The CDEX-10 Experiment at the China Jinping Underground Laboratory: The First Results on Light WIMP Searches

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ABSTRACT

The CDEX-10 experiment, which utilizes a 10 kg germanium detector array immersed in liquid nitrogen (LN_2) at the China Jinping Underground Laboratory (CJPL), has recently published their dark matter search results with a physics data size of 102.8 kg day. The most stringent limits on spin-independent WIMP-nucleon cross sections for a WIMP mass of 4-5 GeV/c^2 with the lowest exclusion of 8×10^{-42} cm^2 were set. The results were published in *Physical Review Letters* (2018, 120, 241301).

INTRODUCTION

Compelling evidence from astronomical observations have demonstrated the existence of dark matter in the Universe, which plays a very important role in understanding the origin of mass and the evolution of the Universe. One kind of the most popular dark matter candidates is the weakly interacting massive particle (WIMP), which is a kind of hypothetical massive particle that could interact with ordinary matter via weak force processes. The masses of possible WIMPs suggested by different theories vary from 1 GeV to 100 TeV, and these ranges can and will be reached by current and future colliders. The detection of WIMPs has been a strong expectation for scientists who study new physics beyond the standard model of particle physics.

In general, there are three kinds of methods to detect the candidates of dark matter: direct detection methods, indirect detection methods, and accelerator-driven dark matter production. For direct detection of dark matter, the incident WIMP bombards the target nucleus of the detector and is scattered off by the nucleus, and at the same time, transfers a tiny energy deposition to the recoiled nucleus in the detector. The deposited energies and the numbers and directions of many recoiled nuclei could be used to derive out the mass of incident dark matter and the interactive cross sections between the incident dark matter particles and target nuclei. In recent years, several direct detection experiments have claimed the discovery of suspected dark matter signals around 10 GeV/c^2, which led to conflicts with other experiments. Therefore, the detection of low mass dark matter has become a hot topic in dark matter research.

THE CHINA DARK MATTER EXPERIMENT

With excellent energy resolution and a low energy threshold, p-type point contact germanium (pPCGe) detectors have been used and further developed for light WIMP searches by the China Dark Matter Experiment (CDEX) [1], which aims at direct searches of light WIMPs with pPCGe detectors at CJPL [2], while the PandaX experiment, a liquid xenon experiment also running at CJPL, focuses on heavy dark matter searches with masses of >10 GeV. The CDEX collaboration was initiated by Tsinghua University and began in 2009. The CDEX collaboration comprises the following institutions and organizations: Tsinghua University, Sichuan University, Nankai University, Beijing Normal University, Peking University, the China Institute of Atomic Energy, the Yalong River Hydropower Development Company, and the TEXONO Collaboration based at Academia Sinica, Taipei.

CDEX-1

In 2010, CDEX started its first generation of experi-

Fig. 1: Group photo of the CDEX collaboration.

ments (CDEX-1) at CJPL. With the largest 1 kg-scale single pPCGe detector element designed by CDEX, the first stage of the CDEX experimental system was built to carry out WIMP searches. In 2013, CDEX-1 published the first physical results obtained at CJPL [3]. In 2014, using anti-Compton technology and the bulk/surface discrimination method, CDEX-1 obtained the best sensitivity from pPCGe detectors in the world [4], which not only improved the spin-independent WIMP-nucleon cross section by an order of magnitude, but also definitively excluded the WIMP area claimed by the CoGeNT experiment with similar pPCGe technology. Furthermore, CDEX-1 conducted a study on axion-like particle (ALP) dark matter and the solar axion, and published the most sensitive limit on the axion-electron coupling parameters for ALPs below the 1 keV energy range in 2017 [5]. The same year, the first CDEX results on ^{76}Ge neutrino-less double beta decay were published [6], laying the foundation for the next generation experiment with higher sensitivity in the future.

CDEX-10

The CDEX-10 experiment, the second stage of CDEX, with a total detector crystal mass of approximately 10 kg, has three encapsulated detector strings called C10A, C10B, and C10C, each of which comprises three pPCGe detectors (denoted as Ge1-Ge3 from bottom to top) encapsulated in a copper vacuum tube. The germanium detector strings were directly immersed in LN_2, which provided shielding and cooling simultaneously. Compared to the cold finger cooling technology used in CDEX-1, this method is more feasible for scaling up the mass of the germanium detector to further improve sensitivity. Although CDEX-10 is an important step forward, there are many challenges, such as the arraying technologies, the LN_2 cooling system and background suppression, that must be resolved before beginning future ton-scale experiments.

The configuration of CDEX-10's experimental setup and the structure of a detector string are shown in Fig. 2 [1]. The whole system comprises a stainless steel LN_2 tank with integrated copper shielding, the 10 kg pPCGe detector array, and a data acquisition (DAQ) system. From inside to outside, the passive shielding system comprises

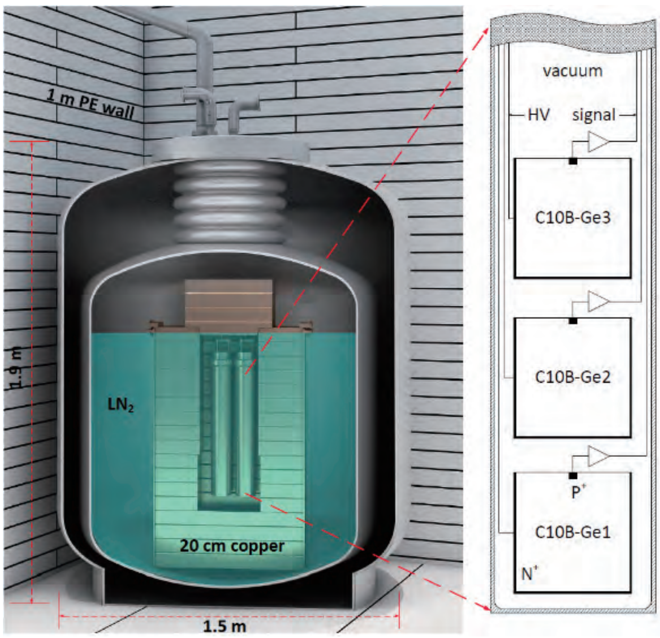

Fig. 2: Configuration of CDEX-10 experimental setup.

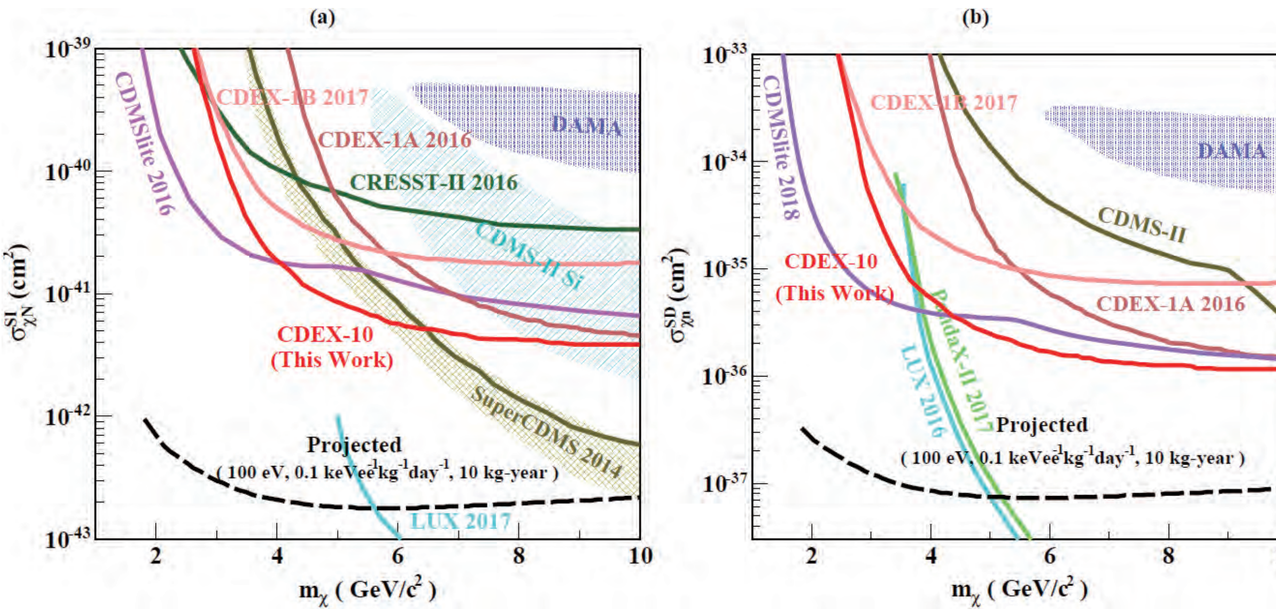

Fig. 3: Exclusion plots of (a) SI χ-N coupling and (b) SD χ-neutron coupling at 90% C.L., superimposed with results from other benchmark direct search experiments.

high-purity oxygen-free high-conductivity copper (20 cm) immersed in the LN_2 and a polyethylene layer (1 m). The dedicated DAQ system was set up and the output signals of the shaping amplifiers and a timing amplifier were digitized by 14-bit 100-MHz flash analog-to-digital converters. The data taking was performed from February 26, 2017 to November 7, 2017.

The latest results from CDEX-10 were from the first physics data set of one of the operational detectors, C10B-Ge1 with a lower energy threshold. The physics data size was 102.8 kg day. At an analysis threshold of 160 eVee ("eVee" represents electron equivalent energy derived from a charge calibration), the lowest threshold and background among the various CDEX data sets to date were achieved, which extended the reach of WIMP mass lower to 2 GeV/c^2. Also, this brought forth almost an order of magnitude improvement over CDEX's previous exclusion bounds, and improved the limits to 8×10^{-42} cm^2 and 3×10^{-36} cm^2 at a 90% confidence level on spin-independent and spin-dependent WIMP-nucleon cross-sections, respectively, at a WIMP mass of 5 GeV/c^2. These are, as of yet, the most stringent limits that have been determined with this kind of detection technology. Especially for spin-independent cross sections, new regions for a WIMP mass of 4–5 GeV/c^2 have been probed and excluded.

CONCLUSION AND PROSPECTS

CDEX is a dark matter direct detection experiment using germanium detectors at CJPL. Currently, the project has just finished the first run of its second phase, CDEX-10. The CDEX-10 detector array will be moved to and installed in a new large LN_2 tank with a volume of about 1725 m^3 at Hall-C of CJPL-II by the end of 2018, where shielding from ambient radioactivity will be provided by 6 m-thick LN_2. At that time, the CDEX-10 experiment and future upgraded phases of the CDEX experiment will run in this cryo-tank toward a ton-scale experiment (CDEX-1T) searching for dark matter and neutrino-less double beta decay [7].

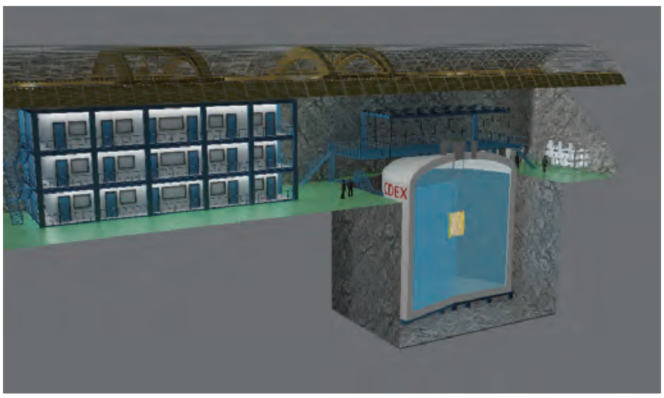

Fig. 4: Conceptual configuration of a future CDEX-1T experiment at CJPL Phase-II.

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Hao Ma is an associate professor at the Department of Engineering Physics, Tsinghua University. He obtained his Ph. D. in 2009 from Tsinghua University and joined the Department of Engineering Physics in 2011 after a postdoctoral fellowship. He also worked on segmented germanium detector technology as a visiting scholar in Max-Planck Institute for Physics from 2014 to 2015. He is a core member of China Dark Matter Experiment (CDEX) collaboration using germanium detectors for direct detection of dark matter in China Jinping Underground Laboratory (CJPL). His current research interest centers on rare event physics experiments, especially the direct search for dark matter and neutrino-less double beta decay experiment.

Litao Yang is a postdoctoral researcher at the Department of Engineering Physics, Tsinghua University. He obtained his Ph. D. in physics from Tsinghua University at this year, and his Ph. D. research focused on the data analysis and physics analysis in CDEX experiment. His current research fields are rare-events searching experiments, especially the direct detection of dark matter and neutrino-less double beta decay experiment.