Recent Results from PandaX experiment

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On behalf of the PandaX Collaboration

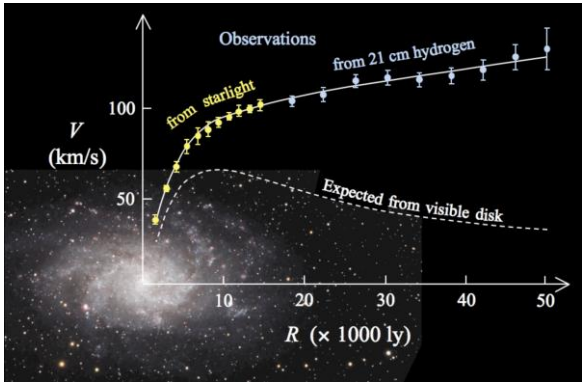
PANDA X

PARTICLE AND ASTROPHYSICAL XENON TPC

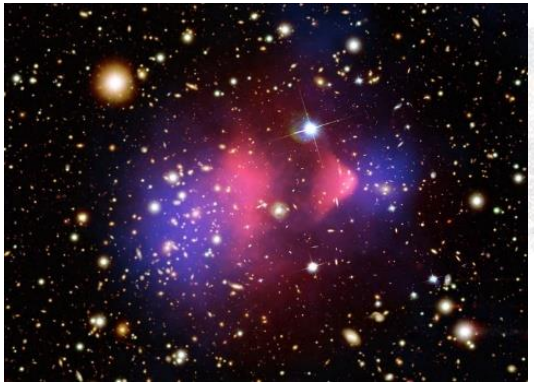
PandaX Collaboration

Dark matter and its evidence

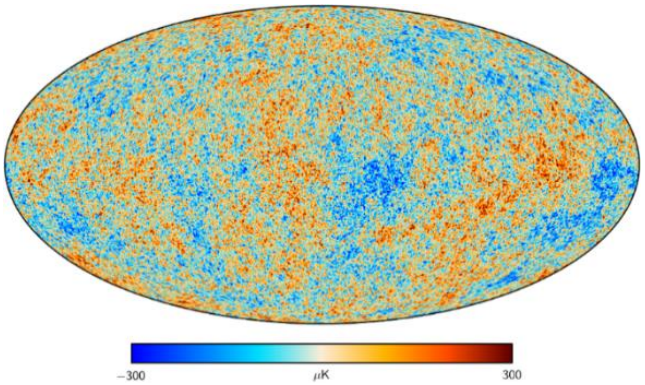
Galactic rotation curve

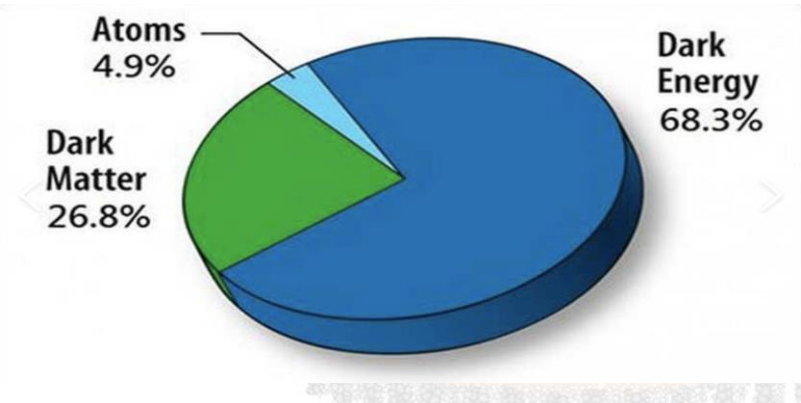


Bullet Cluster



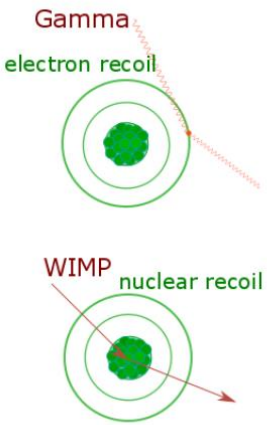
Cosmic Microwave Background

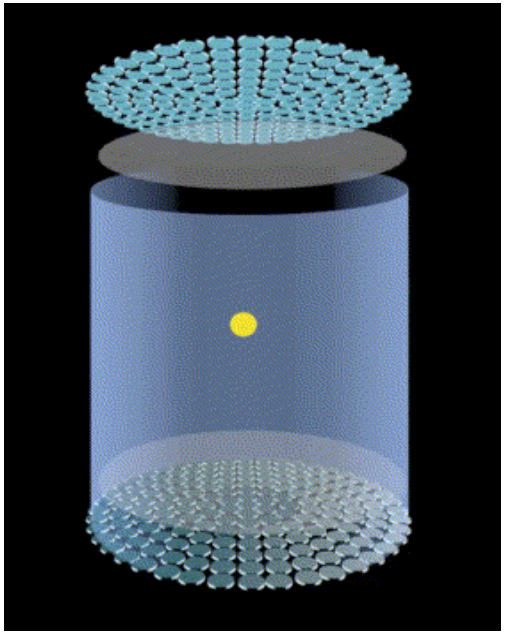




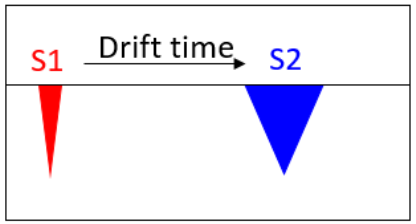
- Gravitational evidences suggest dark matter is the dominant form of matter in Universe!
- The nature of dark matter is still a mystery: WIMPs?

Dual phase xenon TPC

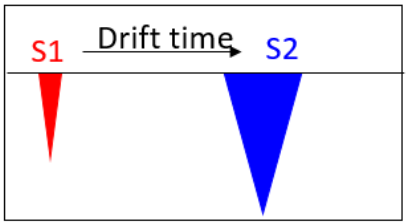




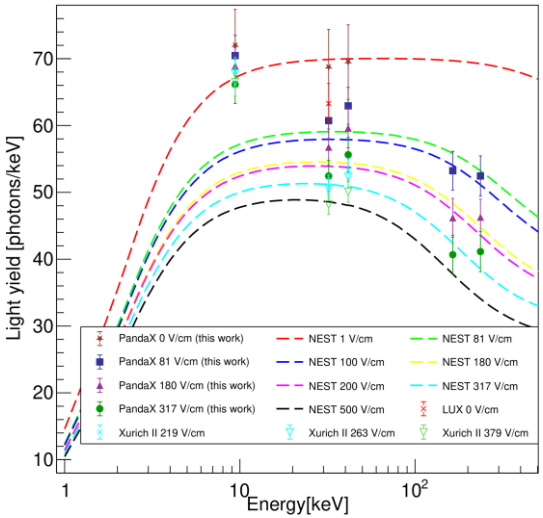
Dark matter: nuclear recoil (NR)



γ background: electron recoil (ER)



$(S2/S1)_{NR} << (S2/S1)_{ER}$



JINST 17 P01008 (2022)

Detector capability:

- ❑ Large monolithic target
- ❑ Good ER/NR rejection
- ❑ 3D reconstruction and fiducialization
- ❑ High light and charge yields

PandaX Experiments

Particle and Astrophysical Xenon Experiments

Collaboration formed

2009.3

2012.7

PandaX-I apparatus moved to Jinping

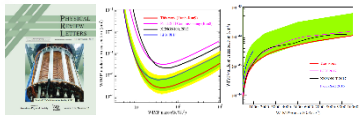
PandaX-I started

2014.3

2014.5-10

PandaX-I, 120 kg operation

PandaX-II, 580 kg operation

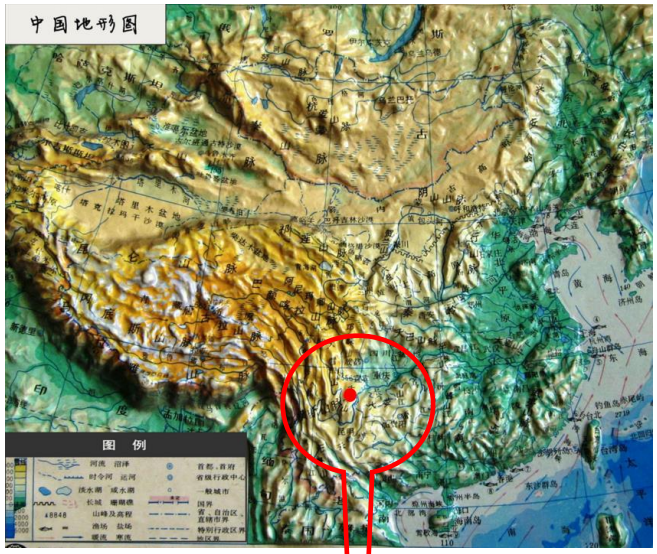


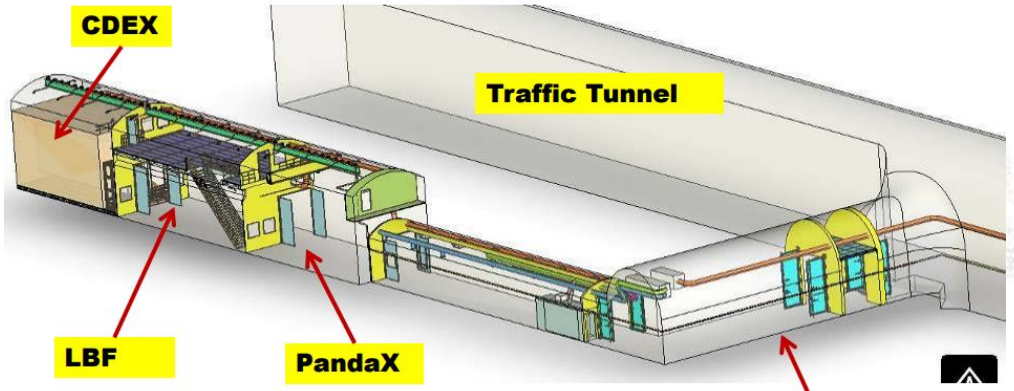
2016.7 -2019.7

2019.8-

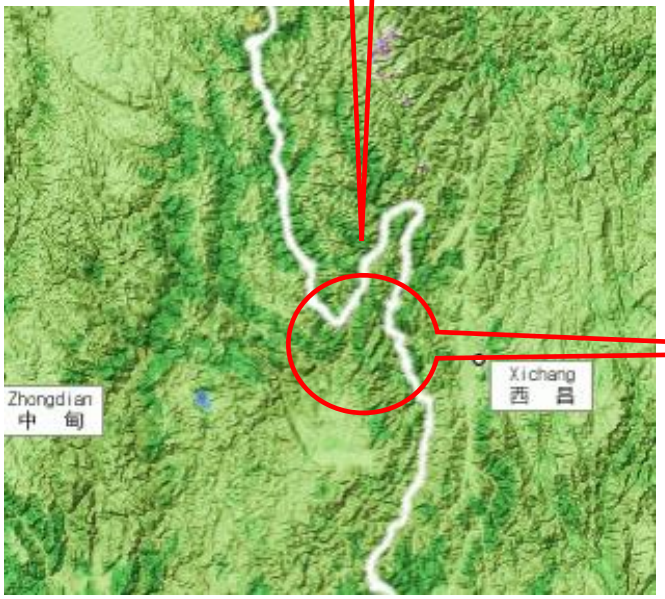
PandaX-4T, 3.7 t moved to CJPL-II

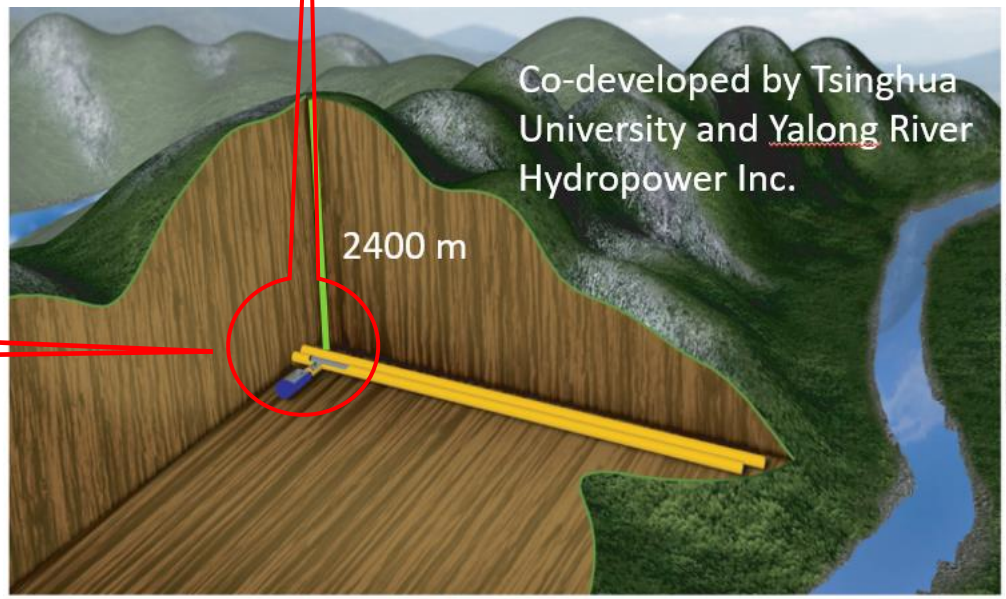
China Jinping underground Laboratory





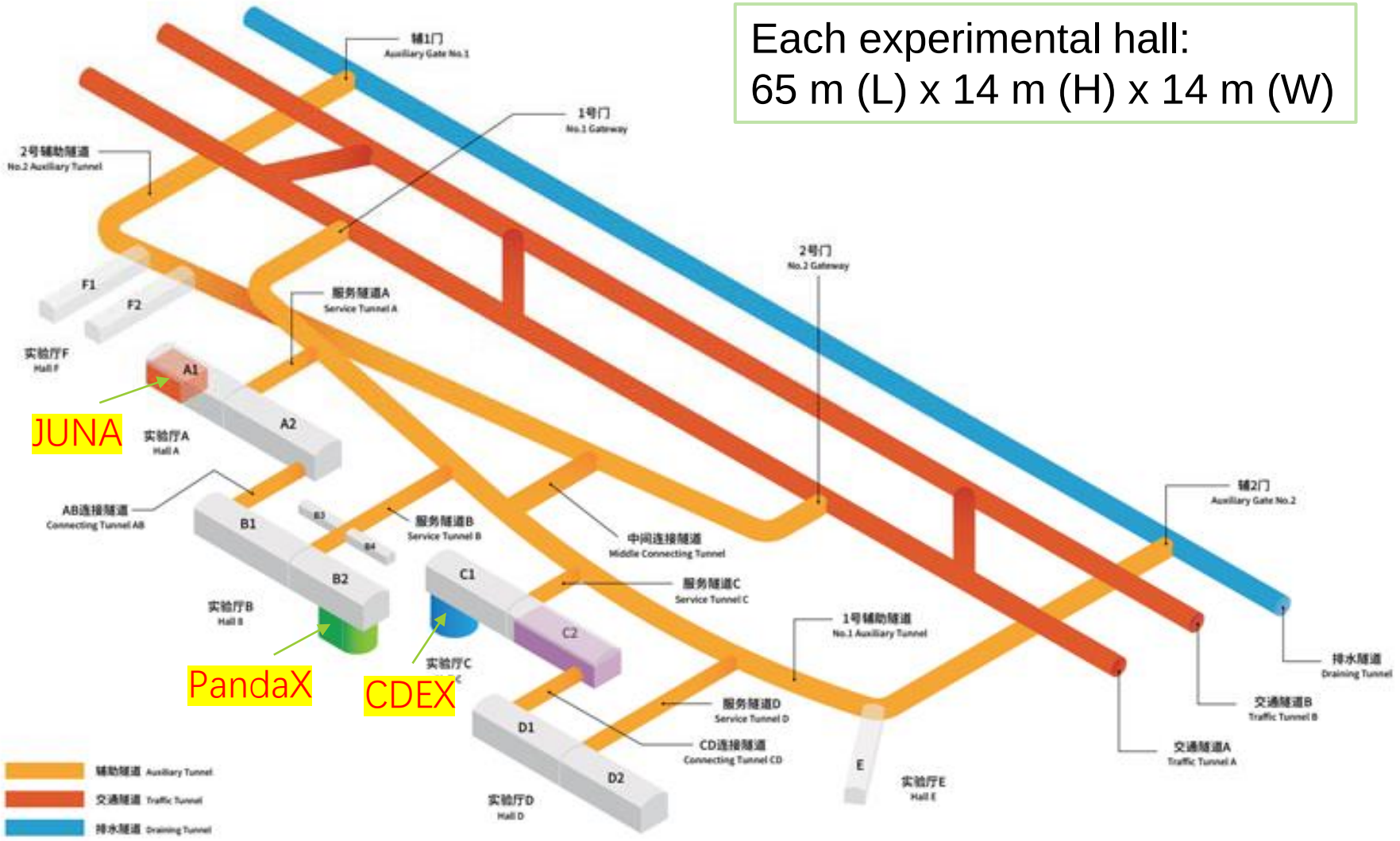
- Total space: 4000 m³
- Main Lab Space: 6.5(W) x 6.5(H) x 42(L)



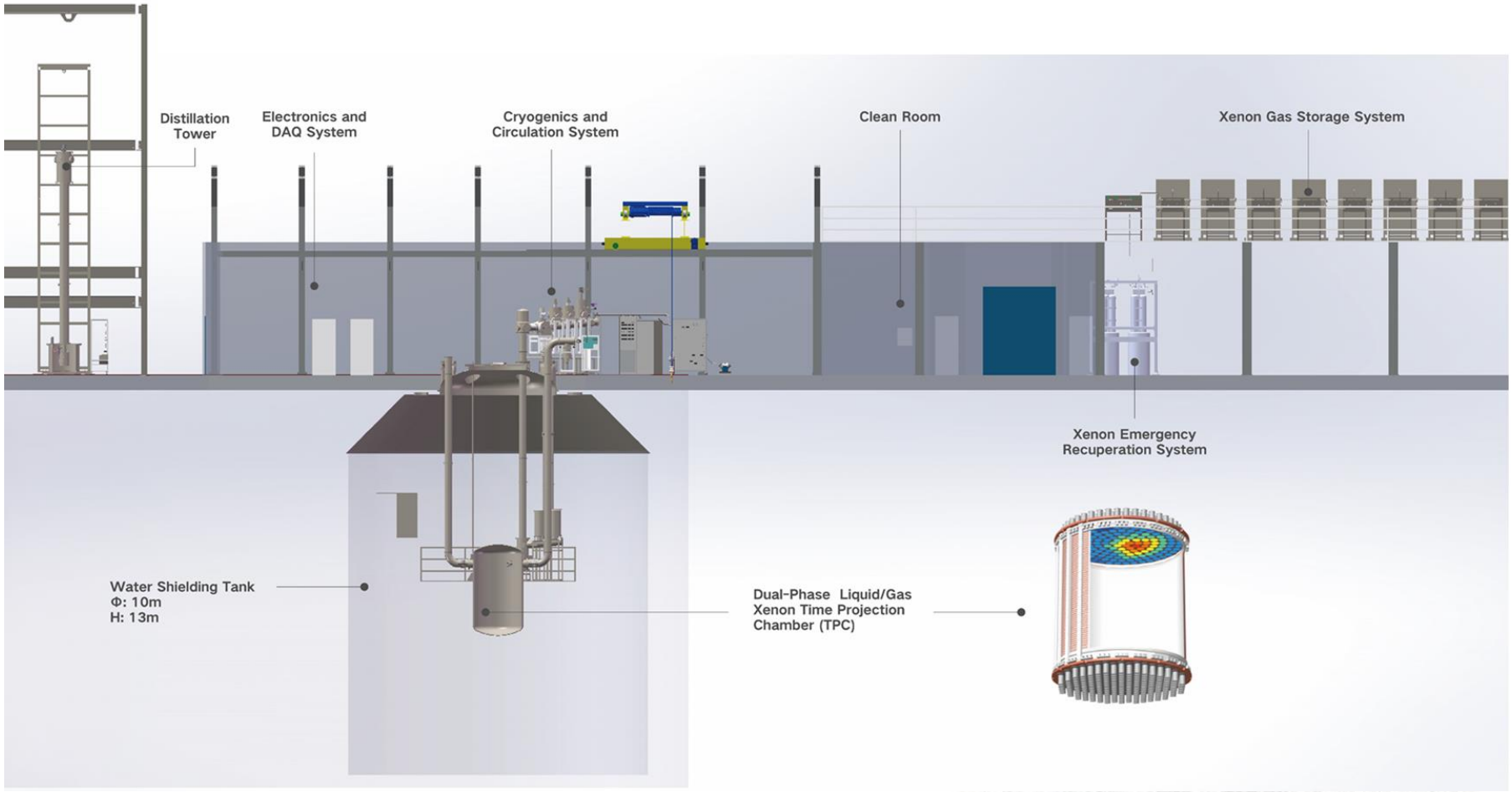


CJPL-II

Each experimental hall:
65 m (L) x 14 m (H) x 14 m (W)

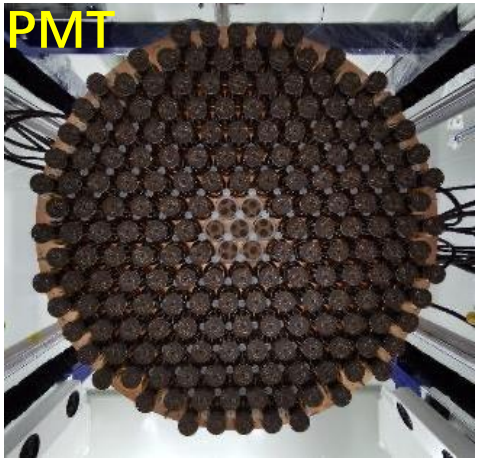


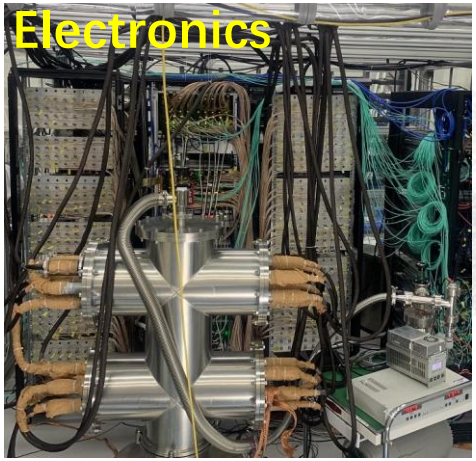
PandaX-4T overview

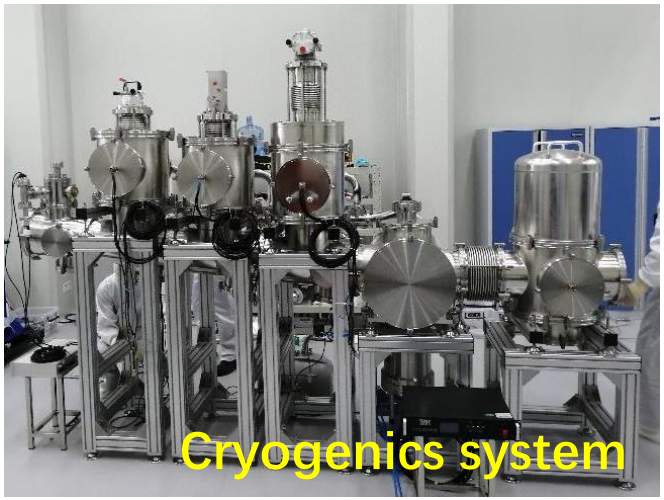


- Ultrapure water shield: 13 m (H) x 10 m (D) ~ 900 m^3
- TPC: 1.2 m (H) x 1.2 m (D)
- 3-in PMTs: 169 top/199 bottom

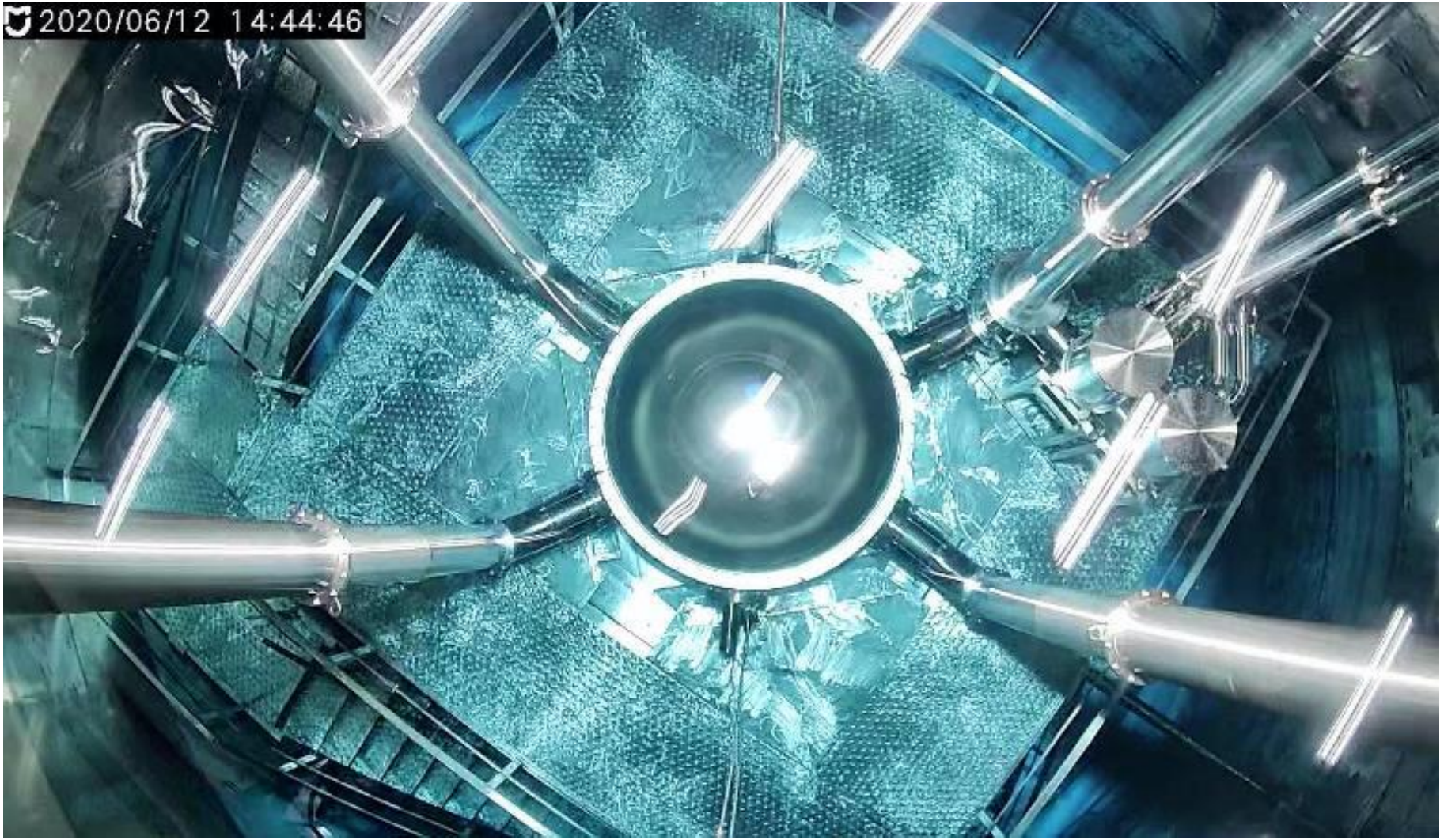
PandaX-4T Subsystems



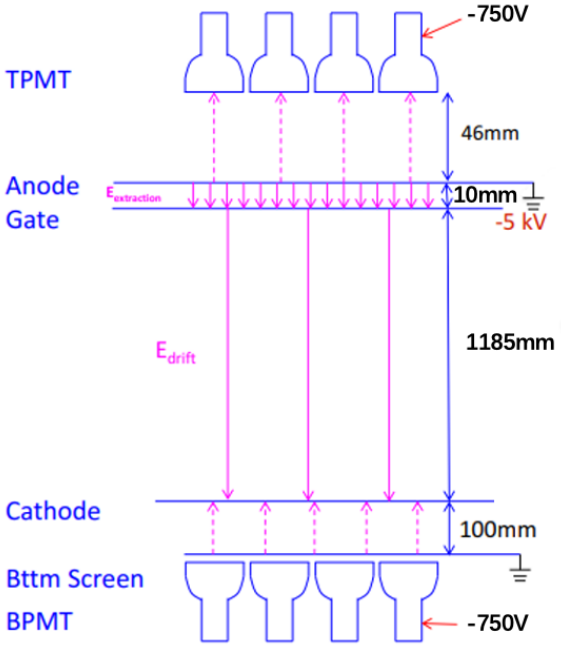


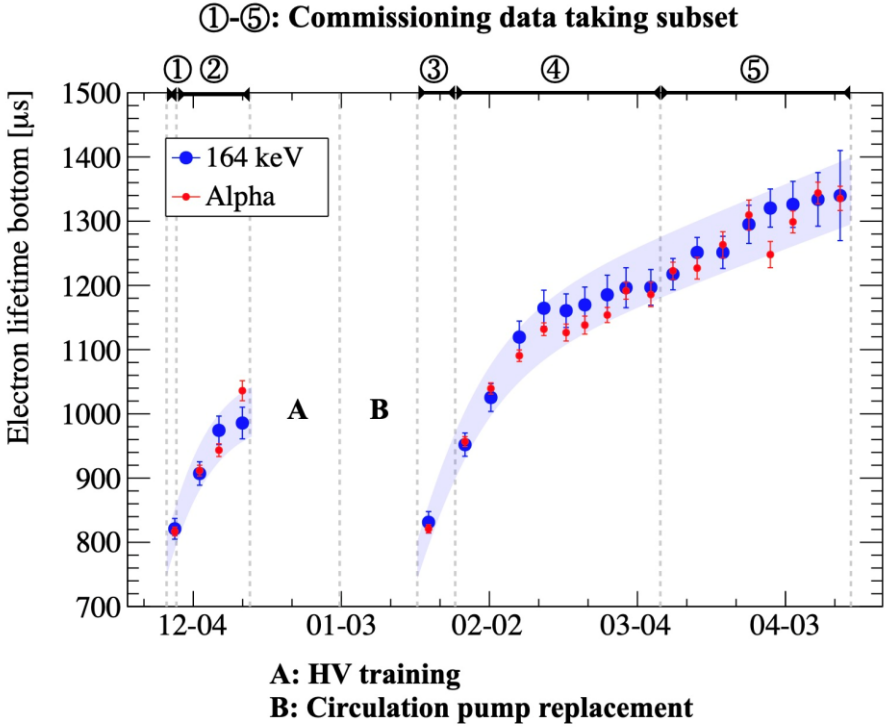


Ultrapure water filling



TPC conditions & data taking history



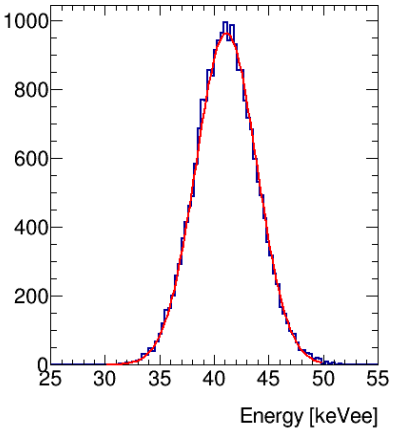


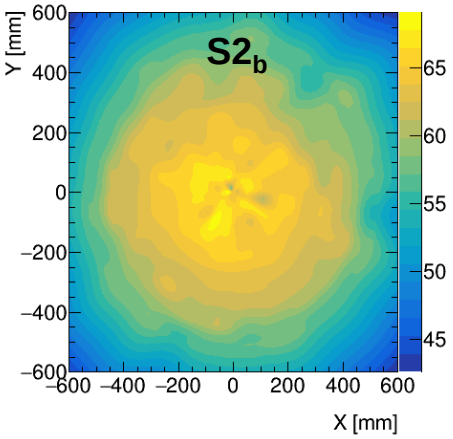
Set	1	2	3	4	5
Duration (day)	1.95	13.25	5.53	35.58	36.51
$\langle\tau_e\rangle$ (μs)	800.4	939.2	833.6	1121.5	1288.2
$dt_{\max}$ (μs)	800	810	817	841	841
V_{cathode} ($-$kV)	20	18.6	18	16	16
V_{gate} ($-$kV)	4.9	4.9	5	5	5
PDE (%)	9.0±0.2		9.0±0.2		
EEE (%)	90.2±5.4		92.6±5.4		
SEG_b (PE/e)	3.8±0.1		4.6±0.1		

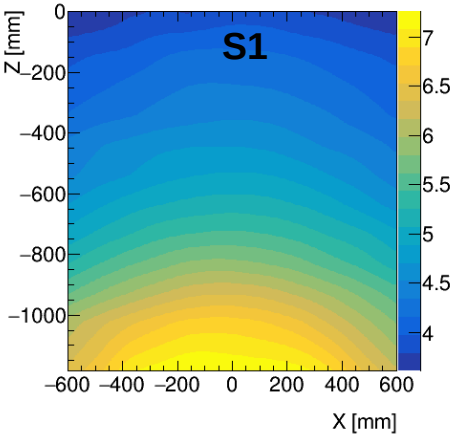
- Different HV to avoid excessive discharges
- Electron lifetime: *in situ* S2 vertical uniformity calibration
- Ref: the maximum drift time ~ 840 μs
- Stable data running period: 95.0 calendar days (86 days after selection)

^{83m}Kr calibration & horizontal uniformity

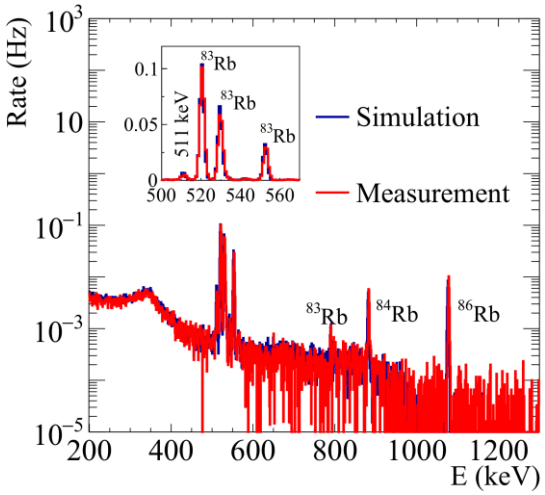
Gaseous source injection panel







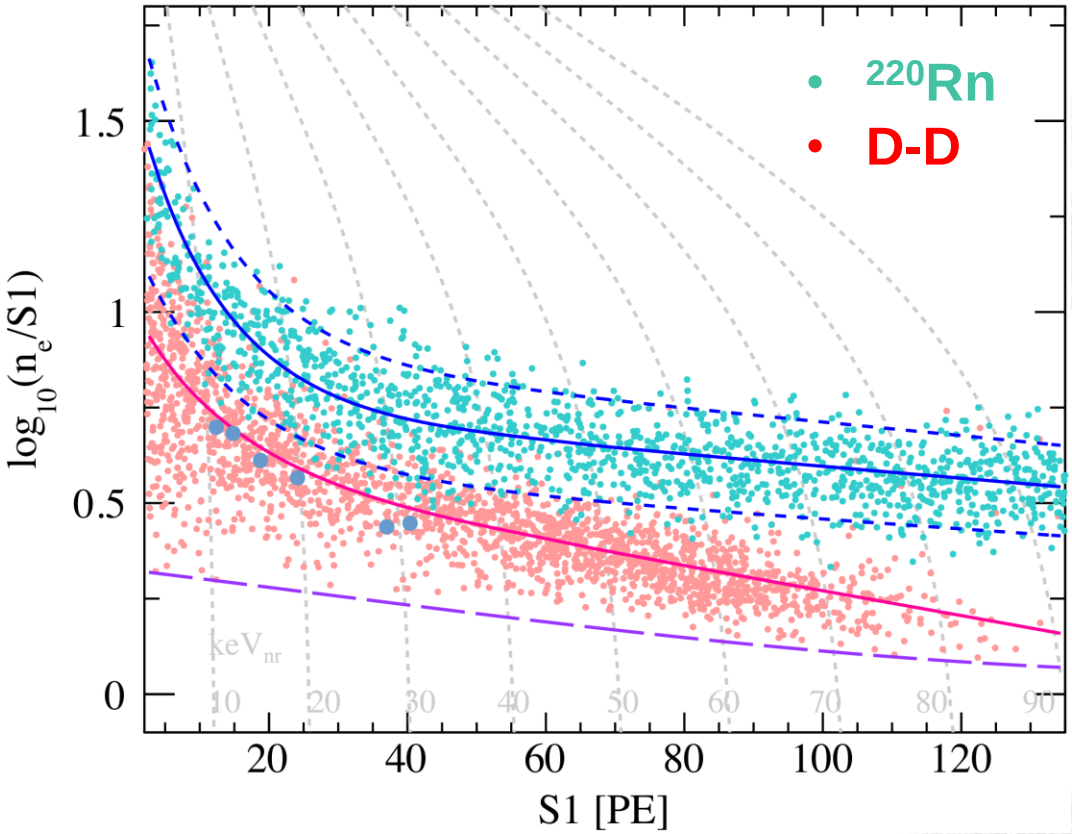
PRC 105, 014604 (2022)



- Internal calibration sources: ^{83m}Kr
- ^{83m}Kr production with 3.4/20 MeV proton beams

  ($p + {}^{nat}Kr \rightarrow {}^{83}Rb \rightarrow {}^{83m}Kr$)
- Energy resolution @ 41.5 keV: 6.8%
- $S2_b$ RMS in FV: 15%
- S1 RMS in FV: 19%

NR and ER calibration

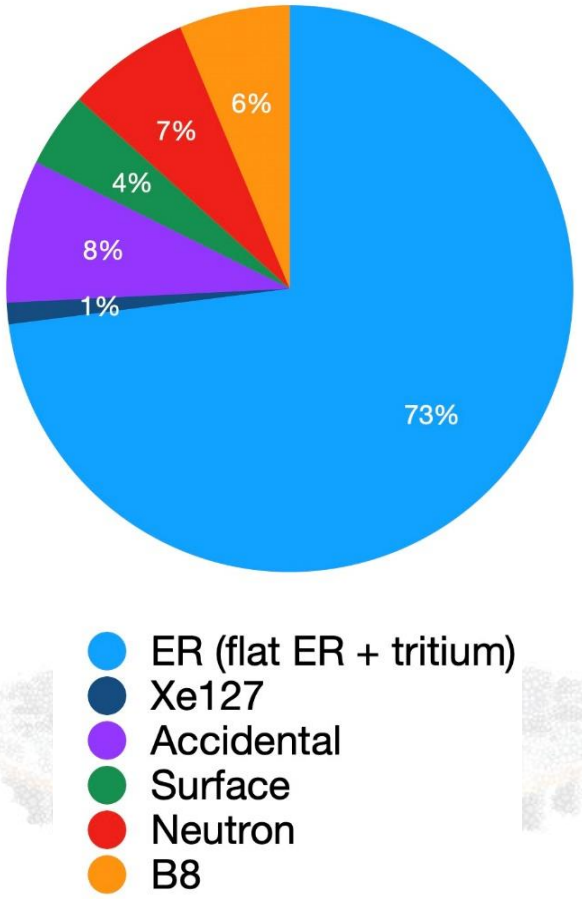


- Nuclear Recoil (NR) calibration with D-D & Am-Be neutrons
- Electron recoil (ER) calibration with ^{220}Rn
- ER leak ratio (below NR median) = 6/1393 = 0.43%±0.18%

Background composition

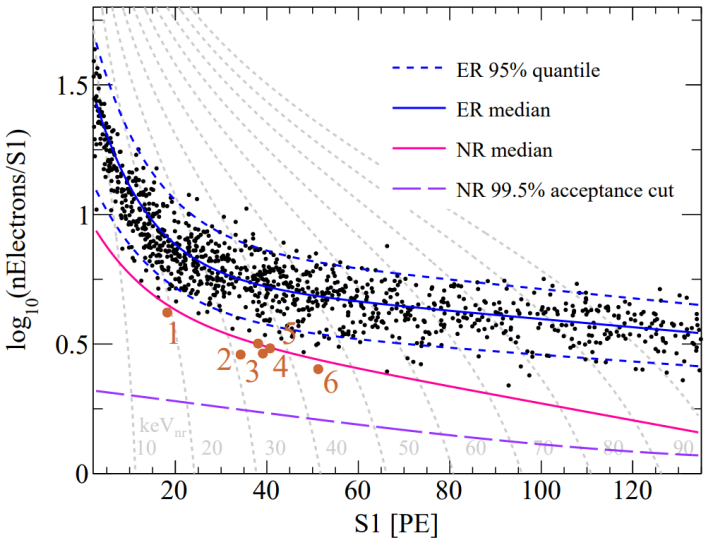
Component	Nominal (evts)
^{3}T (from fit to data)	532 (32)
Flat ER* (18-30keV side band)	492 (31)
Rn	347 (190)
Kr	53 (34)
Material	40 (5)
Xe127	8 (1)
Neutron	0.9 (0.5)
Neutron-X	0.2 (0.1)
Surface	0.5 (0.1)
Accidental	2.4 (0.5)
B8	0.6 (0.3)
Sum	1037 (45)

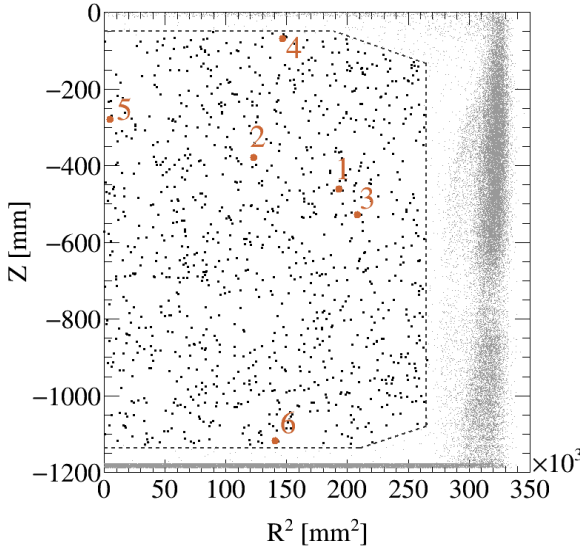
Expected below-NR-median events: 9.8 (0.6) evts

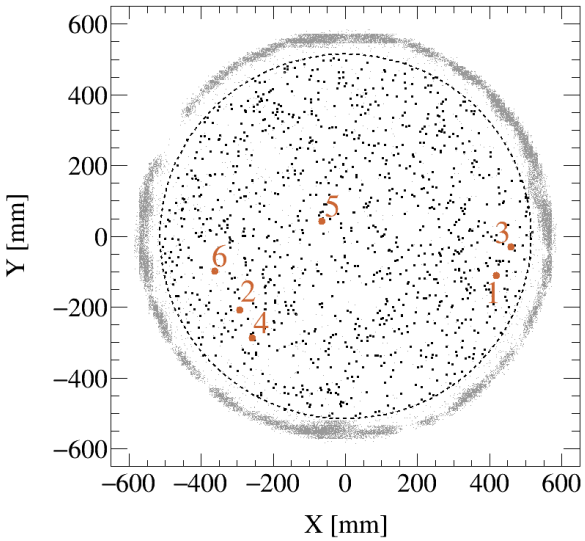


- Flat ER (Rn+Kr+Material) is determined from side band in DM data
- Background per unit target is improved from PandaX-II by 4 times (<10 keV)

DM candidates & position distribution



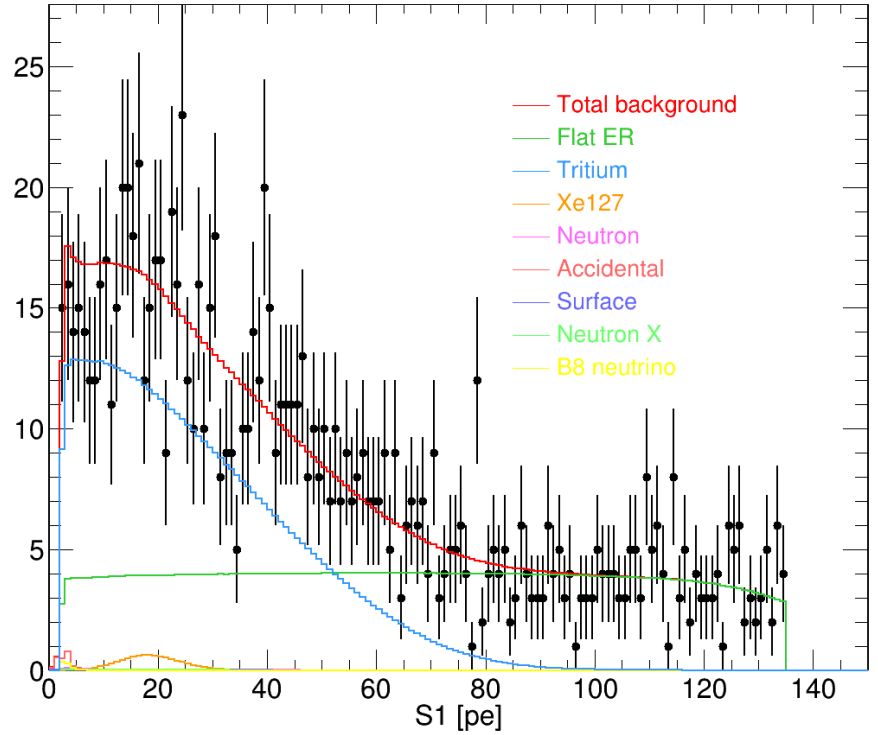




- S1 = (2, 135) PE, $S2_{raw}$ > 80 PE, S2 < 20000
- FV = 2.67 tonne
- 1058 candidates (expected 1054±39), 6 below NR median curve (expected 9.8±0.6)
- Events uniformly distributed in the FV, as expected if dominated by tritium and radon

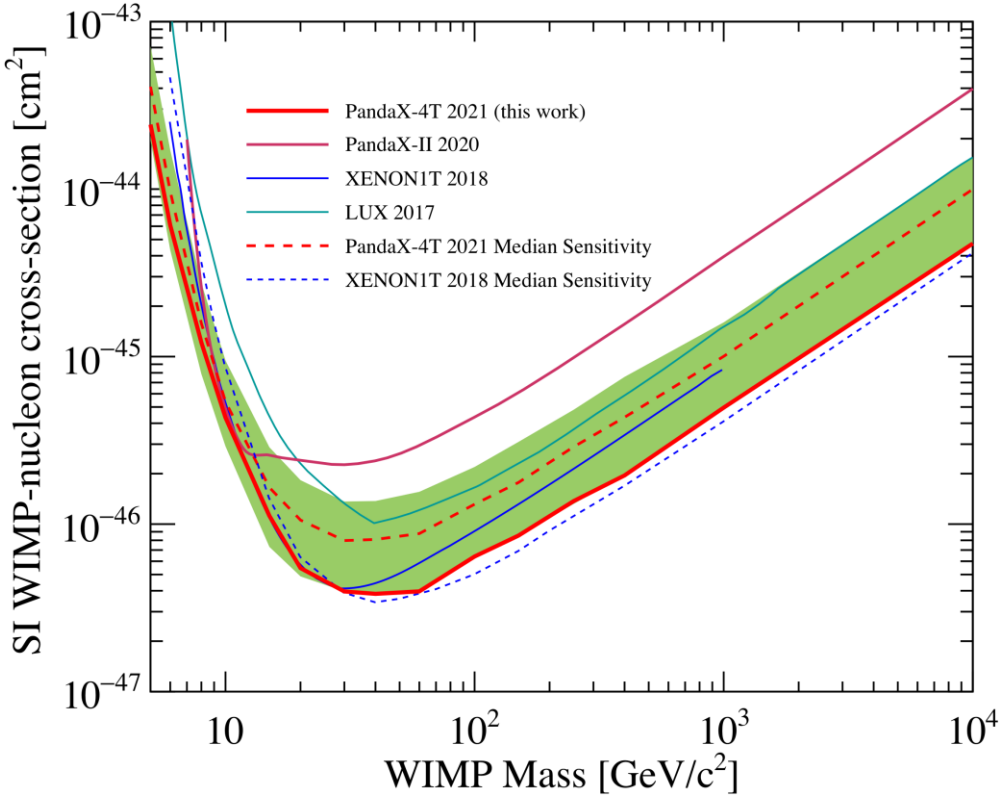
Fitting Methods & Results

$$\mathcal{L}_{\text{pandax}} = \left\{ \prod_{n=1}^{\text{nset}} \left[\text{Poiss}(\mathcal{N}^n_{\text{obs}} | \mathcal{N}^n_{\text{fit}}) \times \prod_{i=1}^{\mathcal{N}^n_{\text{obs}}} (l_s^{n,i} + \sum_b l_b^{n,i}) \right] \right\} \times \left[G(\delta_s, \sigma_s) \prod_b G(\delta_b, \sigma_b) \right],$$



- Fit data with unbinned likelihood with all signal/background PDFs in (S1, $S2_b$)
- No excess found, background-only p-value 0.58
- Projected S1 spectrum agrees with expected background

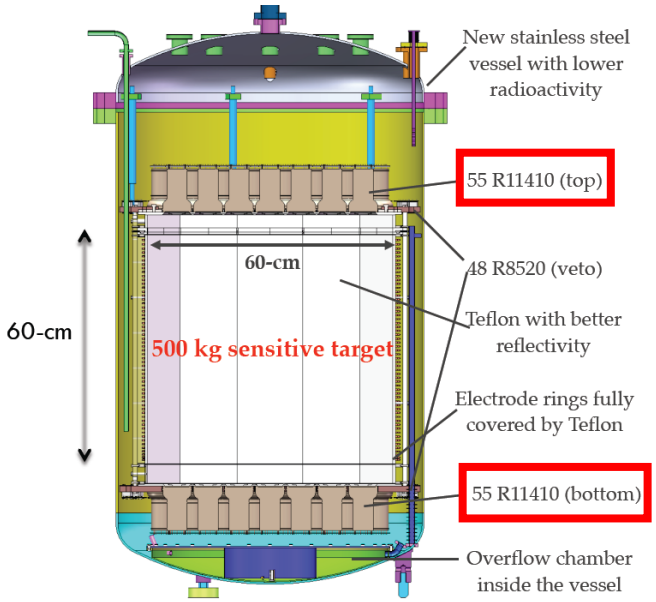
WIMP-nucleon SI exclusion limits

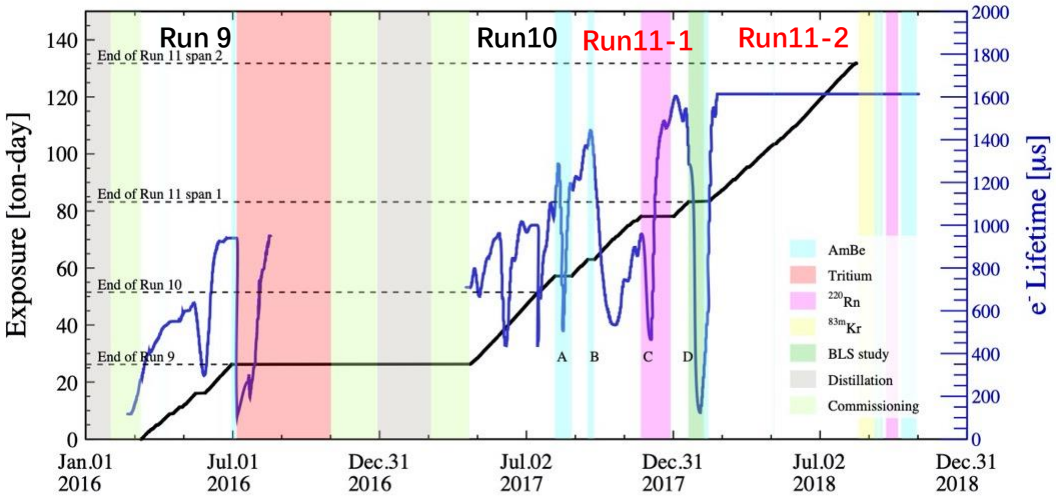


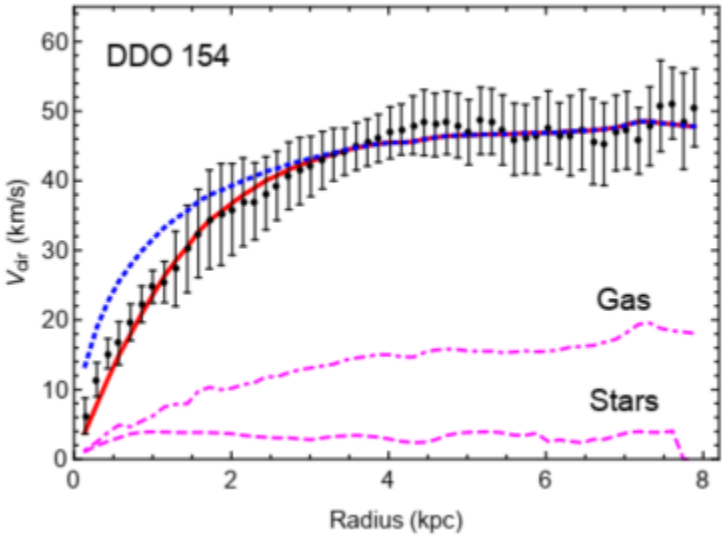
Phys. Rev. Lett. 127, 261802 (2021)

- Exposure: 0.63 tonne·year
- Sensitivity improved from PandaX-II final analysis by 2.9 times (30 GeV/c^2)
- Our limit is ~1.24 times stronger than XENON1T around 30 GeV/c^2
- Dived into previously unexplored territory!
- Approaching the “low E” neutrino floor

PandaX-II & Self-interacting DM

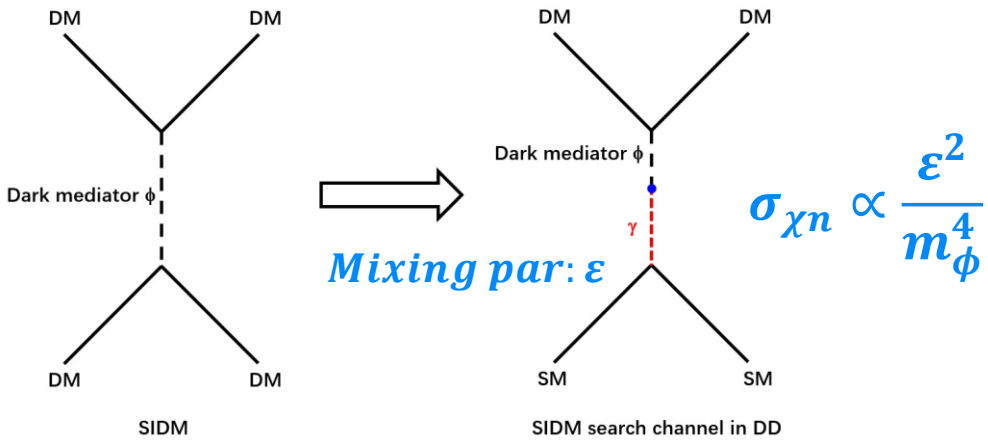




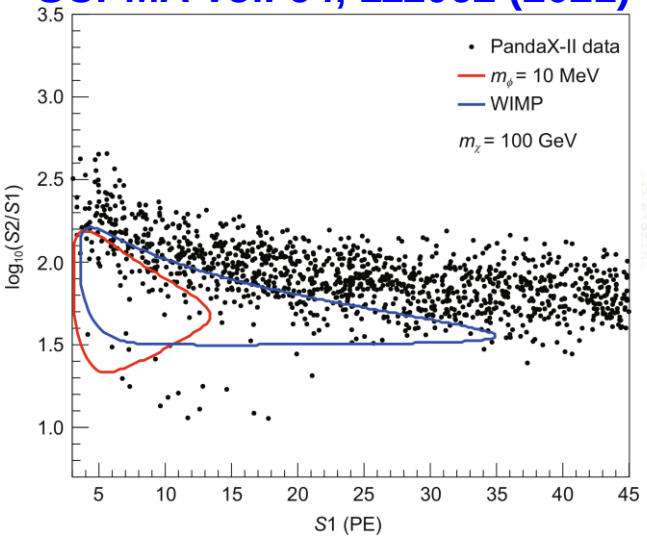


- PandaX-II: 132 tonne-day exposure
- Re-analysis on other DM models
- To solve discrepancies between CDM predictions and galactic observations
  - Self-interacting dark matter (SIDM)
  - Light mediator: m_ϕ ~10 MeV

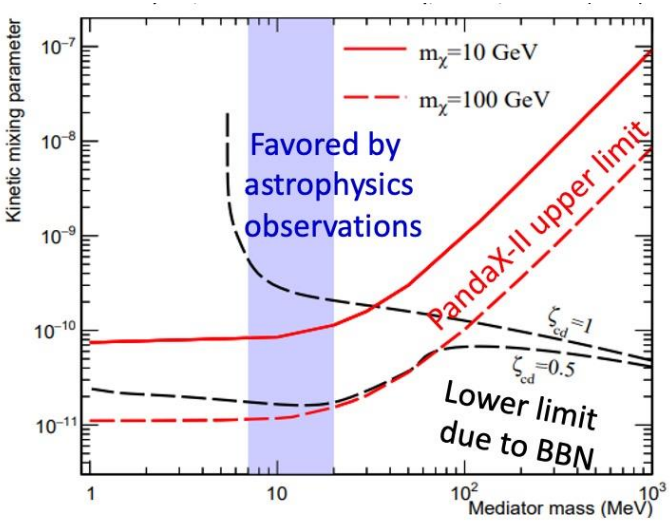
Search SIDM in PandaX-II



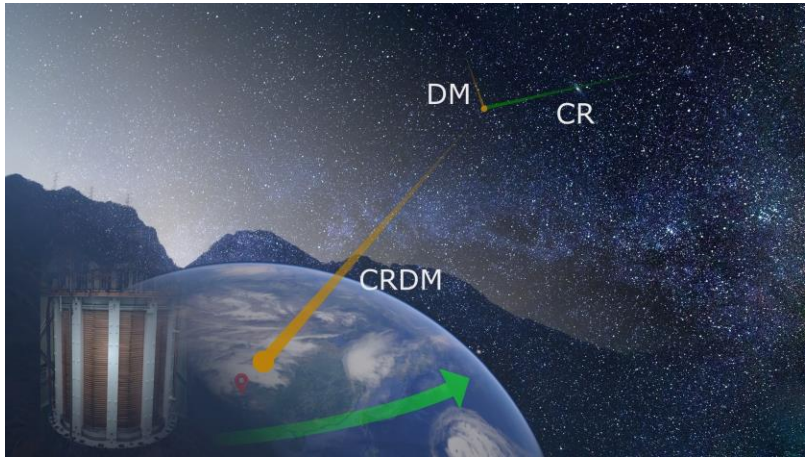
SCPMA Vol. 64, 111062 (2021)



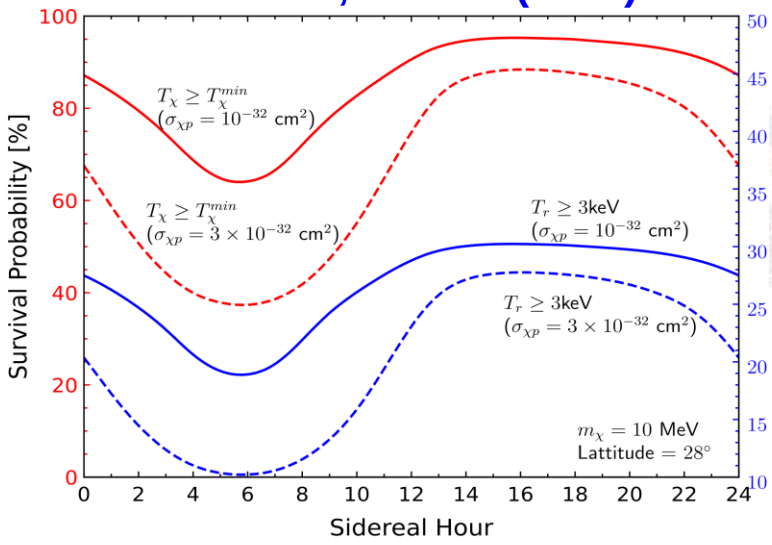
- Light mediator: $m_\phi \lesssim q$
  - Signal spectrum peaked more towards low energy
- PandaX-II results
  - No significant excess is found above background
  - Upper limits on $\sigma_{\chi n} \propto \varepsilon^2 / m_\phi^4$
  - Combination with astrophysics and cosmology
  - Under SIDM, for 10-200 GeV DM mass, dark sector is colder than visible sector in early universe

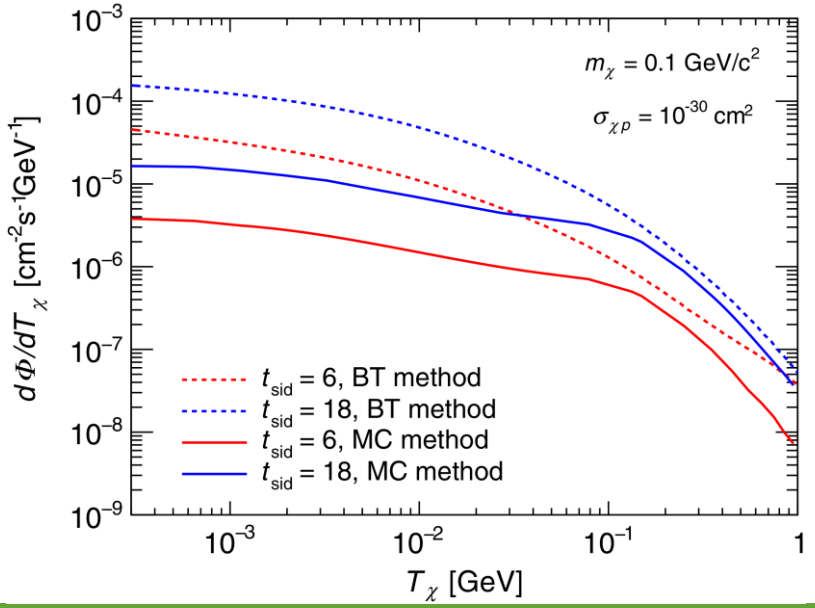


Cosmic-ray boosted dark matter (CRDM)



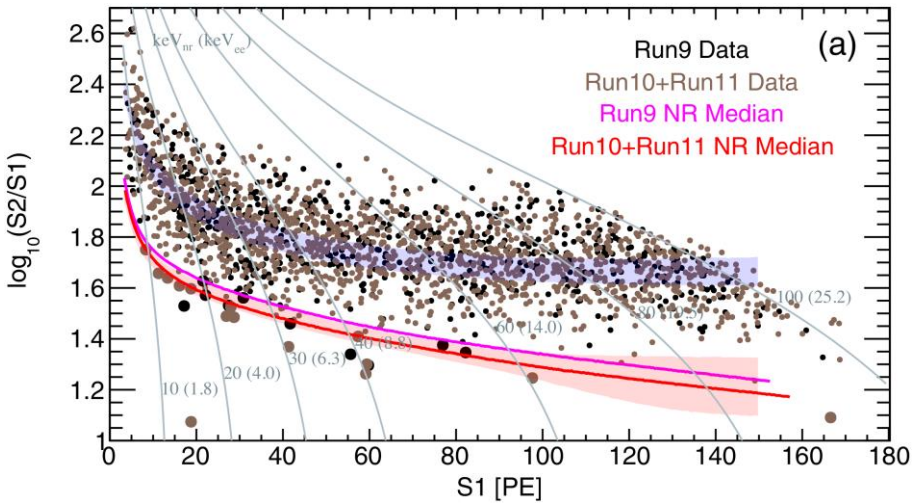
PRL 126, 091804 (2021)

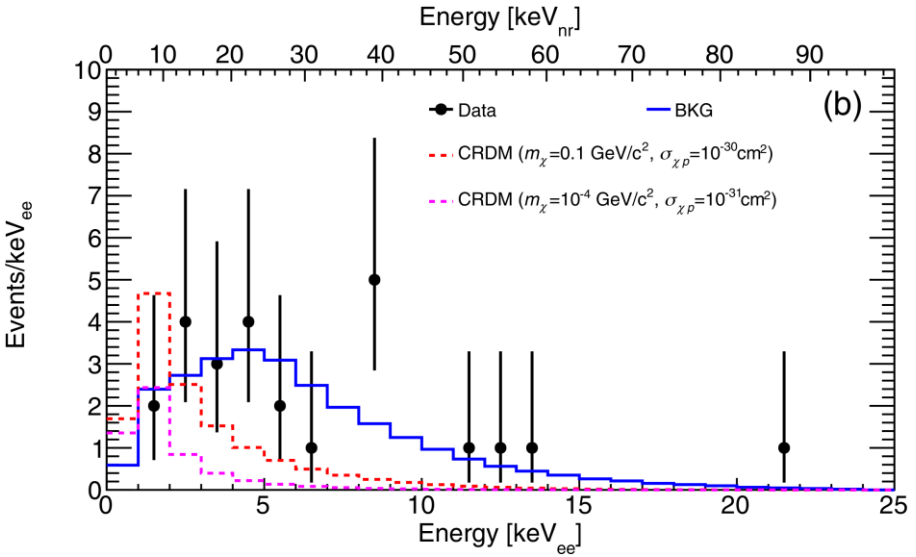




- Cosmic-ray boosts the kinetic energy of Galactic DM with sub-GeV mass
- Sidereal diurnal modulation in CRDM rate and recoil energy spectra
- Calculate attenuated CRDM flux at CJPL using full MC simulation

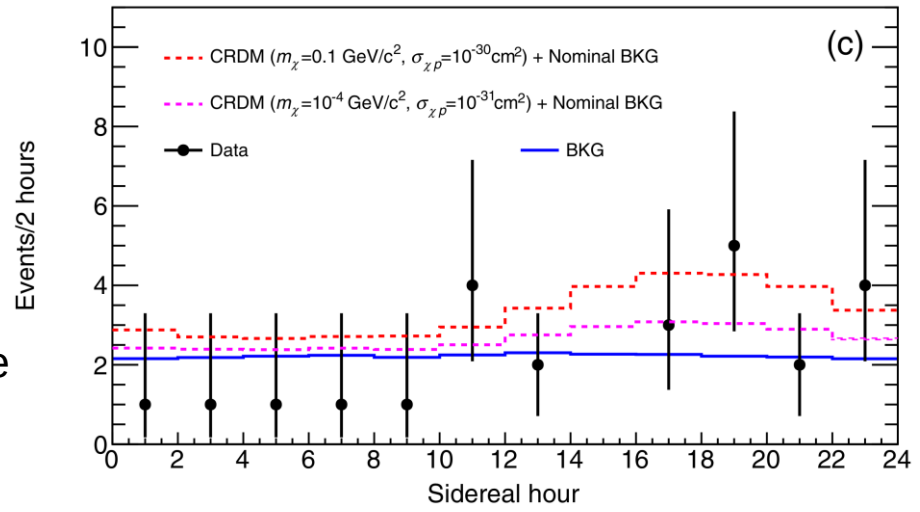
Sub-GeV DM candidates in PandaX-II





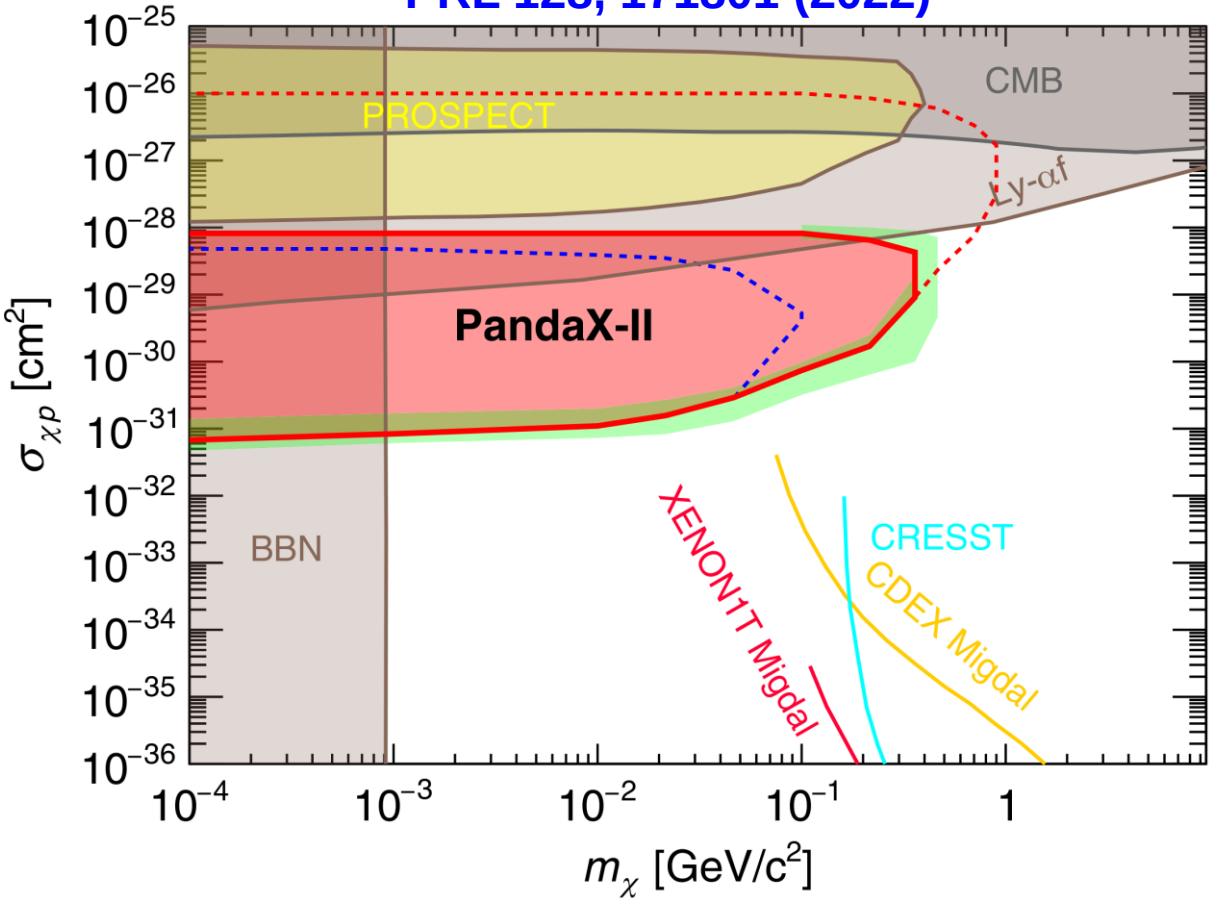
PRL 128, 171801 (2022)

- 100 tonne·day dataset of PandaX-II
- Using events below NR median:25 events (expected 26.6 background)
- No significant CRDM signal is found above background.



PandaX-II constraints on sub-GeV DM

PRL 128, 171801 (2022)

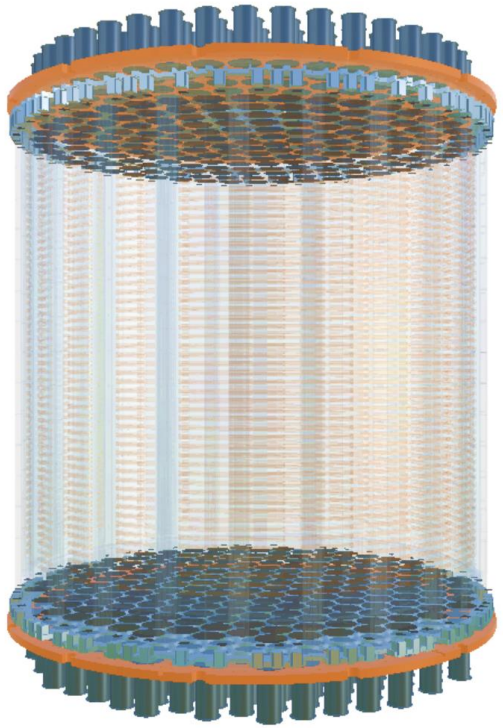


- Exclude $\sigma_{\chi p}$ between 10^{-31} and 10^{-28} cm^2 for DM mass [0.1 MeV, 0.1 GeV]
- Expand to the region beyond the astrophysical and cosmological probes

Conclusion and outlook

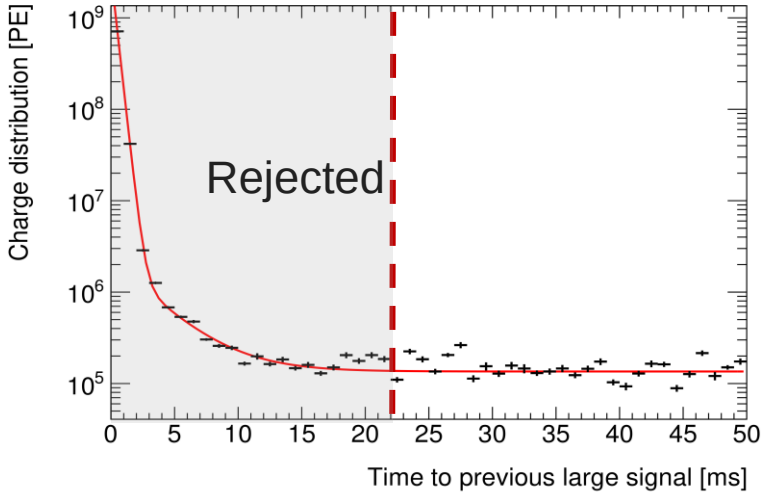
- PandaX-4T has completed its commissioning run
- With a 0.63 tonne·year exposure, PandaX-4T produced the strongest WIMP-nucleon interaction constraint
- An offline tritium removal campaign has been performed, new physics run is on going
- PandaX-II analysis on other physics topics: SIDM, CRDM
- In parallel, the collaboration is developing the plan for the next generation experiment at CJPL, we welcome collaborators!

Backups



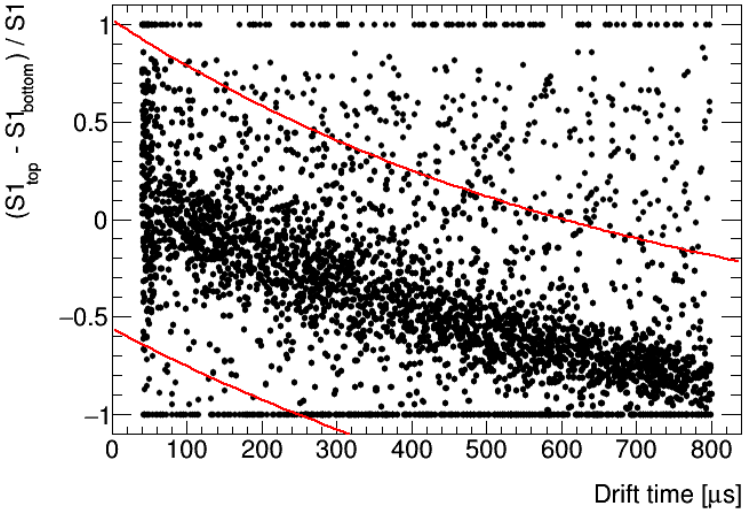
Lower level data selection cuts

Time to previous large signals

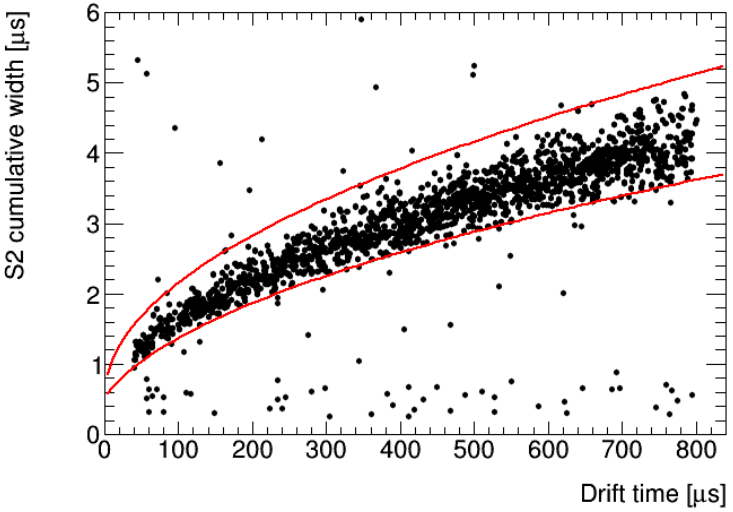


- Livetime fraction: 92.7%
- Rate excursion cuts: 97.7%

T-B asymmetry cut for S1

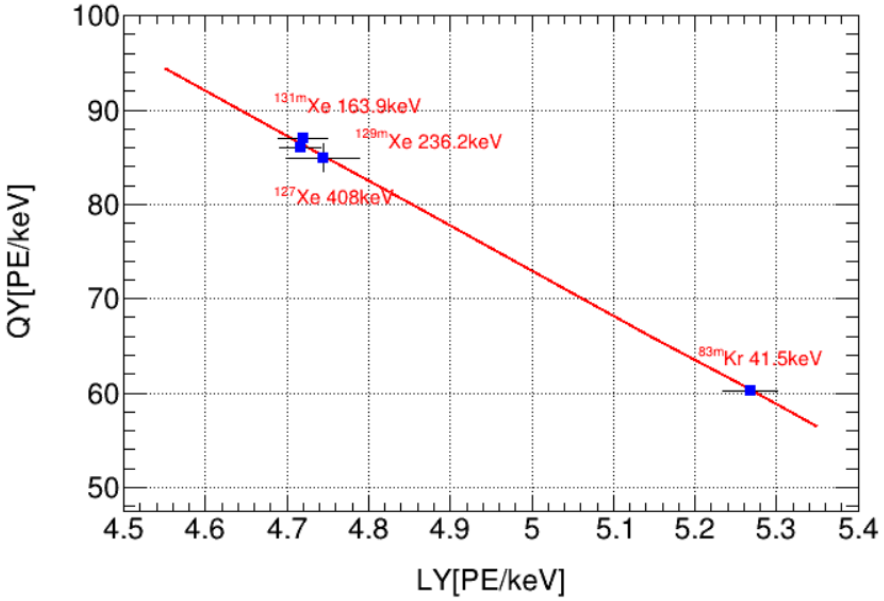


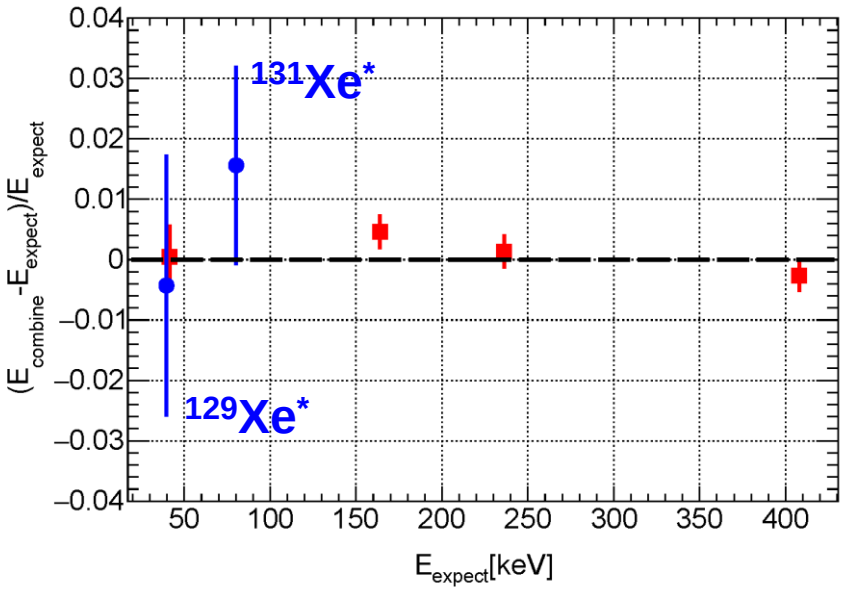
Diffusion cuts



Energy reconstruction

$$E = 13.7\text{eV} \times \left(\frac{\text{S1}}{\text{PDE}} + \frac{\text{S2}_\text{b}}{\text{EEE} \times \text{SEG}}\right)$$



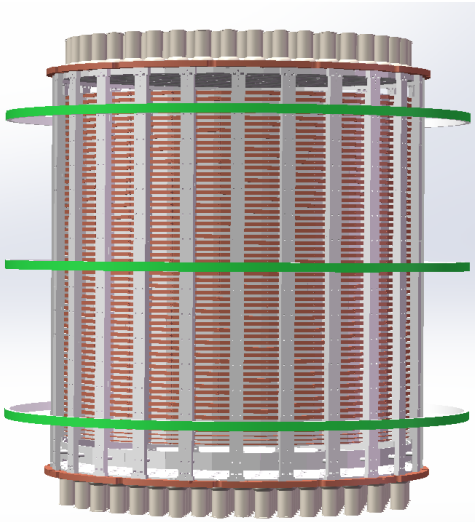


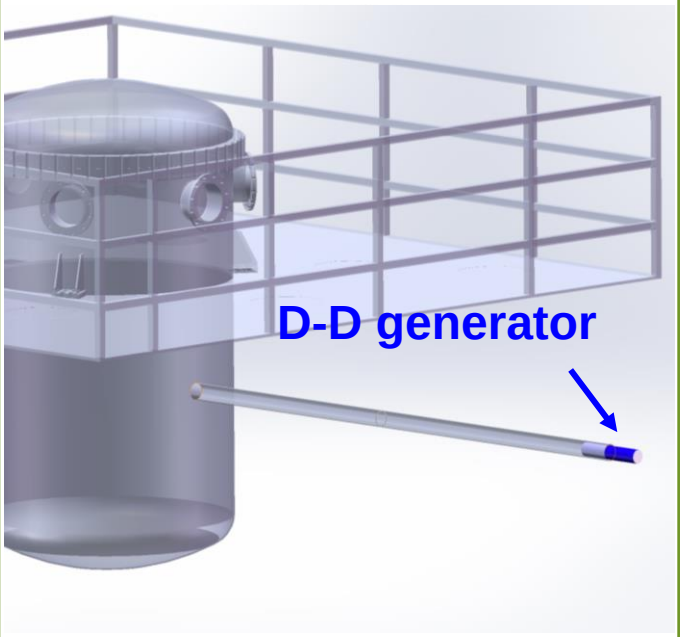
#Set	PDE [%]	EEE [%]	SEG [PE/e]
1-2	9.0±0.2	90.2±5.4	3.8±0.1
3-5	9.0±0.2	92.6±5.4	4.6±0.1

Calibration methods

Gaseous source injection panel

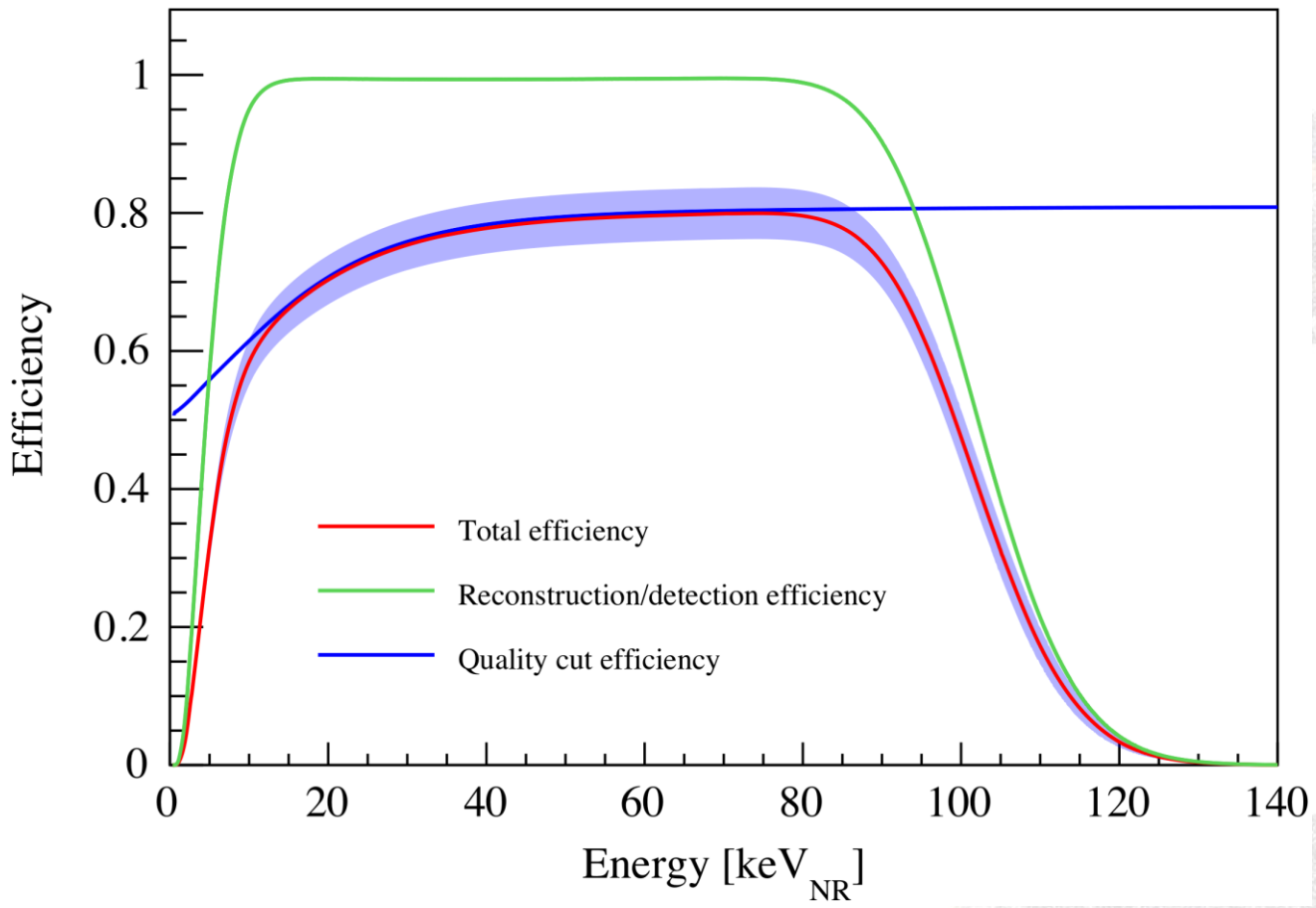
Calibration tubes





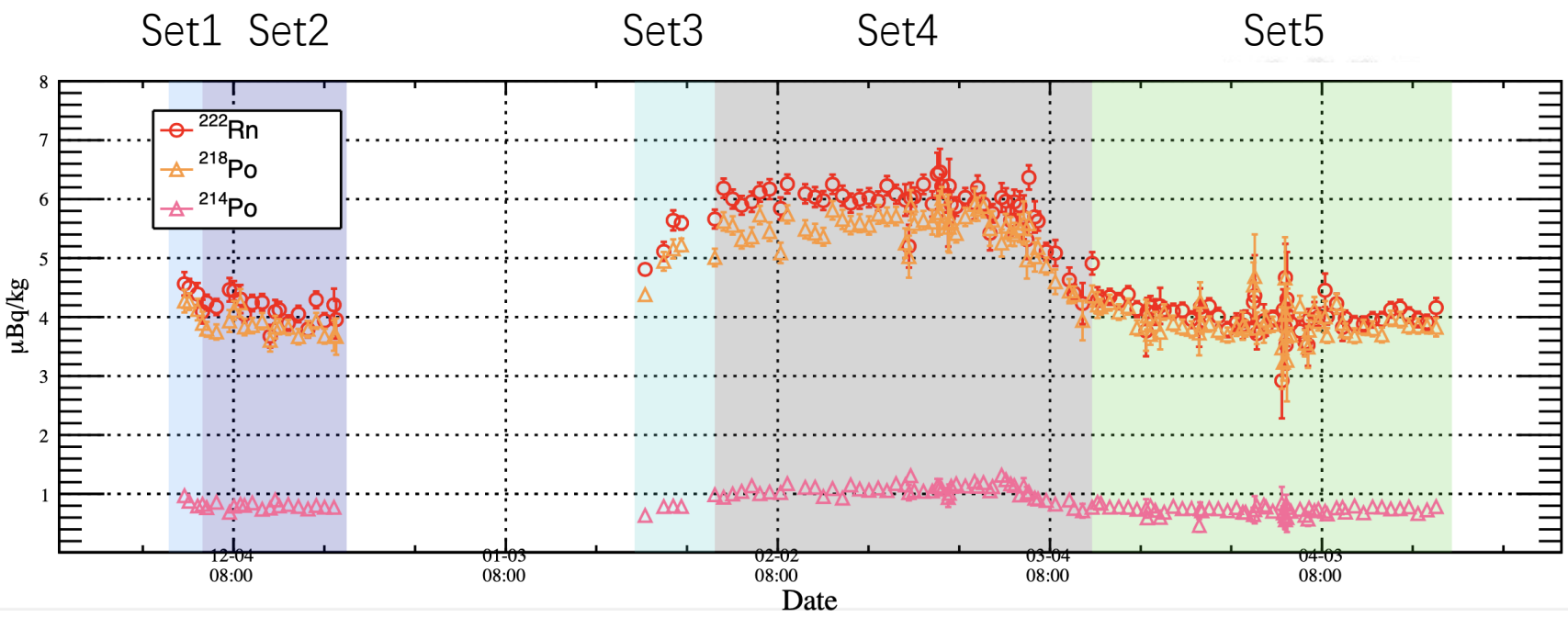
Calibration source	Position
^{83m}Kr/^{220}Rn	Injected from gas panel
^{241}Am-Be	Calibration tubes
D-D neutron	Beam pipe

Efficiencies obtained from calibration data



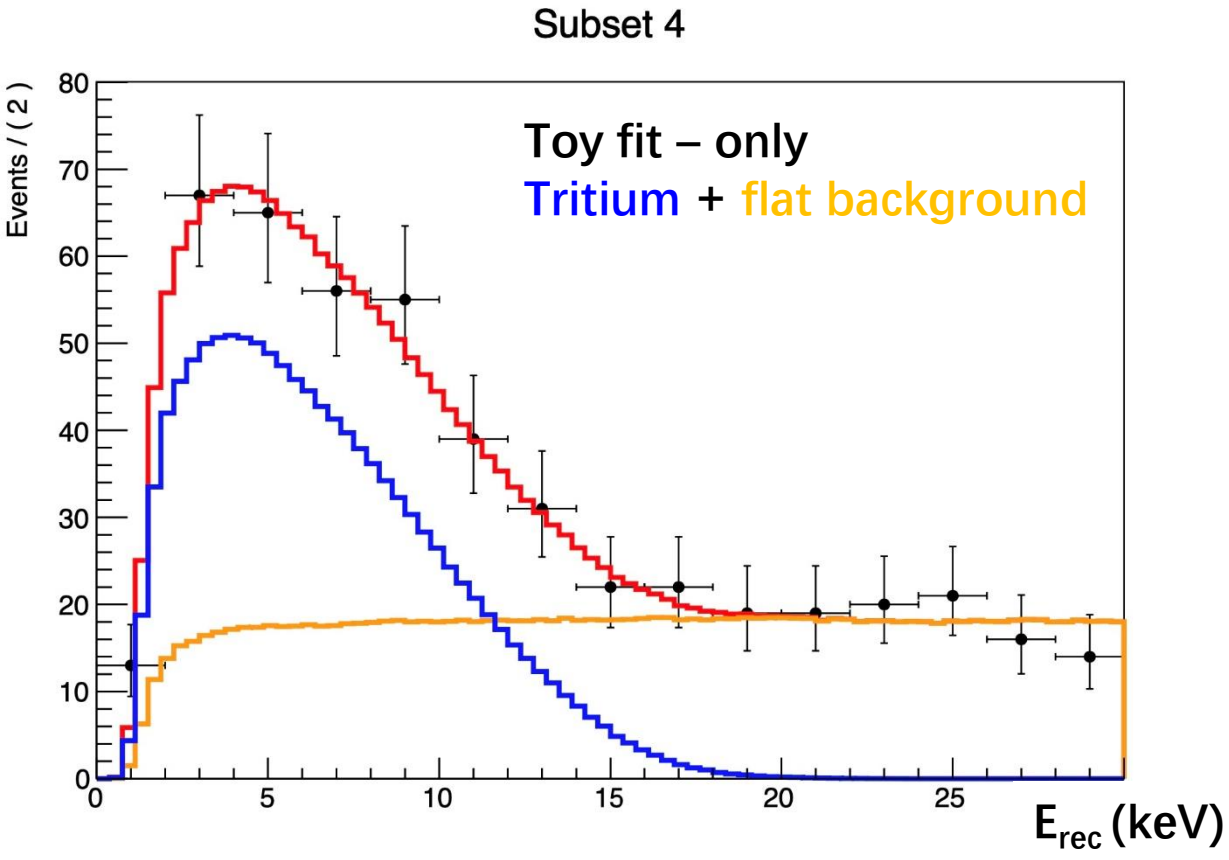
- Same S1 and S2 efficiency obtained from the ER and NR data
- Plateaued efficiency at 40 keV$_{nr}$ ~78%.

^{222}Rn level evolution



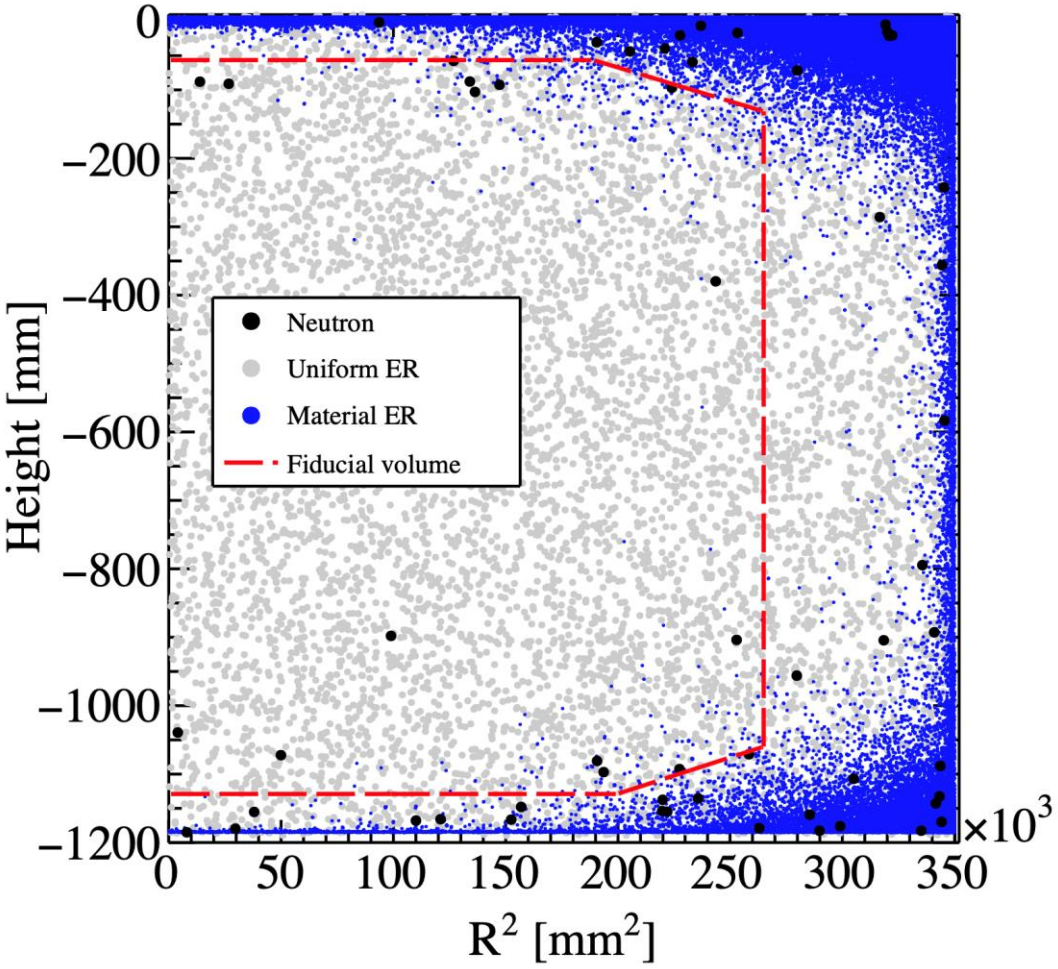
- Set 3→4: online Kr distillation (10 SLPM)
- Set 4→5: distillation off to reduce Rn emanation from the tower
- Low background directly extracted: 347 ± 190 events

Tritium background



- Tritium spectrum identified in the data
- Likely originated from a tritium calibration at the end of PandaX-II
- Level floating in the final dark matter fit: ~ 5(0.3)x10^{-24} (mol/mol)

FV determination



- Based on background simulation (10 t-year)
- Uniform ER (including tritium) normalization come from data
- Define FoM = sqrt(B)/M
- Optimized FV = 2.67 tonne
- FV cuts in the data maintaining the same FV (correcting for reconstruction bias)

Likelihoods of the 6 below-NR events