Features Analysis of Particle Tracks and Sensitivity Estimation on PandaX-III Experiment

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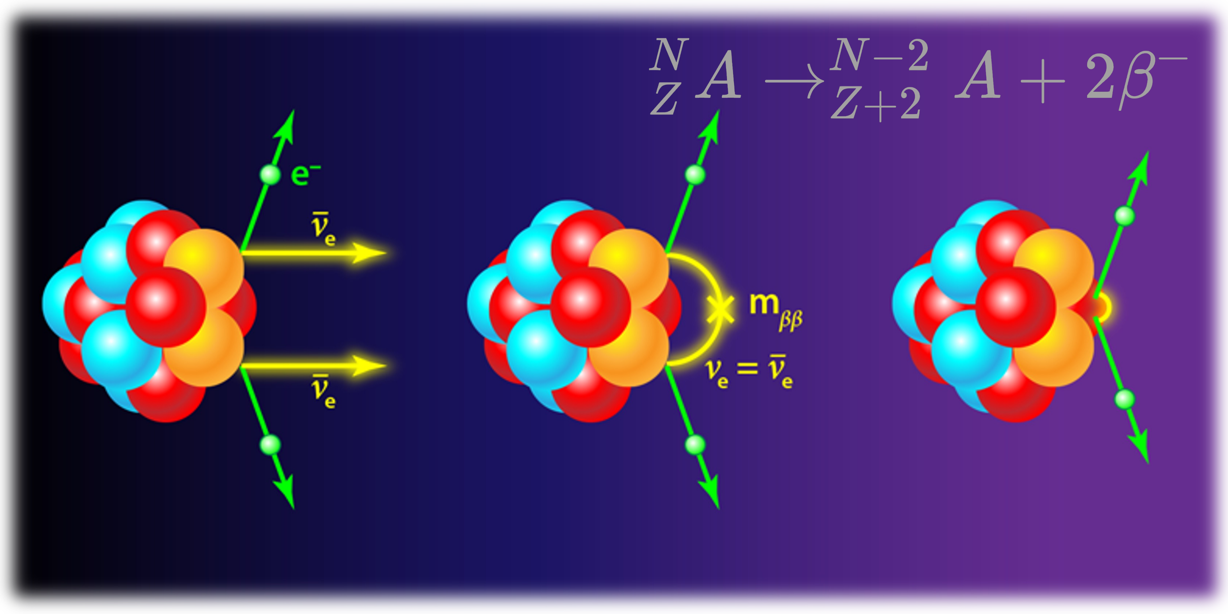
Neutrinoless double beta decay



Ettore Majorana

➢ **Half lifetime of 0νββ on experiment:**

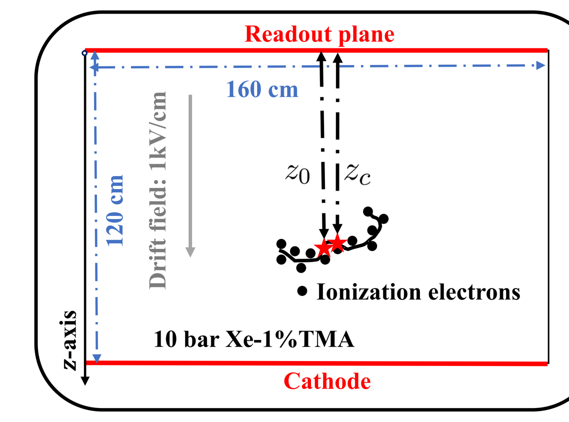
$$T^{0\nu}_{1/2} = ln2 \cdot \frac{N_A \epsilon a}{W} \sqrt{\frac{M \cdot t}{b \cdot dE}}$$

- b: the background index;
- dE: the detector energy resolution;

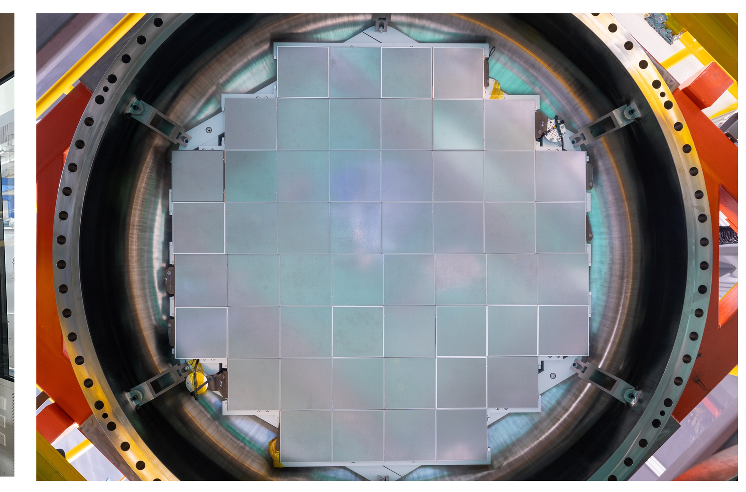
PandaX-III experiment

➢ **High-pressure gaseous time projection chamber:**

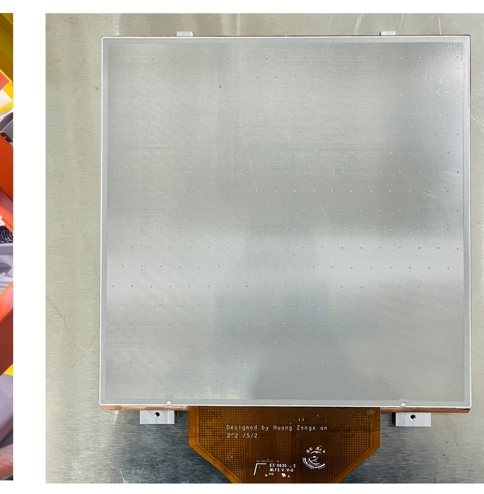
- ❑ 3 % FWHM @$Q_{\beta\beta}$ =2.458 MeV;
- ❑ Active volume: 1.6 m in diameter and 1.2 m high;
- ❑ 137 kg of enriched xenon gas(1% TMA) in 10 bar;
- ❑ Readout: 52 modules of 20 cm × 20 cm (3 mm strips).



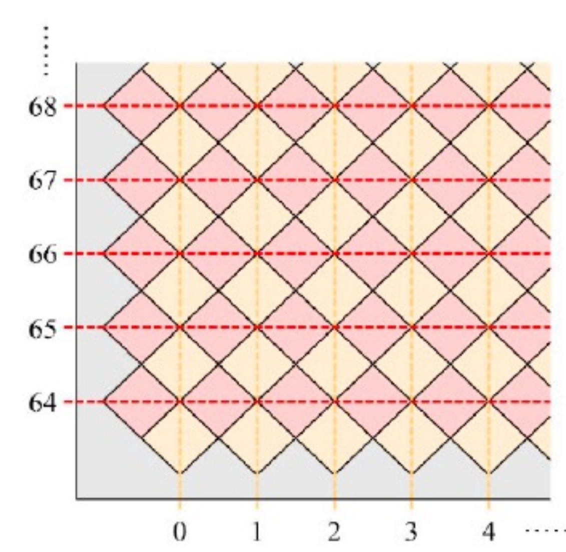
PandaX-III TPC



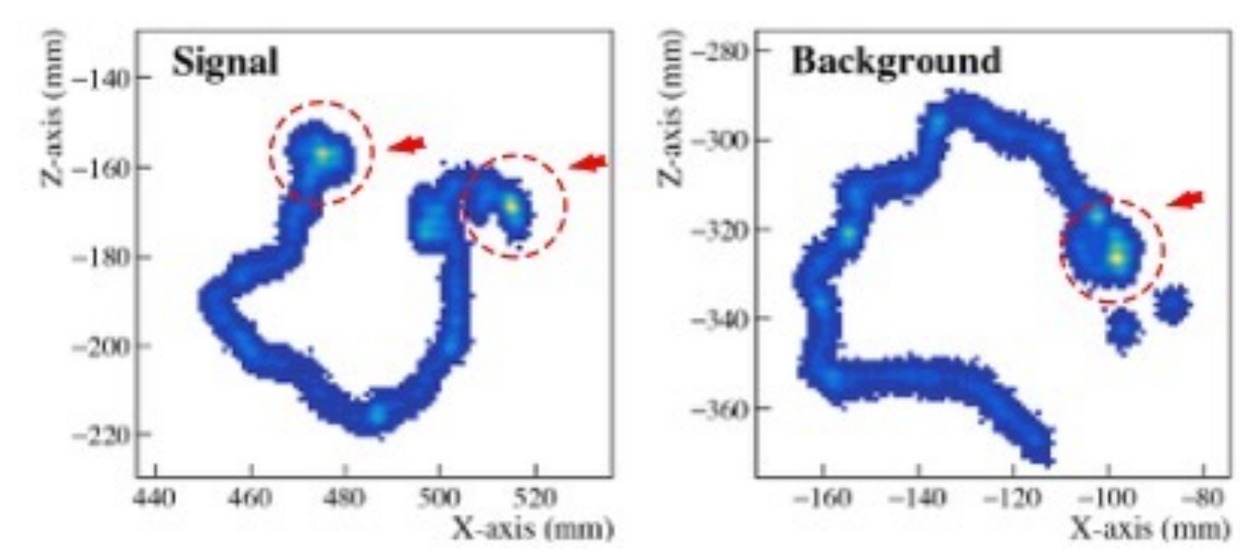
Readout plane



Micromegas



Readout scheme



Simulated track

Features analysis of particle tracks in PandaX-III

- ❑ **Event vertex z_0) is not directly available due to the loss of the scintillation light signal.**
- ❑ **Track features can be extracted more effectively for signal identification.**

I. Signal identification with Kalman filter: Suppress the background events in ROI;

Track reconstruction → **Topological analysis** → **Signal identification**

II. Vertex reconstruction with CNN: Correct spectrum due to electron lifetime;

Z_0 reconstruction → **Electron lifetime estimation** → **Spectrum correction; FV selection;**

Improvement on experimental sensitivity to the half-life of 0νββ !

I. Track reconstruction with Kalman filter[1]

➢ **Track reconstruction**

[1] Identification of the principle track;
[2] Rough reconstruction;
[3] Fine reconstruction with Kalman filter.

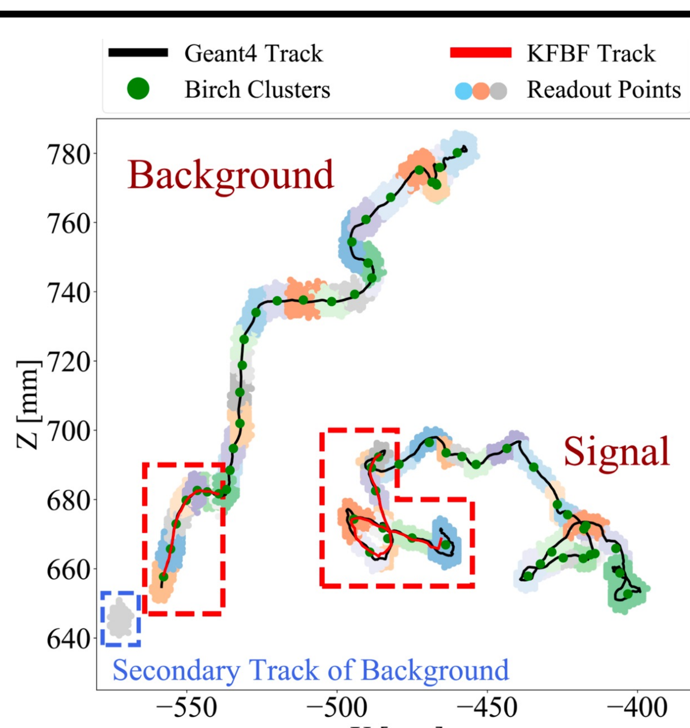
➢ **6D Kalman filter with Bayesian formula**

Coulomb scattering: $\theta^{rms}_{space} = \frac{19.2\,\mathrm{MeV}}{pv}\sqrt{\lambda_0}[1+0.038\ln\lambda_0]$

State equation: $s_k = F s_{k-1} + \omega_k$ (State vector: s_k; Process noise: ω_k)

Measurement equation: $m_k = H x_k + \delta_k$ (State vector: m_k; Measurement noise: δ_k)

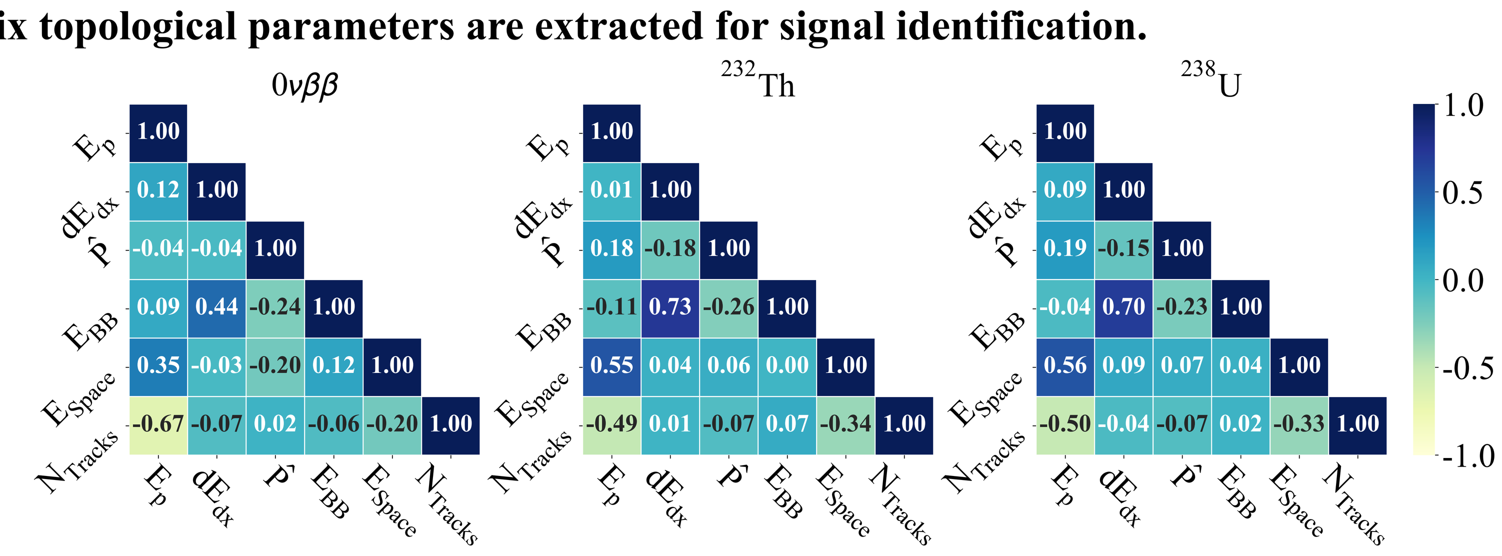
Bayesian formula: $[Q_k, R_k] = \underset{Q_i \in \mathbb{Q}, R_j \in \mathbb{R}}{\arg\max}\,(P(Q_i, R_j \mid \mathcal{M}^k))$



The example of track reconstruction.

➢ **Features analysis**

❑ **Six topological parameters are extracted for signal identification.**



Pearson correlation maps of all the parameters.

➢ **Sensitivity estimation**

Comparation	Overall efficiency	background counts in 5 yr	significance	Sensitivity (90% C.L.)
This work	34.7%	2.4	**8.8**	**2.7×10^{26} yr**
Design target	35.0%	25.3	2.8	9.8×10^{25} yr
Work before	23.2%	7.6	3.3	1.1×10^{26} yr

Table: The $0\nu\beta\beta$ half-life sensitivity estimation of PandaX-III based on MC data.

- ❑ **The estimation of the background level is 152 CPY. After the BDT cut, the background rate is 0.48 CPY.**
- ❑ **Assuming 1 t Xenon and (3 mm, 1%), the background rate is 0.11 CPY, pushing the search towards background-free regime.**

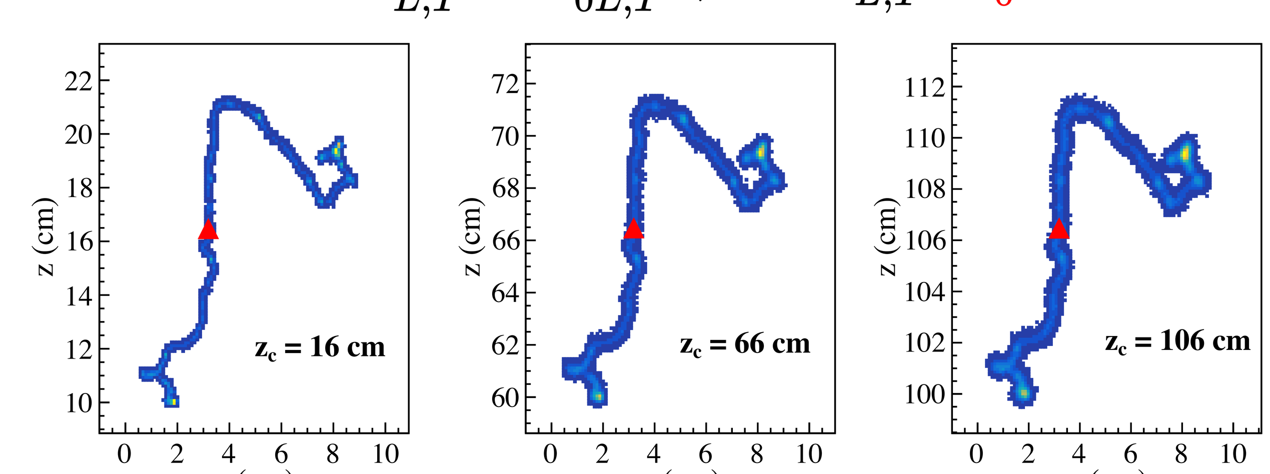
II. Vertex reconstruction with CNN[2]

- ❑ **Distortion of energy spectrum (electron attachment effect due to gas purity);**
- ❑ **Events near the readout plane and cathode can't be identified (Radon degassing).**

➢ **Electron lifetime :** $\tau_e = (\eta_a \nu_d)^{-1}$; $E_c = E_r * e^{-z_0/\tau_e} = \mathbf{F}(E_r; z_0, \tau_e)$

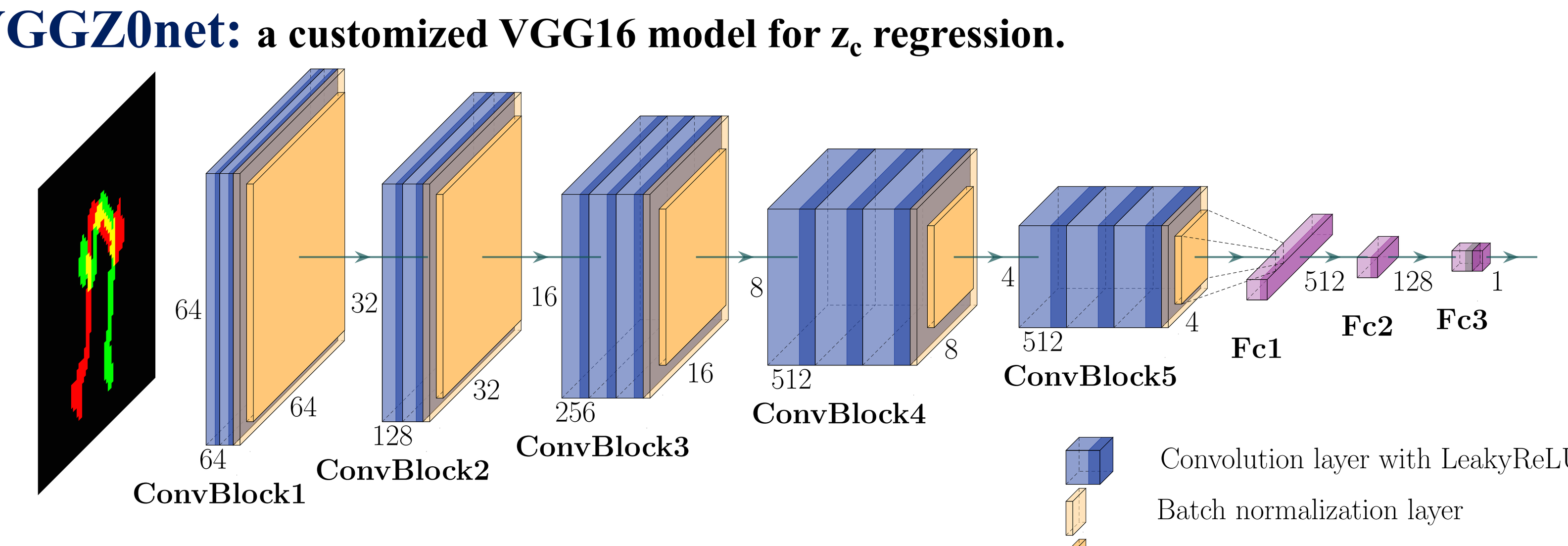
➢ **z_0 is revealed in the degree of trajectory dispersion.**

$$\sigma^2_{L,T} = \sigma^2_{0L,T} + 2 \cdot D_{L,T} \cdot z_0$$



The simulated tracks for the same 0νββ event with different z_c.

➢ **VGGZ0net: a customized VGG16 model for z_c regression.**



The Structure of VGGZ0net.

➢ **Performance on the simulated dataset**

$\sigma(\Delta z)$: prediction error of VGGZ0net; l_e: Setting value of electron lifetime;
$\hat{l}_e, \hat{\tau}_e$: electron lifetime estimation;

l_e (cm)	$\sigma(\Delta z)$ (cm)	$\hat{l}_e$ (cm)	$\hat{\tau}_e$ (ms)	Corrected energy resolution at $Q_{\beta\beta}$ (%) FWHM
Infinity	11	-	-	3.3
2000	11	2015 ± 55	10.83 ± 0.30	3.4
1800	11	1815 ± 53	9.76 ± 0.28	3.5
1600	11	1614 ± 42	8.68 ± 0.23	3.6
1400	11	1408 ± 33	7.57 ± 0.18	3.7
1200	11	1217 ± 30	6.54 ± 0.16	4.0
1000	11	1008 ± 25	5.42 ± 0.13	4.2
800	11	809 ± 20	4.35 ± 0.11	4.6

Table: The performance of vertex reconstruction and energy correction based on VGGZ0net in different electron lifetime scenarios. The corrected energy resolution at $Q_{\beta\beta}$ is presented.

[1] Tao Li et al. JHEP06(2021)106.
[2] Tao Li et al. JHEP05(2023)200.