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Status and prospect of China Jinping Underground Laboratory

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Abstract. China Jinping underground laboratory (CJPL) is located in the Jinping Mountain, Sichuan Province, southwest China, with a rock overburden of about 2400m, and it is currently the deepest underground laboratory in the world, and will become one of the largest with the completion of its extension project (CJPL-II). Based on CJPL-II, the Deep Underground and ultra-low Radiation Background Facility for frontier physics experiments (DURF) was approved in November 2019 and started construction in December 2020. The scientific project at CJPL is mainly focused on dark matter detection, nuclear astrophysics and low background screening techniques. Currently, China Dark matter Experiments (CDEX) and Particle and Astrophysics Xenon Experiments (PandaX) are conducting dark matter searching at CJPL and more experiments are planed or proposed to stationed in CJPL-II in the future.

1. Introduction to CJPL

China Jinping underground laboratory (CJPL) is an underground research facility located in the middle of a traffic tunnel of Jinping hydropower station in Sichuan Province, southwest China. The traffic tunnel runs through the Jinping Mountain, with rock overburden over 1500m along 73% of its length, and the maximum overburden is about 2400m where the laboratory is located, which makes CJPL the deepest underground laboratory in the world [1]. The phase-I of CJPL (CJPL-I) has been in operation since 2010, and the extension project (CJPL-II) started in November 2014.

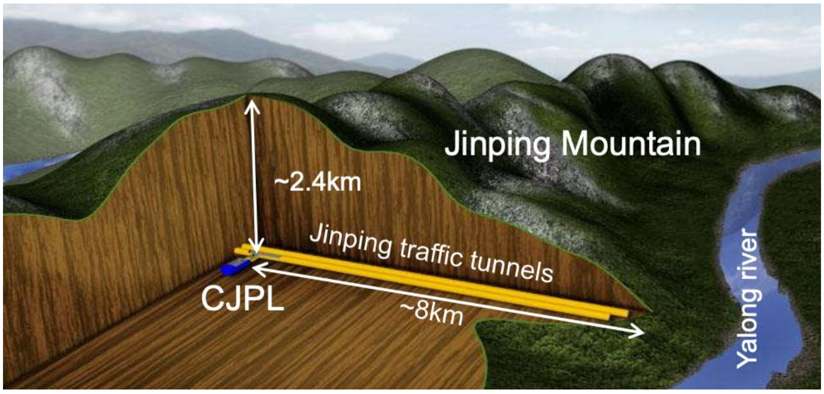

Figure 1. CJPL location in Jinping Mountain.

The CJPL is jointly built and operated by Tsinghua University and Yalong River Hydropower Development Company, LTD. And the DURF project based on CJPL-II, Deep Underground and ultra-low Radiation background Facility for frontier physics experiments, has been approved as one of the National Major Science and Technology Infrastructure Construction Projects of China and started construction in December 2020.

2. Status of CJPL-I

2.1. Features of CJPL-I

The CJPL-I is opened on December 12, 2010. The total space of CJPL-I is about 4000m^3 with the main hall size of 6.5m (width) × 6.5m (height) × 42m (length), shown in Fig. 2.

The Muon flux of CJPL-I was measured to be $(2.0\pm0.4)\times10^{-10}$cm^{-2}s^{-1} [2]. The radioactivity of environment rock samples was measured to be: <1.1 Bq/kg for ^{40}K, 1.8±0.2 Bq/kg for ^{226}Ra, <0.27 Bq/kg for ^{232}Th. CJPL-I is an ideal site for low background experiments.

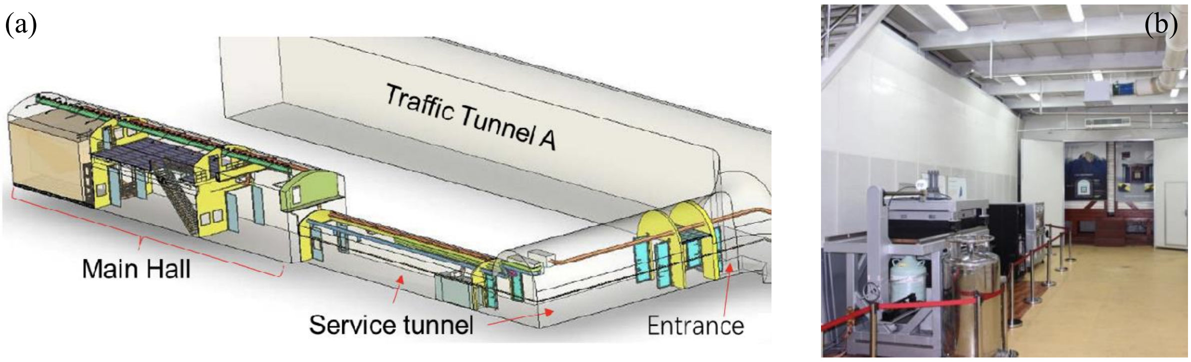

Figure 2. Layout of CJPL-I (a) and photo of the main hall (b).

2.2. Research activities at CJPL-I

Two dark matter direct detection experiments, i.e., CDEX and PandaX, and GeTHU spectrometers for material screening are located in the main hall of CJPL-I.

CDEX-1 used a single-element p-type point contact (PPC) germanium detector to search for weakly interacting massive particles (WIMPs). The detector was shielded with oxygen-free high-conductivity copper, borated polyethylene and lead from innermost to outside. The entire setup was installed in a PE room, with one-meter-thick polyethylene floor, roof and walls [3]. Based on 737.1 kg-day exposure with an analysis threshold of 160 eVee ("eVee" represents electron equivalent energy), the WIMP-nucleon spin-independent (SI) and spin-dependent (SD) coupling were analyzed [3]. And considering the high-energy electron ejection in WIMP-nucleon scattering processes, called Migdal effect, the sensitive windows in WIMP masses are expanded by an order of magnitude to lower DM masses [4]. The time dependence of WIMP-nucleon scattering signals, so-called annual modulation effect, was analyzed using 1107.5 kg-day exposure data with an energy threshold of 250 eVee [5], and excluded allowed regions implied by the DAMA/LIBRA phase 1 [6] and CoGeNT [7] at more than 99.99% and 98% C. L., respectively.

CDEX-10 operated three triple-element PPC germanium detector strings directly immersed in liquid nitrogen in the PE room. The first 102.8 kg-day data from one of CDEX-10 PPC detectors were analyzed with an energy threshold of 160 eVee. An improved limit was achieved on SI and SD WIMP-nucleon cross sections [8], and analysis of solar dark photon and solar dark photon dark matter were conducted and set constraints on the dark photon effective kinetic mixing parameter [9].

The other dark matter experiment, PandaX, uses a dual-phase Xenon Time Projection Chamber (TPC). The PandaX-II operated 580kg Xenon from July 2016 to July 2019. The 54 ton-day exposure data were used to analyze WIMP-nucleon SI coupling with limits at the cutting edge of dark matter searches [10]. And 46.9 ton-day data with analysis threshold of 80eV achieved by analysing S2 signal only were used to constrain light dark matter-electron scattering [11].

GeTHU gamma-ray spectrometers are located in the CJPL-I main hall outside the PE room. GeTHU-1/2/3 are running for material screening for low background experiments, such as CDEX and JUNO. The new member, GeTHU-4, is under commissioning. The detection limit is about 0.1mBq/kg for GeTHU-1, and 1 mBq/kg for GeTHU-2/3, respectively.

3. Status and prospects of CJPL-II

Due to almost filled space of CJPL-I and the requirement of future physical experiments, an extension project (CJPL-II) was agreed to start in August 2014.

Two planned-to-be-refilled auxiliary tunnels were selected for CJPL-II. The construction started on November 25, 2014, and the rock excavation of all experiment halls and two experiment pits were completed in December 2015 and May 2016. The installation of ventilation system was started in December 2016.

The total volume of CJPL-II is about 300k m^3 with four main halls of 14m (width) × 14m (height) × 130m (length) shown in Fig.3. It will be the deepest and largest underground laboratory in the world when completed [12].

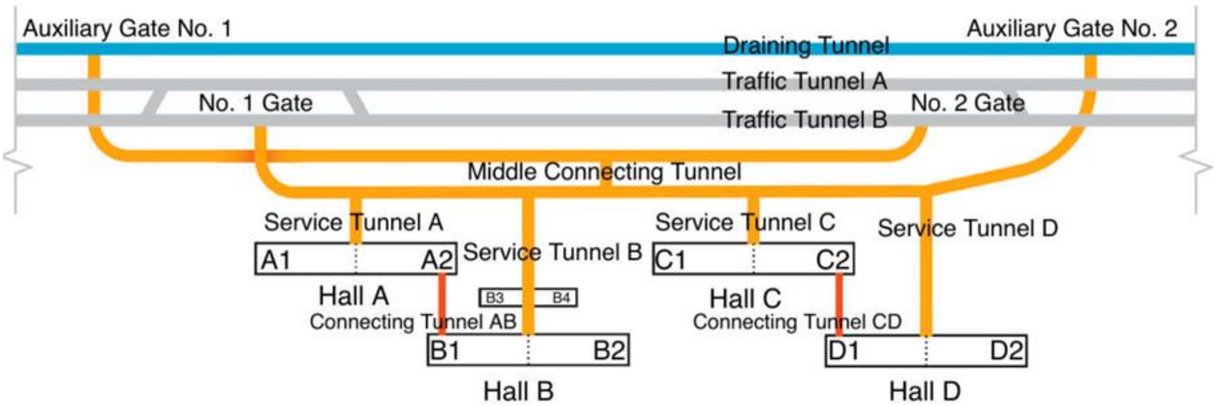

Figure 3. Layout of CJPL-II

3.1. DURF project based on CJPL-II

The DURF project is based on CJPL-II to provide low background environment, shielding and other supporting facility for low background experiments. DURF was proposed as a National Major Science and Technology infrastructure of China in 2016, and was approved by government in November 2019. The construction started in December 2020, and is expected to complete in 2024.

Several facilities will be built in DURF, shown in Fig.4. A large pure water vessel is in hall B2 with a size of 27m × 15m × 13m and is used to provide shielding from environmental radioactivity. A large liquid nitrogen tank located in hall C1, with a diameter of 13m and height of 13m, is used to provide shielding and cryogenic environment for germanium-based experiments. A low background counting facility located in hall C2 consists of one Ultra-low background germanium spectrometer with detection limit of 10 μBq/kg and fifteen low background germanium spectrometers with detection limit of 0.1 mBq/kg.

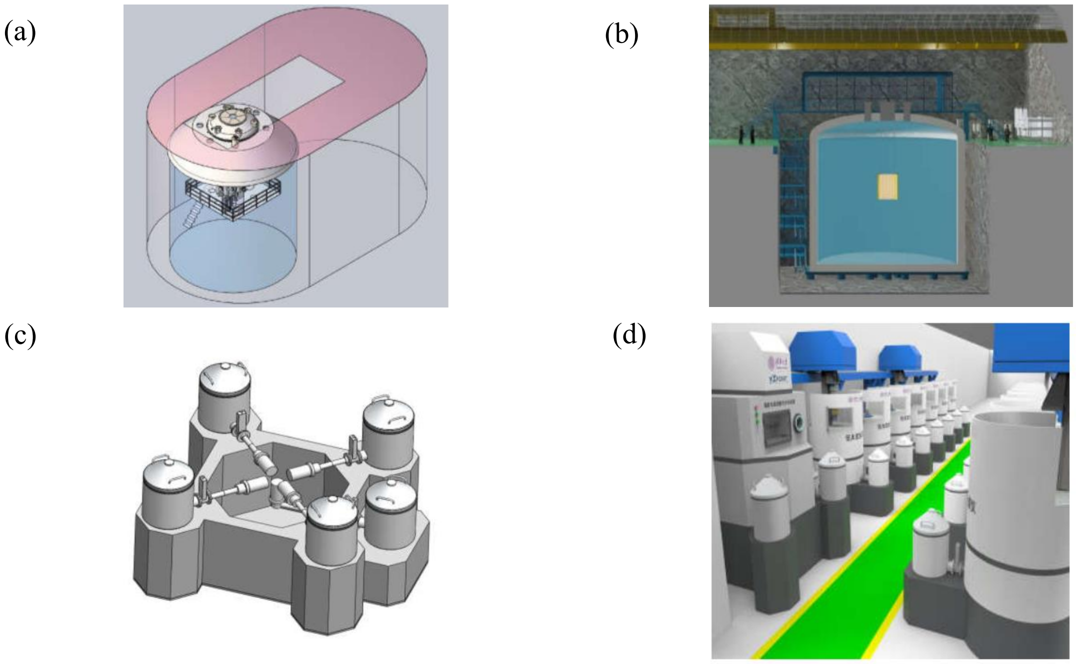

Figure 4. Schematic diagrams of facilities in DURF: Water vessel (a); LN_2 tank(b); Ultra-low background spectrometer (c); Low background spectrometers (d).

3.2. Scientific projects at CJPL-II

Several dark matter, neutrinoless double beta decay and nuclear astrophysics experiments will be located in CJPL-II.

CDEX plans to conduct future dark matter experiment (CDEX-50) and neutrinoless double beta decay experiment (CDEX-300ν) at CJPL-II, aiming at setting limit on WIMP-nucleon SI coupling cross section to 10^{-44} cm^2 at WIMP mass <10 GeV/c^2 and 0νββ decay half-life of ^{76}Ge to >10^{27}yr.

PandaX-4T, with a sensitive target of 3.7-tonne of liquid Xenon, is located in the B2 hall of the CJPL-II [13]. It has finished the commissioning run for dark matter searching and started data taking at July 15, 2021. It aims at setting limit on WIMP-nucleon SI coupling cross section to 10^{-48} cm^2 at WIMP mass of about 40GeV/c^2 [14]. Without enrichment of ^{136}Xe, it can also search for 0νββ decay of ^{136}Xe, expecting half-life sensitivity of >10^{25}yr.

Jinping Underground Experiment for Nuclear Astrophysics (JUNA) is located in hall A1 of CJPL-II to replicate the nuclear processes generating energy within stars and the synthesis of heavier elements from hydrogen and helium in the primordial universe using a particle accelerator.

In addition, Jinping Neutrino Experiment detecting solar/Geo/supernova neutrino [15], CUPID-CJPL experiment searching for 0νββ decay of ^{100}Mo [16] and NvDEx experiment for 0νββ decay of ^{82}Se [17] have submitted their proposals to CJPL. Multidisciplinary researches, e.g. underground radiobiology, are also proposed.

4. Summary

The status and prospects of CJPL-I and CJPL-II were presented in this talk. Benefited from the depth of rock overburden and low radioactivity of surrounding rocks, CJPL is an ideal site for low background experiments and it has promoted frontier physics experiments in China.

In near future, the CJPL-II and DURF project will make CJPL the deepest and largest underground laboratory in the world, and an exceptional infrastructure for next generation low background experiments.

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