Neutrino and Dark Matter Physics with an Ultra-Low-Energy Germanium Detector

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OUTLINE

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$\bar{\nu}_e$N Coherent Scattering

Differential cross-section

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

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

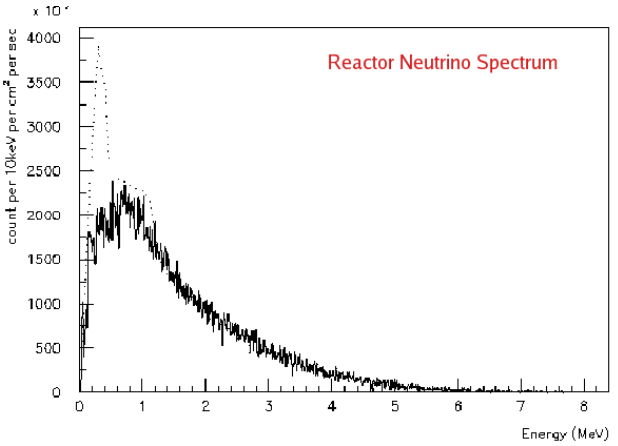
$\bar{\nu}_e N \rightarrow \bar{\nu}_e N$ scattering :

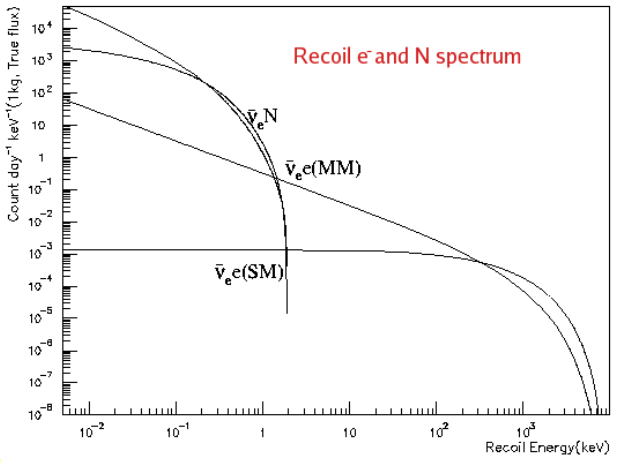
- $(\frac{d\sigma}{dt})_{SM} = \frac{{G_F}^2 m_N}{4\pi}[Z(1 - 4sin^2\theta_W) - N]^2[1 - \frac{M_N T_N}{2E_\nu^2}]$
  $\rightarrow N^2$ enhancement
- $(\frac{d\sigma}{dt})_{MM} = \frac{\pi\alpha^2\mu_\nu^2}{m_e^2}Z^2(\frac{1}{T} - \frac{1}{E_\nu})$

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

- Low recoil energy : $T_{max} = \frac{2{E_\nu}^2}{M_N + 2E_\nu}$ ($\sim$ 1.9 keV for $E_\nu = 8$ MeV, Ge)

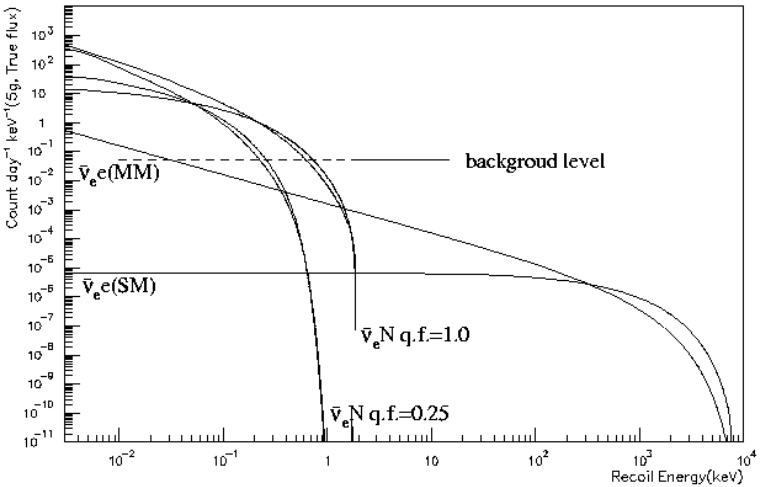
$\bar{\nu}_e$ spectrum and Recoil e^-, N Spectrum





Quenching factor

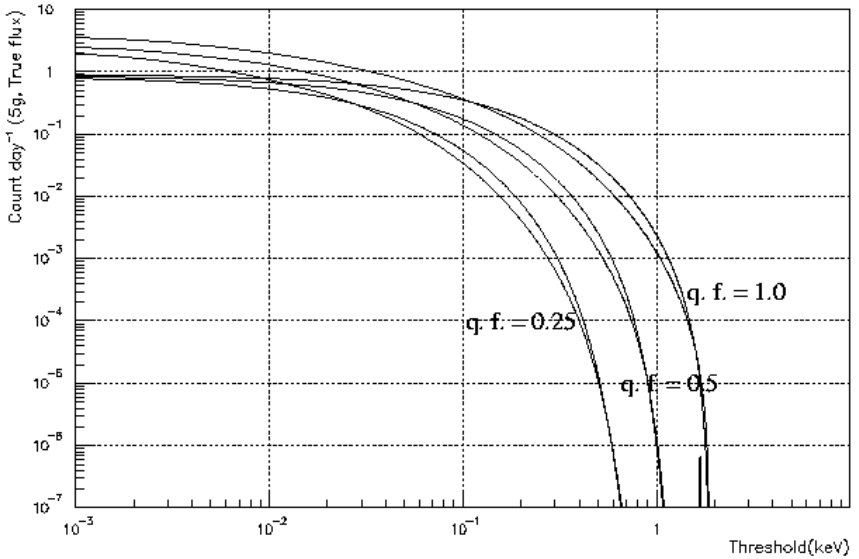
Quenching factor $= 0.25$, $\frac{\Delta E}{E} \sim 0.05$



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

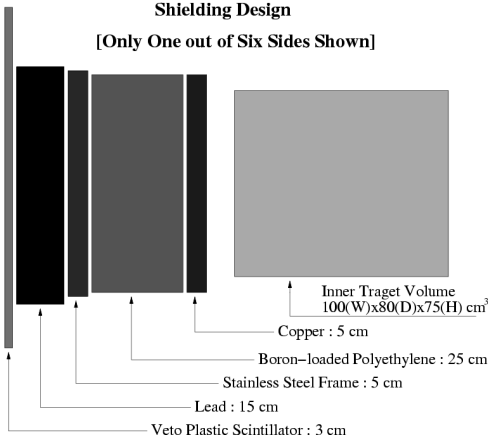


If threshold $\sim$ 100 eV $\rightarrow$ 0.055 count day^{-1} (for 5 g, 11 count day^{-1} for 1 kg)
Signal to noise ratio in this energy range $\sim$ 2.2

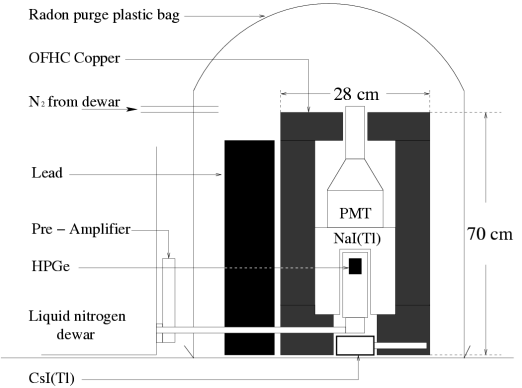
ULE-HPGe detector

ULE-HPGe

target mass : 5 g



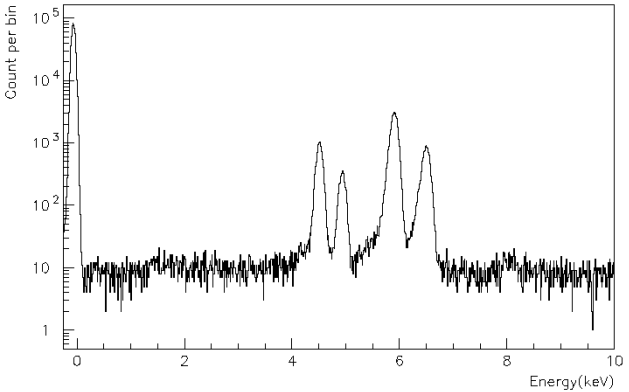
shielding 4π coverage



ULE-HPGe with anti-compton

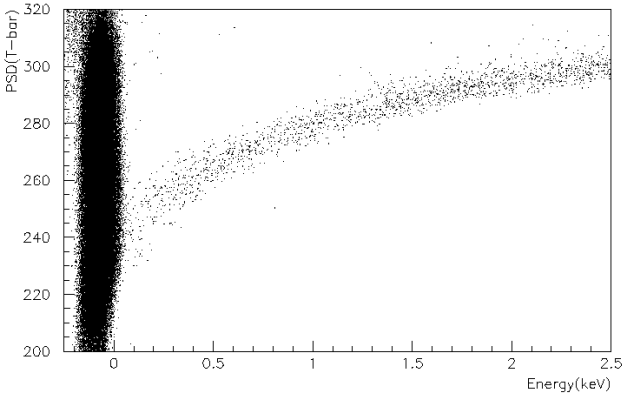
Calibration data

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



Extrapolate energy calibration to low energy

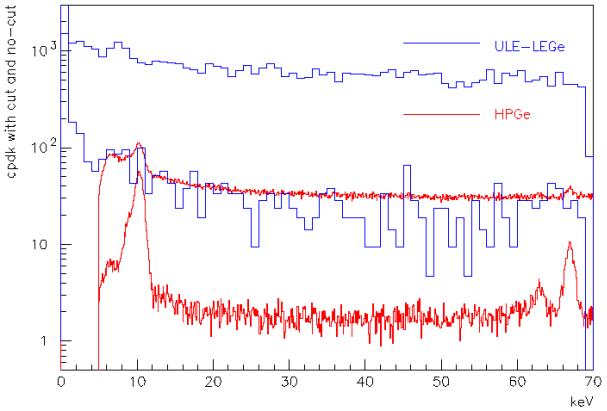
$\longrightarrow$ threshold $\sim$ 60 eV.



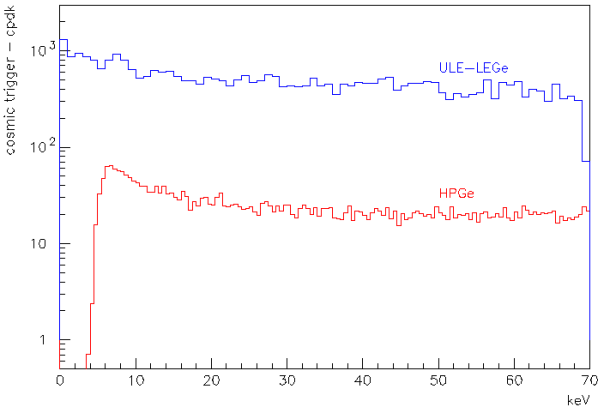
Noise and signal are well seperater

Background with ULE-HPGe

Compare period I HPGe data with ULE-HPGe :

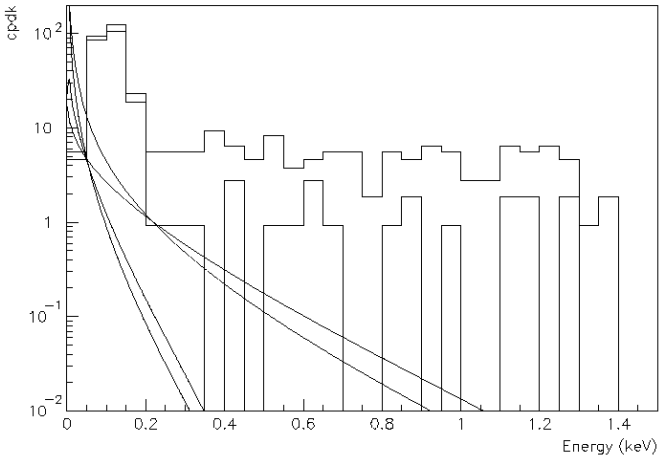


After scale to mass, ULE-HPGe data is 1 order larger then period I data, with or without veto cut.



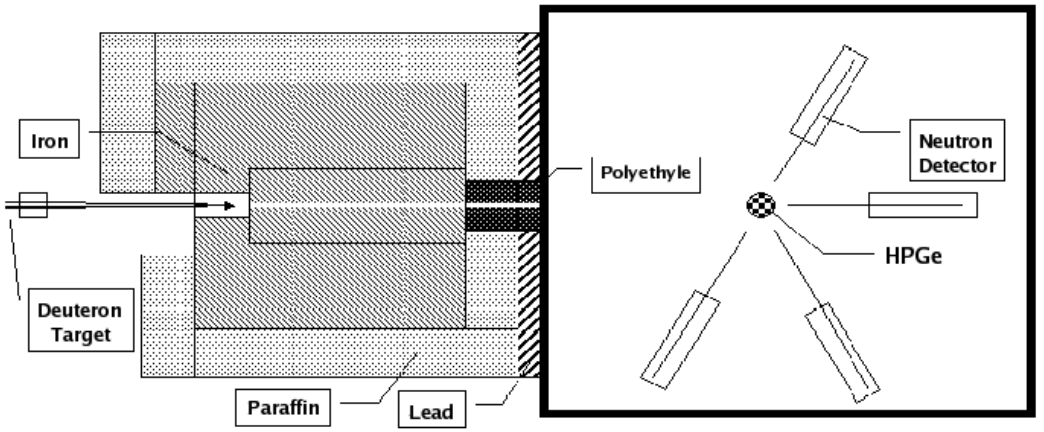
Even the cosmic trigger event rate is 1 order different.
$\longrightarrow$ scale with surface?
$\longrightarrow$ need further simulation to clarify.

Low Energy Noise



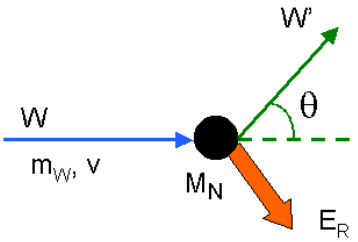
Peak at 100 eV $\rightarrow$ probably noise.
$\rightarrow$ a better PSD analysis is need.

Plan : Quenching Factor Measurement



Last Quenching Factor Measuremen of Ge is 30 years ago.
Quenching Factor by using neutron beam at
Institute of Atomic Energy, Beijing(CIAE).

Dark Matter(WIMP) Experiment



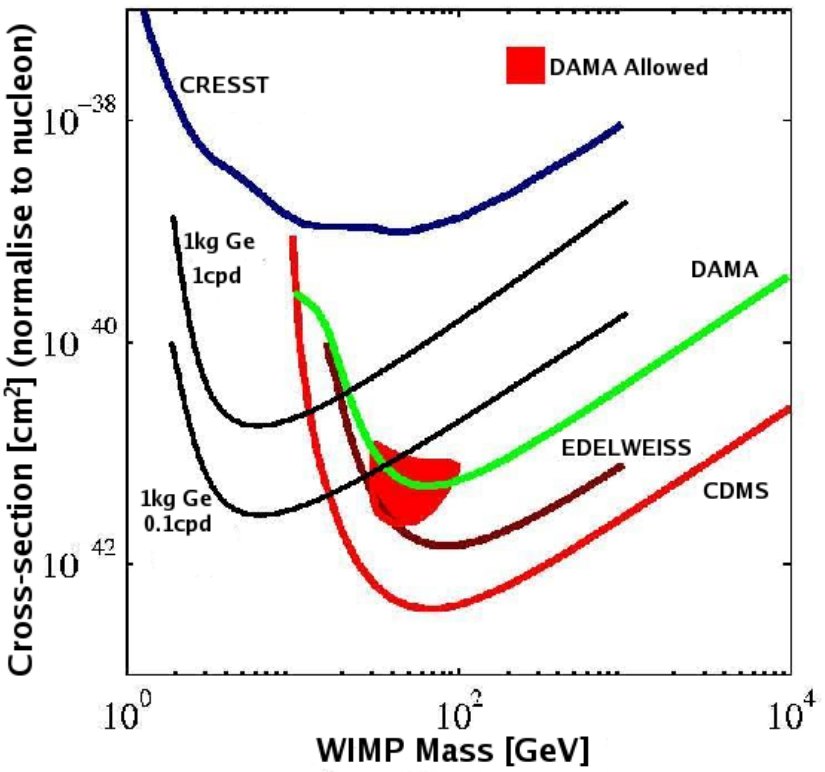
WIMP detection :

- passible mass range 1 GeV - 1 TeV.
- Typical nuclei recoil energy 0 - 100 keV.
- expected background rate $\sim$ 1 cpd, or less.

Rate per recoil energy :

$$\frac{dR}{dE_r} = \frac{\rho\sigma_0|F(q)|^2}{2m_W\mu^2}\int_{v>\sqrt{M_N E_r/2\mu^2}}\frac{f(\vec{v},t)}{v}d^3v.$$

WIMP detection with ULE-HPGe



Low threshold → sensitive to low mass region.

Plan : Background Measurement at Y2L

Background measurement at Yang Yang Underground Lab(South Korea), supported by KIM group.

- with 5 g ULE-HPGe
- 700 m of rock.
- Cosmic-rays level $\longrightarrow$ 5 order less.

Future Plan

- Quenching factor measurement at CIAE.
- Background measurement at Y2L.
- Install 4 $\times$ 5 g array ULE-HPGe at power plant.
- Understand the background level
  $\rightarrow$ simulation and PSD studies
- Background and threshold studies with a 10 g ULE-HPGe.
- Calibration at $<$ keV, e^- source generate X-rays from C, O.

Summary

- explore potentials on $\bar{\nu}_e N$ coherent scattering
  $\rightarrow$ open window on low mass WIMP studies.

- preliminary result :
  $\rightarrow$ threshold $\sim$ 60eV - 120eV could be achieved
  $\rightarrow$ background level is 10$\times$ of period I when scale by mass.
  $\rightarrow$ trying to understand high background rate.

- plans :
  $\rightarrow$ prototype study on multi-array 4$\times$5 g detector on site
  $\rightarrow$ background level study on 10 g detector
  $\rightarrow$ quenching factor with neutron beam exp at CIAE
  $\rightarrow$ background measurement at Y2L

- target : 1 kg multi-array ULE-HPGe detector
  $\rightarrow$ Dark Matter experiment
  $\rightarrow$ $\bar{\nu}_e N$ coherent scattering experiment