Recent Results In Dark Matter Direct Detection In China

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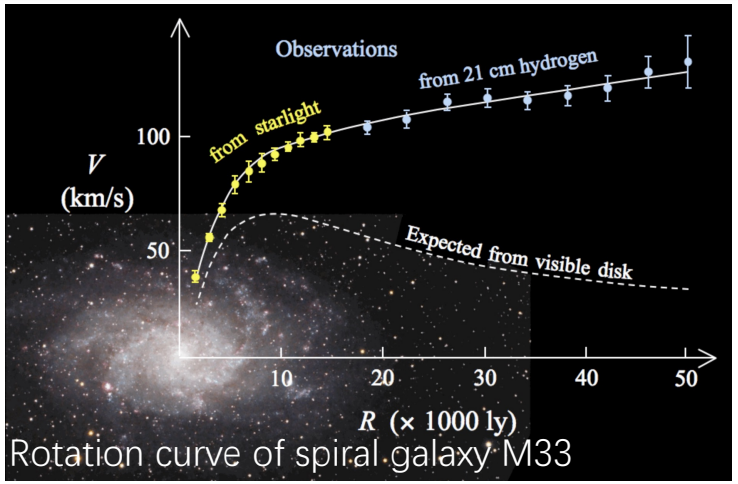
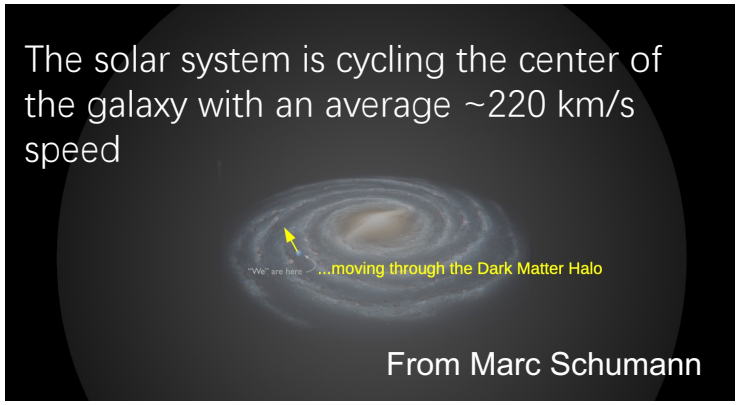
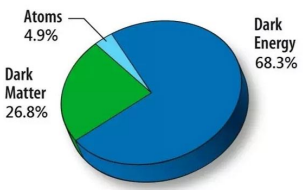
Dark Matter and Its Direct Detection

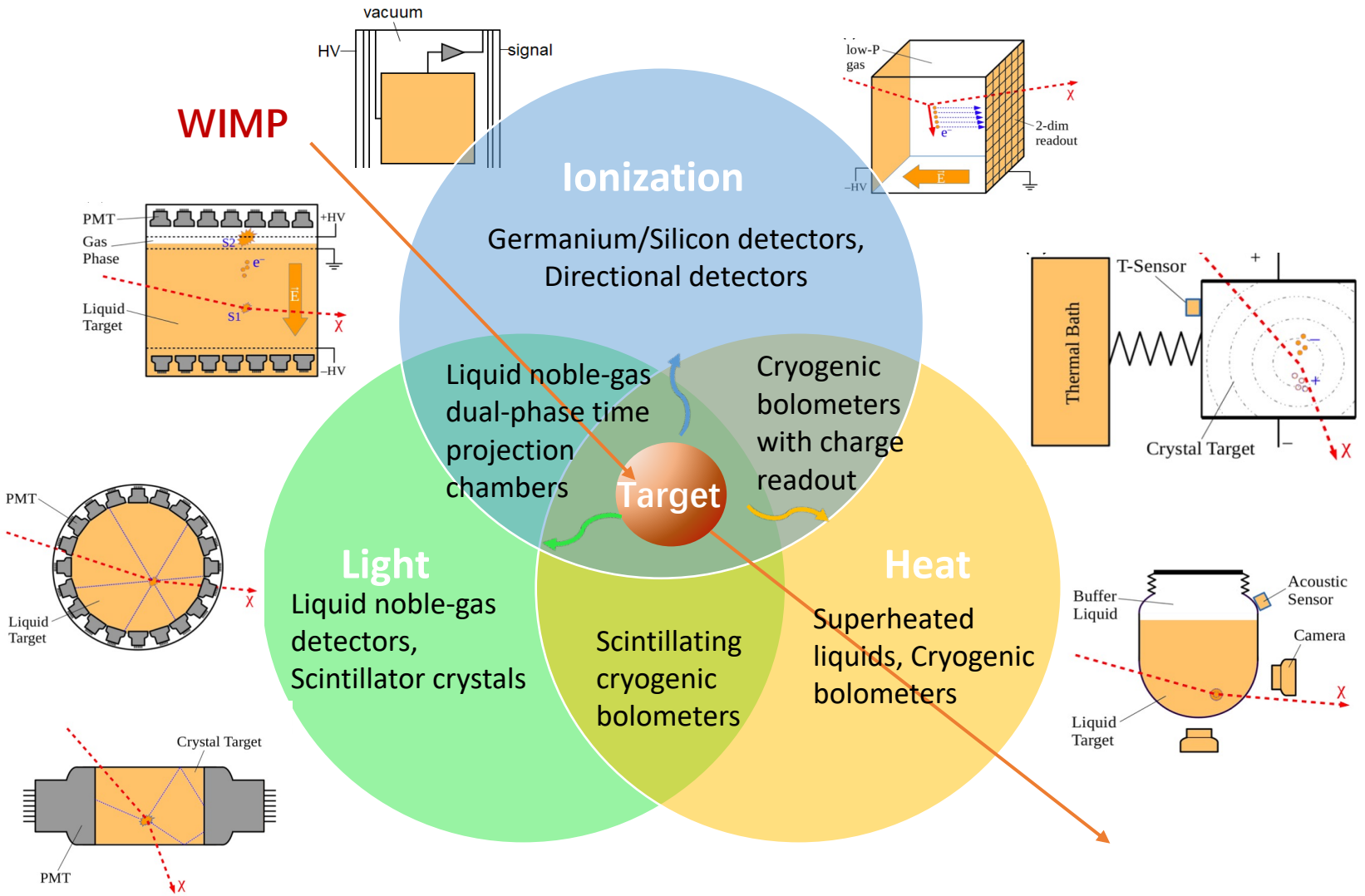


Rotation curve of spiral galaxy M33

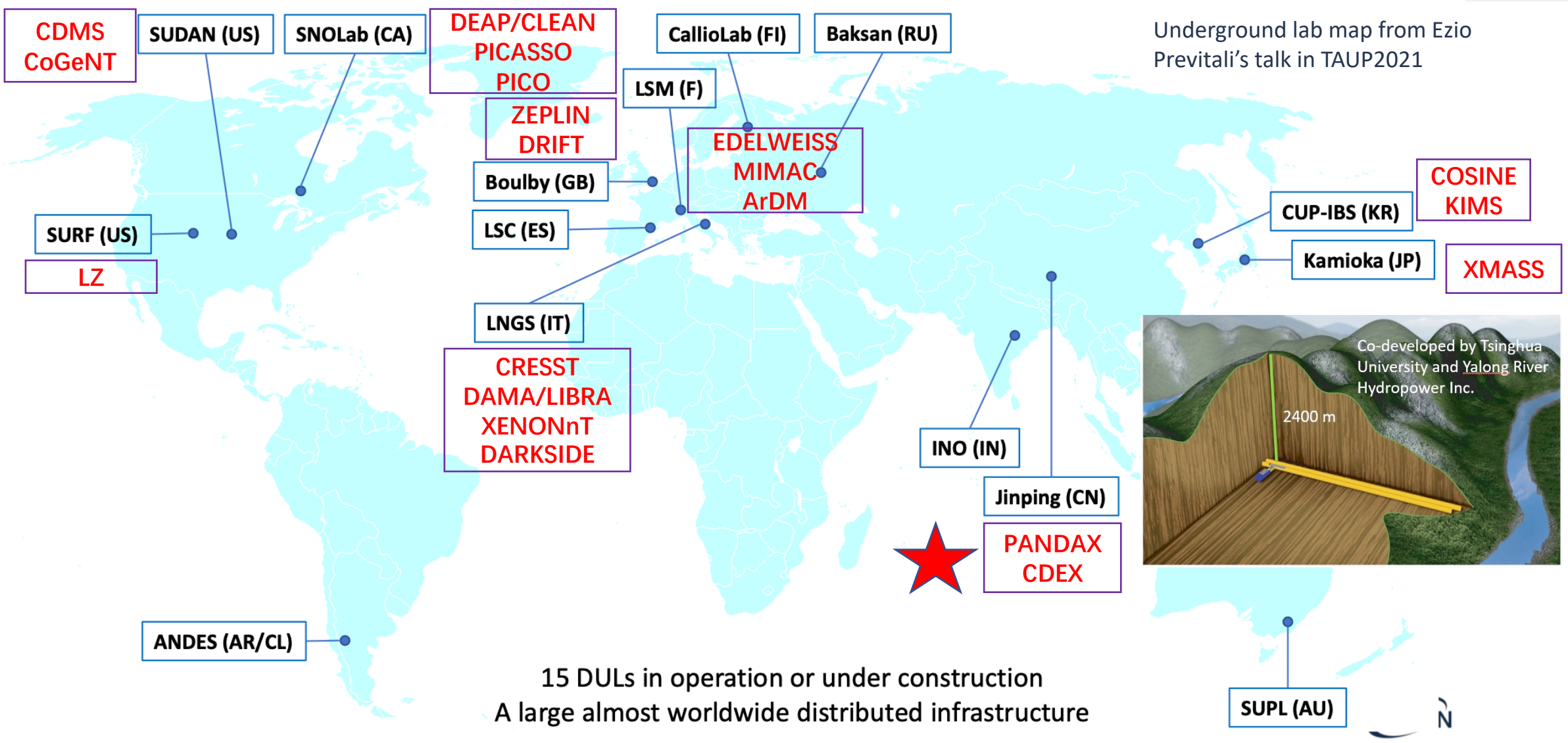


Gravitational evidence suggests dark matter is the dominant form of matter in the Universe!





Underground Laboratories and DM Experiments

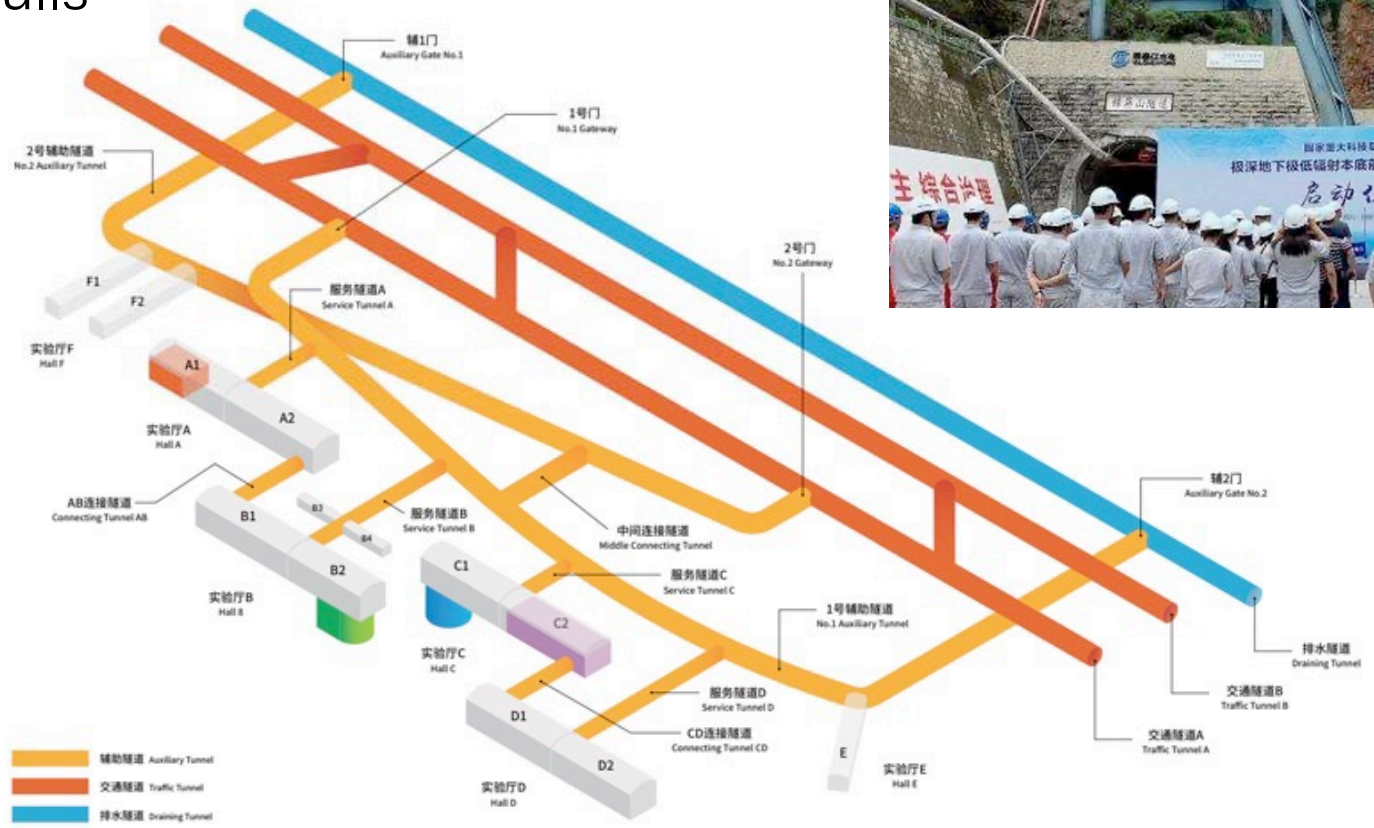


Underground lab map from Ezio Previtali's talk in TAUP2021

15 DULs in operation or under construction
A large almost worldwide distributed infrastructure

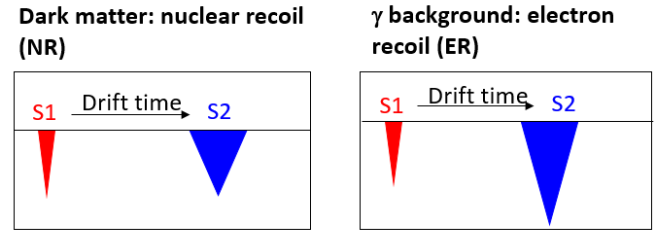
CJPL-II (China Jinping Underground Lab-II)

- Deep underground low background frontier physics experimental platform
- 8 experimental halls
  -- L: 65 m
  -- H: 14m
  -- W: 14m

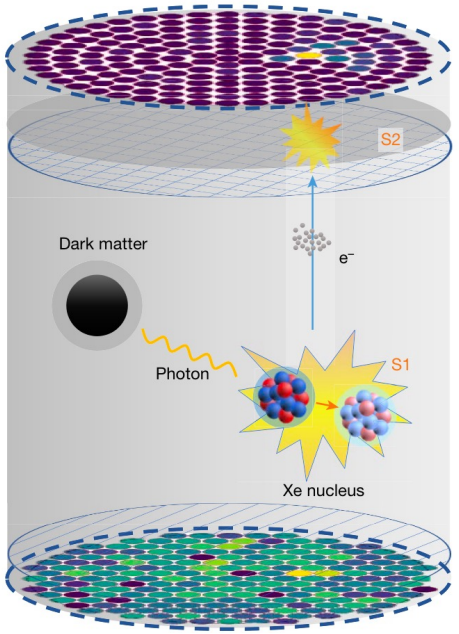


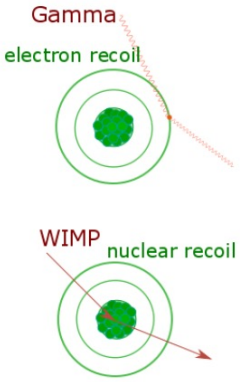
B2: PANDAX
C1: CDEX

PandaX Experiment



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





PandaX Roadmap

Particle and Astrophysical Xenon Experiments

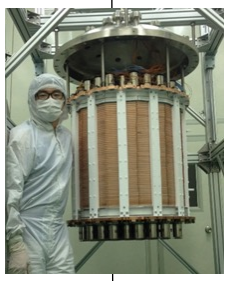
Collaboration formed

2009.3

2014.5-10

PandaX-I, 120 kg operation

PandaX-II, 580 kg operation

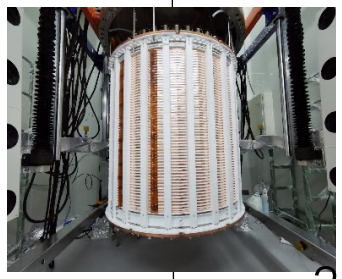


2016.7-2019.7

2019.8

PandaX-4T moved to CJPL-II

PandaX-4T Commissioning (Run0)

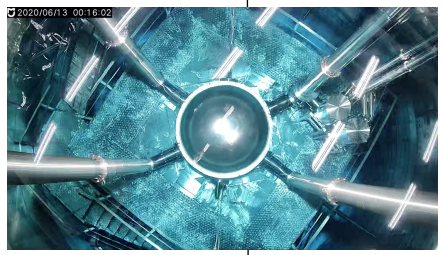


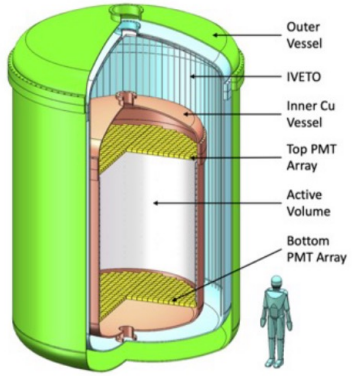
2020.11-2021.5

Ongoing

2021.11-2022.7

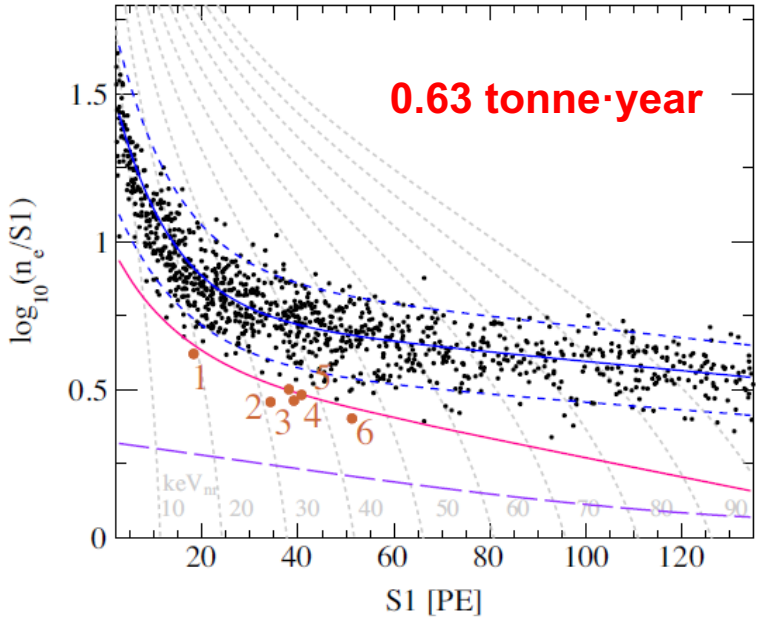
PandaX-4T Run1

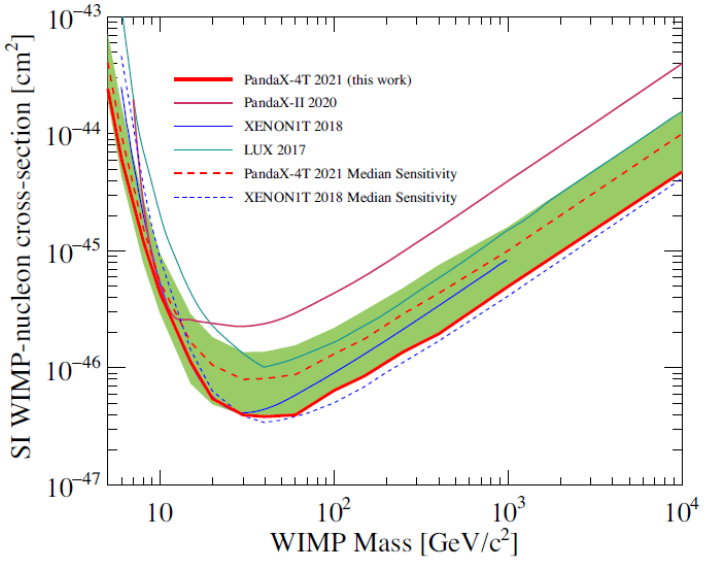




PandaX-xT

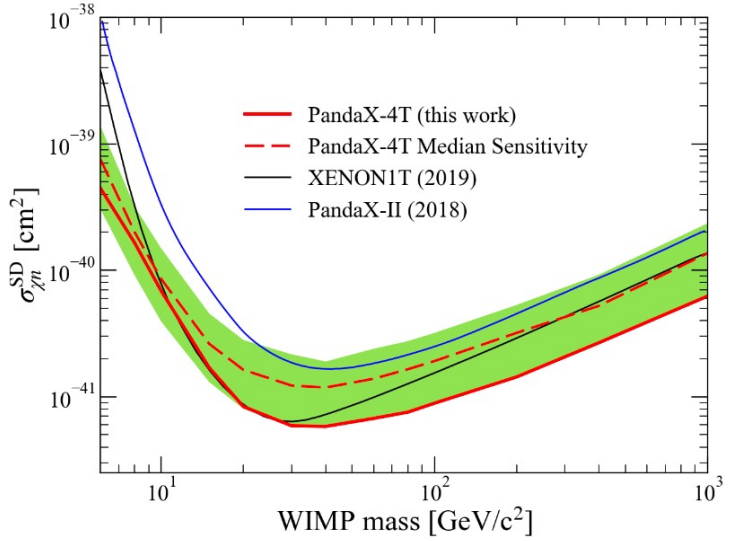
PandaX-4T WIMPs Search (SI & SD)

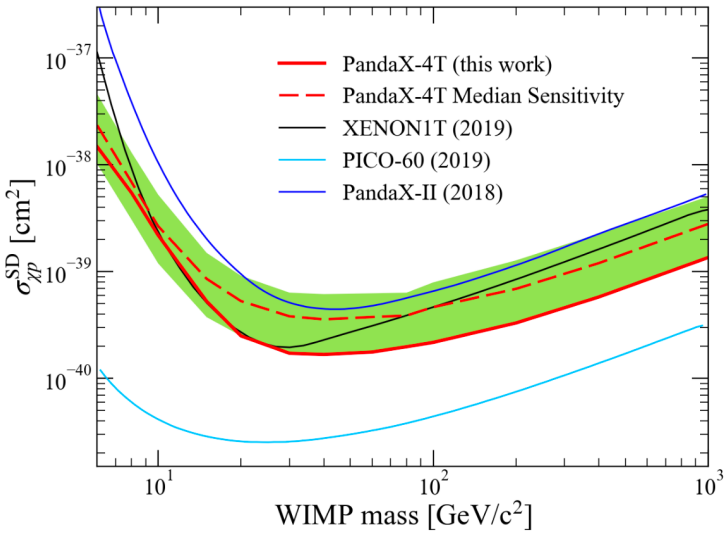




Y. Meng et al. PRL 127, 261802 (2021)

Z. Huang et al. PLB 834, 137487 (2022)





- First result (SI): 1058 candidates (expected 1054±39), 6 below NR median curve (expected 9.8±0.6)
- Sensitivity improved from PandaX-II final analysis by 2.9 times (30 GeV/c^2)
- Scattering cross-section could be connected to the spin of the nucleus

Luminance of DM

How dark is dark matter?

- **Possible residual weak EM properties, coupling with photons**
- **First experimental constraints on DM charge radius**
  - 4 orders of magnitude smaller than neutrino
- **Other EM properties**
  - Up to 3 – 10 times improvement

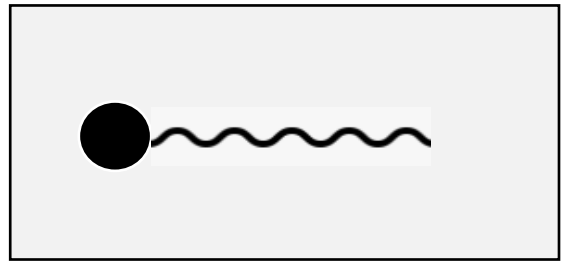
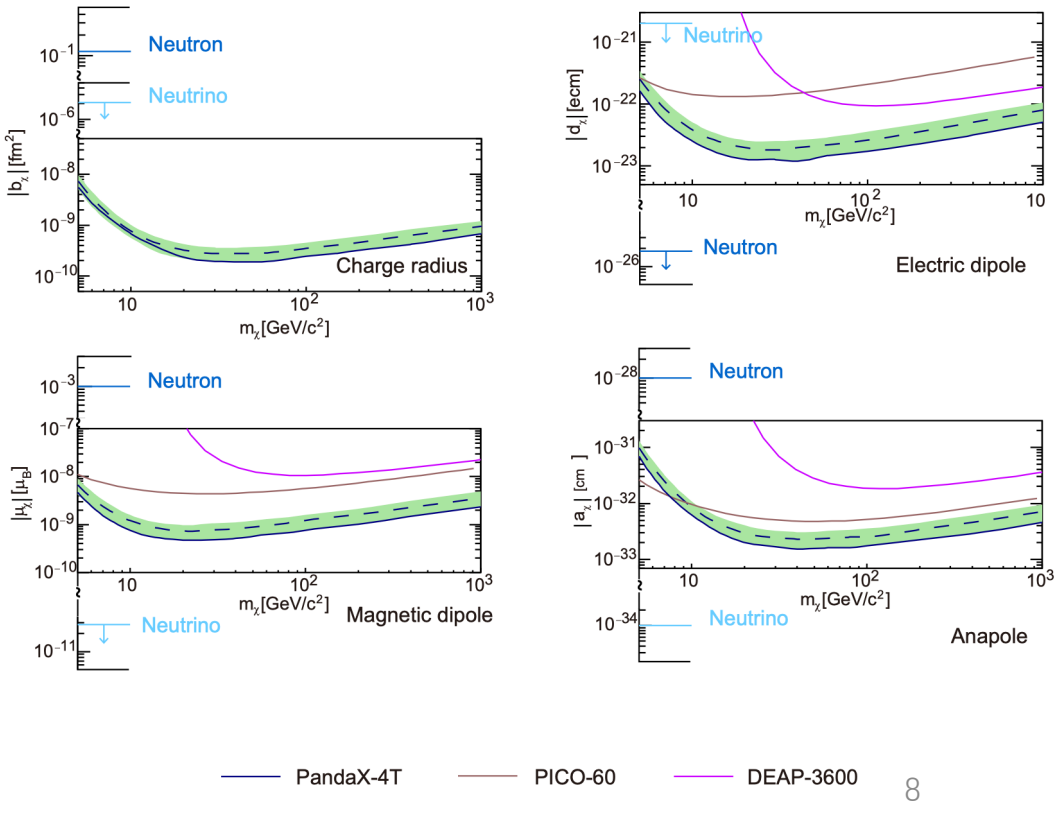


Table 1 | Comparison of electromagnetic properties

	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)	$<1.6\times10^{-33}$	$\sim10^{-34}$ ‡	$\sim10^{-28}$ §

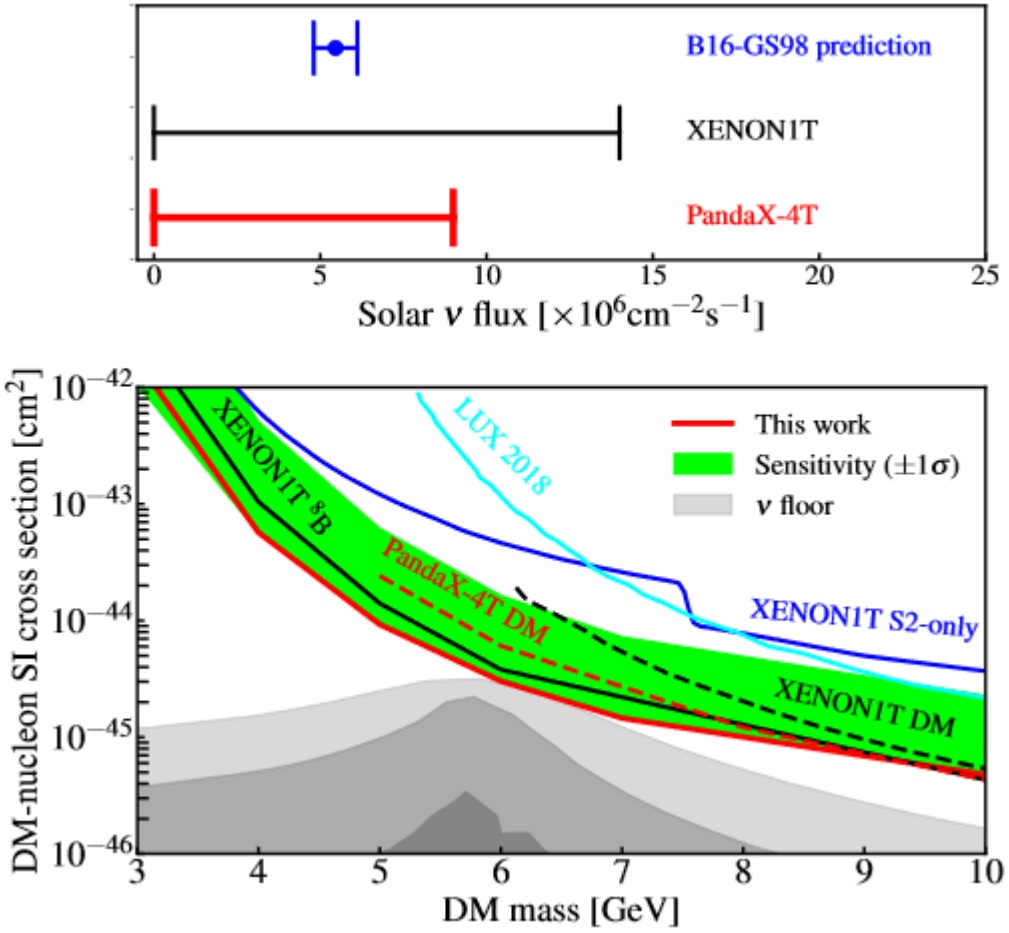
* Datas are taken from PDG [33]
† Taken from [32]
‡ Taken from [34]
§ Taken from [35]

X. Ning et al. Nature (2023)



Constraints on Solar ^{8}B Neutrino

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



- A multi-variate (BDT) algorithm trained to suppress AC background
- Blind analysis: 0.48 ton-year data, excluding data with an increase in noise rate (micro-discharge)
  - Some downward fluctuation

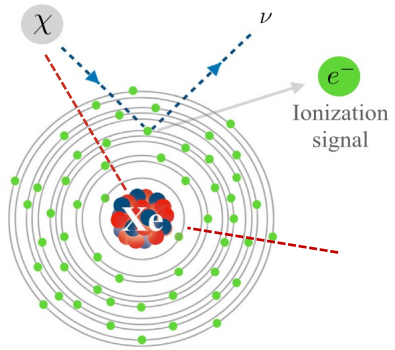
ROI (BDT applied)

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

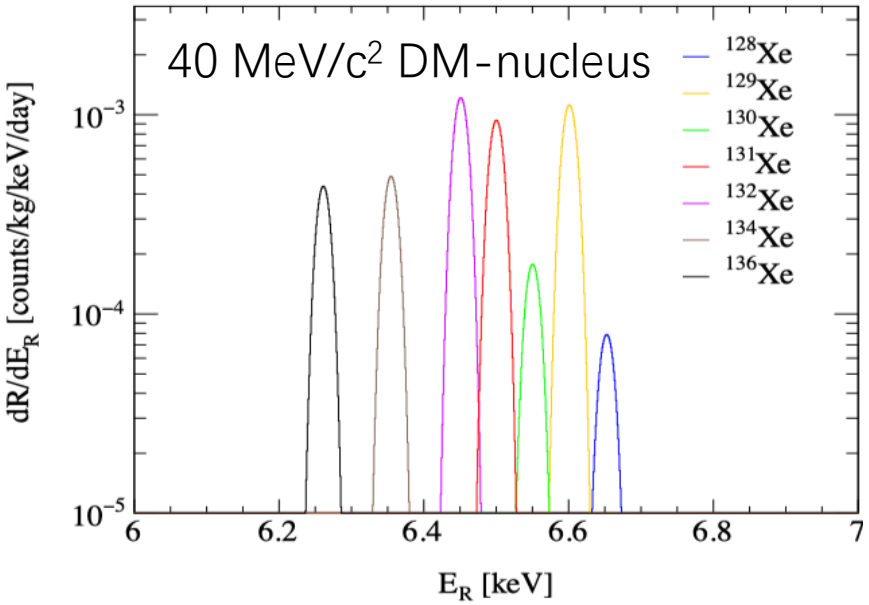
- Leading constraint on ^{8}B neutrino flux through CEvNS process
- Assuming a nominal ^{8}B background, set strongest constraints on light WIMP of 3 -10 GeV

Mono-energetic Signal Search

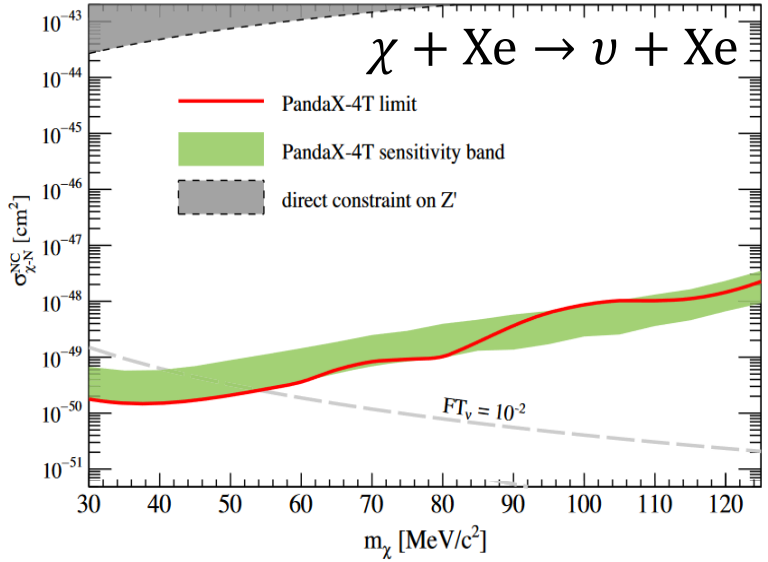
- **Characteristic mono-energetic signal:**
  - (a) Xe-nucleus targets, m_x = 40 MeV, E_R ~ 6.5 keV
  - (b) Electrons targets, m_x = 40 keV, E_R ~ 1.5 keV



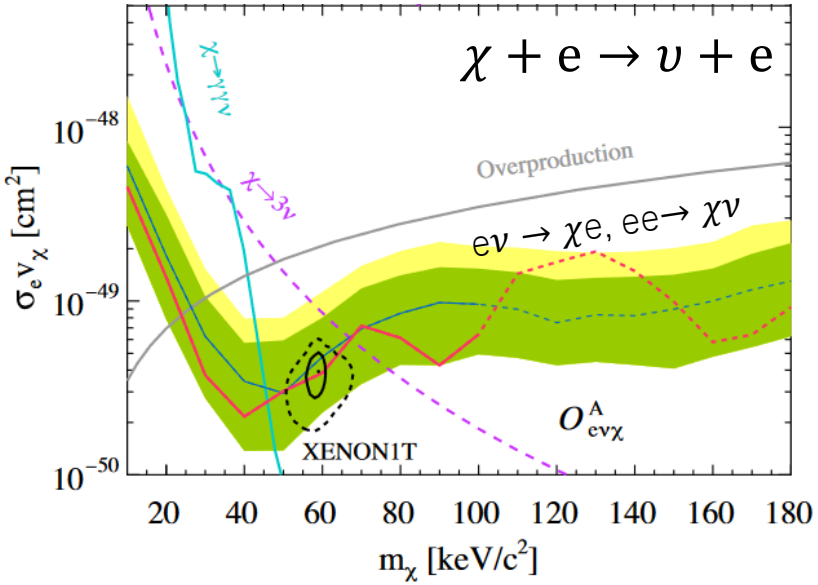
$$E_R = \frac{m_\chi^2}{2(m_T + m_\chi)}$$



Contribution from isotopes in dR/dE



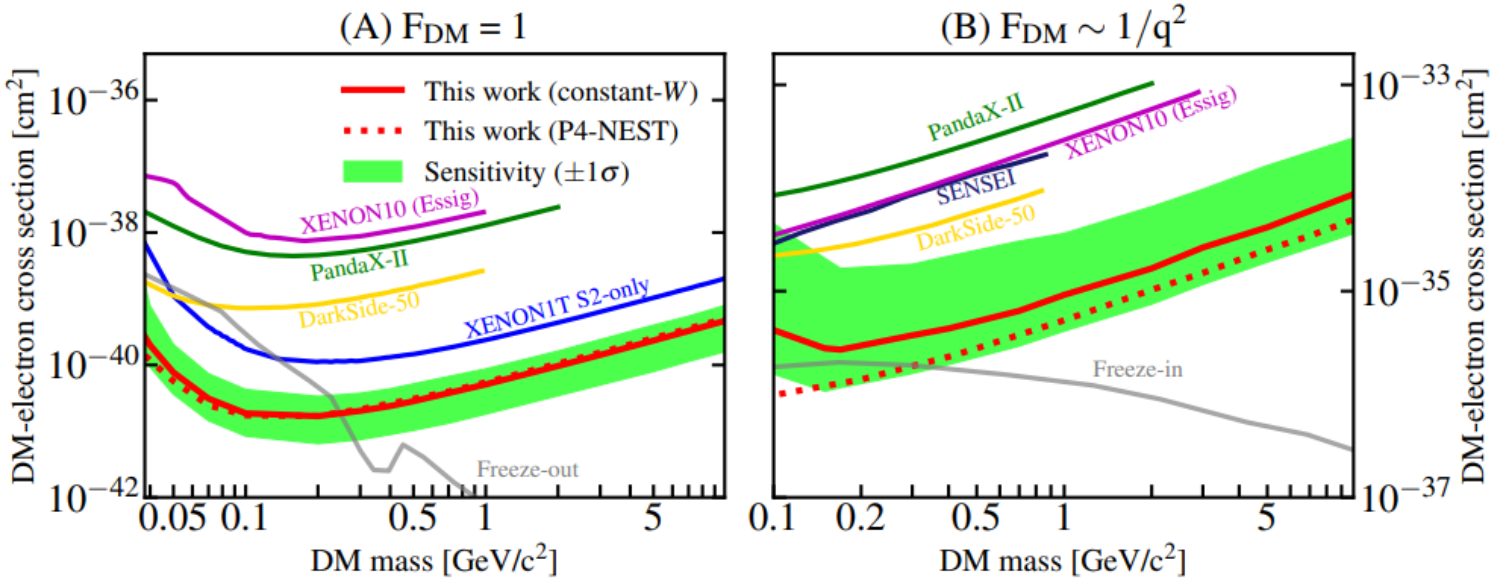
L. Gu et al. PRL 129, 161803 (2022) , Editors' Suggestion

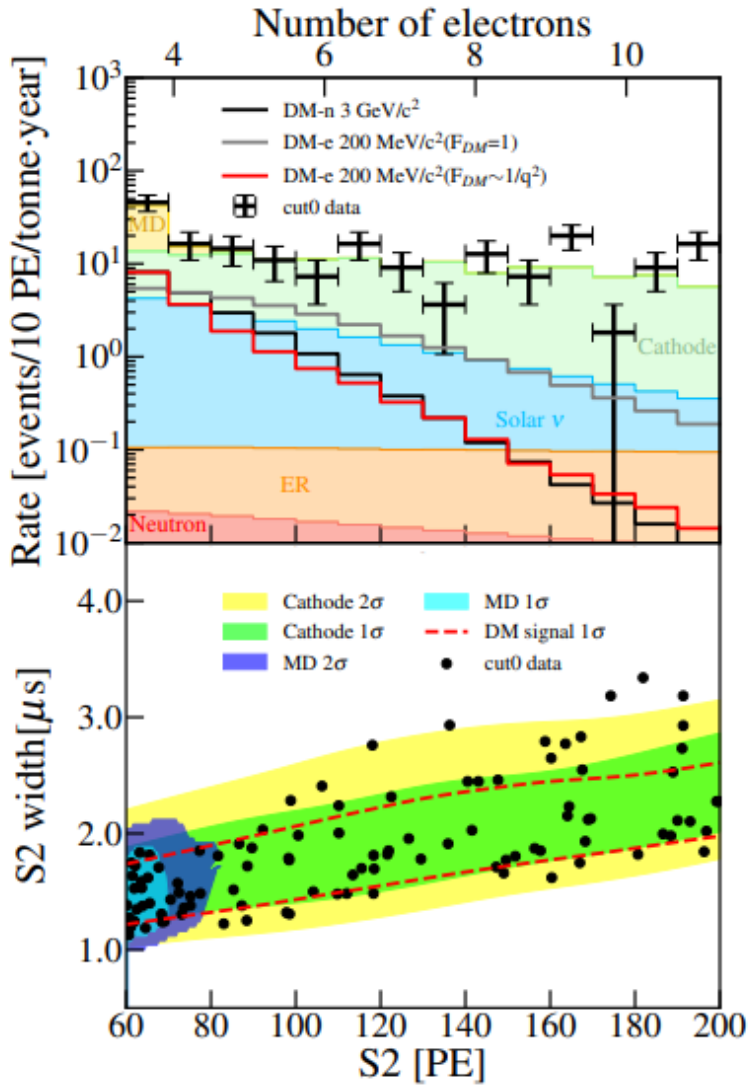


D. Zhang et al. PRL 129, 161804 (2022) , Editors' Suggestion

Light DM via Ionization-only

- **Blind analysis of 0.55 tonne-year exposure, with threshold down to ~100 eV (from ~1 keV)**
- **First detailed background components study: MD & cathode**
- **Most stringent constraints are derived**
  - DM-electron interaction, 2×10^{-41} cm^2



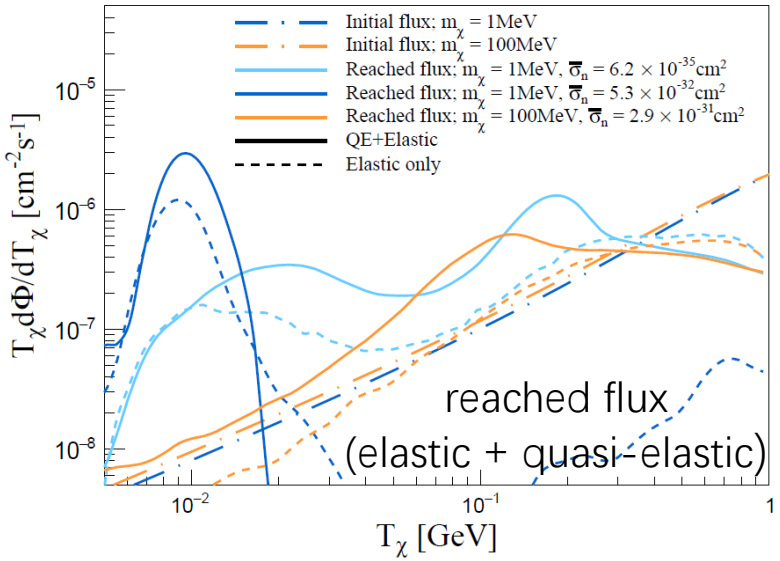


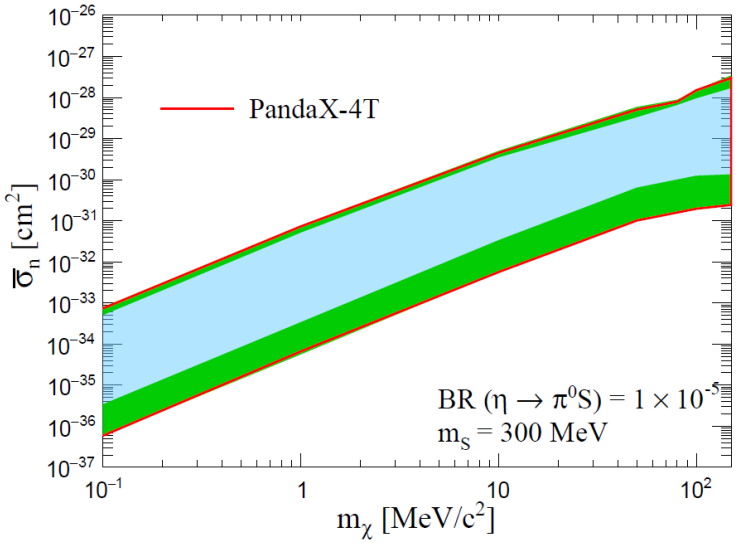
S. Li et al. PRL 130, 261001 (2022), Editors' Suggestion

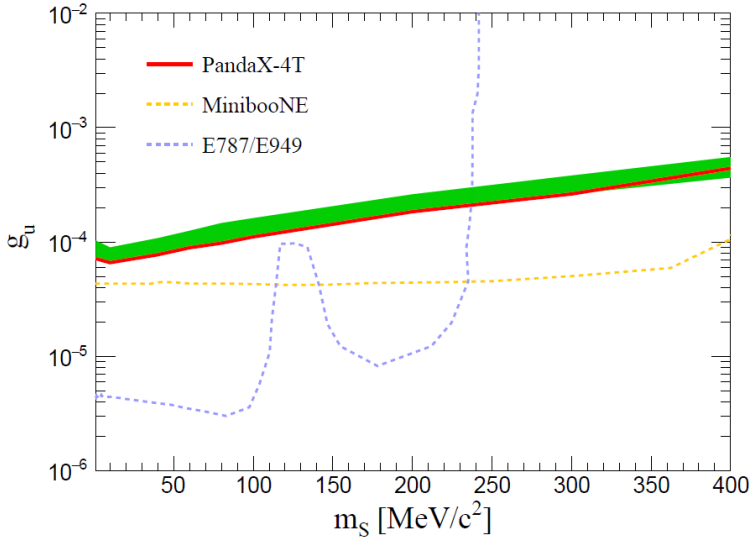
Constraints on Boosted DM

- **Large kinetic energy to overcome threshold**
- **Boosted mechanism**
  - Mesons from cosmic-ray dump in atmosphere may decay into light boosted-DM
- **Cosmic-ray beam dump gives a unique window to search this scalar-mediated DM-nucleon interaction**
- **Same model could be searched in MinibooNE and E787/E949**

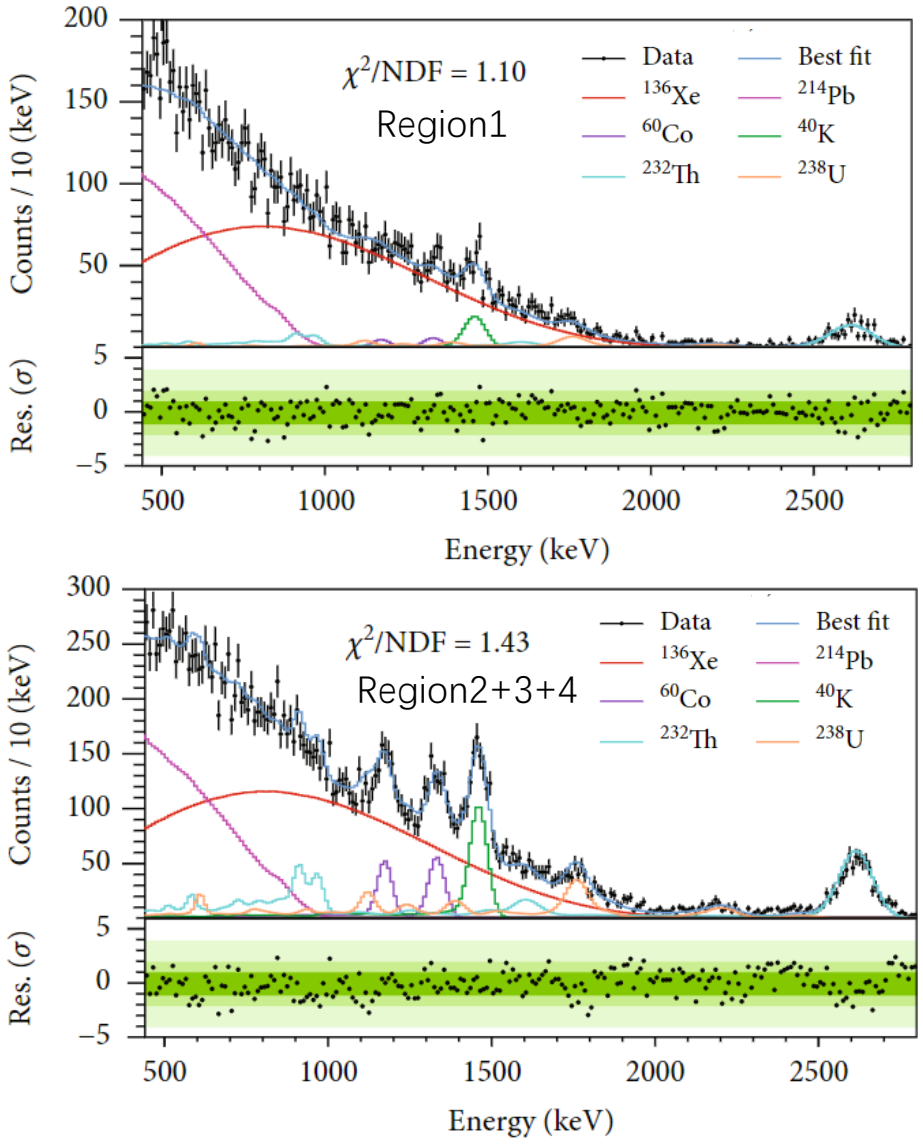
X. Ning et al. PRL 131, 041001 (2023)







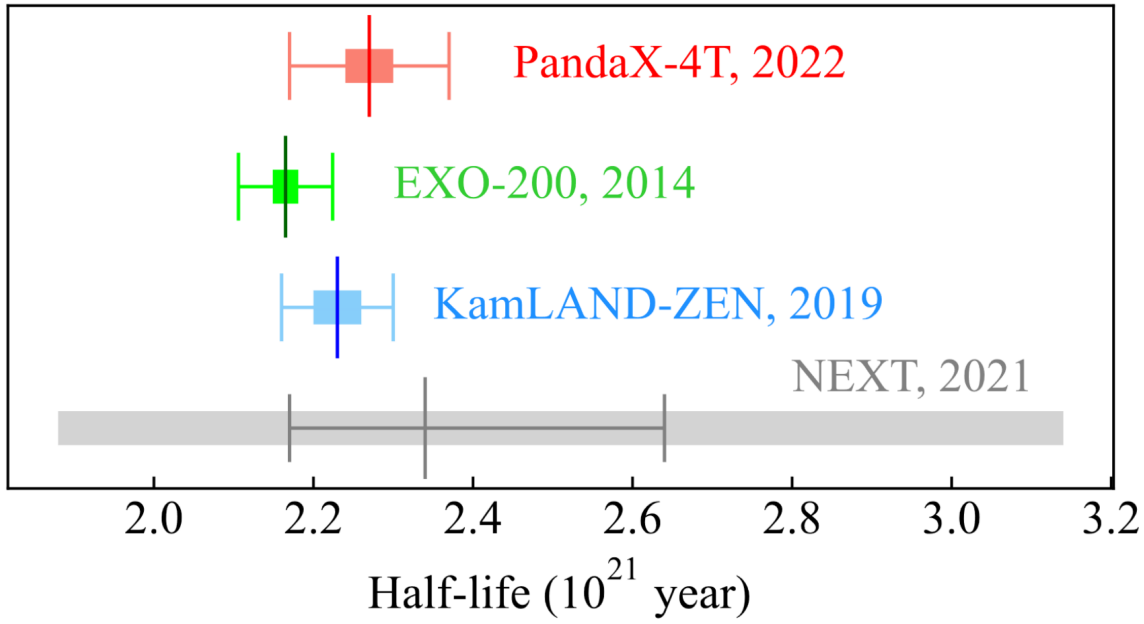
^{136}Xe 2νDBD Half-life Measurement



- PandaX-4T: ^{136}Xe/Xe 8.86%, 59.6kg in FV, up to 2.8MeV
- First natural xenon measurement with a dark matter detector

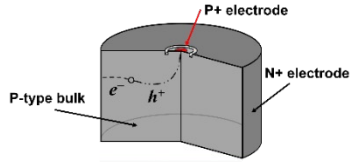
  $2.27 \pm 0.03\ (stat) \pm 0.10\ (syst) \times 10^{21}$ years
- Consistent with ^{136}Xe-enriched experiments.

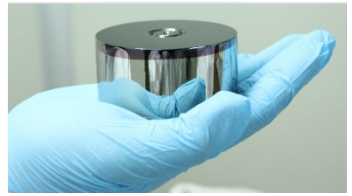
Research Vol 2022, 9798721 (2022)



CDEX Experiment

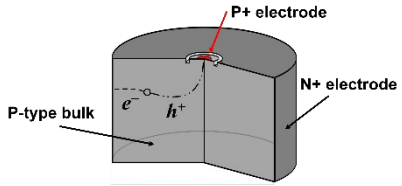
- Formed in 2009, 11 institutions and ~100 people now; http://cdex.ep.tsinghua.edu.cn/
- **Key technology:** P-type Point-Contact (PPC) Ge detectors;
- **Physics targets:** Direct detection of light DM + Ge-76 0νββ

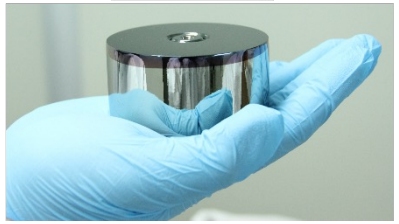


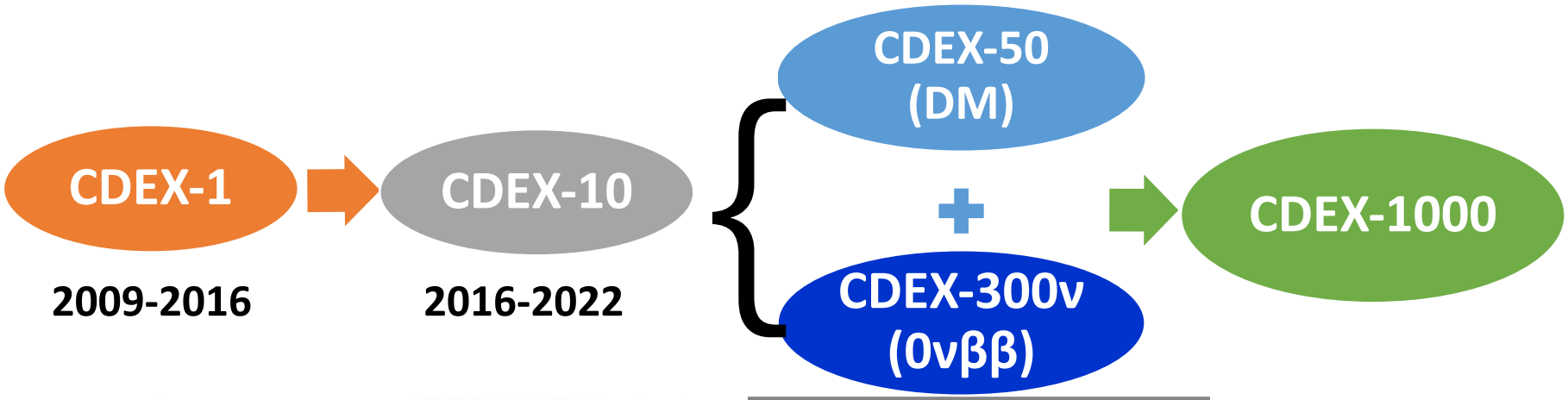


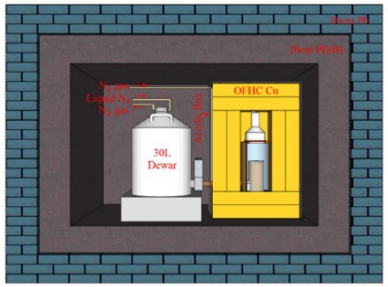
CDEX Roadmap

- **CDEX-1 (2009-2016):** Development of PPC Ge detector, bkg understanding
- **CDEX-10 (2016-2022):** Performances of Ge array detector immersed in LN_2
- **CDEX-50 (2021-202X):** 50kg Ge detector arrays for DM searches
- **CDEX-300v (2021-202X):** 300kg enriched Ge detector arrays for 0νββ Exp.

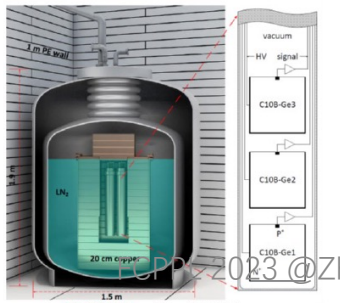




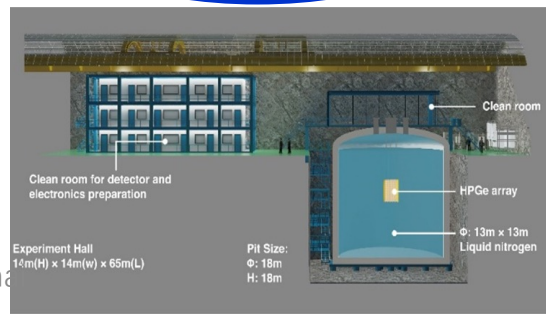




CDEX-1A&B: 1kg PPC Ge×2

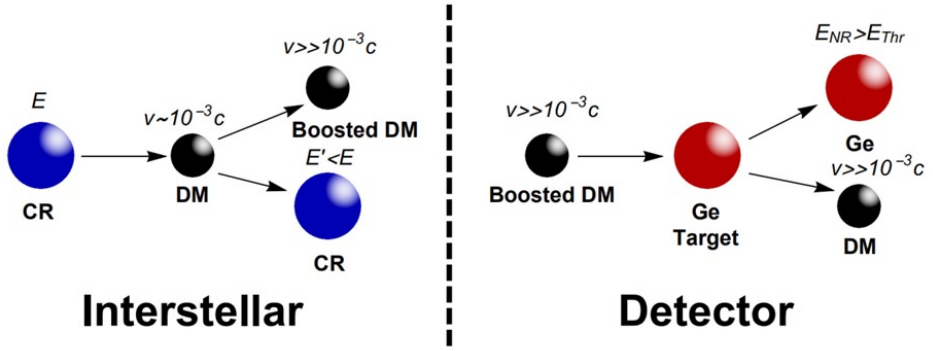


CDEX-10: ~10kg PPC Ge array



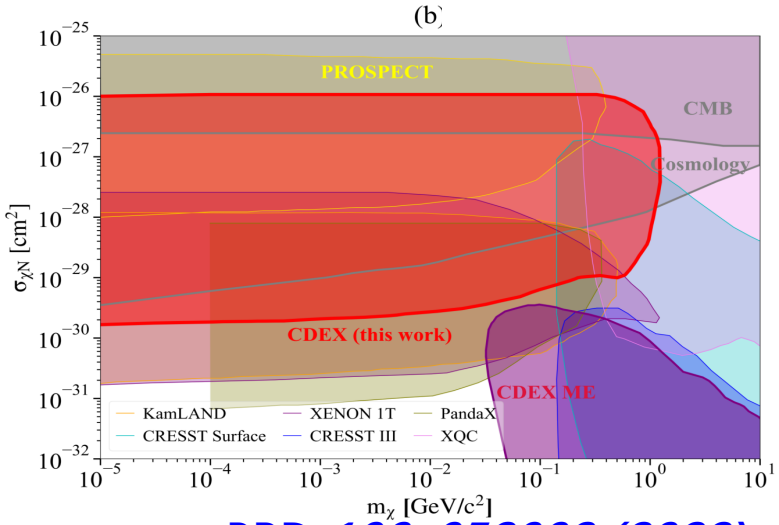
Sub-GeV DM: CRDM, Earth shielding

- **Searches on cosmic ray boosted dark matter**, the low mass reach of DM has been extended from GeV to keV, CDEX-10 results are more sensitive than cosmology;
- **To calculate the earth shielding effect for low mass DM**, CJPL_ESS package has been dedicatedly developed with detail topography of Jinping mountain.

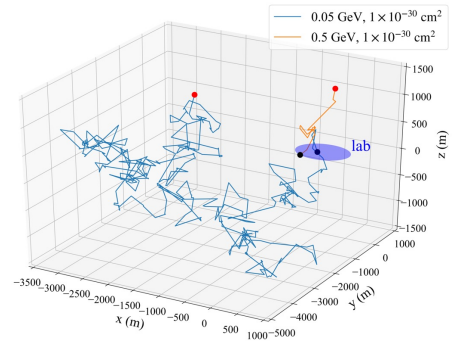


CRDM

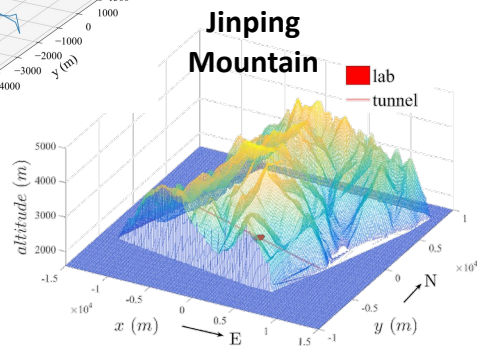
10 keV ⟵ GeV



PRD *106, 052008 (2022)*



Scattering tracks of DM in the crust (simulation)

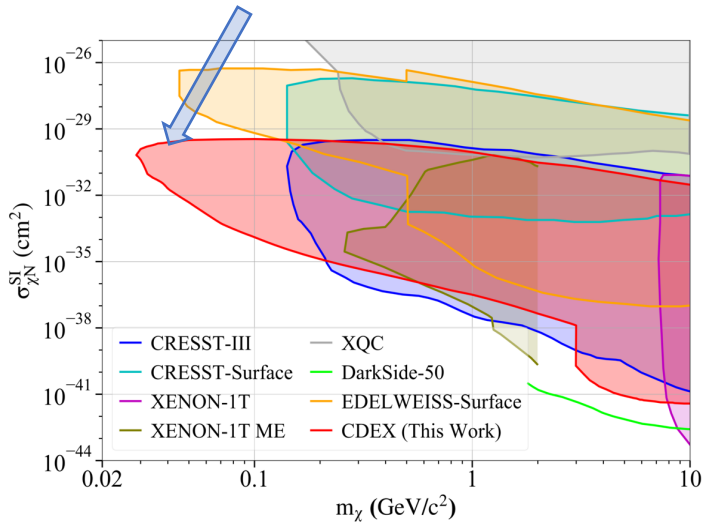


Exclusion line

→Exclusion region

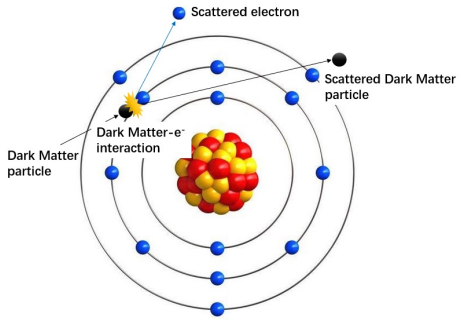
PRD *105, 052005 (2022)*

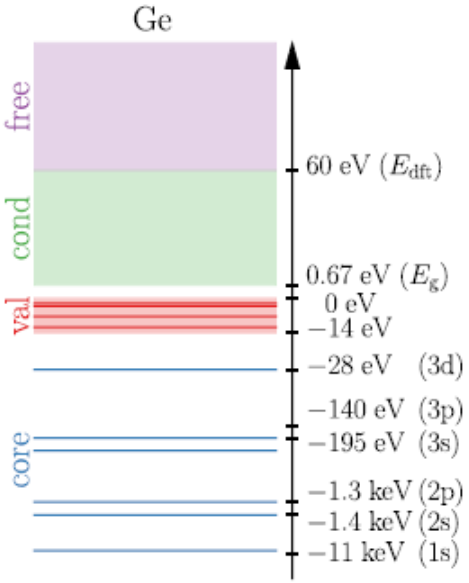
Earth shielding

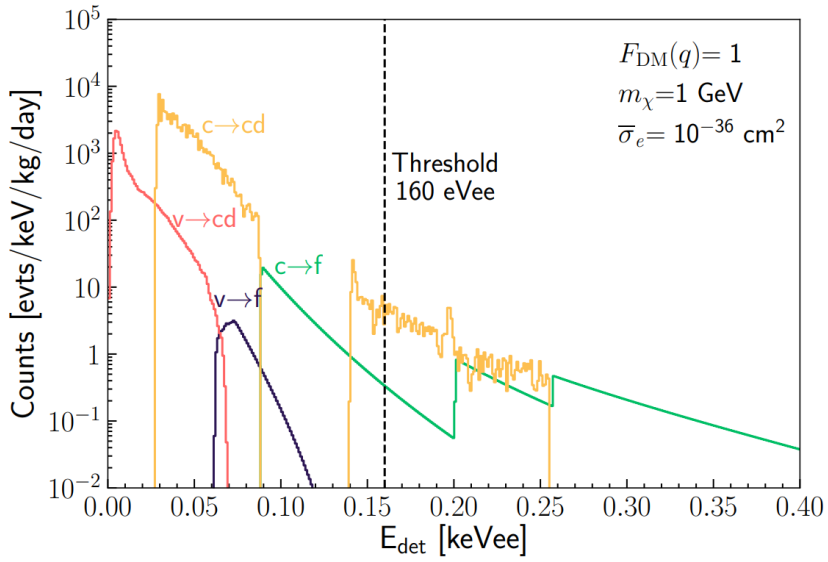


Sub-GeV Dark Matter–Electron Scattering

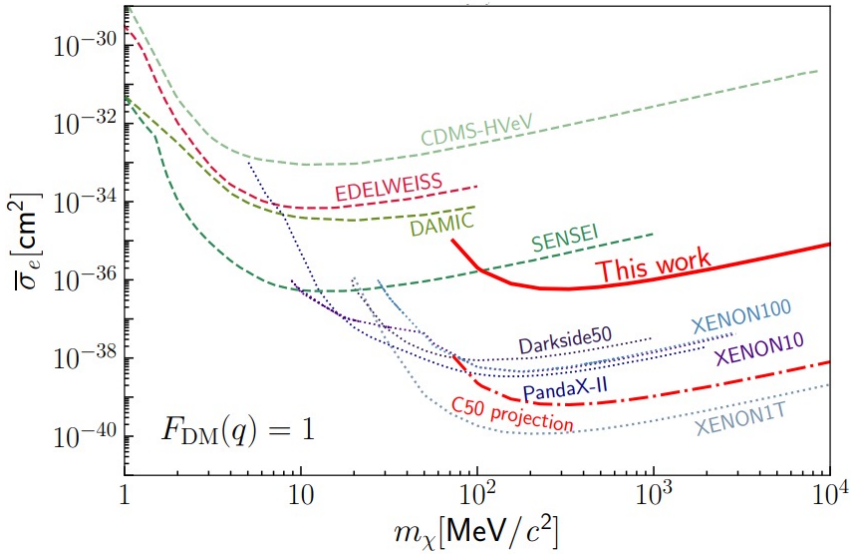
- **The first HPGe detector-based DM-e scattering limits from CDEX;**
- **The most stringent χ-e cross-section limit to date among experiments using solid-state** detectors for m_χ larger than 100 MeV with heavy mediators;







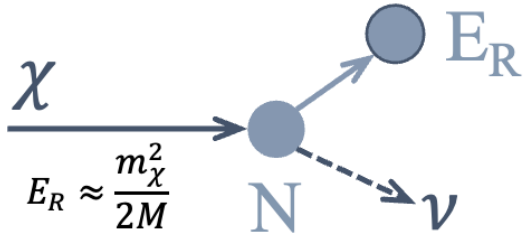
Phys. Rev. Lett. 129:221301 (2022)



Expected rates and CDEX-10 result in the heavy mediator scenario

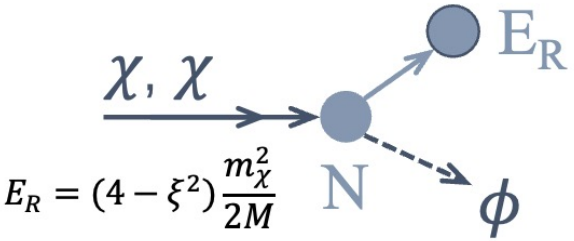
Exotic Dark Matter

- New low mass $\mathcal{O}(\mathrm{MeV}/c^2)$ dark matter（χ）may interact with nucleon (N)：
  - Neutral current fermionic DM absorption：$\chi + N \rightarrow \nu + N$[1]
  - DM-nucleus 3->2 scattering：$\chi + \chi + N \rightarrow \phi + N$ [2]



$\chi + N \rightarrow \nu + N$

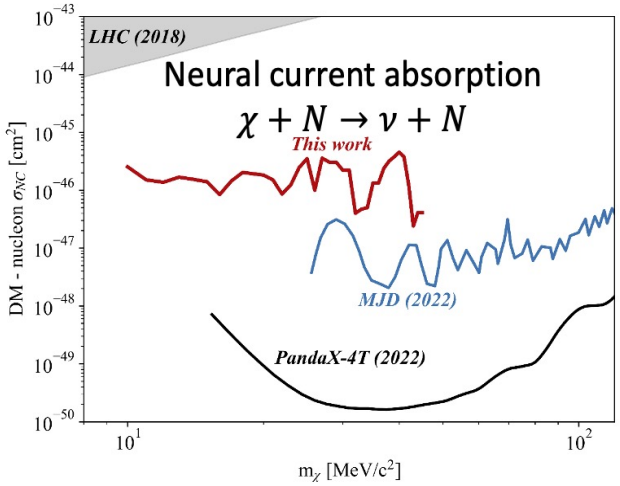
- ν is neutrino
- Generates a monoenergetic signal

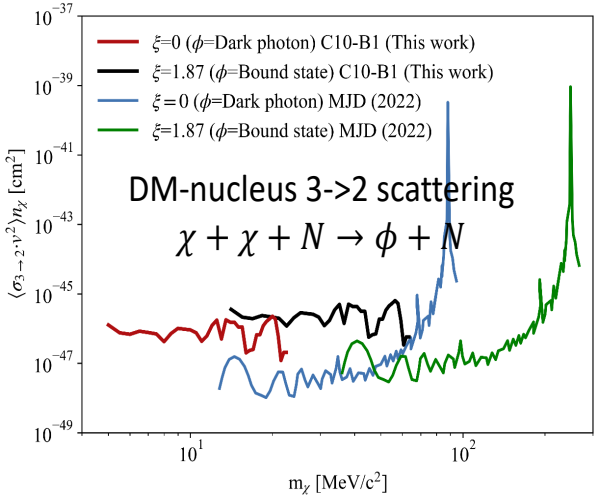


$\chi + \chi + N \rightarrow \phi + N$

- ϕ is either a DM composite state or any dark radiation
- Generates a monoenergetic signal

- Set new experimental limits on lowest mass range for these two channels based on the low energy threshold of 160 eV.



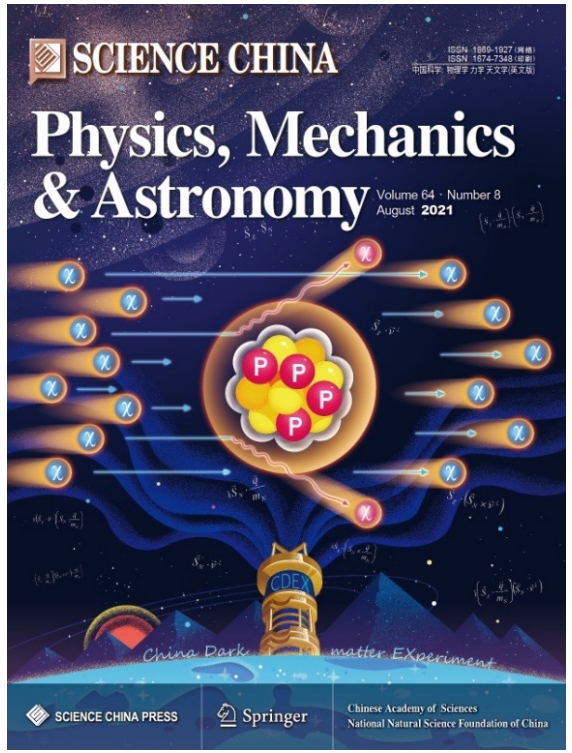


Phys. Rev. Lett. *129, 221802 (2022)*

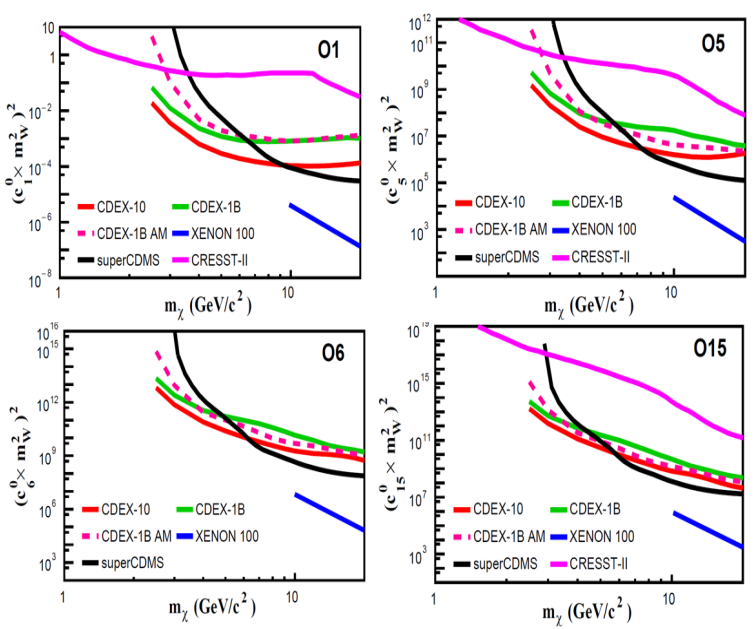
[1] Jeff A. Dror, et al., Phys. Rev. Lett. 124, 181301 (2020);
[2] W. Chao, et al., arXiv:2109.14944 (2021)

WIMP Search Within EFT Framework

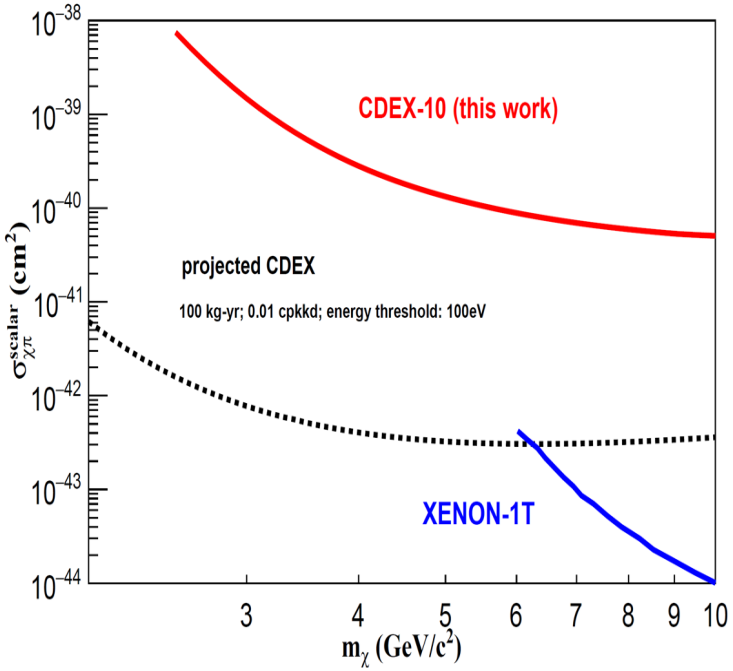
- **Experimental constraints on WIMP couplings in the EFT framework with CDEX data**
- **Set new limits for the coupling of WIMP-nucleon effective operators below 6 GeV**



Sci. Chin. Phys. Mech. Astron. 64, 281011 (2021)



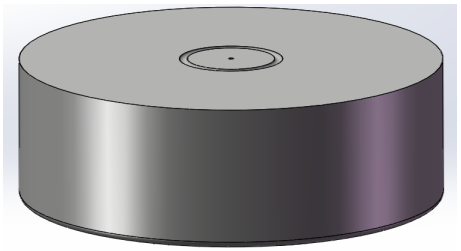
NREFT analysis

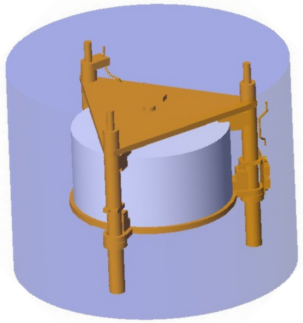


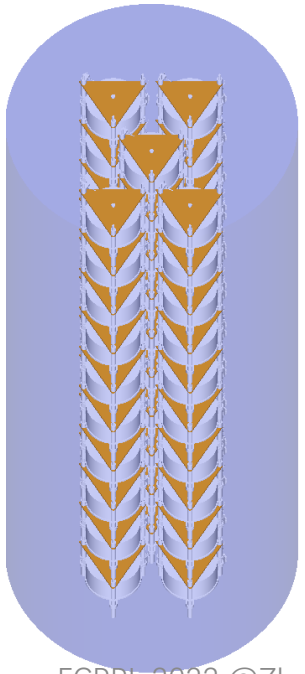
Chiral-EFT analysis

CDEX-50 Projected

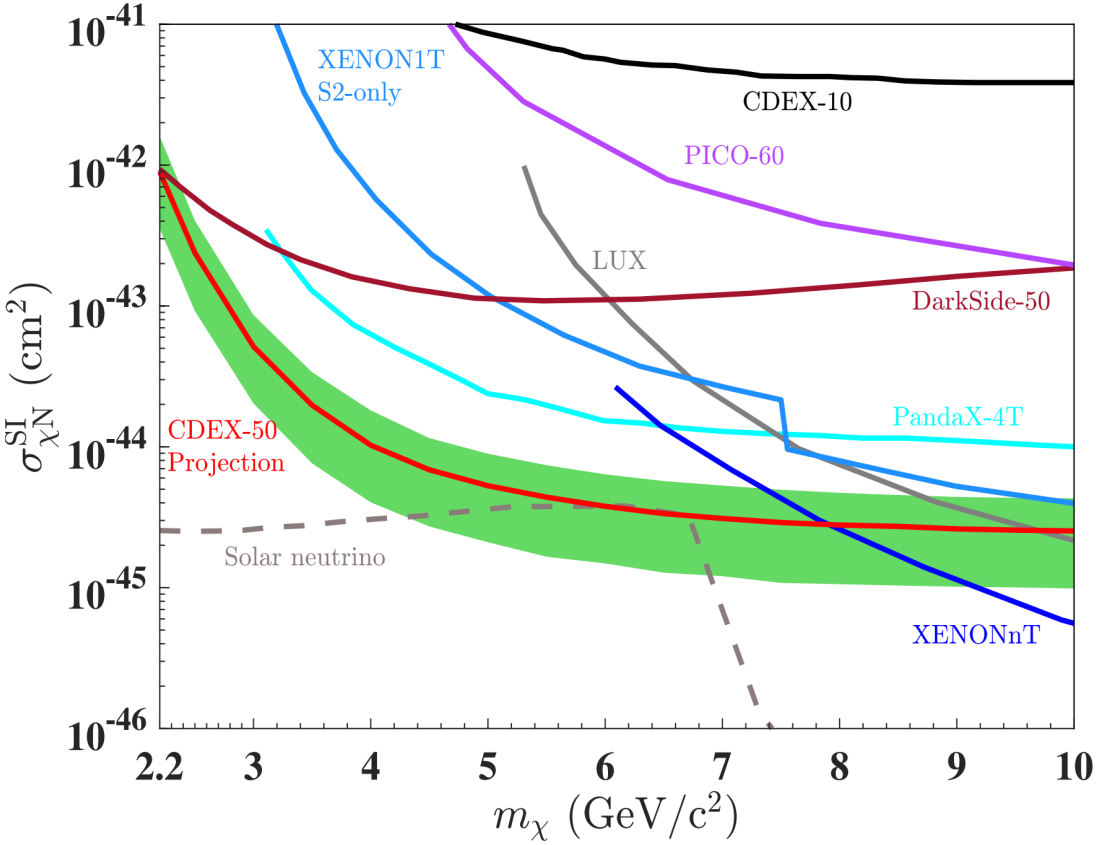
- Target mass (Ge) reaches ~50kg;
- Bkg level: **<0.01 cts/(keV·kg·day) @1 keV**
- Energy threshold for data analysis: **160 eV**
- WIMP SI sensitivity reaches **10^{-44} cm^2**





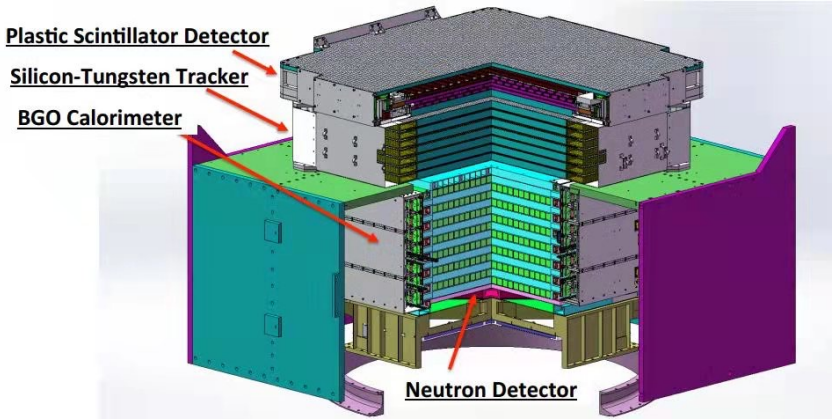


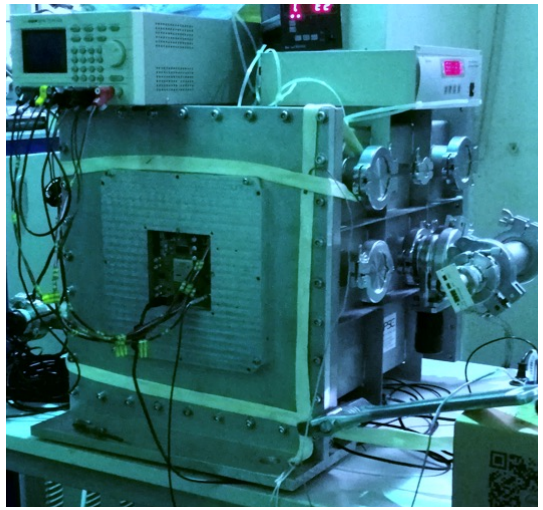
arXiv:2309.01843 (2023)

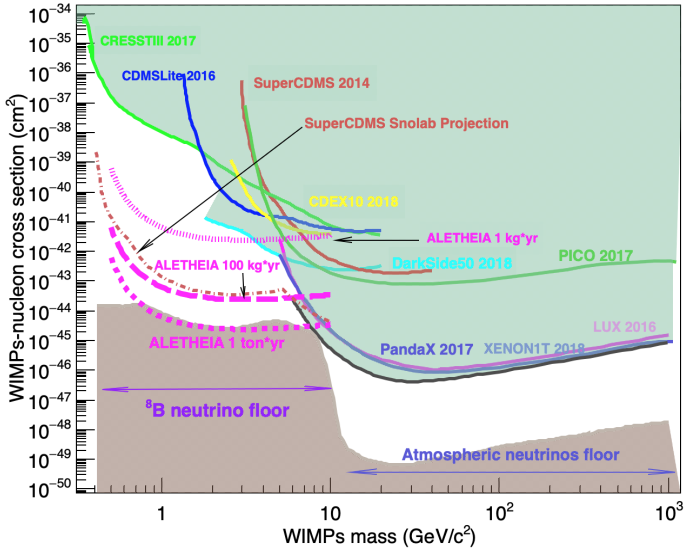


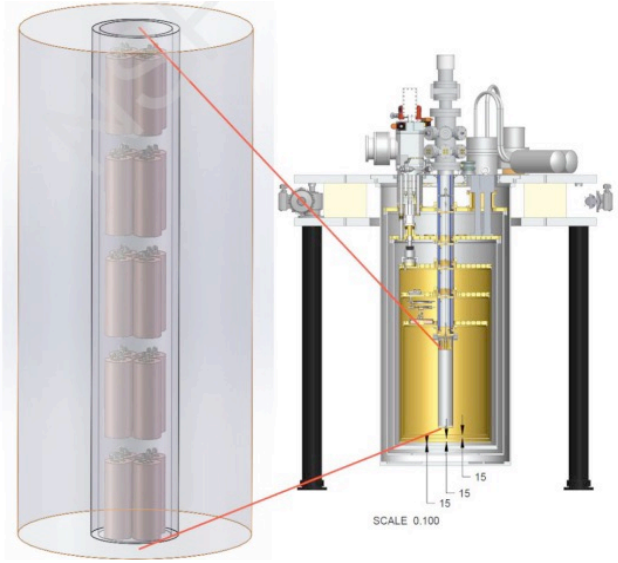
Other DM Search effort in China

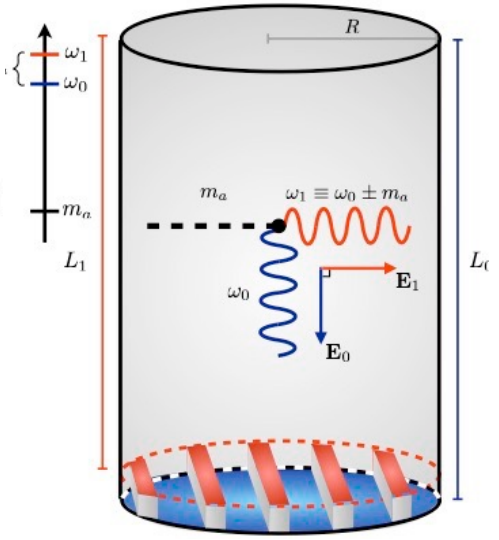
- LHe experiment: ALETHIA @CIAE, Peking Univ. (Junhui Liao et al.)
- Directional detection: MIMAC R&D@IHEP, SJTU, USTC, collaborating with LPSC (France, Grenoble).
- Axion experiment:
  - Resonant cavities (8GHz) @ITP, IOP, IHEP et al.
  - Superconducting RF cavity (1Hz-500MHz) @ITP, Peking Univ. IOP











Summary

- Dark matter direct detection (DMDD) is essential for our understanding of new physics.
- Chinese DMDD experiments keep moving forward to **unexplored lower mass and higher sensitivity region.**
- **Multi-physics channels and novel DM models** have been studied experimentally in China.
- New ideas are put forward and R&D studies are ongoing …

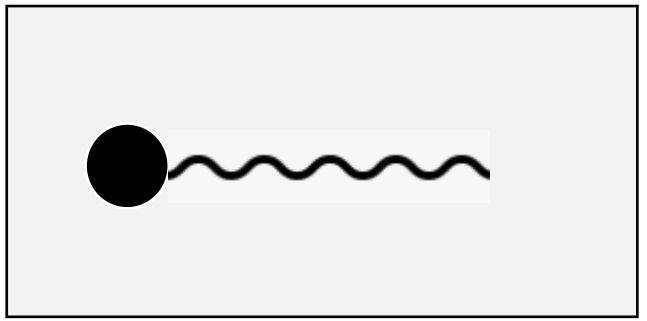
- Stay tuned!

Thank you for listening!

Backups

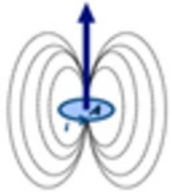
Luminance of DM

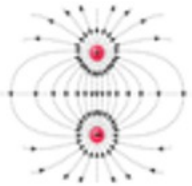
- Possible residual weak EM properties
- Coupling with photons



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

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



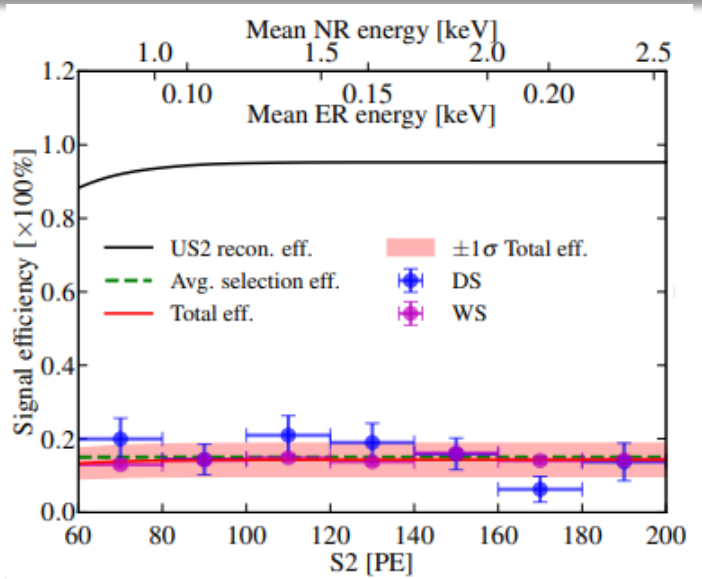


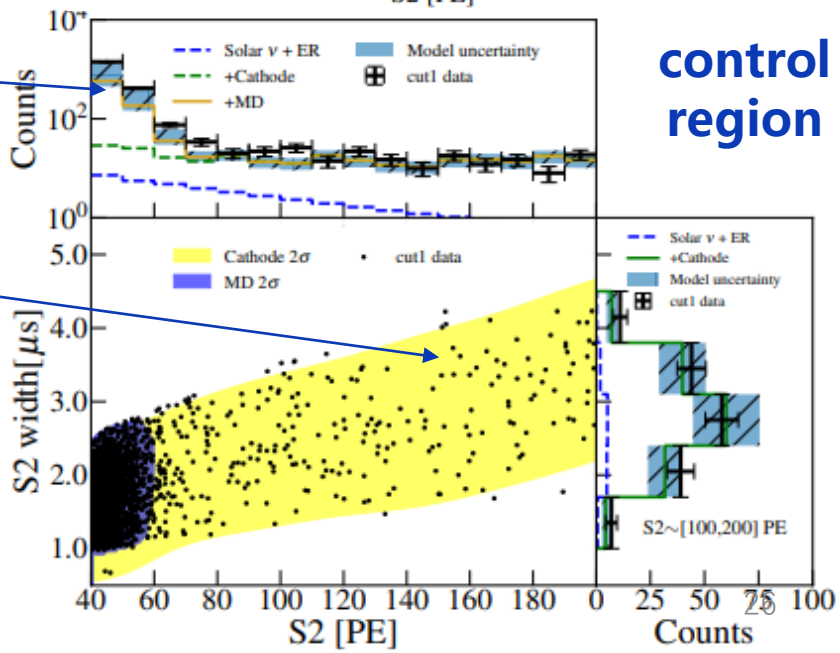
tree-level | **higher-order loop-level**

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

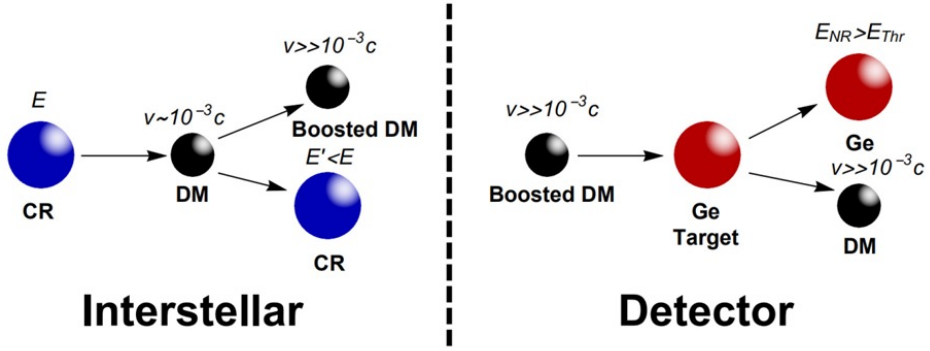


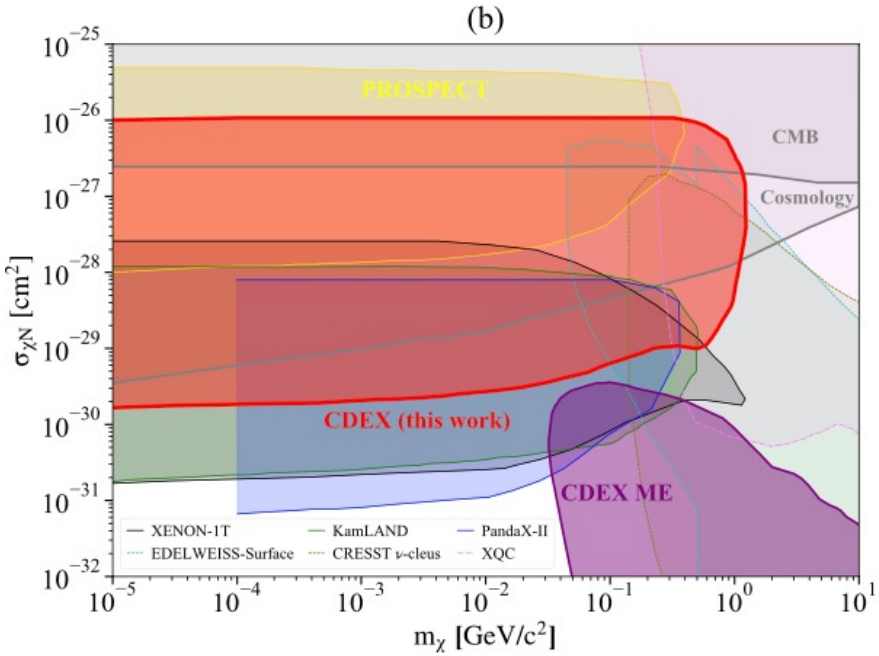


control region

Boosted DM

- Dark matter can be boosted to relativistic or near relativistic via the elastic scattering with cosmic rays in the Milky Way halo.
- The secondary energetic DM particles (CRDM) can transfer sufficient energies to the target nuclei and be extended the detectable m_χ to $\mathcal{O}(10\ \mathrm{keV})$ range
- Excludes the large region from 1.7×10^{-30} to 10^{-26} with considering the earth attenuation effect
- Leading sensitivities among Ge-based Exp., and better than the cosmological limits in the mass range from 10 keV/c² to 1GeV/c²





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