Institute of Physics Publishing Journal of Physics: Conference Series **39** (2006) 266–268
doi:10.1088/1742-6596/39/1/064 TAUP 2005: Proc. Ninth Int. Conf. on Topics in Astroparticle and Underground Physics

Research program towards observation of neutrino-nucleus coherent scattering

H T Wong[1,4], H B Li[1], J Li[2], Q Yue[2] and Z Y Zhou[3]

[1] Institute of Physics, Academia Sinica, Taipei 11529, Taiwan.
[2] Department of Engineering Physics, Tsing Hua University, Beijing 100084, China.
[3] Department of Nuclear Physics, Institute of Atomic Energy, Beijing 102413, China.

E-mail: htwong@phys.sinica.edu.tw

Abstract. The article describes the research program towards an experiment to observe coherent scattering between neutrinos and the nucleus at the power reactor. The motivations of studying this process are surveyed. In particular, a threshold of 100-200 eV has been achieved with an ultra-low-energy germanium detector prototype. This detection capability at low energy can also be adapted to conduct searches of Cold Dark Matter in the low-mass region as well as to enhance the sensitivities in the study of neutrino magnetic moments.

Neutrino coherent scattering with the nucleus [1] $\nu + \mathrm{N} \rightarrow \nu + \mathrm{N}$ is a fundamental neutrino interaction which has never been experimentally observed. The Standard Model cross section for this process is given by:

$$(\frac{\mathrm{d}\sigma}{\mathrm{dT}})^{\mathrm{coh}}_{\mathrm{SM}} = \frac{\mathrm{G_F^2}}{4\pi}\mathrm{m_N}[\mathrm{Z}(1-4\mathrm{sin}^2\theta_{\mathrm{W}})-\mathrm{N}]^2[1-\frac{\mathrm{m_N T_N}}{2\mathrm{E}_\nu^2}] \;\; \& \;\; \sigma_{\mathrm{tot}} = \frac{\mathrm{G_F^2 E}_\nu^2}{4\pi}[\mathrm{Z}(1-4\mathrm{sin}^2\theta_{\mathrm{W}})-\mathrm{N}]^2 \quad ,$$

where $\mathrm{m_N}$, N and Z are the mass, neutron number and atomic number of the nucleus, respectively, E_ν is the incident neutrino energy and $\mathrm{T_N}$ is the measureable recoil energy of the nucleus. This formula is applicable at $\mathrm{E}_\nu < 50$ MeV where the momentum transfer (Q^2) is small such that $\mathrm{Q}^2\mathrm{R}^2 < 1$, where R is the nuclear size. Although the cross-section is relatively large due to the $\sim\mathrm{N}^2$ enhancement by coherence, the small kinetic energy from nuclear recoils poses severe experimental challenges both to the detector sensitivity and to background control.

Measurement of the coherent scattering cross-section would provide a sensitive test to the Standard Model [2], probing the weak nuclear charge and radiative corrections due to possible new physics above the weak scale. The coherent interaction plays important role in astrophysical processes where the neutrino-electron scatterings are suppressed due to Fermi gas degeneracy. It is significant to the neutrino dynamics and energy transport in supernovae and neutrons stars [3]. Being a new detection channel for neutrinos, it may provide new approaches to study other aspects of neutrino physics, such as that for supernova neutrinos [4].

Nuclear power reactors provide powerful and controllable source of electron anti-neutrinos, and can serve as optimal tool for the studies of neutrino-nucleus scatterings. A research program on low energy neutrino physics [5] is intensely pursued by the TEXONO Collaboration at the Kuo-Sheng (KS) Nuclear Power Station in Taiwan. The expected observable spectra due to

[4] Corresponding author

© 2006 IOP Publishing Ltd

$\bar{\nu_e}$-e and $\bar{\nu_e}$-N scatterings with Standard Model (SM) and magnetic moment (MM) interactions at KS are displayed in Figure 1. The maximum nuclear recoil energy T_{max} in $\bar{\nu_e}$-N coherent scatterings is given by: $T_{max} = \frac{2E_\nu^2}{M_N+2E_\nu}$ which corresponds to $T_{max} = 1.9$ keV in the case of Ge target (A=72.6) exposed to the typical reactor neutrino spectra.

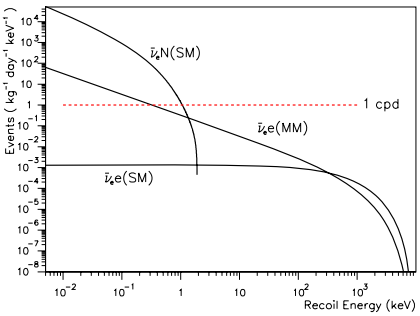

Figure 1. The differential cross-section of the various neutrino interaction channels, at KS-Lab with Ge as the target isotope. The background level of 1 cpd is also shown.

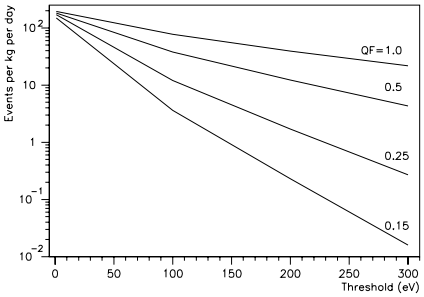

Figure 2. The variations of the neutrino coherent scattering event rates versus threshold at different quenching factors for a 1 kg ULEGe detector at KS Lab.

High-Purity Germanium (HPGe) detectors have been widely and successfully used in various areas of low energy neutrino physics and cold dark matter searches. These detectors are kilogram-scale in mass, and with a detection threshold ("noise edge") of several keV. A sensitive direct search of neutrino magnetic moments [6] was recently performed with a 1 kg HPGe detector at KS. A physics threshold of 12 keV and a background level of ~ 1 day^{-1}kg^{-1}keV^{-1}(cpd) comparable to underground dark matter experiments were achieved.

For ionization detectors like germanium, the measure-able energy of nuclear recoil events is only a fraction of their energy deposited due to charge recombination or "quenching" at large dE/dx. The expected event rates for neutrino-nucleus coherent scattering at different threshold and quenching factors (QF) at KS are depicted in Figure 2. The QF for Ge is typically 0.25 in the several keV region, such that the maximum measure-able energy for nuclear recoil events is only about 480 eV.

"Ultra-Low-Energy" Germanium (ULEGe) detectors, developed originally for soft X-rays detection, are candidate technologies to meet these challenges of probing into a previously unexplored energy domain. These detectors typically have modular mass of 5-10 grams while detector array of up to N=30 elements have been successfully built. Various prototypes based on this detector technology have been constructed. As illustrations, the measured energy spectrum with a 5 g ULEGe prototype is depicted in Figure 3. Pulse shape discrimination (PSD) criteria were applied as illustrated in Figure 4, where <t> is the amplitude-weighed mean time of the pulse. The electronic noise edge can be suppressed and a threshold of 100-200 eV was achieved.

The goal of the ν-N coherent scattering experiment is to develop a ULEGe detector with a total mass of $\sim$1 kg and a modular threshold as low as 100 eV, with a background level below 1 keV in the range of 1 cpd. From Figure 2, at the typical QF=0.25, the event rate for such configurations and projected background levels at KS will be 11 per day, at a signal-to-background ratio of >22. A by-product of such an detector would be to further enhance the searches of neutrino magnetic moment at reactors. An improved sensitivity range down to 2×10^{-11} μ_B can be expected. Such detector can also be used for Cold Dark Matter searches, probing the unexplored low WIMP-mass region, as indicated in Figure 5.

An R&D program towards realizations of these experiments is being pursued. Background simulation studies, as shown in Figure 6, indicate that in order to maintain the same

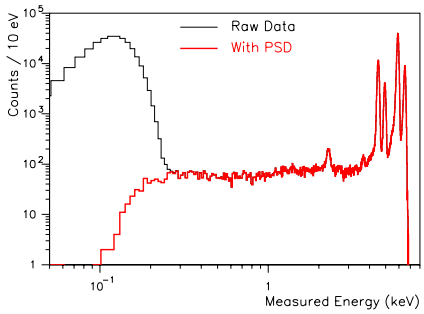

Figure 3. Measured energy spectra with ^{55}Fe source with X-rays from Ti by the ULEGe prototype. The threshold is 100-200 eV after PSD which suppresses the electronic noise edge.

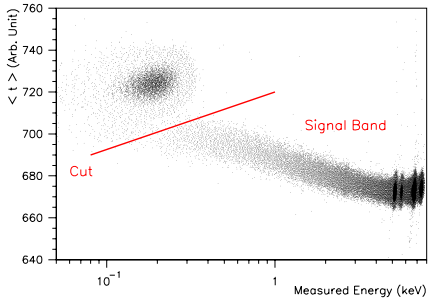

Figure 4. Pulse shape discrimination: mean time versus energy of recorded ULEGe events. Simple selection cuts can be devised to effectively suppress the electronic noise background.

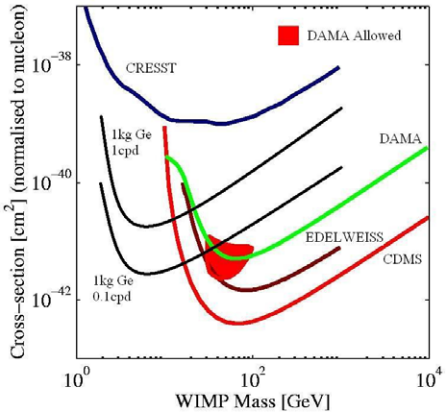

Figure 5. Expected sensitivity region for Cold Dark Matter searches using a ULEGe detector with a total mass of 1 kg.

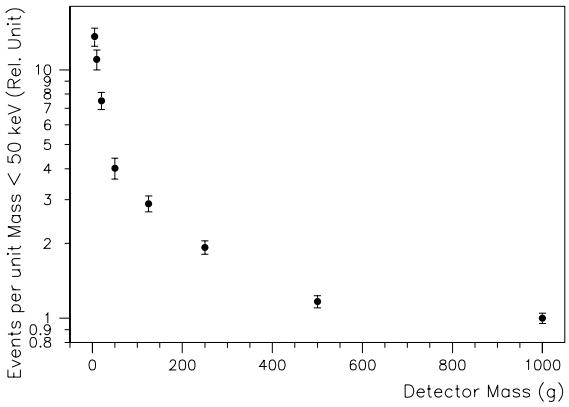

Figure 6. Simulated results on the variations of background per unit mass versus detector mass at the same external γ-background level.

background level of $\sim$1 cpd achieved in the 1 kg HPGe detector, the individual elements of the ULEGe array should be assembled into a compact array to scale up to the kg-range. Alternatively, the "segmented" Ge technology, using integrated circuitry approach, is being investigated. Meanwhile, in situ measurements are performed at both KS as well as the Yang-Yang Underground Laboratory in South Korea. A quenching factor measurement for nuclear recoils in Ge with sub-keV ionization energy is being prepared at a neutron beam facility.

References

[1] Freedman D S 1974 *Phys. Rev.* D **9** 1389
Sehgal L H and Wanninger M 1986 *Phys. Lett.* B **171** 107
[2] Krauss L M 1991 *Phys. Lett.* B **269** 407
Barranco J *et al* 2005 *Preprint* hep-ph/0508299
[3] Wilson J R 1974 *Phys. Rev. Lett.* **32** 849
Freedman D Z *et al* 1977 *Annu. Rev. Nucl. Sci.* **27** 167
[4] Aune S *et al* 2005 *Preprint* hep-ex/0503031.
[5] Wong H T 2004 *Mod. Phys. Lett.* A **19** 1207
[6] Wong H T 2005 *Nucl. Phys.* B *(Proc. Suppl.)* **143** 205
Li H B *et al* 2003 *Phys. Rev. Lett.* **90** 131802