Modern Physics Letters A
Vol. 25, Nos. 11 & 12 (2010) 944–950

DOI: 10.1142/S0217732310000095

DARK MATTER SEARCHES WITH SUB-keV GERMANIUM DETECTOR

HENRY T. WONG
Institute of Physics, Academia Sinica, Taipei 11529, Taiwan
htwong@phys.sinica.edu.tw

The theme of the TEXONO research program is on the studies of low energy neutrino and dark matter physics. The current goals are on the development of germanium detectors with sub-keV sensitivities to realize experiments on neutrino magnetic moments, neutrino-nucleus coherent scattering, as well as WIMP dark matter searches. A threshold of 100−200 eV was achieved with prototype detectors at the Kuo-Sheng Neutrino Laboratory. New limits were placed for low-mass WIMPs. The dark matter program will move to a new underground laboratory currently under construction in Sichuan, China.

Keywords: Dark matter; neutrino physics.

PACS Nos.: 95.35.+d, 14.60.Lm

1. Introduction and Highlights

A research program on low energy neutrino and dark matter physics is pursued at the Kuo-Sheng Neutrino Laboratory (KSNL) by the TEXONO Collaboration.[1] The laboratory is located at a distance of 28 m from a 2.9 GW reactor core and has an overburden of about 30 meter-water-equivalent. Its facilities were described in Refs. 2 and 3, where limits on neutrino magnetic moments with a 1.06 kg germanium detector (HPGe) at a hardware threshold of 5 keV were reported. A background level of ~ 1 event $\mathrm{kg^{-1}keV^{-1}day^{-1}}$(cpd) at 20 keV, comparable to those of underground CDM experiments, was achieved. New results were recently obtained on the measurement of neutrino-electron scattering cross-section and therefore the electro-weak angle $\sin^2\theta_{\rm W}$ with a 200 kg CsI(Tl) scintillating crystal detector array.[4,5] The present goals are to develop advanced detectors with kg-size target mass, 100 eV-range threshold and low-background specifications[6] for the searches of Weakly Interacting Massive Particles (WIMPs)[7] as well as the studies of neutrino-nucleus coherent scattering[8] and neutrino magnetic moments.[9]

2. Results on Dark Matter Searches

A four-channel Ultra-Low-Energy Germanium (ULEGe) prototype detector with a total active mass of 20 g has collected low-background data at KSNL.[7] The trigger

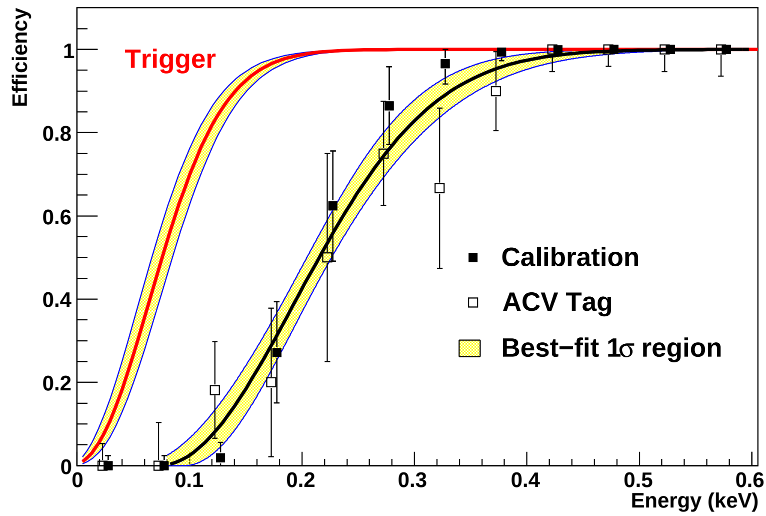

Fig. 1. The trigger and analysis efficiencies of the 20 g ULEGe prototype detector, as derived by the test pulser and *in situ* background events, respectively.

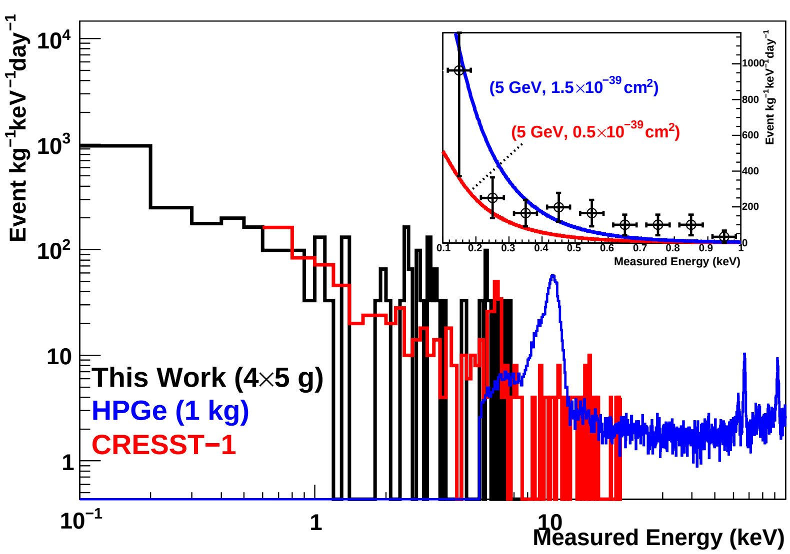

Fig. 2. The measured spectrum of ULEGe with 0.338 kg-day of data, after various background suppression procedures. Background spectra of the CRESST-I experiment and the HPGe are overlaid for comparison.

and analysis efficiencies are shown in Figure 1. An energy threshold of (220±10) eV was achieved at an efficiency of 50%. The background spectrum with 0.338 kg-day of exposure is displayed in Figure 2. Constraints on WIMP-nucleon spin-independent $[\sigma_{\chi N}^{SI}]$ and spin-dependent $([\sigma_{\chi N}^{SD}(n)])$ couplings as functions of WIMP-mass (m_χ)

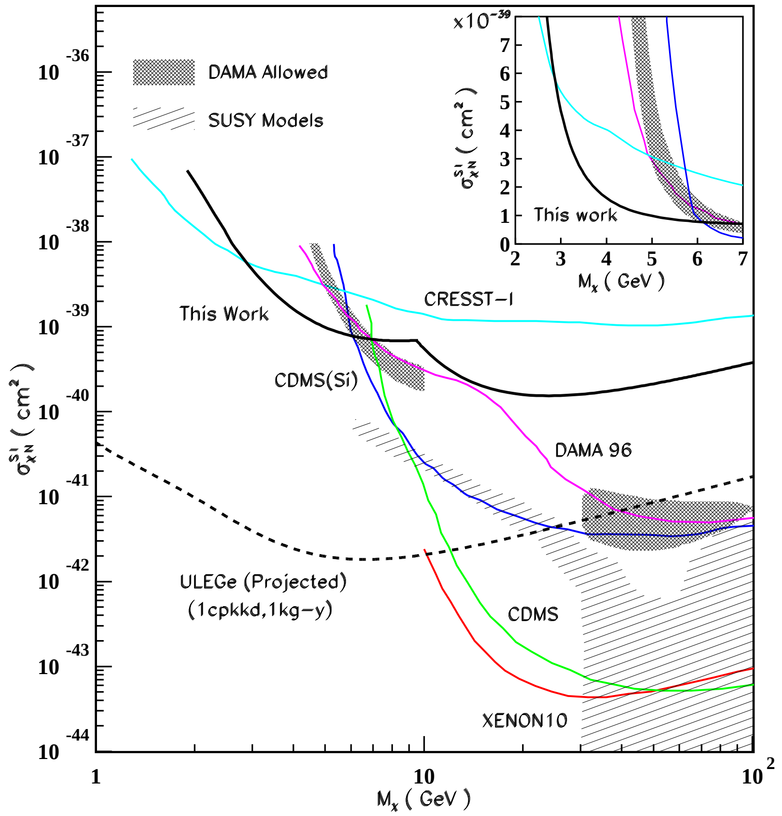

Fig. 3. Exclusion plot of the spin-independent χN cross-section versus WIMP-mass.

were derived, as depicted in Figures 3 and 4, respectively. Overlaid on the plots are results from experiments which define the current exclusion boundaries, the DAMA-allowed regions and that favored by SUSY models.[7,10] The KSNL limits improve over previous results at $m_\chi \sim 3-6$ GeV. Sensitivities for full-scale experiments at 1 cpd background level are projected as dotted lines. The observable nuclear recoils at $m_\chi = 5$ GeV and $\sigma^{SI}_{\chi N} = 0.5\times 10^{-39}$ cm^2(allowed) and 1.5×10^{-39} cm^2(excluded) are superimposed with the measured spectrum in the inset of Figure 2 for illustrations.

3. Performance of Point-Contact Germanium Detectors

The design of Point-Contact Germanium (PCGe) detectors was first proposed in the 1980's,[11] offering the potential merits of sub-keV sensitivities with kg-scale target mass. There are intense recent interest triggered by successful realization and demonstration of the detector technique.[12] A PCGe of target mass 500 g was constructed and has been collecting data in KSNL since early 2009.

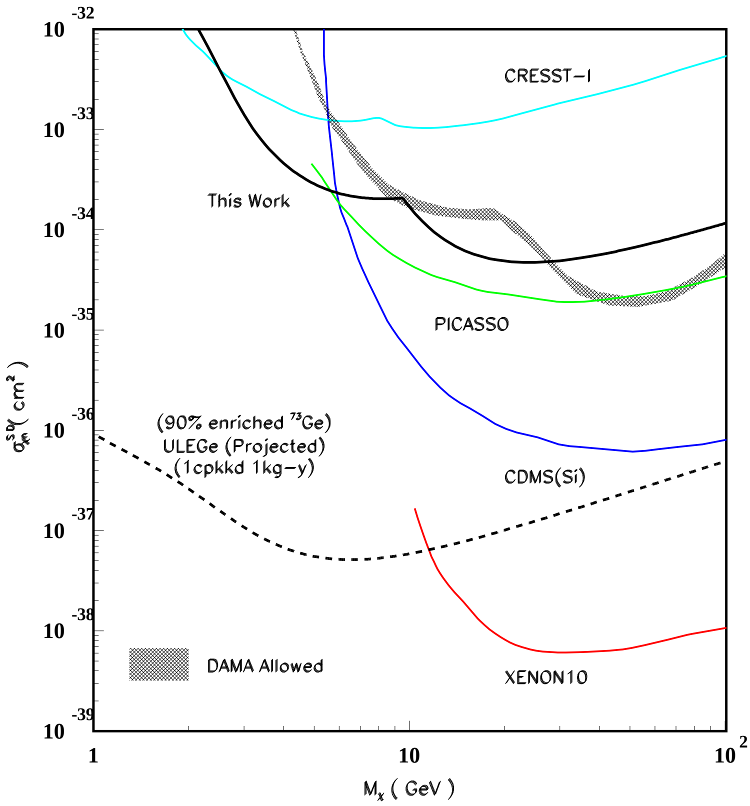

Fig. 4. Exclusion plot of the spin-dependent χ-neutron cross-section versus WIMP-mass.

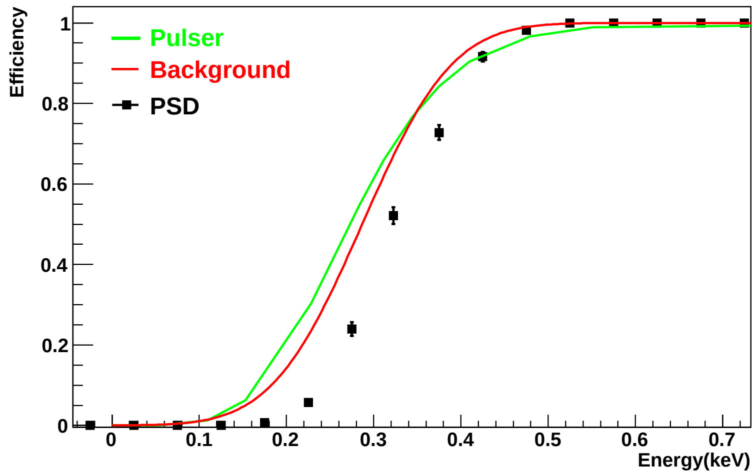

Fig. 5. The trigger and analysis efficiencies of the 500 g PCGe detector, as derived from the test pulser and *in situ* events, respectively.

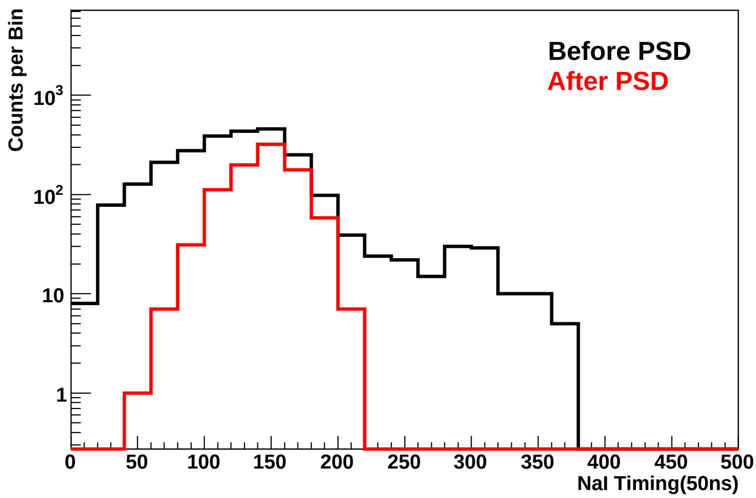

Fig. 6. Events as a function of relative timing between ACV-NaI(Tl) and PCGe systems, before and after PSD selection.

Similar procedures to those developed for the ULEGe were adopted to study the efficiency factors below the electronic noise edge. The results, analogous to those of Figure 1, are displayed in Figure 5. The trigger efficiencies were measured with two methods. The fractions of calibrated pulser events above the discriminator threshold provided the first measurement, while the studies on the amplitude distributions of *in situ* data contributed to the other. The relative timing between the PCGe and anti-Compton (ACV) NaI(Tl) detectors is shown in Figure 6, for "sub-noise edge" events at 200-400 eV before and after the pulse shape discrimination (PSD) selection processes. Events in coincidence with ACV at the "50–200 ns" window are due to multiple Compton scatterings, which are actual physical processes having similar pulse shapes as the neutrino and WIMP signals. It can be seen that only these events have substantial probabilities of surviving the cuts, and the fractions constitute to the PSD efficiencies. The threshold at $\sim$ 50% combined efficiencies is $\sim$ 300 eV. Intensive background and optimization studies with the PCGe at KSNL are underway.

4. China Jin-Ping Underground Laboratory

The dark matter limits of Ref. 7 are by-product results of an experimental configuration optimized for neutrino physics. It is essential that the program will evolve into a dedicated dark matter search experiment in an underground location.

An excellent candidate site for a deep underground laboratory was recently identified in Sichuan, China where the China Jin-Ping Laboratory (CJPL) is being constructed.[13] The map of the region and the tunnel cross section are displayed in Figure 7. The laboratory has more than 2500 m of rock overburden, is accessible

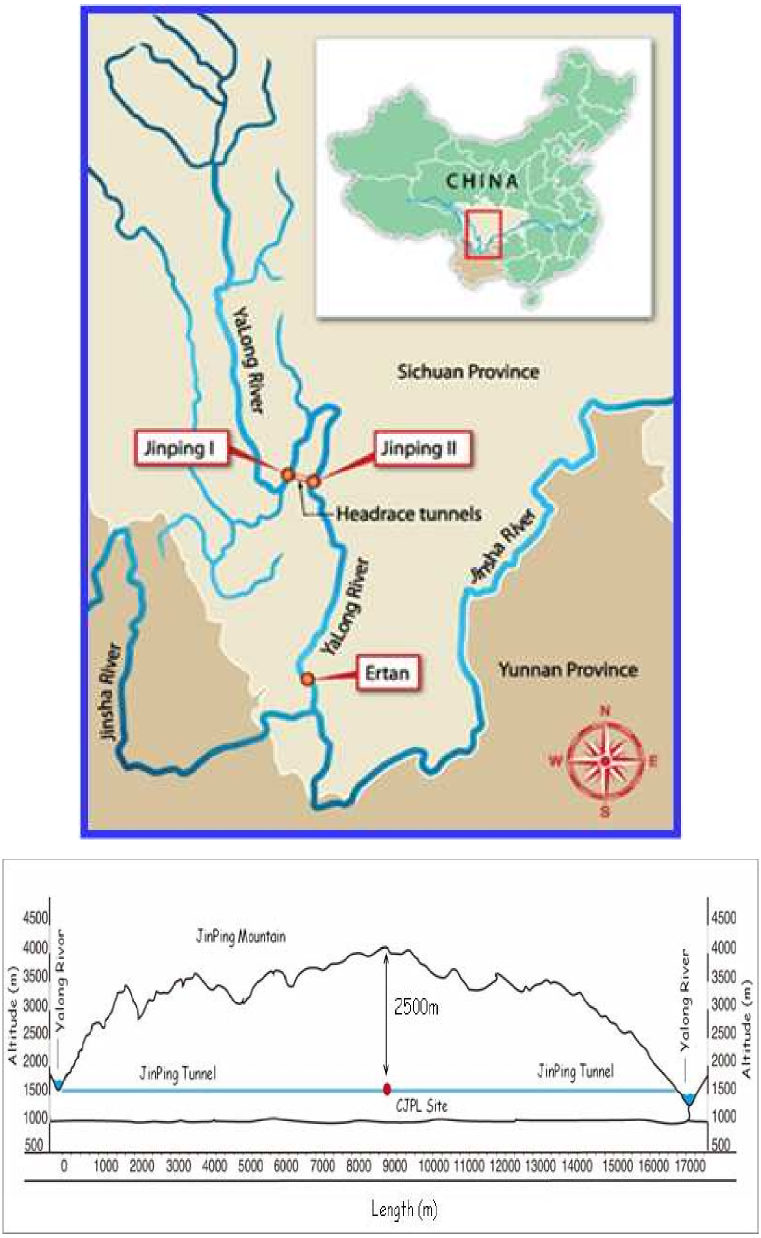

Fig. 7. Location of the China Jin-Ping Underground Laboratory (top) and the cross-section of the Jin-Ping mountain (bottom) showing the overburden and road tunnel access.

by a road tunnel built for public traffic, and is supported by excellent infrastructures already available near the entrance. The first cavern of size 6 m(height) $\times$ 6 m(width) $\times$ 40 m(depth) is scheduled for completion in early 2010.

5. Prospects and Outlook

A detector with 1 kg mass, 100 eV threshold and 1 cpd background level has important applications in neutrino and dark matter physics, as well as in the monitoring of reactor operation. Crucial advances have been made in adapting the Ge detector technology to satisfy these requirements. Competitive limits have been achieved in prototype studies on the WIMP couplings with matter. Intensive research programs are being pursued along various fronts towards realization of experiments which can meet all the technical challenges.

The low energy neutrino physics program will continue at KSNL, where a 900 g PCGe detector will be installed in 2010. Dedicated dark matter search with both 20 g ULEGe and 500 g PCGe detectors will be the first experimental program conducted at CJPL commencing 2010.

Acknowledgments

The author is grateful to the organizers of the workshop for the opportunity to present this report. This work is supported by contracts NSC 97-2112-M-001-010 and NSC 98-2628-M-001-013 from the National Science Council, Taiwan, as well as by the Theme Project Scheme 2008-10 from the Academia Sinica, Taiwan.

References

1. H.T. Wong, Mod. Phys. Lett. A **19**, 1207 (2004).
2. H.B. Li et al., Phys. Rev. Lett. **90**, 131802 (2003).
3. H.T. Wong et al., Phys. Rev. D **75**, 012001 (2007).
4. H.B. Li et al., Nucl. Instrum. Methods A **459**, 93 (2001).
5. M. Deniz et al., arXiv:0911.1597.
6. H.T. Wong, Mod. Phys. Lett. A **23**, 1431 (2008)
7. S.T. Lin et al, Phys. Rev. D **76**, 061101(R) (2009), and references therein.
8. H.T. Wong et al., J. Phys. Conf. Ser. **39**, 266 (2006).
9. H.T. Wong and H.B. Li, Mod. Phys. Lett. A **20**, 1103 (2005).
10. M. Drees and G. Gerbier, Phys. Lett. B **667**, 241 (2008), and references therein.
11. P.N. Luke et al., IEEE Trans. Nucl. Sci. **36**, 926 (1989).
12. P.A. Barbeau, J.I. Collar and O. Tench, JCAP **09**, 009 (2007).
13. D. Normile, Science **324**, 1246 (2009).