Recent Progress and Plan of PandaX Experiment

Ning Zhou
Shanghai Jiao Tong University

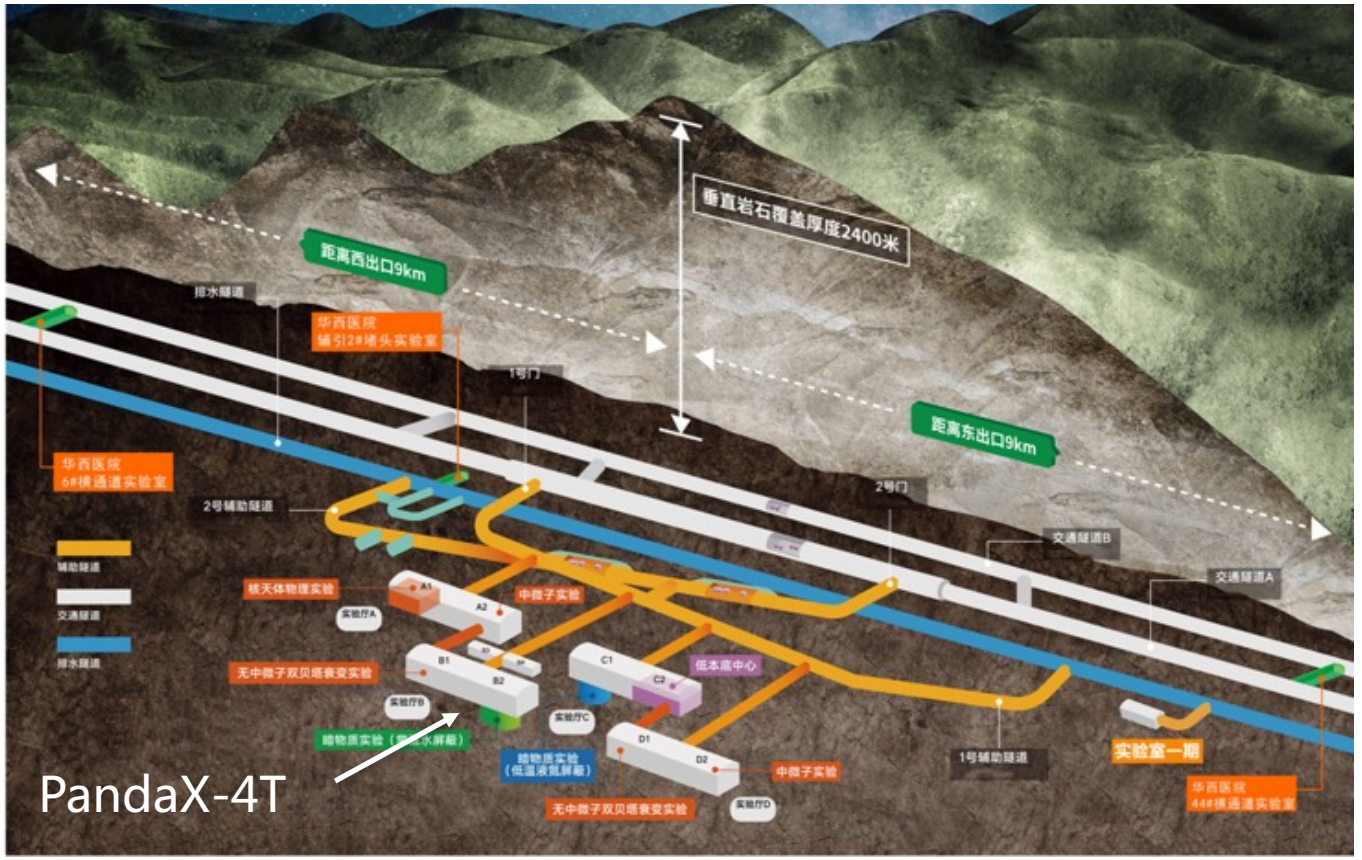
UCLA Dark Matter 2023
2023.03.31

PandaX Collaboration

- **P**article **a**nd **A**strophysical **X**enon Experiment

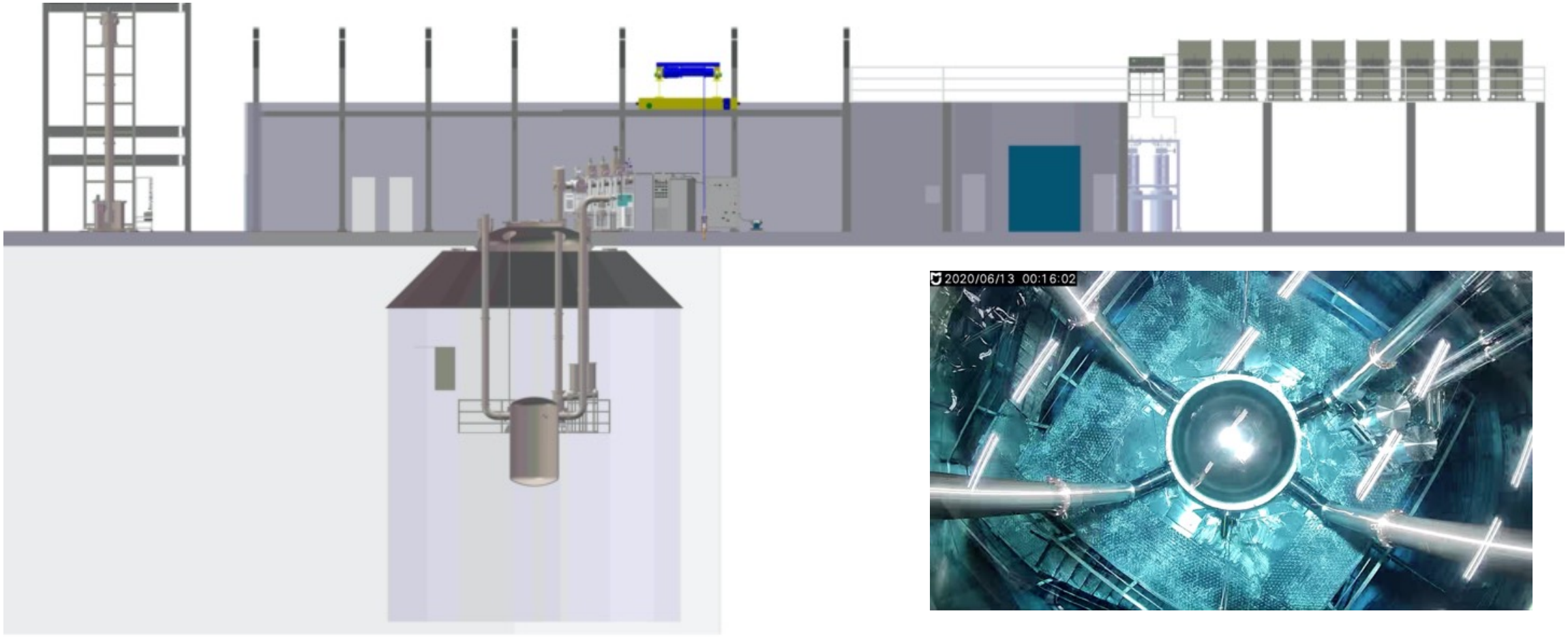
China Jinping Underground Laboratory

- **Deepest underground lab:** 6700 m.w.e. and horizontal access
- **CJPL-II:** 8 experiment halls (14m x 14m x 60m)



PandaX-4T experiment @ CJPL-II

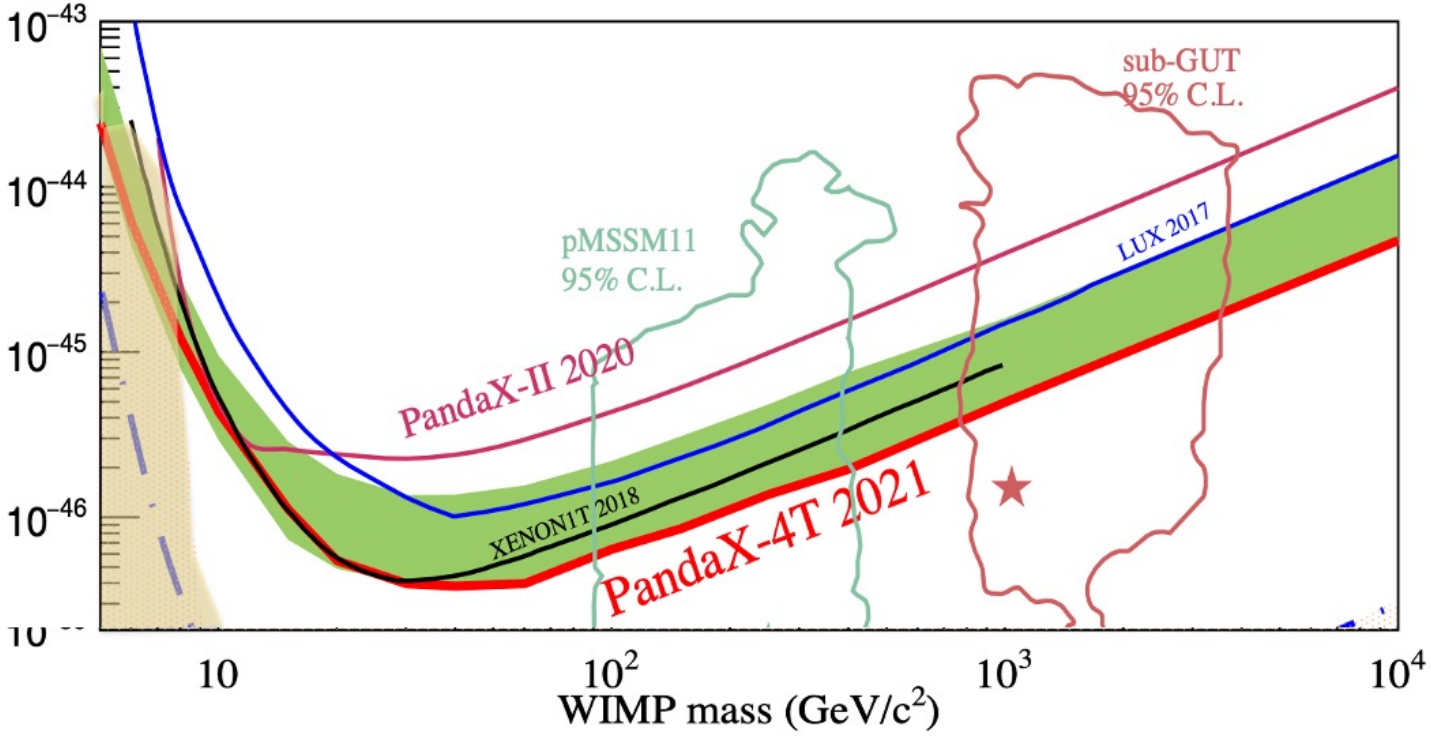
- **Sensitive target volume:** 3.7 tonne liquid xenon
- **Shielding tank:** 900m^3 high-purity water



Commissioning run in 2021

- **Dec 2020 – Apr 2021:** 0.63 tonne-year exposure
  - Limits on WIMP-nucleon spin-independent xsec down to 3.8×10^{-47} cm^2
- **Approaching the "solar neutrino floor"**

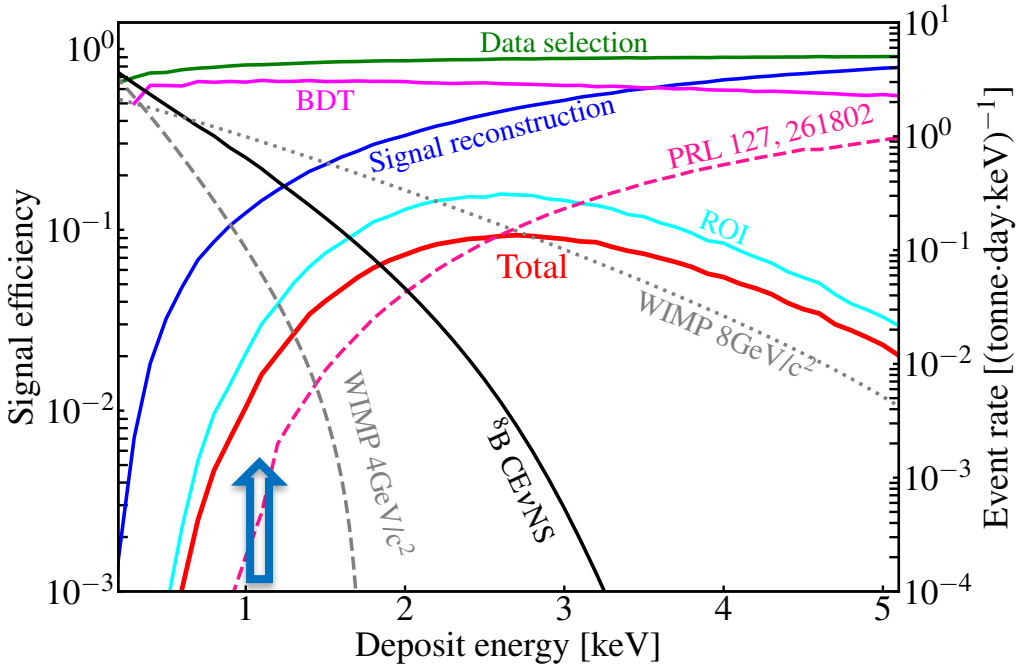
Y. Meng et al. PRL 127, 261802 (2021)

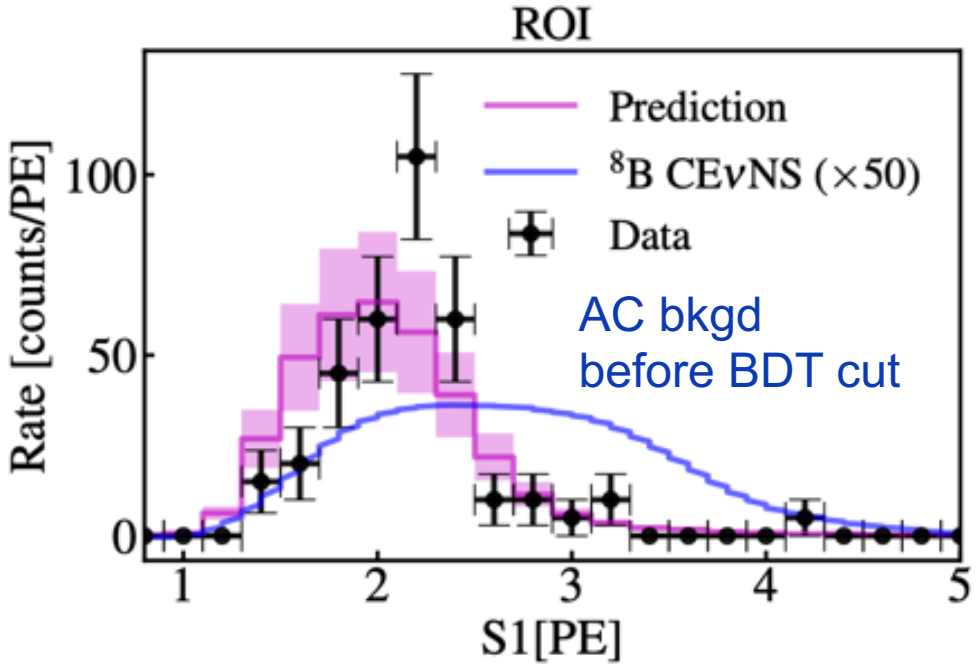


Community progress and success:
LZ, arXiv:2207.03764
XENONnT, arXiv:2303.14729

Towards the neutrino floor

- **Lowering selection threshold for solar B8 CEvNS**
  - Cut on the scintillation signal (S1) from 2 PE to 0.3 PE
  - Optimizing signal selection cuts with waveform simulation
- **Accidental paired (AC) background modeling and rejection**





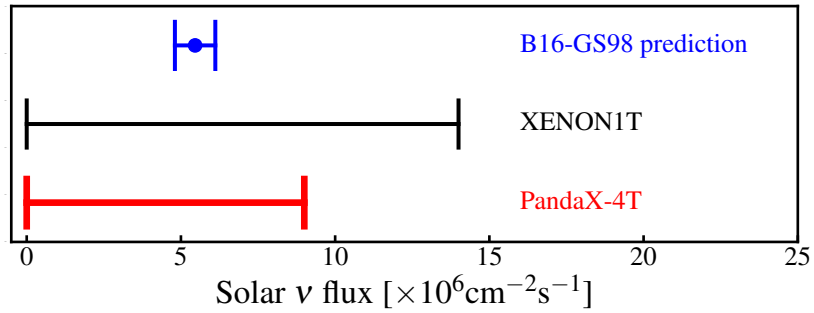
Constraints on B8 and WIMP

- **Blind analysis with 0.48 tonne-year data**
  - Some downward fluctuation

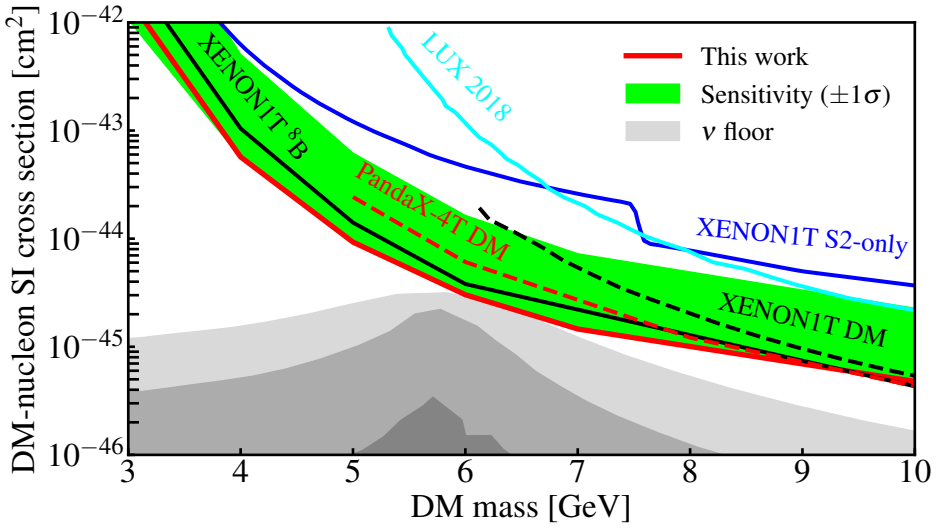
W. Ma et al. PRL 130, 021802 (2023)

ROI (BDT applied)

ER+NR+AC	8B	Total prediction	Unblind data
1.46	1.42	2.88	1
0.04	0.29	0.33	0



- **Leading constraint on B8 neutrino flux through CEvNS**
- **Strongest constraints on light WIMP of mass 3 -10 GeV/c²**



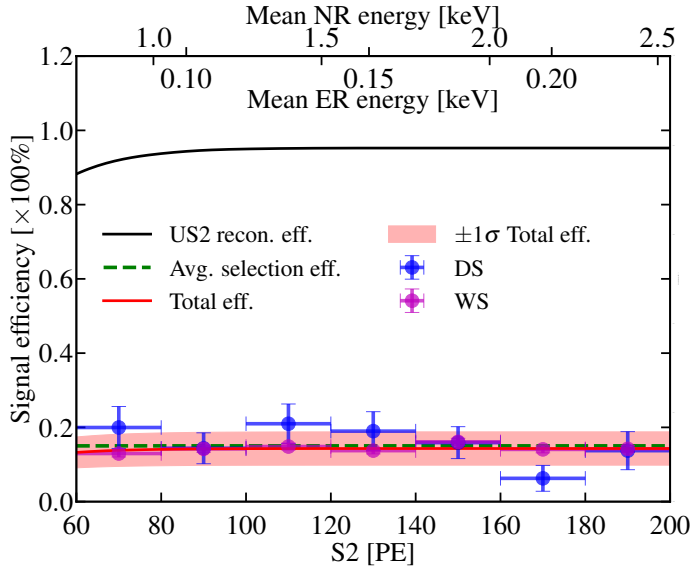
Towards light dark matter

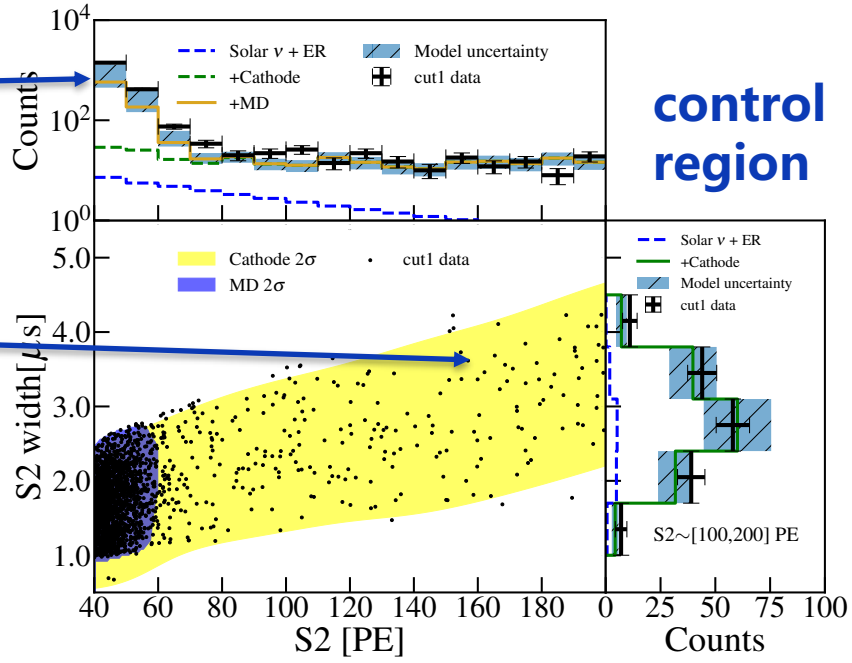
- Several approaches

Low threshold	**PRL 126, 211803 (2021)** **arXiv:2212.10067**
Mass – Energy	**PRL 129, 161803 (2022)** **PRL 129, 161804 (2022)**
Kinetic boosting	**PRL 126, 091804 (2021)** **PRL 128, 171801 (2022)** **arXiv:2301.03010**

Ionization-only search

- **Abandon the scintillation signal cut**
  - ROI: S2 [60, 200]PE
  - Threshold down to ~100 eV (from ~1 keV)
  - Tight quality cuts on the ionization signal
- **Background components**
  - **Micro-discharging (MD)**
    - ➢ Small charge, strong run-condition dependence
  - **Cathode activity**
    - ➢ Large charge, large pulse-shape width
  - **Data-driven estimation**
    - ➢ Validated in control region

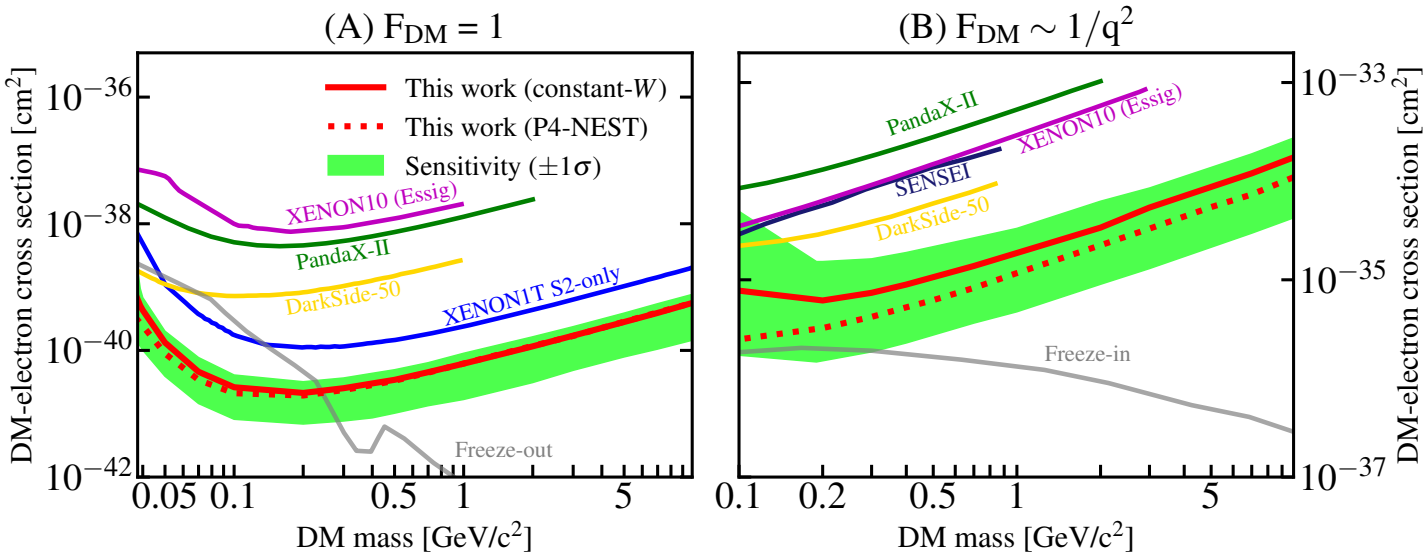


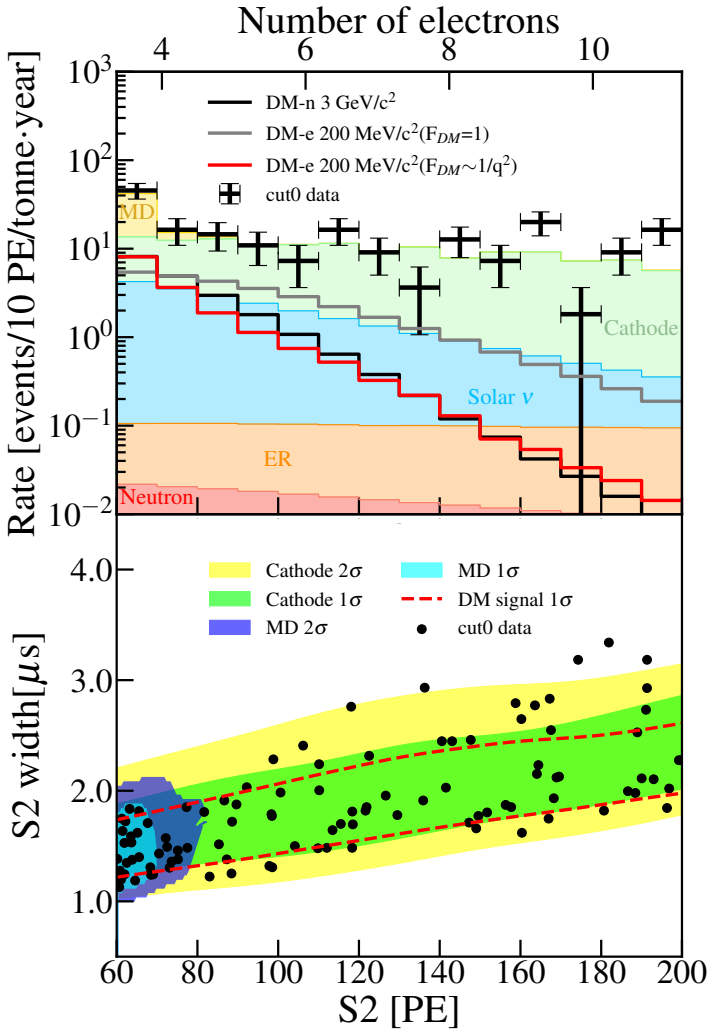


control region

Constraints on light dark matter

- **Blind analysis of 0.55 tonne-year exposure**
- **Most stringent constraints are derived**
  - DM-electron interaction, 2×10^{-41} cm^2

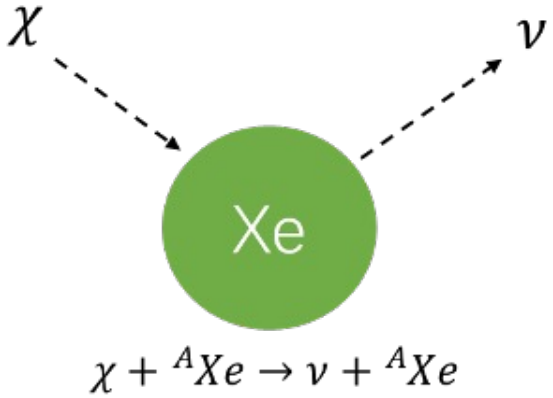




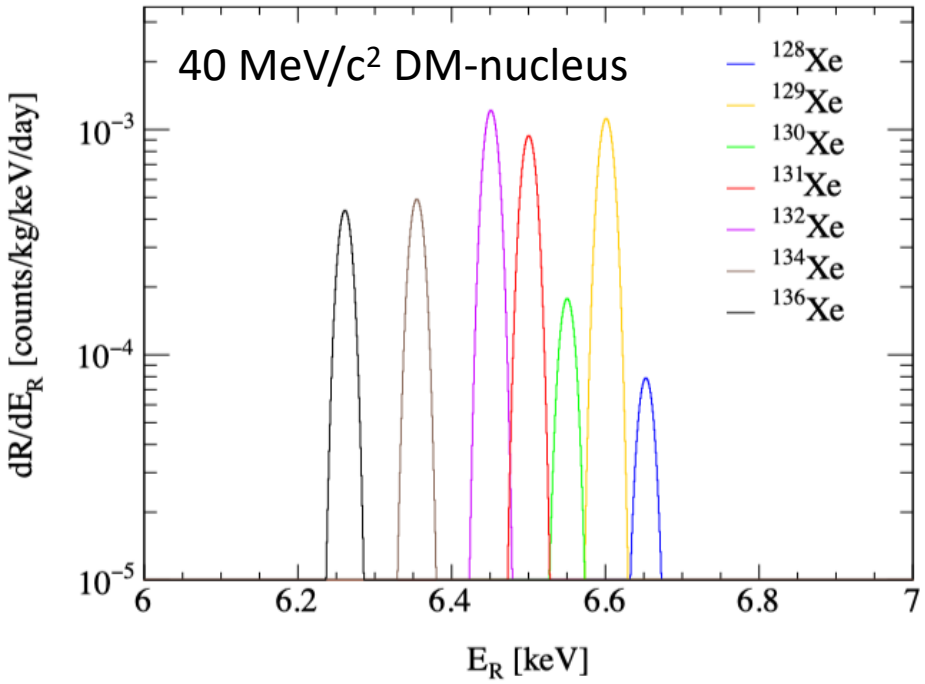
S. Li et al. arXiv:2212.10067

χ–ν conversion

- **DM and neutrino may have a connection**
  - Behave similarly as a heavy neutrino
- **DM interaction with atom**
  - DM converts into a neutrino
  - DM mass gives large recoil energy



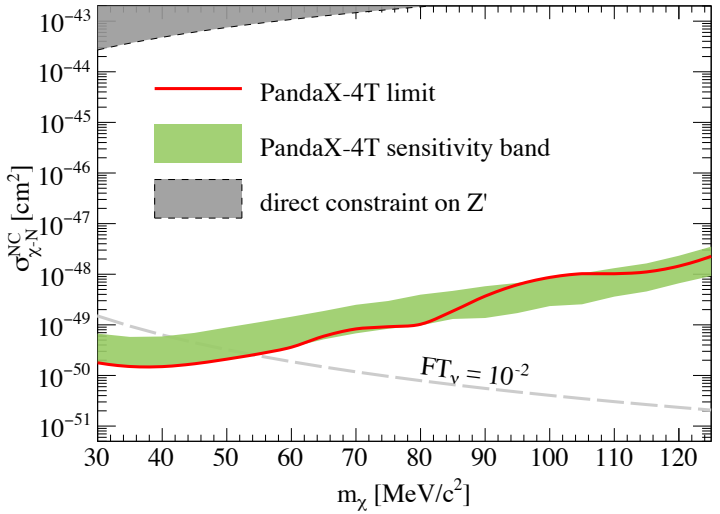
- **Mono-energetic recoil energy**
  - $E_R \simeq \frac{m_\chi^2}{2M_T}$



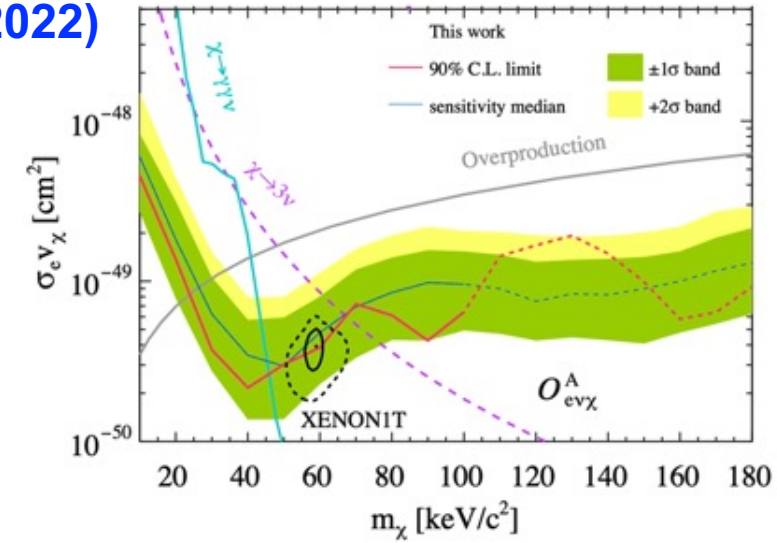
J. Dror, G. Elor, R. McGehee, PRL (2020)

Mono-energetic signal search

- **NR channel:** L. Gu et al. PRL 129, 161803 (2022)
  - Energy reconstruction validated with neutron calibration
  - Strong constraints on 30-125 MeV mass
    - **SI xsec reaching 10^{-50} cm^2, better than collider search**

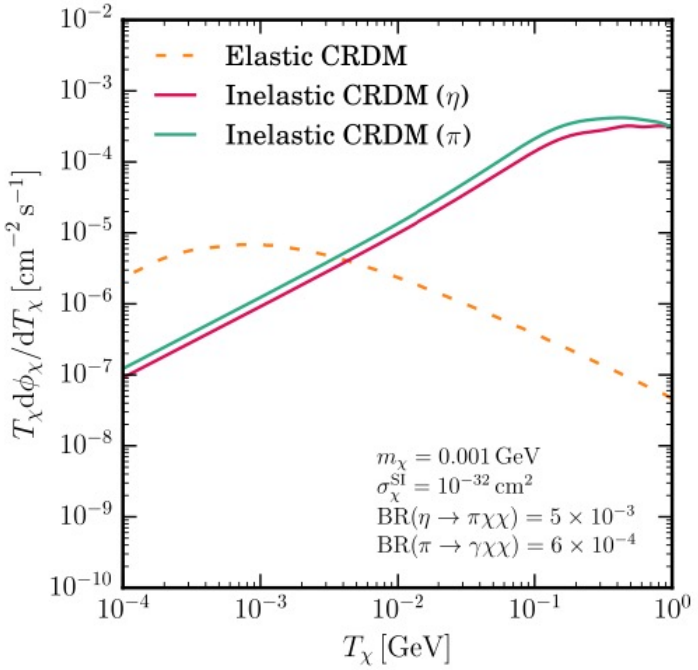


- **ER channel:** D. Zhang et al. PRL 129, 161804 (2022)
  - Similar signature as sterile neutrino
  - Fine scanning of 10-180 keV mass
    - **Combination with constraints from cosmology, DM relic density and x-ray**



Boosted dark matter

- **η mesons from cosmic-ray beam dump in atmosphere may decay into DMs**
  - Hadrophilic scalar mediator
    - $L \supset -g_\chi S \bar{\chi}_L \chi_R - g_u S \bar{u}_L u_R + h.c.$
    - Free parameters: g_χ, g_u, m_S, m_χ
- $BR(\eta \to \pi^0 S \to \pi^0 \chi \bar{\chi})$: no dedicated measurements on this semi-invisible yet
- **Strongly boosted atmospheric dark matter**

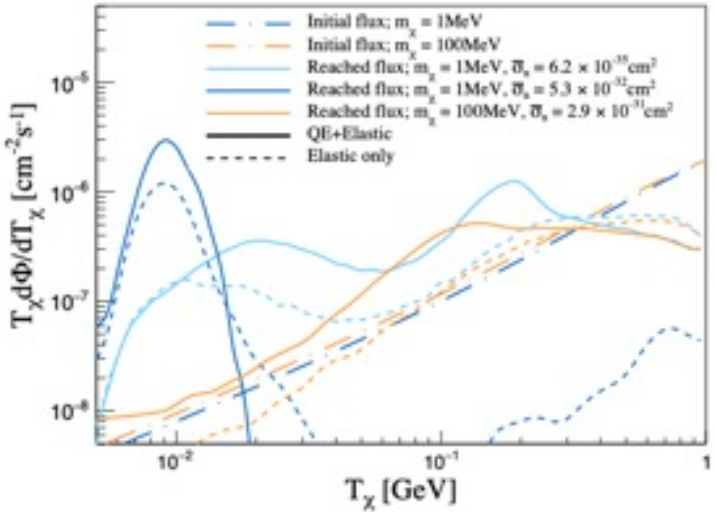


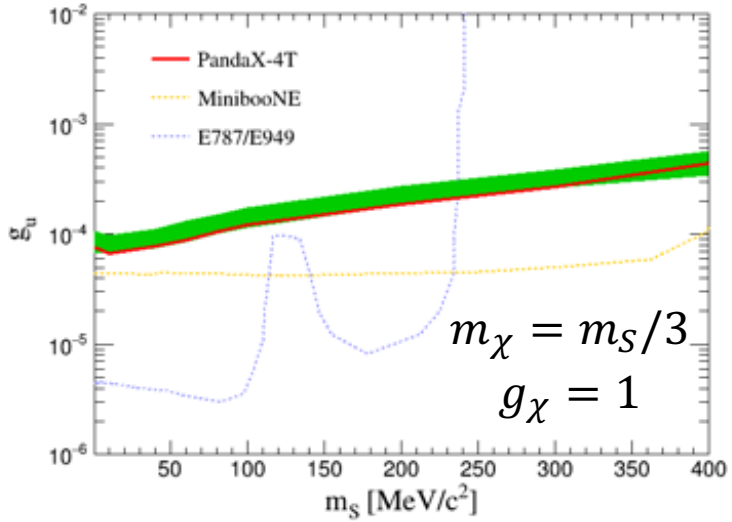
J. Alvey, M. Campos, M. Fairbairn, T. You,
PRL 123, 261802 (2019)

Constraints on the DM-nucleon

- **Earth attenuation**
  - Elastic coherent, quasi-elastic (QE), and inelastic scatterings
  - For $T_\chi > 0.2$ GeV, QE becomes significant
  - **Dedicated QE scattering calculation with light mediator**
- **Cosmic-ray beam dump gives a unique window to search this scalar mediated DM-nucleon interaction**
  - Same model could be searched in beam experiments, like MinibooNE and E787/E949

L. Su, L. Wu, NZ, B. Zhu arXiv:2212.02286



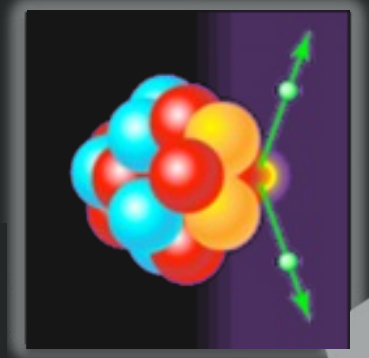


X. Ning et al. arXiv:2301.03010

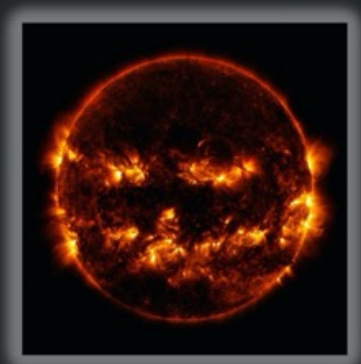
Multi-physics targets

Large energy range: keV ~ MeV

Dark Matter
1 keV – 10 keV



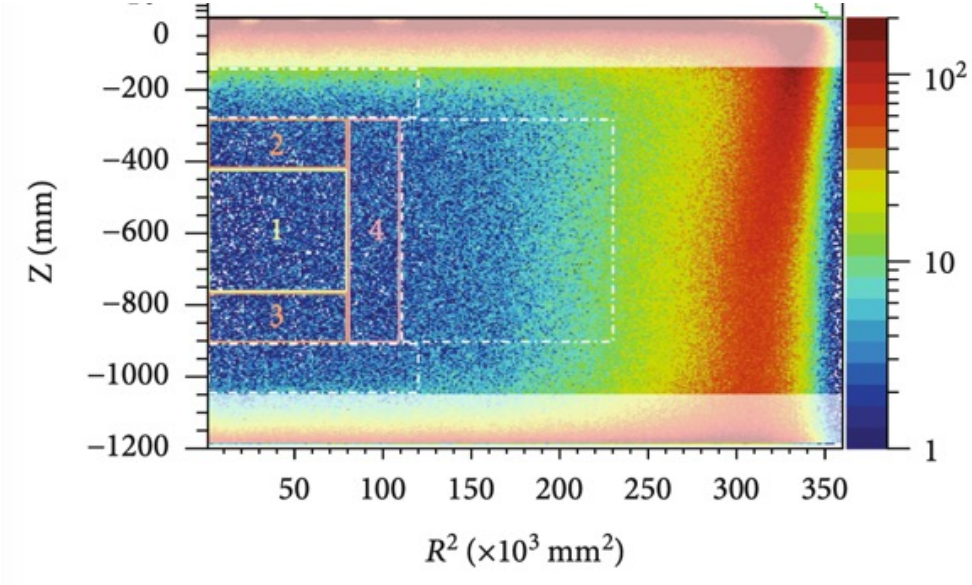
Majorana neutrino
> 2 MeV

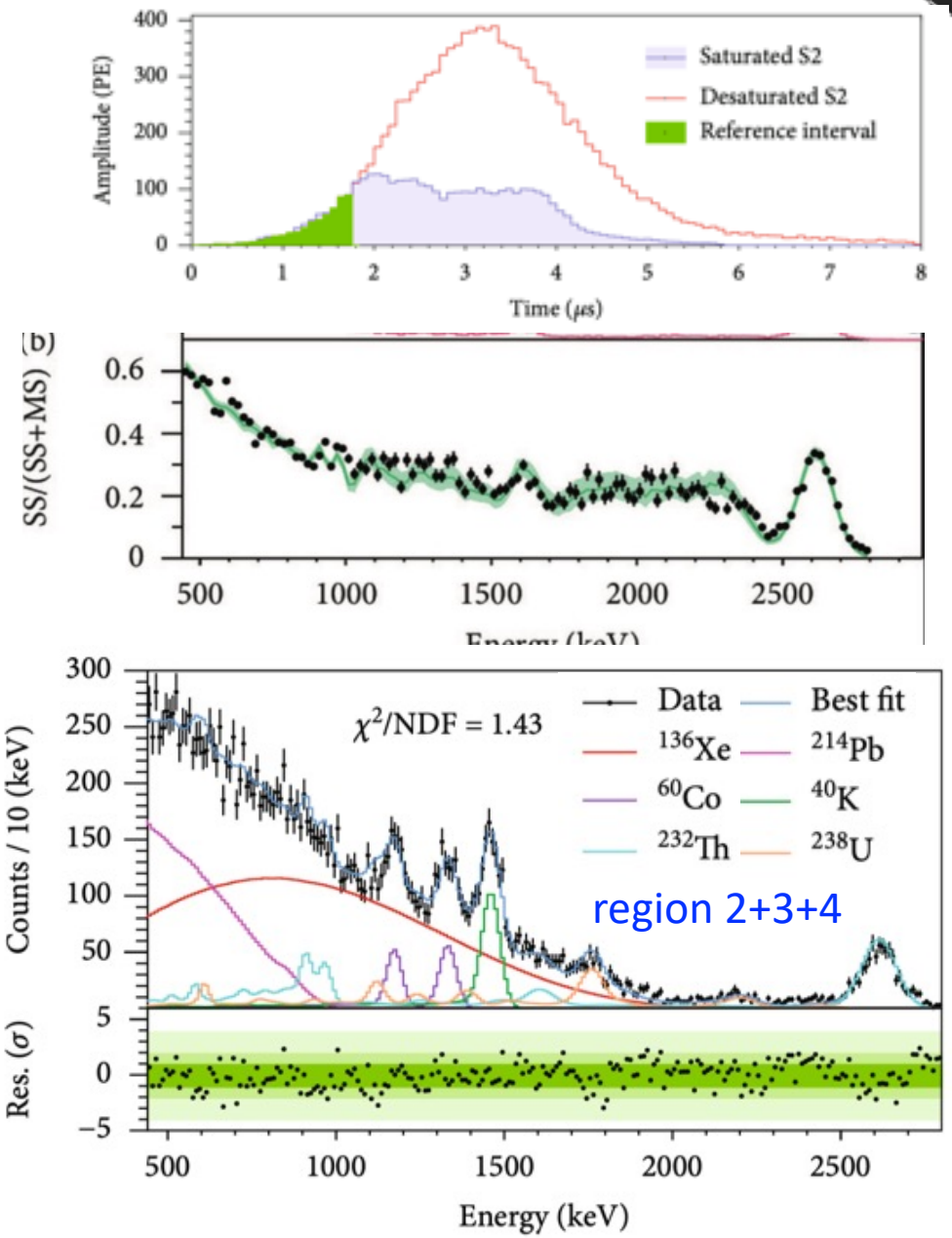


Astrophysics neutrino < 300 keV

^{136}Xe 2vDBD half-life measurement

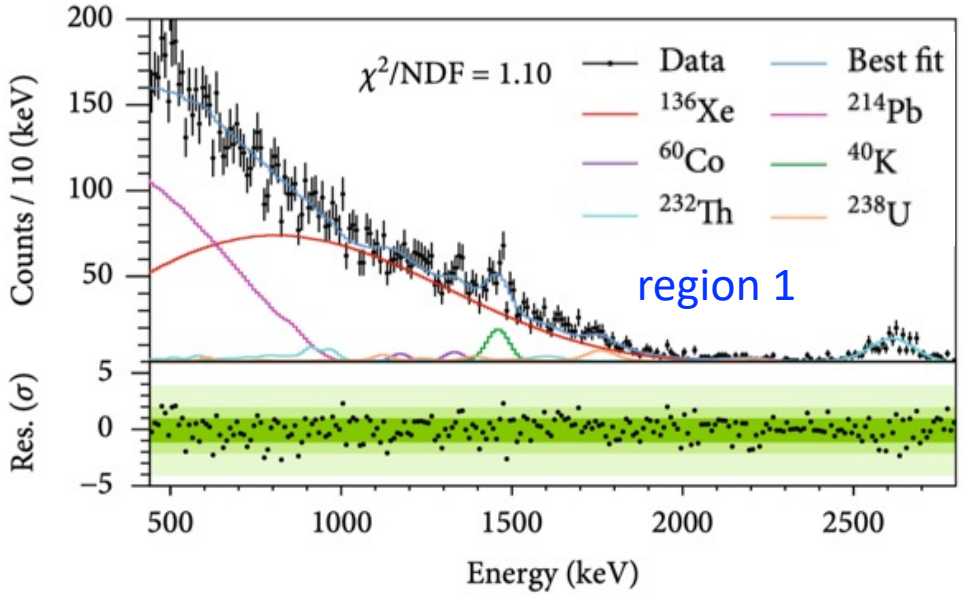
- **Energy window [440, 2800] keV**
  - PMT desaturation algorithm
  - Multi-site vs single-site discrimination
- **Robust estimation of backgrounds**
  - Simultaneous fit in 4 regions



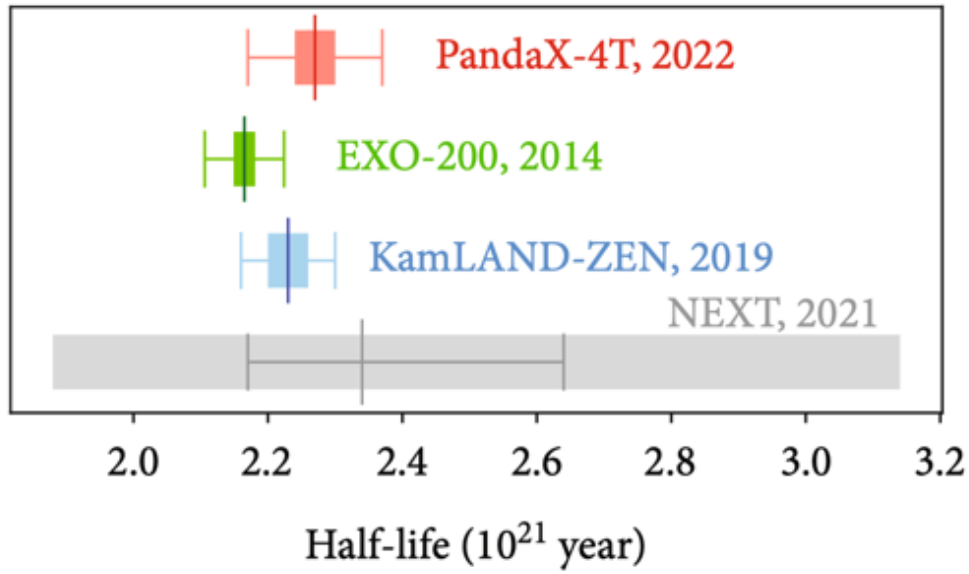


^{136}Xe 2vDBD half-life measurement

- **First result derived from natural xenon experiment**
  - 2.27 +/- 0.03 (stat) +/- 0.10 (syst) x 10^{21} years
  - One of the most precise measurements to date
  - **Comparable with enriched ^{136}Xe experiments**



Research Vol 2022, 9798721 (2022)



After commissioning

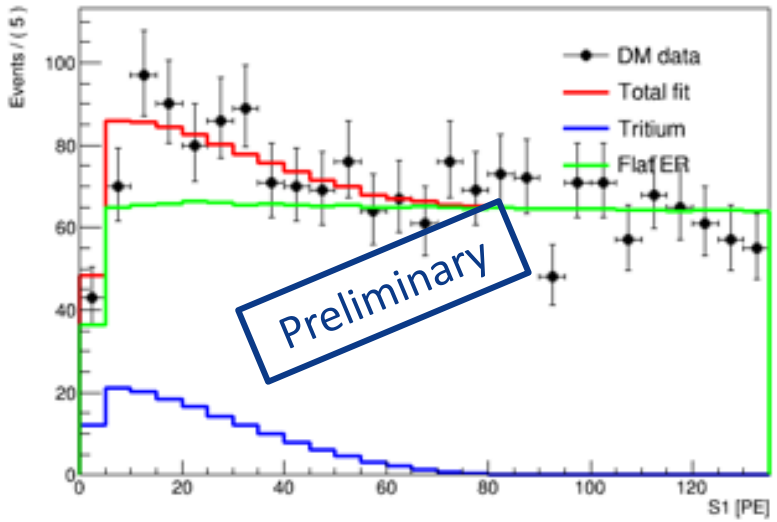
- Tritium identified in commissioning data
- **Offline xenon distillation**
- **1st physics run (Run1)**
  - **Data still under blind analysis**
- **CJPL-II B2 hall construction**
- **Detector upgrade**

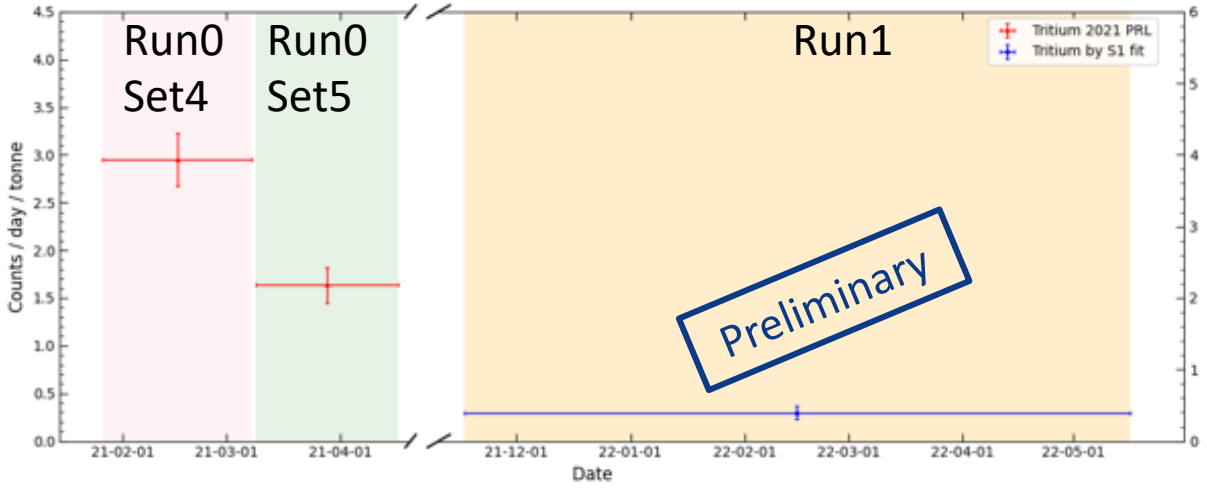
Commissioning (Run 0)	Calibration	Distillation	Physics Run (Run 1)	Calibration	Detector Upgrade
2020/11/28 – 2021/04/16	2021/04/17 – 2021/06/09		2021/11/15 – 2022/05/15	2022/05/16 – 2022/07/08	

Tritium removal

- **Preliminary estimation of tritium level**
  - Fitting S1 spectrum, **keeping S2 blinded**
- **Extensive tritium measures planned for next run (Run 2)**

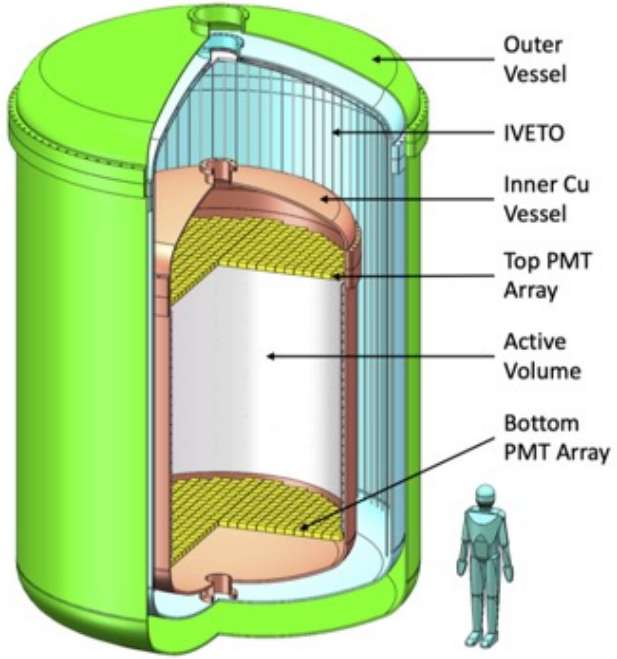
Period	Run0 Set 4	Run0 Set 5	Run1
Tritium Counts/day/tonne	3.0 ± 0.3	1.6 ± 0.2	0.4 ± 0.1

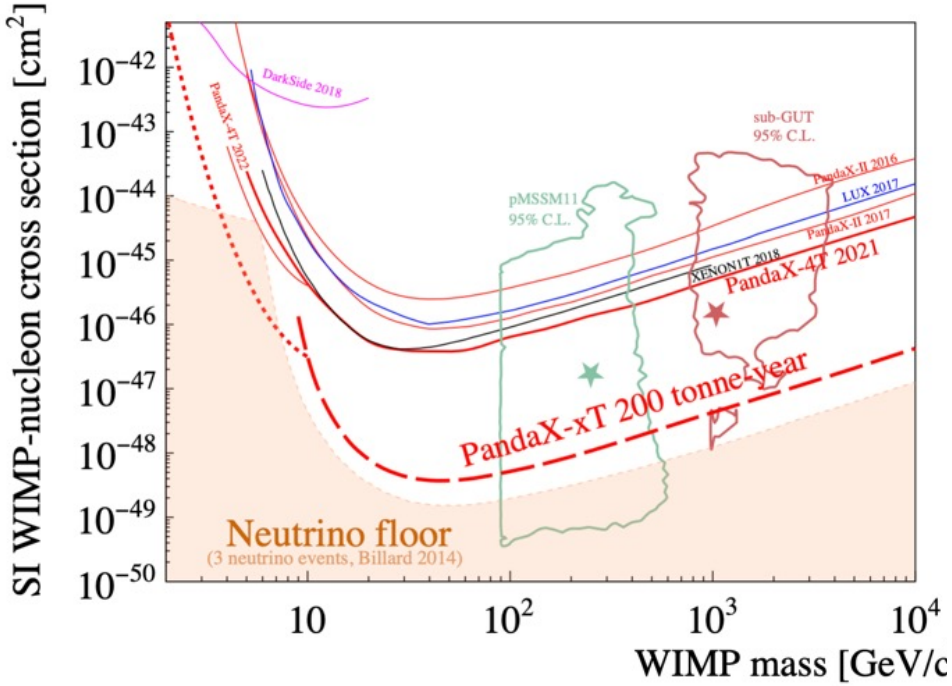


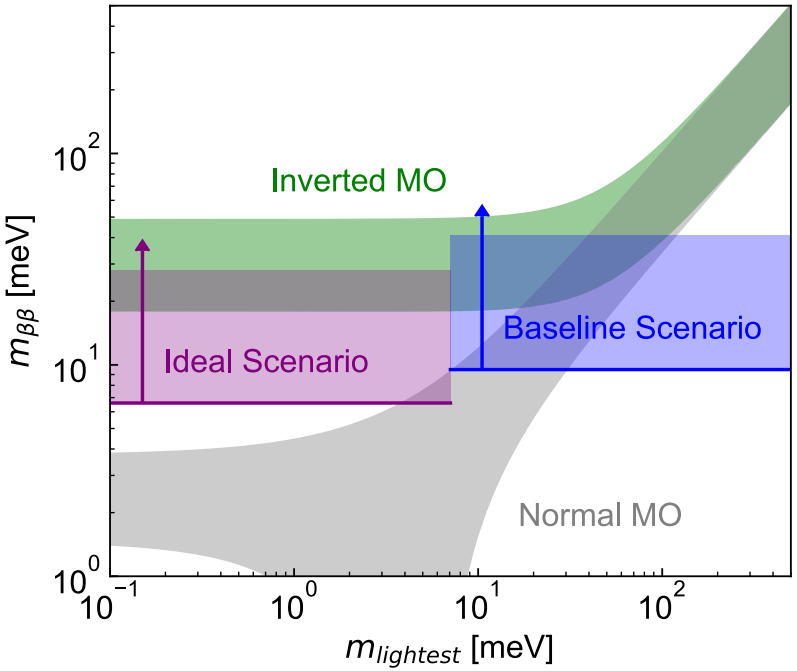


Future plan: PandaX-xT

- **“Ultimate” liquid xenon experiment**
  - With >30 tonne sensitive volume
  - Letter-of-interest sent to Chinese funding agency
  - Decisive test on WIMP and key test on Dirac/Majorana neutrino







Summary

- PandaX-4T is one of the new generation multi-tonne xenon experiments
- Intense searches for various types of physics, including DMs and neutrinos
- Expecting more interesting results from PandaX
- Highly welcome new collaborators!

Thank You !

- Any question about this talk, please email nzhou@sjtu.edu.cn