Recent Status of CENNS-1ton Detector for Coherent Elastic Neutrino-Nucleus Scattering Experiment

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COHERENT Collaboration

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Duke University
TUNL Triangle Universities Nuclear Laboratory
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Laurentian University Université Laurentienne
岡山大学 Okayama University
NC State University
The University of Tennessee Knoxville
NC Central University
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SLAC National Accelerator Laboratory
Virginia Tech
Washington & Jefferson College
Florida State University 1851
MEPhI
NSF
National Nuclear Security Administration
NRF National Research Foundation of Korea

Coherent Elastic Neutrino Nucleus Scattering (CEvNS)

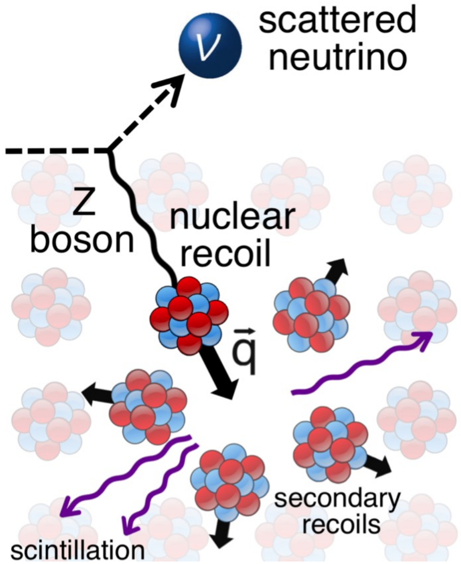
- CEvNS theorized in 1974
- First observed CEvNS using CsI[Na] in 2017 [Akimov et al., Science 357, 1123–1126 (2017)]
- Neutrino interacts with a whole nucleus when QR < 1
- Precise cross section for spoin-0 nuclei within the Standard Model

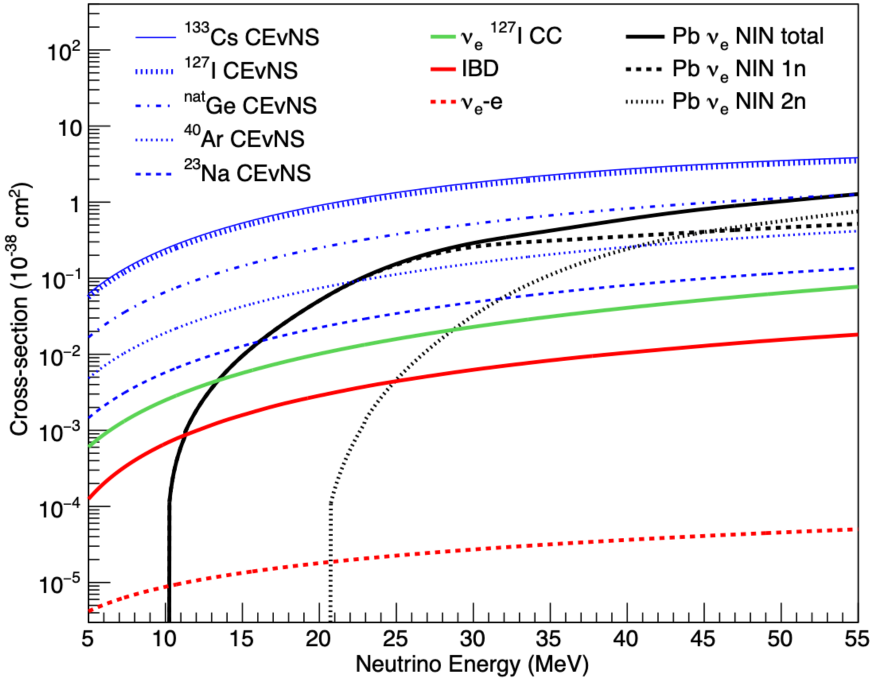
$$\frac{d\sigma}{dT} = \frac{G_F^2 M}{2\pi}\left(2 - \frac{2T}{E_\nu} + \frac{T^2}{E_\nu^2} - \frac{MT}{E_\nu^2}\right)\frac{Q_W^2}{4}F^2(Q^2)$$

M: Nucleus mass, T: recoil energy

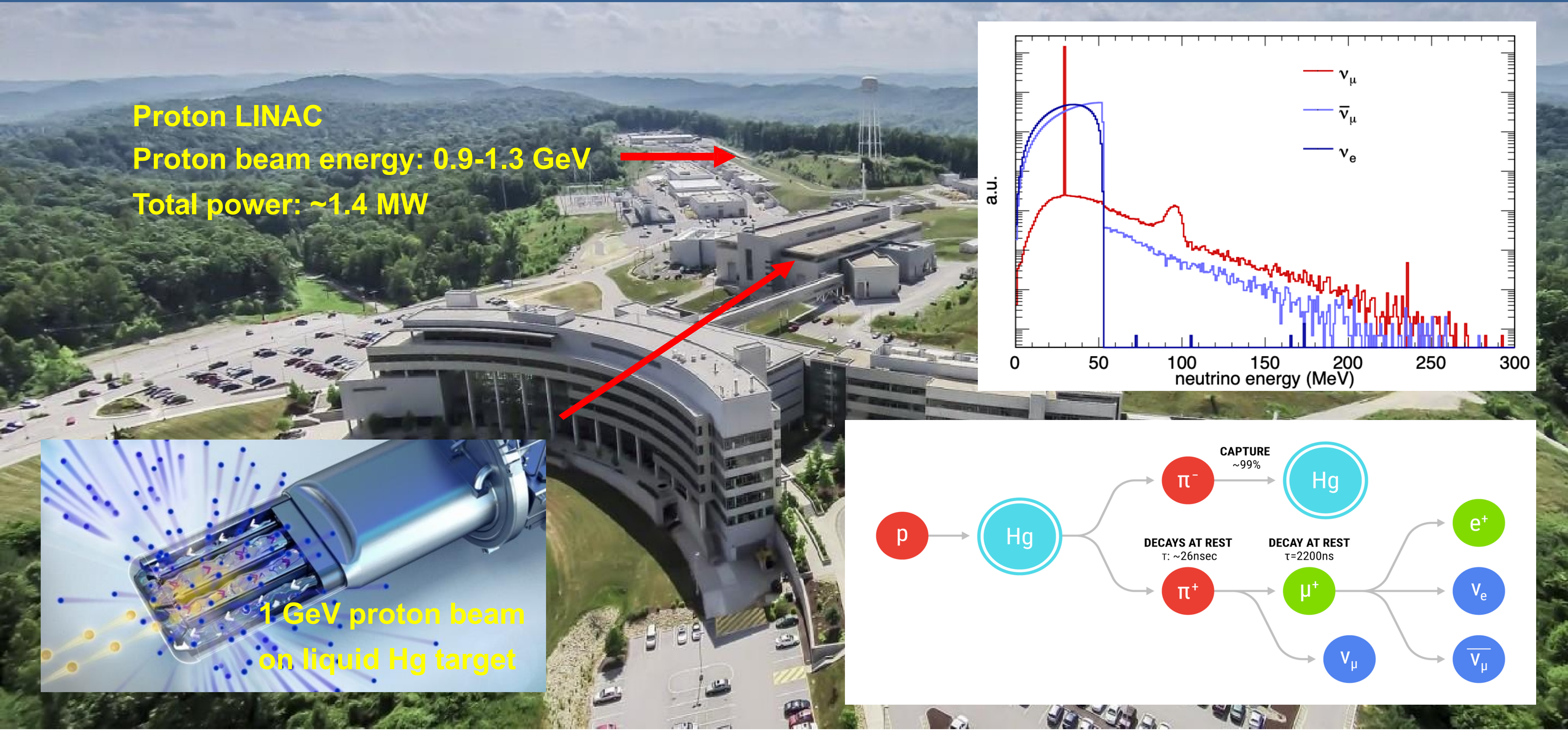
F: Nuclear form factor Q: momentum transfer

- N^2 dependent cross section
  $(Q_W^2 = (N - (1 - 4sin\theta_W^2)Z)^2 \cong N^2)$
- Dominant process in low energy (< 100 MeV)
- Max recoil energy $\cong 2E^2/M < 100$ keV



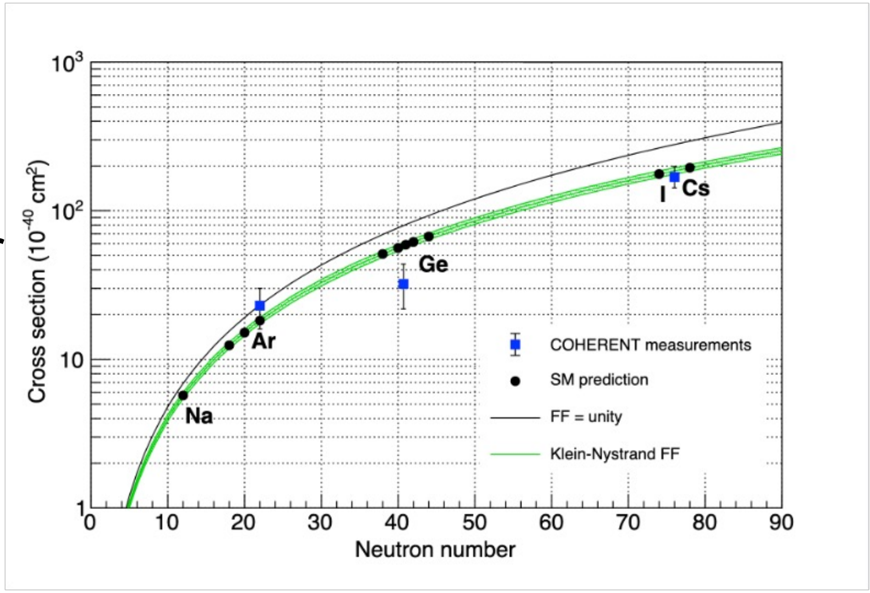


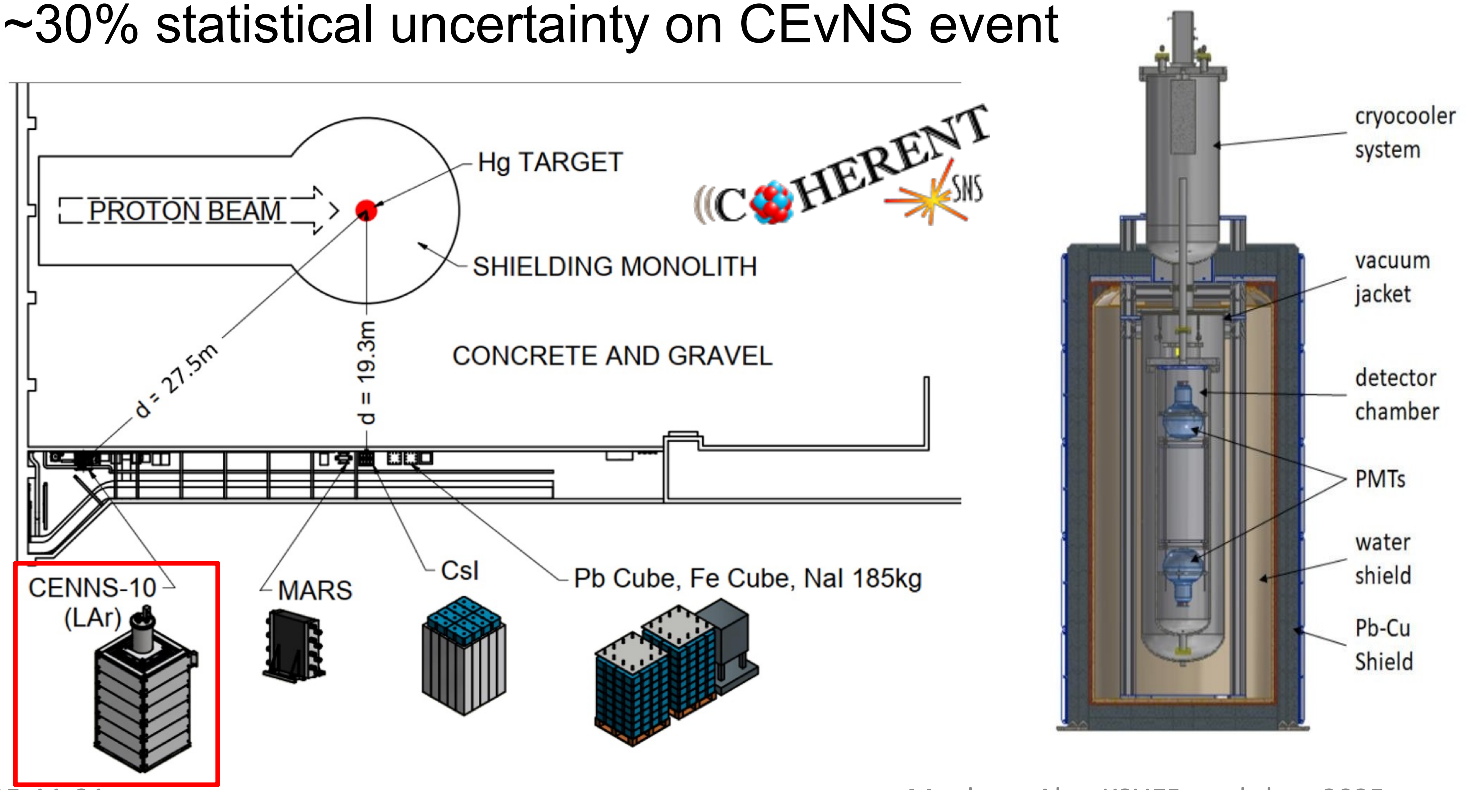
Spallation Neutron Source (SNS) at ORNL

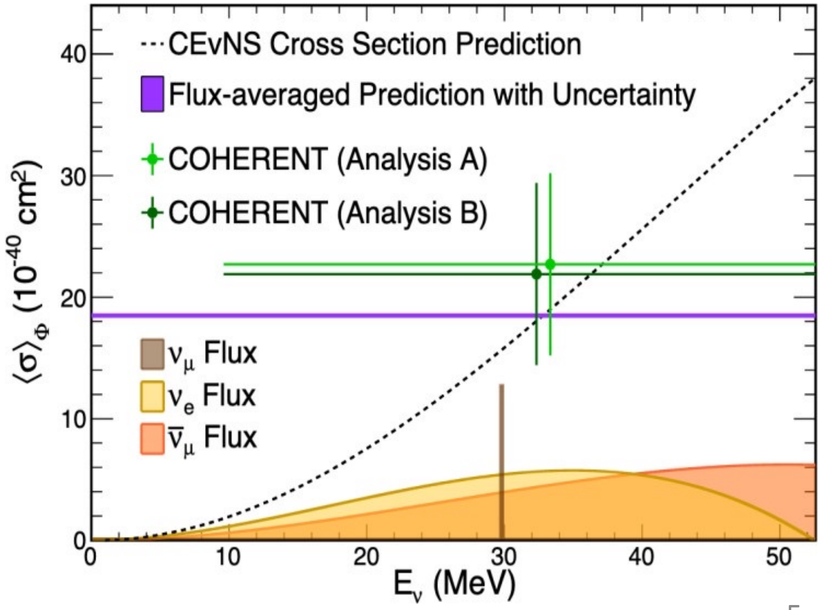


CENNS-10 [Akimov, et al., PhysRevLett.126.012002]

- 24-kg single phase Liquid Argon detector with 2 PMT
- Measured CEvNS cross section 3.5σ in 2020 (within 1σ of SM)
- Verified N^2 dependence of CEvNS cross section with CsI detector
- Measured 159 $\pm$ 43 CEvNS event (SM predicted: 128 $\pm$ 17)
- ~30% statistical uncertainty on CEvNS event

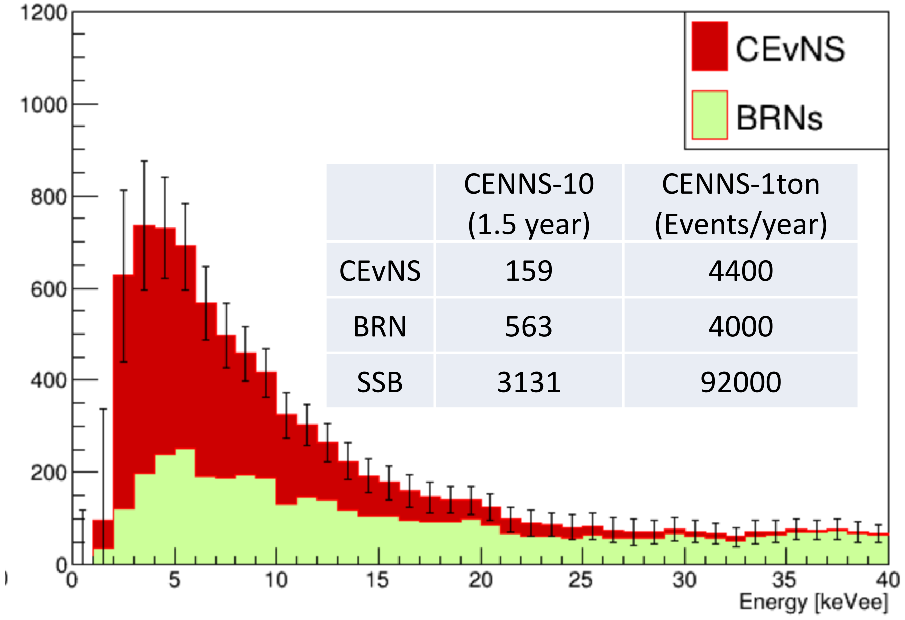




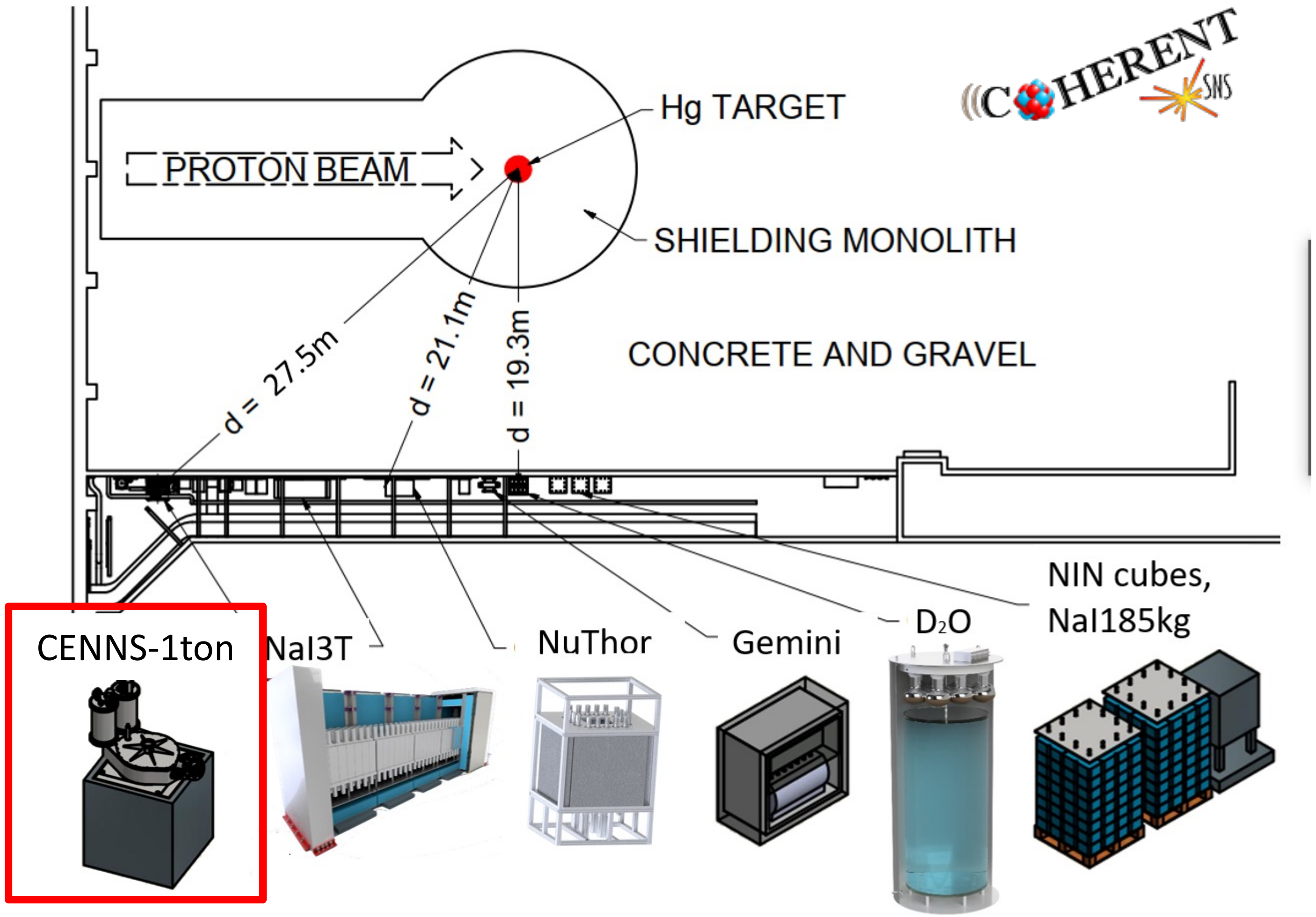


CENNS-1ton

- 750kg Liquid Argon detector with 122 PMTs
- Replacing CENNS-10 at the same location (Neutrino Alley at ORNL)
- Expect ~4400 CEvNS event/year.
- Measure CEvNS with 5% precision in 3 years.
- Precision physics study.

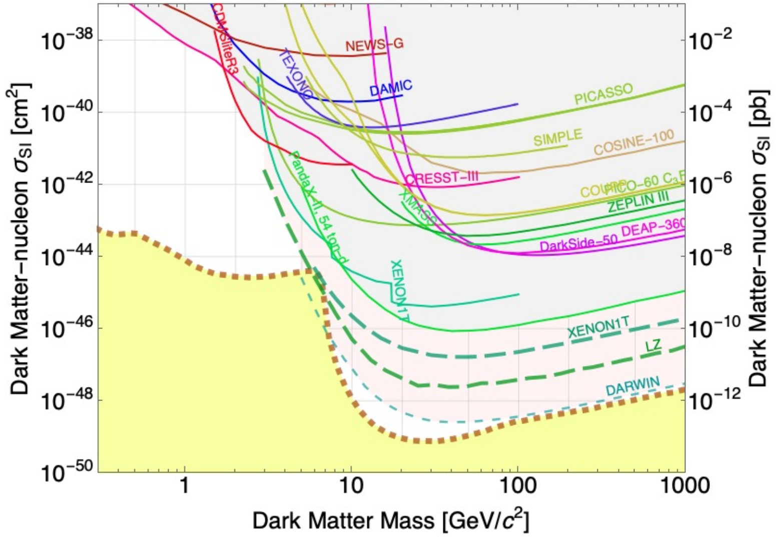


	CENNS-10 (1.5 year)	CENNS-1ton (Events/year)
CEvNS	159	4400
BRN	563	4000
SSB	3131	92000

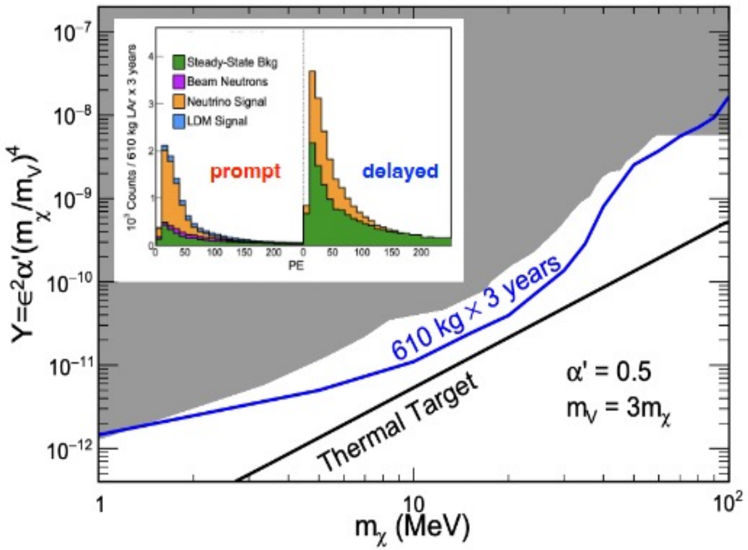


CENNS-1ton: Related physics

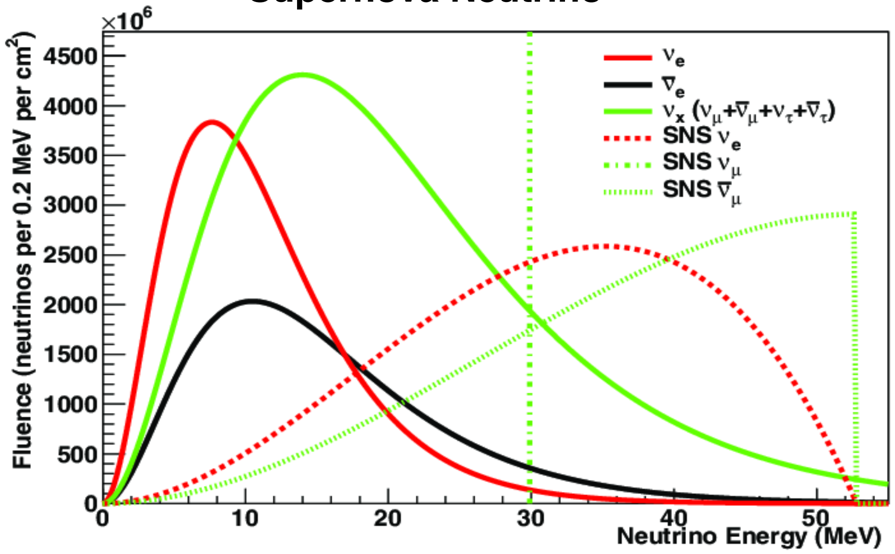
WIMP Search



Light Dark Matter

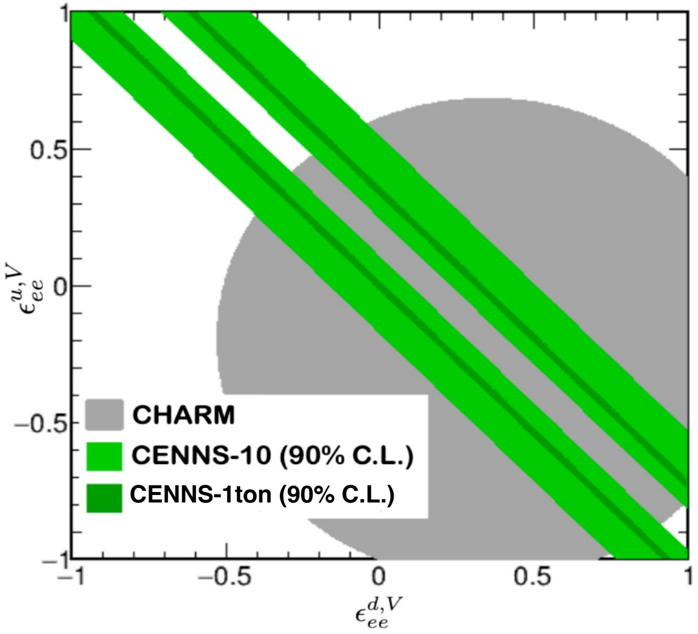


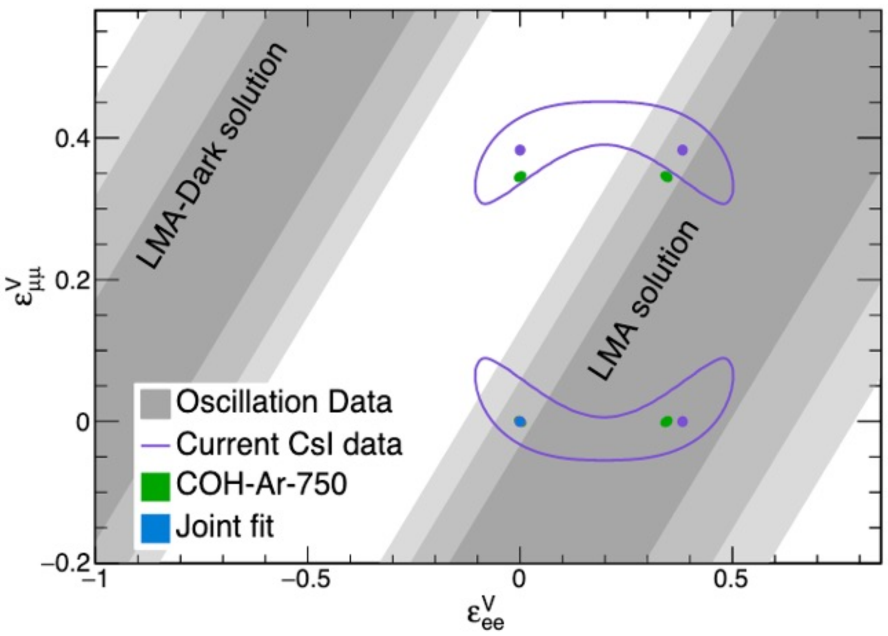
Supernova Neutrino

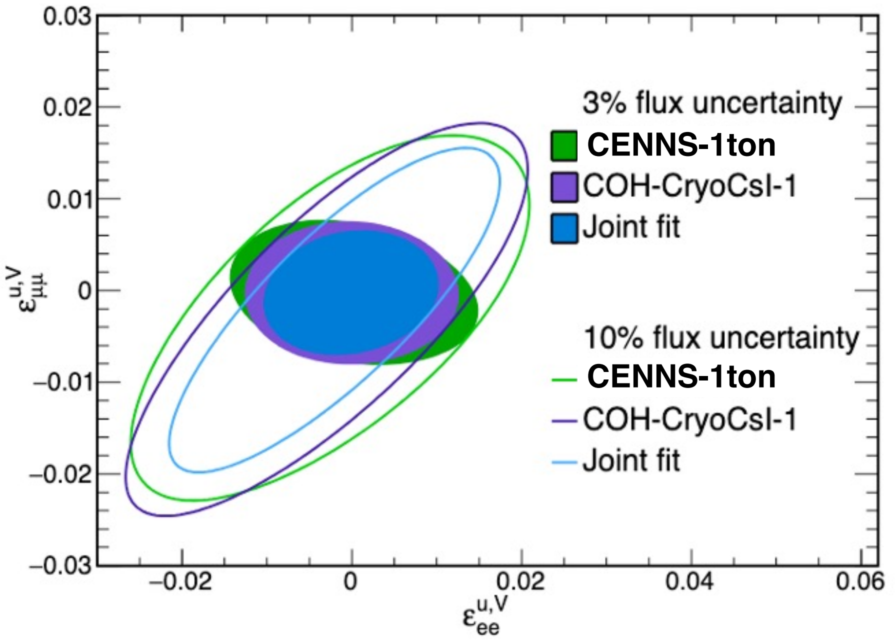


- WIMP search
  - A precise measurement of the CEvNS cross section would help to determine the exact location of the neutrino floor
- Light Dark Matter [Akimov, et al., PhysRevD.102.052007]
  - Stopped-pion neutrino source can produce sub-GeV dark matter, which generate CEvNS-like signal
- Supernova Neutrino
  - Flavor Insensitive
- Neutron Radius
  - Neutron radius is encoded by nuclear form factor

CENNS-1ton: Related physics





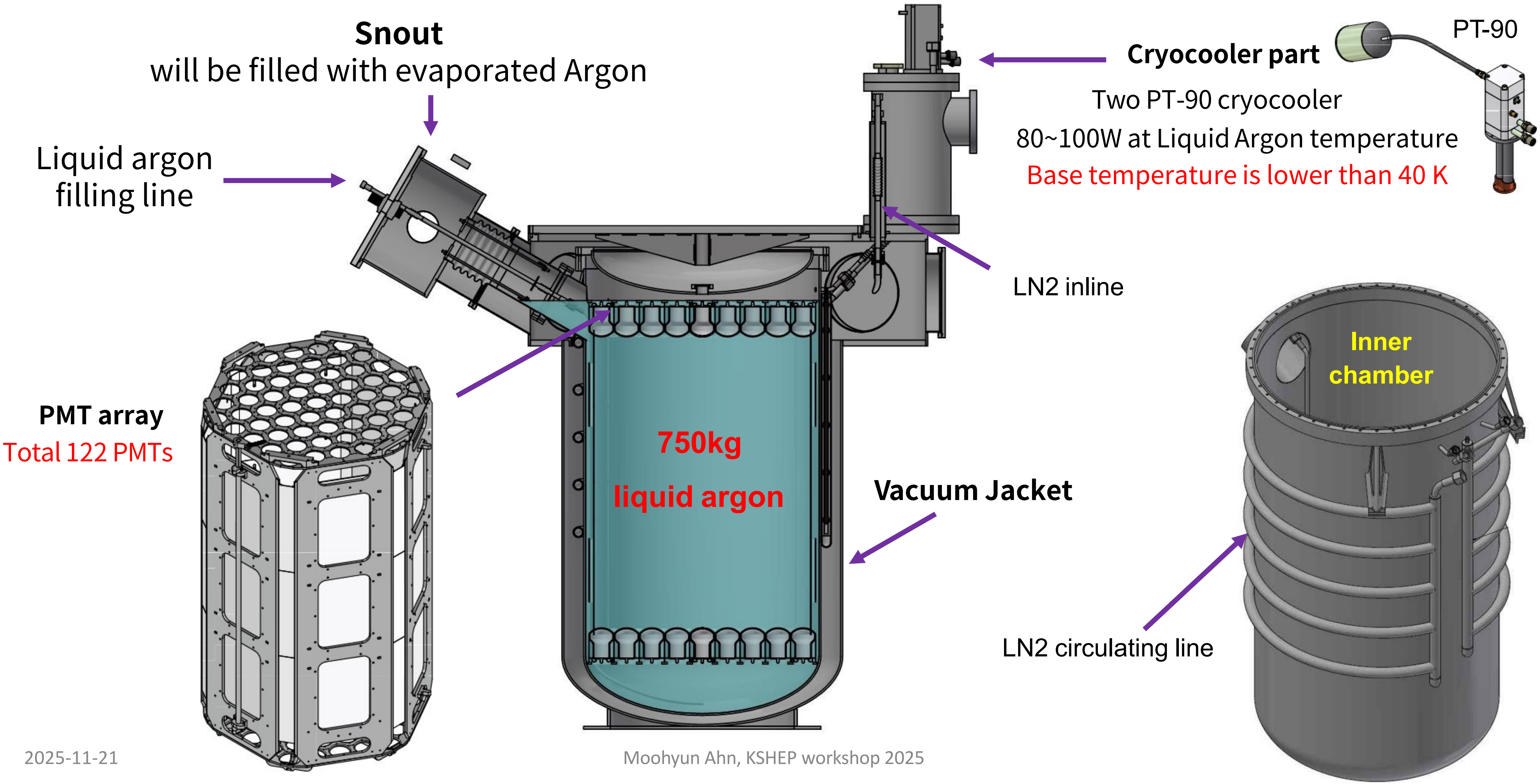


- Non-Standard Neutrino interaction
  - CEvNS spectrum is distorted by NSI

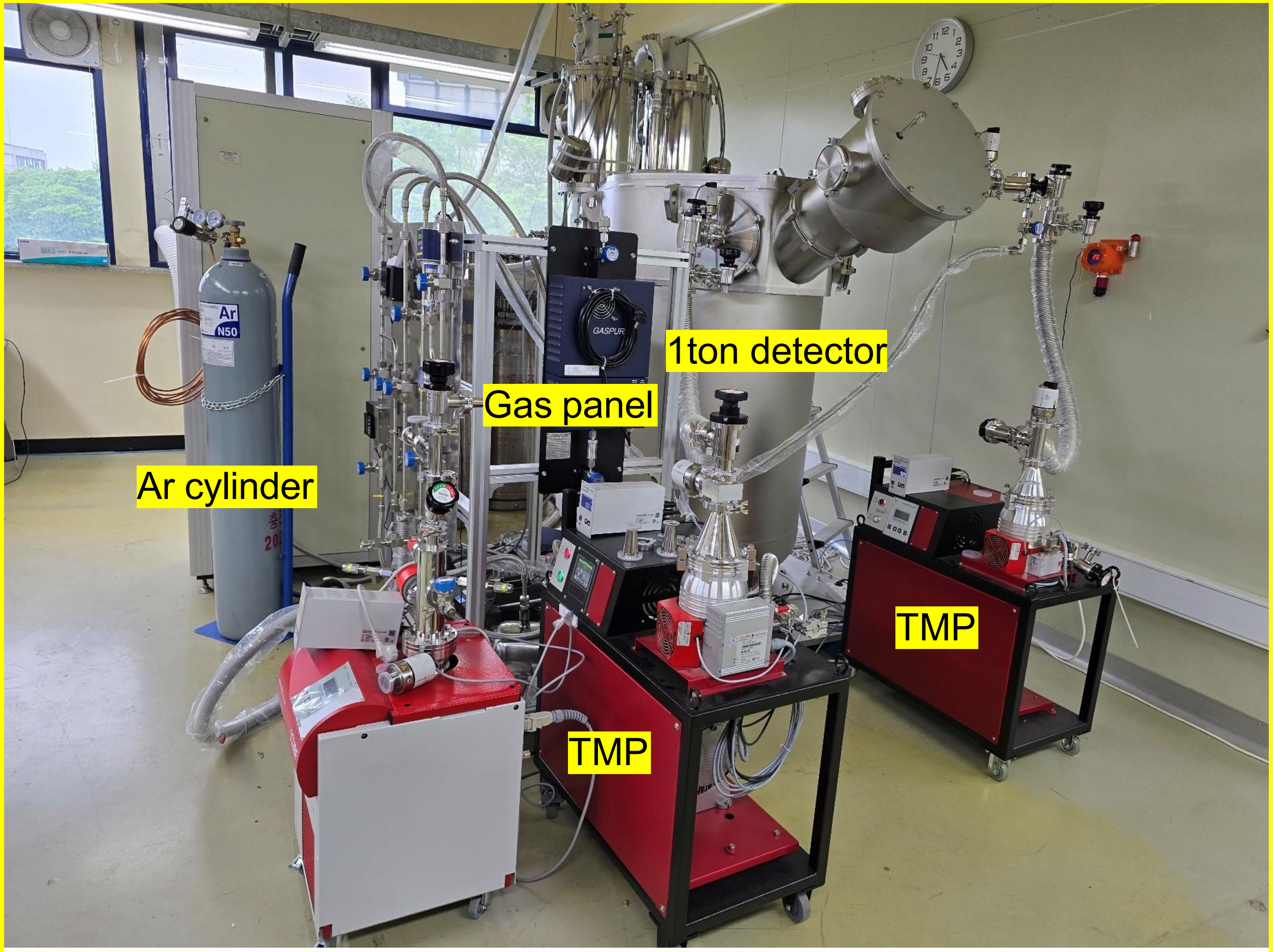
$$Q_W \to Q_{NSI} = \left[\left(g_V^p + 2\epsilon_{ee}^{uV} + \epsilon_{ee}^{dV}\right)Z + \left(g_V^n + \epsilon_{ee}^{uV} + 2\epsilon_{ee}^{dV}\right)N\right]$$

  - Expect 10 times higher sensitivity than CENNS-10

CENNS-1ton detector overview

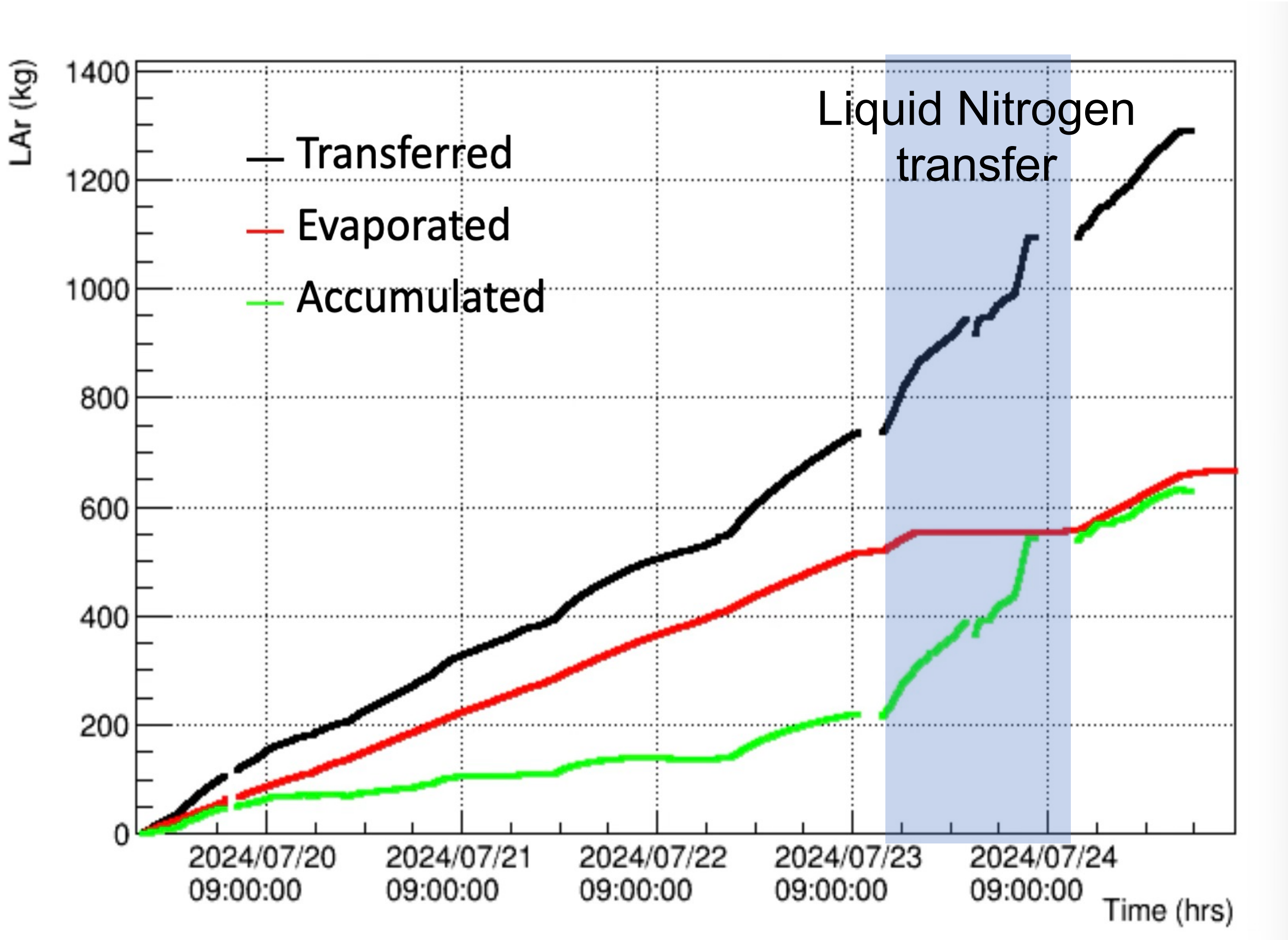


CENNS-1ton detector at SNU



CENNS-1ton chamber test at SNU

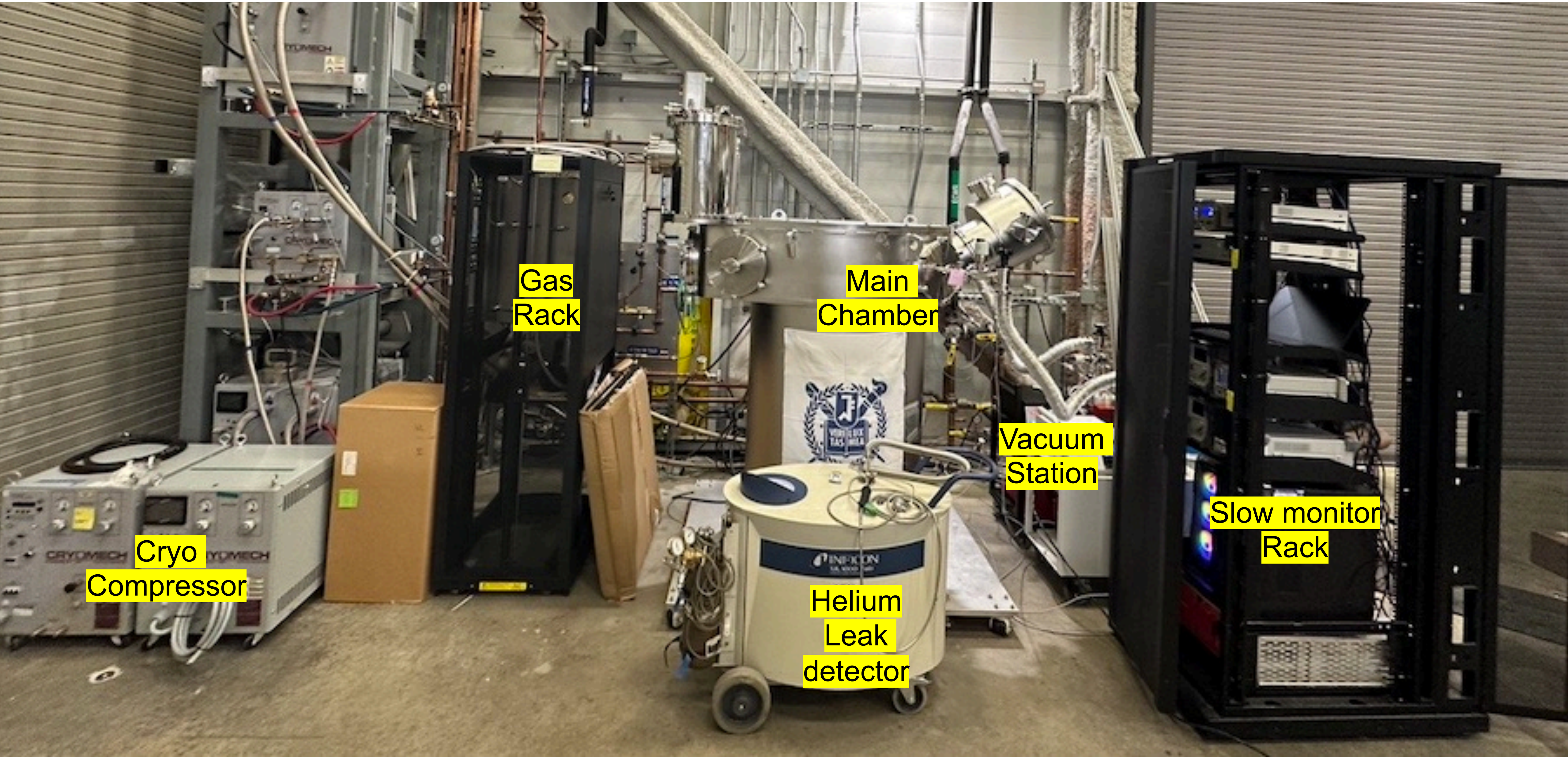
- 1 ton chamber fabricated by Korean company
- Delivered and Assembled at SNU
- Vacuum test done
- Ar condensing and LAr transfer tested
- LN2 precooling worked well



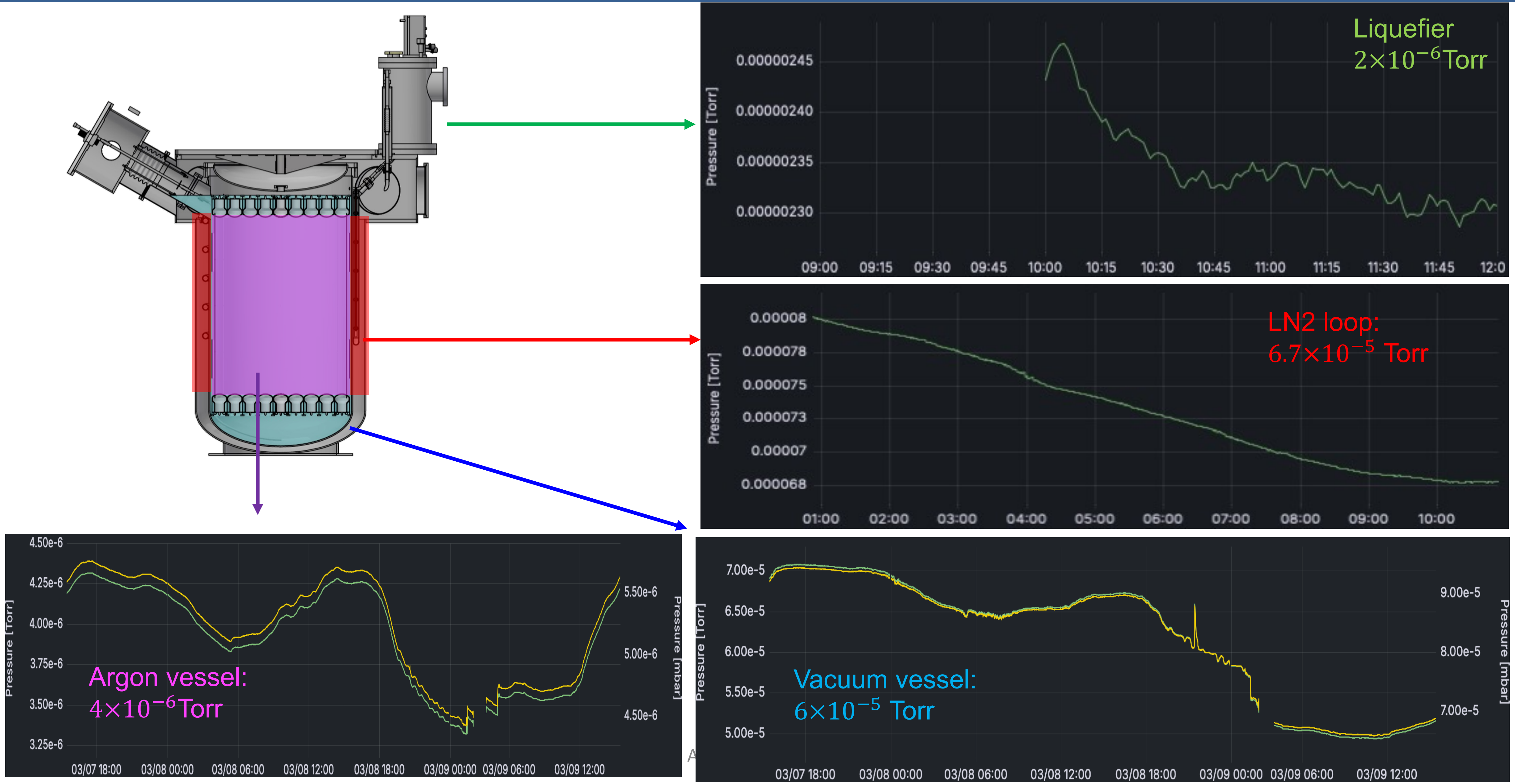
Liquid Argon Transfer test.

Detector Delivery from SNU to ORNL

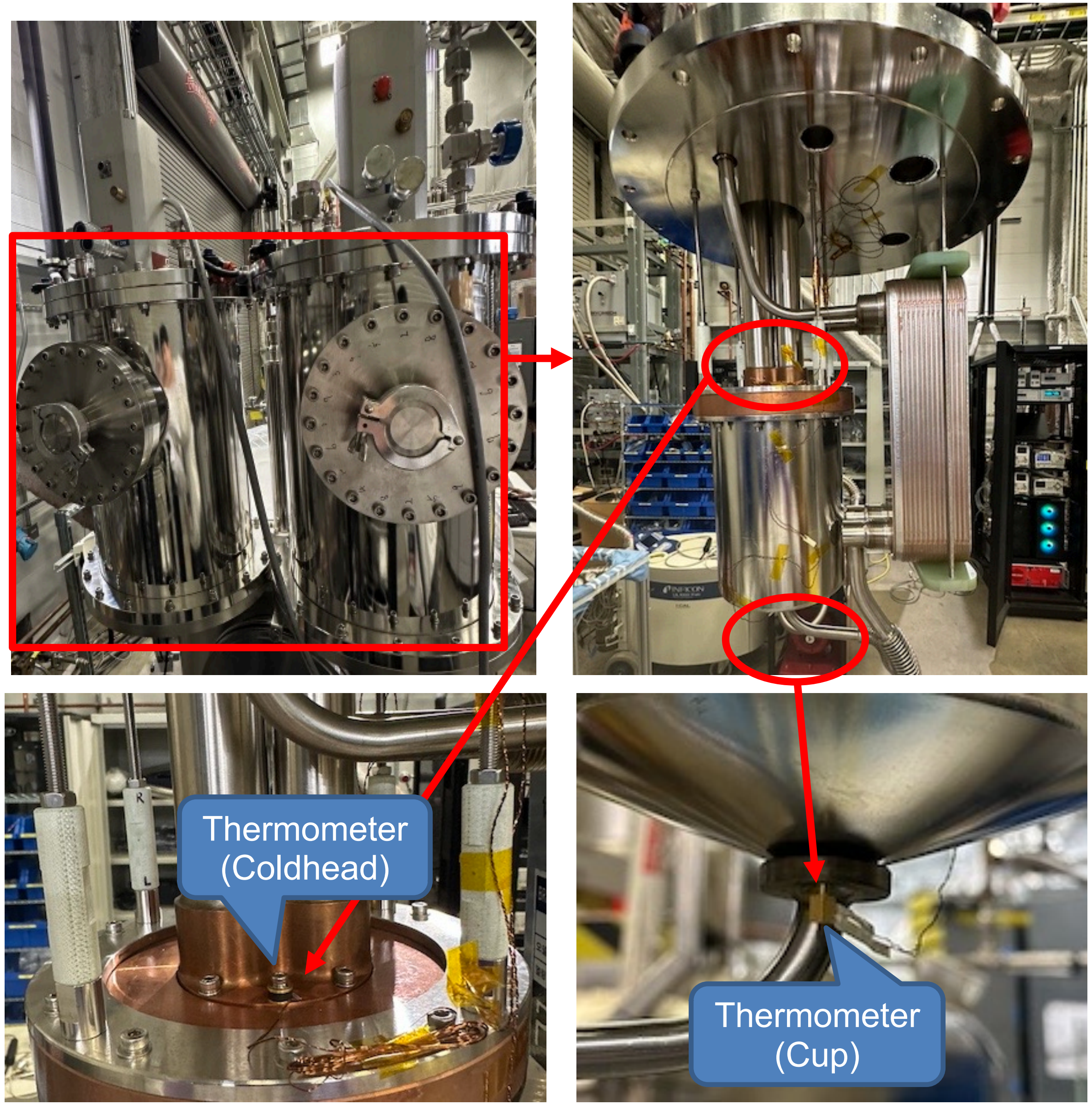
Test Setup at ORNL

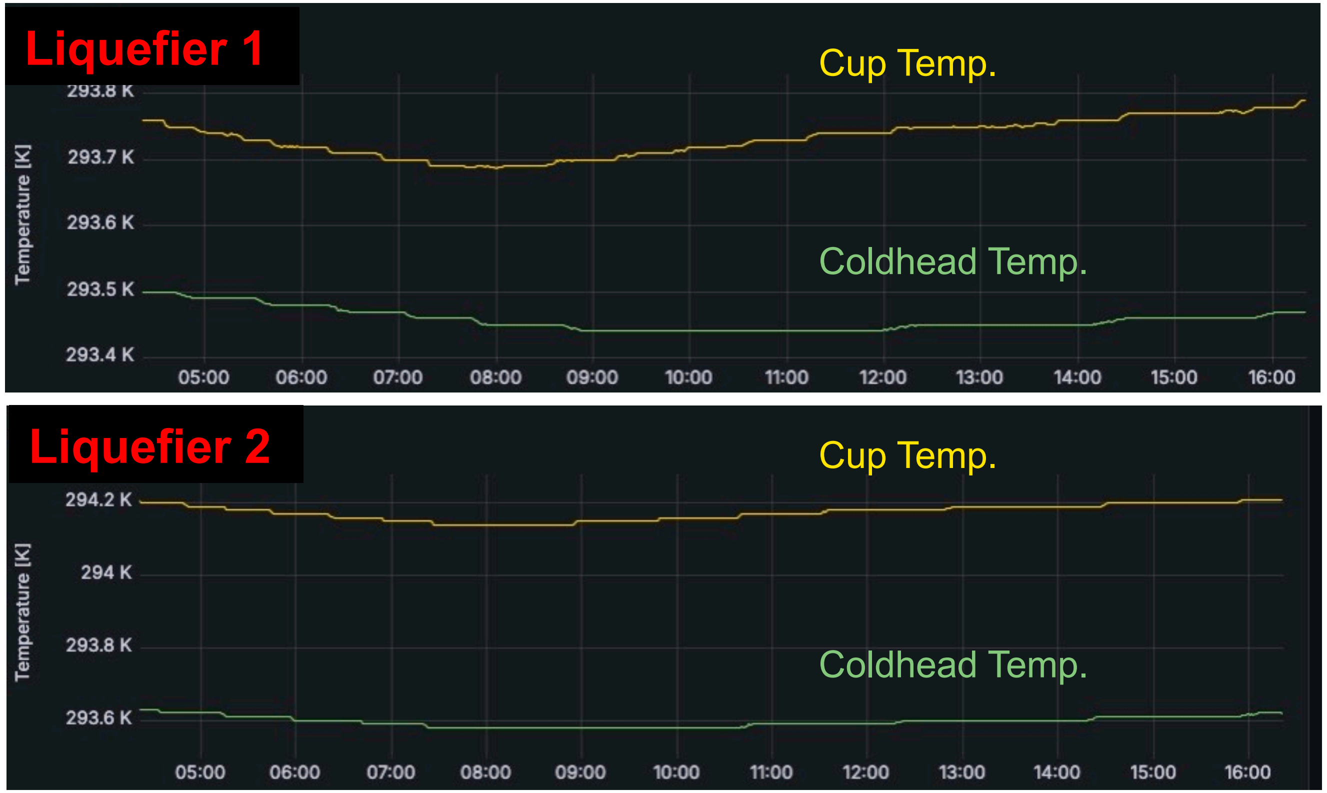


CENNS-1ton detector Vacuum Test at ORNL

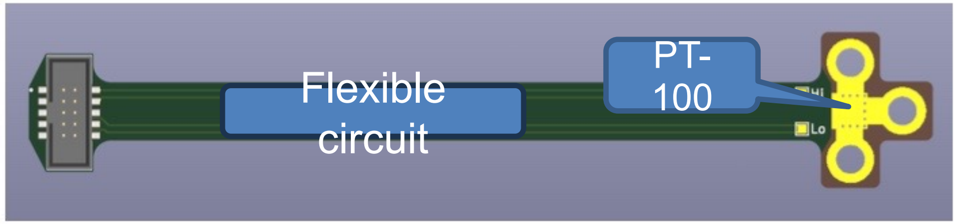


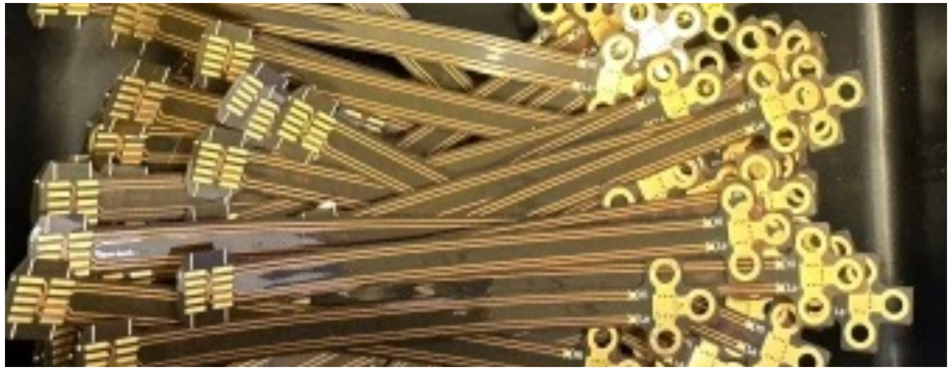
Thermometer Test

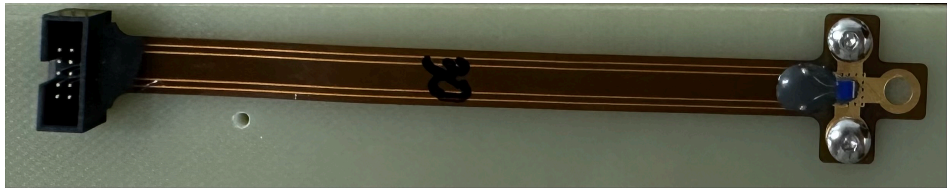


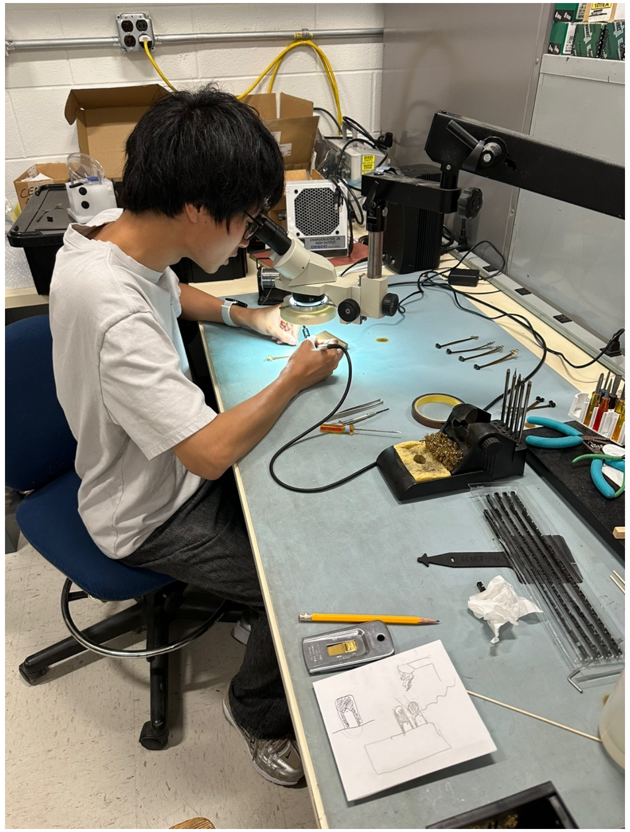


RTD installation



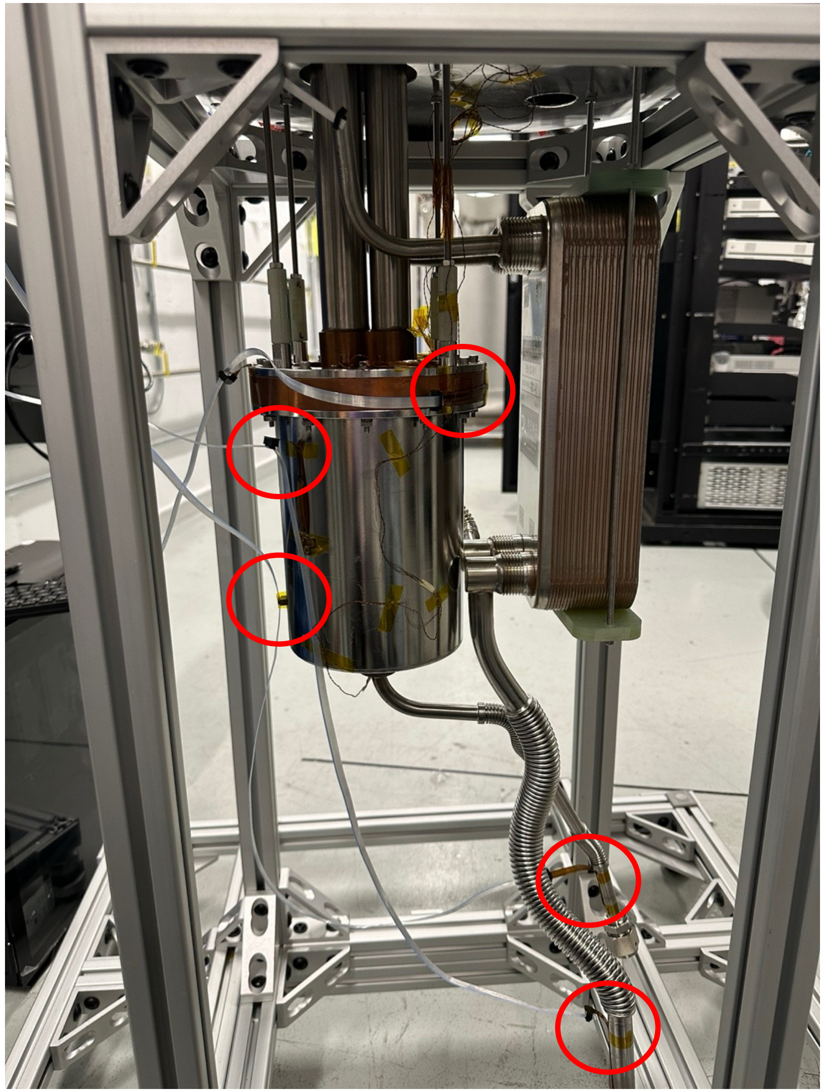




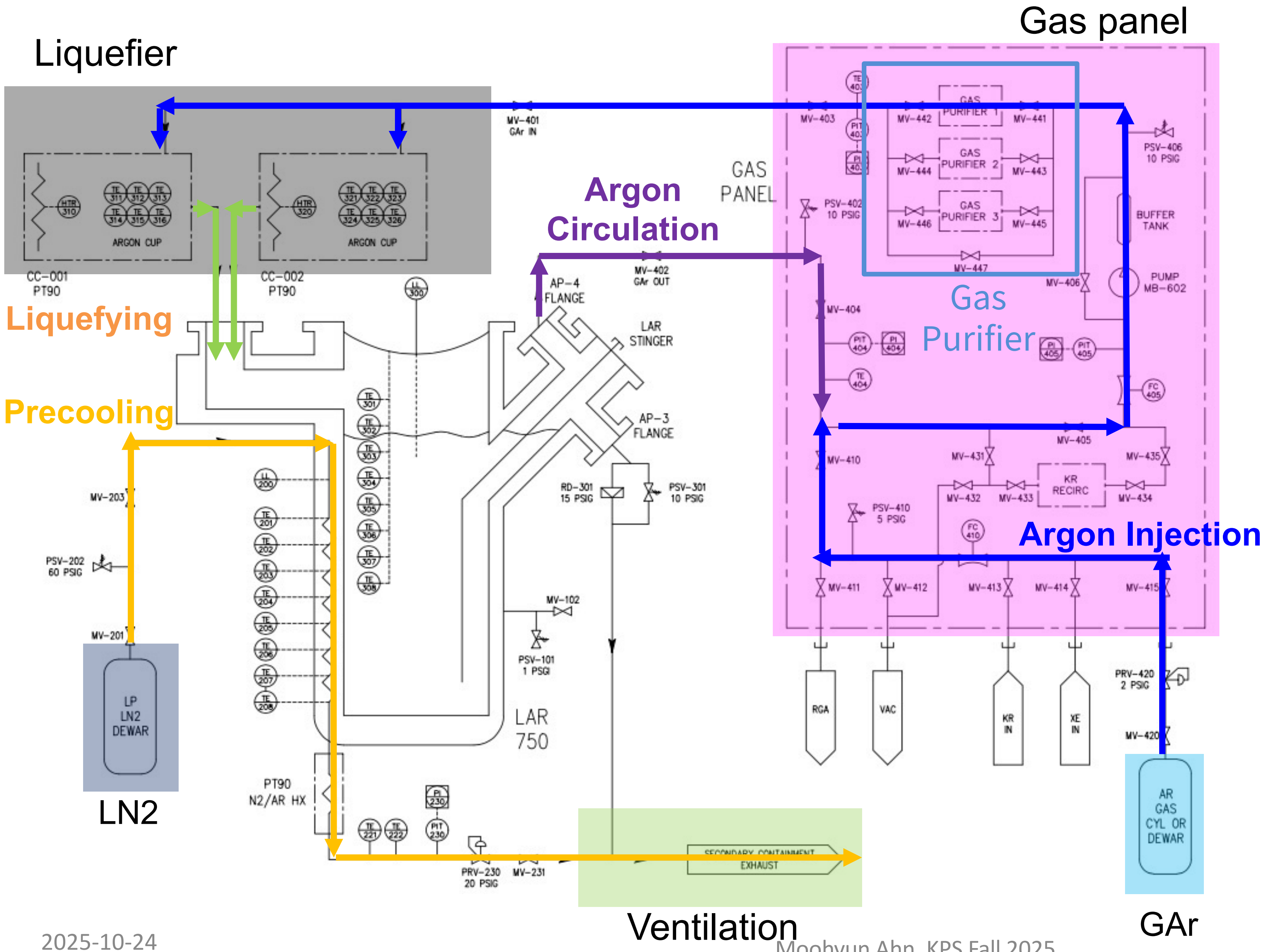


- PT-100 temperature sensors are installed to monitor the temperature of the condensing system and LAr vessel.

RTD installation



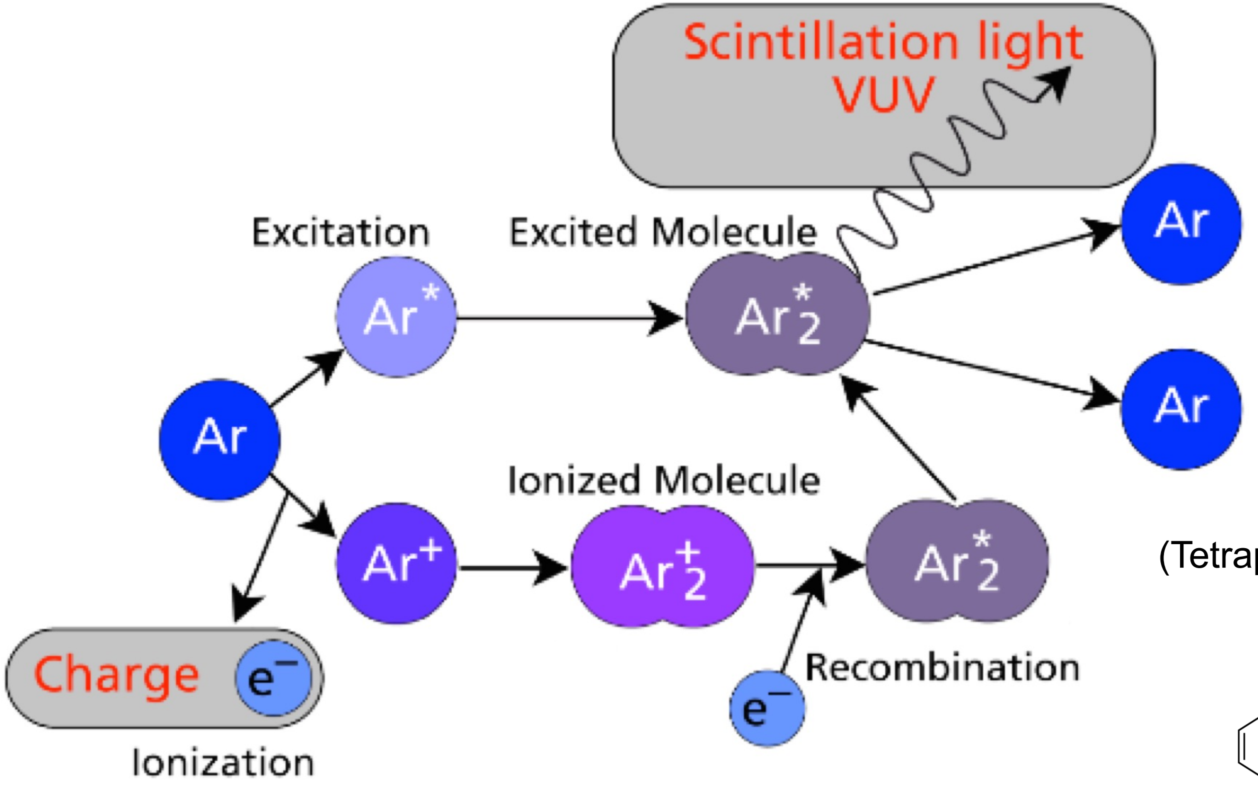
Piping & Instrumentation Diagram



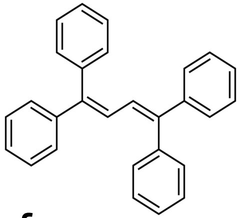
Argon Chamber P&ID

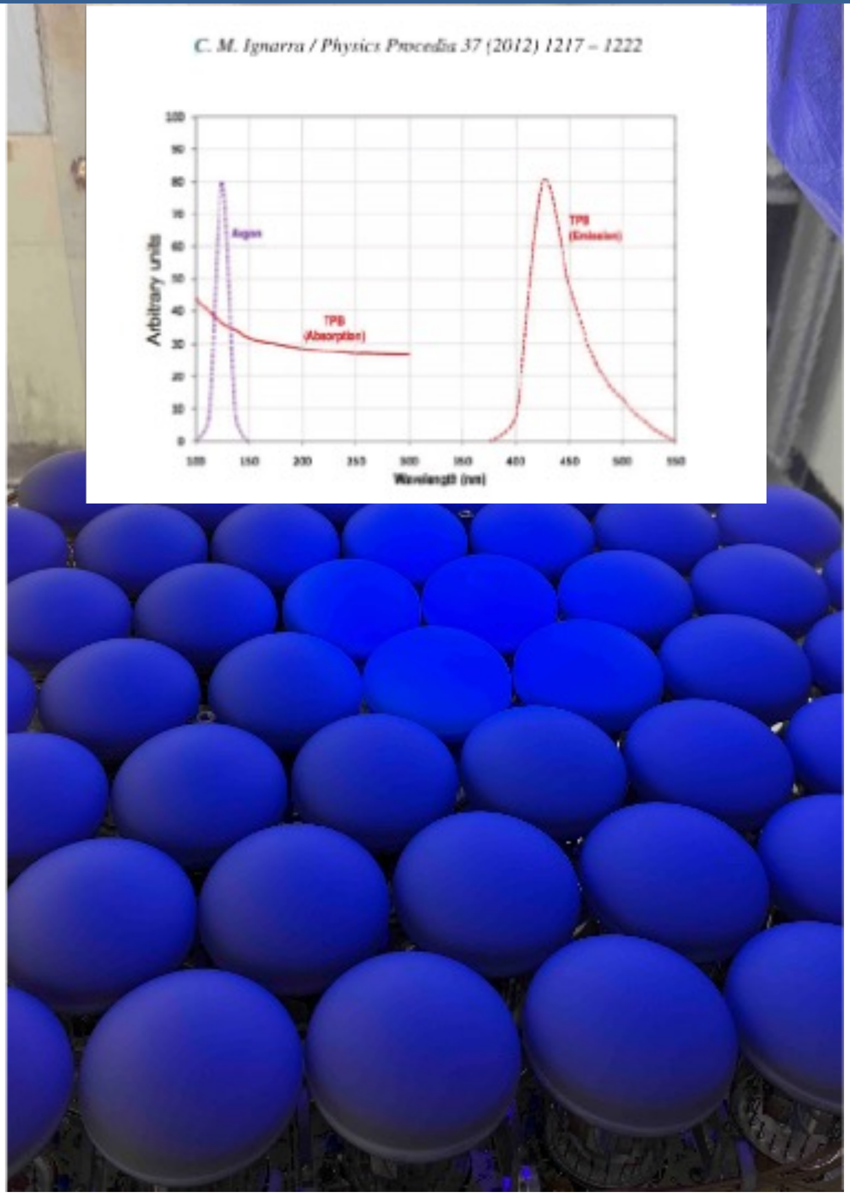
- **Argon:** Injected through the gas panel → liquefied → circulated.
- **LN2:** Used to cool the argon vessel, then vented.
- Thermometers are installed on the liquefier, LN2 loop, and argon vessel.
- Pressure relief valves are installed at various points in the system.

TPB coating



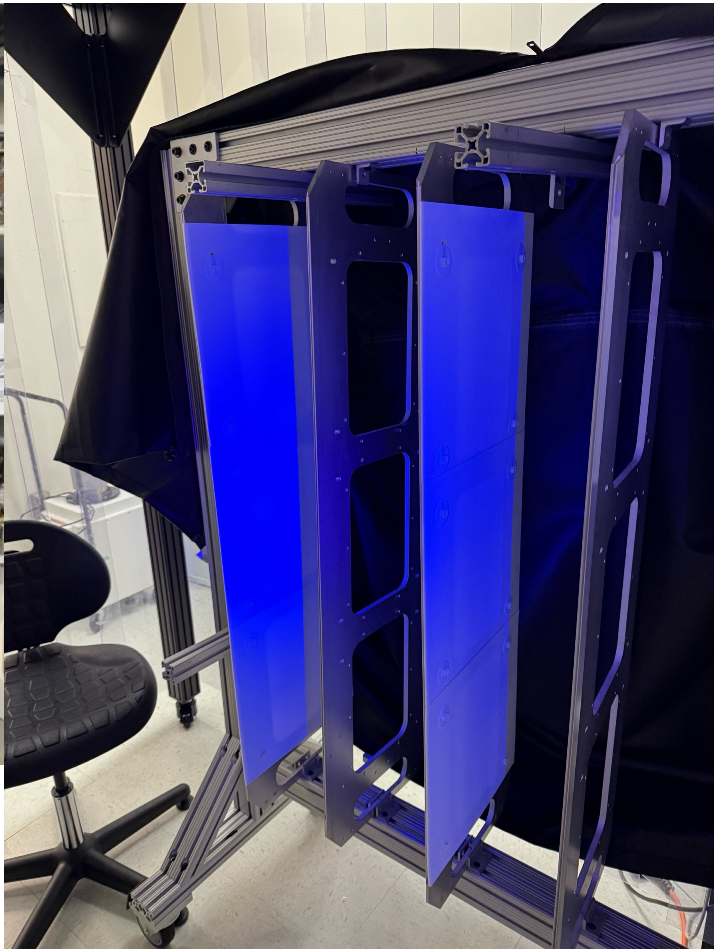
TPB
(Tetraphenyl butadiene)





- 128nm scintillation light from LAr is absorbed at the surface of the detector material.
- PMTs are sensitive to the visible light range.
- TPB (Tetraphenyl butadiene) absorb 128nm scintillation light and rre-emit them as 430nm visible light.

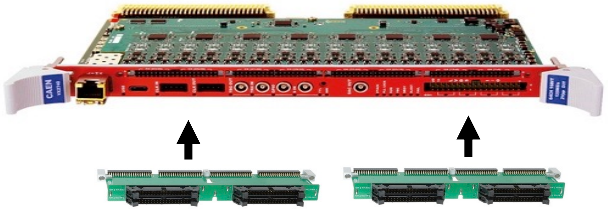
TPB coating and PMT assembly



- PMT TPB coating is in production at a thickness of 0.20 mg/cm² to optimize re-emission and transparency of 430 nm lights.
- The coating thickness is verified by measuring the weight of a witness plate.
- TPB coating on PMT and PTFE plates are completed.
- PMTs are installed on the end plates and completed the signal line works.

DAQ

CAEN VME8004X
- 4 slot mini crate.

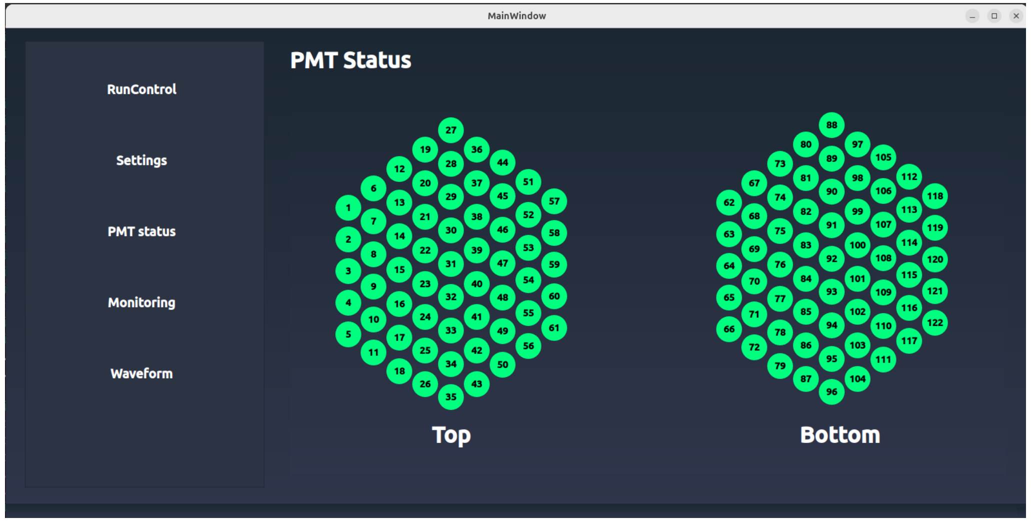


CAEN VX2740B
- 64 Channels.
- ADC resolution: 16bits.
- Sampling rate:125 MS/s.

CAEN SY5527
- Power supply crate.

CAEN A7030P, A7030LP
- Power supply module.

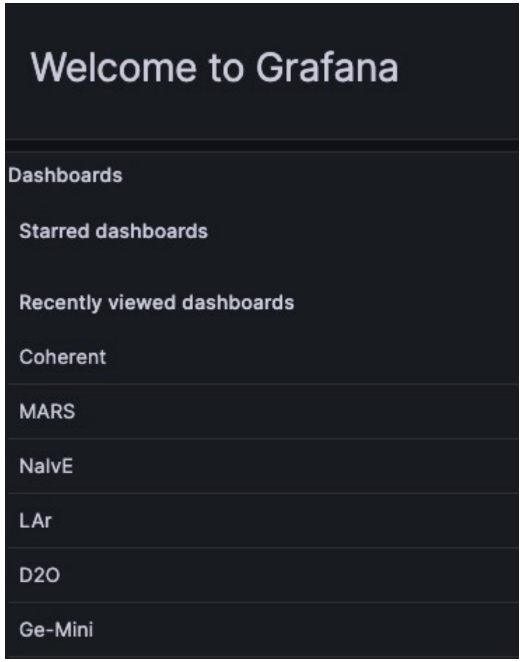
- VX2740 is replaced with the VX2740B due to noise issues.
- The PMT interface
  - Supplies high voltage to the PMTs.
  - Transmits their signals to the PC.



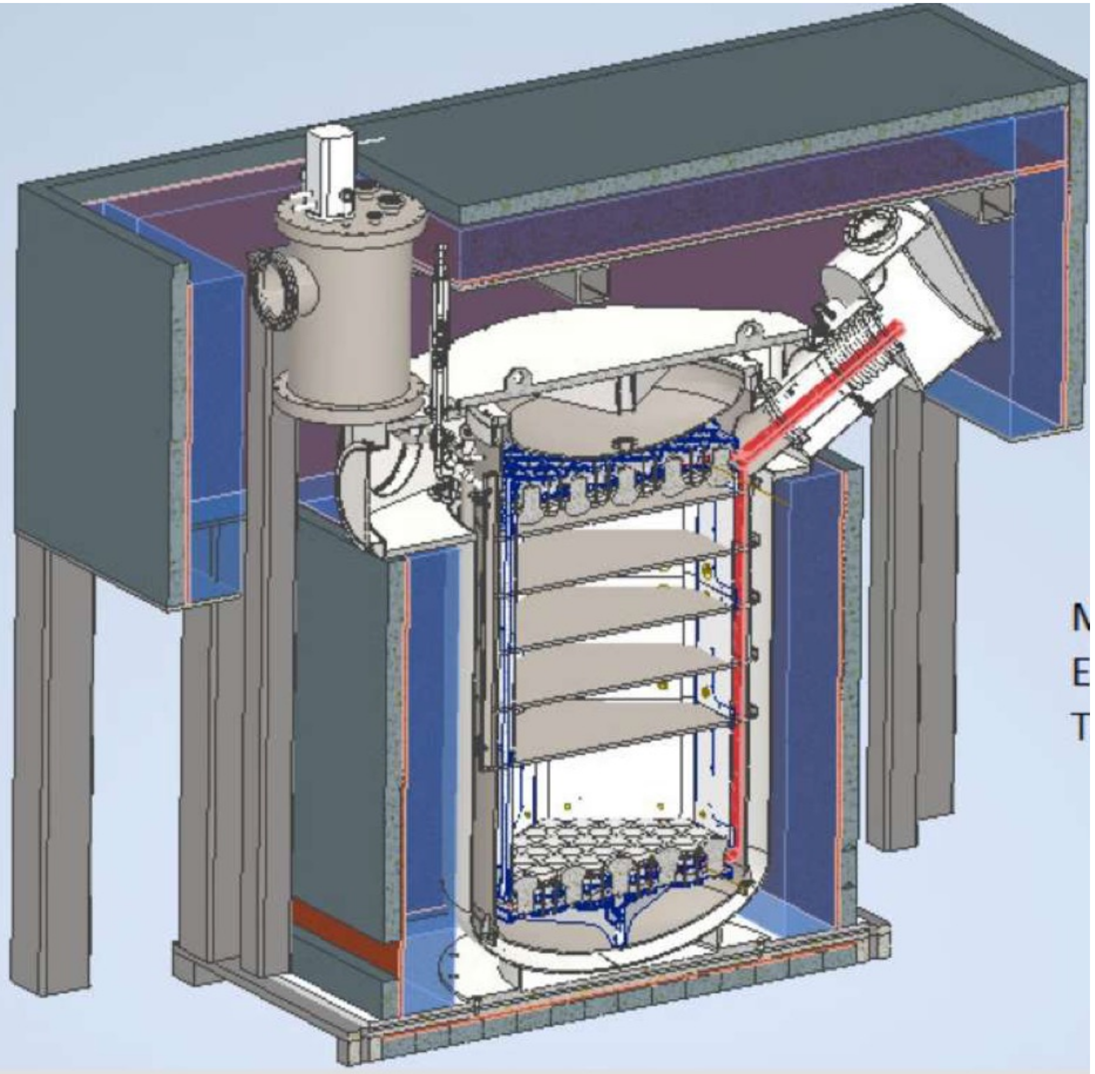
Slow Monitoring

Workflow

- Raw data → InfluxDB → Grafana
- InfluxDB: Data storage
- Grafana: Data visualization through the InfluxDB
- The Coherent collaboration integrates slow monitoring into a Grafana.



Shielding and Veto



Shielding and Veto Design & study

- From outside toward the cryostat
    - **Pb – Water wall – Scintillator**
    - **Pb :** 2” thick chevron-block walls (can reuse those from CENNS-10), constrained by Al panels on outside, water walls on inside
    - **Water wall :** polyethylene tank filled with deionized water to reject Beam Related Neutron
    - **Scintillator :** 8 - 2” thick panels

- Shielding and Veto being fabricated
- MC study for optimization of veto cut

Summary & Future plan

2026-02 | 2026-03 | 2026-04

Operational test → Nu Alley Install → Safety Review Commissioning → Experiment

- CENNS-10 (24kg) observed CEvNS in 2020, with 30% uncertainty
- CENNS-1ton (610kg) will reduce uncertainty 5% in 3 years
- 1ton detector is fabricated, assembled, and tested ay SNU
- 1ton detector has been delivered to ORNL after performance test.
- Assembly has been completed at ORNL and Vacuum test was done.
- RTD install and TPB coating were completed.]
- We will take data next year.

Backup

Non-standard neutrino interaction (NSI)

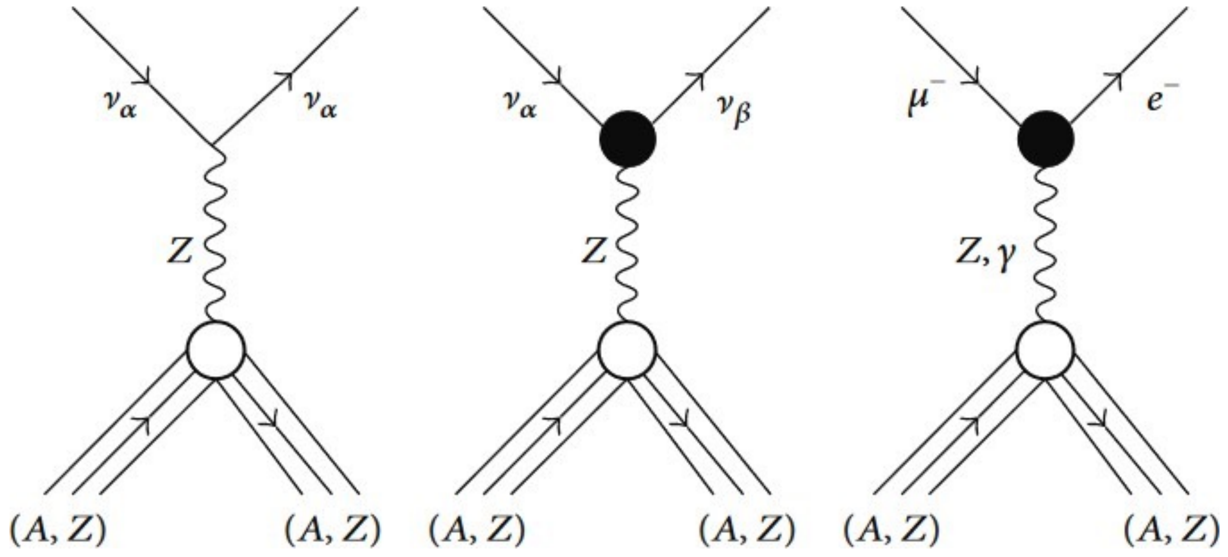
CEvNS spectrum is distorted by NSI

Kinematics term

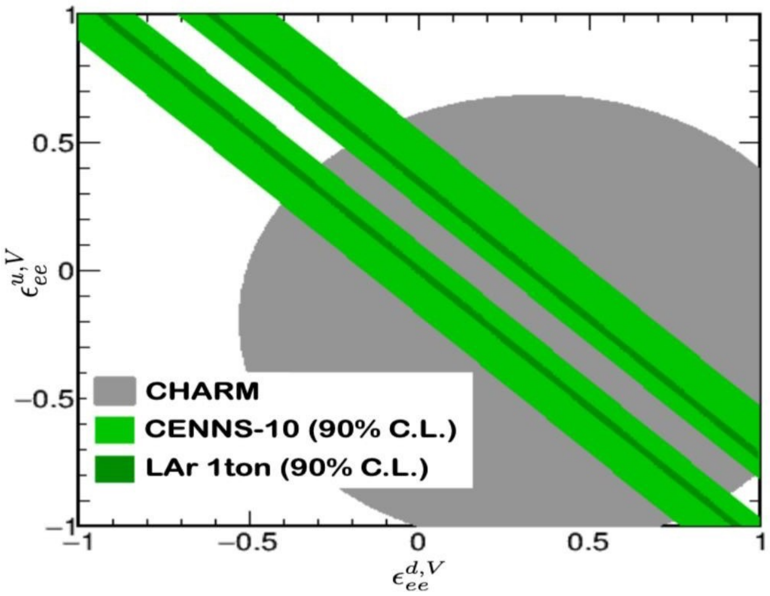
$$\frac{d\sigma}{dT} = \frac{G_F^2 M}{2\pi} Q^2_{NSI} \boxed{\left(2 - \frac{2T}{E_v} - \frac{MT}{E_v^2}\right)}$$

$$Q_W^V \rightarrow Q_{NSI}^V = \left[\left(g_V^p + 2\epsilon_{ee}^{uV} + \epsilon_{ee}^{dV}\right)Z + \left(g_V^n + \epsilon_{ee}^{uV} + 2\epsilon_{ee}^{dV}\right)N\right]F_n(Q^2)$$

Expect 10 times higher sensitivity than CENNS -10



(Left) SM interaction (Middle) neutrino flavor change (Right) muon to electron conversion



NSI sensitivity after 3 years

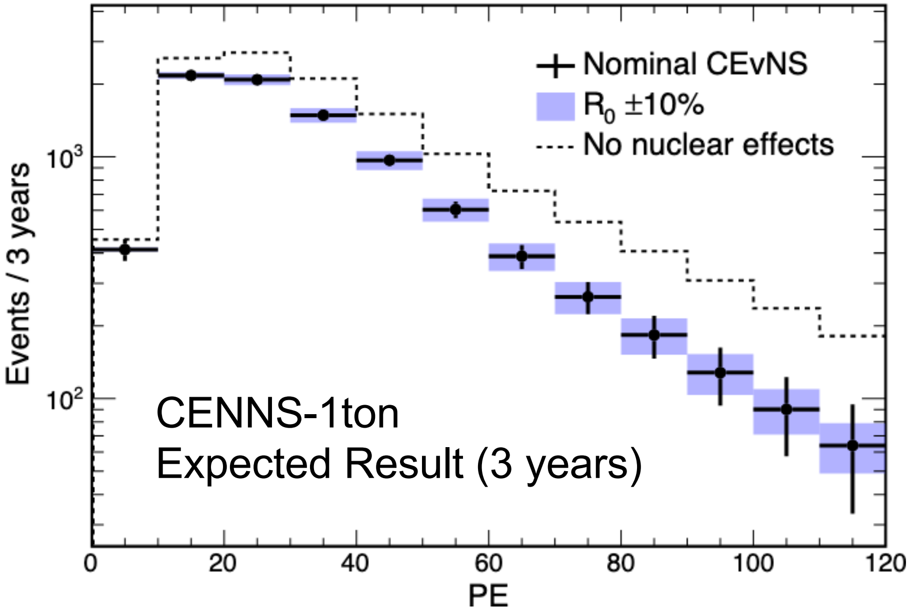
Neutron radius

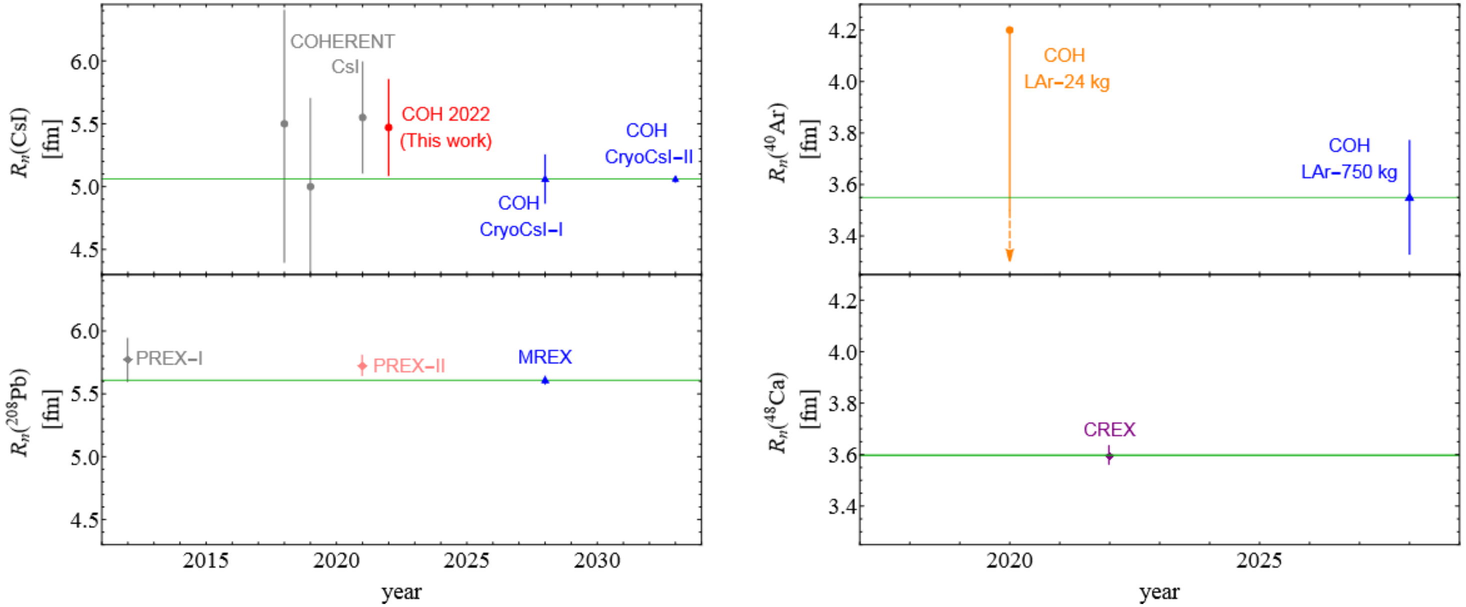
Neutron radius is encoded by nuclear form factor in weak charge

$$\frac{d\sigma}{dT} = \frac{G_F^2 M}{2\pi}\left[g_V^p Z F_p(Q^2) + g_V^n N F_n(Q^2)\right]\left(2 - \frac{2T}{E_\nu} - \frac{MT}{E_\nu^2}\right)$$

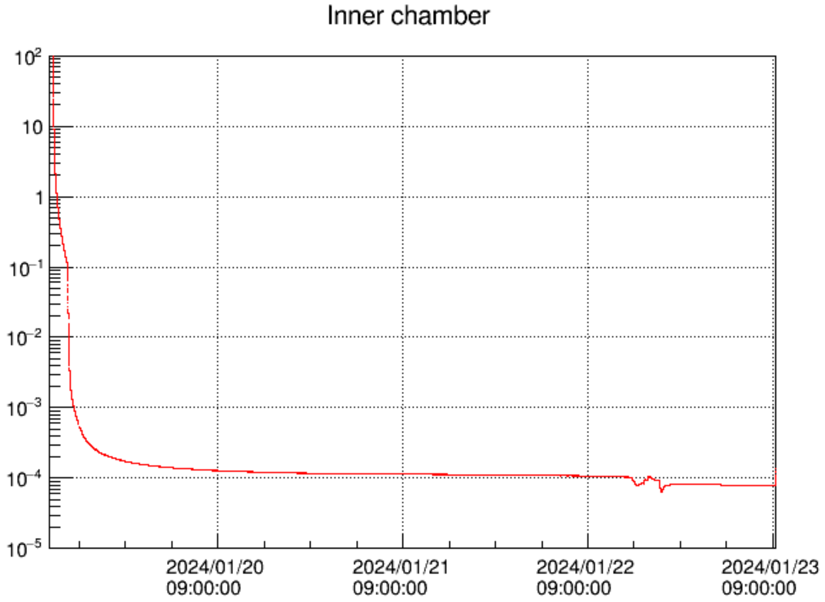
CENNS-10 first experimentally determined neutron radius in Argon

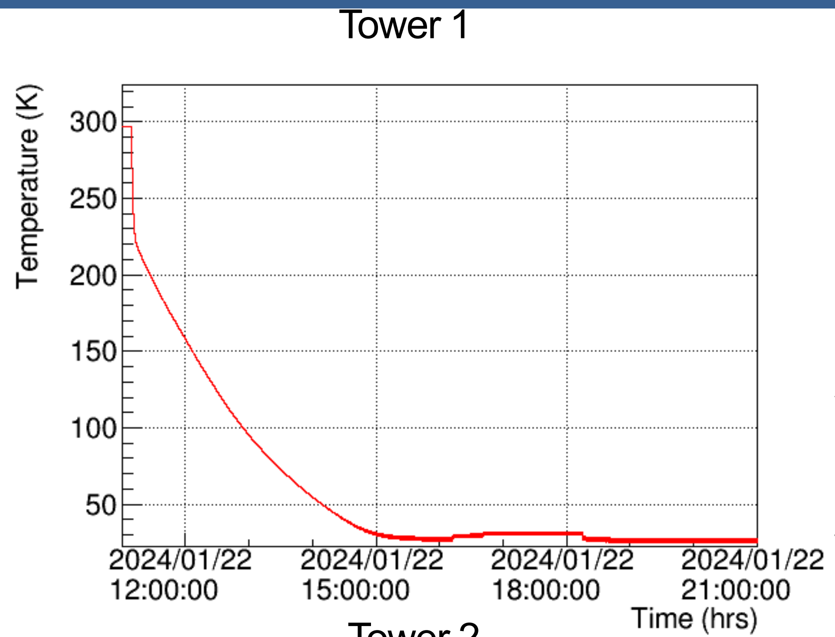
CENNS-1ton will measure $R_n(^{40}\mathrm{Ar})$ to 4.6% after 3 years

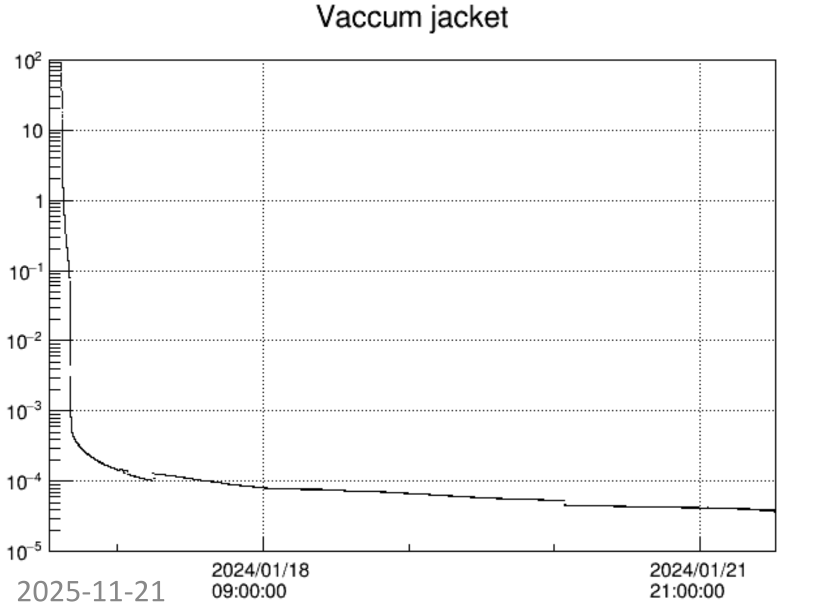


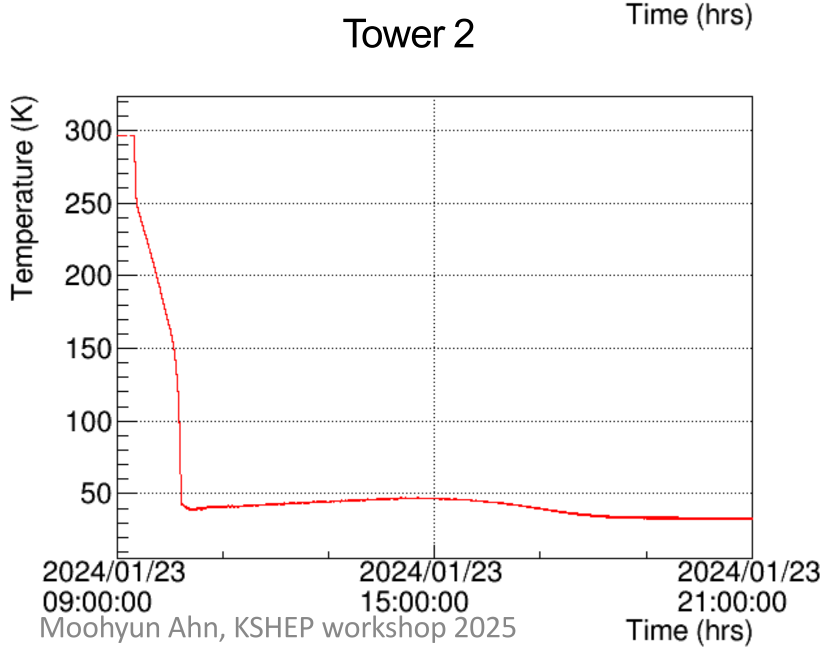


1ton chamber vacuum & cryocooler test





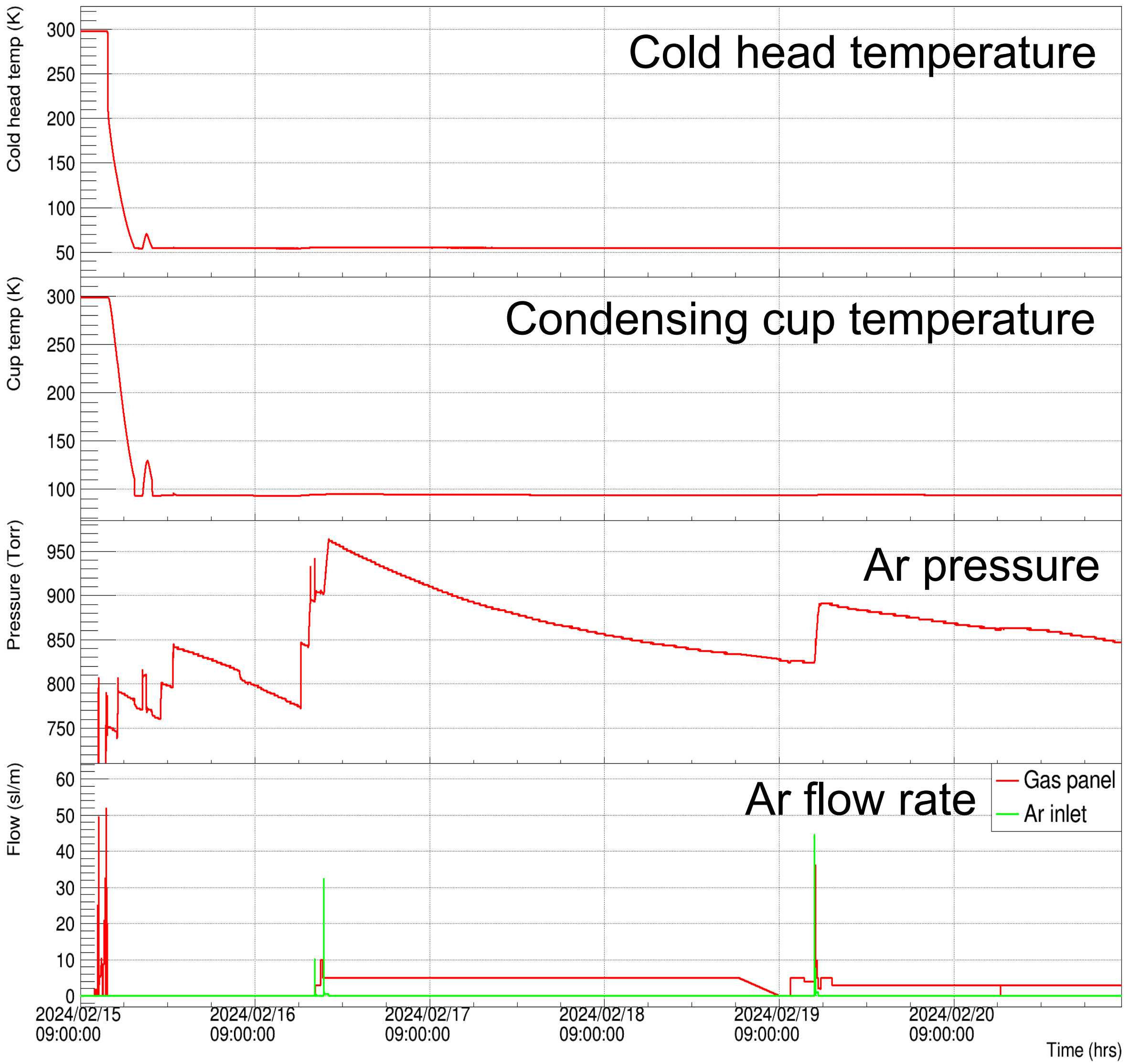


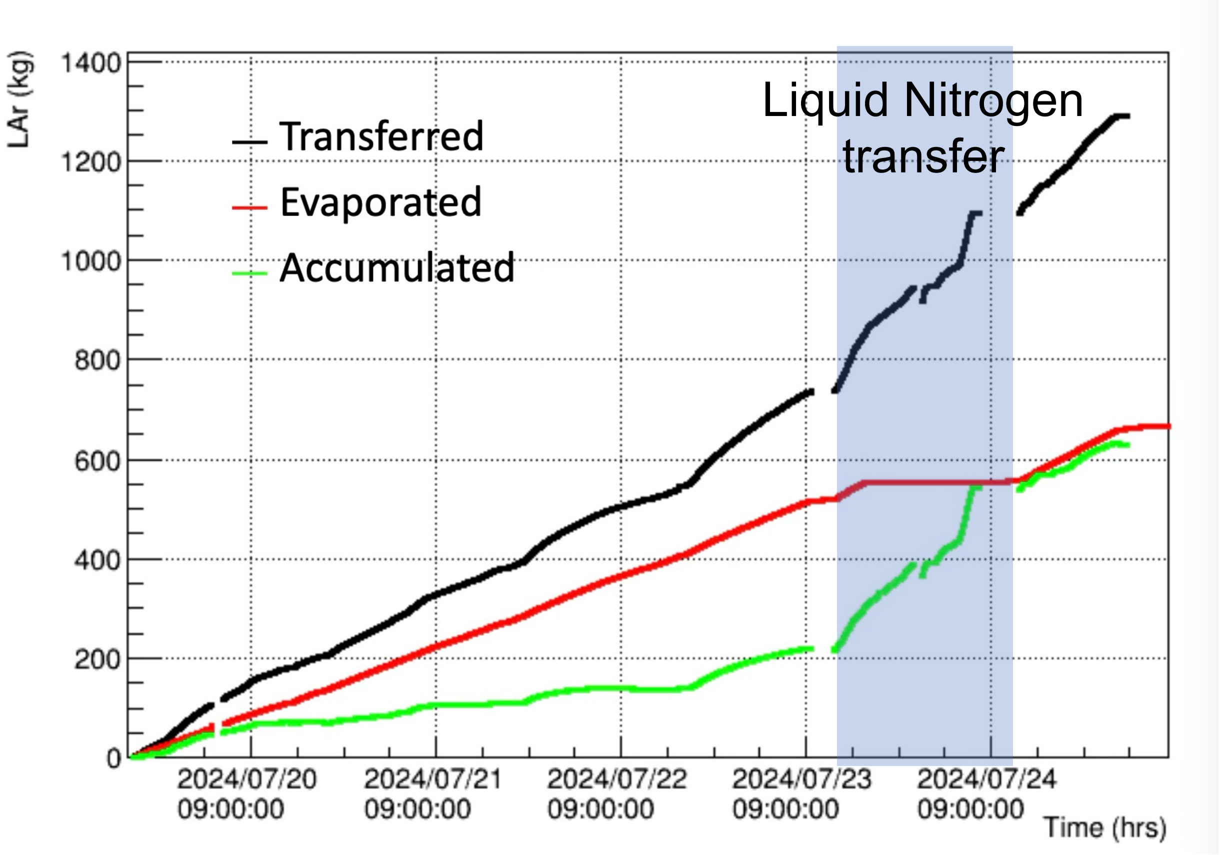


Vacuum lavel of inner cham ber and vacuum jacket is lo wer than 1e-4 torr.

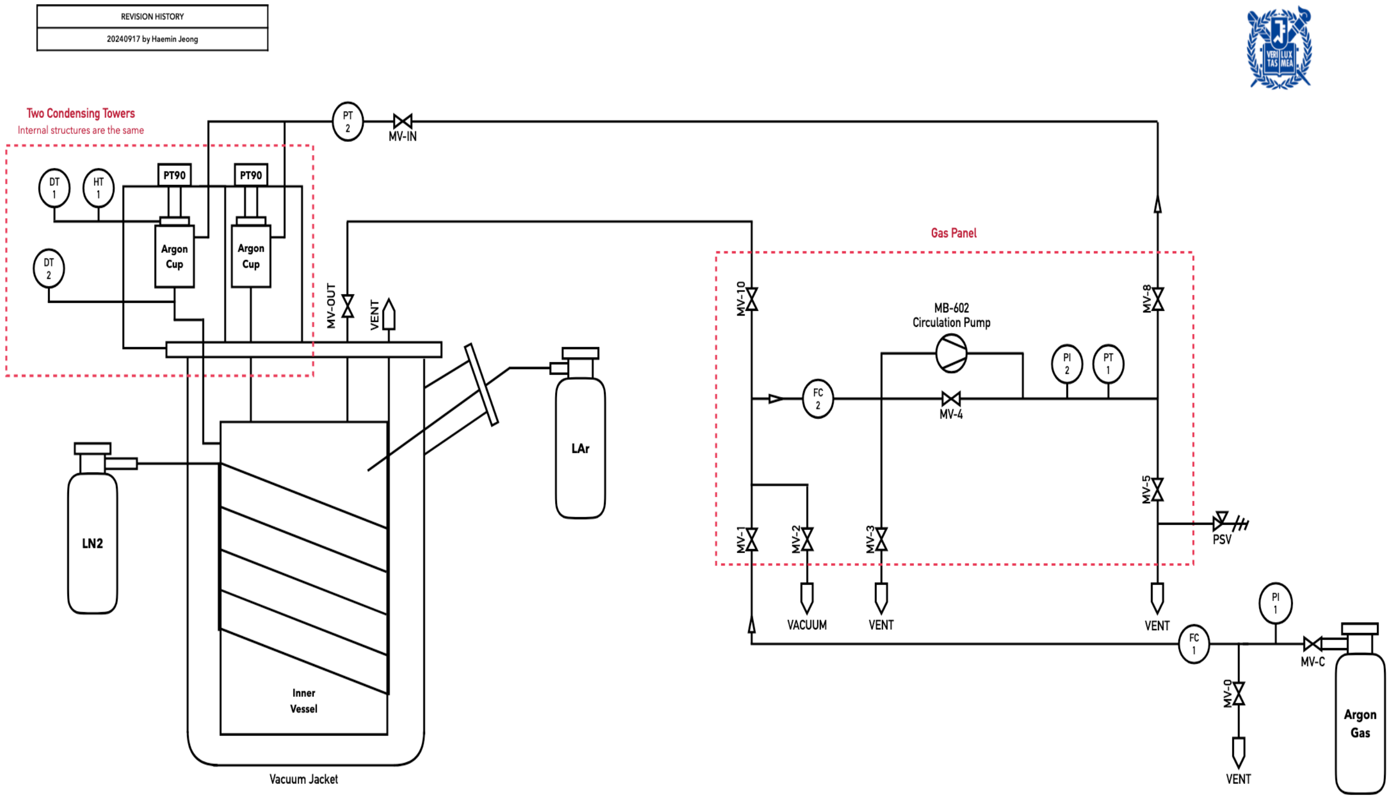
Base temperature of each tower is lower than 40 K.

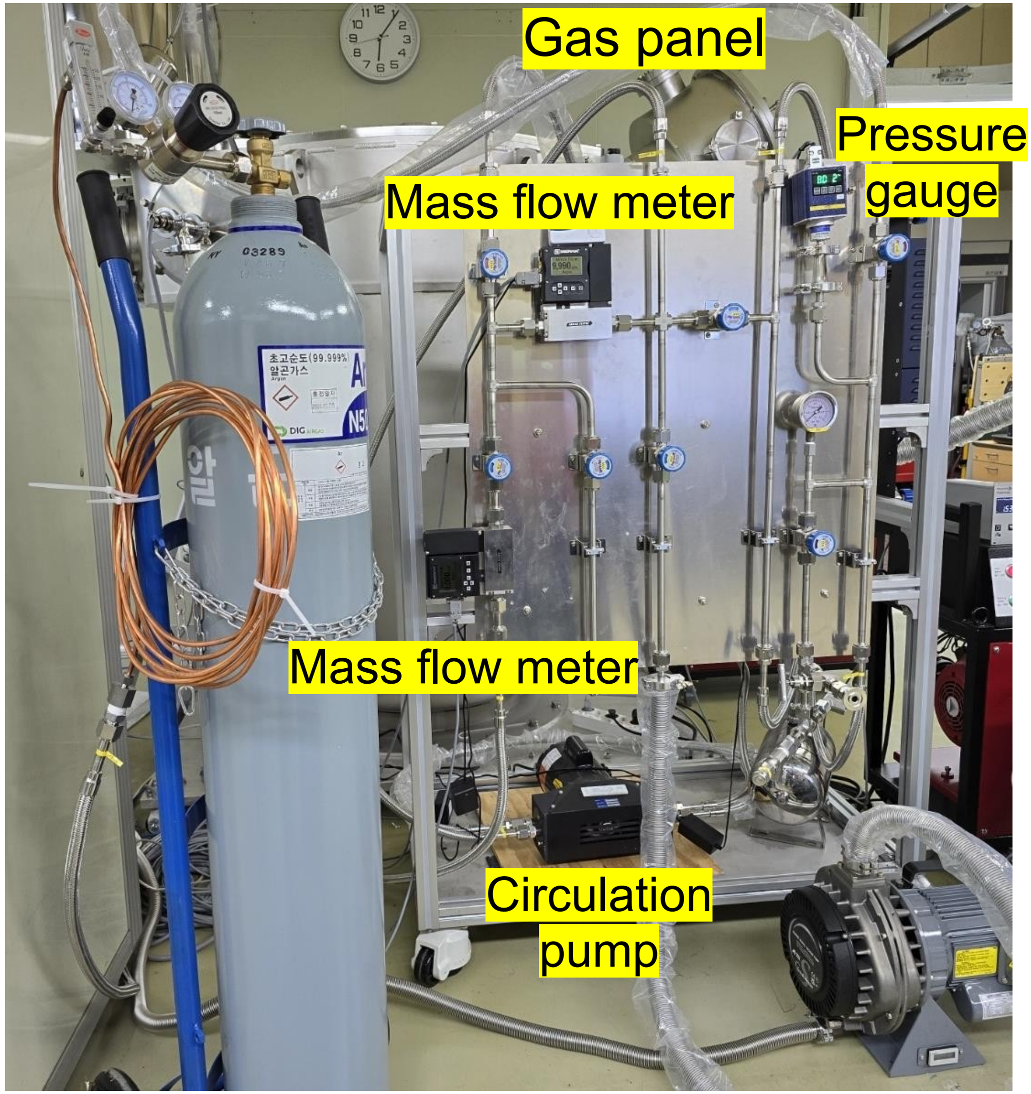
CENNS-1ton chamber test



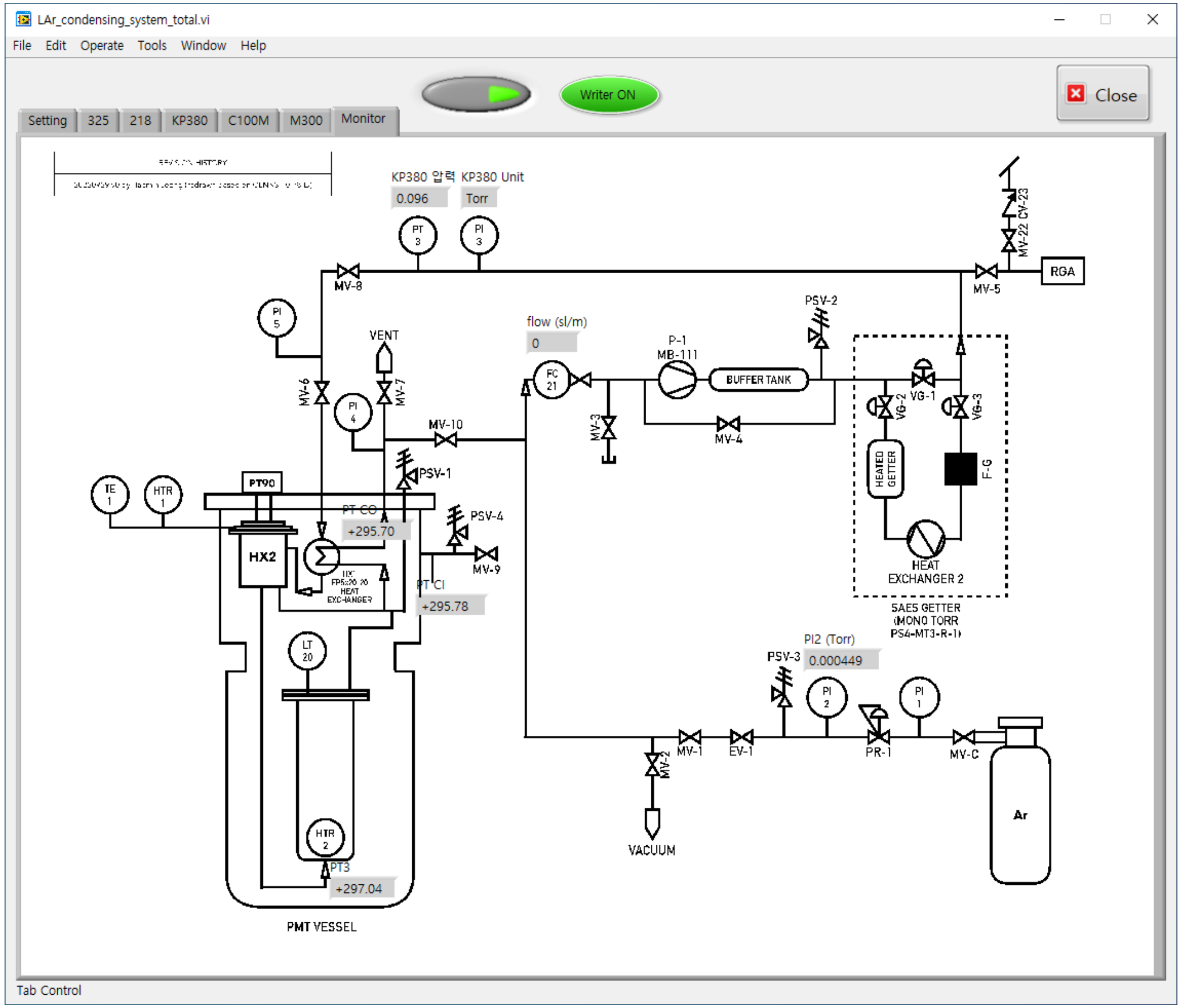


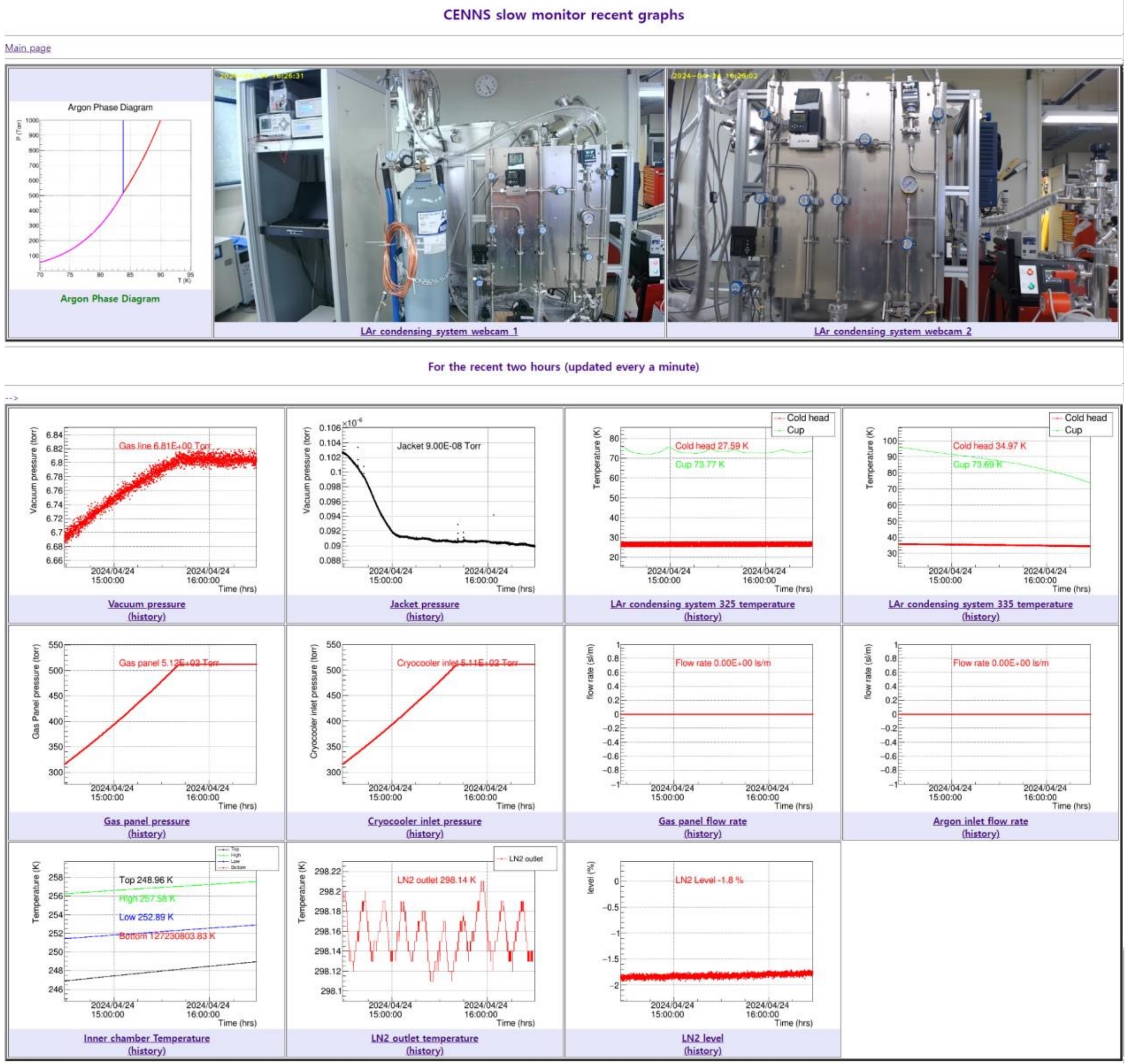
P&ID and Gas panel





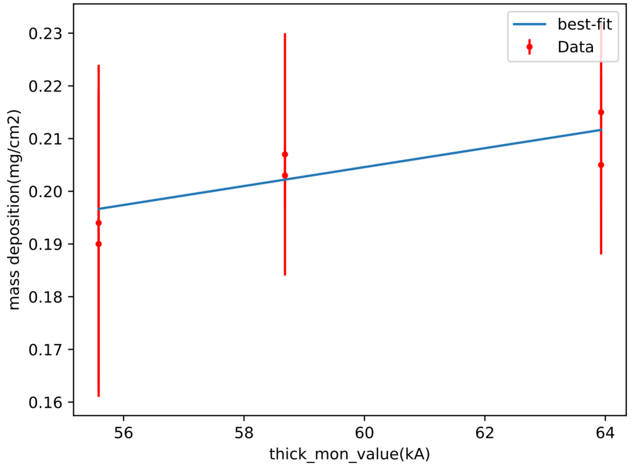
Slow monitor





PMT TPB coating

- Evaporator test has been completed.
- The coating thickness is verified by measuring the weight of a witness plate.
- PMT TPB coating is in production at a thickness of 0.20 mg/cm^2.



Additional R&D at SNU

- The purification speed of liquid argon (~40 kg/h) is much faster than that of gaseous argon (~5 kg/h)
- Purifies impurities by passing through filters (activated copper for O2 and a molecular sieve for H2O)
- Argon purity will be measured through the pulse shape of scintillation light