Grids at the 100 ton scale, with lessons learned from LZ

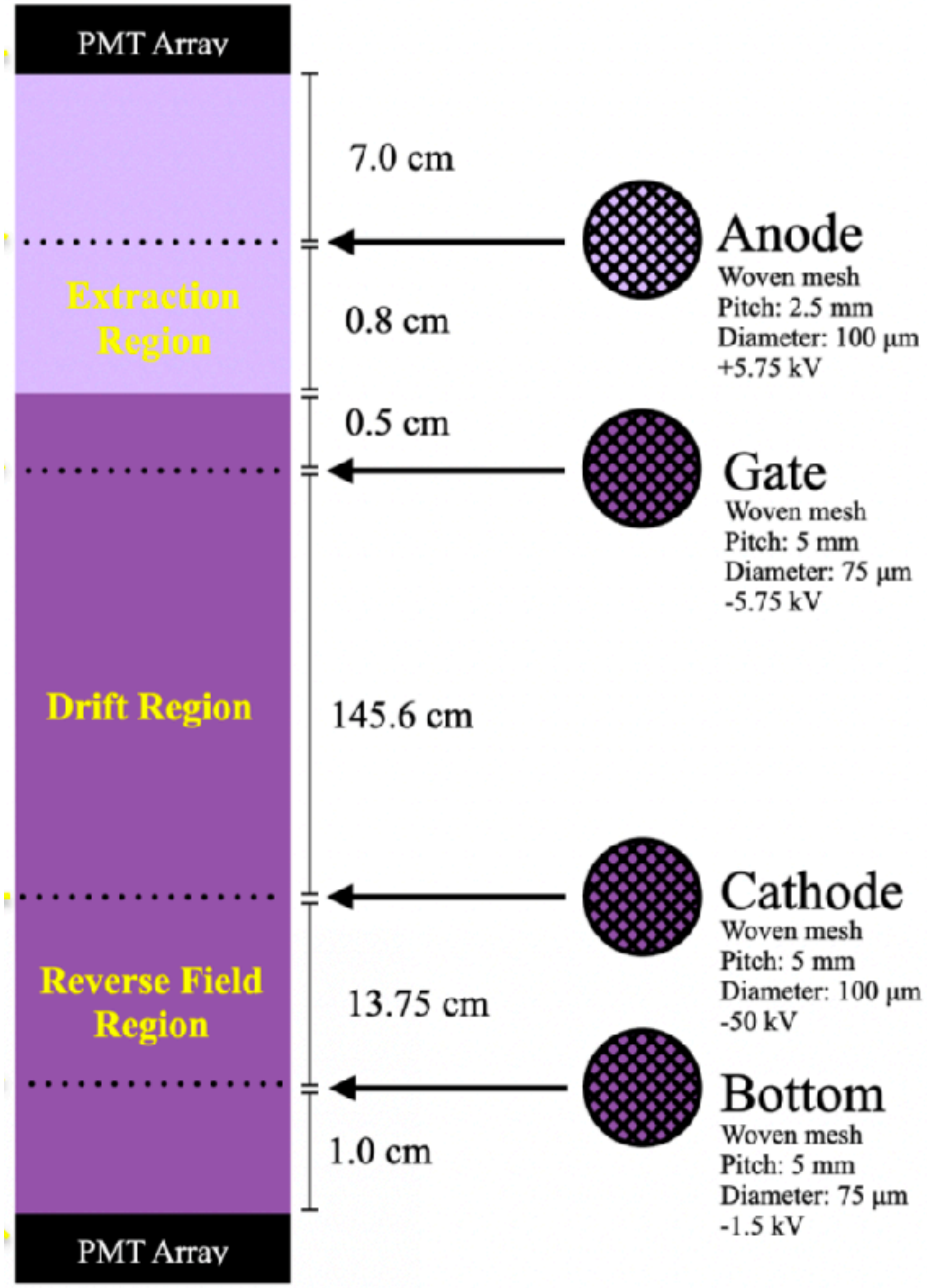
T. Shutt

SLAC

Requirements on the grids

- Establish uniform fields:
  - 100-300 V/cm drift field
  - 5 - 10 kV/cm extraction field
- Minimize spurious emission of charge and light. No sparking.
- Minimize optical footprint
  - Fundamental tradeoff against emission
- Minimize radioactive backgrounds, especially Rn daughters.

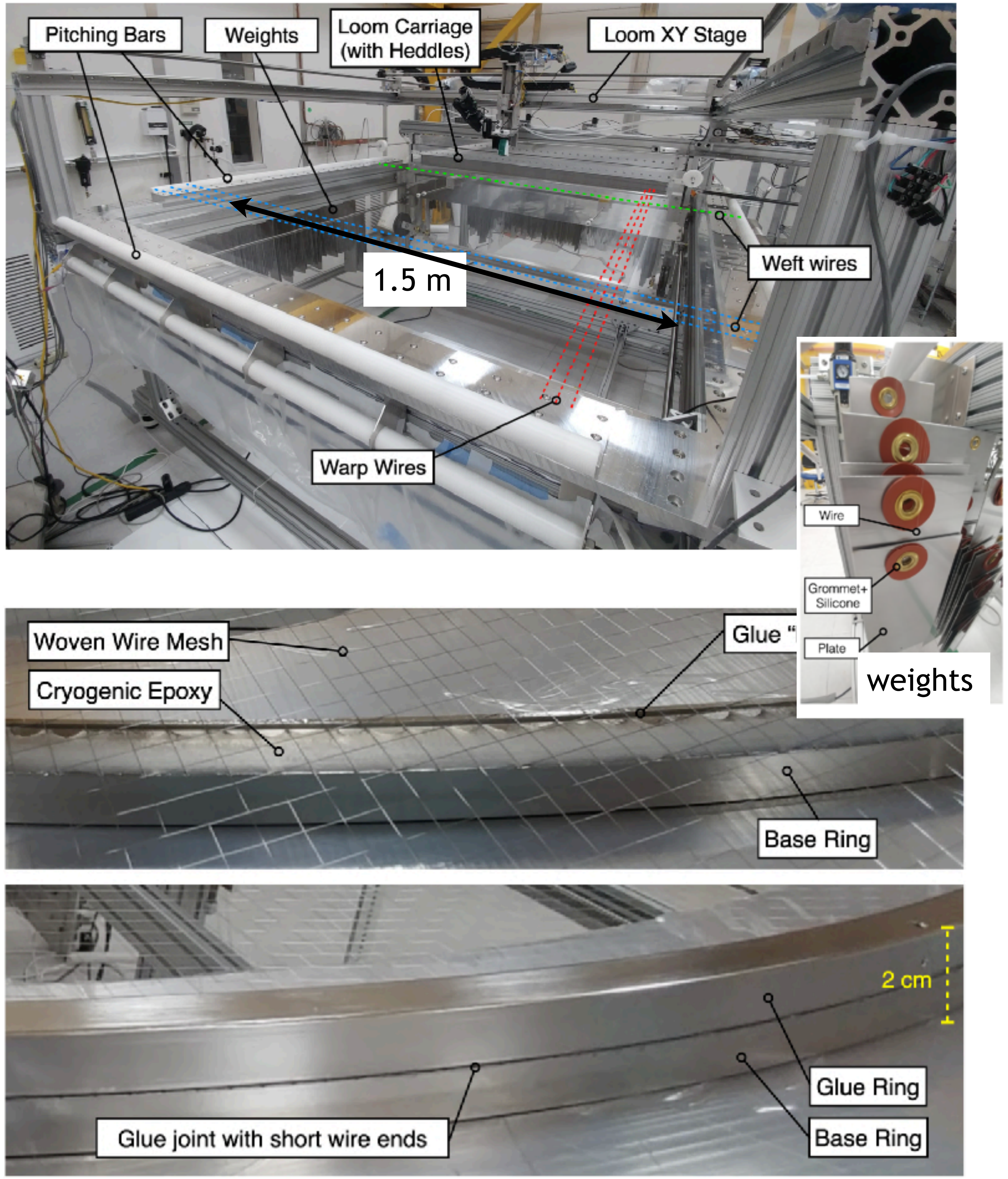
- Summary goal: grids should be boring



R. Linehan, PhD thesis (2022)

LZ woven grids

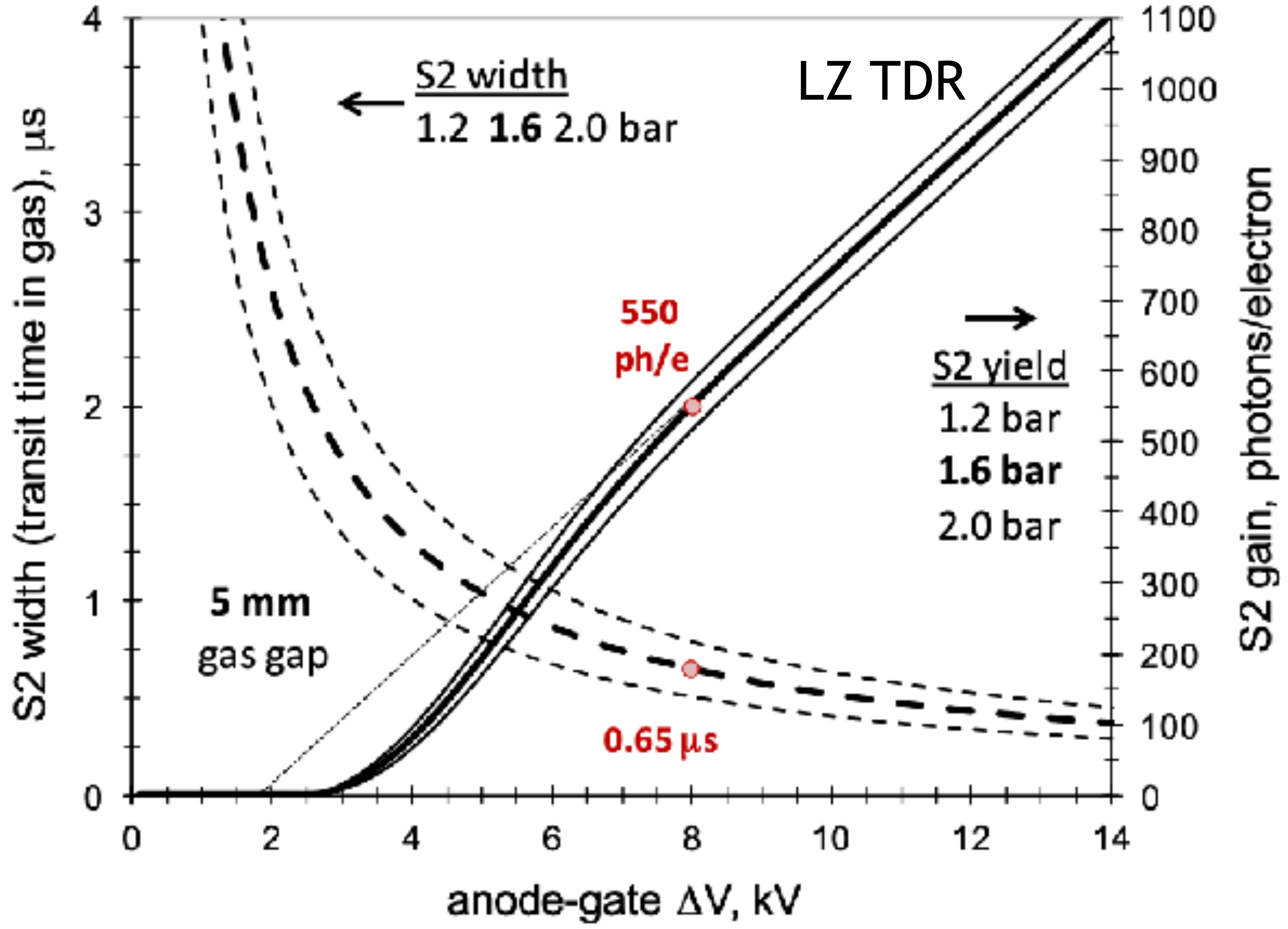
- Why weave a grid, instead of parallel wires?
- Mechanical
  - Roughly uniform force on ring. Ring mass minimized
  - Weave captures wires in case of breakage
  - Loom + glued wires gives uniform tension
- Fields
  - Drift field uniformity substantially better due to reduced field transparency (result not published).
  - Improved S2 shape
- Loom method can scale to 100 ton (3 m ∅) size, though need more automation

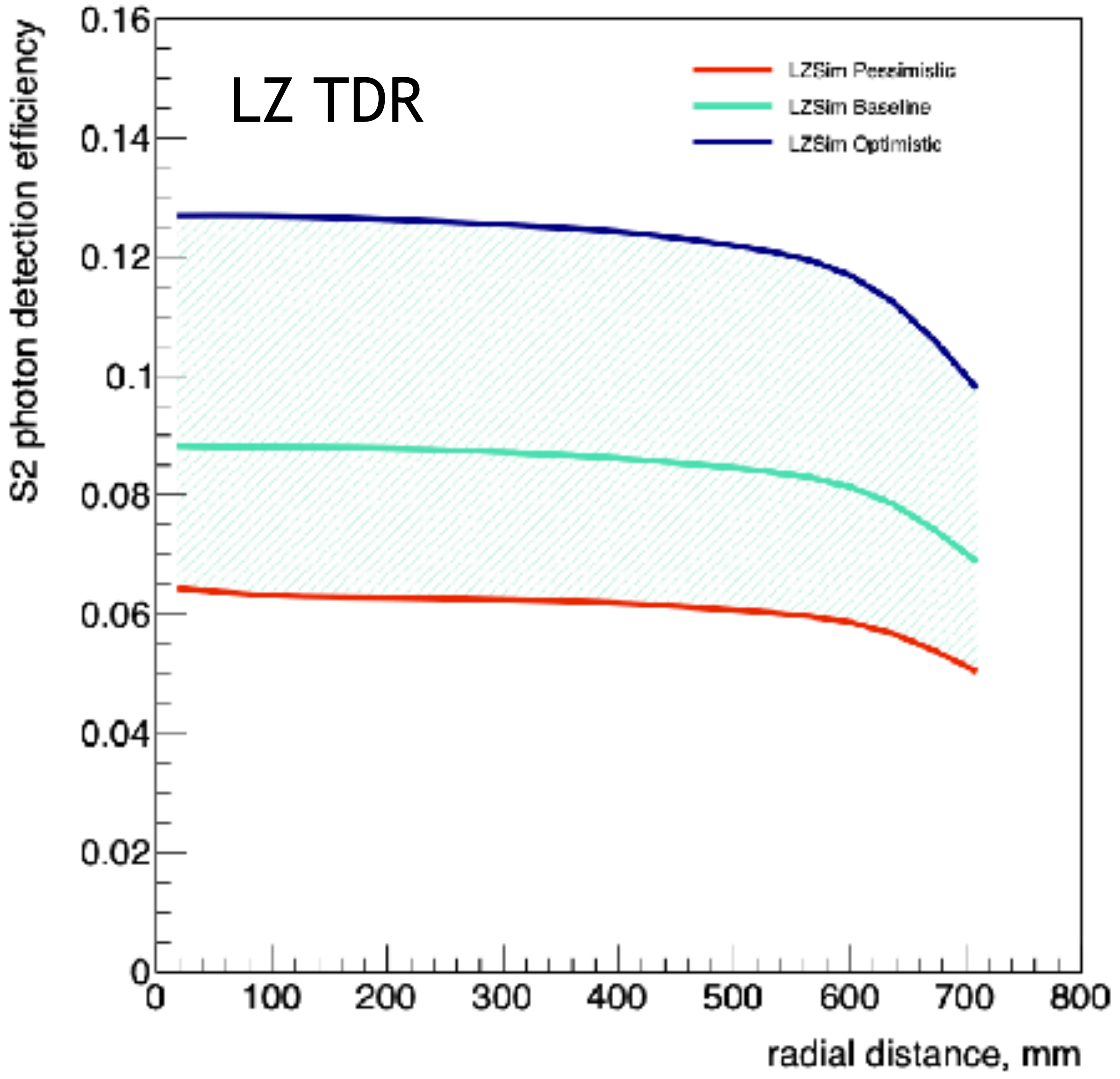


R. Linehan, PhD thesis (2022)

“Extraction region” design

- LZ S2 size motivated by reconstructing wall events.
- Larger S2 better measures shapes - liquid surface events, depth/diffusion, “glue-ring” events, etc.
    - But it increases fluorescence.
- Light readout - tiles, overhang, wall events.
- Minimize electroluminescence elsewhere. Could we zero it?





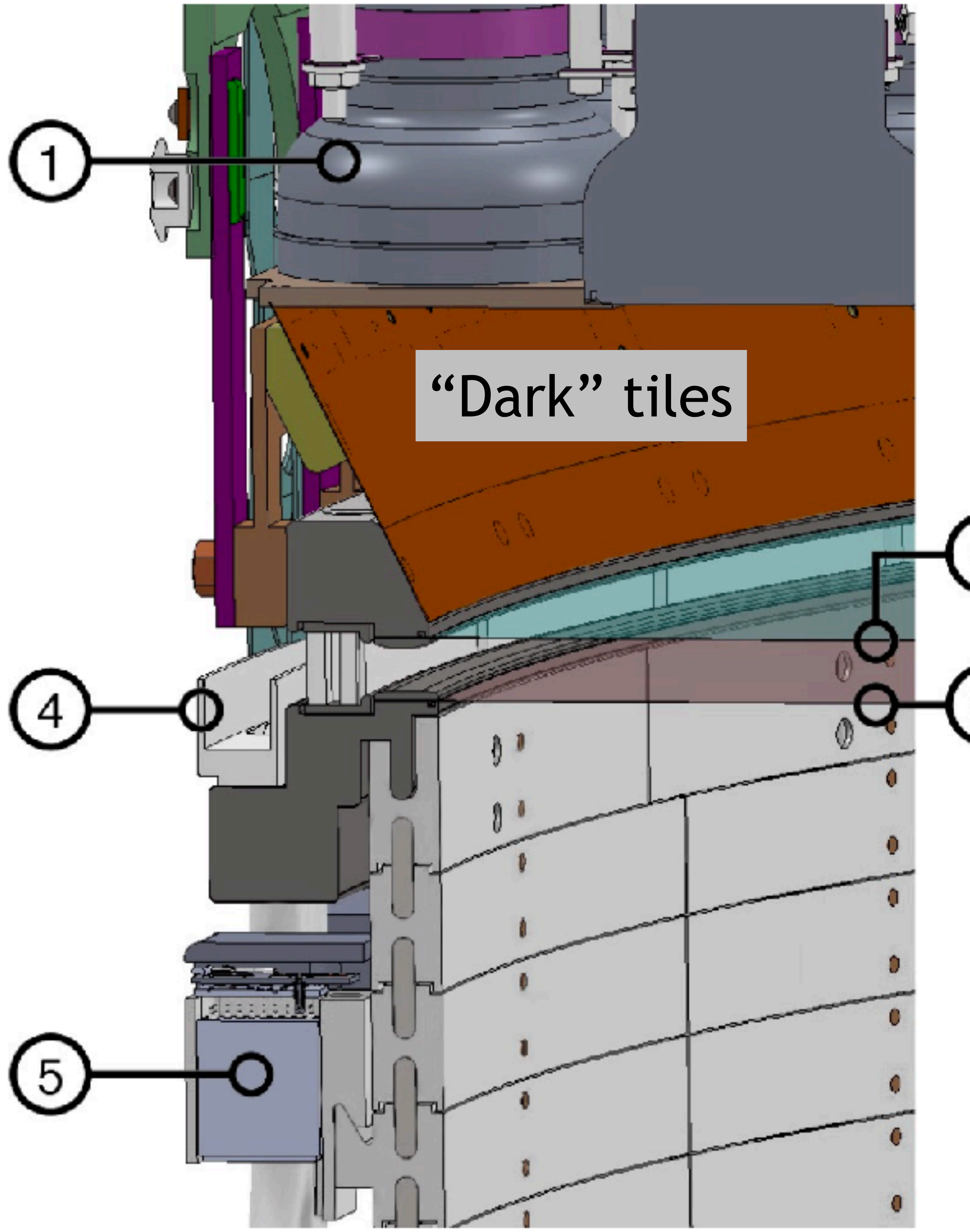
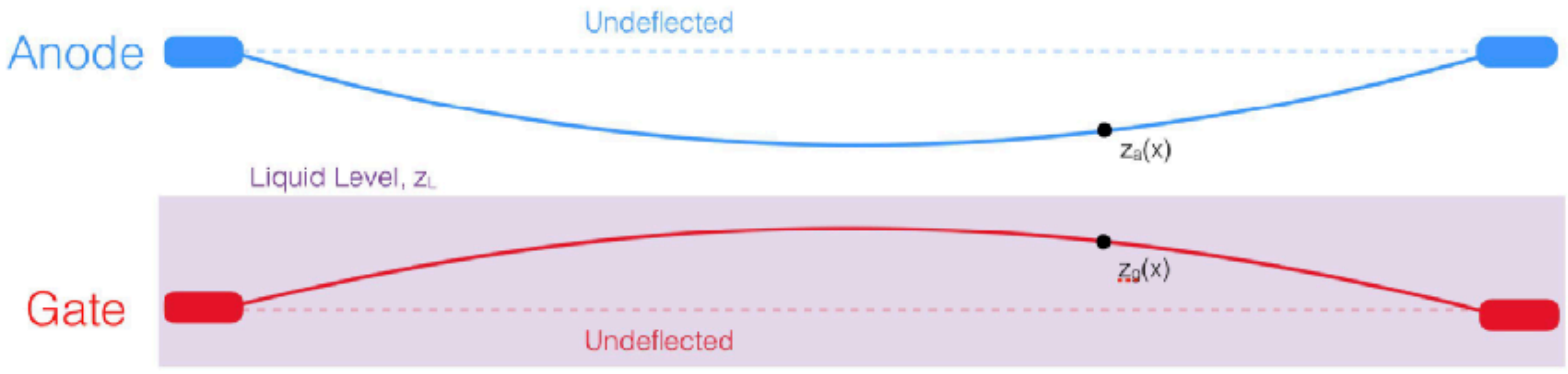


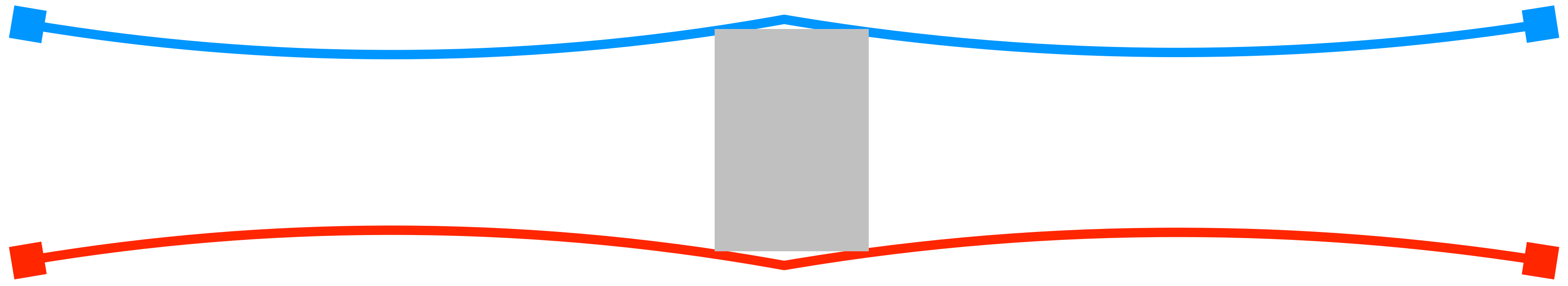
Figure 7: The electron extraction and electroluminescence re
1-TPC PMT; 2-Anode grid; 3-Gate grid; 4-Weir; 5-Xe Skin PM

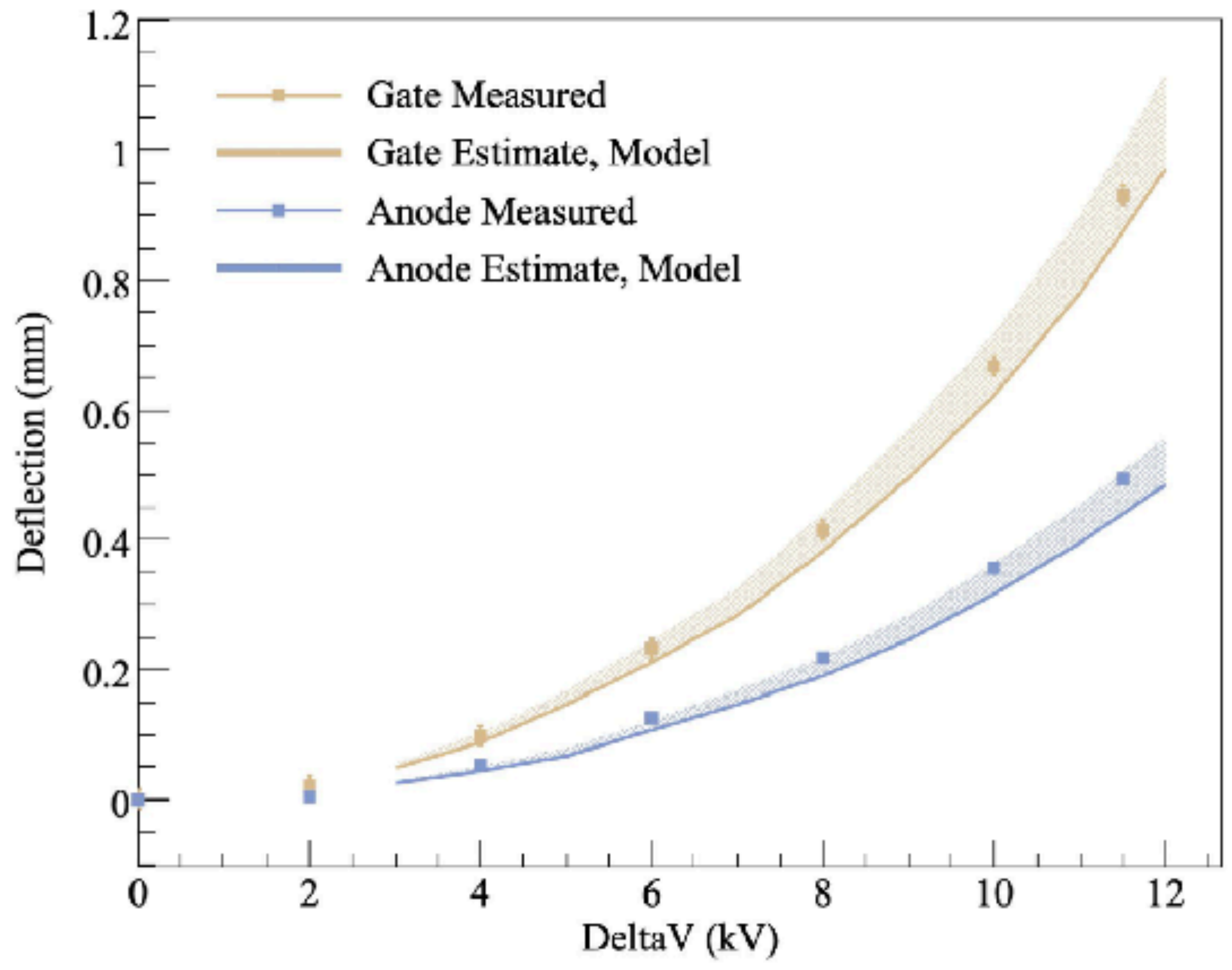
Mechanics of 3 m Ø grids

- Big issue is deflection of gate/anode
  - δz increases by 4 for LZ -> XLZD
- LZ wires close to tension limit, but thicker wires might be possible
- Better: add spacer(s)
  - Similar to spacer between rings

$$\delta z \propto \frac{Tension}{L^2}$$







Measured deflection matches calculation

Grid emission problem

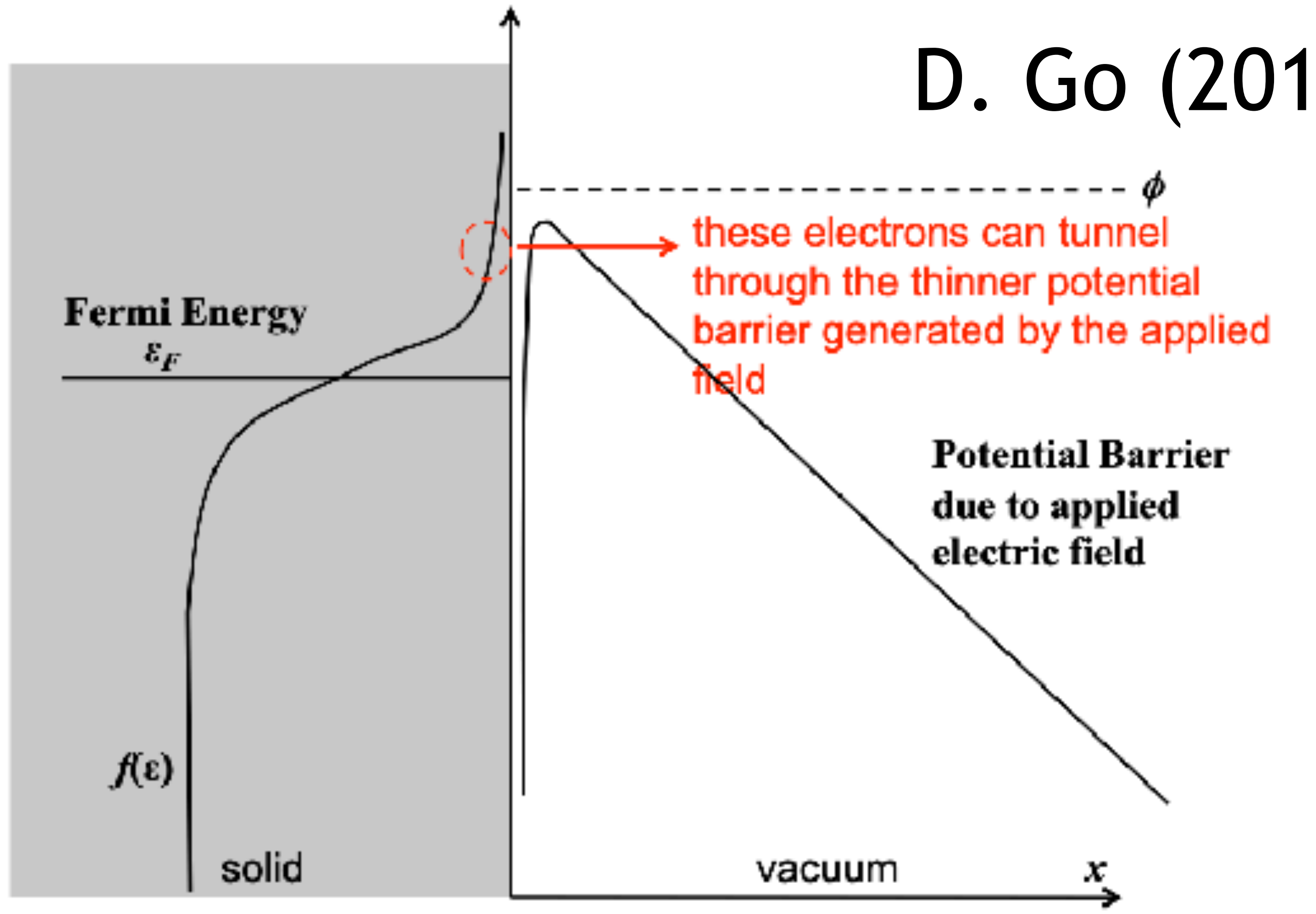
- Minimum requirement: avoid sparking. Townsend discharge.
  - Electron emission
  - Multiplication in gas
  - Feedback to cathodic surface
- We seek to minimize electron emission, both for sparking, and as a background
- Single electrons come from several sources - see J. Xu talk
  - Are a problem when piled-up to mimic multi-electron signal.
- *Multiple electron emission* from grids observed in both liquid and gas in LUX, *often with small light signal* A. Bailey PhD thesis - 2016 - H. Araujo advisor.
  - Consistent with gain process, not poisson.
  - This is direct background for DM searches near threshold, and S2 only.
  - Likely the source of light emission from cathode grid, not accompanied by electrons.

What is the origin of electron emission?

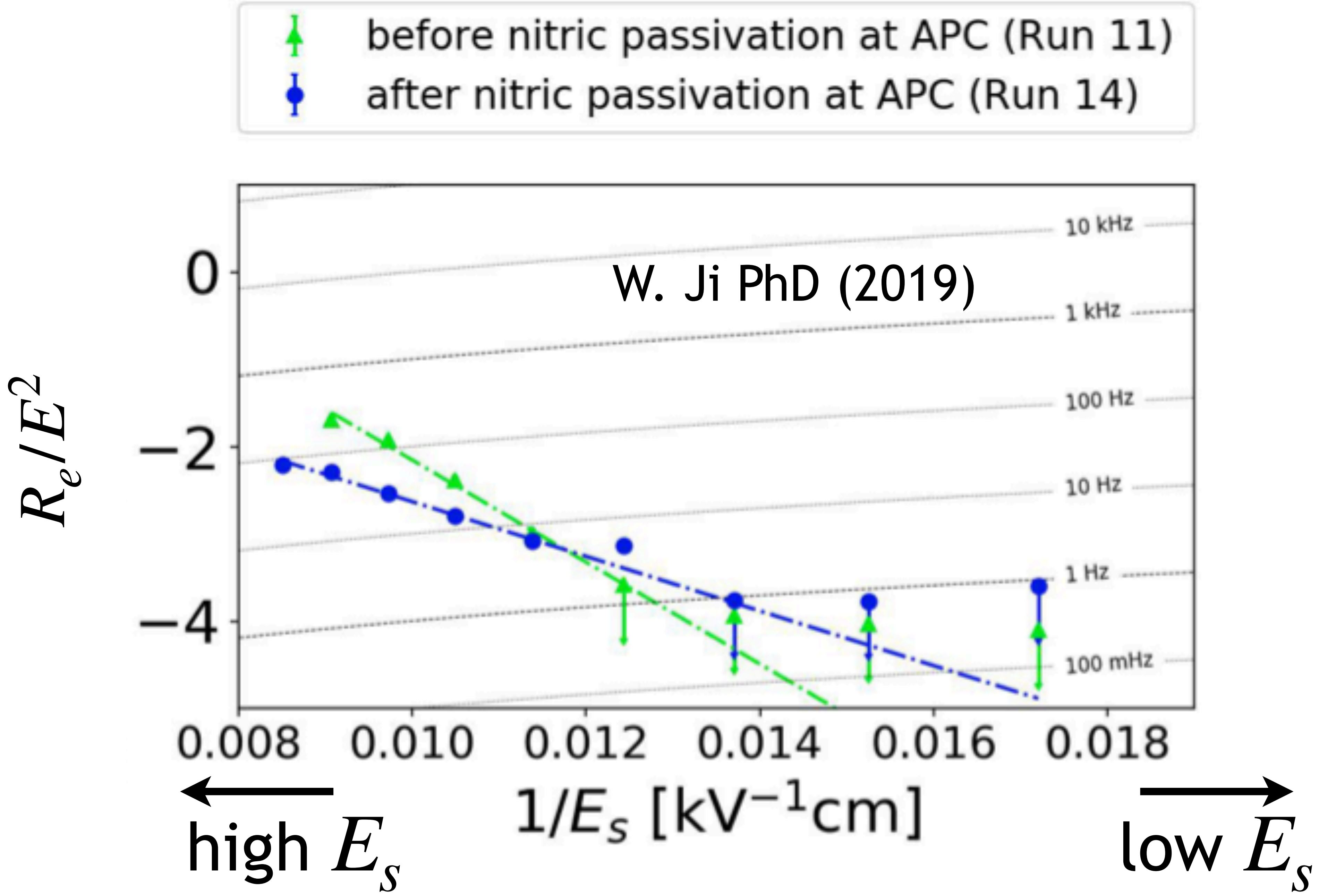
- Field emission a well-established theory - Fowler-Nordheim

$$R_e(E) \propto \frac{A}{e}\frac{E^2}{\phi} exp\left(\frac{B\phi^{3/2}}{E}\right)$$

  - e.g., gas-phase measurement of 15 cm Ø grids by SLAC LZ group.
- But numbers are off. Predicted field for SS in LXe is ~10 MV/cm
- Wide survey of results from LXe experiments, finds soft upper limit of ~50 kV/cm



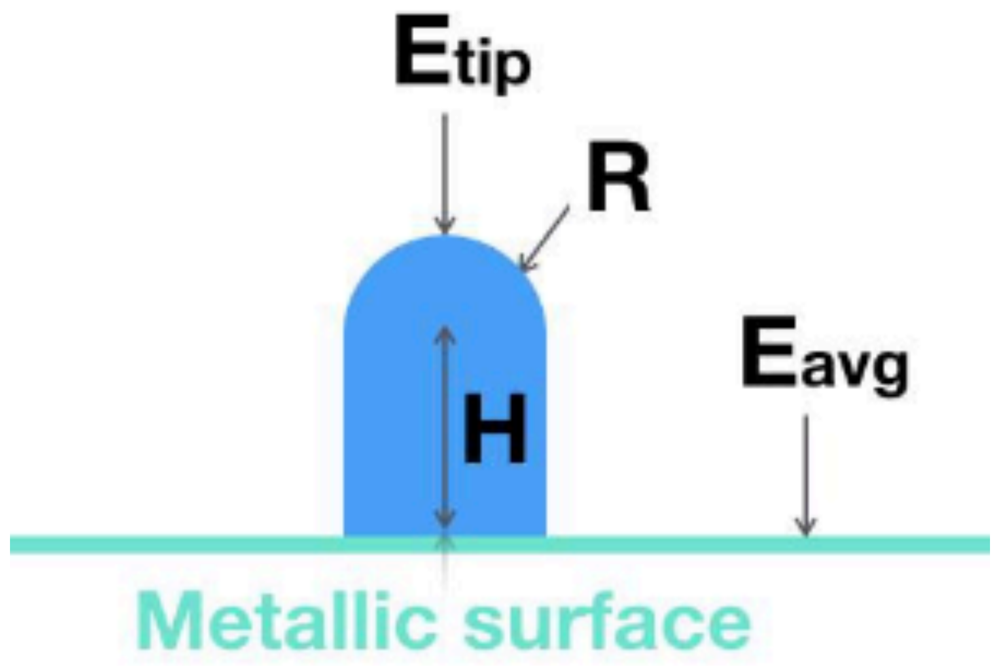
D. Go (2012)

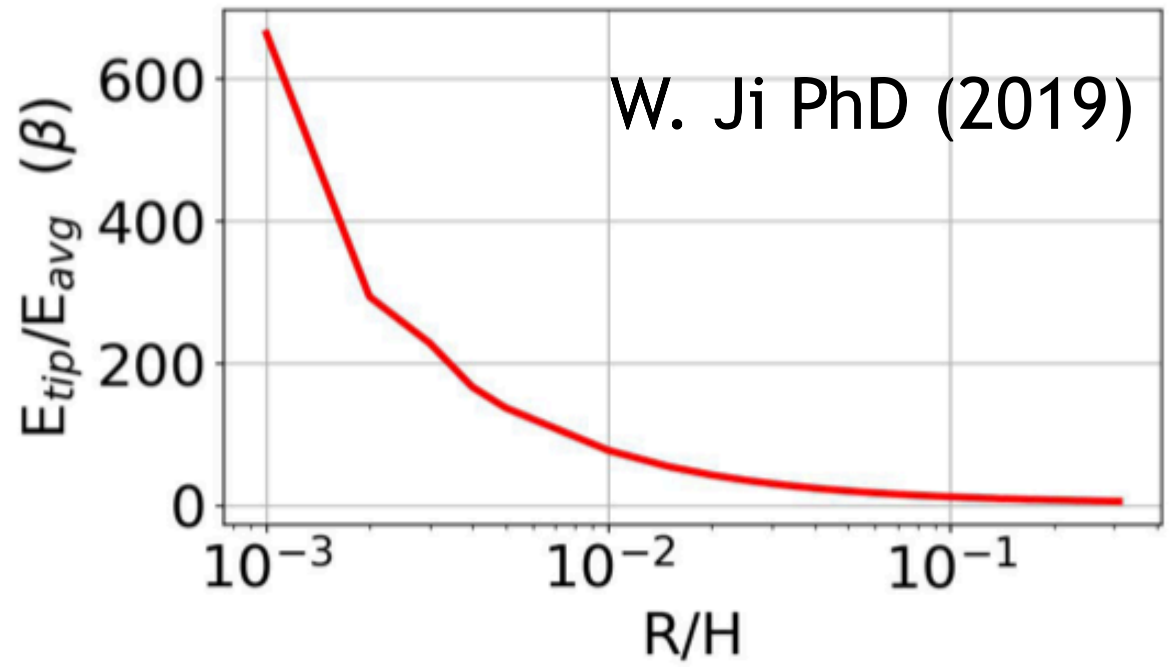


W. Ji PhD (2019)

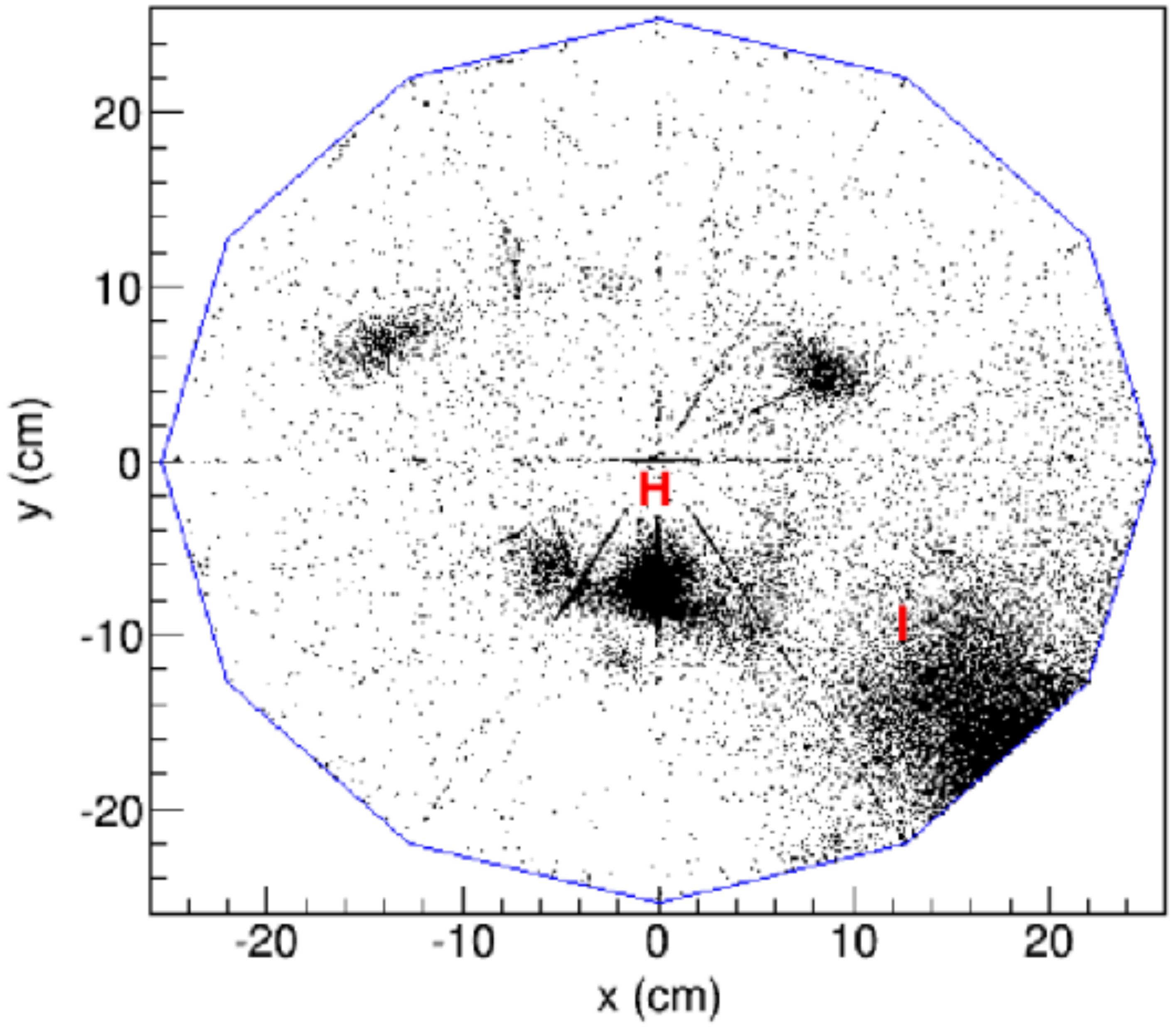
Field emission at sharp points

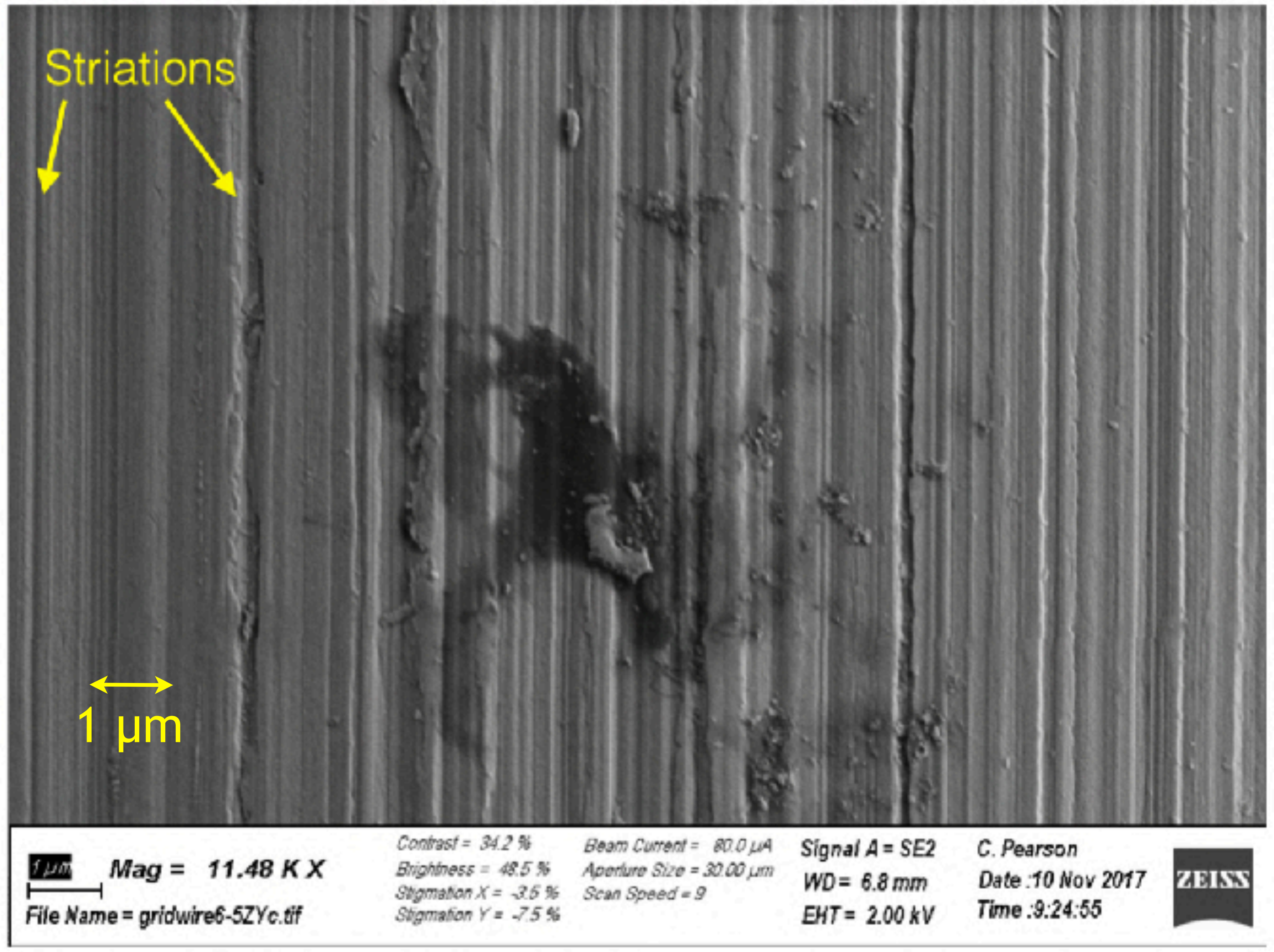
- Modify model - emission at sharp mechanical points.
  - Field enhanced by β ~ 100-500
  - With tiny surface area A ~ nm^2
- Arguments for:
  - Prominent emission is indeed seen at "hot spots"
  - Explains multiple electrons, and light
  - Flaws present on grids
- But:
  - Why time variable?
  - LUX liquid-gas values inconsistent - A. Bailey.





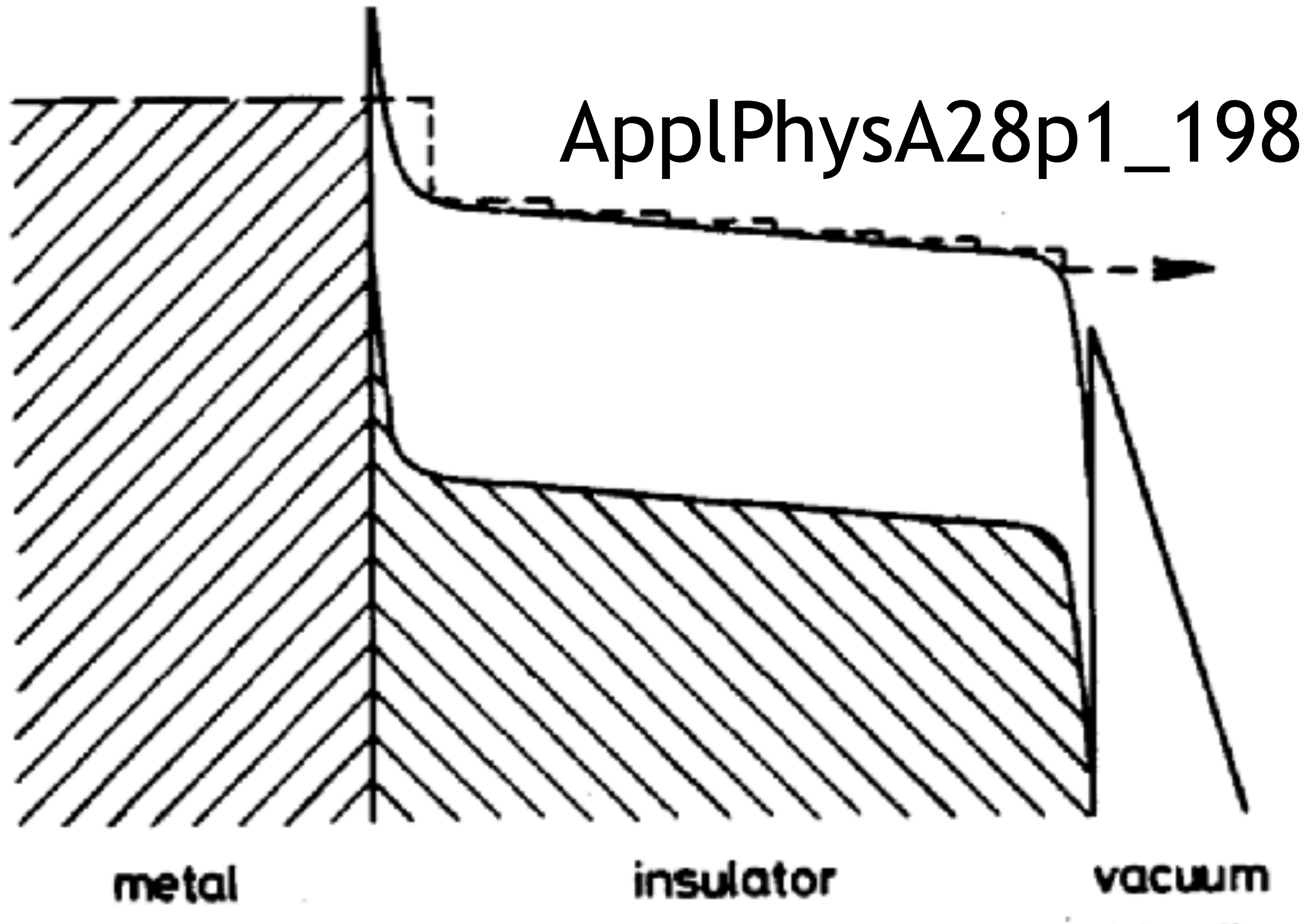
LUX - A. Baily PhD (2016)





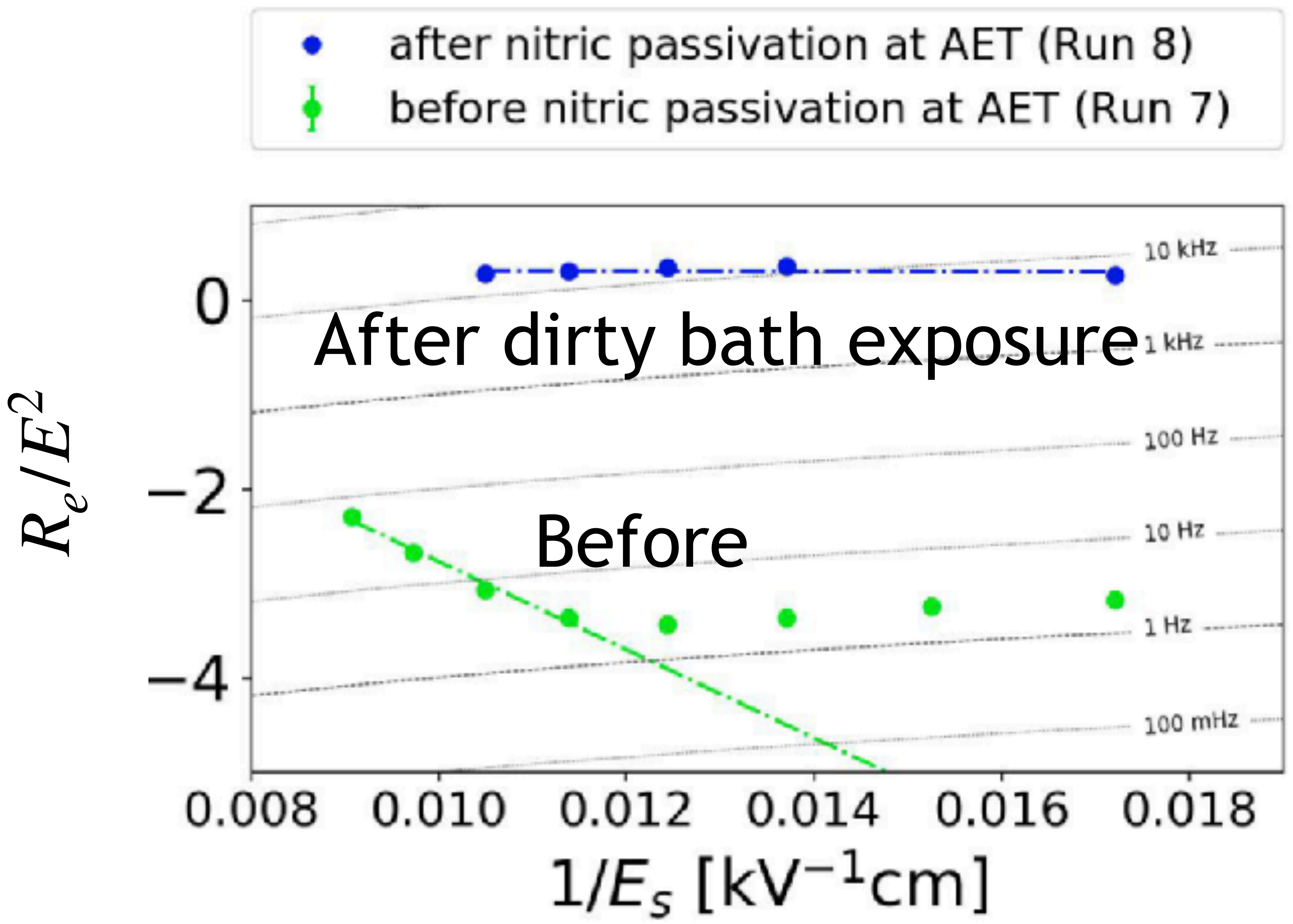
Contaminants? Dust?

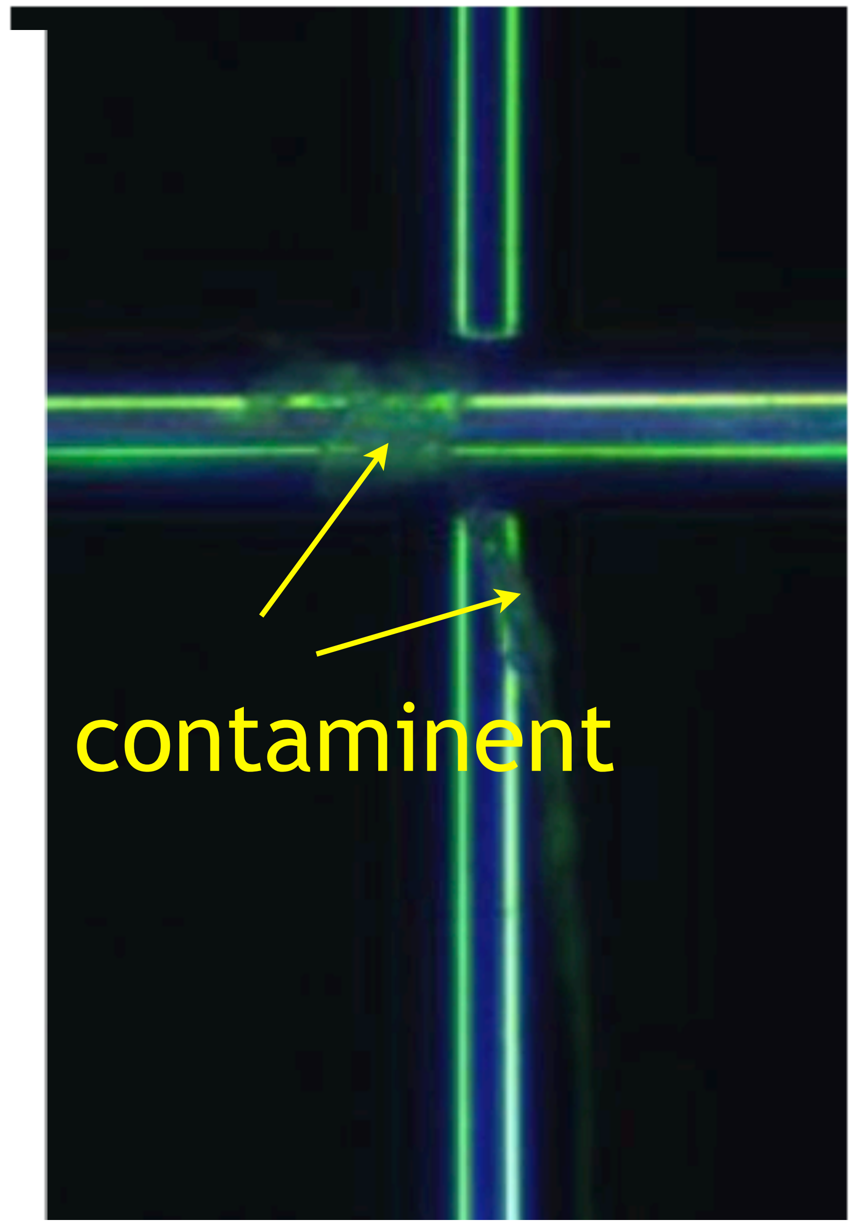
- Contaminants? Wide variety of mechanisms are suggested in the the literature:
  - Surface charging (c.f. Matter)
  - Emission from excited states
  - Electroformed whiskers
  - Band bending
  - …
- Malter effect?
  - but not like HEP application.
- Dust, debris also plays a role.



ApplPhysA28p1_1982

Fig. 6. Field emission through thick insulator with band bending



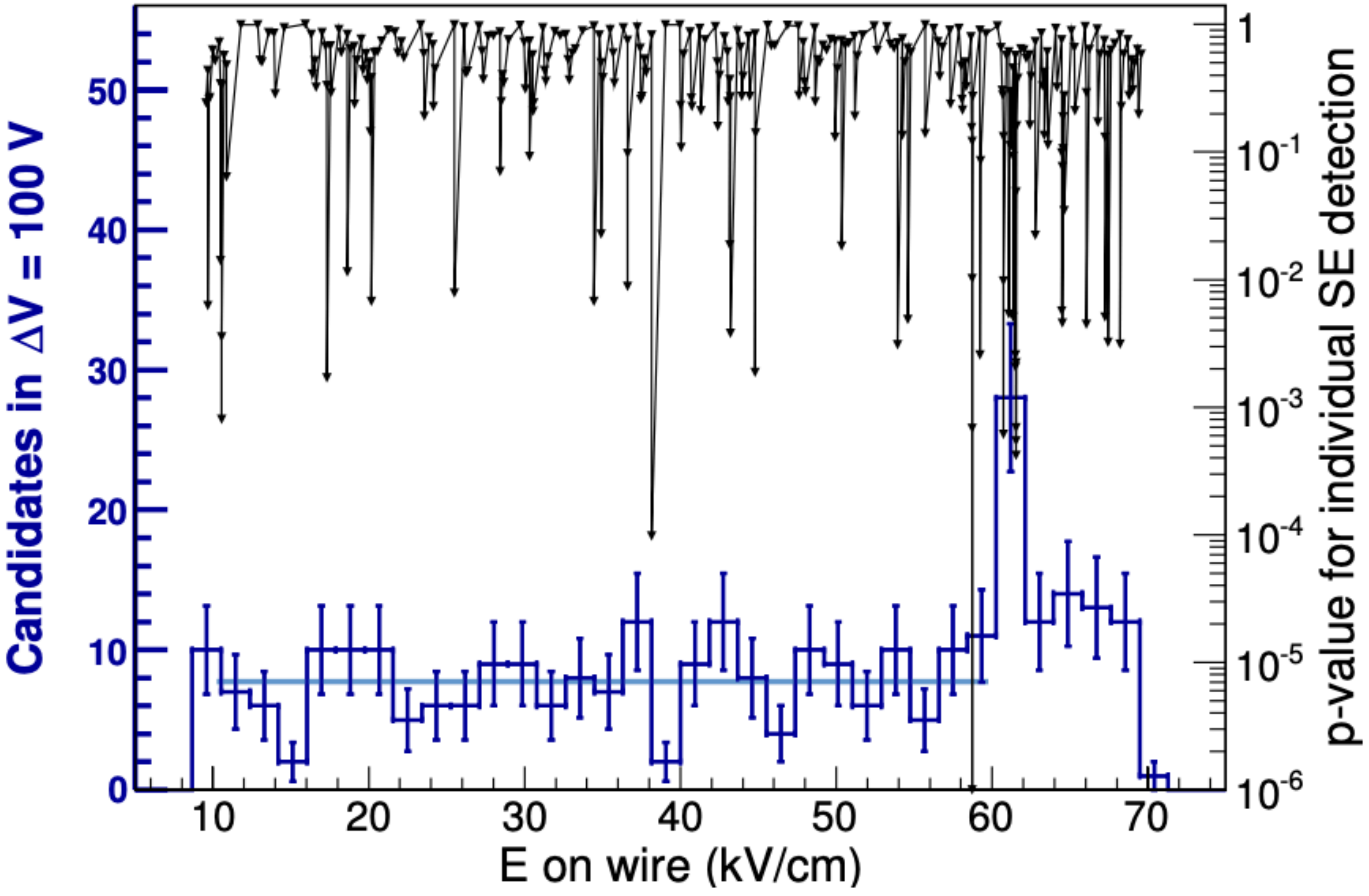


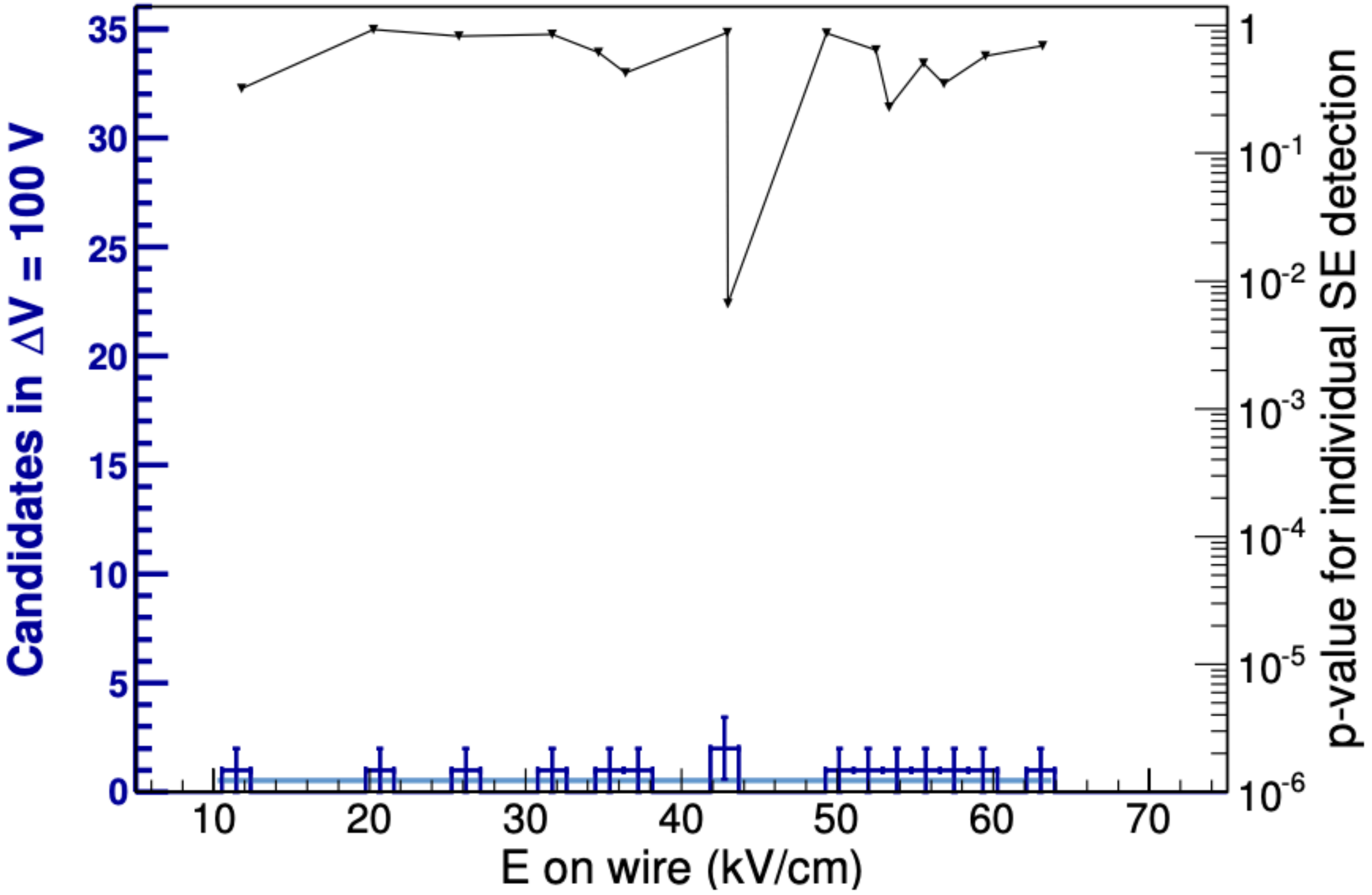
W. Ji PhD (2019)

gas-phase measurement of 15 cm Ø grids

Passivation

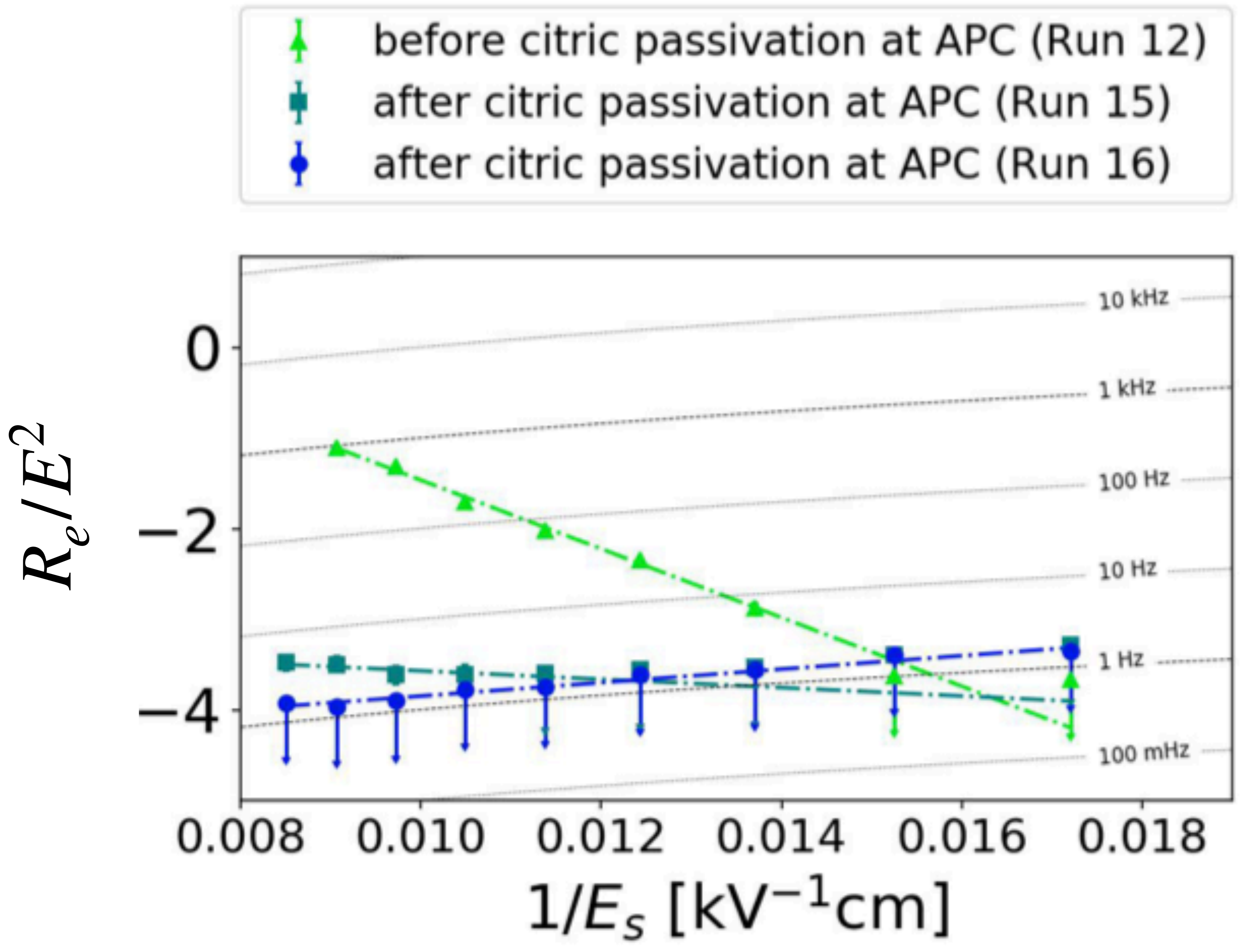
- Imperial College group showed that “passivation” of SS wires lowers emission substantially.
- Passivation: selective removal of Fe from SS, leaving a Cr-rich surface

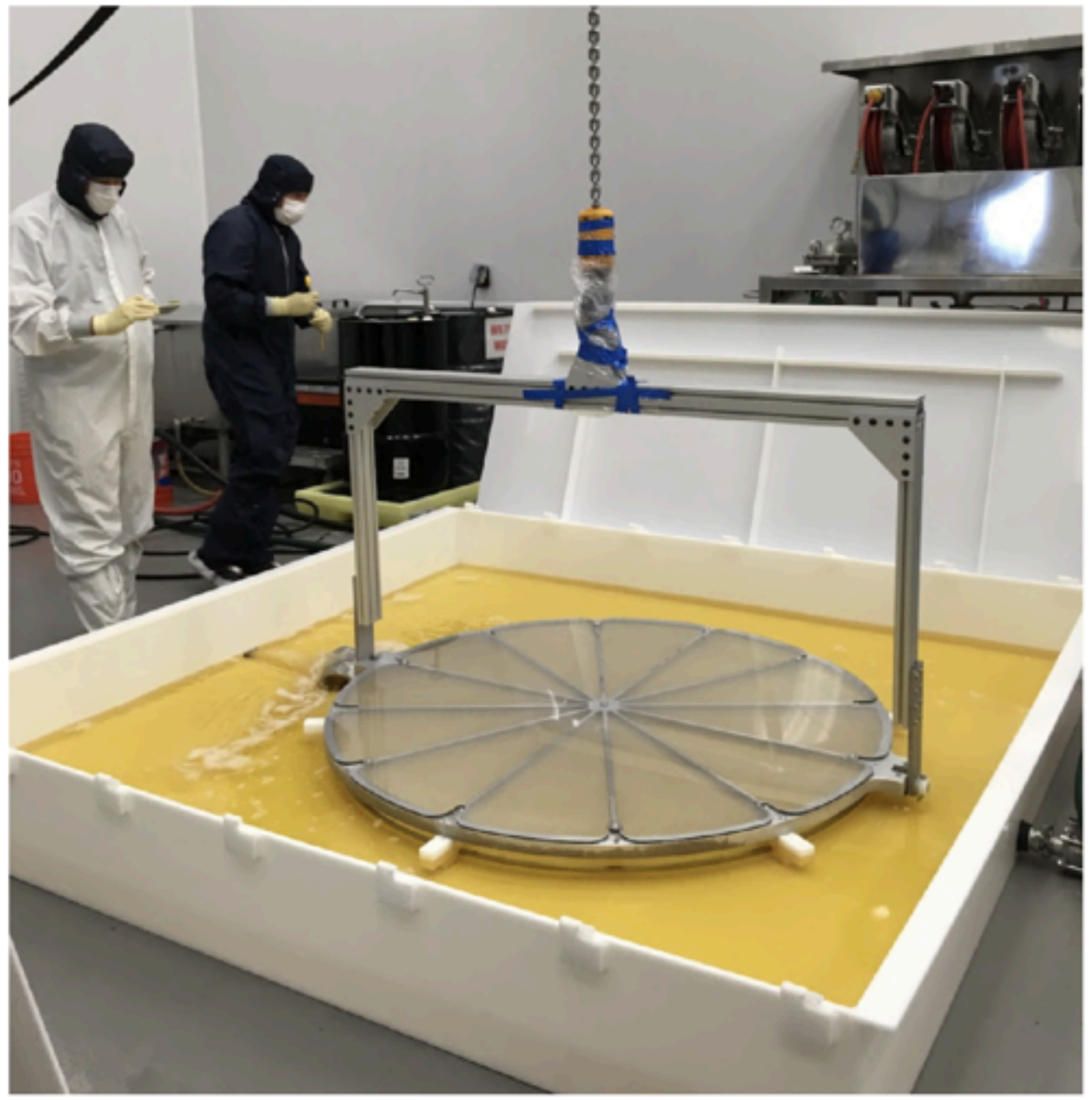

LUX cathode wire


LUX cathode wire after nitric acid passivation

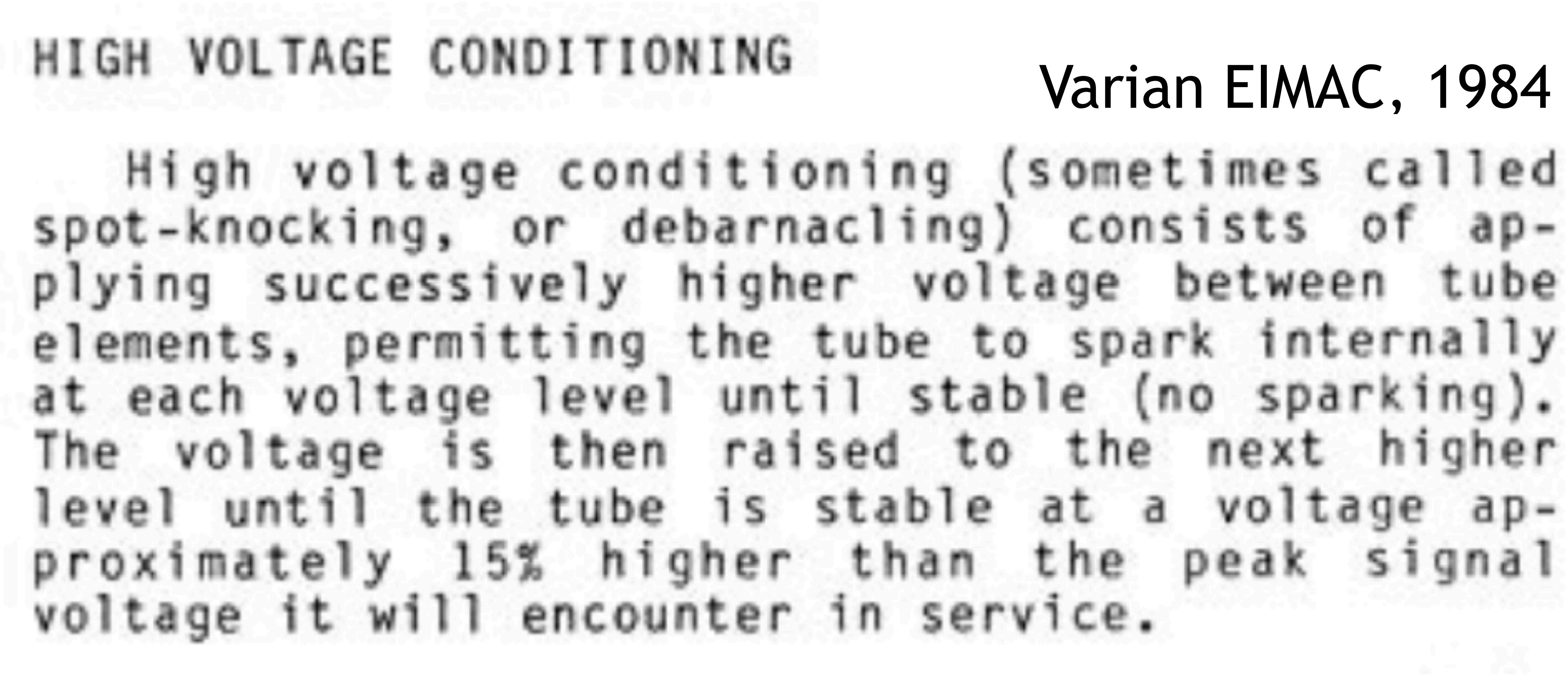
Passivation of LZ grids

- Industry uses citric acid for large scale treatment
- Gas tests showed same benefit
- We did not have a clean before / after measurement on full size LZ grids
- Questions remain:
  - Why does passivation work?
  - Does it work only on hot spots, or also spatially diffuse emission?





Conditioning and Cleaning



HIGH VOLTAGE CONDITIONING

High voltage conditioning (sometimes called spot-knocking, or debarnacling) consists of applying successively higher voltage between tube elements, permitting the tube to spark internally at each voltage level until stable (no sparking). The voltage is then raised to the next higher level until the tube is stable at a voltage approximately 15% higher than the peak signal voltage it will encounter in service.

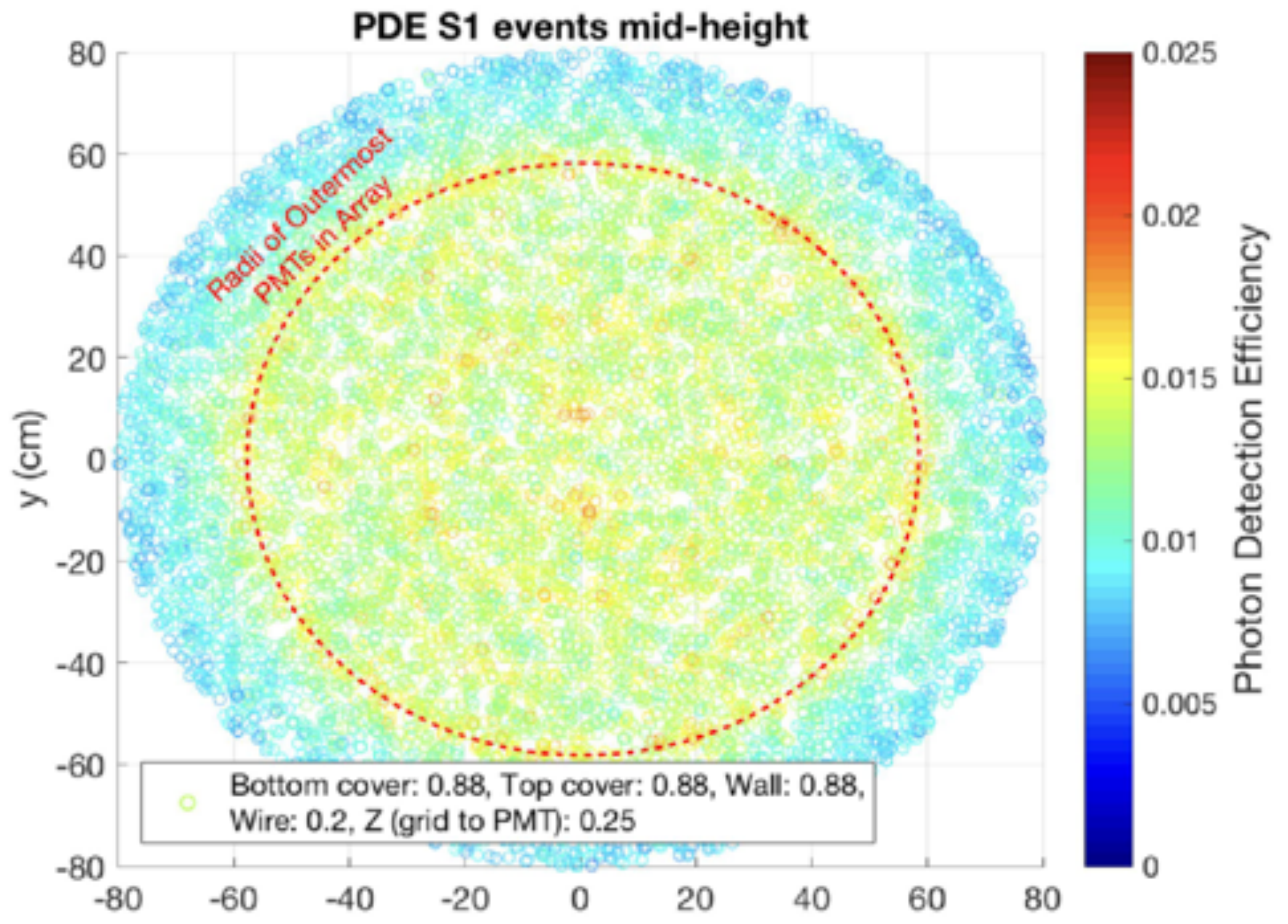
Varian EIMAC, 1984

- Literature of treatment of (SS) cathodes in accelerators, vacuum tubes, and wire chamber detectors.
- Can we make use of it here - presumably prior to installation?
- Related - plasma cleaning
- We should quantify effect of dust, and efficacy of cleaning, and plan for final cleaning.

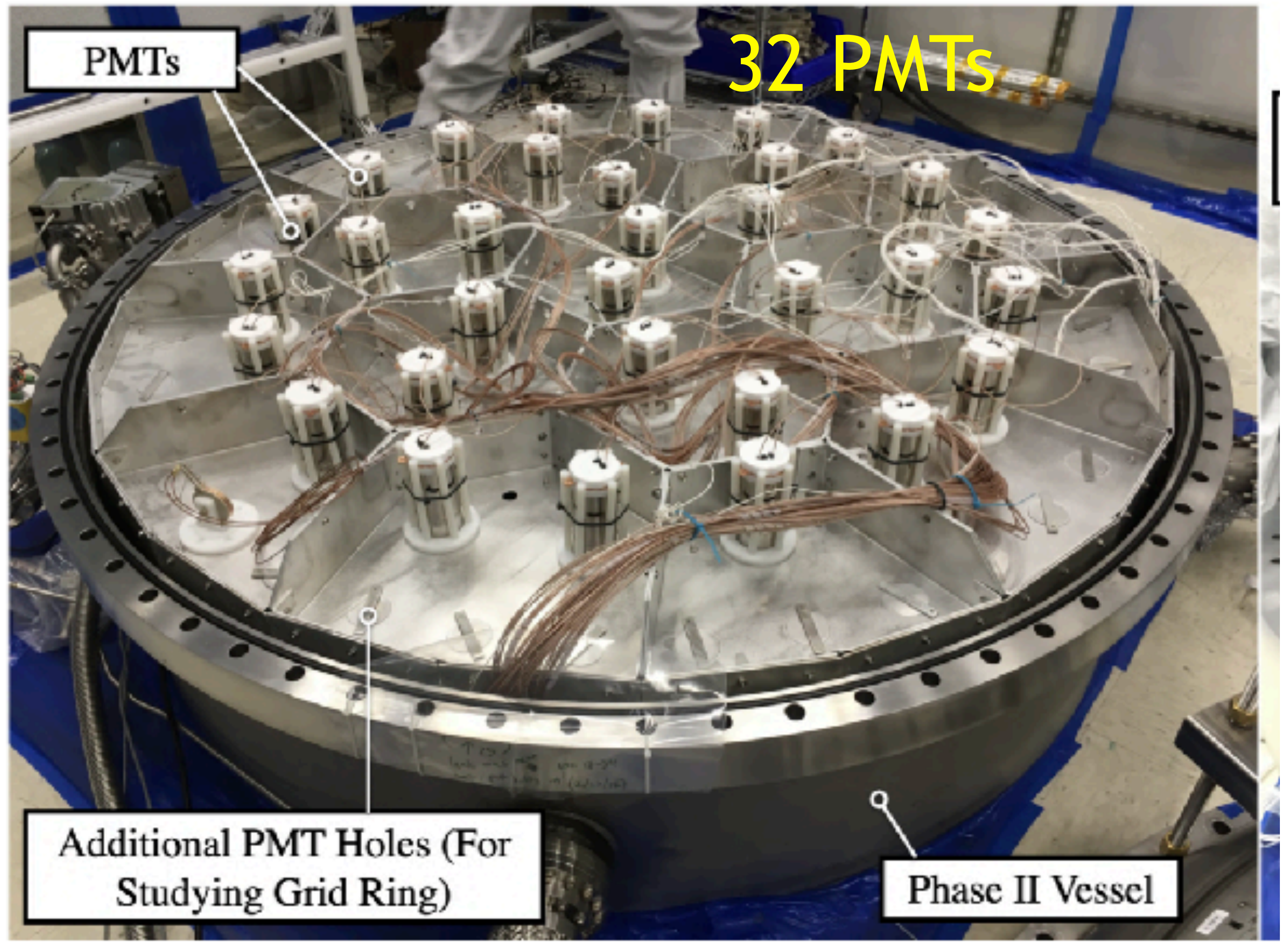
Some comments on grid testing

- Electron emission study is serious endeavor: need position dependence, and single sensitivity
- At SLAC we used a 32 2” Ø PMT array, with MgF/Al reflecting box
- High event rate in unshielded environment - will study elevated rates at higher voltages than final operation.

“Phase II” full LZ grid tests at SLAC.
Linehan PhD Thesis 2022



Plot from R. Mannino



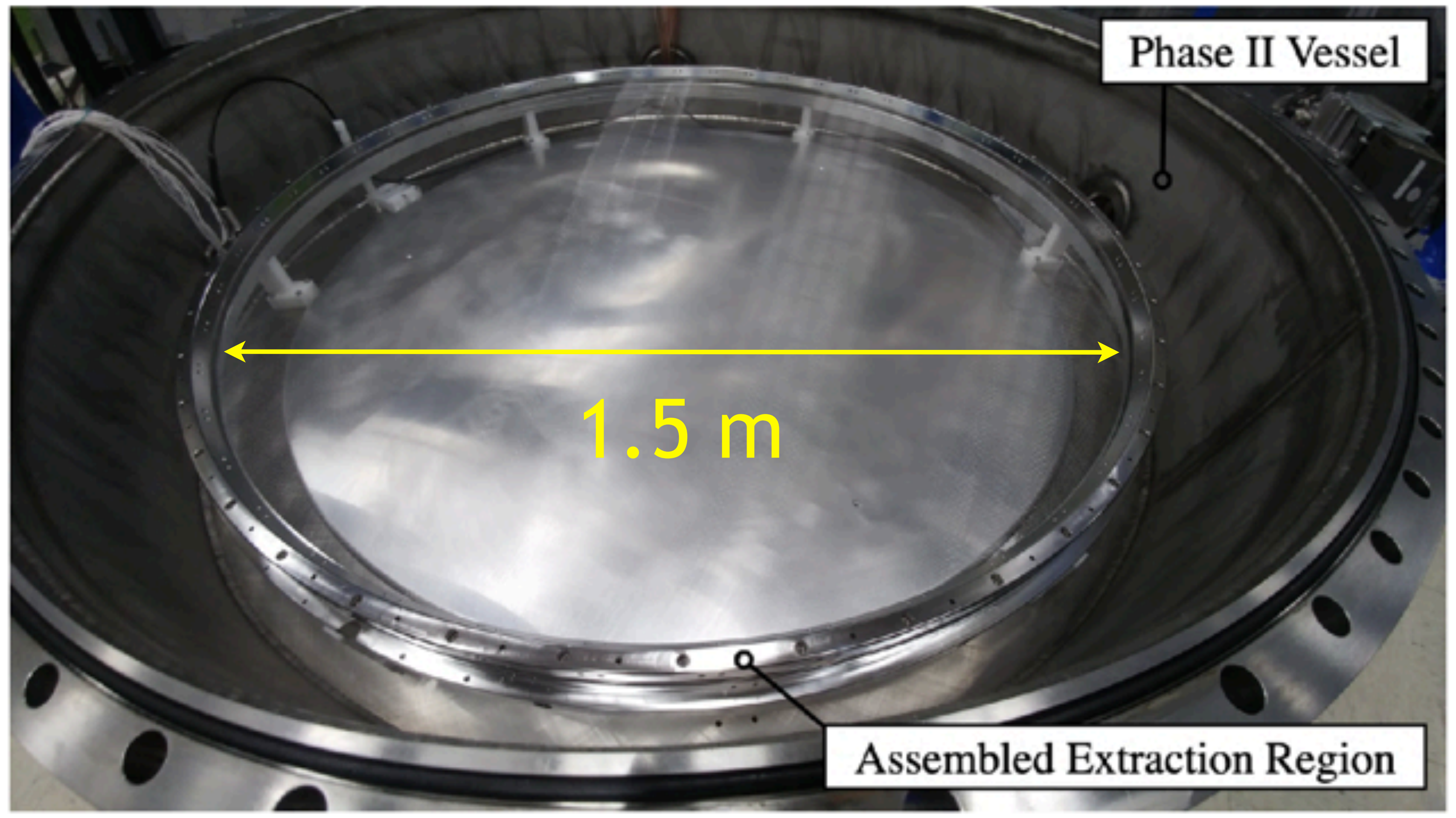
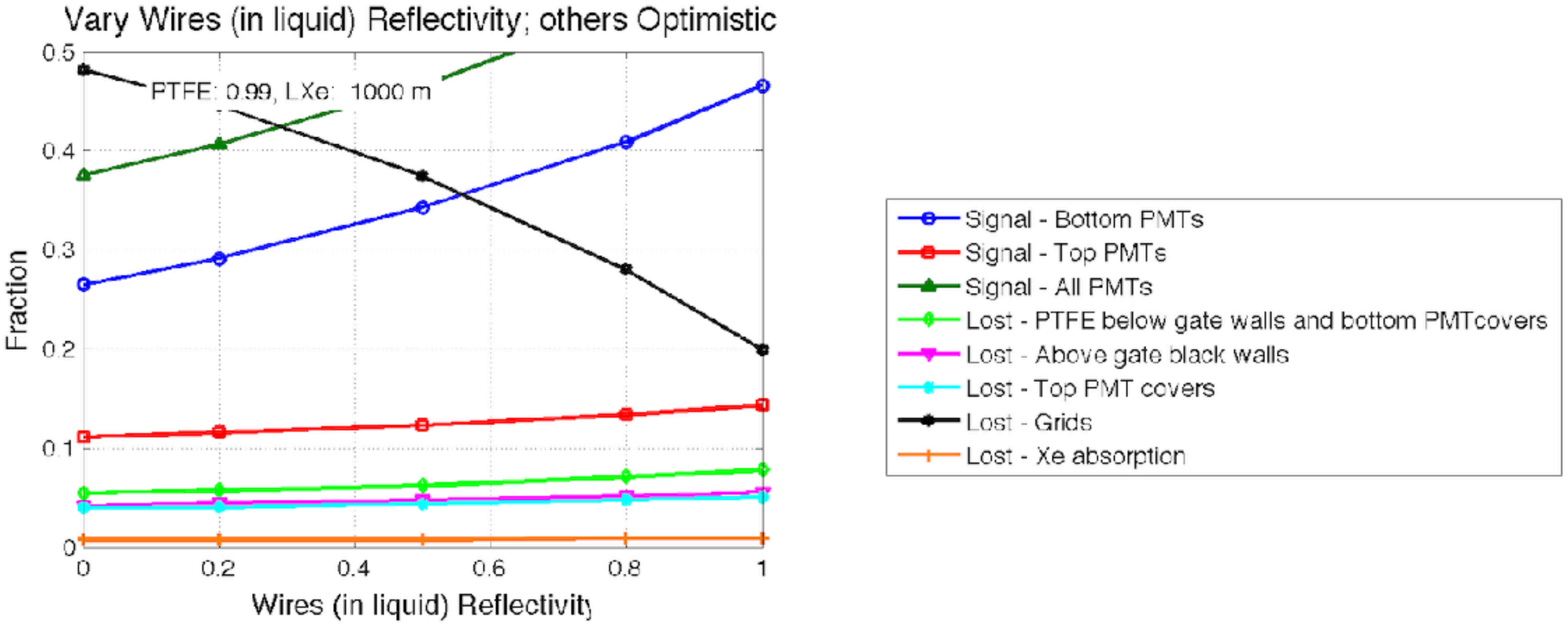


Figure 5.2: The final LZ extraction region ready for testing within the Phase II detector.

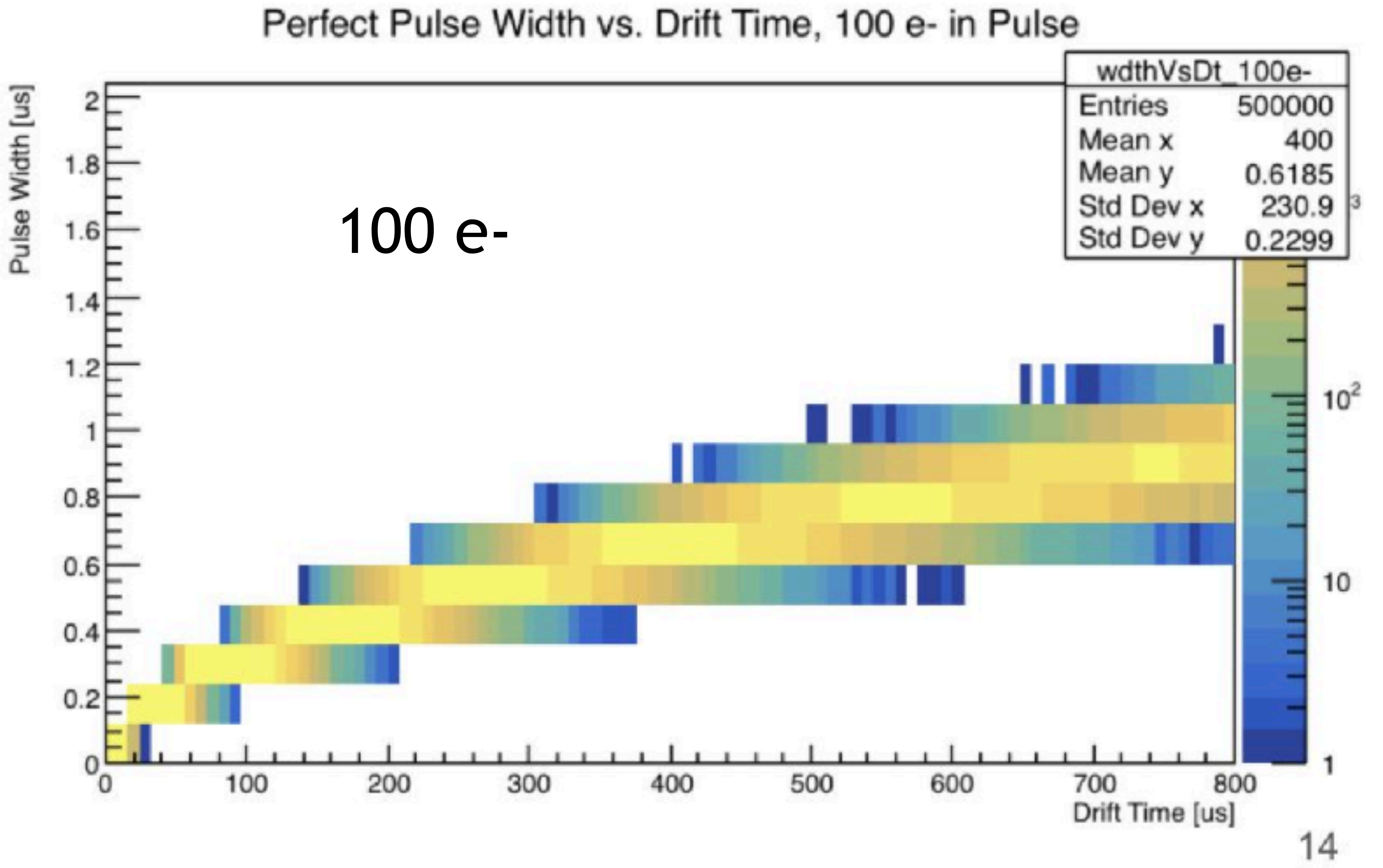
Why not just use lower transparency grids?

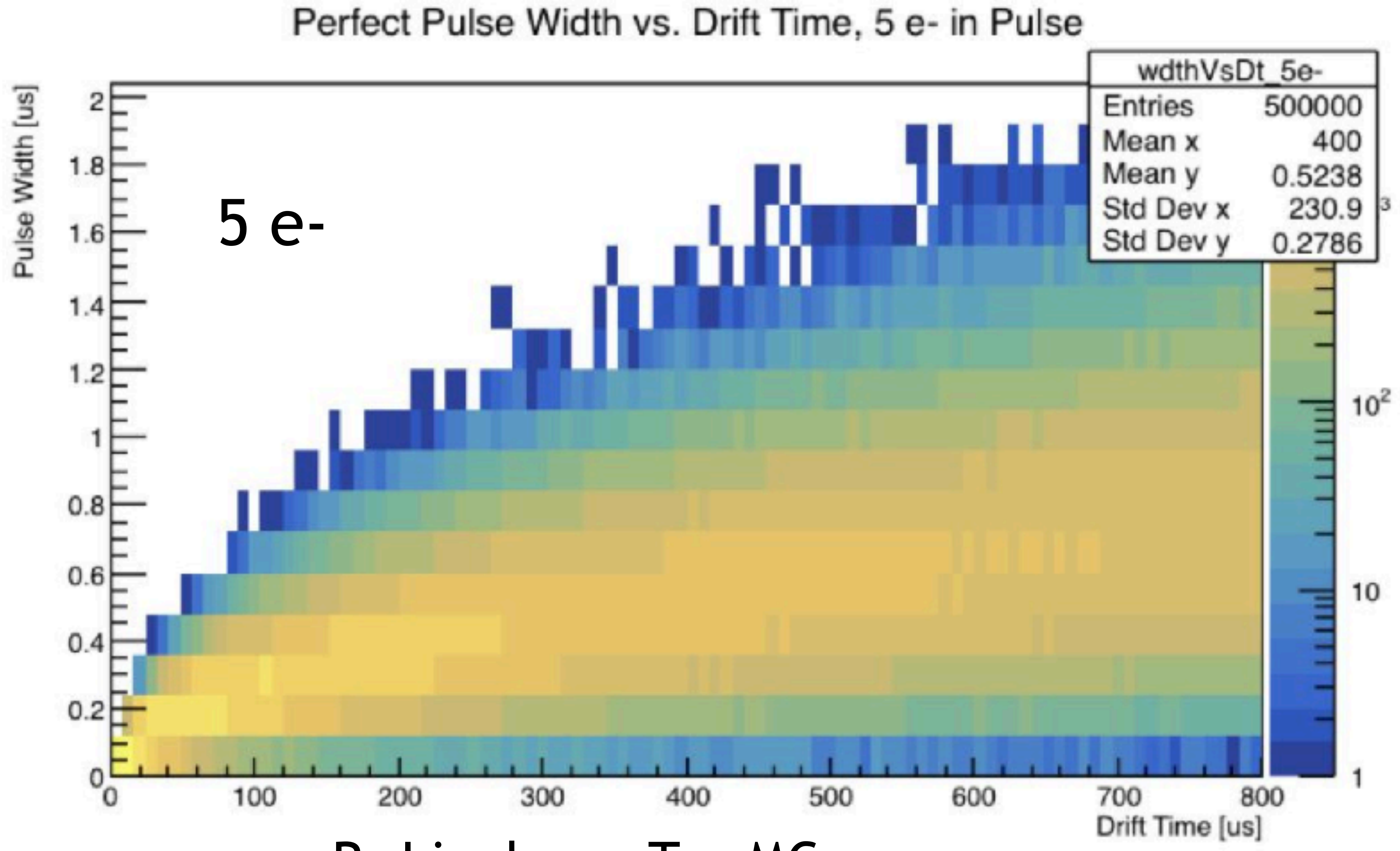
- Operate cathode and gate near 20 kV/cm, instead of 50 kV/cm
- Fundamental tradeoff of optical foot print, and surface electrid fields.
  - Grids are near to dominant source of light loss already.
- Could we coat wires with, say, Al?
  - would be useful in any case



Rn daughters on wires

- Main concern for grids (apart from rings).
- Main concern is S2 only searches, with low energy decays of Rn daughters on surfaces.
- Can use S2 width to eliminate gate events, but not cathode events.

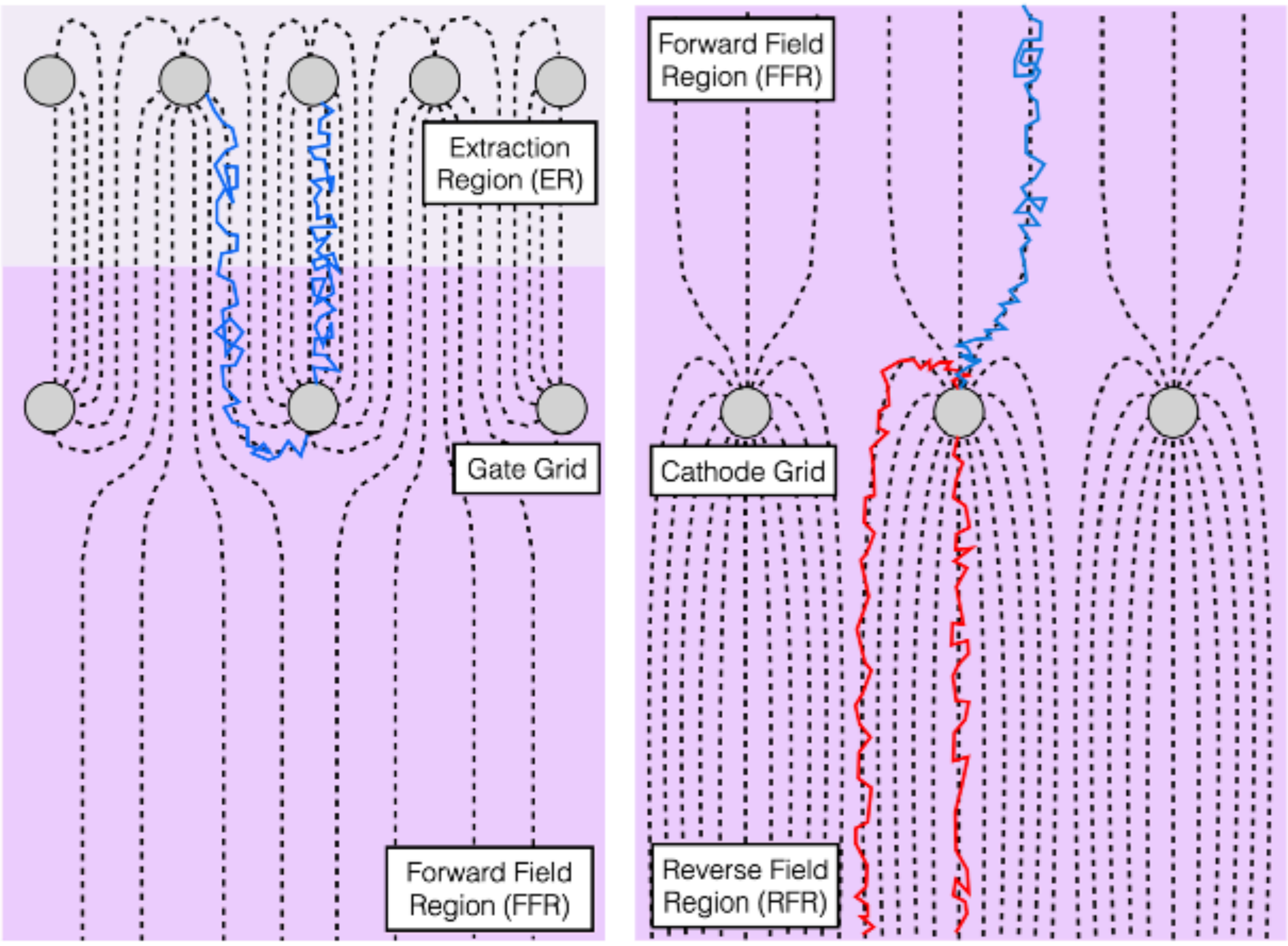


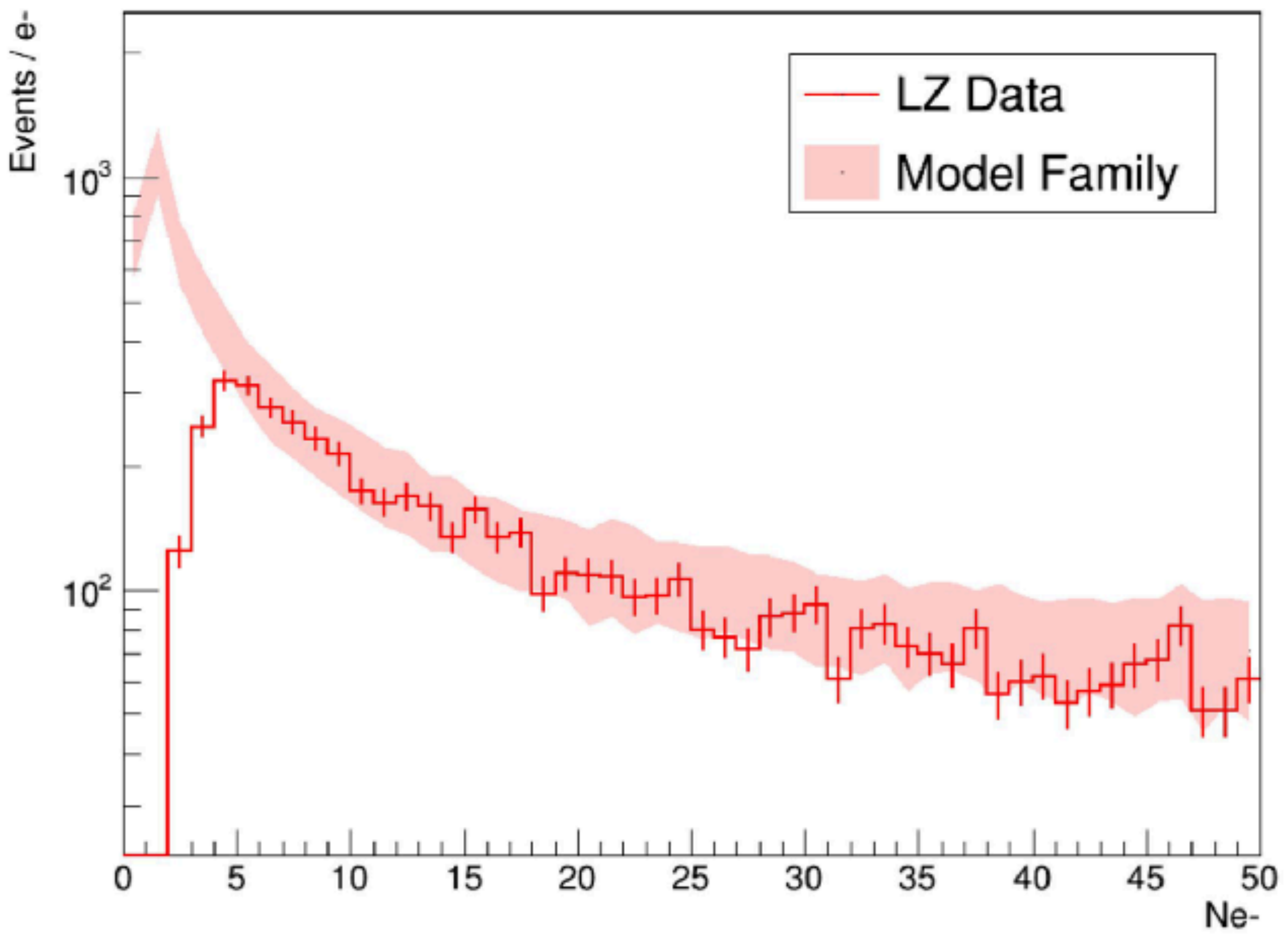


R. Linehan - Toy MC

Modeling Rn backgrounds

- Rates of Rn daughters on wires measured by alphas at high energy
- Gate simple: all decays pulled into S2 region
- Cathode not simple: need to include track lengths and diffusion.
- Rn daughters dominant in S1 + S2 region. Papers coming on S2 only.
- *Bottom line: Rn exposure should minimized for future S2 searches*





Rn scrubbing at SLAC in “LSST “ clean room

- Rn scrubbing of air a well developed process
- Most efficient scrubbers use charcoal VSA technique
- Should use this during grid fabrication
- SLAC XLZD group can use clean room built for LSST
- LZ Kr removal: hardware needed for Rn scrubber

Conclusions

- The 3m Ø grids needed for XLZD could be fabricated using the LZ woven technique, likely with spacer
- We are beginning to understand much about charge and light emission, but important questions remain. LZ data, and (presumably) XnT data should be very informative
- Passivation appears to improve electron emission, and other methods might also be powerful
- A measurement program informed by LZ and other previous efforts will be very powerful for XLZD.

Possible grid upgrade for neutrinoless $\beta\beta$ decay

- Comparing nEXO design vs XLZD.
- Many decisions by nEXO to reduce backgrounds by eliminating materials near active volume.
- Most of this can also be done in DM detector.
- One key difference: S2 cannot readily discriminate multi-scatter events at ~same *z*
  - Could use granular S2 light readout with SiPMs
- Could add induction grids, with charge readout.
  - Use multi-channel cryogenic ASIC charge readout, noise ~200 e^-