Low Energy Neutrino Physics at the Kuo-Sheng Reactor Laboratory

Focus of *This* Talk : Research Program towards Observation of Neutrino-Nucleus Coherent Scattering

- Starting Points (Collaboration ; Laboratory)
- Magnetic Moment Results with HPGe
- Physics & Motivations of νN
- Ultra-Low Energy High-Purity Germanium Detector Prototypes
- Status & Plans

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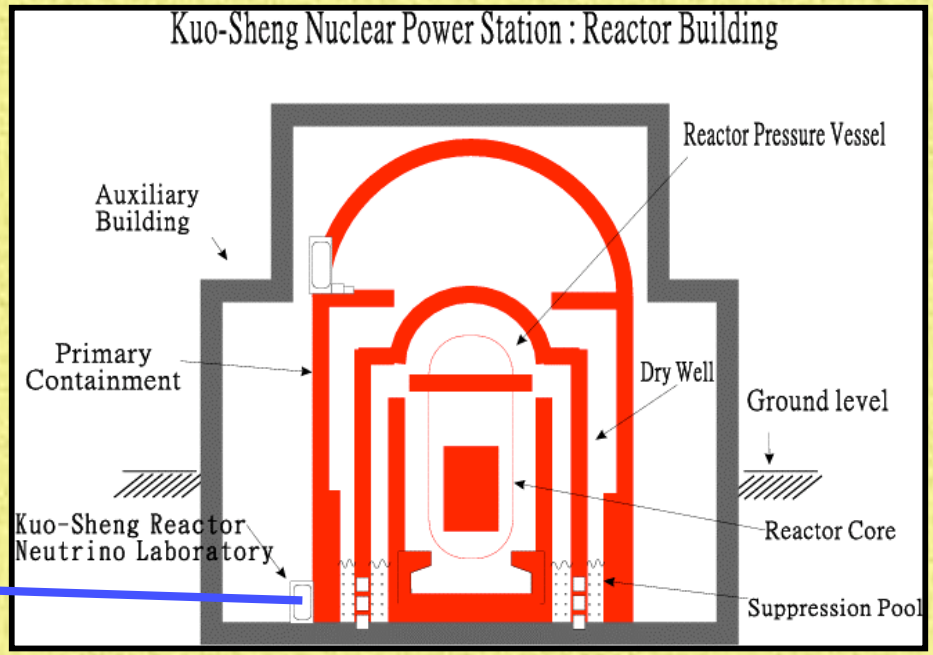
TEXONO Collaboration

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

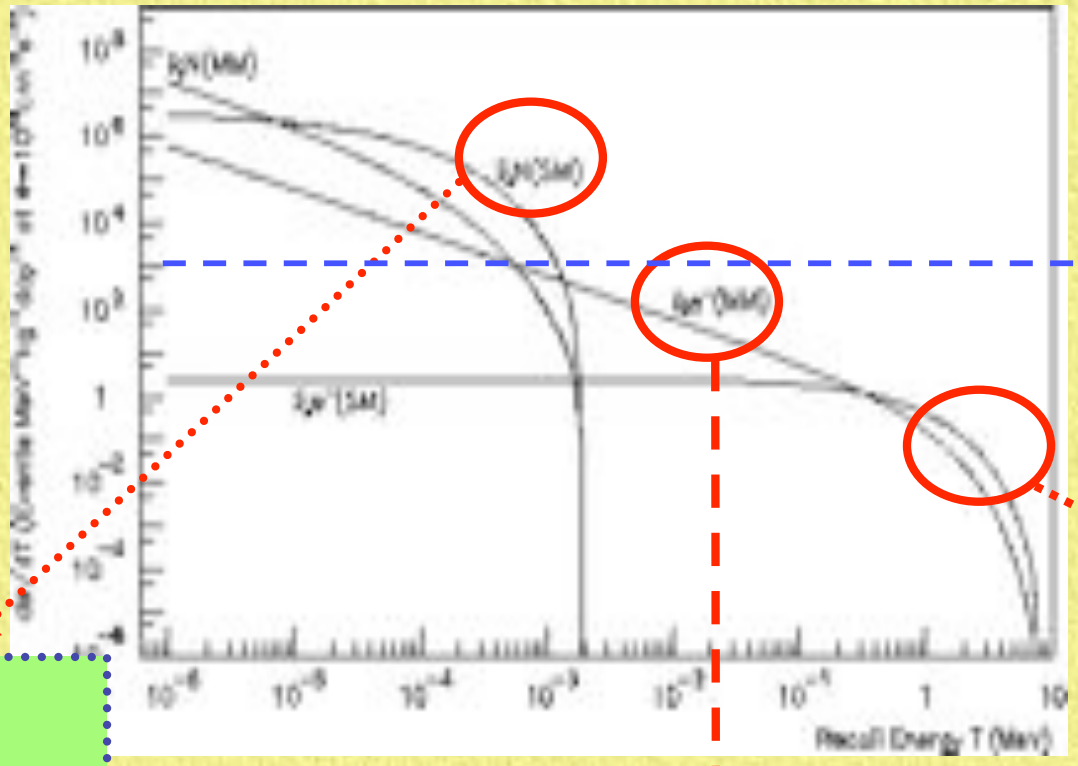
Program: **Low Energy Neutrino & Astroparticle Physics**

Kuo Sheng Reactor Neutrino Laboratory :



Reactor Neutrino Interaction Cross-Sections

quality ← Detector requirements → mass



R&D :

- Coh. (νN)
- T < 1 keV

Results :

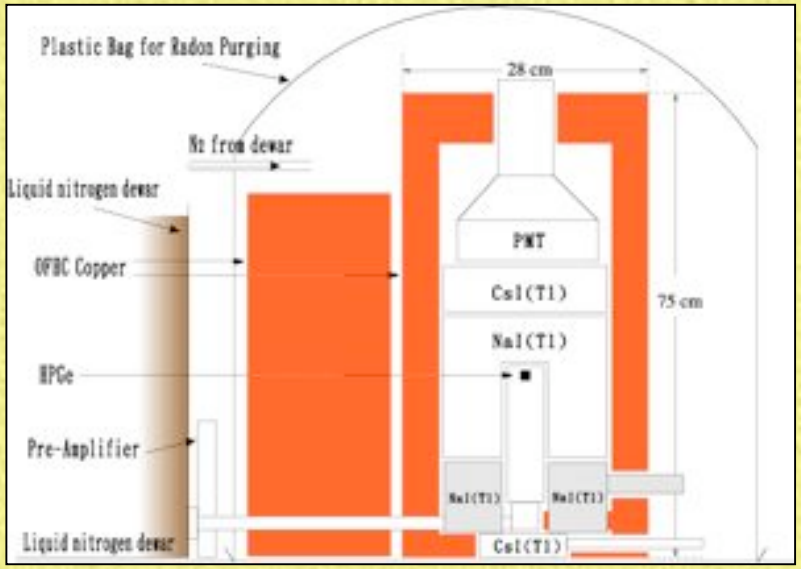
- $\mu_\nu(\nu_e)$
- T ~ 1-100 keV

On-Going Data Taking & Analysis

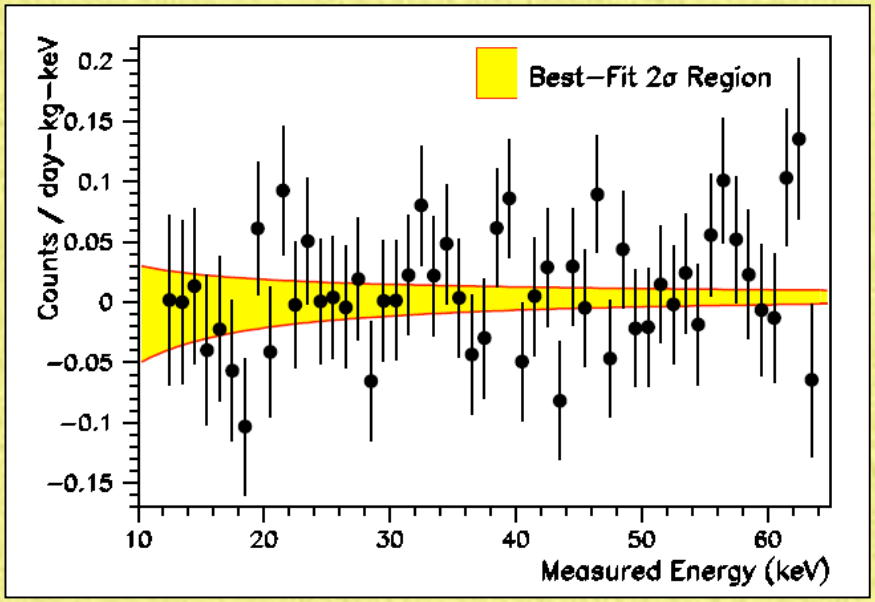
- SM σ(νe)
- T > 2 MeV

Magnetic Moment Searches : Highlights

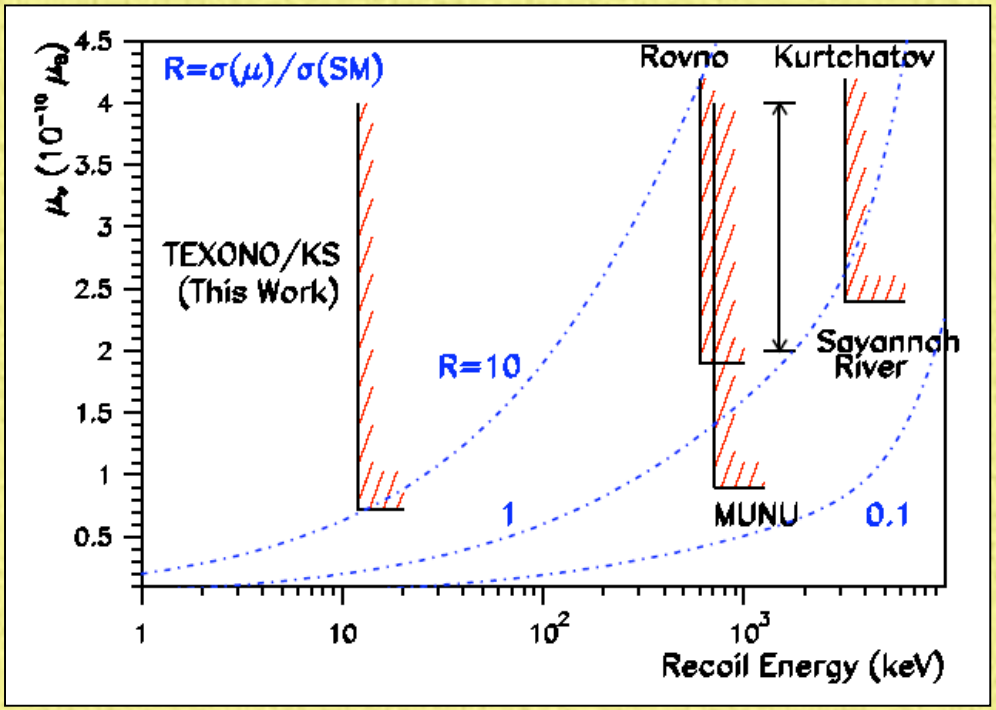
- simple compact *all-solid* design : HPGe (mass 1 kg) enclosed by active NaI/CsI anti-Compton, further by passive shieldings & cosmic veto



- TEXONO data (571/128 days) ON/OFF) [PRL 90, 2003 ; hep-ex/0605006]
  - background comparable to underground CDM experiment : ~ 1 $day^{-1}keV^{-1}kg^{-1}$ (cpd)
  - DAQ threshold 5 keV
    analysis threshold 12 keV
  - $\mu_\nu(\nu_e) < 7.2 \times 10^{-11}\ \mu_B$ (90% CL)



Direct Experiments at Reactors



Search of μ_ν at low energy

⇒ high signal rate & robustness:

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

☺ Other Physics with 1-kg HPGe *[with low threshold, low background, high resolution, large dynamic range, minimal-bias trigger data at reactor]* :

- Reactor ν_e – flux evaluation ; limits on properties ; physics potentials for loaded reactor *[PRD 72, 2005]*
- Reactor axion search – good sensitivities to g_{aee} couplings *[hep-ex/0609001]*

Neutrino-Nucleus Coherent Scattering :

$$\nu + N \rightarrow \nu + N$$

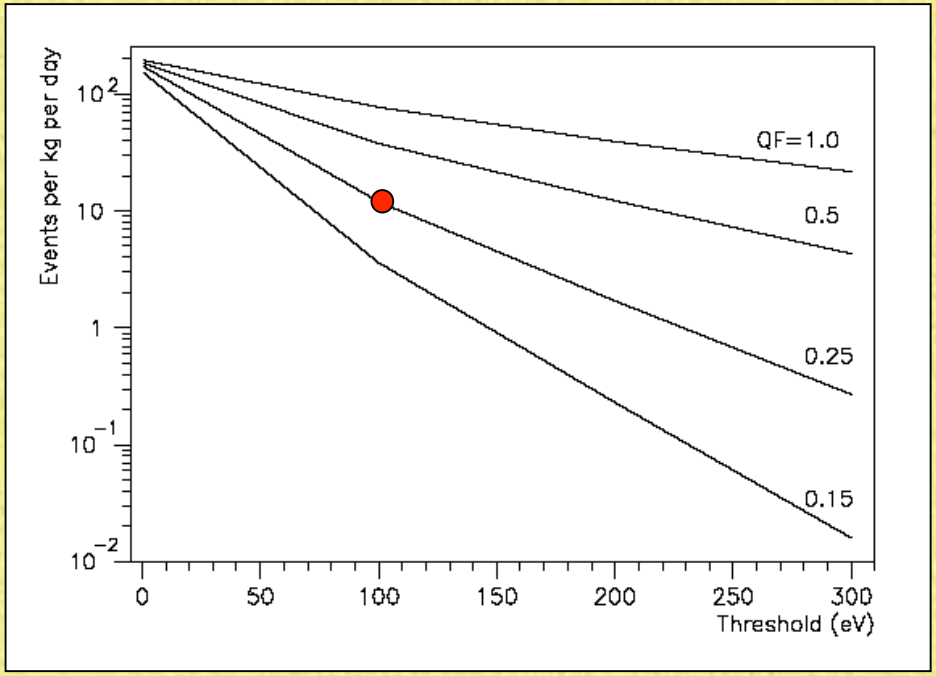
Standard Model Cross-Sections:

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

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

- 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; relative compact detectors possible (implications to *reactor monitoring*); & *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}

c.f. νN (Ge;1 keV) @ accelerator ~ 0.1 kg^{-1} day^{-1} ;

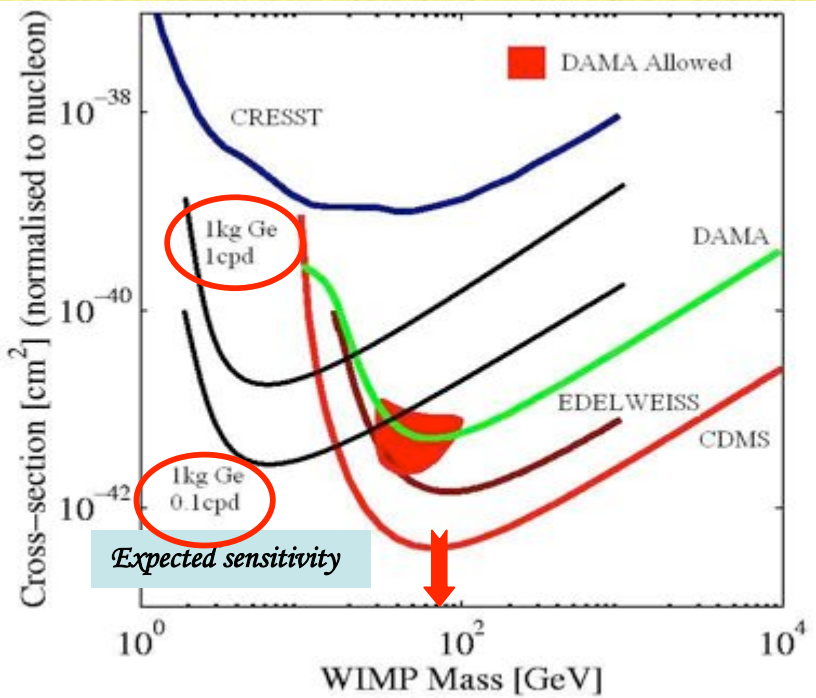
$\bar{\nu}_e$-p (water) @ KS ~ 1 kg^{-1} day^{-1}

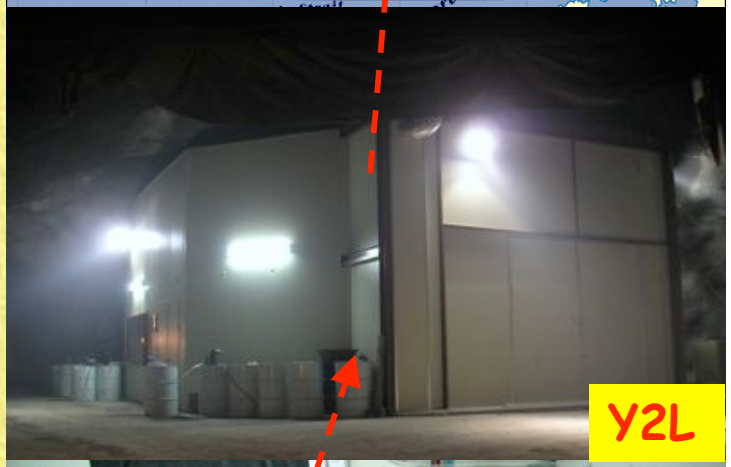
♥ by-product : T>500 eV gives

$\mu_\nu(\nu_e) \rightarrow \sim 10^{-11}\ \mu_B$ at ~ 1 cpd background

TEXONO ⊕ KIMS @ Y2L

- *Yangyang Lab (Y2L)* [700 m of rock overburden] in S. Korea
- Install 5 g ULB-ULEGe at Y2L
- Study background and feasibility for CDM searches
- may evolve into a full-scale *(1 kg) CDM experiment*



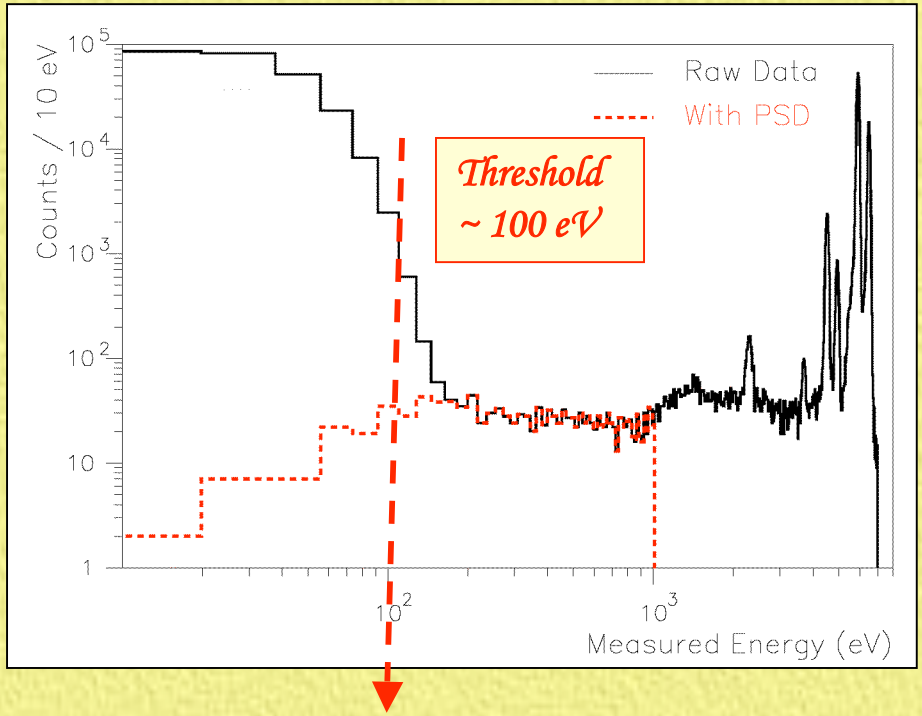


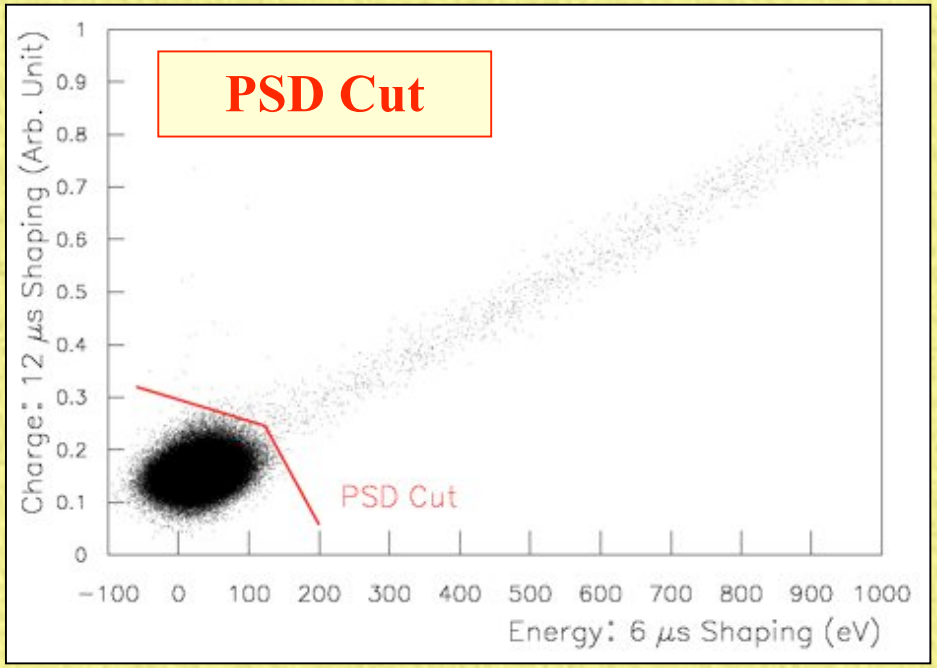
"Ultra-Low-Energy" HPGe Prototype

- **ULEGe – developed for soft X-rays detection ; easy & inexpensive & robust operation**
- **Prototypes built and studied : (I) 5 g at Y2L ; (II) 4 X 5 g at KS ; (III) 10 g at AS**
- **Prototype being built : segmented 20 g**
- **Scale-up options to O(1 kg) in *multi-array* or *integrated* form**
- **threshold <100 eV after modest PSD**
- **Physics for O(1 kg) *"ULE-ULB-HPGe"* detector : (I) νN coherent scattering ; (II) Low-mass WIMP searches ; (III) improvement on μ_ν ; (IV) Surprises (when a new detector window & detection channel is opened up) …….**

Prototype built & being studied :

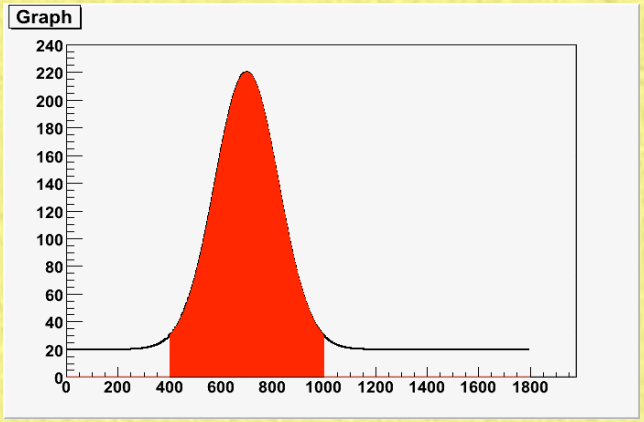
ULE-HPGe Prototype Results



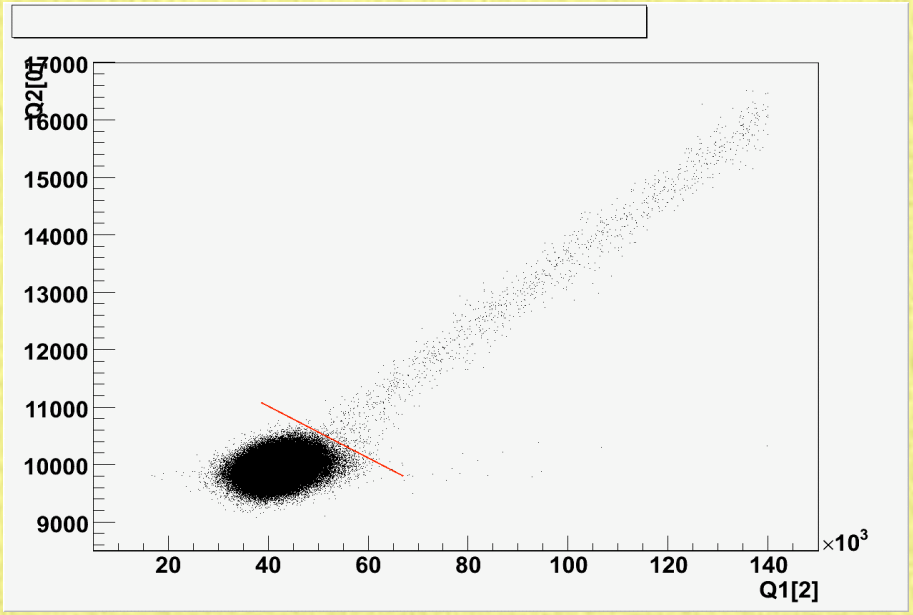


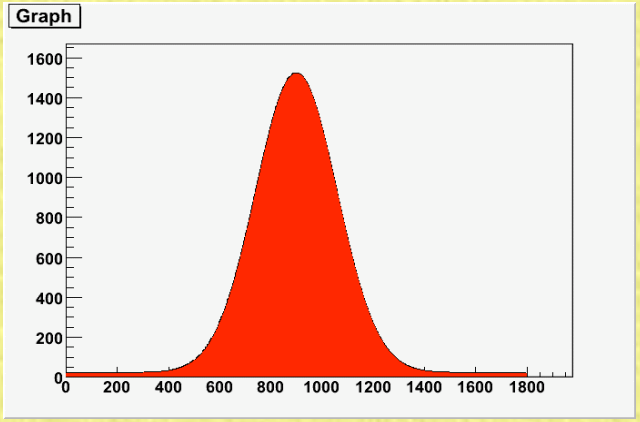
- *Calibrations* by keV lines & "0" from random trigger
- Achieved threshold < 100 eV : lowest for bulk radiation detectors !
- *Background* measurements under way at KS & Y2L

PSD (one of the schemes) : Correlate two gains & shaping time



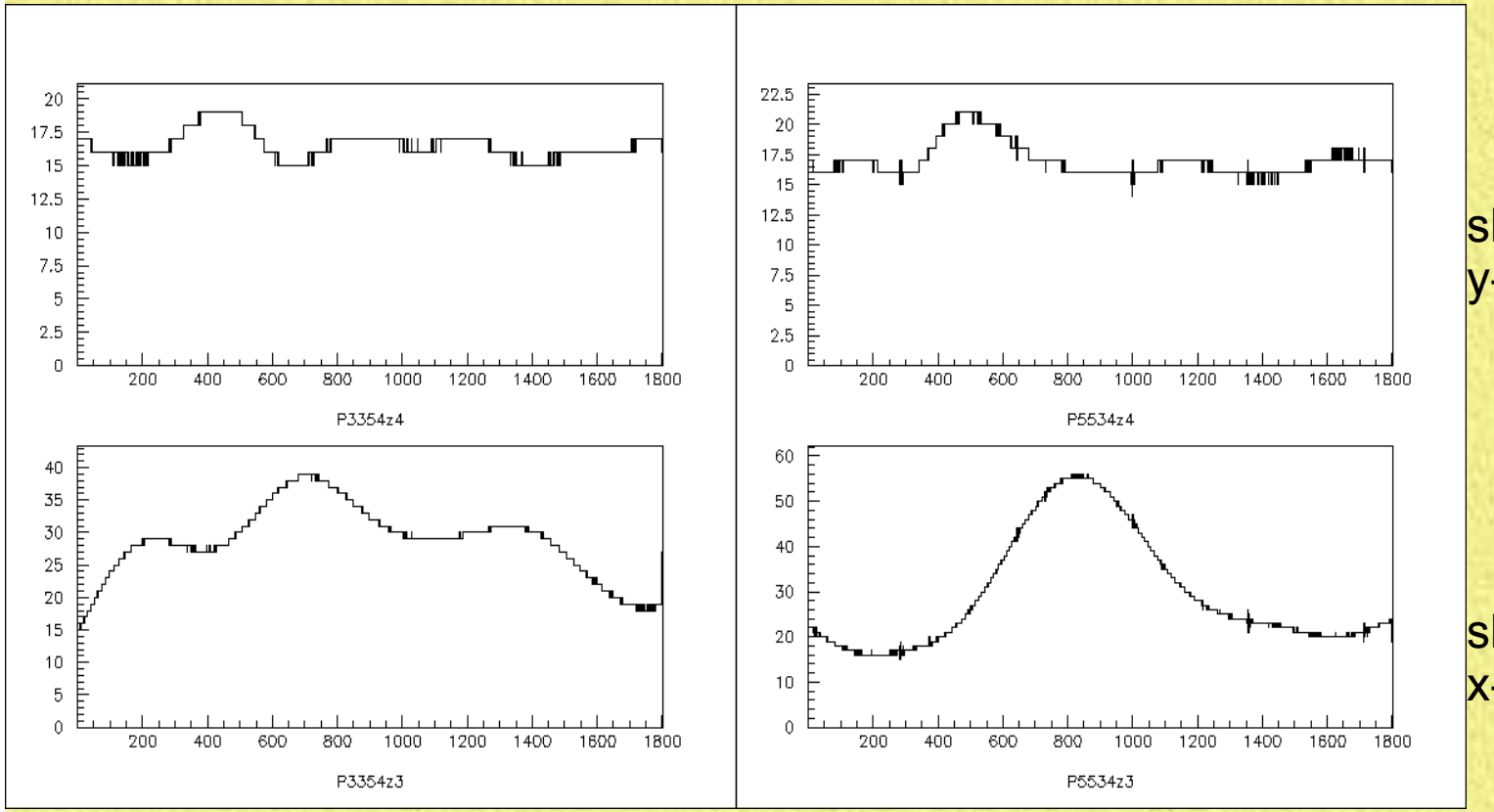
sh=6us, high gain





sh=12us, super gain

Events near threshold



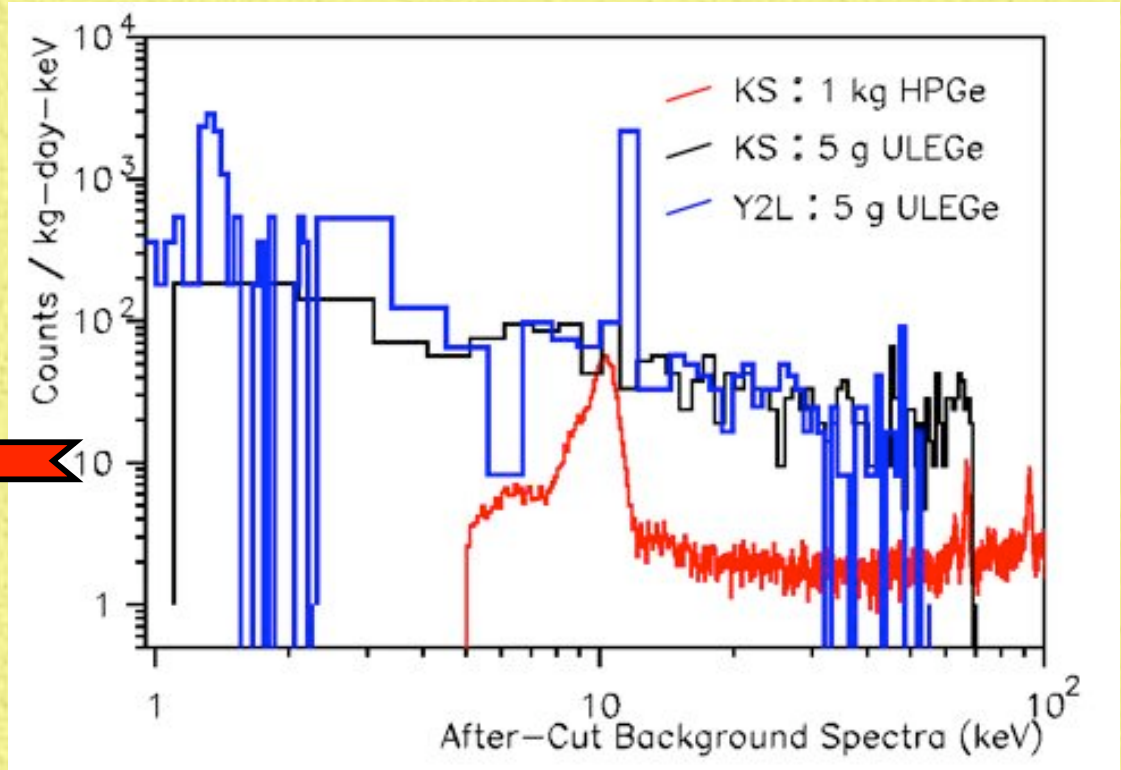
sh=6us, high gain
y-axis

sh=12us, super gain
x-axis

energy=114.7283eV
noise

energy=137.8089eV
signal

Background Measurements & Comparisons



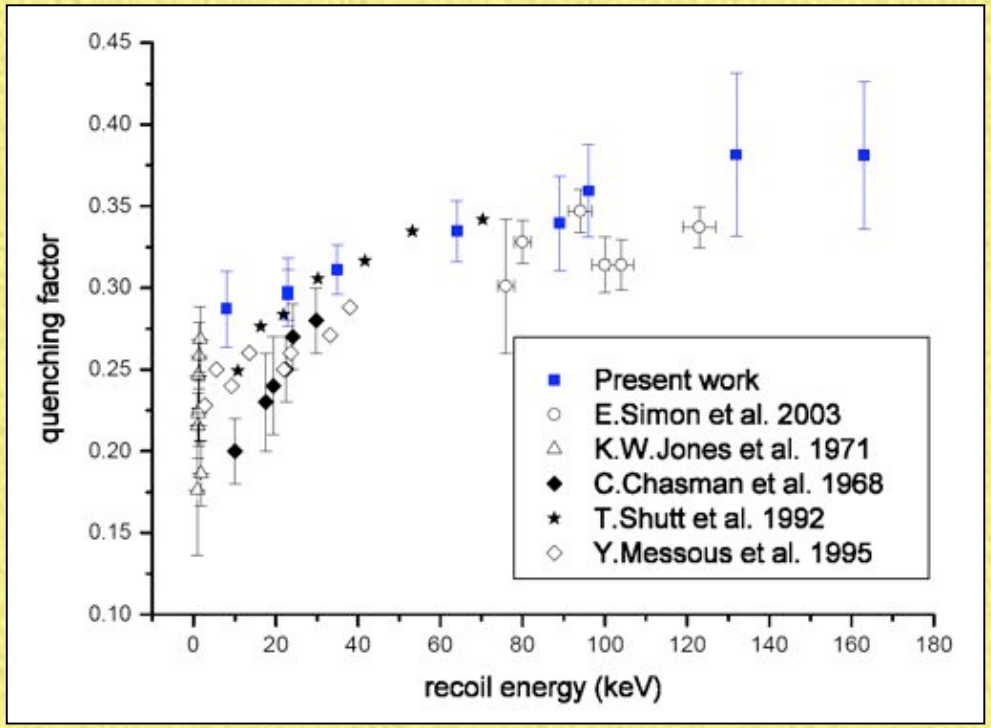
Intensive studies on sub-keV background

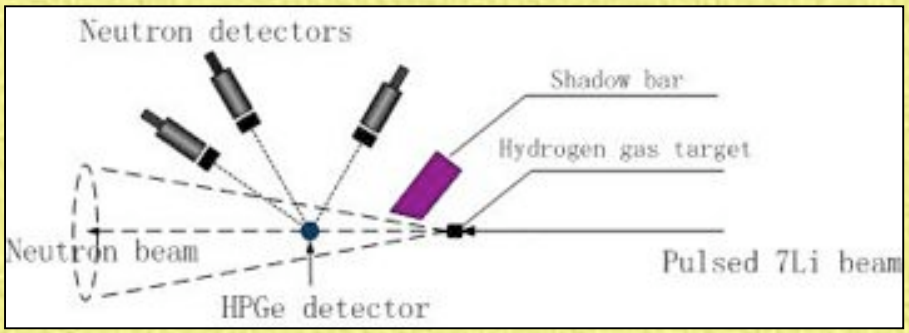
- Similar background at KS & Y2L
- Apparent difference between 5 g & 1 kg due to scaling with surface area instead, reproduced in simulations
- i.e. background can be ~ O(1 cpd) at > 1 keV range for 1 kg ULEGe in *compact array* form
- Intensive studies of *sub-keV* background under way

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

- measure & study background at sub-keV range at KS & Y2L ; design of active & passive shielding based on this.
- compare *performance* of various prototypes
- devise *calibration scheme* at sub-keV range
- measure *quenching factor* of Ge with neutron beam
- develop advanced *PSD techniques* to further suppress noise-edge ⇒ reduce threshold
- studying *scale-up options* ULEGe-detector
  - Discrete elements Vs segmented Ge
  - dual readout channels to suppress electronic noise
- Keep other detector options open

Quenching Factor Measurement for Ge at CIAE's 13 MV Tandem Facility:



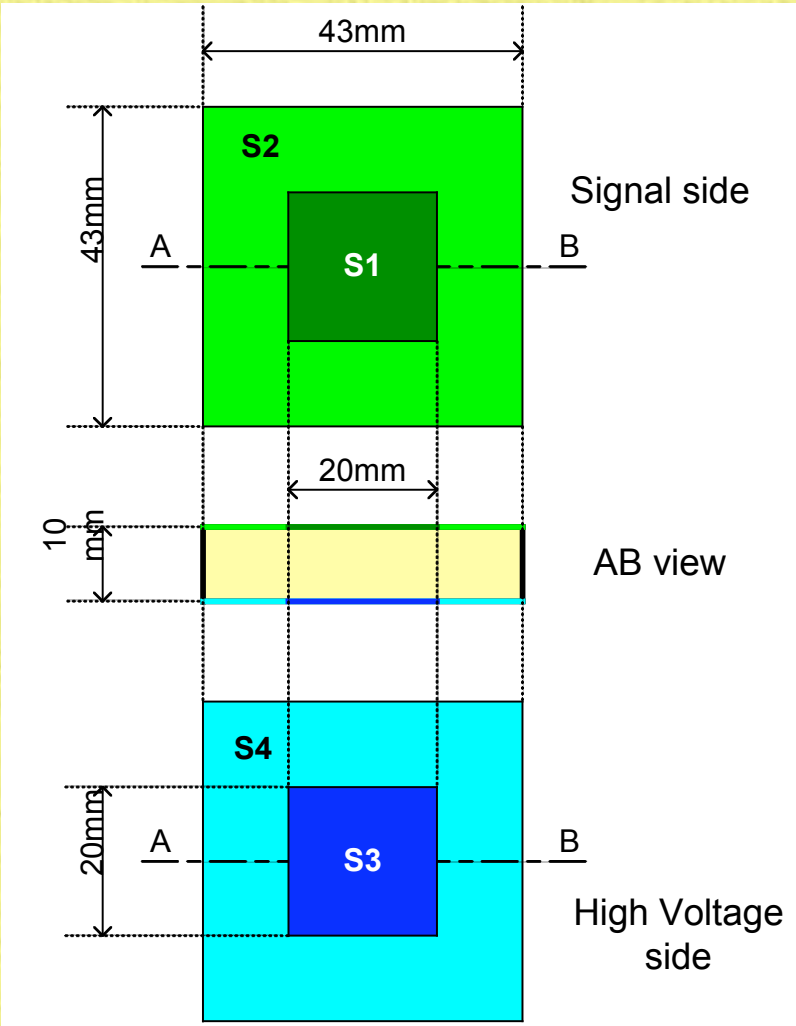


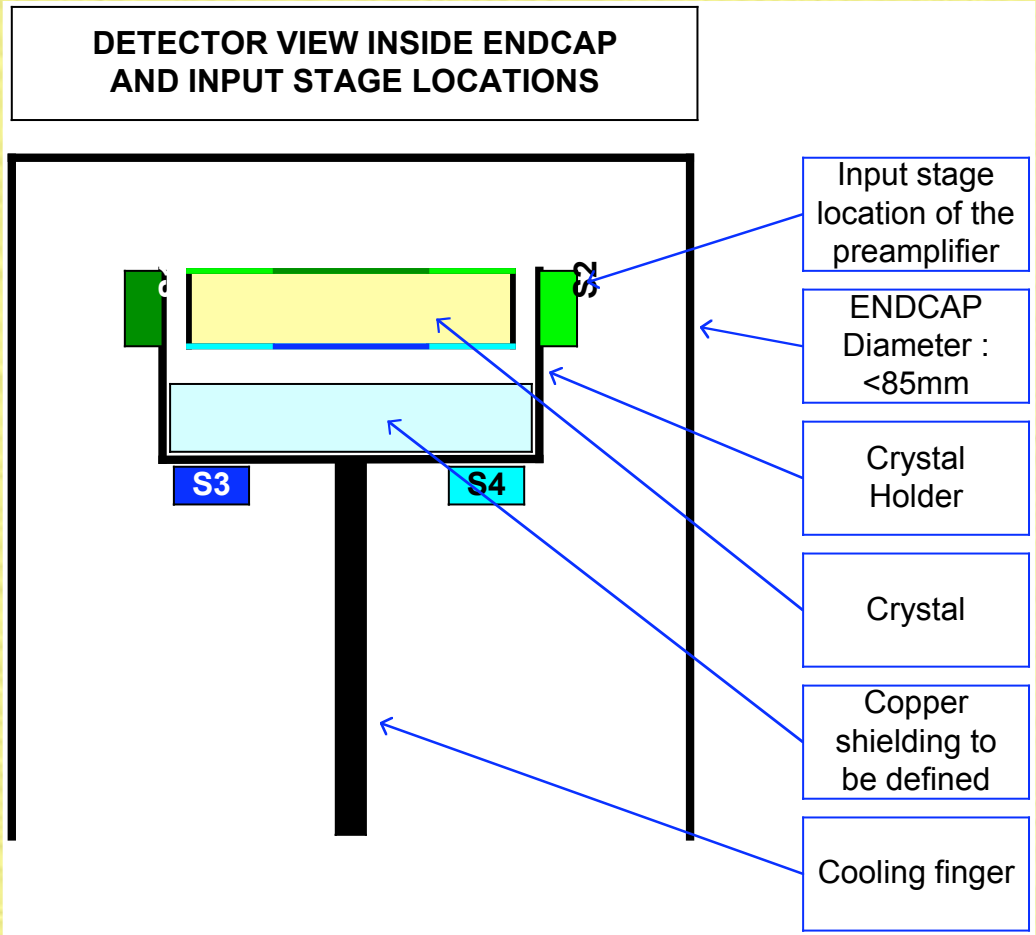
Goals for Oct 06 Run :

- Get to sub-keV
- Improve on present sensitivities

Segmented 20g : Schematics

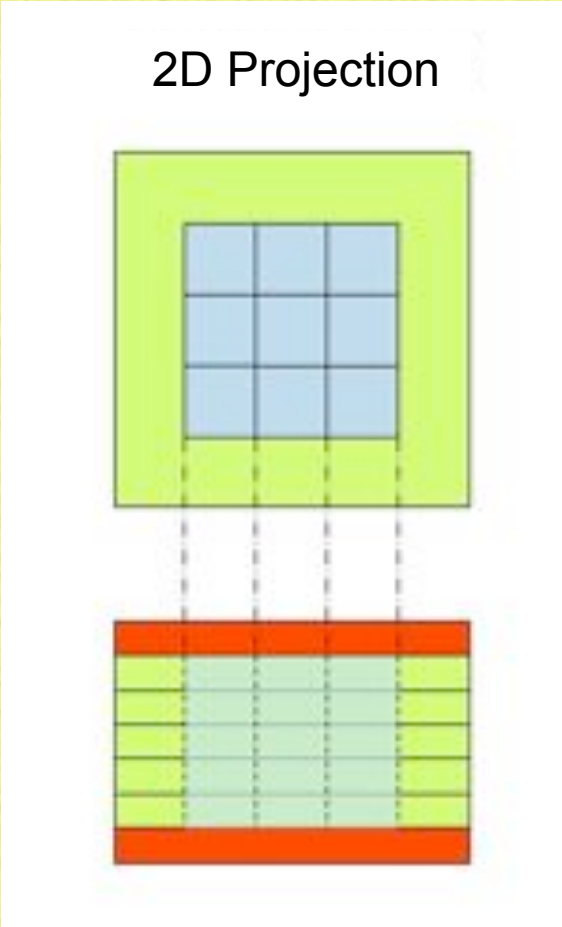
- ♥Active sensor + veto ring ; dual readout
- ♥ Under construction ⇒ Delivery Nov 06





A Possible Design for O(1 kg) detector :

- ※3X3X5 elements @ 20 g each (i.e. 900 g)
- ※Dual readout per element
- ※veto ring ⊕ lids



Summary & Outlook

- **Kuo-Sheng Neutrino Lab.:**
  - **Established & Operational ⇨ Modular & Flexible Design**
    - ※ **Unique HPGe Low Energy Data (@ *10 keV threshold*)**
    - ※ **Bkg Level ~ Underground CDM Expt.**
- **Results on μ_ν (Γ_ν) ⇨ Other Program under way**
- **Future goal : get to *100 eV threshold* ⇒ observe *neutrino-nucleus coherent scattering* ⊕ perform *LE-CDM experiment***
- **R&D program pursued :**
  - ***optimization* of prototype ULEGe's @ ~100 eV threshold**
  - **first *background measurement* in the 100 eV – 1 keV region**
  - **investigate *scale-up options***

A New Detector Window & Detection Channel

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