# Exploring New Physics with PandaX-4T Low Energy Electronic Recoil Data


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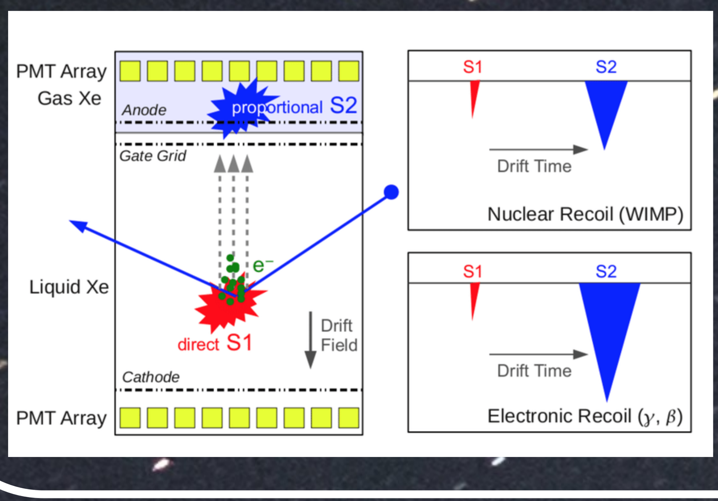
## Dual Phase Liquid Xenon TPC

The PandaX-4T experiment operates a dual-phase liquid xenon time projection chamber (LXe TPC) that is located in China Jinping Underground Laboratory. Energy release in xenon will produce prompt scintillation photon signals (S1) and ionized electrons. Electrons drift up under the influence of a downward electric field in the SV, and the delayed electroluminescence signals (S2) are generated in the gaseous xenon region with a much stronger electric field.

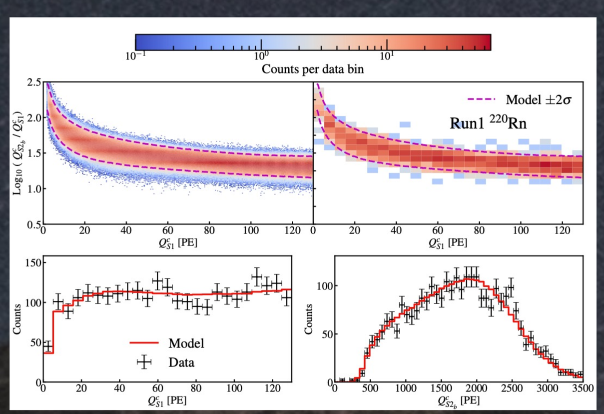


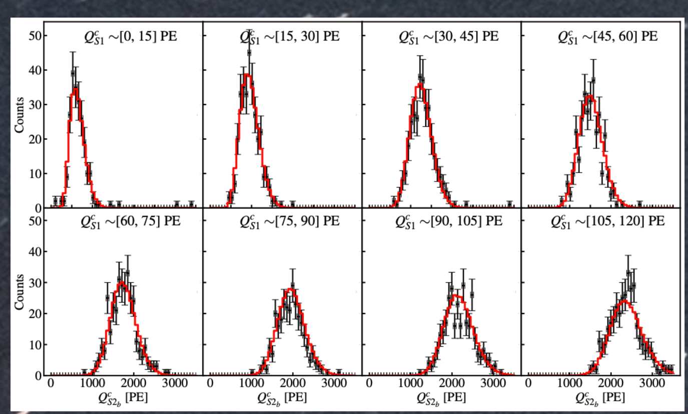

### Why LXe TPC?

1. Large A: large cross section & self-shielding;
2. 3D reconstruction and fiducialization;
3. Scalable;
4. Discrimination power.

## Detector Response

1. The detector response of low energy electronic recoil events is modelled by NEST ( Noble Element Simulation Technique);
2. Detector parameters (e.g. recombination rate, photon detection efficiency) are fit to Rn calibration data using unbinned likelihood fitting with emcee;
3. Calibrated NEST also fits well with sliced calibration data.

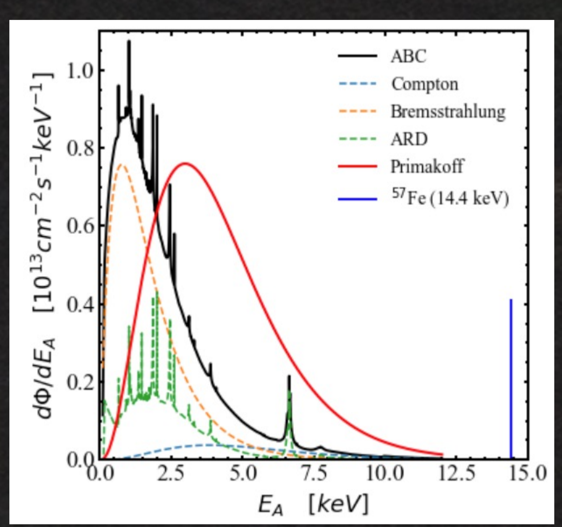


Details can be found in https://doi.org/10.48550/arXiv.2403.04239

## Axions and Neutrinos from Sun

1. Axion production in the sun: Atomic recombination and deexcitation (ARD), Bremsstrahlung, and Compton (ABC); Primakoff effect; M1 nuclear transition of $^{57}$Fe (14.4 keV).
2. Neutrinos may have abnormally large magnetic moment due to the Majorana nature or exotic new physics beyond the Standard Model.




### Detection in PandaX-4T:

1. axio-electric effect;
2. inverse Primakoff effect;
3. neutrino-electron scattering.

$$\sigma_{Ae}(E_a) = \sigma_{pe}(E_a)\frac{g_{Ae}^2}{\beta}\frac{3E_a^2}{16\pi\alpha m_e^2}\left(1-\frac{\beta^{\frac{2}{3}}}{3}\right)$$

$$\frac{d\sigma_{el}}{d\Omega} = \frac{\alpha g_{A\gamma\gamma}^2 E_a^3 p_a \sin^2\theta}{4\pi(E_a^2+p_a^2-2E_a p_a\cos\theta)^2}|Z-F(\boldsymbol{q})|^2$$

$$\frac{d\sigma(E_\nu,E_r)}{dE_r} = \mu_\nu^2\frac{\pi\alpha^2}{m_e^2}\left[\frac{1}{E_r}-\frac{1}{E_\nu}\right]$$

## Background Level

- Tritium spectrum identified in the data, which is likely originated from the tritium calibration at the end of PandaX-II; Tritium estimation comes from pre-fit of S1 spectrum, since no extra experimental constraints;
- Beta events from $^{214}$Pb/$^{212}$Pb is monitored by (5.5/8.8 MeV) $\alpha$ of $^{222}$Rn/$^{220}$Rn. The activity of $^{214}$Pb is estimated to be 4.50 ± 0.20 μBq/kg (Run 0) and 5.52 ± 0.25 μBq/kg(Run 1), and $^{212}$Pb is estimated to be 0.28 ± 0.08 μBq/kg;
- Beta events from $^{85}$Kr based on the delayed $\beta-\gamma$ coincidence events of meta-stable state $^{85m}$Rb, the activity of $^{85}$Kr is estimated to be 0.52 ± 0.27 ± 0.01 ppt and 0.94 ± 0.28 ± 0.02 ppt for Run 0 and Run 1;
- Radioactivity of materials of the detector are estimated from high-purity Germanium counting-station and detailed fit of 0.44 - 2.6 MeV spectrum.
- Long lived xenon isotopes, including $^{136}$Xe and $^{124}$Xe are calculated based on the measured half-life; L-captures (5.2 keV) of cosmogenically activated $^{127}$Xe in Run 0 is fitted from K-capture (408 keV);
- Solar neutrinos are calculated using Standard solar models and the standard model anomalous magnetic moment;
- Accidental backgrounds, resulting from the random pairing of S1 and S2 signals are estimated to be 7.6 ± 2.4 (Run 0) and 7.1 ± 2.3 (Run 1).

S1 spectrum fitted Tritium rate

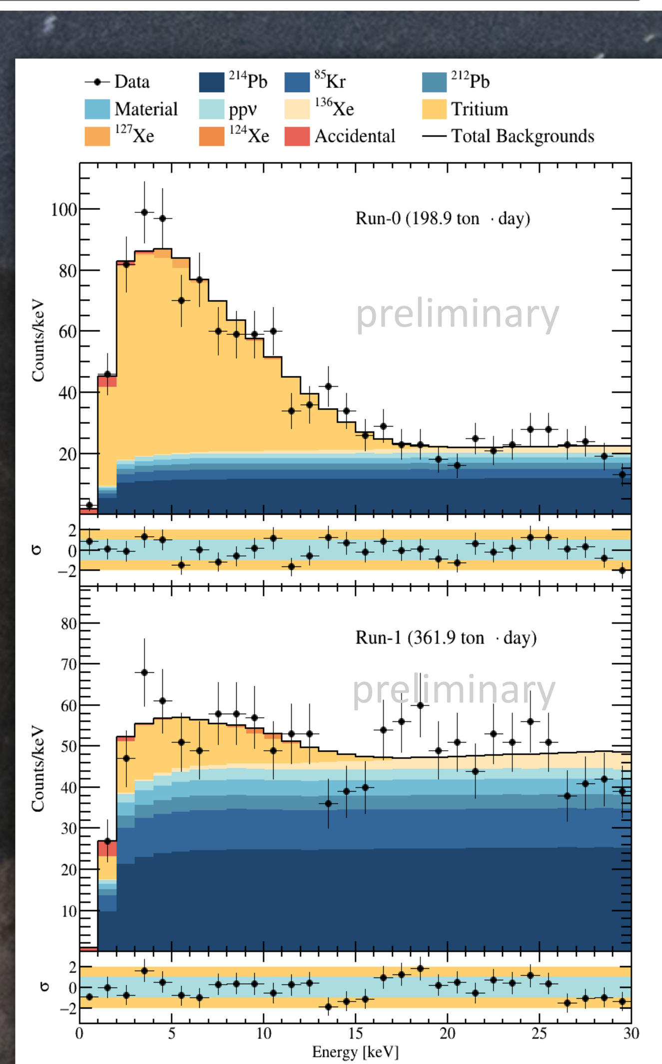
| Dataset | Run0 Set4 | Run0 Set5 | Run1 Set1-4 | Run1 Set5 | Run1 Set6 |
|---|---|---|---|---|---|
| Rate $[ton^{-1}\cdot day^{-1}]$ | $3.23\pm0.20$ | $1.88\pm0.15$ | $0.25\pm0.05$ | $0.23\pm0.05$ | $0.23\pm0.05$ |

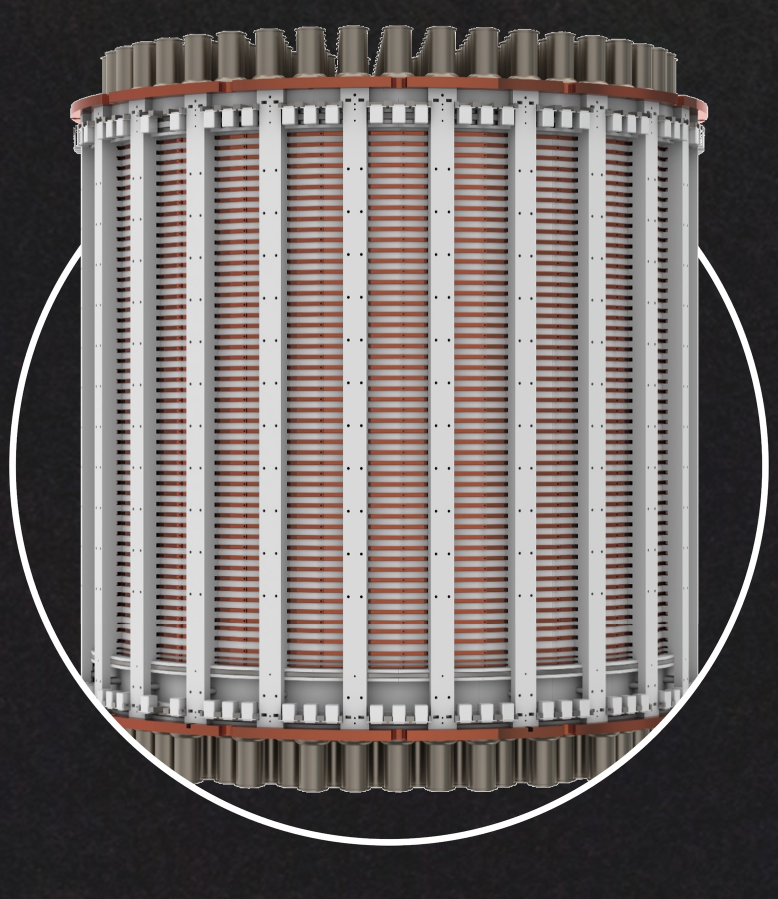
## Data and Bestfit

| Run | Run0 | | | | | Run1 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Set | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 | 6 |
| Duration (days) | 1.95 | 13.20 | 2.21 | 35.26 | 36.61 | 9.05 | 9.56 | 6.18 | 13.60 | 96.81 | 26.47 |
| Live Time (days) | 1.83 | 12.36 | 2.13 | 33.14 | 34.41 | 8.12 | 8.58 | 5.60 | 12.26 | 88.94 | 24.49 |
| $\langle\tau_e\rangle(\mu s)$ | 807.2 | 958.1 | 812.5 | 1110.4 | 1275.4 | 631.2 | 642.3 | 975.7 | 831.5 | 1171.7 | 1719.6 |
| $V_{cathode}$(-kV) | 20 | 18.6 | 18 | 16 | 16 | 16 | | | | | |
| $V_{gate}$(-kV) | 4.9 | 4.9 | 5 | 5 | 5 | 6 | | | | | |
| g1(%) | $9.97^{+0.02}_{-0.05}$ | | | | | $9.07^{+0.02}_{-0.05}$ | | | | | |
| $g2_b(PE/e^-)$ | $4.12^{+0.06}_{-0.04}$ | | | | | $5.03^{+0.07}_{-0.05}$ | | | | | |

A background-only fit is applied to check the consistency of data and background model.

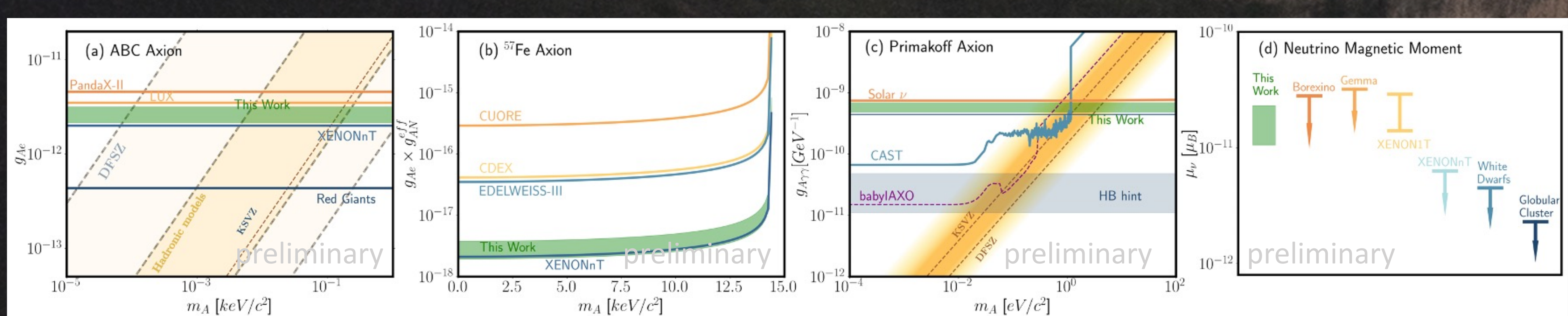
1. Region of interest: qS1 > 2PE, E < 30 keV and above the ER 99.5% quantile;
2. 1D binned likelihood fit is used based on HistFitter;
3. Systematics including error of detection efficiencies and light/charge yield are added to fit;
4. The data are consistent with the background-only hypothesis: $\chi^2$/NDF = 32.0/24.



## Sensitivity to New Physics

Based on $CL_{s+b}$ technique, model-independent sensitivities with 90% confidence level (C.L.) of axion couplings ($g_{Ae}$,$g_{Ae}g_{AN}$,$g_{A\gamma}$), and neutrino magnetic moment $\mu_\nu$ are derived.




Acknowledgement: Thanks for the mentioned theoretical works and the photographer Shibo Zhang