PANDA X

上海交通大学
SHANGHAI JIAO TONG UNIVERSITY

Latest Results of PandaX Experiment

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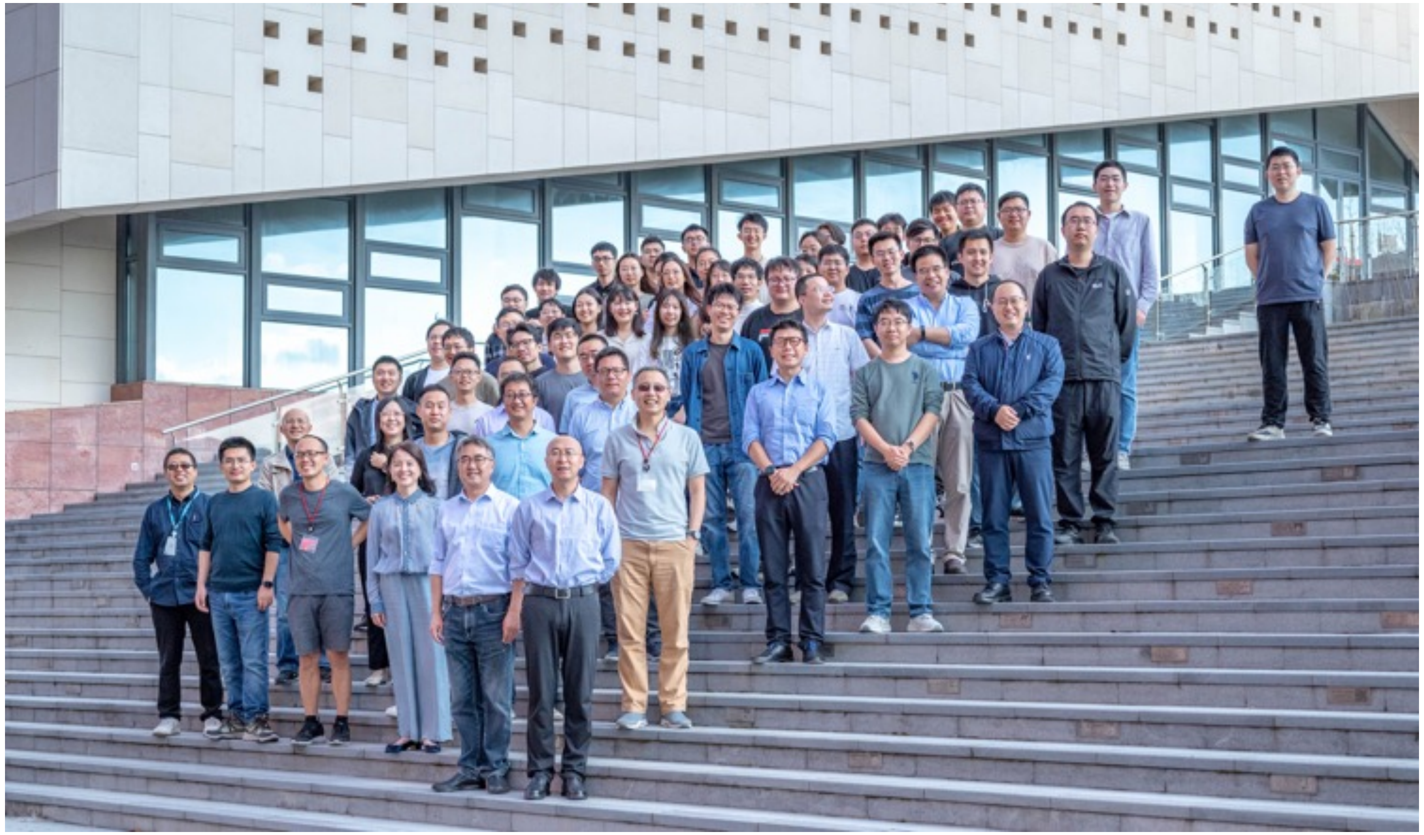
上海交通大学

2023-12-30 紫金山暗物质研讨会

PandaX Collaboration

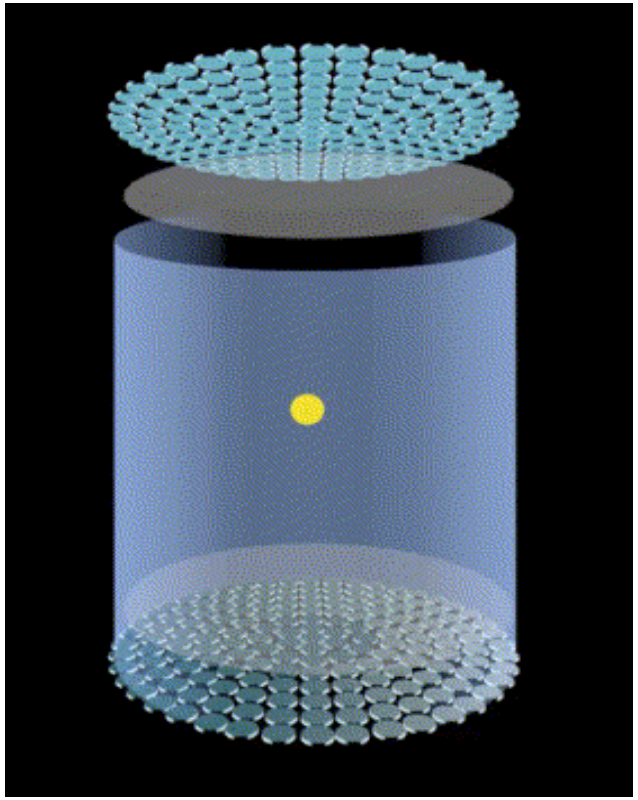
- **PandaX: particle and astrophysical xenon detector**
  - dark matter, Majorana neutrino, astrophysical neutrino

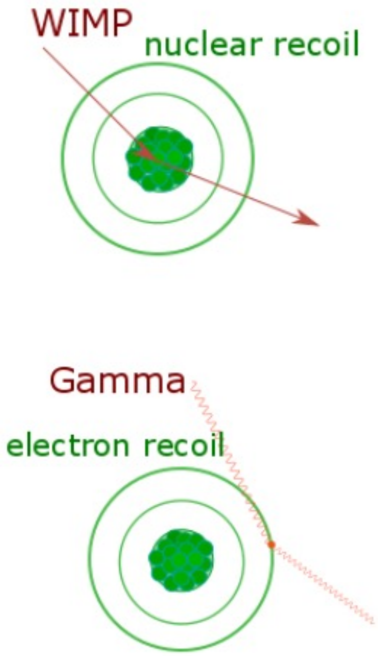
54
Xe
Xenon
131.29

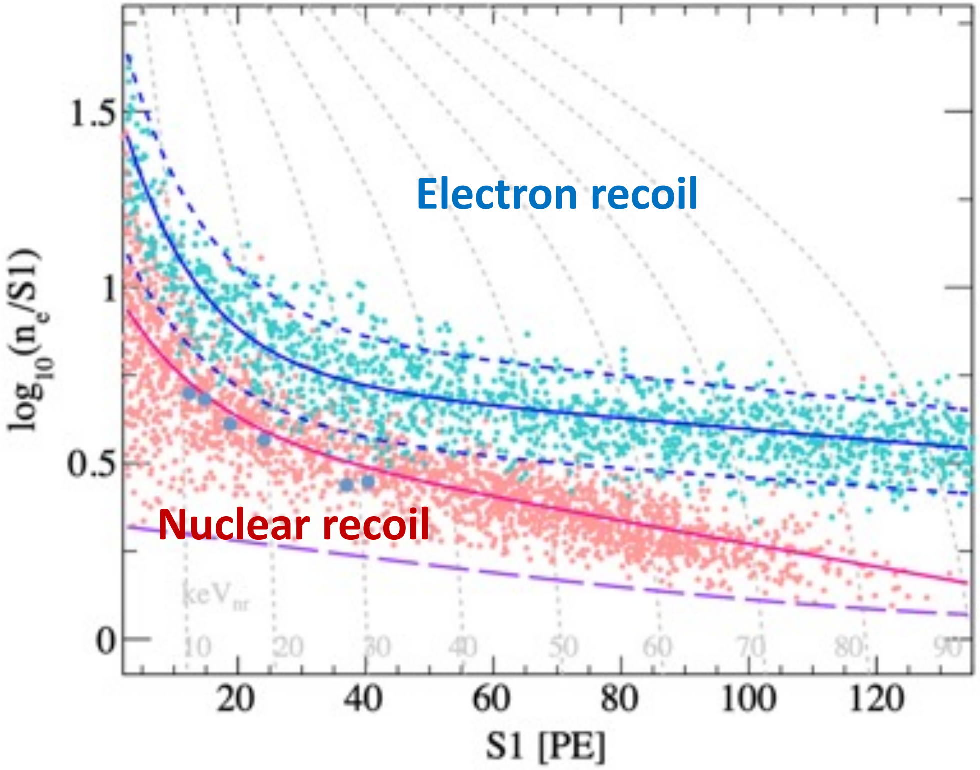


PandaX: Dual-phase xenon TPC

- **Paired scintillation (S1) and ionization (S2) signals**
  - Precise energy measurement and 3-D position reconstruction
  - Discrimination of nuclear recoil and electron recoil signals







PandaX Detectors

- Increasing the detector sensitive target volume
- Lowering radioactive background

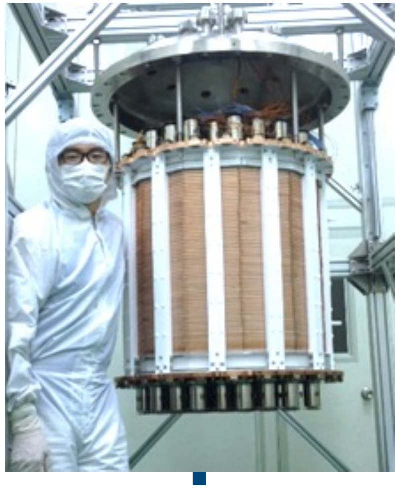
PandaX start

2009

PandaX-I
120kg

2010-2014

PandaX-II
580kg



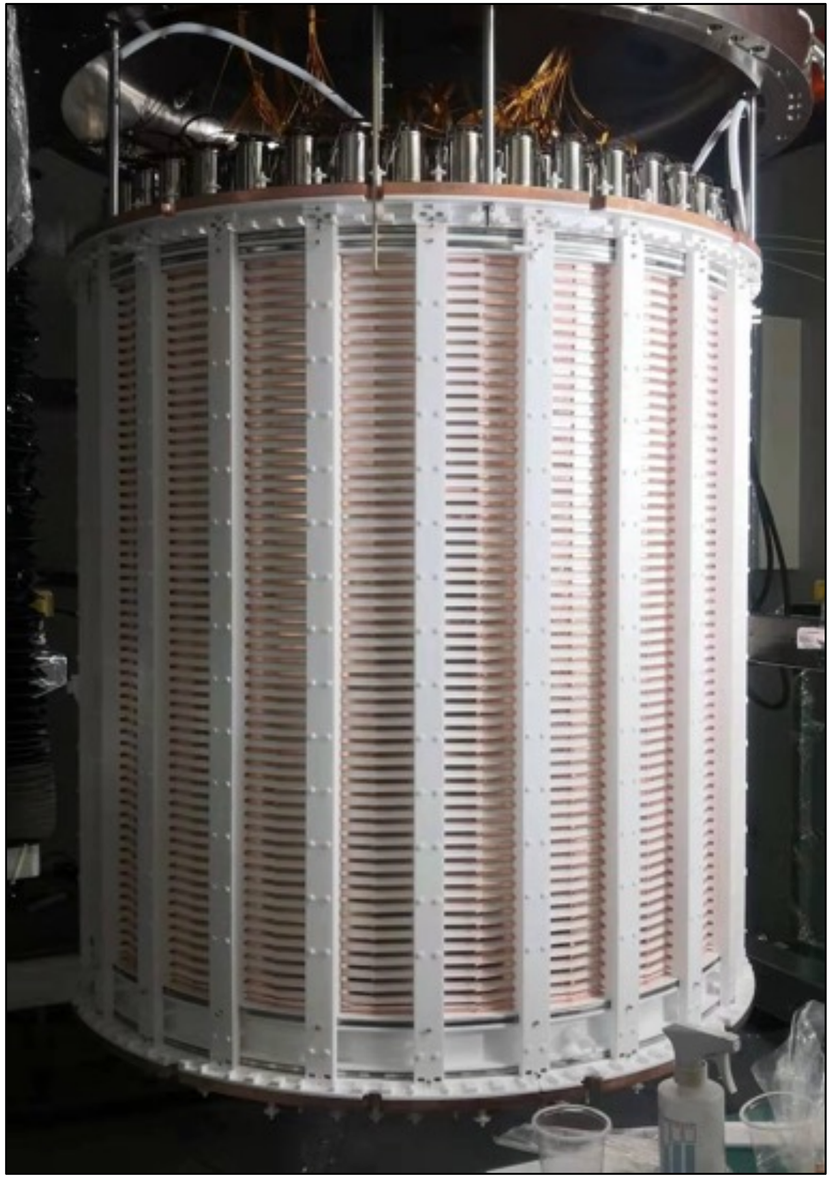
2015-2019

PandaX-4T
(3.7 tonne)

2020-

PandaX-4T Experiment

- **Sensitive volume: 3.7 tonne xenon**
- **900m^3 high-purity water shielding tank**
- **Commissioning started in 2020/11**
  - 95 days: ~0.6 tonne-year



How dark is dark matter?

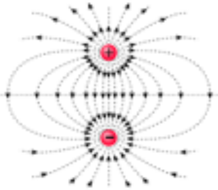
Image Credit: Public Domain

Luminance of Dark Matter

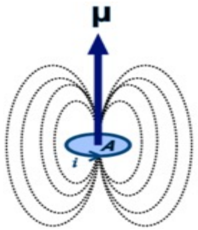
- **Residual weak EM properties: coupling with photons**

微弱电荷
millicharge

电荷半径
charge radius



电偶极矩
electric dipole



磁偶极矩
magnetic dipole

零极矩
anapole

$$\mathcal{L} = Qe\bar{\chi}\gamma^{\mu}\chi A_{\mu} + \frac{\mu_{\chi}}{2}\bar{\chi}\sigma^{\mu\nu}\chi F_{\mu\nu} + i\frac{d_{\chi}}{2}\bar{\chi}\sigma^{\mu\nu}\gamma^{5}\chi F_{\mu\nu} + b_{\chi}\bar{\chi}\gamma^{\mu}\chi\partial^{\nu}F_{\mu\nu} + a_{\chi}\bar{\chi}\gamma^{\mu}\gamma^{5}\chi\partial^{\nu}F_{\mu\nu}$$

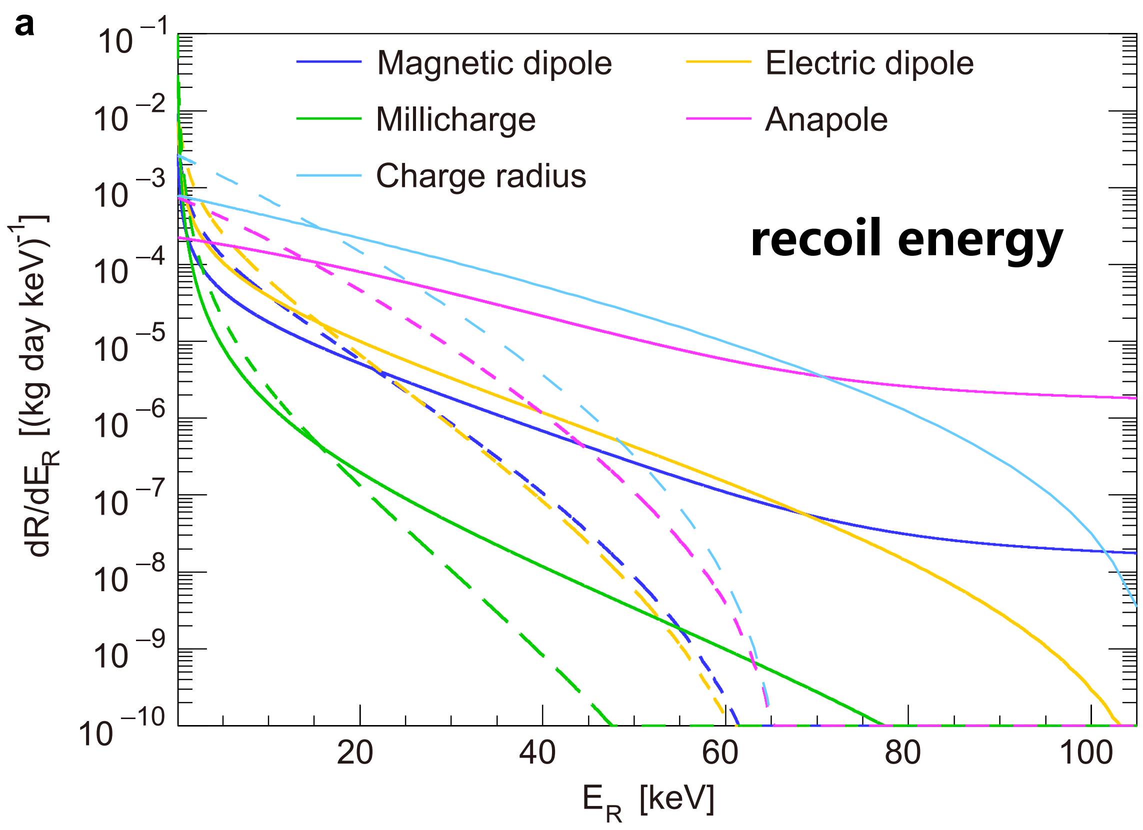
millicharge | magnetic dipole | electric dipole | charge radius | anapole

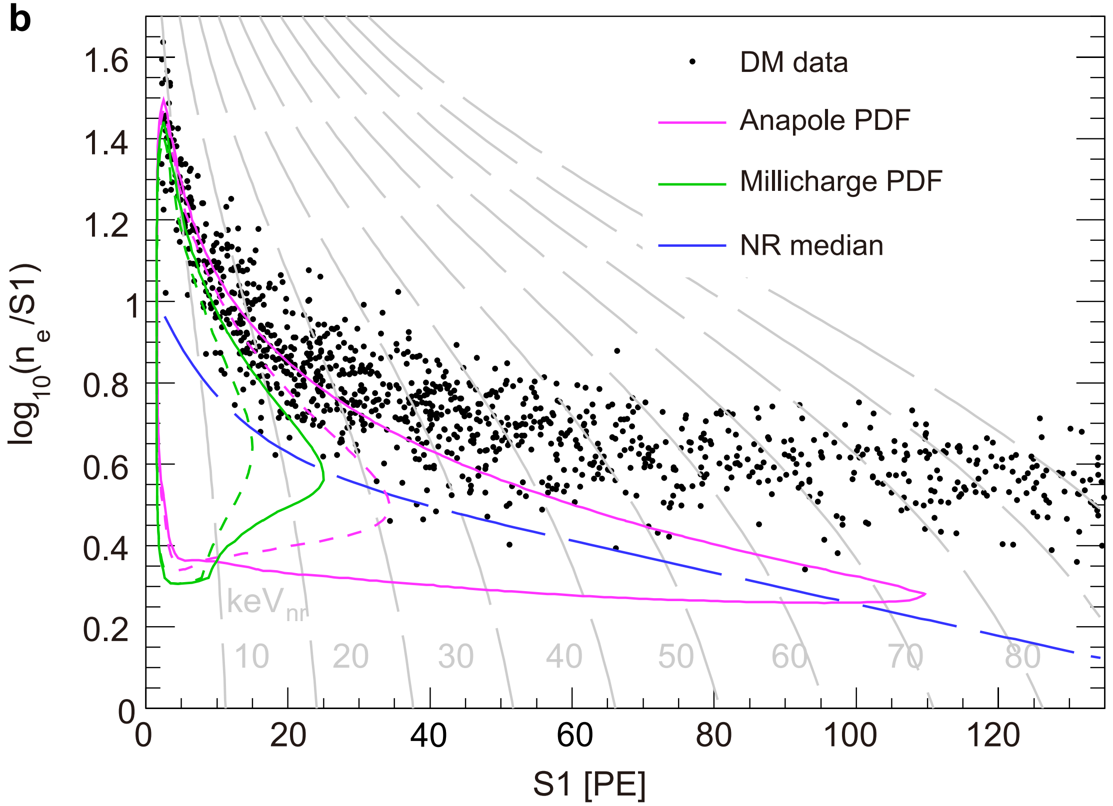
tree-level | **higher-order loop-level**

Photon-Mediated Interaction

- **Various nuclear recoil character**
- **Dedicated searches of these EM properties**

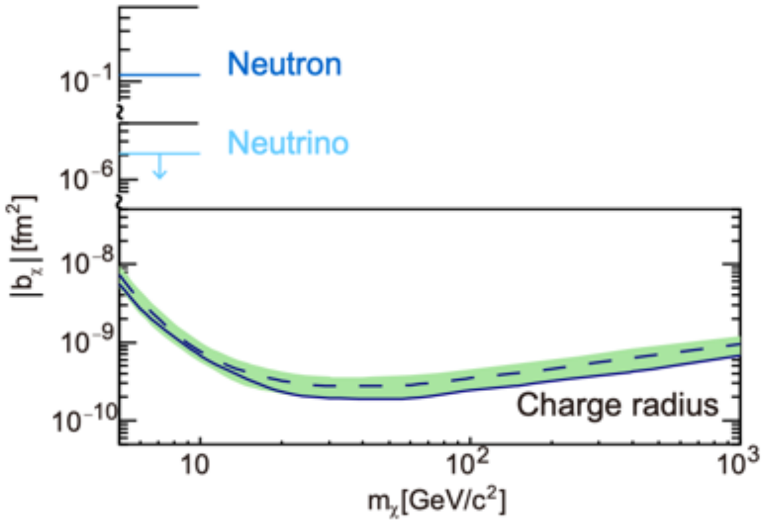
30 and 100 GeV/c² DM





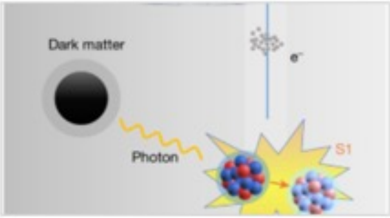
Results from Xenon Recoil Data

- **First experimental constraints on DM charge radius**
  - 4 orders of magnitude smaller than neutrino
- **Strong constraints on other EM properties**
  – up to 3 – 10 times improvement



Limits on the luminance of dark matter from xenon recoil data

A direct search for effective electromagnetic interactions between dark matter and xenon nuclei that produce a recoil of the latter is carried out and the first constraint on charge radius of dark matter is derived.



Xuyang Ning, Abdusalam Abdukerim ... Yubo Zhou

Article | 17 May 2023

Table 1 | Comparison of electromagnetic properties

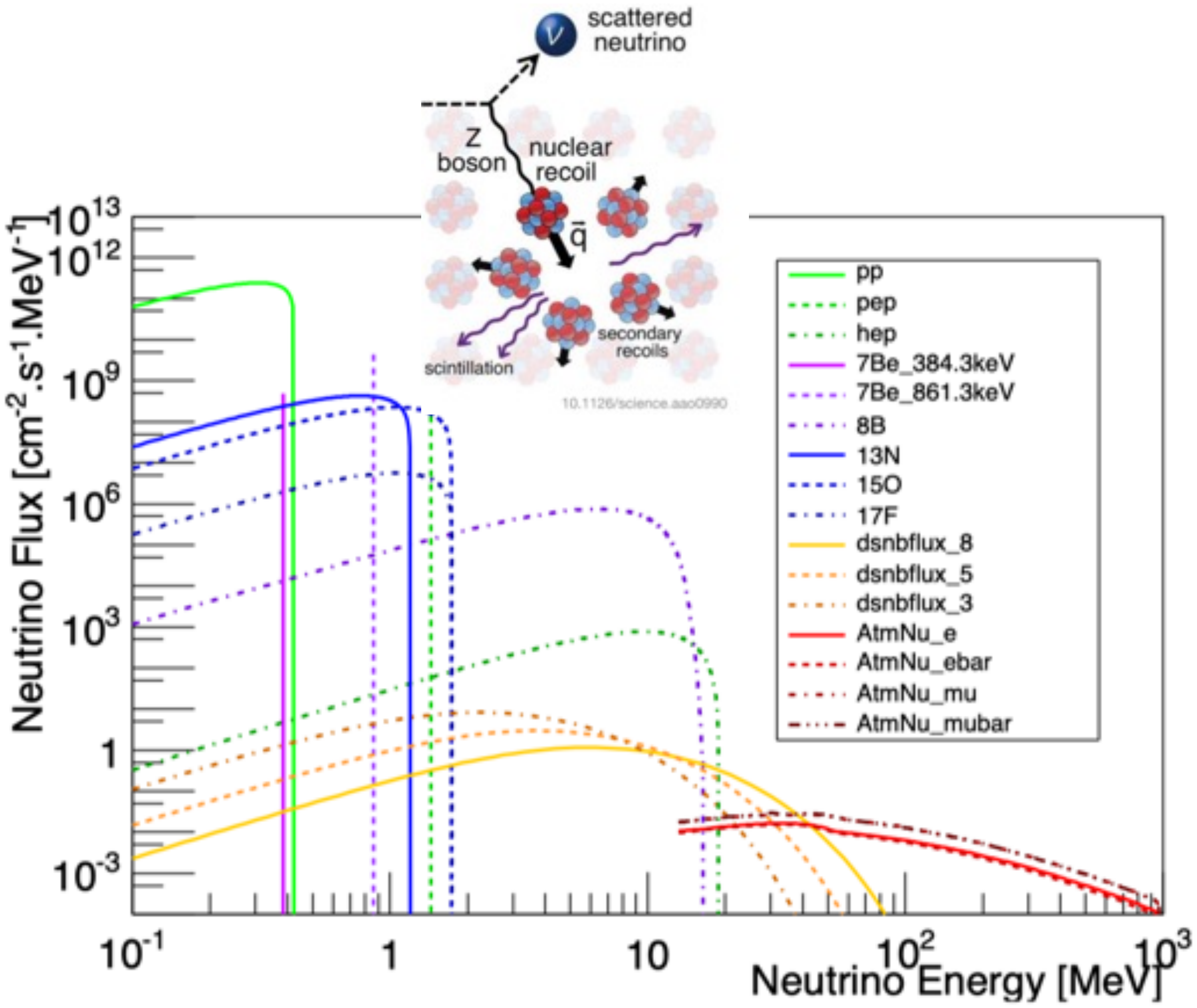
	dark matter	neutrino	neutron
Charge radius (fm^2)	$<1.9\times10^{-10}$	$[-2.1,3.3]\times10^{-6}$ *	-0.1155 *
Millicharge (e)	$<2.6\times10^{-11}$	$<4\times10^{-35}$ *	$(-2\pm8)\times10^{-22}$ *
Magnetic dipole (μ_B)	$<4.8\times10^{-10}$	$<2.8\times10^{-11}$ *	-1×10^{-3} *
Electric dipole (ecm)	$<1.2\times10^{-23}$	$<2\times10^{-21}$ †	$<1.8\times10^{-26}$ *
Anapole (cm^2)	$<1.6\times10^{-33}$	$\sim10^{-34}$ ‡	$\sim10^{-28}$ §

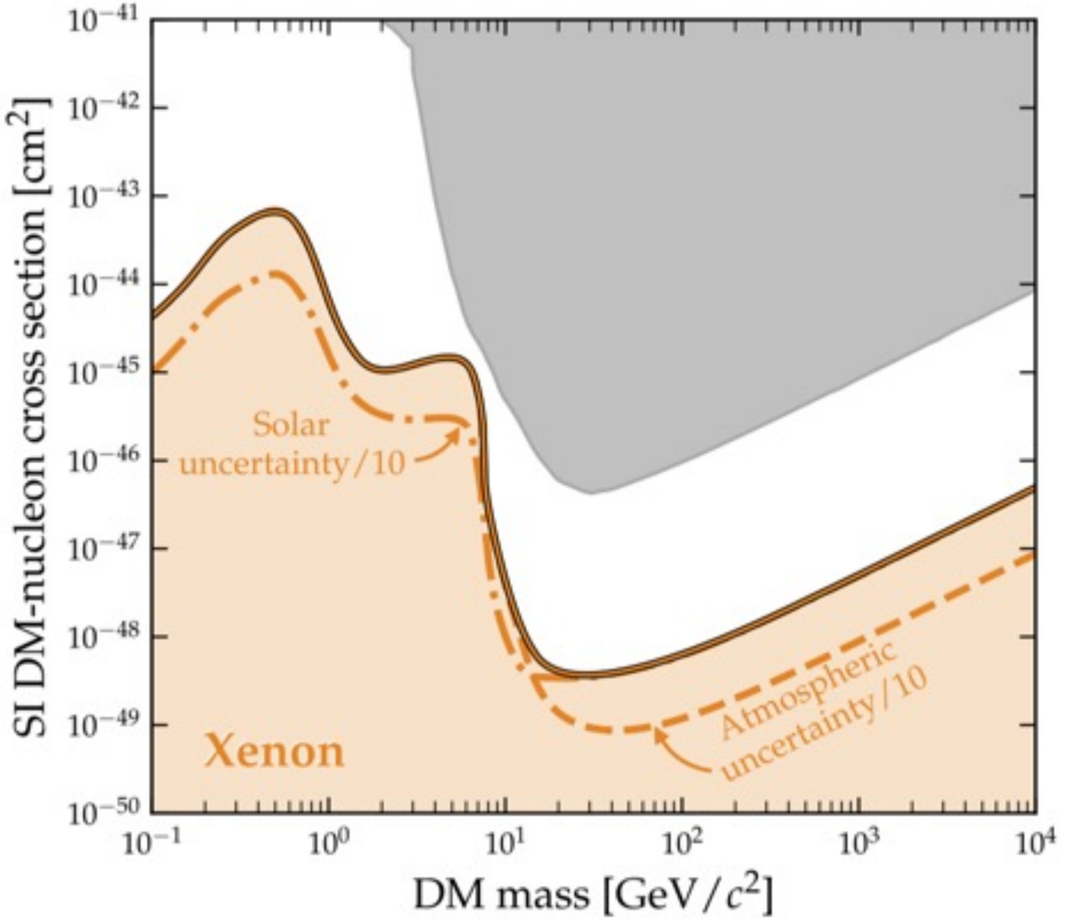
* Datas are taken from PDG [32]
† Taken from [31]
‡ Taken from [33]
§ Taken from [34]

Nature Vol. 618, Issue 7963, 47-50 (2023)

Neutrino Floor

- **Coherent Elastic Neutrino-Nucleus Scattering (CEvNS)**

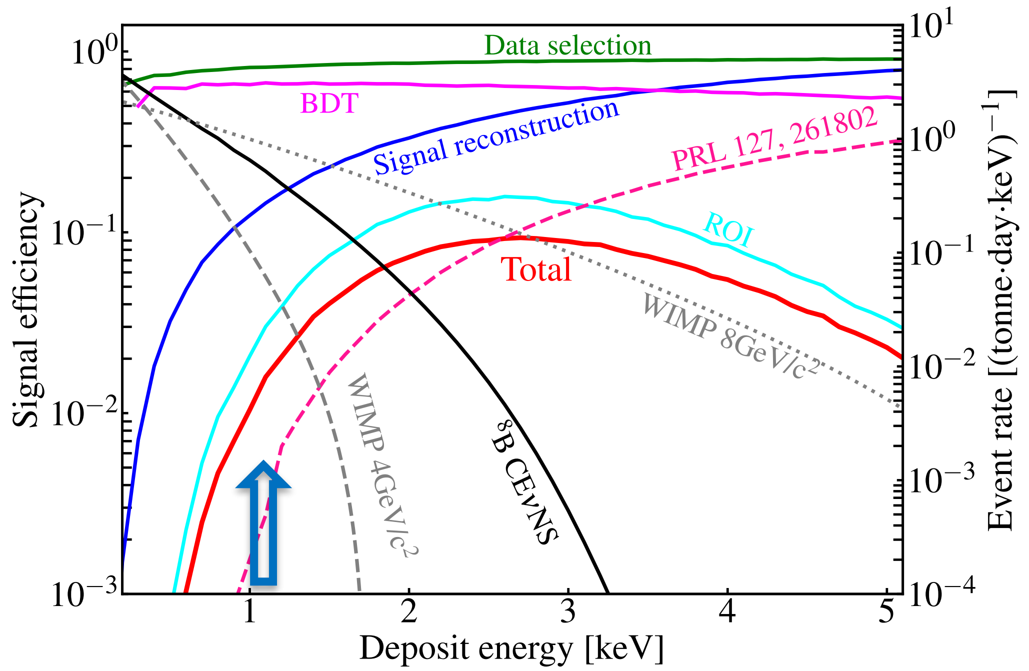


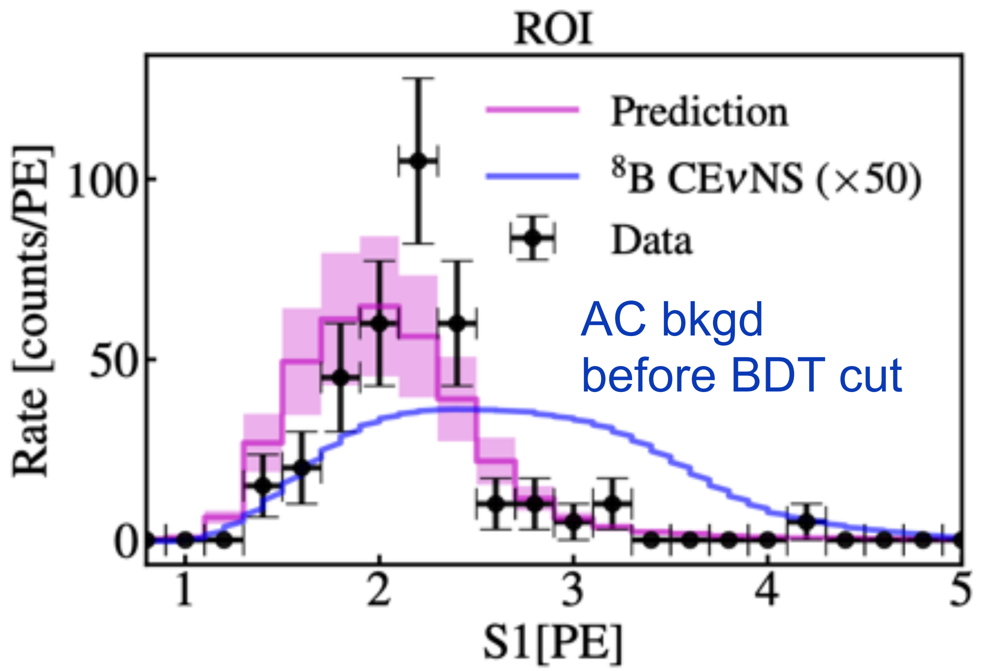


C. O'Hare PRL 127, 251802 (2021)

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**



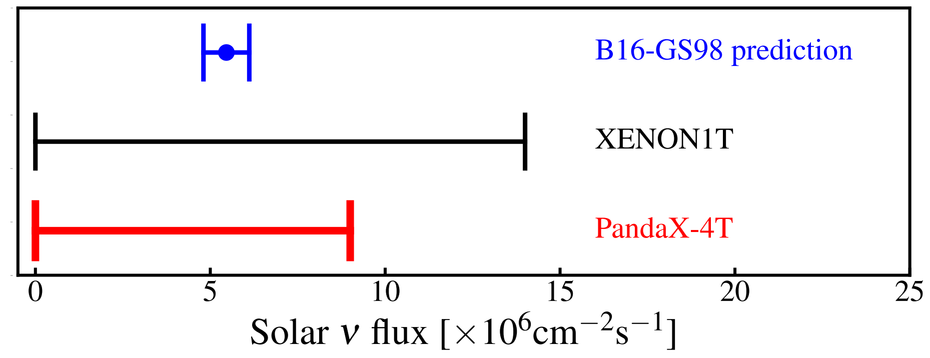


Constraints on B8 and WIMP

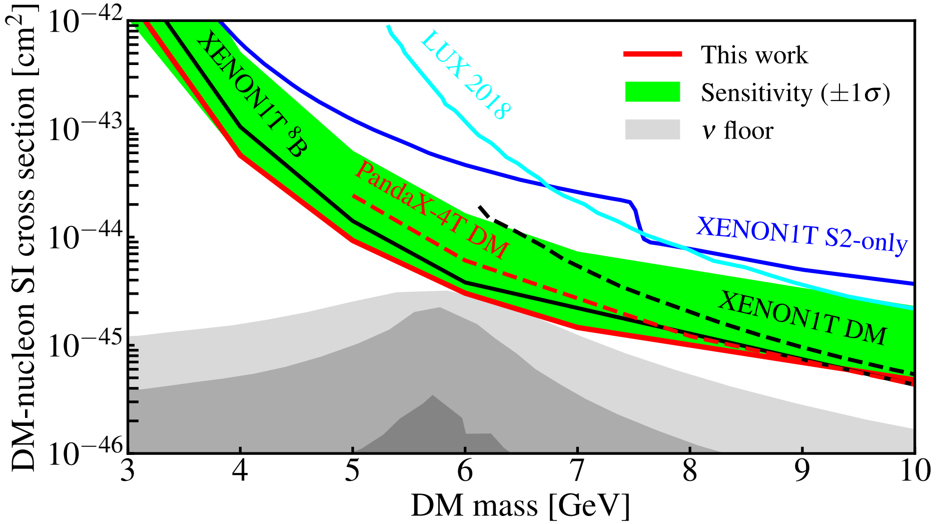
- **Blind analysis with 0.48 tonne-year data**

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

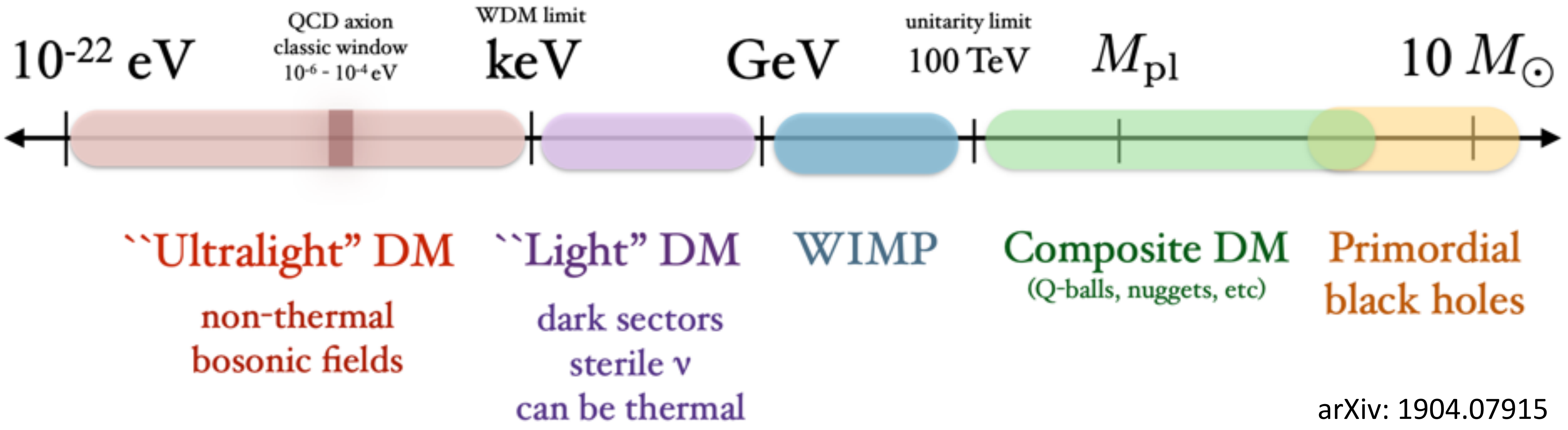


- **Leading constraint on B8 neutrino flux through CEvNS**
- **Strongest constraints on light WIMP of mass 3 -10 GeV/c^2**



Phys. Rev. Lett. 130, 021802 (2023)

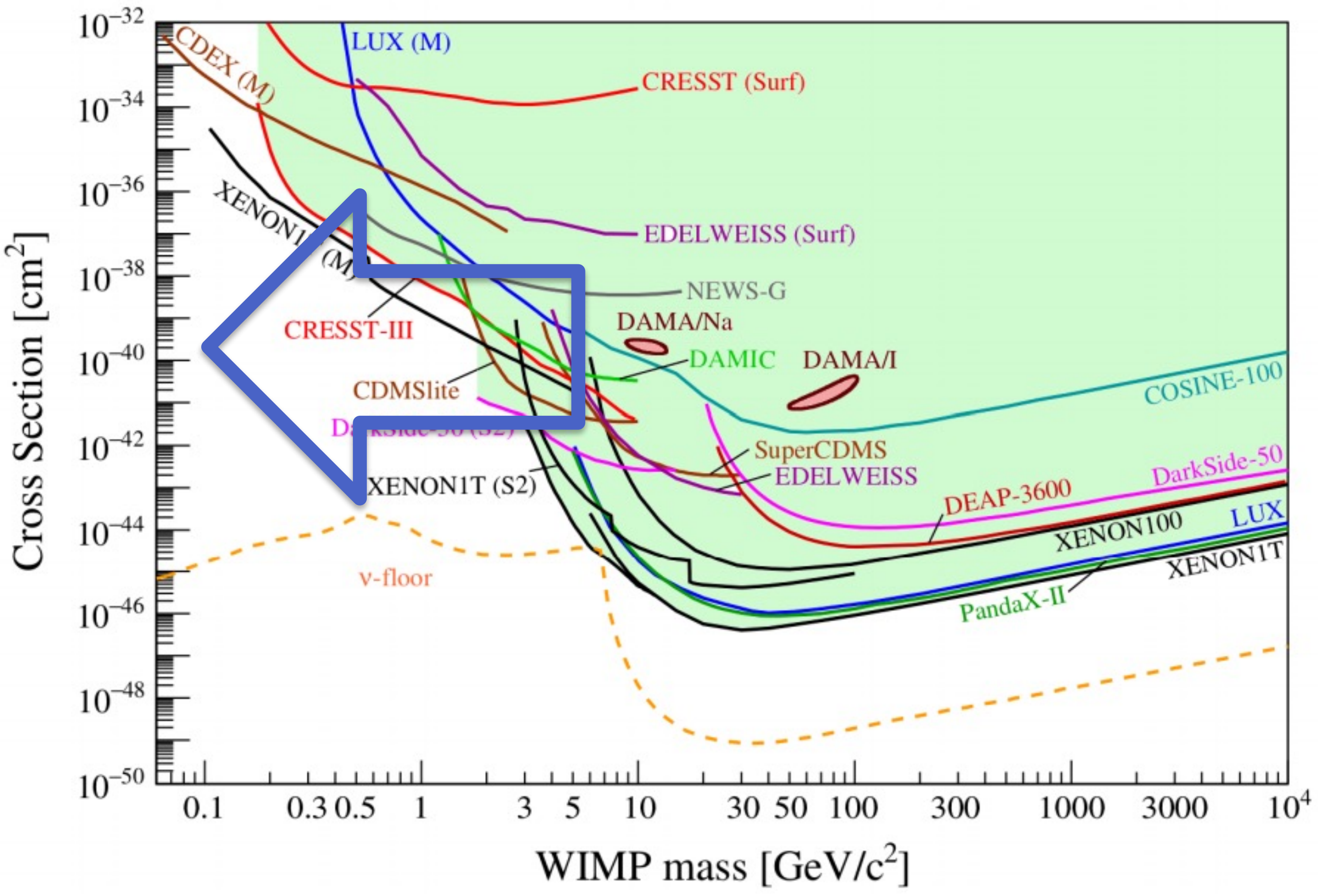
Light dark matter



arXiv: 1904.07915

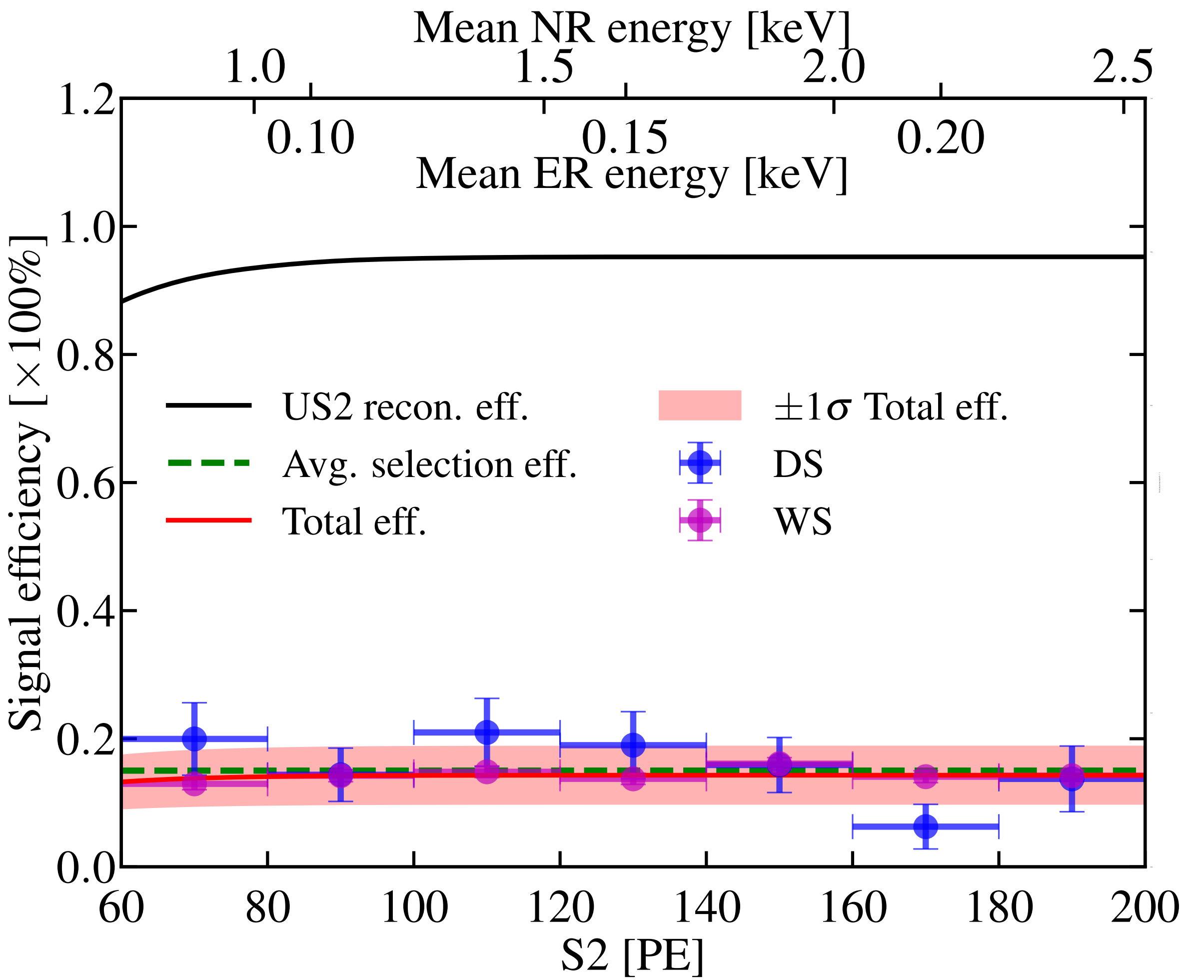
Sub-GeV Dark Matter

- **Traditional approach with energy threshold @ ~1keV**
  - very weak signals from light mass DM
- **New strategies for sub-GeV DM**
  - lowering threshold
  - kinetic boosting, etc



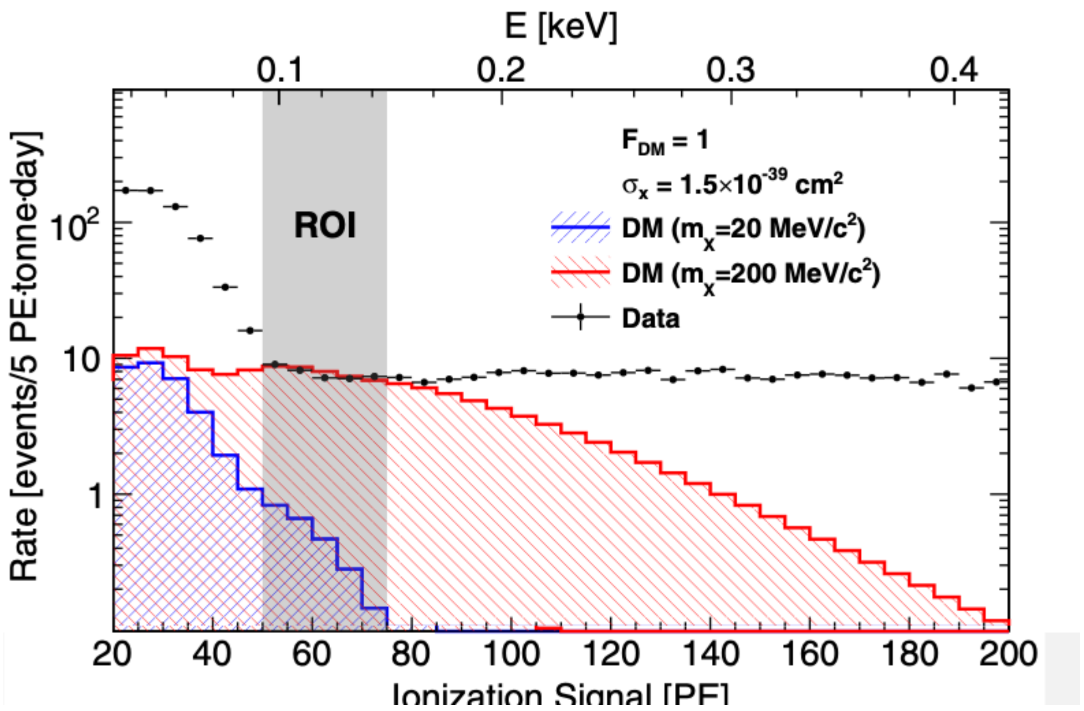
Lower Threshold

- **Ionization-Only: no scintillation signal requirement**
  - ROI S2 [60, 200]PE: threshold down to ~100 eV (from ~1 keV)

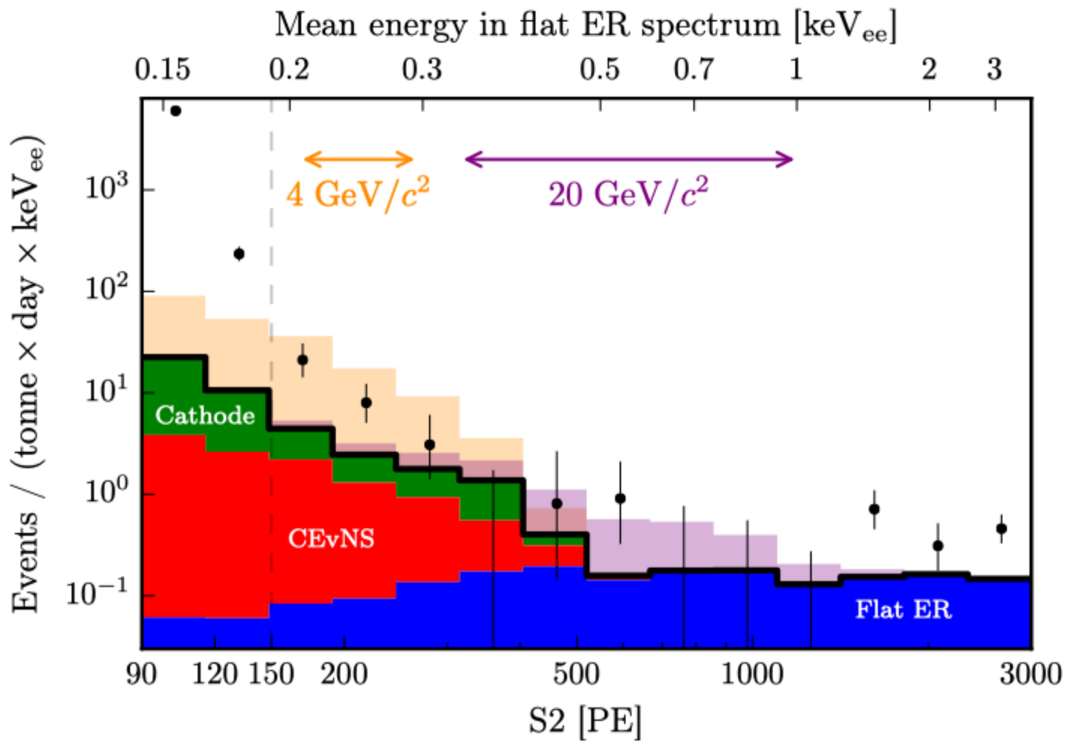


Ionization-only ROI

- **Key challenge: background components**
  - No full picture in previous xenon-based experiments
  - Conservative results only



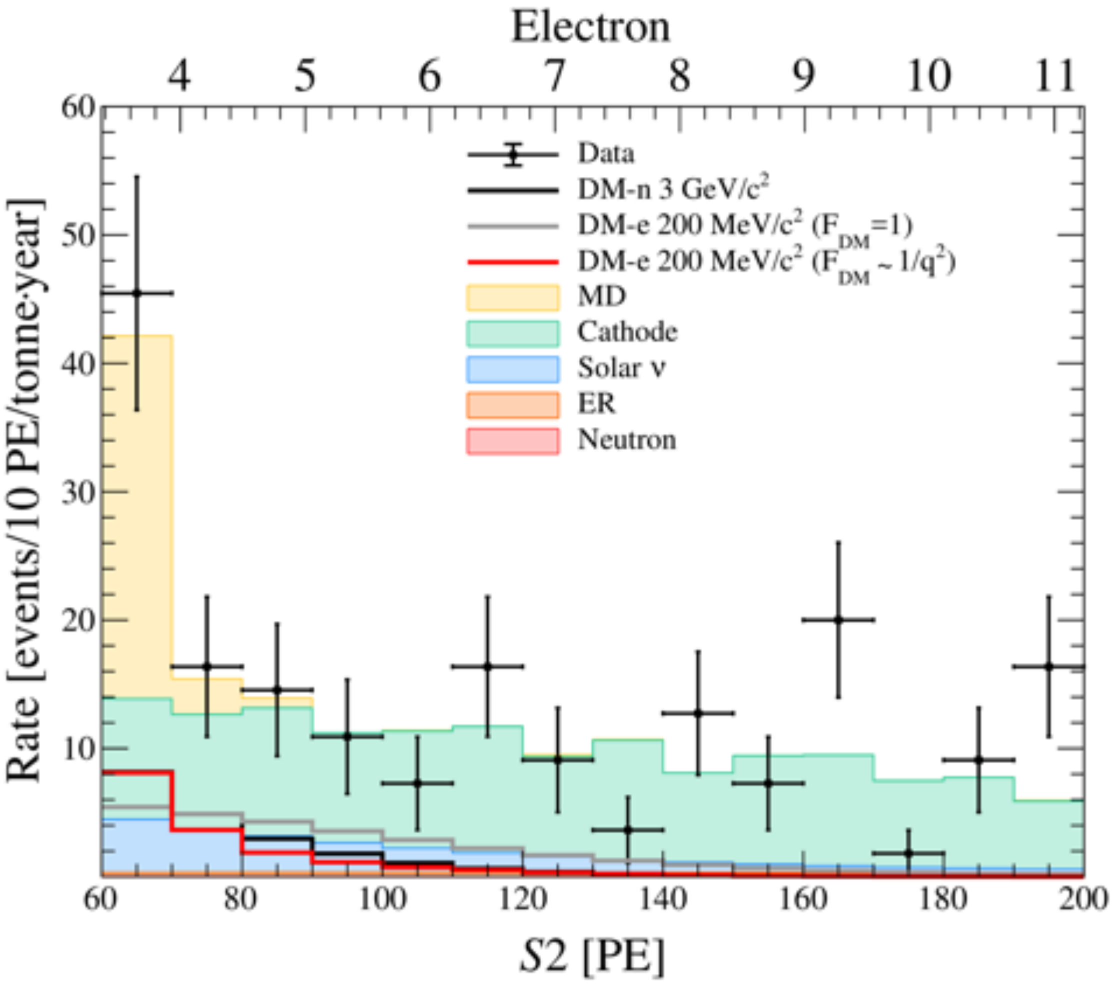
PandaX-II PRL (2021)



XENON1T PRL (2019)

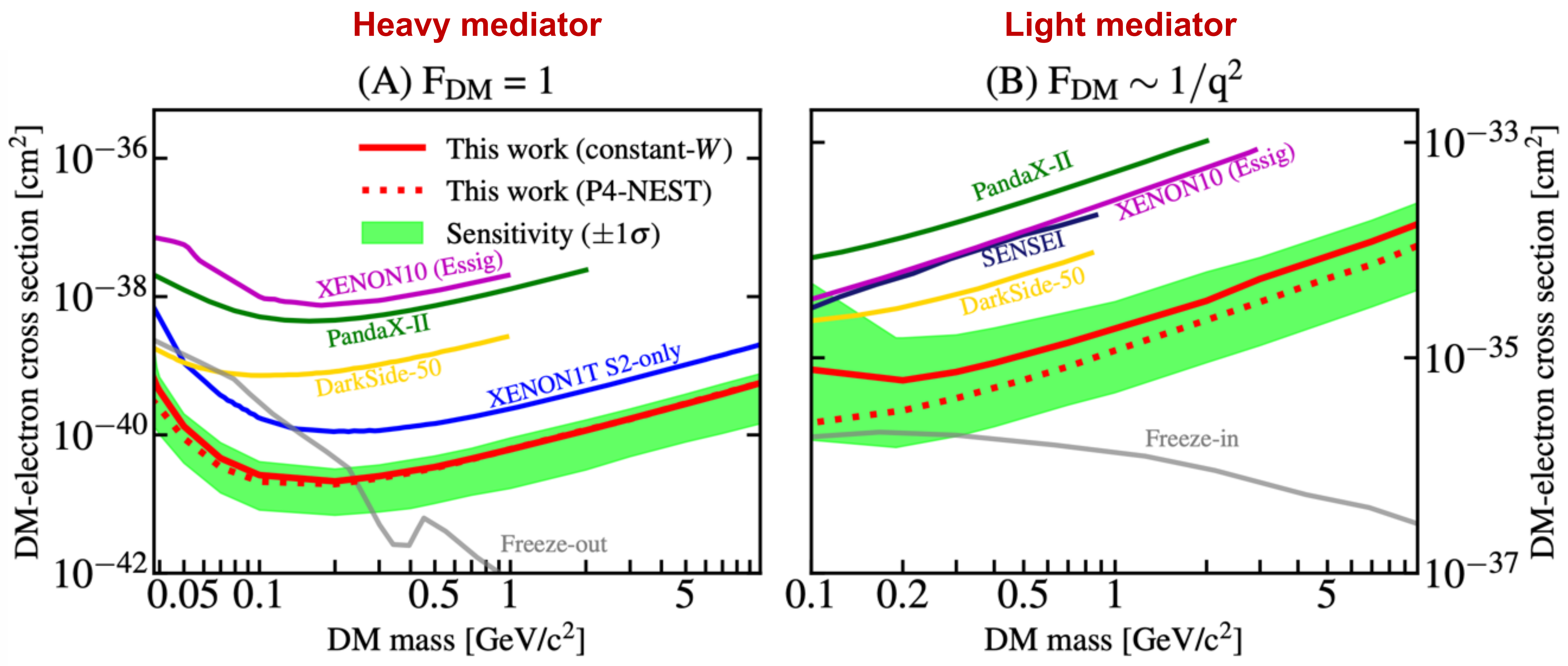
Ionization-only Data

- **First complete understanding of all the main background**
  - Micro-discharging (MD)
    - ➢ Small charge, strong run-condition dependence
  - Cathode activity
    - ➢ Large charge, large pulse-shape width
- **Blind analysis of 0.55 tonne-year exposure**
  - 105 events
  - Best-fit background: 95.8 ± 11.3 events



Constraints on sub-GeV DM-electron scattering

- **Most stringent constraints are derived**

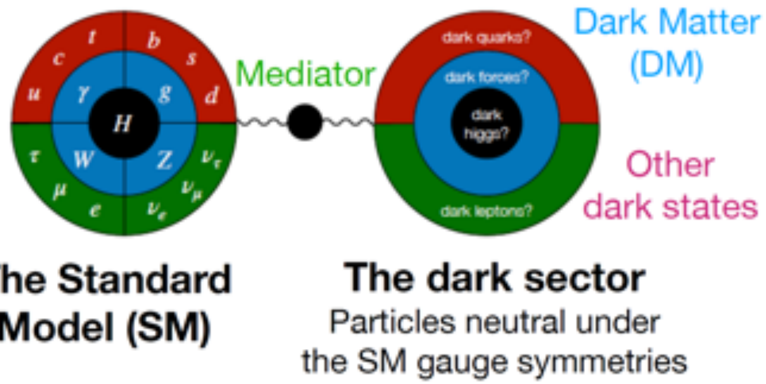


Phys. Rev. Lett. 130, 261001 (2023), **Editors' Suggestion**

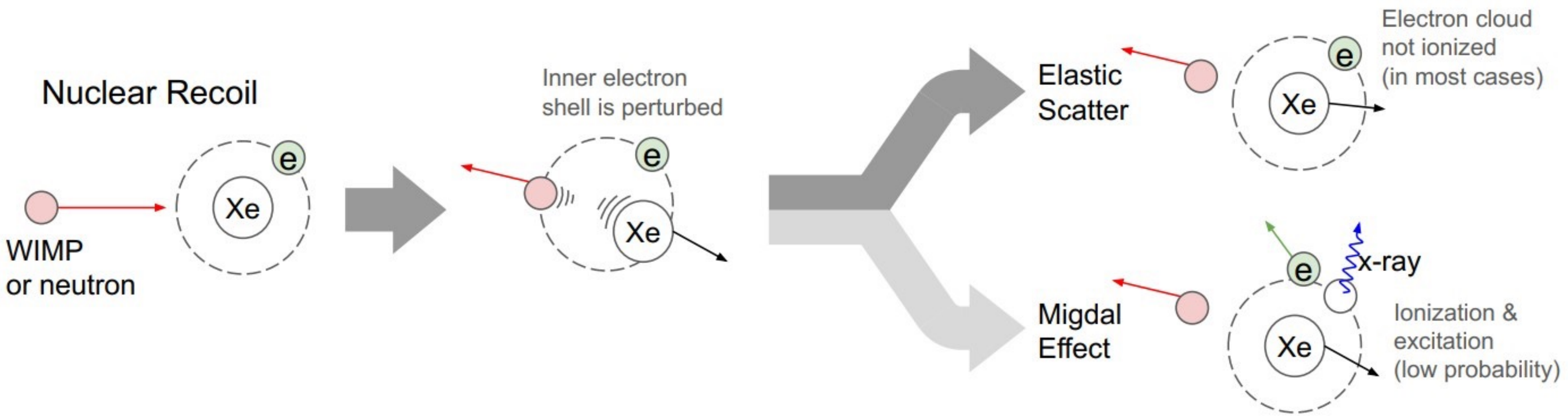
Migdal effect

- **DM-nucleon interaction with a dark mediator / dark photon**

$$\frac{dR}{dE_{\rm NR}} = \sigma|_{q^2=0} \frac{A^2}{\mu_p^2} \frac{m_\phi^4}{(m_\phi^2+q^2)^2} F^2(q^2) \times \frac{\rho}{2m_\chi} \int_{v \geq v_{\rm min}} \frac{f(v)}{v} d^3v$$

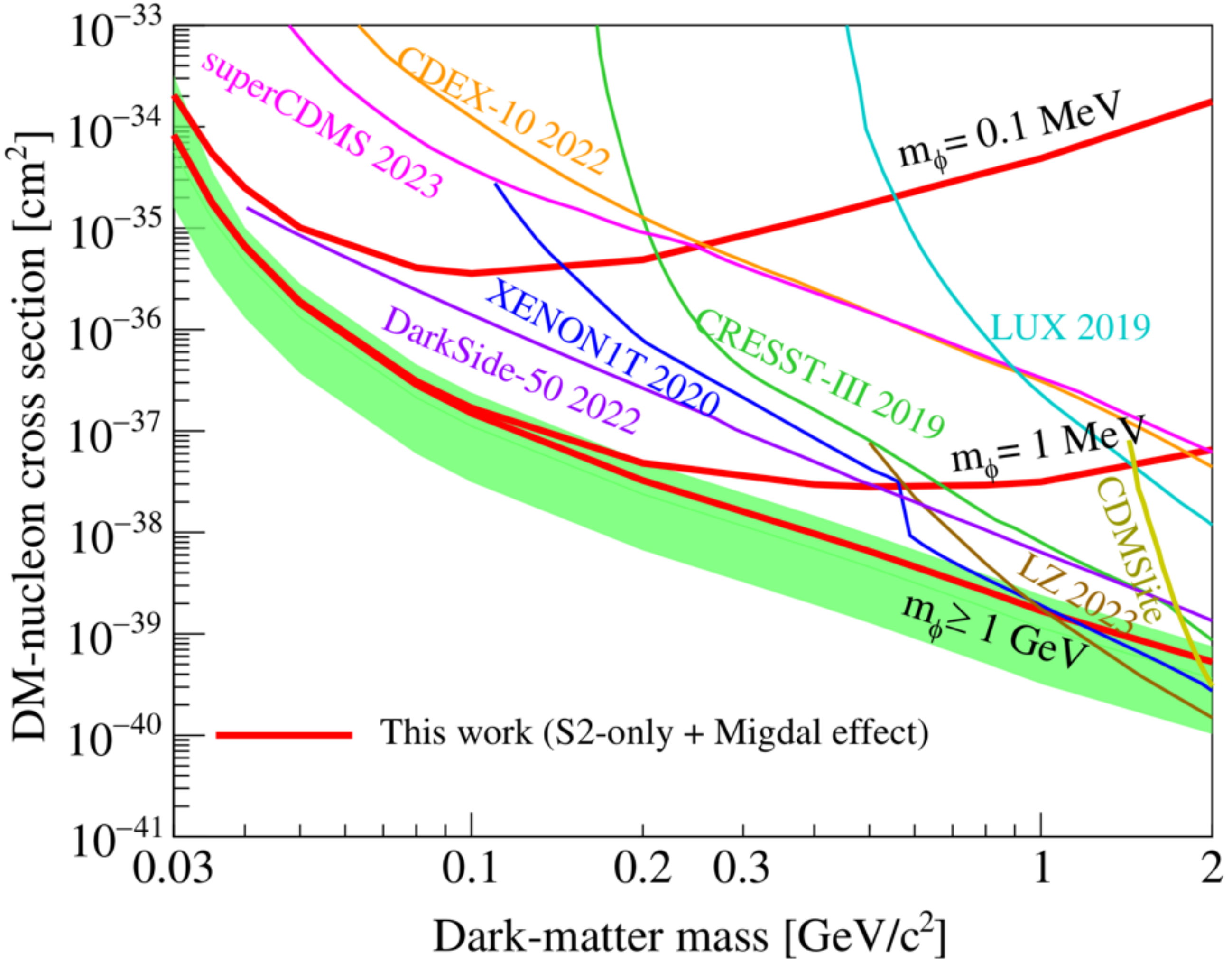


- **NR-induced ER signals by the Migdal effect**
  - probe low-mass DM via ER energy deposition



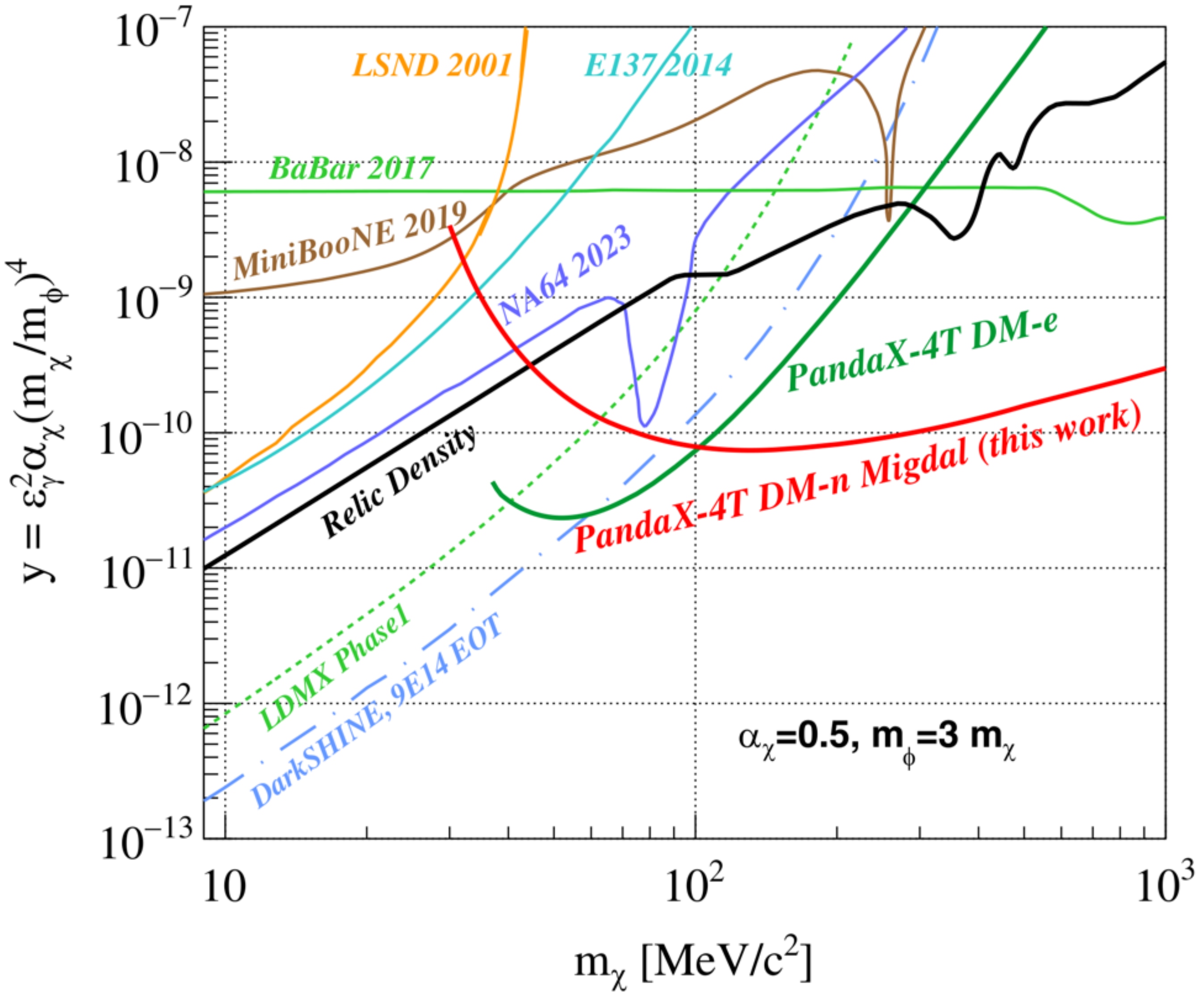
Constraints on sub-GeV DM-nucleon Scattering

- **DM-nucleon interaction with dark mediator**
  - DM mass [30 MeV, 2 GeV]
- **From ionization-only data and Migdal effect, set most stringent constraints**



Constraints on Dark Photon

- **Assume dark mediator is a dark photon**
  - rule out significant parameter space of such thermal relic dark-matter model

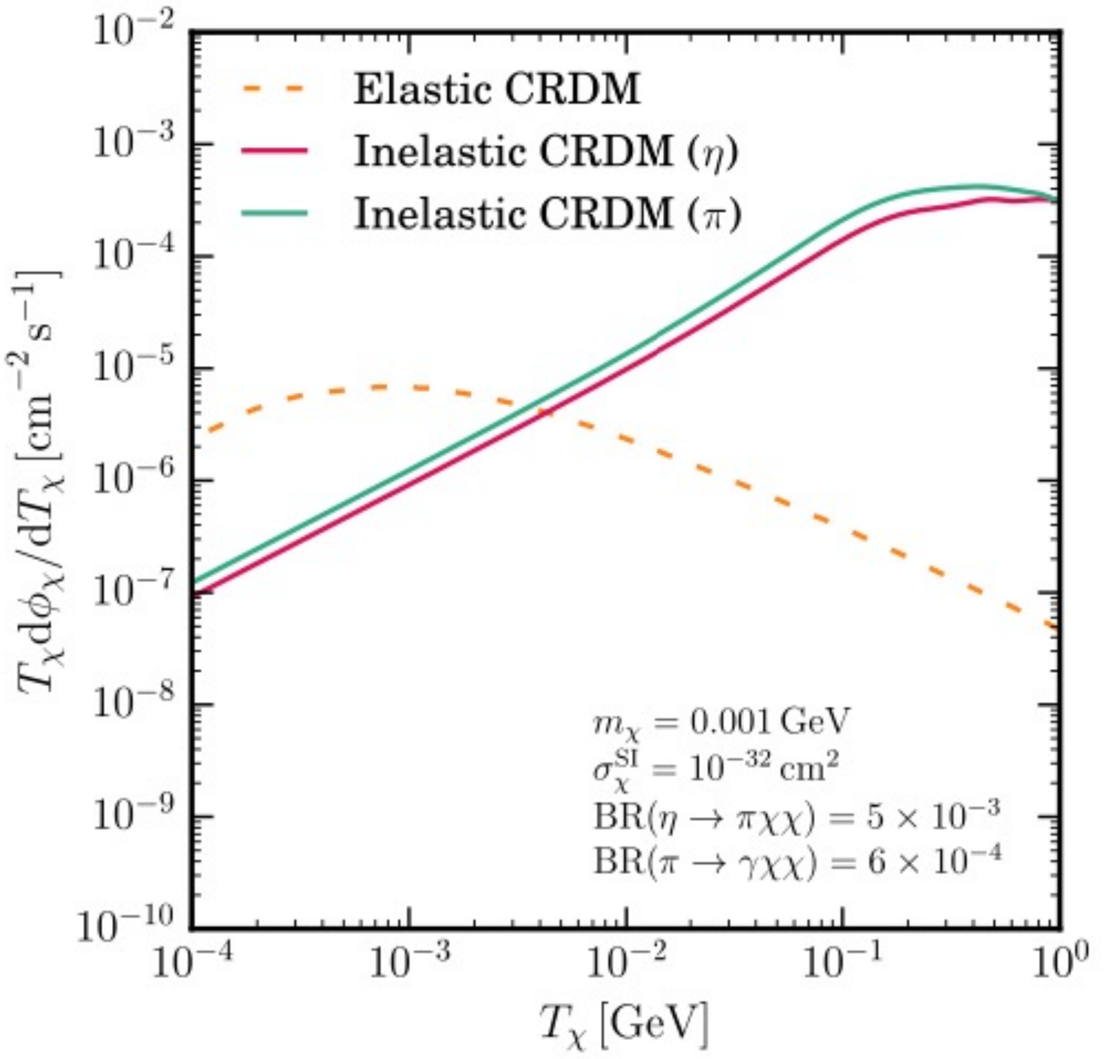


Phys. Rev. Lett. 131, 191002 (2023)

Can light dark matter be boosted?

Dark Matter from Atmosphere

- **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
- **Mesons from cosmic-ray beam dump in atmosphere**
  - $BR(\eta \to \pi^0 S \to \pi^0 \chi \bar{\chi})$
  - no dedicated measurements on this semi-invisible yet
- **Strongly boosted atmospheric dark matter**



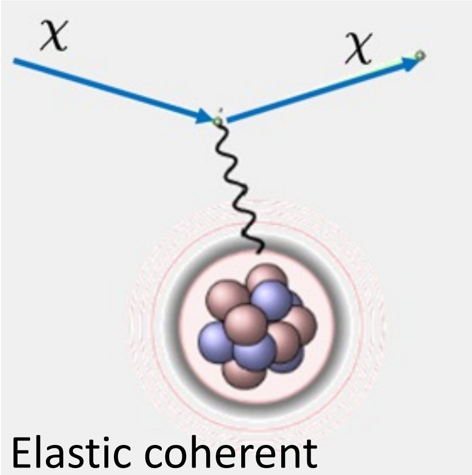
J. Alvey, M. Campos, M. Fairbairn, T. You, PRL 123, 261802 (2019)

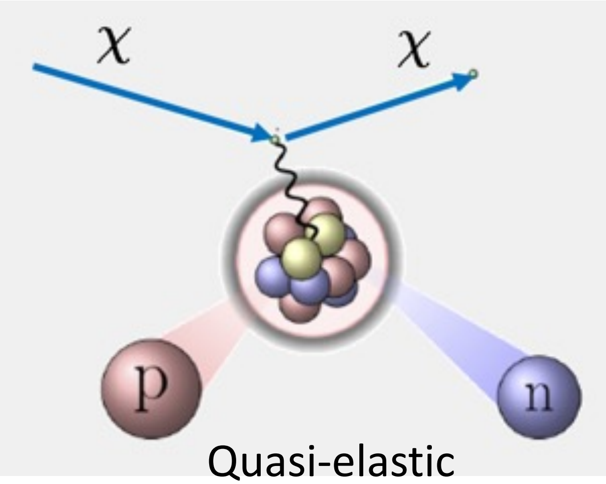
DM – Nucleus Interaction

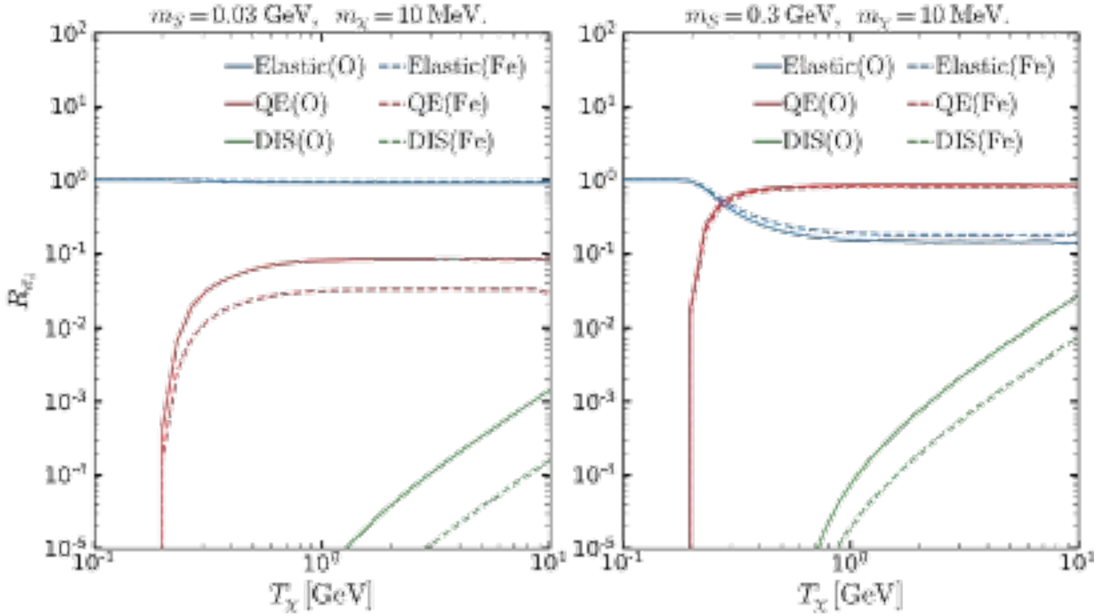
- **Elastic coherent, quasi-elastic (QE), and inelastic scatterings**
  - For $T_\chi > 0.2$ GeV, QE becomes significant
  - **Dedicated QE scattering calculation with light mediator**

$$\chi(k) + A\,(p_A) \to \chi\,(k') + X(\to n + Y)$$

$$\frac{d\sigma_{QE}}{dT'_\chi d\Omega} = Z\frac{d\sigma_p}{dT'_\chi d\Omega} + (A-Z)\frac{d\sigma_n}{dT'_\chi d\Omega},$$







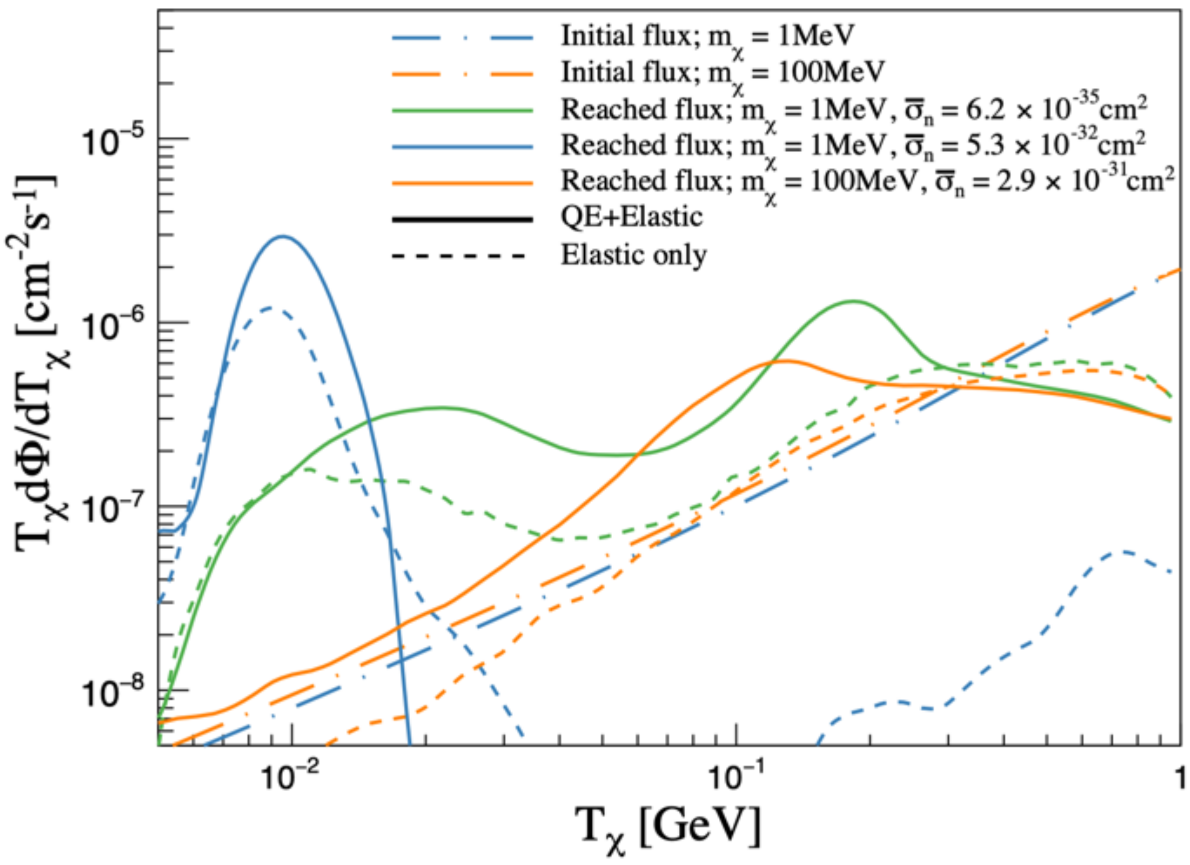
$$R_{\sigma_i} = \frac{\sigma_i}{\sigma_{tot}}, \quad i = \text{ES, QES, DIS}$$

L. Su, L. Wu, NZ, B. Zhu, **Phys. Rev. D** 108, 035004 (2023)

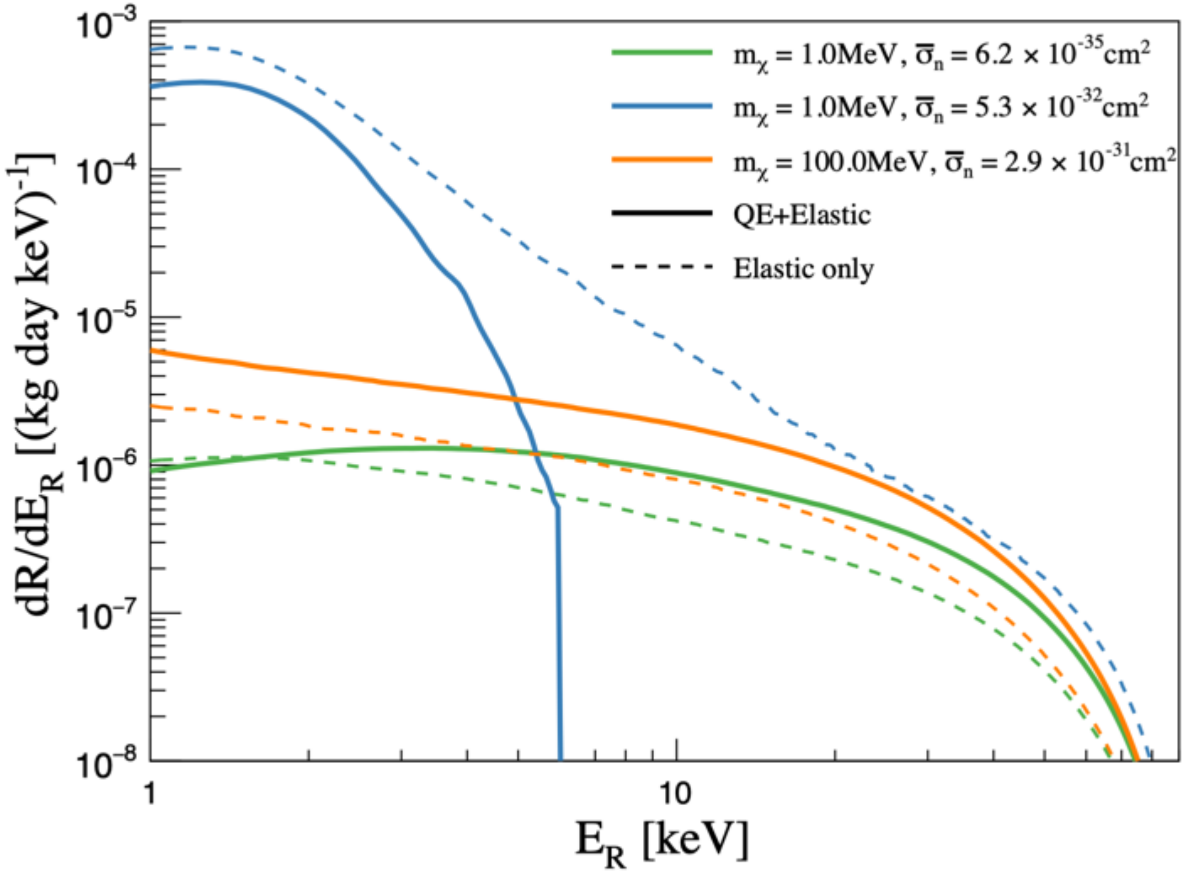
Boosted DM in Detector

- **Earth attenuation**
  - Monte Carlo simulation with both QE and elastic process included

DM flux

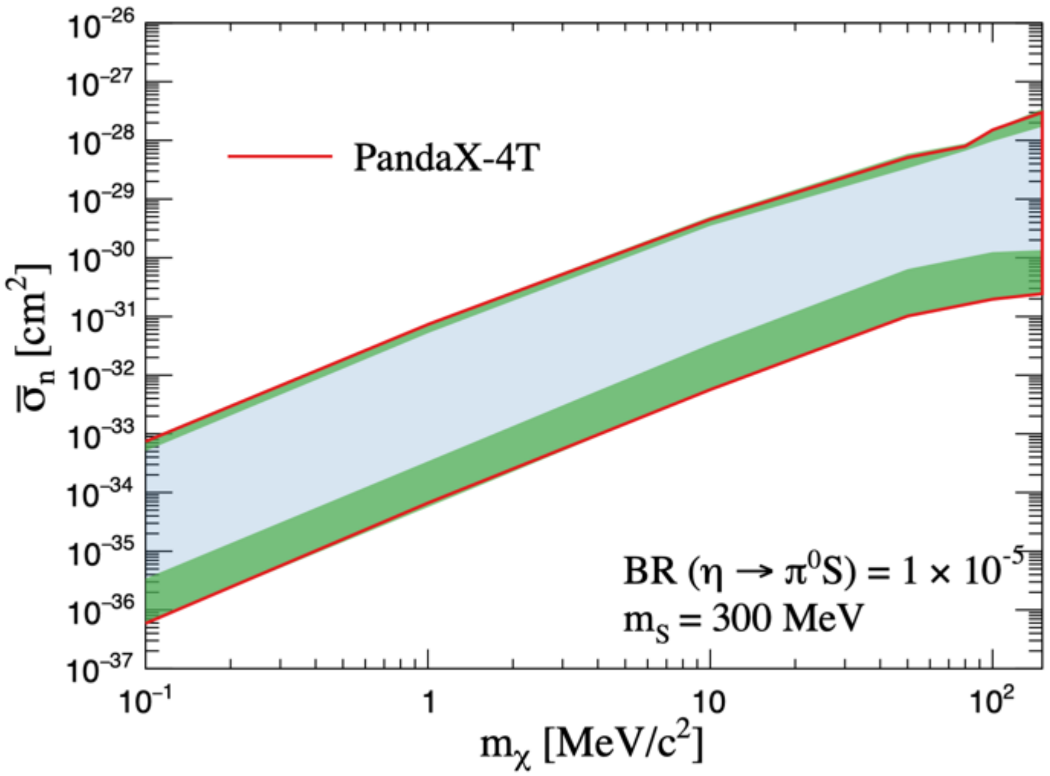


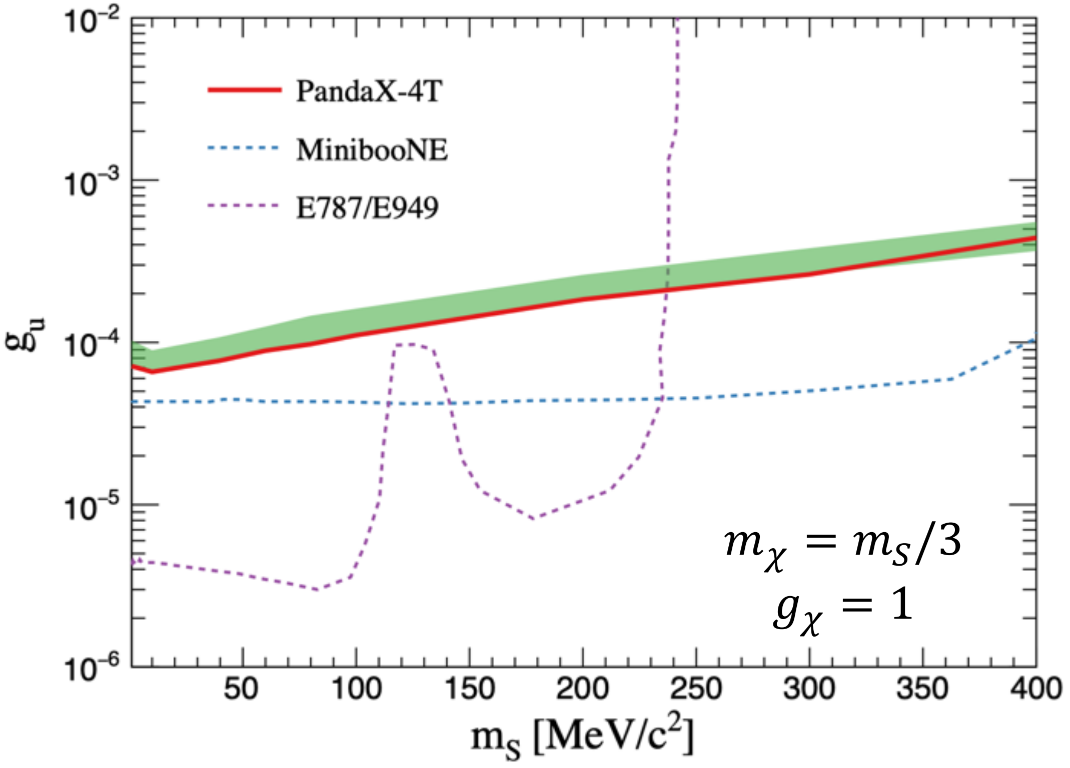
Nuclear recoil energy



Constraints on Coupling Strength

- **Cosmic-ray beam-dump gives a unique window to search for this scalar mediated DM-nucleon interaction**
- **Same model could be tested in beam experiments**

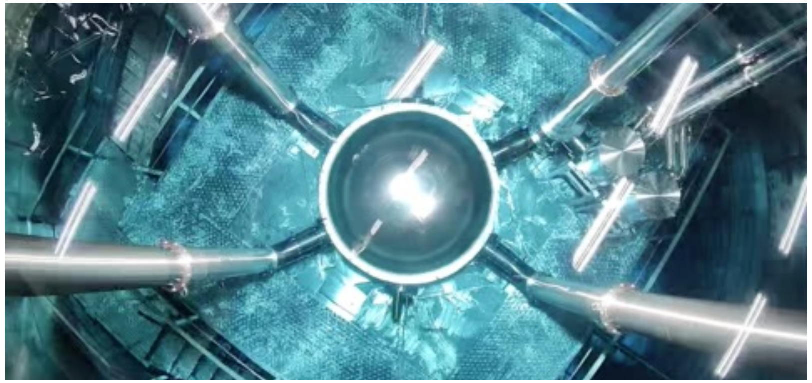




Phys. Rev. Lett. 131, 041001 (2023)

Physics Run of PandaX-4T

2020/11 – 2021/04	**Commissioning (Run 0)** 95 days: ~0.6 tonne-year
2021/07 – 2021/10	**Tritium removal** xenon distillation, gas flushing, etc
2021/11 – 2022/05	**Physics run (Run 1)** 164 days: ~1.0 tonne-year
2022/09 – 2023/09	**CJPL B2 hall constrution** xenon recuperation, detector upgrade
Expect to resume by the end of 2023	

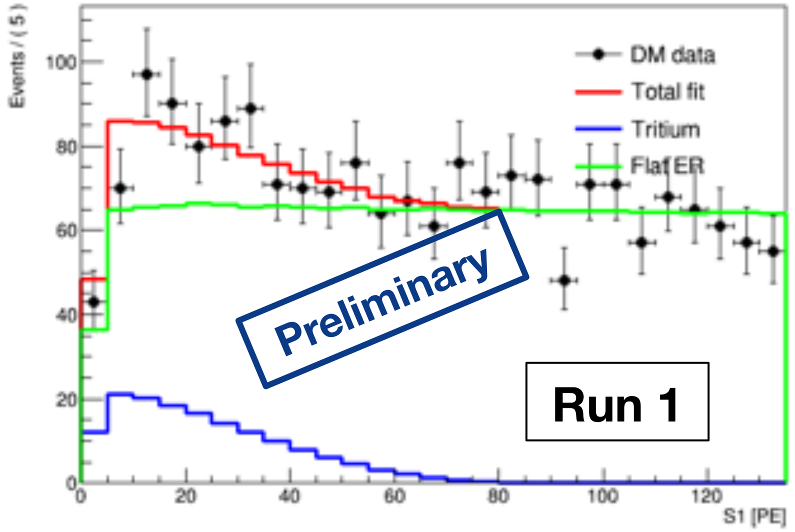


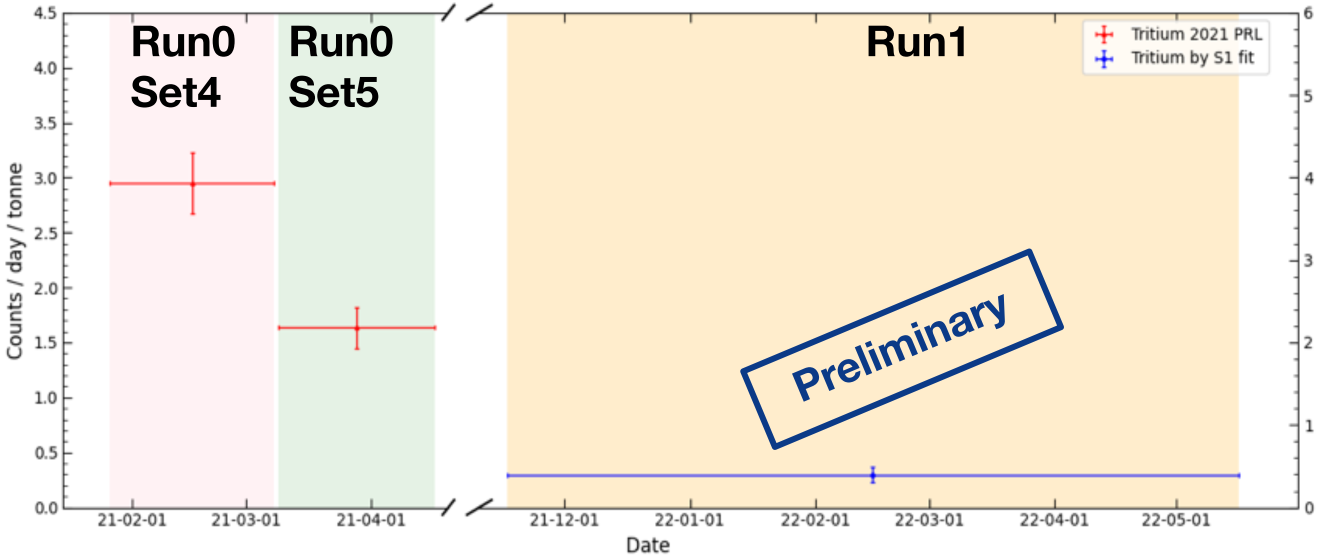
Tritium background in Run 1

- **Preliminary estimation of tritium level in Run 1**
  - fitting S1 spectrum, keeping S2 blinded

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

- **Further extensive tritium measures planned for next run**





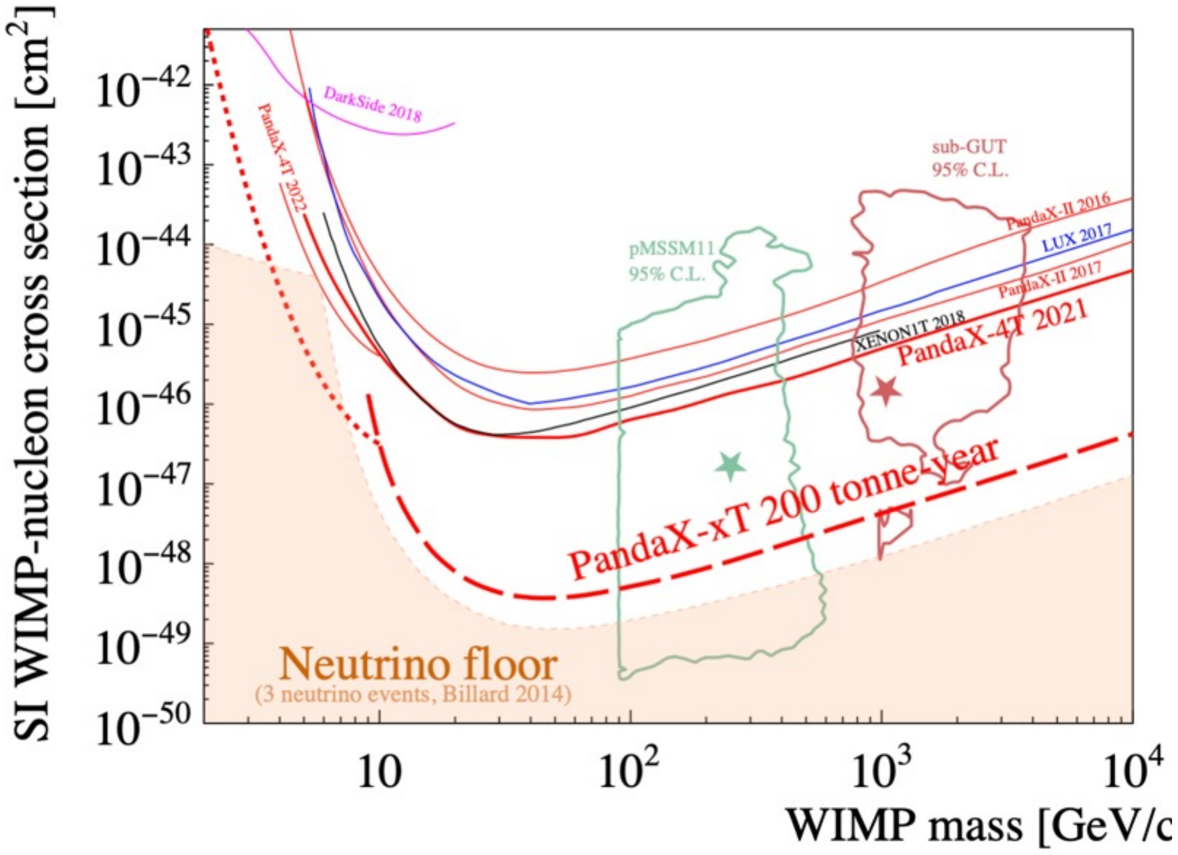
Data analysis on Run 1

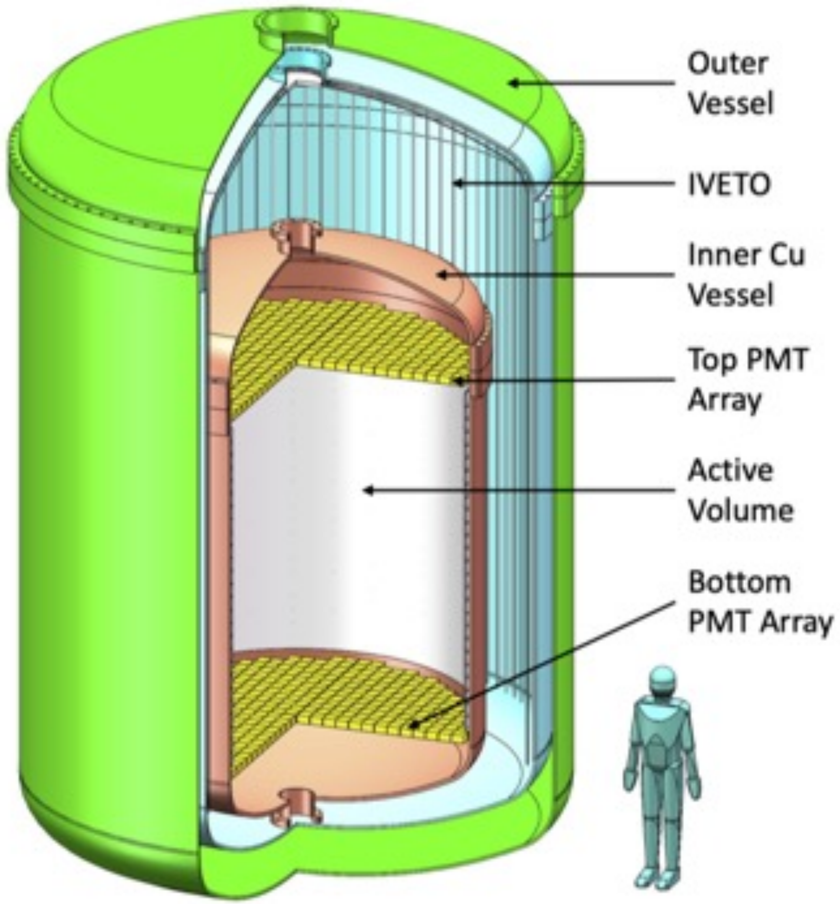
- **Preliminary estimation of background**
- **More results based on Run0+1 are work-in-progress**

Component	Run0: 0.6 tonne-year	Run1: 1.0 tonne-year
Tritium	**2.3 ± 0.2 counts/day/tonne**	**0.4 ± 0.1 counts/day/tonne**
Rn	7.1 ± 0.2 uBq/kg	8.7 ± 0.3 uBq/kg
Kr	0.5 ± 0.3 ppt	0.9 ± 0.3 ppt
Neutron	1.0 ± 0.2 events (total)	2.3 ± 0.4 events (total)
Surface	0.10 ± 0.06 events (total)	0.16 ± 0.09 events (total)
AC	work-in-progress	work-in-progress

Future plan: PandaX-xT

- **Next generation liquid xenon experiment**
  - with >30 tonne sensitive volume
  - decisive test on WIMP with 200 tonne-year





Summary

- **PandaX-4T is exploring various types of DM**
- **Novel probes are tested to expand the physics reach**
- **Combined analysis on Run 0+1 is work-in-progress**
- **Run 2 data-taking will start soon**
- **Planning future PandaX-xT project**

Thank You！