Low background control for PandaX

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On behalf of PandaX Collaboration

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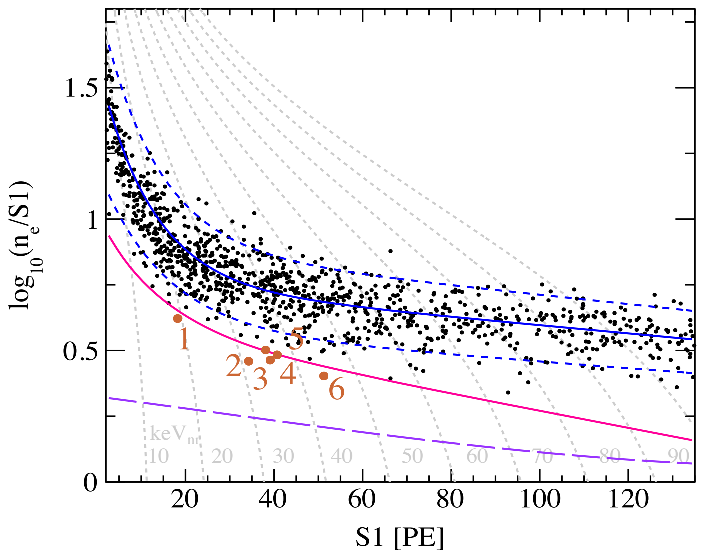
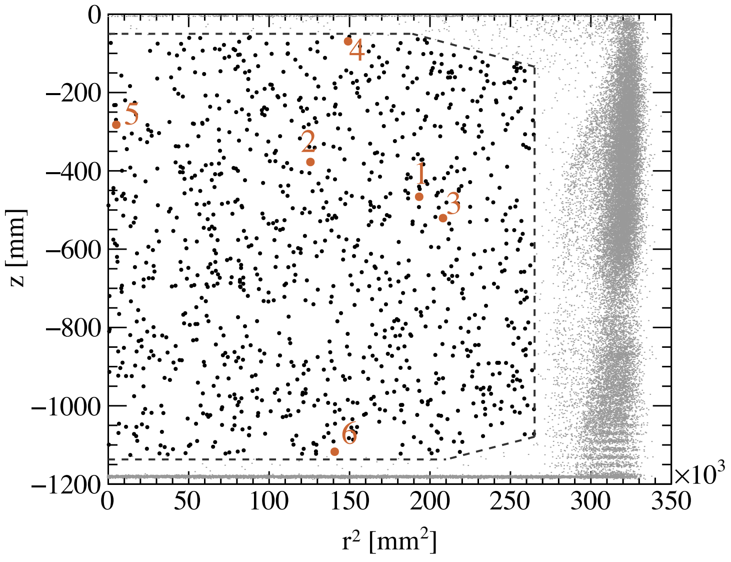
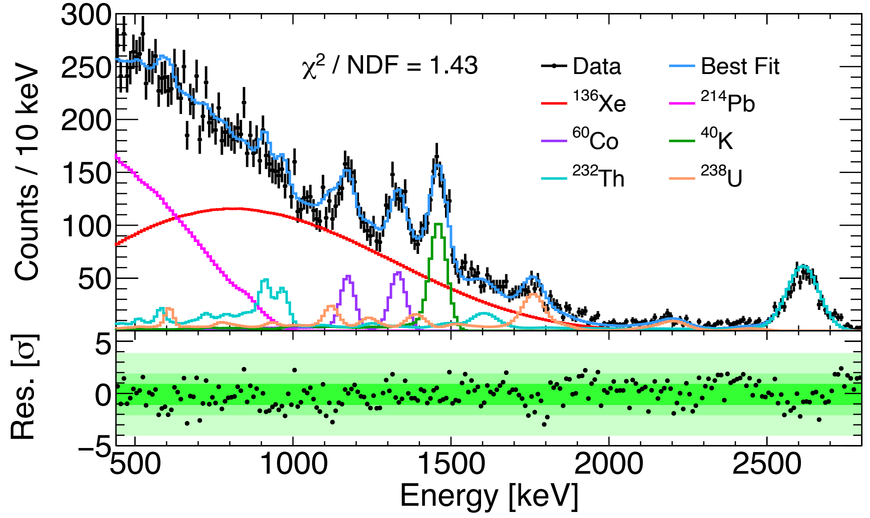
Low background requirement for PandaX

- PandaX-4T searches for rare signals such as dark matter and double beta decay with a multi-ton Liquid Xenon TPC
- Internal background: impurities in xenon (Rn, Kr, etc) are main sources
- External background: radioactive isotopes in detector components (U, Th, Co, K) limits the fiducial volume and determines the background rate/shape





Dark Matter WIMP searches: PRL 127, 261802 (2021)



^{136}Xe DBD half-life measurement: Research, 9798721 (2022)

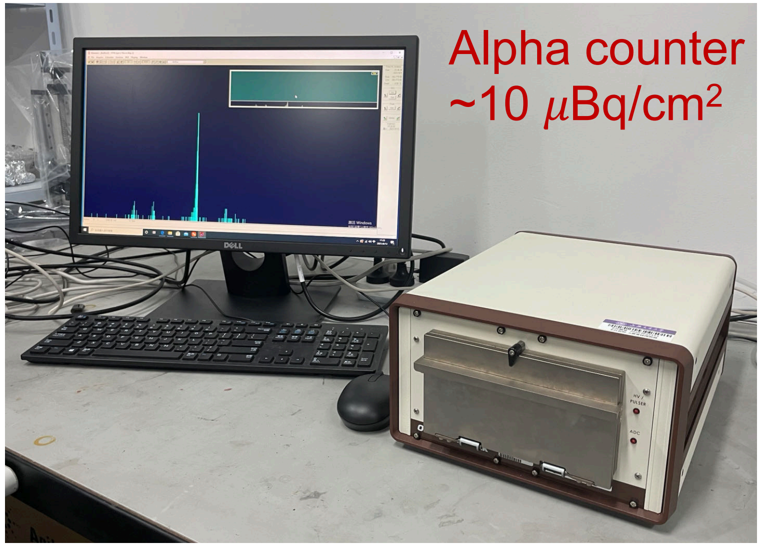
PandaX low background control program

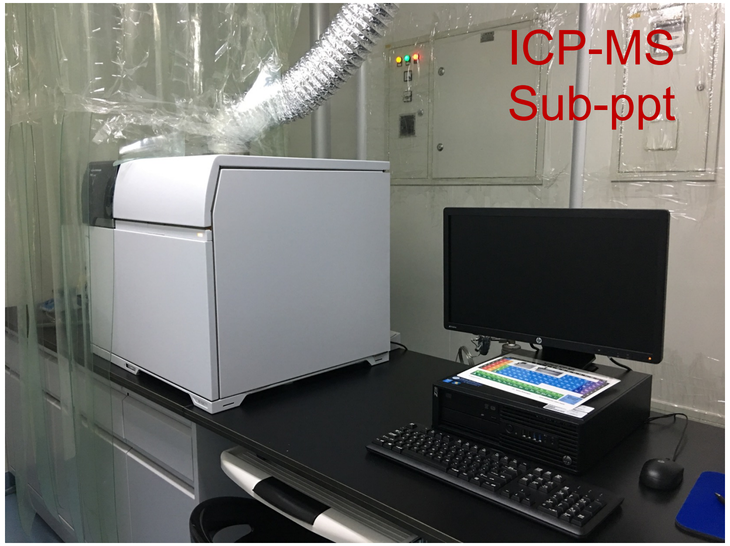
External Background control

- HPGe counting stations
- Alpha particle counters
- ICP-MS

Internal Background control

- Radon emanation measurement and removal
- Krypton assay station





PandaX low background control program

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Internal Background control

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Developing low-background high-granularity R12699 PMTs with Hamamatsu

Three HPGe counting stations at CJPL

- High purity copper and lead shielding
- Vacuum counting chamber to avoid radon in air
- Material screening for multiple experiments (PandaX, JUNO, JUNA, etc), PMT R&D, low background electronics R&D
- 1000 samples counted since 2017

HPGe detector	JP1	JP2	JP3
Crystal mass [kg]	3.7	0.6	0.9
Relative detection efficiency	175%	35%	51%
FHWM@1332 keV [keV]	2.7	2.5	2.0
FHWM@662 keV [keV]	2.5	2.3	1.4

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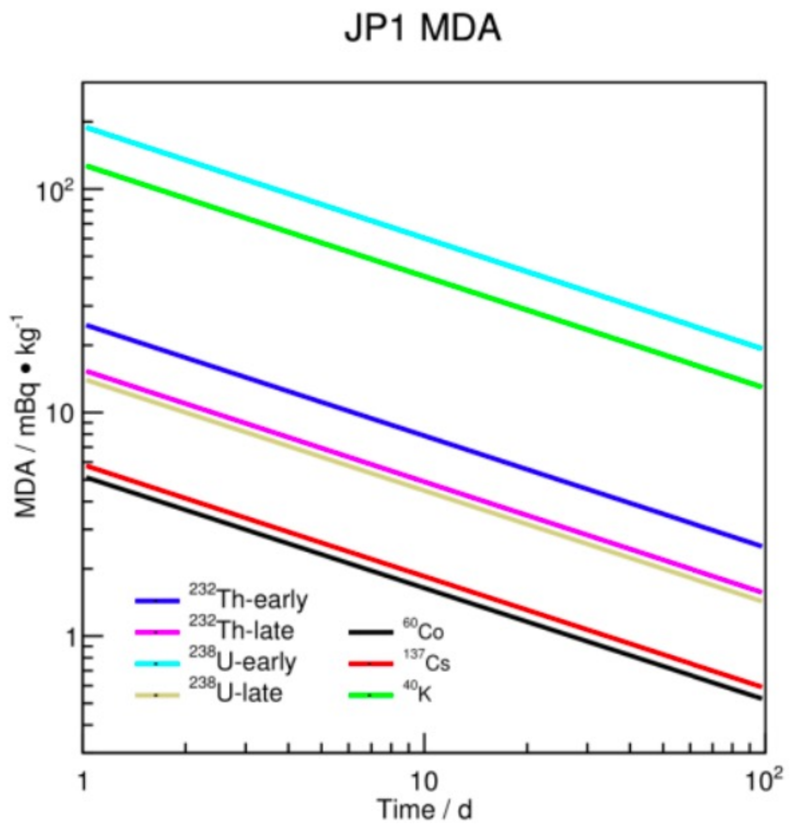


for a typical cylinder Teflon sample
(diameter: 10 cm, height: 1 cm)

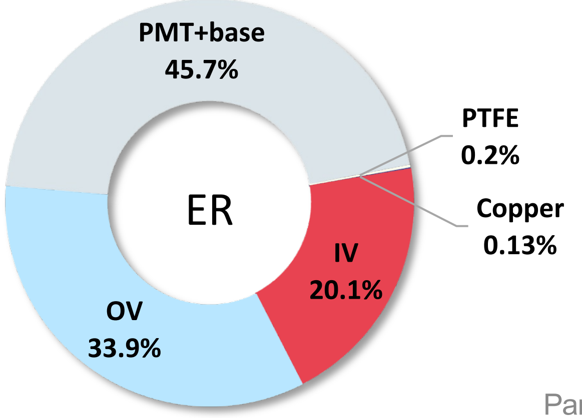
Screening results and background estimation

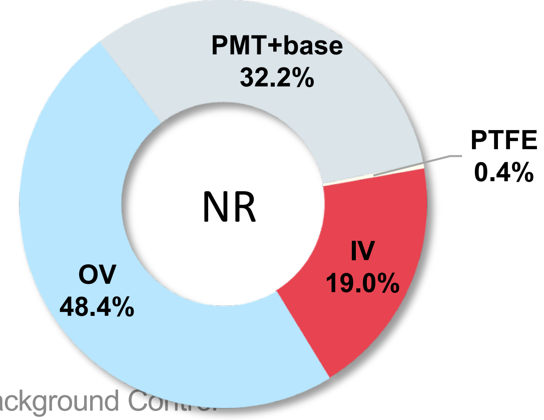
➢ Radioactive screening results of major parts for PandaX-4T for background estimation

Parts	Unit	Detector	Co-60	Cs-137	K-40	Th-232(e)	Th-232(l)	U-235	U-238(e)	U-238(l)
Inner Vessel	mBq/kg	HPGe	<3.14	<2.28	<34.42	<7.62	<3.72	<4.71	<97.94	<4.53
Outer Vessel	mBq/kg	HPGe	<2.10	<1.91	<48.22	<4.90	<4.36	<9.72	<78.32	<2.90
PMT	mBq/pc	HPGe	<2.34	<1.85	<22.31	<7.88	<3.08	<27.16	<54.09	<3.99
PMT Base	mBq/pc	HPGe	<0.12	<0.62	<6.47	<1.60	<0.71	<2.76	9.36±2.56	0.98±0.27
PTFE	ppt	NAA	-	-	1.50±0.06	10±2	-	-	<1.2	-
Copper	ppt	ICPMS	-	-	-	1.27±0.34	-	-	4.53±0.38	-

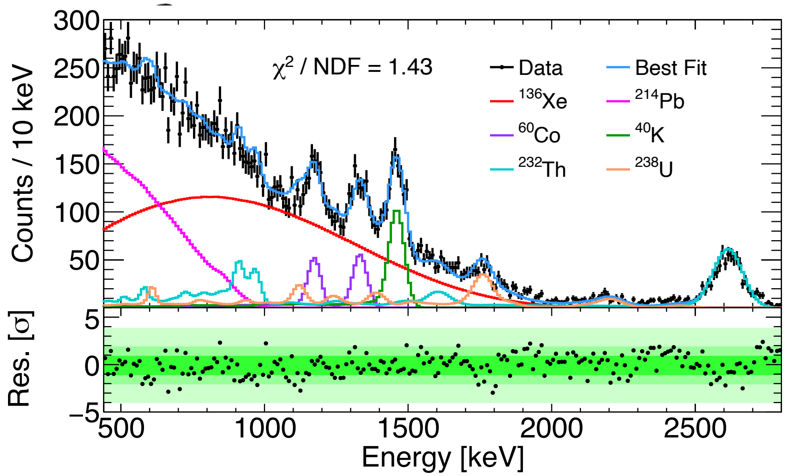
Screening results of bulk radioactivities

➢ Estimate electron recoil and neutron recoil background in [1, 30] keV_{ee} within fiducial volume



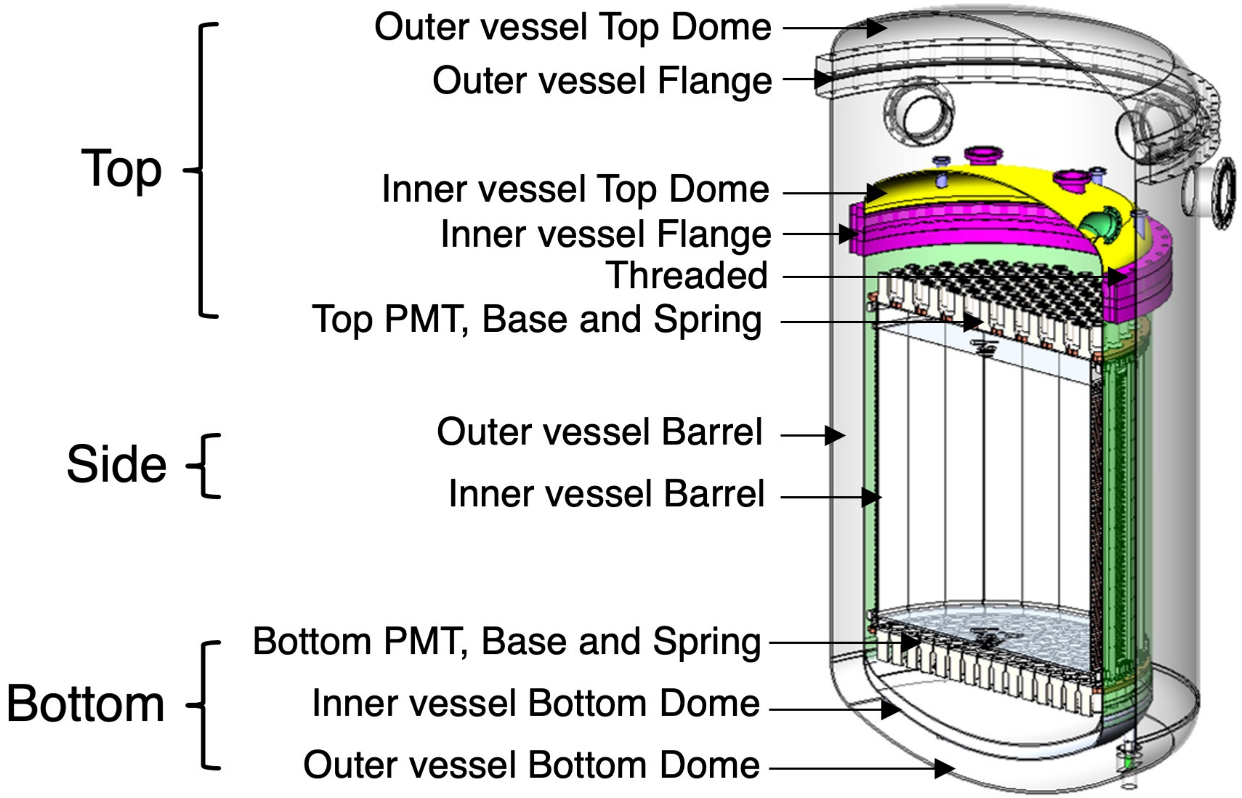


Material background from PandaX-4T data



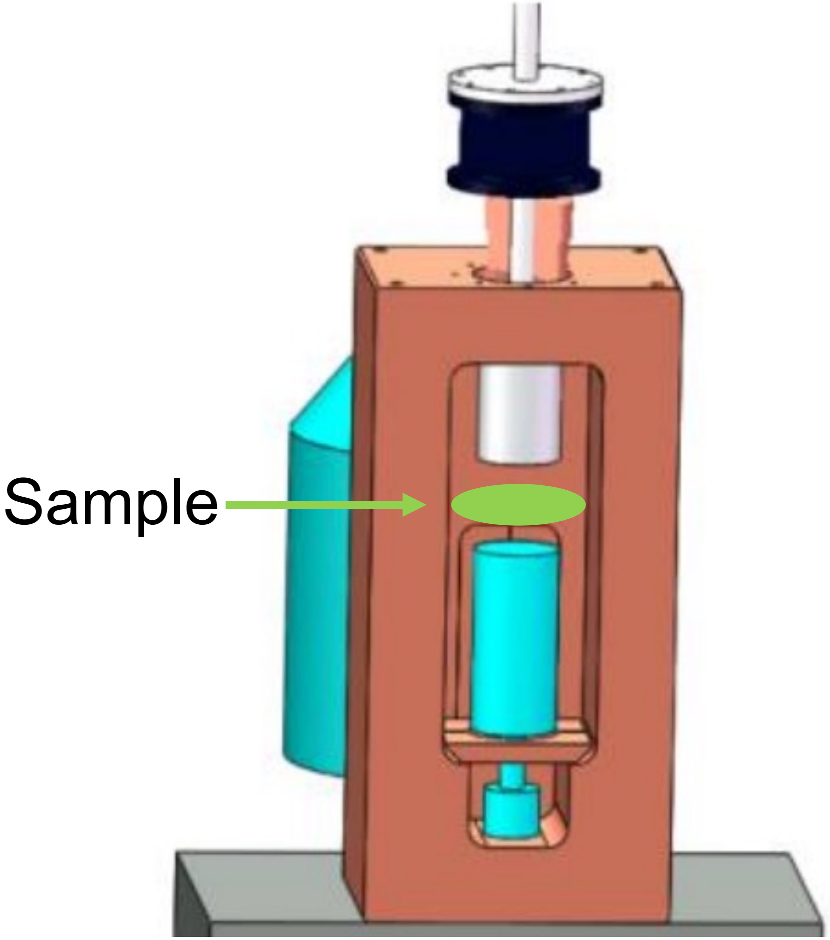
- Background results from spectrum fit and material screening agree within 2 sigma

Detector part	Contamination	Expected counts	Fitted counts
Top	^{238}U	339 ± 129	490 ± 52
	^{232}Th	402 ± 133	670 ± 56
	^{60}Co	327 ± 141	550 ± 49
	^{40}K	300 ± 156	363 ± 40
Side	^{238}U	475 ± 707	1070 ± 118
	^{232}Th	786 ± 959	2194 ± 117
	^{60}Co	1244 ± 945	185 ± 98
	^{40}K	1518 ± 835	782 ± 84
Bottom	^{238}U	141 ± 51	185 ± 40
	^{232}Th	237 ± 119	155 ± 53
	^{60}Co	159 ± 95	183 ± 48
	^{40}K	89 ± 834	100 ± 39



HPGe upgrade: further improving the MDA

- Dual HPGe detectors face-to-face for improved detecting efficiency and coincidence analysis



HPGe upgrade: further improving the MDA

- Better solid angle coverage and copper shielding for improved MDA

Isotopes	JP1 (mBq/kg)	Dual HPGE (mBq/kg)	Improvement
^{60}Co	12	6.5	1.8
^{137}Cs	12	4.8	2.5
^{40}K	267	93	2.9
^{232}Th	32	14	3.3
^{238}U	29	12	2.5

Plastic sample (D: 5 cm, H: 1 cm) for 10 days

- MDA further improved with γ-γ coincidence analysis

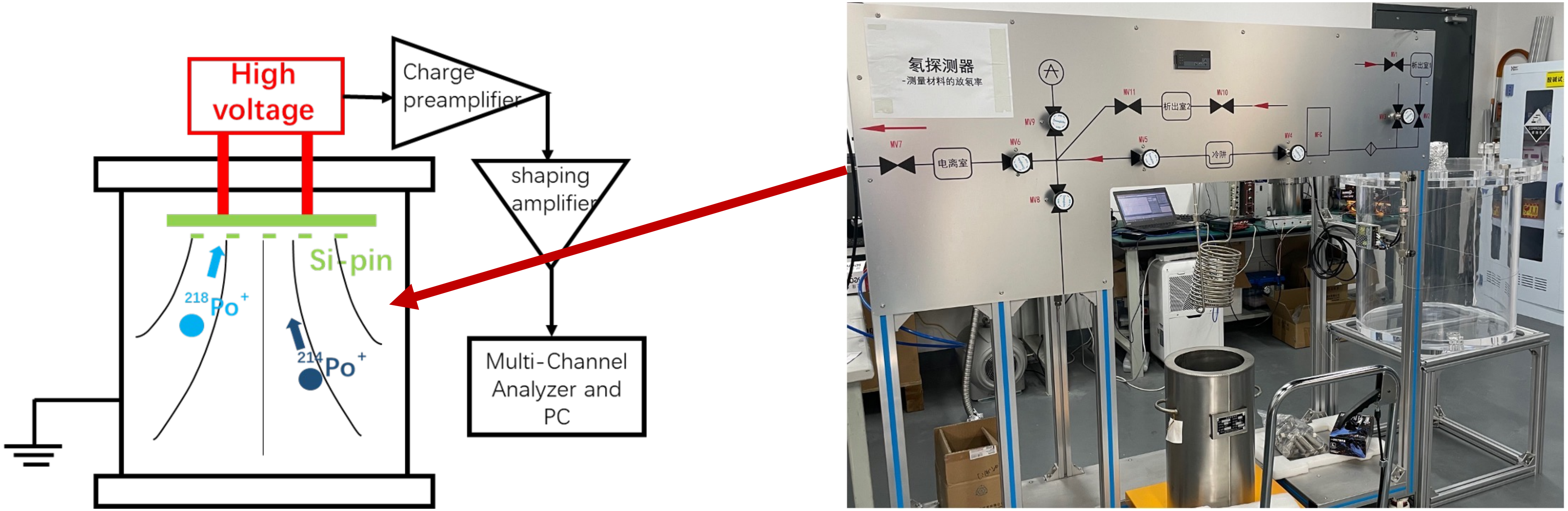
Isotopes	JP1 (mBq)	Dual HPGE (mBq)	Coincidence HPGE (mBq)
^{60}Co	0.18	0.10	0.03
^{208}Tl	0.44	0.19	0.08
^{214}Bi	0.73	0.29	0.28

sample (D: 1 mm, H: 1mm) for 10 days

Radon emanation systems

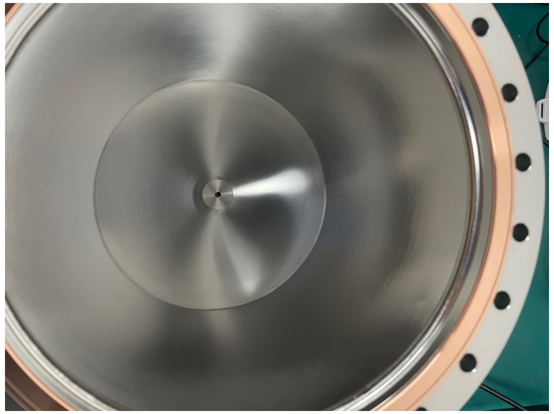
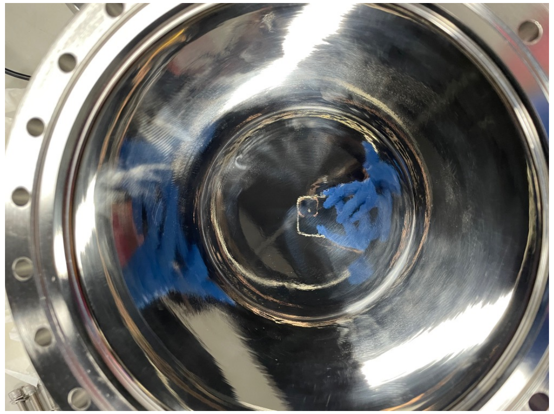
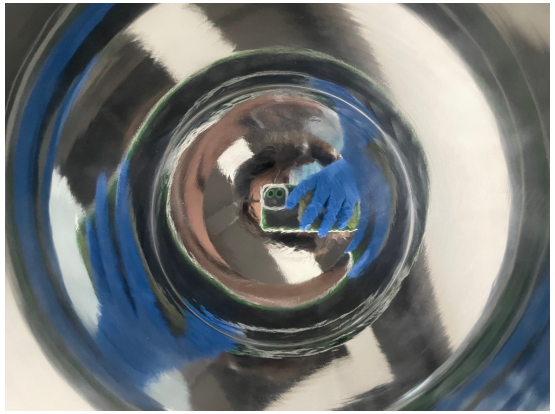
- Electrostatic collection method to measure radon emanation of parts/materials
- Multiple SS and acrylic emanation chambers tested
- Cold trap allows measurements for large-volume chambers

Parts	Rn emanation rate
PMT	<0.1 [mBq/pc]
PMT base	0.02 ± 0.01 [mBq/pc]
Distillation tower	19.4 ± 5.3 [mBq]
Inner vessel	<17.9 [mBq]



Radon emanation vs. surface roughness

- The count rate with no samples reflects the Rn emanation rate of the chamber itself
- Multiple surface treatment methods compared; clear correlation between radon emanation with surface roughness

	Electrochemical	Mirror polishing	Mirror polishing + electrochemical
Roughness [um]	3.00±0.44	0.12±0.04	0.13±0.03
Rn rate [mBq]	1.91±0.15	0.10±0.03	0.07±0.02
Efficiency [%]		28.2±1.0	
^{238}U intrinsic [mBq/kg]		10.2 ± 0.7	

6 events/day

Radon removal with the distillation tower

- A distillation tower can remove radon from xenon due to boiling point difference
- A preliminary radon reduction factor of 190 can be achieved
  - ^{222}Rn intentionally introduced and controlled
  - 10 slpm liquid circulation within the distillation tower only
- Radon reduction with the detector connected is under investigation

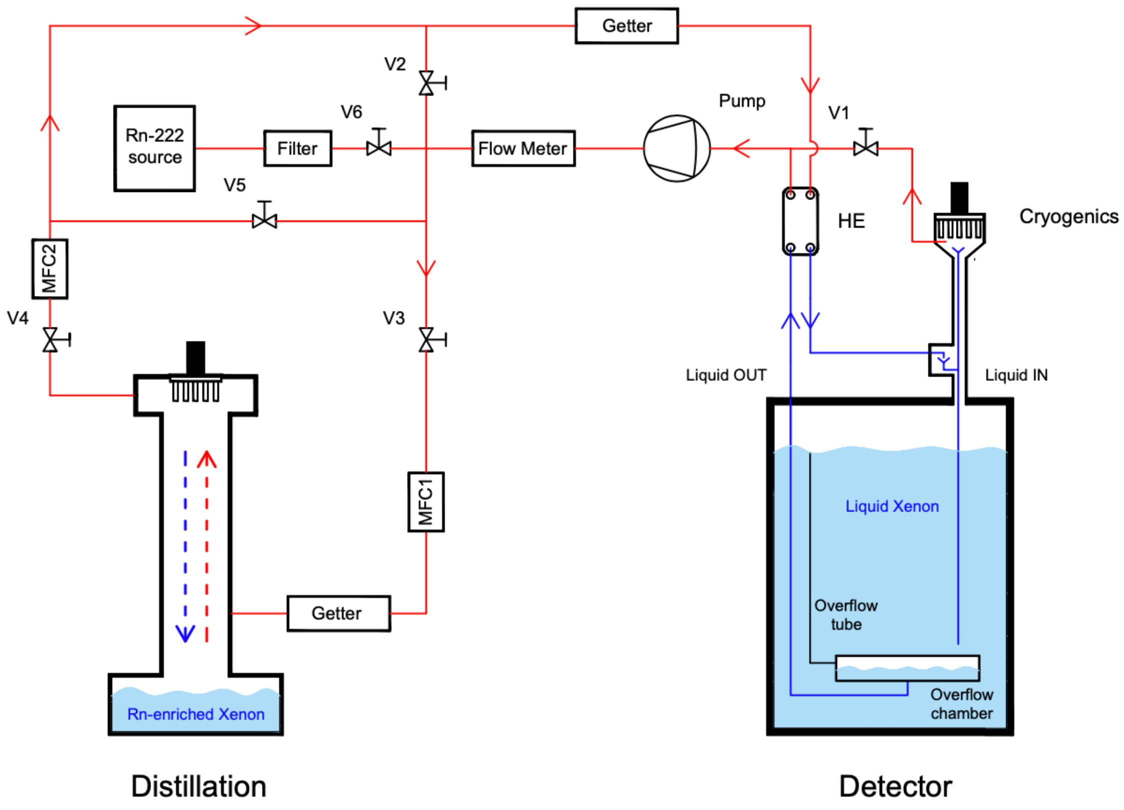


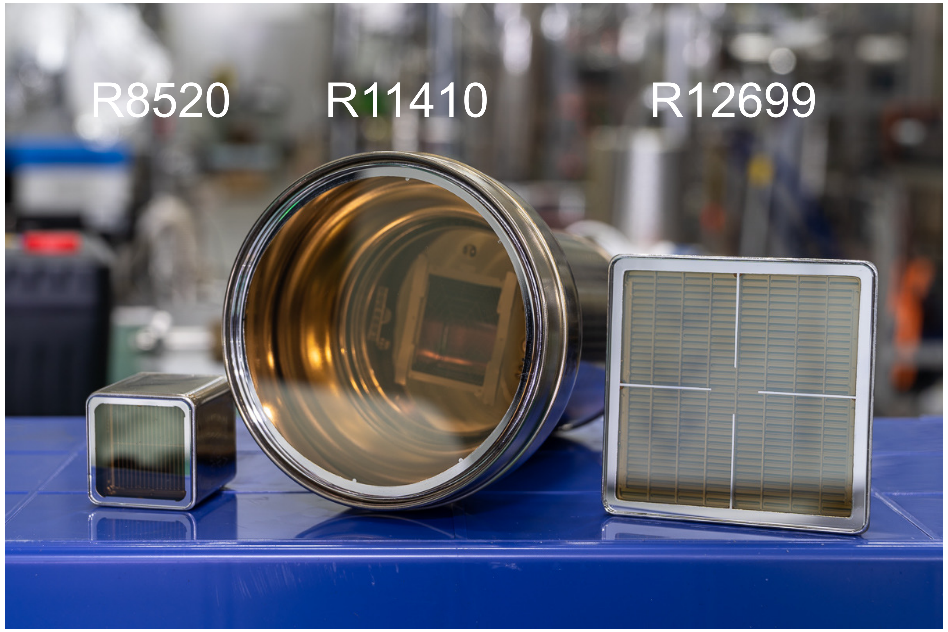
Diagram of the distillation tower and detector

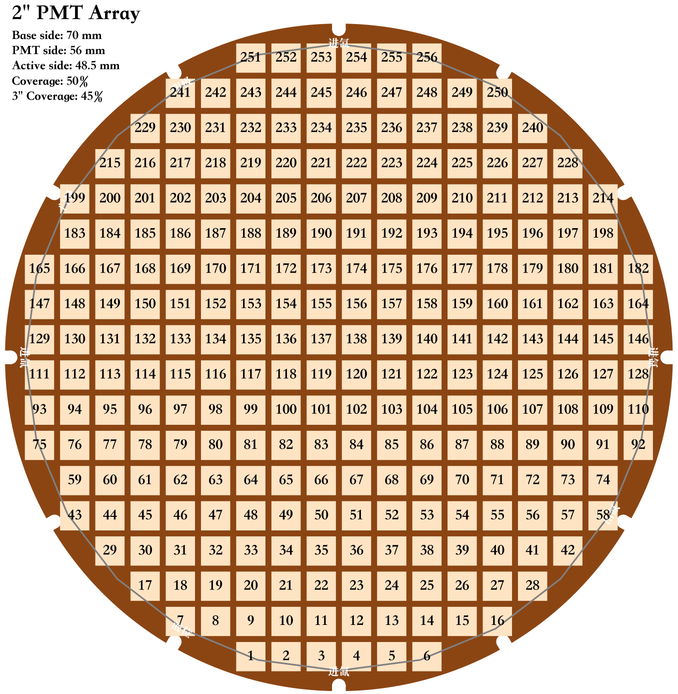
New PMTs for next generation LXe detectors

- New 2” multi-anode R12699 PMT is an attractive option for next generation multi-purpose LXe detectors
  - Higher granularity while maintaining low dark noise: best of both large PMT and SiPM
- Low background requirement is the most critical R&D

High granularity, fast timing

- Improved position reconstruction
- better event topology
- less concerns for PMT saturation





Collaborating with Hamamatsu for background control

PandaX PARTICLE AND ASTROPHYSICAL XENON TPC

- Assay individual PMT parts/materials and PMT pieces to guide PMT material selection
- Collaboration between PandaX and Hamamatsu to bring the low background high-granularity PMTs to the community
- Three versions of PMTs with reduced ^{60}Co and ^{238}U impurities

Unit: mBq/pc	Co-60	Cs-137	K-40	Th-232 (early)	Th-232 (late)	U-235	U-238 (early)	U-238 (late)
PMT R11410	1.16±0.72 <2.34	0.52±0.81 <1.85	8.37±8.49 <22.34	4.29±2.14 <7.82	1.49±0.96 <3.06	13.56±8.96 <28.29	27.42±17.67 <56.48	2.05±1.18 <3.99
PMT R12699 v0	1.01±0.10	0.09±0.07 <0.20	31.54±2.17	0.00±0.16 <0.26	0.38±0.16 <0.64	0.30±0.23 <0.68	1.63±2.08 <5.05	0.61±0.15
PMT R12699 v1	0.00±0.04 <0.07	0.01±0.05 <0.09	30.83±2.14	0.13±0.17 <0.40	0.21±0.12 <0.40	0.13±0.21 <0.48	0.00±0.62 <1.03	0.47±0.11
PMT R12699 v2 (preliminary)	0.09±0.06 <0.19	0.01±0.11 <0.20	36.67±5.08	0.13±0.33 <0.68	0.17±0.13 <0.39	0.00±0.18 <0.30	3.01±1.28 <5.12	0.18±0.12 <0.38

Summary

- Various radioassay program supports the screening measurements for PandaX-4T
- Detector parts/materials are extensively assayed with HPGe and other techniques; A new dual-detector HPGe counting station is under construction
- Correlation between surface roughness and radon emanation rate established with data and a radon reduction factor of 190 with distillation tower is demonstrated
- A new low-background PMT is developing with Hamamatsu for next-generation detector