Abstract:
This work models surface backgrounds in the energy window for the WIMP search (0-10 keV) in the PandaX-II detector. The surface backgrounds in this region are dominated by the β decay of $^{210}$Pb ($T_{1/2}=22.2 \; \text{y}$), which is the daughter of $^{222}$Rn, a noble-gas radioisotope in the $^{226}$U decay chain. Due to the charge loss effect of the surface events, their ionization-to-scintillation ratio mixes with nuclear recoils, leading to undistinguishable backgrounds in the region of interest. Because the mechanism for the charge loss remains unknown and the backgrounds cannot be cut off efficiently, a data-driven model is developed to estimate the surface backgrounds.

Keywords: Dark Matter, Liquid Xenon Detector, Surface Backgrounds

Introduction:

PandaX-II (Fig.1) is aiming at directly detecting the weakly interacting dark matter particle (WIMP), which is one of the most popular dark matter candidates. Our two-phase liquid xenon detector is able to measure the scintillation (S1) and ionization (S2) of the recoiling events. The ionization-scintillation soft-window provides powerful discrimination between nuclear recoils (NRs) and electron recoils (ERs), which helps to suppress the ER backgrounds to a large extent as shown in Fig.2.

The $^{210}$Pb events near the wall are shown in Fig.3. Compared with the neutron band in Fig.4, $^{210}$Pb with charge loss is not distinguishable with NRs.

Modeling:

The goal is to construct the probability distribution function (PDF) of the surface backgrounds, with which we can calculate the surface backgrounds level in the fiducial volume (FV). The procedure is divided into three steps:

- Define soft-window for different $z$ and azimuth angles
- Model the radial part: $P_{\text{rad}}$
- Smooth $P_{\text{rad}}$ with kernel density estimator (KDE)

Add another PDF

Purely data driven

Takeaway messages of soft wall construction:

- Soft wall is the median position of the reconstructed surface events.
- The distance to wall ($r_{\text{wall}}$) is defined according to $^{210}$Pb & $^{210}$Bi data with $S1 \in (50,500)$ PE to blind the WIMP search data.

Fig. 1. Schematic of the PandaX-II detector: a two-phase Time Projection Chamber (TPC)

Fig. 2. Calibration data for PandaX-II detector. The shadow marks the WIMP search region. The calibration done by tritium (black dots) and NR by Ambe (red open circles) are shown.

Fig. 3. Dark matter search events near the wall

Fig. 4. Nuclear recoil calibration events by Ambe source

Fig. 5. Equivalence of the fiducial volume (FV) cut for different position reconstruction algorithms. Old PAF at $R=7200\; \text{mm}$ equivalent to New Stretched PAF at $r_{\text{wall}} = 63 \; \text{mm}$, or New NN at $r_{\text{wall}} = 58 \; \text{mm}$

Radial parameterization:

- For different $S2$s, the resolutions of position reconstruction are different, which are parameterized with Gaussian functions.
- Data with $S1 \in (50,500)$ PE are used to blind the WIMP search data.

Visualization of $P_{\text{wall}}$ with $P_{\text{rad}}$

- $P_{\text{rad}}$ is constructed with $r_{\text{wall}} < 0$ (outward fluctuation) to blind the WIMP search data

Result:
The model is validated by unblinding the Run10 with 77.1 days data and 360 kg Xe in FV. It can be used for future background estimation for PandaX-II detector.

Fig. 6. The radial parameterization for different position reconstruction algorithms (PAF for the left figure and NN for the right)

Fig. 7. The projected visions of $P_{\text{rad}}$ wall, where histogram of $P_{\text{rad}}$ has been smoothed with KDE

Fig. 8. Comparison between the wall model and real data (PAF algorithm), using the same cut in Tab. 1.

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Main Reference:


Dan Zhang (2nd year doctoral student in the Dept. of Phys., UMD)