PandaX-4T Xenon Detector For Rare Physics Search

Ning Zhou (SJTU)
On behalf of PandaX Collaboration

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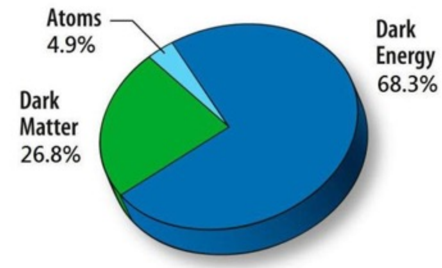
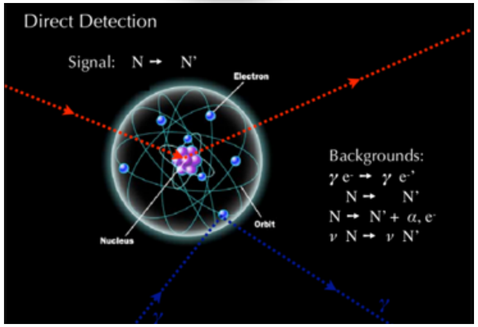
Outline

- Motivation
- PandaX experiment
- 4-ton LXe detector
  - TPC
  - Electronics
  - Background control
  - Xenon handling
- Outlook

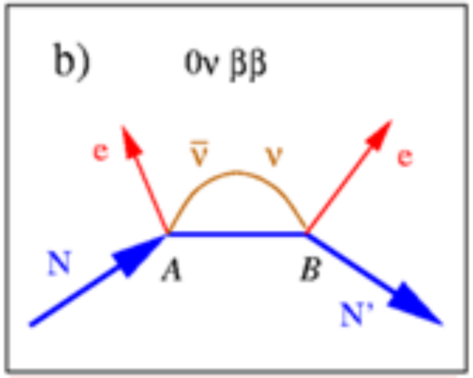
Motivation



- LXe Detector for measuring rare physics events

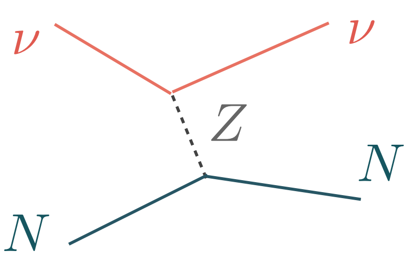


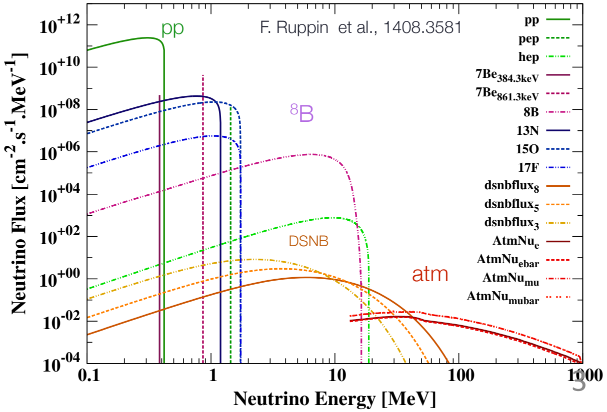
- Dark Matter Direction Detection
  - Xenon detectors leading sensitivity for massive DM
  - Cross-check with indirect detection and collider search



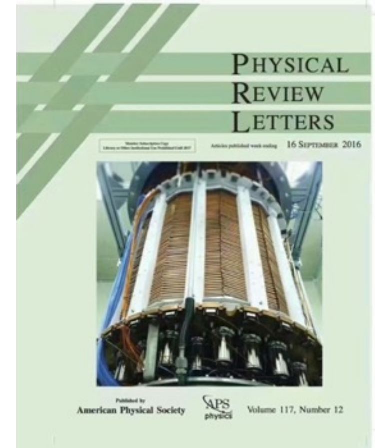
- Neutrinoless double beta decay
  - $^{136}\mathrm{Xe} \rightarrow {}^{136}\mathrm{Ba} + 2e^{-}$
  - Majorana neutrino? Anti-matter? Neutrino mass?

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



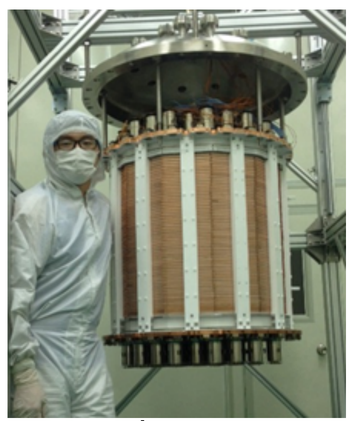


PandaX Experiment

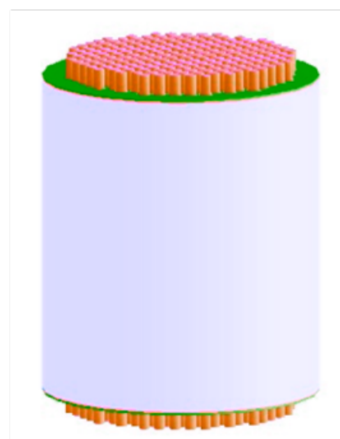


- **P**article **and A**strophysical **X**enon Experiments
  - Formed in 2009, ~50 people
- PandaX-II 500kg results published at PRL
  - World-leading sensitivity in 2016
- **Plan to build a 4-ton Xenon detector**
  - to push the DM SI sensitivity down to 10^{-47} cm^2

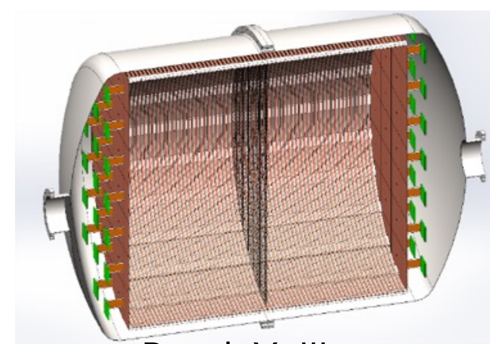
Phase I:
120 kg DM
2009-2014



Phase II:
500 kg DM
2014-2017



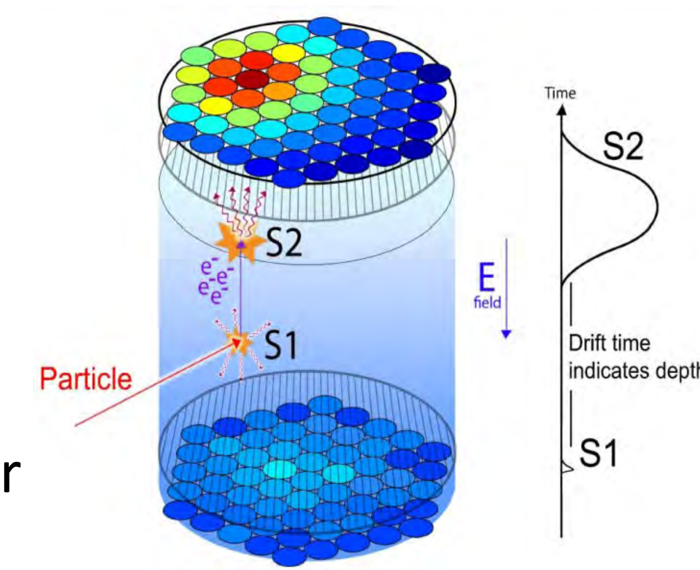
PandaX-xT:
multi-ton DM
2016-



PandaX-III:
200 kg to 1 ton
^{136}Xe 0vDBD
2016-

Detector Principle

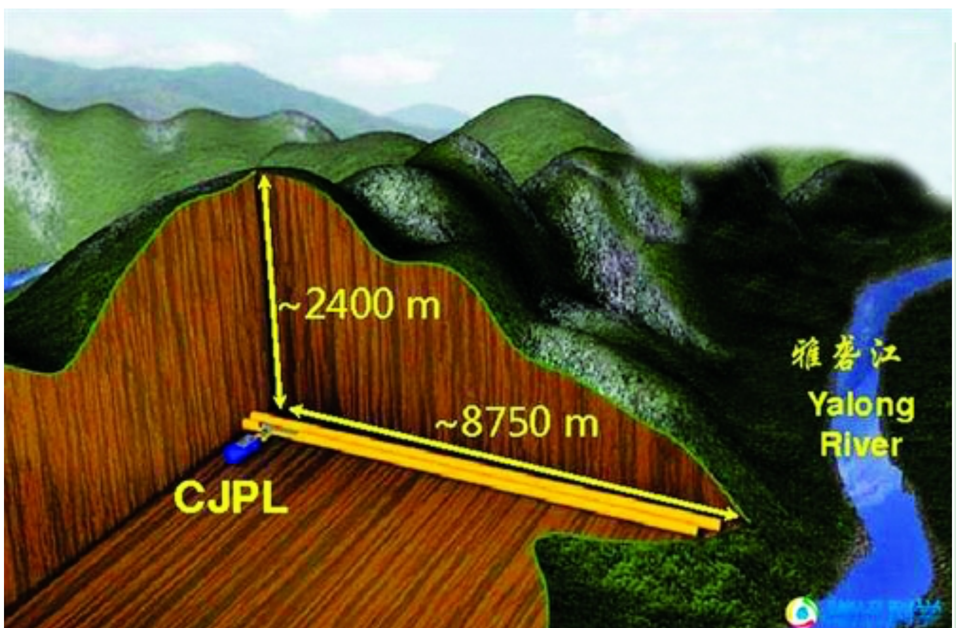
- Double phase Xenon Time Projection Chamber
  - Mature technique
  - Sensitive to massive DM candidate
  - Self-shielding property
  - Signal/background discrimination
  - …

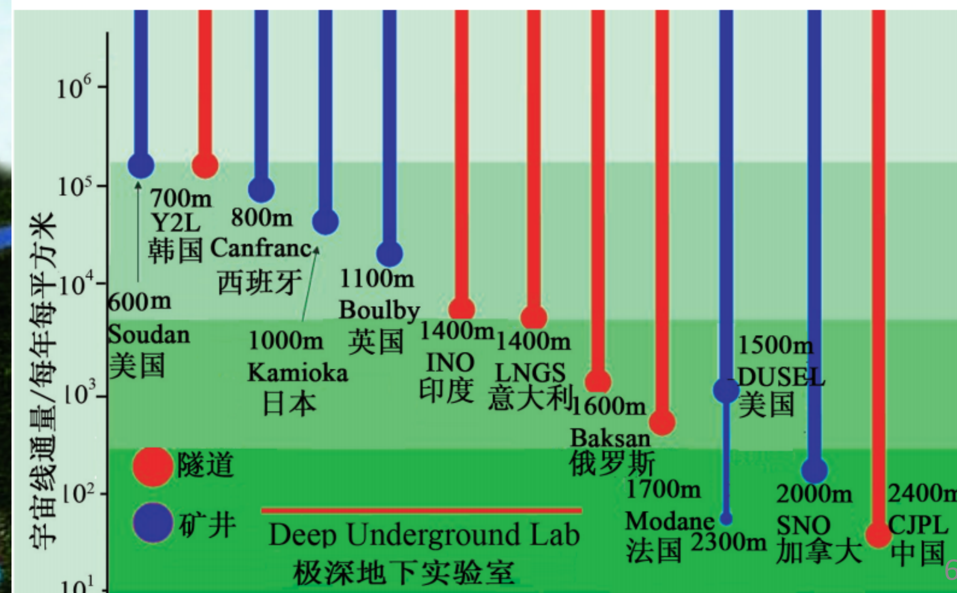


- Dark matter detection in Xenon detector
  - Incoming DM collide with Xenon atom
  - Two signatures
    - S1： scintillation light in LXe upon scattering
    - S2： scintillation light in GXe due to ionization electron
  - Reconstruct the collision energy and 3-D position

China Jinping Underground Laboratory

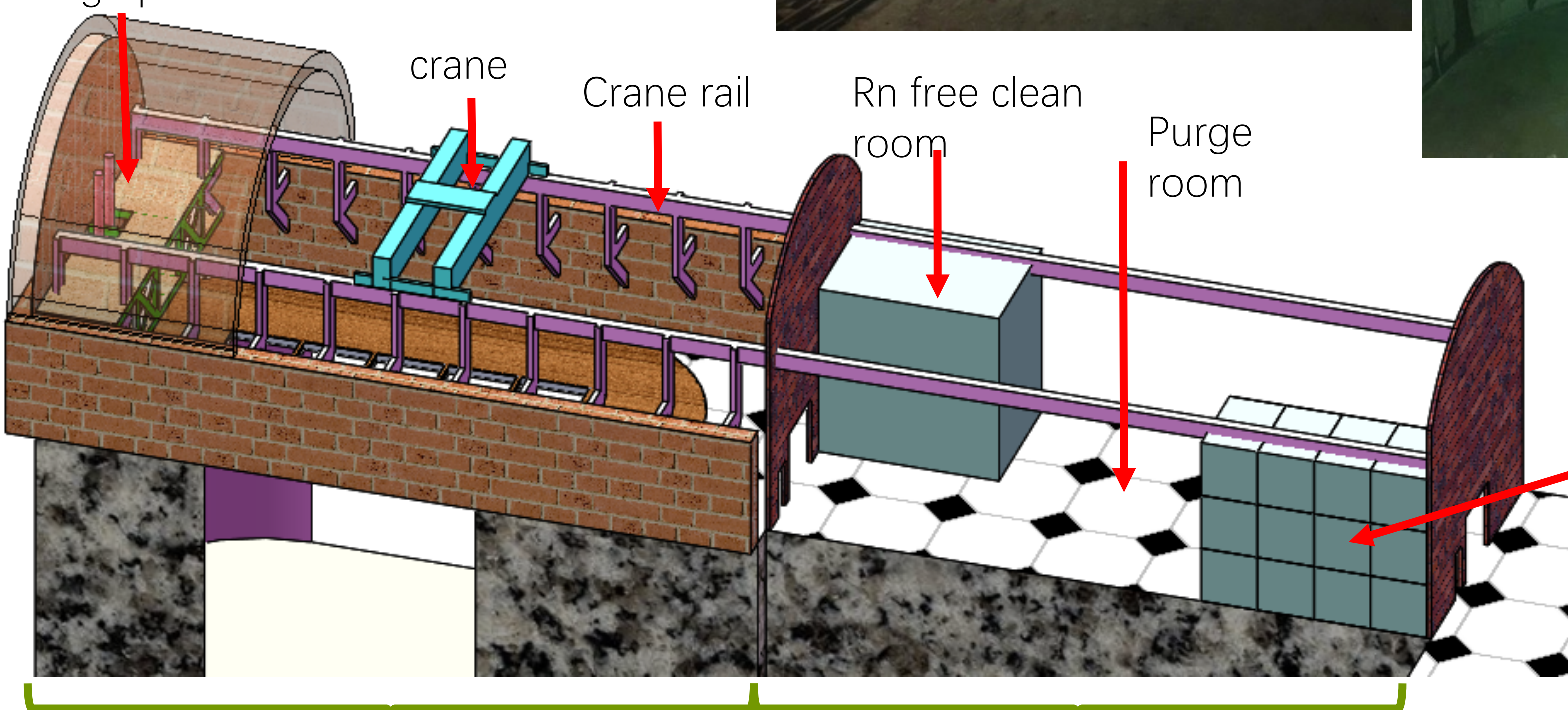
- Deepest in the world (1μ/week/m^2)
- Horizontal access!



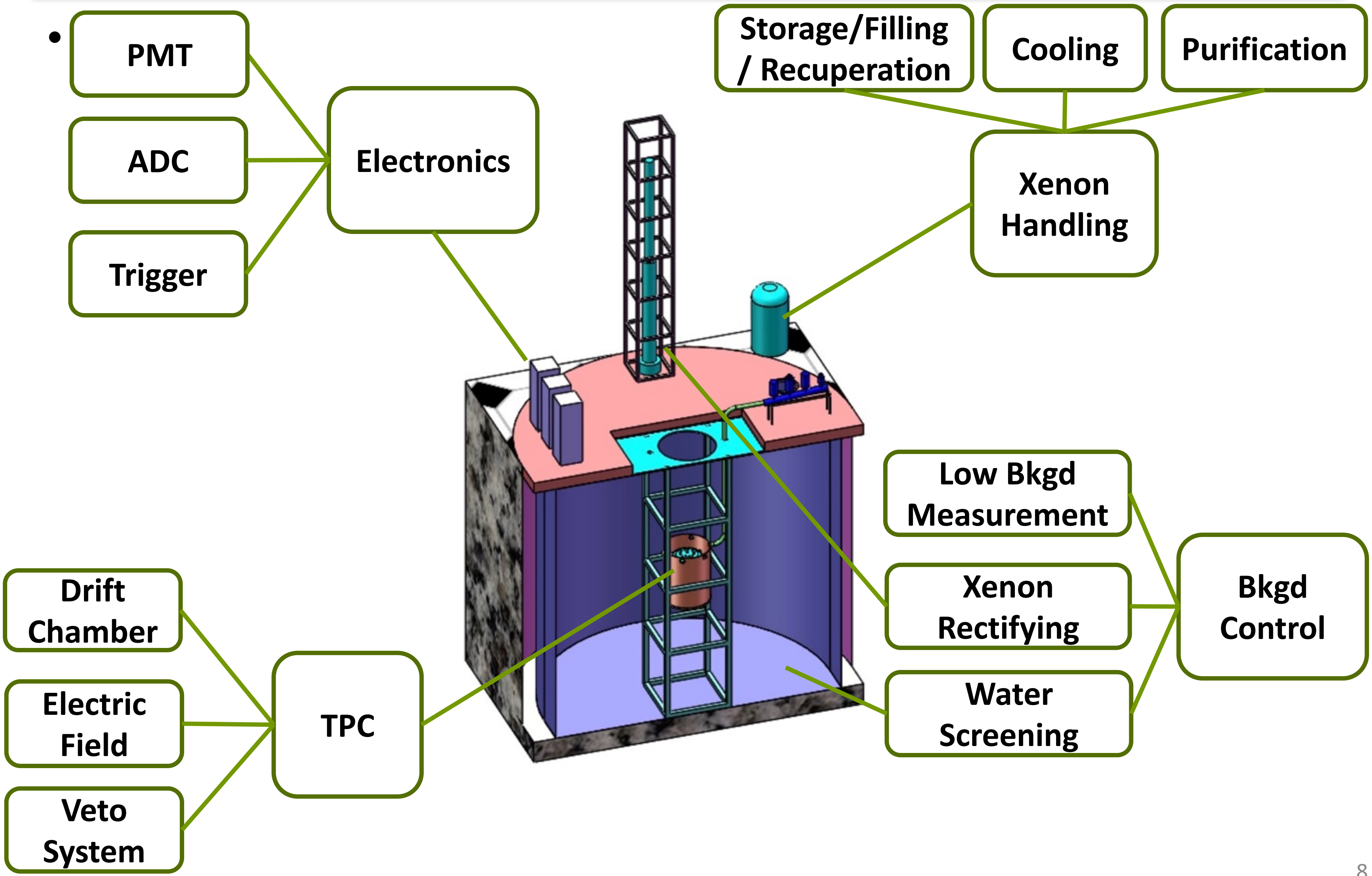


PandaX Experiment Space at CJPL-II

- Height 14m
- Width 14m
- Length 65m
- Water tank, depth of 13m

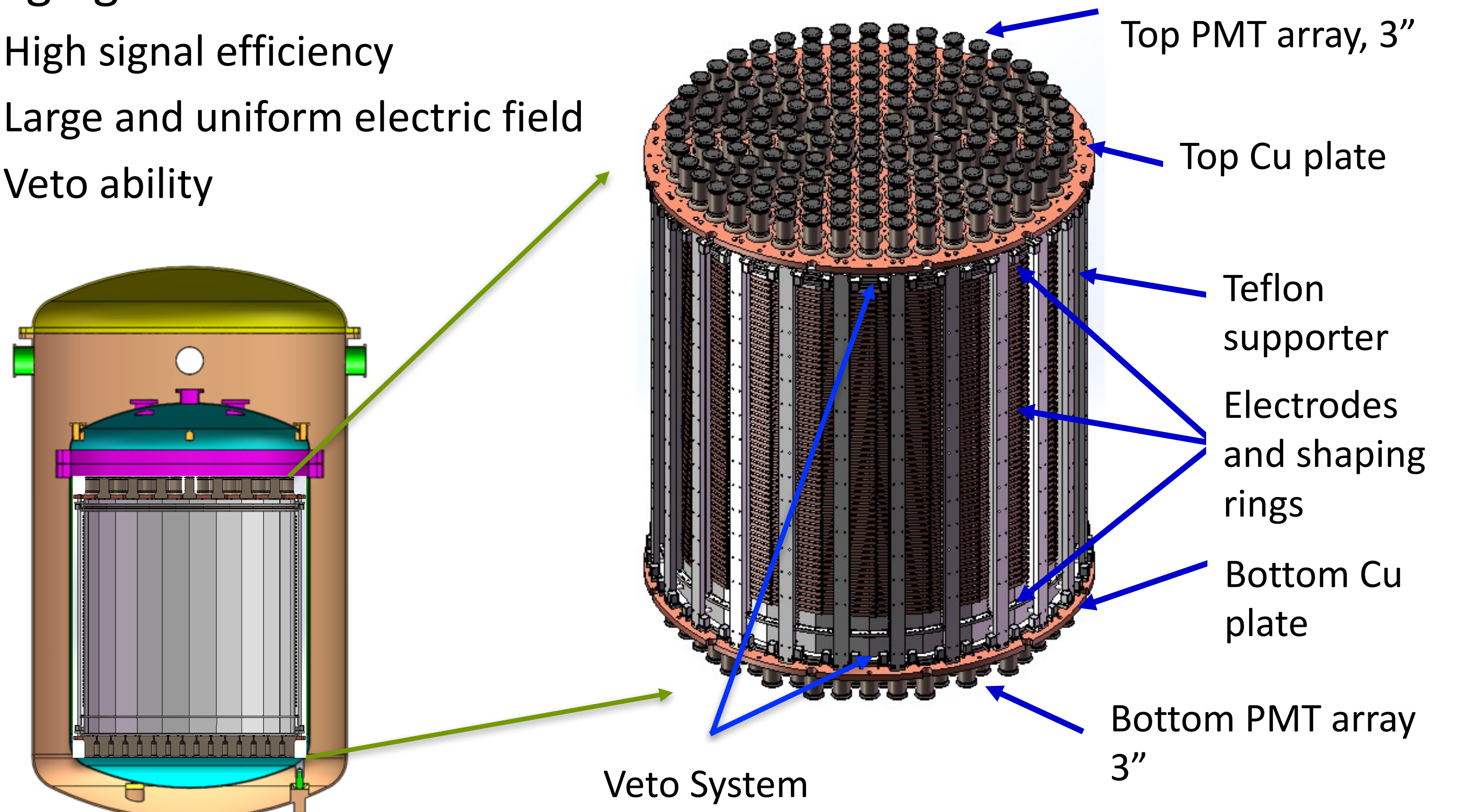


Overview of PandaX-4ton experiment



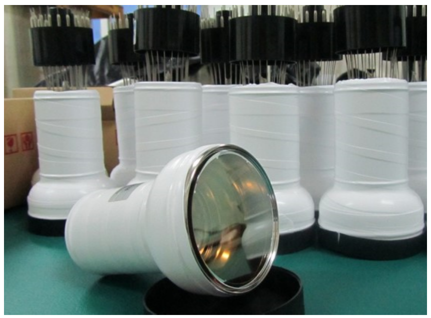
Large Scale TPC

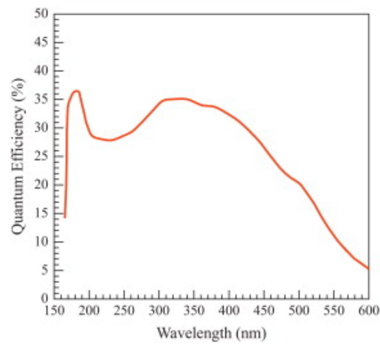
- Drift region: Φ~1.2m， H~1.2m
  - Xenon in sensitive region～4ton
- Design goal:
  - High signal efficiency
  - Large and uniform electric field
  - Veto ability



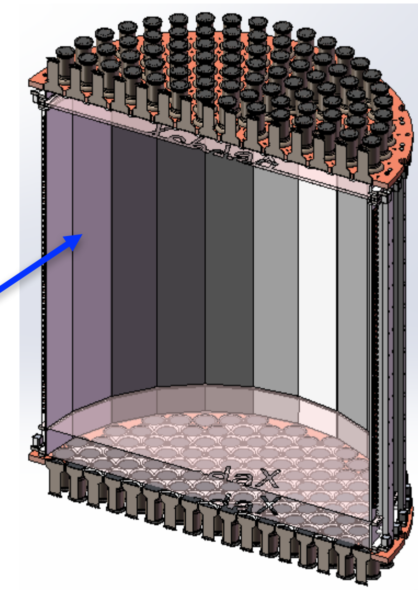
Signal Collection Efficiency

- In PandaX-II, photon detection efficiency reaches 11.76%
- PMT: Hamamatsu R11410 with QE > 30%

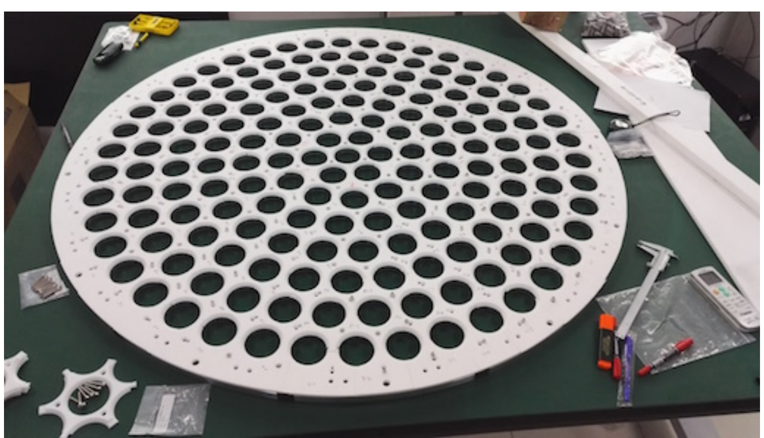


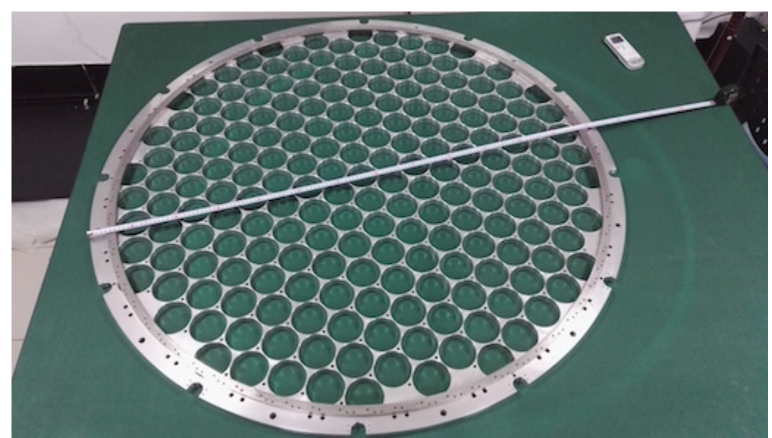


PTFE reflectors



- Light collection efficiency: ~40%
  - High reflectivity of PTFE (full coverage): >98%
  - PMT dense array: 169 in circular array and 199 in hexagonal array



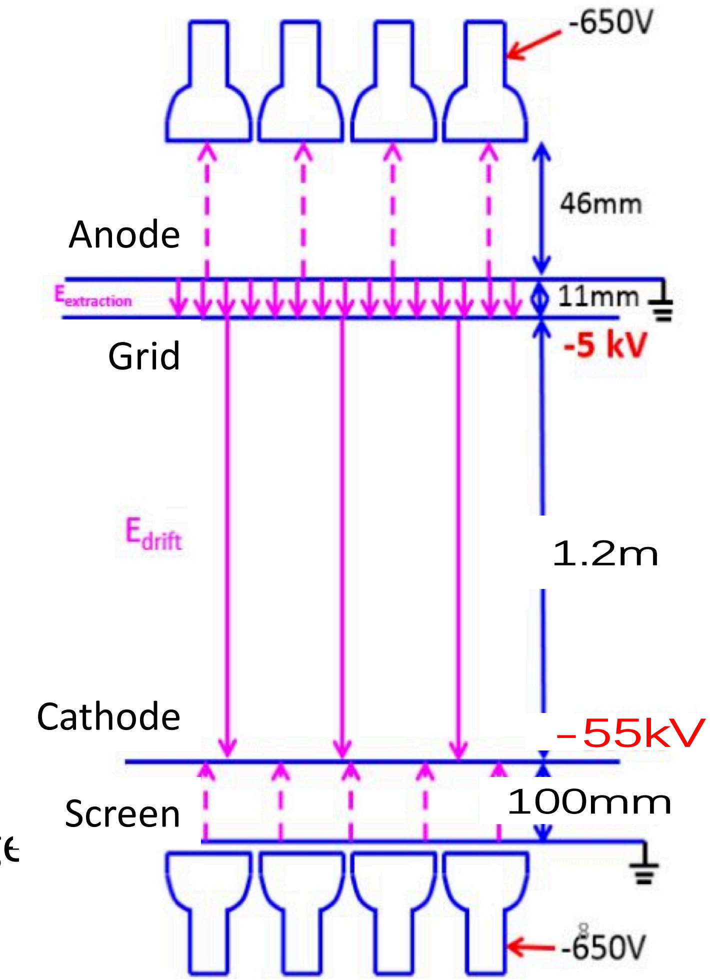


Electric Field

- Large and uniform electric field
  - To ensure ER/NR separation, energy and position resolution, signal efficiency, etc

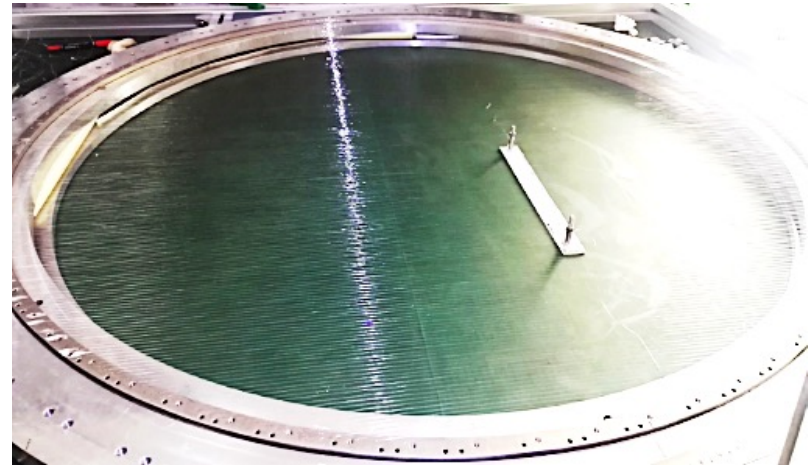
Electric Field (V/cm)	Drift (LXe)	Extraction (GXe)
Xenon100	530	12000
LUX	50-600	3000
PandaX-II	400	6000
PandaX-4ton	400	6000

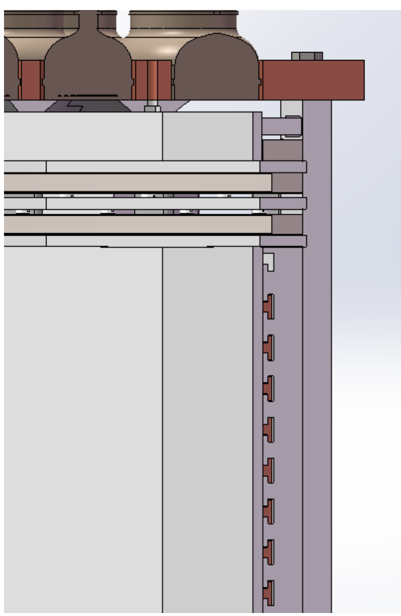
- Four electrodes: drift and extraction
  - Anode, grid, cathode and screen
- Shaping rings:
  - 60 sets to maintain upward field at the edge

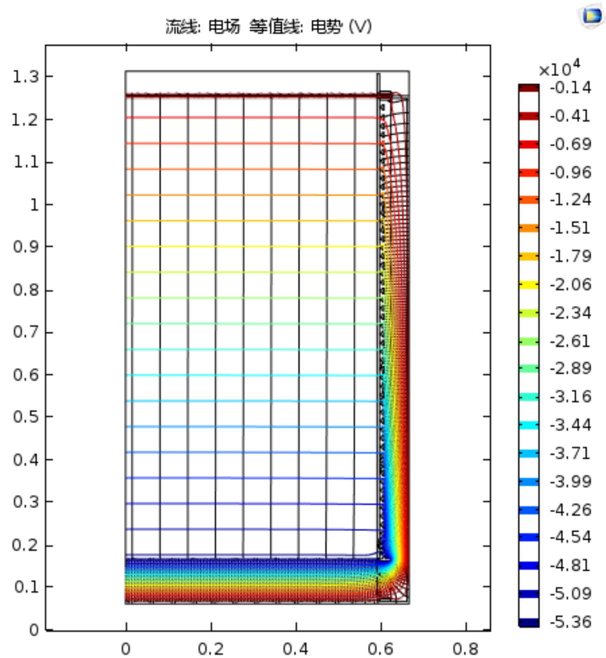


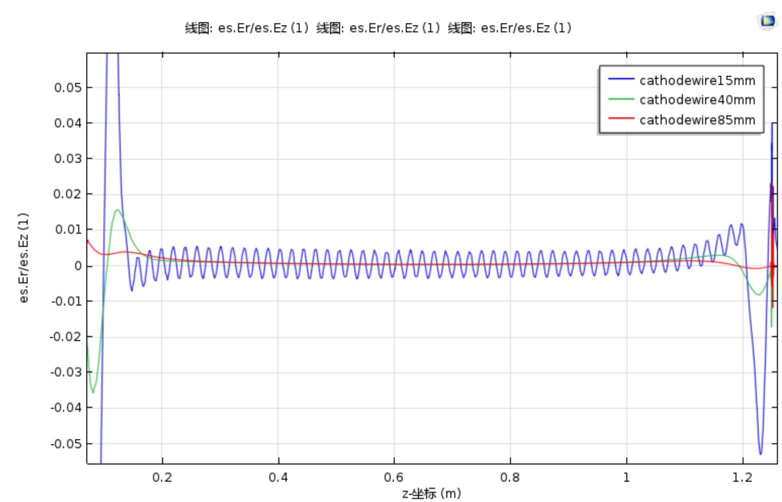
Electrodes and Shaping Rings

- Electrodes:
  - Diameter of 1.2 m: mesh and/or wire
  - High light transparency ~ 90%
  - Sustain high voltage of 55 kV
  - Small deformation ~1mm
- Shaping rings:
  - Deformation of electric field < 1%





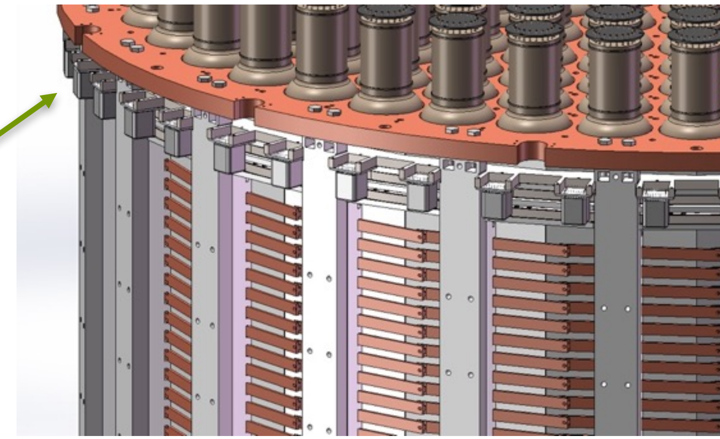


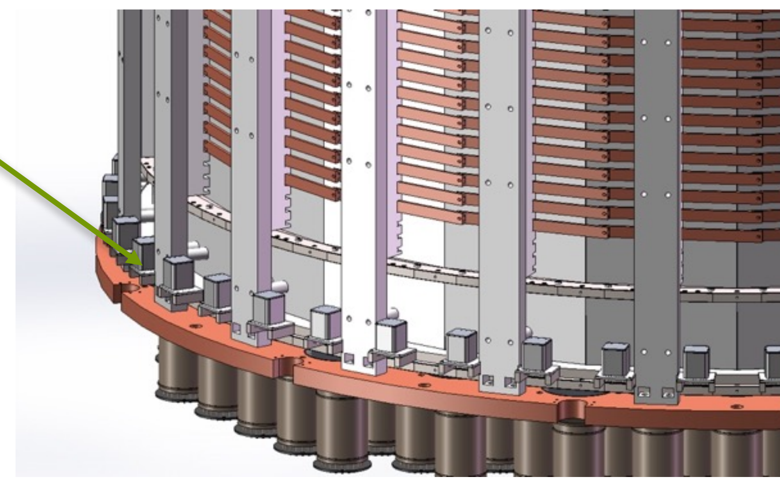


Veto System

- Xenon in skin area: 1 ton
- Suppress gamma background
  - Compton scattering in skin area
  - Veto efficiency 50% (50keV$_{ee}$)

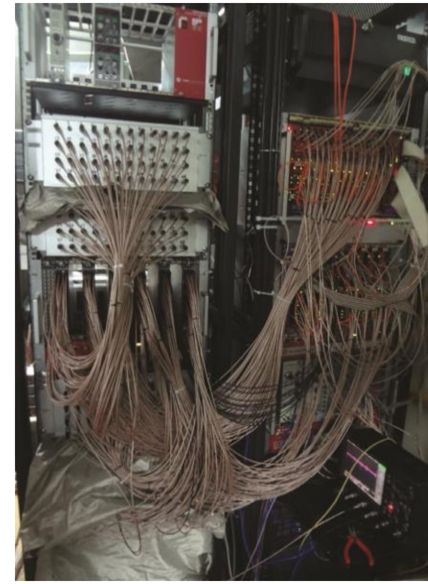
- 1” PMT:
  - 72 top and 72 bottom

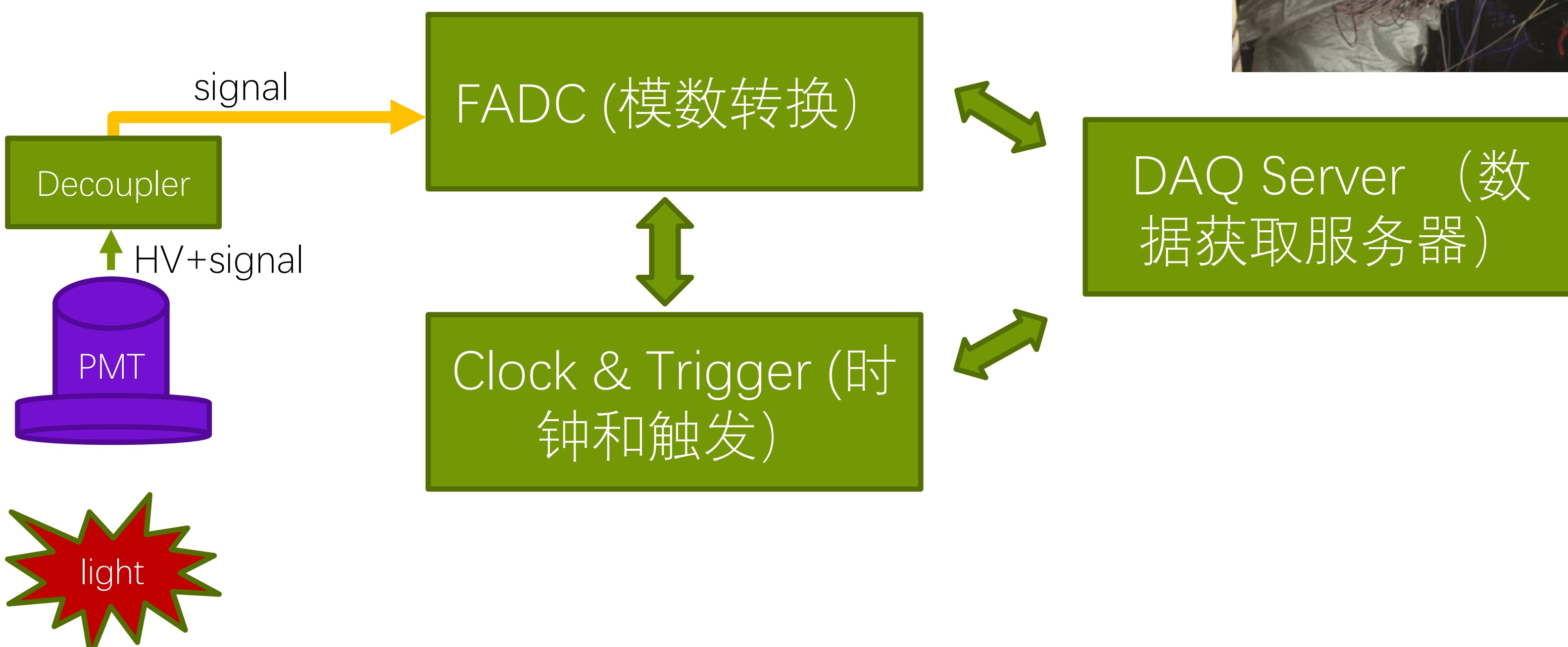




Electronics

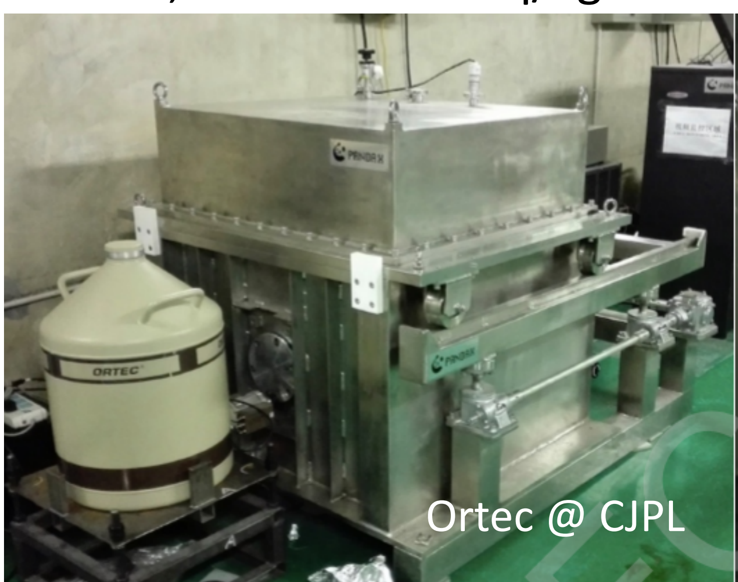
- More channels
  - 512 channels (including 3” PMT and 1” veto PMT)
- Lower threshold
  - Trigger-less data-taking
  - Multi-channel PMT readout



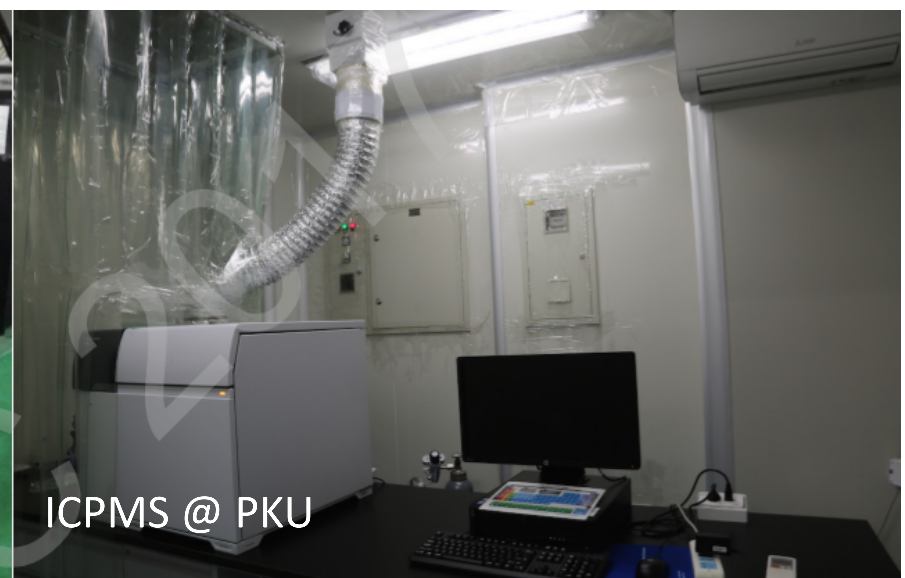


Background Control

- Germanium (Ge) detector and ICPMS
  - Measure the material radioactivity
  - Select pure materials for detector construction
- Inner and outer vessels
  - Stainless steel with the lowest radioactivity
  - Pure copper
- PTFE
  - ^{238}U, ^{232}Th < 0.5 mBq/kg



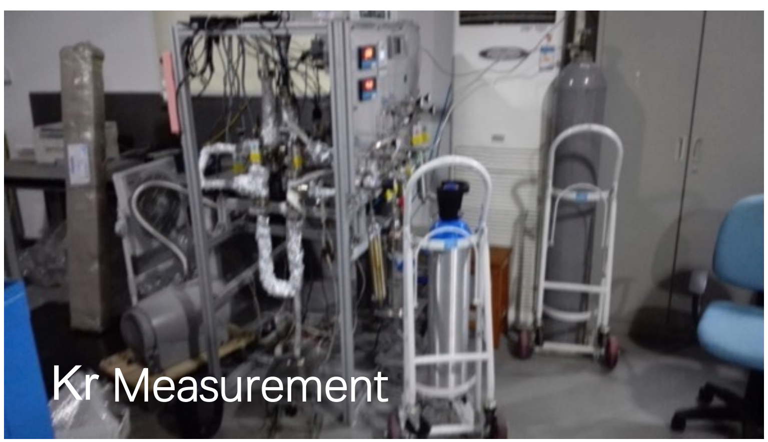
Ortec @ CJPL


ICPMS @ PKU

^{85}Kr Measurement and Rectification System

- ^{85}Kr could be a major background
- Rectifying tower at CJPL
  - ^{85}Kr 1ppb -> 1ppt for 5kg/hour
  - Secondary rectification -> 0.1 ppt
- ^{85}Kr measurement system
  - To reach a sensitivity of 0.1-0.01 ppt

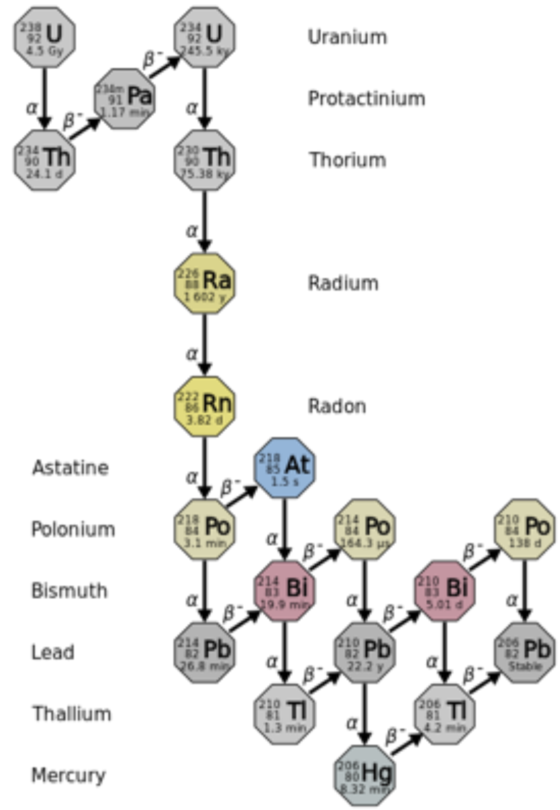
Item	Run 8 (mDRU)	Run 9 (mDRU)
^{85}Kr	11.7	1.19
^{127}Xe	0	0.42
^{222}Rn	0.06	0.13
^{220}Rn	0.02	0.01
Detector material ER	0.20	0.20
Total	12.0	1.95



(b) 精馏塔实际装置

^{222}Rn Control

- ^{222}Rn leaked into Xenon
- Current level at PandaX-II: 50μBq/kg
- For PandaX-4T, the goal is to reach 1μBq/kg



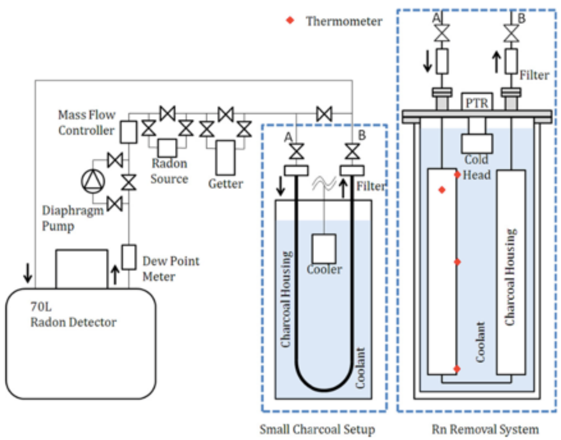
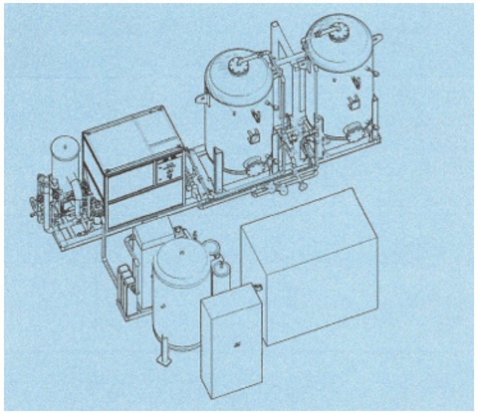


Fig. 1. Layout of the Xe circulation and Rn concentration measurement system. The charcoal traps are connected at points A and B. The right side of the figure shows th layout of the newly designed charcoal trap for XMASS with the location of its temperature sensors, which was also tested in the left side system.

Filtering system

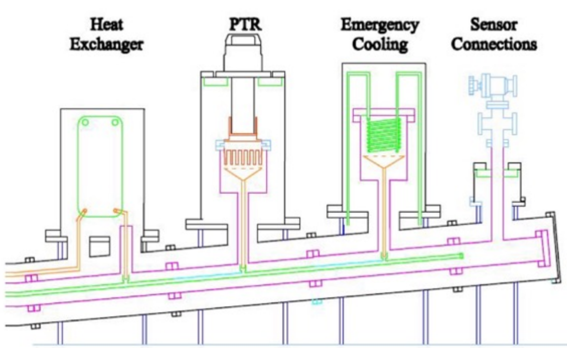
Measurement



Rn-free clean room

Xenon Handling: Storage, Cooling and Purification

- Storage: 5-6 ton xenon
  - 6set 4x4 (50kg, 40L)
  - Filling speed： 600 – 1000kg/day
- Cooling bus: 2 modules
  - modular design at PandaX-II(500kg)

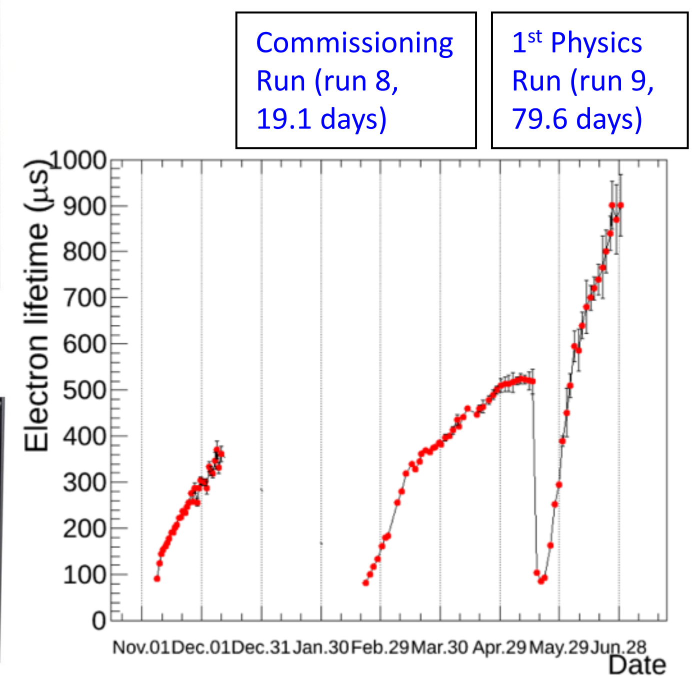


(a) 制冷总线的设计图

(b) 制冷总线实物装置

- Online purification
  - Remove impurities (O_2, H_2O)
  - Maintain a high electron life time

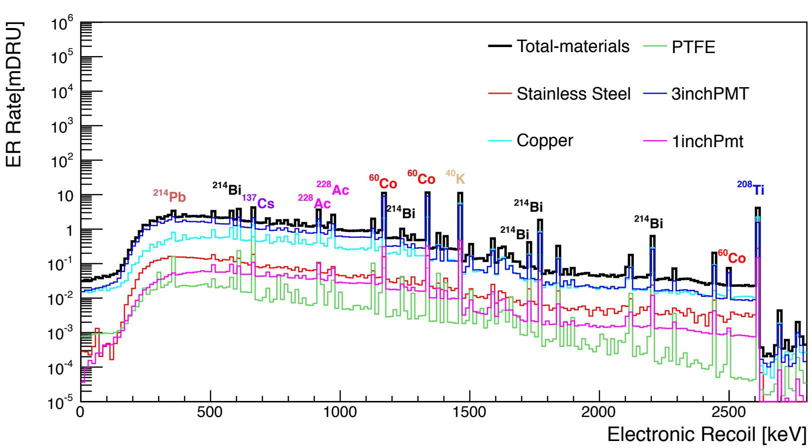
(b) 高温纯化器

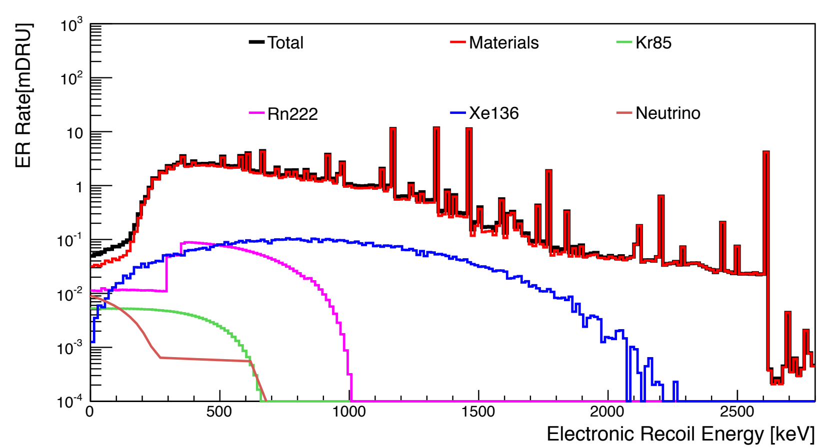


Background Level

- Background from materials and neutrino

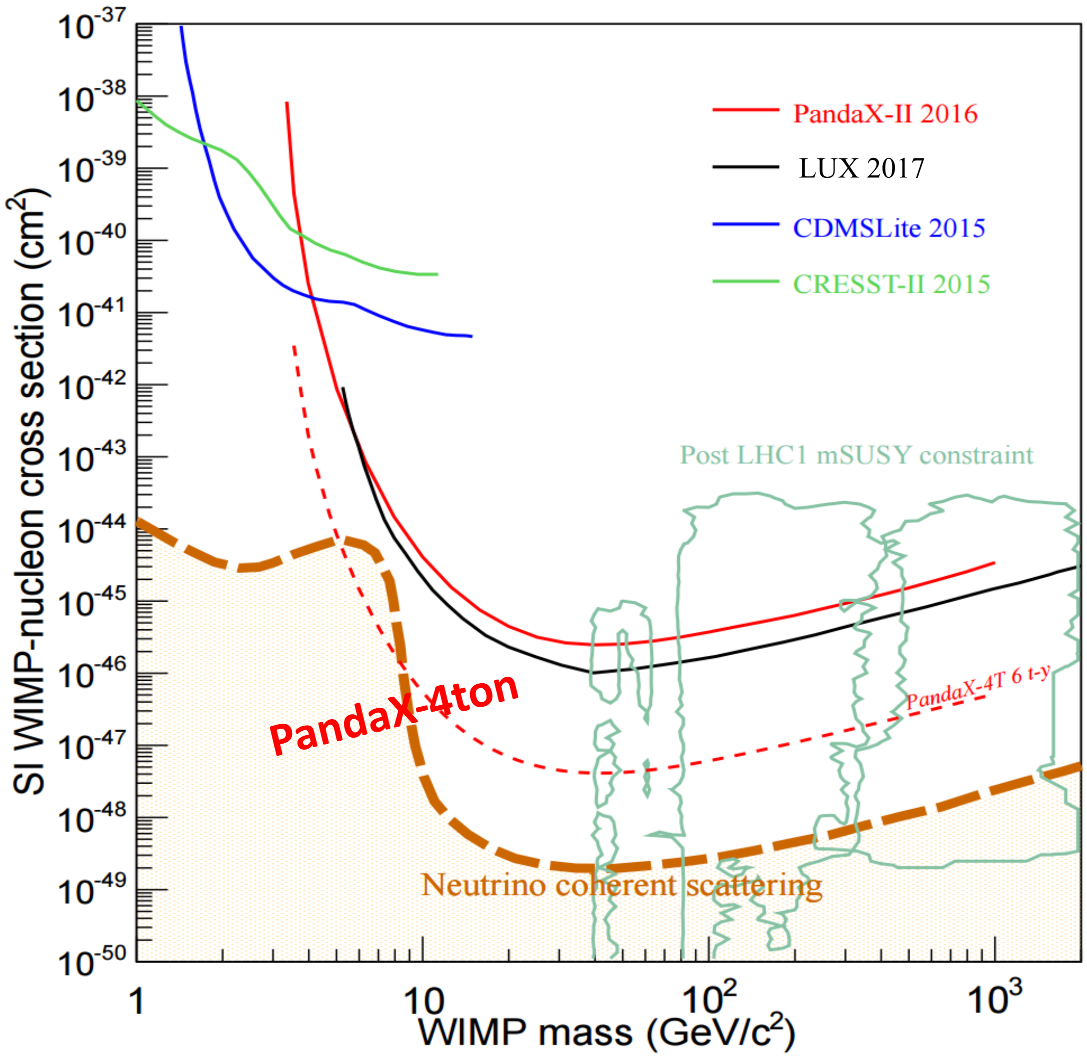
Background for DM search [0, 10 keV_{ee}]	mDRU
Electronic Recoil: materials	0.020
Electronic Recoil: ^{222}Rn	0.011 (1 μBq/kg)
Electronic Recoil: ^{85}Kr	0.005 (0.1 ppt)
Electronic Recoil: ^{136}Xe	0.002
Electronic Recoil: Solar Neutrino	0.009
Total Electronic Recoil	0.047
Total Nucleus Recoil	3 x 10^{-4}





Expected Sensitivity

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



Project Timescale

- 2016: Project R&D started
- 2017-2018: Produce all components and test
- 2019-2020: On-site assembling and commissioning
- 2021-2022: Data-taking

Summary and Outlook

- PandaX experiment with 500kg Xenon has reached the world frontier of dark matter direct detection.
- PandaX-4ton could be a multi-purpose detector for rare signal searches like dark matter, 0vbb and neutrino.
- The new detector is expected to have very high signal collection efficiency, high energy and positron reconstruction resolution and very low background.
- With 8-year's accumulation, PandaX collaboration plan to build the new experiment in the future ~4 years.

- **Thank you!**