# The Radon Emanation Measurement and Reduction for the PandaX-4T Experiment

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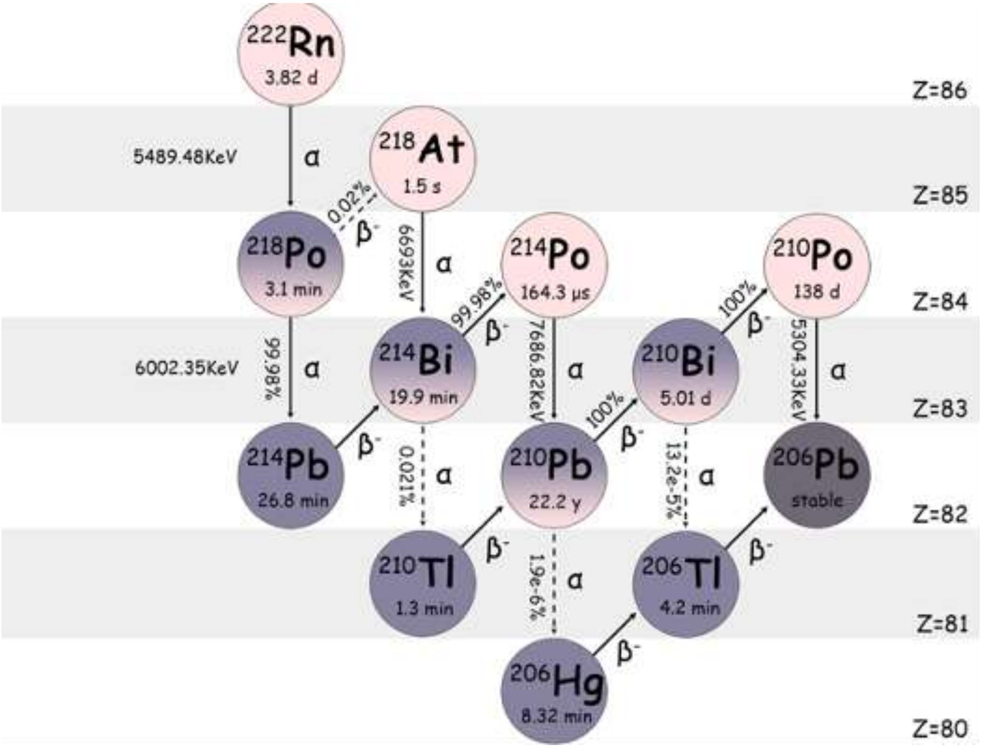
# Part 1

# Radon Background in PandaX-4T Experiment

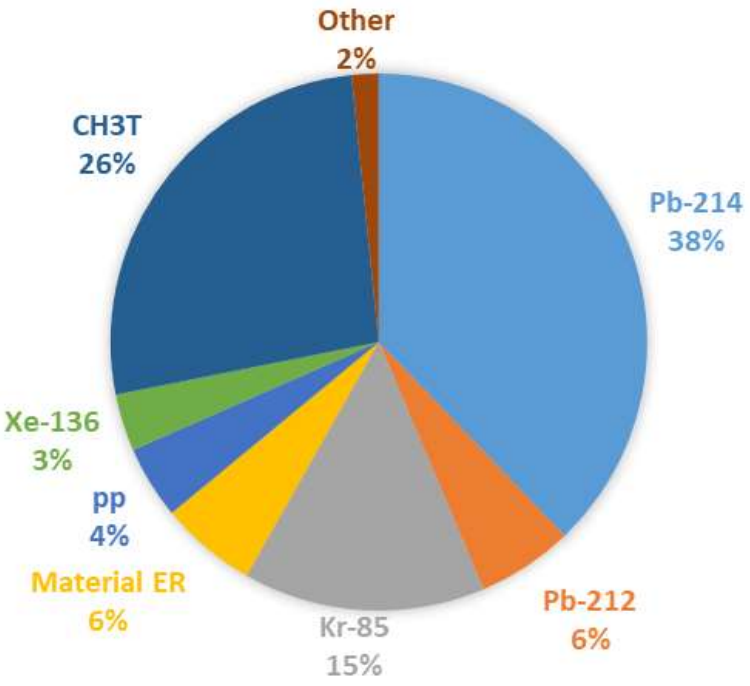
# Radon Background in PandaX-4T Experiment




$^{222}$Rn decay chain

- Radon (particularly $^{222}$Rn) and its decay daughters are significant source of background in rare event search experiments.
- $^{222}$Rn originates from the decay of $^{226}$Ra present in the detector materials and will emanate into xenon.

# Radon Background in PandaX-4T Experiment




PandaX-4T background budget

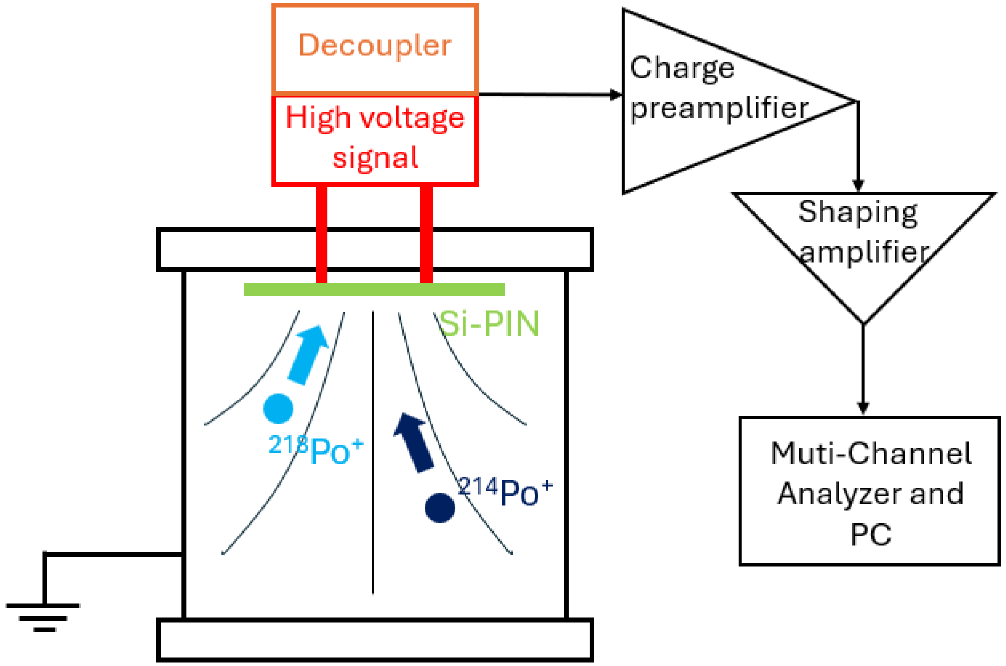
- The current $^{222}Rn$ level in liquid xenon of the PandaX-4T experiment is achieved below 7 μBq/kg. [1]
- In the PandaX-4T commissioning data [2], radon constitutes a significant portion of the background.
- We developed two radon measurement systems to assess radon emanation from individual components and replace or reduce those with high radon levels.

[1] Phys. Rev. Lett. 127 (2021) 261802.
[2] arXiv:2408.00664v1

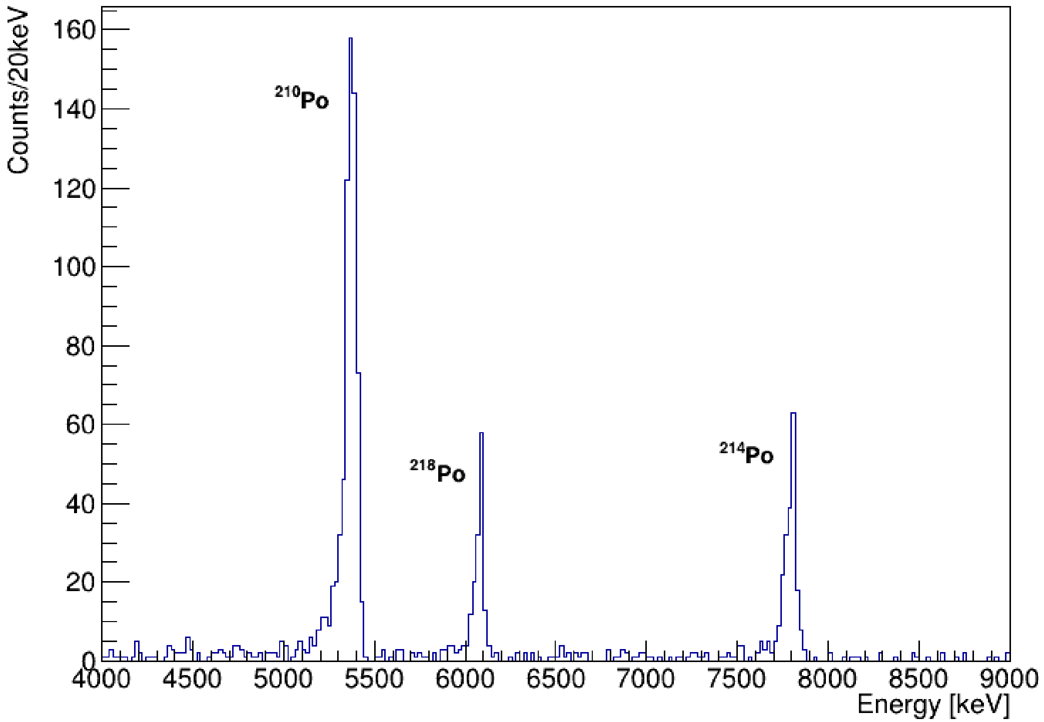
# Radon Emanation Measurement Systems

# Radon Emanation Measurement Systems

- Principle: electrostatic collection technique.
- Si-PIN: Hamamatsu Photonics S3204-09




System layout

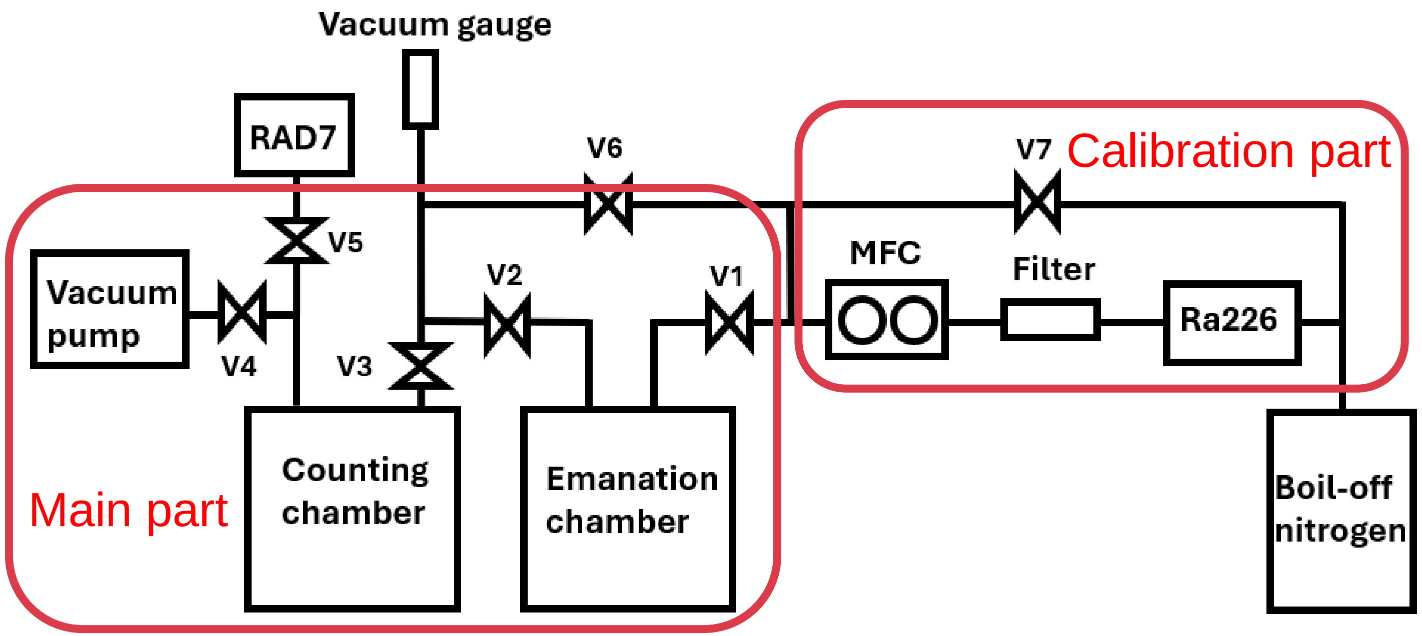



Energy spectrum

# Radon Emanation Measurement Systems

System 1: suitable for small samples

- 1/4 VCR piping system
- Chamber material: 304 stainless steel, cylinder-shaped
- Volume: 12.3L. Radius: 123.6±0.5mm
- Voltage: **-1600V**, Efficiency: **32.89±0.84% in $N_2$**
- Background: **0.03±0.01mBq**



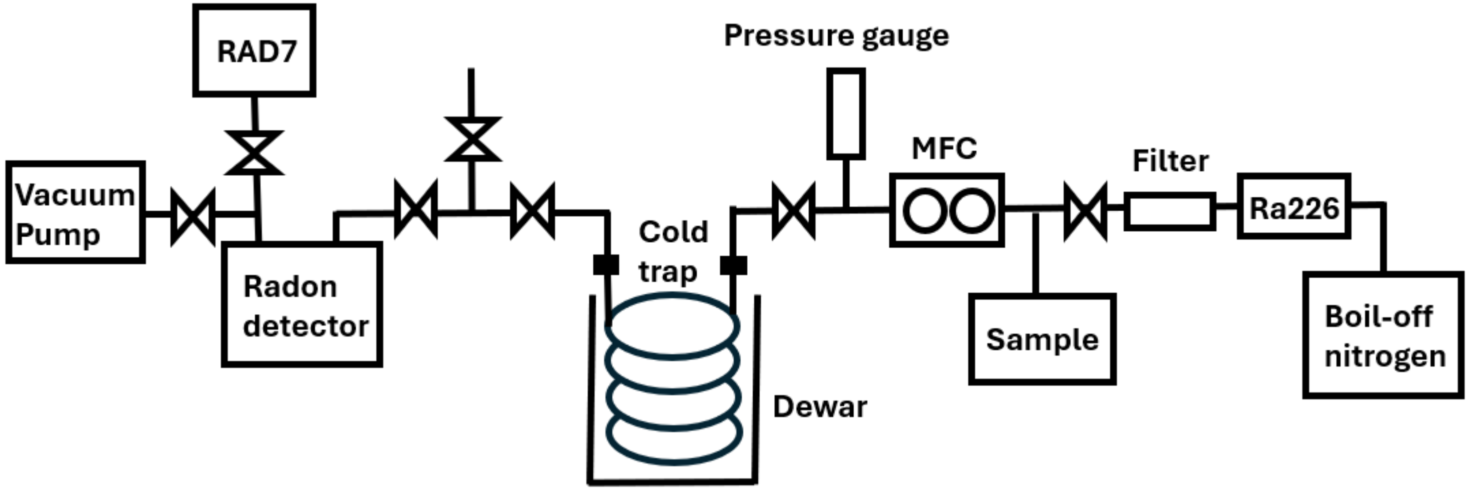

Layout

Picture of radon emanation system

# Radon Emanation Measurement Systems

System 2: suitable for large volume samples

- Trap: 3.6m spiral 1/4 metal piping
- Cooling: submerge into liquid nitrogen
- Typical trapping time: 6 hours in 1slpm
- Sensitivity boost: up to 30 times with 360L enrichment




**Radon trap system layout**

**Picture of radon trap system**

# Part 3

# Surface Treatments to Boost the Sensitivity

# Surface Treatments to Boost the Sensitivity

Different types of polishing methods were tested on the same chamber to lower the radon background.

| | 7.4 SS detector | 7.4 SS detector | 7.4 SS detector |
|---|---|---|---|
| Polishing | Electrochemical | Mirror | Mirror + electrochemical |
| Roughness [um] | 3.00 ± 0.44 | 0.12 ± 0.04 | 0.13 ± 0.03 |
| Blank [mBq/m$^2$] | 9.08 ± 0.71 | 0.48 ± 0.14 | 0.33 ± 0.10 |
| Bulk* [mBq/kg] | | 10.15±0.68 | |

*ICP-MS $^{238}$U-early chain measurement

# Surface Treatments to Boost the Sensitivity

Multiple stainless steel chambers were made to test the efficacy of polishing methods.

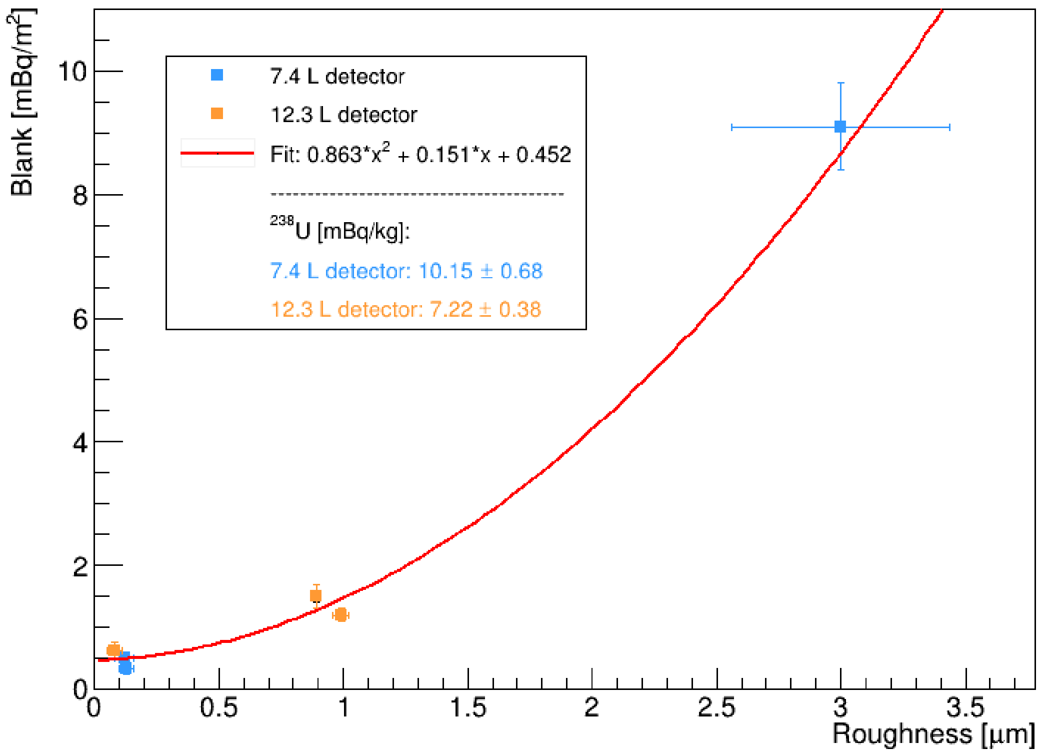
**Mirror polishing:**

•**Clean & Inspect**: Ensure the surface is clean and defect-free.

•**Sand & Smooth**: Sand down imperfections for a smooth surface.

•**Polish with Wax**: Apply polishing wax and buff to achieve a mirror finish.

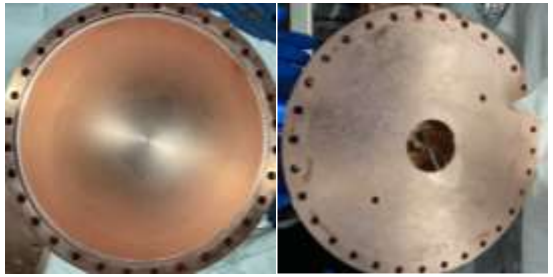
•**Ultrasonic Cleaning**: Use ultrapure water with ultrasonic cleaning for a final pristine surface.




Relationship between roughness and radon emanation, with $^{238}$U intrinsic backgrounds of the two detectors

# Surface Treatments to Boost the Sensitivity

We also tried different materials like copper with low radioactivity of $^{238}U$.


| | 4.93L semi spherical copper detector | | |
|---|---|---|---|
| Polishing | Mechanical polishing | Pickling and passivation | Manual polishing |
| Roughness [um] | - | 0.12 | 0.087±0.058 |
| Efficiency | 27.8±0.5% | | |
| Blank [mBq] | 0.54±0.09 | 0.68±0.06 | 0.32±0.04 |
| Bulk [mBq/kg] | <0.0018@90%C.L. | | |

# Surface Treatments to Boost the Sensitivity

Other surface coating methods were conducted to further deduce radon emanation

| Surface treatment | Blank [mBq/m$^2$] | Reduction factor |
|---|---|---|
| Chamber 1 (untreated) | 6.94 ± 1.25 | 89.8 ± 6.6% |
| Chamber 1 + Epoxy | 0.71 ± 0.44 | |
| Chamber 2 (untreated) | 5.04 ± 0.98 | 59.7 ± 12.2% |
| Chamber 2 + Mylar | 2.03 ± 0.47 | |

Epoxy (LOCTITE band) coating

Aluminized Mylar membrane (0.14mm)

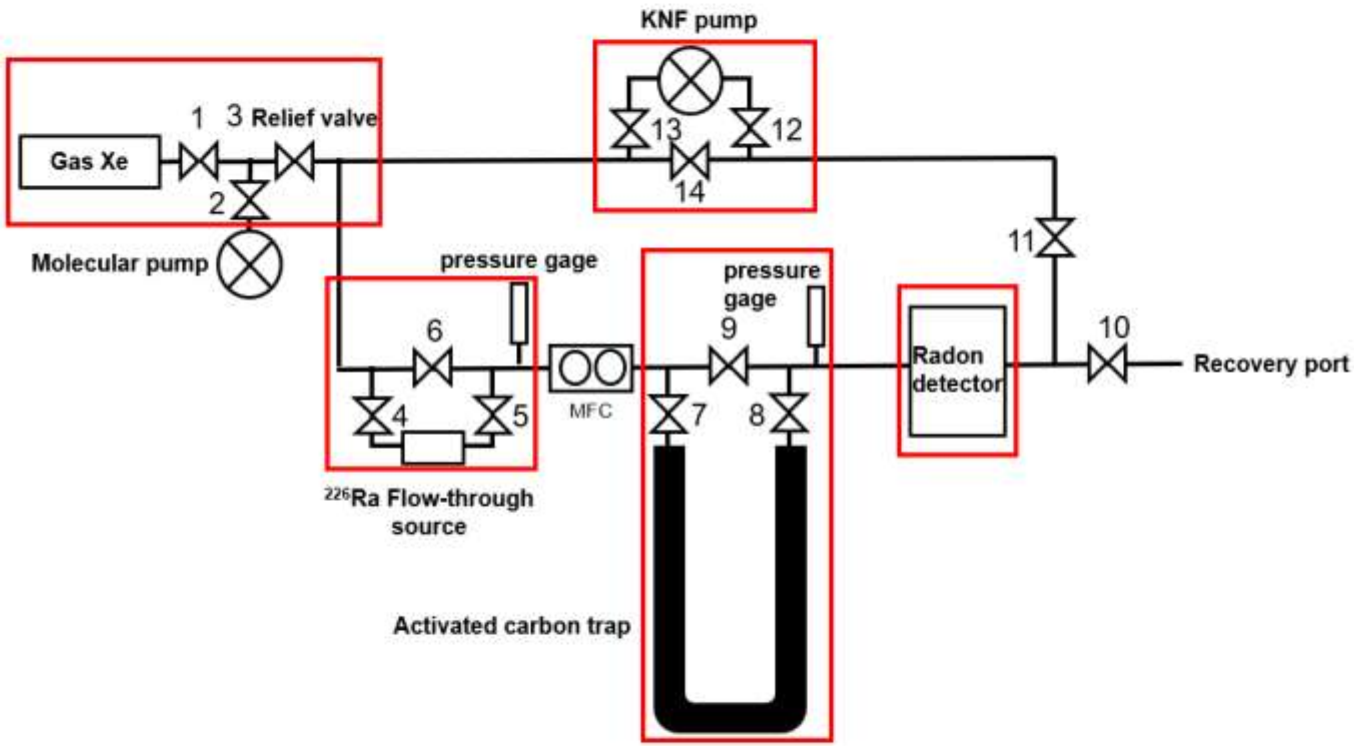
# Part 4

# Radon Removal Prototype

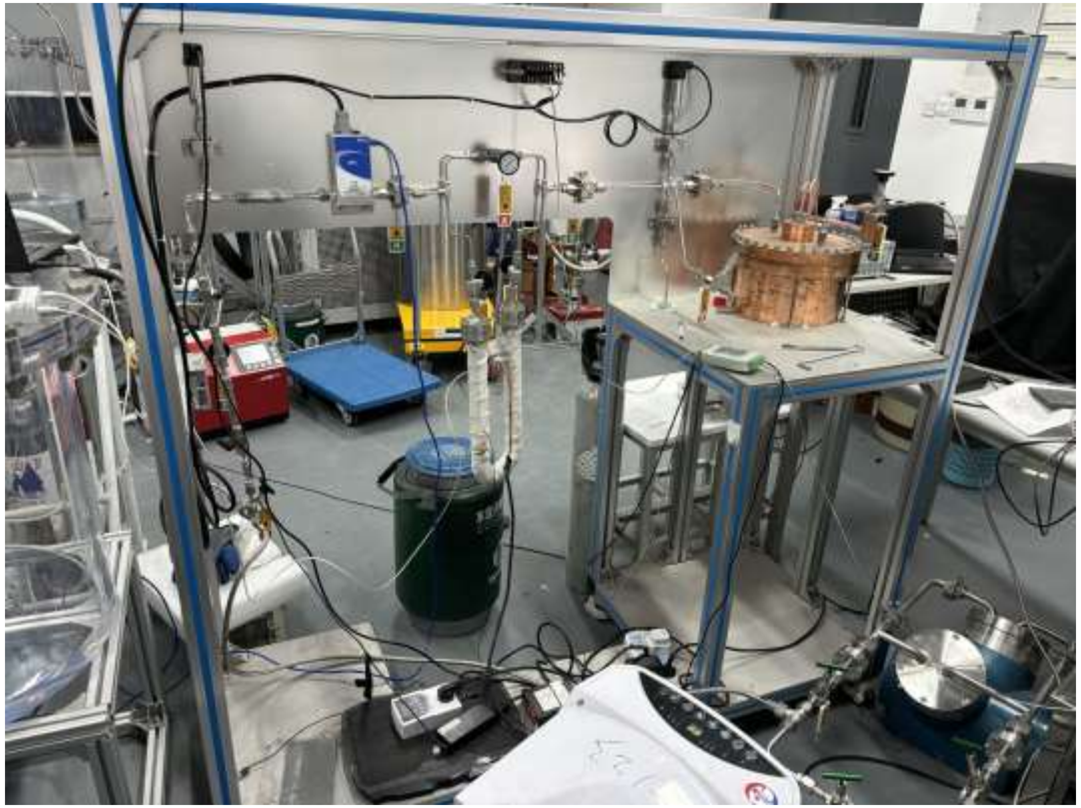
# Radon Removal Prototype

We try to use activated charcoal to remove radon in xenon environment

- 100% VCR and CF metal-seals and UHP plumbing
- 4.93L semi spherical copper detector




System layout



Real picture

# Radon Removal Prototype

Calgon activated carbon fiber

- Pore size: 1.7-2 nm
- Specific surface area: 1800-2000 $m^2/g$
- Raw materials: viscose fiber, polyacrylonitrile based, asphalt based
- Radioactivity: to be measured
- 7510cm$^2$ absorb 4.86L Xe to 1bar at 25℃
- 7510cm$^2$ absorb 31.56L Xe to 1bar at -78℃

Test results

| Flow Rate (slpm) | Temperature (°C) | High radon concentration | Low radon concentration |
|---|---|---|---|
| 1 | 25 | ↓ 94.5 ± 0.7% | Not obvious |
| | -78 | ↓ 95.0 ± 0.5% | ↓ 62.5 ± 13.4% |
| 8 | 25 | ↓ 26.3 ± 1.3% | ↓ 30.5 ± 13.7% |
| | -78 | ↓ 75.5 ± 1.8% | ↓ 56.1 ± 4.3% |

# Radon Removal Prototype

Molecular sieve
- Pore size: 3 Å
- Shape: microgranular
- From 0-1bar, it can quickly absorb 10L nitrogen per kilogram. For gas xenon, it slowly absorbed 23.5L per kilogram, lasting for 2 months

Test results

| Flow 1slpm, 200Hz Rn | Carrier gas $N_2$ | Carrier gas Xe |
|---|---|---|
| 25℃ | ↓ 50.7 ± 0.2% | Not obvious |
| -78℃ | ↓ 99.2 ± 0.1% | Not obvious |

# Summary

- We developed two radon emanation measurement systems.
- The best radon emanation blank: **0.03±0.01mBq** in 12.33L radon detector with **mirror polishing and ultrasonic cleaning**.
- Other different surface treatments like epoxy: **89.8 ± 6.6%** reduction.
- Preliminarily verified activated carbon fiber can reduce radon in gas Xe environment.
- Specifically, at **1 slpm and -78°C**, the radon level decreased by **95.0 ± 0.5%** in high-radon conditions and by **62.5 ± 13.4%** in low-radon conditions.
- These efforts will enhance the sensitivity of PandaX-4T experiment and push the boundaries of low-background experiments.