Recent results and status of PandaX DM experiments

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on behalf of PandaX collaboration

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Outline

- Introduction
  - PandaX
  - China JinPing underground Lab(CJPL)
- Recent results on PandaX-II DM experiment
  - Spin-independent
  - Light-mediator DM models
  - Effective Field Theory interpretations
- Status and Future

PandaX Collaboration

- Particle **and** Astrophysical Xenon Experiments
  - Formed in 2009, ~50 people

PANDA X

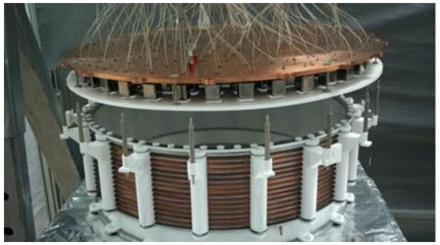
- Alternative Energies & Atomic Energy Commission
- University of Zaragoza
- Suranaree University of Technology

- Shanghai Jiao Tong University
- Peking University
- Shandong University
- Nankai University
- Shanghai Institute of Applied Physics
- Yalong Hydropower Company
- University of Science & Technology of China
- China Institute of Atomic Energy
- Sun Yat-Sen University
- Beihang University
- Fudan University
- Shanghai University of Science and Technology
- Lawrence Berkeley National Lab
- University of Maryland

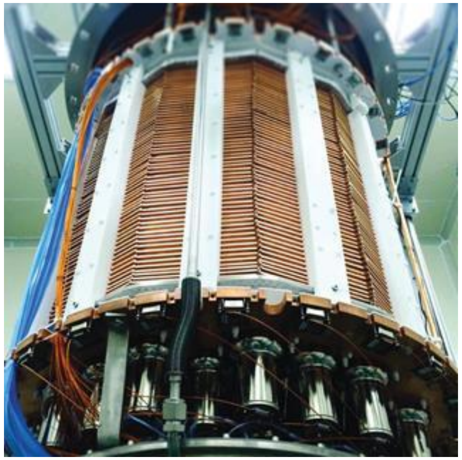
PandaX experiments

series of experiments base on xenon, searching for

- Dark matter with dual-phase time project chamber (TPC)
- $0\nu2\beta$ decays with high pressure ^{136}Xe TPC

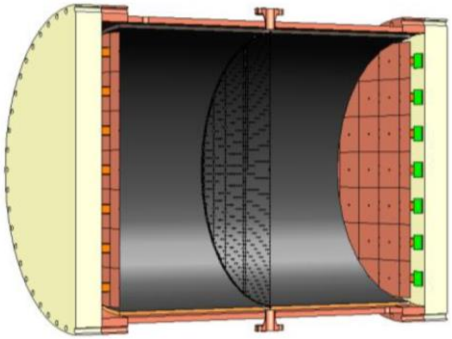


PandaX-I: 120kg Liquid xenon (2009-2014)



PandaX-II: 580kg LXe （2014-2019.6）

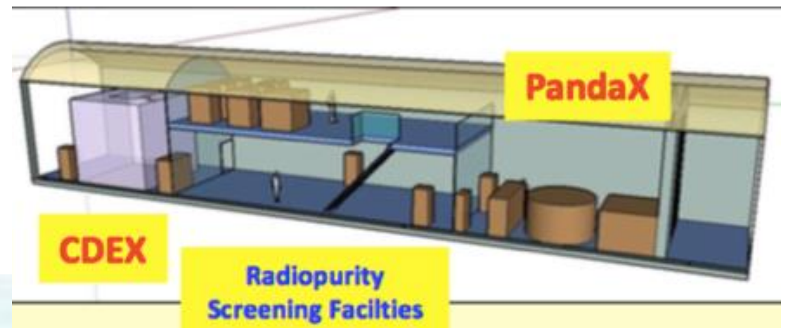
PandaX-xT: Next step, 4ton LXe （future）

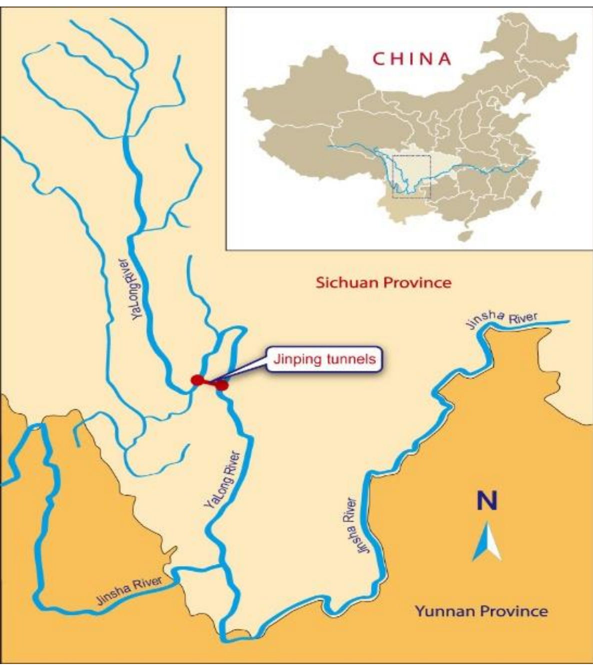


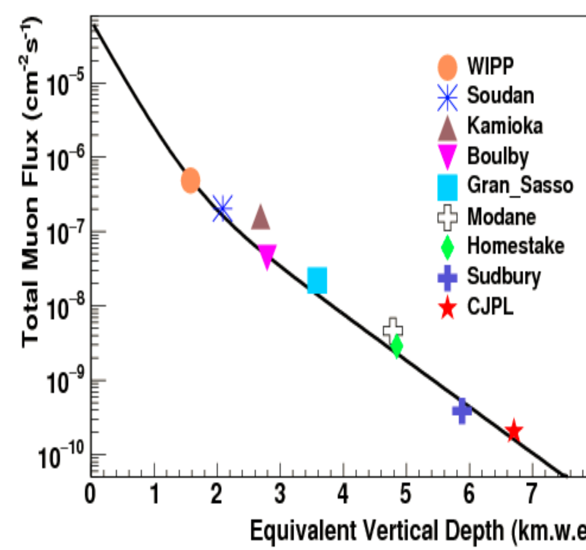
PandaX-III: 200kg-1ton High pressure gaseous xenon (future)

China JinPing Underground Lab

- 2009-2010 Tsinghua University and Yalong Hydropower company constructed world' deepest underground lab (2400m)
- Two DM experiment operated since then:
  - PandaX (for high-mass(>5GeV) WIMPs)
  - CDEX(for lighter masses, 1-5 GeV)

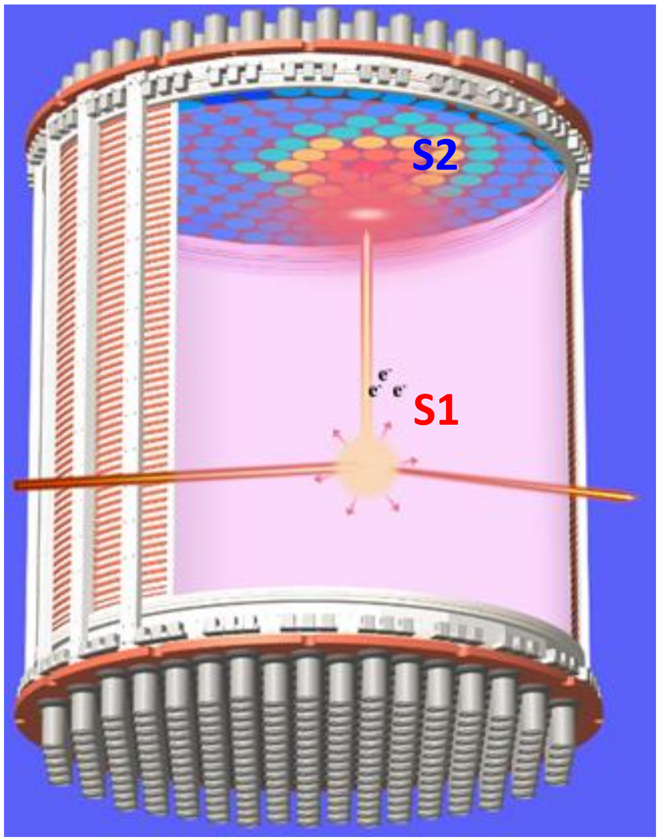


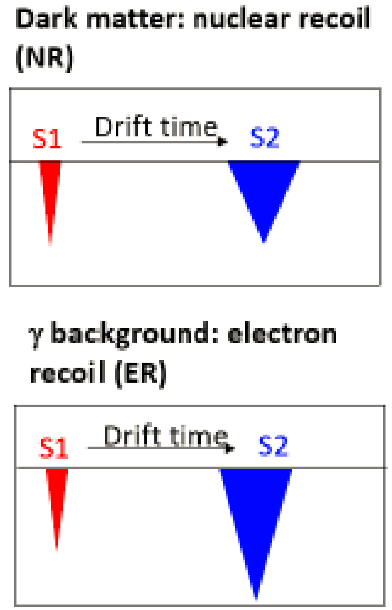




Dual-phase Xenon Time Projection Chamber

Detection principle



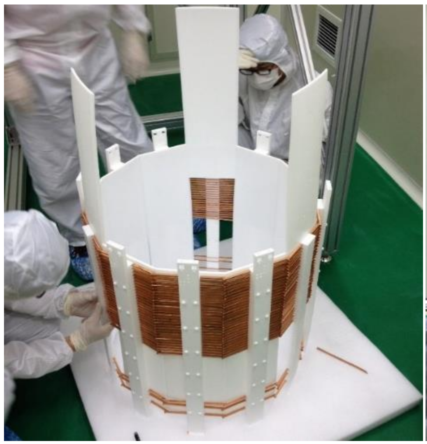


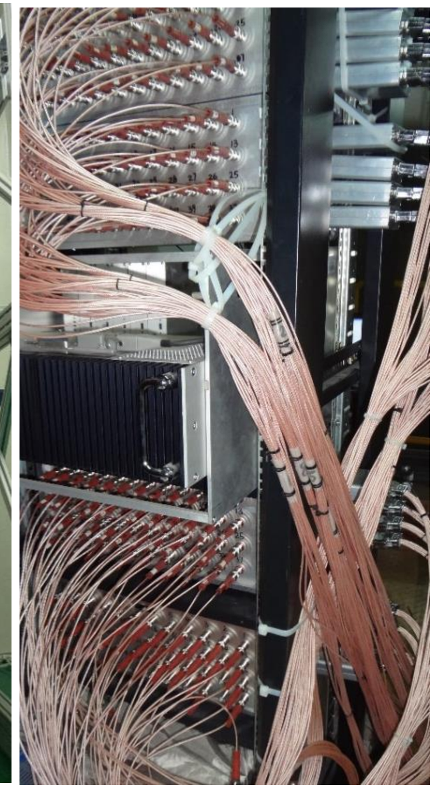
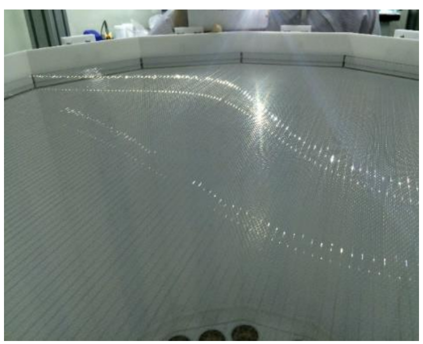
$(S2/S1)_{NR} << (S2/S1)_{ER}$

Advantages :

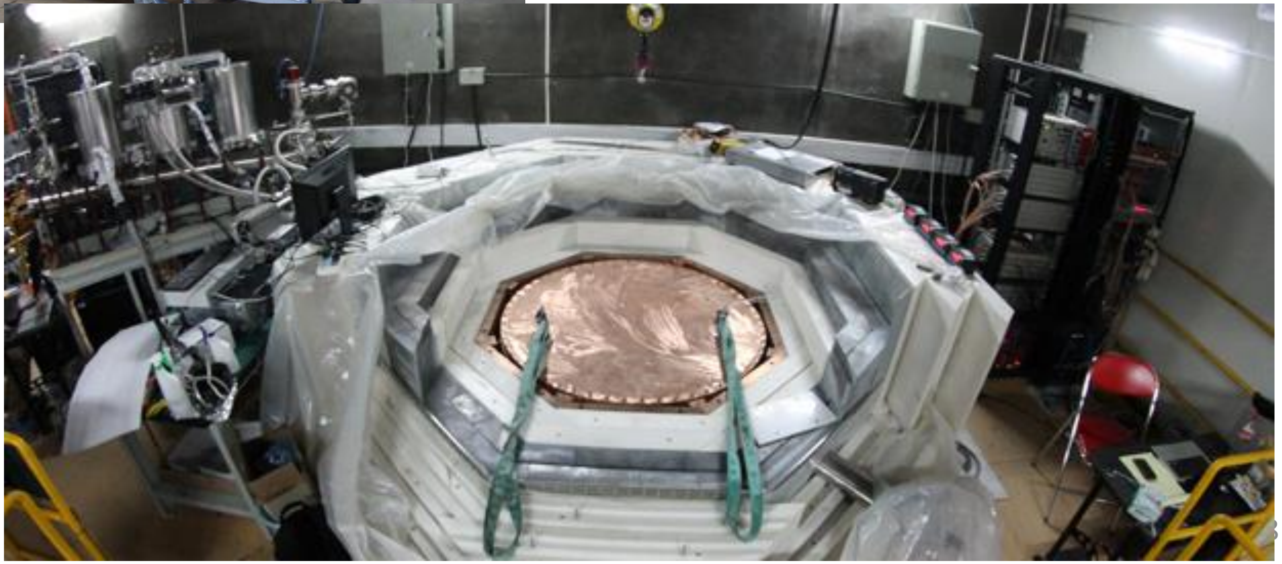
- ✓ Xenon has no long-lived radioactive isotopes
- ✓ Large A: large cross section
- ✓ High Z: self-shielding
- ✓ Excellent discrimination between nuclear and electron recoils and 3D fiducialization
- ✓ Scalability
- ✓ 9% ^{136}Xe for $0\nu2\beta$

Assembling the detector



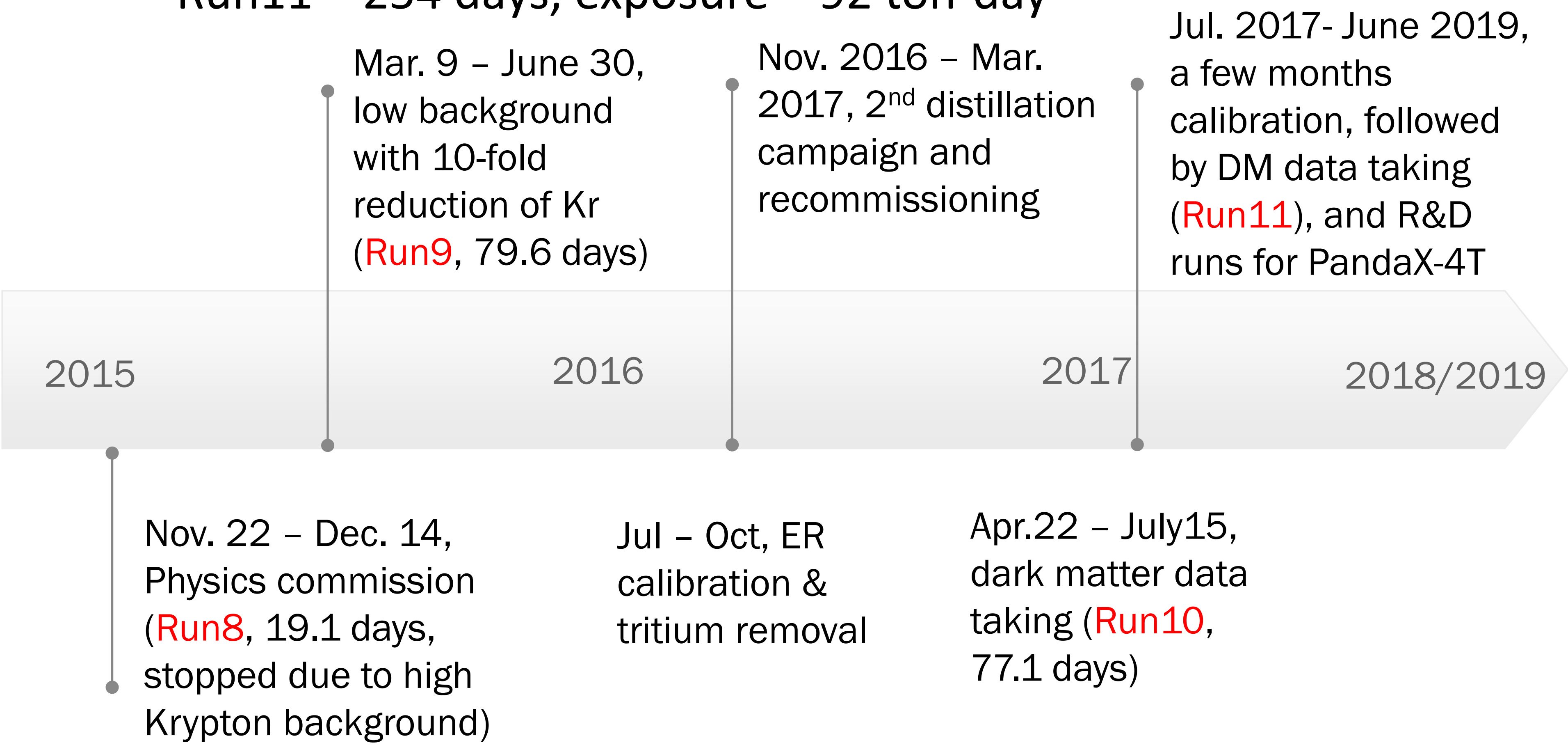





The CJPL-I PandaX Lab

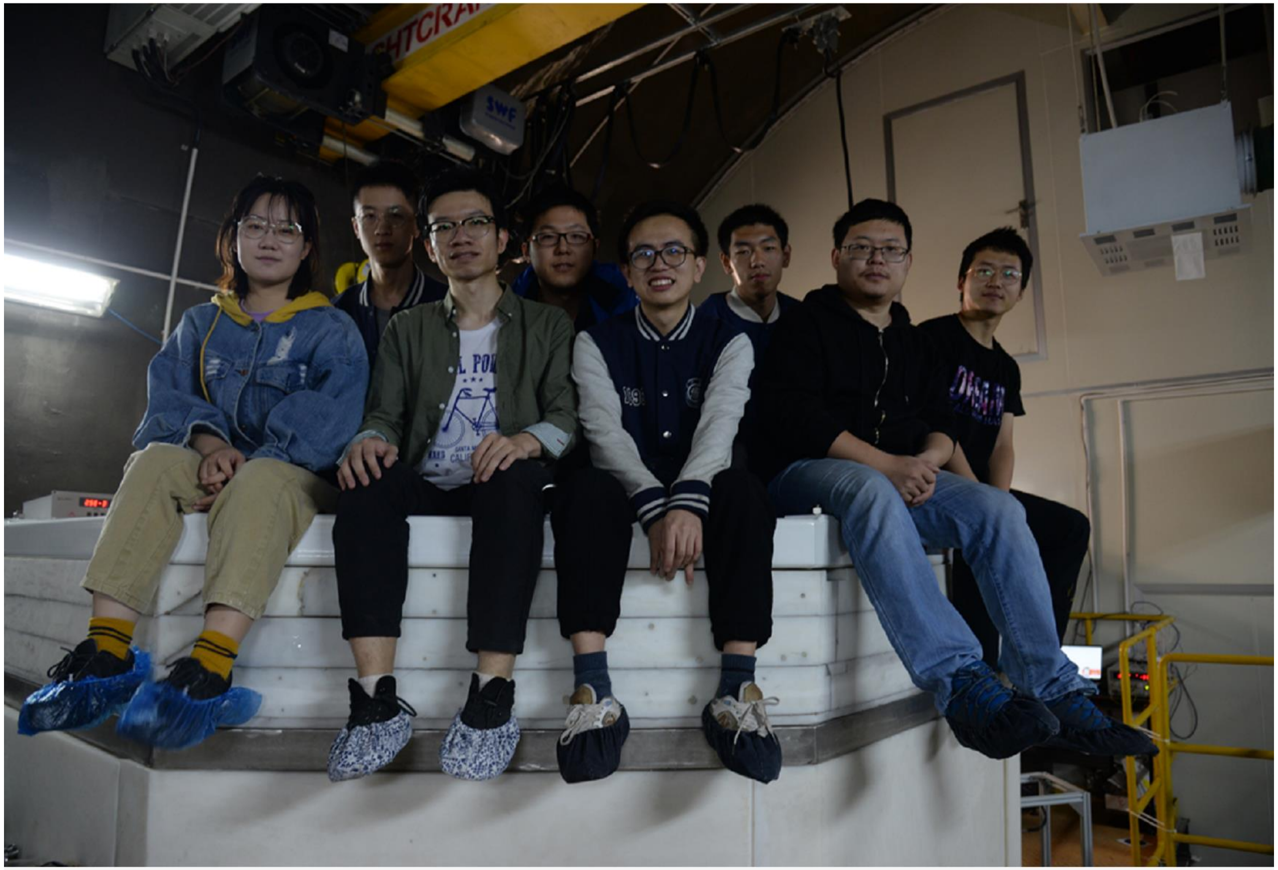


PandaX-II Run history

- Run9 =79.6 days, exposure: 26.2 ton-day
- Run10 = 77.1 days, exposure: 27.9 ton-day
- Run11 ~ 254 days, exposure ~ 92 ton-day



PandaX-II “end-of-run” completed



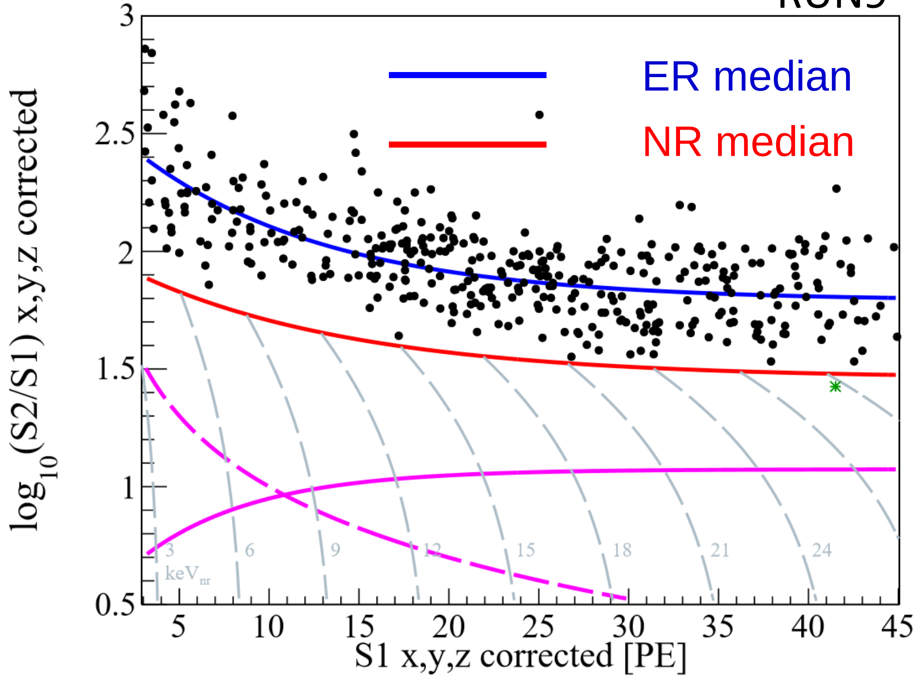
2019/6, On-site crew preparing for recuperating Xenon
1.16 Ton of Xenon has been recuperated.

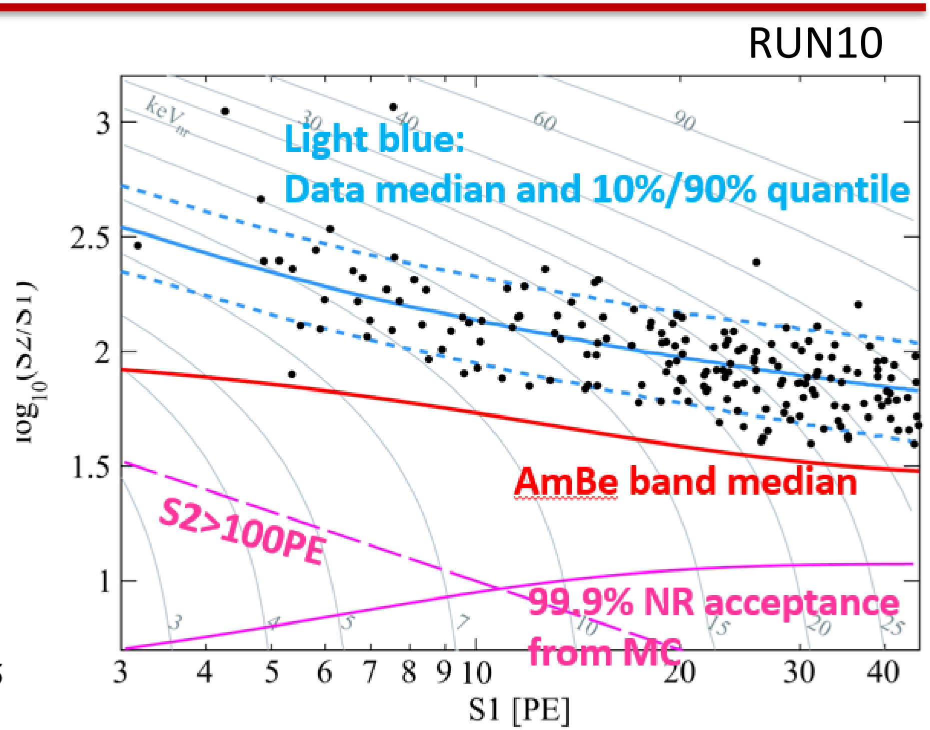
PandaX-II DM search results

Dark matter models	Exposure (Ton-day)	Publications
WIMP-nucleon Spin-Independent	33	PRL 117, 121303 (2016)
WIMP-nucleon Spin-dependent	33	PRL 118, 071301 (2017)
Inelastic scattering	27	PRD 96, 102007 (2017)
Axion and ALP	27	PRL 119, 181806 (2017)
WIMP-nucleon SI	**54**	**PRL 119, 181302 (2017)**
DM models with a light mediator, self-interacting DM (*)	**54**	**PRL 121, 021304 (2018)**
EFT models and SD (*)	**54**	**PLB 792, 193–198 (2019)**

(*) collaborating with theorists: Hai-bo Yu (UCI) and Wick C. Haxton (UCB&LBNL)

PandaX-II 54 ton-day DM data distribution





Item	Run 9 (mDRU)	Run 10 (mDRU)
^{85}Kr	1.19 ± 0.20	0.20 ± 0.07
^{127}Xe	0.42 ± 0.10	0.021 ± 0.005
^{3}H	0	0.27 ± 0.08
^{222}Rn	0.13 ± 0.07	0.12 ± 0.06
^{220}Rn	0.01 ± 0.01	0.02 ± 0.01
ER (material)	0.20 ± 0.10	0.20 ± 0.10
Solar ν	0.01	0.01
^{136}Xe	0.0022	0.0022
Total	1.96 ± 0.25	0.79 ± 0.16

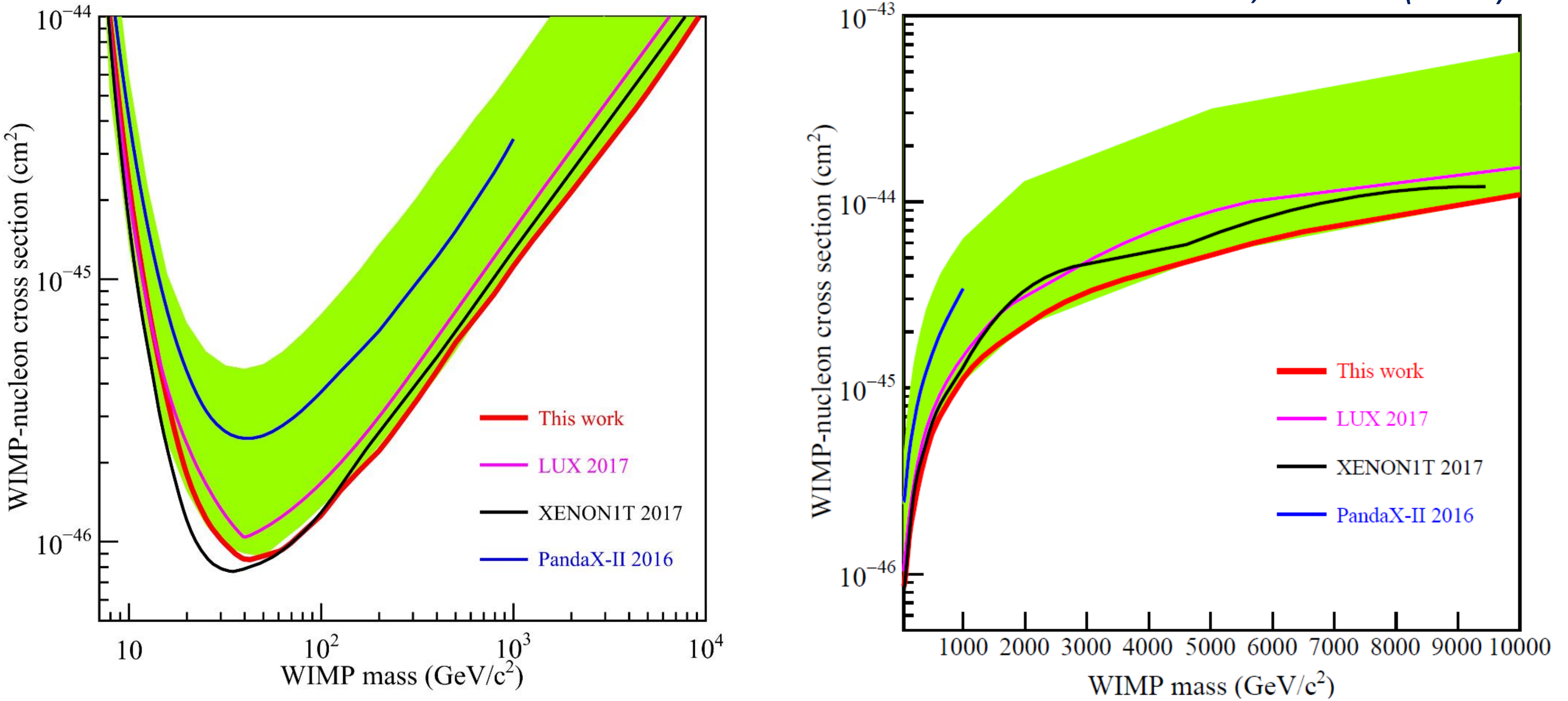
	ER	Accidental	Neutron	Total Fitted	Total Observed
Run 9	376.1	13.5	0.85	390 ± 50	389
Below NR median	2.0	0.9	0.35	3.2 ± 0.9	1
Run 10	172.2	3.9	0.83	177 ± 33	177
Below NR median	0.9	0.6	0.33	1.8 ± 0.5	0

mDRU=10^{-3} events/kg/day/keV

WIMP-nucleon SI cross section limits

PandaX-II 54 ton-day

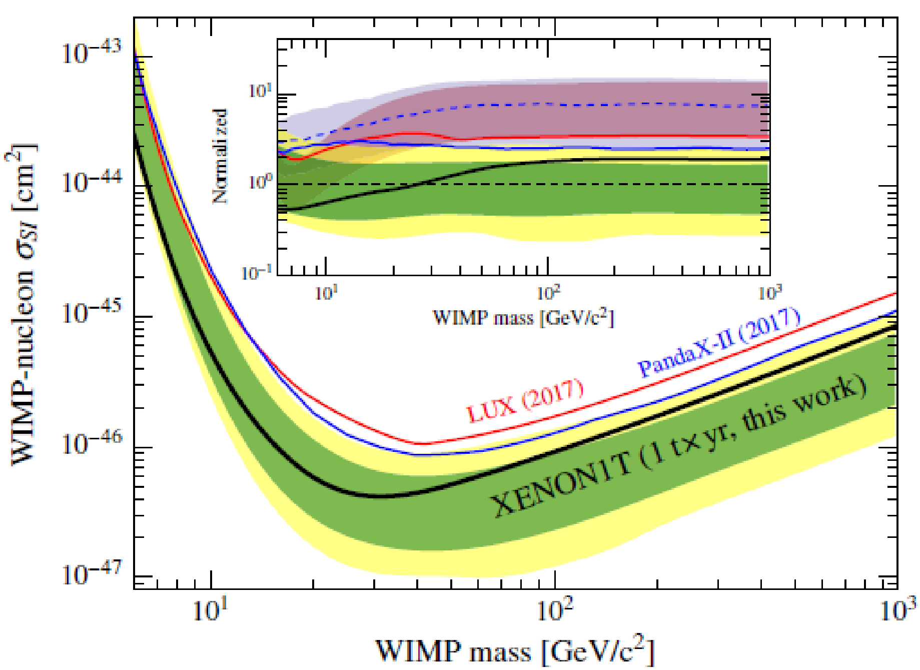
PRL 119, 181302 (2017)

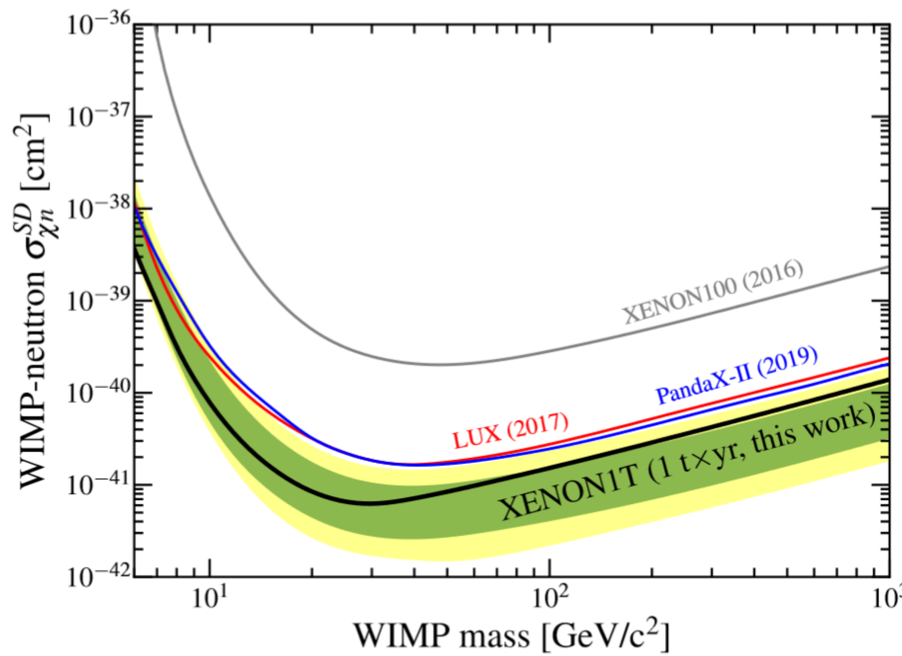


- Improved from PandaX-II 2016 limit about 2.5 time at high masses
- Lowest exclusion at $8.6\times10^{-47}cm^2$ at 40 GeV, most stringent for m_χ > 40 GeV when published

WIMP-nucleon SI and SD cross section limits

- XENON1T published DM search results in 1ton-year of data, no DM observed,

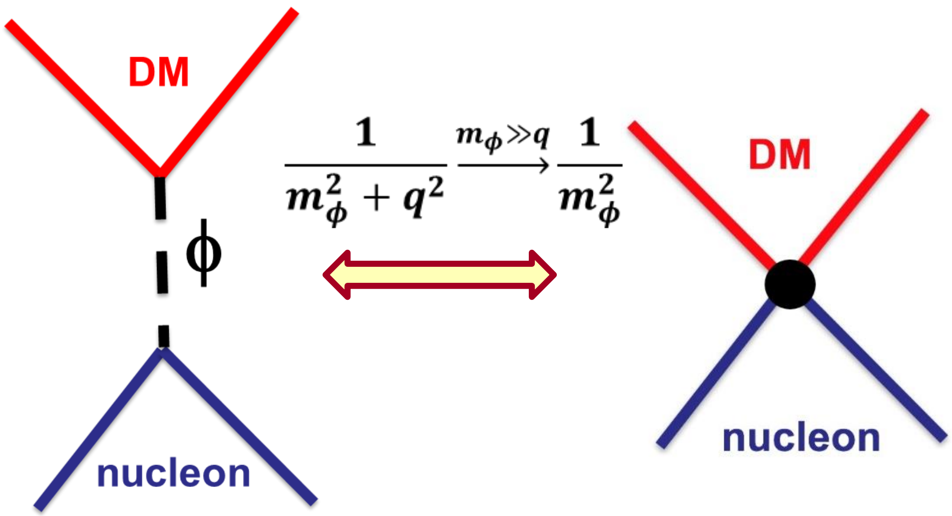




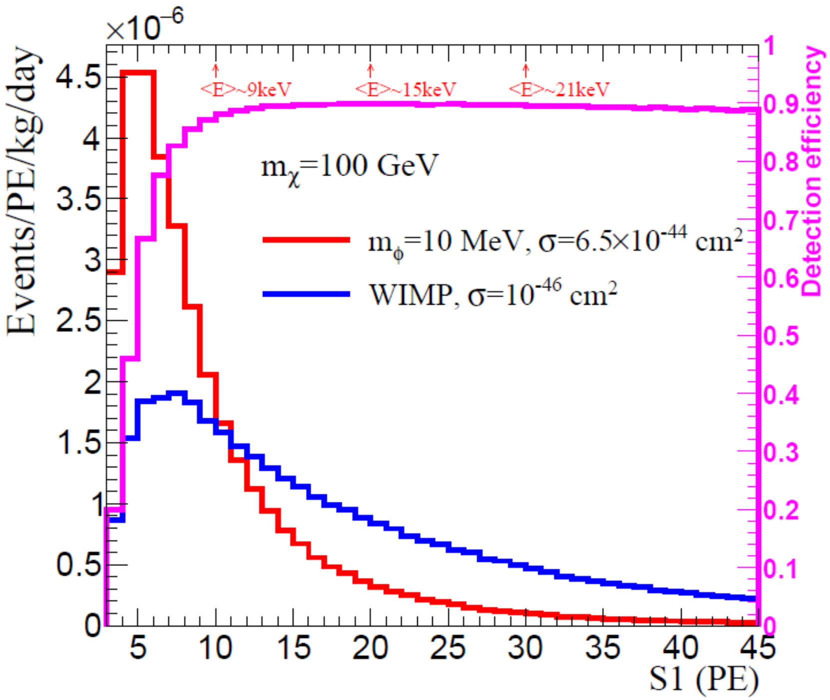
Spin-independent:
LUX, PRL 118, 021303 (2017)
PandaX-II, PRL 119, 181302 (2017)
XENON1T, PRL 121, 111302 (2018)

Spin-dependent:
LUX, PRL118, 251302 (2017)
PandaX-II, PLB 792, 193–198 (2019)
XENON1T, PRL 122, 141301 (2019)

Exploring light-mediator DM models using same data



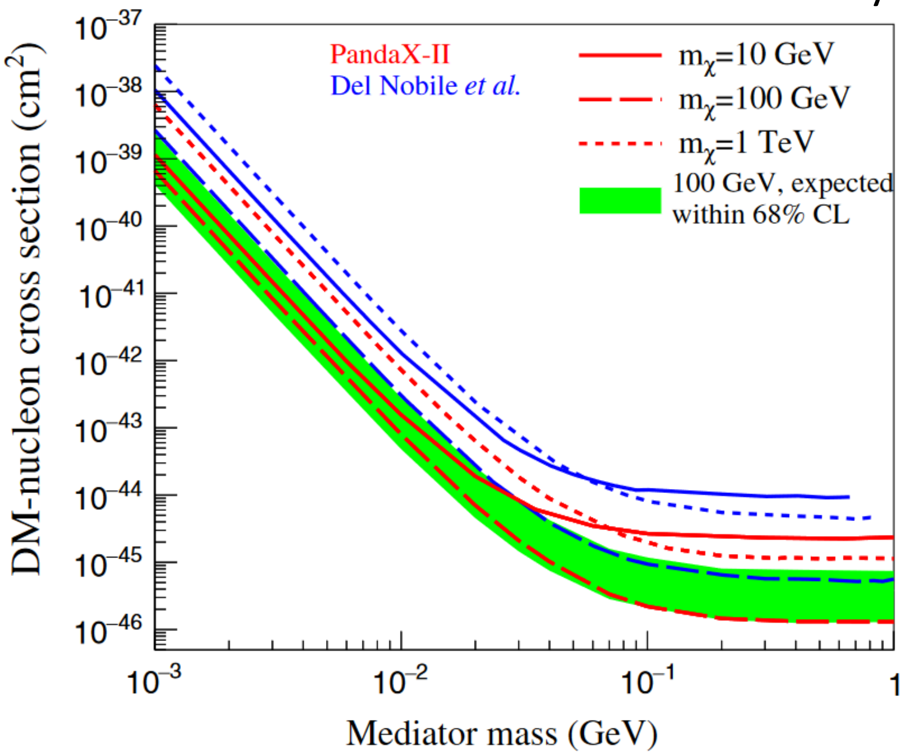
$$\frac{1}{m_\phi^2 + q^2} \xrightarrow{m_\phi \gg q} \frac{1}{m_\phi^2}$$



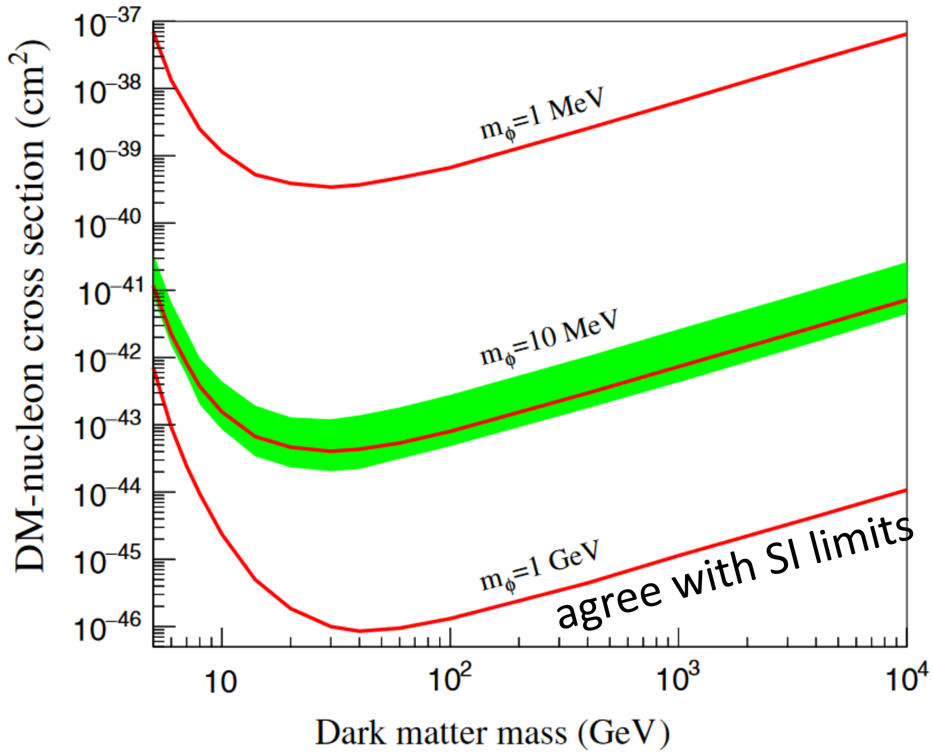
- Heavy mediator ➔ EFT contact interaction
  - Foundation of "main" SI/SD results in direct detection
- Light mediator: mediator m_ϕ is compared to or smaller than q
  - Signal spectrum more peaked towards to low-energy
  - q can not be simply ignored

Constraining DM-nucleon cross section with a mediator

PandaX-II 54 ton-day



PRL 121, 021304 (2018)



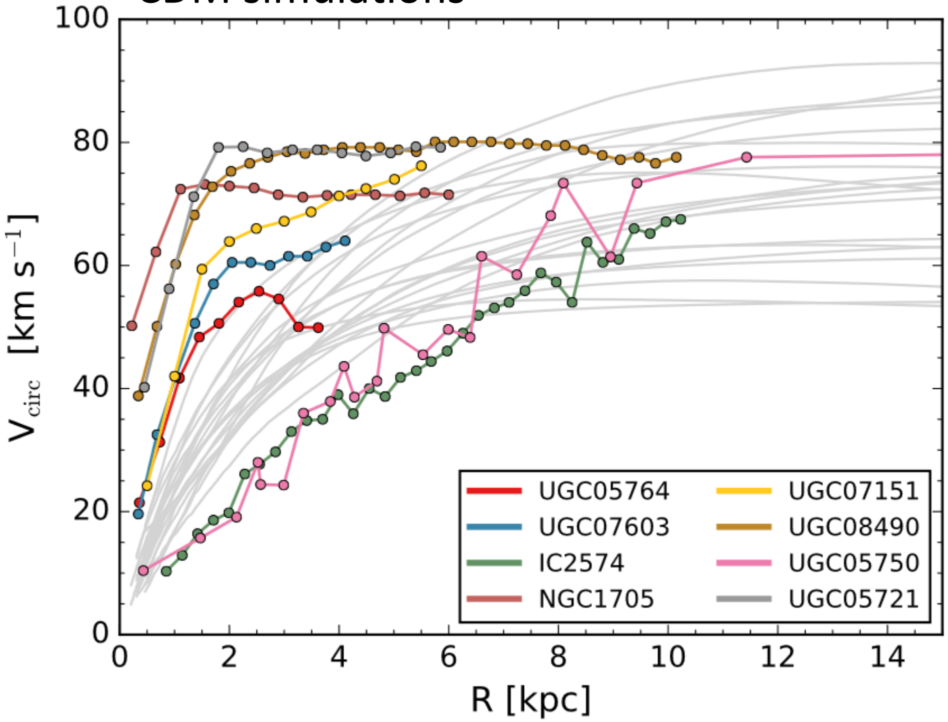
$$\sigma(q^2)_{\chi N} = \sigma|_{q^2=0} A^2 \left(\frac{\mu}{\mu_p}\right)^2 \frac{m_\phi^4}{(m_\phi^2 + q^2)^2} F^2(q^2)$$

Our Limits

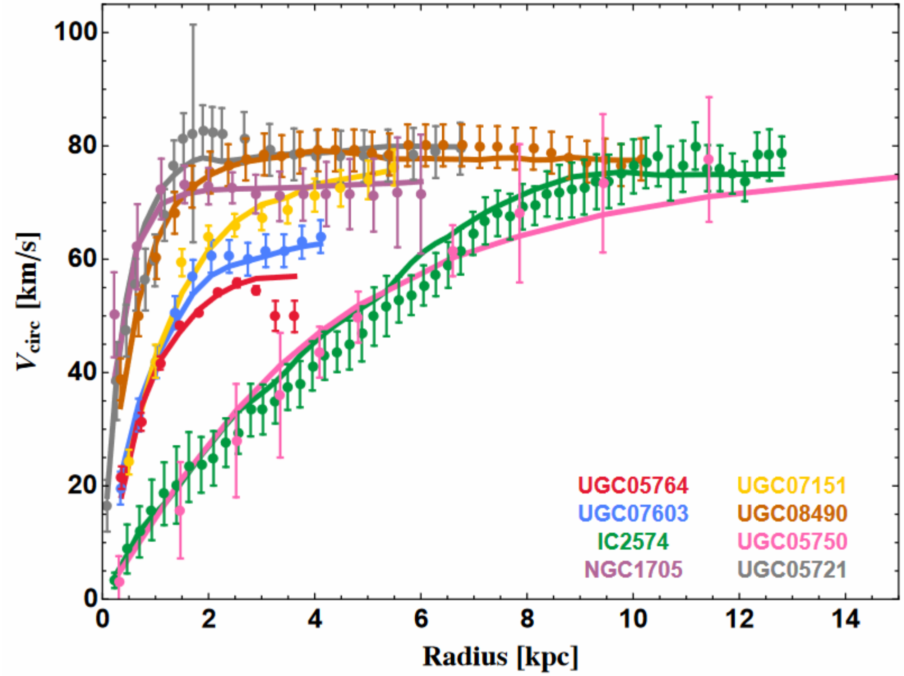
For light-mediator (scalar/vector) DM models

Self-Interacting DM with a light mediator

State-of-art hydrodynamical CDM simulations



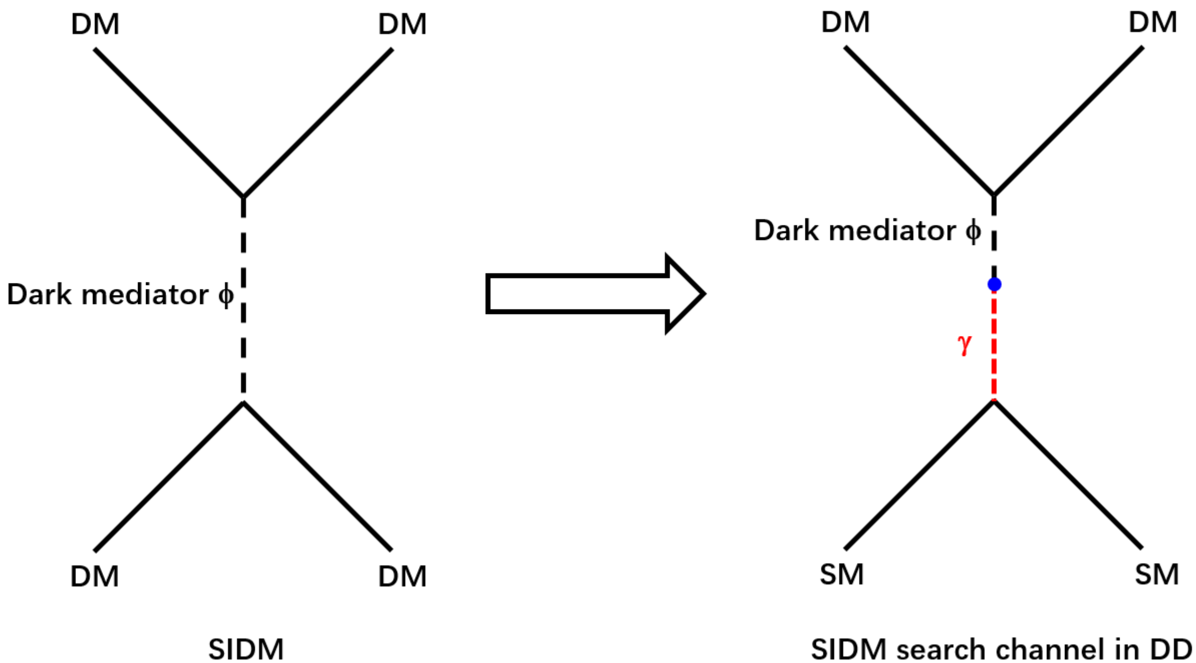
From our collaborator, Hai-Bo Yu (PBSM-2018)



Points : Observed galaxy rotation curves
Gray lines : CDM Simulation

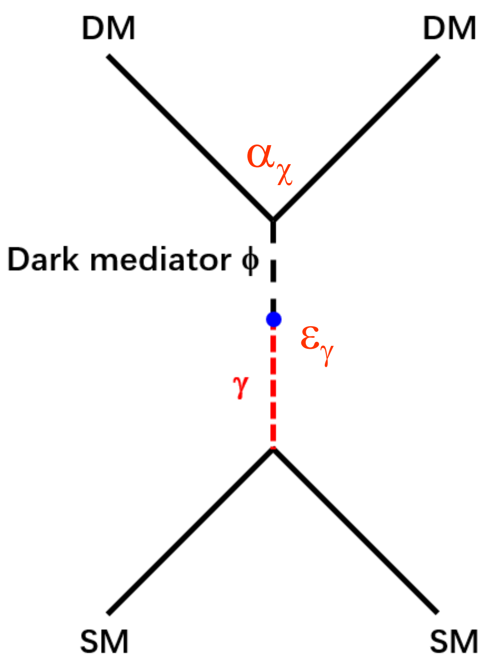
Solid color lines:
SIDM Fits

Detecting SIDM in direct detection experiments



- If the mediator mixes with SM particles (through g/Z/H mixing), SIDM could be detected at direct detection experiments.
- Two previous pheno studies directly comparable to our study:
  - "Direct Detection Portals for Self-interacting Dark Matter", M. Kaplingha *et. al*, PRD 89,035009(2014)
  - "Direct Detection Signatures of Self-Interacting Dark Matter with a Light Mediator", E. Del. Nobile, JCAP1510, 055 (2015)

SIDM particle-physics model at direct detections



SIDM search channel in DD

M. Kaplingha *et. al,* PRD 89,035009(2014)

New Parameter	Description
ε_γ	Mixing parameter between mediator and photon
α_χ	Fine structure in DM sector

- For Symmetric SIDM models, where DM and anti-DM are equally populated in early Universe, α_χ can be fixed by the observed DM relic density.

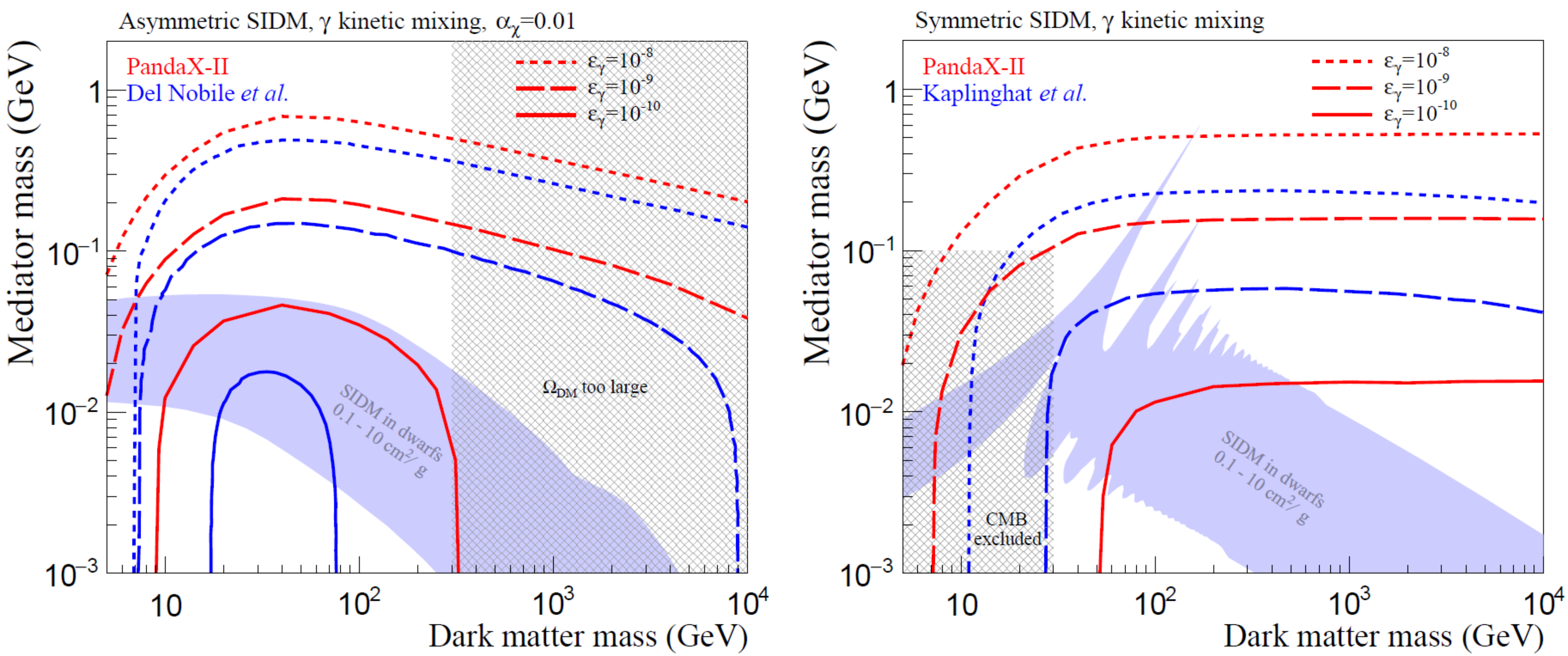
$$\sim 0.2 \times \left(\frac{\alpha_X}{10^{-2}}\right)^{-2} \times \begin{cases} (m_X/300 \text{ GeV})^2 & \text{vector} \\ (m_X/100 \text{ GeV})^2 & \text{scalar} \end{cases}$$

$\alpha_\chi \approx 4 \times 10^{-5} \times (m_\chi/\text{GeV})$, γ/Z mixing

$\alpha_\chi \approx 10^{-4} \times (m_\chi/\text{GeV})$, H mixing

- For Asymmetric SIDM models, α_χ = 0.01 is assumed

Constraining Self-interacting DM



- Lower limits on mediator mass vs DM mass for Asymmetric (left) and Symmetric SIDM with photon kinetic mixing.
- In the favored SIDM parameter space, PandaX-II is sensitive for as small as 10^{-10} mixing parameter

General EFT DM-SM interaction

7 typical relativistic operators studied, complete list in

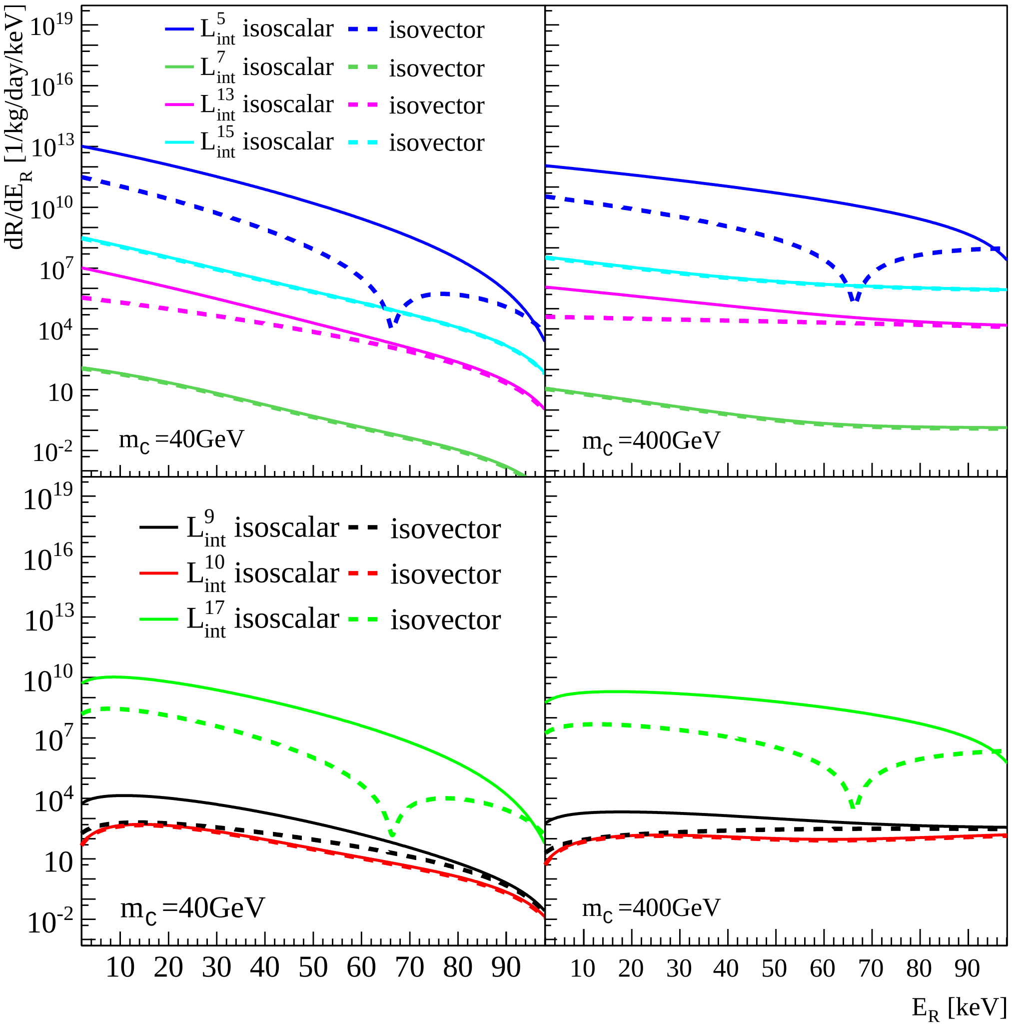
Phys. Rev. C89, 065501 (2014)

Dimension	Operator	Interactions
4	$\mathcal{L}^{5}_{\text{int}} \equiv \bar{\chi}\gamma^{\mu}\chi\bar{N}\gamma_{\mu}N$ $\mathcal{L}^{7}_{\text{int}} \equiv \bar{\chi}\gamma^{\mu}\chi\bar{N}\gamma_{\mu}\gamma^{5}N$ $\mathcal{L}^{13}_{\text{int}} \equiv \bar{\chi}\gamma^{\mu}\gamma^{5}\chi\bar{N}\gamma_{\mu}N$ $\mathcal{L}^{15}_{\text{int}} \equiv \bar{\chi}\gamma^{\mu}\gamma^{5}\chi\bar{N}\gamma_{\mu}\gamma^{5}N$	vector/axial-vector interactions (L5/15: standard SI/SD)
5	$\mathcal{L}^{9}_{\text{int}} \equiv \bar{\chi}i\sigma^{\mu\nu}\frac{q_{\nu}}{m_M}\chi\bar{N}\gamma_{\mu}N$ $\mathcal{L}^{17}_{\text{int}} \equiv i\bar{\chi}i\sigma^{\mu\nu}\frac{q_{\nu}}{m_M}\gamma^{5}\chi\bar{N}\gamma_{\mu}N$	coupling the WIMP magnetic moment or electric dipole moment with the nucleon's vector current
6	$\mathcal{L}^{10}_{\text{int}} \equiv \bar{\chi}i\sigma^{\mu\nu}\frac{q_{\nu}}{m_M}\chi\bar{N}i\sigma_{\mu\alpha}\frac{q^{\alpha}}{m_M}N$	coupling WIMP and nucleon magnetic moments

A unit dimensionless coupling is assumed here, this will be constrained by PandaX-II data.

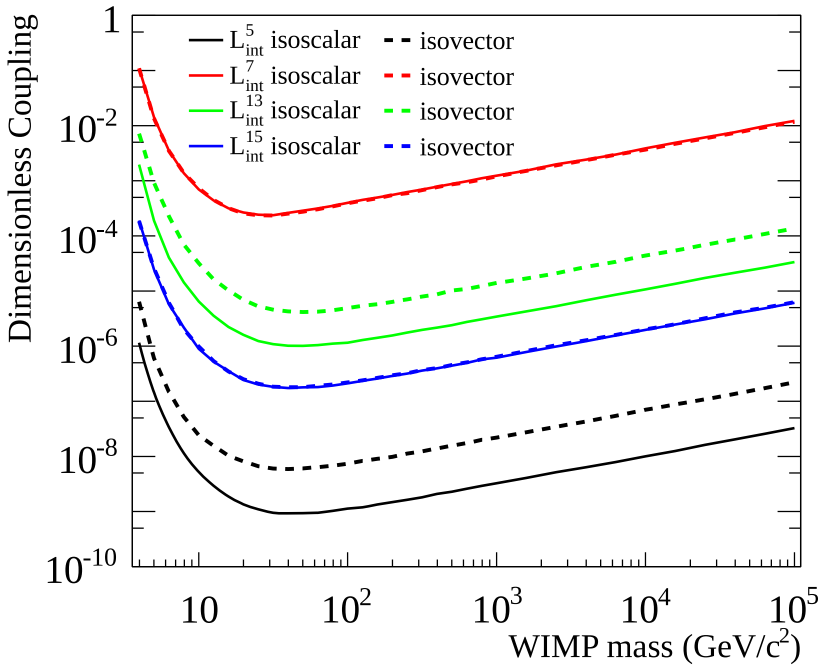
Energy spectra for EFT operators

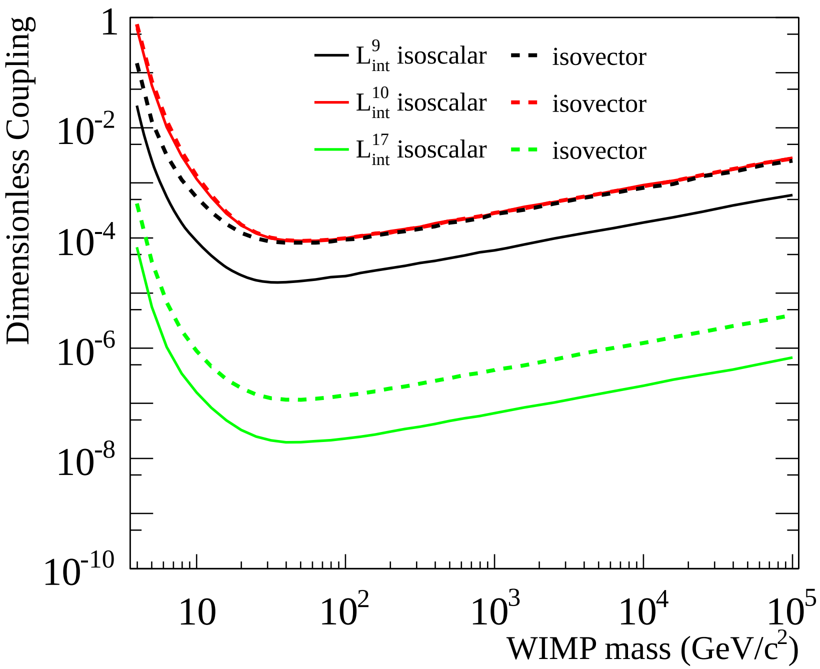
- 7 typical relativistic operator, leading to dramatically different spectra
  - ***q*** and ***v*** dependence
  - Isospin scalar (coupling to proton and neutron with same sign)
  - isospin vector (p,n opposite sign)



Upper limits on coupling

PLB 792, 193–198 (2019)

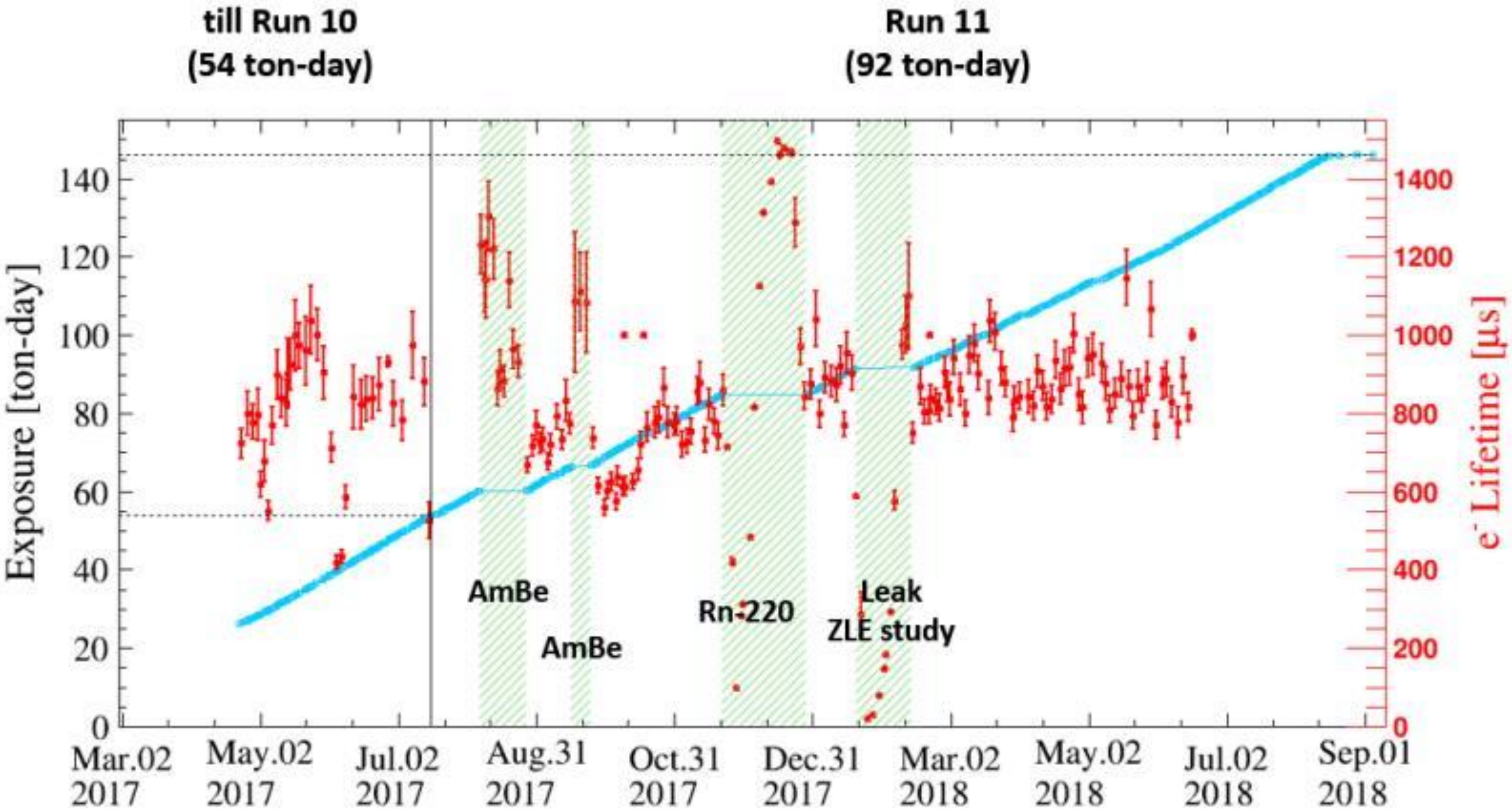




Constraints strongly depending on the operator/isospin

Updated DM data exposure in PandaX-II

- A factor of ~2 more DM data to be unblinded.
- Analysis is ongoing, tentatively releasing new results at next TAUP conference (2019/09)

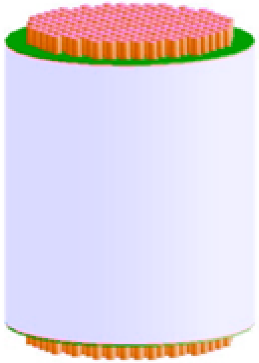


PandaX Future

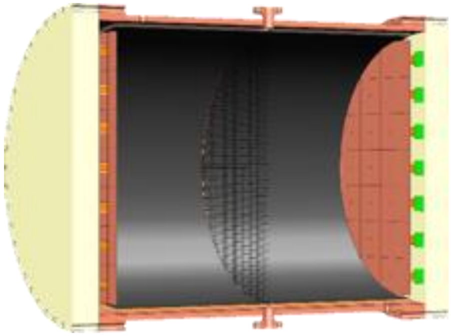
- PandaX-xT for DM search
- PandaX-III for 0vbb search

PandaX-I: 120 kg
DM experiment
2009-2014

PandaX-II: 500 kg
DM experiment
2014-2018



PandaX-xT:
Next stage: 4-ton
DM experiment
Future



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

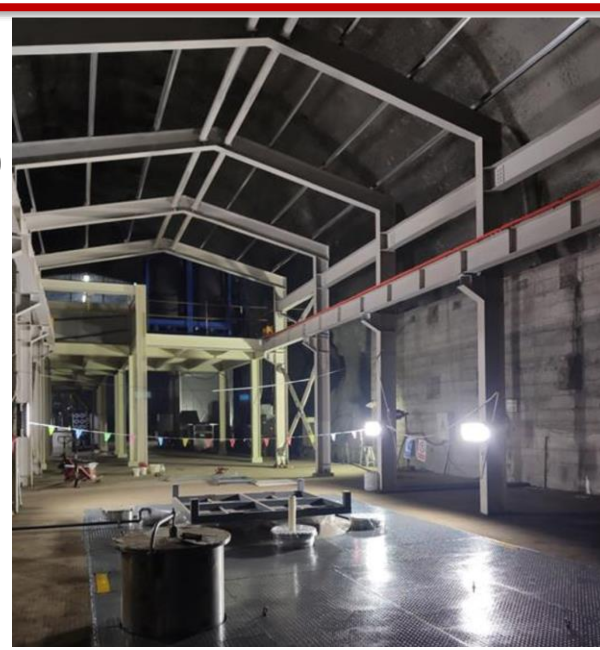
CJPL-I

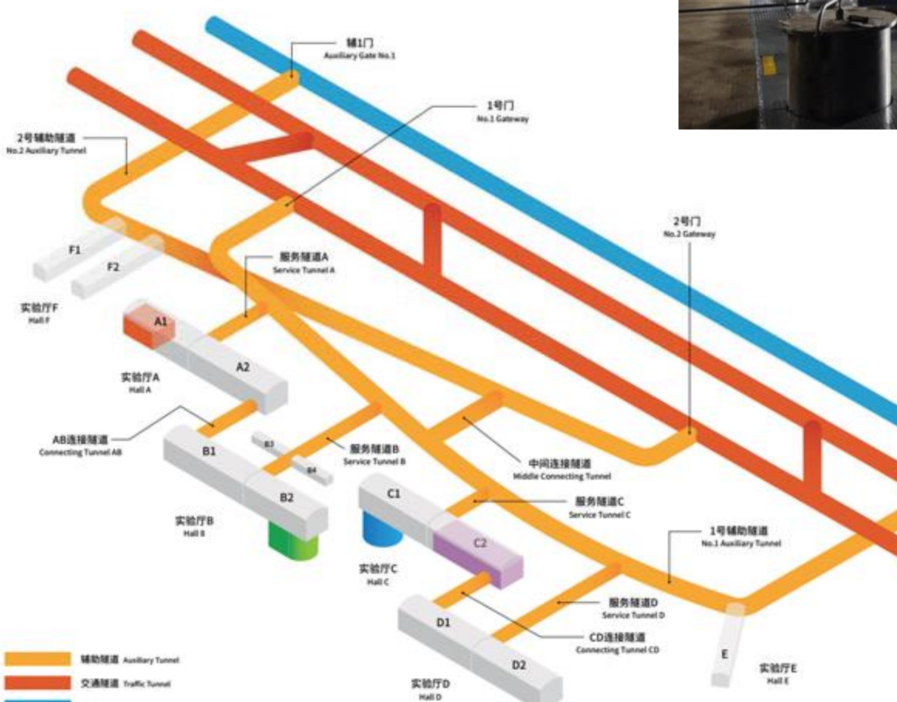
CJPL-II

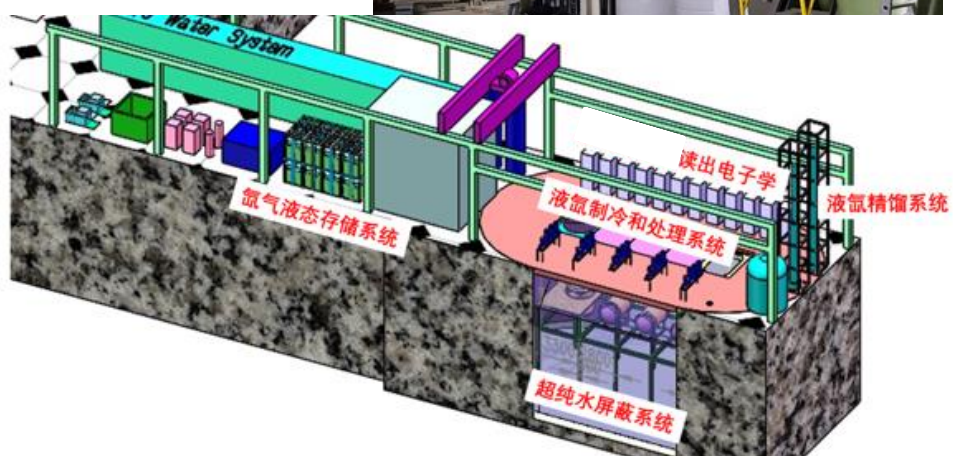
Ke Han's talk this afternoon
For 0NDBD

New experiment hall at CJPL-II

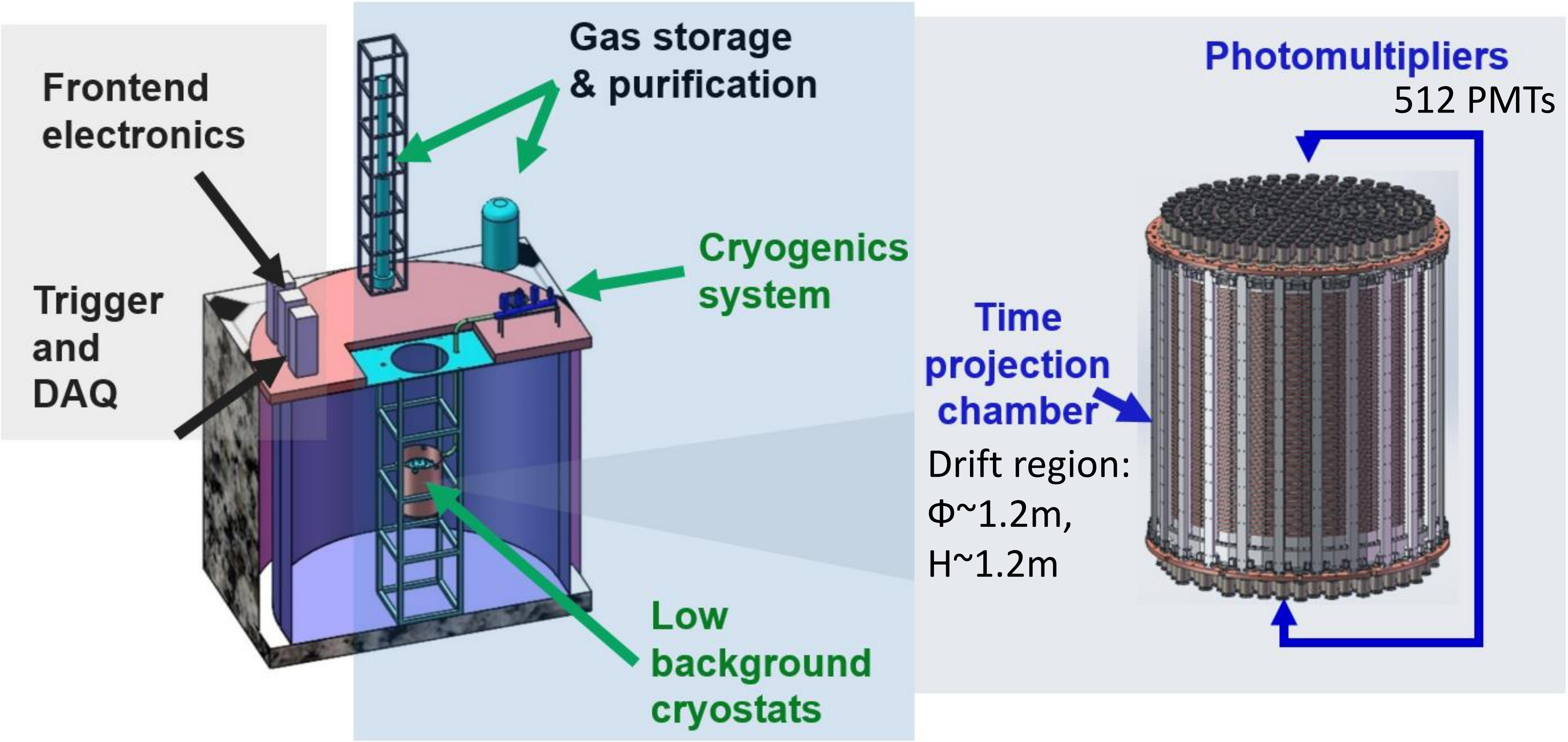
- B2 Hall
- 14m(H)x14m(W)x65m(L)
- Water Shielding
  - 5000 Ton pure water
  - U/Th $<10^{-14}$ g/g







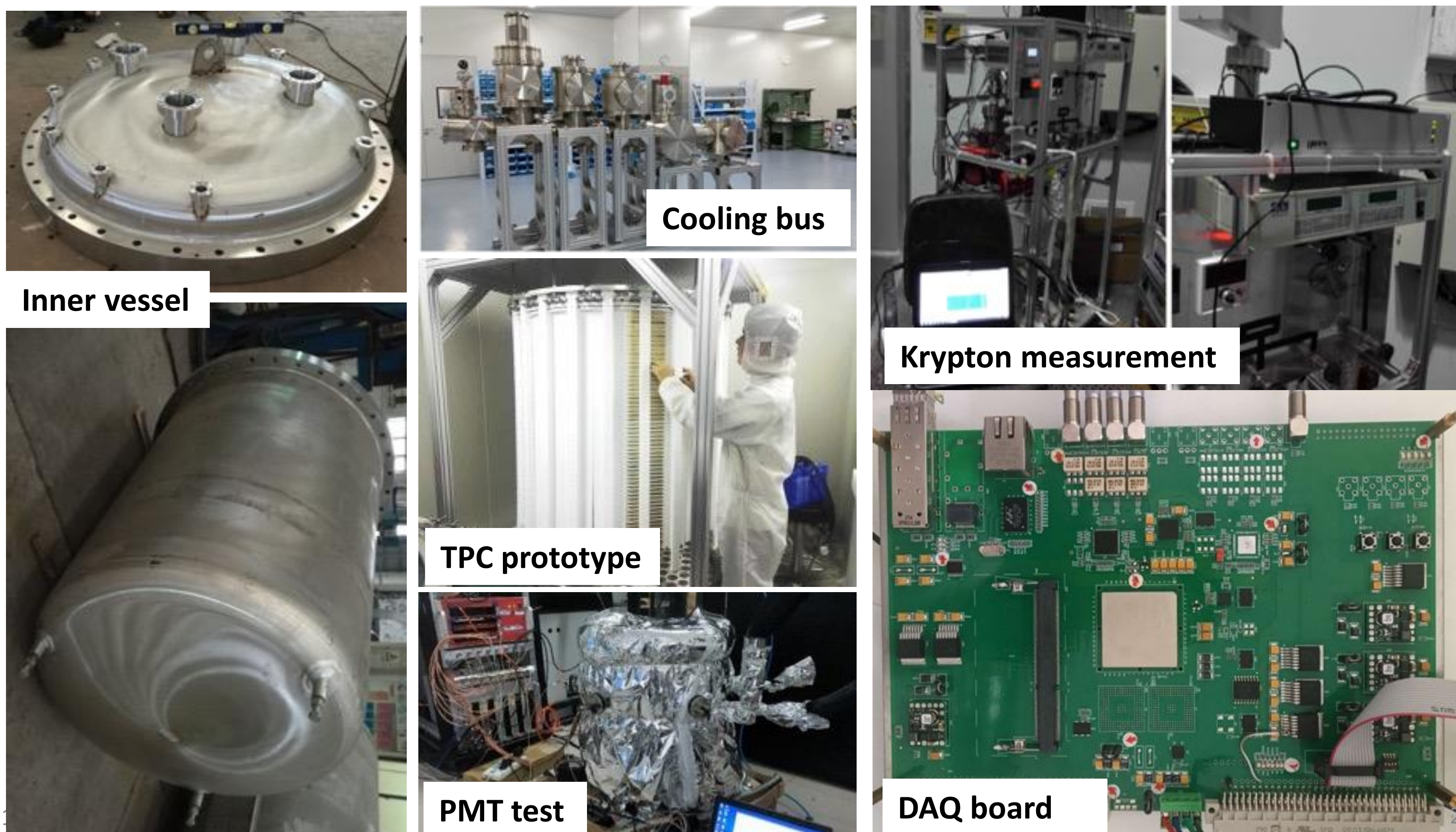
PandaX-xT facilities



- Intermediate stage:
  - **PandaX-4T** (4-ton in sensitive region) with SI sensitivity ~10^{-47} cm^2
  - On-site assembly and commissioning: 2019-2020

PandaX-4T in preparation

- 2019-2020: assembly and commissioning

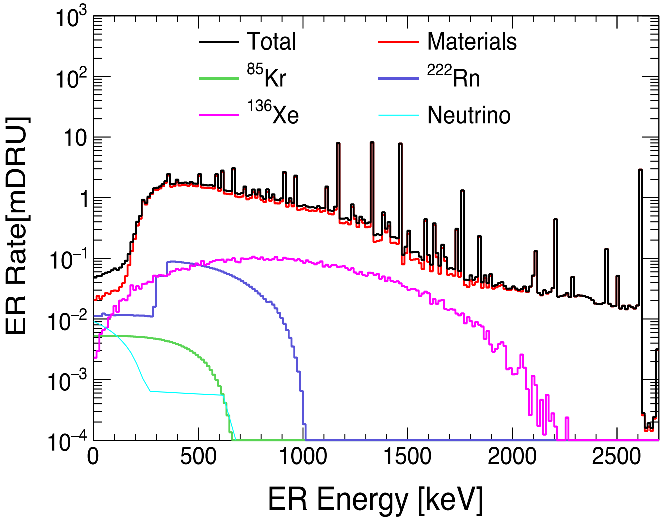


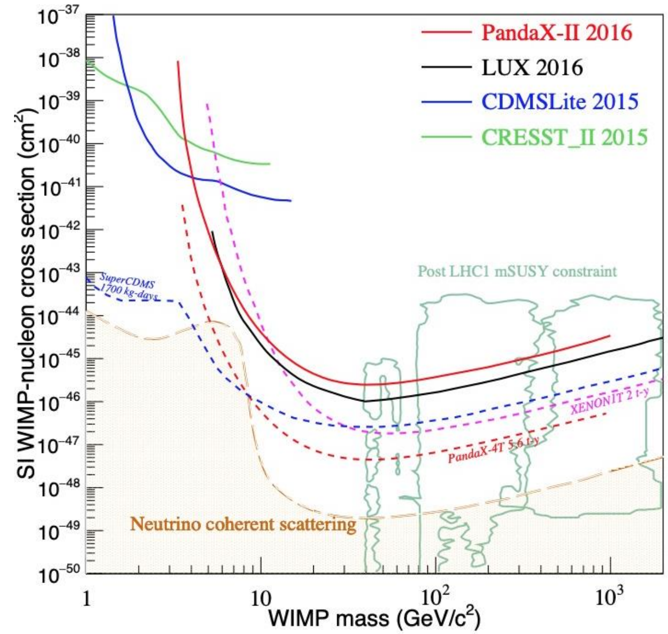
PandaX-4T sensitivity study

- Simulated ER and NR events
  - Detector materials
  - Radioactivity in xenon: ^{85}Kr, ^{222}Rn, ^{136}Xe
  - Neutrino
- Background in signal region
  - Total ER background: 0.05 mDRU (0.8 in PandaX-II)
  - Total NR background: 1 event/(ton-year)
- With two-year exposure, SI DM-nucleon cross section sensitivity to 10^{-47} cm^2

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





Sci. China-Phys. Mech. Astron. 62 3 (2019)

Summary

- Recent results from PandaX-II are presented
  - WIMP SI analysis
  - Interpretations with Light-mediator and SIDM models
  - Generic EFT and SD analysis

- PandaX-4T and PandaX-III under preparation
  - For PandaX-4T, expect 10x improvement on sensitivity over PandaX-II. For SI interaction could reach 10^{-47} cm^2, detector assembly and commissioning is scheduled in late 2019 to 2020
  - PandaX-III and 0NDBD, please attend Ke Han's talk this afternoon

Thanks for your attention!

And many thanks to the particle-physics community for the support to PandaX in last 10 years!