A ton-scale Liquid Argon Detector for Coherent Elastic Neutrino-Nucleus Scattering Experiment

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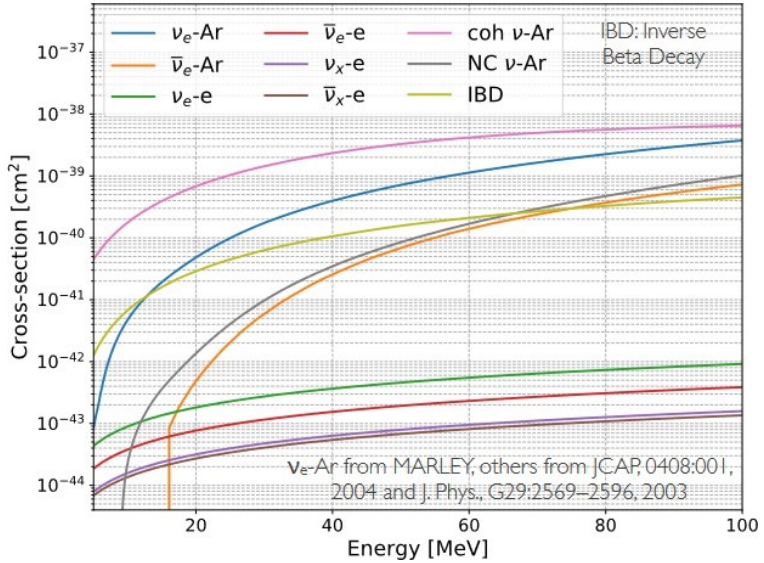
Coherent Elastic Neutrino Nucleus Scattering (CEvNS)

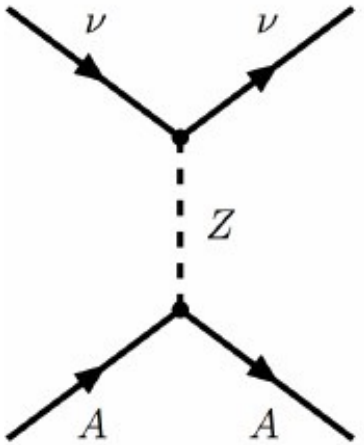
- Neutral weak-current theorized in 1974
- Neutrino interacts with a whole nucleus when QR < 1
- Precise cross section within the Standard Model

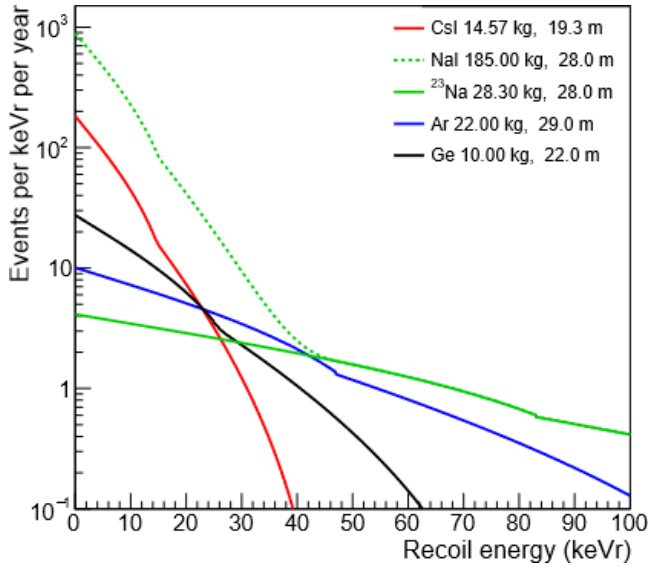
$$\frac{d\sigma}{dT} = \frac{G_F^2 M}{2\pi} Q_W^2 \left(2 - \frac{2T}{E_\nu} - \frac{MT}{E_\nu^2}\right)$$

M: Nucleus mass, T: recoil energy, Q_W : weak charge

- 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

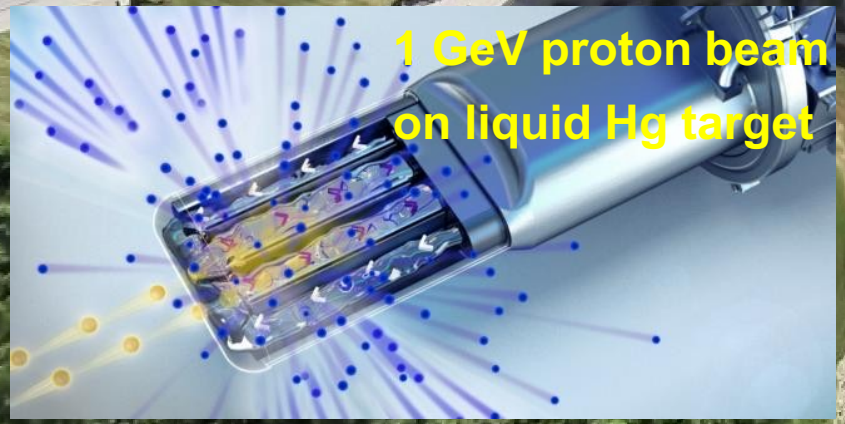


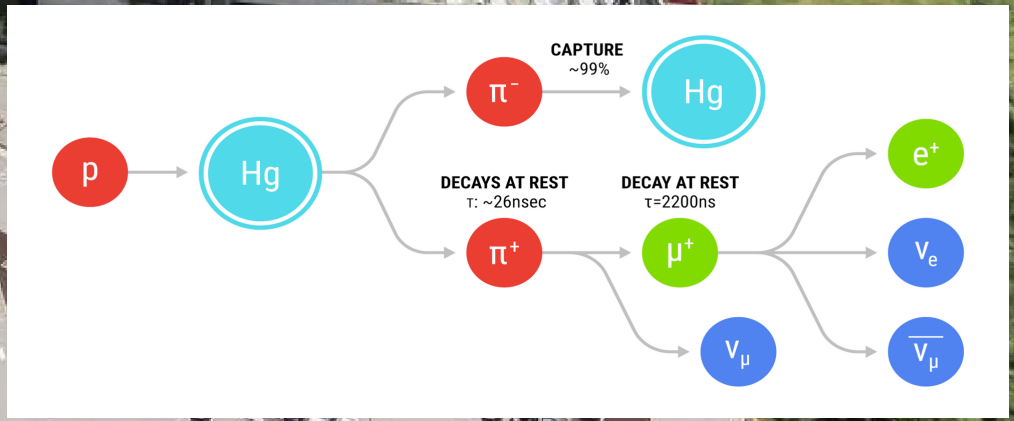




Spallation Neutron Source (SNS) at ORNL

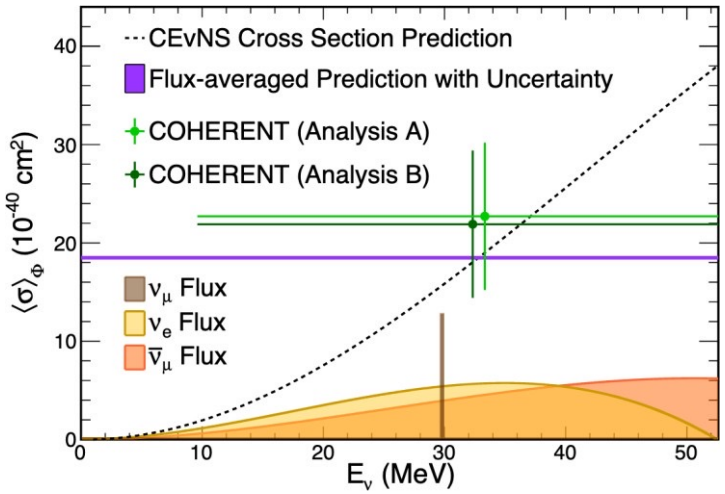
Proton LINAC
Proton beam energy: 0.9-1.3 GeV
Total power: ~1.4 MW

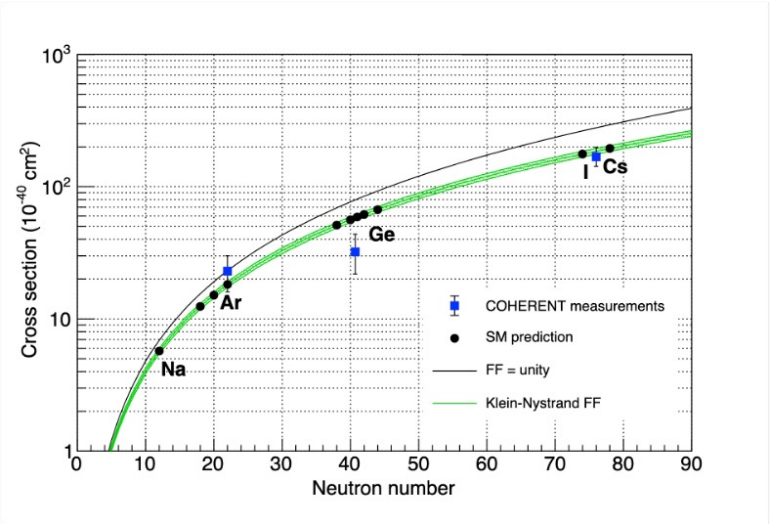


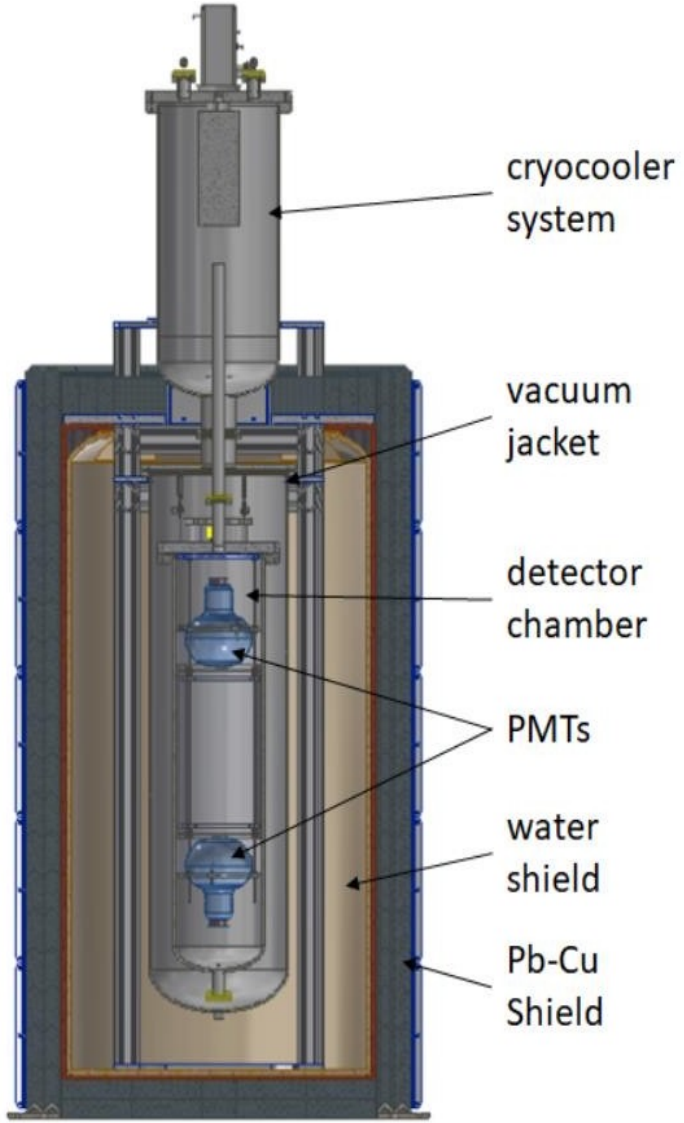


CENNS-10

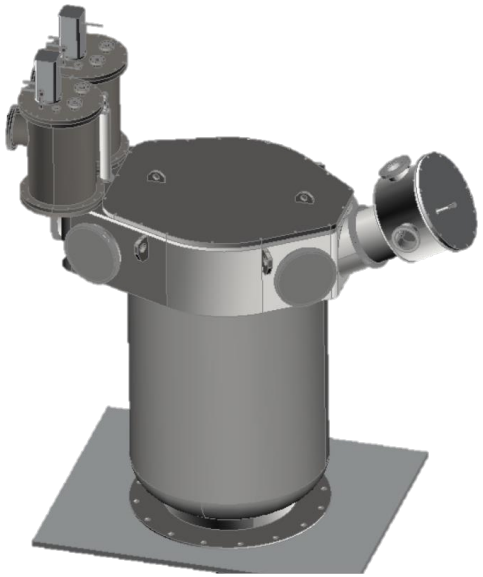
- 24-kg single phase Liquid Argon detector with 2 PMT
- Measured CEvNS cross section 3.5σ in 2020 (within 1σ of SM)
- Verified N^2 dependence of CEvNS cross section with CsI detector
- Measured 159 $\pm$ 43 CEvNS event (SM predicted: 128 $\pm$ 17)
- ~30% statistical uncertainty on CEvNS event

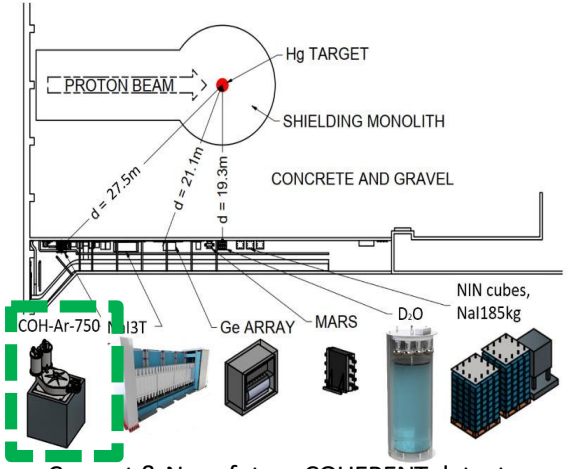




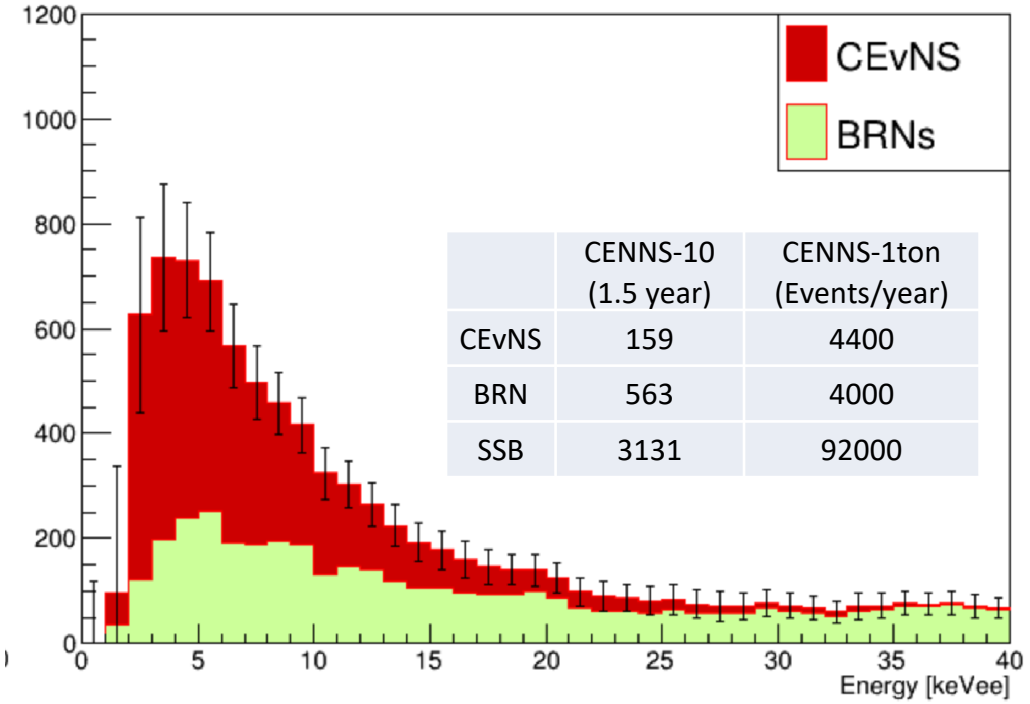


CENNS-1ton





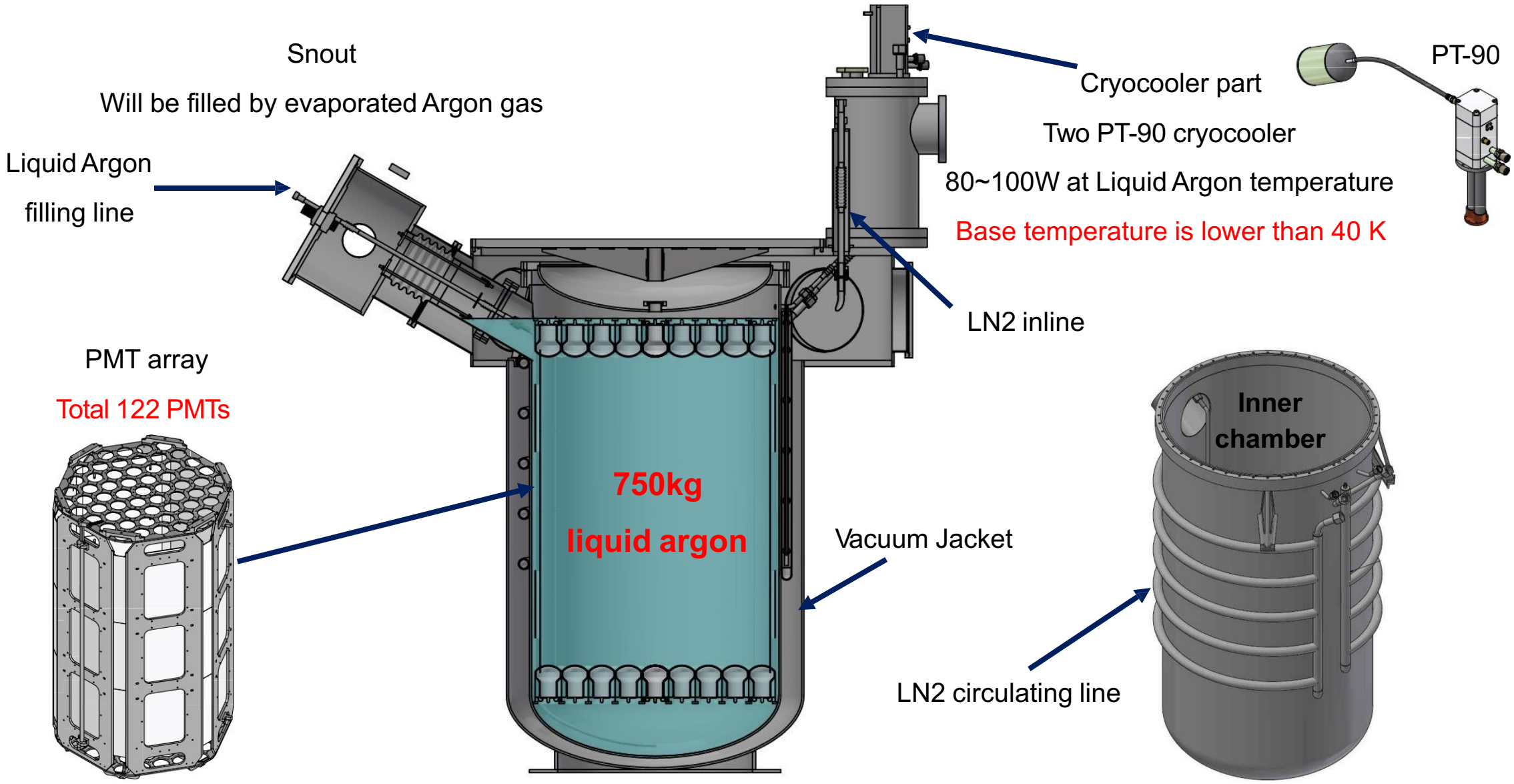
Current & Near-future COHERENT detectors



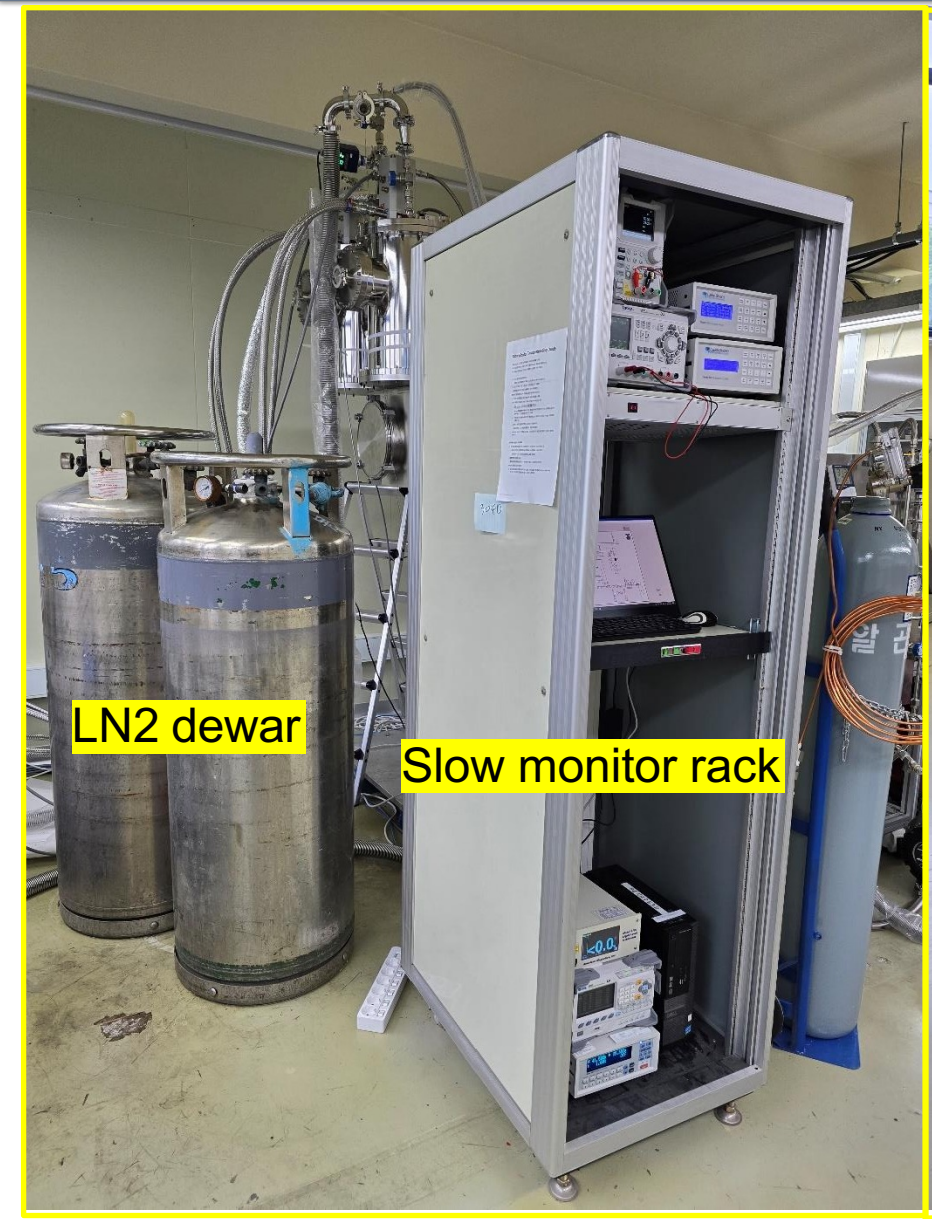
	CENNS-10 (1.5 year)	CENNS-1ton (Events/year)
CEvNS	159	4400
BRN	563	4000
SSB	3131	92000

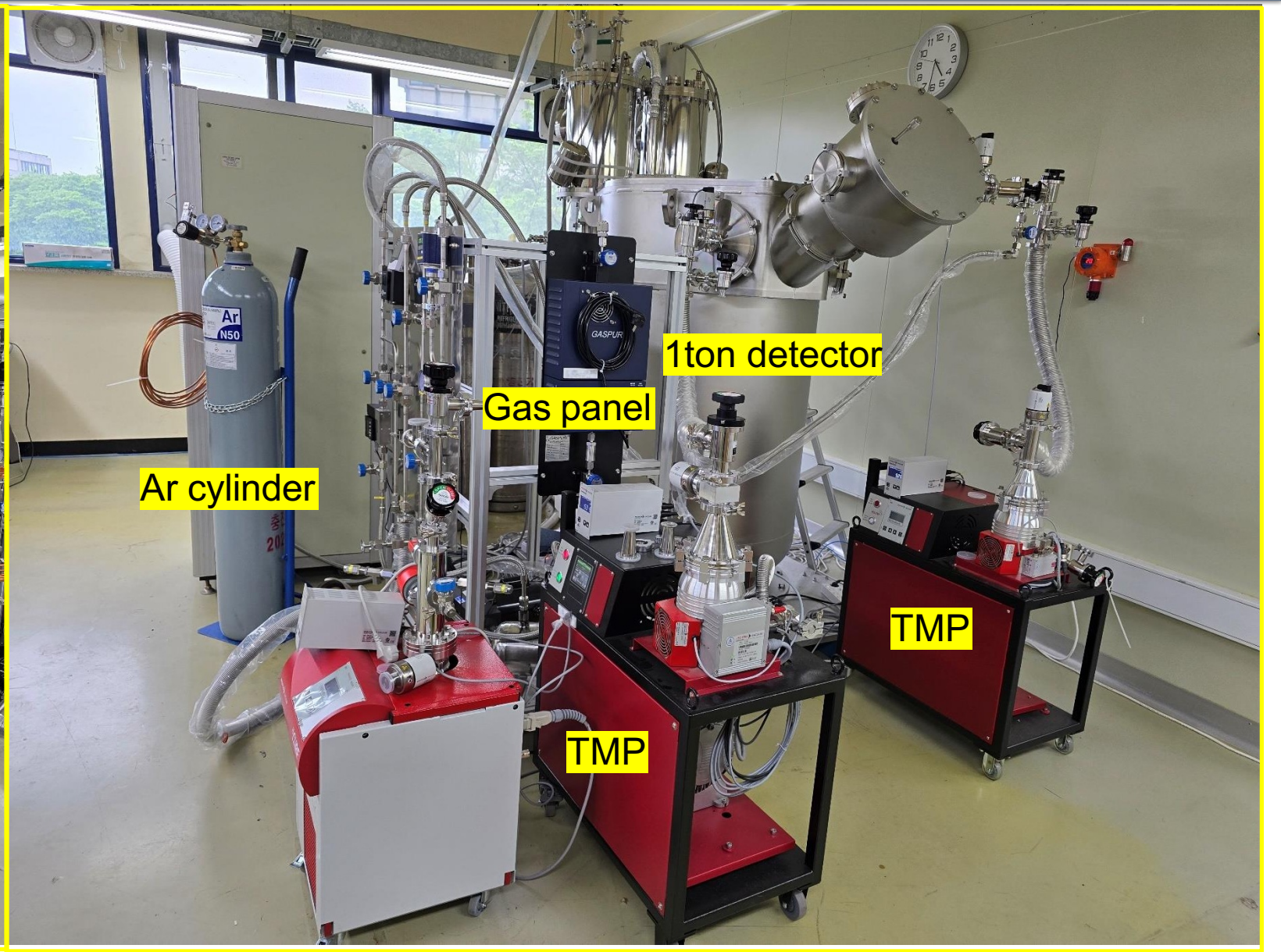
- Liquid Argon detector with 122 PMTs
- Replacing CENNS-10 at the same location (Neutrino Alley at ORNL)
- Expect ~4400 CEvNS event/year.
- Measure CEvNS with 5% precision in 3 years.
- Precision physics study.
  (Non-standard neutrino interaction (NSI), Neutron radius, Beam produced Dark Matter...)

CENNS-1ton detector overview



CENNS-1ton detector at SNU

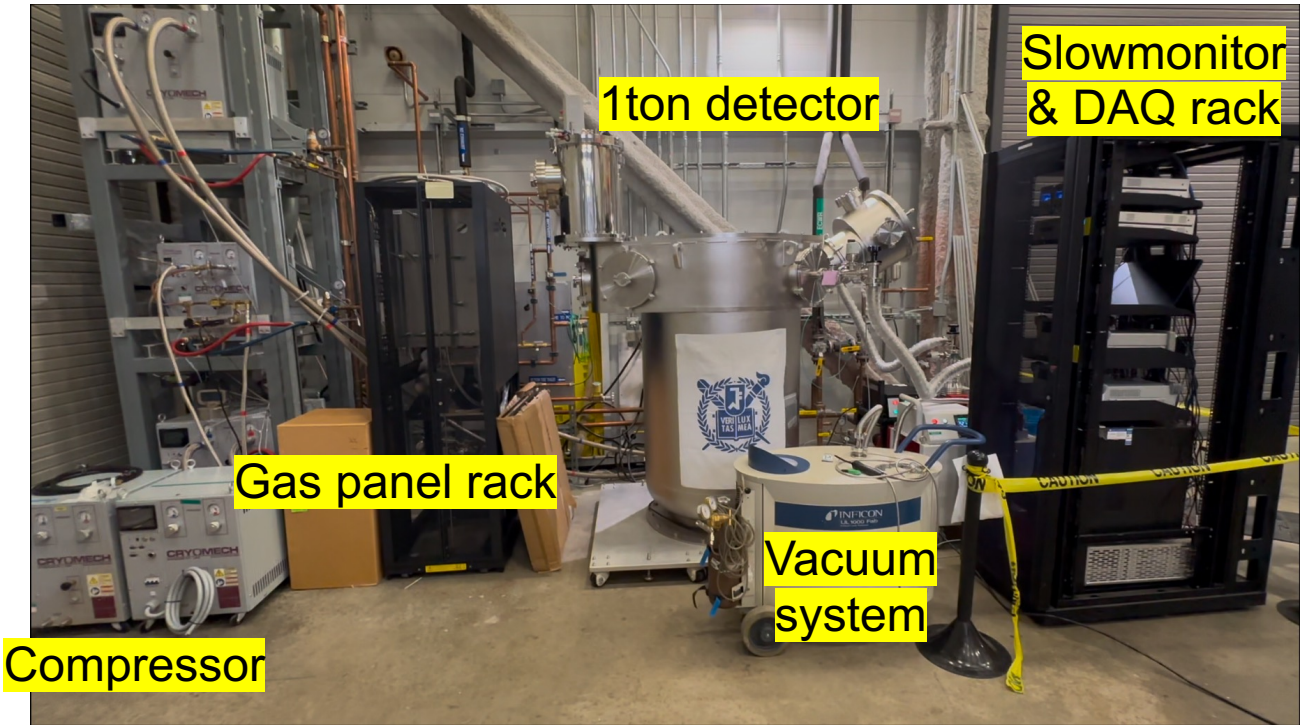


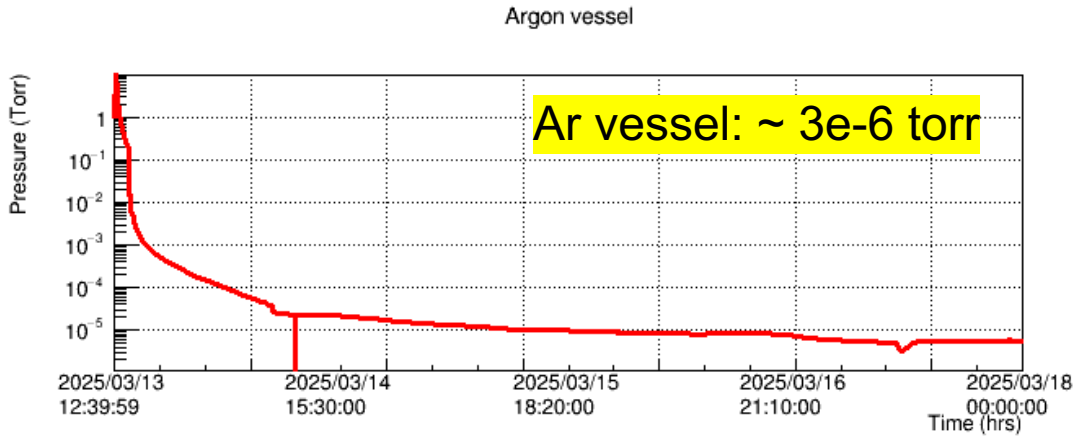


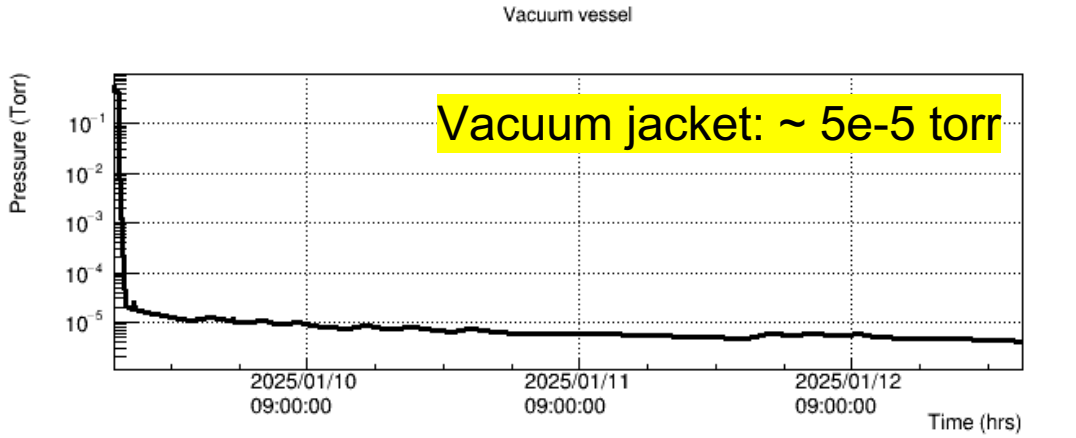
CENNS-1ton detector at ORNL

- Assembled the modules into the main chamber.

- Conducted vacuum tests on each volume.
  - Ar vessel: ~ 3e-6 torr.
  - Vacuum jacket: ~ 5e-5 torr.

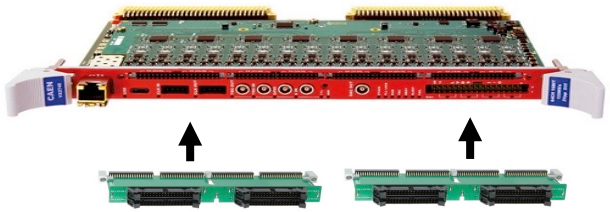






DAQ

CAEN VME8004X
- 4 slot mini crate.

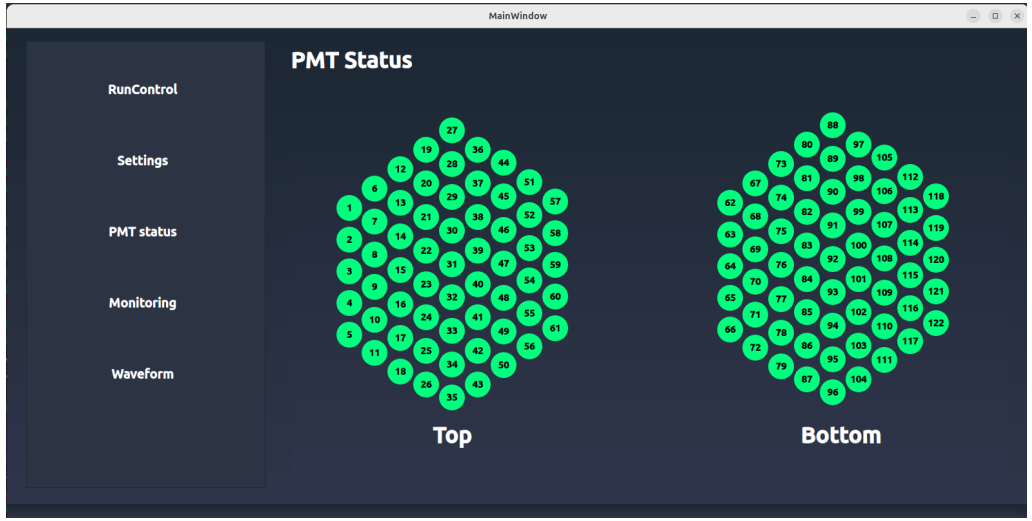


CAEN VX2740
- 64 Channels.
- ADC resolution: 16bits.
- Sampling rate:125 MS/s.

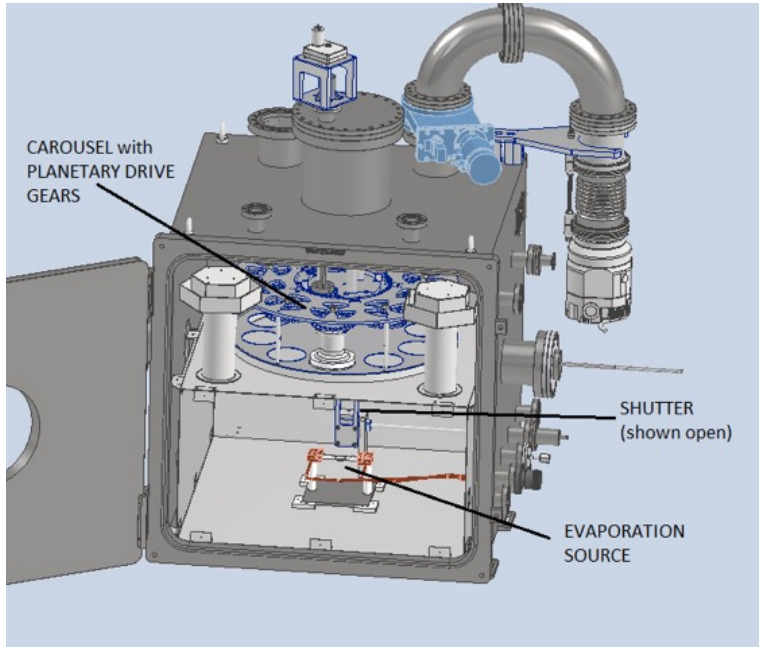
CAEN SY5527
- Power supply crate.

CAEN A7030P, A7030LP
- Power supply module.

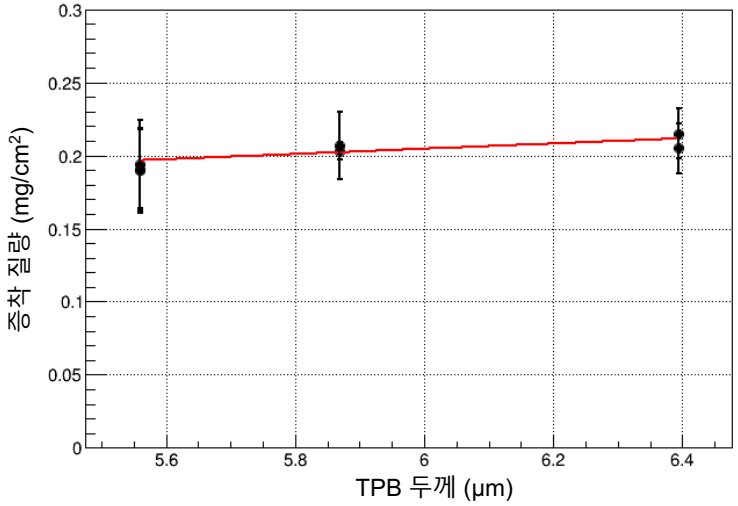
- VX2740 is replaced with the VX2740B due to noise issues.
- The PMT interface
  - Supplies high voltage to the PMTs.
  - Transmits their signals to the PC.



PMT TPB coating

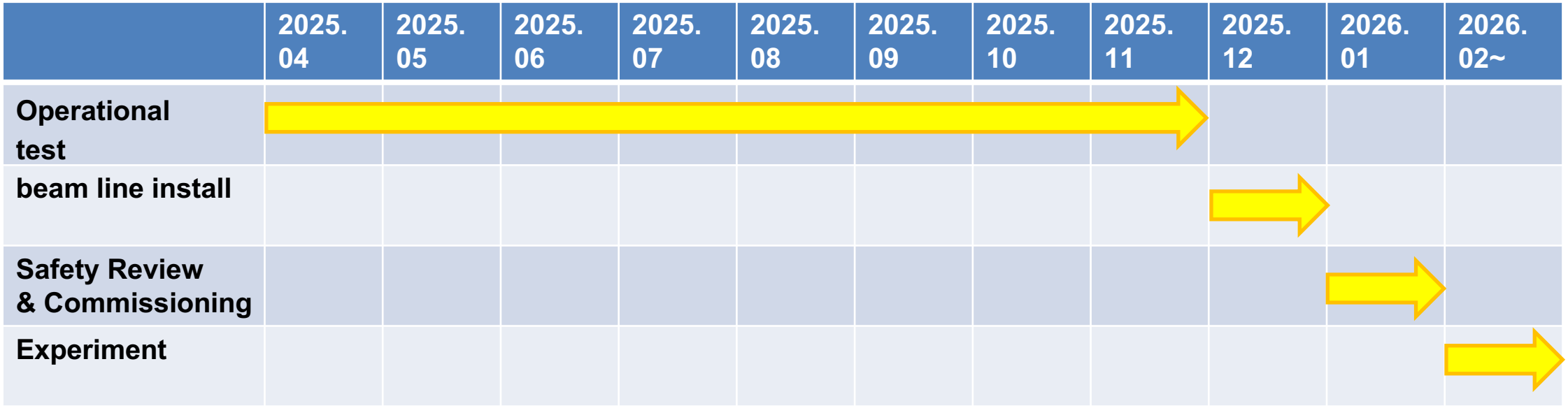


- TPB (Tetraphenyl butadiene) absorb 128nm scintillation light and re-emit them as lower-energy visible light.
- Evaporator test has been completed.
- The coating thickness is verified by measuring the weight of a witness plate.
- PMT TPB coating is in production at a thickness of 0.20 mg/cm².



Summary & Future plan

- CENNS-10 (24kg) observed CEvNS in 2020, with 30% uncertainty
- CENNS-1ton (610kg) will reduce uncertainty 5% in 3 years
- 1ton detector is fabricated and assembled.
- 1ton detector has been delivered to ORNL after performance test.
- Assembly has been completed at ORNL, and performance test is in progress.



Backup

Non-standard neutrino interaction (NSI)

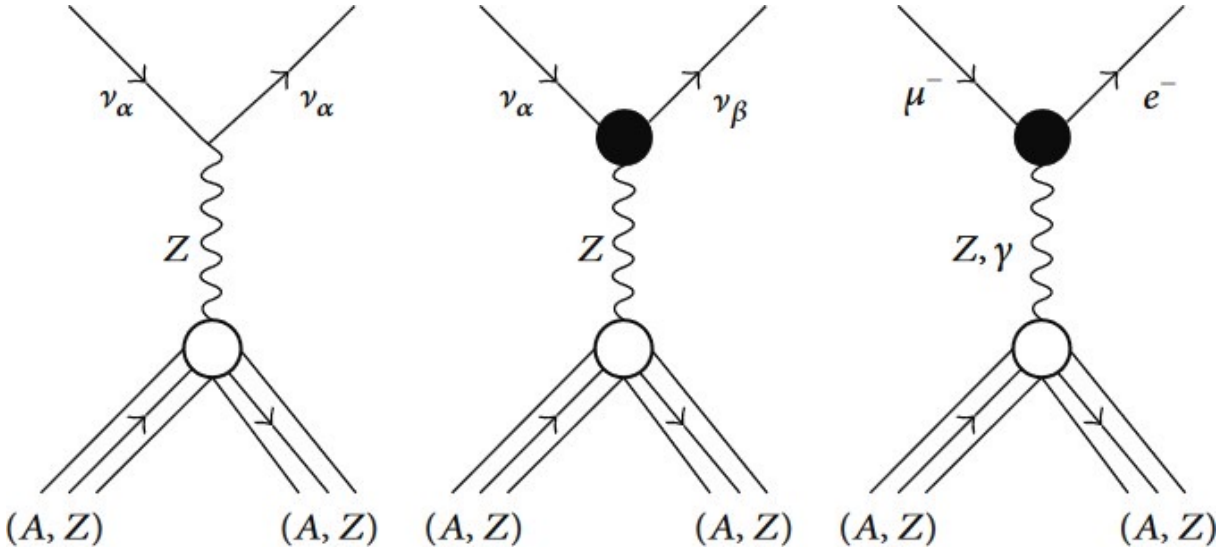
CEvNS spectrum is distorted by NSI

Kinematics term

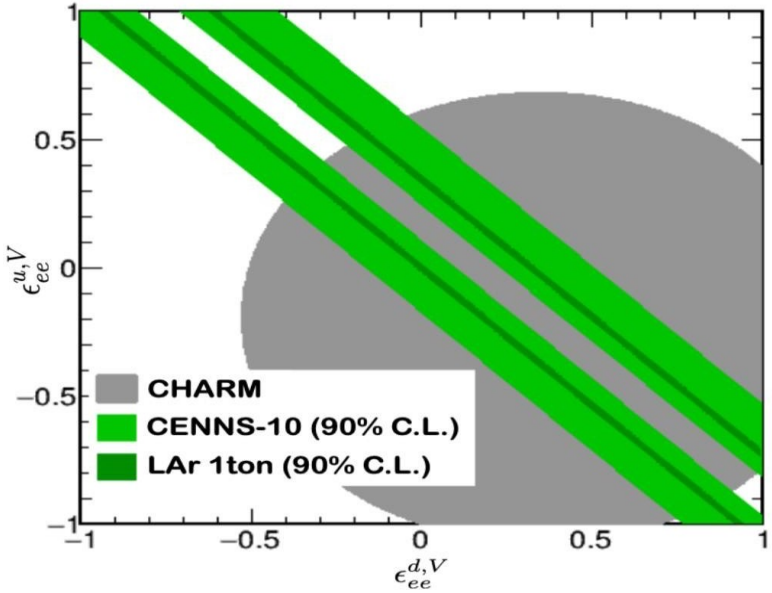
$$\frac{d\sigma}{dT} = \frac{G_F^2 M}{2\pi} Q^2_{NSI} \left(2 - \frac{2T}{E_v} - \frac{MT}{E_v^2}\right)$$

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

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

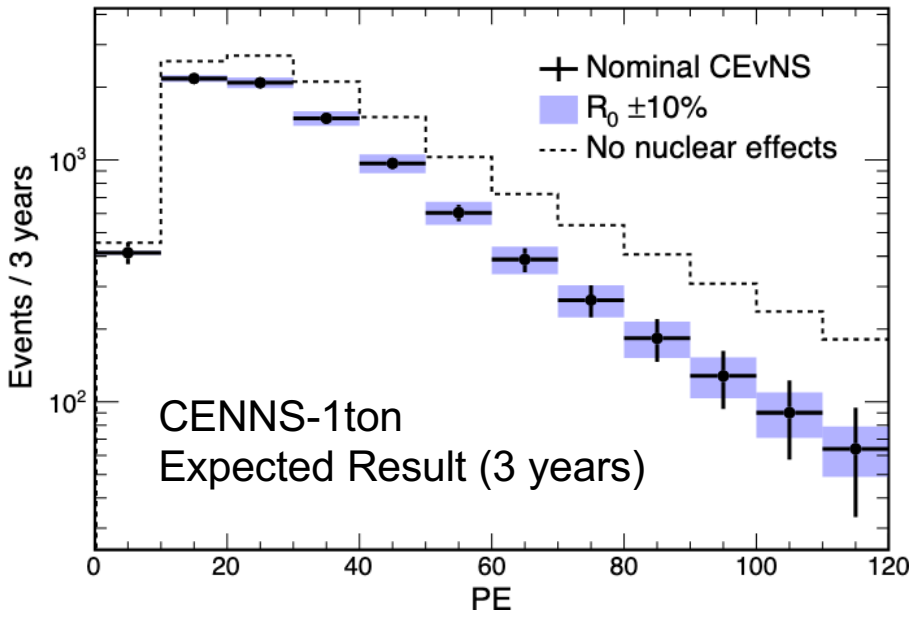
Neutron radius

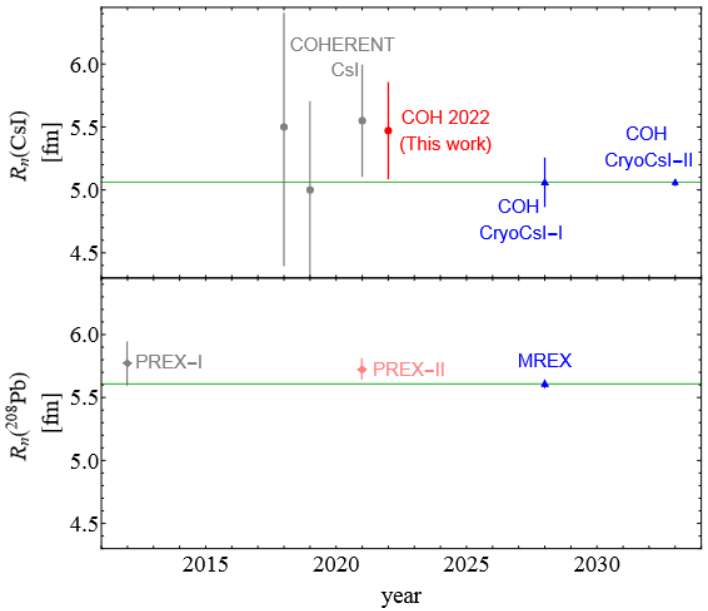
Neutron radius is encoded by nuclear form factor in weak charge

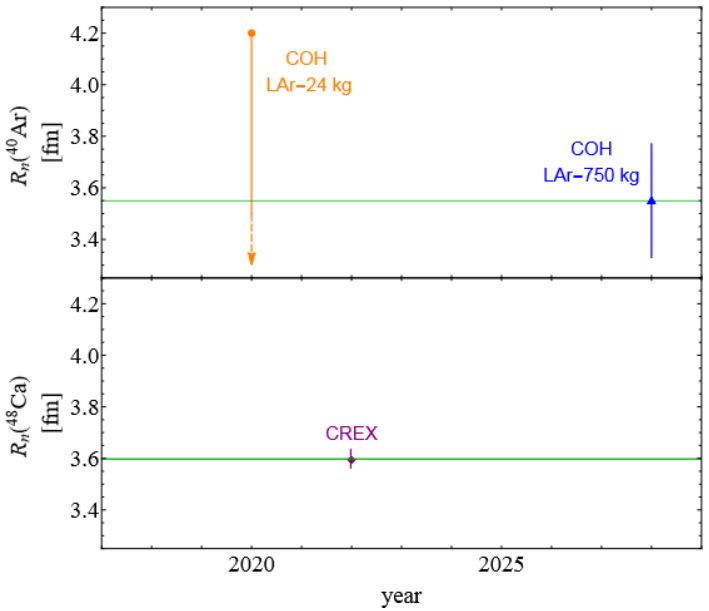
$$\frac{d\sigma}{dT} = \frac{G_F^2 M}{2\pi}\left[g_V^p Z F_p(Q^2) + g_V^n N F_n(Q^2)\right]\left(2 - \frac{2T}{E_v} - \frac{MT}{E_v^2}\right)$$

CENNS-10 first experimentally determined neutron radius in Argon

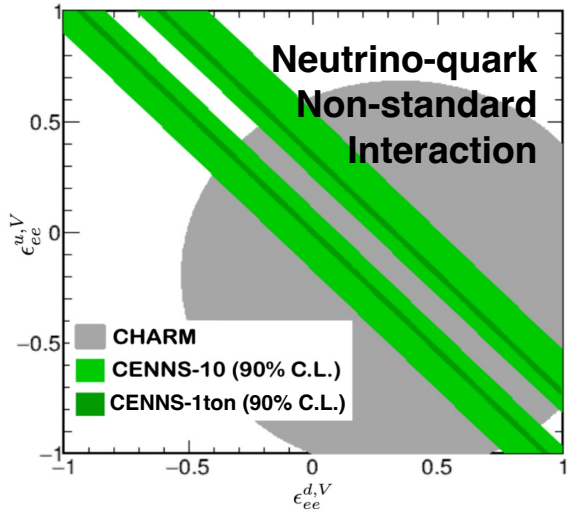
CENNS-1ton will measure $R_n(^{40}\mathrm{Ar})$ to 4.6% after 3 years

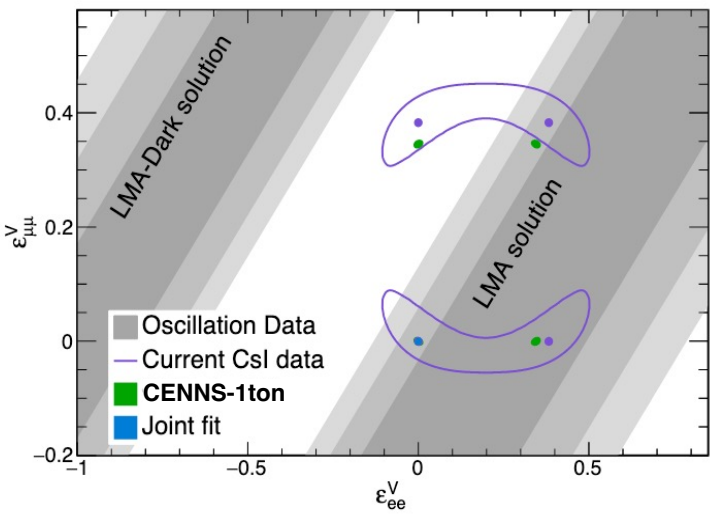


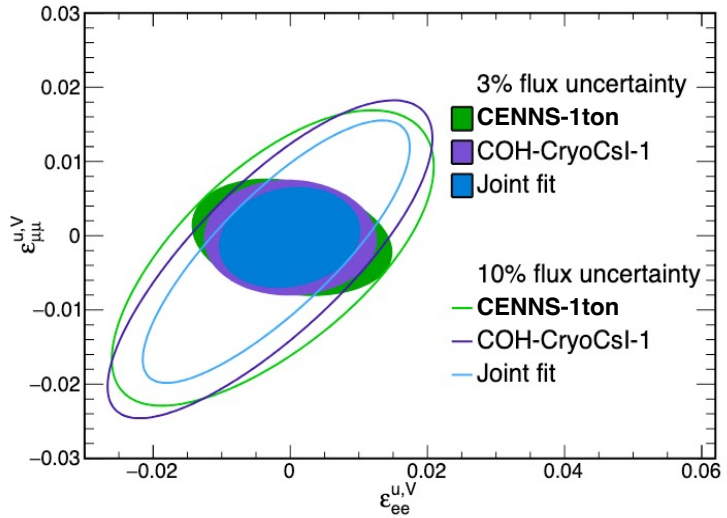


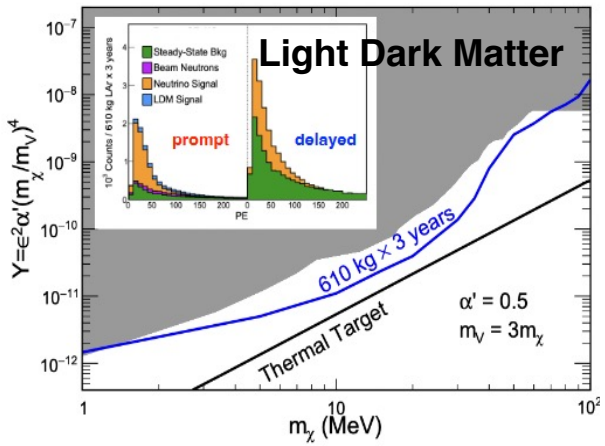


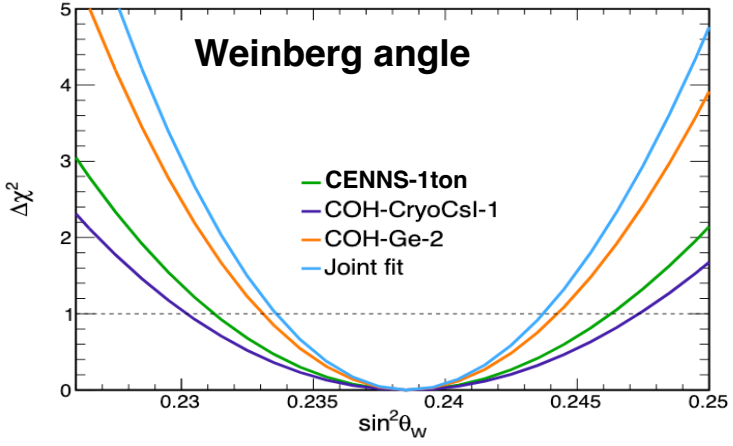
CENNS-1ton: Related physics

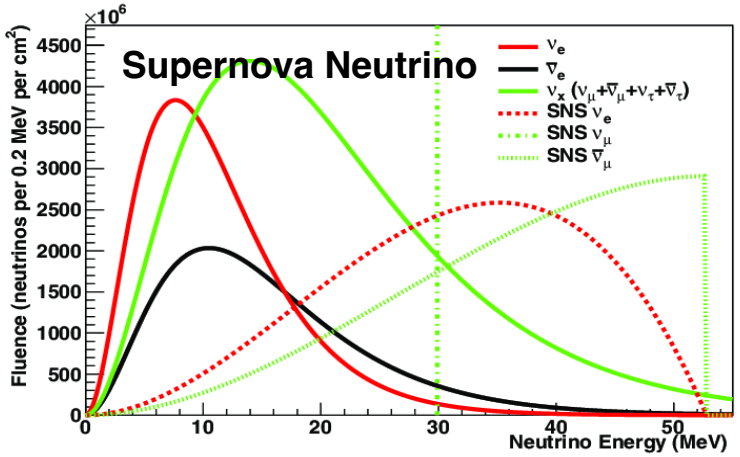




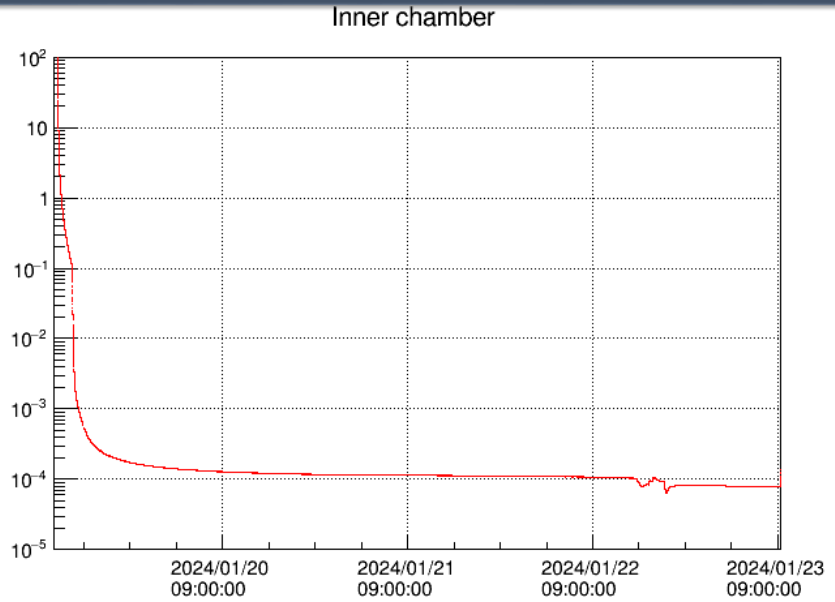


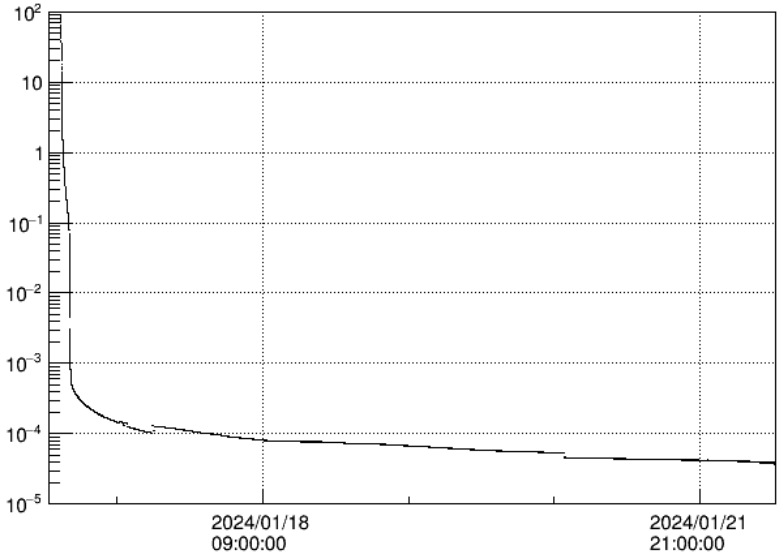


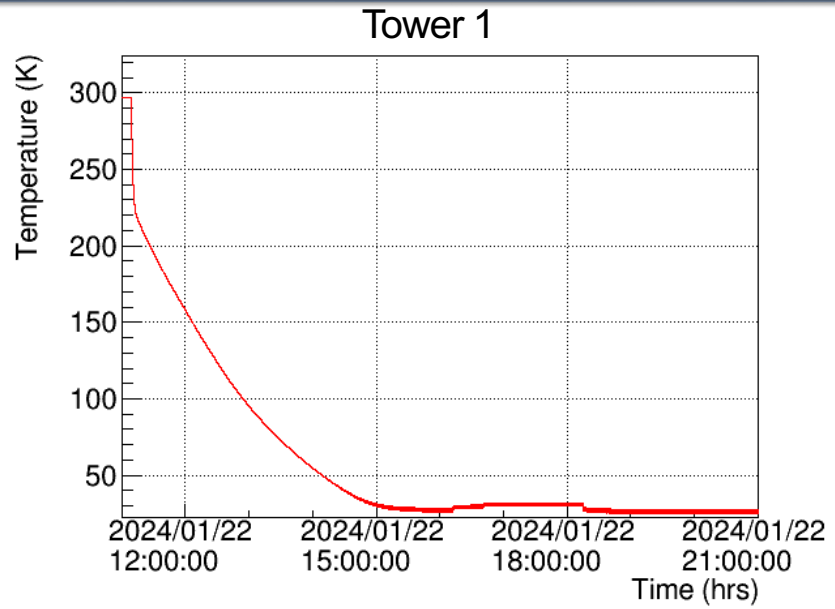


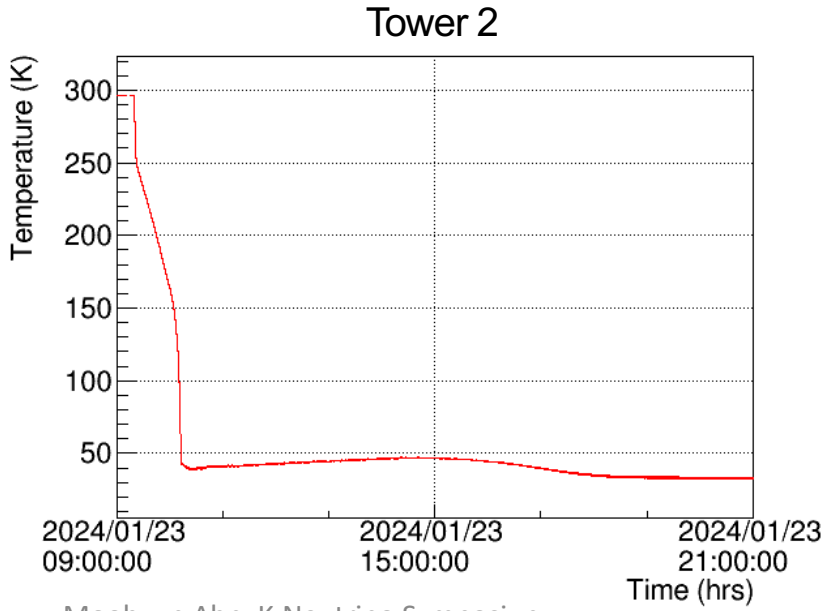


1ton chamber vacuum & cryocooler test





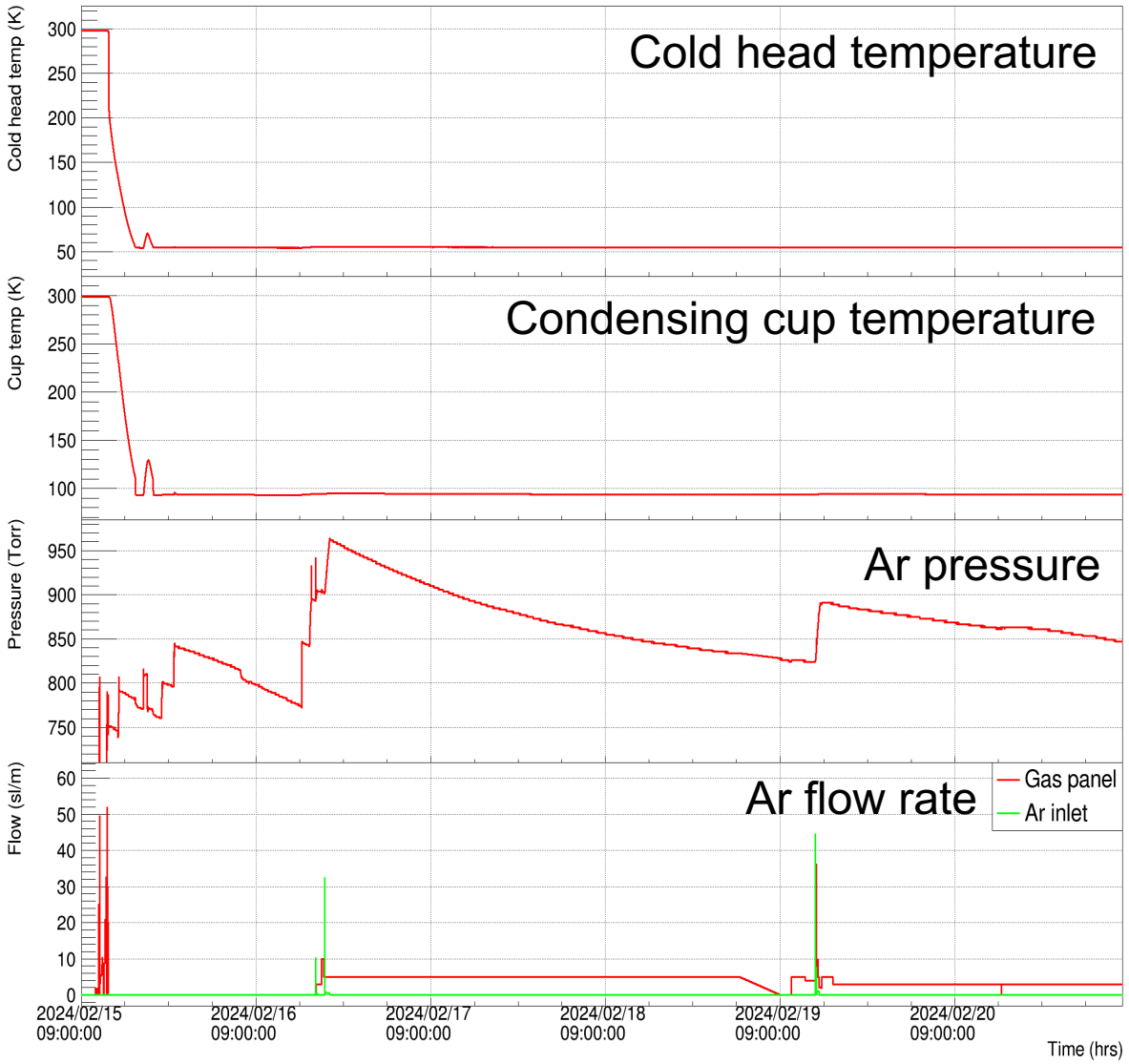


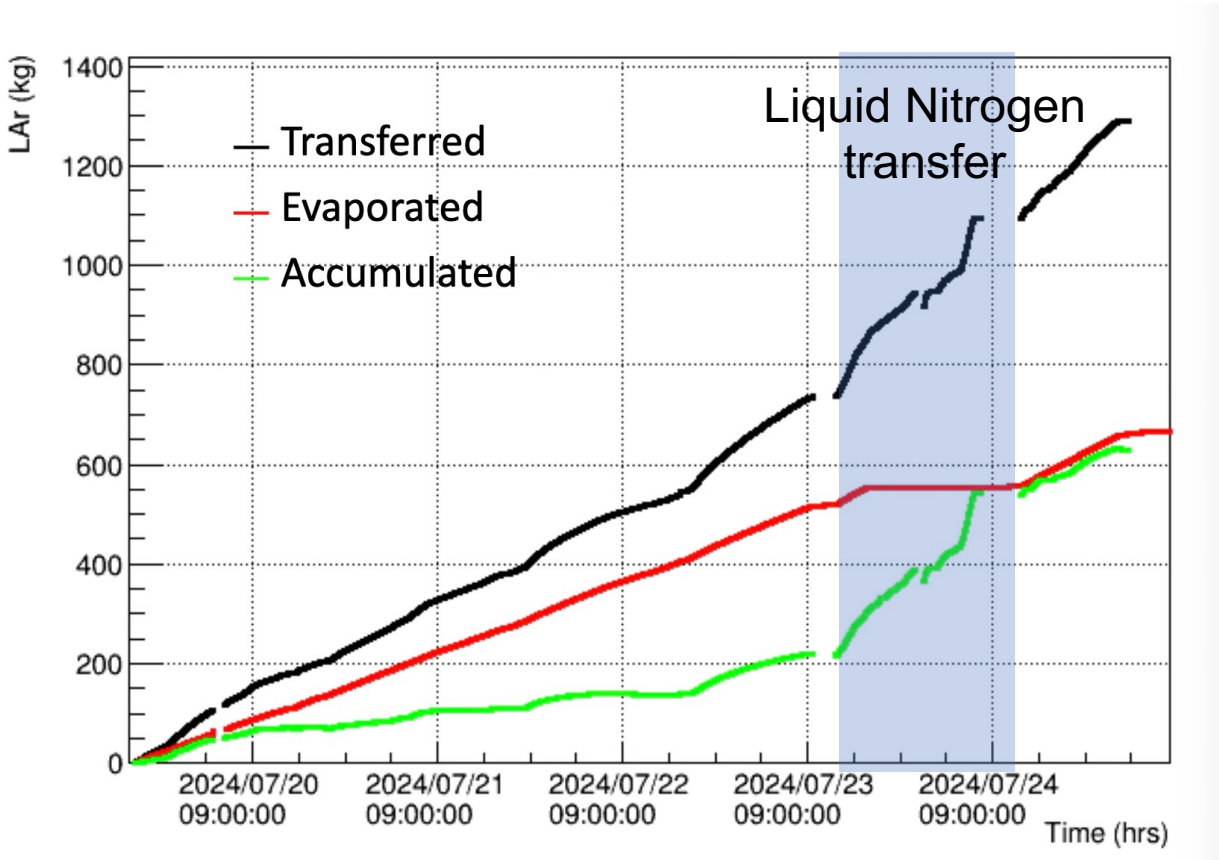


Vacuum lavel of inner cham ber and vacuum jacket is lo wer than 1e-4 torr.

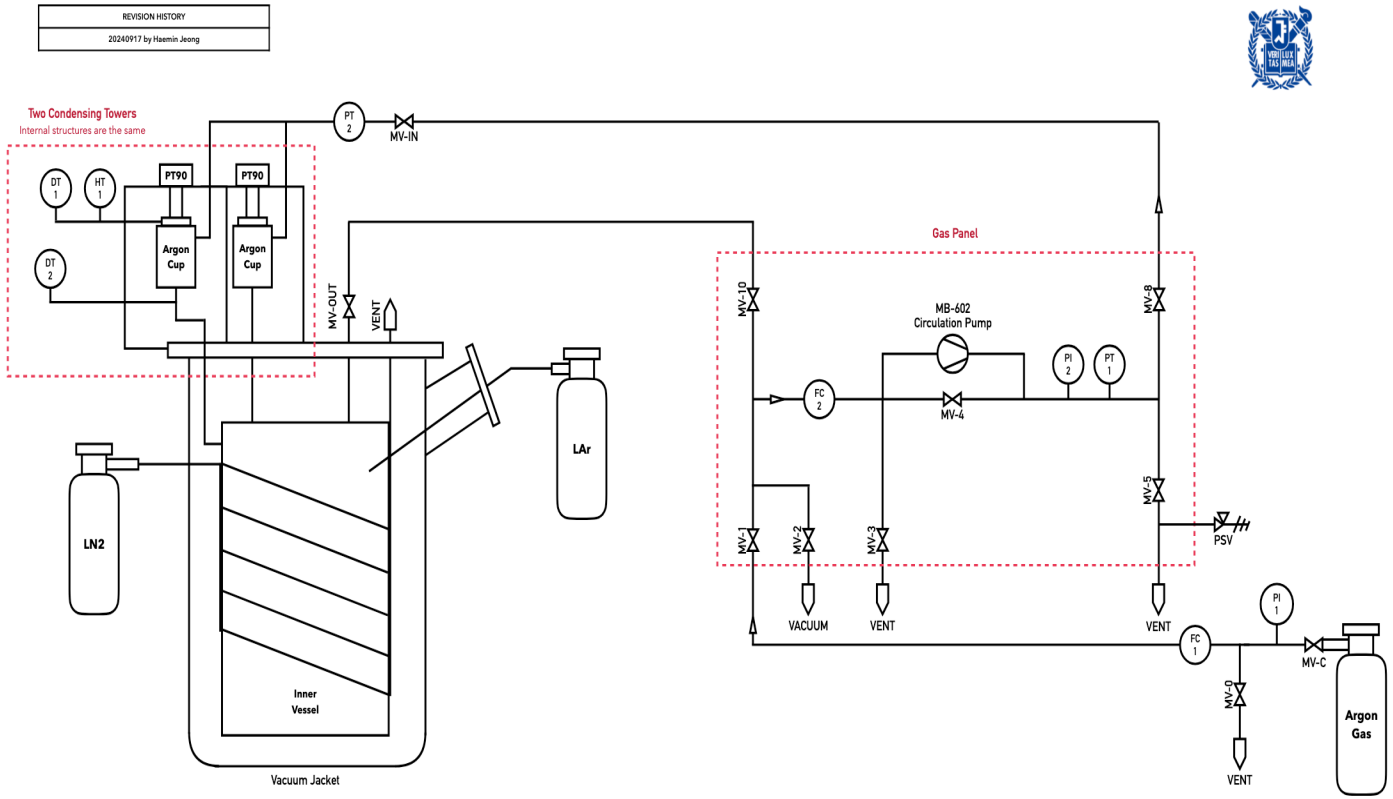
Base temperature of each tower is lower than 40 K.

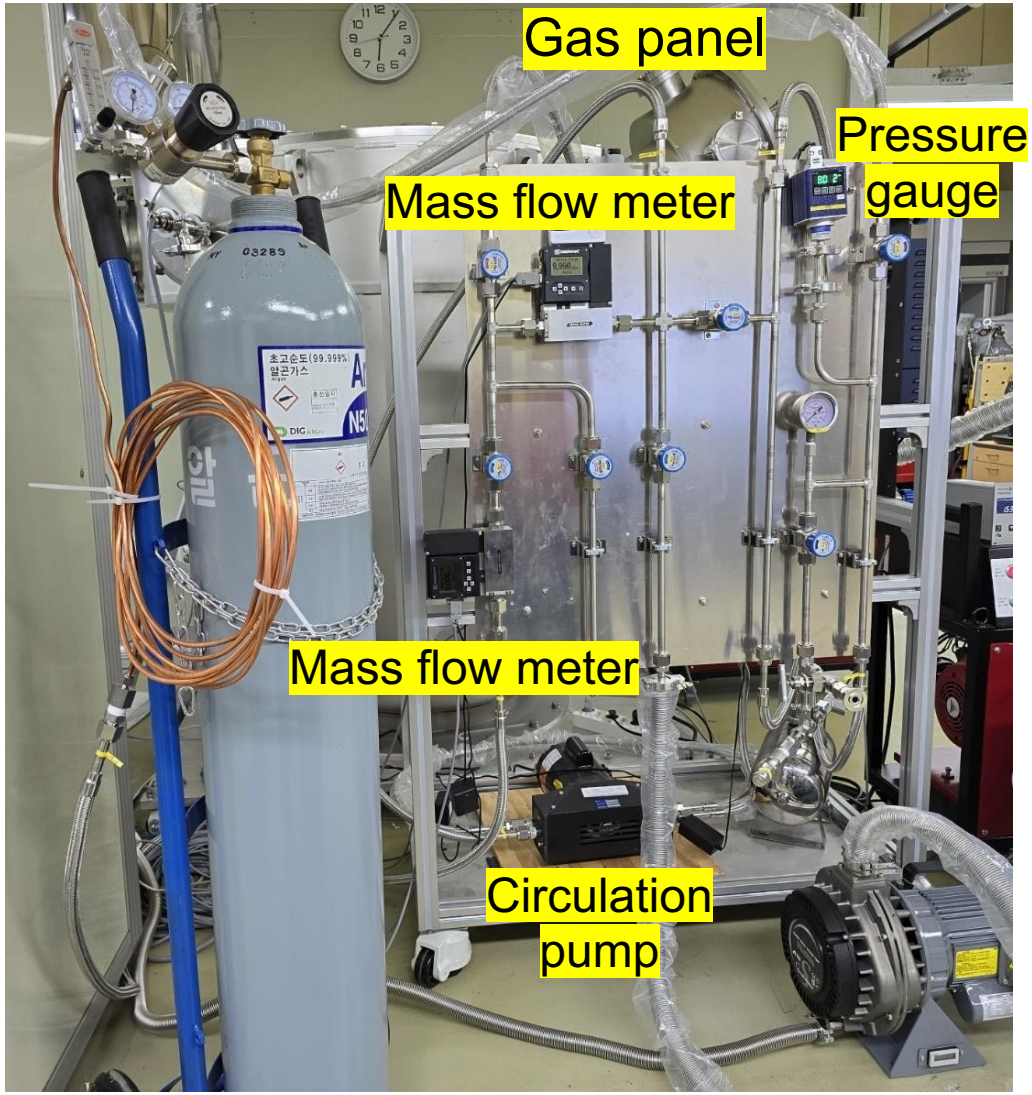
CENNS-1ton chamber test



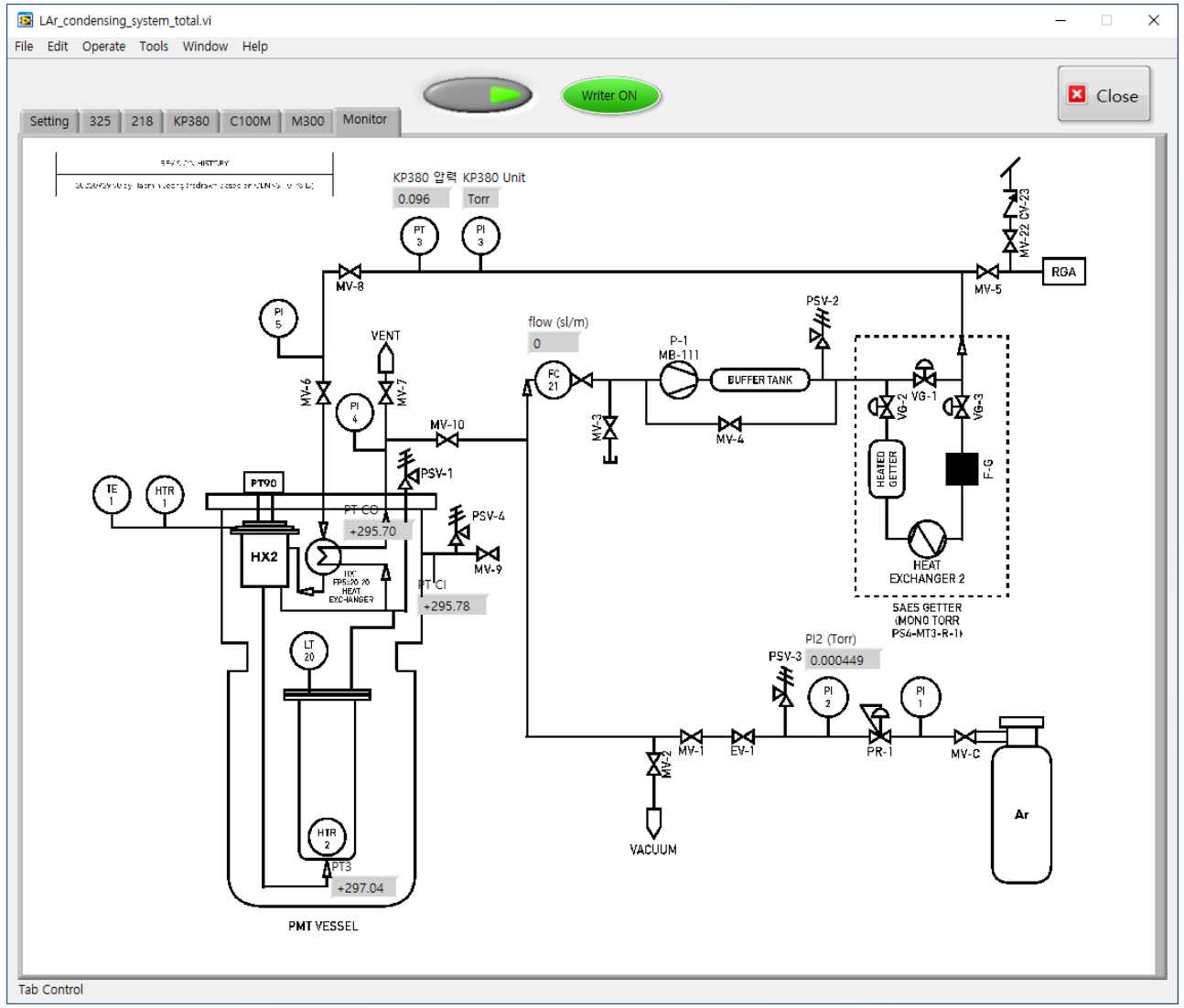


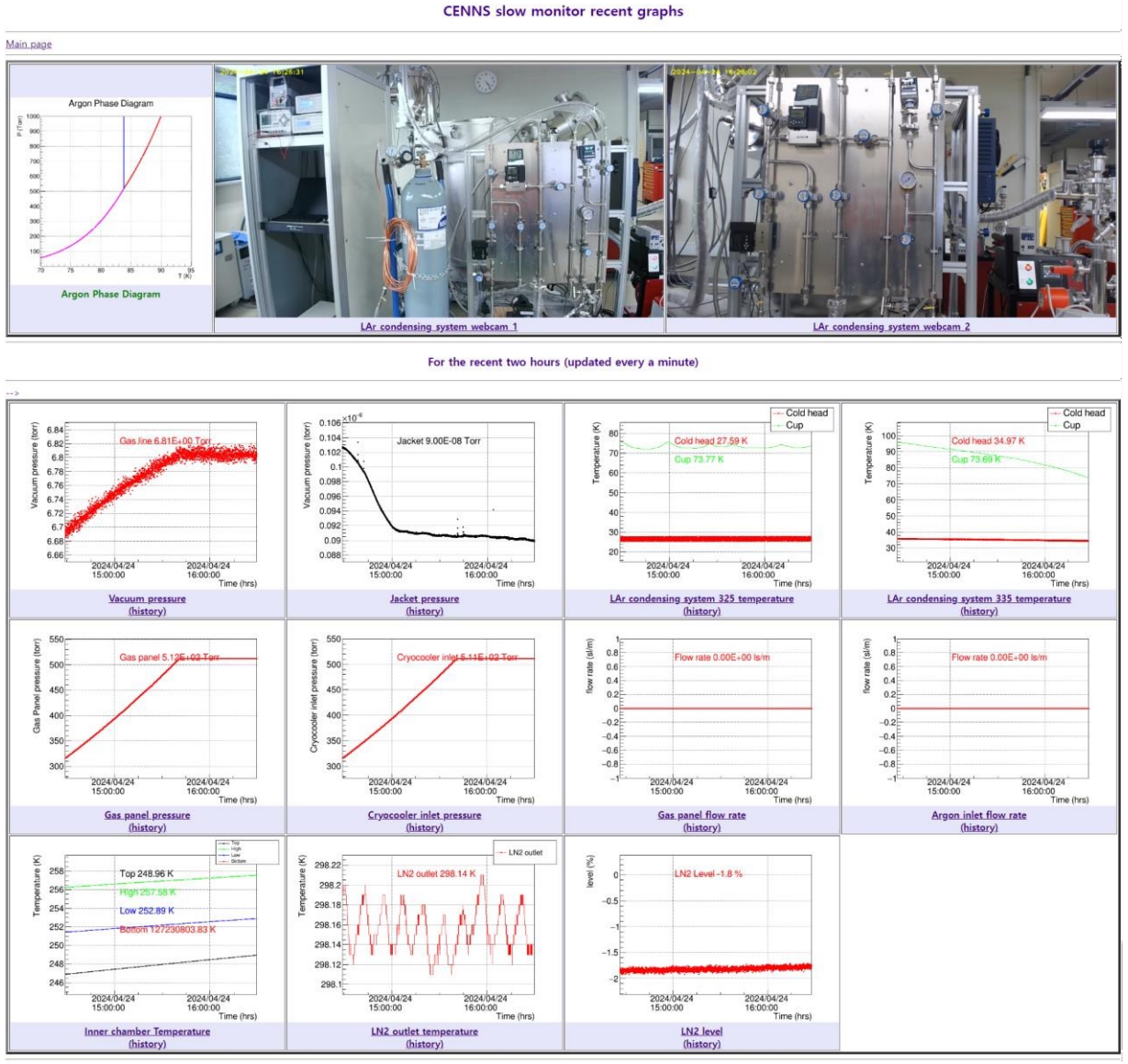
P&ID and Gas panel





Slow monitor

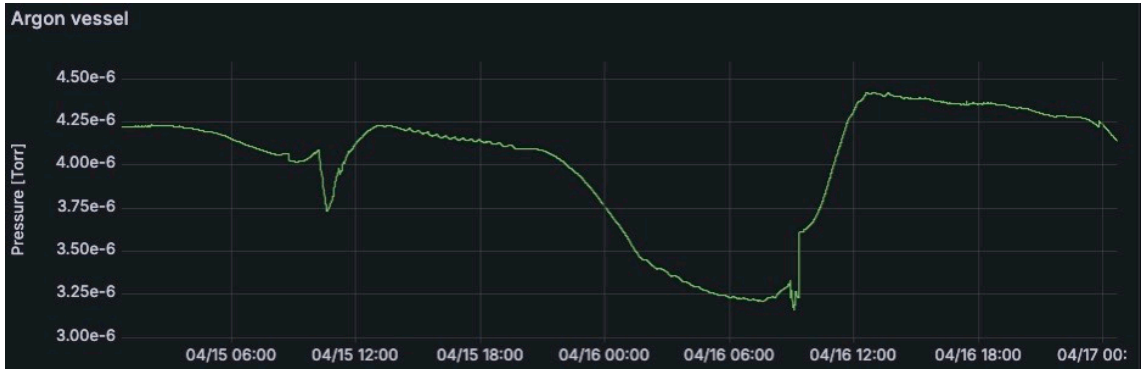


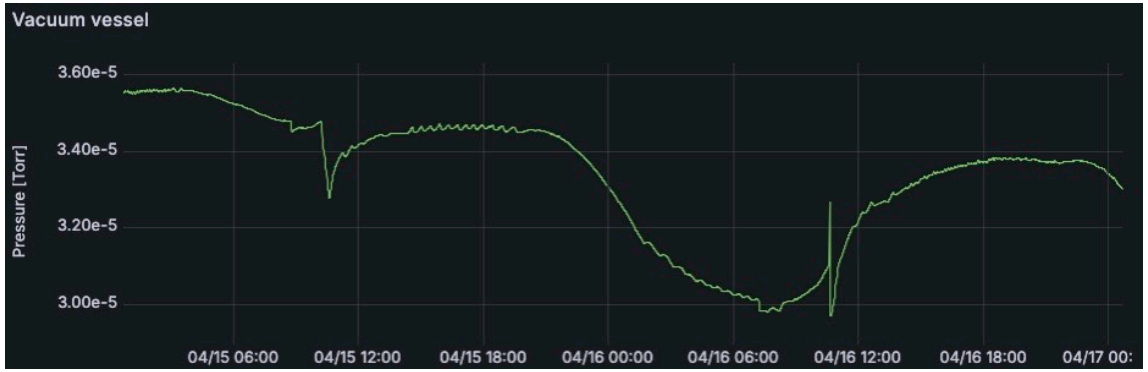


Main Chamber Assembly

- Assembled the modules into the main chamber.

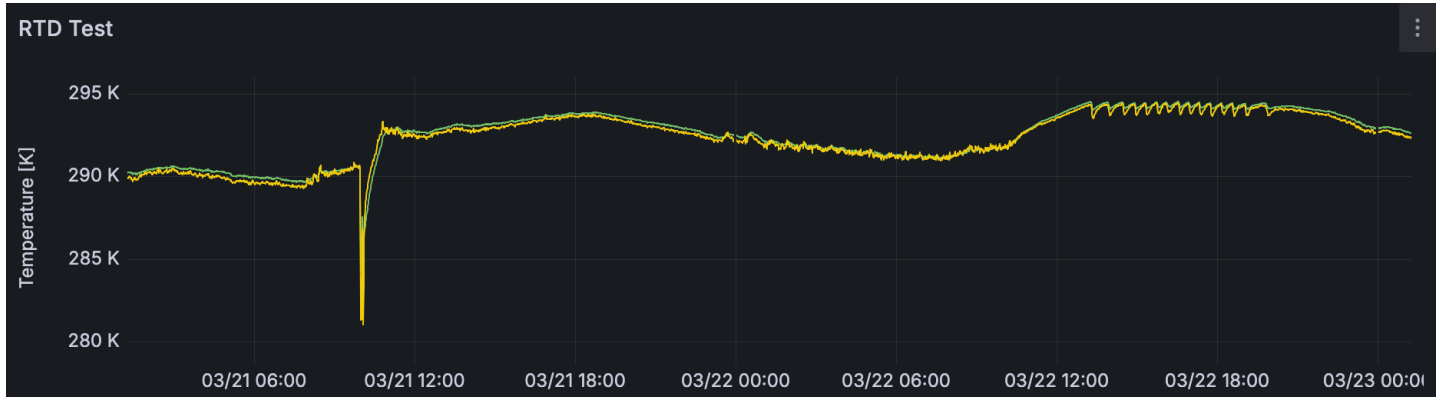
- Conducted vacuum tests on each volume.
  - Ar vessel: ~ 3e-6 torr.
  - Vacuum jacket: ~ 5e-5 torr.

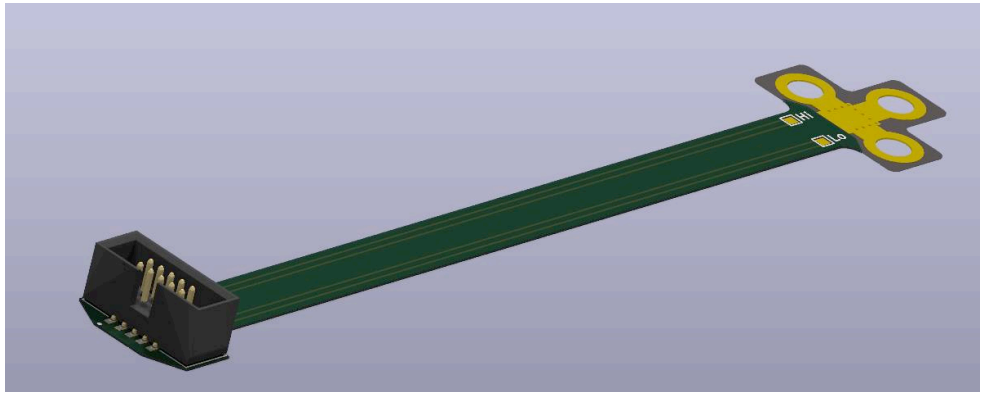




CENNS-1ton chamber test at ORNL

- Vacuum test after reassembly
  - Ar vessel: ~ 3e-6 torr.
  - Vacuum jacket: ~ 5e-5 torr.
- Cooling test and Argon gas condensing test are planned.
- Planning to install RTDs in the 1-ton chamber.
- RTD performance test in progress.

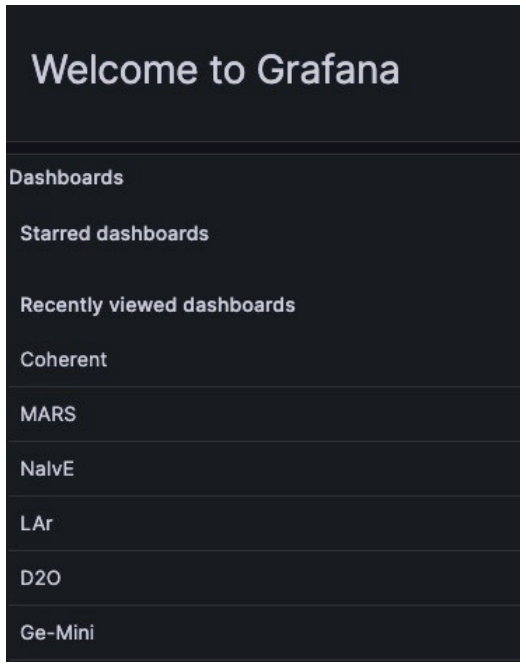




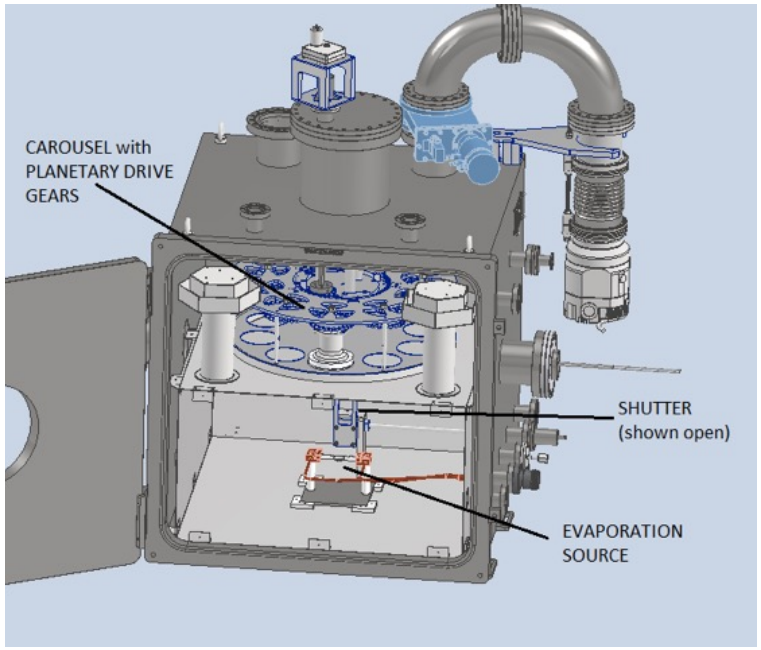
Slow Monitoring

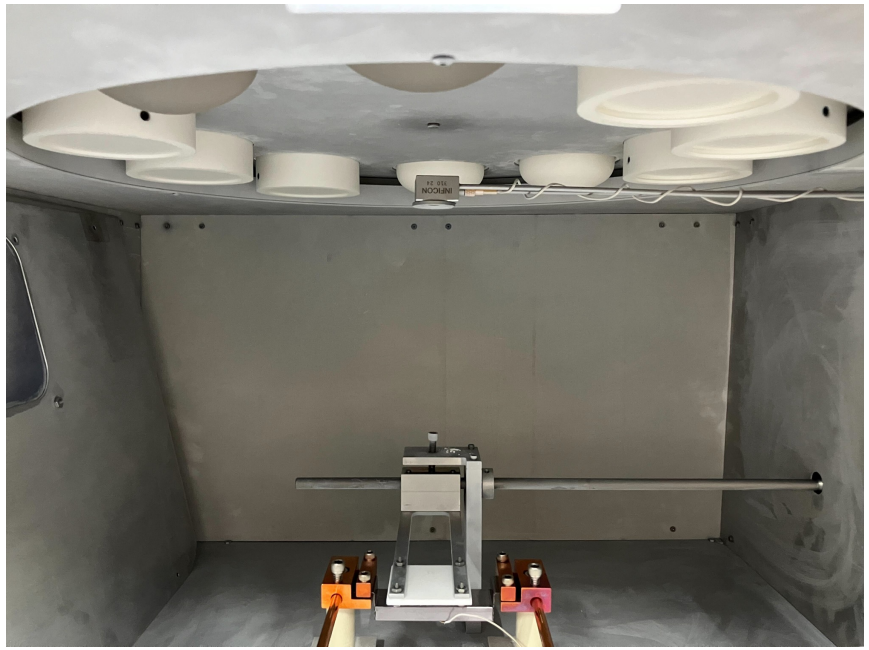
Workflow

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



PMT TPB coating

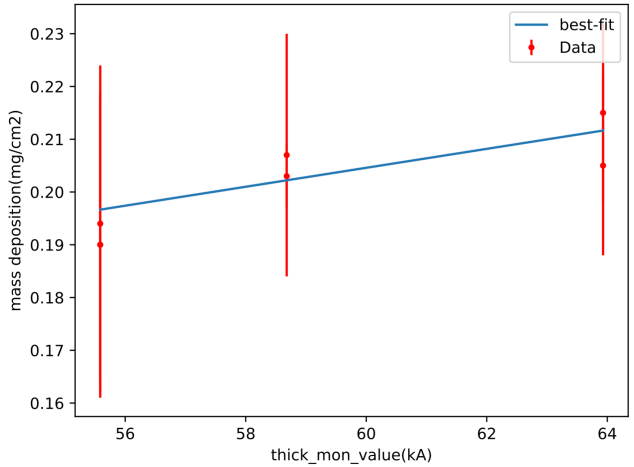




- TPB (Tetraphenyl butadiene) absorb 128nm scintillation light and re-emit them as lower-energy visible light.
- The system is designed to heat TPB under vacuum while monitoring the temperature and thickness in real time.
- The PMT and carousel independently rotate at 2 RPM during the coating process.

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/cm².



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