Modeling for Surface Backgrounds in the PandaX-II Detector

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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 dominant by the β decay of ^{210}Pb ($T_{1/2}$=22.2 y), which is the daughter of ^{222}Rn, a nobel-gas radioisotope in the ^{238}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 detector (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-to-scintillation ratio provides powerful discrimination between nuclear recoils (NR)s and electron recoils (ERs), which helps to suppress the ER backgrounds to a large extent as shown in Fig.2.

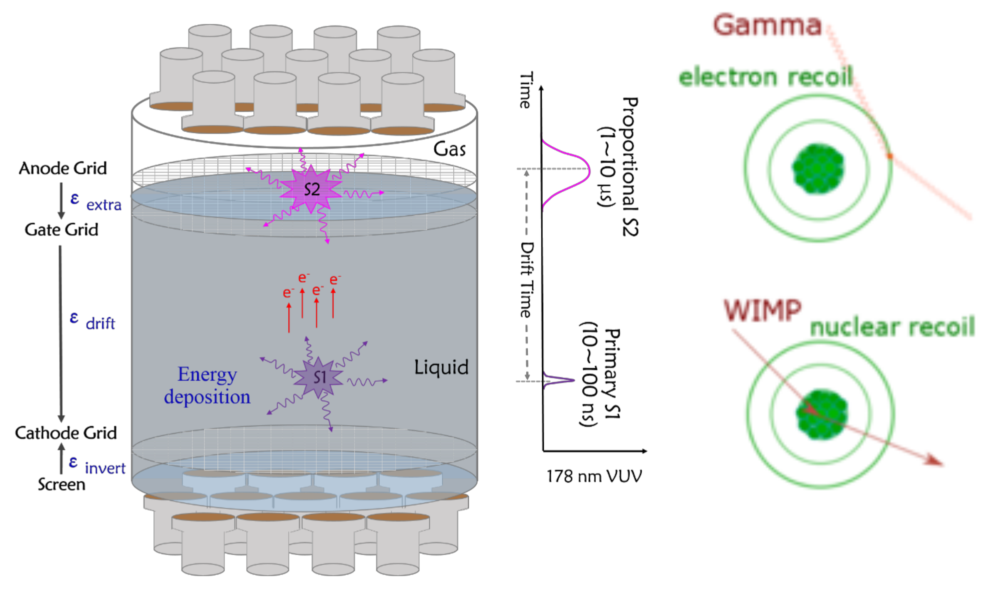


Fig. 1. Schematic of the PandaX-II detector: a two-phase Time Projection Chamber (TPC)

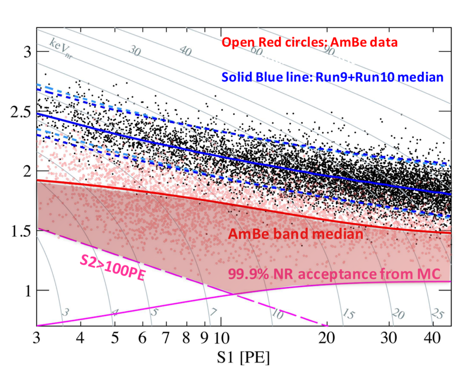


Fig. 2. Calibration data for PandaX-II detector. The shadow marks the WIMP search region. The ER calibration done by tritium (black dots) and NR by AmBe (red open circles) are shown.

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.

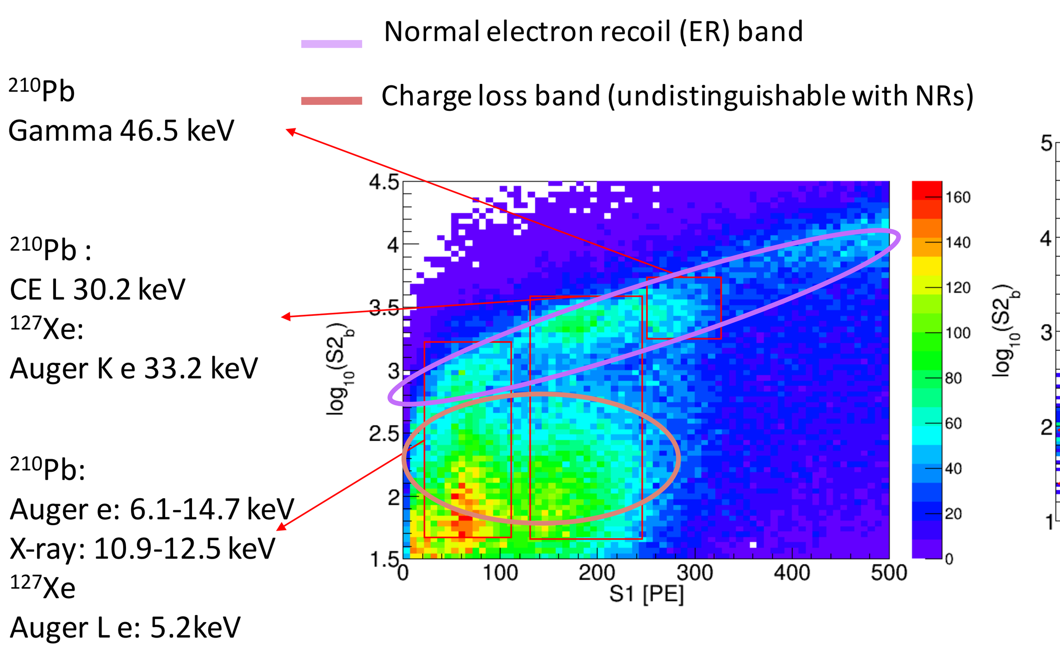


Fig.3. Dark matter search events near the wall

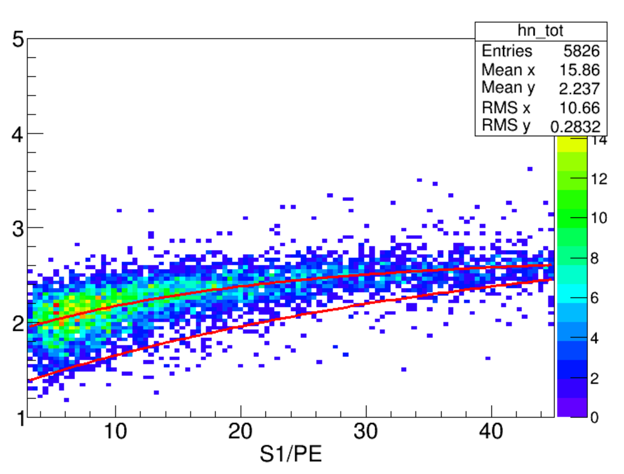


Fig. 4. Nuclear recoil calibration events by AmBe source

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 the soft wall for different z and azimuth angles
- Model the radial part: P_R
- Smooth P_d with kernel density estimator (KDE)

$$\mathcal{L}_{\mathrm{pandax}} = \left[\prod_{n=1}^{\mathrm{nset}} \mathcal{L}_n\right] \times \left[G(\delta_{\mathrm{DM}}, \sigma_{\mathrm{DM}}) \prod_b G(\delta_b, \sigma_b)\right]$$

where

$$\mathcal{L}_n = \mathrm{Poiss}(N^n_{\mathrm{meas}} | N^n_{\mathrm{fit}}) \times \left[\prod_{i=1}^{N^n_{\mathrm{meas}}} \left(\frac{N^n_{\mathrm{DM}}(1+\delta_{\mathrm{DM}}) P^n_{\mathrm{DM}}(S1^i, S2^i)}{N^n_{\mathrm{fit}}} + \sum_b \frac{N^n_b (1+\delta_b) P^n_b(S1^i, S2^i)}{N^n_{\mathrm{fit}}}\right)\right].$$

Add another PDF +

$$P_{b,\mathrm{wall}}(r_w, S1^i, S2^i, z) = P_R(r_w, S2^i) \times P_d(S2^i, S1^i, z)$$

Depend on the Position reconstruction algorithm (P_R)

Purely data driven (P_d)

Takeaway messenges of soft wall construction:

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

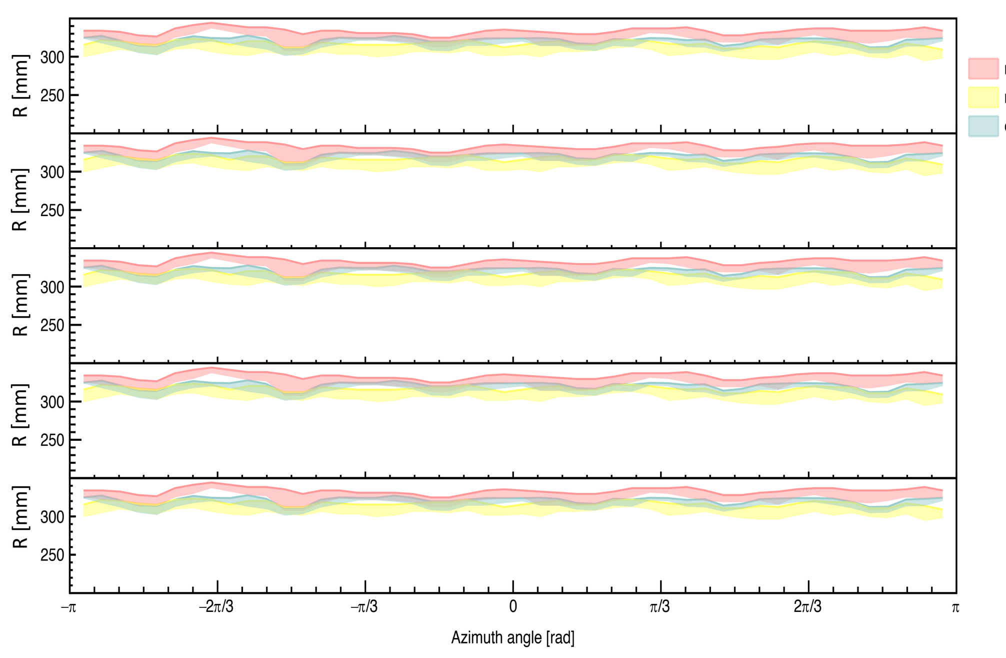


Fig. 4. Comparison of the softwalls for different position reconstruction algorithms (median to 1-sigma inward fluctuation). In PAF, photon acceptance function for each PMT is fitted with data. In NN, photon acceptance functions are constructed according to simulation.

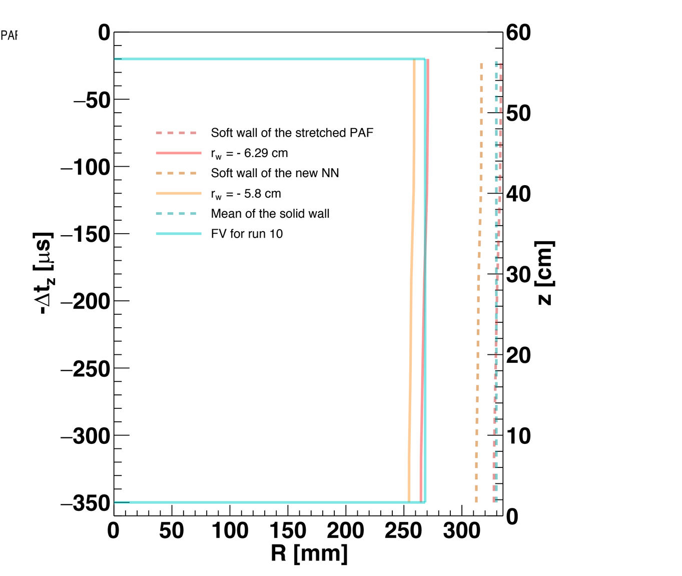
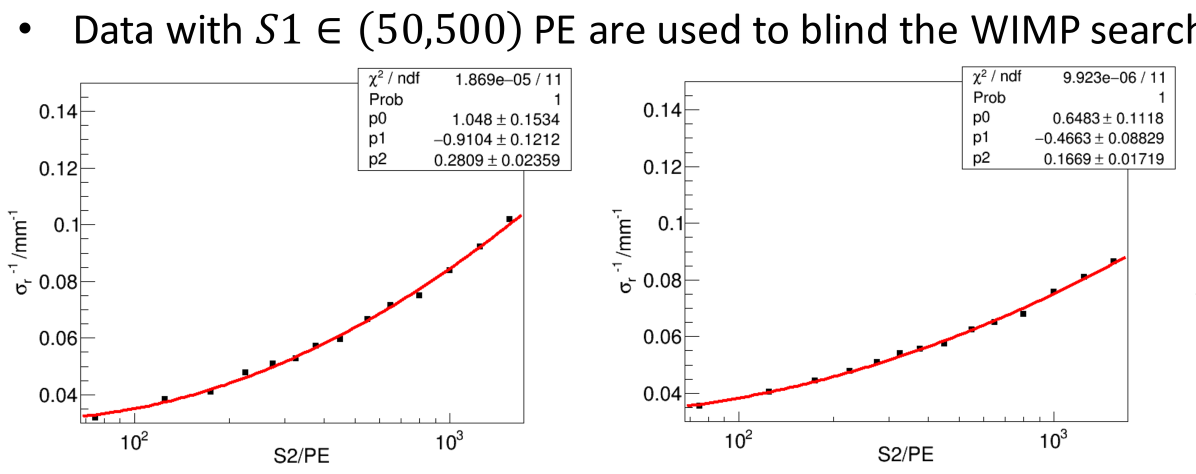


Fig. 5. Equivalence of the fiducial volume (FV) cut for different position reconstruction algorithms. Old PAF at R^2 = 72000mm^2 is equivalent to New Stretched PAF at r_w = -63 mm, or New NN at r_w = - 58 mm.

Radial Parameterization:

- For different S2s, 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.



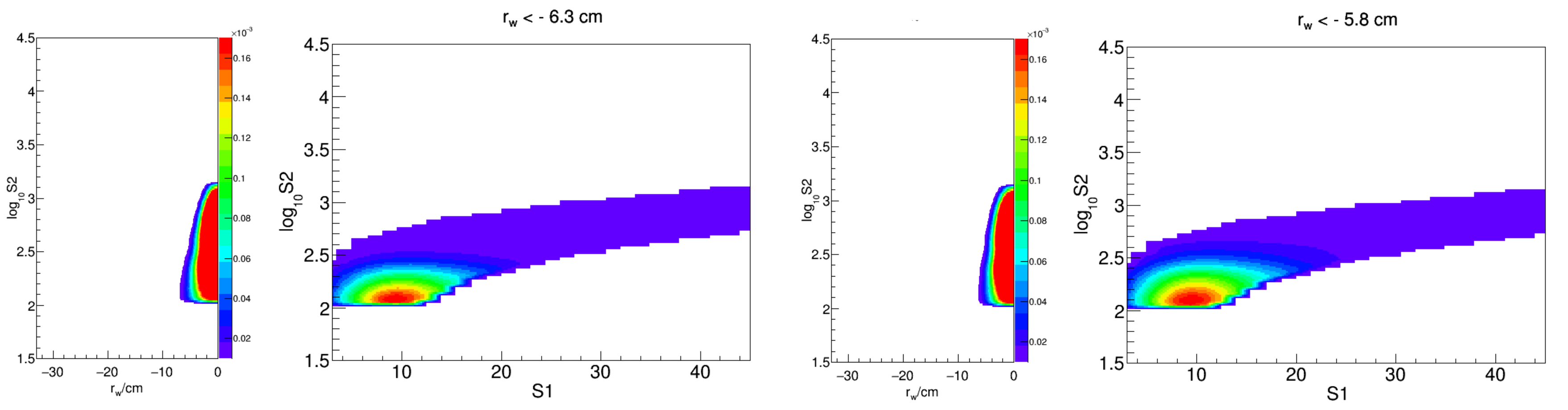
$$\sigma_r(S2) = \frac{1}{p0 - p1 \cdot \log_{10} S2 + p2 \cdot (\log_{10} S2)^2}$$

$$P_R(r_w, S2) = \frac{1}{\sqrt{2\pi\sigma_r(S2)^2}} \cdot \exp\left(-\frac{r_w^2}{\sigma_r(S2)^2}\right)$$

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

Visulization of $P_{b,\mathrm{wall}}$ with P_d:

- P_d is constructed with r_w>0 (outward fluctuation) to blind the WIMP search data



(a) New Stretched PAF (b) New NN

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

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.

Model	Run10 S2>50	Run10 S2>100
Standard	51	20.4
PAF	50^{+12}_{-10}	$19.5^{+5.4}_{-4.3}$
NN	$50.4^{+12.9}_{-10.4}$	$18.6^{+5.8}_{-4.5}$

Tab.1. Run10 data of PandaX-II detector (not all cuts for WIMP search are applied). The standard is calculated by comparing the event in the center with close to the wall.

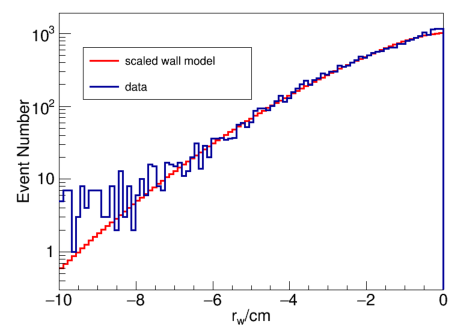


Fig.8. Comparison between the wall model and real data (PAF algorithm), using the same cut in Tab.1.

	BDT applied
PAF	$4.11^{+1.25}_{-0.97}$
$r_{w,\mathrm{PAF}} < -62.9$ mm	5
NN	$4.12^{+1.43}_{-1.08}$
$r_{w,\mathrm{NN}} < -58$ mm	4
$r^2_{\mathrm{PAF}} < 7.2e4$ mm^2	1

Tab.2. Run10 data (all cuts for WIMP search applied)

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Main Reference:

[1] Xiangyi Cui *et. al.* (PandaX-II Collaboration), *Dark Matter Results from 54-Ton-Day Exposure of PandaX-II Experiment*, Phys. Rev. Lett. **119** (2017).

[2] Chang Lee, *Mitigation of Backgrounds for the Large Underground Xenon Dark Matter Experiments*, Ph.D thesis, Case Western Reserve University, 2015.