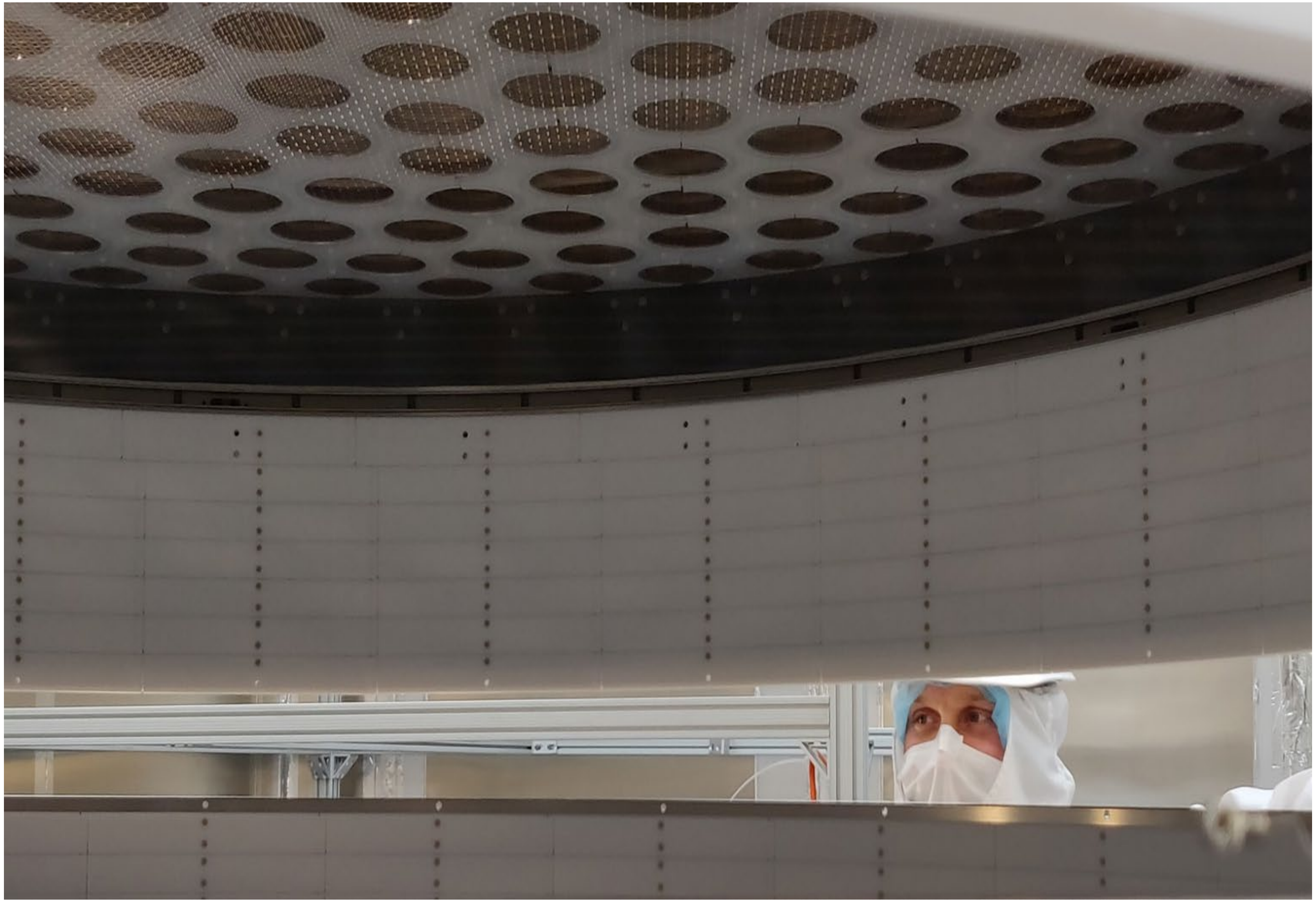
Purification Results from the LZ WIMP Search

Carter Hall,
University of Maryland

February 16, 2024

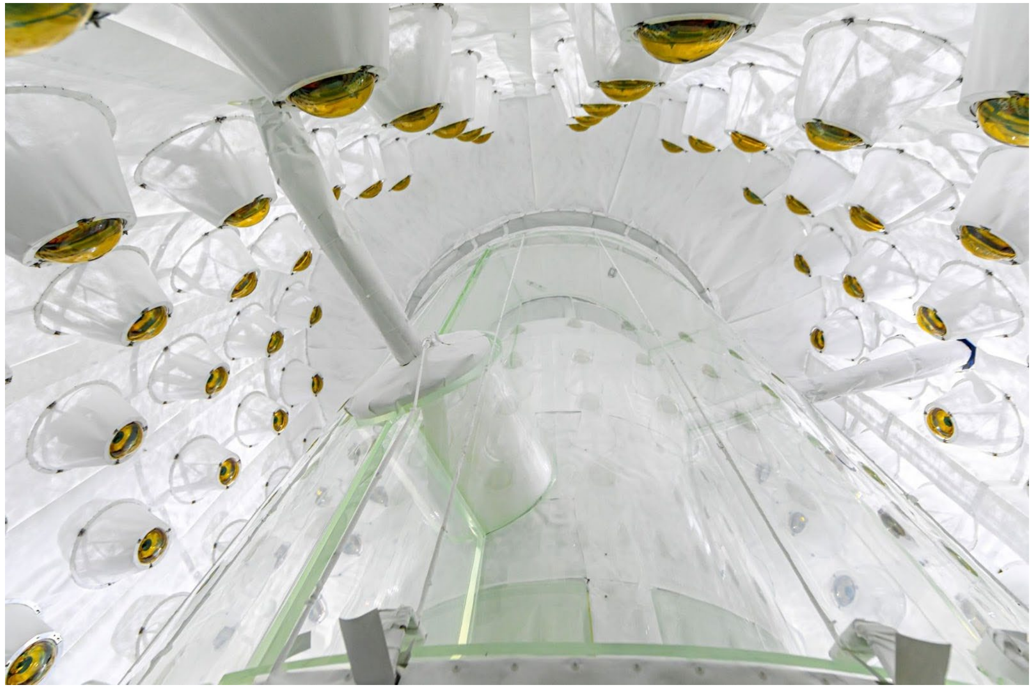
Nagoya Workshop on Technology and Instrumentation in Future Liquid Noble Gas Detectors



Experimental Strategy

- Online gettering of electronegatives in gas phase with SAES Megatorr / St707 technology
  - Continuous gas recirculation and purification at rates up to 500 SLPM driven by two all-metal compressors
  - Two-phase heat exchanger to mate the liquid and gas portions of the circuit

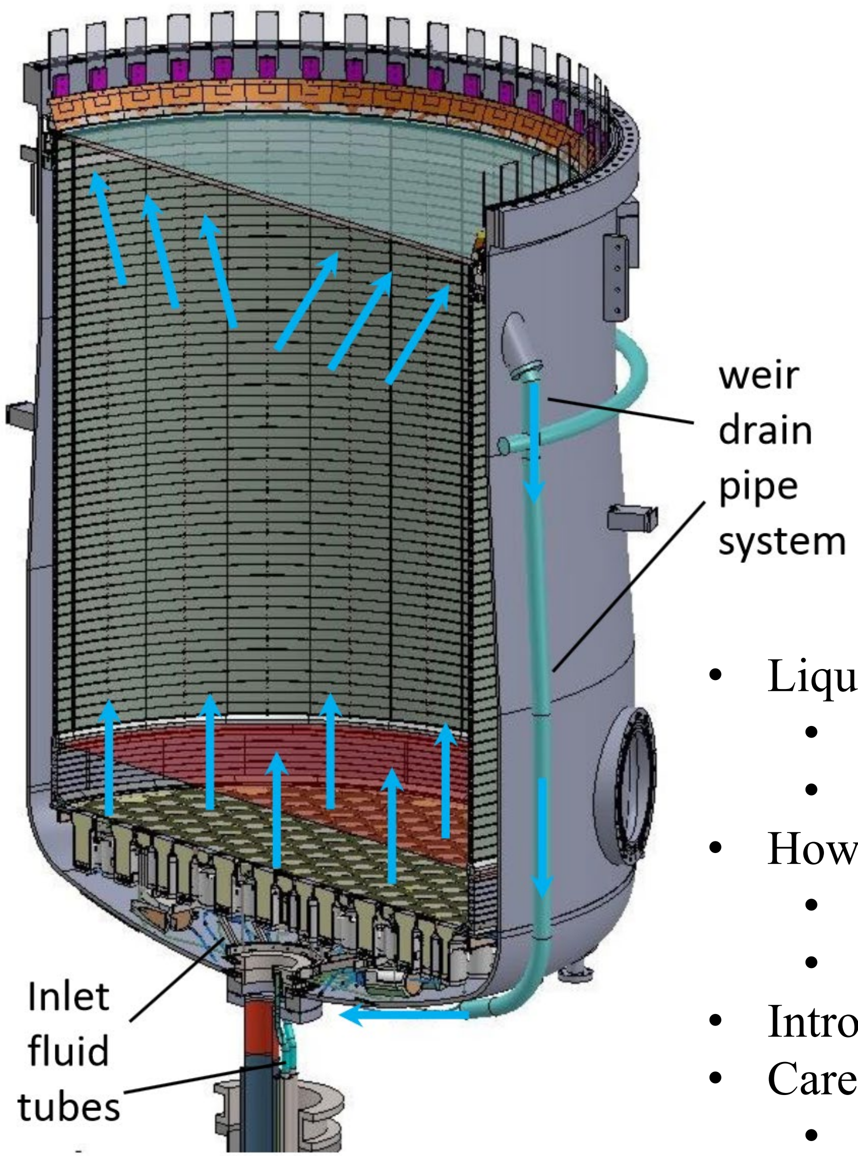
- Removal of trace of Krypton with gas charcoal chromatography
  - Performed off-site at SLAC prior to condensing into LZ cryostat

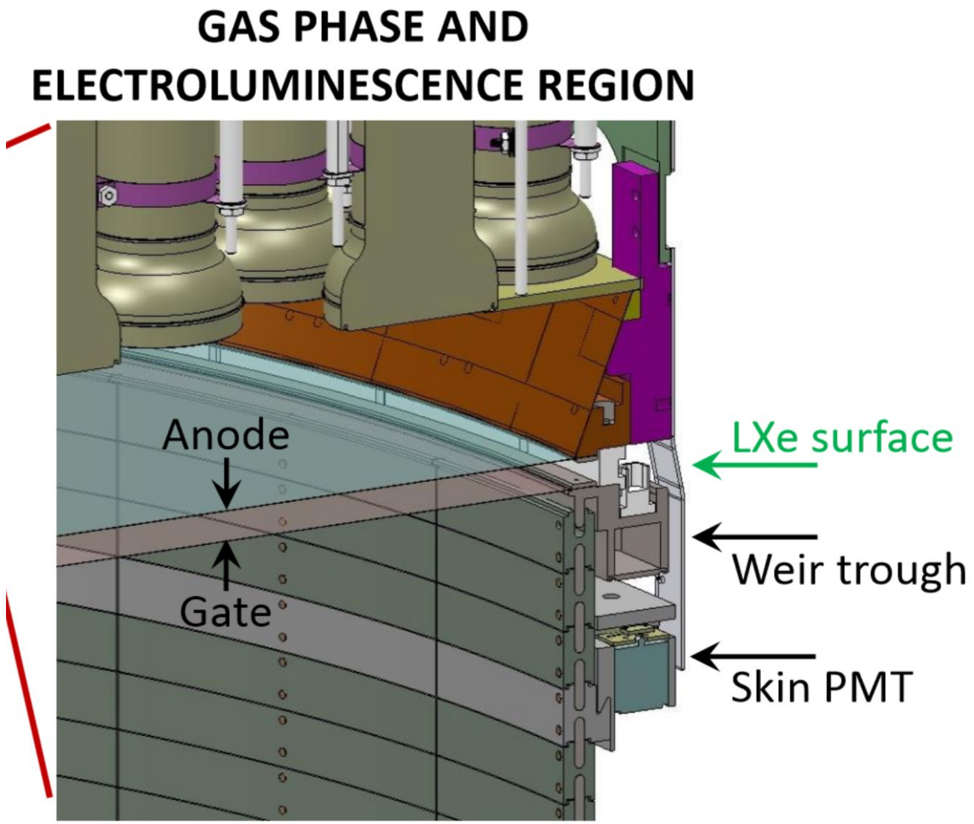


- Control of ^{222}Rn through materials screening, cleaning, & etching
  - Online removal of ^{222}Rn from cable conduits with cold synthetic
  - charcoal.

- Ability to influence and control liquid xenon convection in the TPC
  - Constrain/reject problematic ^{222}Rn daughters such as ^{214}Pb.
- Insert short-lived sources such as ^{83m}Kr and ^{220}Rn.
- Insert and remove via gettering tritiated methane for ER calibration.
- Gas phase Xe recovery
  - Two all-metal gas compressors
  - 144 custom high-purity compressed gas cylinders
  - Diesel generator backup to mitigate power disruptions
- Integrated and intensive purity monitoring campaign with cold-trap mass spectrometry

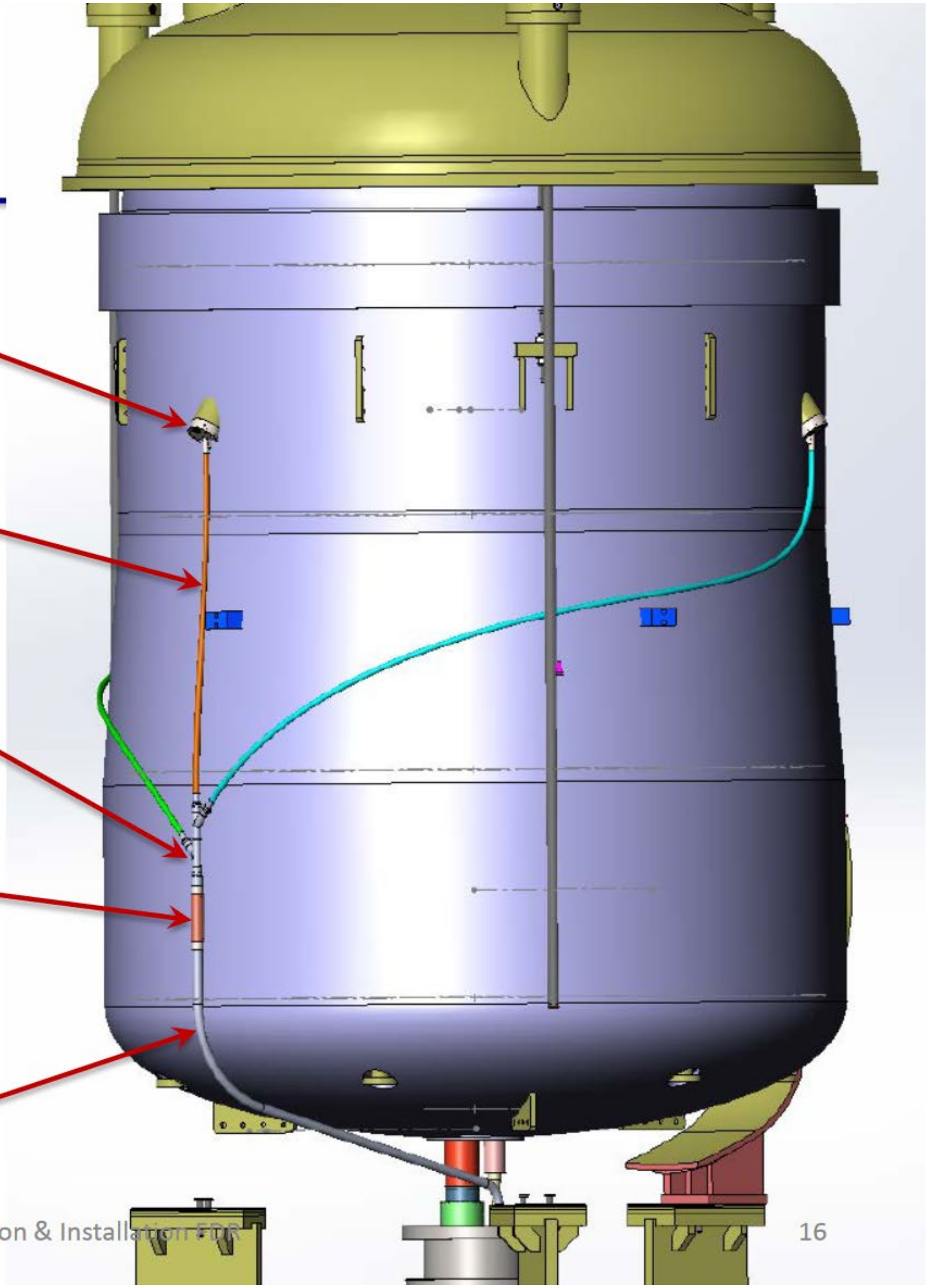
TPC Liquid Flow Design





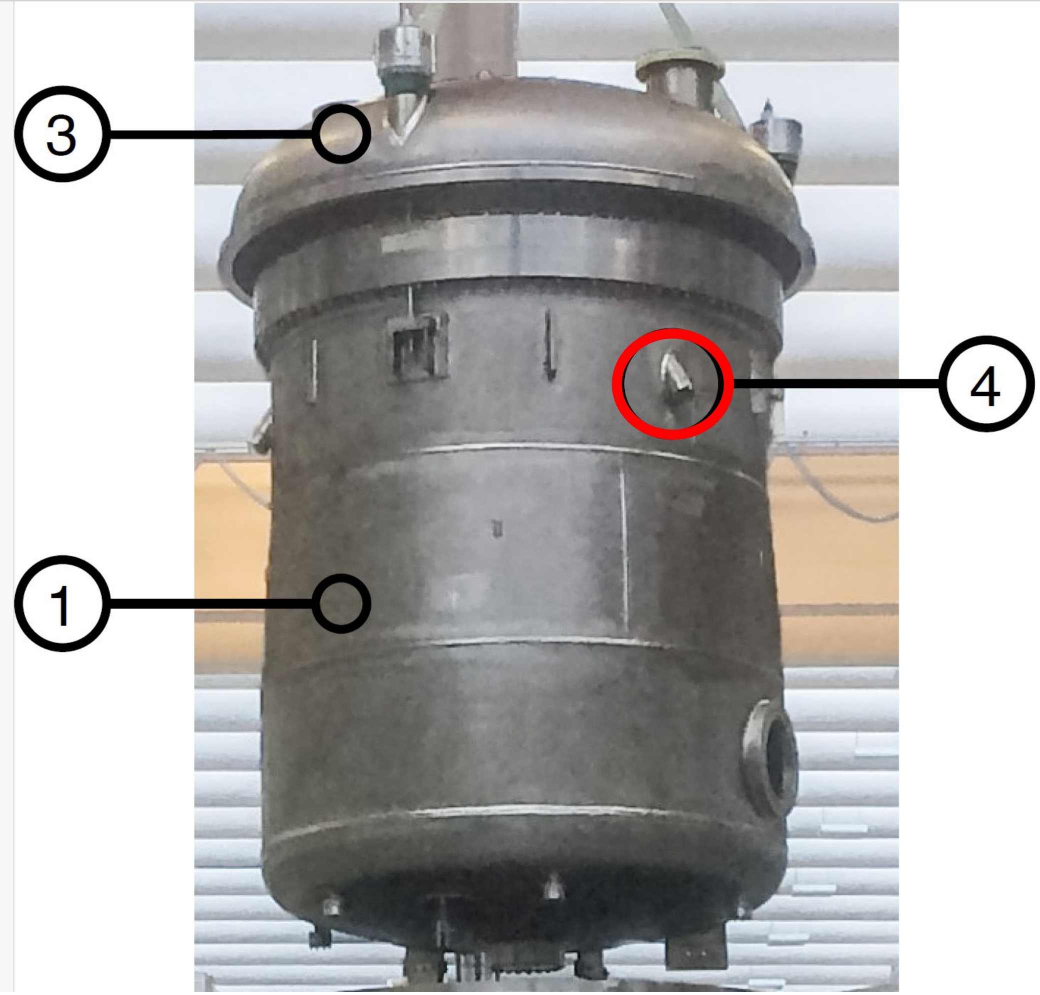
- Liquid removal from the top of the TPC via weir spill-over mechanism.
  - Sets precise LXe level (~10 micron control)
  - Floating particulates, fibers, dust are collected and removed from the TPC
- However: Xe skin region instrumented as S1-only gamma/neutron veto
  - LXe drain pipe is forbidden in the skin.
  - Drain placed in insulating vacuum space, between inner and outer cryostats.
- Introduce purified LXe via seven inlet tubes integrated into lower PMT array.
- Careful thermal design allows temperature of inlet fluid to be controlled.
  - Inlet liquid temperature allows LXe convection to be promoted or suppressed.

Weir Return from TPC

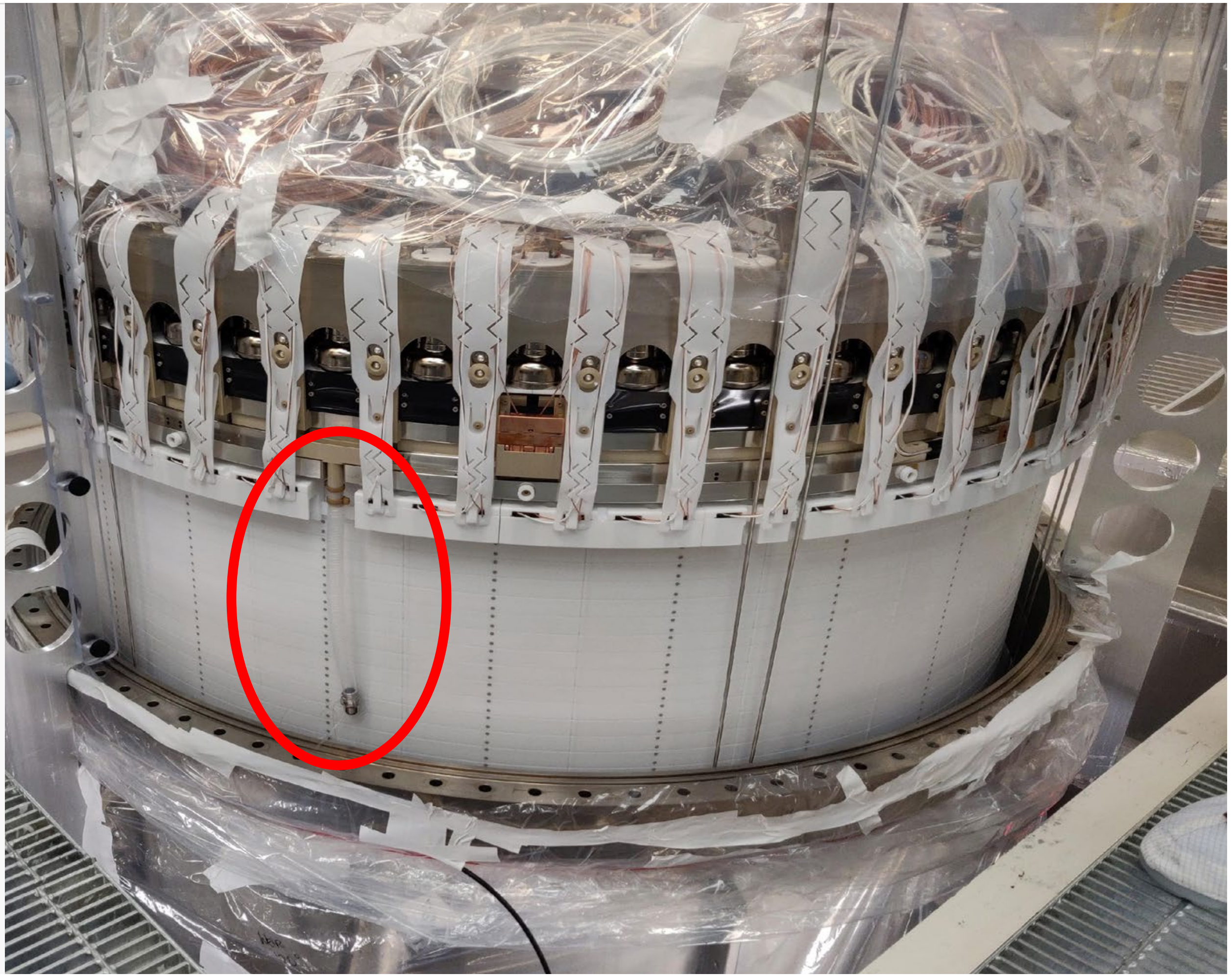


- Three weir drain located at 120° intervals around the TPC.
- One liquid liter per minute of LXe drains through these ports.
- Vapor lock mitigation:
    - cooling strap supplies 10 W of cooling power to the triple-junction.
    - a dedicated gas return path (not depicted)

Weir Drain Assembly – TPC insertion into Inner Cryostat

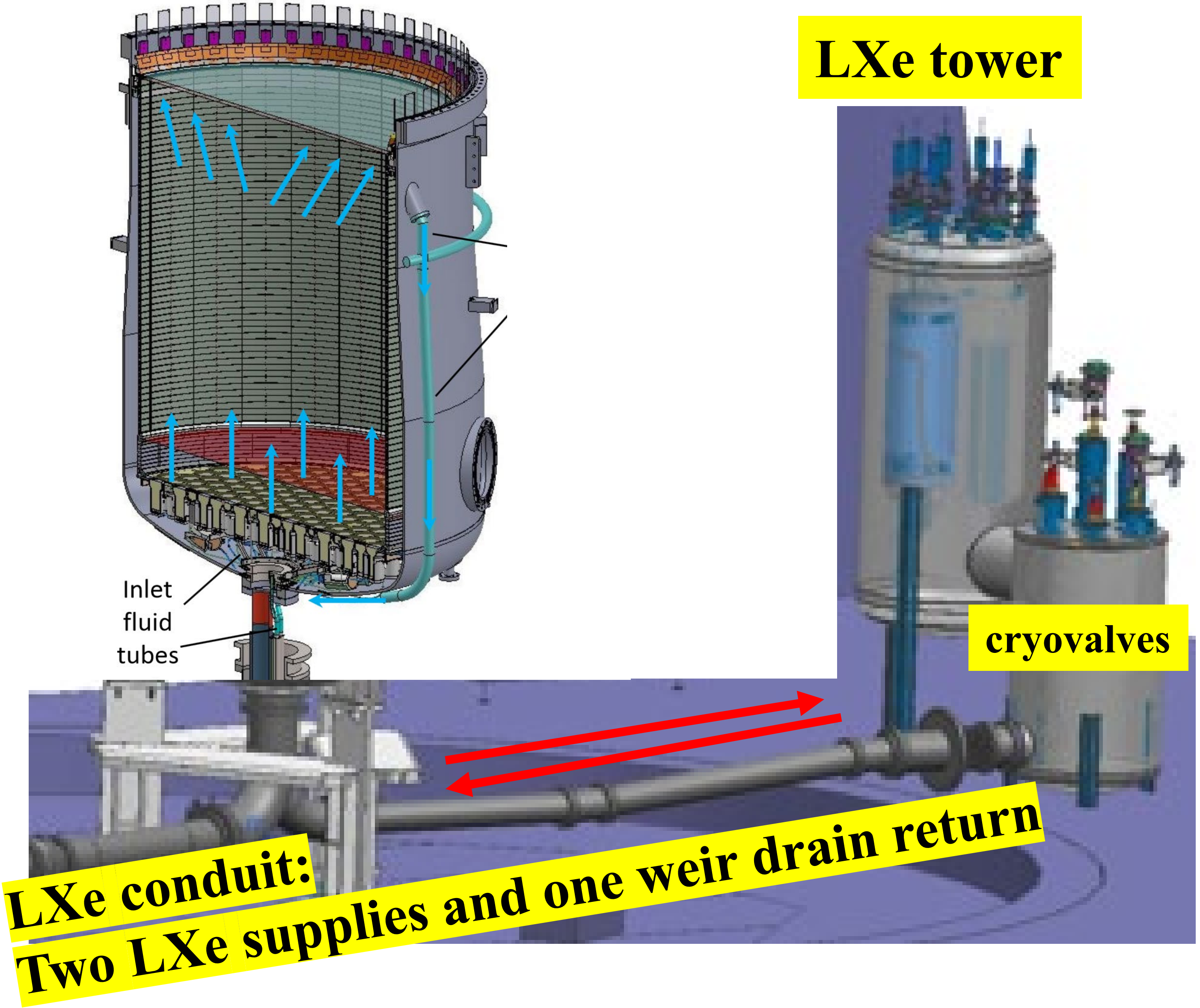


Inner Cryostat Vessel



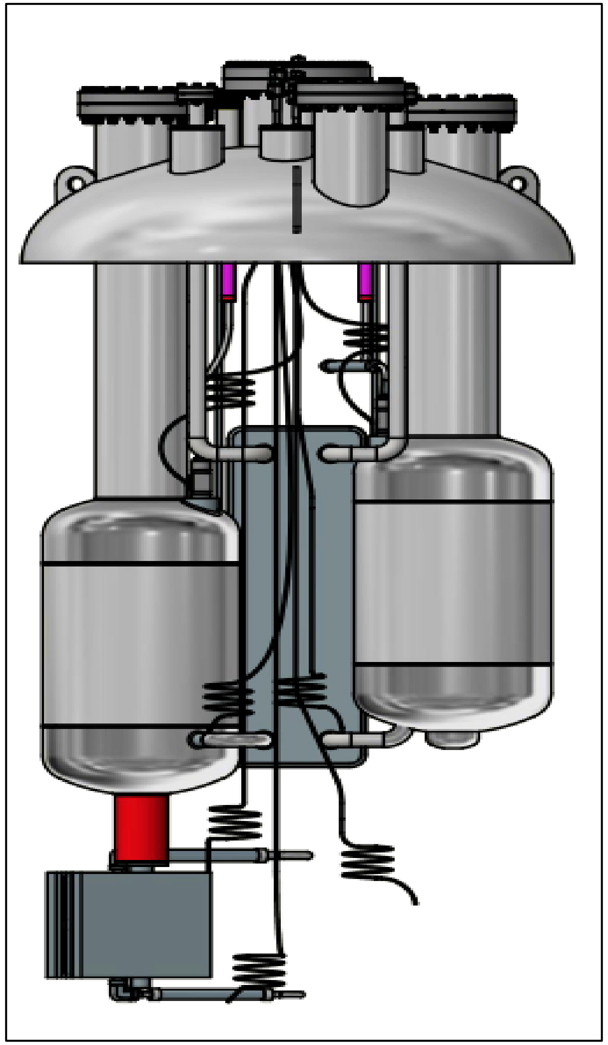
Flexible weir drain is threaded through port and sealed to a ½" SS drain tube which also seals to the ICV vessel.

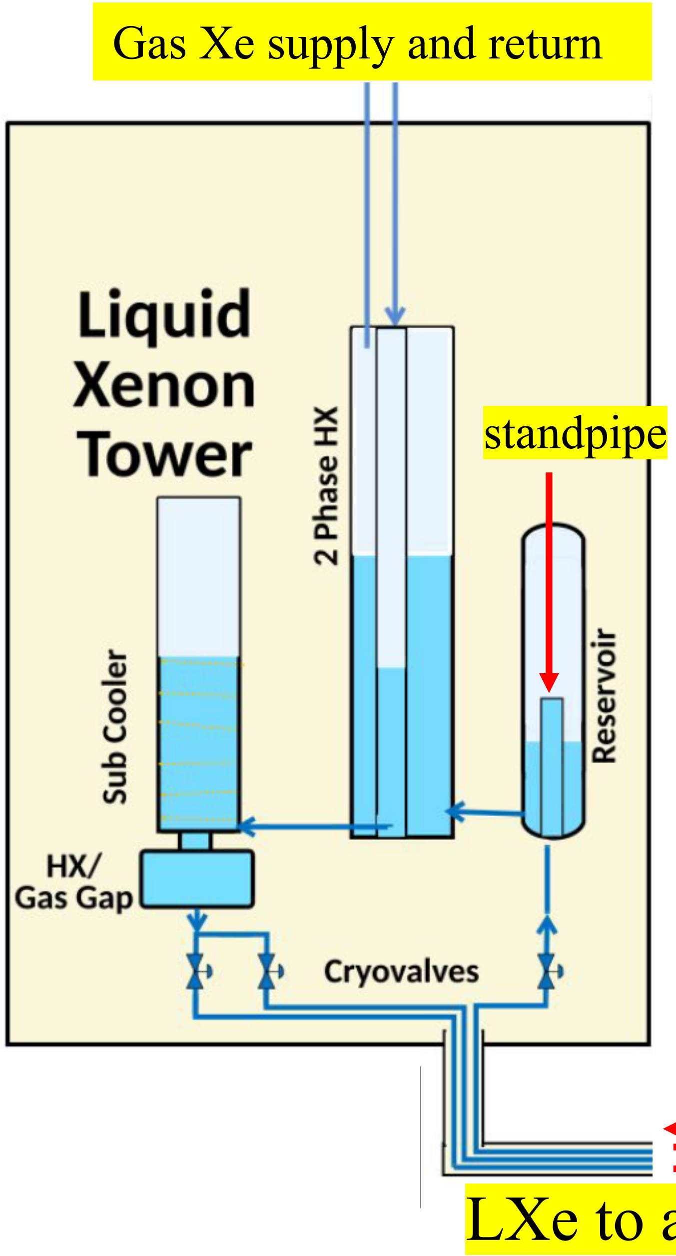
LXe Tower: interface to the external Xe handling system



- Purified LXe is condensed and subcooled in the LXe tower. Located outside the LZ water shield at an elevation below the TPC.
- A vacuum insulated conduit connects the bottom of the inner cryostat to the LXe tower.
- Inside the conduit:
  - Two vacuum-insulated cryogenic lines supplying purified LXe to the bottom of the detector.
    - One feeds the TPC active volume
    - The other supplies and flushes the Xe skin region
  - A third cryogenic line returns the LXe from the weir drain to the LXe in preparation for evaporation and gettering.
- Proportional cryovalves control the flow rates in the three lines.

LXe Tower Architecture





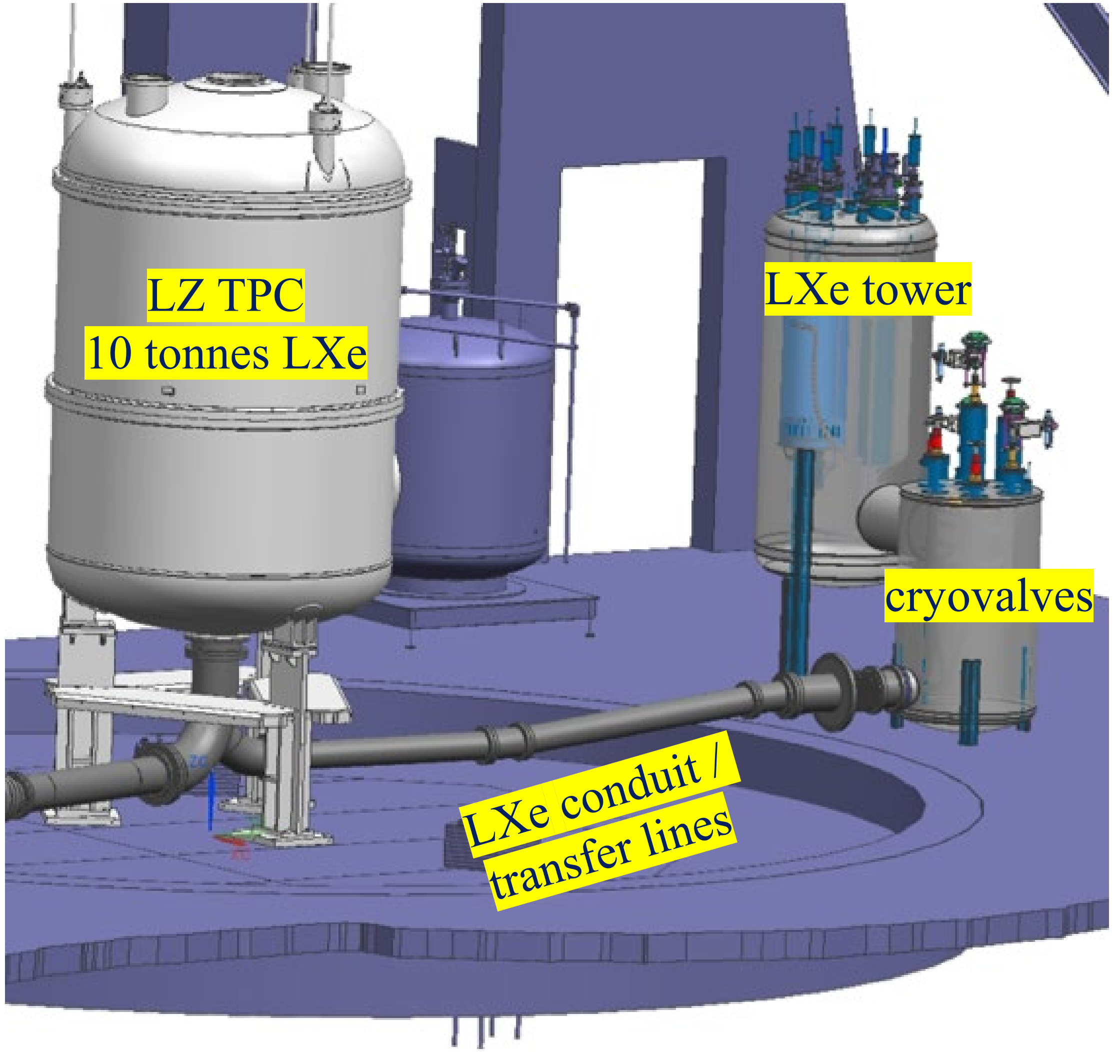
- LXe from the weir drain spills into the reservoir.
- Standpipe construction acts as a flow circuit diode:
  - backflow is not possible
  - dust, fibers, particulates, ect., should become trapped
  - Non-volatile impurities (heavy hydrocarbons) should also become trapped.
- Two-phase heat exchanger mates the LXe and gaseous Xe portions of the circuit.
  - Efficiency is 95%
- LXe Subcooler:
  - removes bubbles and froth from the purified LXe
  - Cools the LXe several degrees below saturation
  - LXe trim heaters make final adjustment to LXe temperature prior to supplying it to the TPC.

SLAC System Test (2015-2019):
Purification & circulation system prototyping

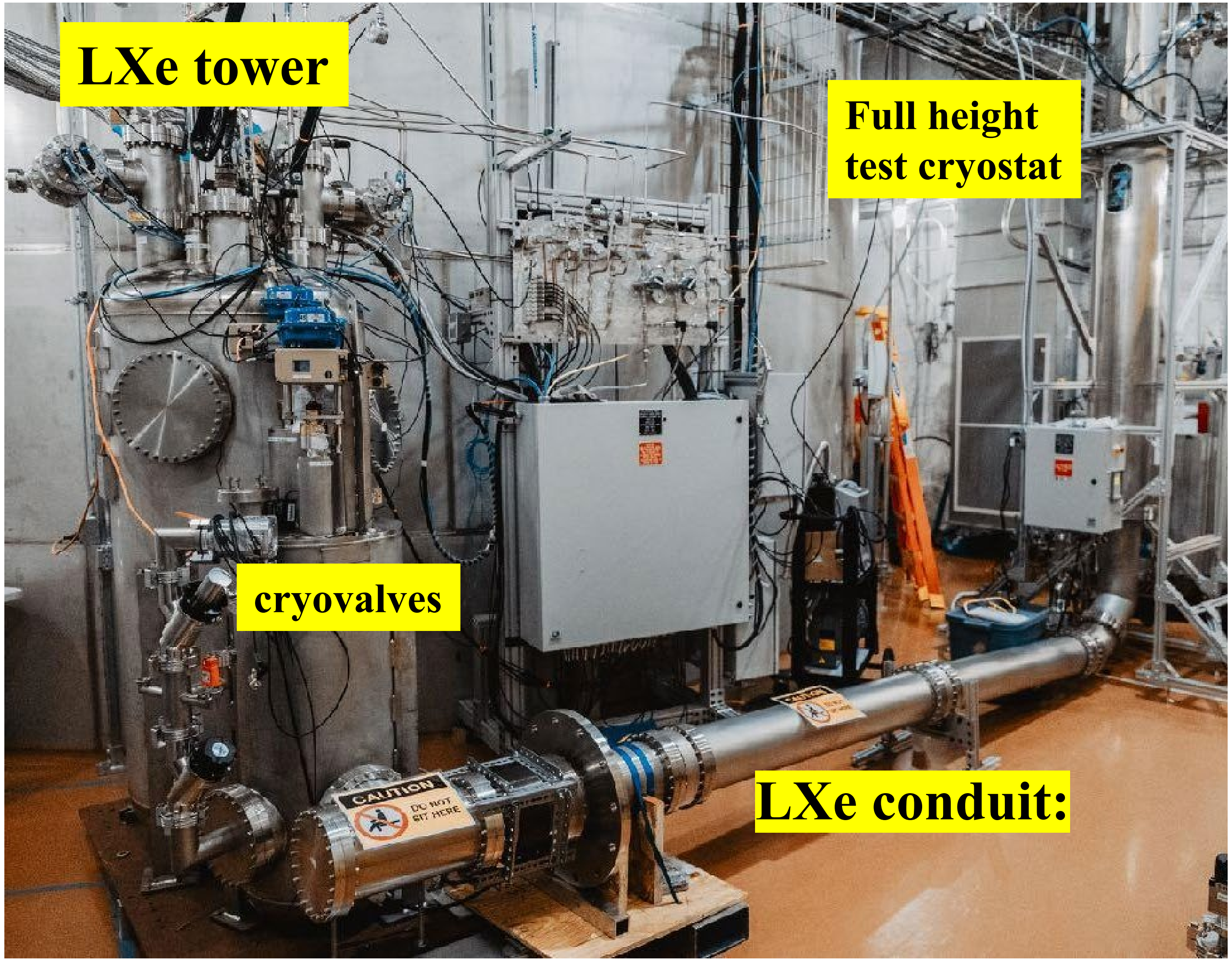
- 100 kg LXe TPC
- 50 SLPM circulation rate
- Prototyping of LXe tower
  - reservoir
  - Heat exchangers
  - Weir drain
- Key findings regarding weir drain line construction and assembly.
- Design strategies to prevent vapor lock in weir drain and transfer lines.

SLAC System Test

LZ @ SURF

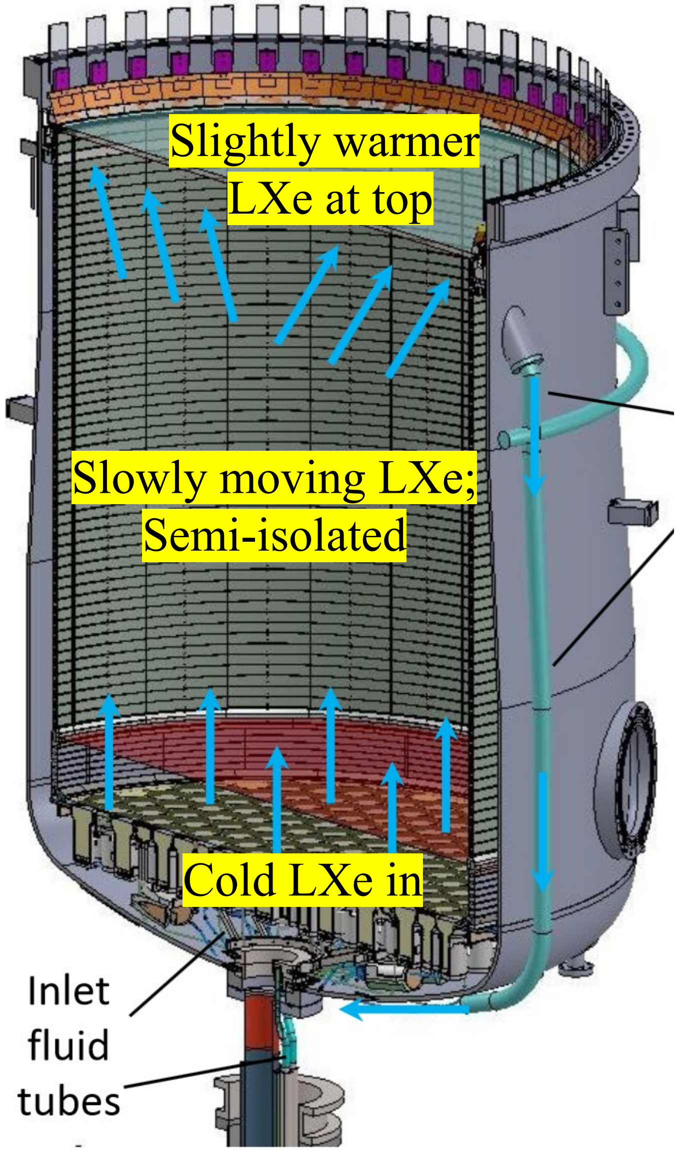


LZ full scale circulation test @ SURF (2020-21)



- Full height test cryostat
  - Necessary to properly replicate the gravity-driven liquid flow between cryostat and LXe tower.
- Complete system exercise:
  - Xe circulation compressors @ 400 SLPM
  - LXe Subcooler & trim heaters
  - Two-phase heat exchanger
- Confirmed that vapor lock mitigations devised in the SLAC System Test remain effective in the full scale LZ hardware.
- Debugging of liquid nitrogen cryogenics systems; reduction of heat leaks.

Thermal control by design: ^{222}Rn and its daughters are not fully mixed in LZ



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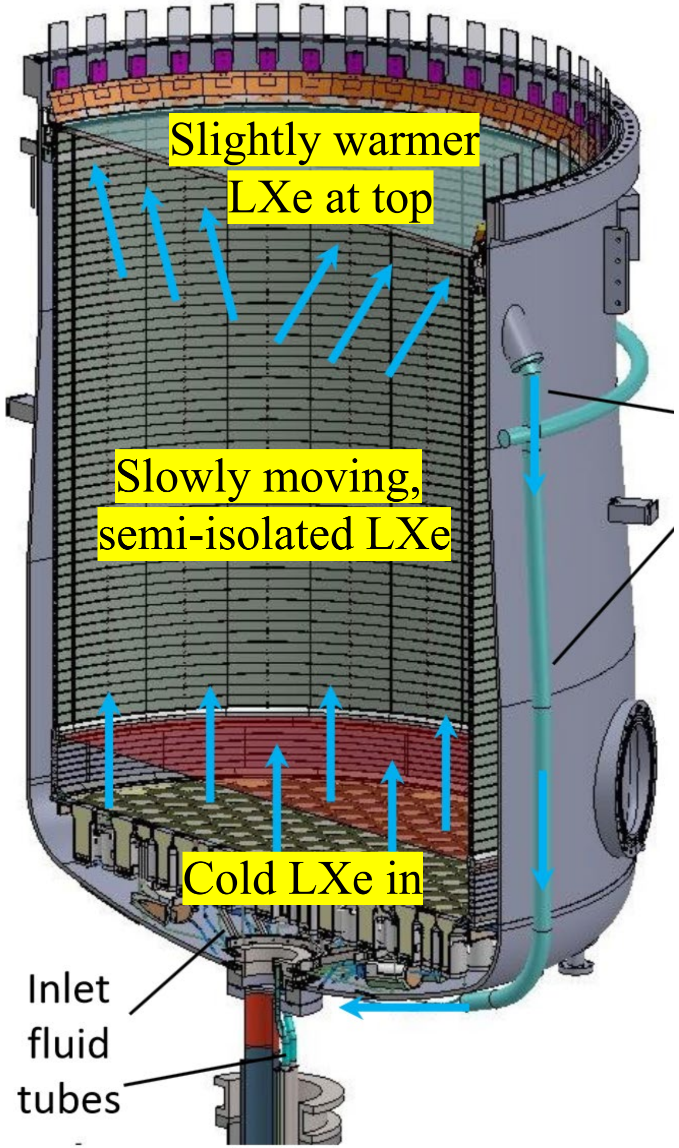
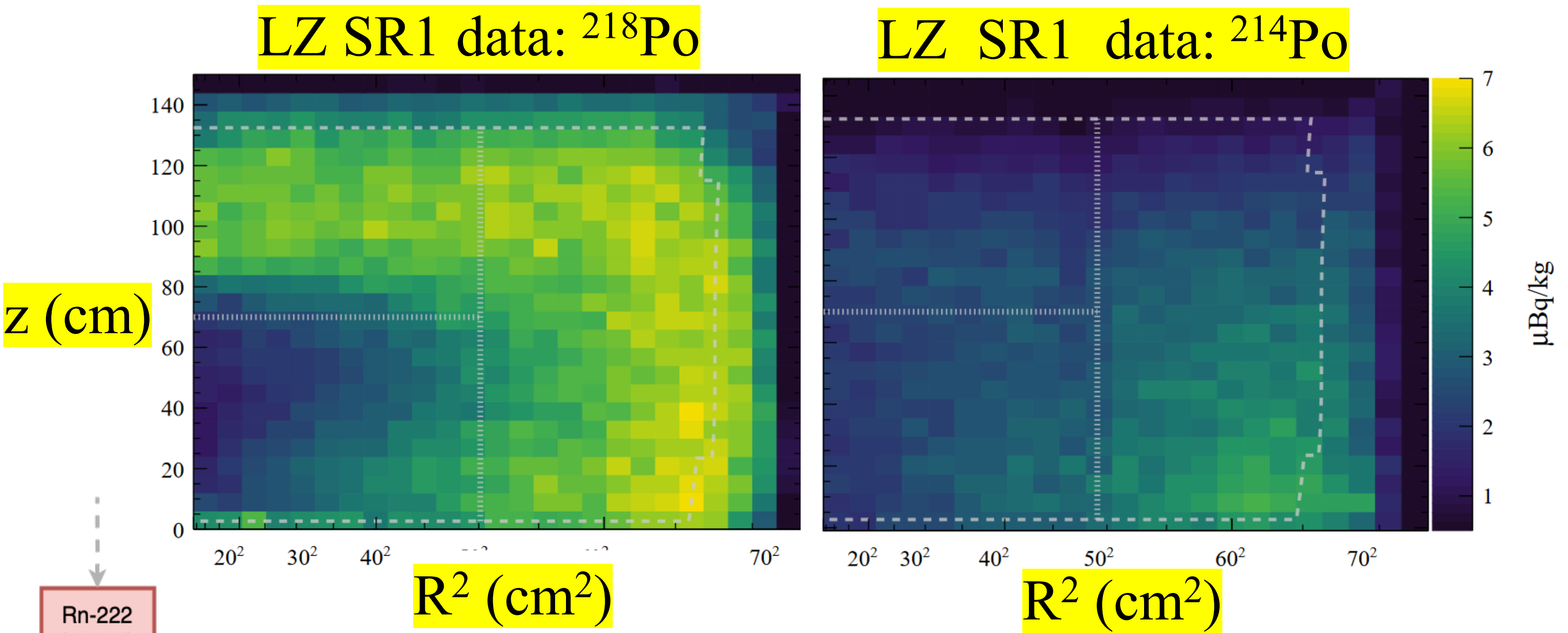
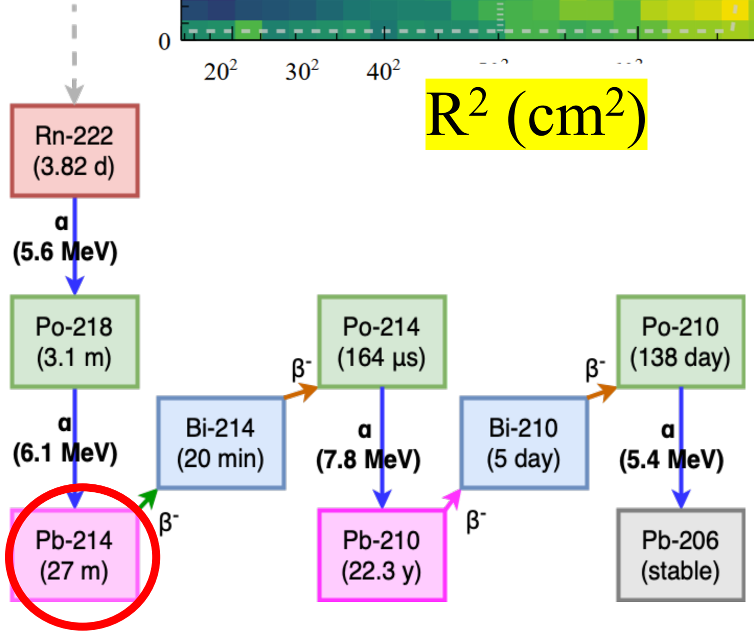


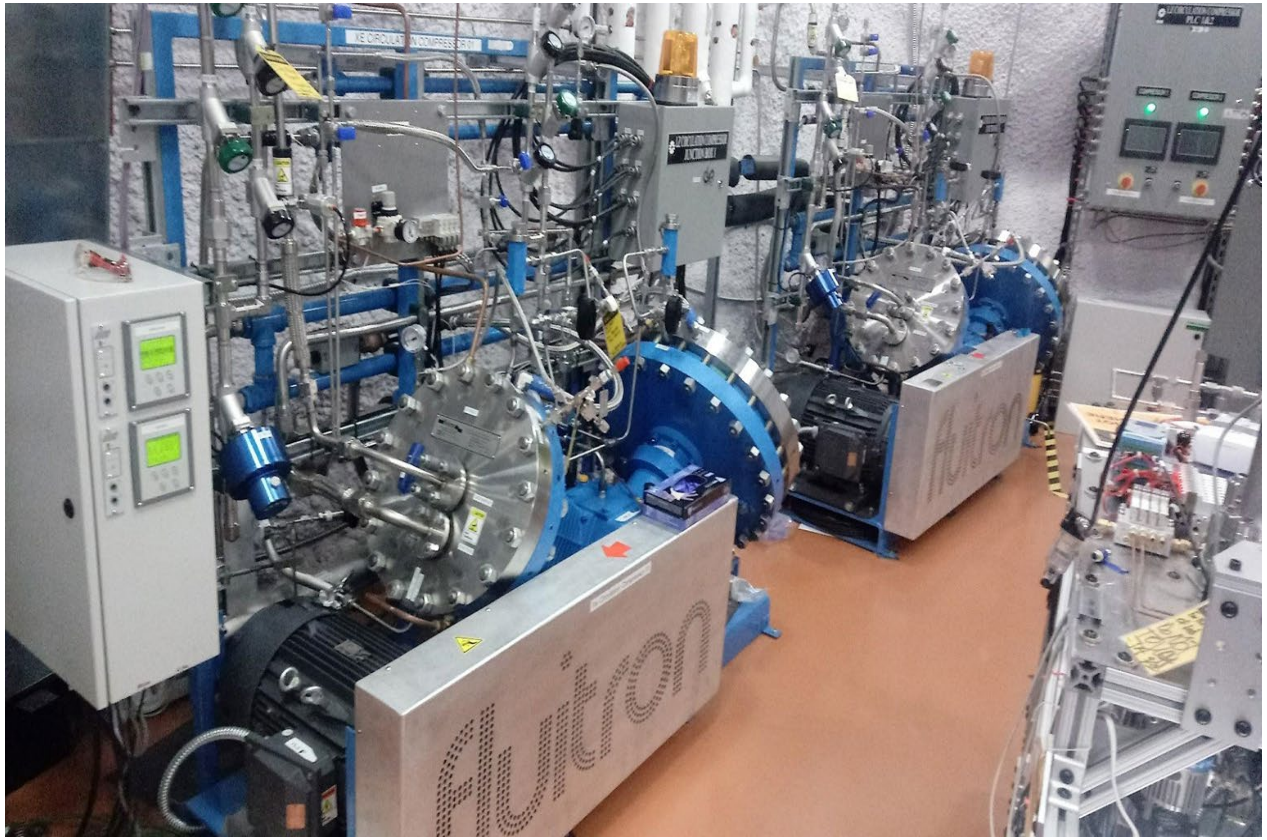




Rn222 (μBq/kg)	Pb214 (μBq/kg)	Po214 (μBq/kg)
4.37 ± 0.31 (stat)	**3.26 ± 0.13(stat) ± 0.57(sys)**	2.56 ± 0.21 (stat)

All-metal Diaphragm Compressors

Two Circulation Gas Xe Compressors

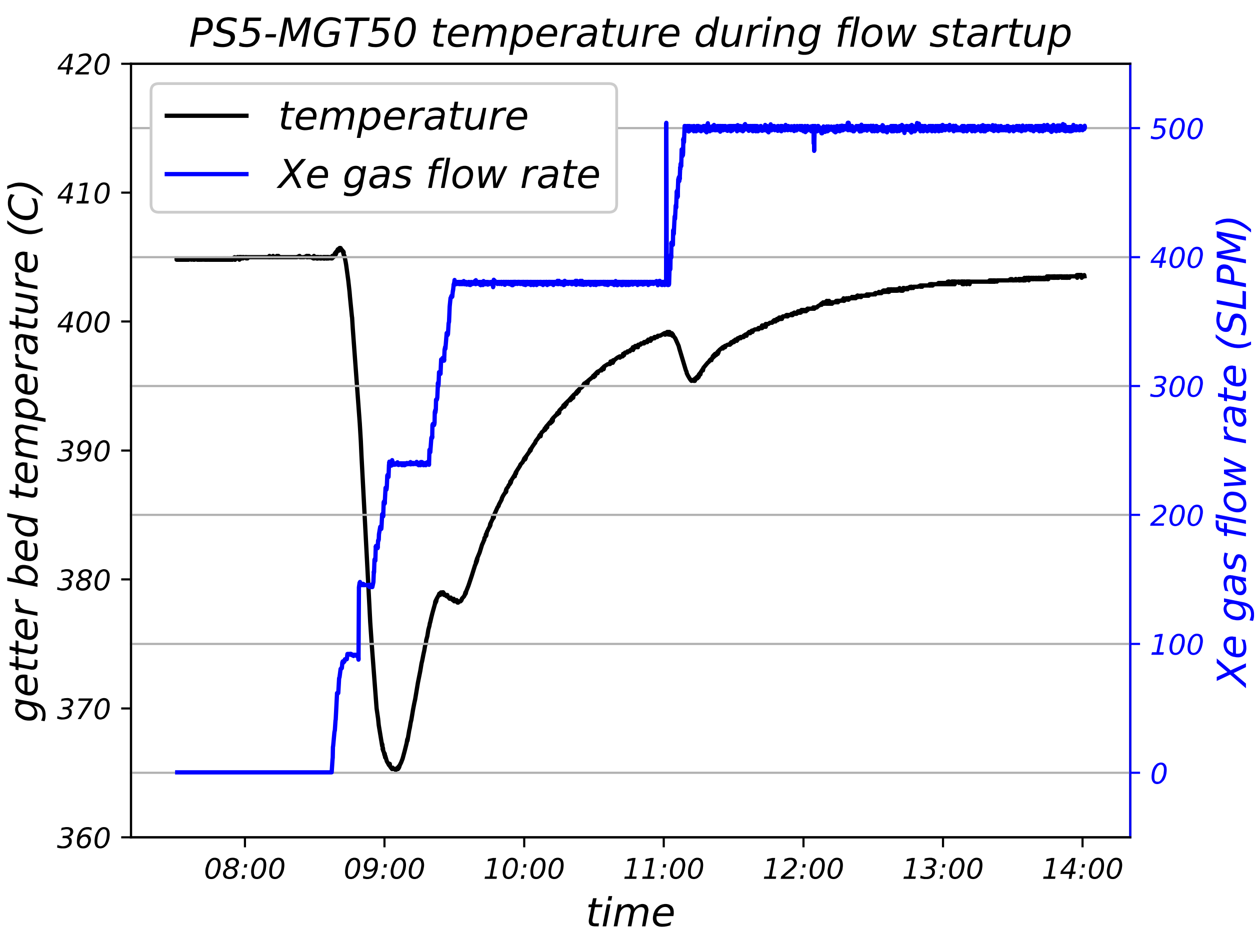


- Triple diaphragm construction.
- Copper plating on diaphragm forms all-metal seal with compressor heads.
- Check valves sealed to the heads with copper gaskets.

Two Recovery Gas Xe Compressors

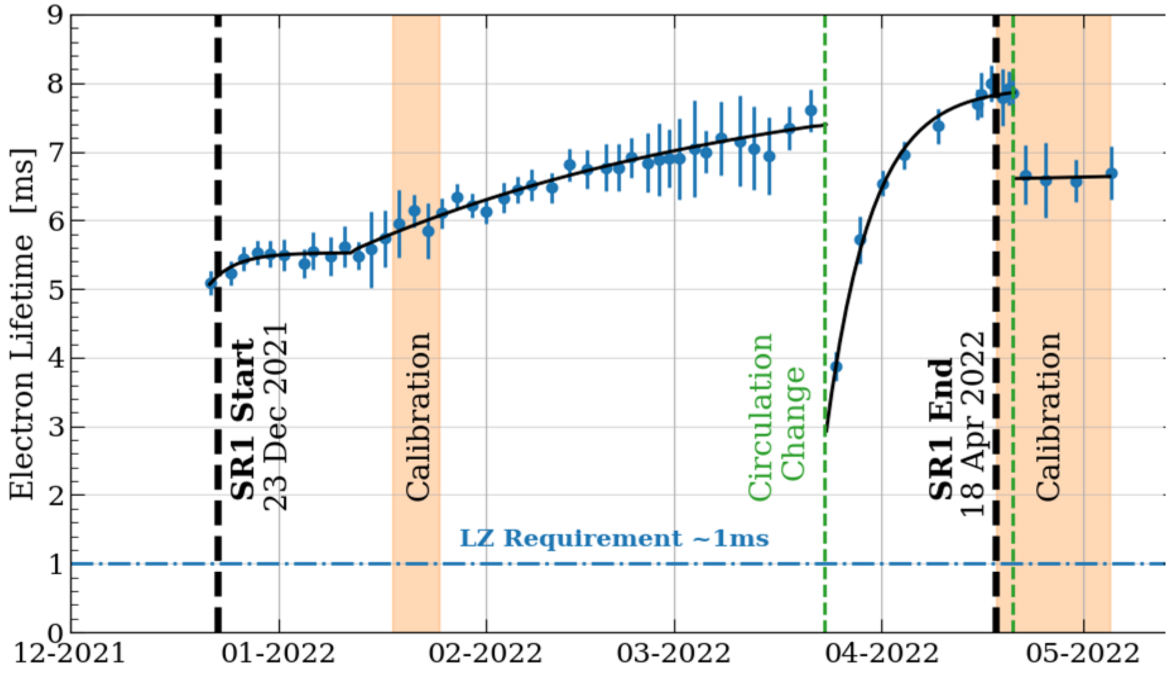
144 high purity Xe gas cylinders

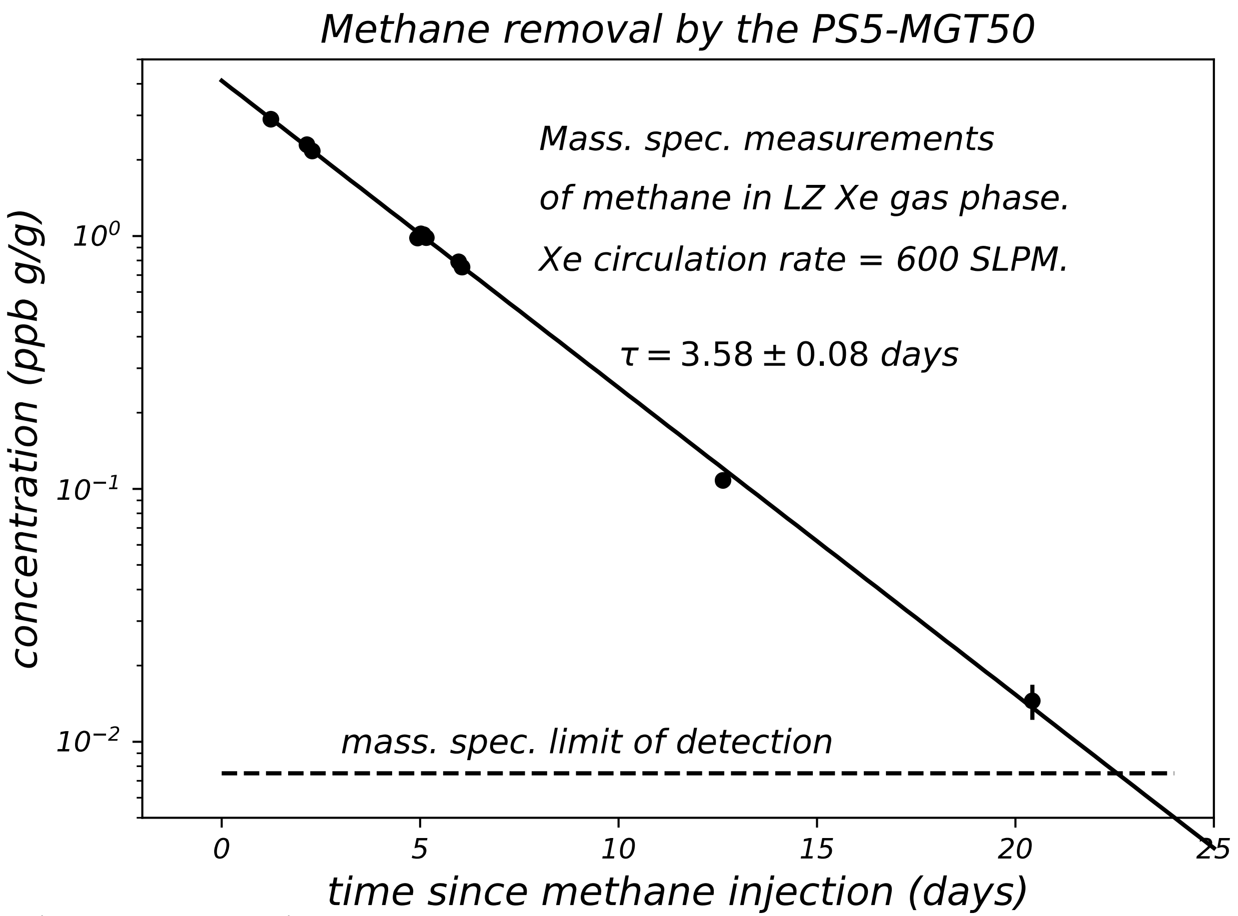
SAES/Entegris PS5-MGT50 Megatorr Getter



- SAES conservatively recommends two parallel MGT50 units at Xe gas flow rates > 275 SLPM.
- To limit Rn emanation burden from the getter, we use only one.
- We fine no degradation in performance up to 500 SLPM.
  - The purifier is able to establish and maintain a temperature of 400 C.

Electronegative and Methane Removal Performance



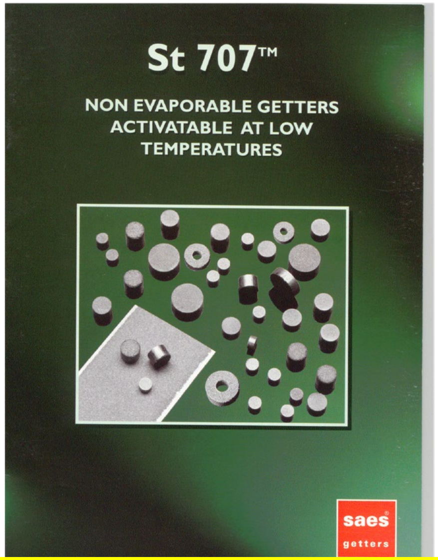


- Electron lifetimes in LZ are near10 ms; far better than the 1 ms requirement.
- To test the getter's ability to remove methane, a 0.07 gram injection was performed. Cold trap mass spec. measurements confirmed good removal with a time constant less than four days.

Radon Emanation measurements of SAES purifiers / St707 getter pills

- Getter pills have high surface area and operate at 400 C; ^{222}Rn is expected to be emanated.
- Literature measurements suggest a factor of eight variation in ^{222}Rn emanation depending on the unit / lot.
- The LZ getter is responsible for about 5% of the ^{222}Rn in LZ.
  - Literature results suggest this could have been reduced to 1% with the most favorable getter pill lot.

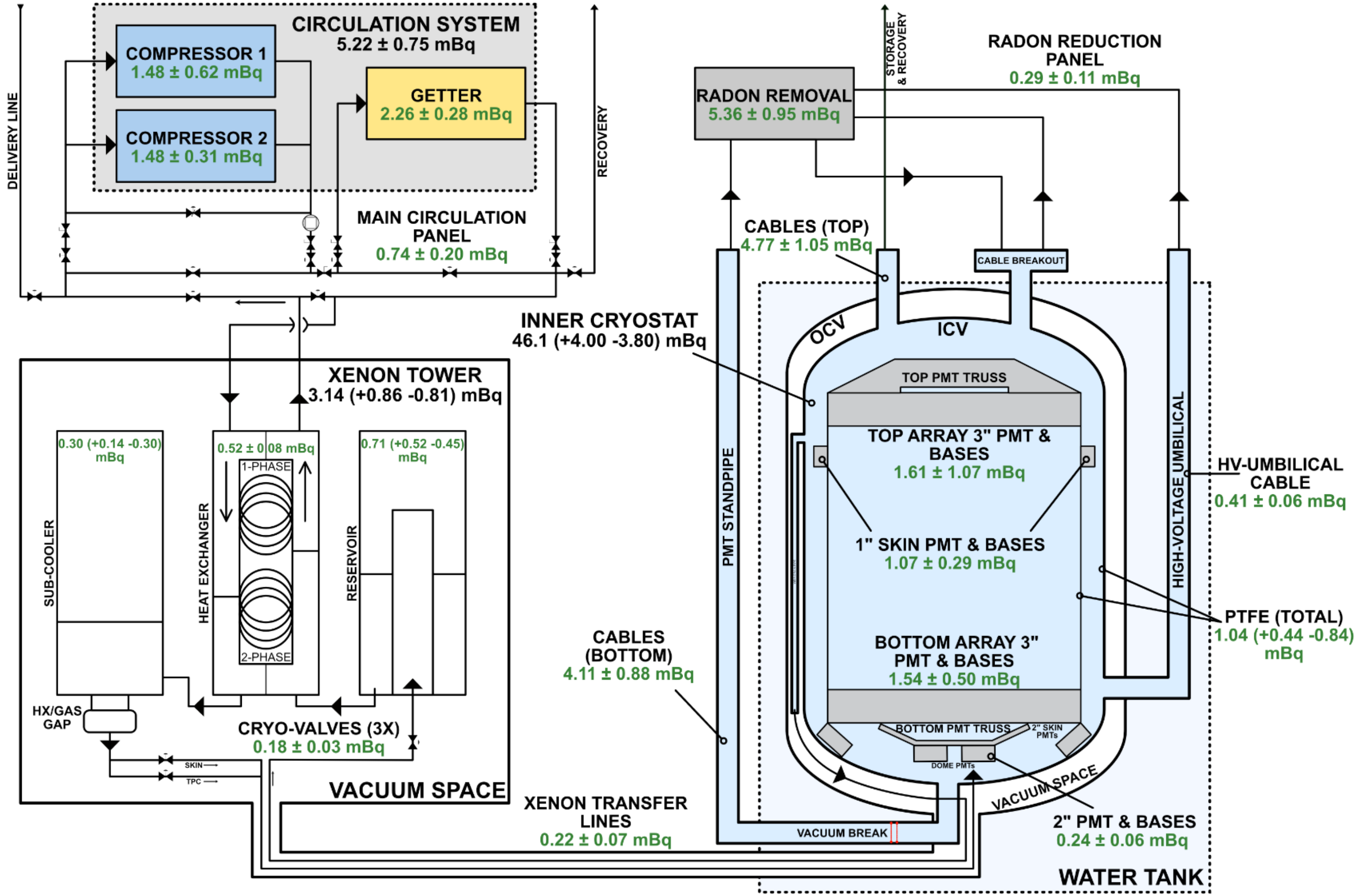
Device	Model	Temp	^{222}Rn Activity (μBq)	Getter Pill Mass (kg)	Activity (μBq/(kg-of-getter))
Maryland [1]	MT50	400 C	142 + 39 - 35	4.4	32±8
Xenon1T (ID #16) [2]	MT50	400 C	1170 ± 150	4.4	265 ± 38
Xenon1T (ID #17) [2]	MT50	400 C	240 ± 30	4.4	55 ± 7
LZ Getter [3]	Megatorr PS5 –MGT50	400 C	2260 ± 2270	15	150 ± 15



St707 Getter Pills

[1] J.E. Armstrong et al., *AIP Conf. Proc.* 2908, 070002 (2023) https://doi.org/10.1063/5.0161727
[2] E. Aprile et al. (XENON), Eur. Phys. J. C 81, 337 (2021), arXiv:2009.13981
[3] D.S. Akerib et al. (LZ), Eur. Phys. J. C (2021) 80:1044, arXiv:2006.02506

Radon emanation measurements of the purification system & TPC

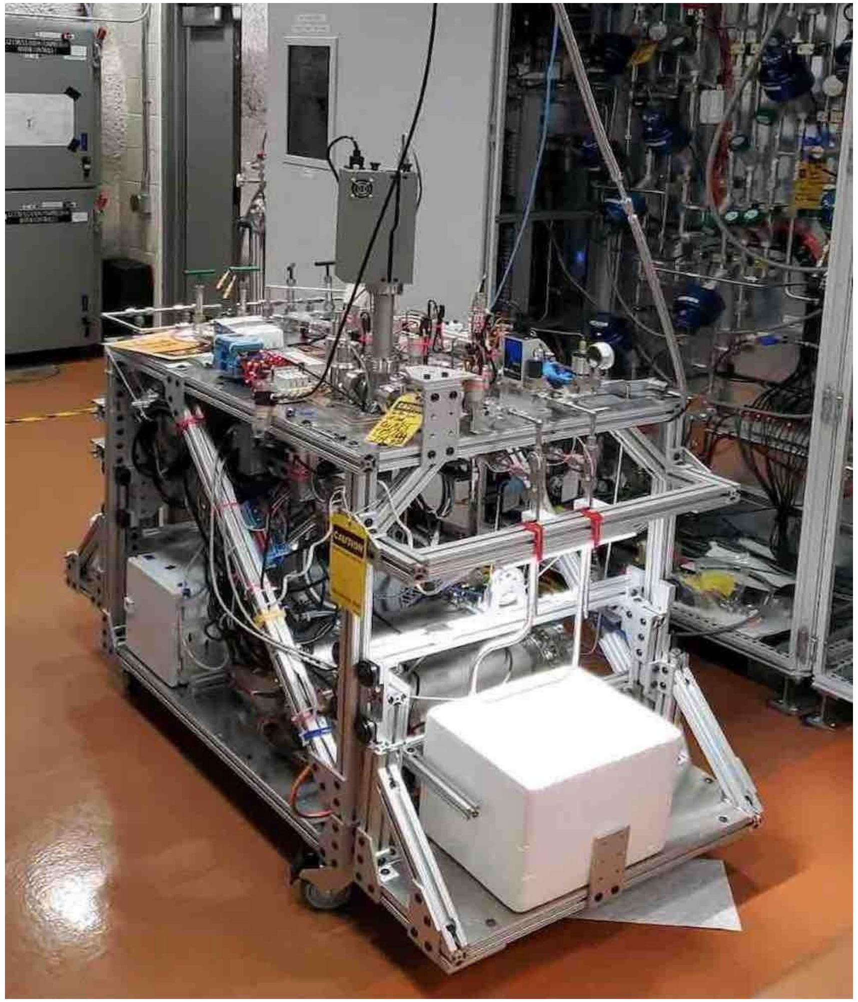


- Comprehensive Rn screening campaign.
- Most of the Xe circulation components were screened at remote facilities using portable Rn traps.
- The single largest contributor appears to be the inner cryostat.

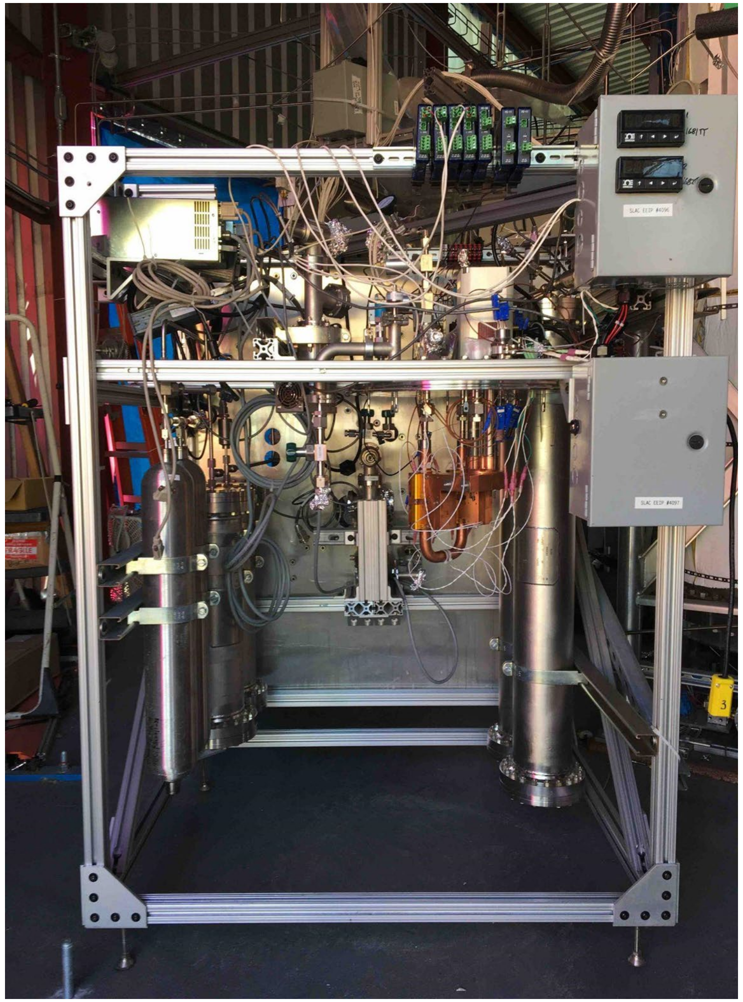
D.S. Akerib et al. (LZ), Eur. Phys. J. C (2021) 80:1044, arXiv:2006.02506

Two cold-trap mass spectrometry systems underground at SURF monitor Kr, Ar, N2, He, CH4

Mobile Sampling System (MSS)



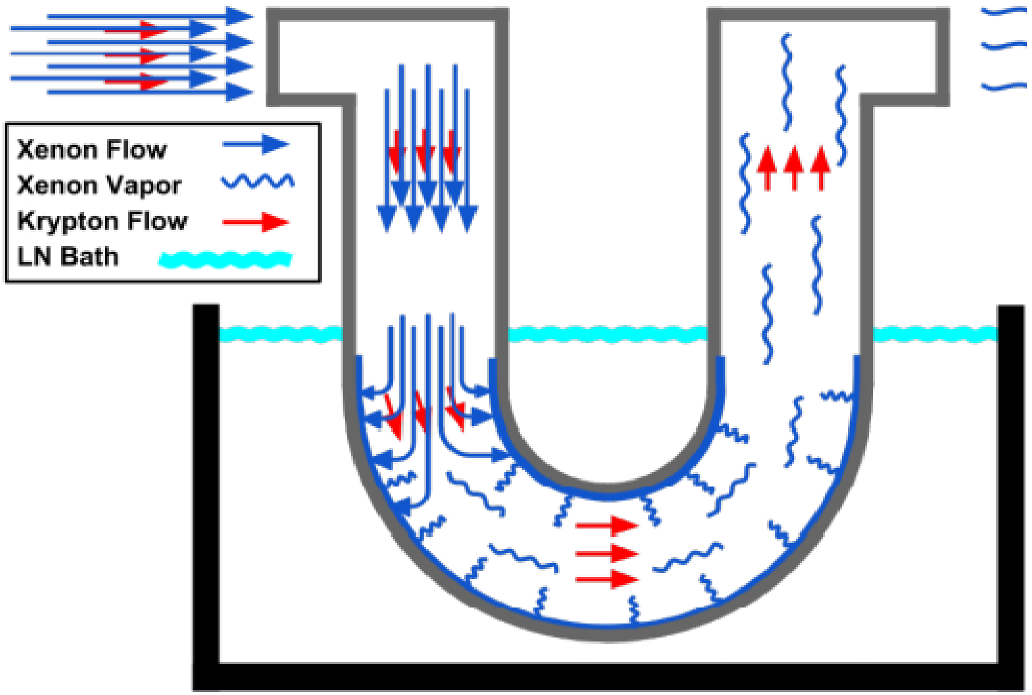
Stationary Sampling System (SSS)



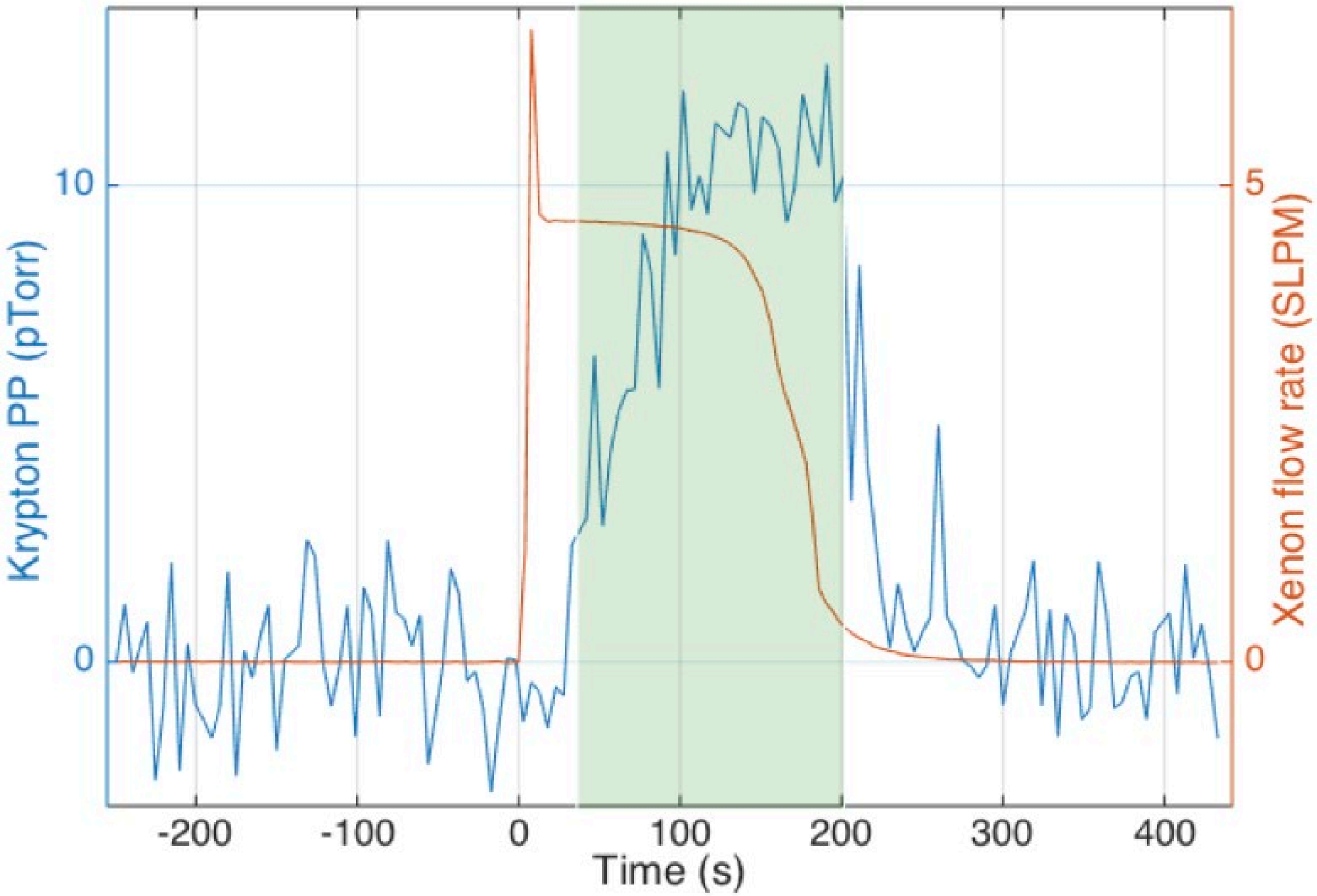
- 77 K cold trap removes most Xe while allowing noble gases and other impurities to pass through.
- Purities are observed with a downstream RGA.
- Sensitivity to Kr is 7 parts-per-quadrillion (g/g)
- Mobile system can be moved and plumbed in to various Xe system components as needed in the Davis cavern. Cold trap is LN cooled.
- Stationary system use a PTR cold head. It is permanently plumbed to the detector.

Two cold-trap mass spectrometry systems underground at SURF monitor Kr, Ar, N_2, He, methane

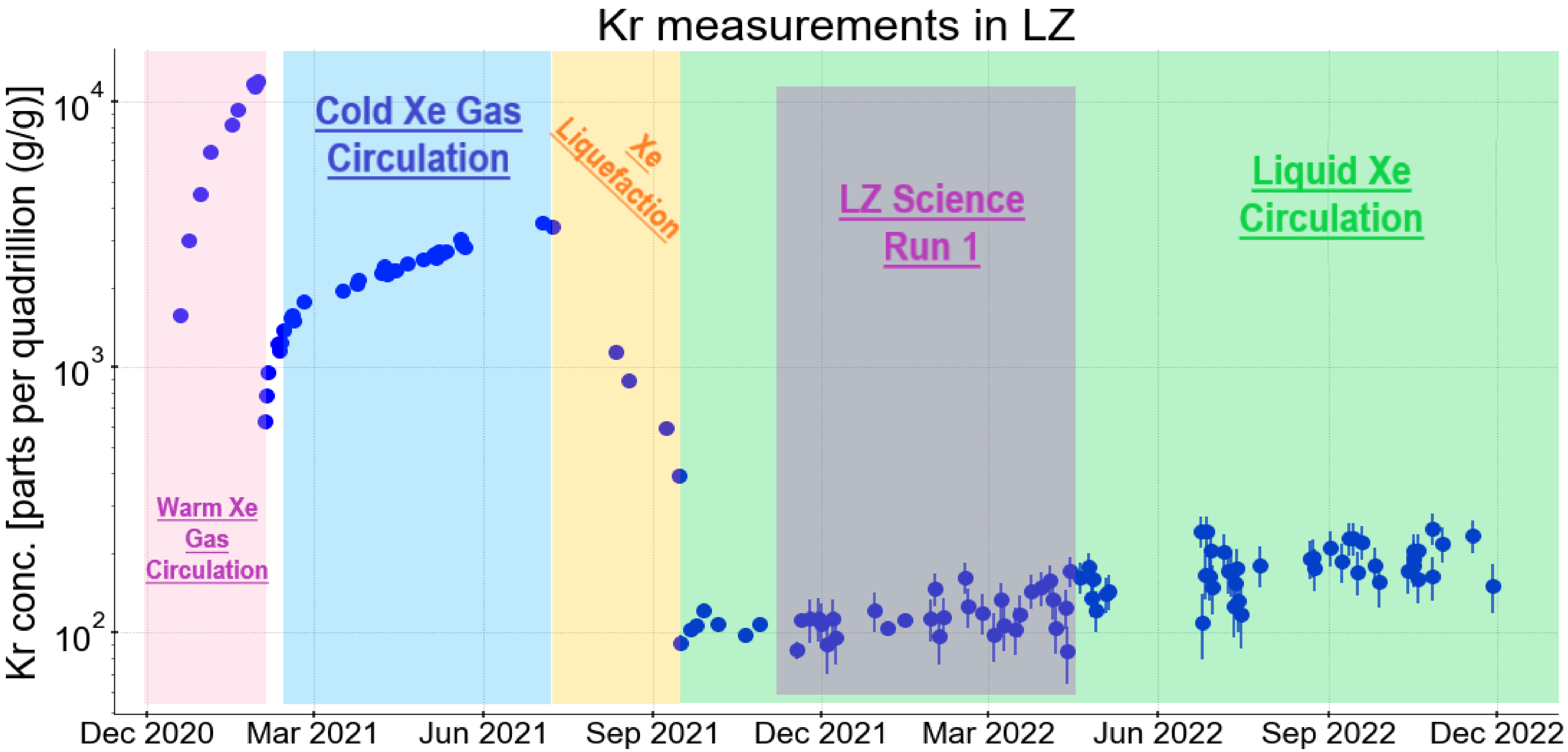
77 K Cold Trap



340 ppq (g/g) Kr signal observed by RGA

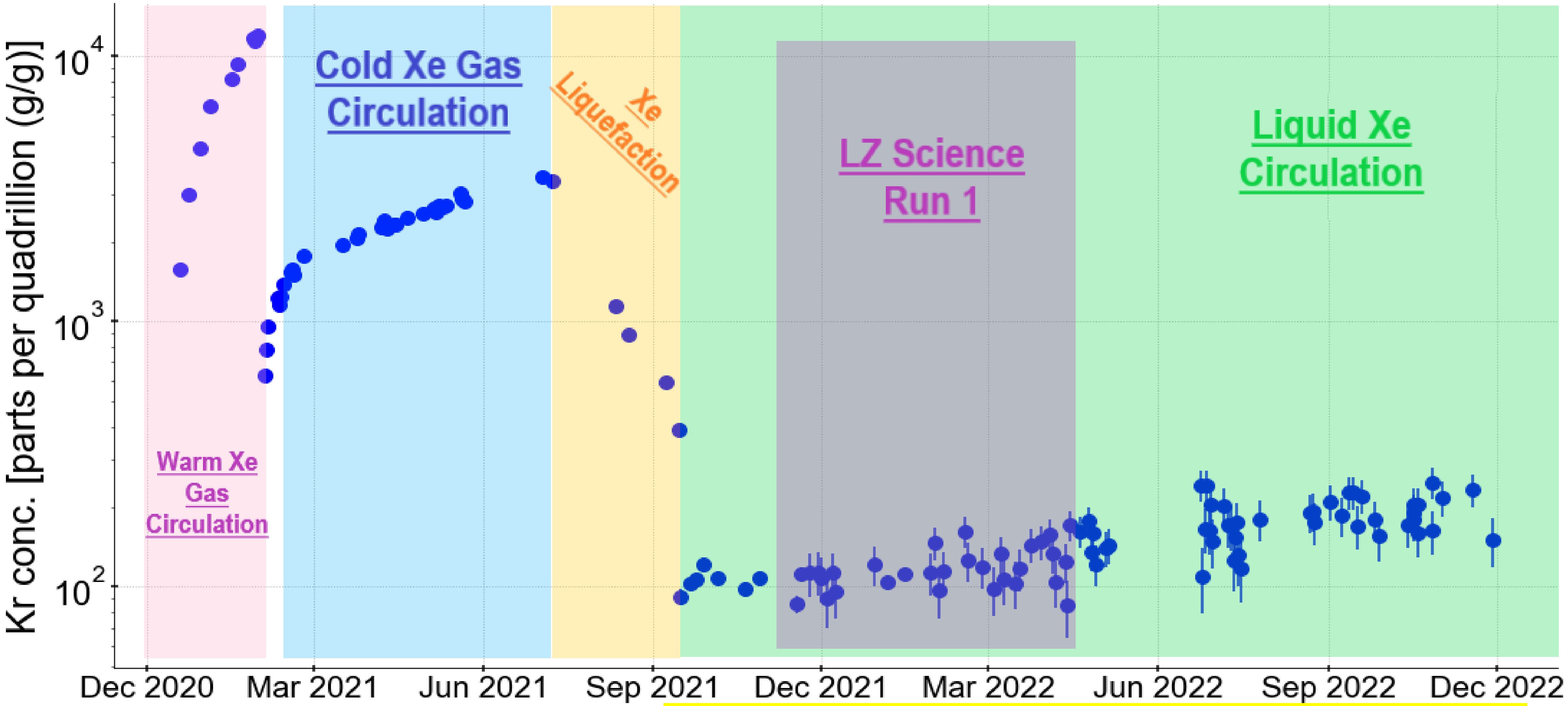


Note: ppq = parts-per-quadrillion



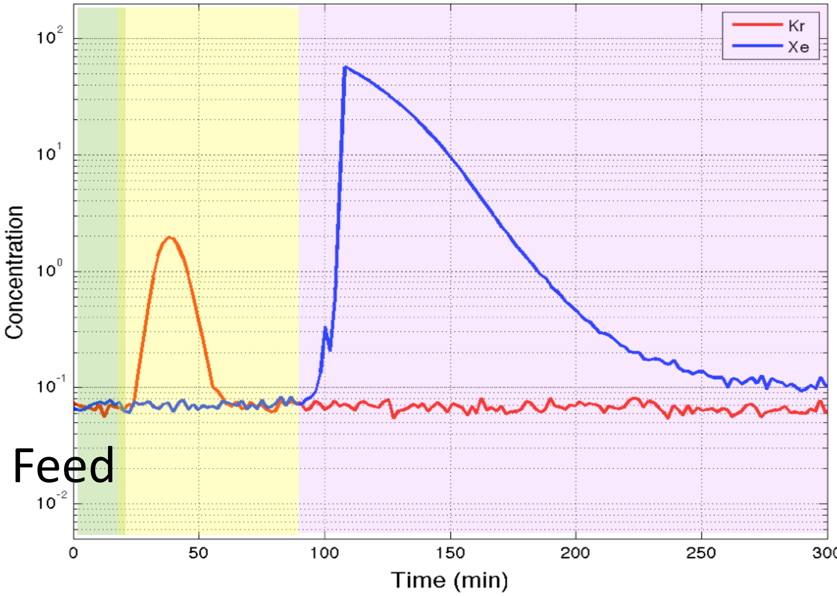
- LZ requirement was < 300 ppq Kr (g/g) at the start of SR1.
- Achieved Kr concentration was near 100 ppq Kr (g/g).

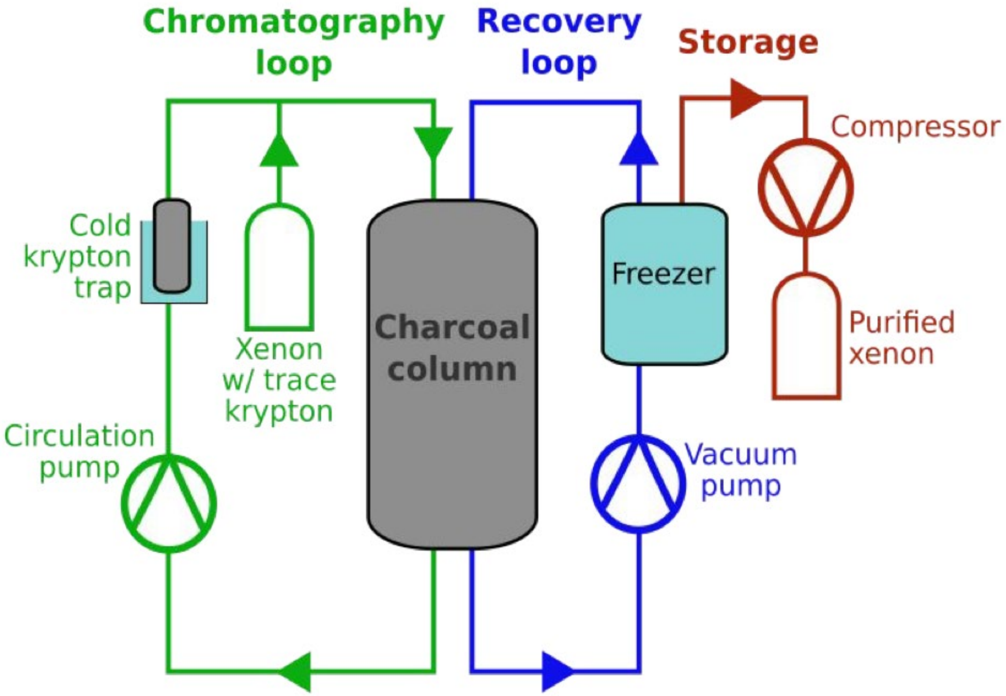
Kr measurements in LZ

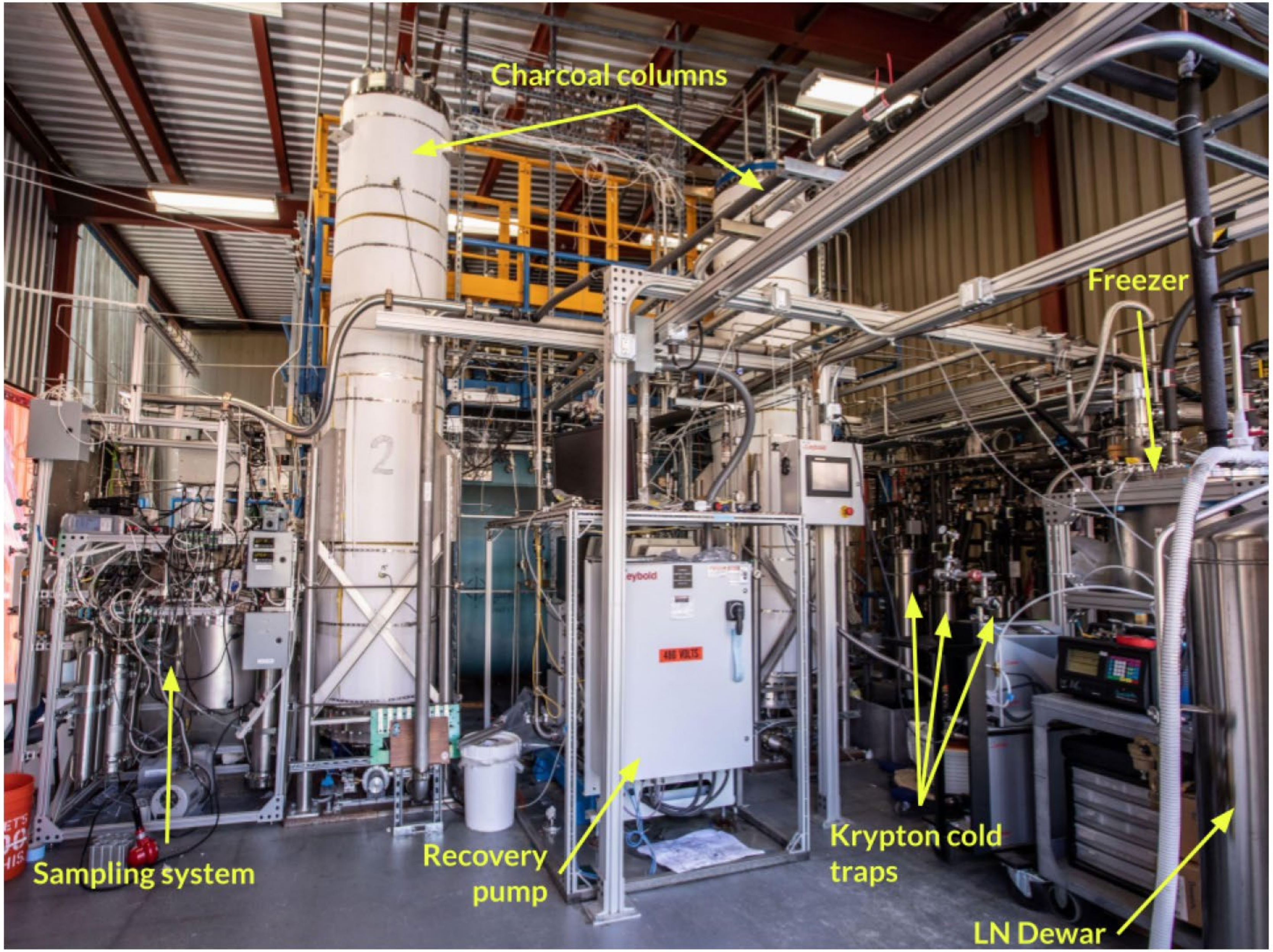


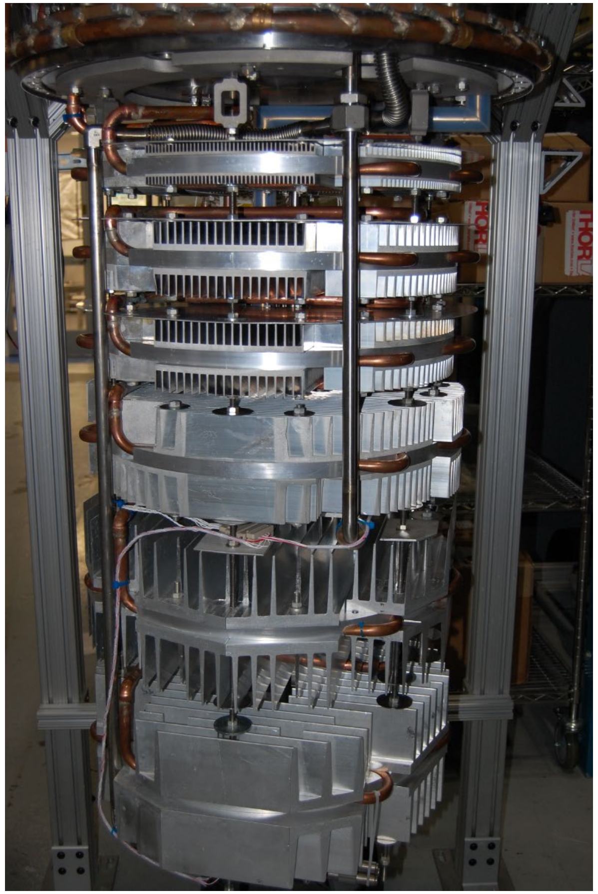
- Slow rise in Kr concentration is expected due to detector outgassing.
- Rate of increase is 50 ppq (g/g) per year. This meets the LX requirement.
- Observed increase was predicted based upon outgassing constants measured during design phase.

Charcoal Gas Chromatography for Kr removal at SLAC (2020-2021)









- Kr concentration reduced from ~10 ppb to 123 +/- 10 ppq (g/g).
- Purified Xe deliveries to SURF complete in September 2021.

Thanks to our sponsors and
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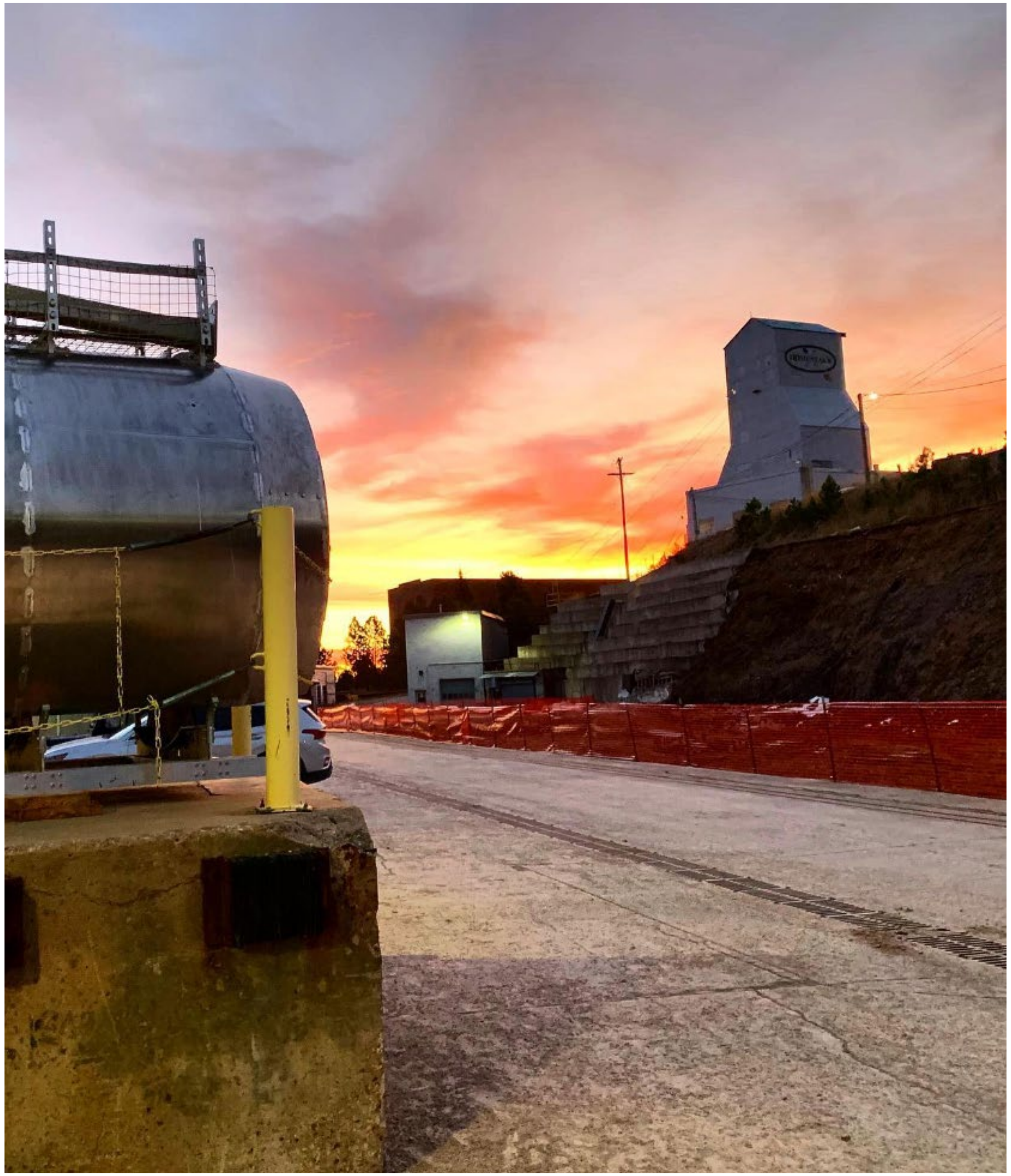
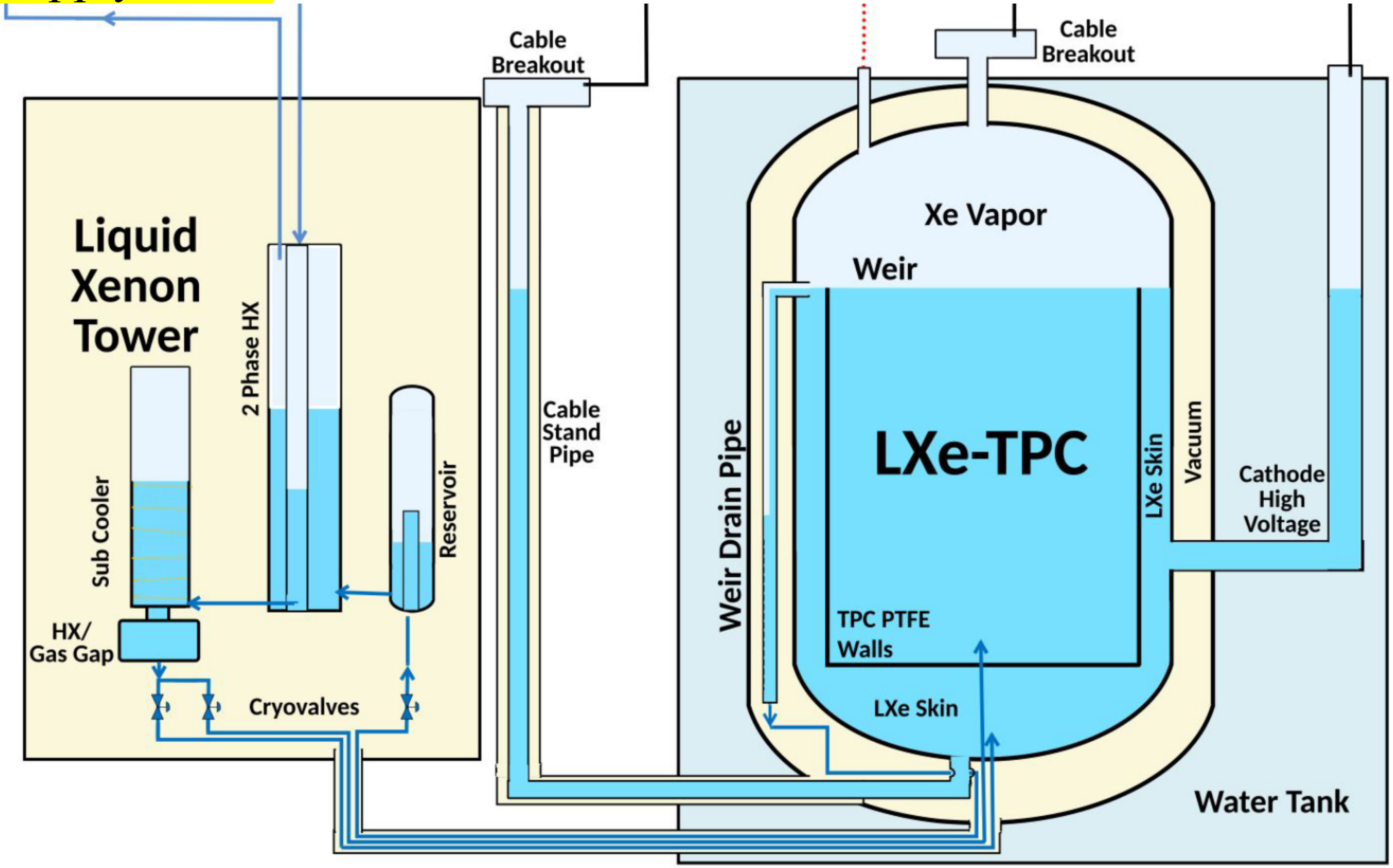
Questions?



Liquid System Elevation Plan

Gas Xe supply/return



Three LXe transfer lines inside conduit