High Electric Field Studies in Liquid Helium for the NEDM@SNS Experiment

nEDM 2021 Conference

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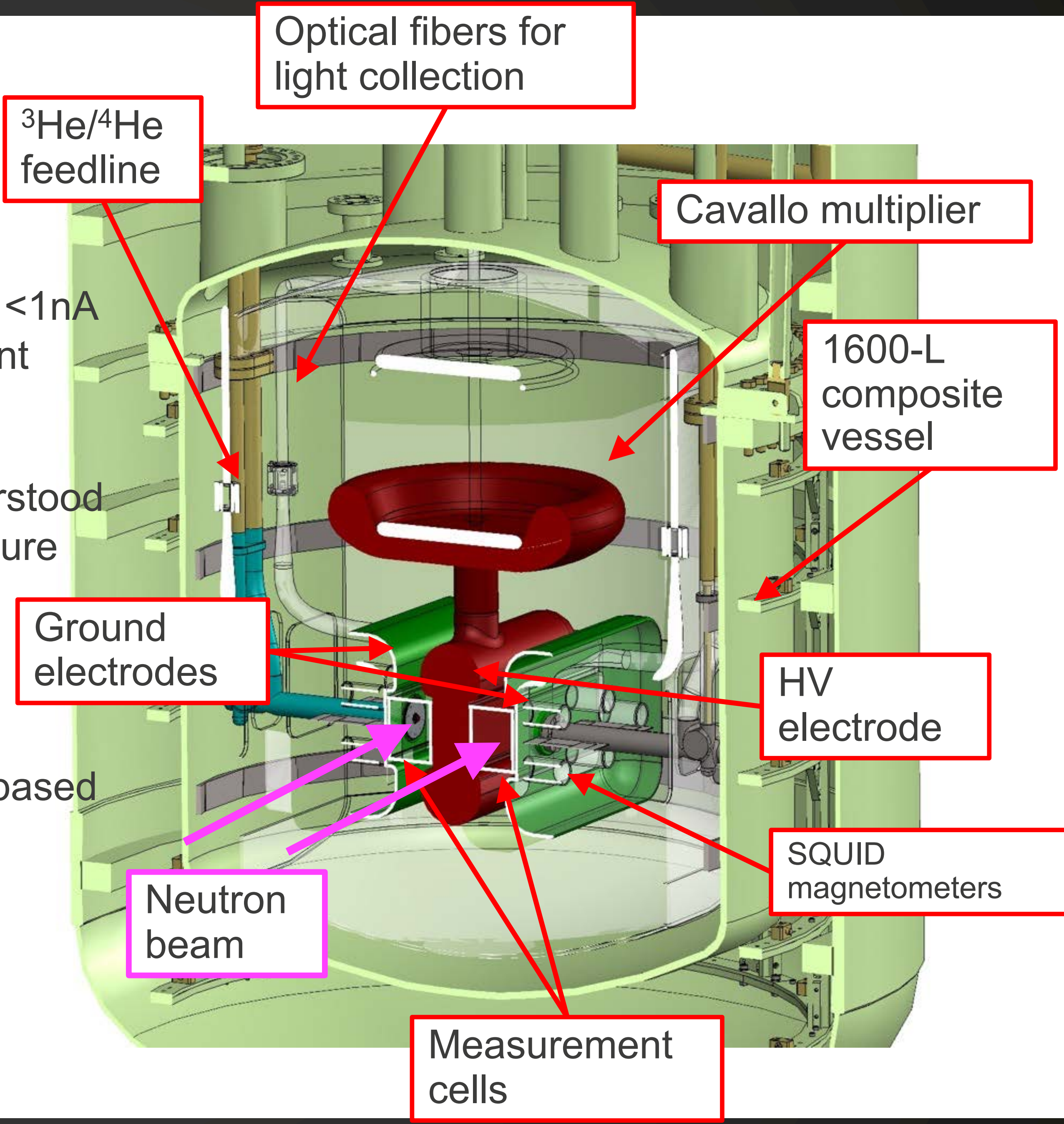
High Electric Field in nEDM@SNS

- **Requirements**
- Electric field up to 75 kV/cm in the measurement cells
- No direct feed line for HV due to thermal and magnetic constraints
- Minimal leakage current through the measurement cells, <1nA
- Electrode coating to keep Johnson noise and eddy current heating low, either Cu or GeCu
- **Challenges**
- Electrical breakdown in Liquid Helium (LHe) poorly understood
- Recent studies at LANL show dependance on LHe pressure dominates over other parameters from literature
- Electrical breakdown may damage electrodes or other components
- **R & D**
- Determine a breakdown probability for full scale system based on studies at smaller scale
- Study breakdown effect on electrode material
- Study breakdown mechanism, dependance on pressure/temperature
- Determine effects of electronics/lightguides on HV performance on half scale system



Previous High Electric Field R&D Program at LANL

- **Small Scale HV**
- Temperature down to 1.5 K, variable pressure
- Studied stainless steel electrodes up to 2 cm, up to 40 kV
- Studied distribution of breakdown voltage and time to breakdown
- Breakdown distribution study led to new understanding of area and pressure scaling

- **Medium Scale HV**
- 6 L Liquid Helium Volume, temperature down to 0.4 K, variable pressure
- Tested stainless steel electrodes and coated PMMA electrodes up to 12 cm, up to 100 kV
    - No breakdowns observed up to 85 kV/cm at few torr for PMMA electrodes
    - No breakdowns observed up to 105 kV/cm at a few torr for SS electrodes
- Pressure and area scaling give expectation that full scale system works, remains to be confirmed
- Studied leakage current through dielectric materials between electrodes (up to 50 kV)
- Observed scintillation in liquid helium at high electric field

- **Cavallo Multiplier**
- Large room temperature prototype
- Extensive simulation effort

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See N. Phan talk #19 (Next)

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Future High Electric Field R&D Program at LANL

- **Small Scale HV**
- Study HV dependance of coated PMMA electrodes and breakdown time dependance

- **Medium Scale HV**
- Study temperature dependance of breakdown between 0.4 K and 2 K

- **Half Scale HV**
- 40 L LHe Volume, temperature down to 1.5 K, variable pressure
- Study stainless steel electrodes and coated PMMA electrodes up to 30 cm, Half scale measurement electrodes, up to 200 kV – verify scaling from SSHV results
- Study electrode damage due to breakdown, leakage currents and effects of lightguides and measurement hardware on HV performance
- Further study of area scaling and time to breakdown

- **Cavallo Multiplier**
- Large cryogenic prototype
- Study voltage multiplication in cryogen, time to full voltage, heating, sparking behavior
- Develop program to mitigate sparking, heating

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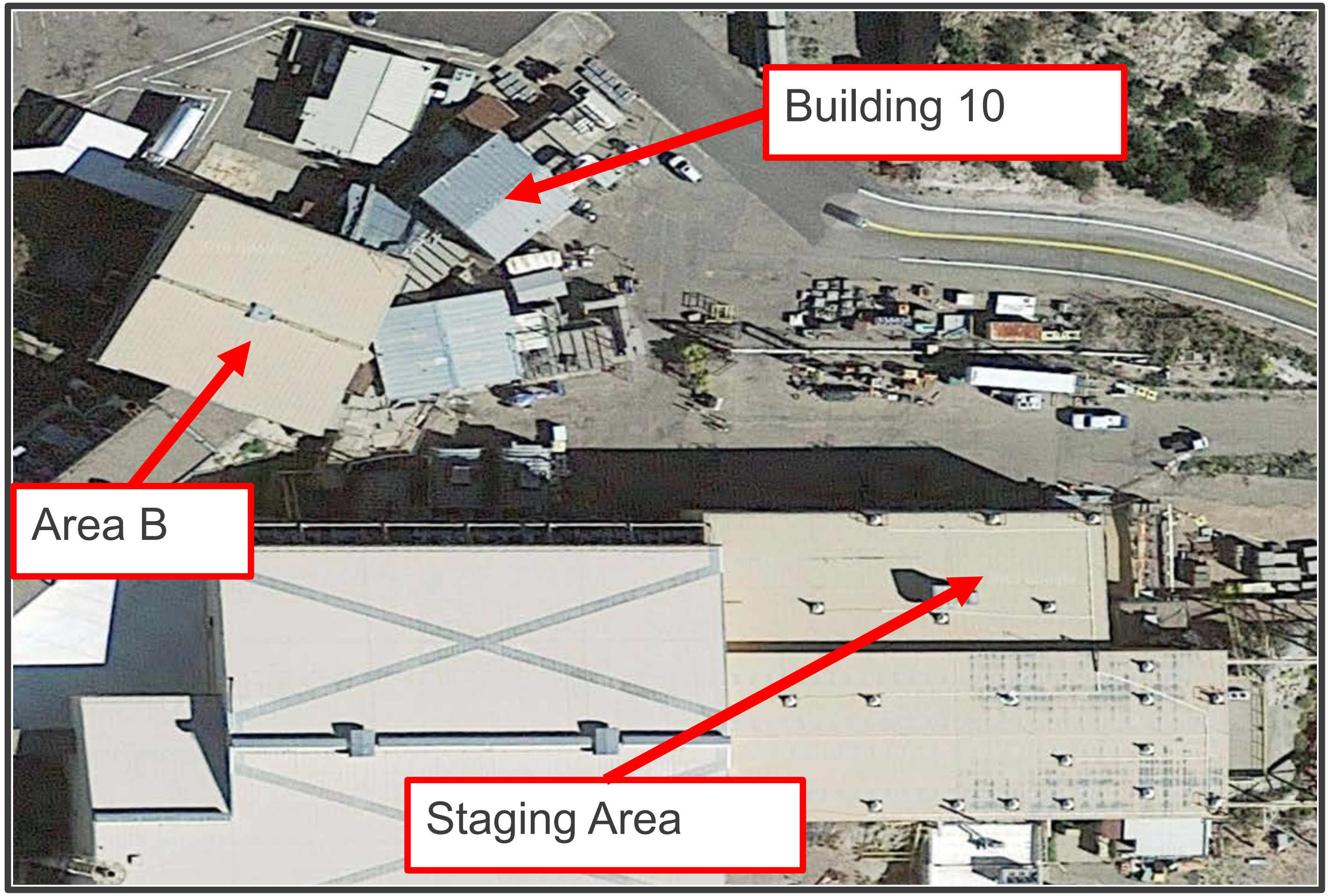
See M. Blatnik talk #20

Los Alamos National Lab Neutron Science Areas

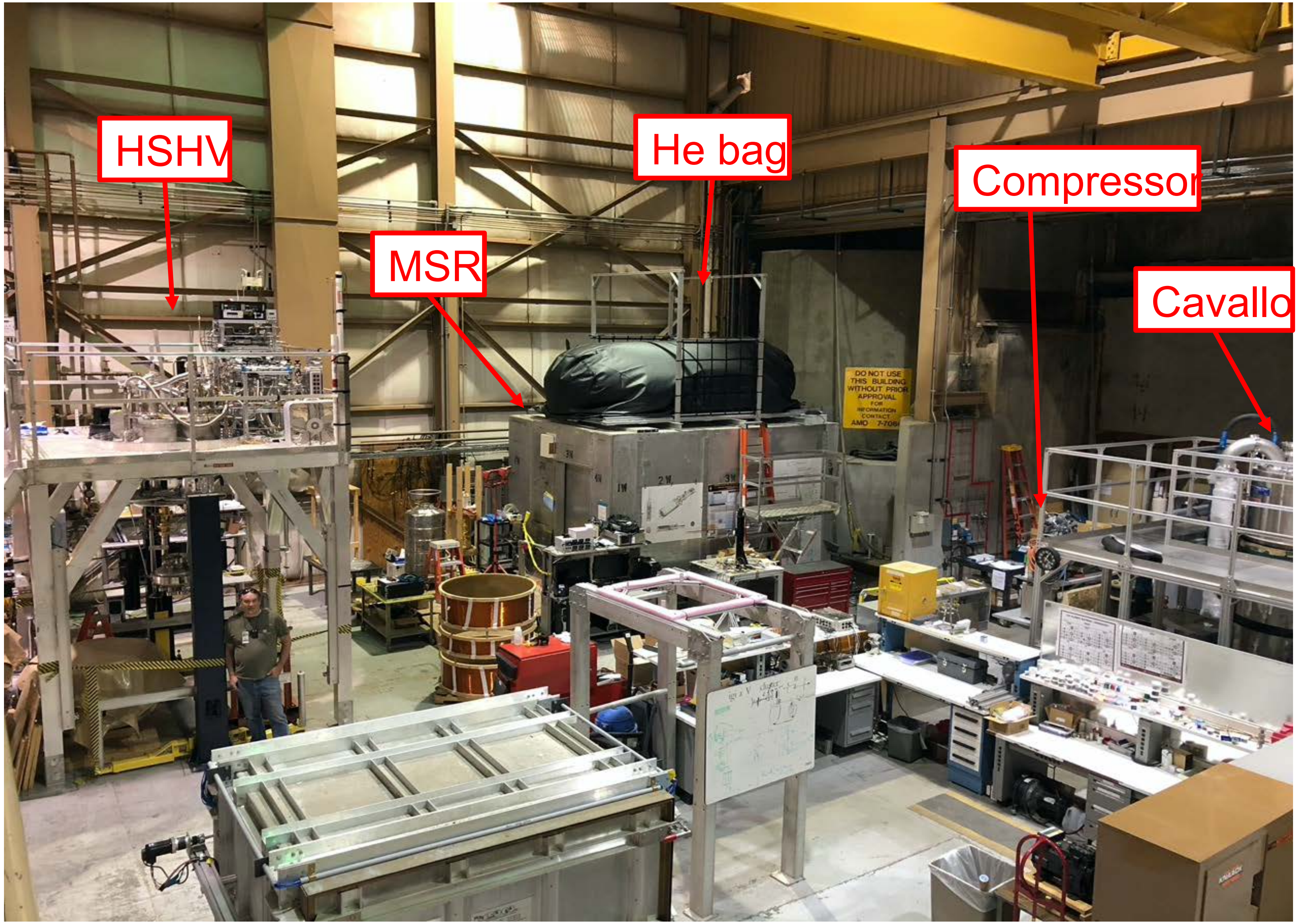
- **Area B**
- Houses UCN experiments like LANL nEDM and UCN Tau
- Helium liquefaction equipment

- **Buliding 10**
- Houses the small scale high voltage (SSHV)
- Medium scale high voltage (MSHV)
- Room temperature high voltage (RTHV)

- **Staging Area**
- Houses the half scale high voltage (HSHV)
- Cavallo high voltage cryostat
- New construction includes a helium recovery system and new helium liquefaction equipment



High Voltage R&D Components in the Staging Area

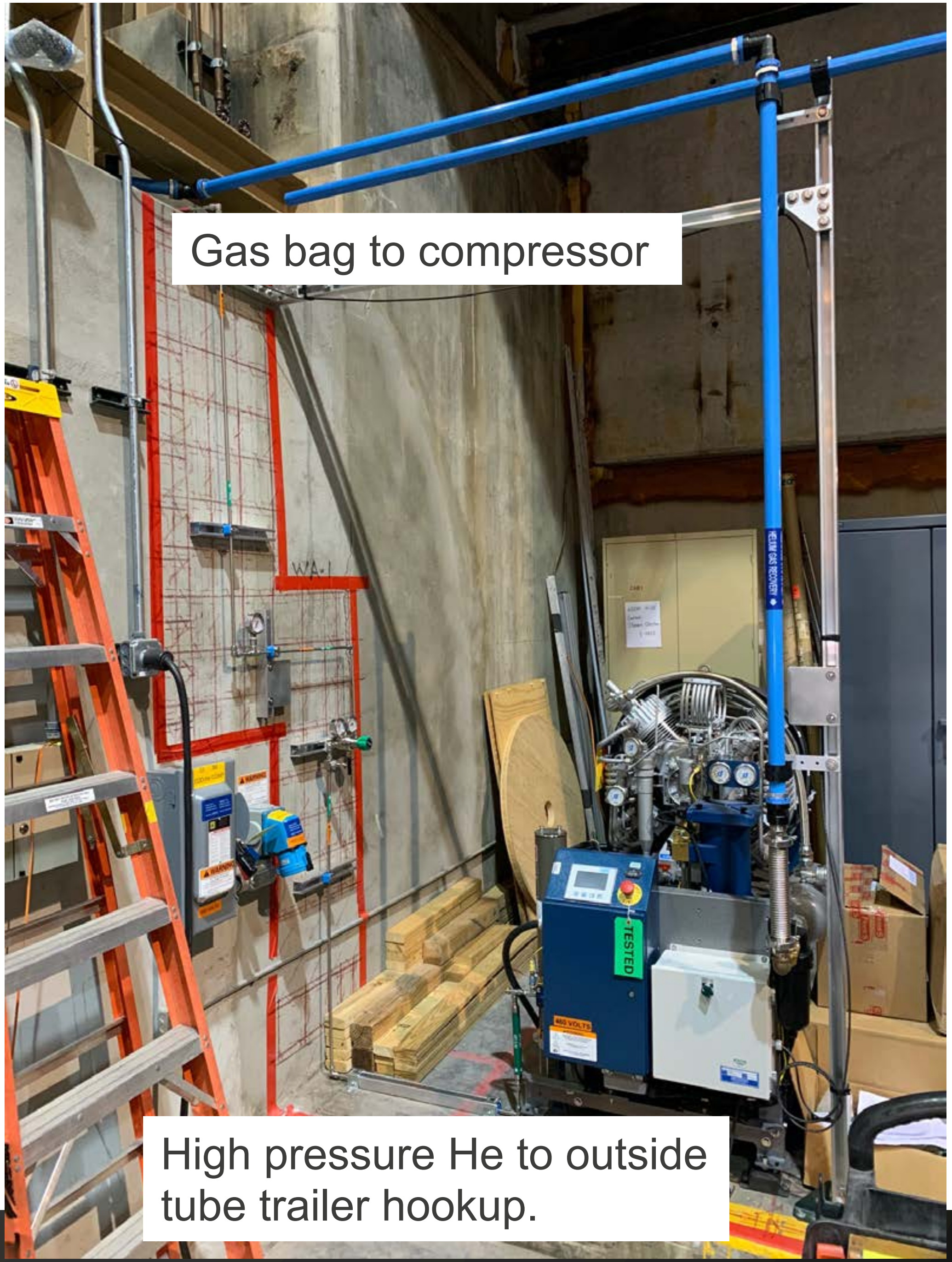


Helium recovery system in the staging area

- Large scale cryogenic R&D activities in the Staging Area require a large quantity of LHe (1000 liters or more per cooldown). Recent increase in LHe price and limited availability have necessitated a recovery system.

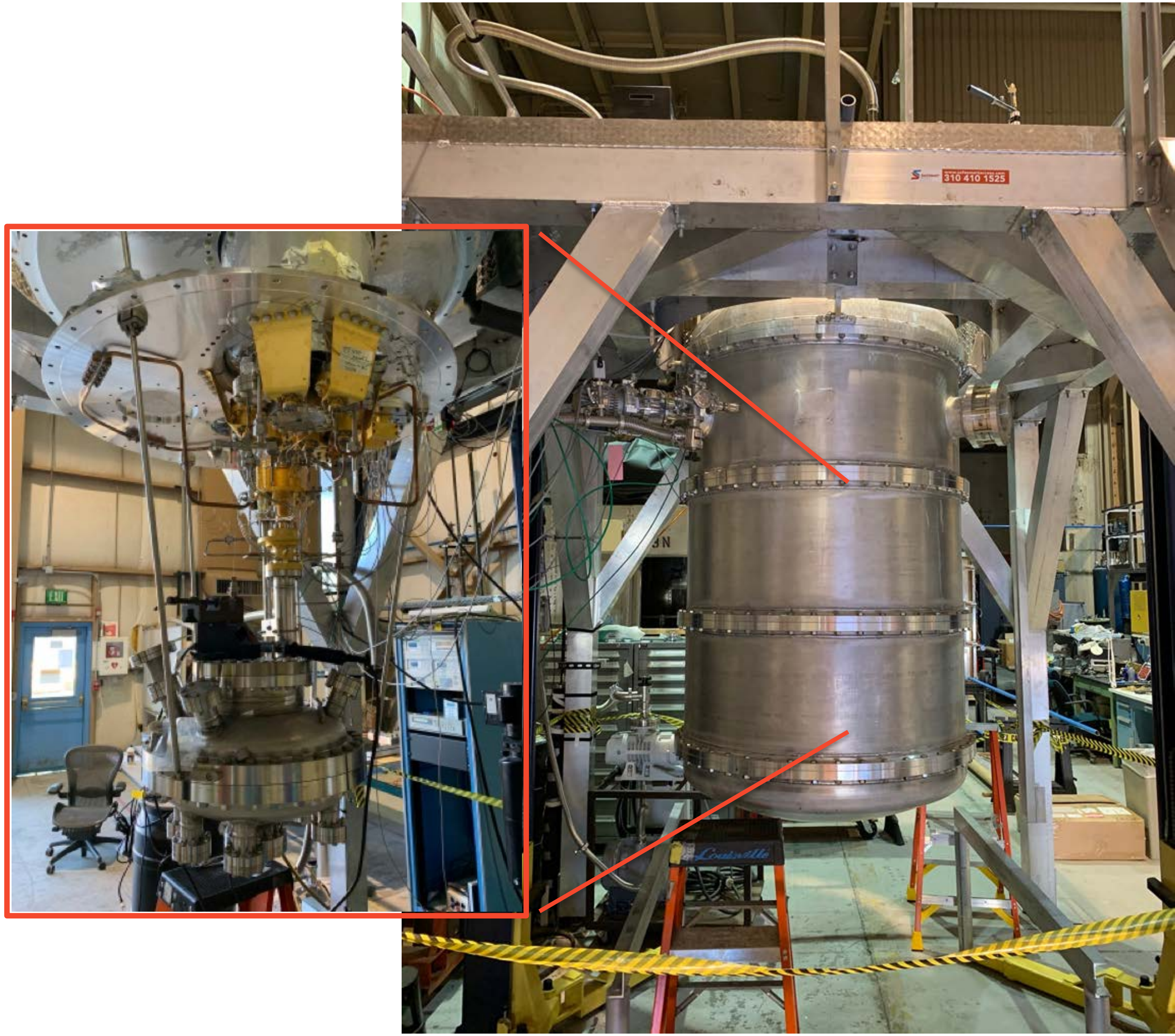
Phase I:
- Capture boil-off He gas in a bag, compress it into a tube trailer, and liquefy it using the liquefiers in Area B.
- Engineering (over 200 hours) and large fraction of installation institutionally funded.
- Completed November 2020.

Phase II:
- Install a liquefier system in the staging area.
- LANL institutional funding received (~700K)
- To be completed in FY21

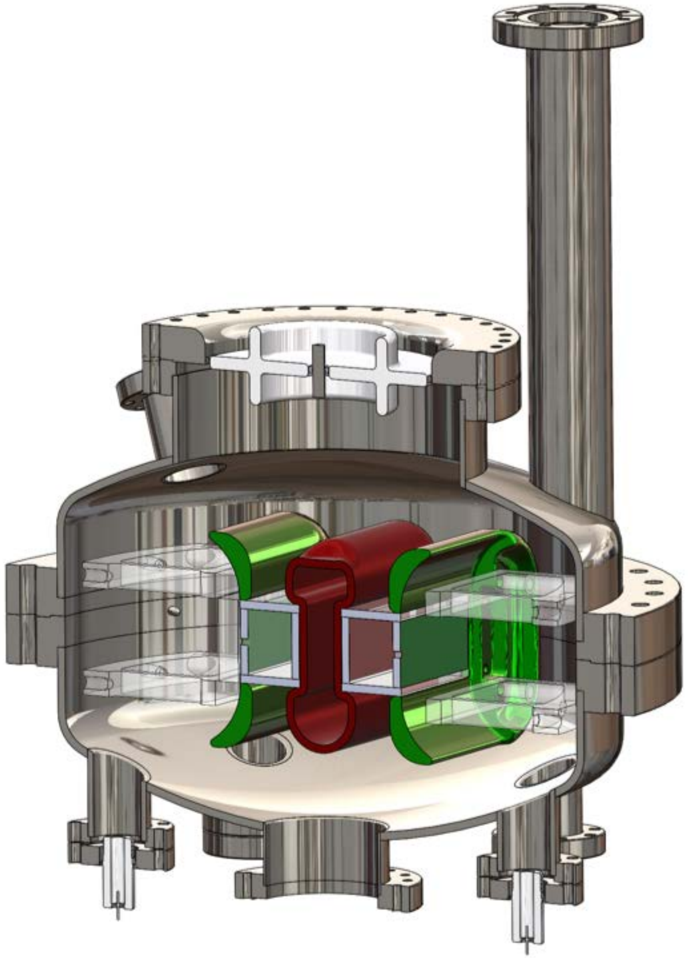


Half Scale High Voltage System

- R&D system designed to study high voltage breakdown in superfluid liquid helium
- Study stainless steel electrodes
- Study coated PMMA electrodes
- PMMA electrodes shaped similarly to the nEDM@SNS experiment electrodes
- Study electrical breakdown probability for nEDM@SNS conditions at half scale
- Study effect of breakdowns on electrode material, surface finish, performance

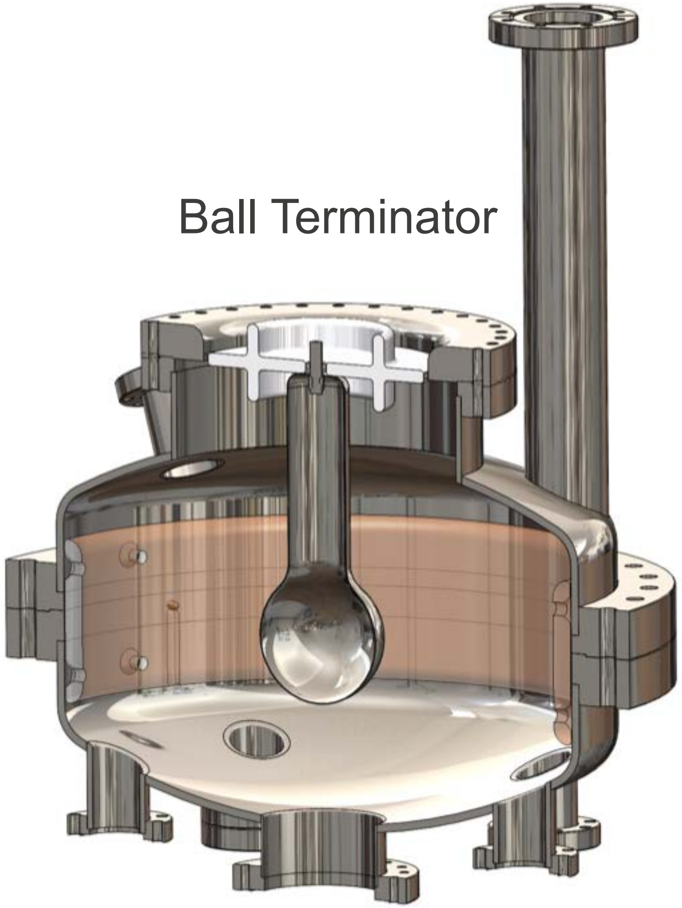


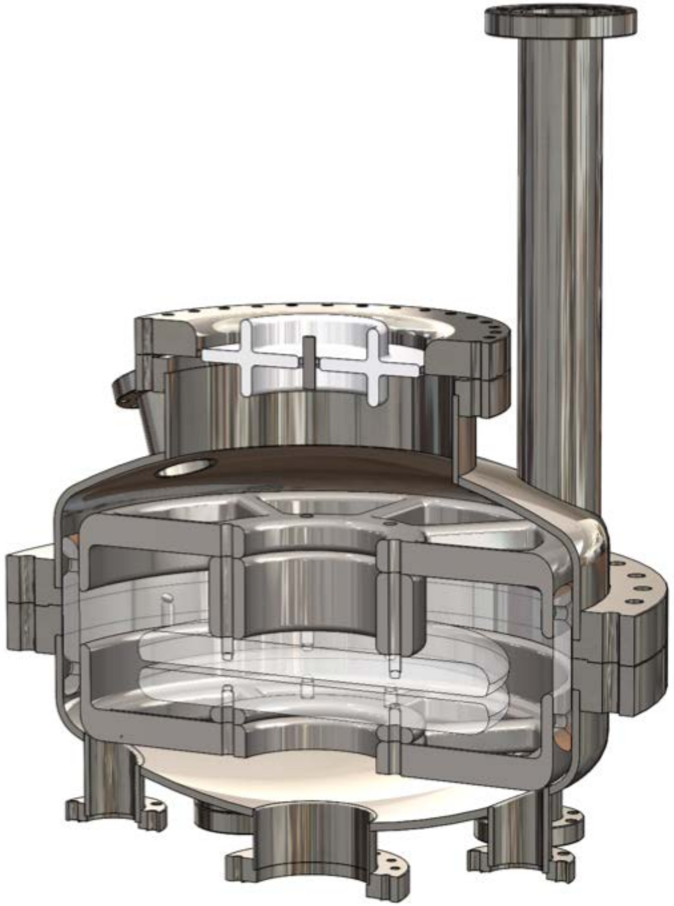
Half Scale Electrode Shapes



Half Scale Electrodes
With Measurement Cells

Ball Terminator





Uniform Field Electrodes

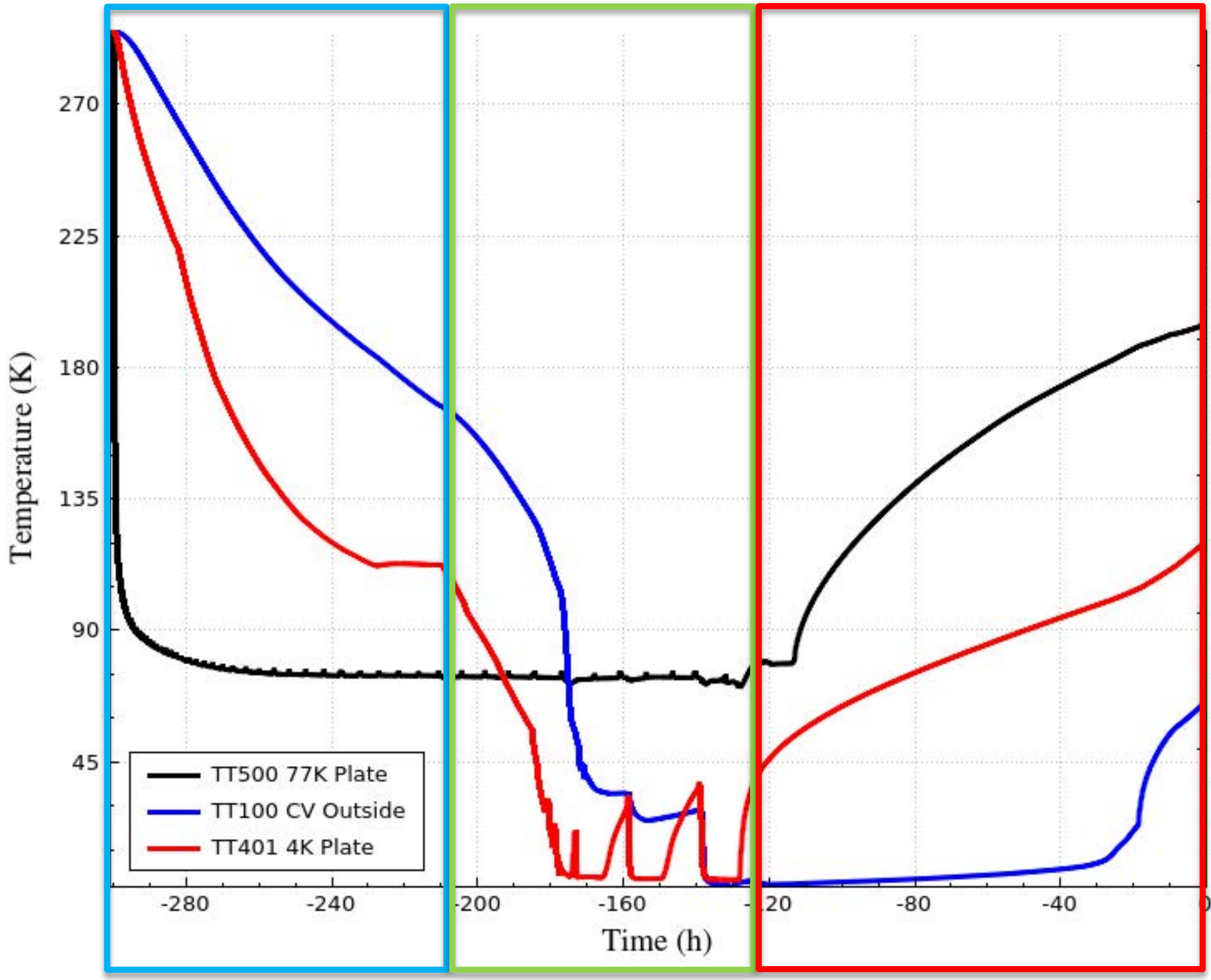
Half scale previous activity

- Previous cooldowns in February 2019, June 2020
- February cooldown: Could not cool CV below 70 K
- June cooldown: Automatic refill capability lost, cooldown aborted
- Between cooldowns
  - Capillary lines re-plumbed inside HSHV
  - Pre-cool dewar outfitted with new lid
  - Internal leak check of all components
  - Helium recovery system constructed and tested
- Goals of November Cooldown
  - Cool Helium bath, inner shield and CV to 4K
  - Cool CV to below 2.1K by pumping on it
  - Determine if 1K pot can cool itself and the central volume (CV) below the superfluid transition with CV sealed
  - Determine if capillary sizes for 1K pot are appropriate to maintain cooling

  - Test helium recovery system
  - Test helium bath heat exchanger
  - Test roots blower integration

Cooldown timeline

- November 16th 4PM to November 29th at 5AM is a 300 hour period which breaks down into 3 major parts
- Nitrogen cooldown
  - Proceeded very similarly to previous 2 cooldowns, relative slower cooling of CV, solved by further opening UIUC valves after several days.
- Helium running
  - Allocated 2x 500L dewars of liquid helium, achieved 4K in Helium bath, ~40K CV with first dewar
  - Pushed for 2K CV with second dewar, Achieved!
- Passive warming
  - System put into safe mode venting all volumes to helium recovery system and allowed to slowly warm



Demonstration of superfluid He in CV and 1K pot

- November 23
- Ruthenium Oxide sensor (ROX) in1K pot calibrated by Lakeshore from 40K to 5E-2K
- Calibration curve from 40K to 5.61K applied
  - Largest error in this region 47.33 mK
  - RMS error of fit in this region 13.69 mK
- Calibration curve from 5.61K to 0.95K applied
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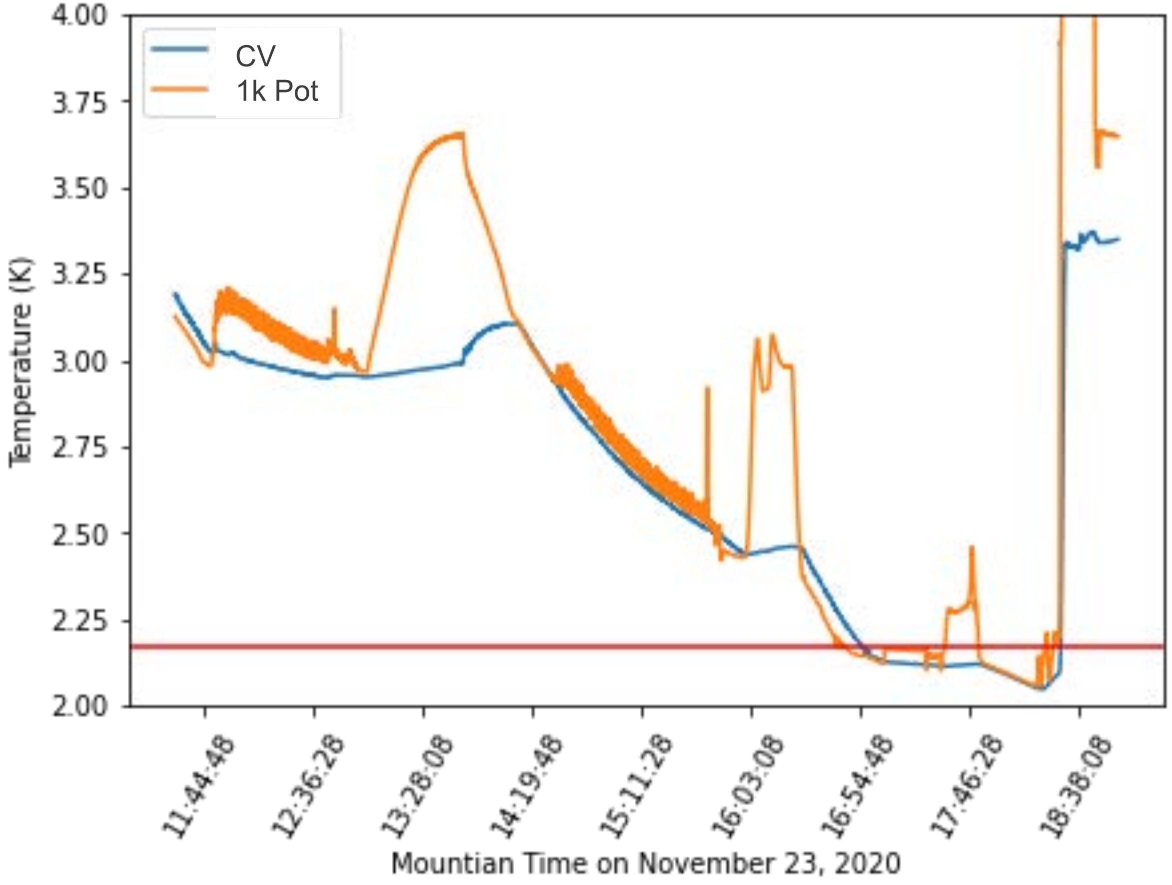
- Used the same calibration for both sensors
- 2.17 K superfluid transition marked with red line



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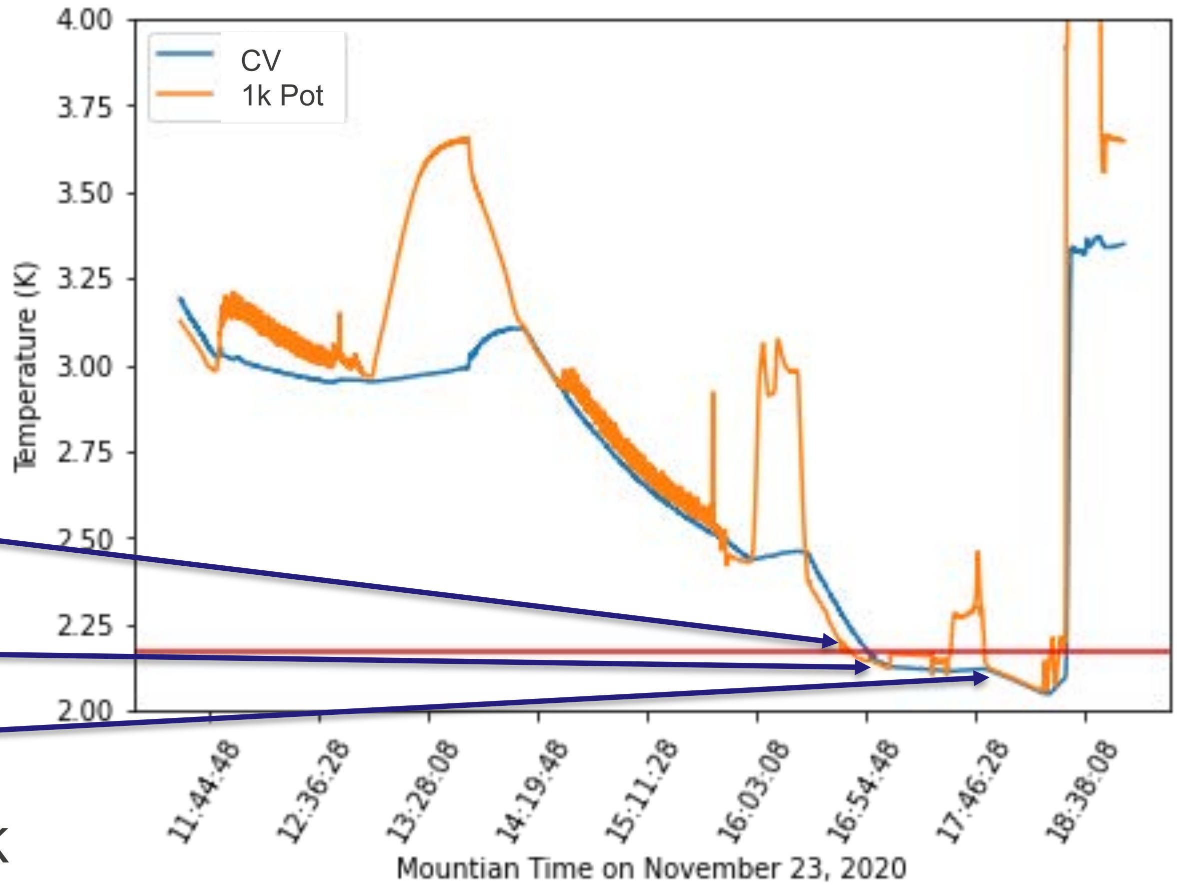
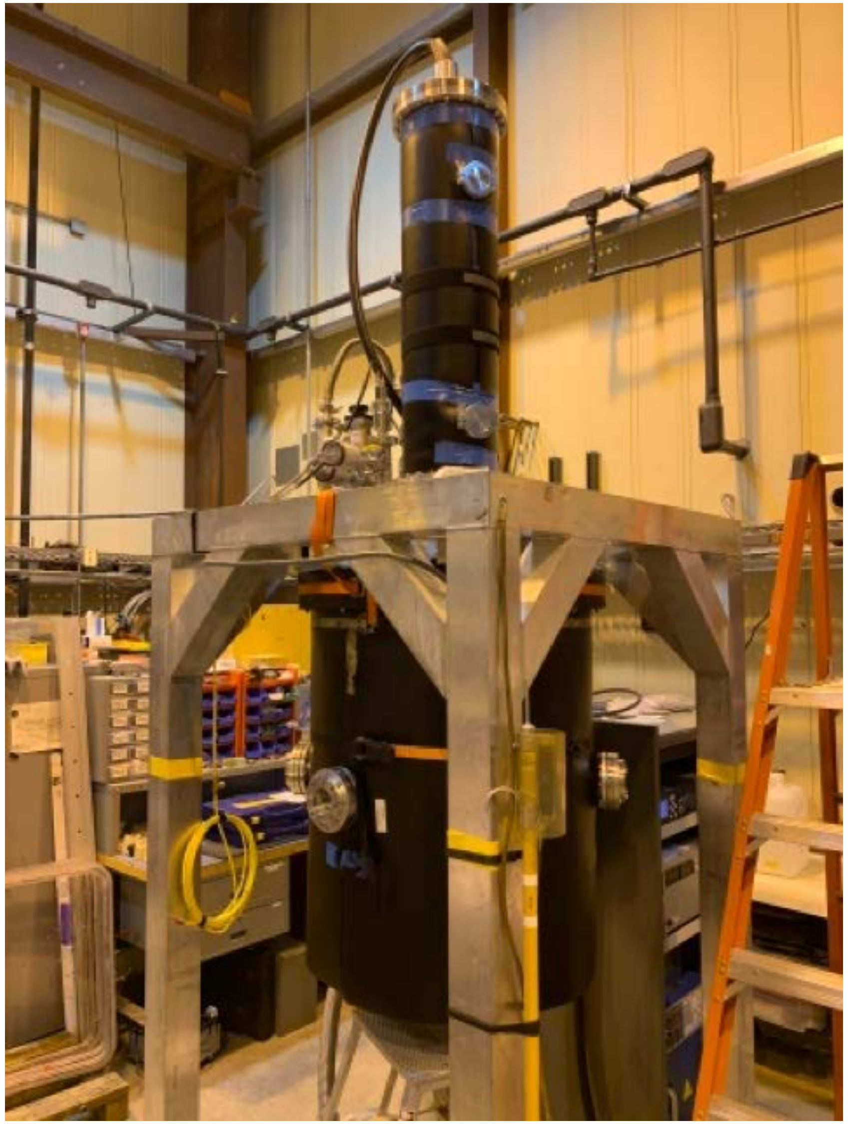
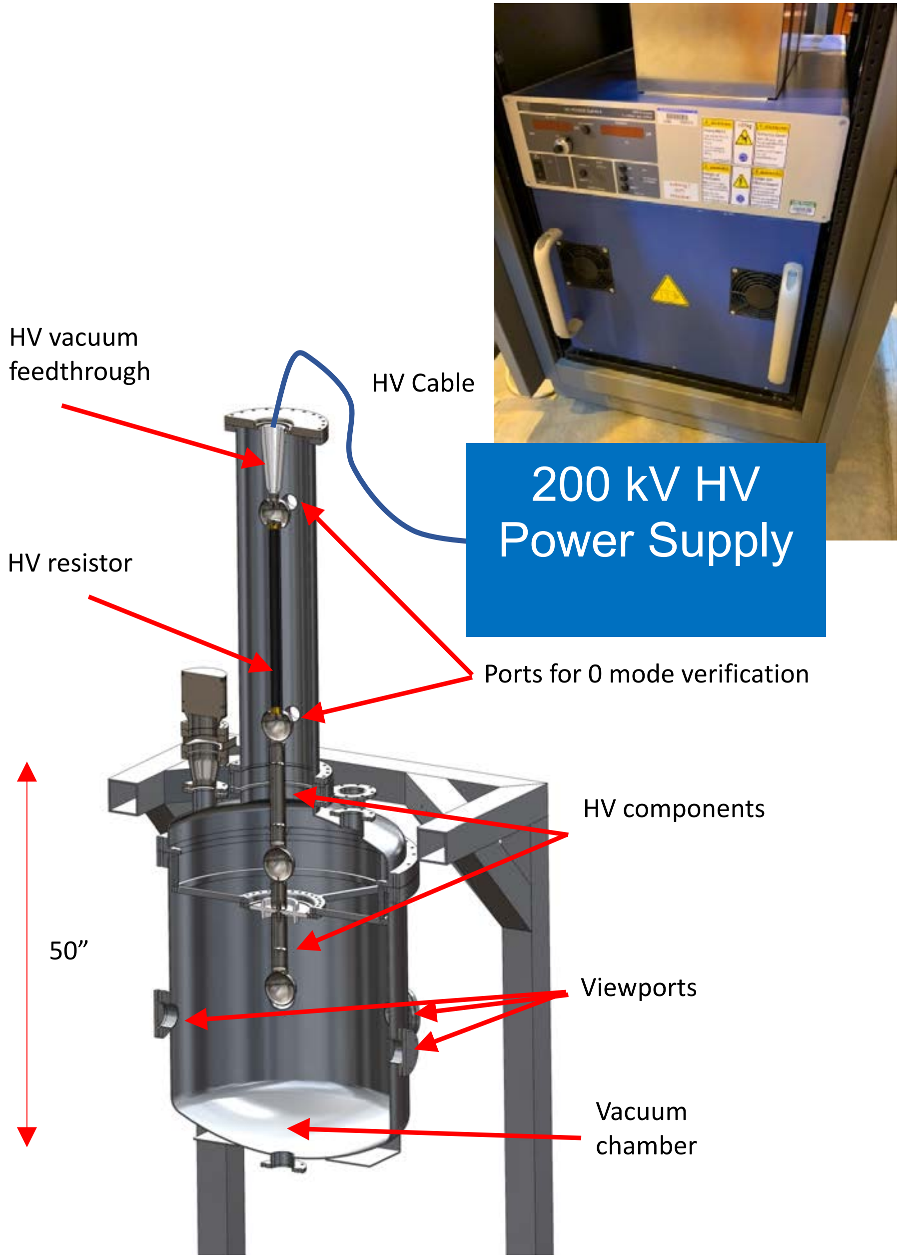
- CV is shown to go below superfluid transition, while pumping on both CV and 1K pot
- CV is closed and 1K pot is refilled, pumping continues on 1K pot
- 1K pot cooling power shown to be sufficient to maintain and even further cool CV.
- Minimum CV temp. 2.048K, Minimum 1K pot temp. 2.057K



Room temperature HV apparatus

- Housed in building 10
- Non cryogenic high voltage test chamber
- Demonstrate the HV capabilities of the components to be installed in HSHV
- Radiation dose calculation required due to x-rays from created by potential breakdown
- Installed X-ray shielding material shell
- Work will inform how HSHV program will proceed

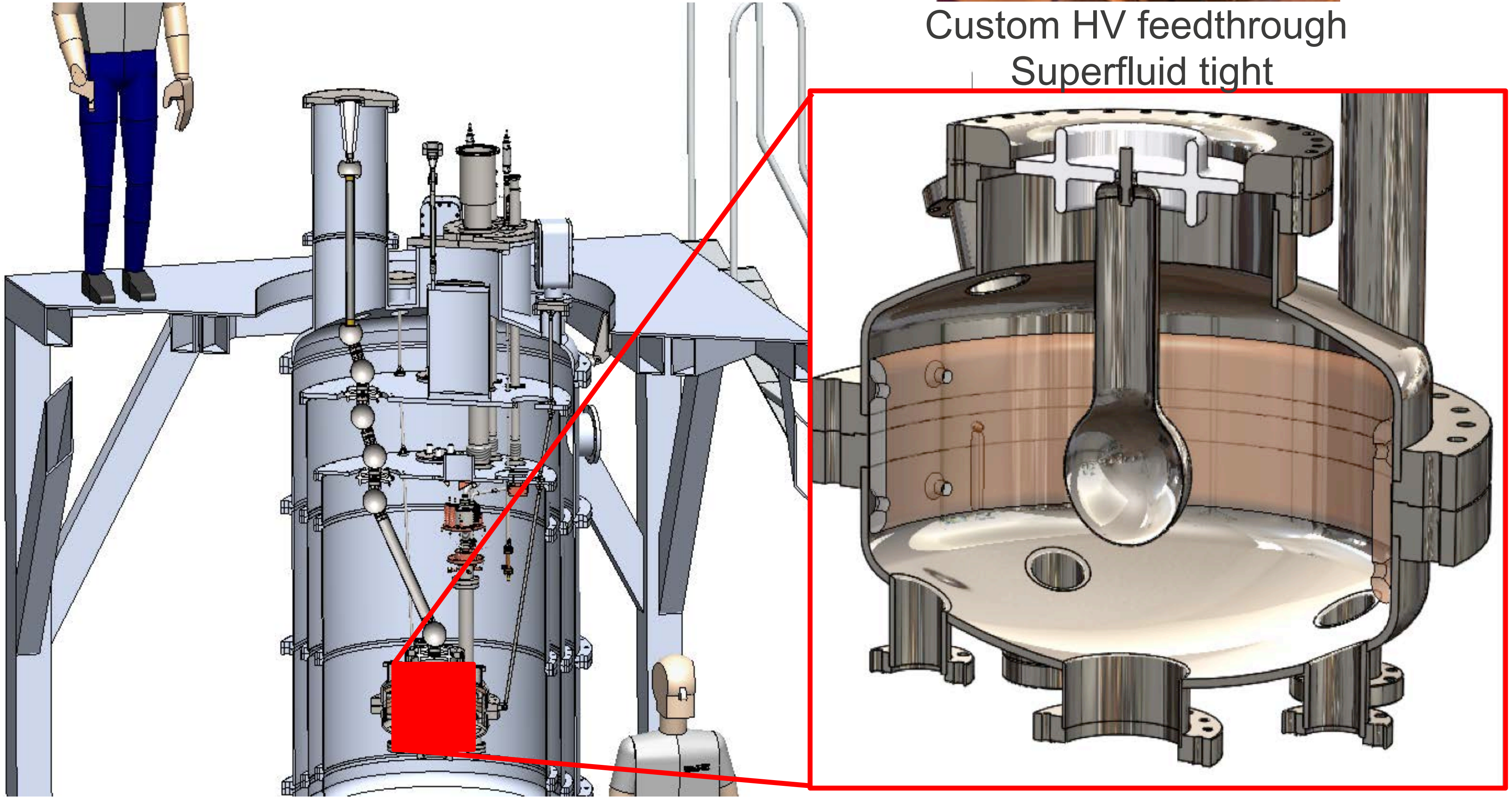




High voltage system addition

- Terminate the HV line in a ball electrode for first test
- Confirm superfluid temperature can be reached and maintained with additional heat load from HV structure
- Determine 200 kV can be delivered to CV

Custom HV feedthrough
Superfluid tight



Conclusions & Future Work on HSHV

- **Successful commissioning cooldown!**
  - Superfluid temperature reached in 1K pot and CV
  - Temperature maintained and further cooled while CV sealed
  - Helium used: ~1300 liters in total

- **Recovery system operated successfully**
  - Estimated ~60% recovery efficiency
  - Reduce helium usage and increase recovery efficiency in future cooldowns

- **Next steps**
  - Test high voltage capability and observe additional heat load on CV
  - Perform HV area scaling studies in superfluid liquid helium with uniform field electrodes
  - Perform HV studies with half scale measurement cell electrodes

Thank you

CDS Subsystem Design for nEMD@SNS