

SNS Neutron EDM Experiment HV R&D

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SNS nEDM Collaboration and Indiana University

Existing data at outset (2002)

Early tests with large HV amplifier and small variable-pressure cryostat

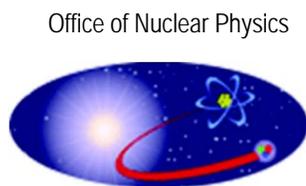
Ongoing HV R&D

Medium-scale HV cryostat

Electrode materials selection

Effect of charge accumulation in measurement cell

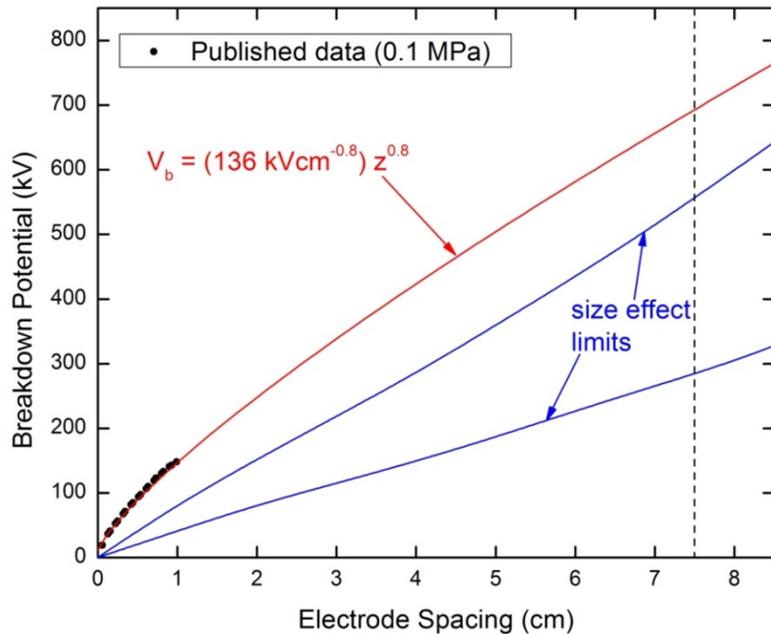
Outlook



Existing data and projections, 2002

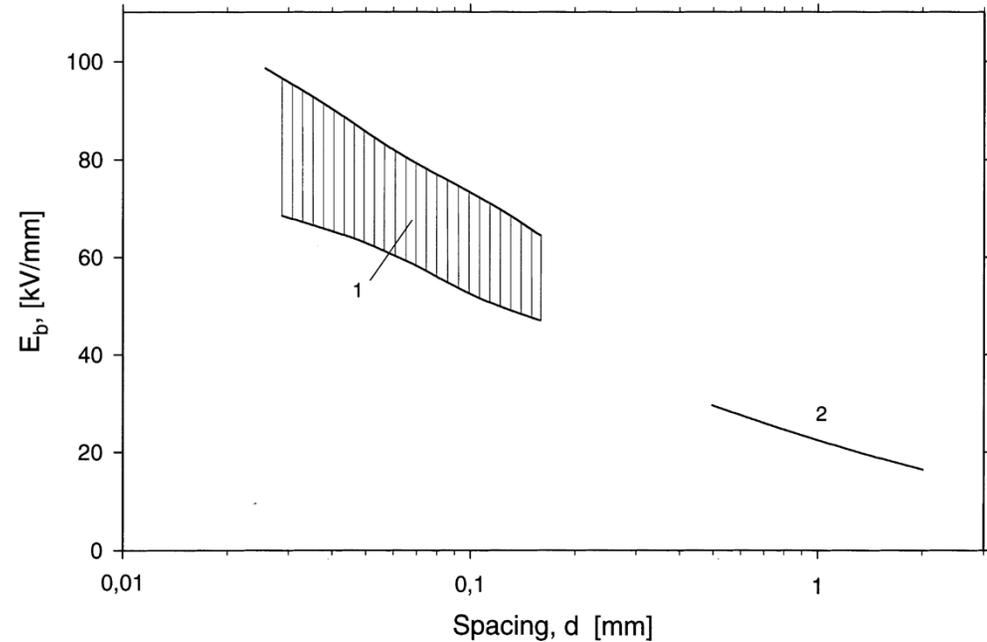
4 K breakdown

Gap and volume projections [1]



2 K superfluid (SF) breakdown

small systems only [1]



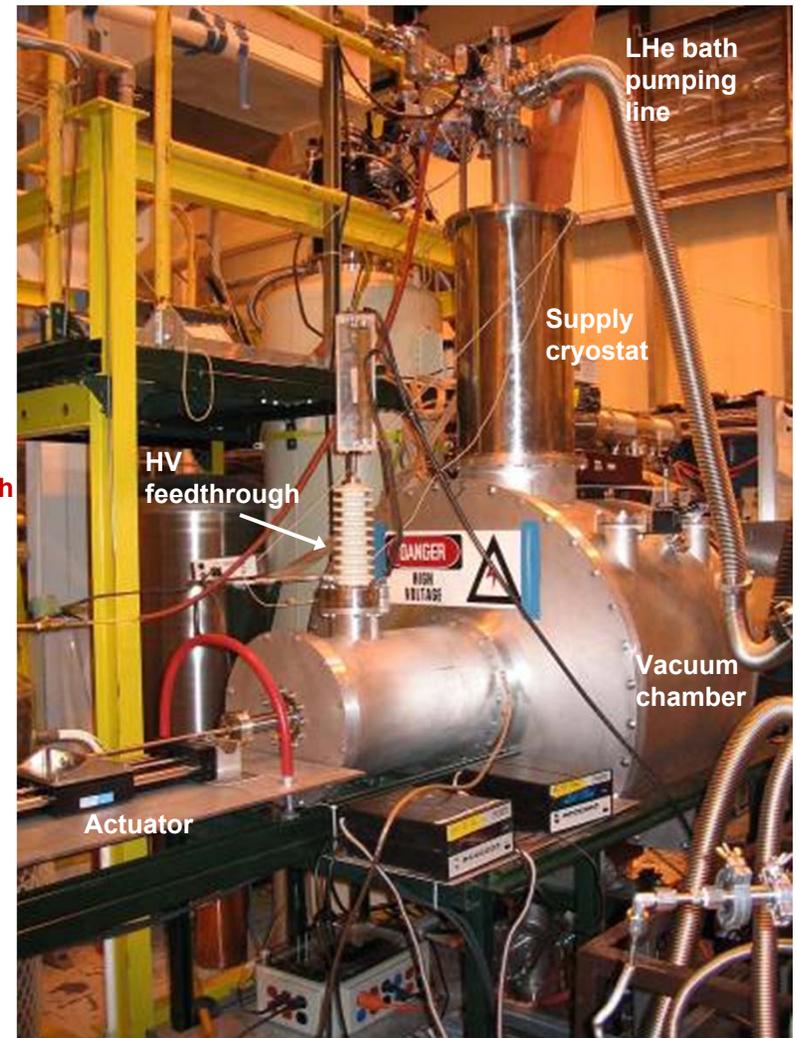
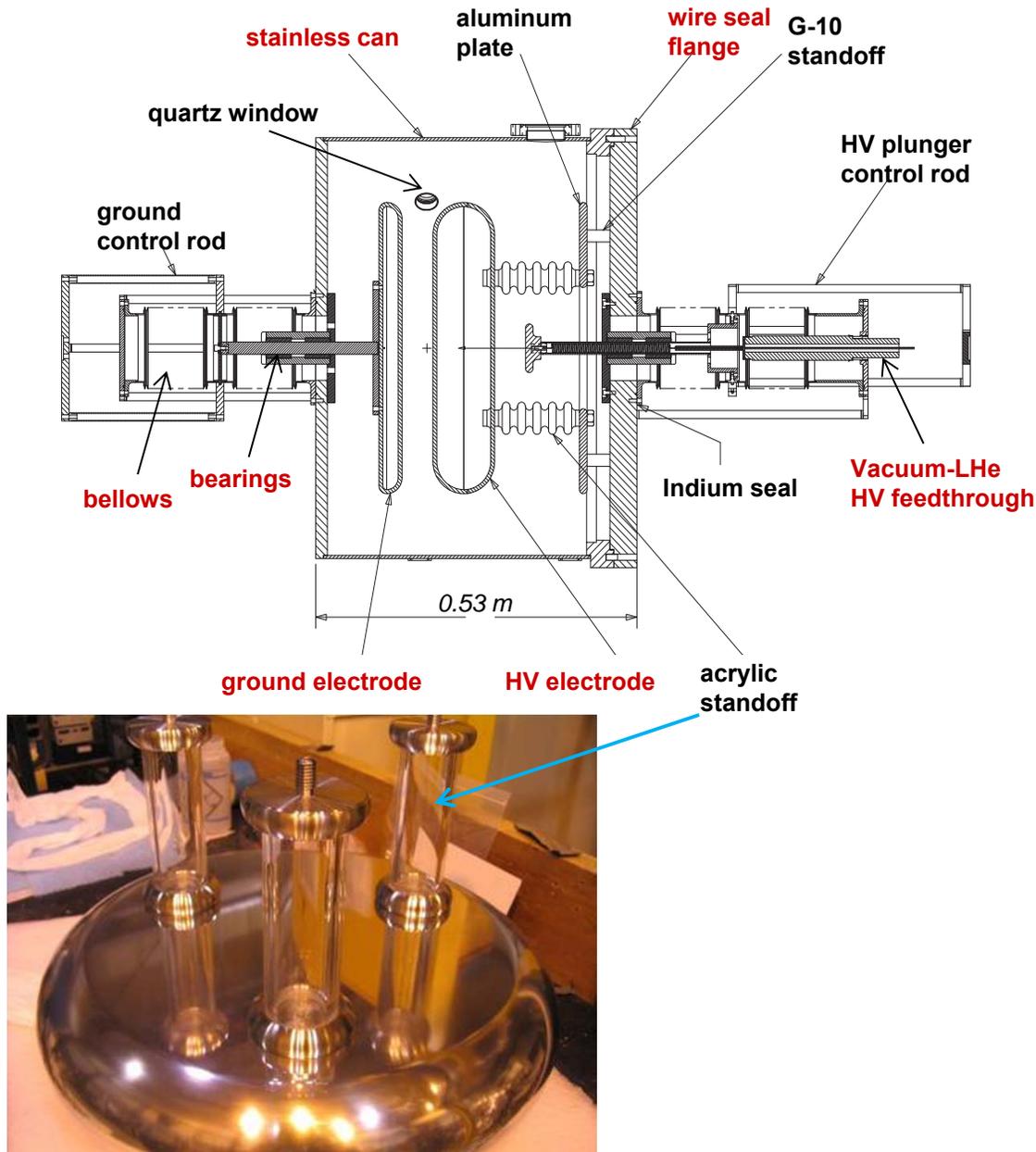
- Extrapolation, size effect: empirical, order-of-magnitude estimates for *full systems* (LHe + electrodes)

“near saturated liquid [HeII] can be assumed in uniform field breakdown strength in the range of LHe I” [1]

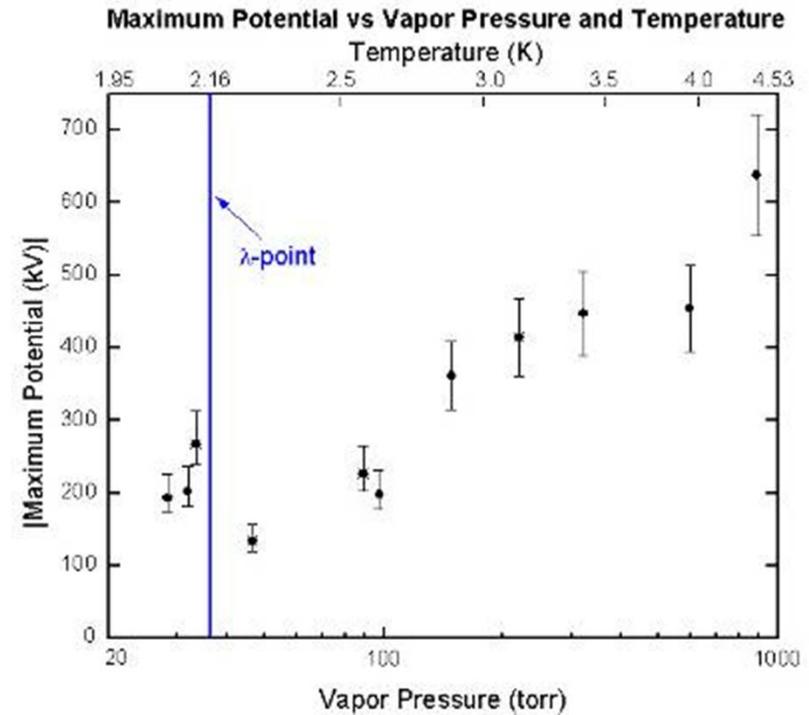
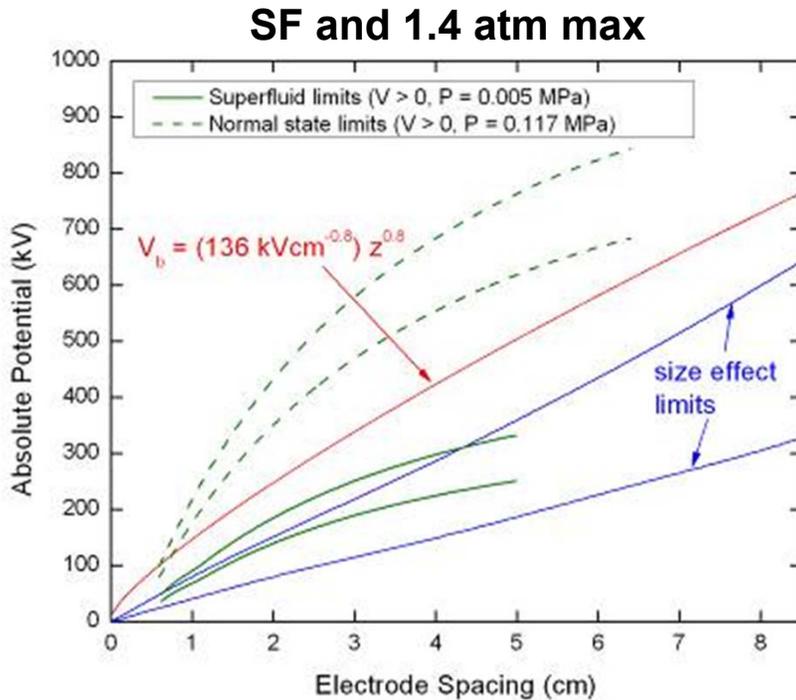
“high pressure can yield a considerably higher strength: up to 2x the strength, but considerable lower pressurized LHe II breakdown values of only 100 kV/cm at ambient pressure have been communicated” [1]

[1] Gerhold, Cryogenics 38 (1998) 1063

Large high voltage system prototype at LANL



Large system results at 2 K, 4.4 K



Maximum potentials sustained

- Hand-polished ($\sim 1 \mu\text{m rms}$) Al electrodes, 40 cm diam.
- 8.2 liters superfluid at 2.14 K, 5.0 cm gap:
 $(290 \pm 40) \text{ kV} \rightarrow (58 \pm 8) \text{ kV/cm}$
- 10.5 liters Normal State (4.38 K), 6.4 cm gap:
 $(760 \pm 70) \text{ kV} \rightarrow (119 \pm 11) \text{ kV/cm}$

Further degradation below 1 K?

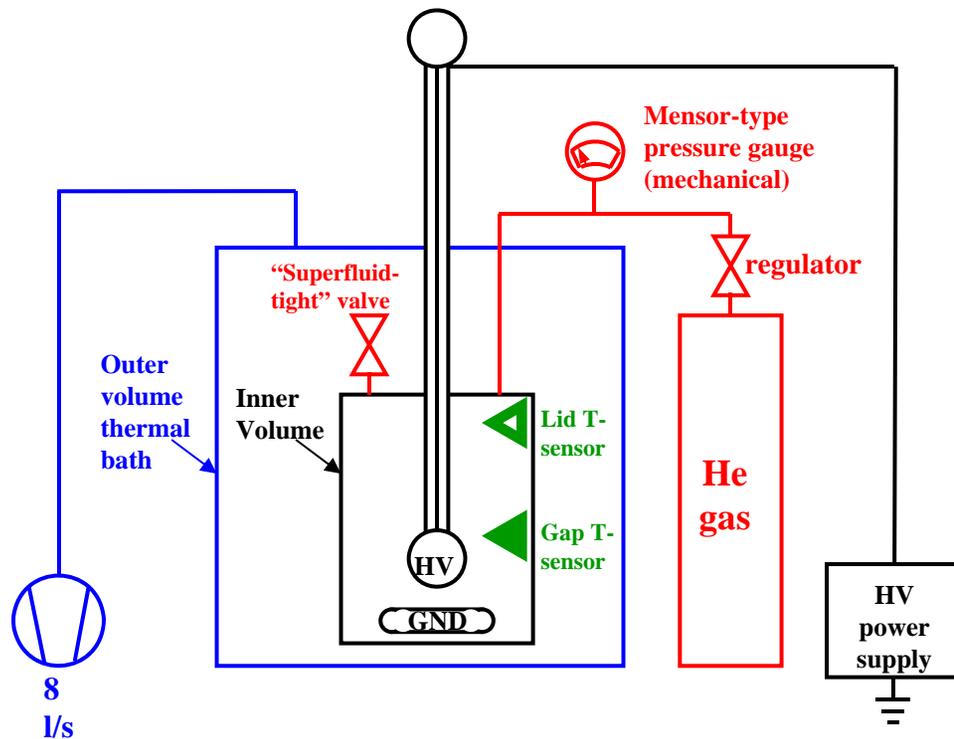
Pressure or temperature effect?

1. Cool large system with DR, pressurize \rightarrow difficult \rightarrow medium-scale experiment
2. Small, pressure-controlled experiment

Adjustable-pressure HV cryostat

C.-Y. Liu, M. Karcz (IU)

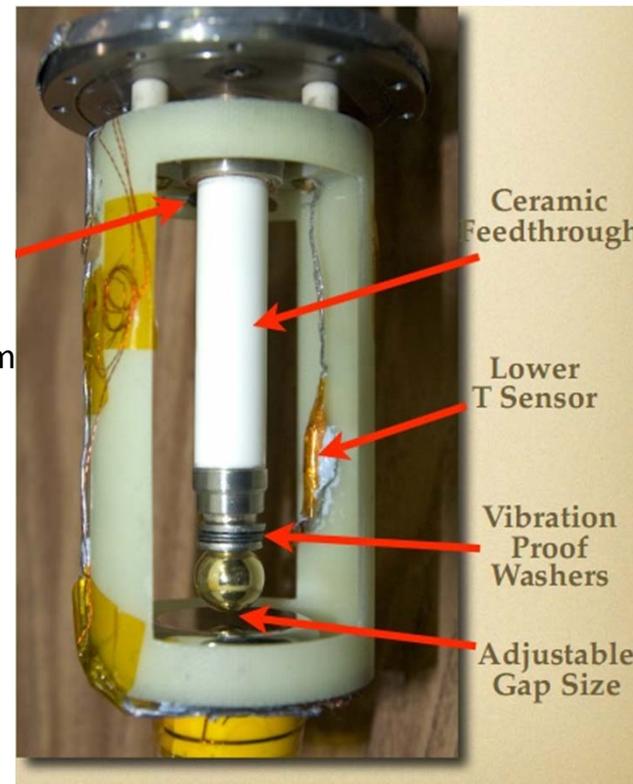
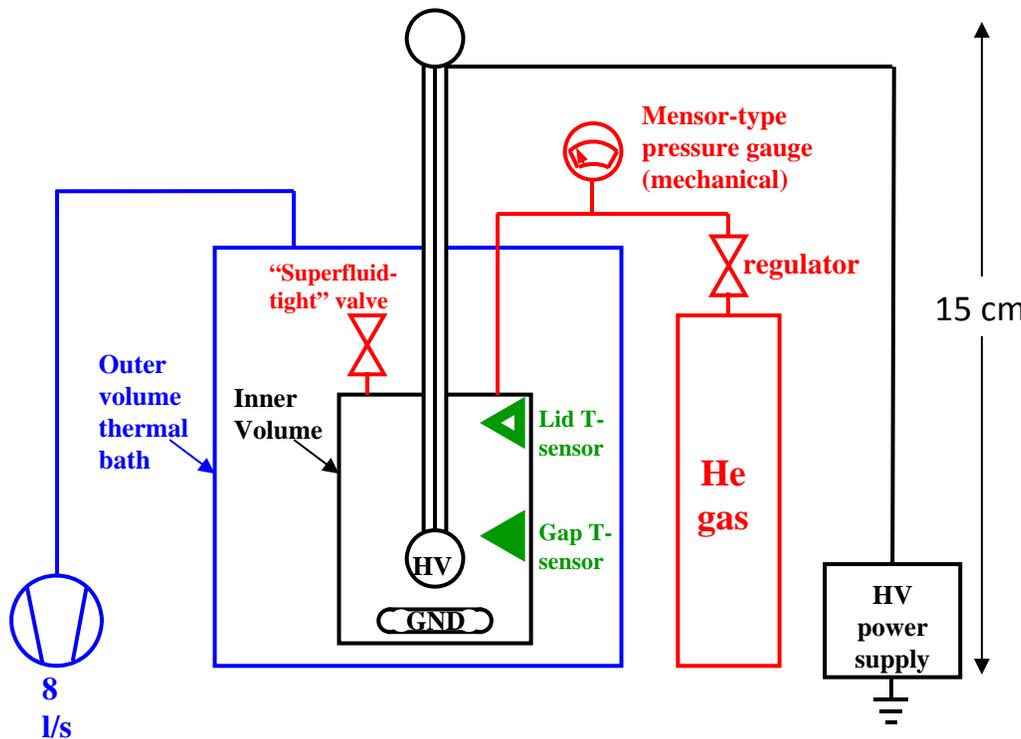
- Small sealed inner LHe volume with HV electrodes, immersed in larger bath
- Small volume pressurized with cold He gas at top; outer bath cooled by pumping (1.6 K)
(G. Seidel)



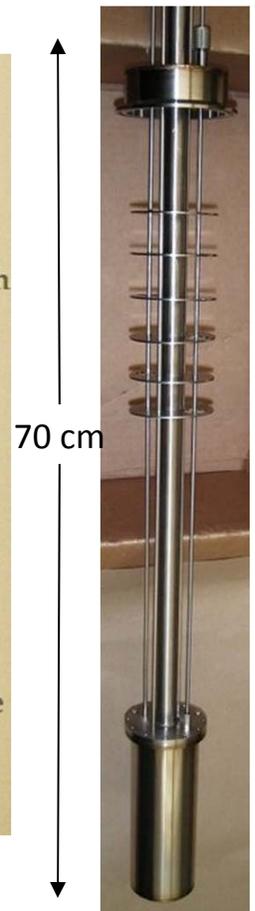
Adjustable-pressure HV cryostat

C.-Y. Liu, M. Karcz (IU)

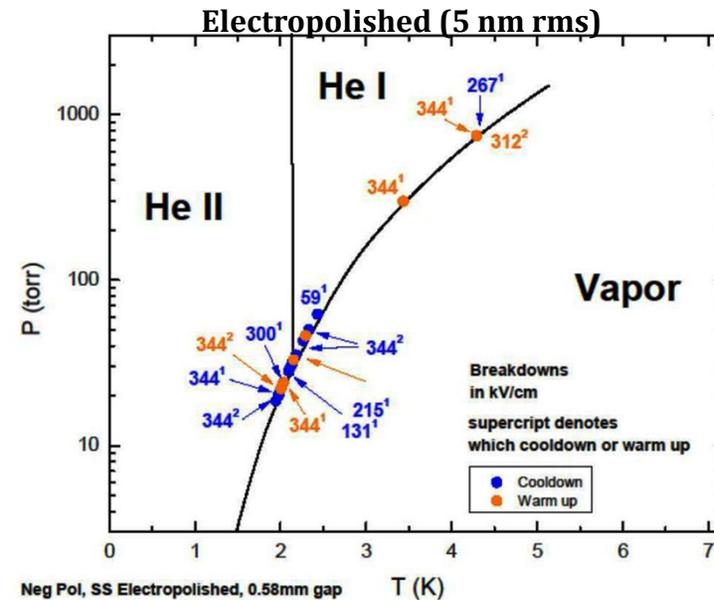
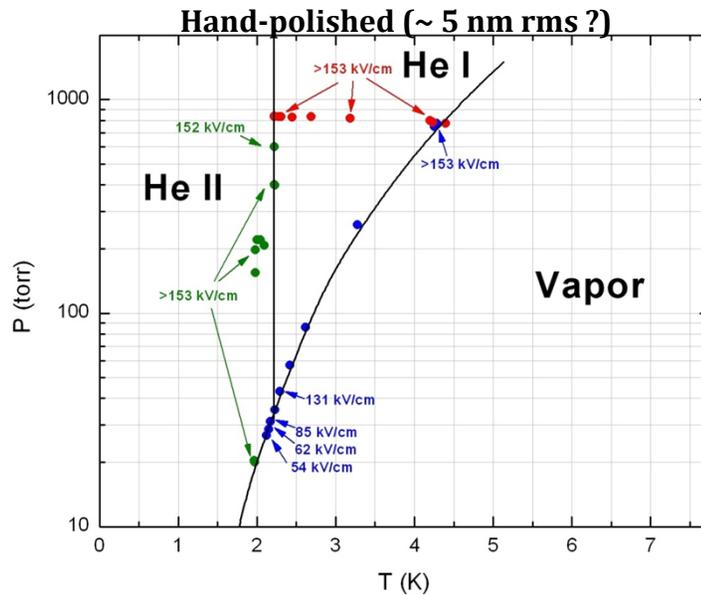
- Small sealed inner LHe volume with HV electrodes, immersed in larger bath
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(*G. Seidel*)



[washer-to-sidewall gap ~ 2cm]



Adjustable-pressure HV cryostat results

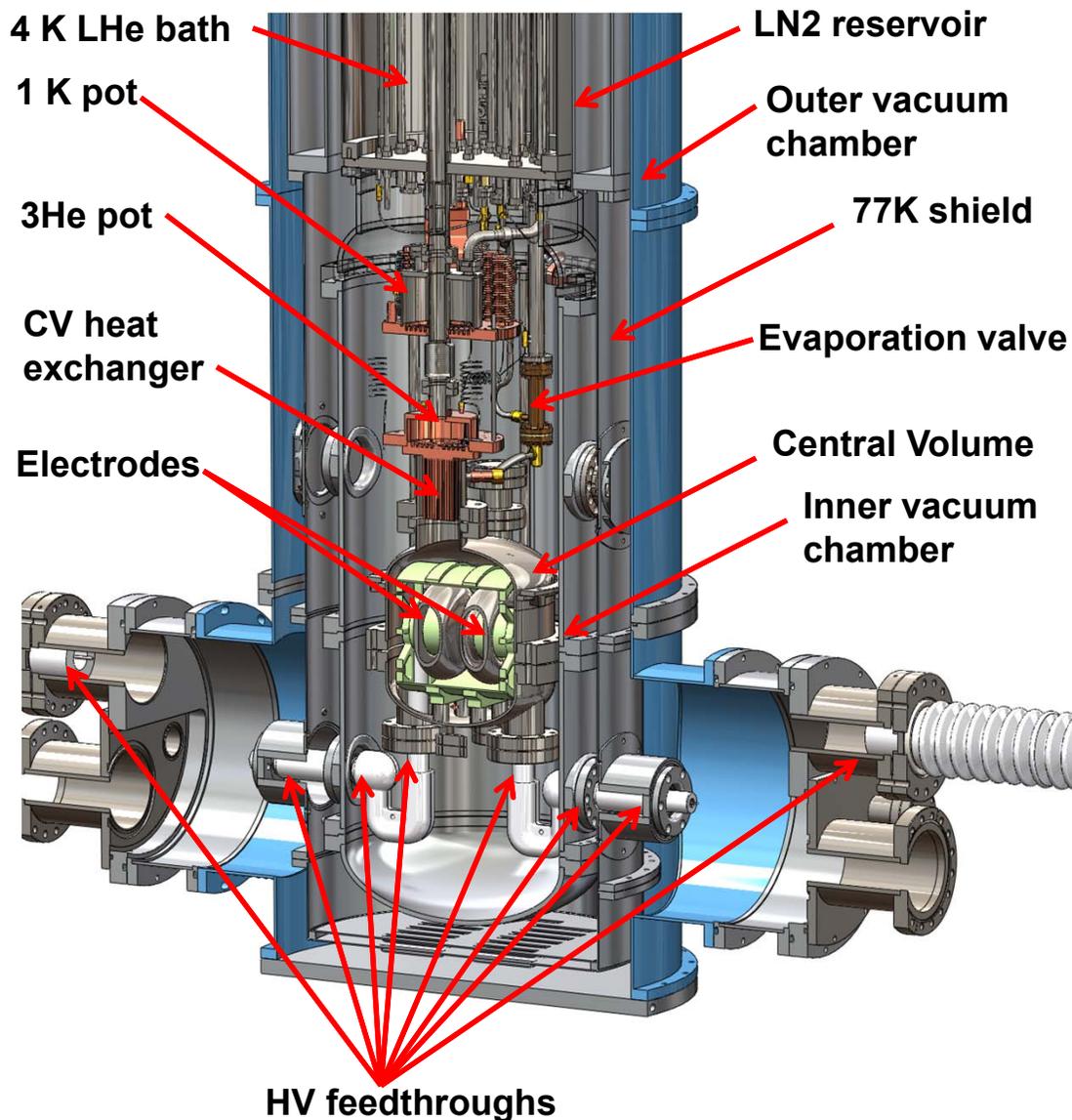


- High breakdown strength preserved if system pressurized (even temporarily at 100 torr)
- Electropolished electrodes: Often recovers near lowest vapor pressure (no pressurization)
- Both effects consistent with breakdown initiation in vapor bubbles; can be suppressed

HV R&D: Four parallel efforts

1. Design and construction of Medium Scale HV(MSHV) test apparatus at LANL → Electrode tests, and tests with a cell between electrodes
2. Identification of candidate electrode materials.
3. Initial tests using a small cryostat at IU (at 1.5 K)
4. Study of the effect of presence of acrylic plates and charge accumulation using the Kerr constant measurement apparatus at UC Berkeley.

New HV test apparatus at LANL



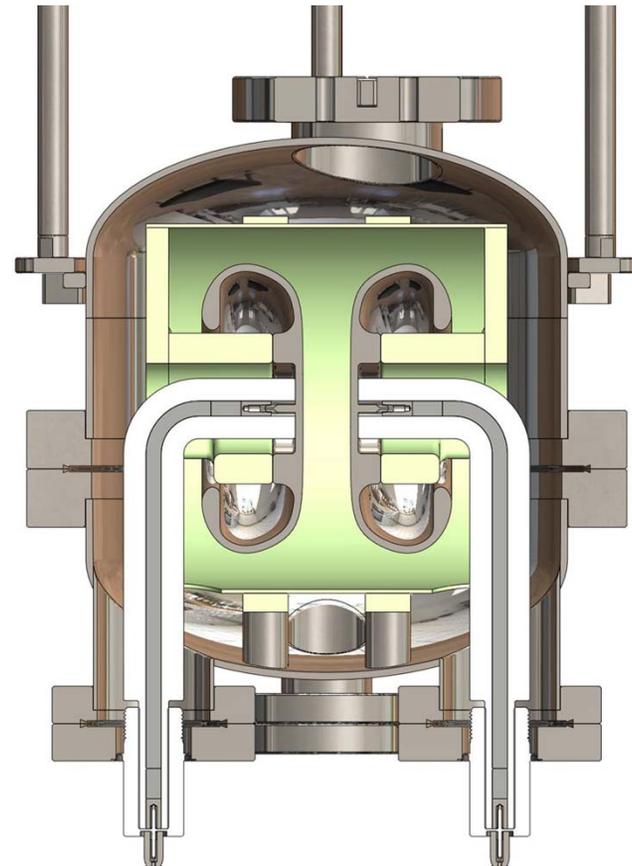
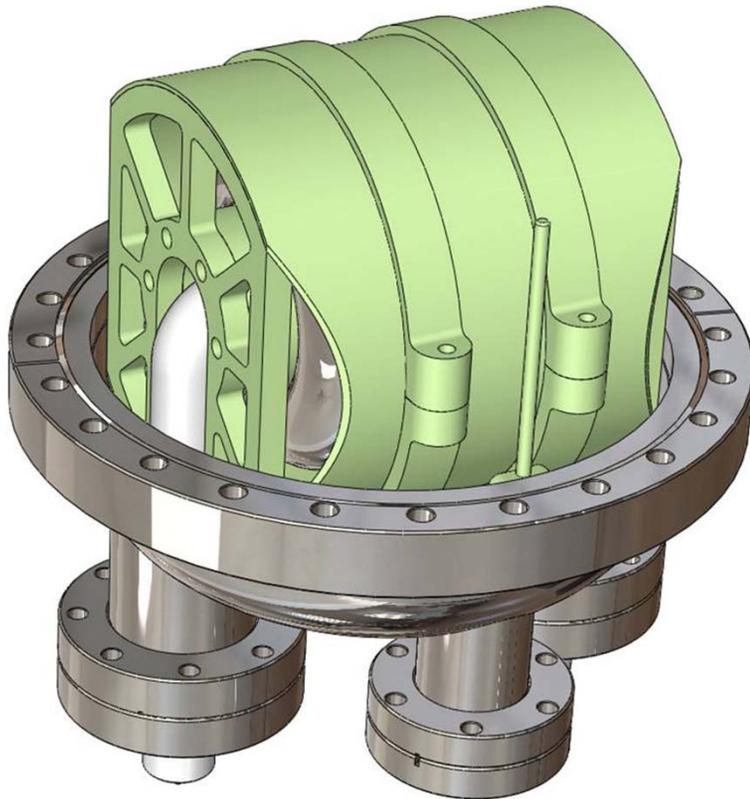
Features

- 6 liter LHe volume is cooled by a 3He fridge
- Electrodes size: ~ 12 cm in diameter
- Electric field: up to 75 kV/cm in 2 cm gap
- Gap size adjustable between 0.5 cm and 2.0 cm
- Lowest temperature: < 0.5 K
- Pressure: variable between SVP and 1 atm
- Turn around time: 2 weeks

Purpose

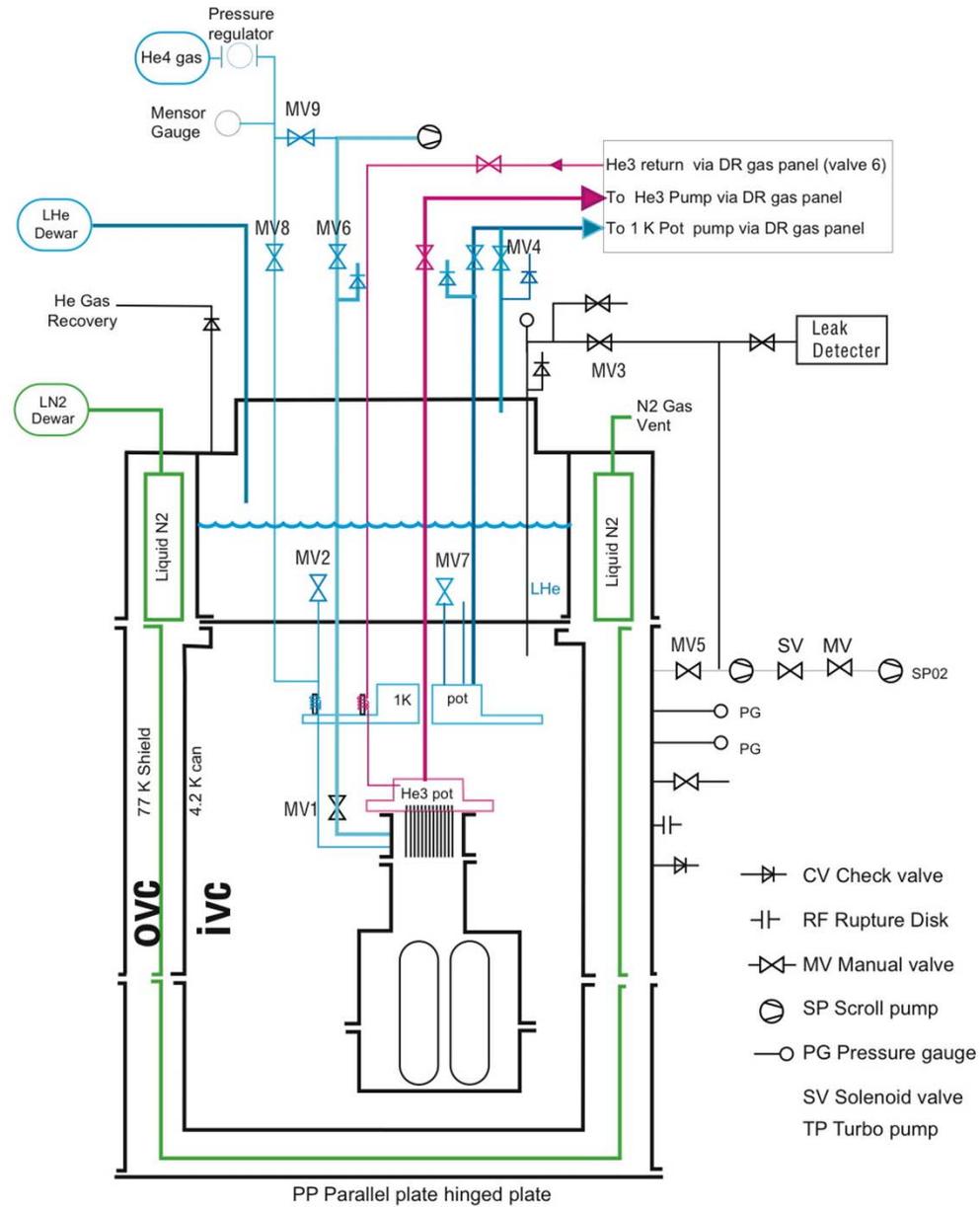
- To study breakdown field dependence on
 - Electrode/cell material
 - Temperature
 - Pressure
 - Gap size

CV and electrodes

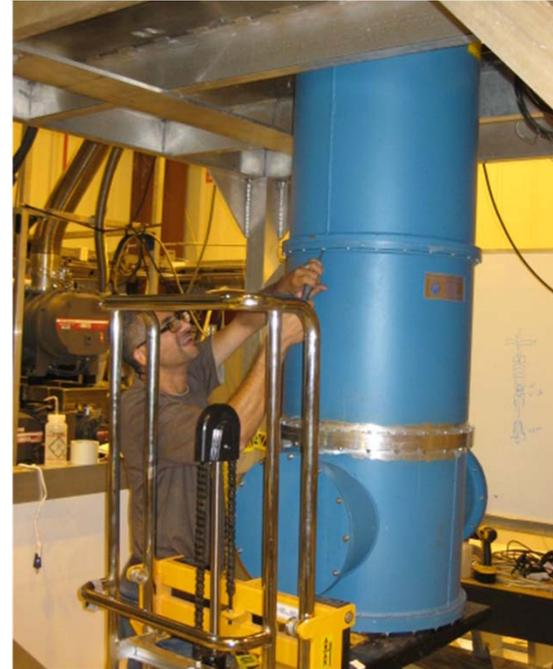


- The electrodes have the Rogowski shape
- The first set of electrodes will be made of electro-polished stainless steel
- The gap size is adjustable between 0.5 cm and 2 cm. The gap size was determined as a compromise between fast turn around time and being close to the nEDM experiment operating condition

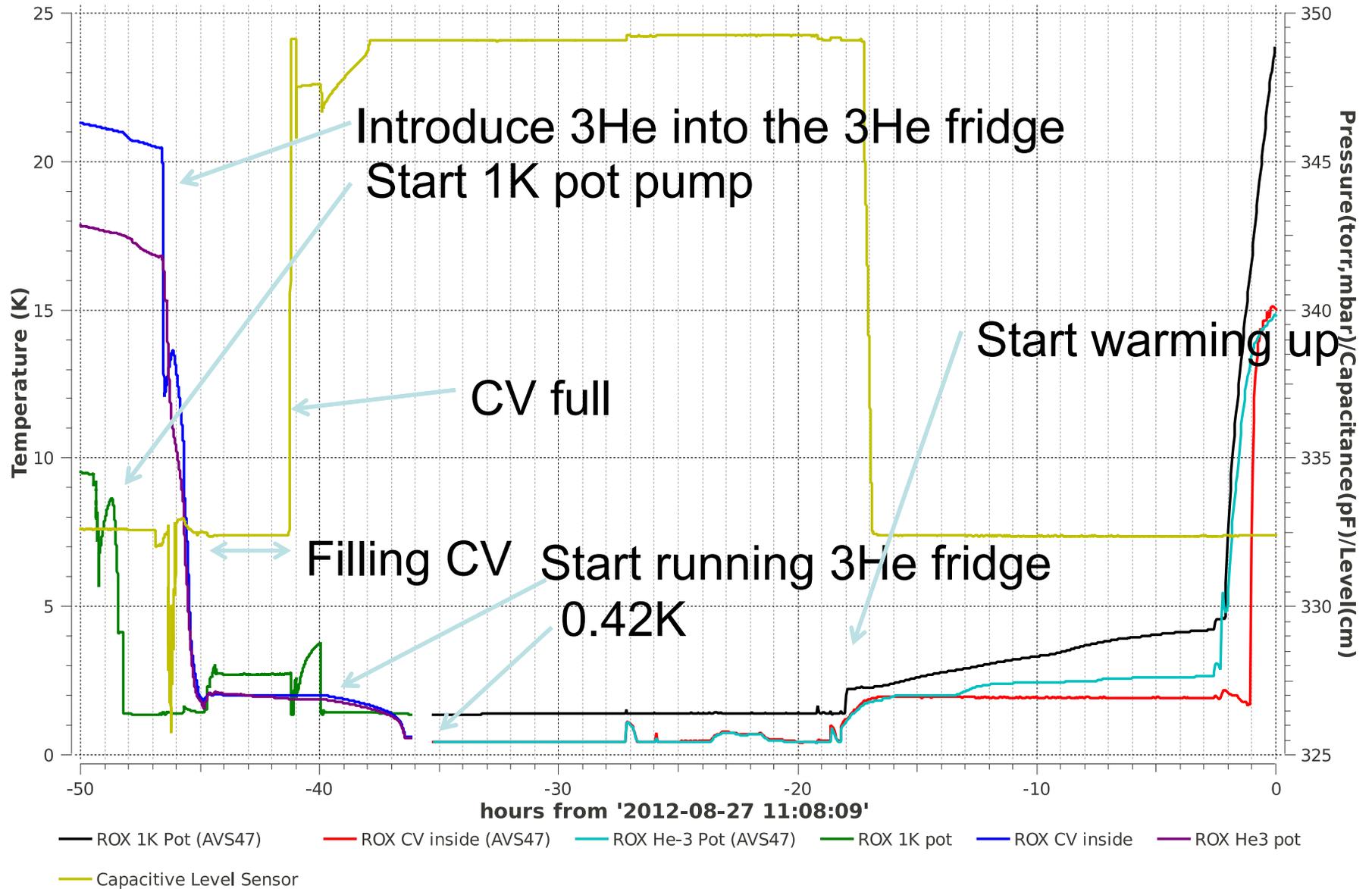
Flow diagram



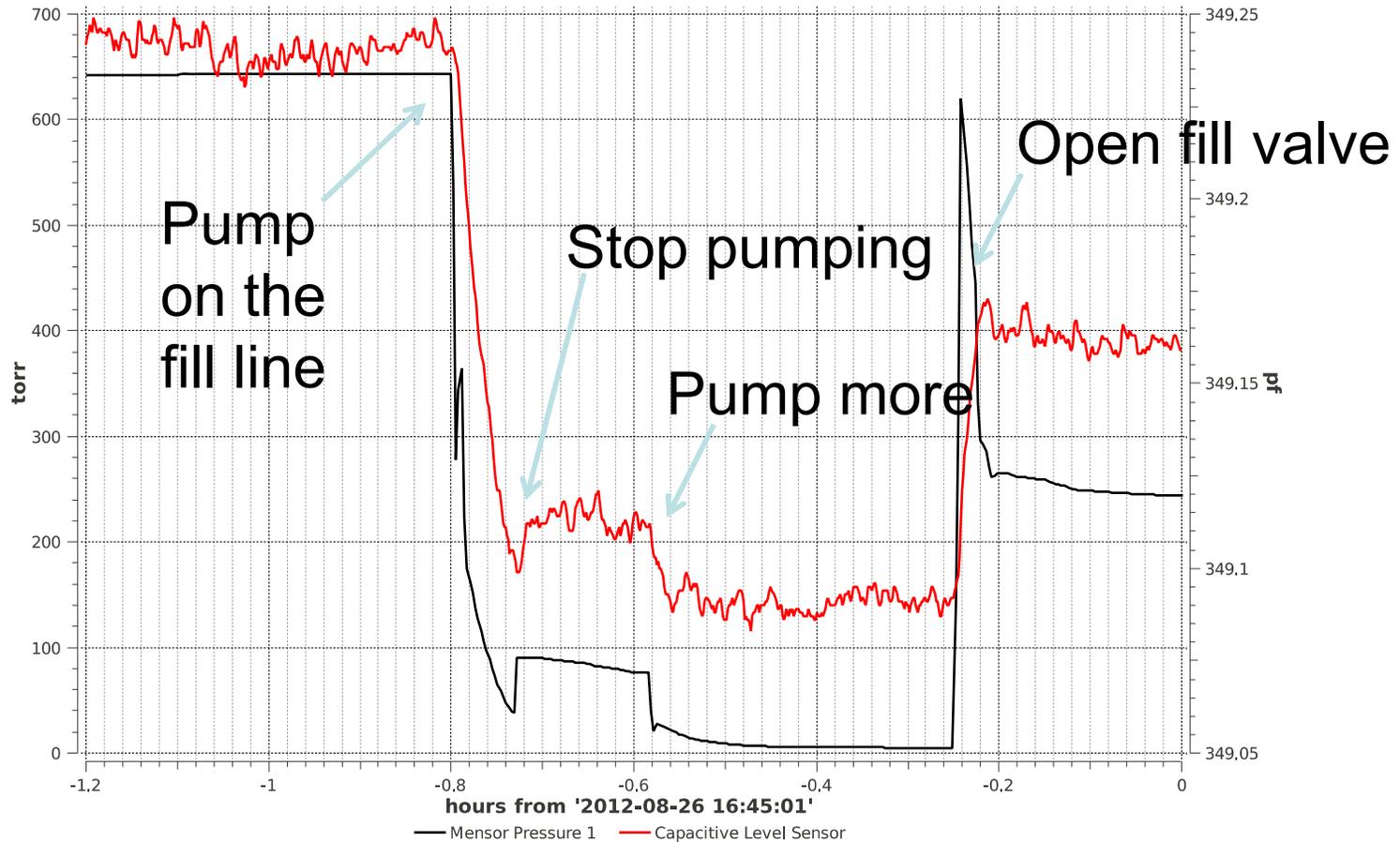
Assembly and commissioning



First full system cooldown (Aug 2012)



Pressure control



- Mensor (mechanical) gauge is at RT and reads the CV pressure through a thin capillary line
- Capacitive level gauge inside the CV is sensitive enough to show the change in dielectric constant due to pressure change and serves as an internal pressure gauge.

Status and outlook

- The first full system cooldown performed in August 2012
- The CV was filled with LHe and cooled to 0.42 K
- The CV LHe pressure was varied between SVP and 600 torr (atmospheric pressure at 7000 ft elevation)
- Currently HV components (SS electrodes, HV feed, HV feedthroughs) are being fabricated or prepared
- The next cooldown will be with all the HV components fully implemented and is scheduled for mid November
- The MSHV system will extend the study done at Sussex to lower temperatures, larger electrodes, and larger gap size (closer to nEDM operating conditions).

Electrode materials R&D

Requirements:

- Electrode made of PMMA coated with conductive material
- Electrical resistivity: $10^2 \Omega/\square < R_s < 10^8 \Omega/\square$
- Robust to thermal cycling and sparks
- Minimal activation due to exposure to neutron beam.
- Non-magnetic
- Fabrication techniques scalable to large (10x40x80 cm³) complicated 3D shape

Some possible coating materials

- Metal oxides, such as indium tin oxide
- Metal nitrides, such as titanium nitride
- Carbon paint
- GeCu
- Ion implantation

Modify surface through metal ion implantation.
 Implantation region extends ~ 10 nm below surface
 SwRI making small 2D samples to test procedure
 Large 3D objects feasible.

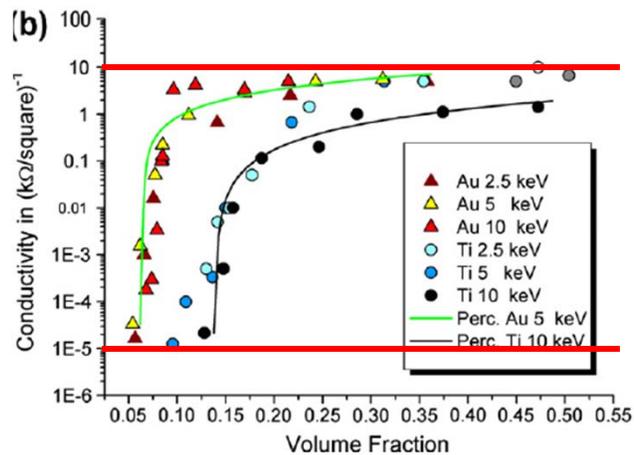
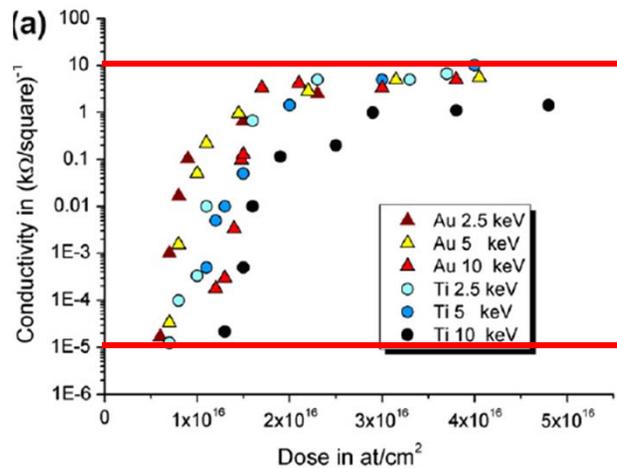
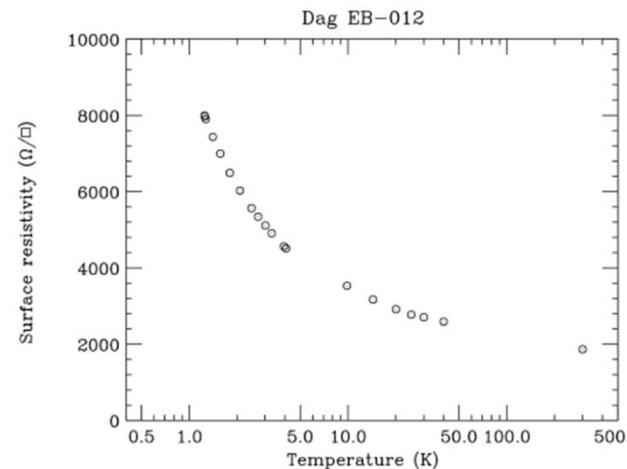
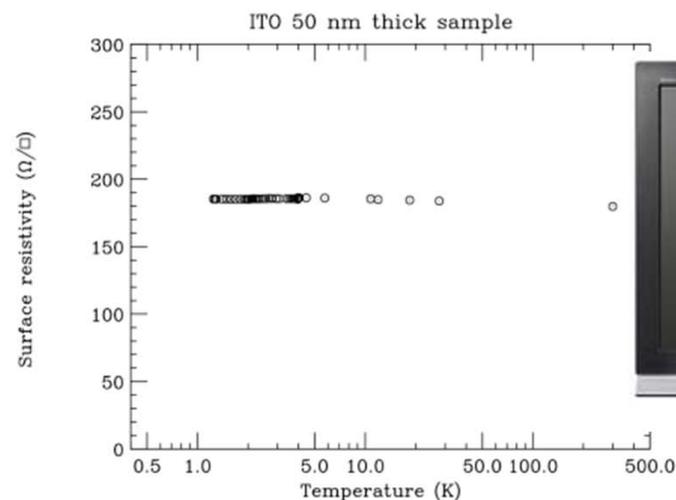


Fig. 6. Electrical conductivity of gold and titanium ions implanted by CVA at 2.5 keV, 5 keV and 10 keV, as a function of: (a) dose and (b) volume fraction. The two lines in (b) are fits of data with Eq. (1a) for 5-V gold-implanted samples, and for 10-keV titanium-implanted samples.



Carbon paint inherently satisfies most requirements.
 LANL testing commercial products.
 ORNL polymer chemists attempting to optimize coating
 (nanoparticle size, filler, etc.)



Desired properties achievable.
 Attempting to obtain acceptable 2D samples from a company
 (SwRI) willing to coat our electrode.

Effect of cell charging on electric field

D. Budker, B.-K. Park, G. Iwata (UCB)

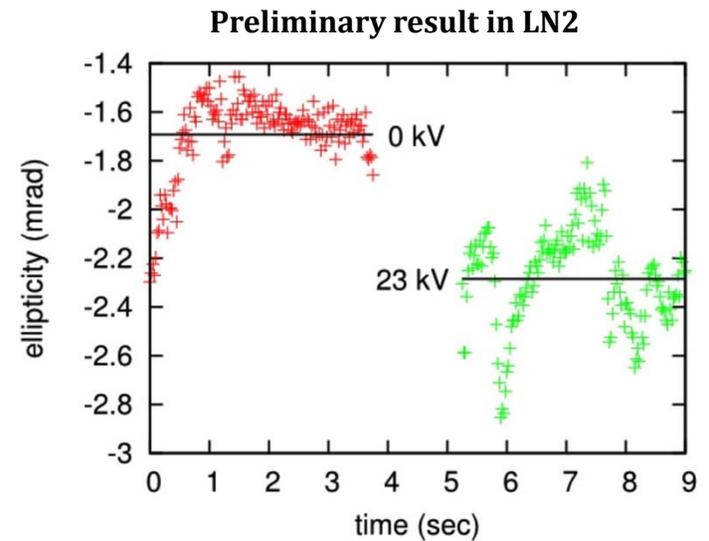
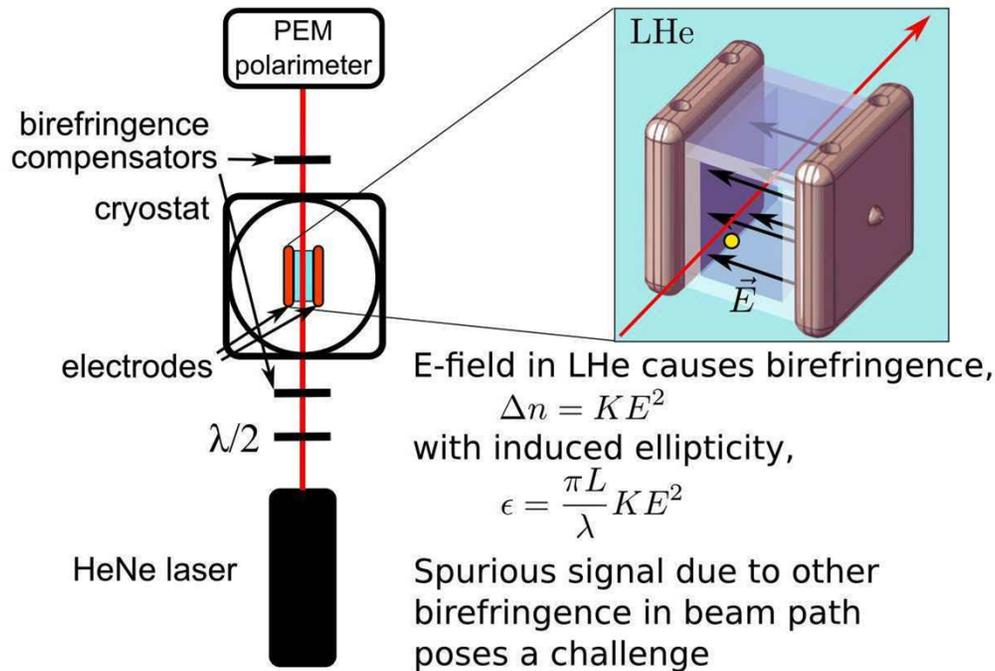
Experimentally verify electric-field strength in a PMMA cell under conditions similar to the nEDM experiment:

- measure E-field in PMMA cell in superfluid LHe over 100s of seconds
- check for effects of potential dielectric relaxation of PMMA
- check for effects of charge accumulation on PMMA in the presence of ionizing radiation and the effect of E-field reversal on accumulated charges

E-field is monitored using the Kerr effect in superfluid LHe [Sushkov et al., PRL 93, 153003 (2004)]

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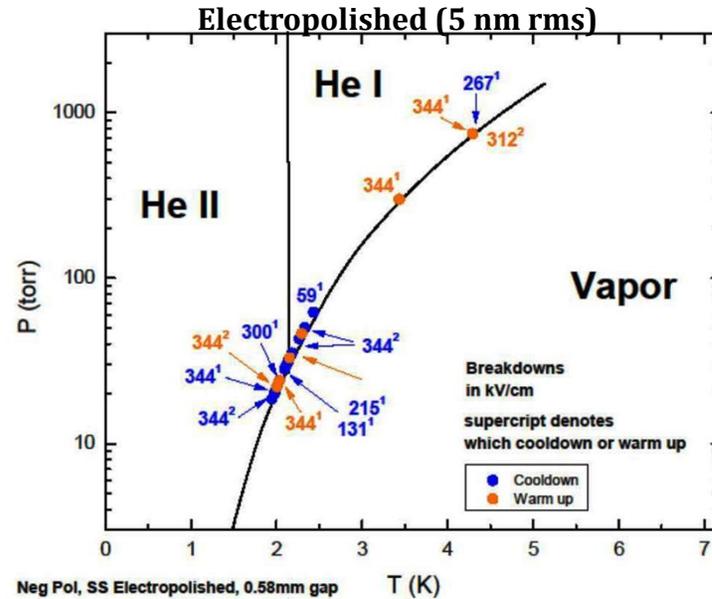
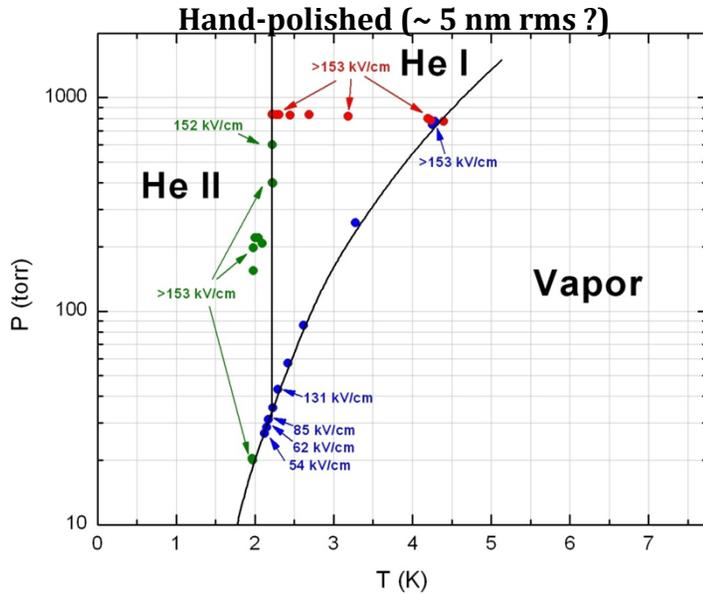


- **New cryostat (low-strain widows) + “double-pass” measurement technique: reduce window birefringence drift**
- **LHe operation: early 2013**

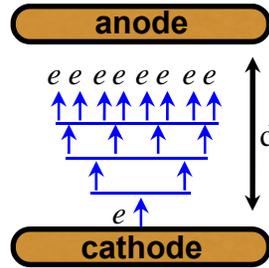
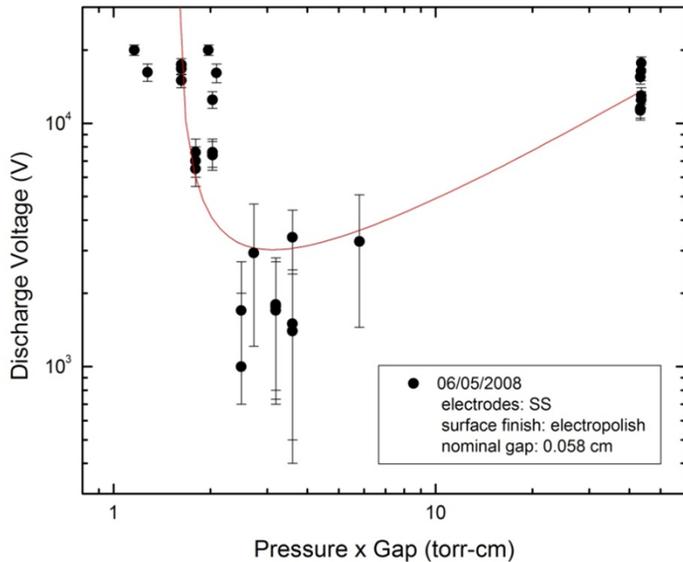
Summary

- The field strength of an 8L volume of 2.1 K SF LHe is at least 58 kV/cm
- Greater field strength of the large test cell at 4 K may be concern for 0.4 K, but there are strong reasons for optimism:
 - The field strength of pumped cells, with small volumes of SF LHe (above 1.6 K) can be recovered by temporarily pressurizing, or spontaneously using highly polished electrodes
- Recovery is consistent with suppression of cavitation at electrode surfaces, which should be reproducible in large systems below 1 K. Testing with specific materials under these conditions is of critical importance.
- Parallel efforts to fabricate electrodes from candidate materials and test them in large volumes of LHe below 1 K are underway
 - A medium-scale cryostat, capable of cooling 6L of SF to 0.42 K at pressures from SVP to 1 atm, has been commissioned
 - A separate experiment with Kerr-effect monitoring of E-field will assess effects of charge accumulation on insulating test cell surfaces
- preliminary results anticipated by early 2013

Adjustable-pressure HV cryostat results

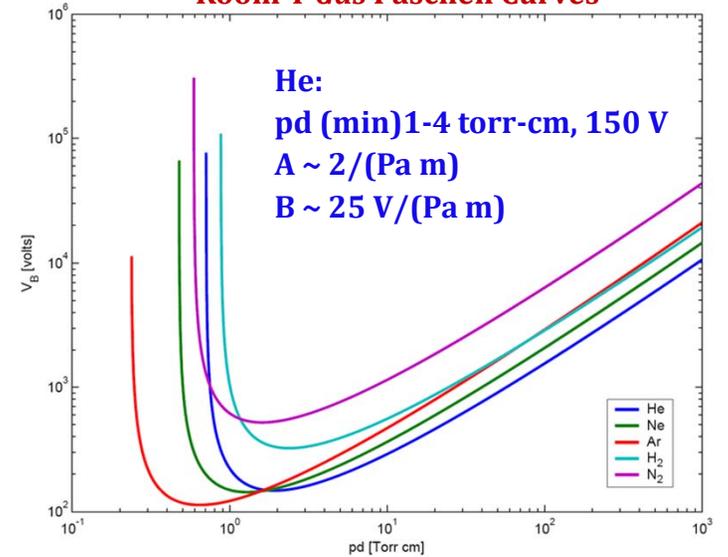


LHe Breakdown V vs. P (x min. gap)



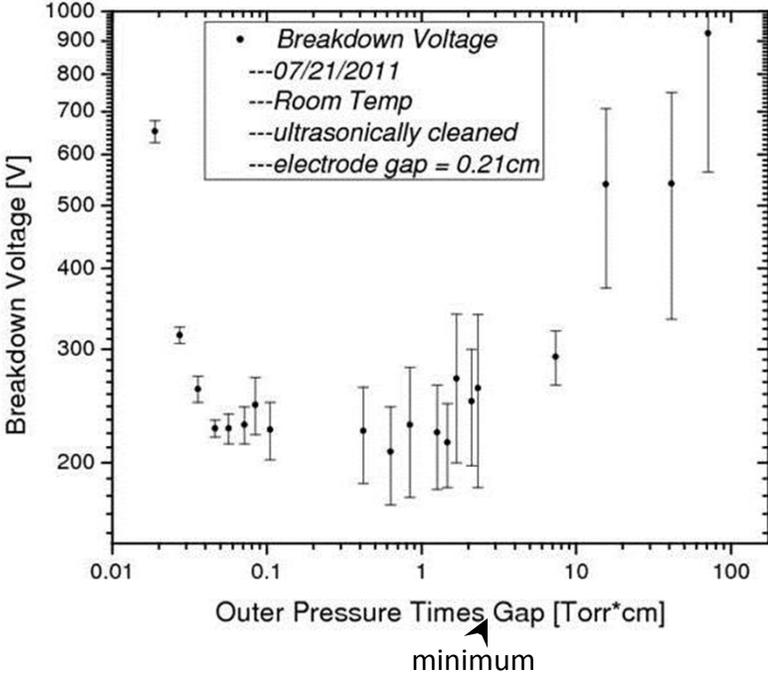
$$V_b = \frac{Bpd}{\ln\left(\frac{Apd}{\ln(1+1/\gamma)}\right)}$$

Room T Gas Paschen Curves

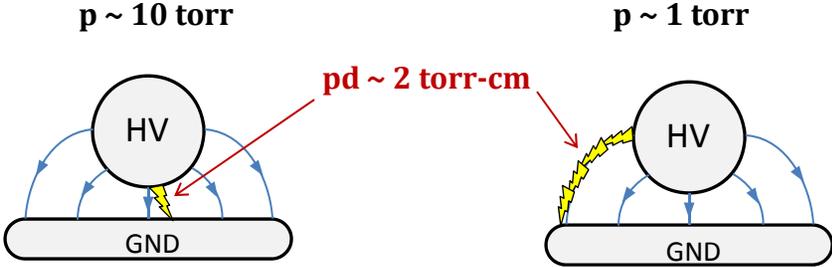


Adjustable-pressure HV cryostat: He gas breakdown

Breakdown V vs pd, 300 K



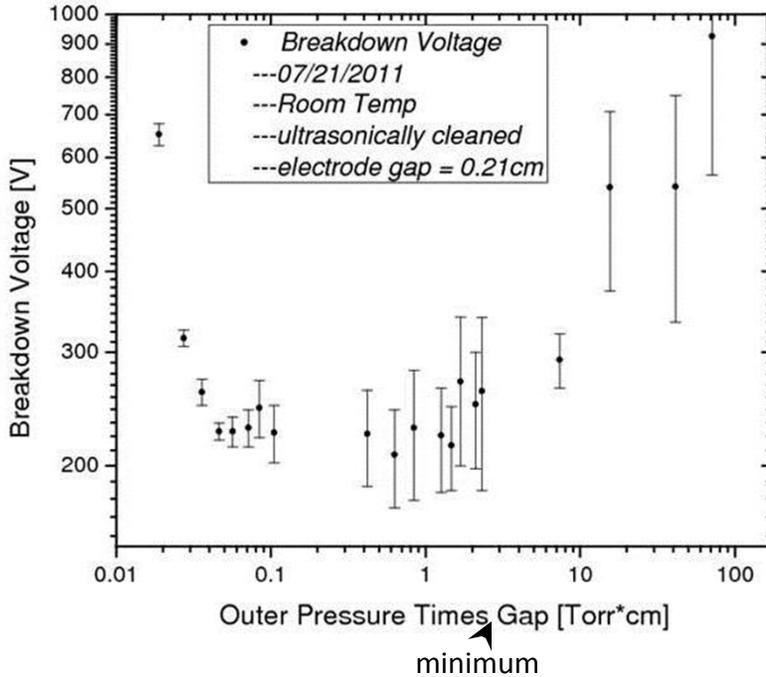
Geometry satisfies minimum condition over range of pressures:



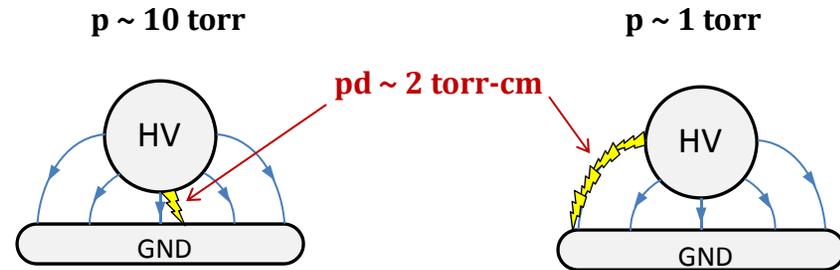
Smallest gap, highest field may not be weakest point

Adjustable-pressure HV cryostat: He gas breakdown

Breakdown V vs pd, 300 K

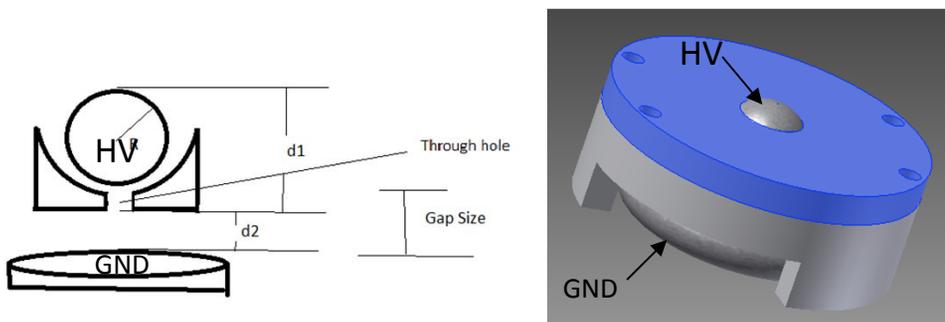


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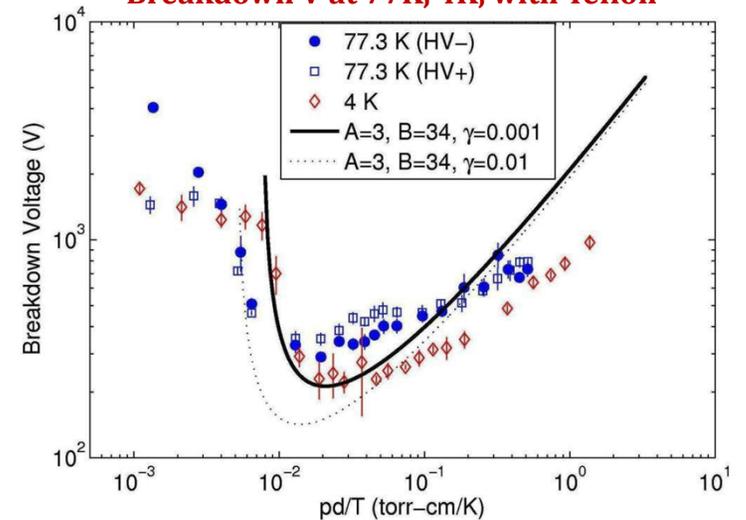


Smallest gap, highest field may not be weakest point

Teflon insulator added: more unique gap



Breakdown V at 77K, 4K, with Teflon



• **Minimum scales as $p \sim nT$**

Adjustable-pressure cryostat: liquid/gas comparison

preliminary

