Topology of neutrino-less double beta decay at the PandaX-III experiment

J. Galan for the PANDA X-III Collaboration

IRFU/DphN - CEA Saclay

Outline

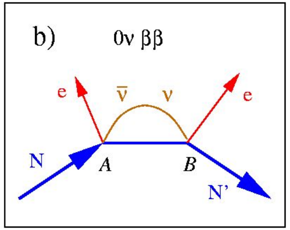
- Quick introduction of $0\nu\beta\beta$ problem and high pressure 136Xe TPC advantages.
- Introduction to PandaX-III experiment and progress.
- Topology studies and final background expectation.
- z-Fidutialization without light measurement.

The search for 0νββ decay mode

Its discovery implies ...

The neutrino is a majorana particle

a new type of elementary particle



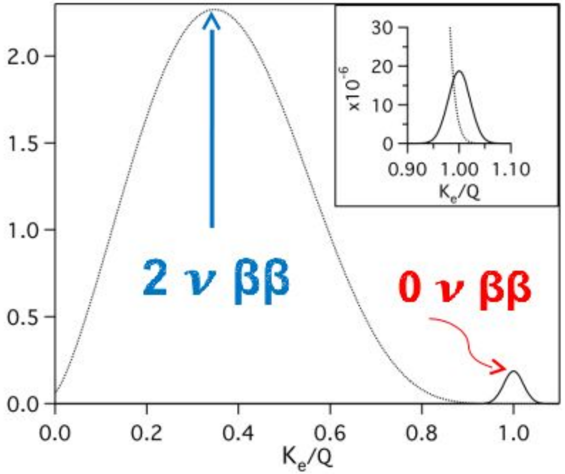
First observation of lepton number violation

Could provide hints about leptogenesis

Measuring the Neutrino mass scale

Oscillation experiments cannot provide absolute mass. They give result as Δm^2.

Next generation experiments will provide insight at least on **neutrino mass hierarchy**.



Any experimental search willing to measure the 0nbb decay mode needs to be able to **resolve this peak from background and the 2nbb process itself**.

Required 2.5%-FWHM for 1-tonne experiment.

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Advantages of high pressure xenon TPC

As an isotope choice

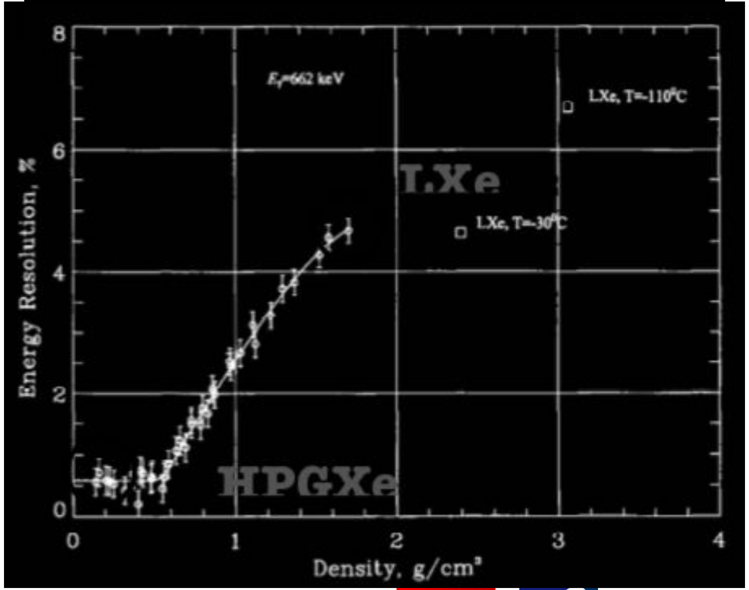
- Different isotope masses make no big difference.
- Relatively high Qbb = 2458 keV. Only Bi214 and Tl208 contributions .

Xenon offers good potential for scalability ("low cost"): with high natural abundance (8.9%), potential for gas purification and gas quality monitoring.
And, in case of signal -> Depleted ^{136}Xe proof.

<u>Gaseous</u> Xenon advantages (versus liquid)

- <u>Better intrinsic energy resolution</u>
- Extended track → Required granularity for topology on mm scale
- Flexibility on operation pressure → → Helps to understand/model backgrounds

Bolotnikov, Ramsey NIM A 396 (1997)

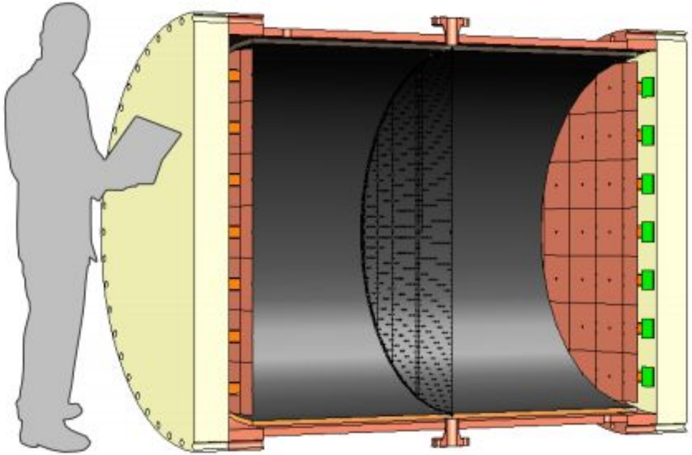


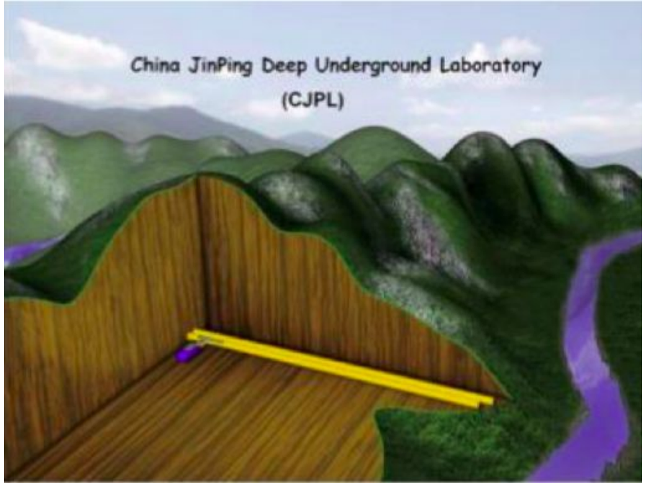
The PandaX-III experiment

The primary goal is to built a 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
- It will be hosted China Jin Ping underground Lab (CJPL-II).
- Main design features: good energy resolution, good tracking capability, and low background.

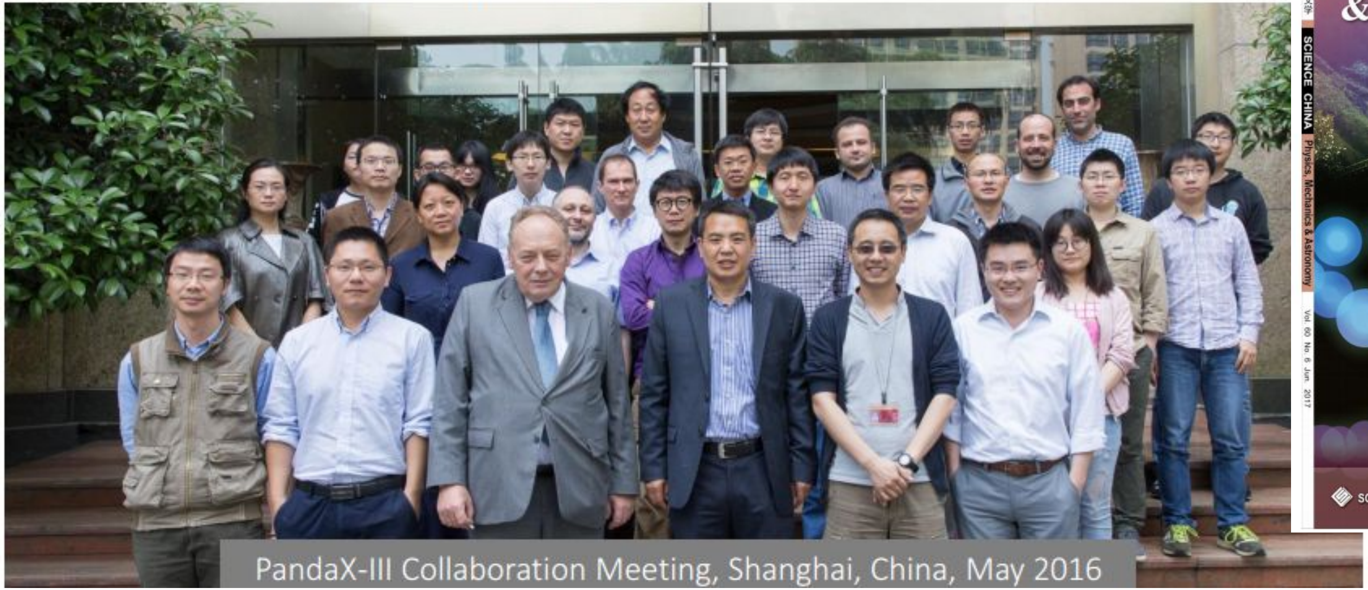




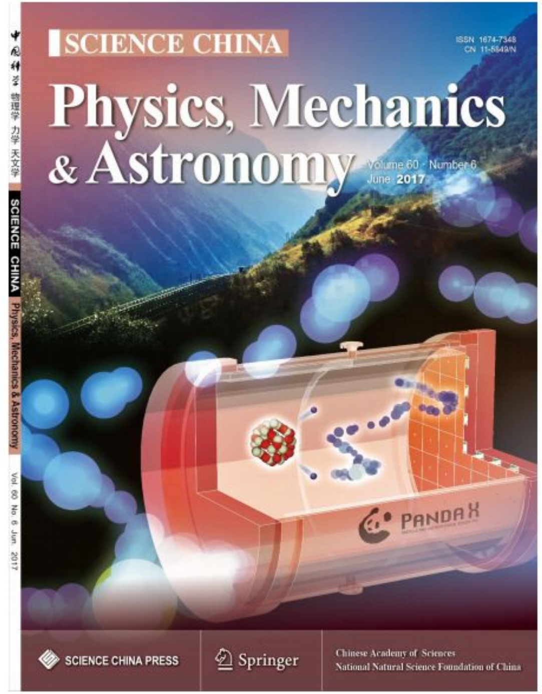
The PandaX-III Collaboration

Collaboration was born middle 2015

- 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

CDR, published, June 2017



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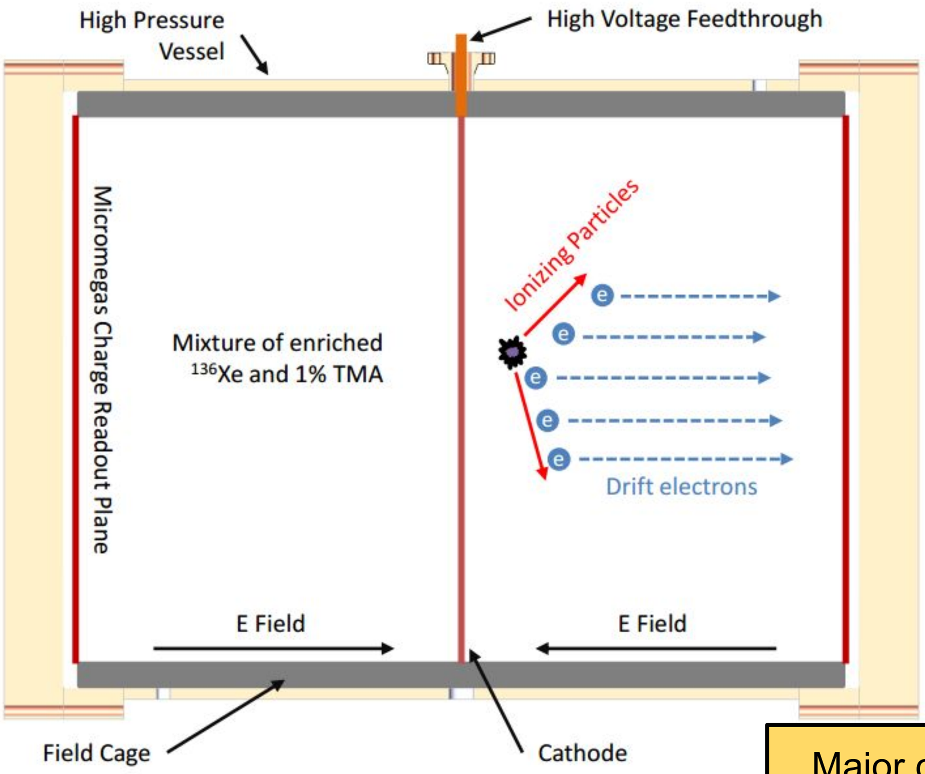
TPC single phase. Charge detection



PandaX-III CDR, Chen, X., Fu, C., Galan, J. et al. Sci. China Phys. Mech. Astron. (2017) 60: 061011.

- Cylindrical TPC of a symmetric design:
  - 100kV cathode in the middle.
  - Two charge readout planes at both ends.
- High pressure vessel using OFHC (oxygen-free high conductivity) copper
- 10 bar, 90% enriched Xe-136 + (1%) TMA

– TMA used to improve the signal quality and suppress diffusion of drift electrons.

· 82 Microbulk Micromegas modules (20x20 cm2 each) to read out the energy and tracking information.

Major changes envisaged for TDR. PandaX-III Collaboration next week.

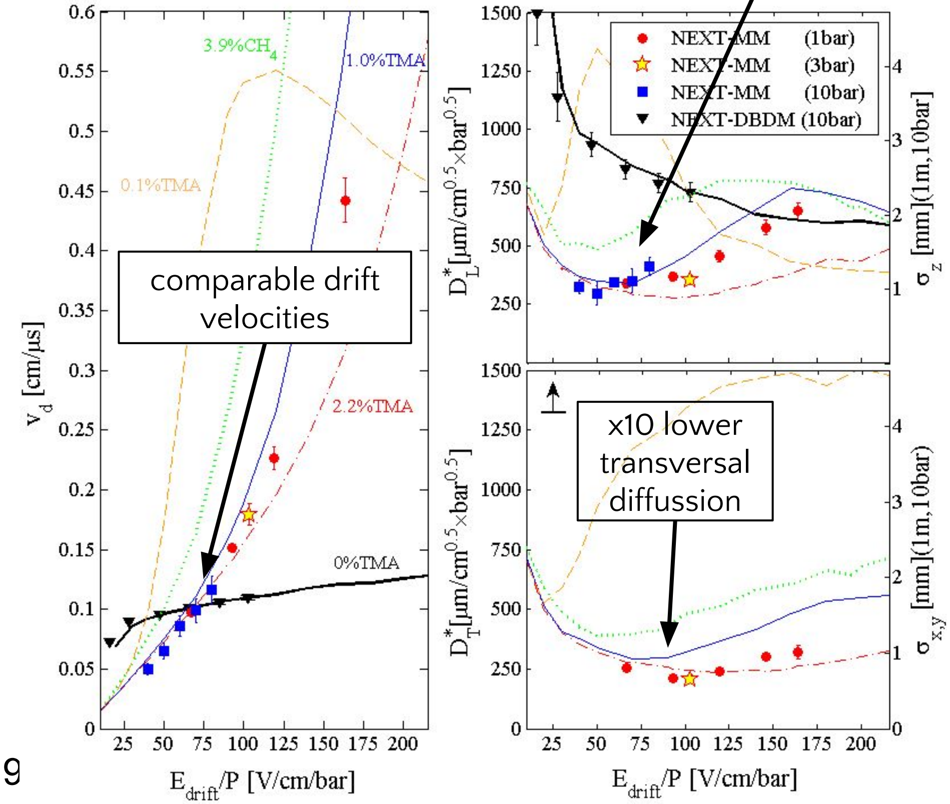
Xe+TMA mixture for charge readout TPC

J. Phys. G40 (2013) (arXiv:1306.3067)

x3 lower longitudinal diffusion

comparable drift velocities

x10 lower transversal diffusion



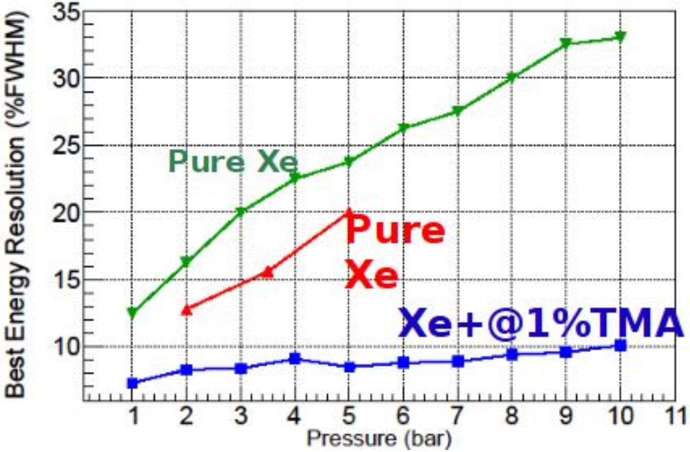
Adding 1% TMA to Xenon

Lower electron diffusion (x10)

+

Improved energy resolution at high pressures

C. Balan et al, 2011 JINST 6 P02006



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Microbulk micromegas

Microbulk technology allows for detector readout with little mass budget, and potentially very radiopure materials (Copper and Kapton).

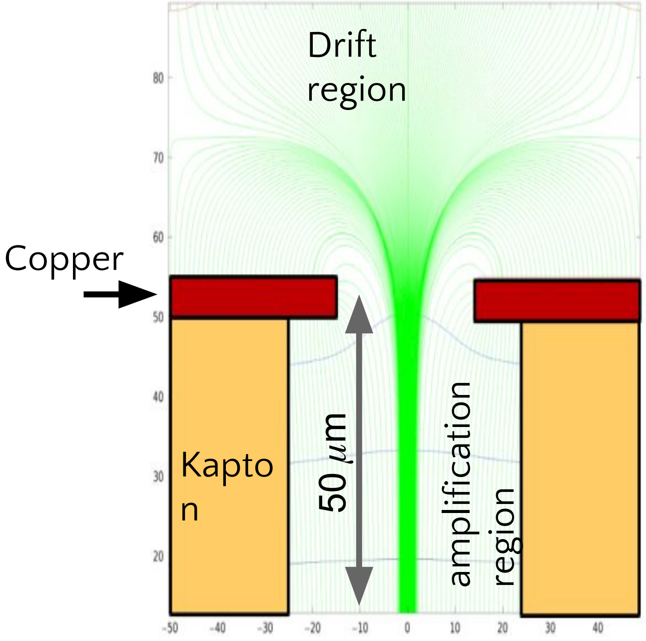
Th^{232} ~ 14 nBq/cm^2 and U^{238} ~ 45 nBq/cm^2

Measurements carried out at BiPo-3 detector in Canfranc Underground laboratory.

Measurements validated by PandaX-III collaboration radio assay program (S. Wang).

Astropart. Phys. (2011) 34, 354

Microbulk detection principle



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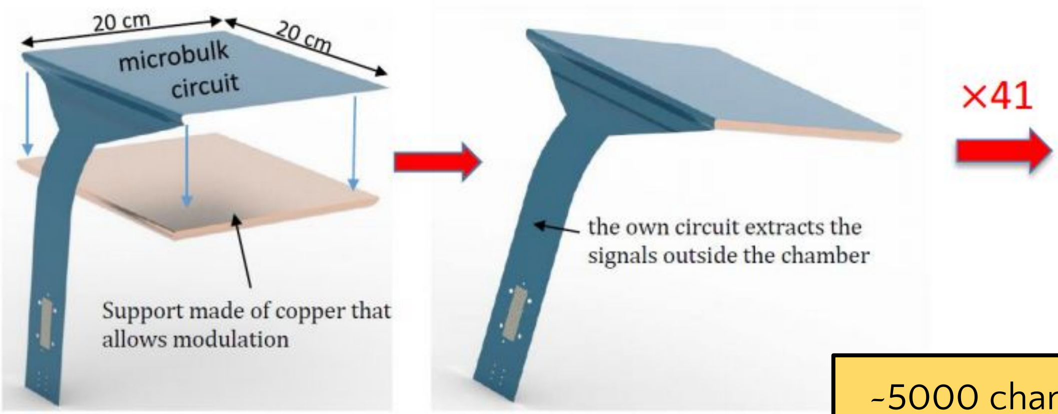
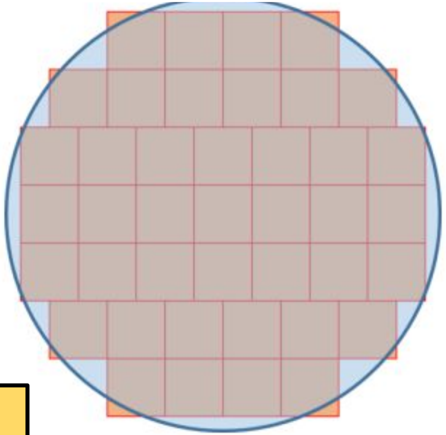
Scalable Radiopure Readout Module (SR2M)

3 mm pitch in both X and Y direction, 128 channels (64X + 64Y) in each module.

20 x 20 cm2 active area, 41 modules in mosaic layout for each readout plane.

Designed and optimized by University of Zaragoza and SJTU.



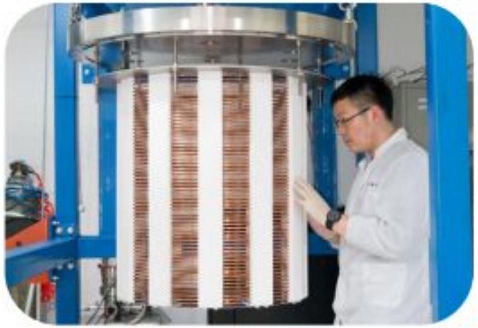


~5000 channels

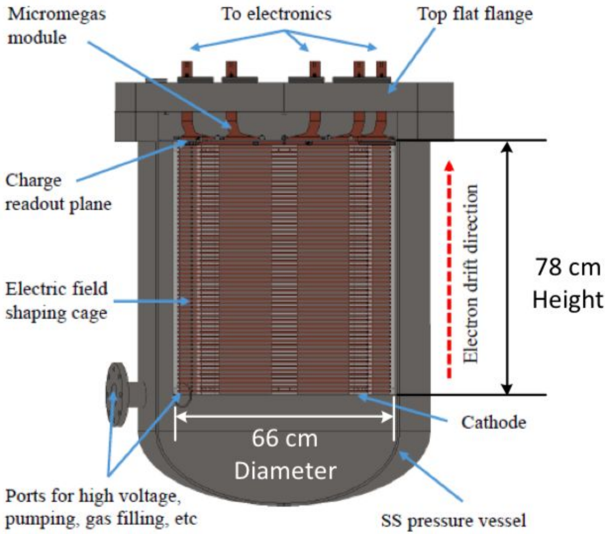
SJTU Prototype TPC description

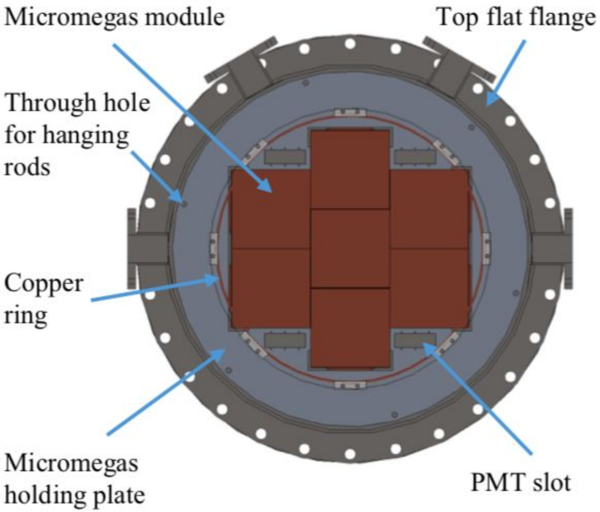
To validate and optimize the detector designs.

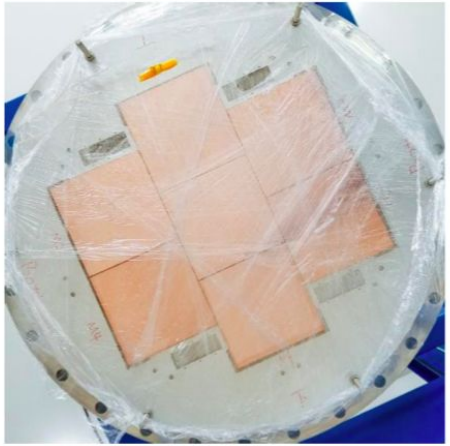
- 600L stainless steel vessel
  - 270L active volume (~20 kg Xe at 10 bar)
  - Validation SR2M tessellation principle (7 MMs capability)
  - Tested with Ar (+ Isobutane) and Xe (+ TMA) gases.



20 kg scale prototype TPC made and taking data with MicroMegas





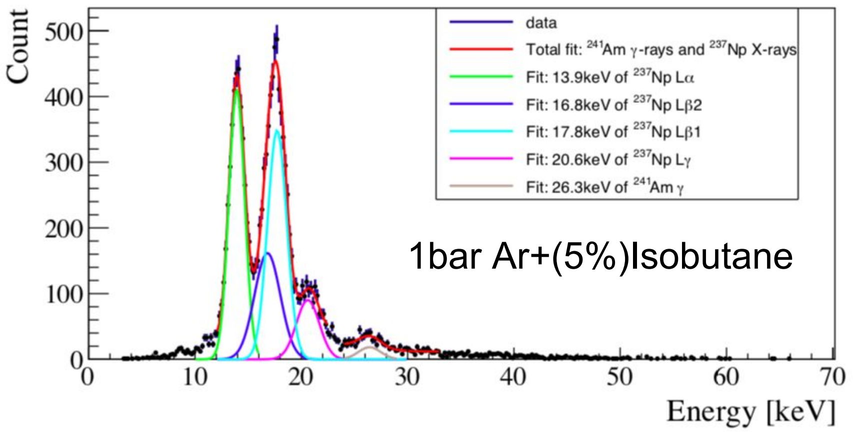


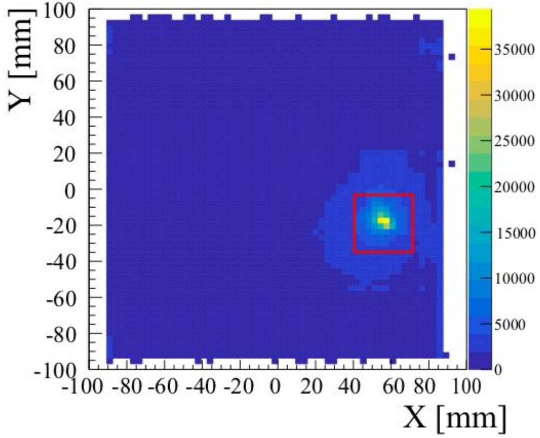
Prototype results on Xenon + TMA

Microbulk micromegas results on SJTU Prototype TPC.
High pressure operation commissioning.

Problems identified which might be limiting energy resolution.

New bunch of enhanced detectors soon to be received from CERN.



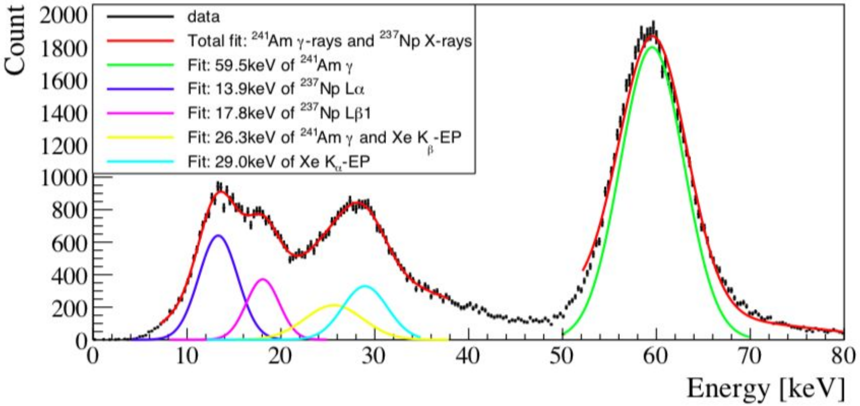


14.1% @ 59.5 keV of Am-241 γ

Extrapolated : 2.19% FWHM @ Qbb

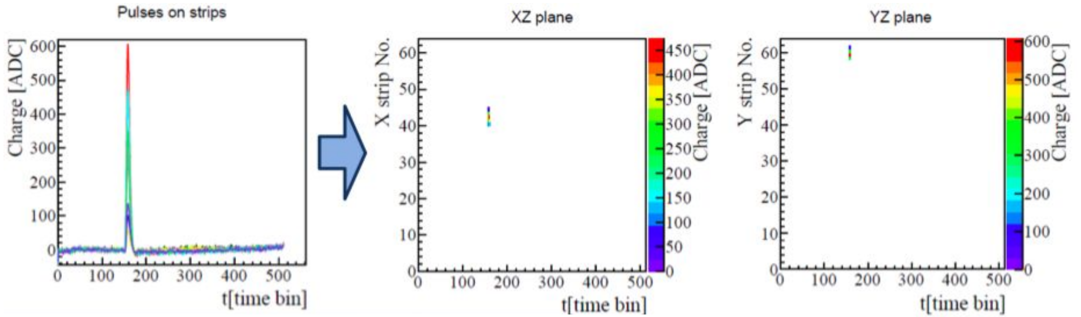
JINST 13 P06012
arXiv: 1804.02863

5bar Xe+(1%)TMA

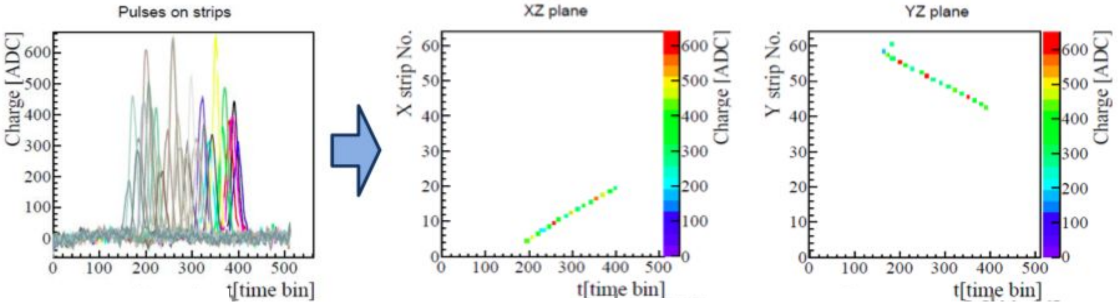


Event samples

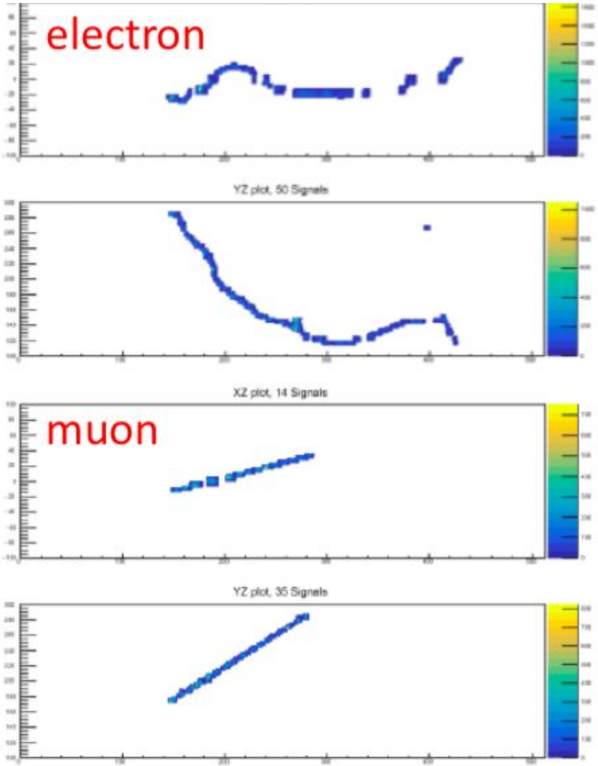
Gamma event 1bar in Ar+5%Isobutane



Muon event 1bar in Ar+5%Isobutane



Tracks in Xenon + 0.75%TMA



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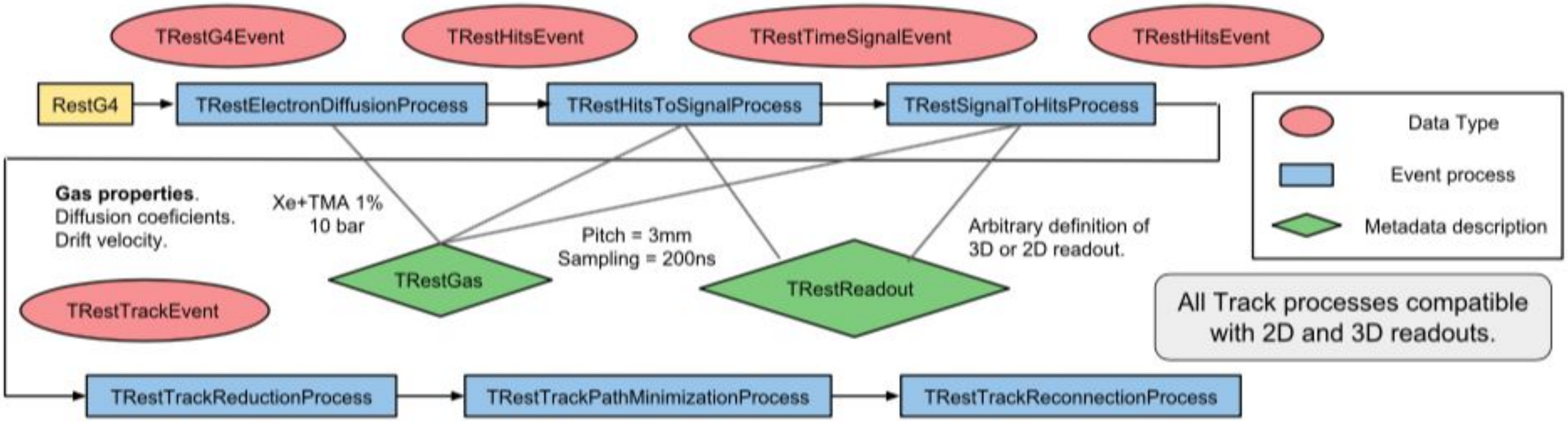
REST. Montecarlo data processing chain

PANDA X

Rare Event Searches with TPCs (REST) Software v2.2.4.

REST v2.0 presented at 8th TPC symposium (2016)

Full reconstruction processing of rawdata and Montecarlo data with compatible processes



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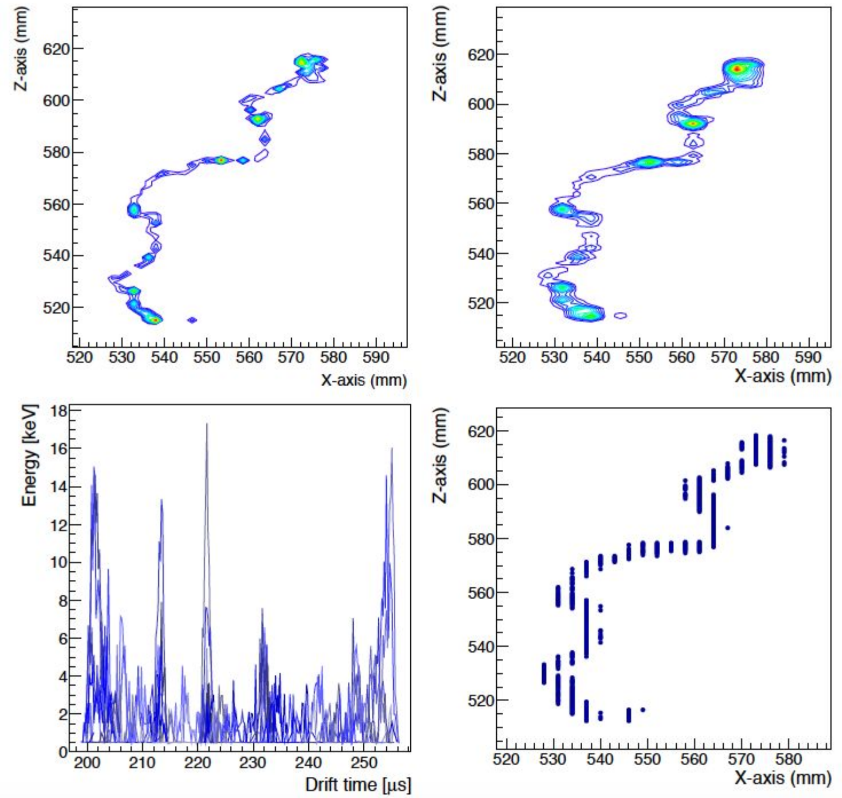
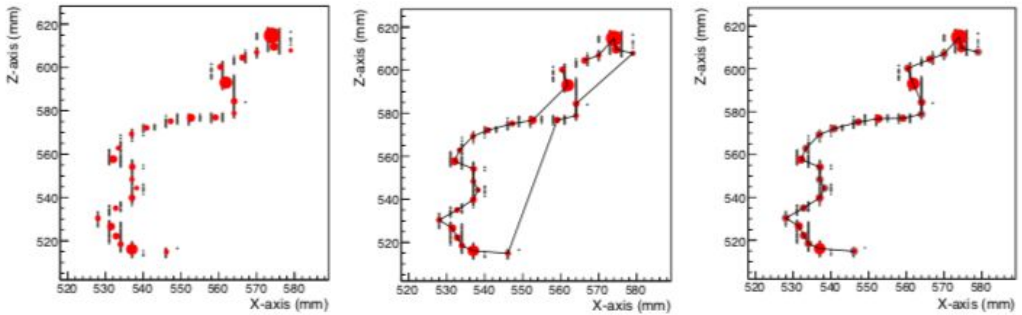
REST. Event processing



Montecarlo generation, reconstruction and signal conditioning to prepare for topological analysis including a detailed response of the detector.

REST uses methods from graph theory to reconstruct the physical track.



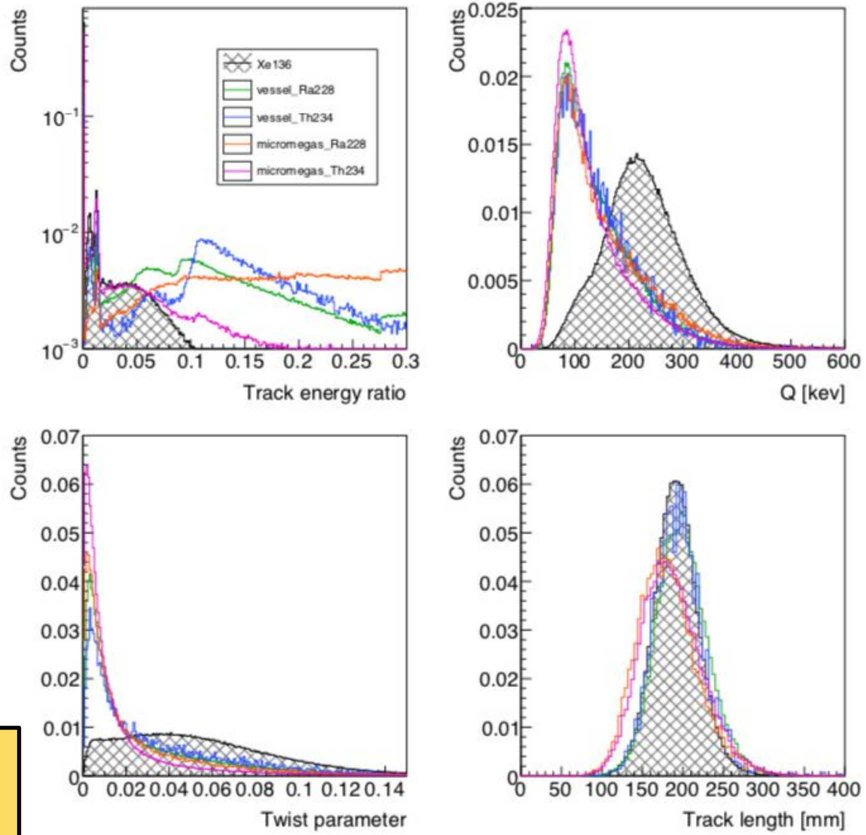
Studies exploiting conventional pattern recognition techniques

Main track parameters used for background-signal discrimination.

- **Track energy ratio** (or total energy of secondary tracks).
- **Low blob energy** (or tail identification).
- **New** Twist parameter. Measures angles at the blob ends.
- **Main track length.**

See also CNN work
for PandaX-III detectors:

Sci.China Phys.Mech.Astron. 61 (2018) no.10, 101007



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Background after topological cuts

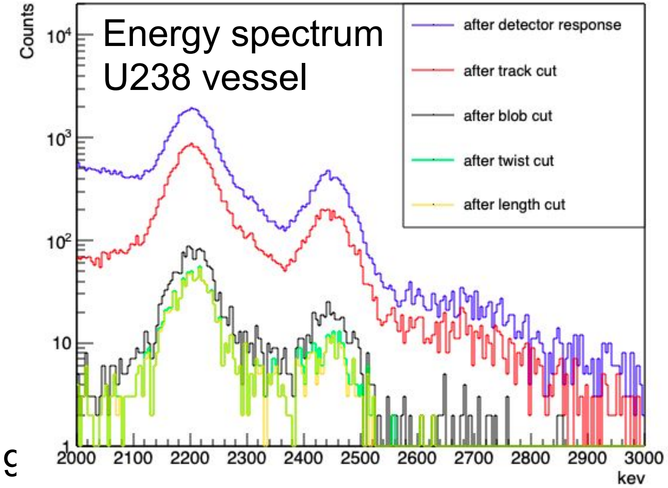
PANDA X

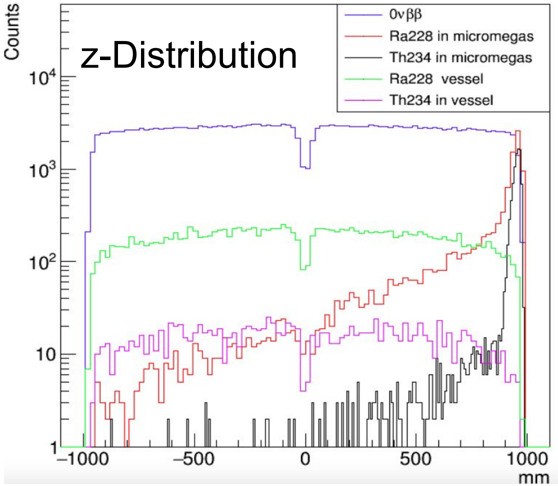
Preliminar results in preparation for publication (Full response, 3mm-pitch, 2D-stripped readout, 41-modules readout, 200ns sampling, time window)

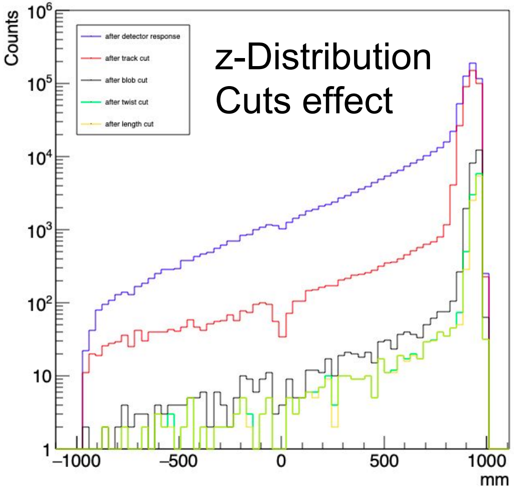
Micromegas readout plane

	NORMALIZED Activity	U238 vessel 0.75 uBq x 3438,6kg	Th232 vessel 0.2 uBq x 3438 kg	U238 mm 45nBq/cm2 x 1m2	Th232 mm 14nBq/cm2 x 1m2
RESPONSE	cpy	0,602	1,924	41,297	3,439
	cpy/keV/kg	3,44E-05	1,10E-04	8,34E-03	6,94E-04
AFTER CUTS	cpy	0,006	0,013	0,767	0,223
	cpy/keV/kg	3,65E-07	7,52E-07	3,10E-04	2,25E-05

<u>Topologica</u>l Signal efficiency ~ 33% Background reduction more







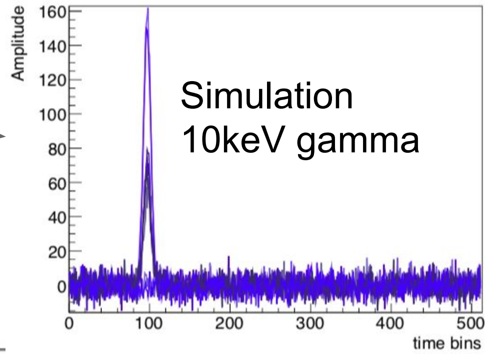
z-Fidutialization exploiting e-Diffusion

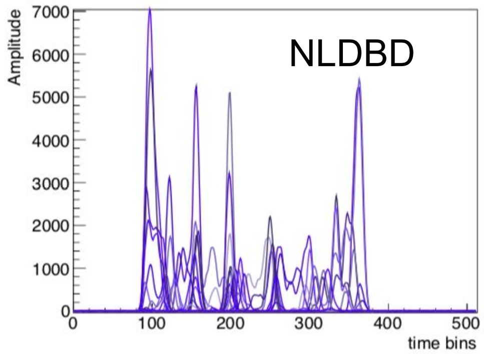
PANDA X

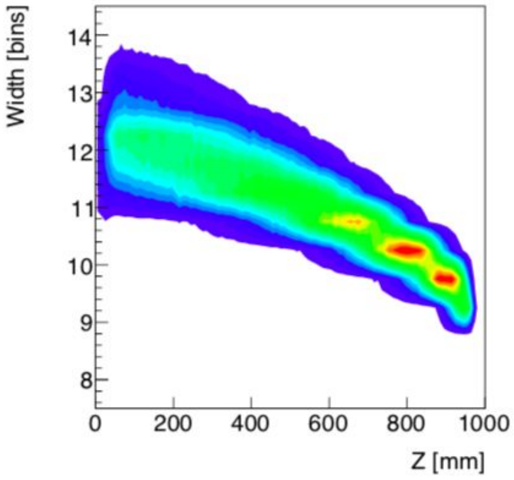
Realistic detector rawsignal reconstruction

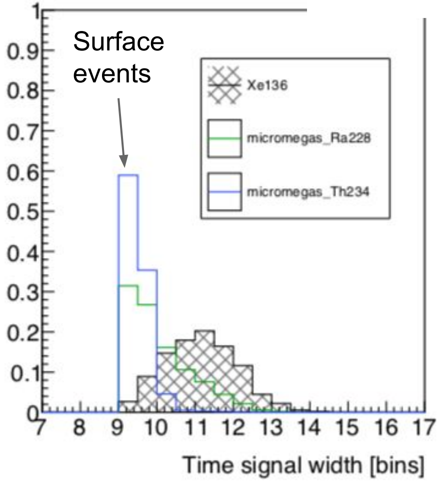
Shaping + noise

Time width parameter obtained using REST Rawsignal analysis process we use for real data









Our analysis shows that we can still exploit the diffusion of events to get a parameter to reject surface events coming from micromegas.

Signal efficiency (Xe136) : 92%
Background efficiency (micromegas-U238): 4%
Background efficiency (micromegas-Th232): 49%

We are **not blind** to surface discrimination on readout planes.

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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

Backup slides

PandaX-III sensitivity prospects

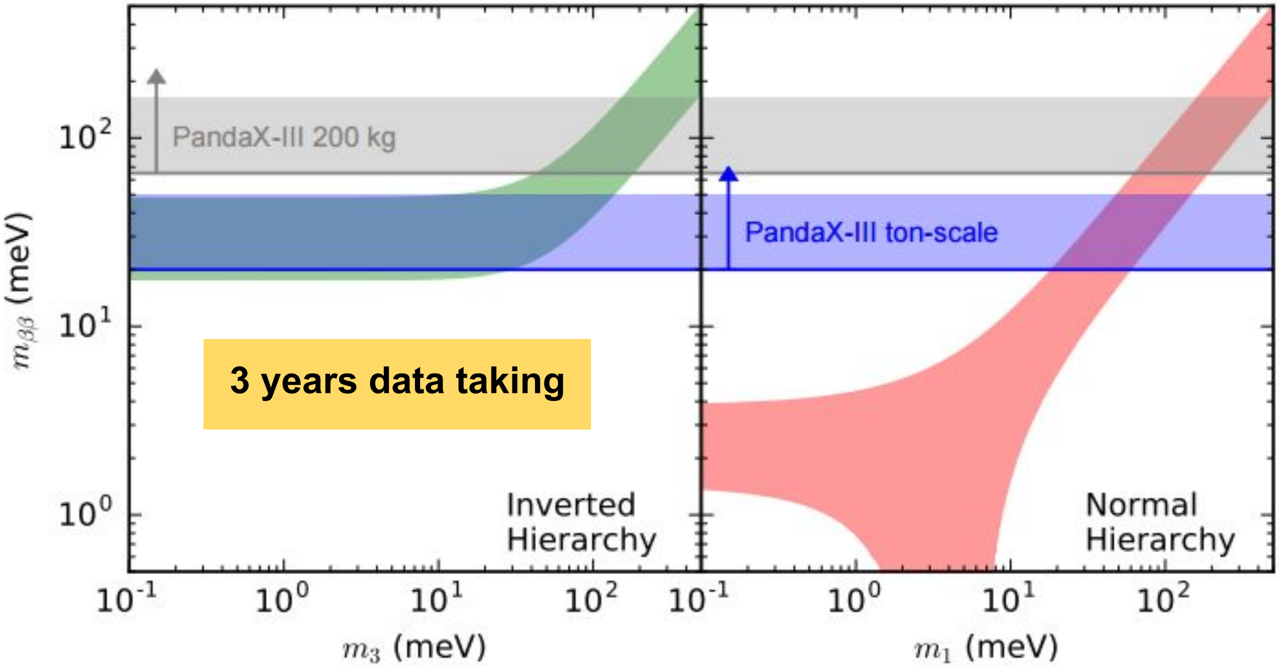
The non-measurement of this process gives an upper limit on the effective neutrino mass.
Next generation experiments **planning to be sensitive to 10-20 meV**

Expected sensitivities by PandaX-III

Panda X-III Background :

10^{-4} to 10^{-5} y^{-1} keV^{-1} kg^{-1}

0.15 to 1.5 counts per year



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Backgrounds

Background contribution from different detector components before topological cuts

Published on

PandaX-III CDR

SCIENCE CHINA Physics, Mechanics & Astronomy 60(6), 061011(2017)
ArXiv:1610.08883

	Isotope	Activity	Background (cpy)		BI (10^{-5}c/(keV·kg·y))	
			BambooMC	RestG4	BambooMC	RestG4
Laboratory walls	^{238}U	9.9 Bq/kg	$< 0.40 \pm 0.03$	$< 0.09 \pm 0.01$	-	<0.4
	^{232}Th	4.4 Bq/kg	$< 0.22 \pm 0.02$	$< 0.15 \pm 0.01$	-	<0.6
Water	^{238}U	0.12 μBq/kg	0.20 ± 0.1	0.22 ± 0.03	0.74	0.86
	^{232}Th	0.04 μBq/kg	0.24 ± 0.06	0.55 ± 0.03	0.96	2.21
Barrel	^{238}U	0.75 μBq/kg	1.73 ± 0.12	1.77 ± 0.1	6.9	7.05
	^{232}Th	0.2 μBq/kg	4.63 ± 0.18	4.55 ± 0.05	18.5	18.2
	^{60}Co	10 μBq/kg	9.8 ± 1.0	9.9 ± 0.9	39.0	39.7
End-caps	^{238}U	0.75 μBq/kg	0.83 ± 0.11	0.90 ± 0.11	3.3	3.6
	^{232}Th	0.2 μBq/kg	2.4 ± 0.1	2.2 ± 0.1	9.8	9.0
	^{60}Co	10 μBq/kg	4.4 ± 1.0	4.2 ± 0.9	17.8	16.7
Bolts	^{238}U	0.5 mBq/kg	7.5 ± 1.5	7.3 ± 0.9	30.1	29.2
	^{232}Th	0.32 mBq/kg	39.8 ± 2.7	46.7 ± 1.9	159	186.3
Field insulator	^{238}U	4.94 μBq/kg	15.0 ± 0.5	15.7 ± 0.3	59.9	62.6
	^{232}Th	0.1 μBq/kg	2.69 ± 0.03	2.61 ± 0.1	10.7	10.4
and rings	^{238}U	0.75 μBq/kg	0.67 ± 0.01	0.72 ± 0.05	2.7	2.9
	^{232}Th	0.2 μBq/kg	0.95 ± 0.01	0.92 ± 0.03	3.8	3.7
Electronics	^{238}U	0.26 Bq	1.0 ± 0.3	2.4 ± 0.5	4.2	9.5
	^{232}Th	0.07 Bq	2.8 ± 0.2	4.1 ± 0.5	11.3	16.3
Micromegas	^{238}U	45 nBq/cm^2	60.5 ± 1.7	63.7 ± 1.8	241.6	254.4
	^{232}Th	14 nBq/cm^2	23.5 ± 0.6	25.3 ± 0.6	93.9	101
Cathode	^{214}Bi	2 nBq/cm^2	4.1 ± 0.2	3.3 ± 0.1	16.5	13.2

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