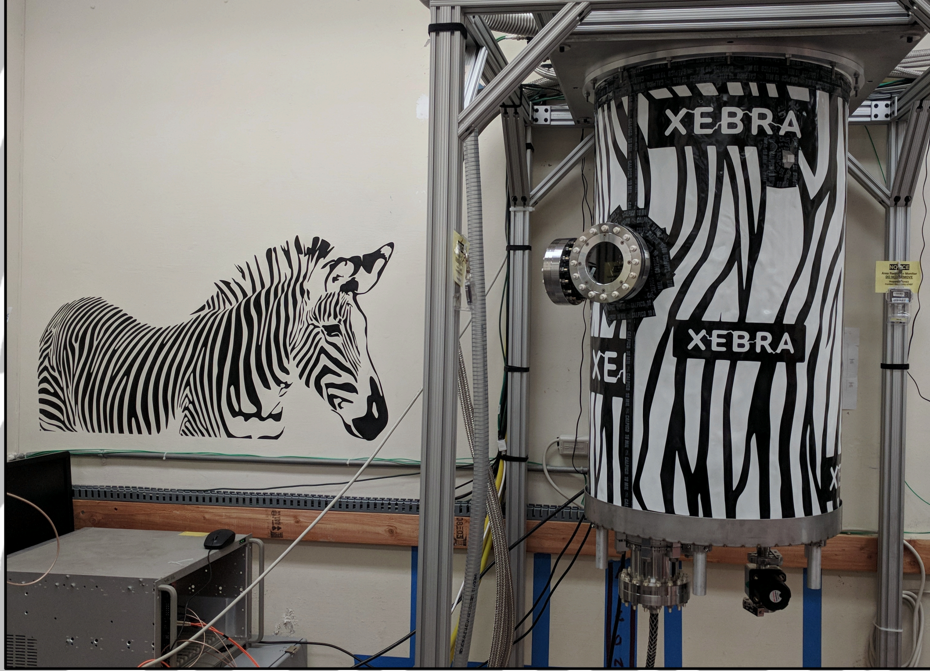
Characterization of high voltage behavior in noble liquids with XEBRA



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UCLA Dark Matter 2018, February 23rd 2018

Motivation for XEBRA

Upcoming experiments

Current measurements  VS 

Problem

- Lack of data characterizing high voltage (HV) behavior in noble liquids needed for dark matter detector design
  - Larger detectors need more HV – is there a threshold that will impede the scale up?

Solution

- Acquire data characterizing HV in liquid argon (LAr) and liquid xenon (LXe) to inform detector design
  - Some data for LAr exist but only for small areas

Good news

- I have data!
  - Improves current measurements in LAr by ~10x in electrode area

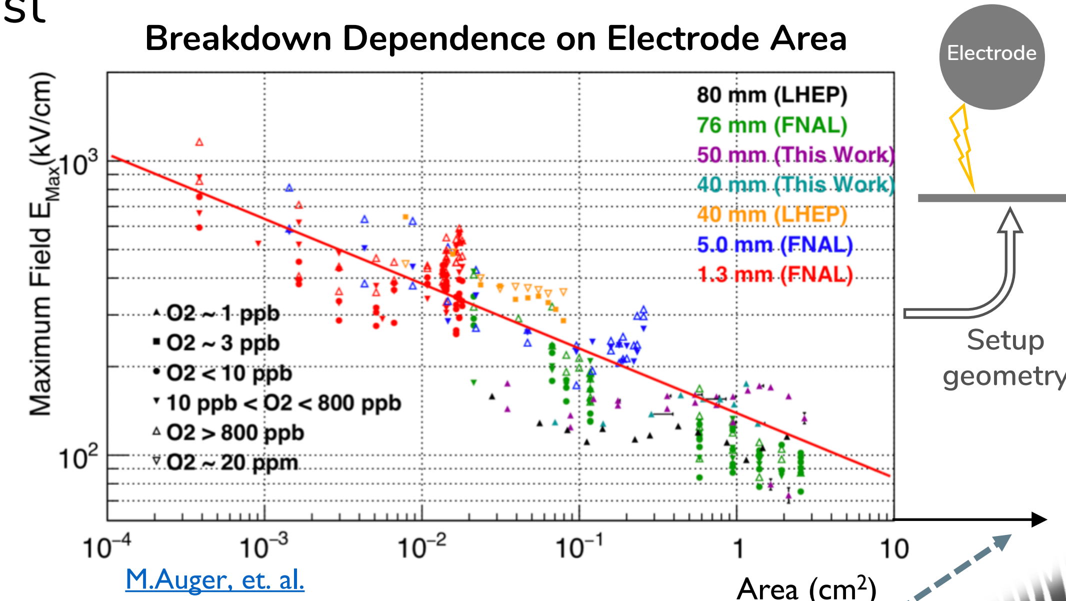
XeBrA = Xenon Breakdown Apparatus

- Detector at LBNL developed by L. Tvrznikova, E. Bernard, K. O'Sullivan, W. Waldron, G. Richardson, S. Kravitz, Q. Riffard & D. McKinsey
  - Supported through the LBNL LDRD program

State of the field for breakdown in LAr

Studies in LAr[1,2] & LHe[3] suggest breakdown depends on:

- Electrode spacing
- Electrode stressed area
- Electrode volume
- Liquid purity
- Electrode geometry
- Surface finish



M.Auger, et. al. JINST 11 P03017 (2016)

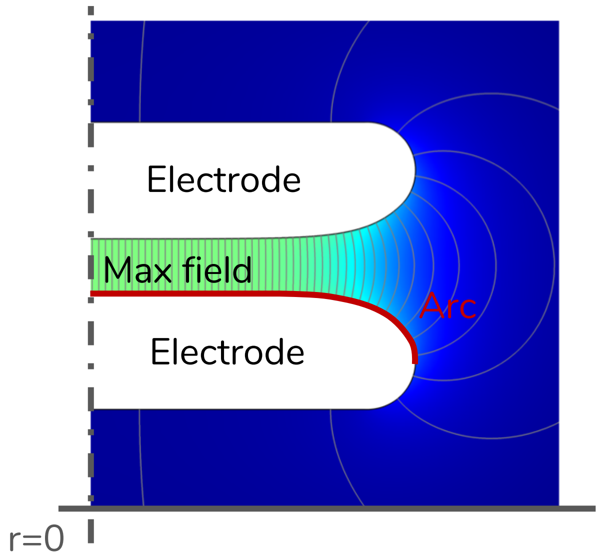
Design for the LZ cathode stressed area (500 cm²)

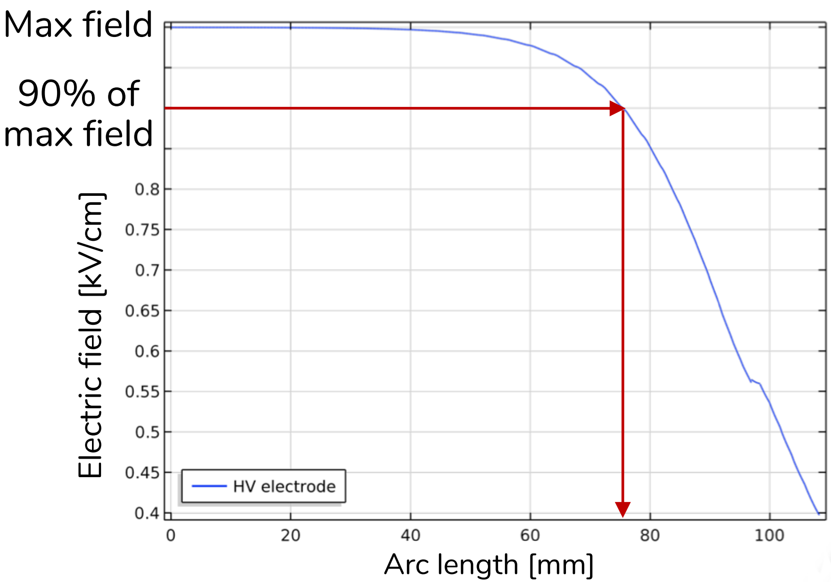
[1]S. Lockwitz, et al., arXiv:1408.0264v1
[2]M.Auger, et. al. JINST 11 P03017 (2016)
[3]J. Gerhold, et al., Cryogenics 34.7 (1994)

Stressed area of cathode

= Area with an electric field greater than 90 % of the maximum electric field

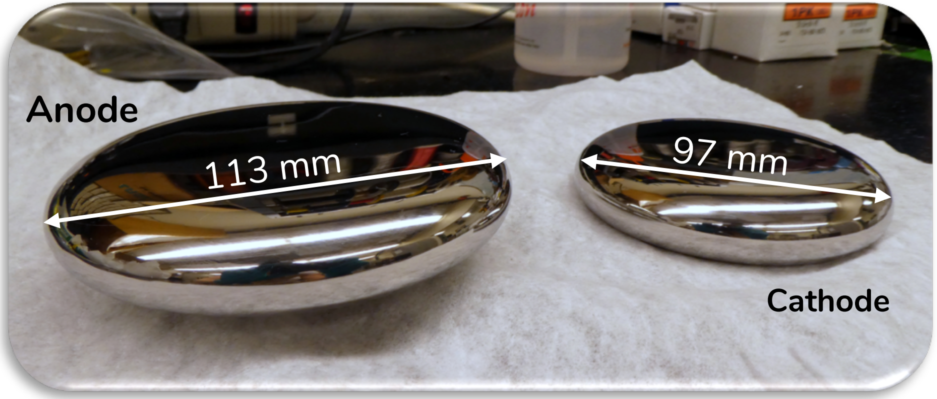
- i.e. where the sparks are most likely to happen



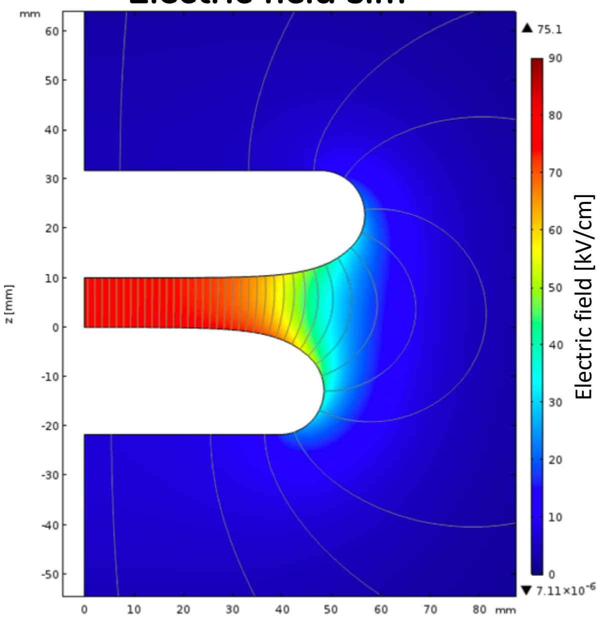


Rogowski electrodes

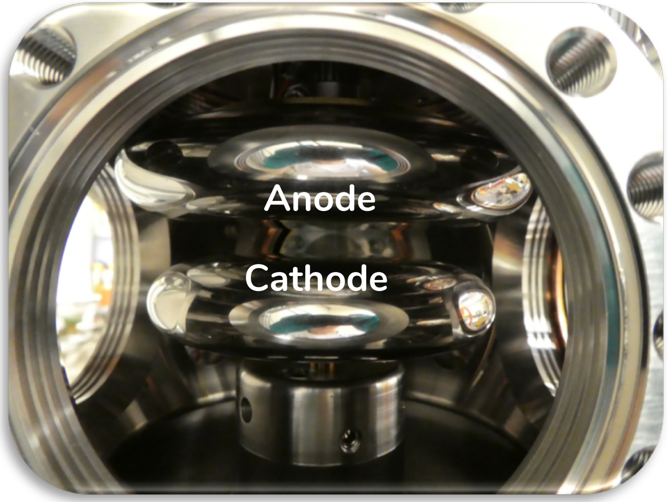
- Electrodes designed to have highest field near the center and maintain a nearly uniform field over a large area



Electric field sim



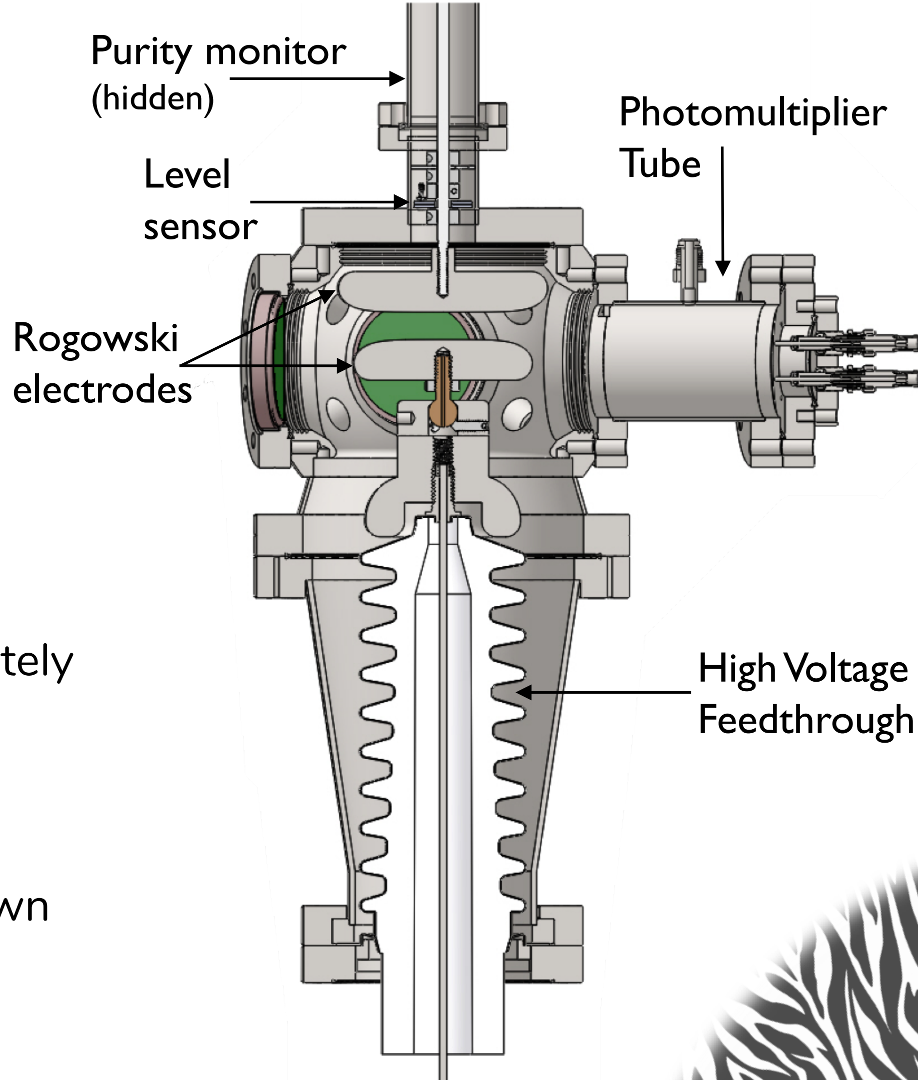
Location of electrodes in the detector



Cathode + HV feedthrough

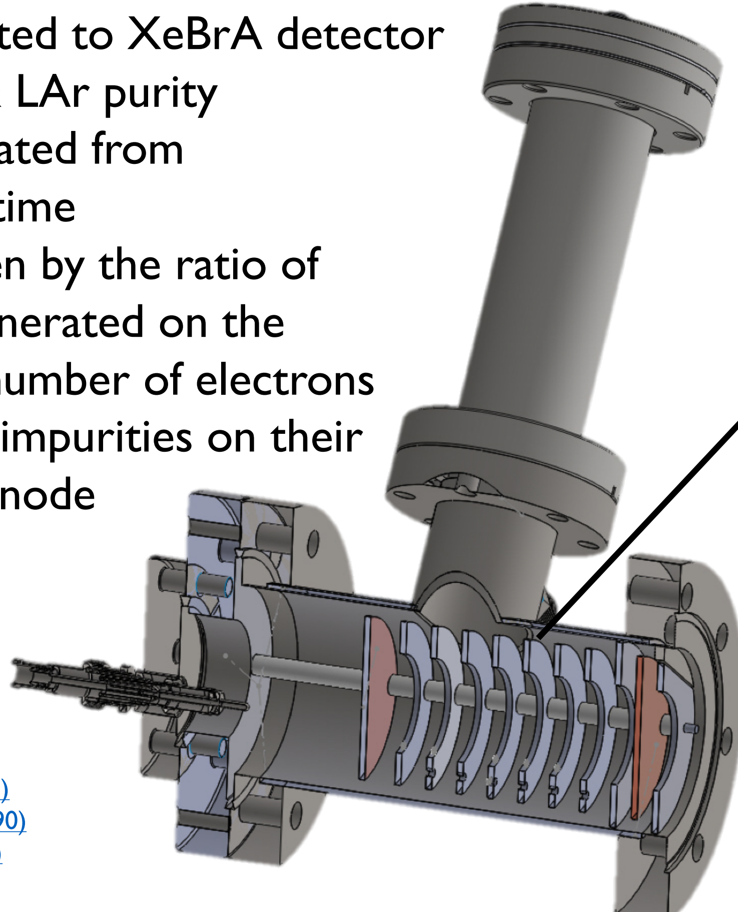
Detector details

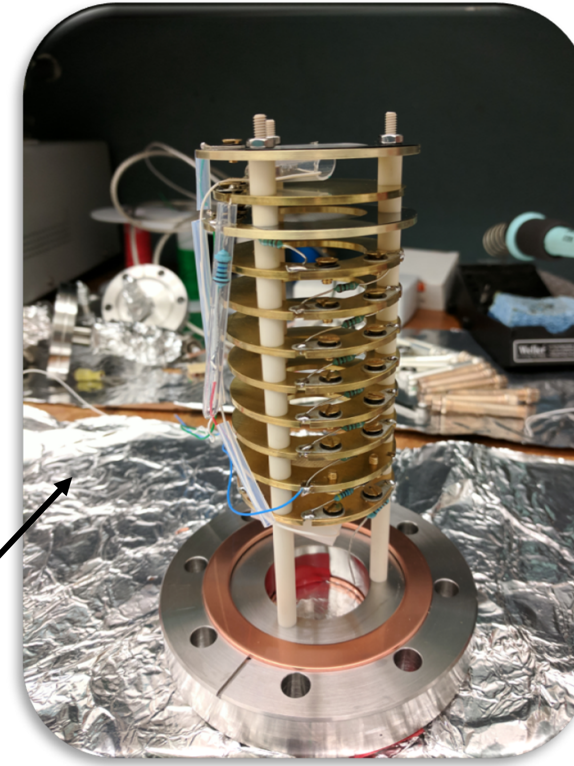
- Can be filled with either LXe or LAr with total experimental volume = 5.6 L
- Designed for HV up to -75 kV
- Max stressed electrode area = 58 cm^2
- Max electrode separation = 10 mm
- Ability to vary electrode separation remotely
- Continuous purification
  - Monitoring of liquid purity
- Detection of both glow onset & breakdown using current sensing, PMT & camera



Purity monitor 2.0

- Directly connected to XeBrA detector
- Monitors LXe & LAr purity
  - Purity calculated from electron lifetime
  - Purity is given by the ratio of electrons generated on the cathode vs number of electrons captured by impurities on their way to the anode

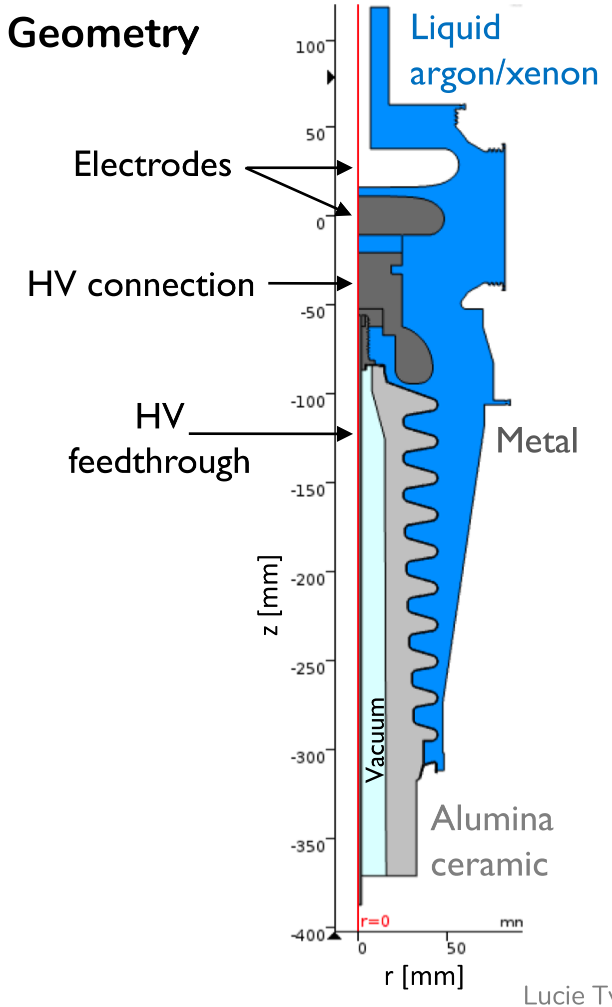


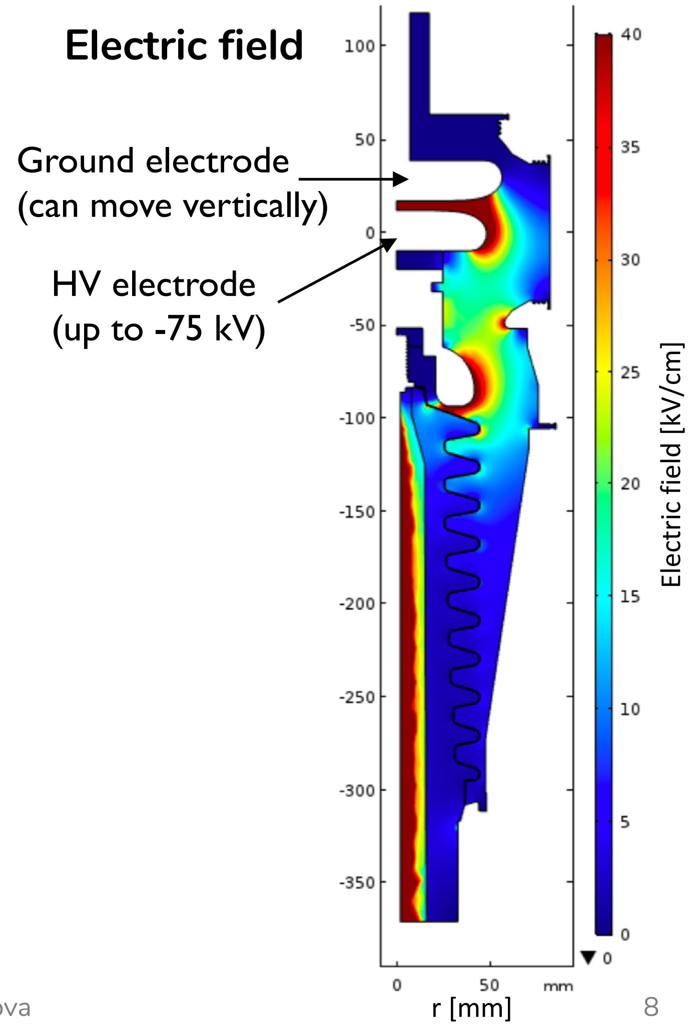


See, for example:

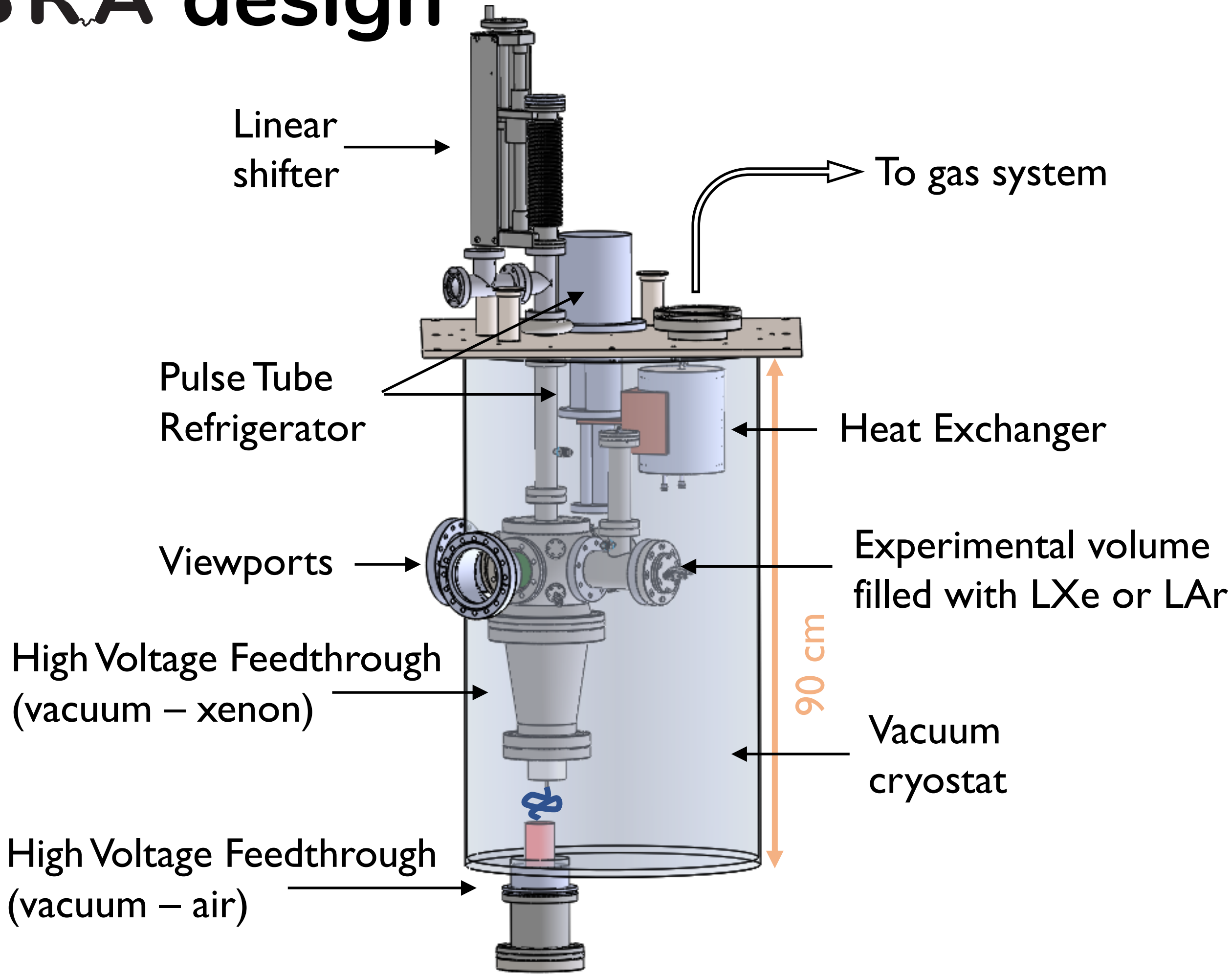
[A. Bettini, et al. NIM A 305.1 (1991)](#)
[G. Carugno, et al. NIMA 292.3 (1990)](#)
[Y. Li, et al. JINST 11 T06001 (2016)](#)

XEBRA simulations (axially-symmetric model)

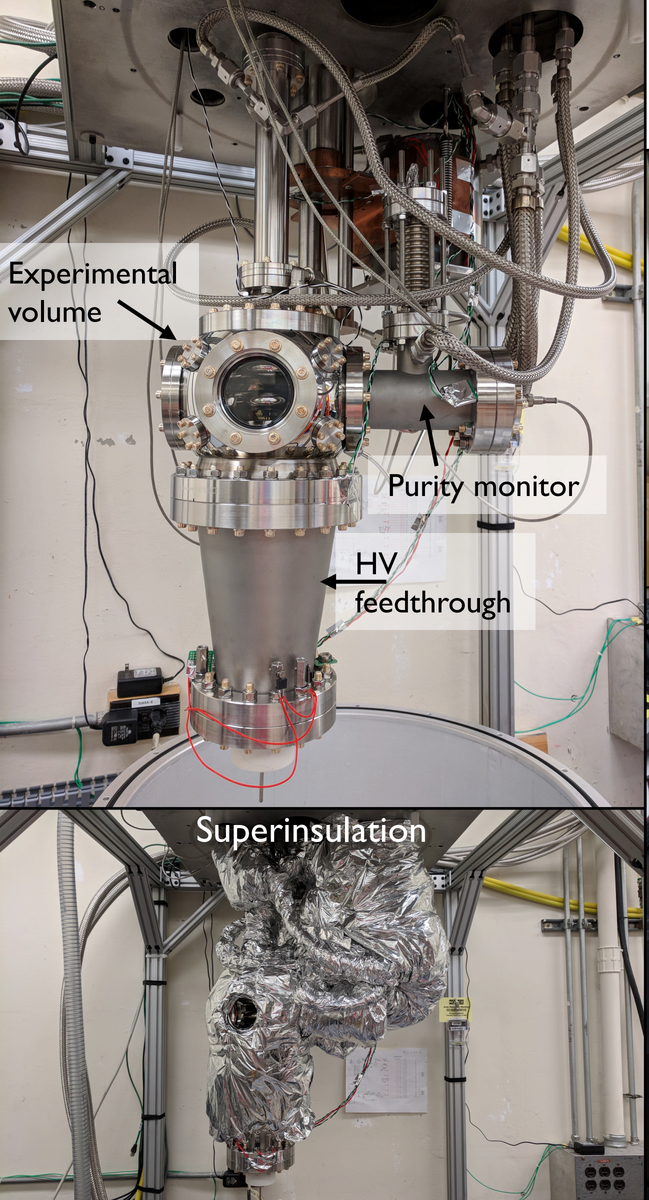


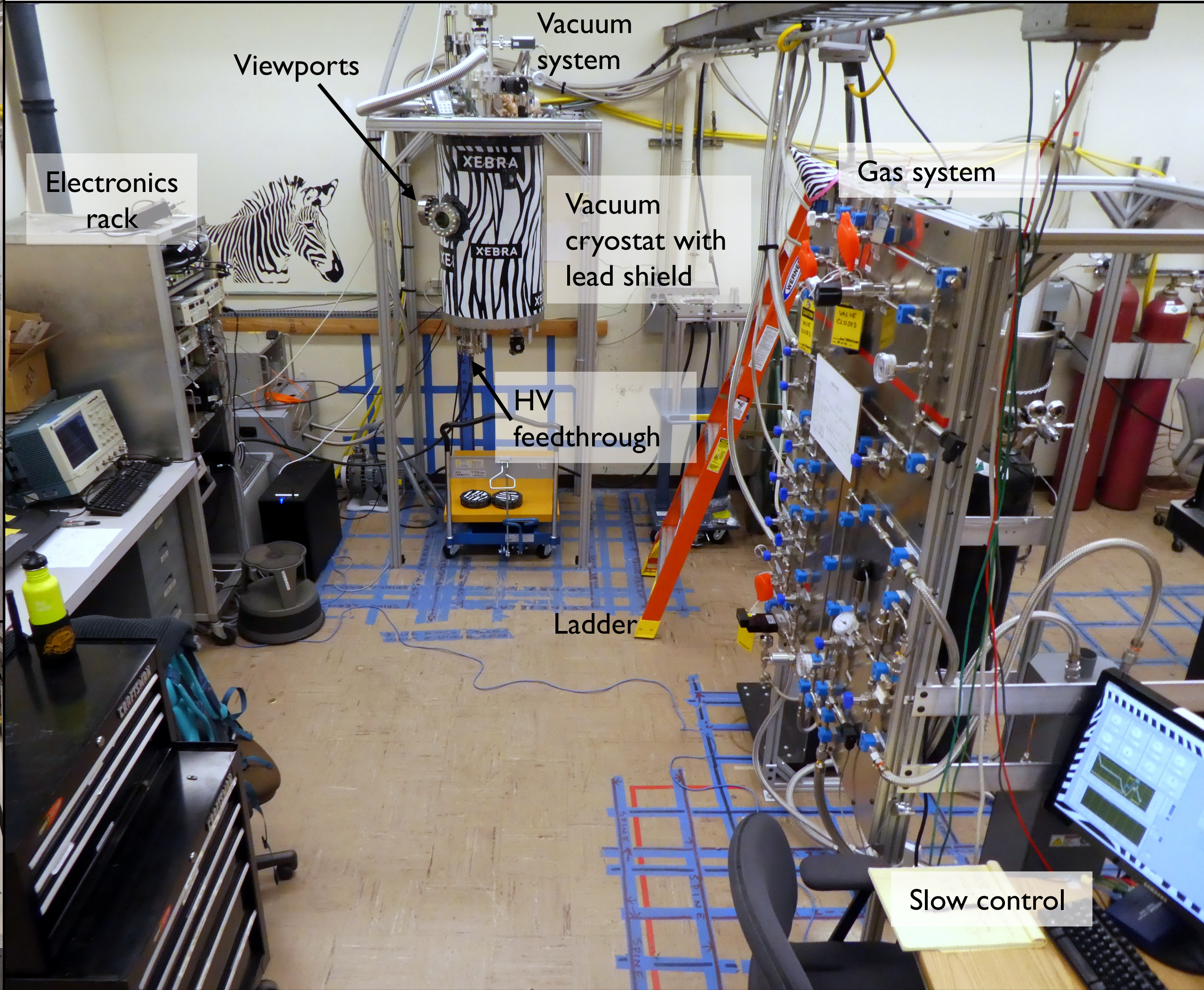


XEBRA design



XEBRA set up

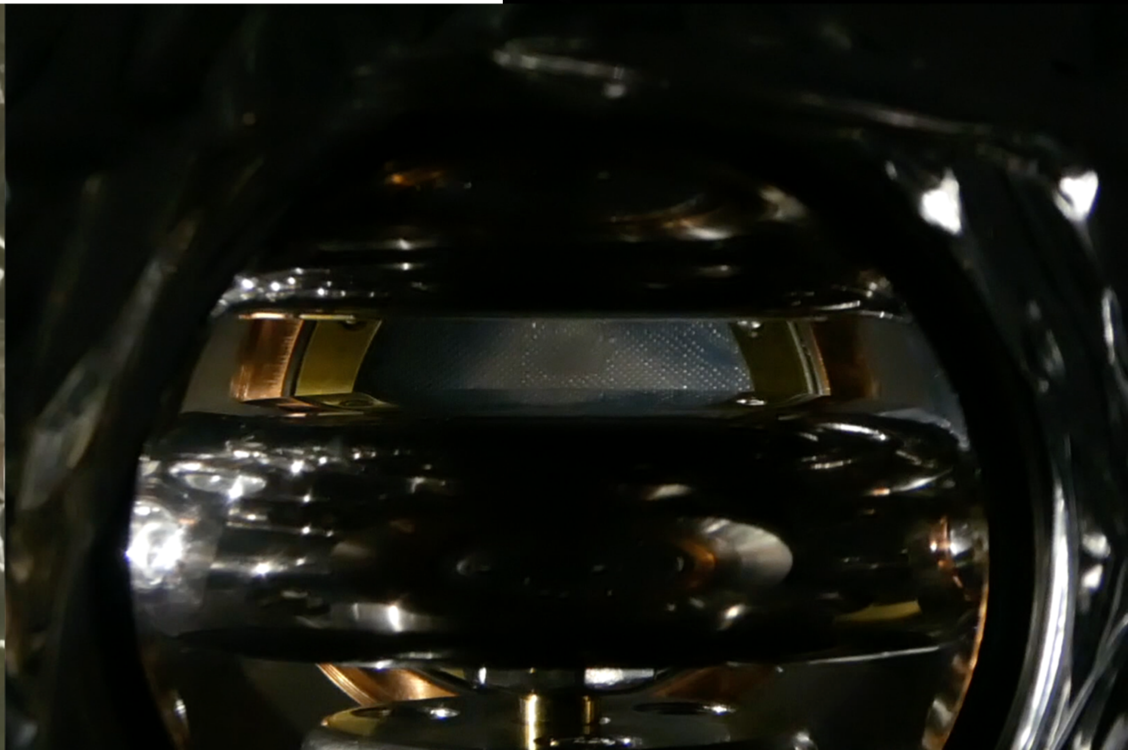

Experimental volume
Purity monitor
HV feedthrough
Superinsulation


Viewports
Vacuum system
Electronics rack
XEBRA
Vacuum cryostat with lead shield
Gas system
HV feedthrough
Ladder
Slow control

Spark fun in liquid argon

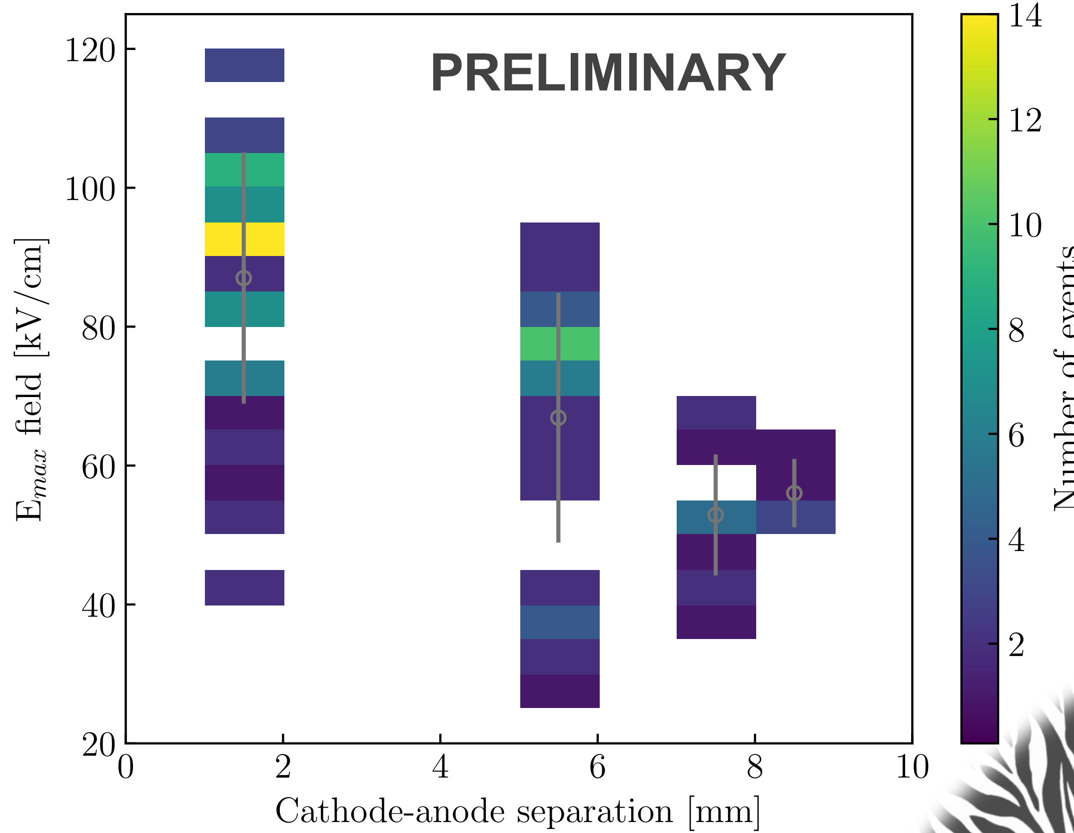
Bubbling liquid argon

Spark at 7 mm separation

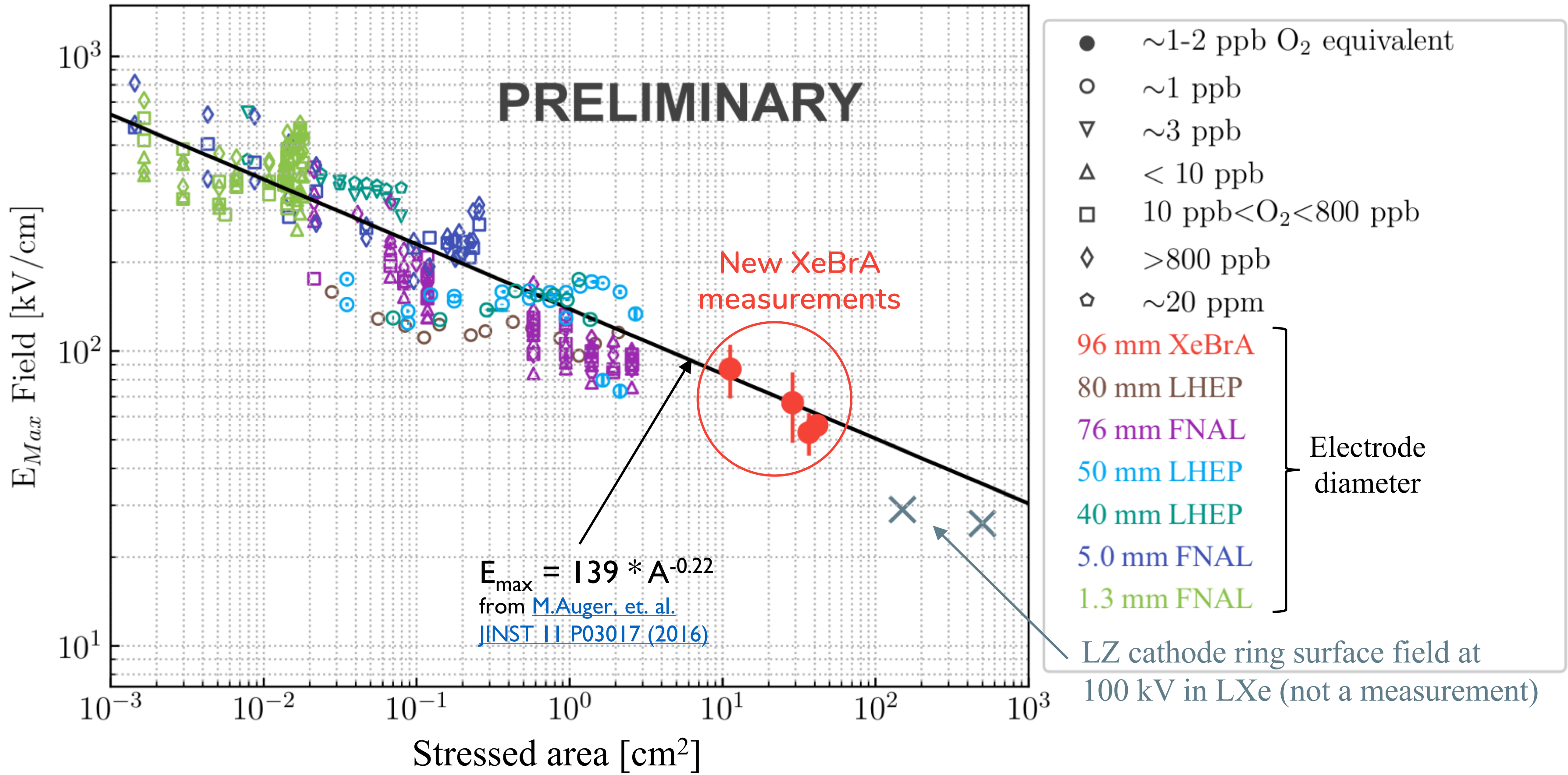


Breakdown field vs electrode separation

- Measurements performed in LAr
- Max voltage delivered to cathode was -67.5 kV
- Data taken at pressures of 0.25 – 1 barg
- "Conditioning" effect observed
- Ensured bubble-free measurements
- 1-2 ppb as measured by the purity monitor

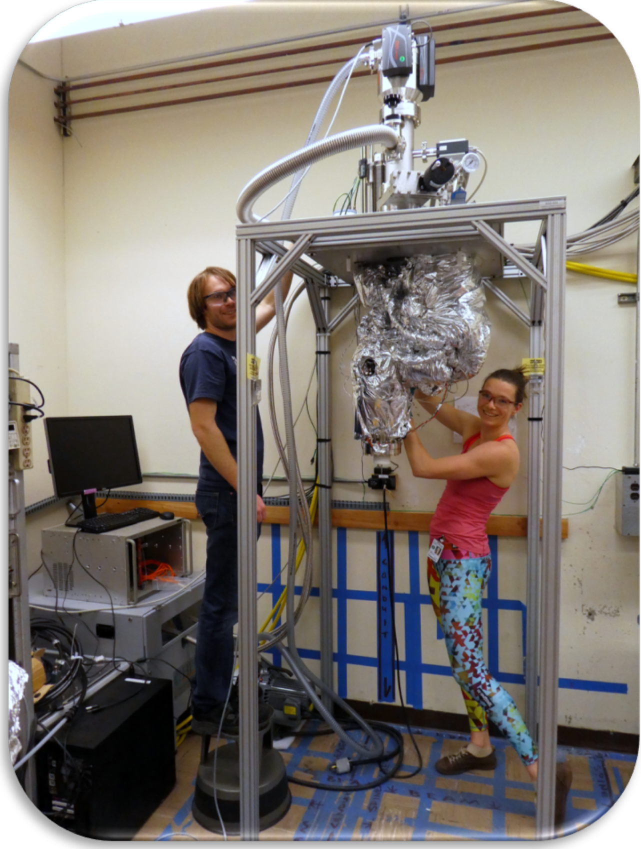


Breakdown field vs area in LAr



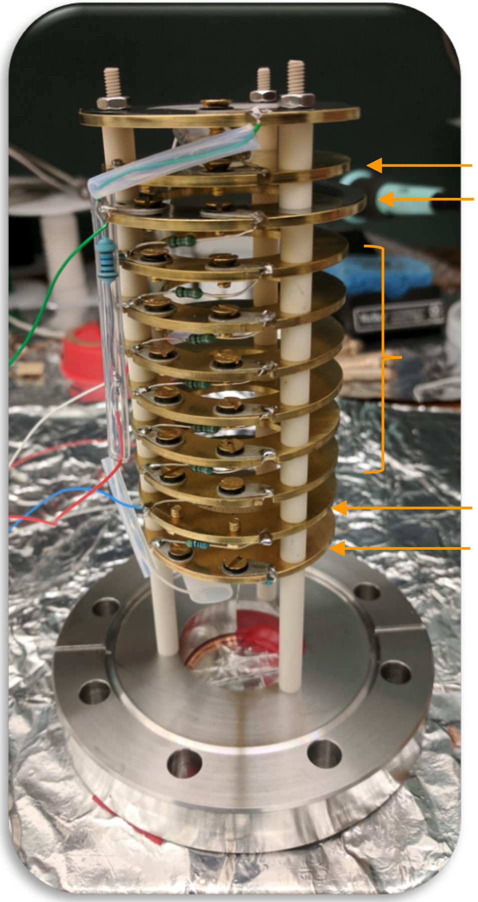
Conclusion & outlook

- XeBrA is now operational and collecting data
- XeBrA will allow LAr and LXe breakdown measurements with higher electrode areas than previously studied
- Upcoming:
  - Collection of higher statistics in LAr and study of the onset of luminescence
  - Collection of breakdown data in LXe
    - Refill detector with LXe to get a direct comparison with breakdown behavior in LAr
- Many parameters of breakdown behavior to study in the future:
  - Electrode geometry
  - Electrode material (varying finishes & coatings)
  - Liquid purity & effect of different impurities
  - …

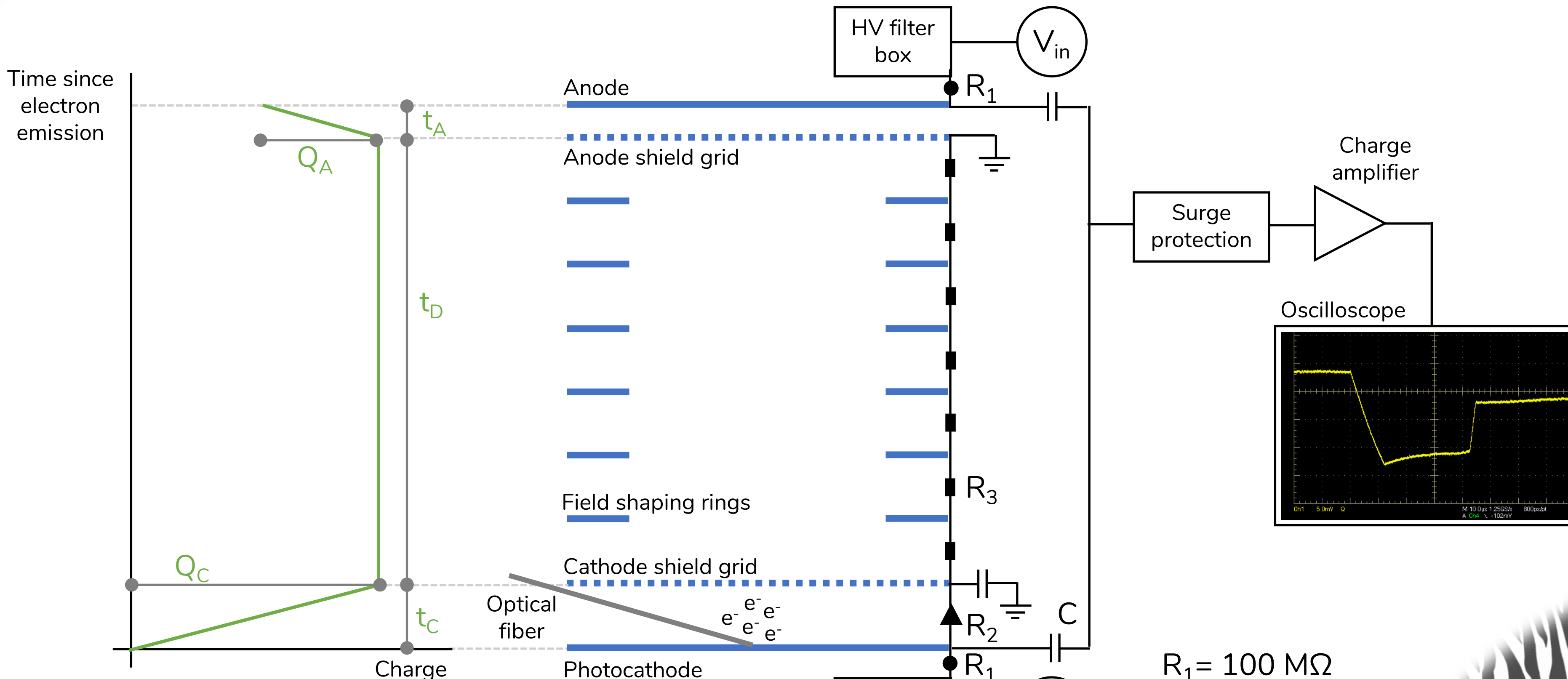


Gas system

Purity monitor



Purity monitor schematics

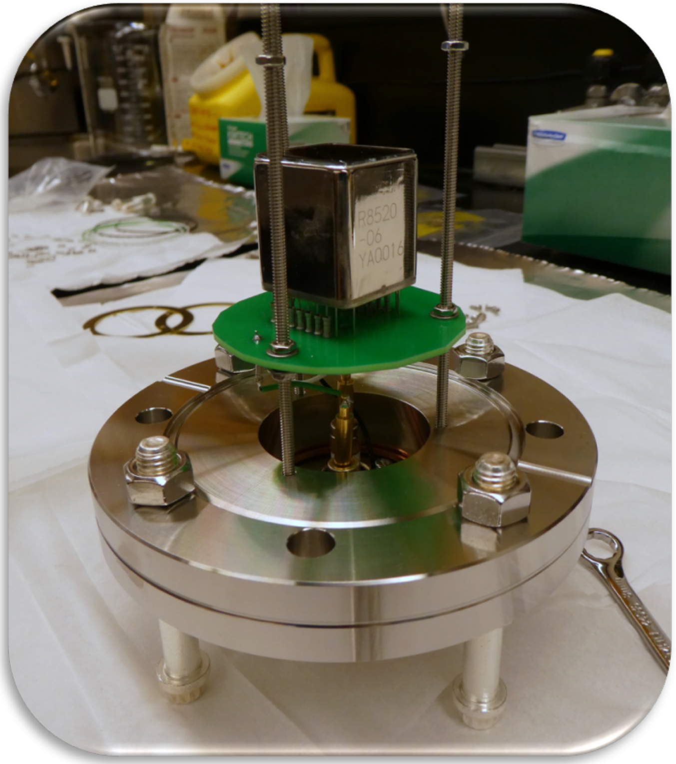


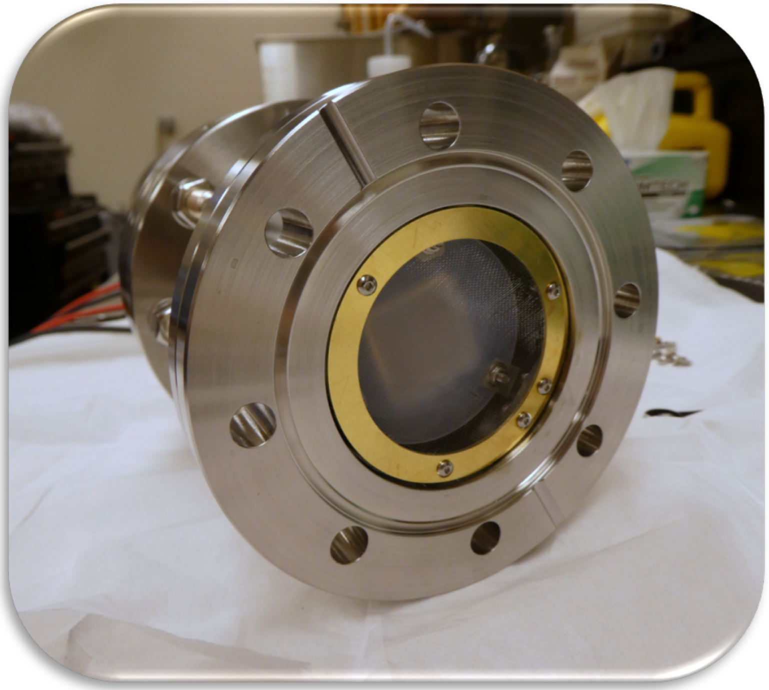
$Q_A/Q_C = e^{-t/\tau}$

$R_1 = 100\ M\Omega$
$R_2 = 390\ M\Omega$
$R_3 = 1\ G\Omega$
$C = 27\ nF$

PMT

- Hamamatsu R8520-06 MOD with platinum underlay





Proposed breakdown mechanism

- As outlined in “On the electric breakdown in liquid argon at centimeter scale” by M. Auger et al. 2016 *JINST* **11** P03017
and “Experimental study of electric breakdowns in liquid argon at centimeter scale” by A. Blatter et al 2014 *JINST* **9** P04006

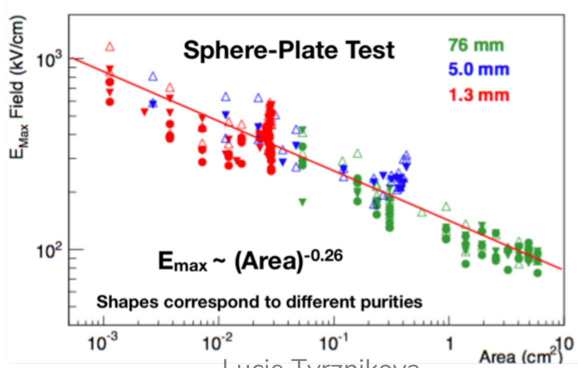
There are three phases of breakdown development:

- Field emission of electrons from cathode.
  Emitted electrons ionize and excite argon atoms on their way to the anode.
- Positive ions drift towards the cathode, raising the surface field and causing an increase of the field emission current.
  This raises temperature on the cathode, causing a formation of a bubble.
- When the streamer reaches the anode a short peak of light emission is registered. This phase is characterized by an acoustic shock and a massive production of gas bubbles in the region of the discharge.
  (Note that depending on the amount of charge in the system, not every streamer results in a third phase spark.)

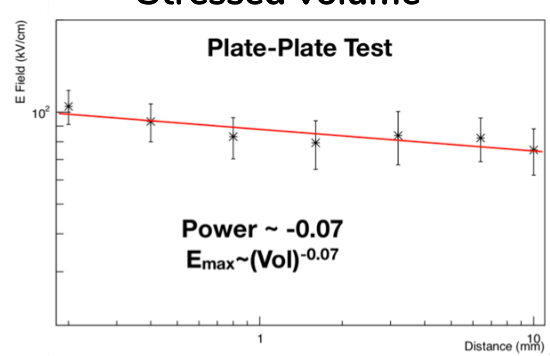
Other notable items

- Cathode surface roughness is important [J. Gerhold, et al., Cryogenics 34.7 (1994)]
- "All authors who have used various shapes of electrodes have reported a polarity effect in LHe. The breakdown voltage is lower when the sharper electrode is the cathode." [J. Gerhold IEEE 24.2 (1989)]
- Is there a dependence of breakdown on pressure?
- Breakdown behavior can be a function of stressed area or volume
  - "Preliminary results show it is mostly area, and volume might contribute on the 10% level" [S. Lockwitz at CPAD]

Stressed area

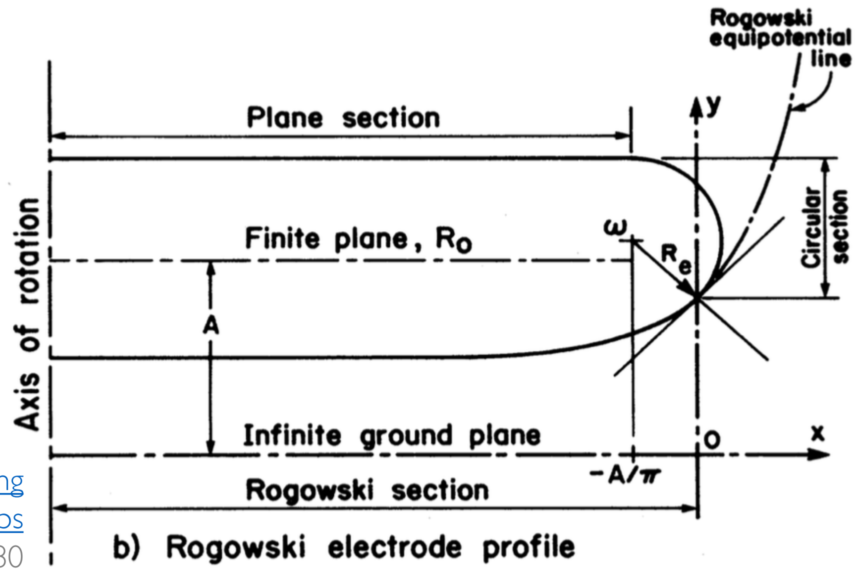


Stressed volume



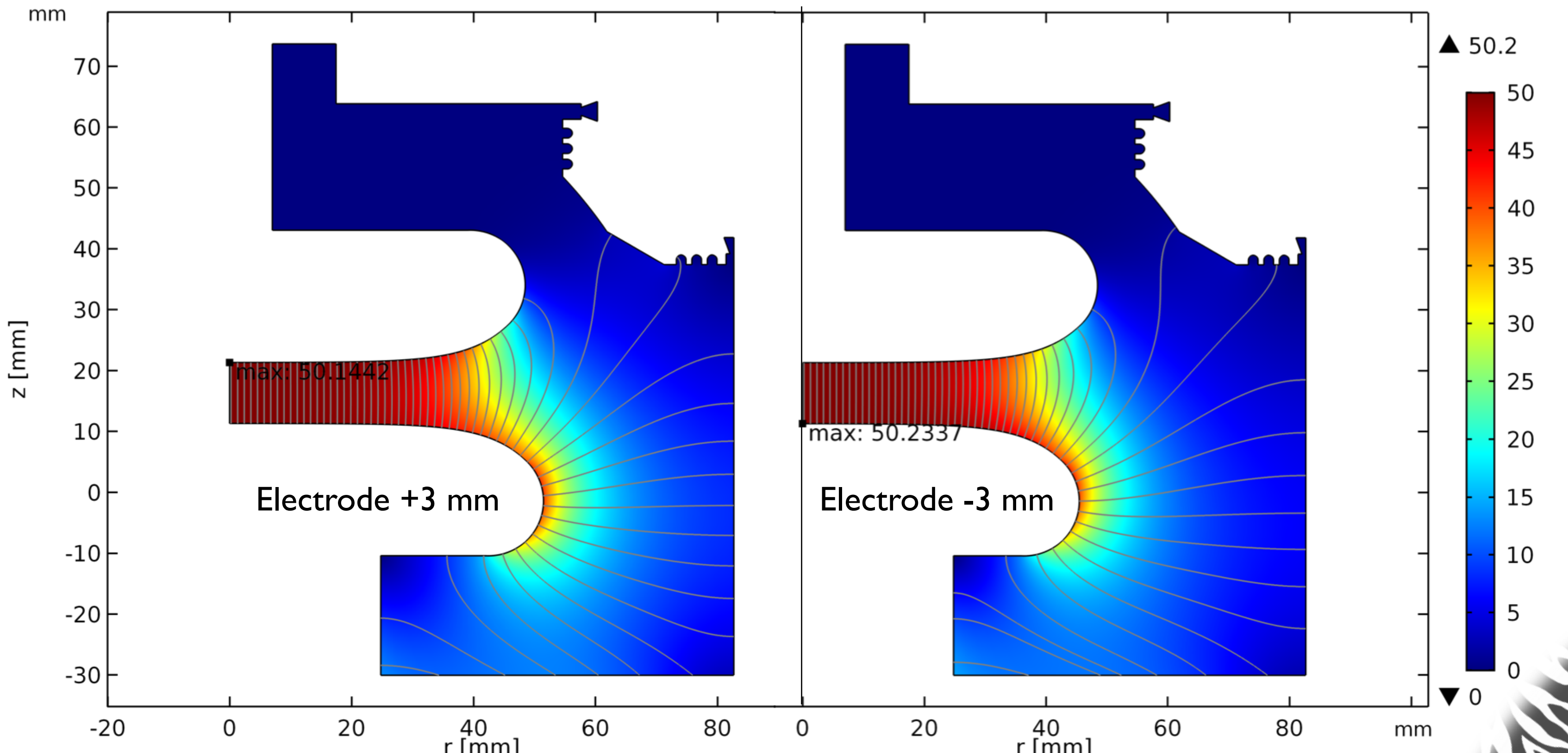
Rogowski electrodes

- Electrodes designed to have highest fields near the center (not near the edges)
- Shape of electrodes depends only on the separation between the electrodes, not on their potential difference



[Electrode Design for Testing in Uniform Field Gaps](#)
N.G.Trinh, 1980

Effect of horizontal shift of electrode



Effect of angular rotation of electrode