Snowmass2021 - Letter of Interest

The PandaX Experiment

Topical Group(s): (check all that apply by copying/pasting ☐/☑)

☑ (CF1) Dark Matter: Particle Like
☐ (CF2) Dark Matter: Wavelike
☐ (CF3) Dark Matter: Cosmic Probes
☐ (CF4) Dark Energy and Cosmic Acceleration: The Modern Universe
☐ (CF5) Dark Energy and Cosmic Acceleration: Cosmic Dawn and Before
☐ (CF6) Dark Energy and Cosmic Acceleration: Complementarity of Probes and New Facilities
☑ (CF7) Cosmic Probes of Fundamental Physics
☑ (Other) *(NF3) Beyond the Standard Model (NF4) Neutrinos from natural sources (NF5) Neutrino properties*

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Collaboration: PandaX

Abstract: (maximum 200 words)

The PandaX (particle and astrophysical xenon) observatory, located in the China Jinping Underground Laboratory, uses a xenon time projection chamber to search for dark matter particles and to study fundamental properties of neutrinos. The experiment has entered a new phase with a 4-ton liquid xenon target (PandaX-4T), and is expected to start data taking in 2021. The next generation of PandaX aims to improve the sensitivity to dark matter-nucleus coherent scattering to the "neutrino floor" for dark matter masses above 10 GeV/c^2, to search for Majorana neutrinos above an effective Majorana mass of 20 meV, and to perform new physics signal searches with unprecedented low background levels.

Key words: dark matter, neutrinoless double-beta decays, new physics beyond the standard model

The Experiment

The PandaX (Particle and Astrophysical Xenon) experiment, located in the world's deepest underground laboratory, China Jinping Underground Laboratory (CJPL), is dedicated to search for dark matter particles and to study fundamental properties of neutrinos [1]. Two phases of experiments, PandaX-I and PandaX-II have been completed in the past [2][3], equipped with liquid xenon time projection chambers (TPC) of 120 and 580 kg, respectively. PandaX-4T, with a sensitive target of 4-ton liquid xenon, is under preparation in the B2 hall of the newly expanded CJPL-II laboratory. The detector is located in the center of an ultrapure water shield with 10 m in diameter and 13 m in height. A double-vessel cryostat contains about 6 tons of liquid xenon, of which 4 tons is enclosed in a cylindrical dual phase xenon TPC confined by PTFE wall panels. The expected background event rate in a 3-ton fiducial volume is 0.05 event/ton/day below 10 keV. The sensitivity to dark matter-nucleon spin-independent elastic cross section is expected to reach 6×10^{-48} cm^2 at 40 GeV/c^2 with a 6-ton year exposure [4].

PandaX is also planning the next generation of experiment (PandaX-xT), with a target ranging from 30 to 100-ton. The detector configuration will be decided soon based on the results from the current generation-experiments [4,5,6]. However, most of the infrastructure for PandaX-4T can be reused. This includes the ultrapure water shield, the class 10,000 and 1000 clean rooms, the air radon removal system, etc. CJPL-II is also being transformed into a national major scientific facility (Deep Underground and ultra-low Radiation background Facility for frontier physics experiments, DURF), which will provide infrastructure and logistic support to future experiments.

Physics Potentials

1) *Dark matter search*: A major scientific goal of PandaX-xT is to improve the sensitivity to dark matter-nucleus coherent scattering to the "neutrino floor" [7] for a dark matter mass above 10 GeV/c^2. As a benchmark point, at a dark matter mass of 40 GeV/c^2, the sensitivity for spin-independent isoscalar dark matter-nucleon elastic cross section will reach 10^{-49} cm^2. This will cover most of the allowed parameter space from the so-called phenomenological supersymmetric models [8]. Novel techniques explored in recent years, for example searching for electron recoils [9-11] and the subdominant electromagnetic radiations from nuclear recoils [12-14] in dark matter interactions can advance the search for sub-GeV dark matter particles. Axions or axion-like particles can also be investigated through the electron-recoil channel with unprecedented sensitivity. This is of particular interest given the intriguing excess observed in XENON1T [15].
2) *Neutrinoless double beta decay of ^{136}Xe*: with 8.9% natural abundance of ^{136}Xe, PandaX-xT can also perform a sensitive search for the neutrinoless double beta decay of ^{136}Xe, first demonstrated by PandaX-II [16]. The major technological advantage is the self-shielding of liquid xenon TPC (~3 m in diameter and height) and the three-dimensional reconstruction of the interaction position. This provides powerful means of peripheral background suppression, and allows detailed understanding of the background. In terms of energy resolution, XENON1T has demonstrated that σ/E at the 2.46 MeV Q value can reach a superior sub-percent level, a major step forward in the community [17]. Combining all the advantages, the expected sensitivity of PandaX-xT to the neutrinoless double beta decay of ^{136}Xe can reach

10^{27} years, even without any isotope enrichment investment. The half-life can be translated to an effective Majorana mass of around 20 meV, under the assumption of light Majorana neutrinos. This sensitivity can cover most of the allowed space if the neutrino mass ordering is inverted.

3) *Astrophysical neutrinos and new physics:* More generally, given the ultralow background level anticipated in the range from keV to 10 MeV, PandaX-xT is a compelling facility to search for novel and rare astrophysical events and events predicted by the physics beyond the Standard Model of particle physics. Just as an example, PandaX-xT can perform precise measurements of spectrum of solar neutrinos from the pp chain, allowing a more sensitive search for the anomalous neutrino magnetic moment. The coherent scattering of solar ^{8}B neutrinos and atmospheric neutrinos with the xenon nucleus will also be studied, leading to a sensitive search of non-standard neutrino interactions.

R&D efforts

PandaX collaboration is actively pursuing R&D on TPC technology for this future scale with the aim to effectively cover physics from the keV to the 10-MeV range. Key directions include:

1) Design and demonstrate a liquid xenon TPC with dimensions of more than 3 meters while maintaining effective photon and electron collections over the wide energy range.
2) Develop high-sensitivity, high-granularity, fast-response, and low-background photosensor arrays with 4-pi coverage and accompanying electronics. We aim to identify track features and separate Cherenkov photons from scintillation in a liquid xenon detector.
3) Explore the physics reach and feasibility of separating xenon into high mass and low mass by 131.5 amu and operating two different targets [18]. Comparing results would lead to a better control of background contributions for spin-(in)dependent interaction between dark matter and nucleus and low energy solar neutrino observations. The search sensitivity for the double beta decay of ^{136}Xe is also expected to improve.
4) Pursue the operation of a 100-kg-scale high pressure gaseous xenon TPC detector (PandaX-III), as a pathfinder utilizing a tracking calorimeter to search for the neutrinoless double beta decay of ^{136}Xe [19]. PandaX-III will emphasize on the spatial resolution and develop a background-free search with track reconstruction.

Global Aspects

The PandaX-xT welcomes international collaborations, particularly with the worldwide dark matter and neutrinoless double beta decay communities. With multi-ten-tons of natural xenon, liquid xenon TPC becomes a compelling approach to forge a joint venture in these two directions that share very similar experimental challenges. The horizontal tunnel access of CJPL facilitates construction of large scale experiments. At the depth of CJPL, an external muon detector is not necessary and risks due to cosmogenic background such as ^{137}Xe may be avoided. China may have potential capability of providing a stable xenon supply at a level exceeding the present world-wide yearly supply.

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