# PandaX-III and its prototype detector: Micromegas for rare event searches

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2017/11/11

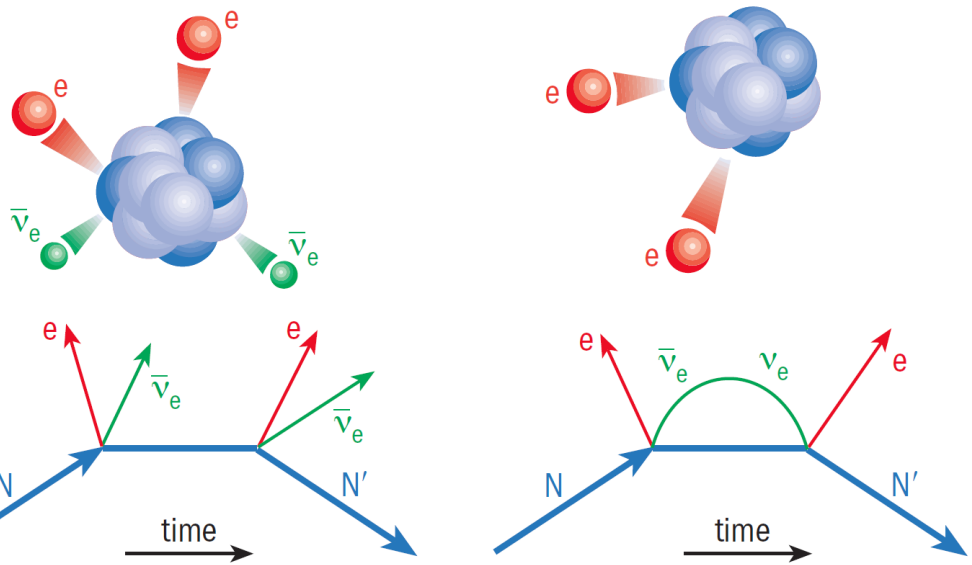
On Behalf of the PandaX-III Collaboration

# Outline

PANDA X
PARTICLE AND ASTROPHYSICAL XENON TPC

- Neutrinoless double beta decay
  - physics and detection
- PandaX-III project
  - high pressure Xe gas TPC with Microbulk Micromegas
- Micromegas modules
  - Scalable Radio-pure Readout Module
  - Readout plane design
- Prototype TPC
  - Preliminary data with one/two Micromegas
  - Commissioning of 7 Micromegas modules

# Neutrinoless double beta decay




From Physics World

Majorana Neutrino

$$\bar{\nu} = \nu$$

- Explores the Majorana nature of neutrinos
- Tests lepton number conservation
- Explains naturally the origin of tiny neutrino mass
- Connects to broad neutrino oscillation physics picture

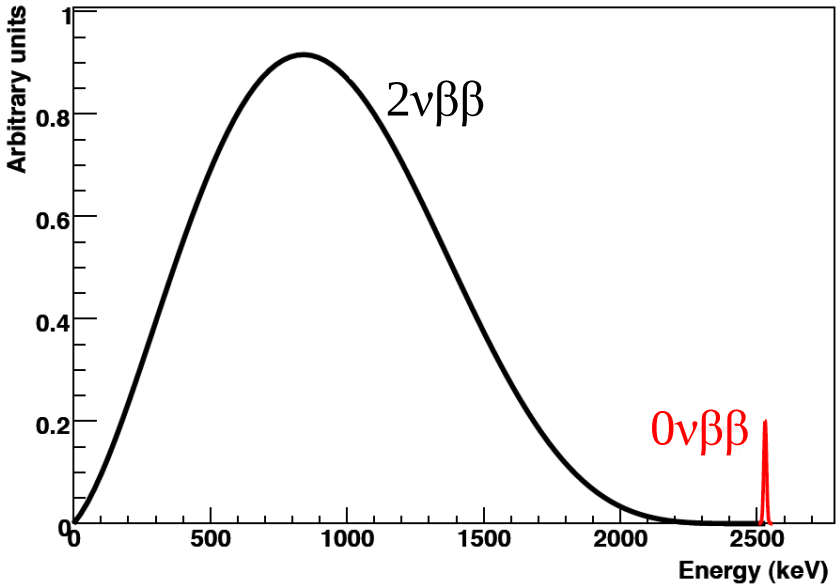
# Detection of double beta decay

- Examples:

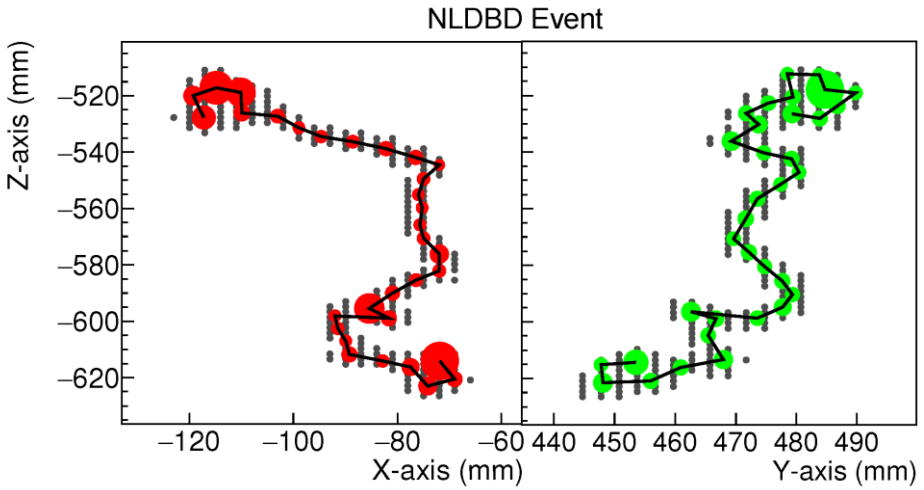
$$^{136}Xe \rightarrow {}^{136}Ba + 2e^- + (2\bar{\nu}_e)$$

$$^{130}Te \rightarrow {}^{130}Xe + 2e^- + (2\bar{\nu}_e)$$

- Measure energies of emitted e-
- Electron tracks are a huge plus
- Daughter nuclei identification

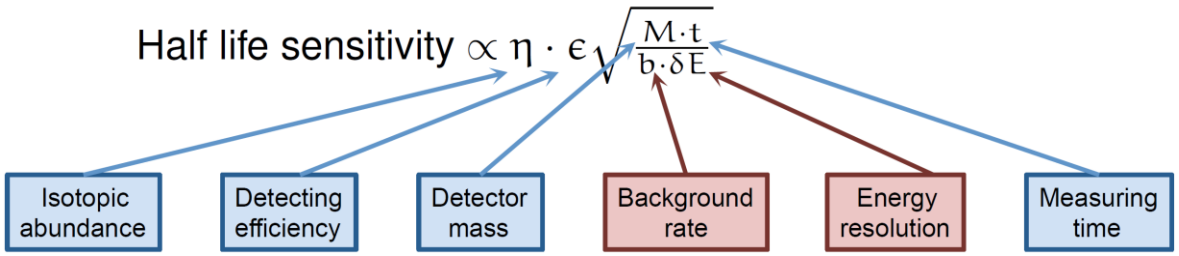



Sum of two electrons energy

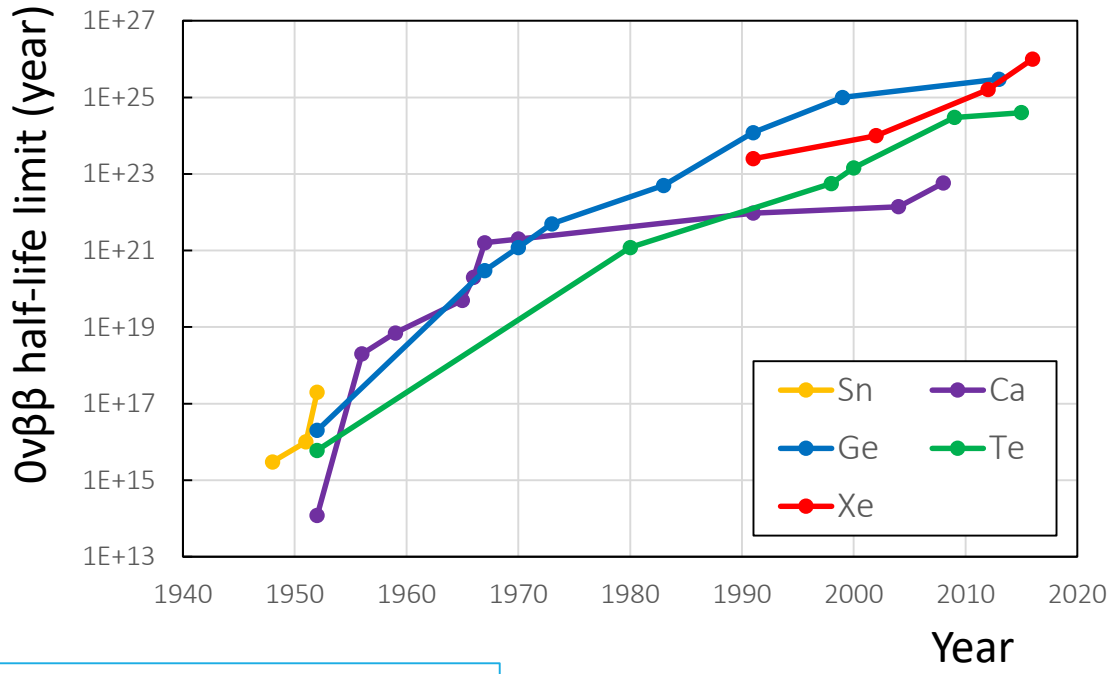



Simulated track of 0νββ in high pressure Xe

# Impressive experimental progress




- ~100 kg of isotopes
- ~100-person collaborations
- Deep underground
- Shielding + clean detector

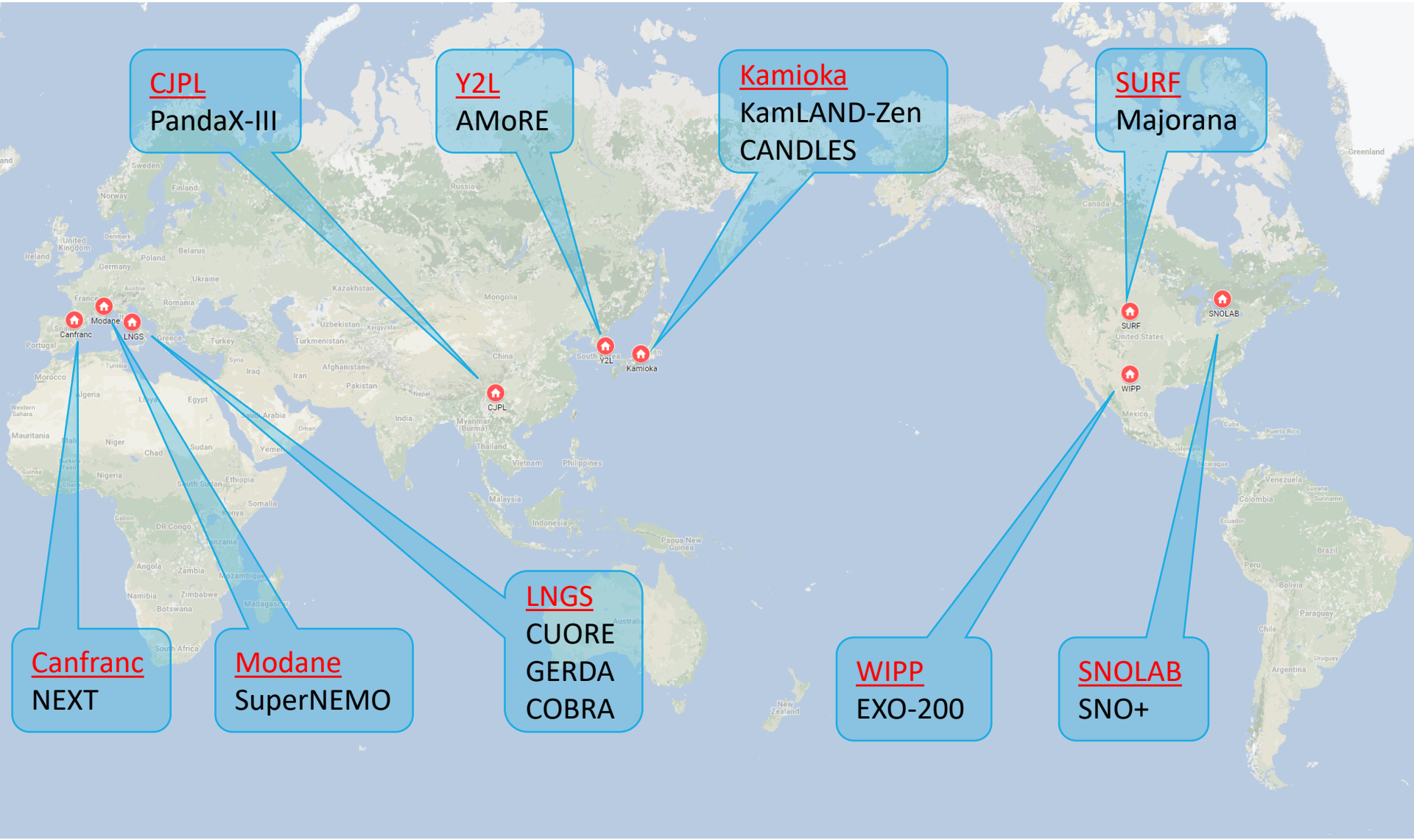



- Grams of isotopes
- Table-top experiment
- Above-ground
- Little shielding

Partial list of selected isotopes; Pre-1984 data points from review article by Haxton and Stephenson, Jr.

# Major 0νββ experiments around the world

PANDA X
PARTICLE AND ASTROPHYSICAL XENON TPC

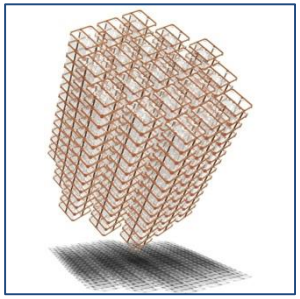



Running or under construction (partial list)

# Detection channels

PANDA X
PARTICLE AND ASTROPHYSICAL XENON TPC

## Phonons



CUORE

AMoRE
CUPID

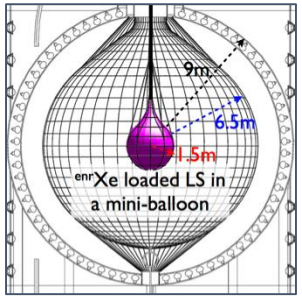
## Electrons holes

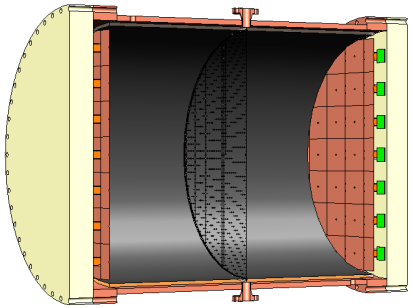
GERDA
Majorana
COBRA
PandaX-III

EXO/nEXO
NEXT
SuperNEMO

## Photons

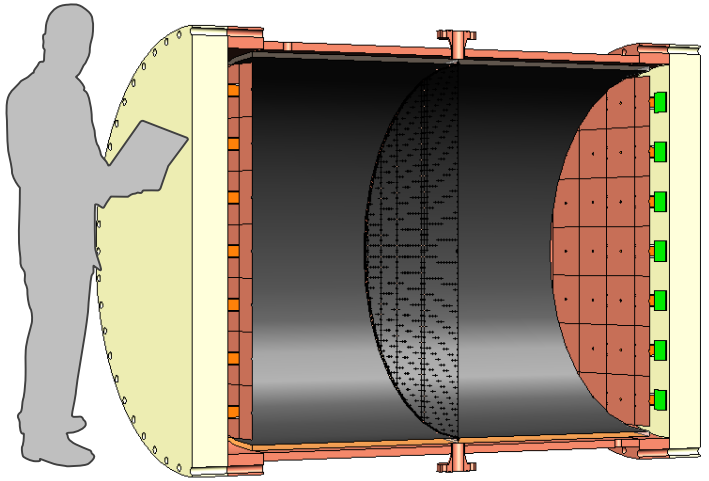
KamLAND-Zen
SNO+
CANDLES

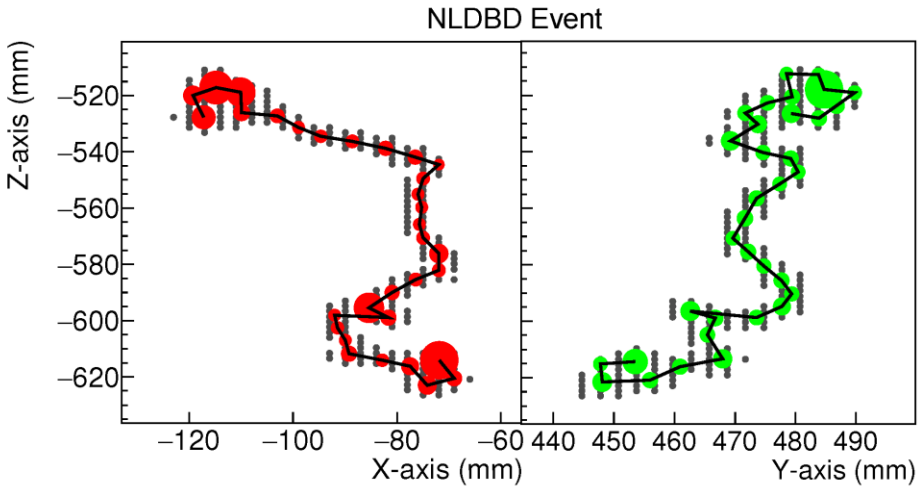


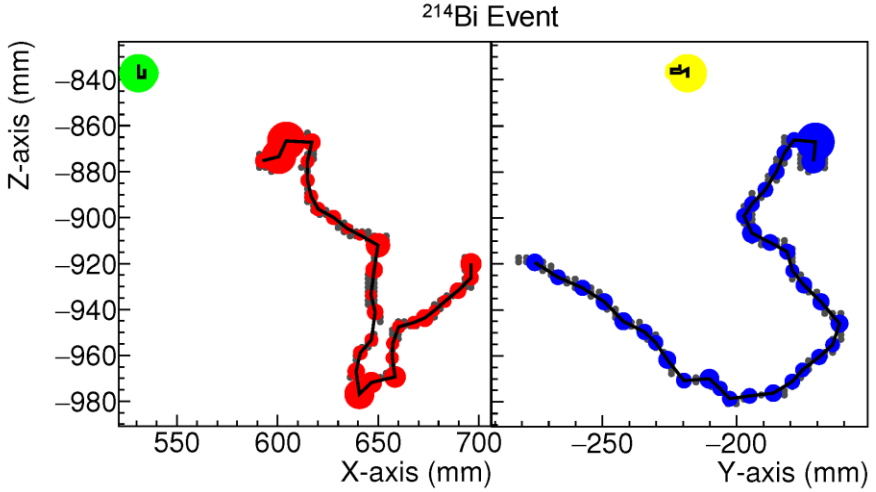



# PandaX-III high pressure gas TPC

- TPC: 200 kg scale, symmetric, double-ended charge readout, with 10 bar of $^{136}Xe$
- Main features: good energy resolution and background suppression with tracking



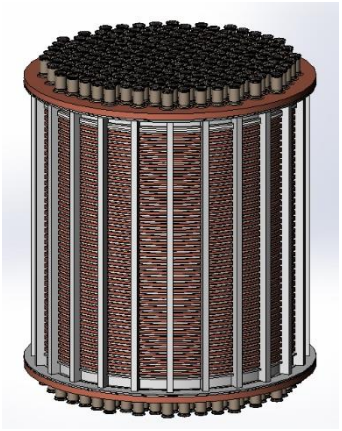


# PandaX Projects

PandaX-I: 120kg LXe
(2009 – 2014)

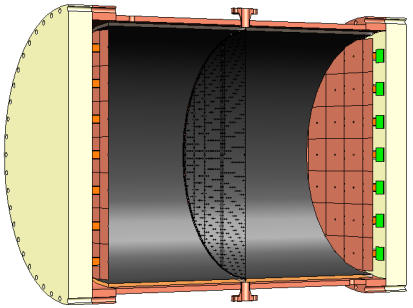
PandaX-II: 500kg LXe
(2014 – 2018)



PandaX-xT LXe
(Future)

Dark matter WIMP searches


PRL 117,
121303 (2016)

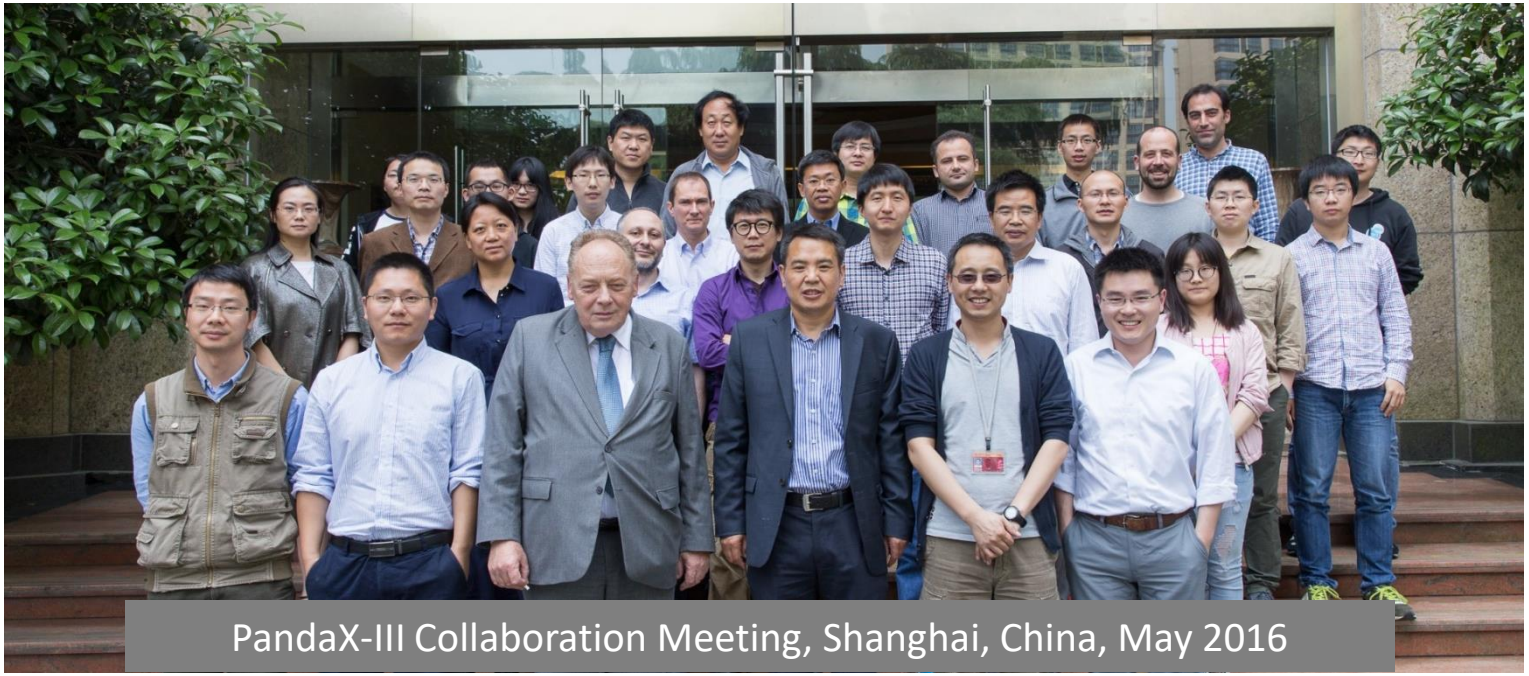


PandaX-III:
200kg - 1 ton HPXe (Future)

0νββ searches

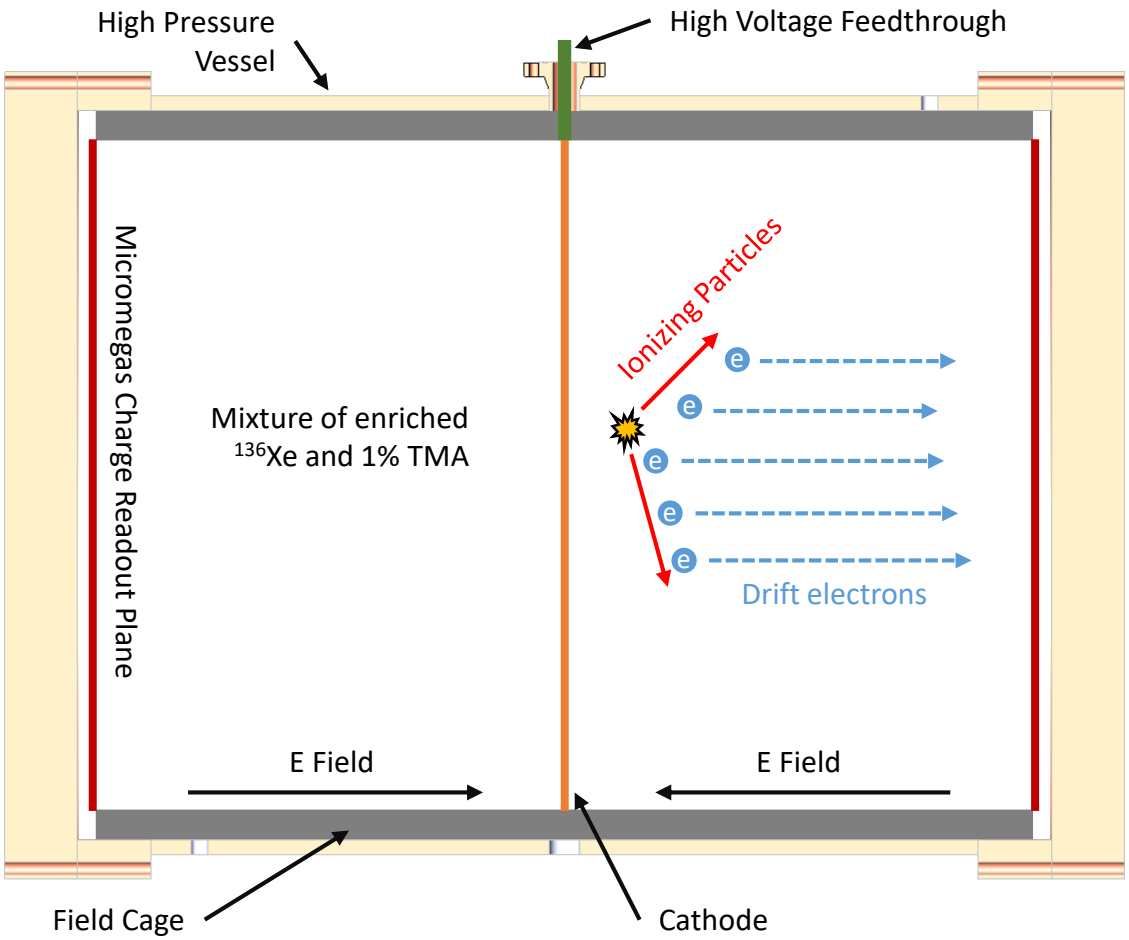
# PandaX-III collaboration

- 上海交通大学
- 中国科学技术大学
- 中国原子能科学研究院
- 北京大学
- 中山大学
- 山东大学
- 华中师范大学
- 美国University of Maryland
- 美国Berkeley Lab
- 法国CEA Saclay
- 西班牙University of Zaragoza
- 泰国苏拉那里技术大学 SUT



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

# PandaX-III TPC illustrated



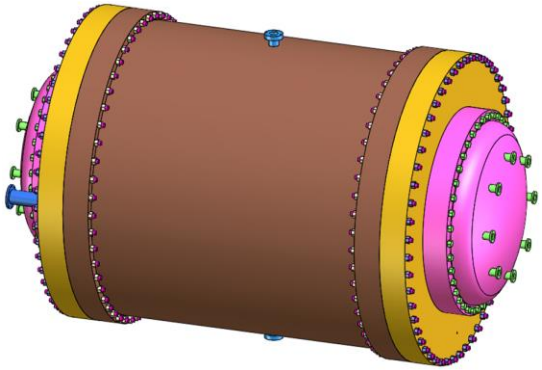

- ~4m$^3$ active volume
- 10 bar working pressure
- ~10000 readout channels
- Xe+TMA gas mixture
- Charge-only readout with Microbulk Micromegas

PandaX-III TPC is unique:

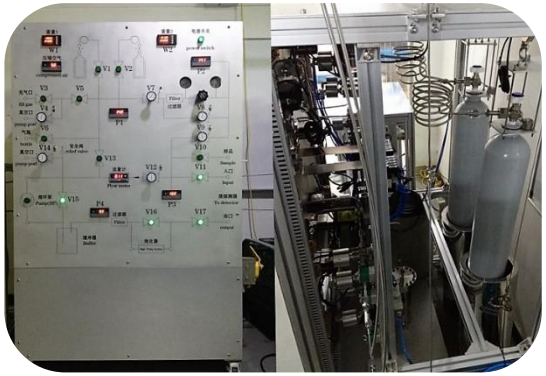
- Radio-purity
- Energy resolution
- High pressure

# “Other” critical pieces of PandaX-III

145 kg of 90% enriched $^{136}$Xe at Shanghai

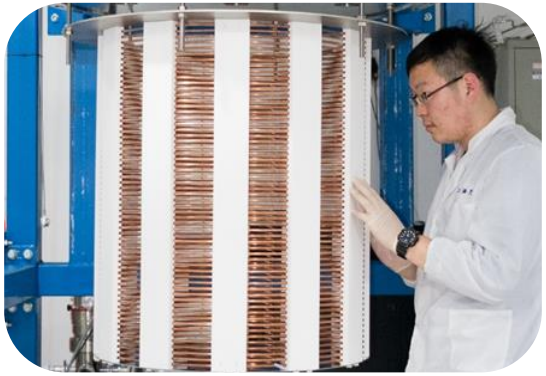


Design and Fabrication of copper vessel in progress



Gas mixing, circulation, and purification system ready

Third version of FEC ready for testing with MM

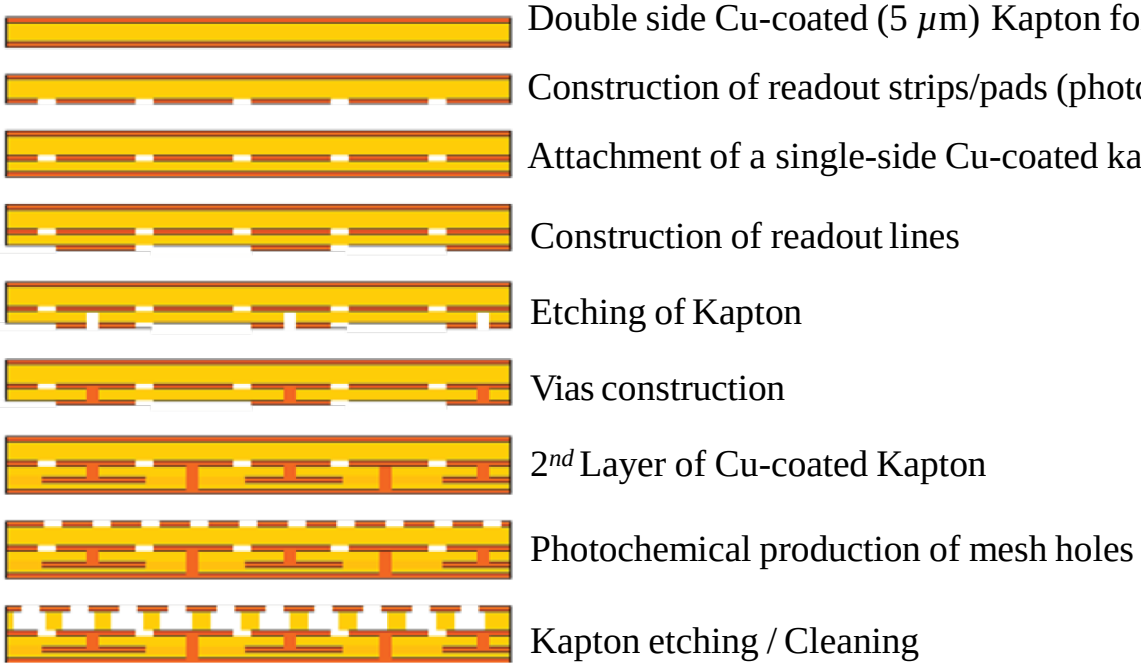


Prototype TPC has been running with Micromegas

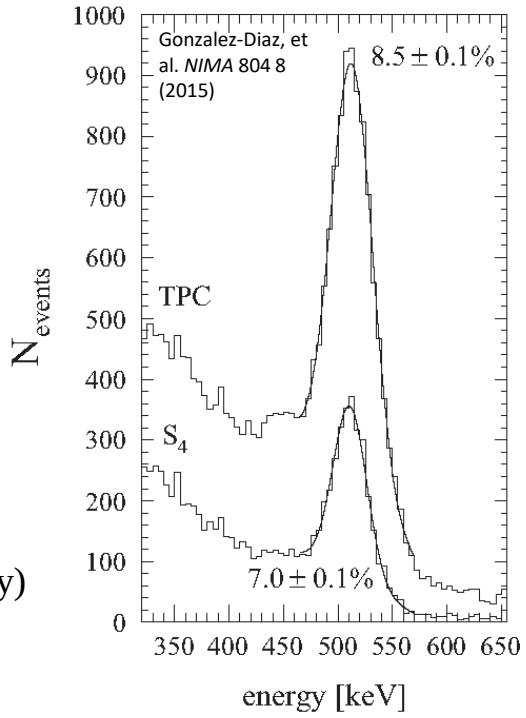
CJPL-II infrastructure under construction

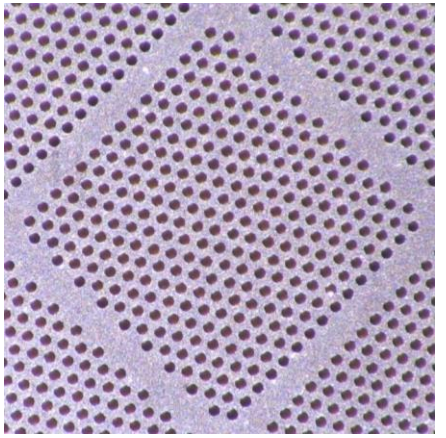
# Microbulk MicroMegas (MM)

- Microbulk MicroMegas films made of Copper and Kapton only
  - Perfect for radio-purity purpose
- ~ 1000X gain
- 3% energy resolution expected at 2.5 MeV.




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



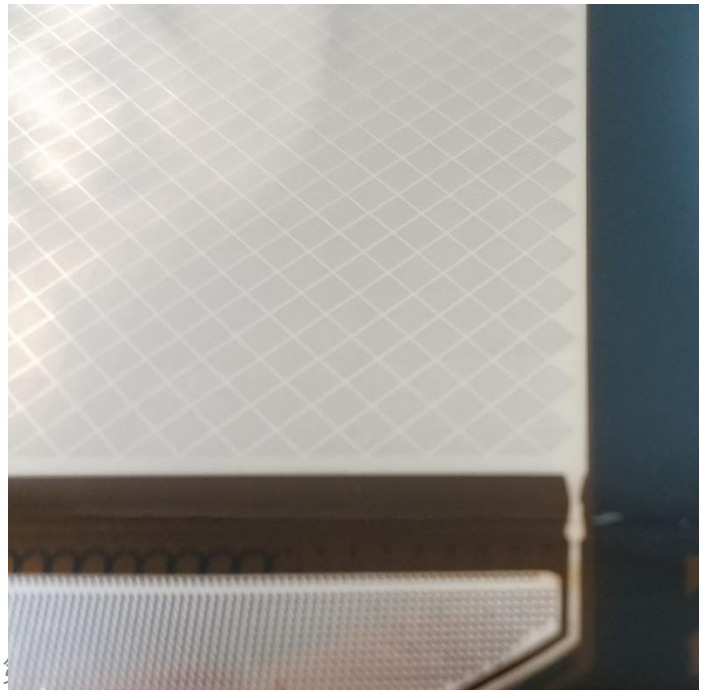
# PandaX-III MM

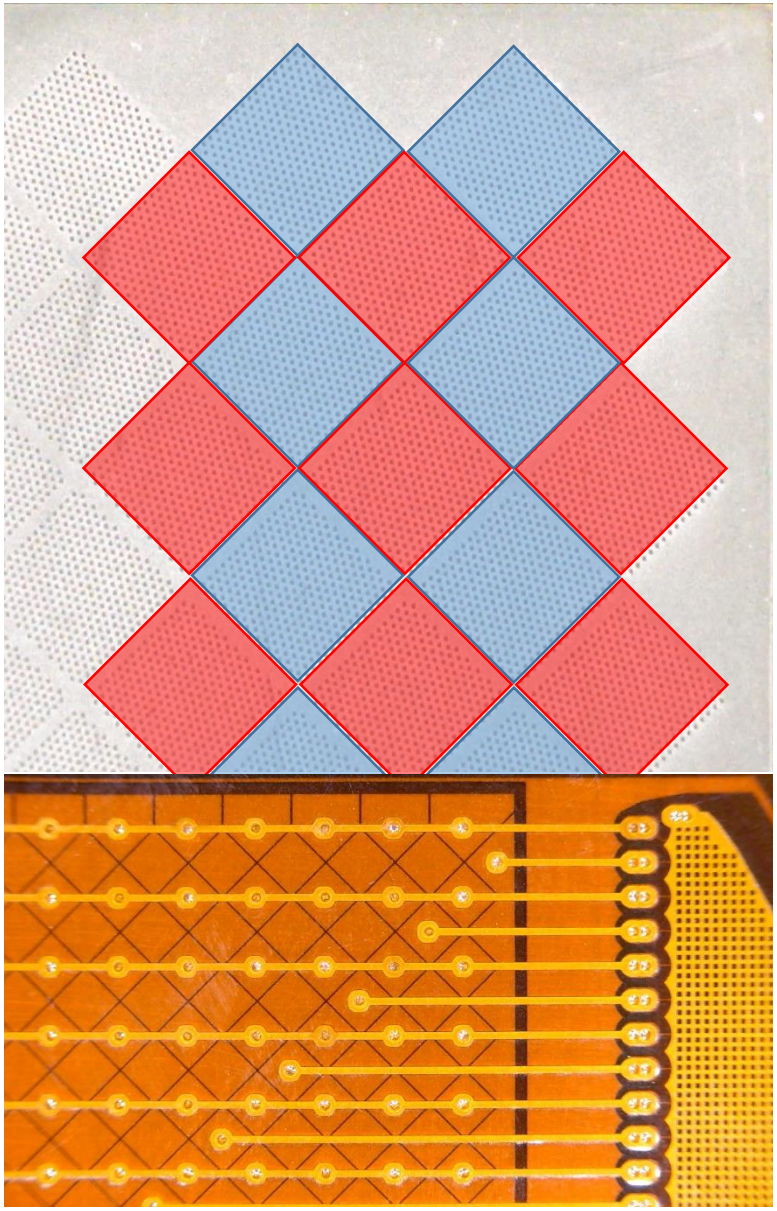
- 20 cm by 20 cm module
- 50 um amplification gap

- 3 mm pitch size
  - XY strip readout
  - 128 channels per module
- Commercial Samtec connector for readout
  - First version only; will change
- Manufactured by CERN
  - 12 modules so far: 8 at SJTU; 1 at CIAE; 1 at Zaragoza and 2 at Saclay

# MM X-Y strip readout

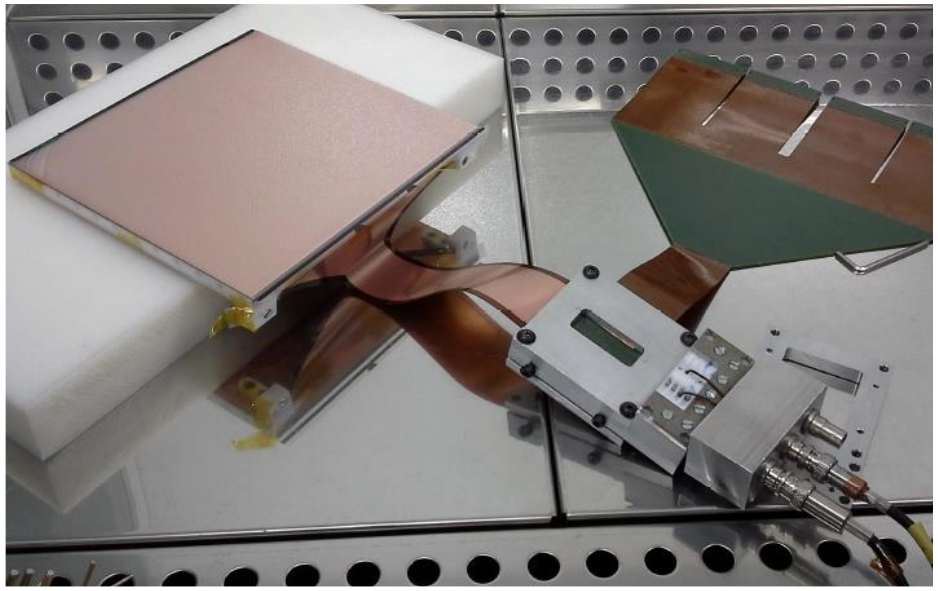
- Balance between granularity and readout channel numbers
  - 1 and 2 mm pitches considered
  - >10000 channels for PandaX-III
- X and Y strip share the total deposited energy
  - Difficulty in 3D track reconstruction

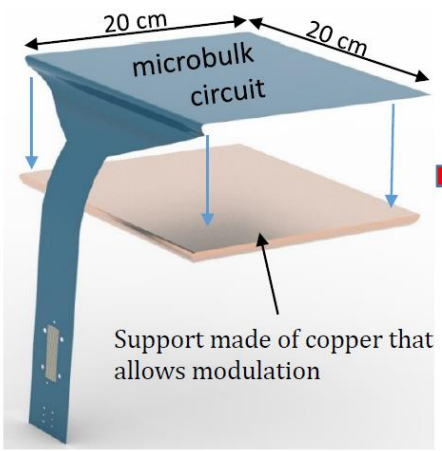


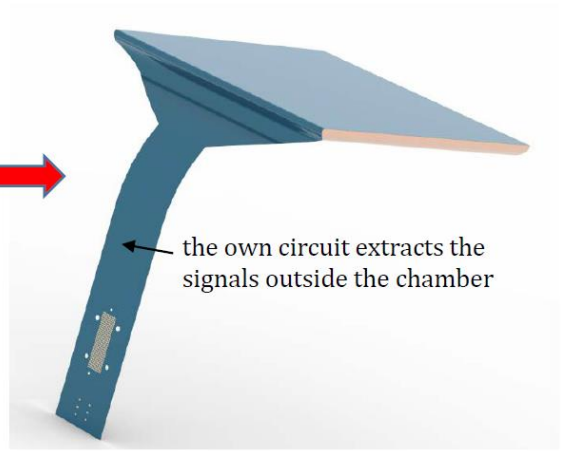


# Scalable Radio-pure Readout Module (SR2M)

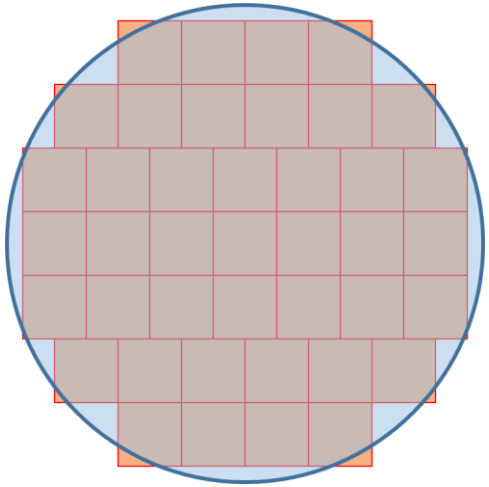
- SR2M: Mosaic layout to cover readout planes
  - Solderless system
  - Strip and mesh signal readout
  - Dead-zone-free arrangement
  - Designed by Zaragoza and SJTU





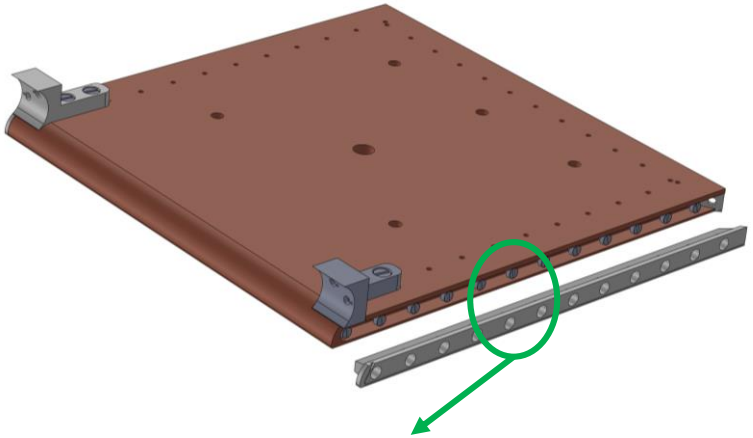

×41

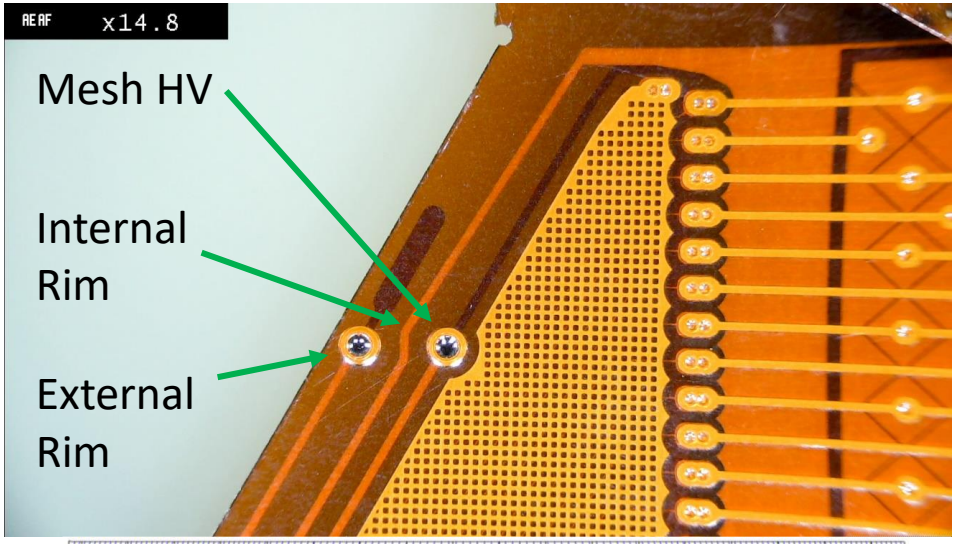


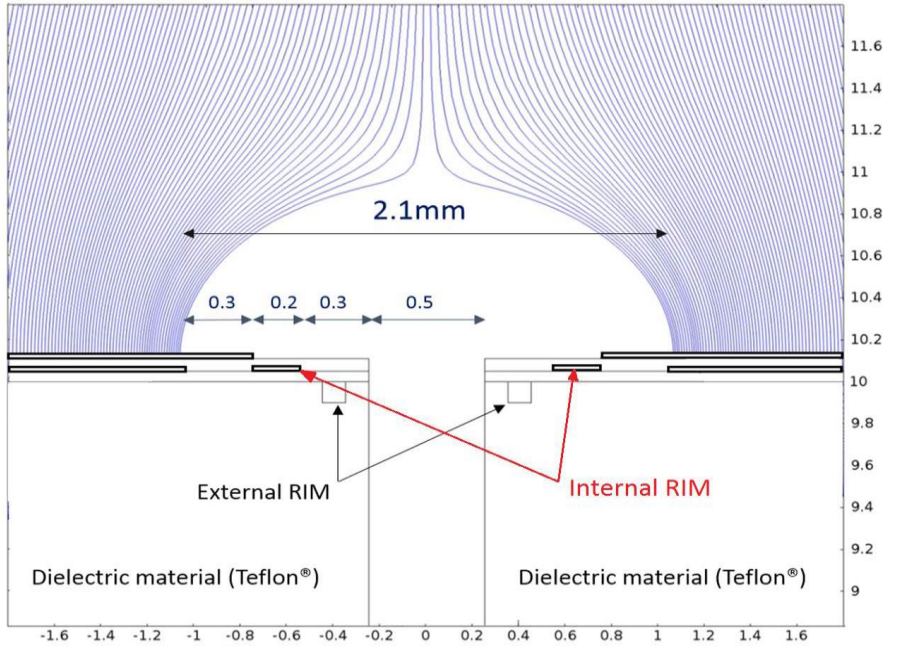
# Field shaping around SR2M

Internal rim and external rim

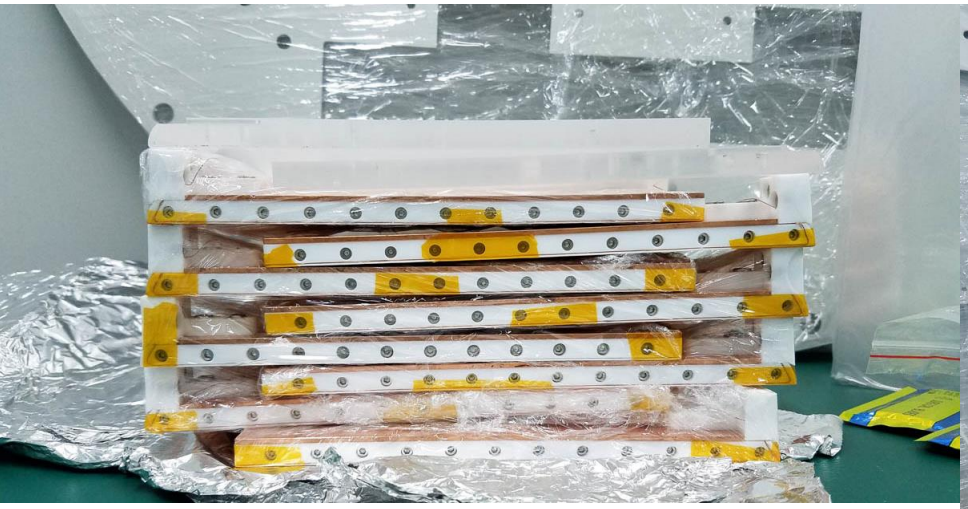
- Shape E field
- Guide electrons to active area

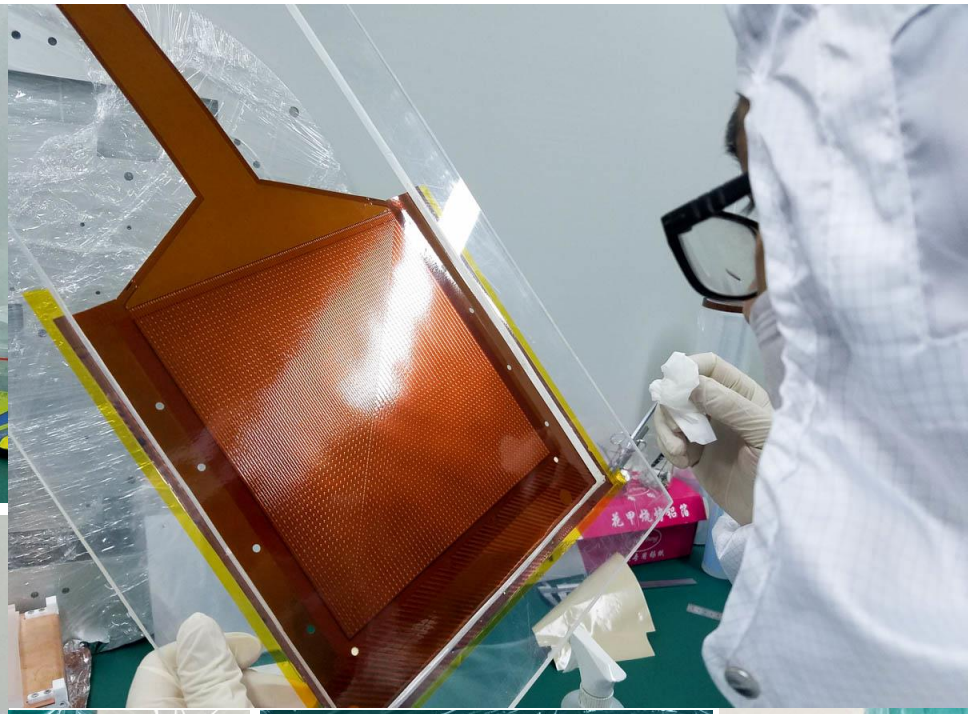


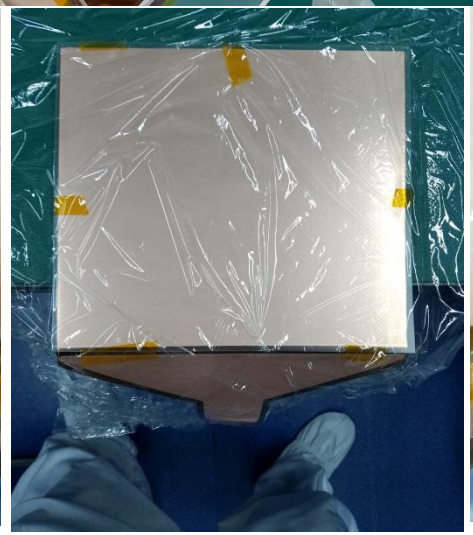


# From MM films to SR2M



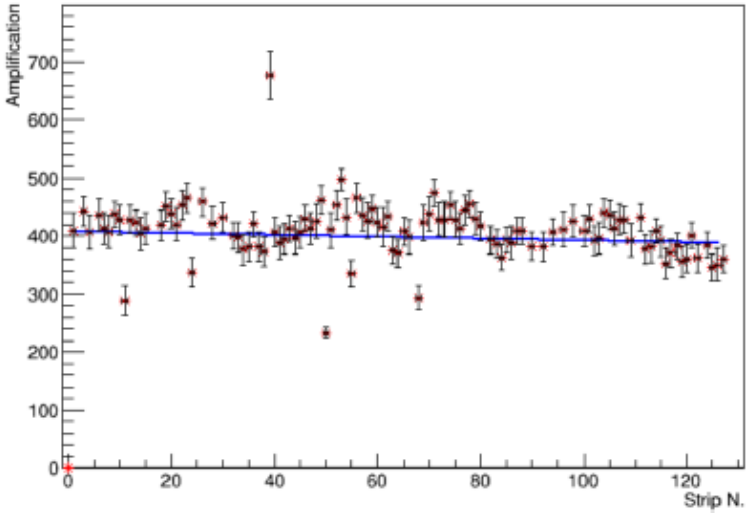




# MM Characterization

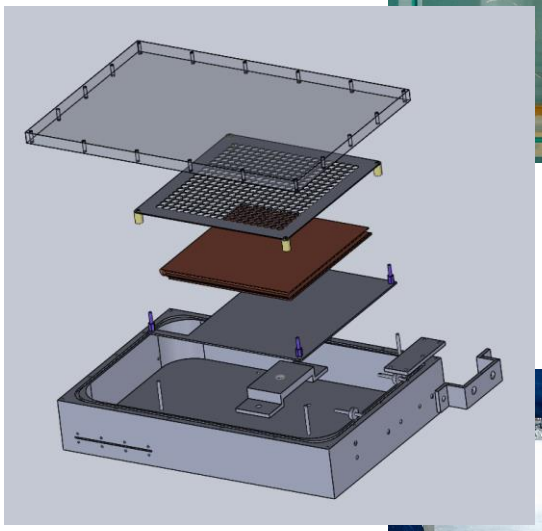
Gain and gain uniformity measured

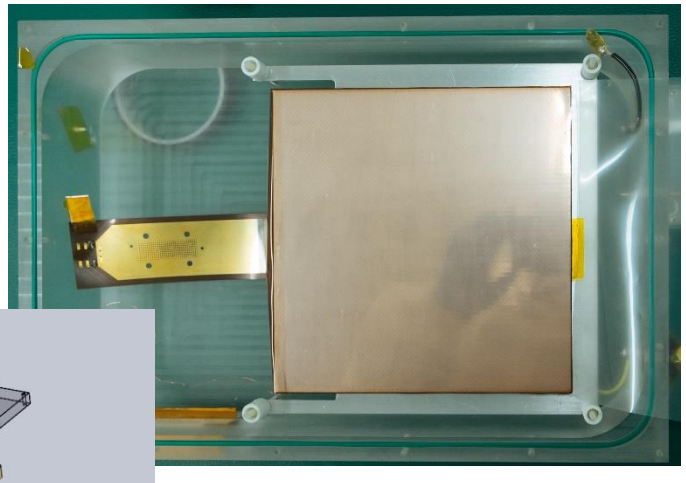
- Argon + $CO_2$ (30%)
- 1 bar flowing gas
- 7.5% RMS uniformity




Future updates:

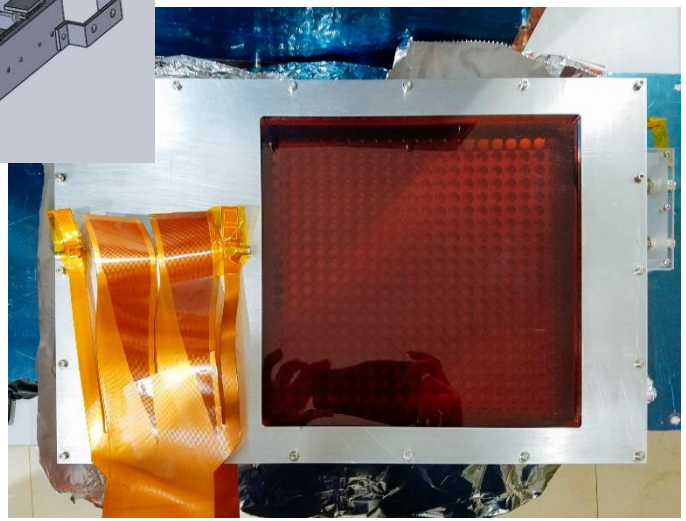
- Motorized source scanning
- More uniform drift field
- Pressurized xenon gas
- Multiple MM cross comparison





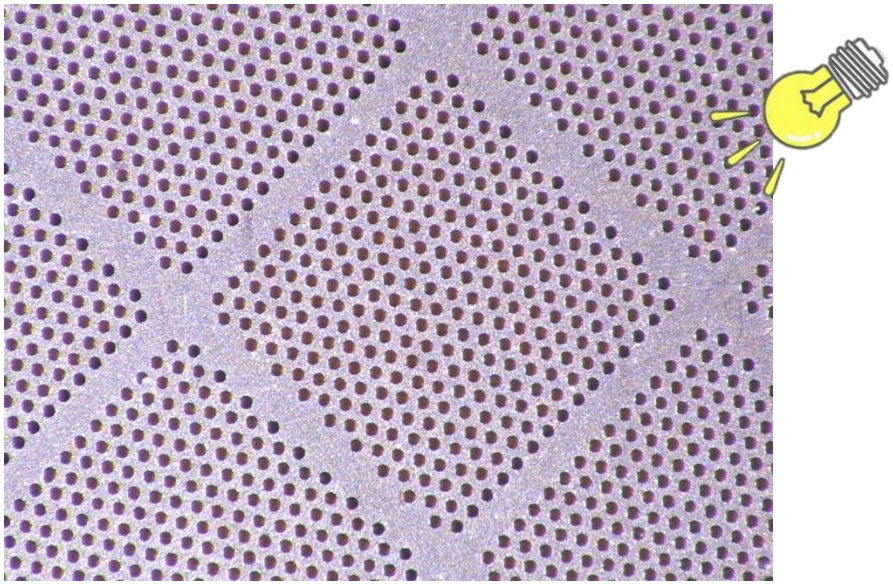
Without

with cathode, top lid

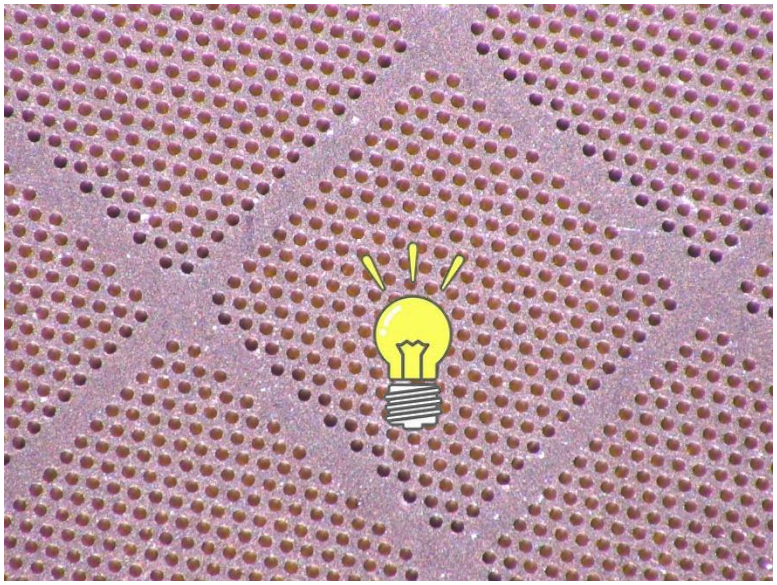


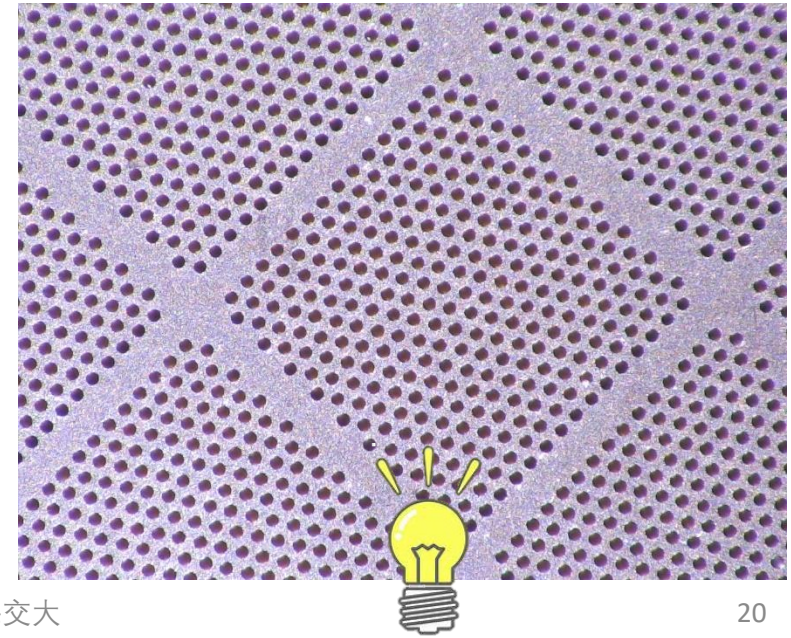
# Visual check of bad channels

- Hard to spot defects from microscope images
- Lighting plays a critical role



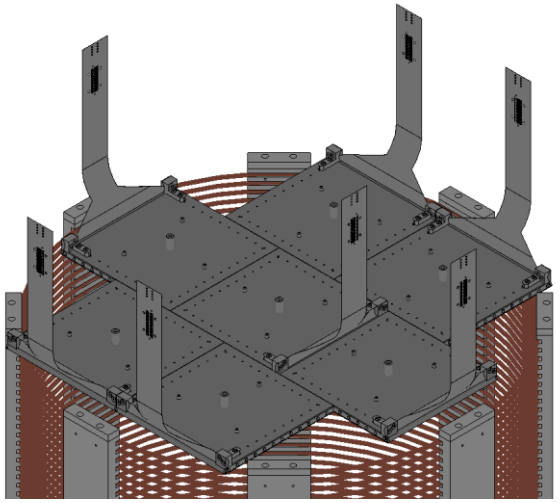
MM under different lighting conditions

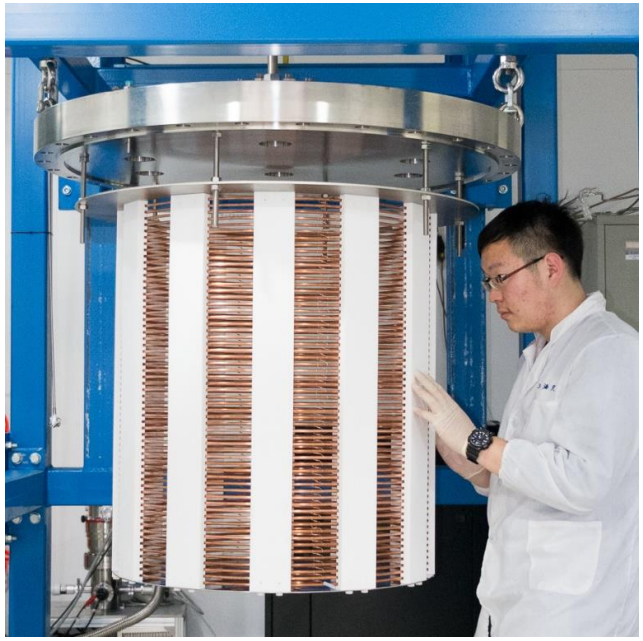


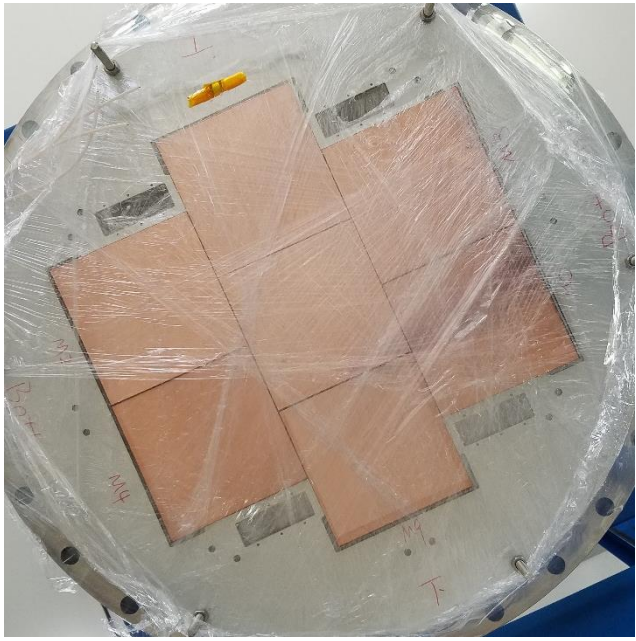


# Prototype TPC at SJTU

- 16 kg of xenon at 10 bar (active mass within TPC)
  - Single-ended TPC
- Data taking with Ar, Xe, Xe+TMA at different pressures
- Ran with 1 and 2 Micromegas modules installed.
- Commissioning with 7 MM.

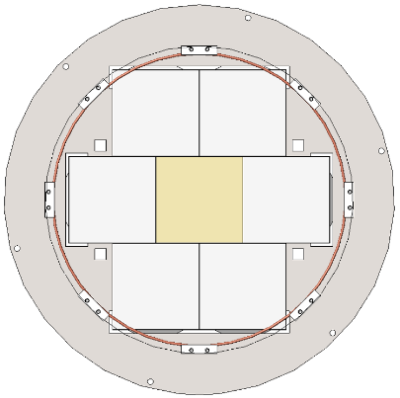


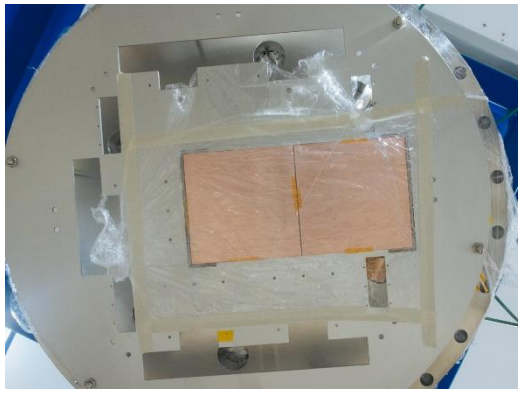


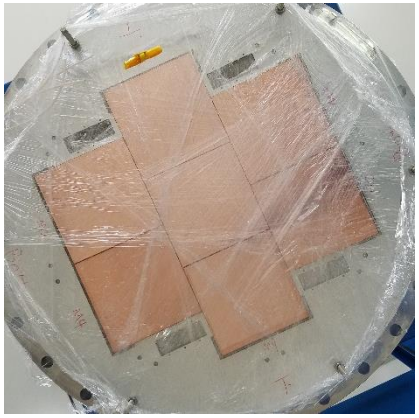


# Progress towards prototype

| | 1 MM run | 2 MM run | Full Prototype |
|---|---|---|---|
| Number of MM | 1 | 2 | 7 |
| channels | 128 | 256 | 896 |
| Gas medium | Ar/$CO_2$, Ar/Iso, | + Xenon/TMA | + Xenon/TMA |
| Pressure | Up to 5 bar | Up to 5 bar | Up to 10 bar |
| Calibration | Internal $^{241}$Am | + Motorized $^{55}$Fe | + $^{137}$Cs + $^{232}$Th |
| Electronics | ASAD/CoBo | ASAD/CoBo | + Custom FEC |
| Status | Done | Data analysis | Commissioning |



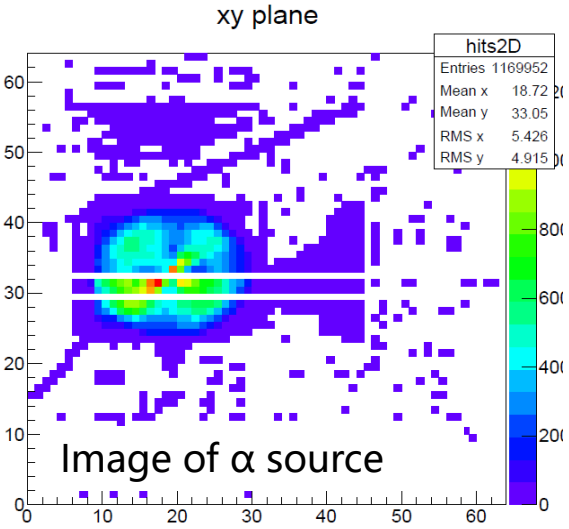


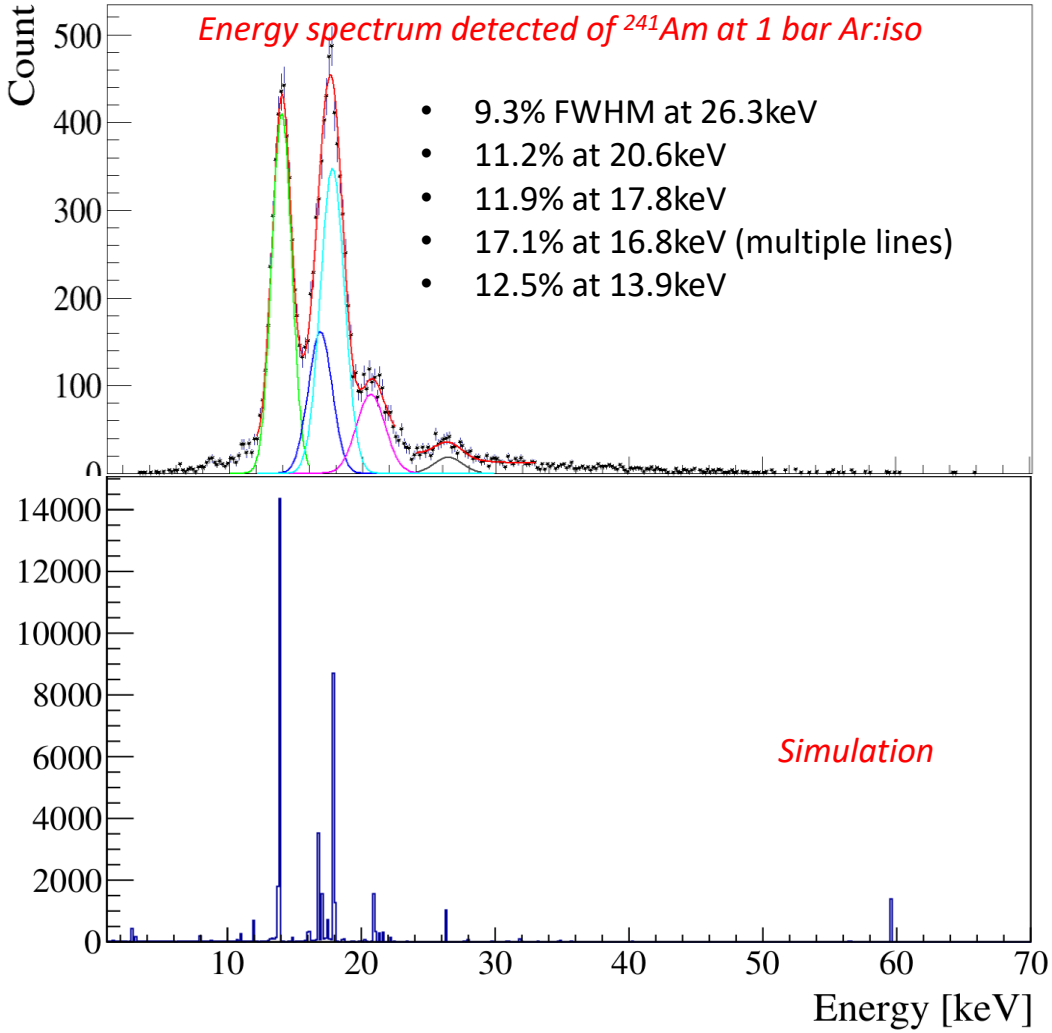


# Data taking with 1 MM + Ar:(5%)isobutene

- $^{241}$Am Gamma source
- 1bar Ar:(5%)isobutene
- Voltage configuration:
  - Mesh: -370V
  - Drift: -2.8 kV ~-11.8 kV
- Electronics range: 1pC

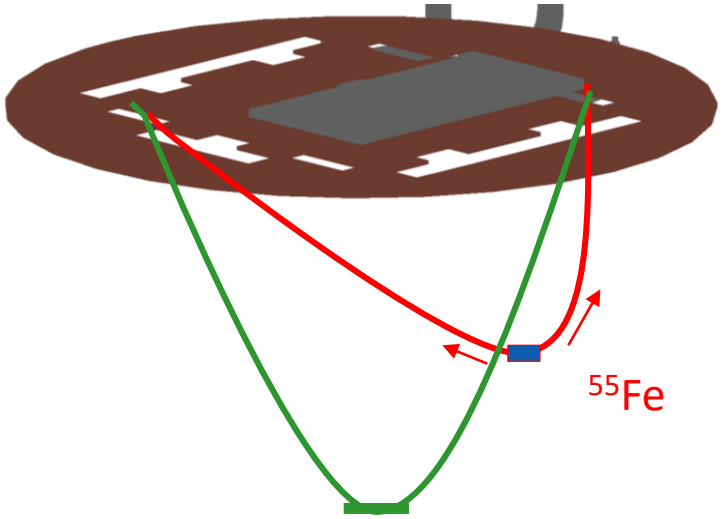
## Detector gain ~8000



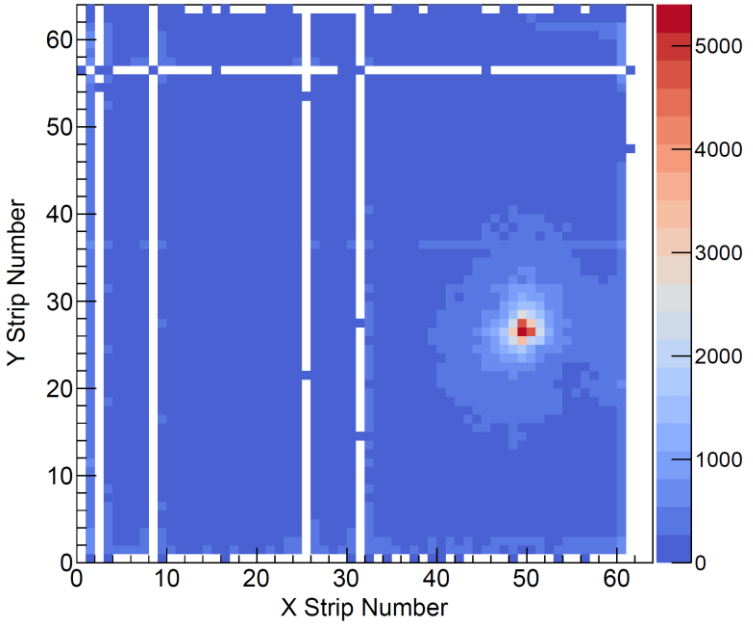
# Data taking with 2MM + Xe:(1%)TMA

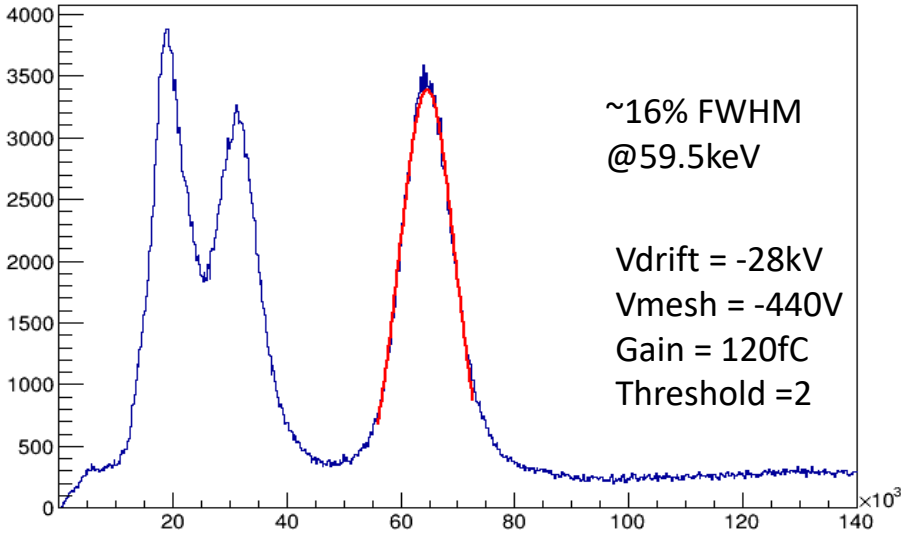
- Commissioned with remodeled field cage
- Circulation and purification for Xe and Xe:TMA.
- Data analysis is on-going




*$^{241}$Am at 5 bar Xe:TMA*

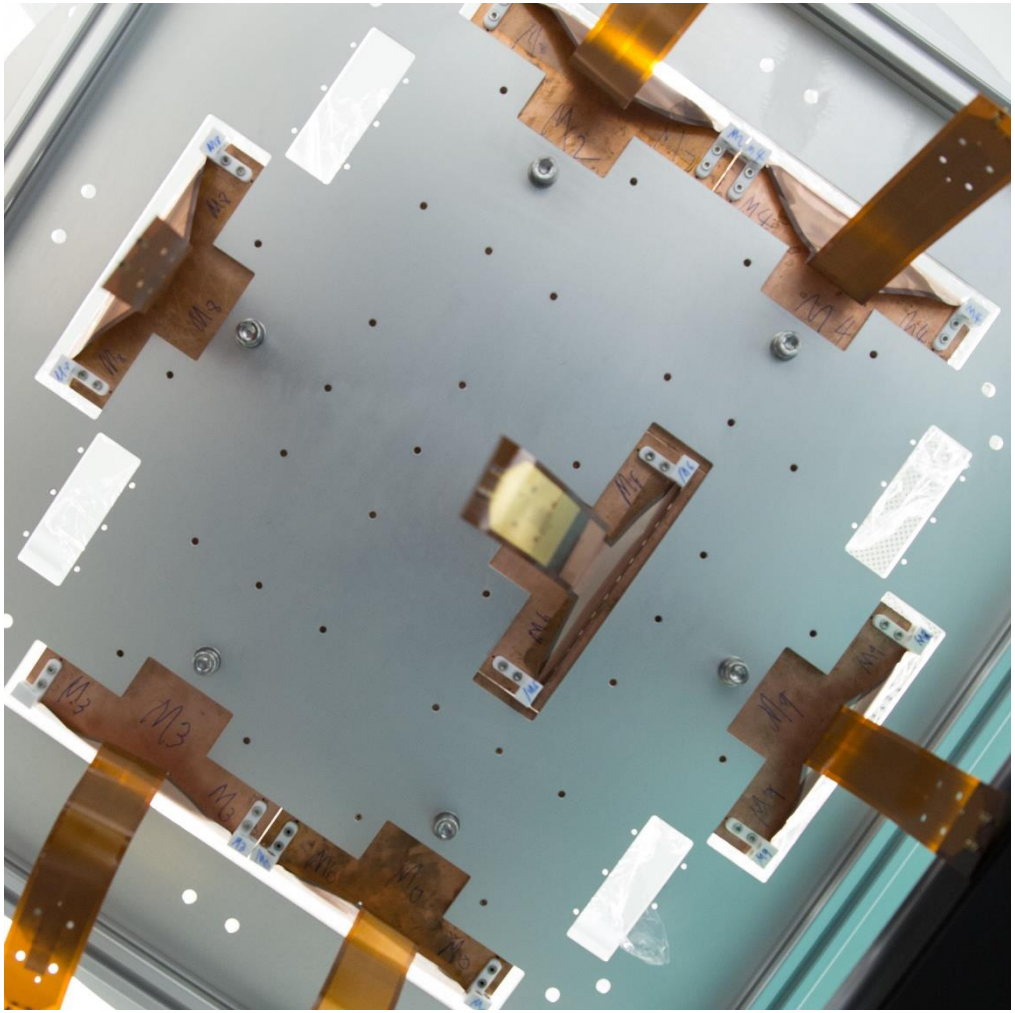
Shielded $^{241}$Am



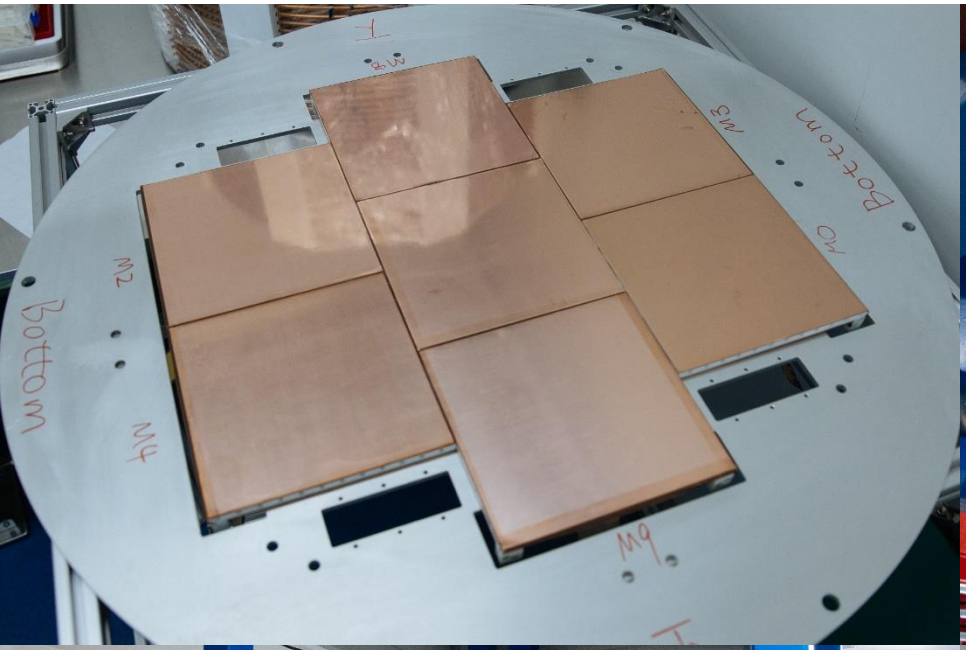
# The 7 MM setup

- To see MeV electron track
- To demonstrate required energy resolution with a large-scale high pressure TPC
- To optimize the design of Micromegas readout plane
- To develop algorithm of 3D track reconstruction
- To explore the impact of $t_0$ with light readout
- To test custom electronics from USTC



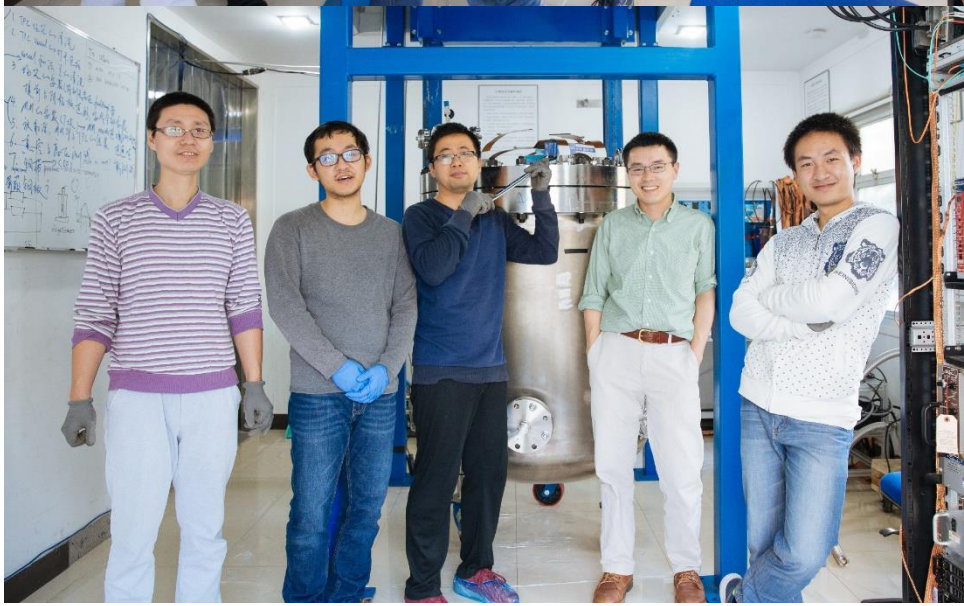
# Installing 7 MM modules

PANDA X
PARTICLE AND ASTROPHYSICAL XENON TPC



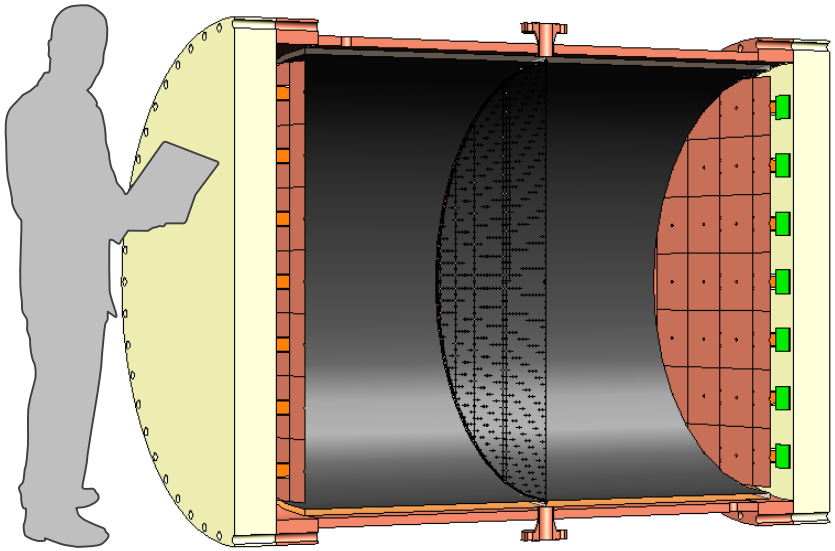

# Commissioning on-going

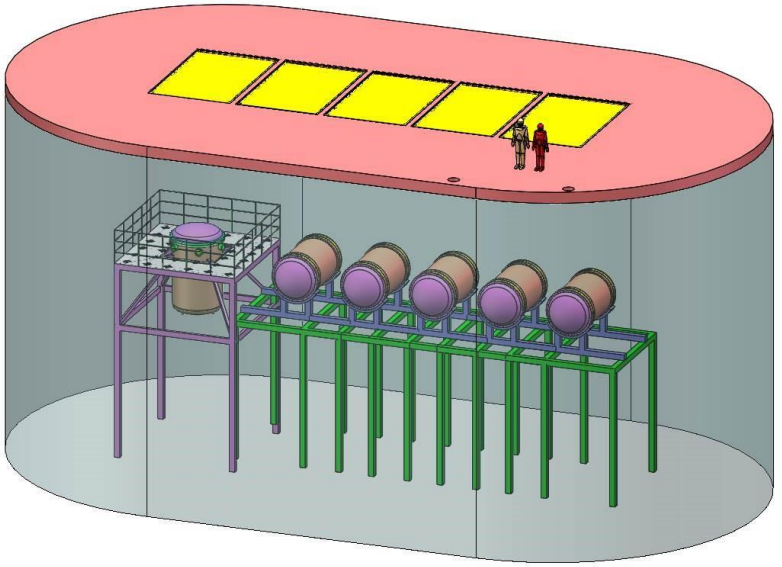
- 7 MM modules have been installed to the TPC
- Now filled with 5 bar Ar:Iso to benchmark its performance
  - No leaks
  - Drift and mesh HV are Okay.
  - Checking bad strips and getting ready for data taking.
- $^{137}$Cs and $^{241}$Am gamma sources are installed in the TPC
- Will run up to 10 bar of Xe+TMA



# Conclusions

- 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-III is an unique application of gas TPC and Micromegas

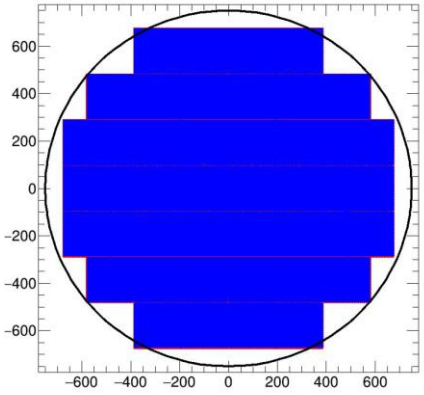


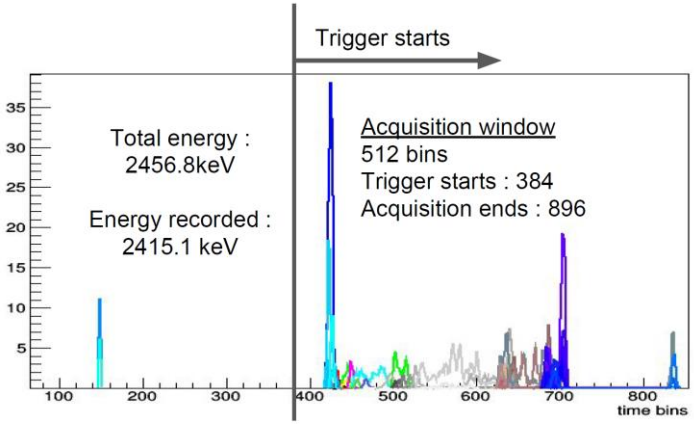


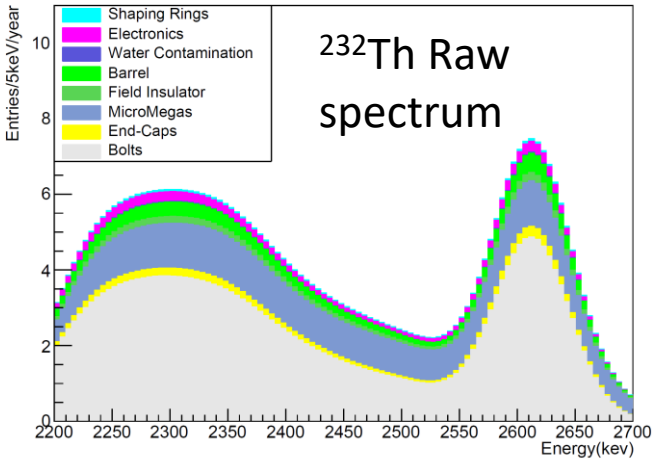
# Background budget

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

- Treat PandaX-III as a simple calorimeter
- Then add detector response
- Calculate signal efficiency and background rejection
- ×35 background reduction from topological analysis
  - Track reconstruction and blob identification at both ends
  - Convoluted neural network



# Sensitivity projection

- First 200-kg module:
  - Microbulk Micromegas for charge readout
  - 3% FWHM, 1 x $10^{-4}$ c/keV/kg/y in the ROI
- Ton-scale:
  - Four more modules with upgraded charge readout and better low-background material screening.
  - 1% FWHM, 1 x $10^{-5}$ c/keV/kg/y in the ROI