

Recent PandaX-II Results on Dark Matter Search and PandaX-4T Upgrade Plan

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On behalf of **PandaX** Collaboration

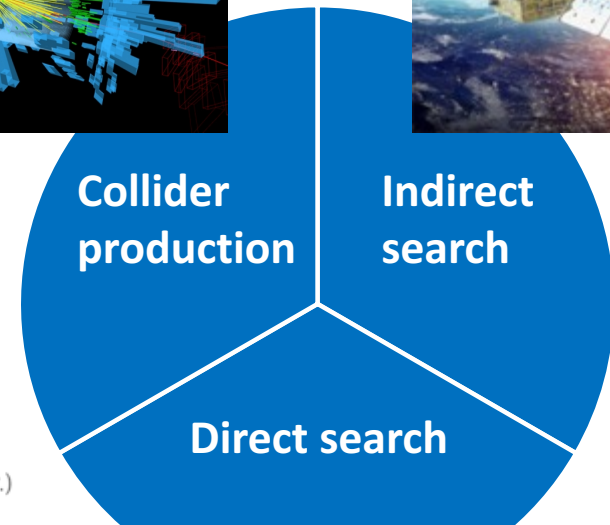
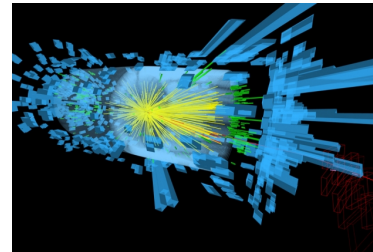
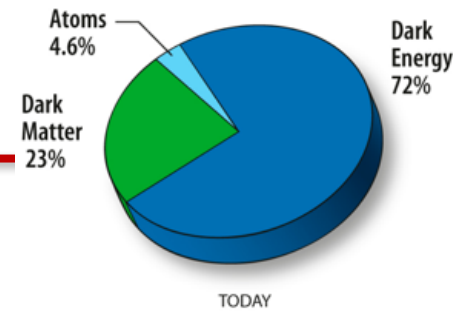
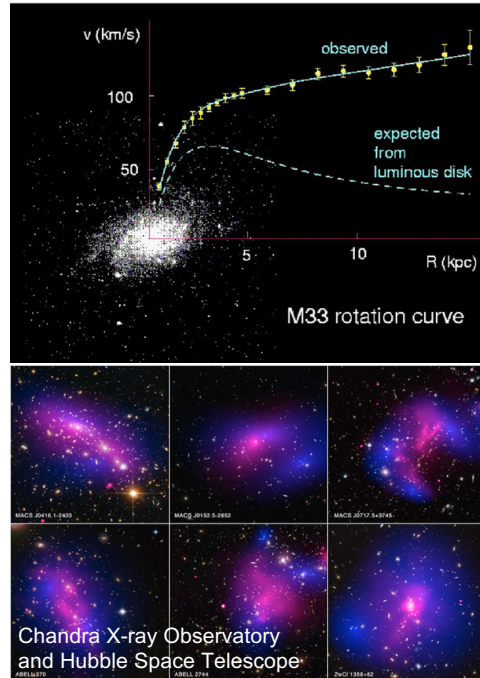
COSMO18, 2018-07-27

Outline

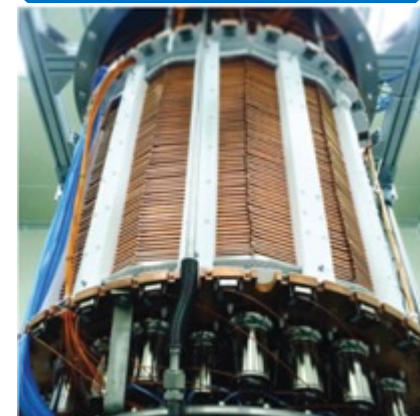
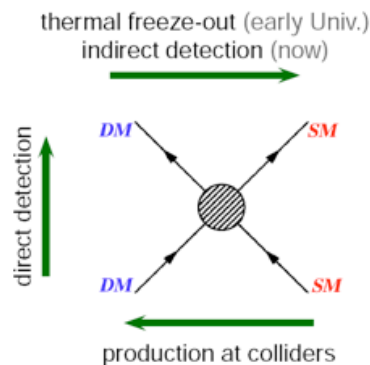
- WIMP direct detection
- PandaX experiment
- PandaX-II operation and results
- PandaX-4T upgrade plan
- Summary

Dark Matter

- Strong evidences for the existence of dark matter



- DM search methods
 - **Direct detection**
 - Indirection detection
 - Collider search



PandaX Collaboration

- **P**article **and A**strophysical **X**enon Experiments

- Formed in 2009, ~50 people

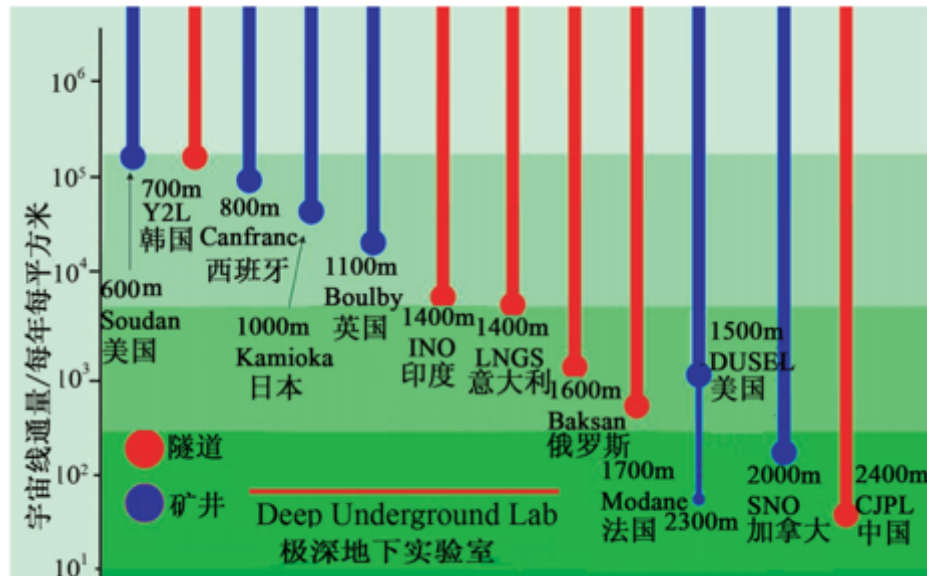
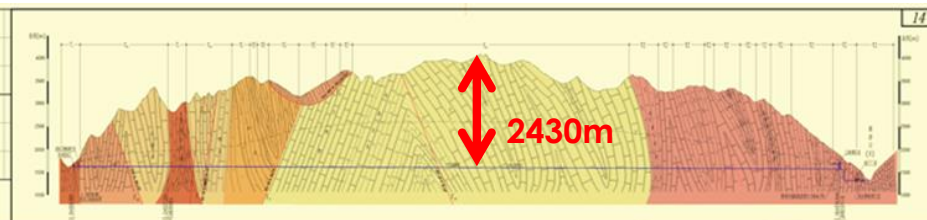
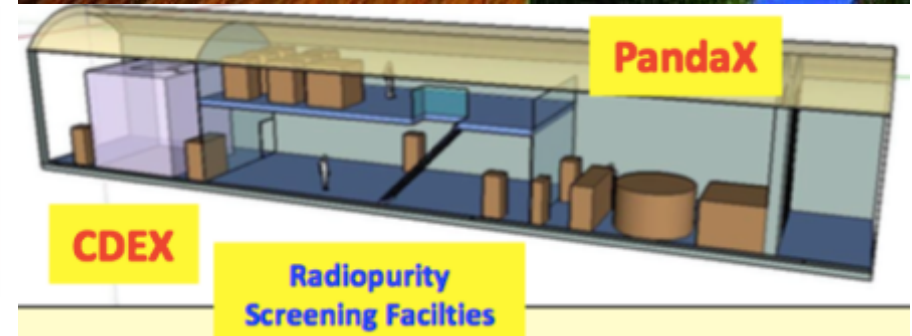
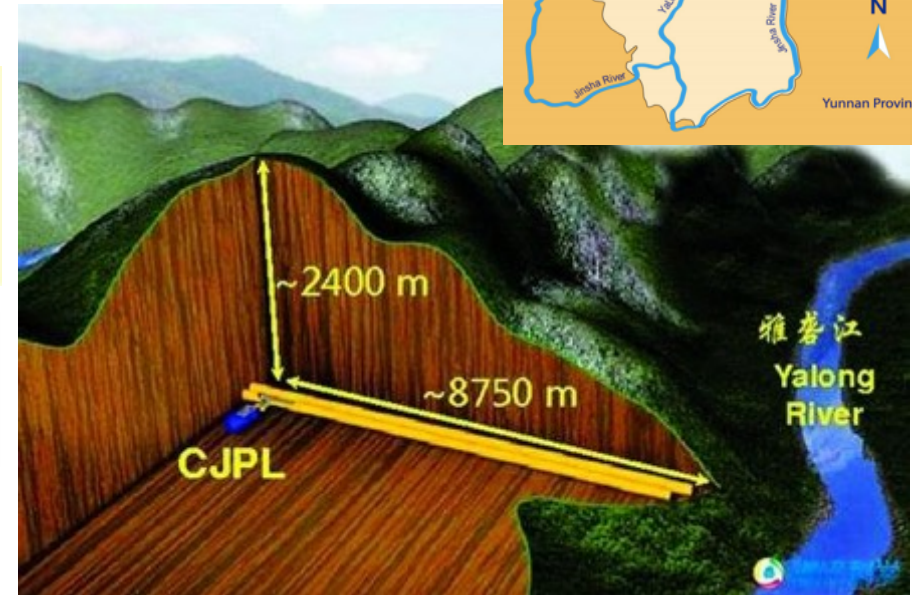


- Shanghai Jiao Tong University
- Peking University
- Shandong University
- Nankai University
- Shanghai Institute of Applied Physics
- Yalong Hydropower Company
- University of Maryland
- University of Science & Technology of China
- China Institute of Atomic Energy
- Sun Yat-Sen University
- Lawrence Berkeley National Lab
- Alternative Energies & Atomic Energy Commission
- University of Zaragoza
- Suranaree University of Technology



China Jinping Underground Laboratory

- China Jinping underground laboratory (CJPL)
 - Deepest (6800 m.w.e)!
 - Horizontal access!



PandaX Experiment

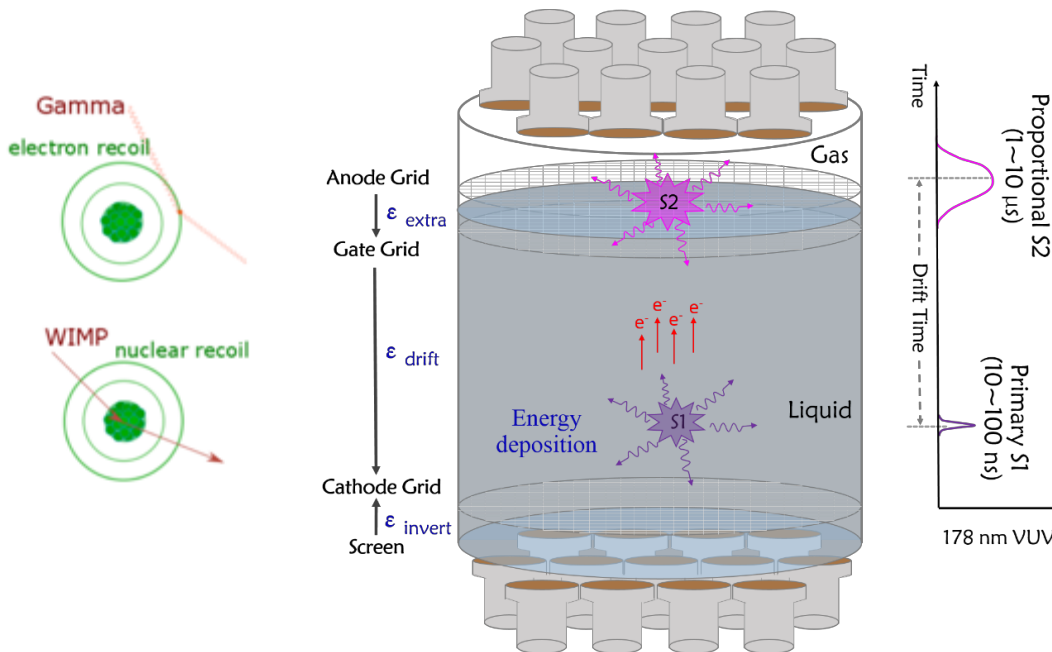
- Dark matter direct detection through xenon
- **PandaX-I: 2009-2014**
- **PandaX-II: 2014-2018**
 - 60 cm x 60 cm dual-phase xenon TPC
 - 580 kg LXe in sensitive volume



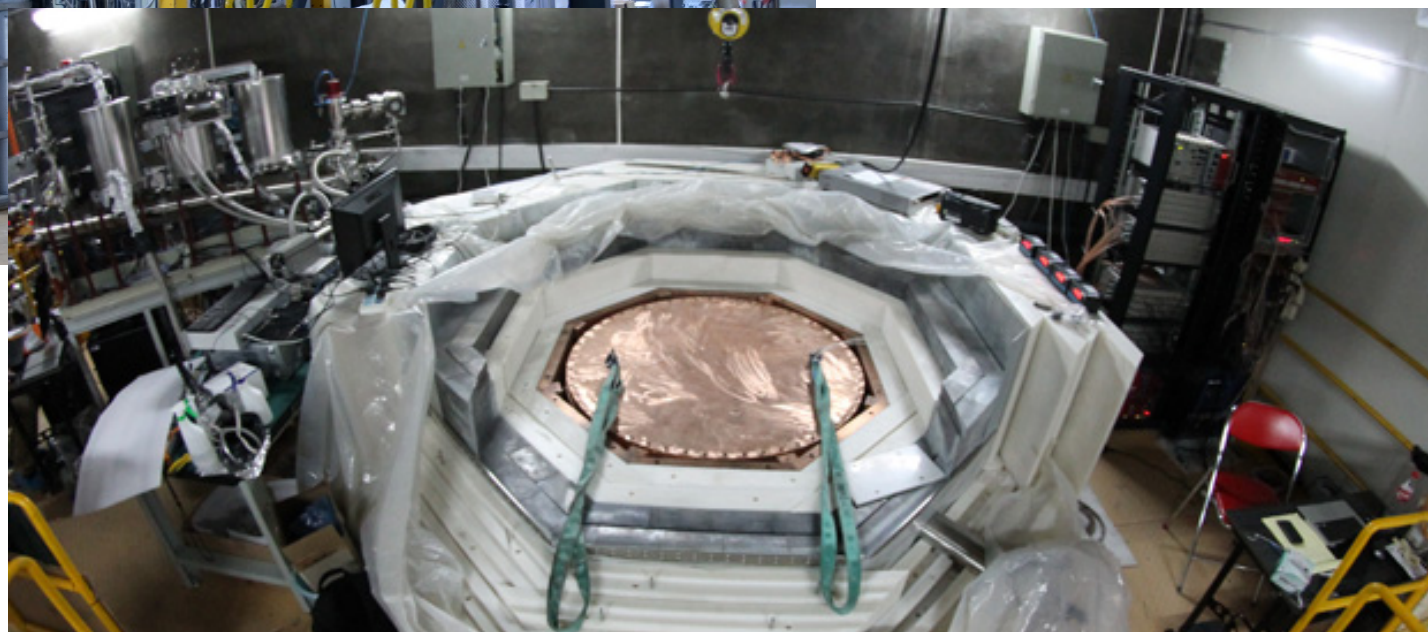
Phase I: 120 kg
2009-2014



Phase II: 580 kg
2014-2018

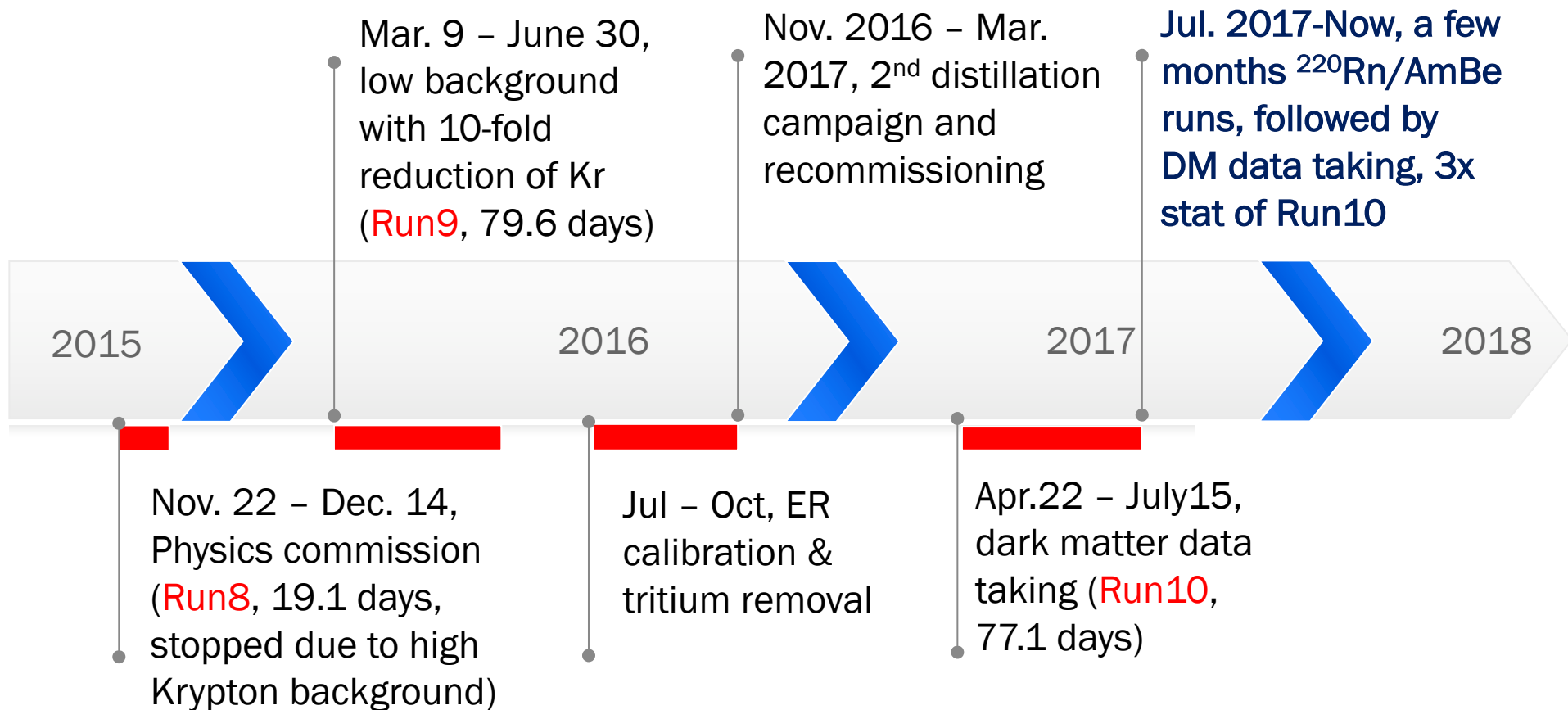


PandaX-II On-Site



PandaX-II Run Status

- Run9 = 79.6 days, exposure: 26.2 ton-day
- Run10 = 77.1 days, exposure: 27.9 ton-day

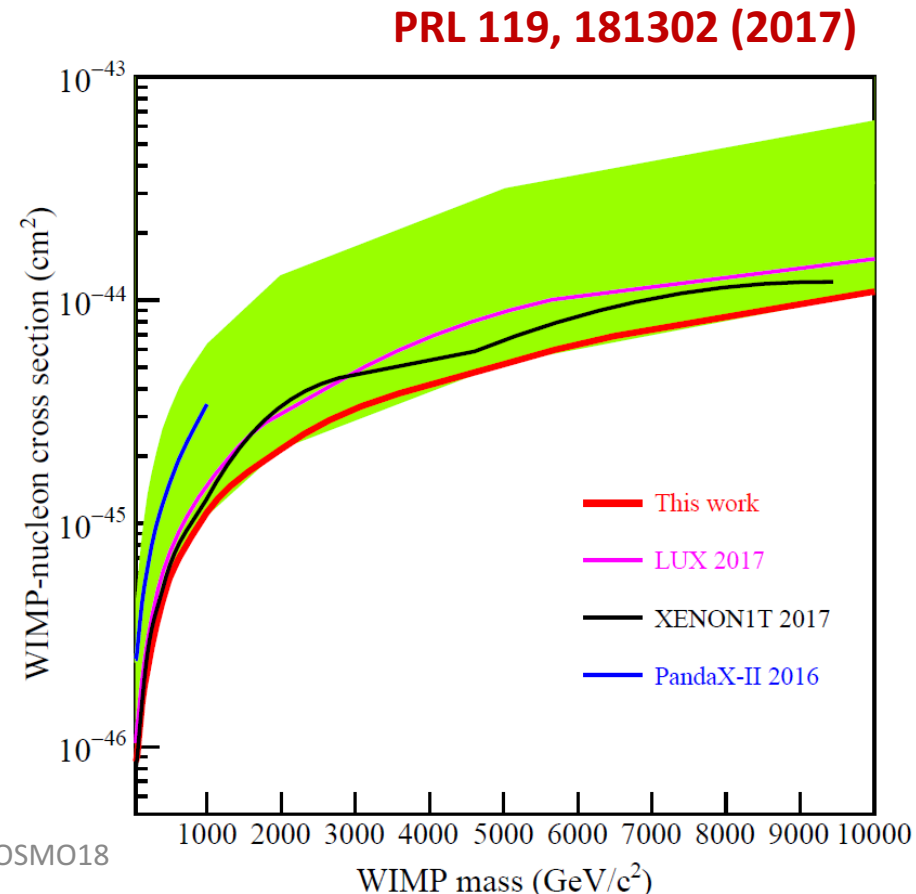
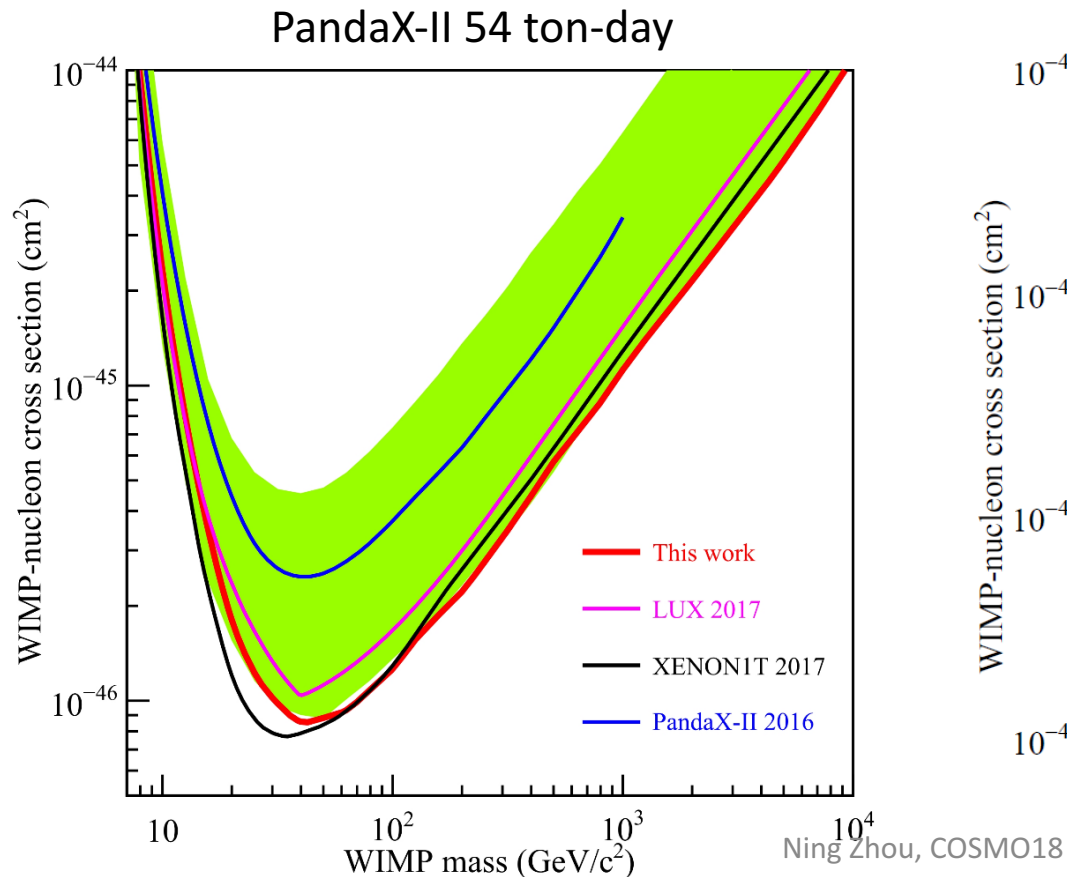


Highlights of PandaX Results

- 33 ton-day: spin independent search, [PRL 117, 21303 \(2016\)](#)
- 33 ton-day: spin dependent search, [PRL 118, 071301 \(2017\)](#)
- 27 ton-day: inelastic scattering search, [PRD 96, 102007 \(2017\)](#)
- 27 ton-day: axion and ALP search, [PRL 119, 181806 \(2017\)](#)
- 54 ton-day: spin independent search, [PRL 119, 181302 \(2017\)](#)
- **new** 54 ton-day: light mediator search, [PRL 121, 021304 \(2018\)](#)
- **new** 54 ton-day: general EFT and spin-dependent search, [arXiv:1807.01936](#)
- **new** PandaX-4T sensitivity study, [arXiv:1806.02229](#)

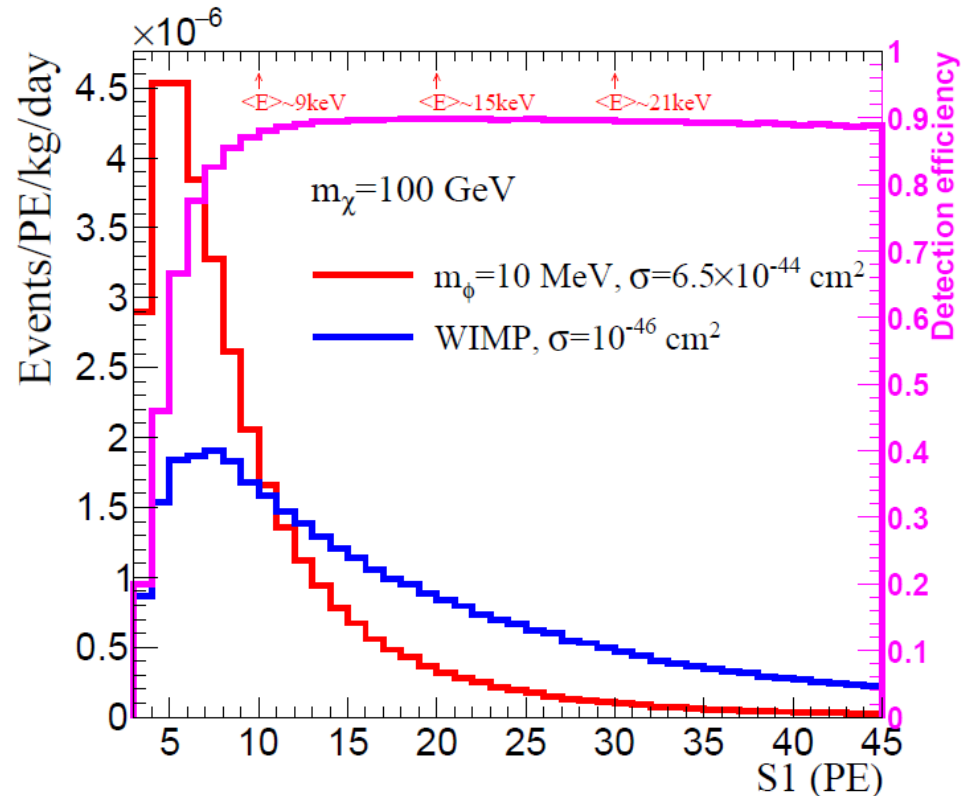
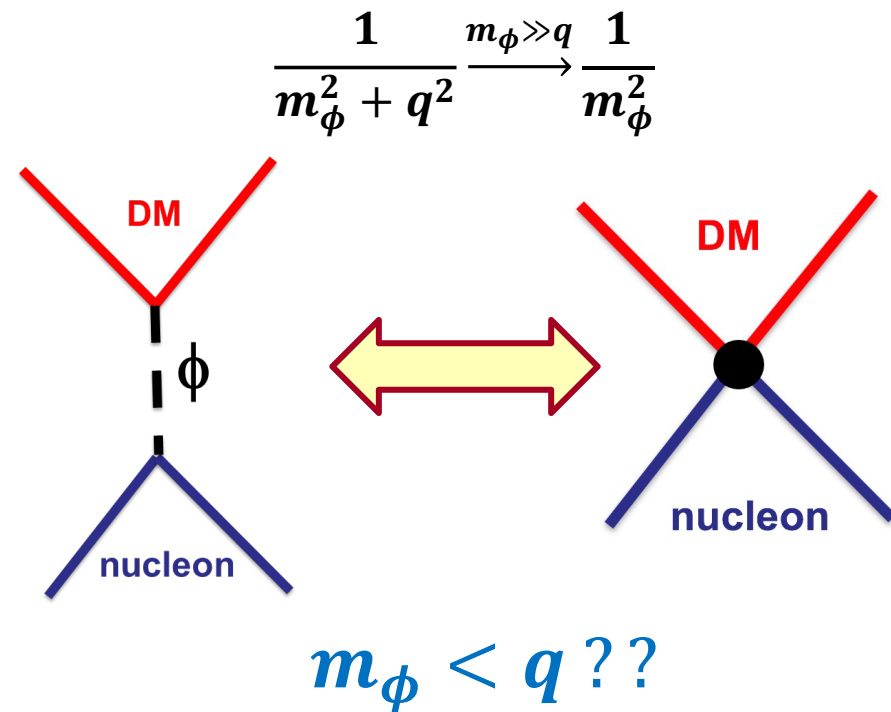
Spin-independent WIMP-nucleon Scattering

- Improved from PandaX-II 2016 limit about x2.5 at high masses
- Lowest exclusion at $8.6 \times 10^{-47} \text{cm}^2$ at 40GeV, most stringent for $m_\chi > 100 \text{ GeV}$ when published



Light Mediator DM-SM Interaction

- Heavy mediator $\rightarrow$ EFT contact interaction
 - Foundation of “main” SI/SD results in direct detection
- Light mediator: mediator m_ϕ is compared to or smaller than q
 - Different signal spectrum

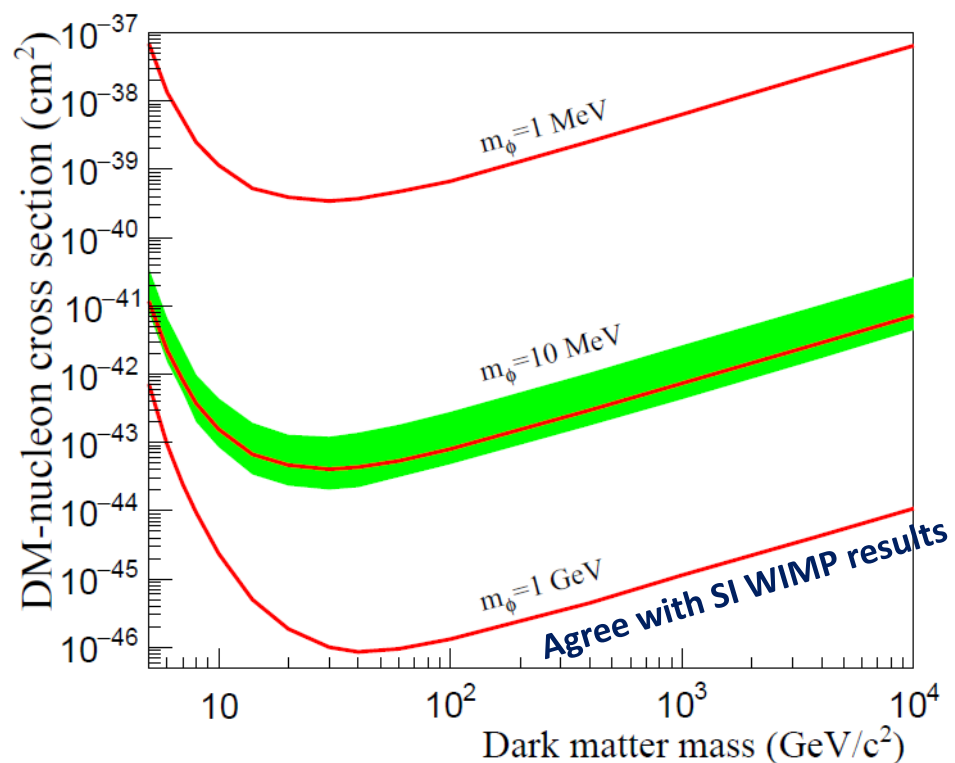
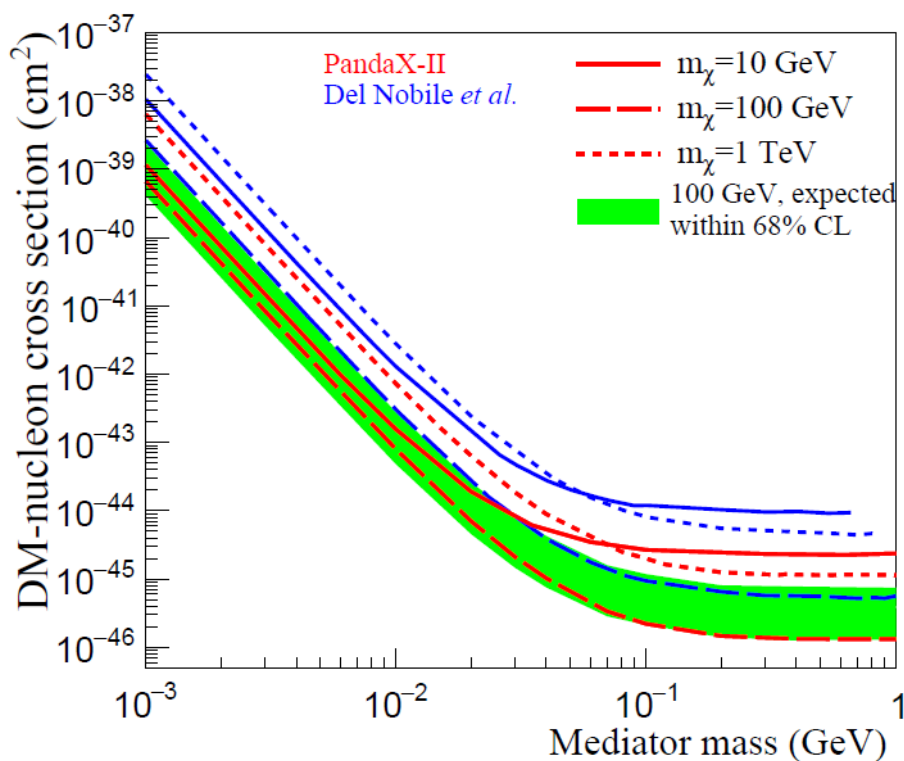


New Constraints on DM-nucleon

PRL 121, 021304 (2018)

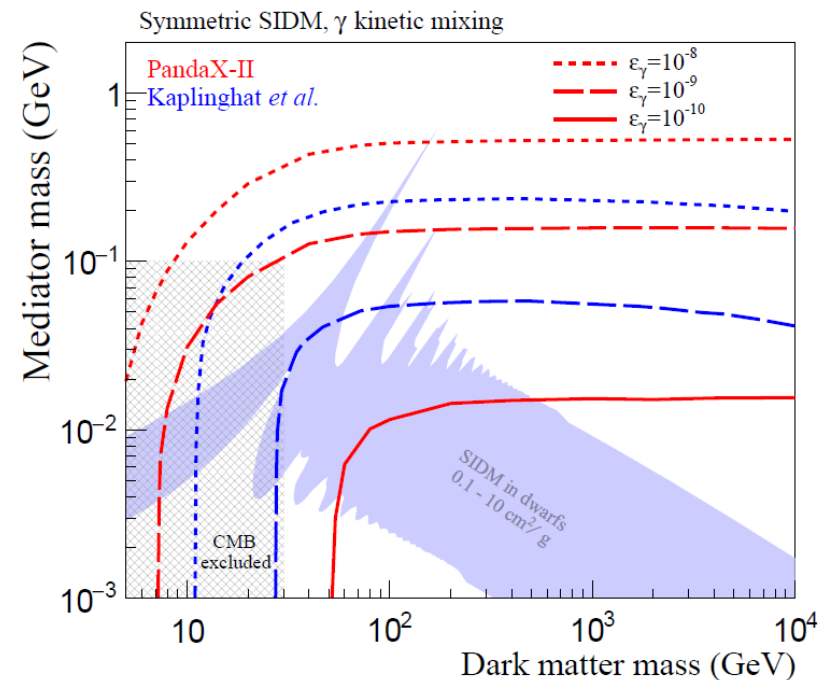
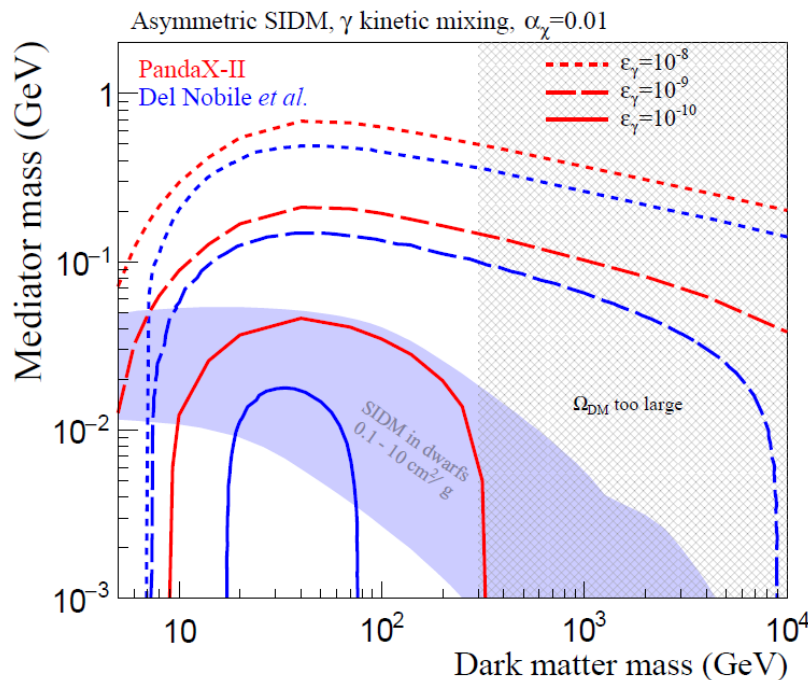
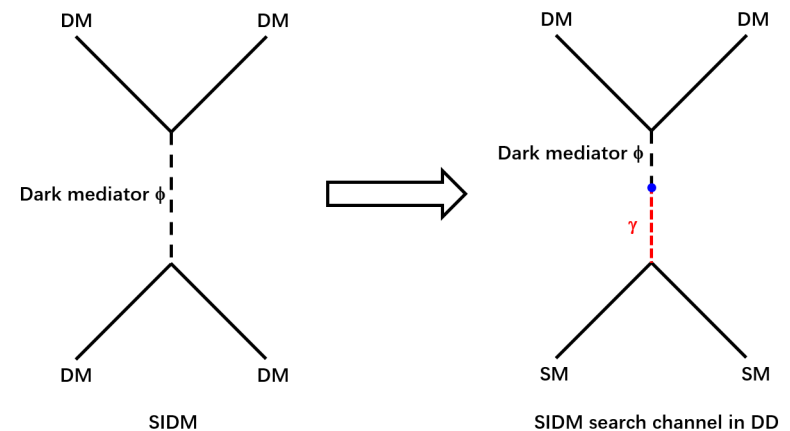
- From 54-ton-day exposure data
- Constraints on DM-n cross section are significantly weakened for light mediator interaction

$$\sigma(q^2)_{\chi N} = \sigma|_{q^2=0} A^2 \left(\frac{\mu}{\mu_p} \right)^2 \frac{m_\phi^4}{(m_\phi^2 + q^2)^2} F^2(q^2)$$



Constraints on Self-Interacting DM

- Self-interacting DM model can have light mediator mixing with SM particles
 - Mixing parameter ε
 - Fine structure in dark sector α



General EFT DM-SM Interaction

- 14 non-relativistic EFT operators constructed with four basic variables
 - Relative perpendicular velocity between the WIMP and the nucleon ($\vec{v}^\perp$)
 - Momentum transfer ($\vec{q}$)
 - Spin of WIMP ($\vec{S}_\chi$)
 - Spin of nucleon ($\vec{S}_N$)

- Considering all interactions through NNLO

Phys. Rev. C89, 065501 (2014)

- Spin independent / Spin dependent: 2 EFT operators
 - SI: $\mathcal{O}_1$ SD: $\mathcal{O}_4$

$\mathcal{O}_1 = 1_\chi 1_N$ $\mathcal{O}_3 = i\vec{S}_N \cdot \left(\frac{\vec{q}}{m_N} \times \vec{v}^\perp \right)$ $\mathcal{O}_4 = \vec{S}_\chi \cdot \vec{S}_N$ $\mathcal{O}_5 = i\vec{S}_\chi \cdot \left(\frac{\vec{q}}{m_N} \times \vec{v}^\perp \right)$ $\mathcal{O}_6 = \left(\vec{S}_\chi \cdot \frac{\vec{q}}{m_N} \right) \left(\vec{S}_N \cdot \frac{\vec{q}}{m_N} \right)$ $\mathcal{O}_7 = \vec{S}_N \cdot \vec{v}^\perp$ $\mathcal{O}_8 = \vec{S}_\chi \cdot \vec{v}^\perp$	SI SD $\mathcal{O}_9 = i\vec{S}_\chi \cdot \left(\vec{S}_N \times \frac{\vec{q}}{m_N} \right)$ $\mathcal{O}_{10} = i\vec{S}_N \cdot \left(\frac{\vec{q}}{m_N} \right)$ $\mathcal{O}_{11} = i\vec{S}_\chi \cdot \left(\frac{\vec{q}}{m_N} \right)$ $\mathcal{O}_{12} = \vec{S}_\chi \cdot (\vec{S}_N \times \vec{v}^\perp)$ $\mathcal{O}_{13} = i(\vec{S}_\chi \cdot \vec{v}^\perp) \left(\vec{S}_N \cdot \frac{\vec{q}}{m_N} \right)$ $\mathcal{O}_{14} = i \left(\vec{S}_\chi \cdot \frac{\vec{q}}{m_N} \right) (\vec{S}_N \cdot \vec{v}^\perp)$ $\mathcal{O}_{15} = - \left(\vec{S}_\chi \cdot \frac{\vec{q}}{m_N} \right) \left[(\vec{S}_N \times \vec{v}^\perp) \cdot \frac{\vec{q}}{m_N} \right]$
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Relativistic EFT Operators

- 7 typical relativistic operators

$$\mathcal{L}_{\text{int}}^9 \equiv \bar{\chi} i \sigma^{\mu\nu} \frac{q_\nu}{m_M} \chi \bar{N} \gamma_\mu N$$

$$\rightarrow -\frac{\vec{q}^2}{2m_\chi m_M} \mathcal{O}_1 + \frac{2m_N}{m_M} \mathcal{O}_5 - \frac{2m_N}{m_M} \left(\frac{\vec{q}^2}{m_N^2} \mathcal{O}_4 - \mathcal{O}_6 \right)$$

$$\mathcal{L}_{\text{int}}^{17} \equiv i \bar{\chi} i \sigma^{\mu\nu} \frac{q_\nu}{m_M} \gamma^5 \chi \bar{N} \gamma_\mu N \rightarrow \frac{2m_N}{m_M} \mathcal{O}_{11}$$

$$\mathcal{L}_{\text{int}}^{10} \equiv \bar{\chi} i \sigma^{\mu\nu} \frac{q_\nu}{m_M} \chi \bar{N} i \sigma_{\mu\alpha} \frac{q^\alpha}{m_M} N \rightarrow 4 \left(\frac{\vec{q}^2}{m_M^2} \mathcal{O}_4 - \frac{m_N^2}{m_M^2} \mathcal{O}_6 \right)$$

Dim-6

- Dramatically different spectra
 - q and v dependence
 - Isospin scalar vs isospin vector

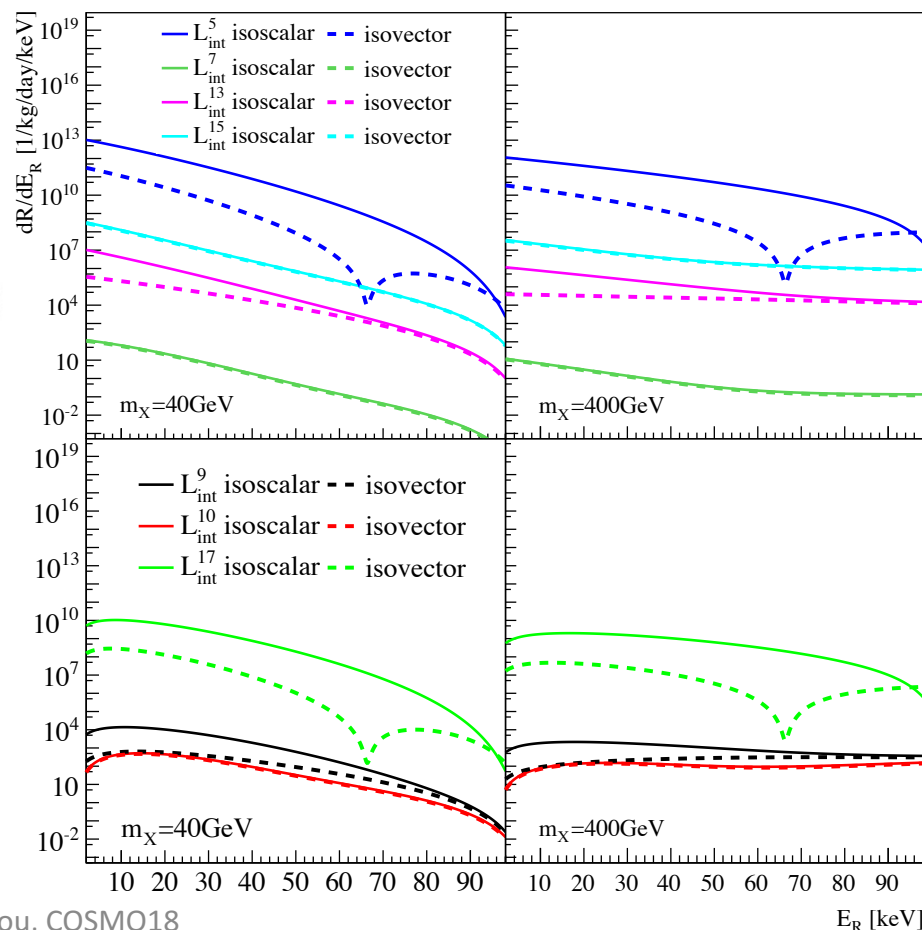
$$\mathcal{L}_{\text{int}}^5 \equiv \bar{\chi} \gamma^\mu \chi \bar{N} \gamma_\mu N \rightarrow \mathcal{O}_1$$

Dim-4

$$\mathcal{L}_{\text{int}}^7 \equiv \bar{\chi} \gamma^\mu \chi \bar{N} \gamma_\mu \gamma^5 N \rightarrow -2\mathcal{O}_7 + 2 \frac{m_N}{m_\chi} \mathcal{O}_9$$

$$\mathcal{L}_{\text{int}}^{13} \equiv \bar{\chi} \gamma^\mu \gamma^5 \chi \bar{N} \gamma_\mu N \rightarrow 2\mathcal{O}_8 + 2\mathcal{O}_9$$

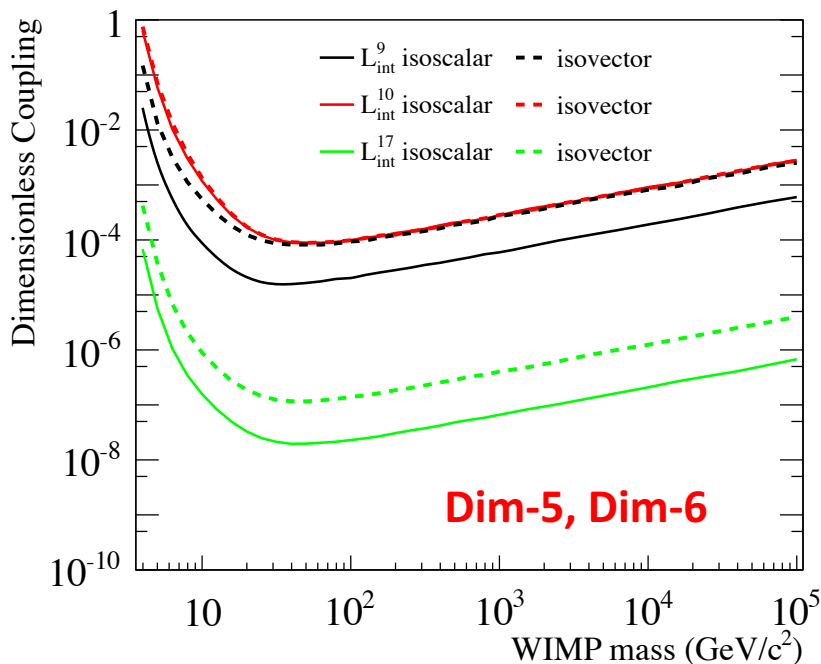
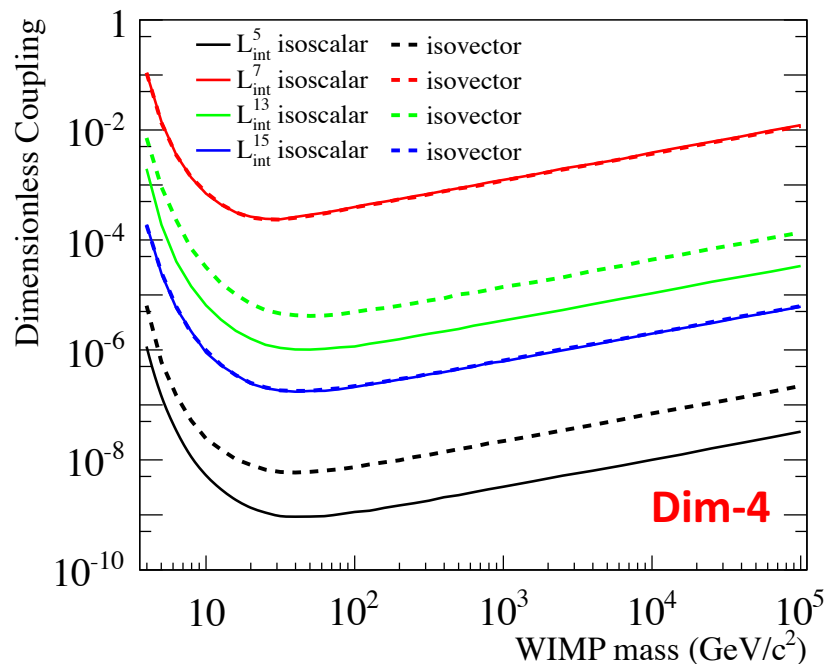
$$\mathcal{L}_{\text{int}}^{15} \equiv \bar{\chi} \gamma^\mu \gamma^5 \chi \bar{N} \gamma_\mu \gamma^5 N \rightarrow -4\mathcal{O}_4$$



Constraints on EFT Couplings

arXiv:1807.01936

- 54-ton-day exposure data
- Signal window selection same as SI
 - To be further optimized for various EFT in the future
- Constraints strongly depending on the operator/isospin



Constraints on Spin-Dependent Interaction

- O_4 SD EFT operator

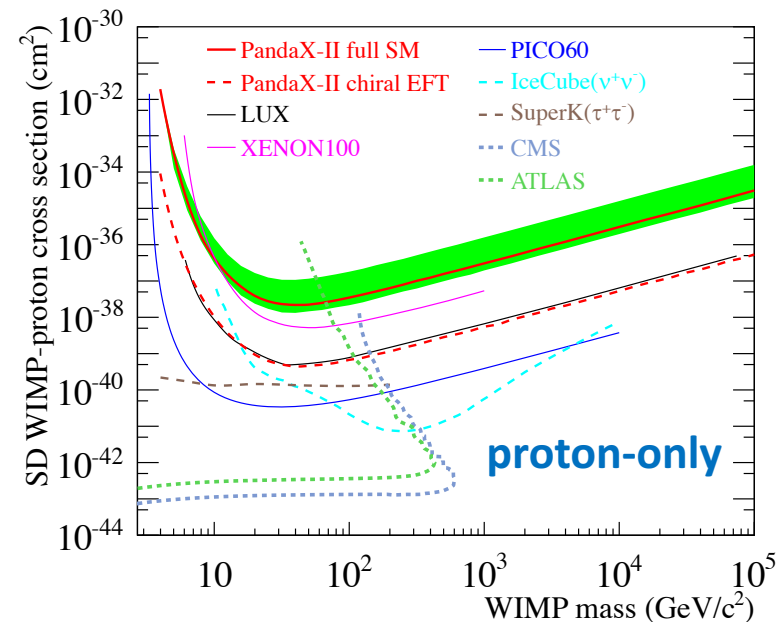
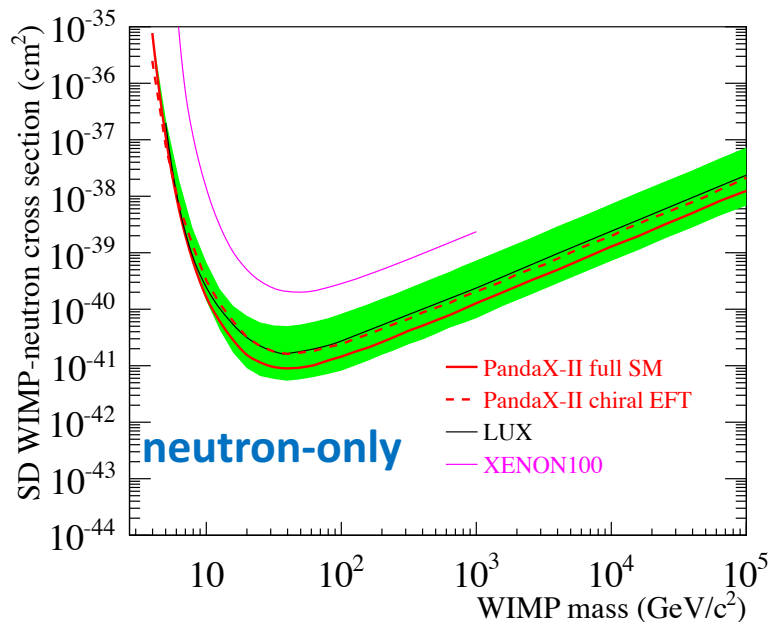
- Full basis shell-model GCN5082

$$\mathcal{O}_4 = \vec{S}_\chi \cdot \vec{S}_N$$

- For proton-only coupling in Xe nucleus

- O_4 SD EFT interaction largely suppressed

$$\sigma_{p,n}^{\text{SD}}(v) = \left(\frac{c_4}{m_V^2} \right)^2 \frac{\mu_{p,n}^2}{\pi} \frac{J_\chi(J_\chi + 1)}{4}$$



PandaX – in Future

- PandaX-4T for DM search
- PandaX-III for 0vbb search



PandaX-I: 120 kg
DM experiment
2009-2014

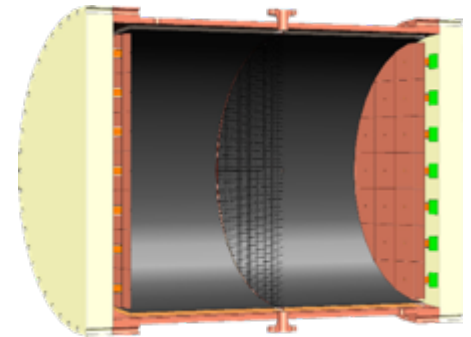


PandaX-II: 500 kg
DM experiment
2014-2018

CJPL-I



PandaX-xT:
multi-ton (~4-T)
DM experiment
Future

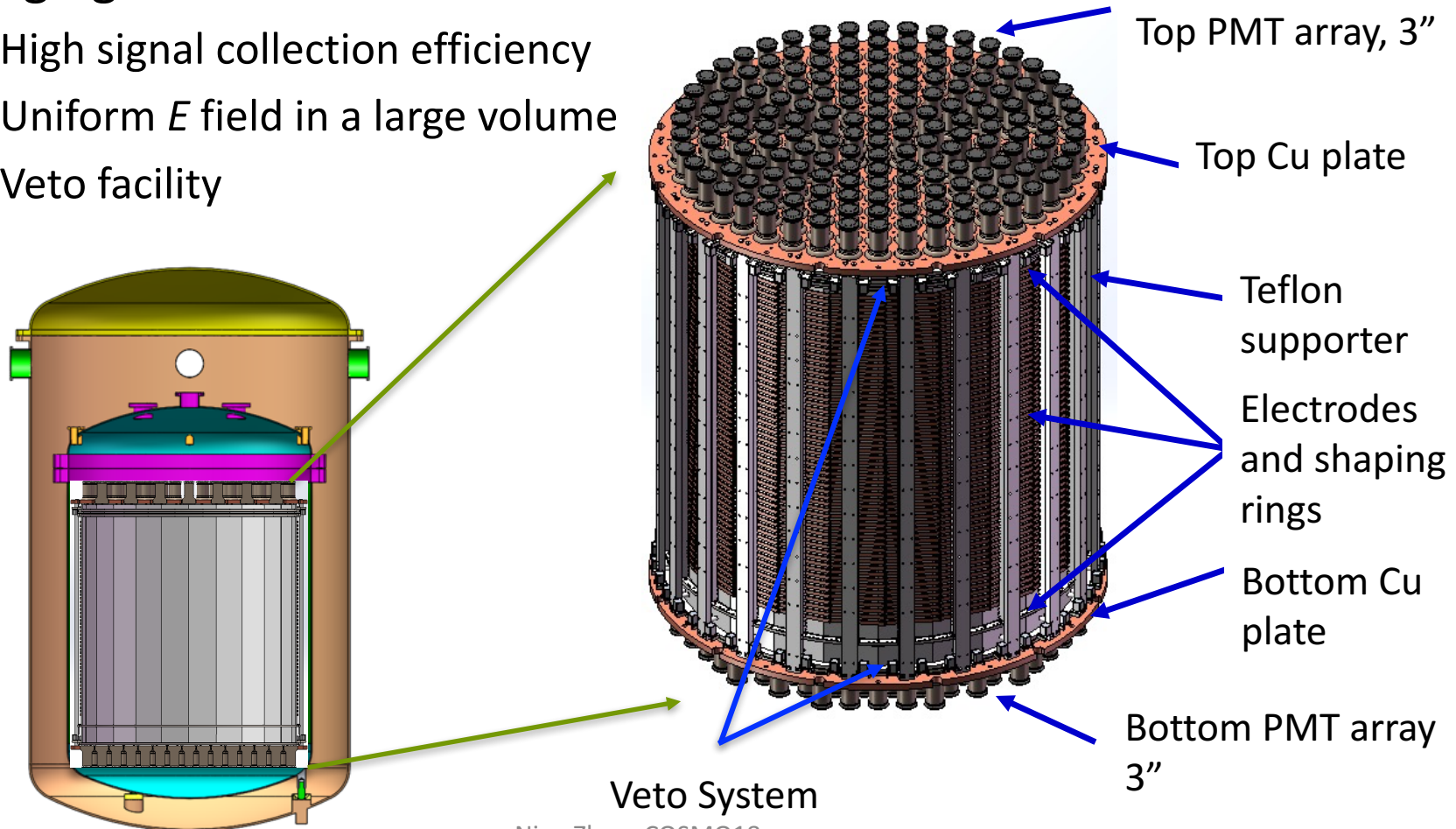


PandaX-III: 200 kg to
1 ton HP gas ^{136}Xe
0vDBD experiment
Future

CJPL-II

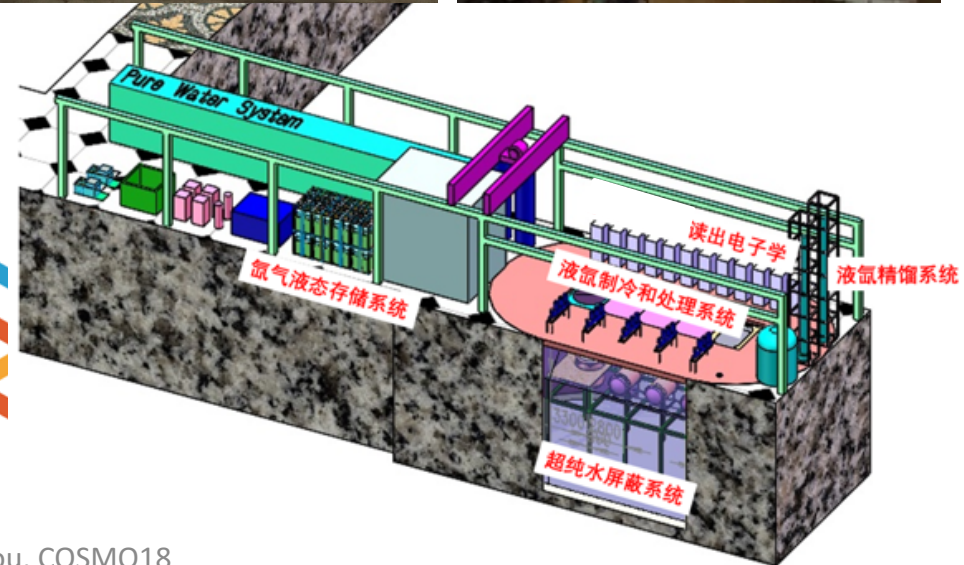
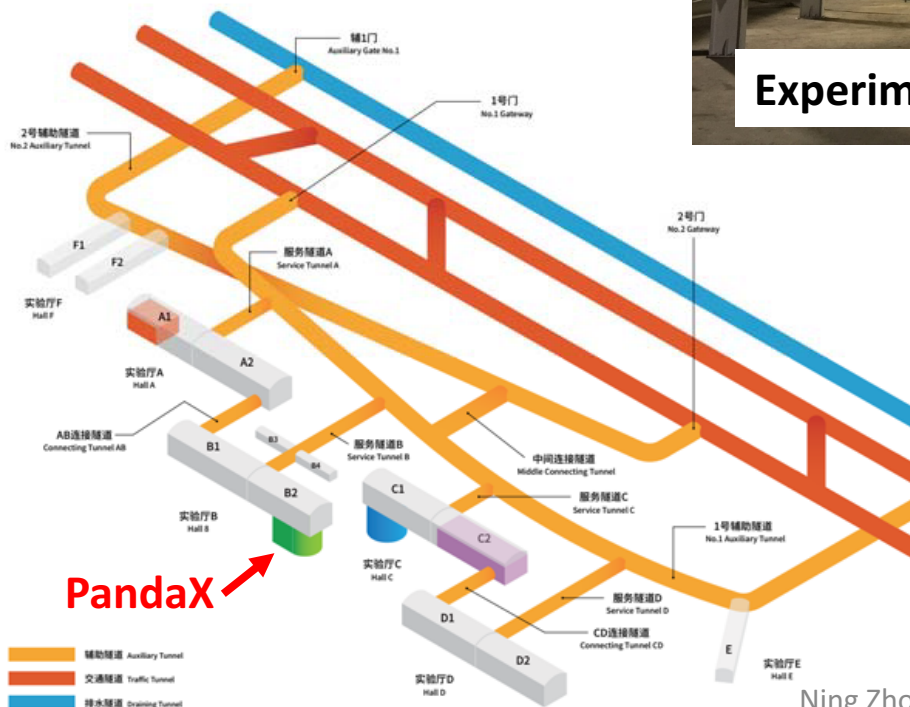
PandaX-4T Large Scale TPC

- Drift region: $\Phi \sim 1.2\text{m}$, $H \sim 1.2\text{m}$
 - Xenon in sensitive region ~ 4 ton, drift field 400 V/cm
- Design goal:
 - High signal collection efficiency
 - Uniform E field in a large volume
 - Veto facility



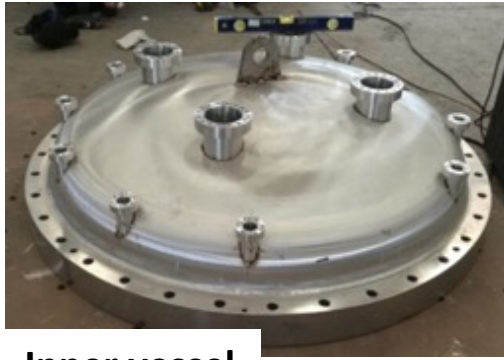
New Experiment Hall at CJPL-II

- B2 Hall
- 14m(H)x14m(W)x65m(L)
- Water Shielding
 - 5000Ton pure water
 - $U/Th < 10^{-14}$ g/g



Current Status and Schedule

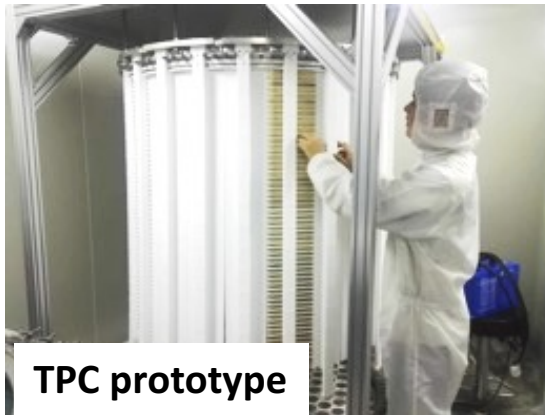
- R&D work-in-progress
- 2019-2020: assembly and commissioning



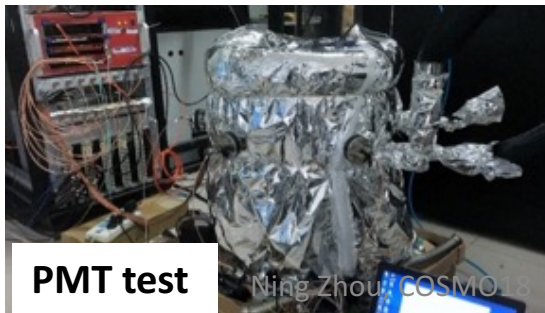
Inner vessel



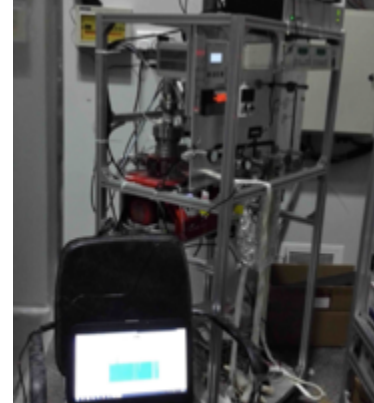
Cooling bus



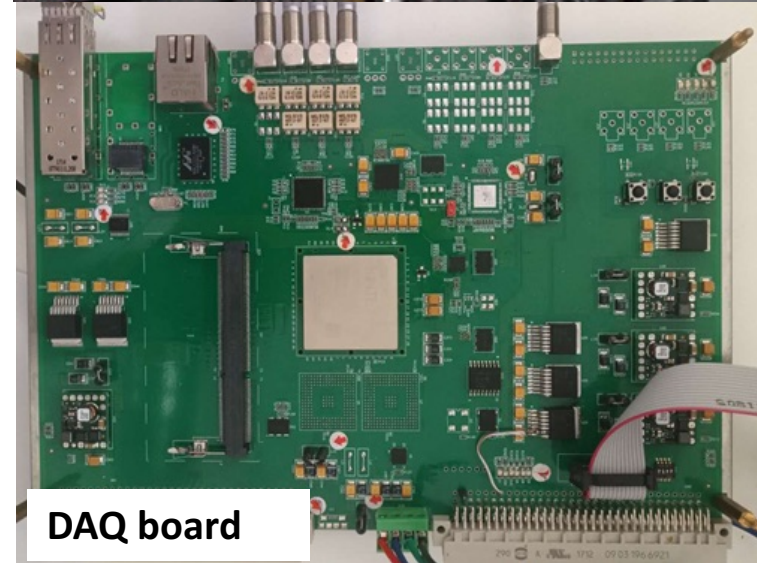
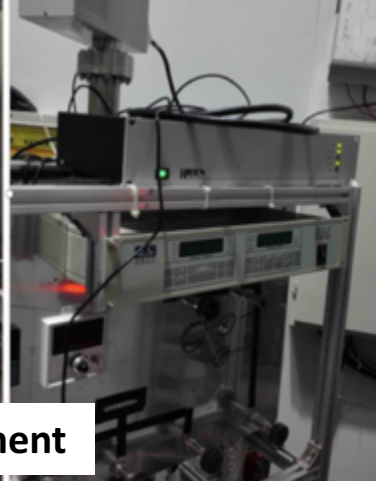
TPC prototype



PMT test



Krypton measurement



DAQ board

PandaX-4T Background Simulation

arXiv:1806.02229

- **Simulate the ER and NR events**
 - **Detector materials:** inner/outer vessels, flanges, copper plates, electrodes, PTFE materials, PMTs etc
 - **Radioactivity in xenon:** ^{85}Kr , ^{222}Rn , ^{136}Xe
 - **Neutrino**
- **Background in signal region**
 - Total ER background: 0.05 mDRU
 - Total NR background: 1 event / ton / year

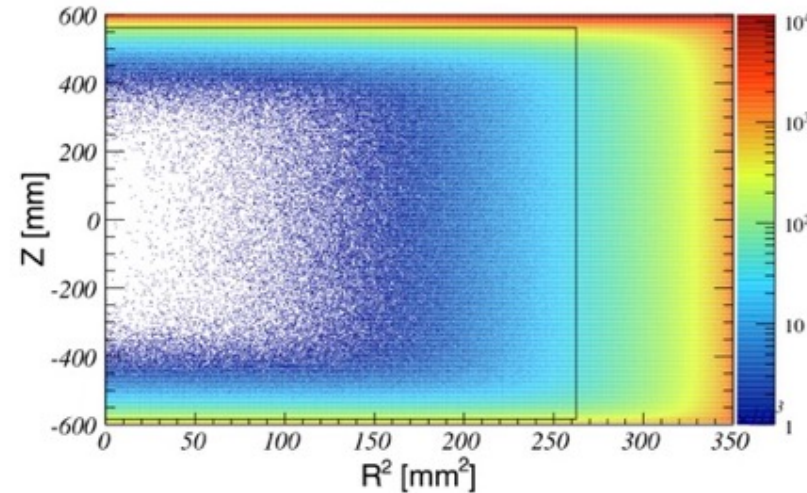
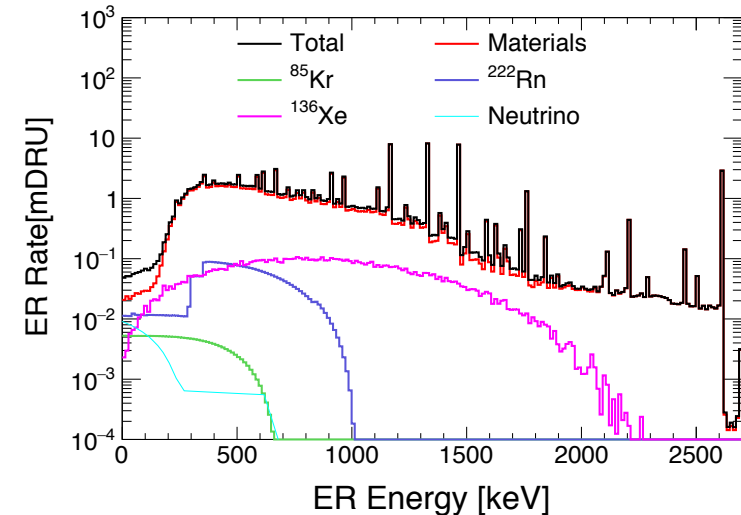


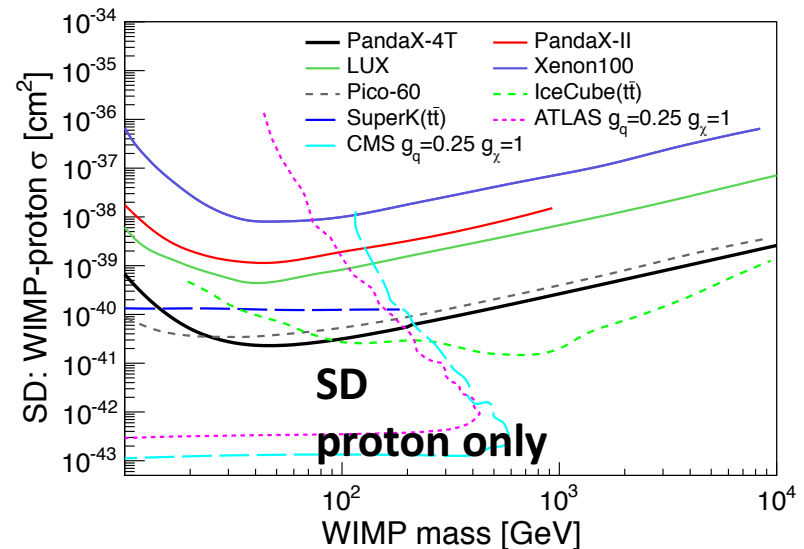
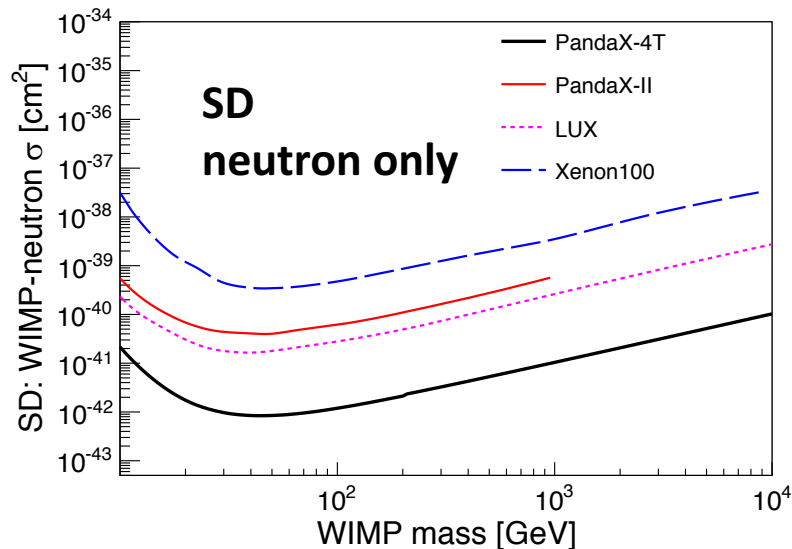
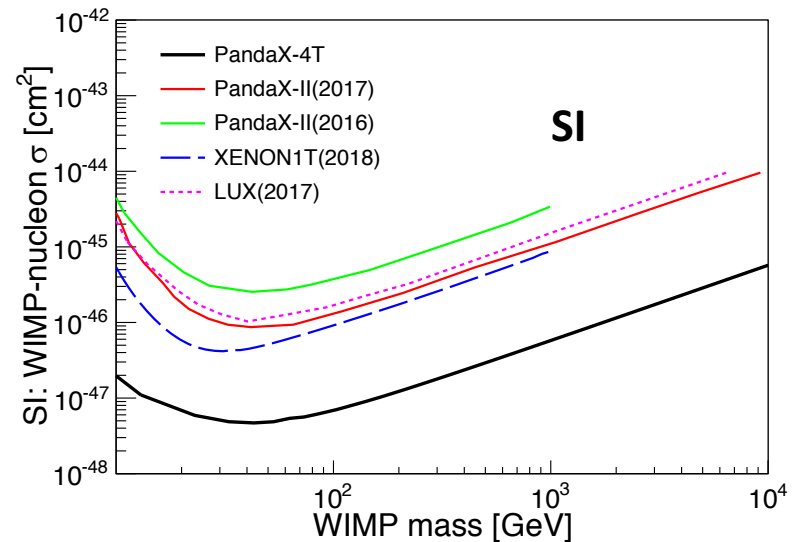
Table 4 Final background budget within the WIMP search window.

Sources	ER in mDRU	NR in mDRU
Materials	0.0210 ± 0.0042	$2.0 \pm 0.3 \cdot 10^{-4}$
^{222}Rn	0.0114 ± 0.0012	-
^{85}Kr	0.0053 ± 0.0011	-
^{136}Xe	0.0023 ± 0.0003	-
Neutrino	0.0090 ± 0.0002	$0.8 \pm 0.4 \cdot 10^{-4}$
Sum	0.049 ± 0.005	$2.8 \pm 0.5 \cdot 10^{-4}$
2-year yield (evts)	1001.6 ± 102.2	5.7 ± 1.0
after selection (evts)	2.5 ± 0.3	2.3 ± 0.4

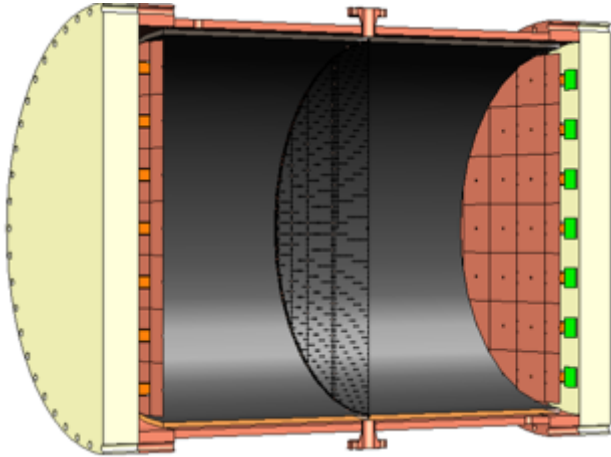


PandaX-4T Expected Sensitivity

- With two-year exposure, x10 improvement on sensitivity could be achieved.
- SI DM-nucleon sensitivity: 10^{-47}cm^2
- SD DM-neutron: 10^{-42}cm^2



PandaX-III: in preparation

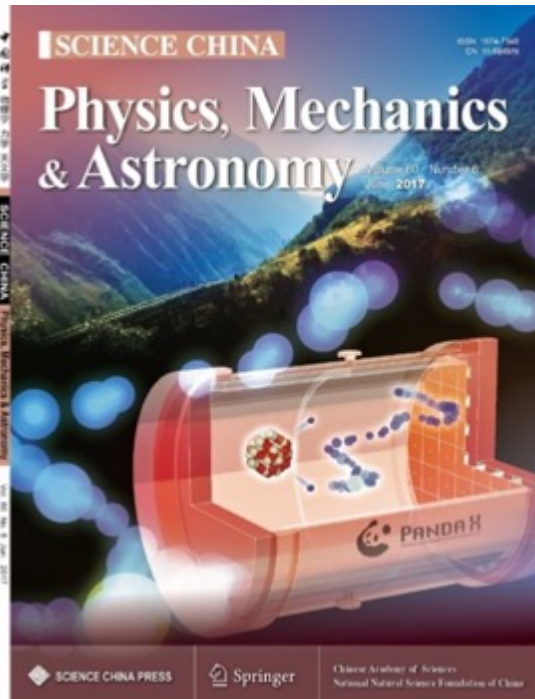


Looking for ^{136}Xe $0\nu\beta\beta$ decay

Lepton number violation

200-kg High pressure Xe detector

Prototype detector in Lab



Ning Zhou, COSMO18

Summary and Outlook

- PandaX experiment with 580kg Xenon has reached the world frontier of dark matter direct detection.
 - PandaX-II continues data-taking smoothly.
 - Recently, light mediator and EFT results are obtained
 - More results are expected.
- The future PandaX-4T experiment R&D is work-in-progress.
 - Expected sensitivity to SI interaction could reach 10^{-47} cm^2
 - Detector assembly and commissioning is scheduled in 2019-2020
- PandaX-III $0\nu\beta\beta$ search detector is in preparation.
- **Thank you!**

Backup

-

Constraints on Spin-Dependent Interaction

- O_4 SD EFT operator $\mathcal{O}_4 = \vec{S}_\chi \cdot \vec{S}_N$
 - Full basis shell-model GCN5082
- For proton-only coupling in Xe nucleus
 - O_4 SD EFT interaction largely suppressed

$$\sigma_{p,n}^{\text{SD}}(v) = \left(\frac{c_4}{m_V^2} \right)^2 \frac{\mu_{p,n}^2}{\pi} \frac{J_\chi(J_\chi + 1)}{4}$$

- “Standard” SD calculation:
 - chiral EFT
 - $O_4 + O_6 + \text{two nucleon pion-exchange}$

