Latest Results of PandaX Experiment

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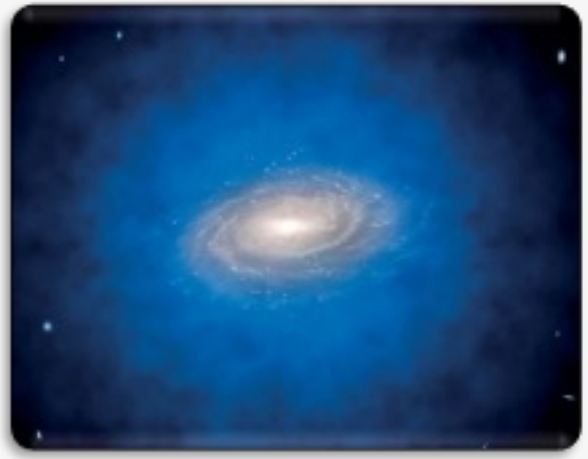
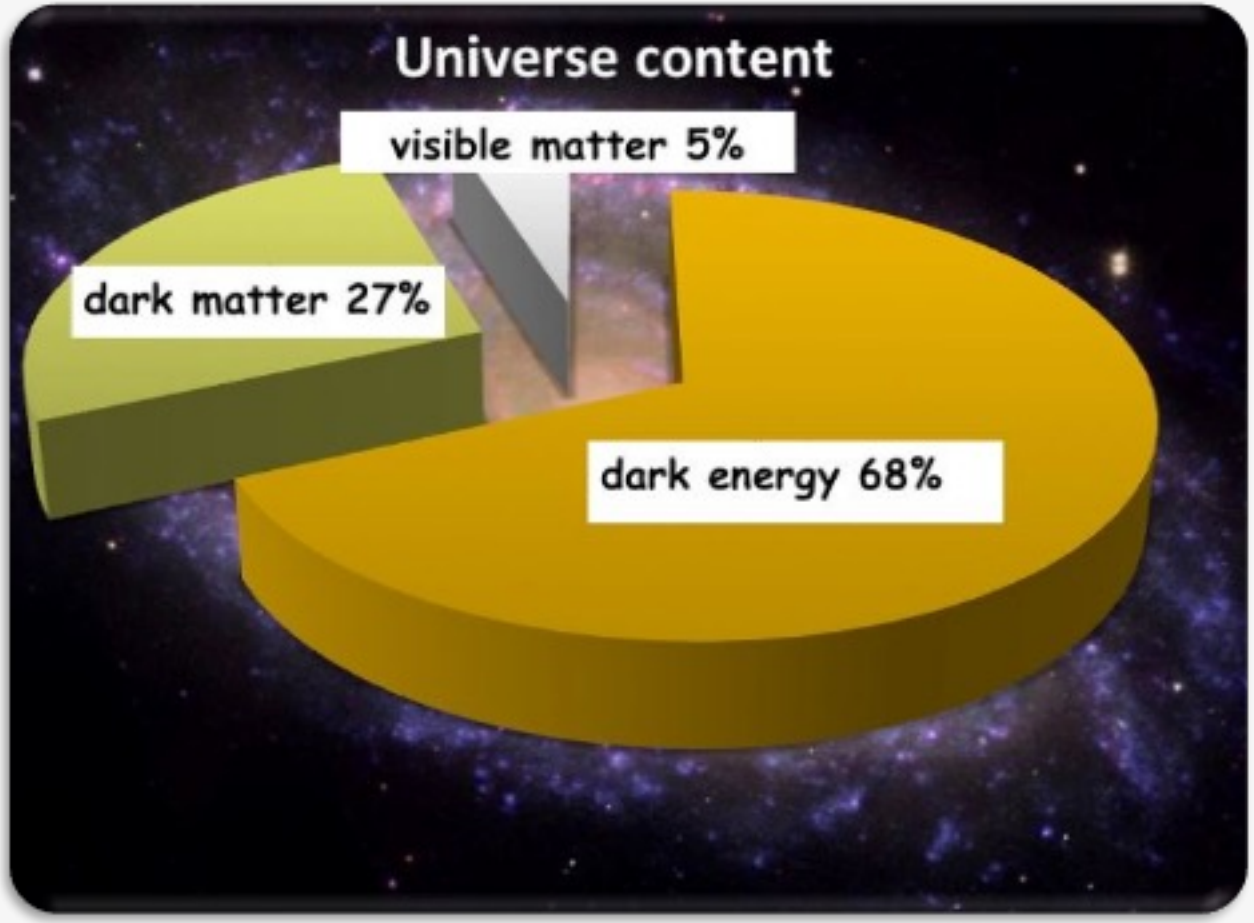
The 2nd AEI and 10th KIAS Workshop

2022-11-18

Dark Matter

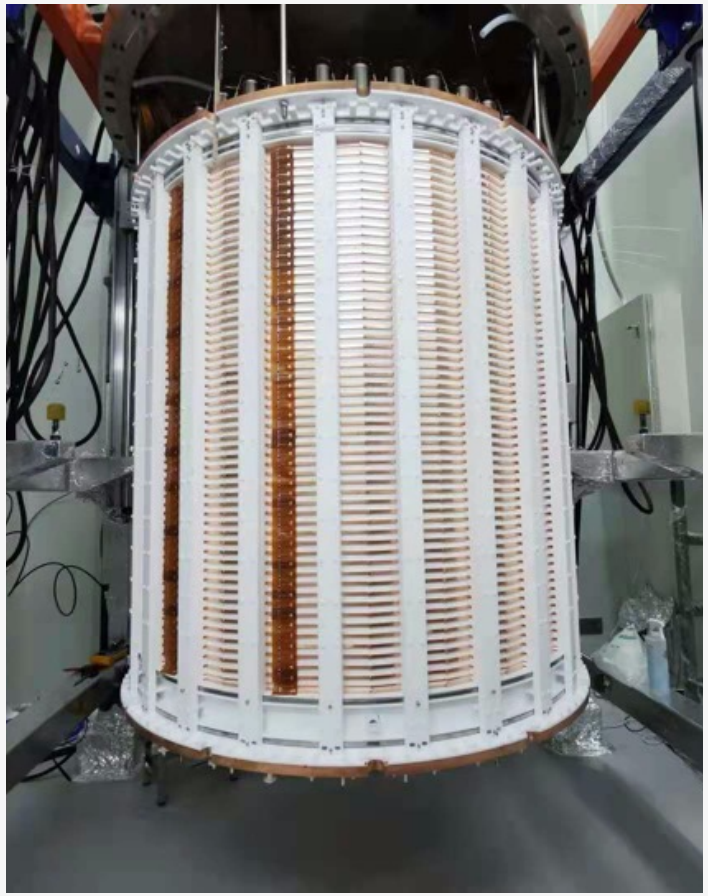
- Strong evidences for the existence of dark matter
- The nature of dark matter is unknown

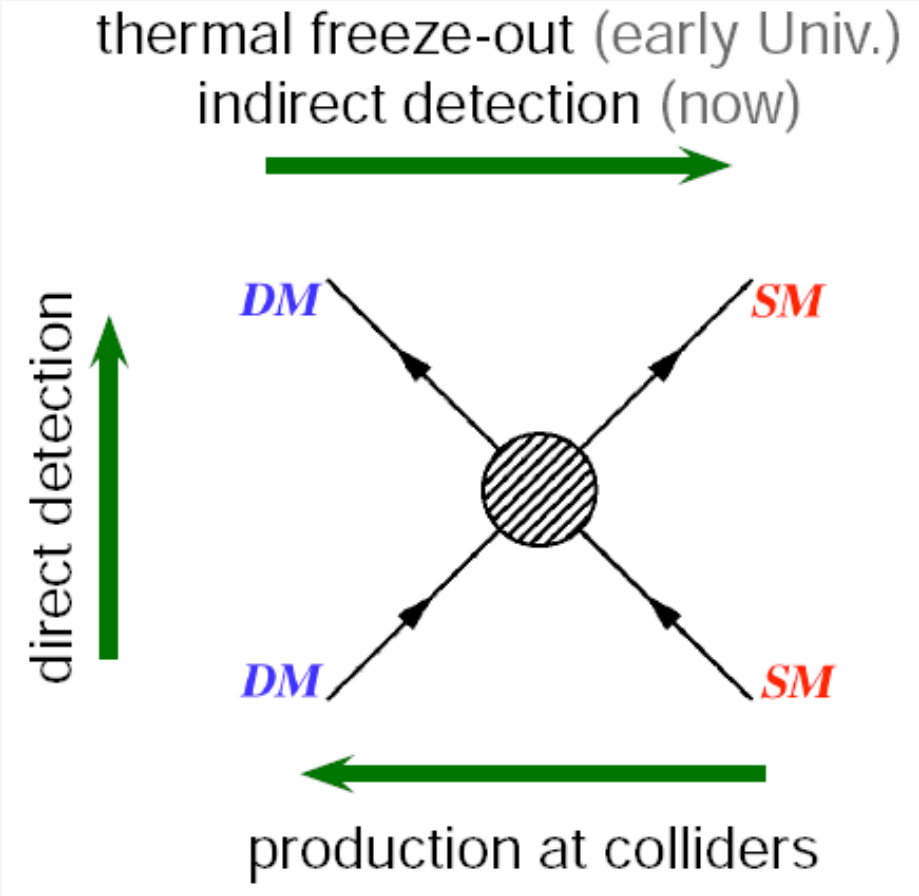


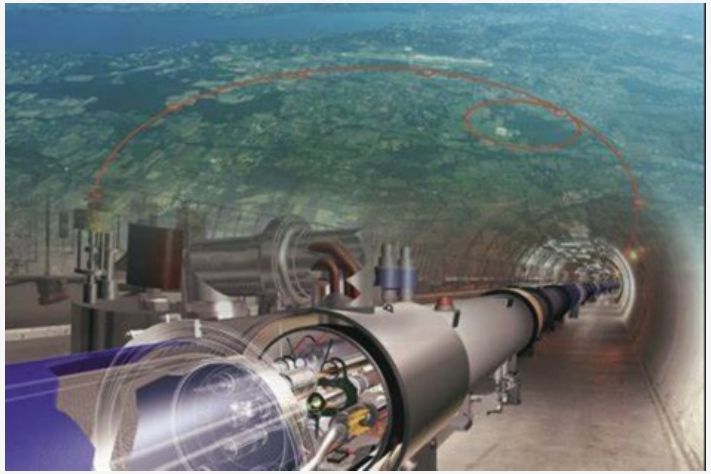


Dark Matter Searches

- Direct detection, indirect detection, collider search

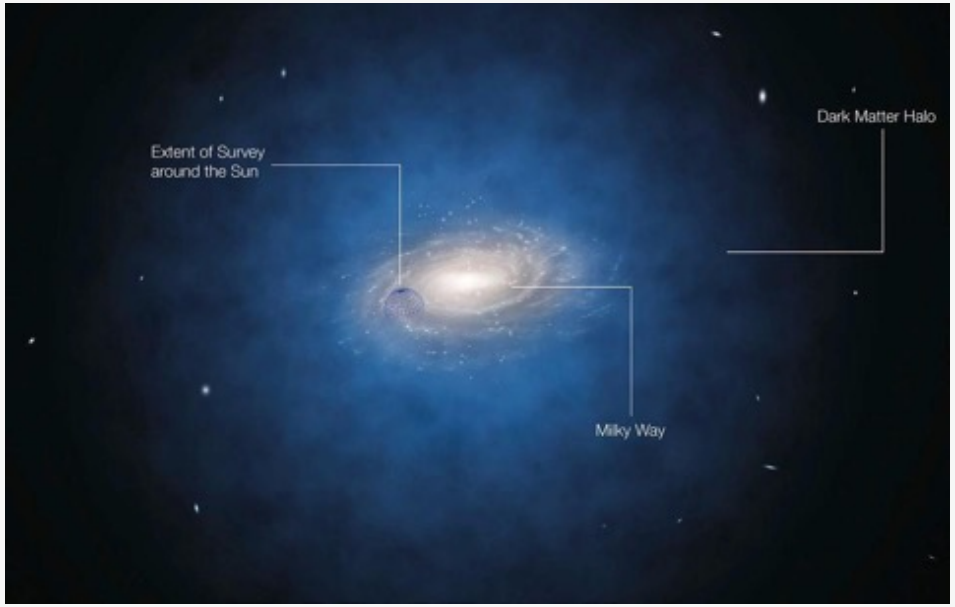




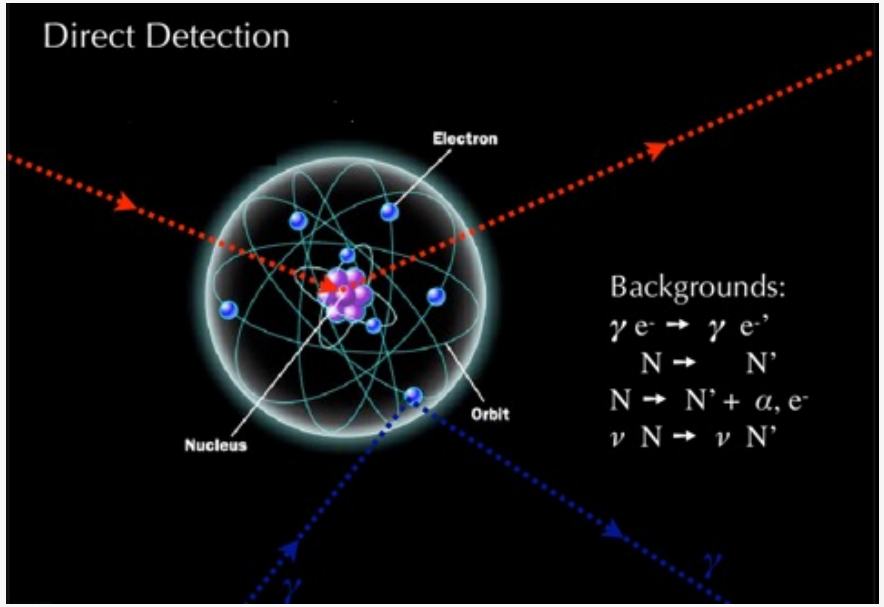


Direct Detection

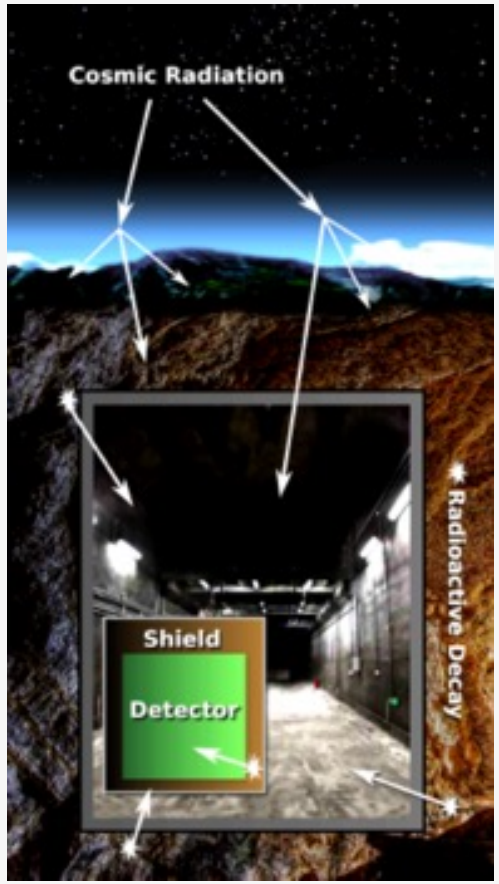
- Solar system in the dark matter halo
- Detection of incoming dark matter scattering off target atom
  - Nuclear recoil (NR) or electronic recoil (ER) signature
  - Small and rare signals: underground laboratory



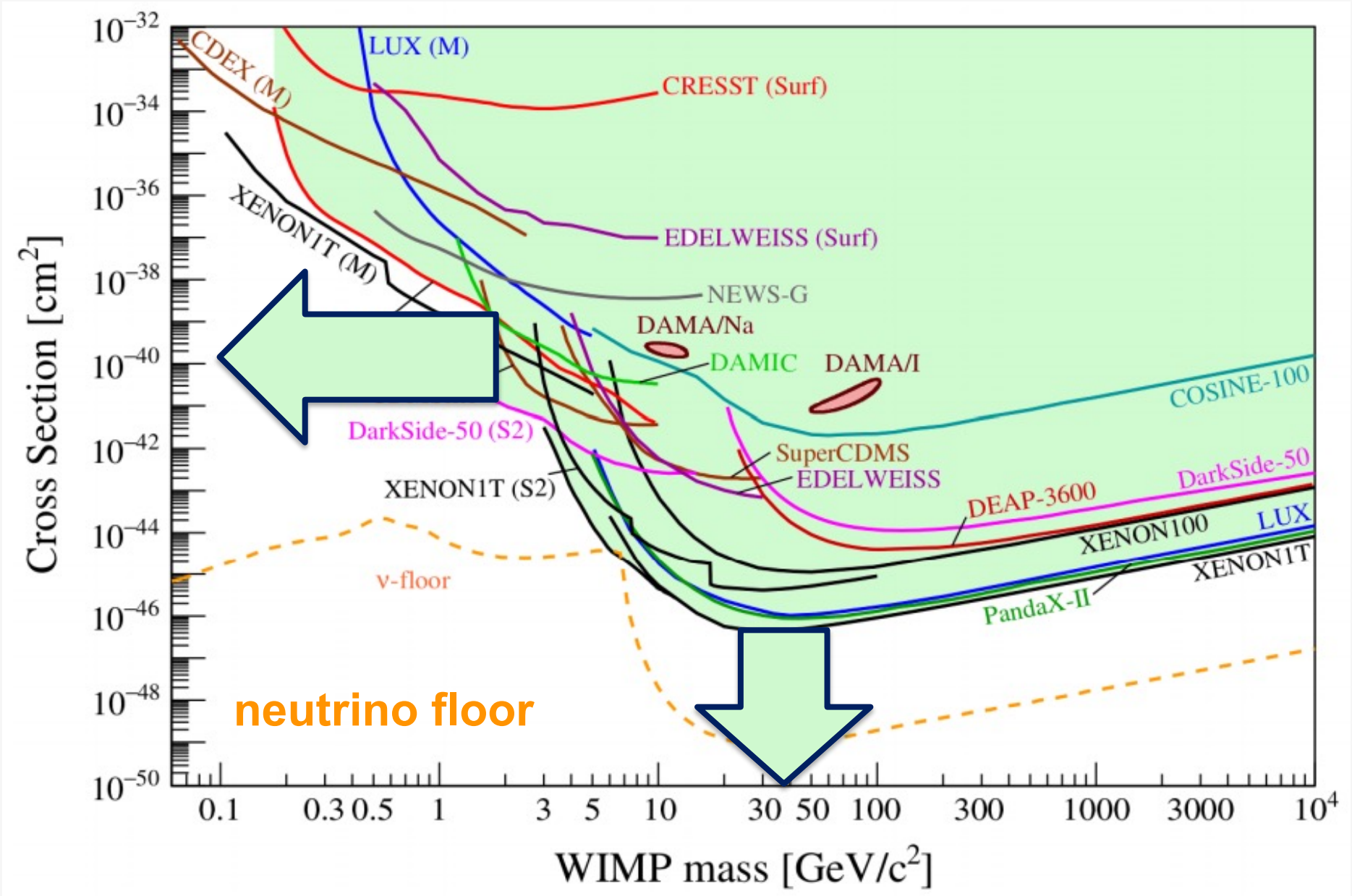
ESO / L. Calçada.



DARK MATTER OVERVIEW: COLLIDER, DIRECT AND INDIRECT DETECTION SEARCHES - QUEIROZ, FARINALDO S. ARXIV:1605.08788



Direct Detection

- 

Global Efforts

- Multi-tonne scale xenon experiments @ underground labs

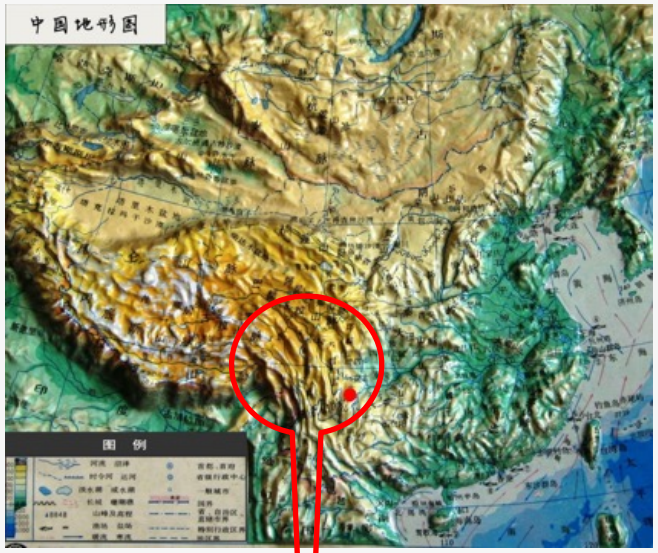
LZ, 7t LXe,
Sanford Lab, US

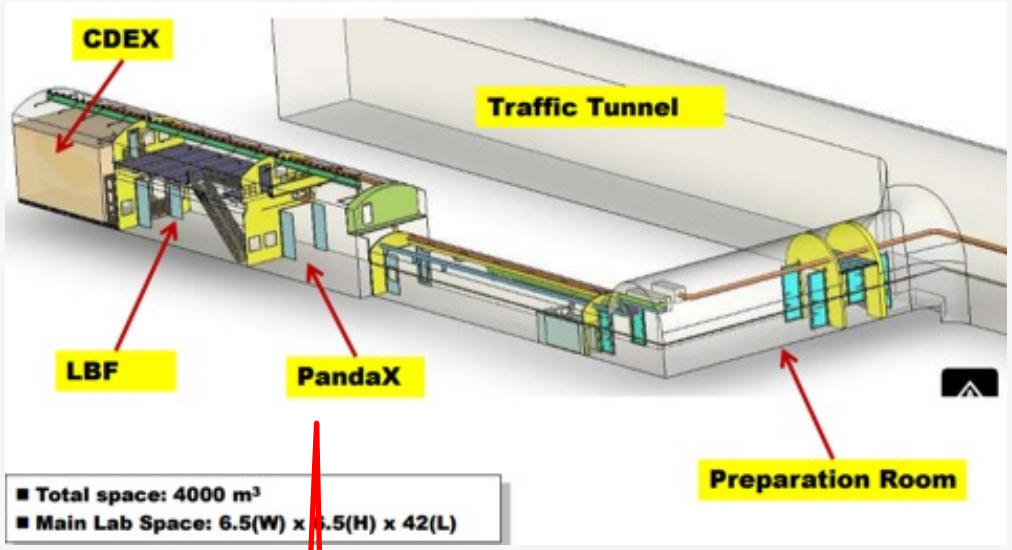
XENONnT, 6t LXe
LNGS, Italy

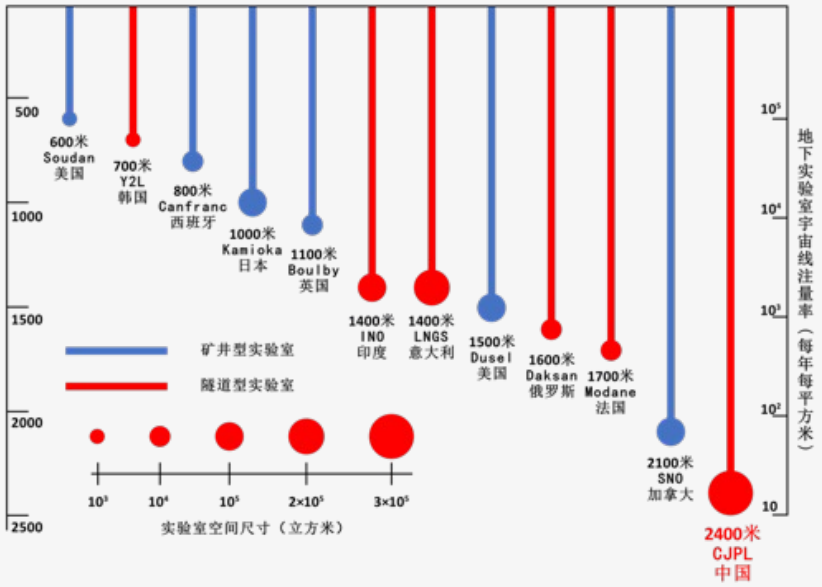
PandaX-4T, 4t LXe
CJPL, China

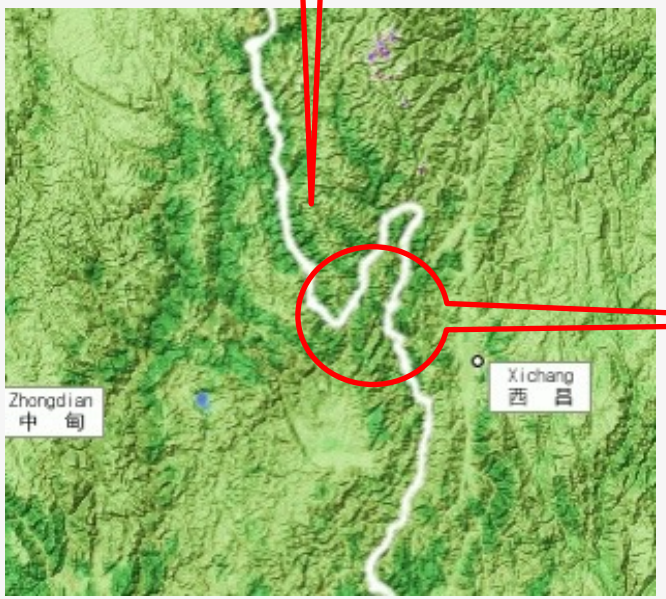
China Jinping Underground Laboratory (CJPL)

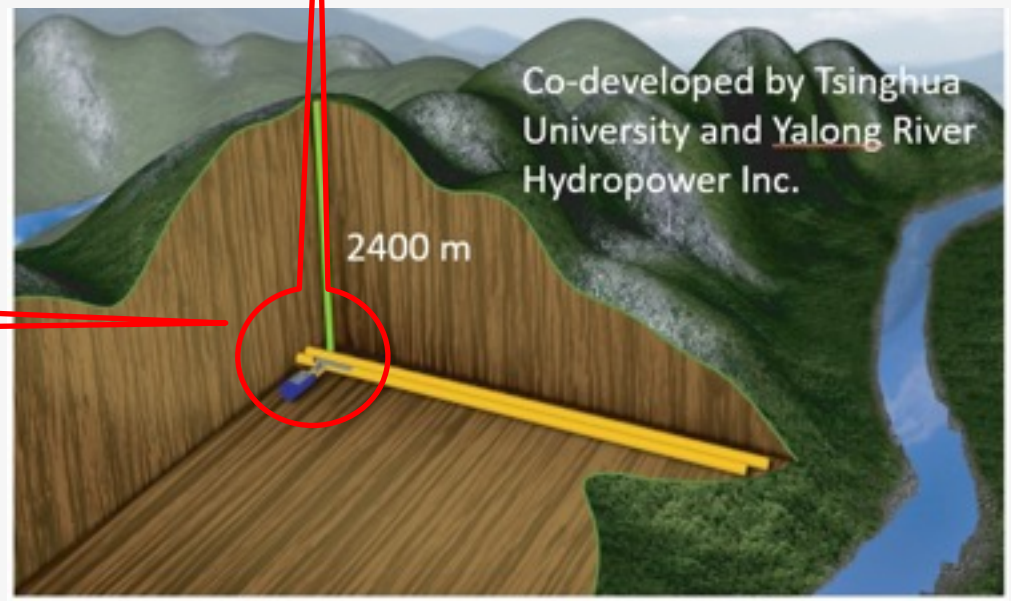
- Deepest
  - 6800 m.w.e.
  - < 0.2 muons/m^2/day
- Horizontal access
  - 9 km long tunnel





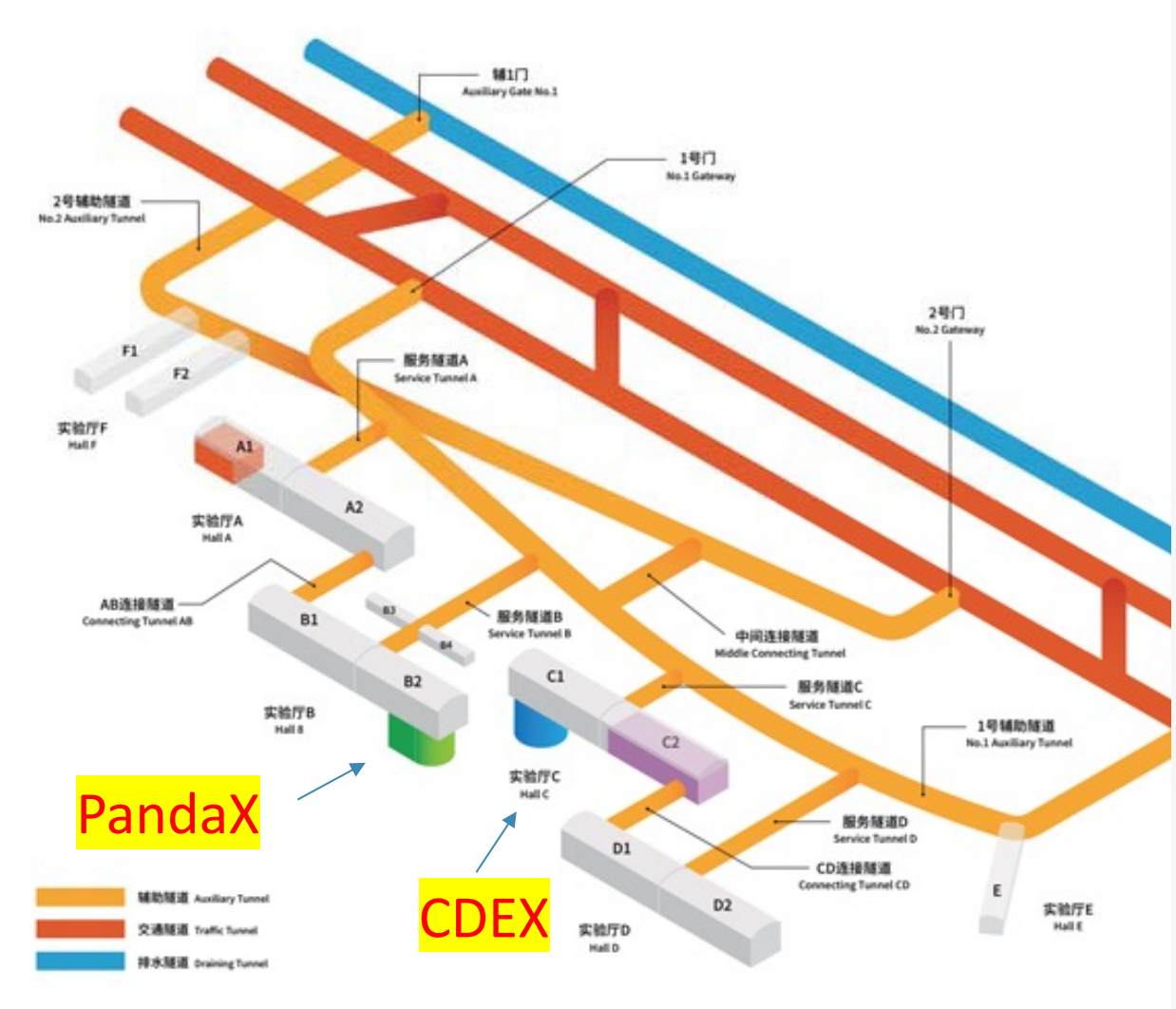






CJPL-II

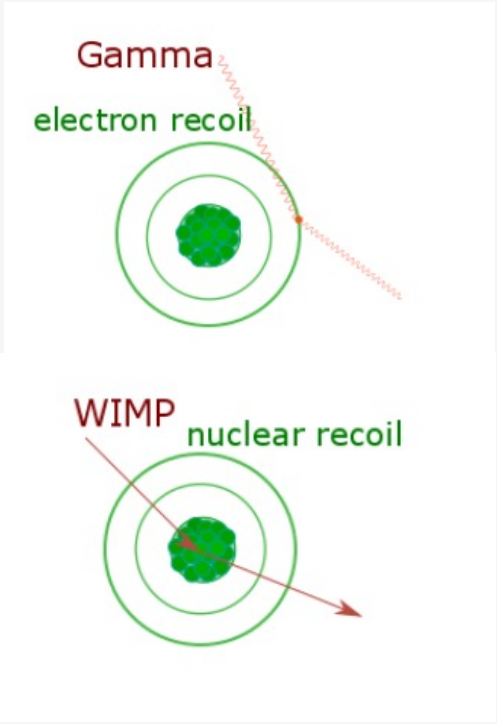
- 8 new experimental halls (L: 65m H: 14m W: 14m)
- PandaX and CDEX experiments

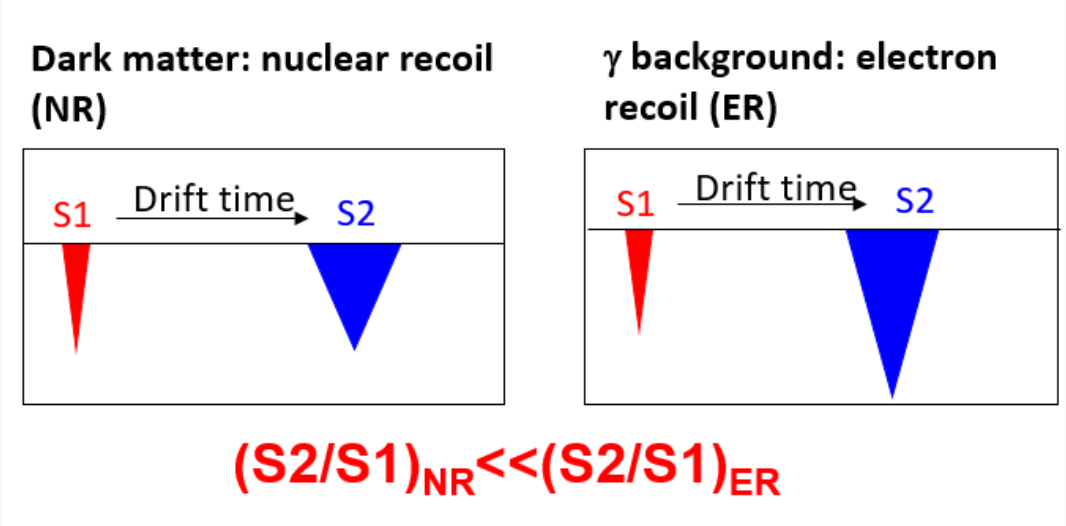


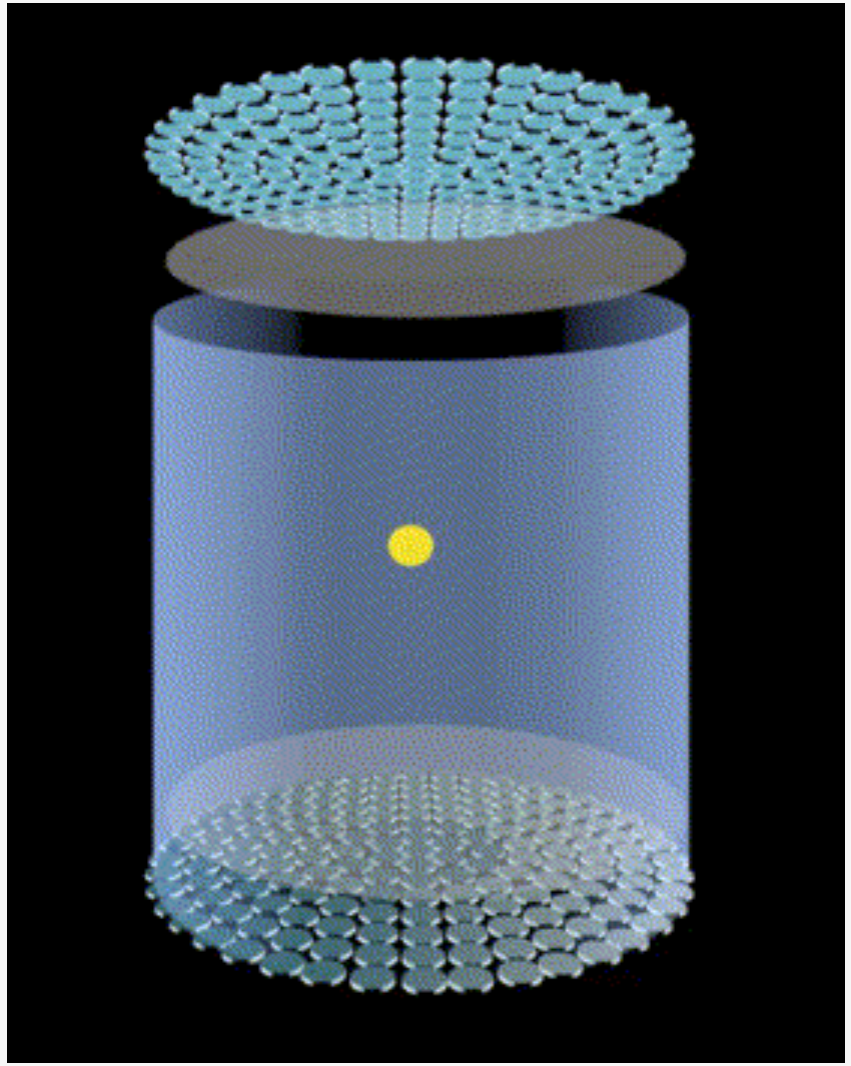
PandaX Collaboration

PandaX Detector

- Dual-phase xenon TPC
  - Scintillation light (S1) and ionized electrons (S2)
  - Precise energy and 3D-positon reconstruction
  - NR and ER discrimination power







PandaX Experiment

- **Particle and Astrophysical Xenon experiment**
  - Increase the detector sensitive target volume
  - Lower radioactive background

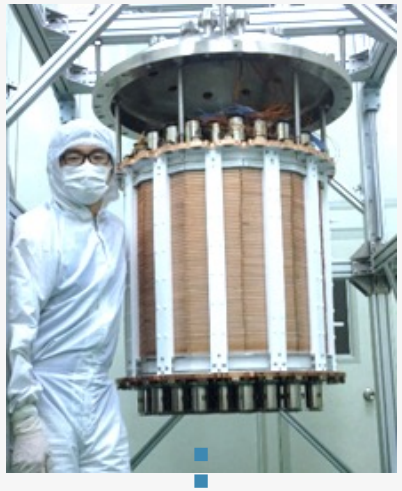
PandaX start

2009

PandaX-I
120kg

2010-2014

PandaX-II
580kg



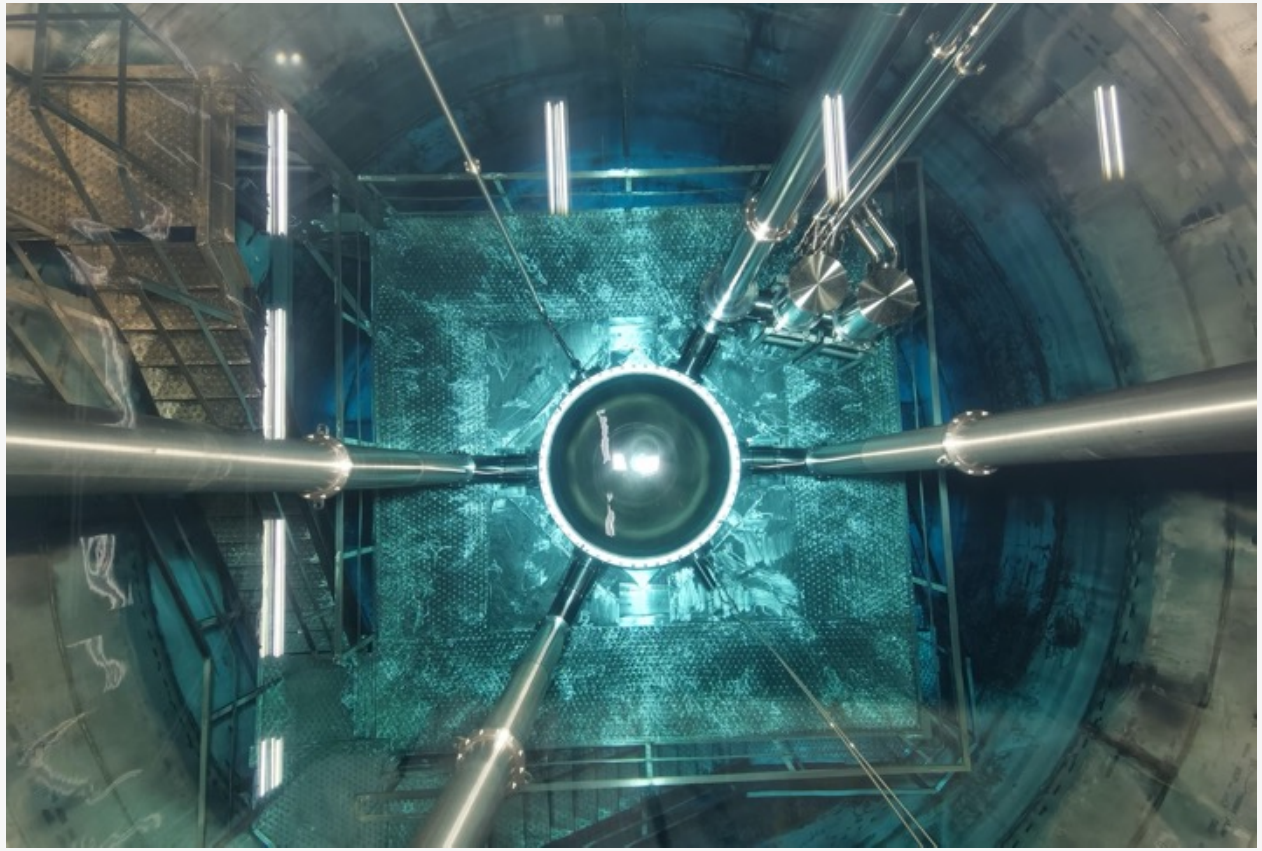
2015-2019

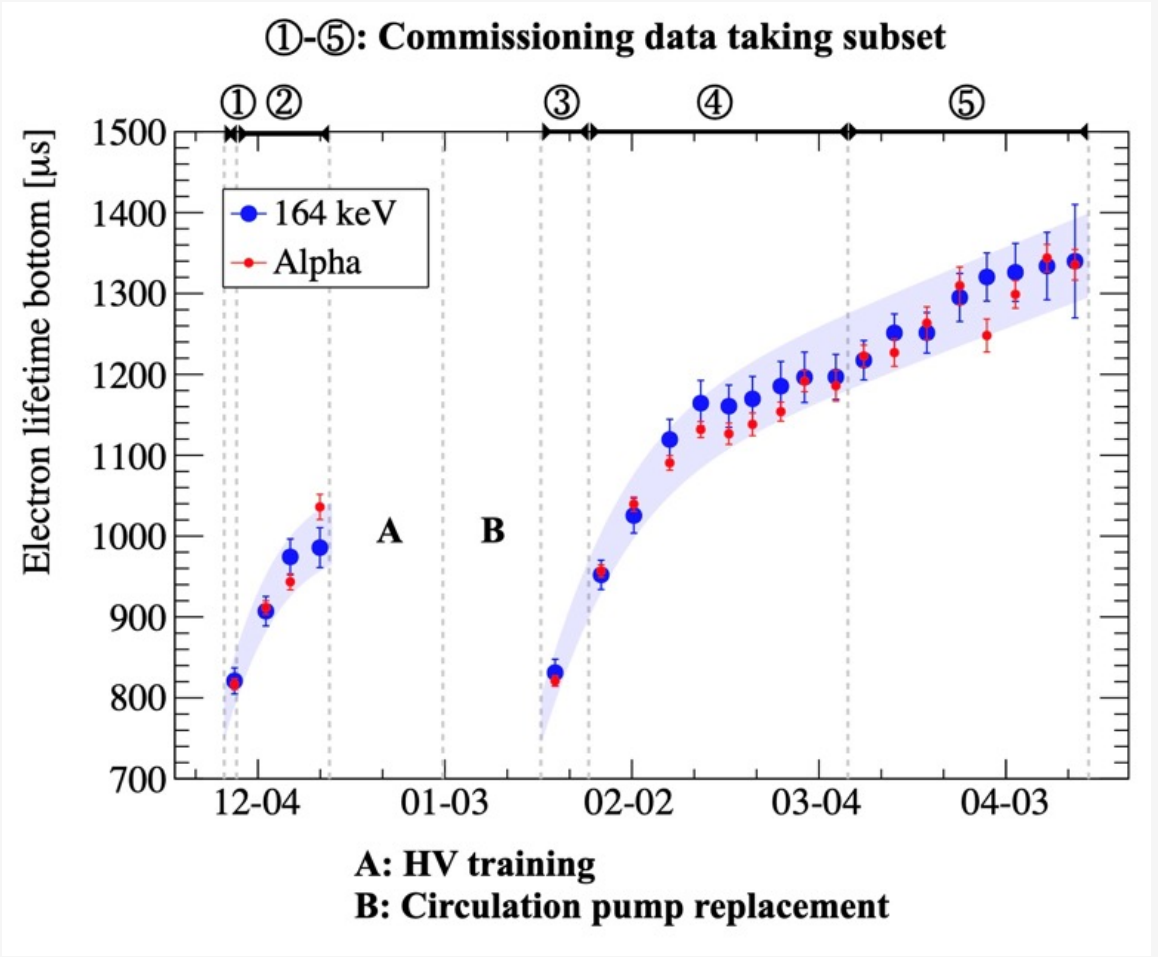
PandaX-4T
(3.7 tonne)

2020-

PandaX-4T Operation

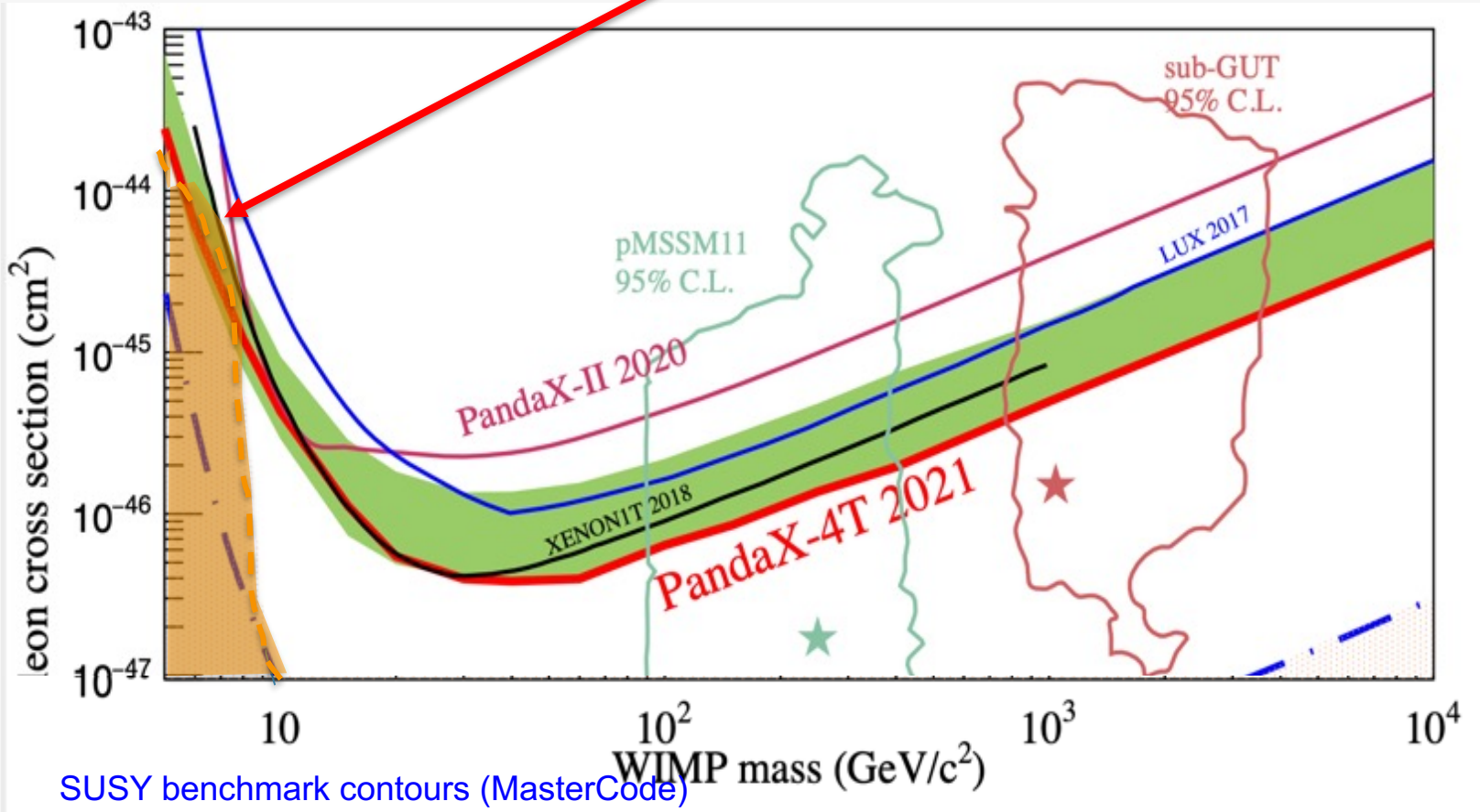
- Start physics data taking from 2020/12
- Commissioning data: 95.0 calendar days





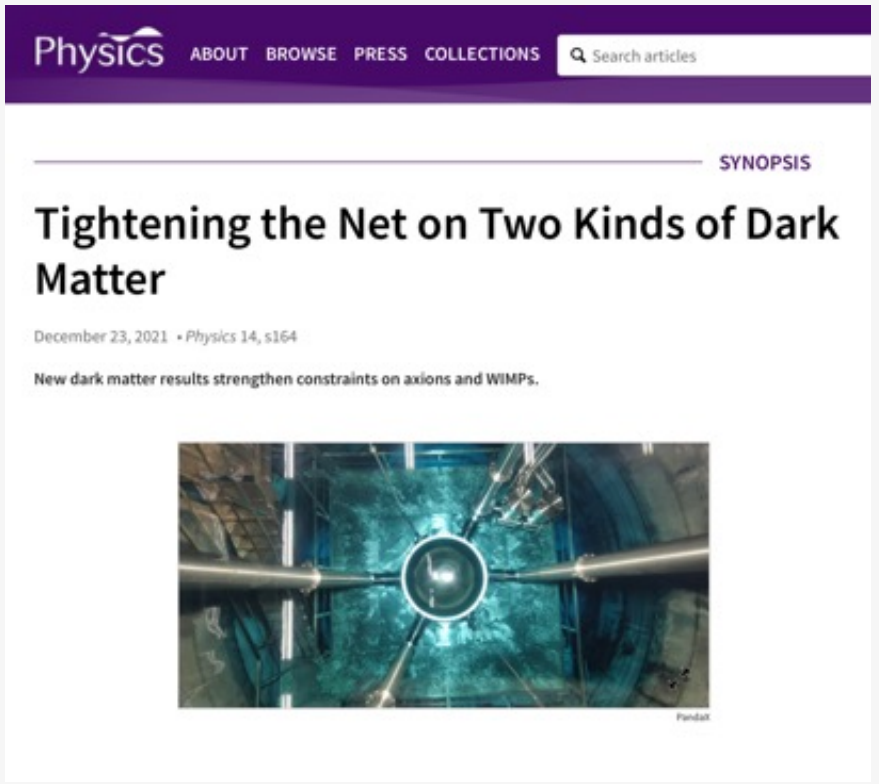
WIMP-nucleon spin-independent exclusion limits

- 0.63 tonne-year: dived into previously unexplored territory!
- Approaching the “low E” neutrino floor



SUSY benchmark contours (MasterCode)

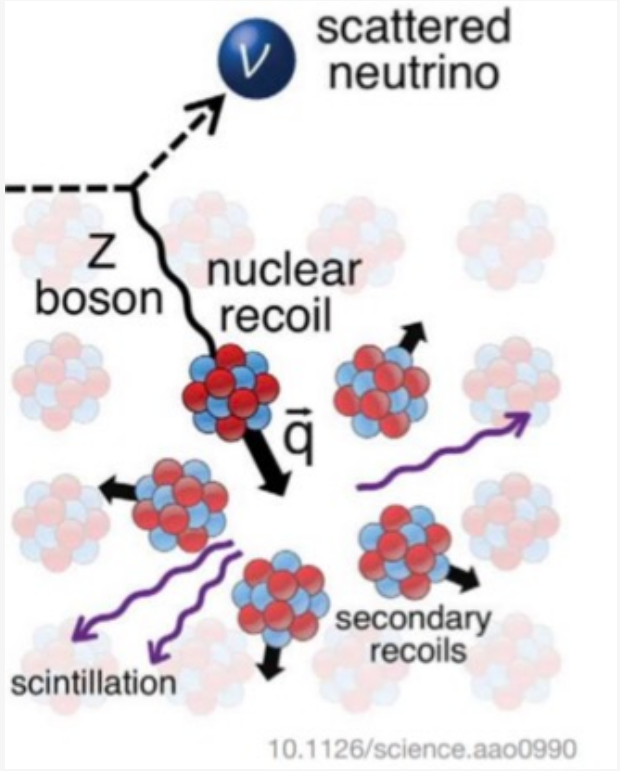
EPJC 78, no.3, 256 (2018), EPJC 78, 158 (2018)

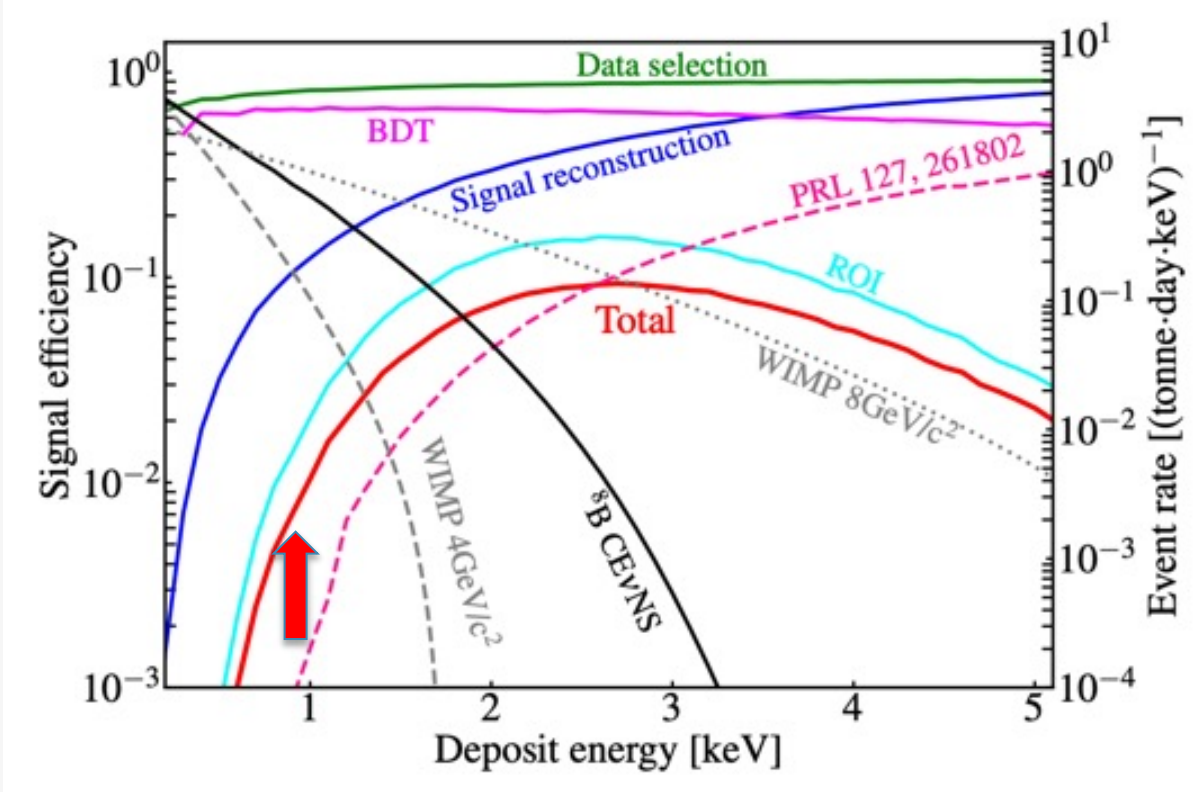


PRL 127, 261802 (2021)
Editors’ Suggestion

Neutrino Floor

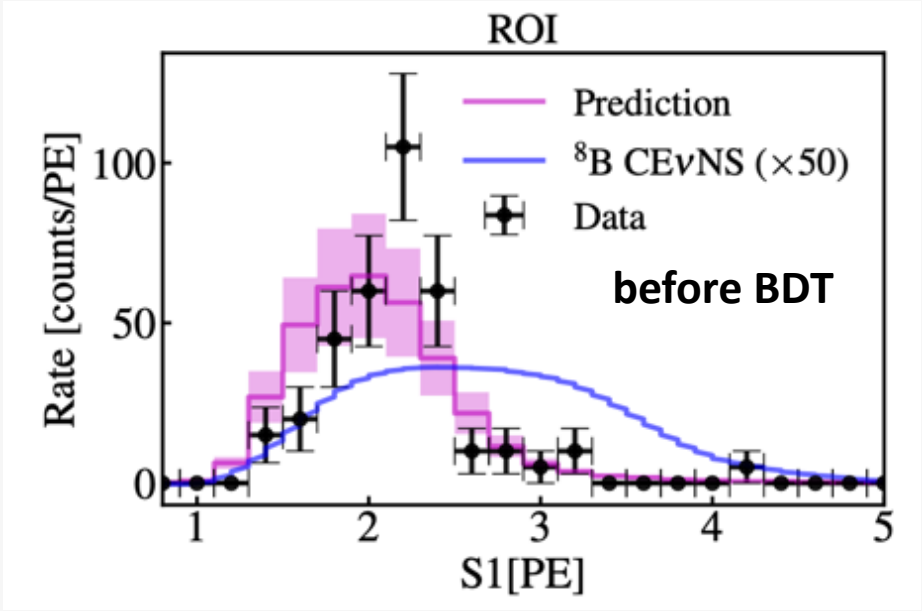
- Neutrino floor due to B8 CEvNS
- Reduce the threshold
  - Lower scintillation light (S1) signal selection threshold
  - Further optimize the quality cuts for low energy region





Data Analysis

- Dominant background: accidentally paired S1-S2
  - develop a boosted decision tree (BDT)
- Blind analysis is performed with 0.48 tonne-year data



ROI

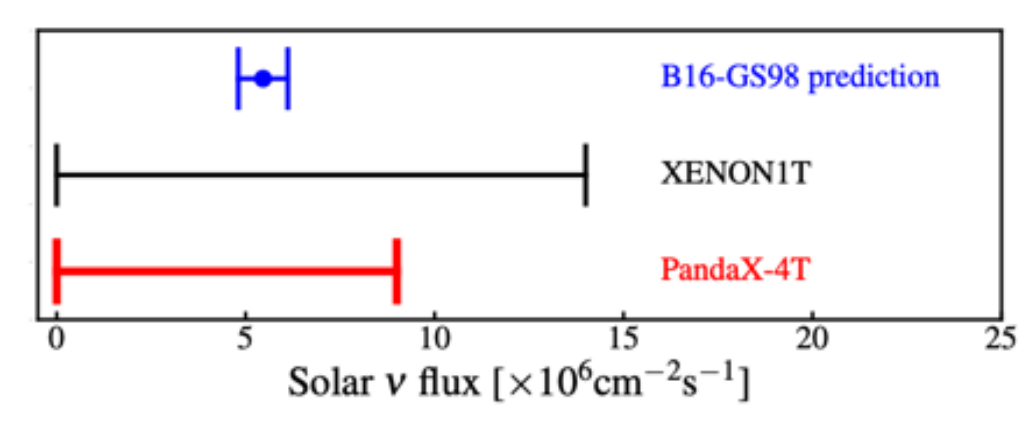
	ER+NR+AC	8B	**Total prediction**	**Unblind data**
Two Photon	62.57	2.32	**64.89**	**59**
Three Photon	0.85	0.42	**1.27**	**2**

ROI (BDT applied)

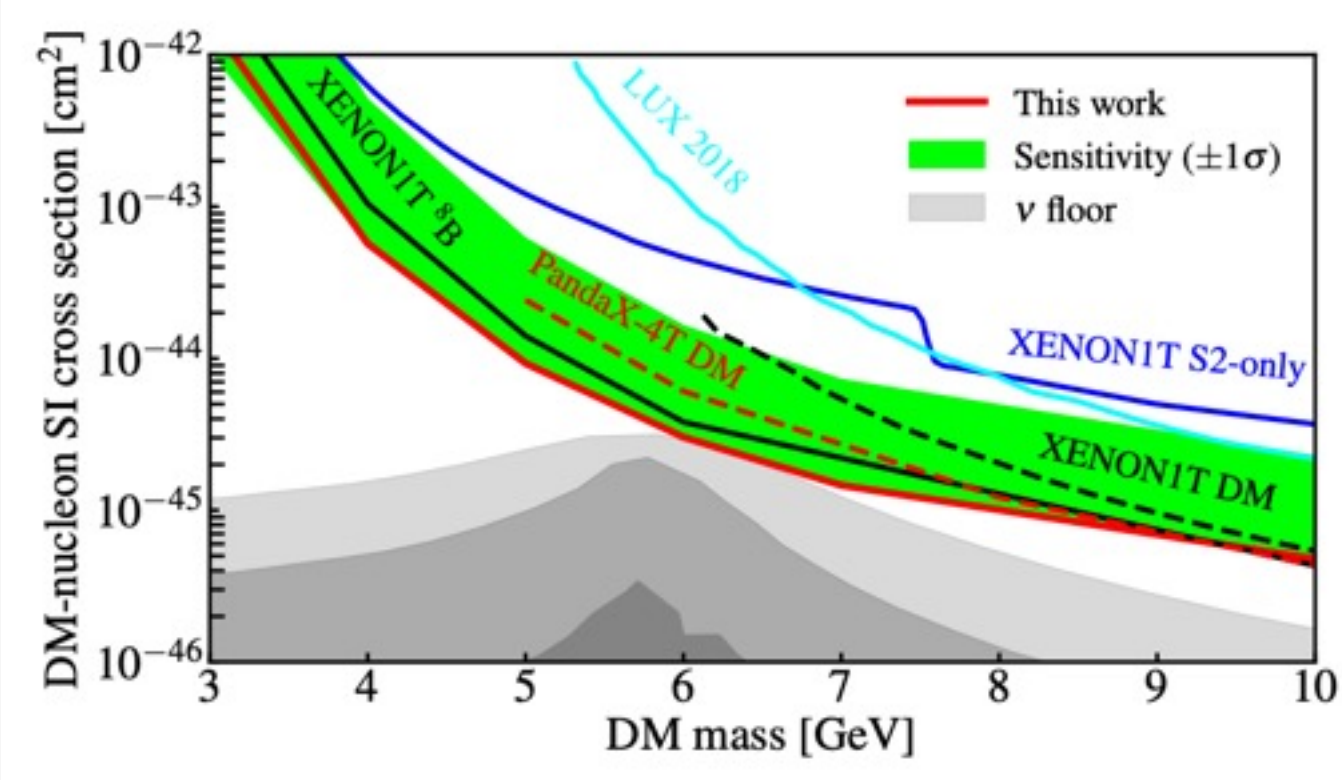
ER+NR+AC	8B	**Total prediction**	**Unblind data**
1.46	1.42	**2.88**	**1**
0.04	0.29	**0.33**	**0**

Constraints on B8 and WIMP

- Leading constraints on B8 neutrino flux through CEvNS
  - Into sensitivity of the “neutrino floor”. Can cast new insight on neutrino-nucleus interactions.
- Strongest constraints on WIMP in 3-10 GeV region



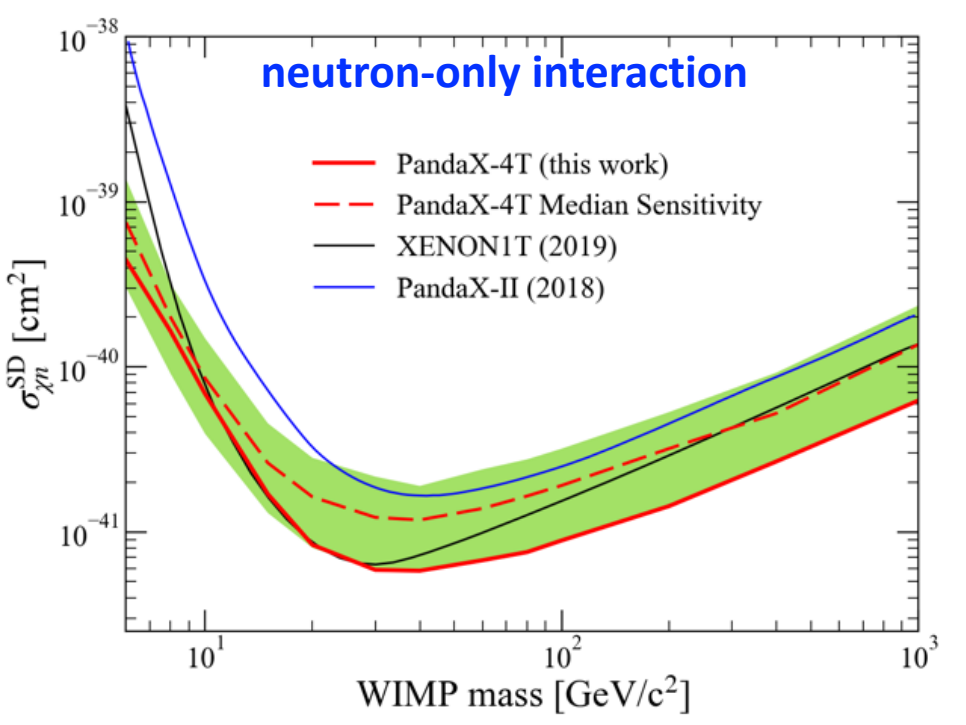
arXiv:2207.04883

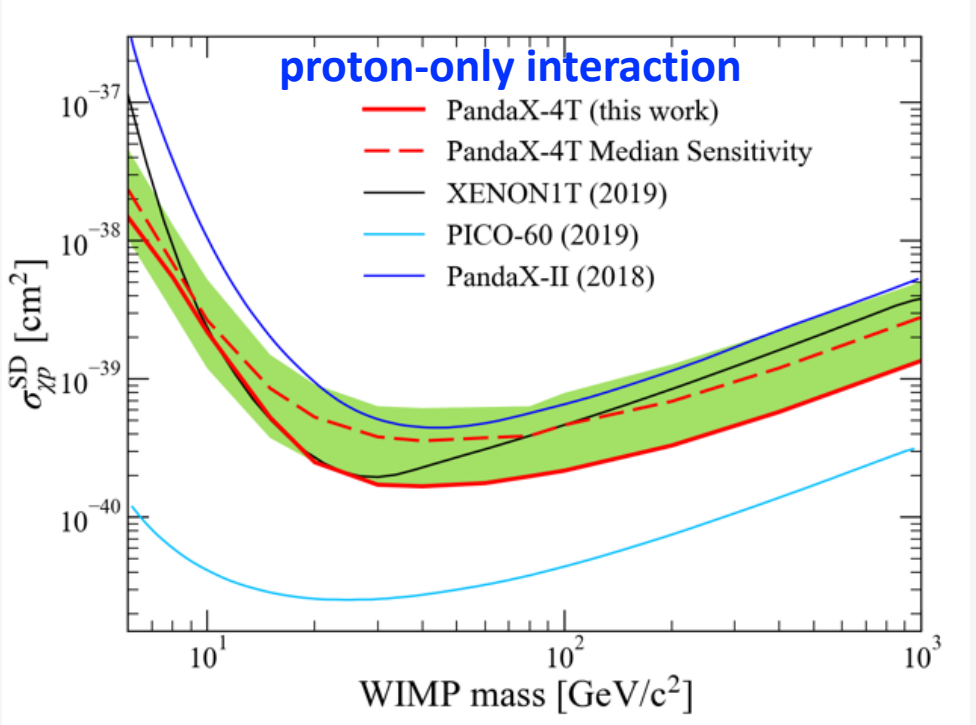


Spin-Dependent Interaction

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

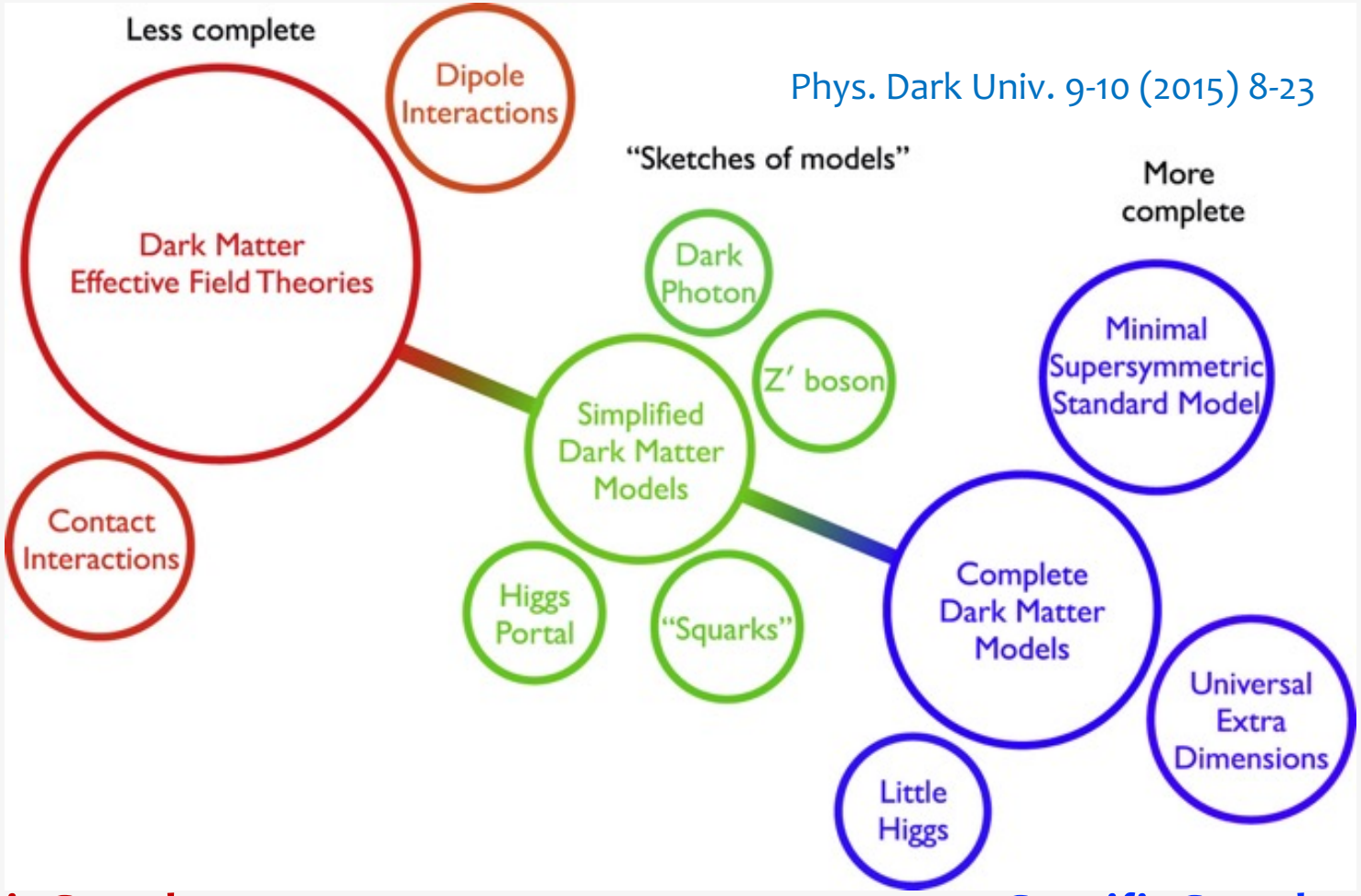
PLB 834 (2022) 137487



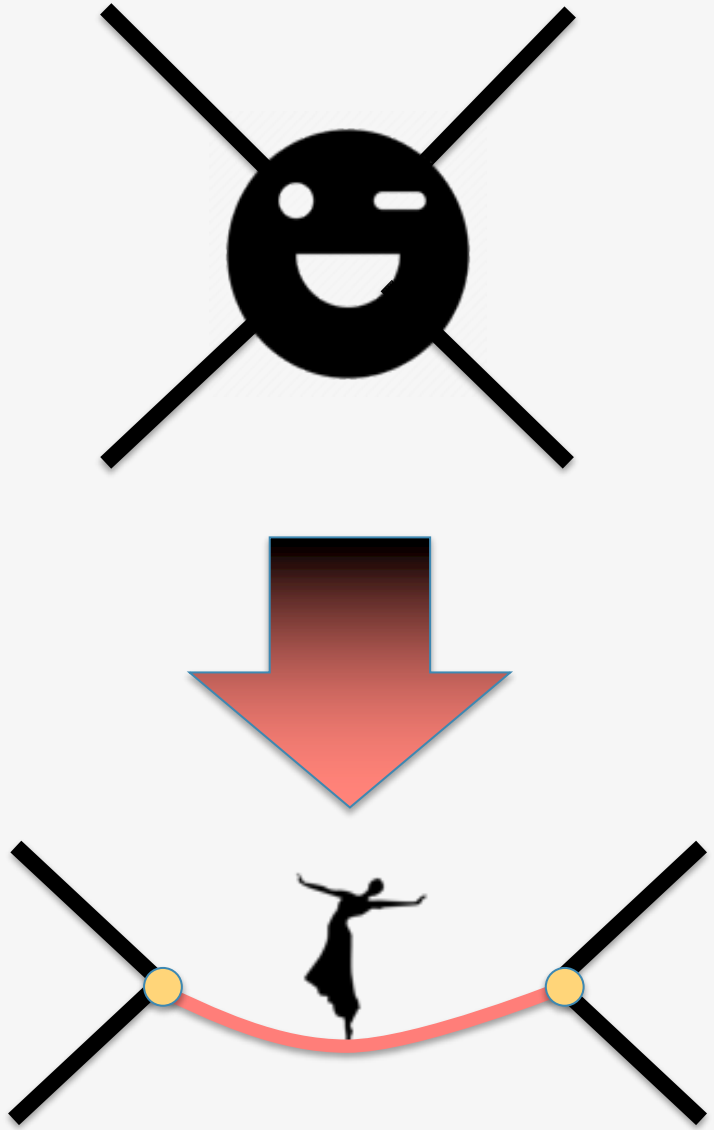


Mediator of Interaction

- Toward simplified model or UV-complete model
  - some interesting signatures come out



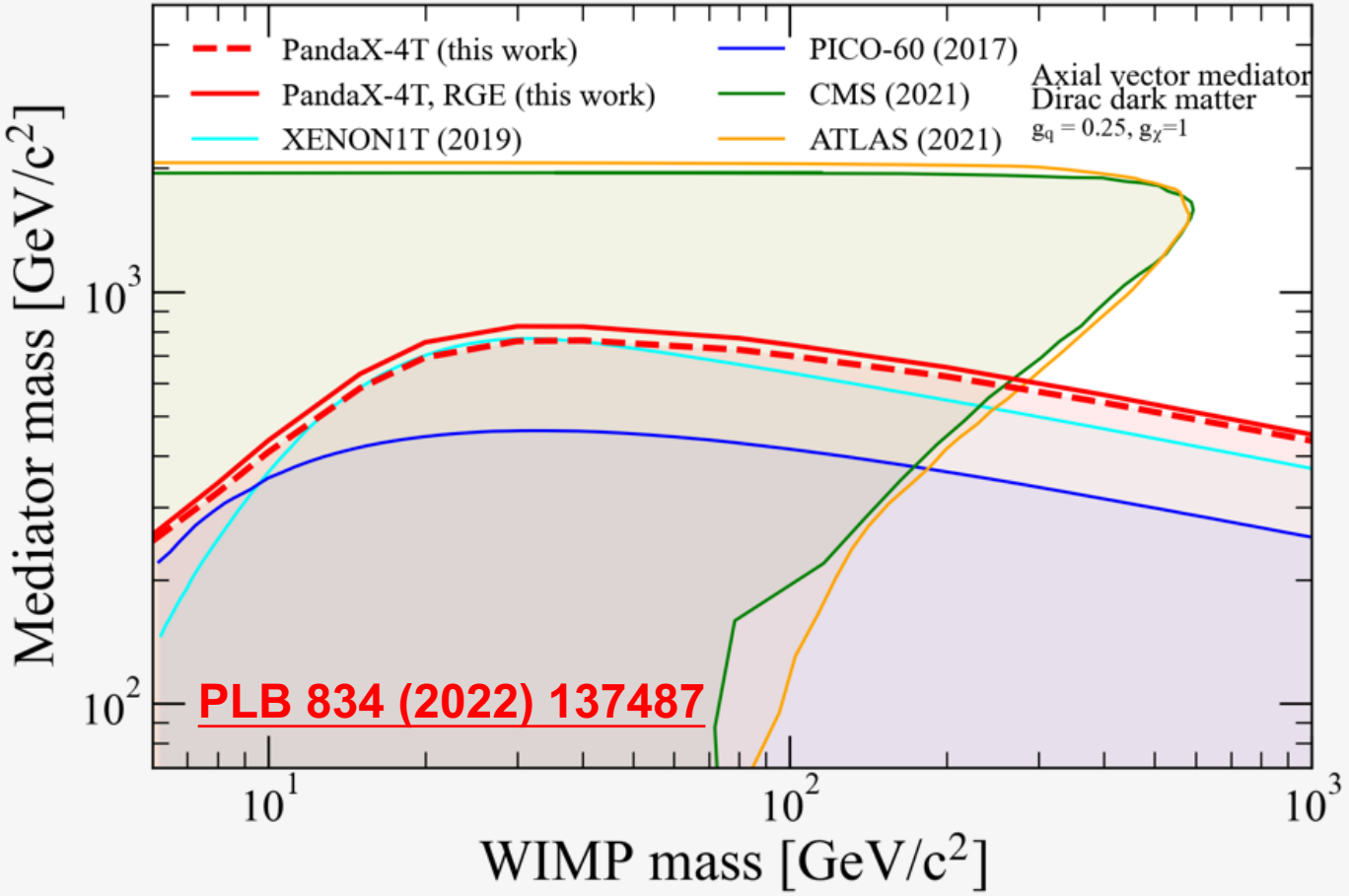
Phys. Dark Univ. 9-10 (2015) 8-23



Generic Searches ⟷ Specific Searches

Axial-vector Mediator

- Axial-vector mediator with universal couplings to quarks
- Scan mediator and WIMP mass parameters

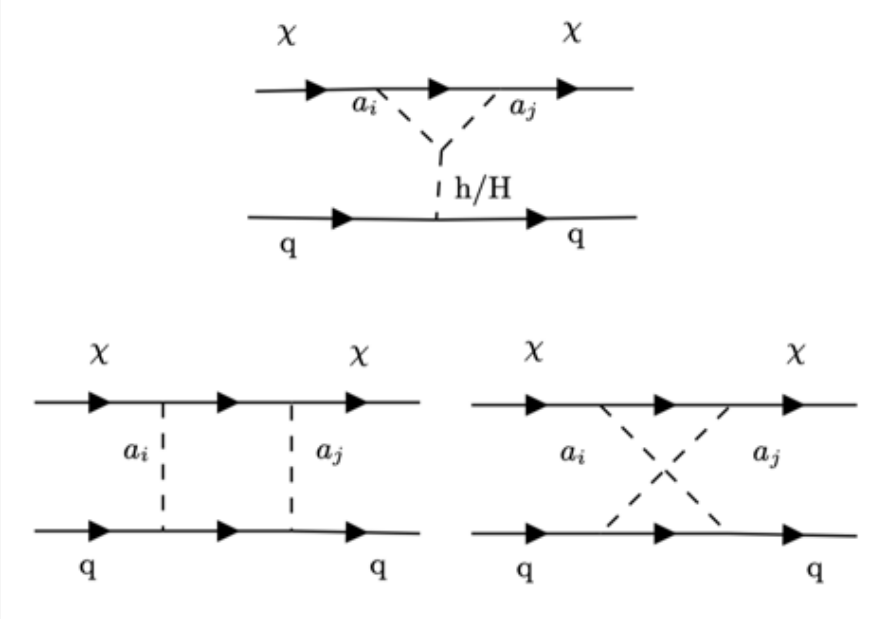


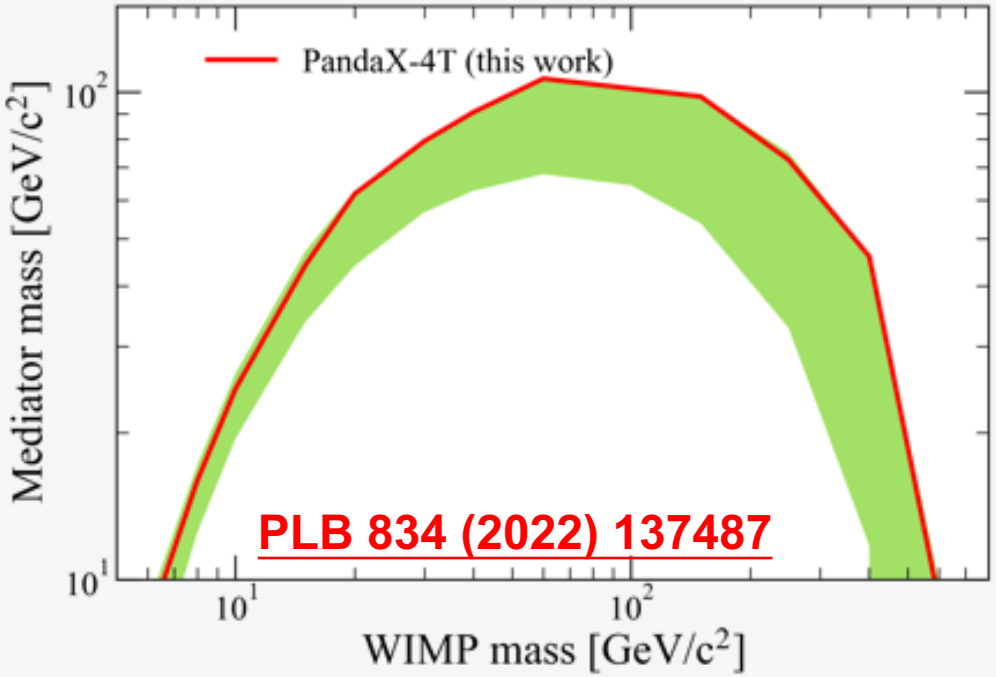
complementary information from collider search and direct detection

Pseudo-scalar Mediator

- Tree-level process: $\bar{\chi}\gamma^5\chi N\gamma^5 N \rightarrow -(\vec{S}_\chi \cdot \vec{q})(\vec{S}_N \cdot \vec{q})$ T. Li, P. Wu 1904.03407
  - momentum-suppressed spin-dependent scattering cross section
  - undetectable signal rate
- Loop-level process: spin-independent scattering
  - Example: 2HDM+a model

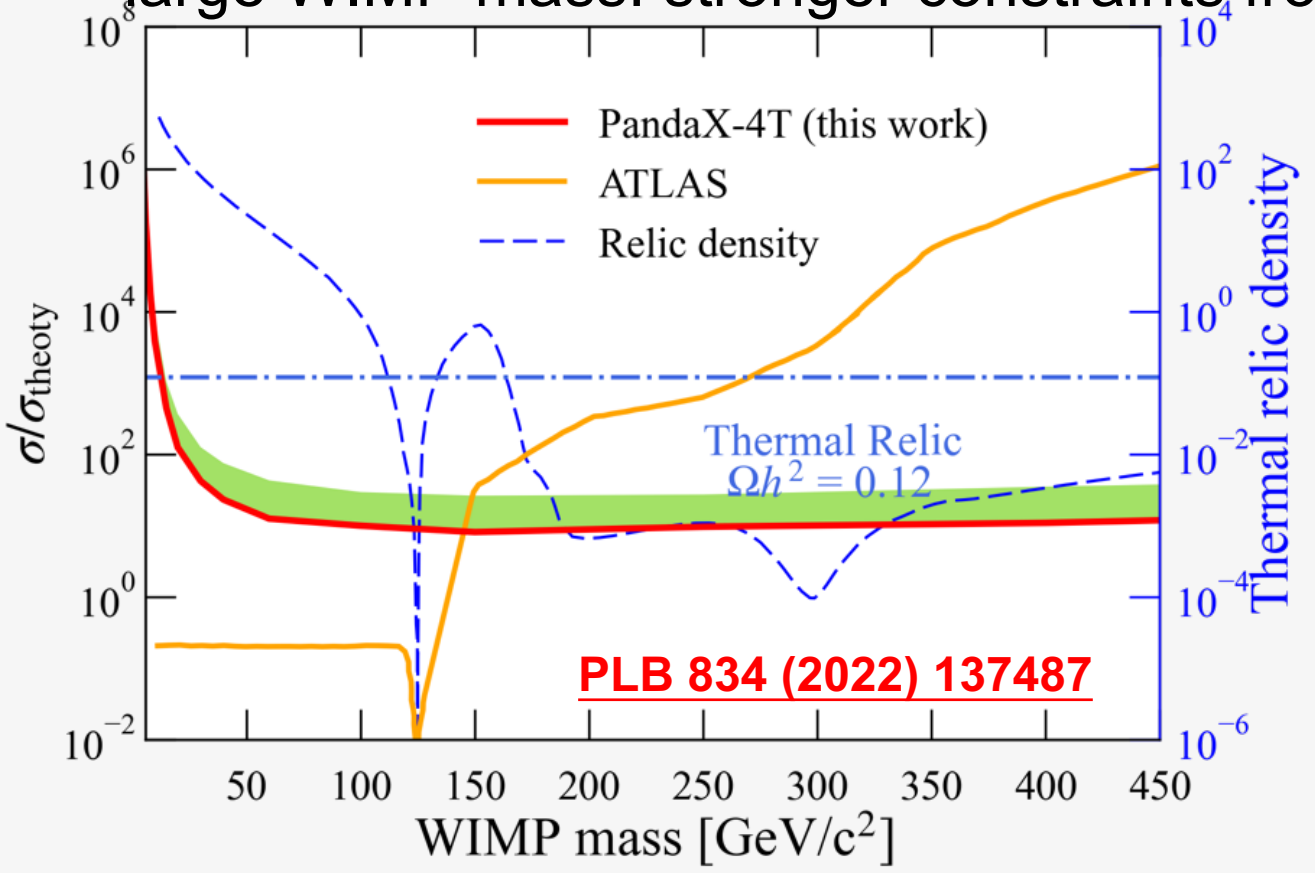
$$m_H = m_{H^\pm} = m_A = 600\ \mathrm{GeV}/c^2,$$
$$\cos(\beta-\alpha) = 0,\ \tan\beta = 1,\ \sin\theta = 0.35,$$
$$g_\chi = 1,\ \lambda_3 = \lambda_{P1} = \lambda_{P2} = 3.$$





2HDM+a Model

- For $m_a = 250$ GeV
  - small WIMP mass: excluded by ATLAS
  - large WIMP mass: stronger constraints from direct detection



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$$g_\chi = 1,\ \lambda_3 = \lambda_{P1} = \lambda_{P2} = 3.$$

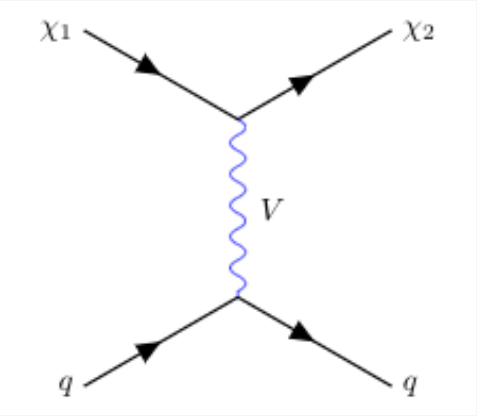
Parameters recommended by LHC DM group

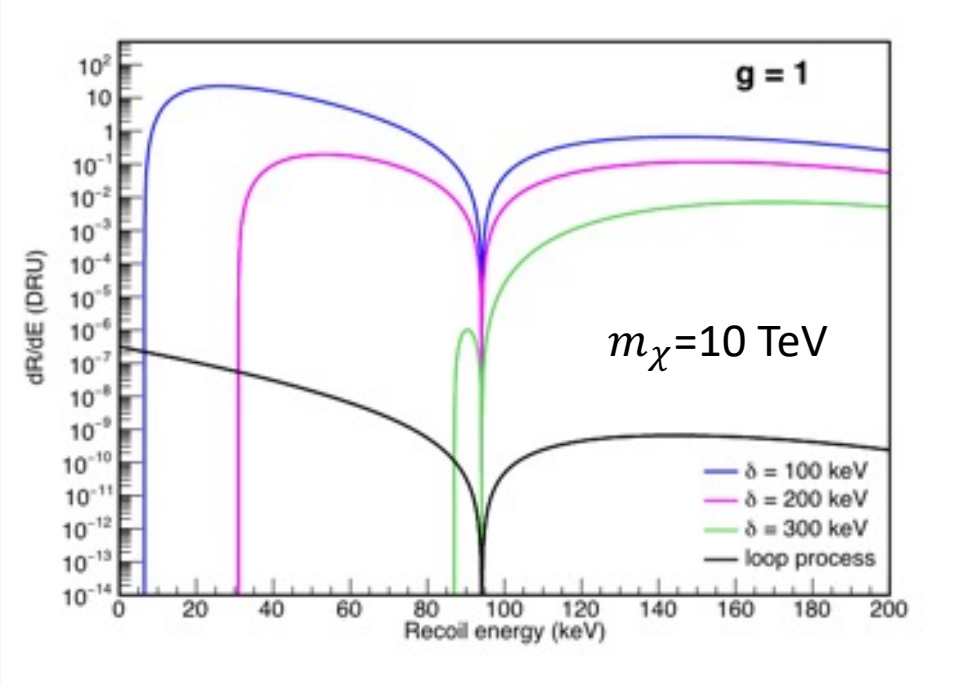
Direct detection is expected to cover the remaining parameter space in near future

Two-component Majorana DM

- A pair of dark Majorana fermions with a large Dirac mass, split by a small Majorana mass term
  - reduce the elastic scattering rate, avoid strong constraints from direct detection
  - keep enough annihilation rate
- χ_1 (DM candidate) is lighter than χ_2
  - inelastic scattering at tree-level
  - mass splitting $\delta = m_2 - m_1$
  - kinematically suppression

$$L_{\text{tree}} = \frac{g^2}{M^2}\bar{\chi}_1\gamma^\mu\chi_2\bar{q}\gamma_\mu q \rightarrow c_5^N\bar{\chi}_1\gamma^\mu\chi_2\bar{N}\gamma_\mu N$$

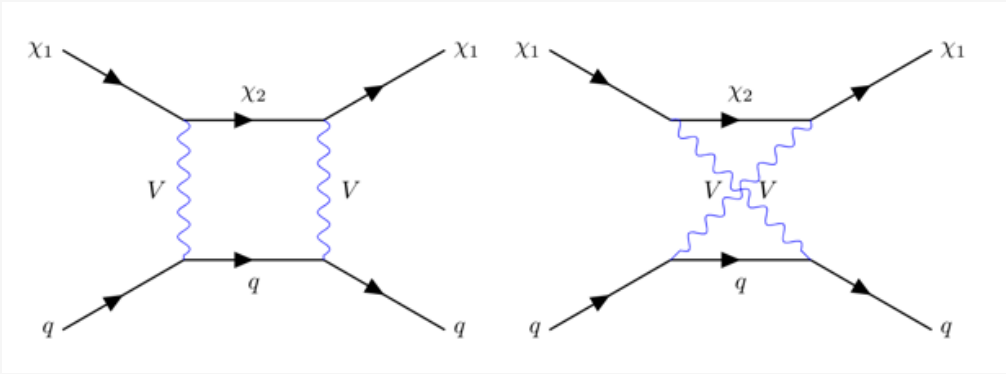




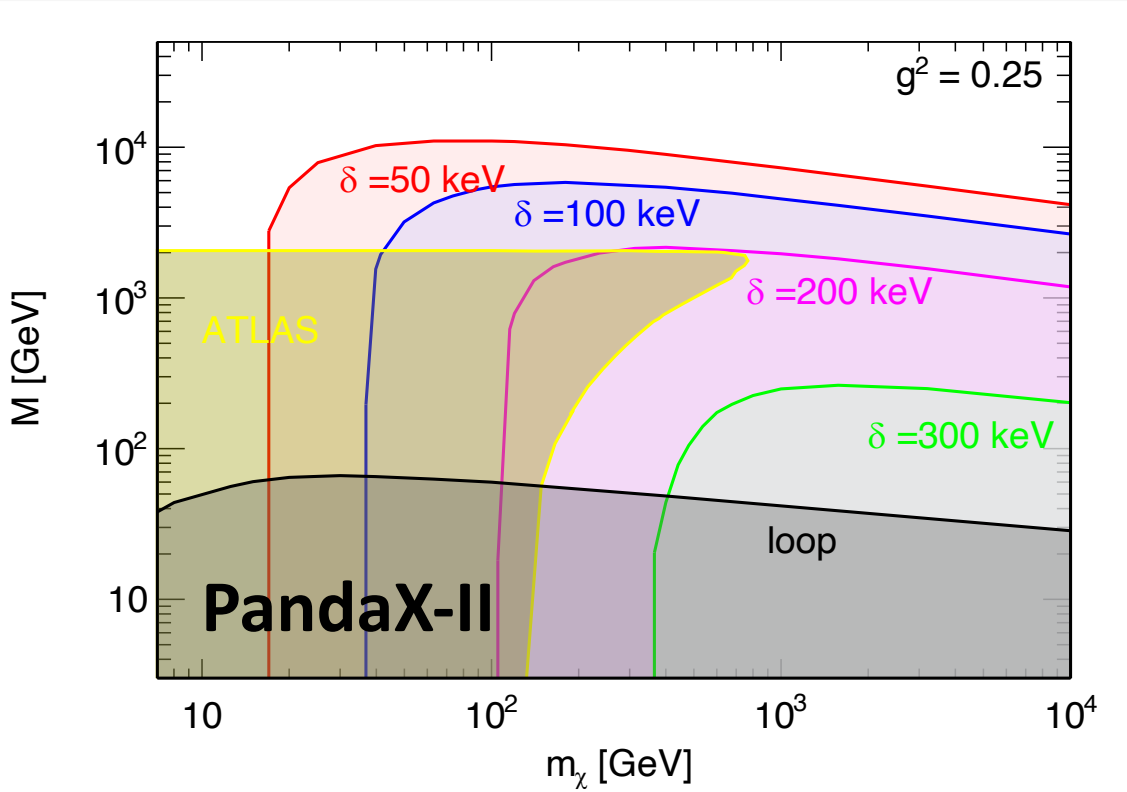
Loop Contribution

- Box diagram
  - elastic scattering, no kinematic suppression
  - but with mediator mass suppression
- Complementary to tree-level especially for large mass splitting

PLB 832 (2022) 137254

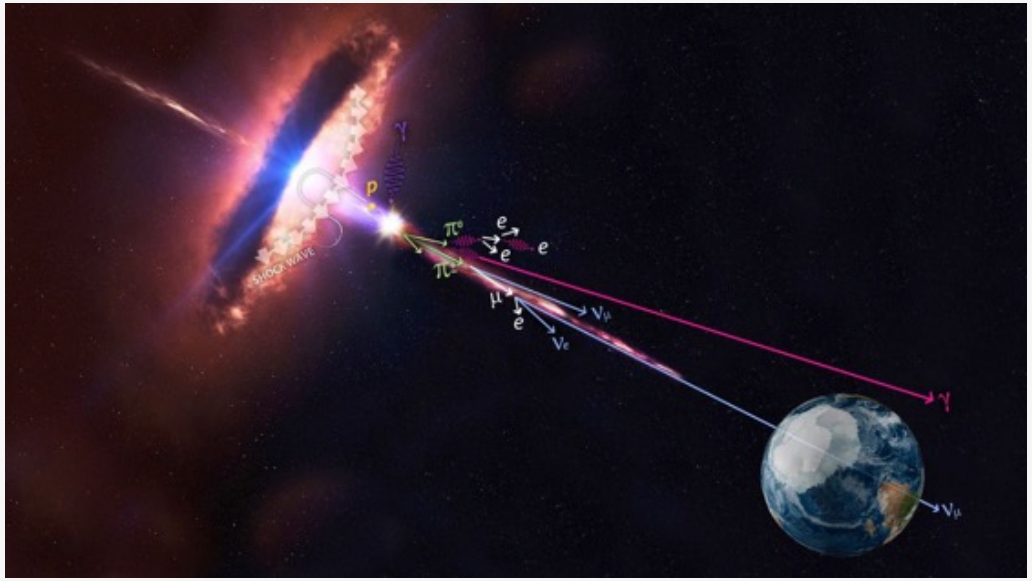


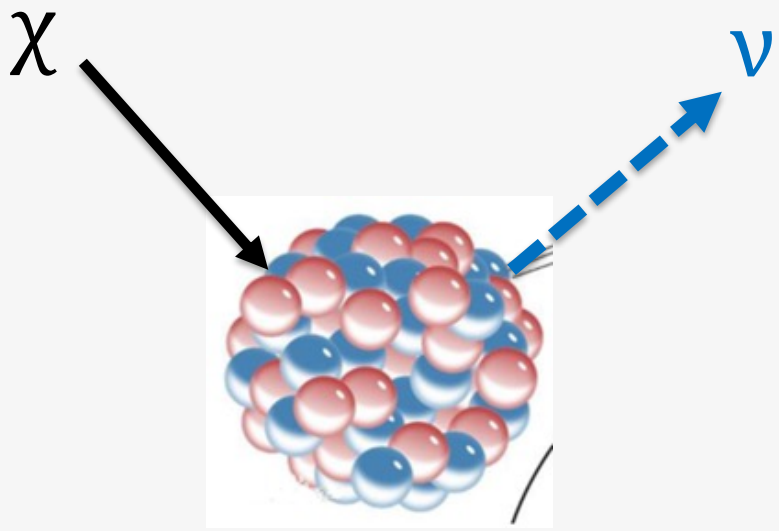
$$L_{\text{loop}} = \frac{4g^4 m_{\chi_1} m_q}{16\pi^2 M^4} F_3\left(\frac{m_{\chi_1}^2}{M^2}\right) \bar{\chi}_1 \chi_1 \bar{q} q \rightarrow c_1^N \bar{\chi}_1 \chi_1 \bar{N} N,$$

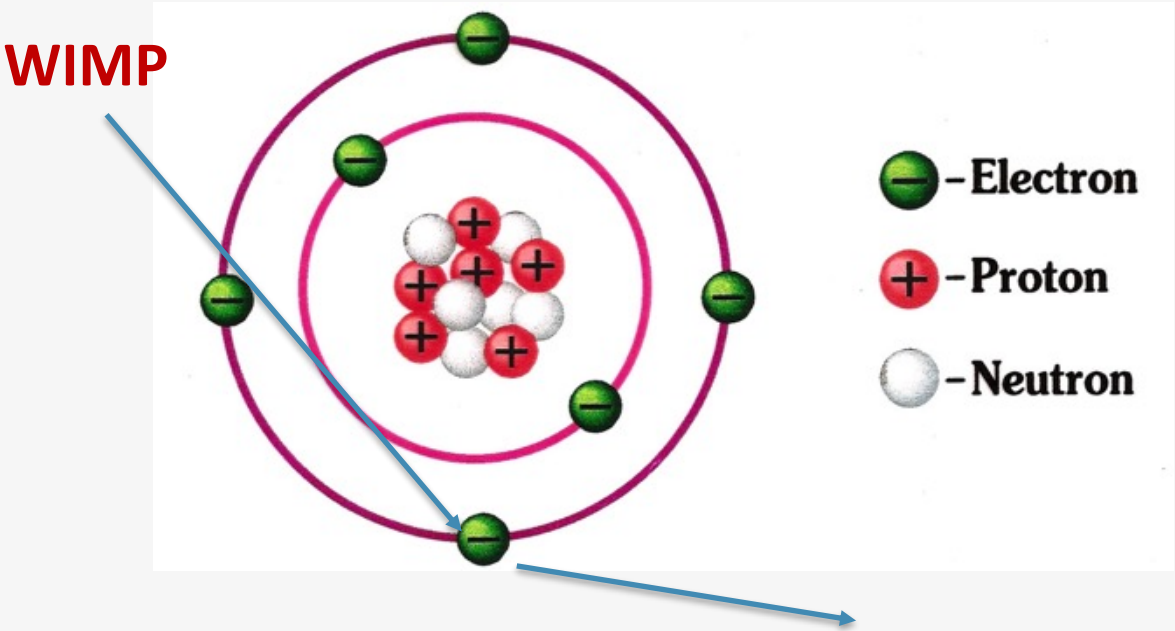


Towards sub-GeV DM

- Boosted DM
- Absorption DM
- Electron scattering
- Migdal effect

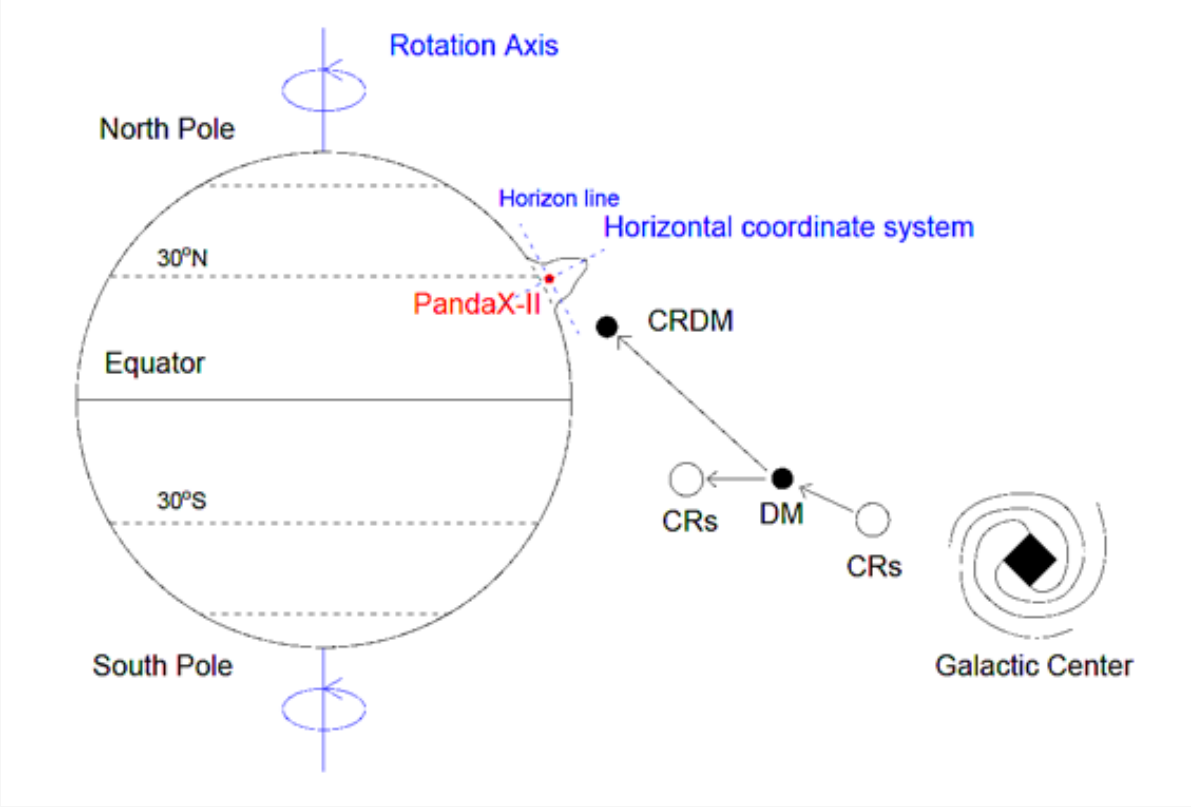


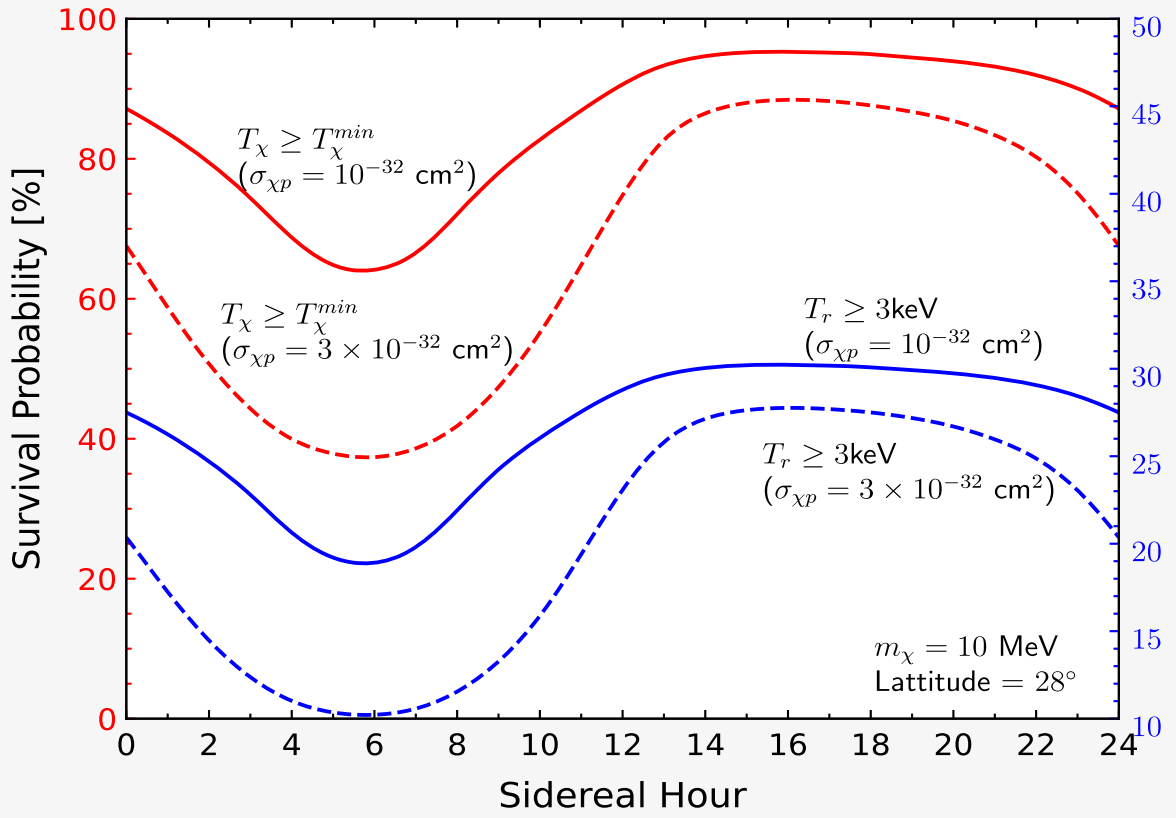




Cosmic-ray Boosted Dark Matter

- Light DM with cosmic ray boosting
- New signature: diurnal modulation due to earth shielding

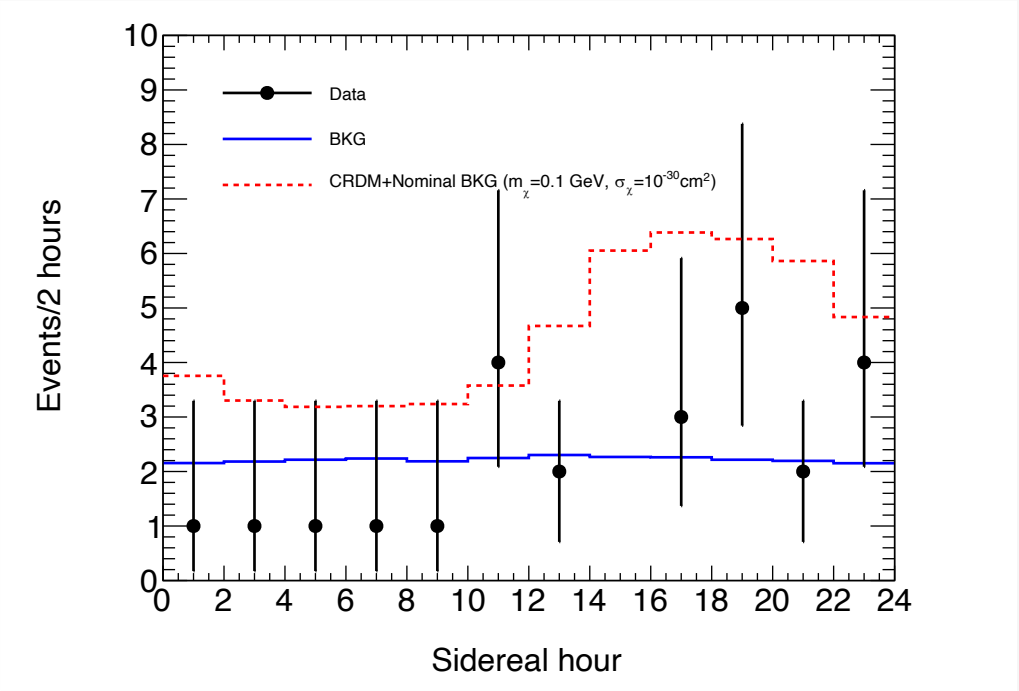


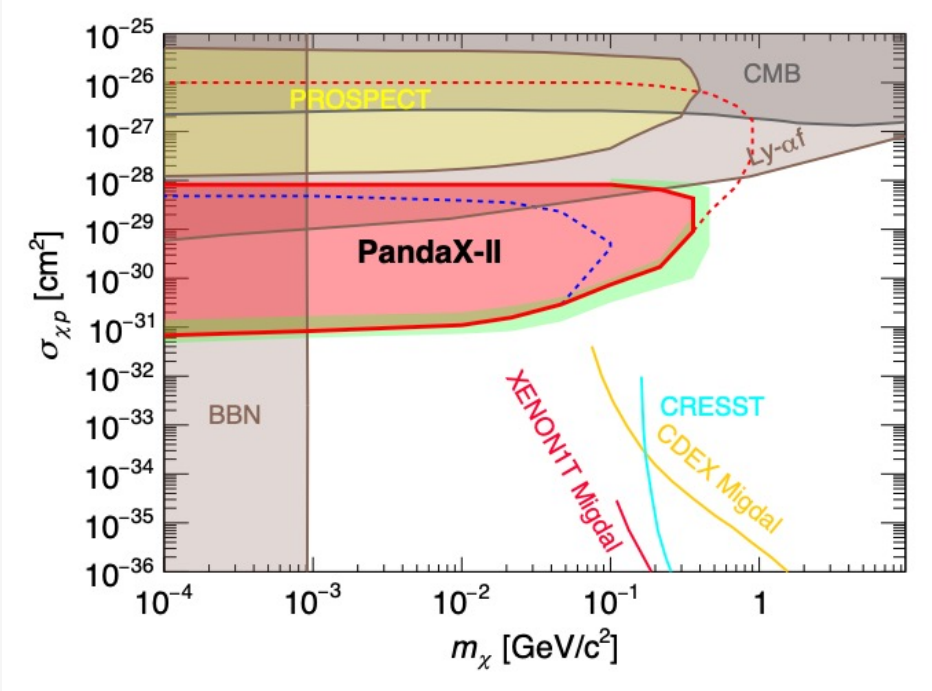


PRL 126, 091804 (2021)

Cosmic-ray Boosted Dark Matter

- PandaX-II data
  - Using events below NR median: 25 events (expected 26.6 background)
- Extend the DM search window to sub-GeV
  - Expand to the region beyond the astrophysical and cosmological probes





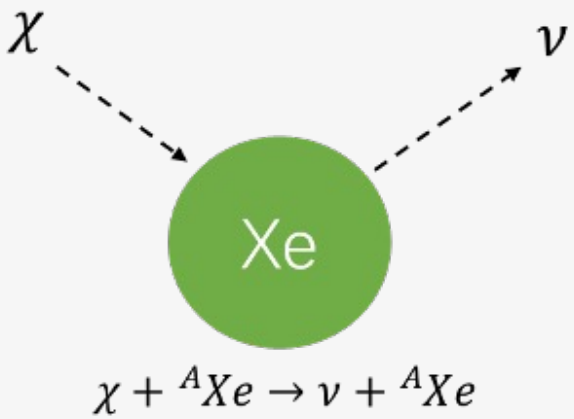
PRL 128, 171801 (2022) Editors' Suggestion

Absorption DM-nucleon Interaction

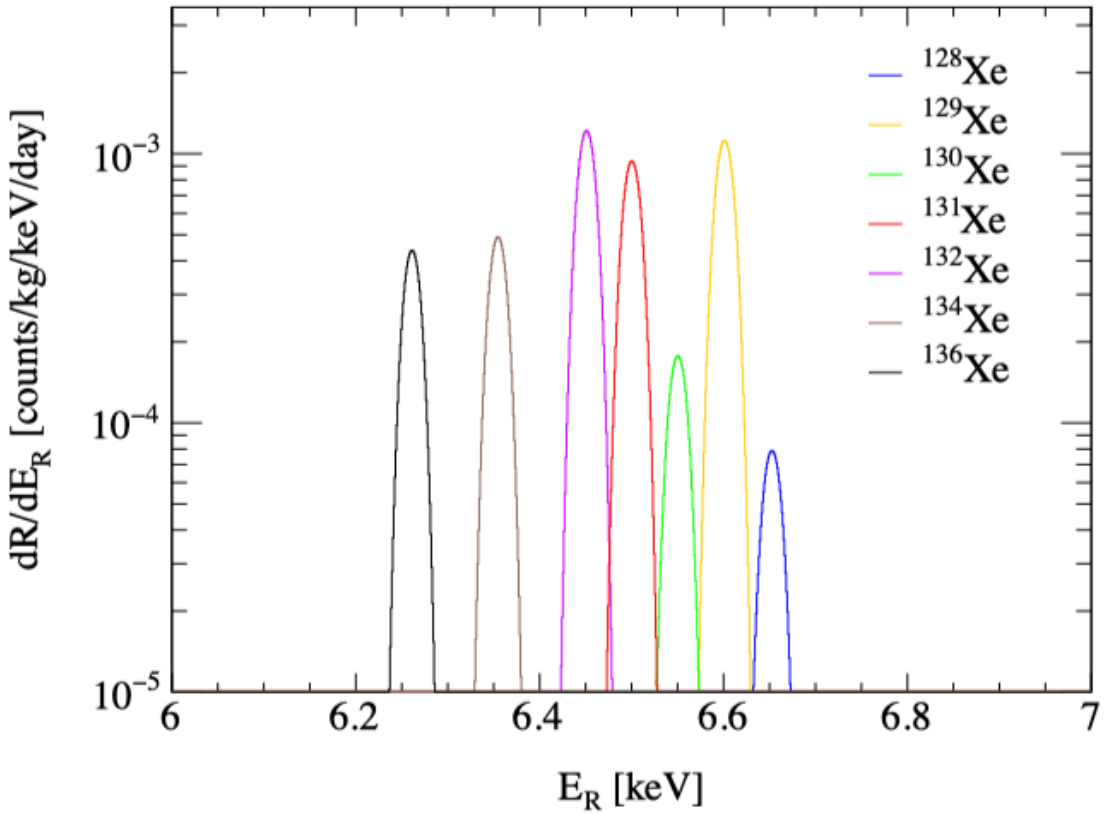
- Dark matter is mixed with right-handed neutrino
- DM-nucleus interaction
  - incoming DM absorption

$$\overset{(-)}{\chi} + {}^{A}\mathrm{Xe} \rightarrow \overset{(-)}{\nu} + {}^{A}\mathrm{Xe}$$

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



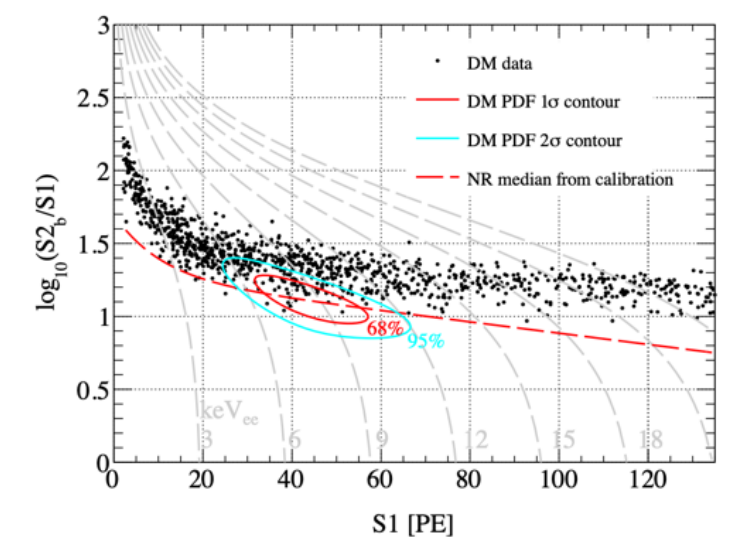
$\chi + {}^{A}Xe \rightarrow \nu + {}^{A}Xe$



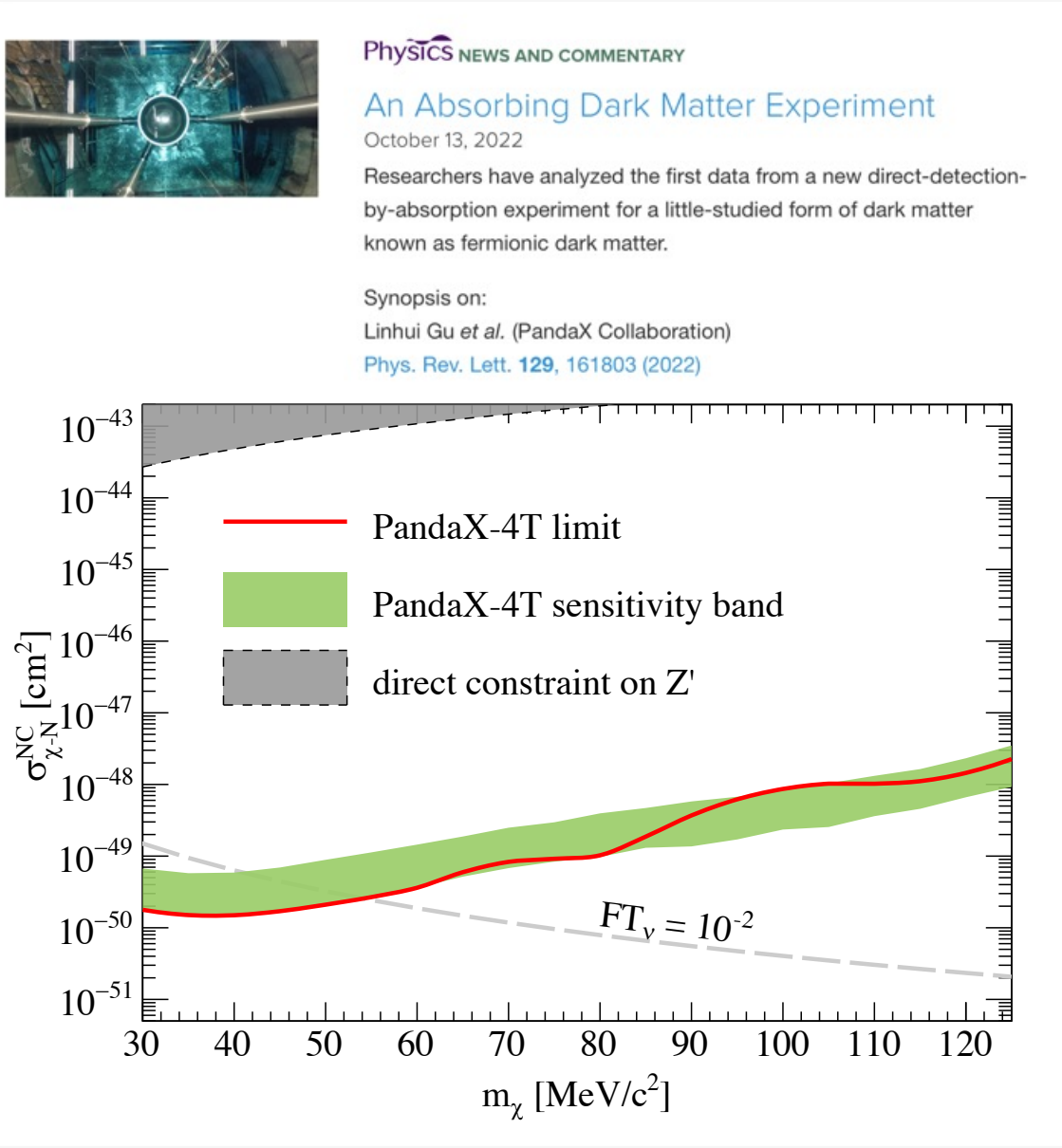
J. Dror, G. Elor, R. McGehee, PRL 2020

Absorption DM-nucleon Interaction

- First mono-energetic NR signal search



- PandaX-4T gives extreme strong constraints on sub-GeV DM
  - reaching 10^{-50} cm^2

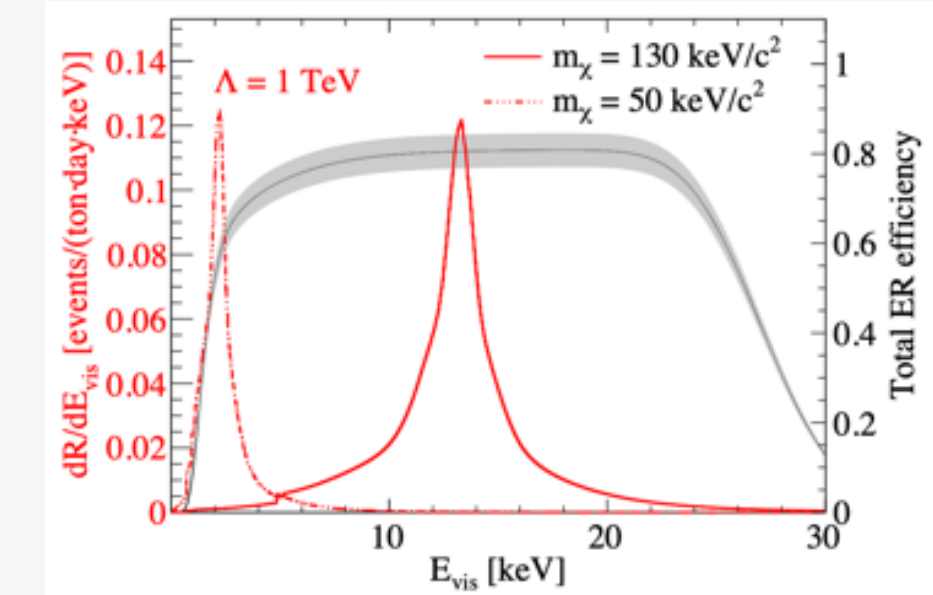


PRL 129, 161803 (2022) Editors' Suggestion

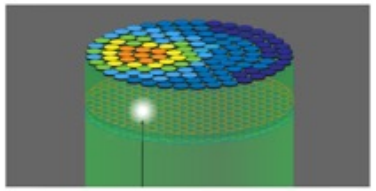
Absorption DM-electron Interaction

$\chi e \rightarrow e\nu$

- A general Fermionic dark matter absorption on electron
  - Similar signal as search for keV sterile neutrino DM in direct detection
- Challenging XENON1T low energy excess



PRL 129, 161804 (2022)



Physics NEWS AND COMMENTARY

Potential Dark Matter Signal Gives Way to New Limits

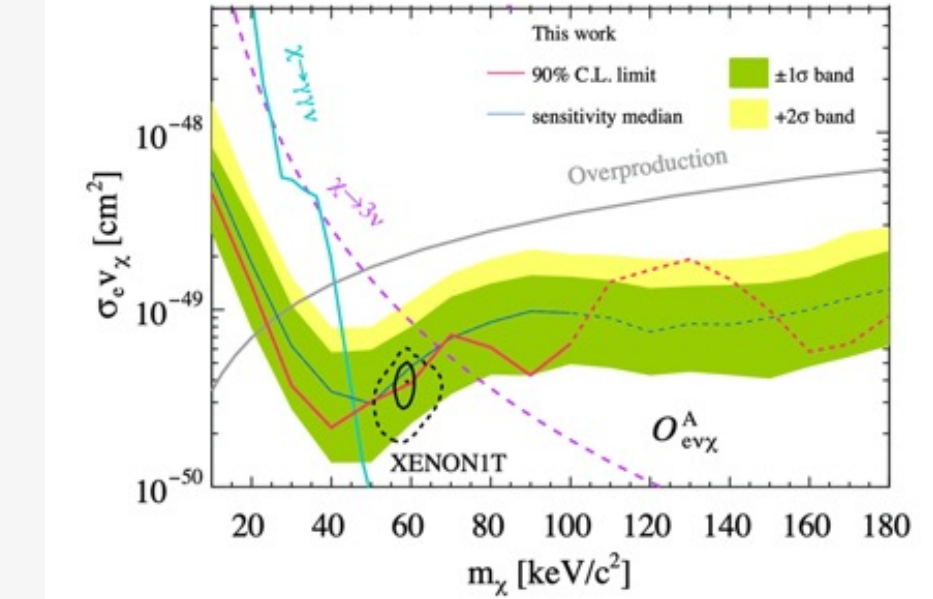
October 13, 2022

Results from two leading dark matter experiments—XENONnT and PandaX-4T—rule out an enigmatic signal detected in 2020 and set new constraints on dark matter particle candidates consisting of light fermions, respectively.

Feature on:

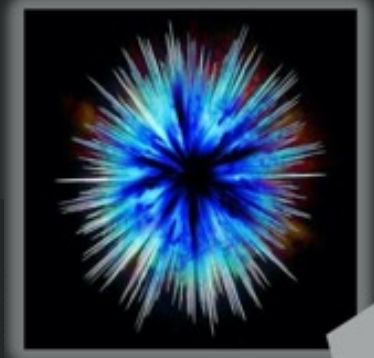
E. Aprile *et al.* (XENON Collaboration)
Phys. Rev. Lett. **129**, 161805 (2022)

Dan Zhang *et al.* (PandaX Collaboration)
Phys. Rev. Lett. **129**, 161804 (2022)



Multi-physics Goal

dark matter
1– 30 keVee

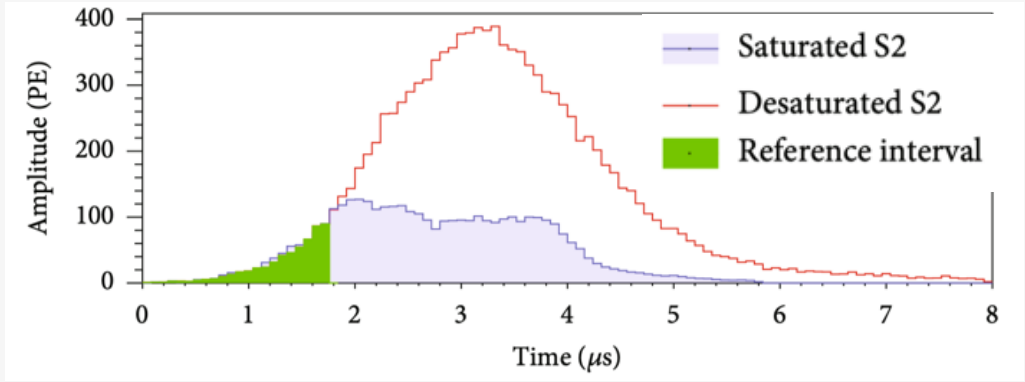


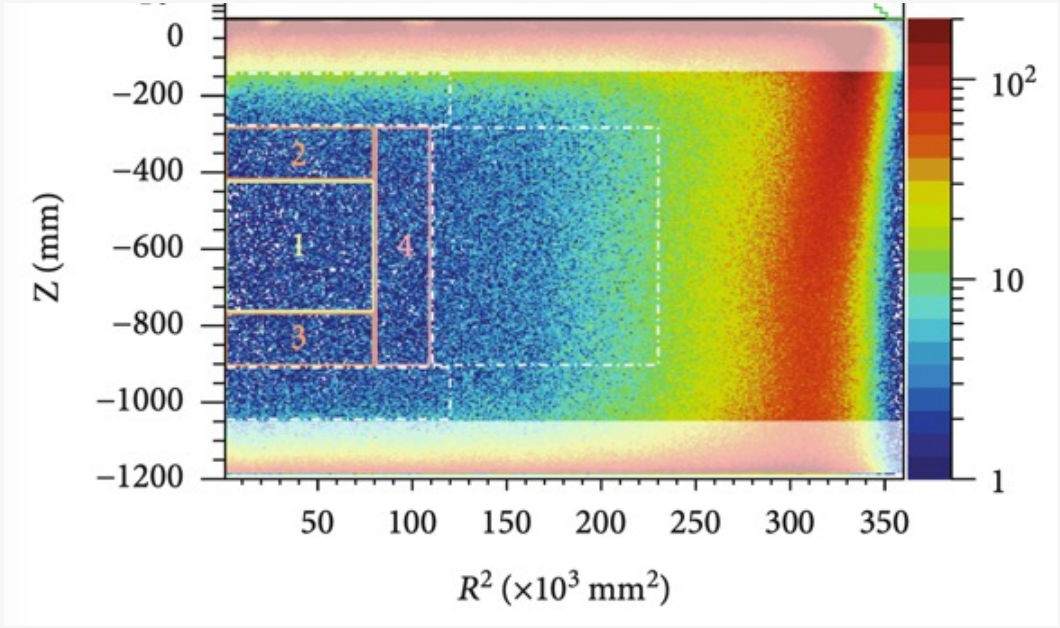
0vDBD
> 2MeVee

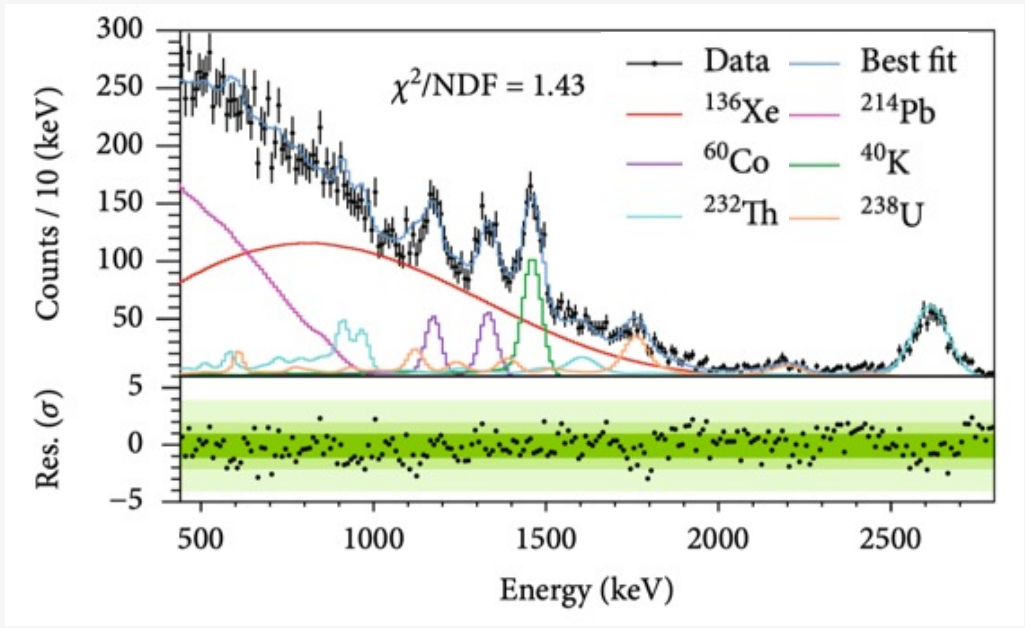
Astro neutrino
< 200 keVee

^{136}Xe 2vDBD Lifetime Measurement

- Energy window [440, 2800] keV
  - PMT desaturation algorithm
  - Multi-site vs single-site discrimination
- Fiducial volume: 4 regions
  - Robust estimation of backgrounds



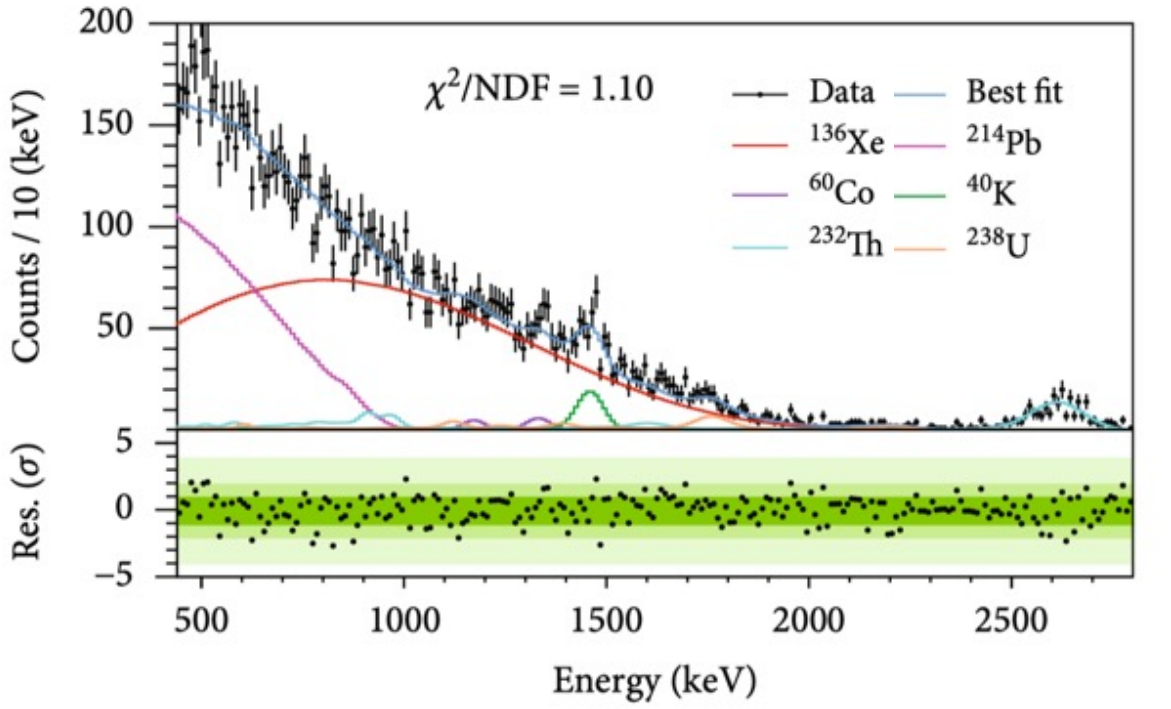


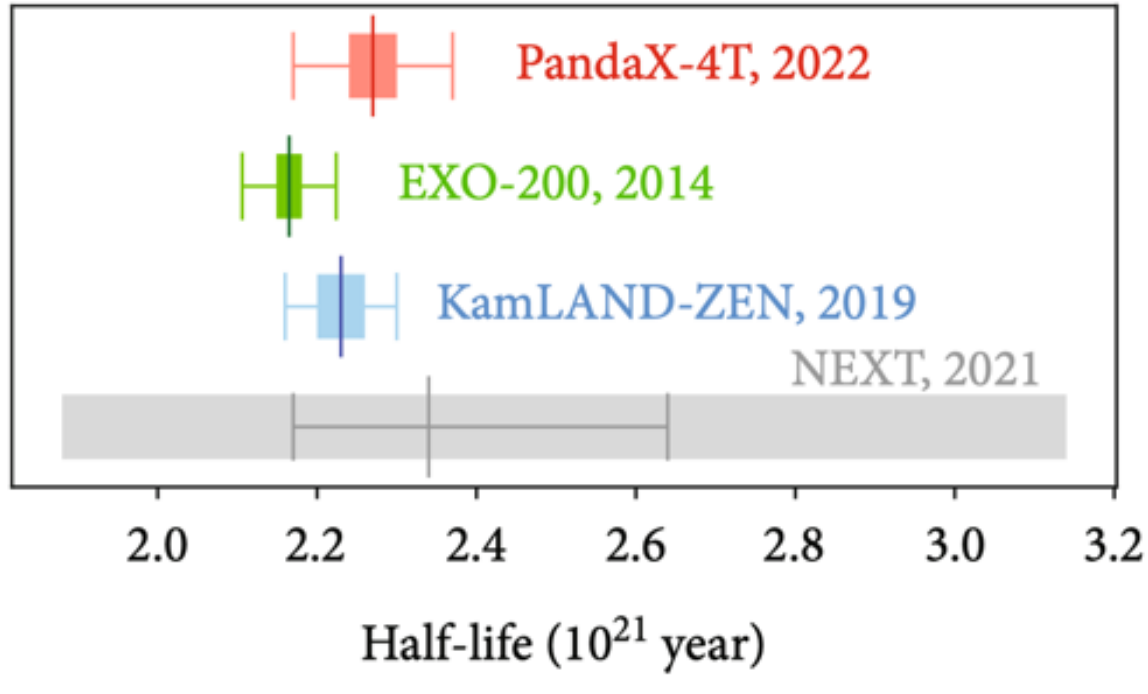


^{136}Xe 2vDBD Lifetime Measurement

- 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

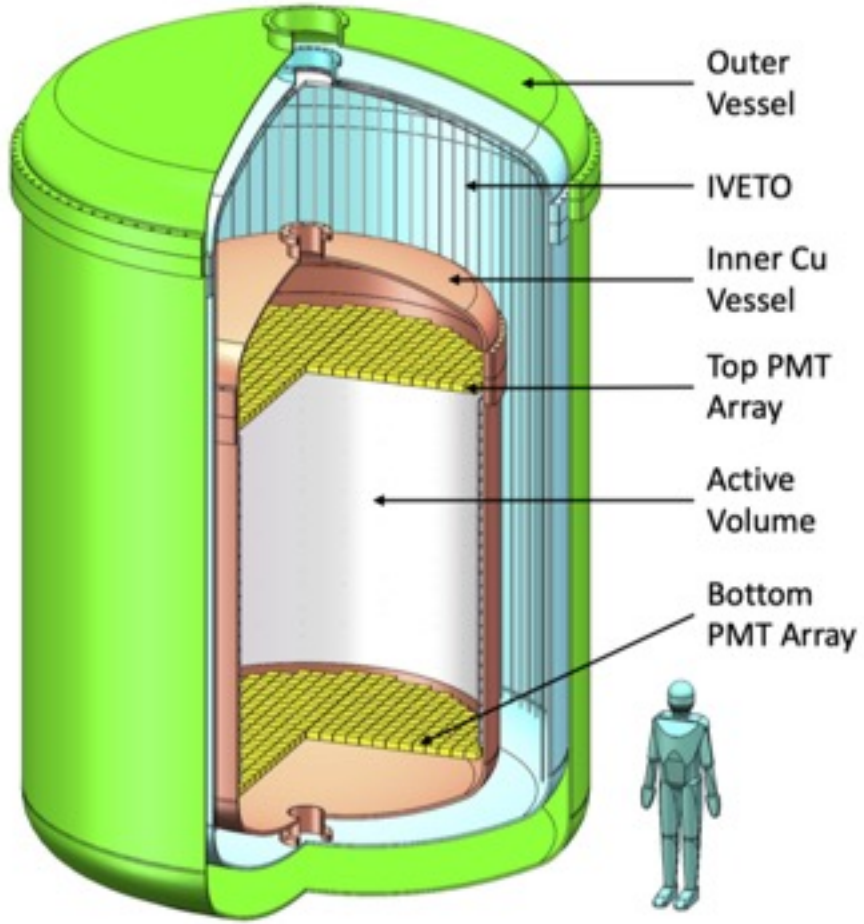
arXiv:2205.12809

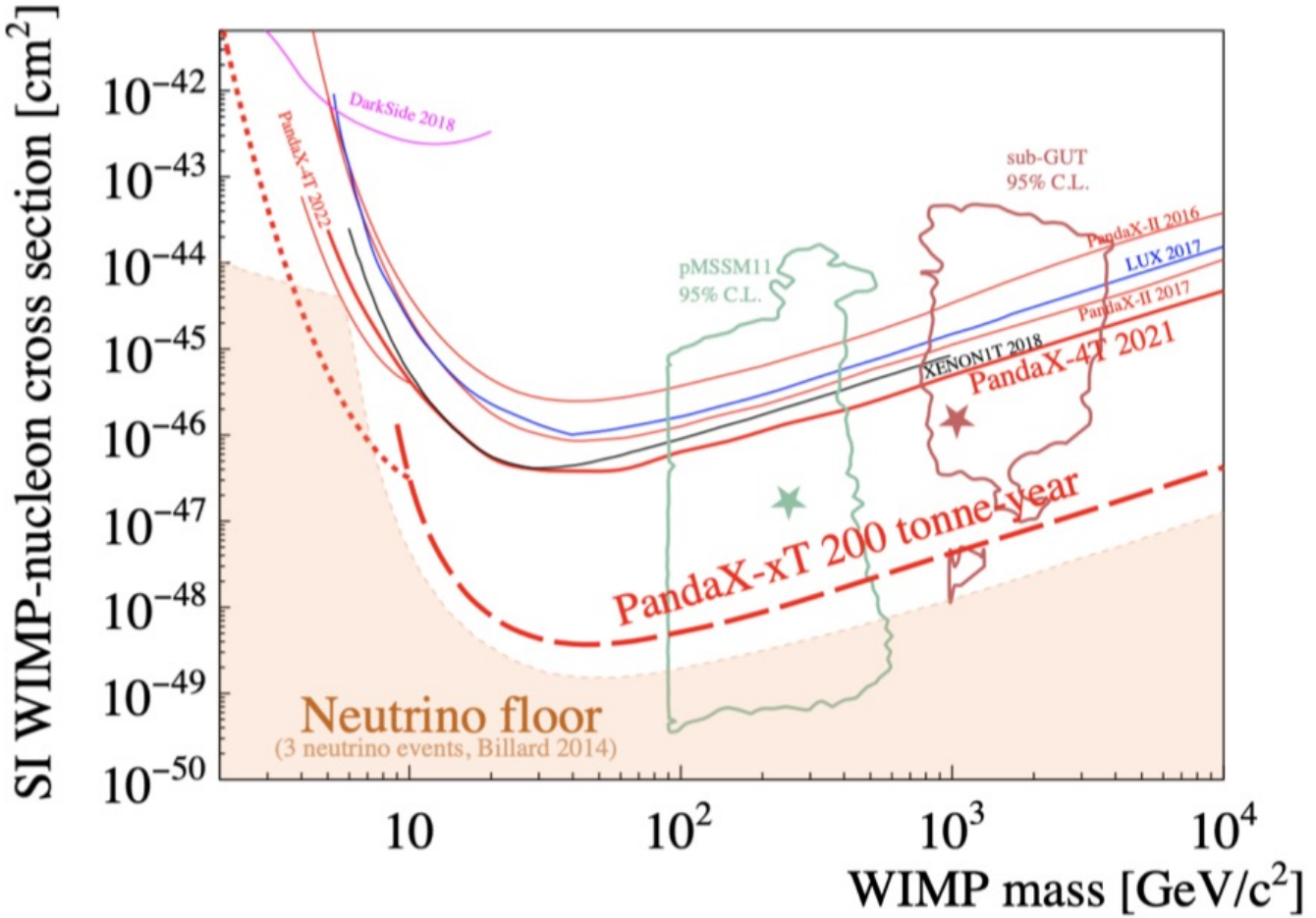




Future Plan: PandaX-xT

- **“ultimate”** liquid xenon experiment
  - Towards the neutrino floor





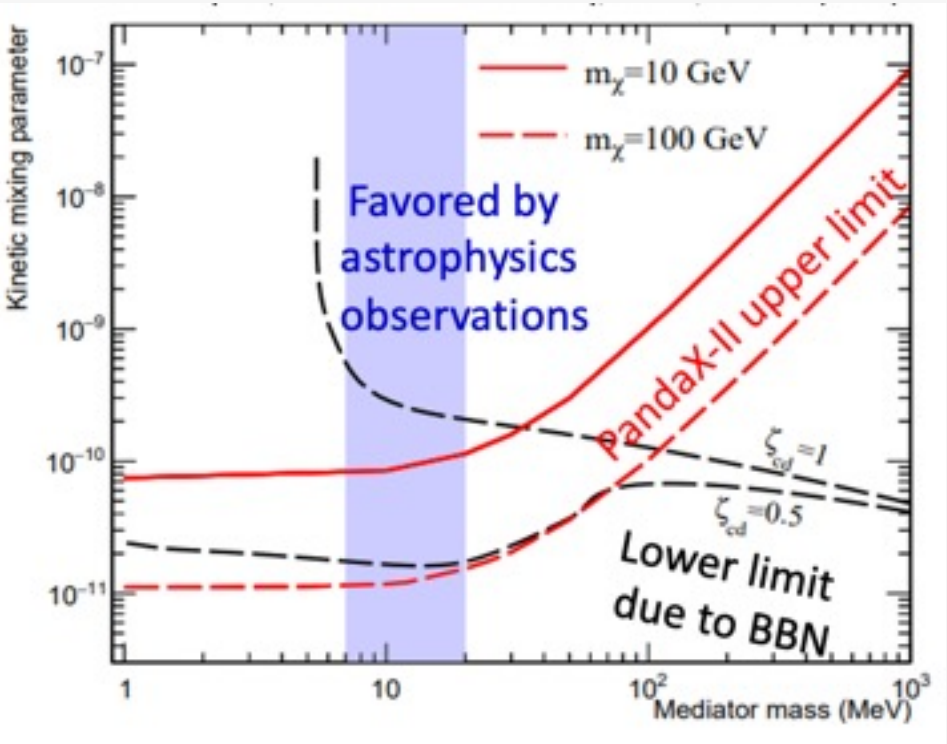
Summary

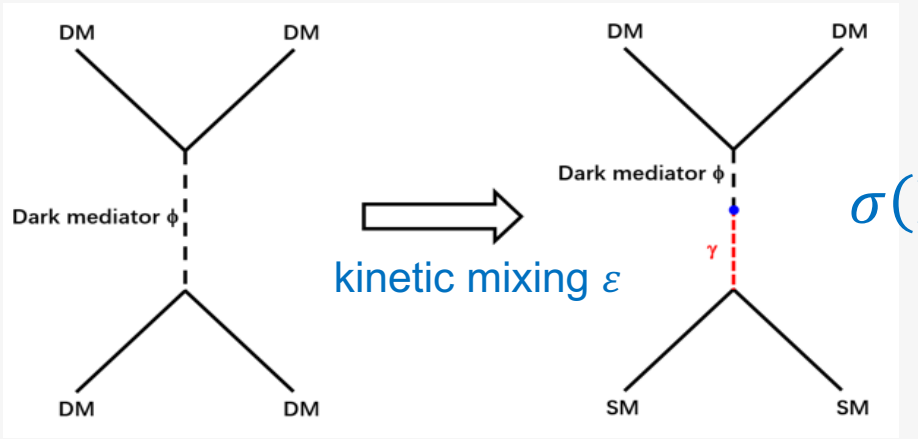
- Dark matter detection plays a key role in new physics search.
- PandaX-4T is one of the new generation multi-tonne xenon experiments
- Interesting searches towards various types of DMs
- Expecting more results at CJPL

Thank you!

Self-interacting DM with Light Mediator

- **Direct detection + astronomy + cosmology**
  - Upper limit of mixing parameter from direct detection
  - Under the SIDM model considered，if DM mass is 10-200 GeV/c^2 , dark sector is colder than visible sector in early universe





$$\sigma(\mathrm{DM}-\mathrm{nucleon}) \propto \frac{\varepsilon^2}{m_\phi^4}$$

Editorial | Published: 29 September 2021

New connection between dark matter direct detections, astrophysical and cosmological observations with self-interacting dark matter

YiPeng Jing

Editor's Focus

Research Highlight | Published: 28 September 2021

PandaX-II set constraints to self-interacting dark matter using the full dataset

Wan-Zhe Feng

SCPMA Vol. 64, 111062 (2021)