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Progress on the NvDEx high pressure vessel and gas system

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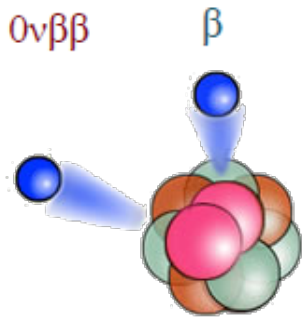
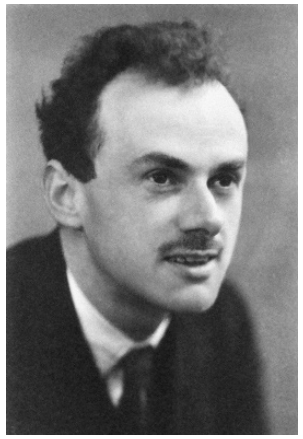
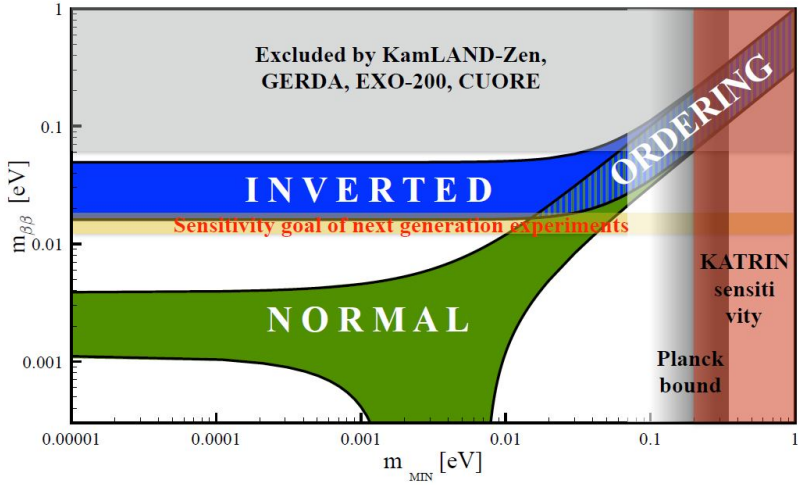
Motivation and the NνDEx concept

Motivation







Observation of 0νββ decay will be very important

- **ν is a Majorana particle ➔beyond Standard Model**
- **explain the finite but tiny ν masses**
- **constrain absolute ν mass & mass hierarchy**
- **explain matter-antimatter asymmetry in the universe via CP and lepton number violation**

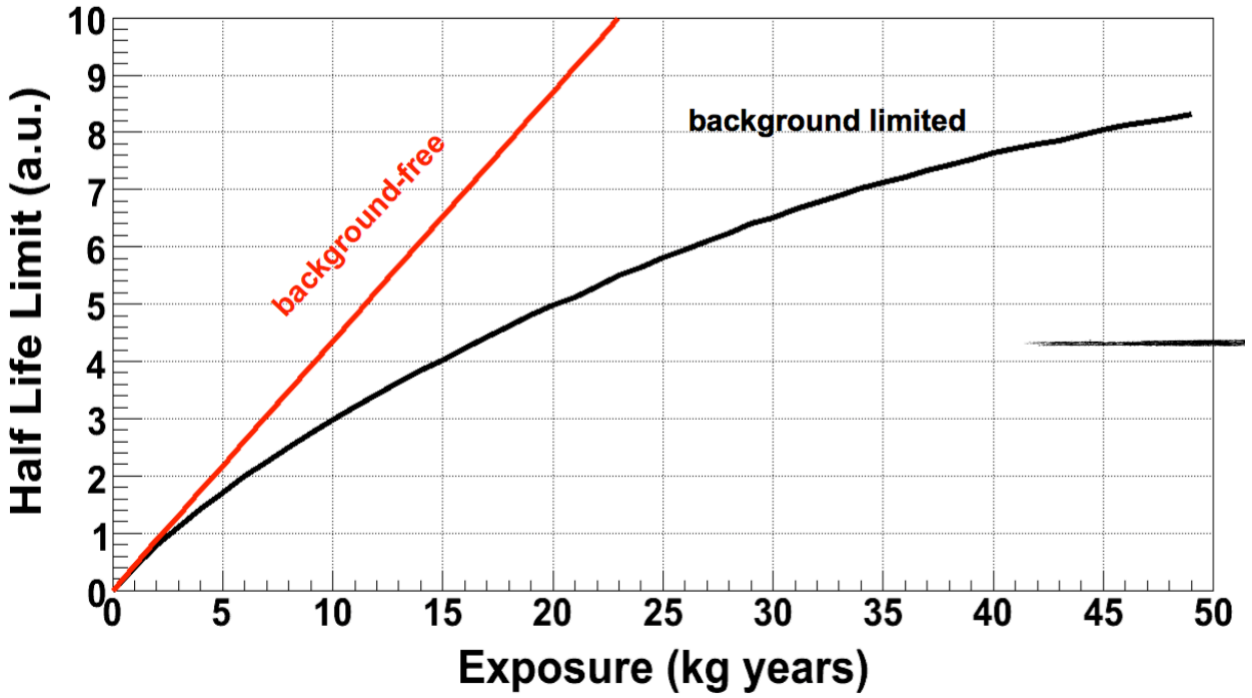
- **Inverted hierarchy: $m_{\beta\beta}$ >~10 meV, goal of next generation experiments**
- **Normal hierarchy: $m_{\beta\beta}$ >~1 meV**
- **Currently, both oscillation experimental results and physics naturalness slightly prefer normal hierarchy**

Motivation

$$\frac{1}{T_{\beta\beta}^{0\nu}} = G^{0\nu} \cdot \left|M^{0\nu}\right|^2 \cdot \langle m_{\beta\beta}\rangle^2$$

0 bkg: $$T_{1/2}^{0\nu}(\exp) = (\ln 2) N_a \frac{a}{A} \varepsilon \frac{MT}{n_{CL}}$$

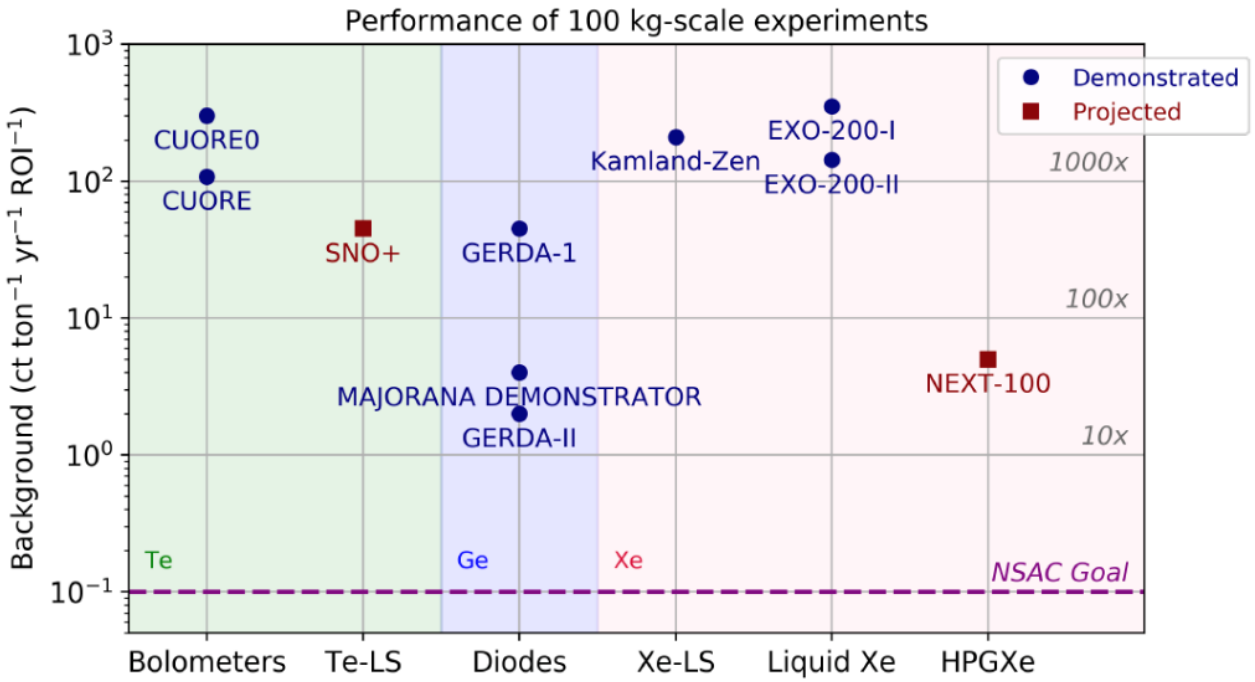
high bkg: $$T_{1/2}^{0\nu}(\exp) = (\ln 2) N_a \frac{a}{A} \varepsilon \sqrt{\frac{MT}{b\Delta E}}$$



- **Reducing bΔE is the key to increase experiment sensitivity**
- **0 background: $m_{\beta\beta}$ sensitivity $\propto (MT)^{-1/2}$**
- **High background: $m_{\beta\beta}$ sensitivity $\propto (MT)^{-1/4}$**
  - **1-t for normal hierarchy → 10k t for inverted hierarchy**
    same background level

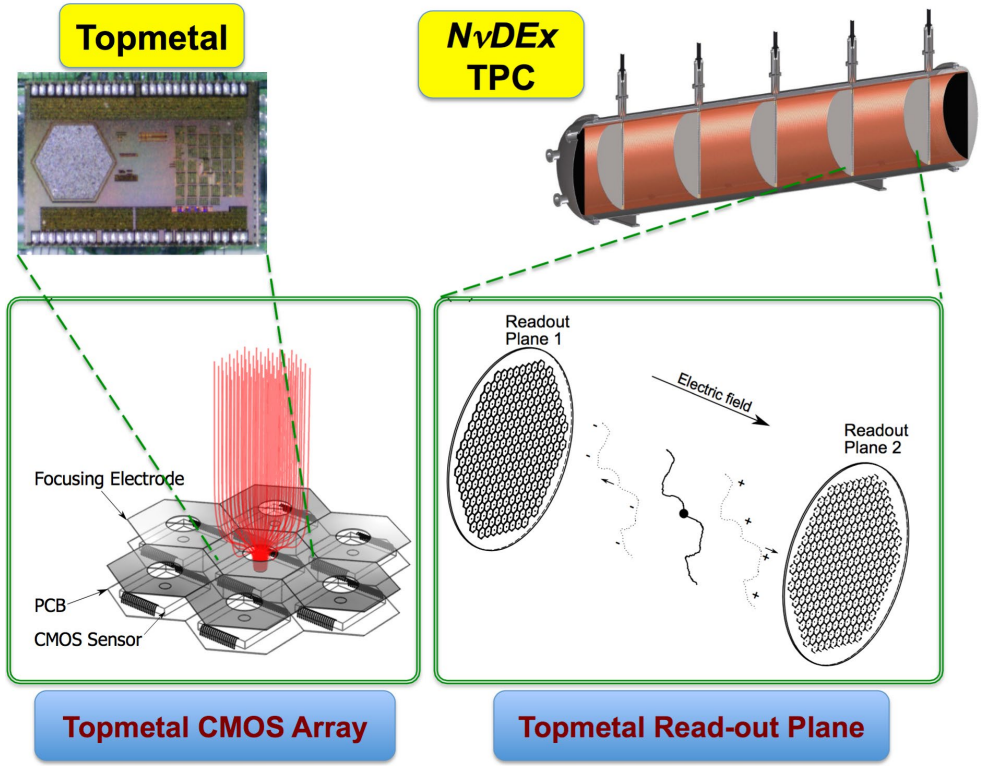
Motivation

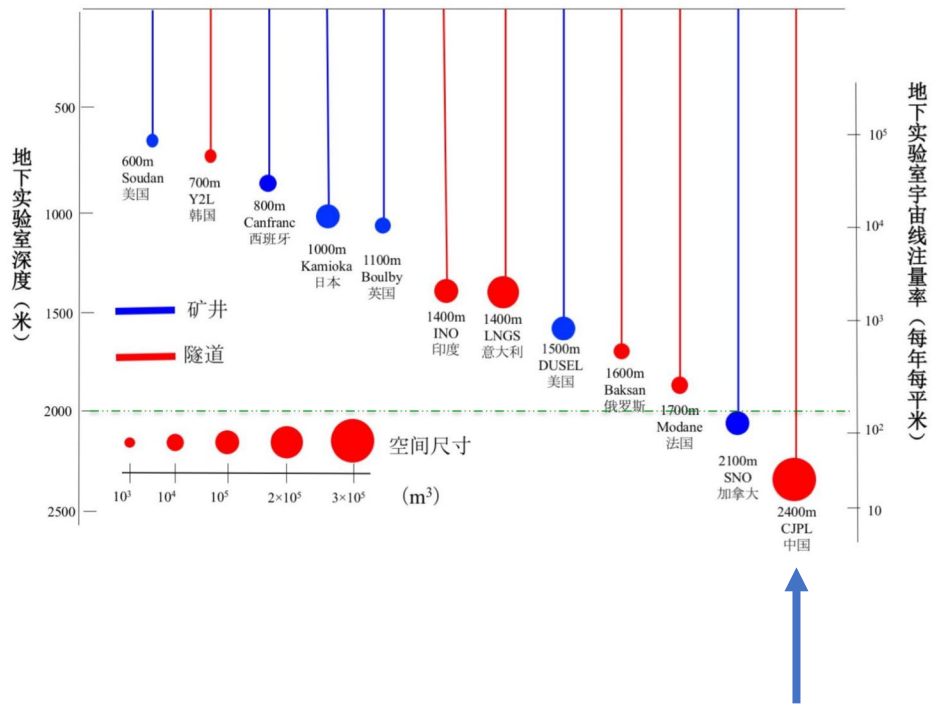
"100kg-class" experiments:

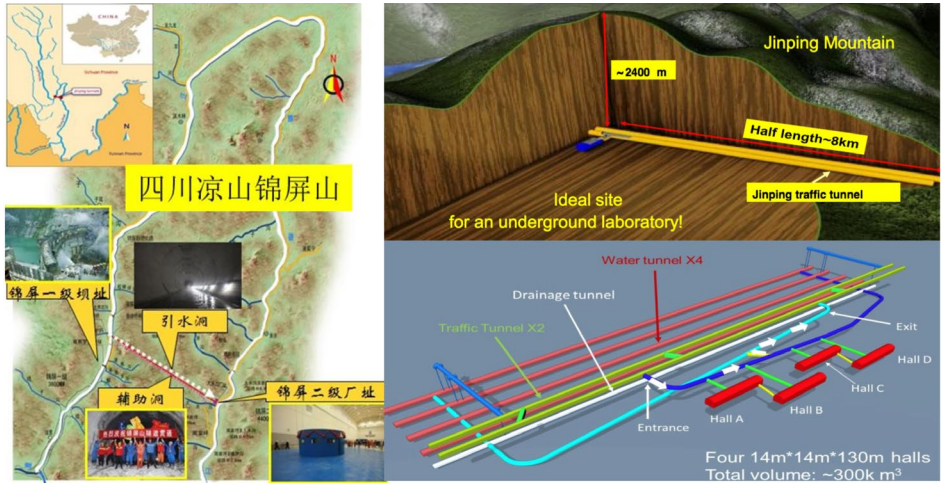


- For ~0 background experiments, $T_{1/2} \sim 10^{29}$ yr ➔ ~ several 10 ton yr exposure
- ➔ In order to use the isotopes (funding) efficiently, we need background level of $\sim< 0.1$ ct / ton yr ROI
- Most of current experiments are >= 1 order of magnitude away from this goal

NvDEx concept







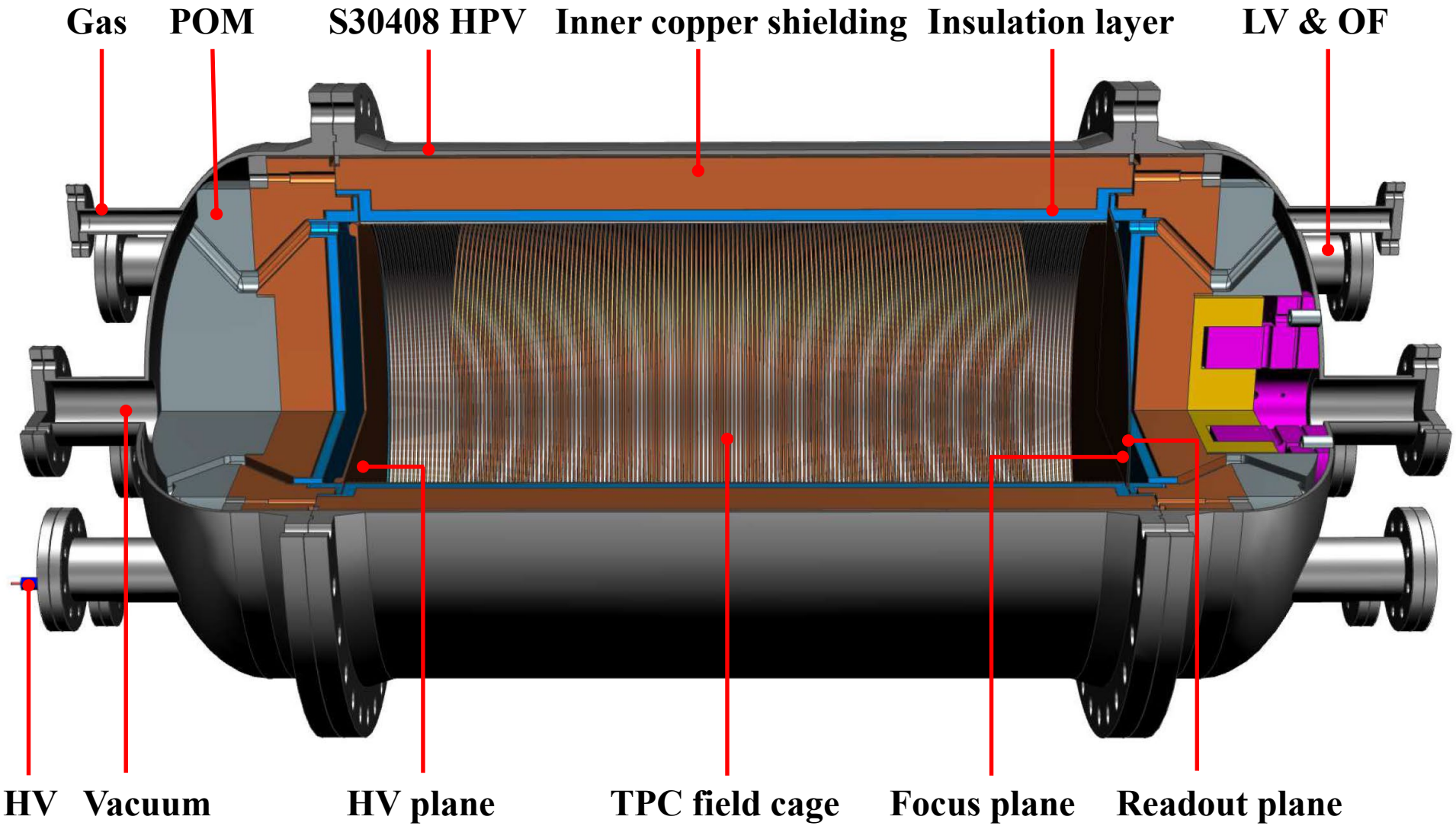
Advantages

- ✓ High Q(^{82}Se)~2.996 MeV
- ✓ High pressure TPC ($^{82}SeF_6$) ➔ good signal and background distinguish ability
- ✓ Read out with Top-metal CMOS chips，energy resolution can reach ~1%(FWHM)
- ✓ CJPL: the deepest underground laboratory

$^{82}SeF_6$ is toxic ➔ A high pressure vessel with extremely low leak rate is necessary!

D.R. Nygren, Y. Mei et al 2018 JINST 13 P03015

NvDEx concept

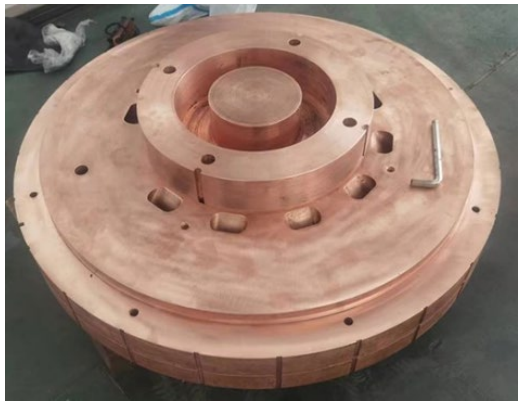


Operation pressure：<=1.5 MPa

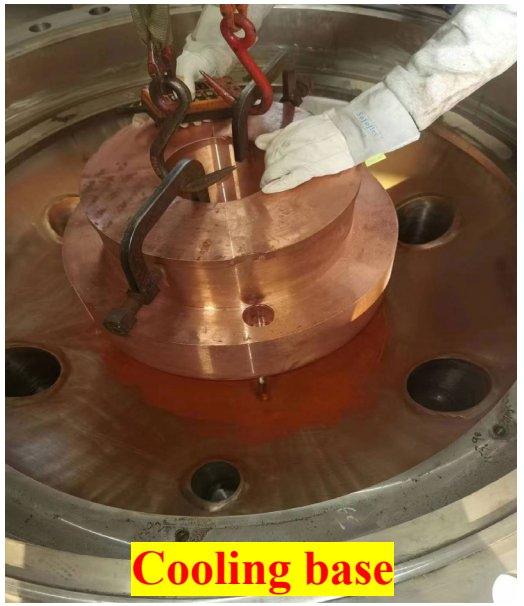
Development of the NνDEx high pressure vessel

Copper shielding, thermal conductor, cooling jacket and filler

Barrel



Cooling tube

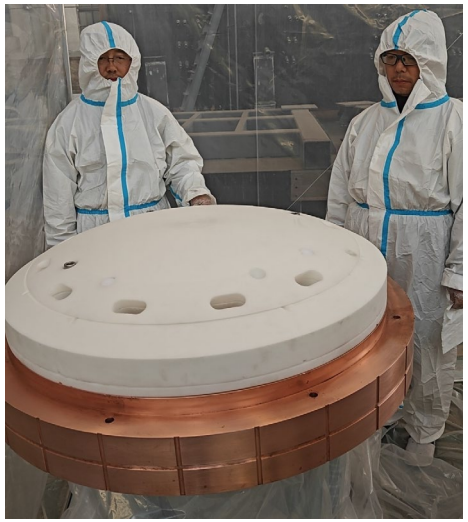


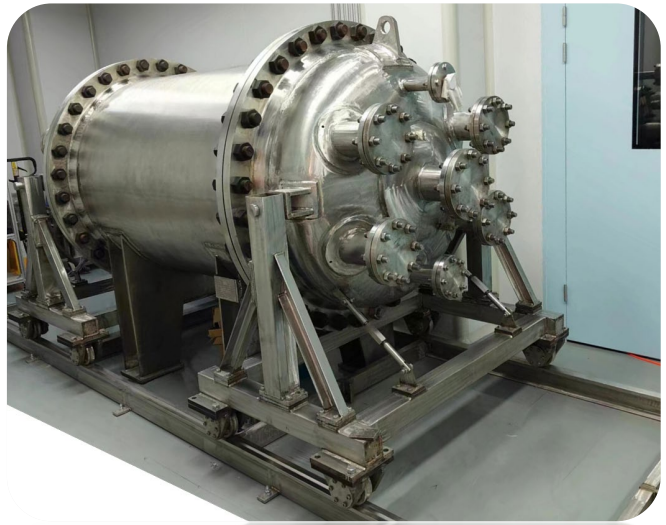
End cap

Filler (POM)

The copper shielding, thermal conductor, cooling jacket and filler have been completed.

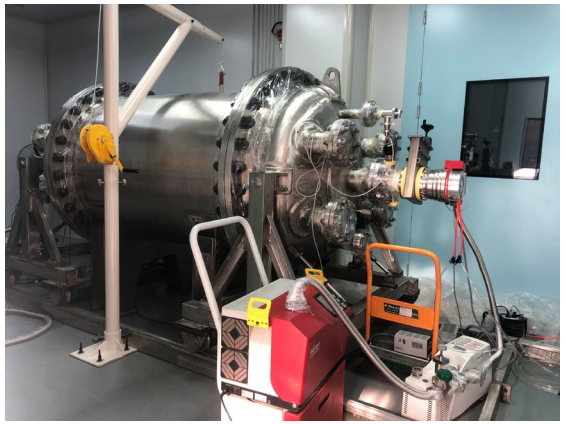
Cleaning and assembly





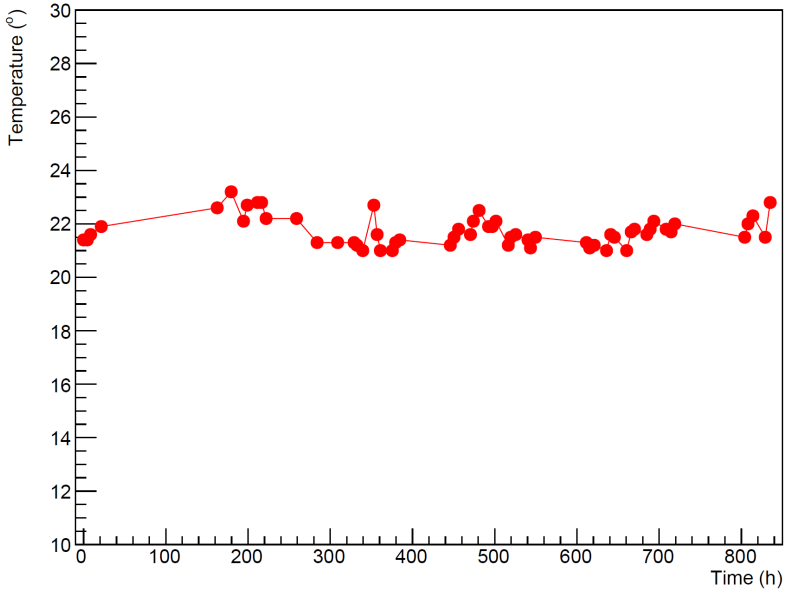
Cleaning and final assembly of the high pressure vessel have been finished.

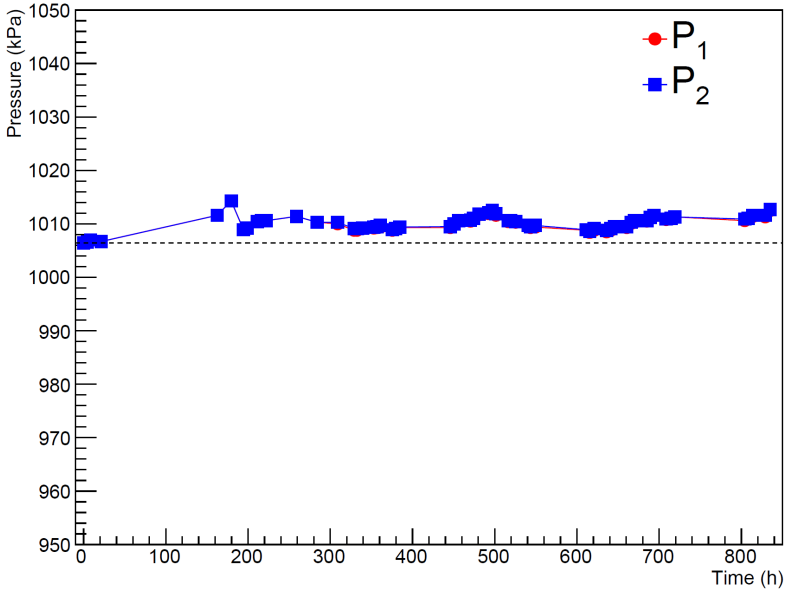
Helium hood test



The biggest challenge is the leak tightness of the DN1200 flange
After preliminary optimization, the leakage of the DN1200 flange reached about $1*10^{-11}$ mbar*l/s

Pressure hold test





After about 5 weeks pressure hold test at ~ 1 MPa, no significant leakage was observed

Gas system

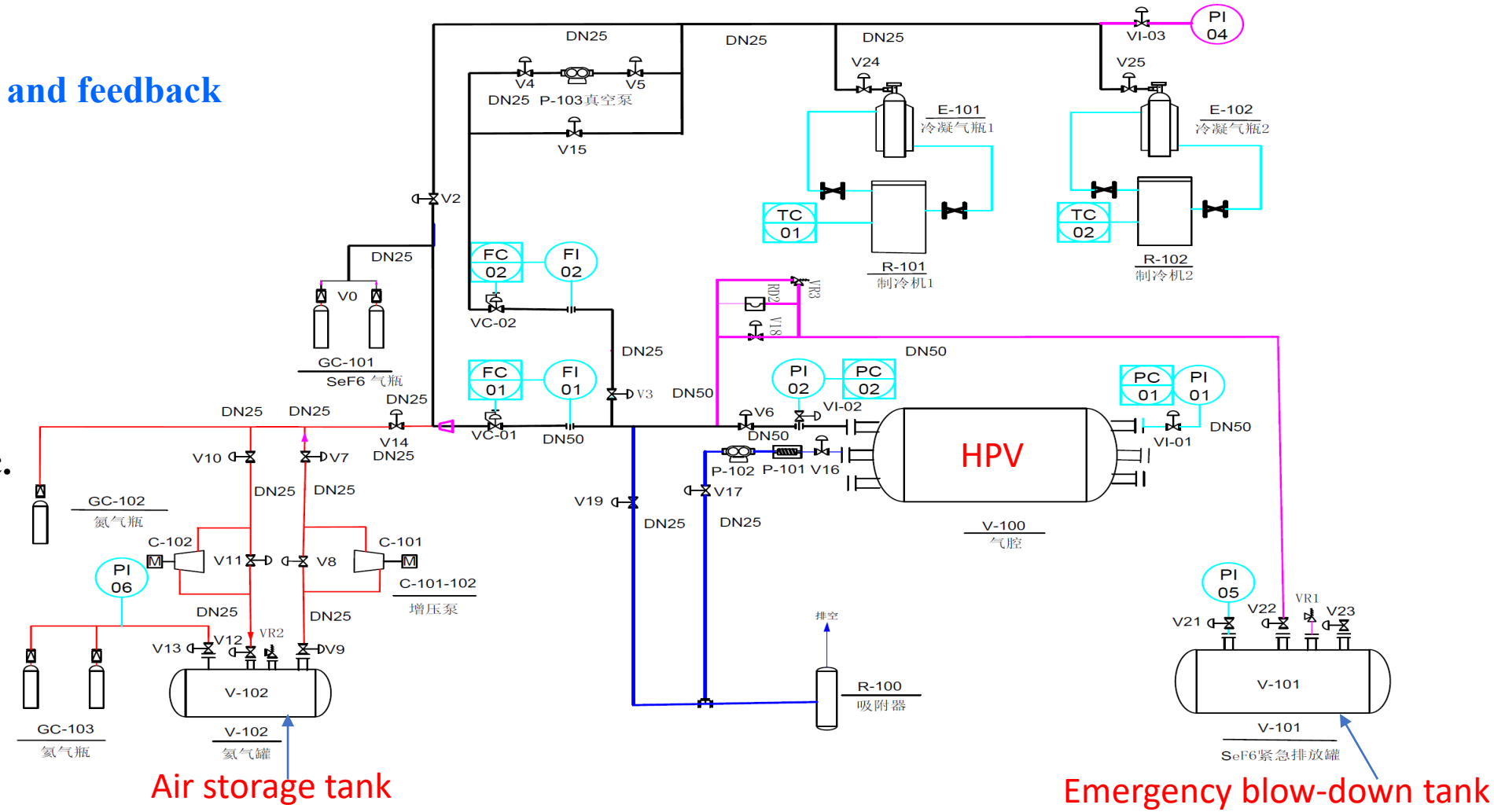
Design of the gas system

- Closed-loop control
- Real-time monitoring and feedback

Main equipment

High pressure vessel, chiller unit, condenser, air storage tank, emergency blow-down tank, vacuum pump, etc.

1. Preparation
2. Start-up
3. Shut-down
4. Start-up



Main equipment


Chillers


Condenser


Dry pump

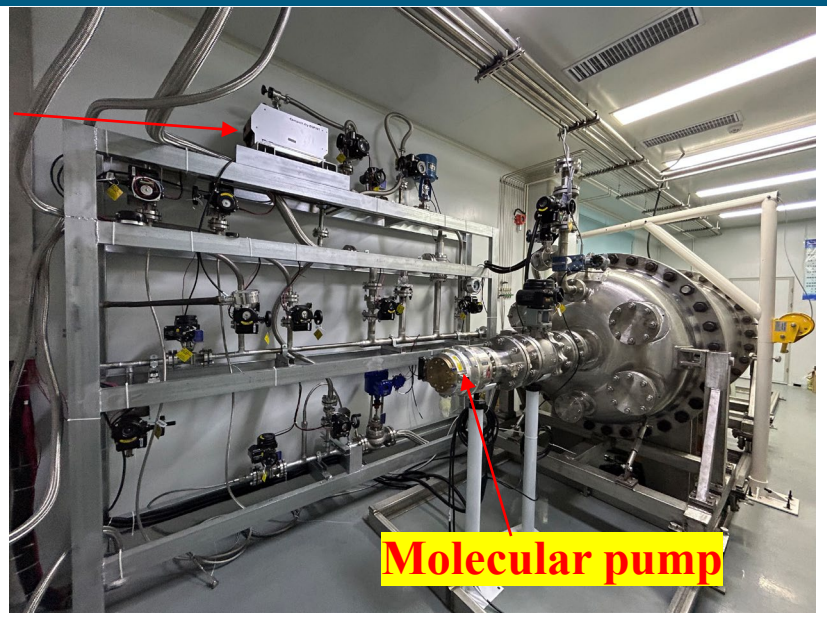

Molecular pump

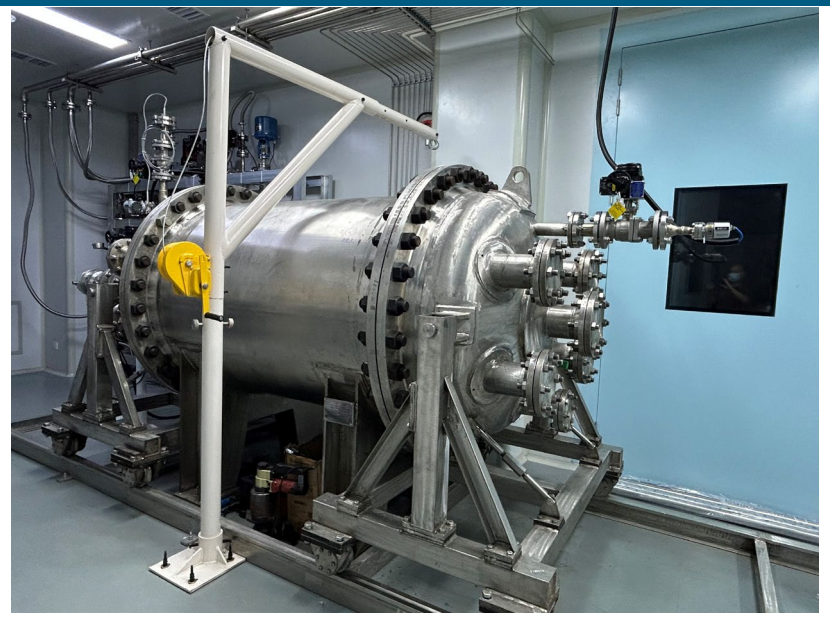

Emergency blow-down tank

Air storage tank

Pipeline processing

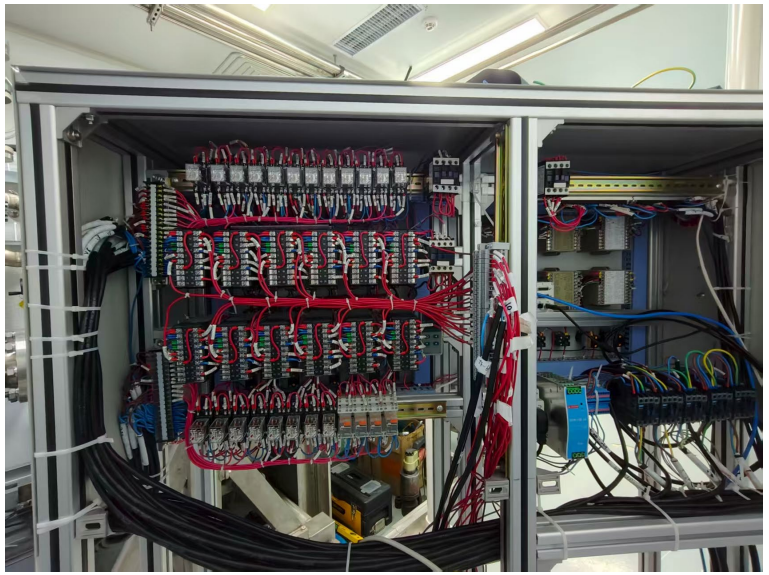
Dry pump





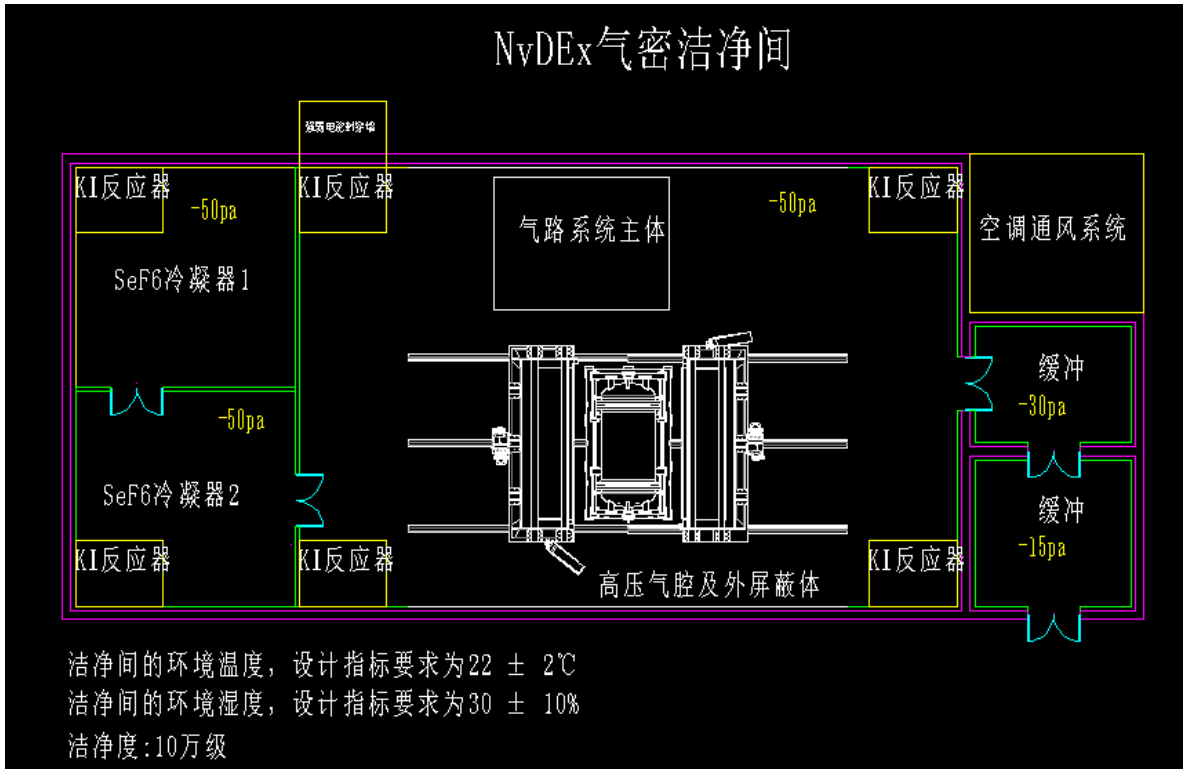
The gas pipeline is finished, and commissioning is ongoing

Remote control



The control circuit and software have been developed

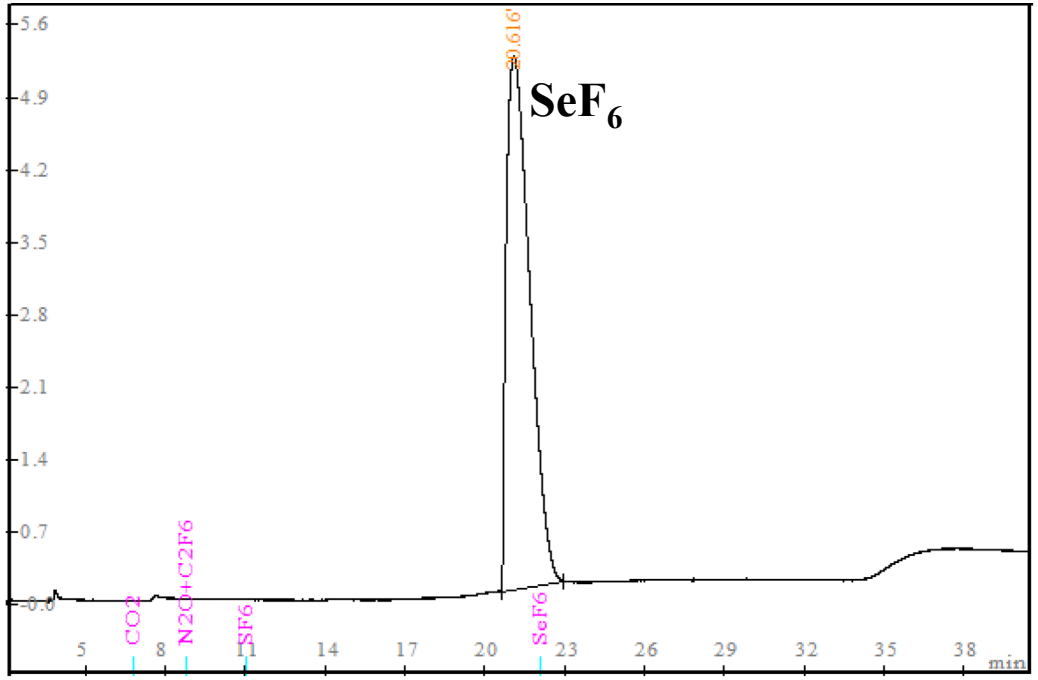
Airtight clean room



- The entire experimental set-up will be placed in an airtight clean room
- During data taking, the clean room will be kept airtight, and the whole experiment will be controlled remotely
- SeF_6 gas reactor (molten NaOH) in the room to absorb any leaked gas
- When accessing the experiment, SeF_6 will be condensed in isolated airtight rooms

Safety is the most important !!!

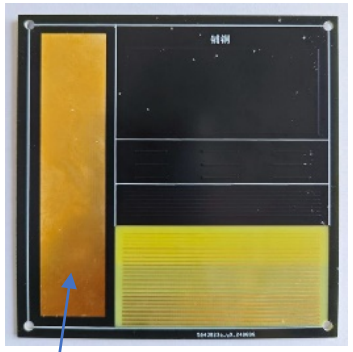
SeF_6 gas



The purity of SeF_6 after rectification is >=99.9%

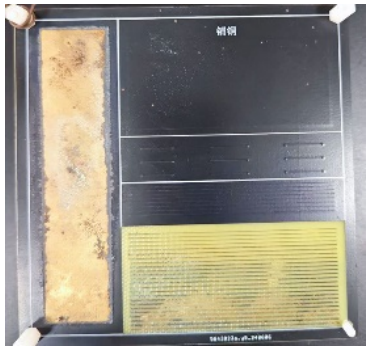
SeF6 has been produced by Shandong Zhongshan Photoelectric Materials Co., Ltd.

Corrosion test (2 weeks)



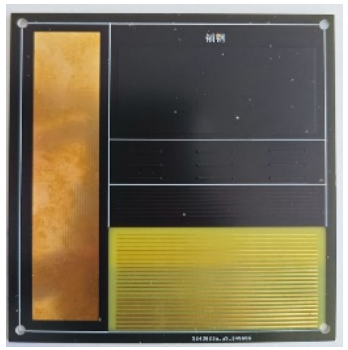
Initial state

Gold plated (1 μ)

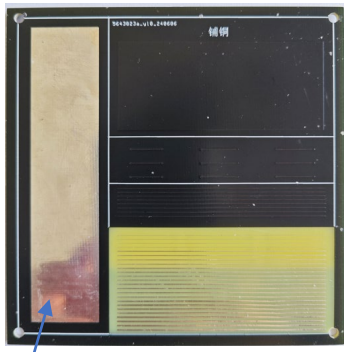


H_2O:1.2%

H_2O:0.3%

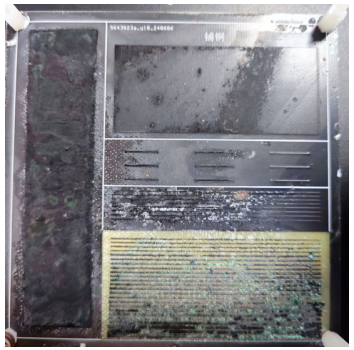


H_2O:0.01%

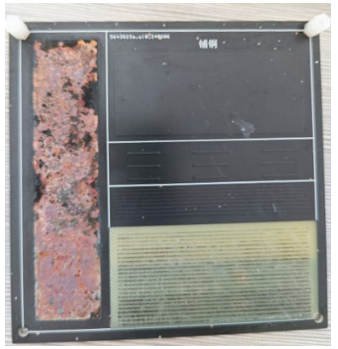


Initial state

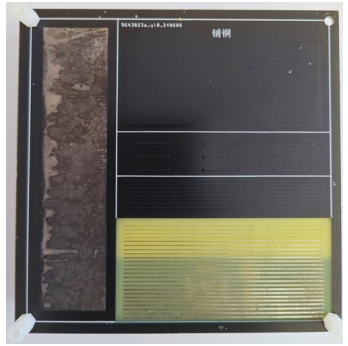
Tin



H_2O:1.2%

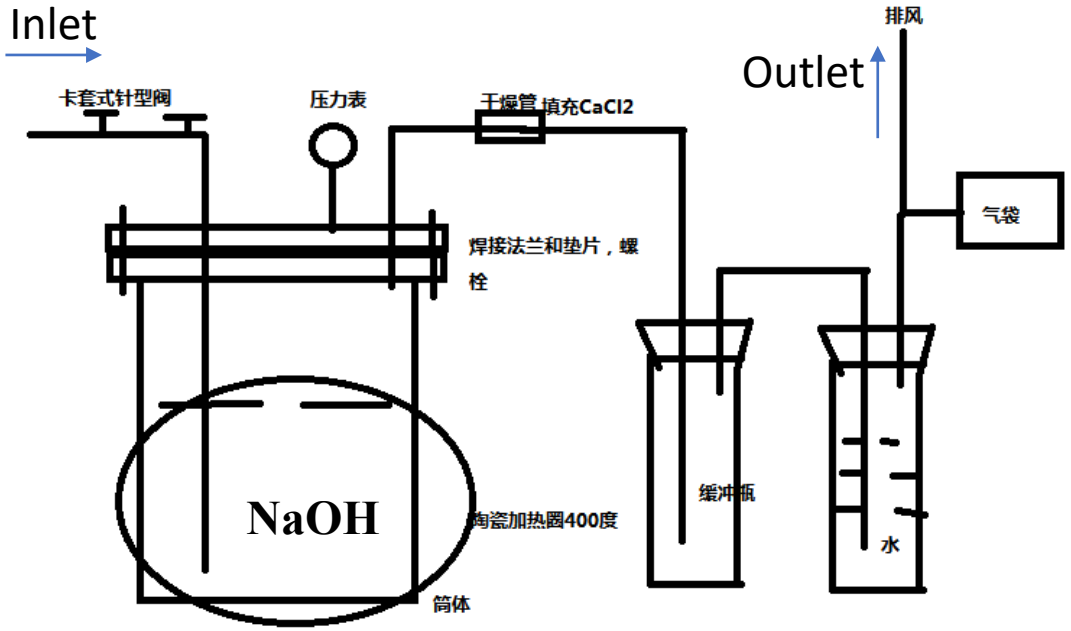


H_2O:0.3%



H_2O:0.01%

Gas absorption treatment



	Inlet concentration (SeF6)	Temperature (°C)	Inflow rate	concentration
1	1%	150	1.5 L/min	> 1ppm
2	1%	320	1.5 L/min	> 1ppm
3	1%	320	0.5 L/min	/

	Inlet concentration (SeF_6)	Temperature (°C)	Inflow rate	Outflow rate	Absorption efficiency
1	99%	100	1.5 L/min	300 mL/min	80%
2	99%	150	1.5 L/min	0 （no bubble）	100%
3	99%	320 (molten)	1.5 L/min	0 （no bubble）	100%

The SeF_6 can be absorbed with the proposed method.

Summary

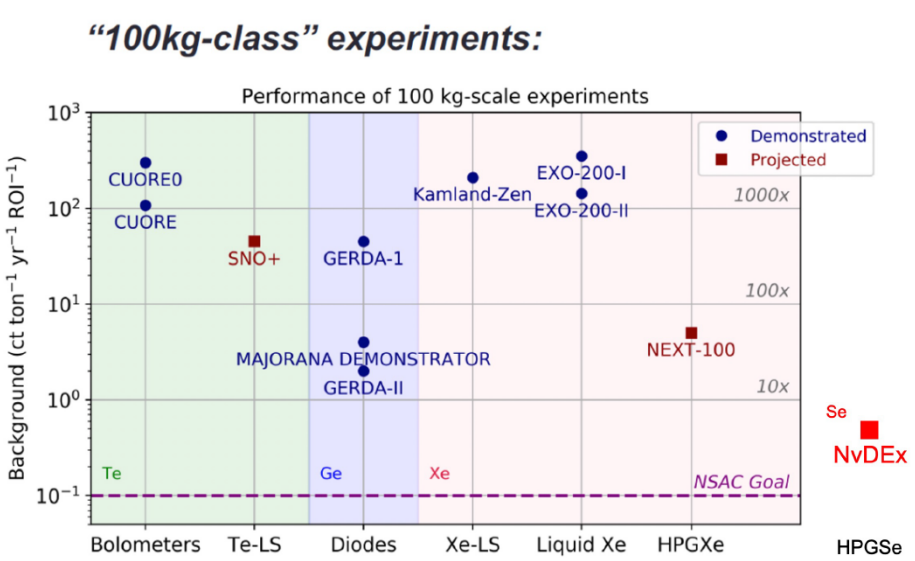
- **The NνDEx high pressure vessel, copper shielding and filler have been developed**
- **The leakage of the NνDEx high pressure vessel has been tested with different methods**
- **The gas pipeline is being built**
- **SeF_6 has been produced and used for corrosion test**
- **The proposed method for SeF_6 absorption treatment is feasible**

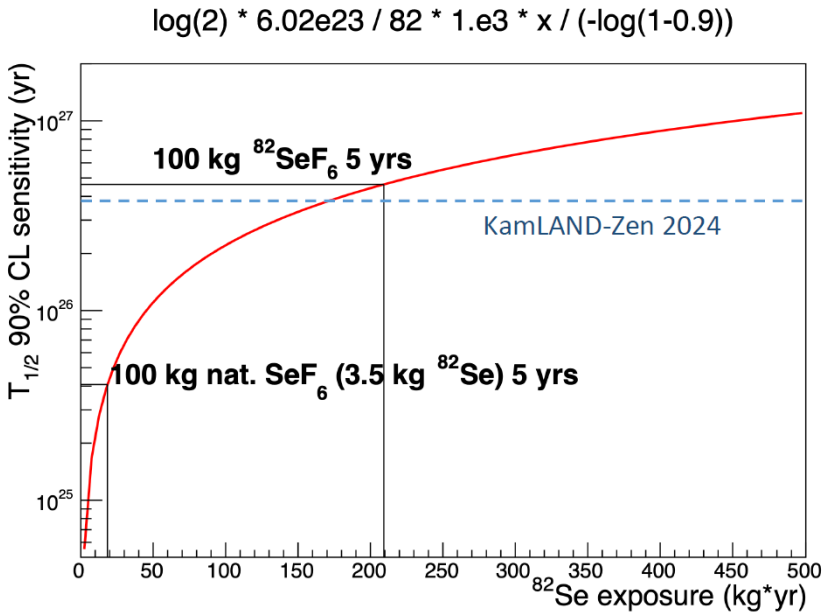
Future plan

- **Optimize the sealing of the high pressure vessel and gas system**
- **Integrated commissioning of the high pressure vessel and the gas system in the ground laboratory at Lanzhou**
- **System assembly and commission, begin taking data (using SF6 gas, w/o airtight cleanroom) (2027)**

Thank you for your attention!

Background & sensitivity estimations





- ~<0.05 counts / year in ROI ⇒ ~0.5 cts / (ton yr ROI)
  - Below the world's major existing experiments
- $T_{1/2} > 4 \times 10^{26}$ yr at 90% CL with 100 kg $^{82}SeF_6$ 5 yrs, better than the current world record - KamLAND-Zen