High Voltage in Liquid Argon

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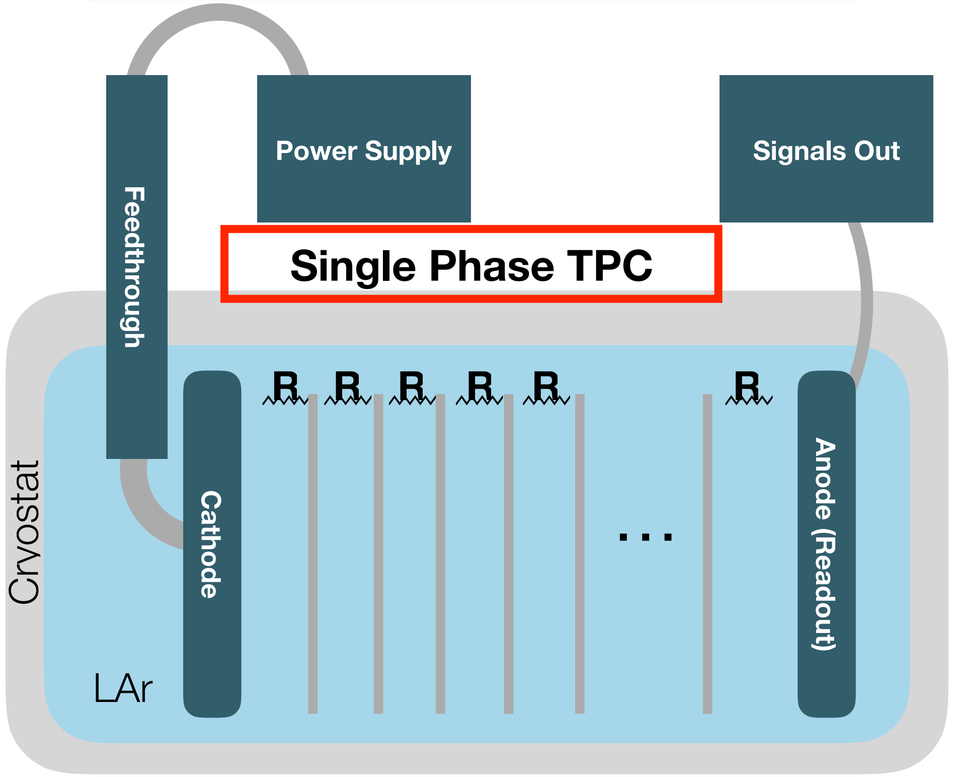
CPAD, Caltech
October 2016

Introduction

- LArTPCs are a popular detector choice for neutrino and DM experiments
- High voltage (HV) is necessary for their operation
- Fields typically are targeted for 500 V/cm
  - ~2 m drift —> 100 kV on the cathode

Experiment	Design Voltage
ICARUS	75 kV (150 kV)
Darkside 50	60 kV
MicroBooNE	128 kV
CAPTAIN	50 kV
DUNE	180 kV / 600 kV
WA105	300-600 kV



History

- Recently, [some] LArTPCs were designed with the assumption the dielectric strength was ~ MV/cm
  - With this value, large safety margins were assumed
    - Peak field ~100 kV/cm —> Factor 10 safety

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

from High-Voltage Technology, L.L. Alston ed. (1968)

History

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  - With this value, large safety margins were assumed
    - Peak field ~100 kV/cm —> Factor 10 safety
- A few years ago while testing a feedthrough, I saw breakdown *through* the LAr
  - —>Definitely not ~ MV/cm!!
  - The MV/cm value is an upper bound at small (< mm) distances:

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Vol. 107, No. 3 ELECTRODE SURF

Table II. Mean strengths for liquified gases (mv/cm)

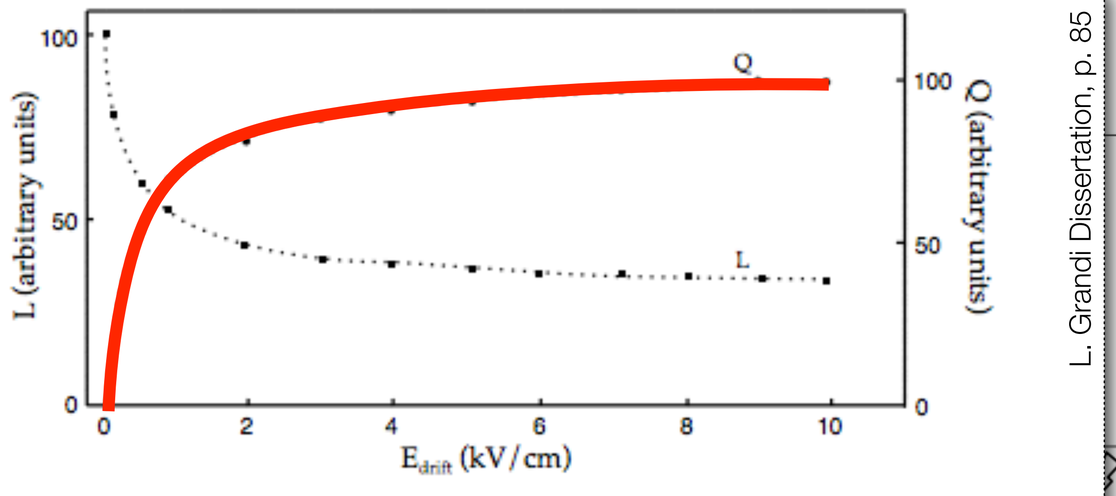
	Platinum electrodes		Stainless steel electrodes	
	from Fig. 2	from ref. (2)	from Fig. 3	from ref. (2)
Argon	1.10	0.86	1.42	1.00
Oxygen	2.00	0.93	2.38	1.04
Nitrogen	2.26	0.93	1.88	1.00

planation of the effect. The nonlinear plot for argon and stainless steel suggests that the strength of argon for really large spacings (> 100 μ) would be much less than that quoted in Table II, and any increase for smaller

D. Swan and T. Lewis, *J. Electrochem. Soc.* 107 (1960) 180.

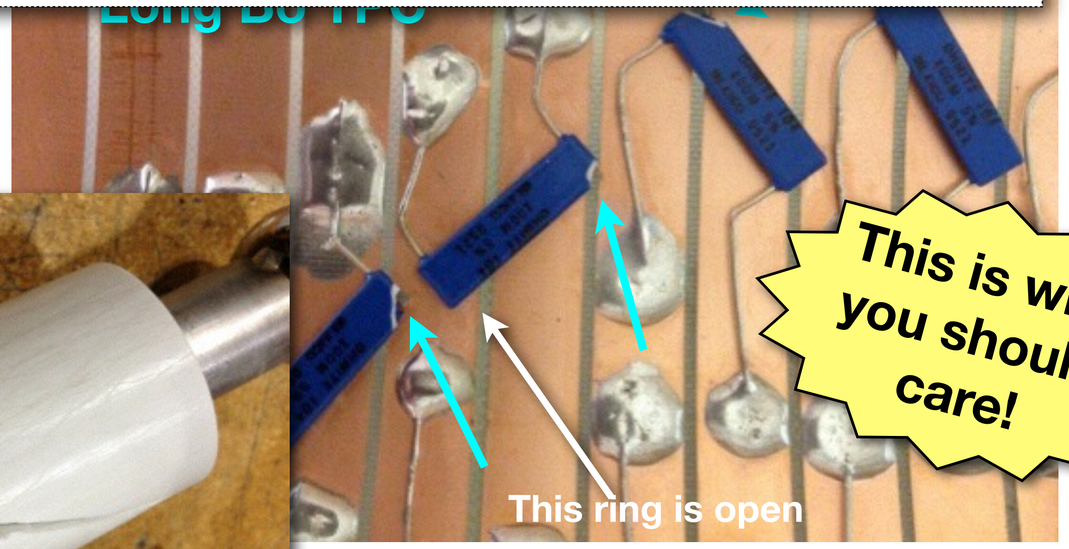
Why Care?

- Running at a reduced field limits the physics
- Breakdown can break the TPC
  - A sudden discharge creates a large over-voltage condition and can break resistors
  - Cathode is capacitively coupled to the anode. A sudden loss of voltage can induce a large current on the wires —> Damage electronics
  - Breakdowns can physically break parts of the TPC



L. Grandi Dissertation, p. 85

Figure 3.7: The graph shows the behaviour of the luminescence light intensity and of the collected charge as function of the electric field strength. The y axis scales



This is why you should care!

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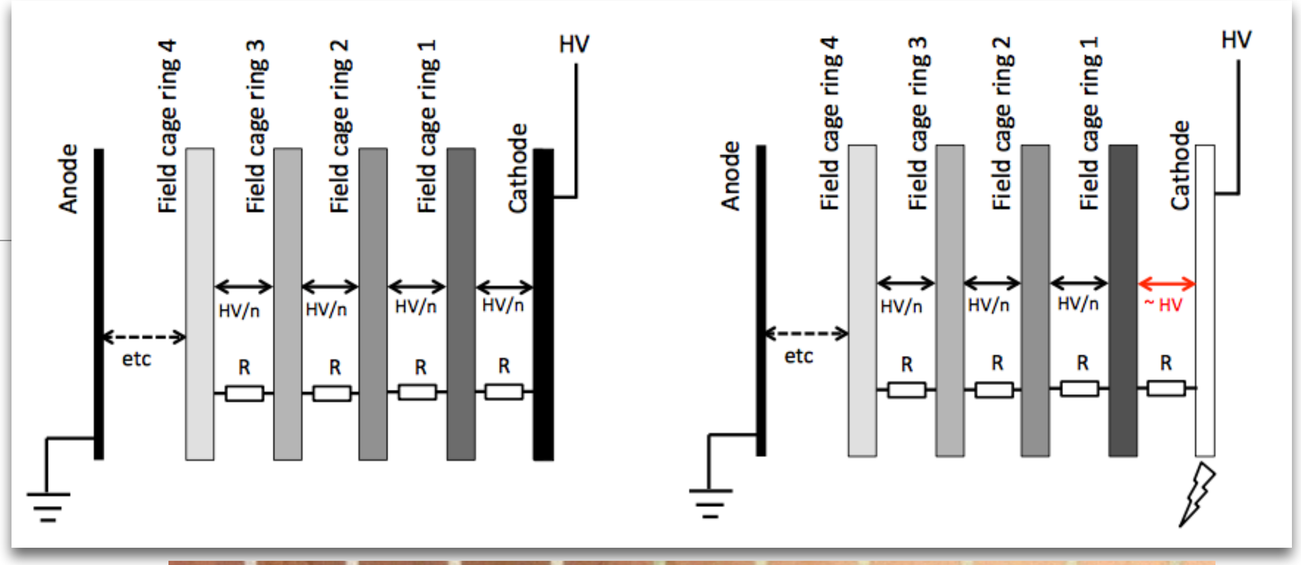
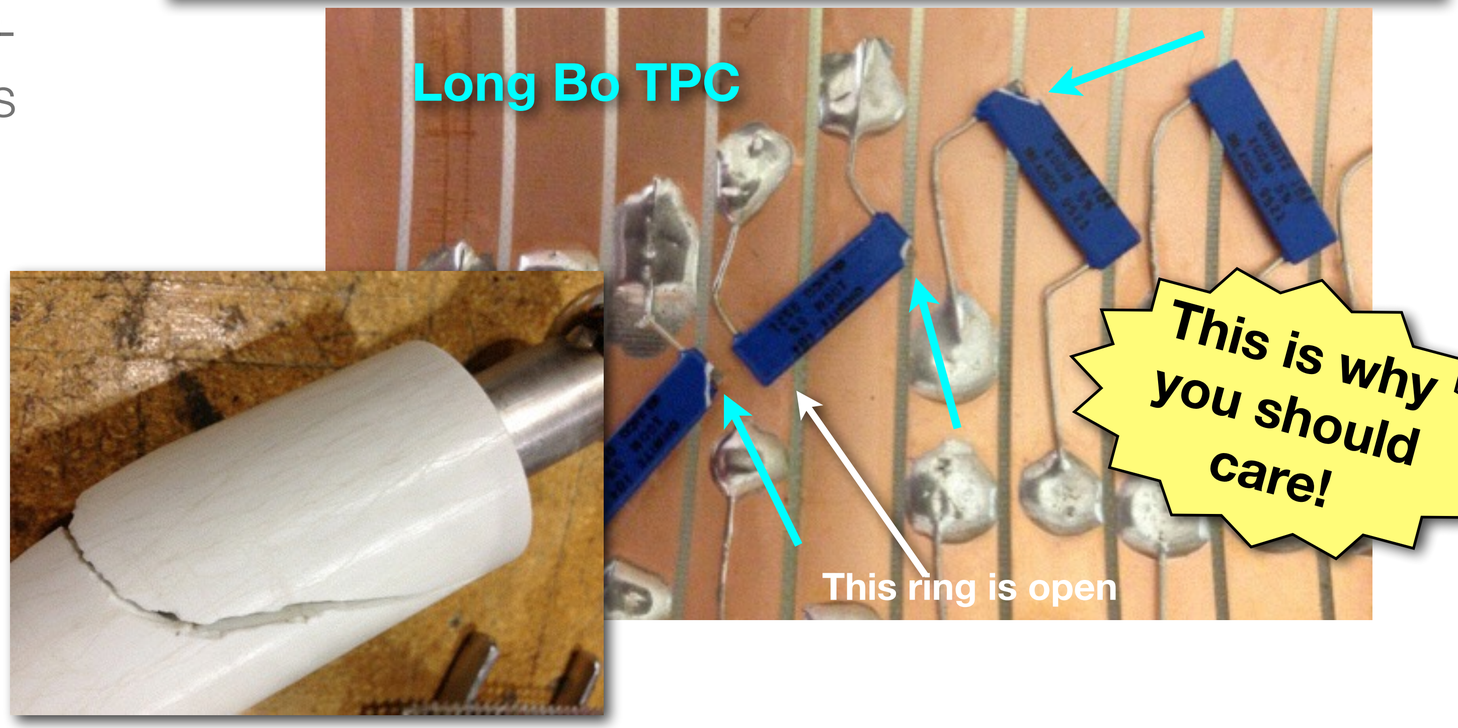
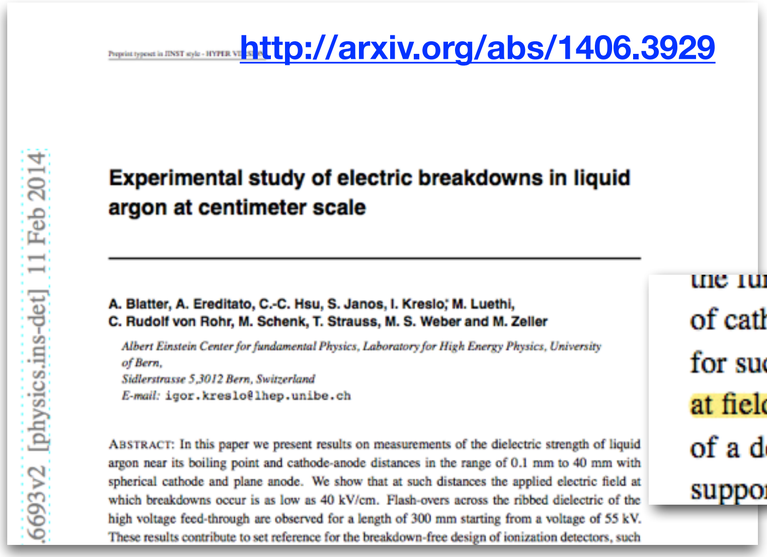




Not ~MV/cm!

- LHEP Bern studied breakdown using a sphere (cathode) - plate (anode) geometry
- Observed breakdowns as low at 40 kV/cm


http://arxiv.org/abs/1406.3929

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
E-mail: igor.kreslo@lhep.unibe.ch

ABSTRACT: In this paper we present results on measurements of the dielectric strength of liquid argon near its boiling point and cathode-anode distances in the range of 0.1 mm to 40 mm with spherical cathode and plane anode. We show that at such distances the applied electric field at which breakdowns occur is as low as 40 kV/cm. Flash-overs across the ribbed dielectric of the high voltage feed-through are observed for a length of 300 mm starting from a voltage of 55 kV. These results contribute to set reference for the breakdown-free design of ionization detectors, such

.6693v2 [physics.ins-det] 11 Feb 2014

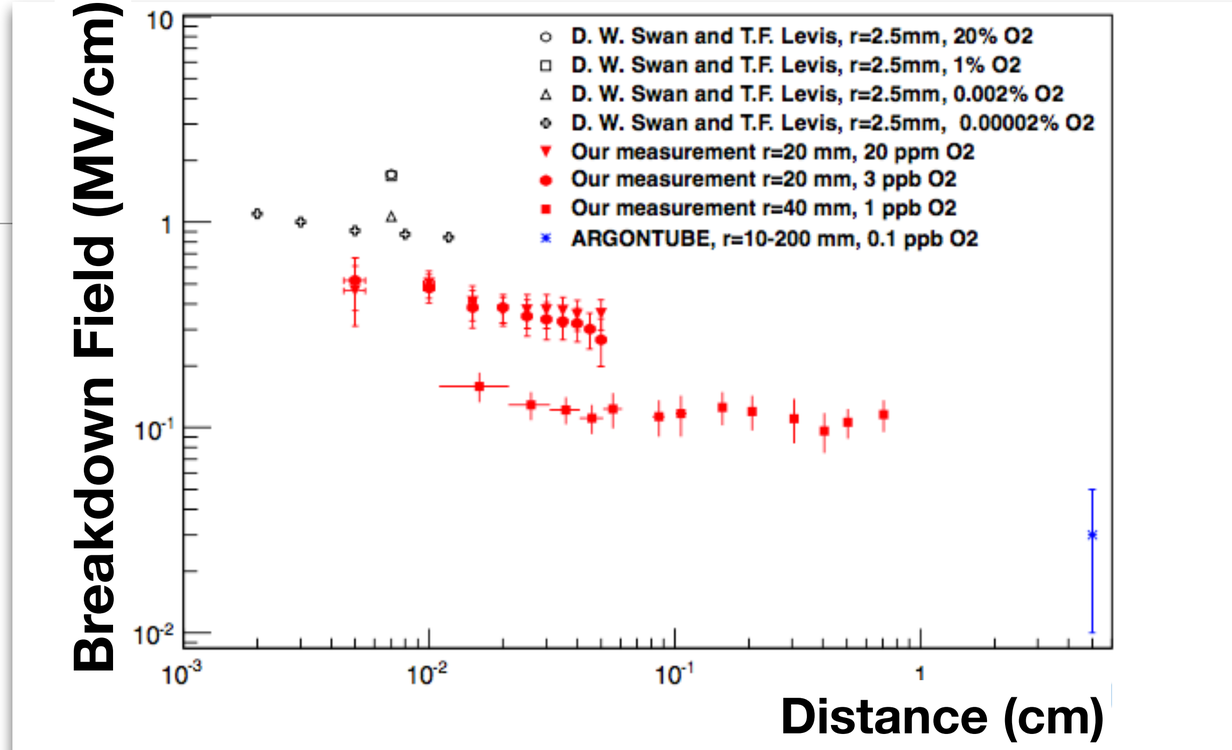


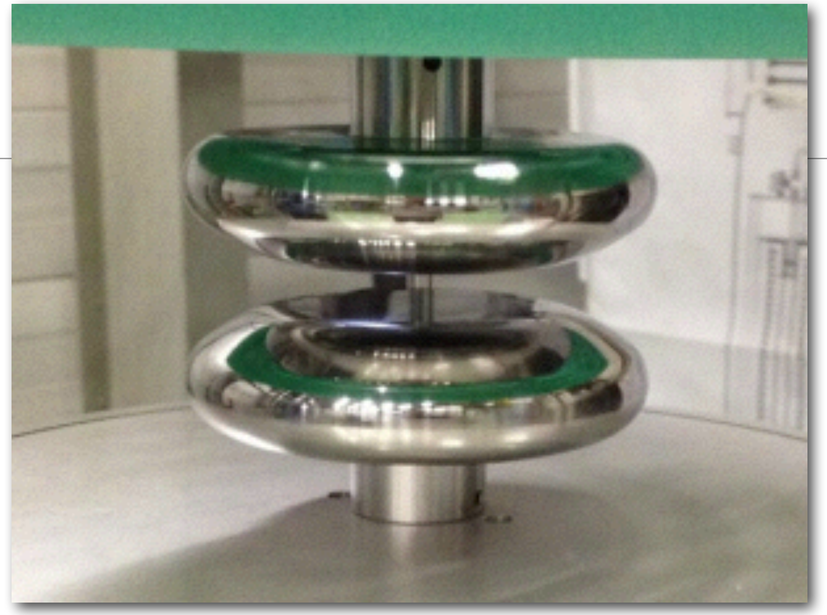
Figure 7. Compilation of the experimental data on the electric strength of liquid argon including resu
from

Breakdowns at fields as low as **40 kV/cm**

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

Not ~MV/cm

- The ETH Zurich group also performed a breakdown test in liquid argon
- They used two plates at a 1 cm spacing with a uniform E field (Rogowski profile)
- Observed breakdowns as low as 40 kV/cm in boiling argon



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)

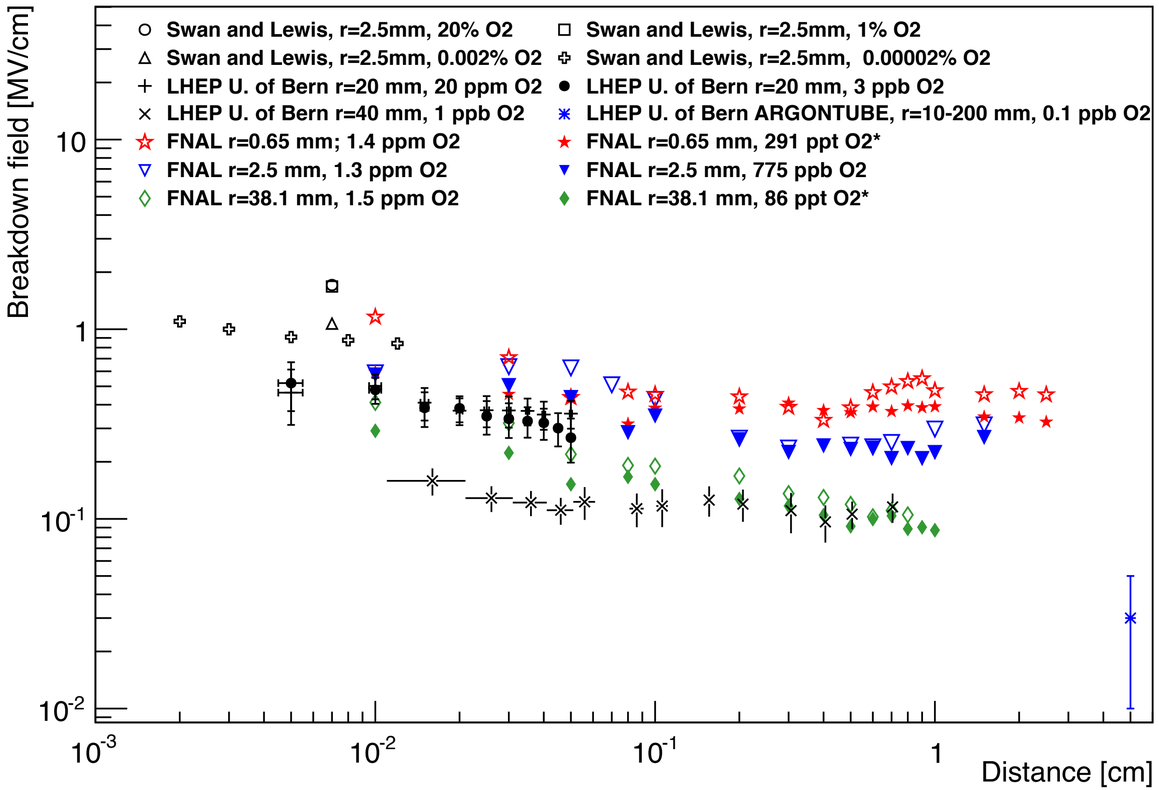
(Dated: 13 January 2014)

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.

det] 13 Jan 2014

Unifying Parameter

- At FNAL, we also performed a breakdown test (**JINST 9 (2014) P11001**, http://arxiv.org/abs/1408.0264)
- Also used a sphere plate geometry & different sized spheres
  - Similar results to the Bern group



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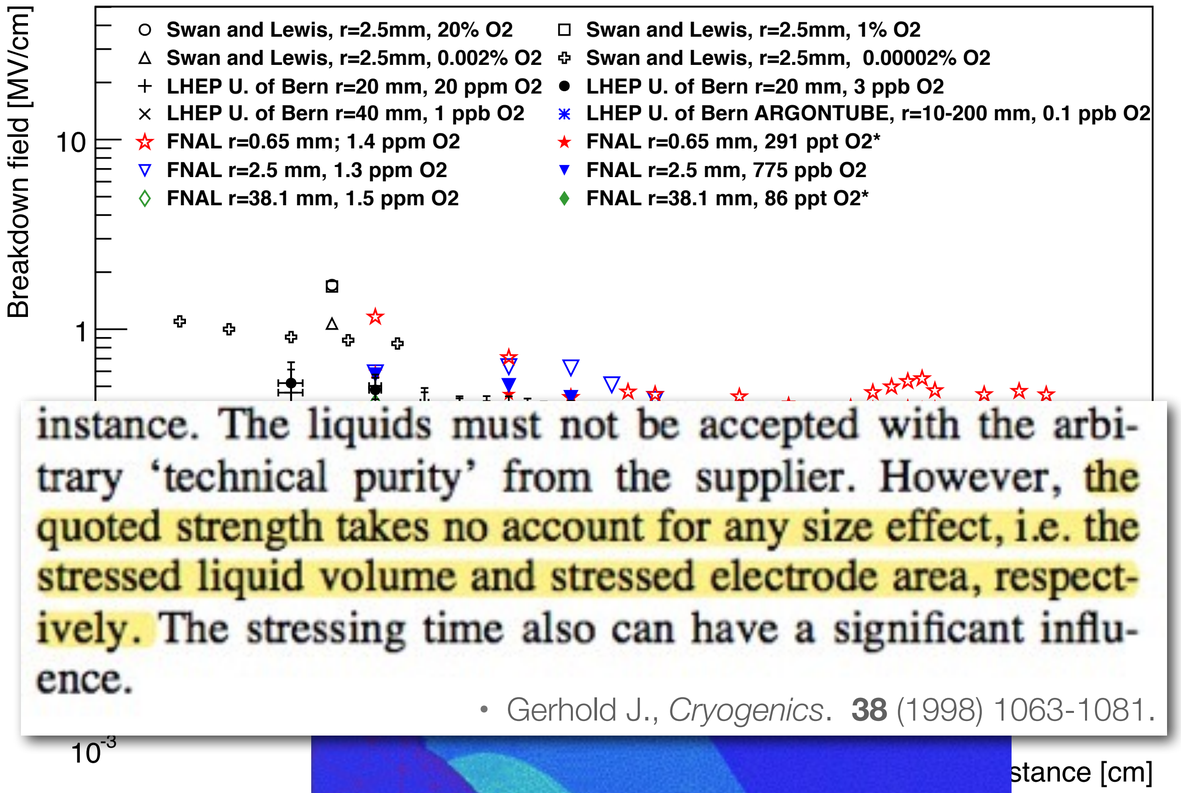
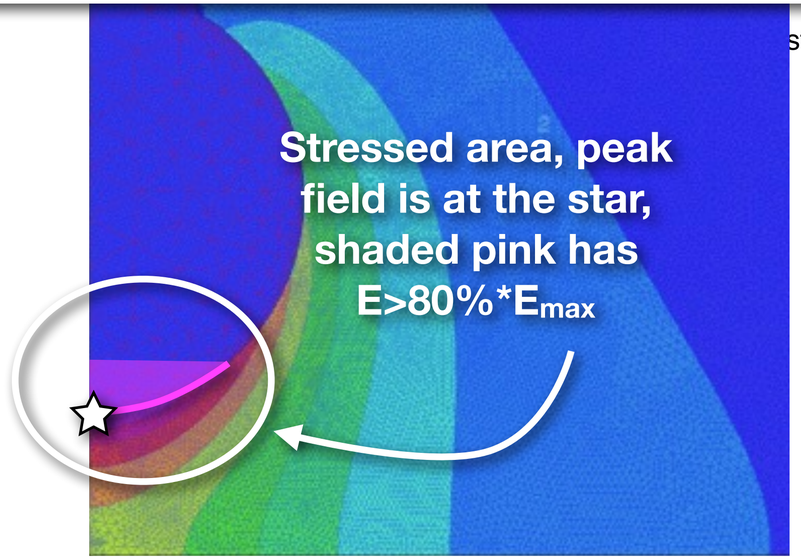


instance. The liquids must not be accepted with the arbitrary 'technical purity' from the supplier. However, the quoted strength takes no account for any size effect, i.e. the stressed liquid volume and stressed electrode area, respectively. The stressing time also can have a significant influence.

- Gerhold J., *Cryogenics*. **38** (1998) 1063-1081.



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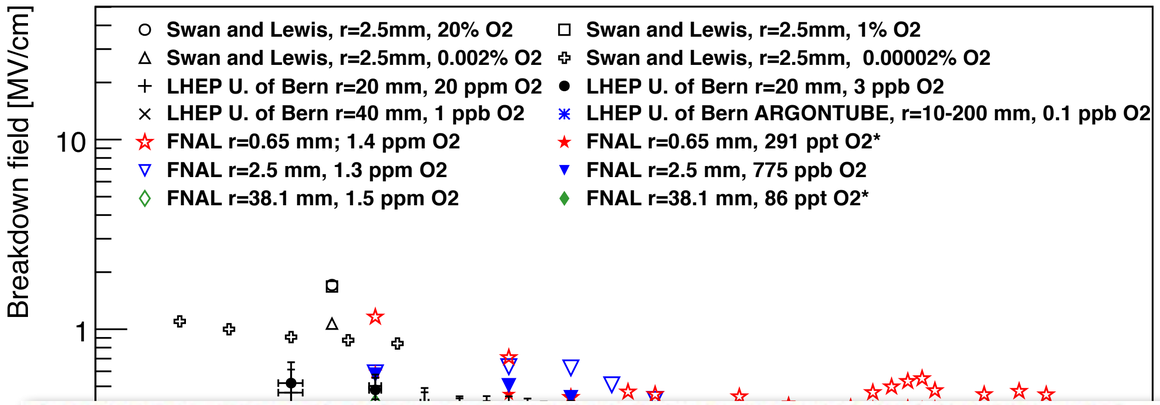
- It unified the trend across our data!
  - Currently the best metric for predicting breakdown voltage



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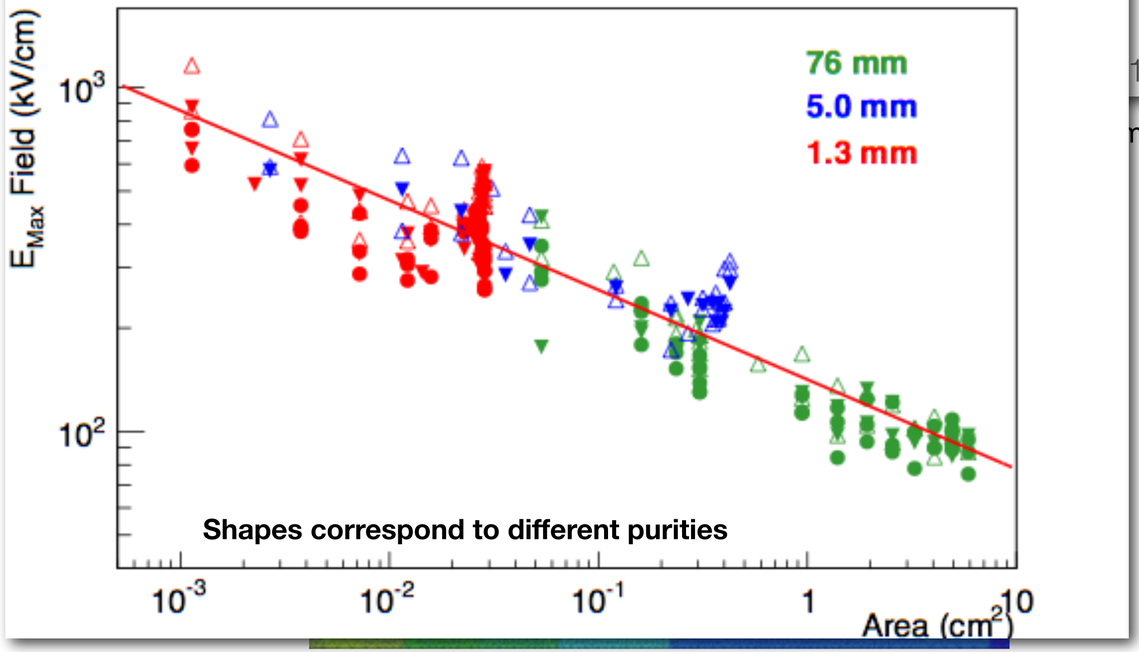

Volume or Area?

- We performed a measurement to evaluate how the breakdown field depended on volume and area
- Test was done in the Blanche cryostat at FNAL (access to pure argon)
- Plate-plate geometry based on a Rogowski profile but the gap could be varied
  - *Stressed area* is roughly constant versus gap, but the *volume* scales linearly

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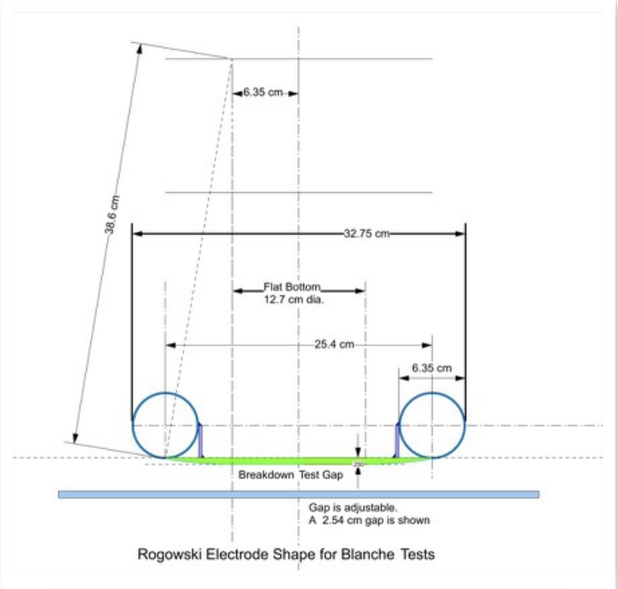
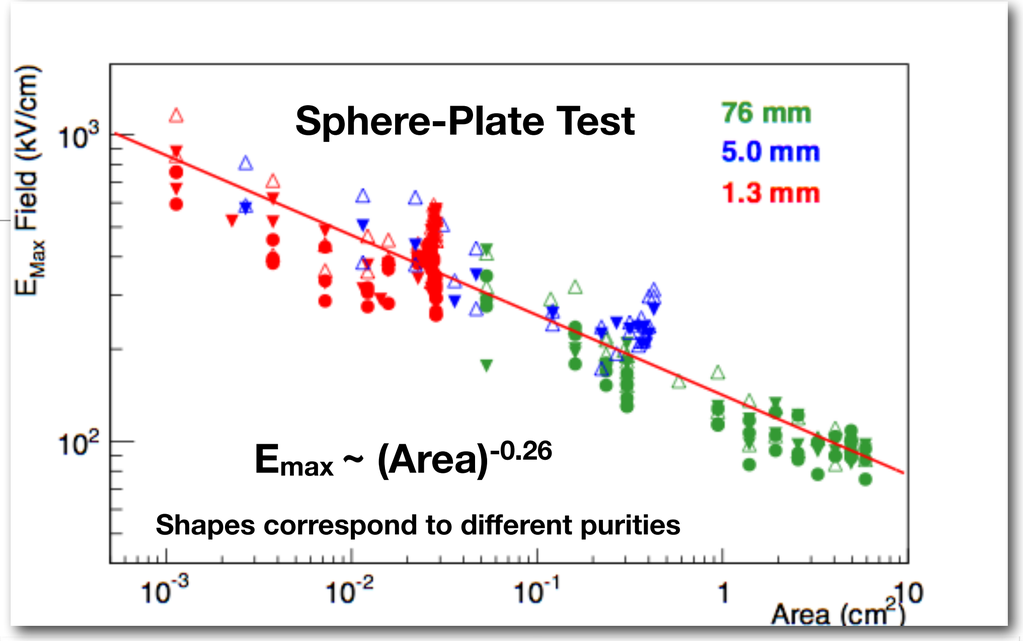
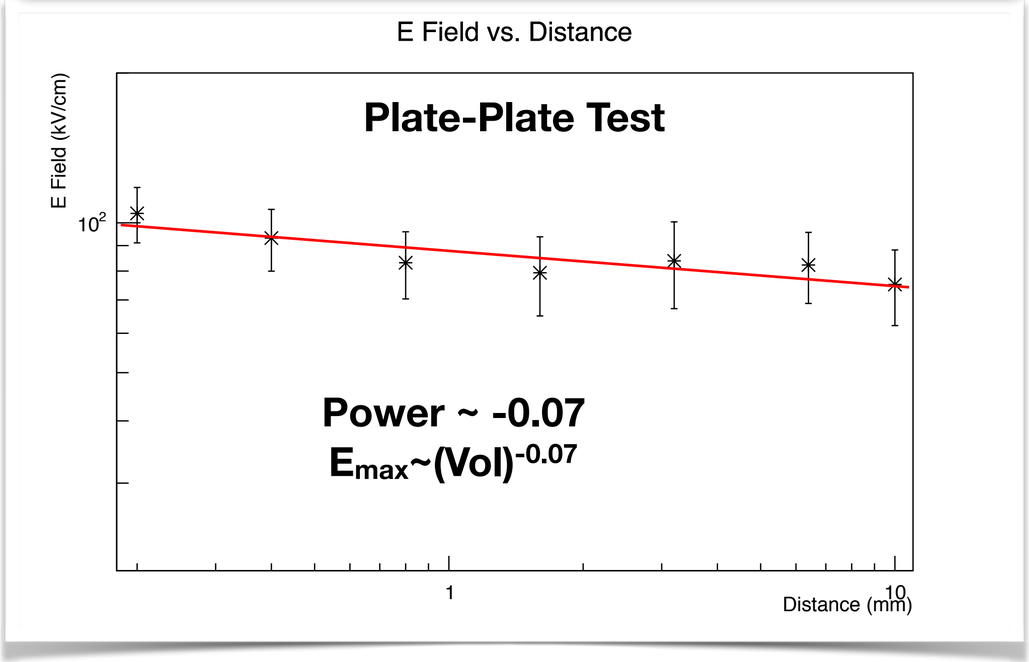


Volume or Area?

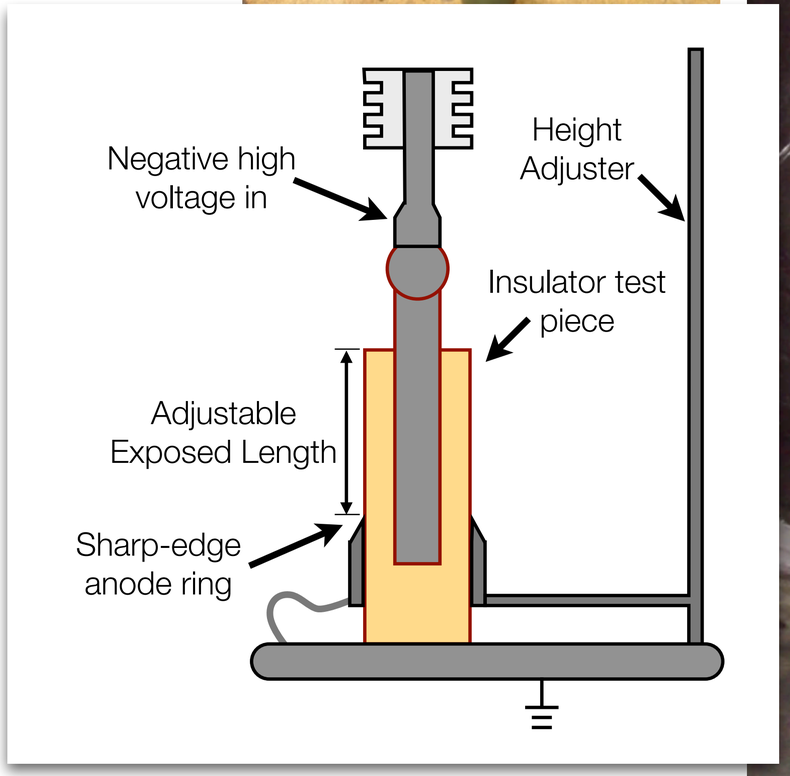
- The data from both the probe test and this plate test can be described by a **power law**
- In the sphere-plate test, the area and volume were highly correlated
  - The power law for the sphere-plate test ~ -0.26
- In the plate-plate test, only the volume changes
  - Here, we find about -0.07
- So preliminary results show it is **mostly area**, and volume might contribute on the 10% level.
- Results are in draft form — plan to be published





Other Fronts: Insulators

- Test of insulator performance in a feedthrough-like geometry
  - Insulator surrounding a conductor
- Evaluate materials, length, grooves/ profiles
- Caveat: this was done in an open cryostat
  - N2 kills late light, O2 eats electrons, impurities can perturb the local field.



2016_JINST_11_P03026, http://arxiv.org/abs/1506.04185

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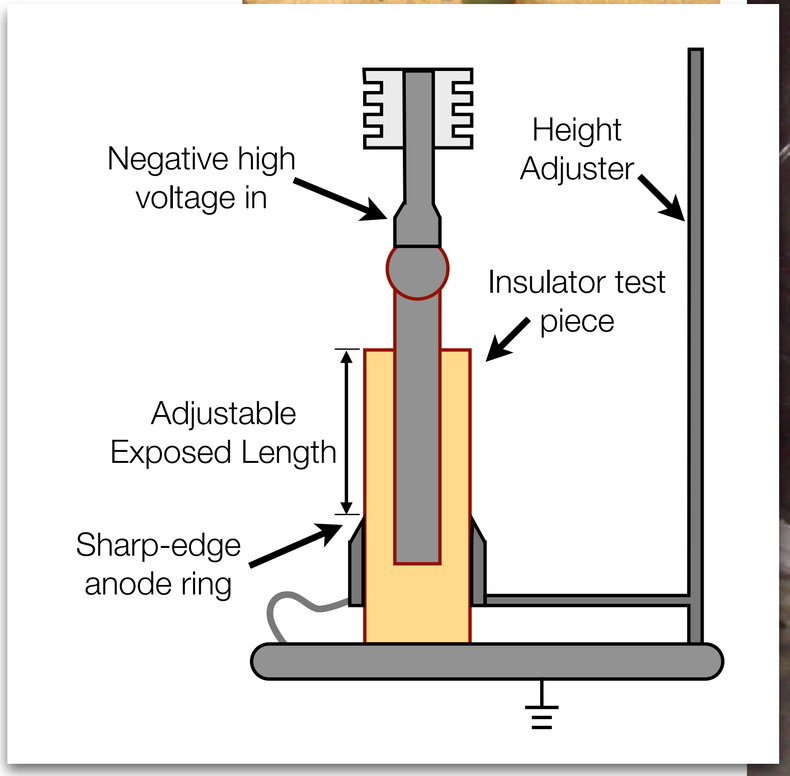

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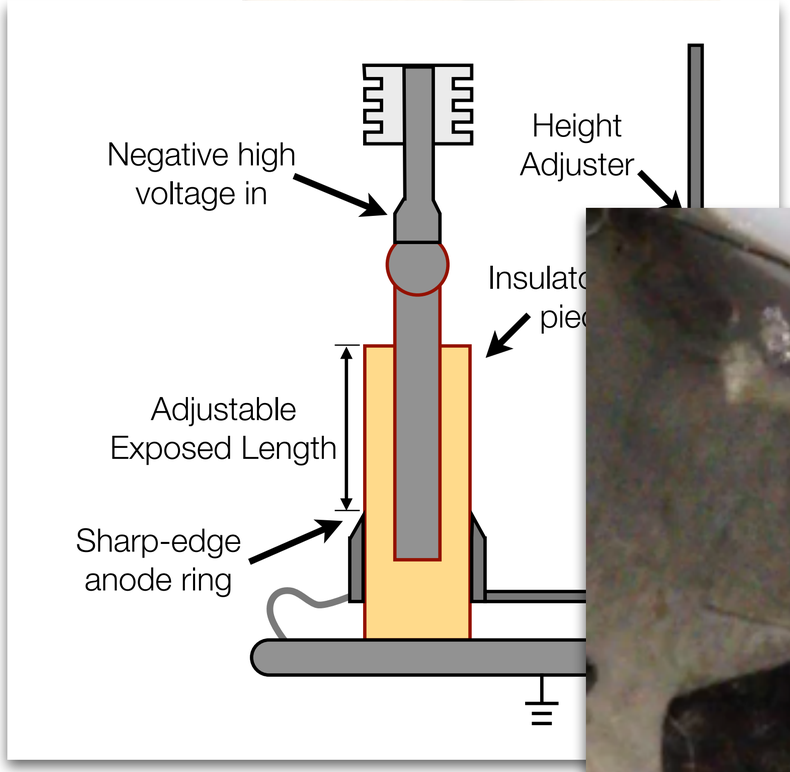

2016_JINST_11_P03026, http://arxiv.org/abs/1506

Insulator Study: Materials

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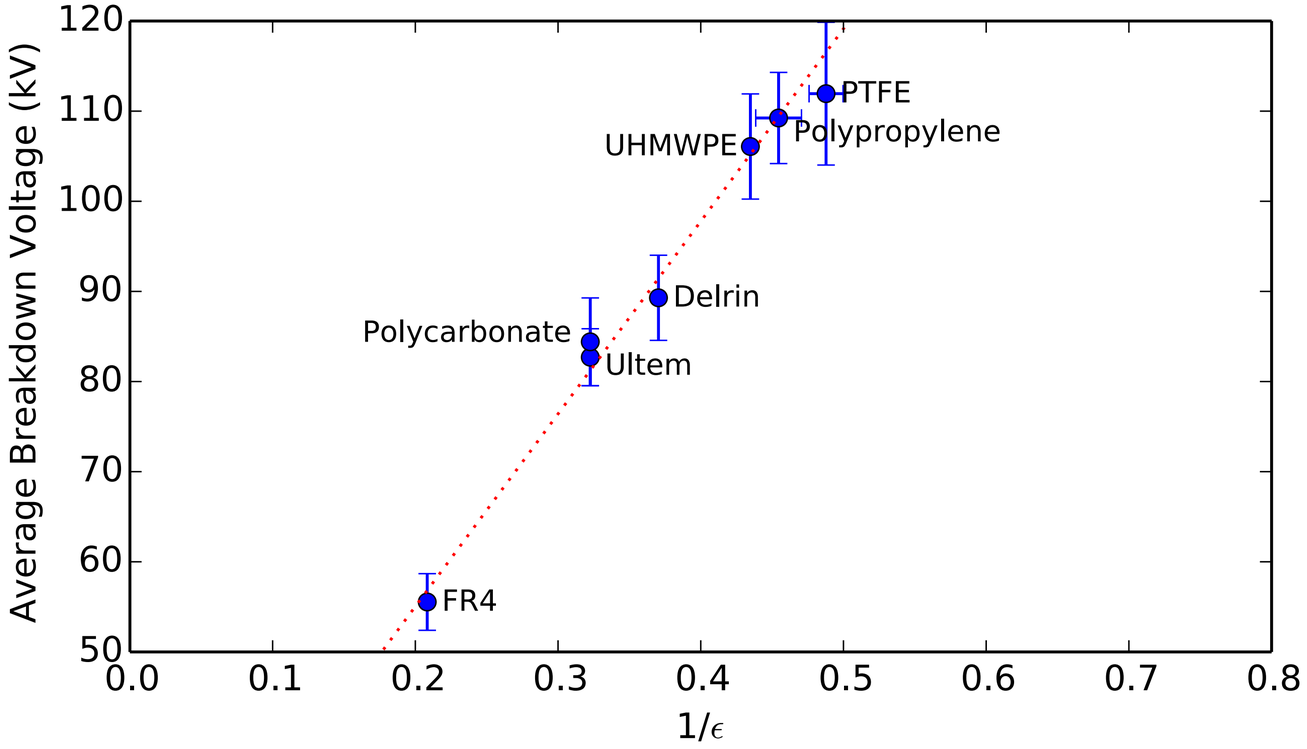
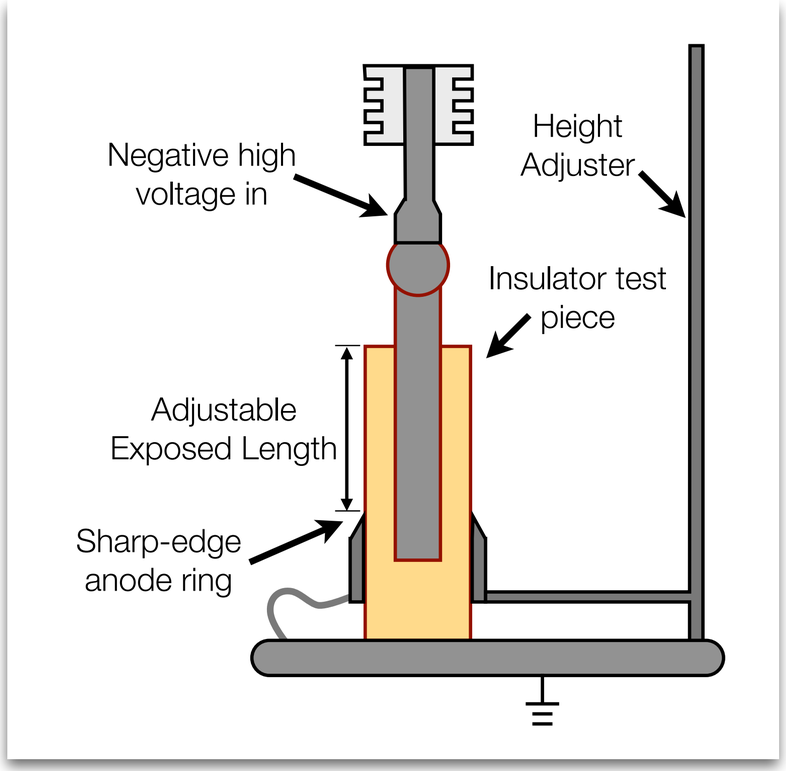
- We found that <u>differences in breakdown voltage between **materials** could be explained by differing permittivities</u> (—> resulting electric field at the insulator surface)



Insulator Study: Length

- We considered the exposed insulator length:



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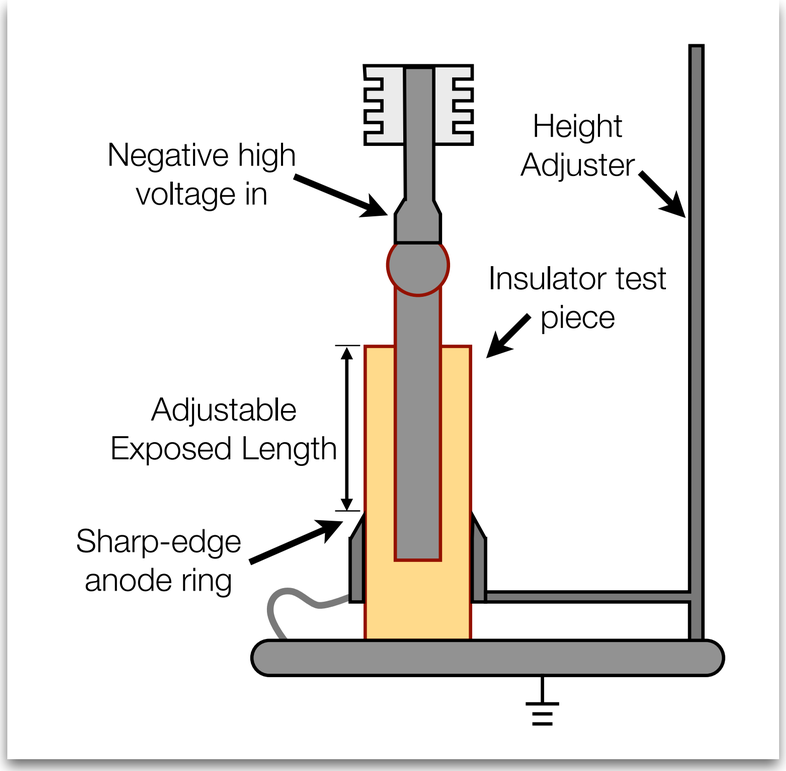

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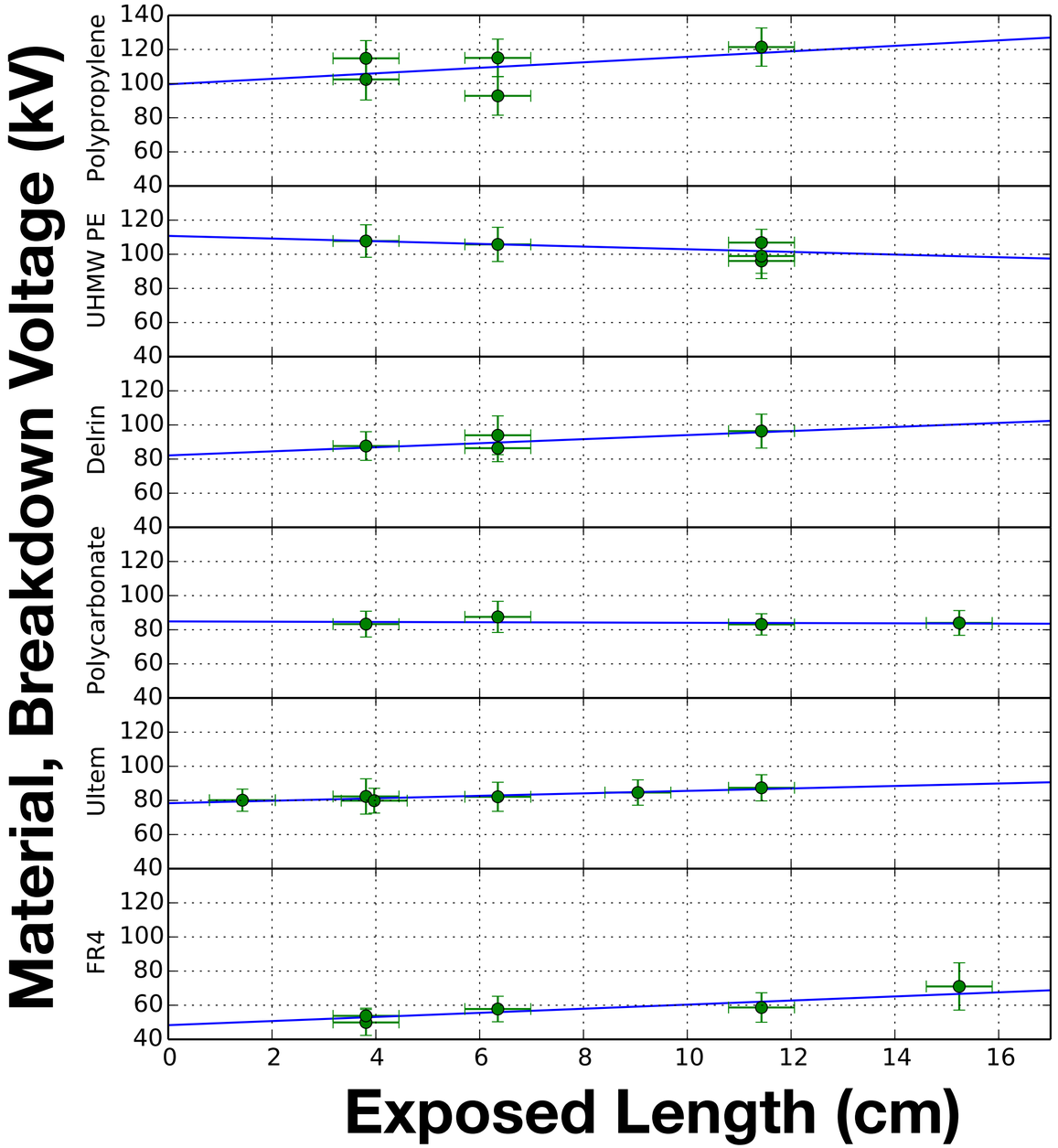

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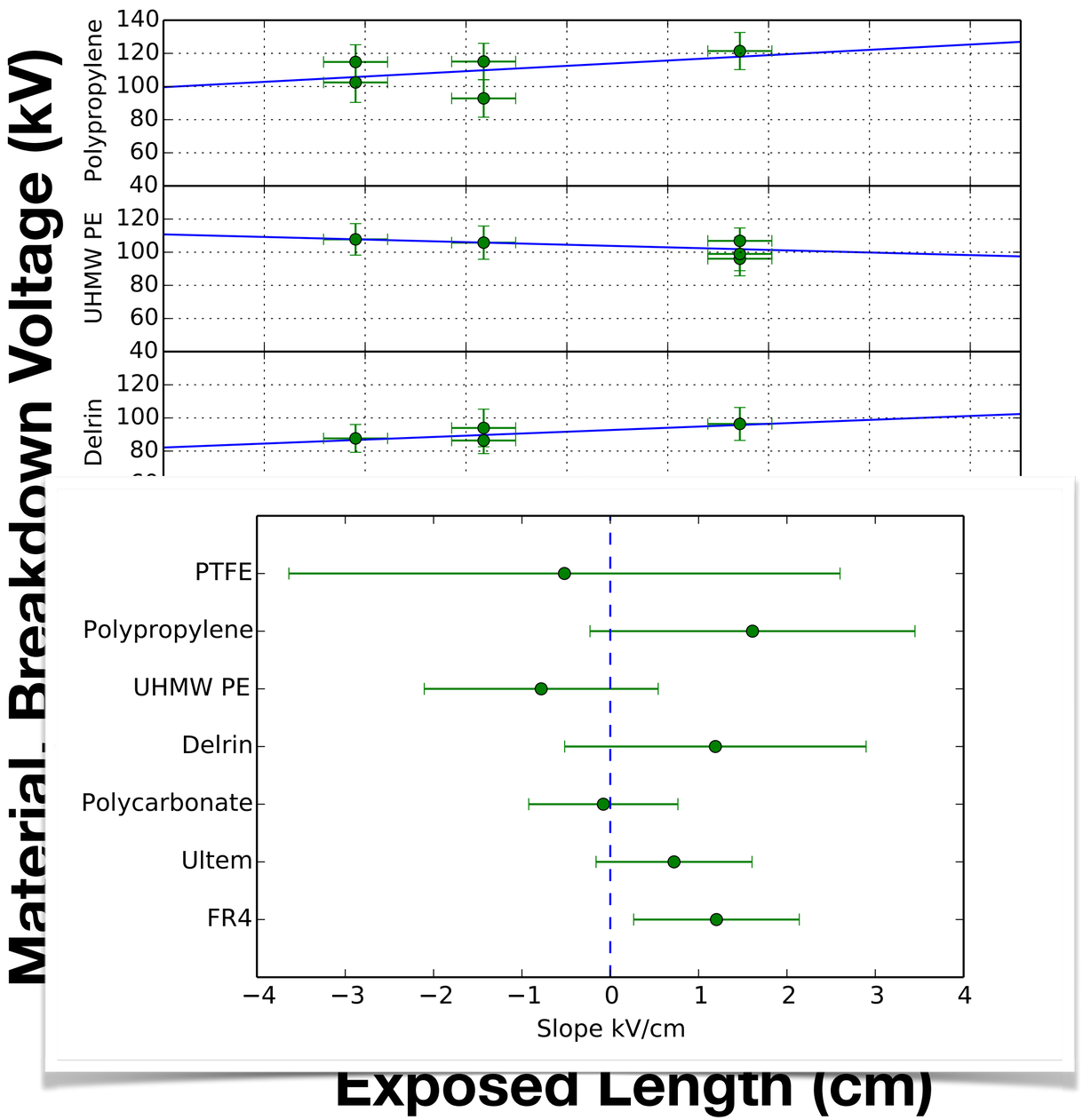
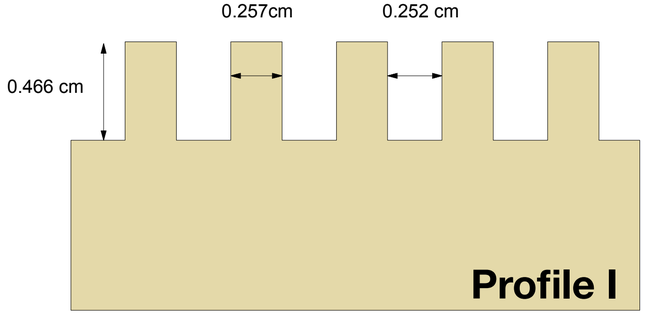
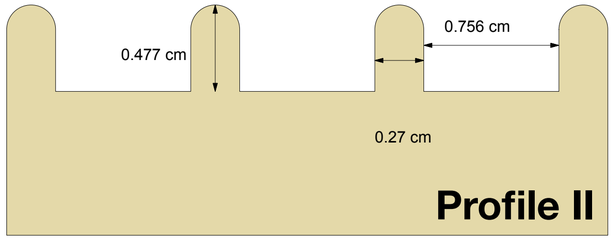


Insulator Study: Grooves

- Grooves are sometimes added to the surface of insulators to improve HV performance
  - This is seen frequently in HV bushings & standoffs
  - There, the idea is to increase the creepage path
  - In liquid argon, it's less clear
    - Surface with a component anti-parallel to the E field to inhibit travel?
    - Islands where charges collect reducing the local field?

HV bushing from the Baltimore Museum of Industry

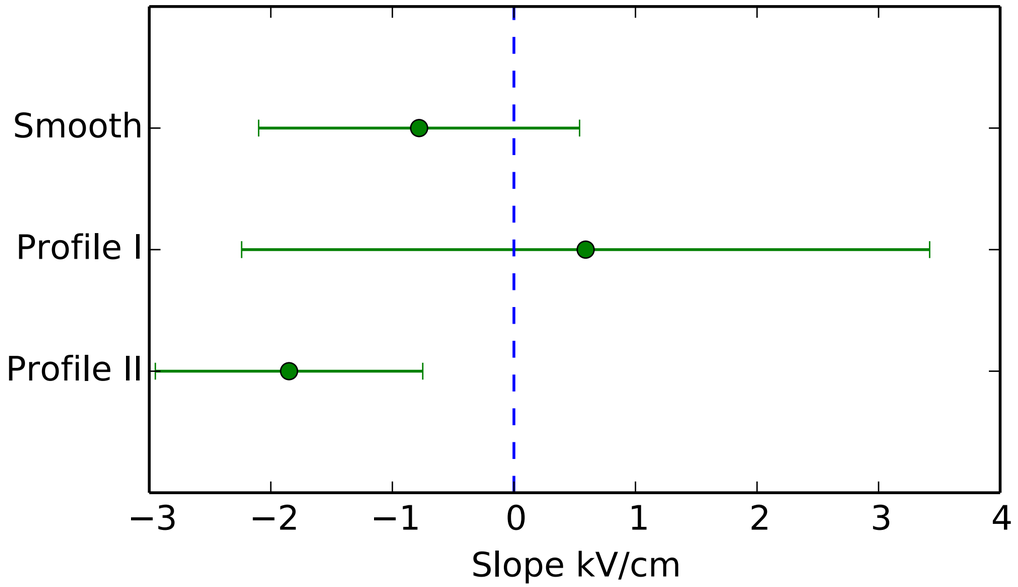


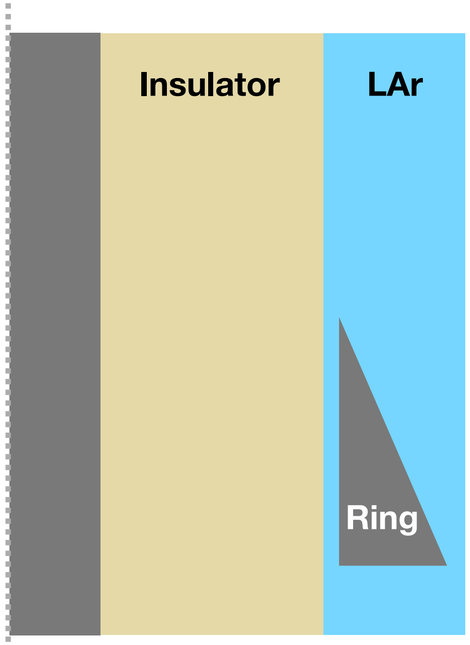


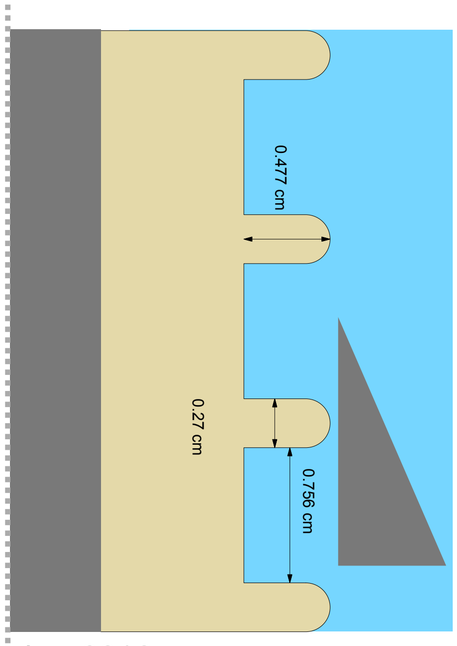
Insulator Study: Grooves

- However, an initial test of the effect of adding **grooves** to the surface showed little effect on breakdown voltage (at most ~10%).

- The effect could be explained by the change in electric field simply by removing material (different permittivity changes the local field)

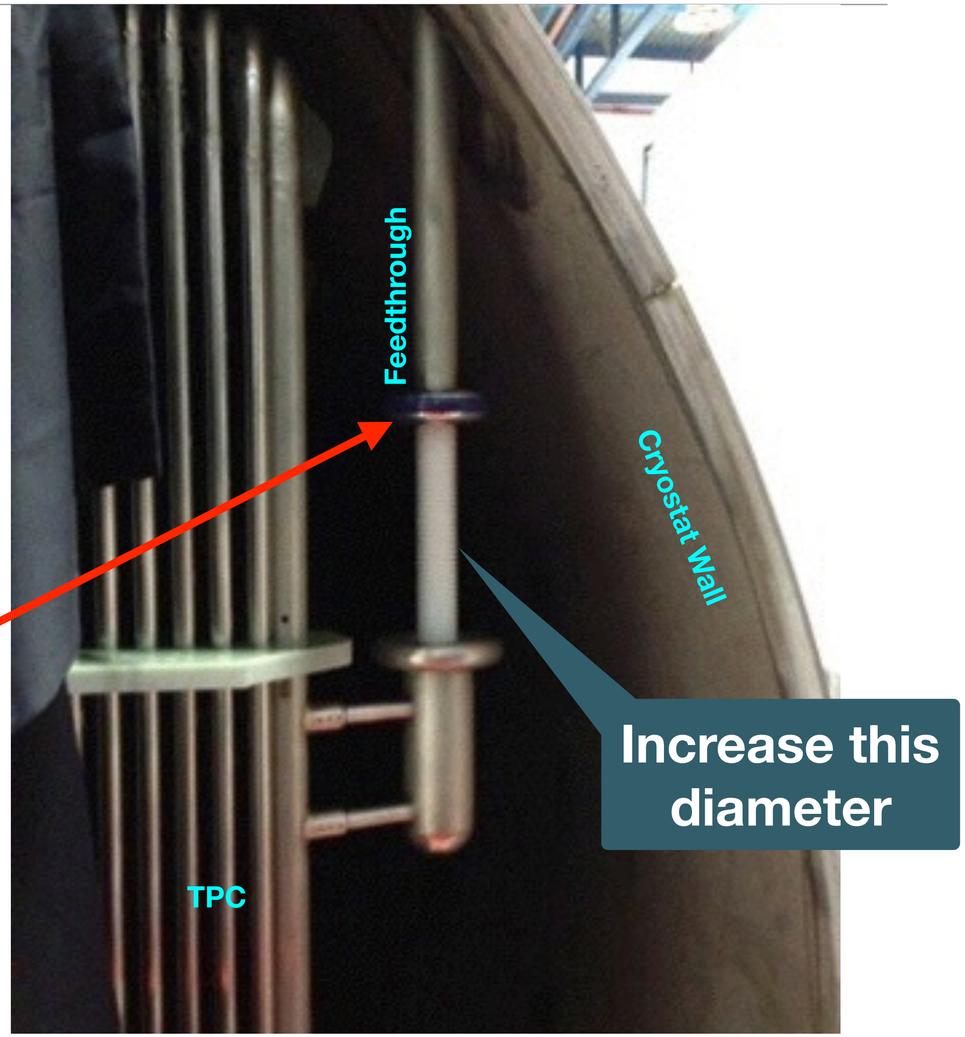






Insulator Study: Implications for HV Feedthroughs

- The length independence is supportive of a narrative where once the streamer starts, it can be self-sustaining
- This along with the material independence suggests that the key parameter is the **peak electric field**
  - One can reduce this with
    - Selection of material
    - Careful design of the ground tube
    - Increasing the insulator radius



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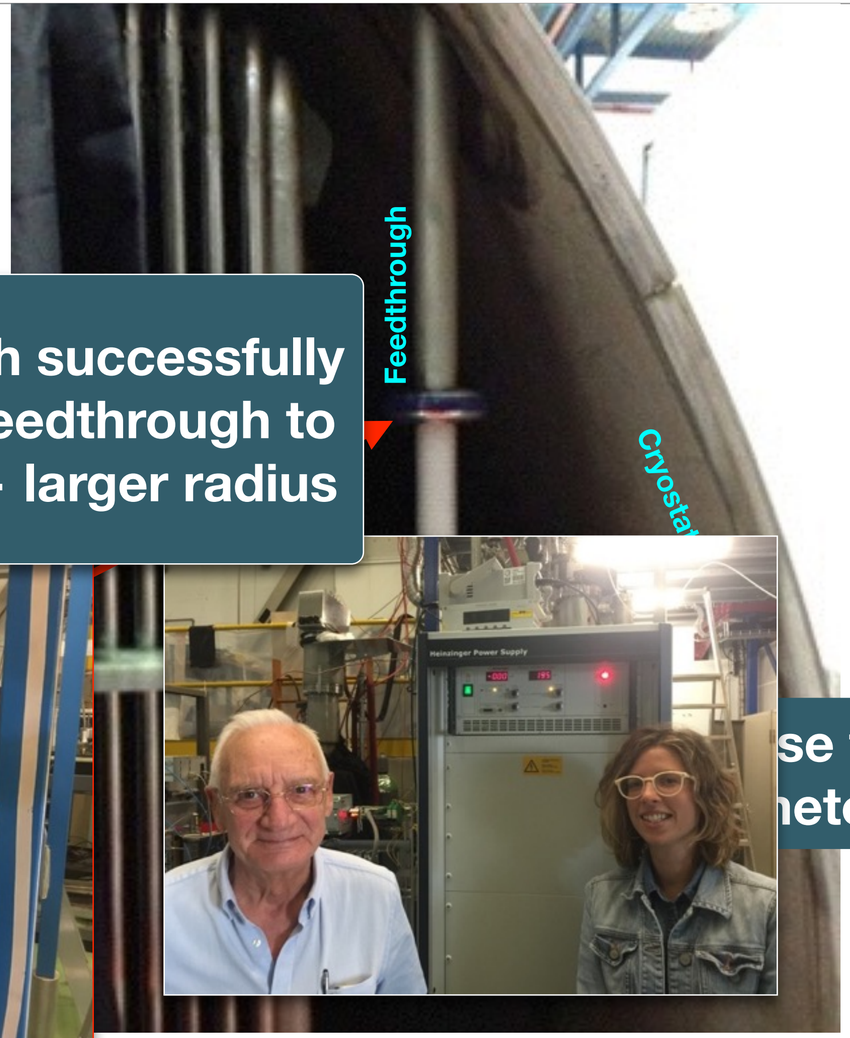
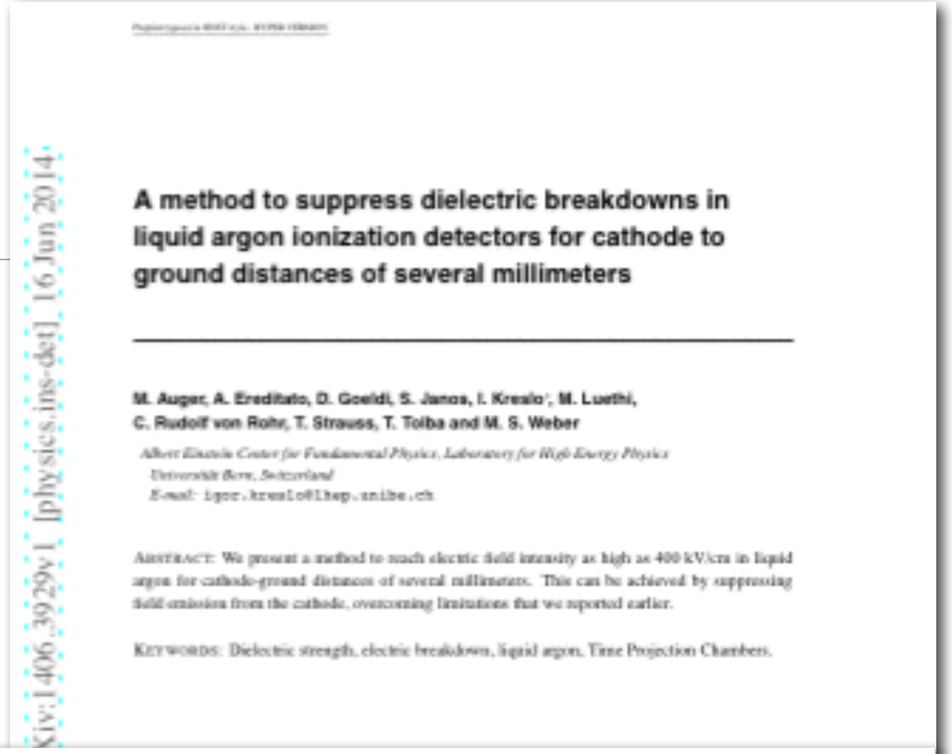


ETH Zurich successfully tested a feedthrough to 280 kV!! — larger radius

se this neter

Other Practical Matters: Prevention

- LHEP Bern has investigated increasing the max field a component can withstand under HV with a polymer coating (http://arxiv.org/abs/1406.3929v1)
- Prevents streamer from starting!
- Fields as high as **412 kV/cm** were reached over several mm before breakdown



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

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

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ABSTRACT: We present a method to reach electric field intensity as high as 400 kV/cm in liquid argon for cathode-ground distances of several millimeters. This can be achieved by suppressing field emission from the cathode, overcoming limitations that we reported earlier.

KEYWORDS: Dielectric strength, electric breakdown, liquid argon, Time Projection Chambers.

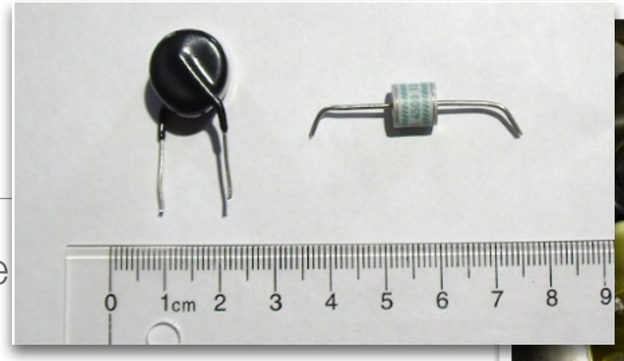
Closing

- HV in LAr is an important area of study for LArTPC design and development
- Much has been learned in the past few years that has allowed us to build better components/detectors
- Outstanding questions remain
  - To allow us to efficiently design robust & powerful TPCs in the future
    - Insulator charge up?
    - Universal parameter of interest?
    - Dependence on time?
  - More general R&D
    - What role does light play?
    - Spark mechanics including time scale

Back-Up Slides

Other Practical Matters: Protection

- Protect the TPC: varistors & GDTs offer effective over voltage protection (http://arxiv.org/abs/1406.5216)
  - Added to MicroBooNE, LArIAT, ProtoDUNE, and more
- Robust resistors: resistors that can withstand a large over-voltage/power condition
  - Resistor failure study: 2014 JINST 9 T11004, arxiv.org/abs/1408.4013
  - The first 1/4 of MicroBooNE was replace with durable resistors
- Increase the time of a discharge/limit the energy: resistive cathode
  - ProtoDUNE



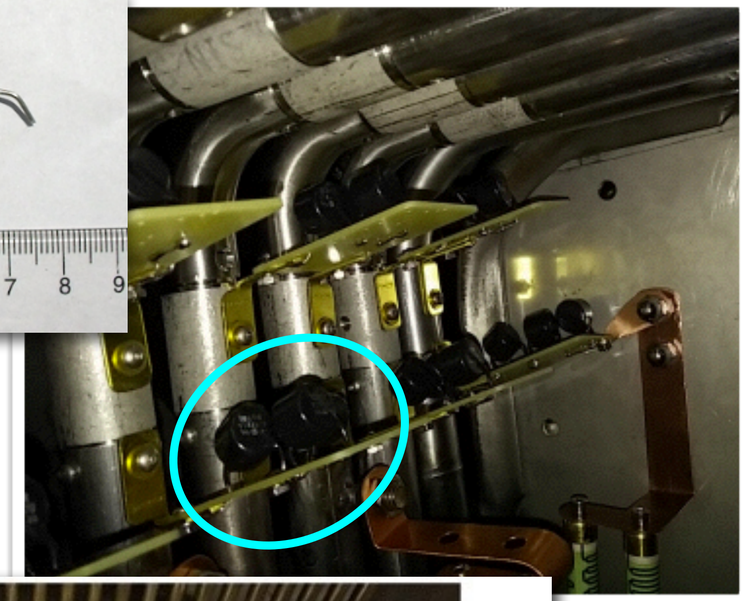


Figure 10. The Metallux HVR 969.23 resistors mounted on the 16 field cage loops closest to the cathode.