PROCEEDINGS OF SCIENCE

CDEX-300ν program for ^{76}Ge $0\nu\beta\beta$ search

H. Ma,[a] **W.H. Dai**[a] **and L.T. Yang**[a,*]

[a] *Key Laboratory of Particle and Radiation Imaging (Ministry of Education) and Department of Engineering Physics, Tsinghua University, Beijing, China, 100084*

E-mail: mahao@tsinghua.edu.cn, yanglt@mail.tsinghua.edu.cn

Searching for the neutrinoless double beta ($0\nu\beta\beta$) decay is a promising way to probe the Majorana nature of neutrinos and provide insight into beyond Standard Model physics which might solve the matter-antimatter asymmetry in our current Universe. The China Dark matter EXperiment (CDEX) collaboration is planning and constructing a next-generation $0\nu\beta\beta$ experiment (CDEX-300ν) to search for the $0\nu\beta\beta$ decay of ^{76}Ge in China Jinping Underground Laboratory (CJPL). CDEX-300ν will use about 225 kg ^{76}Ge enriched germanium detectors coupled with passive and active background suppression technologies to conduct a "background free" search for the ^{76}Ge $0\nu\beta\beta$ decay signal. The target ^{76}Ge $0\nu\beta\beta$ decay half-life sensitivity of CDEX-300ν is 10^{27} yr with one ton-yr exposure at a background level of 10^{-4} counts/(kg·keV·yr) in the signal region, corresponding to a effective neutrino mass of 28.5-68.0 meV ranging by the uncertainty of the nuclear matrix element. In this paper, we present $0\nu\beta\beta$ search efforts from CDEX and the pre-conceptual design of the CDEX-300ν experiment.

XVIII International Conference on Topics in Astroparticle and Underground Physics (TAUP2023)
August 28 - September 1, 2023
University of Vienna

[*] Speaker

PoS(TAUP2023)200

1. Introduction

The neutrinoless double beta ($0\nu\beta\beta$) decay is a key to probe the nature of neutrinos. The observation of such lepton number violation process can identifiy the Majorana nature of neutrinos and provide insight into beyond Standard Model physics which might solve the baryon asymmetry in the Universe [1]. The current experimental efforts achieve limit on $0\nu\beta\beta$ decay half-life at a scale of 10^{26} yr [2, 3]. The next generation experiments will target at a half-life sensitivity of 10^{27} yr and searching for the $0\nu\beta\beta$ signal in the inverted neutrino mass ordering region [4, 5].

The CDEX collaboration, persistently focused on dark matter detection [6, 7], has proposed a next generation $0\nu\beta\beta$ experiment (CDEX-300ν) using ^{76}Ge enriched high purity germanium (HPGe) detectors with excellent energy resolution and background rejection power in China Jinping Underground Laboratory (CJPL). In this paper, we will describe the $0\nu\beta\beta$ results from the different types of HPGe detectors in CDEX and the pre-conceptual design of the CDEX-300ν experiment.

2. $0\nu\beta\beta$ results from CDEX

The CDEX collaboration has conducted $0\nu\beta\beta$ searches using p-type point contact Ge (PPCGe) and broad energy Ge (BEGe) detectors to study various background suppression technologies.

The first $0\nu\beta\beta$ search conducted by CDEX was performed on a natural PPCGe detector (called CDEX-1A) previously used in the dark matter search [8]. The detector was operated in a complex passive shielding consisting of copper, lead, borated polyethylene, and polyethylene in the phase-1 of CJPL (CJPL-I) [9]. Based on 304 kg·day exposure data without active background suppression, CDEX-1A set a ^{76}Ge $0\nu\beta\beta$ half-life limit at $T^{0\nu}_{1/2} \geq 6.4 \times 10^{22}$ yr (90% C.L.) [10].

A natural BEGe detector was operated in CJPL-I to study the pulse shape discrimination (PSD) method and its background suppression power. The PSD method reduced the background in $0\nu\beta\beta$ signal region by a factor of 3.7, and a half-life limit was set to $T^{0\nu}_{1/2} \geq 5.6 \times 10^{22}$ (90% C.L.) with an exposure of 186.4 kg·day [11].

Another natural PPCGe detector (CDEX-1B) was operated with a NaI anti-coincidence detector to test the joint background suppression power of anti-veto and PSD method. The two methods together suppressed the background in the signal region by a factor of 23. An updated half-life limit of $T^{0\nu}_{1/2} \geq 2.2 \times 10^{23}$ (90% C.L.) in CDEX experiments was derived from the 504 kg·day CDEX-1B exposure data [12].

3. Pre-conceptual design of CDEX-300ν

CDEX-300ν is designed to achieve a half-life sensitivity of 10^{27} yr with 5 years operation. The baseline design of CDEX-300ν is to have 225 kg ^{76}Ge enriched (>86% enrichment) BEGe detectors directly immersed in liquid argon (LAr) for cooling and veto. The reentrant tube containing LAr will be submerged in a 1725 m^3 liquid nitrogen (LN$_2$) for cooling and shielding. The whole experiment setup is located in the Hall-C of phase-II of CJPL. The 2400 m rock overburden of CJPL can shield the cosmic muons to $O(10^{-10})$ cm^{-2}s^{-1} [9], which makes the μ-induced background negligible for CDEX-300ν. Fig.1 shows the layout of the CDEX-300ν experiment setup.

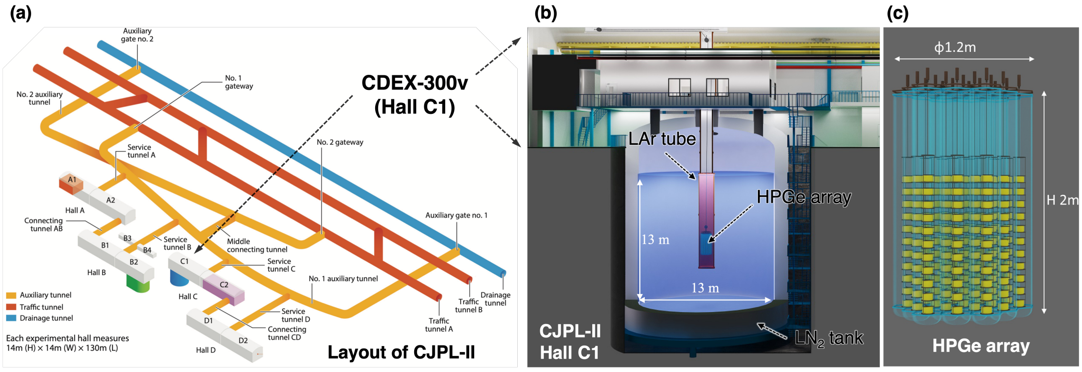

Figure 1: Layout of the CDEX-300ν experiment. (a) the layout of CJPL-II. (b) the CDEX-300ν experiment setup in Hall-C1. (c) the HPGe detector array with optical fibers (in blue) used to collect the LAr scintillation light to SiPMs.

The large LN_2 tank has been constructed in Hall-C1 and is planning to be filled with 1725 m^3 LN_2. The LN_2 within the large LN_2 tank is both a passive shield for HPGe detectors and cryogen for inside LAr. For the central HPGe detectors, over 4 m thick LN_2 could shield most backgrounds from outside the LN_2 tank.

The LAr will be held in a reentrant tube made in copper or stainless-steel. The LAr will be constantly recycled to remove the radon and optical impurities. The LAr will be evaporated to gas form for purification, then condensed to liquid and sent back to the LAr tube. To maintain the light yeild and transmission in LAr, the O_2 and H_2O impurities will be controlled in <10 ppb level by purifiers. The radon within LAr will be removed to μBq/m^3 scale via active carbon.

The BEGe detectors, 200 in total, will be arranged in 19 strings and deployed in the LAr. The detector module will be further optimized to have fewer surrounding structures to reduce their backgrounds. Light readout equipments, SiPMs and optical fibers, will be installed with the detector array to collect and readout the scintillation light of LAr for veto purpose.

The BEGe detectors in CDEX-300ν will be enriched in ^{76}Ge and are designed to achieve an energy resolution of 2.5 keV (full-width-half-maximum) in the 2 MeV signal region. We have established the technical chain from Ge material preparation to detector fabrication. Measures have been taken to protect detectors from cosmic rays during the production and transportation.

All materials used in the construction of the CDEX-300ν will be measured and selected to control background. A perliminary background simulation indicates that after the pulse shape discrimination and LAr veto, a background of 0.95×10^{-4} cpkky in the $0\nu\beta\beta$ signal could be achieved according to the CDEX-300ν pre-conceptual design. Researches and developments on underground material production and detector fabrication are also ongoing to further reduce the cosmogenic background for future larger scale experiments.

4. Summary

CDEX-300ν is a next generation $0\nu\beta\beta$ search experiment in CJPL, aiming at achieving a half-life sensitivity of 10^{27} yr with 1 ton-yr exposure. The recent pre-studies and the pre-conceptual design for CDEX-300ν are outlined in this paper. The CDEX-300ν is currently under construction in CJPL and is planning to start in-situ detector test in 2024.

Acknowledgments

This work was supported by the National Key Research and Development Program of China (2022YFA1604701) and the National Natural Science Foundation of China (12175112, 12322511). We thank CJPL and its staff for supporting this work. CJPL is jointly operated by Tsinghua University and Yalong River Hydropower Development Company.

References

[1] M. Bilenky, and C. Giunti. Neutrinoless double-beta decay: a brief review. *Mod. Phys. Lett. A* **27**, 1230015 (2012).

[2] M. Agostini, *et al*. (GERDA Collaboration), Final results of GERDA on the search for neutrinoless double-β decay. *Phys. Rev. Lett.* **125**, 252502 (2020).

[3] S. Abe, *et al*. (KamLAND-Zen Collaboration), Search for the Majorana nature of neutrinos in the inverted mass ordering region with KamLAND-Zen. *Phys. Rev. Lett.* **130**, 051801 (2023).

[4] M. Agostini, *et al*. Toward the discovery of matter creation with neutrinoless $\beta\beta$ decay. *Rev. Mod. Phys.* **95**, 025002 (2023).

[5] N. Abgrall, *et al*. (LEGEND Collaboration), The large enriched germanium experiment for neutrinoless double beta decay (LEGEND). *AIP Conf Proc* **1894**, 020027 (2017).

[6] H. Jiang *et al*. (CDEX Collaboration), Limits on light weakly interacting massive particles from the first 102.8 kg×day data of the CDEX-10 experiment. *Phys. Rev. Lett.* **120**, 241301 (2018).

[7] W.H. Dai *et al*. (CDEX Collaboration), Exotic dark matter search with the CDEX-10 experiment at China Jinping Underground Laboratory. *Phys. Rev. Lett.* **129**, 221802 (2022).

[8] Q. Yue, *et al*. (CDEX Collaboration), Limits on light weakly interacting massive particles from the CDEX-1 experiment with a p-type point-contact germanium detector at the China Jinping Underground Laboratory. *Phys. Rev. D* **90**, 091701 (2014).

[9] J.P Cheng, *et al*. The China Jinping Underground Laboratory and its early science. *Annu. Rev. Nucl. Part. Sci.* **67**, 231-251 (2017).

[10] L. Wang, *et al*. (CDEX Collaboration), First results on ^{76}Ge neutrinoless double beta decay from CDEX-1 experiment. *SCI CHINA PHYS MECH* **60**, 071011 (2017).

[11] W.H. Dai, *et al*. (CDEX Collaboration), Search for neutrinoless double-beta decay of ^{76}Ge with a natural broad energy germanium detector. *Phys. Rev. D* **106**, 032012 (2022).

[12] B.T. Zhang, *et al*. (CDEX Collaboration), Searching for ^{76}Ge neutrinoless double beta decay with the CDEX-1B experiment. *arXiv*: 2305.00894 (2023).