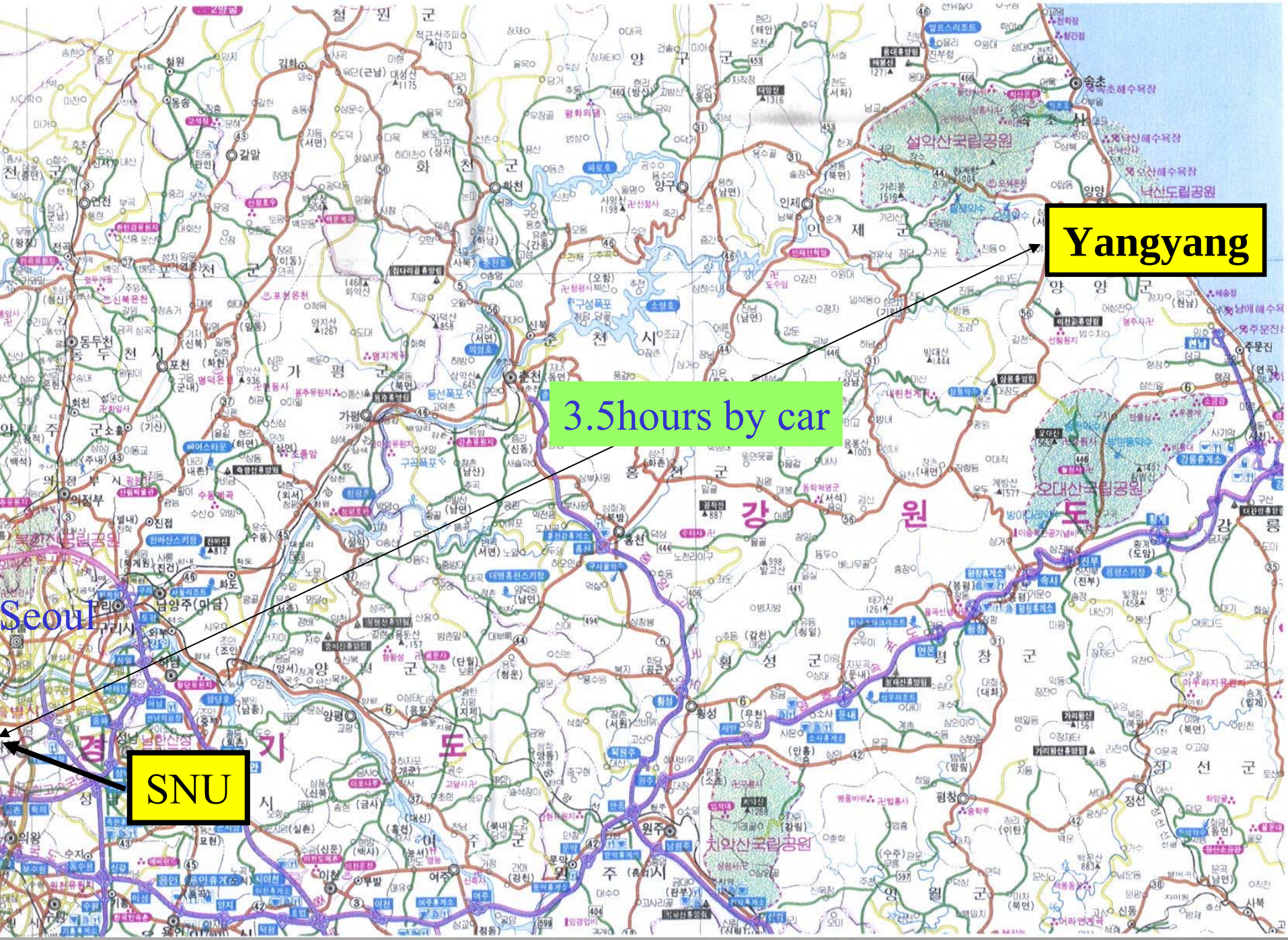
→ Signal by recoiled nucleus

$$L = f_q(\bar{\chi}\chi)\cdot(\bar{q}q) + d_q(\bar{\chi}\gamma^{\mu}\gamma^{5}\chi)\cdot(\bar{q}\gamma_{\mu}\gamma^{5}q) + \ldots.$$

scalar interaction *spin-dep. interaction*

$$\sigma_{scalar} = \frac{4}{\pi} m_r^{\,2}\left[Zf_p + (A-Z)f_n\right]^2 \qquad \sigma_{spin} = \frac{32}{\pi} G_F^{\,2} m_r^{\,2} \Lambda^2 J(J+1)$$

$$\propto A^2 \qquad \Lambda \equiv \frac{1}{J}(a_p < S_p > + a_n < S_n >)$$


Yangyang
3.5hours by car
Seoul
SNU

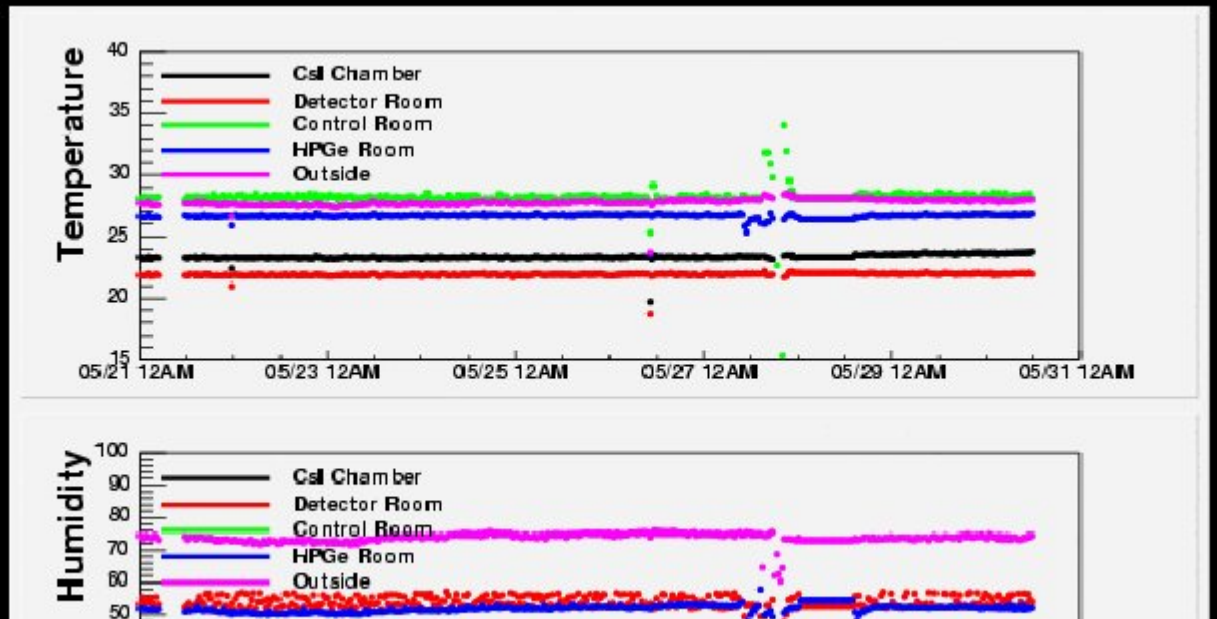
Yangyang Underground Laboratory

Korea Middleland Power Co.

Yangyang Pumped Storage Power Plant

Min

Access to the lab by car (~2km)



DAQ

Research Topics

Publication / Presentation

Notes /Memo / Info

Meetings

Seminars

Shift Schedule

Internal Memo

CsI(Tl) Crystal

Advantage

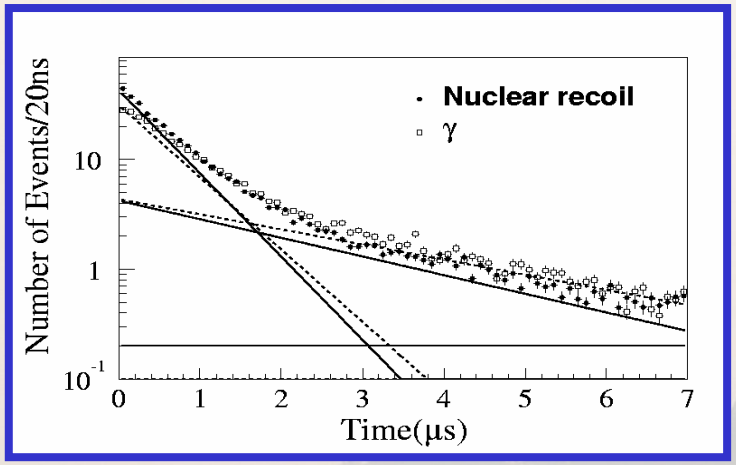
- High light yield ~60,000/MeV
- Pulse shape discrimination
- ➔ Moderate background rejection
- Easy fabrication and handling
- Easy to get large mass with an affordable cost
- ➔ Good for AM study

Disadvantages

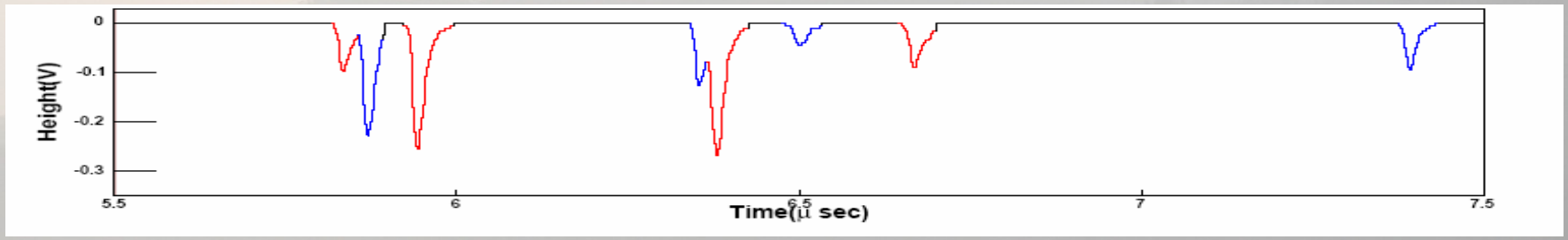
- Emission spectra does not match with normal bi-alkali PMT
  => Effectively reduce light yield
- $^{137}Cs(\tau_{1/2}\sim30y)$,$^{134}Cs(\tau_{1/2}\sim2y)$ may be problematic

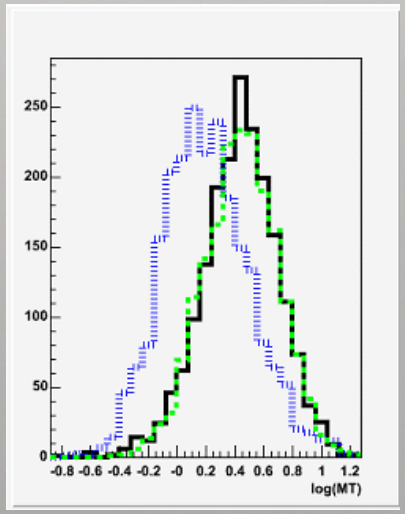
	CsI(Tl)	NaI(Tl)
Photons/MeV	~60,000	~40,000
Density(g/cm3)	4.53	3.67
Decay Time(ns)	~1050	~230
Peak emission(nm)	550	415
Hygroscopicity	slight	strong

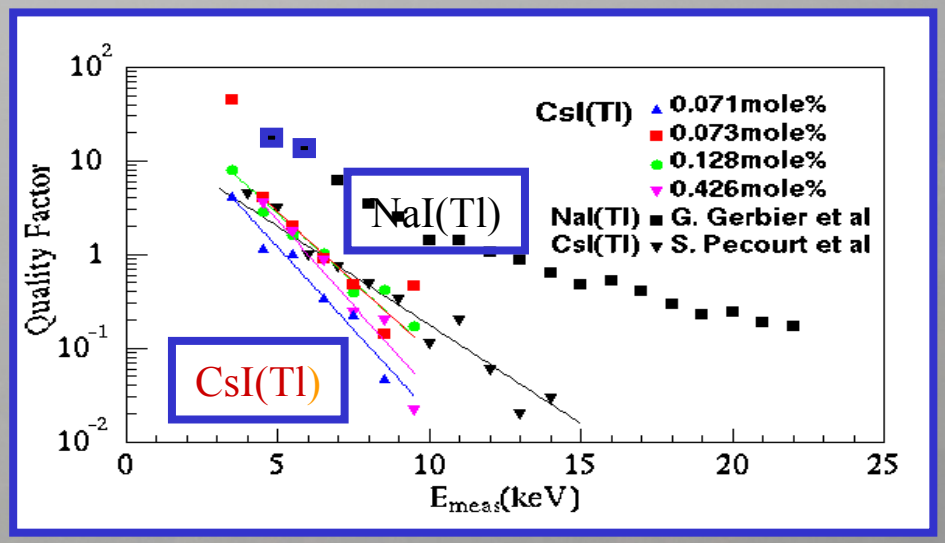
Pulse shape discrimination of gamma background



$$\langle t \rangle = \frac{\sum A_i t_i}{\sum A_i}$$







External backgrounds

1. External gamma
   - ❑ Isotopes in surrounding materials (Rock)
     - Decay chain of U^{238} and Th^{232}
     - Isotopes (K^{40}, …)
     - Rn^{222} in air
   - ❑ Shielding structure made of pure and high Z materials
   - ❑ Partially or fully distinguishable from WIMP signal by PSD
   - ❑ N_2 flowing to remove air contaminated by Rn^{222}

2. Neutron background
   - ❑ Indistinguishable from WIMP signal (Nuclear recoil)
     - (α, n) reaction
     - Nuclear fission
     - Induced by cosmic muon (E_{mean} ~ 230 GeV)
       - possible to veto with muon detector
   - ❑ Neutron moderator made of material with High Hydrogen density
   - ❑ Veto system using Muon detector

KIMS

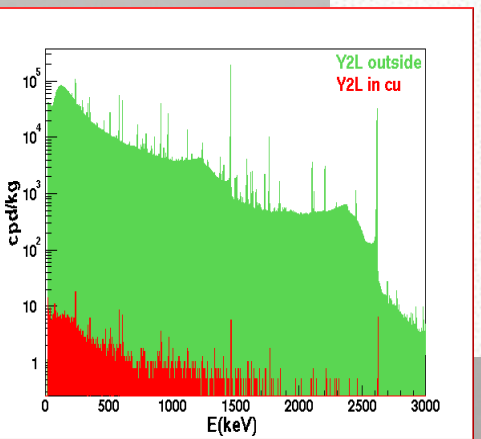
CsI(Tl) crystal

Neutron shield / Muon det.

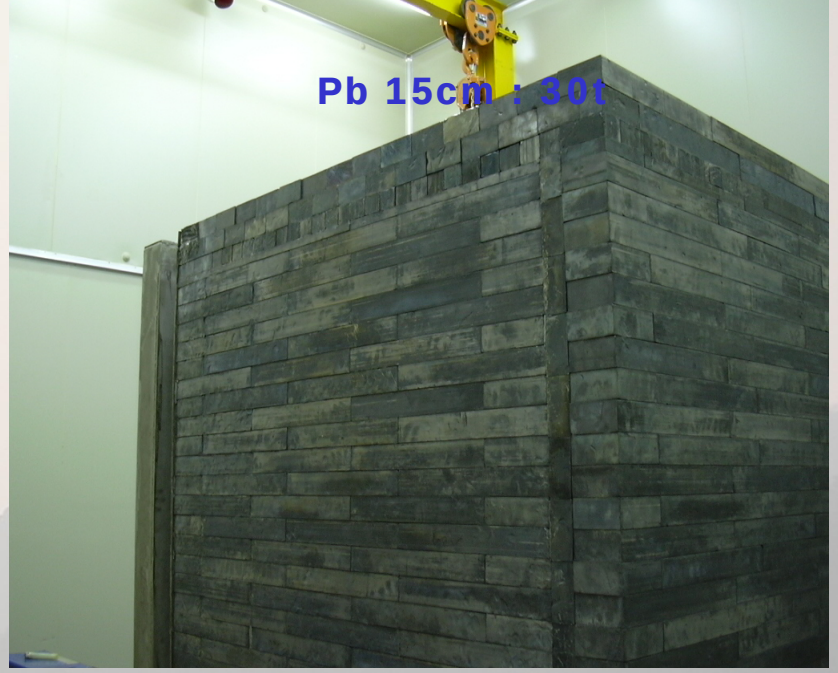
Lead shield

Polyethylene

Copper shield




Mineral oil 30cm

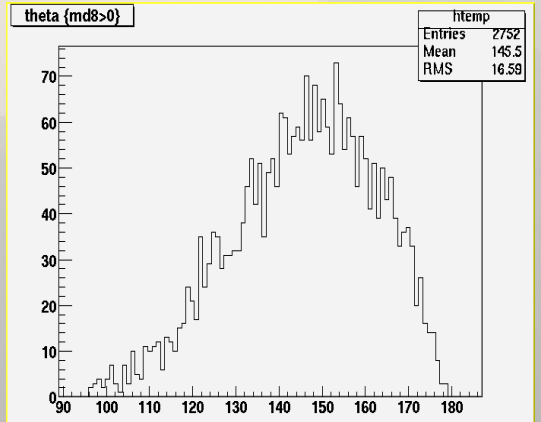

Pb 15cm : 30t

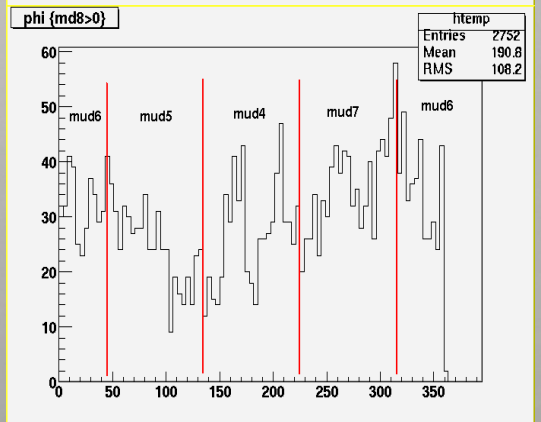

PE 5cm

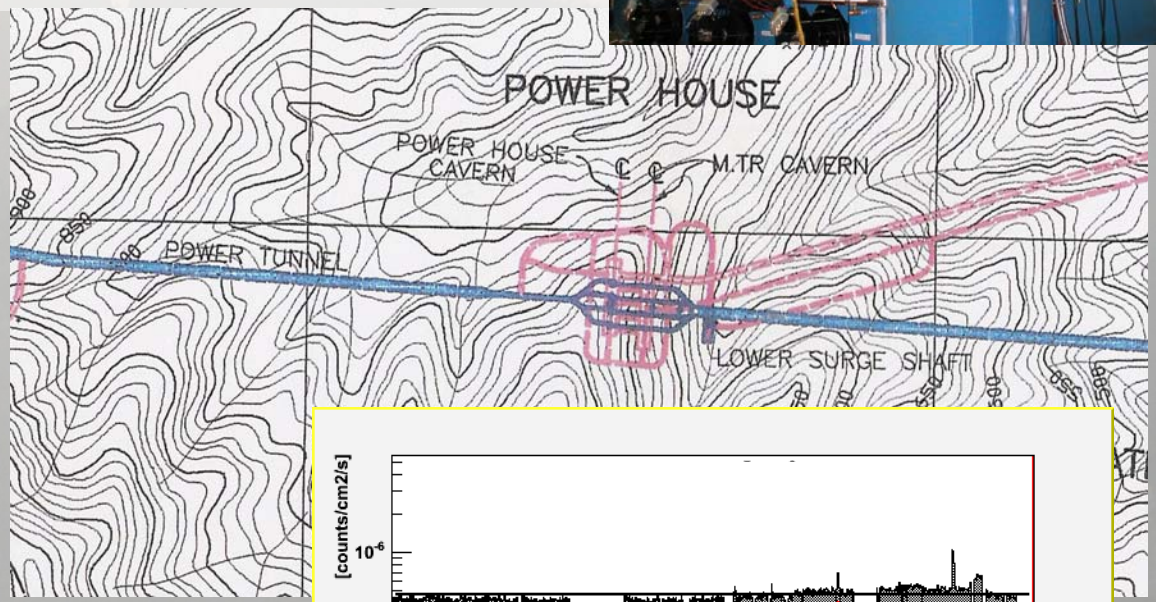

OFHC Cu 10cm : 3t

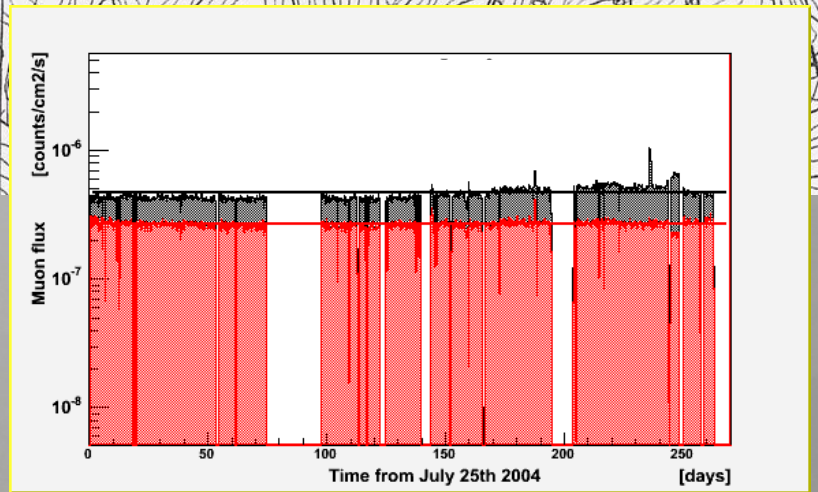
Muon Detector

- 4π coverage muon detector : 28 channels
- Liquid Scintillator(5%) + Mineral Oil (95%) = 7 ton
- Measured Muon flux = 2.7×10^{-7} /cm^2/s
- Position resolution : $\sigma_{x,y} \sim 8$ cm
- Reconstructed muon tracks with hit information
- Muon veto efficiency ~99.9%







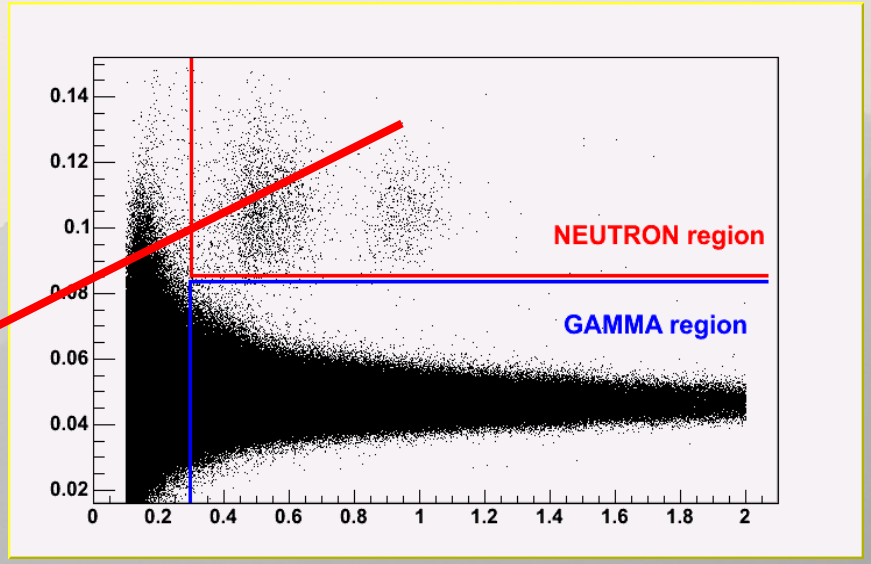


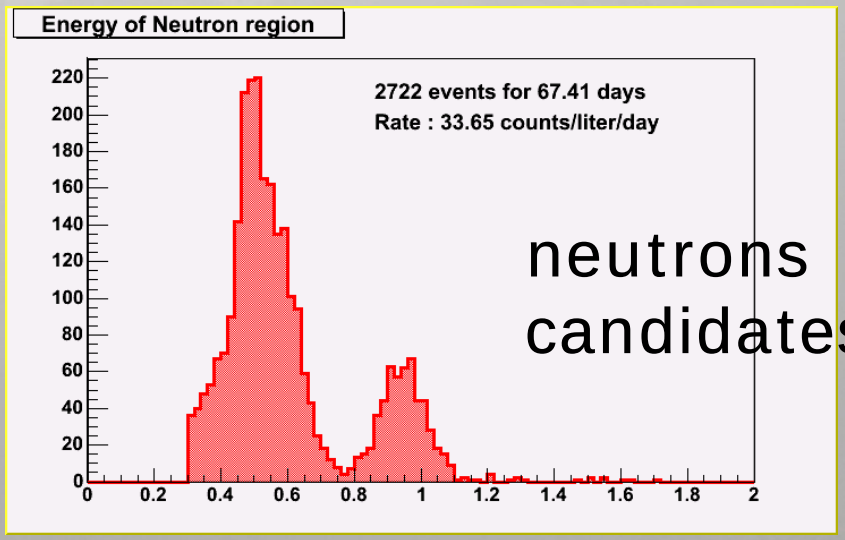
Neutron Monitoring Detector

1liter BC501A liquid scintillator

n/g separation using PSD

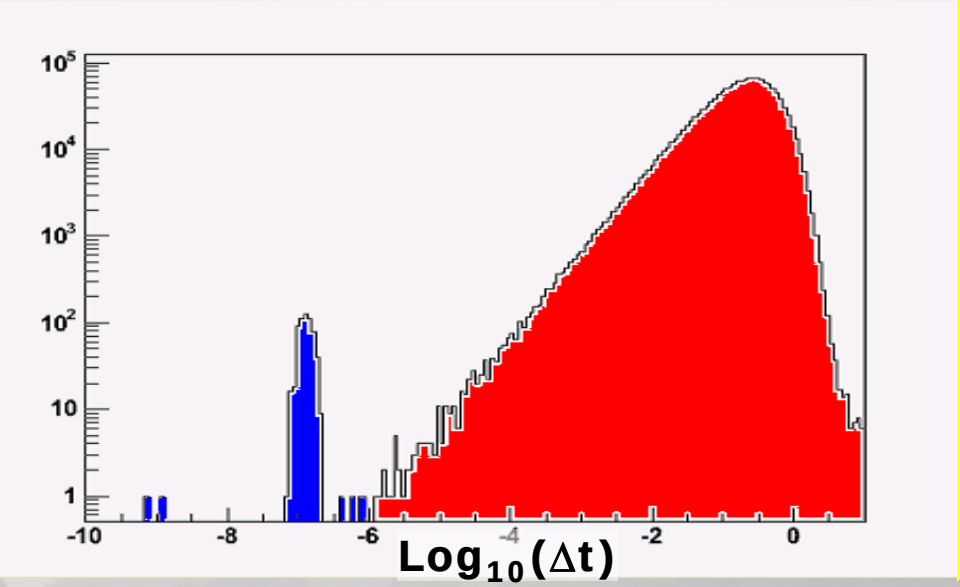
E_vis > 300 keV

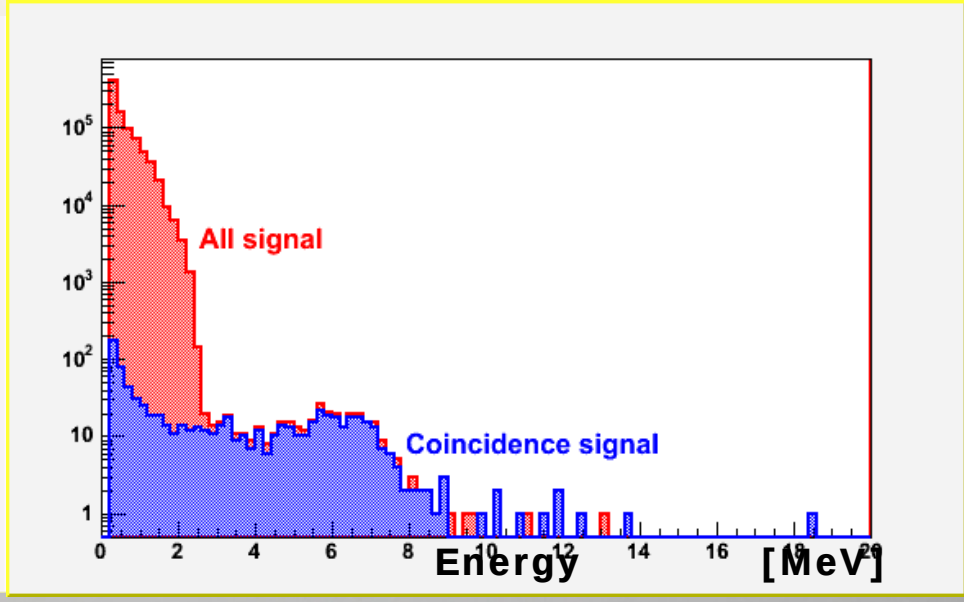


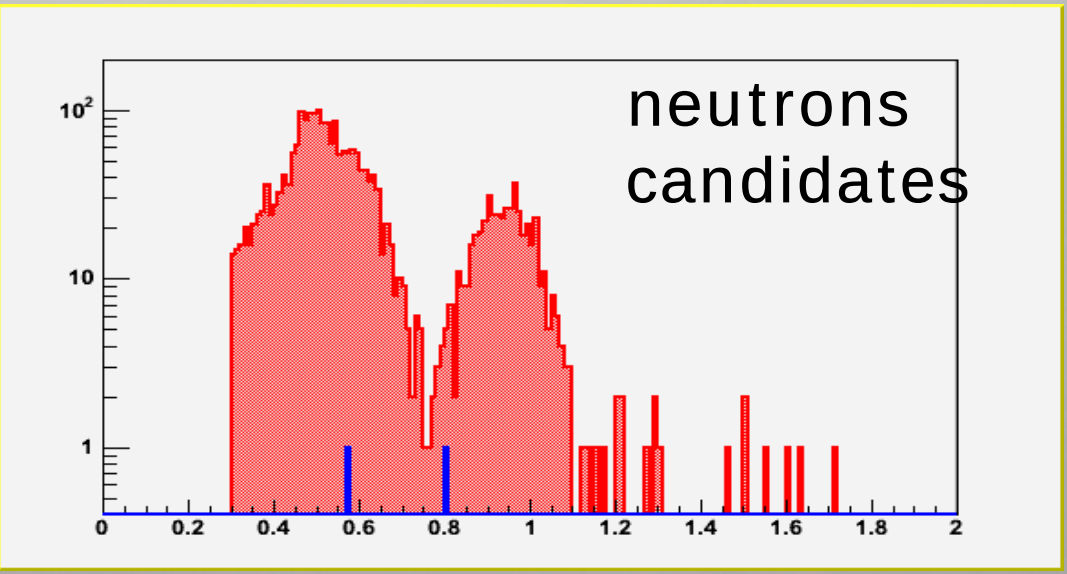


neutrons candidates

Muon induced neutrons





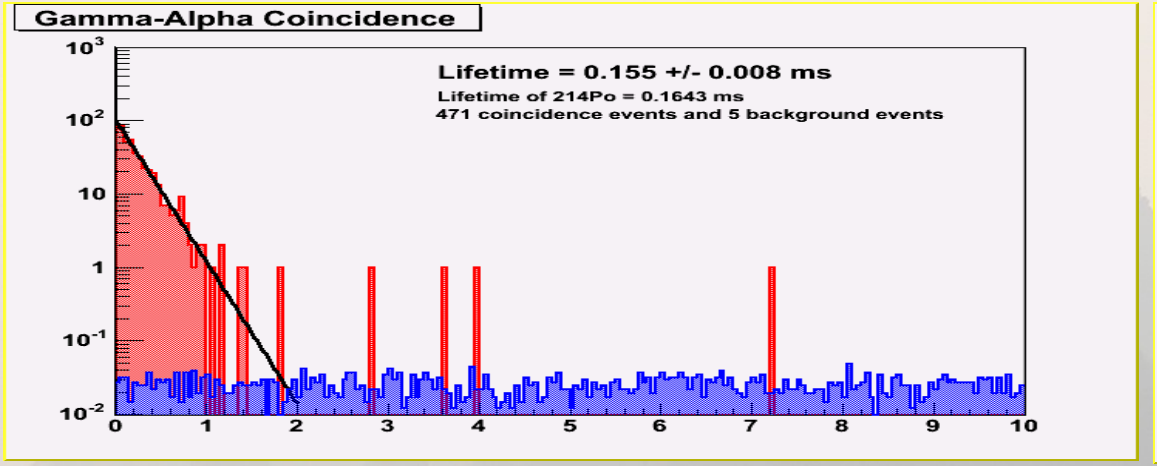


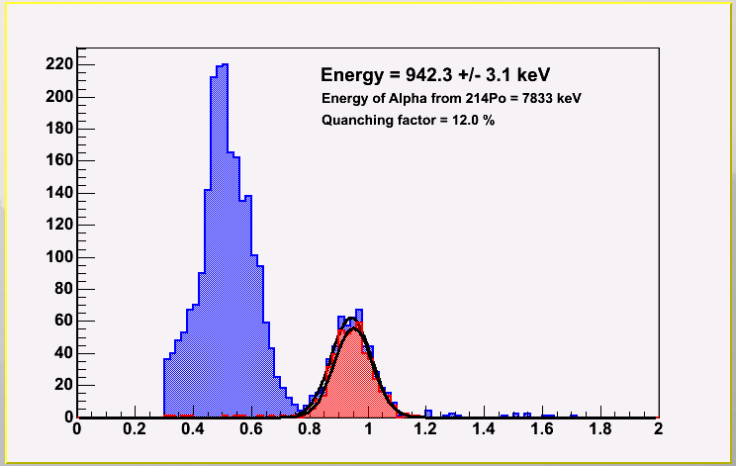
2 events of Muon induced neutron during 67.4 days

~ 0.03 counts/day/liter

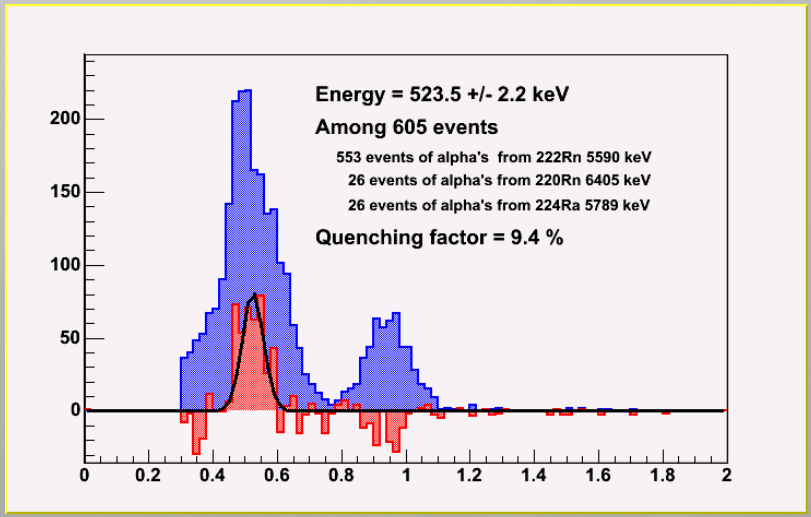
Neutron Monitoring Detector

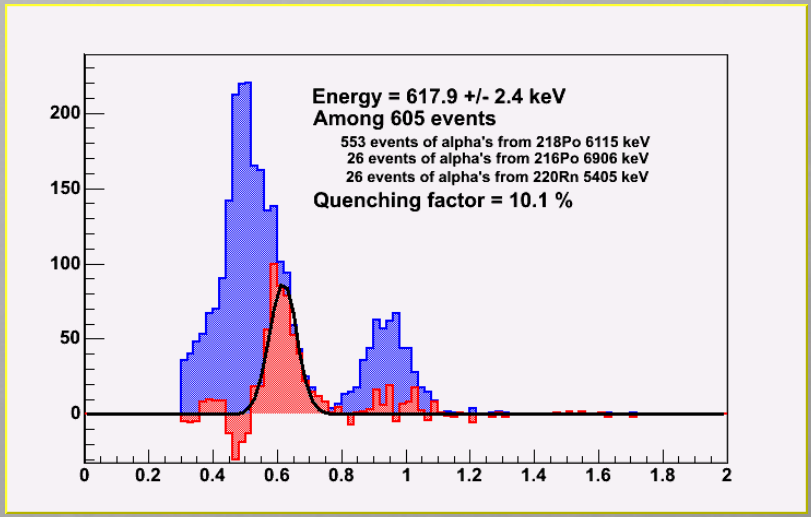
^{214}Bi β-decay → ^{214}Po α-decay





^{222}Rn α-decay → ^{218}Po α-decay





Neutron Monitoring Detector(cont'd)

^{230}Ra dominant contamination in ^{238}U chain

- 6.66 +- 0.27 cnts/liter/day – 1.5 x10^{-6} ppt of ^{230}Ra level

^{232}Th dominant contamination in ^{232}Th chain

- 0.32 +- 0.06 cnts/liter/day - 0.63 ppt of ^{232}Th level

- All neutron events : alphas from internal sources

  Neutron rate < 1.8 cpd (90 % C.L.) inside the shield

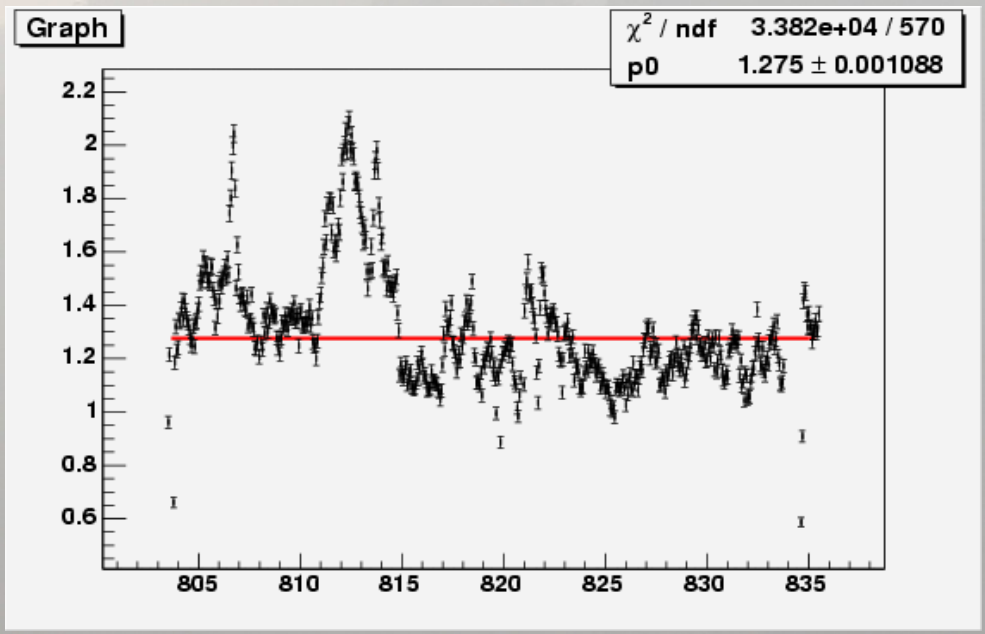
- Neutron rate outside the shield

  8 x 10 $^{-7}$ /cm^2/s (1.5 < E neutron < 6 MeV)

  After subtracting internal background estimated from the data inside the shield

Radon Monitoring

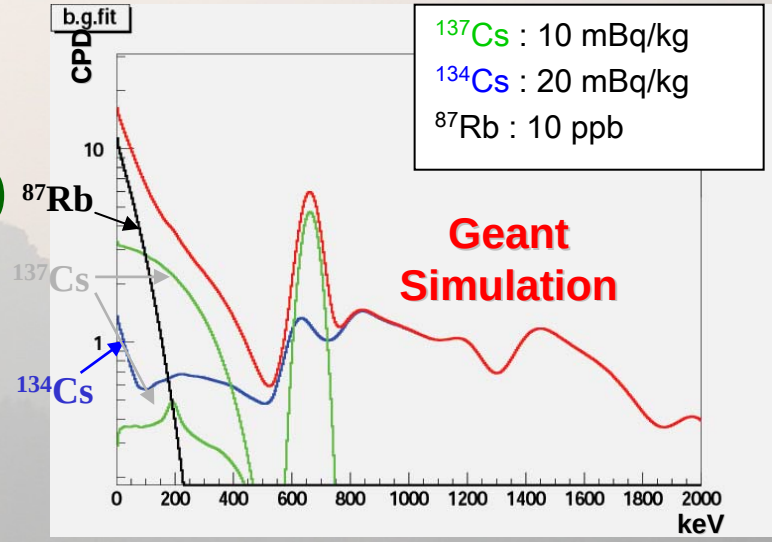
- **Electrostatic alpha spectroscopy : 70 liter stainless container**
- **Use Si(Li) photodiode : 30 x 30 mm**
- **Estimate ^{222}Rn amount**
  with energy spectrum of a from ^{218}Po & ^{214}Po.
- **Photodiode calibration : ^{210}Po, ^{241}Am**
- **^{222}Rn in air = 1 ~ 2 pCi/liter**
- **Absolute efficiency calibration done with ^{226}Ra**



Internal background of CsI Crystal

- ^{137}Cs (artificial)
  - serious background at low energy
- ^{134}Cs (artificial+^{133}Cs(n,gamma))
- ^{87}Rb (natural)
  - Hard to reject

  → reduction technique in material is known



Single Crystal (~10 kg) background @ ~10keV

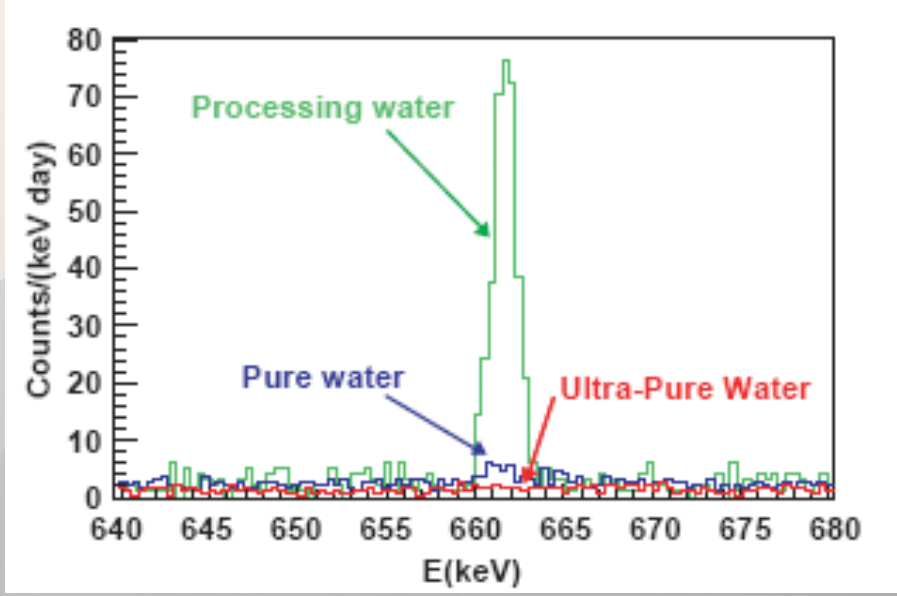
^{87}Rb	1.07 cpd/1ppb
^{137}Cs	0.35 cpd/1mBq/kg
^{134}Cs	0.07 cpd/1mBq/kg

From simulation

Reduction of Internal Background

Cs137 Reduction

- Water is main source of Cs137
- It was reduced by using purified water

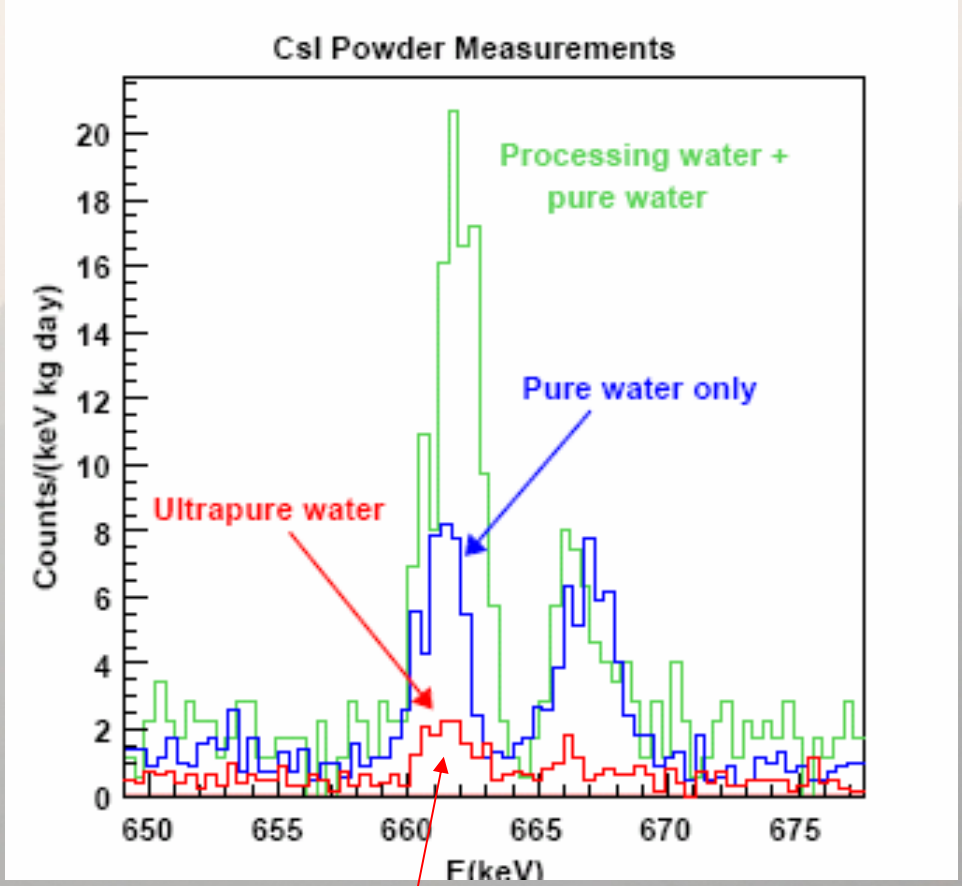


Rb87 Reduction

- CsI solubility in water is very high.
- Recrystallization reduces Rb87.
- 10 ppb powder → ~ 1 ppb (< 1.1cpd)

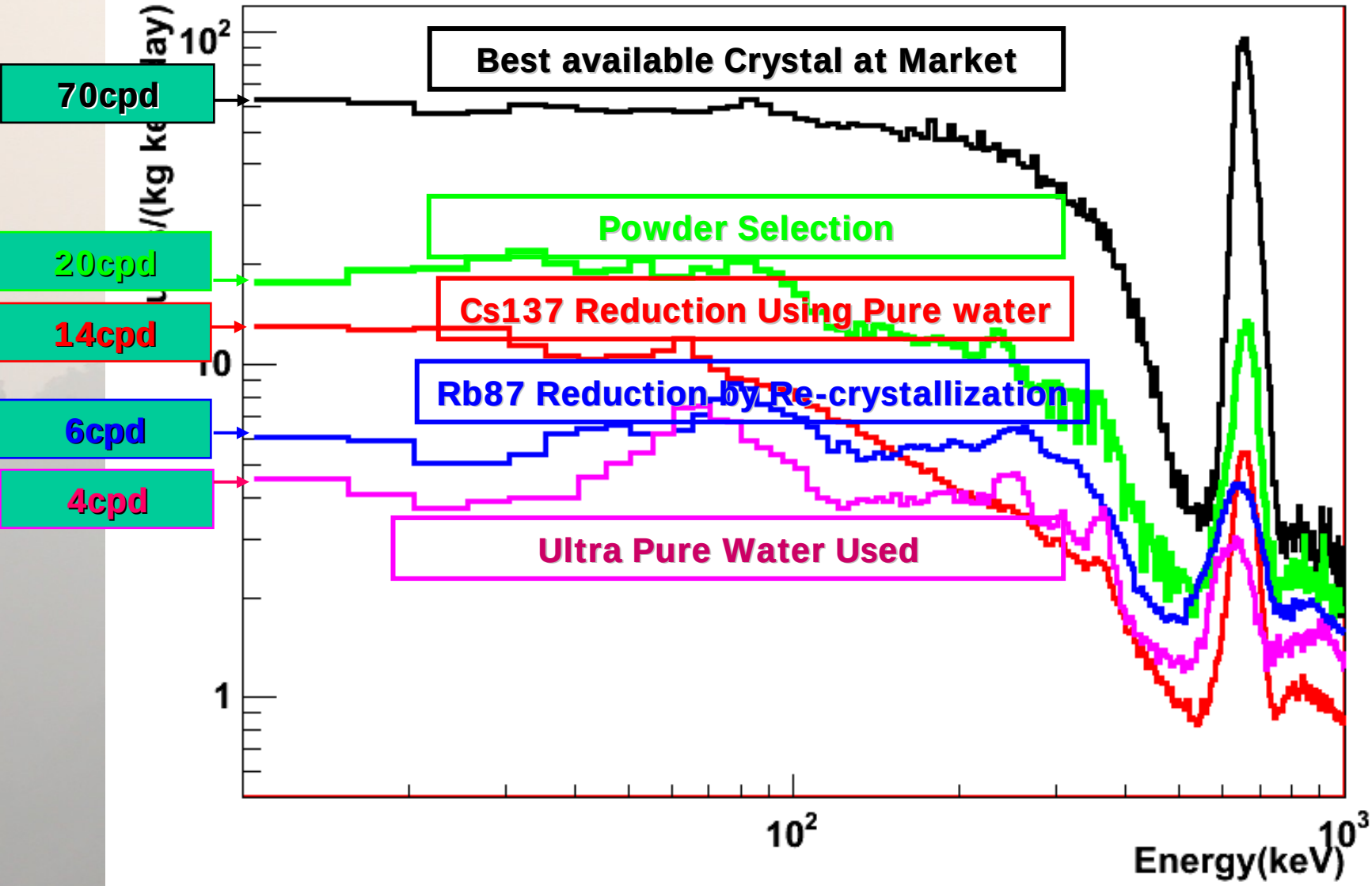
Further reduction of internal background

New CsI powder produced with ultra pure water



2mBq/kg → 0.7 cpd internal background

Reduction of Internal Background cont'ed



Data taking with CsI(Tl)

CsI(Tl) Crystal 8x8x30 cm^3 (8.7 kg)

3" PMT (9269QA)

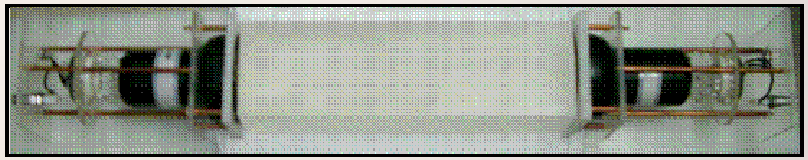
Quartz window, RbCs photo cathode

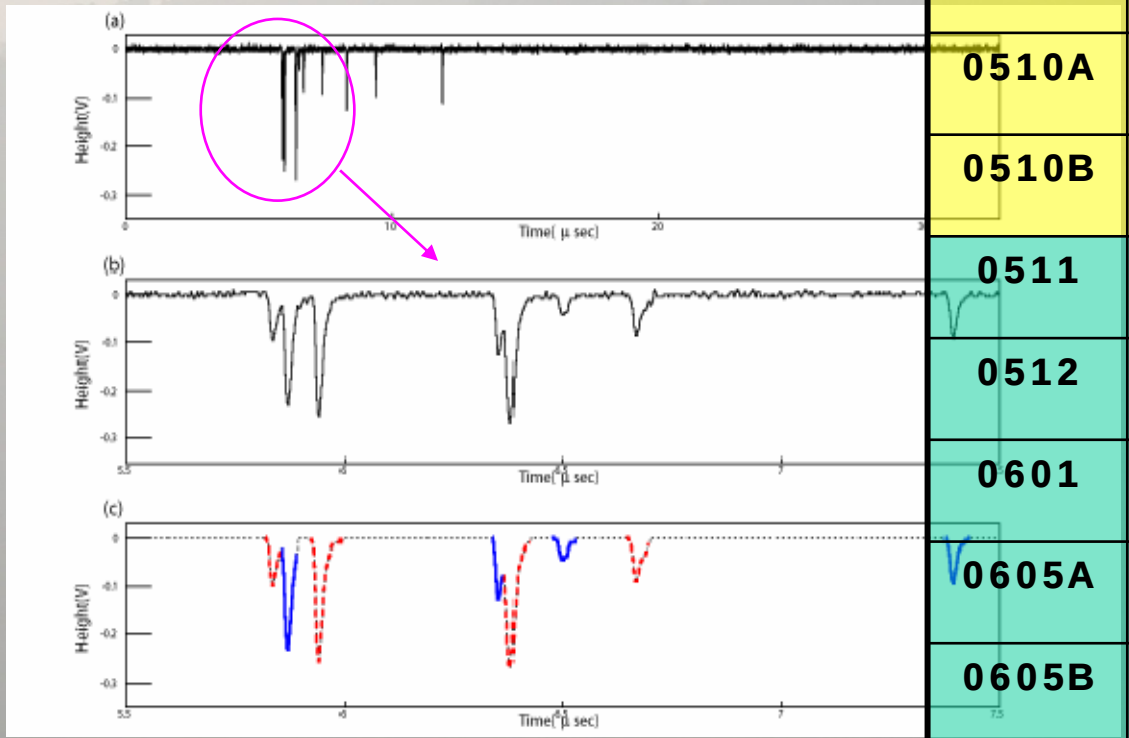
4~6 Photo-electron/keV

DAQ 500MHz Home Made FADC

5 photo-electron within 2μsec trigger condition

total 32μsec window





Name	B.G.	Weight	Company
0406	6CPD	6.7 kg	shanghai
0501A	6CPD	8.7 kg	shanghai
0501B	6CPD	8.7 kg	shanghai
0510A	~4CPD	8.7 kg	beijing
0510B	~4CPD	8.7 kg	beijing
0511	~4CPD	8.7 kg	beijing
0512	~4CPD	8.7 kg	beijing
0601	~4CPD	8.7 kg	beijing
0605A	~4CPD	8.7 kg	beijing
0605B	~4CPD	8.7 kg	beijing

Neutron calibration facility in SNU

300 mCi Am/Be source

→ neutron rate 7 x 10^5 neutrons /sec

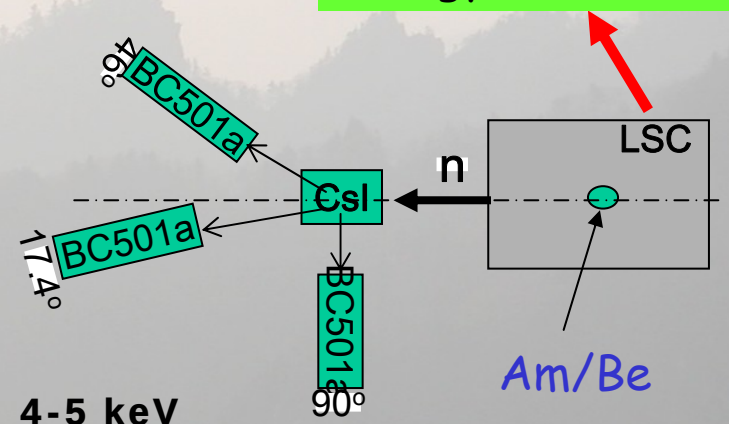
→ a few 100 neutrons/sec hit 3cmX3cm crystal

→ Quenching factor of Recoil Energy

Take Neutron calibration data

PSD check – Quality factor

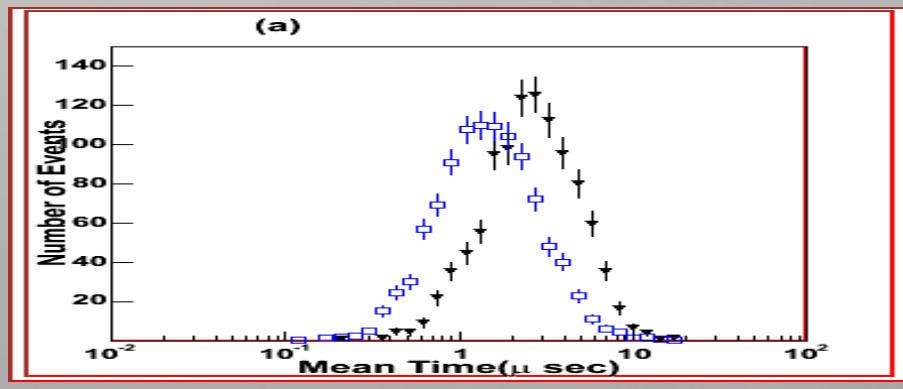
Tag γ(4.4MeV) to measure TOF and energy of neutrons

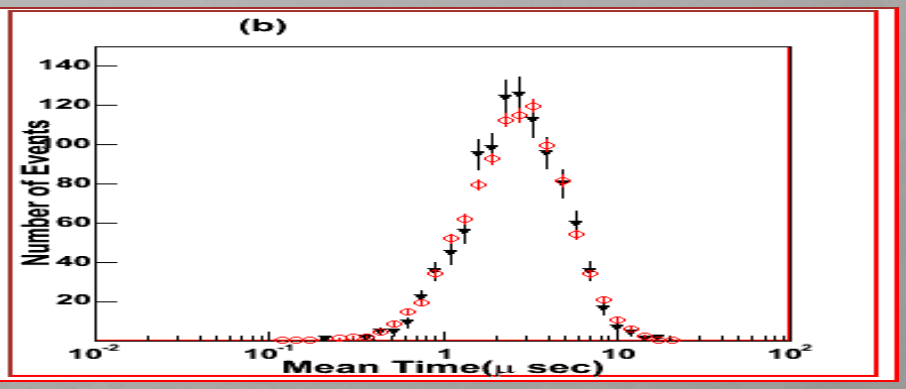


PSD discrimination

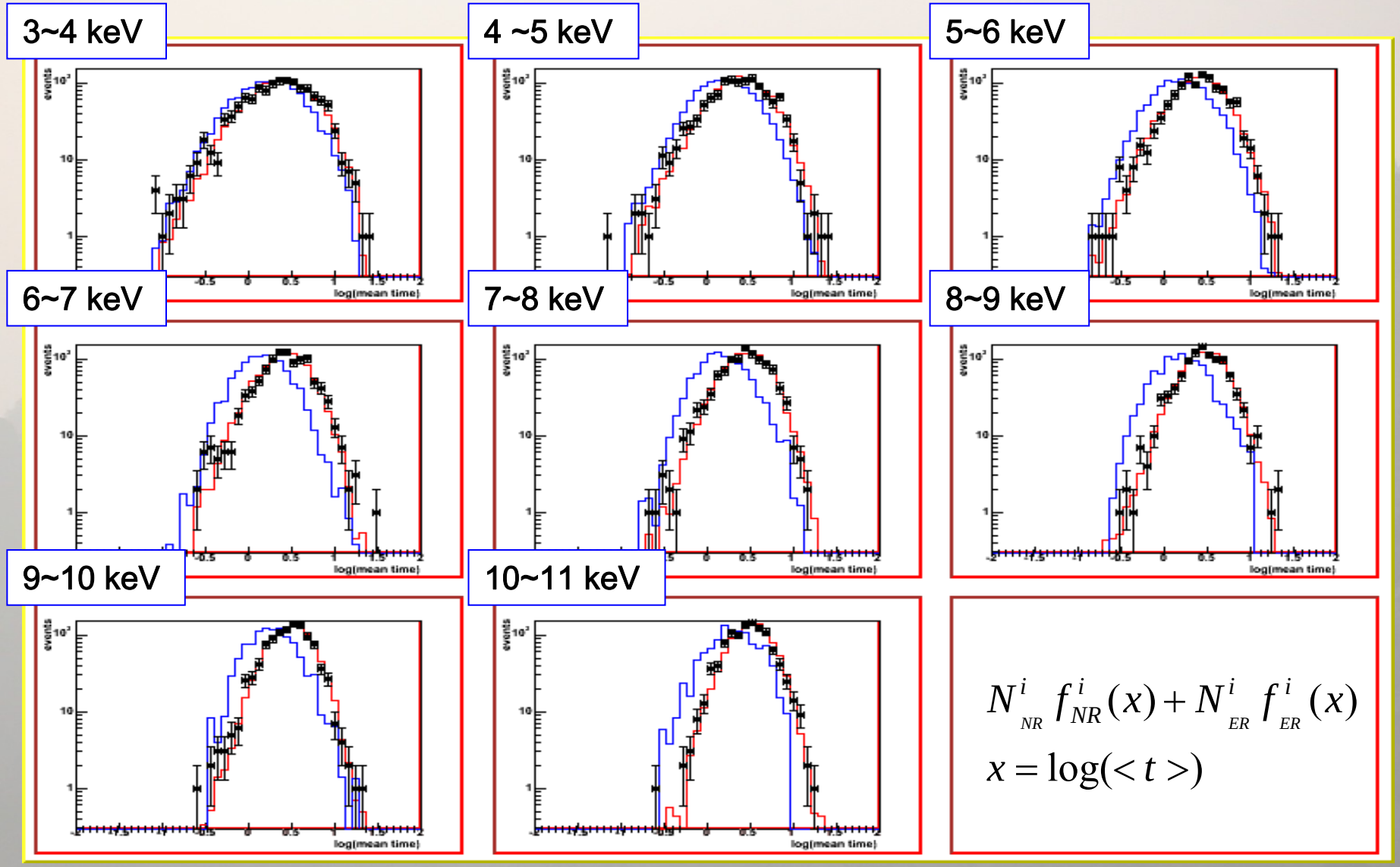
Mean time distribution

@Energy = 4-5 keV
137 Cs Compton
Neutron Recoil





Extraction of nuclear recoil events

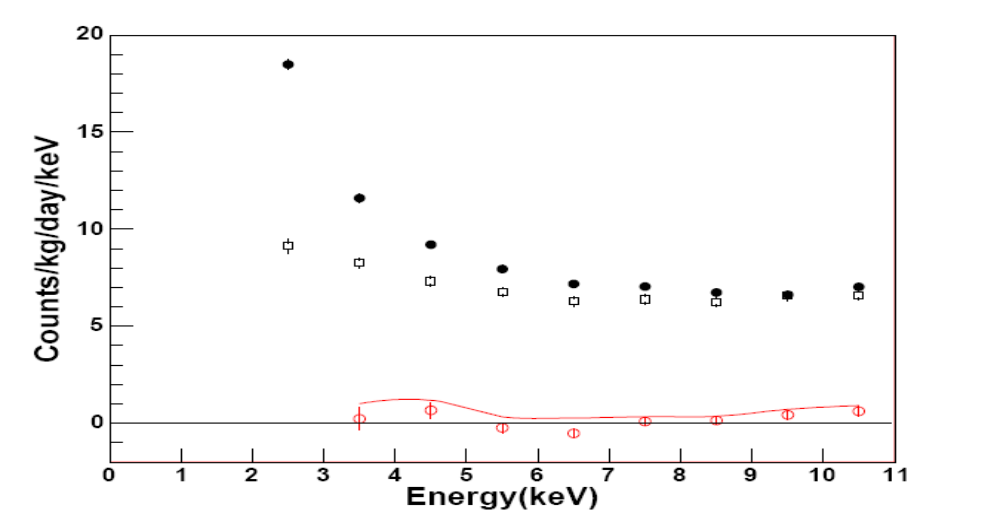


$$N^i_{NR} f^i_{NR}(x) + N^i_{ER} f^i_{ER}(x)$$

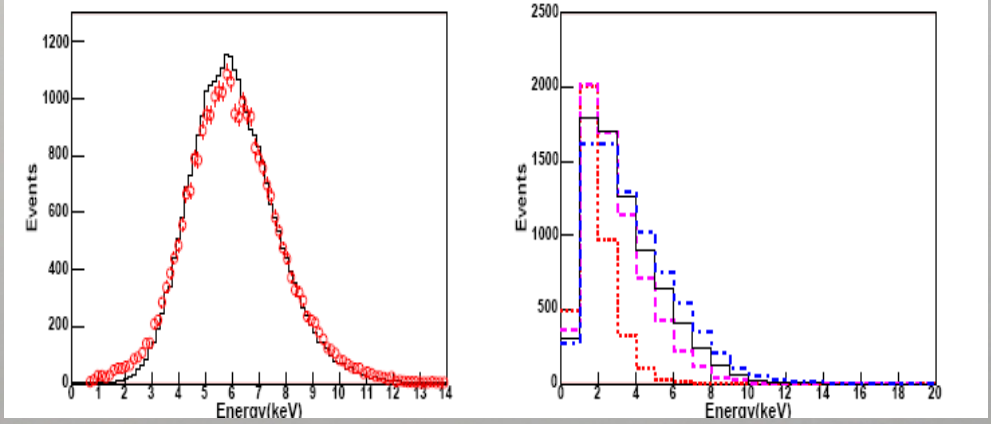
$$x = \log(< t >)$$

Rate of nuclear recoil events

Log mean time distribution of background events are fitted to distributions of Compton events and neutron events



Filled circle :
w/o PMT noise cut
Open square :
with PMT noise cut - efficiency corrected
Open circle :
fitted the number of nuclear recoil events



^{55}Fe energy distribution
solid line for MC and dotted points for data

Simulated energy distributions of WIMP for different masses

20 GeV,50 GeV,100 GeV,1 TeV

Interaction rate of WIMP

Local WIMP density ~ 0.3GeV/cm³

Maxwellian velocity distribution with $\bar{v}$ ~ 270km/s

➔ Local flux of WIMP ~ 100 GeV/m_χ x 10^5/cm²/s

$$\frac{dR}{dE} = \frac{\rho_\chi}{4 v_E M_\chi M_{red}^2 (M_{nuc})} \left[\mathrm{erf}\left(\frac{v_{min} + v_E}{v_0} \right) - \mathrm{erf}\left(\frac{v_{min} + v_E}{v_0} \right) \right], \left[\sigma_{\chi N}^{SI} F_{SI}^2(E) + \sigma_{\chi N}^{SD} \frac{S_A(E)}{S_A(0)} \right],$$

$$v_{min} = \sqrt{\frac{E M_{nuc}}{2 M_{red}^2}},$$

ρ_χ = galatic halo density

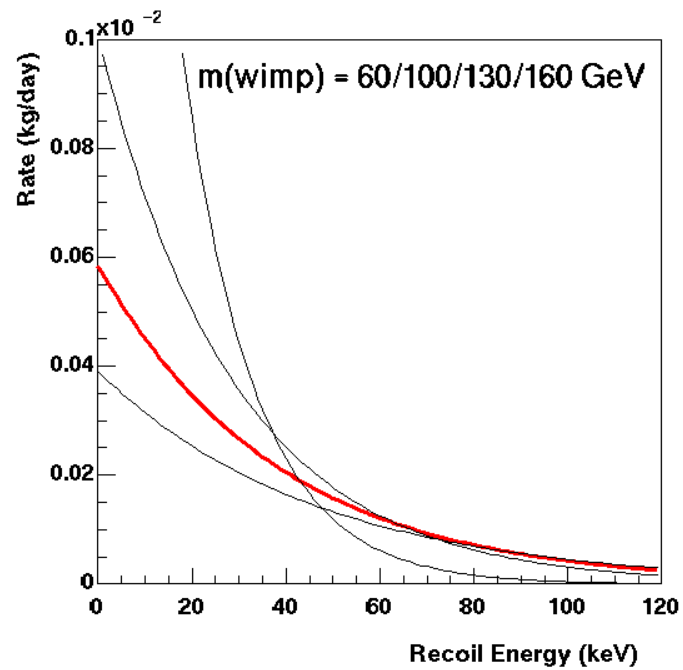
v_E = earth velocity in galatic frame

v_0 = sun velocity in galatic frame

$$E_{recoil}(\max) = 2 v_x^{\,2} m_N \frac{m_\chi^{\,2}}{(m_N + m_\chi)^2}$$

Recoil energy < 100 keV

Measured energy < 10 keV due to quenching

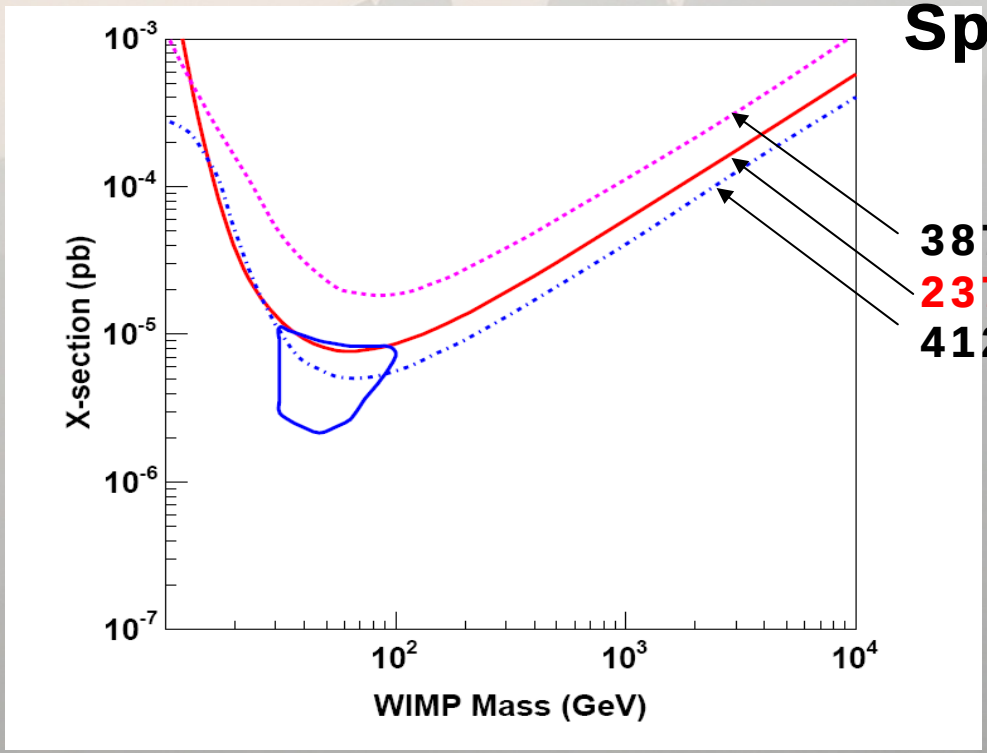


KIMS First WIMP Limit

- **Dark matter density at the solar system**

  $\rho_D = 0.3$ GeV c^{-2} cm $^{-3}$
- **Use annual average parameters**

  $\mathcal{V}_0 = 220$ km s^{-1}, $\mathcal{V}_E = 232$ km s^{-1}, $\mathcal{V}_{Esc} = 650$ km s^{-1}

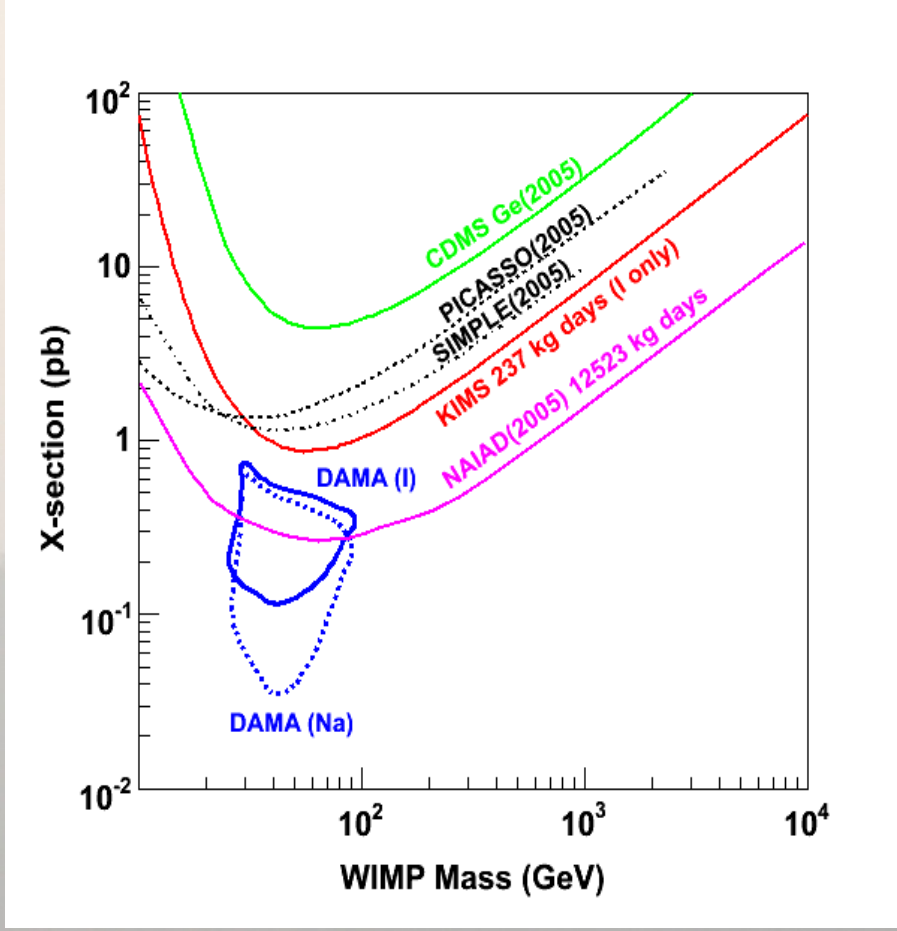


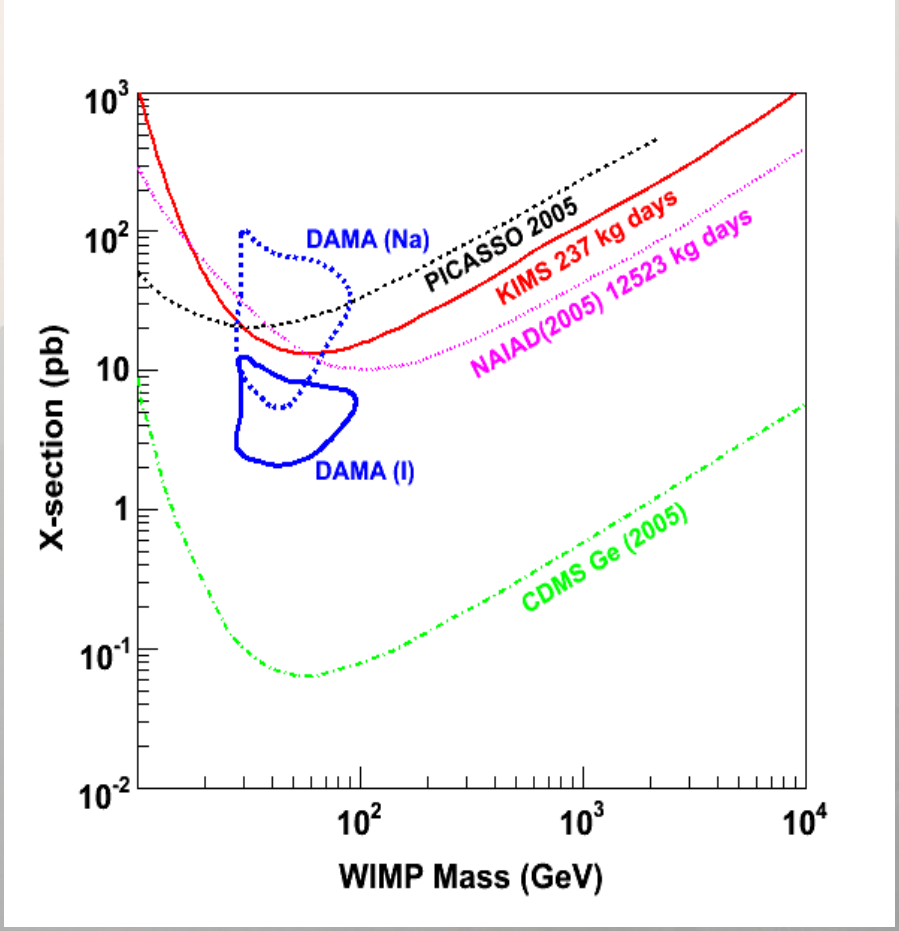
Spin Independent Limit

3879 kg days NAIAD - NaI(Tl)
237 kg days KIMS - CsI(Tl)
4123 kg days DAMA - NaI(Tl)

PLB 633(2006) 201
In Feb. 2006

Spin dependent WIMP limit only with I





Pure proton case **Pure neutron case**

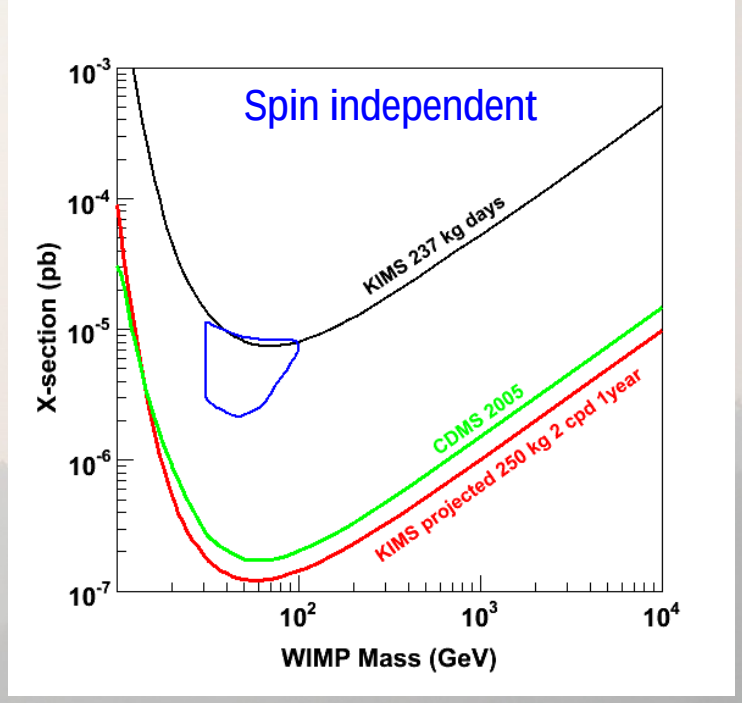
Form factor and spin expectation value for "I" are obtained from

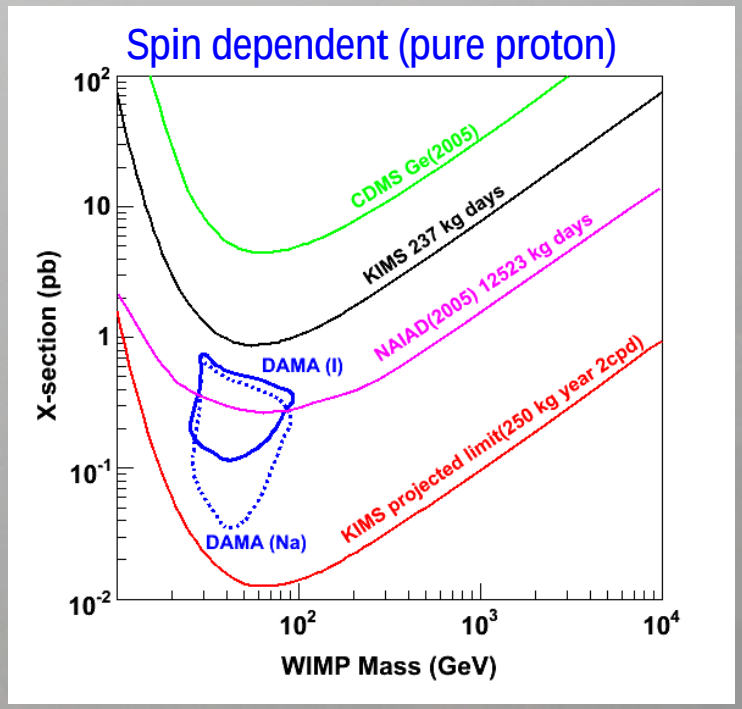
"M.T.Ressel and D.J.Dean PRC 56(1997) 535

WIMP search with CsI(Tl) crystal

Summary & Prospects

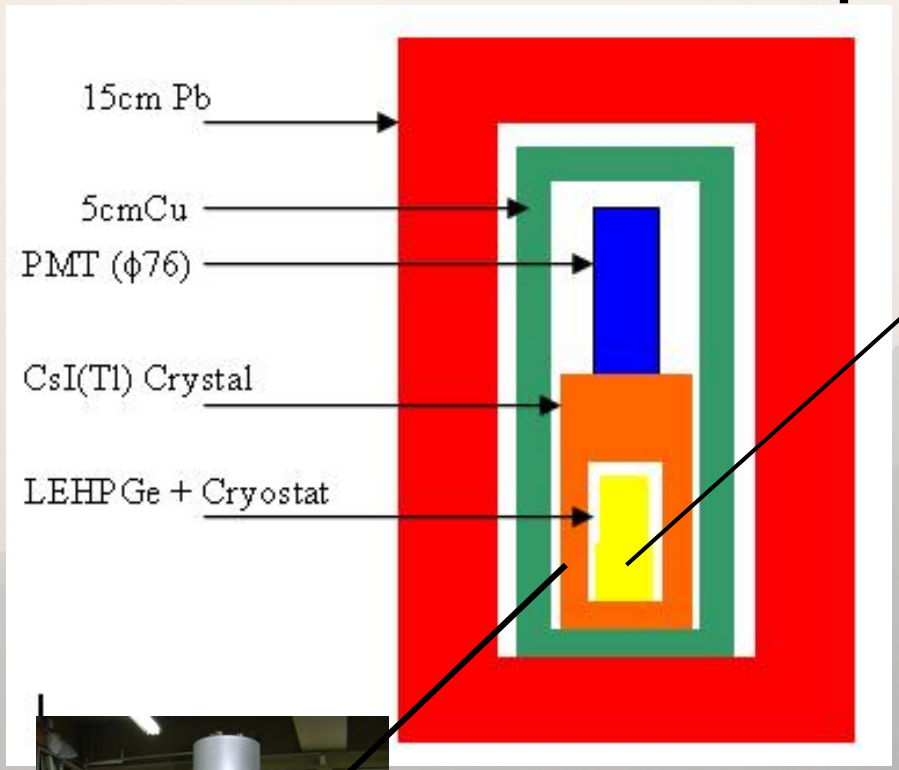
- First physics result was published
- Various R&D run was done
  - About 4000 kg day data acquisited
  - With and without quartz block (5cm thick)
  - 0 degree and Room temperature operation
  - Analysis is ongoing
- Successfully reduce internal backgrounds of CsI(Tl) crystals
  - 70 kg full size crystals(8x8x30cm3) are being prepared
  - Mass production stage
    - 2 Crystal/Month growing is possible
- With more than 100 kg crystals, we start to probe
  - Annual modulation
  - SD+SI interaction search





Search for Low Mass WIMP

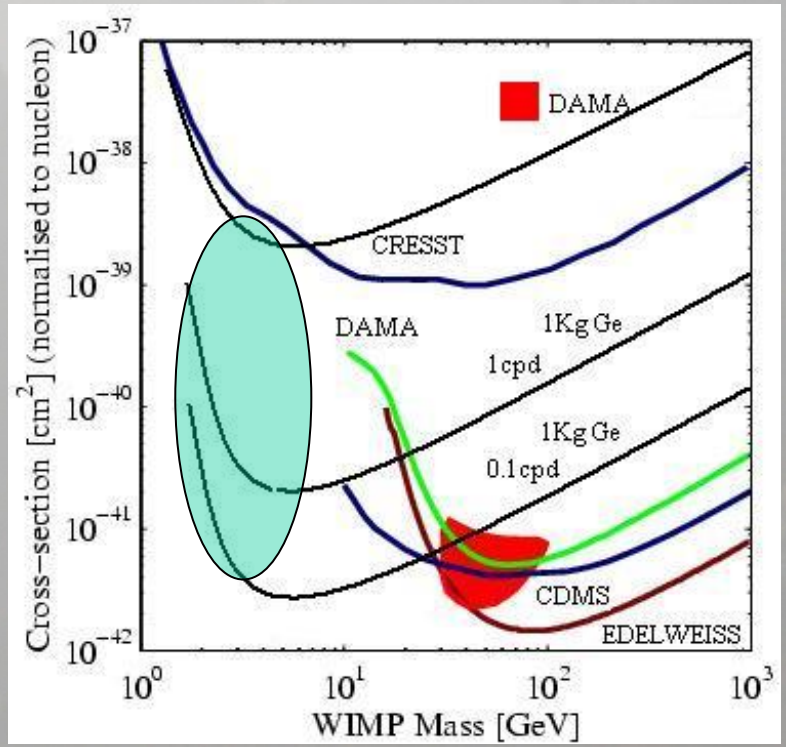
ULE HPGe detector setup



5g 1 cpd level detector
Tested at Academia Cinica, Taiwan and delivered to SNU in Dec, 2004.

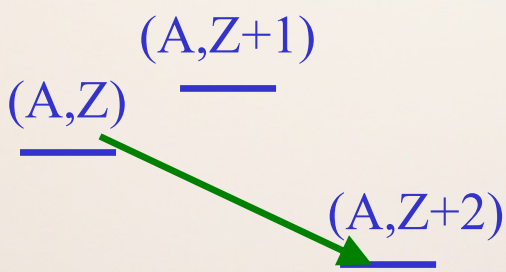
If successful → upgrade to 1kg mass

CsI(Tl) crystal
Compton veto
→ Built by TU
→ Delivered to SNU



Collaboration with China and Taiwan

Double beta decay



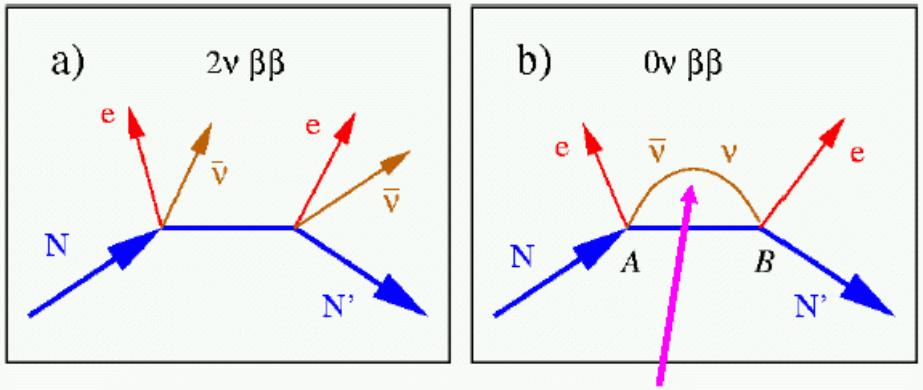
(A,Z) -> (A,Z+2) + 2β +2ν

Candidate nuclei with Q>2 MeV

Candidate	Q (MeV)	Abund. (%)
$^{48}Ca \rightarrow ^{48}Ti$	4.271	0.187
$^{76}Ge \rightarrow ^{76}Se$	2.040	7.8
$^{82}Se \rightarrow ^{82}Kr$	2.995	9.2
$^{96}Zr \rightarrow ^{96}Mo$	3.350	2.8
$^{100}Mo \rightarrow ^{100}Ru$	3.034	9.6
$^{110}Pd \rightarrow ^{110}Cd$	2.013	11.8
$^{116}Cd \rightarrow ^{116}Sn$	2.802	7.5
$^{124}Sn \rightarrow ^{124}Te$	2.228	5.64
$^{130}Te \rightarrow ^{130}Xe$	2.533	34.5
$^{136}Xe \rightarrow ^{136}Ba$	2.479	8.9
$^{150}Nd \rightarrow ^{150}Sm$	3.367	5.6

2ν mode: a conventional 2nd order process in nuclear physics

0ν mode: a hypothetical process can happen only if:
- $M_\nu \neq 0$ Since helicity has to "flip"
- $\nu = \bar{\nu}$



Several new particles can take the place of the virtual ν

But 0νββ decay always implies new physics

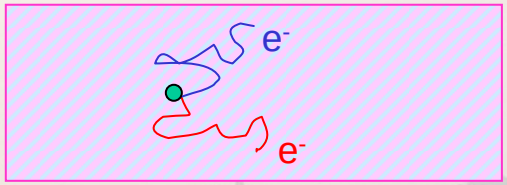
$$1/T_{1/2}^{0\nu} \propto < m_{\beta\beta} >^2$$

$$< m_{\beta\beta} > = \left| \sum_i |U_{ei}|^2 m_{\nu_i} e^{i\alpha_i} \right|^2$$

Experimental search for DBD

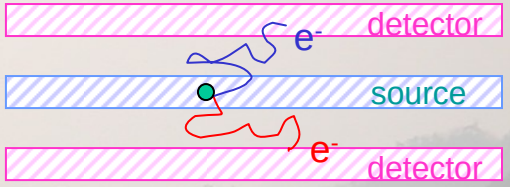
- Two approaches:

①



Source ≡ Detector
(calorimetric technique)
+ high energy resolution
+100% efficiency
- no event topology

②



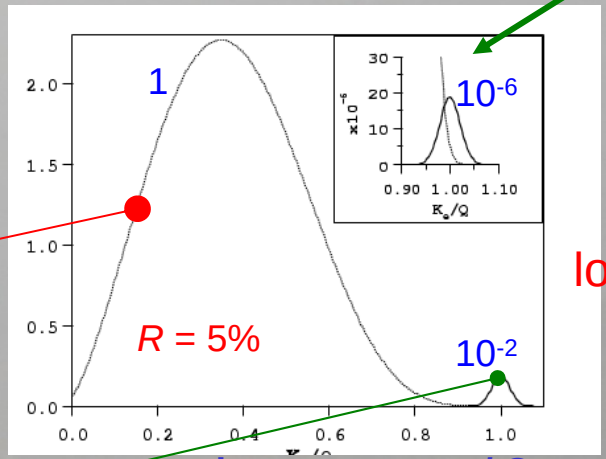
Source ≠ Detector
+ event shape reconstruction
- low energy resolution
- low efficiency

- If you use the calorimetric approach

Signature: shape of the two electron sum energy spectrum

two neutrino DBD
continuum with maximum at ~1/3 Q

neutrinoless DBD
peak enlarged only by the detector energy resolution



low energy resolution

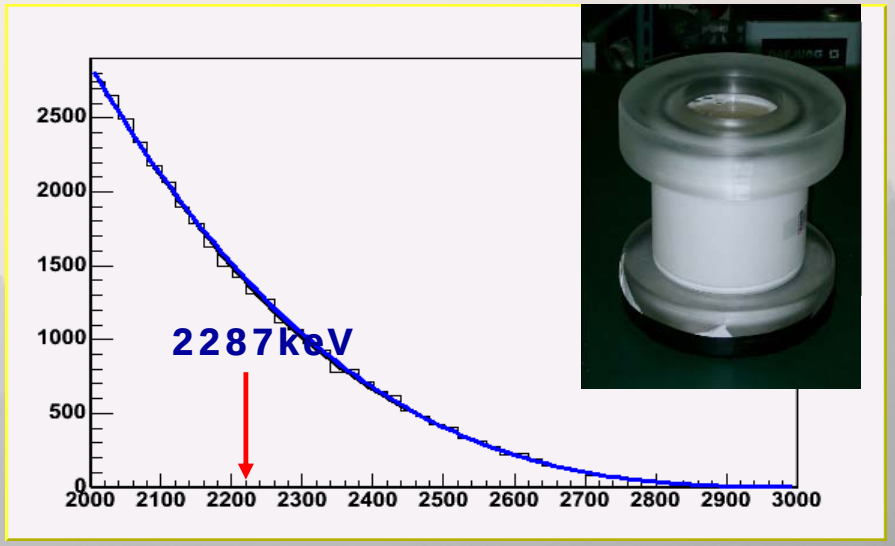
2ν events can mask 0ν ones

low background
- underground operation
- shielding
- low radioactivity of materials

Double beta decay R&D

1. TMSN50% + STD Liquid scintillator
   $^{124}Sn \rightarrow {}^{124}Te + 2\beta$–decay

$T_{1/2} > 3.41 \times 10^{19}$ yr at 90% C.L



2. $CaMoO_4$ Crystal 1.8x1.8x3.5 cm^3
   $^{100}Mo \rightarrow {}^{100}Ru + 2\beta$–decay

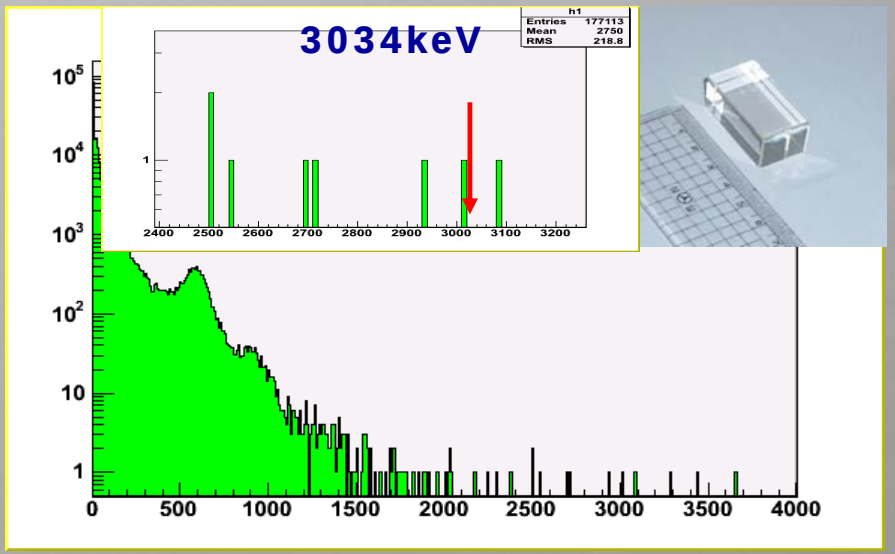
10kg Mo-100 $CaMoO_4$

5-year running

$T_{1/2} > 1 \times 10^{25}$ yr at 68% C.L.

Present Best Limit >

4.6×10^{23} yr @ 90% C.L.



Other activities

Summary and prospect

ULE HPGe detector for low mass WIMP search

→ Compton veto detector delivered

→ Prototype detector and shield is being soon

Cryogenic detector for low energy detection

→ Fabrication and test of TES sensor on-going

→ Need fast cycling of sample test for the TES optimization

Metal loaded liquid scintillator for $0\nu\beta\beta$ decay

→ Pilot experiment with 1 liter 50% Sn loaded LS → encouraging result

→ Study on internal background in progress

→ Loading other element in progress

$CaMoO_4$

→ Test with a 50g crystal has been done → encouraging resut

→ R&D for growing optimization and background reduction in progress

→ 10kg crystal can be easily installed in the current WIMP search setup