Neutrino and Dark Matter Experiments with Sub-keV Germanium Detectors

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Introduction

Germanium ionization detectors with sensitivities as low as 100 eV_{ee} open new windows for the studies of neutrino and dark matter physics[1]. Sensitivities and dynamic ranges on several important research programs in neutrino and dark matter physics can be significantly enhanced with low energy physics signal detection at sub-keV region. This motivates efforts to characterize detector behaviour and to devise optimal analysis methods in the sub-keV energy region where the physics signals is comparable to the electronic noise[1]. Various experimental issues have to be addressed before the promises of this new detector technique can be fully exploited[1-3]. The theme of TEXONO (Taiwan EXperiment On NeutrinO) is to develop detectors with modular mass of Ø(1 kg), physics threshold of Ø(100 eVee) and background level at threshold of Ø($1kg^{-1}keV^{-1}day^{-1}$).

Low Energy Neutrino Physics

The physical origin and experimental consequences of finite neutrino masses and mixings are not fully understood. Investigations on anomalous neutrino properties and interactions are crucial to address these fundamental questions and may provide hints or constraints to new physics beyond the Standard Model[2]. Neutrino magnetic moments (μ_ν) is an intrinsic neutrino property which is most investigated as compared to other electromagnetic properties of neutrino[2]. The experimental studies on μ_ν and q_ν is make use of neutrino interactions with bound electrons of detectors. The differential cross section due to q_ν has $(1/T^2)$-dependence which is different from that of $(1/T)$ for μ_ν at $T \ll E_\nu$ where T is the measurable recoil energy of electron and E_ν is the energy of the incoming neutrino[2]. Figure 1 reveal that the experimental sensitivity to both μ_ν and q_ν values critically depend on lowering the energy threshold of the detector employed for measurement of the recoil-electron spectrum[2].

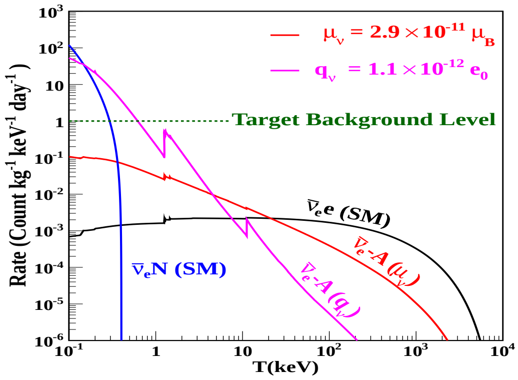

FIG. 1: The observable spectra due to neutrino interactions on Ge target with reactor $\bar{\nu}_e$ at $\phi_{\bar{\nu}_e} = 10^{13}\ cm^{-2}s^{-1}$, with current experimental bound on neutrino magnetic moment,neutrino millicharge, together with the SM $\bar{\nu}_e - e$ and coherent scattering $\bar{\nu}_e - N$.

Dark Matter Searches

The WIMPs interact with matter predominantly via the same coherent scattering mechanism like the neutrinos: $\chi + \mathrm{N} \rightarrow \chi + \mathrm{N}$. There may be both spin-independent and spin-dependent interactions between WIMP and matter. Most experimental programs op-

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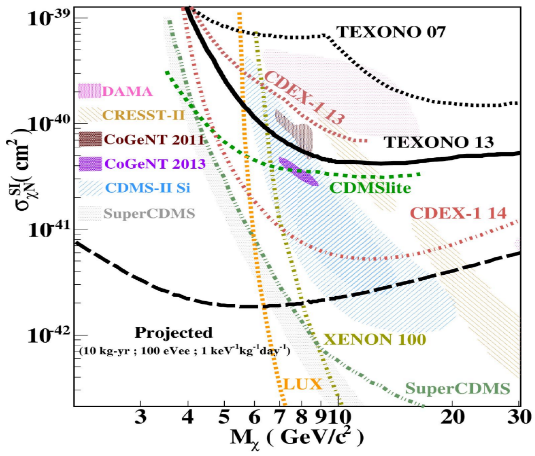

FIG. 2: Exclusion plot of spin-independent coupling, superimposed with the results from other benchmark experiments.

TABLE I: Summary table of performance parameters on detector hardware and signal selection of the various Ge detectors, with data taken at KSNL.

Items	CoaxGe	ULEGe	pPCGe	nPCGe
Modular Mass (g)	1000	5	500	500
RESET Amplitude (V)	N/A	8.0	6.8	6.8
RESET Time Interval (ms)	N/A	$\sim$ 700	$\sim$ 160	$\sim$ 170
Pedestal Noise RMS (eV)	840	38	58	52
Pulser FWHM (eV)	1566	80	110	133
Noise-Edge (eV)	5000	387	350	350
Trigger Threshold (eV)	3500	78	171	208

timize their design in the high-mass region and exhibit diminishing sensitivities for mχ < 10 GeV [3]. To probe the low-mass region, detector with sub-keV threshold is necessary. Such threshold presents a formidable challenge to detector technology and to background control.

Based on data taken at the KSNL and CJPL with p-type point-contact germanium detector having fiducial mass 840 g and 994 g respectively [3], We reported new limits on a spin-independent weakly interacting massive particle (WIMP)-nucleon interaction cross section as shown on figure 2[3].

Sub-keV Germanium Detector

Data taken from measurements with four Ge-detectors and their performance are described in Table 1. The detectors are (1) conventional coaxial p-type high purity Ge detector with 1 kg in mass (CoaxGe), (2) 4-element array of n-type Ge detector with 5 g modular mass (ULEGe), (3) p-type point-contact Ge detectors (pPCGe) with 500 g mass, and, (4) n-type point-contact Ge detector (nPCGe) with 500 g mass. And their respective sensor schematics are shown in figures 3 of Ref.[1].

Signals are first amplified by the front-end JFETs in the vicinity of the Ge diodes. The output are fed to reset preamplifier placed ~30 cm away. The preamplifier signals are further processed by shaping and timing amplifiers. The timing amplifier (TA) output preserves the rise-time information for distinguishing bulk versus surface events. The shaping amplifier signals at 6 μs shaping time (SA6) are optimized for energy measurement, the discriminator output of which provides the data acquisition (DAQ) trigger. The SA and TA signals are digitized by 60 and 200 MHz flash analog-to-digital converters, respectively.

Germanium detectors with sub-keV sensitivities have opened the new windows for the studies of SM and exotic neutrino interactions as well as for the searches of light WIMPs. Projects on the improvement of electronics and sub-noise-edge analysis are being pursued.

References

[1] A. K. Soma, et al., arXiv:1411.4802 (2014).

[2] Jiunn-Wei Chen et al, Phys. Rev. D 90, 011301(R)(2014).

[3] H. B. Li et al., Phys. Rev. Lett. 110, 261301 (2013); H. B. Li et al., Astroparticle phys. 56, 1-8 (2014); Q. Yue et al., Phys. Rev. D 90, 091701(R)(2014).