PandaX-4T 液氙探测实验

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On behalf of PandaX Collaboration

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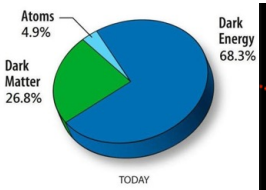
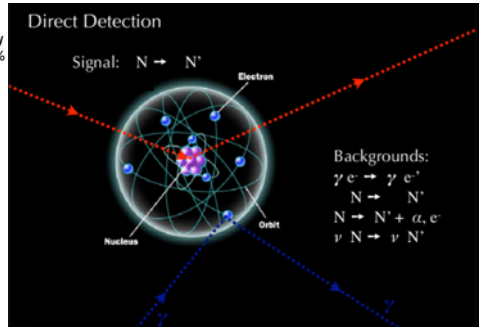
Outline

- Motivation
- PandaX experiment
- PandaX-4T Proposal
  - TPC
  - Electronics
  - Xenon handling
  - Background control
- Summary

Motivation

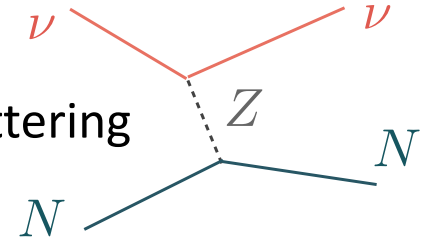
- LXe Detector for measuring rare physics events

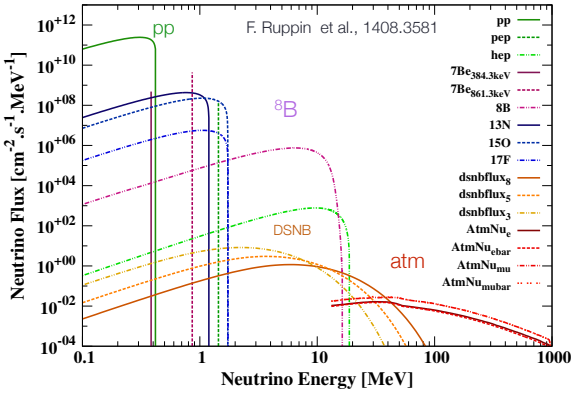




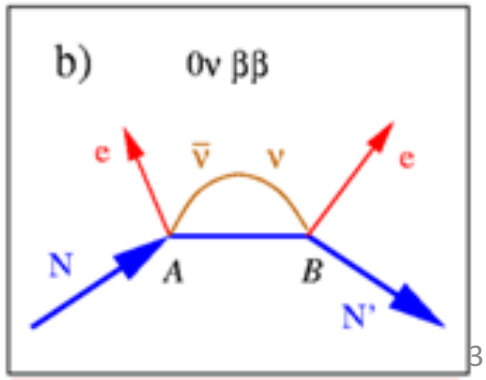
- Dark Matter Direction Detection
  - Xenon detectors leading sensitivity for massive DM
  - Cross-check with indirect detection and collider search

- Neutrino detection
  - Neutrino-nucleus coherent scattering
  - Solar pp, ^{8}B, DSNB





- Neutrinoless double beta decay
  - $^{136}\mathrm{Xe} \rightarrow {}^{136}\mathrm{Ba} + 2\mathrm{e}^{-}$
  - Majorana neutrino? Anti-matter? Neutrino mass?



Interesting Signatures from Indirect Search

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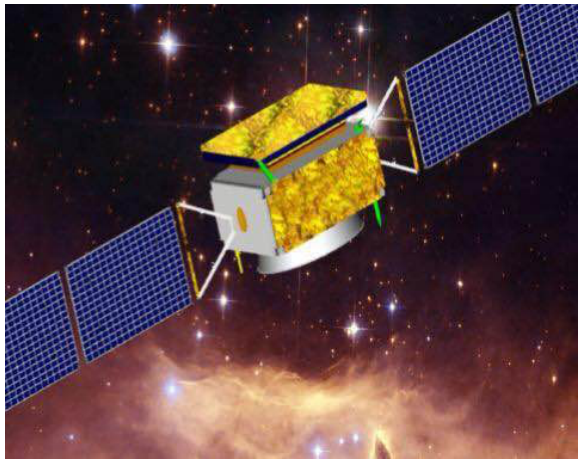
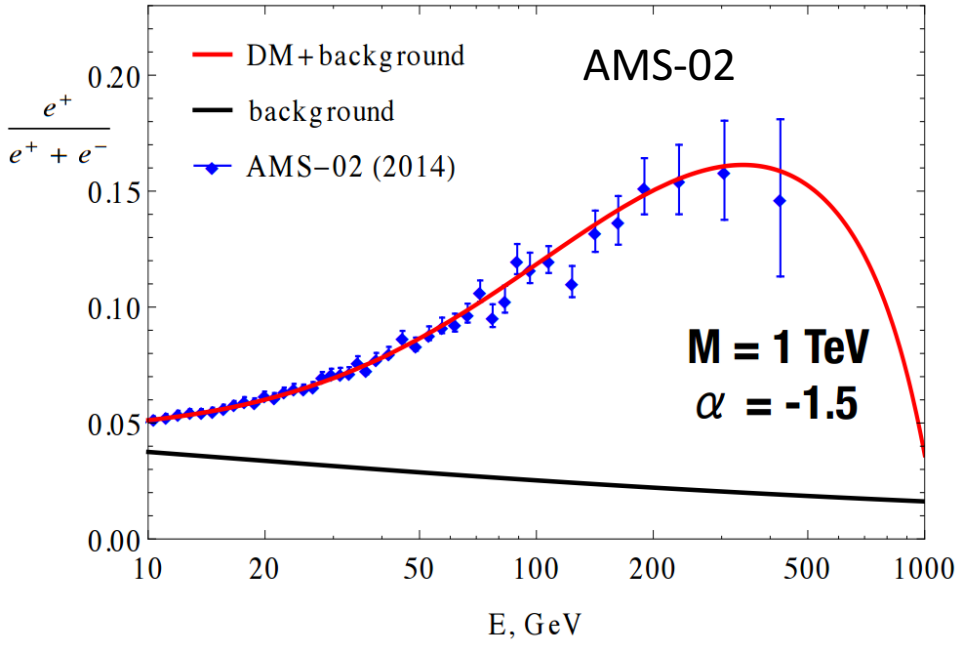
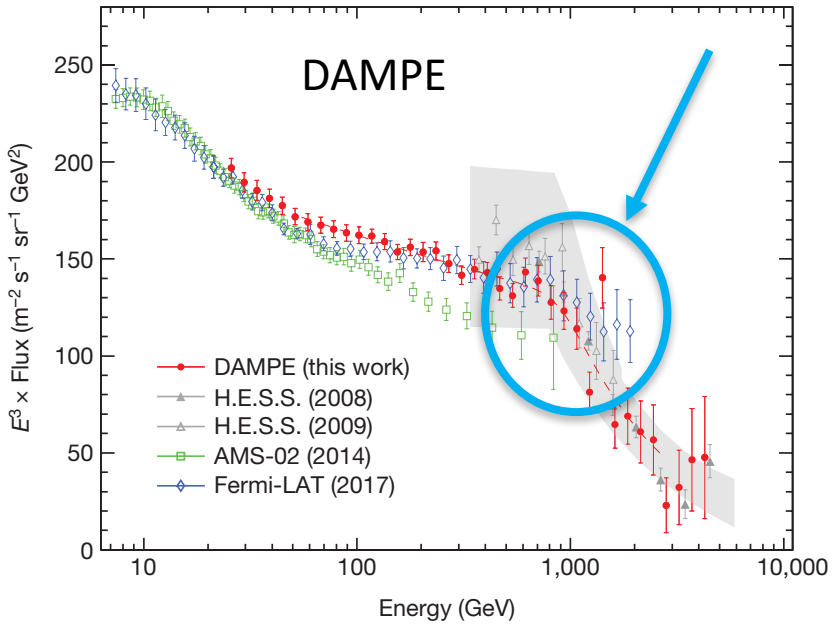


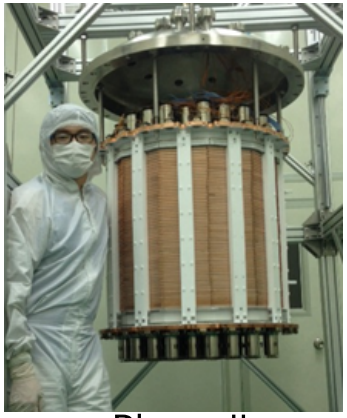




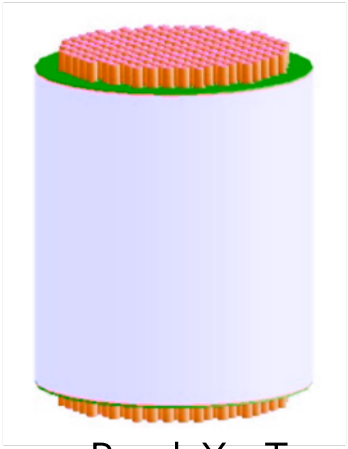
PandaX Experiment

- **P**article **and A**strophysical **X**enon Experiments
  - Formed in 2009, ~50 people
- PandaX-II 580kg results published at PRLs
  - **World-leading exclusion limit**
- Future: PandaX-xT multi-ton DM experiments

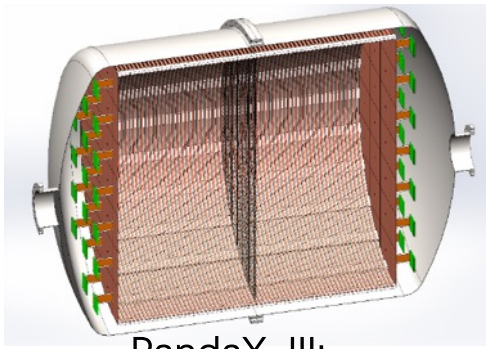
Phase I:
120 kg DM
2009-2014



Phase II:
500 kg DM
2014-2018

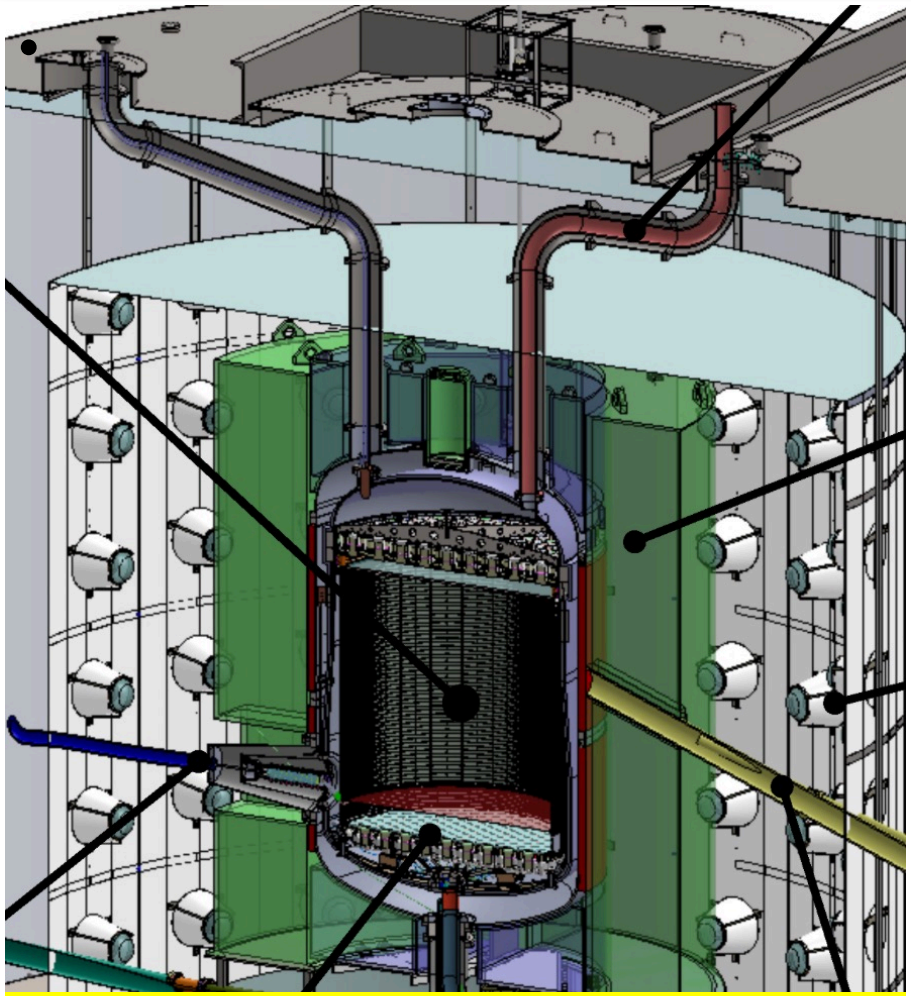


PandaX-xT:
multi-ton DM
Future



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

Multi-ton Xenon Detectors in the World



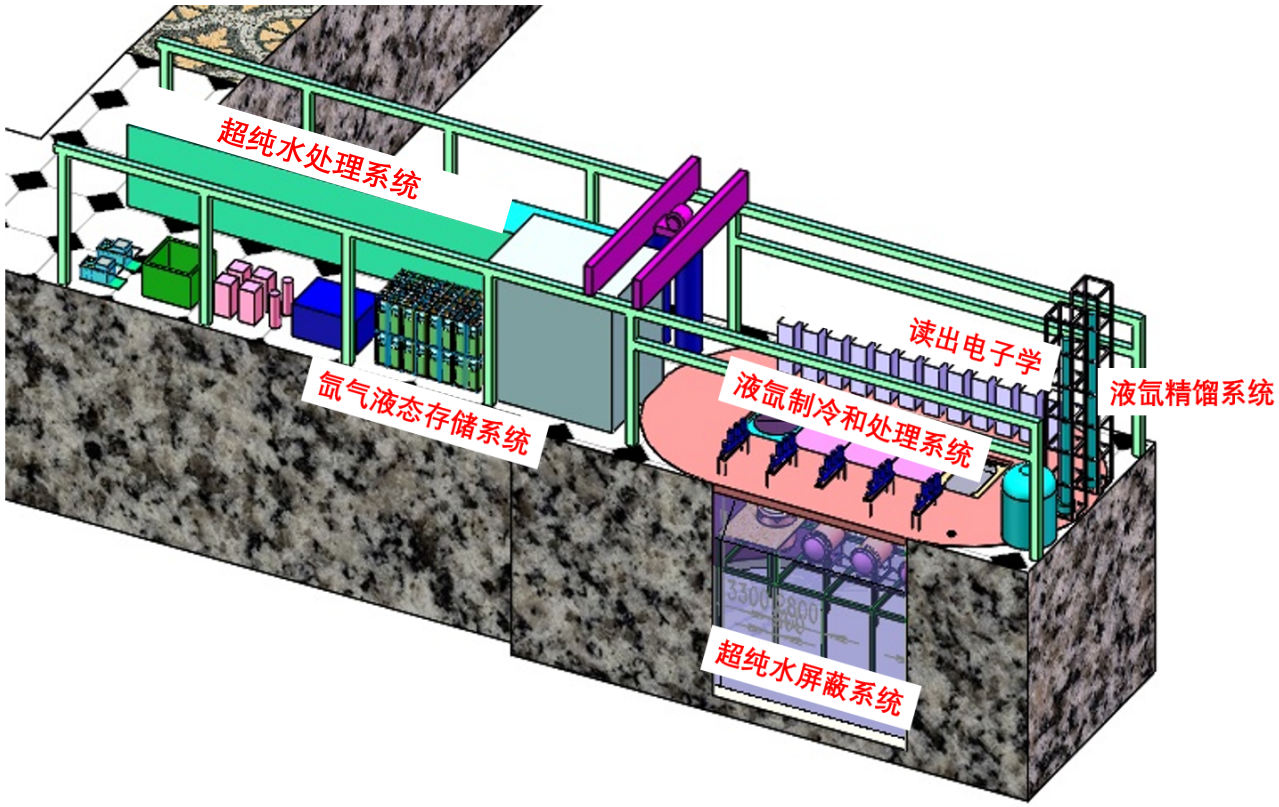
LZ, 7-ton, in preparation,
Sanford Lab

XENON1T

largest LXe TPC ever built
cylinder: 96 × 97 cm
active LXe target: 2.0t (3.2t total)
248 PMTs (Hamamatsu R11410-21)

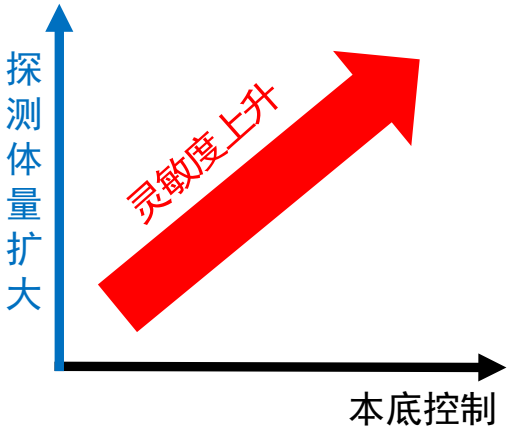
PandaX-4T Experiment

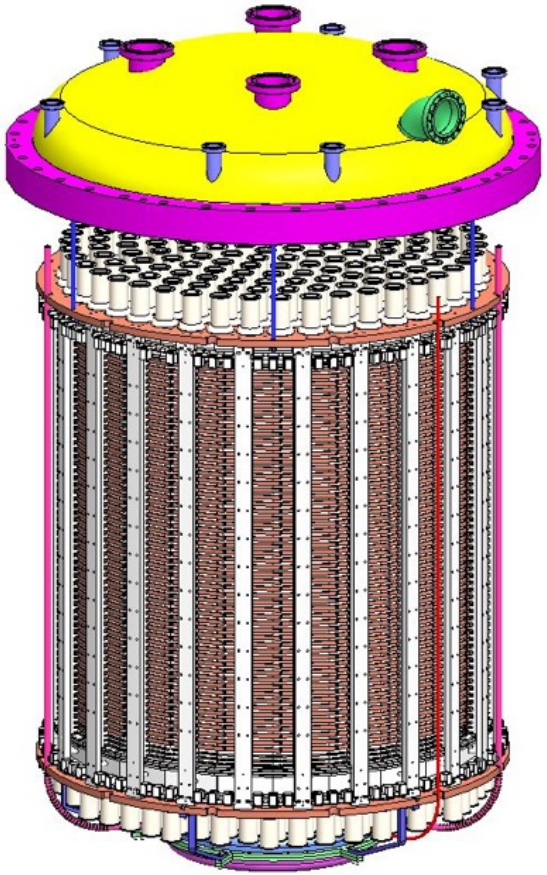
- Propose **4-ton liquid xenon experiment**
- Located in CJPL-II B2 hall
- Onsite assembly and commissioning: 2019-2020
- To push the DM SI sensitivity down to ~10^{-47} cm^2

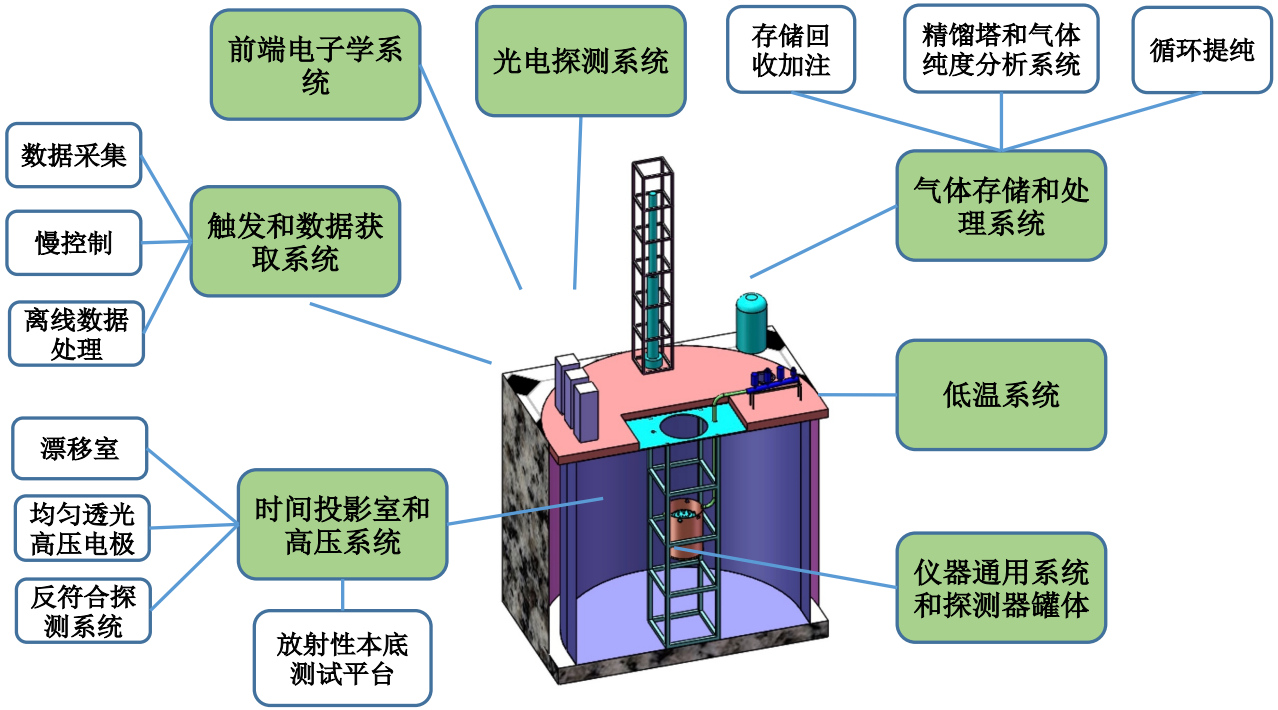


PandaX-4T Key Technologies

- **Large-scale TPC**
- **Electronics and DAQ**
- **Xenon handling**
- **Background control**

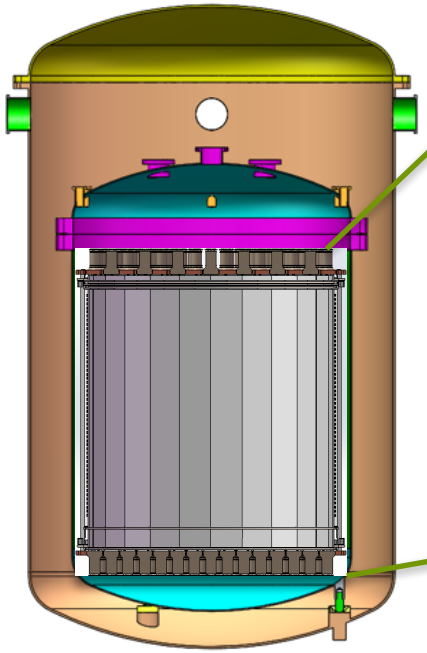


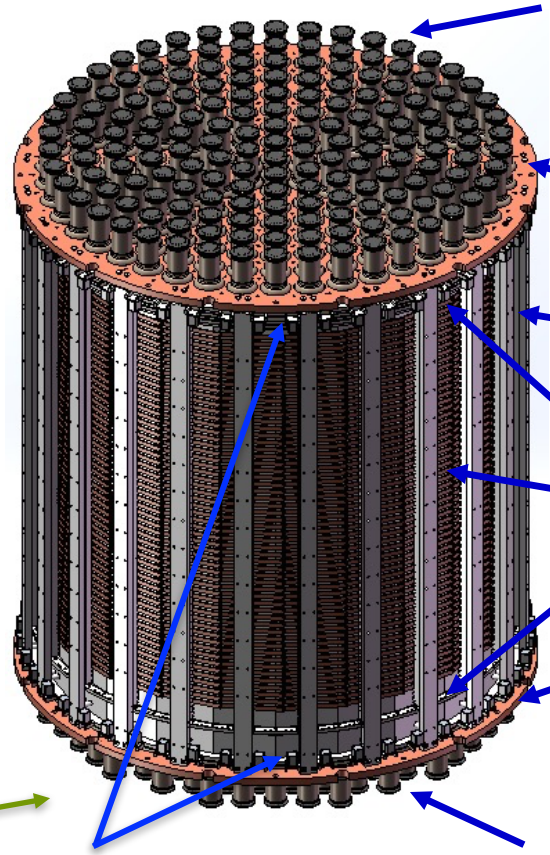




Large Scale Time Projection Chamber

- Drift region: **Φ~1.2m，H~1.2m**
  - Xenon in sensitive region～4ton
- **Design goal**:
  - High signal efficiency
  - Uniform *E* field in a large volume
  - Veto ability



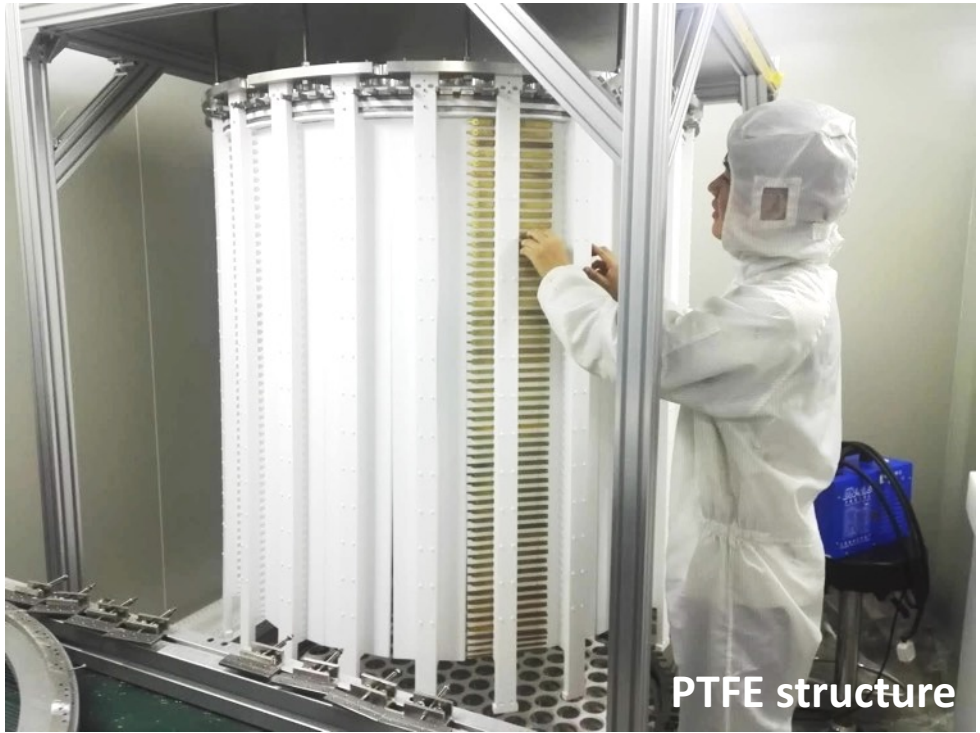


TPC: Signal Collection Efficiency

- High reflectivity of **PTFE** (full coverage): >98%
- **PMT dense array**: 169 in circular array and 199 in hexagonal array


PMT supporter

In PandaX-II, photon detection efficiency reaches 11.76%

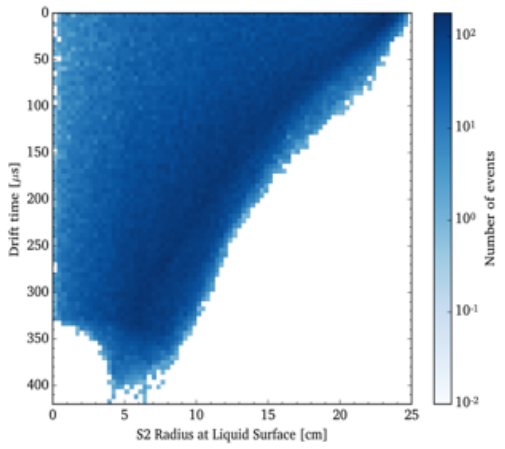

PTFE structure

Electric Field

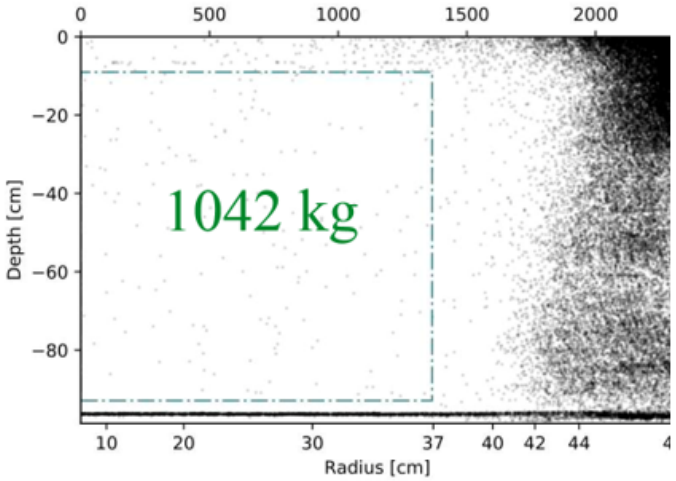
- **Uniform electric field in a large volume**
  - To ensure ER/NR separation, energy and position resolution, signal efficiency, etc
- We have accumulated a lot experience in PandaX-I and II

Drift Field	Design (V/cm)	Actual run (V/cm)
LUX	400	180
XENON1T	400	120
PandaX-II	400	400

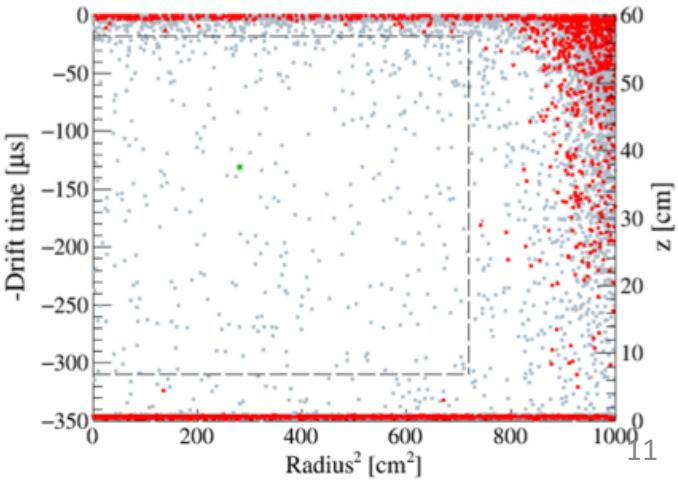
LUX



XENON1T

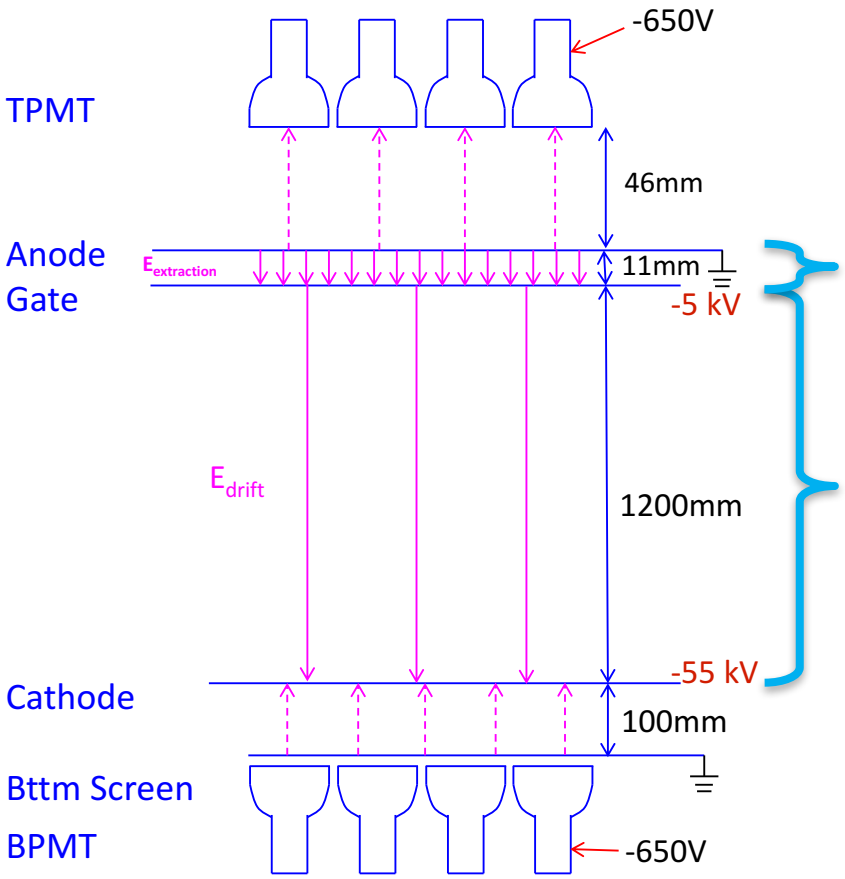


PandaX-II



Electric Field

- Four electrodes: anode, gate, cathode and screen



Extraction field: 6000 V/cm

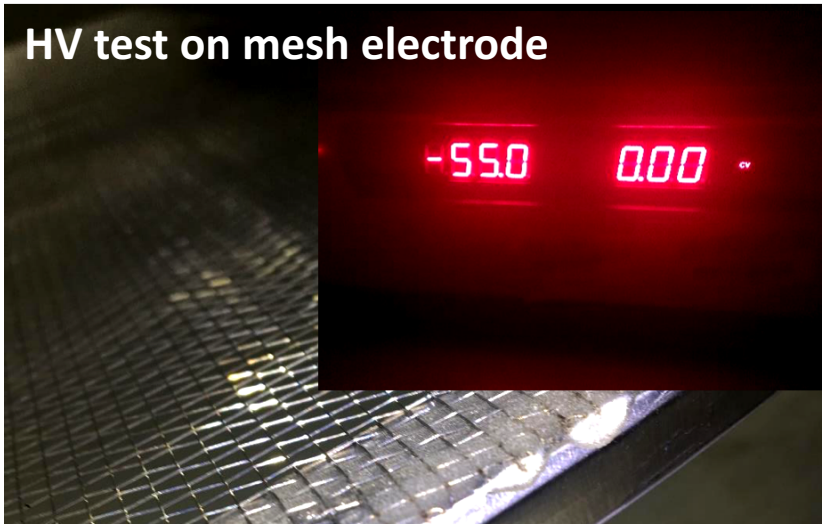
Drift field: 400 V/cm

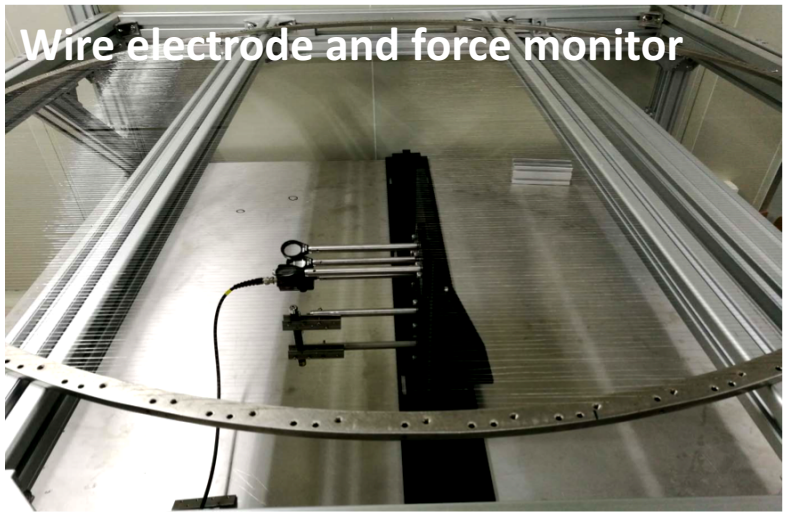
Gate electrode: -5 kV

Cathode electrode: -55 kV

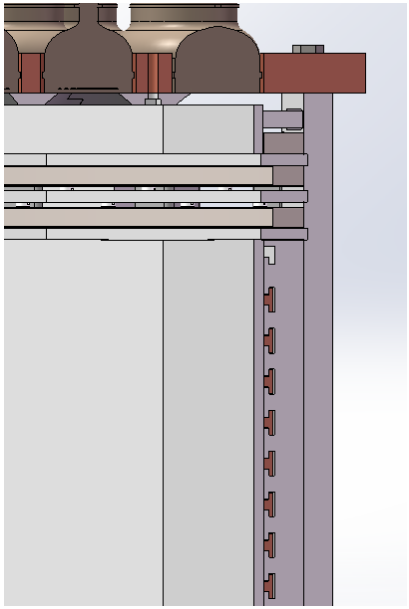
Electrodes and Shaping Rings

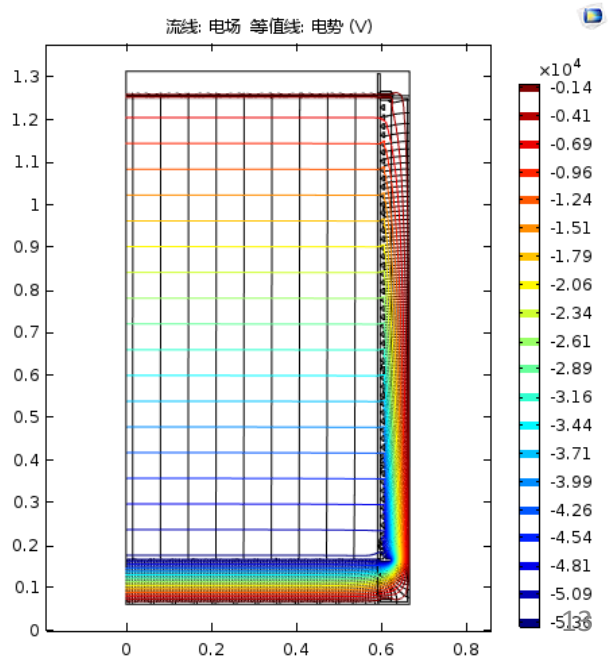
- **Φ=1.2m Electrodes:**
  - Designed two types: **mesh and wire**
  - High light transparency ~ 90%
  - Small deformation ~1mm





- **Shaping rings**: 59 sets
  - Deformation of E field < 1%

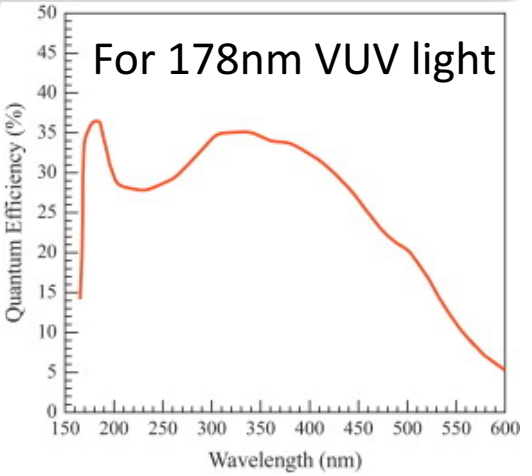


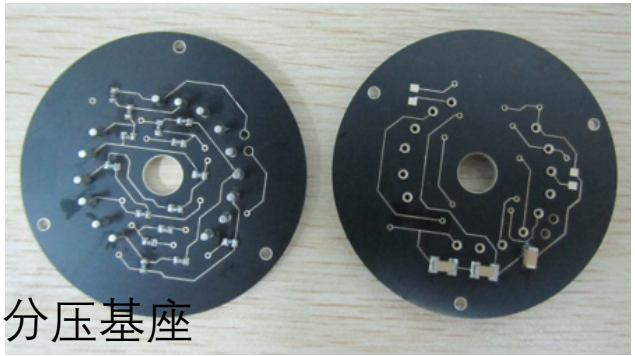


PMTs

- PMT: Hamamatsu R11410 with QE > 30%
  - Very low dark noise rate (~50Hz in LXe)
- 1500V High voltage distribution R&D
  - Optimize the base with high amplification
- Rigorous quality control in low temperature

Collaborating with SDU





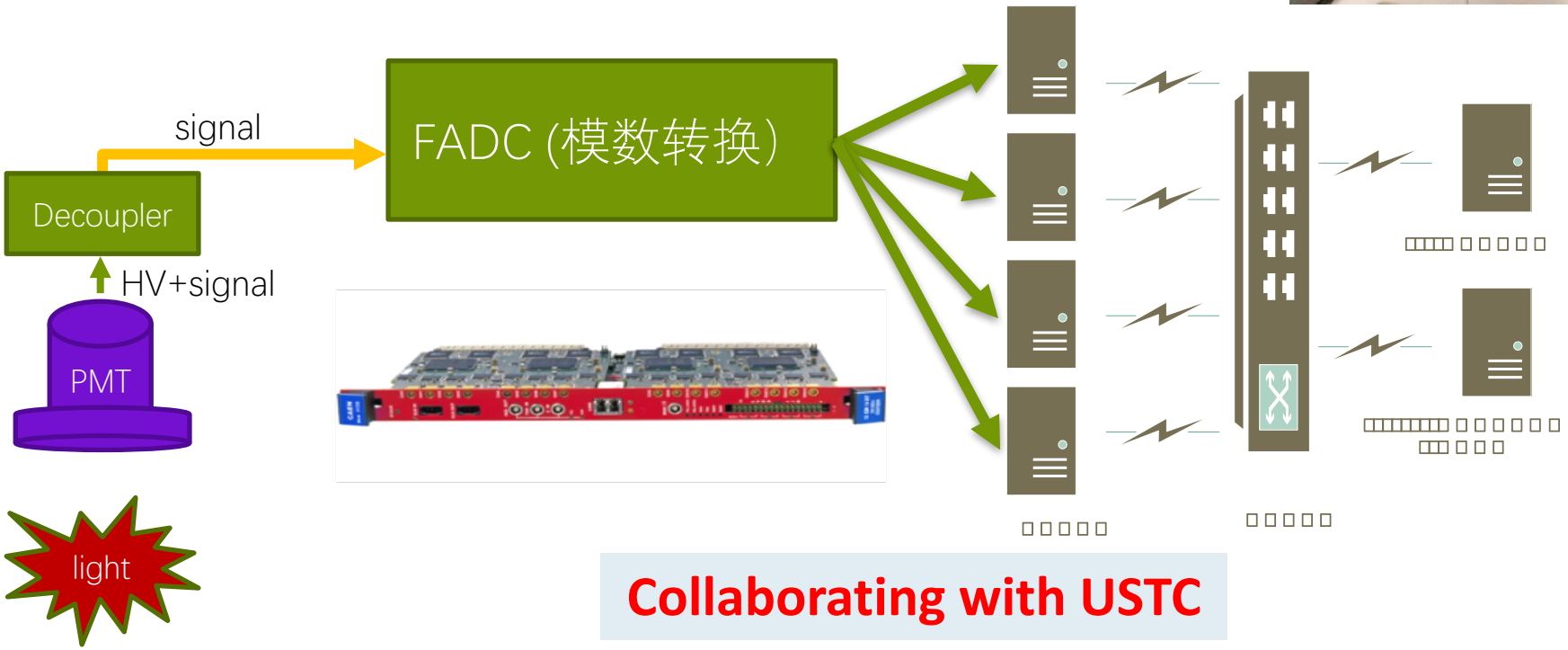
分压基座

电磁屏蔽连通器

Electronics and DAQ

- More channels
  - 512 channels (including 3” PMT and 1” veto PMT)
  - Calibration run 2GB/s, physics run 0.4GB/s

Trigger-less data-taking
High speed parallel readout

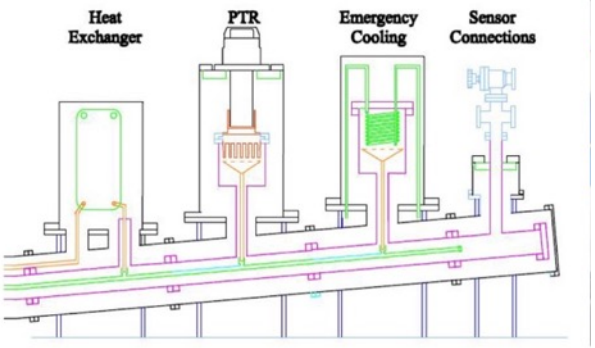


Collaborating with USTC

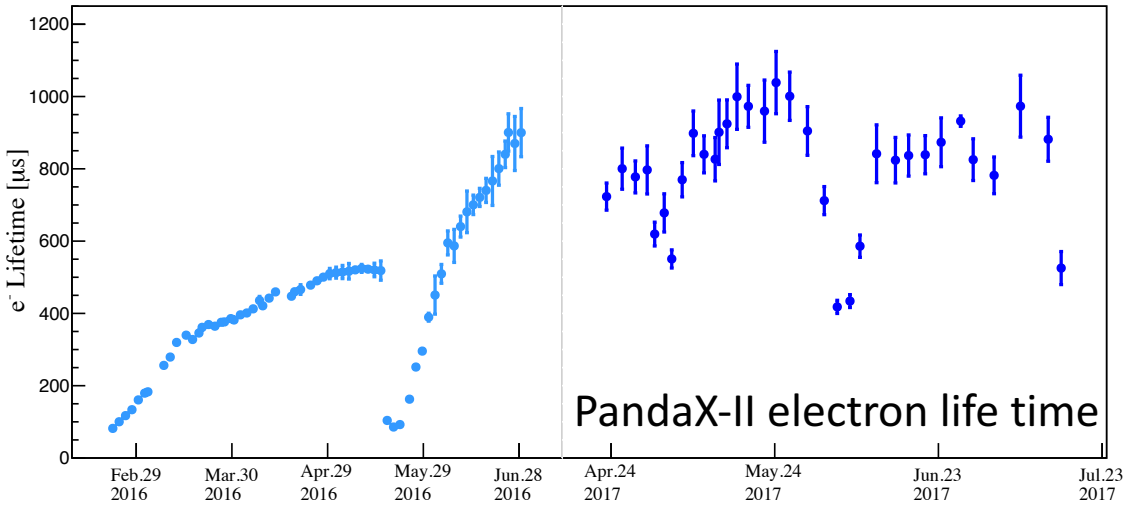
Xenon Handling: Storage, Cooling and Purification

- **Storage**: 6 ton xenon
  - 6 set 4x4 (50kg, 40L)
  - Filling speed： 600 – 1000kg/day

- **Cooling bus**:
  - PandaX-II: one cold head (180W)
  - PandaX-4T: **three cold heads** (620W)



(a) 制冷总线的设计图

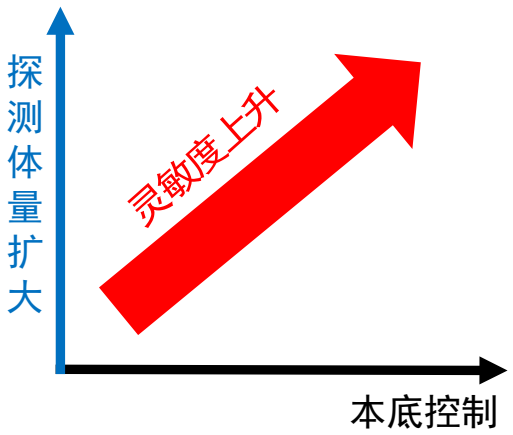


- **Online purification**
  - PandaX-II: one circulation loop (50 slpm)
  - PandaX-4T: **two circulation loops (100 slpm x 2)**

Background Control

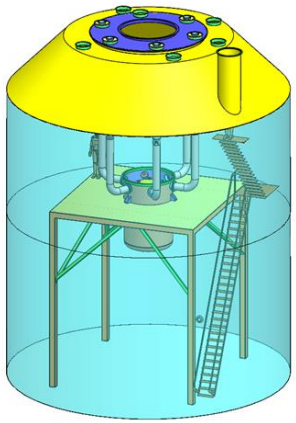
- Current background level at PandaX-II: **0.8 mDRU**

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



- **PandaX-4T key issue: Background control**
  - Materials: 0.01 mDRU
  - ^{nat}Kr: 0.1 ppt
  - ^{222}Rn: 1 μBq/kg
  - **Total ER background: 0.04 mDRU**
  - **Total NR background: 0.5 event / ton / year**

Detector Material

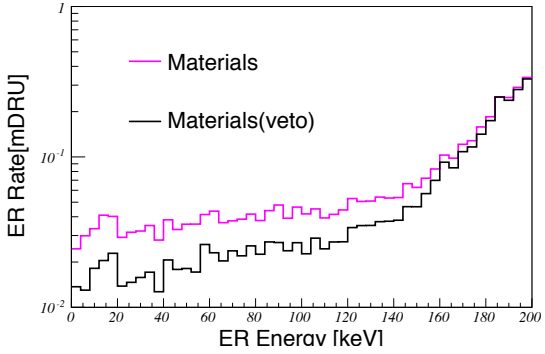


- **5m pure water shielding**
- **Low radioactive materials**
  - Obtaining the lowest ^{60}Co in SS

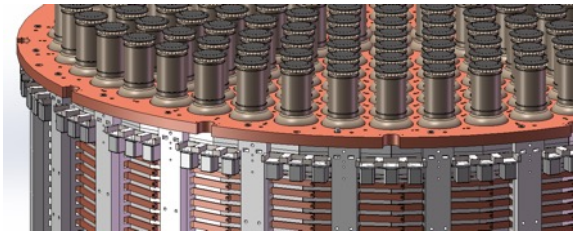
Collaborating with PKU

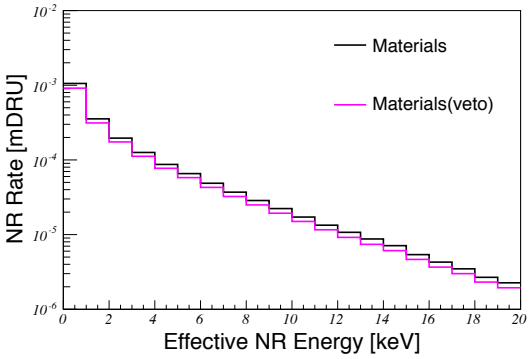
表 2 PandaX-II 压力容器钢板本底数据（mBq/kg），A 和 B 是两个样品，验证测量的可靠性，“<”是指灵敏度未到，这里仅列出上限

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

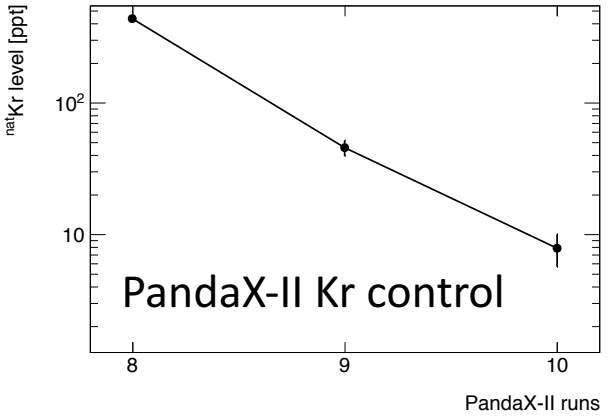




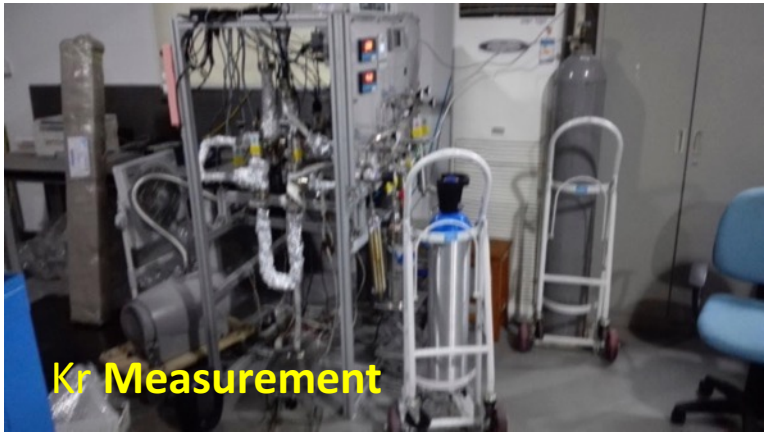
^{85}Kr Control

- ^{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



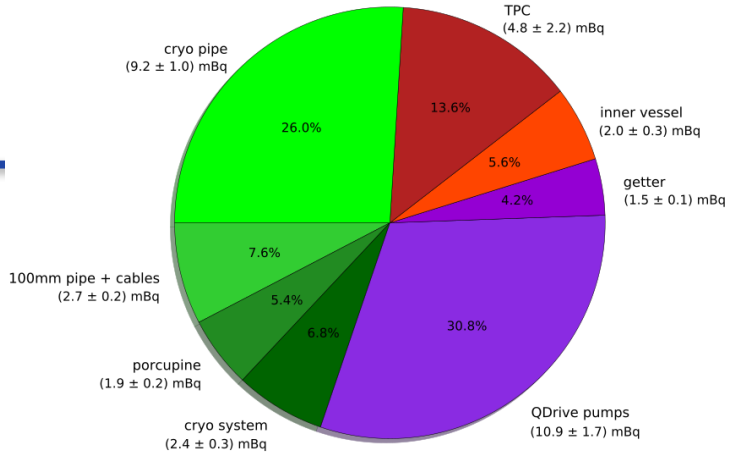
^{222}Rn Control

- 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

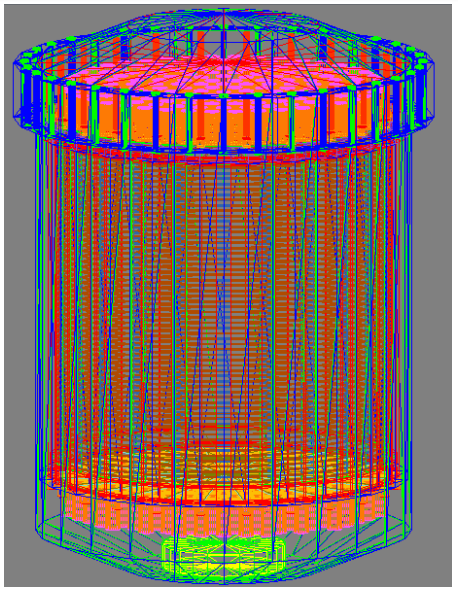
- Rn filtration/distillation plan in consideration



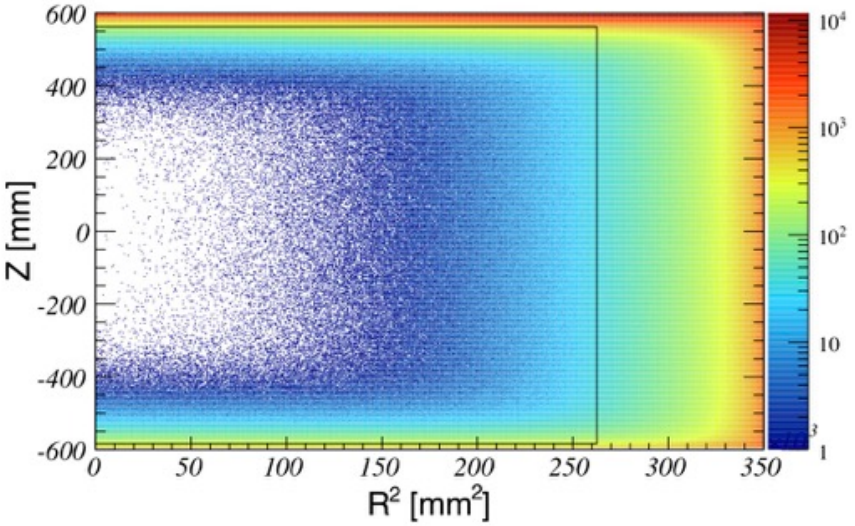
xenon1T Rn budget

Background Simulation

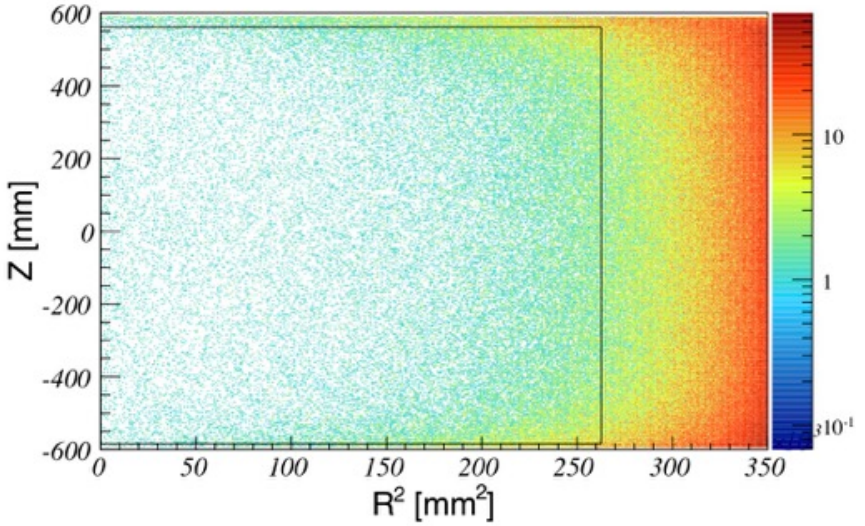
- **Simulate the ER and NR backgrounds**
  - Detector materials: inner/outer vessels, flanges, copper plates, electrodes, PTFE materials, PMTs etc
  - Radioactivity in xenon: ^{85}Kr, ^{222}Rn, ^{136}Xe
  - Neutrino: electron scattering and coherent nucleus scattering



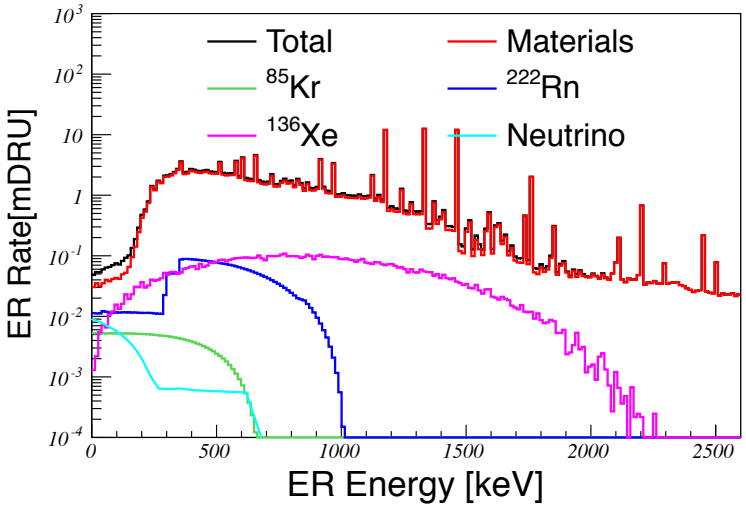
ER from materials



NR from materials

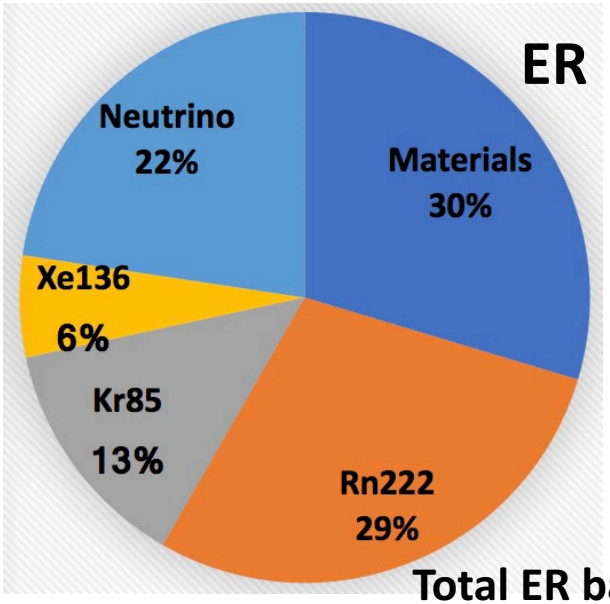


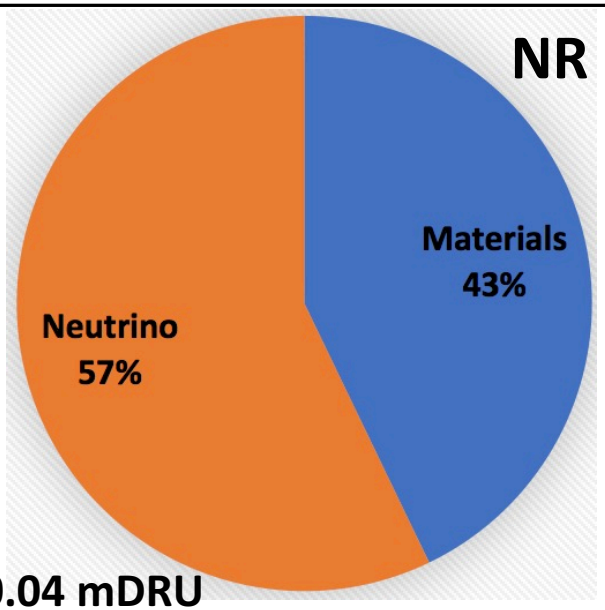
Background Simulation



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



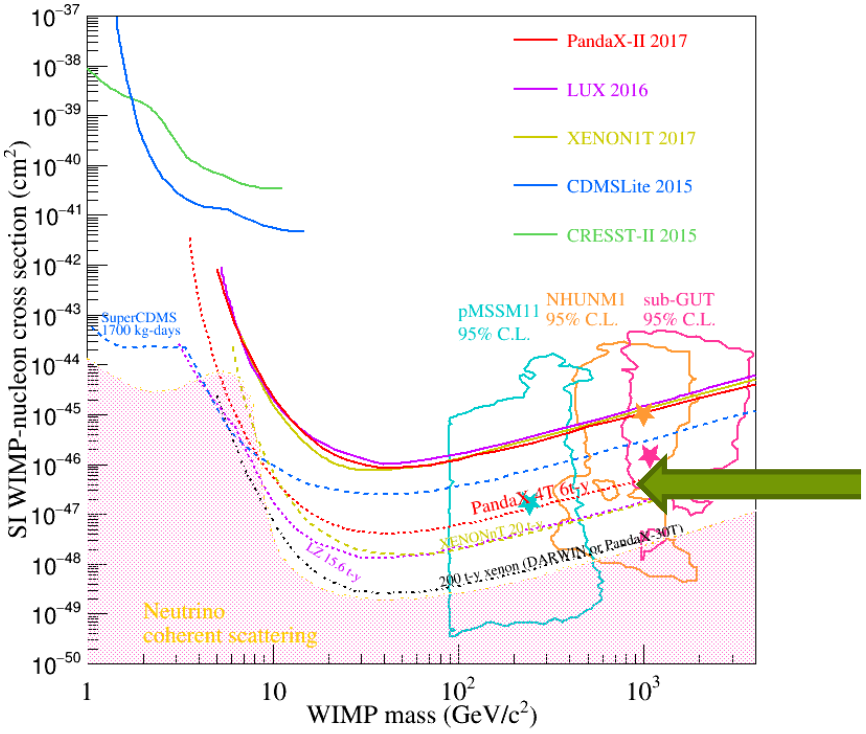


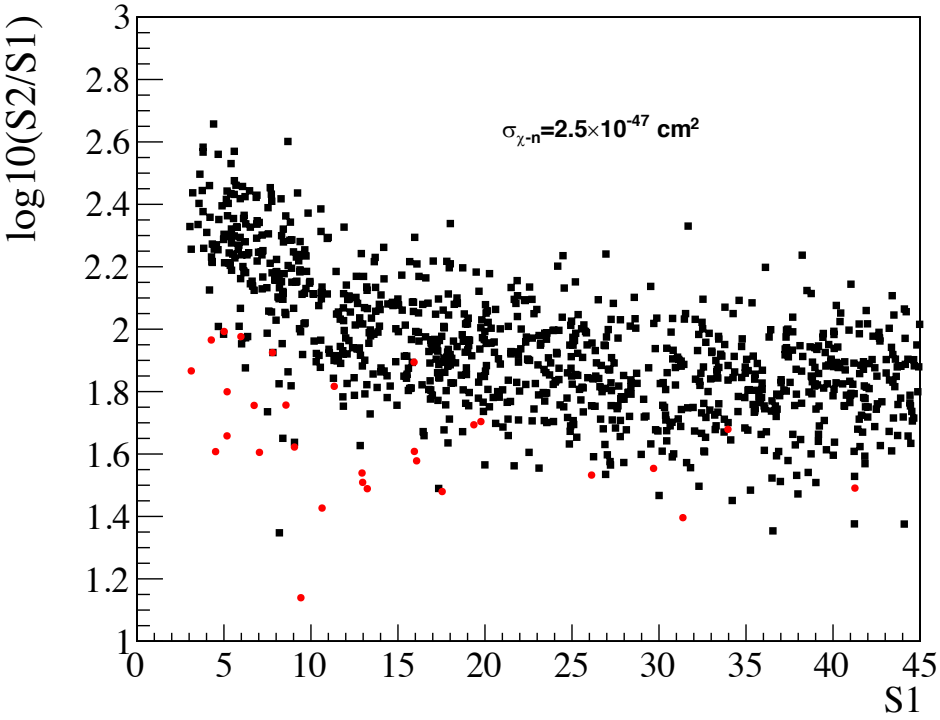
Total ER background: 0.04 mDRU

Total NR background: 0.5 event / ton / year

Expected Sensitivity

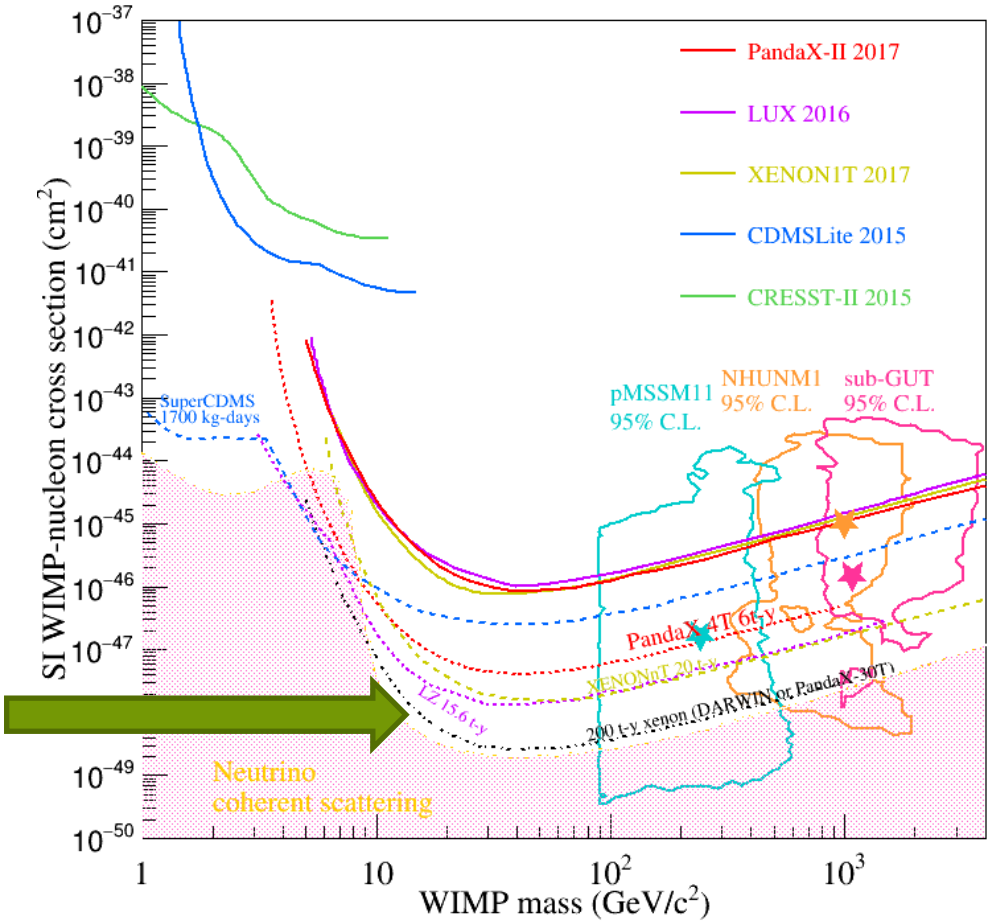
- With exposure reaching **6 ton-year**
- DM SI sensitivity could reach ~10^{-47}cm^2





PandaX-30T

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



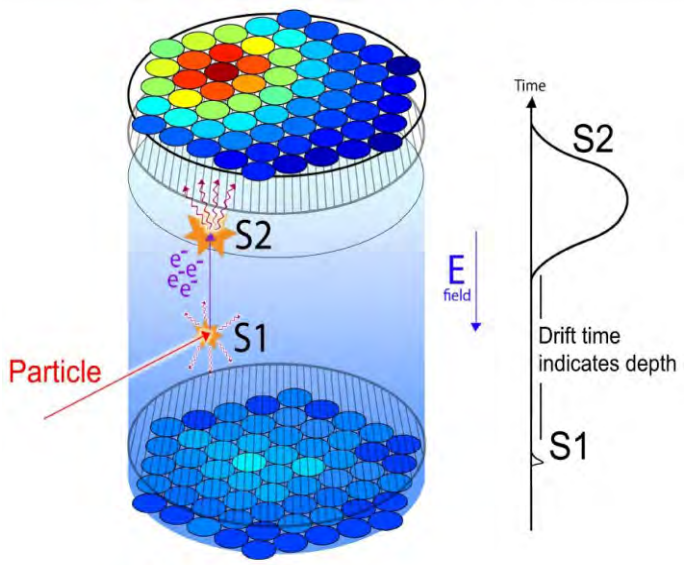
Summary and Outlook

- PandaX experiment with 580kg Xenon has reached the world frontier of dark matter direct detection.
- PandaX-4T could be a multi-purpose detector for rare signal searches like dark matter, neutrino, etc
- The sensitivity to SI DM could reach ~10^{-47}cm^2 with 6ton-year
- Future PandaX-30T could go 1-2 more orders of sensitivity to DM, capable of observing CNS.

- **目前加入PandaX-4T的单位有:** 上海交大，山大，北大，上海应物所，中科大，南开，雅砻水电
- **我们欢迎更多的合作单位!**
- **谢谢!**

Detector Principle

- Double phase Xenon Time Projection Chamber
  - Mature technique
  - Sensitive to massive DM candidate
  - Self-shielding property
  - Signal/background discrimination
  - …



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

PandaX-II Detection Efficiency

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