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

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On behalf of PandaX Collaboration

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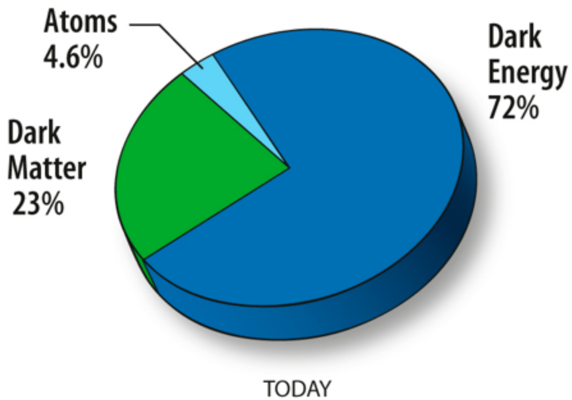
Outline

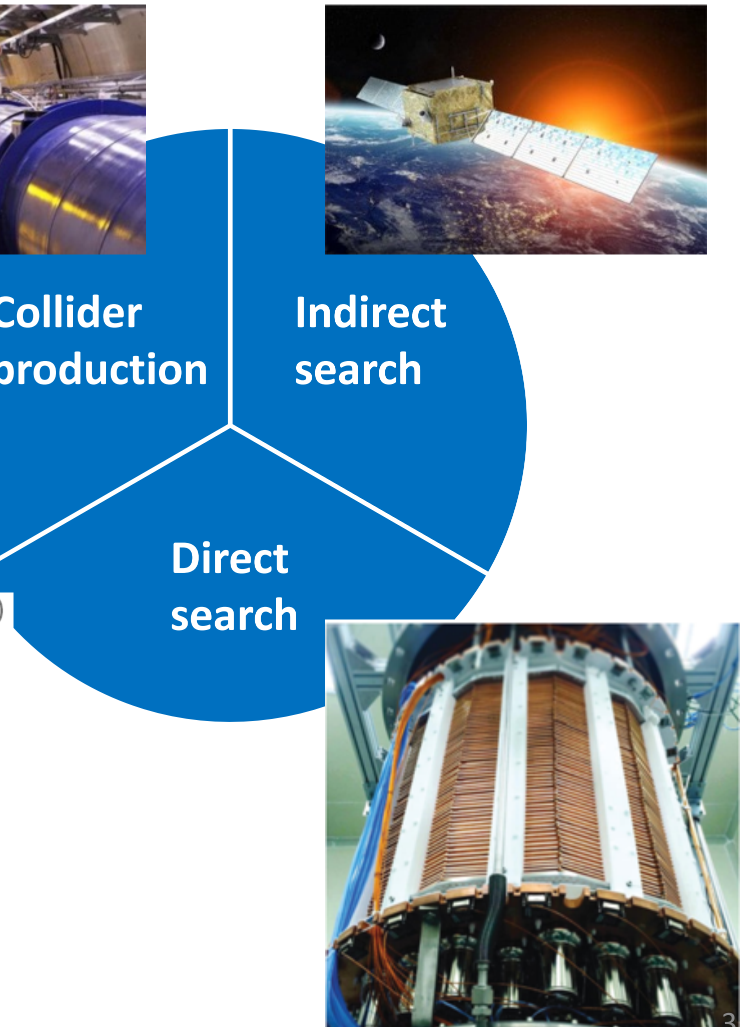
- WIMP direct detection
- PandaX experiment
- PandaX-II operation and results
- PandaX-4T upgrade plan
- Summary

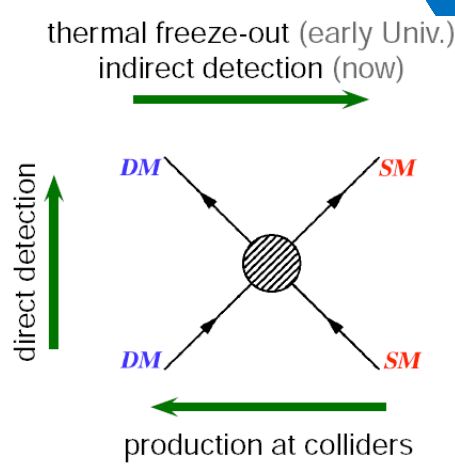
Dark Matter

- Strong evidences for the existence of dark matter



- DM-SM interaction
  - Direct detection
  - Indirection detection
  - Collider search





Interesting Signatures from Indirect Search

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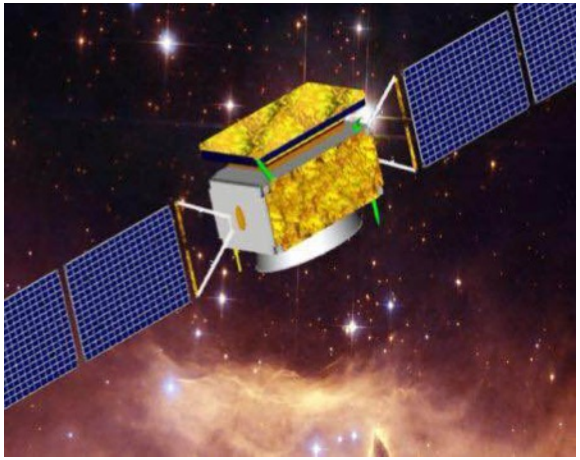
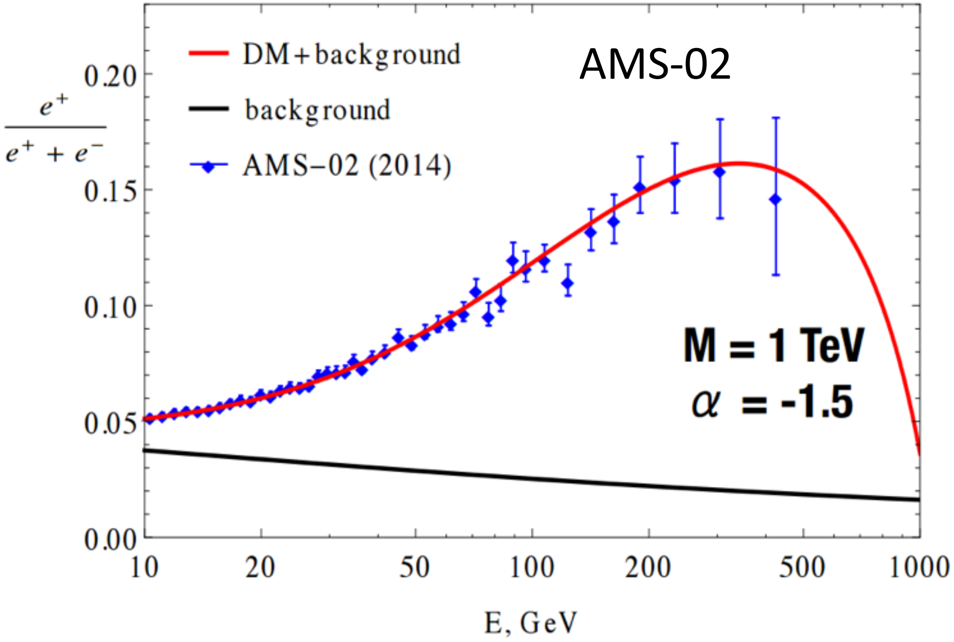
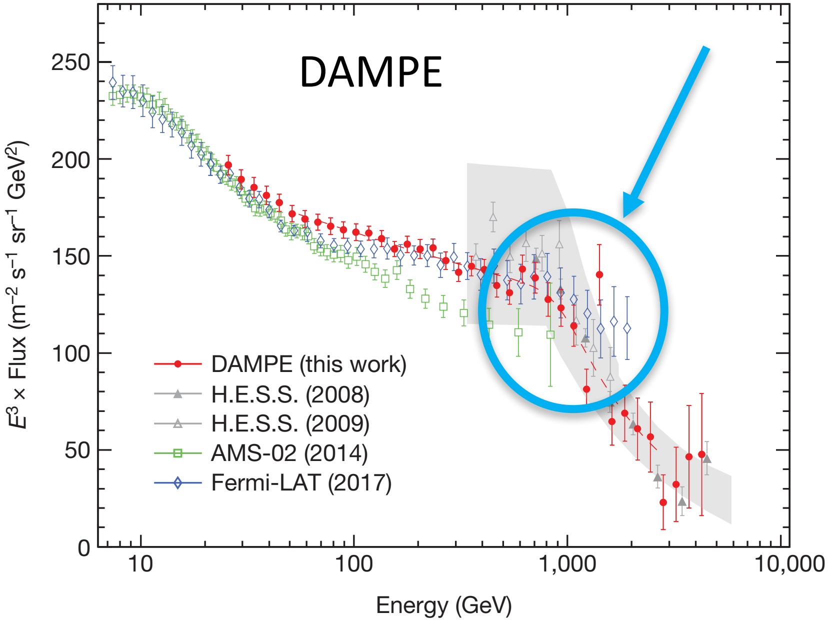
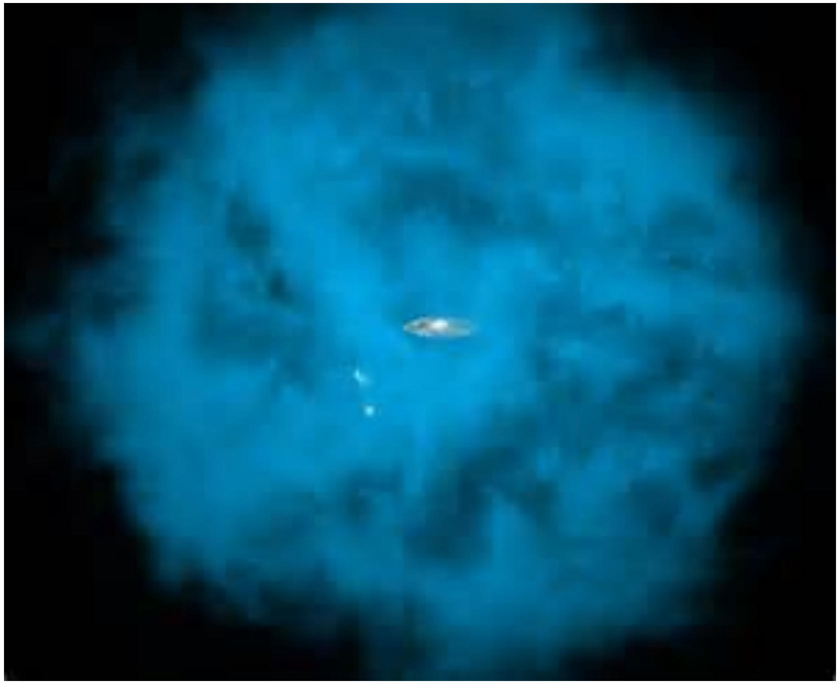


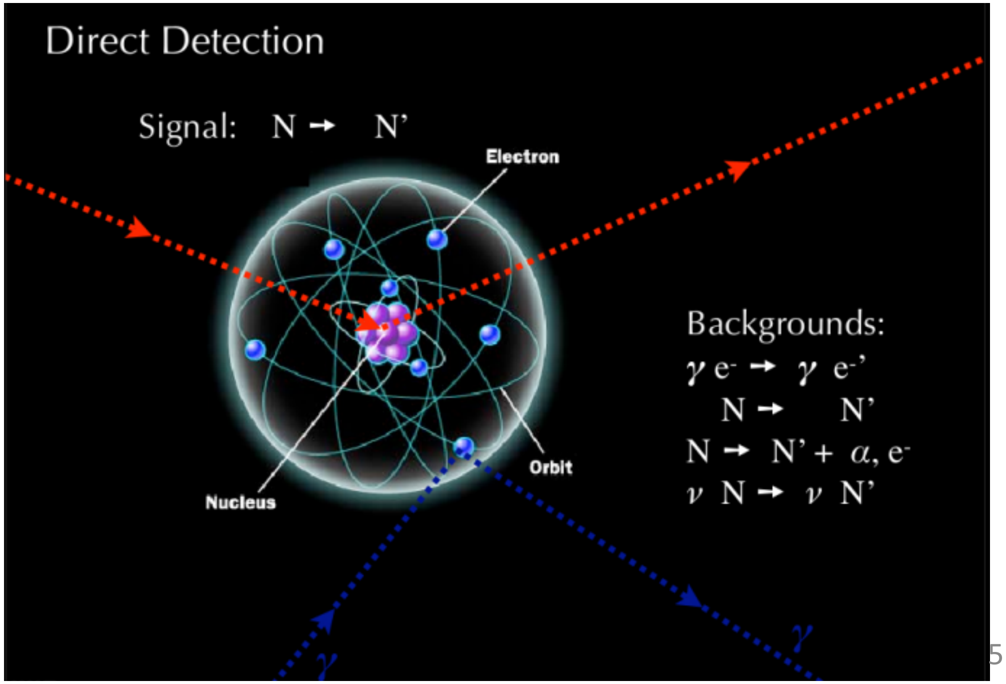




Dark Matter Direct Detection

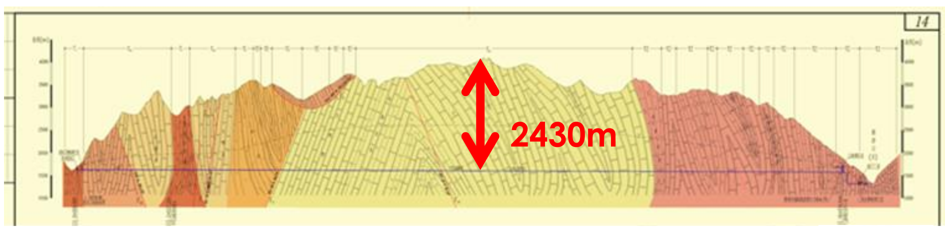
- DM: velocity ~1/1500 c, mass ~100 GeV, KE ~ 20 keV
- Nuclear recoil (NR): recoiling energy ~10 keV
- Electron recoil (ER): 10^{-4} suppression in energy, very difficult to detect

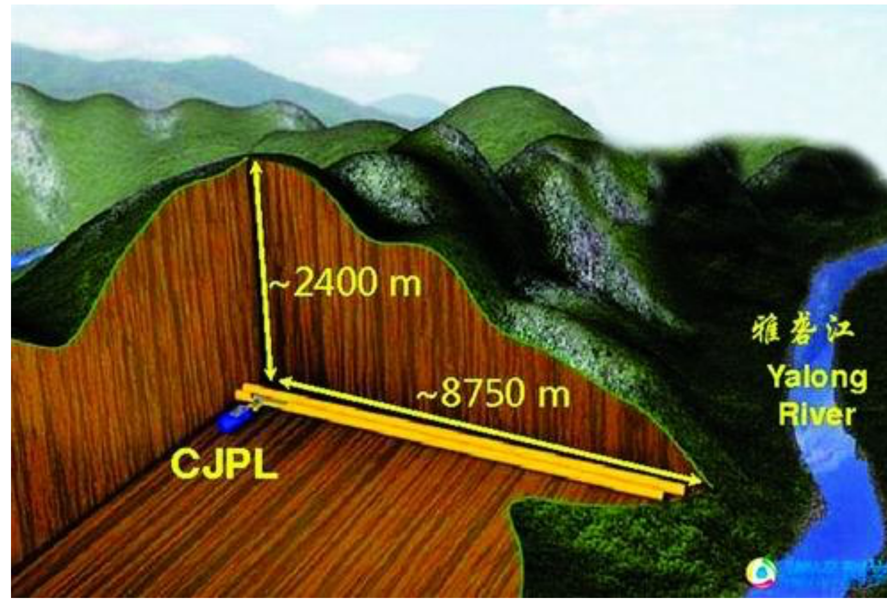


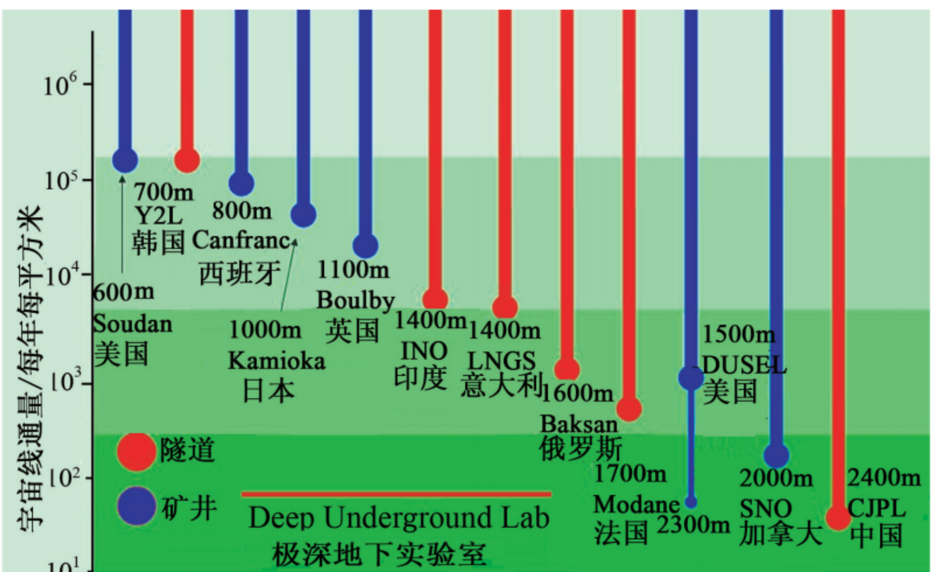


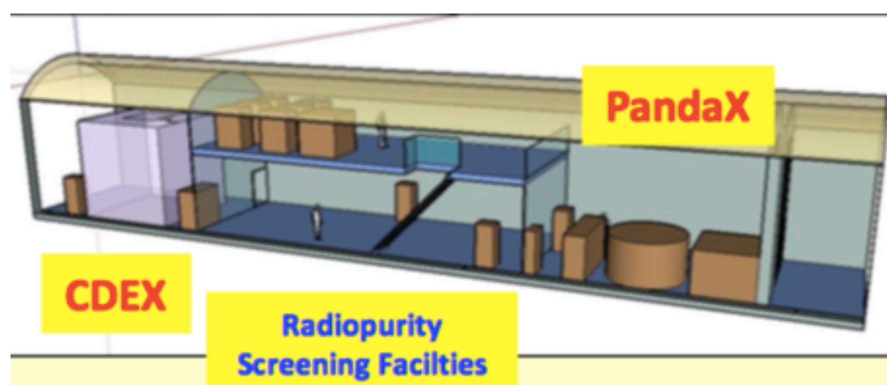
China Jinping Underground Laboratory

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





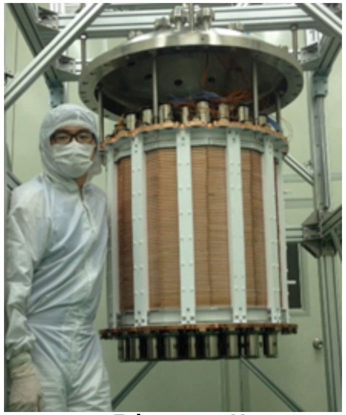




PandaX Experiment

- **Particle and Astrophysical Xenon** Experiments
  - Formed in 2009, ~50 people
- PandaX-II 580kg results published at PRLs
  - **World-leading exclusion limit**
- Future: PandaX-xT multi-ton DM experiments

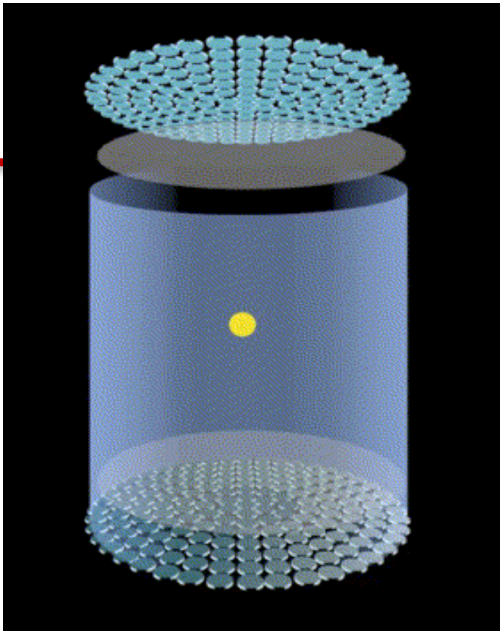
Phase I:
120 kg DM
2009-2014

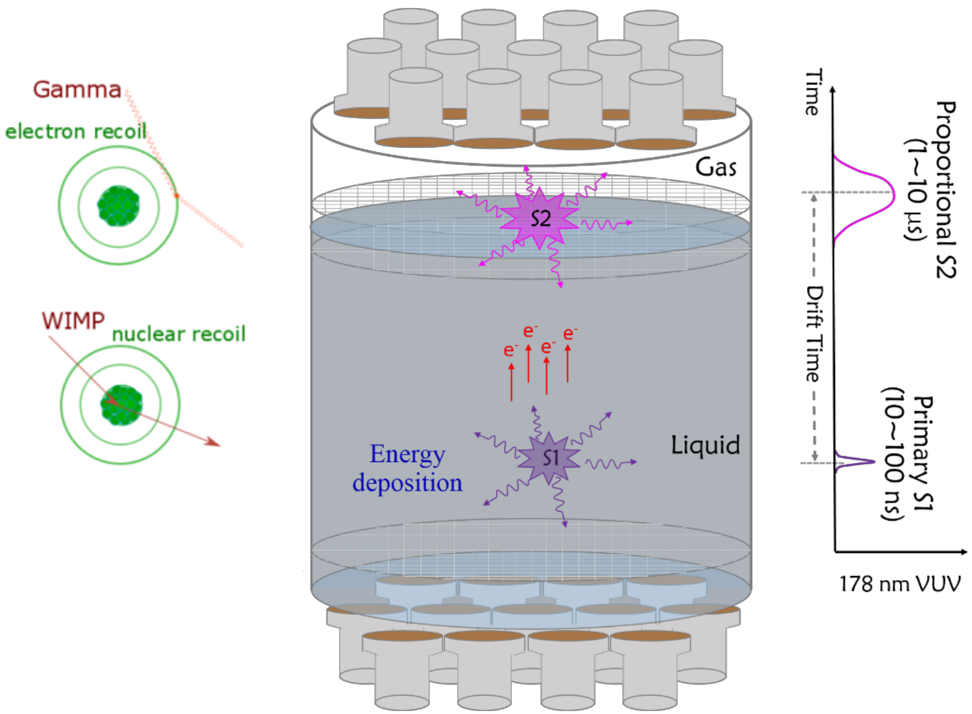


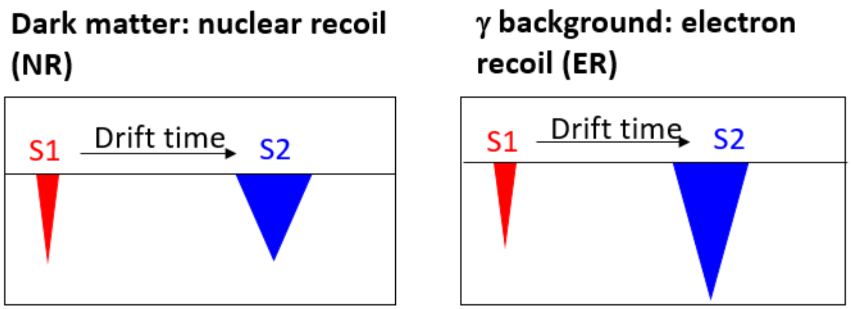
Phase II:
500 kg DM
2014-2018

PandaX-II: Dual-phase Xenon TPC

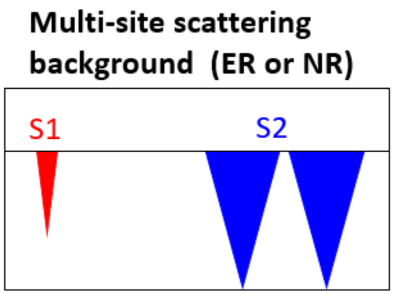
- Dark matter detection in Xenon detector
- Incoming DM collide with Xenon atom
  - S1： scintillation light in LXe upon scattering
  - S2： scintillation light in GXe due to ionized electron
- Reconstruct collision energy and 3-D position



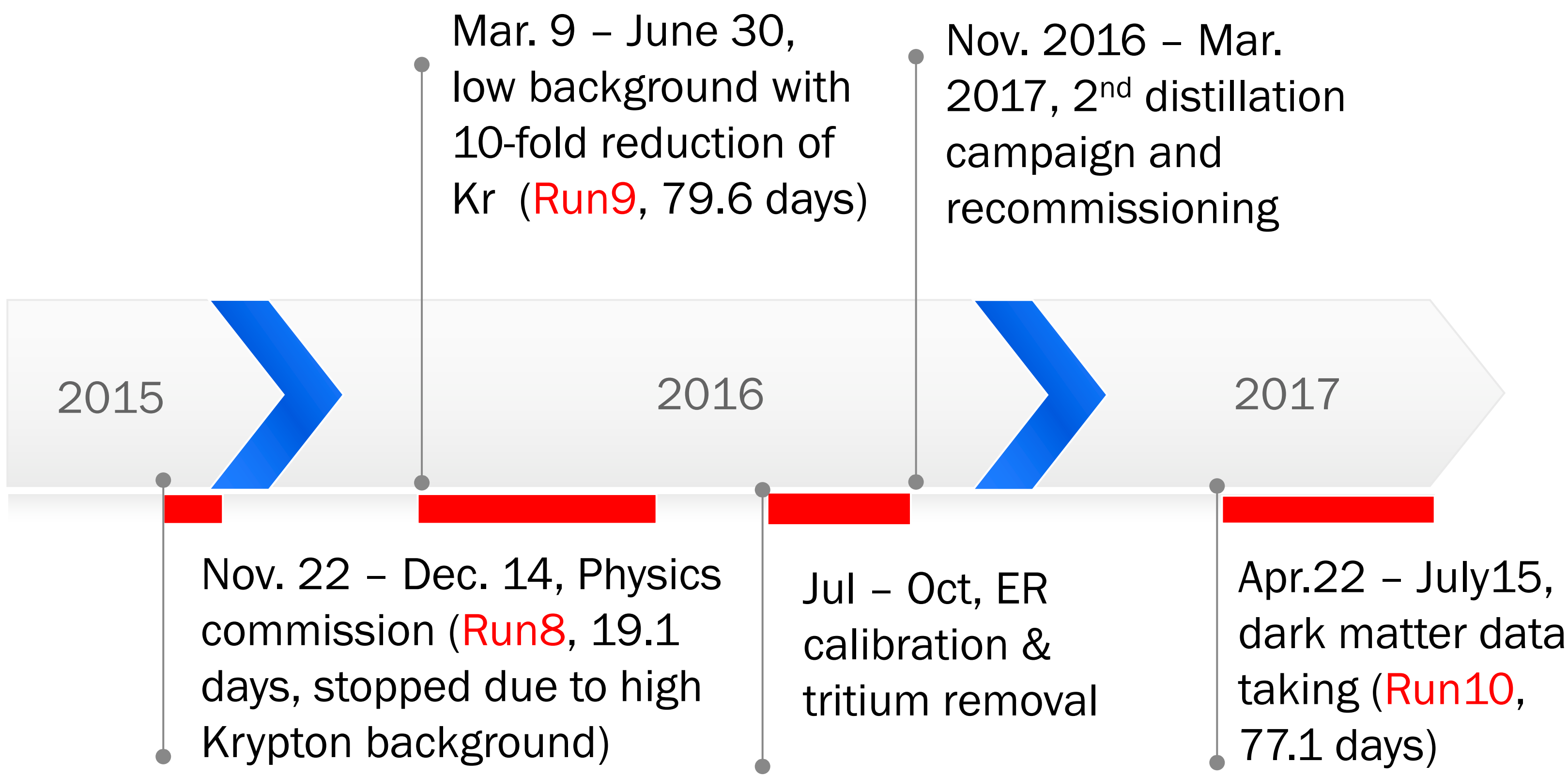




$(S2/S1)_{NR} << (S2/S1)_{ER}$



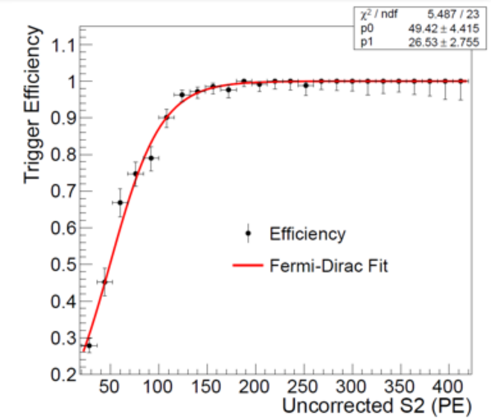
PandaX-II run history



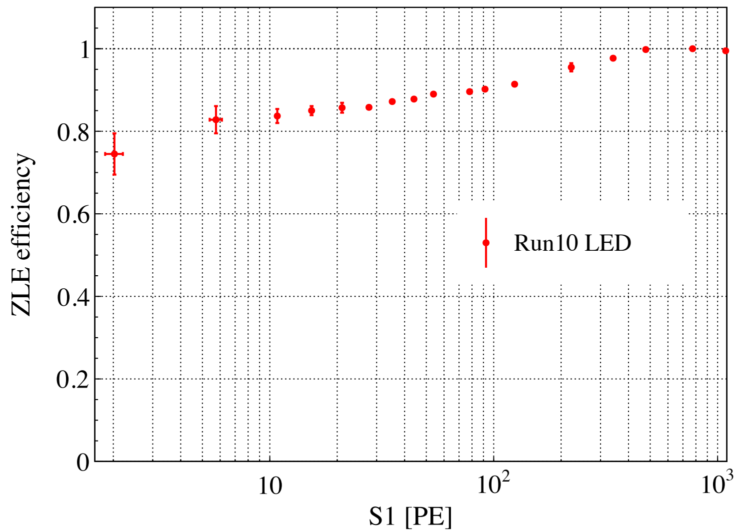
- Run9 =79.6 days, exposure: 26.2 ton-day
- Run10 = 77.1 days, exposure: 27.9 ton-day
- Largest reported DM exposure to date

Improvement since PandaX-II 2016 results

- Run 9 + Run 10: exposure doubles
- FPGA-based trigger
  - real-time programmable noise rejection algorithm
  - lowering the trigger threshold
- Channel-by-channel SPE efficiency (ε_{ZLE})
  - Average efficiency at S1 threshold ~80%
- Improved detector ER/NR response model
  - Calibration
- 2.5 times reduction in background
  - Kr85 ↓ 6 times
  - Accidental ↓ 3 times
  - Xe127 ↓ 20 times

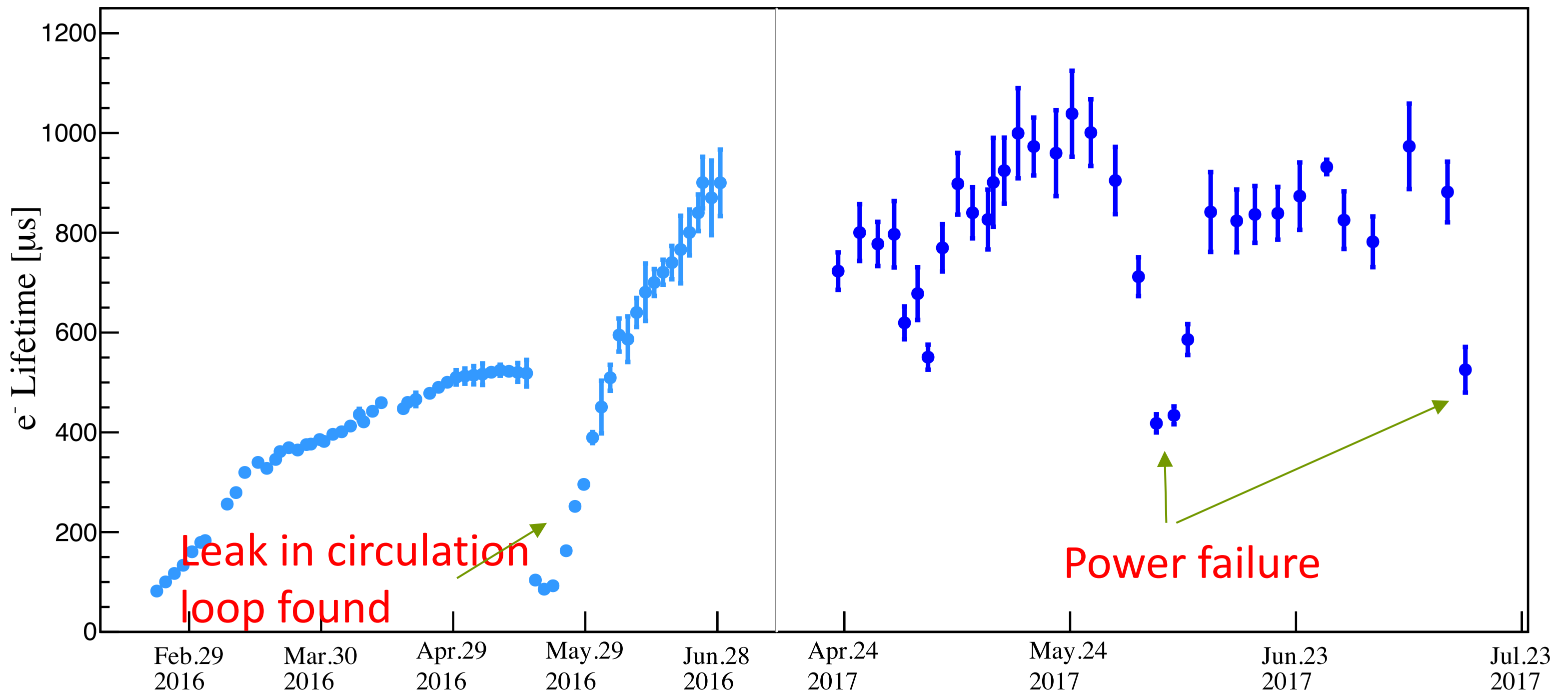


JINST 12 (2017) no.08, T08004

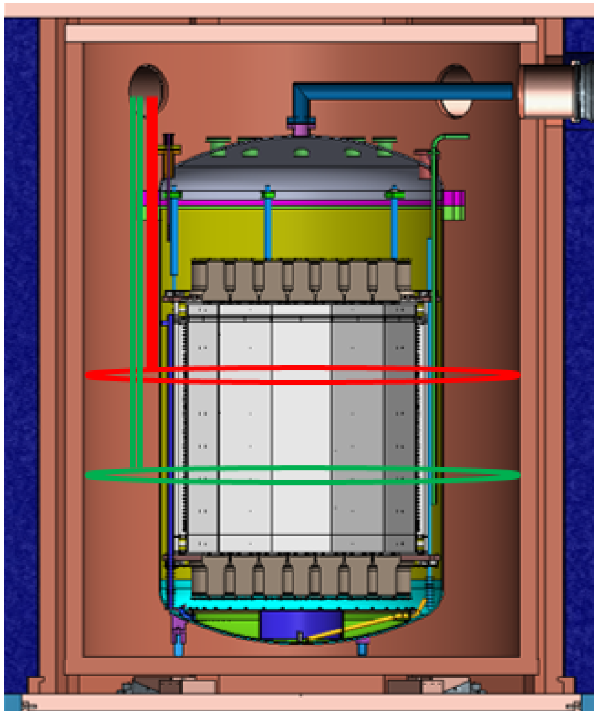


Electron Lifetime

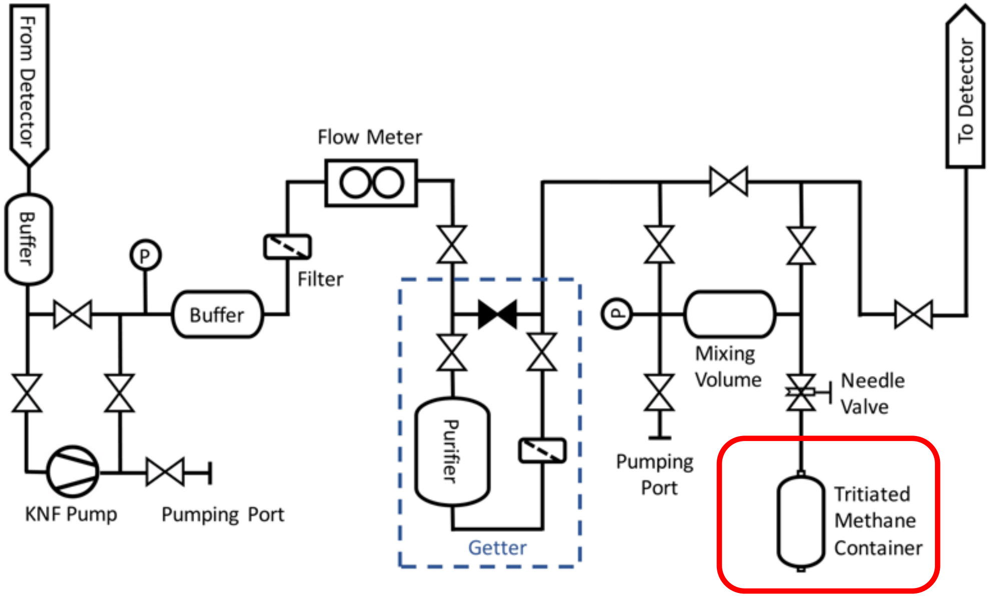
- Electron lifetime on average 800 μs (1.4 m drift distance) in Run 10, and generally stable
- Significantly improved from Run 9

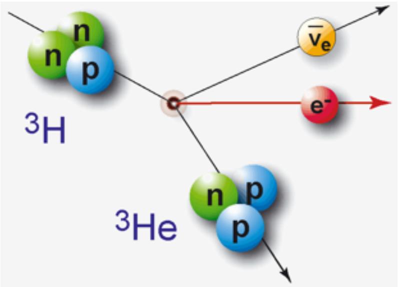


Calibration



Neutron calibration: AmBe source deployed (Energy spectrum measured in Daya Bay detector)

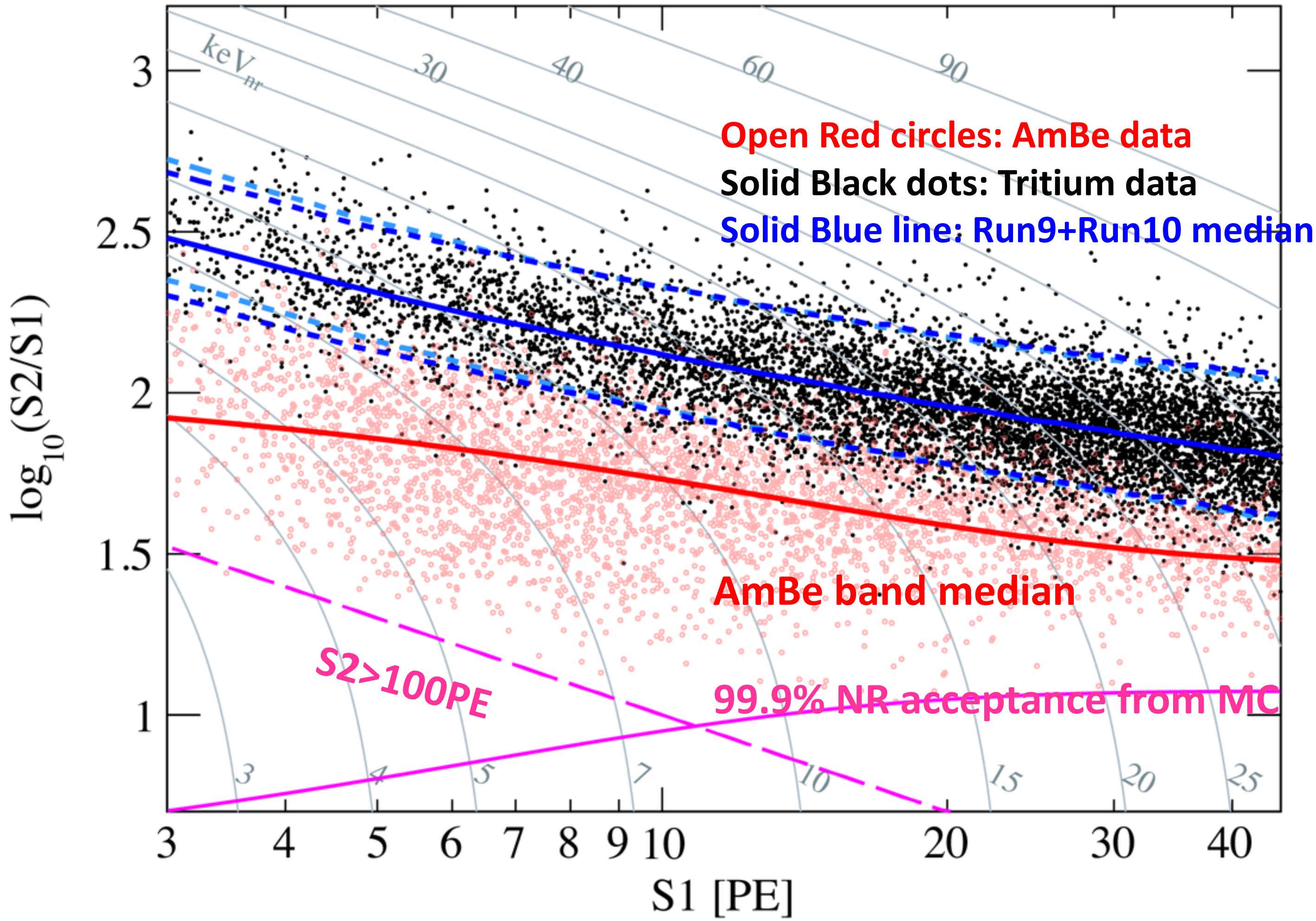




ER calibration using tritiated methane (pioneered by LUX)

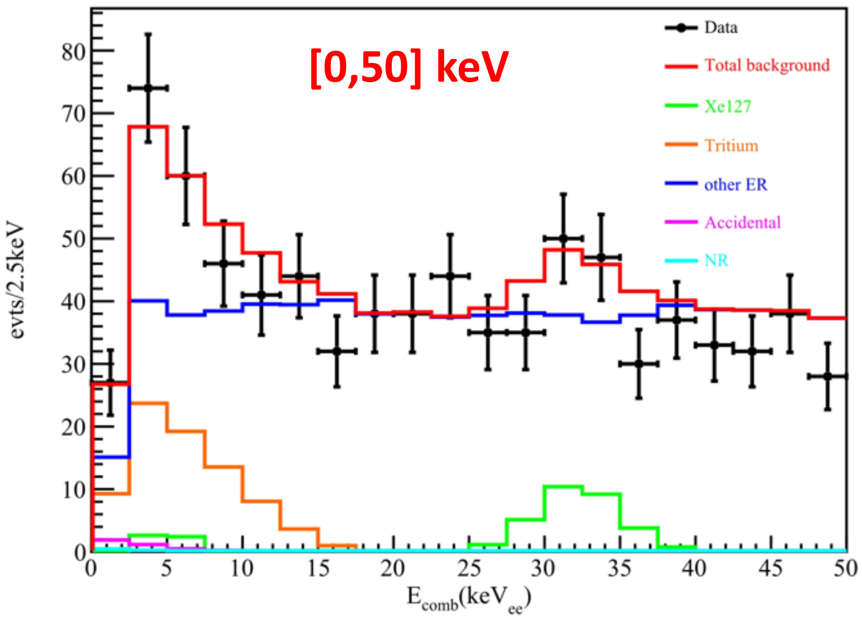
Selected data with electron lifetime ~700 μs, ~8000 low energy ER events

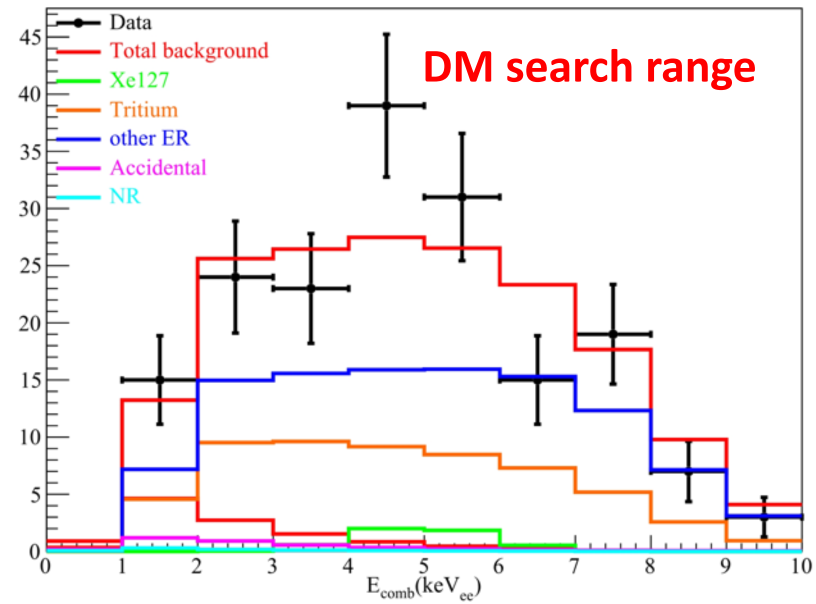
NR & ER data



Events leaked below the NR median: 0.53(8)%

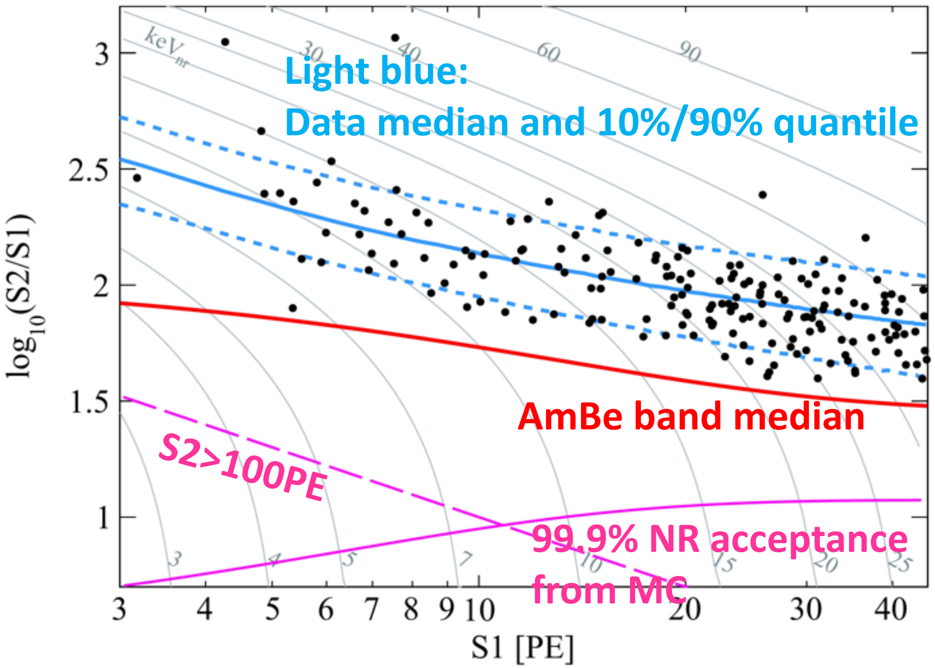
Energy spectrum in Run 10





Data and expected background in good agreement

Distribution of events (run10)

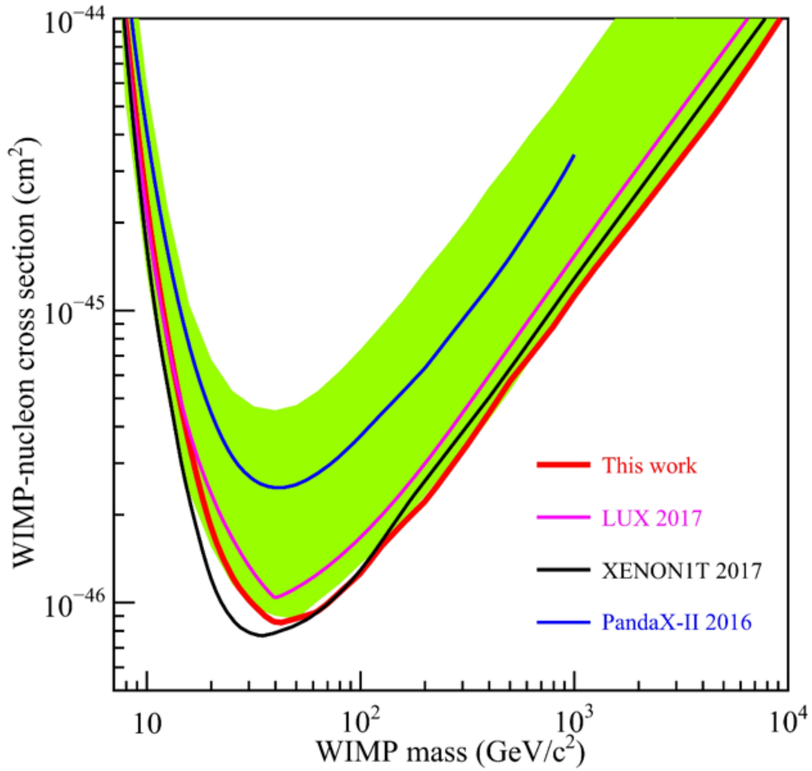


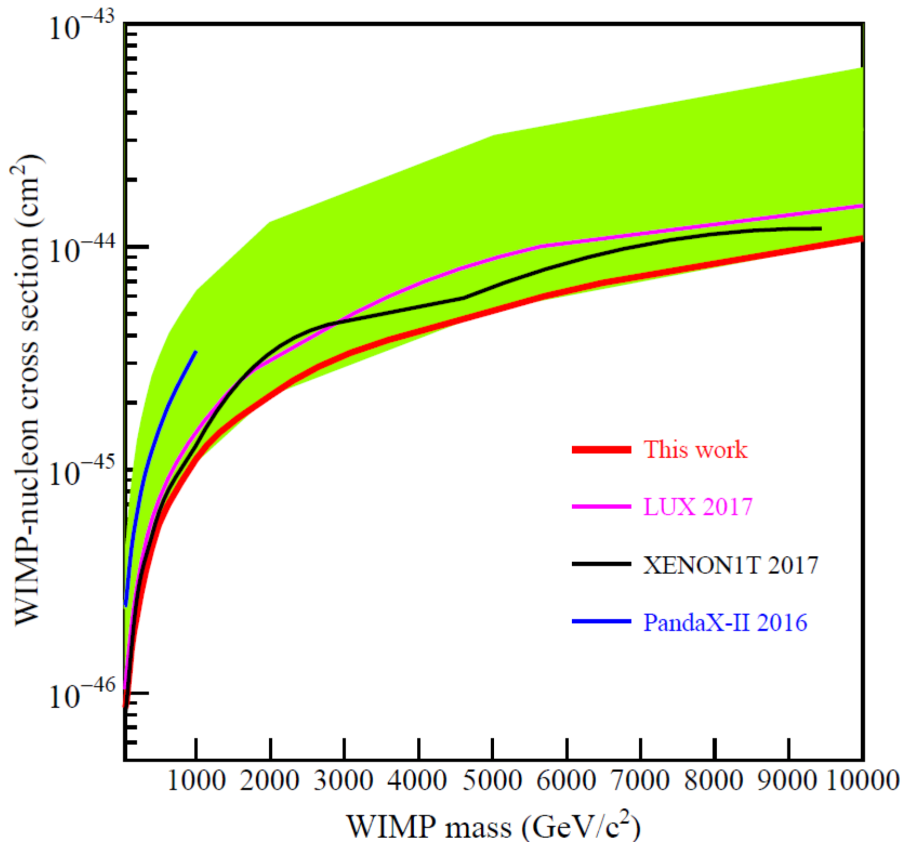
	ER	Accidental	Neutron	Total Fitted	Total Observed
Run 9	376.1	13.5	0.85	390 ± 50	389
Below NR median	2.0	0.9	0.35	3.2 ± 0.9	1
Run 10	172.2	3.9	0.83	177 ± 33	177
Below NR median	0.9	0.6	0.33	1.8 ± 0.5	0

- Total events: 177
- Expected background below NR median: 1.8±0.5 evts
- Observed: 0
  - Appears to have a downward fluctuation of background (p value 7% for run9+10)

SI WIMP (Run9+Run10)

PRL 119, 181302 (2017)



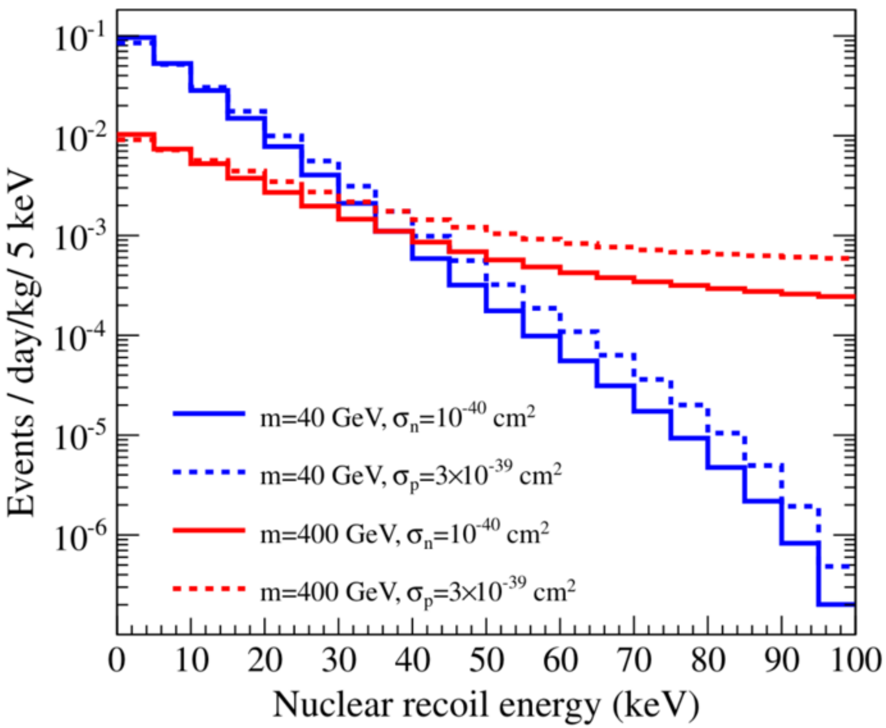


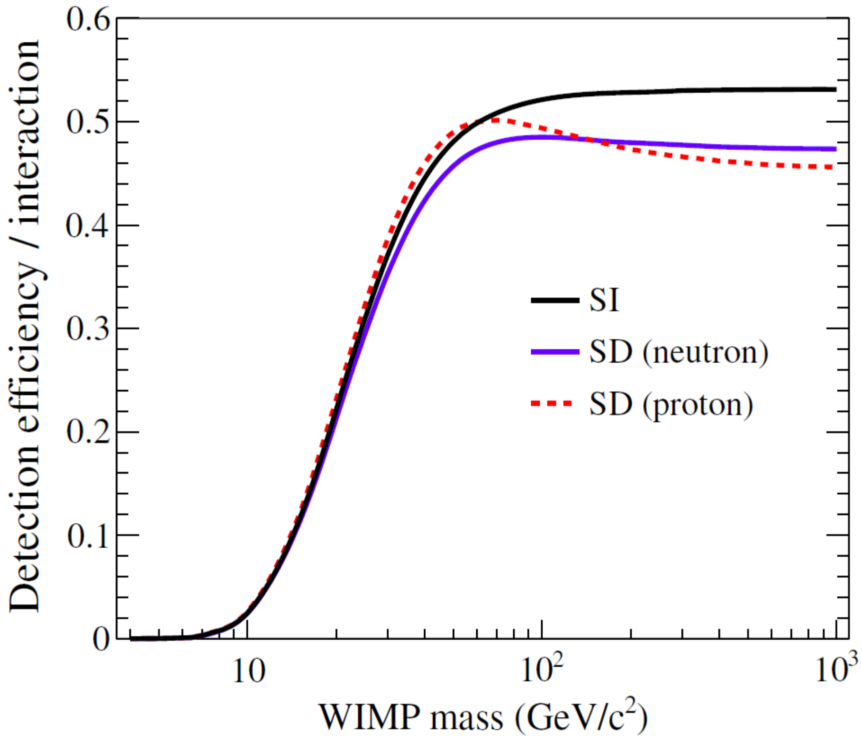
- Improved from PandaX-II 2016 limit about 2.5 time for mass>30 GeV
- Lowest exclusion at 8.6$\times 10^{-47}$cm^2 at 40GeV/c^2
- Most stringent limit for WIMP-nucleon cross section for mass >100GeV

Spin Dependent WIMPs

$$\sigma^A_{p,n}(q) = \frac{4\pi\mu^2 S_{p,n}(q)}{3(2J+1)\mu^2_{p,n}}\sigma_{p,n}$$

Only ^{129}Xe (J =1/2) and ^{131}Xe (J =3/2) are sensitive to the SD interaction.

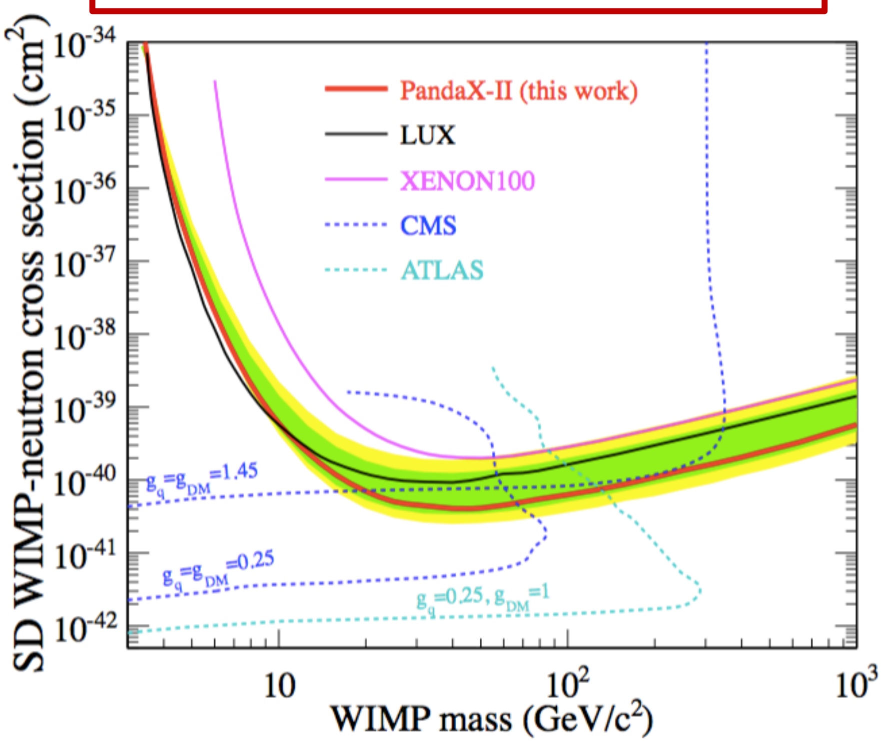


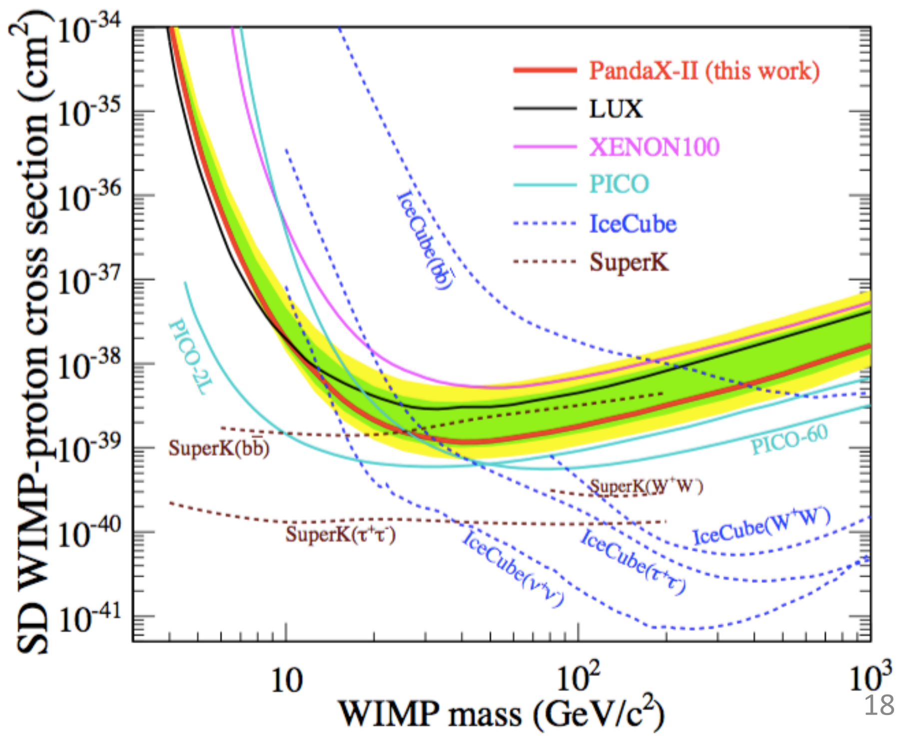


SD WIMP (Run8+Run9)

- Spin-dependent WIMP-nucleon scattering
- 3.3×10^4 kg-day exposure
- Constraints at 4.1×10^{-41} cm^2 on WIMP-neutron for 40 GeV WIMP

Phys. Rev. Lett. 118, 071301 (2017)

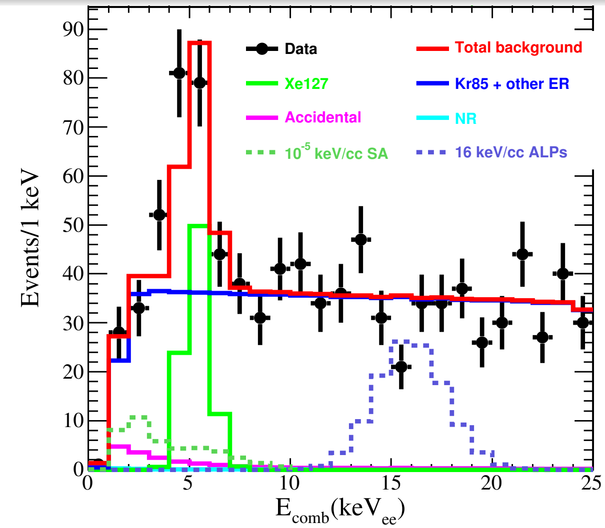




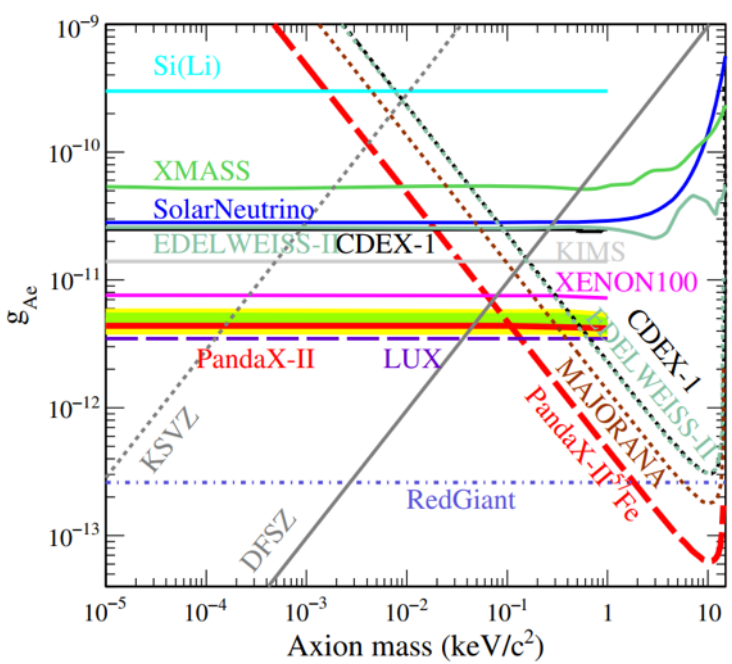
Axion (Run9)

- Solar Axion and Axion-like Particles
- ER signal, E < 25 keV_{ee}
- Leading upper limits are set, paper is being prepared.

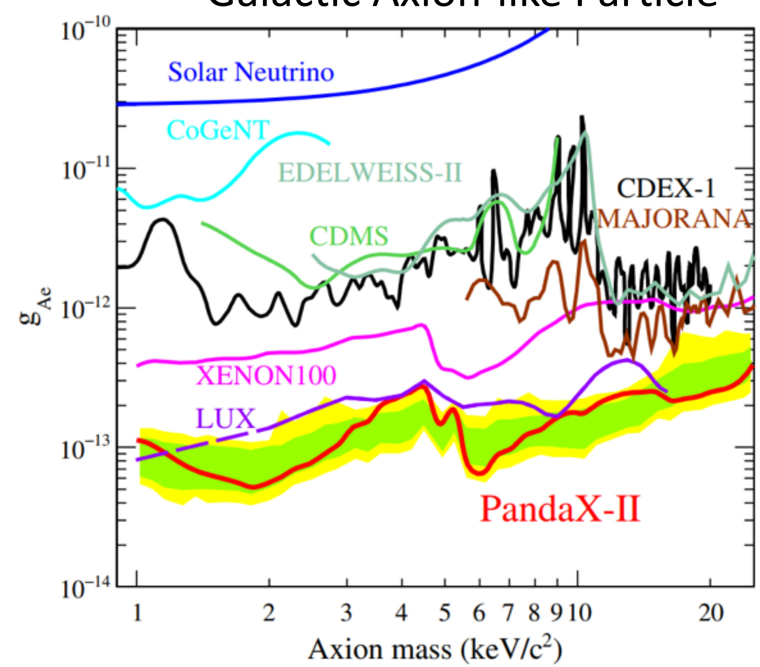
Phys. Rev. Lett. 119, 181806 (2017)



Solar Axion



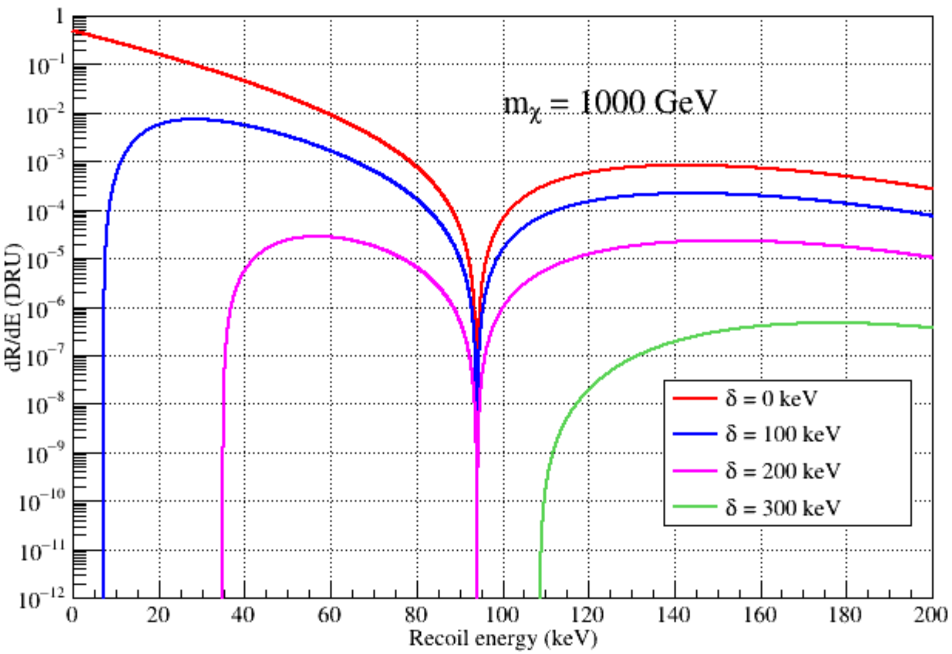
Galactic Axion-like Particle



Inelastic scattering

- Mass splitting δ between two different state of WIMPs
- Limited phase space due to the minimal velocity

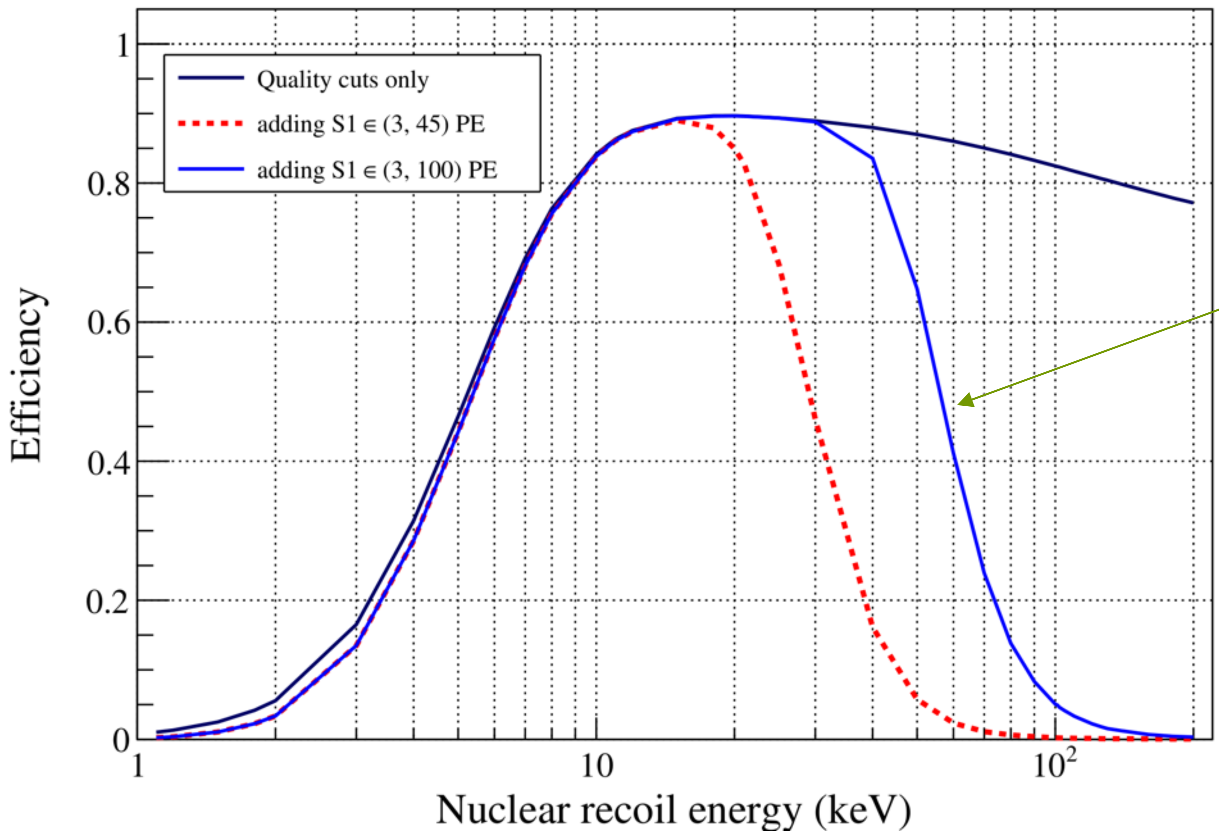
$$v_{\min} = \frac{1}{\sqrt{2E_R m_N}} \left(\frac{E_R m_N}{\mu} + \delta \right)$$



- The signal rate decreases with the increasing of the mass splitting.
- Minimal recoil mass exists.
- Signal band moves to higher energy region with the increasing of mass splitting.

Detection efficiency for Inelastic Scattering

- Expand the S1 signal window to (3, 100) PE.
  - 68.6 keV_{nr} (18.3 keV_{ee})



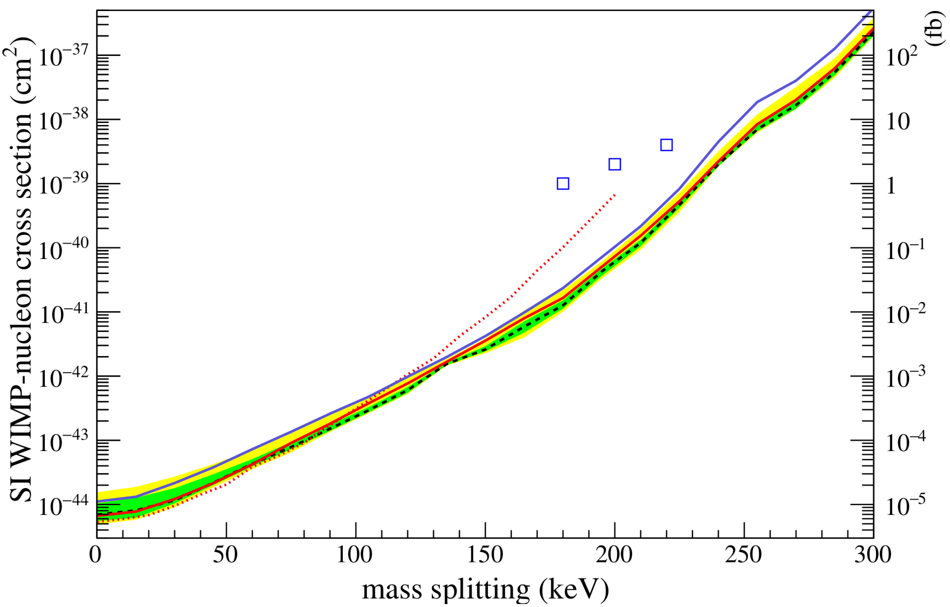
Better efficiency for high energy event with the expansion of signal window.

Inelastic (Run9)

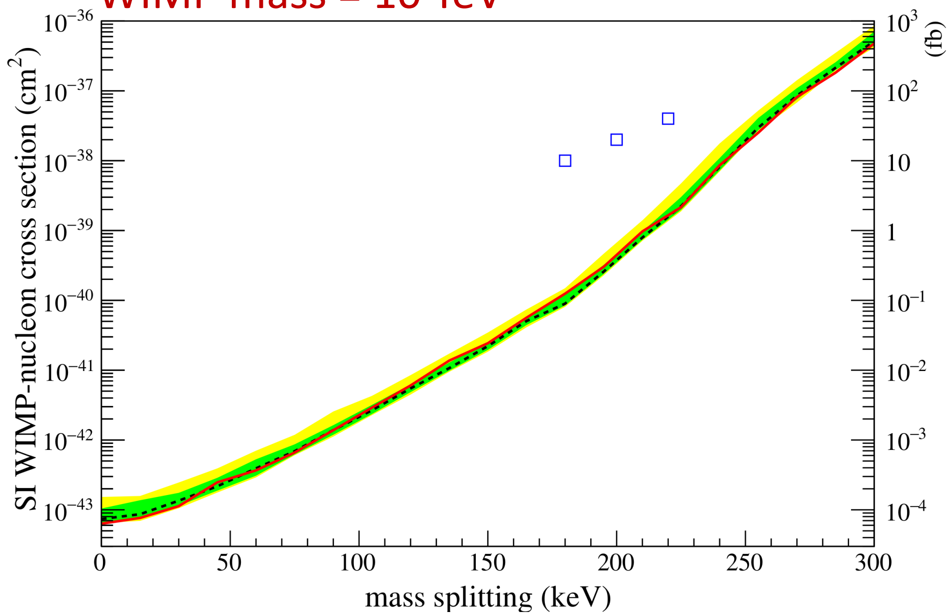
- Inelastic DM beyond 1TeV in mass

Squares from the interpretation of the CRESST high recoil energy events.

WIMP mass = 1 TeV



WIMP mass = 10 TeV



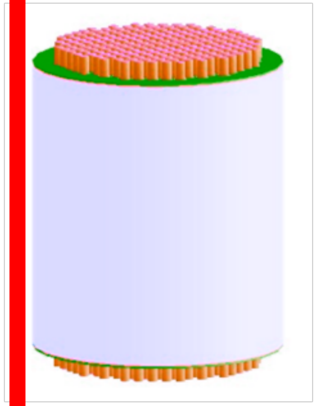
Phys. Rev. D96, 102007 (2017)

PandaX – in Future

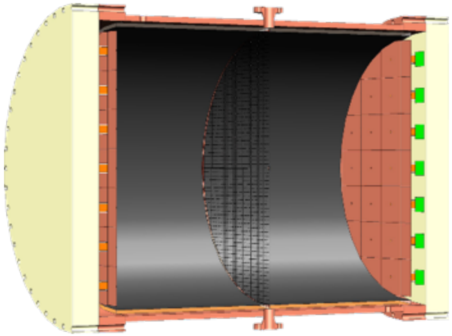
- PandaX-4T for DM search
- PandaX-III for 0vbb search

PandaX-I: 120 kg DM experiment 2009-2014

PandaX-II: 500 kg DM experiment 2014-2018



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



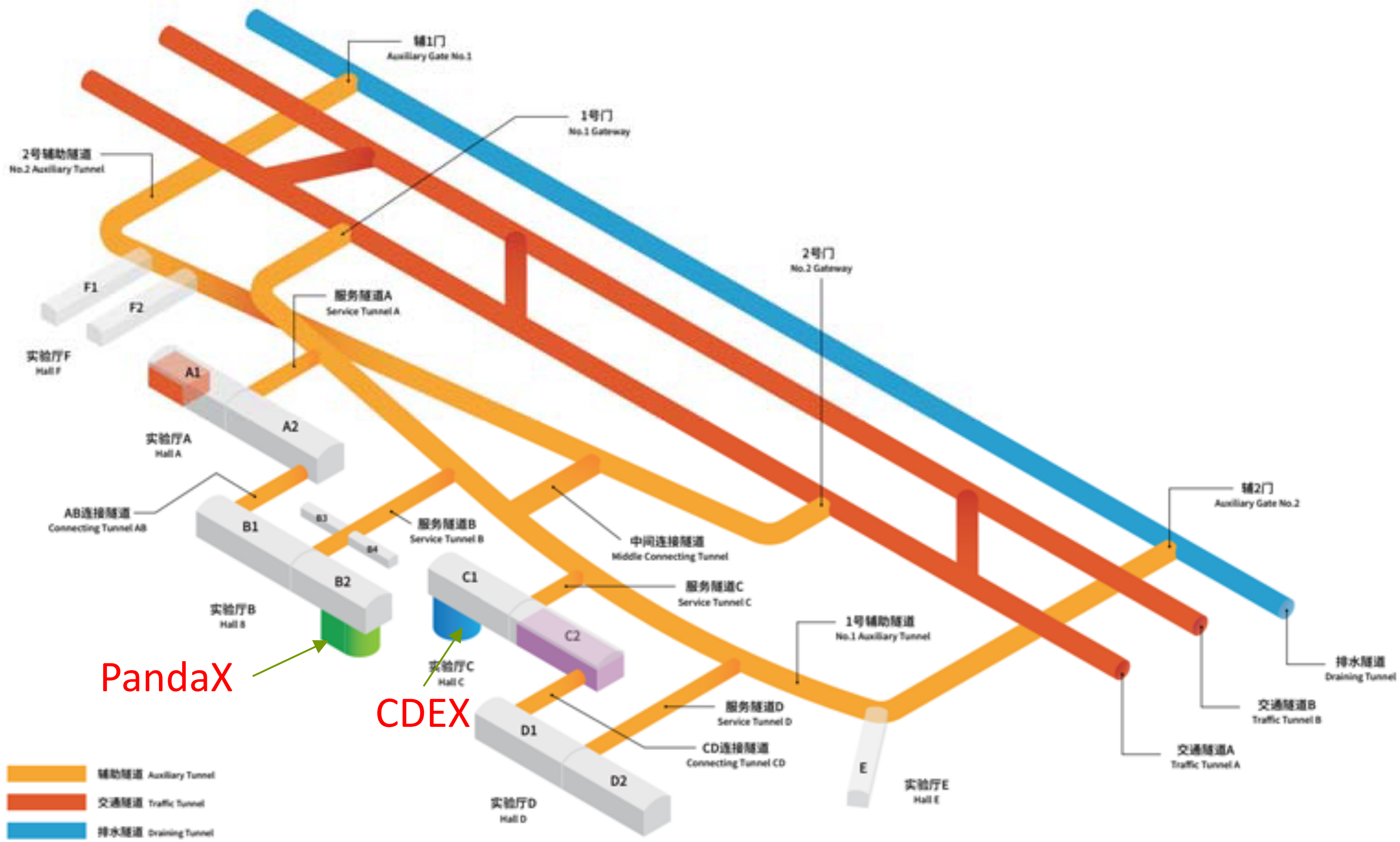
PandaX-III: 200 kg to 1 ton HP gas ^{136}Xe 0vDBD experiment Future

CJPL-I

CJPL-II

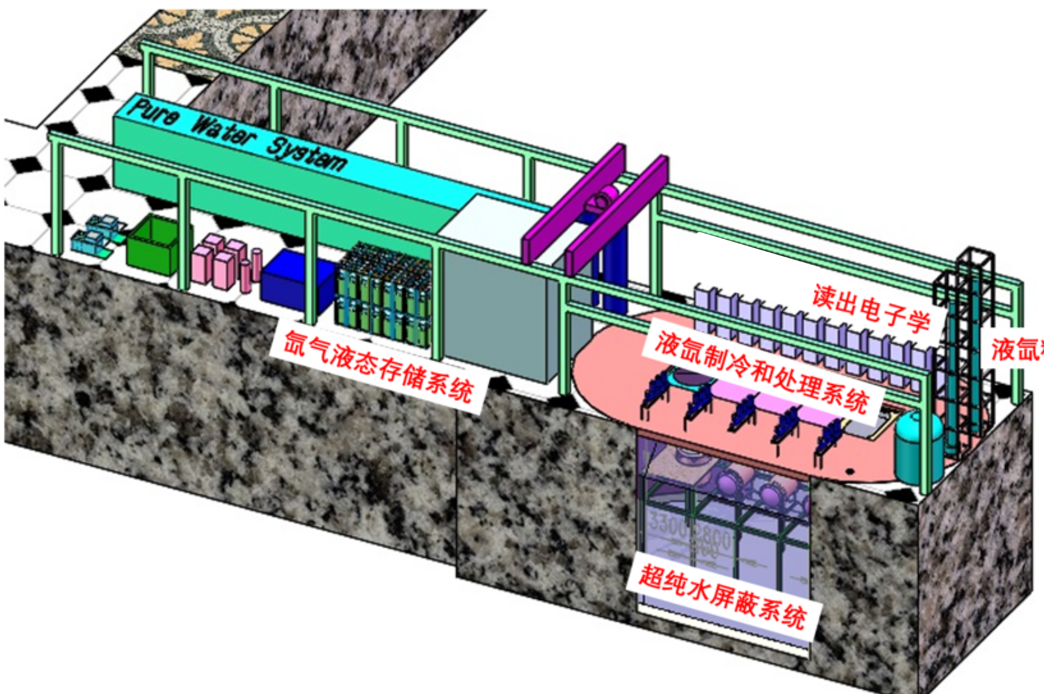
CJPL-II

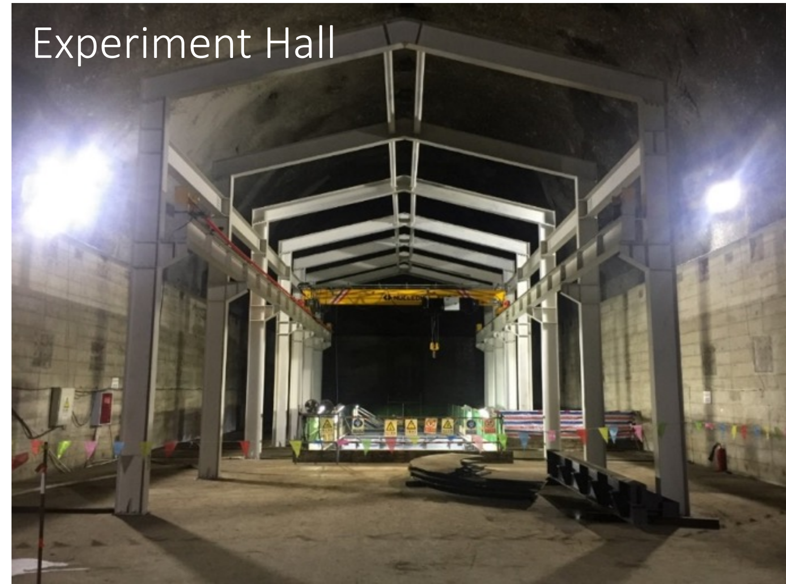
- 8 experimental Halls, 14(H)x 14(W)x65(L) m each.
- Dark matter, 0vDBD, nuclear astrophysics, low background experiments

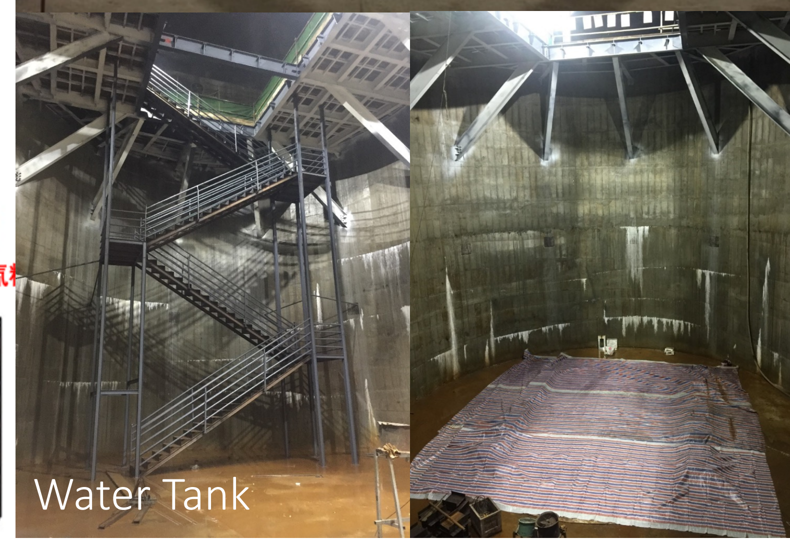


New Experiment Hall at CJPL-II

- Water Shielding
  - 5000Ton pure water
  - U/Th <10^{-14} g/g
- Rn ctrl.
  - <1mBq/m^3 in water;
  - ~10Bq/m^3 in the cave
- Fresh air

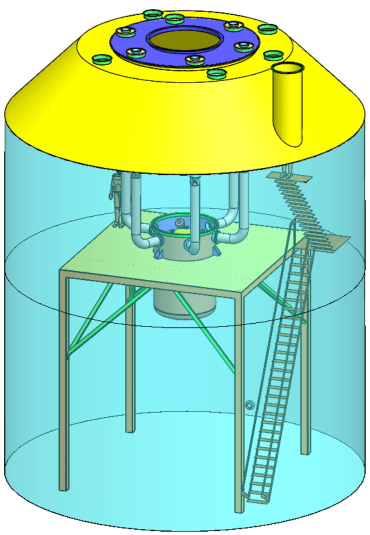


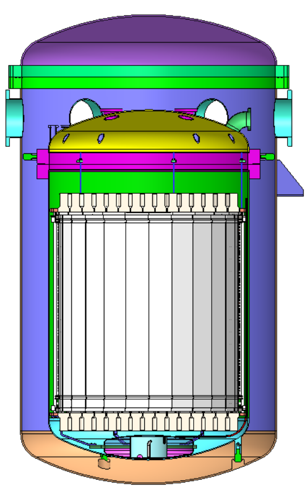


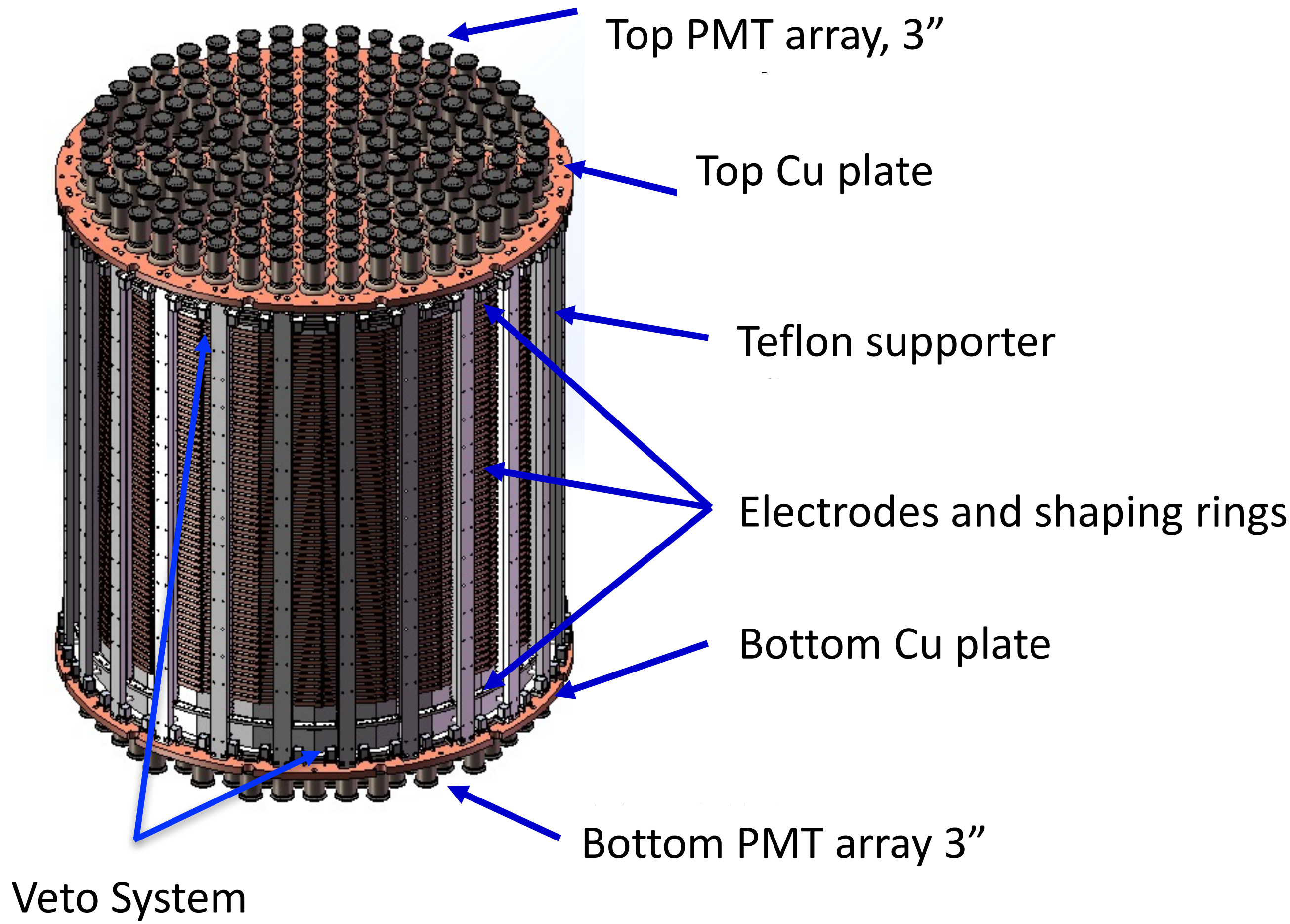


PandaX-4T

- Drift region: Φ ~1.2m， H ~1.2m
  - Xenon in sensitive region ~4ton







R&D in progress

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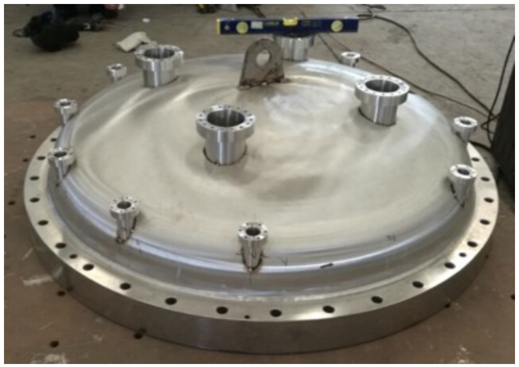
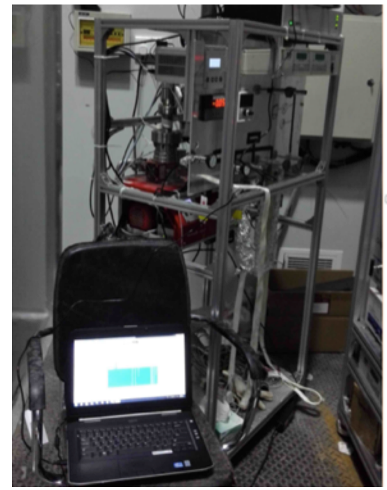
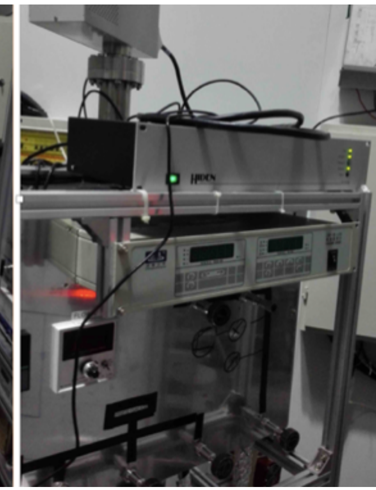
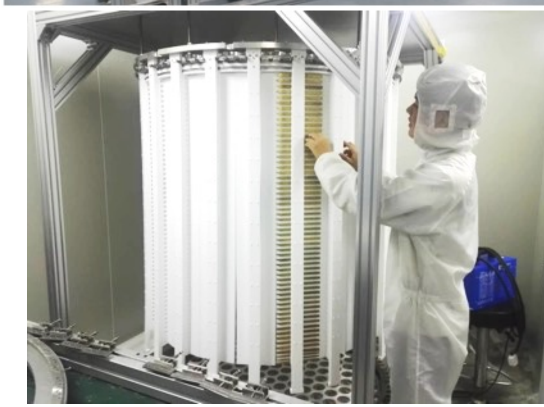
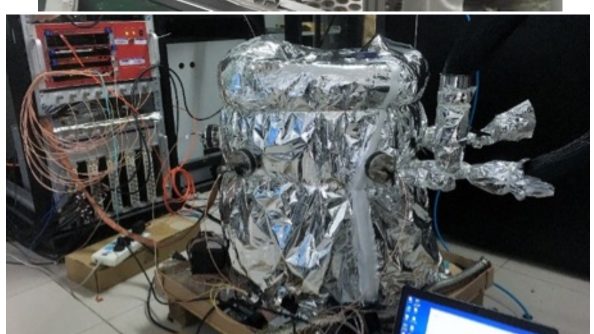
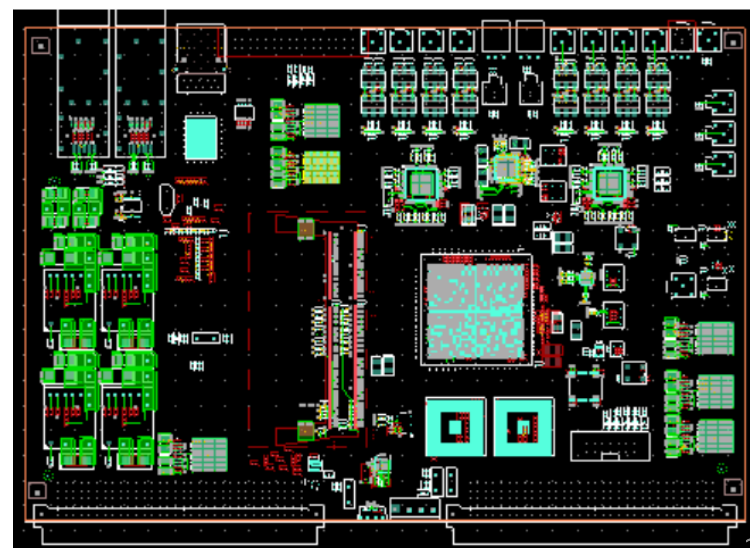
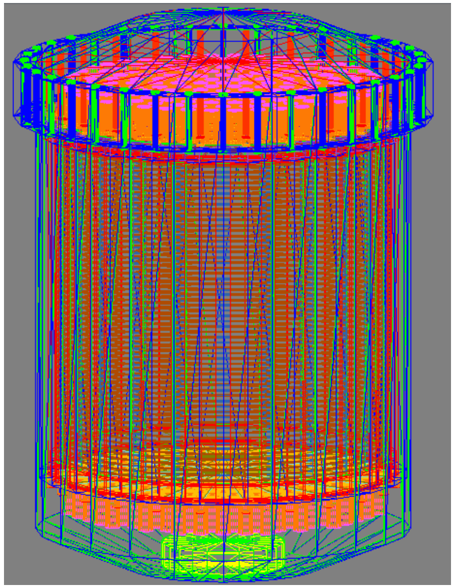


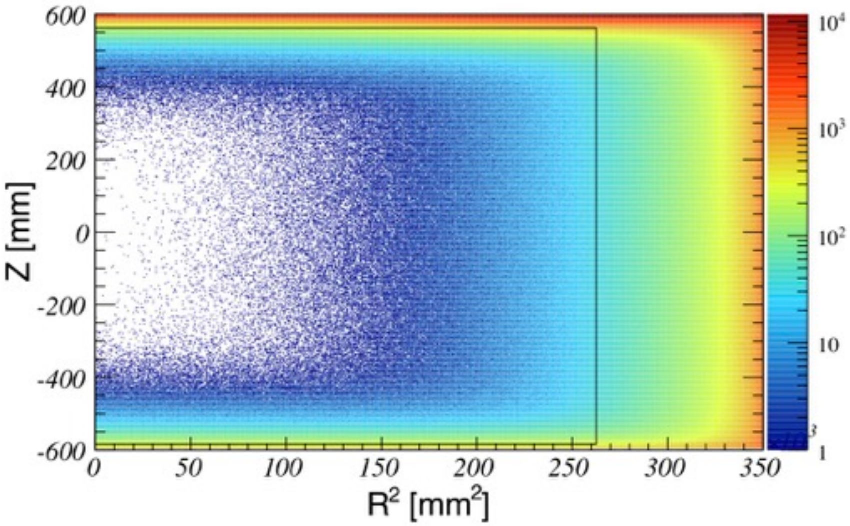




Background Simulation

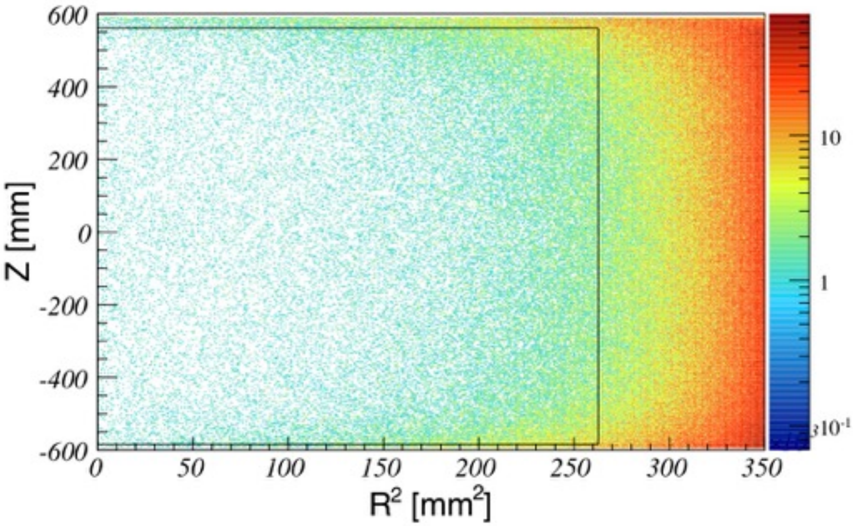
- **Simulate the ER and NR backgrounds**
  - Detector materials: inner/outer vessels, flanges, copper plates, electrodes, PTFE materials, PMTs etc
  - Radioactivity in xenon: ^{85}Kr, ^{222}Rn, ^{136}Xe
  - Neutrino: electron scattering and coherent nucleus scattering



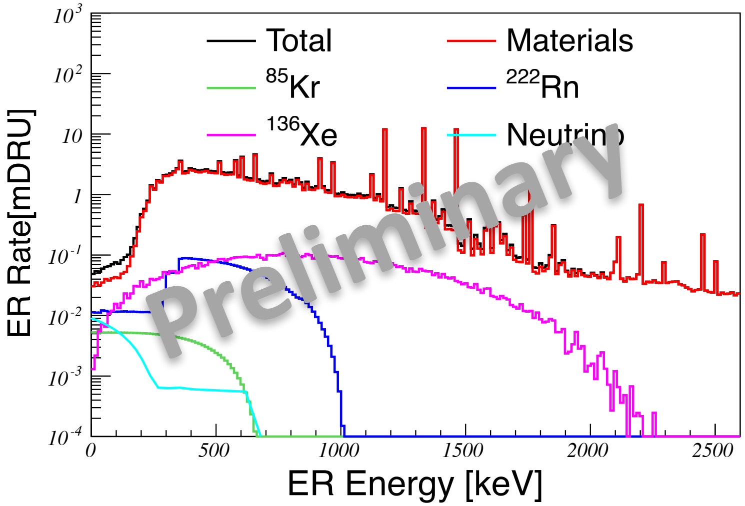
ER from materials



NR from materials



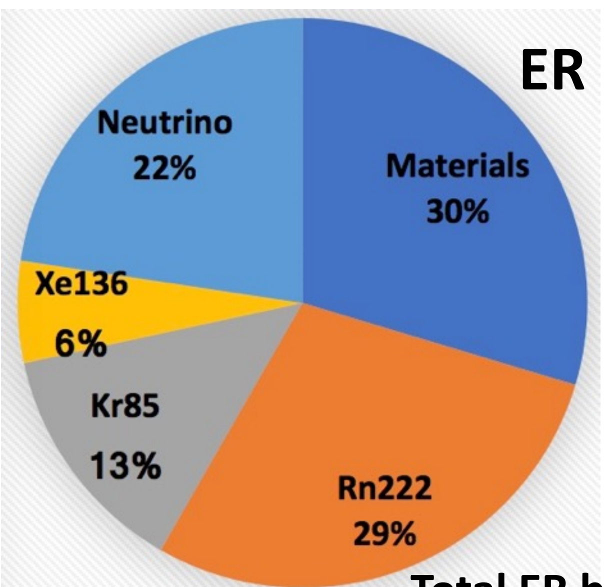
Background Simulation

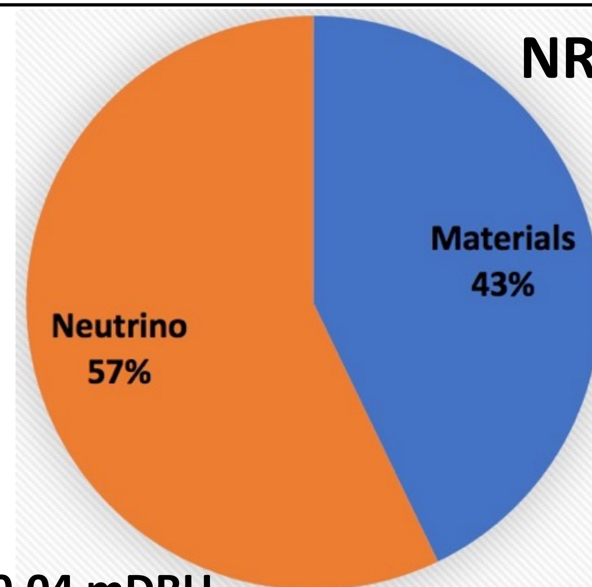


Assuming ^{nat}Kr ~ 0.1 ppt, ^{222}Rn ~1 μBq/kg

Dark Matter Background with Veto		
Source	ER in mDRU	NR in mDRU
Materials	0.0118±0.0021	0.00006± 0.00006
^{222}Rn	0.0114±0.0012	-
^{85}Kr	0.0053±0.0011	-
^{136}Xe	0.0023±0.0003	-
Neutrino	0.0090±0.0002	0.00008± 0.00004
Sum	0.040 ±0.003	0.00014± 0.00007
2-year yield	832.2± 62.4	2.9±1.5
after selection	2.1±0.2	1.2±0.6

Preliminary



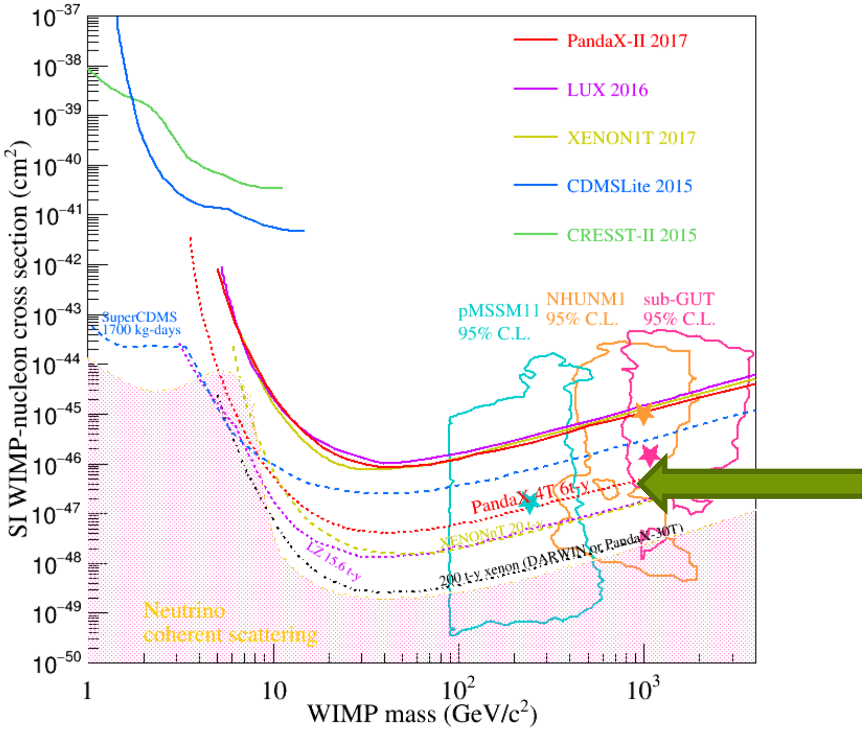


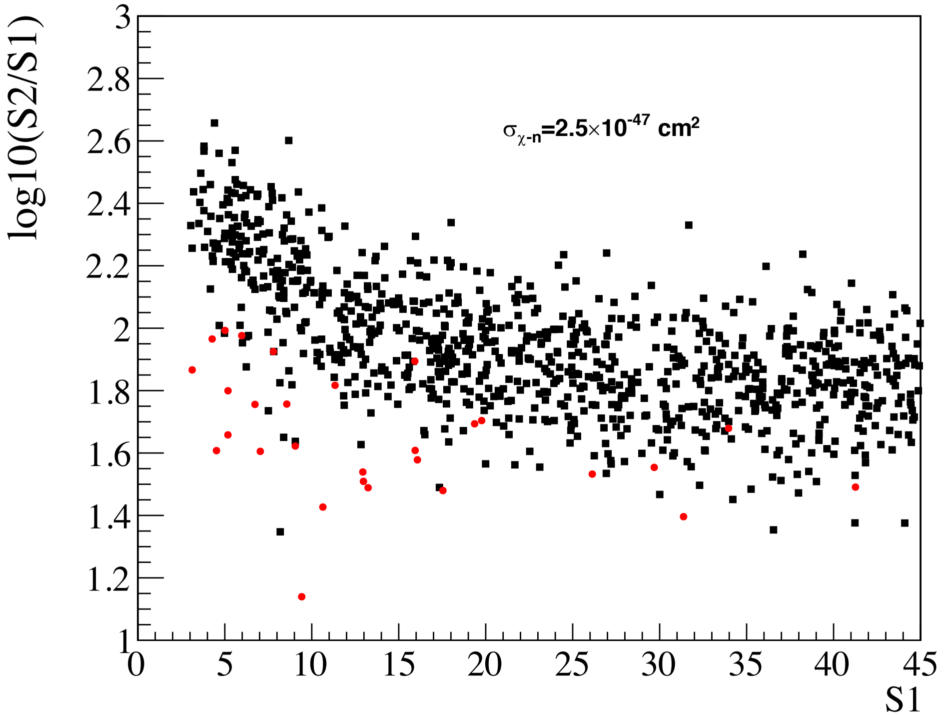
Total ER background: 0.04 mDRU

Total NR background: 0.5 event / ton / year

Expected Sensitivity

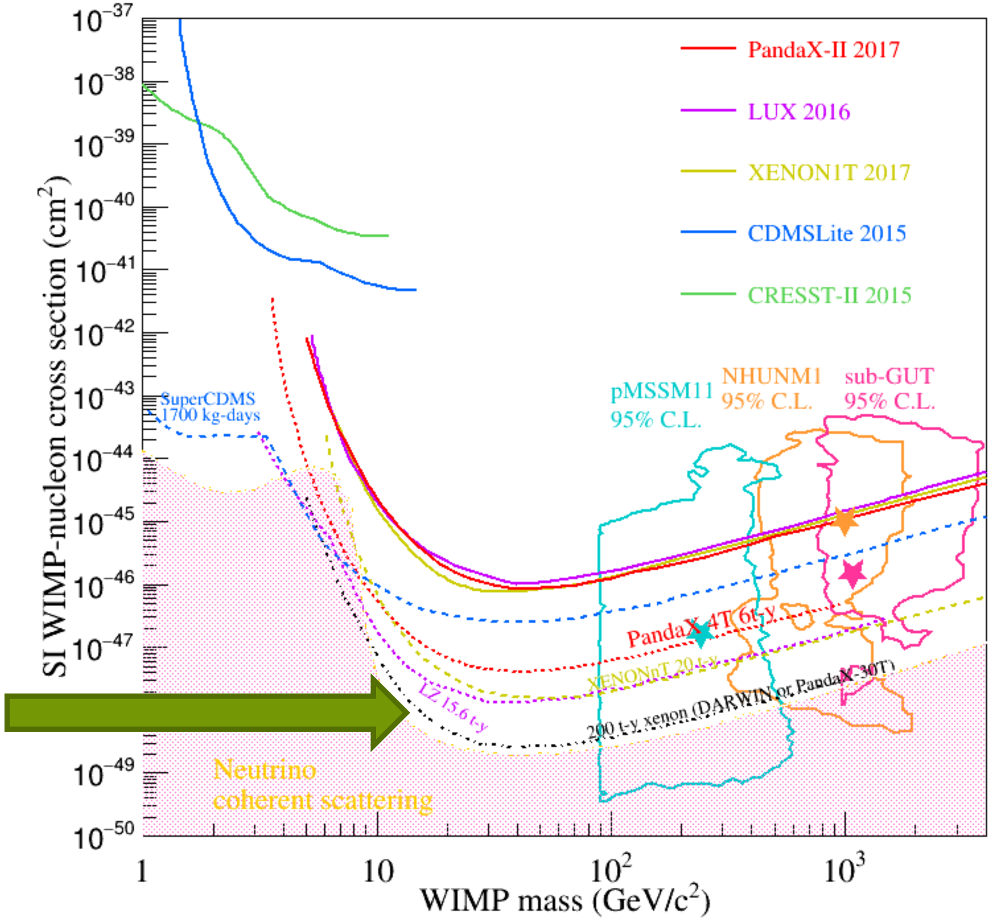
- With exposure reaching **6 ton-year**
- DM SI sensitivity could reach ~10^{-47}cm^2



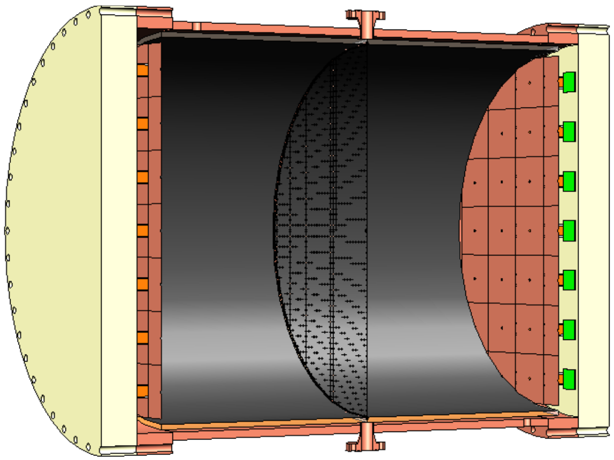


PandaX-30T

- To reach the neutrino floor with **200 ton-year exposure**
- Diameter 2.4m, Height 2.4m
- Sensitive volume: **30 ton**



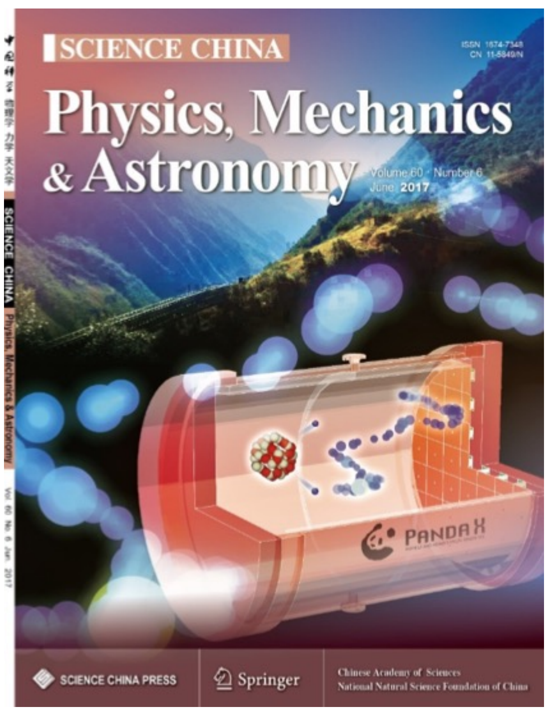
PandaX-III: in preparation



Looking for Majorana neutrino

Lepton number violation

200-kg High pressure Xe detector



Prototype detector in Lab

Summary and Outlook

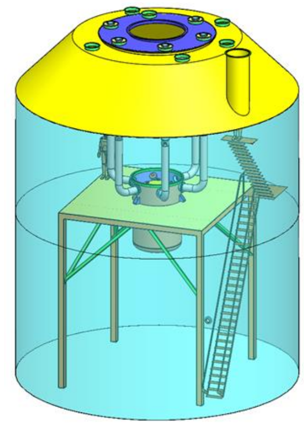
- PandaX experiment with 500kg Xenon has reached the world frontier of dark matter direct detection.
  - Limits on SI and SD WIMP-nucleon cross sections were obtained.
  - Limits on solar axion, galactic ALP and inelastic scattering were set recently.
  - PandaX-II continues data-taking smoothly.
  - More results are expected.

- We are in preparation for the future PandaX-4T program.

- **Thank you!**

Backup

Detector Material

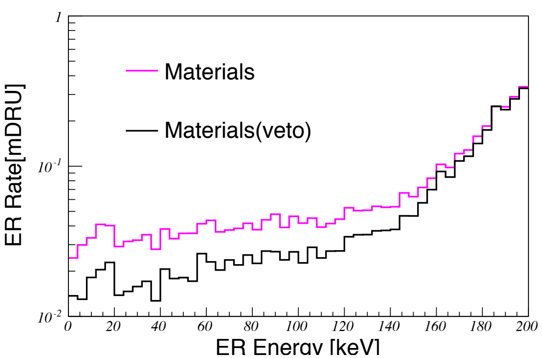


- **5m pure water shielding**
- **Low radioactive materials**
  - Obtaining the lowest ^{60}Co in SS

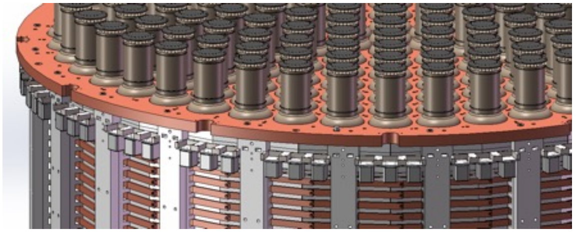
Collaborating with PKU

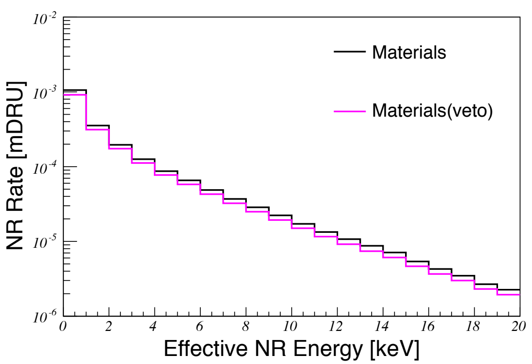
表 2 PandaX-II 压力容器钢板本底数据（mBq/kg），A 和 B 是两个样品，验证测量的可靠性，“<”是指灵敏度未到，这里仅列出上限

编号	^{226}Ra	^{228}Ac	^{228}Th	^{235}U	^{137}Cs	^{60}Co	^{40}K
A	<1.70	<2.74	<1.71	<2.43	2.36±0.9	1.03±0.75	<13.95
B	<1.9	<3.0	<3.4	<2.7	1.4±1.0	<0.7	<16.2



- **TPC veto facility**: ~140 1” PMTs
  - Assume 60 keV_{ee} veto threshold
  - 60% ER background, 15% NR background

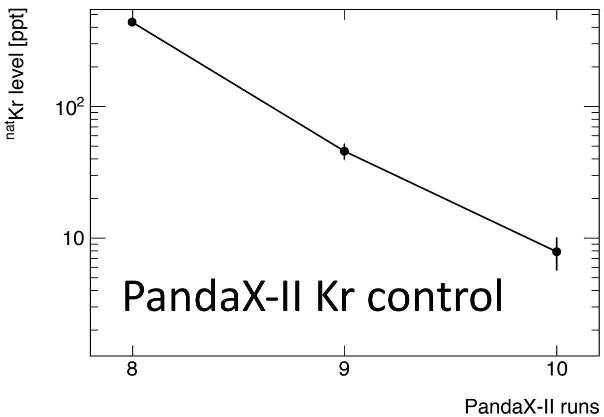




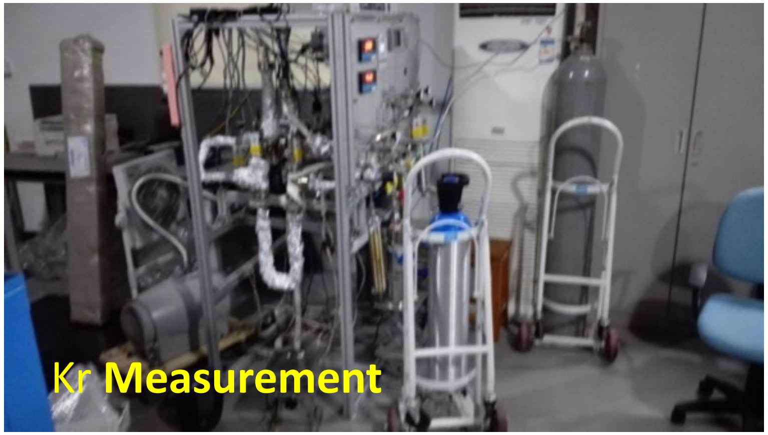
^{85}Kr Control

- ^{85}Kr could be a major background
- **Distillation is very effective in removing it**

PandaX-II	Run 8	Run 9	Run 10
Kr level	437 ± 13 ppt	44.5 ± 6.2 ppt	6.6 ± 2.2 ppt

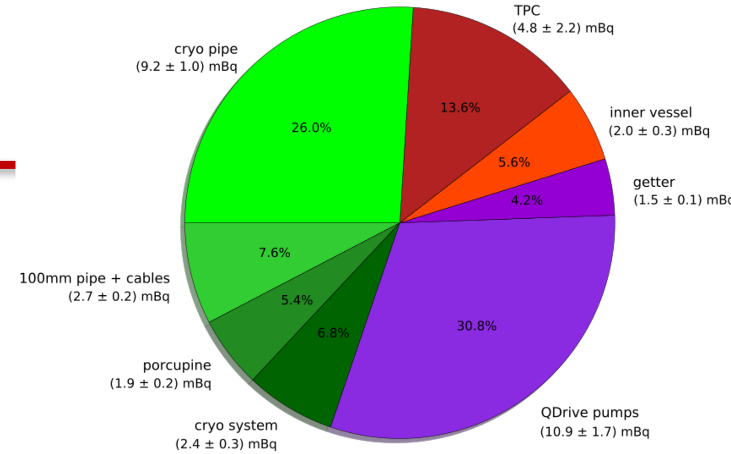


- Distillation tower at CJPL
  - Online distillation continuously -> ^{nat}Kr below 0.1 ppt
- ^{nat}Kr measurement system
  - To reach a sensitivity of 0.1-0.01 ppt



^{222}Rn Control

- Current level at PandaX-II: 8.6μBq/kg
  - Internal Rn emanation is primarily from the plumbing (warm section)
  - Consistent with findings from XENON1T
- PandaX-4T:
  - Plumbing length similar to PandaX-II
  - **The goal is to reach 1μBq/kg**
- To use Rn emanation measurement chamber to screen components
- Rn filtration/distillation plan in consideration



xenon1T Rn budget