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# Recent Results and Future Plans of XeBrA

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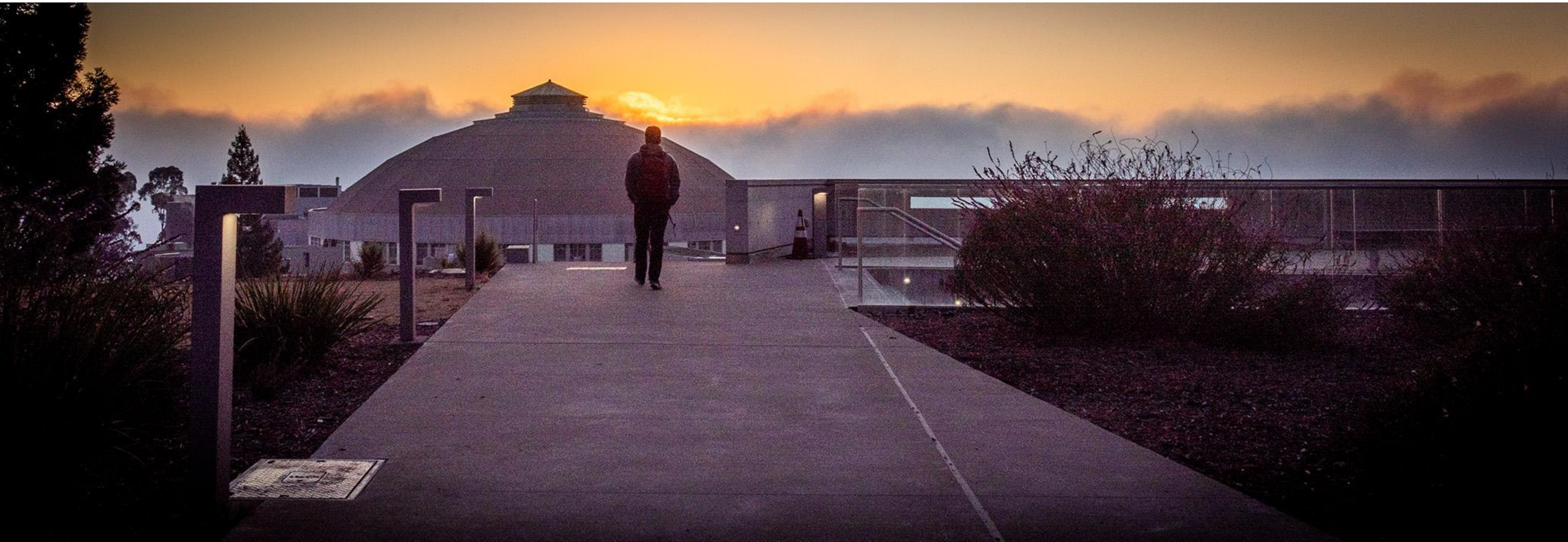
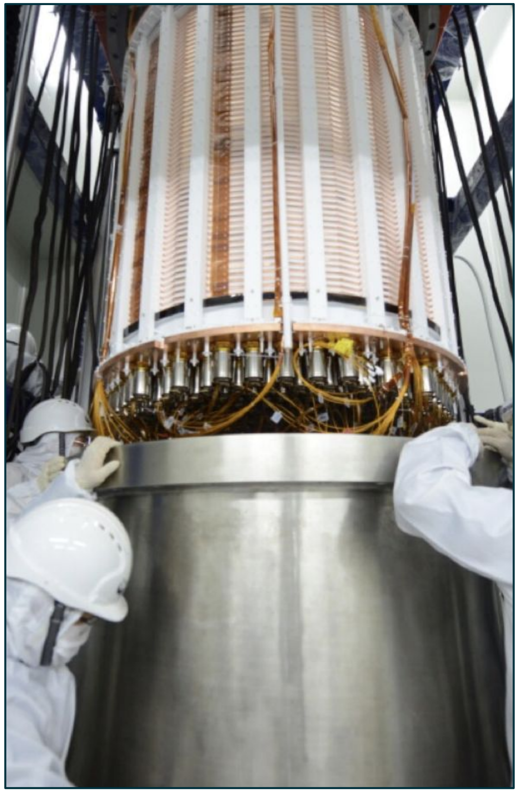
CPAD at University of Tennessee, Knoxville - Nov. 20, 2024



# Introduction

Characterisation of dielectric breakdown in liquid xenon is of great importance for current and next-generation direct detection dark matter experiments because dielectric breakdown will lower the sensitivity of such experiments and could potentially damage their light sensors.

**LZ**: Drift field = 97 V/cm, Cathode = 18 kV



**PandaX-4T**: Drift field = 93 V/cm, Cathode = 16 kV

**XENONnT**: Drift field = 23 V/cm, Cathode = 2.75 kV

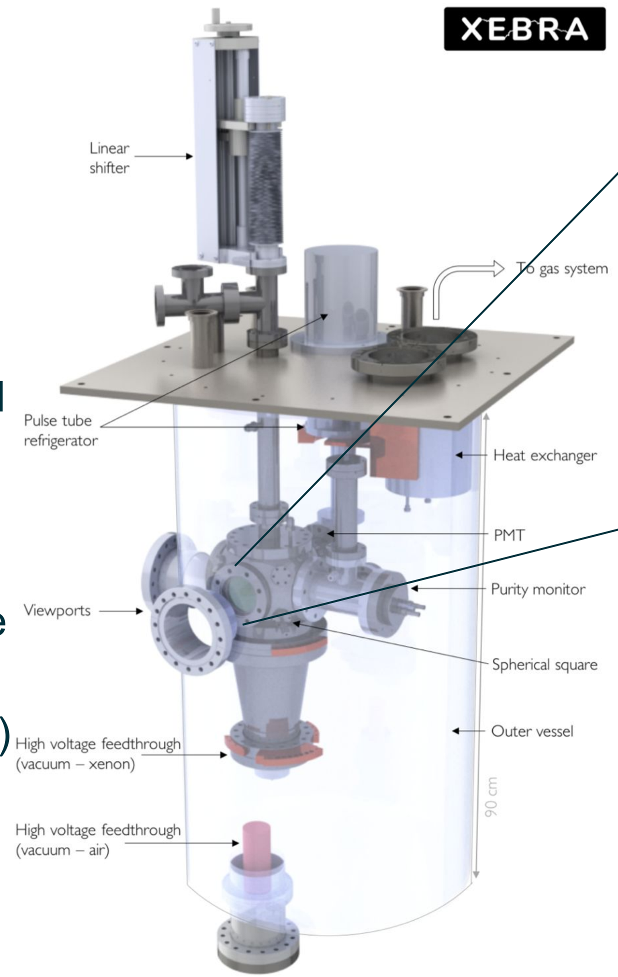
Current generation of experiments made informed decisions on high-voltage operation conditions, but lack reliable data on when dielectric breakdowns become a risk.

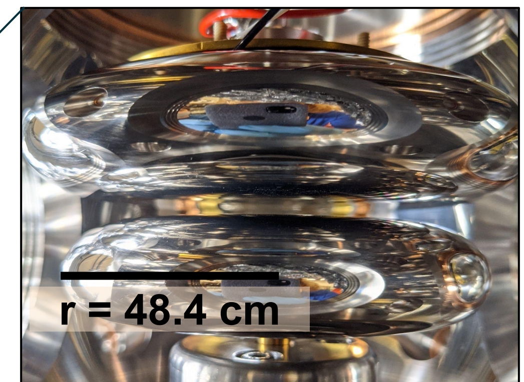
# Xenon Breakdown Apparatus (XeBrA)

This has been the goal of XeBrA, located at the Lawrence Berkeley National Lab and part of Dan McKinsey's research group, and we began collecting data May 2018.

Main components of XeBrA:

- 5L high voltage test chamber
- Large area electrodes
  - ~ 33 $cm^2$
- Dual viewports
- Pair of high speed cameras
  - Started to use in second campaign
- In-line purity monitor
- Getter for purification
- Current monitor on the anode
- SiPM
- PMT (not used when running)



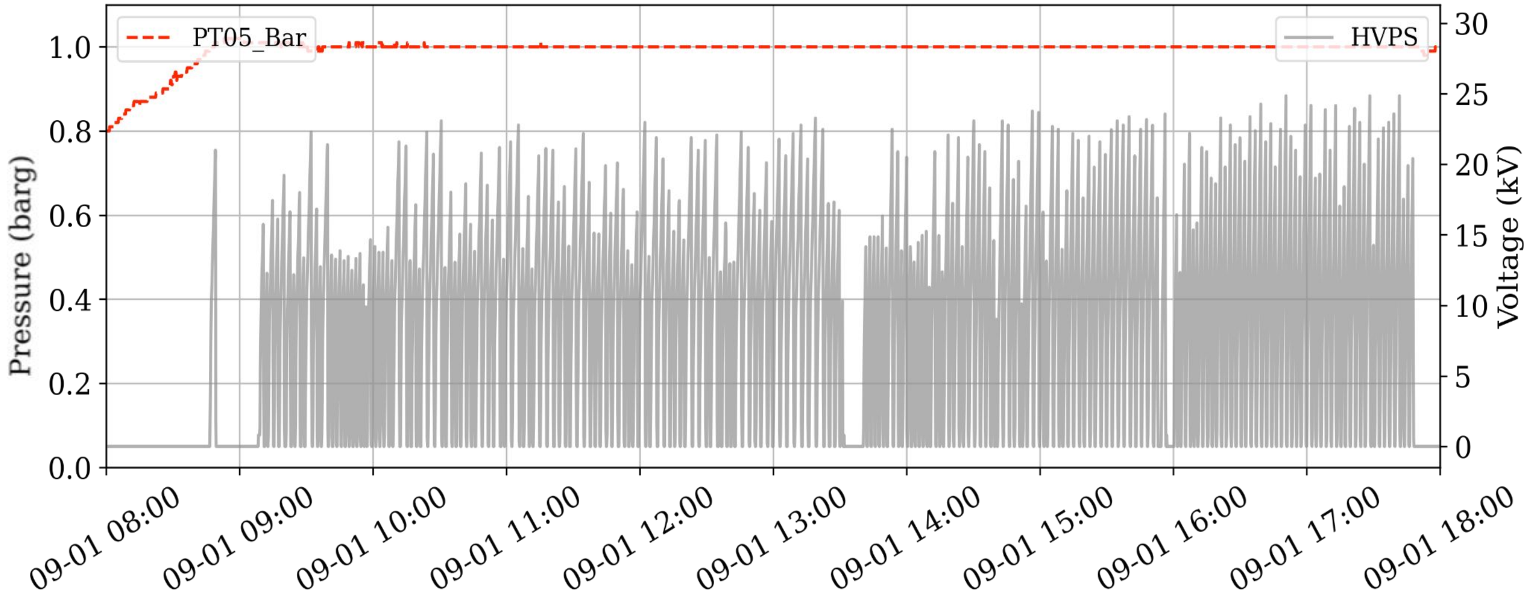




*Photograph of XeBrA's electrodes as seen through the front-side viewport*

# XeBrA Operation Details

Runs, or a cycle of liquid xenon filling and recovery, are typically a week long

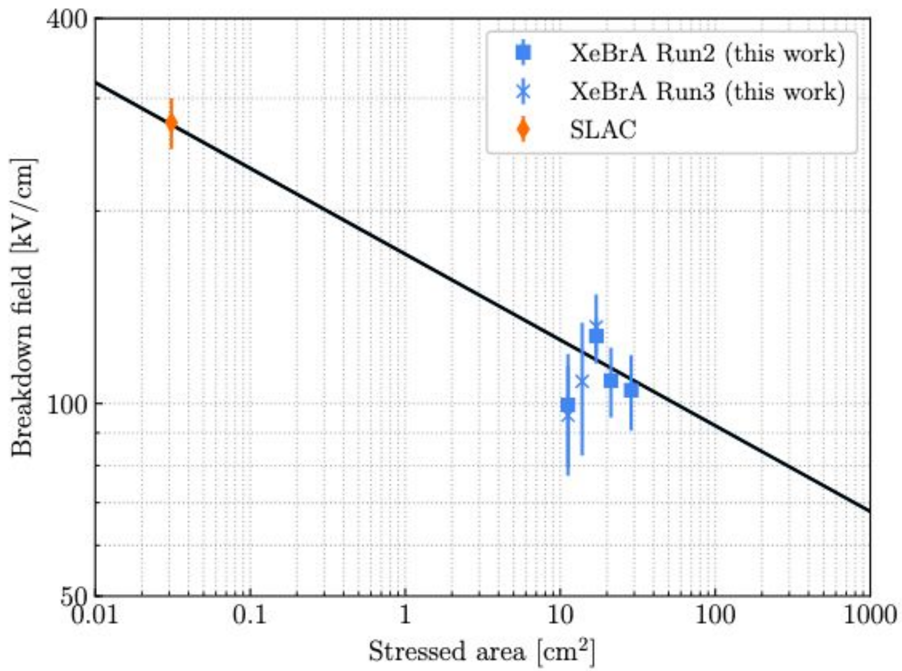
- High voltage supply ramp up till a specific voltage, or a current threshold is exceeding, then ramps down to zero
- Take data at different stressed areas, pressures, ramp speeds, or with different surface finishes
- $O_2$-equivalent **impurity**: < 25 ppb




*Monitoring plot from a run showing a scan over ramp speed*

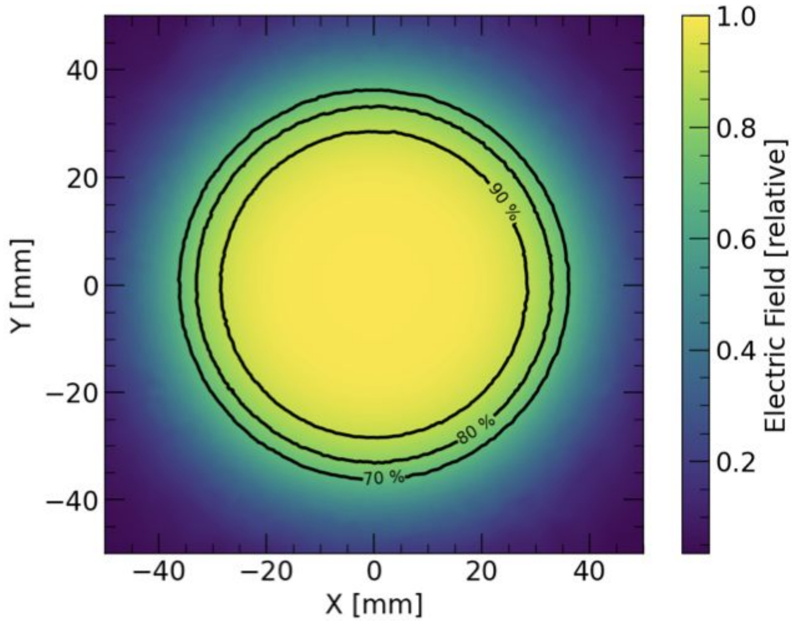
# XeBrA Results: First Campaign

We were the first experiment to systematically study dielectric breakdown in liquid xenon and liquid argon for stressed areas greater than 3 cm$^2$ and validated the existence of an area scaling effect for breakdown behavior in liquid xenon.




*A plot of breakdown vs. stressed electrode area in liquid xenon*

L. Tvrznikova *et al* 2019 *JINST* **14** P12018

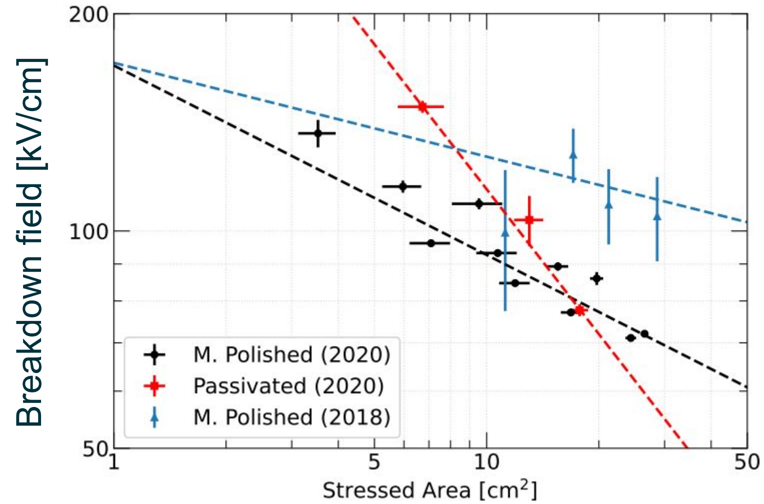



Example of the stressed area from simulation. Isocontours are indicated in black and the color map shows the electric field distribution normalized by its peak value.

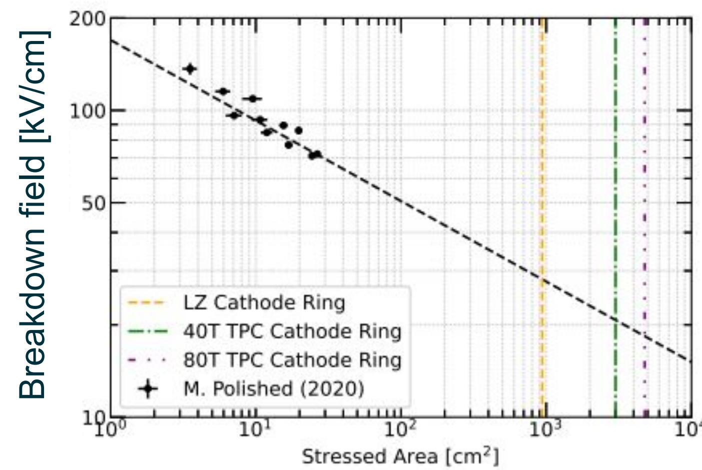
# XeBrA Results: Second Campaign

Results from XeBrA's second campaign confirmed that there is a direct dependance of breakdown field on stressed electrode area

- Two different types of surface finishes were used across runs
  - M. Polished: mechanically polished electrodes
  - Passivated: electrodes passivated with citric acid



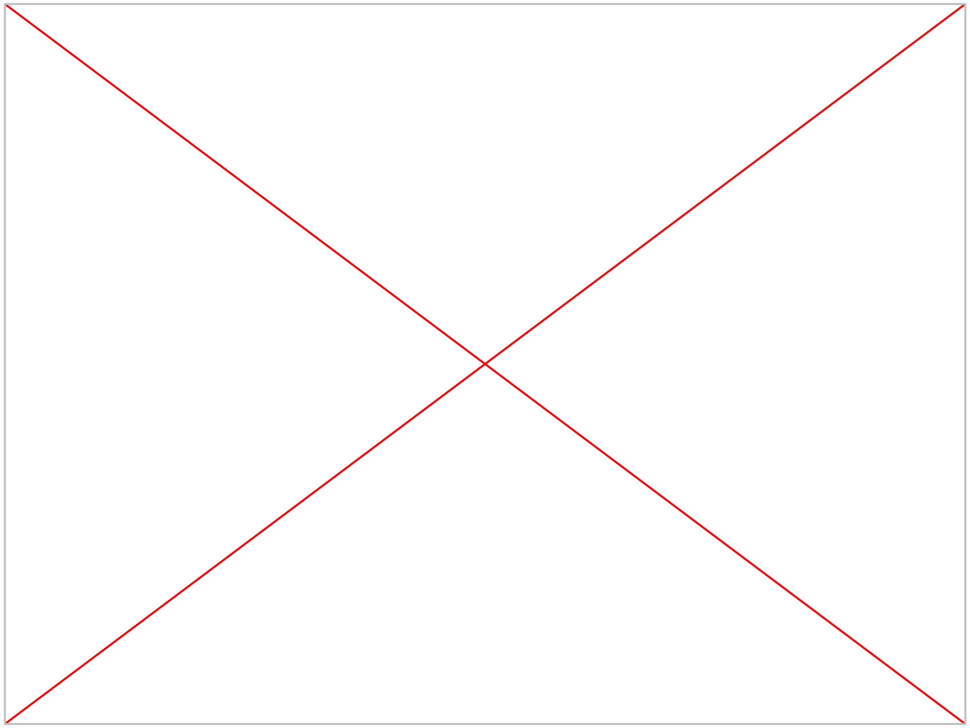

- Extrapolations to larger areas can inform next-generation TPC designs.




J. Watson, I. Olcina, **J. Soria**, D. N. McKinsey, et. al.; Study of dielectric breakdown in liquid xenon with XeBrA: The xenon breakdown apparatus. *Rev. Sci. Instrum.* 1 January 2023; 94 (1): 015112. https://doi.org/10.1063/5.0107082

# XeBrA Results: Second Campaign cont.

From the high speed cameras we see signs that bubbles are an essential mechanism for originating dielectric breakdown.



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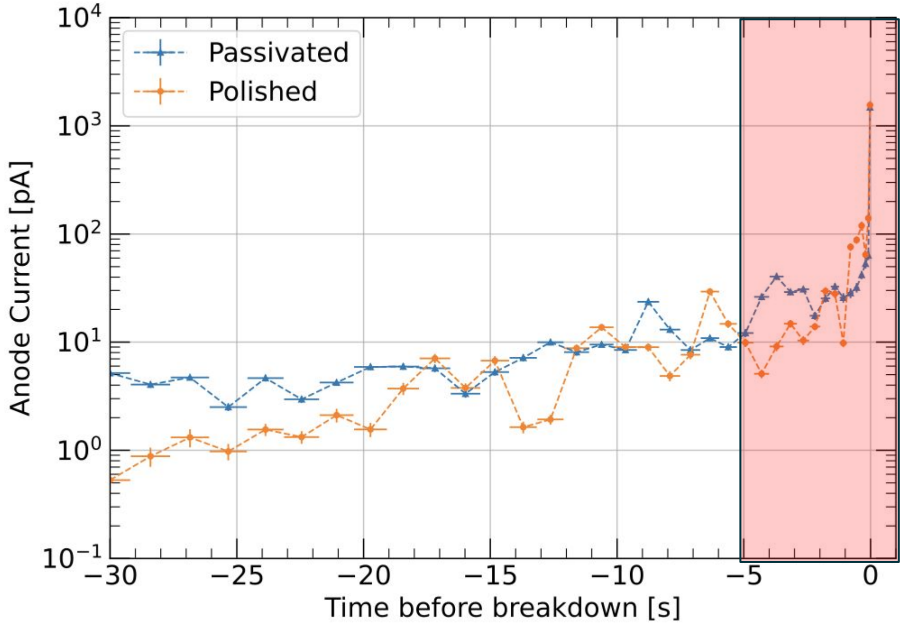
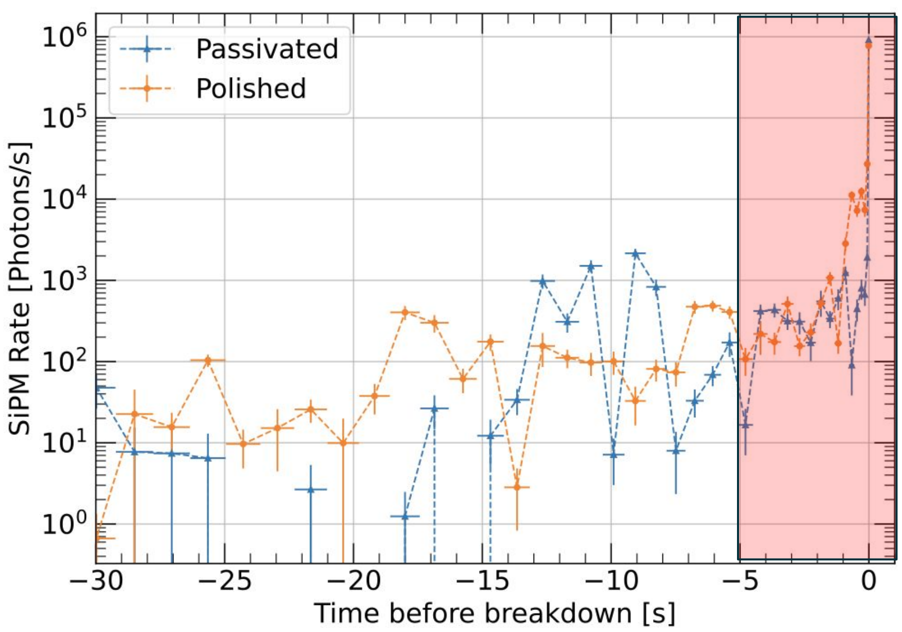
# XeBrA Results: Second Campaign cont.

Are there signs beforehand that signal that a breakdown is about to happen?




See a shape rise in current and light 5 seconds before a breakdown

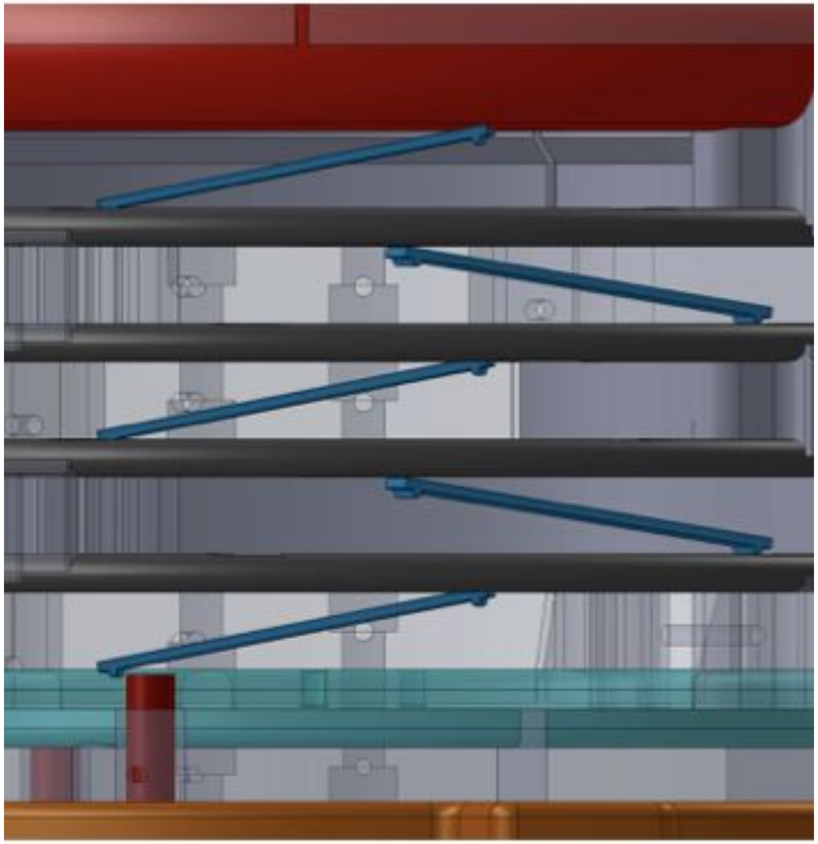
J. Watson, I. Olcina, **J. Soria**, D. N. McKinsey, et. al.; Study of dielectric breakdown in liquid xenon with XeBrA: The xenon breakdown apparatus. *Rev. Sci. Instrum.* 1 January 2023; 94 (1): 015112. https://doi.org/10.1063/5.0107082

# Future Plans of XeBrA

# Test Resistors in High Voltage (HV) Environments

Current generation of direct detection experiments have reported spurious emission of light from the field cage. In LZ, one plausible explanation is that light is coming from the resistor chain.

- The resistors used in the reverse field region of LZ are 5GΩ resistor with by OHMITE (similar models are used in different experiments).
- Possible explanation is that current could flow through, or out, of a small crack in the resistive film and cause light emission.
  - Can the electrostatic forces at high voltages cause such breaks?



*Placement of reverse field region resistors in LZ*

# Using XeBrA to Test Resistors in HV Environments

With a few changes we can modify the current experimental setup to test LZ resistors in a realistic setting.

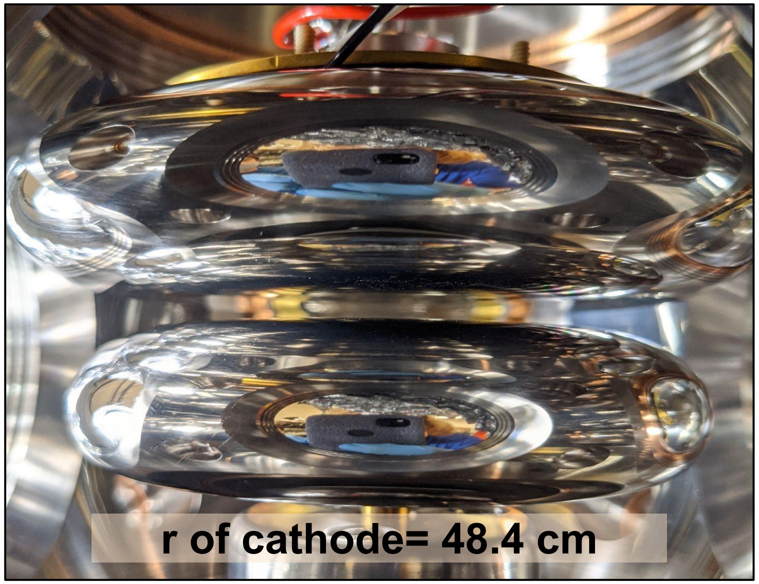
Notable changes from previous XeBrA measurements:

- Want to introduce a resistor into the high voltage environment and have current travel through them
- No longer interested in intentional breakdowns and instead will be running at fixed voltage for longer periods
- Monitor light activity with a PMT

Findings will be important for next-generation experiments, which will have even more complex high voltage systems

# Introducing the Resistor to XeBrA

Currently commissioning the new detector system and expect to conduct first science run before the end of the year




*XeBrA electrodes*

*XeBrA electrodes with tapped threaded holes and resistor in place.*

# Summary

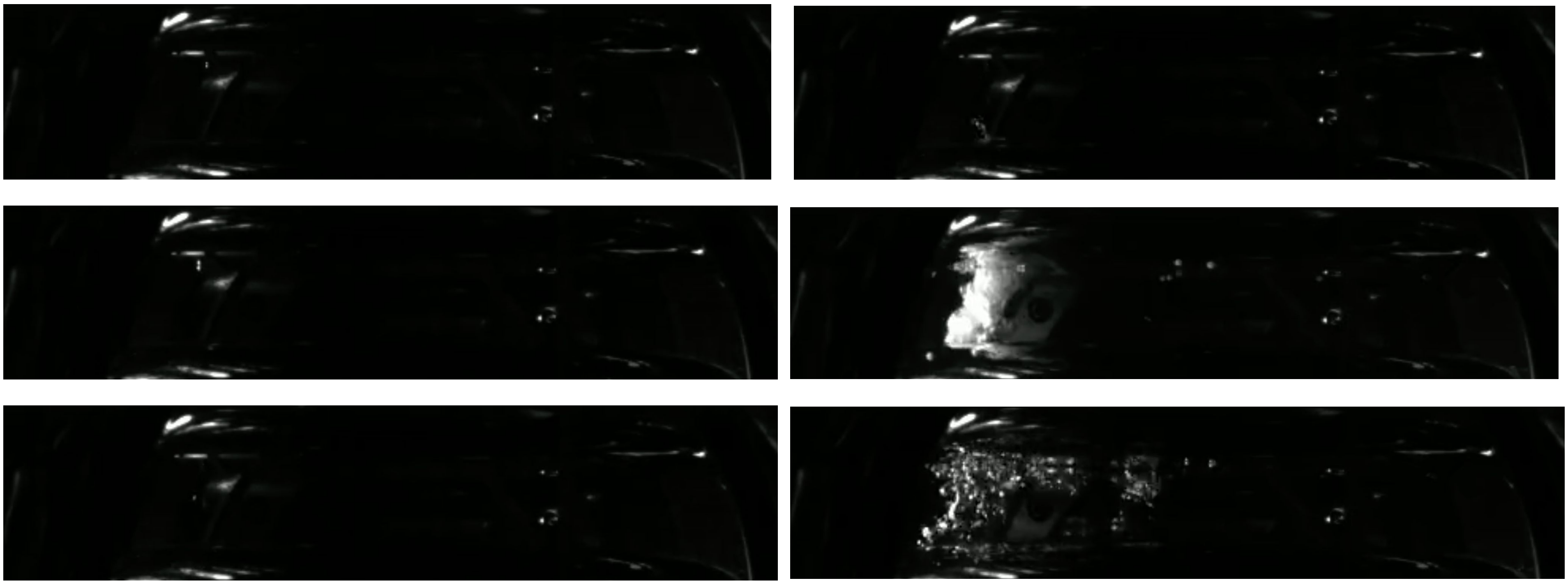
- XeBrA is an R&D experiment at LBNL to conduct high-voltage testing in noble liquids.
- We confirmed that dielectric breakdown scales with stressed area and provided recommendations to mitigate risk.
- See a rise in current and light before breakdown, could be used in prevention measures
- We have modified the detector system to study the degradation of resistors over time
- Stay tuned!

# Thanks

# Back Up

# XeBrA Results: Second Campaign cont.

From the high speed cameras we see signs that bubbles are an essential mechanism for originating dielectric breakdown.



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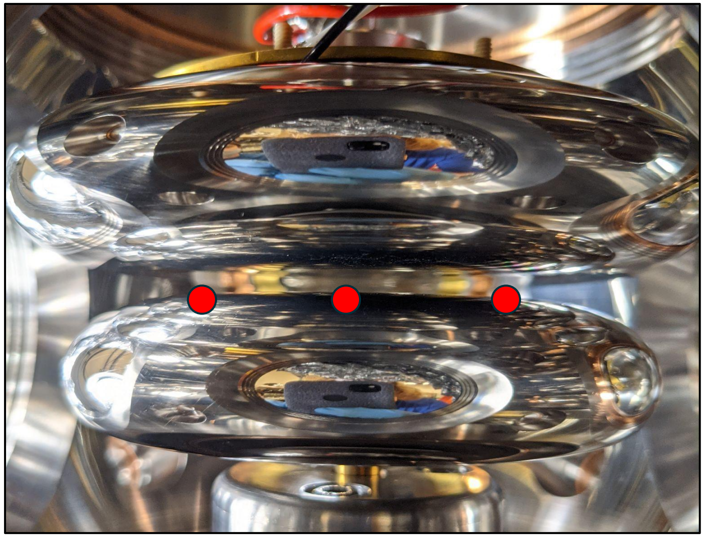
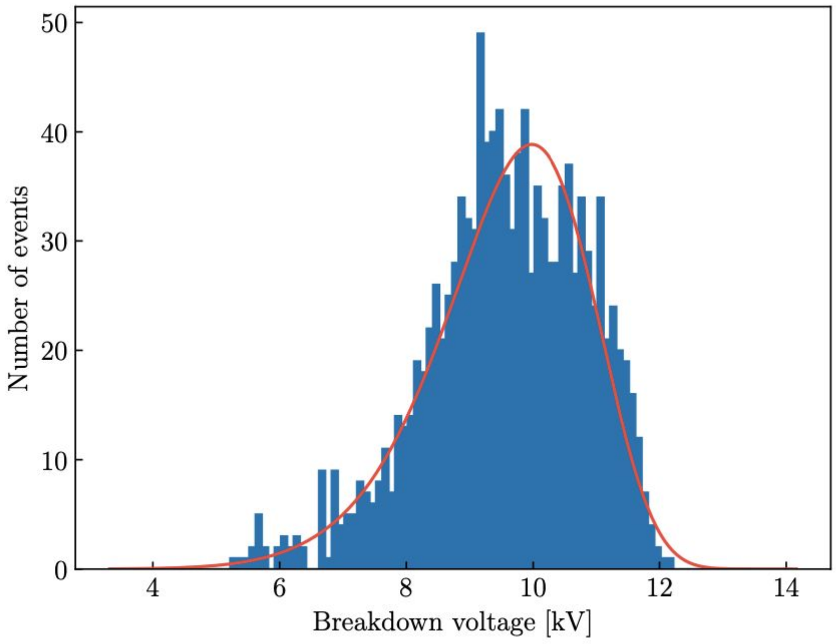
# Tilt estimation

- Two electrodes together with a piece of contact paper, graphite sheet between two pieces of white paper, between them
- Tilt was estimated using photogrammetry:
  - Photos were taken from each viewport at a fixed camera perspective for different separation distances. One blind to the analyser.
  - The y-intercepts of points on either side of the center provide an estimate of the tilt angle from that perspective.



# Weibull Analysis

- Reliability analysis
  - Follow the Weibull weakest-link model to describe surface-initiated breakdown
  - Failure of a system is determined by its weakest element → electrode is broken up into smaller elements
  - Failure probability density function is the Weibull probability density function



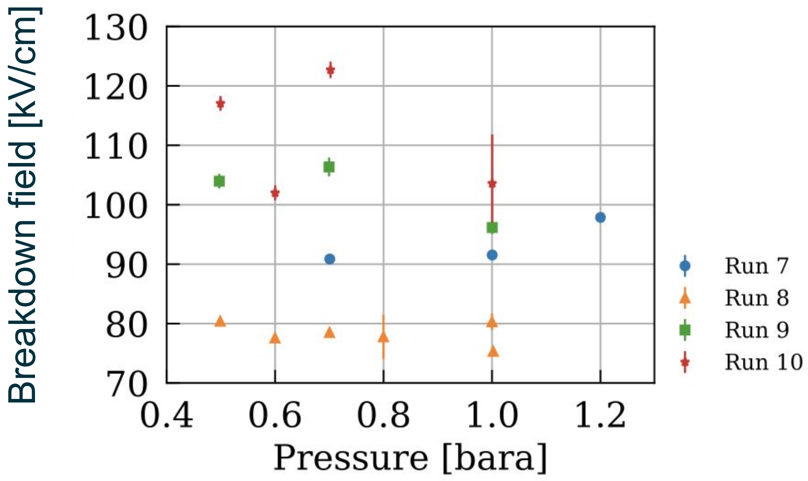

1mm separation in liquid xenon

# XeBrA Results: Second Campaign cont.

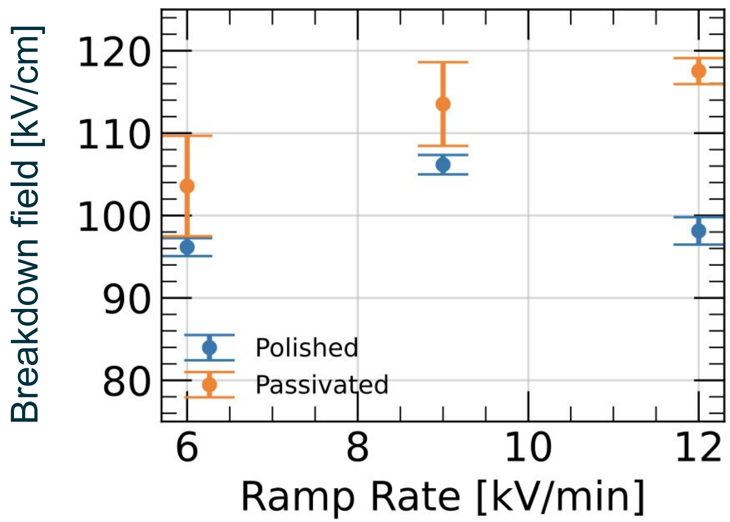
With XeBrA we varied different parameters and investigated how they impact the dielectric strength of liquid xenon

A few of these parameters include:

- Pressure
  - Does suppressing bubble nucleation and growth by increasing the pressure change the likelihood of breakdown?
  - No clear pattern seen

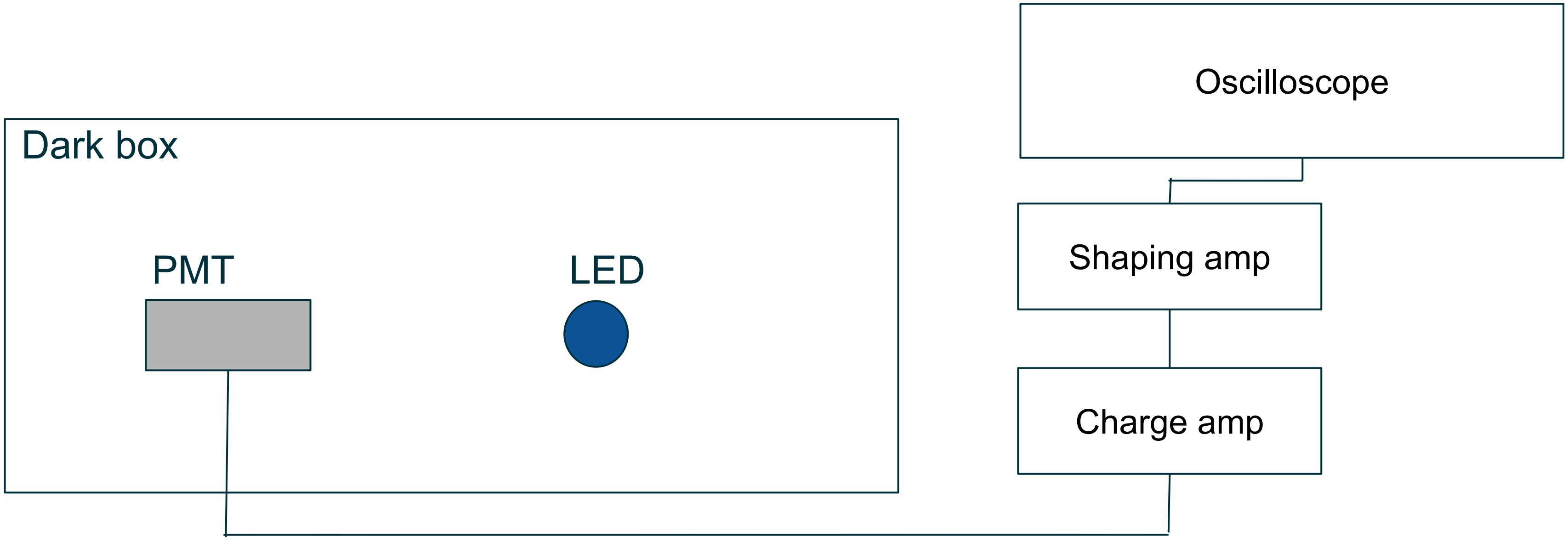



- Ramp speed
  - Different materials (i.e. borosilicate glass, alumina, and etc.) do show that the breakdown voltage does depend on the ramp speed. What can we say about liquid xenon using XeBrA?
  - No clear pattern seen



# XeBrA PMT testing

- Given that we haven't collected and analyzed PMT in our previous results, we have been dedicating some time to reassessing that PMT signal chain for these new studies
- Using a Hamamatsu R9288 with a bialkali photocathode
  - Testing it with a test setup
- DAQ has a timing resolution of 10 ns




PMT test setup