PANDA X

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PMTs upgrade of PandaX-4T
—an introduction of new 2-inch R12699 PMTs

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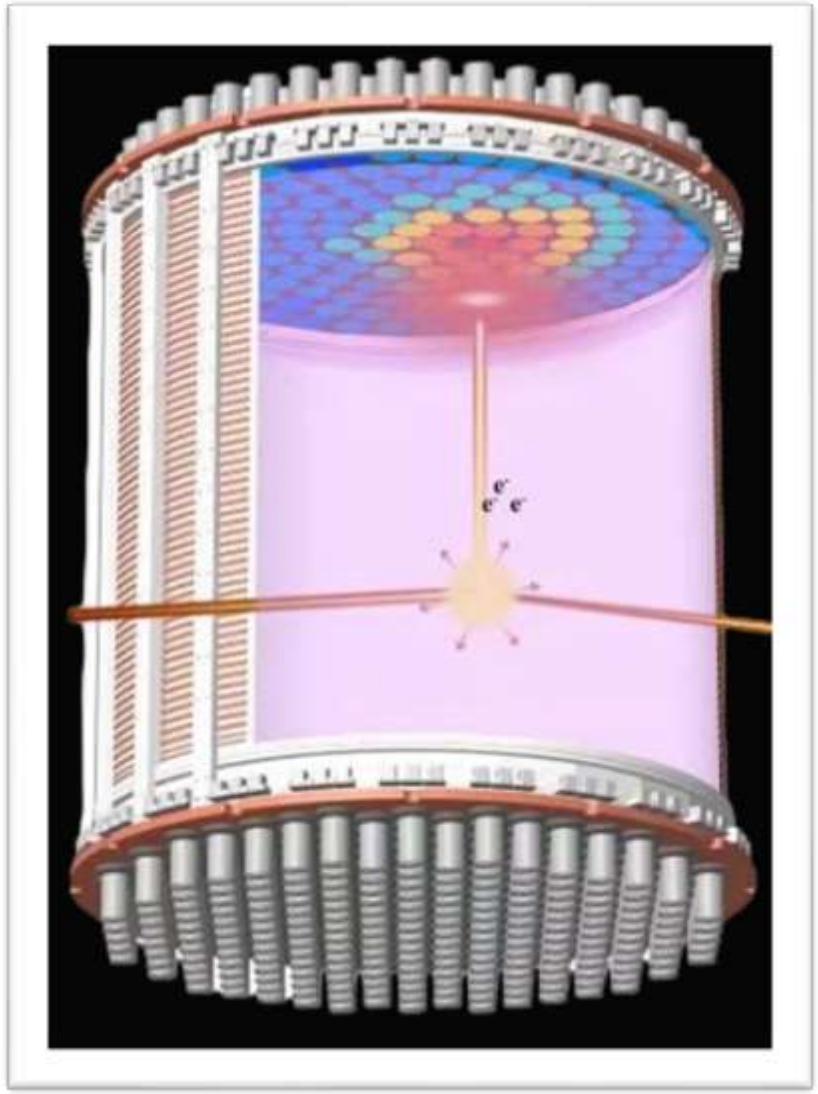
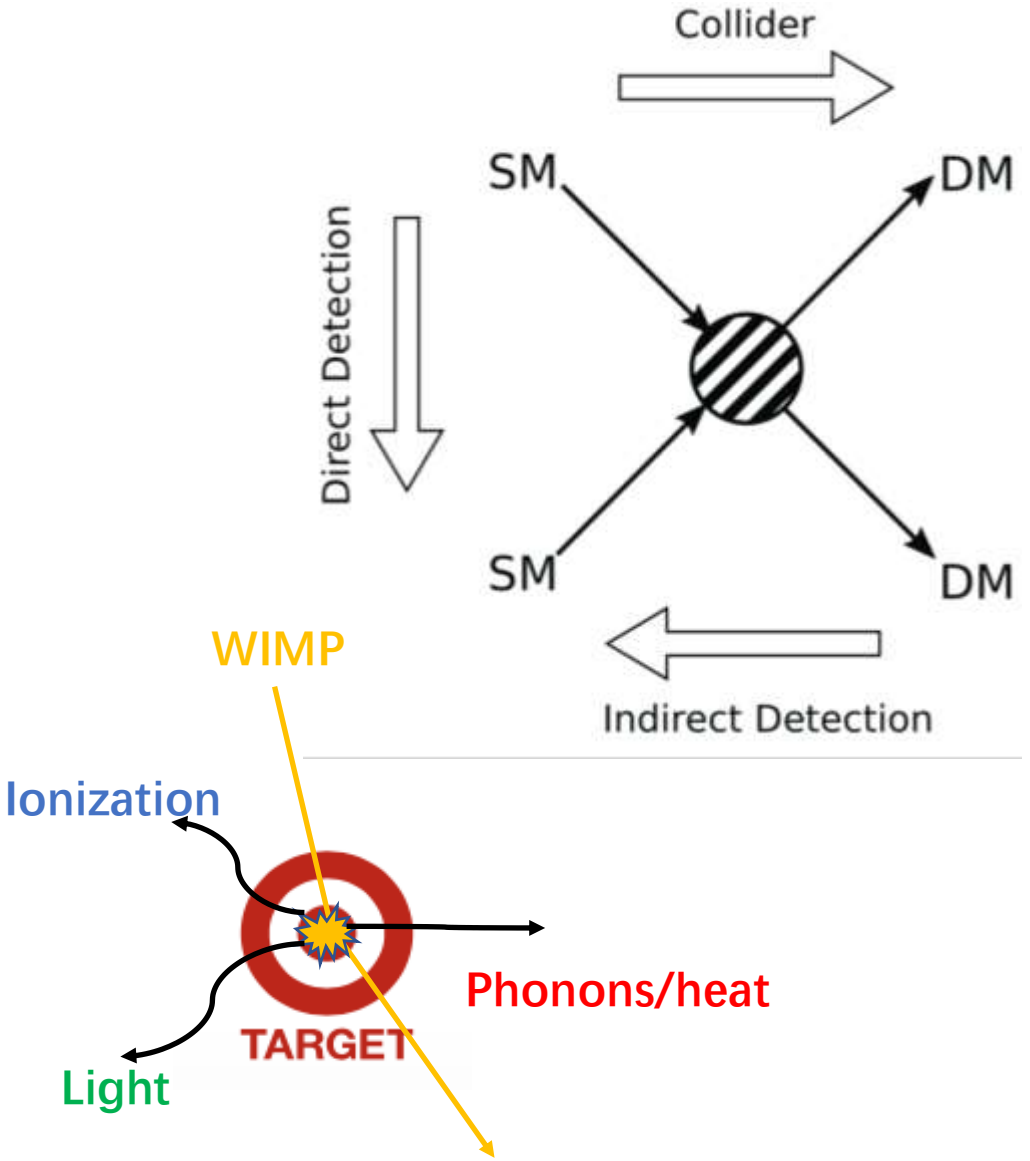
On behalf of the PandaX Collaboration

XeSAT2023, Nantes

Contents

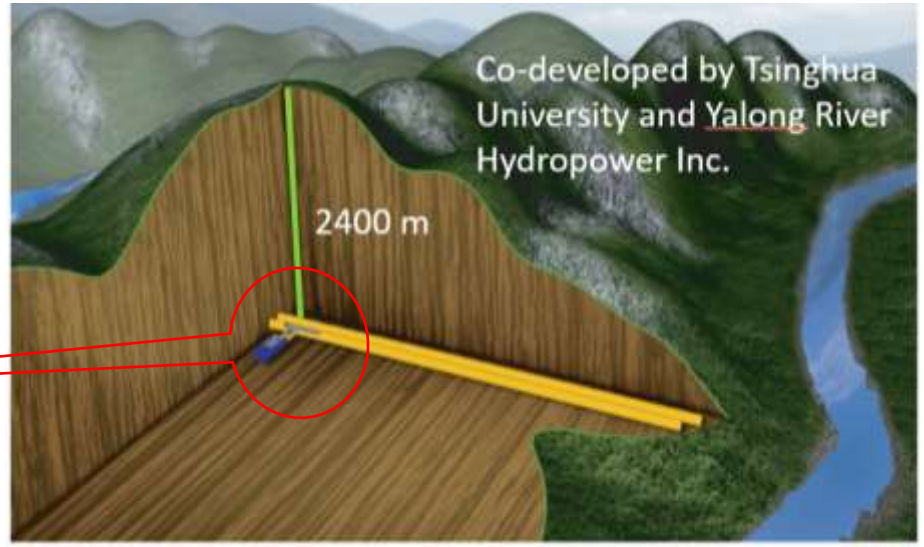
Dark Matter Detection

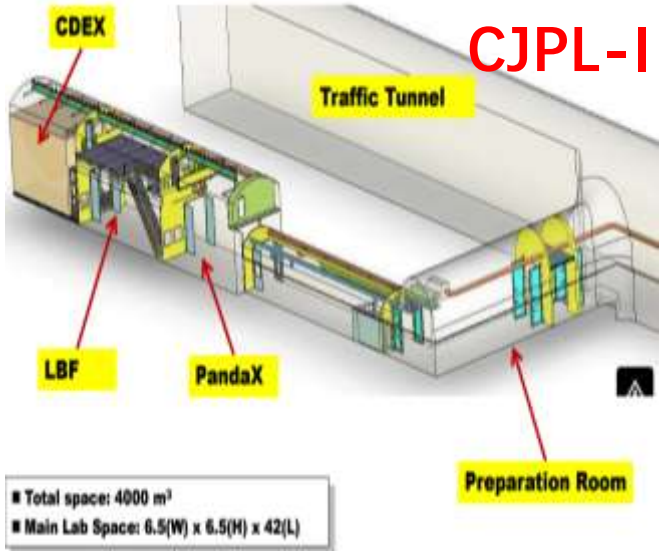


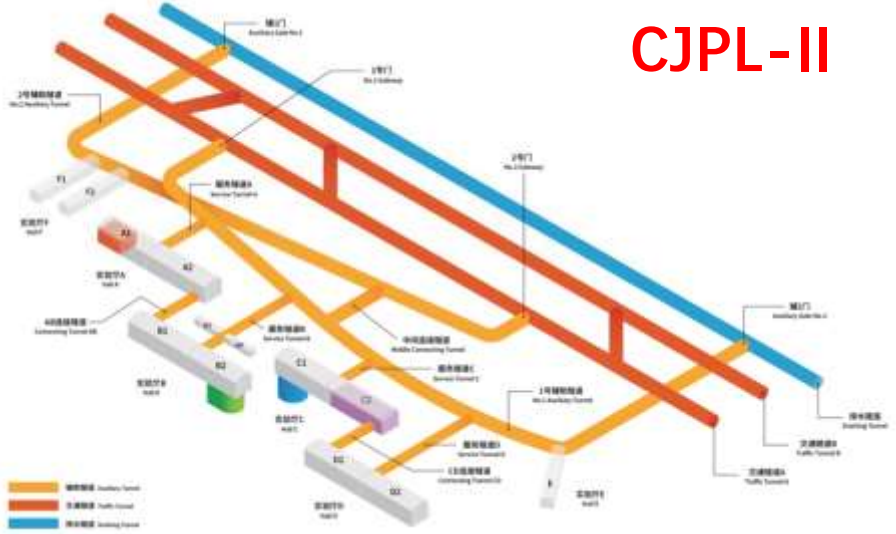


PandaX Collaboration

China JinPing Underground Laboratory – CJPL







- Deepest (6800 m.w.e)
- Horizontal access
- Muon rate:
  1 count/week/m^2

PandaX Particle and Astrophysical Xenon Experiments

Collaboration formed

2009.3

PandaX-I started

2012.7

PandaX-I apparatus moved to CJPL-I

2014.3

PandaX-II, 580 kg xenon operation

2014.5-10

PandaX-I, 120 kg xenon operation

2016.7-2019.7

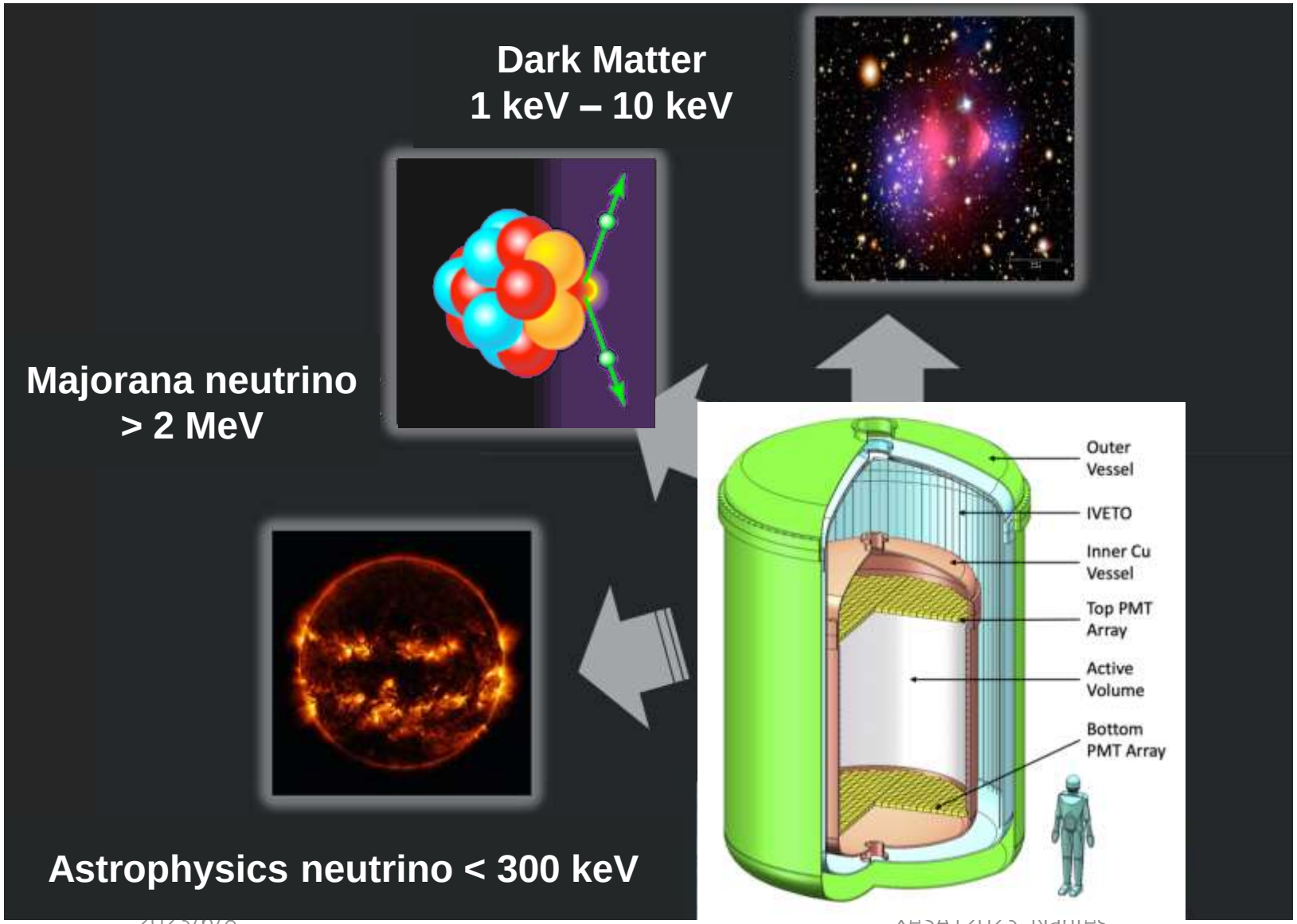
PandaX-4T online

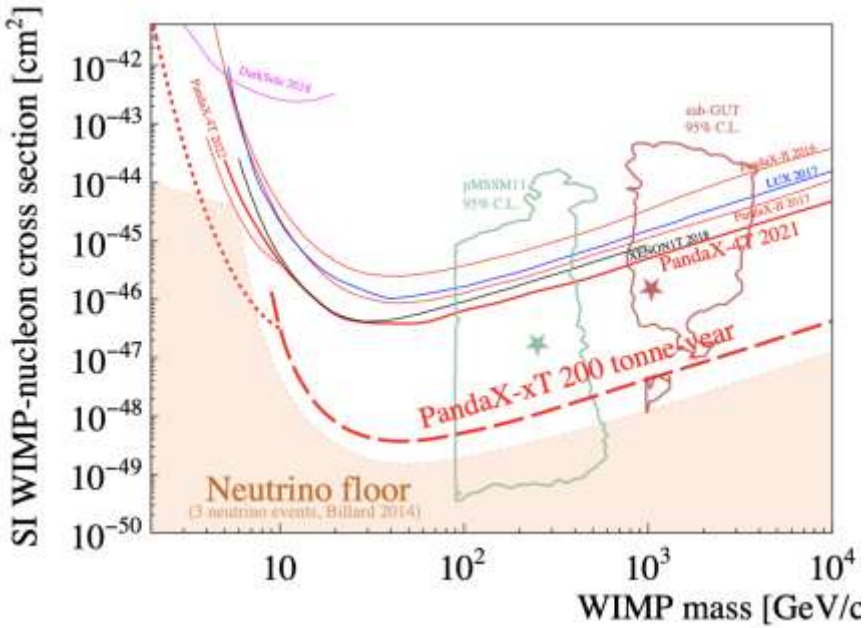
2019.8

PandaX-4T, 3.7 ton moved to CJPL-II

2020.11-

Nest generation: PandaX-xT

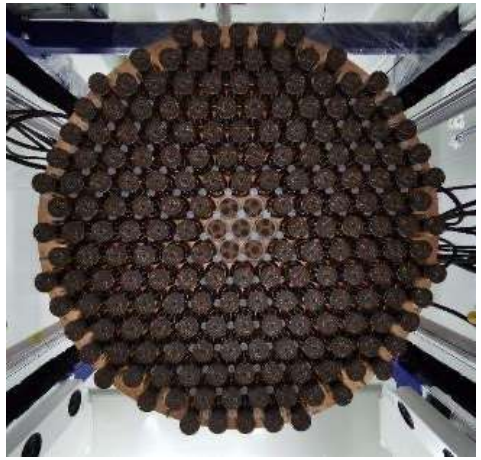




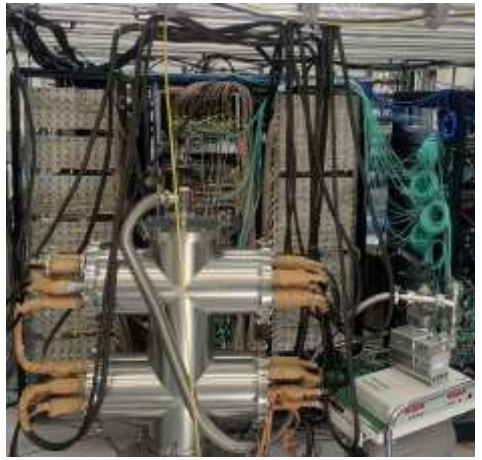
- With >30 tone liquid xenon in the sensitive volume
- Decisive test on WIMP and key test on Dirac/Majorana neutrino

PandaX-4T subsystems

TPC



PMT



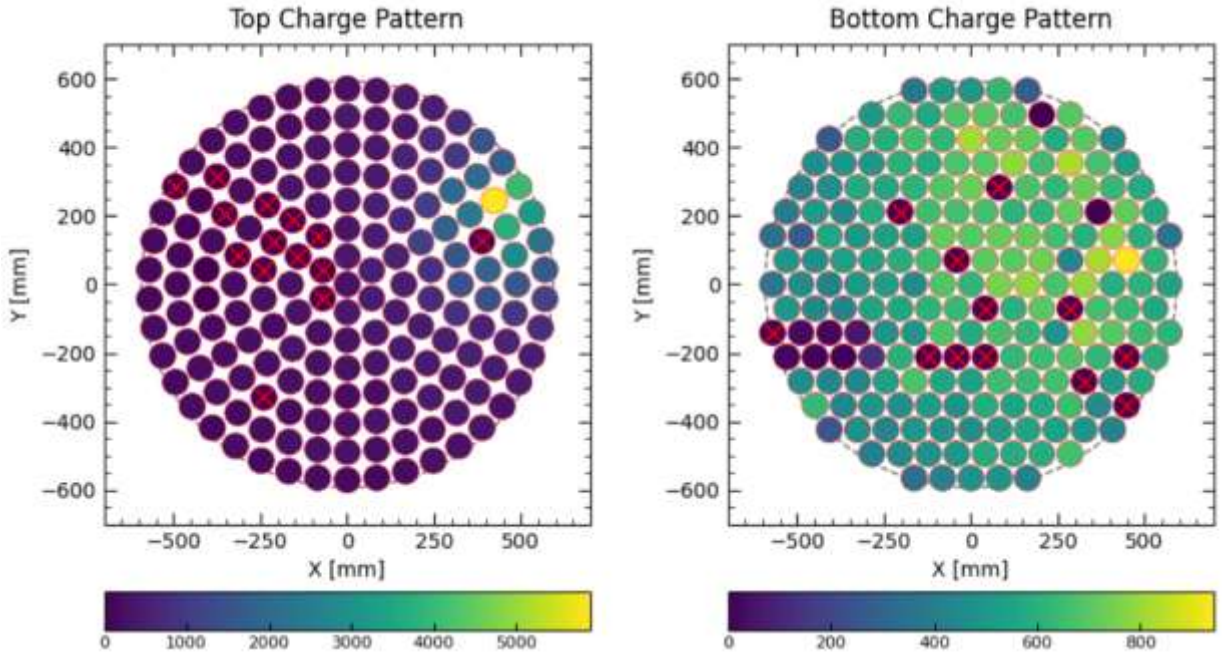
Electronics

Distillation tower

Cryogenics system

Gas storage system

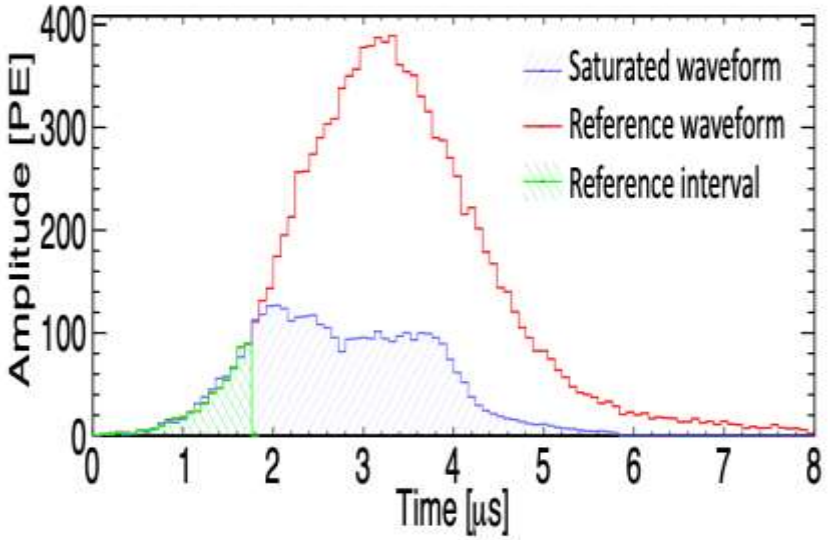
3-inch PMTs status at end of Run1



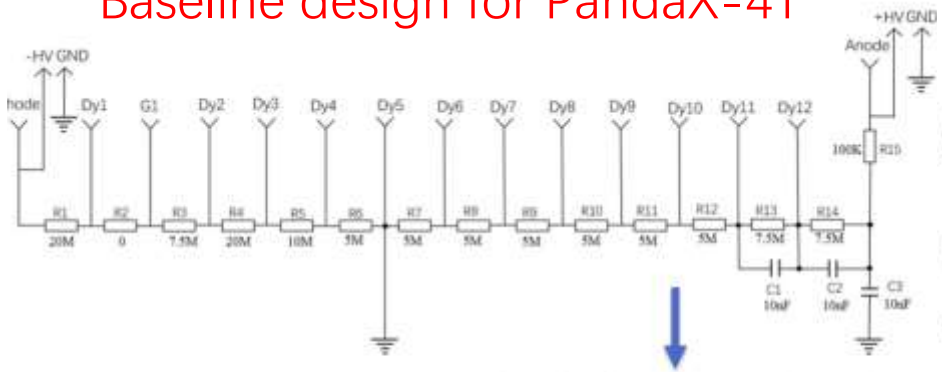
Off reason	quantity
Base broken	12
High app	7
Bad connection	8
sum	27

- 169(Top) + 199(bottom) 3-inch PMTs (R11410) are used in PandaX-4T
- 27 out of 368 were off at the end of Run1
- Fix these problems during PandaX-4T updating

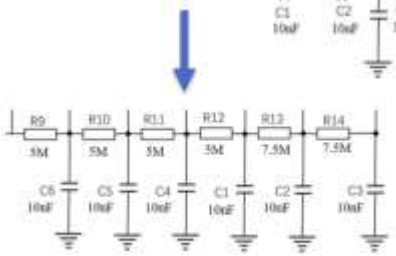
Challenge of PandaX-4T PMT： Saturation

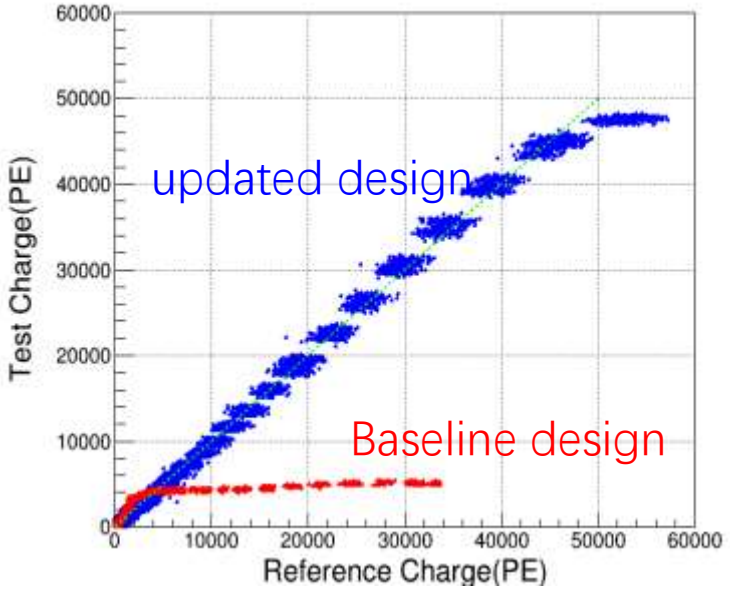


Baseline design for PandaX-4T



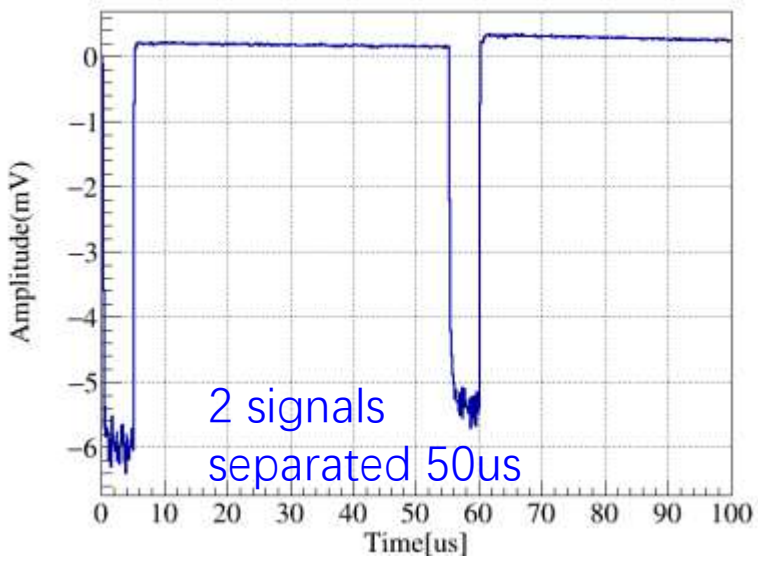
Updated design

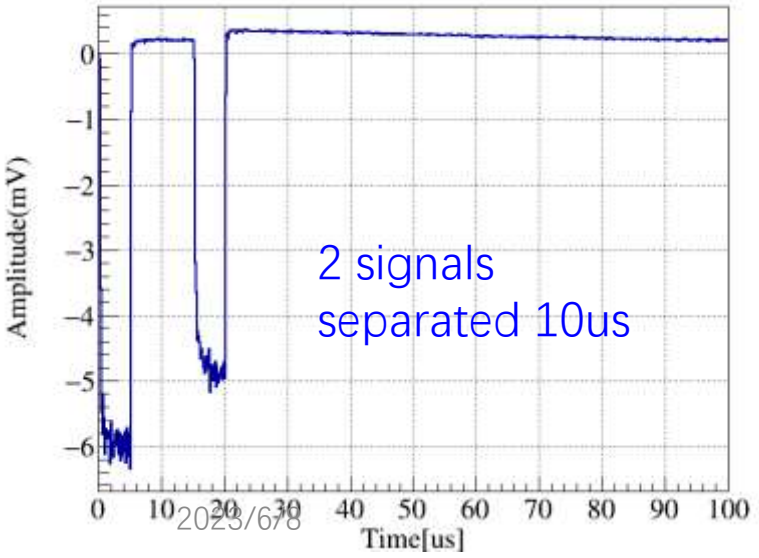


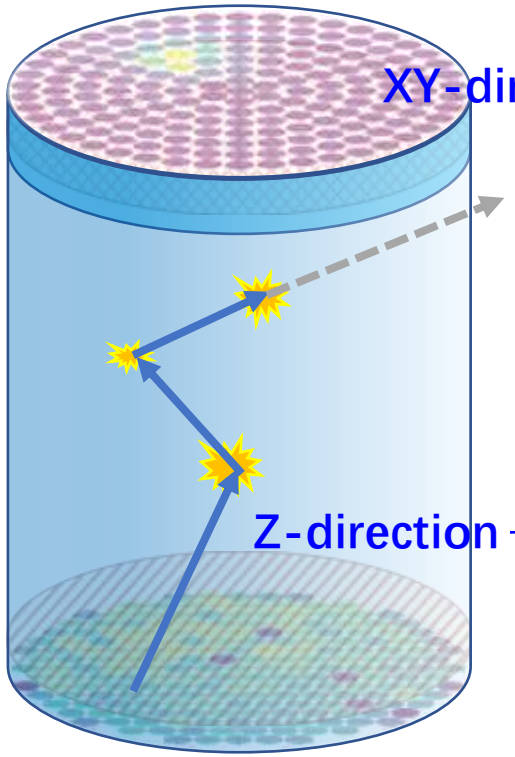


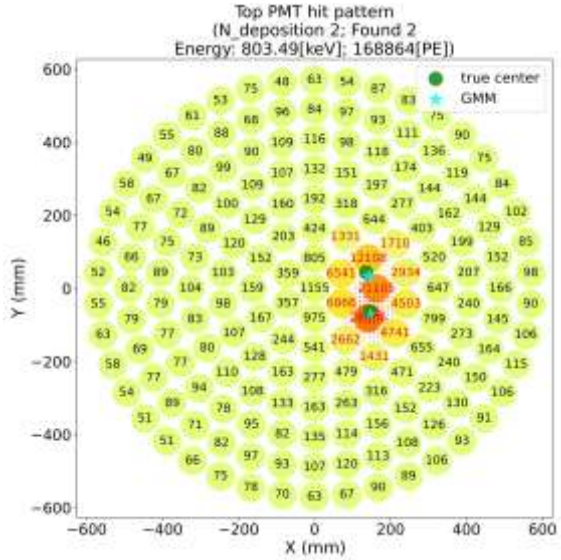
- Baseline design specially for DM search with few capacitors
- Updated the configuration of de-saturation capacitors for future PandaX-4T upgrade
- Radioactivity at the same level
- Dynamic range increases significantly

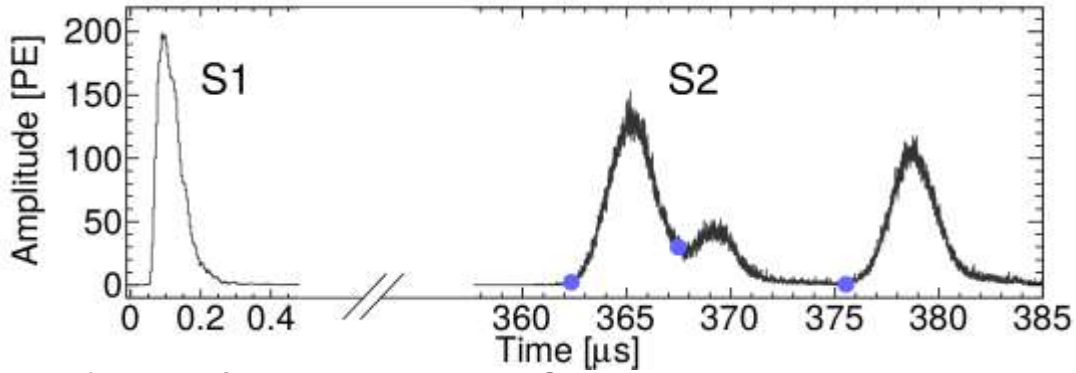
Challenge：suppression effect of multi-site events











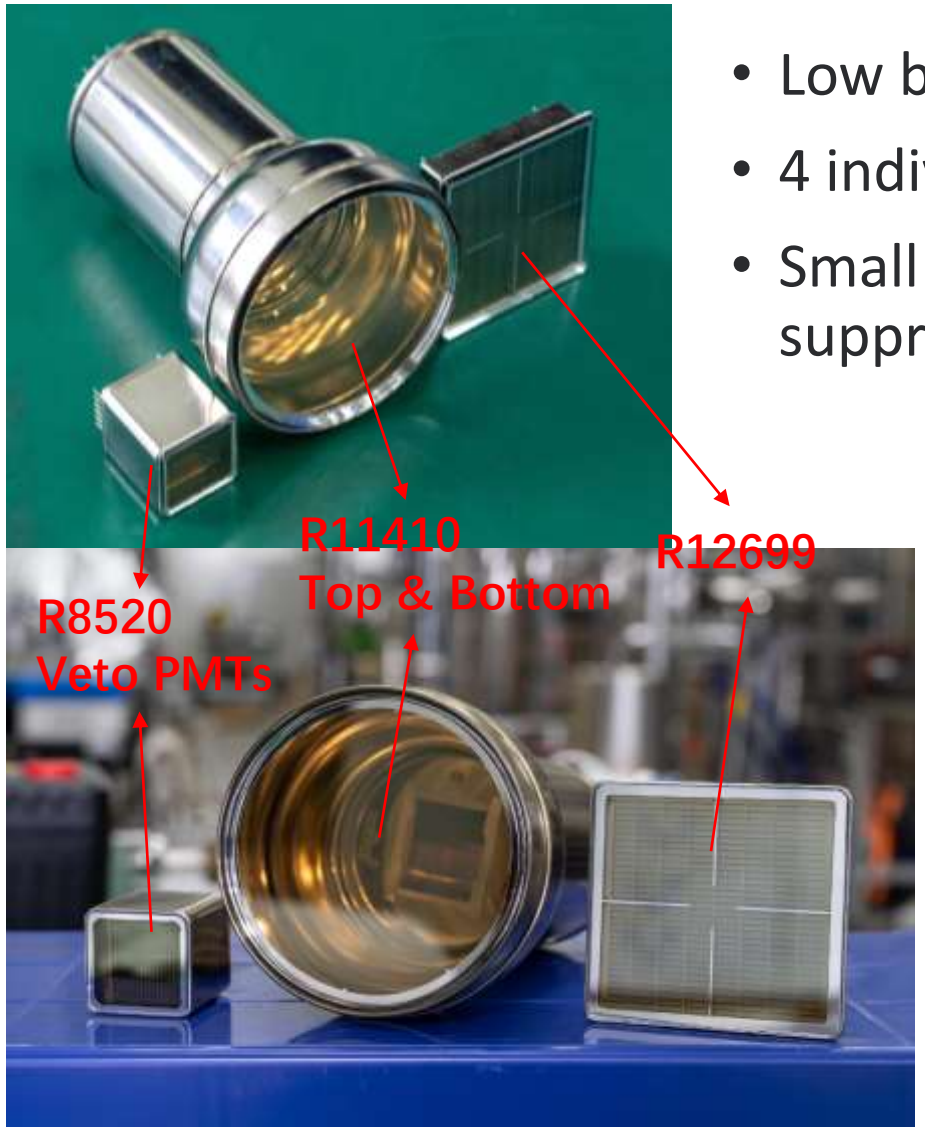
- Identifying MS backgrounds with PMT waveforms
- Obvious suppression effect for baseline design base
- New designed base without suppression effect within 40kPE

Challenge: radioactivity

Unit: mDRU	ER	NR
PMT (PMT+Base)	$(5.1 \pm 1.2) \times 10^{-3}$	$(2.3 \pm 0.4) \times 10^{-4}$
PTFE	$(2.1 \pm 0.3) \times 10^{-5}$	$(8.4 \pm 1.3) \times 10^{-6}$
Copper	$(1.6 \pm 0.2) \times 10^{-6}$	$(7.2 \pm 0.5) \times 10^{-8}$
Inner vessel	$(1.8 \pm 0.8) \times 10^{-3}$	$(1.4 \pm 1.2) \times 10^{-4}$
Outer vessel	$(2.6 \pm 1.3) \times 10^{-3}$	$(5.2 \pm 1.9) \times 10^{-4}$
Total Material	$\mathbf{(9.5 \pm 1.9)} \times 10^{-3}$	$\mathbf{(9.1 \pm 2.2)} \times 10^{-4}$

- PMT+Base contribute a half of the material radioactivity

New 2-inch PMT: R12699



- Low background, high granularity, fast timing performance
- 4 individual anodes
- Small size of effective photocathode is good for saturation and suppression effect

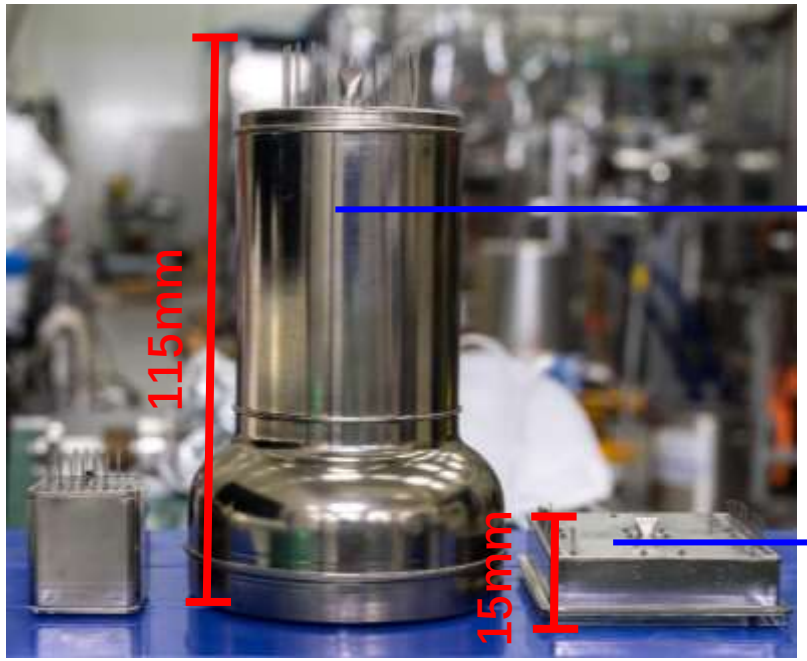
General

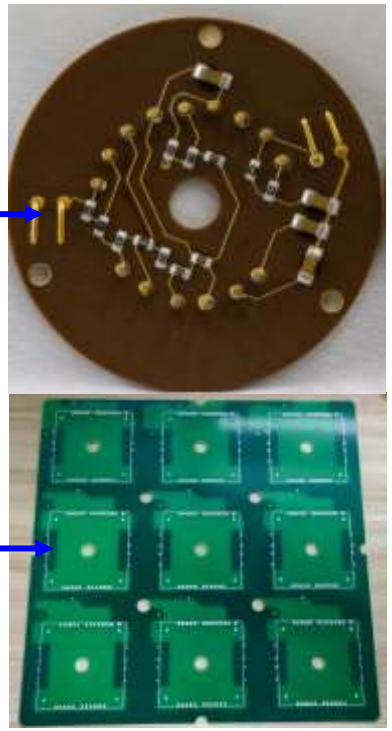
Parameter		R12699-406-M4	R11410-20	Unit
Spectral Response Range		160 to 650	160 to 650	nm
Wavelengh of Maximum Response		400	420	nm
Window Material / Thickness		Silica glass / 2.5	Silica glass / 3.5	- / mm
Photocathode	Material	Bialkali	Bialkali	-
	Minimum Effective Area	48.5 x 48.5	φ64	mm
Dynode Structure		Metal channel Dynode	Box & Linear-focused	-
Number of Stages		10	12	-
Number of Anode(s)		4	1	-
Weight		104	233	g
Operating Ambient Temperature		-110 to +50	-110 to +50	deg C
Storage Temperature		-110 to +50	-110 to +50	deg C

Maximum Ratings (Absolute Maximum Values)

Parameter	R12699-406-M4	R11410-20	Unit
Supply Voltage Between Anode and Cathode	1100	1750	V
Average Anode Output Current in Total	0.1	0.1	mA
Pressure-resistance (Guage)	0.5	0.3	Mpa

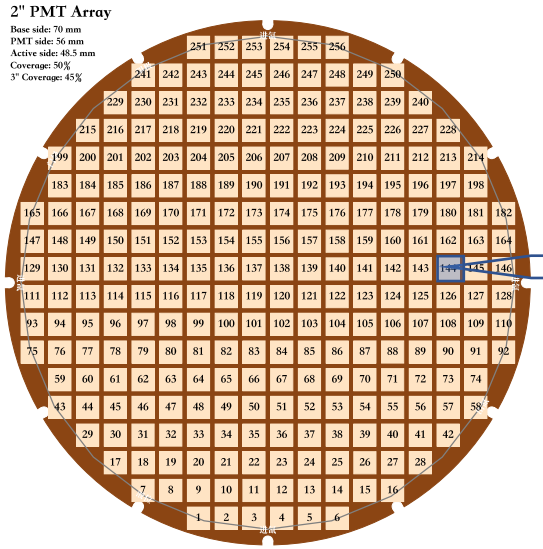
Advantage：space saving



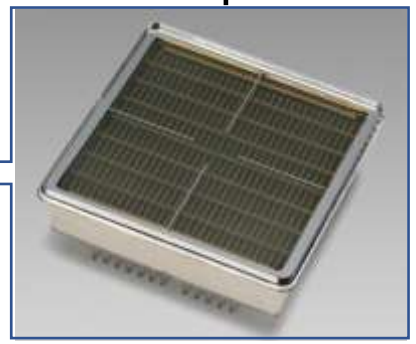


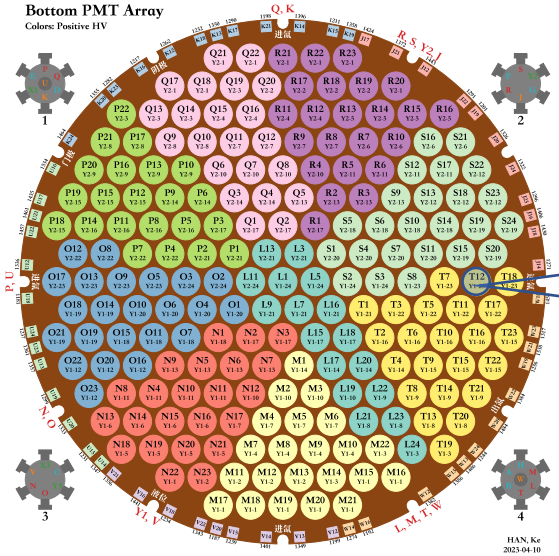
- Significant space saving for bottom array, could save a few hundred kg of LXe
- Integrated installation design

Advantage: position reconstruction

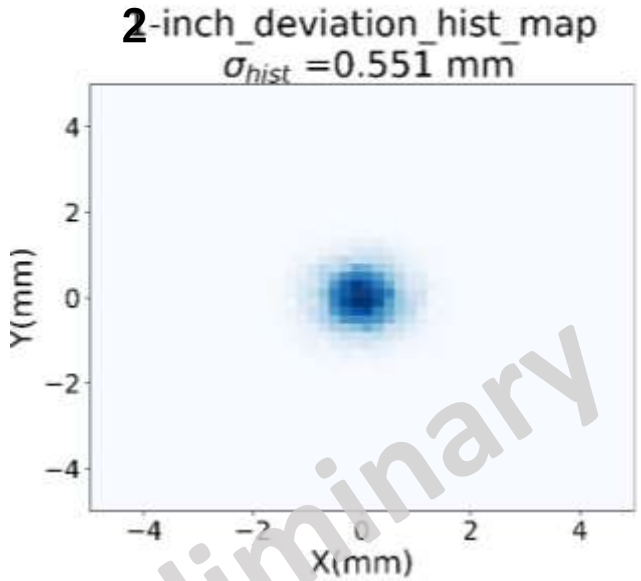


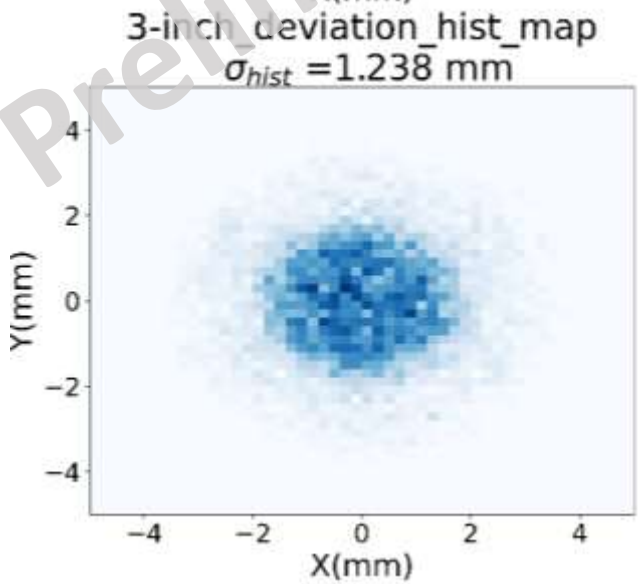
256pcs





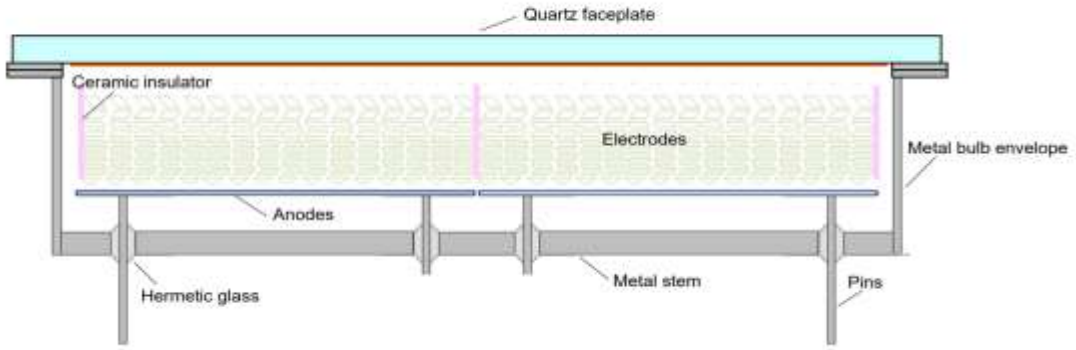
169pcs





- Pixel density
  ×6 higher
- Position reconstruction
  ×2 better

Advantage: radioactivity



		R12699	R11410
Radioactivity [mBq/pc]	Co-60	<0.07	1.16±0.72
	Th-232	<0.40	4.33±2.16
	U-238	0.47±0.11	26.29±16.90

- Lower radioactivity than PandaX-4T R11410
- Further effort are making to optimize the radioactivity

Advantage: time response

Characteristics at 25 deg C

Parameter		R12699-406-M4	R11410-20	Unit
Cathode Sensitivity	Luminous (2856K)	95	90	uA/lm
	Blue Sensitivity Index	10.0	10	-
Anode Sensitivity	Luminous (2856K)	140	315	A/lm
Gain		1.5×10^6	3.5×10^6	-
Anode Dark Current (Each anode) (after 30min. storage in darkness)		1.5	10	nA
Time Response	Rise Time	1.2	5.5	ns
	Transit Time	5.9	46	ns
	Transit Time Spread (FWHM)	0.41	9	ns
Uniformity Between Each Anode		1:1.5	-	-
Pulse Linearity (Each Anode)	at ±2% Deviation	8	20	mA
	at ±5% Deviation	20	-	mA

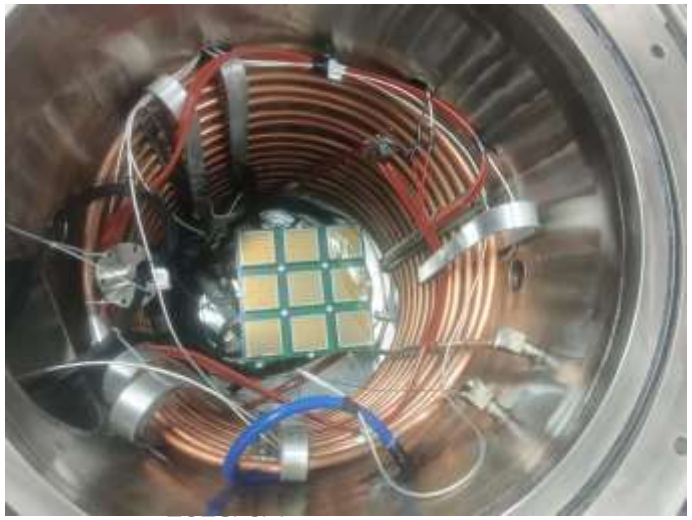
Better time response may benefit pulse shape discrimination

Test Setup

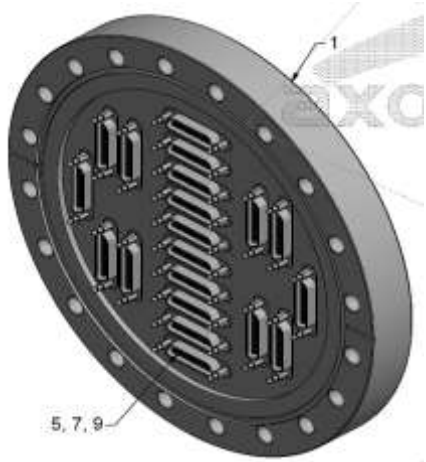
Prototype TPC for LXe test

AXON Micro-D feedthrough

Triggerless 500MHz FADC

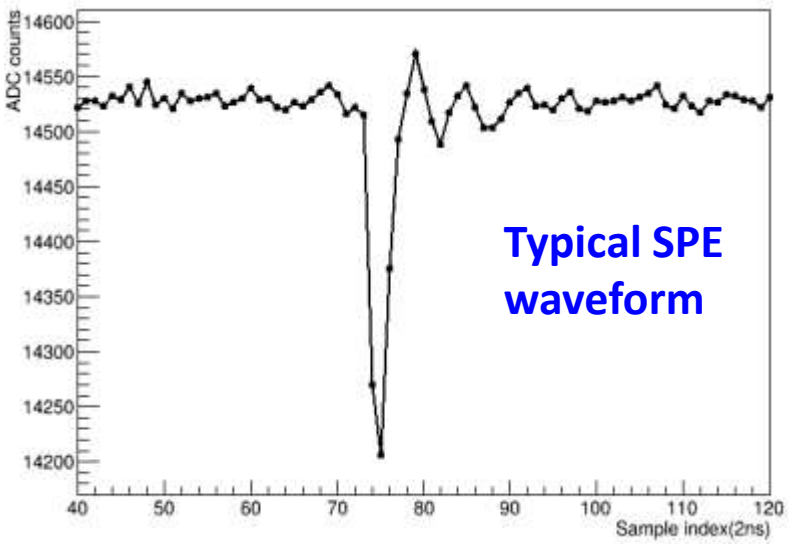


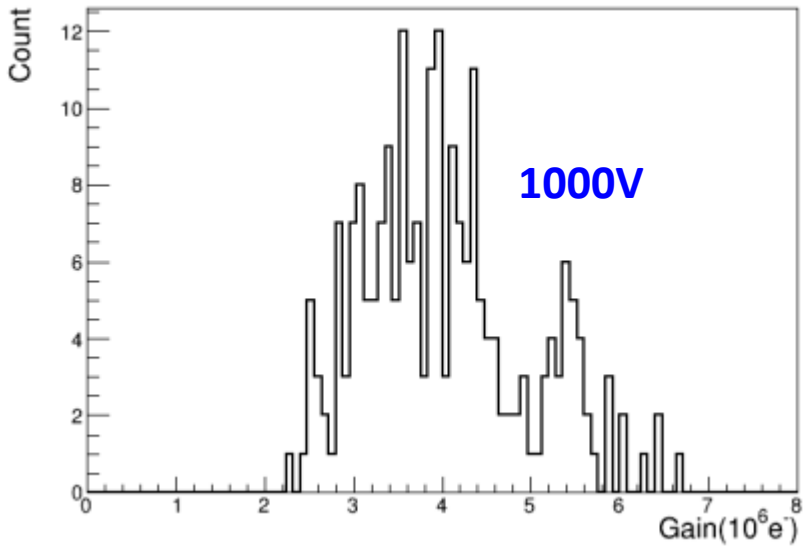
Dewal refrigerator filled with GN_2

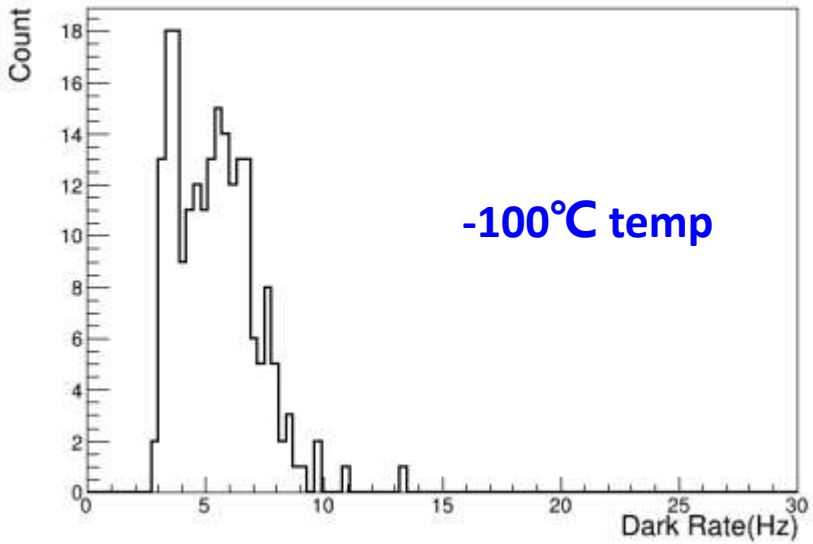


Item	Parameters
Temperature	-110℃-50℃
Gas pressure	< 4 bar
Gain	$> 1.5\times10^6 e^-$ @1000V
Dark rate	$<$ 2kHz/channel @ room temp
QE@175nm	>26%
After Pulse	$< 5\%$ (0.4-2us)
Cathode uniformity	$< 10\%$
Anode cross-talk	$< 1\%$

First batch test result







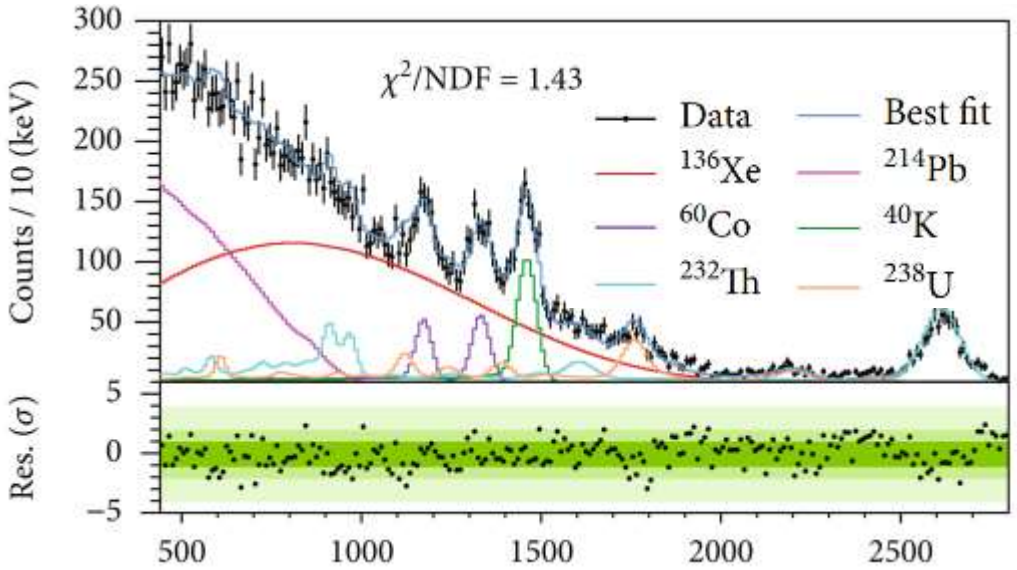
- Gain each channel more than 2×10^6 e^-
- Dark rate at -100℃ is less than 10Hz per channel
- The basic parameters can meet the requirement of liquid Xenon TPC

Summary

- Base updated design with more capacitors for PandaX-4T updating
- R12699 PMTs make some improvements: space saving, saturation, time response and radioactivity
- The photoelectric parameters can meet the requirement of liquid Xenon TPCs in GN_2 environment
- Still at the early stage of testing

Thanks for your listening

Chanllenge: radioactivity



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Total Material	$\mathbf{(9.5 \pm 1.9)} \times 10^{-3}$	$\mathbf{(9.1 \pm 2.2)} \times 10^{-4}$

- ^{136}Xe DBD T1/2 = 2.27 ± 0.03(stat.) ± 0.10(syst.) × 10^{21} year
- PMT+Base contribute a half of the material radioactivity