



***Neutrinoless double-beta decays in a high-pressure gaseous Xenon-136 TPC:  
the PandaX-III experiment***

***Damien Neyret***

***CEA Saclay IRFU/DPhN***

***XeSAT 2020 workshop***

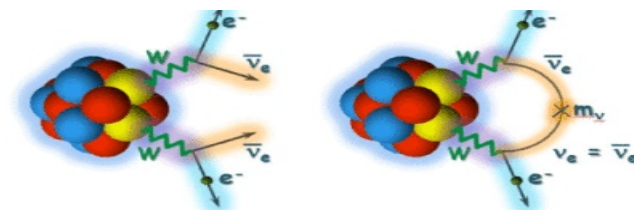
***24/05/2022***

## Search for neutrinoless double-beta decays

Neutrino = antineutrino  $\rightarrow$  Majorana neutrino

Violation of the leptonic number

Physics beyond standard model



## PandaX-III experiment

Double-beta decay in **Xenon 136**

**Gaseous TPC** at 10 bar, 200kg ( $\rightarrow$  1t) of  $^{136}\text{Xe}$  + 1% TMA

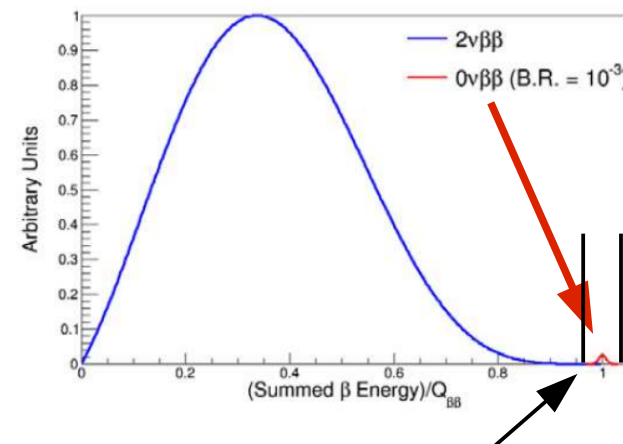
**Charge readout** with gaseous detectors

## Experimental constraints

Excellent **energy resolution** (goal 1% at  $Q_{\beta\beta}=2.458$  MeV)

Excellent **radiopurity**

Background rejection by factor 100 using **event topology**



Region of interest (ROI) around 2.5MeV peak

# The PandaX-III collaboration

## International collaboration

China → 7 institutes (lead by SJTU)

France → CEA Saclay

Espagne → Zaragoza

USA → BNL + Maryland University

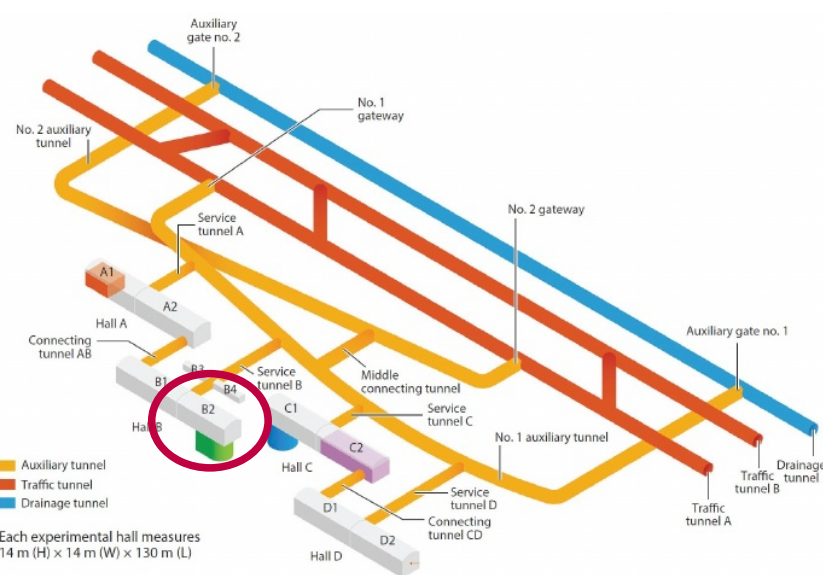
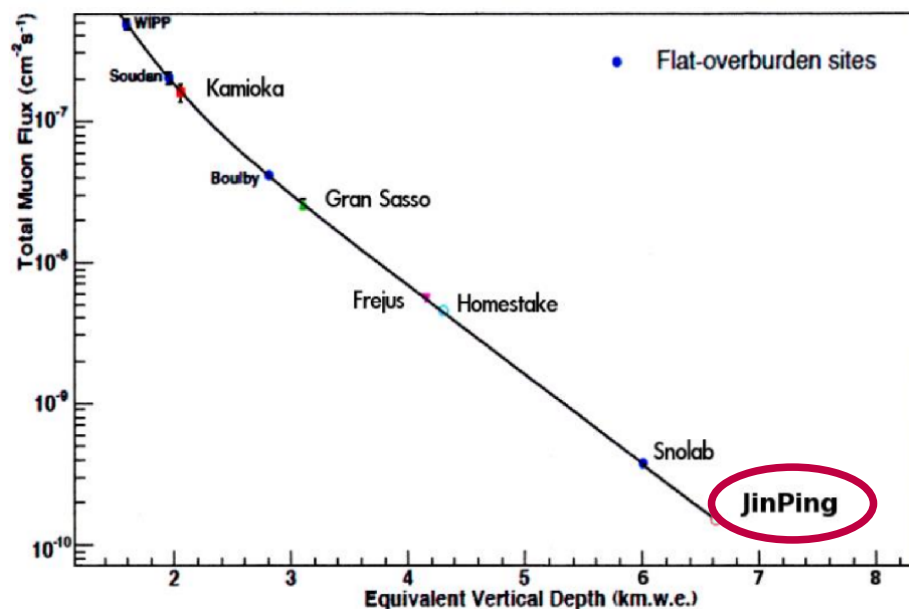
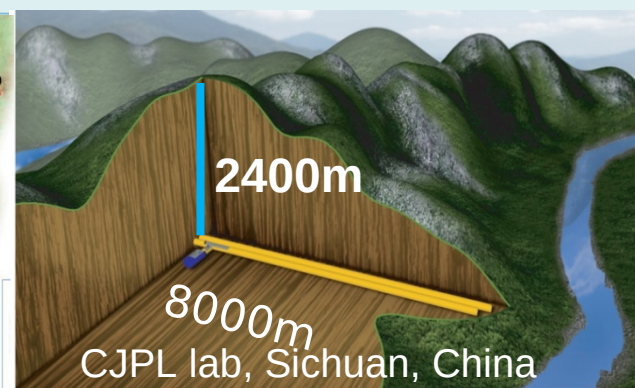
Thailand → Nakhon Ratchasima

## Laboratory

Jinping CJPL-II underground laboratory (Sichuan, China)

One of the worldwide lowest muon flux

Large caverns, easy access to trucks



# The PandaX-III experiment

## Detection principle

10 bar  $^{136}\text{Xe}$  (90% enriched) time projection chamber (TPC)

Ionization electron readout by Micromegas detectors

Double-beta vs gamma discrimination using event topology

## Experimental setup

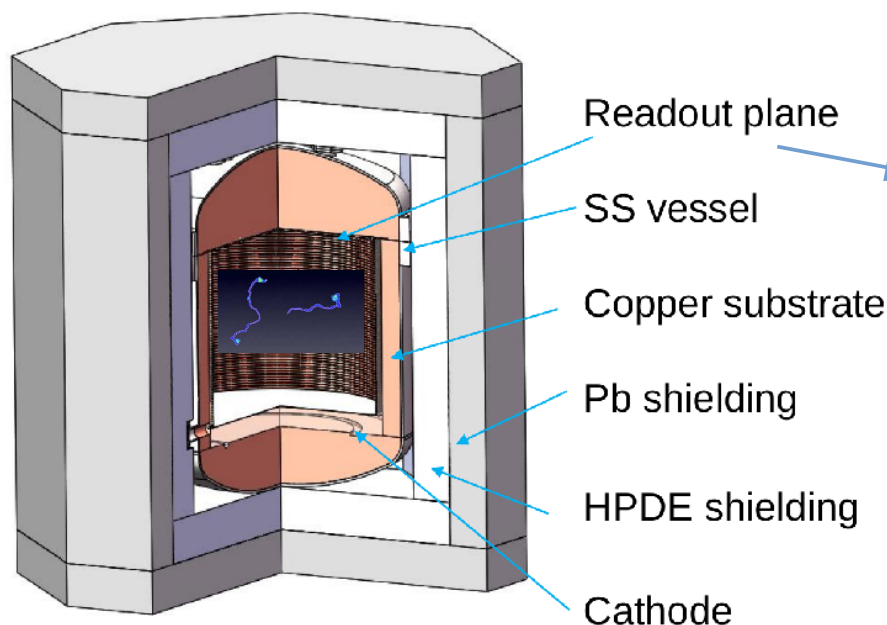
Goal: 5 x 200kg TPC modules in total with pure water shielding

But final position not available for now (PandaX-4t)

1<sup>st</sup> module: 145kg Xenon in stainless steel vessel + dry shielding

Shielding against gammas and neutrons: copper, lead, HPDE

A lot of efforts to reduce U ( $^{214}\text{Bi}$ ) and Th ( $^{208}\text{Tl}$ ) contamination



# Double-beta decay event detection

## Characteristics of the double-beta decay events

Double-beta decay: 2 electrons  $\rightarrow$  2 Bragg peaks

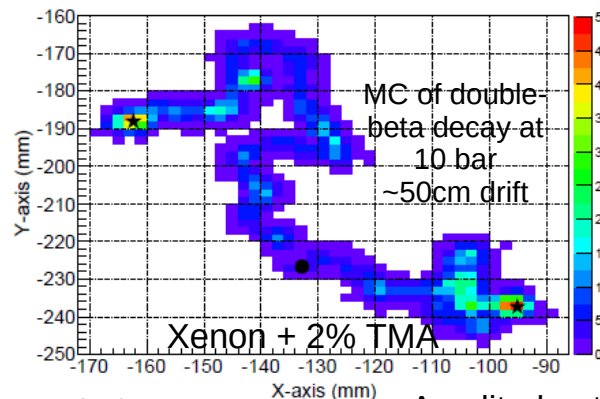
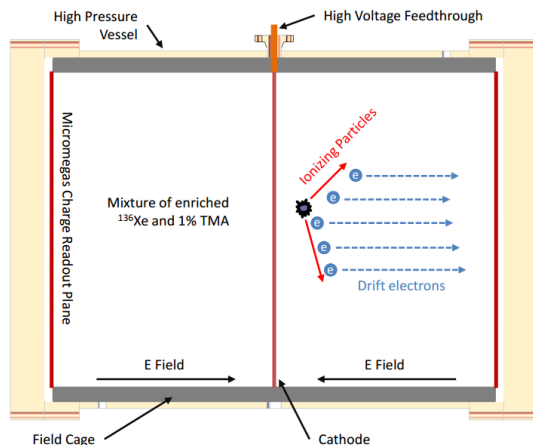
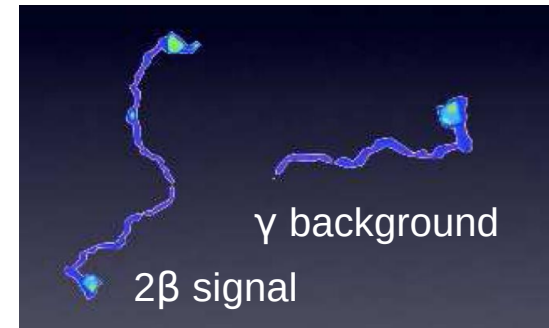
Background gamma events: 1 electron  $\rightarrow$  1 Bragg peak

But very scattered tracks, recognition not always obvious

Also need to reconstruct precisely the deposited energy

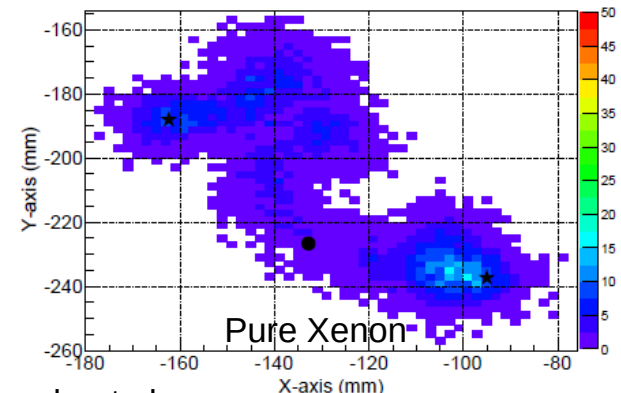
1% tri-methyl amine (TMA) in gas mixture helps a lot:

- Lower diffusion
- Better energy resolution
- Quencher for the gaseous amplification
- Suppress scintillation



Plot from T-REX project

Amplitude at read-out plane



# Read-out with Micromegas gaseous detectors

## Charge readout with Micromegas

Fast gaseous detector

Ionization and amplification decoupled

Able to work in high pressure Xenon

Two kind of Micromegas detectors studied

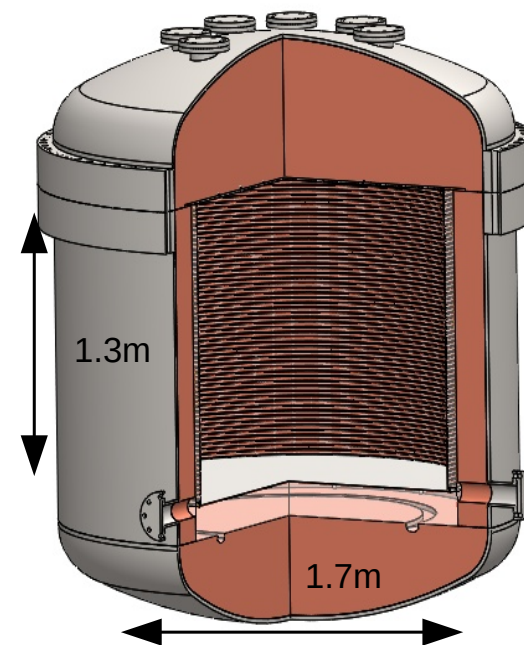
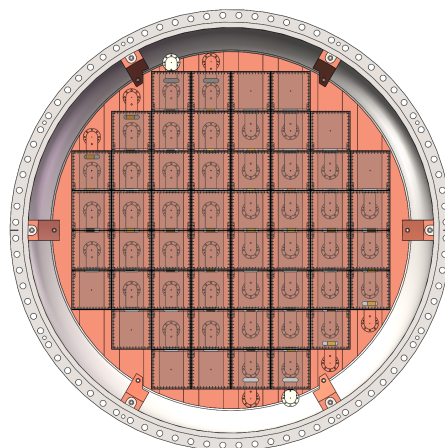
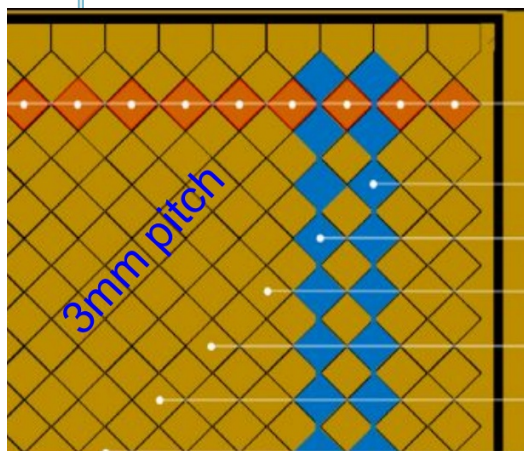
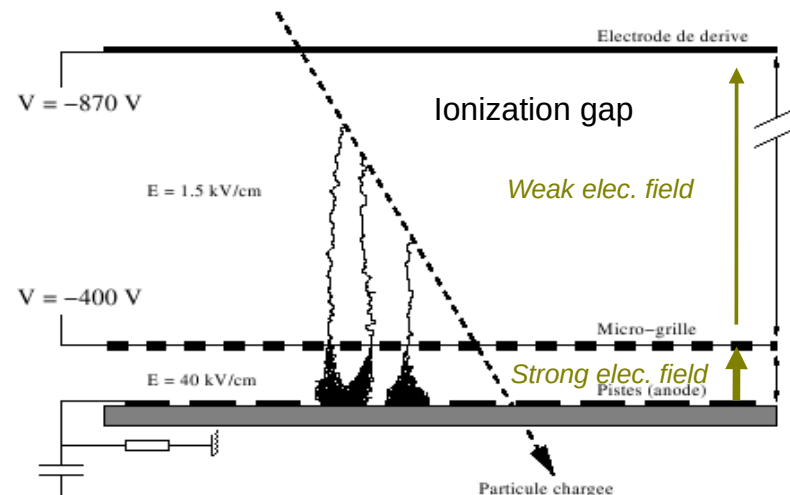
- Microbulks Micromegas
- Thermo-bonded Micromegas

## 2 x 2D readout plane

52 20x20 cm large Micromegas, 3mm pitch

X and Y readout on same board, 64 channels each

But not 3D, XZ and YZ read independently



# Micromegas Microbulk detectors

## Principle and advantages

Micromegas based on a copper clad 50 $\mu$ m-thick kapton foil

40 $\mu$ m diameter holes

Top face  $\rightarrow$  mesh

Bottom face  $\rightarrow$  read-out plane

Constant kapton foil thickness

$\rightarrow$  very good gain homogeneity

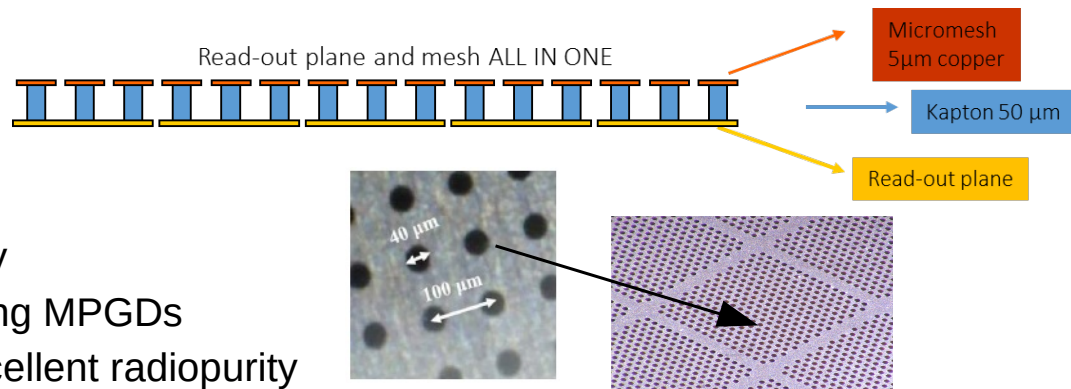
$\rightarrow$  best energy resolution among MPGDs

Only kapton and copper  $\rightarrow$  excellent radiopurity

$\sim 0.1 \mu\text{Bq}/\text{cm}^2$  for  $^{214}\text{Bi}$  and  $^{208}\text{Tl}$

Studied by Zaragoza, IRFU and SJTU

Built at CERN, used at CAST, n\_TOF

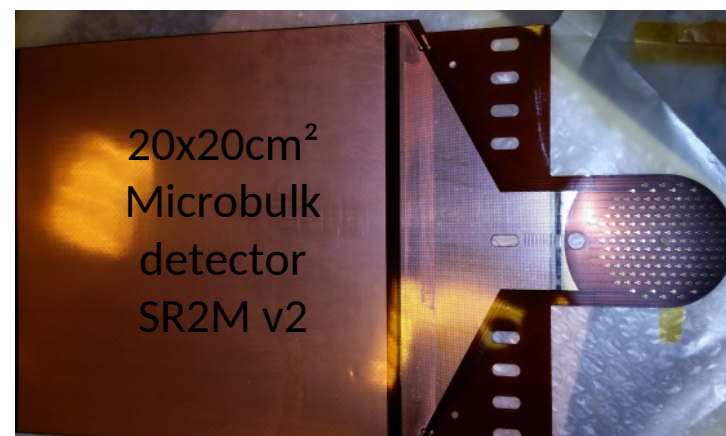


## Status

2 + 1 productions of prototypes studied (14 in total)

Some production flaws

Fragility issues



# Thermo-bonded Micromegas detectors

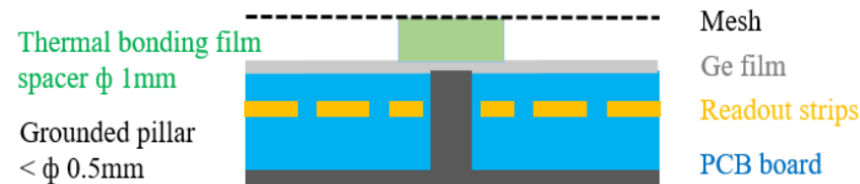
## Principle and advantages

Regular Micromegas with resistive Germanium layer

Mesh spacing by thermo-bonded polyester layer, placed manually

Comparison with Microbulk:

- more robust
- low radioactive material
- sparks protection with resistive layer
- larger energy resolution expected compared to Microbulks

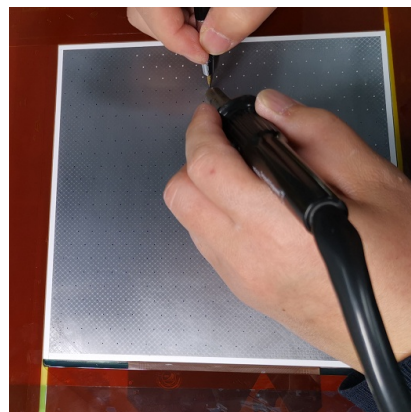


Developed and built at USTC (Hefei, China), local chinese production (not linked to CERN)

## Status

Several productions at USTC

5<sup>th</sup> generation of design

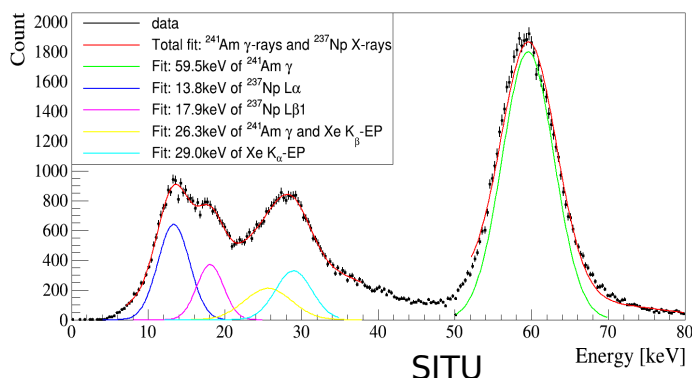


# Micromegas detector performance

## Microbulks

Fragile detectors: cut channels, dark currents  
 Gain inhomogeneity for some detectors (not all) linked to production problems  
 Rather good resolution but not as good as expected

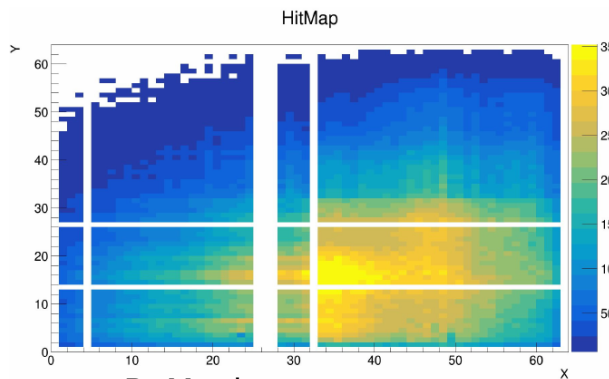
<sup>241</sup>Am source, 5 bar Xe+1%TMA



SJTU

Energy [keV]

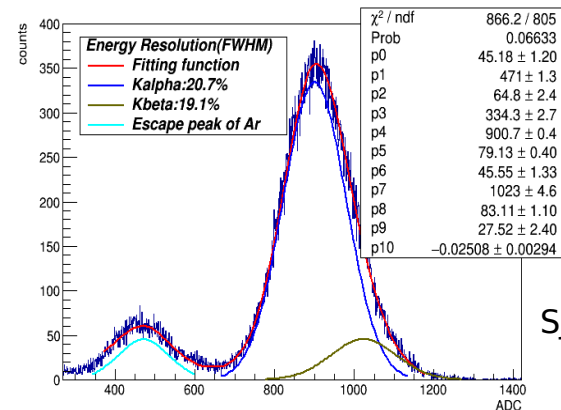
Work in progress



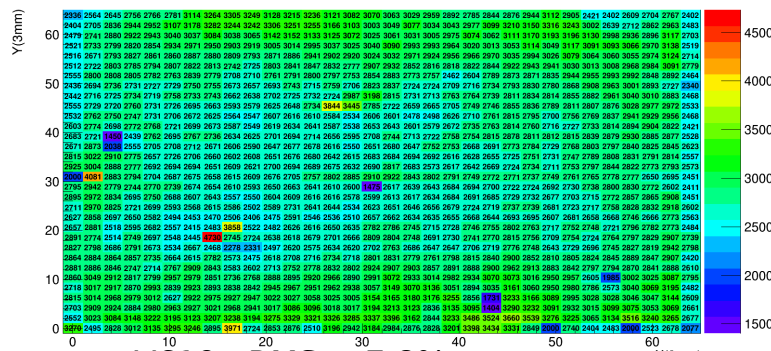
B. Manier

## Thermo-bonded MM

Good energy resolution of 15% at 6 keV (Ar + 5% isobutane 1 bar)  
 Some non-uniformity of the gain a priori due to production methods, improved performance with new methods  
 Unstable dark current at high pressure



SJTU



V619 RMS = 7.8%

USTC

## AGET read-out ASIC

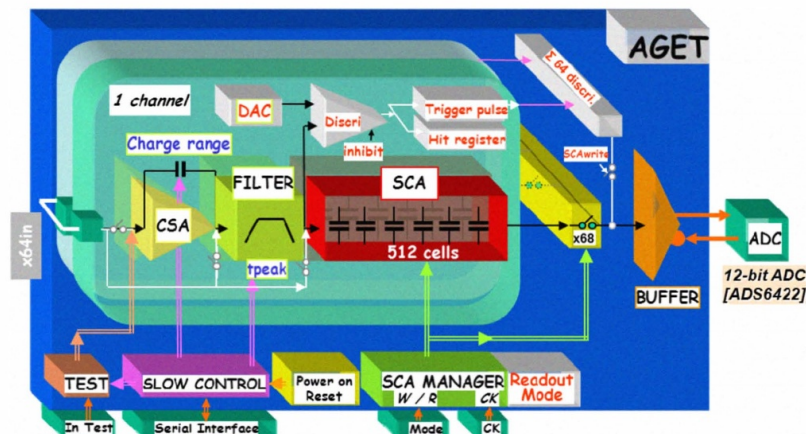
Charge sensitive preamplifier 120fC to 10pC  
dynamic range

Analog filter 50ns to 1μs peaking time

64 channels sampled at 1 to 100MHz, 512  
samples / channel

Multiplicity signal available

Developed by consortium lead by CEA Saclay  
IRFU



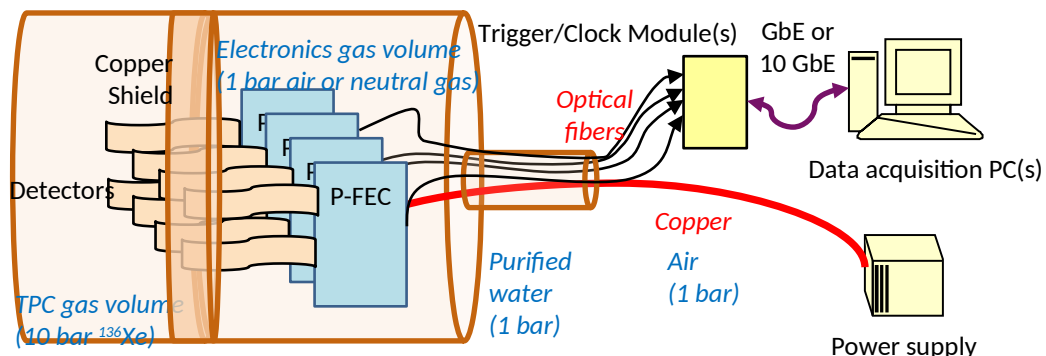
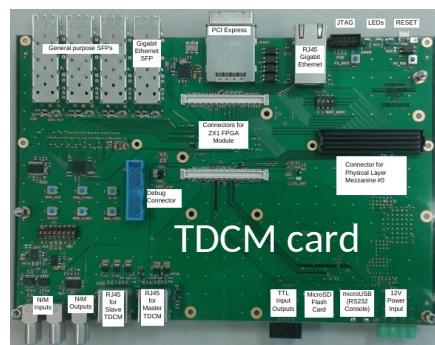
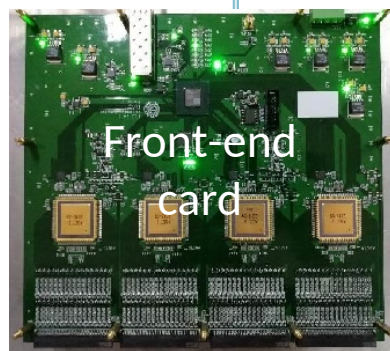
## Read-out electronics

Front-end cards (USTC) close to detectors, 1 card for 2 Micromegas (4 AGET chips)

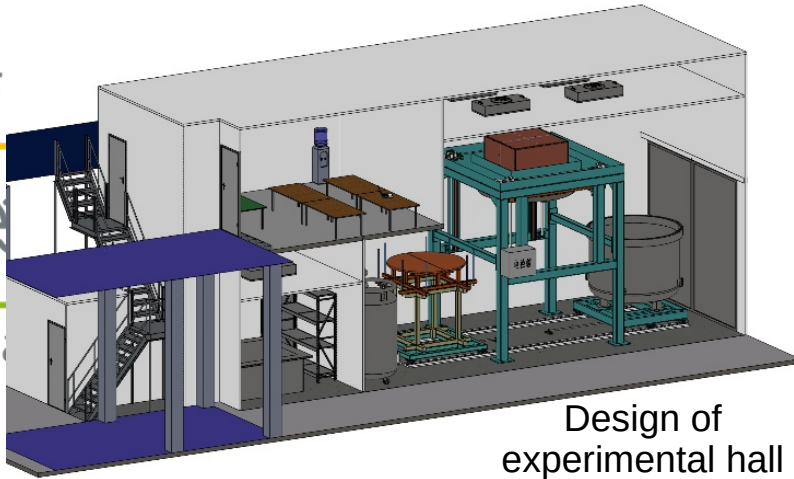
Special radio-pure design with polyimide PCB material (990 → 193 mBq/card)

Back-end TDCM cards (Saclay) out of the TPC, optical fiber connection

Specific trigger and clock card



# Infrastructure and TPC vessel at CJPL



# Field cage of the TPC

l r f u

cea

sac lav

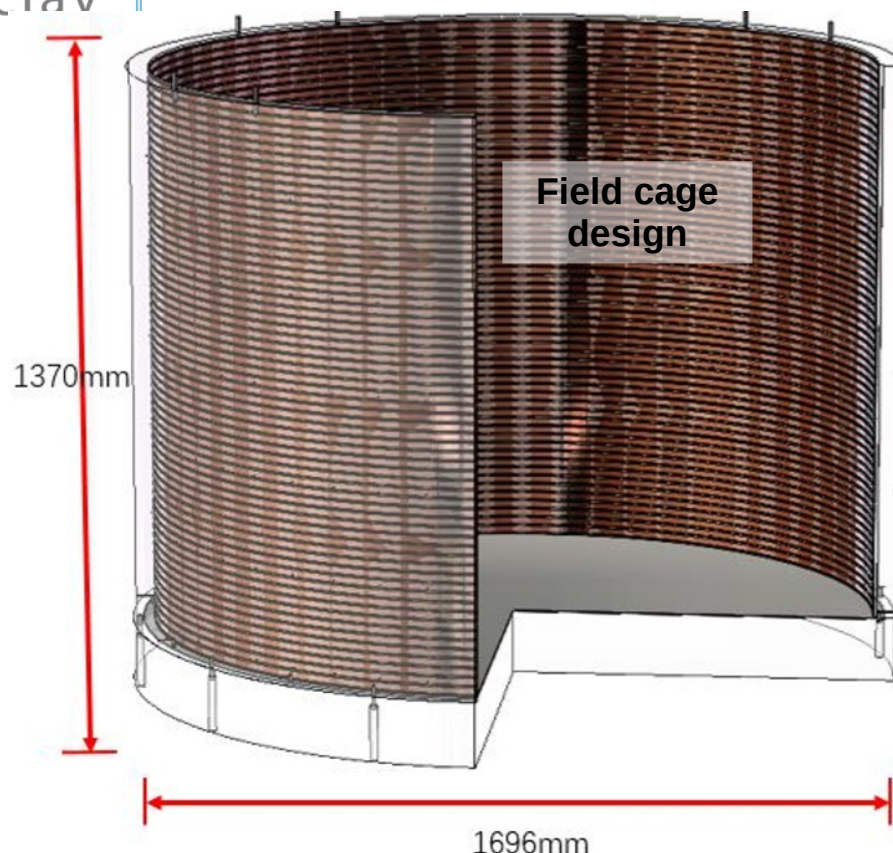
## Field cage characteristics

Tiled kapton flexible PCB

Low radioactive material

Built by TangChen (JUNO vendor)

Tested successfully at 120kV voltage



# Studies on a smaller TPC prototype

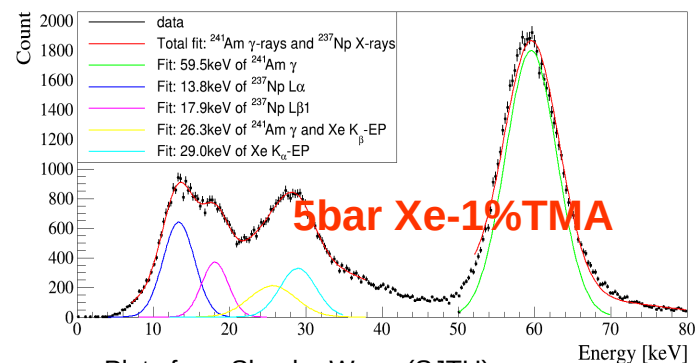
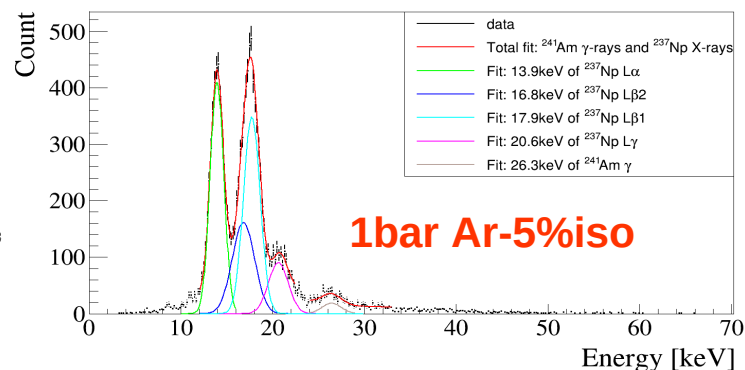
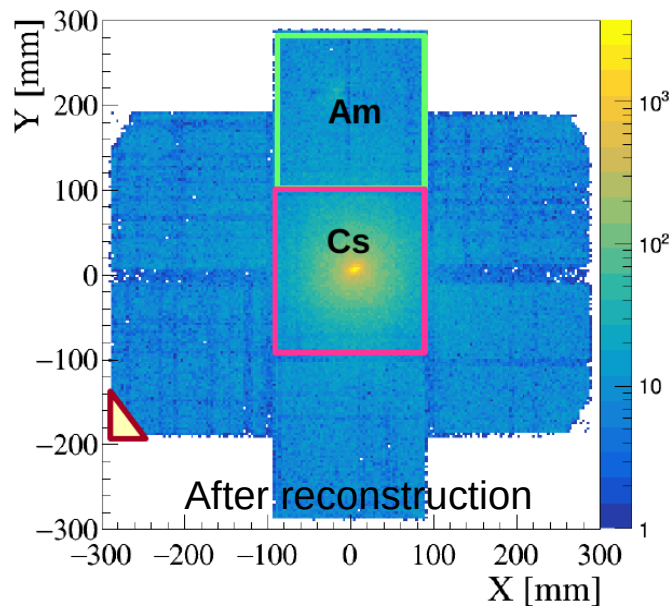
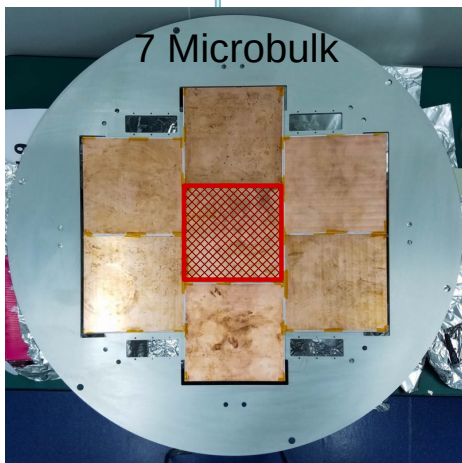
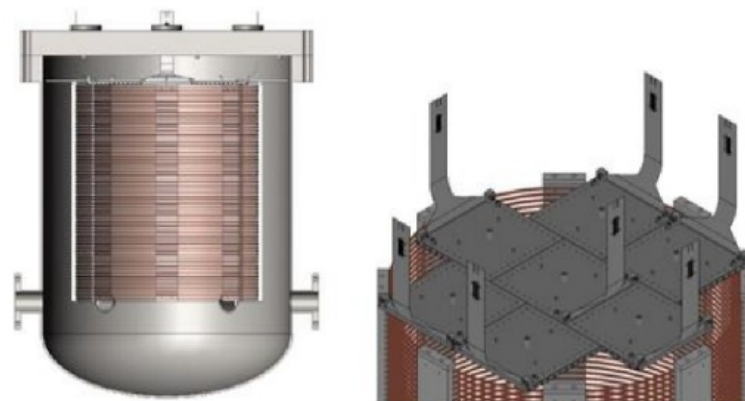
## 7-MM TPC prototype

7 mounted Microbulks → thermo-bonded MM

Tested at SJTU with different pressures and gas mixtures (Ar, Xe)

Several issues studied: mechanics, connections to electronics, cut channels, high dark currents at large pressure

Gain and energy resolution measurements with different sources ( $^{241}\text{Am}$ ,  $^{237}\text{Cs}$ )



Plots from Shaobo Wang (SJTU)

## Studies on background rejection

Based on REST-for-physics data reconstruction and analysis environment developed by Zaragoza

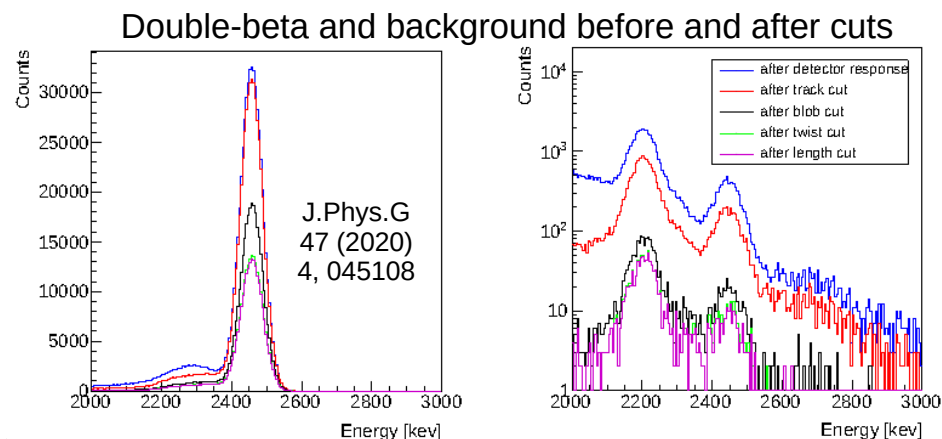
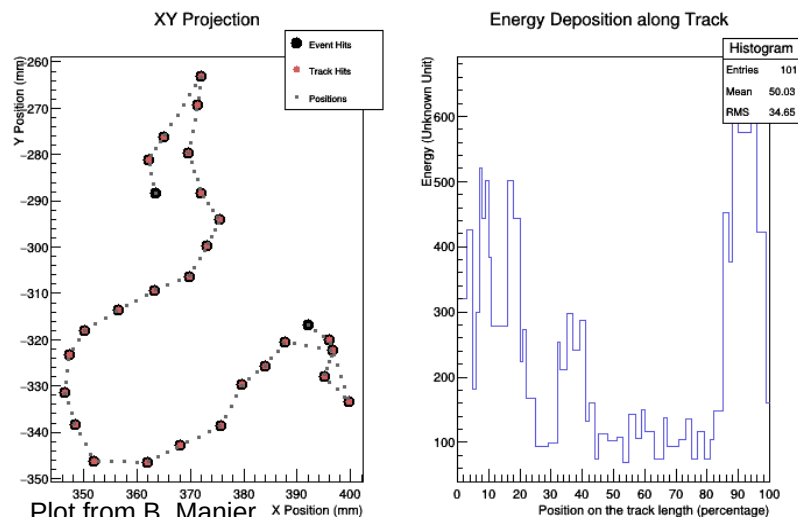
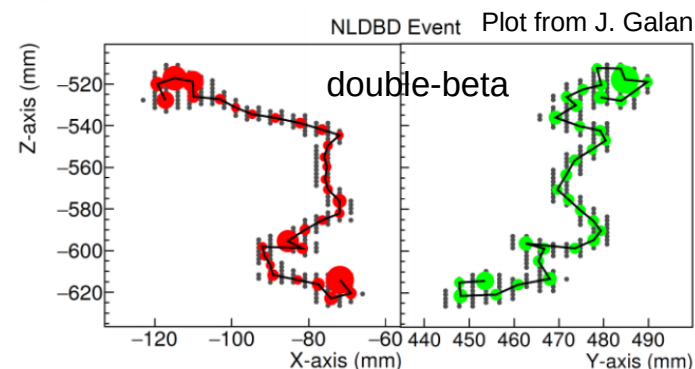
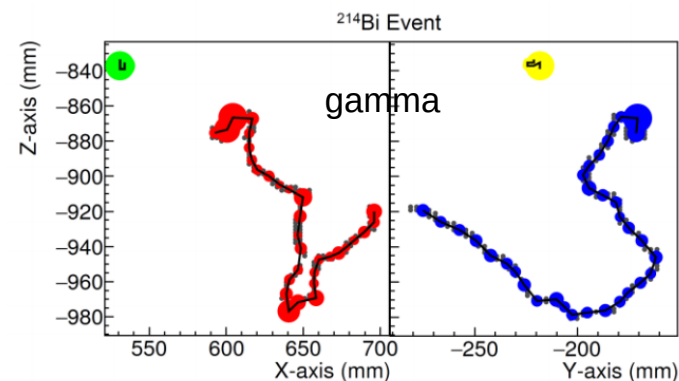
MC studies, include electron diffusion and raw signal formation, 2 x 2D readout (XZ and YZ)

Main criterion: two energy blobs (2 Bragg peaks)

Other criterions: secondary tracks, track length, blob energies, twist at end of track

Performance to be improved (~43% efficiency with ~1% background surviving cuts in ROI)

Study on Fisher discriminant on energy along the track (86% efficiency, 14% background in ROI)



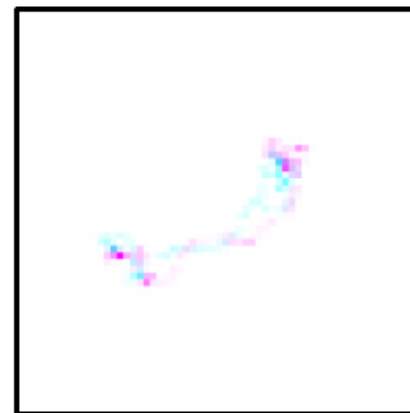
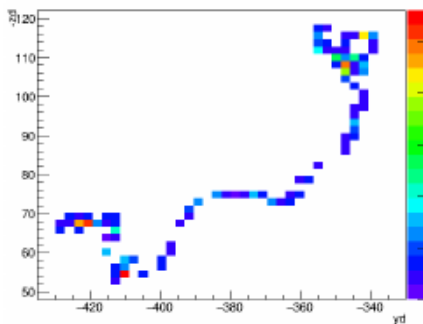
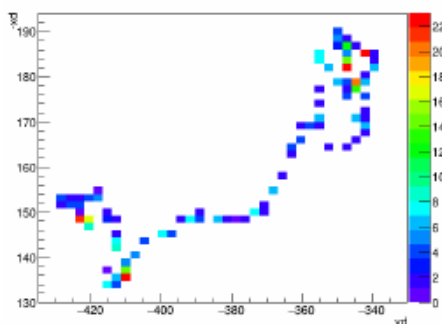
## Selection with neural networks

Studies in China and at Saclay

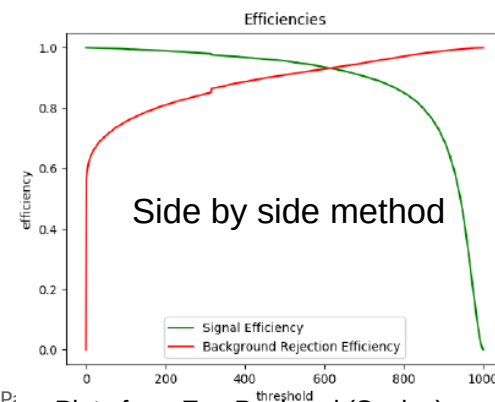
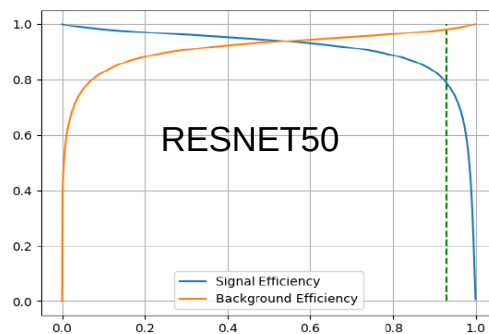
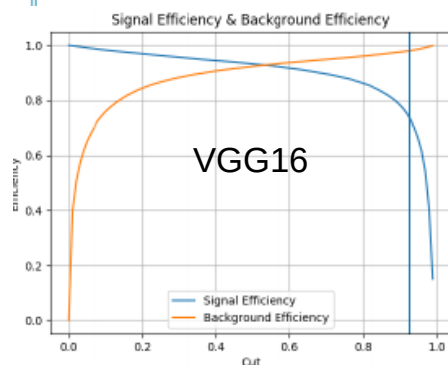
Based on pictures built from XZ and YZ projections, given to image recognition neural network tools

CNN network training with MC double-beta decay and gamma background events

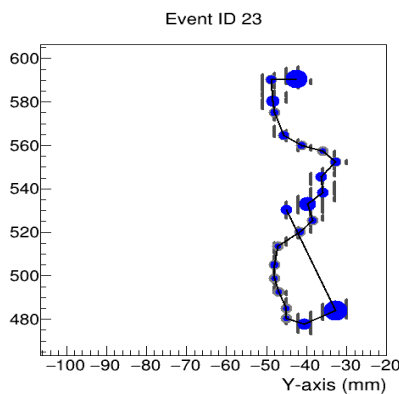
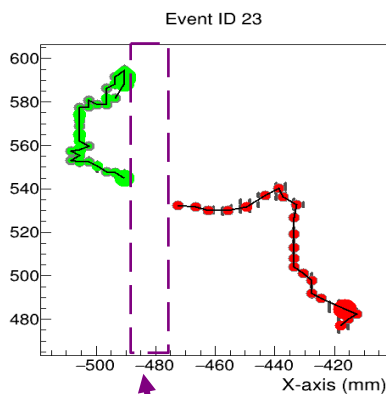
Looks promising with ~80% efficiency, 2% background surviving



Convert x-z-e and y-z-e info into picture.

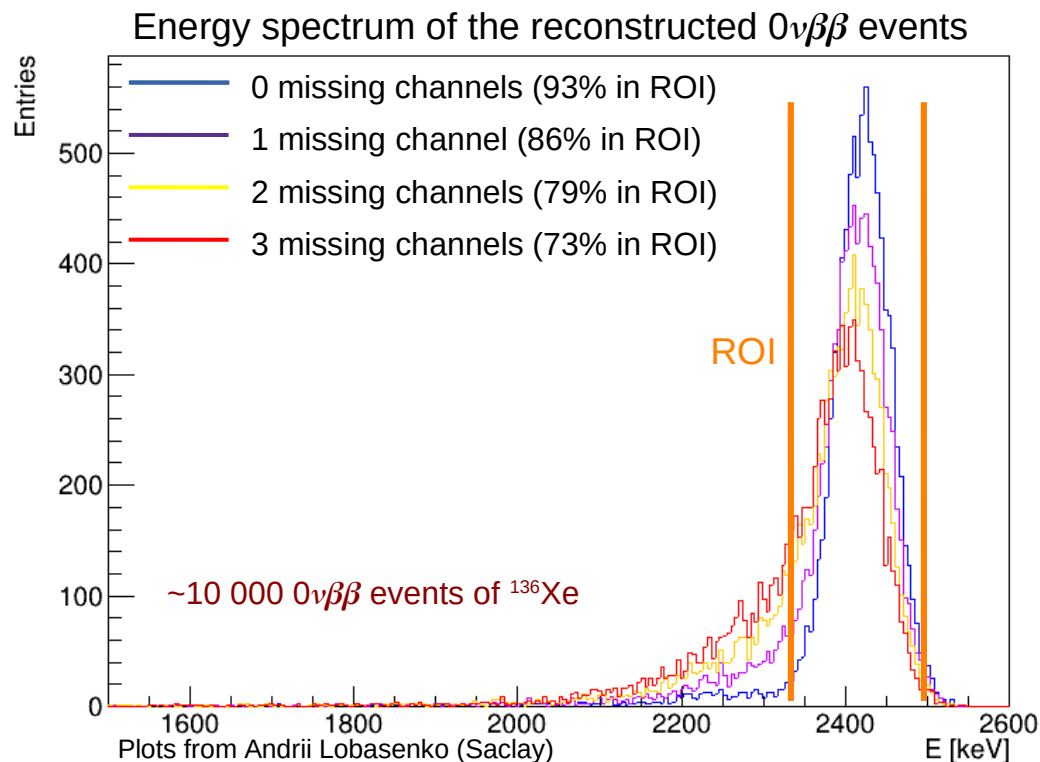


# Impact of missing channels



Due to missing channels not all the energy of the event would be measured  
May also result in track separation

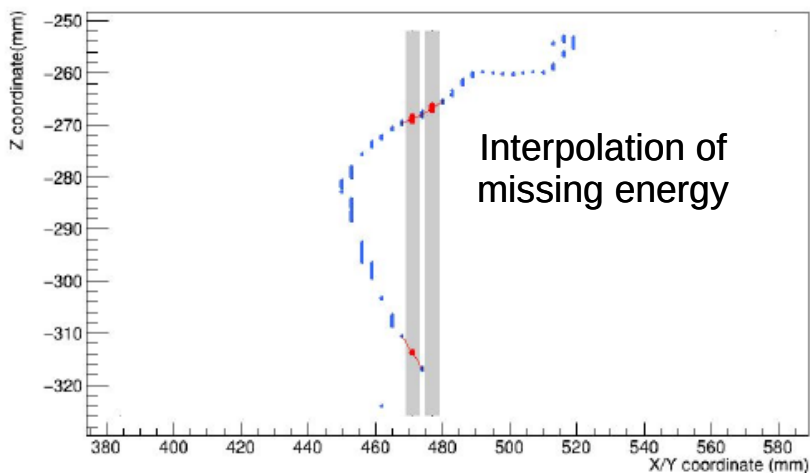
**21%** of all the events in ROI are lost due to only 2 missing channels per Micromegas module on the readout plane



# Missing channels repair: analytic method

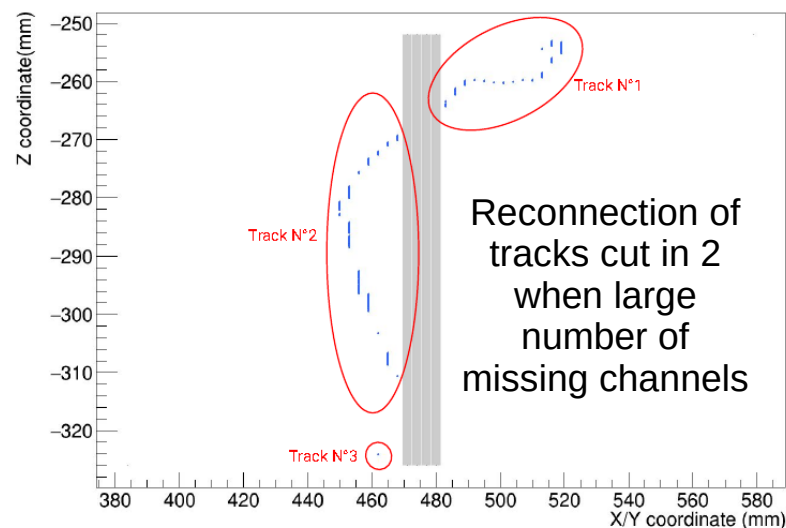
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View of TRestHits(Gen0) for a PandaX-III MM



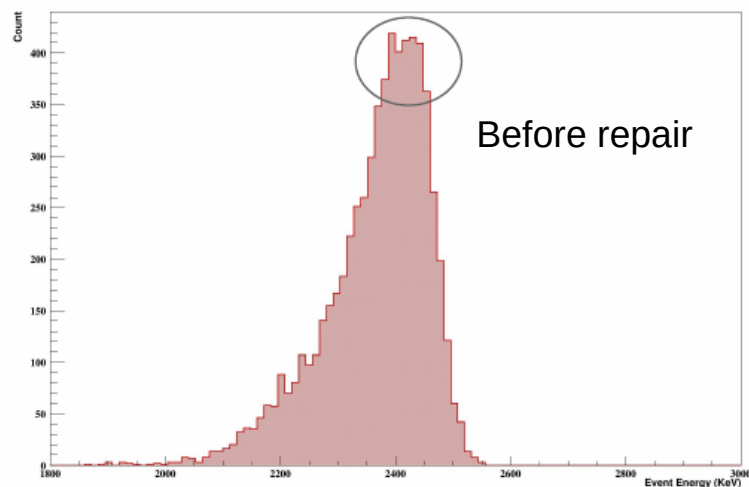
Plots from Benjamin Manier (Saclay)

View of TRestHits(Gen0) for a PandaX-III MM

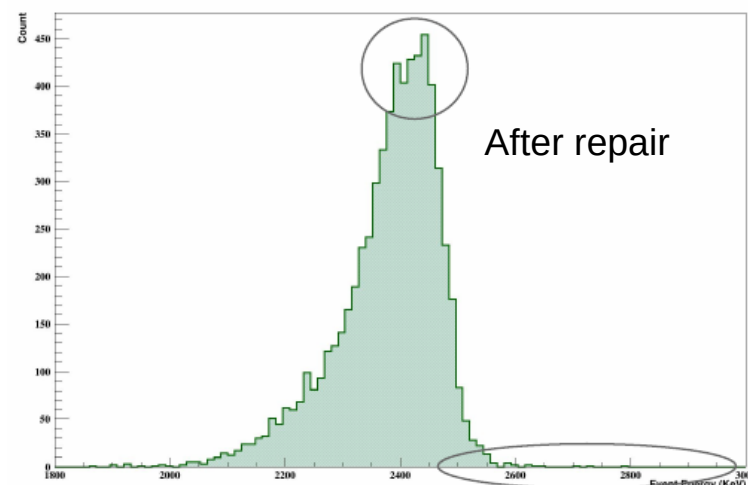


Very preliminary

Energy Spectrum, Double beta decay, after cuts

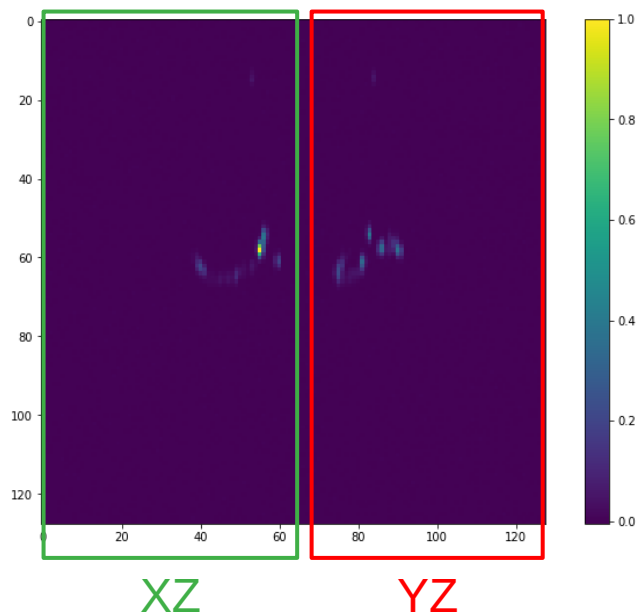


Energy Spectrum, Double beta decay, after repair



# Missing channels repair: ML techniques

128x128 images of raw  
signal projections

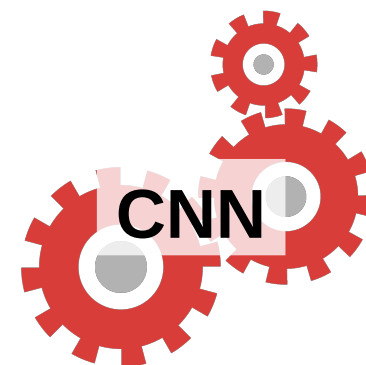


Plots from Andrii Lobasenکو (Saclay)



ML techniques being  
applied to predict the initial  
energy stored on the  
projections, despite missing  
channels

Would also include  
correction of gain non-  
uniformity



Study in progress...

# Background budget and expected sensitivity

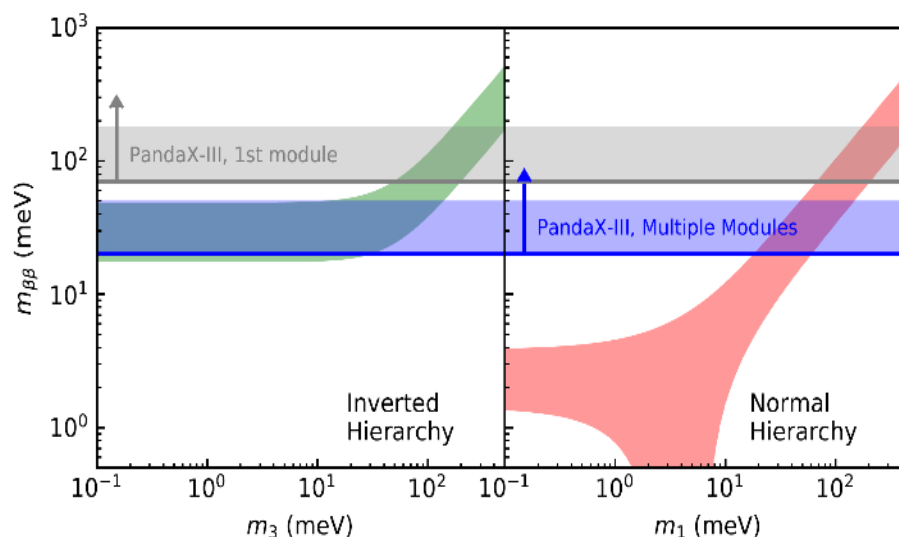
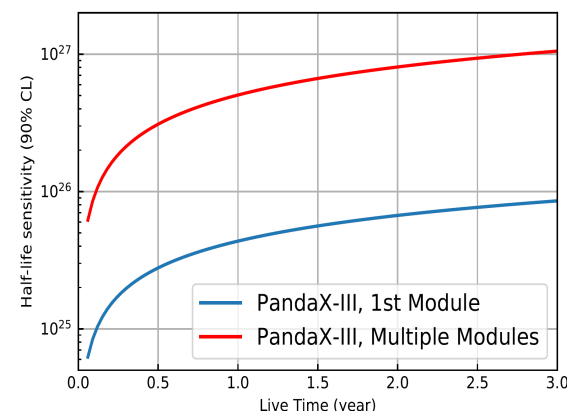
## Background rate

Study with two different Geant 4 MC  
 Analytical and NN topological analysis  
 Expected rate  $10^{-4}$  hit/keV/kg/year in the ROI

## Sensitivity with 3 years data taking

1<sup>st</sup> module:  $9 \times 10^{25}$  years half-life limit in 3 years

5 modules (1t):  $10^{27}$  years half-life limit



## Summary

High pressure gas TPC with charge readout based on Micromegas detectors

1<sup>st</sup> module using 145kg of  $^{136}\text{Xe}$

Final goal: 5 modules of 200kg

Unique background suppression based on tracking capability

Large effort to reduce U and Th contamination

## Prospects

Construction of the experimental setup in progress

- Underground cave ready
- Clean room and support structures ready
- Stainless steel TPC vessel built and tested, procurement of radiopure copper for internal shielding in progress
- Field cage with new design built, tests in progress
- Radiopure front-end cards in production, back-end cards built
- Tests of thermo-bonded Micromegas still ongoing, efforts to solve remaining problems, production to be launched mid 2022
- A lot of work to prepare data reconstruction and analysis, and to deal with hardware limitations

Expected to begin commissioning beginning of 2023