TPC Tracker Detector Technology

Mini-workshop, IHEP, Beijing

TPC in PandaX

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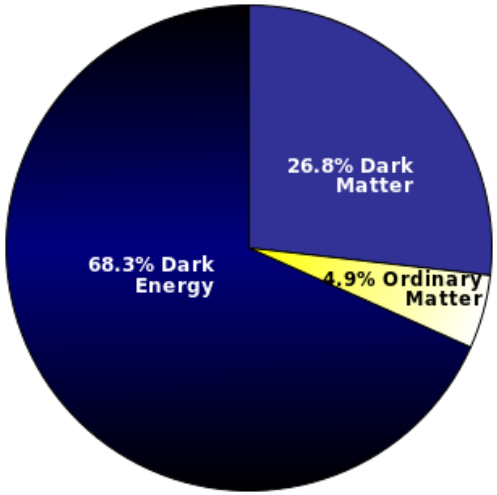
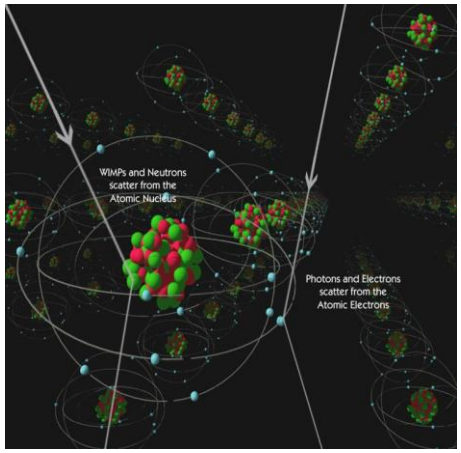
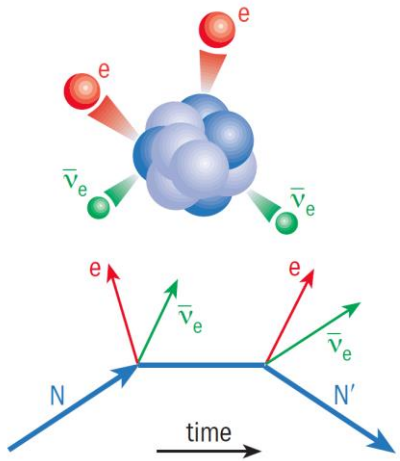
PandaX: Particle and astrophysical Xenon experiments

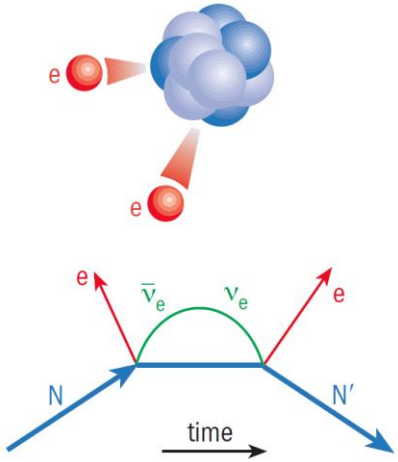
- Searching for new physics beyond the Standard Model with TPC
- Dark matter WIMPs
  - Explore the particle nature of dark matter
  - Recent results of PandaX-II got accepted by PRL
- Neutrinoless Double-Beta Decay
  - Directly check whether neutrinos are their own anti-particles: Majorana neutrinos
  - Test lepton number violation



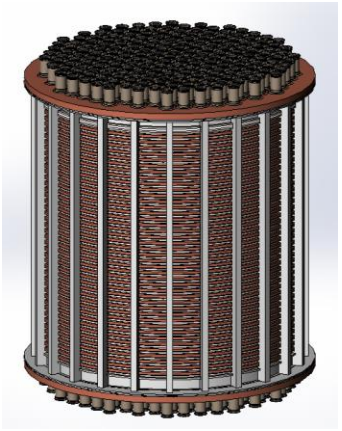


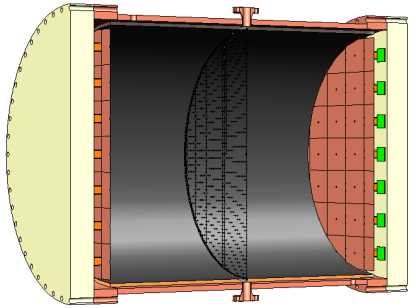
$\bar{\nu} = \nu$





PandaX Detectors



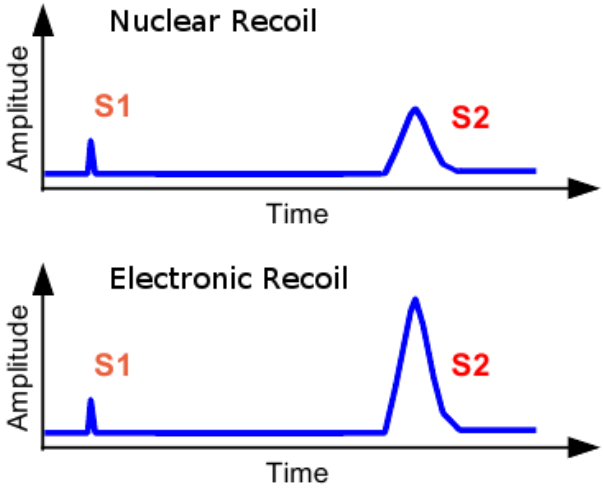


I: 120kg LXe DM
2009 - 2014

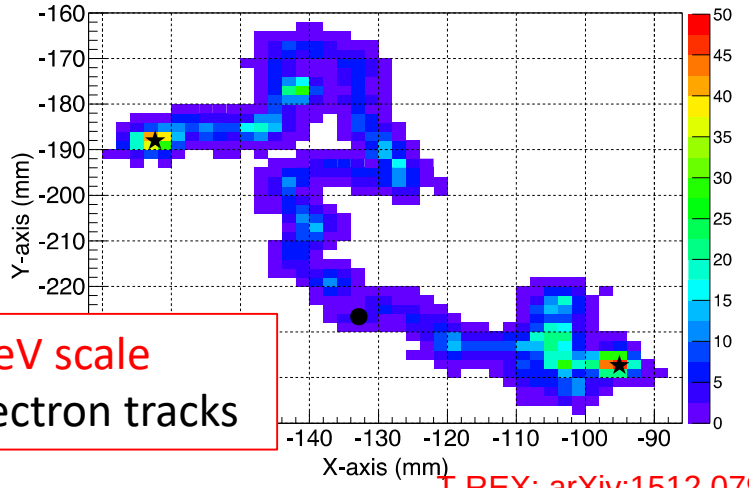
II: 500kg LXe DM
2014 - 2017

Multi-ton LXe DM
2017 -

III: 200kg - 1 ton HPXe 0νββ
2016 - 2022



keV scale
nuclear recoil
signal

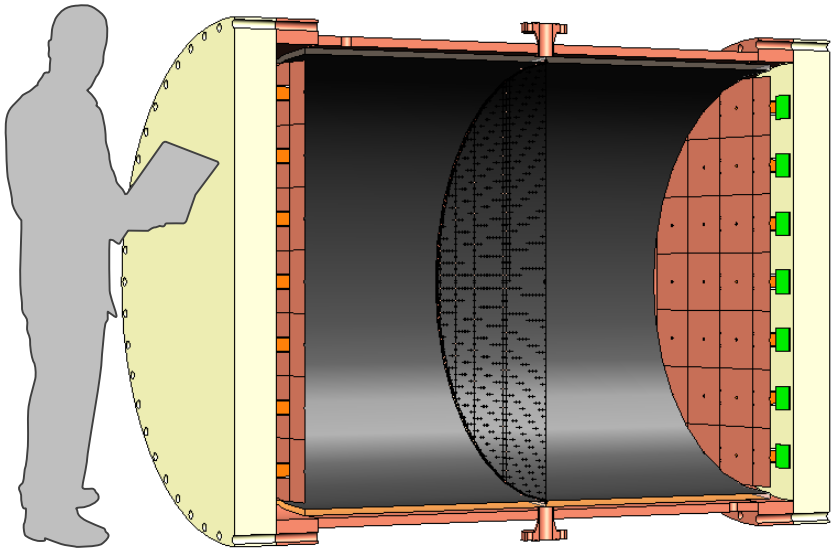


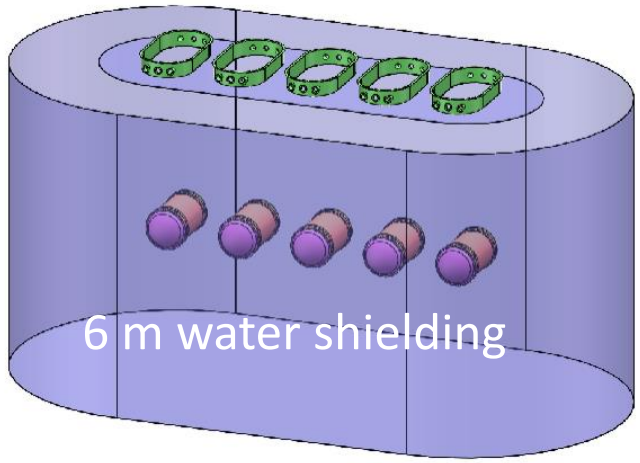
MeV scale
electron tracks

T-REX: arXiv:1512.07926

PandaX-III: The first large-scale NDBD experiment in China

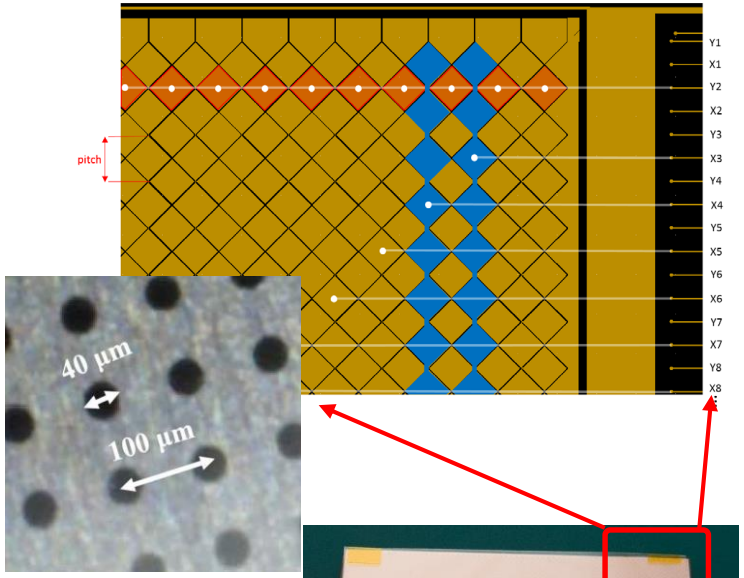
- TPC: 200 kg scale, symmetric, double-ended charge readout with cathode in the middle
  - Charge readout plane: tiles of square microbulk Micromegas (MM) modules with X, Y strips
  - The largest low-background high pressure TPC
- Four more upgraded modules for a ton scale experiment
- PandaX-III will be located at Hall #B4 at China Jin Ping underground Laboratory (CJPL-II).

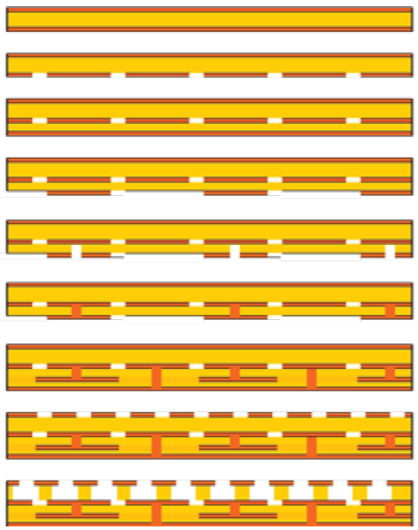




Microbulk MicroMegas

- Microbulk MicroMegas films made of Copper and Kapton only
  - Perfect for radio-purity purpose
- 20 cm by 20 cm
- XY strip readout; 3mm pitch size; 128 channel
- 100 ~ 1000 gain
- 3% energy resolution at 2.5 MeV





Double side Cu-coated (5 μm) Kapton foil (50 μm)

Construction of readout strips/pads (photolithography)

Attachment of a single-side Cu-coated kapton foil (25/5 μm)

Construction of readout lines

Etching of kapton

Vias construction

2nd Layer of Cu-coated kapton

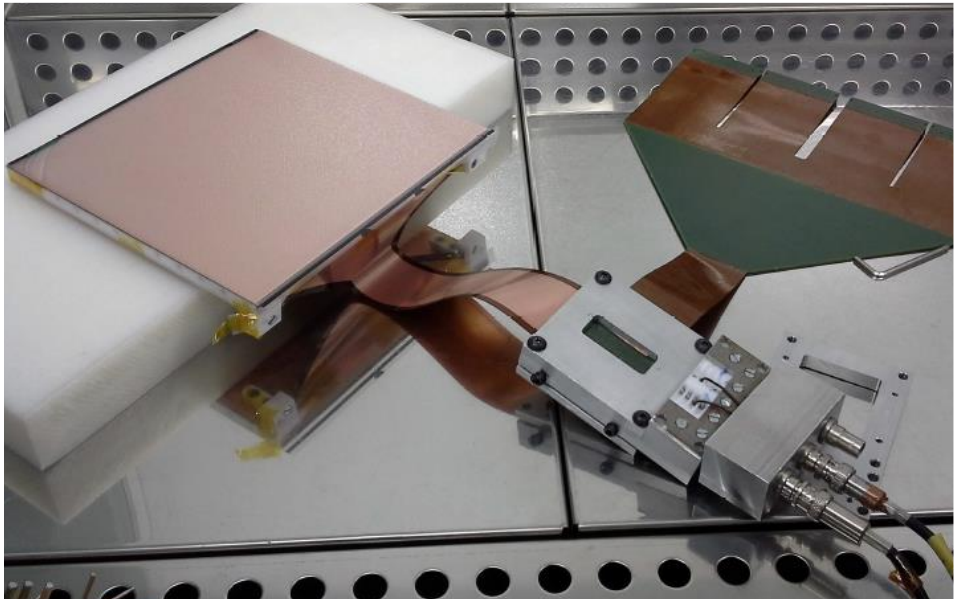
Photochemical production of mesh holes

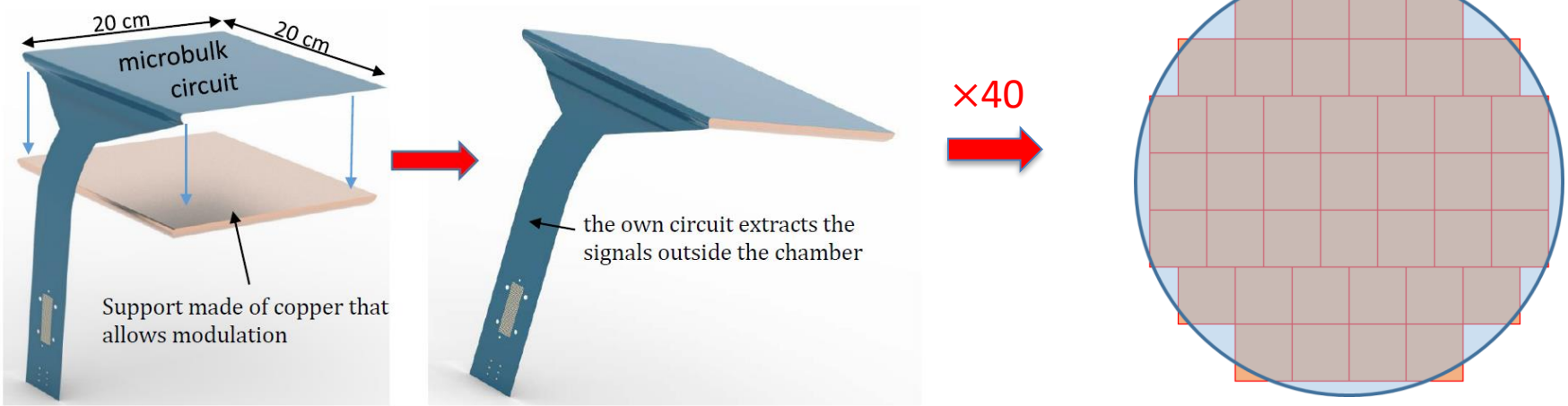
Kapton etching / Cleaning

Andriamonje, S. et al. JINST 02 (2010): P02001

Scalable Radio-pure Readout Module (SR2M)

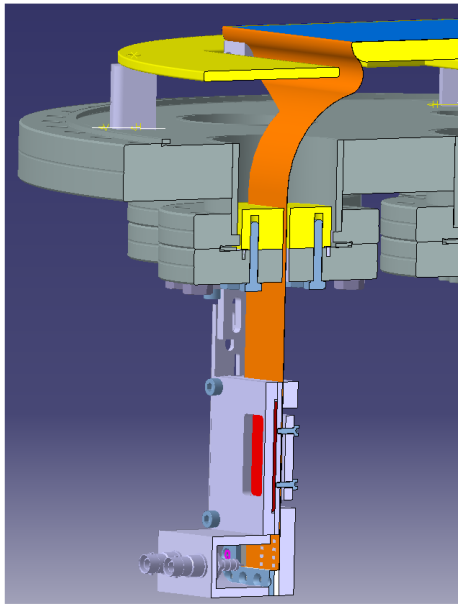
- Scalable Radio-pure Readout Module (SR2M): Mosaic layout to cover large readout planes
  - Solderless system to extract pixel and mesh signal
  - Dead-zone-free arrangement
- Two SR2Ms produced at CERN, now being tested at SJTU and Zaragoza
  - 20 by 20 cm



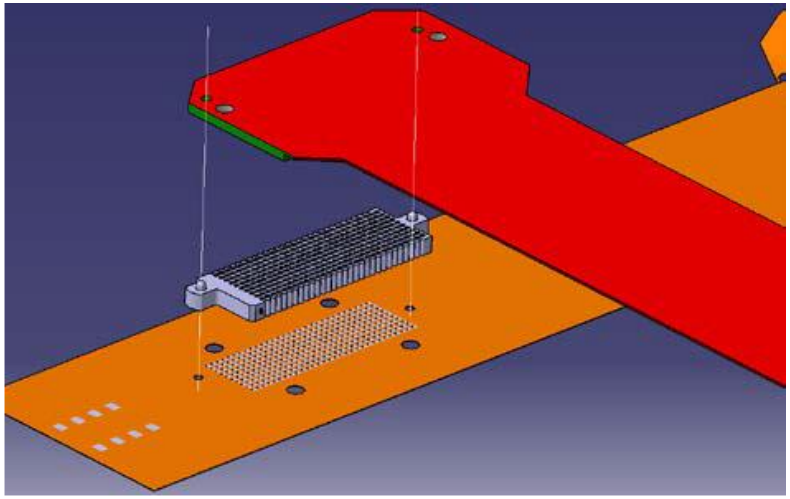


More SR2M design features

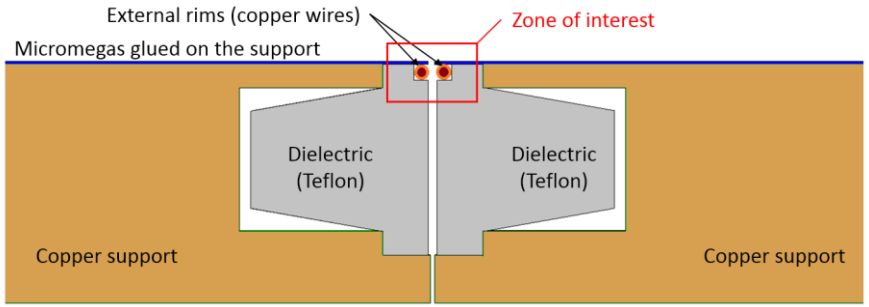
Hermetic seal

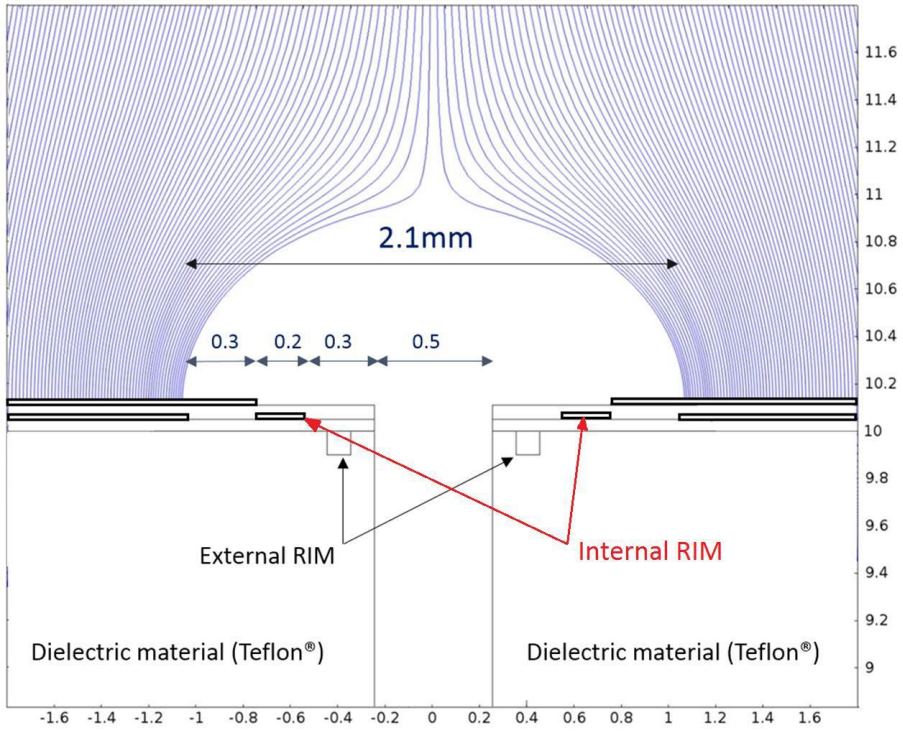


Electrical connection



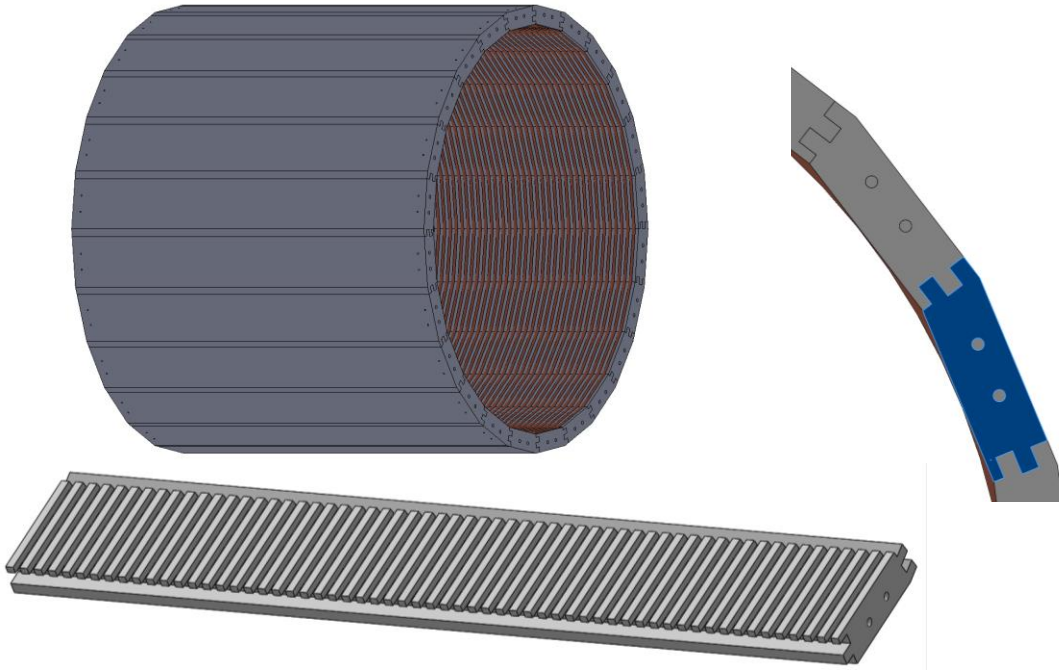
Joining two SR2Ms



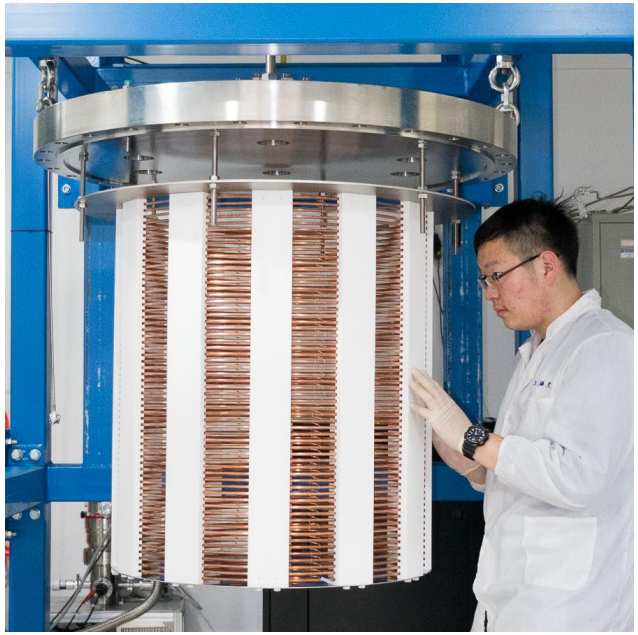


TPC Field Cage – option 1 (mature)

- Copper shaping rings + resistors + external Teflon (or Acrylic) supporting bars
  - Mature technology
  - Used and tested extensively in PandaX-I and PandaX-II
- Supporting bars are critical
  - Dielectric strength
  - Displacer for ^{136}Xe

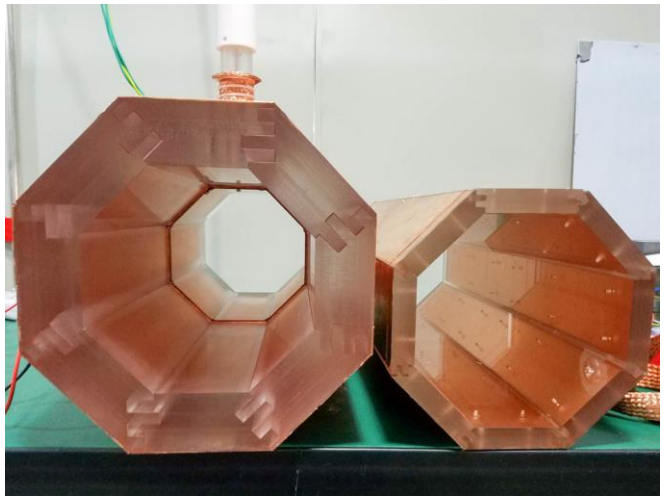


PandaX-III prototype TPC; showing the field cage

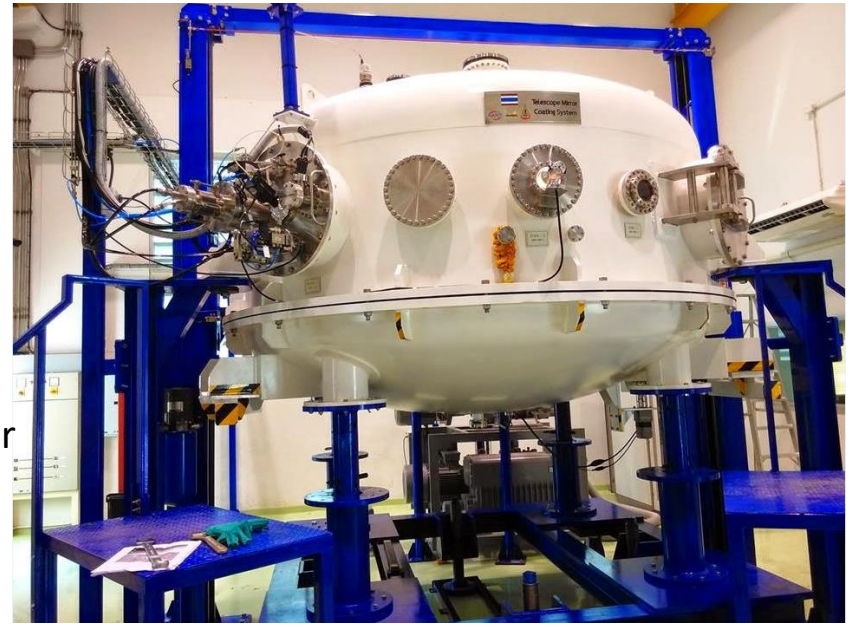


TPC Field Cage – option 2 (more elegant)

- Resistive coating on the acrylic pieces. The resistive layer works as continuous field shaping rings.
  - No more resistors
  - No more soldering
  - No copper rings
- Diamond-like carbon sputtering was developed for MM for ATLAS.
  - Can be very thin and resistive



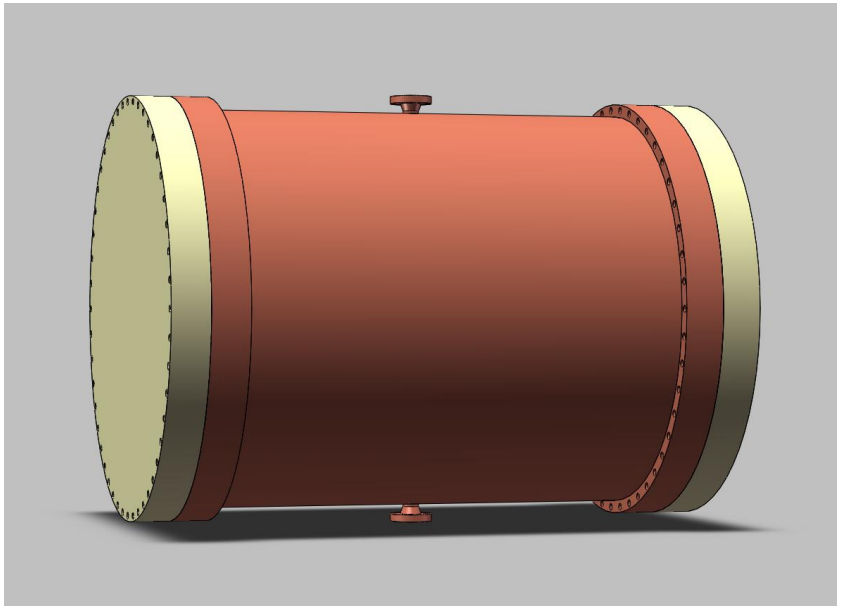
- Challenges remain:
  - Uniformity of the coated resistivity
  - Radio-purity
  - Cost
- SUT (Thailand) is collaborating with SJTU on developing this option

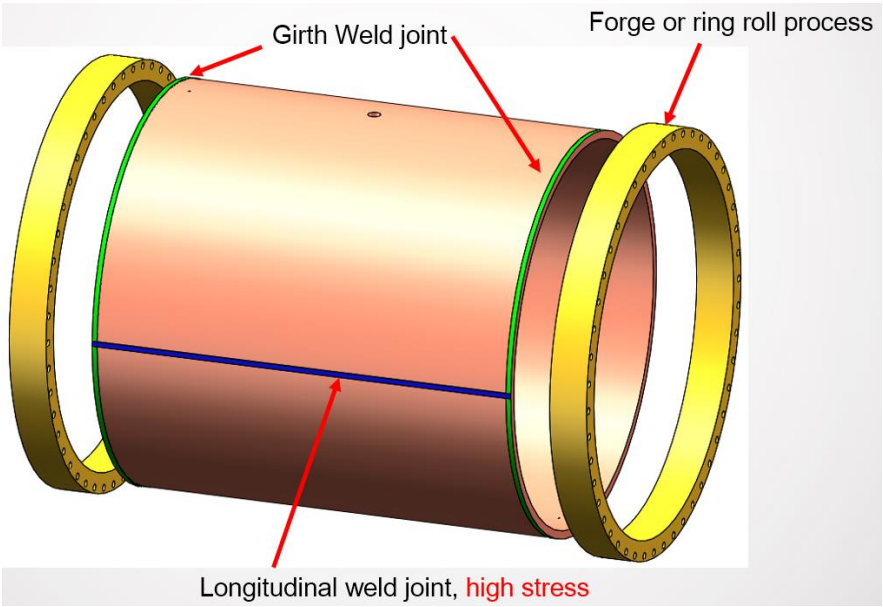


Large sputter station at NARIT (SUT has access)

High pressure vessel

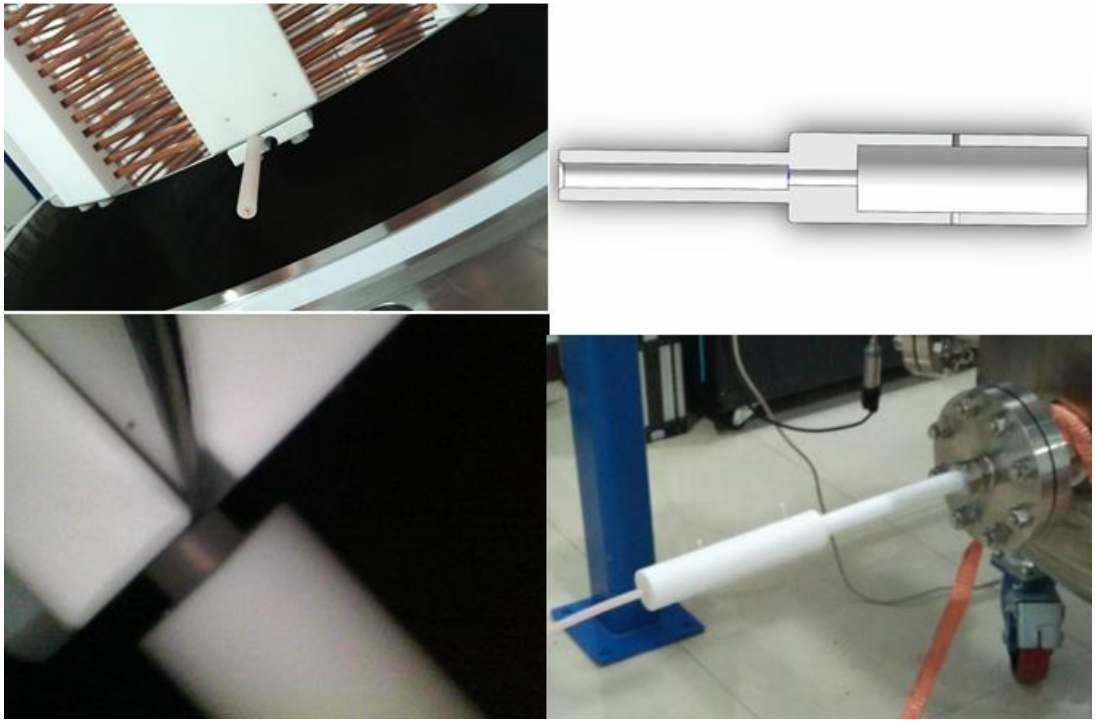
- High gas pressure and radio-pure
- Baseline approach: oxygen-free copper welded with E-beam technique
  - Technologically challenging
  - Still a major contributor to our background budget
- Alternatively:
  - Titanium vessel with copper lining
  - SS vessel with copper lining





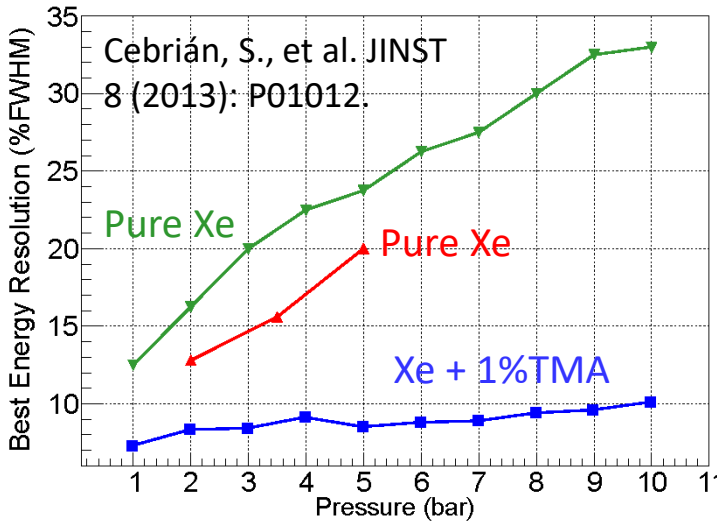
High voltage system

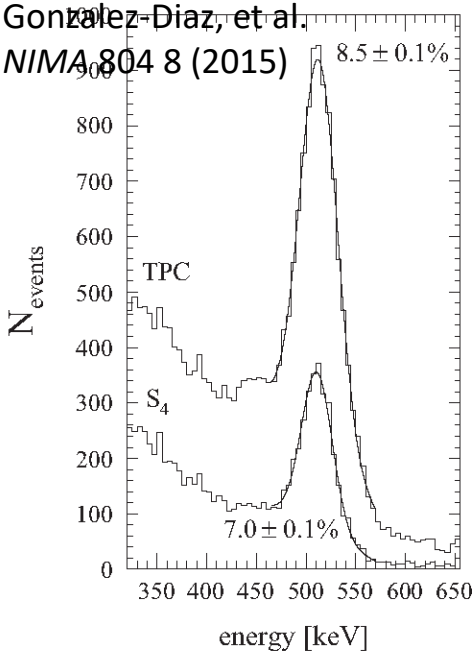
- Feedthrough for high voltage and withstand 10 bar gas pressure
  - Teflon wrap with a stainless steel core
  - Squeezed by a Swagelok for gas tightness
- Tested on the prototype TPC
  - 70 kV in air
  - 95 kV in 10 bar N_2

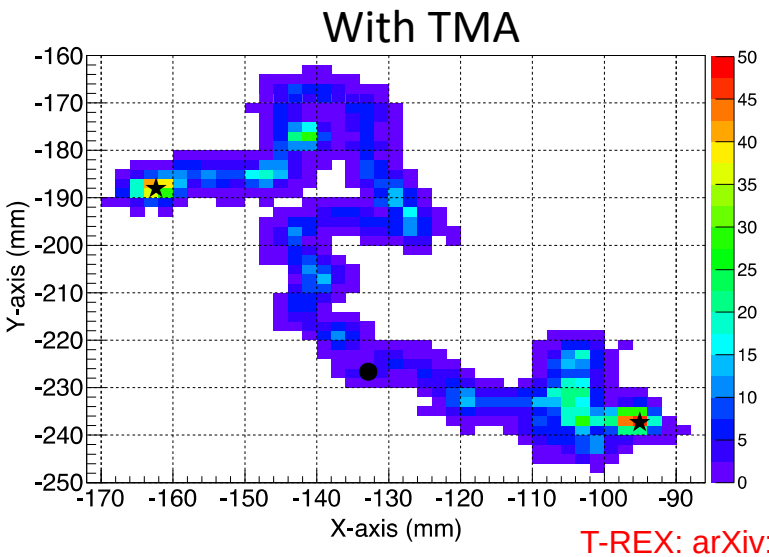


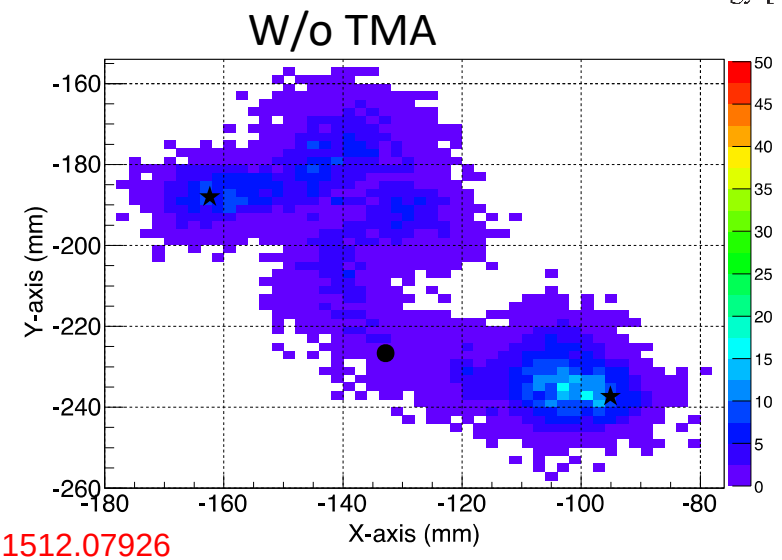
Xe +TMA mixture

- Better energy resolution
  - Extrapolated from 511keV and 1.2MeV peaks: 3% FWHM (@$Q_{0\nu\beta\beta}$)
- Better tracks
  - TMA suppress electron diffusion
- Better operation
  - TMA as a quencher





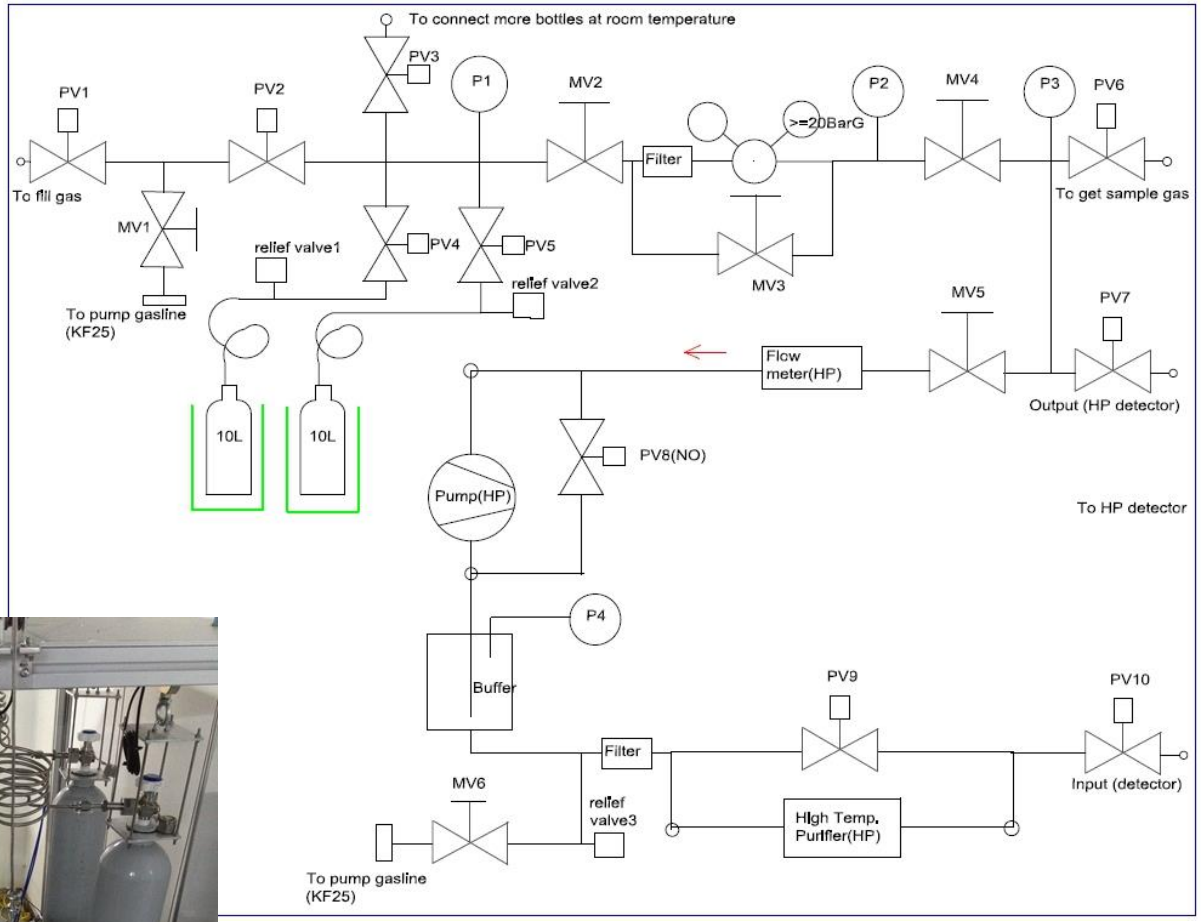


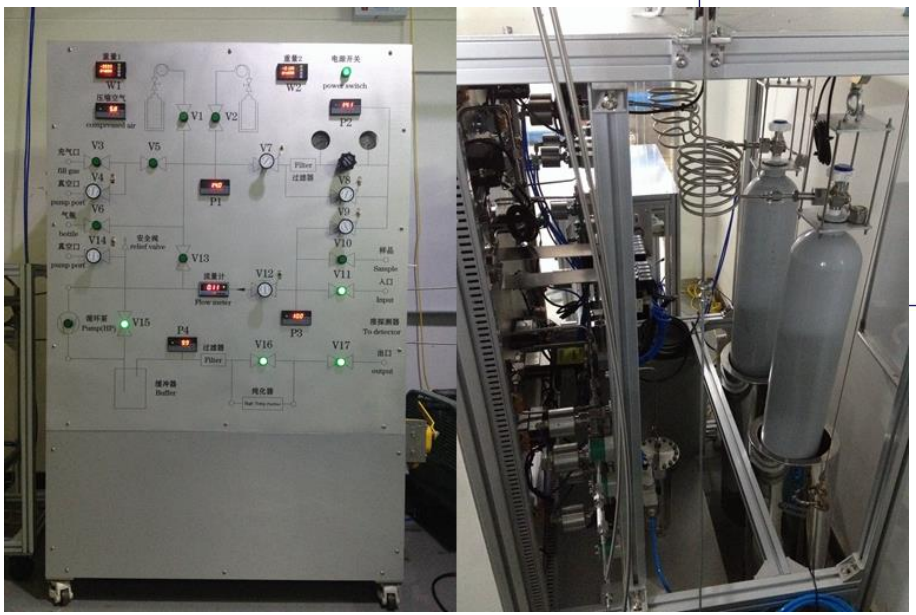


T-REX: arXiv:1512.07926

Gas handling system

- A gas handling system at high pressure (10 bar) was designed and manufactured.
- Used successfully for mixing Xe and TMA and extracting TMA from Xe.



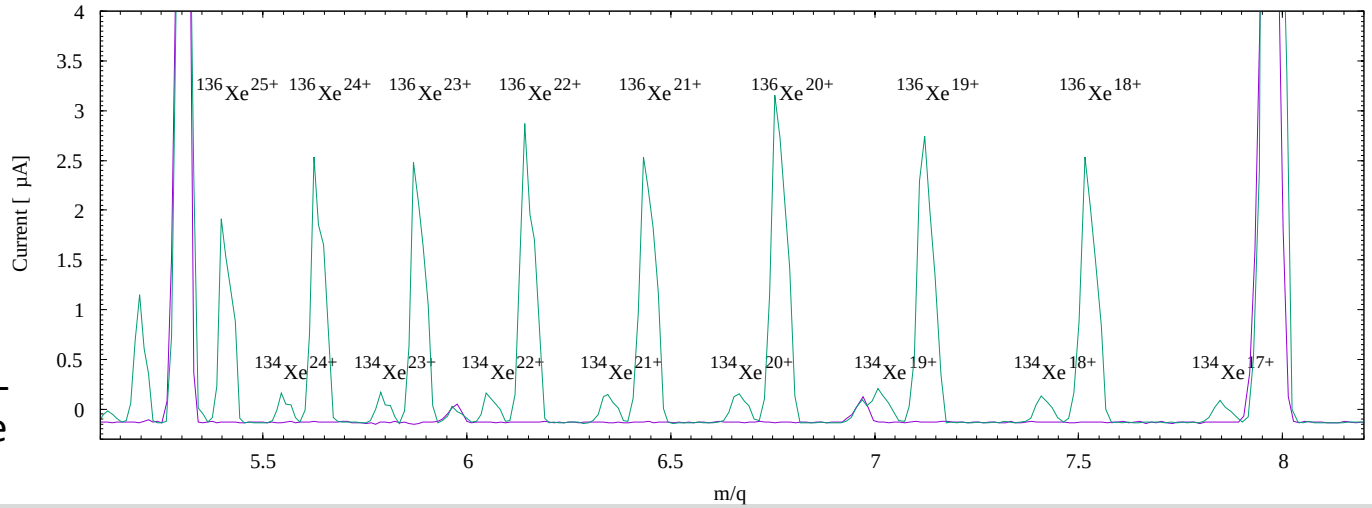


- An online gas analyzing system is being added.

^{136}Xe enriched gas

- 145 kg of 90% Xe-136 enriched gas purchased and arrived at SJTU.
- Gas content measured at LBNL with an ion source and double checked at SJTU with a sniffer.
- 55 kg more will be procured later this year.

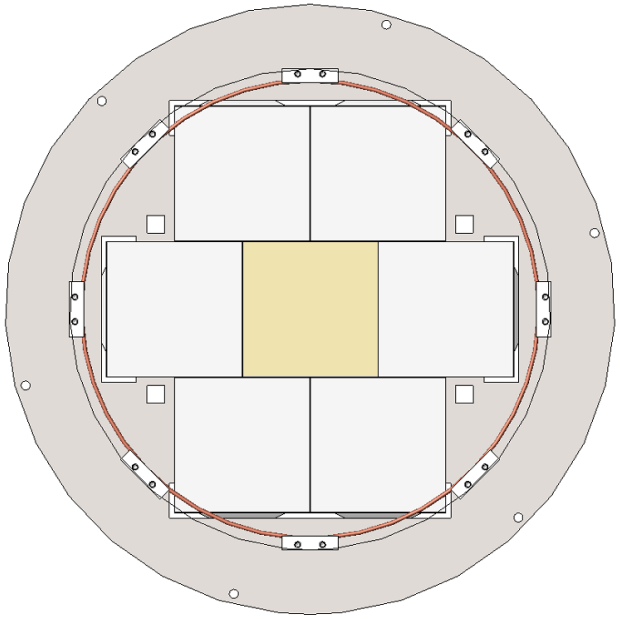
Results from LBNL ion source

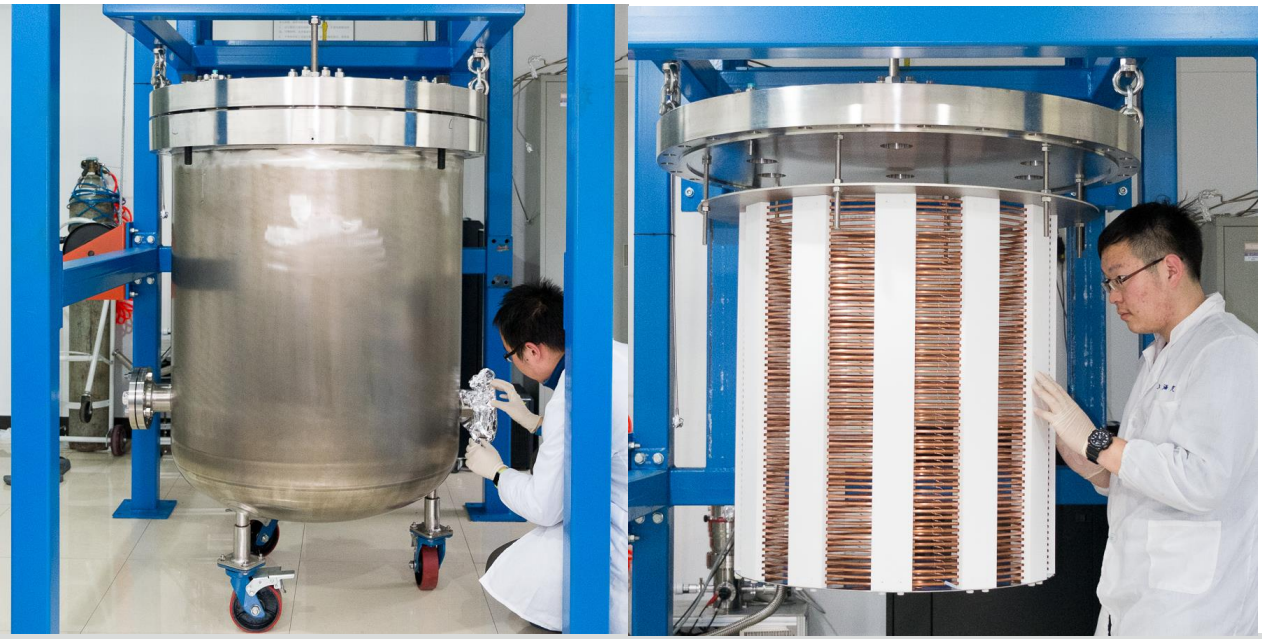


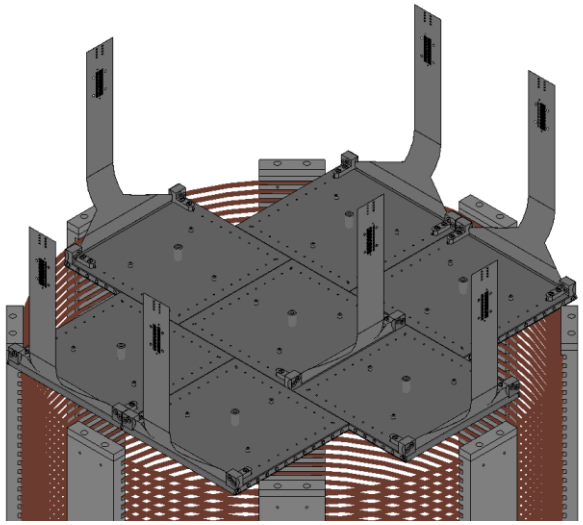
Prototype TPC at SJTU

- 16 kg of Xenon at 10 bar (active mass within TPC)
  - Single-ended TPC

- To optimize the design of Micromegas readout plane
- To study the energy calibration of TPC
- To develop algorithm of 3D electron track reconstruction

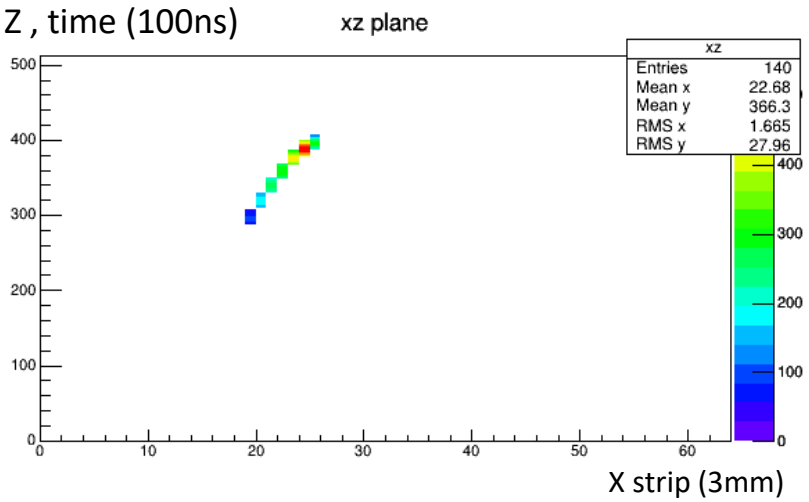


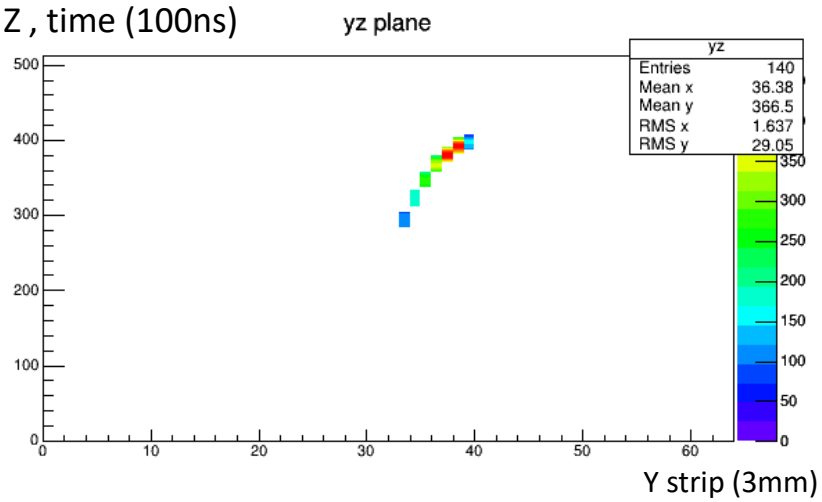


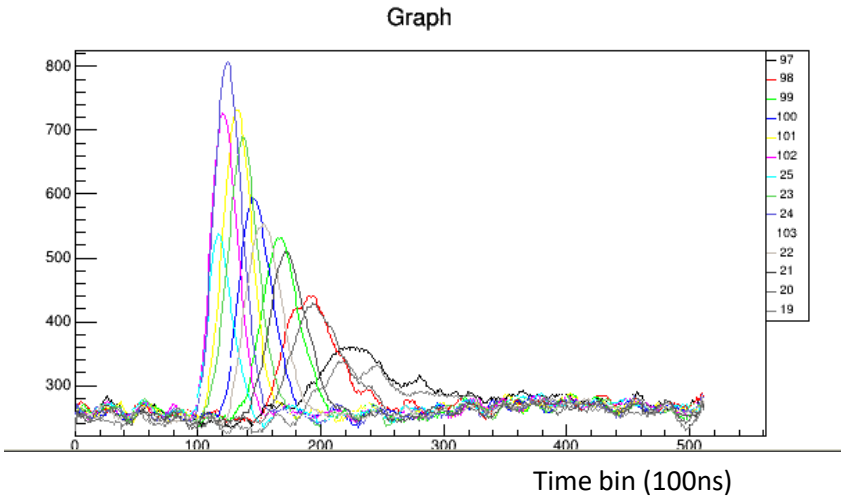


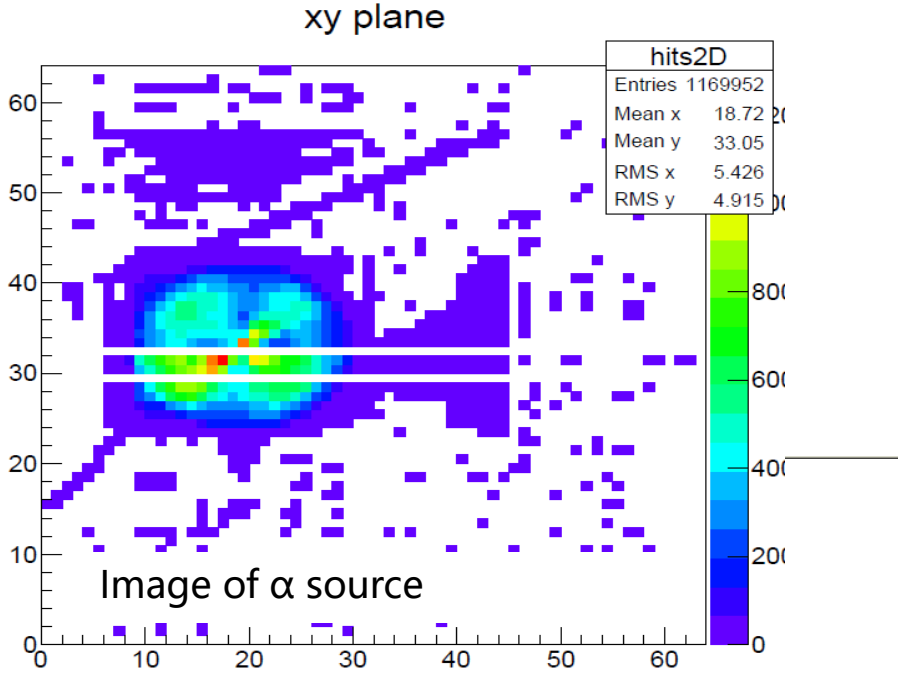
7 MicroMegas

2D track


Z , time (100ns)
xz plane
xz
Entries 140
Mean x 22.68
Mean y 366.3
RMS x 1.665
RMS y 27.96
X strip (3mm)

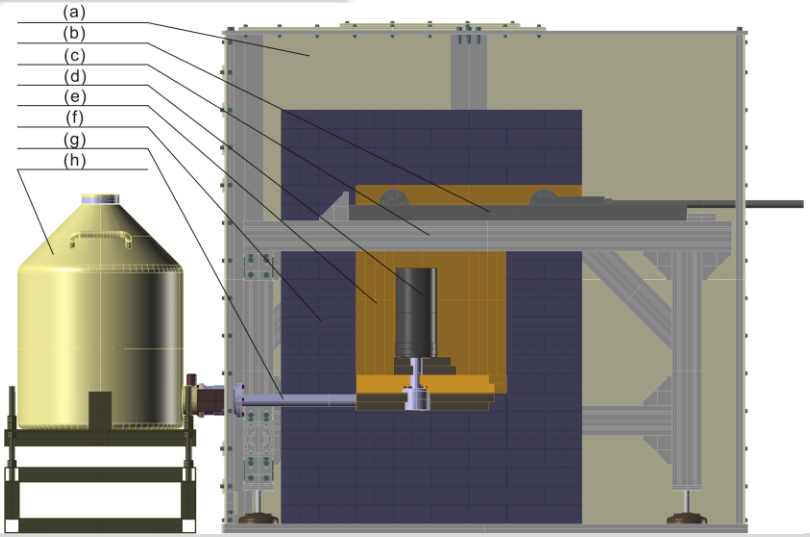

Z , time (100ns)
yz plane
yz
Entries 140
Mean x 36.38
Mean y 366.5
RMS x 1.637
RMS y 29.05
Y strip (3mm)


Graph
Time bin (100ns)


xy plane
hits2D
Entries 1169952
Mean x 18.72
Mean y 33.05
RMS x 5.426
RMS y 4.915
Image of α source

Radio-purity control

- ICP-MS recently commissioned at PKU (Beijing)
  - Agilent 7900 ICP-MS
  - Class 10 clean room; class 1 for the ICP-MS hood
- HPGe detectors at CJPL and SJTU
- Low radioactivity environment
  - Radon sealant on the wall of Hall 4
  - Rn-free air in the detector assembly region of the lab
  - Rn-control in water shield
  - Rn-emanation measurements
- Copper vessel and SS bolts are the main contributors to background budget.

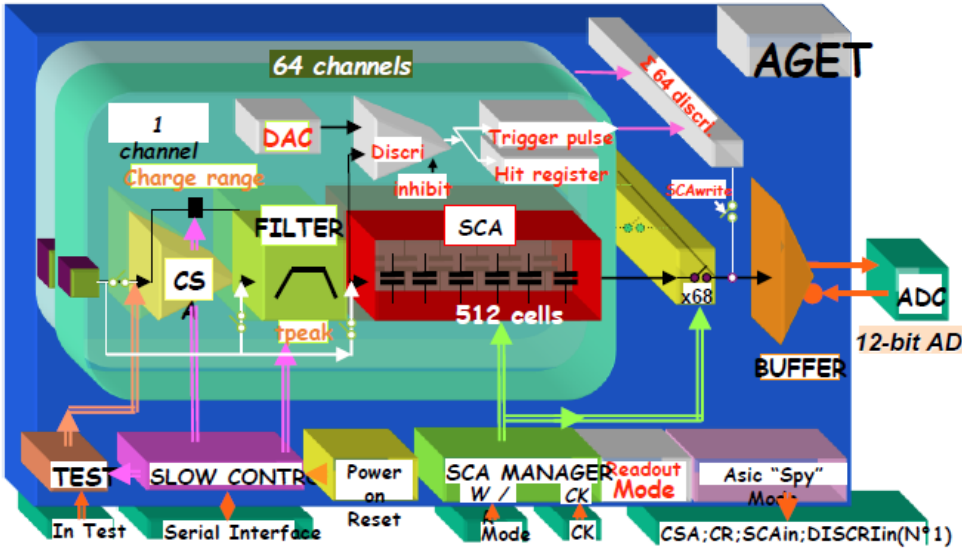


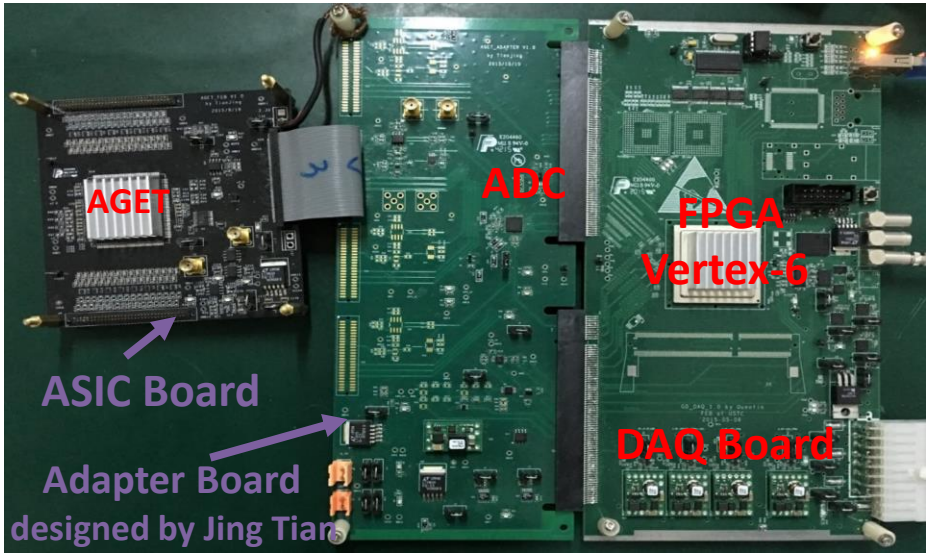
Electronics

- ASIC AGET chips: generic electronics for TPC from CEA-Saclay
  - 350 nm CMOS, mature technology
  - 64 channel multiplex
  - 512 sampling point per channel
  - 12 bit ADC
  - Dynamic range up to 10 pC
  - Sampling rate: 1 MHz to 100 MHz

Ensure high energy resolution

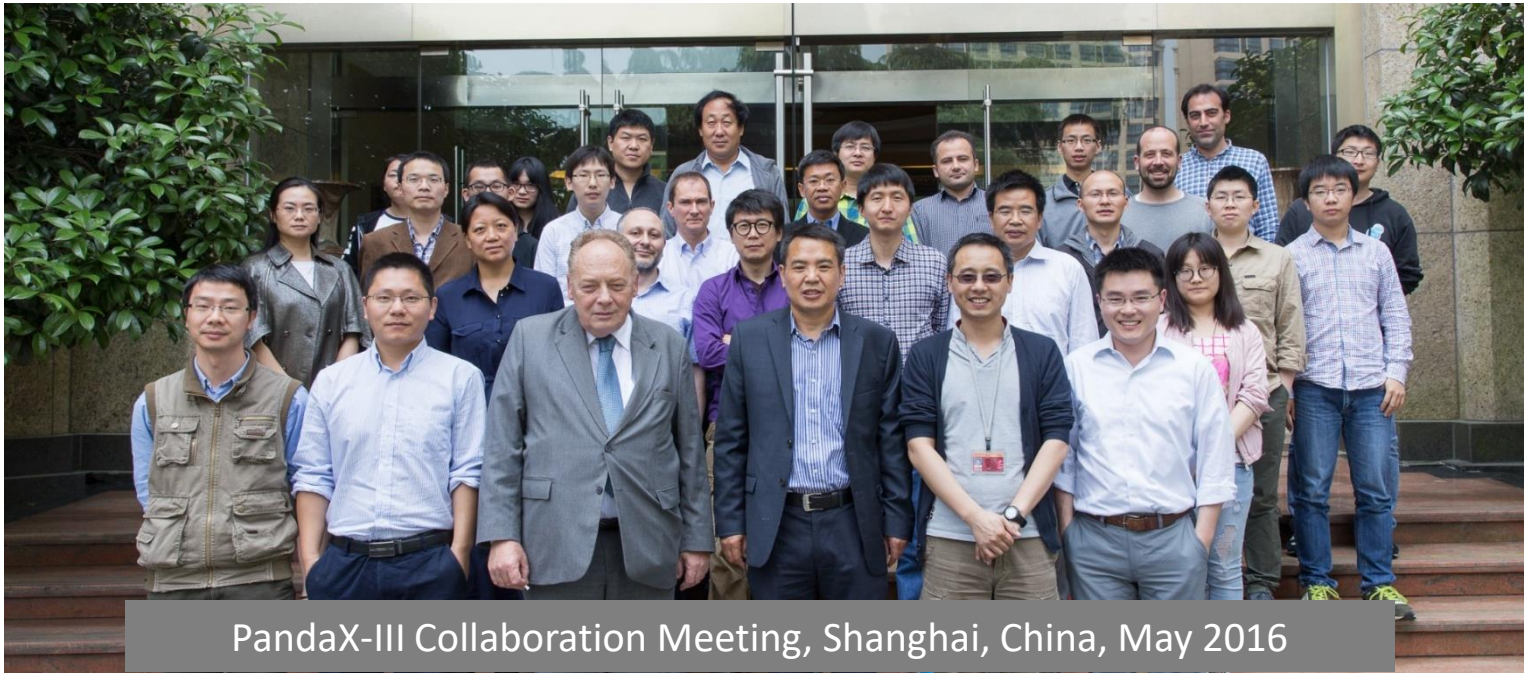
AGET and the commercial version ASAD are being tested and studied at Zaragoza, USTC, and SJTU





PandaX-III collaboration

- China: Shanghai Jiao Tong University, University of Science and Technology of China, Peking University, China Institute of Atomic Energy, Shandong University, Sun Yat-Sen University, Central China Normal University
- Spain: Universidad de Zaragoza
- France: CEA Saclay
- US: University of Maryland, Lawrence Berkeley National Laboratory
- Thailand: Suranaree University of Technology



PandaX-III Collaboration Meeting, Shanghai, China, May 2016

Conclusion

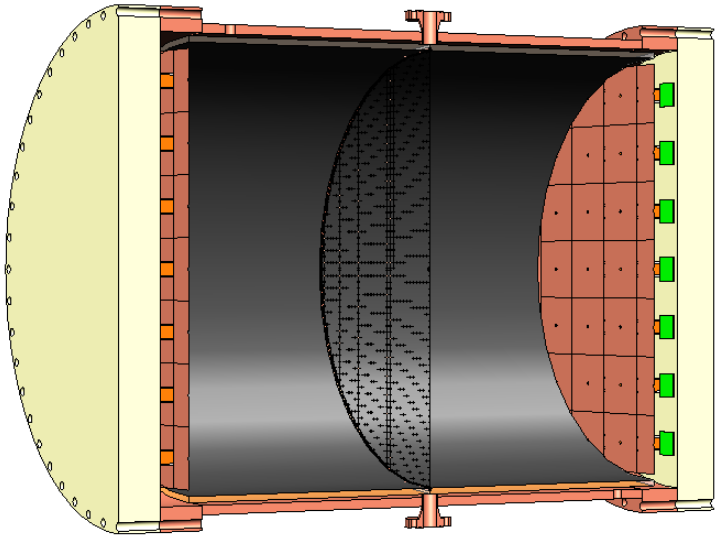
- PandaX-III is using a high pressure xenon TPC to search for double beta decay

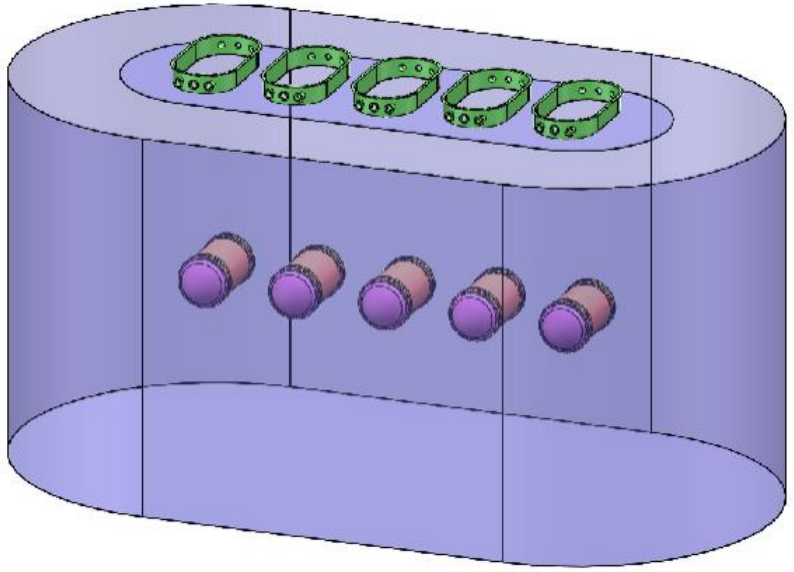
PandaX-III TPC is unique:

- Radio-purity
- Energy resolution
- High pressure

Shared TPC technology:

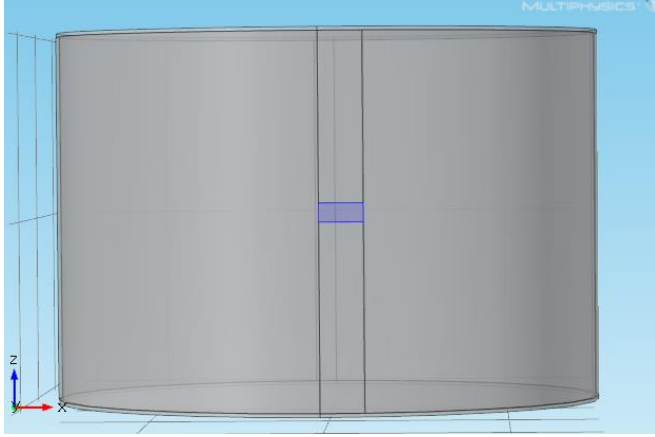
- Micromegas
- Electronics
- Energy and track reconstruction



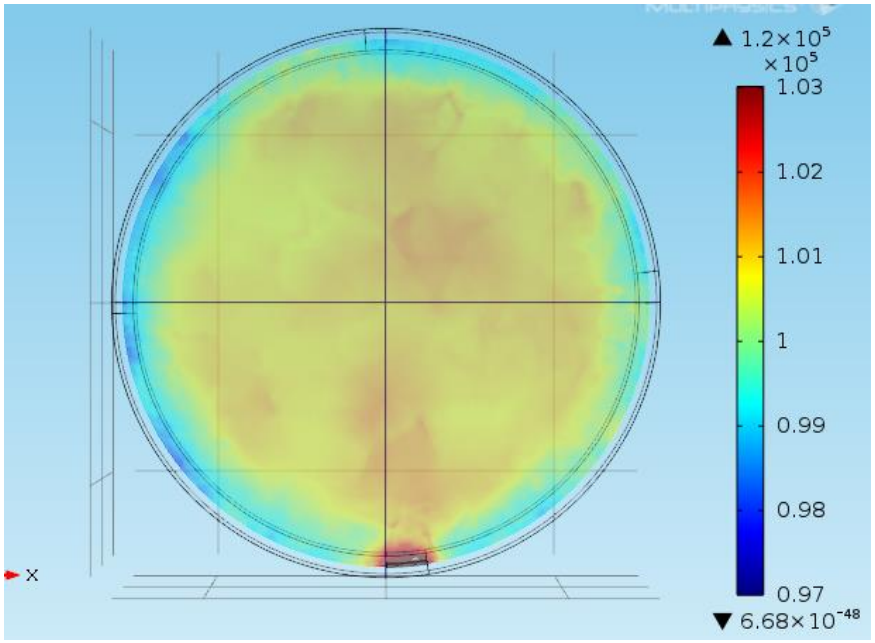


How the field changes with thickness

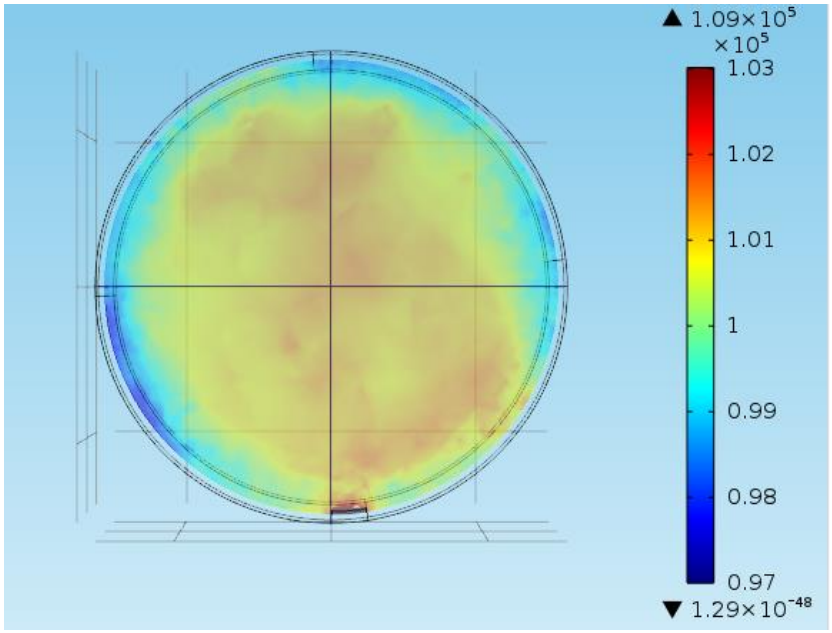
Width 12cm



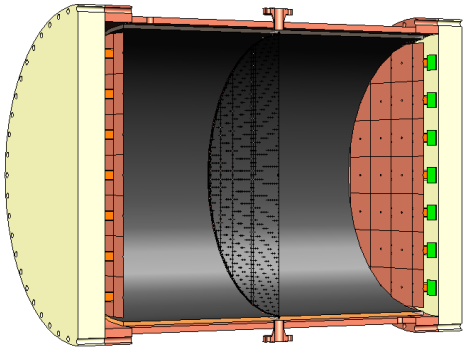
20%thinner
Max:120% of the average;
E field deviation goes below 5% in 3 cm from the boundary ;

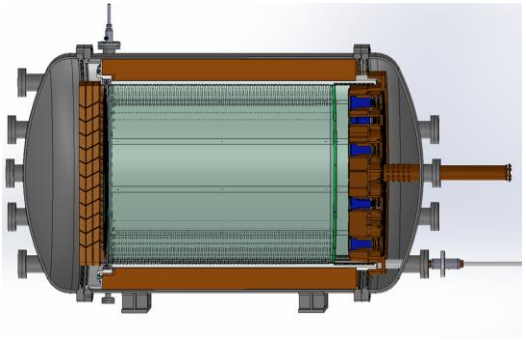


10%thinner
Max:109% of the average;
E field deviation goes below 5% in 1.7cm from the boundary ;



PandaX vs. NEXT





PandaX-III first TPC		NEXT-100
200 kg Xe(enriched) + 1% TMA	Detector medium	100 kg pure Xe (enriched)
----------	Light	Primary + electroluminescence light readout by PMTs
Micromegas	Charge/Tracking	SiPM
3%	Projected energy resolution	0.7%
2-3 mm	Tracking pitch size	1 cm
X,Y	Fiducialization	X,Y,Z
Since 2015		Since ~2008

Xe+TMA

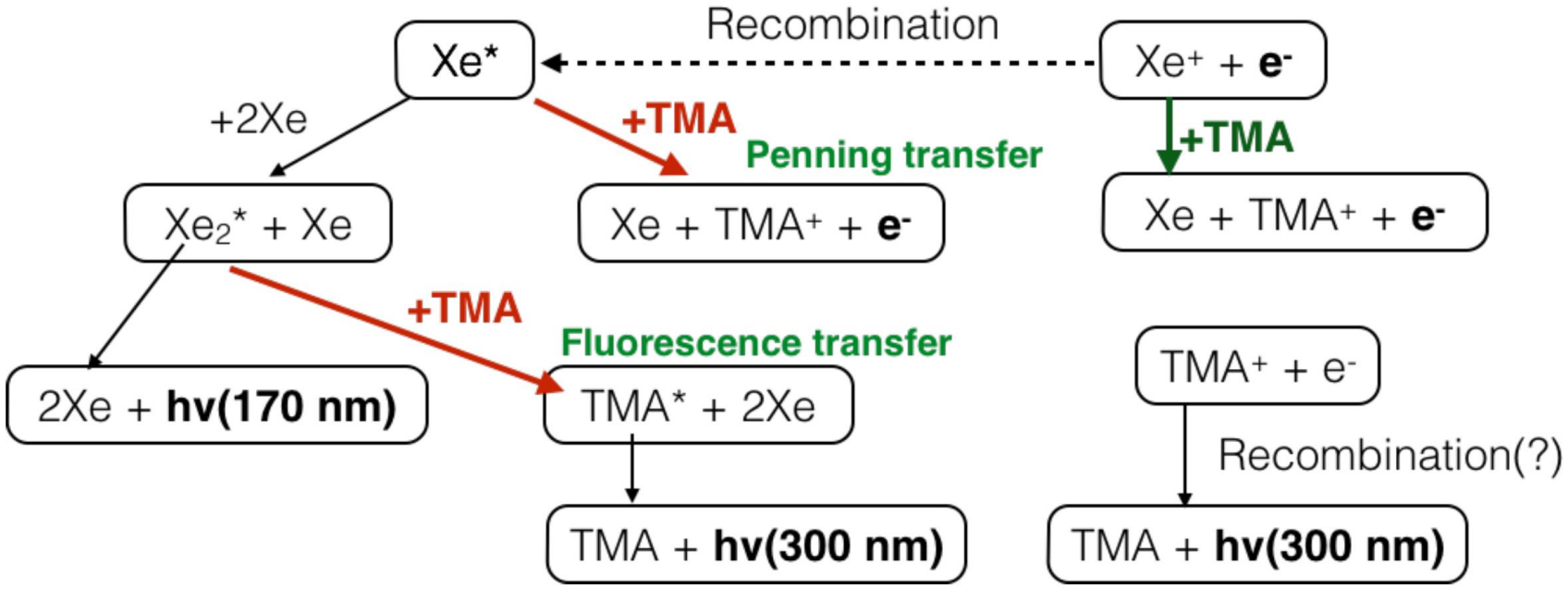
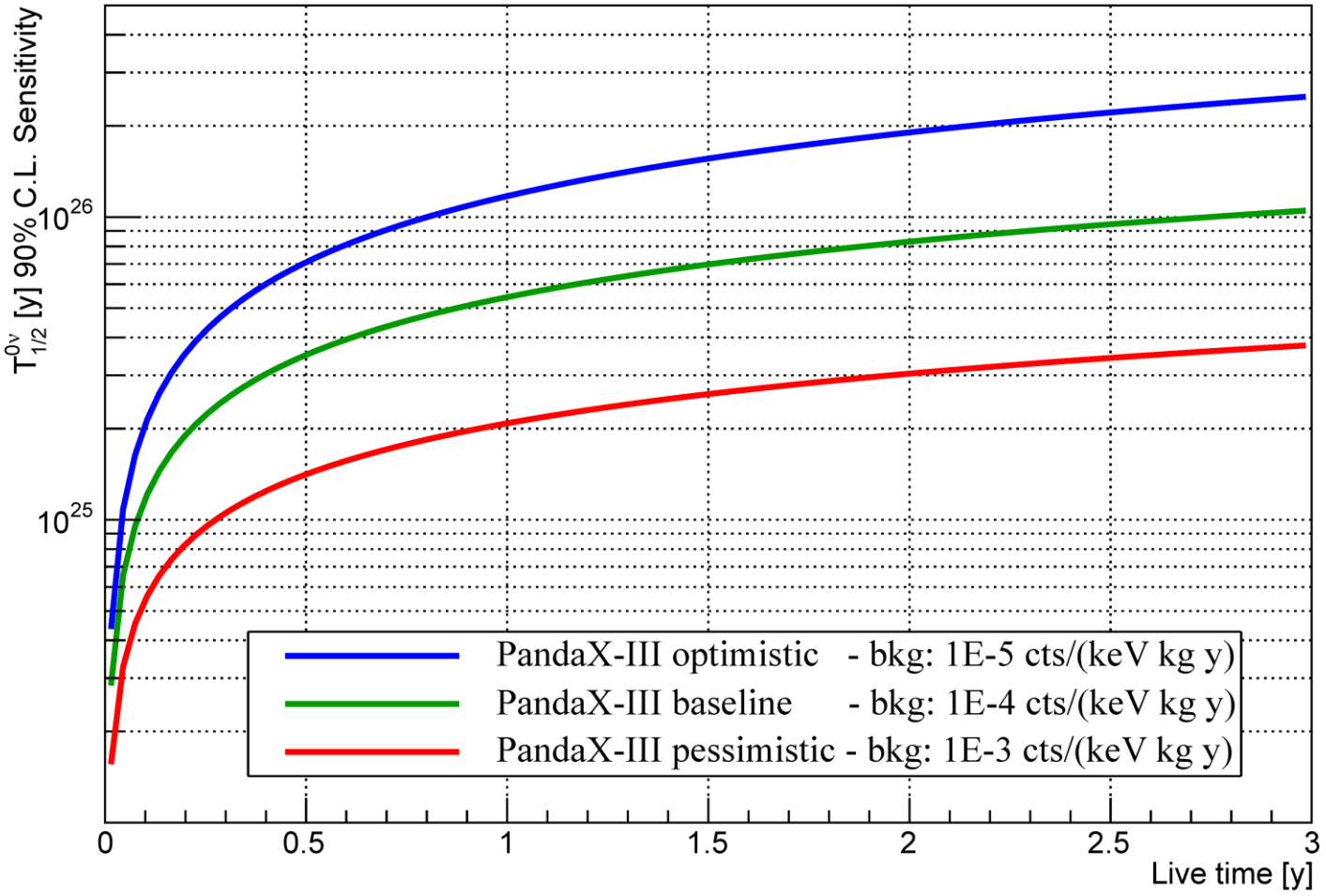


Figure 1. Simplified schematic of Xe and TMA reactions after initial ionization and excitation of Xe. We made the first direct measurement of the processes shown with red arrows.


$T^{0\nu}_{1/2}$ [y] 90% C.L. Sensitivity
10^{26}
10^{25}
PandaX-III optimistic - bkg: 1E-5 cts/(keV kg y)
PandaX-III baseline - bkg: 1E-4 cts/(keV kg y)
PandaX-III pessimistic - bkg: 1E-3 cts/(keV kg y)
0
0.5
1
1.5
2
2.5
3
Live time [y]