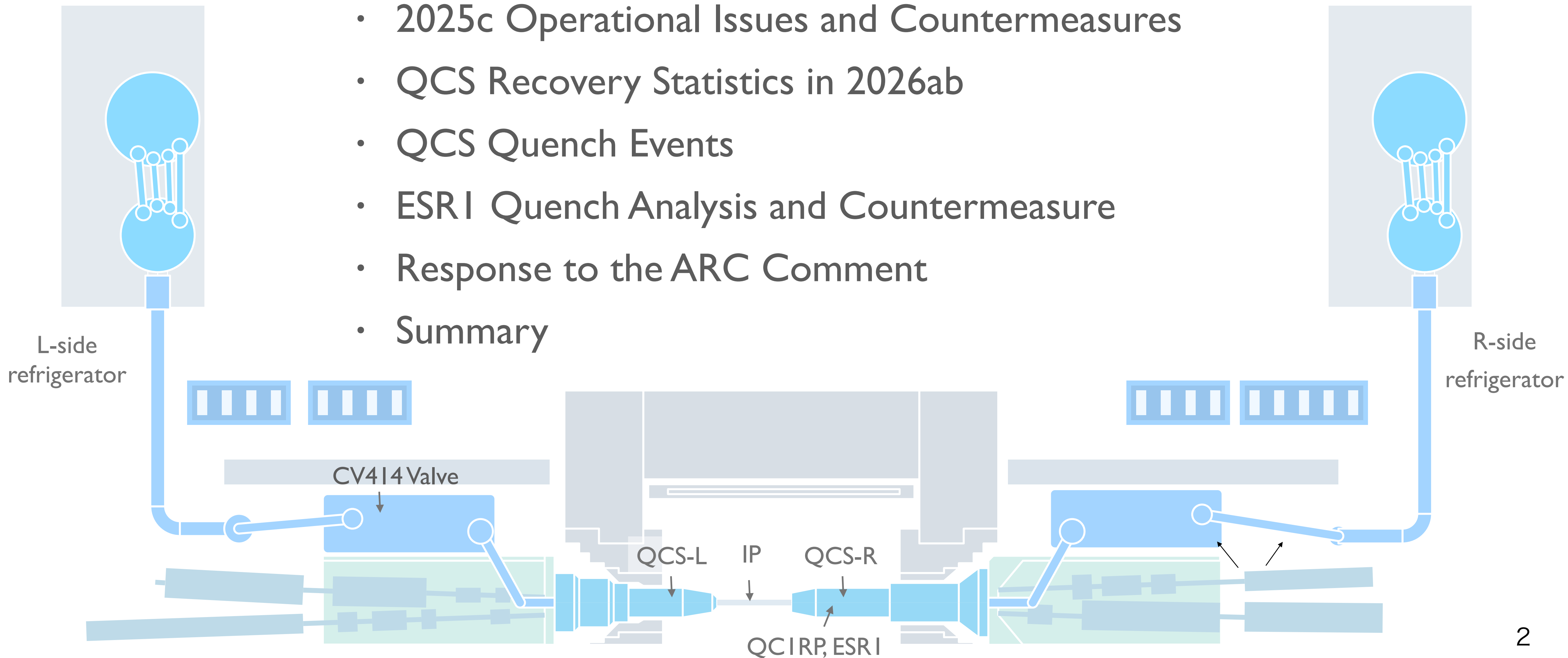


QCS

Y.Arimoto on behalf of magnet group of SuperKEKB
2026-10-26 The 29th KEKB Accelerator Review Committee

Contents

- 2025c Operational Issues and Countermeasures
- QCS Recovery Statistics in 2026ab
- QCS Quench Events
- ESRI Quench Analysis and Countermeasure
- Response to the ARC Comment
- Summary



From the 2025c run

- **Main Issue**

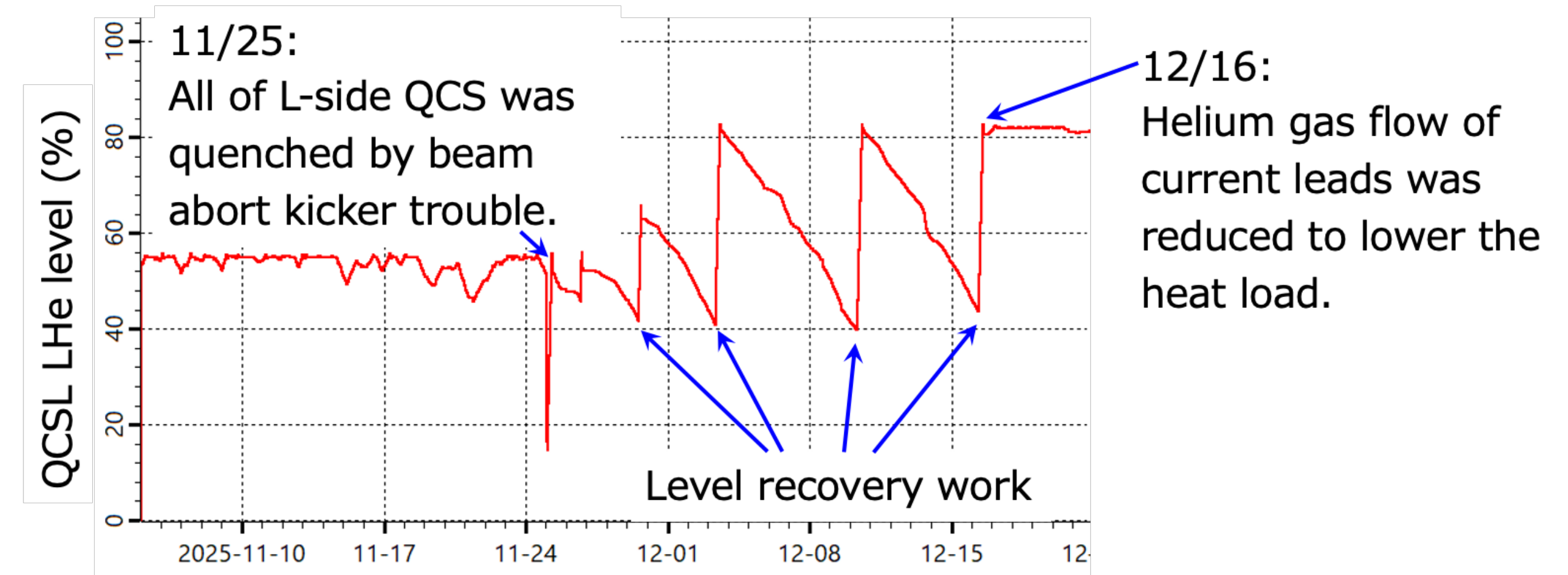
- Moisture contamination in the helium circuit reduced the heat-exchanger efficiency.
- The resulting loss of refrigeration capacity prevented stable liquid-level control.

- **Countermeasures**

- The helium-gas purification time before operation was doubled.
- The restored heat-exchanger performance recovered the nominal refrigeration capacity.
- Stable liquid-level control was subsequently achieved.

QCS problem caused weekly interruptions in 2025c

- After a quench on Nov. 25th, it became impossible to keep the liquid helium level of L-side QCS system. So that the accelerator operation was interrupted every week, and the liquid level recovery work was carried out.



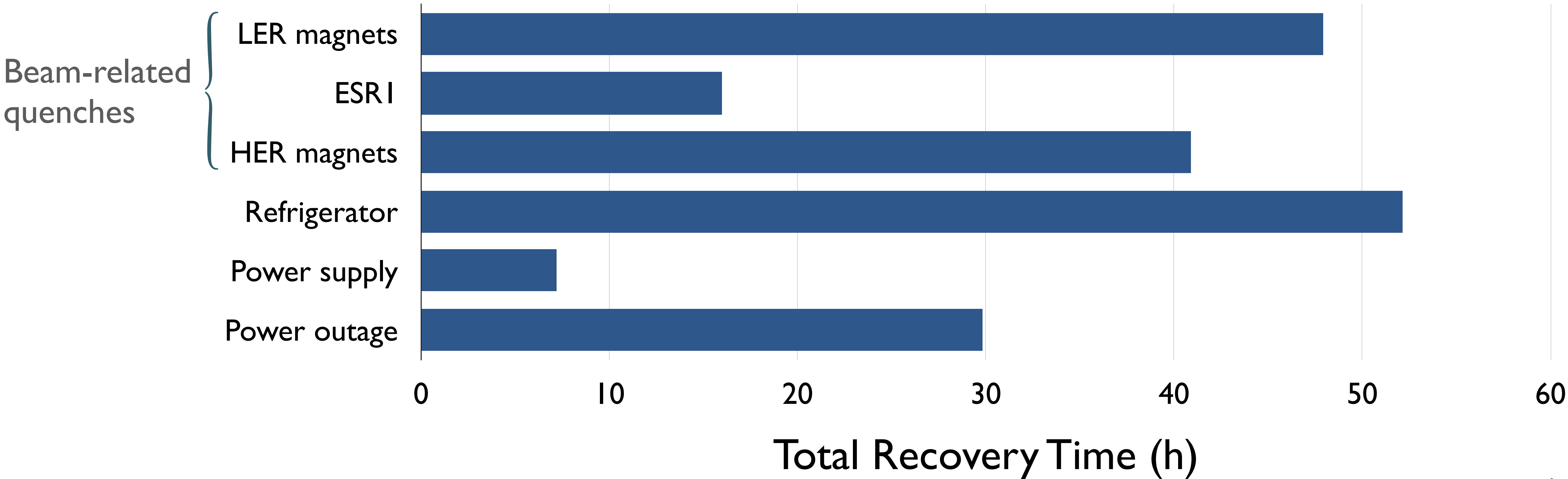
- Helium gas flow of current leads was reduced for lower heat load on Dec. 16th. Since then, the liquid level has been kept.

Recovery Time Statistics for QCS Failures (2026ab)

Total Recovery Time from QCS Current Interruption to Full Recovery

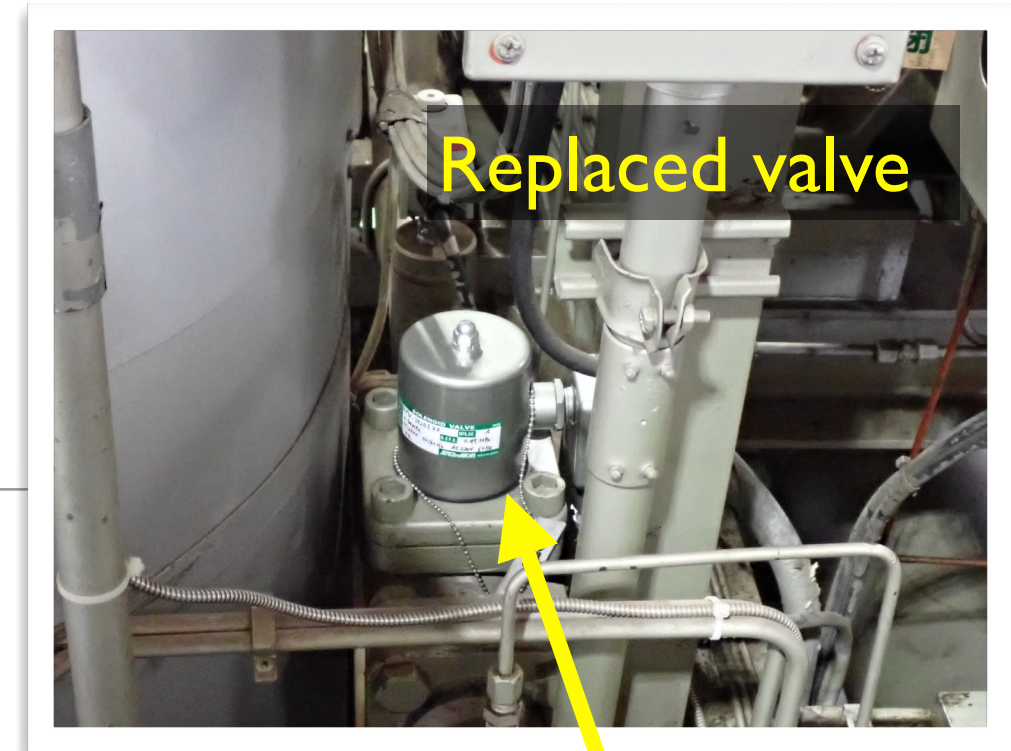
Total recovery time = 194 h*

*Includes 30 h due to the site-wide power outage.



Refrigerator-related Issues

- The two major refrigerator-related incidents that resulted in extended QCS downtime during the 2026ab run were:
 - **Feb. 15:** Failure of a compressor solenoid valve. A temporary repair was carried out.
 - → **The valve has since been replaced.**
 - **Jun. 19:** A momentary power outage was followed by the temporary mitigation of a seat leak at valve CV414 in the L-side service cryostat.
 - → **Further adjustments by the manufacturer are scheduled for November.**

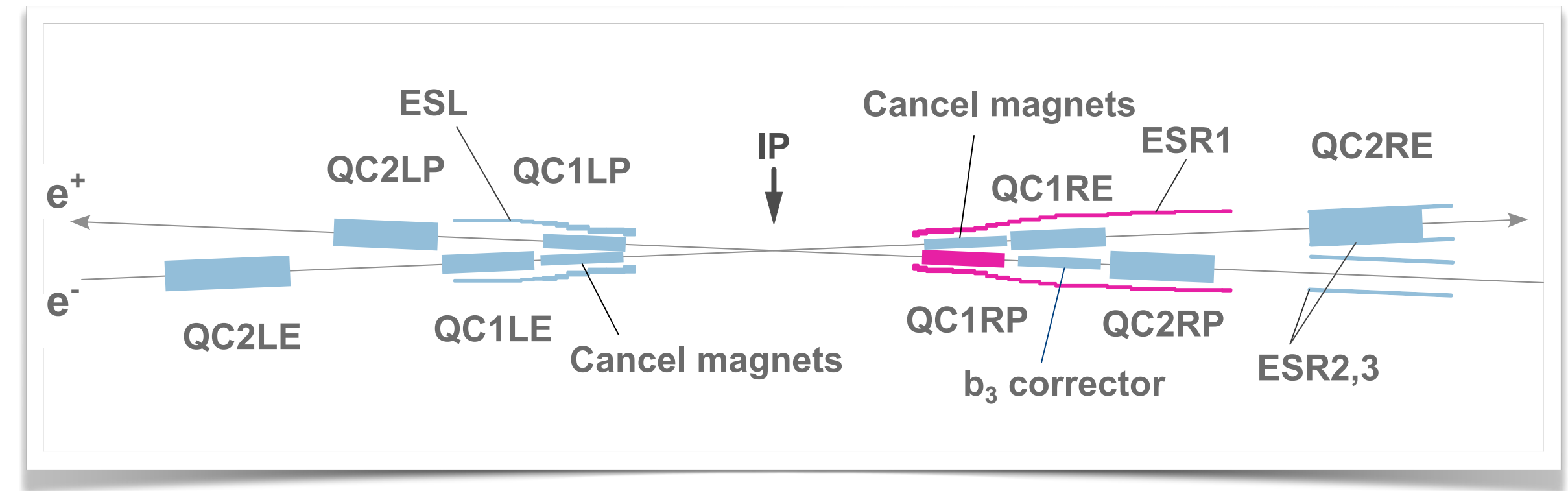
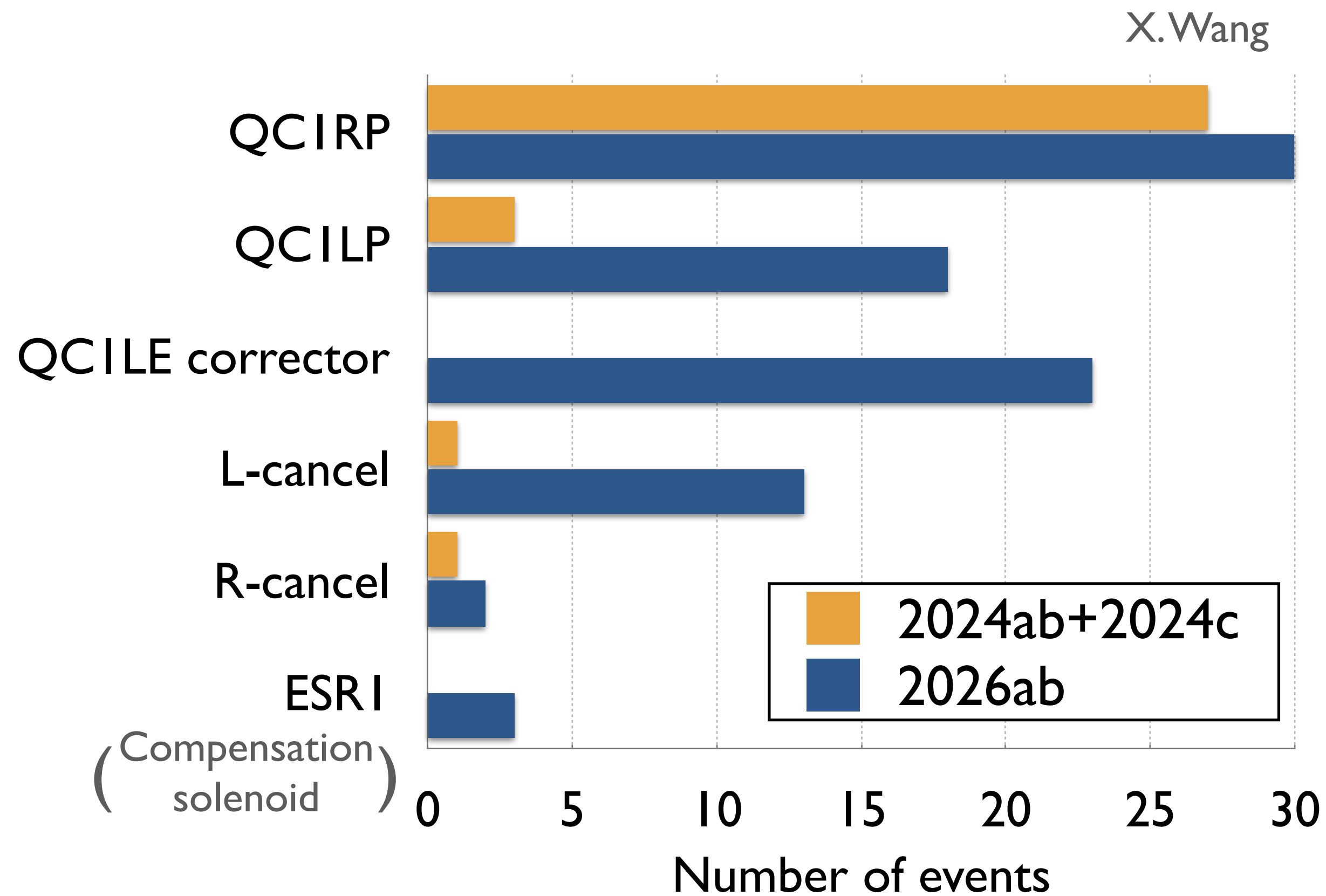


Broken solenoid coil of compressor-related valve



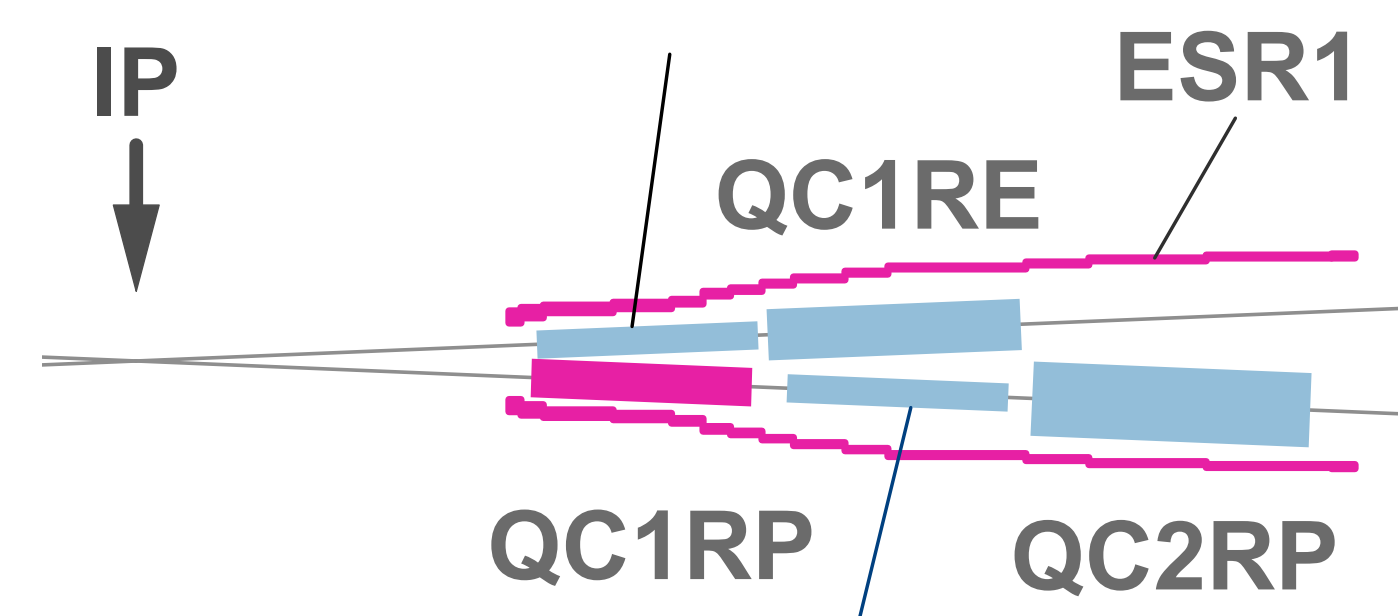
CV414 Valve ⁵

QCS Quench Statistics



- Beam-related events accounted for 57 of the 61 QCS quench/trip events.
- QCIRP and QCILE corrector were the dominant quench locations. Beam-induced quenches in HER magnets increased significantly in 2026ab, and three ESR I quenches were recorded.

Impact of ESR I Quench on Luminosity Recovery Time



Typical QCIRP quench

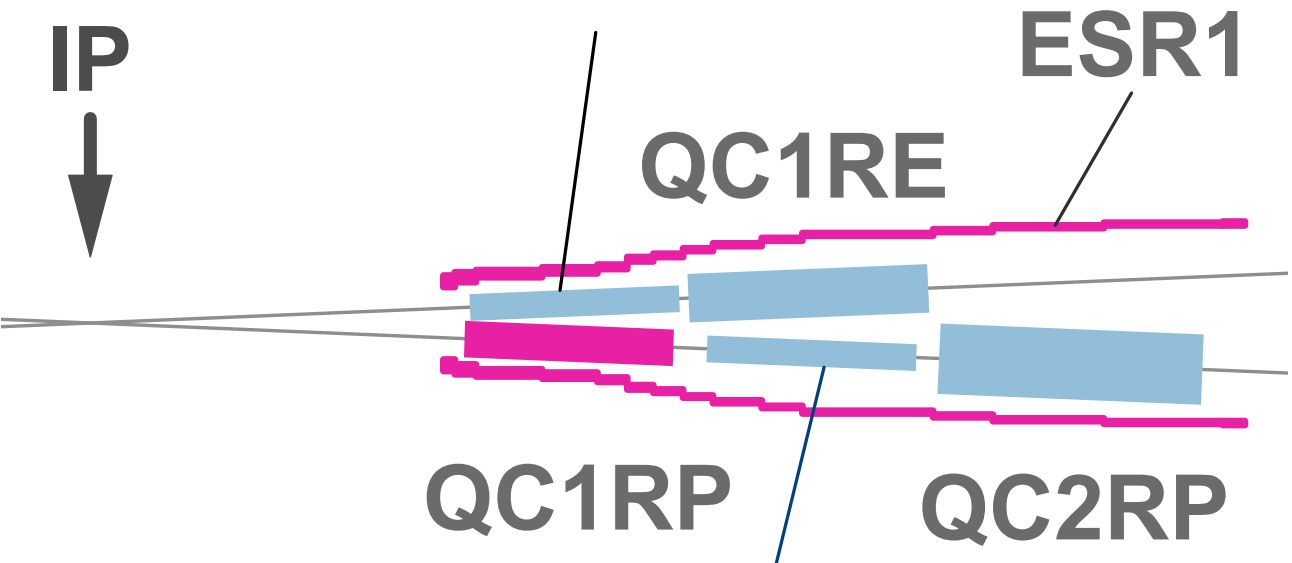


QCIRP quench triggering ESR I quench

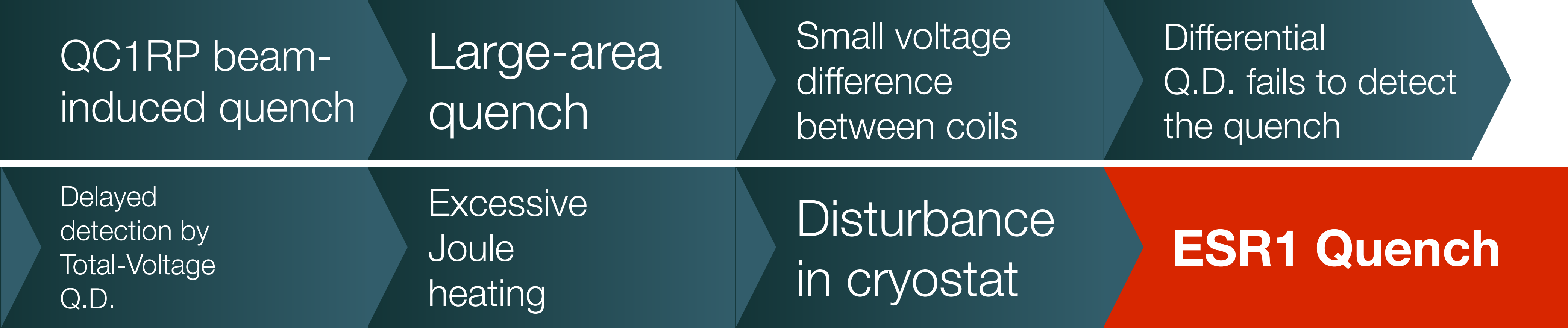


- A typical QCIRP quench results in approximately 2 hours of luminosity recovery time.
- A QCIRP quench that triggers an ESR I quench results in approximately 14 hours of luminosity recovery time.

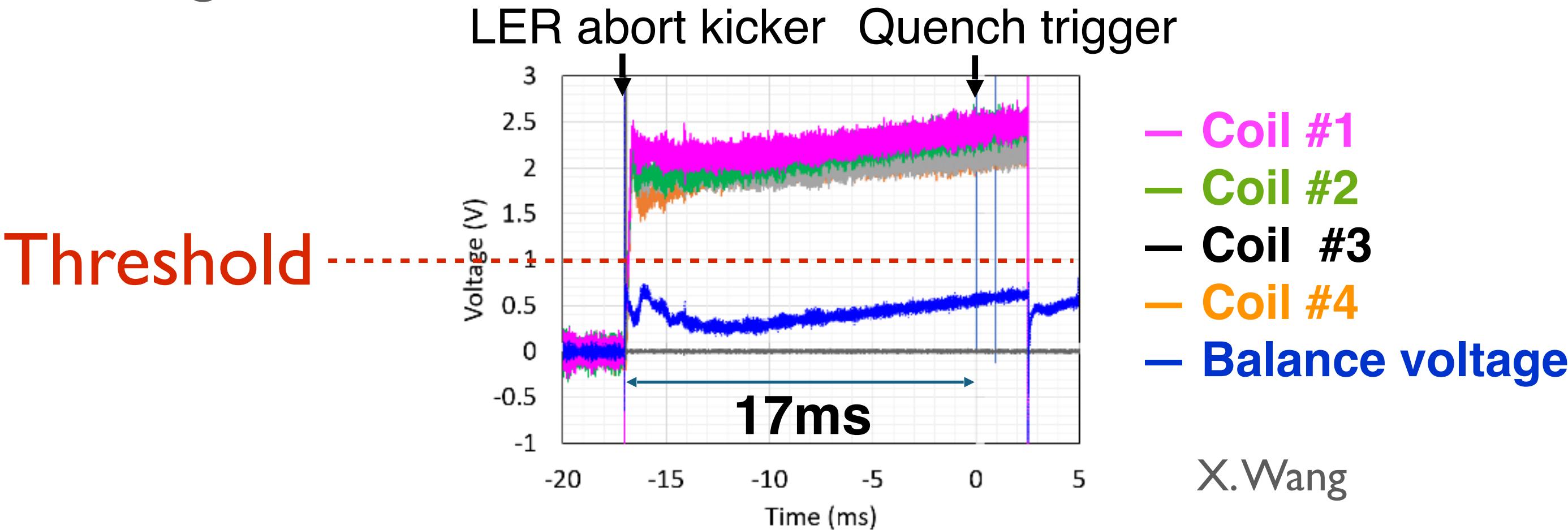
Possible ESR1 Quench Scenario



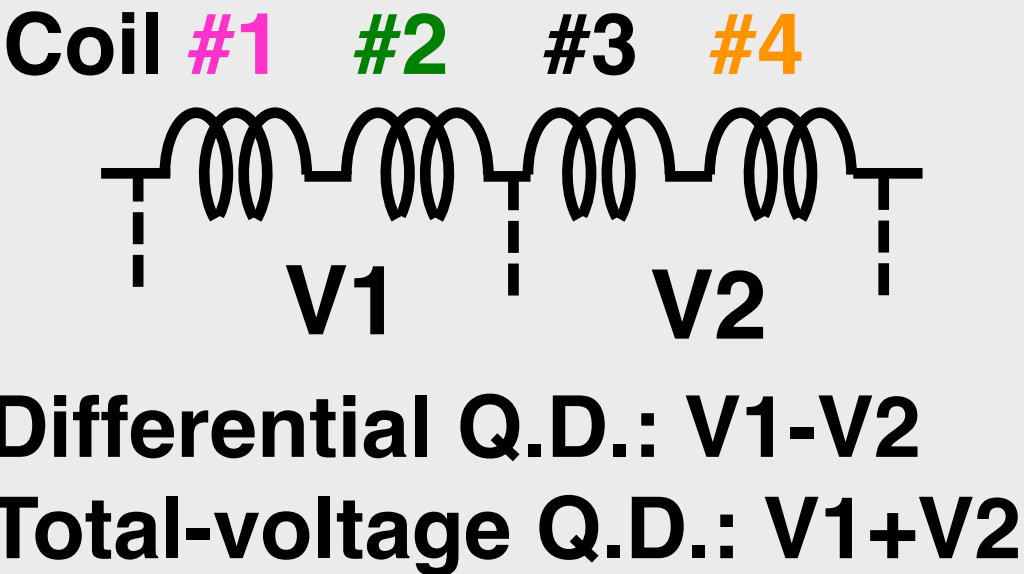
First observed during operation above 0.8 mA/bunch in the 2026ab run.



Coil voltage of QC1RP



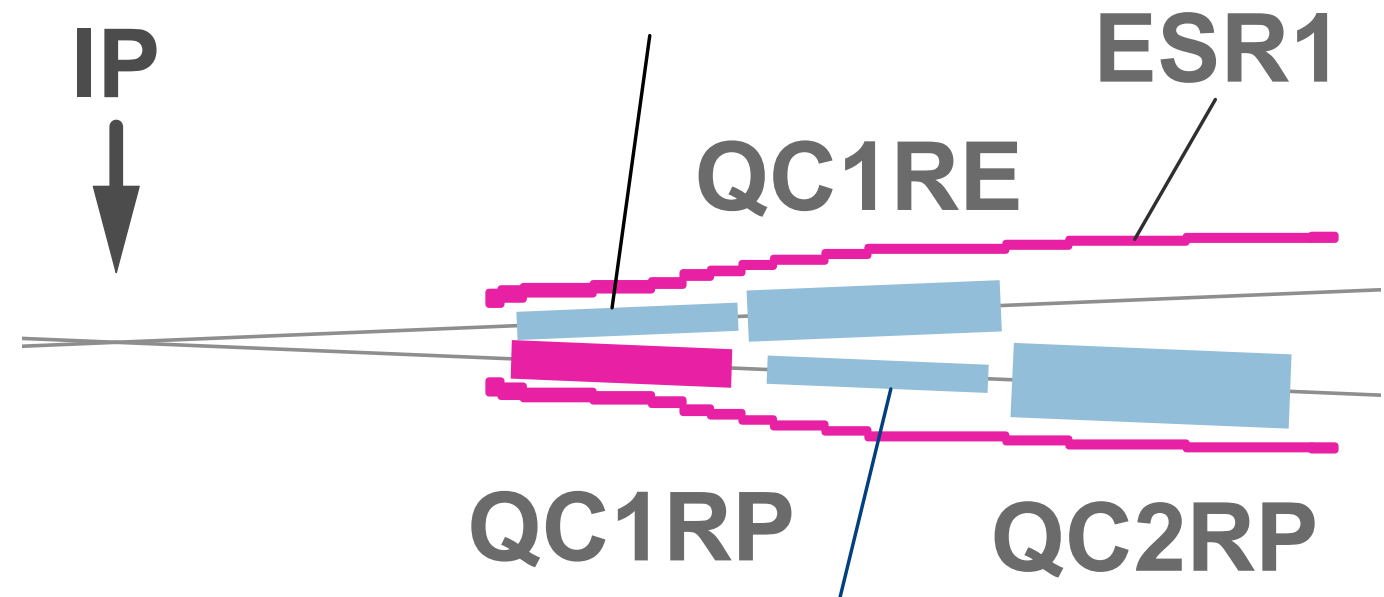
Quench detection



The balance voltage remains below the threshold.

X.Wang

Countermeasure for ESR1 Quenches

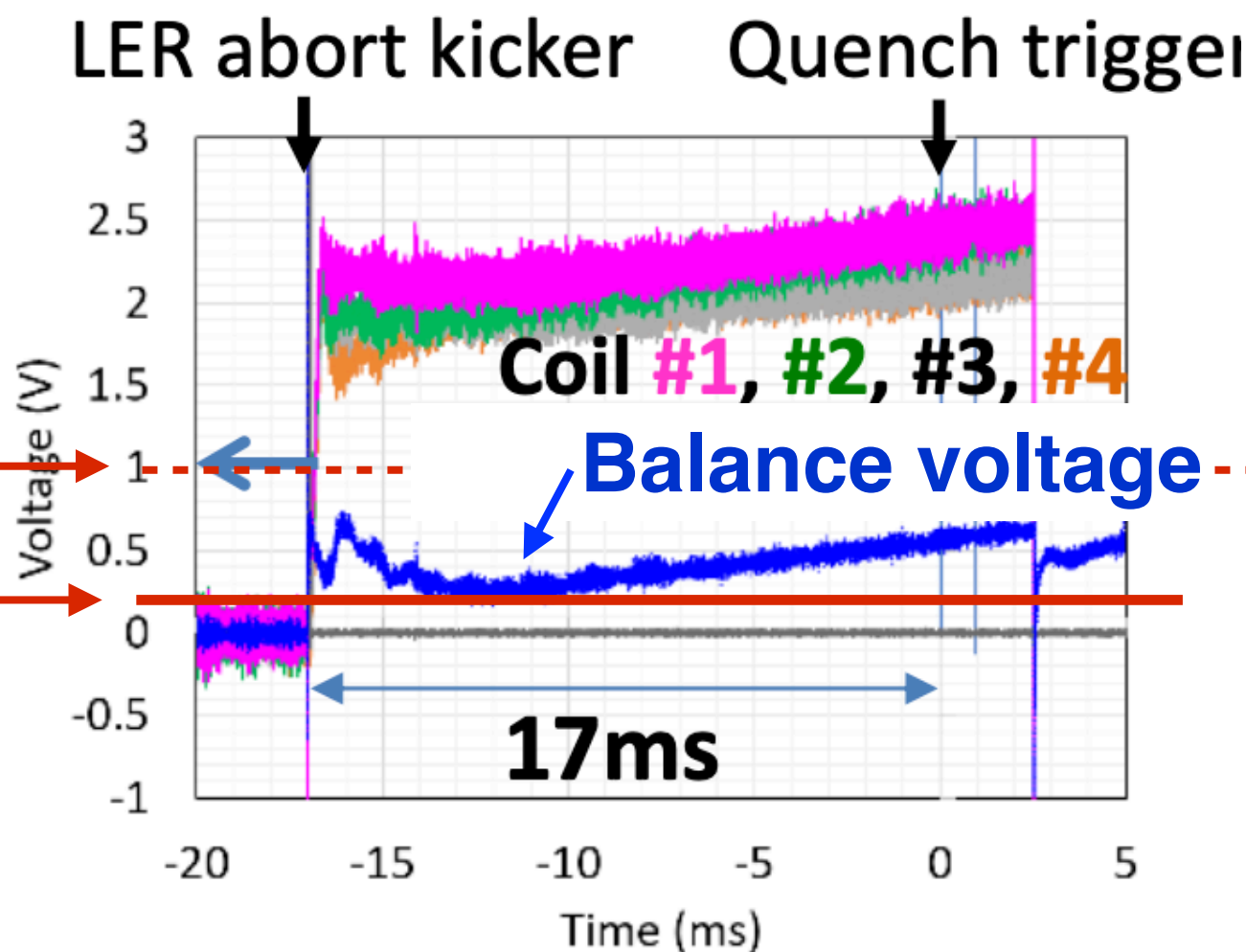


Large-area quench : QCIRP coil voltages

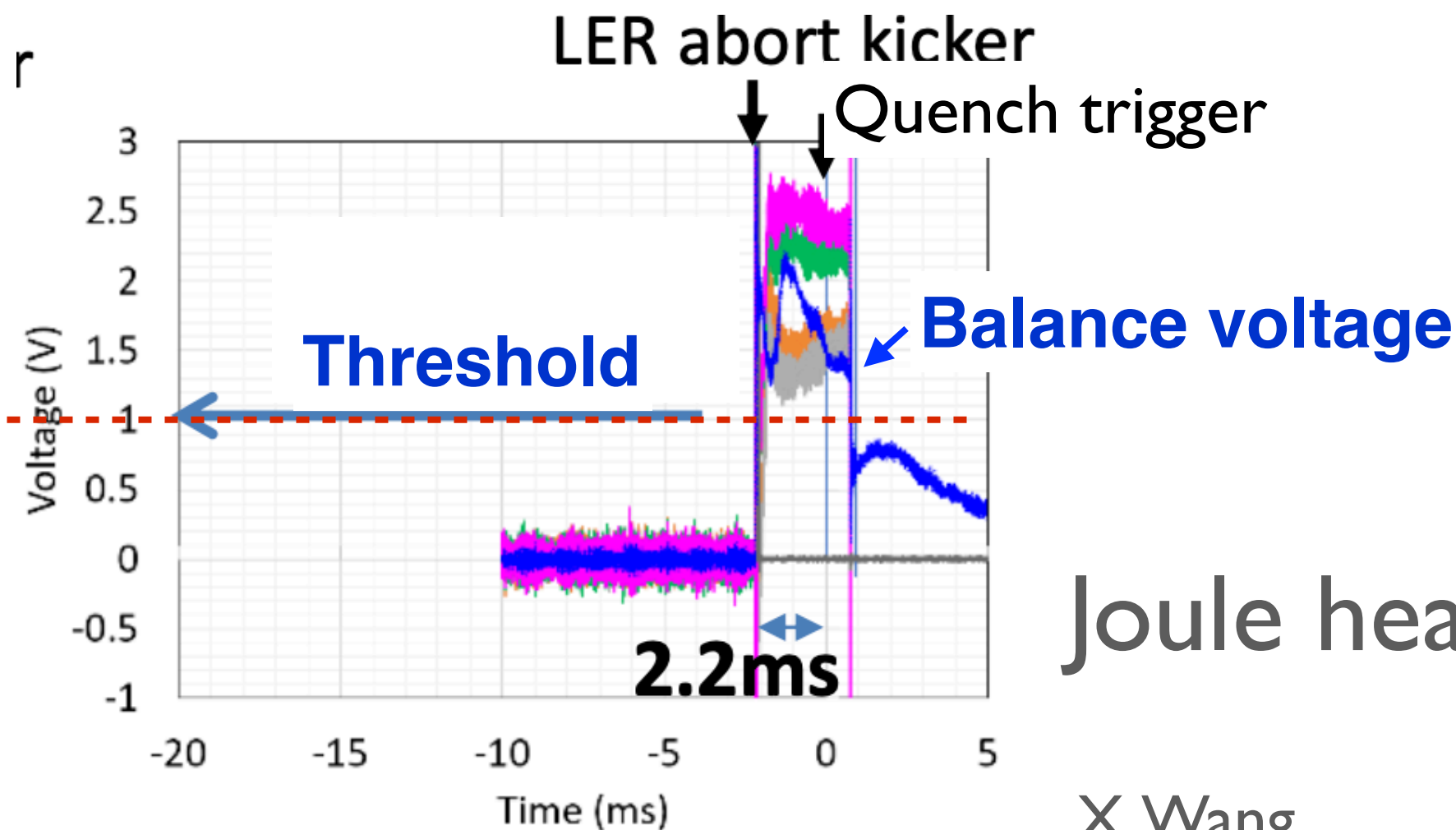
Joule heating: 240 J

Current threshold

New threshold



Typical quench: QCIRP coil voltages



Joule heating: 30 J

X.Wang

Lowering the threshold to 0.2 V is expected to reduce the deposited energy from about 240 J to about 30 J.

Comments on the Previous ARC

- Complete the study of whether the radiation doses to the SC magnet coils due to SBLs, other beam aborts, and accumulated backgrounds will ultimately degrade the integrity of the SC magnets.

Radiation Dose and Material Degradation of the QCS Superconducting Magnet

- **Radiation dose and material degradation caused by abnormal beam losses**

- **Assumption**

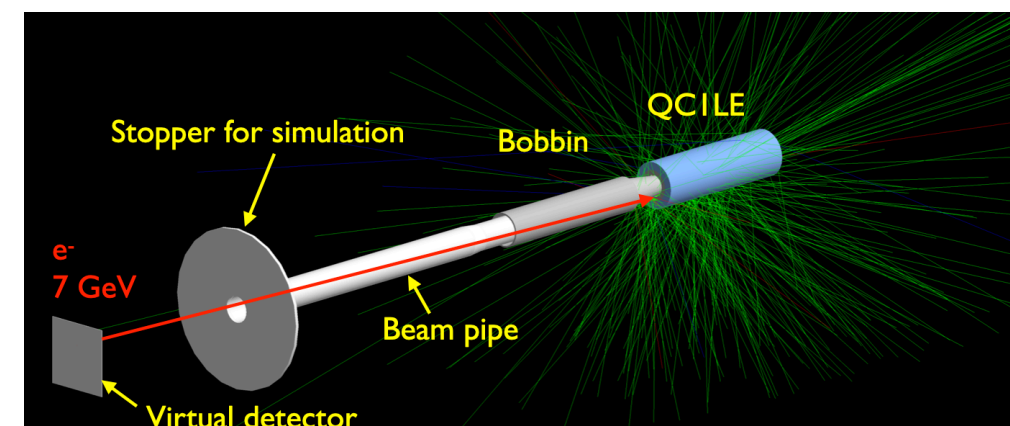
- Weak-bend event in November 2025
- 610 mA HER beam loss near the IR

- **Estimated Dose on QCILE**

- Realistic (8% local loss): 0.009 MGy
- Worst case (100% local loss): 0.11 MGy

- **Estimated Material Degradation**

- Kapton insulation: **0.05%**
- Stycast adhesive: **0.3%**

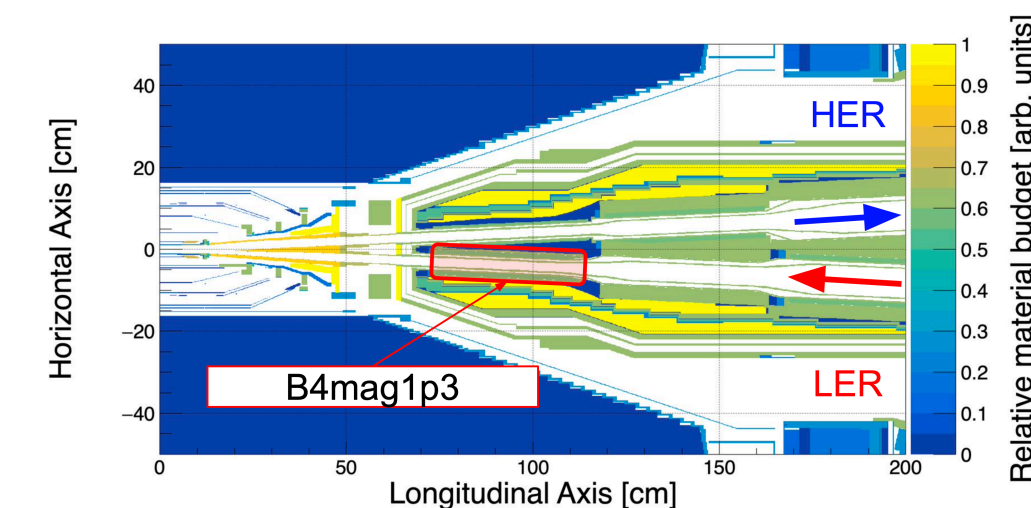


- **Accumulated background dose up to 2026ab based on estimates by A. Natochii (2021)**

- LER Single beam, $\beta y^* = 0.8$ mm
- QCIRP
- Integrated beam current = 1.5×10^4 A h
- Dose rate per beam current = 1.01×10^2 mrad/s/A
- Estimated dose = 0.055 MGy
- Degradation of Stycast adhesive: **2 %**

- **Estimated accumulated background dose after five years**

- LER beam current = 2.6 A
- Operation time = 200 days / year
- Integrated beam current = 6.24×10^4 A h
- Estimated dose = 0.227 MGy
- Degradation of Stycast adhesive: **8 %**



Material degradation due to abnormal beam loss-event is estimated to be small.

The accumulated background dose is larger than that from the abnormal beam-loss event; however, the resulting material degradation remains small.

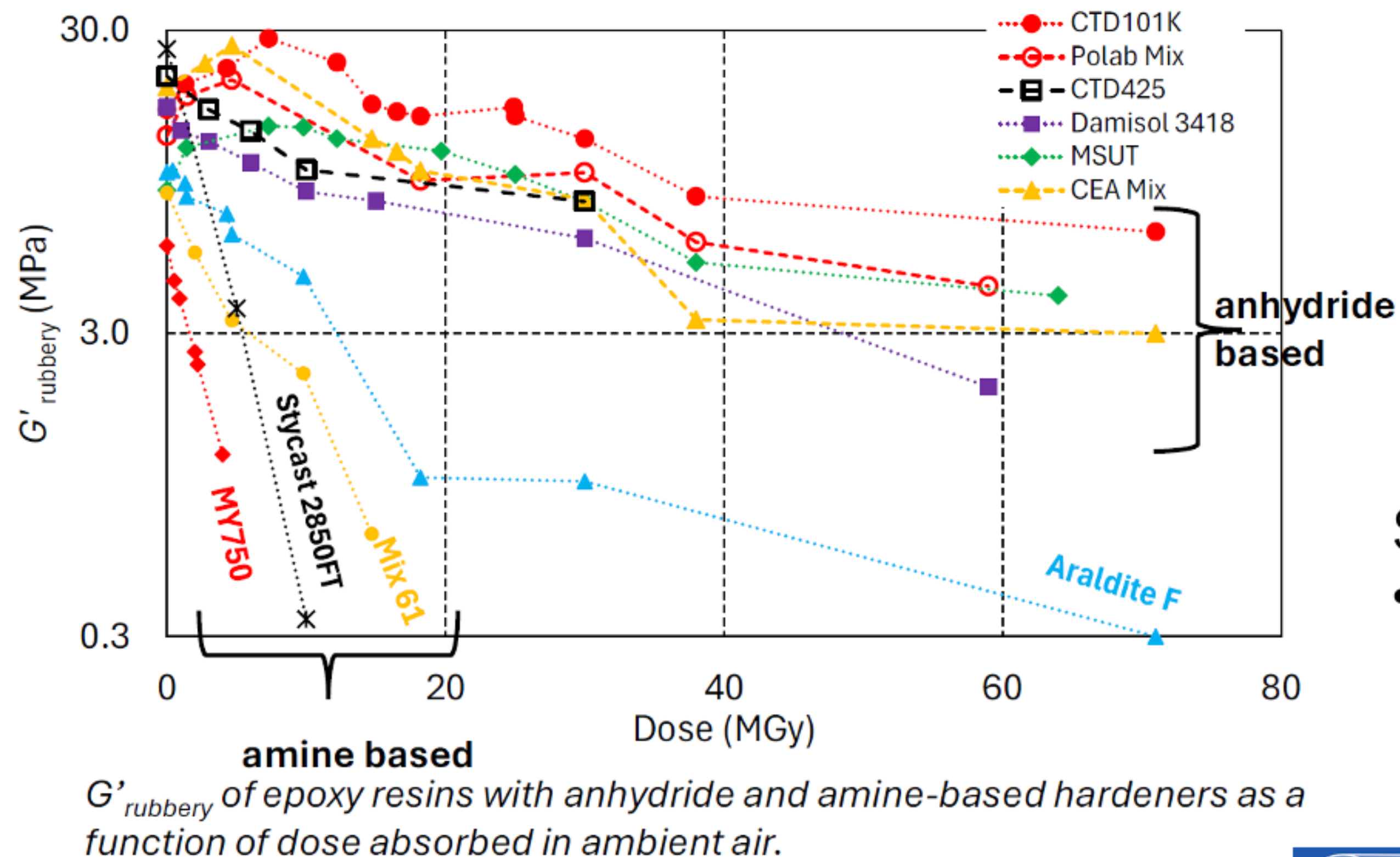
Summary

- The cumulative QCS downtime during the 2026ab run was 194 hours (164 hours excluding the site-wide power outage).
- HER magnet quenches increased significantly during the 2026ab run. Delayed quench detection was identified as a possible contributor to ESR I quenches, and lowering the Q.D. threshold is expected to reduce the deposited energy and the risk of ESR I quenches.
- Refrigerator-related issues observed during the 2025c and 2026ab runs have either been resolved or are being addressed during the current shutdown period.
- Radiation-dose simulations indicate that material degradation remains small for both abnormal beam-loss events and the expected accumulated background radiation.

Backup

Pre-selection of most radiation hard epoxy resins based on DMA results

- Most radiation hard resins can be distinguished by a comparatively smaller decrease of $G'_{rubbery}$ with increasing dose.
- Epoxy resin systems with amine-based hardeners degrade at much lower doses than those with anhydride-based hardeners.
- Proton doses >100 MGy will be achieved at IRRAD by the end of 2025.



Stycast2850FT

- 10MGyの放射線照射で強度は1/100まで劣化。

C. Scheuerlein, TE-TM meeting, 14 July 2025

23



$G'_{rubbery}$:粘弾性係数

日本ゴム協会誌 第91巻第9号 (2018)

特論講座 五十野義信 ゴムの粘弾性 第1講 高分子の粘弾性

Update on polymer irradiation damage studies for accelerator magnets

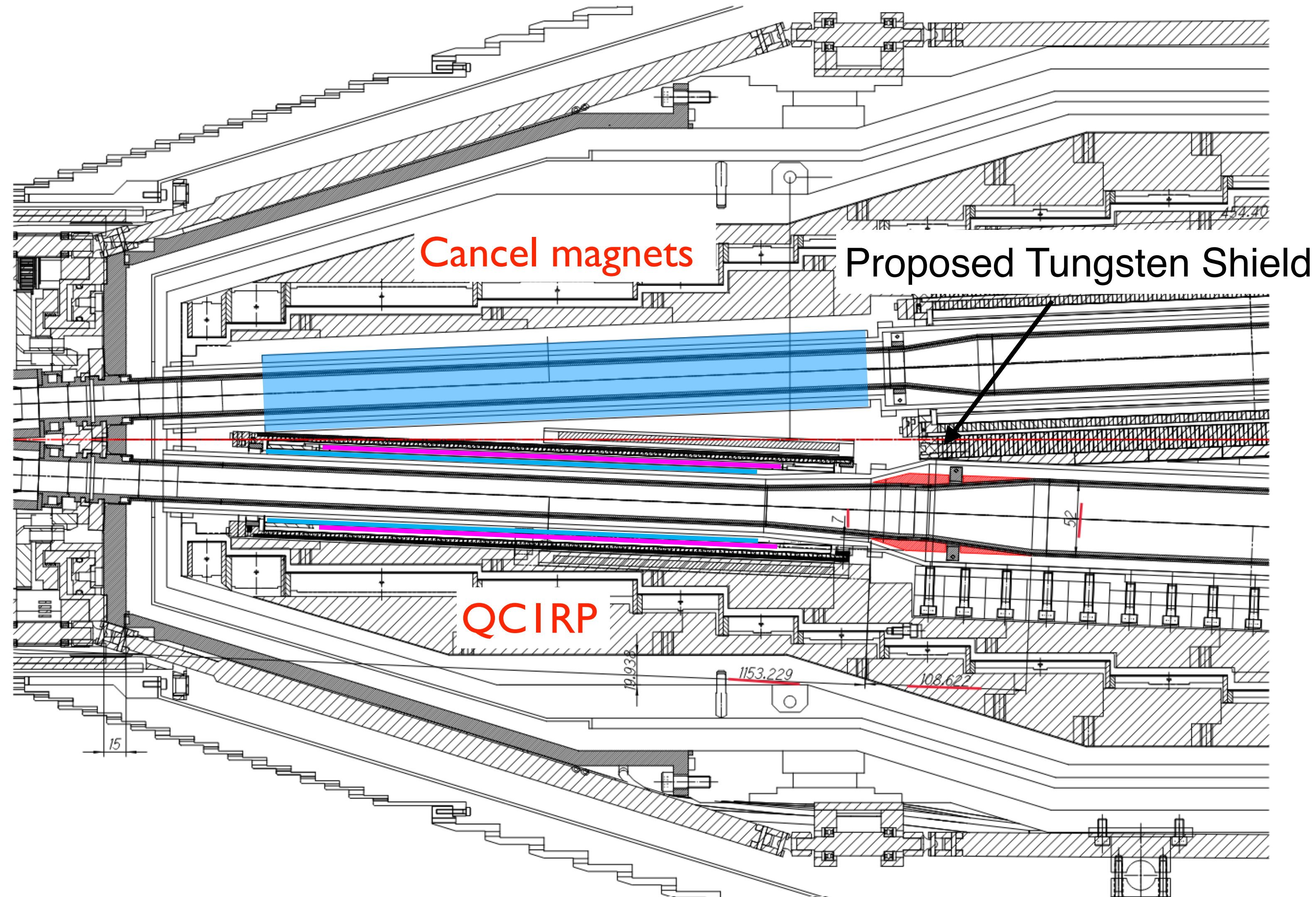
C. Scheuerlein, TE-MSC-SMT

TE-TM meeting, 14 July 2025

<https://indico.cern.ch/event/1557591/>

Current QCSR Cryostat Cross Section and Additional Tungsten Shield

An additional tungsten shield is proposed in the available space between the beam pipe and the liquid-helium vessel. The shield is expected to mitigate the risk of quench.



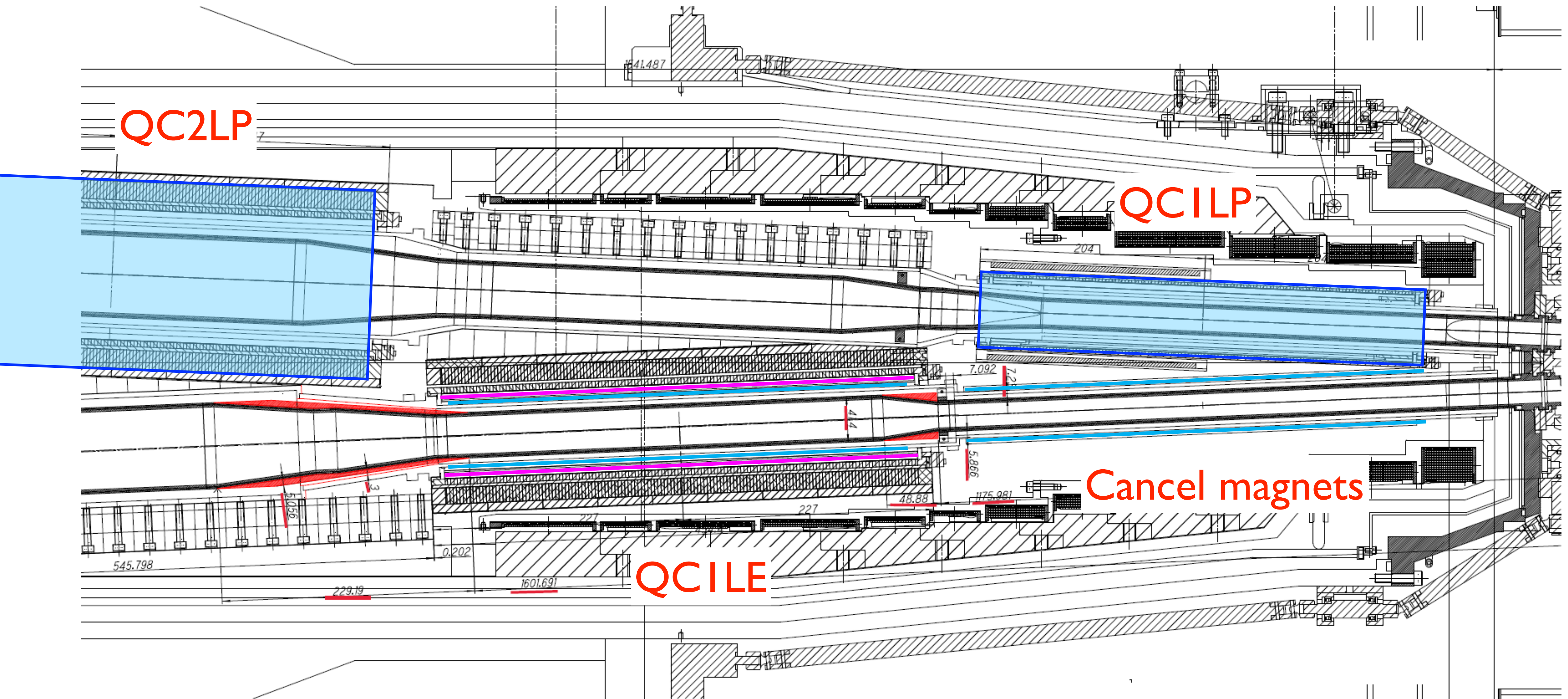
The geometry of the super-insulation (SI) layers is not included in this drawing.

The beam pipe can be moved 10 mm toward the IP, providing the clearance required for installation.

The thickness of the SI is approximately 1.5 mm for 10 layers.

The current beam pipe is wrapped with five SI layers.

Additional Tungsten Shield to QCS-L

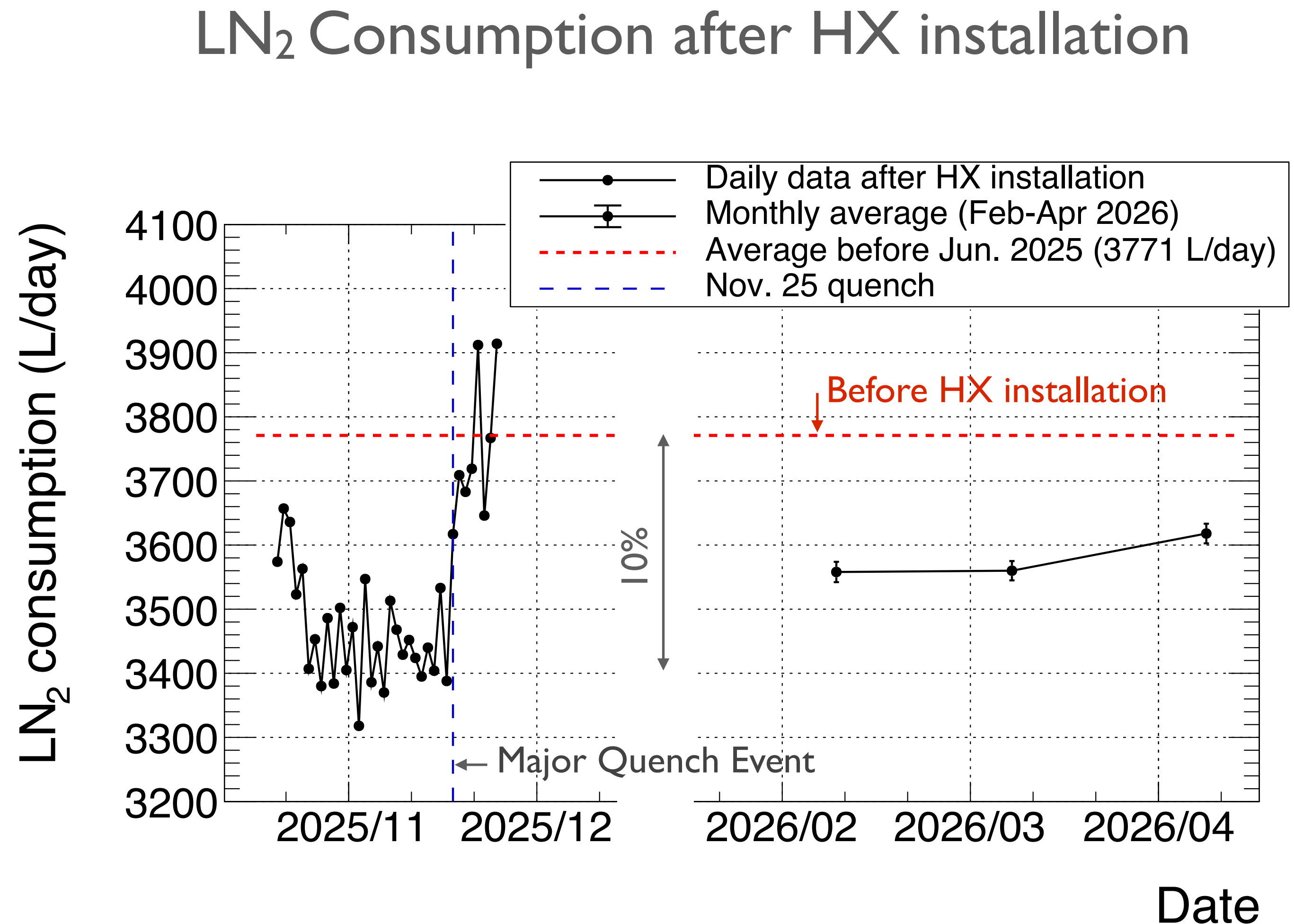


The geometry of the super-insulation (SI) layers is not included in this drawing.

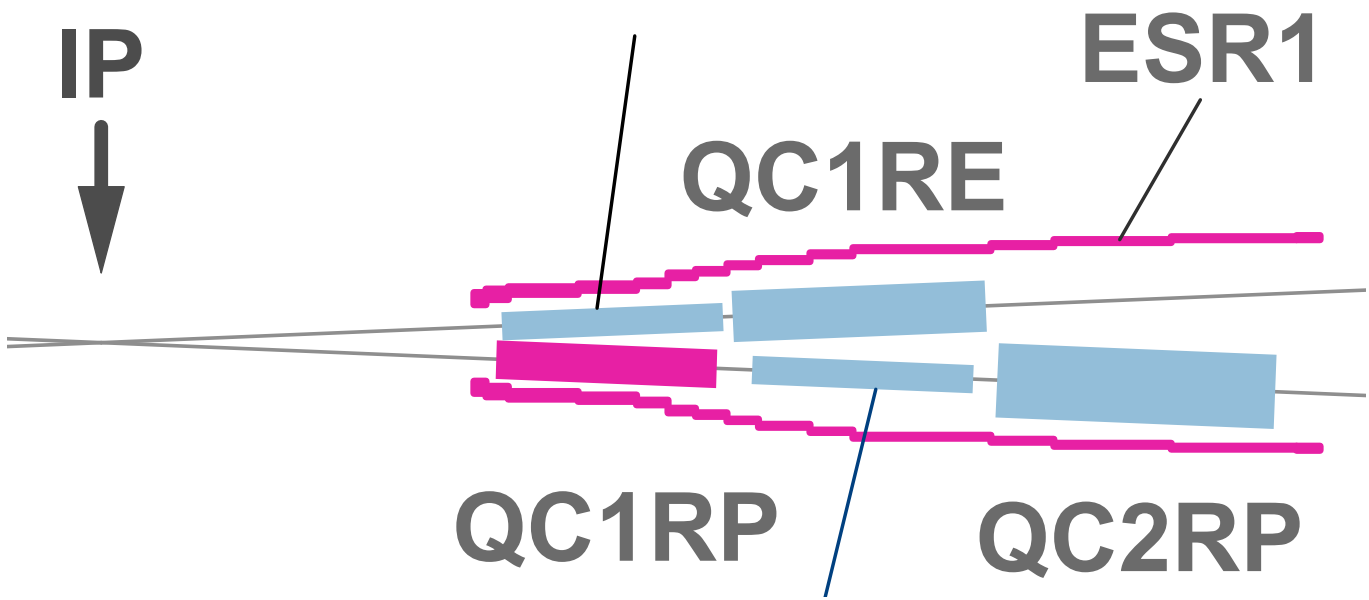
The beam pipe can be moved 7 mm toward the IP, providing the clearance required for installation.

Reduction of liquid nitrogen consumption for refrigerator

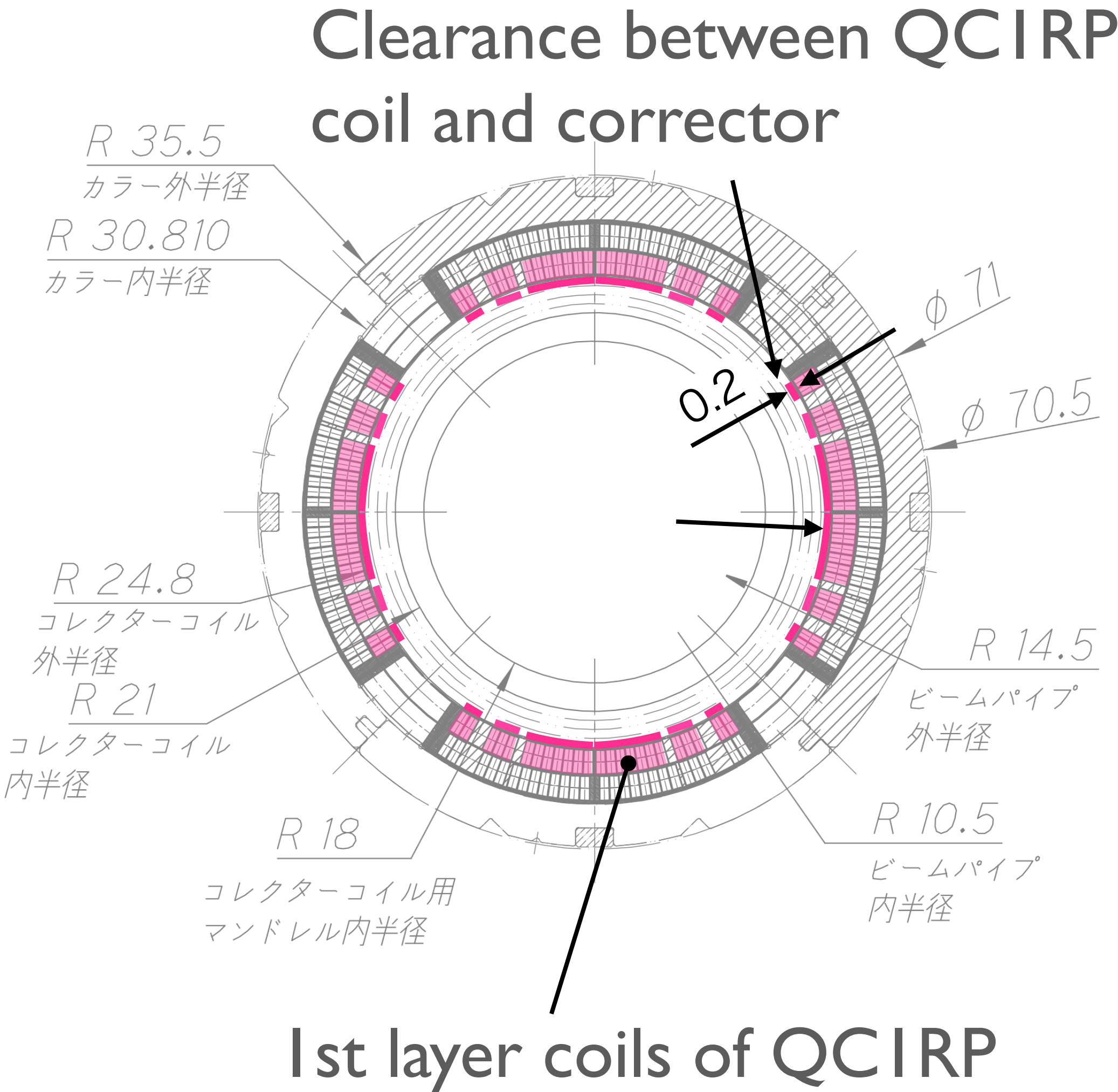
- A heat exchanger (HX) was installed on the R-side refrigerator in September 2025.
- The HX has been operating successfully and has reduced liquid nitrogen (LN_2) consumption by 9 %.
- Consumption increased following the November 25 quench; however, it remains below the level observed before the HX installation.
- We plan to install a similar heat exchanger on the L-side refrigerator next summer.



Possible Thermal Impact of 240 J Energy Deposition



- Assumptions
 - LHe in strand gaps and 0.2 mm clearance (red region)
 - LHe volume: 0.017 L
- Estimated Energy Balance
 - Deposited energy: 240 J
 - Vaporization energy: ~44 J
 - Remaining energy: ~196 J
 - Estimated gas temperature rise: ~**18 K**
- Interpretation
 - A 240 J energy deposition could generate helium gas with a temperature rise of approximately 18 K.
 - Such a temperature rise may contribute to an ESR I quench.
- Limitations of This Analysis
 - Heat transport to ESR I
 - ESR I conductor heat capacity
 - Helium flow dynamics
- Relevance to the Proposed Countermeasure
 - Proposed threshold reduction: 240 J → ~30 J
 - 30 J < ~44 J (estimated vaporization energy)
 - Significant helium-gas temperature rise is therefore not expected.

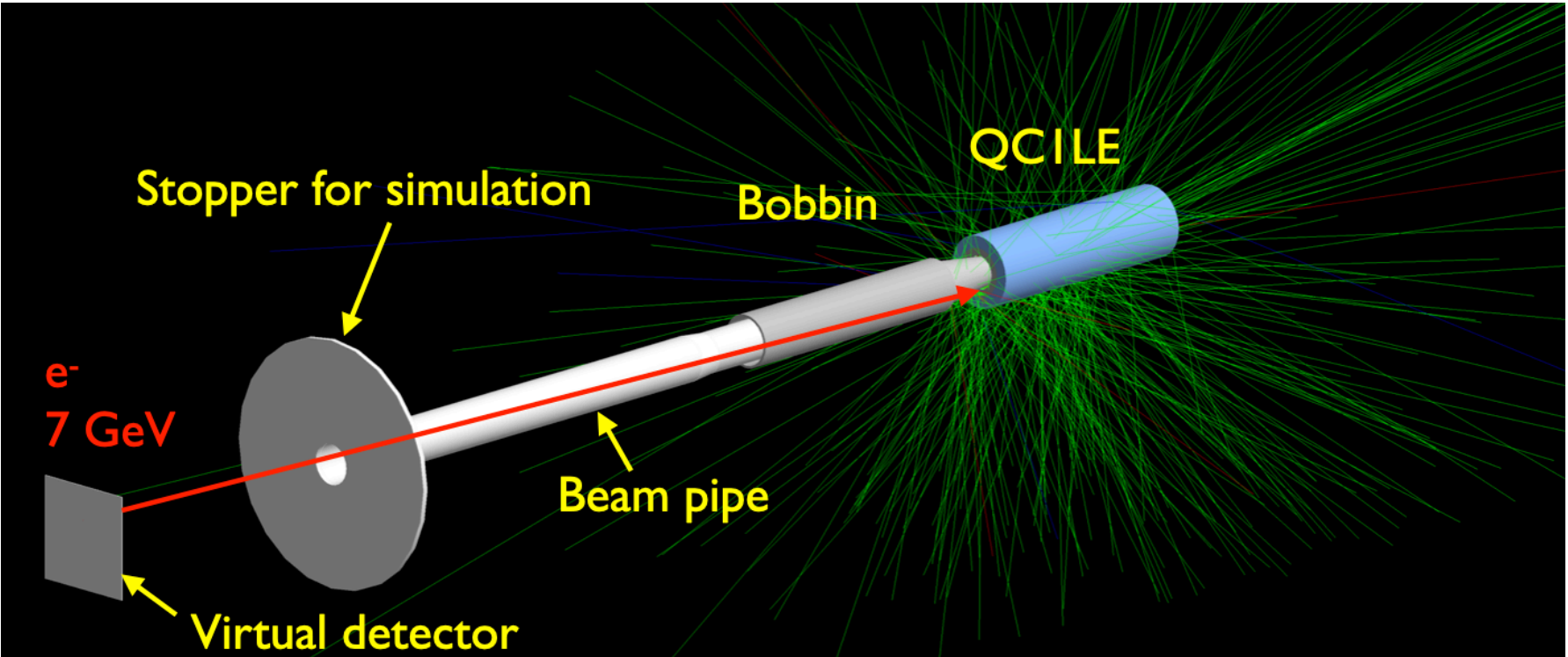
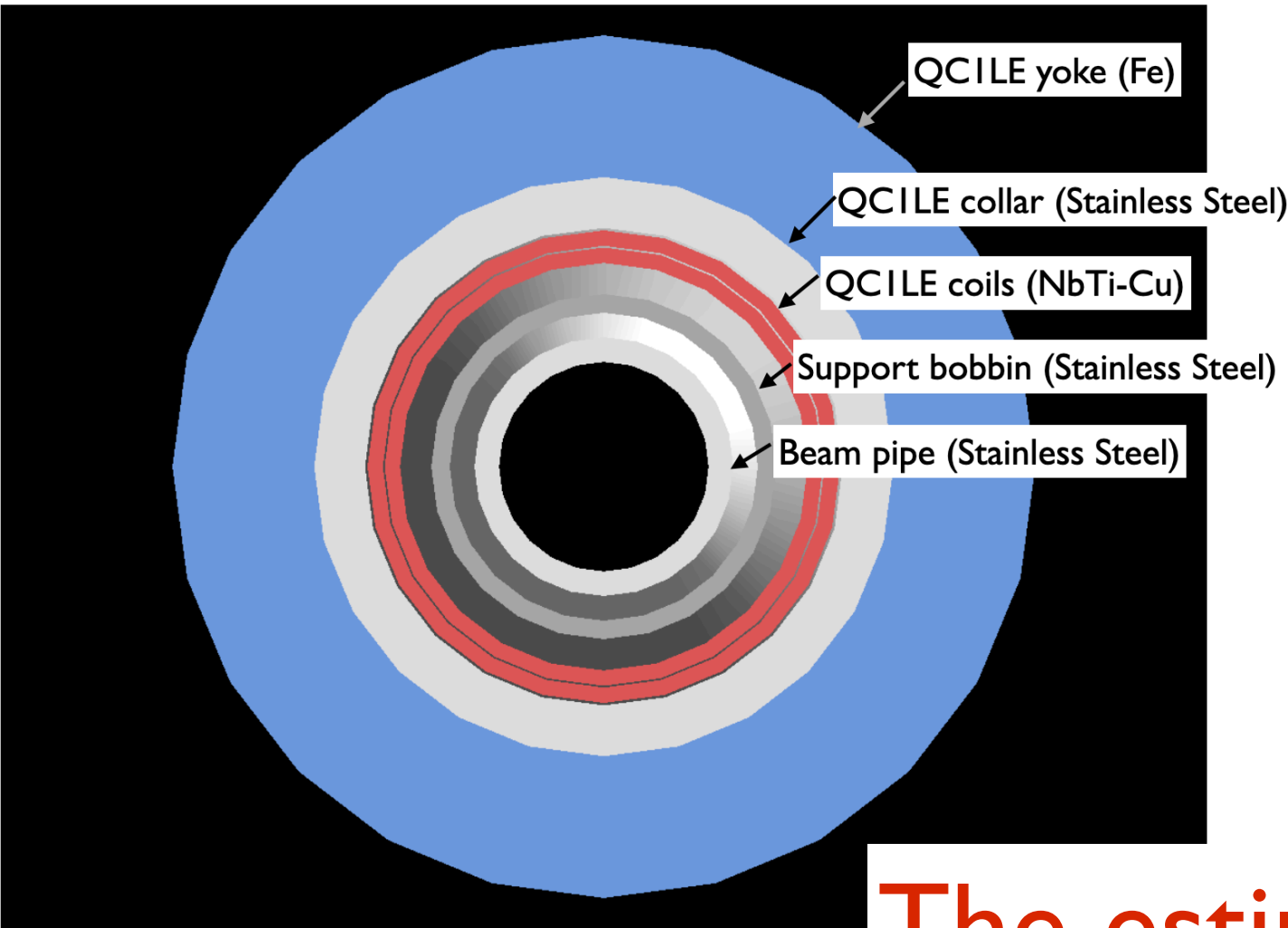
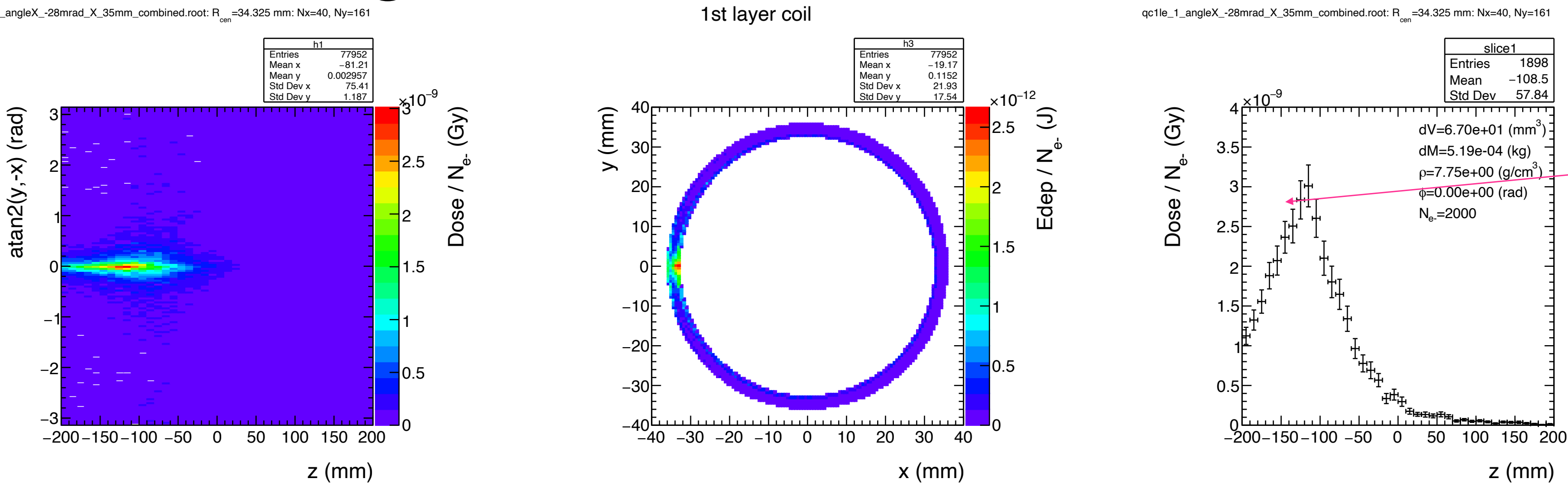


Radiation Dose Evaluation for QCILE

Weak bend event



$x = 35 \text{ mm}, x' = -28 \text{ mrad} @ z=4000 \text{ mm}$



The estimated Kapton degradation is negligible.