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Low-energy neutrino and dark matter physics with sub-keV germanium detectors

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Abstract. The TEXONO-CDEX Collaboration (Taiwan experiment on neutrino–China dark matter experiment) explores high-purity germanium (HPGe) detection technology to develop a sub-keV threshold detector for pursuing studies on low mass weakly interacting massive particles (WIMPs), properties of neutrino and the possibilities of neutrino-nucleus coherent scattering observation. This article will introduce the facilities of newly established China Jing-Ping Underground Laboratory (CJPL), preliminary result of cosmic ray background studies at CJPL, the dark matter studies pursued at Kuo-Sheng Neutrino Laboratory (KSNL) and research efforts to accomplish our physics goals.

Keywords. TEXONO-CDEX Collaboration; PCGe detector; neutrino and dark matter; CJPL underground laboratory.

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1. Introduction

One of the prominent results of the 20th century is the establishment of compelling evidences on the existence of dark matter. The discovery of dark matter is of fundamental importance in the present-day particle physics and cosmology. The origin and the nature of dark matter remain largely unknown, which is a great challenge of the present decade. With the advancement of experimental facilities and technologies, rapid progresses have been achieved in improving the sensitivity on dark matter detection.

Germanium by virtue of its low-energy band gap (0.67 eV) provides feasibility to develop low-energy threshold detector. Additionally, high-purity germanium (HPGe) detection technology is well-matured to scale up detector mass economically. Thus, HPGe technology possesses basic requirements to pursue studies on dark matter.

The collaboration has developed and used several HPGe detectors like commercially available 1 kg coaxial HPGe [1], partially customized 4 × 5 g ultralow background (ULB) HPGe, 500 g and 900 g point contact germanium detectors (PCGe). These novel detectors also find application in understanding properties of neutrino and monitoring nuclear reactor performance [2]. An ultralow energy (ULE) threshold of ∼220 eV was achieved with 4 × 5 g ULB-HPGe detector. Thus, we are approaching towards the goal of developing kilogram scale detectors having ∼100 eV threshold with low background specifications.

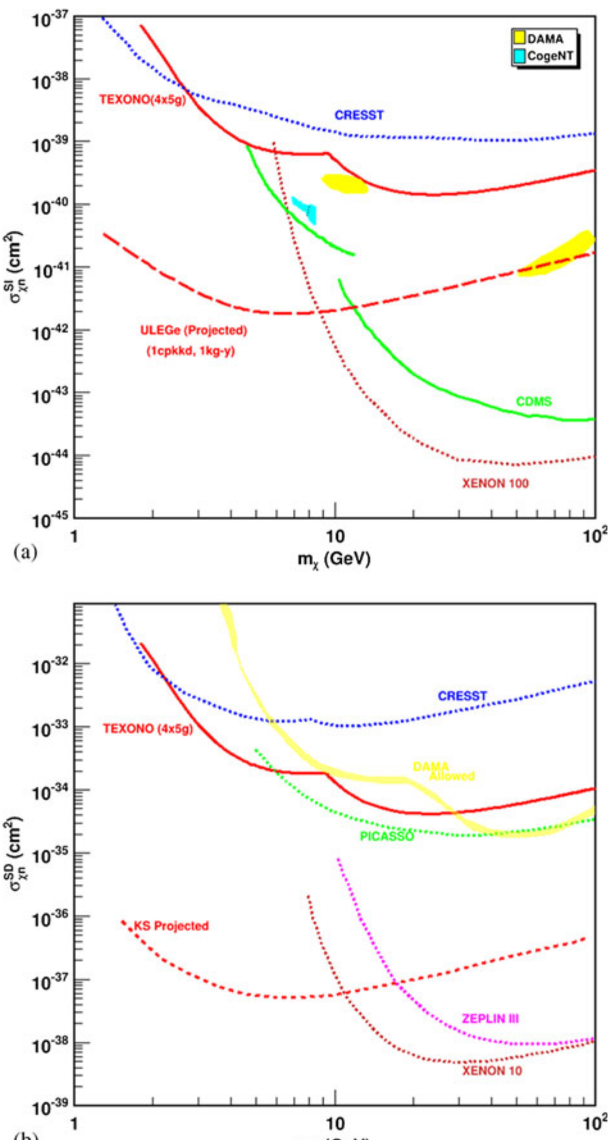

Figure 1. (**a**) Spin-independent χN cross-sections vs. WIMP mass exclusion plot. (**b**) Spin-dependent χ-neutron cross-sections vs. WIMP mass exclusion plot.

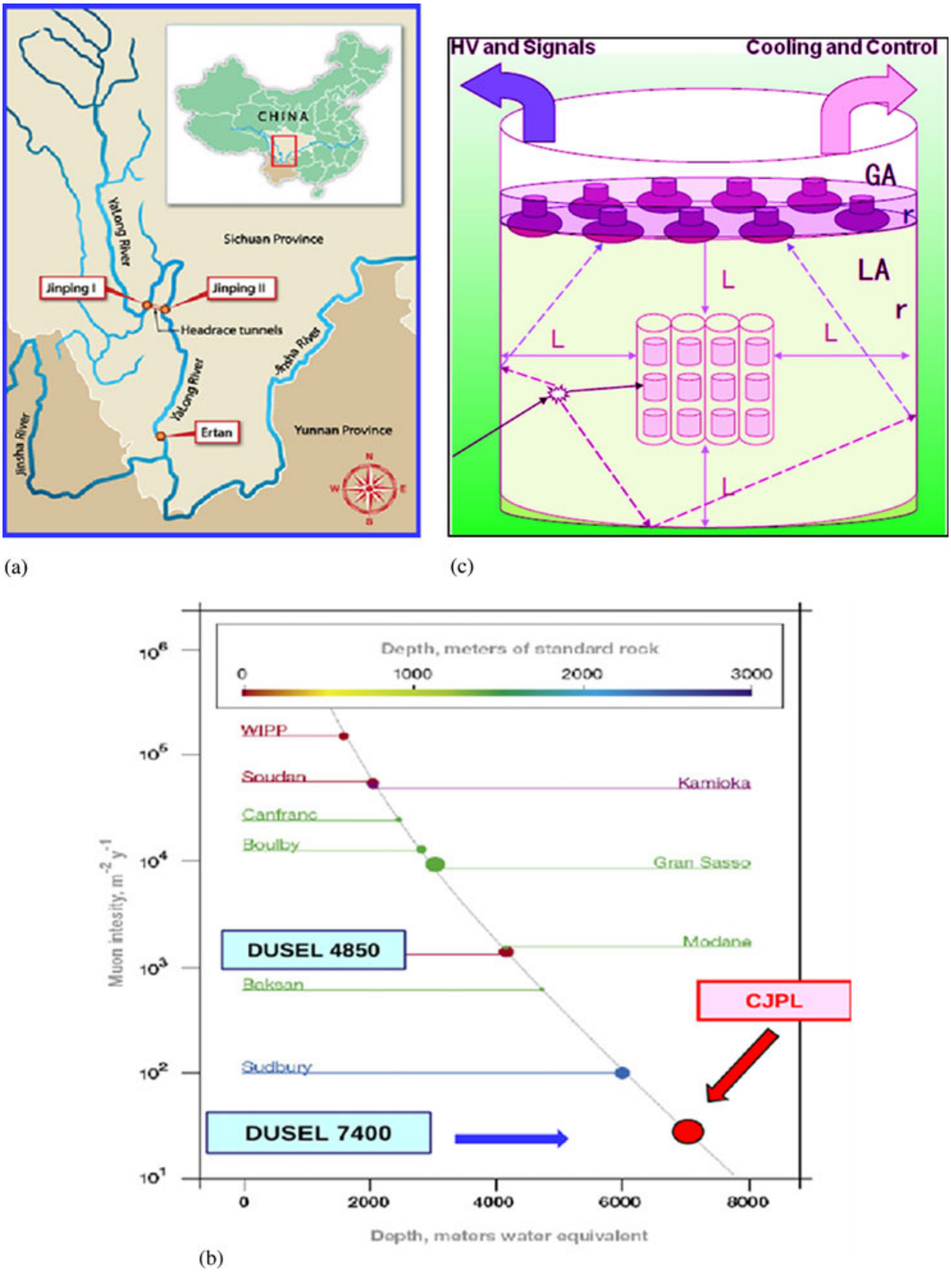

Figure 2. (**a**) Geographical location of CJPL, (**b**) the expected cosmic muon flux with respect to depth and (**c**) schematics of the proposed multiarray germanium detectors with liquid argon as anti-Compton veto at CJPL.

2. Dark matter studies with 4×5 g ultralow energy–ultra low background HPGe

The details of the detector design, shielding configuration, data acquisition and data analysis are described in ref. [3]. Data with a live time of 0.338 kg-day was used to derive constraints on galactic bound WIMPs. The limits improve over previous results on both spin-independent WIMP-nucleon and spin-dependent WIMP-neutron cross-section for WIMP mass between 3 and 6 GeV as shown in figure 1. The observable nuclear recoils at $m_\chi = 5$ GeV are $\sigma^{\rm SI}_{\chi \rm N} = 0.5 \times 10^{-39}$ cm^2 (allowed) and $\sigma^{\rm SI}_{\chi \rm N} = 1.5 \times 10^{-39}$ cm^2 (excluded). Thus, the remaining dark matter (DAMA)-allowed low m_χ region is probed and excluded for both spin-independent and spin-dependent interactions.

3. CJPL: A dark matter laboratory

CJPL is located in Jin-Ping Mountains. The mountains are located at a distance of 350 km south-west of Chengdu, capital of Sichuan province, China. The laboratory has ∼2500 m of marble and sandstone above it; more shielding than any similar site in the world, making it the world's deepest operational dark matter lab. The geographical location and expected muon flux at the 6 m × 6 m × 40 m cavern in one of 17.5 km long tunnels is depicted in figure 2b.

The ULE-ULB 4 × 5 g HPGe detector used in ref. [3] has been commissioned at CJPL lab and collecting data since February 2011. Studies on cosmic ray muon flux are also being performed with plastic scintillators shown in figure 3. We observed 0.18±0.03 counts/day/m^2 cosmic events. The observed results are consistent with expectation.

4. Status and plans

We shall be repeating the dark matter analysis as in ref. [3] by the end of 2011. The studies on ambient radioactivity (gamma, neutron and radon) are currently underway. A 1 kg PCGe is installed at CJPL and the detector behaviour is being studied. We shall

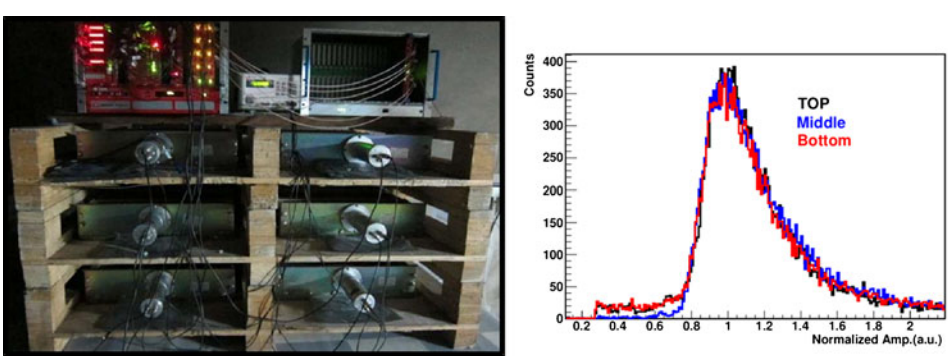

Figure 3. Cosmic ray muon set-up at CJPL with the calibration performed at sea level.

then proceed towards 10 kg range and higher mass array of the detector with liquid argon anti-Compton veto configuration are shown in figure 2c in 2012–14.

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