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Recent Status and Prospects of CDEX dark matter search at CJPL

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The China Dark Matter Experiment (CDEX) is located at the China Jinping Underground Laboratory (CJPL) with a 2400 m rock overburden and aims for direct detection of light dark matter (DM) with high purity germanium (HPGe) detectors. CDEX has finished two stages: CDEX-1 and CDEX-10. Moreover, numerous leading results have been published exploring multiple physics channels. For the next generation in the CDEX experiment, CDEX-50 will be located at CJPL-II and large-scale detector arrays with a total mass of approximately 50 kg will be used. Research and development (R&D) processes for many key technologies regarding the CDEX have been performed, and notable progress has been achieved.

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1. Direct Detection of Dark Matter

The existence of dark matter (DM), which contributes to approximately one-quarter of the energy density of the Universe, has been supported by astronomical and astrophysical evidence. As the most competitive DM candidates, weakly interacting massive particles (WIMPs) can interact with the nuclei of common matter through the elastic scattering process and deposit energy, which can be detected in ultralow background underground laboratories [1]. Direct detection experiments aim to detect signals generated by scattering between the DM and target nuclei. The China Dark Matter Experiment (CDEX) is dedicated to the direct detection of light DM using p-type Point Contact Ge (pPCGe) detectors at the China Jinping Underground Laboratory (CJPL) [2, 3]. In this paper, the CDEX-1 and CDEX-10 results are reported. Moreover, a future plan for CDEX-50 at CJPL-II, as well as the advancements in research and development (R&D) of key technologies, will be presented.

2. Recent Status of CDEX-1 and CDEX-10

The CDEX-1 experiment operates two single-element 1 kg pPCGe detectors (CDEX-1A and CDEX-1B) in the PE room of CJPL-I. The detectors use low background lead, oxygen-free high purity copper, and polyethylene for passive shielding, whereas NaI(TI) serves as an anti-Compton detector. Furthermore, the CDEX-1B ran for more than 4 years and accumulated an exposure of more than 1200 kg day. The energy threshold achieved 160 eVee, while the exclusion sensitivity was extended to a DM mass of 2 GeV/c^2 [4].

CDEX-10, the second generation of CDEX, operates a detector array of three strings with three detectors each directly immersed in liquid nitrogen for cooling and shielding. The first 102.8 kg-day data from CDEX achieved a background level of 2 counts keV^{-1} kg^{-1} day^{-1} (cpkkd) between 2 and 4 keV with an analysis energy threshold of 160 eVee. The exclusion limits reached 8×10^{-42} and 3×10^{-36} cm^2 at 90% C.L. on spin-independent (SI) and spin-dependent (SD) DM-nucleon cross sections, respectively, at a DM mass of 5 GeV/c^2 [5].

The CDEX-1 and CDEX-10 data were analyzed considering various physics channels. The time dependence of the DM-nucleon elastic scattering signals, namely, the annual modulation effect, was studied using the CDEX-1B data [6]. The Migdal effect, which indicates that high-energy electrons are ejected through the inelastic DM-nucleon scattering process [7], was also analyzed using the CDEX-1B data. By incorporating the Migdal effect, the DM mass-search-sensitive region was expanded to as low as 50 MeV/c^2 [8]. The DM-electron scattering process in semiconductor detectors, such as Ge, is somewhat difficult to explore as the electrons are bound within the crystal environment. With the development of computing techniques, novel constraints on the DM-electron scattering cross section have been proposed using the CDEX-10 205.4 kg-day dataset [9]. Limits on the solar dark photon mixing parameter κ were also proposed using CDEX-10 data [10]. Furthermore, new low-mass dark matter searching channels, neutral current fermionic DM absorption, and DM-nucleus 3$\rightarrow$2 scattering have also been analyzed using the CDEX-10 data [11]. Meanwhile, the cosmic-ray boosted DM (CRDM) [12], boosted DM from evaporating primordial black holes [13], and DM exotic interactions with solar neutrinos [14] have also been analyzed with the CDEX-10 205.4 kg-day dataset. A new simulation package, CJPL_ESS, was developed to evaluate the Earth shielding effect, in which DM particles transport through the rock overburden, lose energy, and change their direction [15].

3. Future Prospect of CDEX at CJPL-II and R&D of Key Technologies

The CDEX experiment progresses to new stages in CJPL-II, the second phase of CJPL laboratory. In the next generation of CDEX, CDEX-50 is composed of five detector strings with 10 detectors each and achieves a total mass of approximately 50 kg. Furthermore, it is designed to reach a background of less than 0.01 cpkkd at 1 keV and an energy threshold of 160 eVee with an exposure of 50 kg year. The expected WIMP SI exclusion sensitivity from CDEX-50 will reach 10^{-44} cm^2, and multiple physics channels will also be explored. To better understand the contributions of various radioactive sources to the total background, a detail simulation was conducted and a background model was established. The background contributions in the low energy region are mainly from ^3H and cosmogenetic radionuclides inside the crystal [16].

The R&D of several key technologies was performed to achieve the required objectives of the next-stage CDEX experiment. Therefore, we developed a bare Ge detector that is directly immersed in liquid nitrogen to further reduce the radioactive background from ambient materials. The system has been tested and demonstrated long-time stability. The CMOS ASIC-based preamplifier works well in liquid nitrogen. In addition, CMOS front-end electronics have been developed to achieve lower noise, lower mass, and lower radioactive background. To produce radiopure copper, an electric-form copper production facility was established and tested at Tsinghua University and then moved to CJPL-I.

The CJPL-II laboratory, where the next-stage CDEX will be located, is currently under construction, with a target year of completion of 2025. Compared with CJPL-I, the room of the laboratory expanded from 4000 m^3 to 300,000 m^3 with 8 main experimental halls. A 1725 m^3 liquid nitrogen cooling and shielding system was built in the C1 hall of CJPL-II to prepare the new-generation CDEX expeiment.

4. Summary

The CDEX experiment is a competitive endeavor in the DM direct detection, given its unique advantages of high-purity Ge detectors, including its low energy threshold and high energy resolution. Recently, CDEX has made noteworthy progress by publishing leading results for low mass DM detection and exploring multiple physics channels and different DM candidates. The next-stage CDEX-50 project has already commenced and will be located at the C1 hall of CJPL-II. Many R&D processes of key technologies are ongoing and have made good progress.

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