Research Program towards the first observation of neutrino-nucleus coherent scattering

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OUTLINE

- Reactor Neutrino Physics at Low Energy
  - Magnetic Moment Search
  - $\bar{\nu}_e N$ Coherent Scattering
- LEGe Prototype Measurements with Sources
- Background Level at Reactor & Underground Lab.
- Simulation Results
- Plans & Summary

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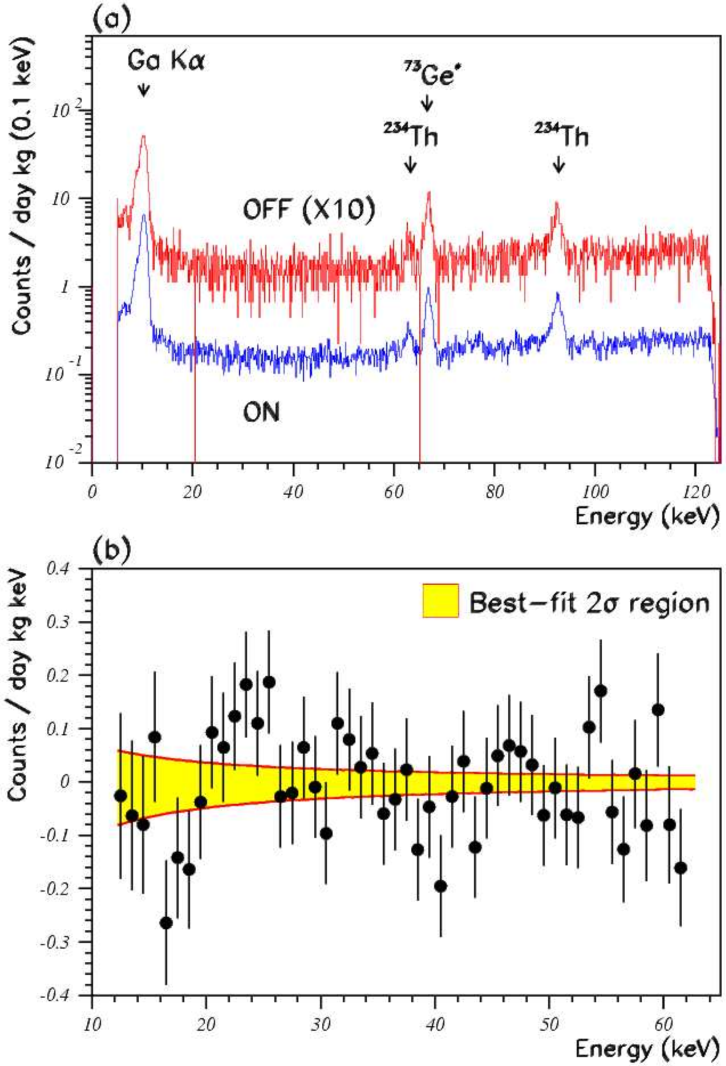
$\bar{\nu}_e$ Magnetic Moment Search

- 1 kg HPGe detector at reactor 4712/1250 hours ON/OFF data.
- Background level $\sim$ 1 cpd
- $\mu_\nu < 1.3 \times 10^{-10} \mu_B$ 90% C. L. [PRL **90**, 2003]
- Improve analysis : combine ON/OFF spectrum before/after cut
  $\Rightarrow \mu_\nu < 1.0 \times 10^{-10} \mu_B$
- $\times$3 more data : expect $\rightarrow \mu_\nu < 0.8 \times 10^{-10} \mu_B$
- New detector : threshold $\sim$ 500 eV
  $\Rightarrow \mu_\nu \rightarrow 2 \times 10^{-11} \mu_B$



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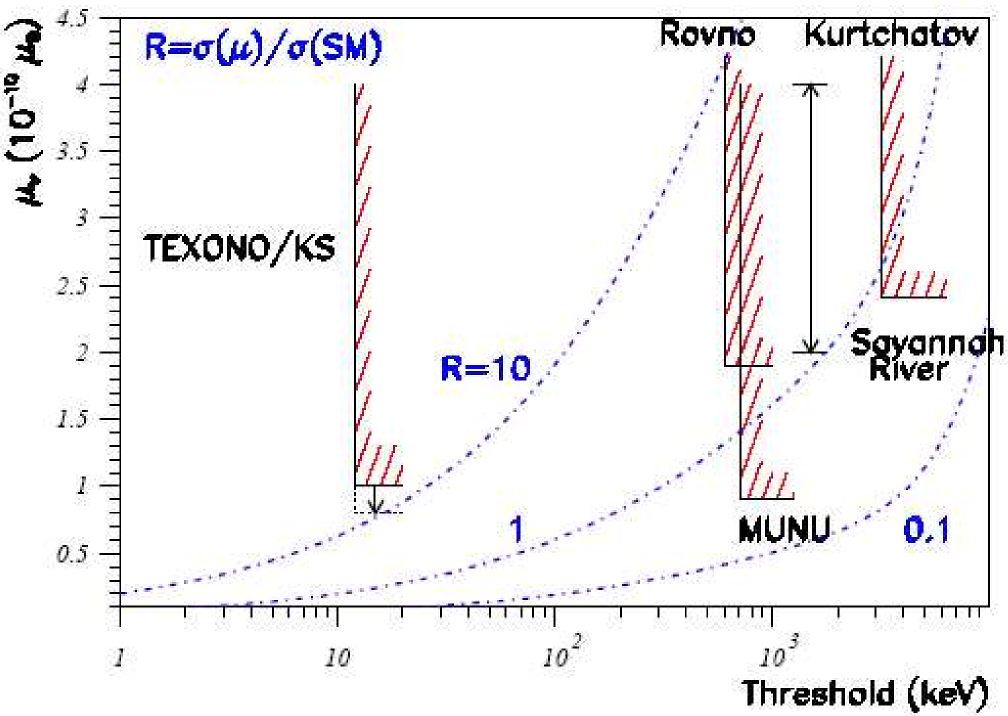
$\bar{\nu}_e$ at Low Energy



- $(\frac{d\sigma}{dt})_{MM} = \frac{\pi\alpha^2\mu_\nu^2}{m_e^2}(\frac{1}{T} - \frac{1}{E_\nu})$
- Low Energy $\rightarrow (d\sigma/dT)_{MM} >> (d\sigma/dT)_{SM}$
  decouple bkg & unknown sources
- For $T << E_\nu \rightarrow d\sigma/dT$ depends on total flux $\phi\nu$
  NOT shape of $\phi\nu(E_\nu)$

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

- $\nu + N \rightarrow \nu + N$
  - $(\frac{d\sigma}{dt})_{SM} = \frac{{G_F}^2 m_N}{4\pi}[Z(1-4sin^2\theta_W) - N]^2[1 - \frac{M_N T_N}{2E_\nu^2}]$
    $\rightarrow N^2$ enhancement
  - Low recoil energy : $\sim$ 1.9 keV for $E_\nu = 8$ MeV, Ge
- A fundamental neutrino interaction never been expermentally observed.
- A sensitive test to Standard Model.
- An important interaction/energy loss channel in astrophysics media.
- A promising new detection channel for neutrinos, without strict lower bound on E_ν & the channel for WIMP direct detection.
- Involves new energy range at low energy, many experimental challenges & much room to look for scientifi c surprises.

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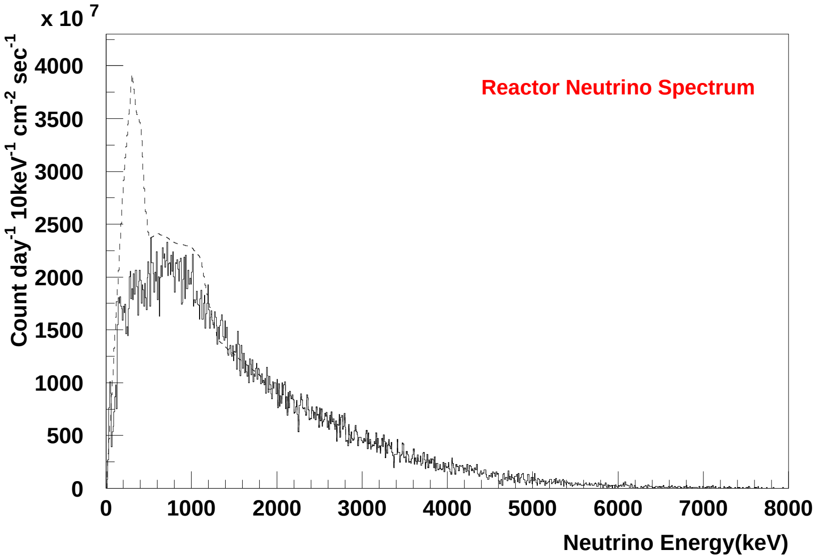
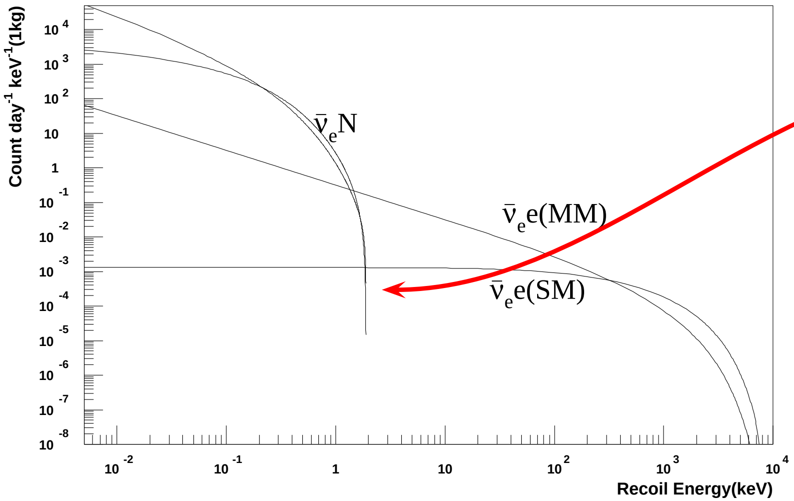
$\bar{\nu}_e$ Spectrum and Recoil e^-, N Spectrum





Maximum energy loss

$\sim$ 1.9 keV

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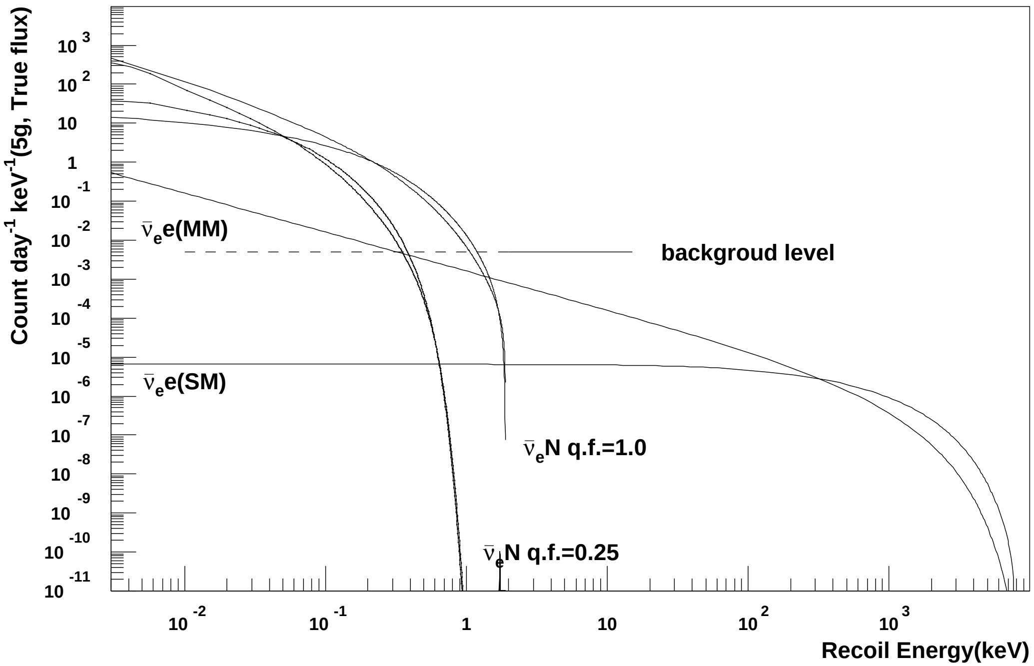
Quenching Factor

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



- Take Q. F. $= 0.25$, extrapolate background to eV level $\Rightarrow$ signal/noise > 1 at 300 eV
- At threshold $\sim$ 100 eV $\Rightarrow$ 11 count day^{-1} kg^{-1}
- Signal to noise ratio $\sim$ 22

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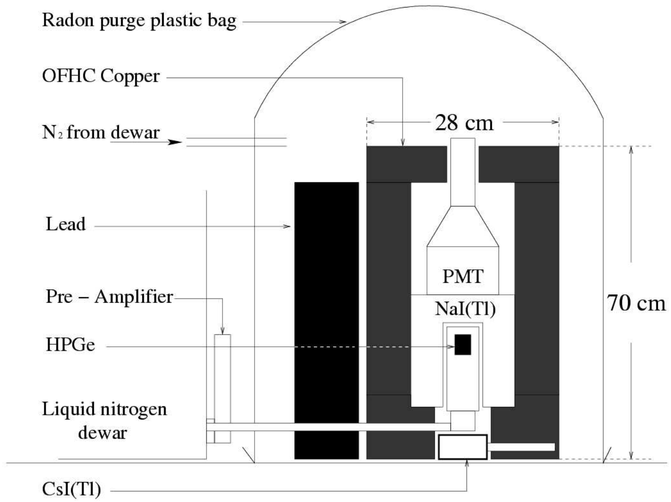
ULE-HPGe detector

ULE-HPGe

target mass 5 g



ULE-HPGe with anti-Compton detector

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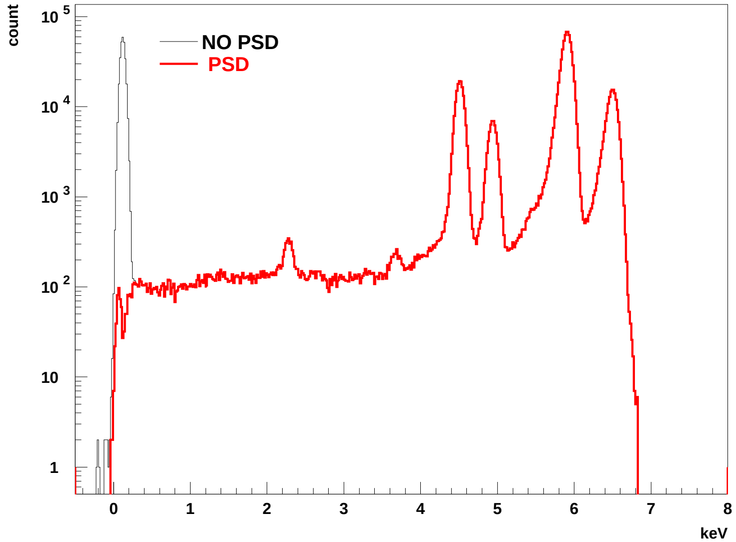
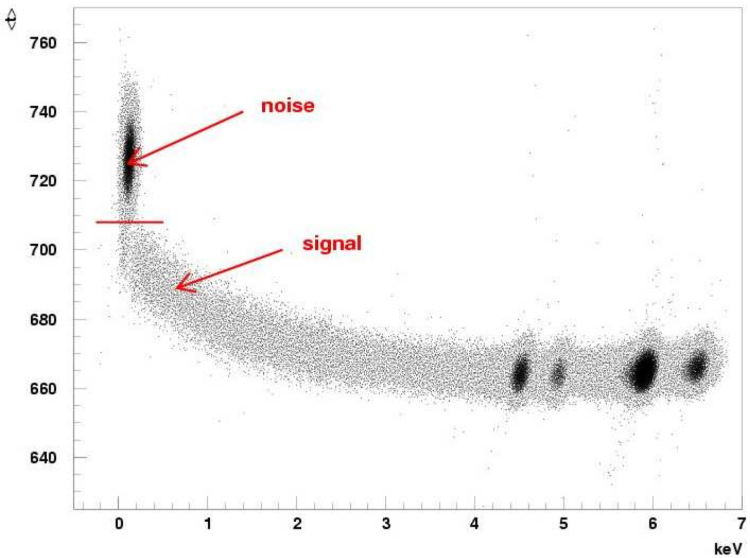
Calibration & Threshold

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



Extrapolate energy calibration to low energy



$\Rightarrow$ threshold $\sim$ 100-200 eV.
Need calibration in low energy to comfi rm this!

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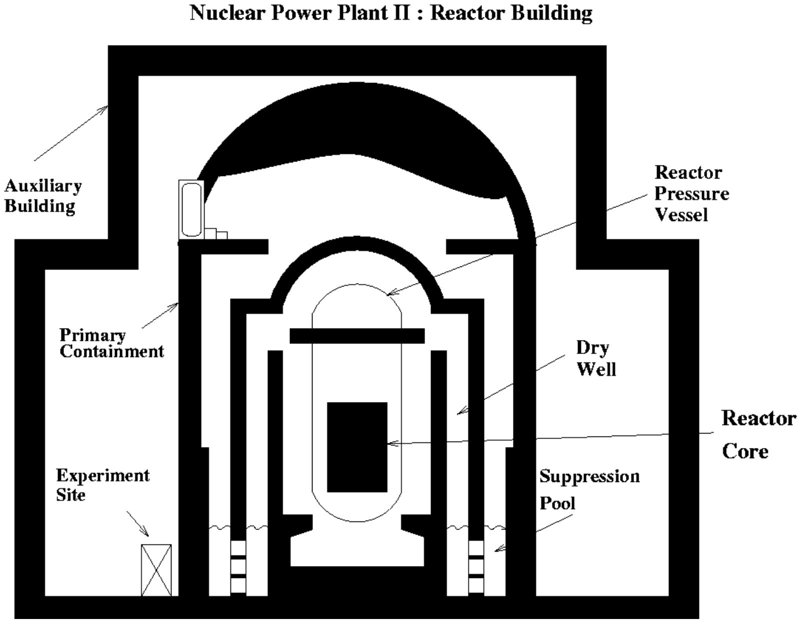
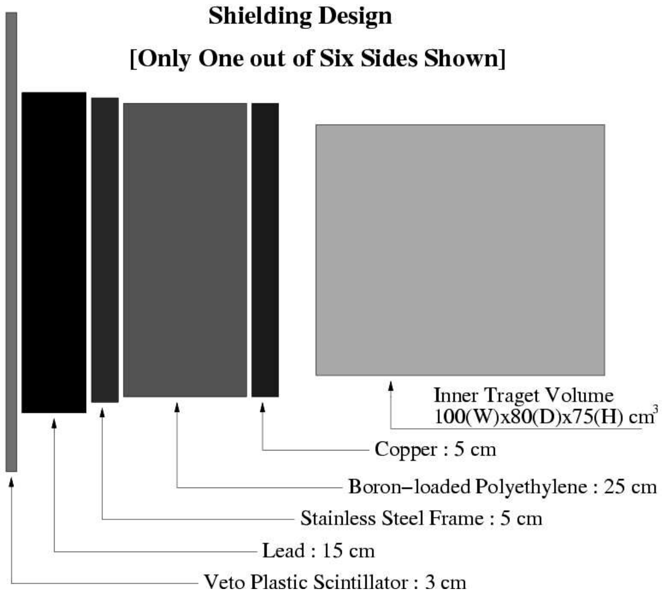
Kuo-Sheng Neutrino Lab





Yangyang Underground Lab.(Y2L), Korea

- 700 m of rock → Cosmic-rays level 5 order less.

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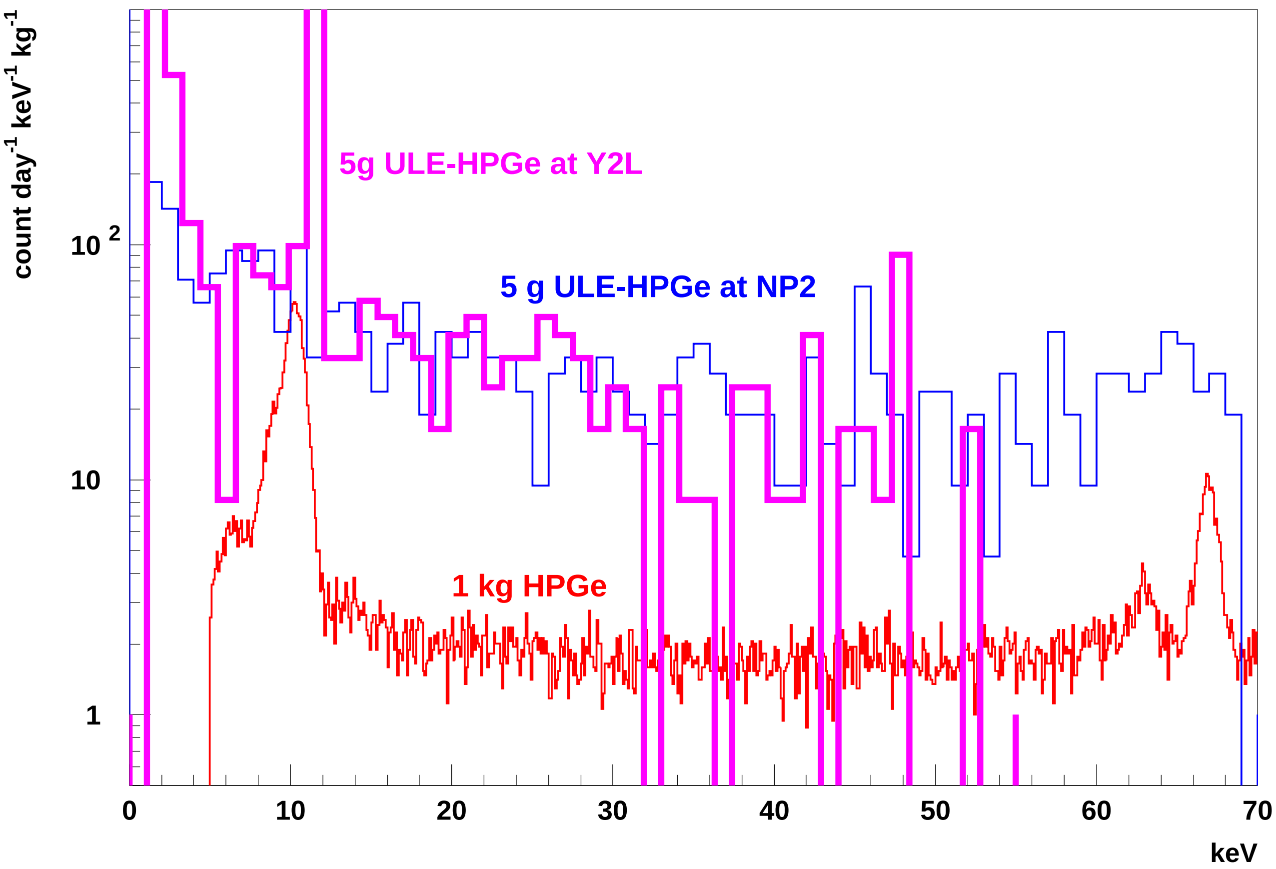
Background Measurement at KS Lab. & Y2L



- KS Lab. & Y2L give same background level.
- Background : 10× more then 1 kg detector.
- Active shielding at power plant is "nearly" as effi ciency as underground lab.

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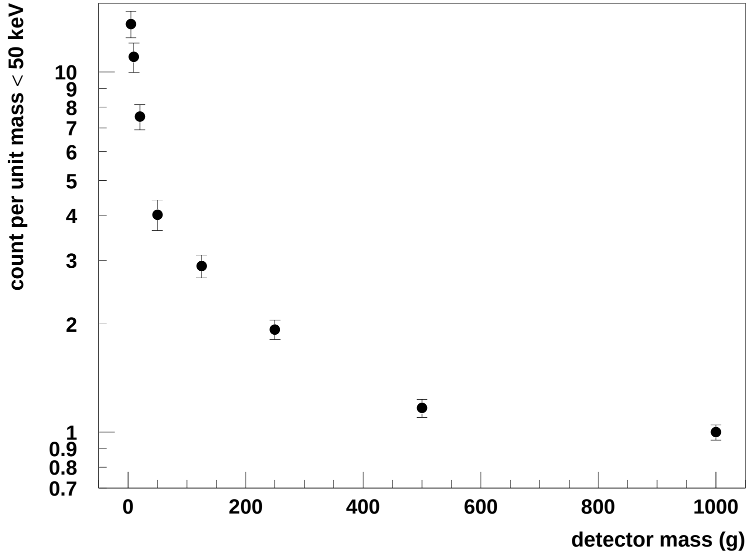
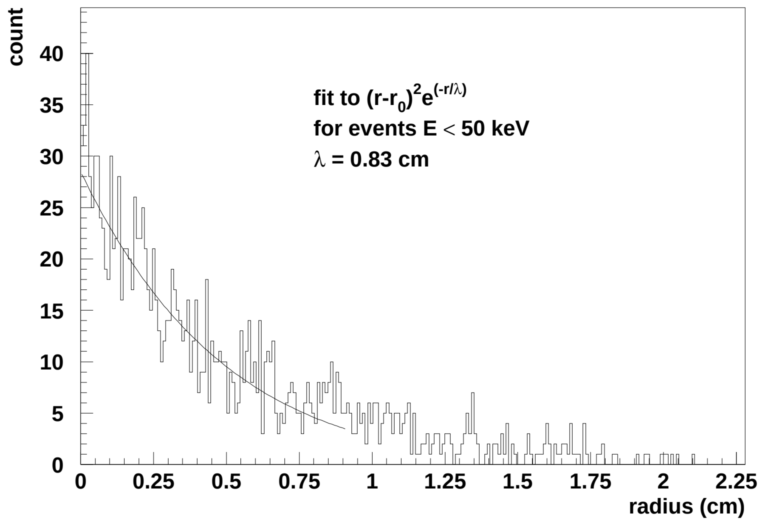
Simulation Result





- Attenuation length $\sim$ 0.8 cm for E $<$ 50 keV.
  $\Rightarrow$ Deposit energy at the surface of detector.
  $\Rightarrow$ Background rate $\propto$ Surface area of detector.

- Compact & multi-array
  $\Rightarrow$ good background suppression.

- 125$\times$5 g detector with outer elements as veto
  $\Rightarrow$ 10% of background rate of 1 kg detector in one pieces.

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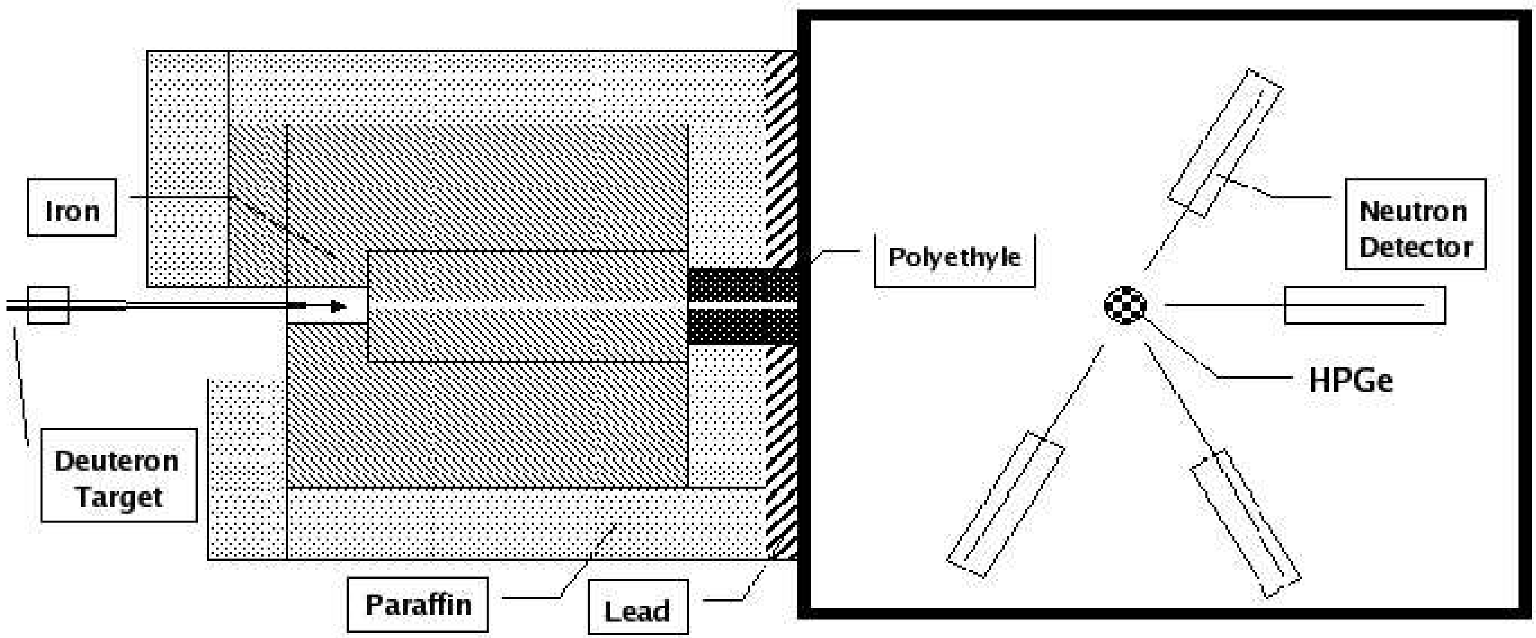
Plan : Quenching Factor Measurement



- Quenching Factor Measuremen of Ge at sub-keV range.
- Measure the Quenching Factor by using neutron beam at Institute of Atomic Energy, Beijing(CIAE).

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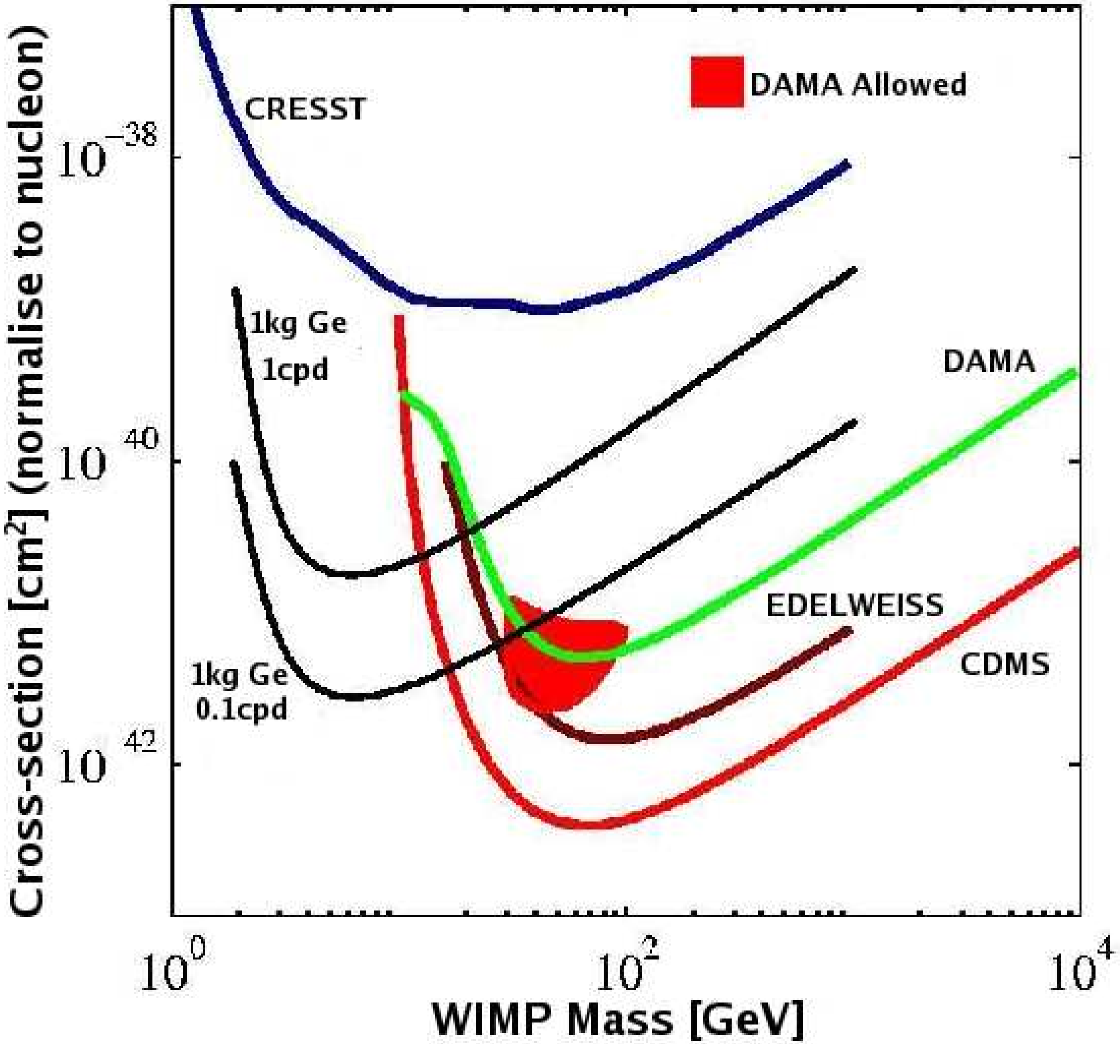
WIMP Detection with ULE-HPGe Detector



- Low threshold → sensitive to low mass region.

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Summary

- physics goal :
  - $\bar{\nu}_e N$ coherent scattering experiment
  - Dark Matter experiment
- 5 g detector result :
  - threshold $\sim$ 100eV - 200eV could be achieved.
  - 10$\times$ more background $\leftarrow$ understood.
- plans :
  - calibration at energy $<$ 3 keV, e^- source
    generate X-rays from C, O.
  - prototype study on multi-array 4$\times$5 g detector on site.
  - Threshold with PSD studies.
  - quenching factor with neutron beam exp at CIAE.
- target : $\sim$ 1 kg segmented ULE-HPGe detector

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