SHANGHAI JIAO TONG UNIVERSITY

PANDA X
PARTICLE AND ASTROPHYSICAL XENON TPC

PandaX-III:

0νββ with High Pressure ^{136}Xe Gas TPC

Ke HAN (韩柯)

Shanghai Jiao Tong University

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DBD16

International Workshop on "Double Beta Decay and Underground Science"

Outline

- PandaX-III project overview
- The first 200-kg module
  - Charge readout plane
  - Field cage
  - Pressure vessel
  - Gas
  - Electronics
- Prototype TPC
- Infrastructure
  - Low background facilities
  - PandaX hall at CJPL-II
- Physics reach of PandaX-III

More details from our recently submitted conceptual design report: ArXiv1610.08883

ins-det] 28 Oct 2016

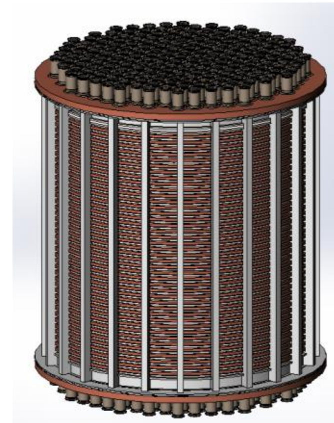
PandaX-III: Searching for Neutrinoless Double Beta Decay with High Pressure ^{136}Xe Gas Time Projection Chambers

Xun Chen[1], Changbo Fu[1], Javier Galan[1], Karl Giboni[1], Franco Giuliani[1], Linghui Gu[1], Ke Han*[1], Xiangdong Ji[1, 10], Heng Lin[1], Jianglai Liu[1], Kaixiang Ni[1], Hiroki Kusano[1], Xiangxiang Ren[1], Shaobo Wang[1], Yong Yang[1], Dan Zhang[1], Tao Zhang[1], Li Zhao[1], Xiangming Sun[2], Shouyang Hu[3], Siyu Jian[3], Xinglong Li[3], Xiaomei Li[3], Hao Liang[3], Huanqiao Zhang[3], Mingrui Zhao[3], Jing Zhou[3], Yajun Mao[4], Hao Qiao[4], Siguang Wang[4], Ying Yuan[4], Meng Wang[5], Amir N. Khan[6], Neill Raper[6], Jian Tang[6], Wei Wang[6], Jianing Dong[7], Changqing Feng[7], Chen Li[7], Jianbei Liu[7], Shubin Liu[7], Xiaolian Wang[7], Danyang Zhu[7], Juan F. Castel[8], Susana Cebrián[8], Theopisti Dafni[8], Javier G. Garza[8], Igor G. Irastorza[8], Francisco J. Iguaz[8], Gloria Luzón[8], Hector Mirallas[8,1], Stephan Aune[9], Eric Berthoumieux[9], Yann Bedfer[9], Denis Calvet[9], Nicole d'Hose[9], Alain Delbart[9], Maria Diakaki[9], Esther Ferrer-Ribas[9], Andrea Ferrero[9], Fabienne Kunne[9], Damien Neyret[9], Thomas Papaevangelou[9], Franck Sabatié[9], Maxence Vanderbroucke[9], Andi Tan[10], Wick Haxton[11], Yuan Mei[11], Chinorat Kobdaj[12], and Yu-Peng Yan[12]

PandaX Projects

PandaX-I: 120kg LXe
(2009 – 2014)

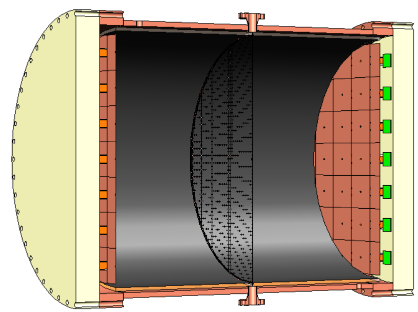
PandaX-II: 500kg LXe
(2014 – 2018)



PandaX-xT LXe
(2017 -)

Dark matter WIMP searches

PRL 117, 121303 (2016)

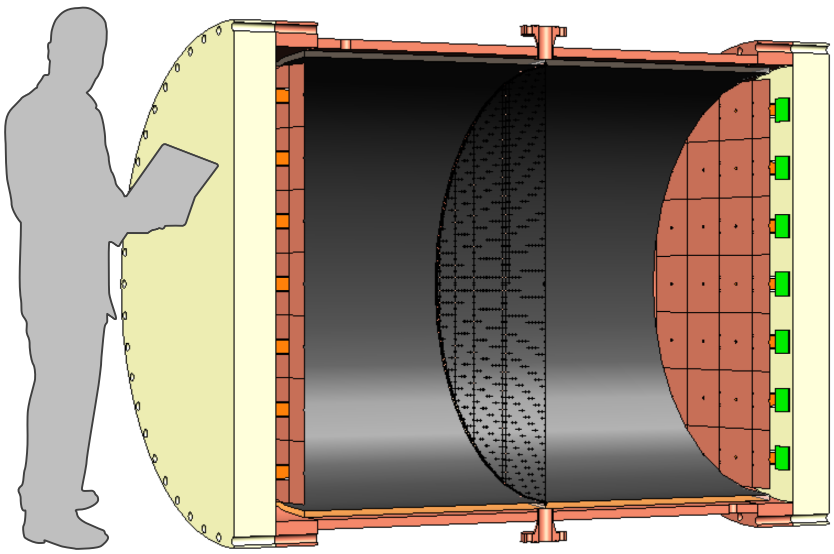


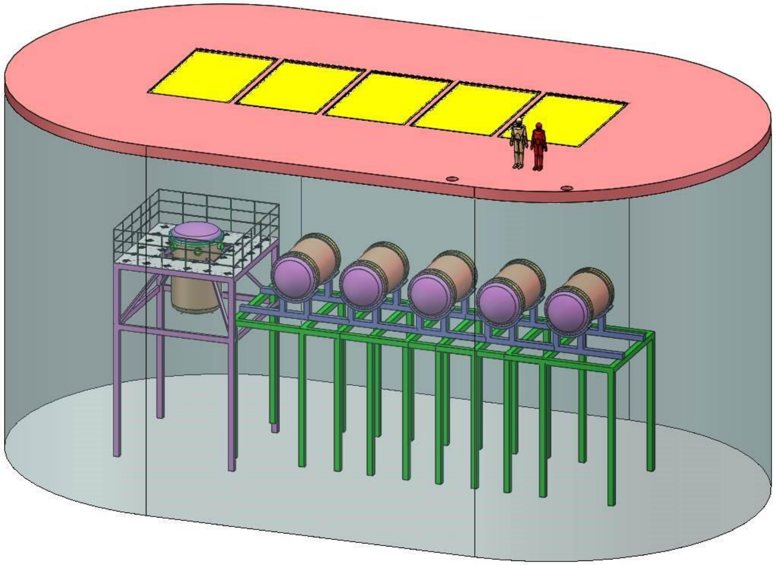
0νββ searches

PandaX-III:
200kg - 1 ton HPXe (2016 -)

PandaX-III: high pressure xenon gas TPC for 0νββ of ^{136}Xe

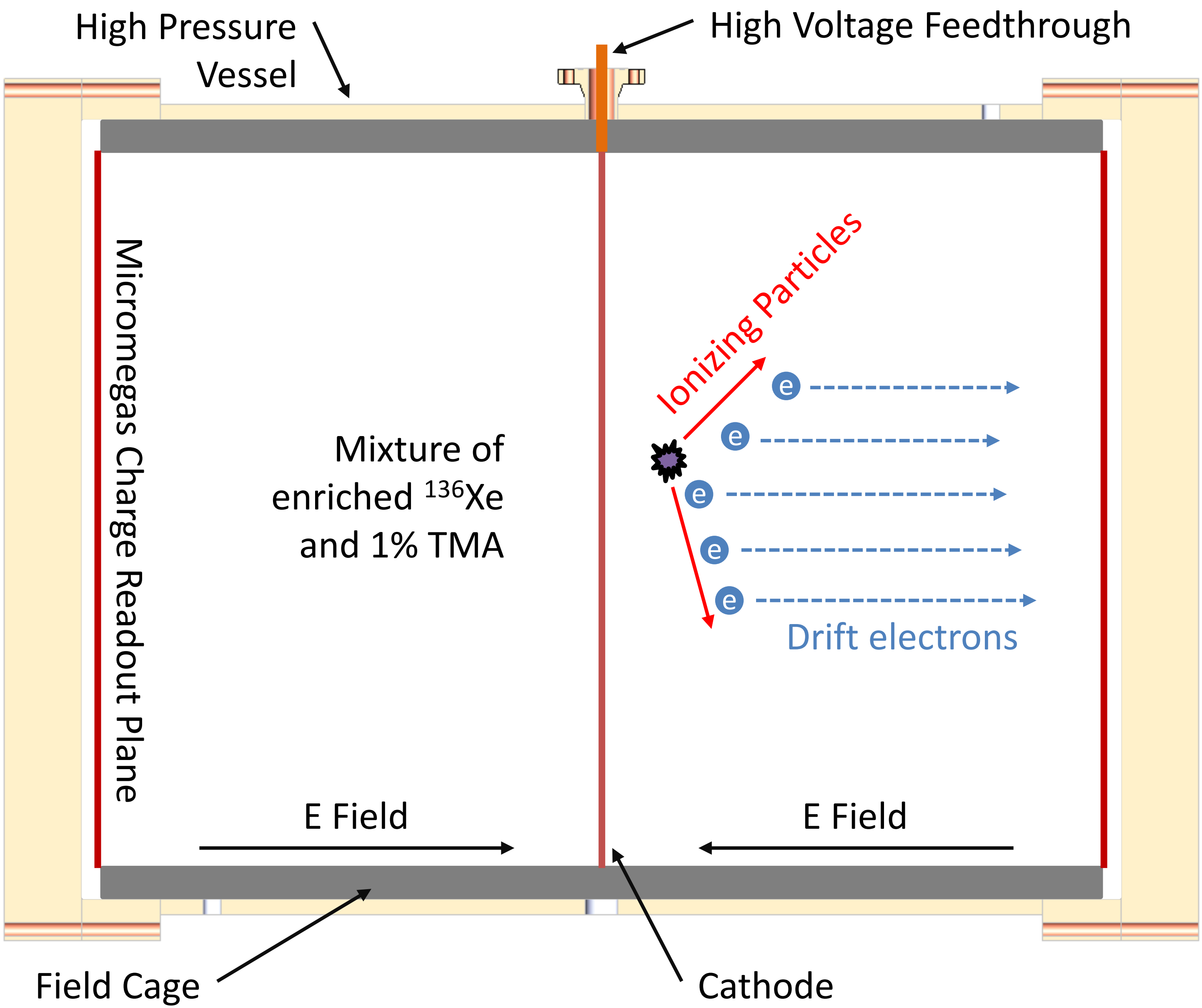
- TPC: 200 kg scale, symmetric, double-ended charge readout with cathode in the middle
  - Charge readout plane: tiles of microbulk Micromegas (MM) modules with X, Y strips
- Four more upgraded modules for a ton scale experiment
- @ Hall #B4 at China Jin Ping underground Lab (CJPL-II).
- Main design features: good energy resolution, good tracking capability, and low background.





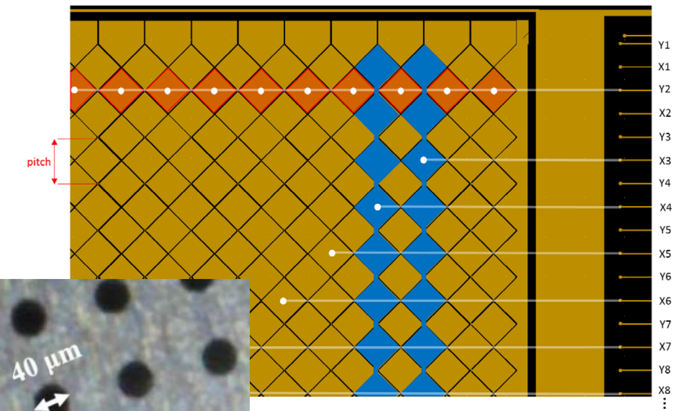
6 m water shielding

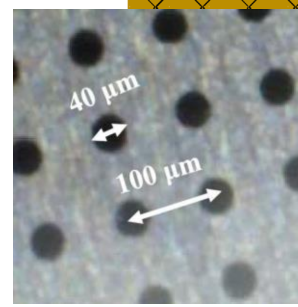
PandaX-III TPC illustrated

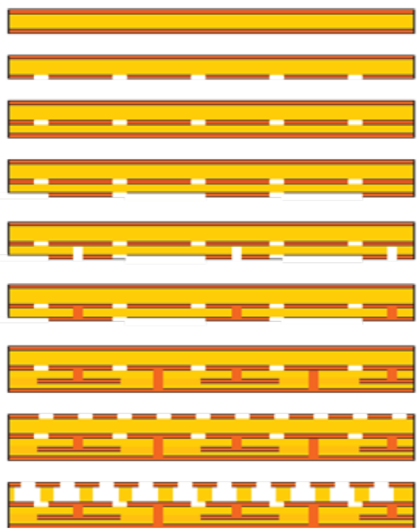


Microbulk MicroMegas (MM)

- Microbulk MicroMegas films made of Copper and Kapton only
  - Perfect for radio-purity purpose
- XY strip readout
- ~ 1000X gain
- 3% energy resolution expected 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

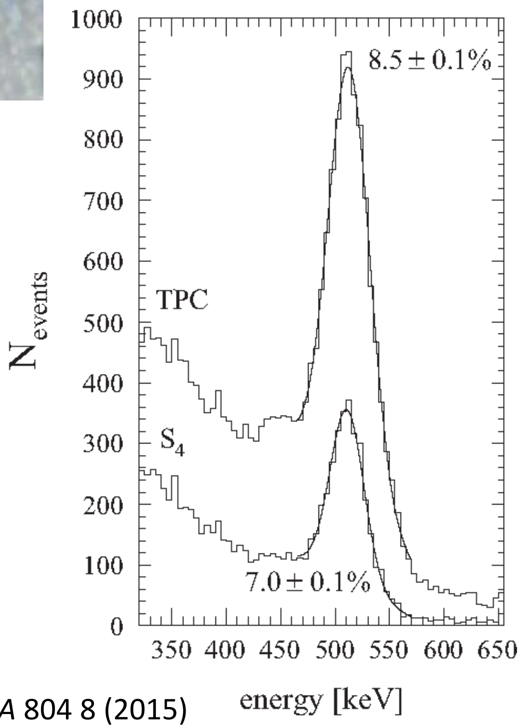
Vias construction

2^{nd} Layer of Cu-coated kapton

Photochemical production of mesh holes

Kapton etching / Cleaning

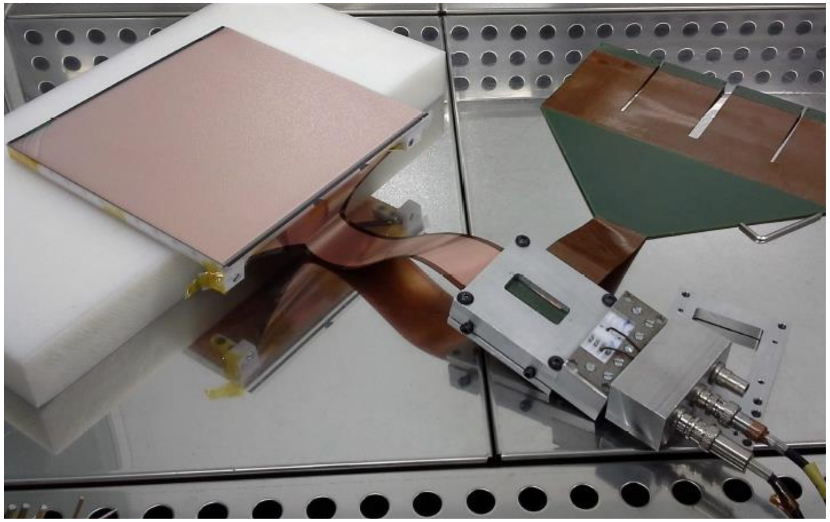
Andriamonje, S. et al. JINST 02 (2010): P02001

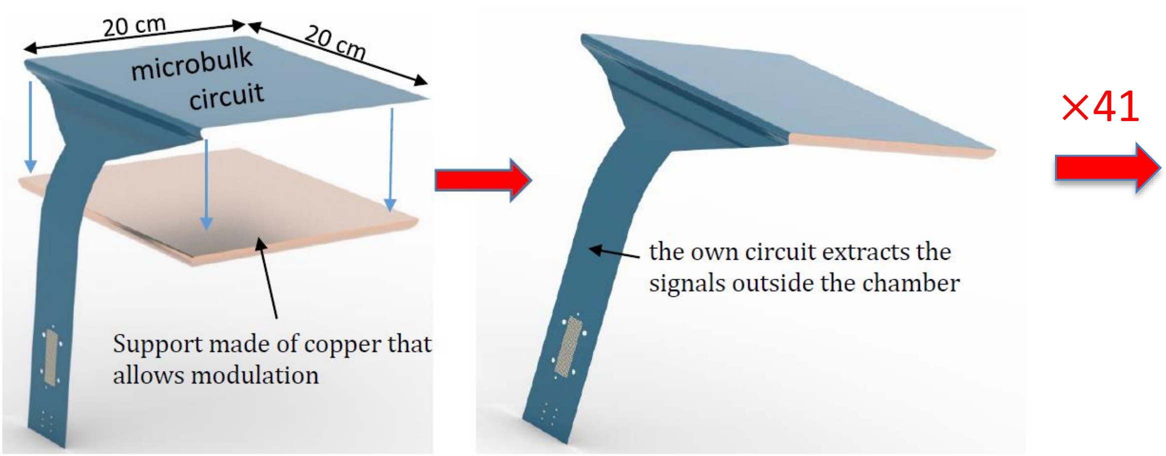


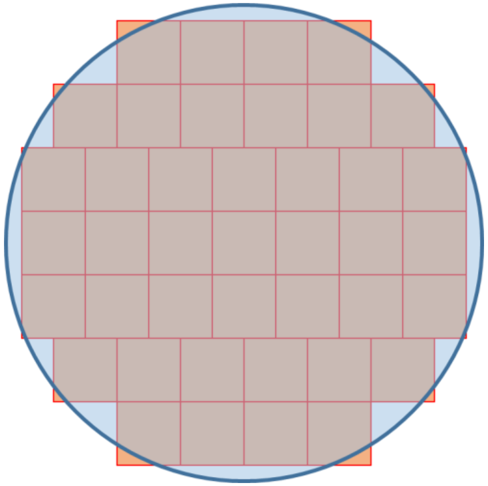
Gonzalez-Diaz, et al. *NIMA* 804 8 (2015)

Scalable Radio-pure Readout Module (SR2M)

- SR2M: Mosaic layout to cover readout planes
  - Solderless system
  - Strip and mesh signal readout
  - Dead-zone-free arrangement
  - Designed by Zaragoza and SJTU
- Eleven MM films produced at CERN
  - 20 by 20 cm
  - 3 mm pitch size, 128 strip readouts

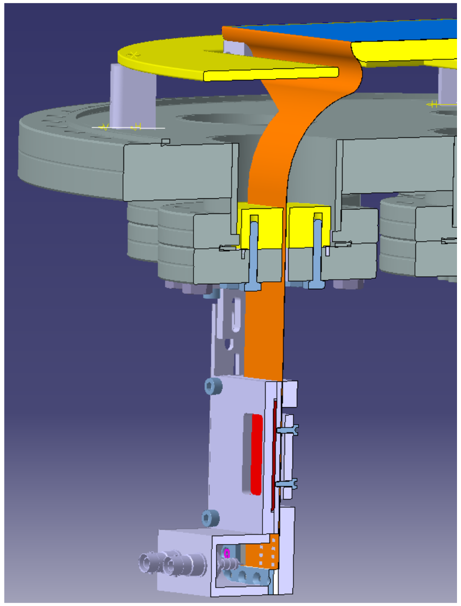




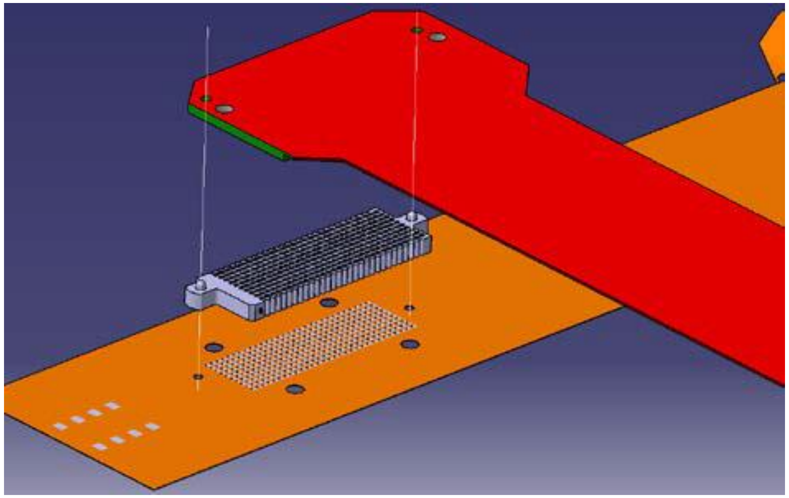


More SR2M design features

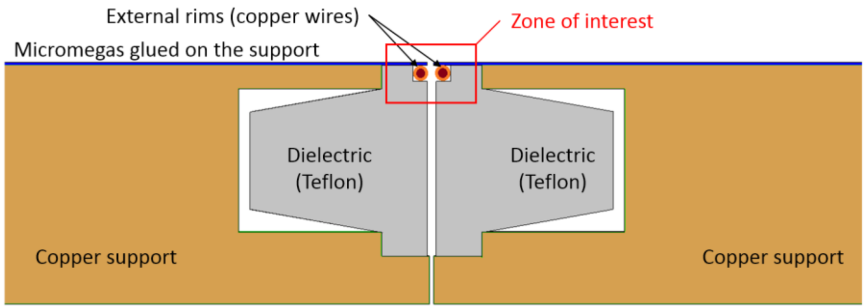
Hermetic seal

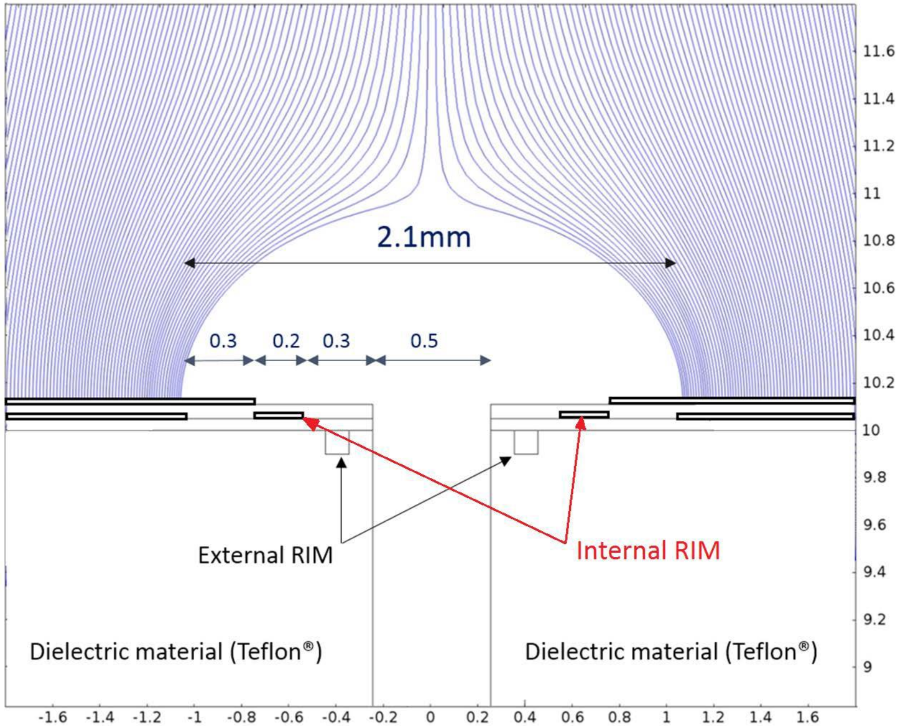


Electrical connection

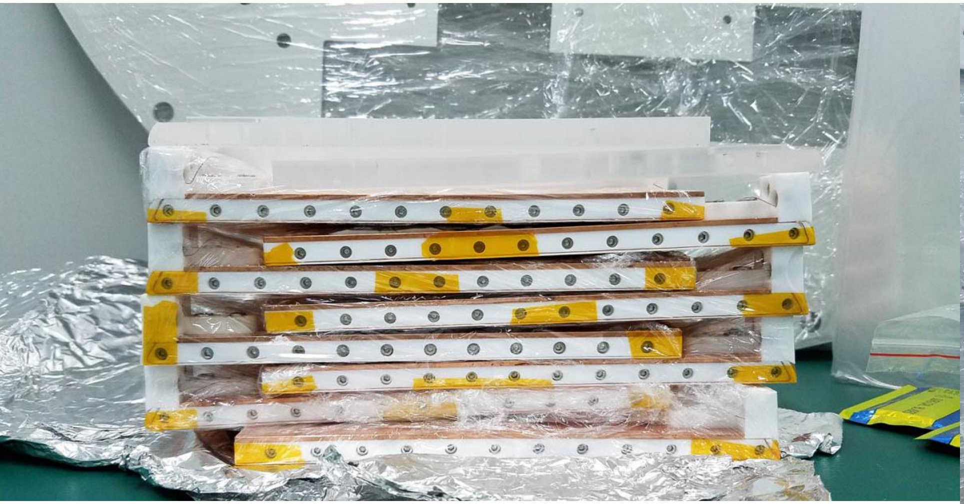


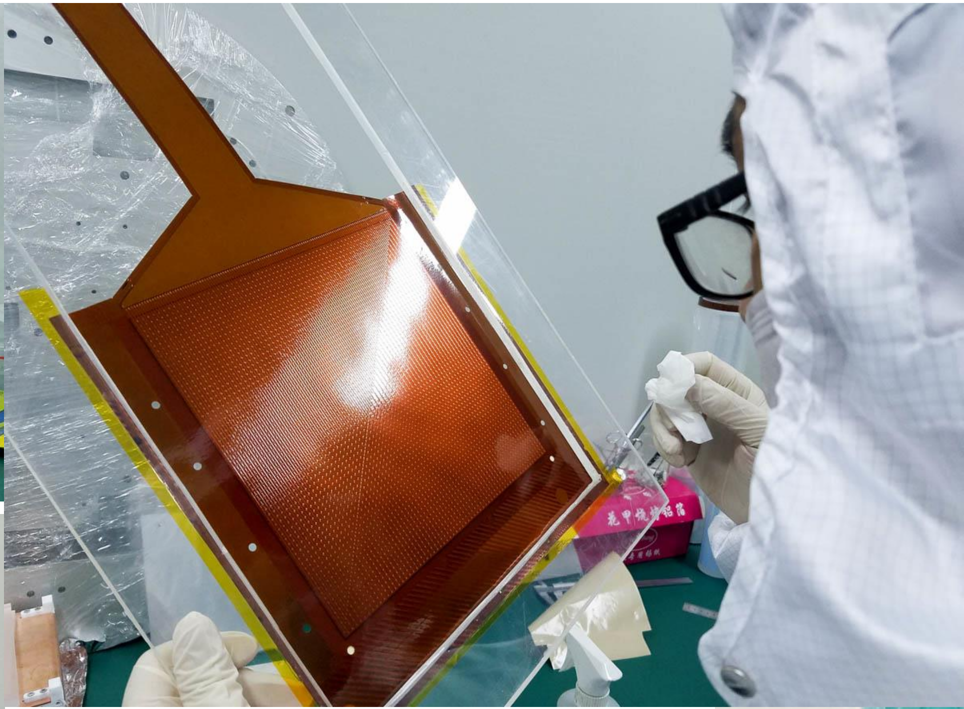
Joining two SR2Ms

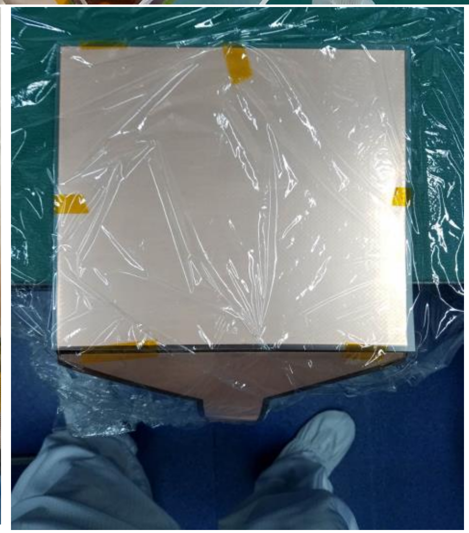




From MM films to SR2M

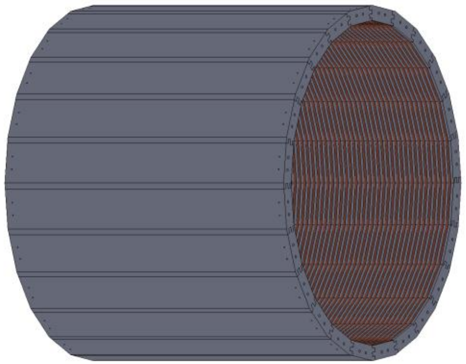


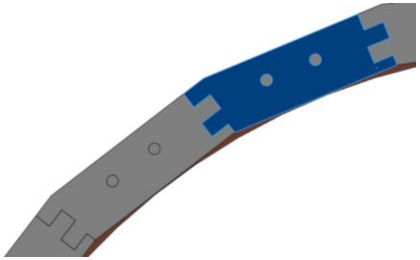


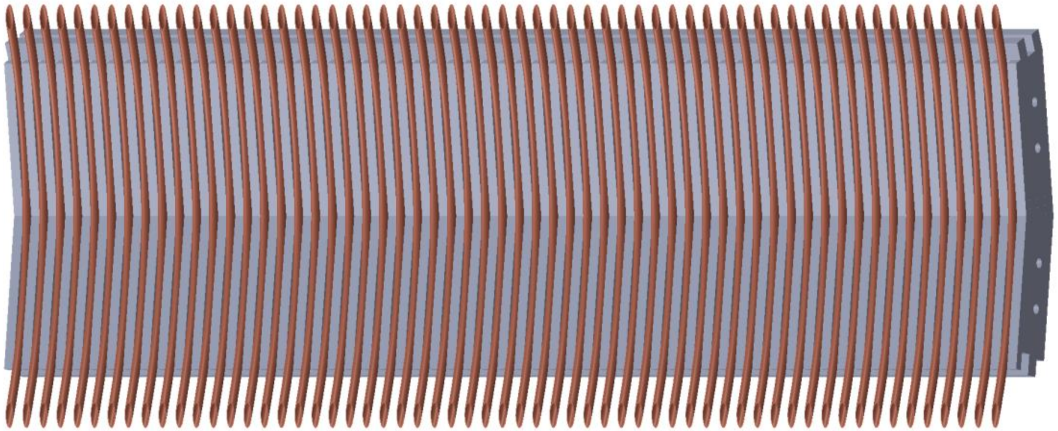


TPC Field Cage – option 1 (mature)

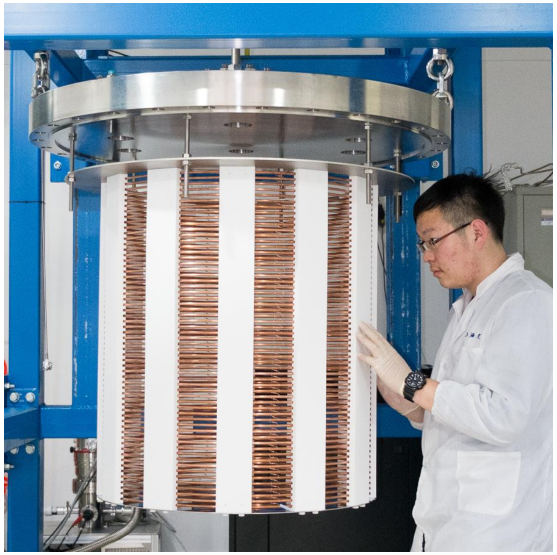
- Copper shaping rings + resistors + external Teflon (or Acrylic) supporting bars
  - Mature technology
  - Used and tested extensively in PandaX-I and PandaX-II
- Supporting bars are critical
  - Dielectric strength
  - Displacer for ^{136}Xe





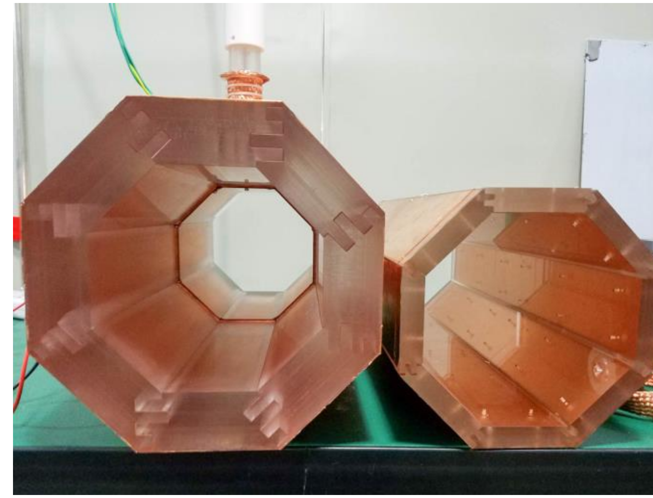


Prototype TPC field cage



TPC Field Cage – option 2

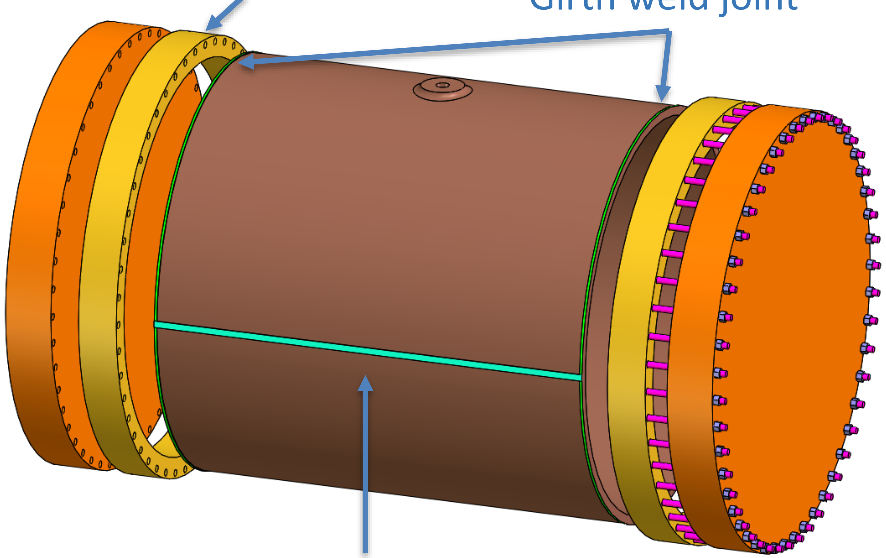
- Resistive coating on the acrylic pieces. The resistive layer works as continuous field shaping rings.
  - No more resistors
  - No more soldering
  - No copper rings
- Diamond-like carbon sputtering or commercial DLC or Ge film
- SUT (Thailand) is collaborating with SJTU on developing this option
- Field simulation is under way



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



Copper Vessel:

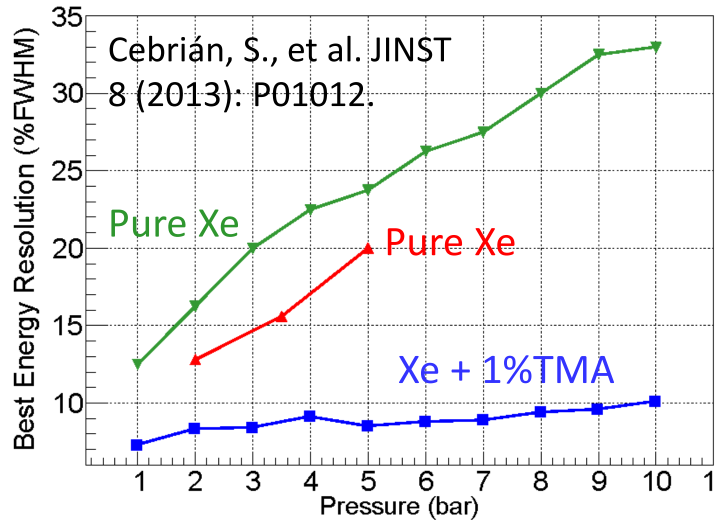
- 15 cm thick end caps
- 3.2 cm thick side wall
- About 9 ton of OFHC copper

Possibility of fabrication in China or Germany

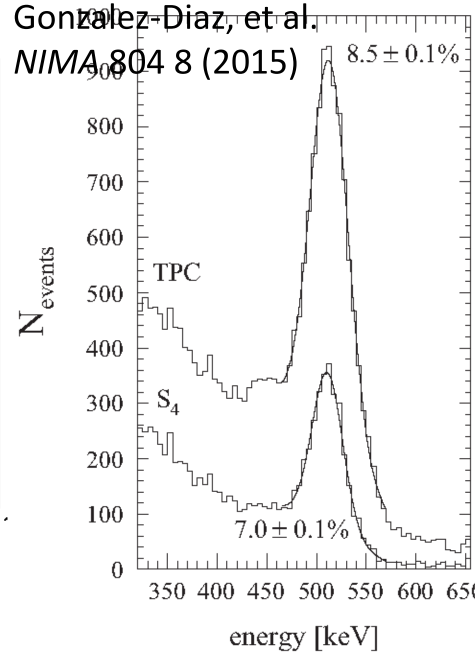
- Connex (contractor, machining)
- Pro-Beam (E-beam welding)
- CSN (OFHC copper)

Xe +TMA mixture

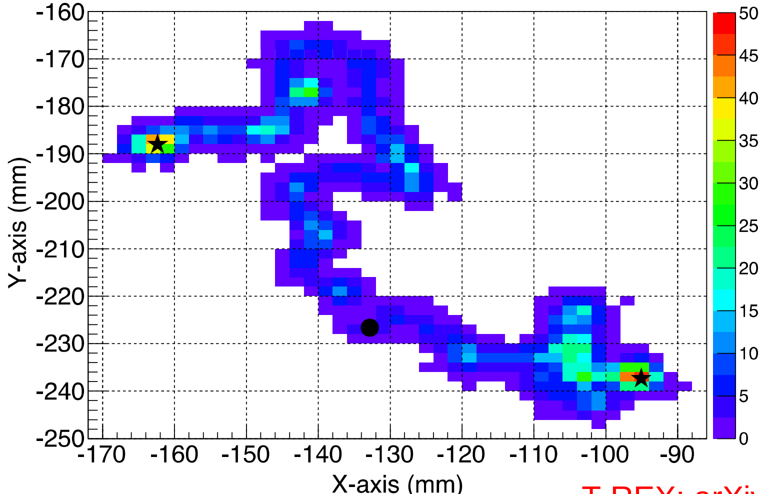
- Better energy resolution
  - Extrapolated from 511keV and 1.2MeV peaks: 3% FWHM (@$Q_{0\nu\beta\beta}$)
- Better tracks
  - TMA suppress electron diffusion
- Better operation
  - TMA as a quencher



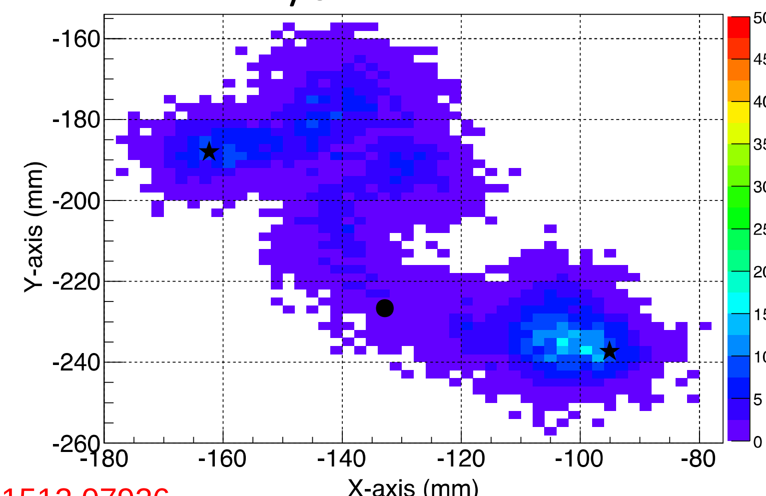
Gonzalez-Diaz, et al. *NIMA* 804 8 (2015)



With TMA



W/o TMA

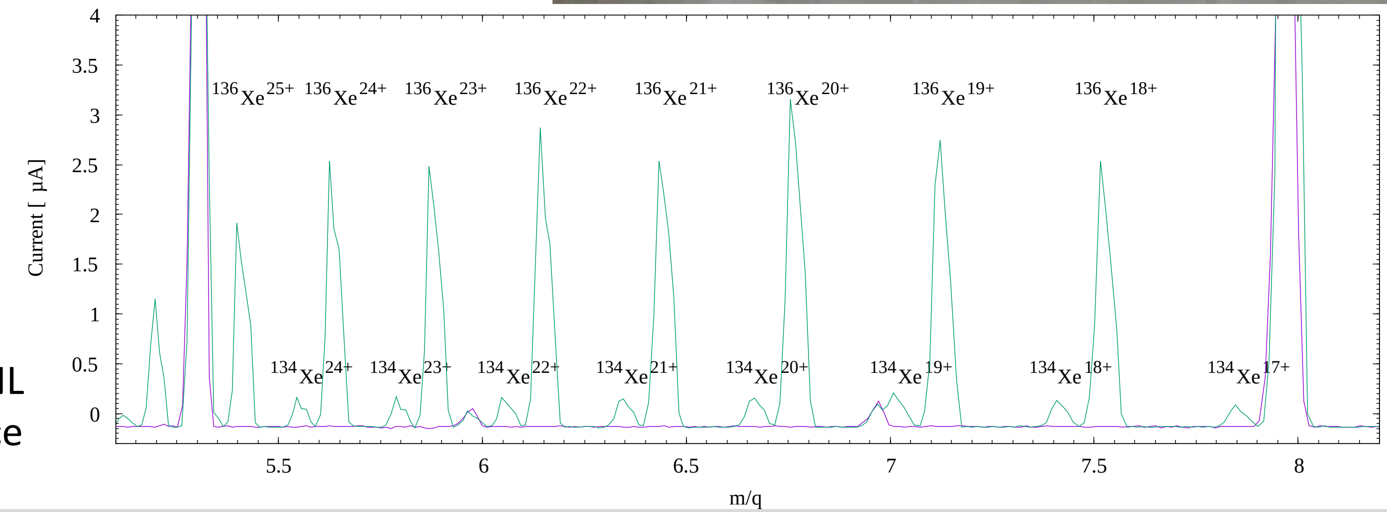


T-REX: arXiv:1512.07926

^{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.

Results from LBNL ion source

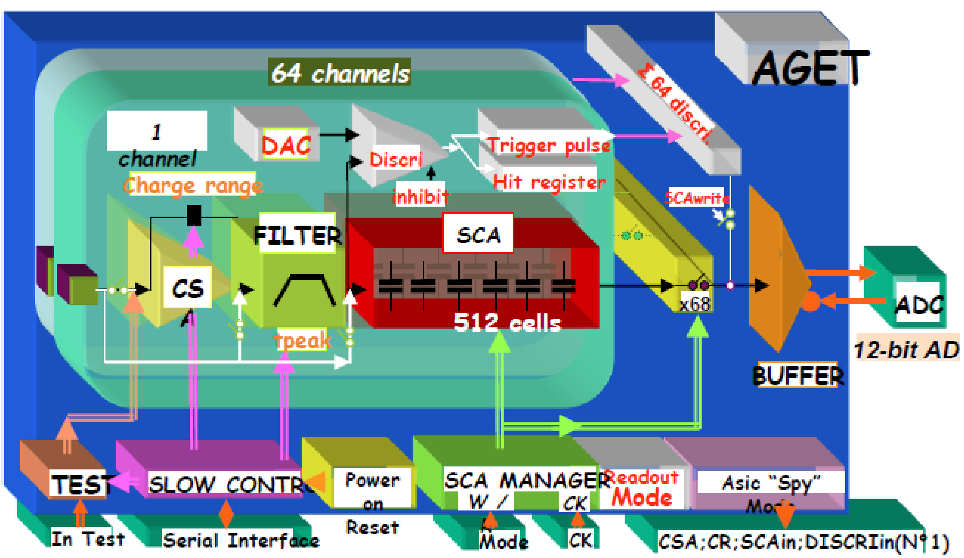


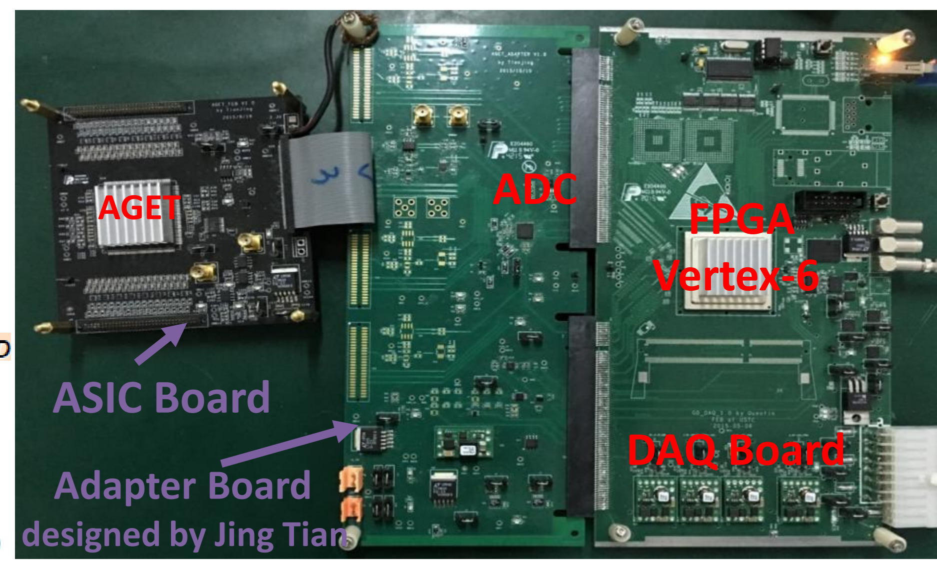
Electronics

- 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

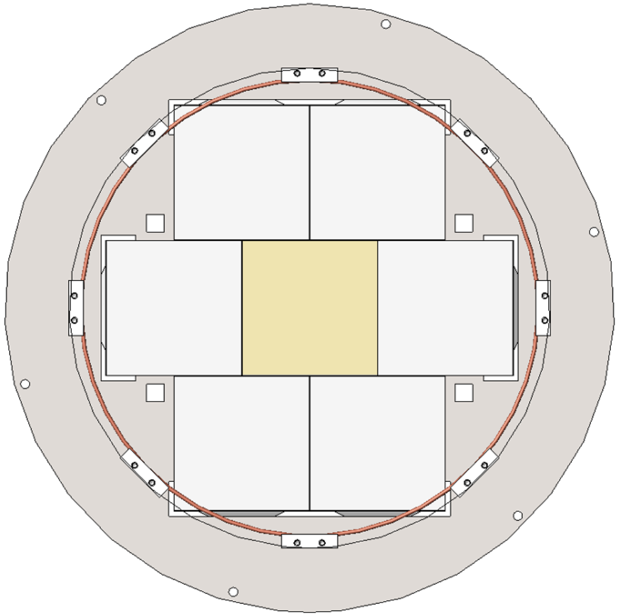
AGET and the commercial version ASAD are being tested and studied at Zaragoza, USTC, and SJTU

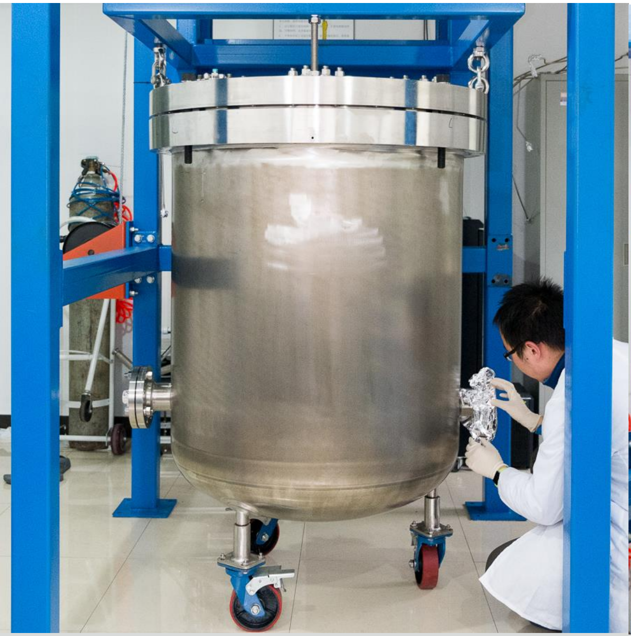


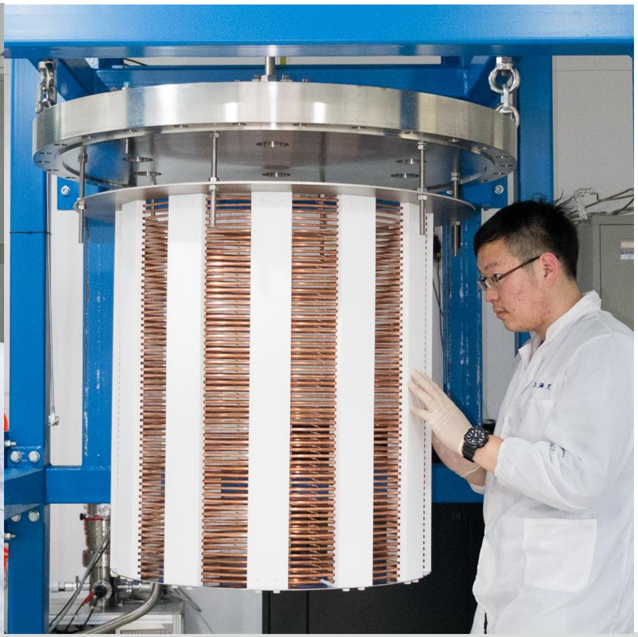


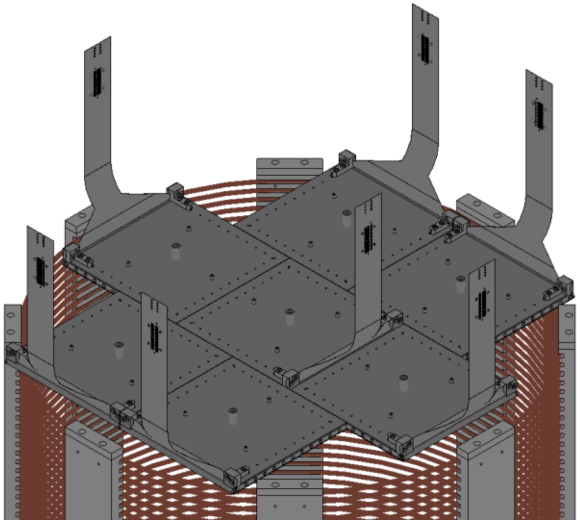
Prototype TPC at SJTU

- 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 track reconstruction
- To explore the impact of t_0 with light readout





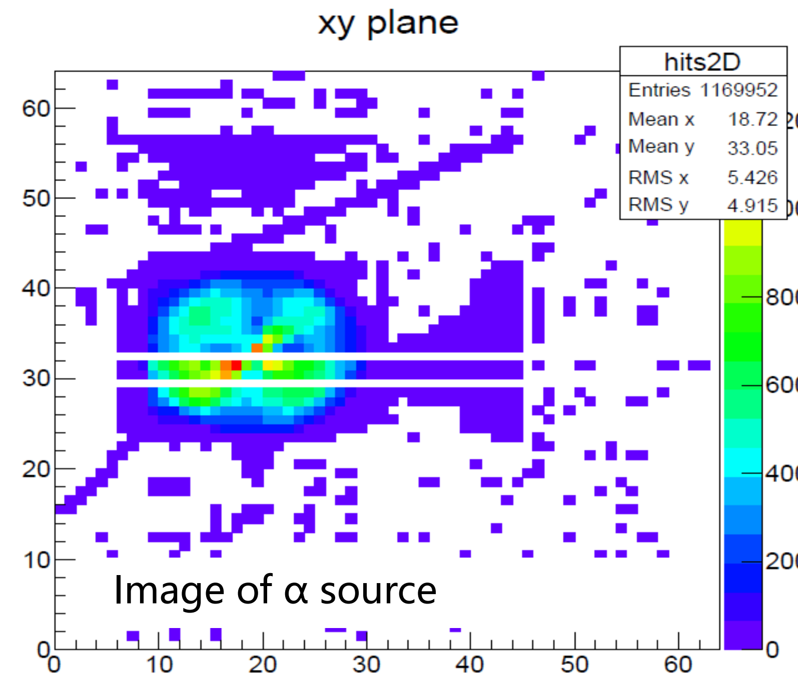




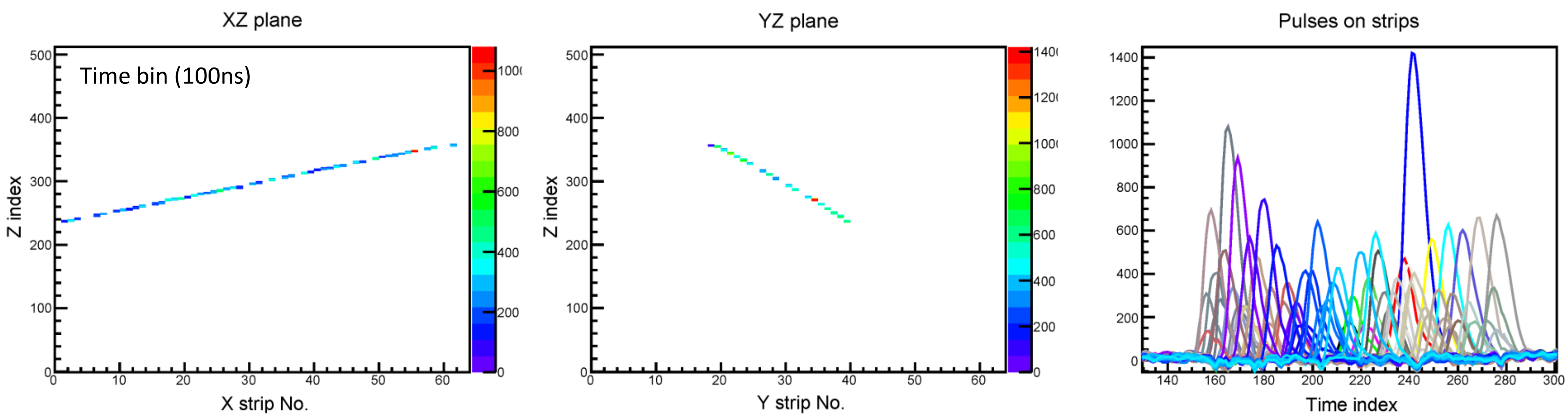
7 MicroMegas

Commissioning the prototype TPC

- One SR2M mounted
- Data taking with Ar+CO_2, Ar+Isobutane, Xe, Xe+TMA at different pressures
  - Up to 5 bar
- ^{241}Am alpha source with low energy gamma (59 keV); ^{137}Cs gamma source, muons

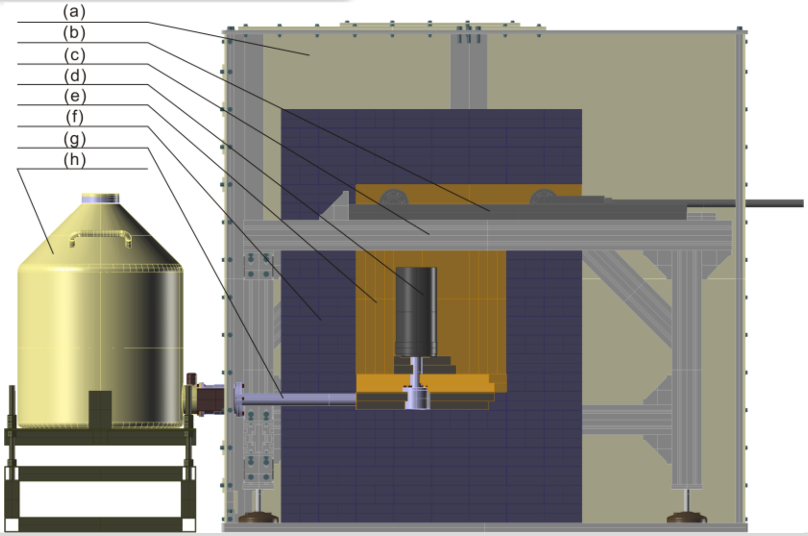


Muon track



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



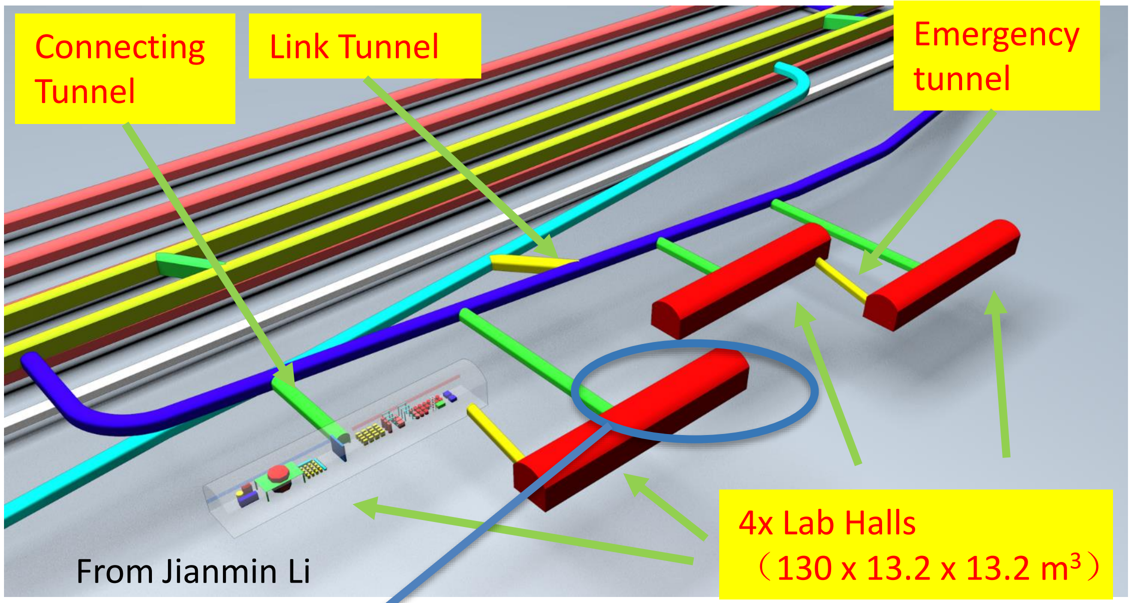
PandaX hall at CJPL-II

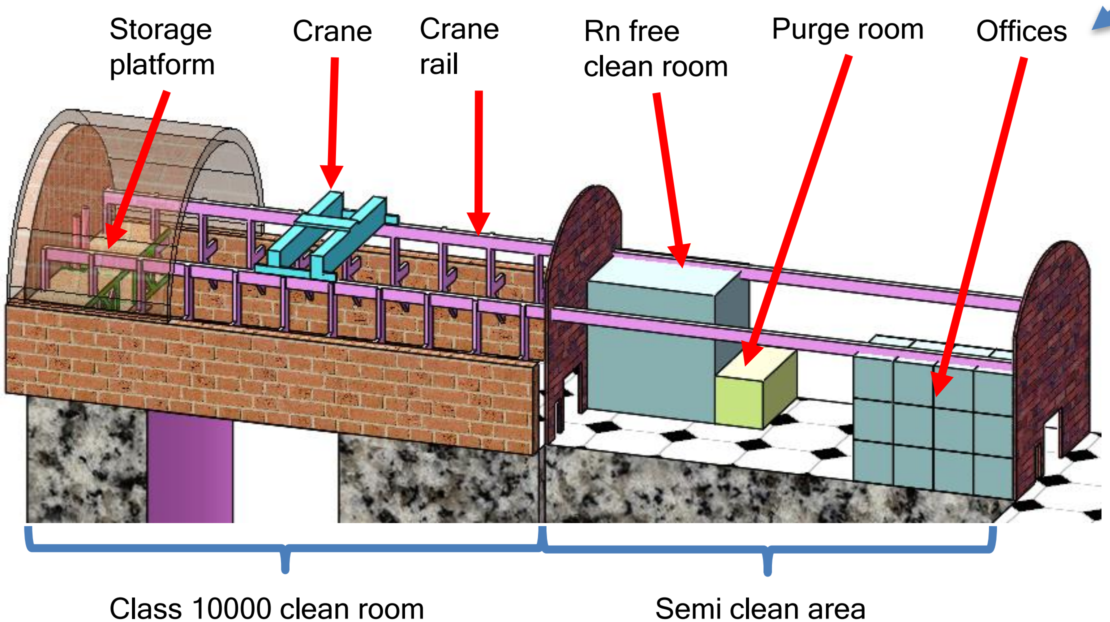
CJPL phase II

- Civil excavation finished

Experiments

- PandaX projects
- CDEX WIMP search
- JUNA (accelerator)
- Solar neutrino LS detector
- ……





PandaX at Hall B4

- Extra excavation for the water shielding pool (finished)
- Shared facility of DM and 0νββ searches
- Beneficial occupancy by the beginning of 2018

Progress of the water shielding pool

2015/12/2: Before digging

2016/4/9: Inner wall finishing

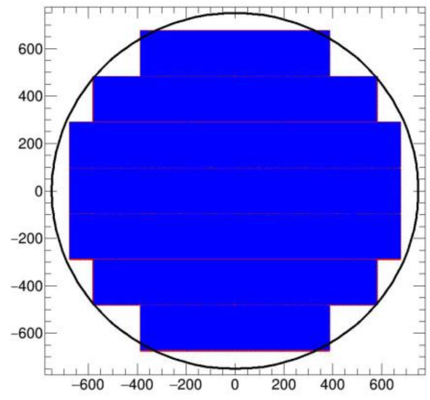
2016/3/28: After digging

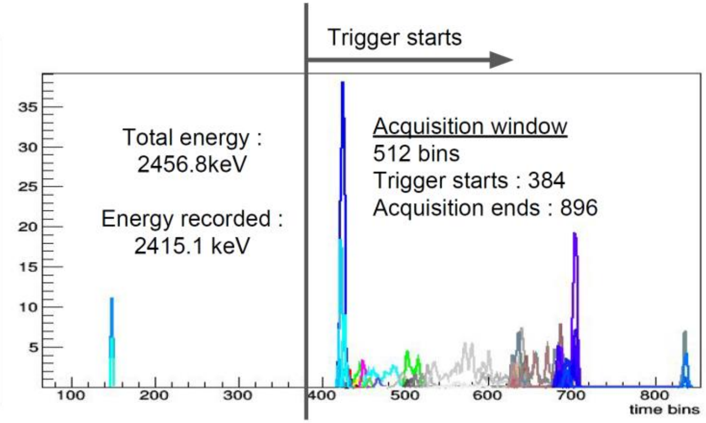
About Now

Simulations

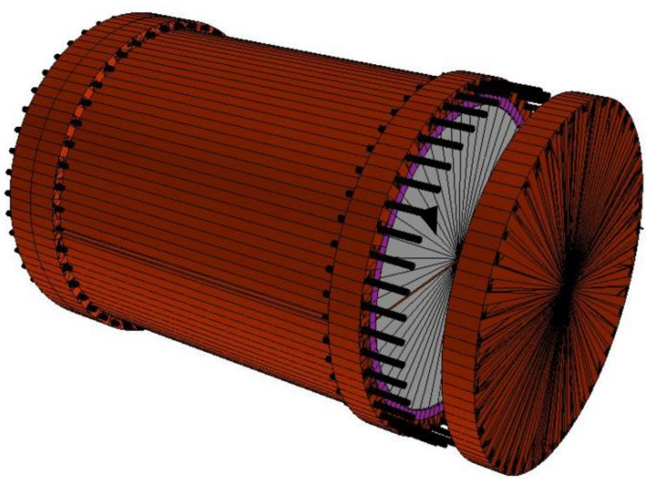
Two independent Geant-4 based MC packages: RESTG4 and BambooMC

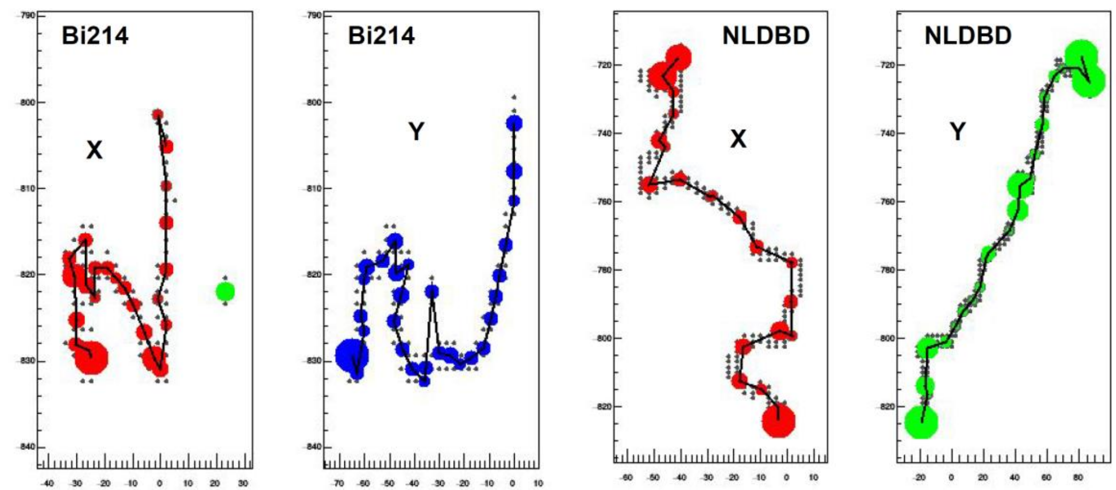
- Treat PandaX-III as a simple calorimeter
- Add detector response
- Signal efficiency
- No PandaX-specific topological analysis yet





Simulation includes detector response

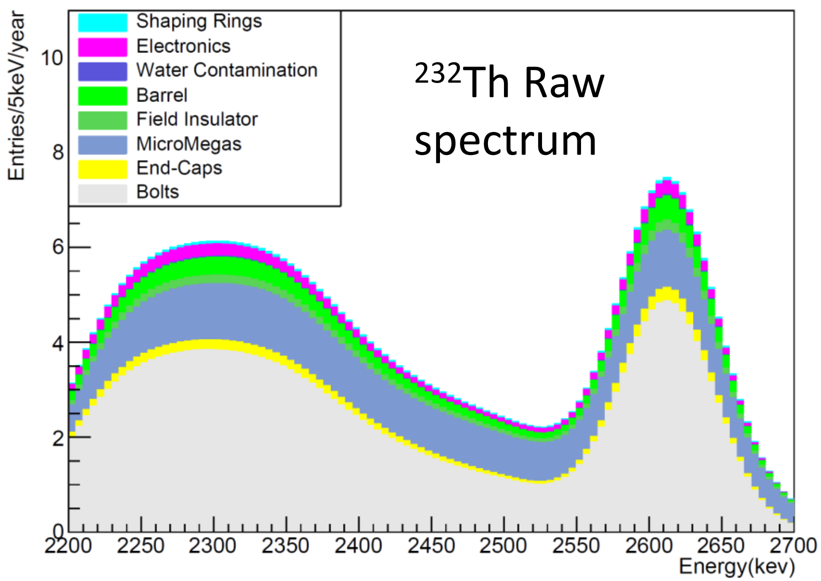


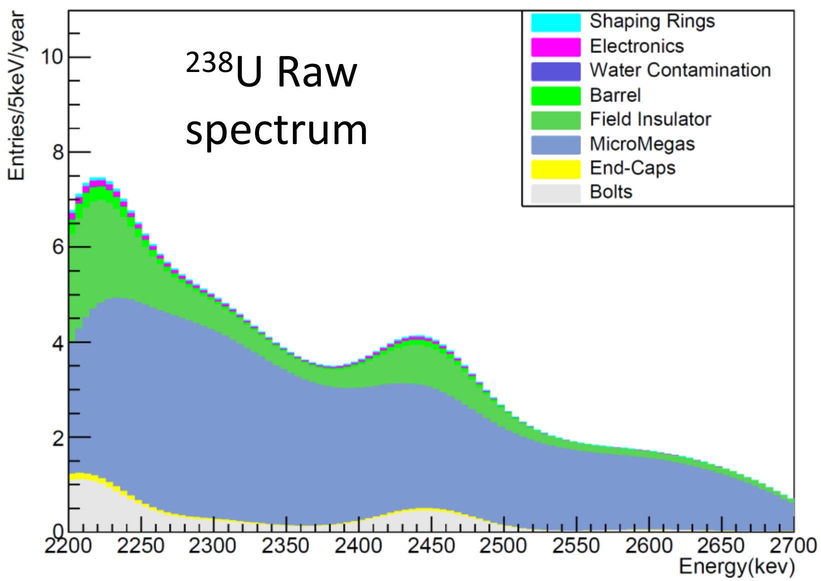


Simulation does not include topological analysis yet

Background budget

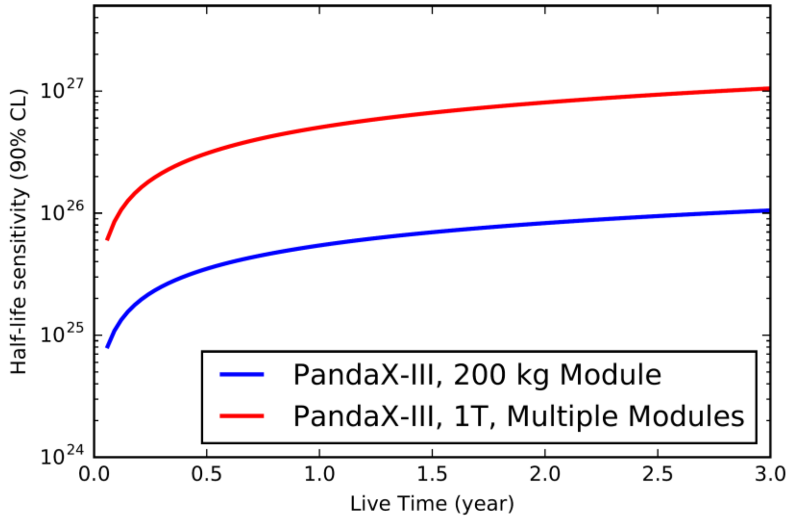
- Use measured U/Th contamination upper limits from literature as inputs
  - 3.5×10^{-3} c/keV/kg/y in the ROI
  - Bolts and MM are dominating (MM input contamination is "weak", since little material mass is available for counting)
- X35 background reduction from topological analysis were assumed
  - 1×10^{-4} c/keV/kg/y in the ROI





Sensitivity projection

- First module:
  - 3% FWHM, 35% signal efficiency
  - 1 x 10^{-4} c/keV/kg/y in the ROI
- Ton scale:
  - 1% FWHM
  - 1 x 10^{-5} c/keV/kg/y in the ROI
- Single-bin counting

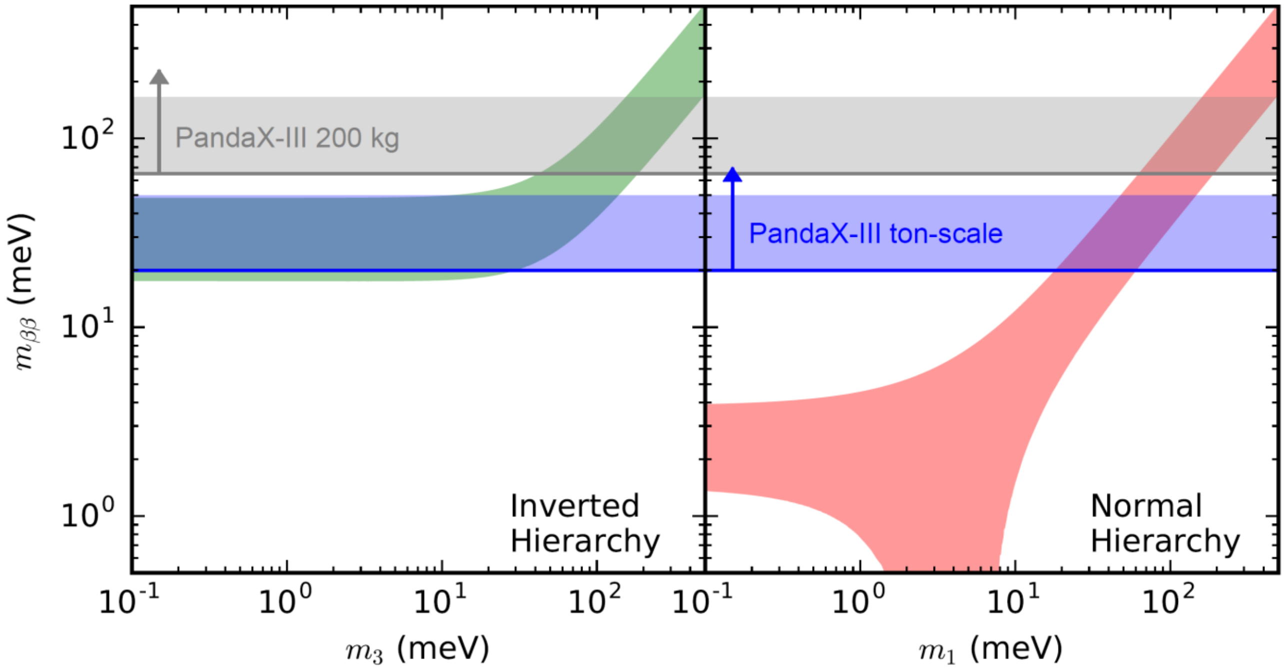


First module:

- 10^{26} y half-life limit
- 65 – 165 meV $m_{\beta\beta}$

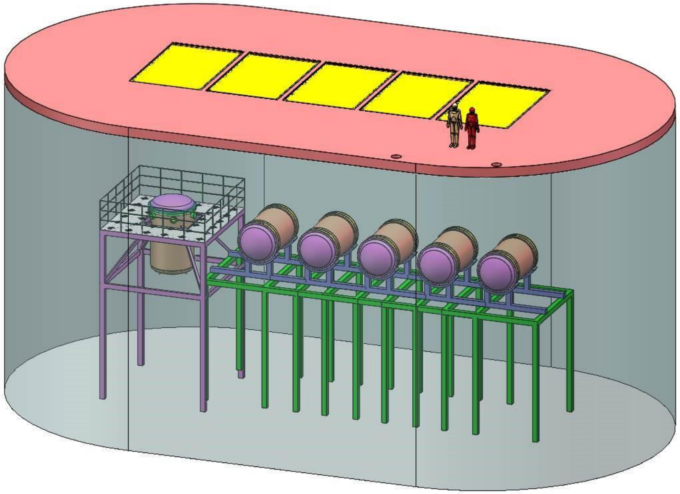
Ton-scale

- 10^{27} y half-life limit
- 20 – 50 meV $m_{\beta\beta}$

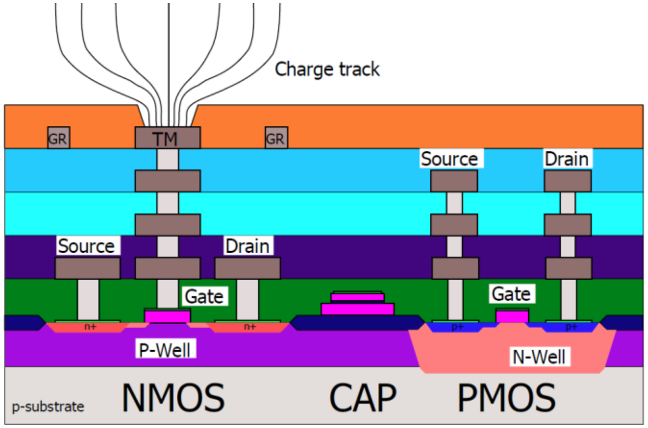


Future beyond the first TPC module

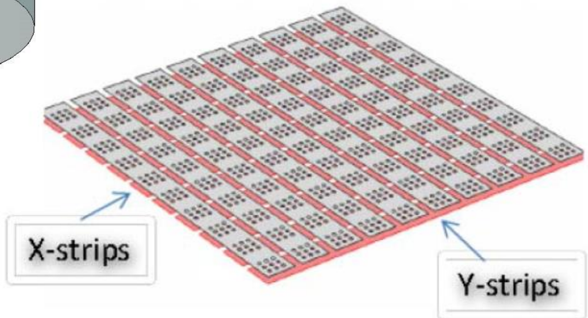
- Additional modules with upgraded options will be installed in the same water shielding pit.
  - 1% energy resolution to approach the intrinsic resolution of high pressure xenon gas with TMA
  - Better material screening
- Reaches ton-scale in 2022.

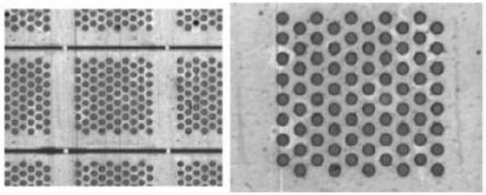


- TopMetal Direct Charge Sensor
  - Direct pixel readout without gas amplification



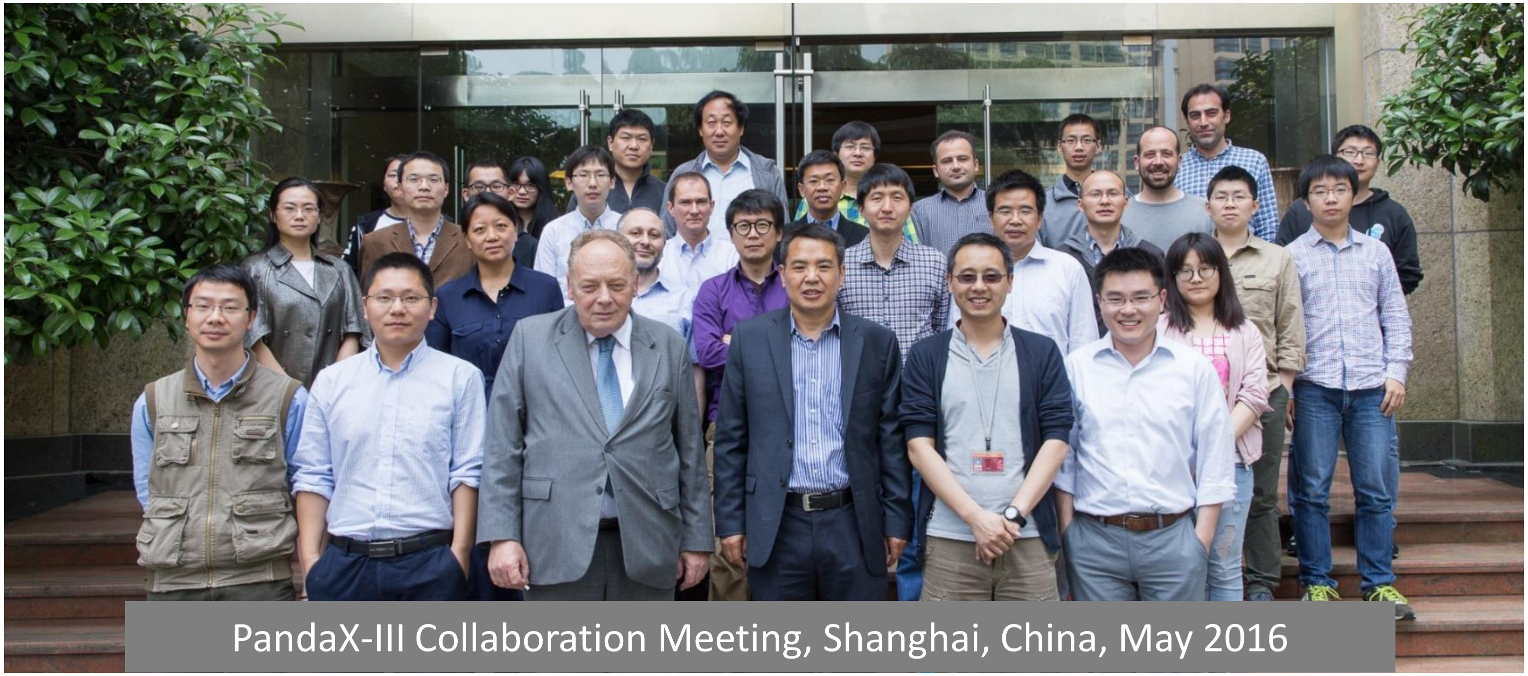
- Alternative readout technologies
  - Improvement on bulk and microbulk technologies





PandaX-III collaboration

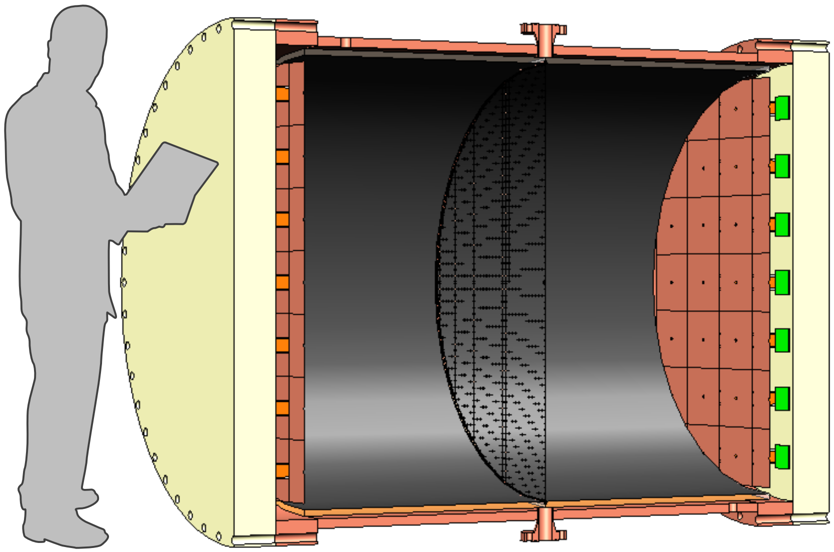
- China: Shanghai Jiao Tong University, University of Science and Technology of China, Peking University, China Institute of Atomic Energy, Shandong University, Sun Yat-Sen University, Central China Normal University
- Spain: Universidad de Zaragoza
- France: CEA Saclay
- US: University of Maryland,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

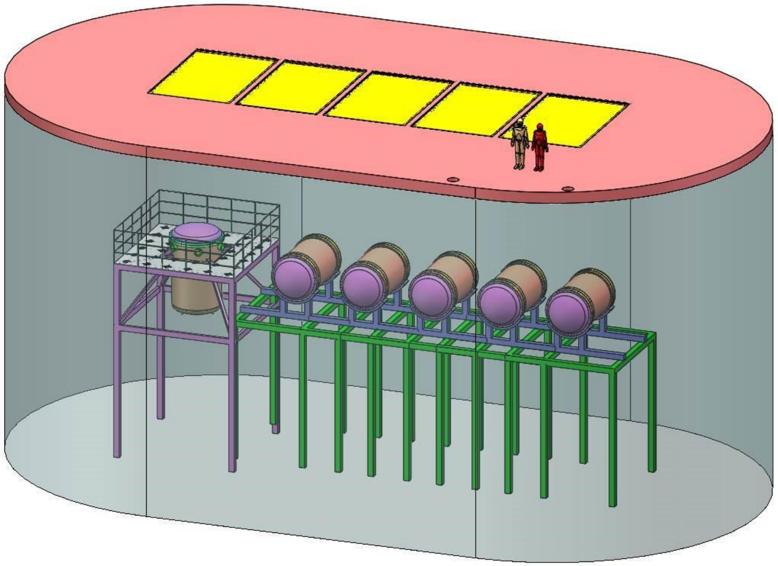


PandaX-III Collaboration Meeting, Shanghai, China, May 2016

Conclusion

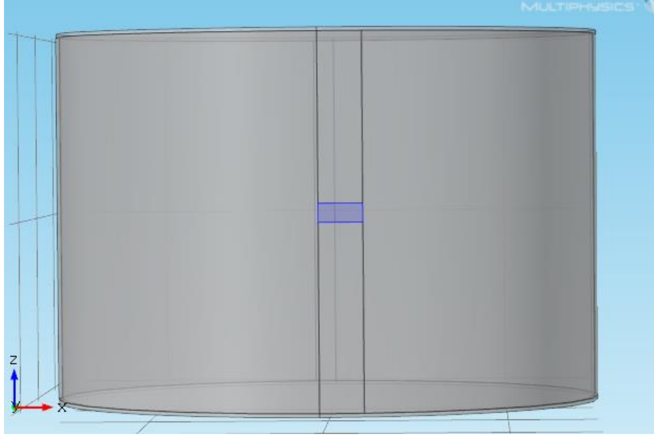
- PandaX-III uses high pressure xenon TPCs to search for double beta decay
- Phased approach: 200 kg first, then ton-scale with multiple modules
- 20-kg scale prototype TPC has been built and under commissioning
- PandaX Hall B4 at CJPL is being furbished for future $0\nu\beta\beta$ and dark matter detectors.



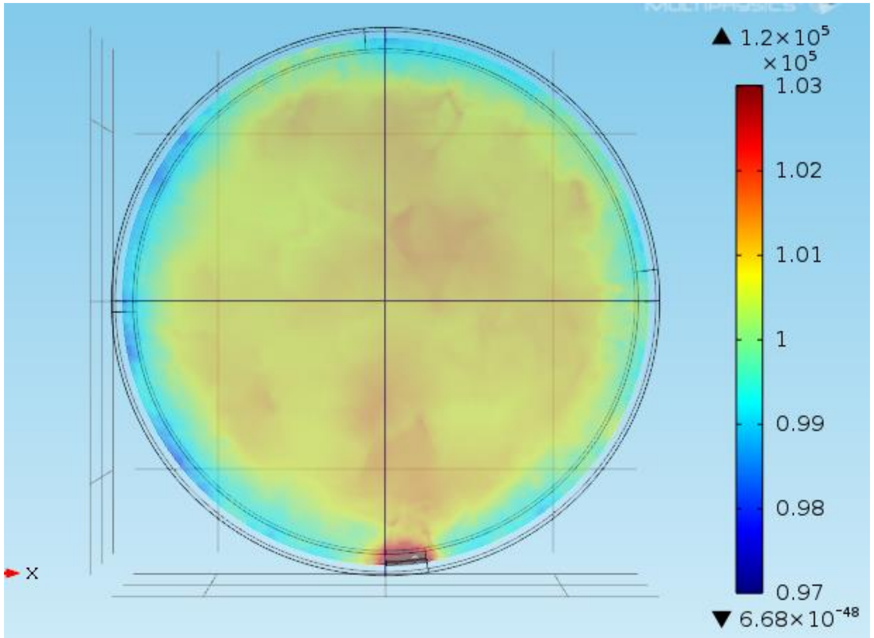


How the field changes with thickness

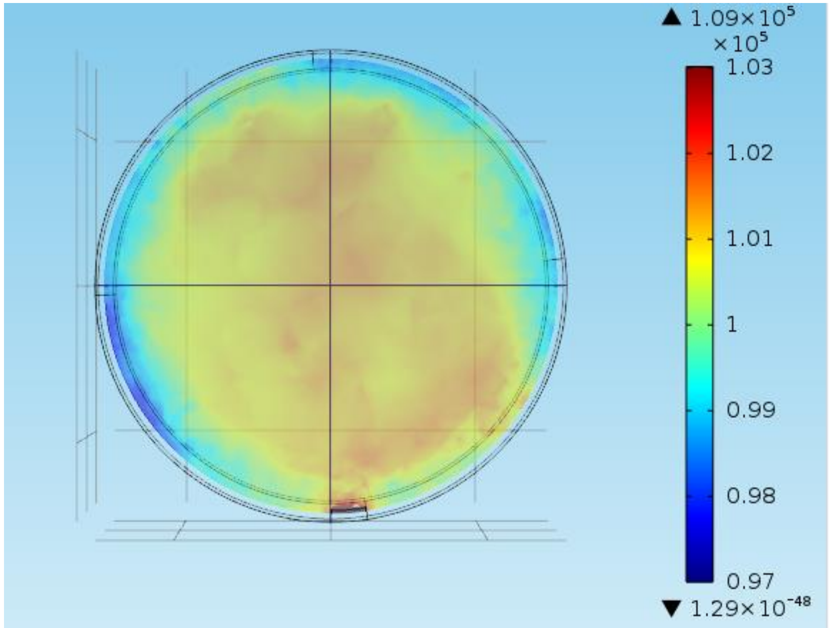
Width 12cm



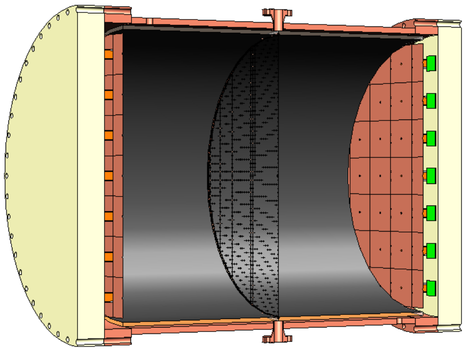
20%thinner
Max:120% of the average;
E field deviation goes below 5% in 3 cm from the boundary ;

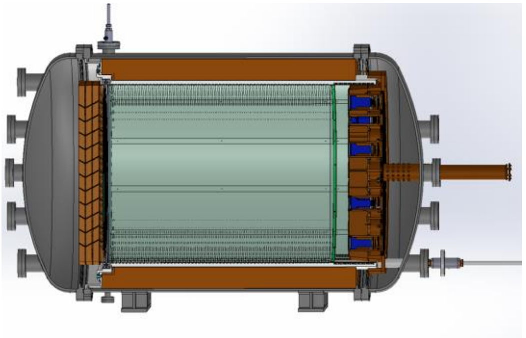


10%thinner
Max:109% of the average;
E field deviation goes below 5% in 1.7cm from the boundary ;



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
Micromegas	Charge/Tracking	SiPM
3%	Projected energy resolution	**0.7%**
mm	Tracking pitch size	cm
X,Y	Fiducialization	X,Y,Z
Since 2015		Since ~2008

Xe+TMA

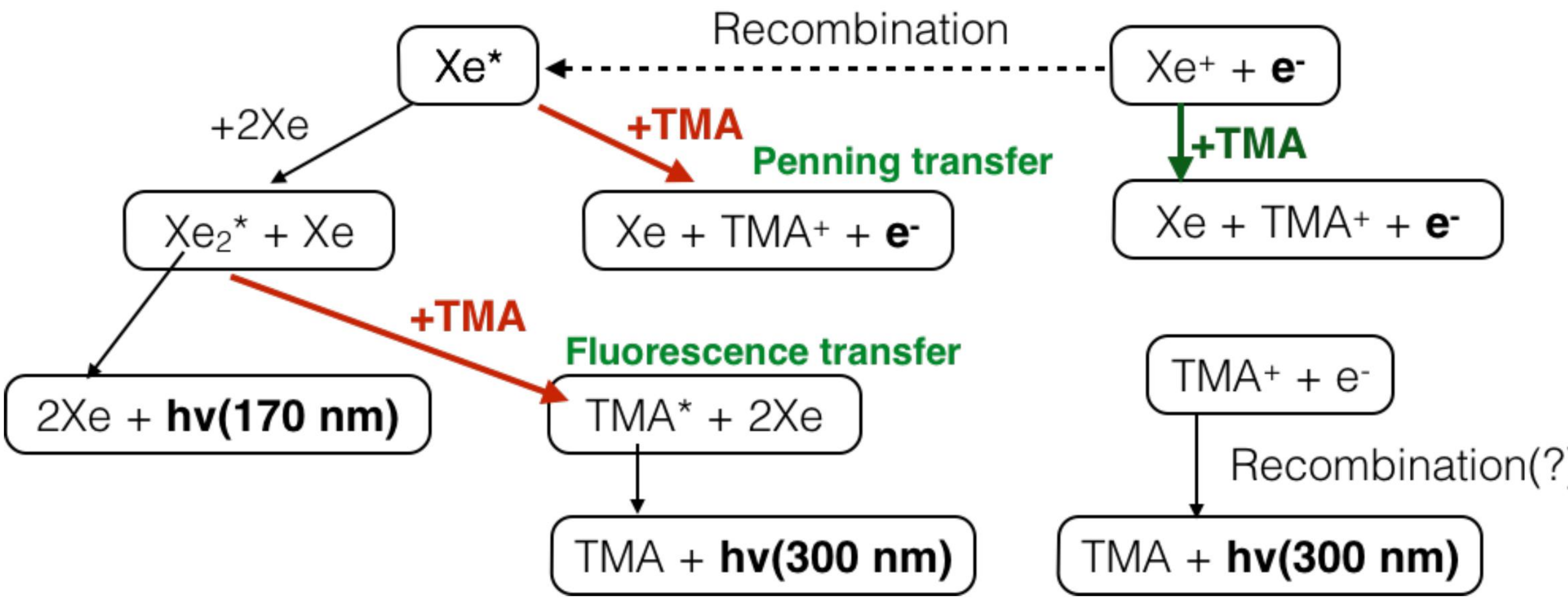
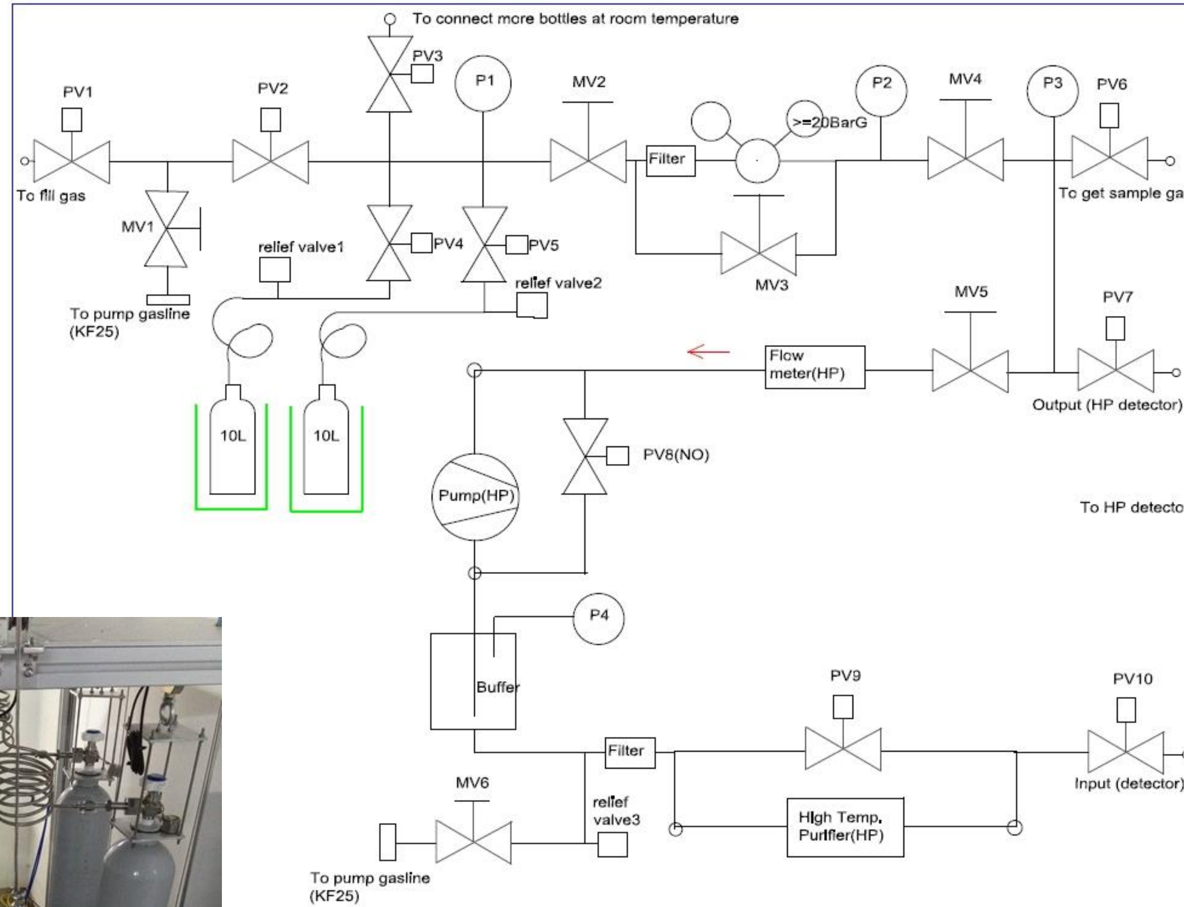
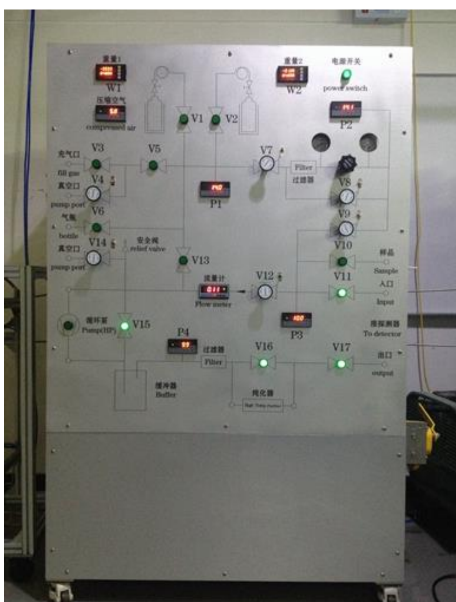


Figure 1. Simplified schematic of Xe and TMA reactions after initial ionization and excitation of Xe. We made the first direct measurement of the processes shown with red arrows.

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.

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