Liquid Argon Dielectric Strength Measurements

Sarah Lockwitz
Fermilab

LArTPC R&D Workshop
July, 9 2014
Fermilab

Recent Interest in LAr High Voltage (HV)

Experiment	Voltage
ICARUS	75 kV
Darkside 50	60 kV
MicroBooNE	128 kV
CAPTAIN	50 kV
LBNE	170 kV
GLACIER	1-2 MV

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TABLE 6.2

Electric strengths of liquefied gases

Liquid	Strength (MV cm^{-1})
Nitrogen	1·6–1·88
Oxygen	2·38
Argon	1·10–1·42
Hydrogen	>1·0
Helium I, II	0·7

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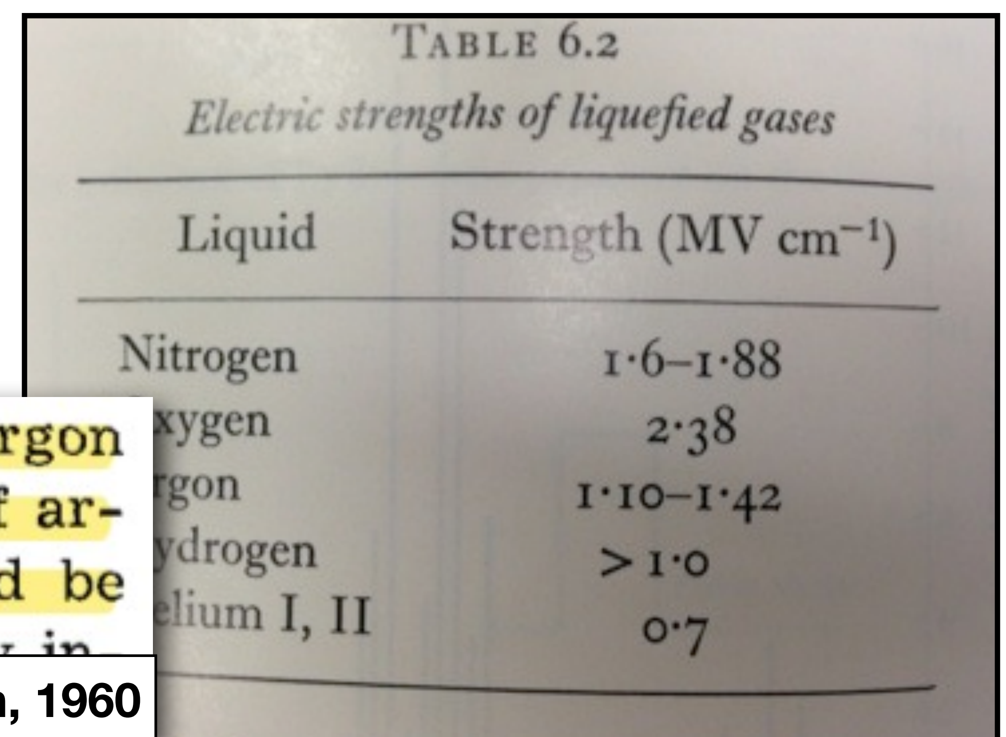
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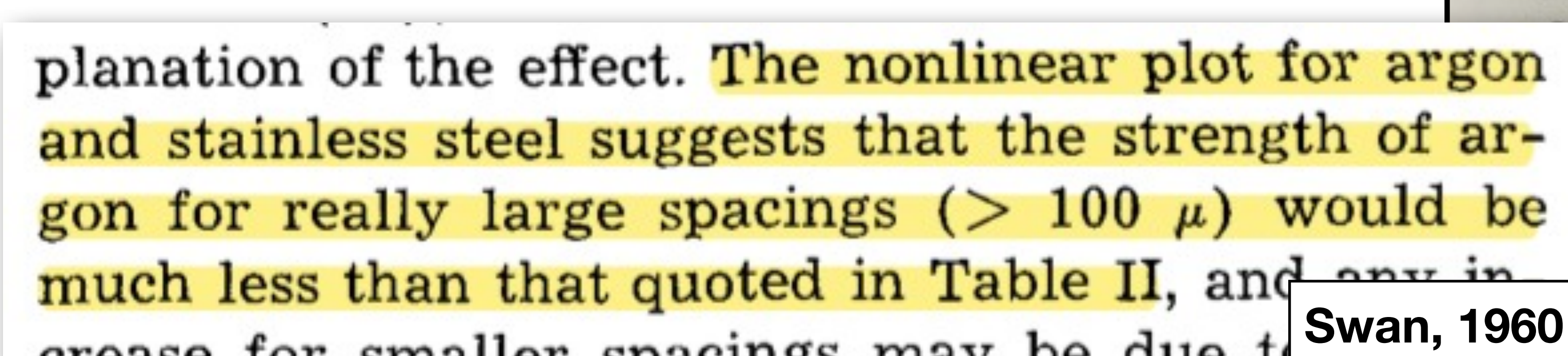
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much more precise and controlled measurements. These are liquified gases and, although they are of no importance as practical insulants, much information can be gained from them which helps in understanding the processes occurring in the organic liquids.

Of the possible liquified gases, argon, oxygen, and nitrogen are most suitable for study since they may

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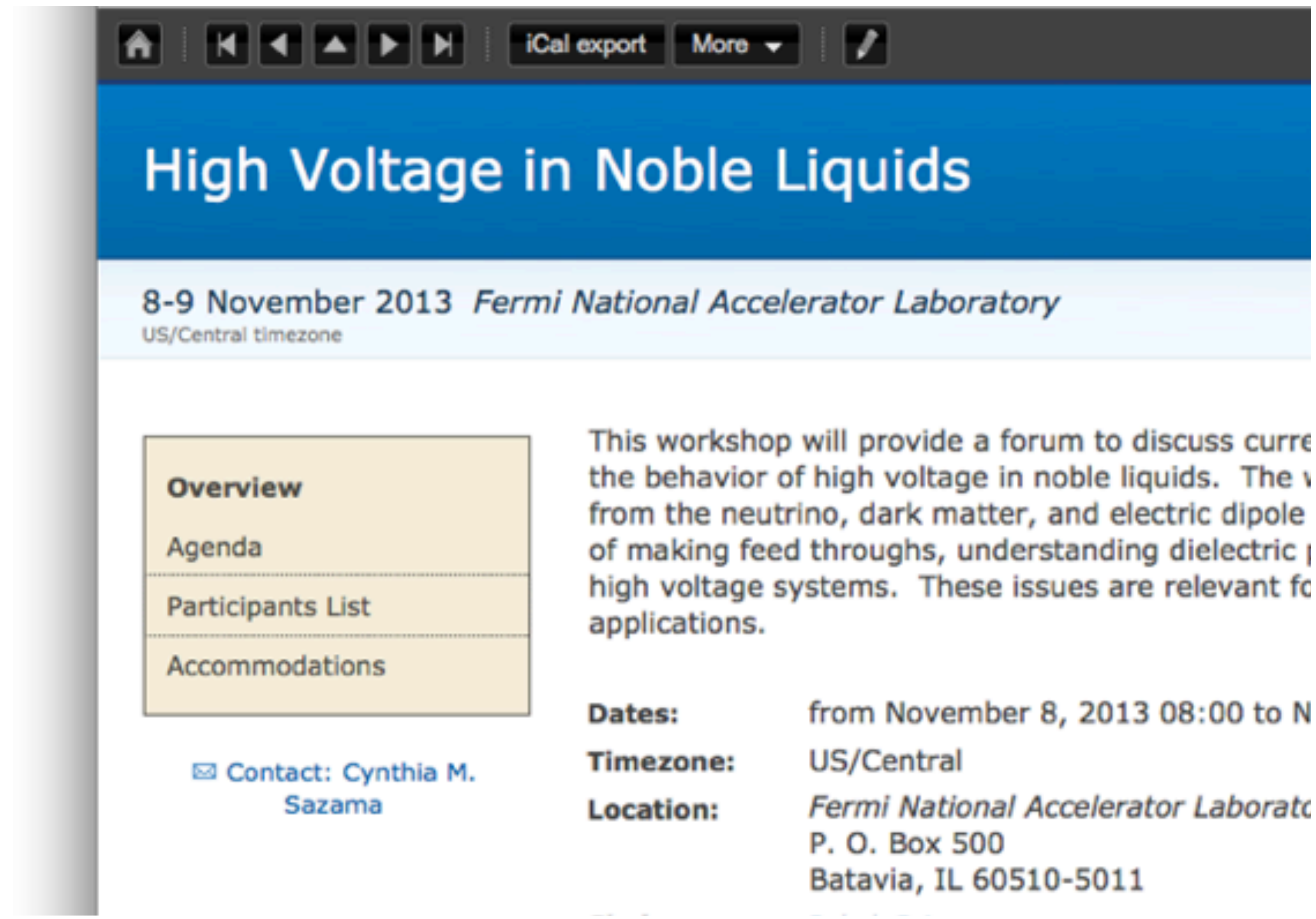

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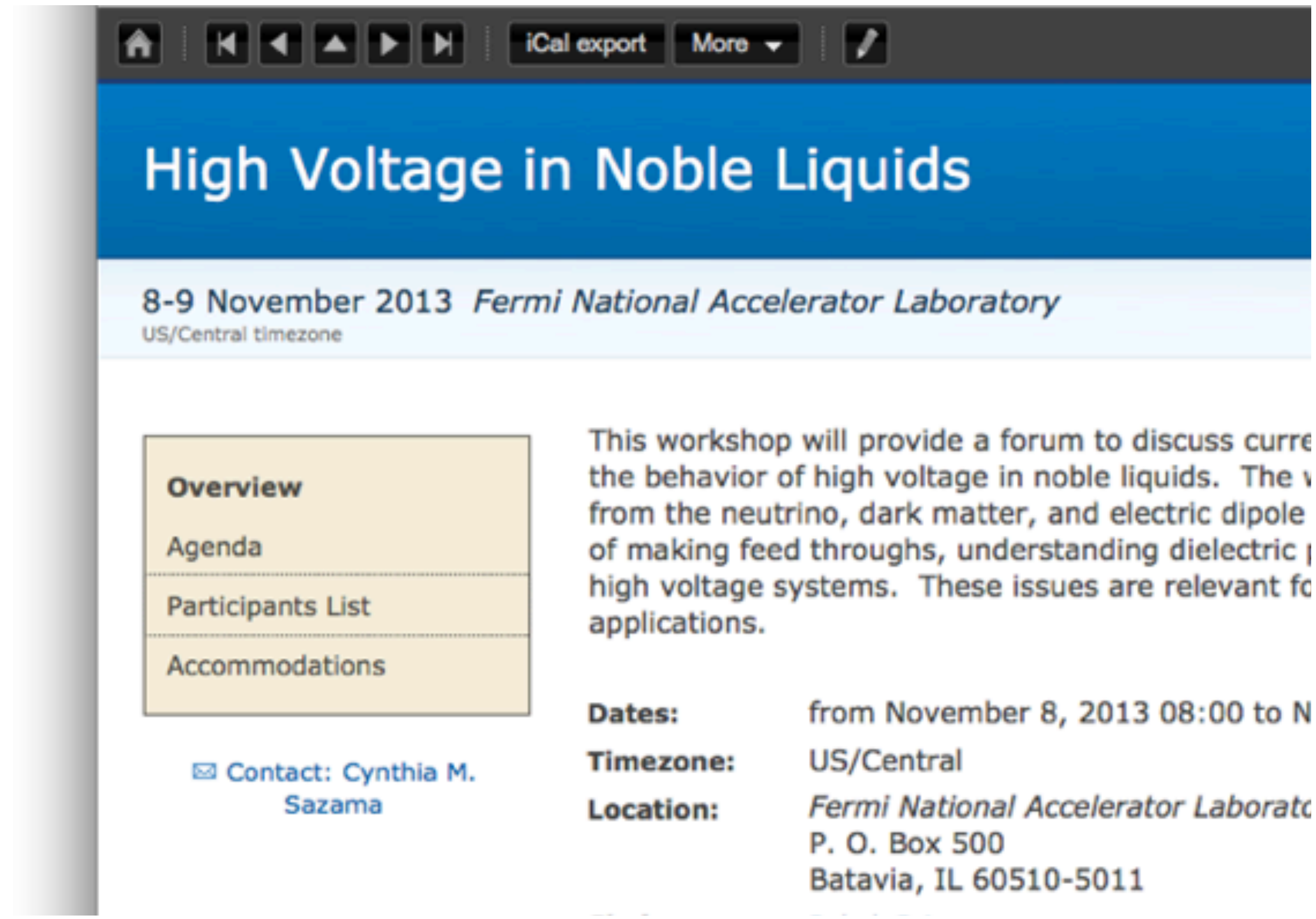

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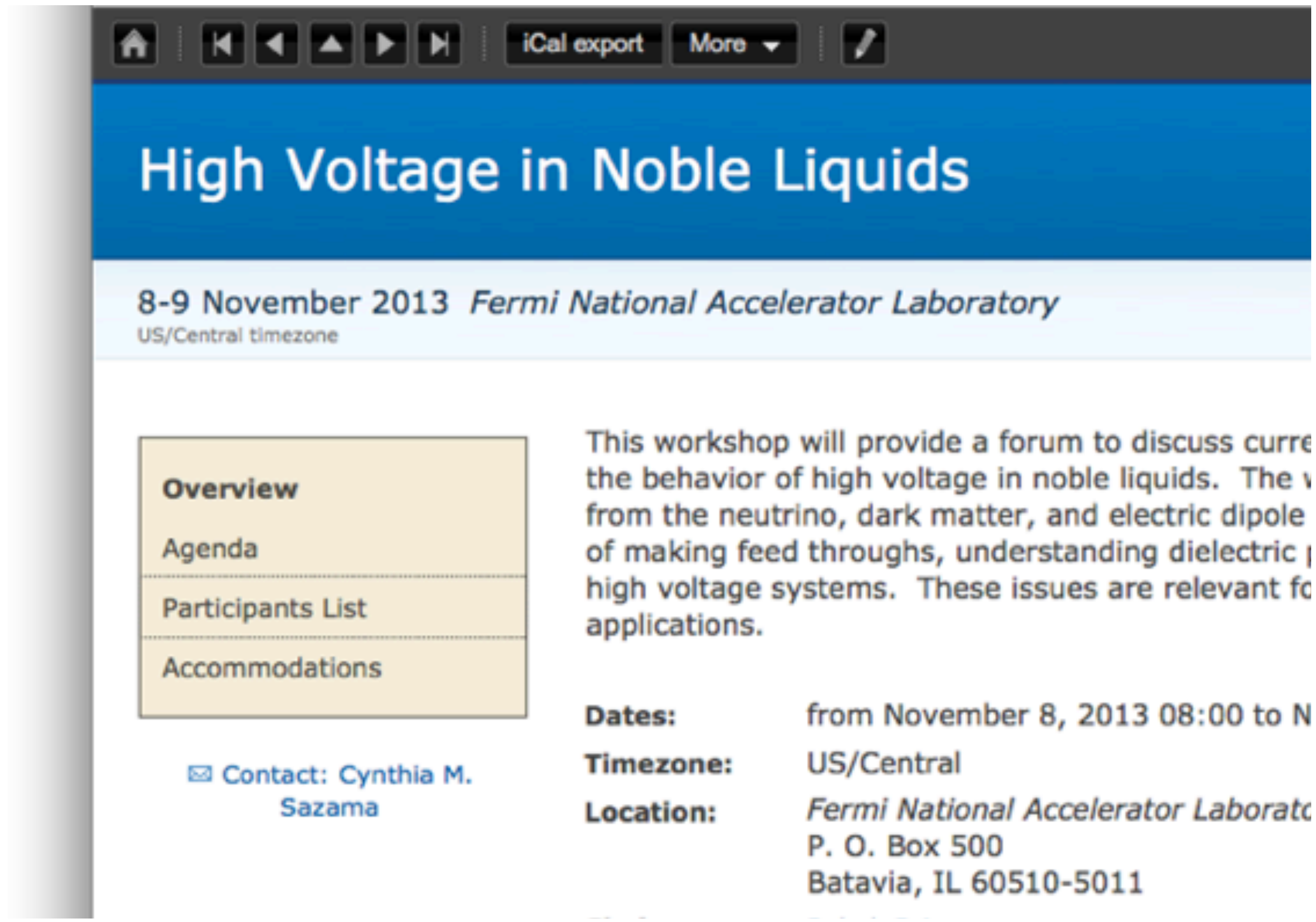

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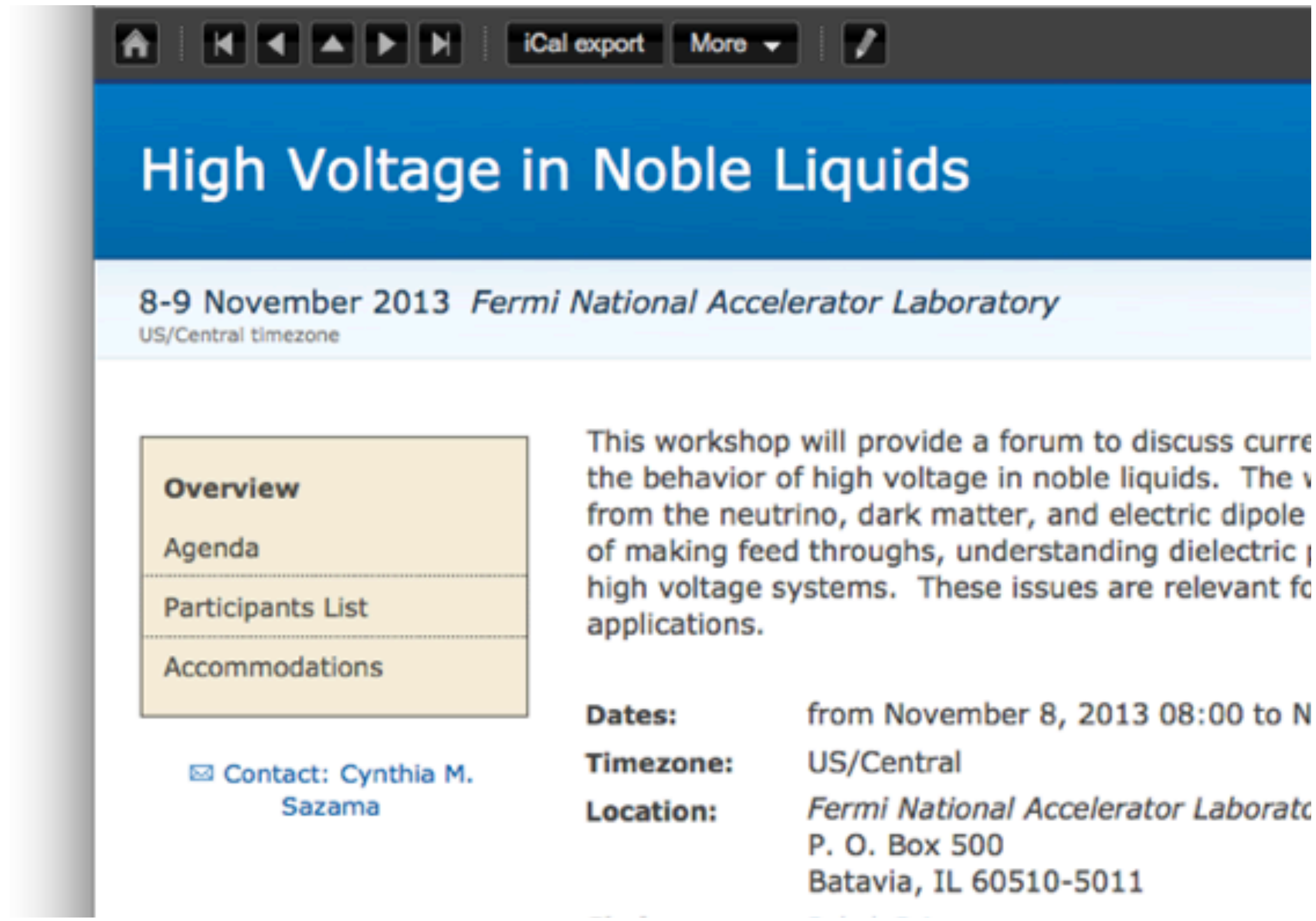

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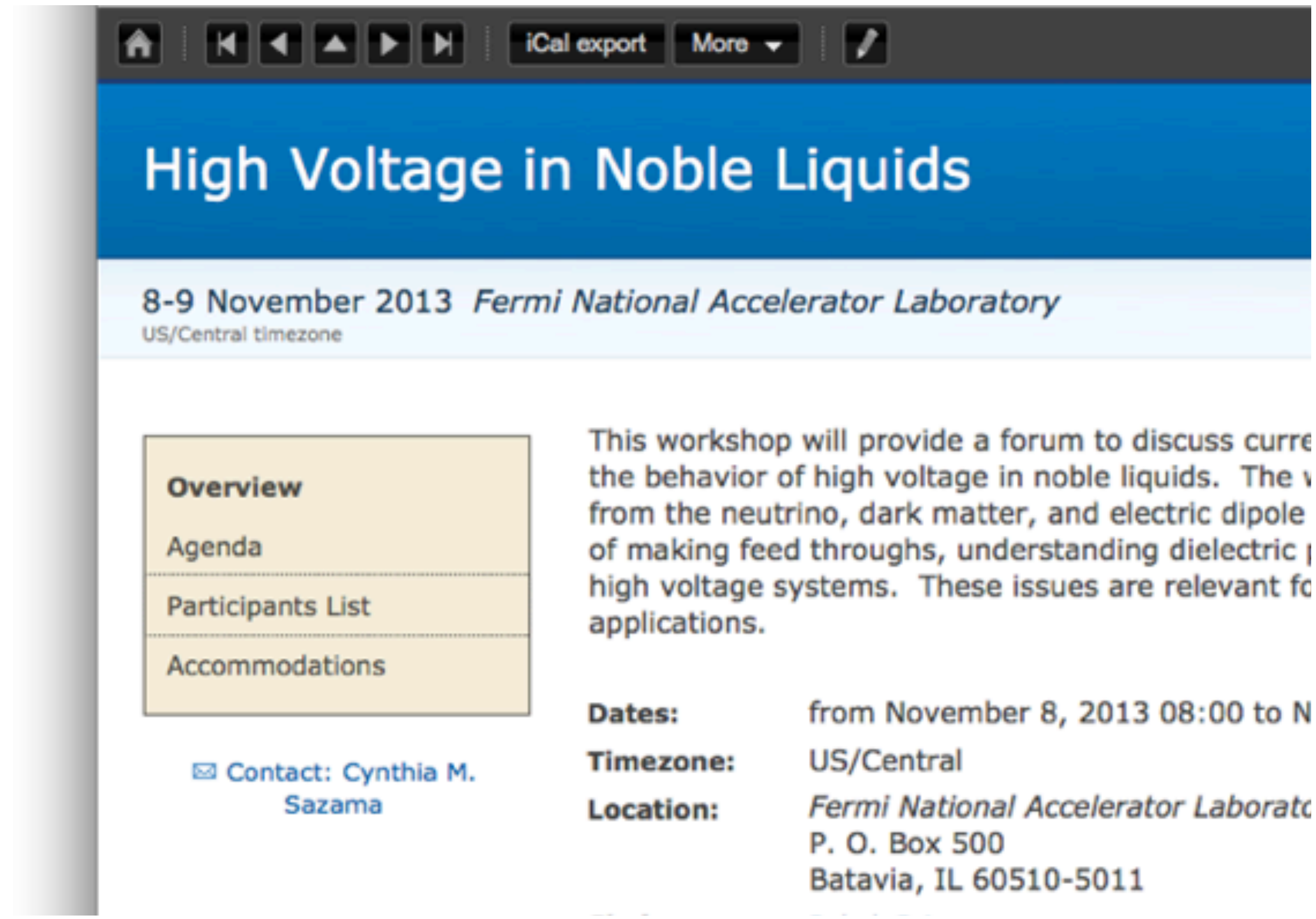
  - *and LAr breakdown tests*



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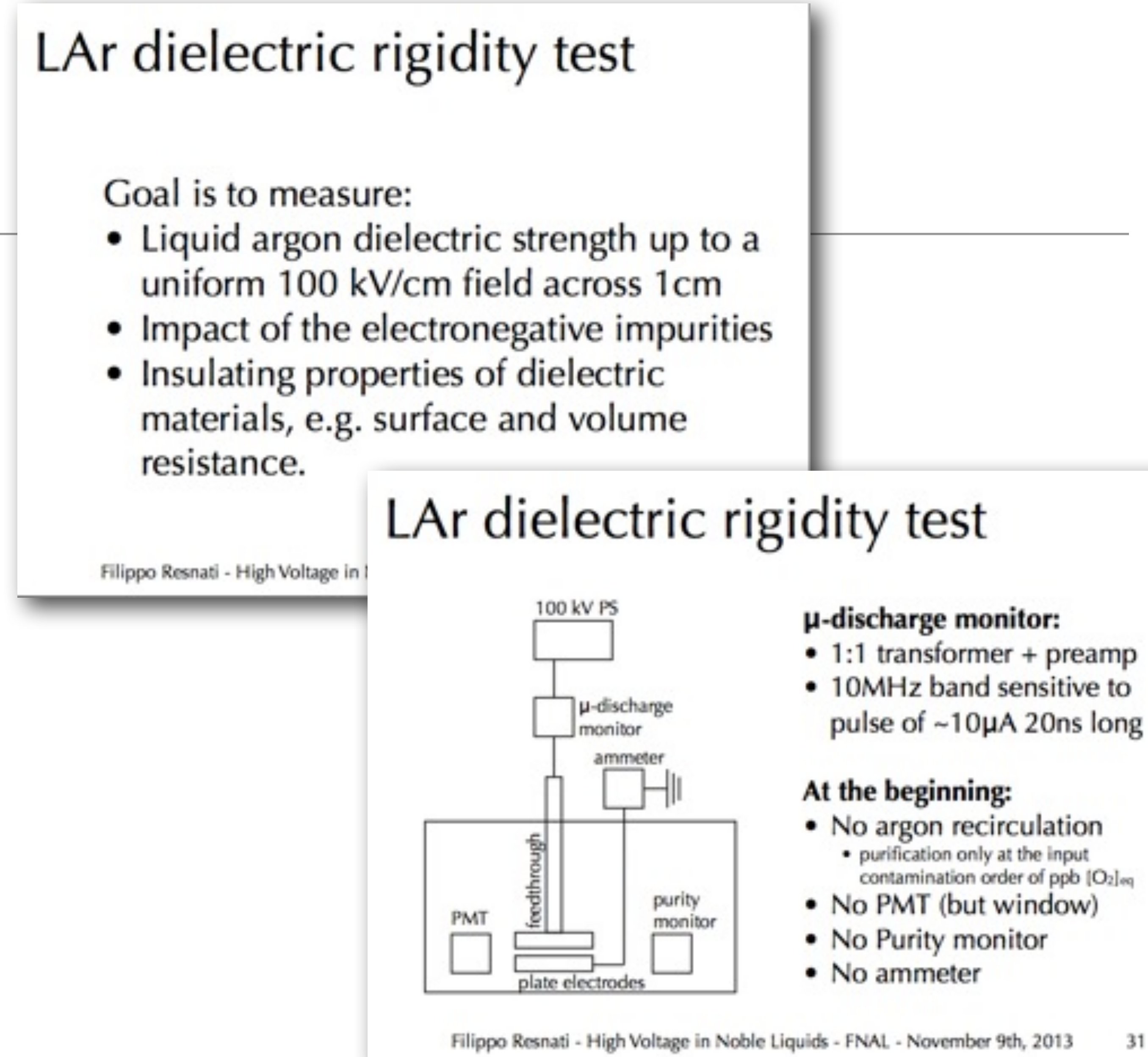

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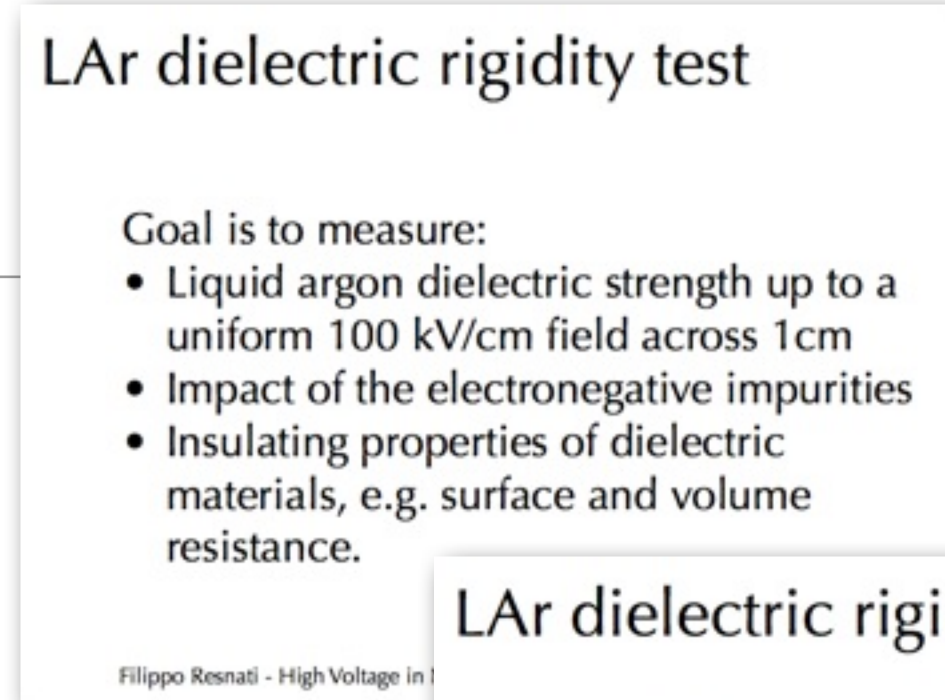
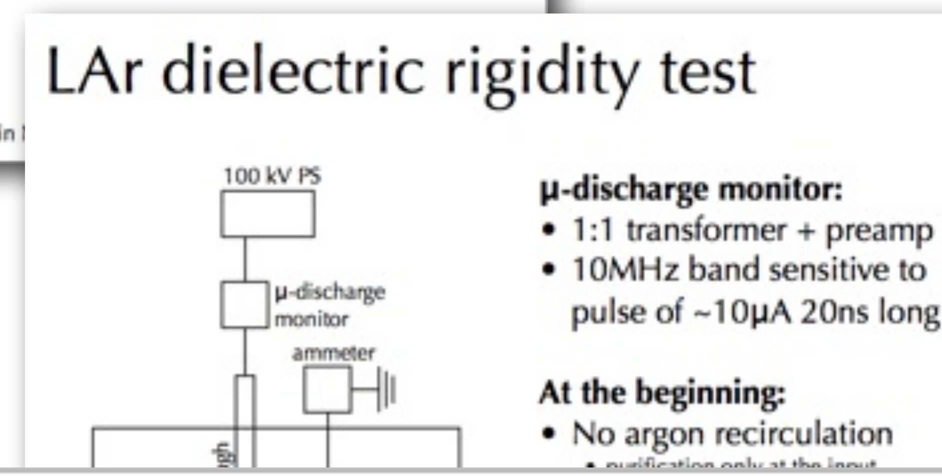
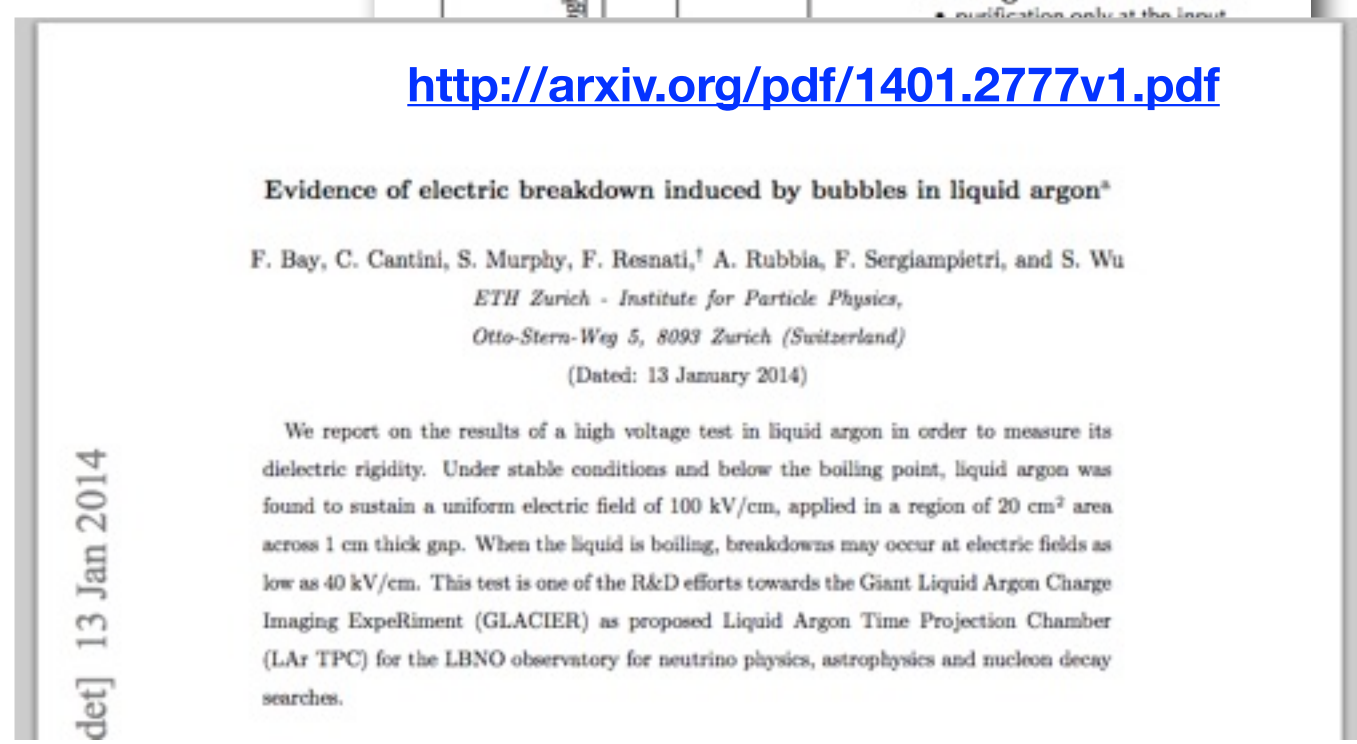
  - Included a plan for a LAr dielectric strength test
  - Used Rogoski profile to create a uniform 100 kV/cm electric field between two 20 cm2 plates separated by 1 cm
- Since then, published their result
  - 100 kV/cm sustained between the profiles (4 hours)
  - Breakdowns as low as 40 kV/cm in **boiling** liquid







http://arxiv.org/pdf/1401.2777v1.pdf

Evidence of electric breakdown induced by bubbles in liquid argon[a]

F. Bay, C. Cantini, S. Murphy, F. Resnati,[†] A. Rubbia, F. Sergiampietri, and S. Wu
ETH Zurich - Institute for Particle Physics,
Otto-Stern-Weg 5, 8093 Zurich (Switzerland)
(Dated: 13 January 2014)

We report on the results of a high voltage test in liquid argon in order to measure its dielectric rigidity. Under stable conditions and below the boiling point, liquid argon was found to sustain a uniform electric field of 100 kV/cm, applied in a region of 20 cm^2 area across 1 cm thick gap. When the liquid is boiling, breakdowns may occur at electric fields as low as 40 kV/cm. This test is one of the R&D efforts towards the Giant Liquid Argon Charge Imaging ExpeRiment (GLACIER) as proposed Liquid Argon Time Projection Chamber (LAr TPC) for the LBNO observatory for neutrino physics, astrophysics and nucleon decay searches.

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Slides from T. Strauss

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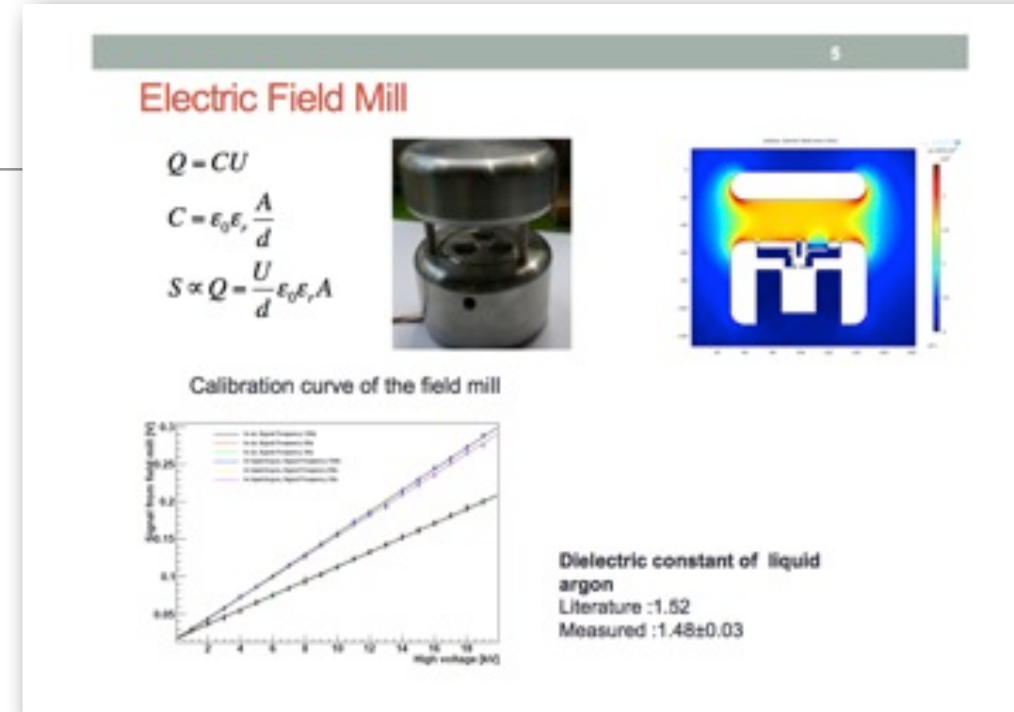

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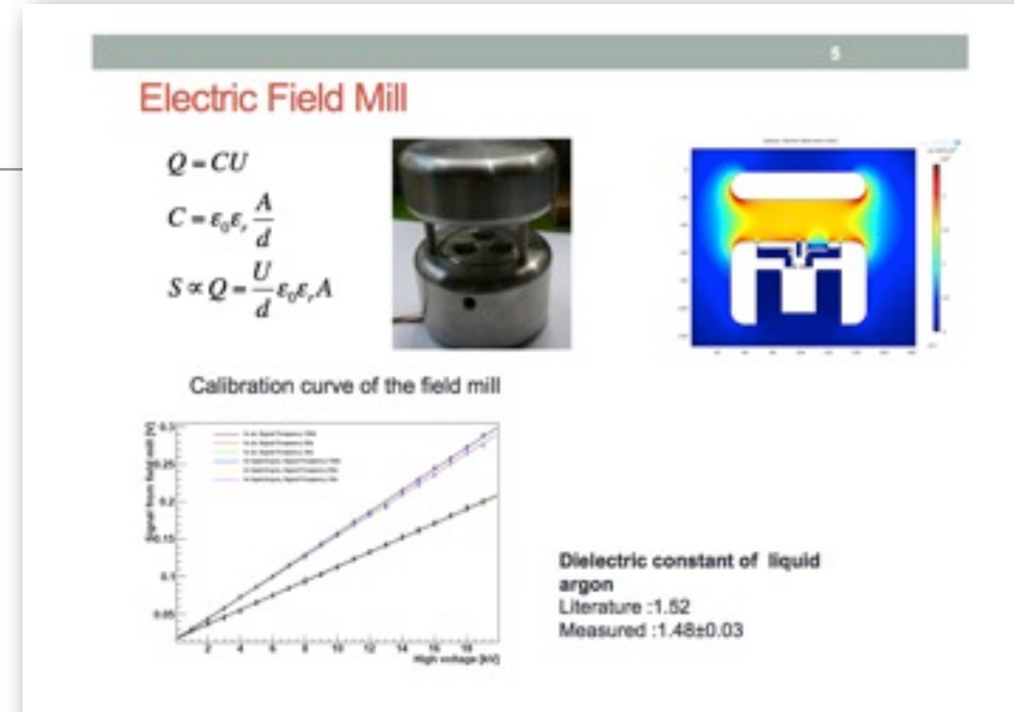
  - A dielectric constant measurement
  - Breakdown field measurements between two spheres



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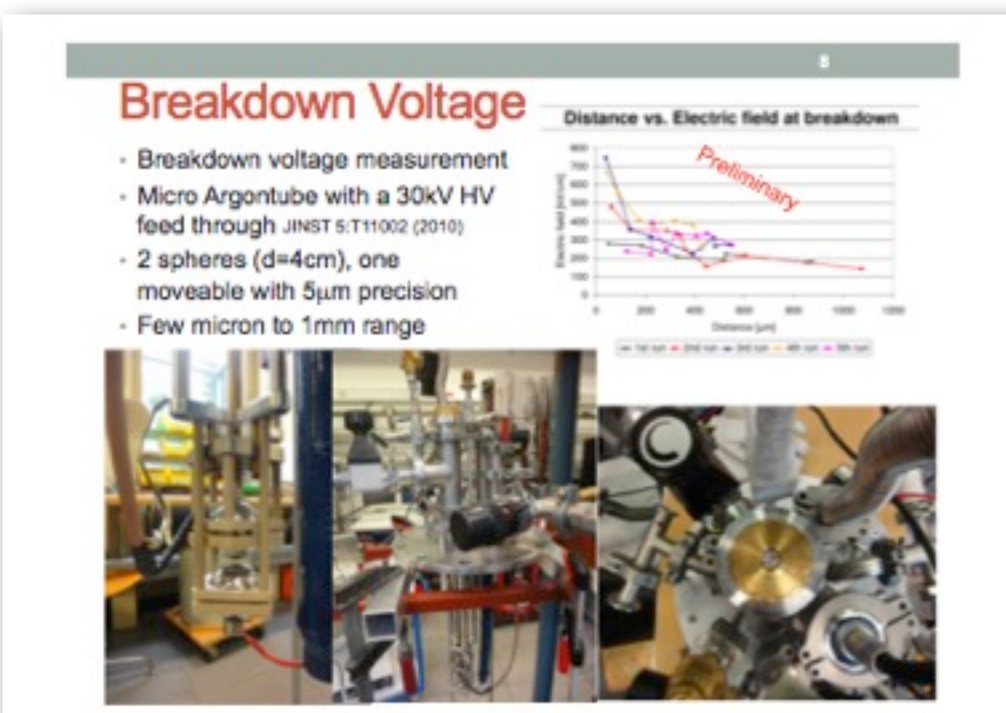

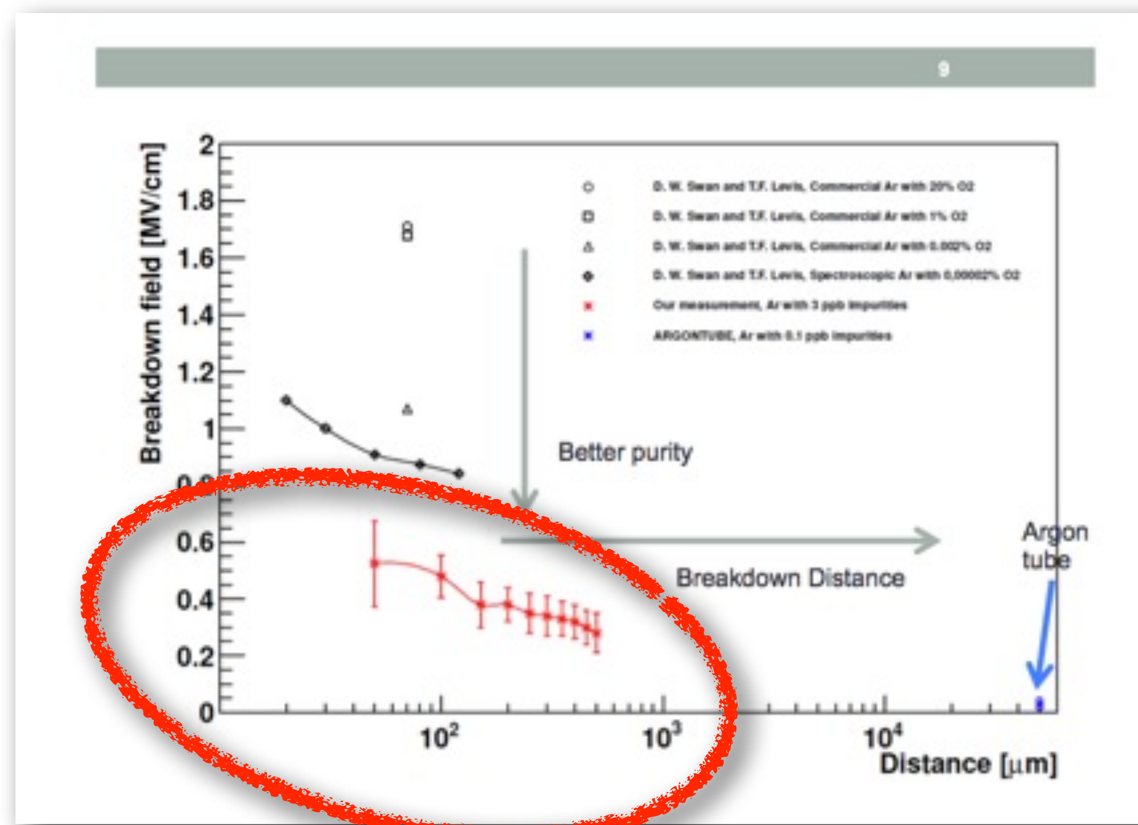

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  - Published on dielectric strength measurements up to the cm scale
    - Breakdown measurements between 1 ppb - 20 ppm

arXiv:…[physics.ins-det] 26 Jan 2014

Experimental study of electric breakdowns in liquid argon at centimeter scale

A. Blatter, A. Ereditato, C.-C. Hsu, S. Janos, I. Kreslo, M. Luethi, C. Rudolf von Rohr, M. Schenk, T. Strauss, M. S. Weber and M. Zeller

Albert Einstein Center for fundamental Physics, Laboratory for High Energy Physics, University of Bern, Sidlerstrasse 5,3012 Bern, Switzerland

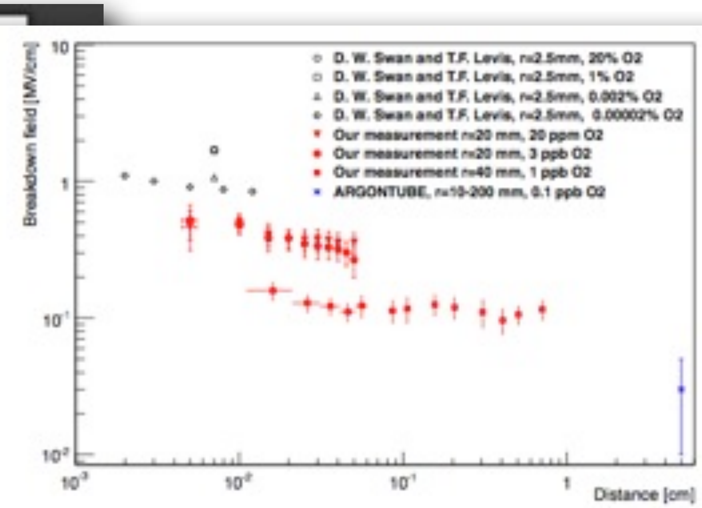

Figure 7. Compilation of the experimental data on the electric strength of liquid argon including results from our measurements.

the further development of the studies. The measurements presented in this paper extend the scale of cathode-anode gap widths up to 10 mm with spherical cathode and plane anode. It is shown that for such scale electric breakdowns in highly purified liquid argon (1 ppb oxygen equivalent) occur at field intensities significantly lower then expected, namely as low as 40 kV/cm. The observation of a dependence of the breakdown field on the cathode-anode distance and on the cathode shape supports the hypothesis that the breakdown is governed by space-charge effects in the volume and

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  - Published a study using a cathode coating to suppress discharges

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A method to suppress dielectric breakdowns in liquid argon ionization detectors for cathode to ground distances of several millimeters

M. Auger, A. Ereditato, D. Goeldi, S. Janos, I. Kreslo, M. Luethi, C. Rudolf von Rohr, T. Strauss, T. Tolba and M. S. Weber

arXiv:1406.3929v1 [physics.ins-det] 16 Jun 2014

This is significantly higher from the previous BD measurement

Table 1. Summary of the breakdown test measurements with 200 μm and 450 μm thick polyisoprene layers coating 5 cm and 4 cm diameter spherical cathodes, respectively.

Gap width	Max. field strength	Sphere diameter	Polyisoprene thickness	Breakdown
5 mm	298 kV/cm	4 cm	450 μm	no
4 mm	358 kV/cm	4 cm	450 μm	no
3 mm	412 kV/cm	4 cm	450 μm	yes
5 mm	296 kV/cm	5 cm	200 μm	yes

Work at Fermilab

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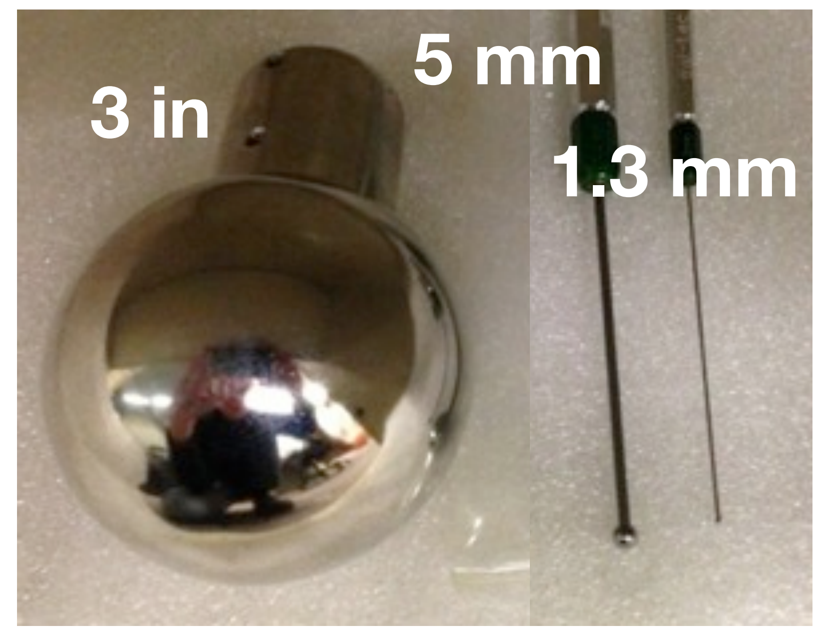

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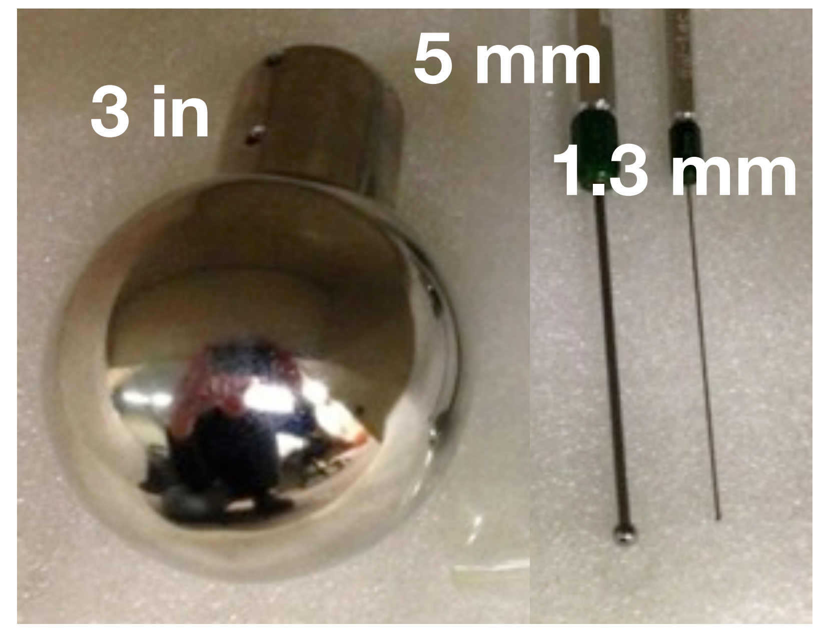

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- We plugged into MicroBooNE's phase 1 cryosystem at LArTF

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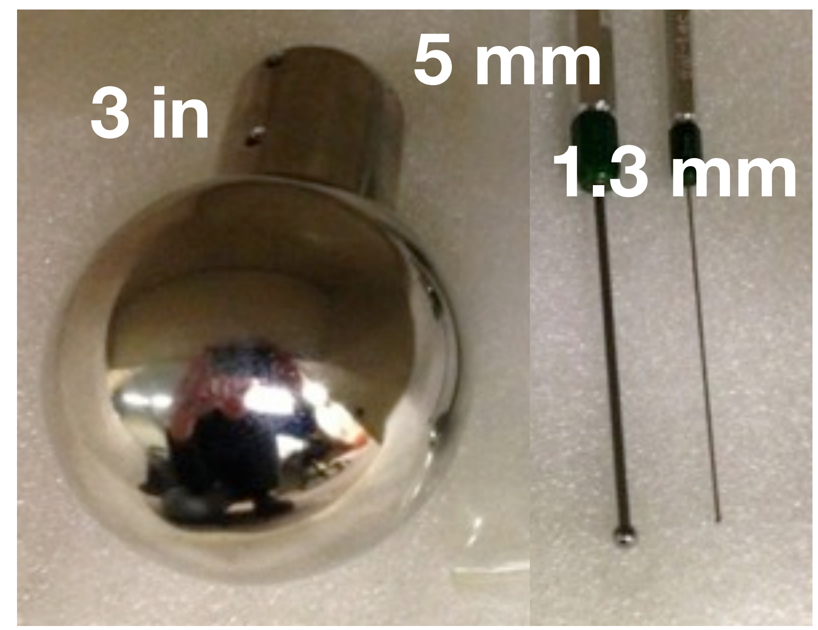

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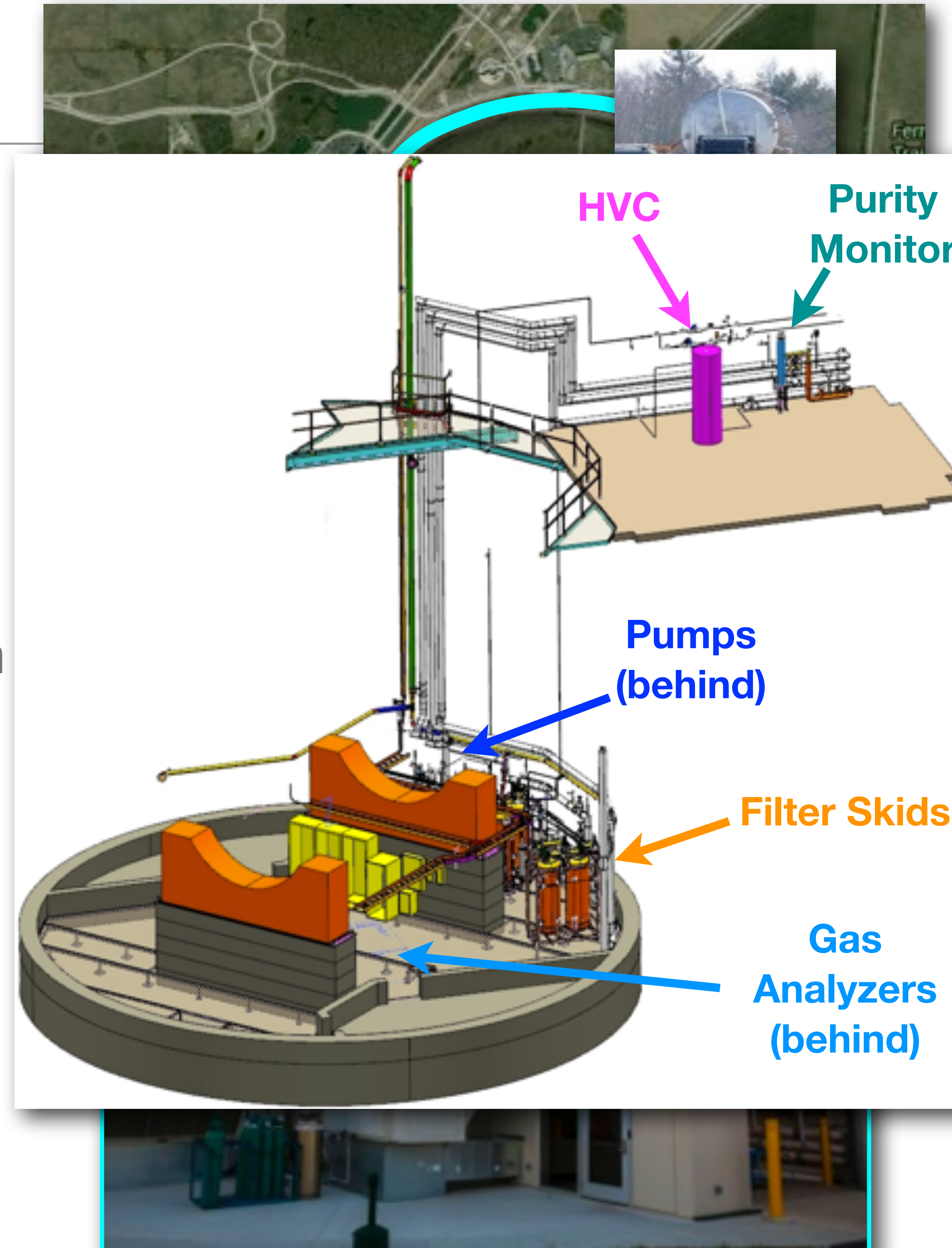
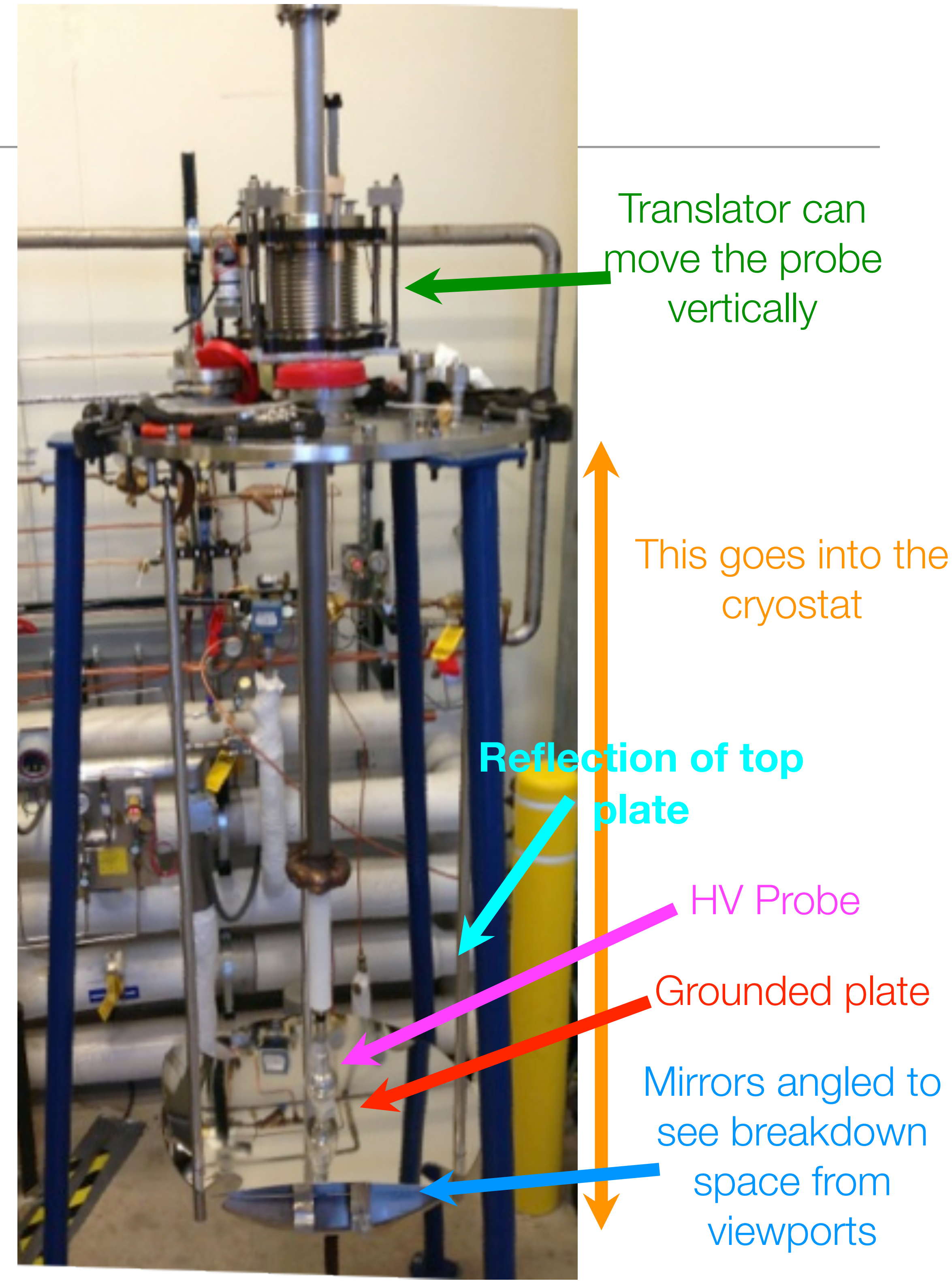
        - **Gas Analyzers** read from cryostat liquid
        - Liquid sent to **purity monitor** vessel after use



Test Setup


Translator can move the probe vertically
This goes into the cryostat
Reflection of top plate
HV Probe
Grounded plate
Mirrors angled to see breakdown space from viewports

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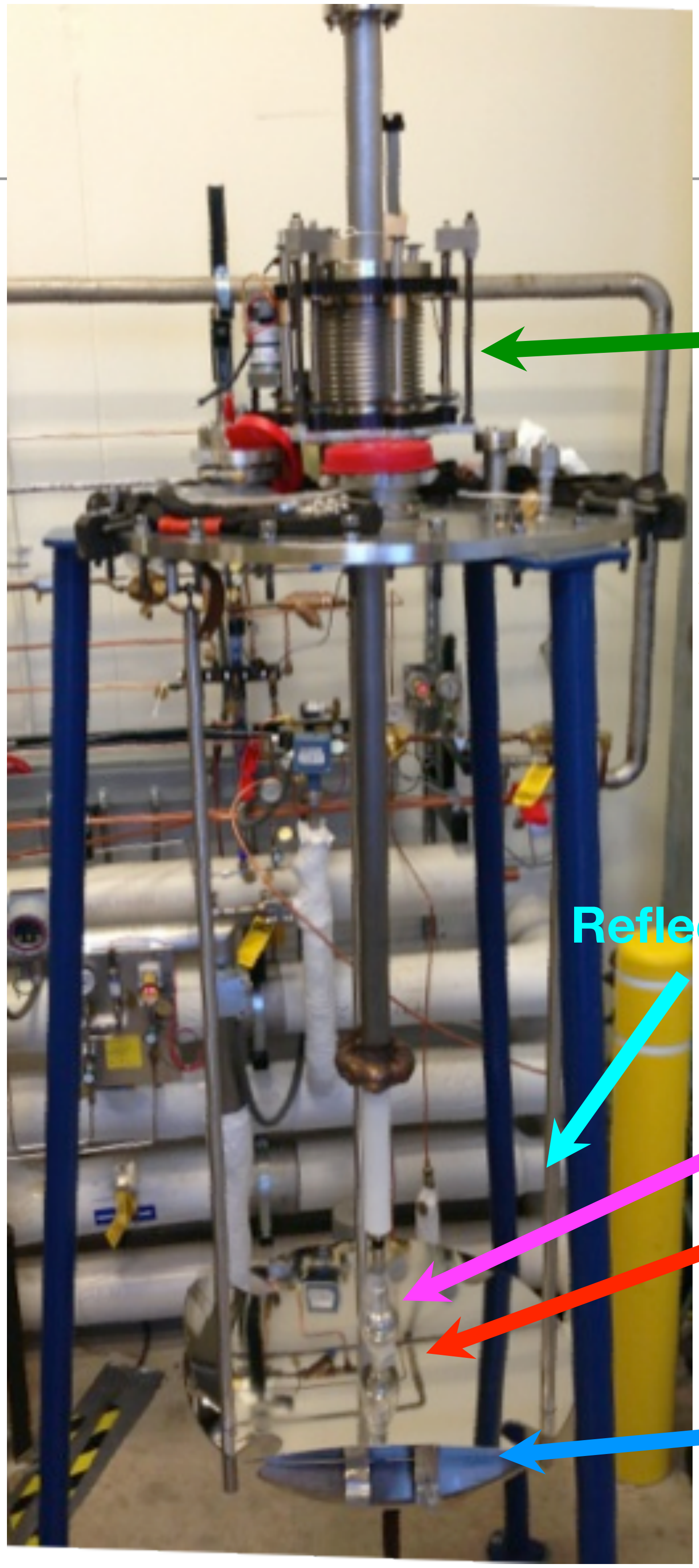

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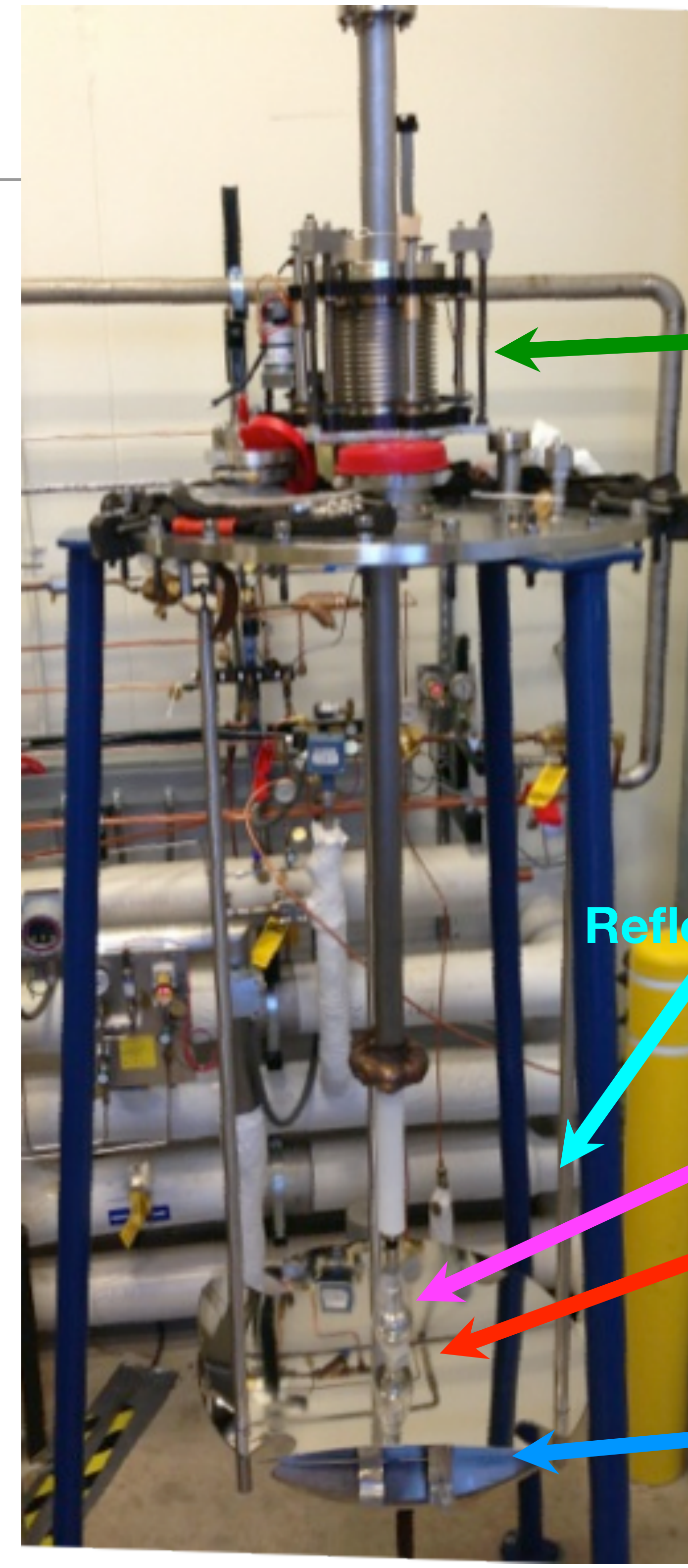

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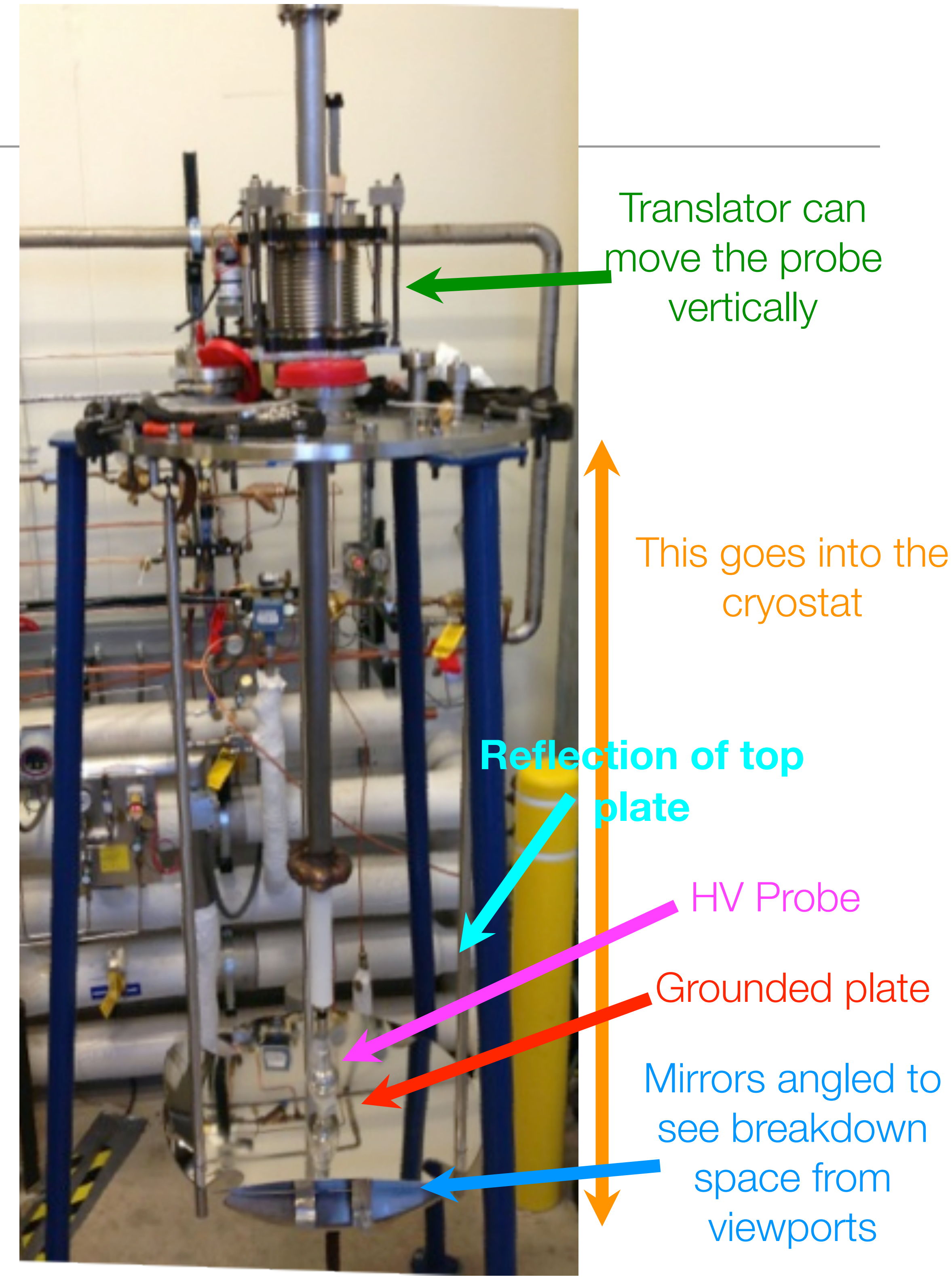

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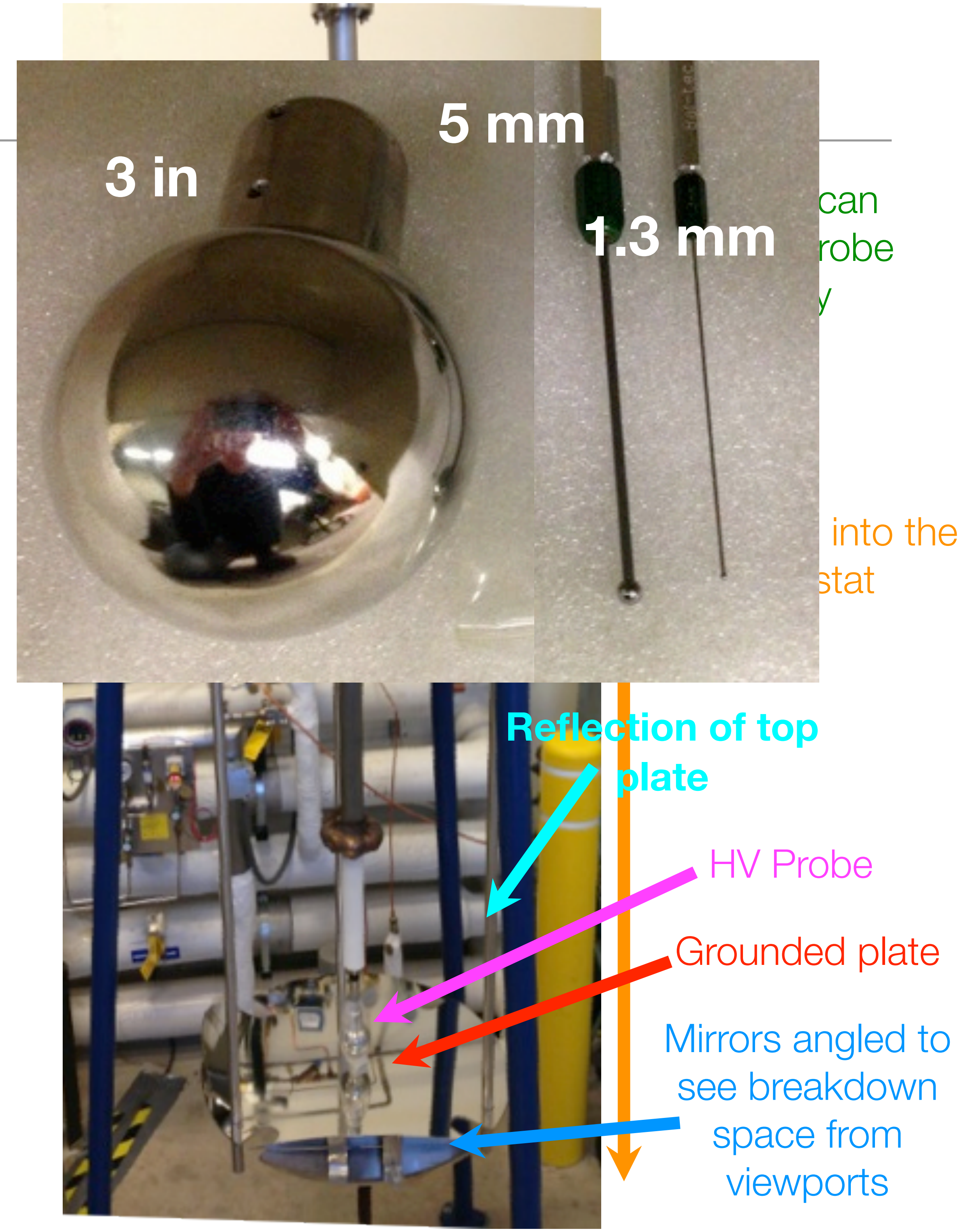

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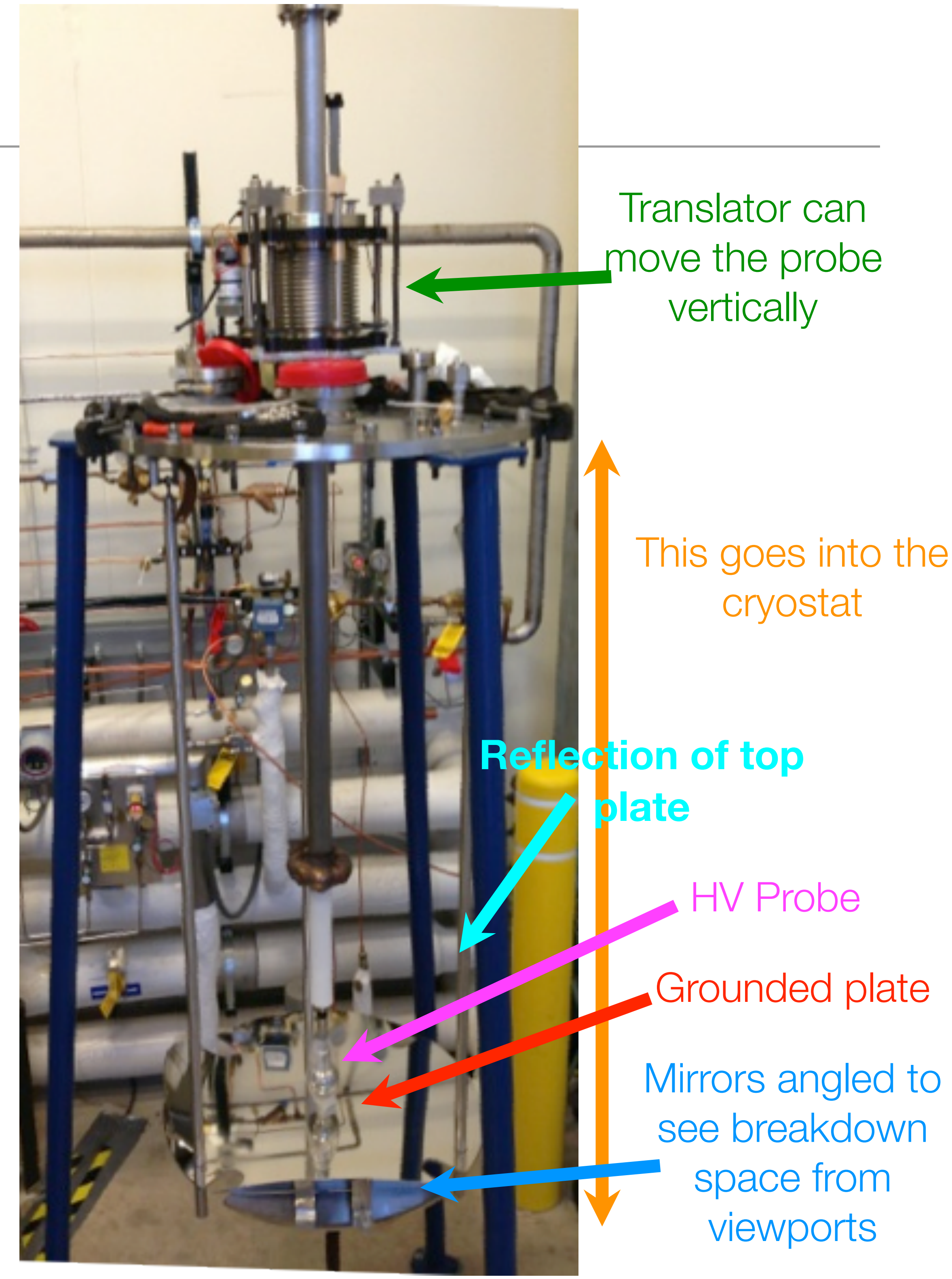

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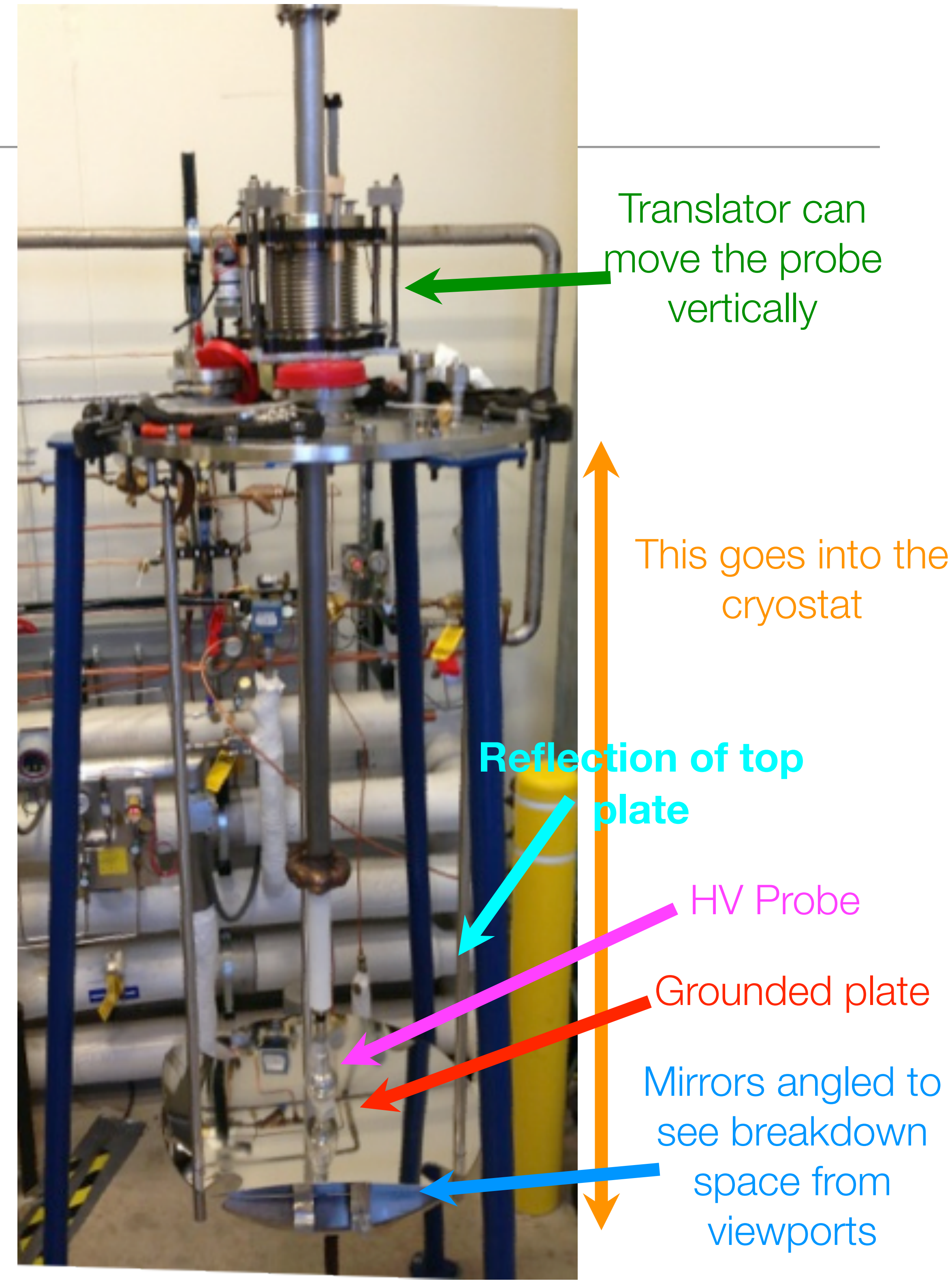

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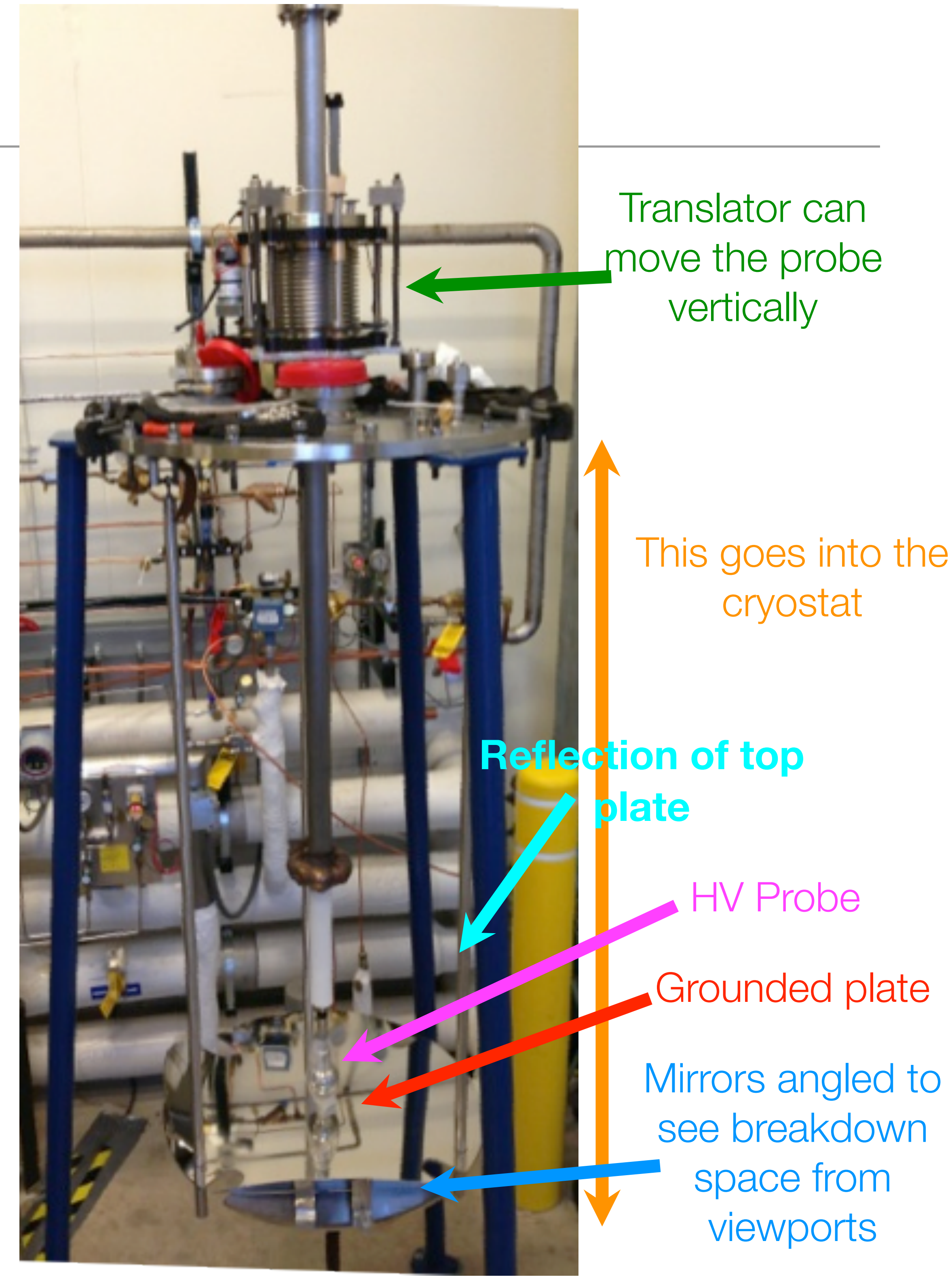

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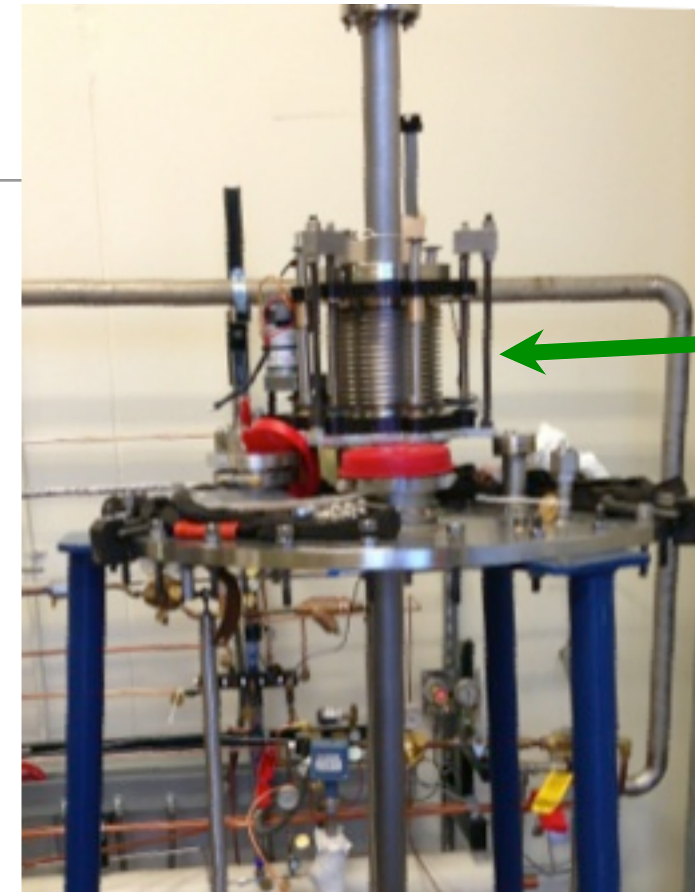

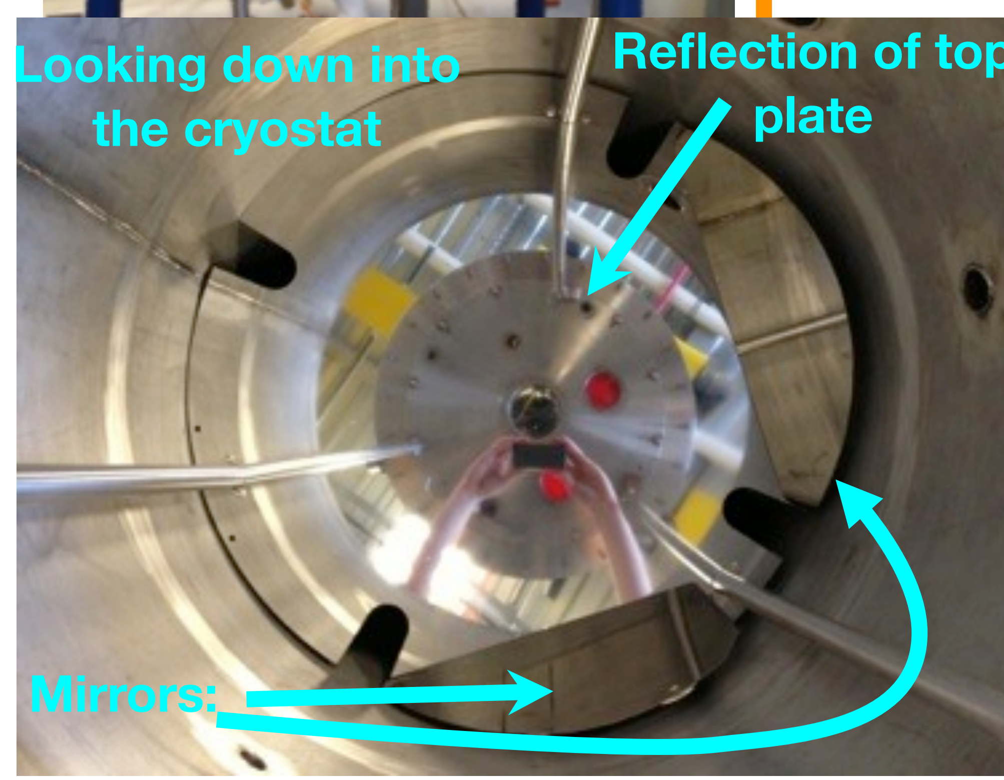

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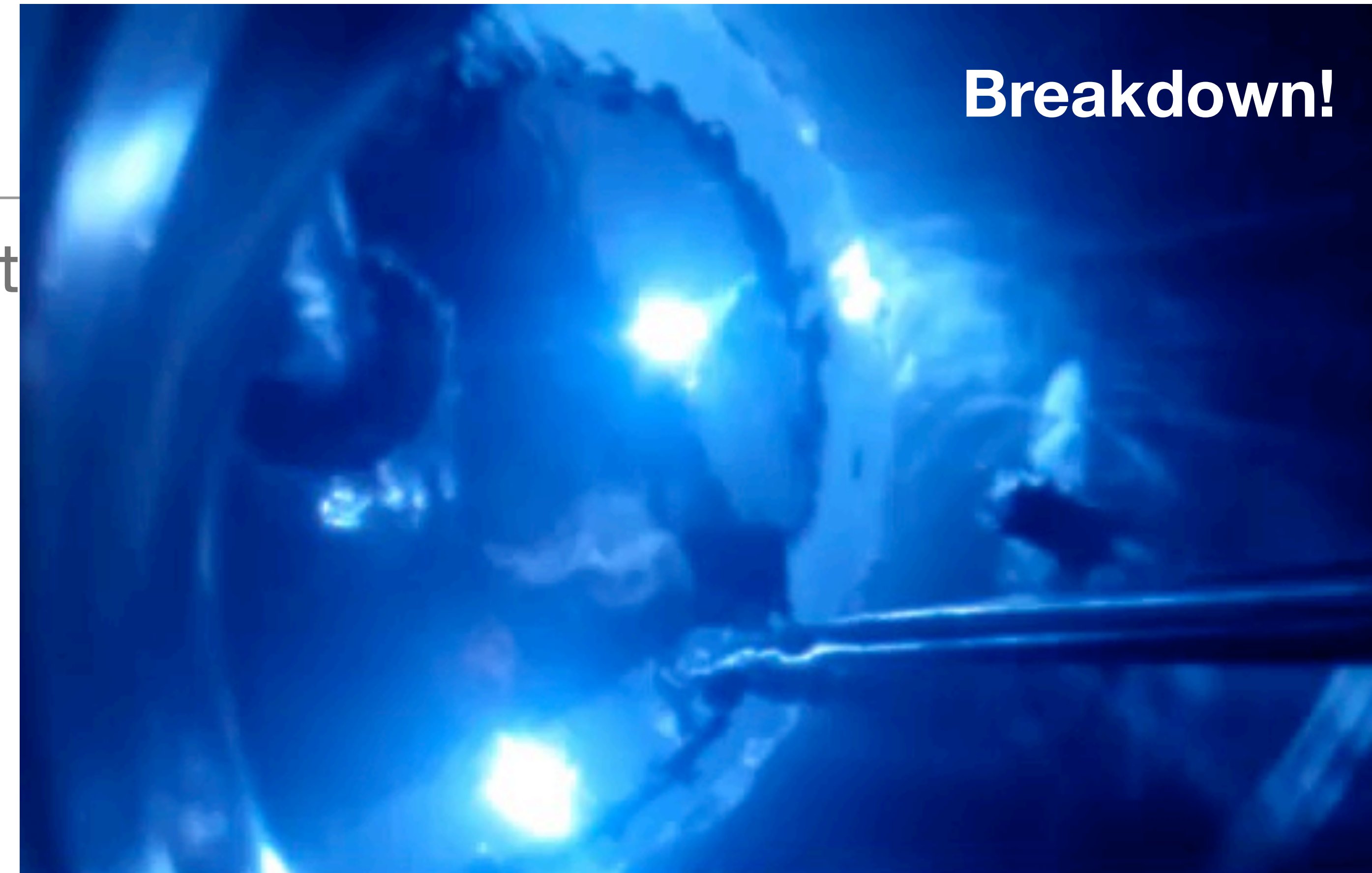

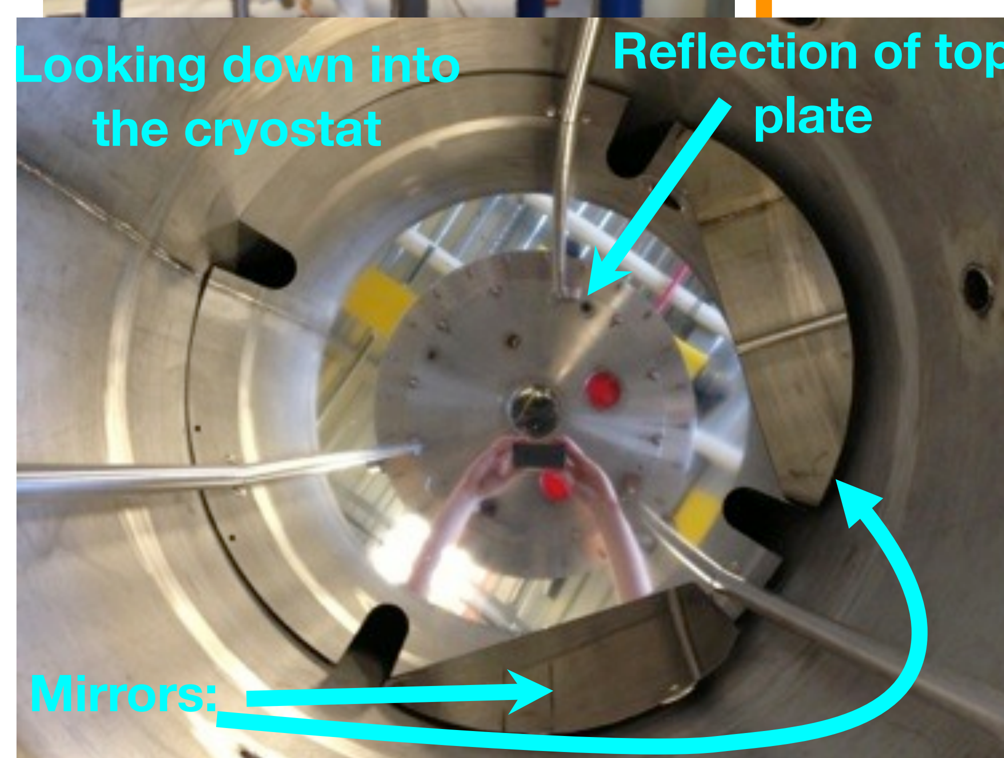

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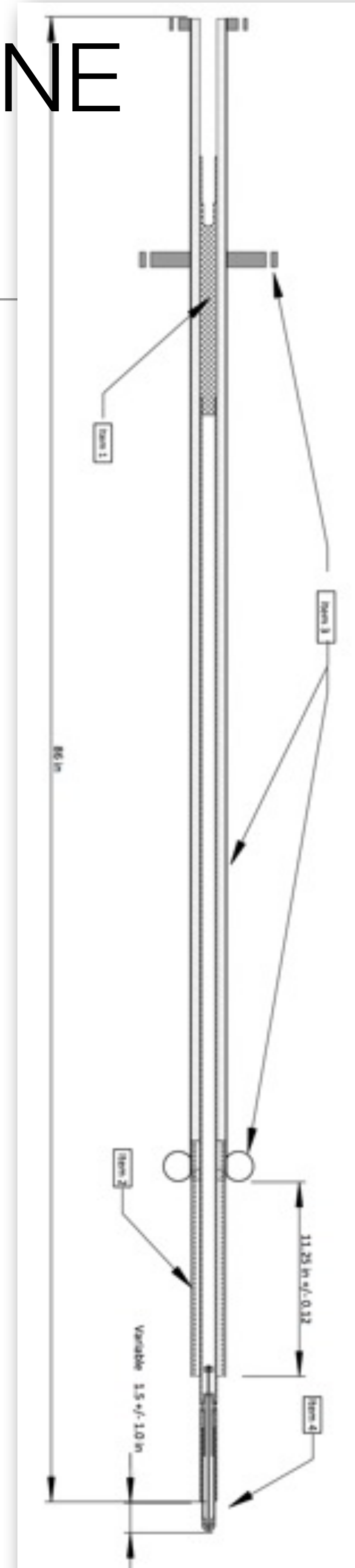

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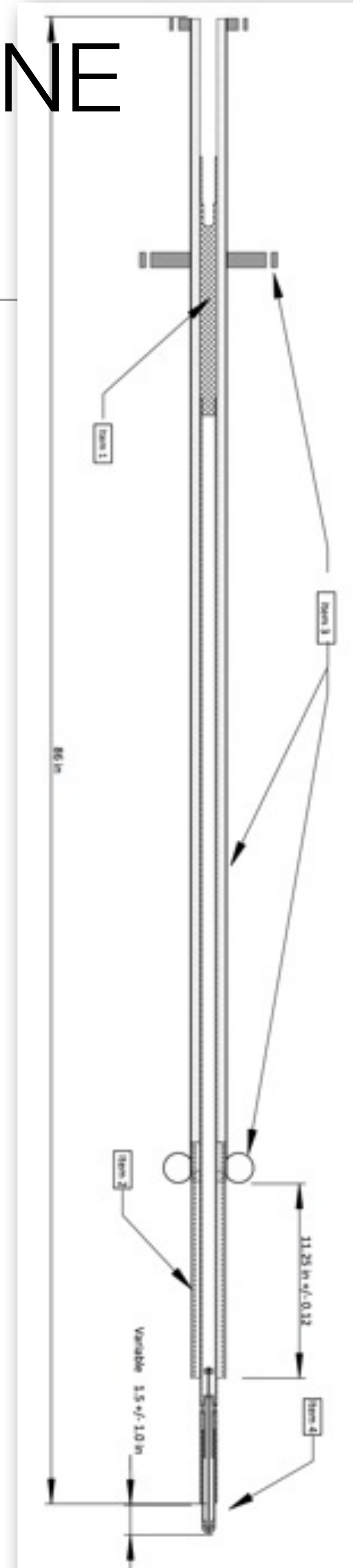

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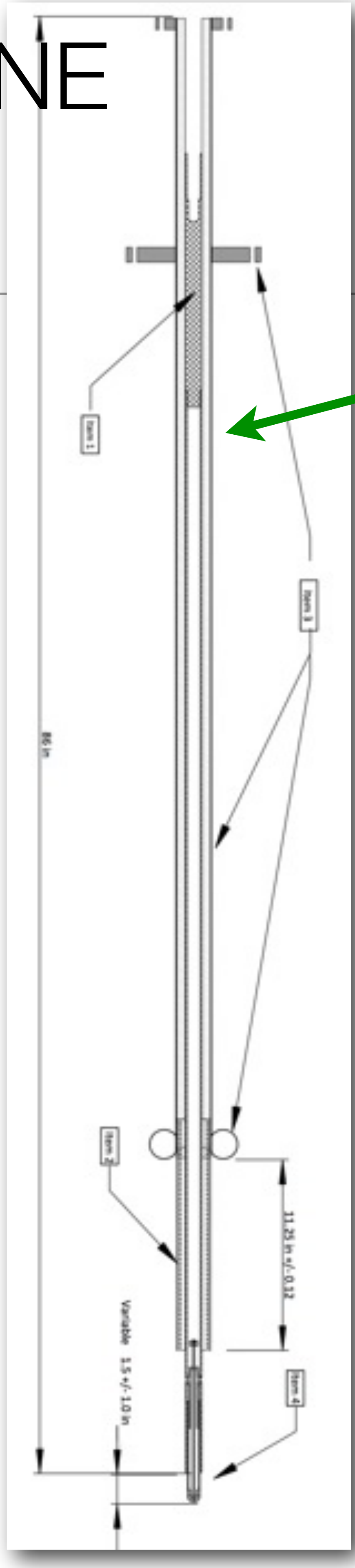

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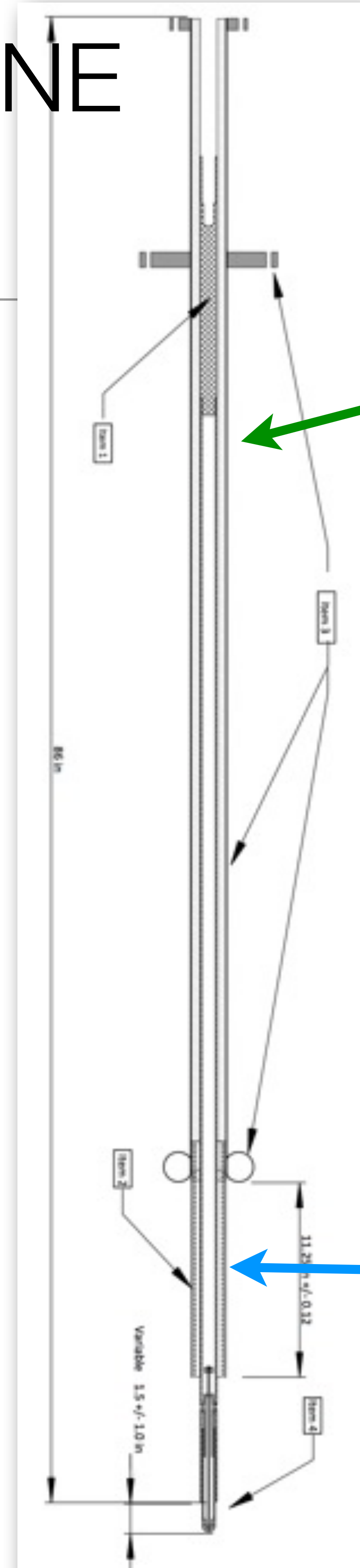
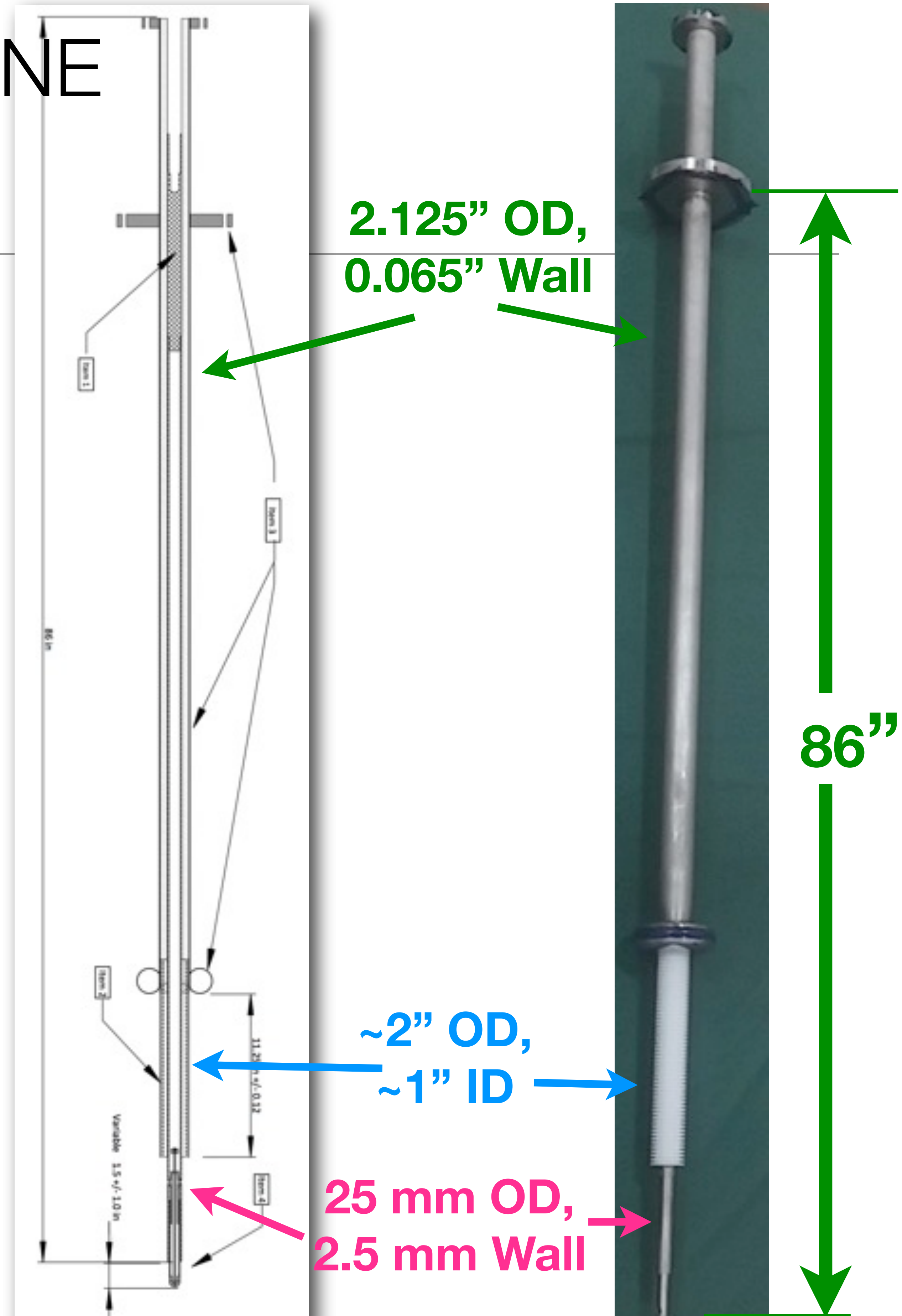
  - An UHMW PE insulating layer



Test Setup: The MicroBooNE HV Feedthrough

- Based on the ICARUS feedthrough with
  - A stainless steel outer ground tube
  - An UHMW PE insulating layer
  - And a stainless steel inner conductor



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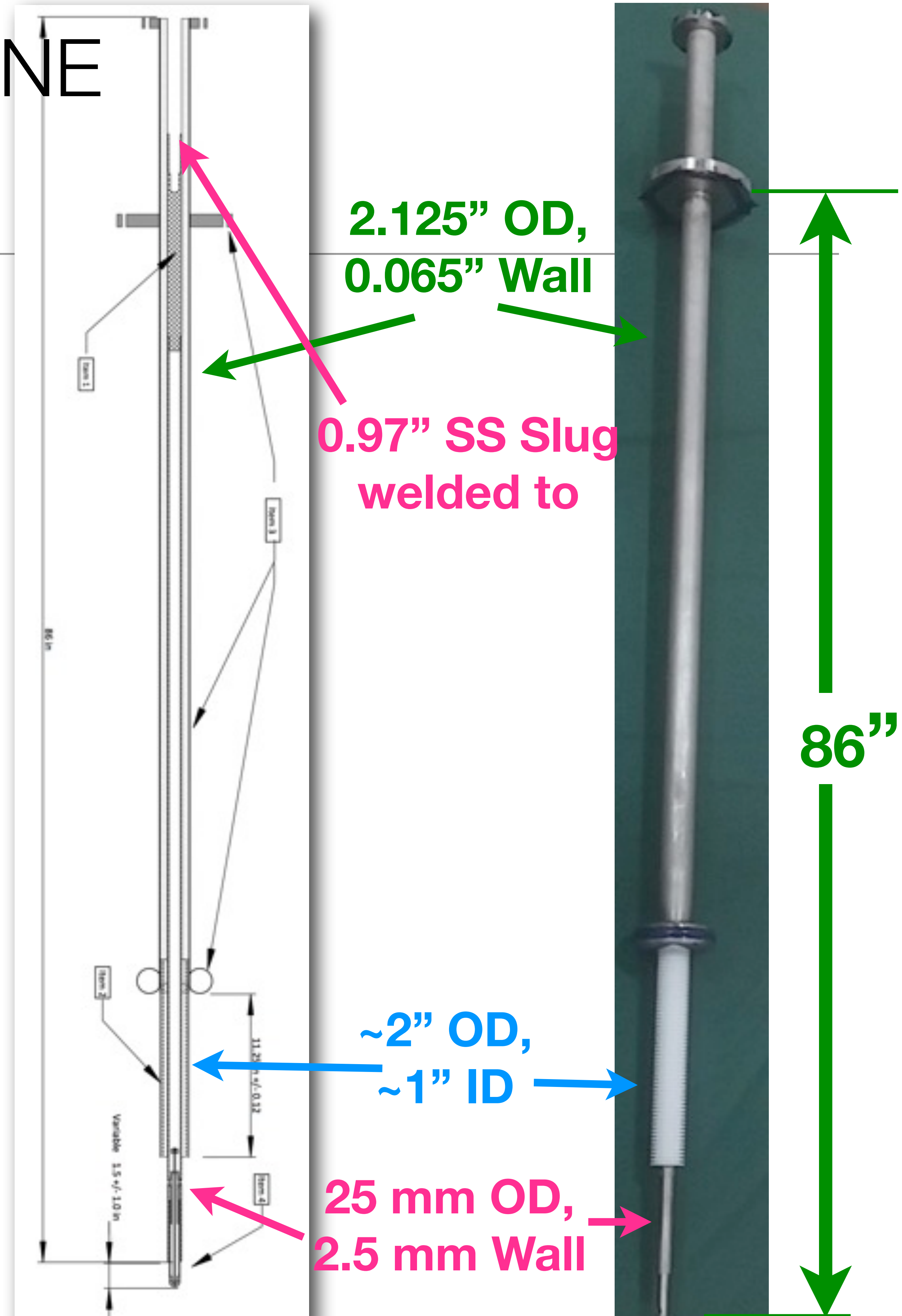

Test Setup: The MicroBooNE HV Feedthrough

- Based on the ICARUS feedthrough with
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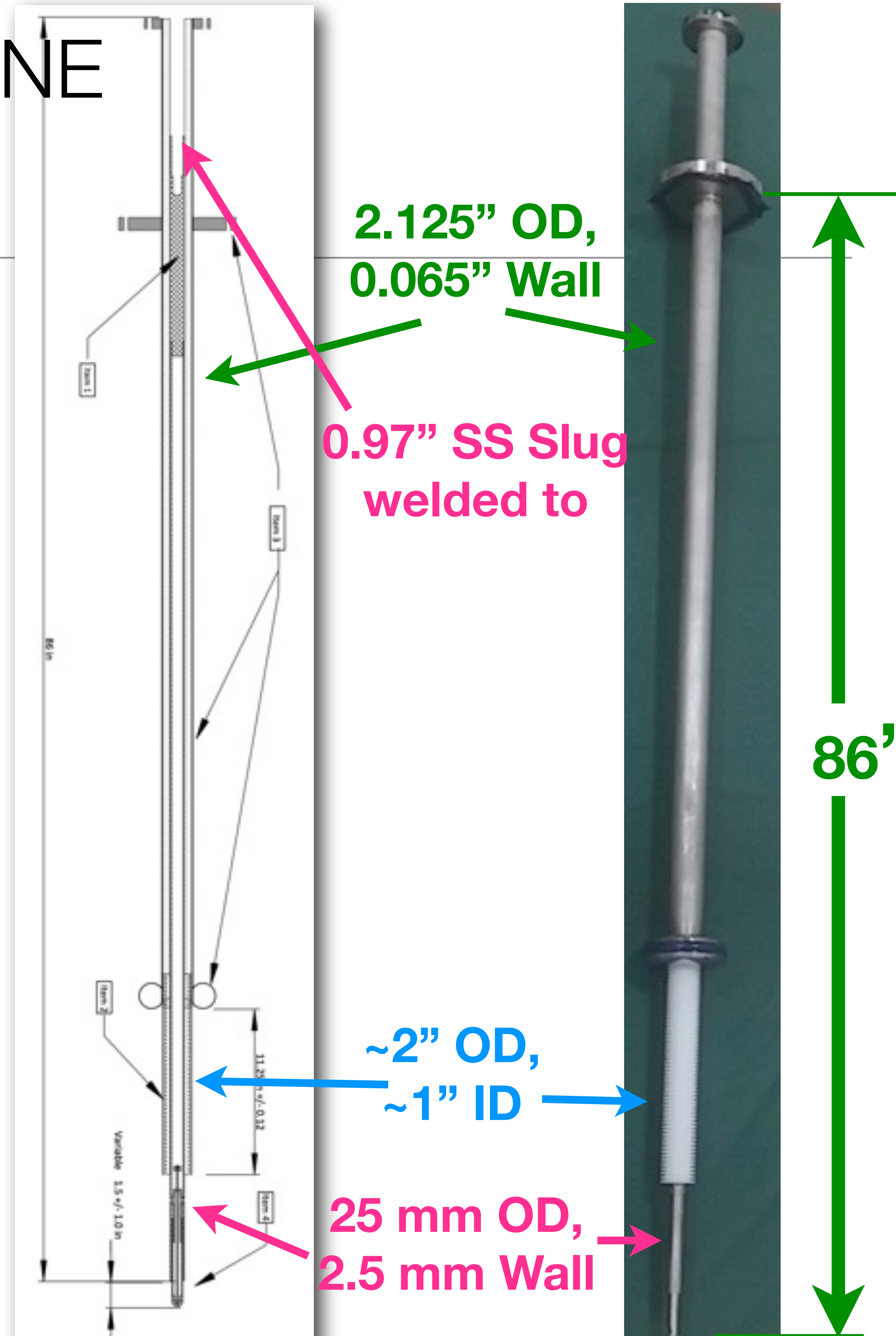
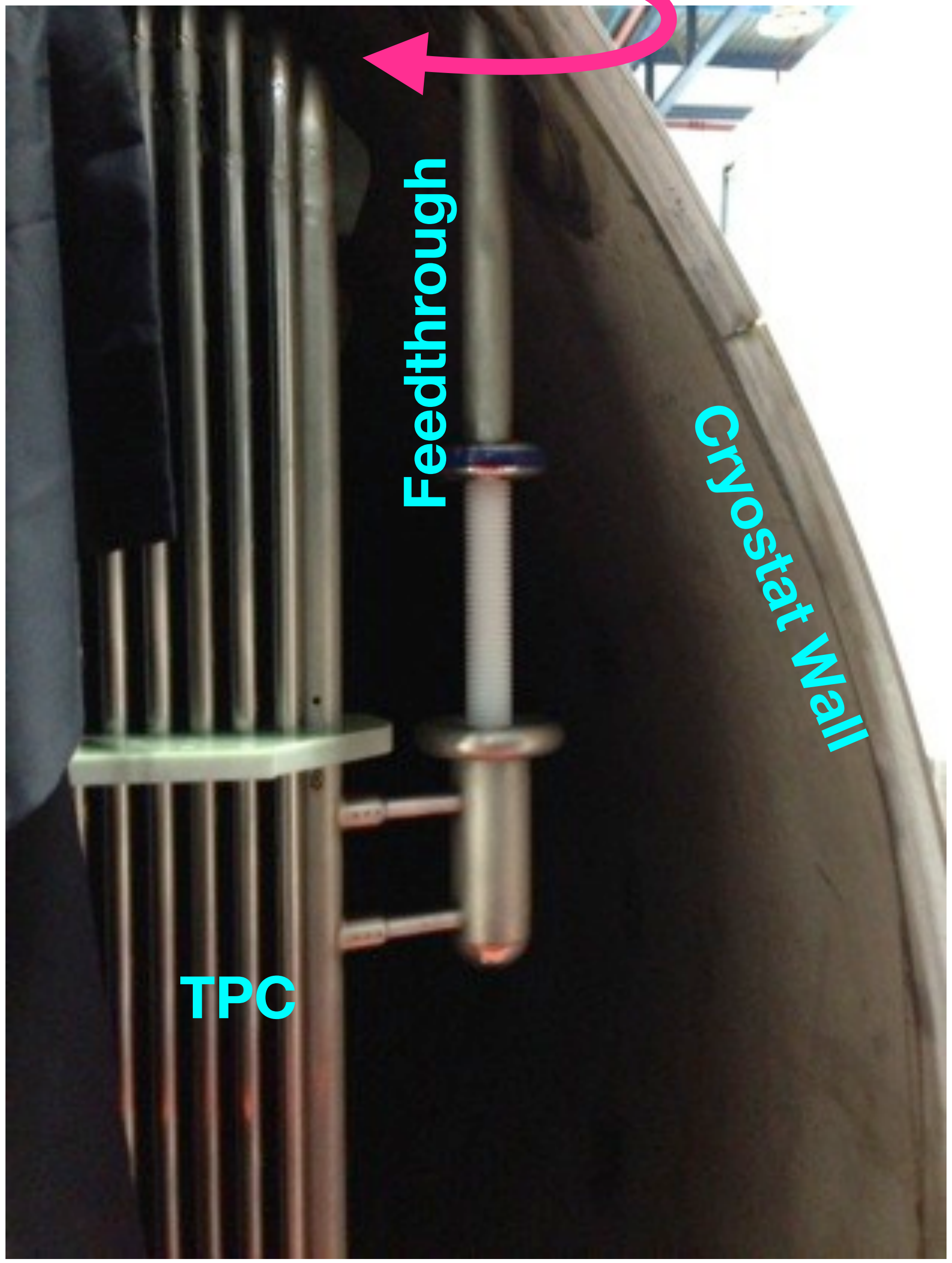
  - And a stainless steel inner conductor
- Tight fit is near the warm 8” CF flange
  - Accomplished by interference of materials
- Electrical connection is made by a spring tip attached to the end of the FT
  - Allows for shrinking/movement



Test Setup: The MicroBooNE HV Feedthrough

The max E field on the cathode is ~28 kV (~4in to ground)



Test Setup:
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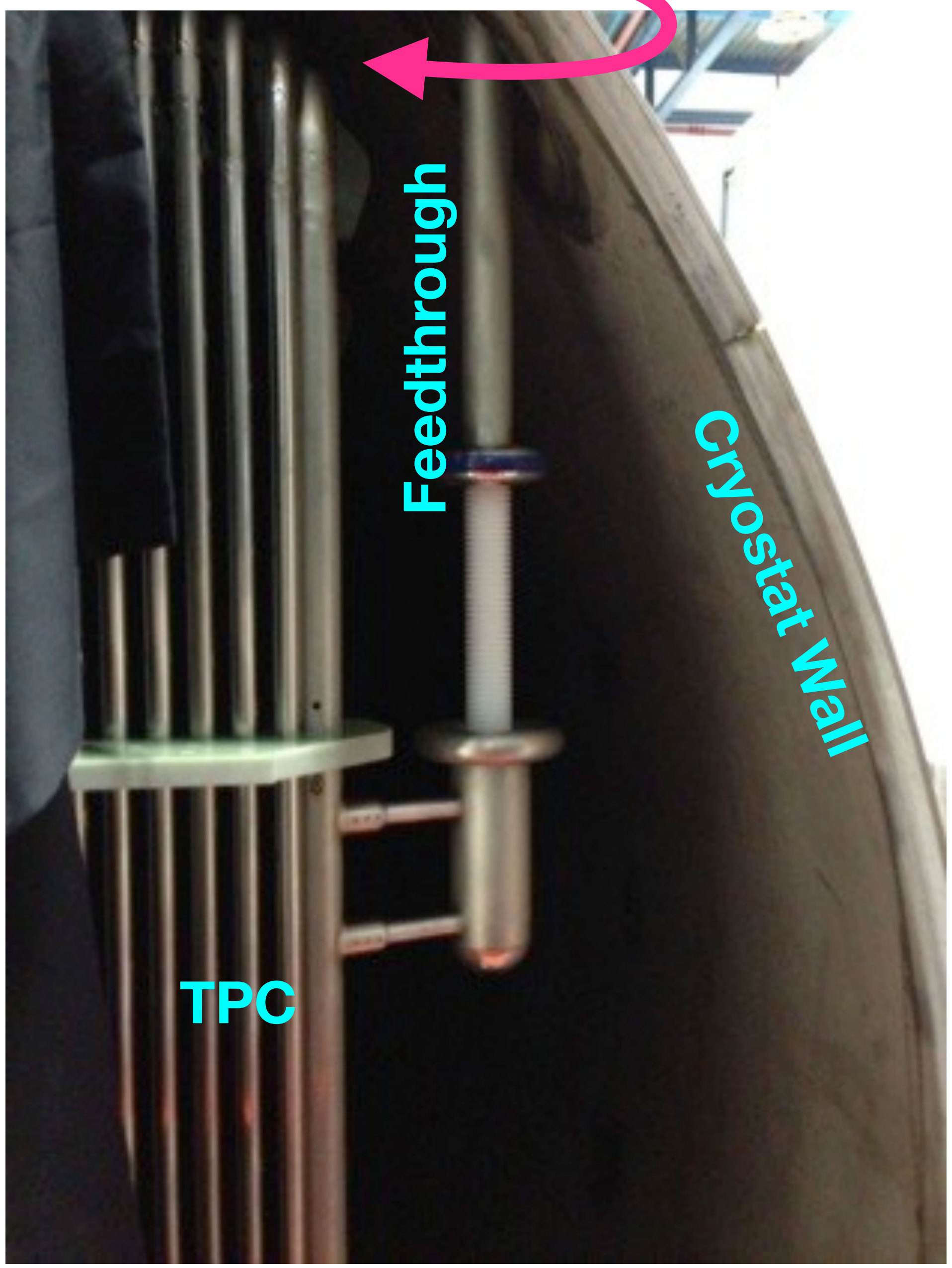
- Longer than the ICARUS feedthrough
  - Because cryostat is cylindrical, we have to extend the ground sheath deeper to avoid high fields with the cryostat wall



Test Setup:
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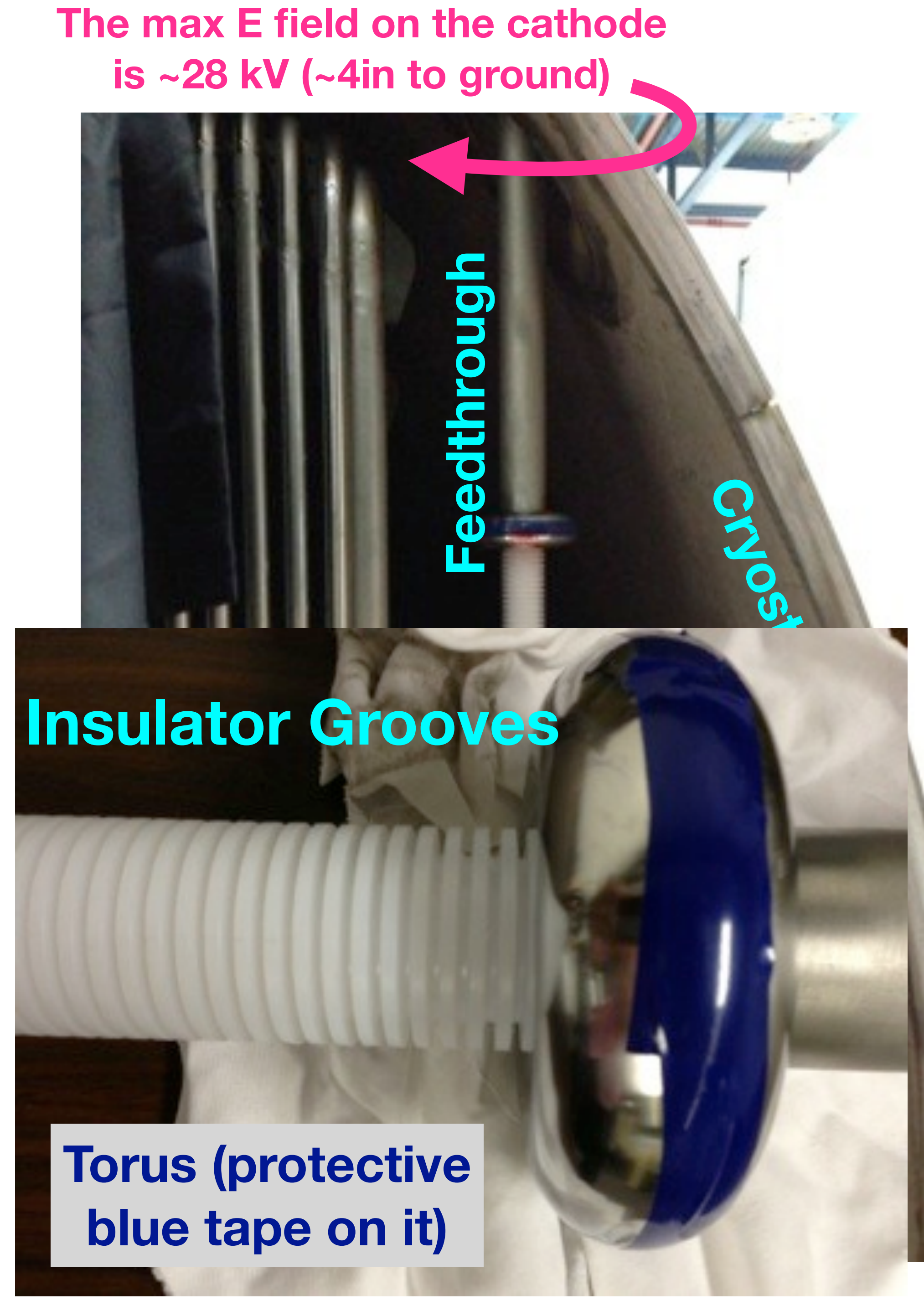
  - Reduce breakdown along PE surface



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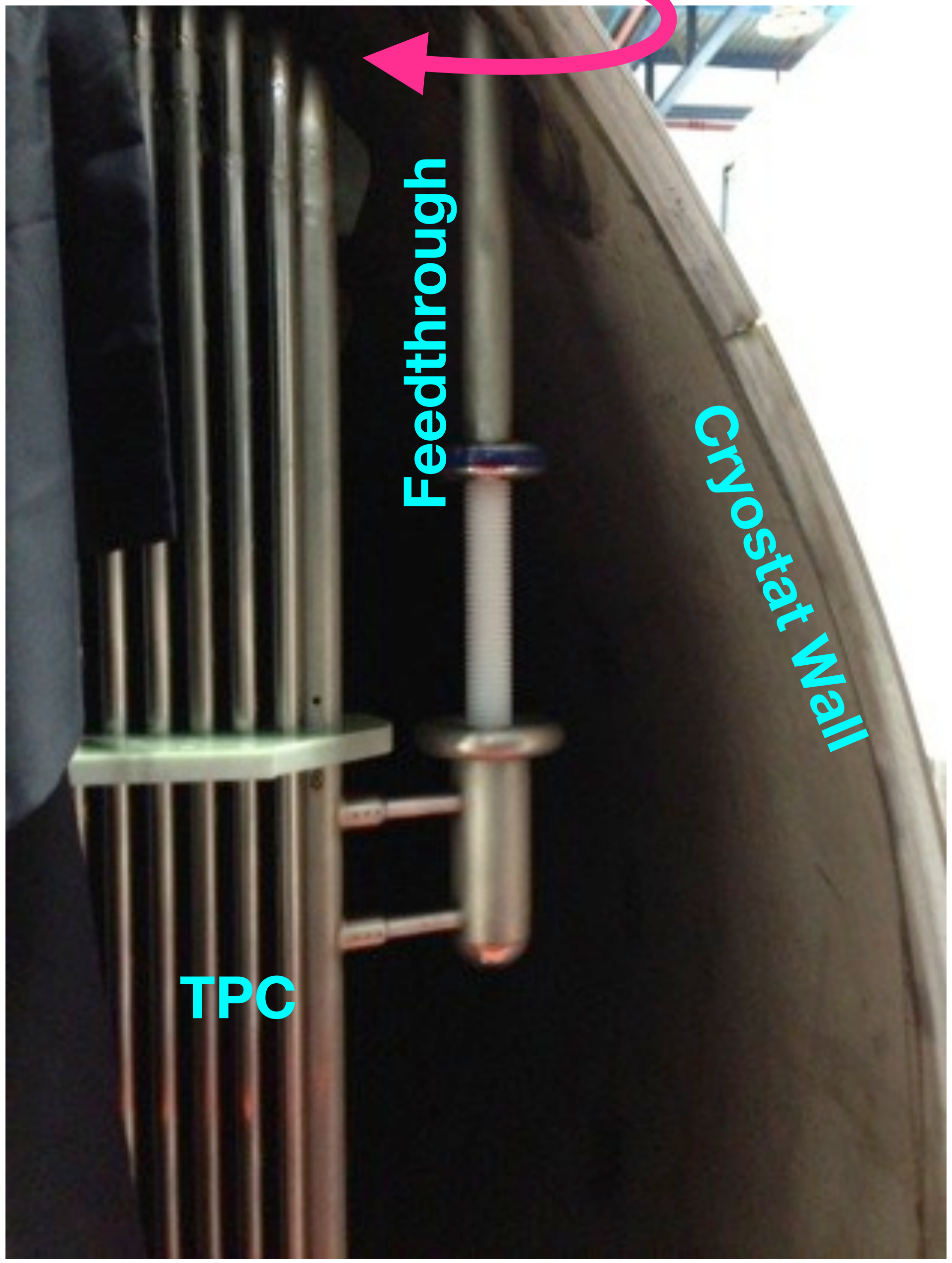

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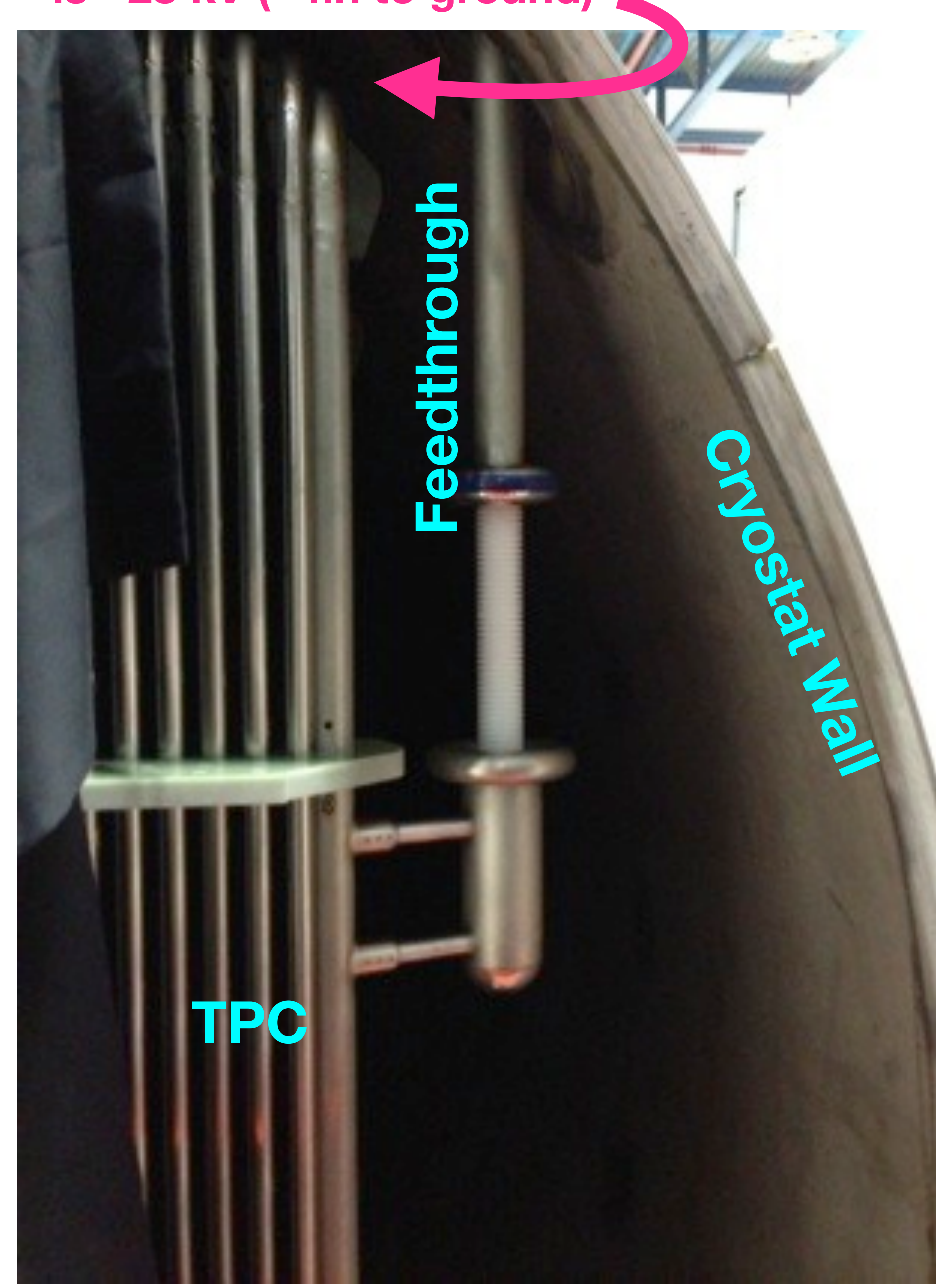
  - Reduce breakdown along PE surface
- A **torus** was added to the bottom of the ground tube
  - Reduce electric field here
- Tested at -128 kV in pure LAr (500 ppt O_2) for 63.5 hours
  - Time was limited by LAr boil off

The max E field on the cathode is ~28 kV (~4in to ground)



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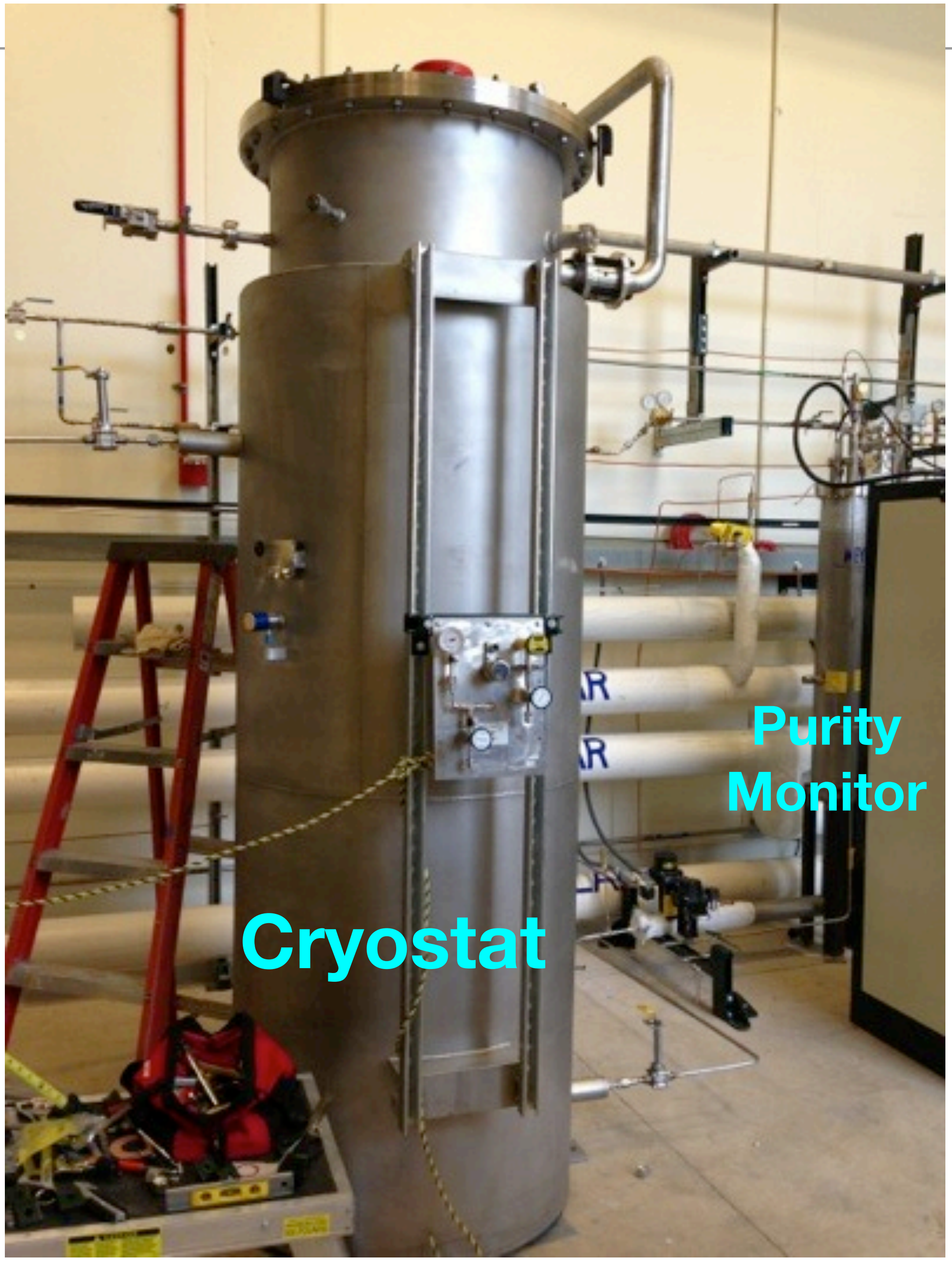

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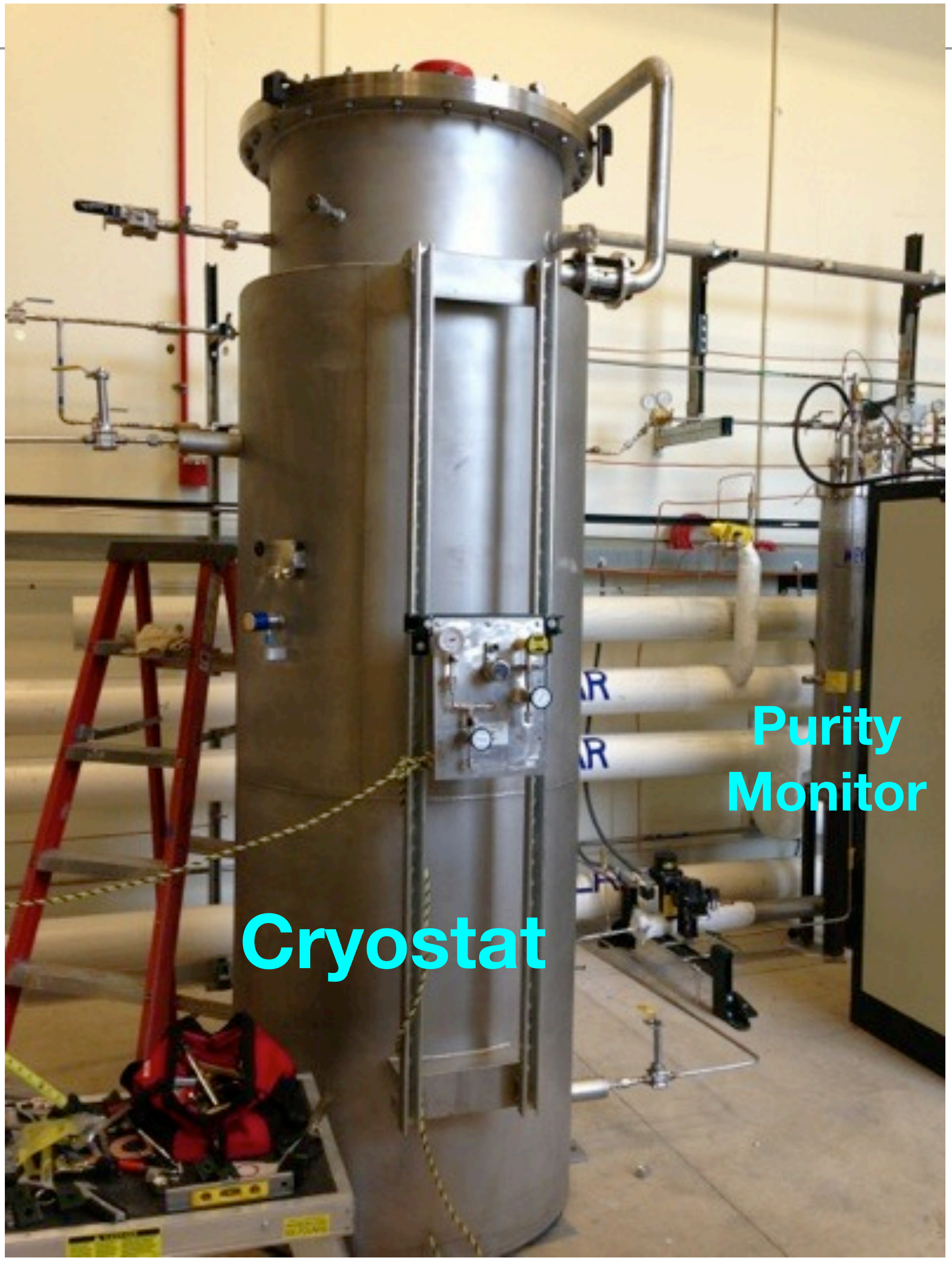

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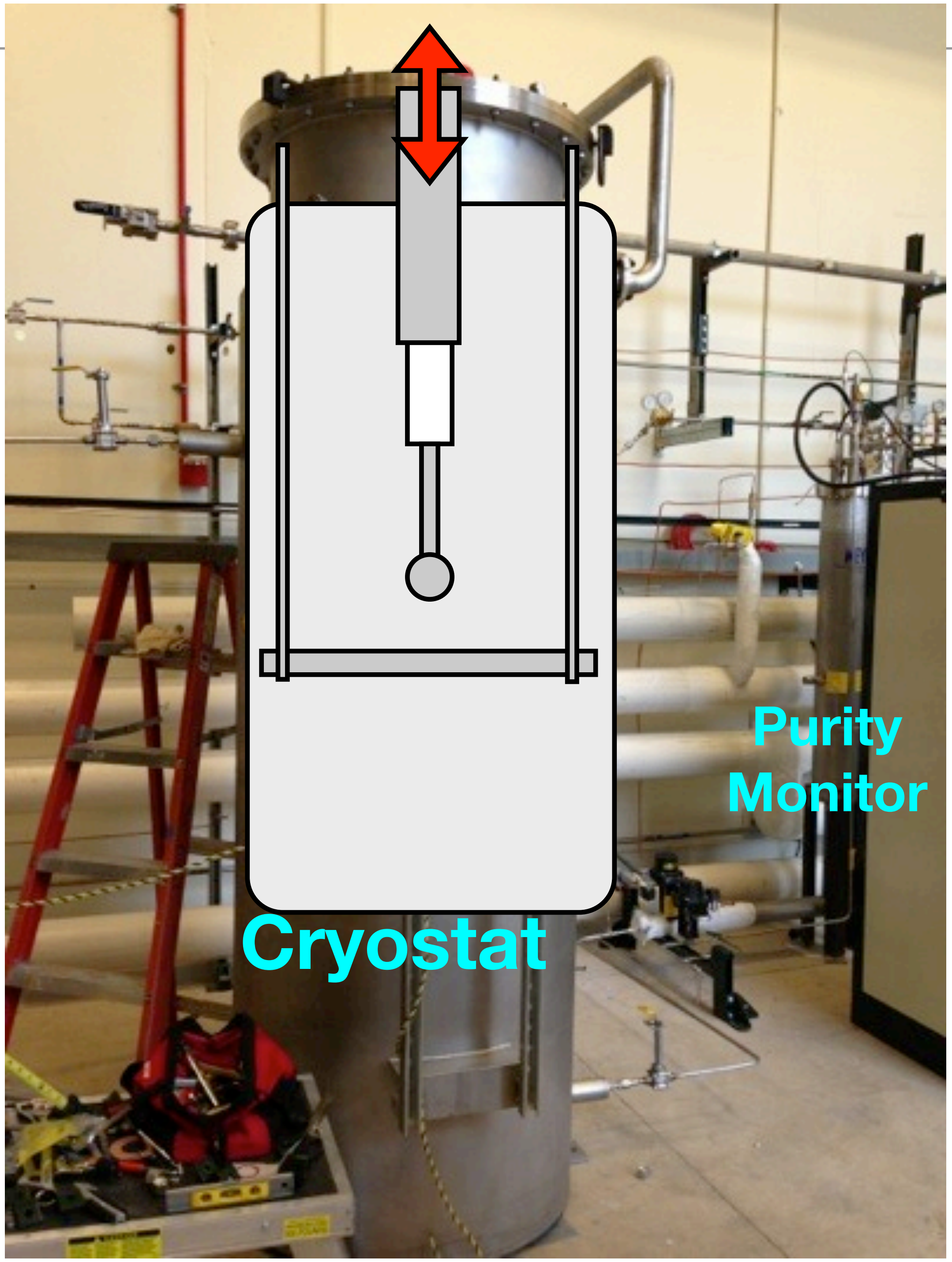

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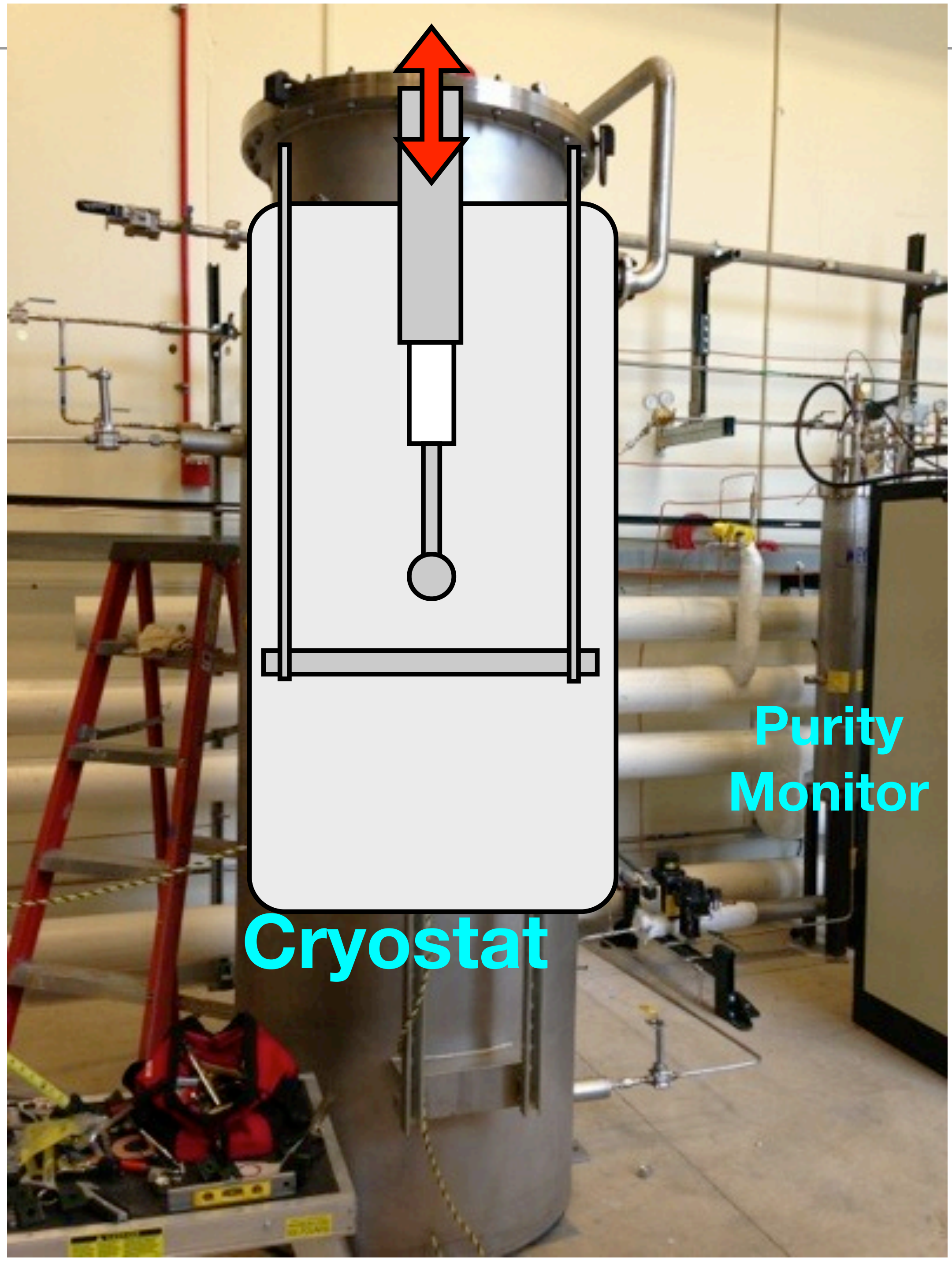
- Find zero point
- Go to desired distance



Test Procedure

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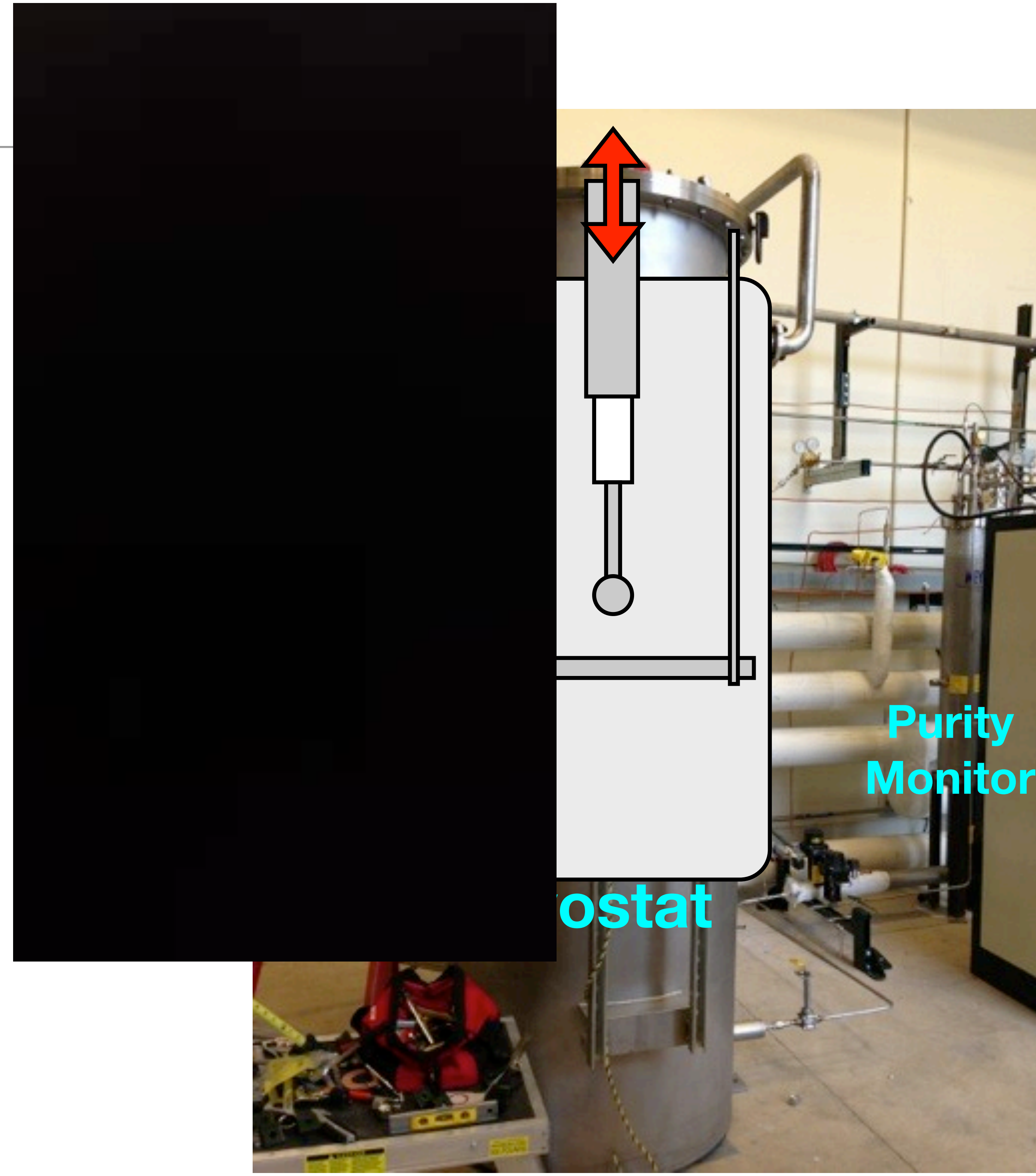
- Go to desired distance
- Ramp voltage until breakdown
  - Normally obvious; current trip level was set to a few micro-Amps



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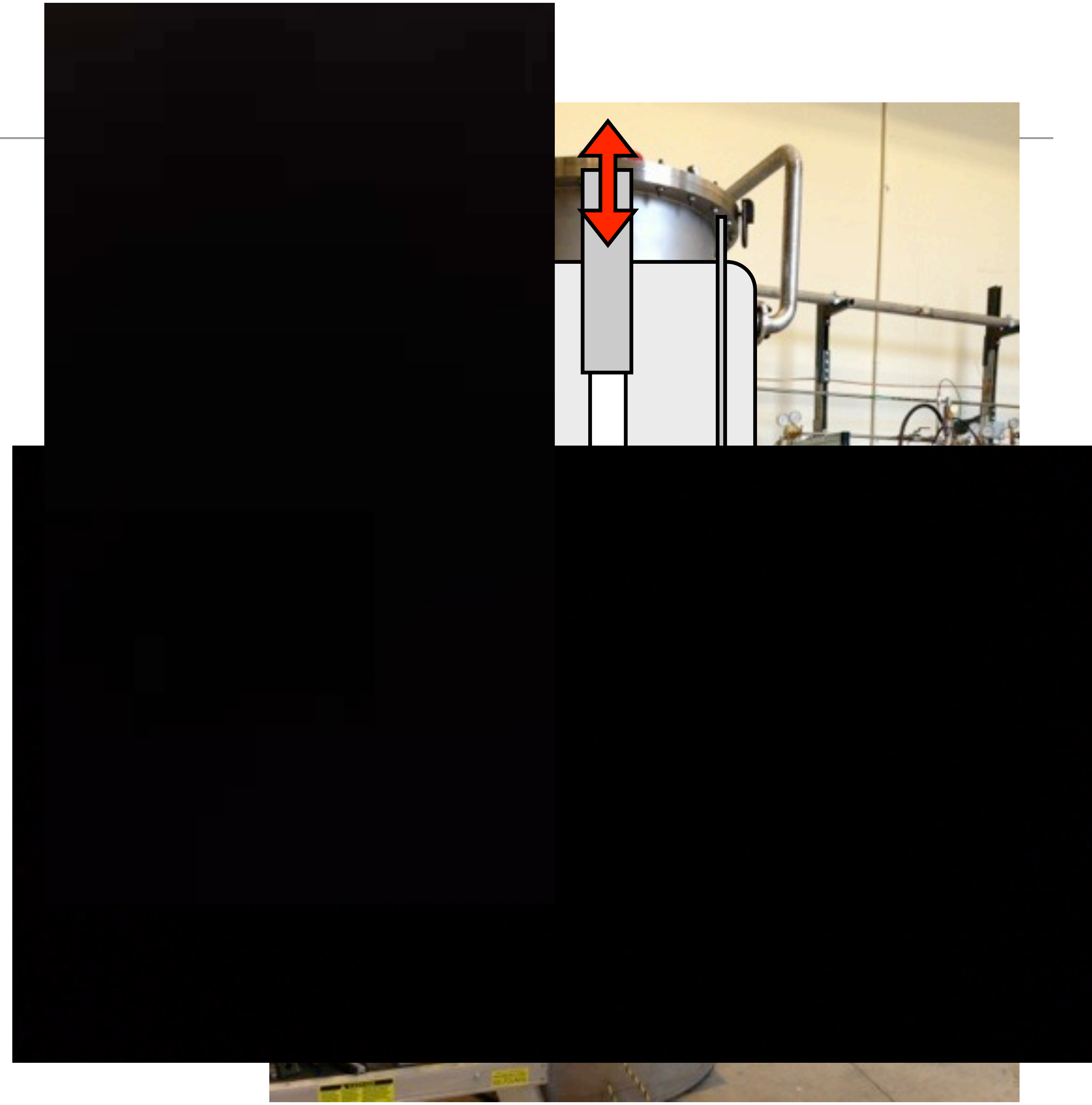
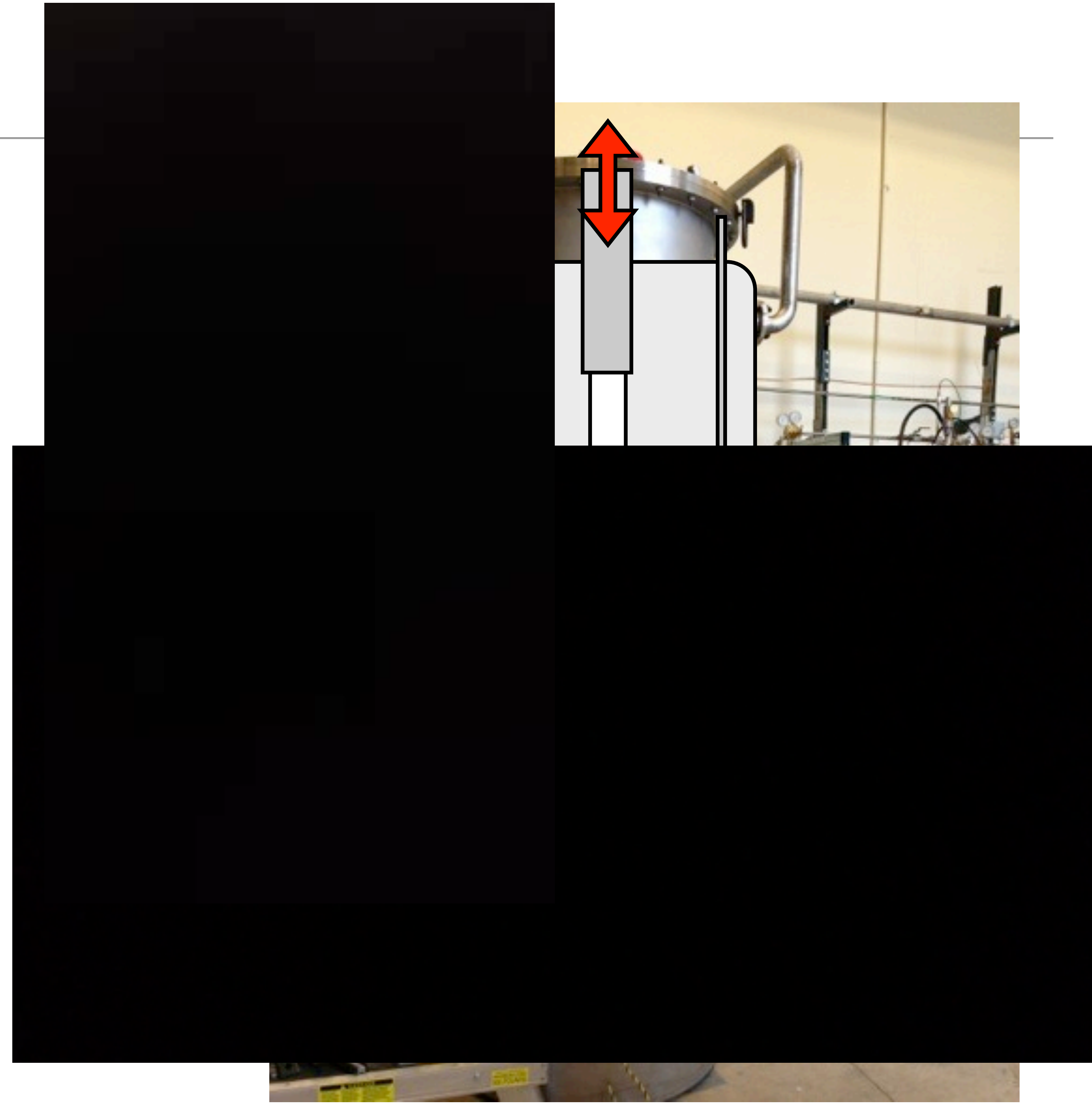


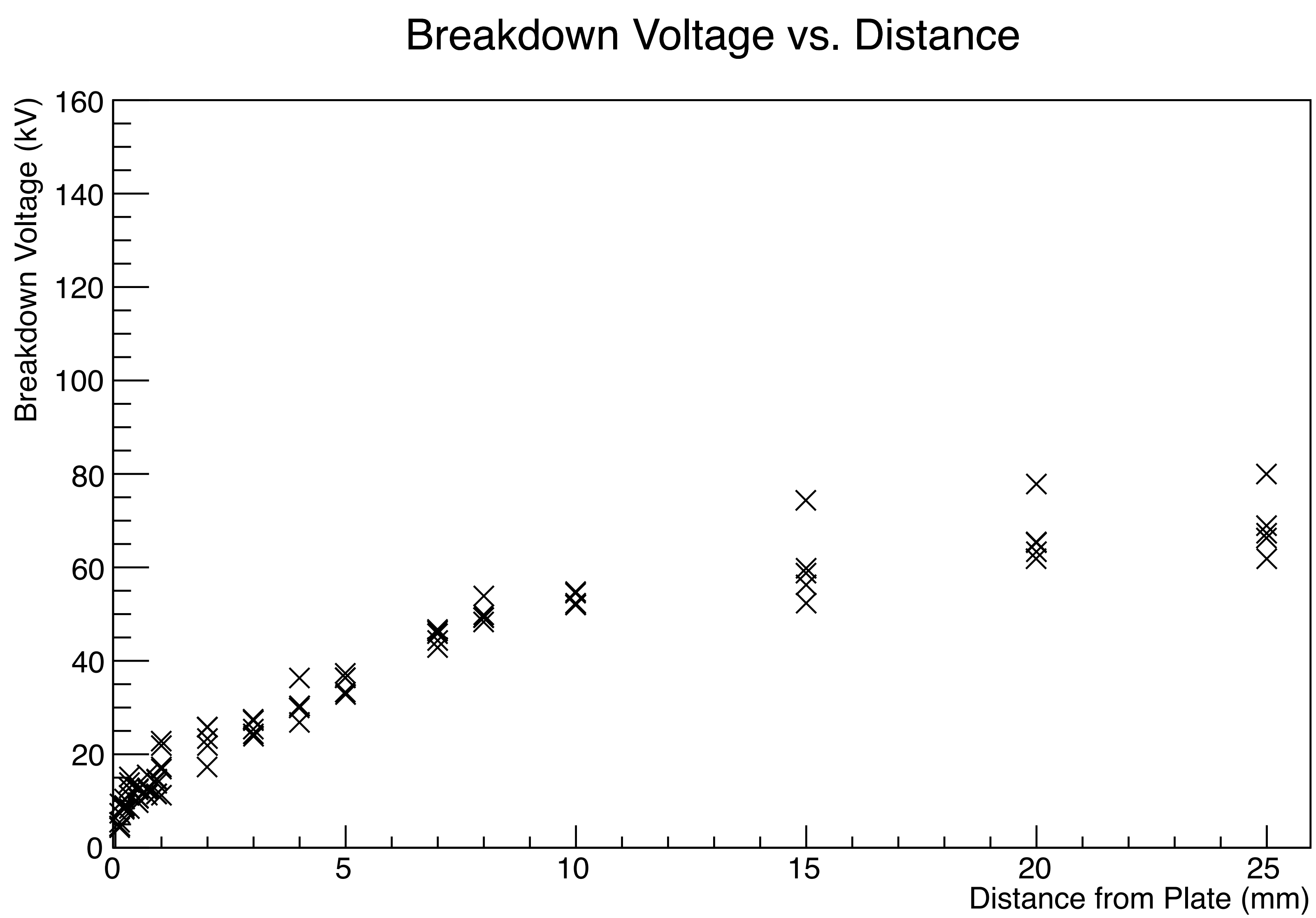
Test Procedure

- Find zero point
- Go to desired distance
- Ramp voltage until breakdown
  - Normally obvious; current trip level was set to a few micro-Amps
- Repeat ~5x for each distance



A Sample: Data from 02/27/2014

- Plot of voltage vs distance (1.3 mm sphere):



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- We found we could mitigate this by adding more liquid, but to ensure that we are not including FT breakdown data points, we have excluded points beyond 1 cm for the 3 in probe, and 1.5 cm for the 5 mm probe.

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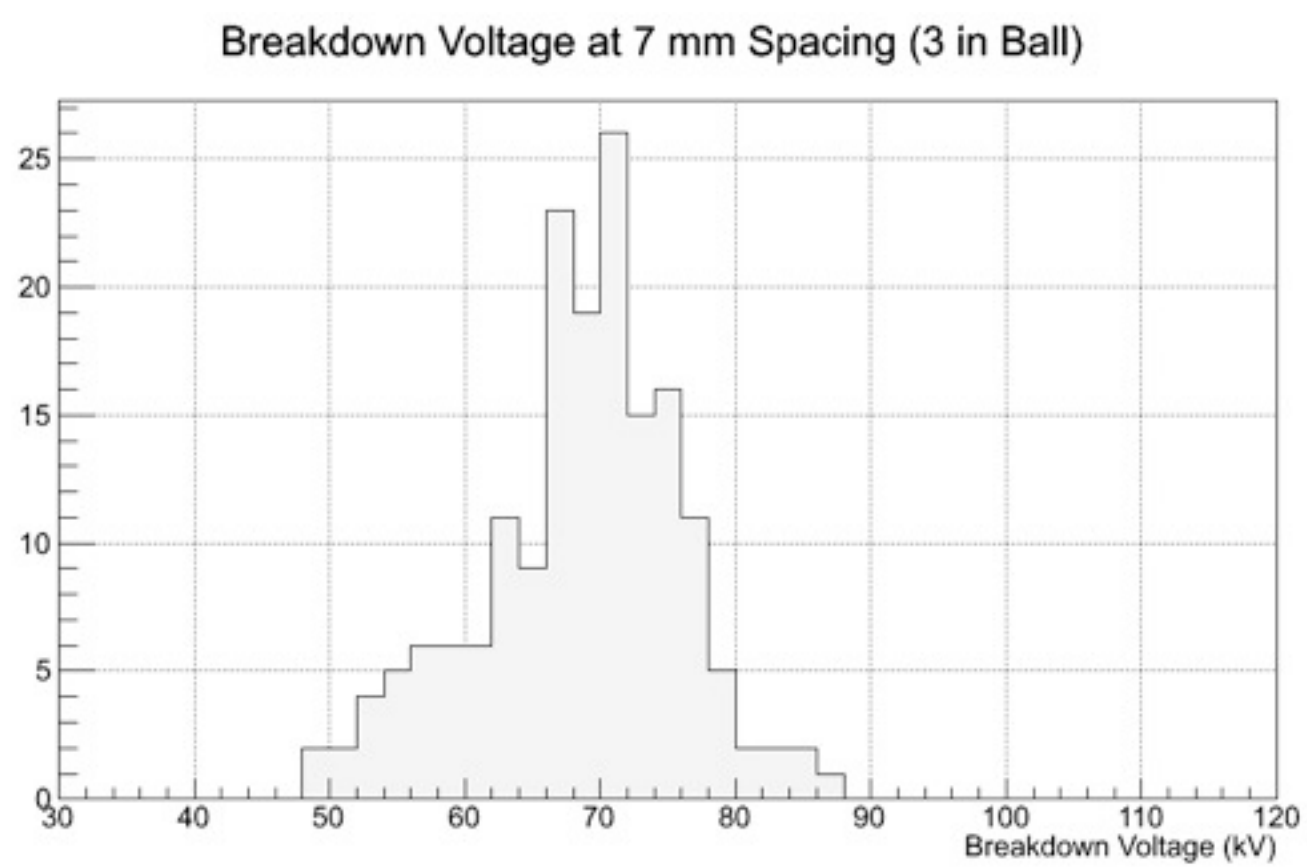

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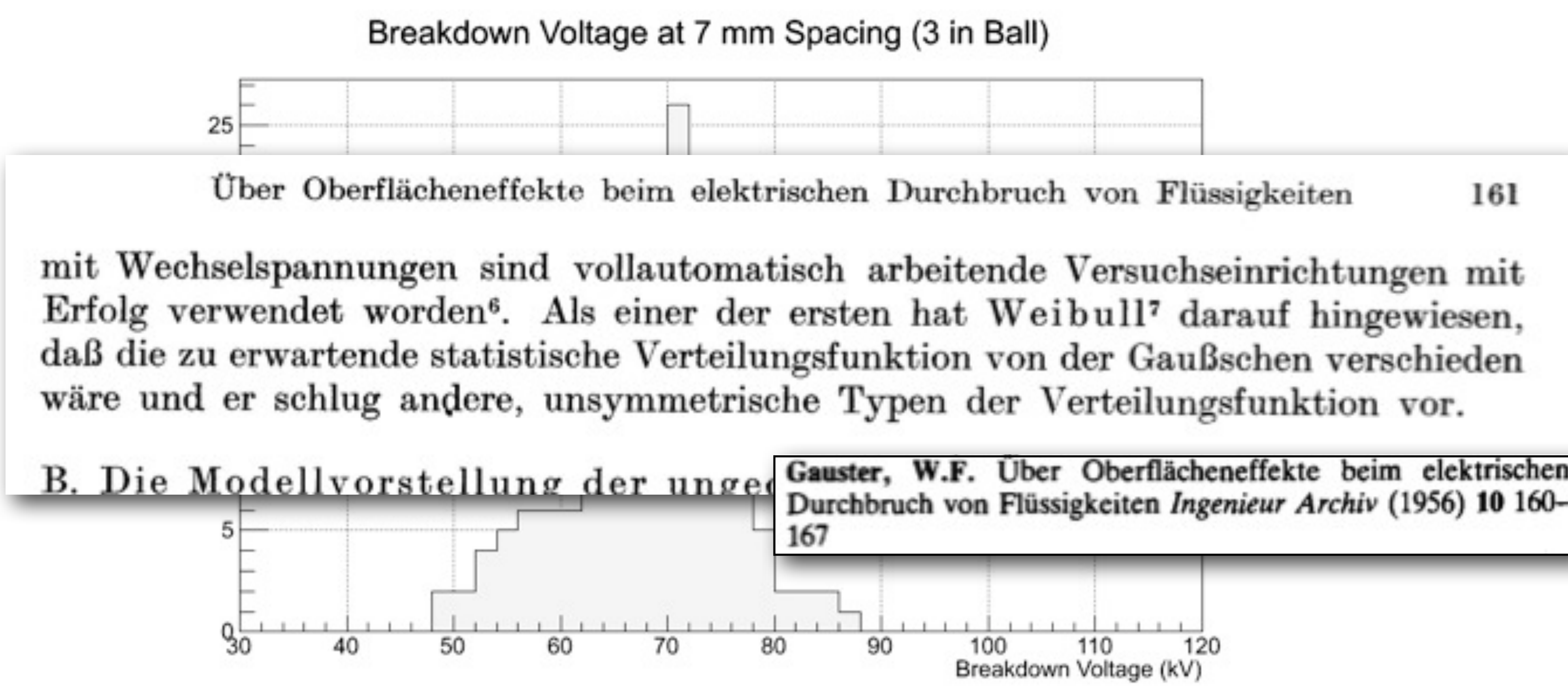

Über Oberflächeneffekte beim elektrischen Durchbruch von Flüssigkeiten 161

mit Wechselspannungen sind vollautomatisch arbeitende Versuchseinrichtungen mit Erfolg verwendet worden[6]. Als einer der ersten hat Weibull[7] darauf hingewiesen, daß die zu erwartende statistische Verteilungsfunktion von der Gaußschen verschieden wäre und er schlug andere, unsymmetrische Typen der Verteilungsfunktion vor.

B. Die Modellvorstellung der unge

Gauster, W.F. Über Oberflächeneffekte beim elektrischen Durchbruch von Flüssigkeiten *Ingenieur Archiv* (1956) **10** 160–167

We can fit this with a Weibull function (as the literature suggests)

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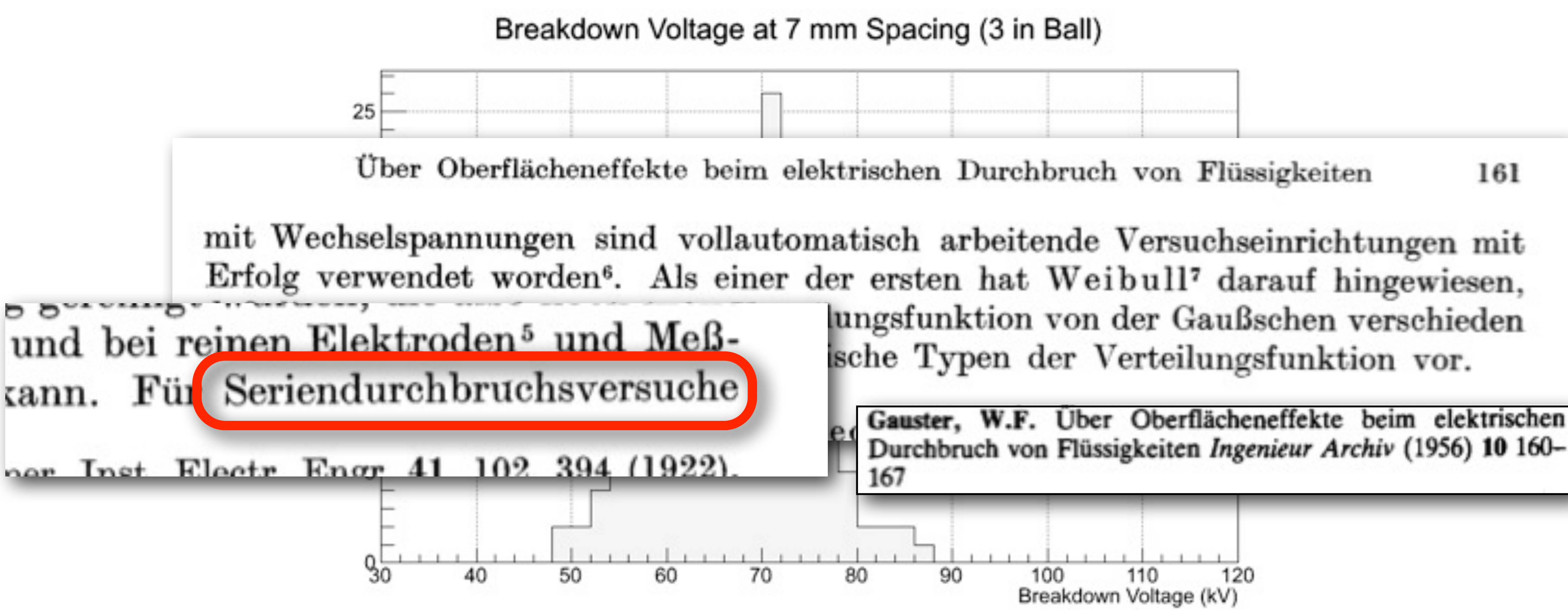

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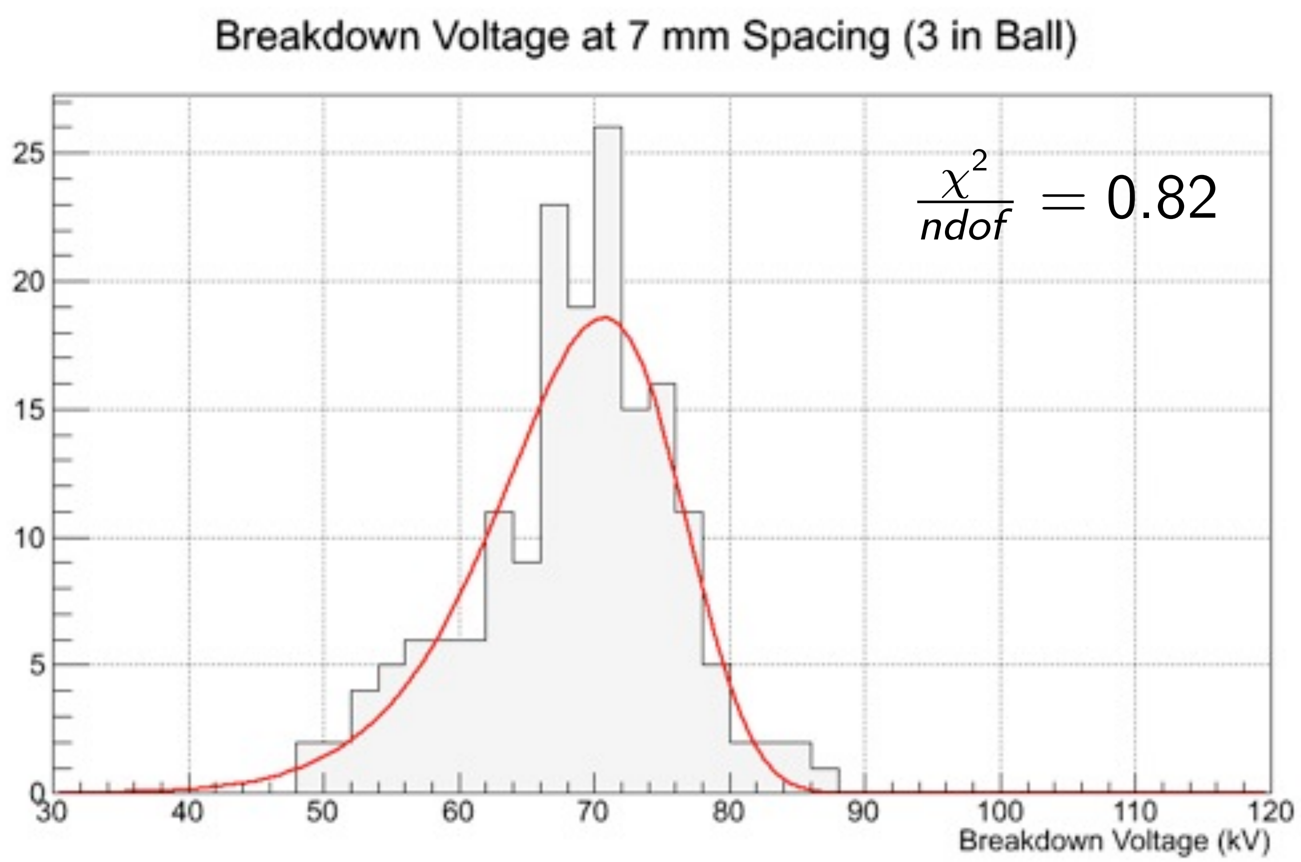

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Data Collected

Purity Monitor Data:

Date	Probe	Lifetime (ms)
04/15-16/14	3 in	1.31
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05/05/14	1.3 mm	1.03

Gas Analyzer Data:

Date	Probe	O_2 (ppb)	N_2 (ppm)
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- We were able to run with the 1.3 mm, 5 mm, and 3 in diameter probes earlier this year
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- We were able to run with the 1.3 mm, 5 mm, and 3 in diameter probes earlier this year
- Evaluated purities between 1500-0.1 ppb O_2 equivalent
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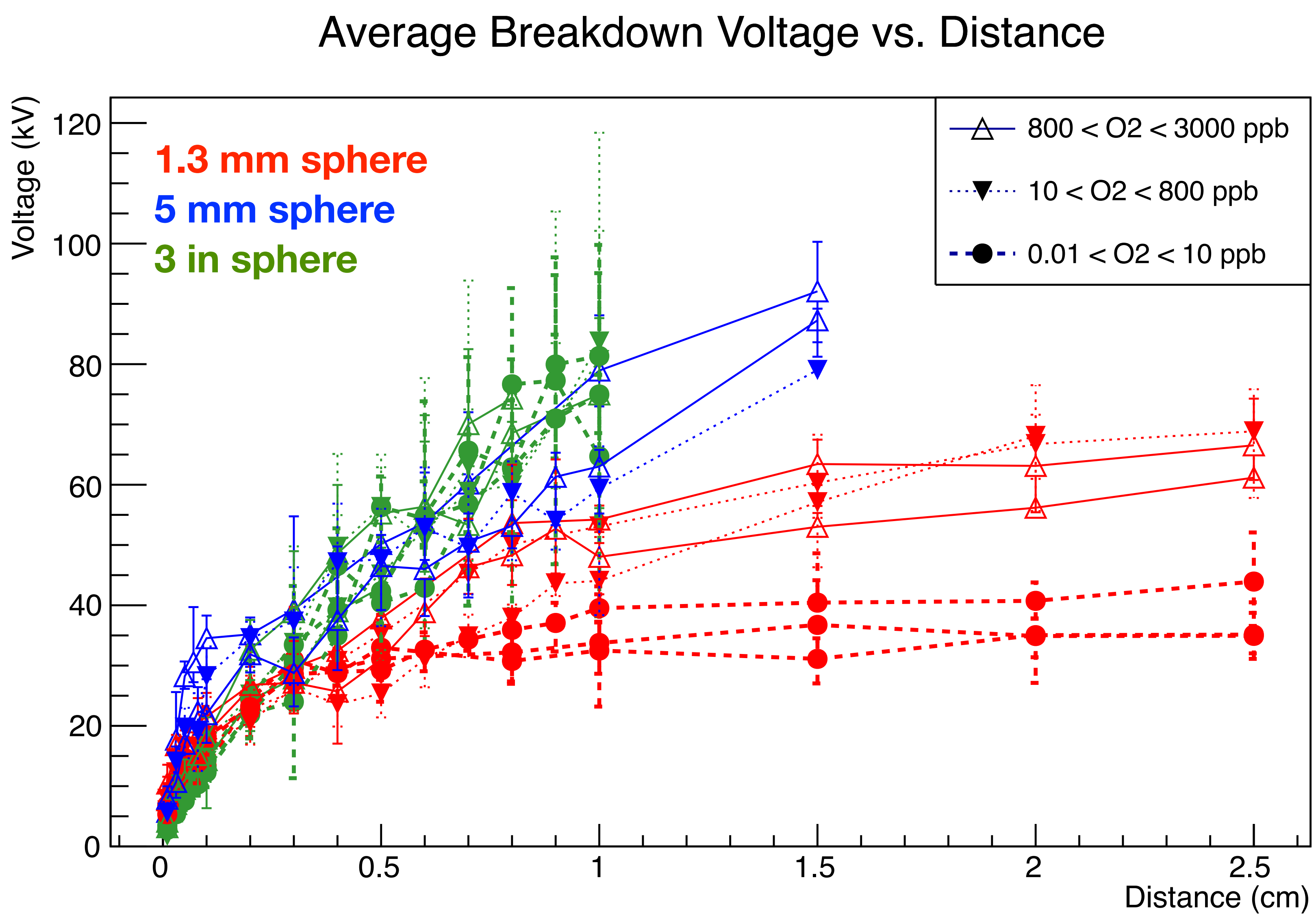
$V_{Breakdown}$ vs. Distance

- Plotted average V_{bd} at a given distance for a given date's data (specific purity and probe)



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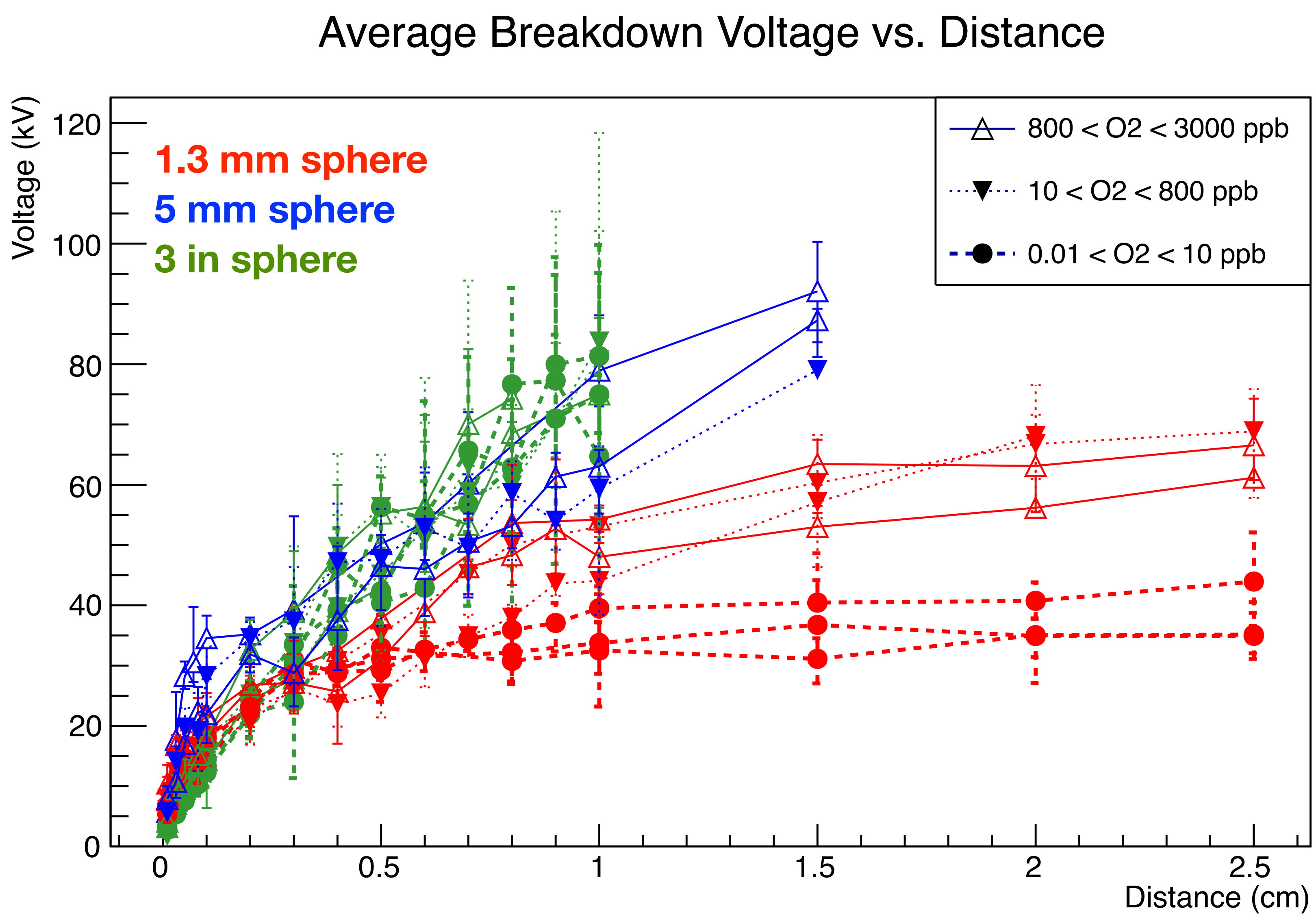

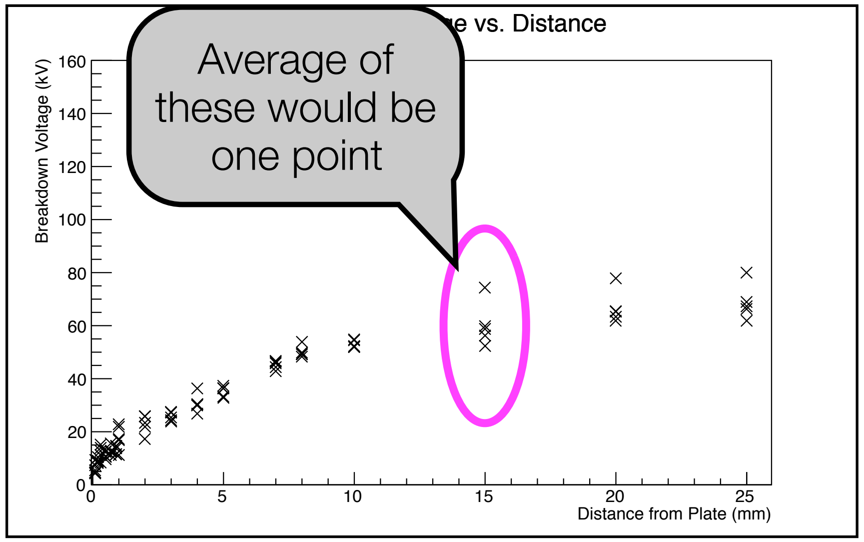

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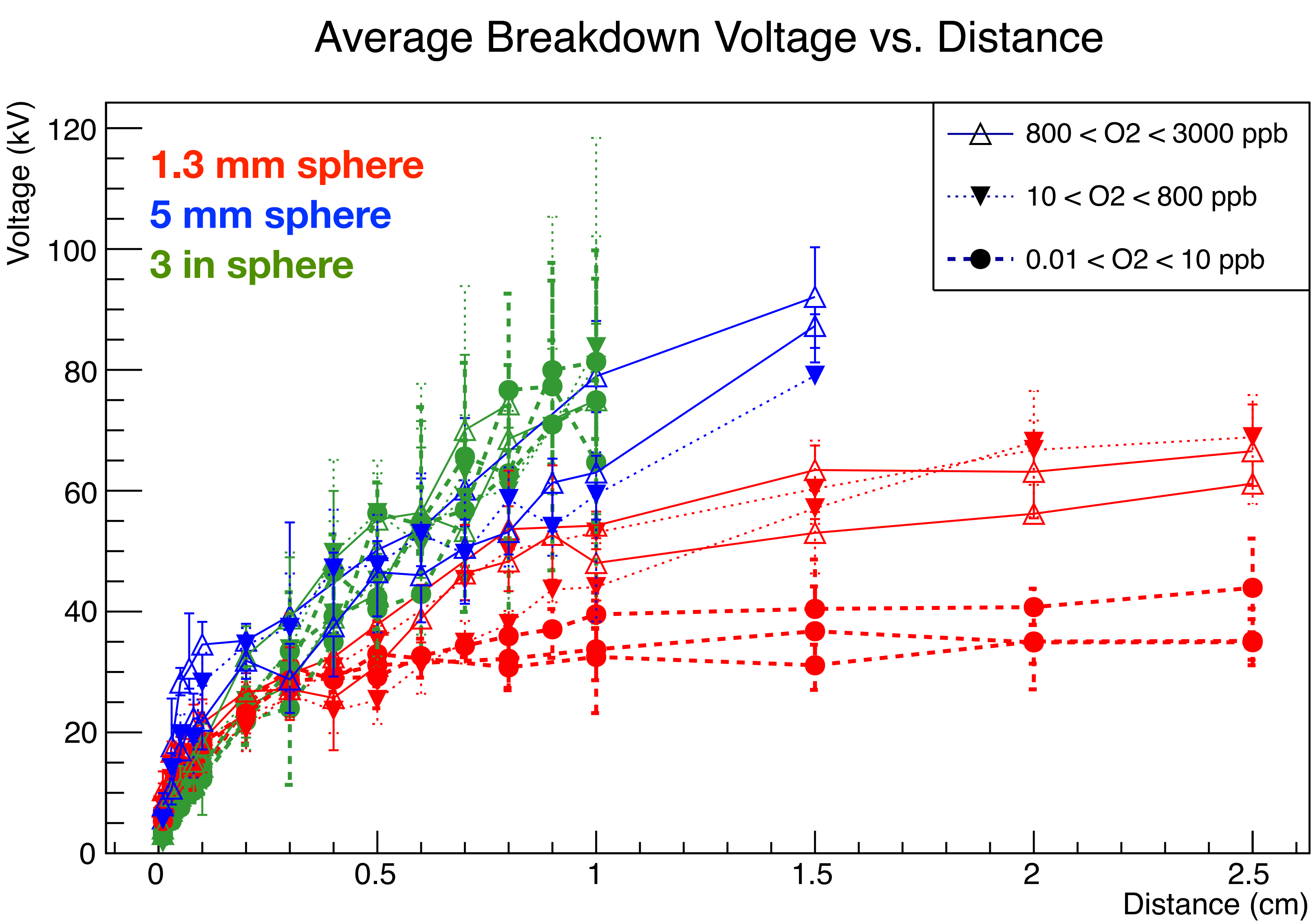
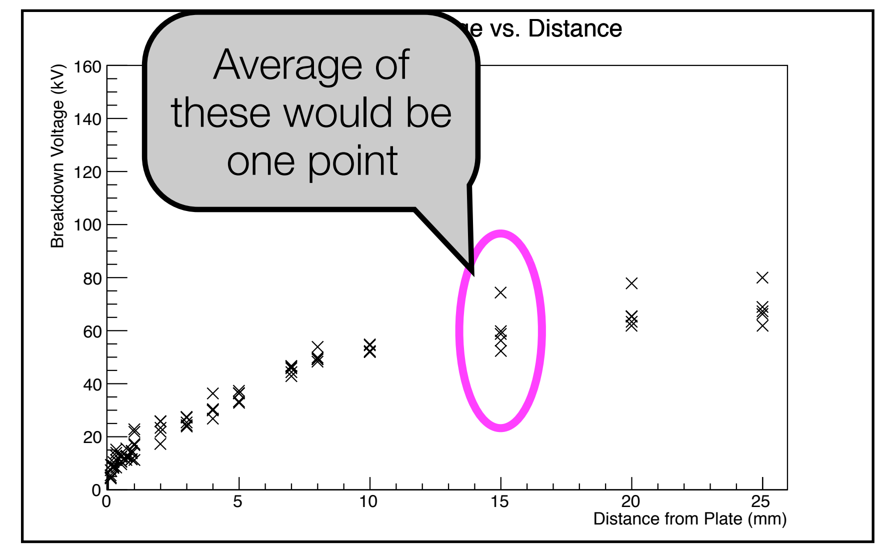


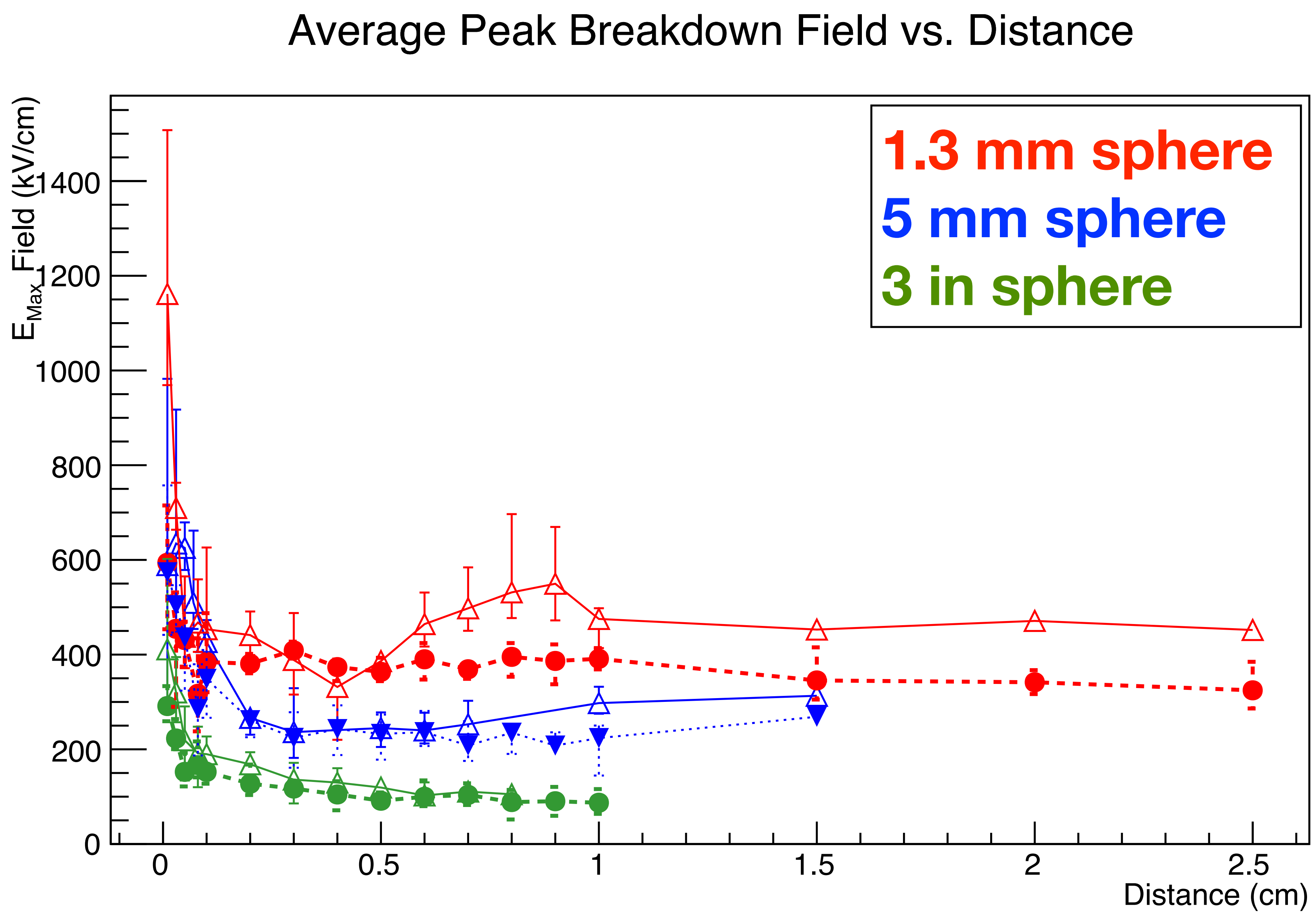


200-1400 ppb O_2

0.29-1.8 ppb O_2

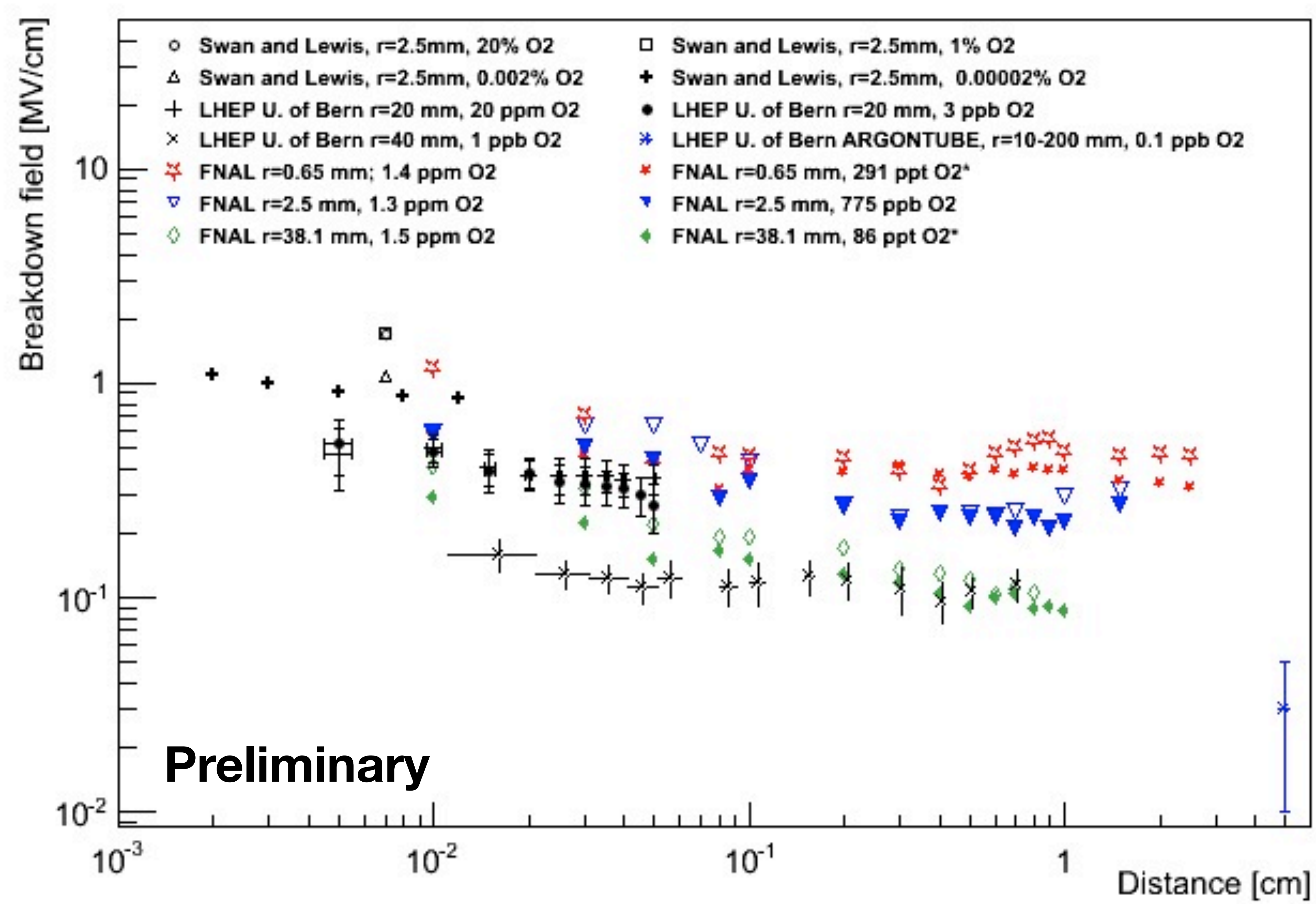
E_{Max} vs Distance

- Doesn't appear to be just E_{max}



Comparison to Others' Data

Plot inspired from LHEP Bern. Earlier data provided by LHEP Bern



Other Quantities of Interest

Gerhold *et al.*, Cryogenics (1994)

Area effect

The impact of an area effect on LHe breakdown has been recognized by several authors. It is generally accepted that LHe breakdown is triggered at weak-links adjacent to the cathode, i.e. protrusions. The area

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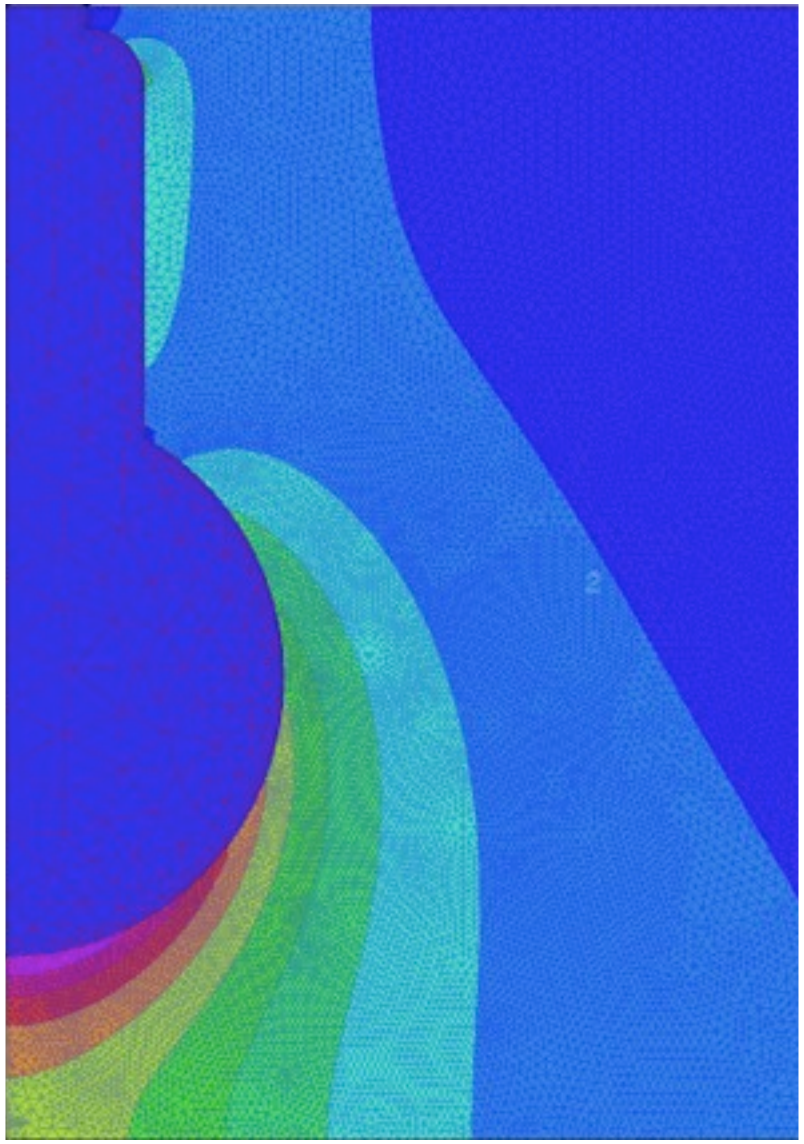

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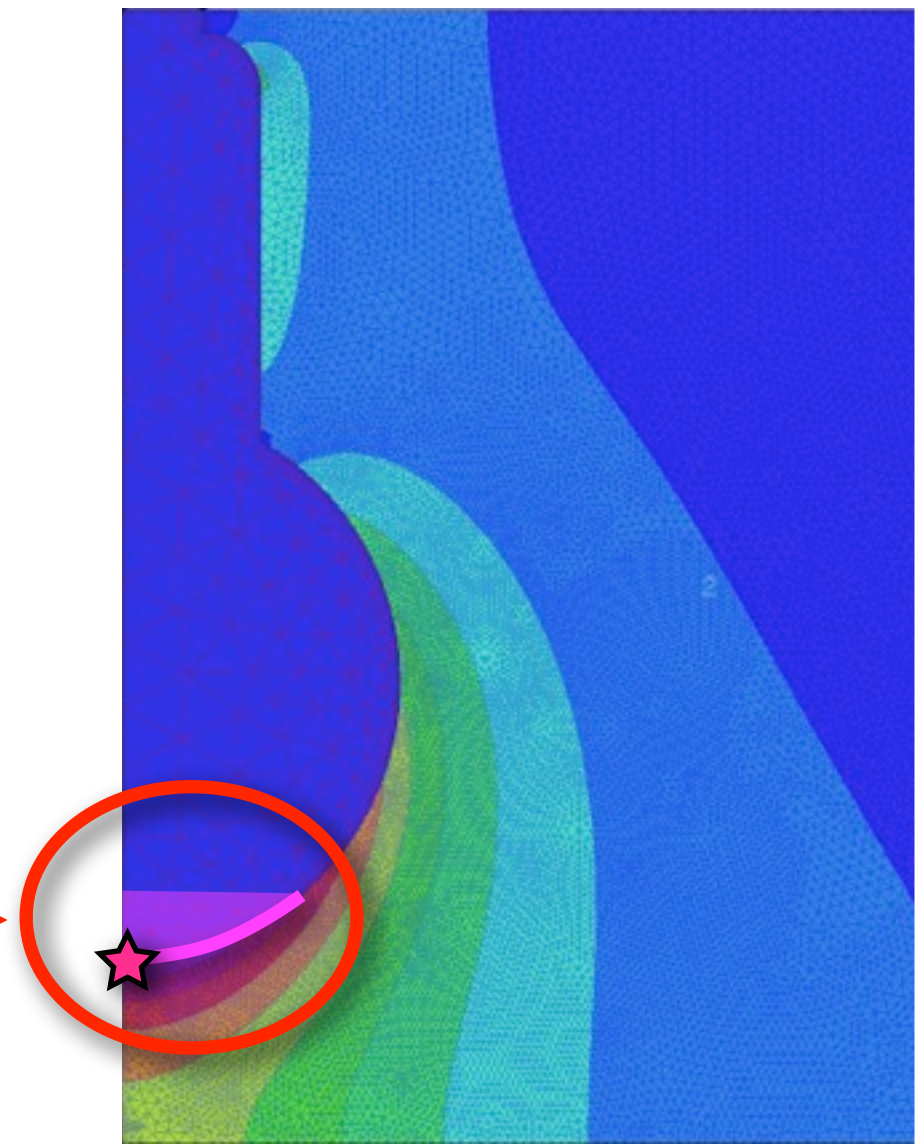
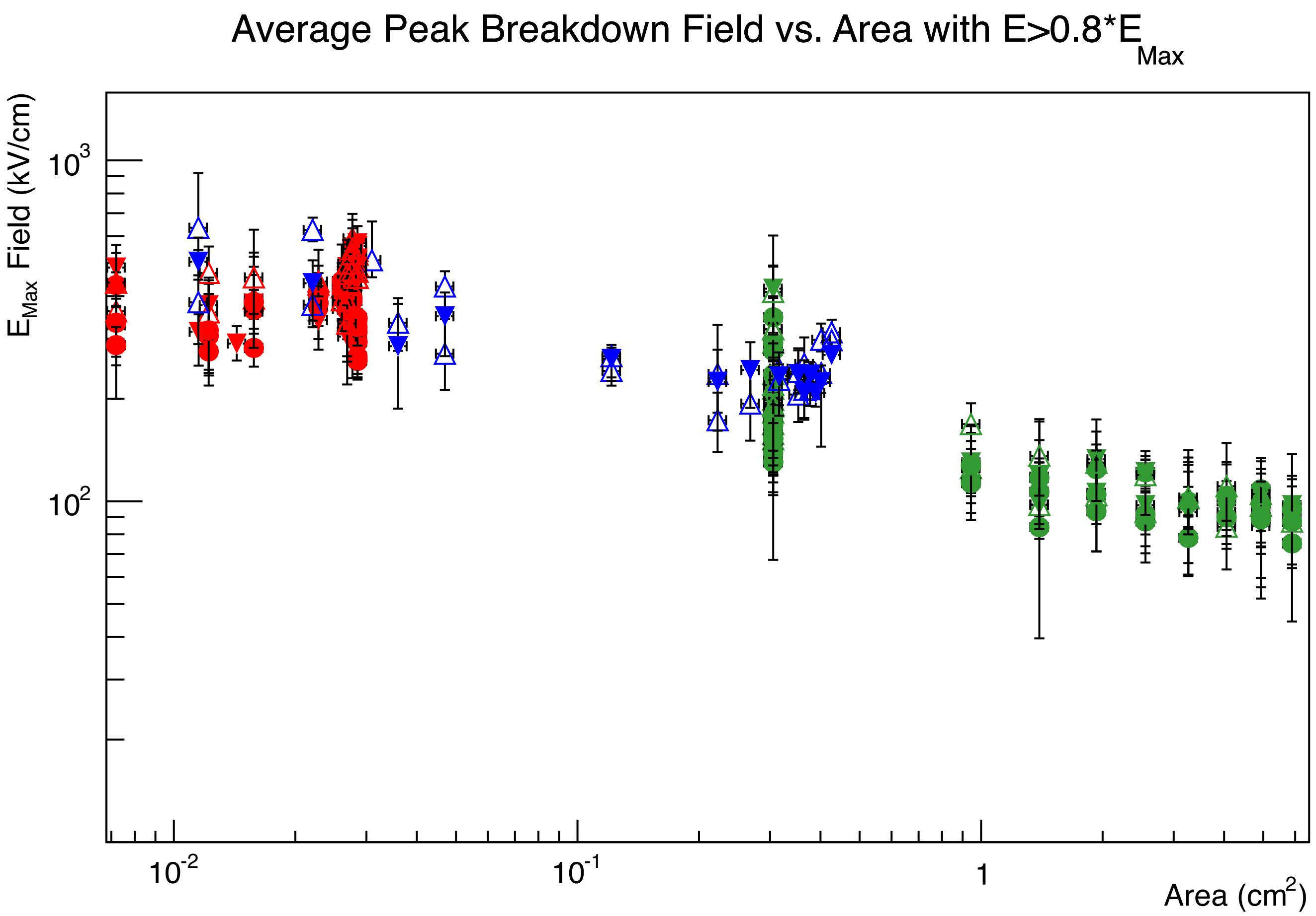
The impact of an area effect on LHe breakdown has been recognized by several authors. It is generally accepted that LHe breakdown is triggered at weak-links adjacent to the cathode, i.e. protrusions. The area

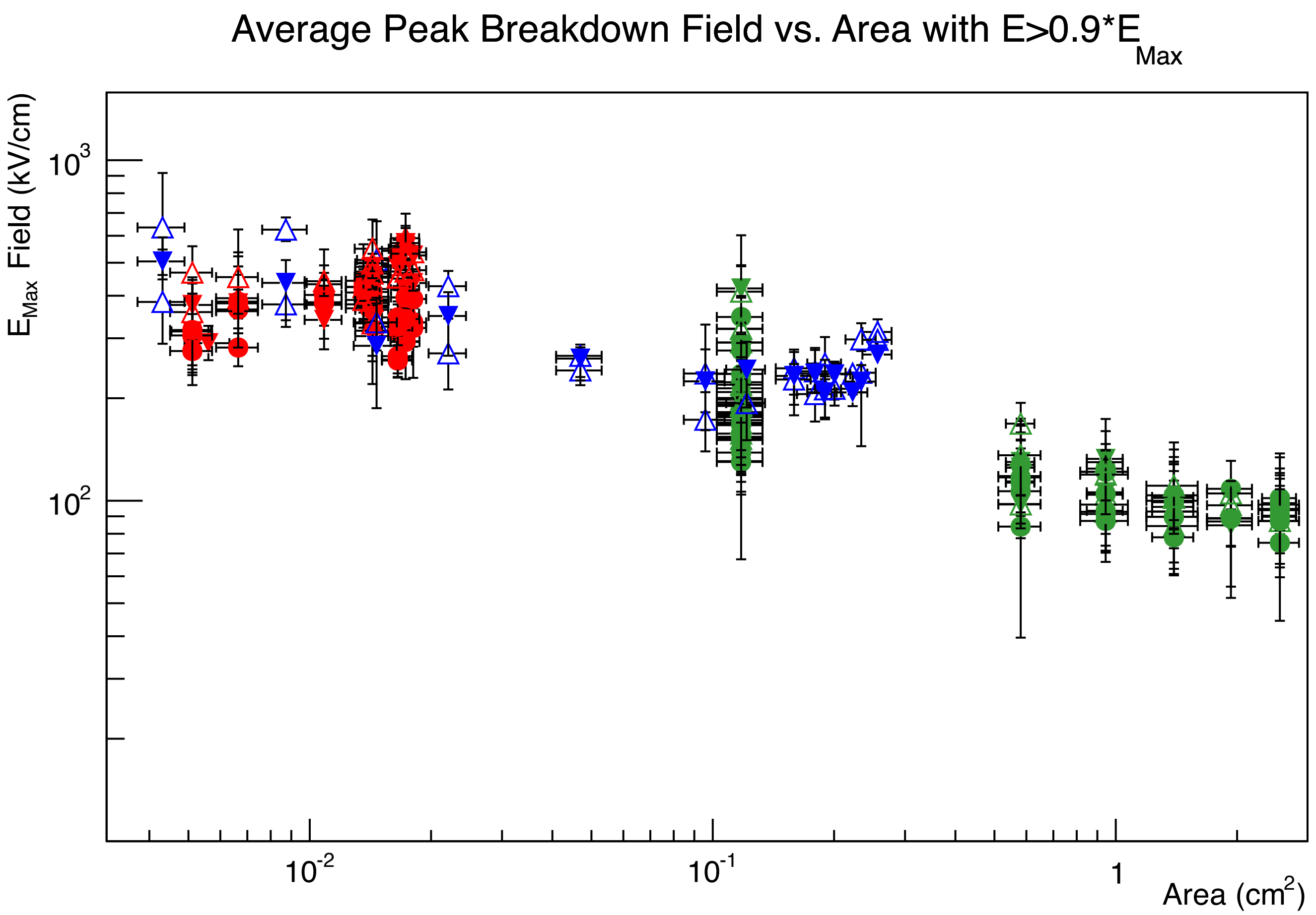
Stressed area, peak field is at the star, shaded pink has E>80%*E_{max}



Other Quantities of Interest

- E_{max} vs Area (80% E_{max} left; 90% right)





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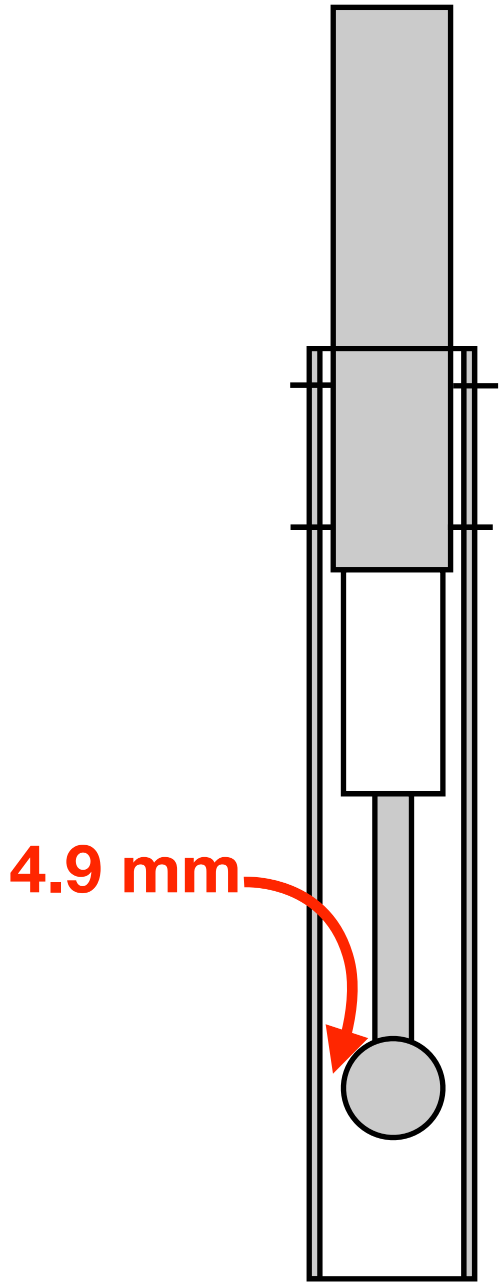

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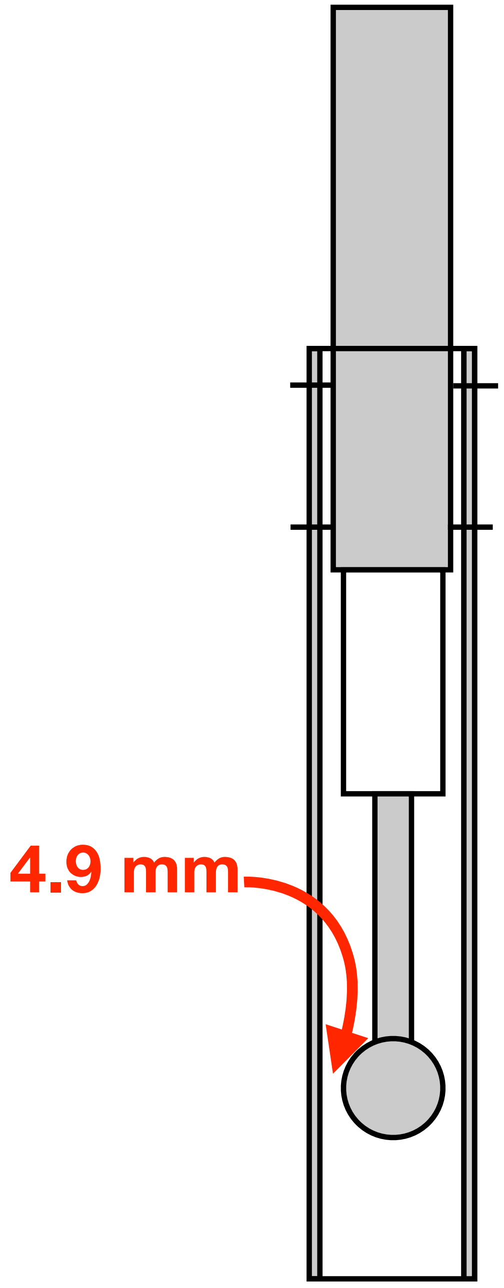

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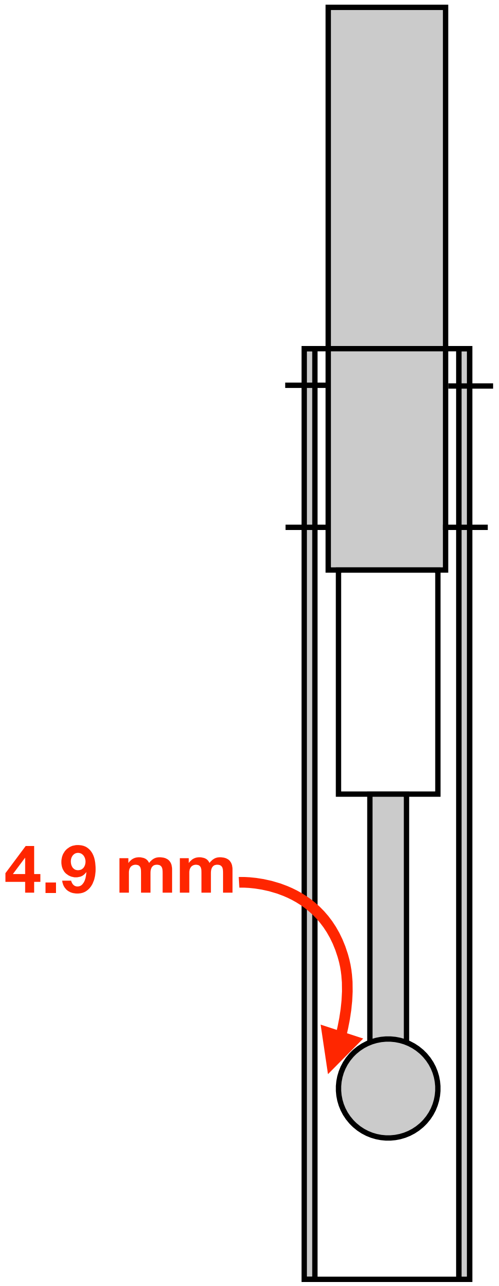
  - (so we likely will not publish this)



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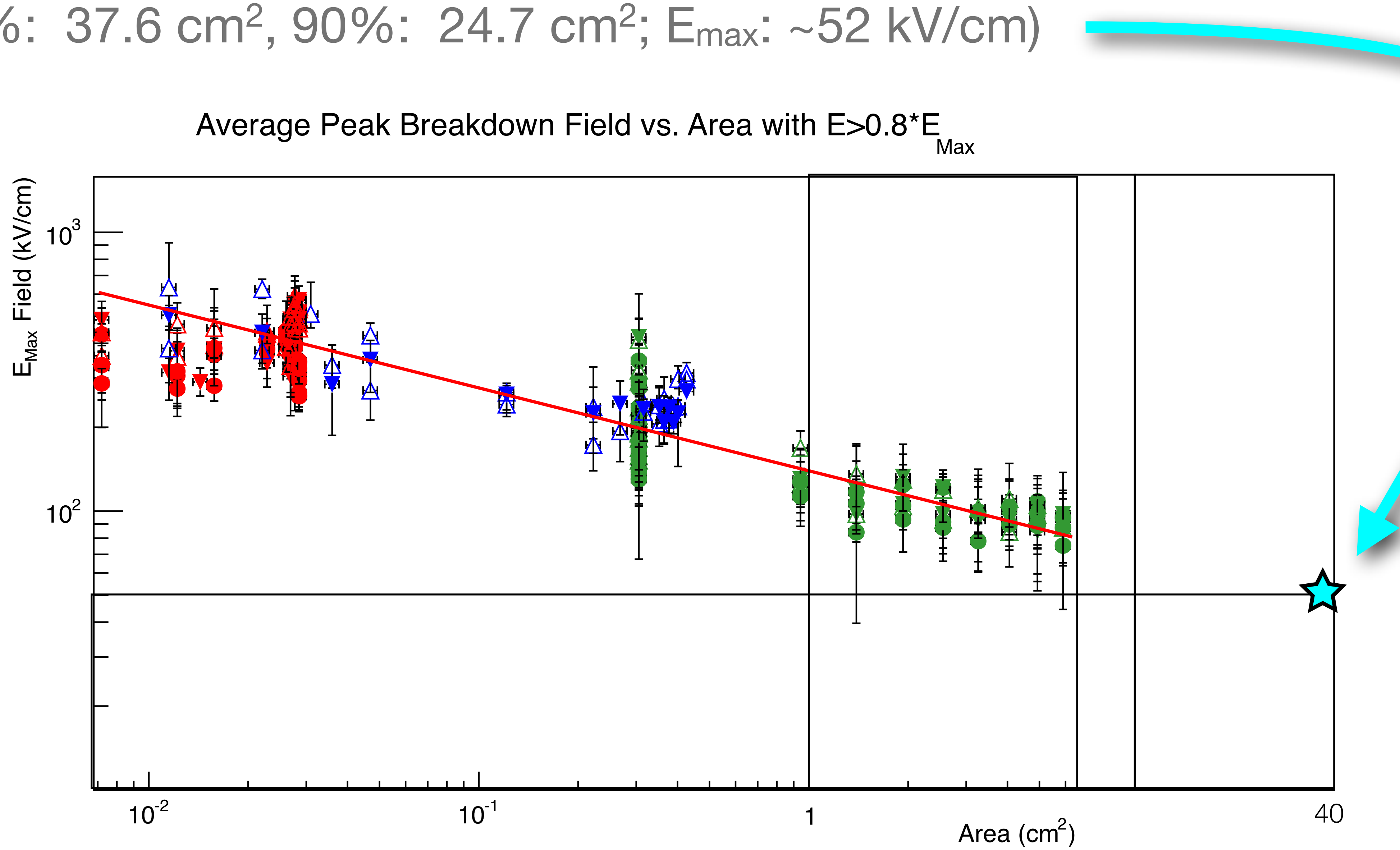
  - We have something with an order of magnitude more stressed area
- (80%: 37.6 cm^2, 90%: 24.7 cm^2; E_{max}: ~52 kV/cm)



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- Our group will have a paper on the arXiv later this month
- We plan to continue HV R&D efforts with an LDRD grant:
  - **Blanche**: **B**reakdown (or Big) **l**iquid **a**rgo**n** **c**ryostat for **h**igh-voltage **e**xperiments

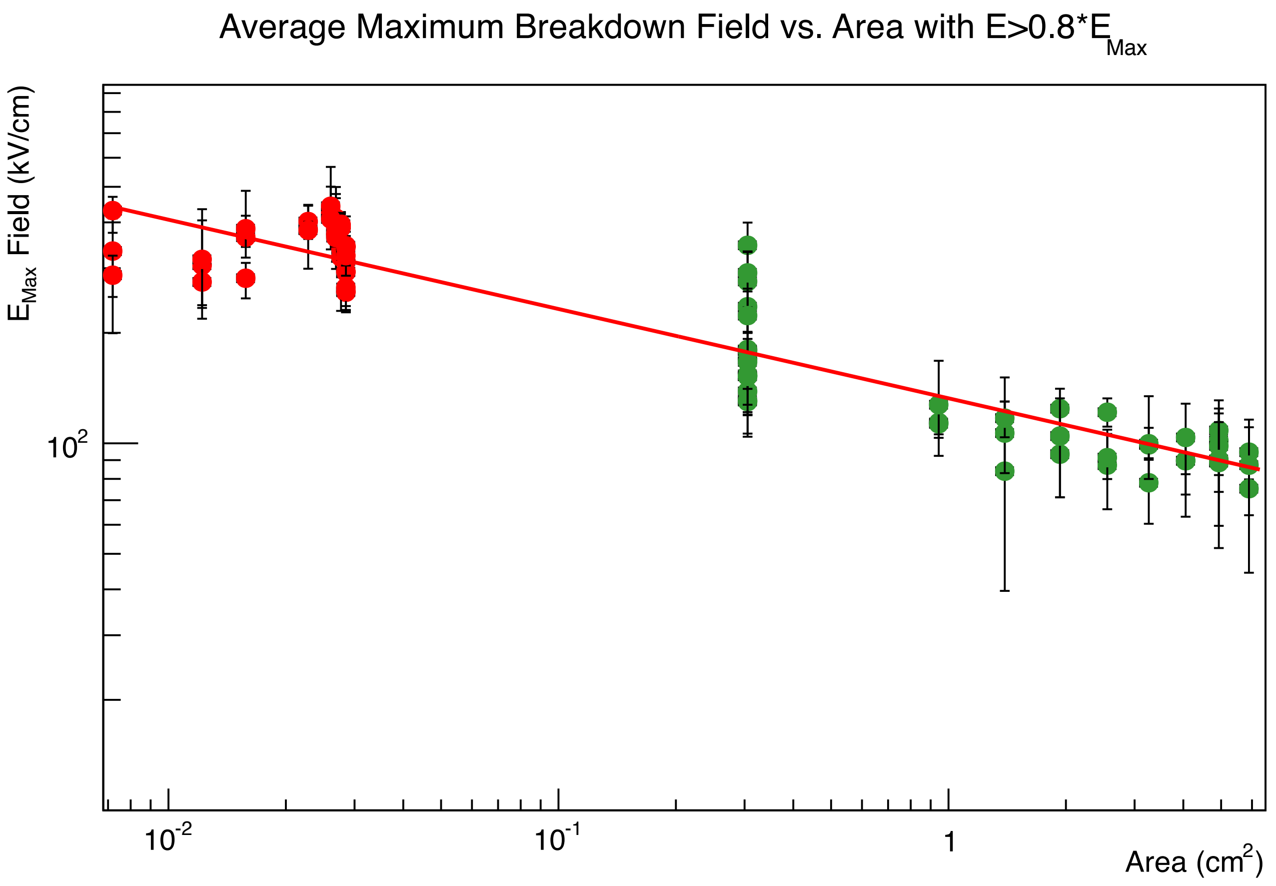
HVC Thank You's

- Cryo design and operation: M Zuckerbrot
- Data collected by B. Carls, R. Acciarri, & S. Lockwitz
- Lots of design & construction work by H. Jostlein
- Task Force members & others with helpful discussions: B. Lundberg, G.P. Zeller, G. Rameika, J. Raaf, and C. James

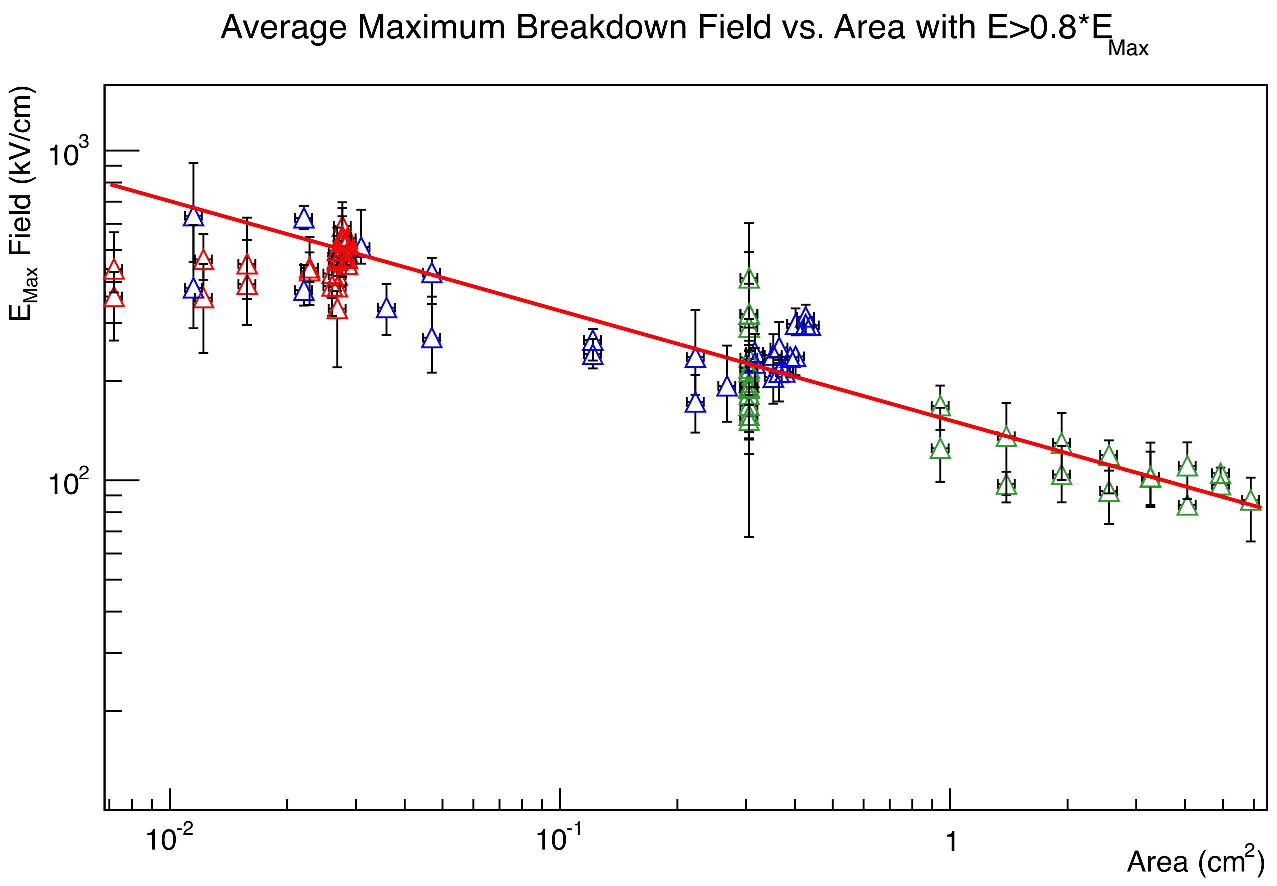
Back up slides...

Looking Closer at Purities...

O_2<10 ppb



O_2>800 ppb



Slide from C. Thorn

HV Breakdown in GAr & LAr

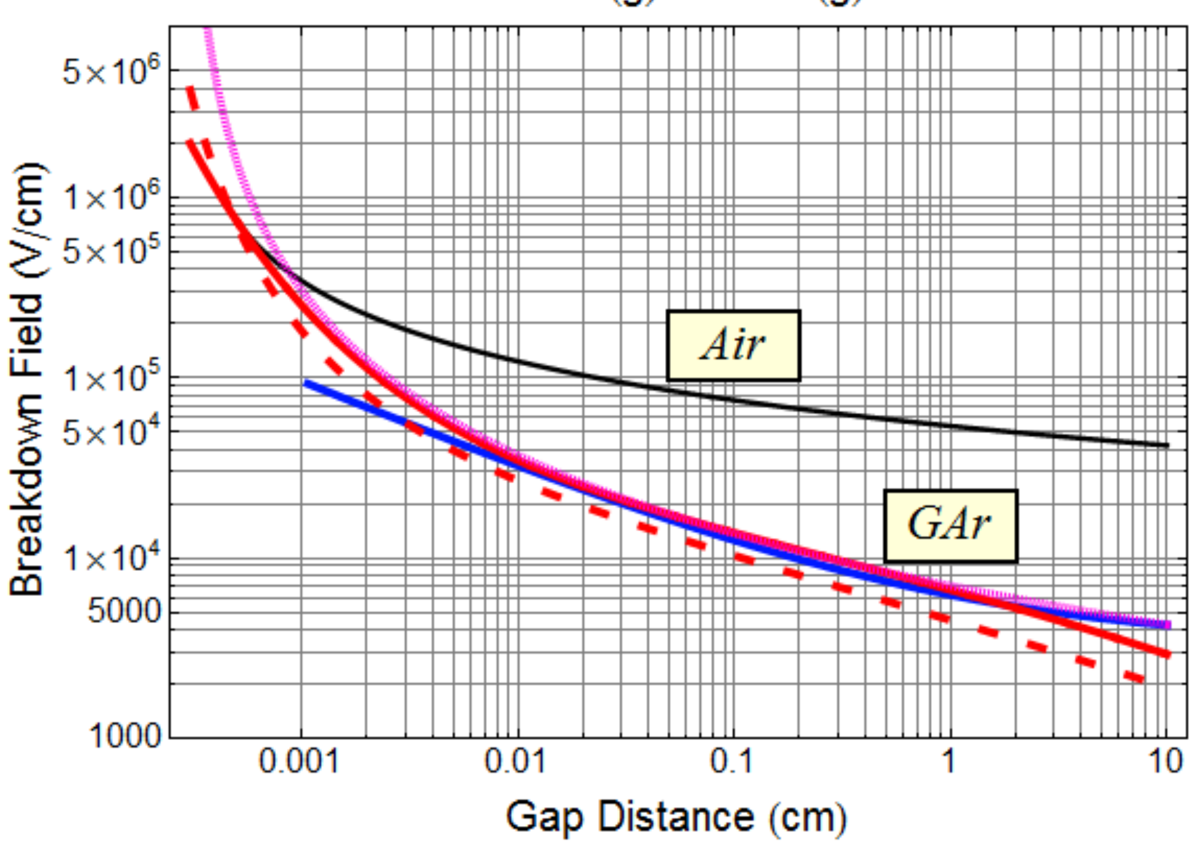
GAr

Breakdown in gas is understood: a Townsend process, as described by Paschen in 1905:

$$\alpha(E/\rho) = A\rho\, e^{-\frac{B\rho}{E}}$$

$$V_B = \frac{Bd\rho}{Log[Ad\rho] - Log[Log[1+\frac{1}{\gamma}]]}$$

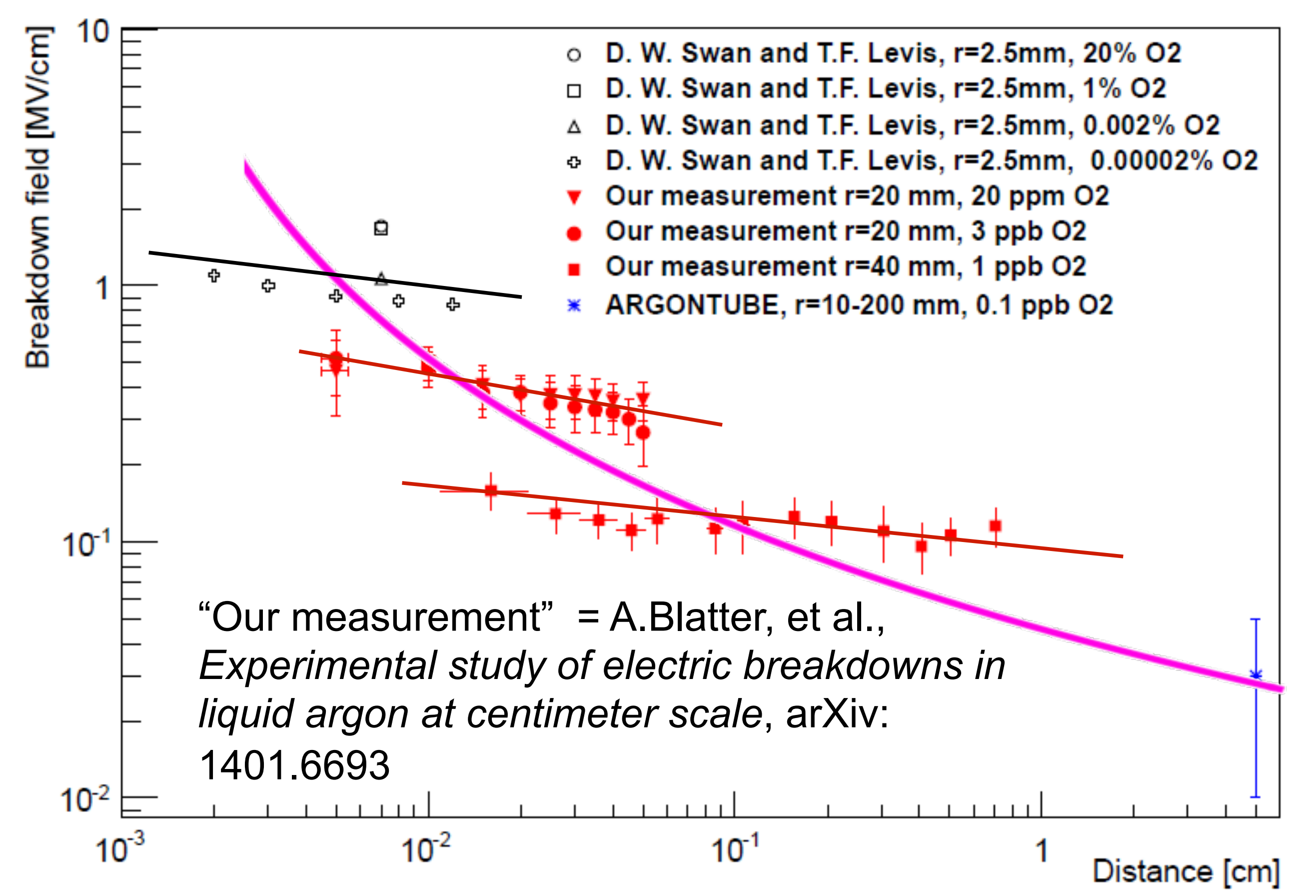
Breakdown Field for Ar(g) and Air (g) at 293K & 1 bar



LAr

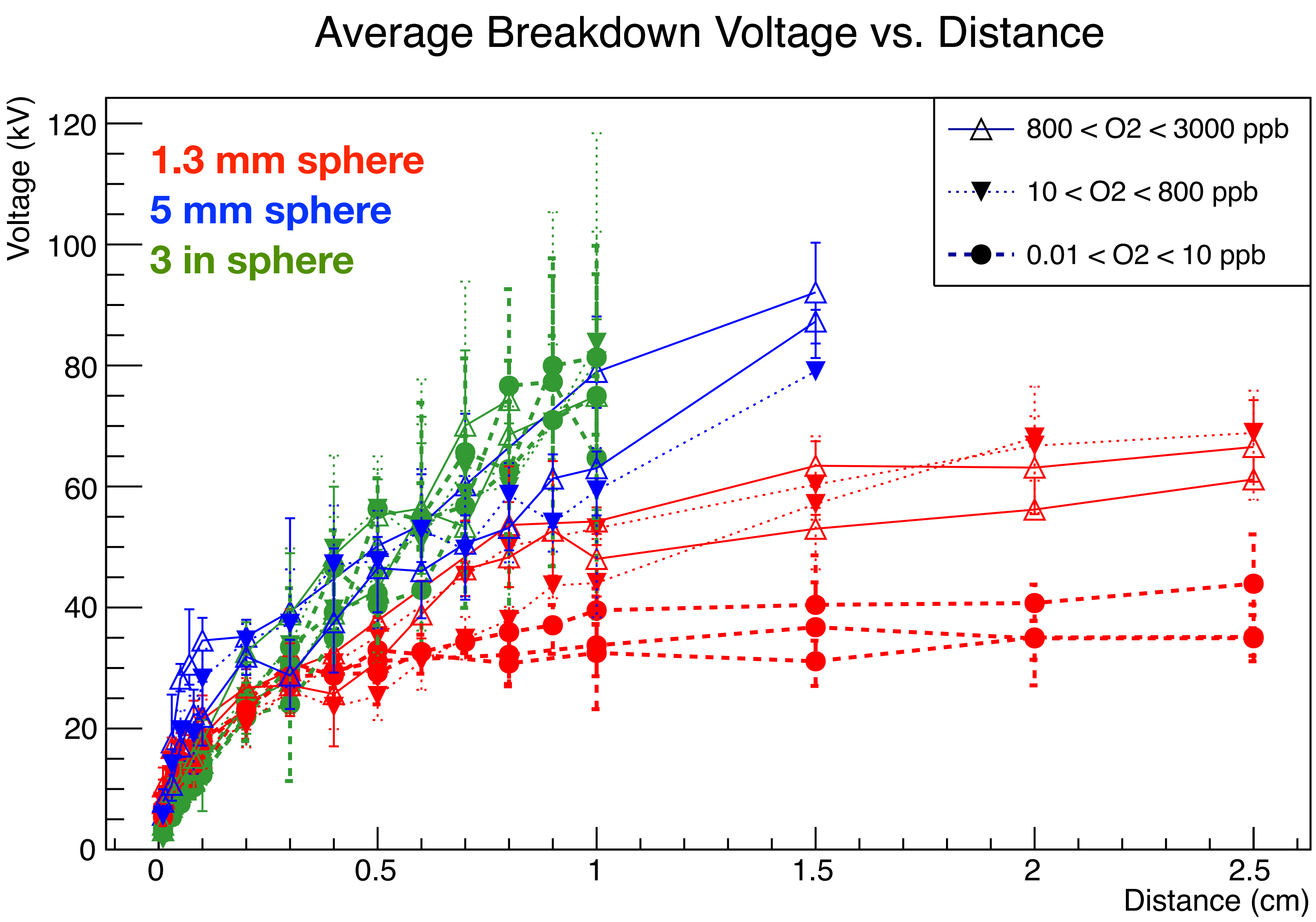
Breakdown in cryogenic liquids is NOT understood: it depends on thermodynamic state, surface effects, purity and much else. See J. Gerhold, *Properties of cryogenic insulants*, Cryogenics **38** (1998) 1063: “discharge voltages can only be measured as a function of the overall electrode/liquid system; extrinsic parameters have an important effect”

Breakdown Field for LAr at ~89K



A Purity Note from C. Thorn

The mean free path for attachment to O2 at 10kV/cm is 0.15 cm for 1ppm and 150 cm for 1ppb (these increase by ~2x per decade of field). Thus below ~10ppb there should be no change in breakdown voltage for gaps greater than a few cm, if the mechanism for the purity dependence is attachment



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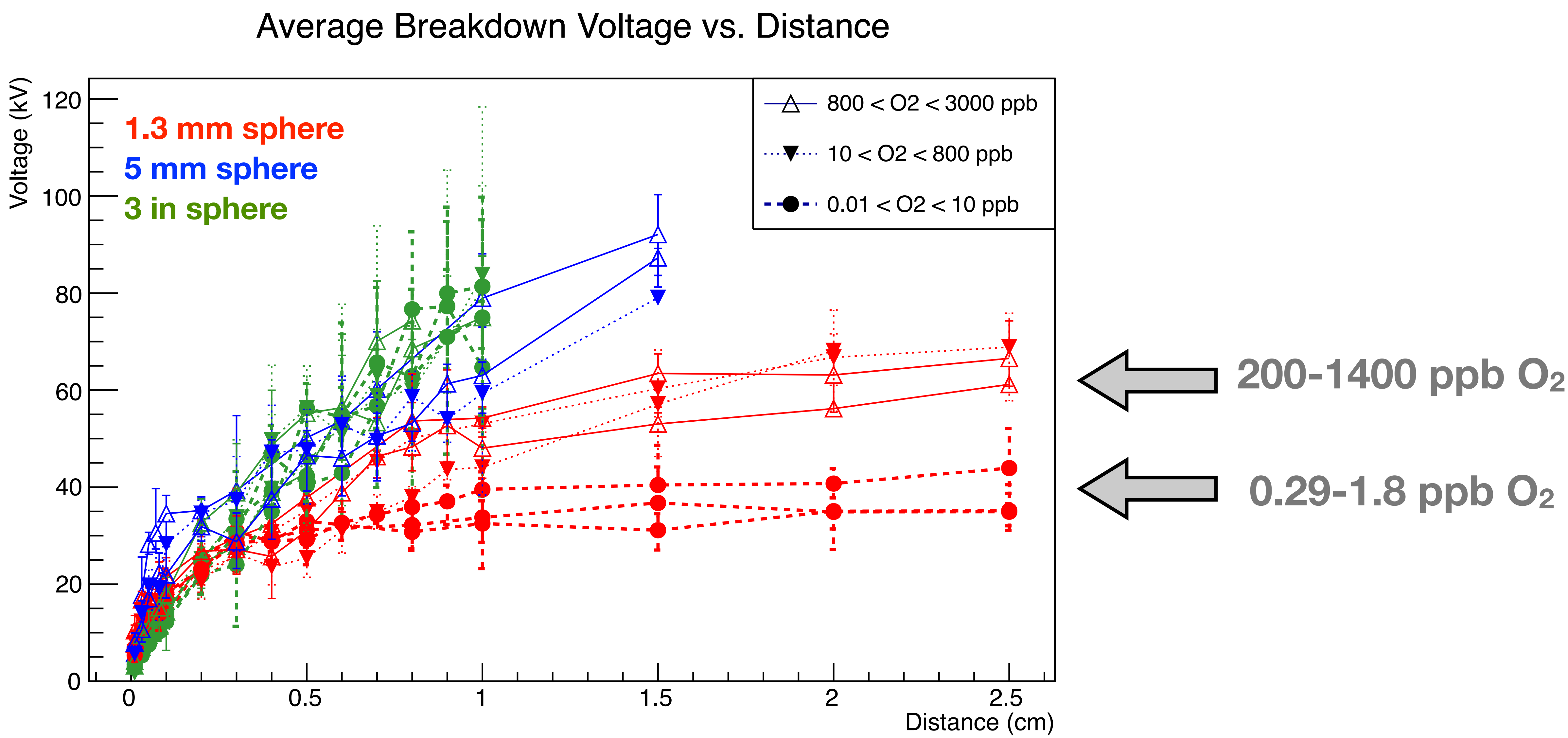

Test Setup

- Voltage was supplied by a Glassman LX150N12 capable of up to -150 kV
- Same filter pot as uB
  - filters ripple
  - isolates energy
- Voltage controlled by a LabView program (monitoring voltage, and some current)
- Current additionally monitored by analog outputs on the back of the supply

HV Line Drawing