Development of Hermetic Liquid Xenon Detector for the DARWIN Experiment

Ryuta Miyata （Nagoya University, ISEE）

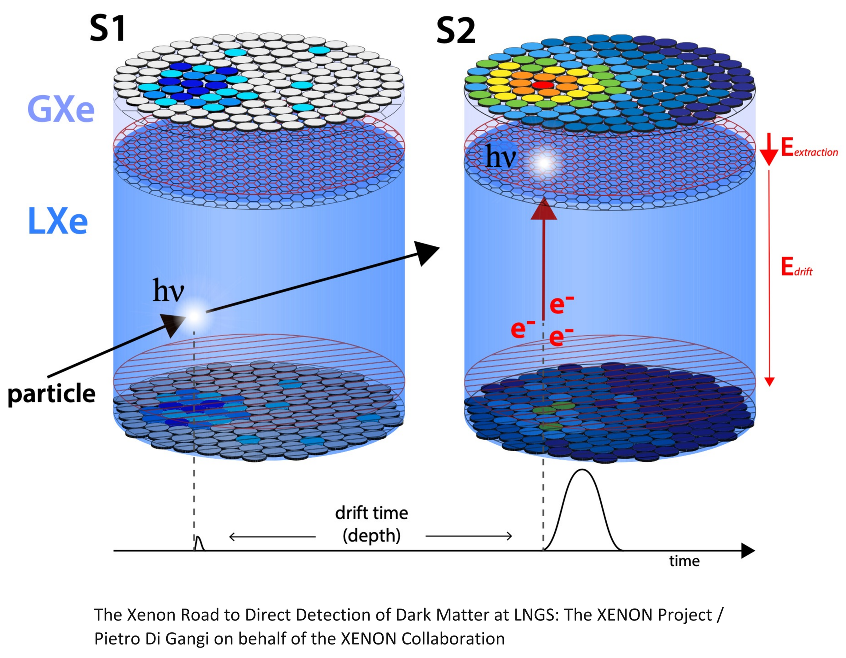
Abstract

The DARWIN experiment is a future direct dark matter search with 50 tons of LXe. For the DARWIN experiment, it is necessary to reduce the ^{222}Rn concentration in the detector to 10% of XENONnT to reduce the ^{222}Rn background. To achieve this ^{222}Rn concentration, hermetic xenon detector, which seals the center of LXe volume with high purity quartz and prevents contamination of ^{222}Rn emanating from other detector components, has been proposed.

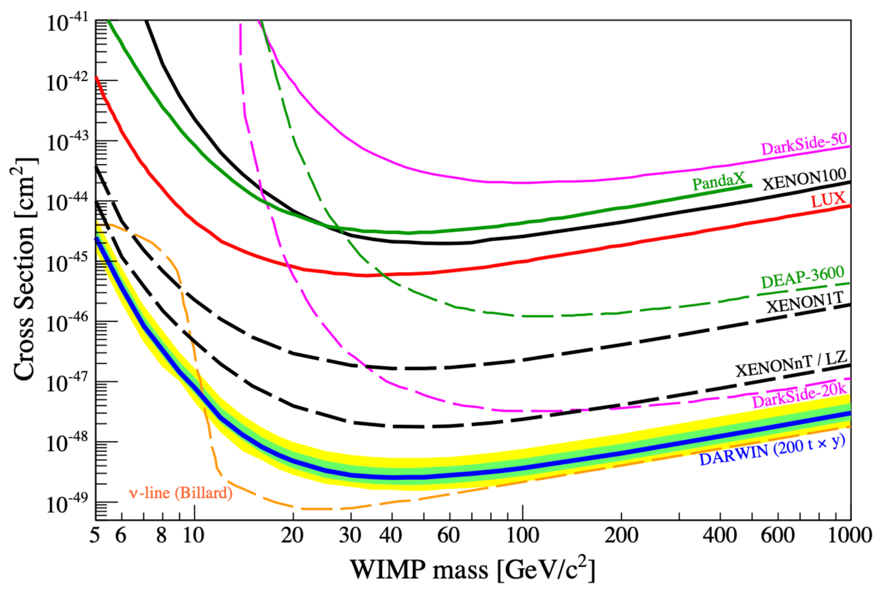
In this poster presentation, I will report on the development of the hermetic chamber made of quartz and PTFE, and the development of separated circulation systems for inside and outside the hermetic chamber to evaluate its sealing performance.

1. DARWIN experiment

- DARWIN : A future direct dark matter(DM) search after XENONnT or LZ with 50 ton liquid xenon(LXe).
- By detecting both the primary scintillation light (S1) and the electroluminescence scintillation light (S2) produced from the drifting electrons, WIMPs/BG events can be reconstructed.



The Xenon Road to Direct Detection of Dark Matter at LNGS: The XENON Project / Pietro Di Gangi on behalf of the XENON Collaboration



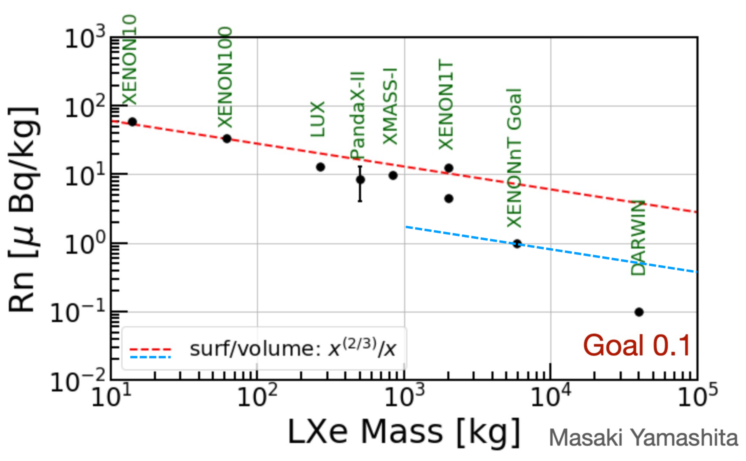
DARWIN: towards the ultimate dark matter detector / DARWIN collaboration

- Our main goal is to search WIMPs down to the neutrino fog, which is a region made difficult to explore by the neutrino background(BG).
- the major background to achieve this sensitivity is radon-induced one.

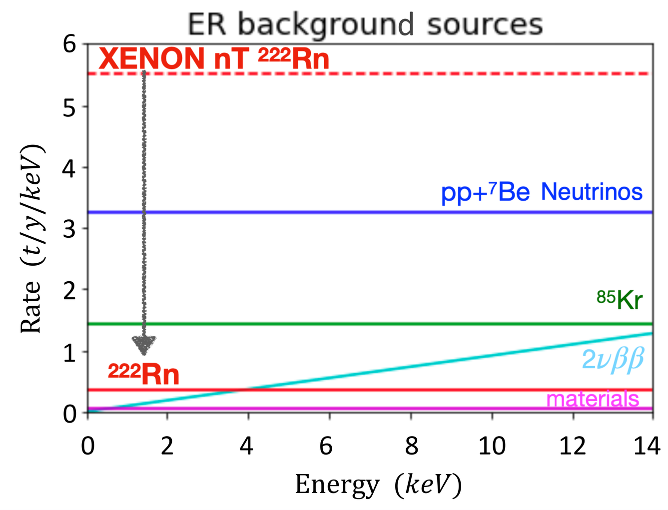
2. ^{222}Rn-induced BG

- The β decay of ^{214}Pb, the daughter of ^{222}Rn, causes electronic recoil background.
- ^{222}Rn emanates from the detector components(PMT cable, cryostat, etc.).
- β-rays is distinguished from DM by the S1/S2 ratio, however, it is not possible to identify β-rays completely. (In the DARWIN experiment, the probability of distinguishing them is expected to be 99.9%.)
- In the DARWIN experiment, **the ^{222}Rn concentration in LXe need to be reduced to 10% of that in the XENONnT experiment.**
- In XENONnT, ^{222}Rn-induced BG was reduced by xenon purification system, but we need a new way to further reduce the ^{222}Rn concentration to achieve our goal.

^{222}Rn concentration in various direct DM search



ER background sources



3. Hermetic liquid xenon detector

Conventional xenon detector

^{222}Rn emanates from detector components (stainless steel vessel, PMT cables, etc.), and it contaminates the sensitive volume.

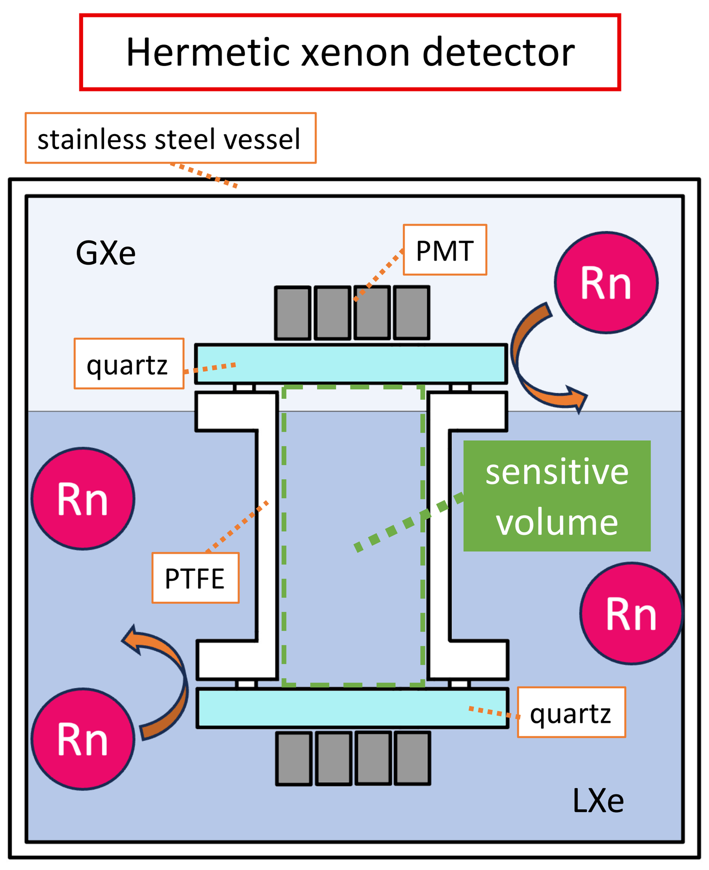
Hermetic xenon detector

Seal the sensitive volume to prevent ^{222}Rn contamination.

< Requirements >

- Achieve ^{222}Rn concentration inside the hermetic detector to 1% of the outside.
- The top and bottom flanges must be transparent to xenon scintillation light (175 nm).
- The material must be low radioactive.

↳ **Material: Quartz and PTFE (already used for PMT windows and reflective materials in XENONnT)**



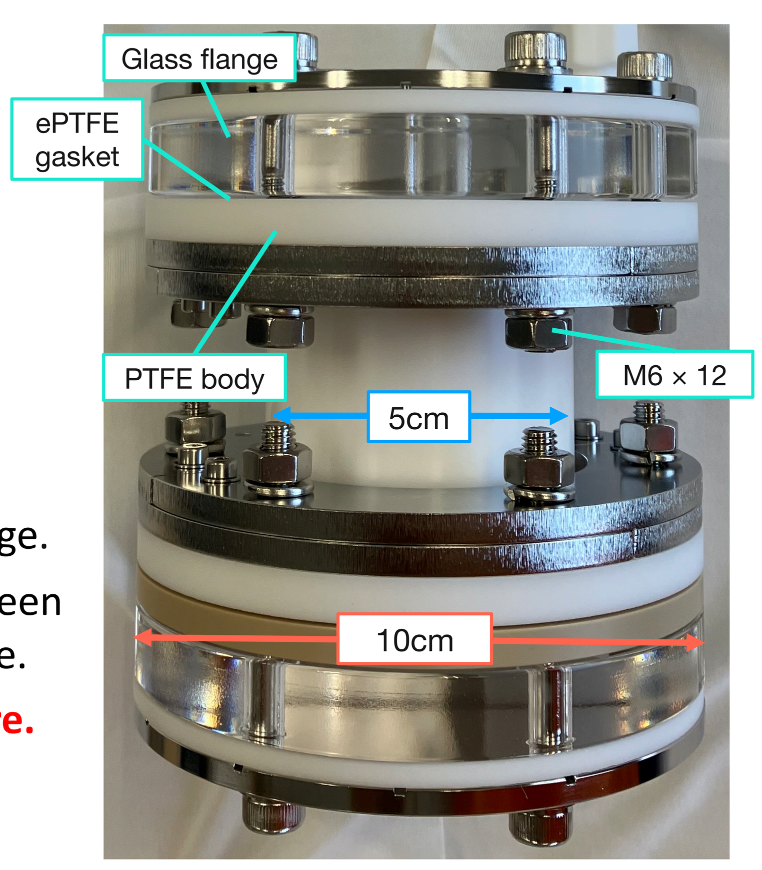
4. Development of a hermetic chamber

< Key points in development >

- To prevent the quartz from breaking, I need to tighten the flange with as little force as possible.
- Gasket material has to be softer than quartz and PTFE, and available at low temperatures(≈-100°C) plus high pressure(≈2atm). Expanded PTFE(ePTFE) fits these ctiterion.

< Road map >

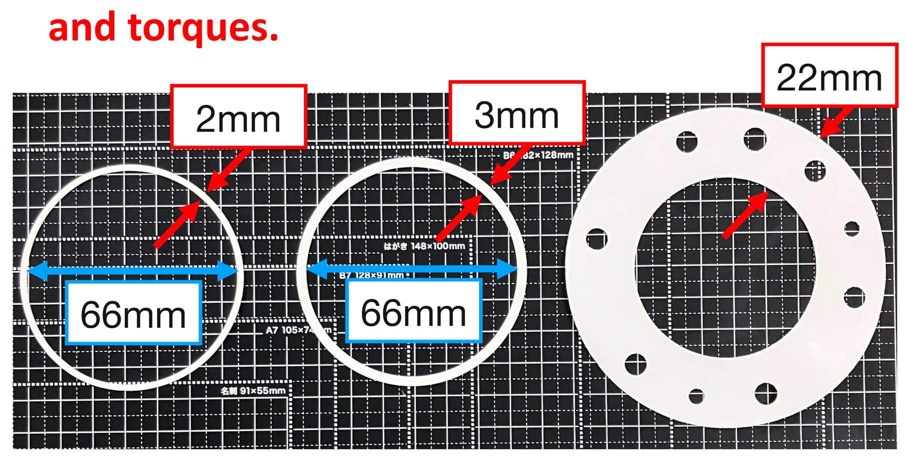
1. **Design the hermetic detector** with 10cm diameter flange.
2. **Optimize gaskets** and investigate the relationship between the torque applied to the bolts and sealing performance.
3. **Evaluate the sealing performance at room temperature.**
4. **Evaluate the sealing performance in gaseous xenon(GXe)/LXe**



5. Optimization of gasket

< Optimization of gasket >

- In general, the greater the surface pressure applied to the gasket, the better the sealing is.
- Based on our experiences, however, the quartz is likely to break around $7.5(N \cdot m)$ of torque.
- **Using He leak detector, I tested the sealing performance with multiple shapes of gaskets and torques.**



← multiple shapes of gaskets

I tested with gaskets of 2 mm and 3 mm widths.

< Estimation of ^{222}Rn concentration at DARWIN scale >

- Based on the result of the test, I estimated the ^{222}Rn concentration in DARWIN.
  - Assumption 1 : the leak rate depends only on the difference of partial pressure.
  - Assumption 2 : the ^{222}Rn concentration in GXe outside the hermetic chamber is $10(\mu Bq/kg)$.
- Under these assumptions, ^{222}Rn concentration inside the hermetic chamber in DARWIN($C_{Rn-inside}$) follows

$$C_{Rn-inside} = F_{He} \times \frac{C_{Rn-outside}}{C_{He-air}} \times R \times \frac{1}{M} \times \tau$$

F_{He} : He leak rate

$C_{Rn-outside}$: ^{222}Rn concentration in GXe outside the hermetic chamber in DARWIN

C_{He-air} : He concentration in the air

R : Ratio of the diameter of this hermetic chamber and the hermetic chamber in DARWIN

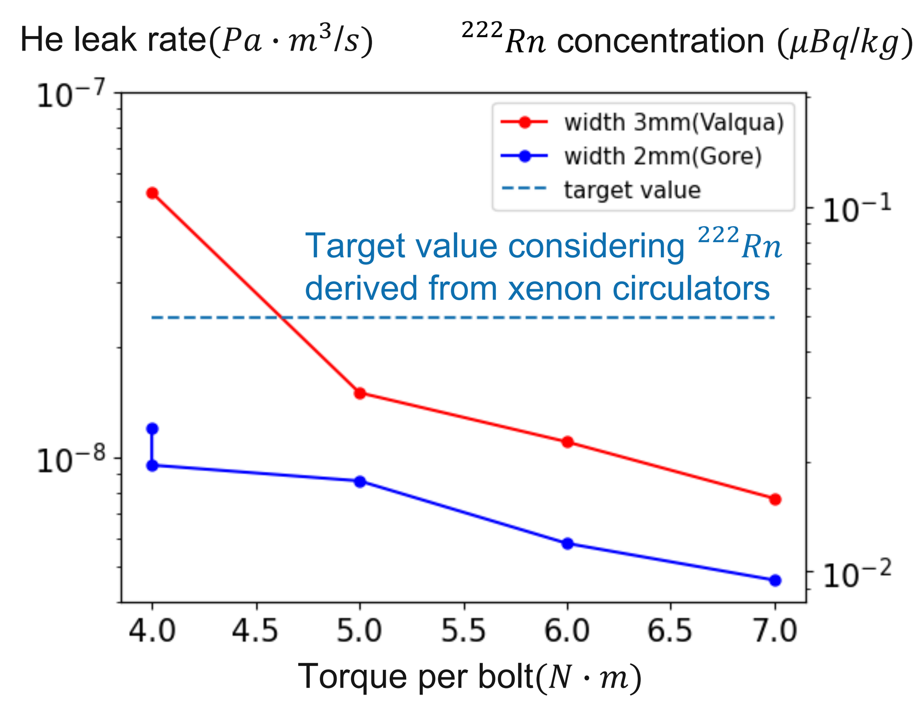
M : Xenon mass in the sensitive volume

τ : ^{222}Rn lifetime

< Results >

- Leak rates decreased as the torque applied to bolts was increased.
- **We achieved the target leak rate at room temperature. 2 mm wide gasket is better** than 3mm.
- I also measured the leak rate periodically for 34 days at $7(N \cdot m)$ and confirmed that **the leak rate remained constant.**

→ **The next step is test in GXe/LXe.**

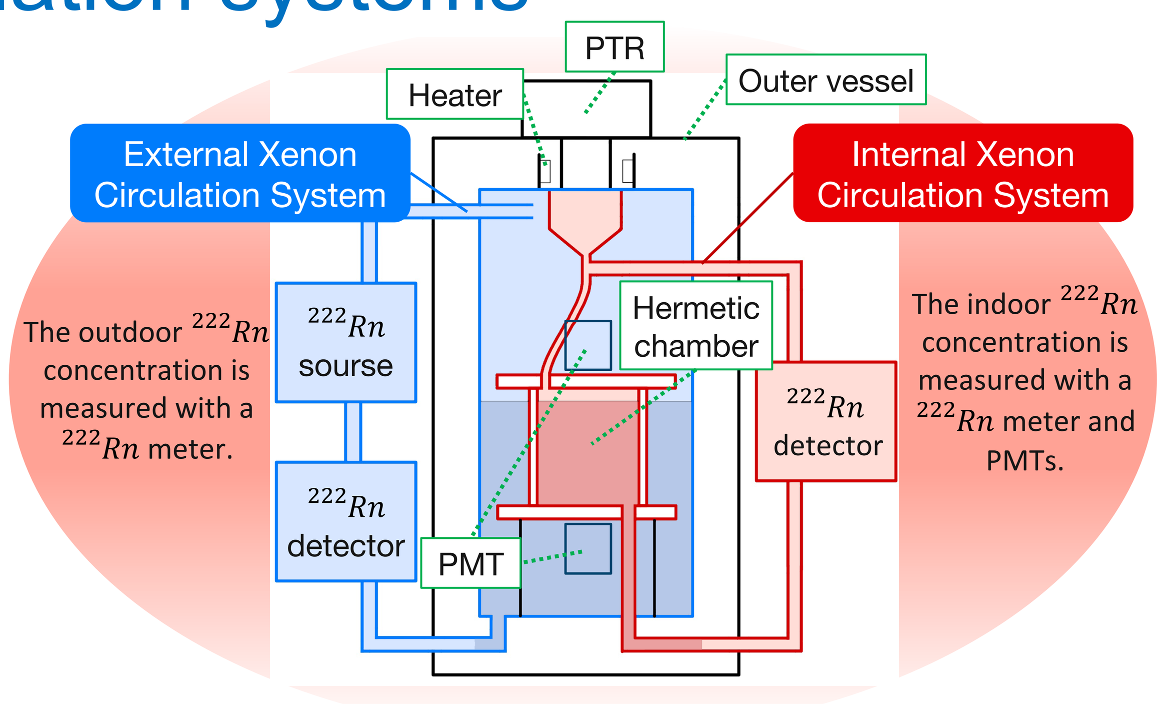


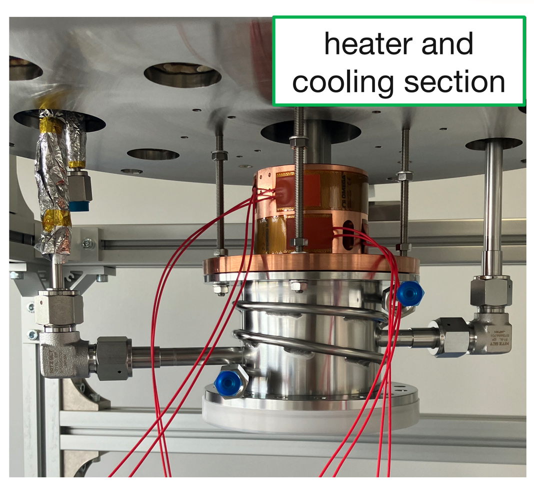
Left axis: He leak rate measured

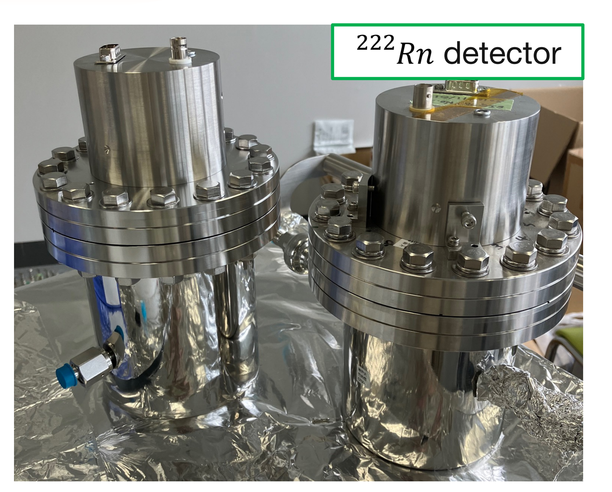
Right axis: corresponding ^{222}Rn concentration

6. Xenon circulation systems

- **Two circulation systems** separated for inside and outside the hermetic chamber is required to evaluate sealing performance in GXe/LXe.
- Inject ^{222}Rn source outside the hermetic chamber, and compare the concentration inside and outside.







7. Conclusion

- For the DARWIN experiment, the ^{222}Rn concentration needs to be reduced to 10% of that of the XENONnT experiment. **We are proposing the technique of hermetic detector.**
- I developed a hermetic chamber with a PTFE body and optimized the width of gaskets. **I achieved the target leak rate at room temperature.**
- Now, I'm preparing separated circulation systems for inside and outside the hermetic detector to evaluate sealing performance in GXe/LXe.