Neutrino Physics with Gemanium Detector at the Kuo-Sheng reactor neutrino laboratory

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OUTLINE

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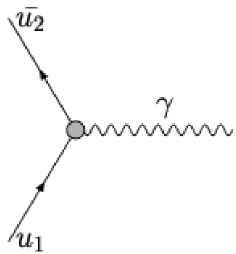
- Neutrino magnetic moment : Overview
- Period I experiment : Magnetic moment results
- Period II, III status and plans
- $\bar{\nu}_e N$ coherent scattering
- LEGe prototype measurements with sources
- Summary

$\bar{\nu}_{\rm e}$ Magnetic moment



$$= e\bar{u}_2\Gamma_\mu u_1 A^\mu$$

general form of Γ_μ

$$= (q^2\gamma_\mu - q_\mu q.\gamma)(R(q^2) + r(q^2)\gamma_5)$$
$$+\sigma_{\mu\nu}q^\nu(D_\mu(q^2) + iD_E(q^2)\gamma_5)$$

$$\sigma_{\mu\nu}q^\nu A^\mu \sim \mathbf{B}\cdot\sigma$$

D_μ : magnetic moment

D_E : electric dipole moment

$$\mu^2_{eff} \equiv |D_\mu - D_E|^2$$

$\mu_\nu \approx 10^{-10}\mu_B$

$\rightarrow$ consistent with solar data(before KamLand results)

$\rightarrow$ could be reached by present lab. exp.

OUTLINE

Limits of neutrino magnetic moment

♯ PDG quoted :

- Fit on SuperK data, $\mu_\nu < 1.5\times10^{-10}\mu_B$ ($\nu_e e^-$ scattering)

♯ Reactor $\bar{\nu}_e e^-$ scattering :

- Savannah River(plastic scintillator), $\mu_\nu \approx 2-4\times10^{-10}\mu_B$
- Kurtchatoc(fluorocarbon scintillator), $\mu_\nu < 2.4\times10^{-10}\mu_B$
- Rovno(Si(Li)), $\mu_\nu < 1.9\times10^{-10}\mu_B$
- MUNU(CF^4), threshold $\sim$ 1 MeV.

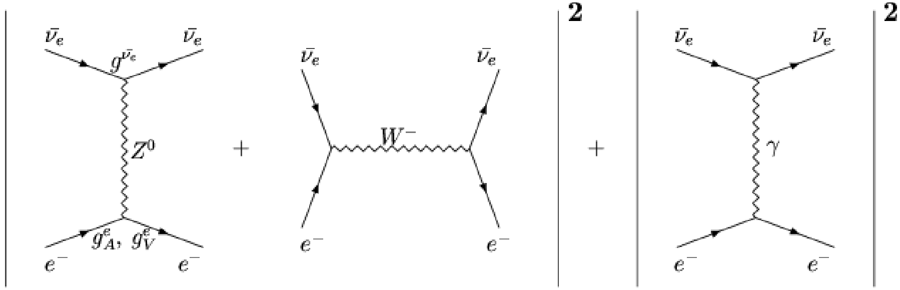
♯ Astrophysics bound :

- $\nu_L \rightarrow \nu_R$ in SN1987A, $\mu_\nu < (0.01-0.04)\times10^{-10}\mu_B$
- Constraint on nucleosynthesis, $\mu_\nu < 0.62\times10^{-10}\mu_B$
- Red giant luminosity, $\mu_\nu < 0.03\times10^{-10}\mu_B$
  – depend on neutrino mass/interaction.
  – depend on stellar model.

$\bar{\nu}_e e^- \rightarrow \bar{\nu}_e e^-$ Scattering

$\bar{\nu}_e e^- \rightarrow \bar{\nu}_\times e^-$

Mesurement : Recoil energy of e^-

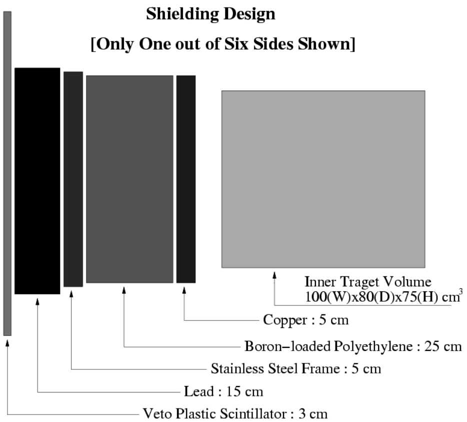


When recoil energy T $\rightarrow$ 0

$$(\frac{d\sigma}{dT})_{SM} \rightarrow constant, \qquad (\frac{d\sigma}{dT})_{MM} \rightarrow \frac{1}{T}$$

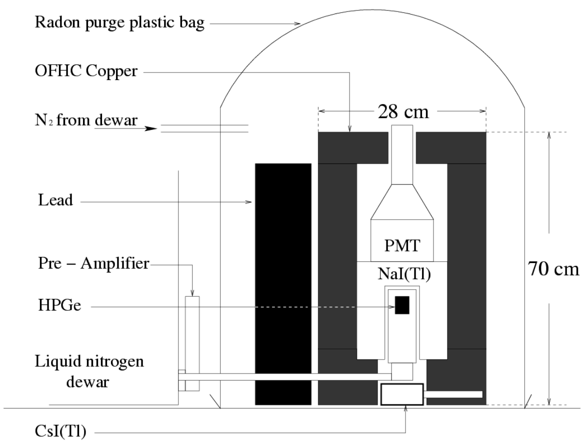
KS Expt. : Period I Configuration

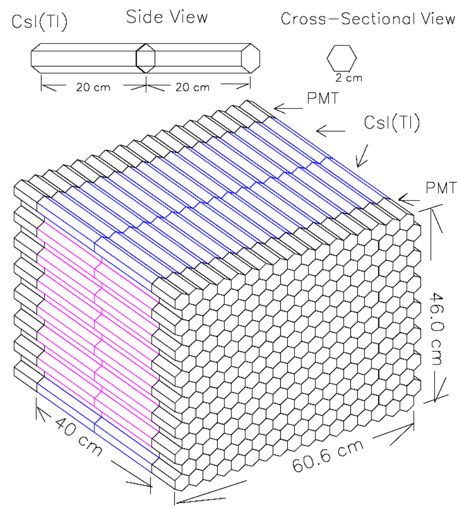
Period I : June 01 - April 02



Two detectors in inner target : HPGe and CsI(Tl) array.

Inner targer flush with nitrogen.

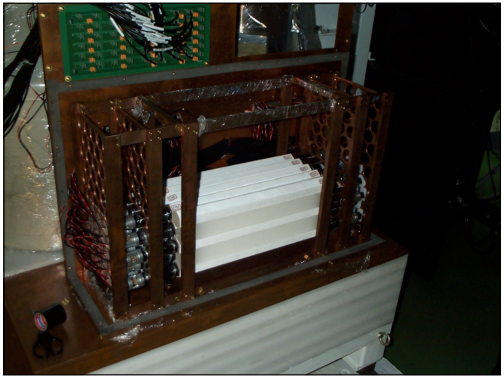


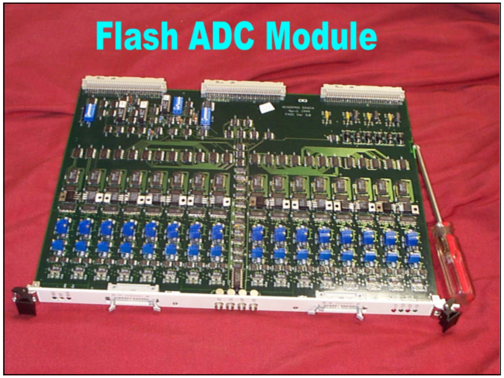


KS Expt. : Period I Detectors

ULB-HPGe [1 kg]

CsI(Tl) [46 kg]





**FADC : 16 ch.,
20 MHz, 8 bit**

Data : 600 Gb

μ_ν with Reactor $\bar{\nu}_e$

★ μ_ν :

▶ parametrize possible ${\nu_i}^L \rightarrow {\nu_j}^R + \gamma$ vertices

▶ $\exists$ both $i = j$ "diagonal" & $i \neq j$ "transition" moments

★ Experimental Probe :

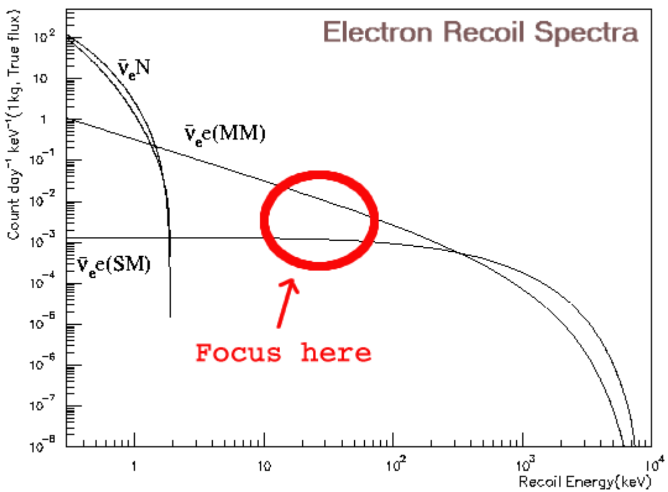
▶ Study $\bar{\nu_e} + e^- \rightarrow \bar{\nu_x} + e^-$

▶ Focus on low recoil energy

- $\sigma_\mu \sim T^{-1}$
- decouples SM "backround"

▶ Look for excess in Reactor ON/OFF

[LE Reactor $\phi(\bar{\nu_e})$ not accurately known]



★ Neutrino Radiative Decay :

▶ σ_μ & Γ_μ related : $\Gamma = \frac{1}{2\pi} \frac{(\Delta m^2)^3}{m^3} {\mu_\nu}^2$

▶ real γ for same vertices

KS/P1/Ge/μ_ν Data

♯ **Data Volume :**

- Total 4712/1250 hours ON/OFF

♯ **HPGe Performance :**

- 1.06 kg mass
- 0.4 keV RMS at 10 keV
- 5 keV detector threshold
- Background at O(1 cpd)[counts kg^{-1} day^{-1} keV^{-1}] background c/f Dark Matter expt.

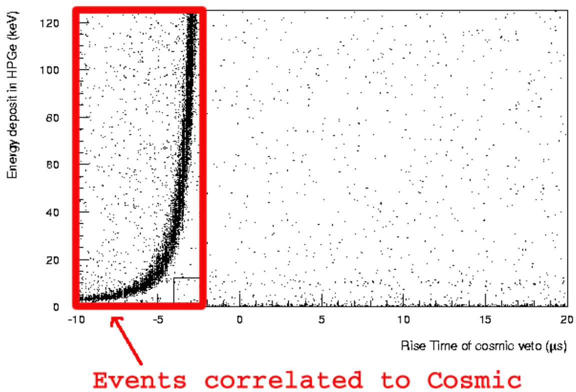
♯ **Analysis :**

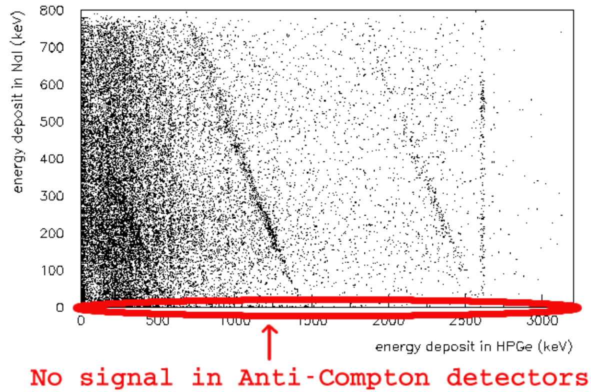
- Cosmic veto ($5\ \mu s$)
- Anti-Compton (Well + Base detectors)
- Pulse Shape Disc. (rise time, fall time, amp. to charge ratio)

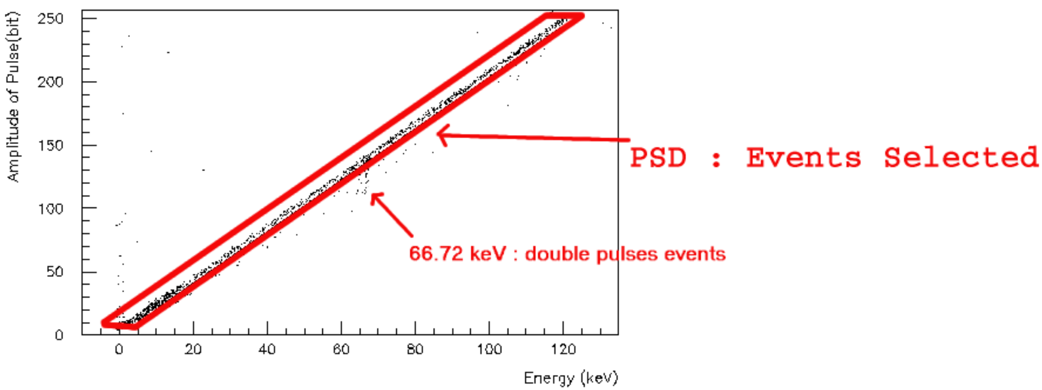
♯ **Efficiencied Normalization : (to $<$0.2%)**

- DAQ book keeping $\rightarrow$ hardware status, deadtime
- Random Trigger $\rightarrow$ Eff. of Veto
- Stability of ^{40}K peaks
- Monitor 10 keV Ga X-rays peak

Cosmic Veto, Anti-Compton & PSD







Efficiency & Uncertainties

Event selection	Suppression	Efficiency
Raw data	1.0	1.0
Anti-Compton (AC)	0.06	0.99
Cosmic-ray veto(CRV)	0.96	0.95
Pulse shape analysis	0.86	1.0
Combined efficiency	0.05	0.94

Sources	Uncertainties	$\sigma(\kappa_e^2)10^{-20}\mu_B^2$
DAQ live time ON/OFF	<0.2%	<0.30
Efficiencies for magnetic scattering	<0.2%	<0.01
Rates for magnetic scattering	24%	0.23
SM background subtraction	23%	0.03
Combined systematic error	$\cdots$	<0.4

KS/P1/Ge/μ_ν : Result

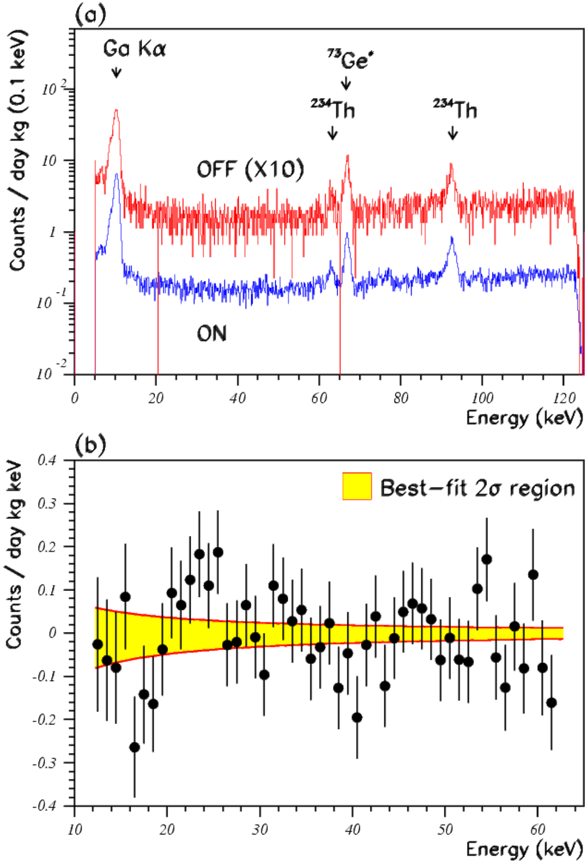
♯ **Fit OFF spectra to p5**
$\rightarrow \quad [\phi_{OFF} ; \delta\phi_{OFF}]$
(@ $\chi^2/dof = 80/96$)

♯ **Fit ON spectra to**
$\phi_{OFF} + \phi_{SM} + \kappa^2 \phi_{MM} [10^{-10} \mu_B]$

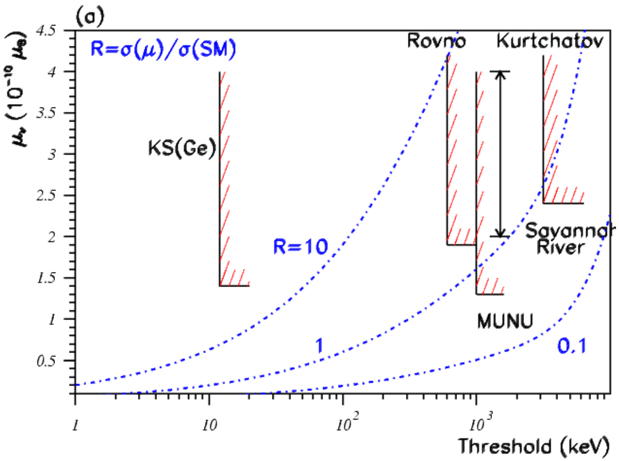
Fit Results :
(@ $\chi^2/dof = 48/49$)
$\kappa^2 = -0.4 \pm 1.3(\text{stat.}) \pm 0.4(\text{sys.})$

$\Longrightarrow$ **Limit :**
$\mu_\nu < 1.3(1.0) \times 10^{-10} \mu_B$
@ 90(68)% C. L.

H. B. Li et. al., TEXONO Coll.,
Phys. Rev. Lett. **90**, 131802(2003)



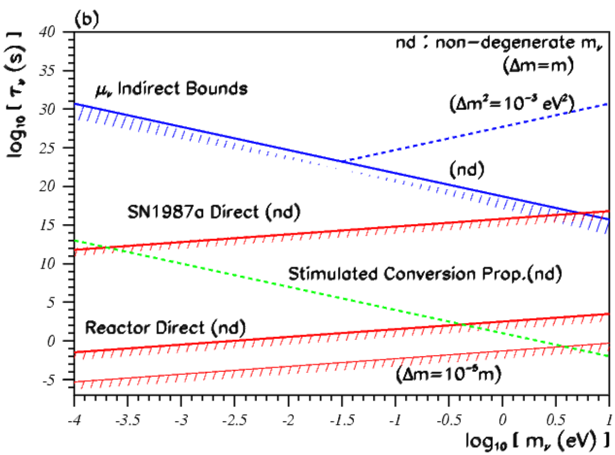
Sensitivity



$\bar{\nu}_e$ magnetic moment :

At high $\sigma(\mu)/\sigma(SM)$ ratio :

$\rightarrow$ decouple from SM "background"



$\bar{\nu}_e$ decay constant :

A better Γ_ν limit than direct search.

Period II & III Summary

♯ **Period II : HPGe**

- μ_ν analysis : + 1400/790 hours ON/OFF
  improved background & analysis

♯ **Period II : CsI(Tl) [186 kg]**

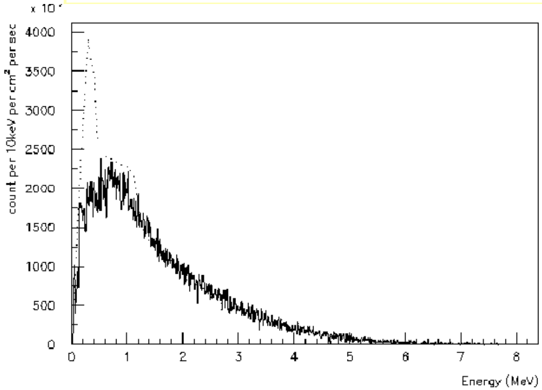
- attempt measurement of Standard Model $\sigma(\bar{\nu}_e e^-)$
  $\rightarrow sin^2\theta_W$ at MeV range

♯ **Period III : ULE-HPGe [5 g]**

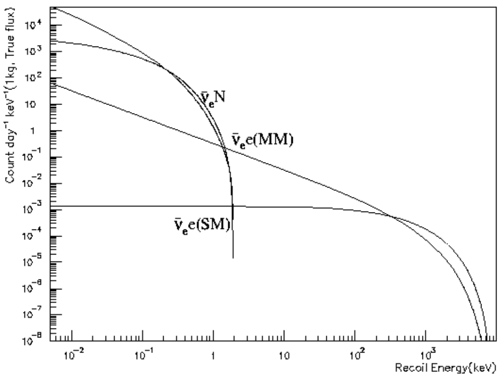
- threshold $\sim$ 60eV
- explore potentials on $\bar{\nu}_e N$ coherent scattering
- study quenching factor & pulse shape, neutron beam exp.

$\rightarrow$ trying to get onsite calibration...

$\bar{\nu}_e$ spectrum and $\bar{\nu}_e$N coherent scattering



Reactor anti-neutrino spectra



Recoil e⁻ and N spectrum

$\bar{\nu}_e e^- \rightarrow \bar{\nu}_e e^-$:

- $(\frac{d\sigma}{dt})_{SM} = \frac{{G_F}^2 m_e}{2\pi}[(g_V - g_A)^2 + (g_V + g_A)^2(1 - \frac{T}{E_\nu})^2 + (g_A^2 - g_V^2)\frac{m_e T}{E_\nu^2}]$
- $(\frac{d\sigma}{dt})_{MM} = \frac{\pi\alpha^2\mu_\nu^2}{m_e^2}(\frac{1}{T} - \frac{1}{E_\nu})$

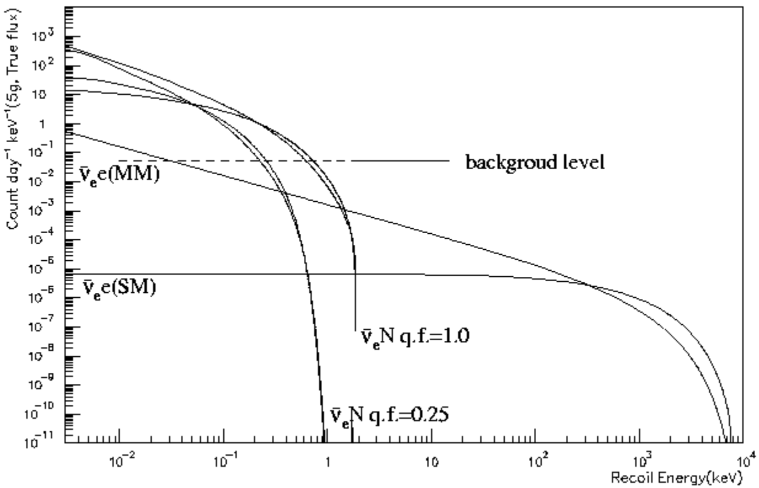
$\bar{\nu}_e N \rightarrow \bar{\nu}_e N$:

- $(\frac{d\sigma}{dt})_{SM} = \frac{{G_F}^2 m_N}{4\pi}[Z(1 - 4sin^2\theta_W) - N]^2[1 - \frac{M_N T_N}{2E_\nu^2}]$
- $(\frac{d\sigma}{dt})_{MM} = \frac{\pi\alpha^2\mu_\nu^2}{m_e^2}Z^2(\frac{1}{T} - \frac{1}{E_\nu})$

[A. C. Dodd, et. al. Phys. Lett. **B 266** 434]

Quenching factor

Quenching factor $= 0.25$, $\frac{\Delta E}{E} \sim 0.05$

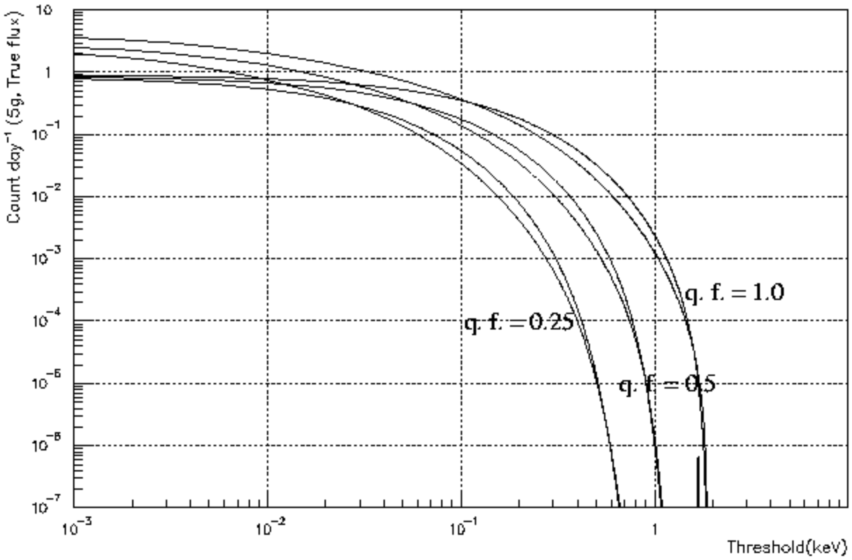


At quenching factor $= 0.25$: $\sim$ 0.05 count day^{-1}keV^{-1} at $\sim$ 140 eV.

P1 data with HPGe : 0.05 count day^{-1}keV^{-1} below 10 keV for 5g.

Integral Spectrum

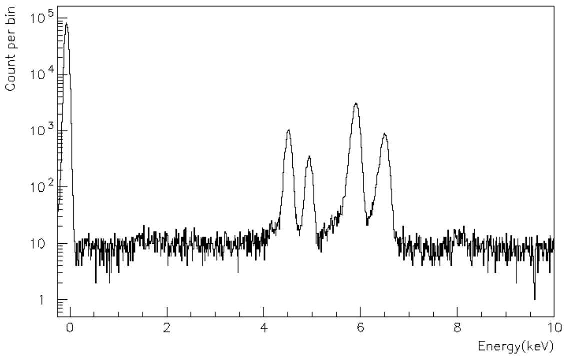
For quenching factor = 1.0, 0.25, 0.5



If threshold $\sim$ 100 eV $\rightarrow$ 0.055 count day^{-1}
Signal to noise ratio in this energy range $\sim$ 2.2

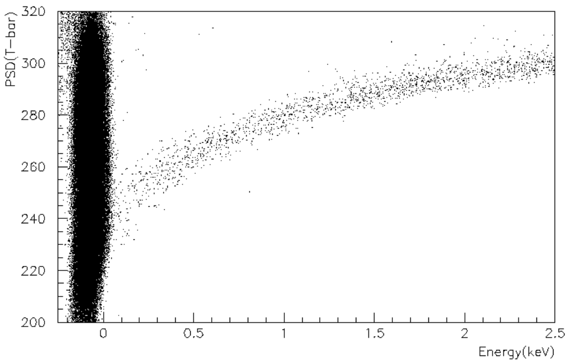
Calibration data

Source : $^{55}\mathrm{Fe}$(5.9 keV, 6.49 keV) and Ti(4.51 keV, 4.93 keV) :



Extrapolate energy calibration to low energy

$\longrightarrow$ threshold $\sim$ 60 eV.



Noise and signal are well seperater

Summary

♯ **Period I : HPGe**

- μ_ν analysis : results published

♯ **Period II :**

- analysing additional data on HPGe and CsI-array detectors

♯ **Period III : ULE-HPGe [5 g]**

- how to do calibration on-site?
- study quenching factor & pulse shape, neutron beam exp.
- upgrade to 1 kg multi-array ULE-HPGe.

♯ **Meanwhile :**

- other projects go on parallel