

Search for dark matter from the first data of the PandaX-II experiment

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Results of WIMP dark matter search from the first data of the PandaX-II experiment are presented. PandaX-II experiment uses a 500 kg scale dual phase liquid xenon time projection chamber, operating at the China JinPing Underground Laboratory. The first data correspond to a total exposure of 3.1×10^4 kg-day. The observed data after selections are found to be consistent with background expectation, and upper limits of the spin-independent WIMP-nucleon cross sections are derived for a range of WIMP mass between $5 \text{ GeV}/c^2$ and $1000 \text{ GeV}/c^2$. The lowest cross section limit obtained is $2.5 \times 10^{-46} \text{ cm}^2$ at a WIMP mass of $40 \text{ GeV}/c^2$.

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1. Motivation and Overview of PandaX-II

The existence of dark matter (DM) in the Universe has been established by overwhelming astronomical and cosmological evidences. However its particle nature remains to be elusive. One of the most promising candidates for DM is the weakly interacting massive particles (WIMPs), a class of hypothetical particles predicted by many extensions of the standard model of particle physics. Detection for WIMP signals has been the goal of many past, ongoing and future experiments, including DM direct detection experiments, indirect detection experiments and experiments at high energy particle colliders.

The PandaX project consists of a series of xenon-based experiments. PandaX-I experiment, the first phase the project, uses a 120-kg liquid xenon target to search for WIMPs. It has completed in 2014 and produced stringent limits on the WIMP-nucleon cross sections for low mass WIMPs [1, 2]. PandaX-II, with a half-ton scale xenon target, has started to take data since the end of 2015. The third experiment PandaX-III [3], which is being prepared, will search for neutrino-less double beta decay of ^{136}Xe . Both PandaX-I and PandaX-II experiments use the dual-phase xenon time projection chamber (TPC) technique to search for WIMPs. This technique allows the measurement of both the prompt scintillation photons (S1) produced in liquid xenon and the delayed electroluminescence photons (S2) produced in gas xenon for each physical event, leading to powerful background suppression and signal-background discrimination.

The experimental hall for PandaX-I and PandaX-II experiments is located at the China JinPing underground Laboratory (CJPL), which is the deepest underground laboratory in the world, where the muon flux is only about 60 events $/\text{m}^2/\text{year}$ due to the above shield of 2400 m of rocks or 6800 m water equivalent depth. The background due to muon-induced neutrons for DM search is negligible.

PandaX-II reuses most of the infrastructures of PandaX-I, such as the passive shielding, outer copper vessel, cryogenics and electronics and data acquisition system. The new inner vessel is constructed from stainless steel with much lower radioactivity, reducing the ^{60}Co activity by more than an order of magnitude. A new and larger xenon TPC is also constructed. It contains 580 kg liquid xenon in the sensitive volume enclosed by polytetrafluoroethylene (PTFE) reflective panels with an inner diameter of 646 mm and a vertical maximum drift length of 600 mm defined by the cathode mesh and gate grid. For each physical event, both S1 and S2 signals are collected by two arrays of 55 Hamamatsu R11410-20 photomultiplier tubes (PMTs) located at the top and bottom, respectively. A skin liquid xenon region outside of the PTFE wall was instrumented with 48 Hamamatsu R8520-406 1-inch PMTs serving as an active veto. More detailed descriptions of the PandaX-II experiments can be found in Ref. [4].

2. Data and Detector Calibration

The data for DM search presented in this proceeding consist of 19.1 and 79.6 effective days of data collected during the first commissioning run (Run 8, Nov. 21 to Dec. 14, 2015) and the first physics run (Run 9, March 9 to June 30, 2016) of PandaX-II, respectively. Taking into account the fiducial volume (FV, defined in next section), this data set corresponds to a total exposure of 3.1×10^4 kg-day.

To calibrate the detector response, a neutron source (^{252}Cf) and two γ sources (^{60}Co and ^{137}Cs) were deployed through two PTFE tubes at different heights surrounding the inner vessel. Neutrons can excite xenon nuclei or produce metastable nuclear states, leading to de-exciting γ rays at 40 (^{129}Xe), 80 (^{131}Xe), 164 (^{131m}Xe), and 236 keV (^{129m}Xe). Photo-absorption γ peaks were used to calibrate the detector response. The 164 keV γ events were uniformly distributed in the detector and were used to produce a uniformity correction for the S1 and S2 signals. A 3-D correction map was produced for S1. For the S2 signals, the vertical uniformity correction was obtained by fitting S2 vs. the drift time using an exponential decay constant τ , known as the electron lifetime, which is a key parameter to indicate the purity of the liquid xenon. The evolution of the measured electron lifetime in Run 8 and Run 9 is shown in Fig. 1 left. Only data with electron lifetime longer than 205 μs were used for the DM search.

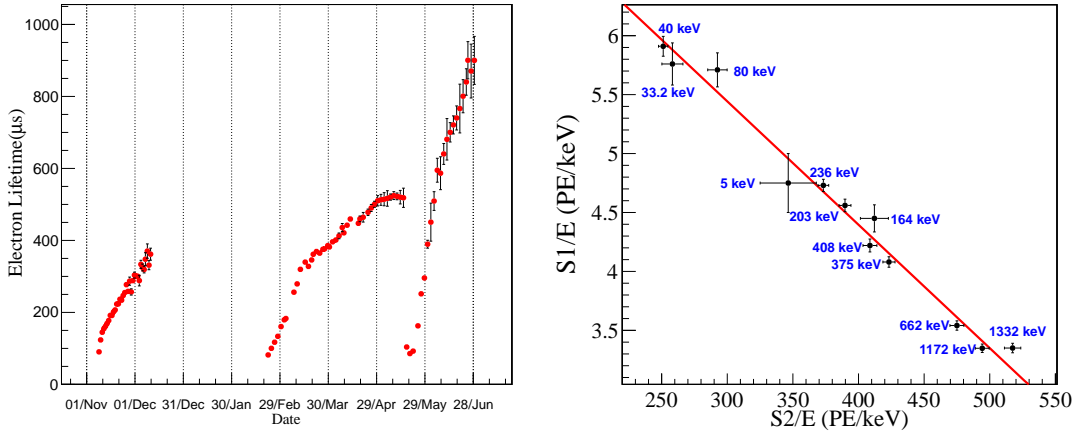


Figure 1: Left, evolution of the electron lifetime in Run 8 and Run 9. Right, Linear fit in $S2/E$ vs. $S1/E$ for all ER peaks in data to determine the PDE and EEE.

After the above uniformity corrections for S1 and S2, the deposited energy (electron equivalent energy E_{ee}) of each event is reconstructed as

$$E_{ee} = W \times \left(\frac{S1}{\text{PDE}} + \frac{S2}{\text{EEE} \times \text{SEG}} \right), \quad (2.1)$$

where $W = 13.7$ eV is the average work function to produce either an electron or photon [5]. PDE, the photon-detection efficiency, EEE, the electron extraction efficiency, and SEG, the single-electron gain in PE/e, are the three key detector parameters to be determined. SEG can be determined from the distribution of the smallest S2 signals in the data that were identified as the single electron signals. Then the other two parameters PDE and EEE can be extracted from fitting the $S2/E$ vs $S1/E$ obtained from all γ peaks, shown in Fig. 1 right. Extraction of these detector parameters was carried out for each detector running condition, arising from different TPC field settings that were used to maximize the drift and electron extraction fields while avoiding spurious photons and electrons emission from the electrodes.

In Run 9, nuclear recoil (NR) calibrations were performed using a low-intensity (approximately 2 Hz) $^{241}\text{Am-Be}$ (AmBe) neutron source with improved statistics, and a low energy electron

recoil (ER) calibrations were performed by injecting tritiated methane [6], leading to a better understanding of the distributions of the NR and ER events than before. Distributions of $\log_{10}(S2/S1)$ vs. S1 from these calibration data after selections (described in next section) are shown in Fig. 2, which also shows the medians and widths of $\log_{10}(S2/S1)$ from NR data and simulation. Reasonably good agreement is observed.

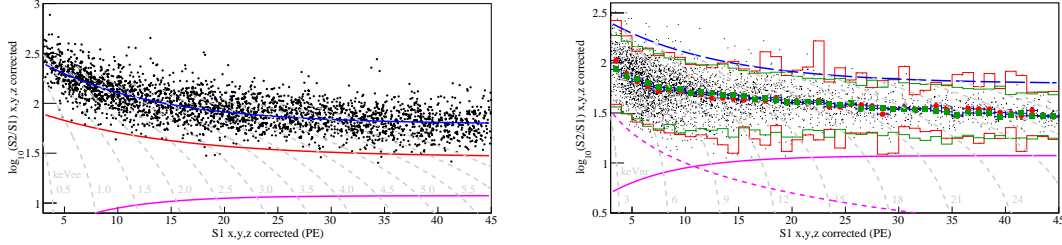


Figure 2: Left: tritium calibration data in $\log_{10}(S2/S1)$ vs. S1, and fits of medians of ER (blue) and NR (red) data. Right: AmBe calibration data in $\log_{10}(S2/S1)$ vs. S1, together with medians from the data (red solid circles) and simulation (green squares), and the fit to ER medians (blue dashed). The 2.3- and 97.7-percentiles from the data (red lines) and simulation (green lines) are overlaid.

3. Event Selections and Background Estimation

The following selections are applied. All collected events are required to pass a set of data quality selections to remove noises and abnormal events. Only events with single S2 are selected, and S2 is required to be between 100 photoelectrons (PE) and 10000 PE. The maximum number of S1 signals is limited to two, and the maximum one is chosen to pair with S2. The S1 is required to be between 3 PE and 45 PE. The event is vetoed if there is a coincidence between signals from veto PMT arrays and the S1. The reconstructed event vertex is required to be inside the FV. The vertex position in horizontal plane is required to be less than 268 mm. The drift time is required to be between 20 to 346 μ s for Run 8, and between 18 to 310 μ s for Run 9, where a more stringent maximum drift time cut is needed to suppress the below-cathode γ energy deposition (so-called “gamma-X”) from ¹²⁷Xe decays which were not present in Run 8.

Background of DM searches in PandaX-II can be separated into three types: ER, neutron, and accidental background. In the first data, the ER background is dominated by decays of ⁸⁵Kr which was likely introduced by an air leak during the previous fill and recuperation cycle before Run 8, and by decays of ¹²⁷Xe which was generated during the krypton distillation campaign in early 2016, when the xenon was exposed to about one month of sea level cosmic ray radiation. ⁸⁵Kr background is identified using the delayed $\beta - \gamma$ coincidence from ⁸⁵Kr decay. ¹²⁷Xe background is identified by the 33 keV and 5.2 keV X rays originating from ¹²⁷Xe decays. A parameterized tritium event distribution was used to simulate expected distributions for different ER background components. Neutron background comes from detector components and is estimated from simulation. Accidental background is estimated by randomly pairing single S1 and single S2 events. A multivariate technique is developed to suppress this background. A factor of three rejection is achieved while maintaining a 90% signal efficiency.

4. Results

The observed events in data and expected background rates of various types after event selections are summarized in Table 1. No excess of events is observed above background expectation, both before and after the NR median selections. Figure 3 shows the distribution of $\log_{10}(S2/S1)$ vs. S1 for the DM search data in Run 8 and Run 9.

	ER	Accidental	Neutron	Total Expected	Total observed
Run 8	622.8	5.20	0.25	628 ± 106	734
Below NR median	2.0	0.33	0.09	2.4 ± 0.8	2
Run 9	377.9	14.0	0.91	393 ± 46	389
Below NR median	1.2	0.84	0.35	2.4 ± 0.7	1

Table 1: The expected background events in Run 8 and Run 9 in the FV, before and after the NR median selection. Number of events from the data are shown in the last column.

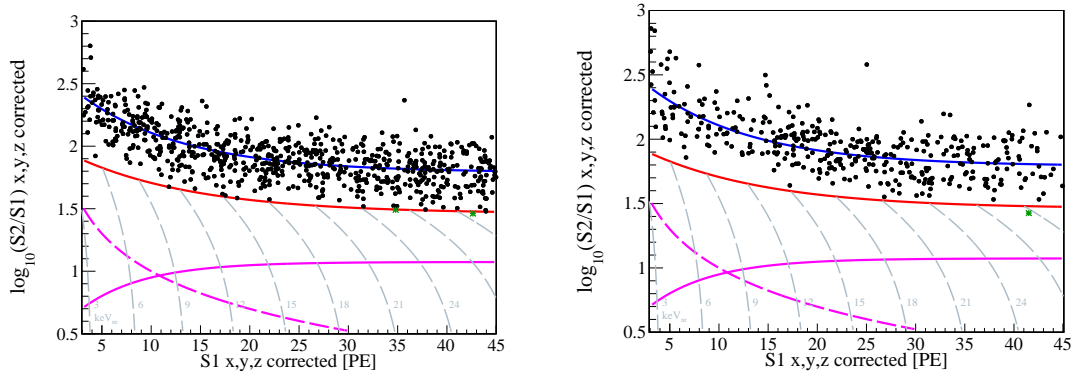


Figure 3: The distribution of $\log_{10}(S2/S1)$ versus S1 for the DM search data in Run 8 (left) and Run 9 (right). The median of the NR calibration band is indicated as the red curve. The dashed magenta curve represents the equivalent 100 PE cut on S2. The solid magenta curve is the 99.99% NR acceptance curve. The gray dashed curves represent the equal energy curves with NR energy indicated in the figures. Data points below the NR median curve are highlighted as a green star.

In the absence of possible WIMP signals in data, the 90% confidence level (CL) upper limits of the spin-independent isoscalar WIMP-nucleon cross section are derived and shown in Fig. 4. Our observed limits lie within the $\pm 1\sigma$ sensitivity band, and the lowest limit is $2.5 \times 10^{-46} \text{ cm}^2$ at a WIMP mass of $40 \text{ GeV}/c^2$, which represents an improvement of more than a factor of 10 from PandaX-I (Ref [4]). In the high WIMP mass region, our results are more than a factor of 2 more stringent than the previously best results from LUX experiment [7].

The PandaX-II collaboration has recently reported the spin-dependent (SD) WIMP-nucleon upper limits using the same data [9]. Most stringent limits on the WIMP-neutron cross sections for WIMPs with masses above $10 \text{ GeV}/c^2$ are set in all direct detection experiments, with more

than a factor of two improvement on previously best available limits. The PandaX-II experiment is expected to run till end of 2017. Meanwhile the collaboration is preparing for a multi-ton scale xenon detector to further improve the WIMP DM detection sensitivity.

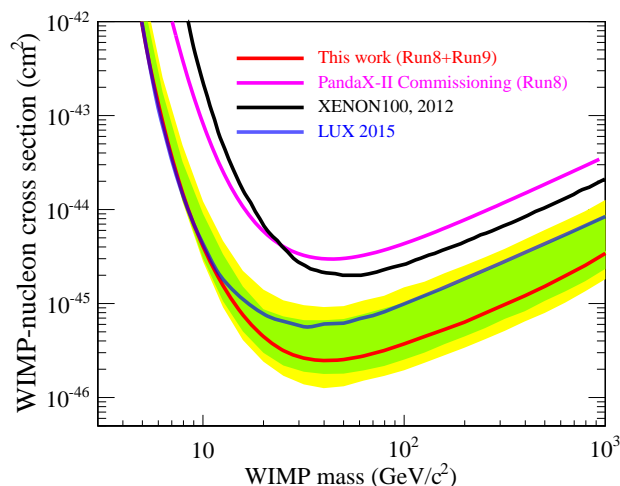


Figure 4: The 90% CL upper limits for the spin-independent isoscalar WIMP-nucleon cross sections from the combination of PandaX-II Run 8 and Run 9 (red solid). Selected recent world results are plotted for comparison: PandaX-II Run 8 results [4] (magenta), XENON100 225 day results [8] (black), and LUX 2015 results [7](blue). The 1 and 2- σ sensitivity bands are shown in green and yellow, respectively.

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