Recent Results from the PandaX-4T Experiment

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On behalf of the PandaX Collaboration

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PANDA X
PARTICLE AND ASTROPHYSICAL XENON TPC

Outline

PANDA X
PARTICLE AND ASTROPHYSICAL XENON TPC

- Introduction of dark matter
- PandaX-4T experiment
- Recent physics results
  - SI/SD WIMP
  - DM absorption
  - ^{8}B CEνNS
  - ^{136}Xe ($0\nu/2\nu$) $\beta\beta$ decay
- Summary and outlook

Dark matter evidences

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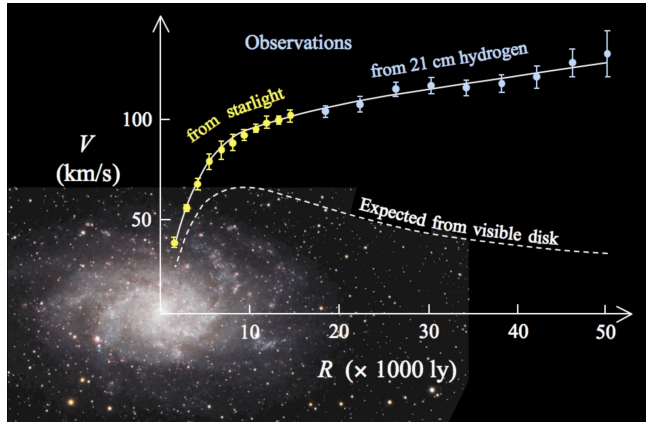
Galactic rotation curve

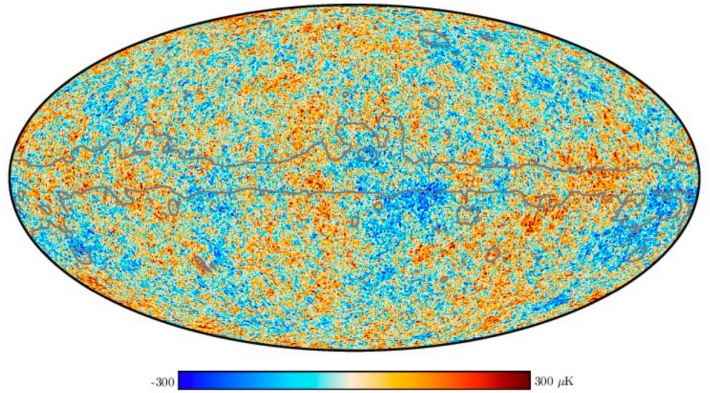


Mon. Not. R. Astron. Soc. 311, 411-447(2000)

Bullet Cluster

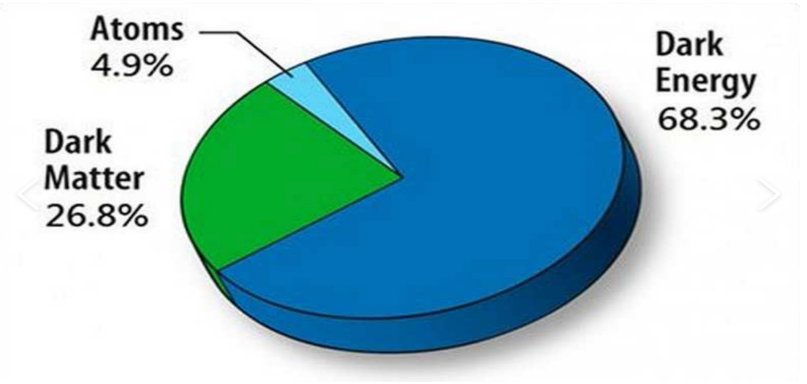
Monthly Notices of the Royal Astronomical Society 382 (2007): 29-47

Cosmic Microwave Background



Planck 2018 results I Overview and the cosmological legacy of Planck

Gravitational evidences suggest dark matter is the dominant form of matter in the Universe



Dark matter candidates

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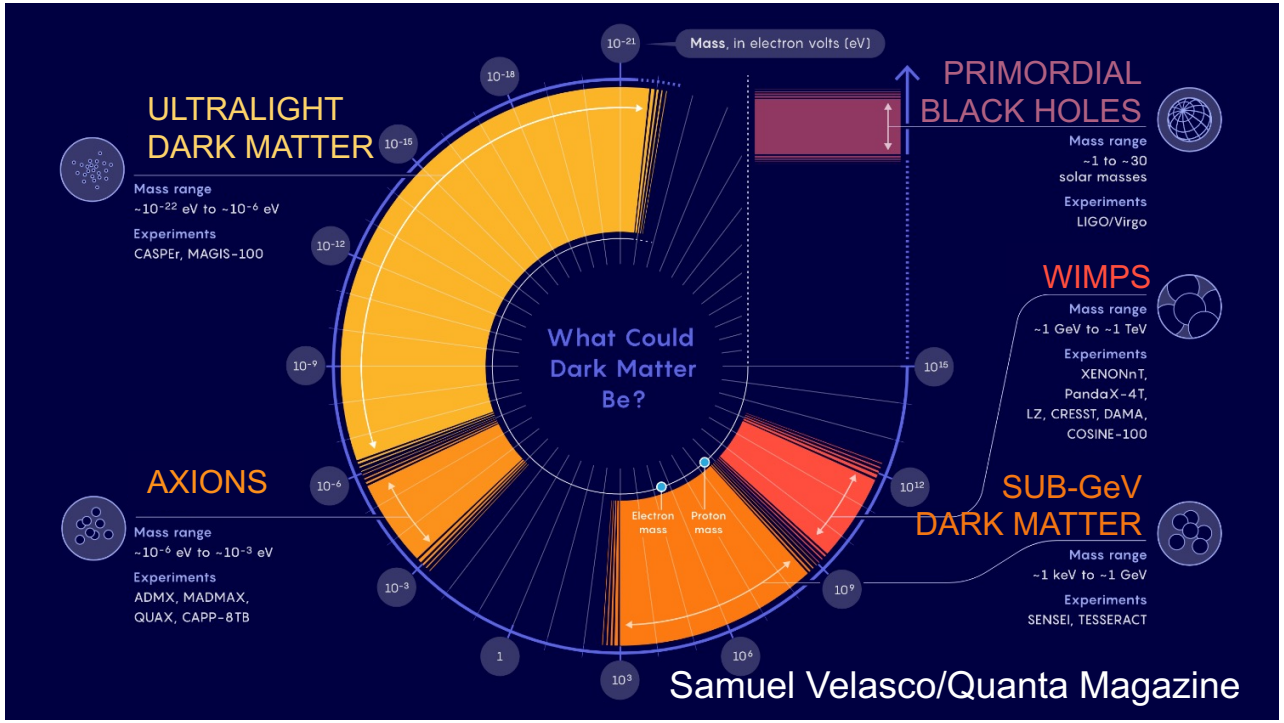
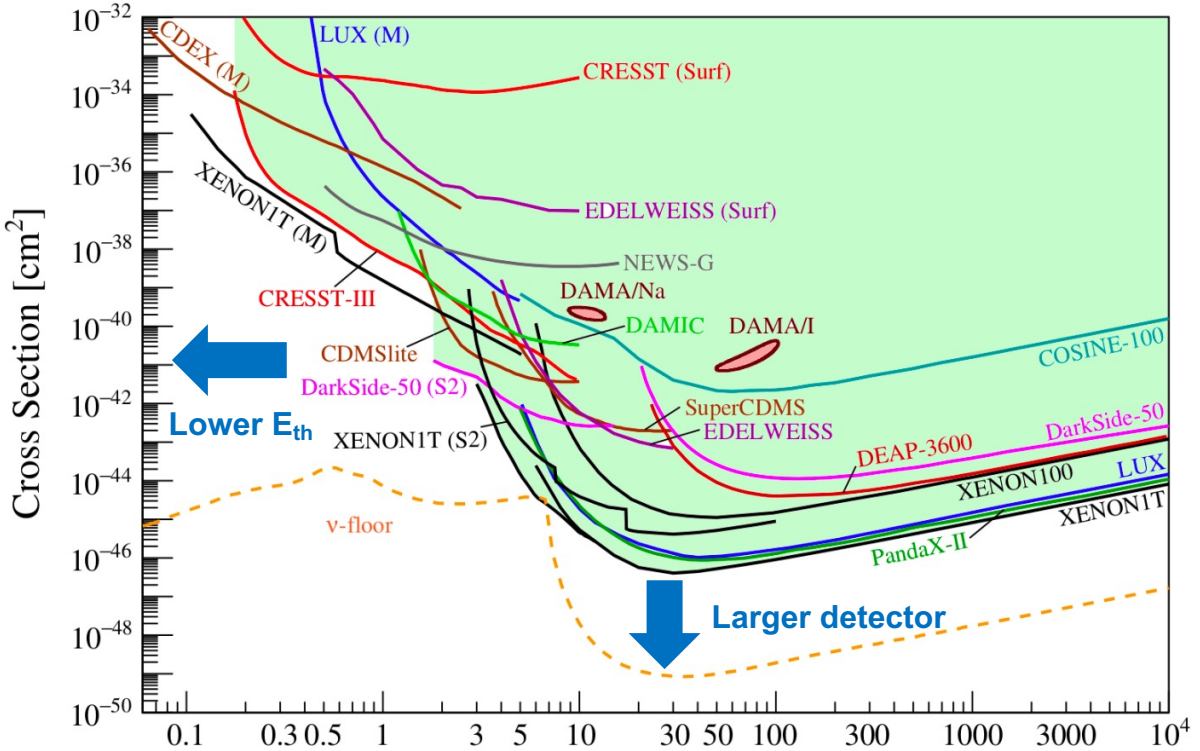
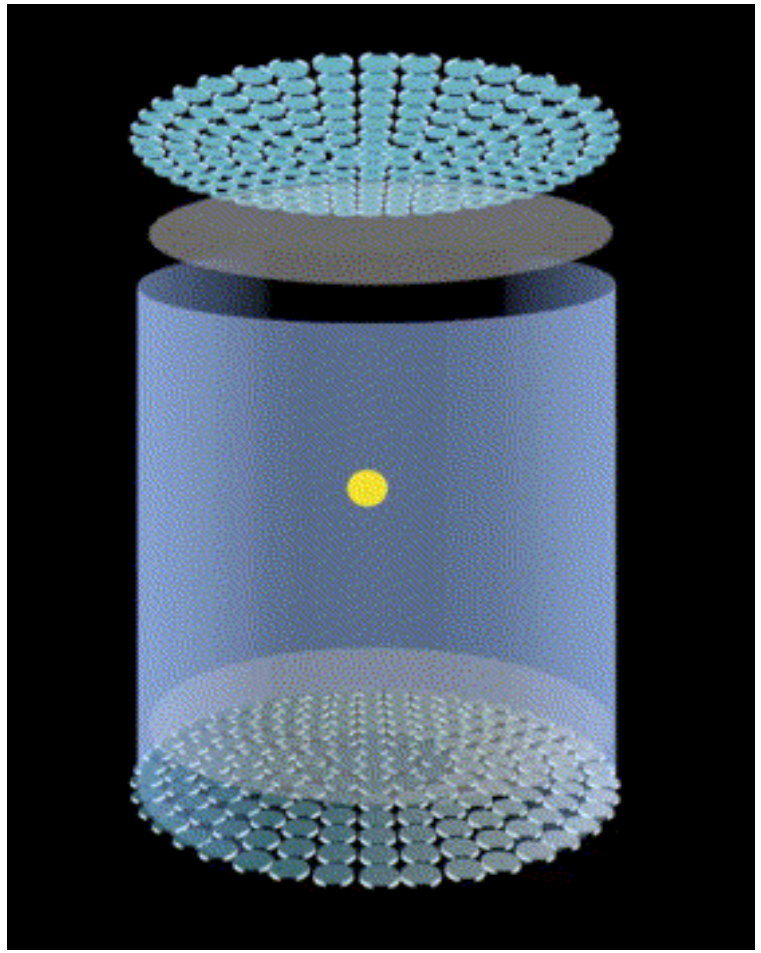


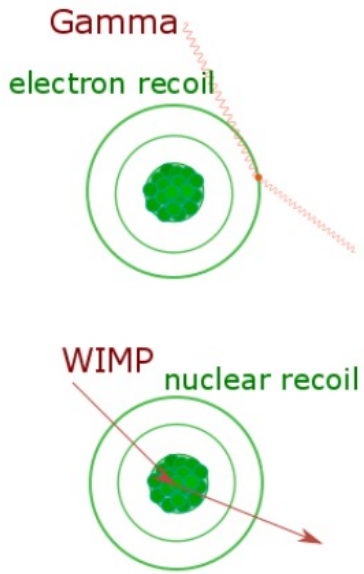


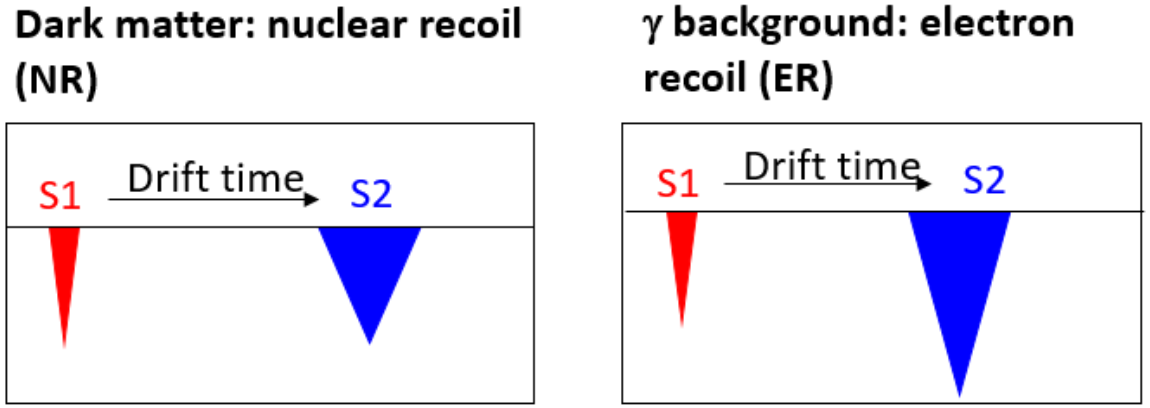
APPEC Committee Report (arXiv:2104.07634)

Dual-phase xenon time projection chamber



Dual-phase xenon time projection chamber (TPC)





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

- S1: prompt scintillation signal
  - High light yield
- S2: delayed ionization signal
  - Electroluminescence in vapor phase
  - Sensitive to single ionization electrons
- ER/NR identification
- 3D reconstruction and fiducialization
- Calorimeter from sub keV to MeV

PandaX collaboration

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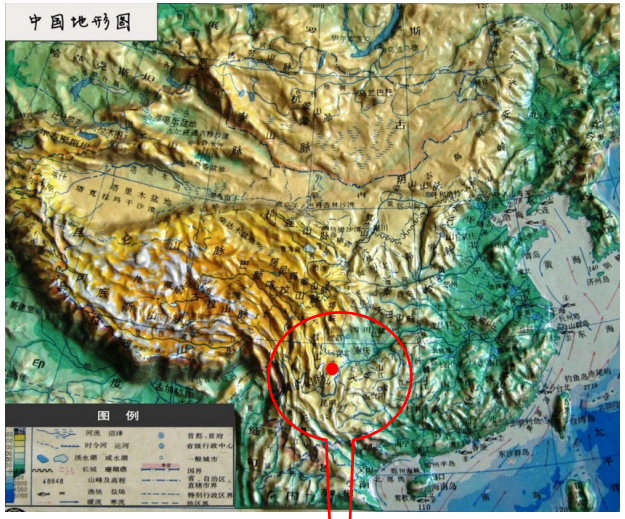
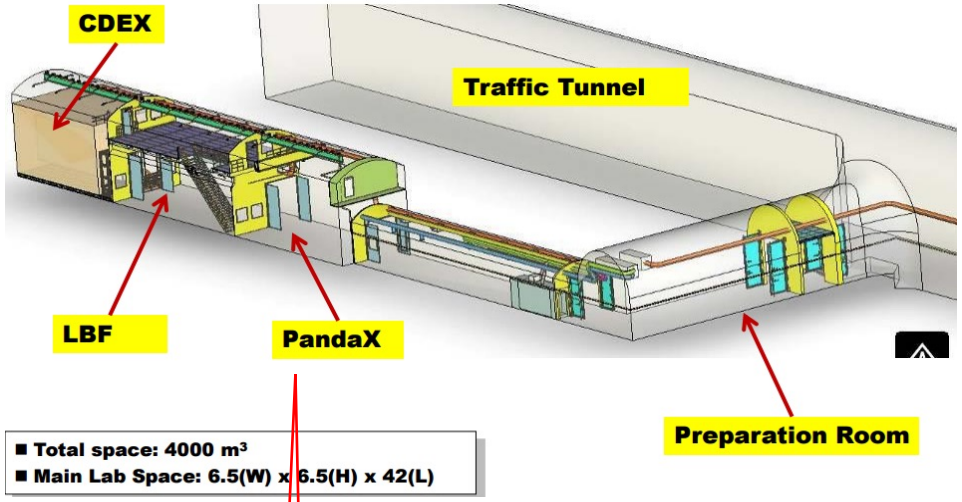
PARTICLE AND ASTROPHYSICAL XENON TPC

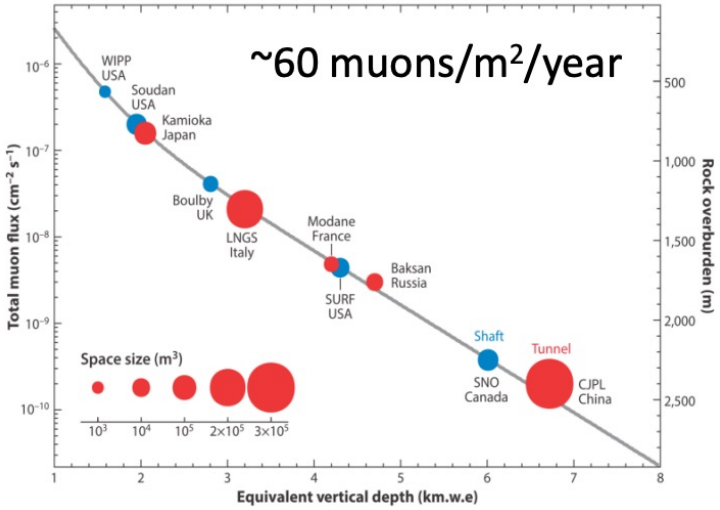
Particle and Astrophysical Xenon Experiments

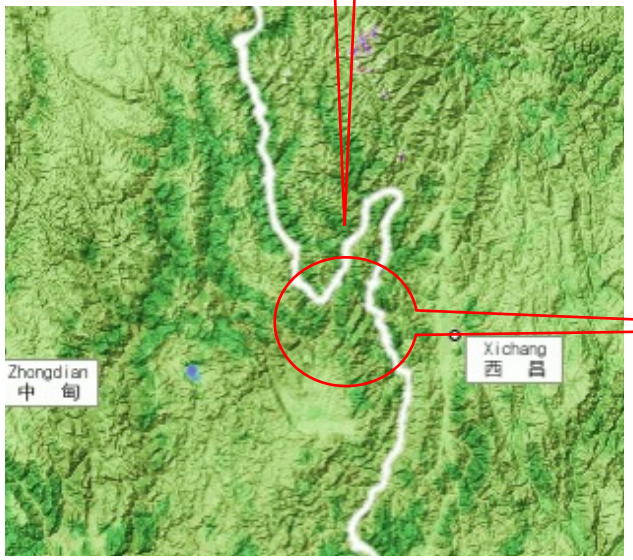
PANDA X

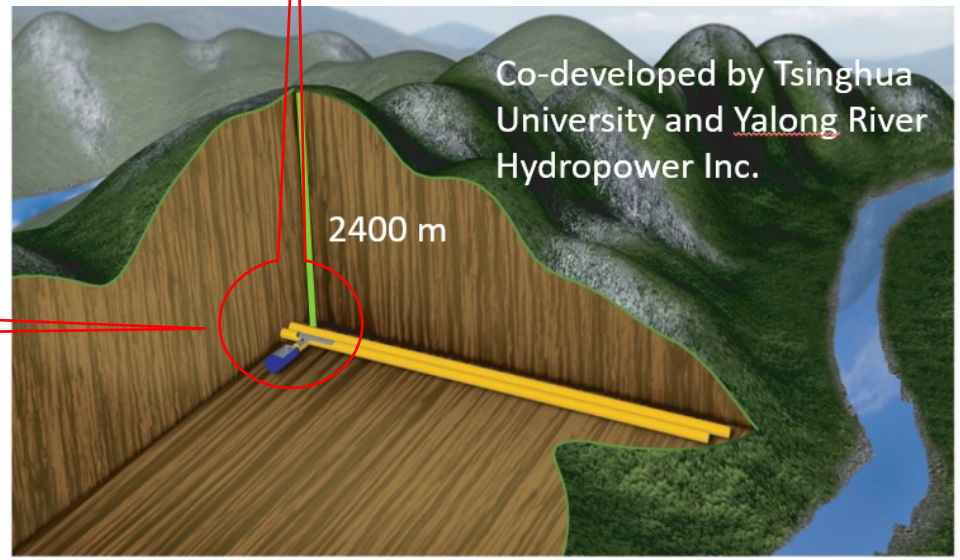
China Jinping Underground Laboratory











CJPL

- Deepest (equivalent vertical depth)
- Horizontal access
- **Muon rate:**

  ~60 muon/m²/year

  CPC 37,086001 (2013)

Journey of PandaX

PANDA X
PARTICLE AND ASTROPHYSICAL XENON TPC

Collaboration formed

2009.3

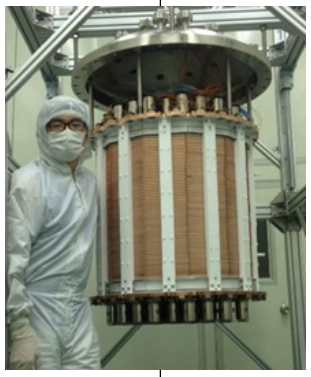
PandaX-I started

2012.7

PandaX-I apparatus moved to CJPL-I

2014.3

PandaX-II, 580 kg xenon operation



2014.5-10

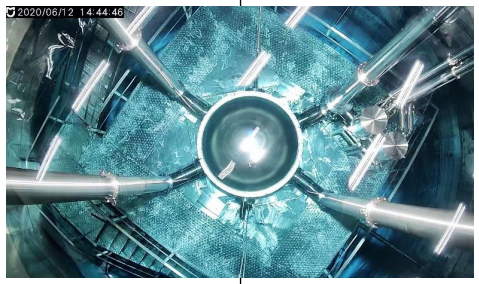
PandaX-I, 120 kg xenon operation

2016.7-2019.7

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

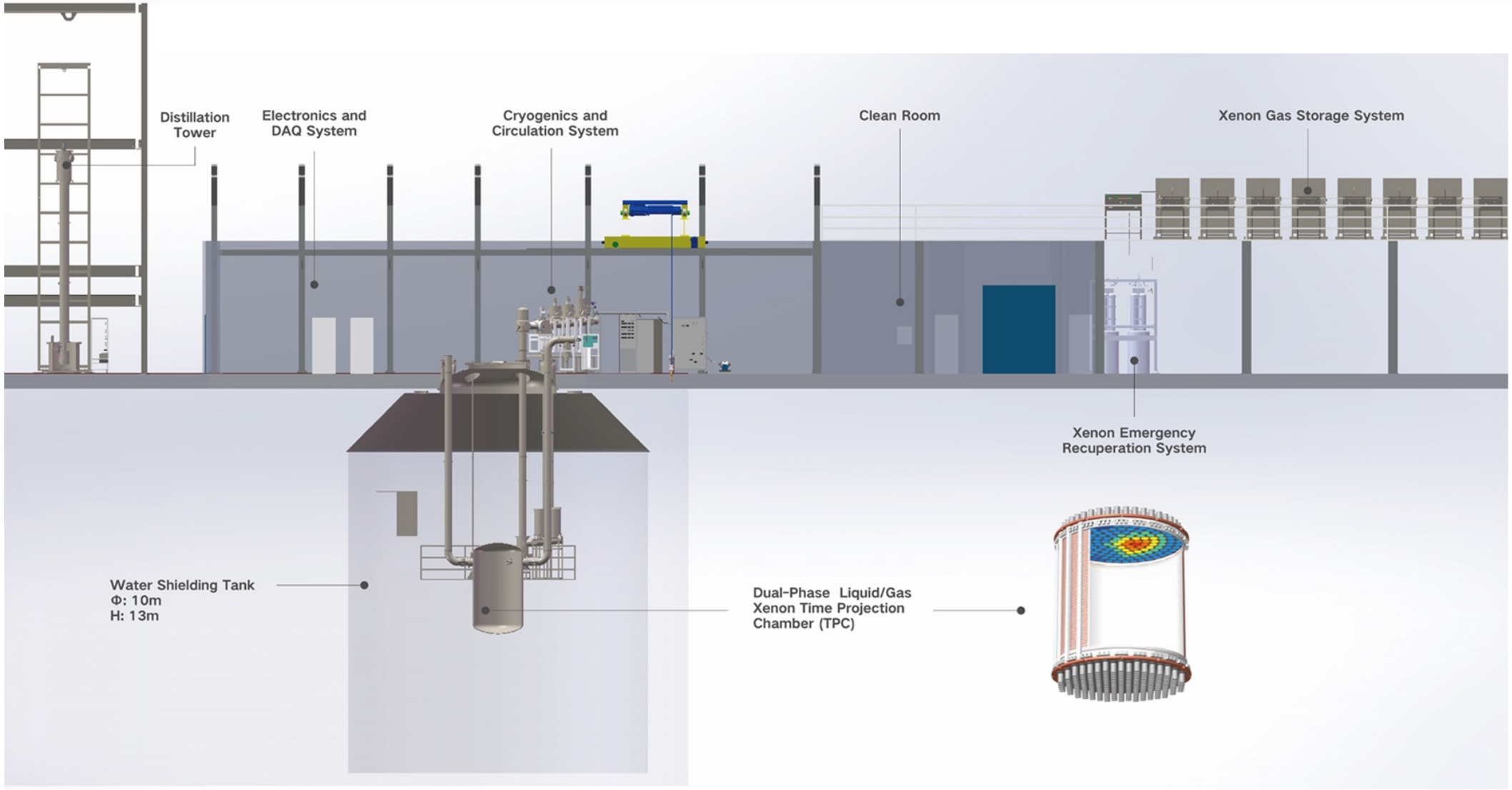
2019.8

PandaX-4T online



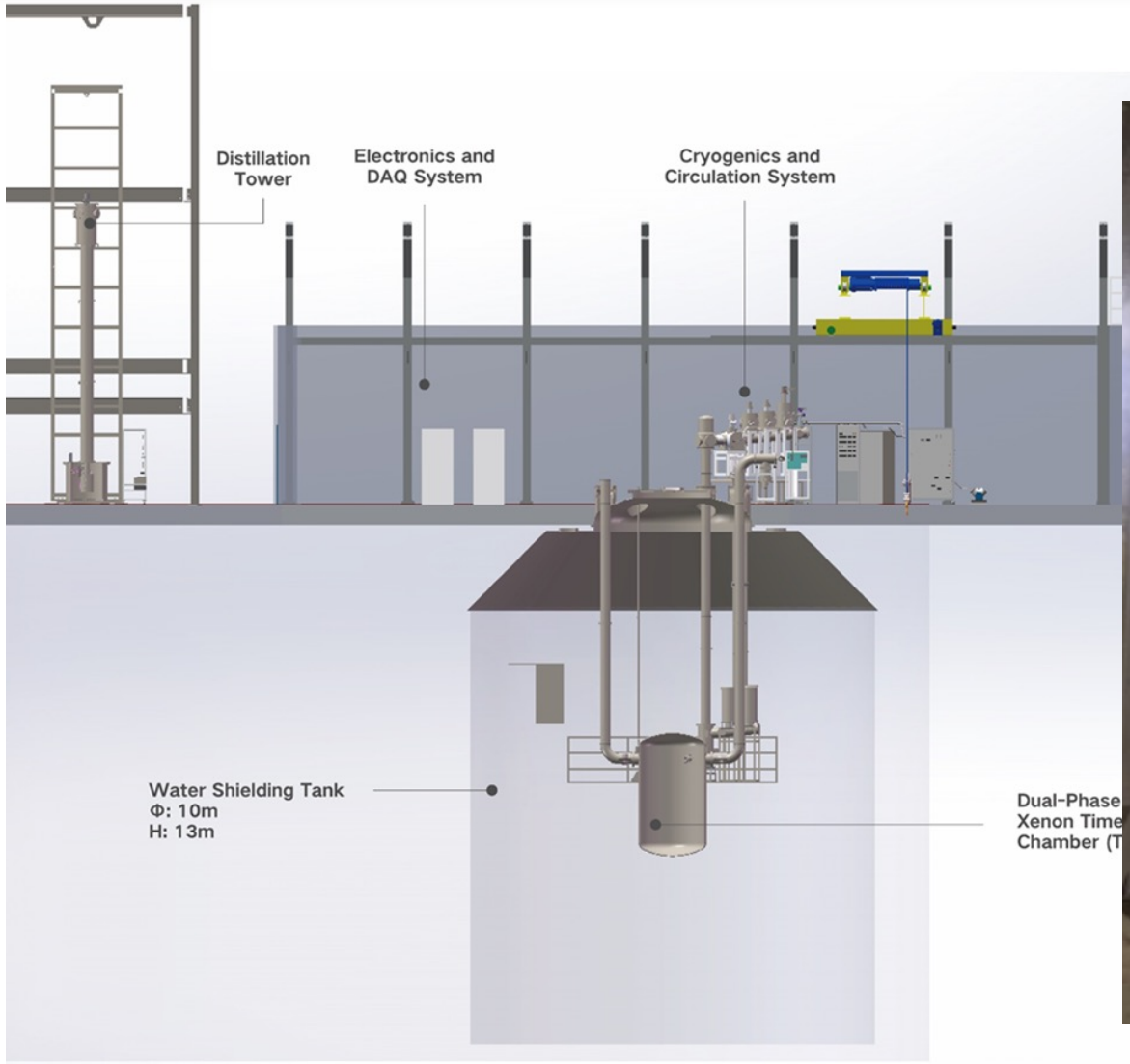
2020.11-

PandaX-4T experiment layout



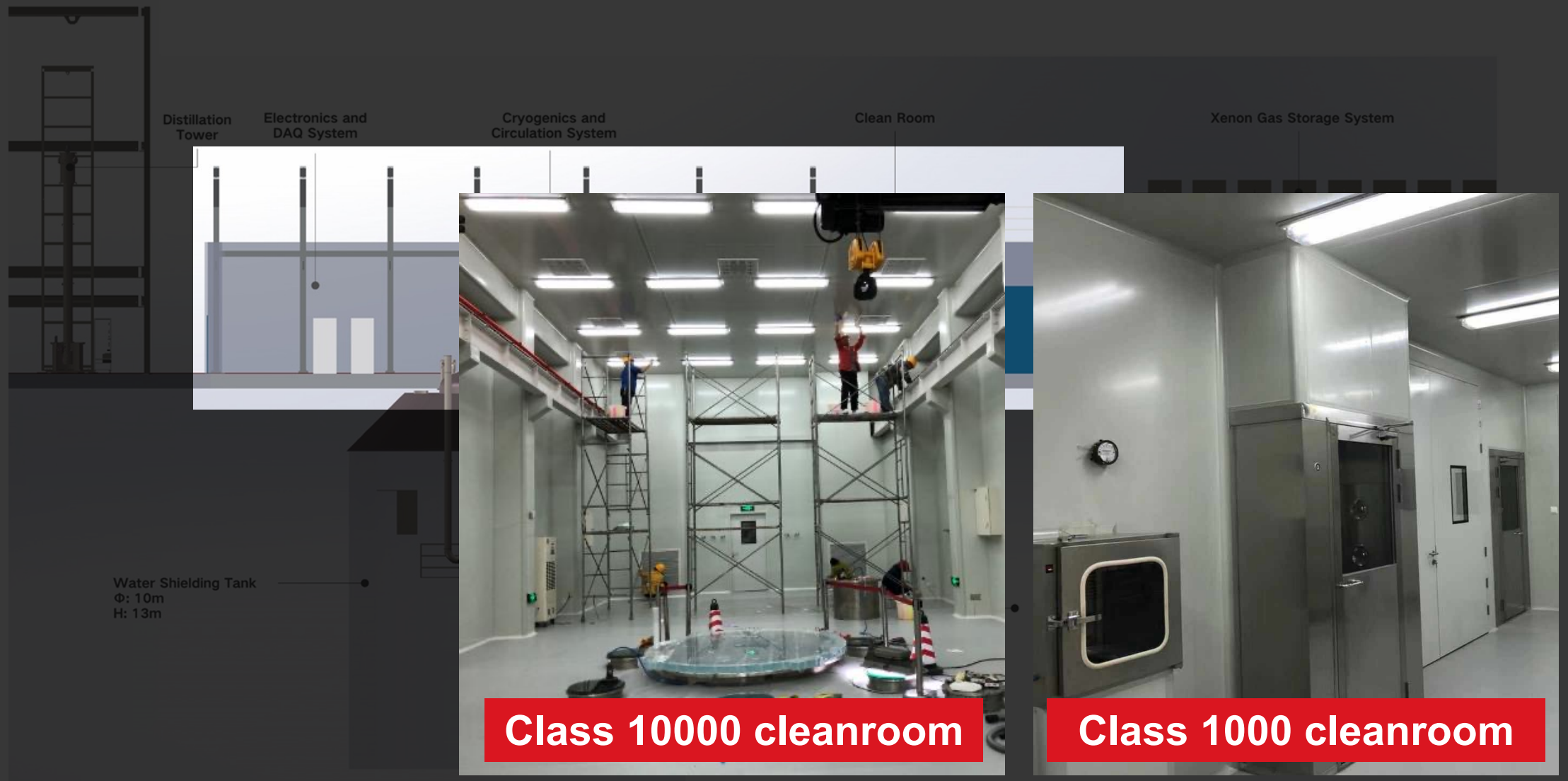
PandaX-4T experiment layout

PANDA X
PARTICLE AND ASTROPHYSICAL XENON TPC



PandaX-4T experiment layout

PandaX-4T experiment layout



PandaX-4T experiment layout

PANDA X
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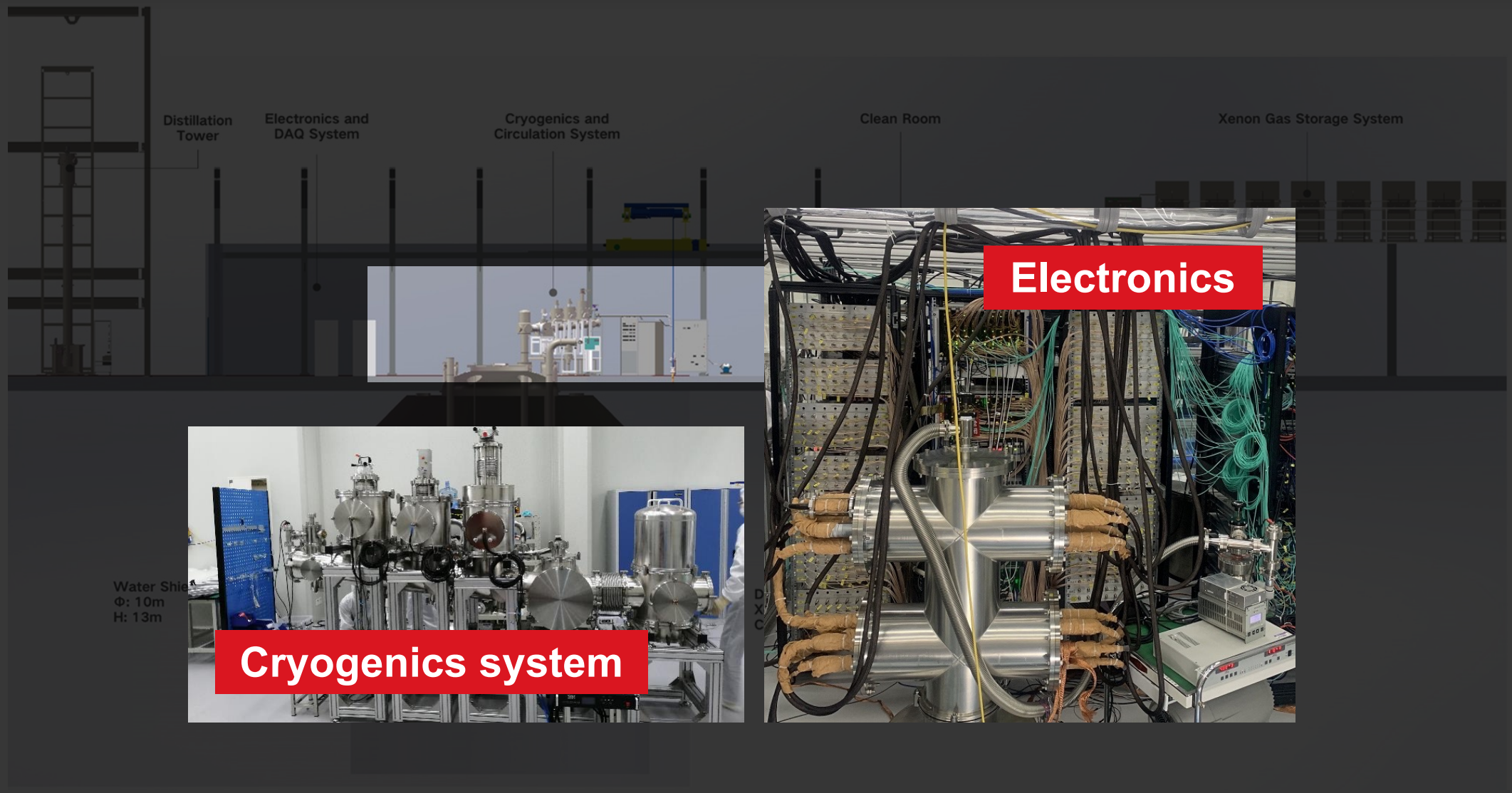

PandaX-4T experiment layout

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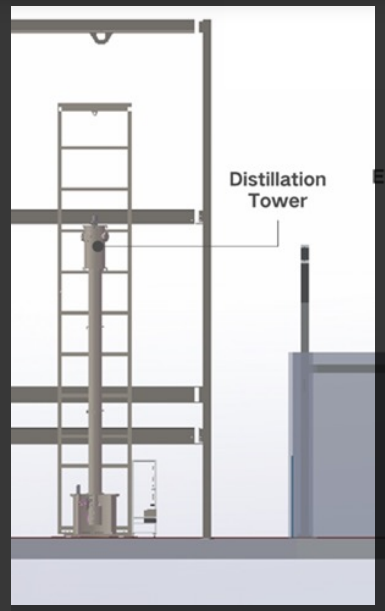
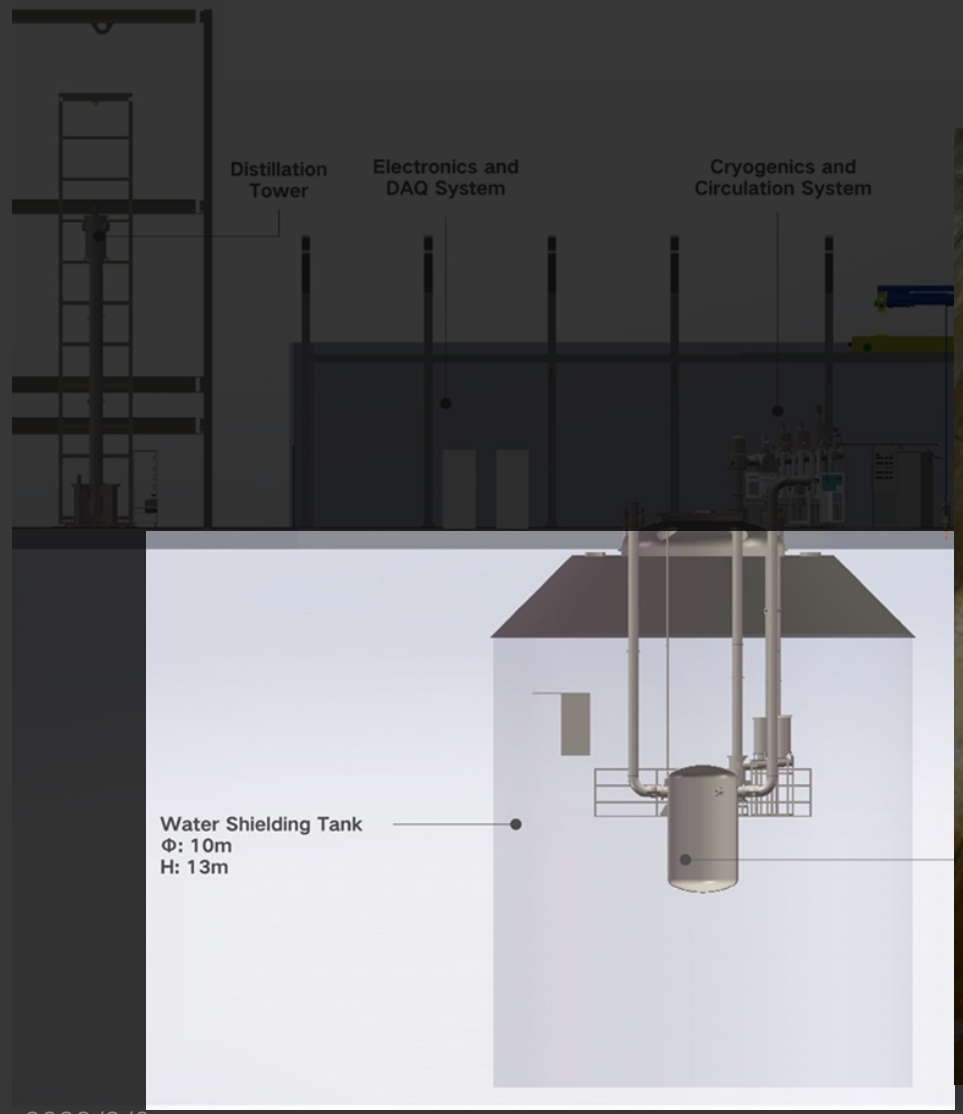
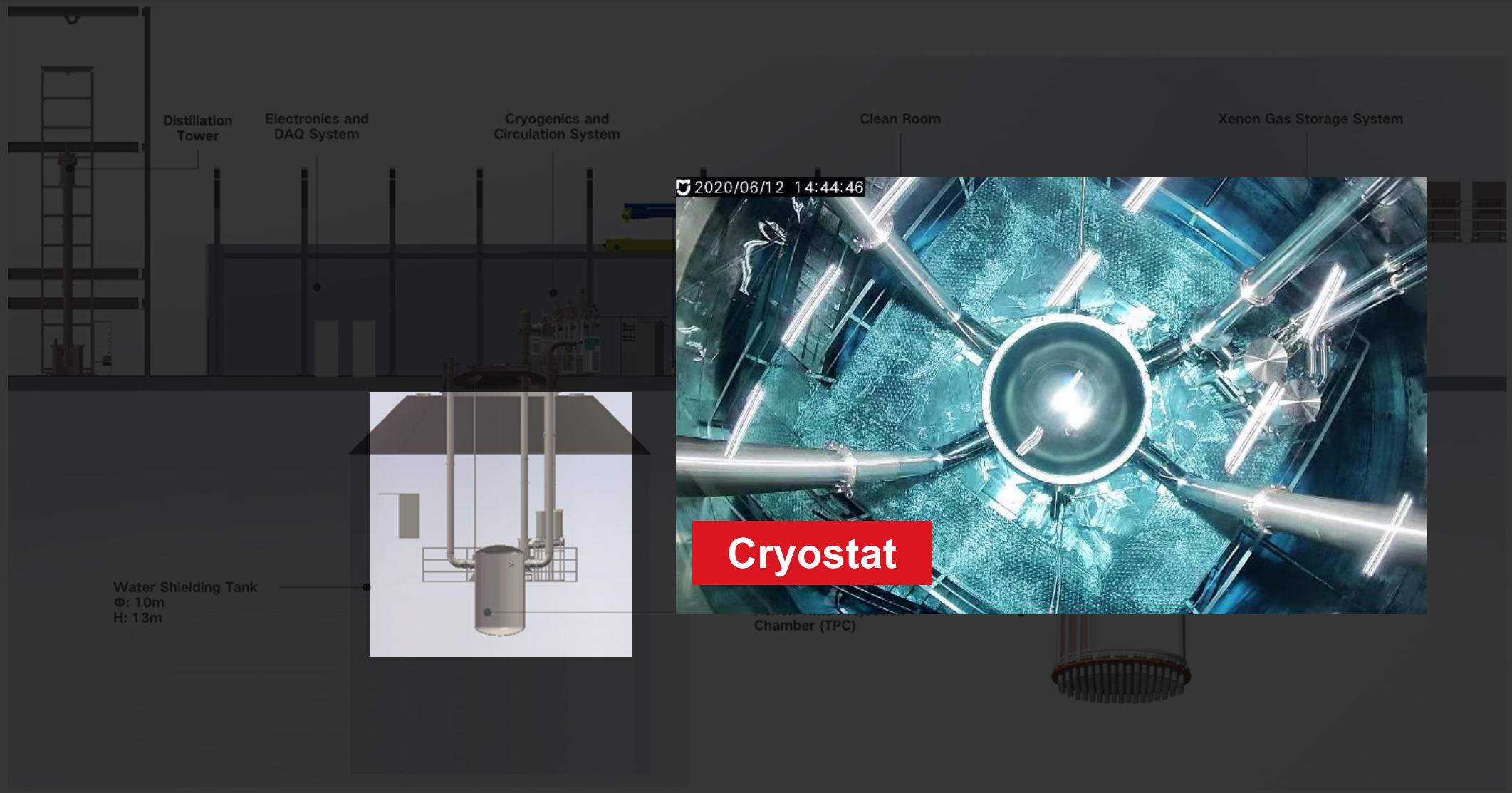


Distillation tower

PandaX-4T experiment layout



PandaX-4T experiment layout



PandaX-4T experiment layout

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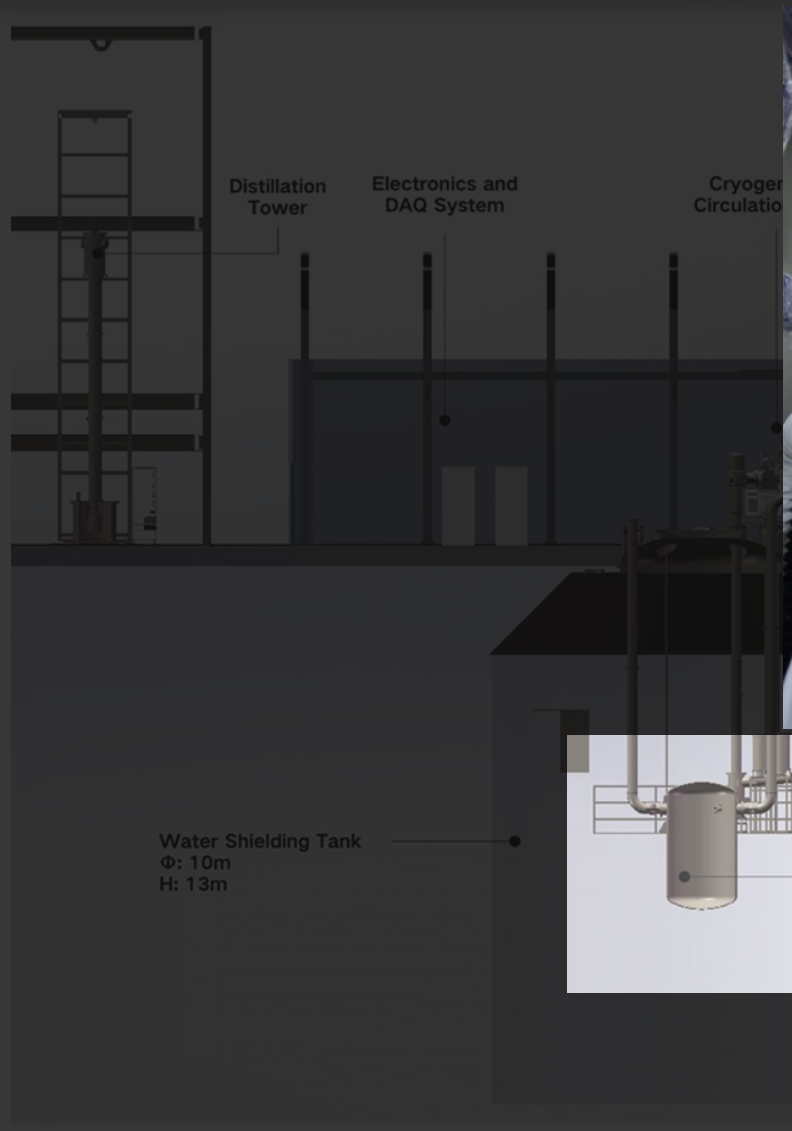
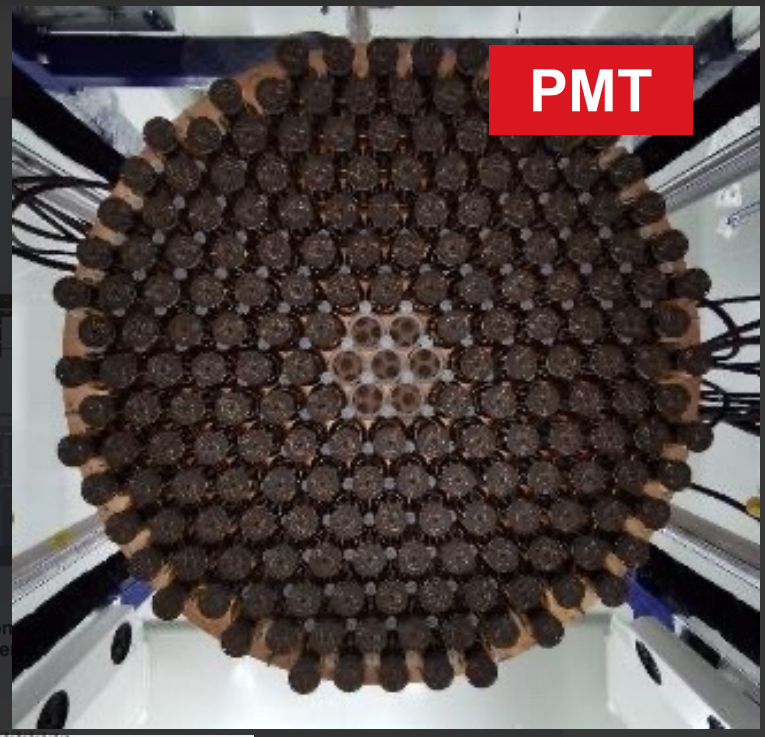
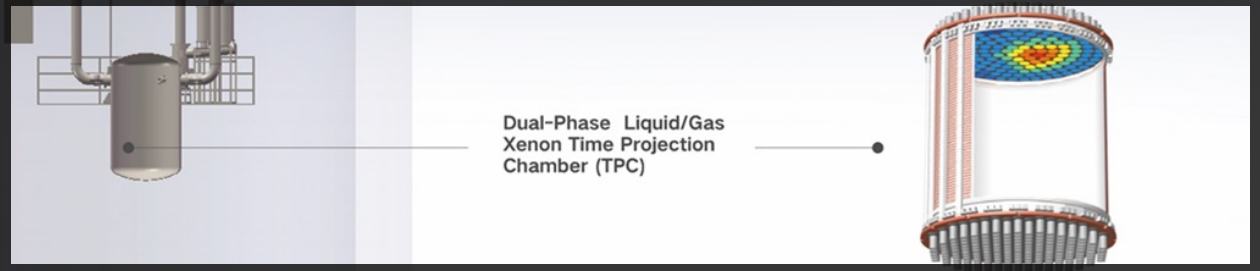
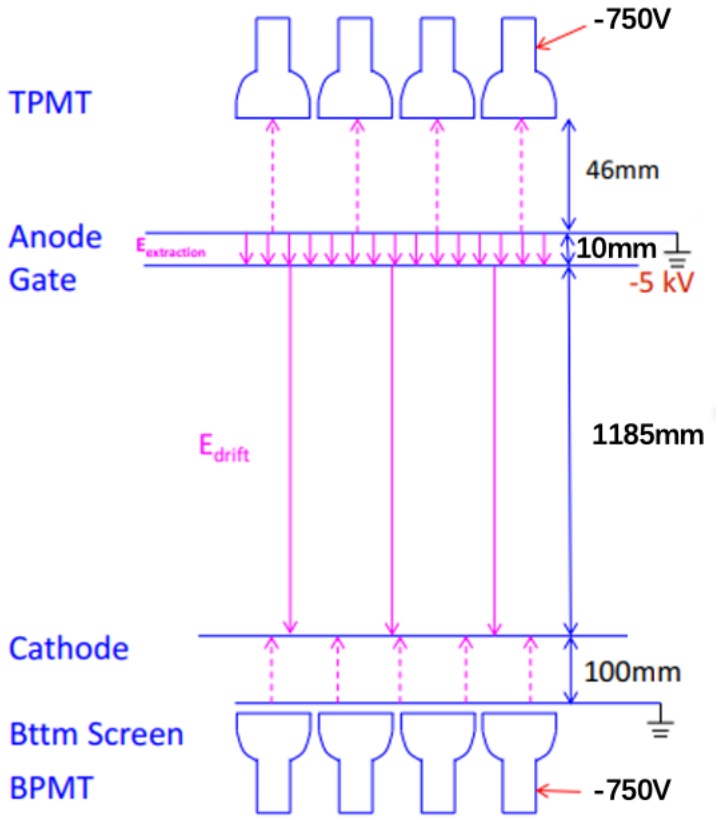






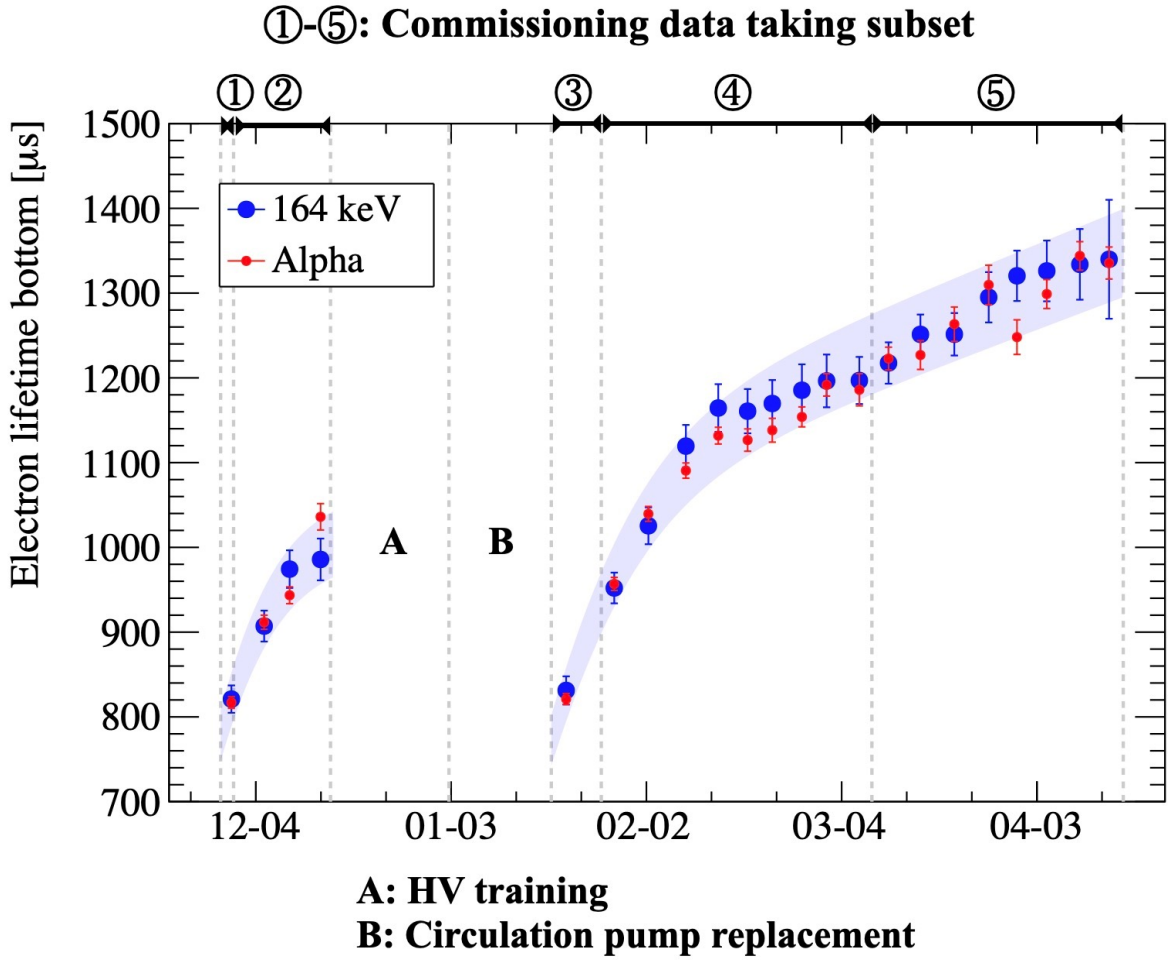
TPC operation conditions



During the run, HV set at a few different values to avoid excessive discharges

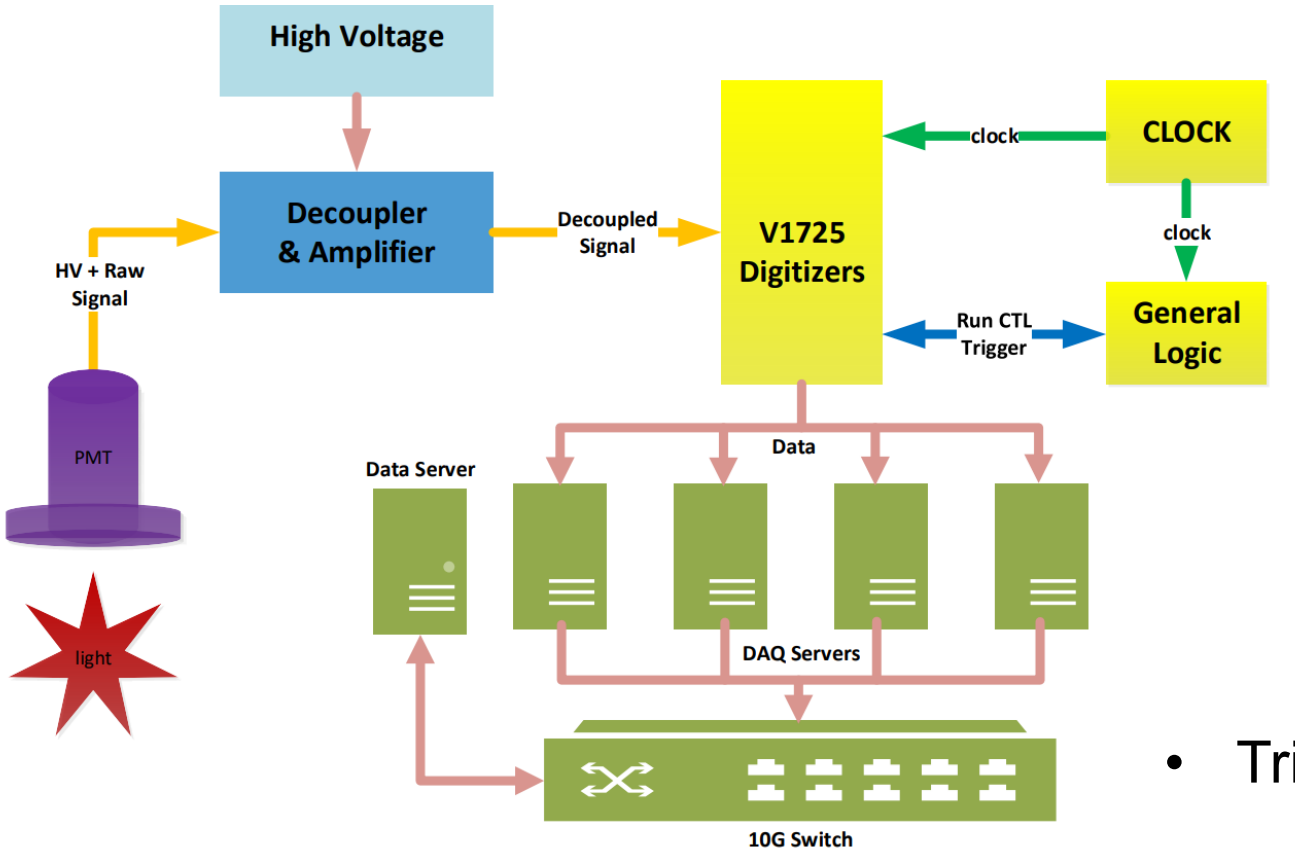
Set	1	2	3	4	5
Duration (days)	1.95	13.25	5.53	35.58	36.51
$\langle \tau_e \rangle$ (μs)	800.4	939.2	833.6	1121.5	1288.2
$dt_{\max}$ (μs)	800	810	817	841	841
V_{cathode} (−kV)	20	18.6	18	16	16
V_{gate} (−kV)	4.9	4.9	5	5	5
PDE (%)	9.0 ± 0.2			9.0 ± 0.2	
EEE (%)	90.2 ± 5.4			92.6 ± 5.4	
SEG_b (PE/e)	3.8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

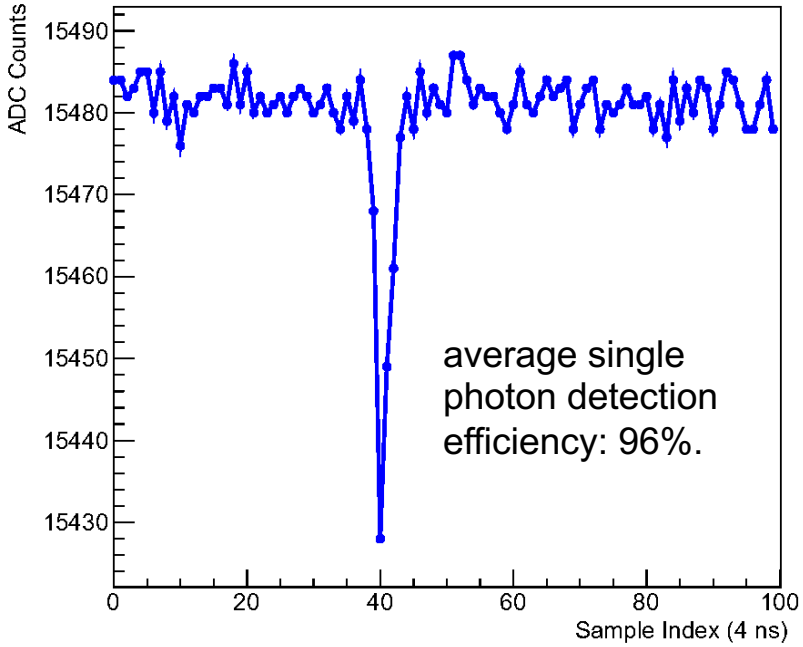
Data taking history



- Electron lifetime: in situ S2 vertical uniformity calibration
- Two gas loops for purification
- Stable data running period: 95.0 calendar days (86 days after selection)

Major improvement of electronics





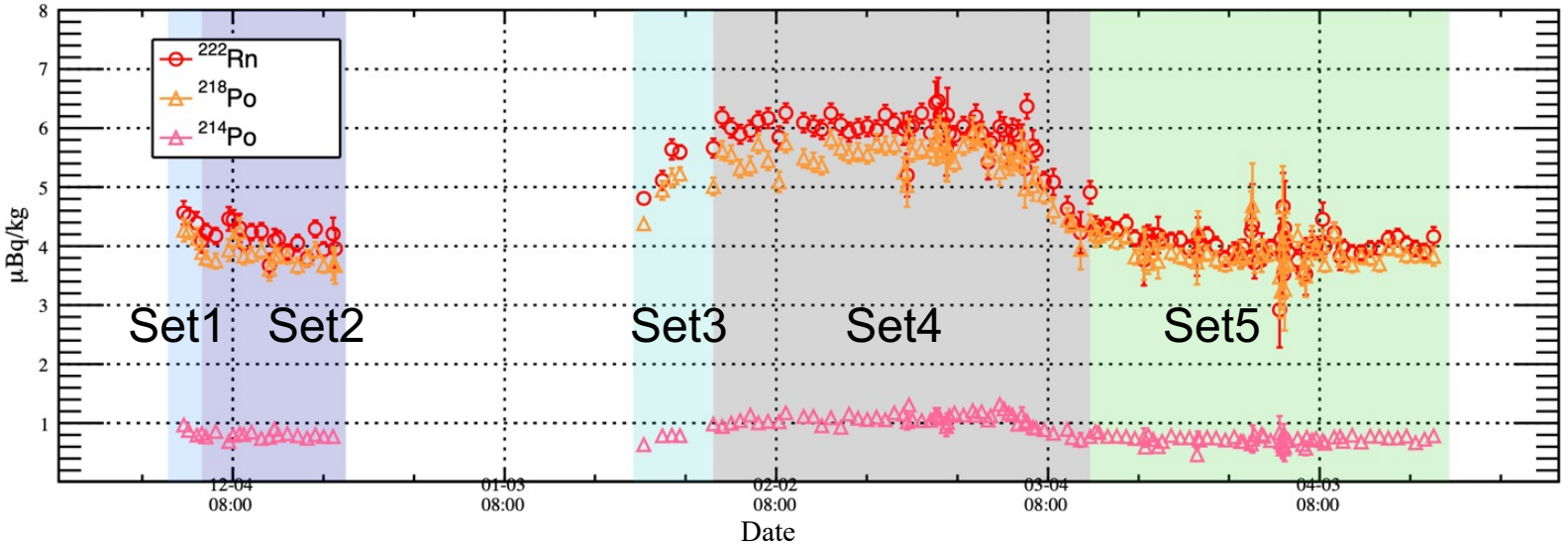
- Triggerless DAQ: low threshold
  read out pulses above 20 ADC (~1/3 PE)

Major improvement of background

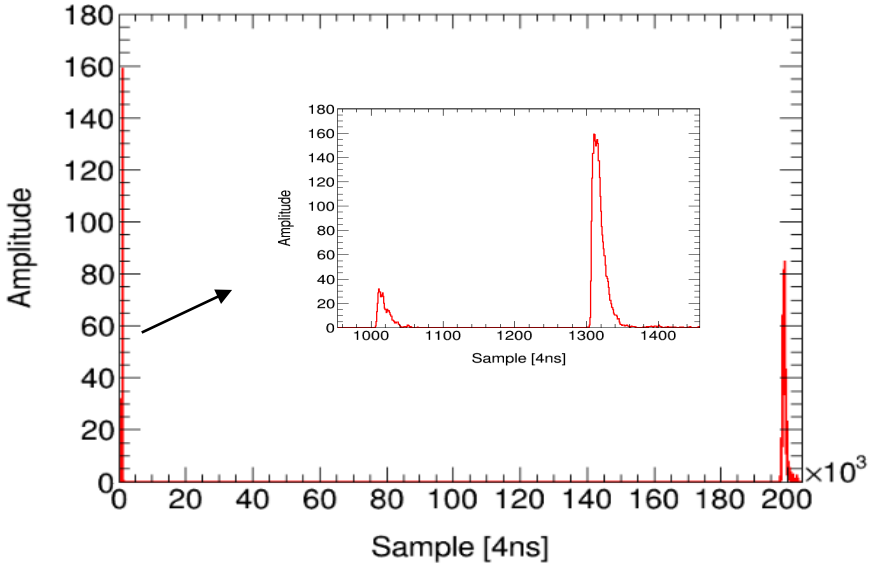
- **^{222}Rn:** ~ 5 uBq/kg
  1/6 of PandaX-II

- **^{85}Kr:** ~0.3 ppt mol/mol
  1/20 of PandaX-II

Radon evolution



Waveform of ^{85}Kr's β-γ coincidence



WIMP-nucleon SI exclusion limits

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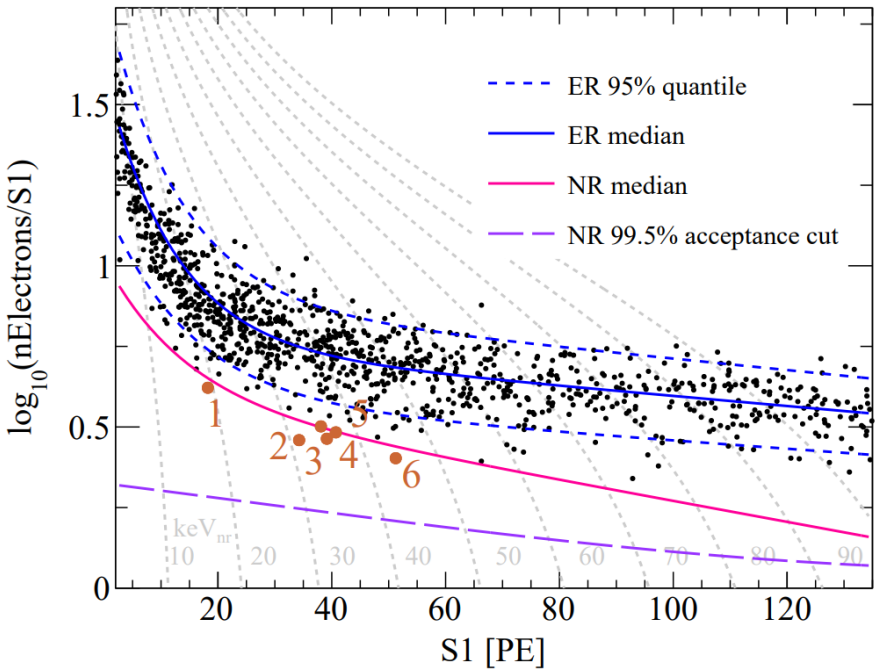
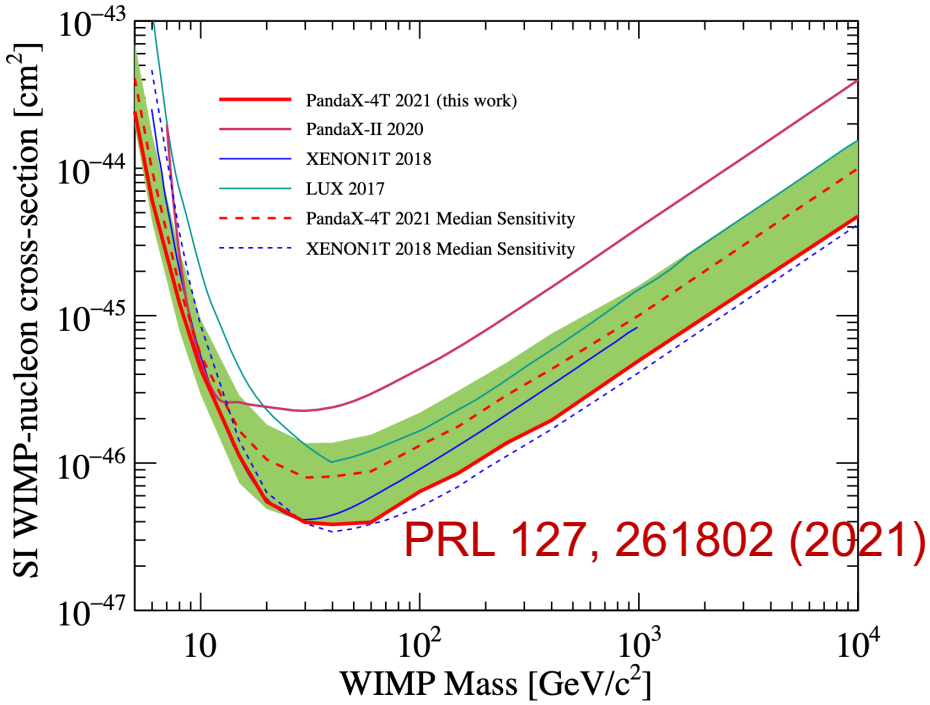
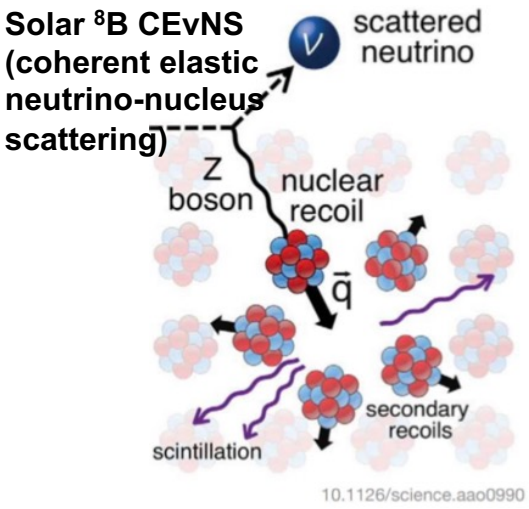
- Sensitivity improved from PandaX-II final analysis by 2.9 times (30 GeV/c^2)
- Dived into previously unexplored territory
- Approaching the neutrino floor

DM candidates: 6 / 1058

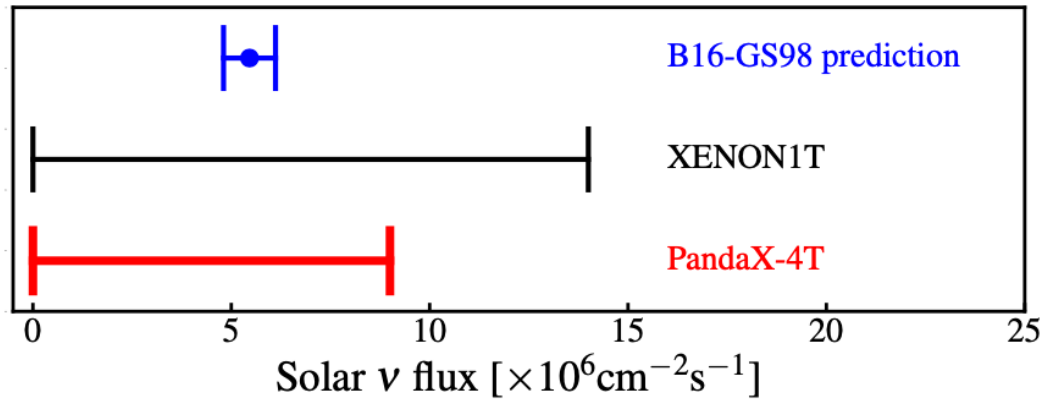




Constraints on ^{8}B ν and WIMP

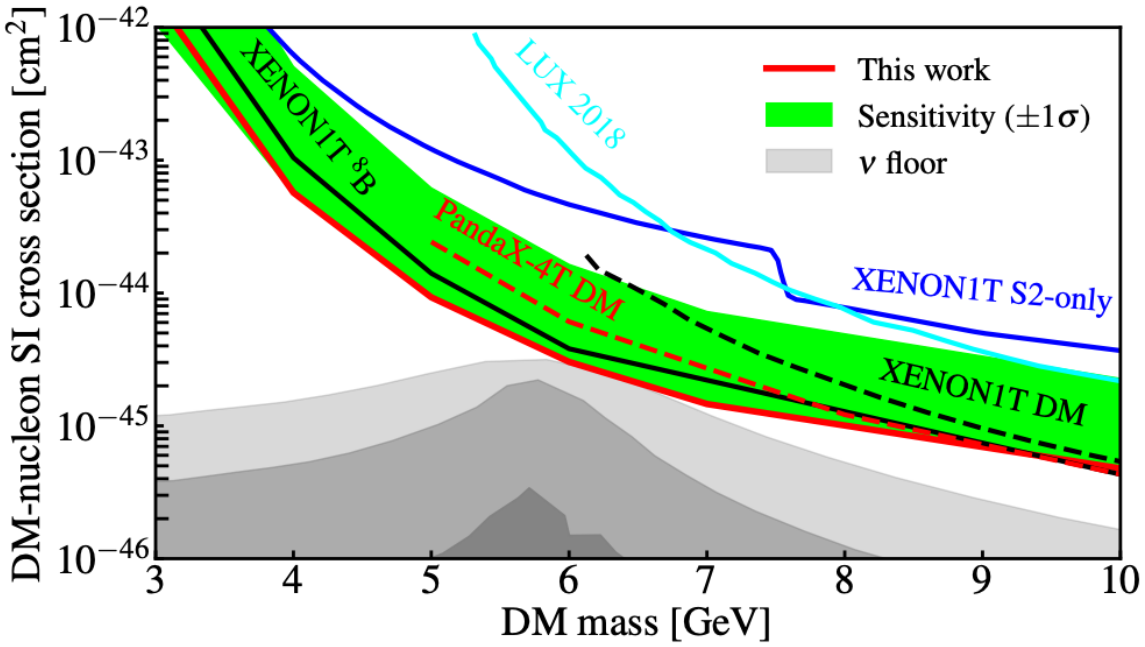


- Leading constraints on ^{8}B neutrino flux through CEνNS
  - Touching neutrino floor
  - New insight on neutrino-nucleus interactions



PRL. 130, 021802(2022)

- Strongest constraints on WIMP in 3-10 GeV region

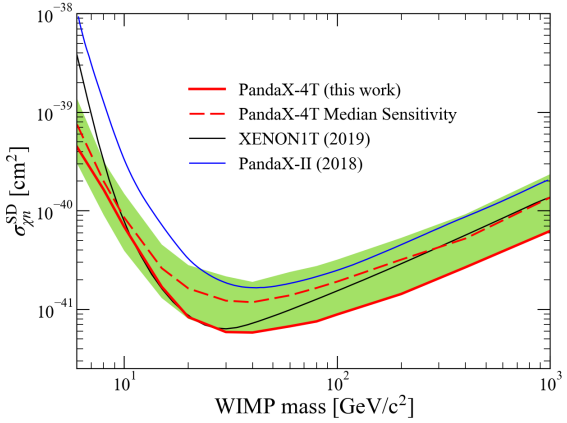


WIMP-nucleon SD exclusion limits

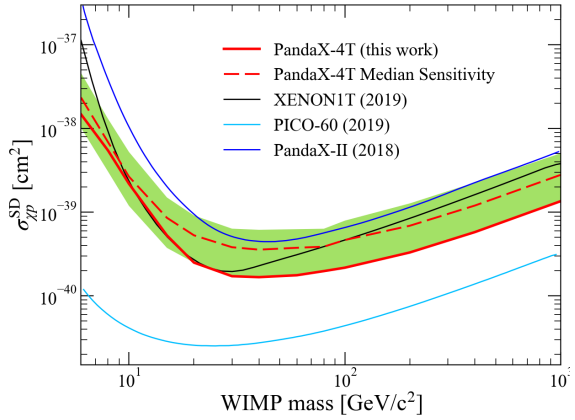
- Scattering cross-section could be connected to the spin of nucleus
- Typical SD interaction is through axial-vector effective operator
  - $\mathcal{L} = \bar{\chi}\gamma^{\mu}\gamma^{5}\chi\bar{N}\gamma_{\mu}\gamma^{5}N \rightarrow \vec{S}_{\chi} \cdot \vec{S}_{N}$
- Target ^{129}Xe, ^{131}Xe with unpaired neutron

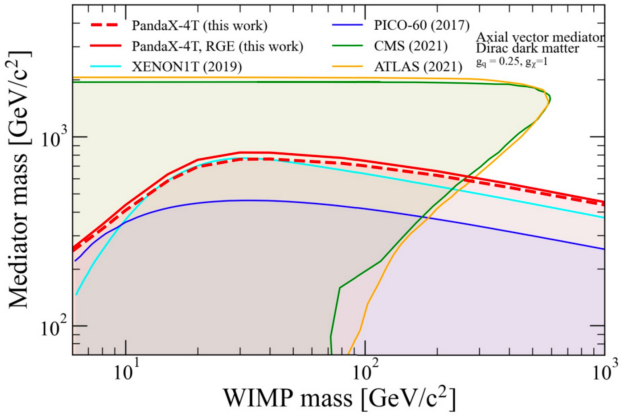
PLB 834 (2022) 137487

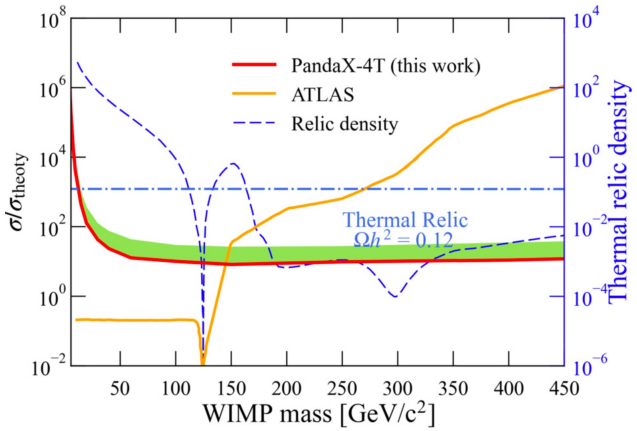
neutron-only interaction



proton-only interaction

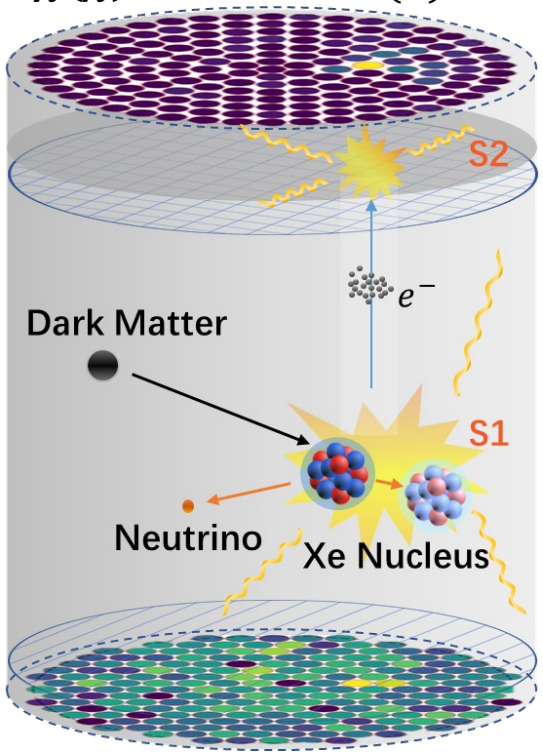


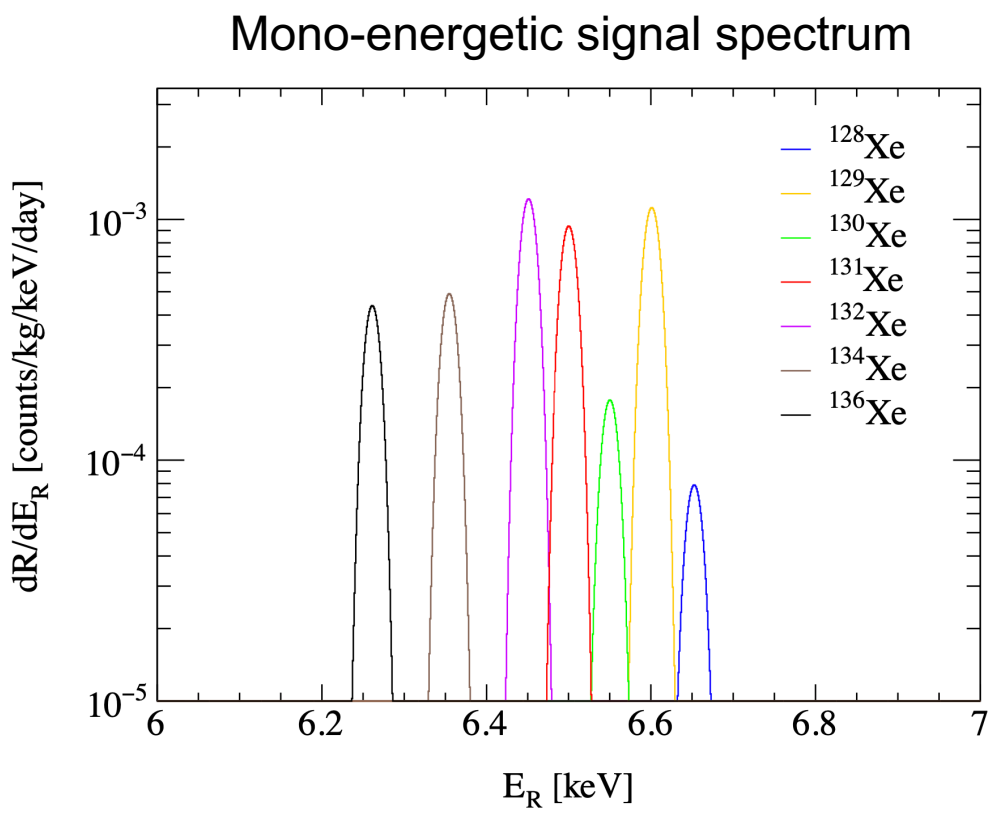




New DM searching channel: absorption

$\chi(\bar{\chi}) + {}^{A}Xe \rightarrow \nu(\bar{\nu}) + {}^{A}Xe$

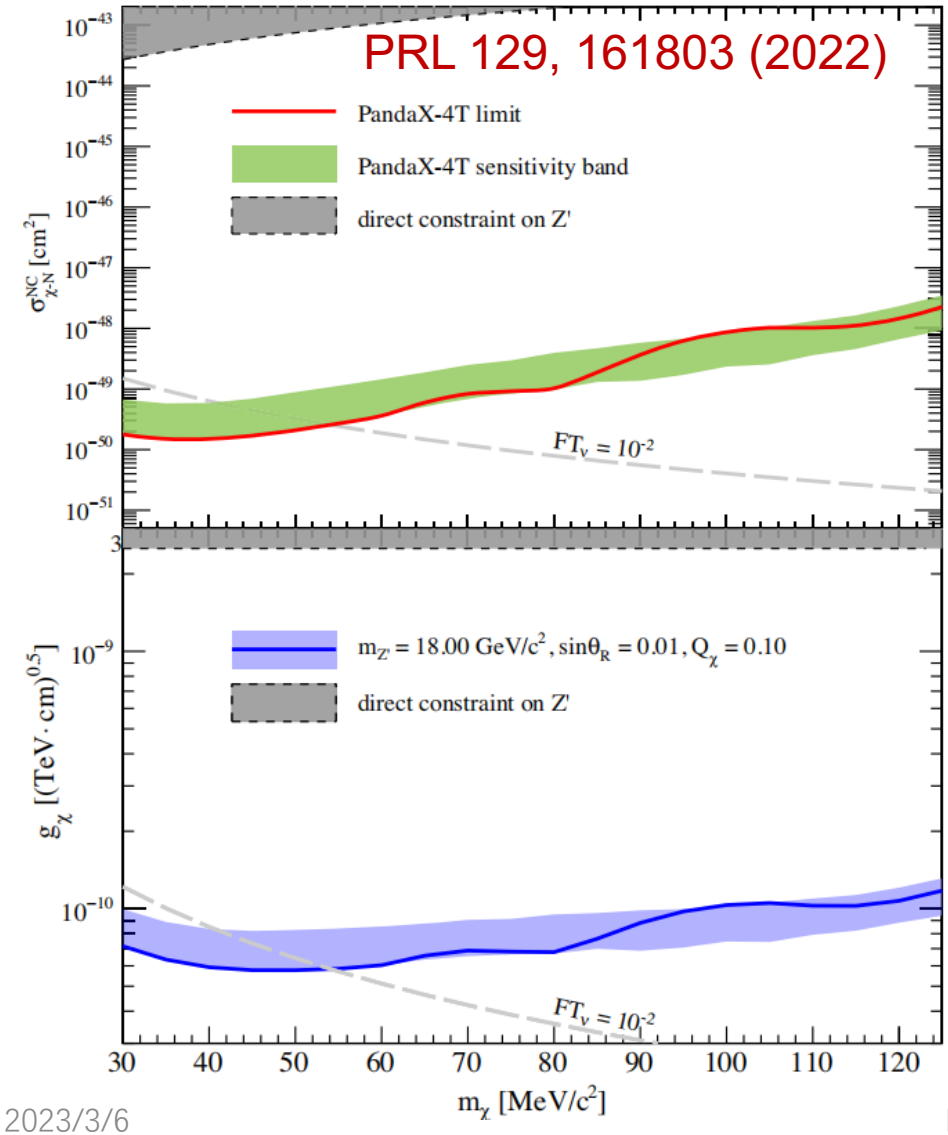




Neutral current fermionic DM absorption model:

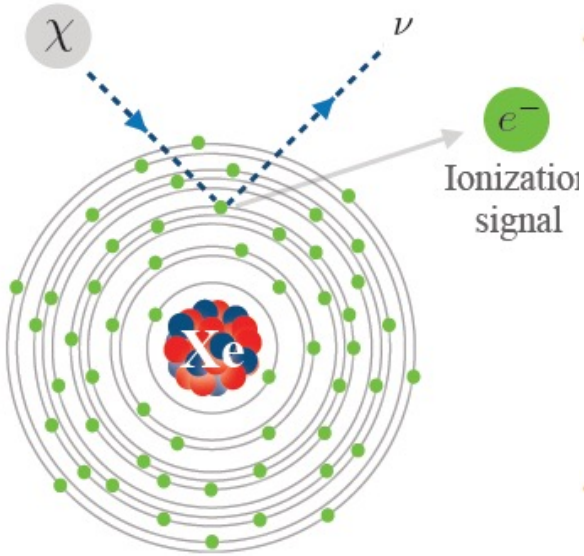
- DM being absorbed, with an outgoing neutrino ν
- Detectable NR signals
- DM mass range: MeV

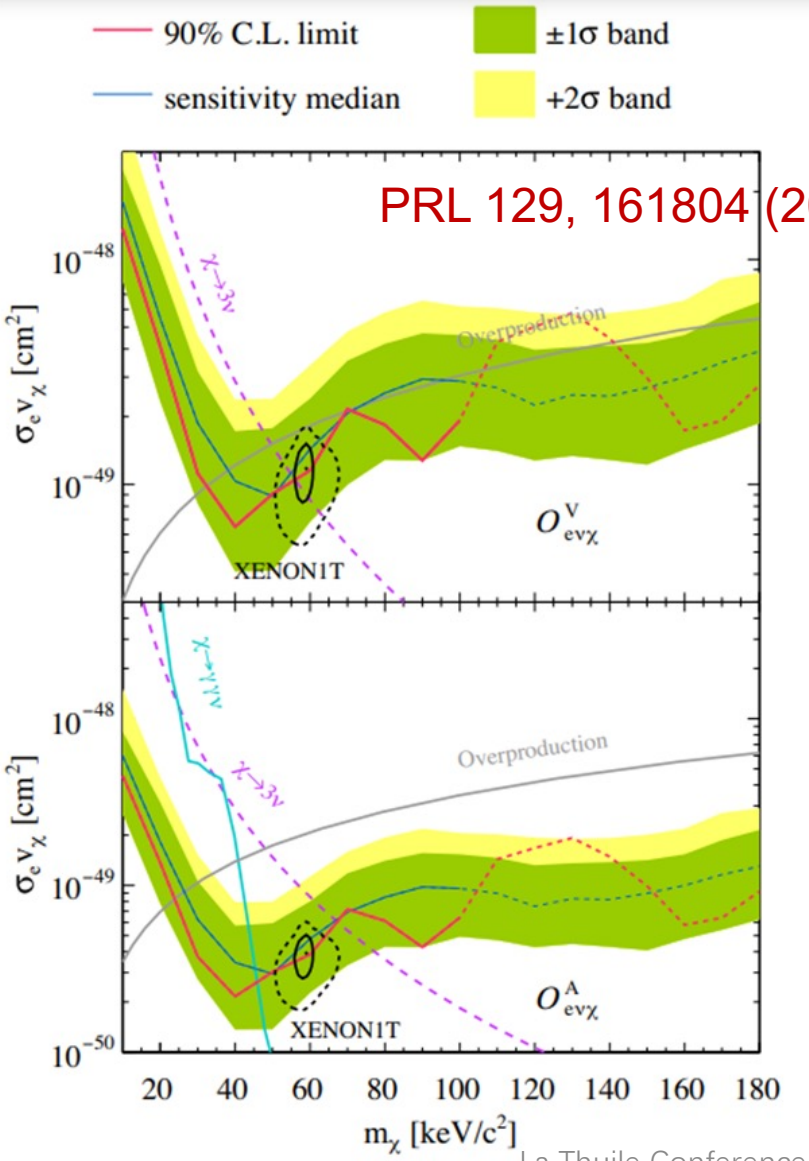
Absorption on nucleus



- First search for fermionic dark matter absorption signal in direct detection experiments
- Strongest limit of 1.5 x $10^{-50}\,\mathrm{cm}^2$ achieved at 40 $\mathrm{MeV/c^2}$ fermionic DM mass
- Constraints on the coupling g_χ to the order of $10^{-10}(\mathrm{TeV}\cdot\mathrm{cm})^{0.5}$

Absorption on electron



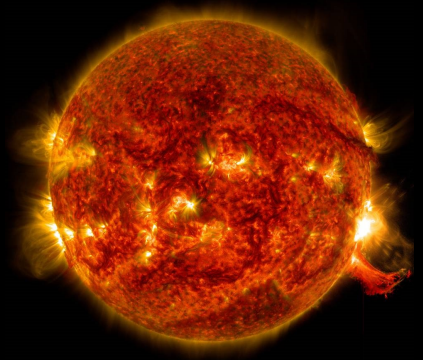


- General fermionic (sterile neutrino-like) dark matter absorption on e^-
- Strong sensitivity to vector and axial-vector mediators, complementary to astrophysical constraints, with much less theoretical uncertainties
- Competitive constraint in 20-55 keV/c^2

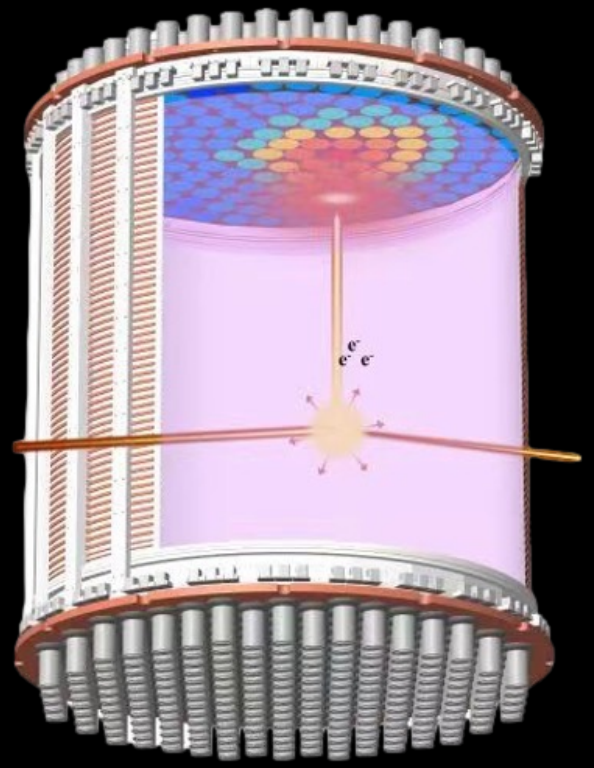
Multiple physics topics

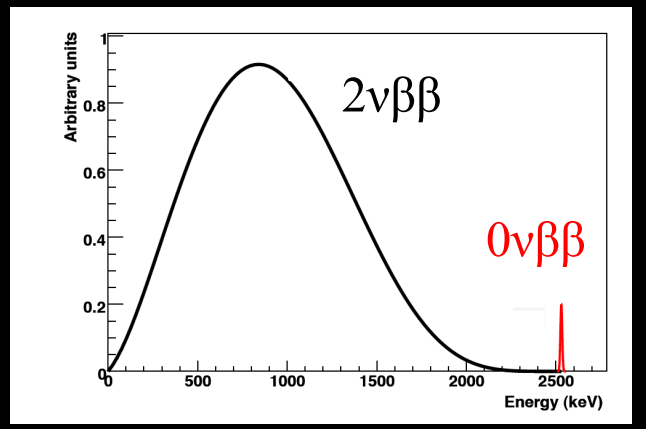
PANDA X
PARTICLE AND ASTROPHYSICAL XENON TPC

Dark matter
Energy region: 1-10 keV



Astronomical neutrinos
Energy region: <200 keV





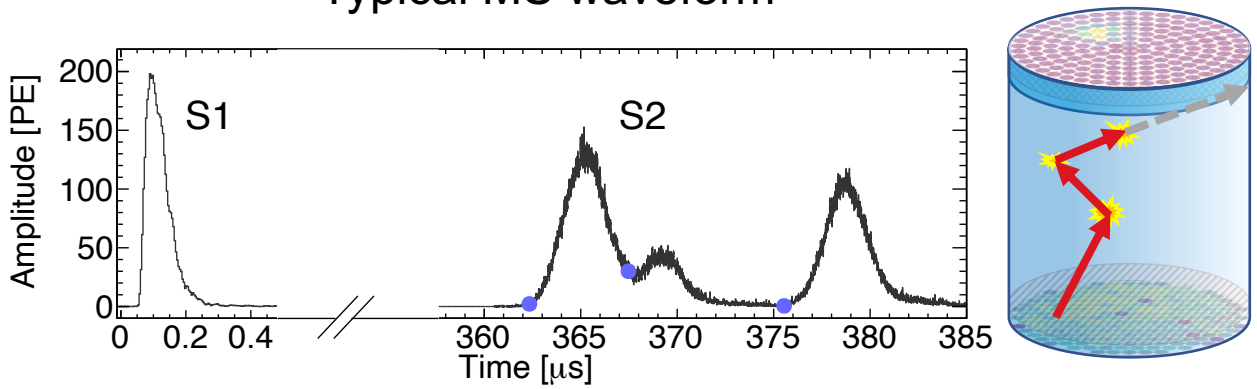
Neutrinoless/neutrino double beta decay (NL)DBD
Energy region: ~MeV

Wide energy range:
~keV–10 MeV

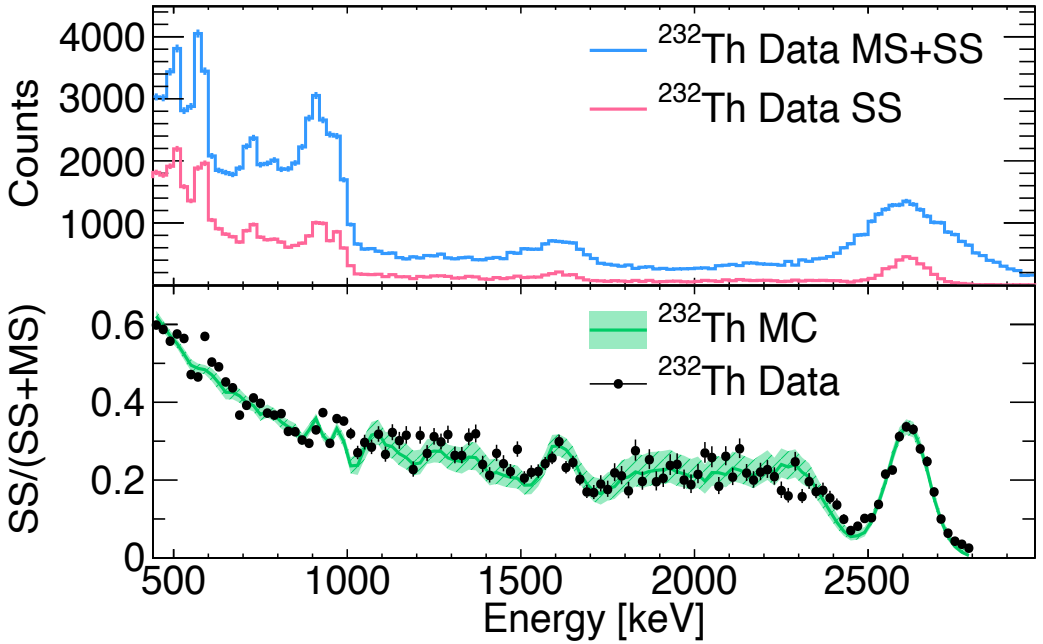
Identifying MS and SS

- Gamma events in MeV region are mostly multi-site (MS) events, while signals are mostly single site (SS)
- Identifying MS events with PMT waveforms
- SS/(MS+SS) ratios agree within 1.7% between calibration data and MC

Typical MS waveform

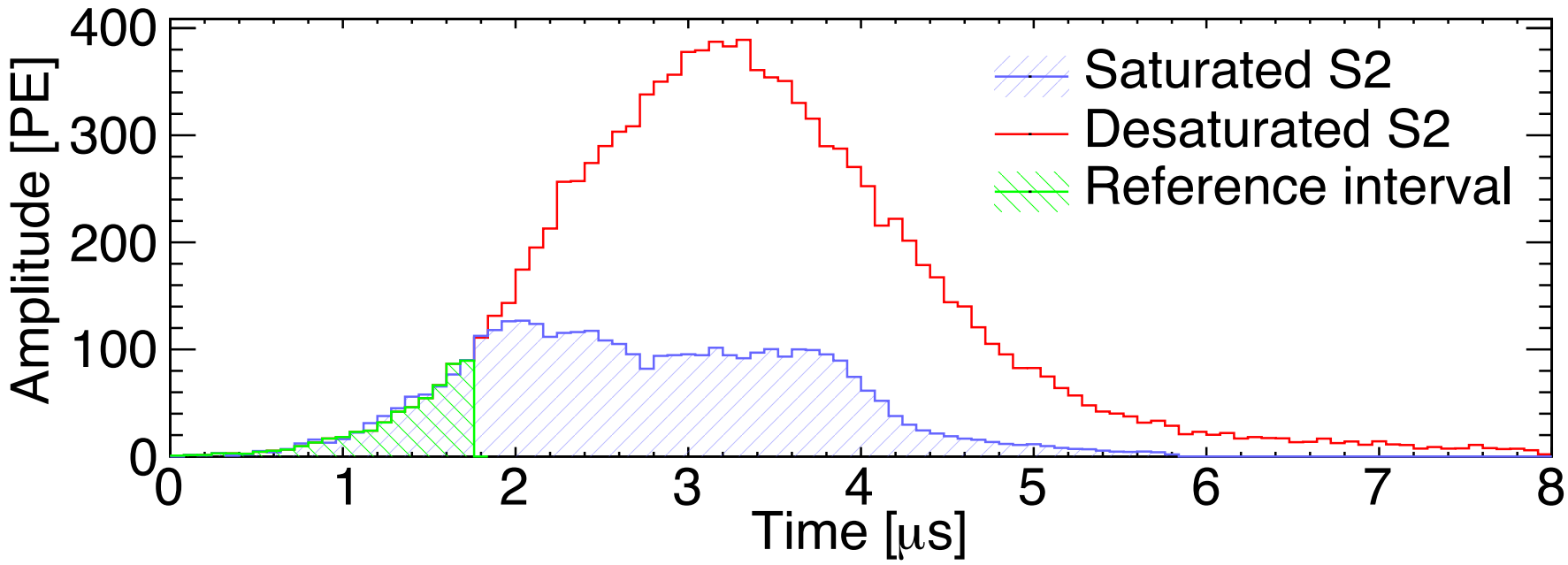


Validation with calibration data



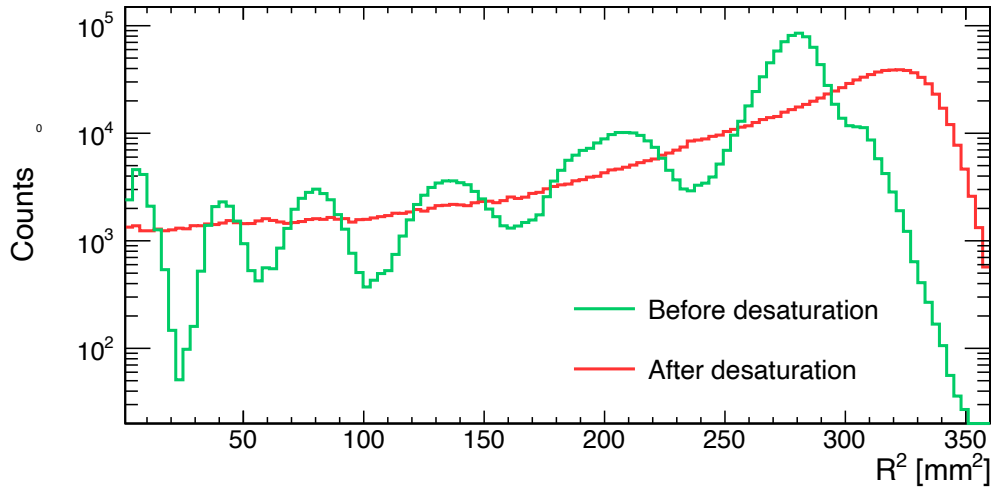
PMT pulse saturation and desaturation

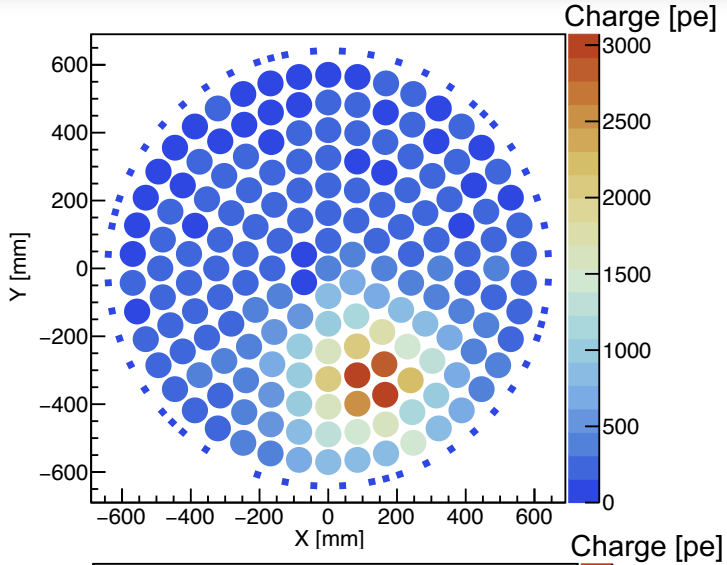
- PMT bases suffer serious saturation for MeV range events.
- Match the rising slope of the saturated to the non-saturated templates in the same events $\xrightarrow[\text{by minimizing the reduced chi-square}]{\text{dynamic reference interval}}$ True charge collected



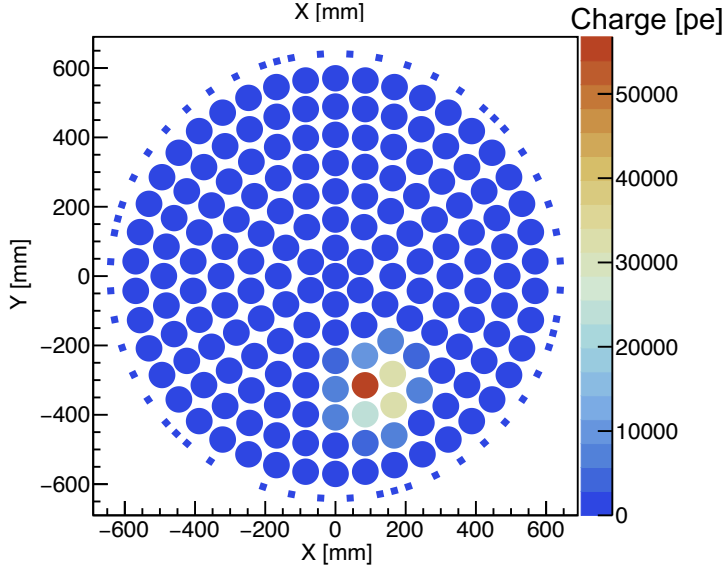
Position reconstruction

- Position reconstruction based on PAF (photon acceptance function) methods devloped in DM analysis
- Reconstruction at MeV range is significantly improved with desaturation
- Removed the wiggles in R^2 distribution





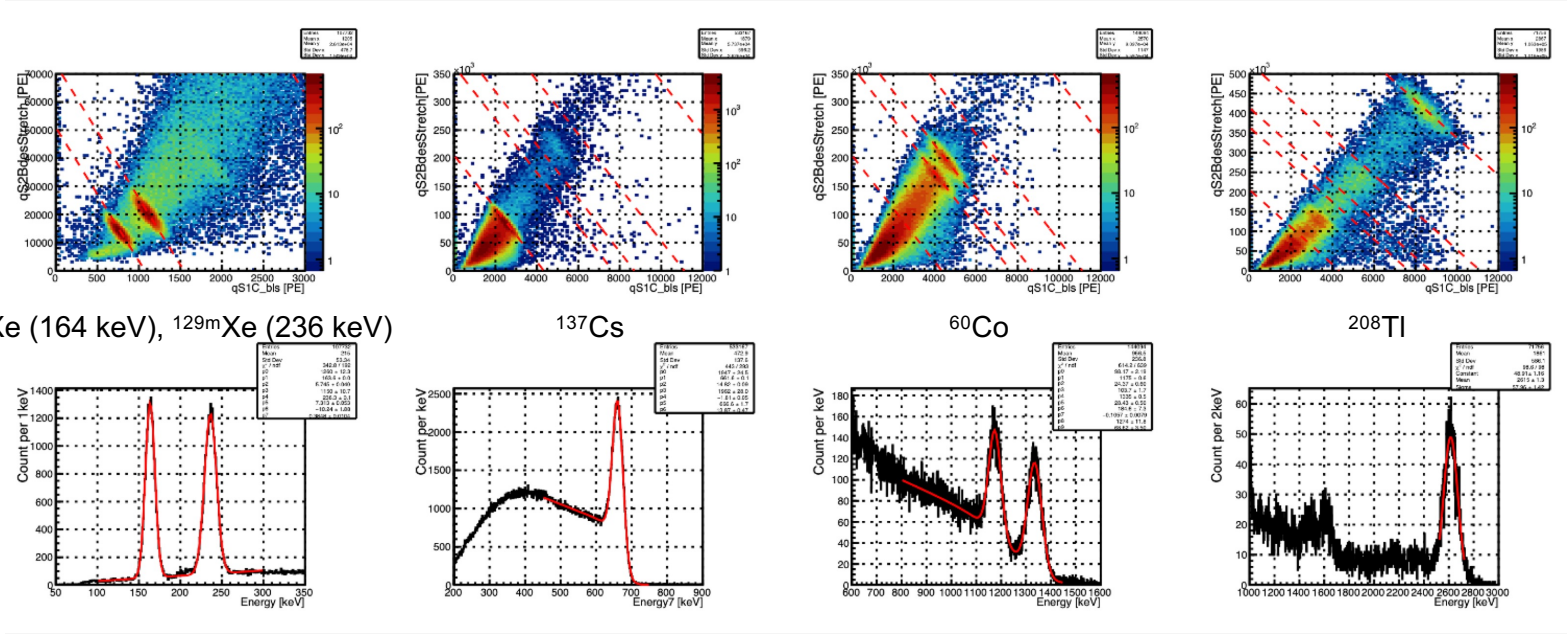
Before

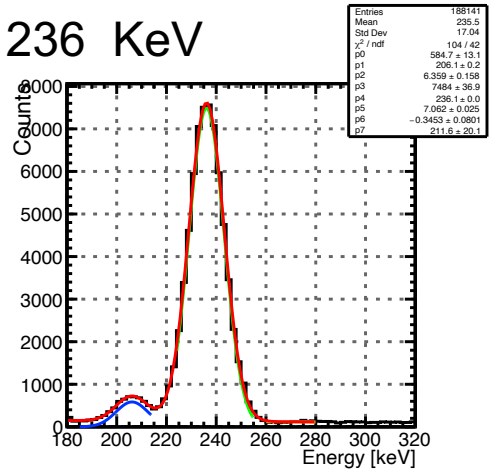


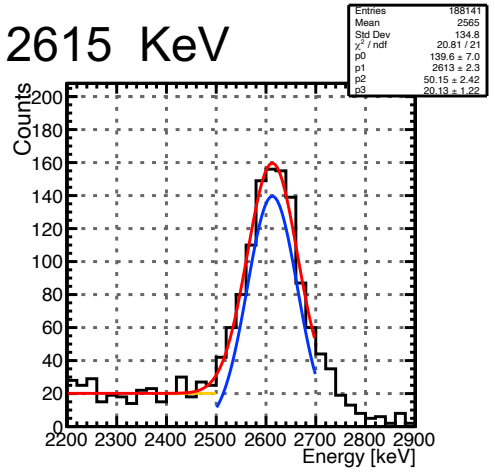
After

Energy reconstruction

- Energy reconstruction: $E = 13.7\ eV \times (S1/PDE + S2_b/(EEE \times SEG_b))$
- Signals are corrected according to the reconstructed gamma peaks of the calibration data in different regions
- Resolution of background data: 1.9% at 2615 keV; 3.0% at 236 keV







PDE: photon detection efficiency for S1

EEE: electron extraction efficiency

SEG_b: single-electron gain for $S2_b$

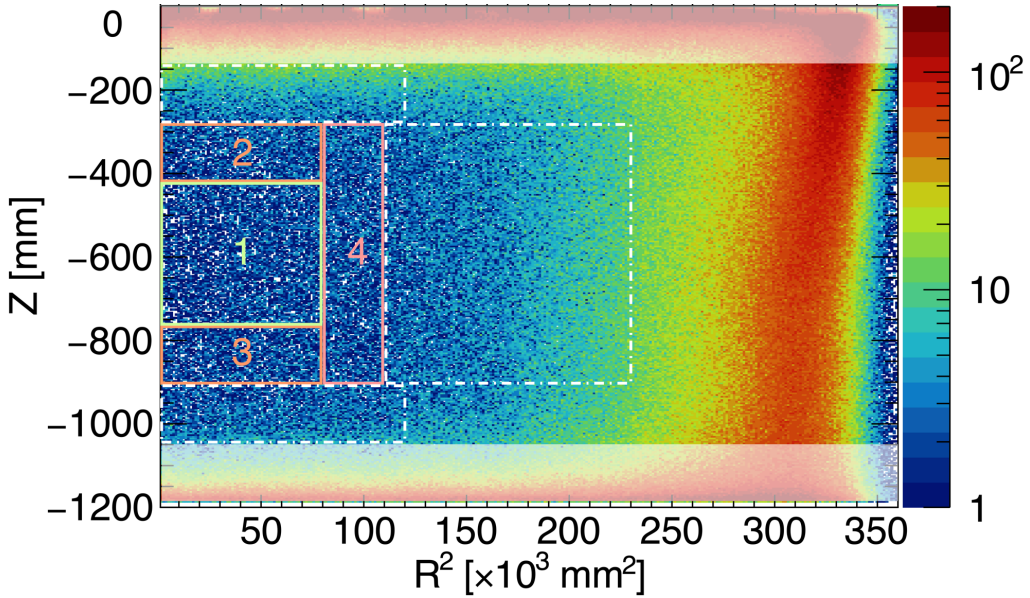
Establish an accurate background model

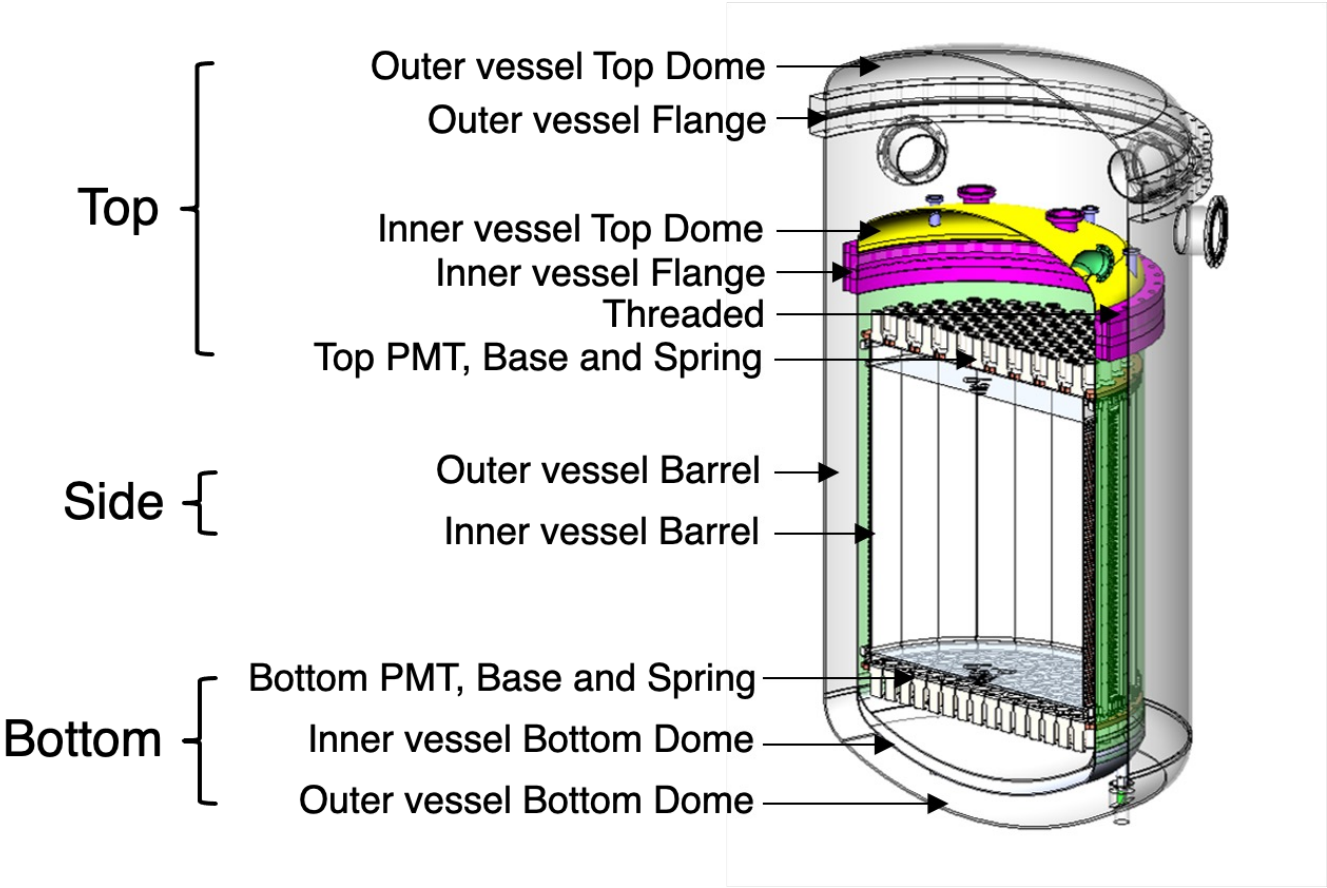
Energy window [440, 2800] keV

- PMT desaturation algorithm
- Multi-site vs single-site discrimination

Fiducial volume: 4 regions

- Robust estimation of backgrounds



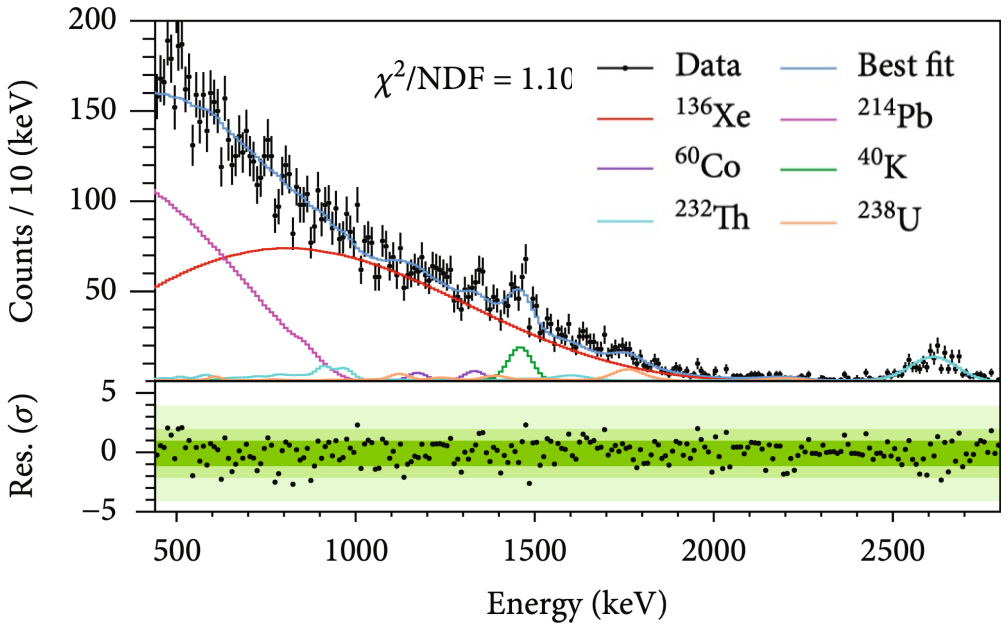


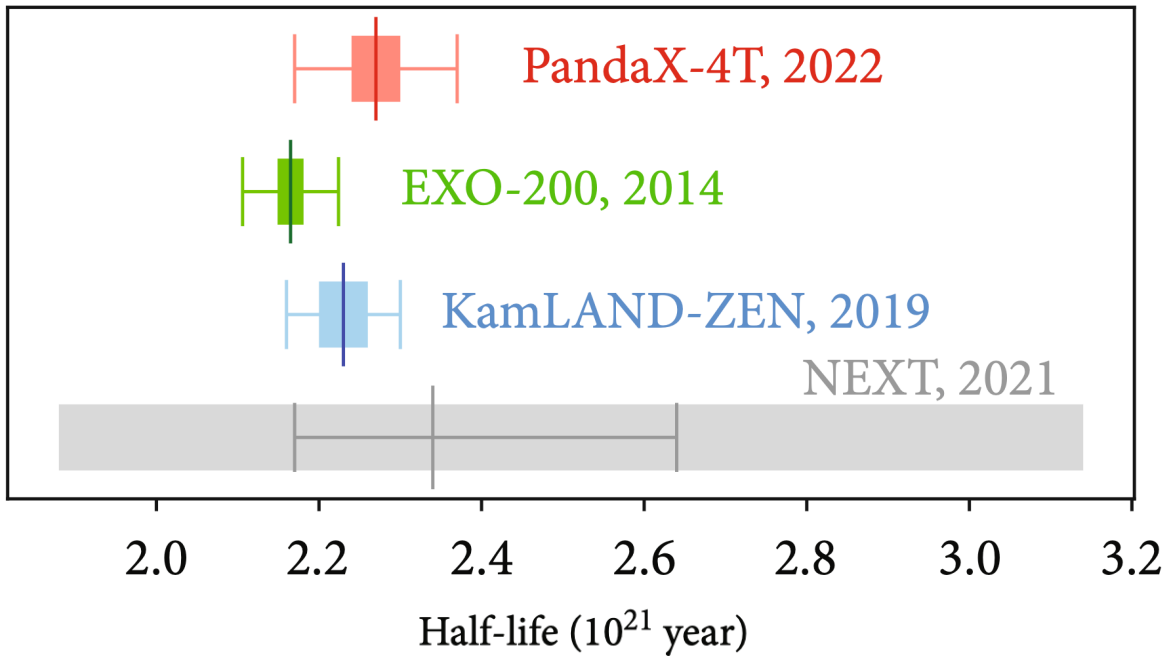
^{136}Xe 2νDBD half-life measurement

First result from a dark matter detector with natural xenon

- 2.27 +/- 0.03 (stat) +/- 0.10 (syst) x 10^{21} years
- Comparable with enriched ^{136}Xe experiments
- The widest ROI from 440 keV to 2800 keV

Research.10.34133/2022/979872





Summary and outlook

PANDA X
PARTICLE AND ASTROPHYSICAL XENON TPC

- PandaX-4T has completed its commissioning run
- PandaX-4T provides leading results on multiple topics
  - SI/SD WIMP
  - DM absorption
  - ^{8}B CEνNS
  - ^{136}Xe ($0\nu/2\nu$) $\beta\beta$ decay
- Scientific run is ongoing
  - 6 ton-year
  - Online distillation
  - Further background suppression

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Thank you