Low Energy Neutrino Physics at Reactors

- Kuo-Sheng Neutrino Laboratory & Program
- Update of Neutrino Magnetic Moment results
- Sensitivities of Magnetic Moment Searches
- Neutrino-Nucleus Coherent Scatterings : Physics & Motivations
- Ultra-Low Energy High-Purity Germanium Detector Prototype
- Status & Plans

Henry T. Wong

Academia Sinica @

WIN-05, Delphi

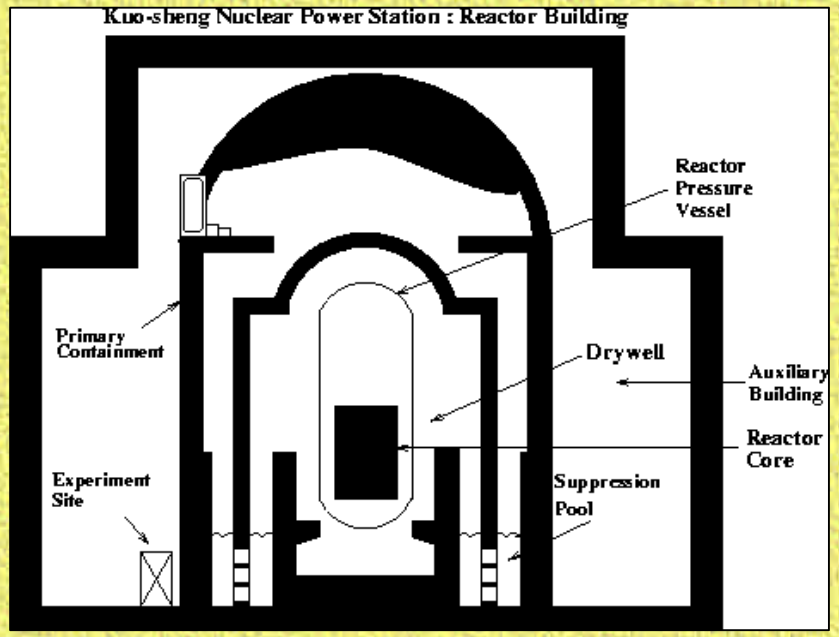
TEXONO Collaboration

Collaboration : **Taiwan (AS, INER, KSNPS, NTU) ; China (IHEP, CIAE, THU, NJU) ; Turkey (METU) ; USA (UMD)**

Program: **Low Energy Neutrino & Astroparticle Physics**

- **Kuo-Sheng (KS) Reactor Neutrino Laboratory**
  - reactor : high flux of low energy electron anti-neutrinos
  - oscillation expts. $\Rightarrow$ $m_\nu \neq 0$ $\Rightarrow$ anomalous ν properties & interactions
  - ν physics full of surprises , need intense ν-source
    - ※ study/constraint new regime wherever experimentally accessible
    - ※ explore possible new detection channels
- **Diversified R&D Projects**

Kuo Sheng Reactor Neutrino Laboratory



Front View *(cosmic vetos, shieldings, control room …..)*

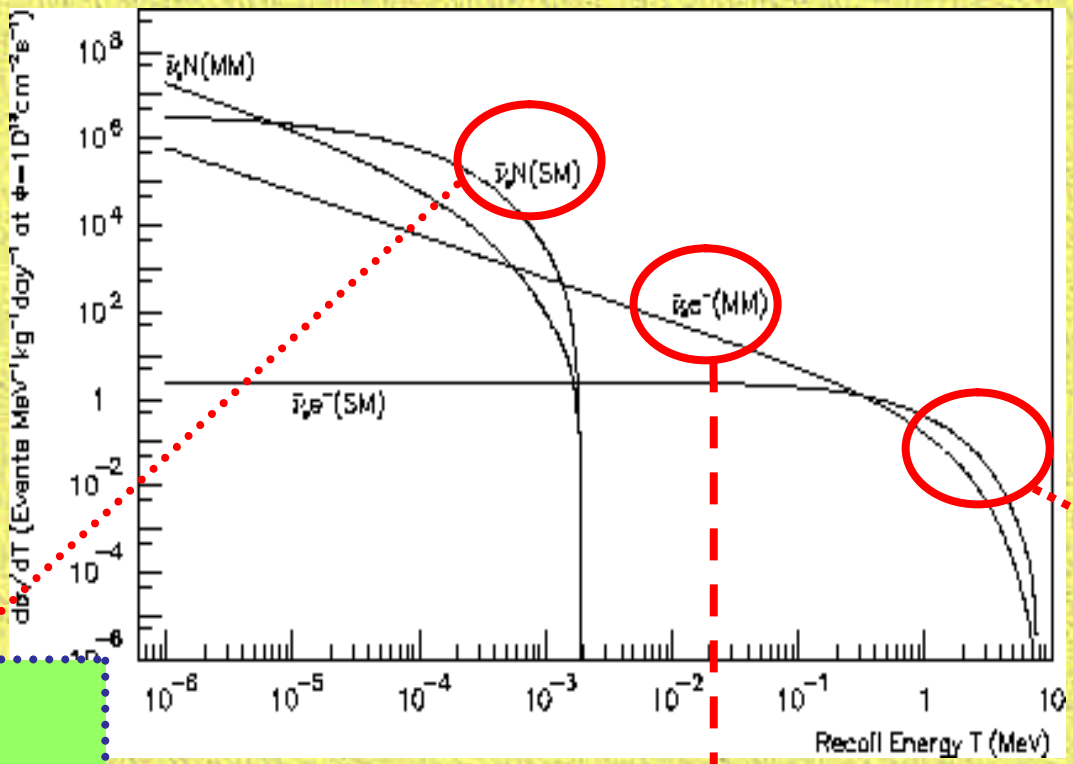
Inner Target Volume

Configuration: **Modest yet Unique**

Flexible Design: **Allows different detectors conf. for different physics**

Reactor Neutrino Interaction Cross-Sections

quality ← Detector requirements → mass



R&D :

- **Coh. (νN)**
- **T < 1 keV**

Results & More Data:

- **$\mu_\nu(\nu_e)$**
- **T ~ 1-100 keV**

On-Going Data Taking & Analysis

- **SM σ(νe)**
- **T > 2 MeV**

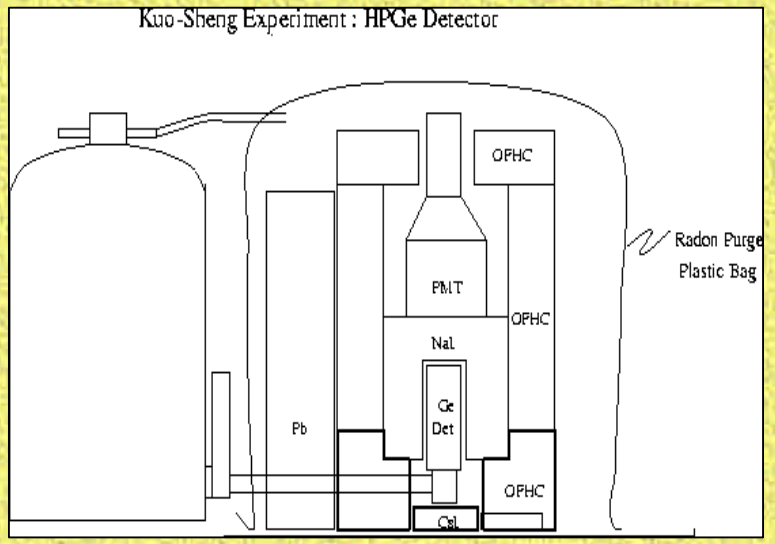
Other (More Speculative / Fun) Studies :

- production and physics potentials of ν_e's at reactors (hep-ex/0502001)
- looking for neutrino-induced nuclear transitions
- production of axions at reactor & their searches

…… not discussed here

Improved Magnetic Moment Analysis

- simple compact *all-solid* design : HPGe (mass 1 kg) enclosed by active NaI/CsI anti-Compton, further by passive shieldings & cosmic veto
- selection: single-event after cosmic-veto, anti-Comp., PSD
- TEXONO data (4712/1250 hours ON/OFF) [PRL 90, 2003]
  - background comparable to underground CDM experiment : ~ 1 $day^{-1}keV^{-1}kg^{-1}$ (cpd)
  - DAQ threshold 5 keV analysis threshold 12 keV



Combined Analysis with all Information :

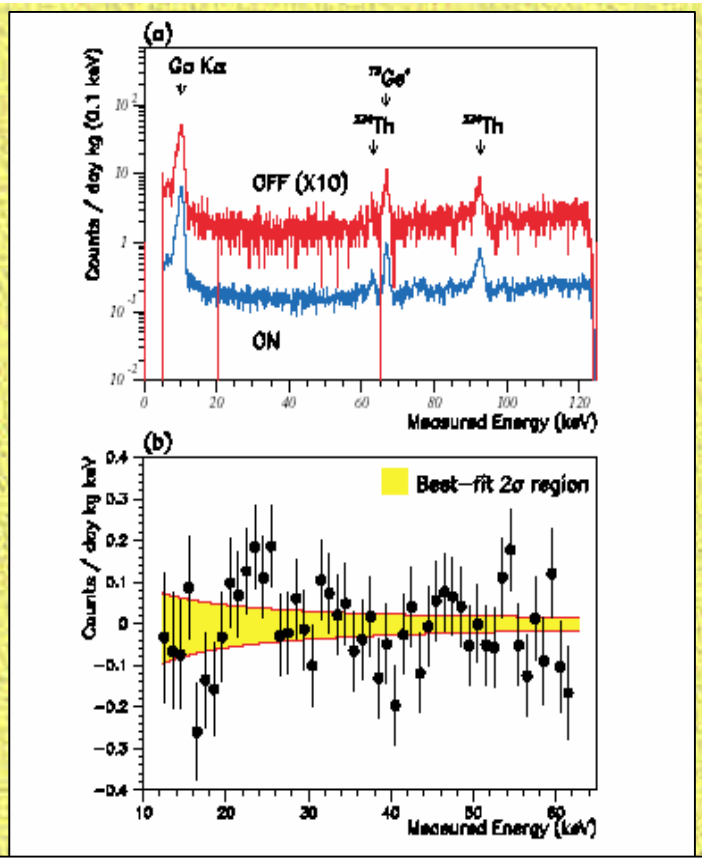
- **Denote**

$g = \text{ON};\ f = \text{OFF};\ 1,2 = \text{before, after cuts};$
$\nu = \text{SM} + \mu_\nu\ ;\ \Delta g = \text{cut spectra};\ \lambda = \text{supression}$

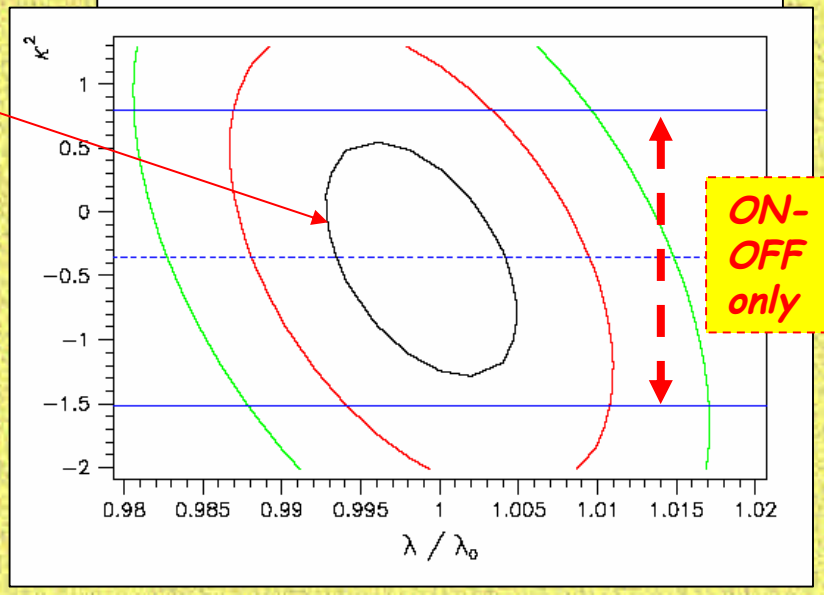
$$\nu = g_2 - f_2$$

$$\lambda = 1 - \frac{\Delta g}{f_1}$$

$$\lambda = \frac{g_2 - \nu}{g_1 - \nu}$$



1σ contour



- **Limit:**

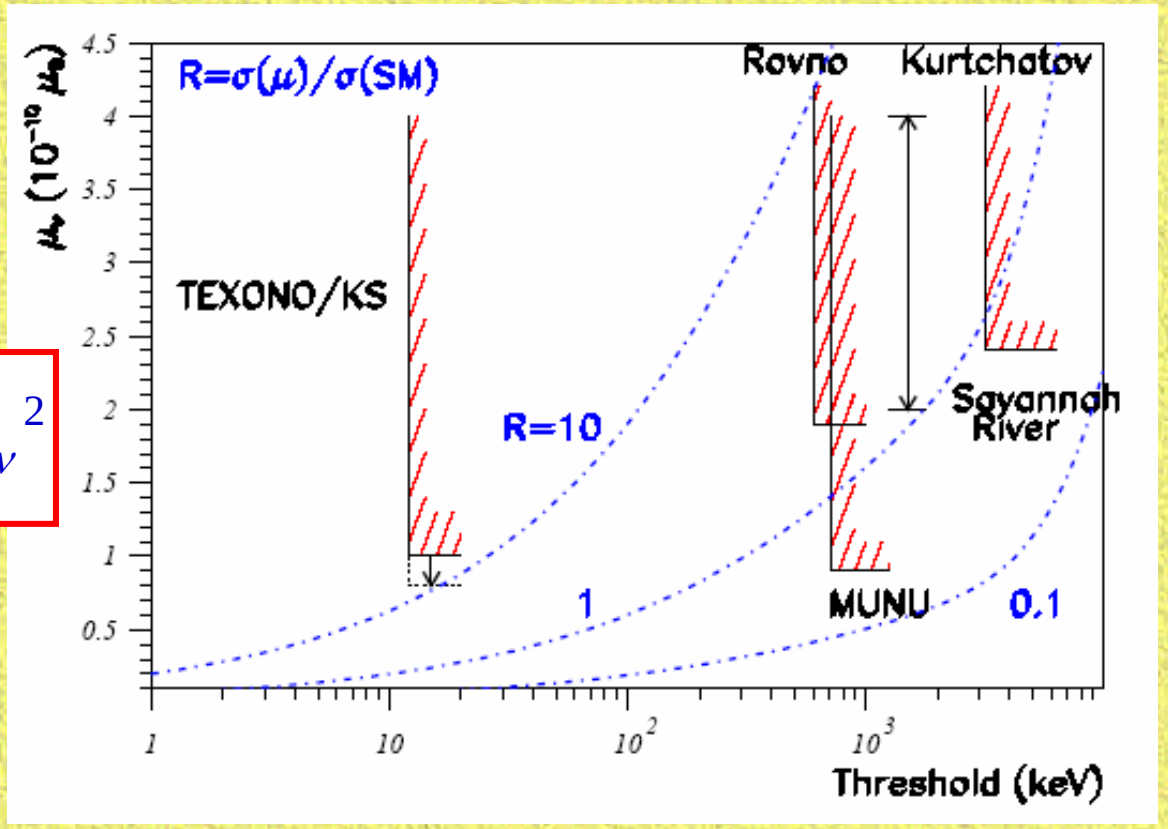
$\mu_\nu(\nu_e) < 1.0 \text{ X } 10^{-10}\ \mu_B$ (90% CL)

- **X 3 data volume : expect sensitivity range**

$\mu_\nu(\nu_e) \rightarrow 8 \text{ X } 10^{-11}\ \mu_B$

μ_ν

$$\frac{d\sigma}{dT}(\nu e)_\mu = \frac{\pi\alpha^2}{m_e^2}\left[\frac{1}{T} - \frac{1}{E_\nu}\right]\mu_\nu{}^2$$



Search of μ_ν at low energy

⇒ **high signal rate & robustness:**

- μ_ν>>SM [decouple irreducible bkg ⊕ unknown sources]
- T << E_ν ⇒ dσ/dT depends on total ϕ_ν flux but *NOT* spectral shape [flux well known : ~6 fission-ν ⊕ ~1.2 ^{238}U capture-ν per fission]

Sensitivity Improvement

Statistically cales as:

$$\mu_\nu \propto \frac{1}{\sqrt{N_\nu}} \left(\frac{B}{mt}\right)^{\frac{1}{4}}$$

- N_ν : signal events
- **B** : background level
- **m** : target mass
- **t** : measurement time

- $N_\nu \propto \phi_\nu$ (neutrino flux) & related to T-threshold
- **T-threshold** : e.g. N_ν increase X~3 from 10 keV to 10 eV in Ge (1/T ⊗ atomic energy level threshold)

∴ **BIG** statistical boost in μ_ν comes from enhancement in ϕ_ν by, e.g. artificial ν-sources, β-beams etc.

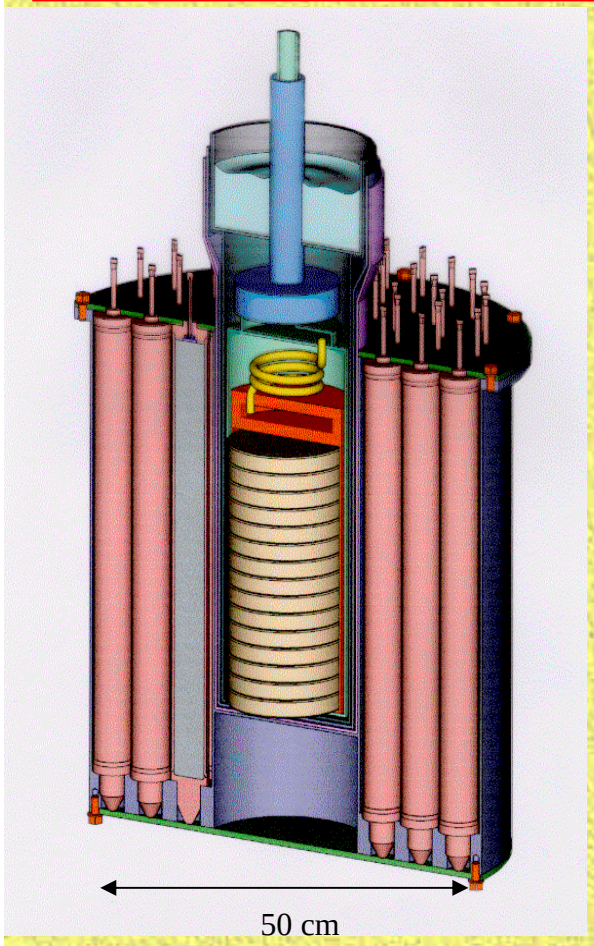
BUT: for systematics control, coupled with

※ low threshold to keep μ_ν >> SM rates

※ maintain low background level

e.g. As Illustrations……

MAMONT Project : ^{3}H-source (Russia, USA, Germany)



Conceptual layout of the ν-e scattering experiment with 40 MCi tritium source

- $\bar{\nu}_e$ **TRITIUM SOURCE of 40 MCi activity (4 kg ^{3}H) with flux of 6×10^{14} cm^{-2}s^{-1} (!)**
- **ULTRA-LOW-THRESHOLD DETECTORS E_{th}~10 eV (!):**
  - **SILICON CRYODETECTOR 15×100cc M=3kg, *ionization-into-heat conversion effect (CWRU-Stanford-JINR)***
  - **HIGH-PURITY-GERMANIUM DETECTOR 6×150cc, M=4.8kg, *internal amplification by avalanche multiplication (ITEP)***

SENSITIVITY (95% C.L.): **$\mu_\nu \rightarrow 2.5\times10^{-12}\mu_B$**

Status : **R&D**

Neutrino-Nucleus Coherent Scattering :

$$\nu + \mathrm{N} \rightarrow \nu + \mathrm{N}$$

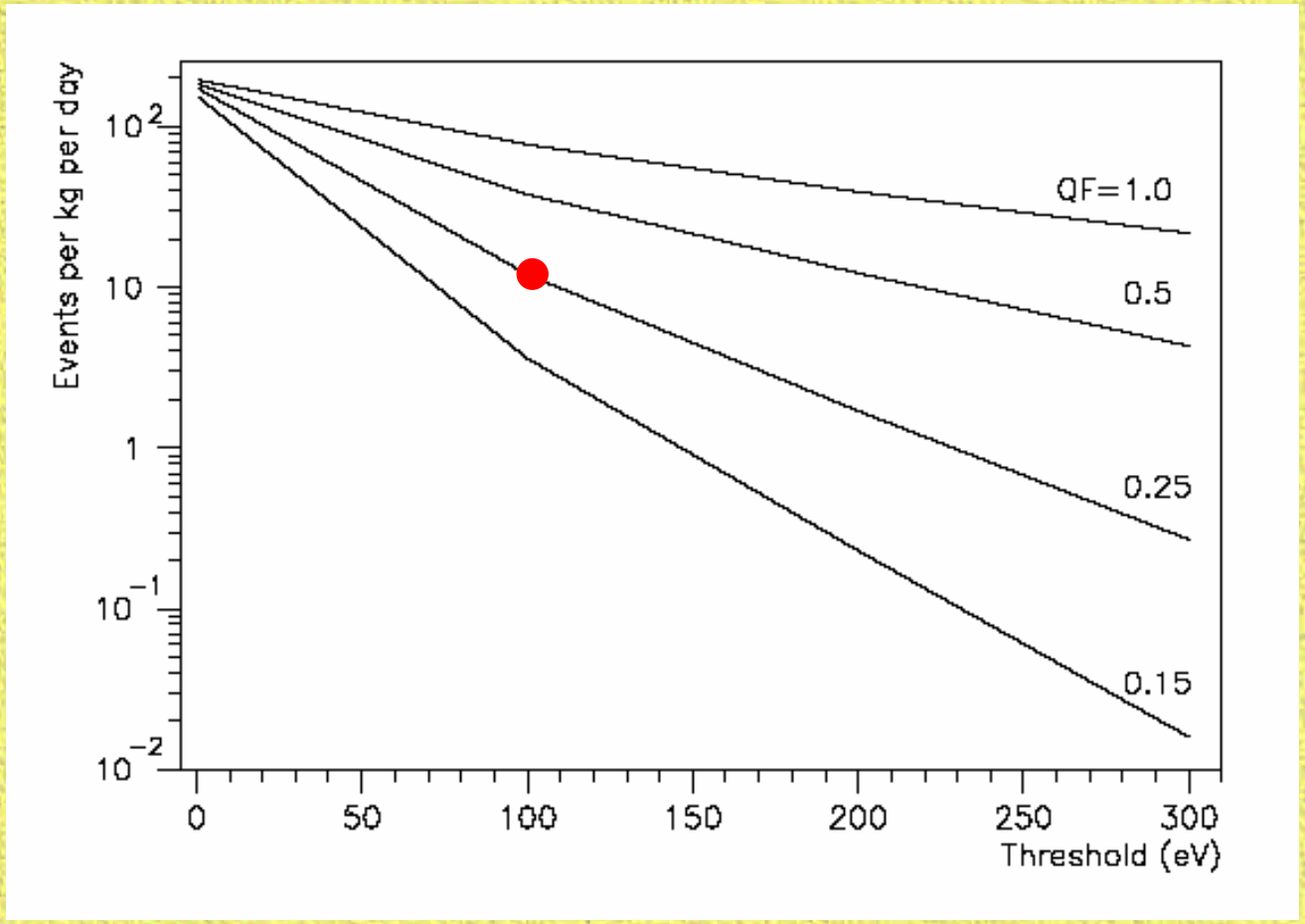
Standard Model Cross-Sections:

$$\left(\frac{d\sigma}{dT}\right)^{coh}_{SM} = \frac{G_F^2}{4\pi} m_N [Z(1 - 4\sin^2\theta_W) - N]^2 \left[1 - \frac{m_N T_N}{2E_\nu^2}\right]$$

$$\sigma_{tot} = \frac{G_F^2 E_\nu^2}{4\pi} [Z(1 - 4\sin^2\theta_W) - N]^2$$

- a fundamental neutrino interaction never been experimentally-observed
- $\sigma \propto \sim N^2$ applicable at $E_\nu < 50$ MeV where $q^2 r^2 < 1$
- a sensitive test to Stardard 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 scientific *surprises*

Expected Interaction Rates at KS @ different Quenching Factors



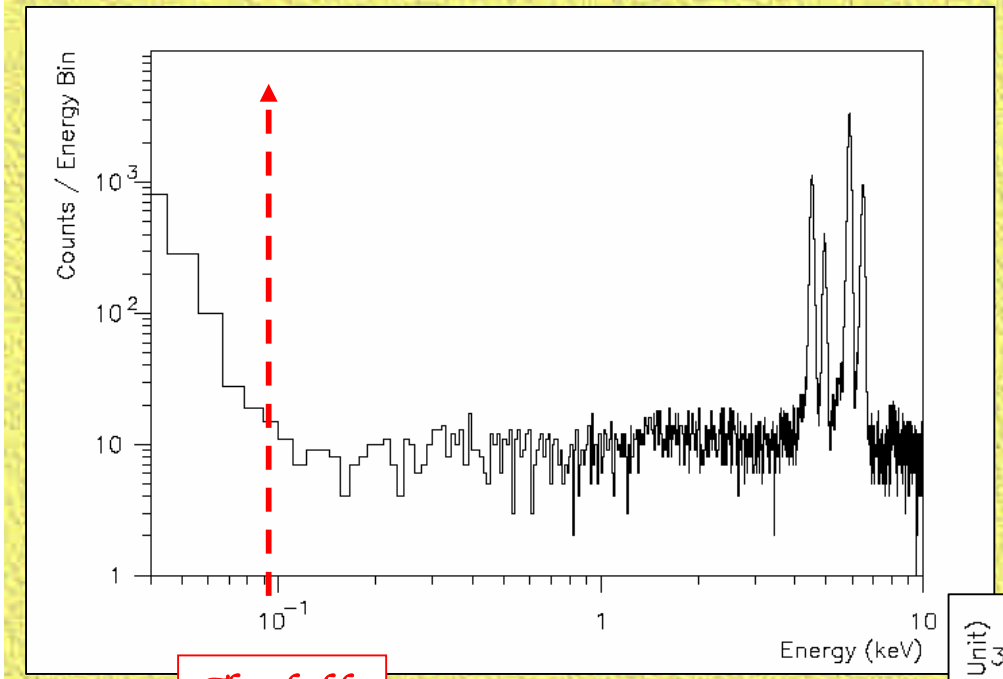
e.g. at QF=0.25 & 100 eV threshold

Rate ~ 11 kg^{-1} day^{-1}

"Ultra-Low-Energy" HPGe Prototype

- **ULEGe – developed for soft X-rays detection ; easy & inexpensive & robust operation**
- **Prototype : mass 5 g ; can be constructed in multi-array form**
- **threshold <100 eV after modest PSD** *[lowest achieved for bulk radiation detectors]*
- **study feasibilities in νN coherent scattering and Dark Matter searches** *[μ_ν search a by-product]*

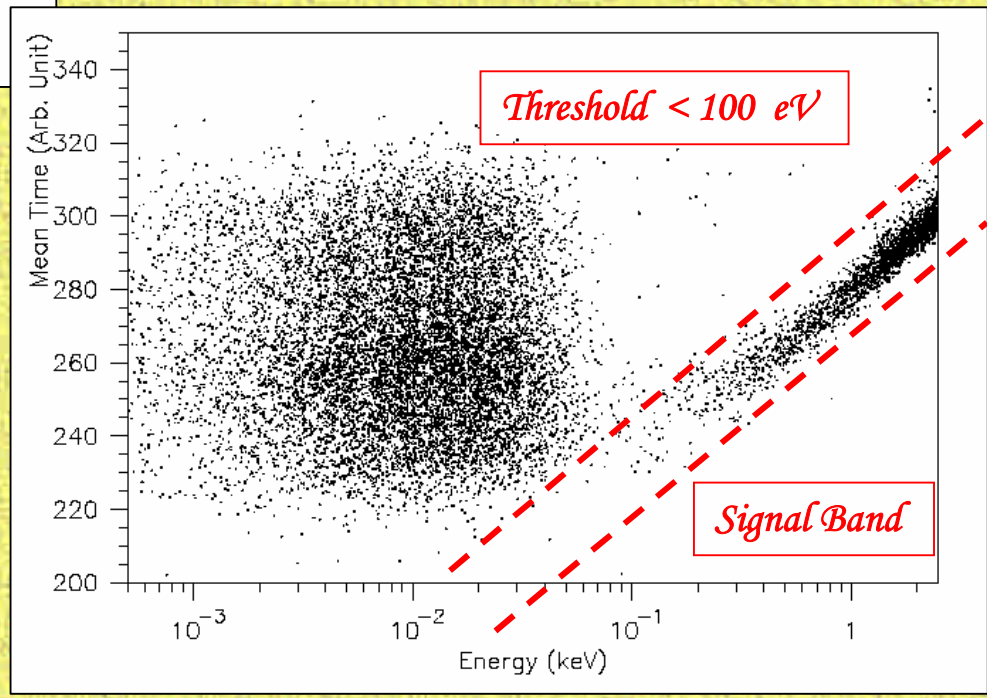
ULE-HPGe Prototype Results



Threshold ~ 100 eV

※ threshold <100 eV , calibration by linear extrapolation from 1-6 keV

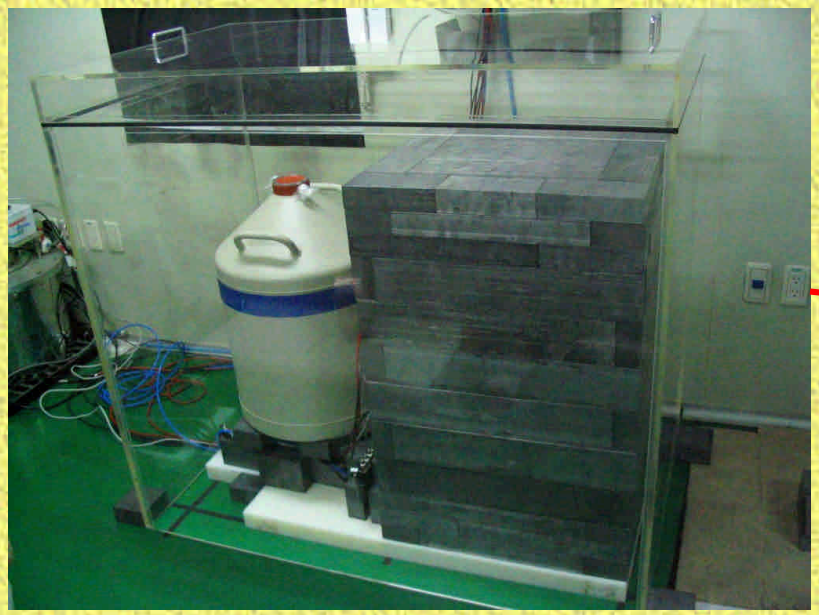
PSD Cut



※ background measurement at KS Nov 03 – May 04

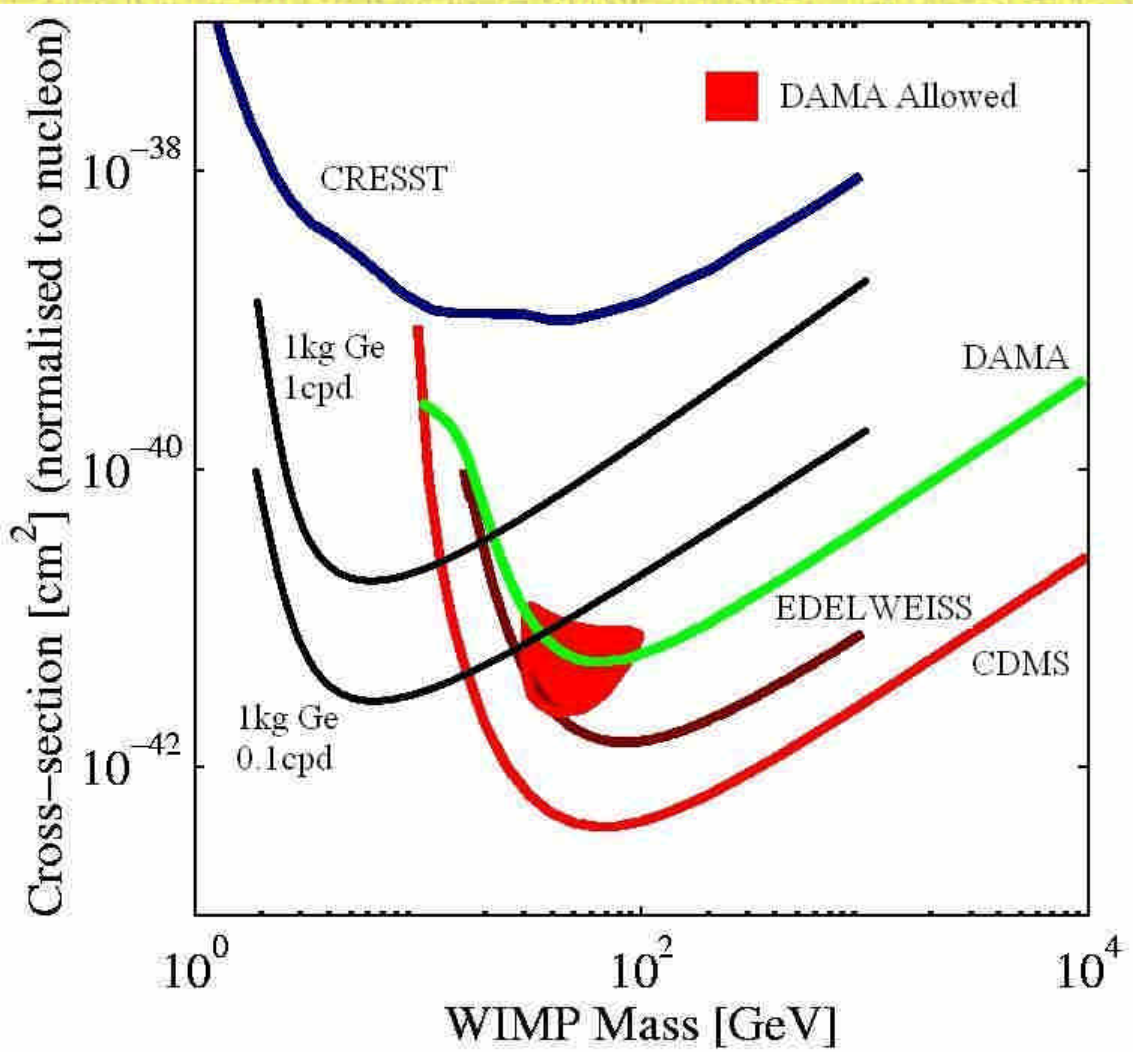
TEXONO ⊕ KIMS @ Y2L

- Install 5 g ULB-ULEGe at Y2L on January 2005
- Study background and feasibility for CDM searches
- may evolve into a full-scale (1 kg) CDM experiment

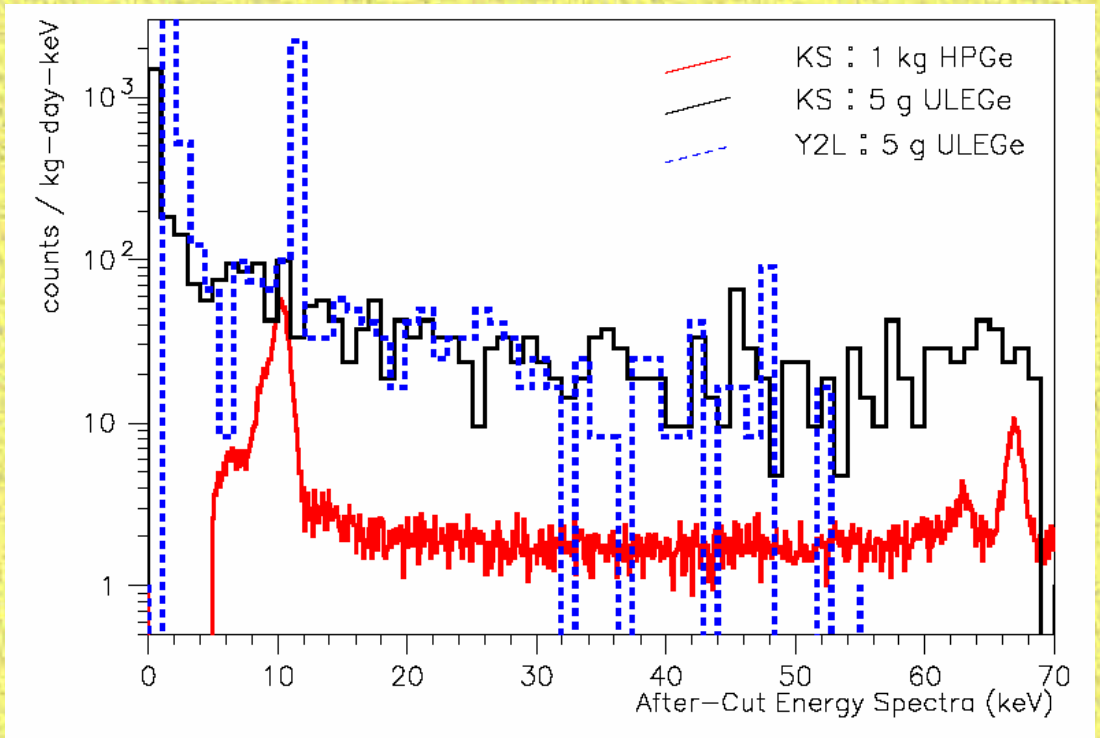


Yangyang（襄陽）Lab (Y2L)
min. 700 m of rock overburden

Sensitivity Plot for CDM-WIMP search with 1 kg ULEGe at 100 eV threshold ……

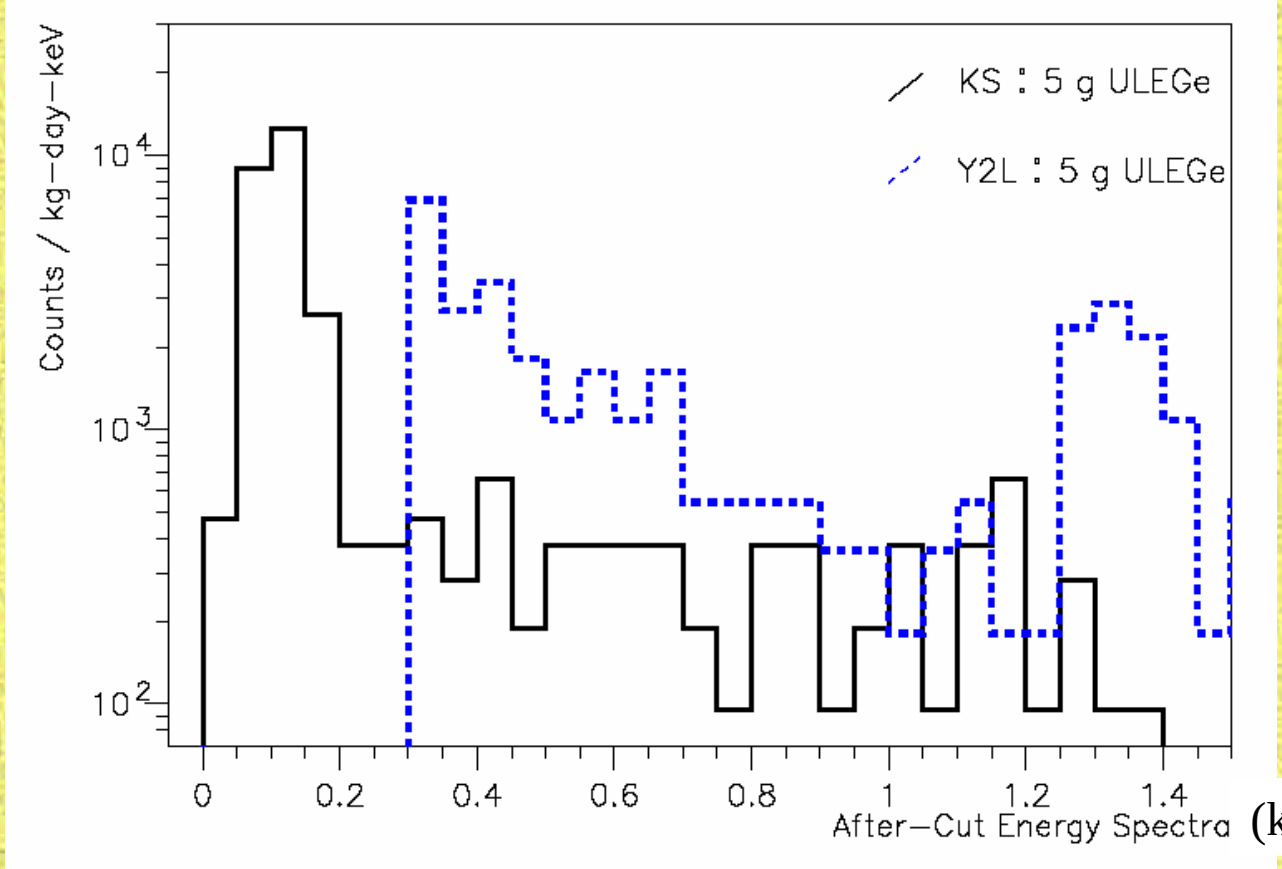


Background Measurements & Comparisons



- Similar background at KS & Y2L
- Apparent difference between 5 g & 1 kg due to scaling with surface area instead, reproduced in simulations
- i.e. background can be ~ O(1 cpd) at > 1 keV range for 1 kg ULEGe in *compact array* form

First-Ever Low Background Data down to 100 eV ……. !



….. detailed analysis & background understand underway

" don't know what to expect & what are expected ."

R&D Program towards Realistic O(1 kg) Size Experiments (both νN & CDM) :

- measure & study background at sub-keV range at KS & Y2L
- N=4 elements array produced & being studied
- devise calibration scheme at sub-keV range
- measure quenching factor of Ge with neutron beam

- develop advanced PSD techniques to further suppress noise-edge $\Rightarrow$ reduce threshold
- studying new possibilities with Ge-detector
  - larger modular mass
  - segmented Ge
  - dual readout channels
- by-product : T>500 eV gives $\mu_\nu(\nu_e) \rightarrow 2 \times 10^{-11}\ \mu_B$ at ~1 cpd background

Summary & Outlook

- **Kuo-Sheng Neutrino Lab.:**
  - **Established & Operational ⇨ Modular & Flexible Design**
  - **Physics Data Taking since June 01**
    - **※ Unique HPGe Low Energy Data (*@ 10 keV threshold*)**
    - **※ Bkg Level ~ Underground CDM Expt.**
- **Results on μ_ν (Γ_ν) ⇨ Other analyses under way**
- **Future goals : get to *100 eV threshold* ⇒ observe neutrino-nucleus coherent scattering ⊕ perform LE-CDM experiment**
- **R&D program pursued :**
  - **prototype ULEGe with ~100 eV threshold**
  - **first background measurement in the 100 eV – 1 keV region**