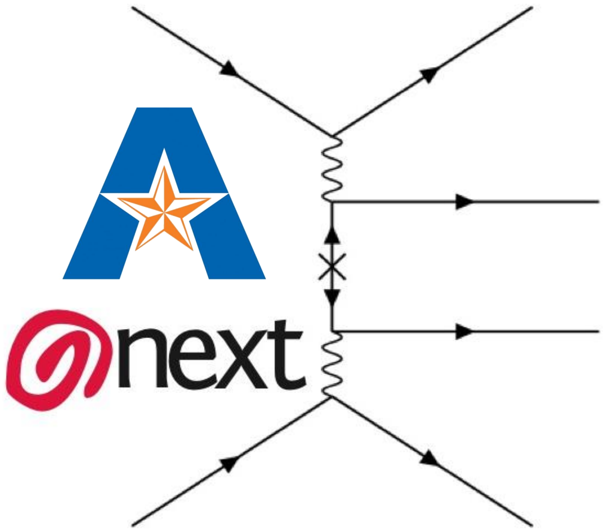


Electroluminescence R&D Toward Ton-Scale HPGXe Neutrinoless Double Beta Decay Experiments

Leslie Rogers on behalf of the NEXT experiment

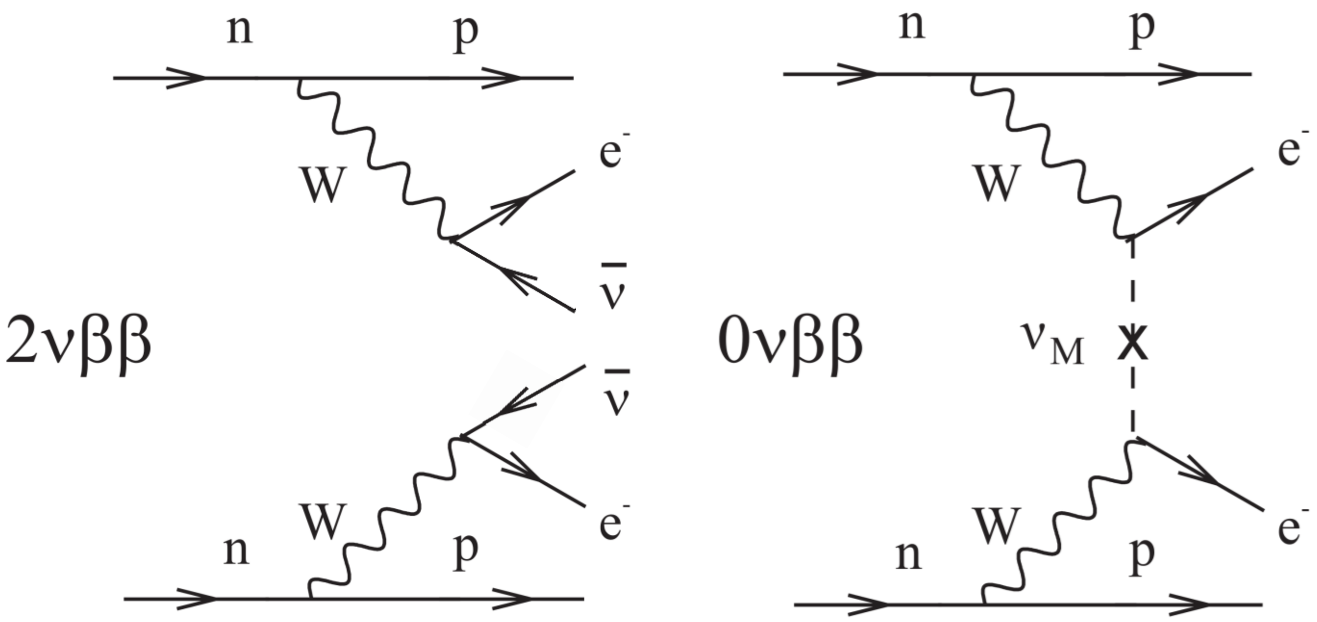
University of Texas at Arlington

December 4, 2018

Supported by:

U.S. DEPARTMENT OF ENERGY

Neutrinoless Double-Beta Decay

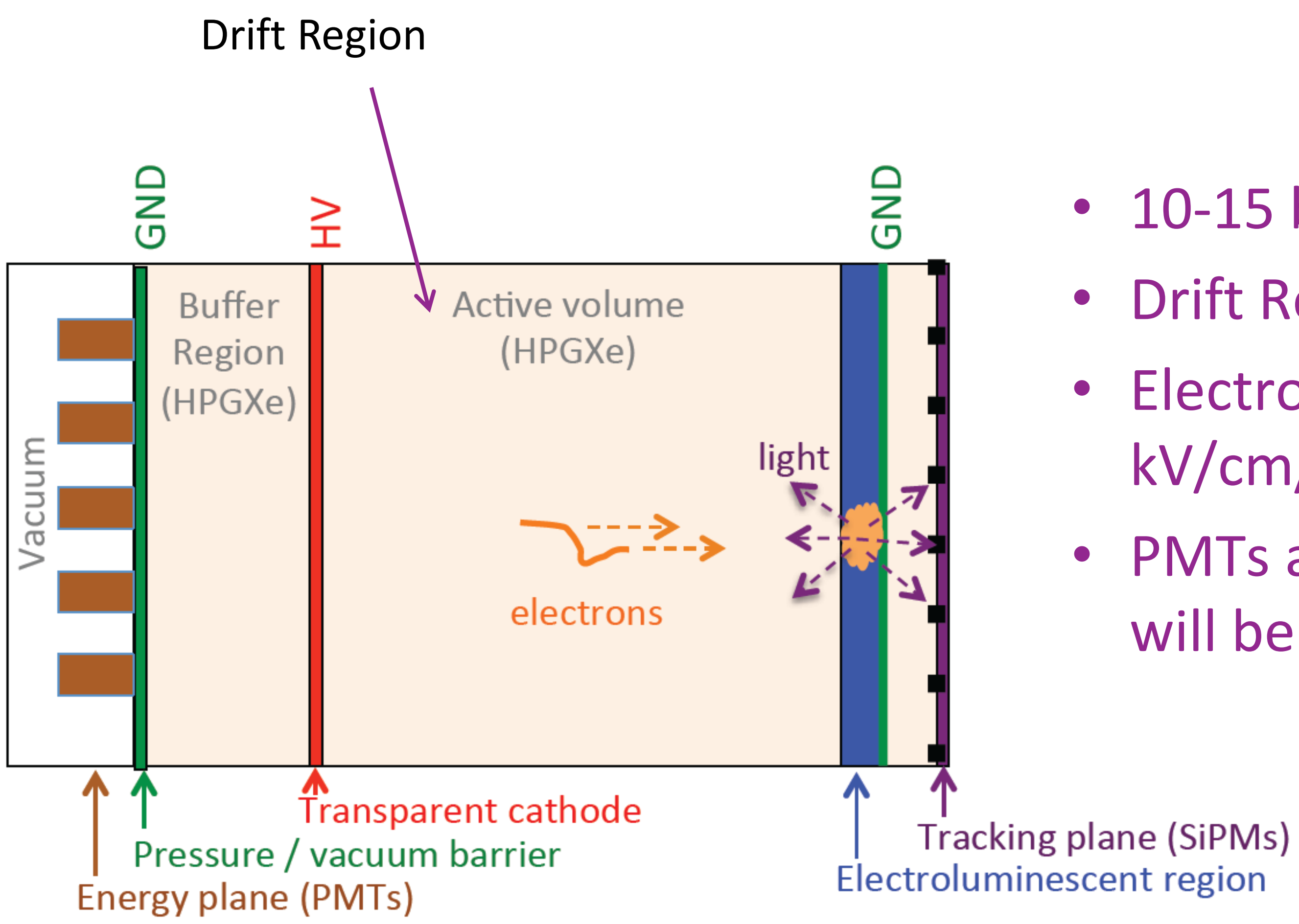


•If a neutrino is it's own antiparticle (Majorana) a double beta decay without emission of antineutrinos is possible

•This would cause the two beta particles to carry all the energy difference from the initial and final nuclei

•Seeing this event would tell us that Lepton number is not conserved

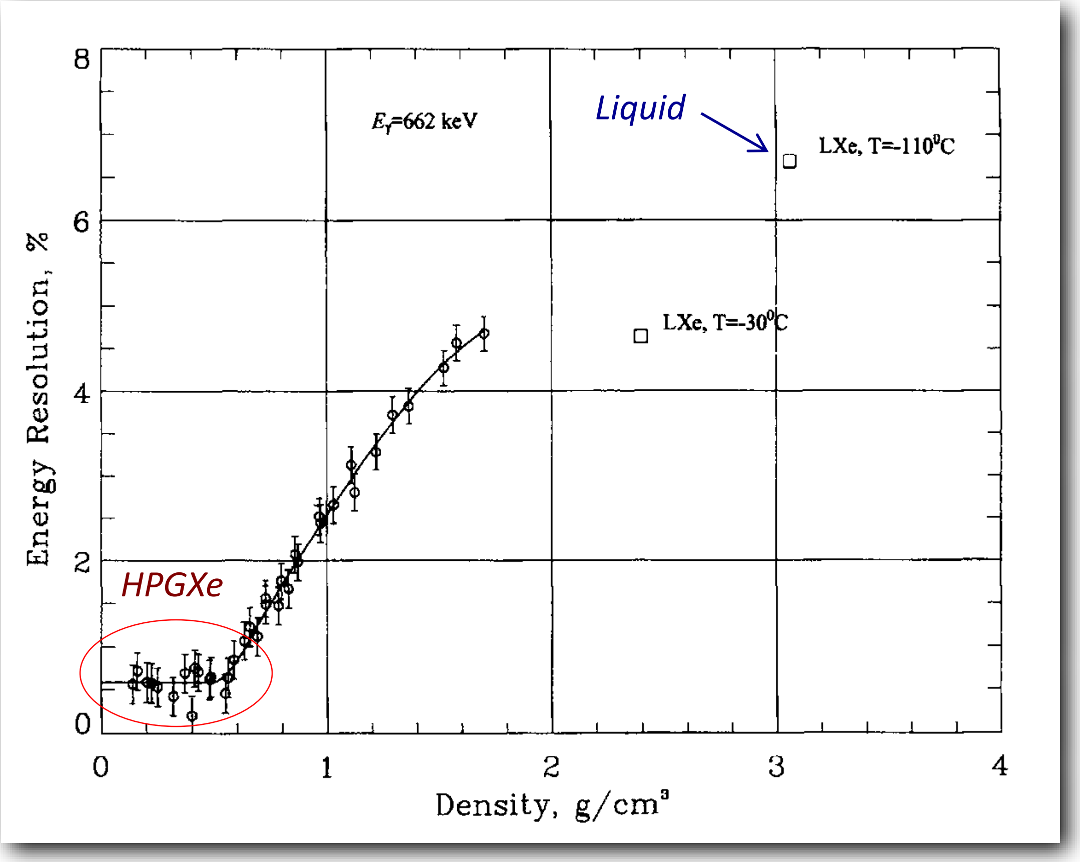
Basic Principles of the Detector



- 10-15 bar of HPGXe136
- Drift Region 300 V/cm
- Electroluminescent Region of 56 kV/cm (5.6 kV/cm/bar at 10 bar, 3.73 kV/cm/bar at 15 bar)
- PMTs and SiPMs for capturing 175nm light that will be wavelength shifted with TPB

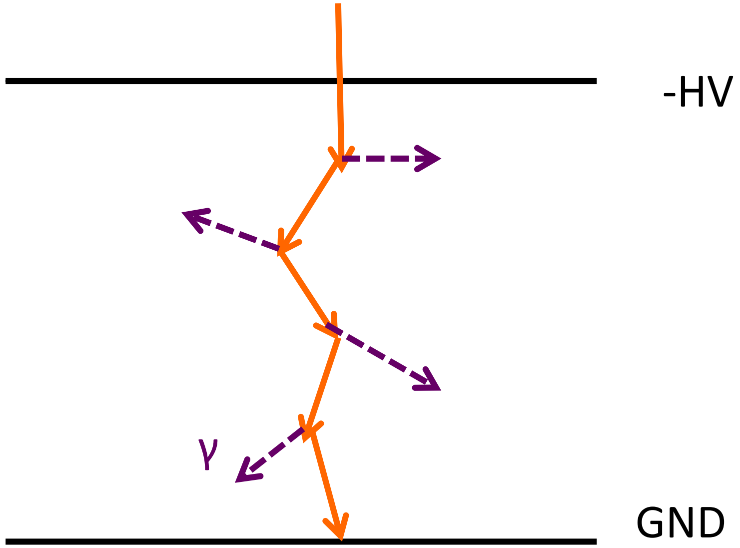
Advantages of HPGXe136

Measuring ionization only (@662 keV)



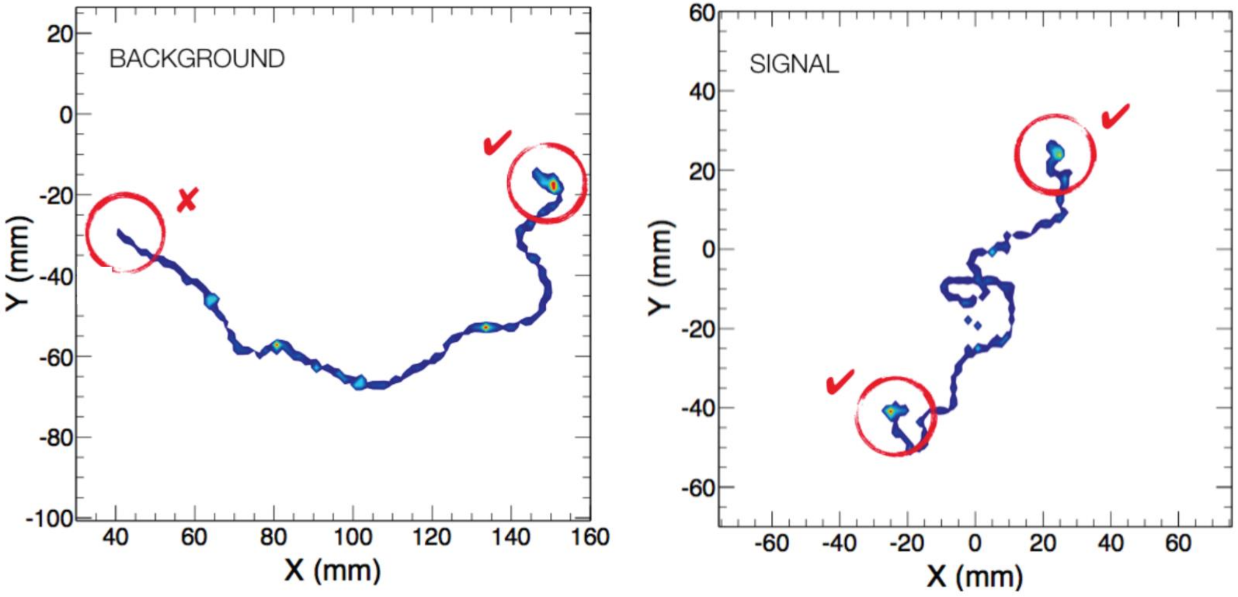
Bolotnikov, & Ramsey NIMA, 396, 360–370.

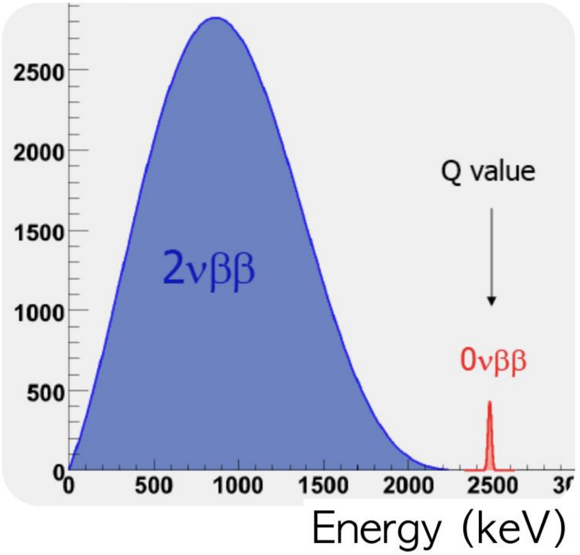
Using gaseous Xenon versus liquid allows a clear topological reconstruction and low fluctuation gain using electroluminescense



$e^- + Xe \rightarrow e^- + Xe^* \rightarrow e^- + Xe + \gamma$

How to Tell if We Have a 0νββ Decay





2 Steps

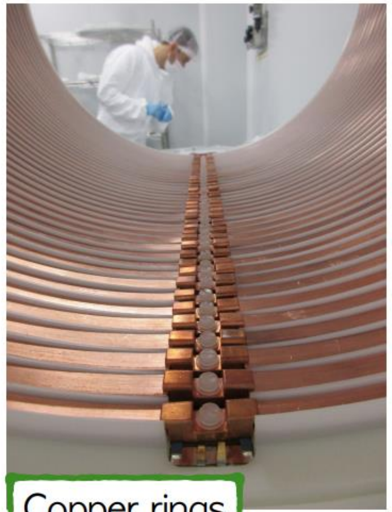
- First, topology: spaghetti with two meatballs
- Second, energy resolution

To do this we need a way to separate single electron tracks from signal using the event topology

Sequence of Detectors for NEXT Program

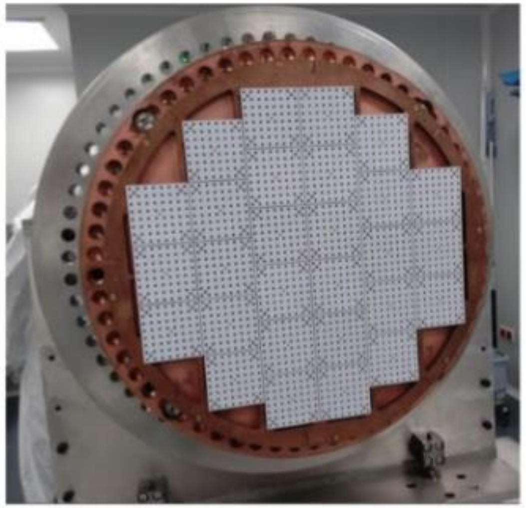
- NEXT-DBDM <1kg located in Berkeley National Lab
- NEXT-DEMO 1-2kg located in Valencia
- NEXT-NEW 5-10kg currently collecting second run of data in Laboratorio Subterráneo de Canfranc (LSC)
- NEXT-100 100kg under construction in the tunnels of Canfranc
- NEXT-XXX 1 tonne with location to be determined

NEXT-NEW Components



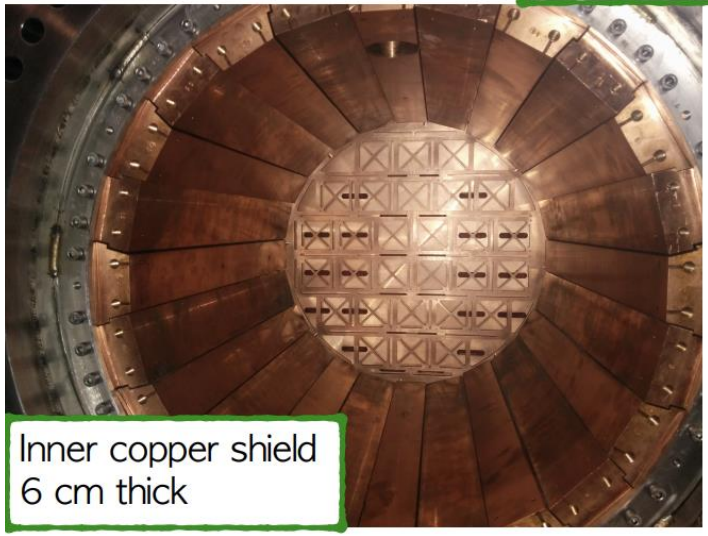
Copper rings

HDPE field cage + teflon reflector

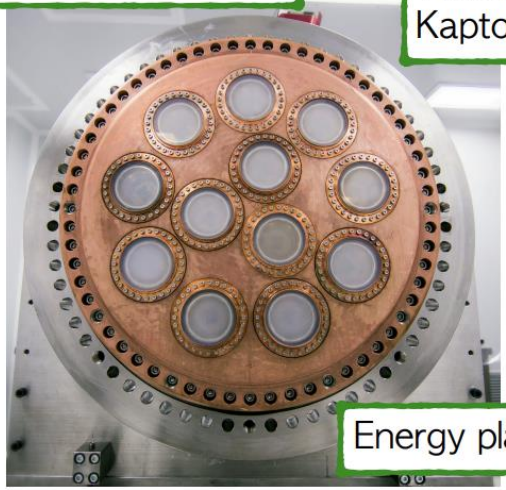


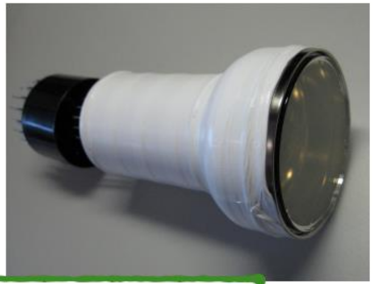
Tracking plane of 1 cm pitch, Kapton boards, teflon masks

High Voltage Feedthrough



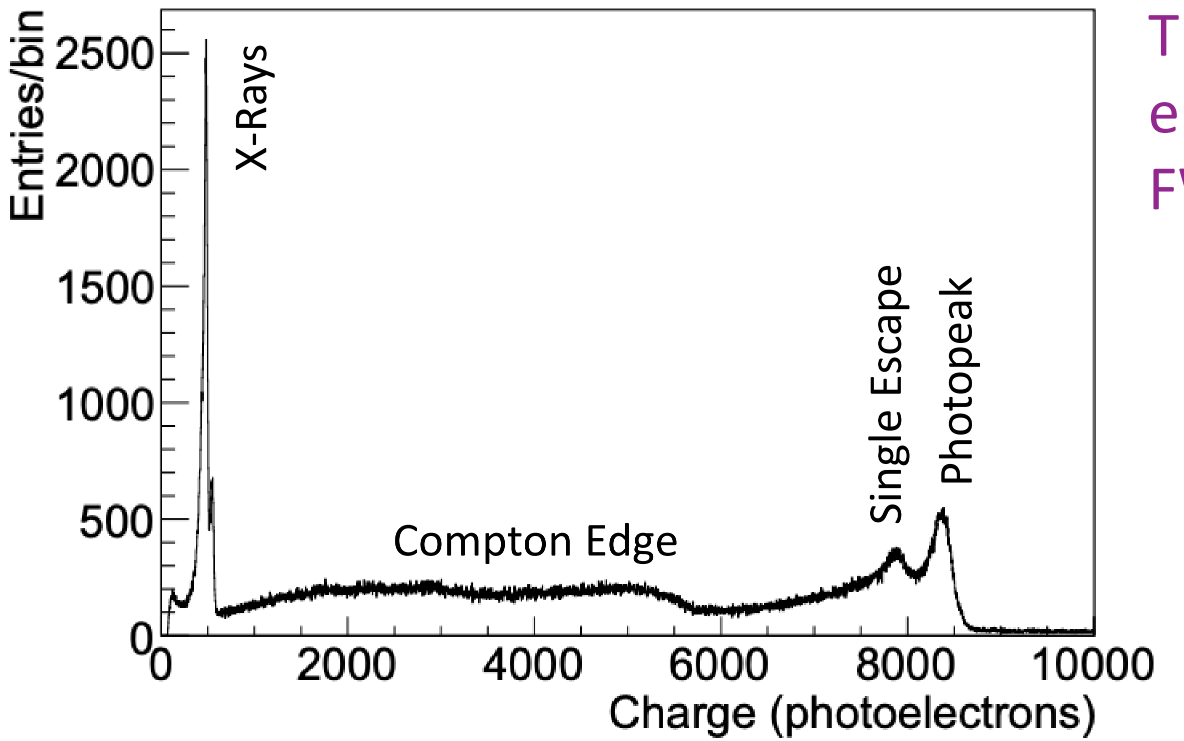
Inner copper shield 6 cm thick





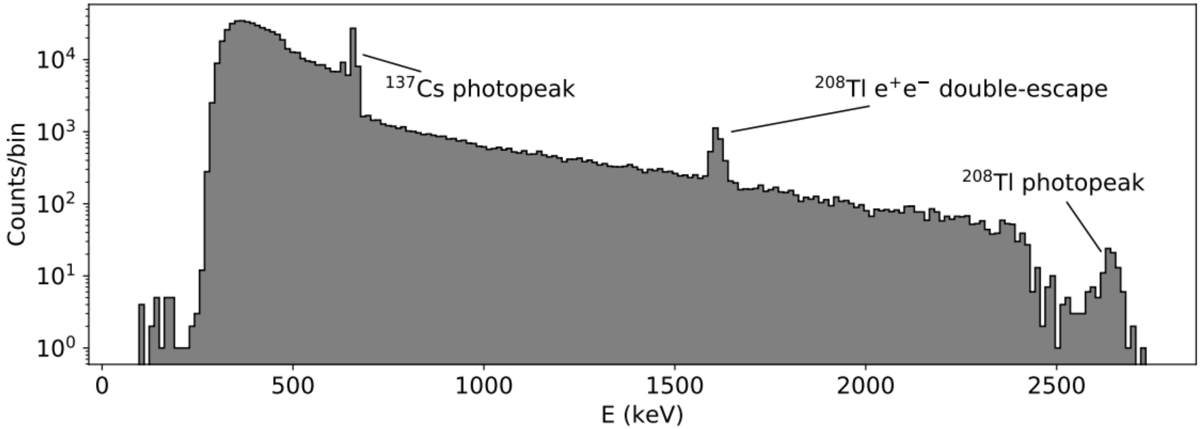
Energy plane, 30% coverage

NEXT Energy Results



Energy peaks when using Sodium source

The most recent run of NEXT-NEW provided an energy resolution that extrapolates to 0.43% FWHM at Qbb assuming no constant term.



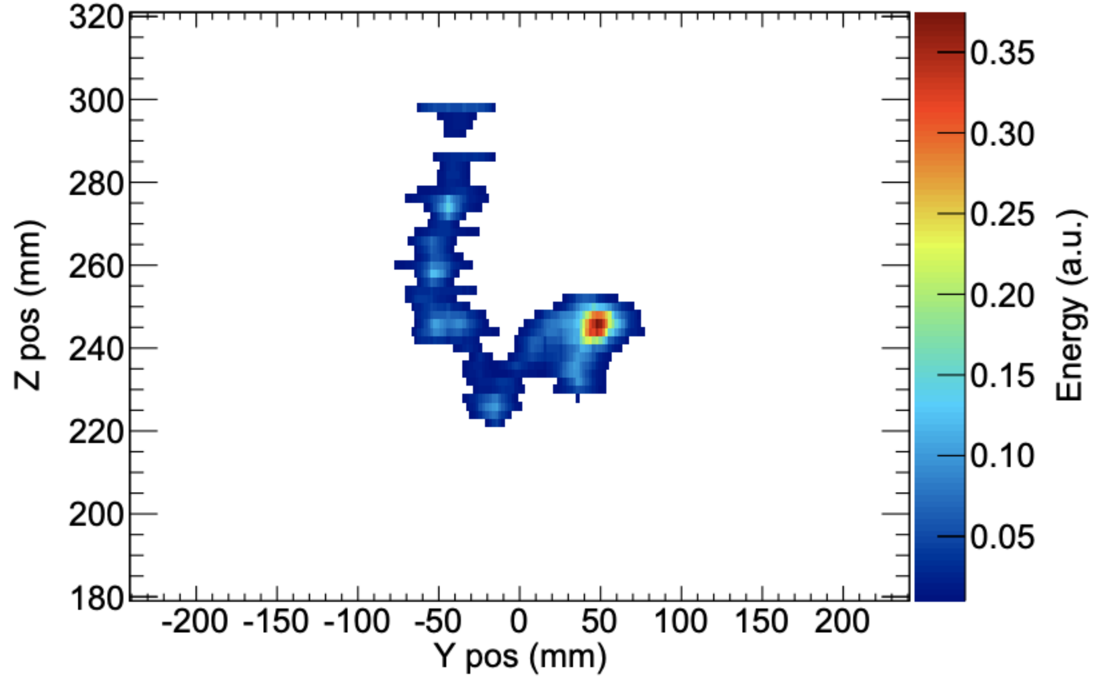
Energy peaks when using Thalium and Cesium source

D. Lorca et al., Characterisation of NEXT-DEMO using xenon Kα X-rays, JINST 9 (2014) , P10007, [arXiv:1407.3966]

J. Renner et al., Initial results on energy resolution of the NEXT-White detector, JINST 13 (2018) ,no.10 P10020, [arXiv:1808.01804]

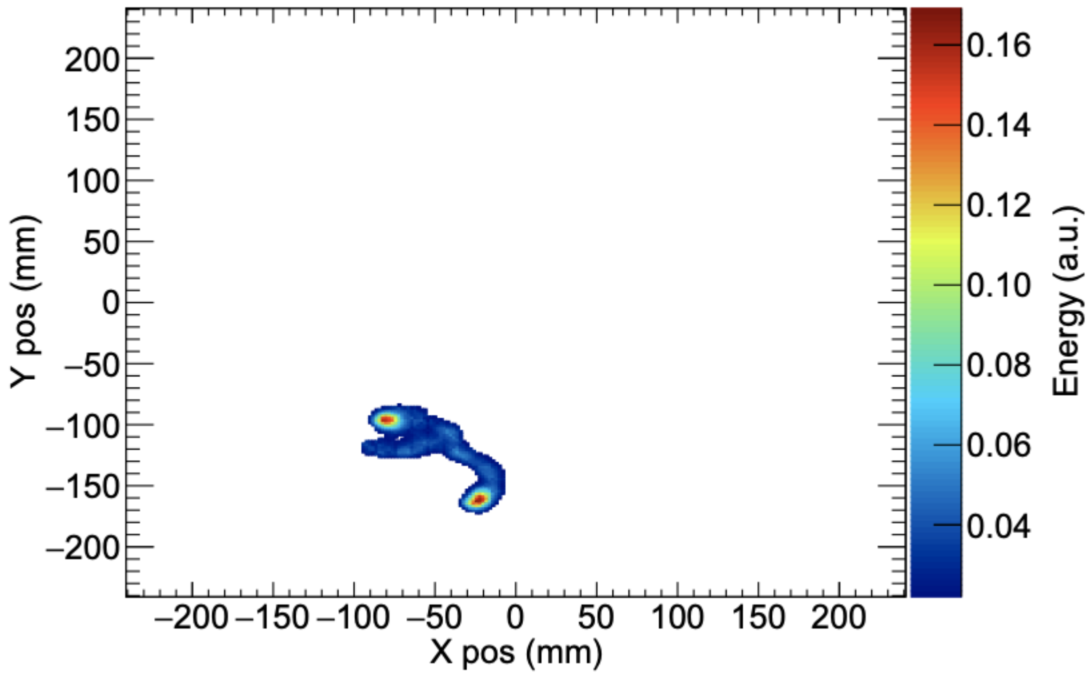
NEXT-NEW Results Using Co-56

Background-like Event



Single electron event resembling backgrounds

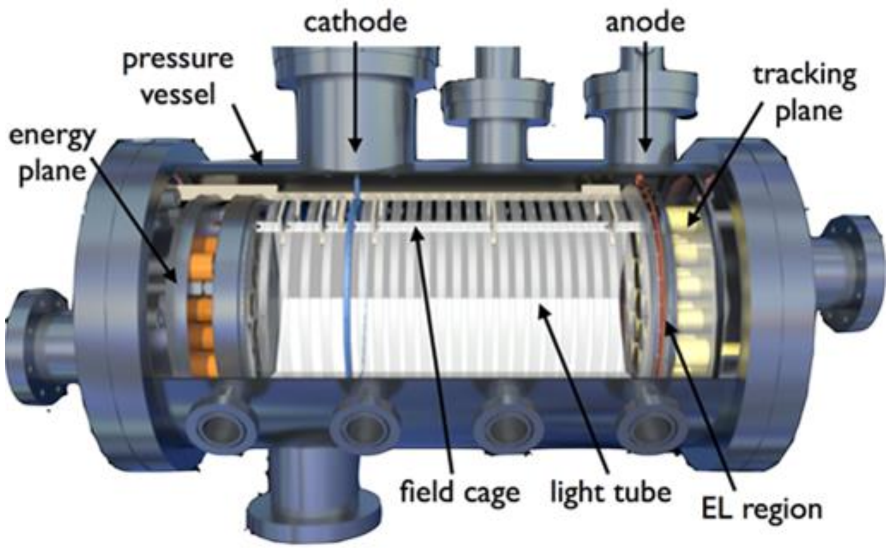
Signal-like Event



Double escape event resembling double beta decay

Paola Ferrario, The NEXT double beta decay experiment, [arXiv:1710.03022]

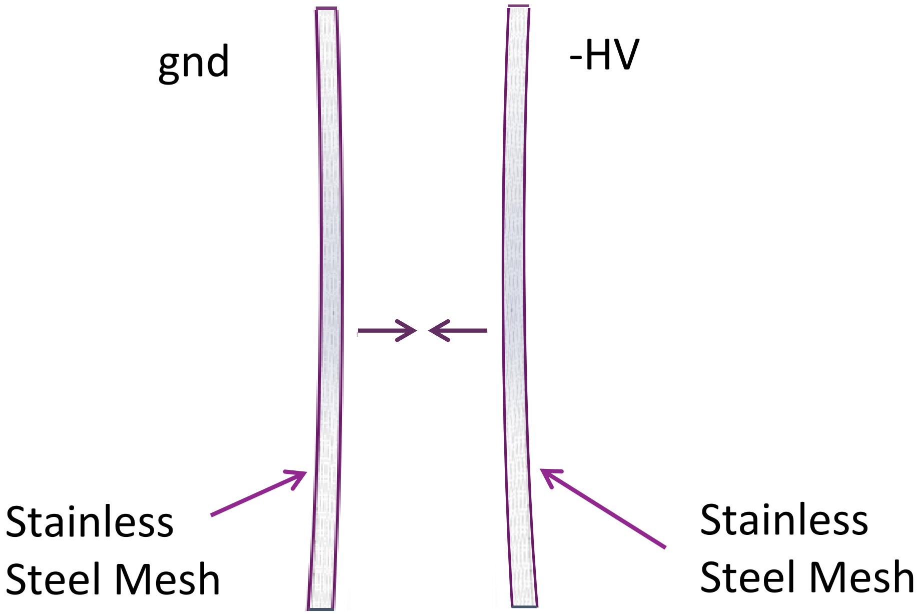
Electroluminescence Requirements



NEXT-DEMO Components

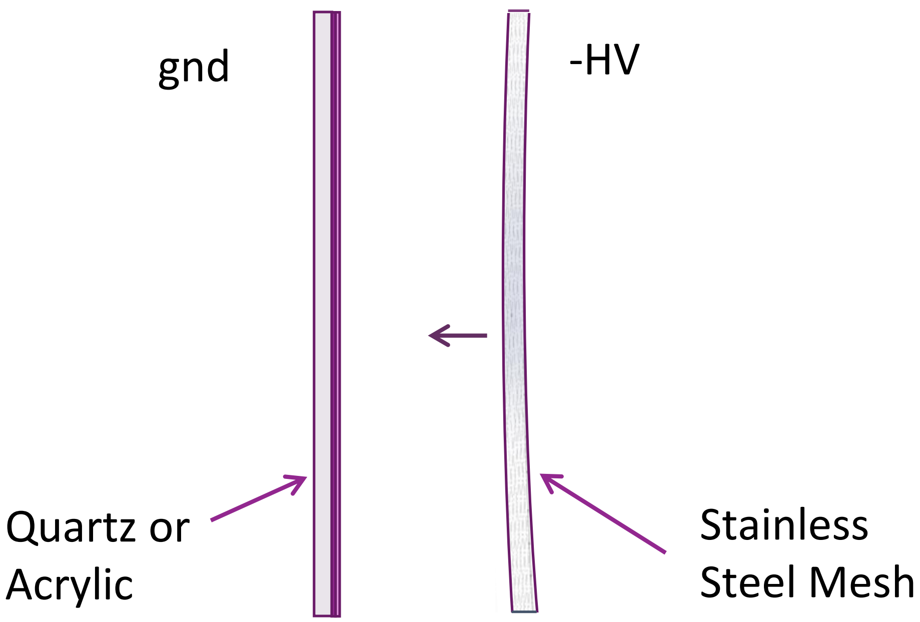
- Robust under HV discharges
- >80% photon transparency
- EL response to be smooth and better than 0.5% FWHM after calibration
- < 1% peak-to-peak gain stability over time once charged
- Radio purity better than 20% of tracking plane
- Small photoelectric yield ($<10^4$) i.e. number of released photoelectrons by the 175 nm VUV photons, per primary electron entering the EL region must be $<10^4$

Scaling up Electroluminescence



- Large electric fields create electrostatic forces which warp the thin meshes (standard in smaller diameter EL regions)

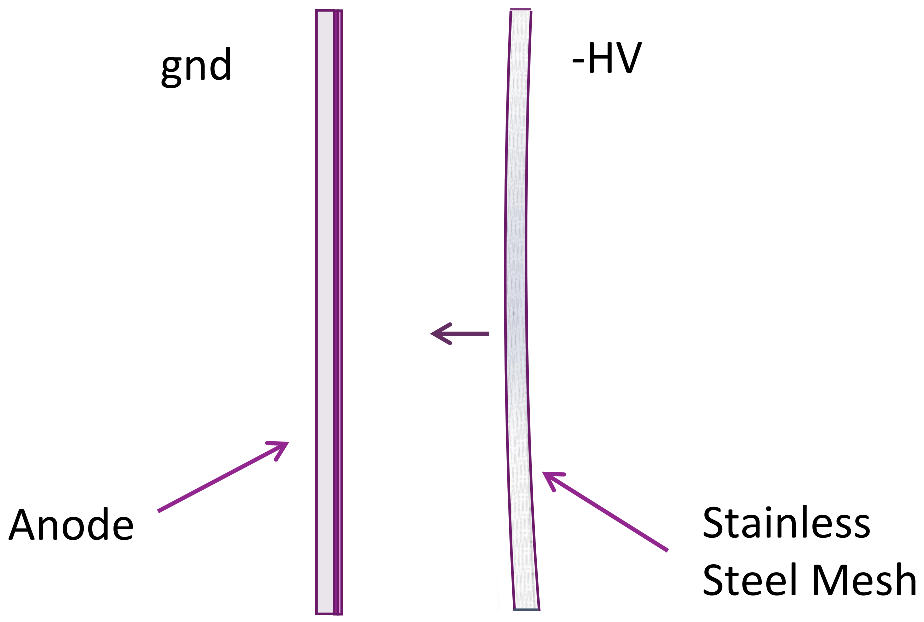
Scaling up Electroluminescence



- Large electric fields create electrostatic forces which warp the thin meshes which are standard in smaller diameter EL regions
- Make Anode out of a solid piece of transparent and resistive material so only dealing with the warping on one side

Anode Requirements

- Robust under HV discharges
- Transparent to visible light
- Resistive
- Minimal deflection under high electrostatic forces



Anode Material Options

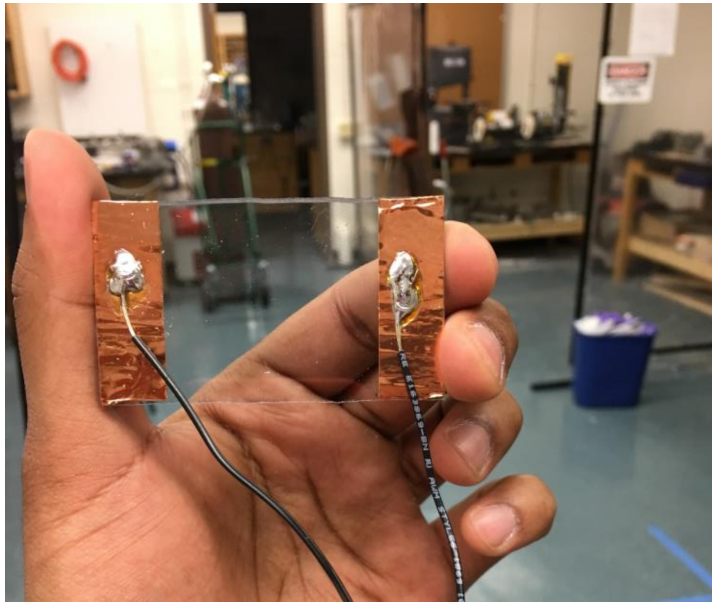
Two transparent, resistive anode configurations were considered

Static dissipative acrylic

- Pro: simplicity of manufacture, guaranteed uniformity
- Pro: radio-purity measured to be acceptable

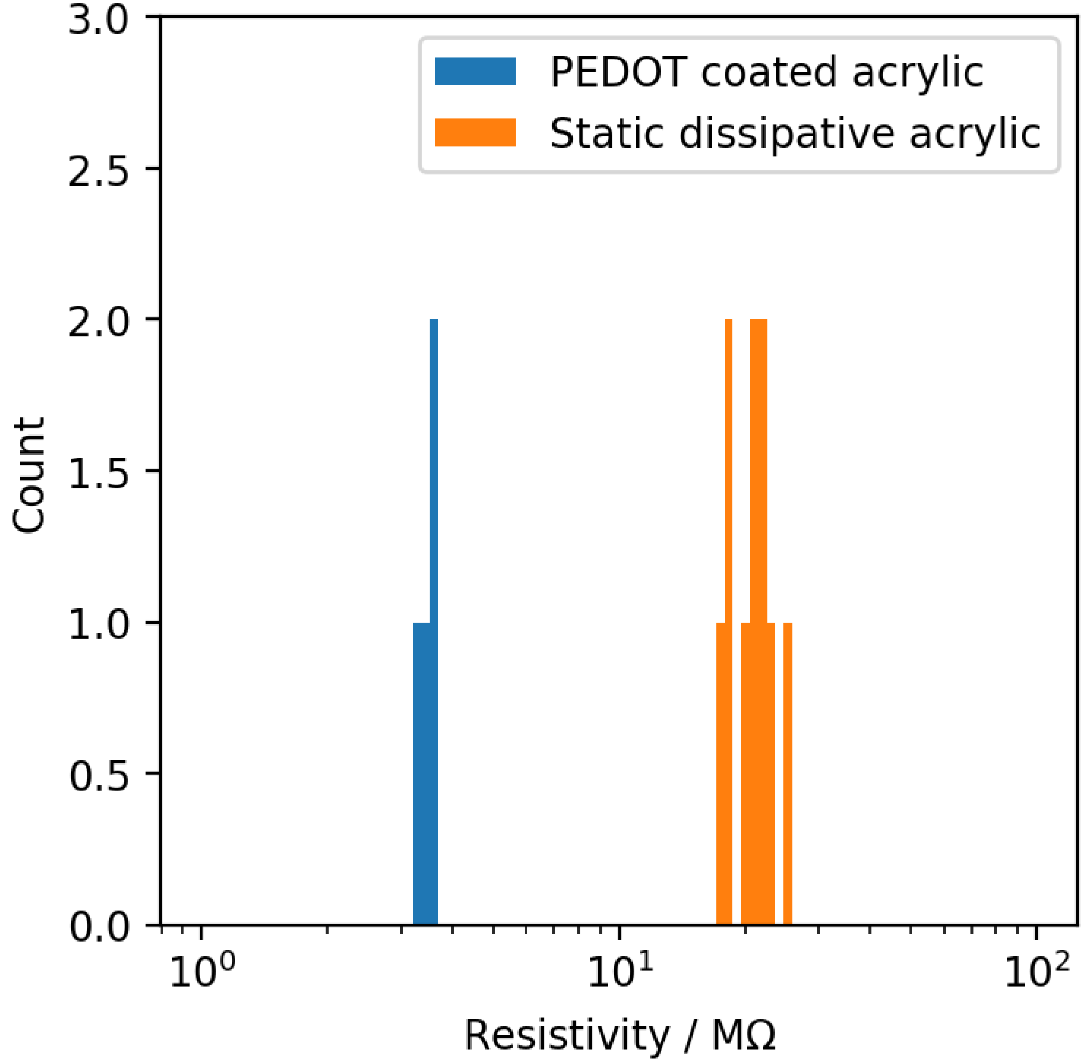
PEDOT coating on acrylic or quartz

- Pro: known radio-pure
- Con: Manufacture at large scale is awkward, maybe non-uniform



PEDOT coated acrylic, spin coated onto large disk at UTA and cut up

Anode Material Resistivity Properties



Resistivity Uniformity of both samples has been quantified:

SDA: 20.9±2.4 MΩ/sq.

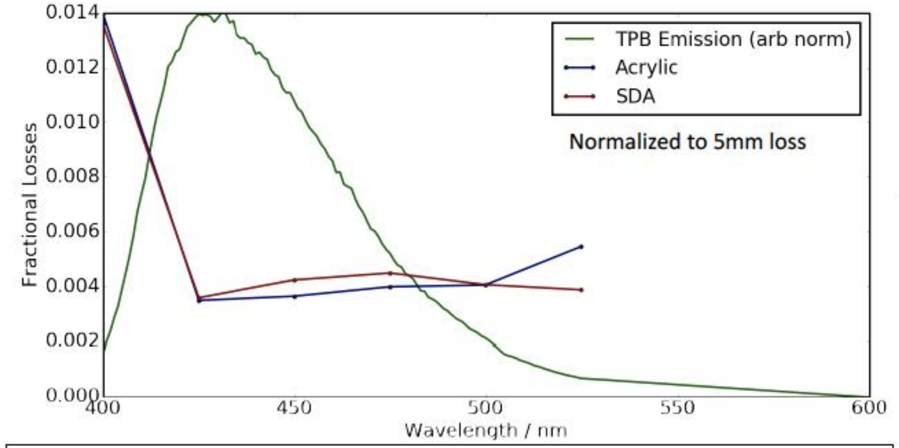
Pedot: 3.16±0.15 MΩ/sq. *(but tunable in principle)*

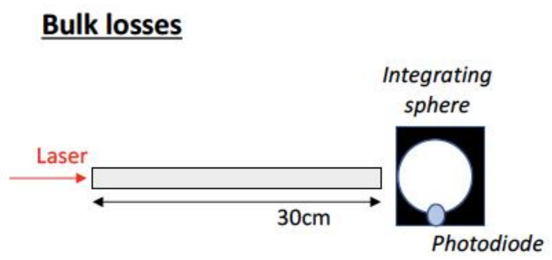
Anode Material Optical Properties

Optical transparency of both samples has been quantified.

Bulk Losses:

<0.5% light loss for both

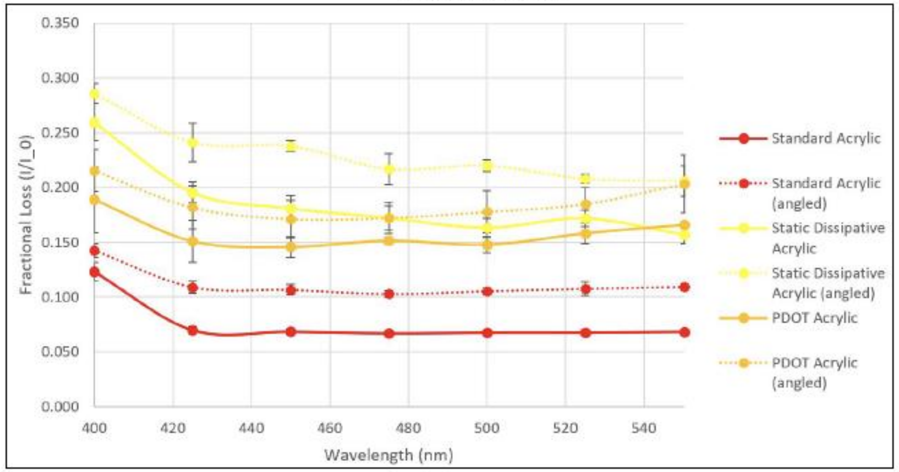


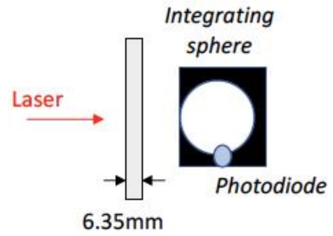


Sheet Losses:

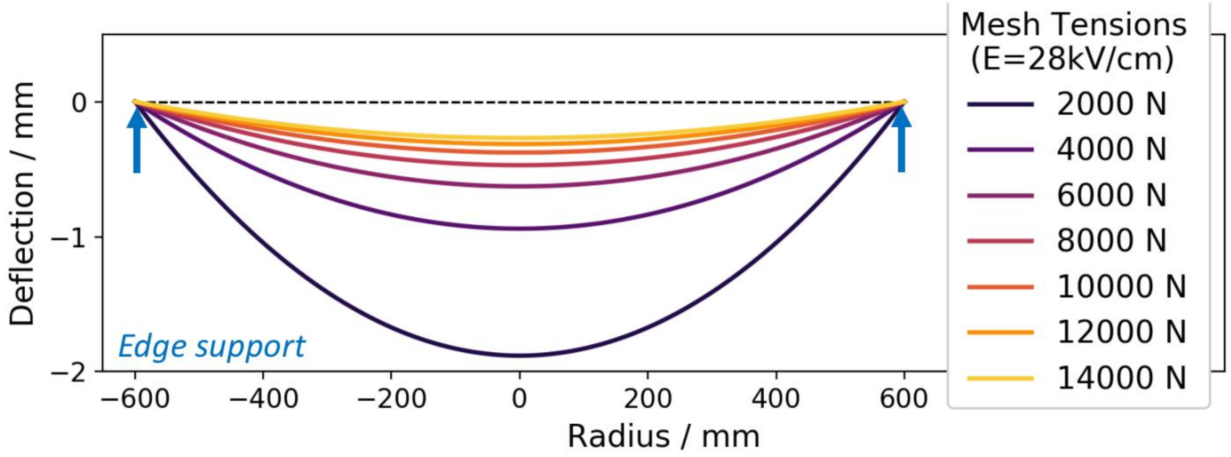
SDA: 84% transparent

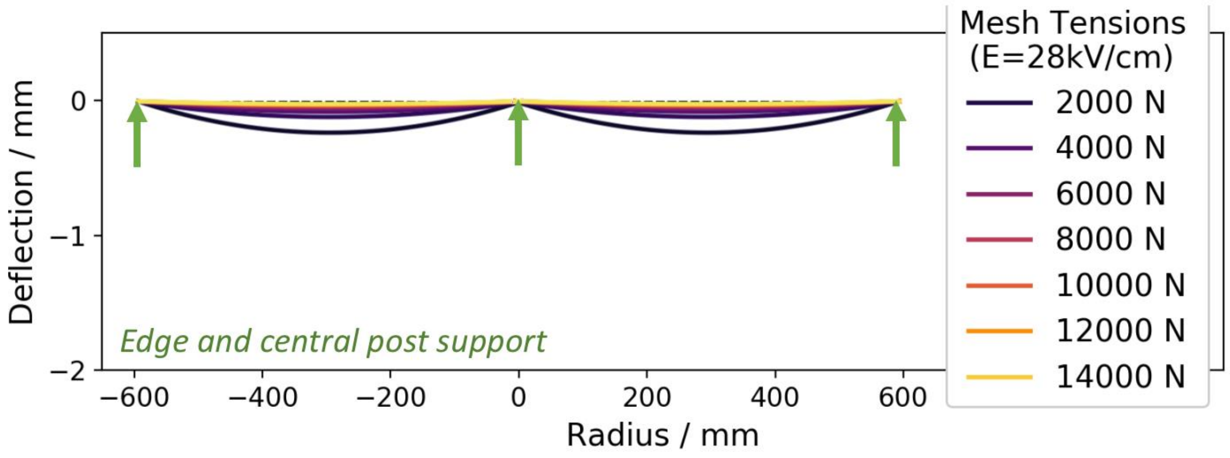
Pedot: 83.3% transparent





Scaling up Electroluminescence Mesh

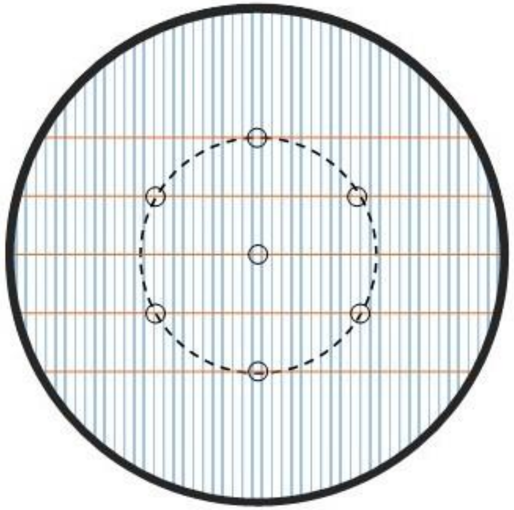




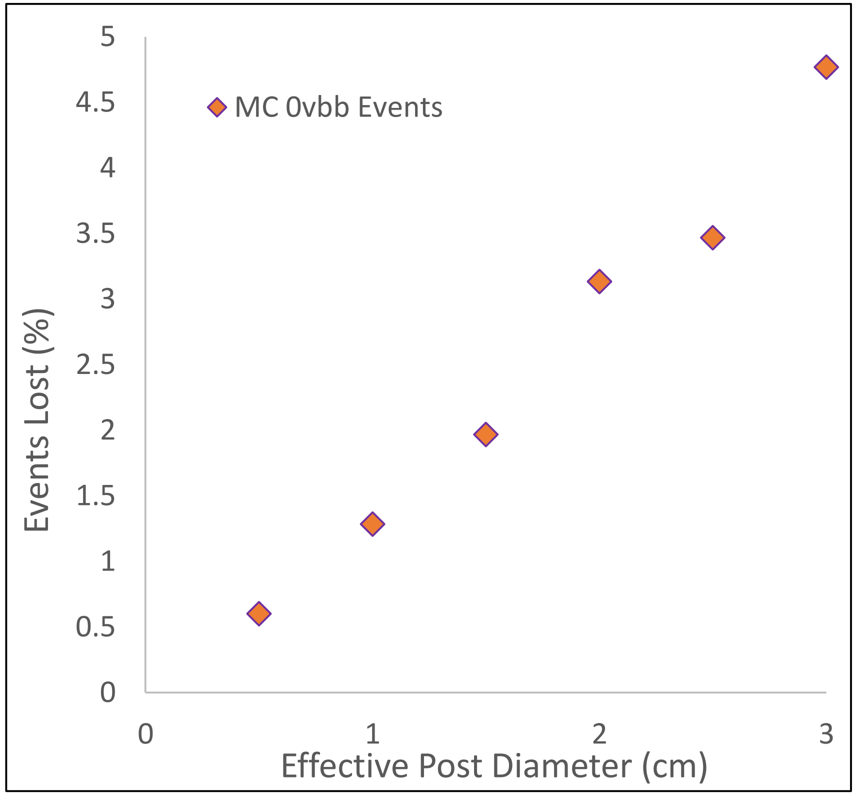
- The tighter the mesh is tensioned the less it deforms
- A single support post greatly decreases the amount of deflection under the same tension
- The post must be insulating but enough leakage current to avoid surface charge up effects

Effect on EL Due to Support Posts

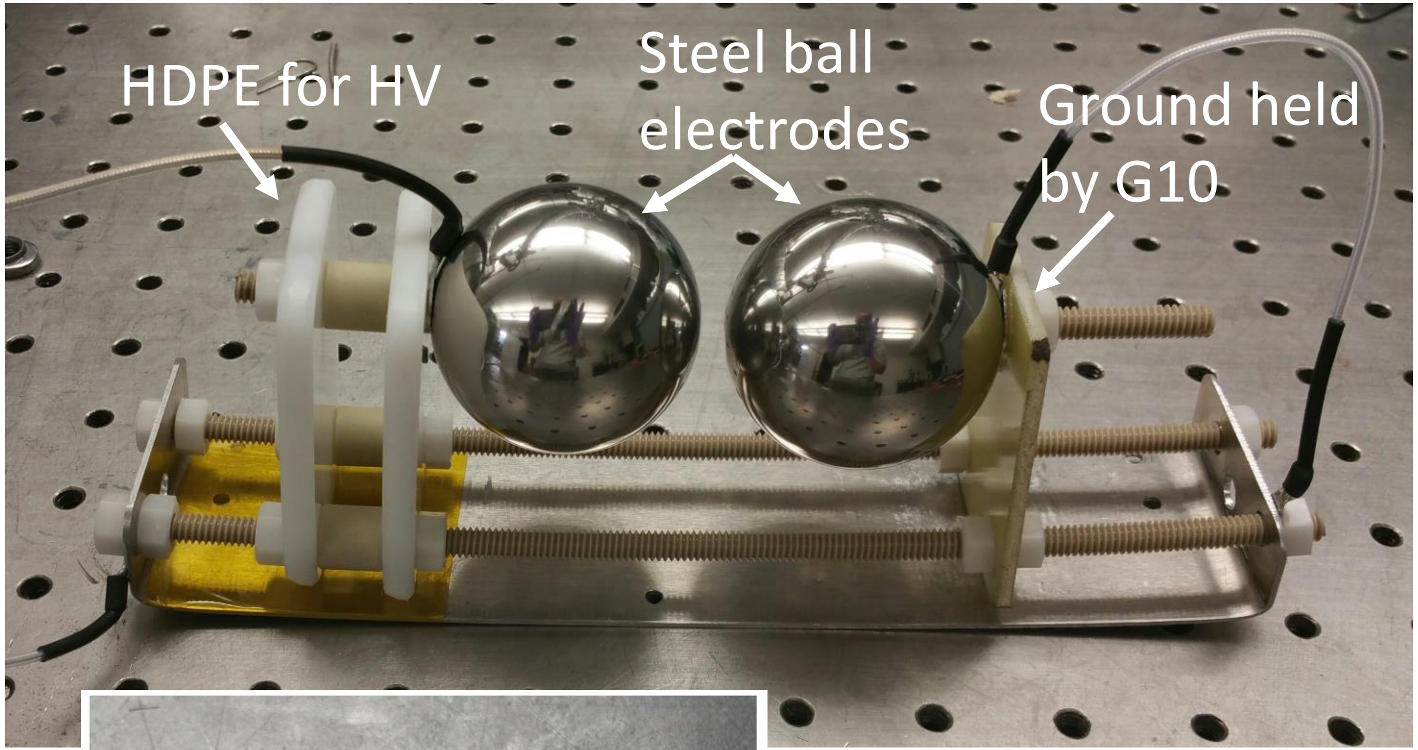
- Affected region of support post is likely to be slightly larger than the post itself due to local field and optical response distortions
- Assume events passing within some distance of a support post must be discarded
- Inefficiency was assessed for various effective support post diameters using NEXT-100 MC neutrinoless double beta decay events.

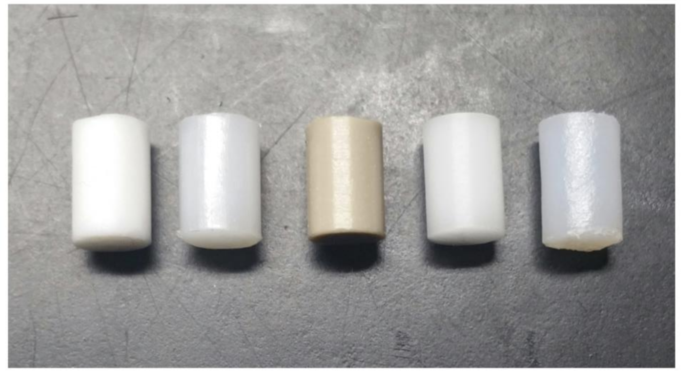


(not to scale)



Break Down Test Set Up

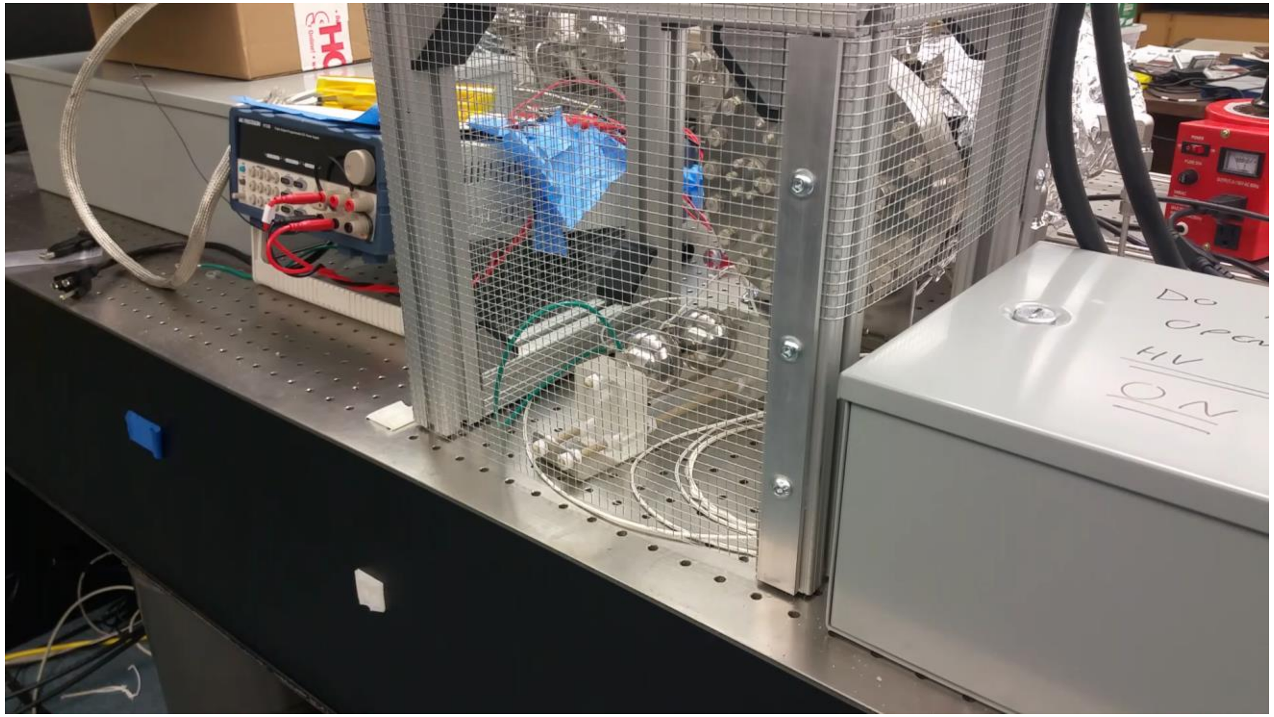




← ***Sample materials***

- Spherical electrodes with test insulator pieces held between for breakdown tests.
- One (right) was grounded to vessel and other (left) brought to HV to stress insulator
- Electrodes were ground down slightly to hold a 6.4mm post of material between them
- Voltage was slowly increased until a spark was heard

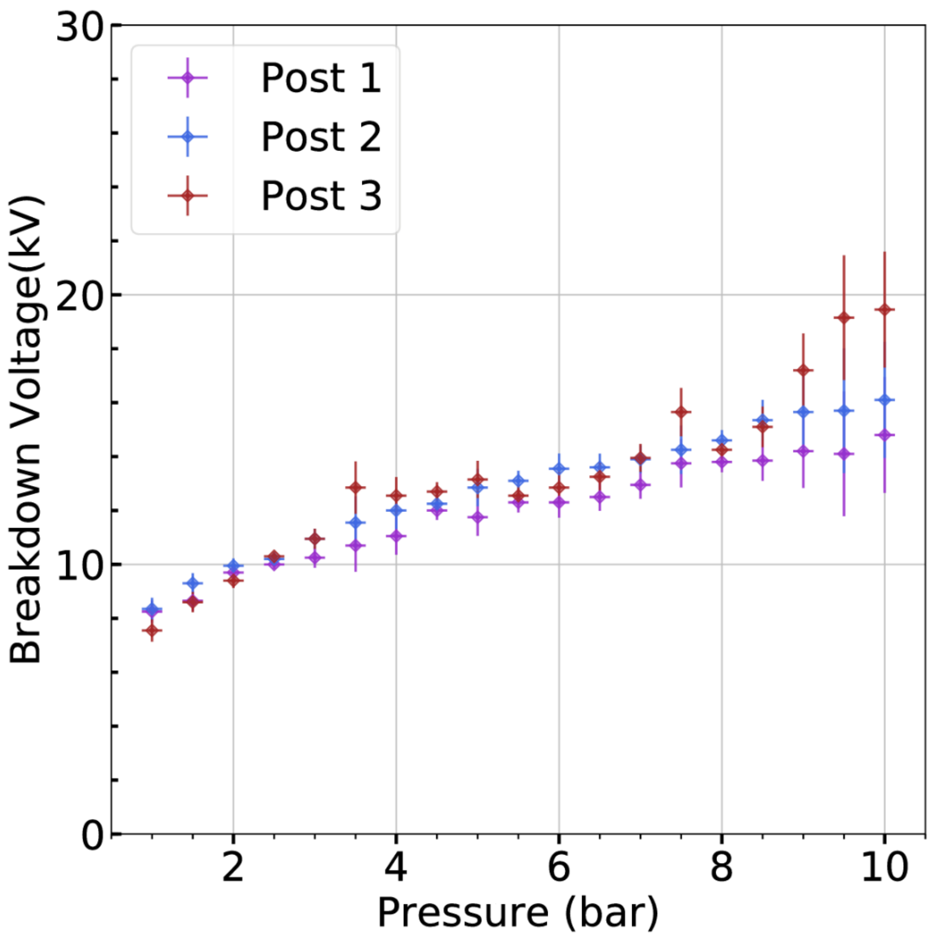
Preliminary Tests in Air



- Preliminary screening of materials in air to test for particularly weak insulators.
- Resistive UHMW, intended to grade potential, drew large surface current (much higher than DC resistance), sparked and failed destructively.
- Other than resistive UHMW, all other materials passed preliminary testing

Repeatability

- Before systematic scan of materials in HPG, repeatability was quantified.
- Three HDPE posts of 8.4mm lengths were tested in argon gas to establish repeatability of breakdown strength.
- Error bars on each point correspond to stat error from repeated spark measurements.
- Found to be repeatable within ~10%



Destructive Failure

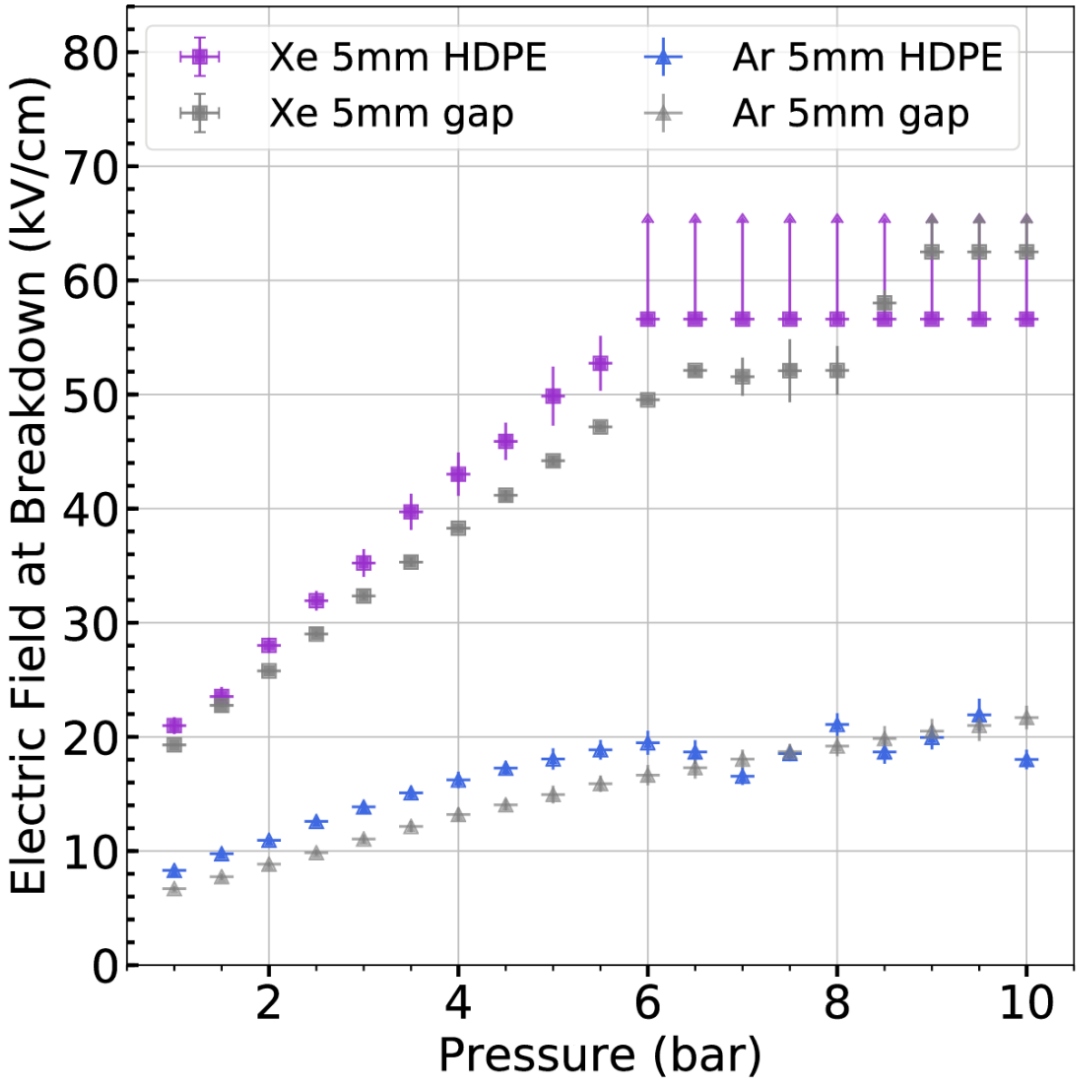
← PEEK failed destructively at low voltage (~15 kV) in argon gas.

Further testing of PEEK suspended on this basis.

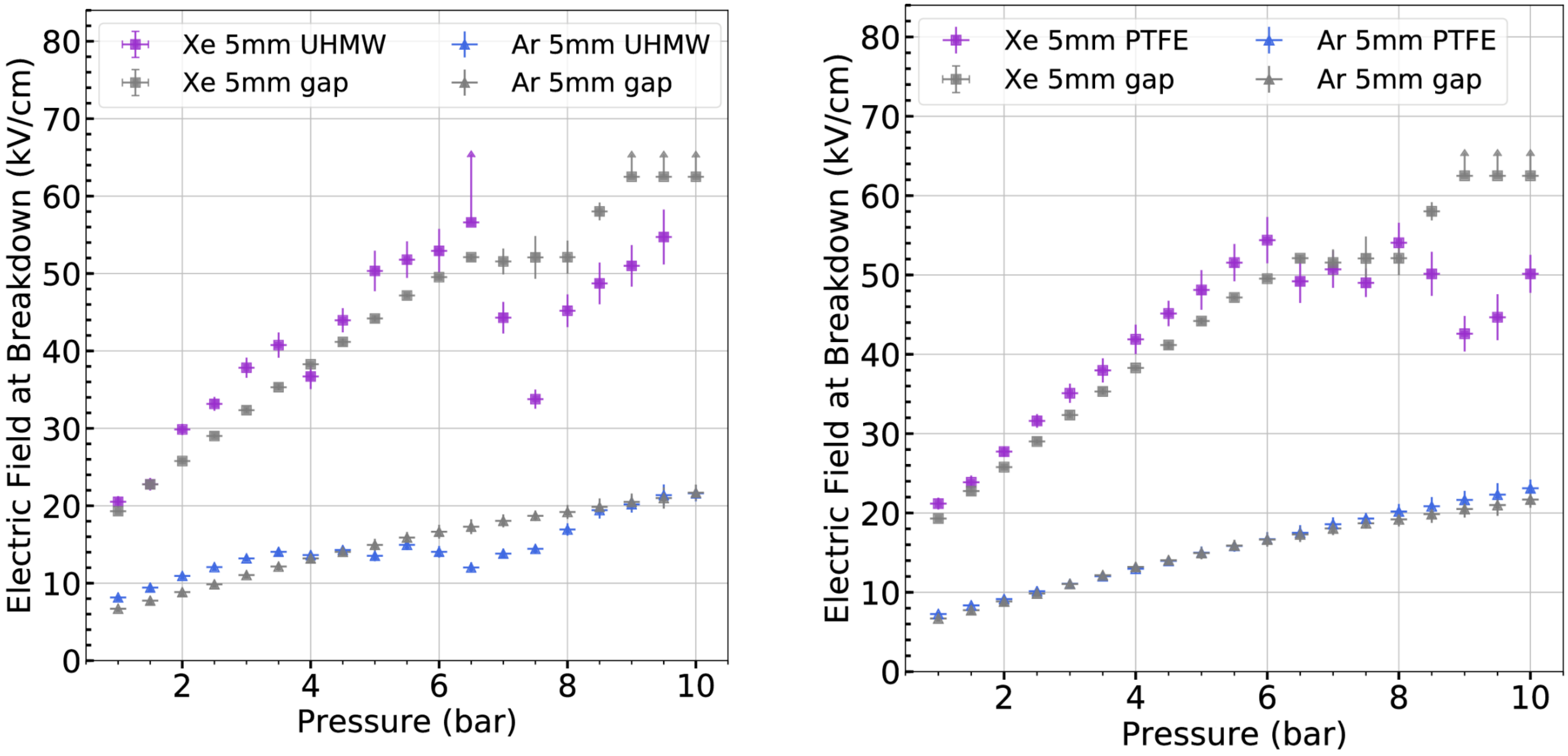
All other tested materials could be sparked but recovered their original behavior after breakdown.

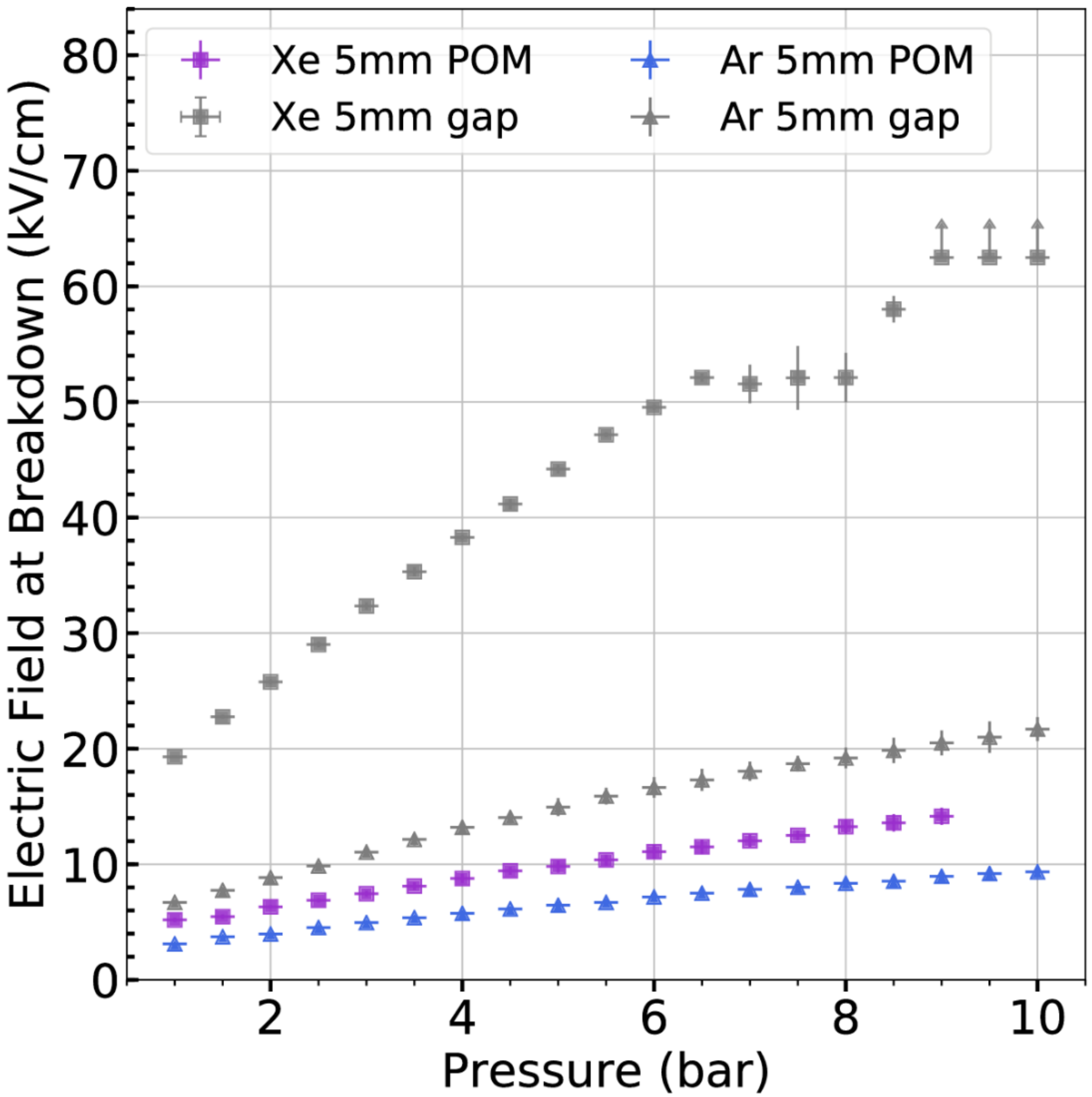
Spoiler Alert, HDPE is Best

- Also compared to empty argon and xenon gap strength.
- HDPE compared favorably to the gap, suggesting its main contribution is to reduce the stressed area of argon / xenon gas.



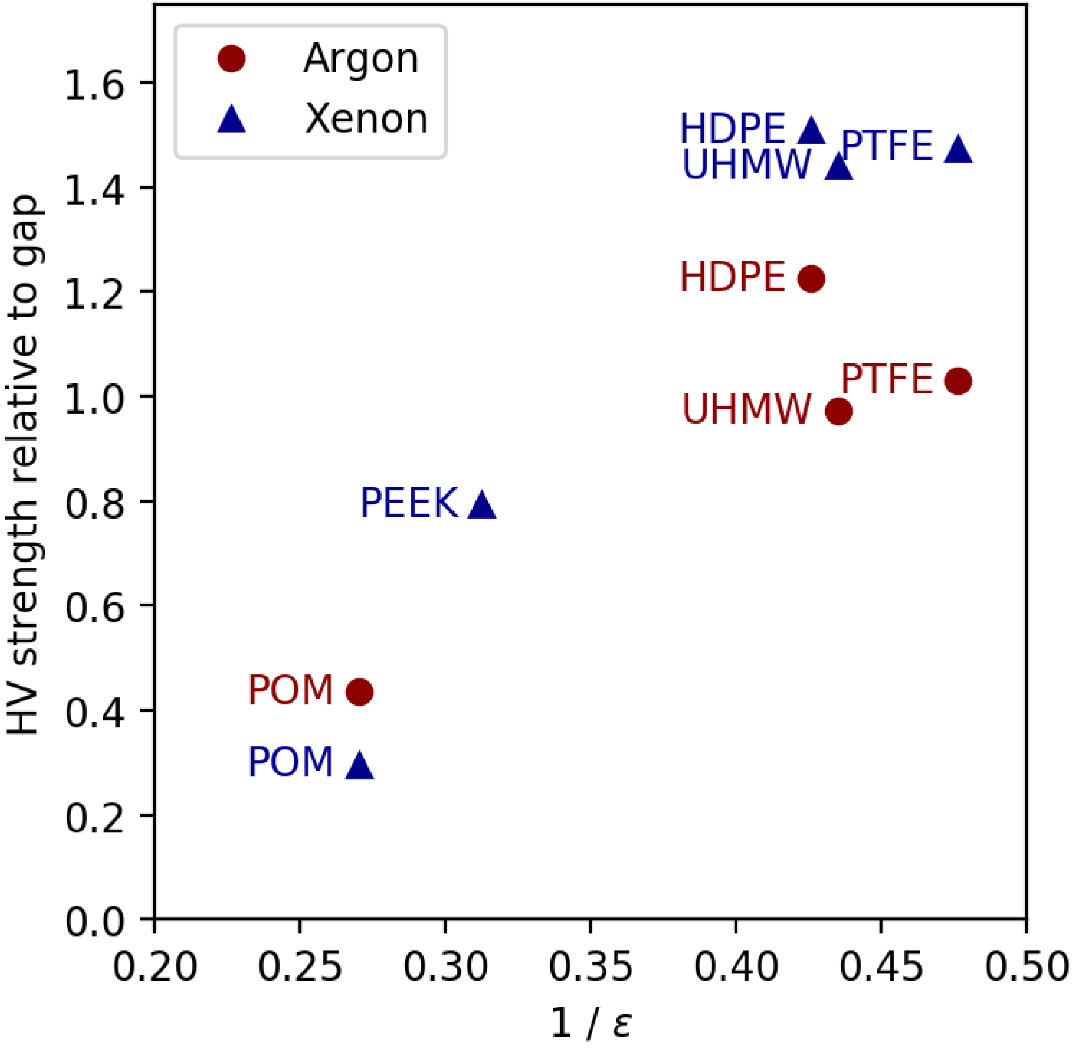
Good performance from PTFE and UHMW but more stochastic at the highest pressures / E fields.





- POM (acetyl) had low breakdown of less than half that of gas
- Breakdown was still non-destructive
- Suggests acetyl surface somehow facilitates gas breakdowns.

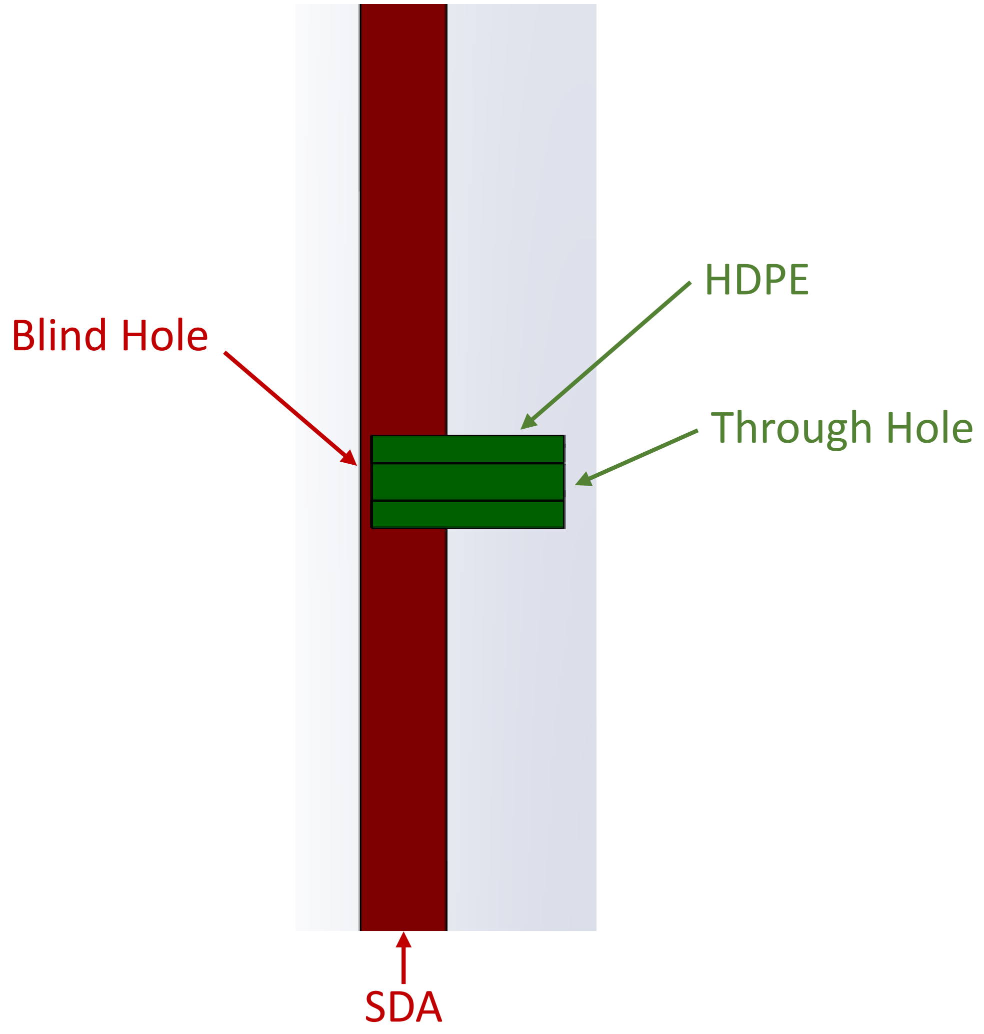
Material Dependence on Breakdown Voltage



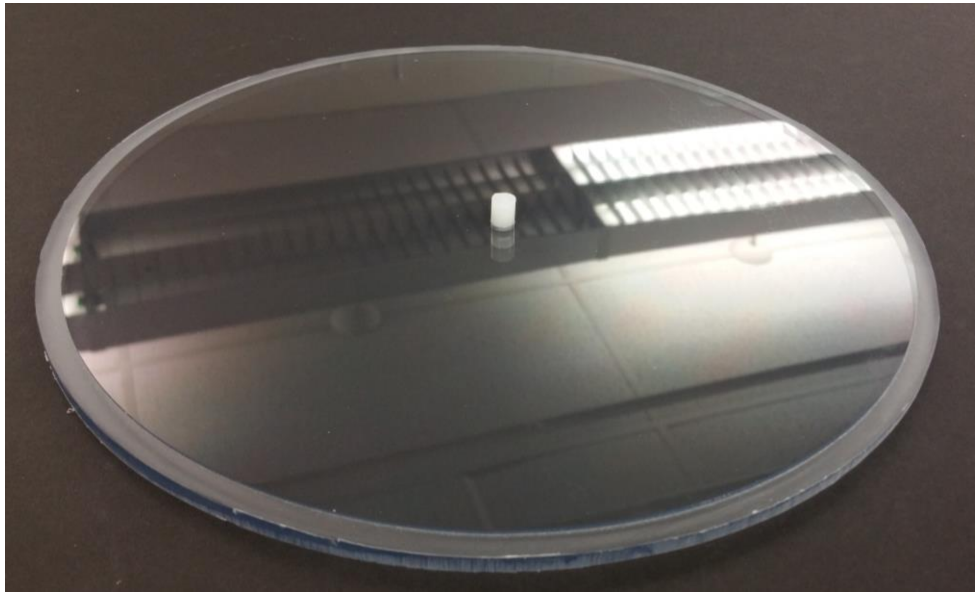
- Following suggestion of Lockwitz and Jostlein paper, compared to dielectric permittivity.
- HV strength found to be inversely proportional to dielectric constant
- Materials with high permittivities induce larger electric fields near the interfaces which may initiate breakdowns

S. Lockwitz and H. Jostlein, A Study of Dielectric Breakdown Along Insulators Surrounding Conductors in Liquid Argon,JINST11(2016), no. 03 P03026, [arXiv:1506.04185]

SDA Anode with HDPE Support Installed



- Drilling through HDPE so they're vented to prevent virtual leaks
- Putting blind holes in the SDA and cryofitting the posts into the anode

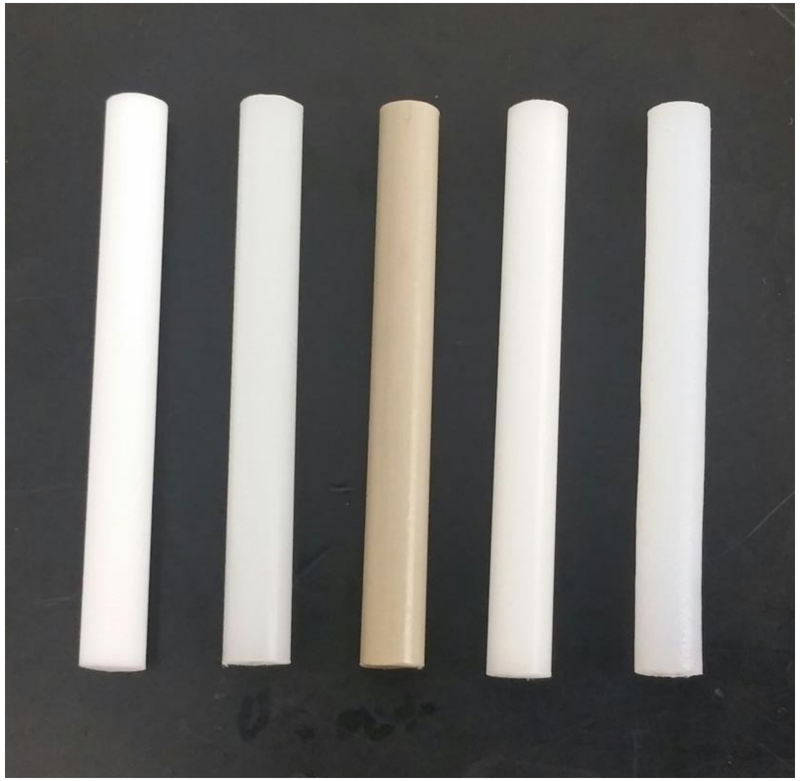


Anode for DEMO++ with Support Post inserted

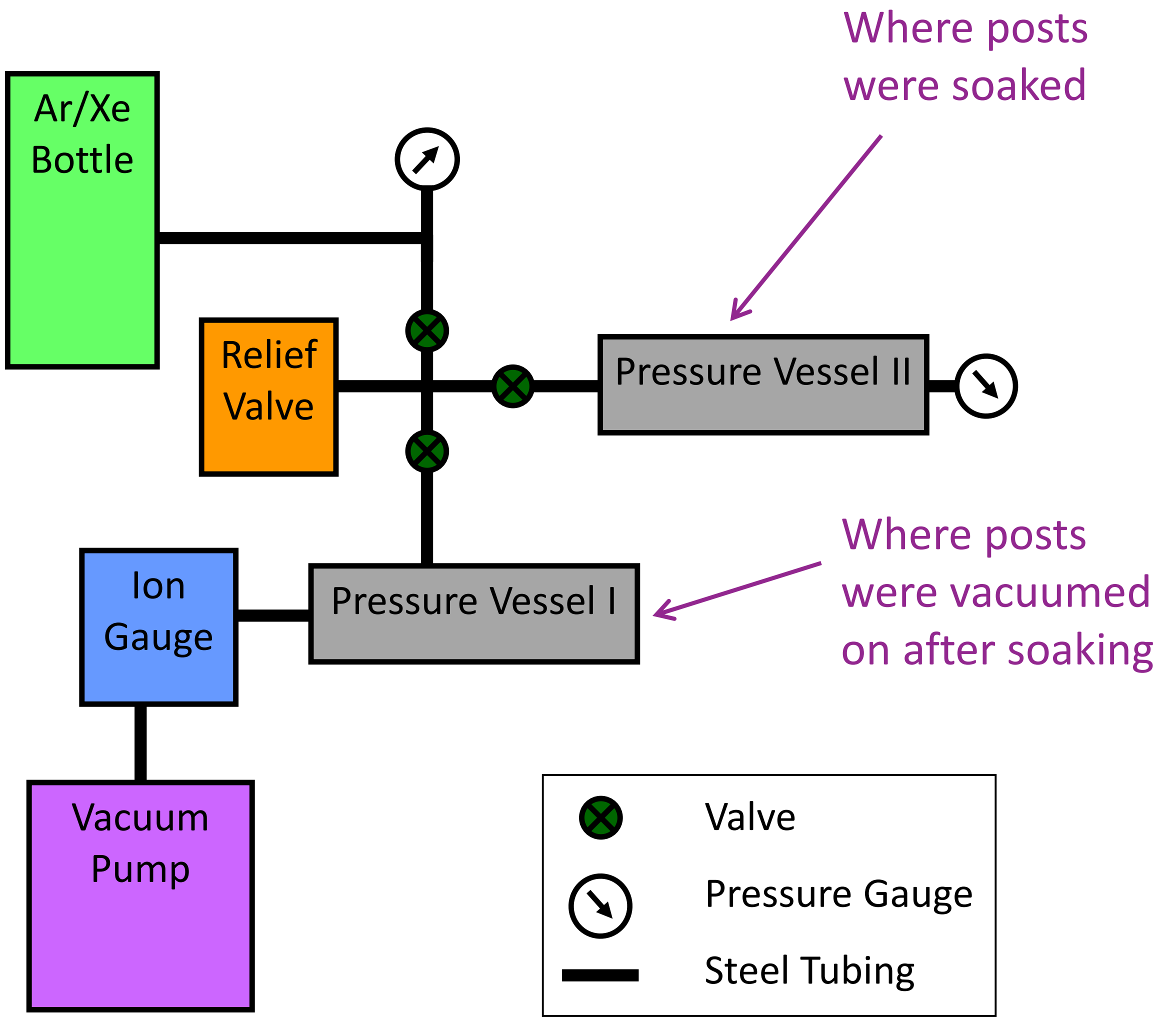
Absorption Tests

- Indications (from our collaboration and others) suggested high pressure gasses may absorb into some polymers and cause them to swell mechanically.
- This is a problem for TPC construction, if sufficiently severe.
- We tested mass and volume changes of polymers under gas exposure to explore this effect.

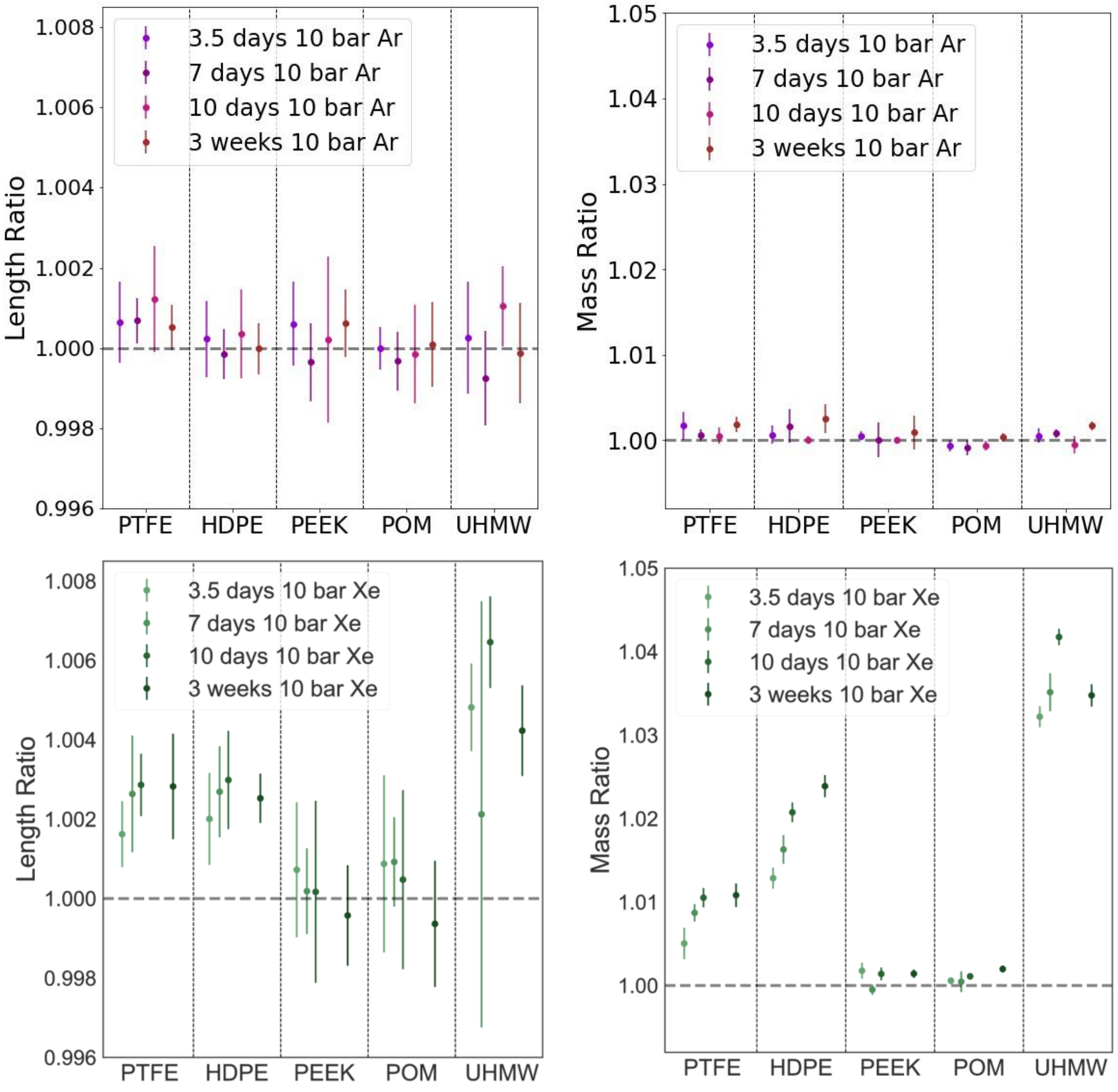
Absorption Tests Set Up



Typical 6cm posts that were soaked in Xenon and Argon



Absorption Test Results



- Minimal swelling was observed in Argon for all materials
- PEEK and POM did not appear to swell
- PTFE, HDPE, and UHMW all increased in both length and mass

Conclusions of HV Breakdown and Absorption Tests

- HDPE has been selected as the material to be used for insulating HV supports in NEXT.
- HPGAr shows similar trend in HV strength to xenon, but at lower voltages.
- While significant for xenon, absorption and swelling does not appear to be a large effect in HPGAr.

High voltage insulation and gas absorption of polymers in high pressure argon and xenon gases

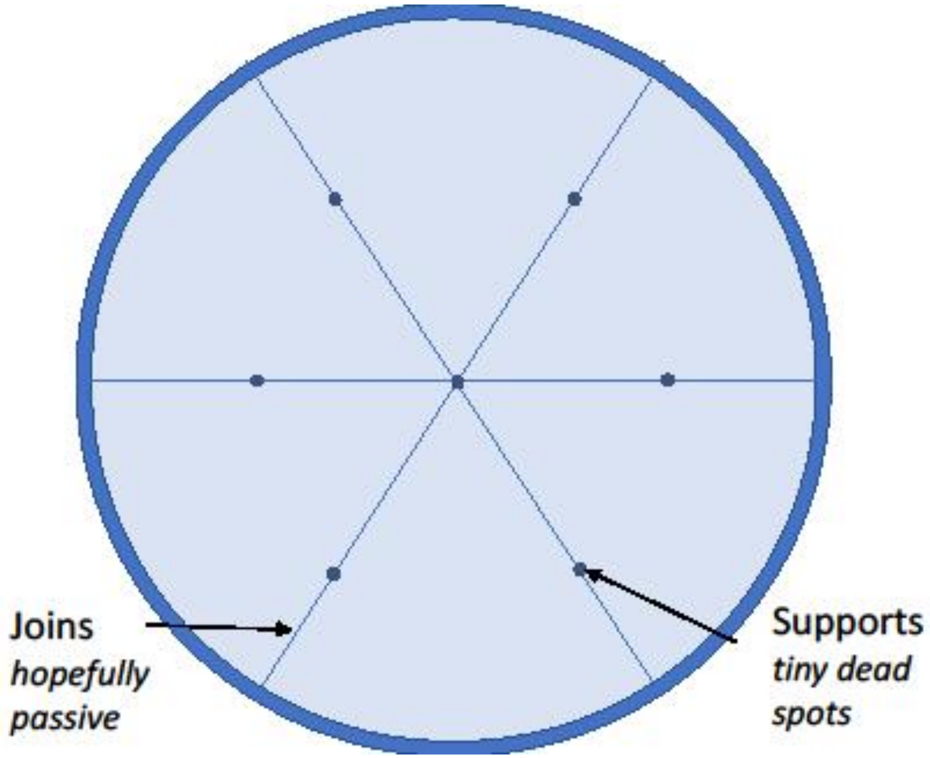
L. Rogers[c], R.A. Clark[c], B.J.P. Jones[c], A.D. McDonald[c], D.R. Nygren[c], F. Psihas[c], C. Adams[j], V. Álvarez[q], L. Arazi[f], C.D.R Azevedo[d] +Show full author list

Published 1 October 2018 •

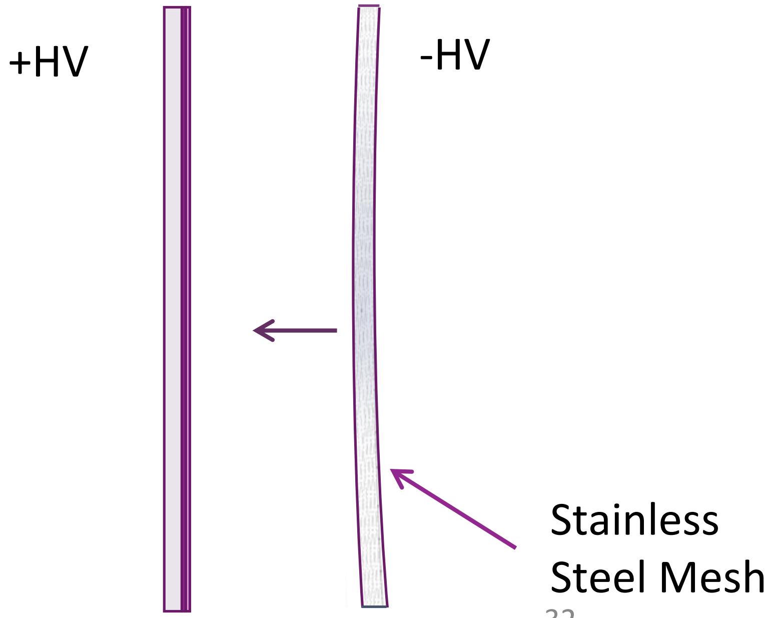
Journal of Instrumentation, Volume 13, October 2018

JINST 13 (2018) no.10, P10002

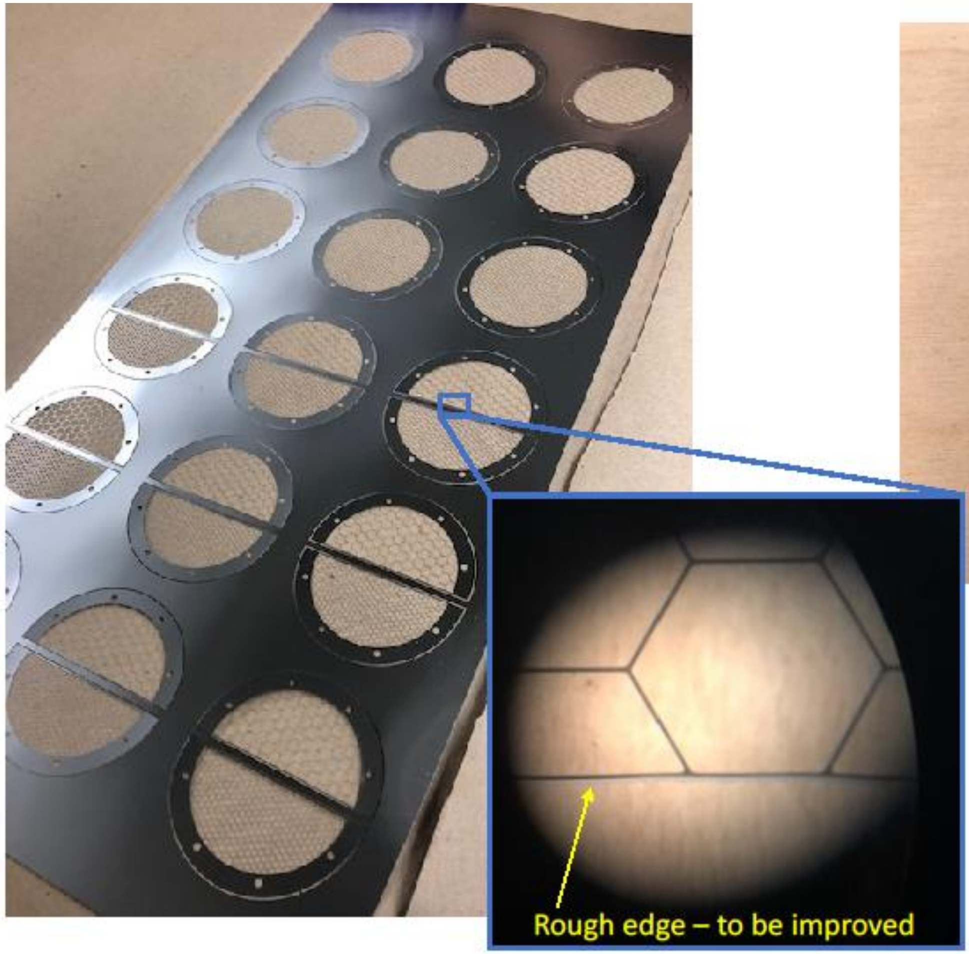
Photoetching Large Scale Mesh

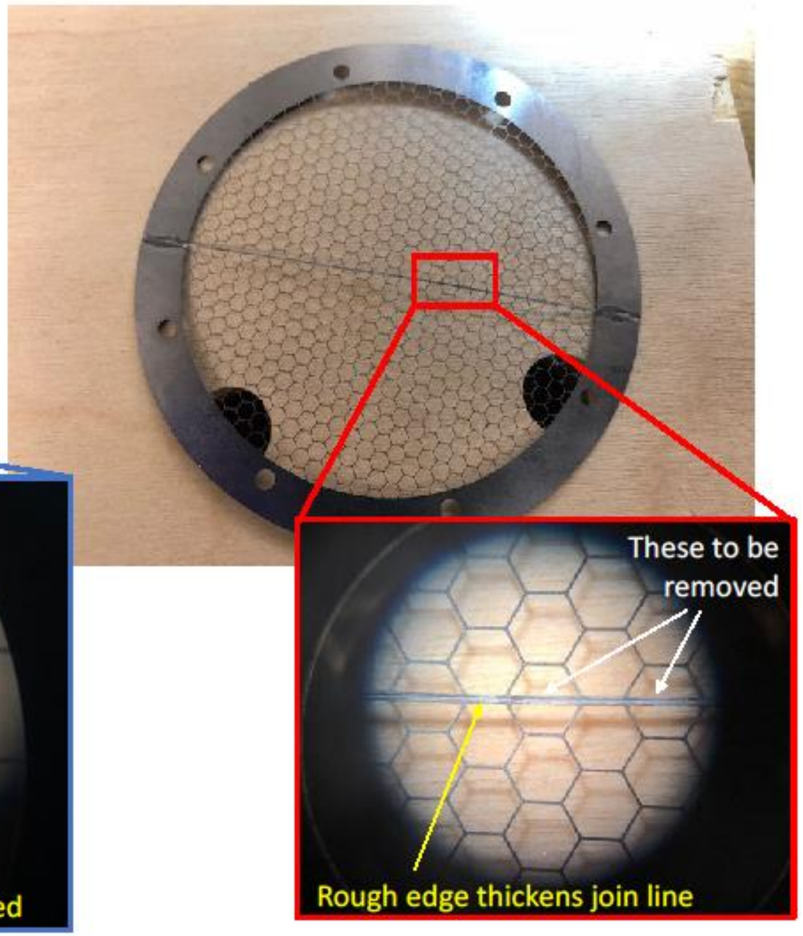


- Large unsupported mesh is a challenge
- We are exploring photoetching meshes
- Largest piece that can be manufactured 61 cm so we are looking at soldering together six “pie slices”



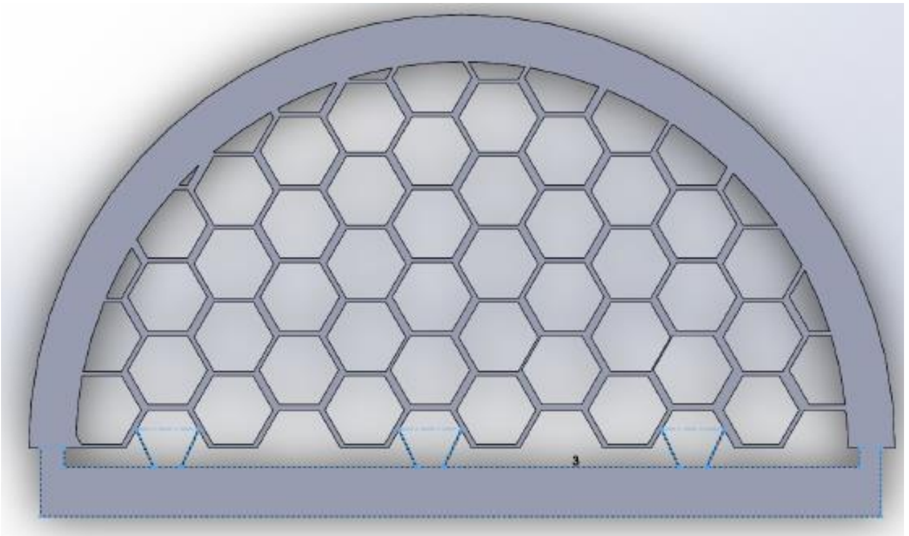
Photoetching Large Scale Mesh



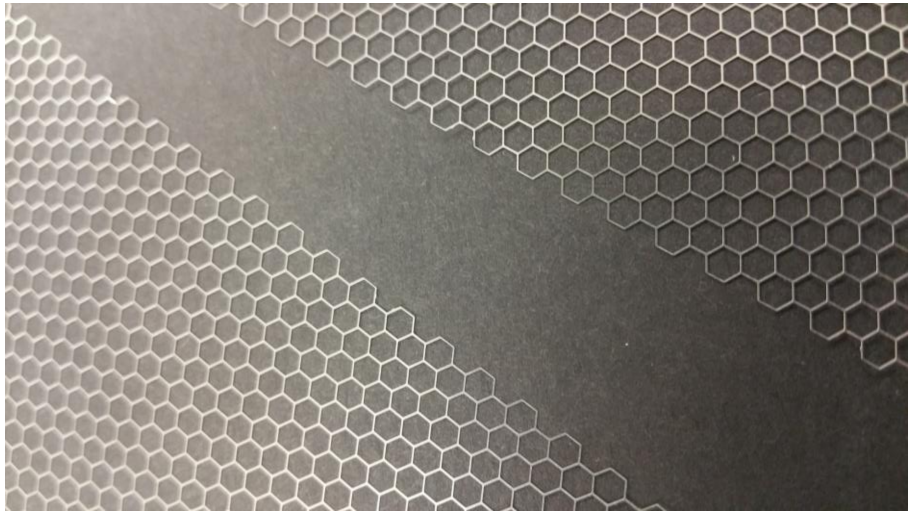


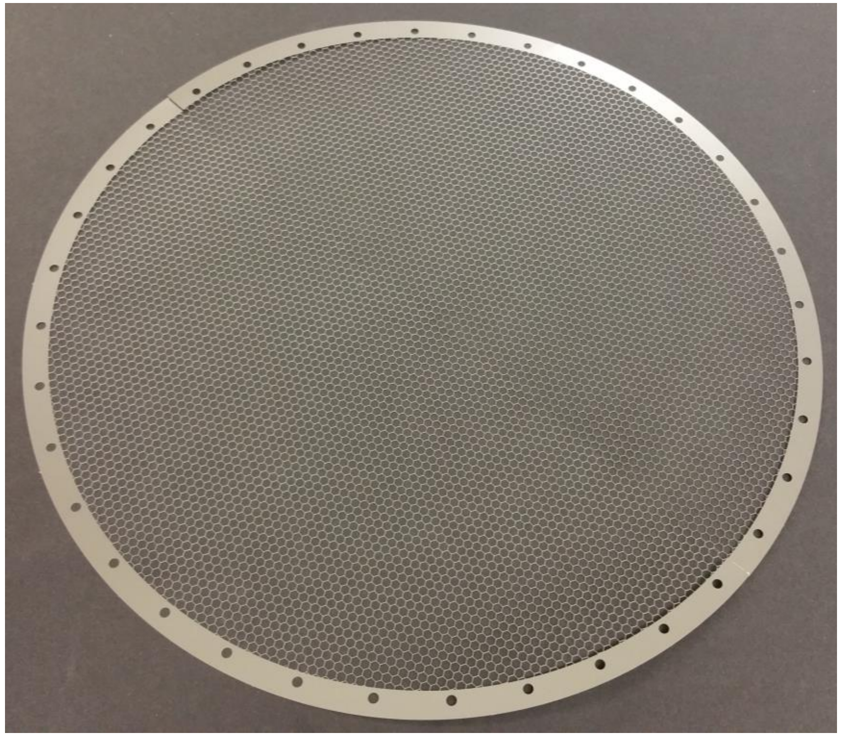
- We tested both Nickel and Stainless Steel mesh
- Able to solder the Stainless Steel mesh together
- Because the mesh is so thin, the manufacturer needed a thicker edge to hold onto on the outside which resulted in a rough edge once removed

Photoetching Large Scale Mesh

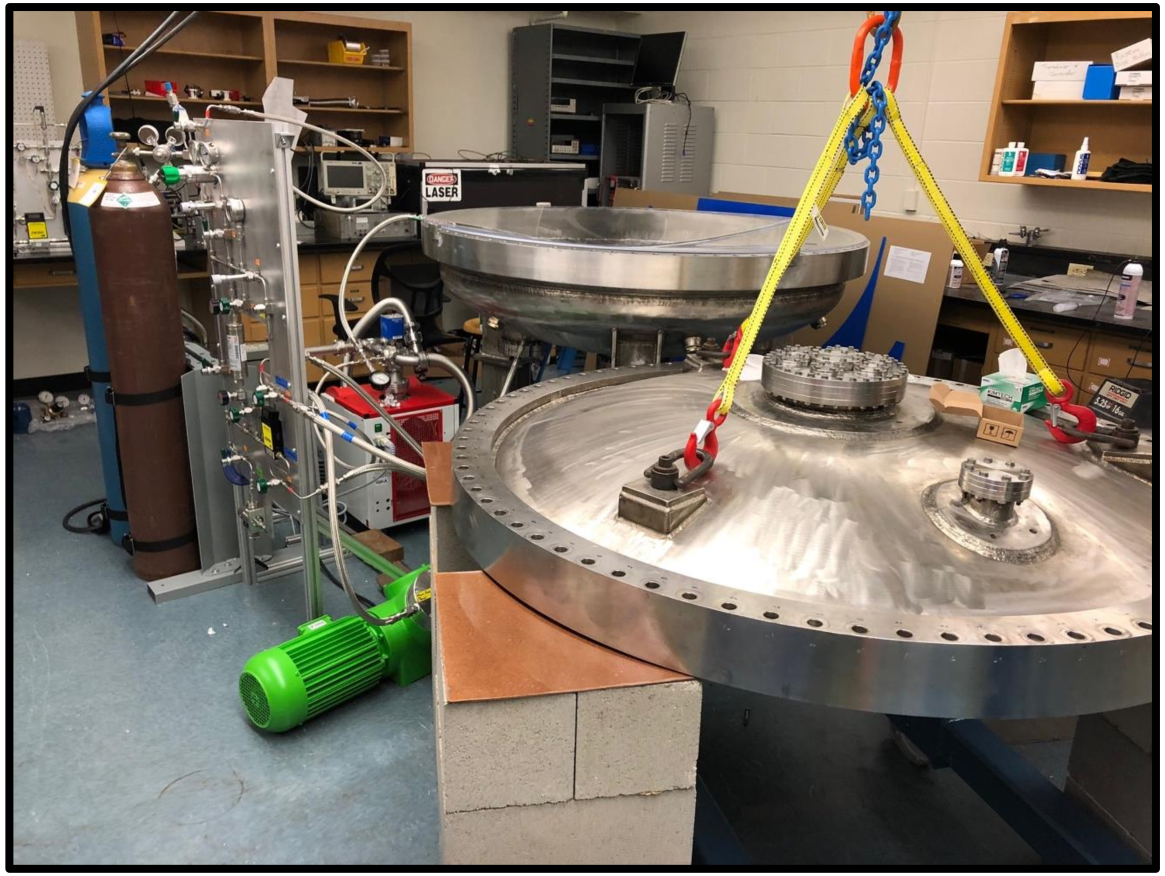


- Phase 2 mesh used “breakpoints” rather than an edge all the way along resulting in a uniform thickness





Large Scale Electroluminescence Testing Facility



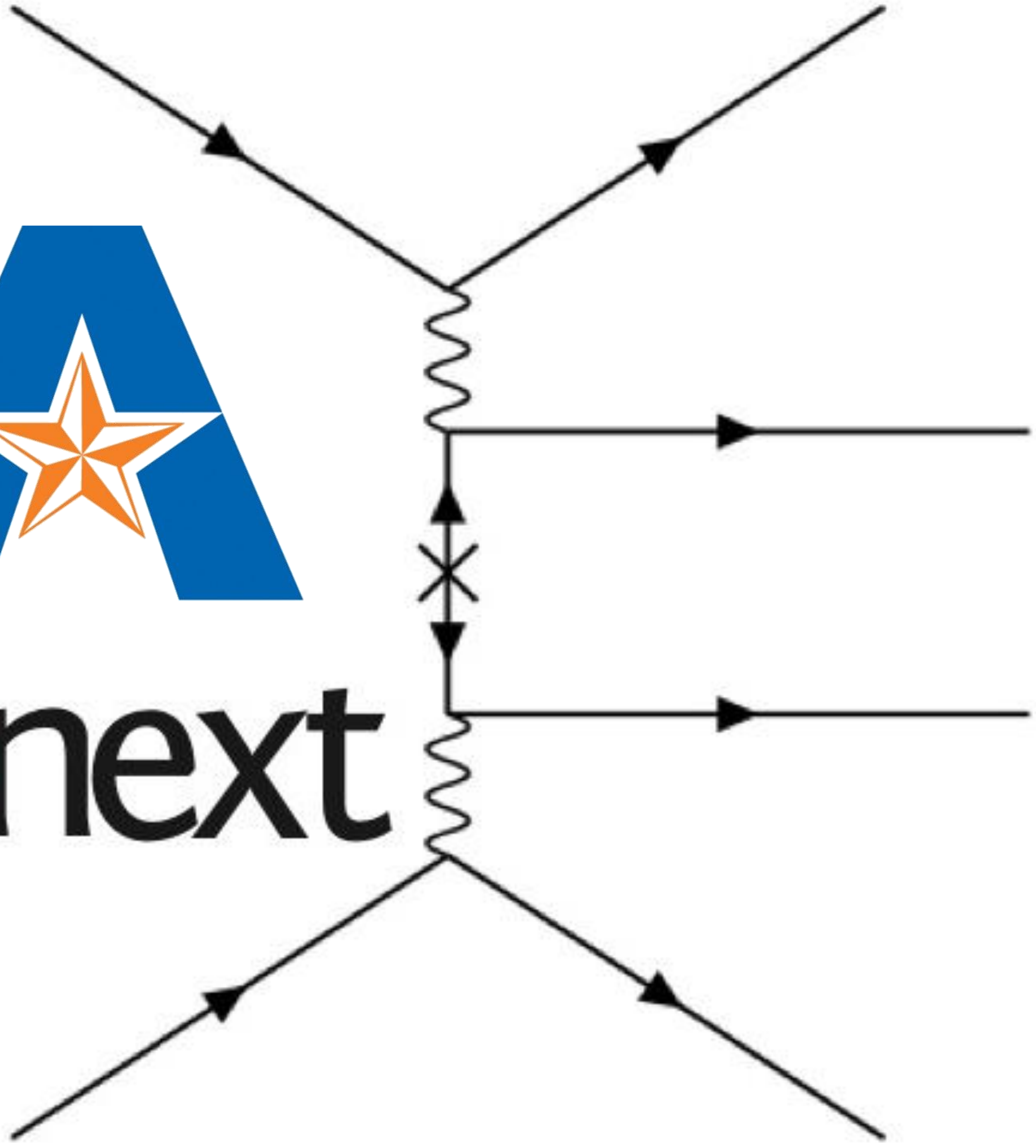
High Capacity vessel for testing large scale EL regions

- In commissioning now
- 1.5 m diameter HPGAr test vessel for large readout planes
- Pressure rating 10 bar
- Hot and cold getters
- 100kV HV feedthrough in progress
- High capacity system (1067 liters)
- No recapture (so HPGAr only, for now)

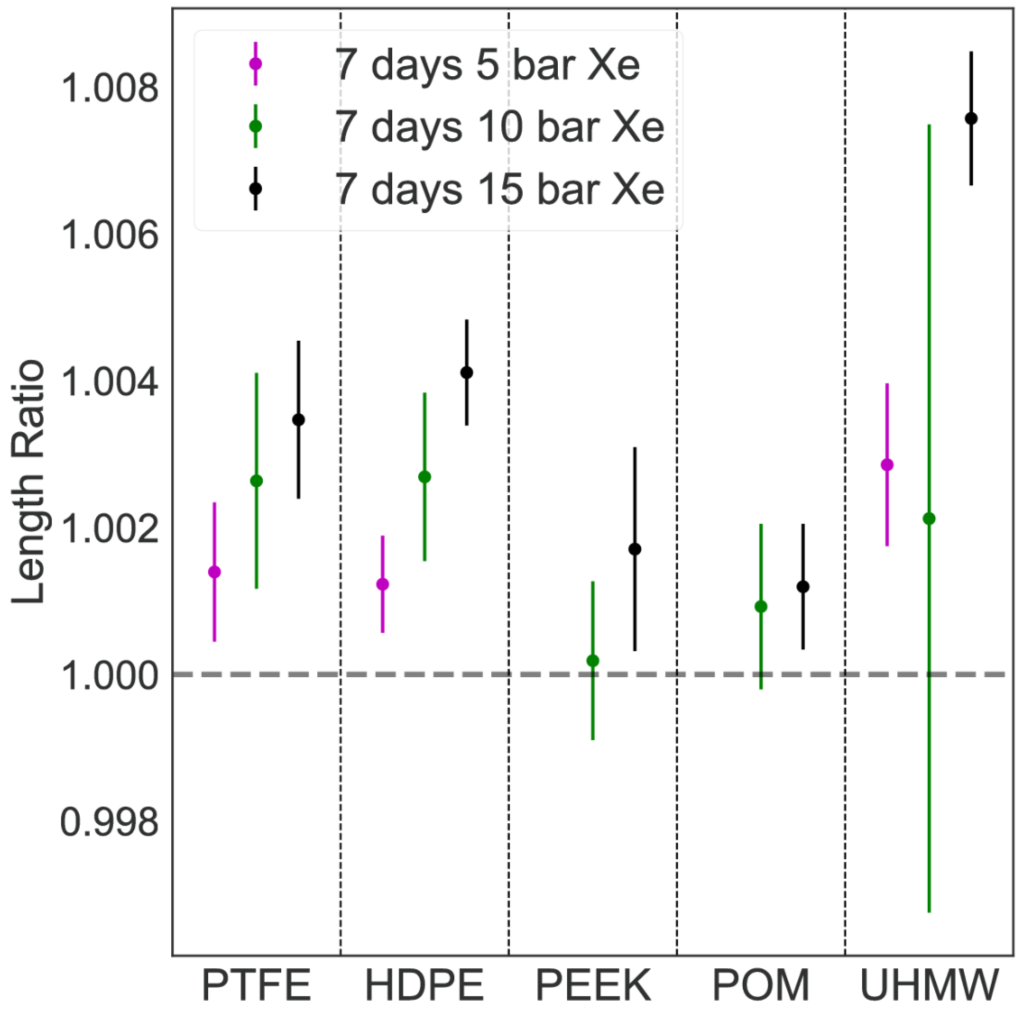
Summary

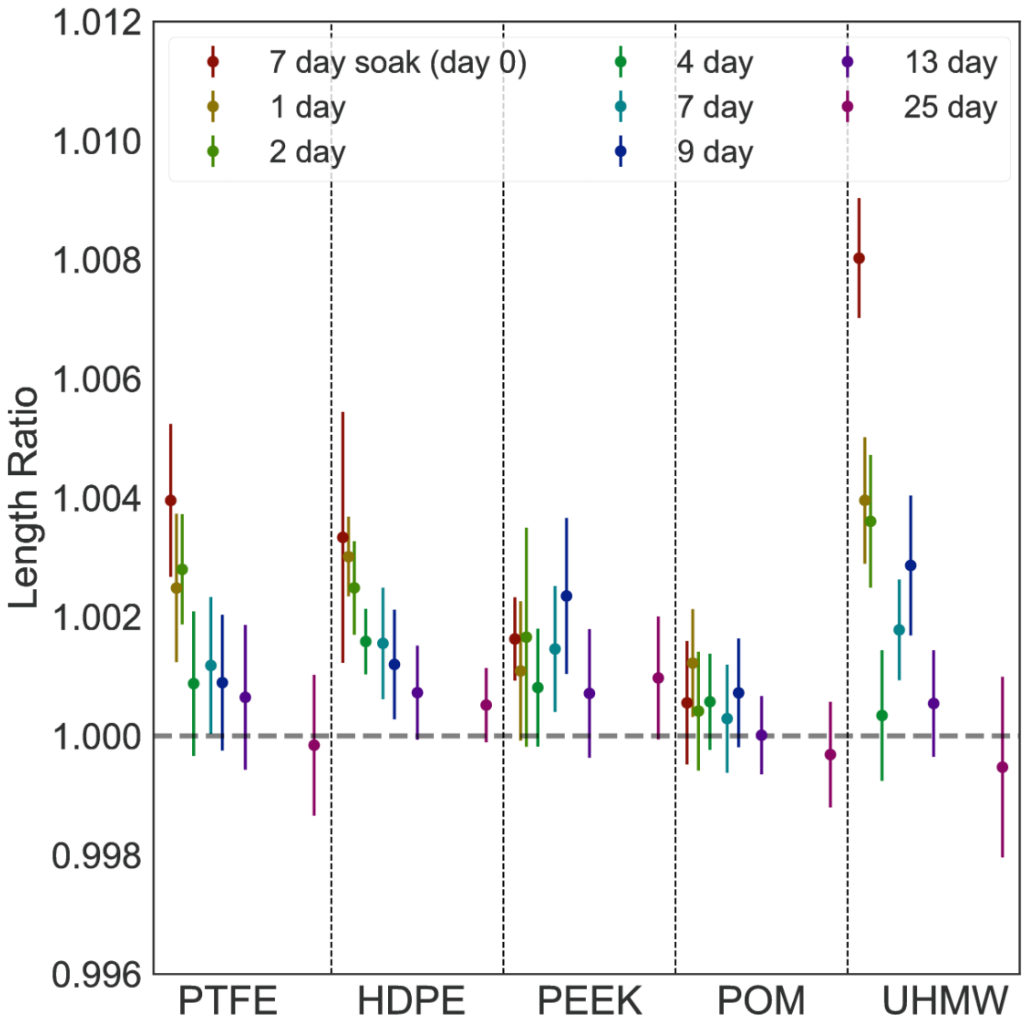
- There are several challenges with scaling up Electroluminescent regions
- Static dissipative acrylic works well for a new method of a transparent and resistive surface
- Support posts within the EL region can be made from HDPE
- Photoetched stainless steel meshes are showing promise

Backup Slides



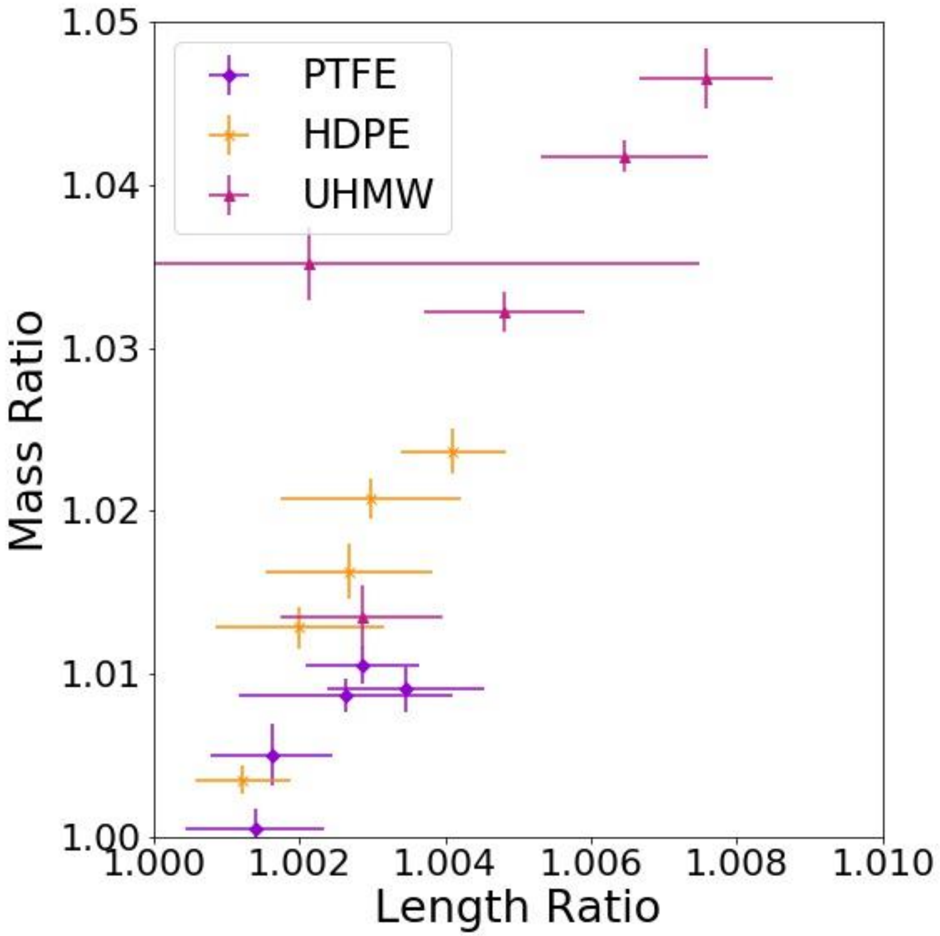
- Higher pressures increased in mass and length faster for PTFE, HDPE, and UHMW
- Evacuation restored all materials to original condition.





Xenon Absorption Tests

- Clear correlation between mass and length change ratio for each of the materials
- PTFE appears to display a distinct slope compared to the other two



Micromegas readouts for double beta decay searches

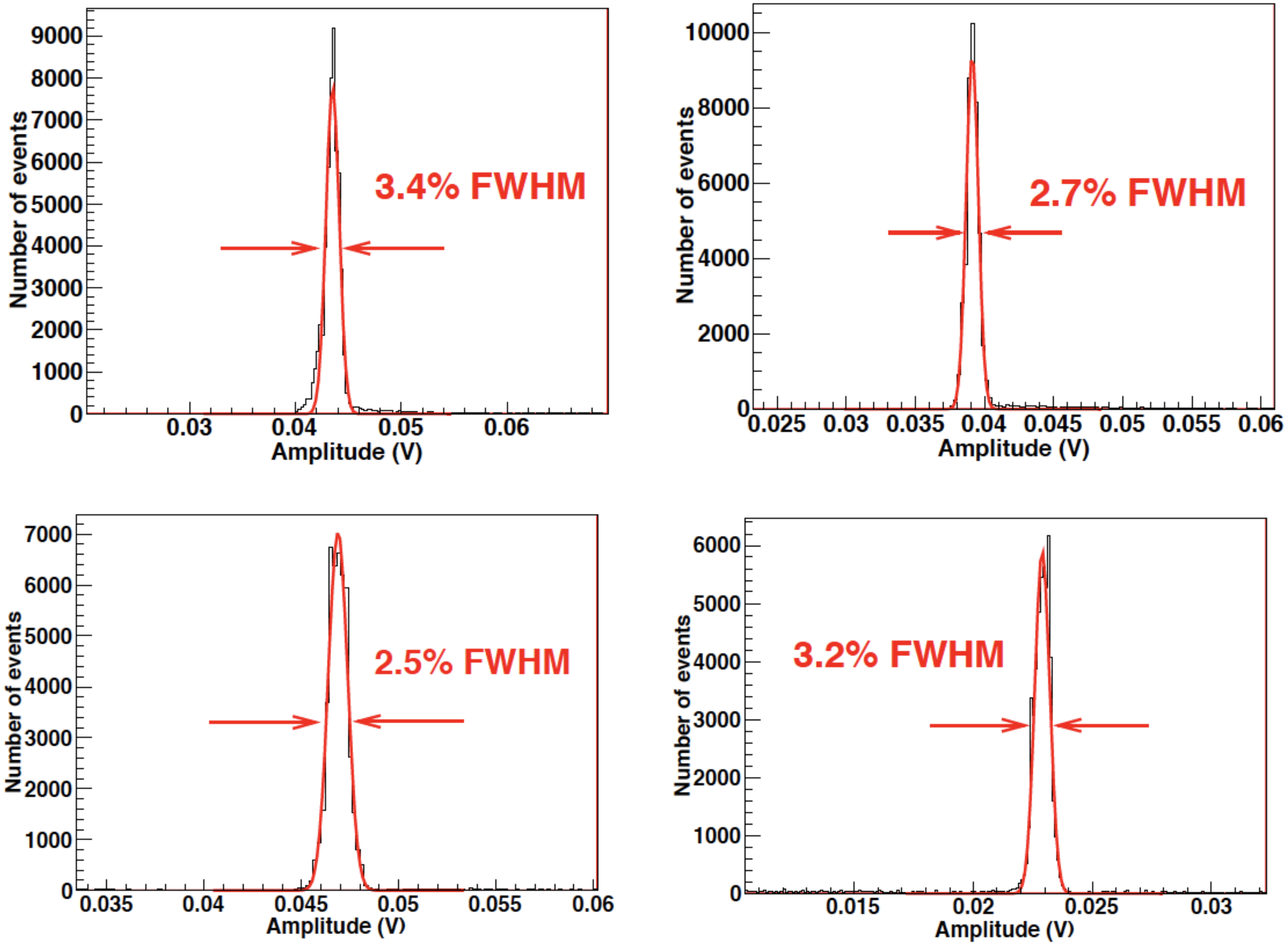


Figure 6. Energy spectra of the ^{241}Am alpha peak measured in the setup at 2 (top left), 3 (top right), 4 (bottom left) and 5 bar (bottom right). The red line and the value for the energy resolution are the result of the fit to a Gaussian function.

S. Cebrián, et al, Micromegas readouts for double beta decay searches, arXiv:1009.1827