Liquid Argon Time-Projection Chambers

S. Lockwitz, *FNAL*
July 17, 2014

The Road to LArTPCs

Thanks R. Guenette

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- 1960s-70s, Bubble chambers (hydrogen, other liquids)

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    - A piston would release suddenly changing the pressure allowing bubbles to form


Gargamelle
CERN


FNAL's 15' Bubble Chamber

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  - Visible tracks made
  - Took pictures
  - It worked (detected neutral current)


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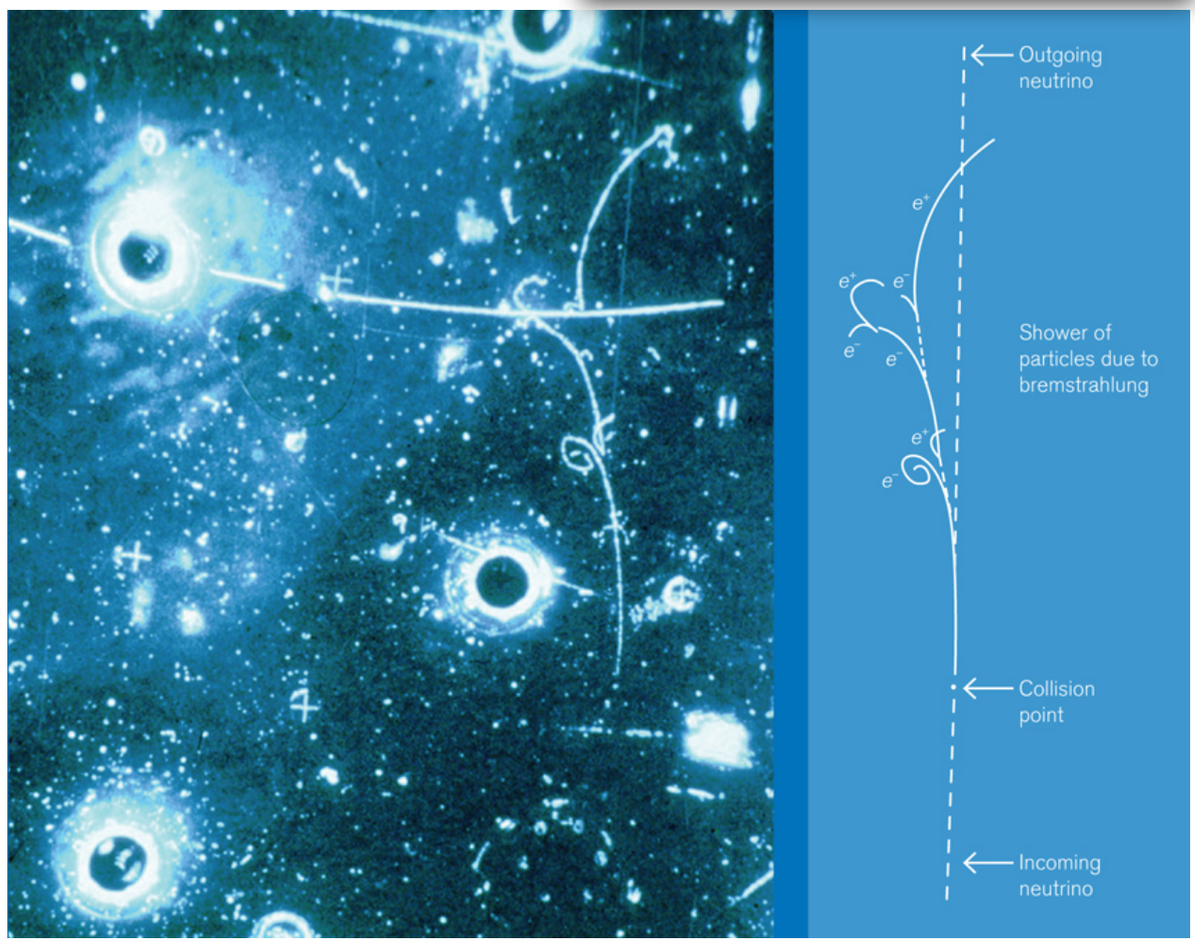

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  - A piston would release suddenly changing the pressure allowing bubbles to form
  - Visible tracks made
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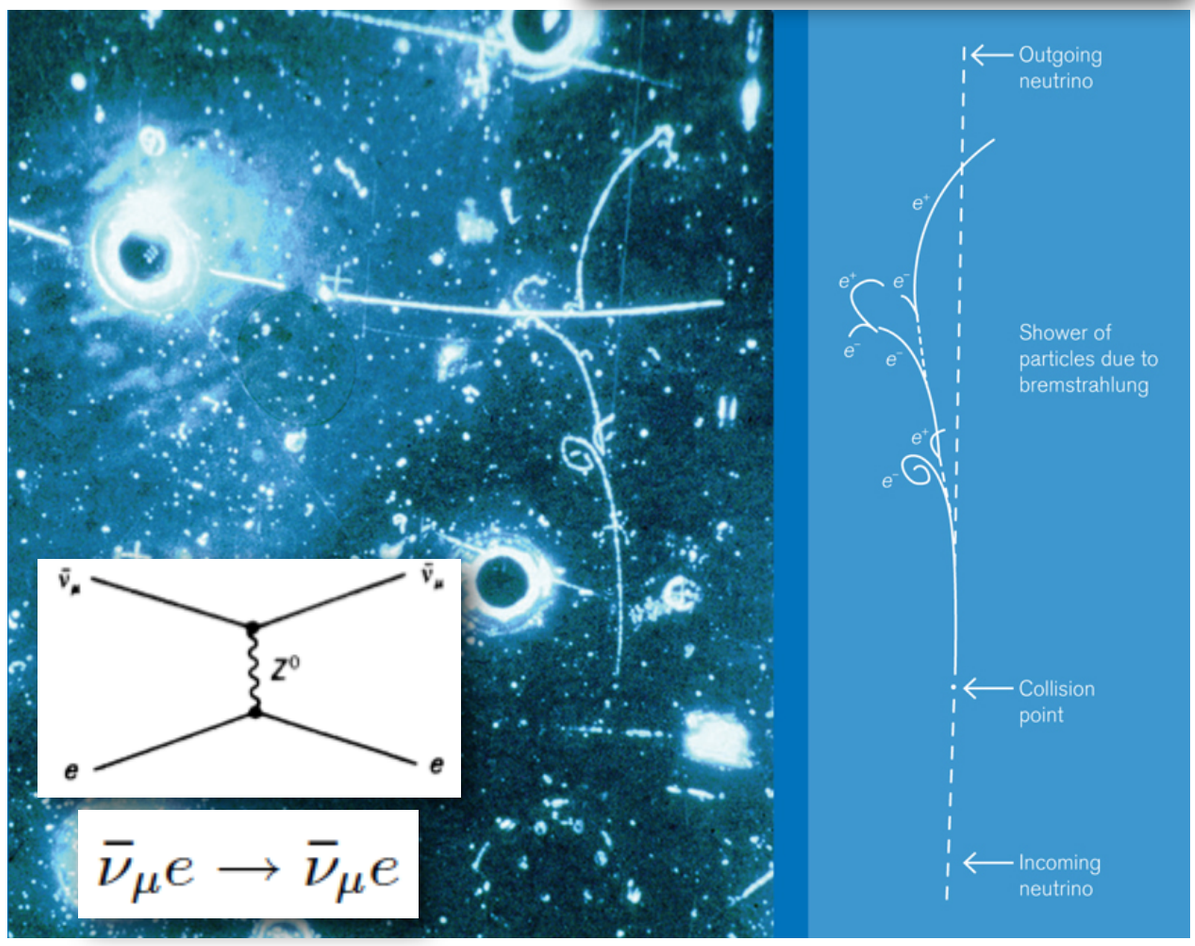
  - It worked (detected neutral current)
  - Slow (recompression ~1sec), low density, not very scaleable



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Scanning Bubble Chamber Film

- Slow.... Some computing was eventually involved, but the initial steps relied upon *hand scanning*

Vol. 7 No. 11 March 13, 1975

FERMILAB SCANNERS UNCOVER SECRETS ON FILM

Glimpses of the unique regions of high energy physics explored in the Fermilab 15-Foot Bubble Chamber's first experimental runs are beginning to emerge from the Film Analysis Facility on the 9th floor of the Central Laboratory. In the hands of a group of twelve specially-skilled employees lie the clues to this vast reservoir of new knowledge. In their darkened headquarters, the scanners of the Film Analysis Facility combine their visual observations with electronic techniques to analyze film produced by the 15-Foot Chamber when two major experiments ran there, and the film of two experiments run in the 30" Bubble Chamber, in the latter half of 1974.

FAF's present scanning staff consists of Karen Carew, Steve Condon, Barbara Cox,

...Steve Condon..Georgia Sykes..Sue Poll...

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The 15-Foot film is so rich and complex that no completely automated method can be devised to study it. The scanning procedure at Fermilab begins with the sharp observations of the scanners, as the film is run across a lighted table at the scanner's direction, magnified first at 12 times, then 66 times to examine fine details. A beginning scanner is provided a basic set of instructions -- how to identify the interactions and then to record the location and a number of characteristics of the tracks. This is pure scanning, or reviewing, of the film, resembling the assembly of a library catalog of the film's contents. When the interactions have been identified, the scanner must measure the position of about ten points on each track, with a precision digitizing plane. These points are fed by the scanner into the PDP-9/L computer by tapping a foot-controlled device. Eventually, these points are analyzed by sophisticated PDP-10 programs to produce values for the momentum and direction of each track.

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The Road to LArTPCs

- 1968: L.W. Alvarez first proposes the use of Liquid Noble Gases for particle detectors
- 1974: W. Willis and V. Radeka propose LAr ionization chambers
  - Idea was to use sampling plates in LAr for calorimetry

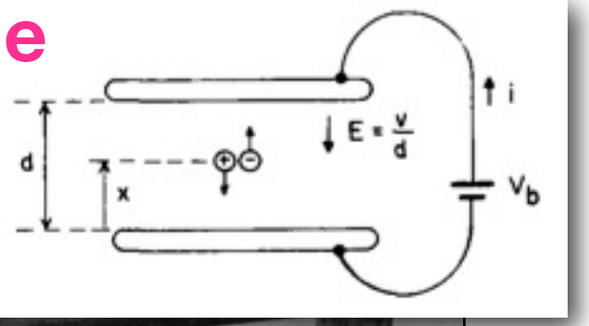
Benefits of LAr:

i) it is dense (1.4 g/cm^3);
ii) it does not attach electrons;
iii) it has a high electron mobility (~5 mm/μs at 1 kV/mm);
iv) the cost is low ($0.14→0.50/kg, depending on source and quantity);
v) it is inert, in contrast to flammable scintillators;
vi) it is easy to obtain in a pure form and easy to purify;
vii) many electronegative impurities are frozen out in liquid argon.

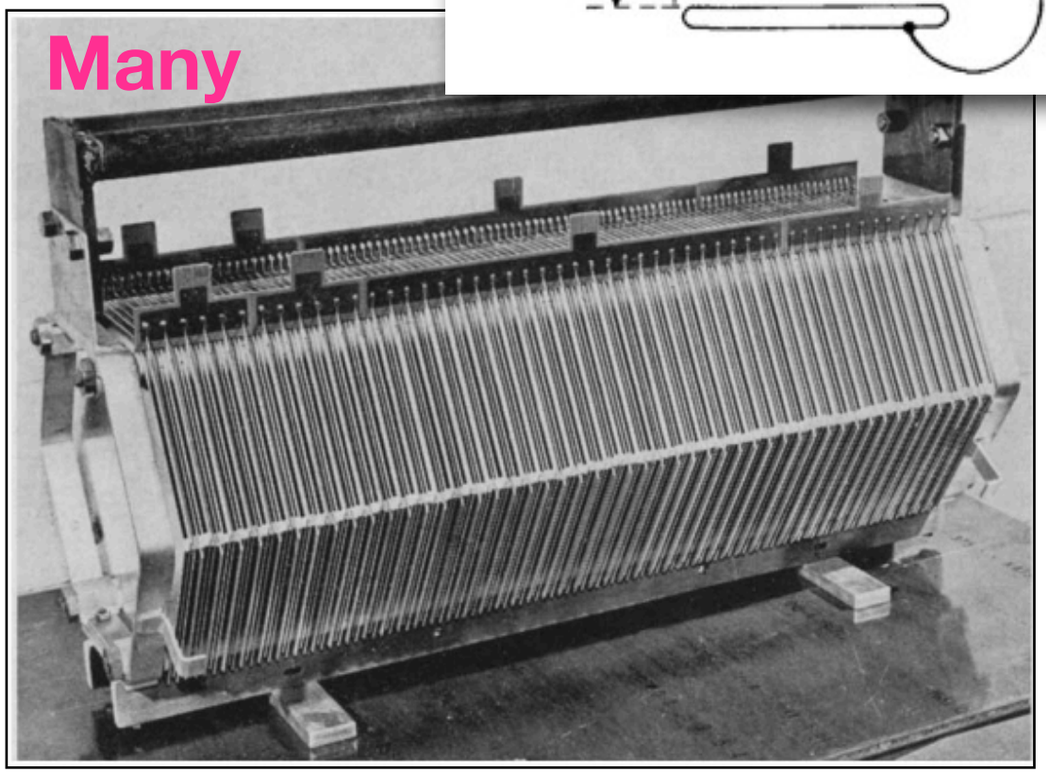
The disadvantage is that the container must be insulated for liquid-argon temperature (86 K).

Willis & Radeka, NIM 120 (1974)

One

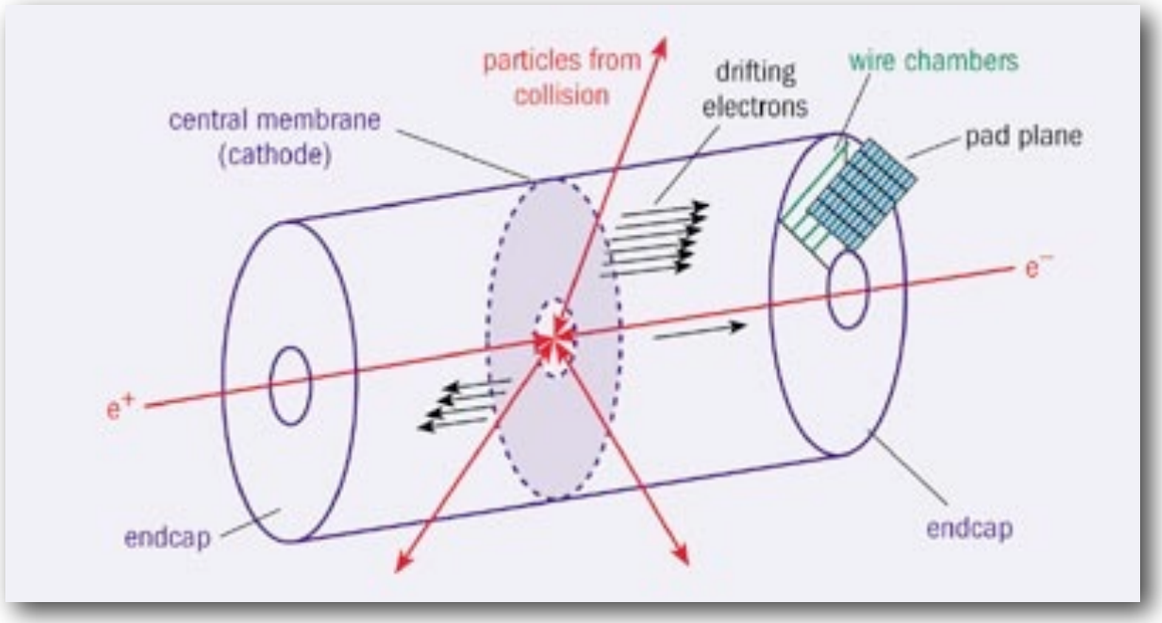


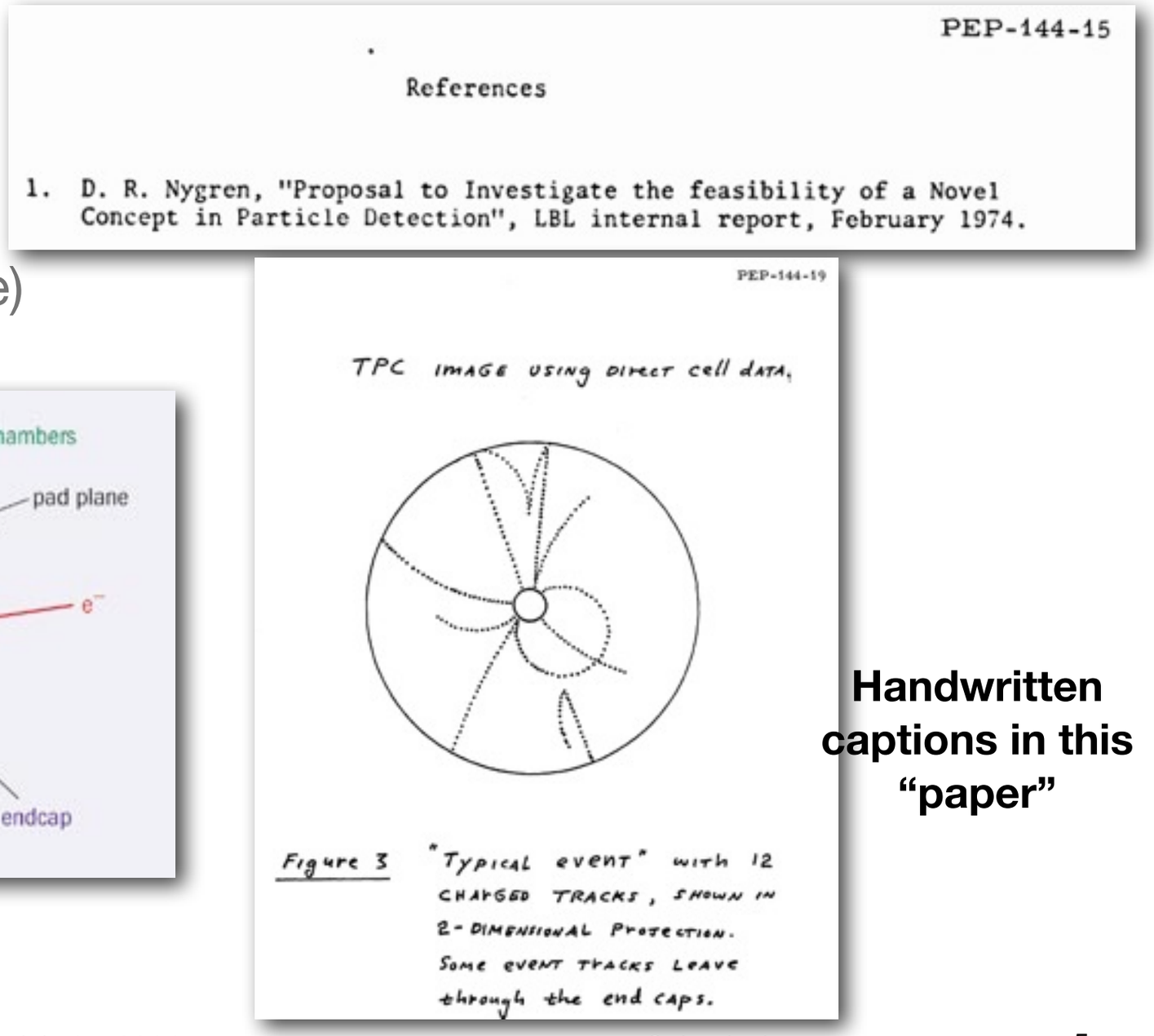
Many



The Road to LArTPCs

- 1974: D. Nygren proposes the time-projection chamber
  - For the PEP collider at SLAC
  - Gas mixtures (e.g. Ar+Methane)




PEP-144-15

References

1. D. R. Nygren, "Proposal to Investigate the feasibility of a Novel Concept in Particle Detection", LBL internal report, February 1974.

PEP-144-19

TPC IMAGE USING DIRECT CELL DATA.

Figure 3 "TYPICAL EVENT" WITH 12 CHARGED TRACKS, SHOWN IN 2-DIMENSIONAL PROJECTION. SOME EVENT TRACKS LEAVE through the end caps.

Handwritten captions in this "paper"

How Do Particles Interact in Liquid Argon

From DEAP & T. Miceli

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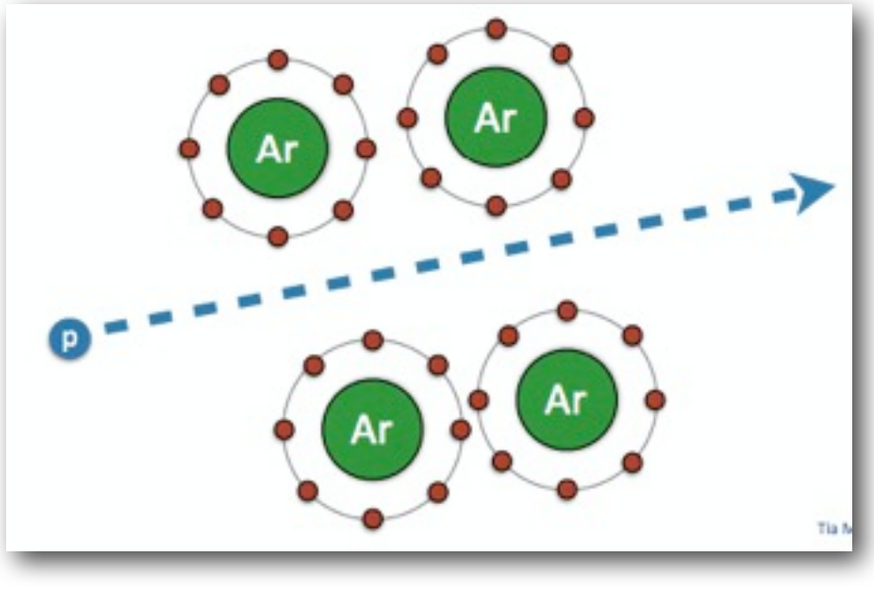

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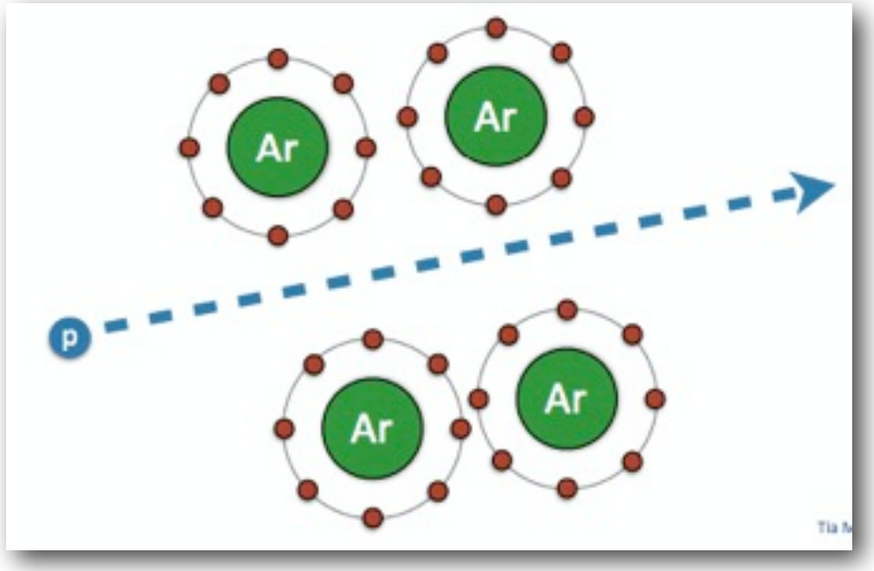

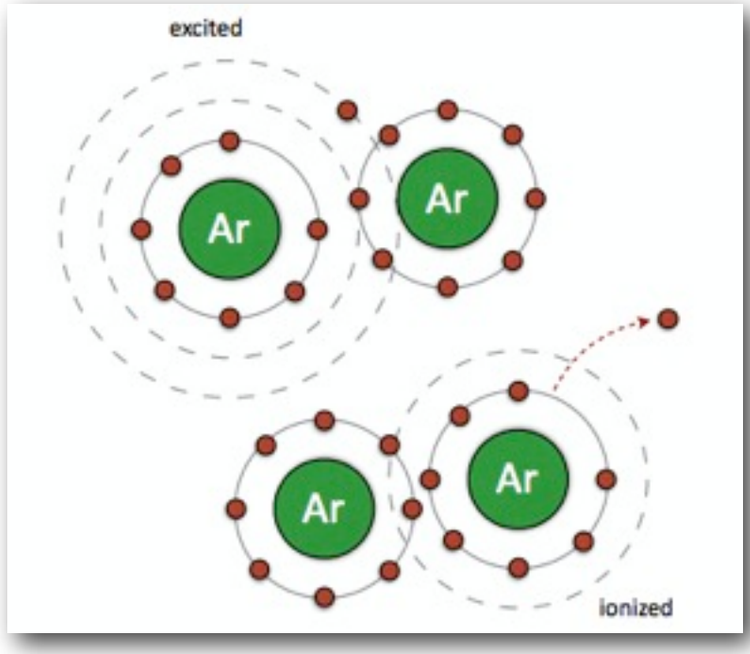

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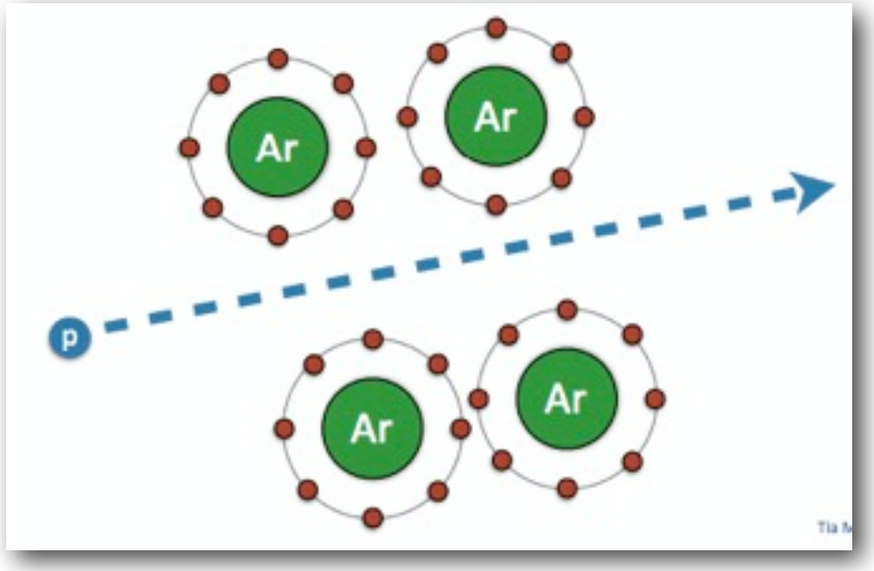

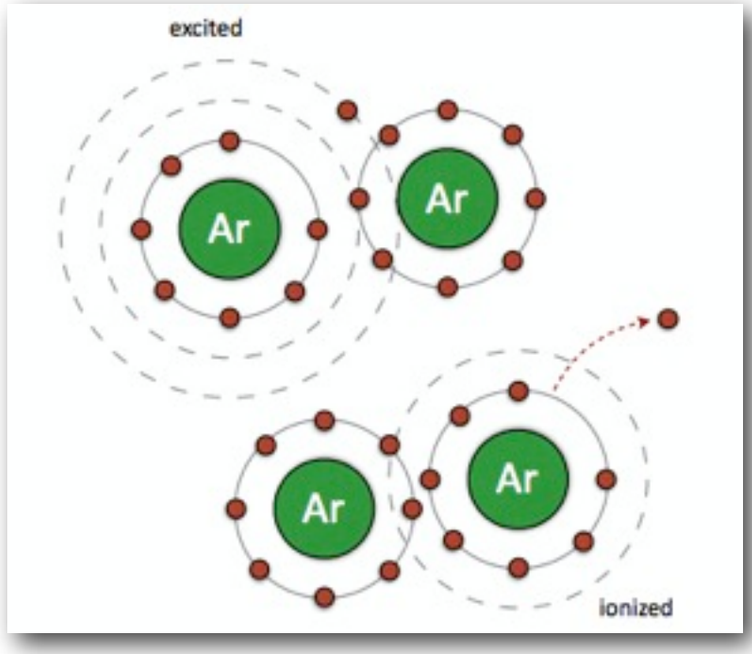

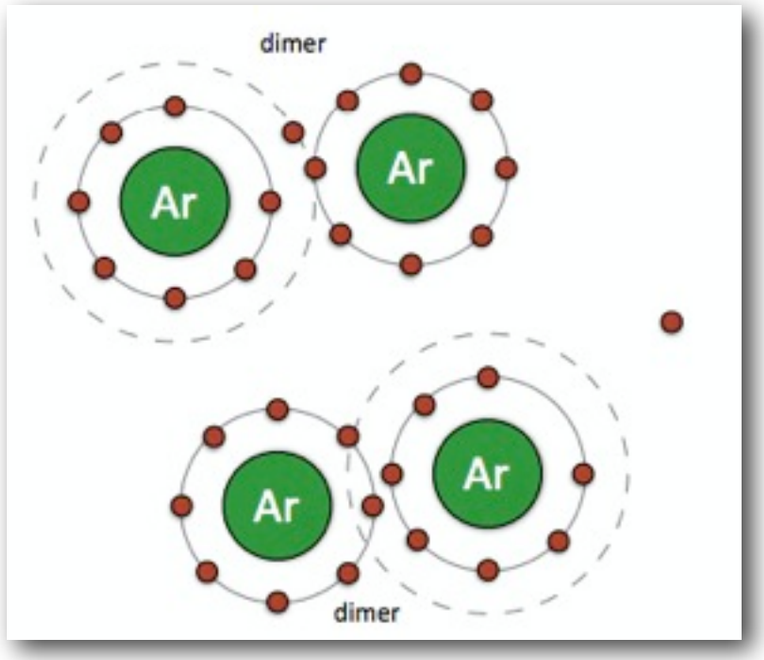

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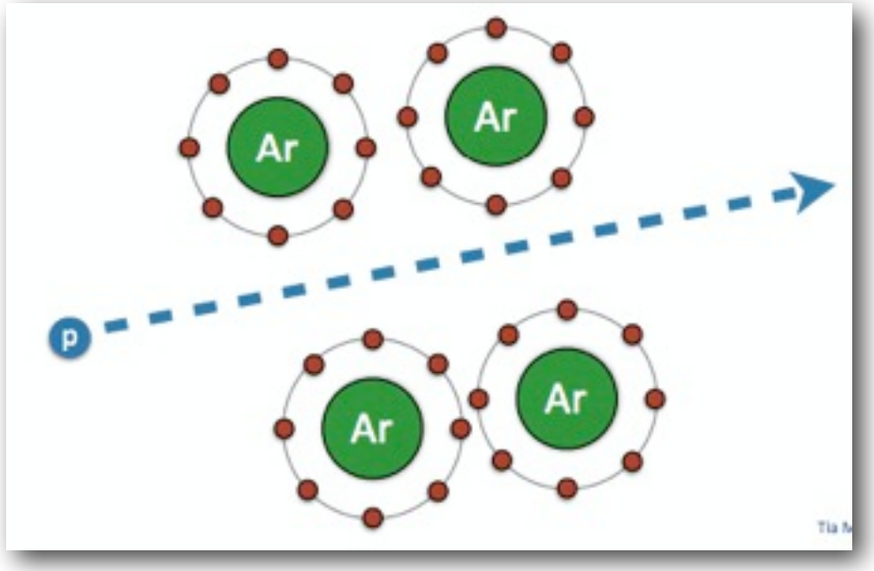
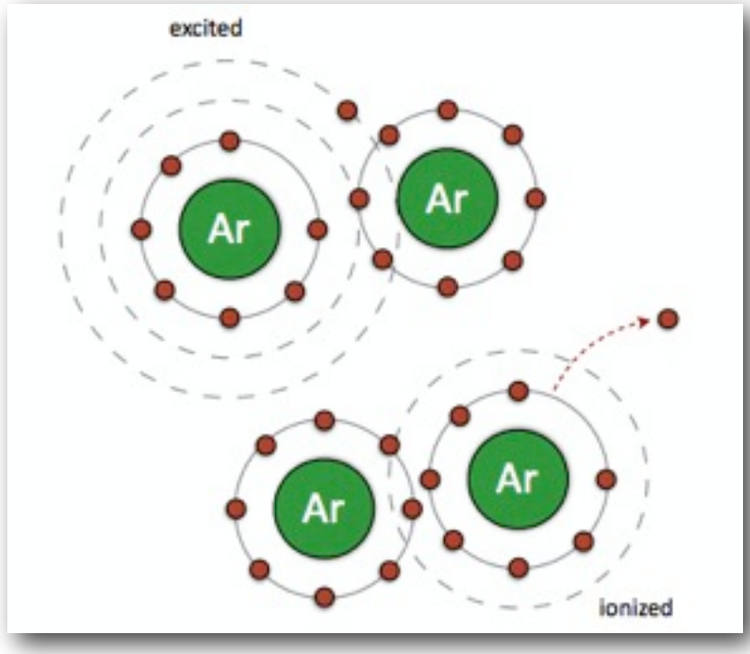
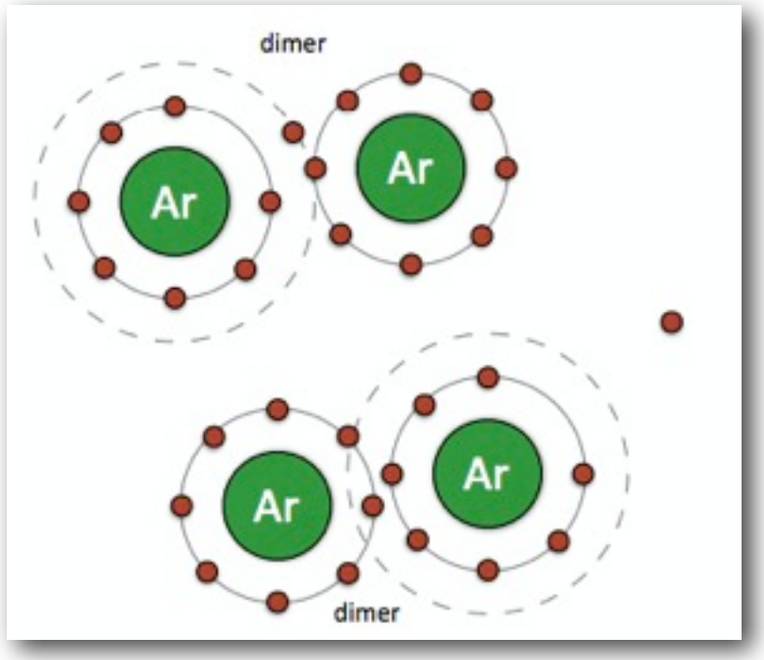
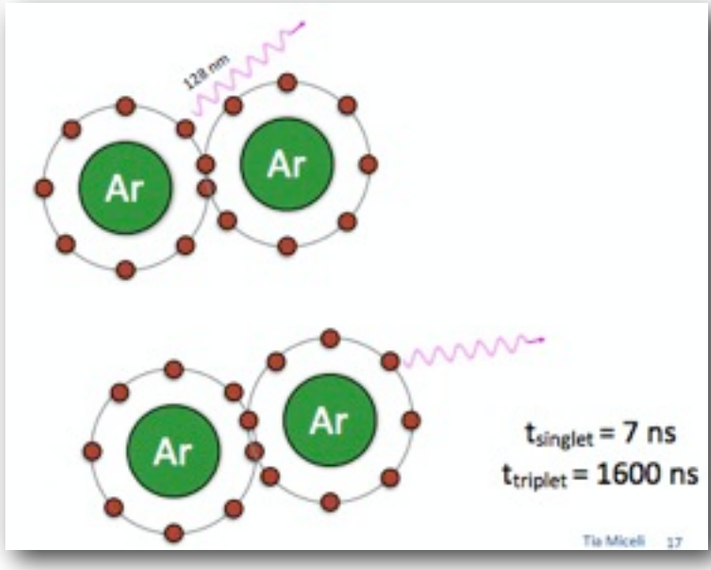
How Do Particles Interact in Liquid Argon

- Charged particle passes through
- Argon is ionized or forms an excited state
- De-excite non-radiatively to either singlet or triplet state
- Decay into the ground state by emitting a 128 nm photon









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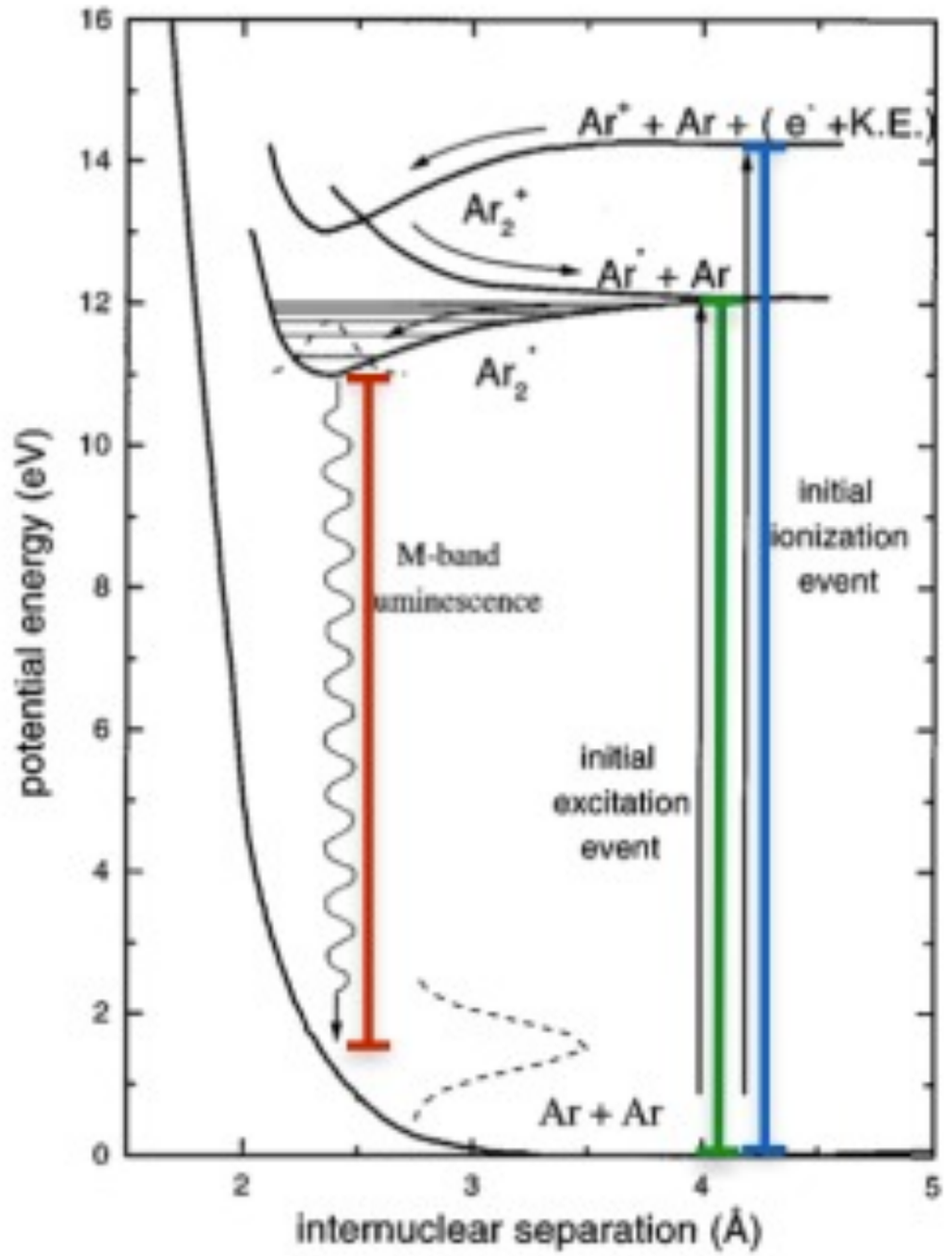
Particle Interaction in LAr: Scintillation Light



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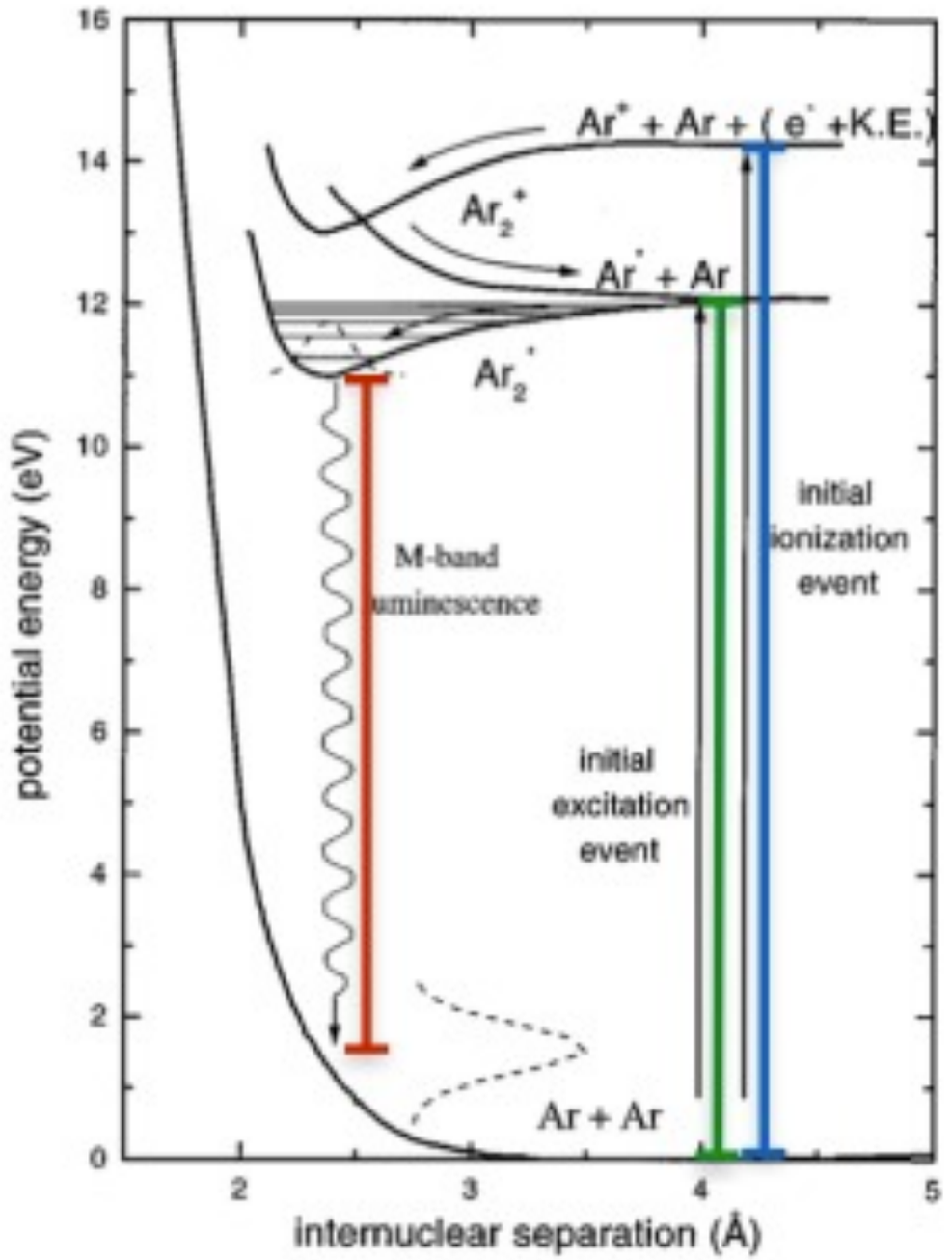
Particle Interaction in LAr: Scintillation Light

- **Red**: Energy of scintillated photon



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Particle Interaction in LAr: Scintillation Light

- **Red**: Energy of scintillated photon
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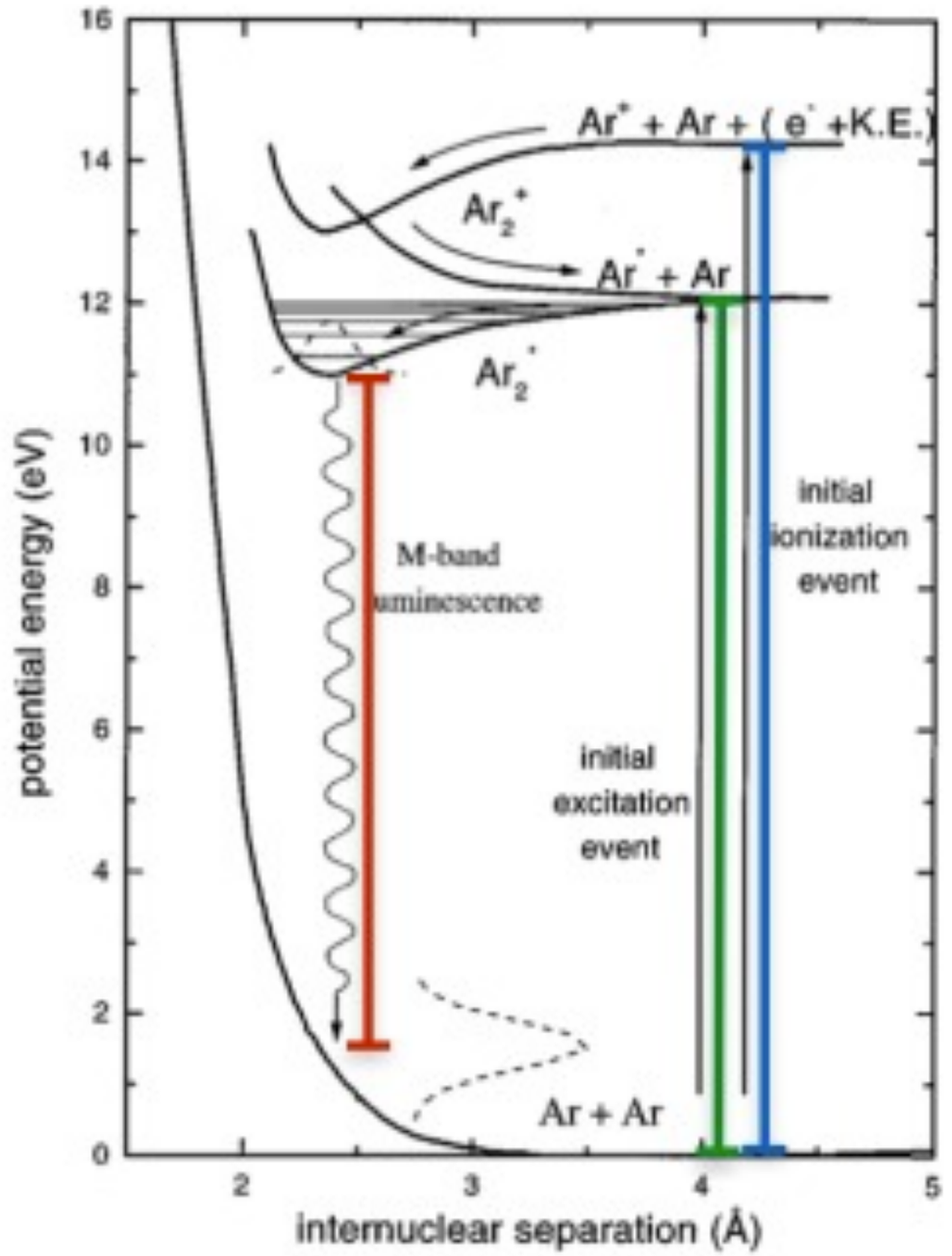

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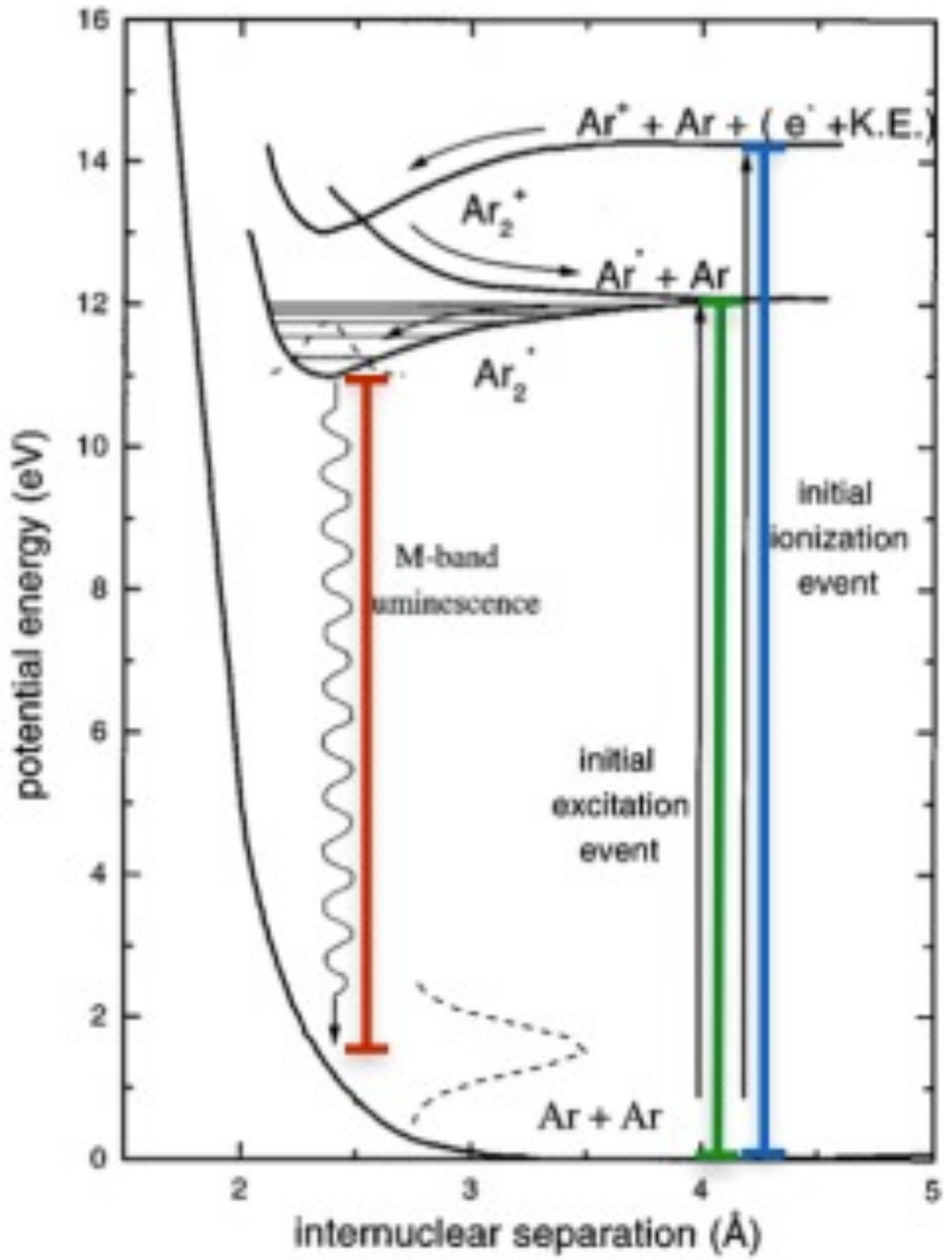

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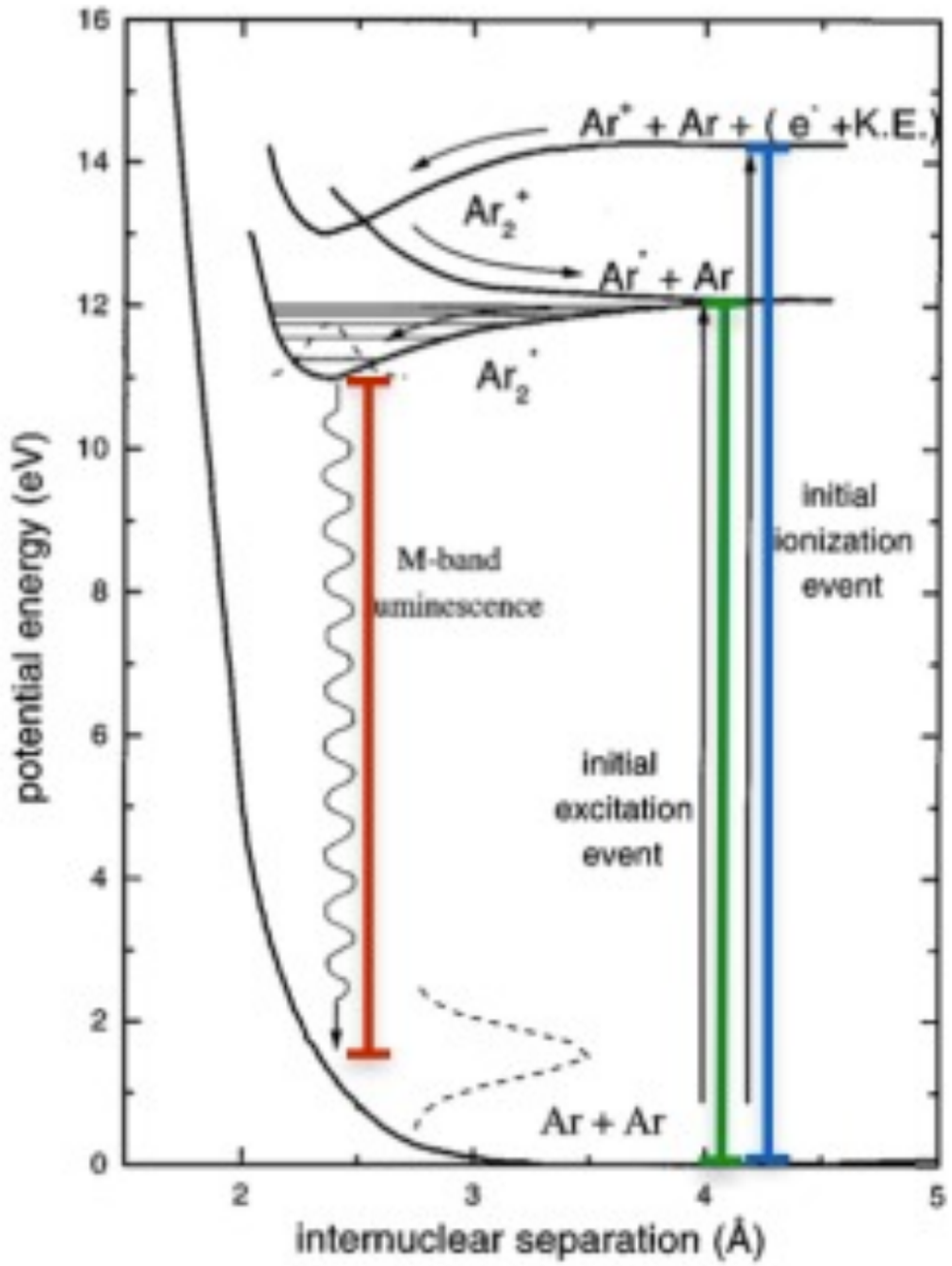
Particle Interaction in LAr: Scintillation Light

- **Red**: Energy of scintillated photon
- **Green**: Energy of excited Ar molecule
- **Blue**: Energy of ionized pair
- The red is less than the other two
  - The scintillated photon is not energetic enough to put the argon into an excited state
- So argon is transparent to its scintillation light



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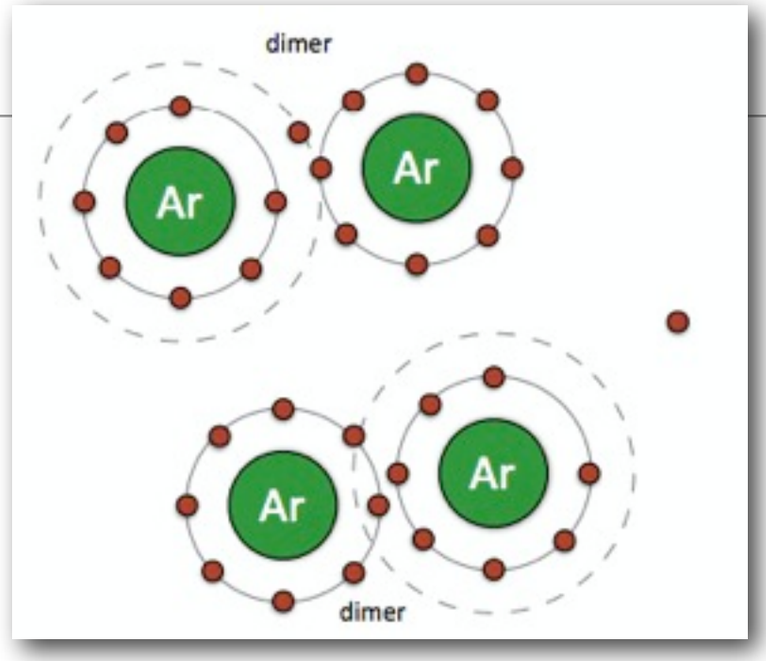
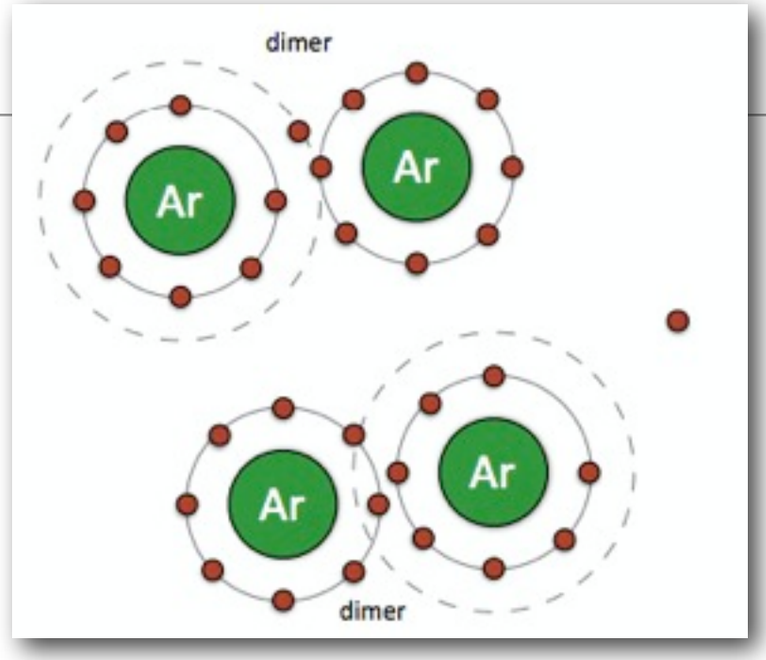
Signal Dependence on E Field



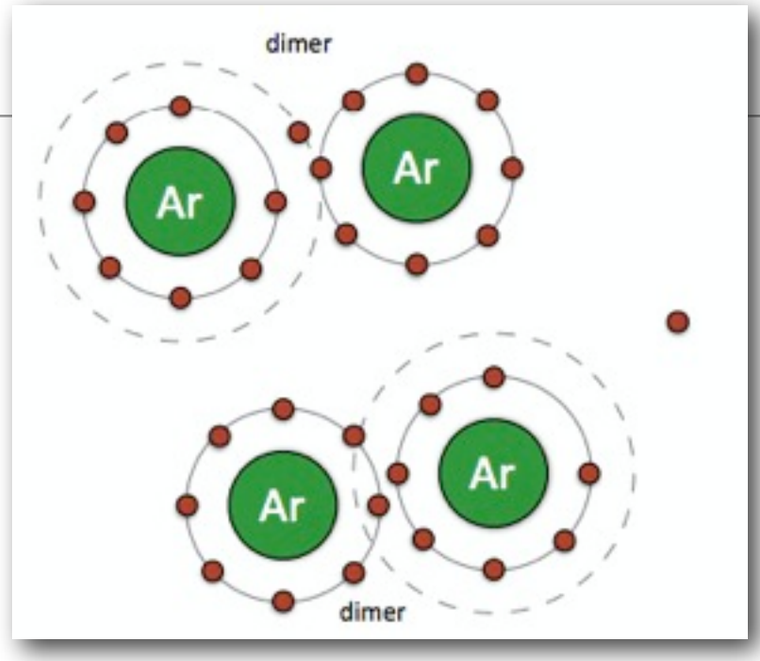
Signal Dependence on E Field

- If the LAr is in an E field, we can drift some of these liberated electrons away before they are reabsorbed



Signal Dependence on E Field

- If the LAr is in an E field, we can drift some of these liberated electrons away before they are reabsorbed
- The amount of these signal electrons depends upon the electric field:
  - More electric field = more electrons
  - Less field = more recombination (more light emitted from ***recombination***)



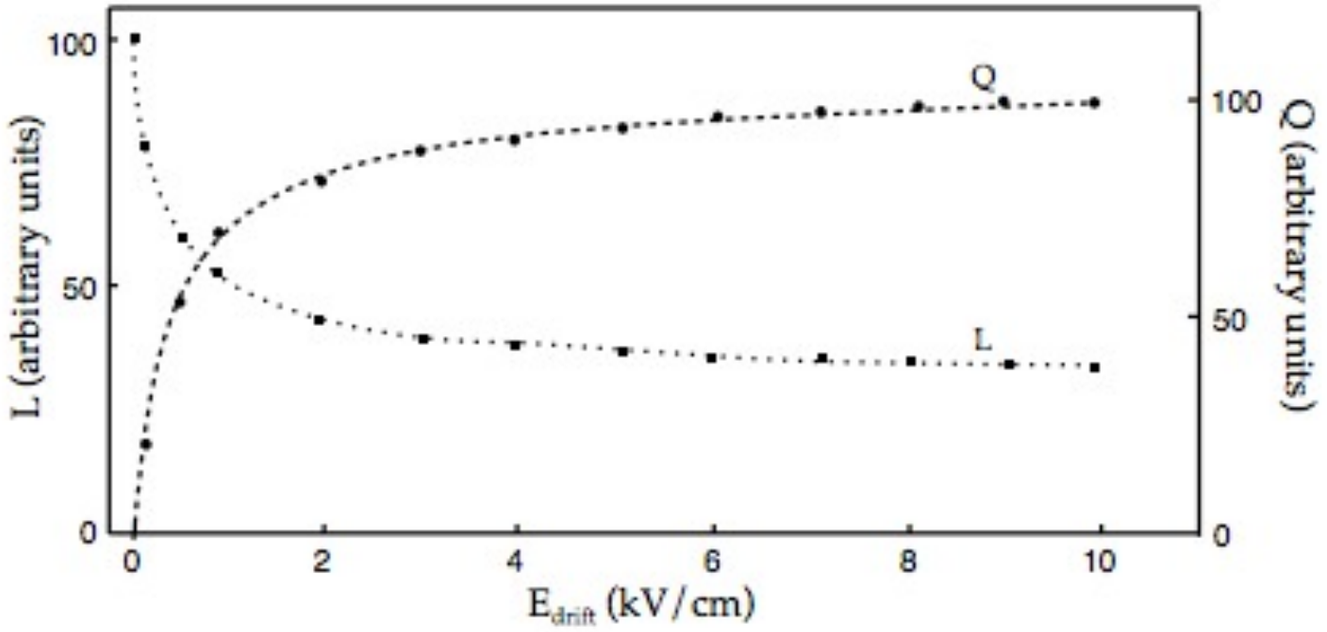
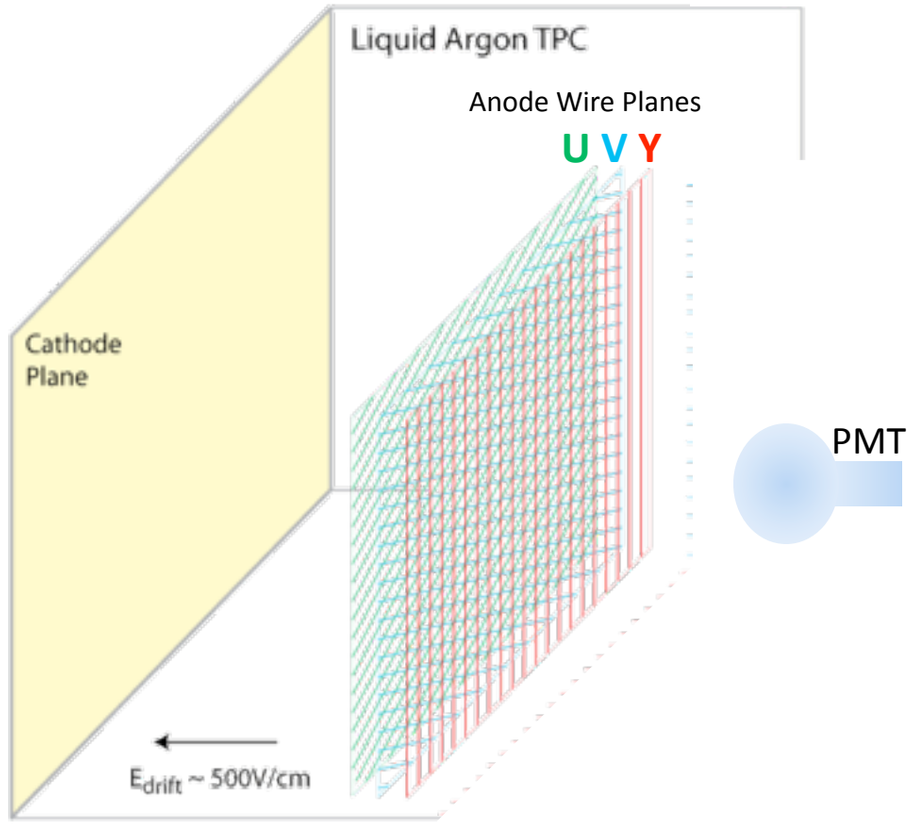


Figure 3.7: The graph shows the behaviour of the luminescence light intensity and of the collected charge as function of the electric field strength. The y axis scales

L. Grandi Dissertation, p. 85

How Would This Work



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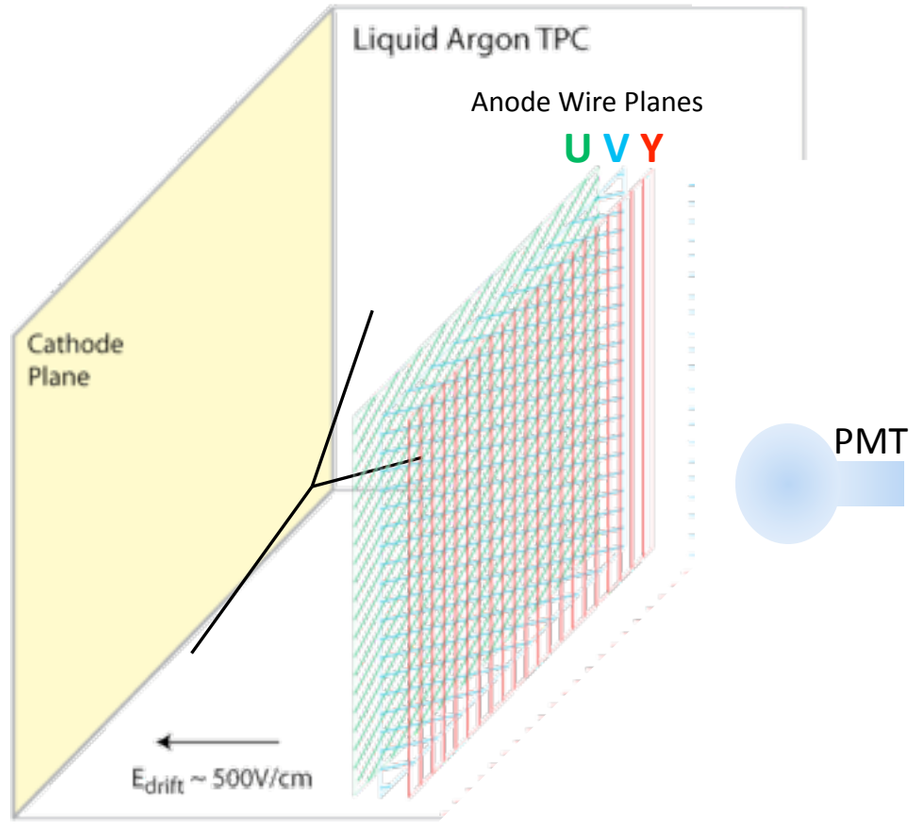
- Energy loss by charged particles → Ionization & excitation of Ar



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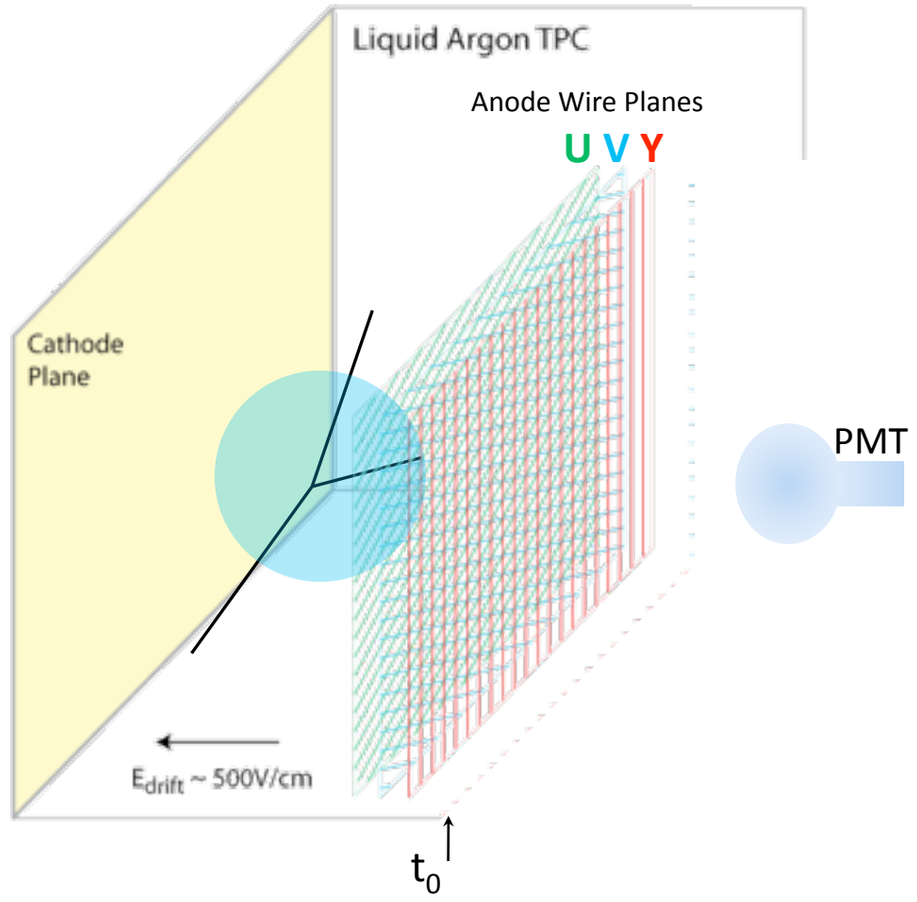

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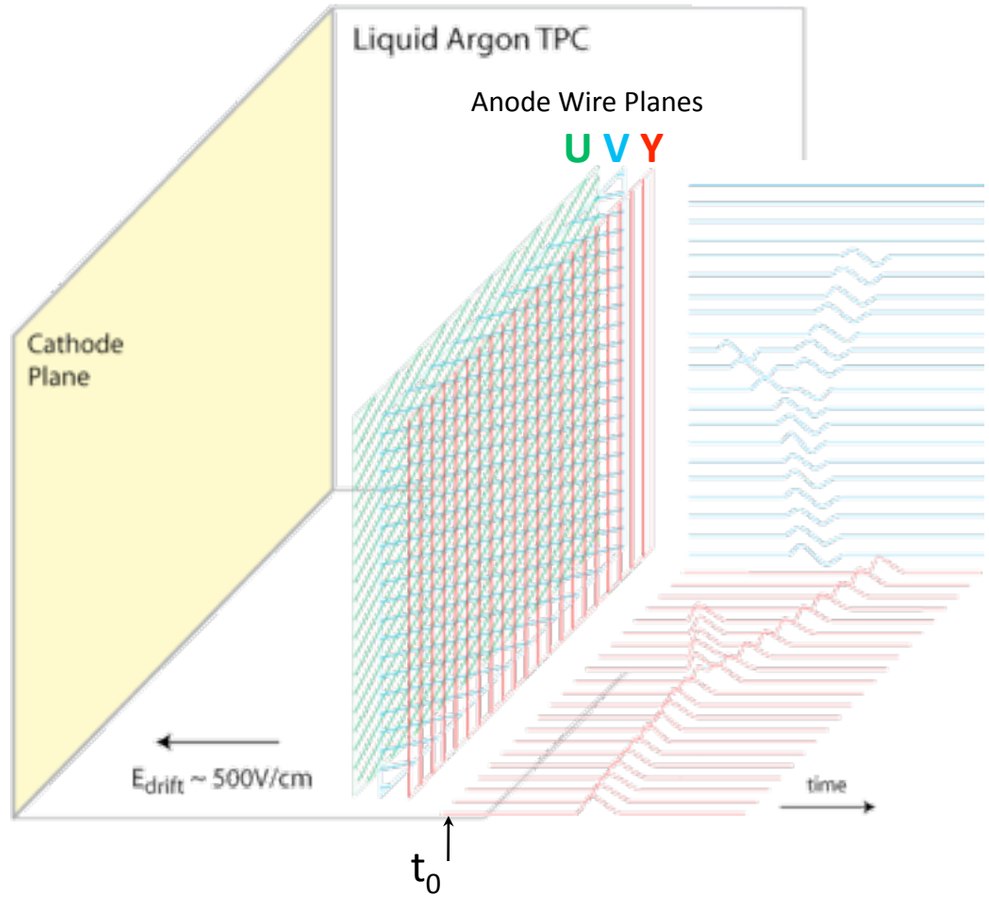

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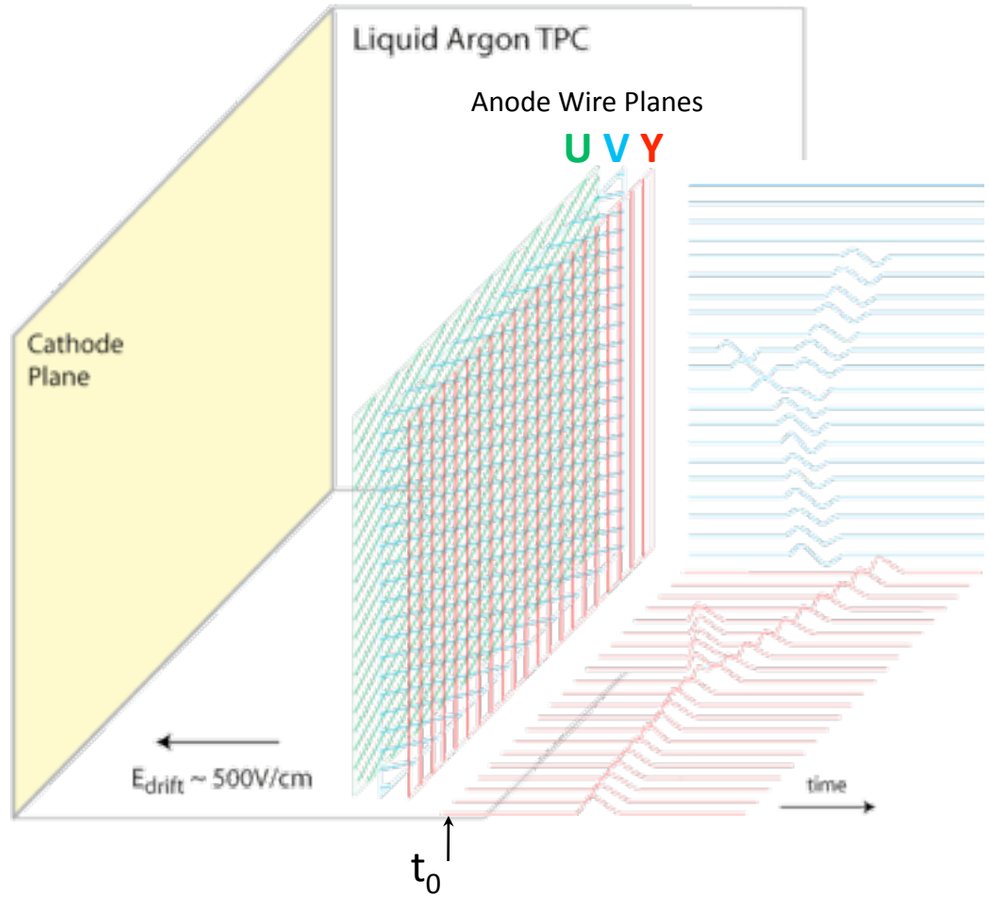

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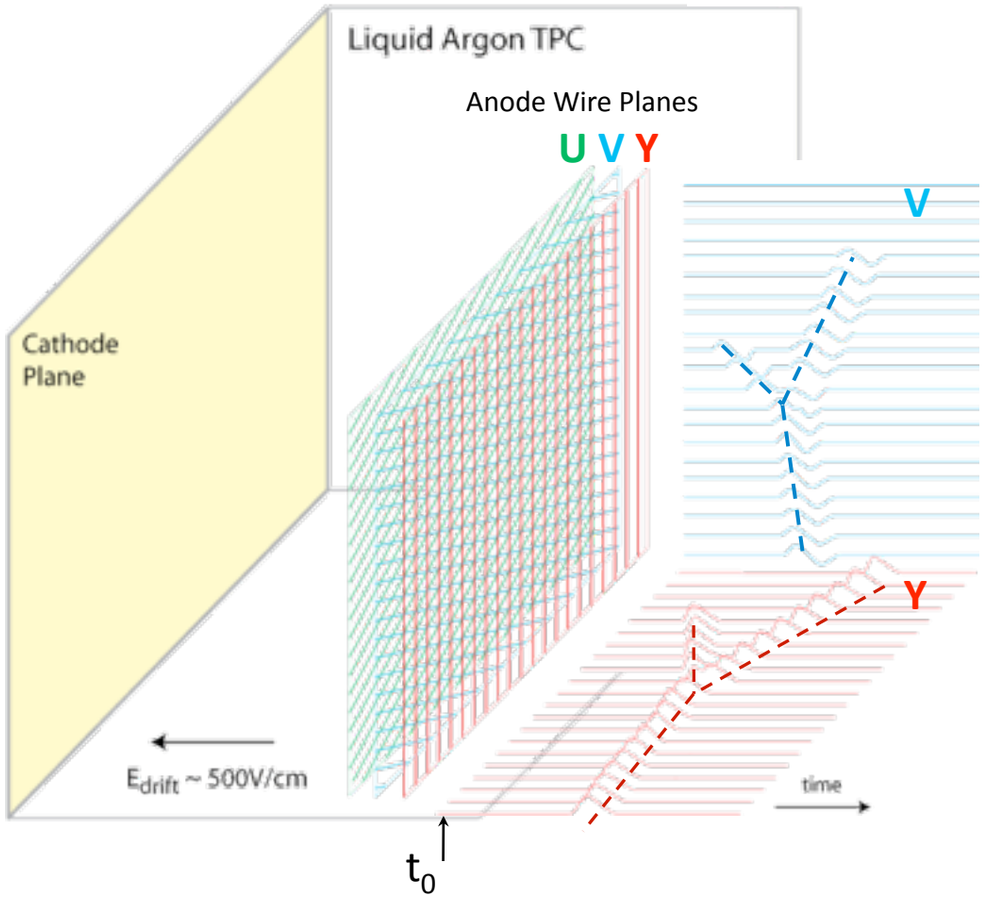

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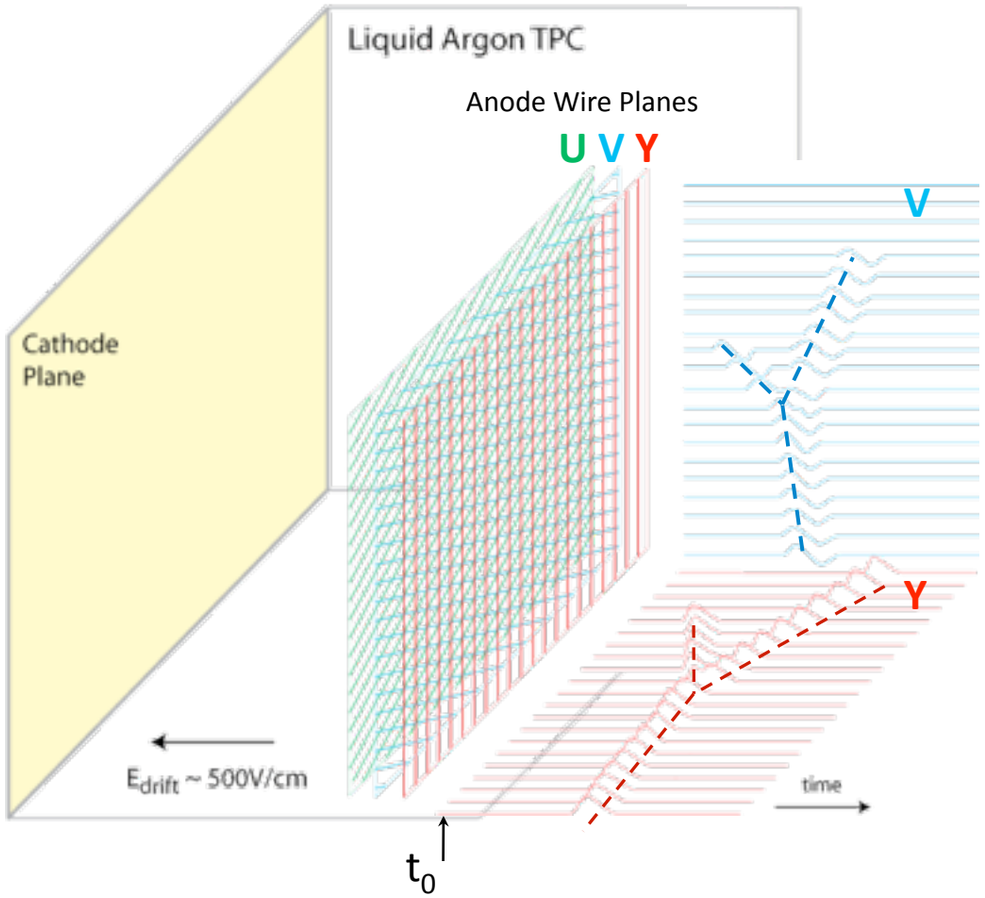

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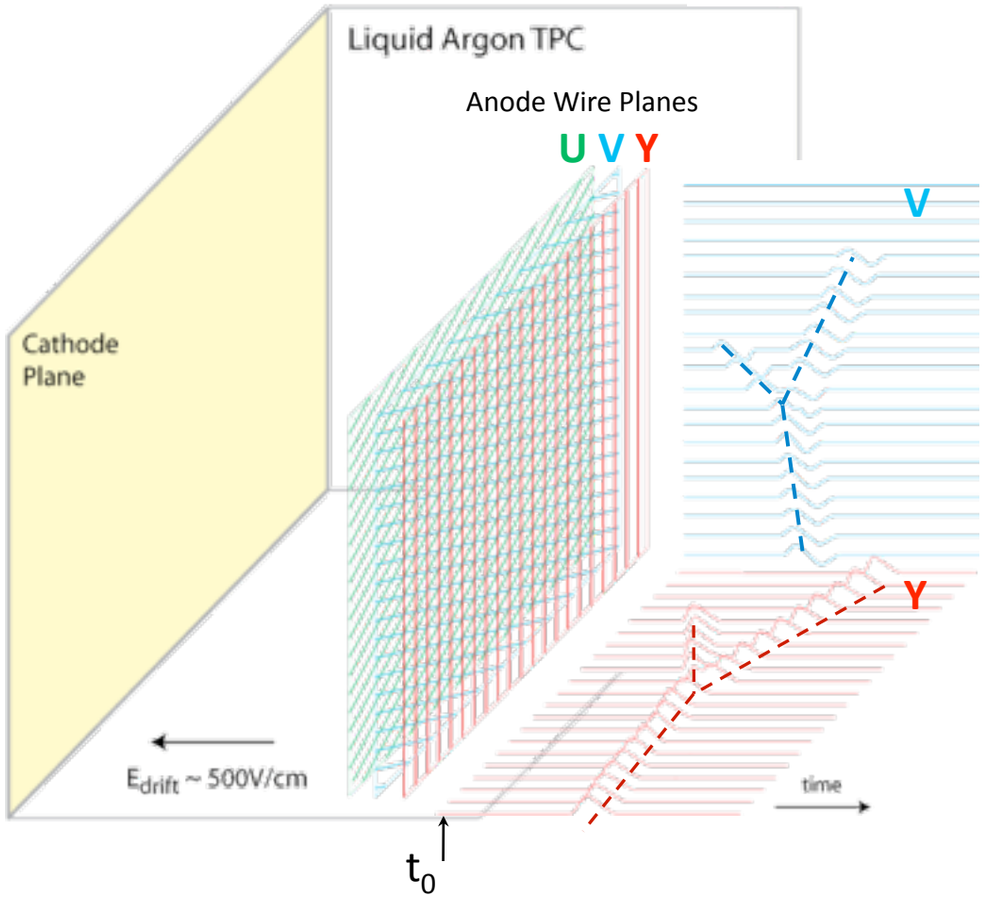
  - Drift distance is found from knowing t_0 & v_d → Time projection!



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Why LAr?

- We need to drift electrons from ionization to sense wires → closed shell
- Scintillation light gives us t_0
- Need good dielectric properties for HV stability (needed for E field)
- Noble elements are a good choice for this:

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Boiling Point [K] @ 1atm	4.2	27.1	87.3	120.0	165.0	373
Density [g/cm^3]	0.125	1.2	1.4	2.4	3.0	1
Radiation Length [cm]	755.2	24.0	14.0	4.9	2.8	36.1
Scintillation [γ /MeV]	19,000	30,000	40,000	25,000	42,000	
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From M. Soderberg

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Dense

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Can be cooled by LN_2

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~$10/L

~$500/L

~$2/L

~$700/L

~$3000/L

From M. Soderberg

Let’s See Some Event Displays

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- LArTPCs have great imaging potential

Let's See Some Event Displays

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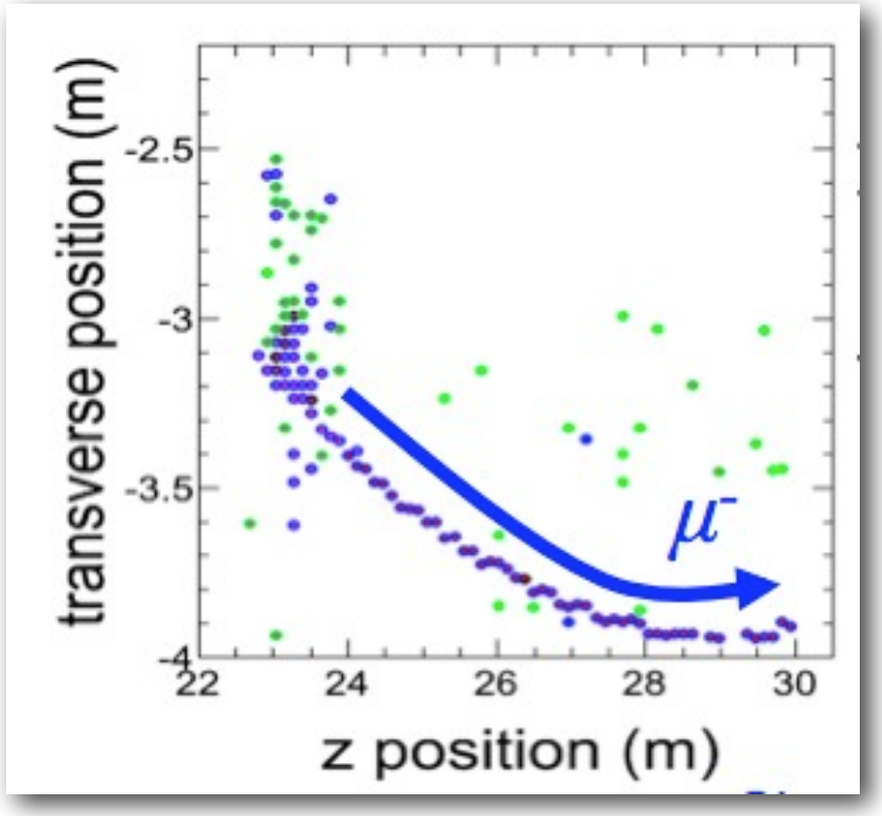
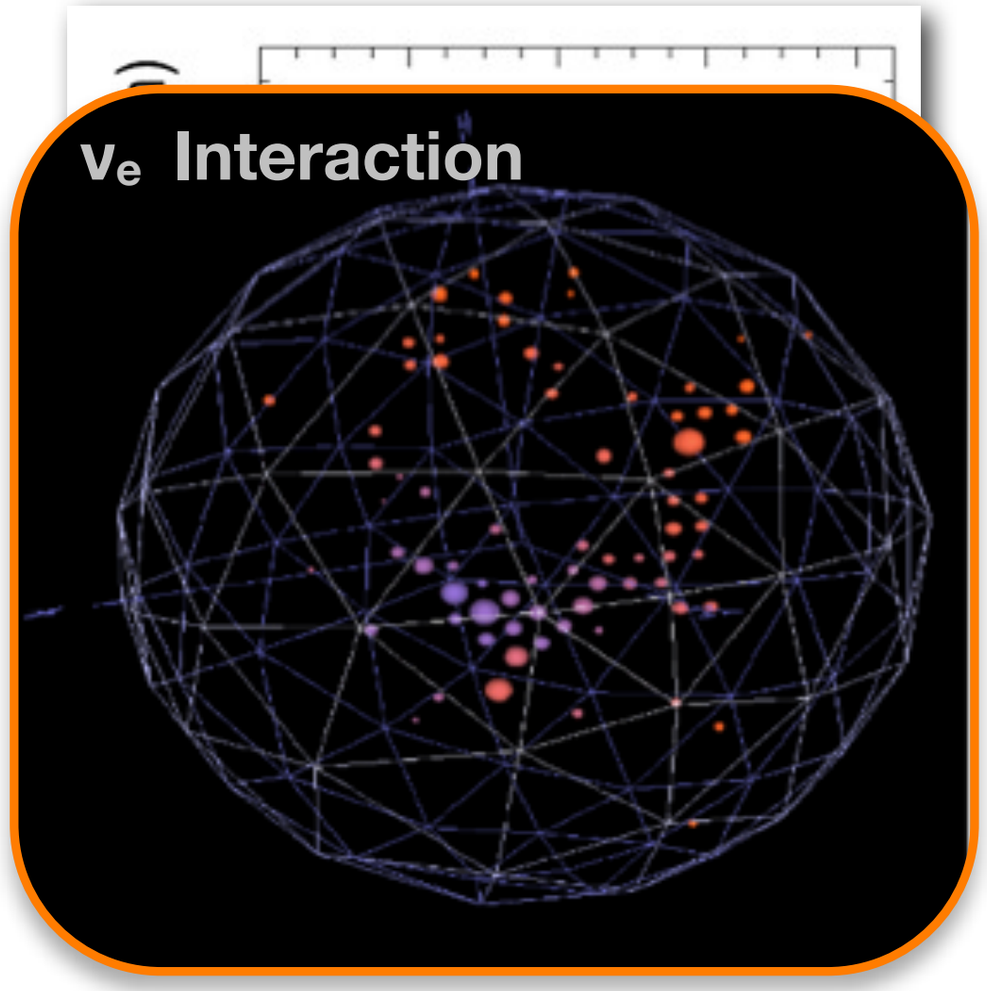
  - MINOS event display:



Let's See Some Event Displays

- LArTPCs have great imaging potential
  - MINOS event display:
  - MiniBooNE event display:



Let's See Some Event Displays

- LArTPCs have great imaging potential
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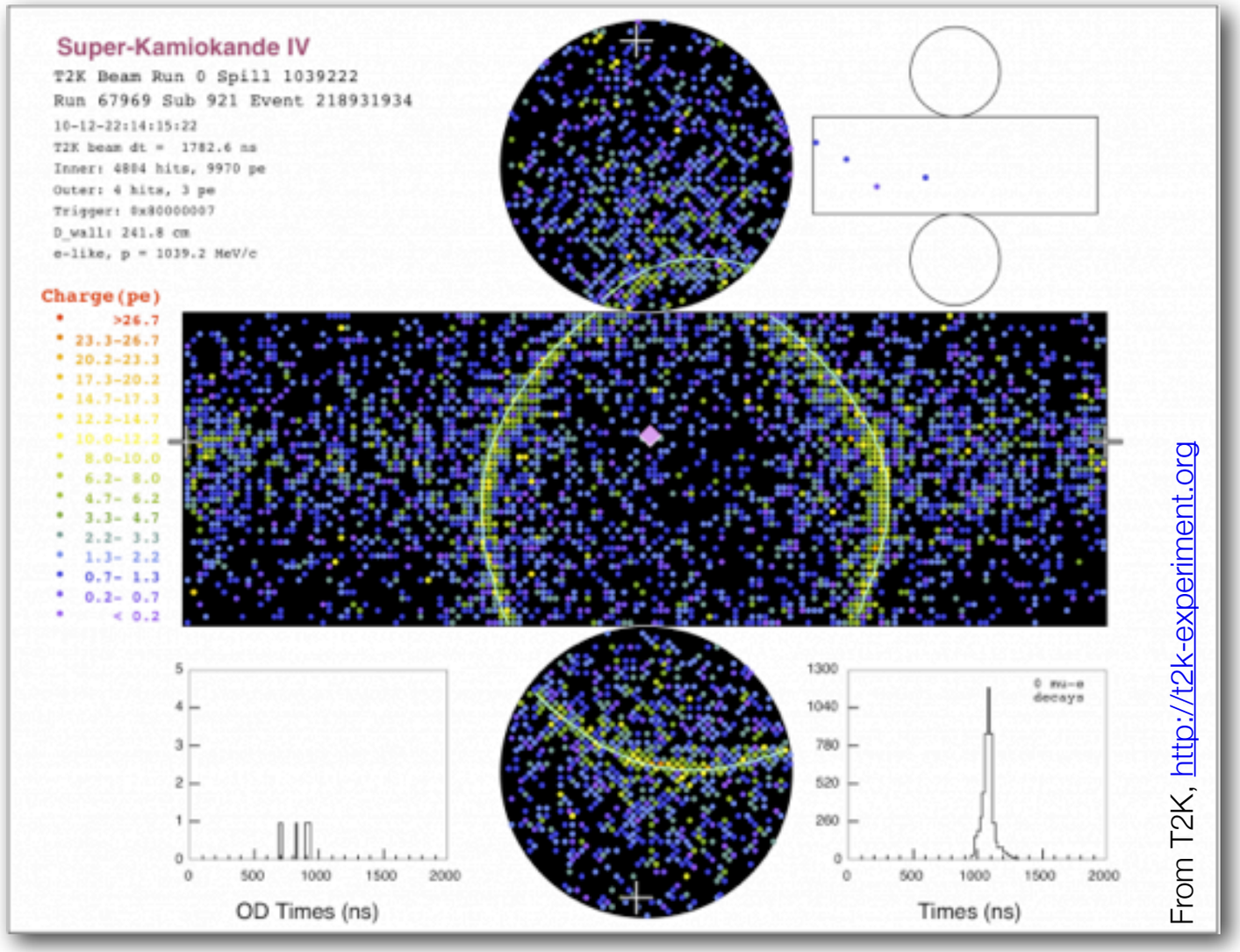

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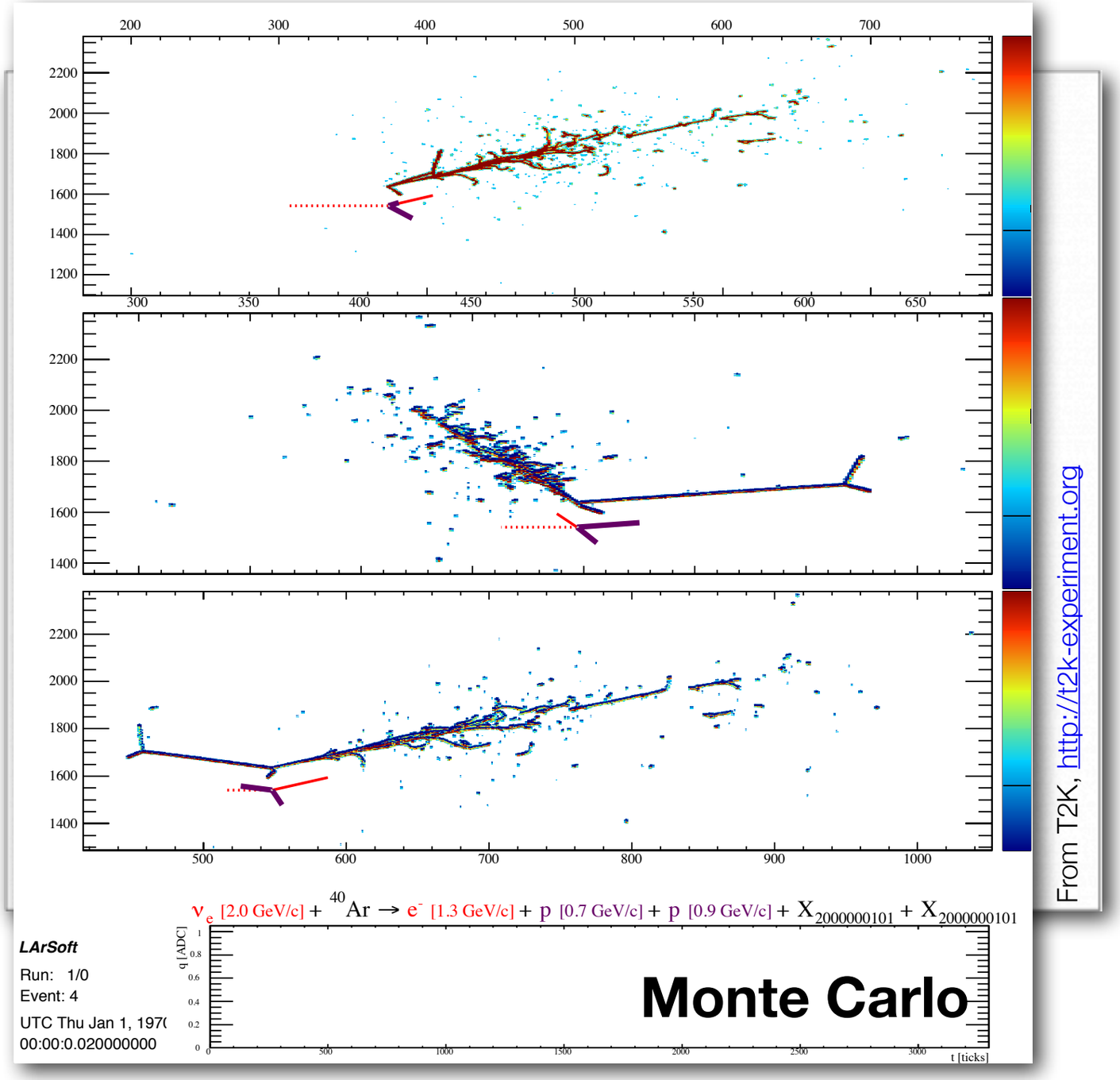

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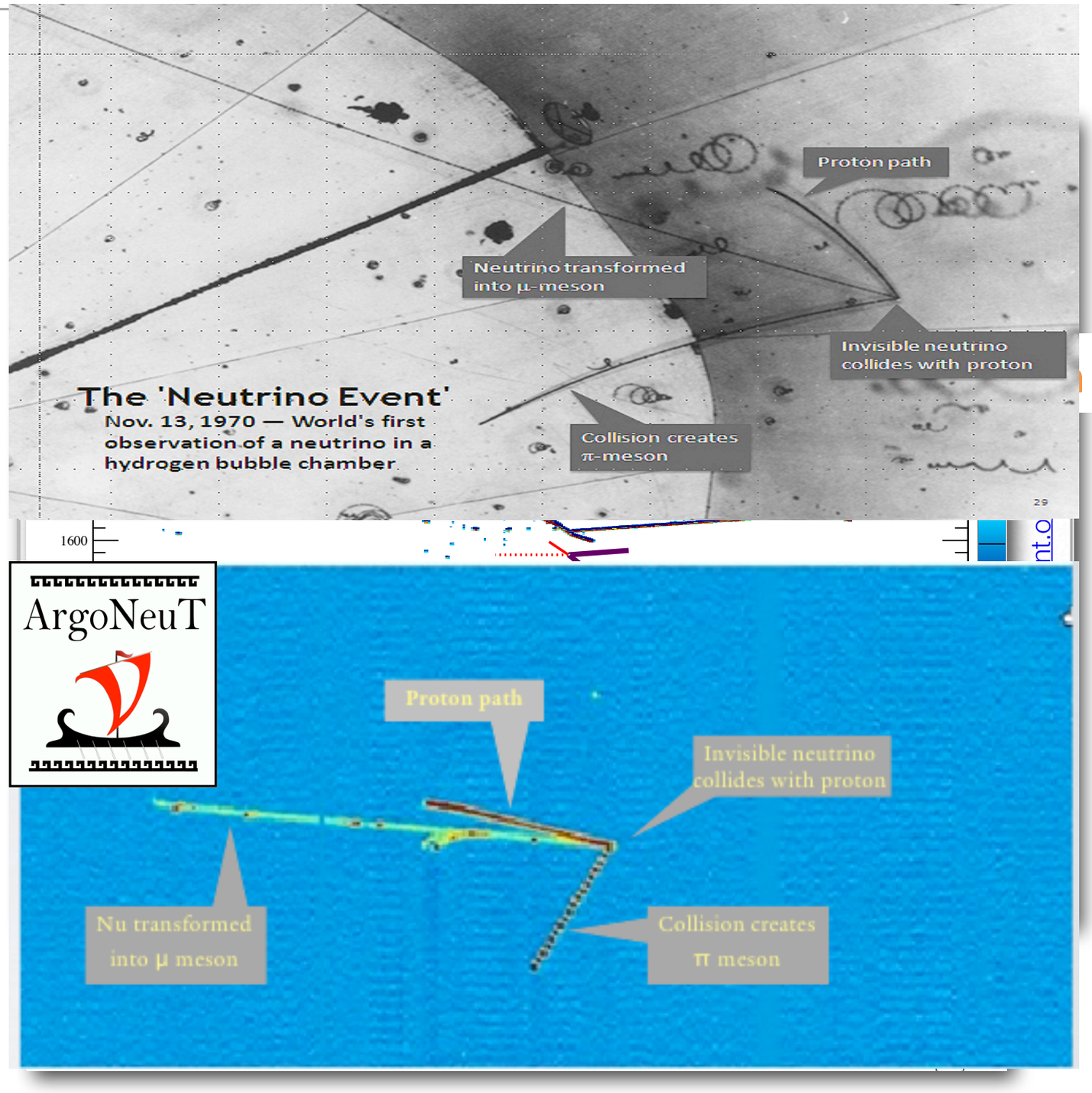
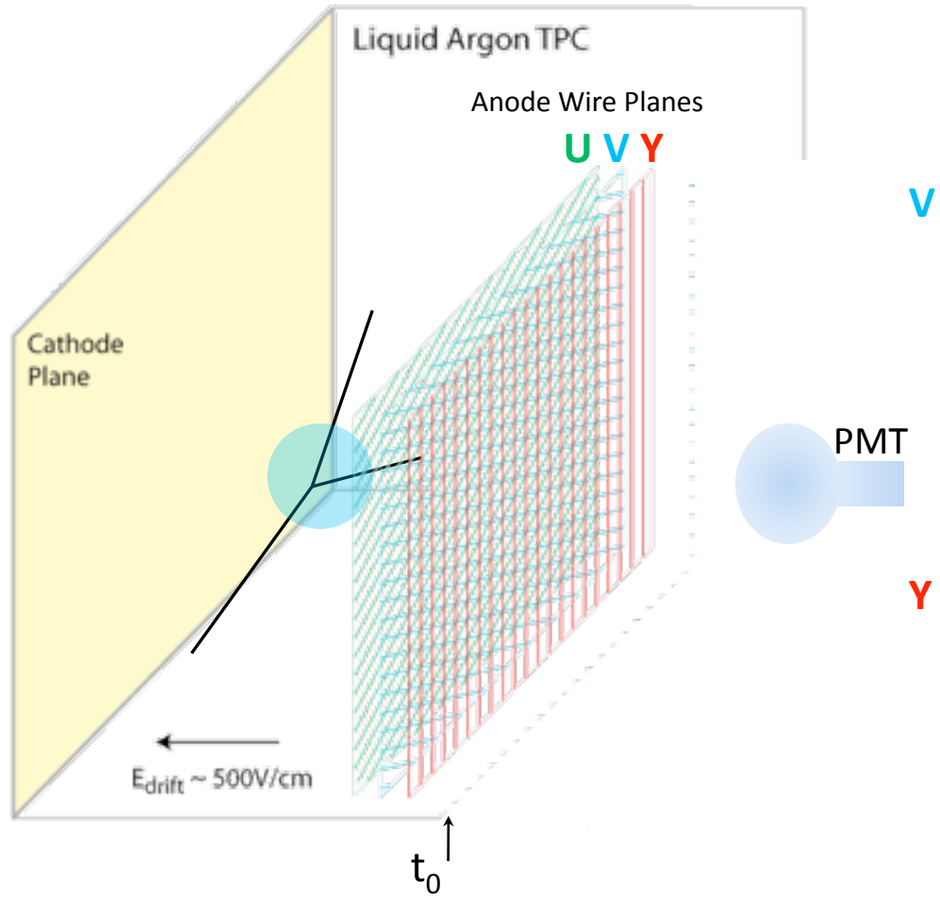


Requirements for a TPC (some technical challenges)



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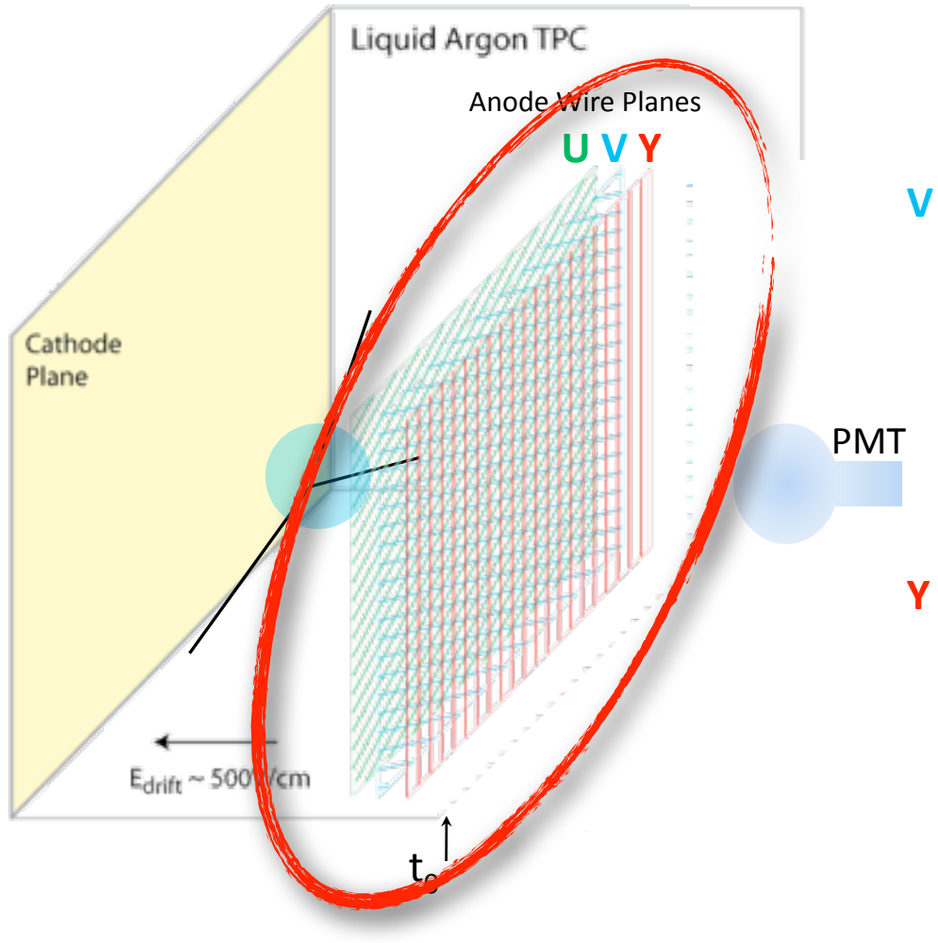

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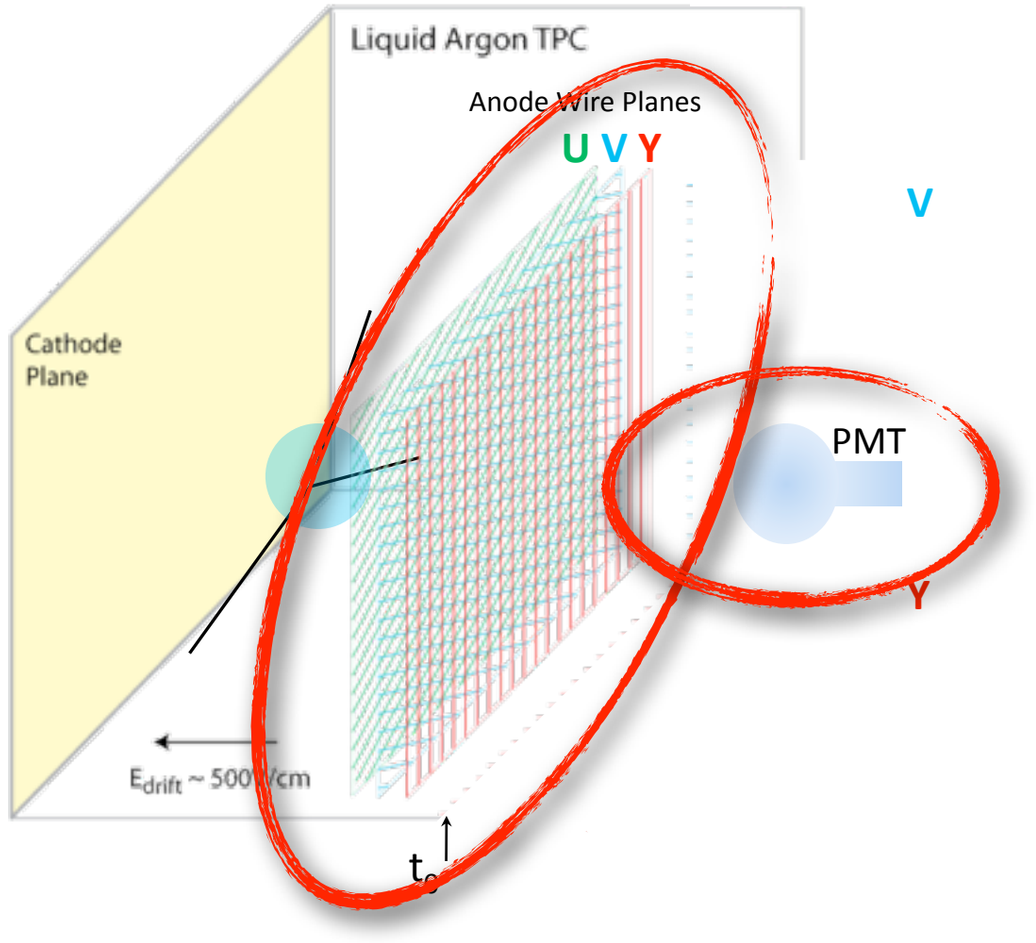

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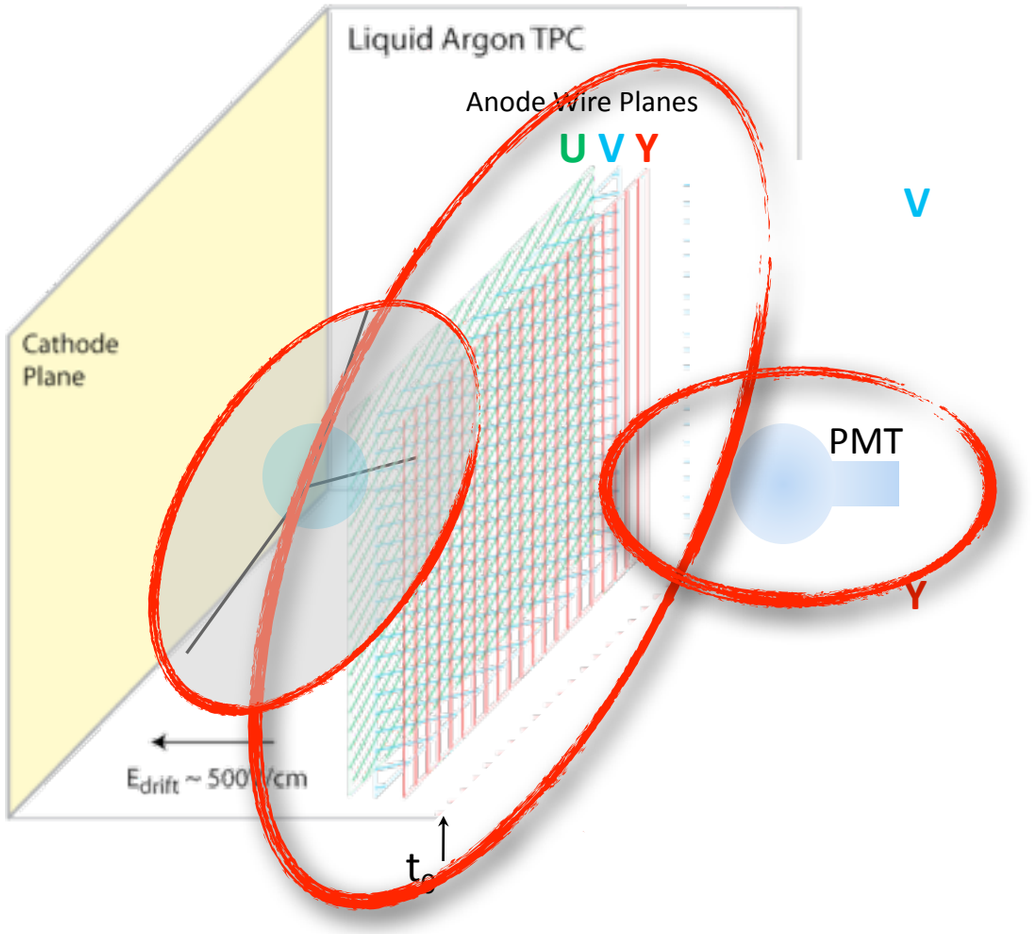

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  - More fiducial space --> greater $V_{cathode}$ to maintain electric field
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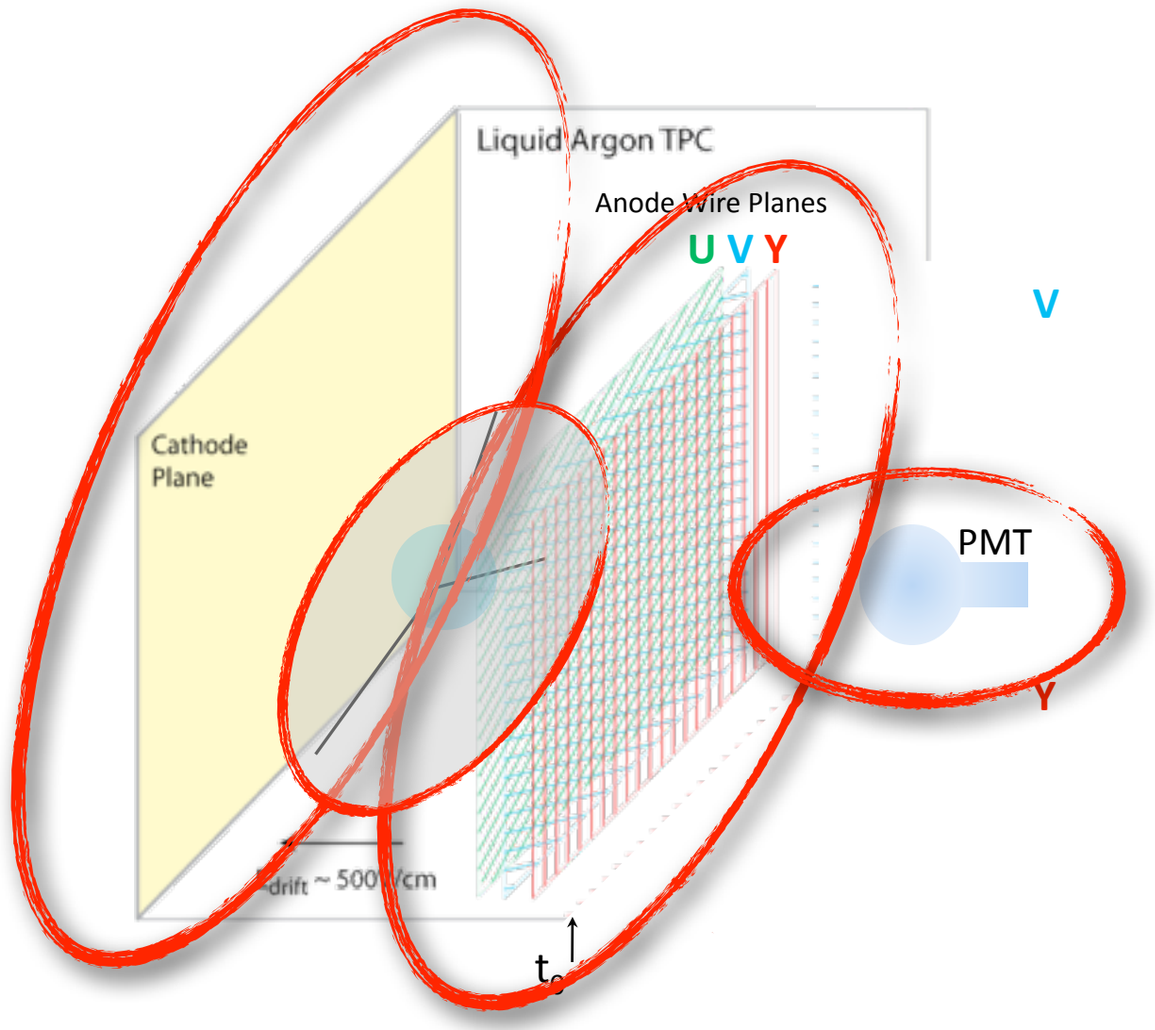

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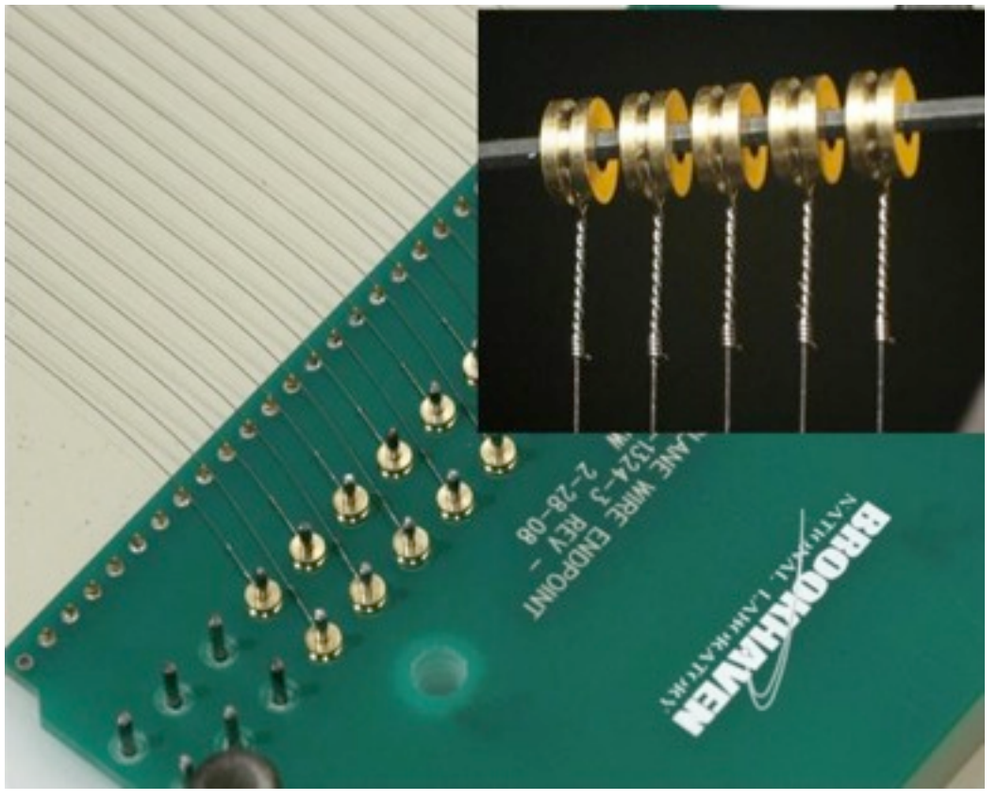

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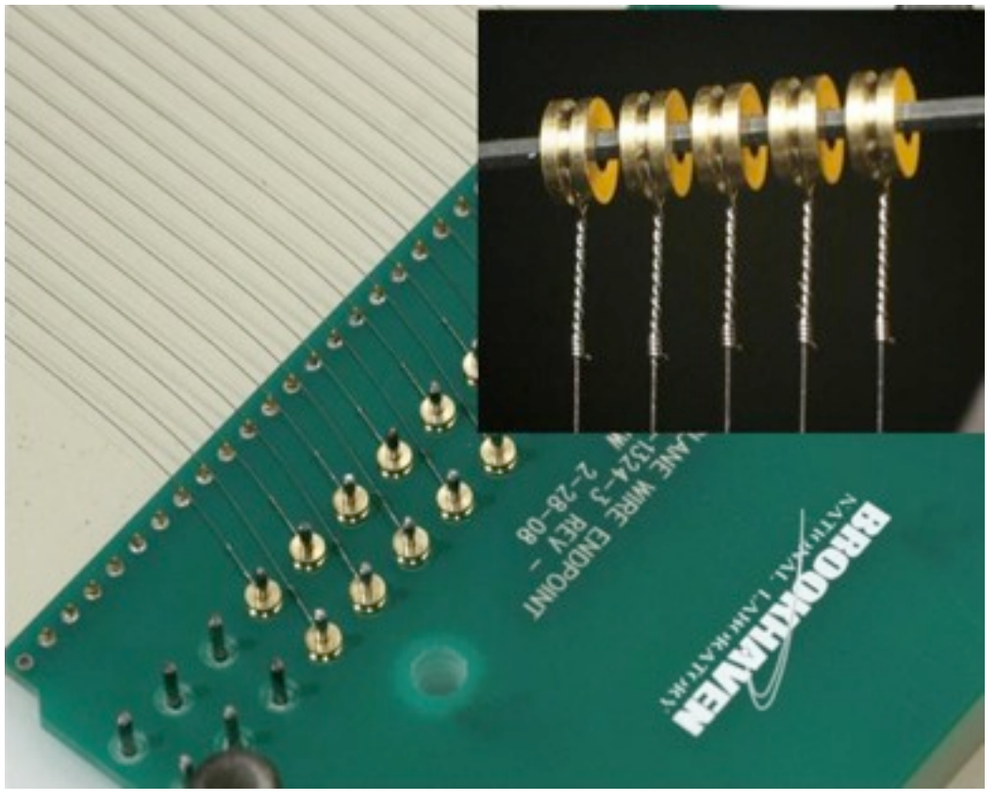
- Wires are 150 μm stainless with 2 μm thick copper plating with a thin flash of gold
  - The 150 μm is large enough to withstand the tension; the copper reduces the resistance, and the gold prevents copper oxidation
  - Similar coefficient of thermal expansion to the anode frame -- reduces change in T



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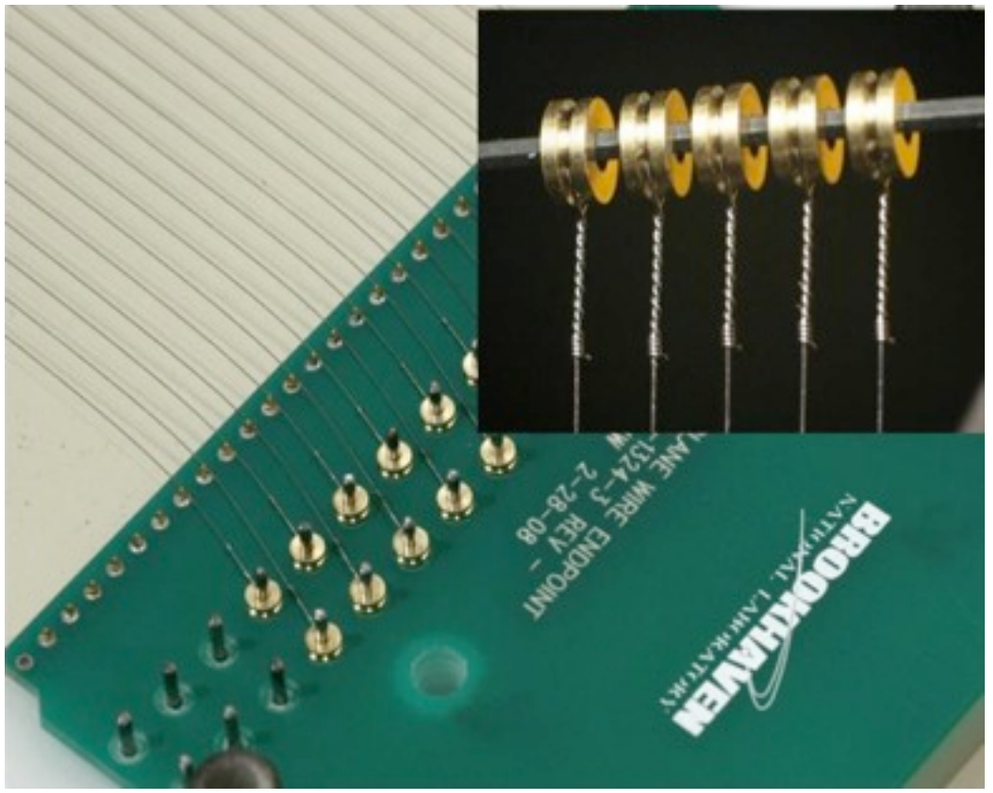

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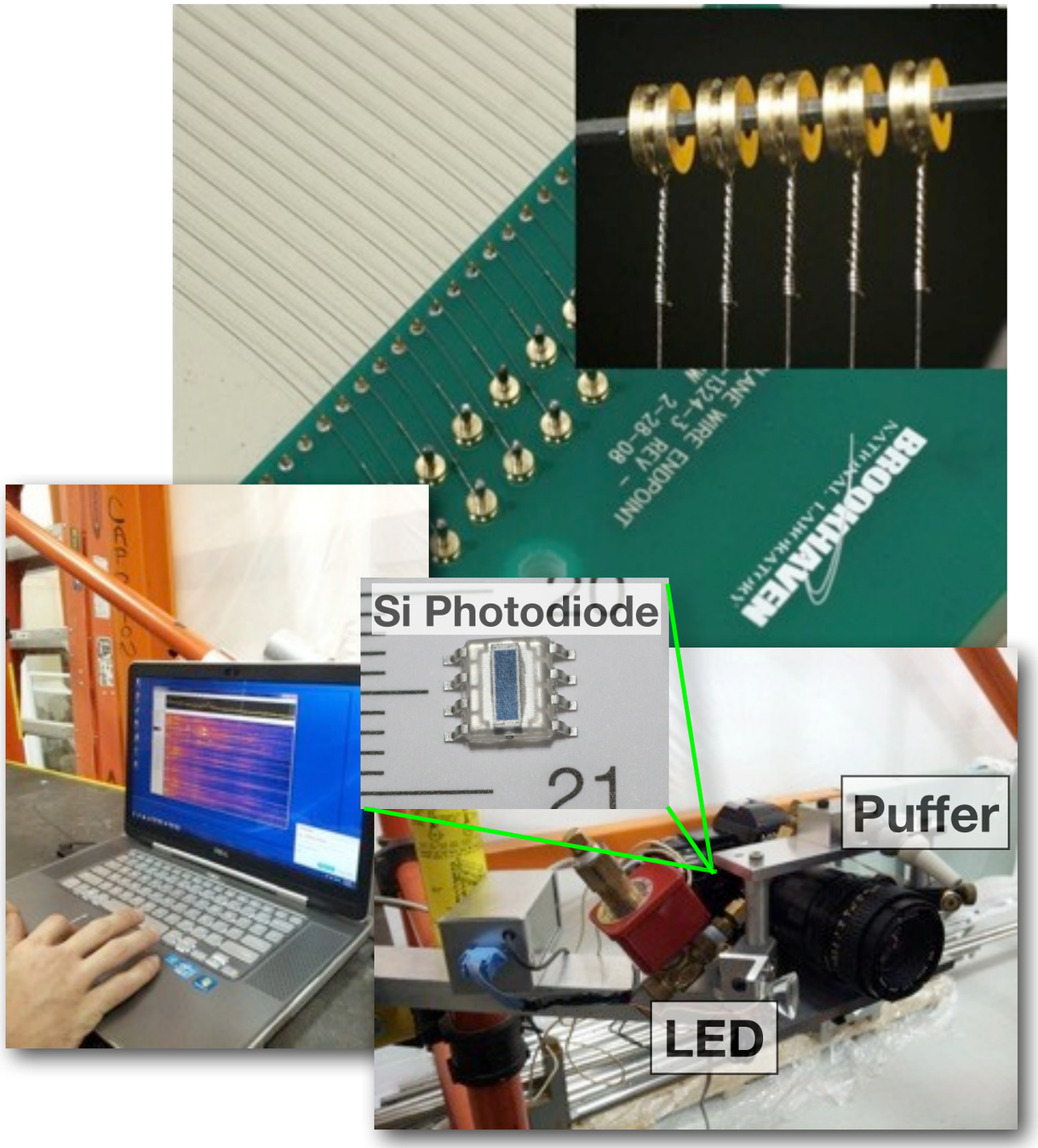
  - to prevent wire sag greater than 0.5 mm (for any 5 m long wire), and
  - to prevent wire breakage during cool down



Wire Planes: Prototype Winding Machine

- Movie in B. Yu's talk docdb 1532

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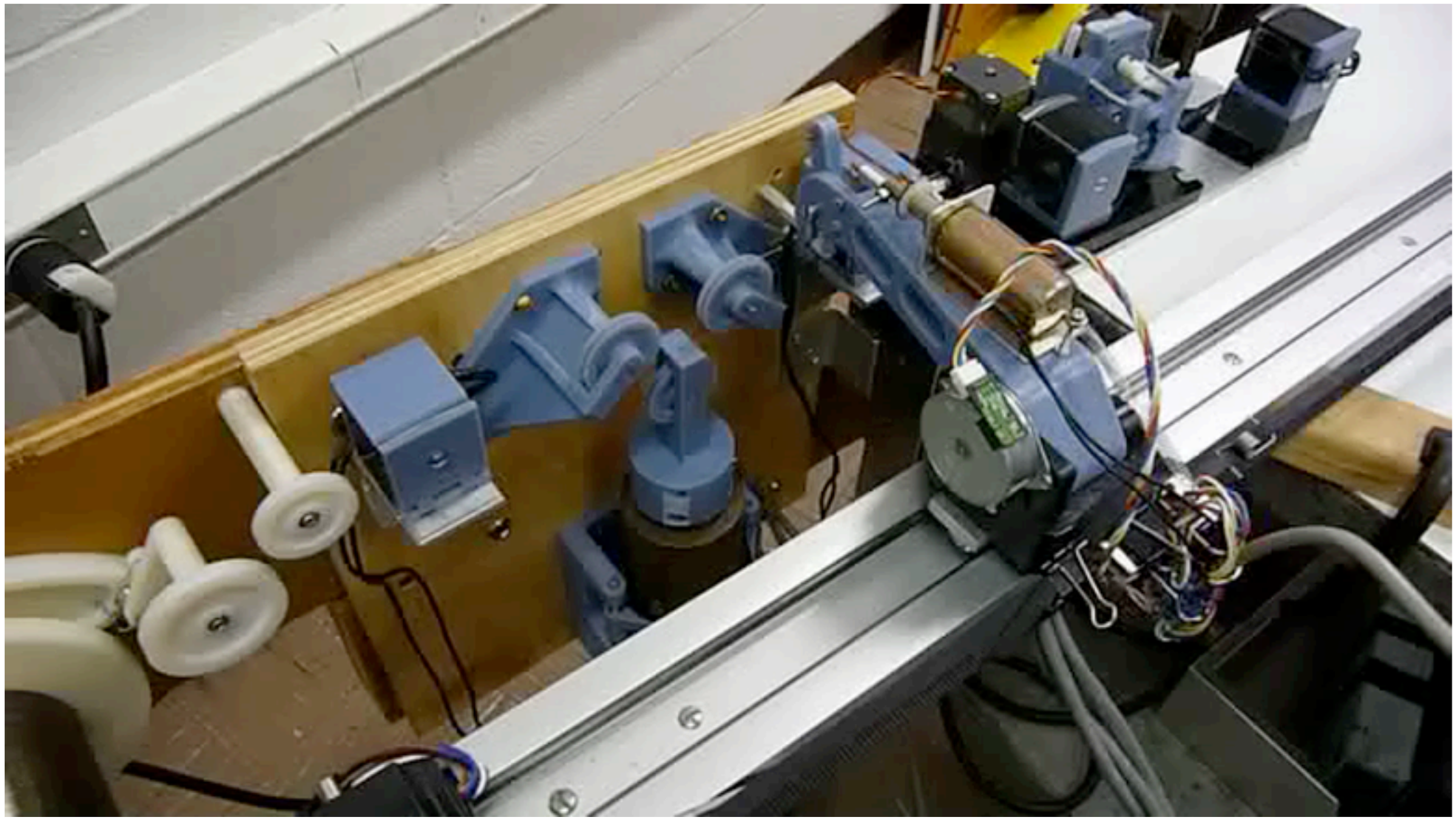

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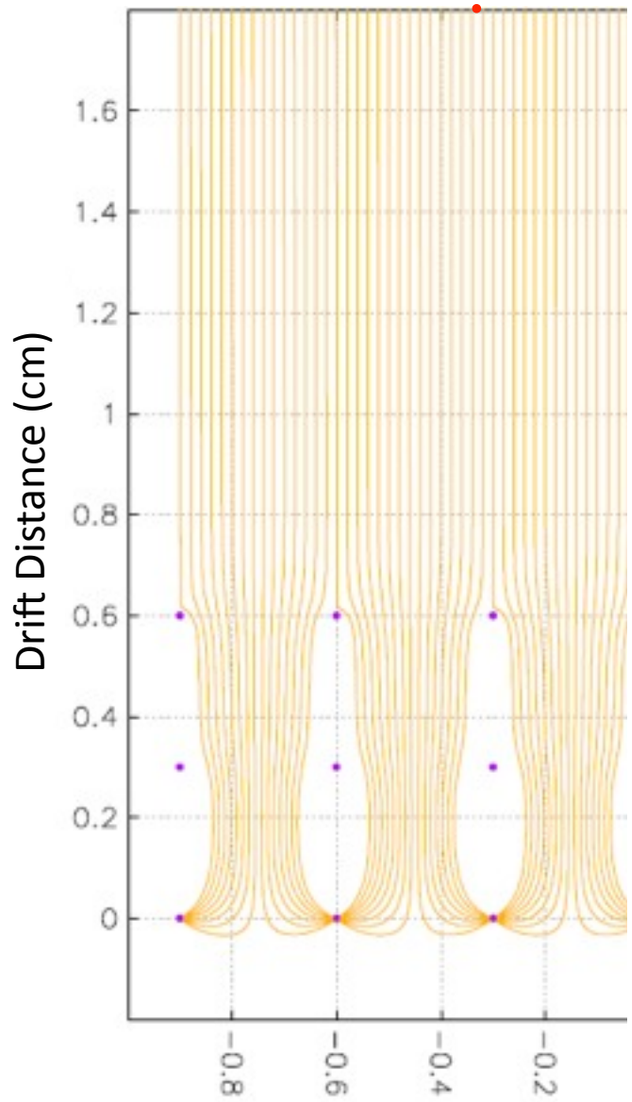
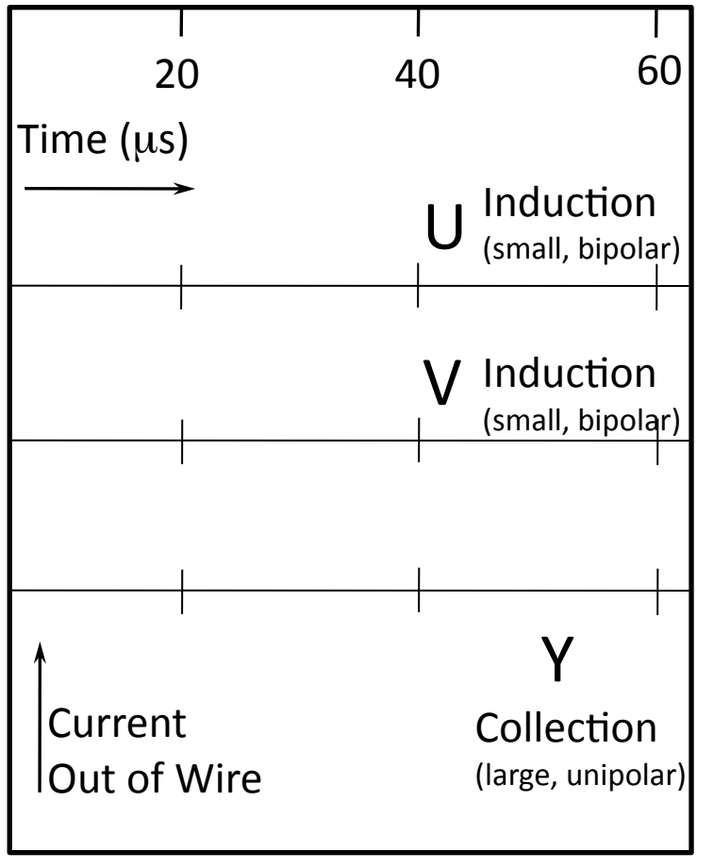


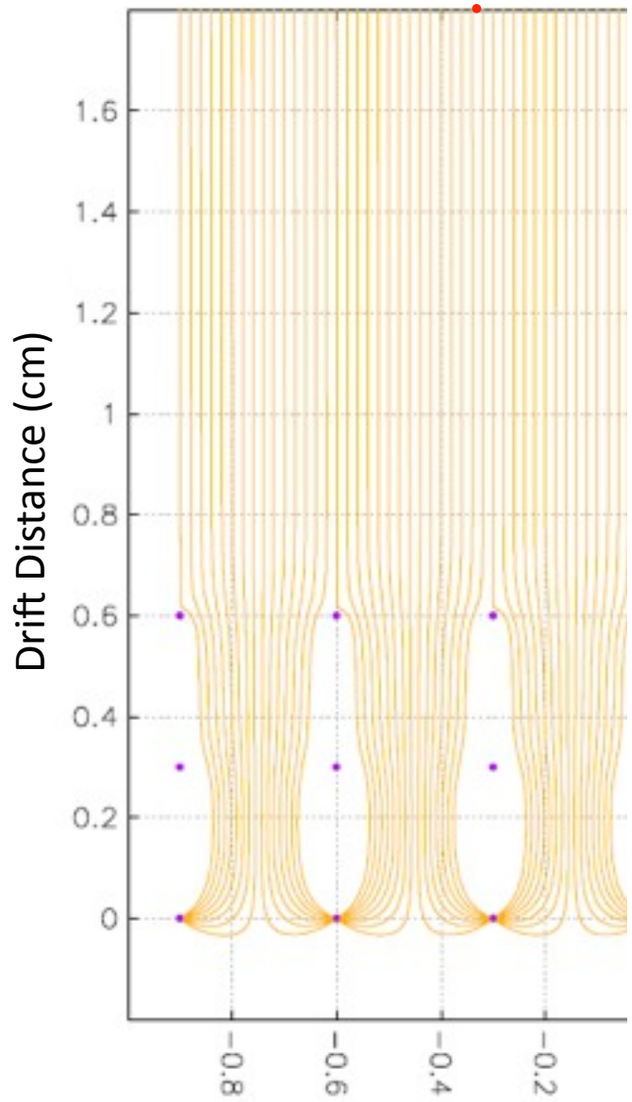


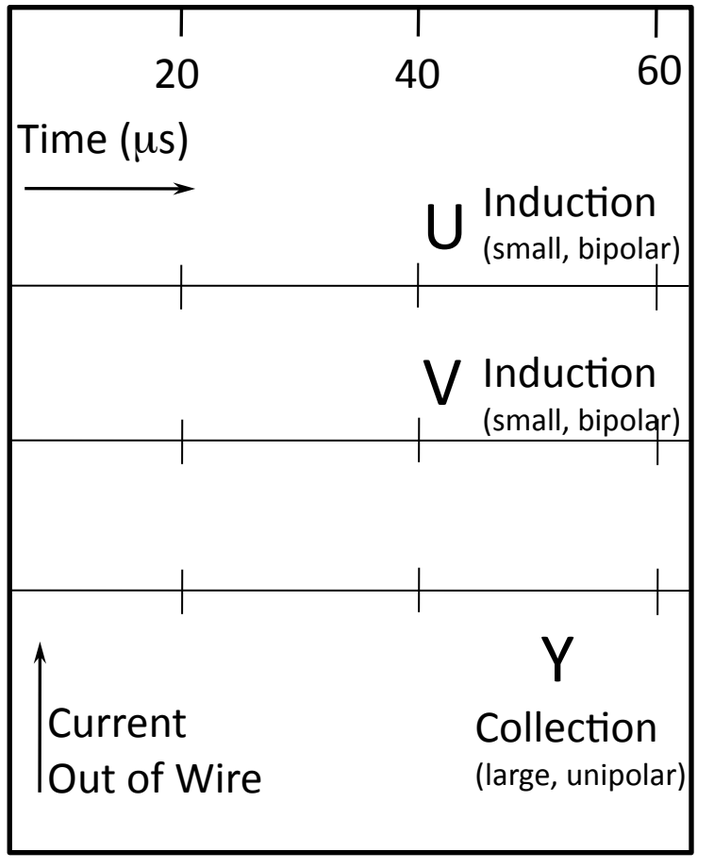
Stolen from Craig

Further details in B. Yu DocDb 1634

Wire Planes

- U & V Planes are induction sense wires (bipolar signal as the electrons pass by)





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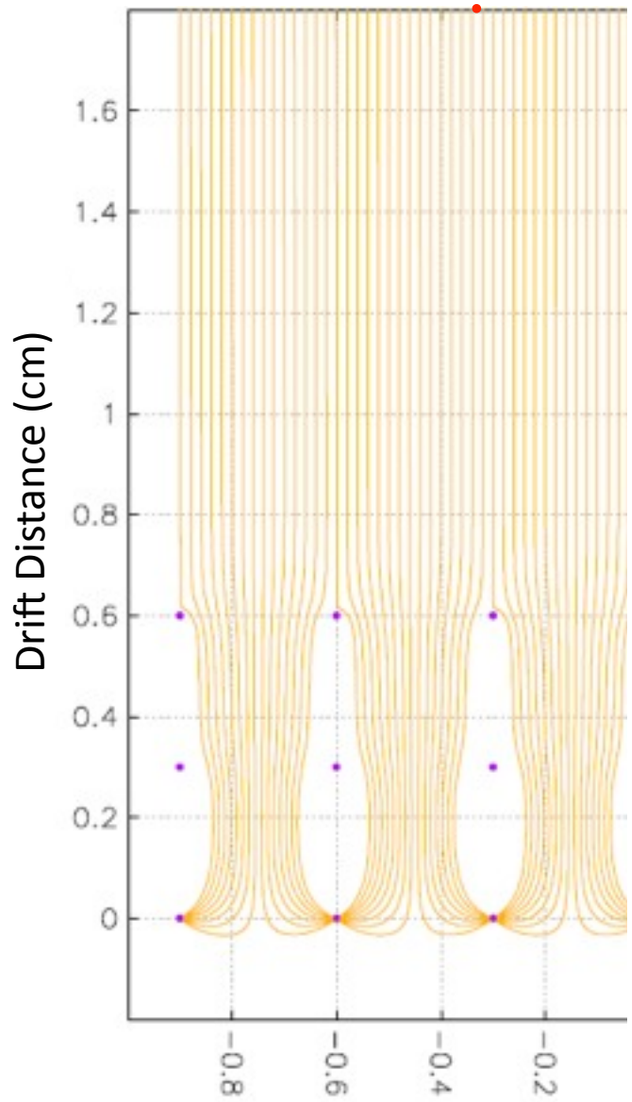

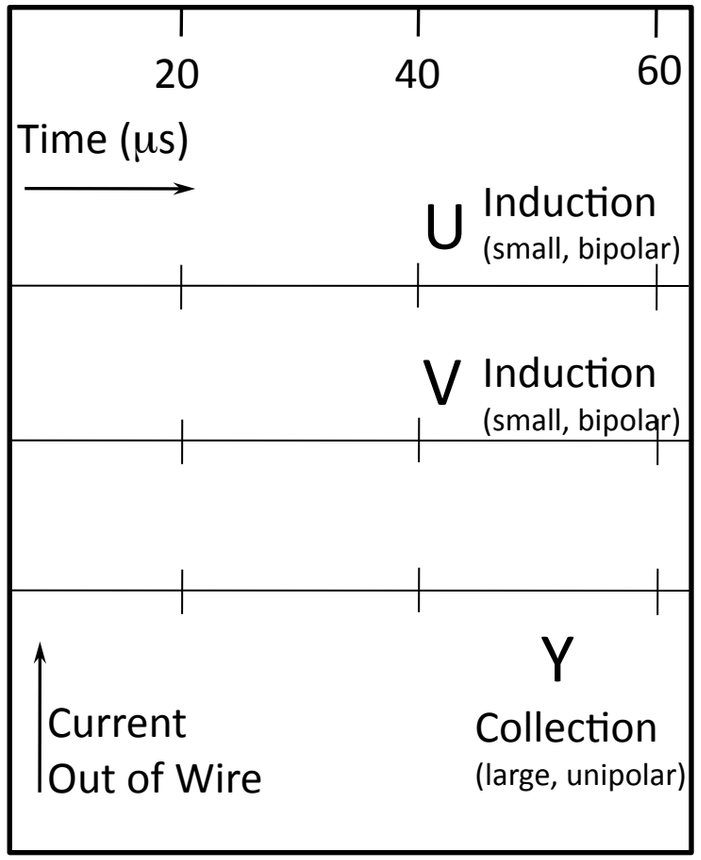

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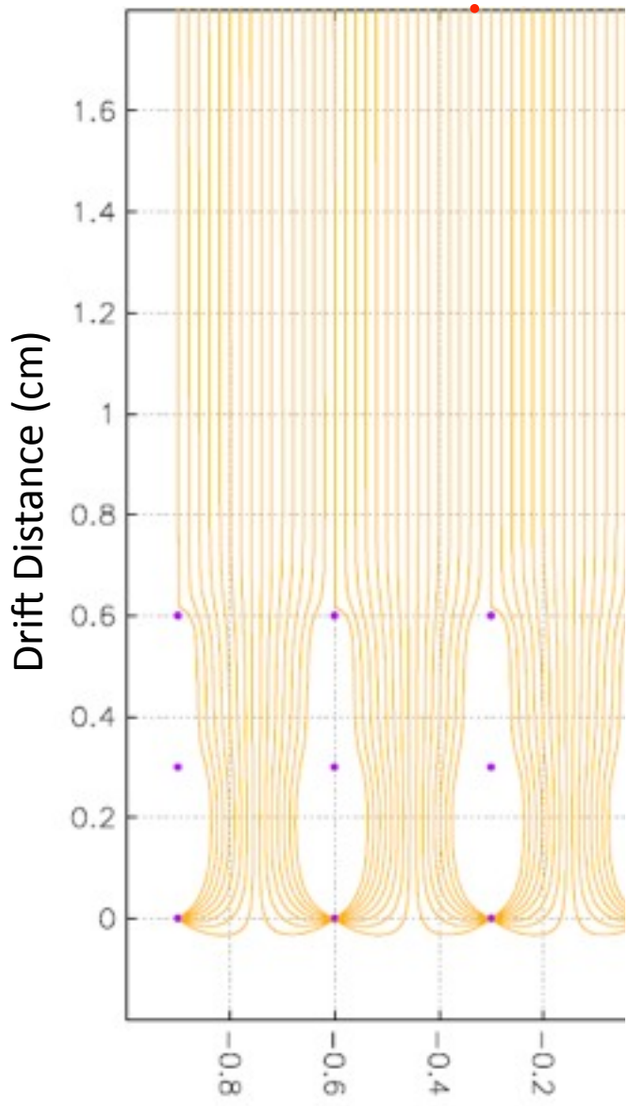

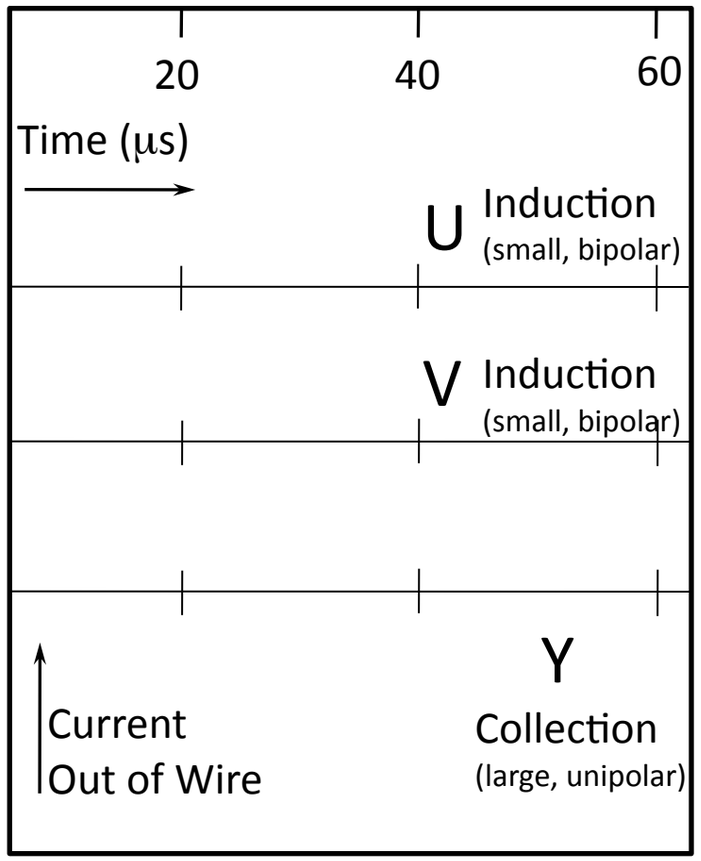

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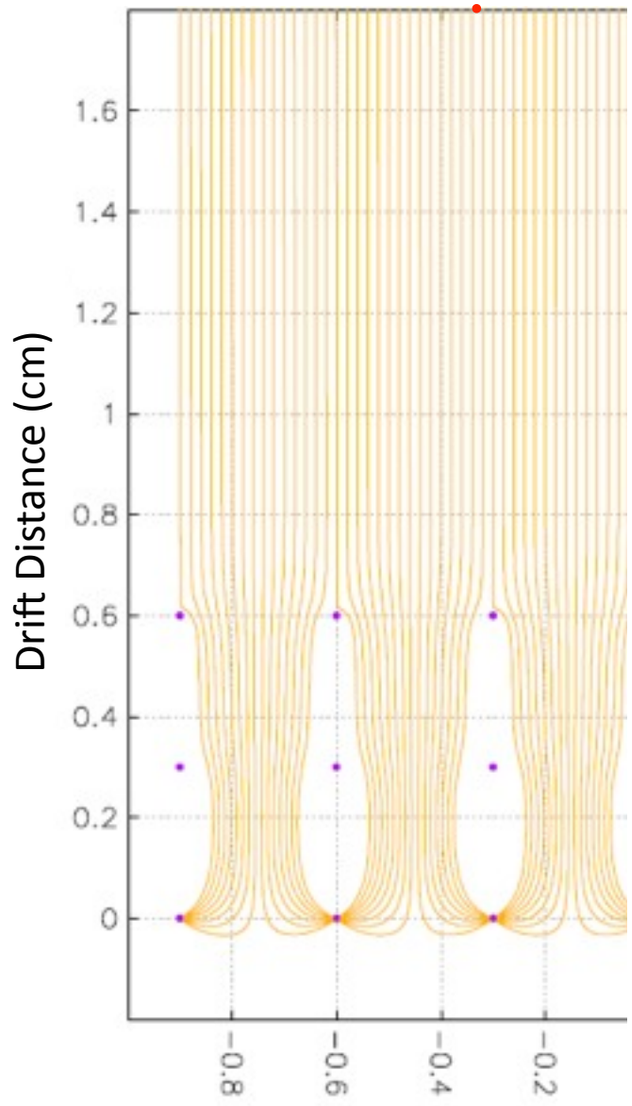

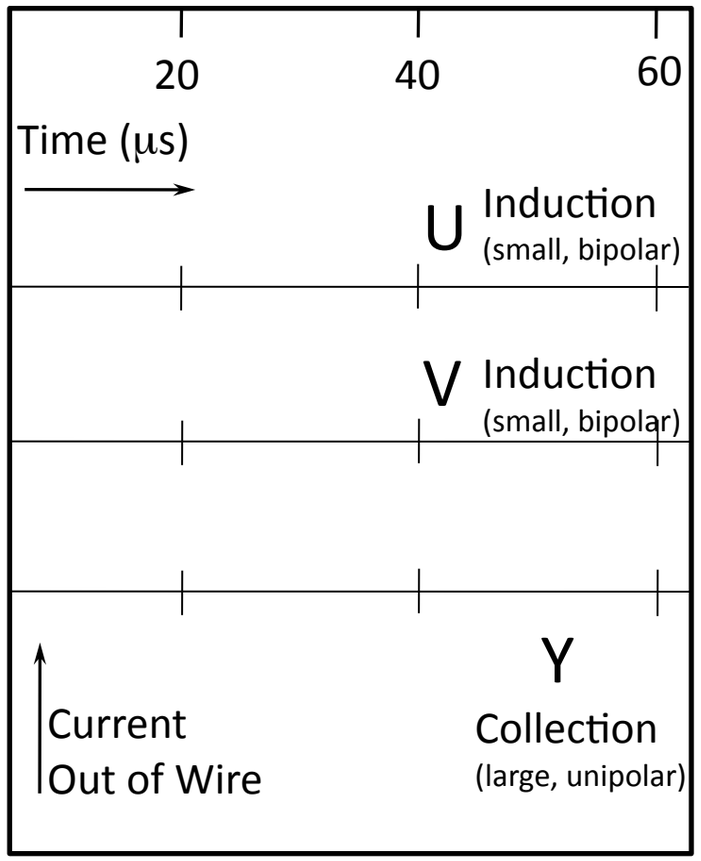

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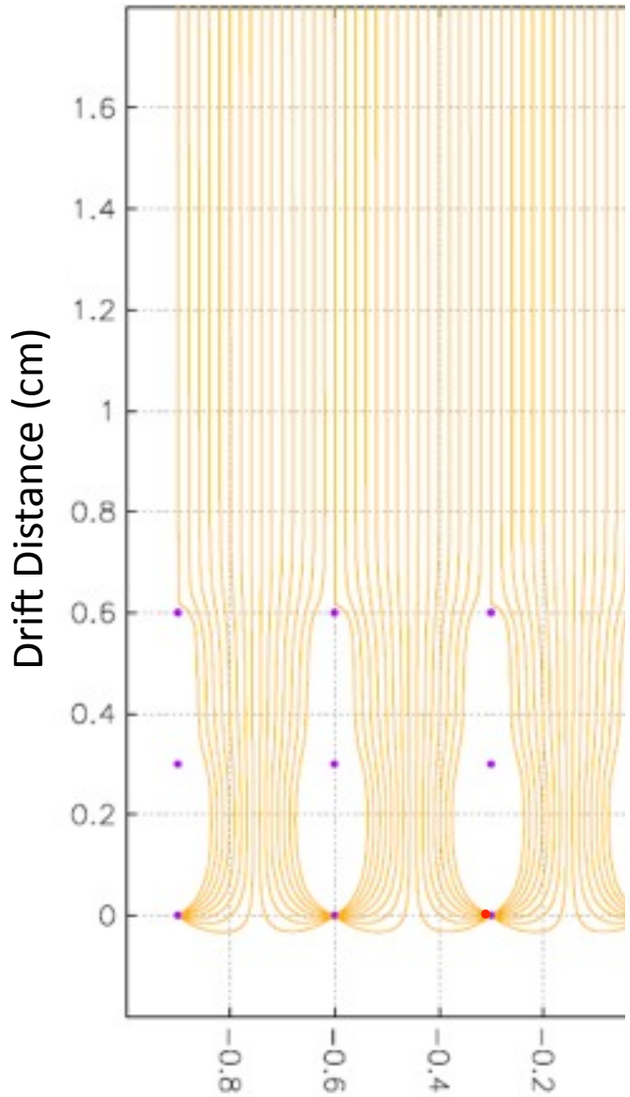

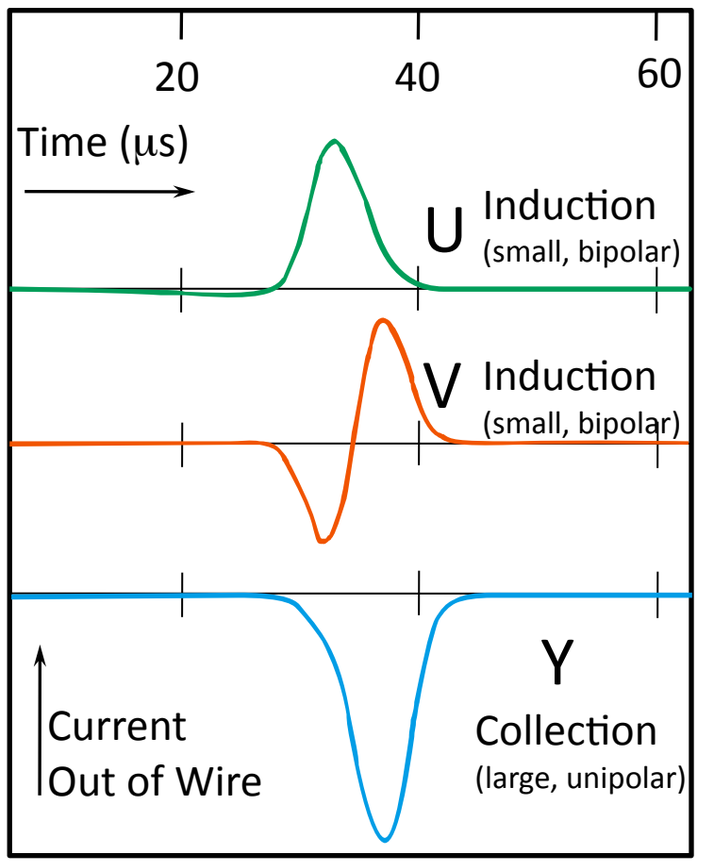

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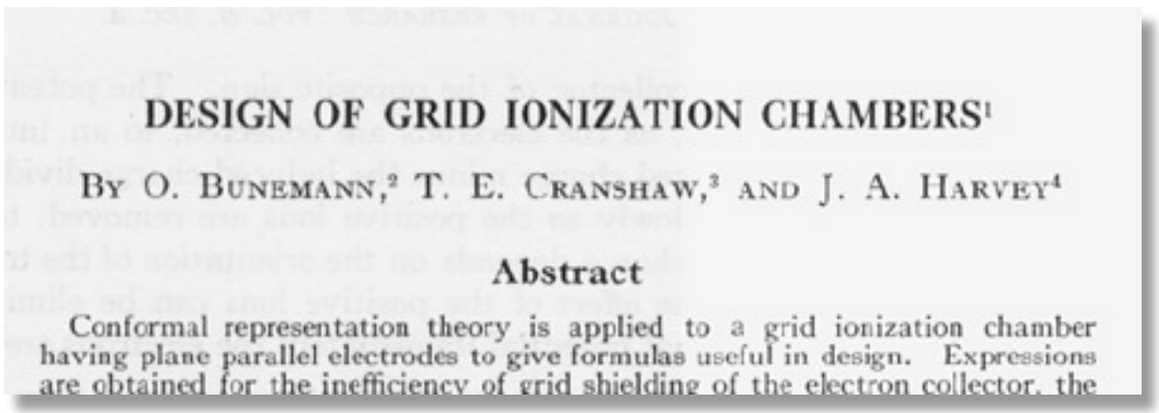


DESIGN OF GRID IONIZATION CHAMBERS[1]

By O. Bunemann,[2] T. E. Cranshaw,[3] and J. A. Harvey[4]

Abstract

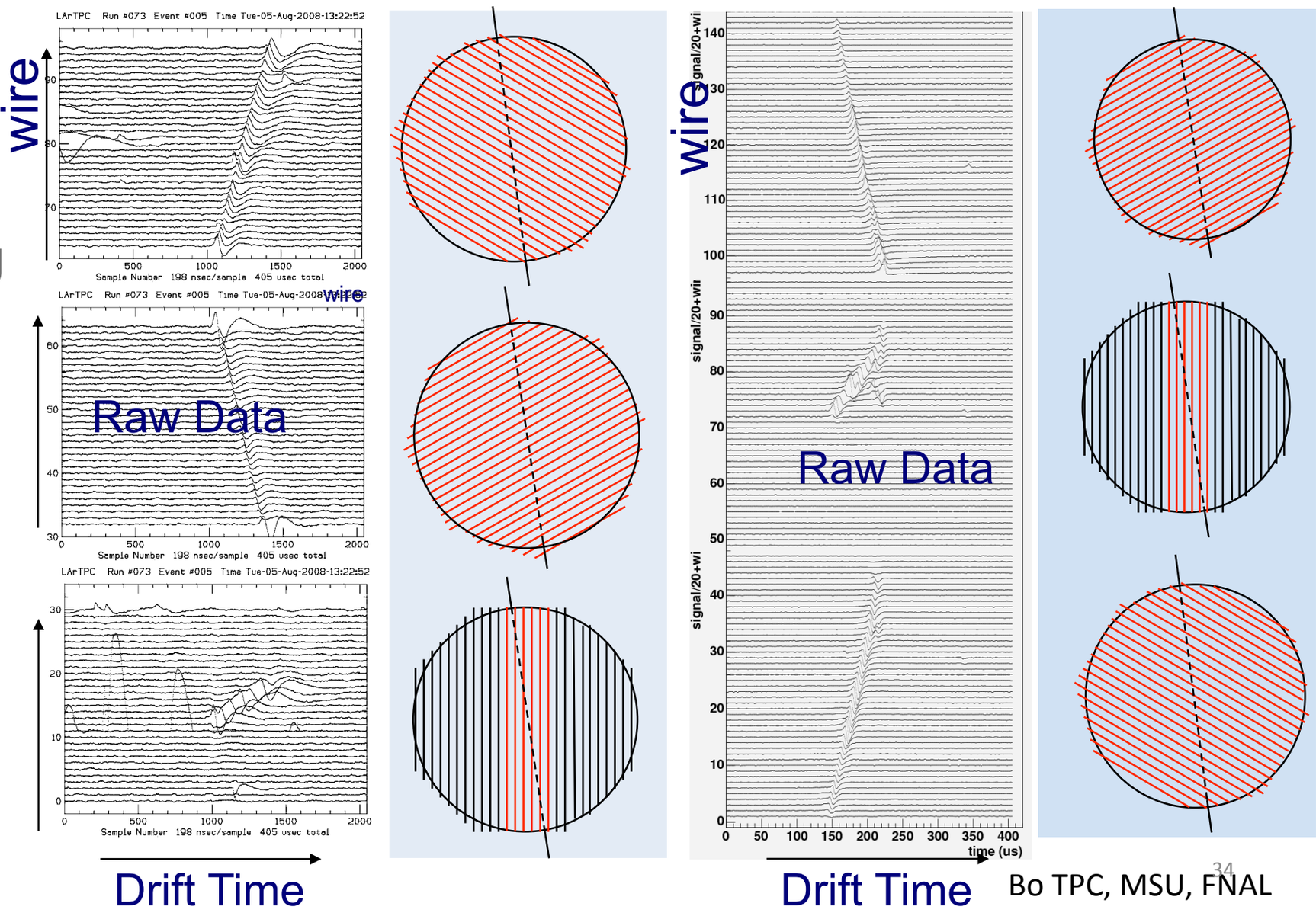
Conformal representation theory is applied to a grid ionization chamber having plane parallel electrodes to give formulas useful in design. Expressions are obtained for the inefficiency of grid shielding of the electron collector, the

Also described in Blum & Rolandi. *Particle Detection with Drift Chambers.* pp108-112.

Further details in B. Yu DocDb 1634

One Slide on Electronics

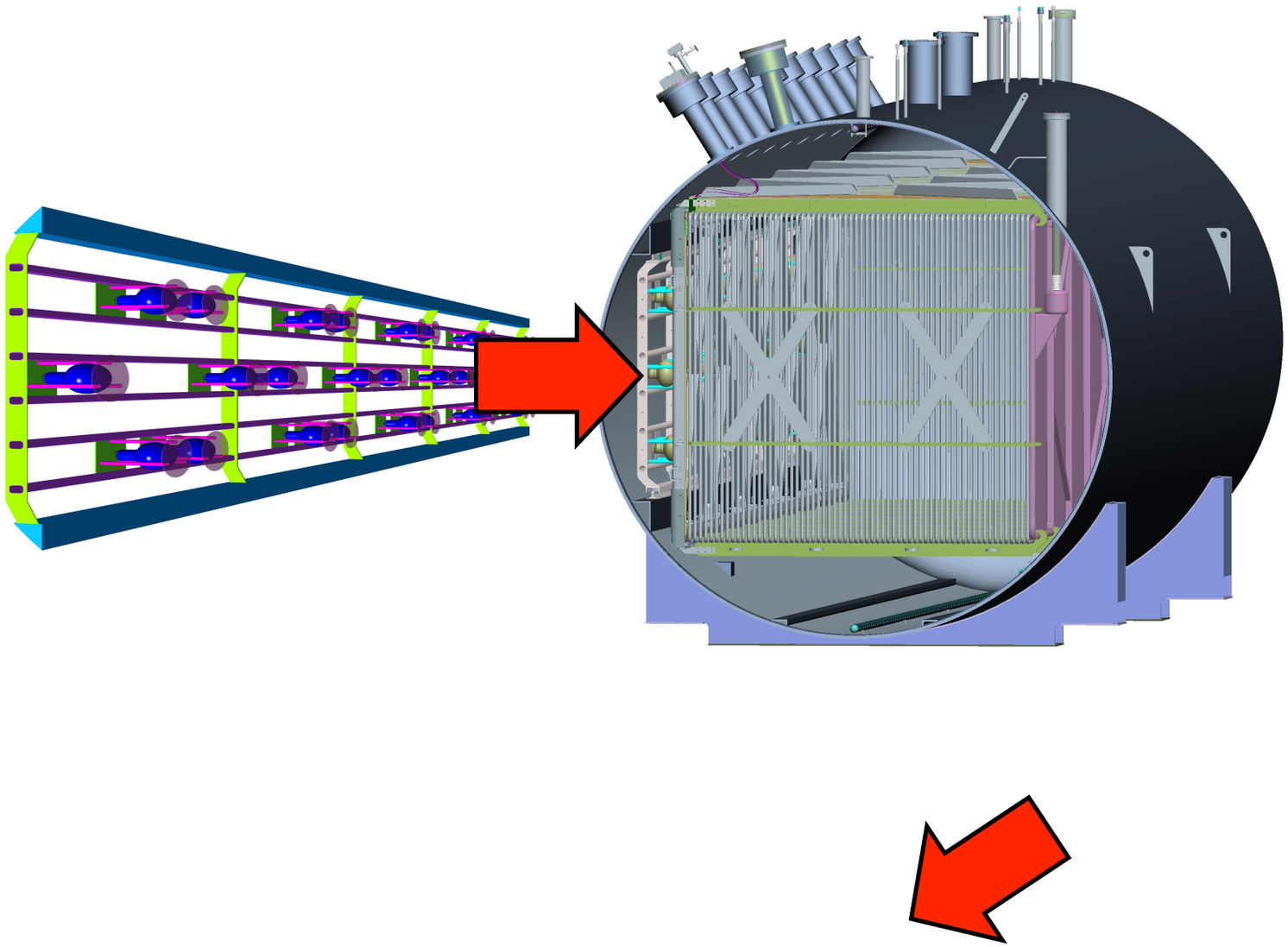
- The wires have to be read out
- I'm not going to go into depth on this or anything down stream (DAQ etc)
- A note, the motherboards can go in the argon
  - Less noise --> Better S/N!



Bo TPC, MSU, FNAL

Slide from T. Yang

Timing Information



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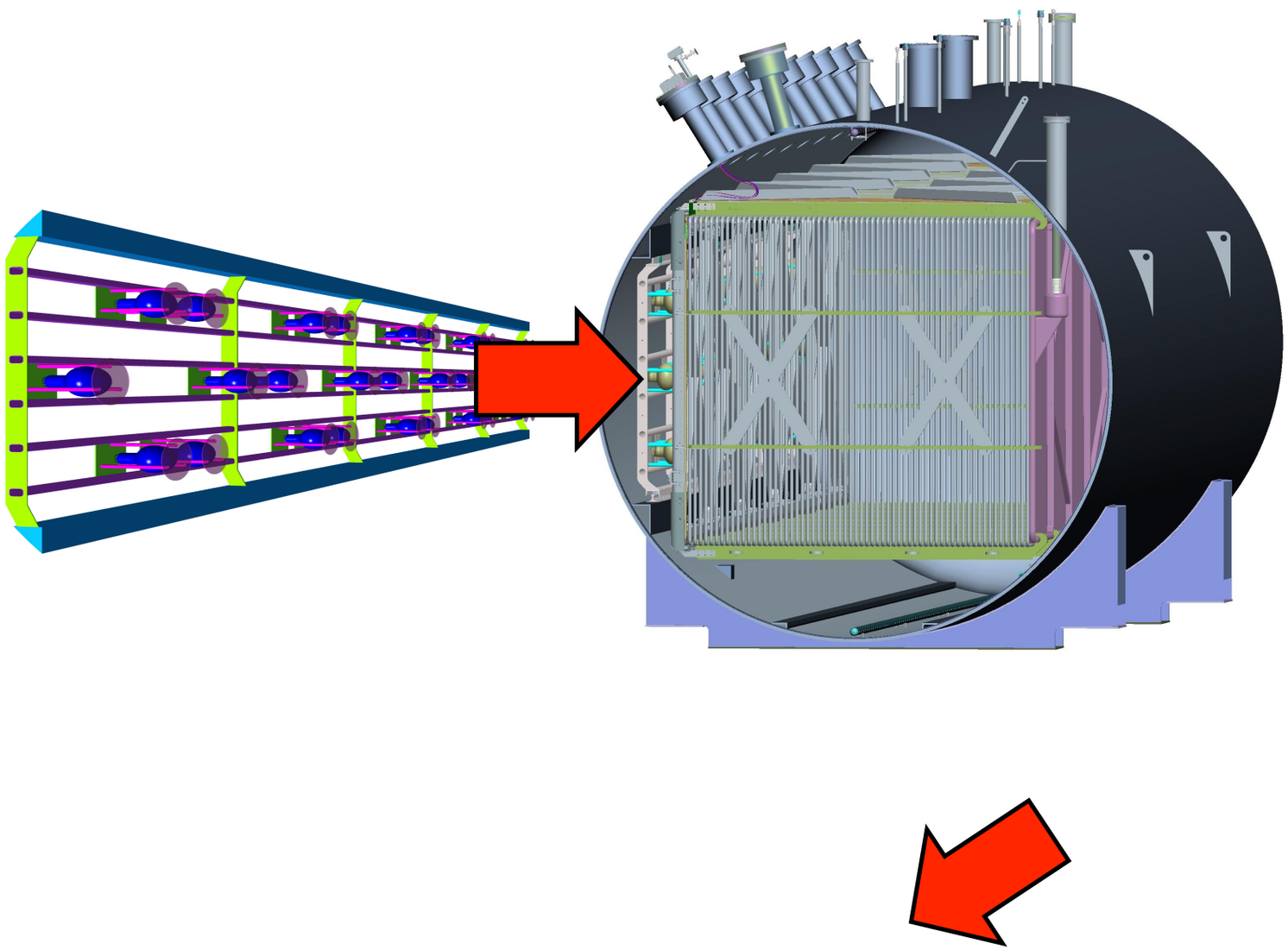

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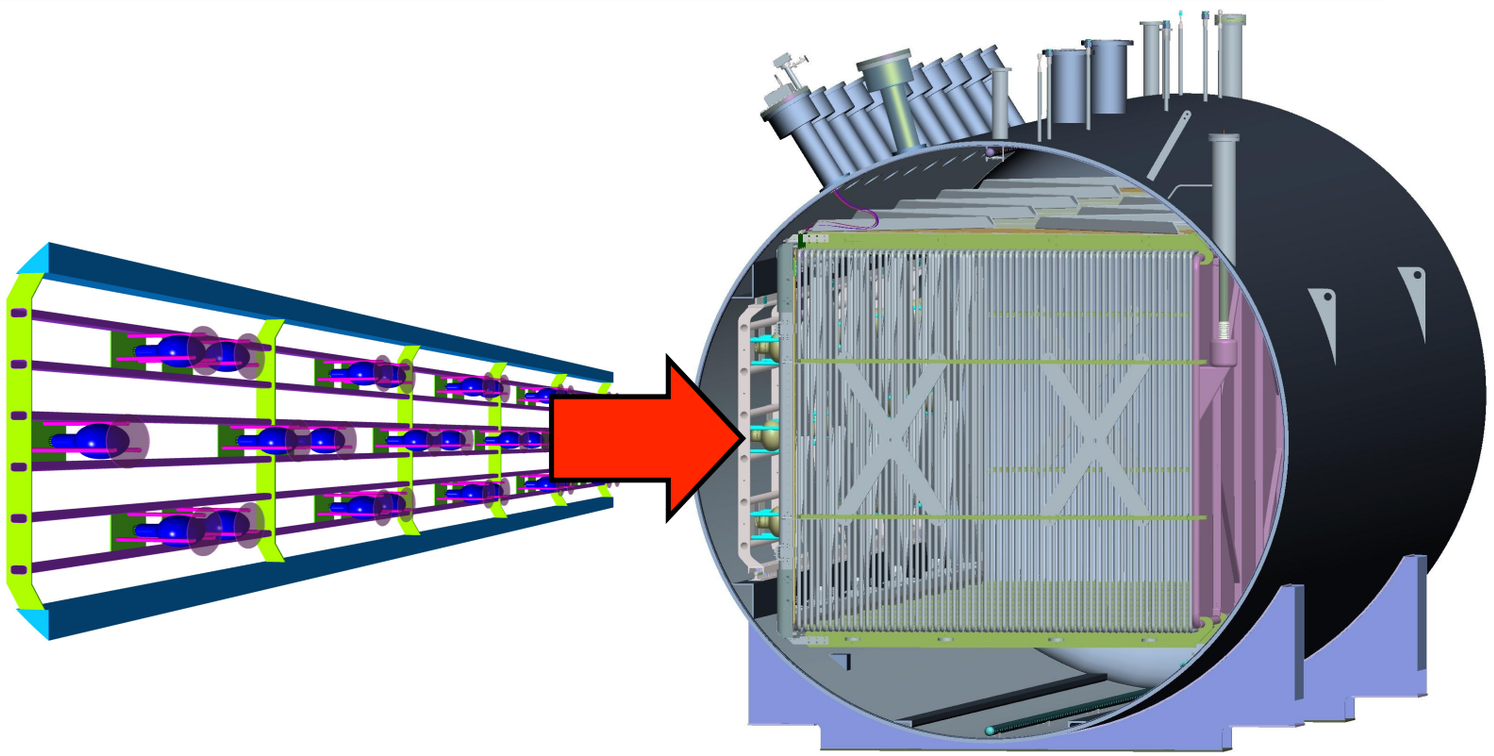

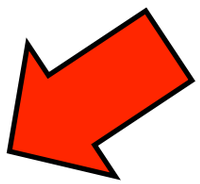

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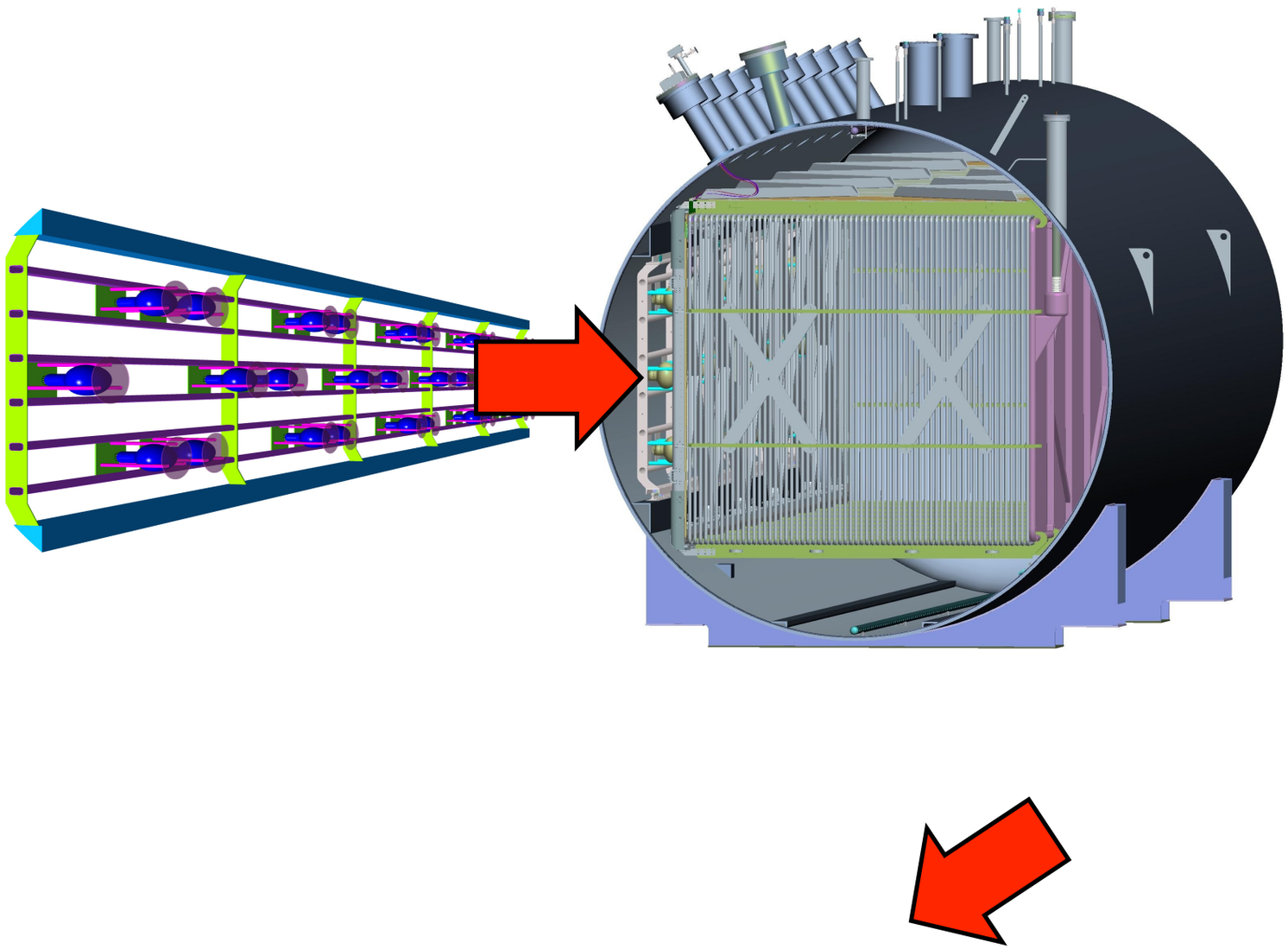

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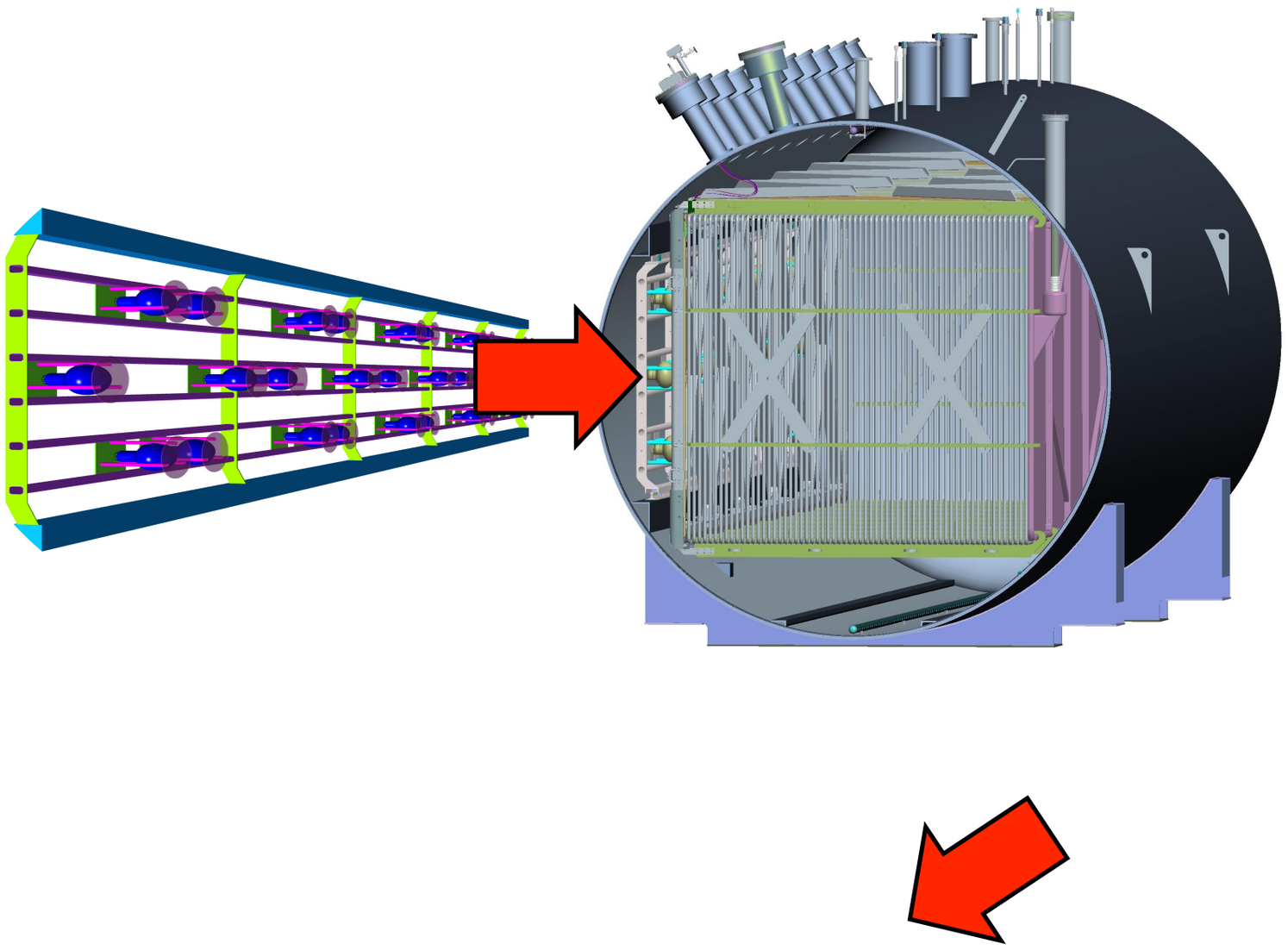

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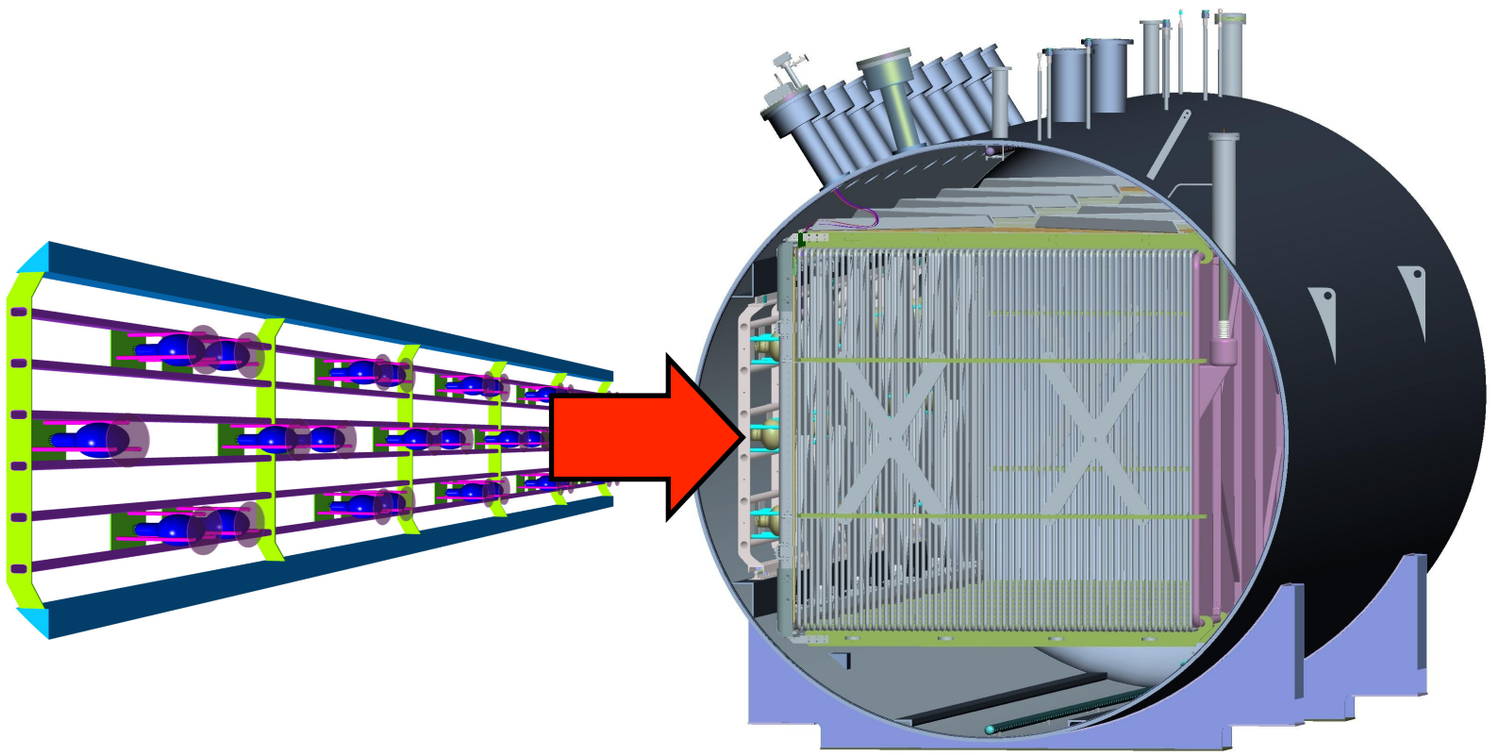

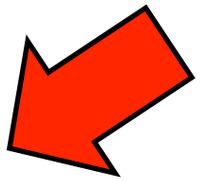

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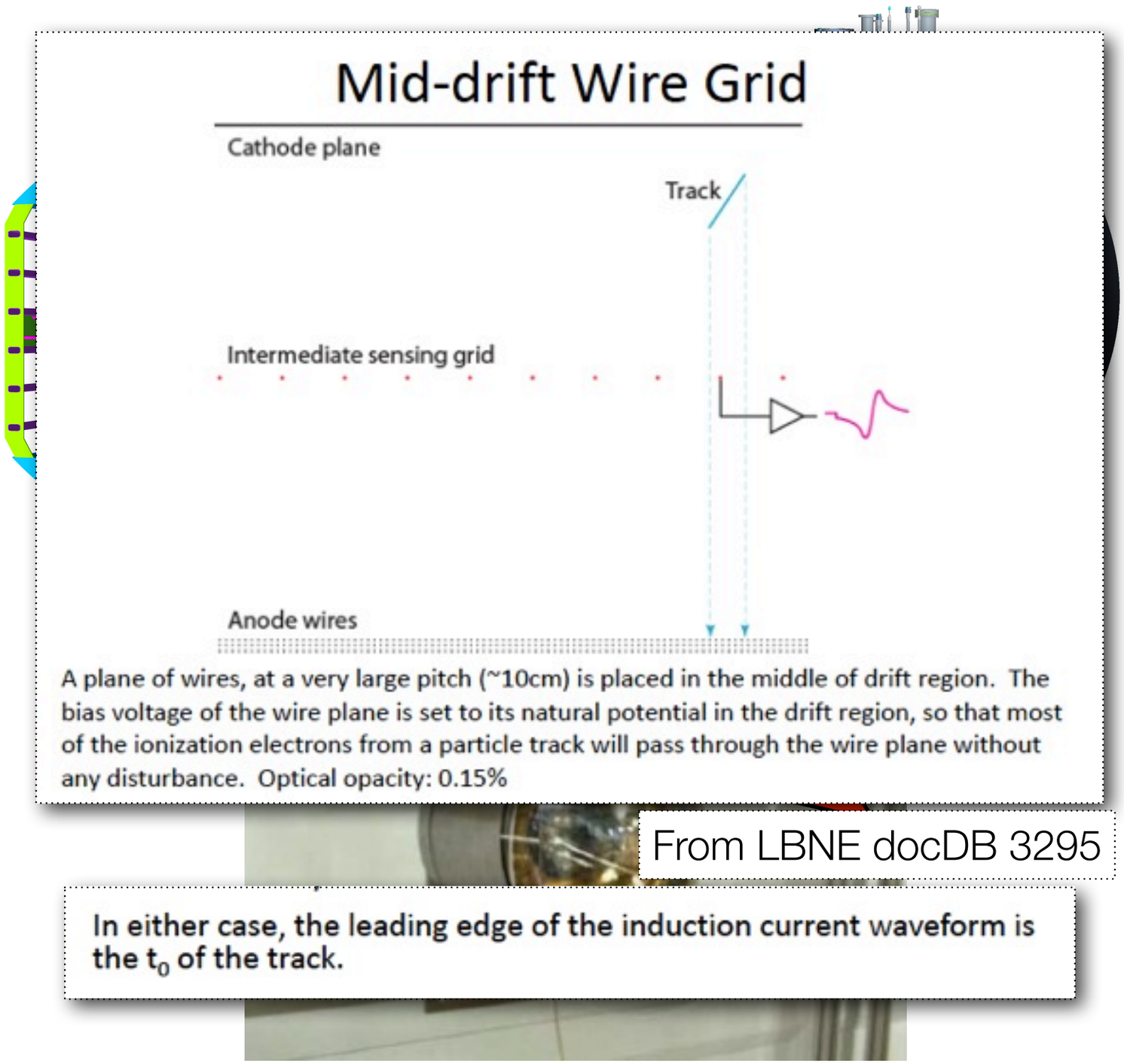

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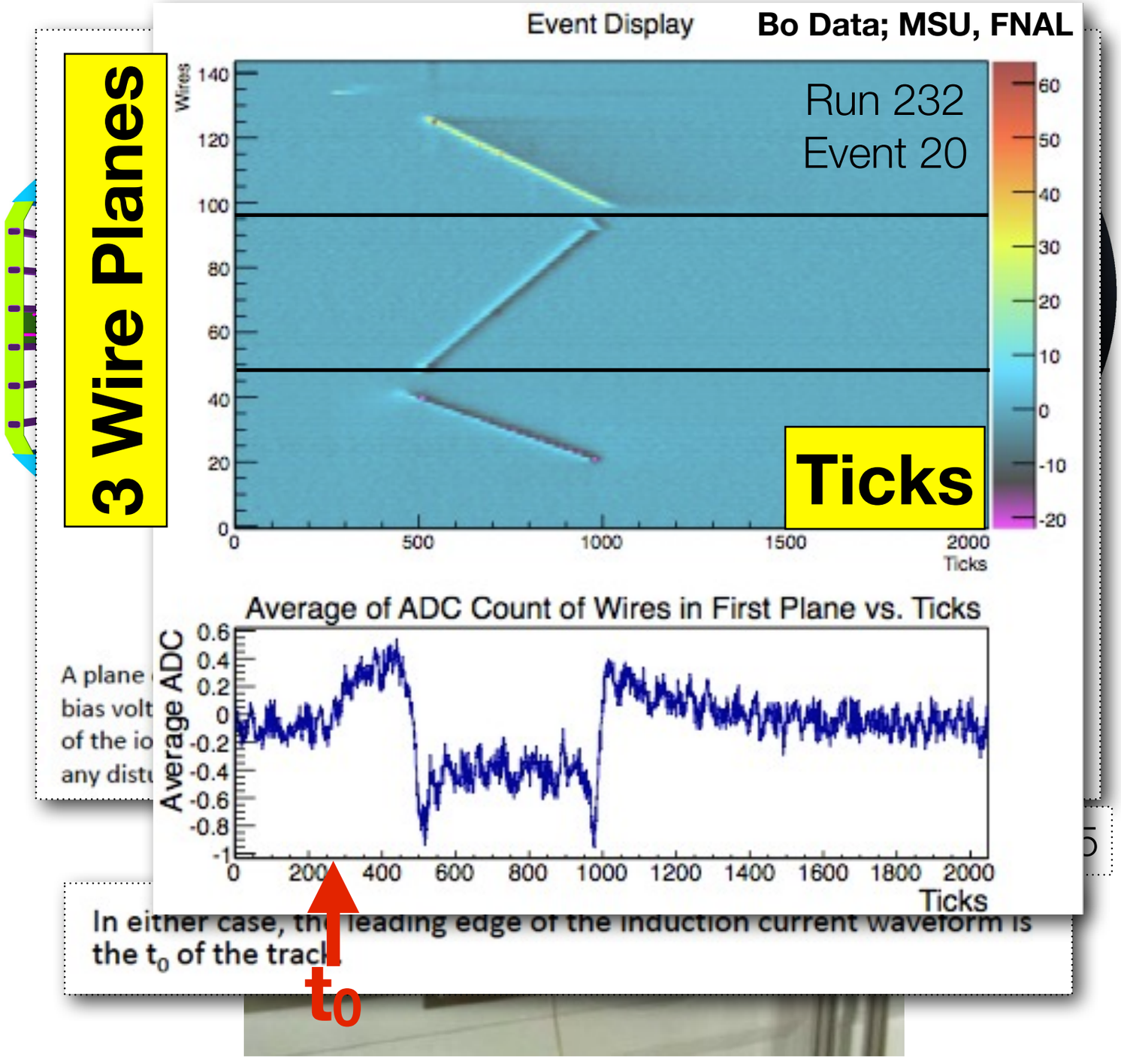
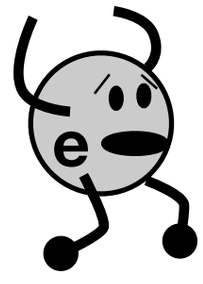


LAr Purity

(Electro-negative impurities diminish (eat) our signal; Nitrogen quenches scintillation light)



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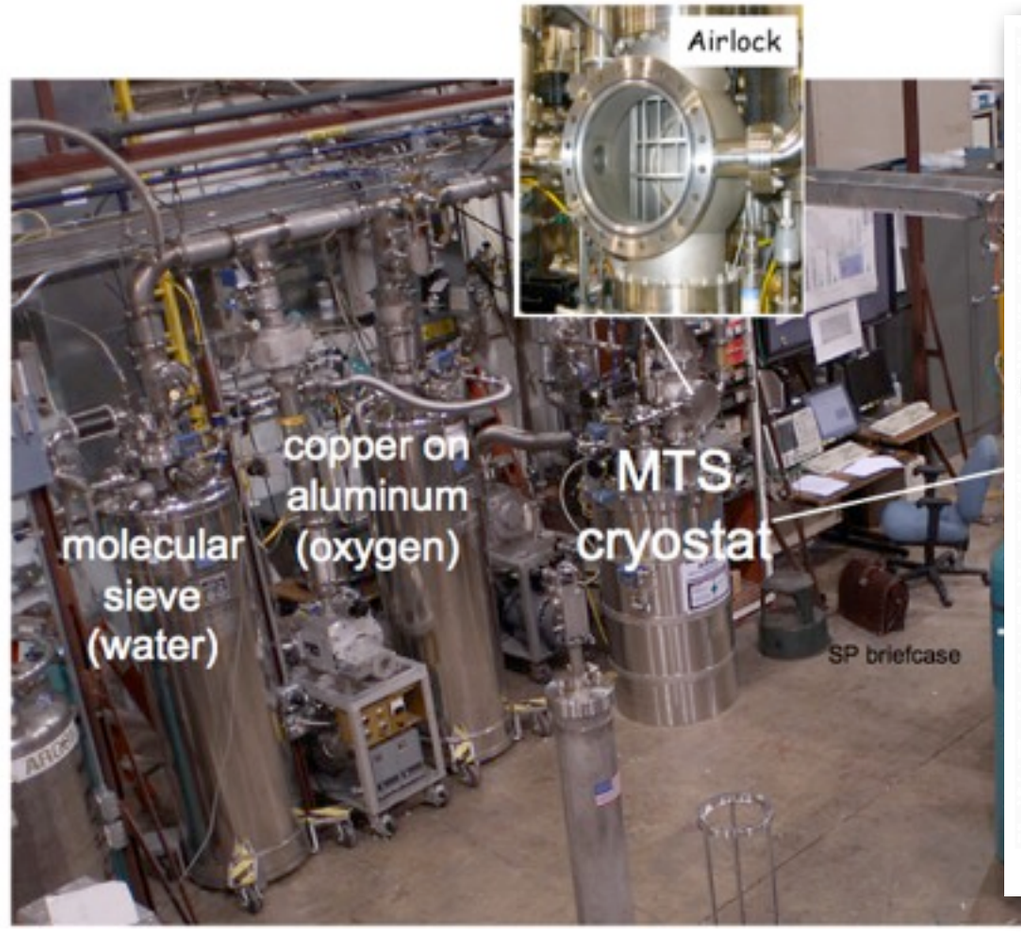

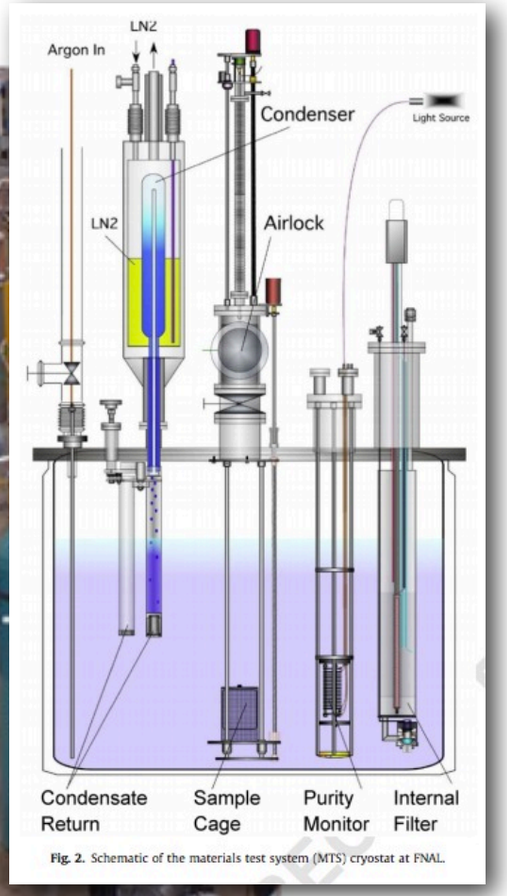

Fig. 2. Schematic of the materials test system (MTS) cryostat at FNAL.

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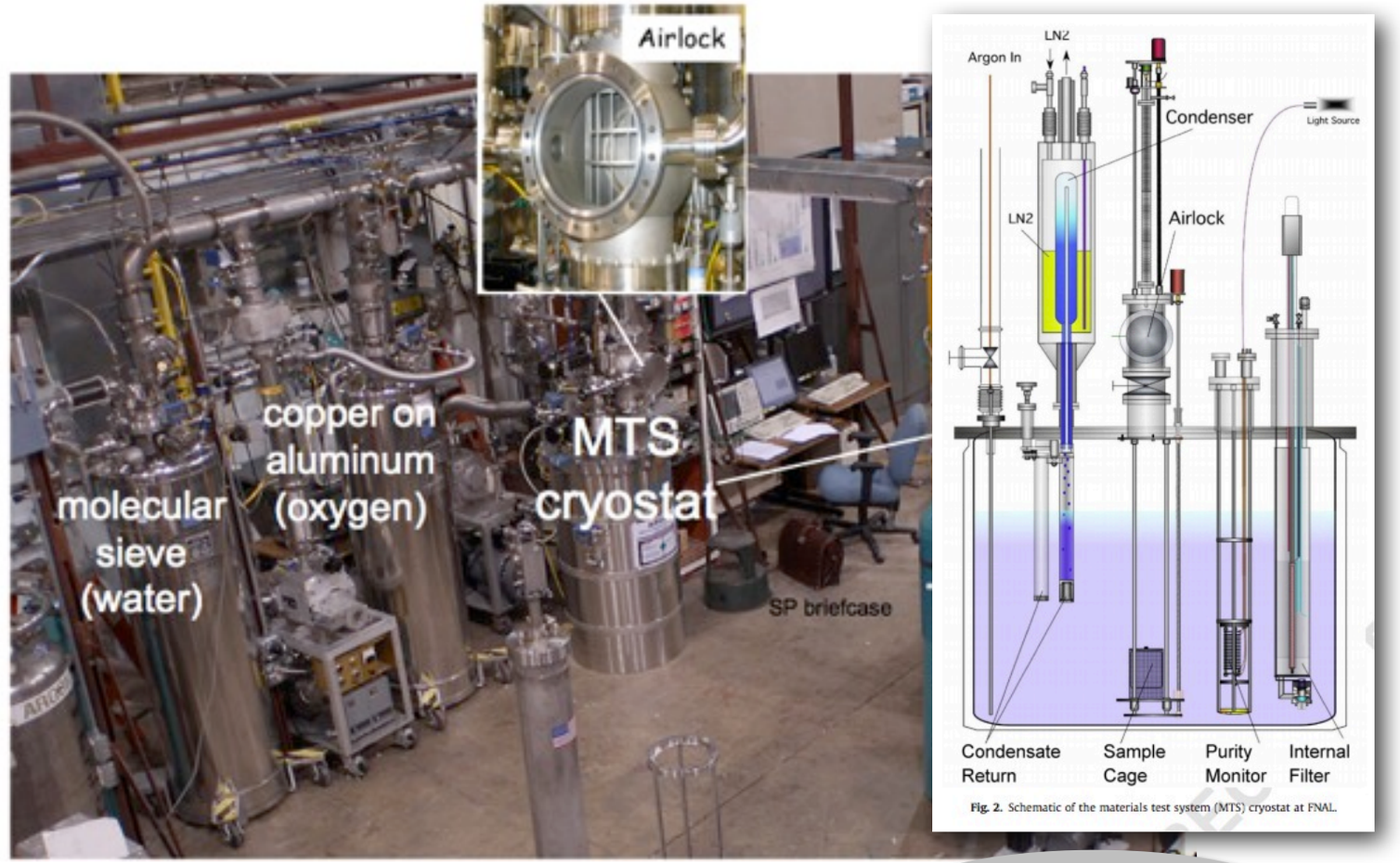
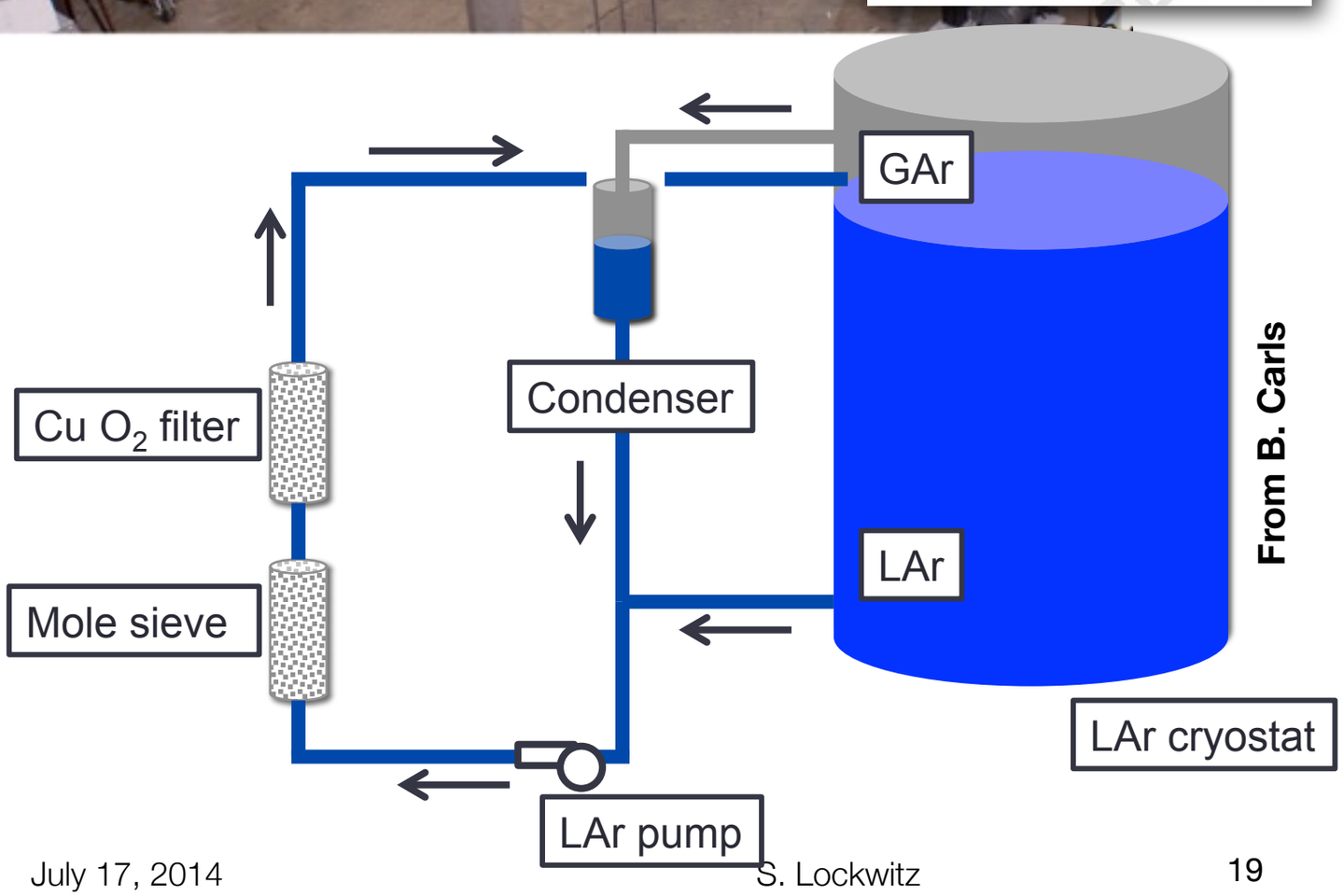
- We can purify the LAr with filters:





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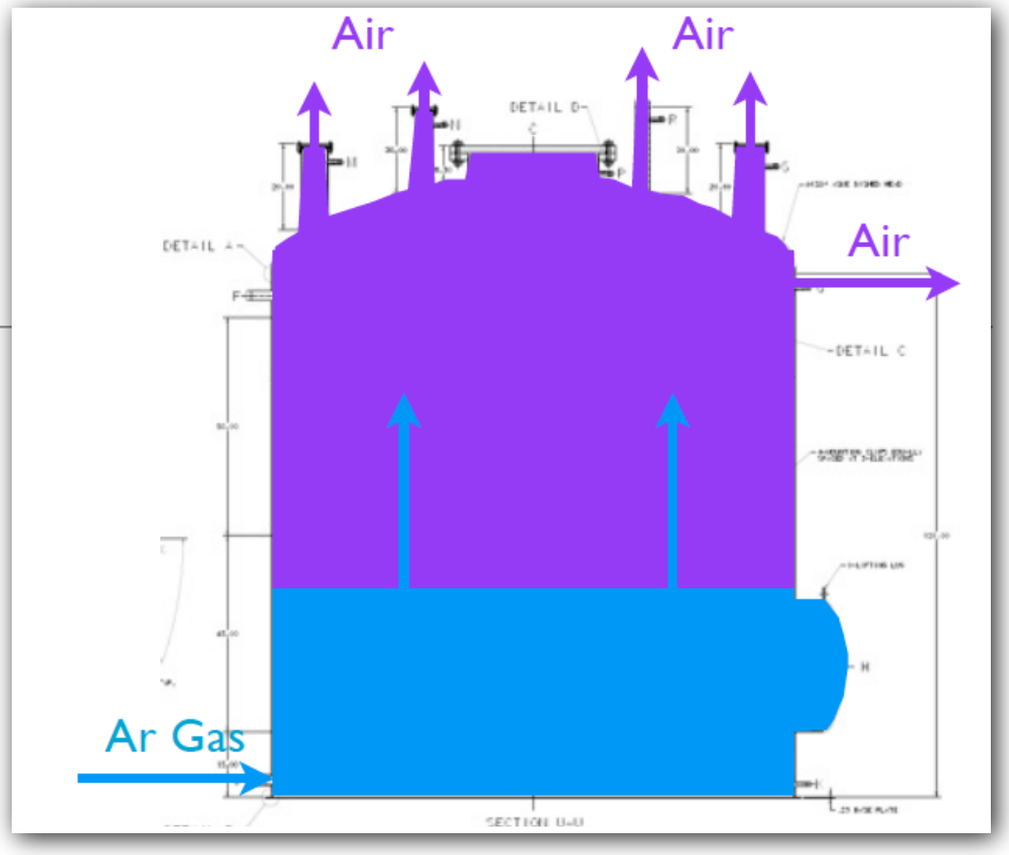
  - ICARUS, Argoneut
- LAPD showed that purity requirements could be attained **without** the need for evacuating (~30 ton vessel)
  - They employed an argon-gas piston



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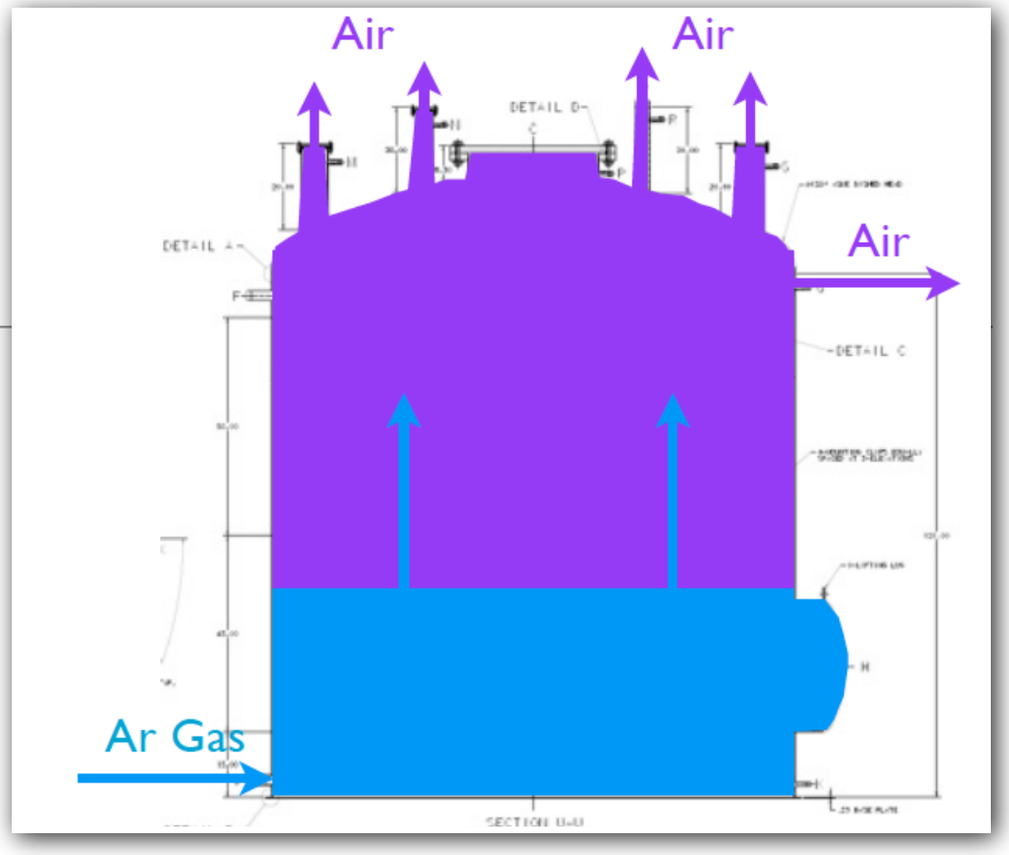

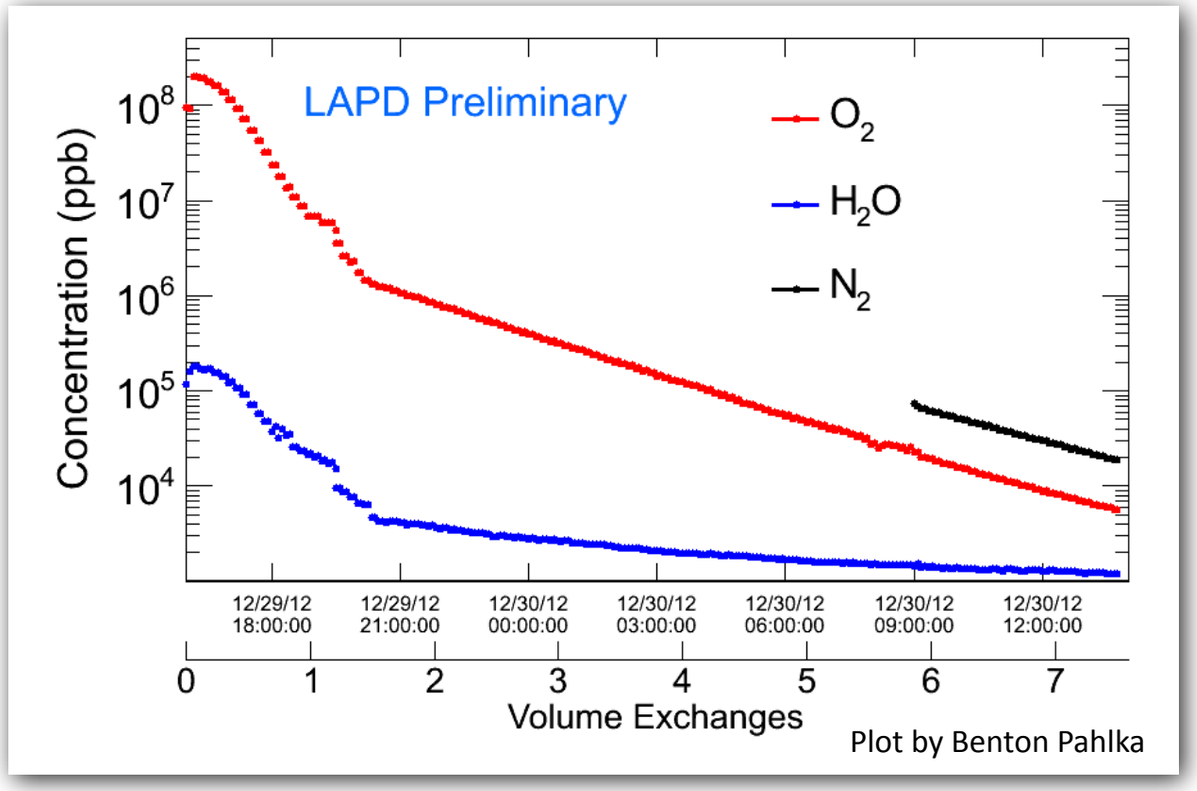

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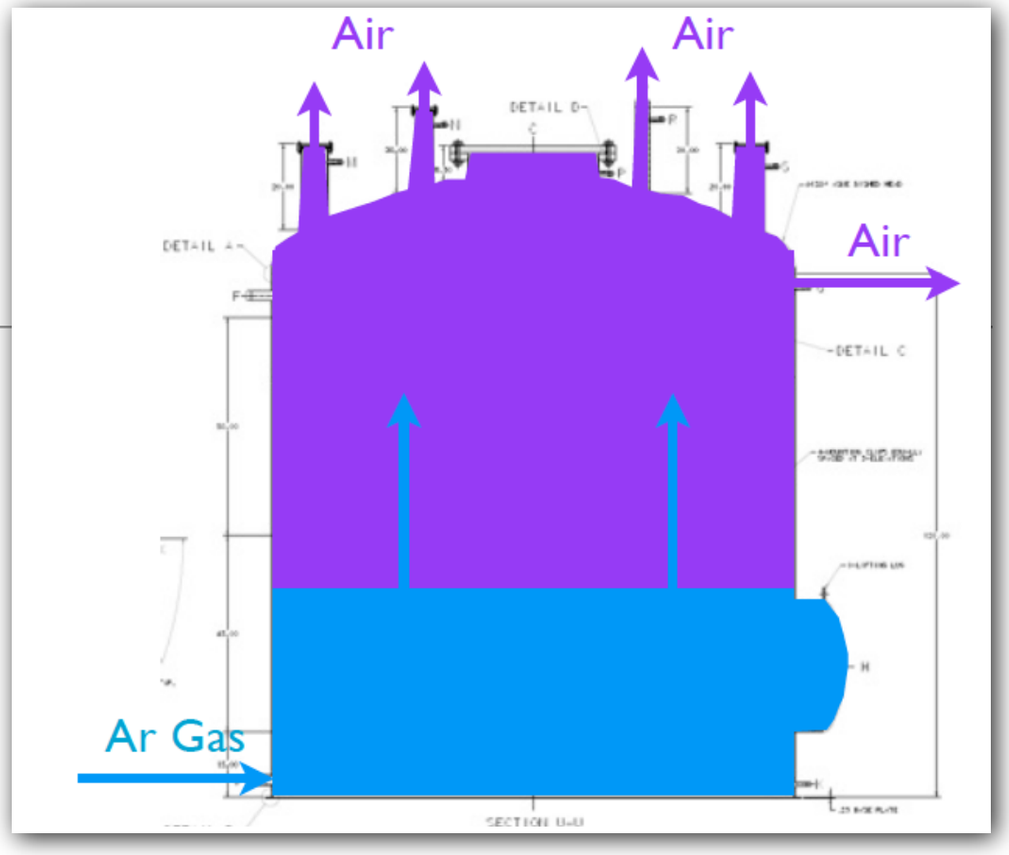
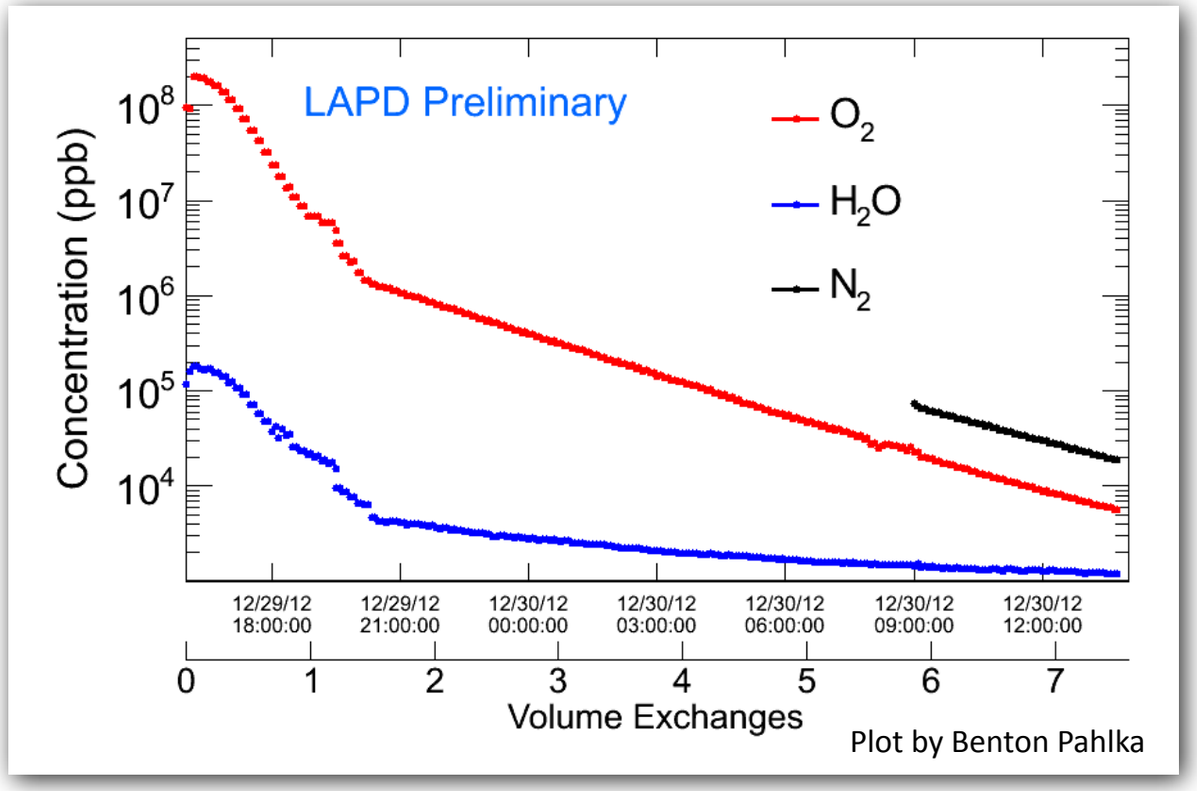
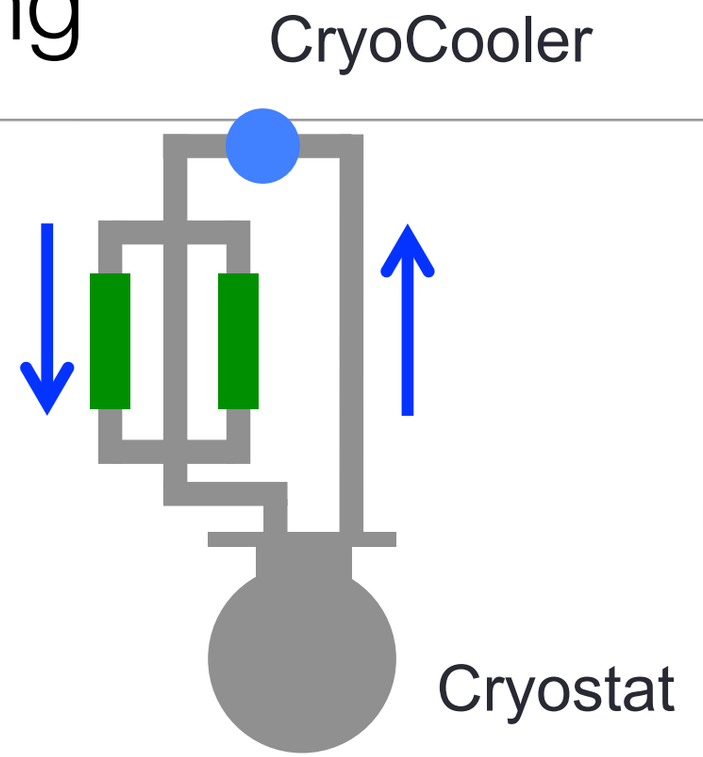


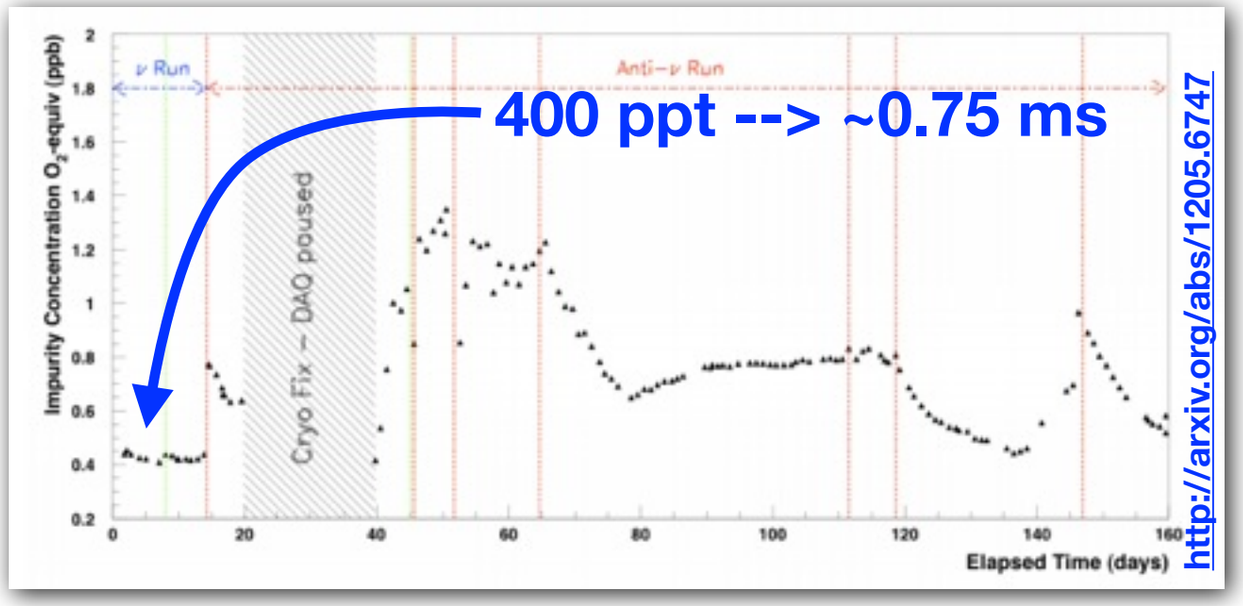


More Comments on Purity & Purging

- Even though Argoneut evacuated, their purity could have been improved upon
  - The system condensed argon from the gas space (good -- a lot of impurities live here) and filtered it
  - But a faster filtration rate (pumps) would lead to better purity
- Lesson -- evacuation is not a cure all!



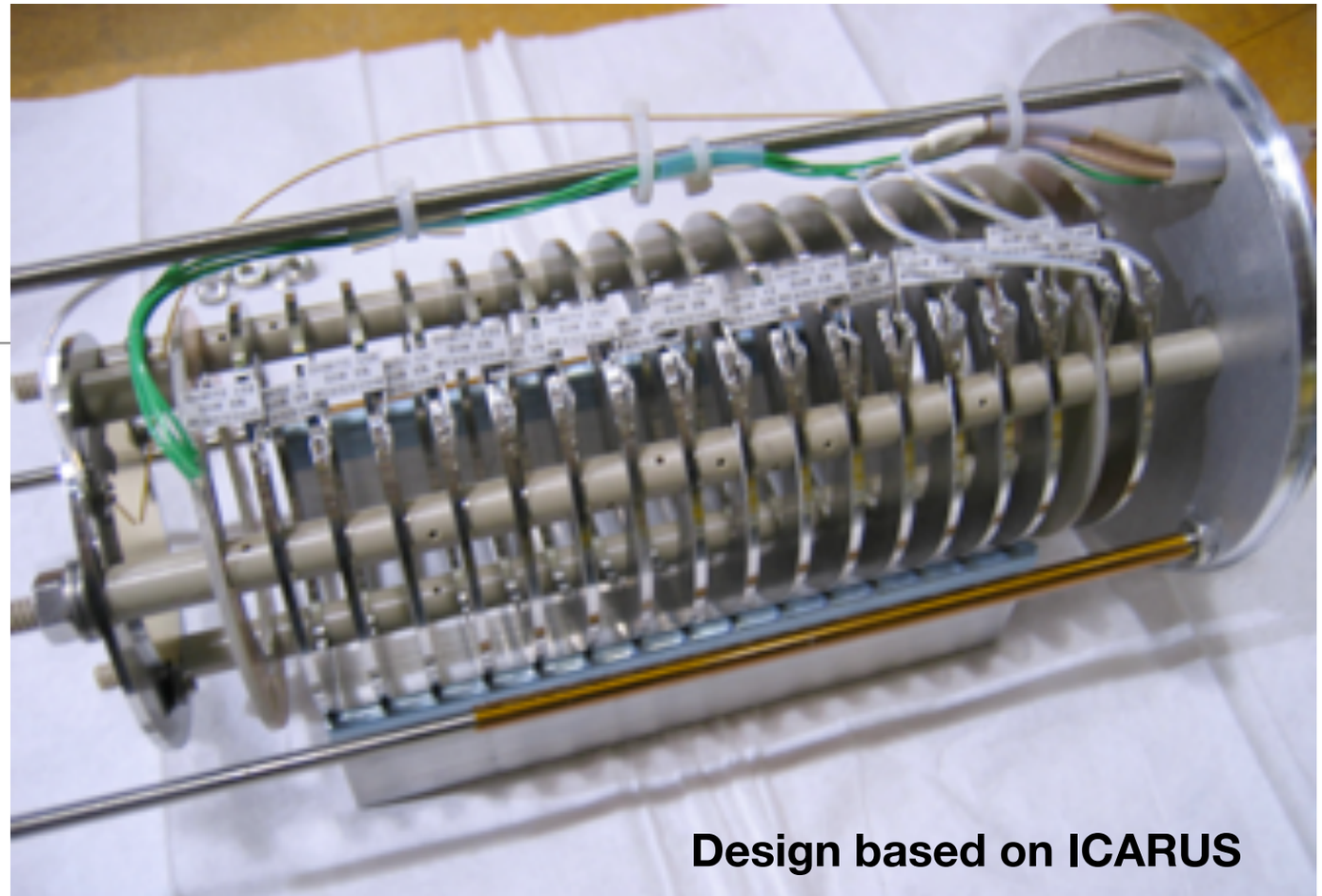
From B. Carls

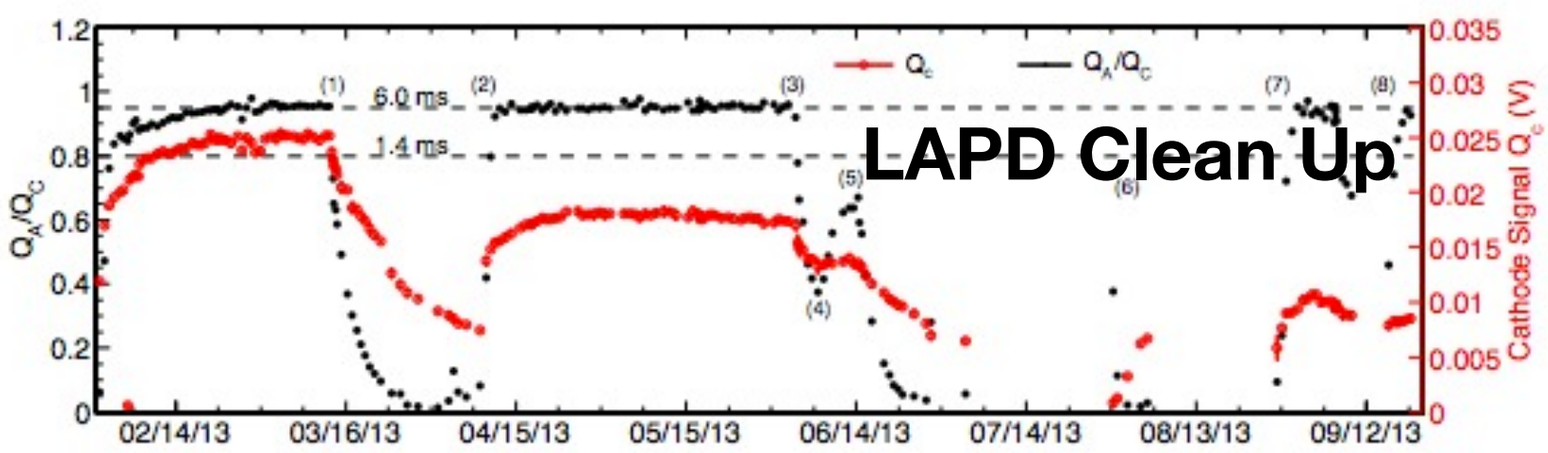


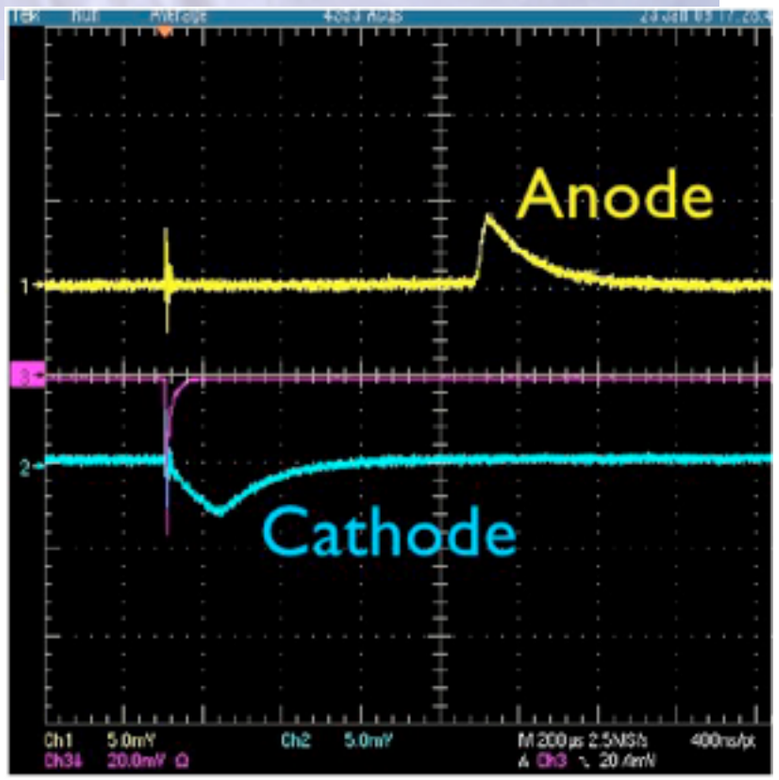
Monitoring Purity

- Purity monitors placed in the tank and in the cryosystem will give attenuation measurements
  - Use a xenon flash lamp on a photocathode
- Cathode signal is Q_0, anode is Q

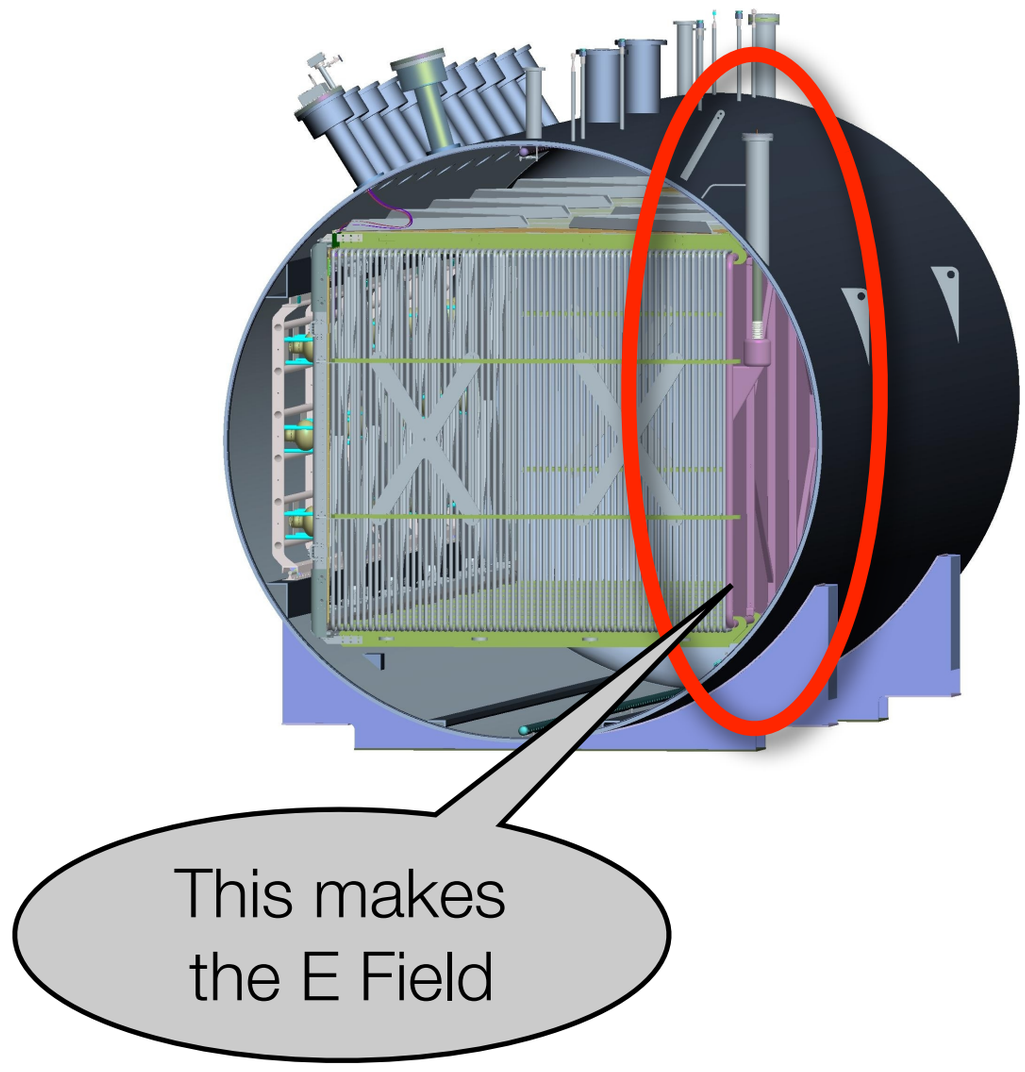
$$\frac{Q_0}{Q} = e^{t_d/\tau}$$







Cathode HV



Cathode High Voltage

- Again, a high voltage on the cathode supplies the drift field
  - A Cockcroft-Walton/ Greinacher system generates the HV **inside** of the cryostat
  - ARGONTUBE at Bern uses this
    - 5 m drift
    - Able to get to 125 kV (stable; E = 250 V/cm); 150 kV max

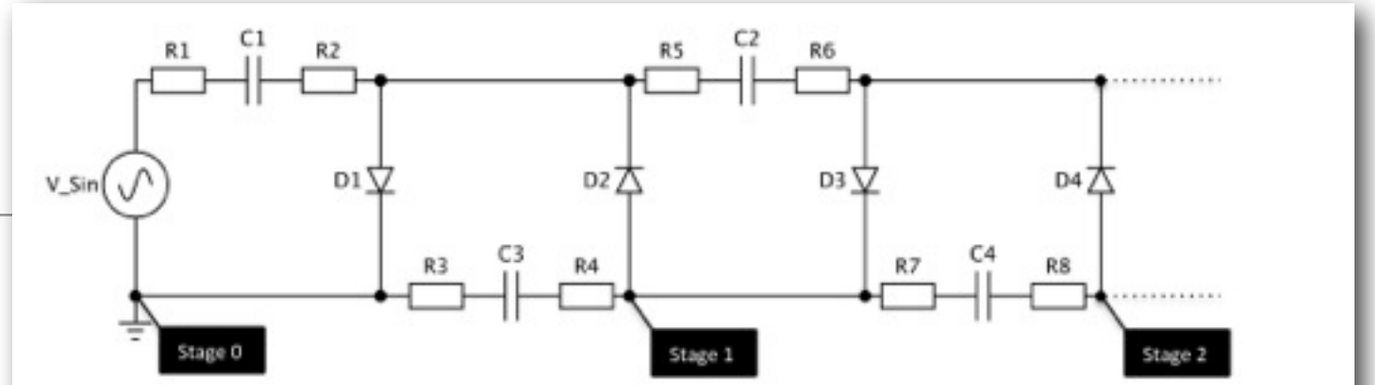
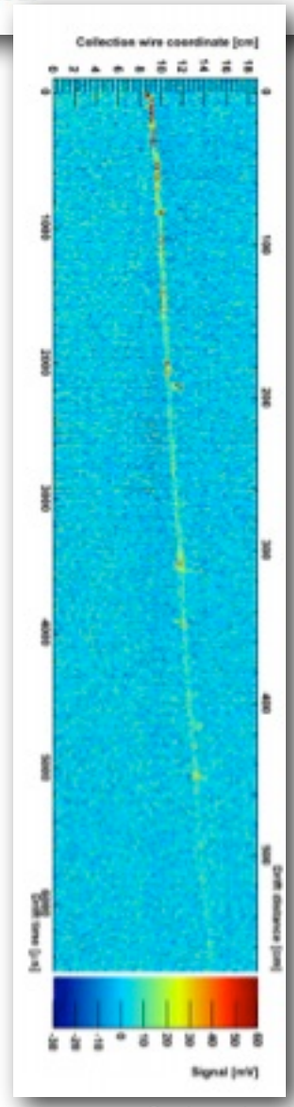
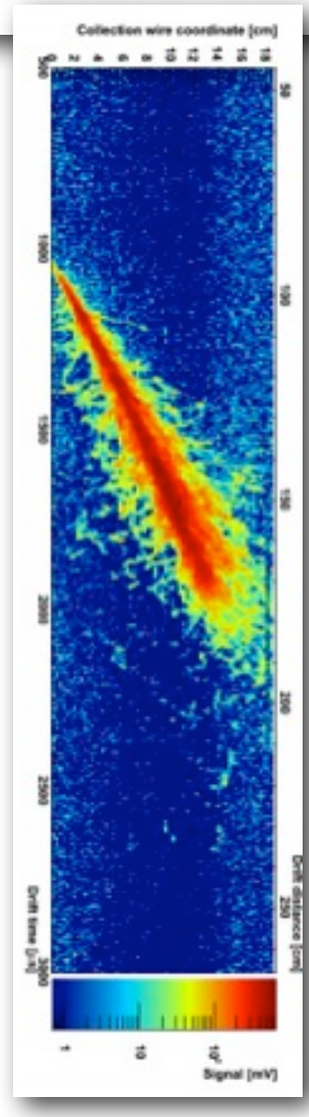


Figure 6. Wiring diagram of the Greinacher circuit for negative high voltage. Two stages of this circuit are shown, in ARGONTUBE 125 stages are mounted.

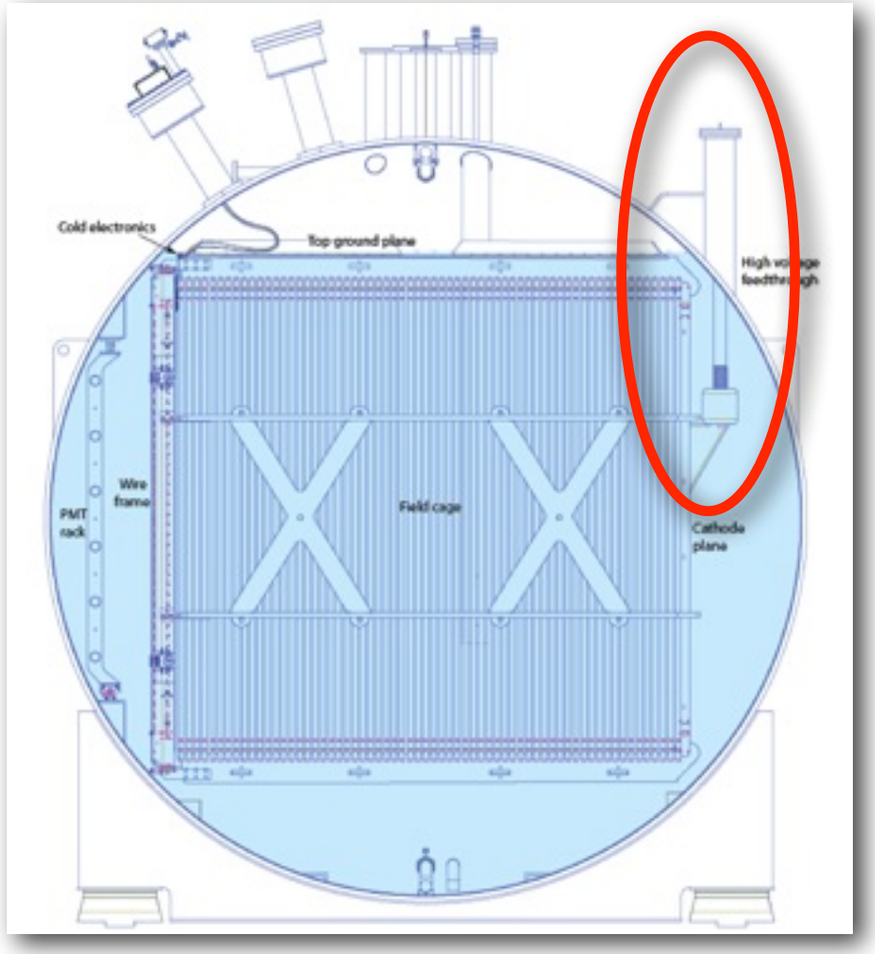




http://arxiv.org/pdf/1304.6961v2.pdf

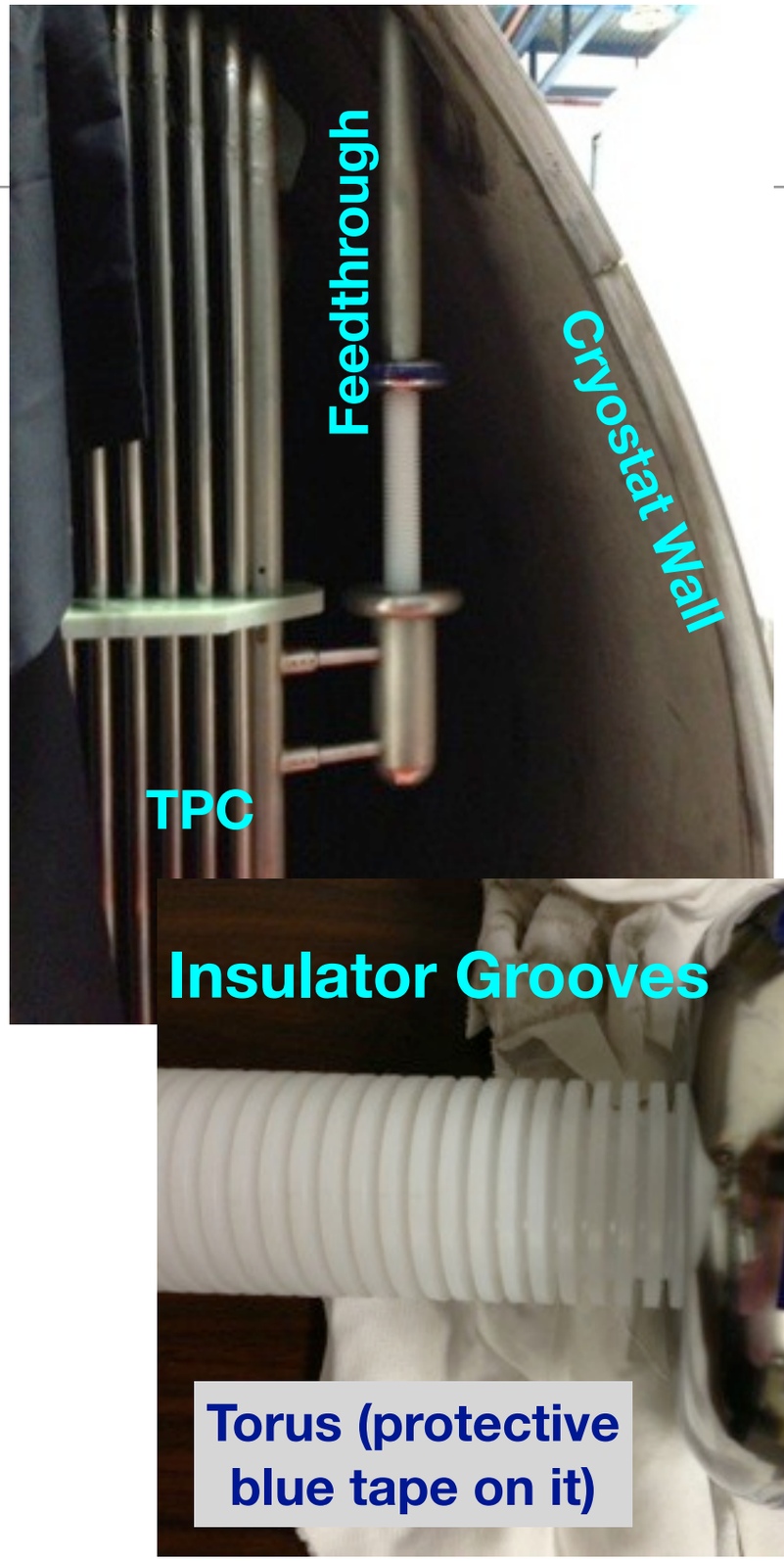
Cathode High Voltage

- Or the high voltage can be made **outside** of the cryostat and connected to the cathode via an HV **feedthrough**
  - This is what MicroBooNE (among others) uses
  - Can buy supplies (-150 kV Glassman)
  - Have to make the feedthrough

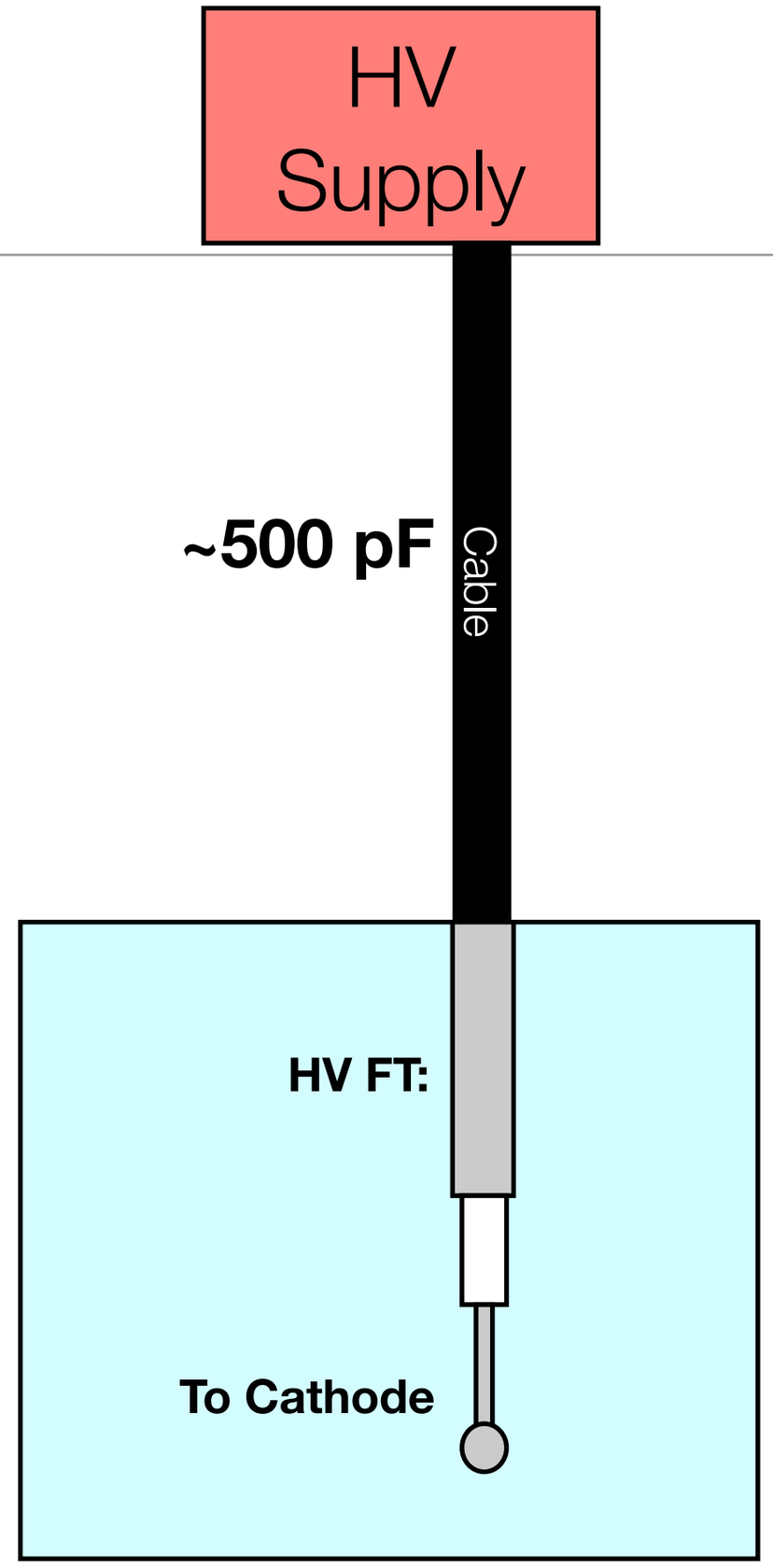


Feedthrough

- Needs to take 100+ kV into a cryostat
  - Maintain a good seal from room temperature to 87 K
- Inner stainless steel conductor
- Inserted into UHMW PE insulator
- Outer ground tube is cryo-fit over
  - Flange/warm part makes a tight seal



HV an Aside



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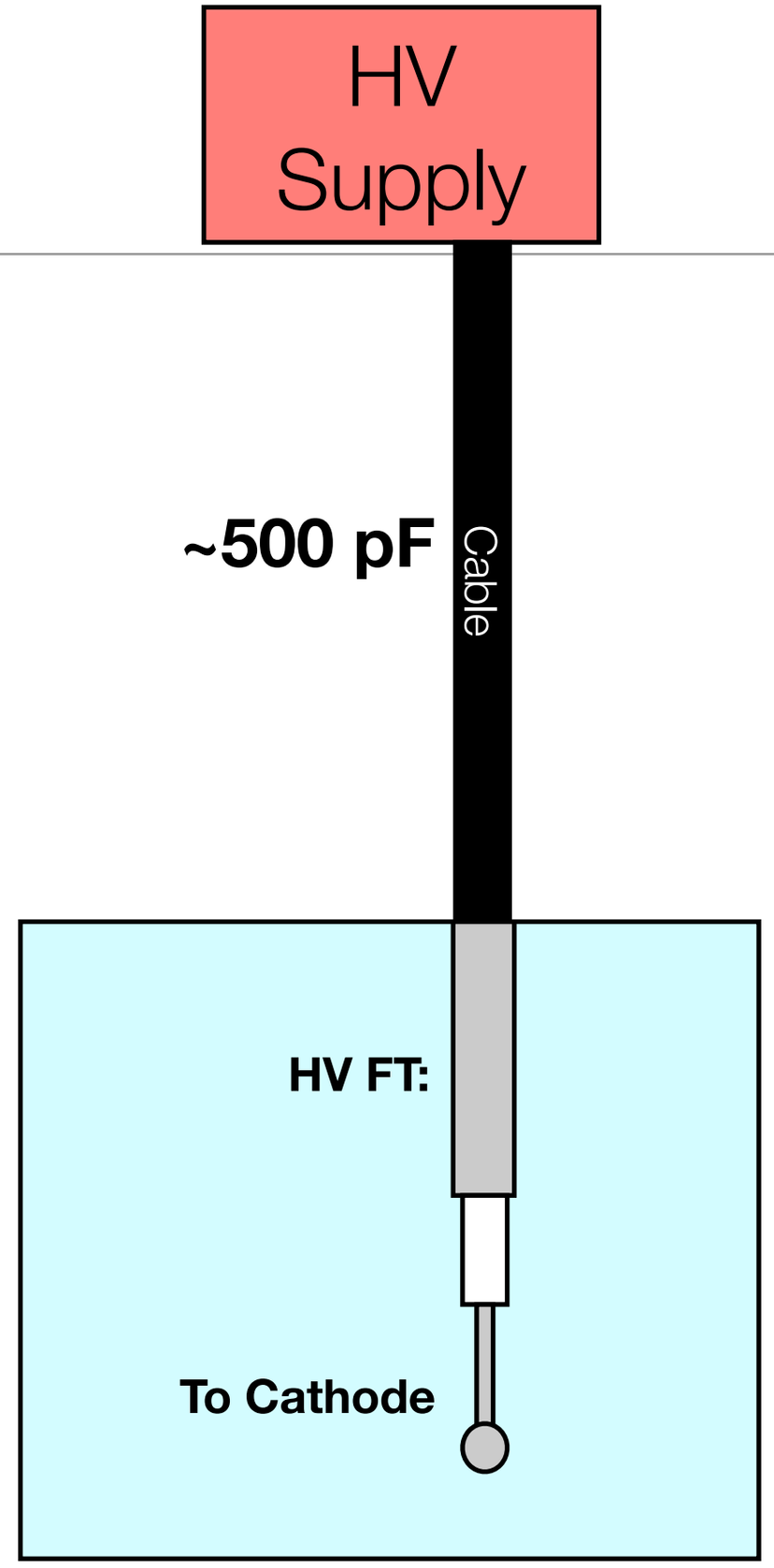
- It there was a discharge, this could put a lot of energy into the TPC



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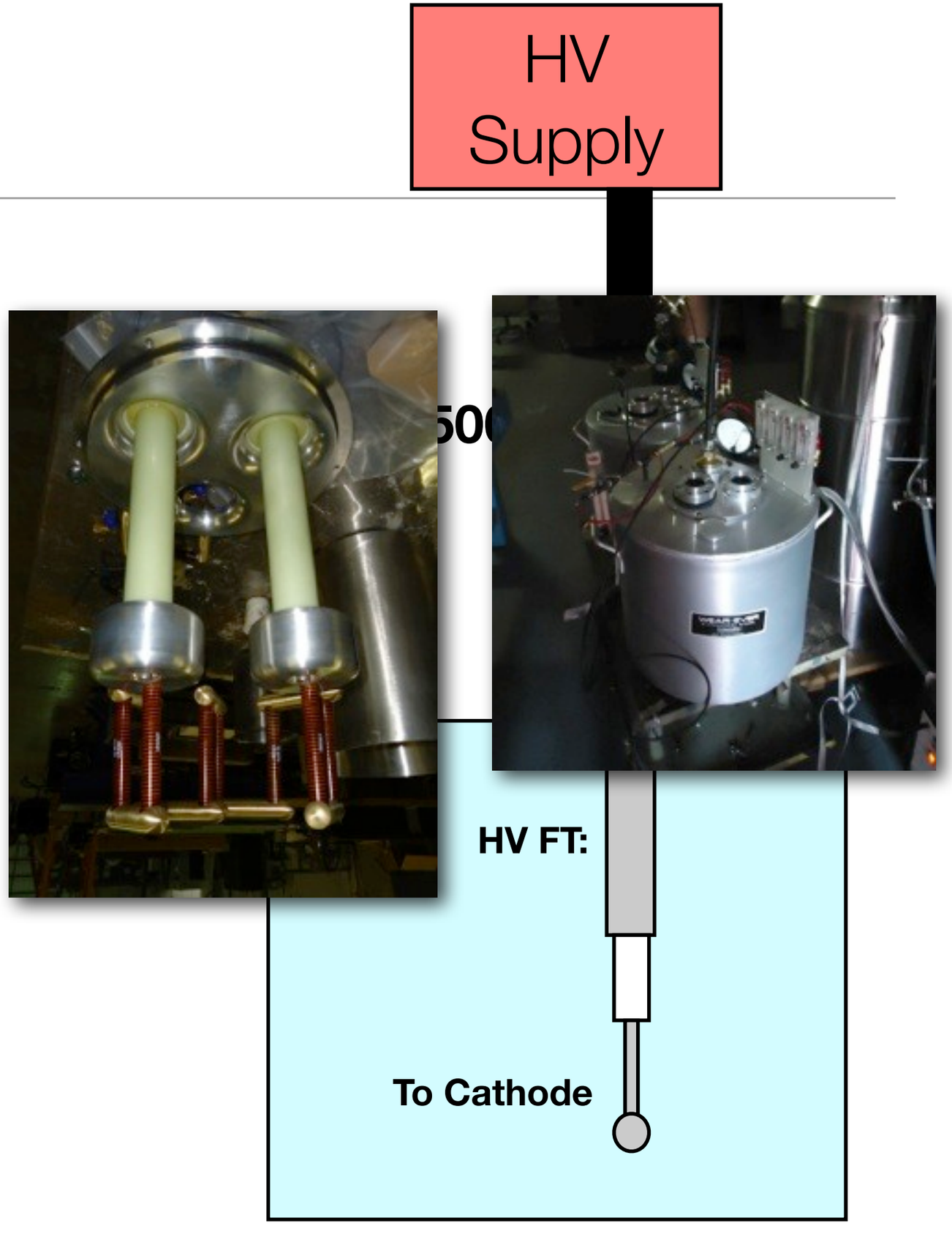

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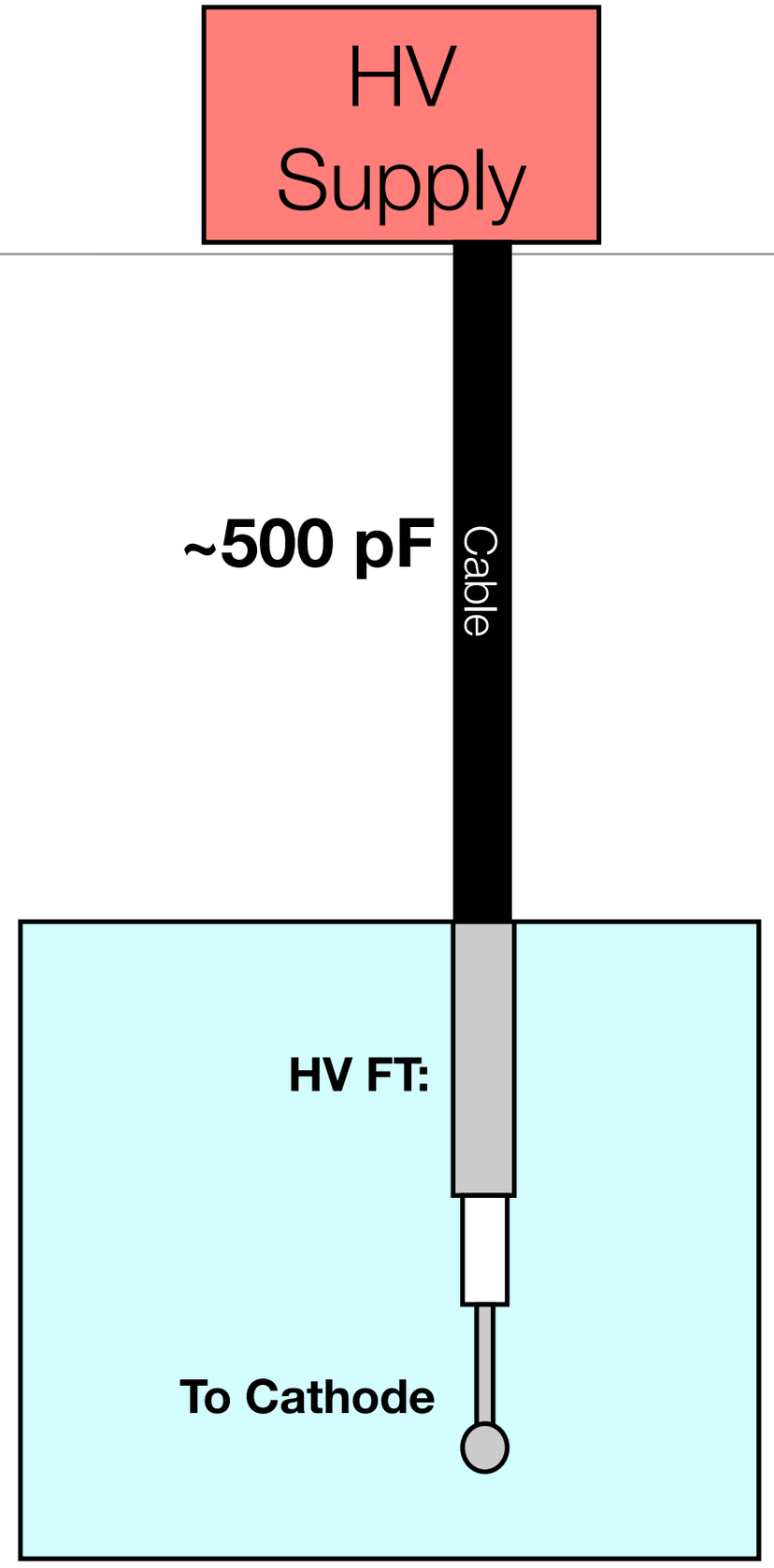

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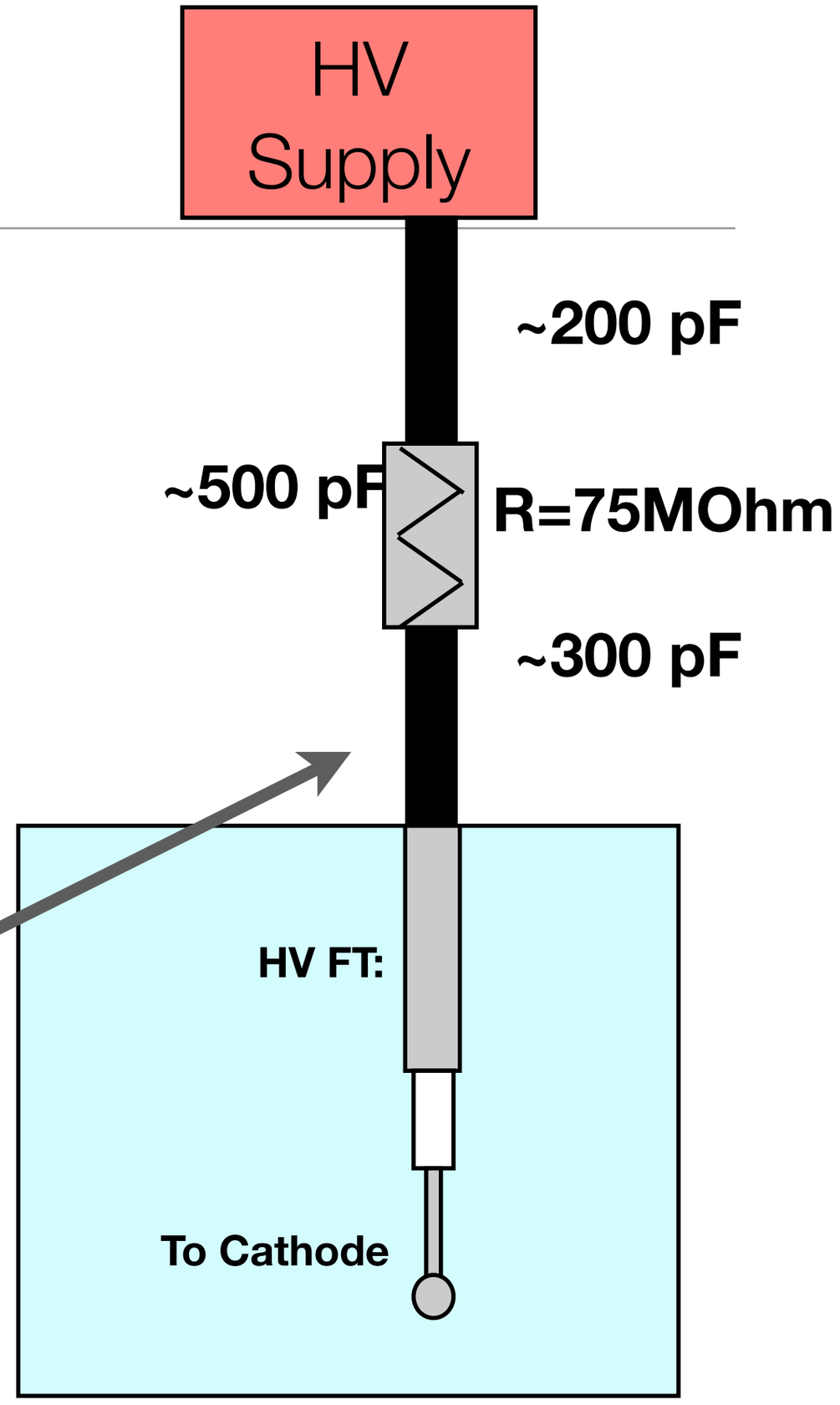
  - "Filter" refers to this low pass filter
  - Only this part will **quickly** enter the cryostat.



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Liquid	Strength (MV cm^{-1})
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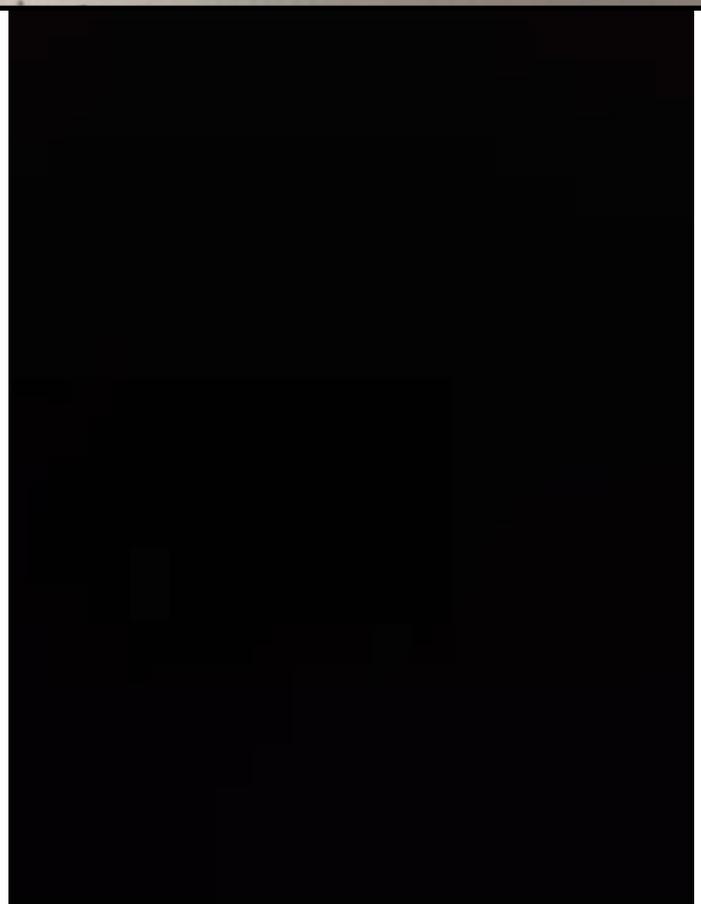

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Of the possible liquified gases, argon, oxygen, and nitrogen are most suitable for study since they may

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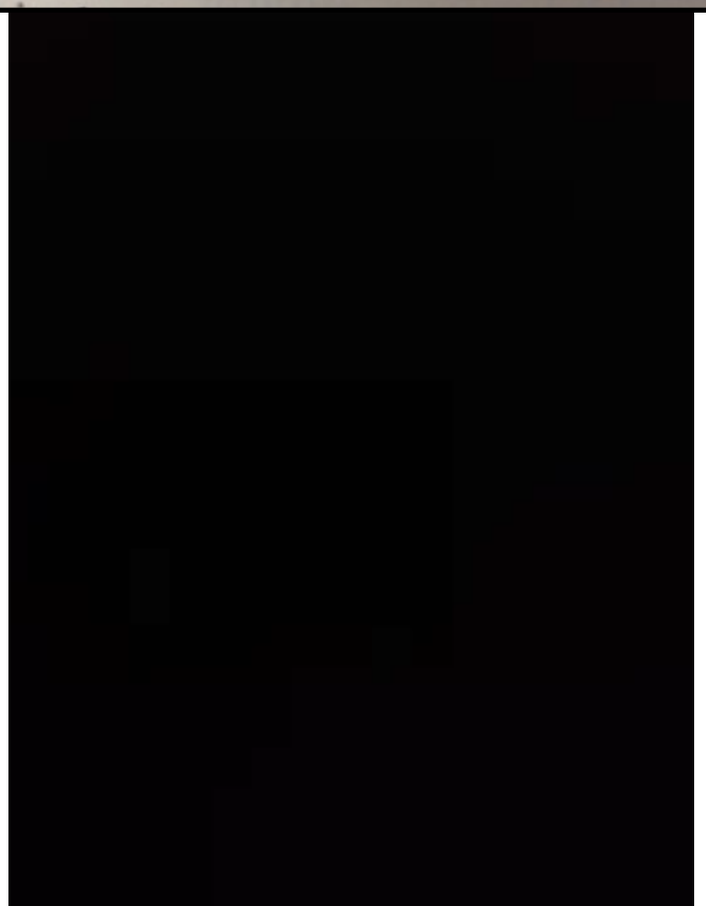

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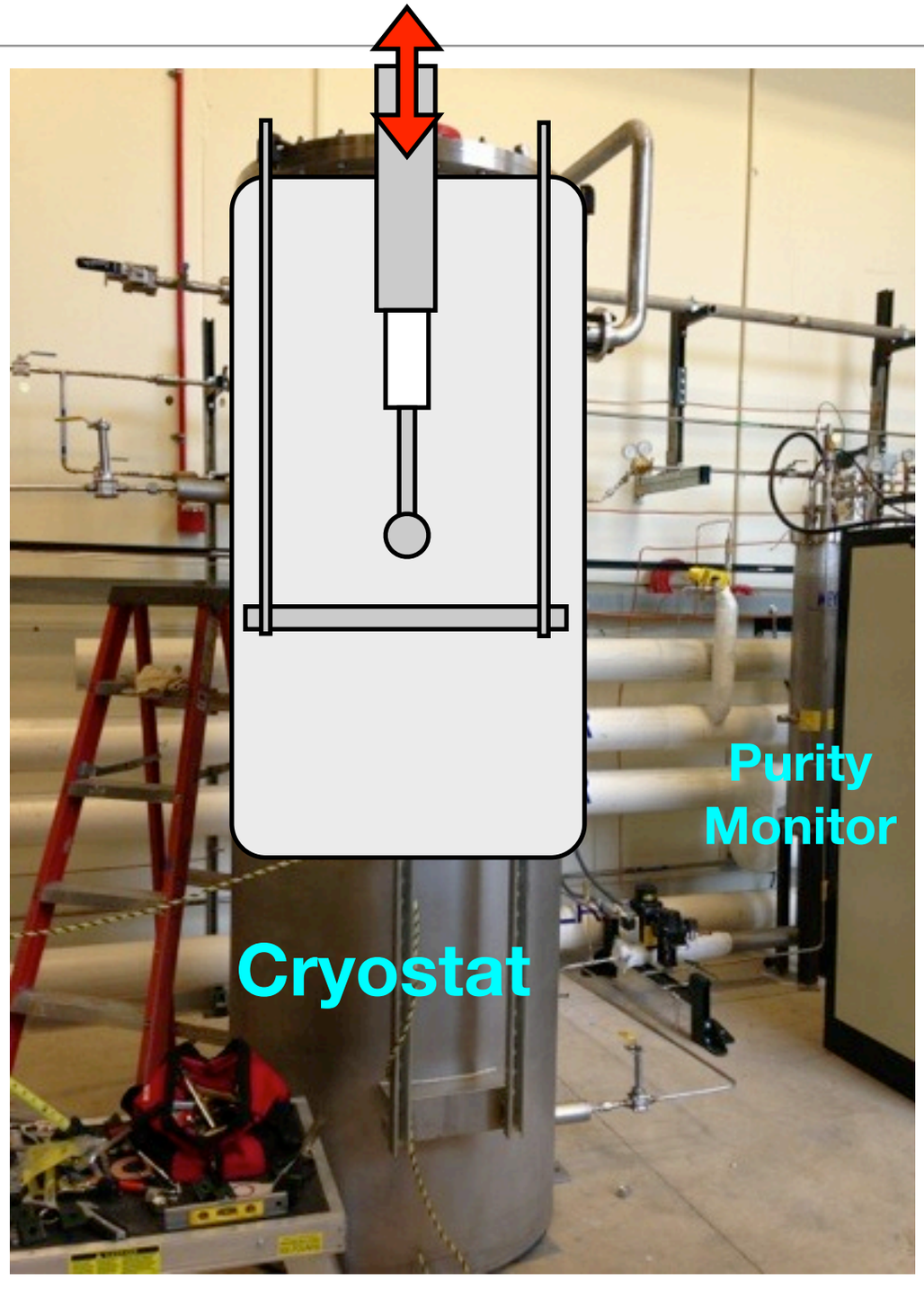

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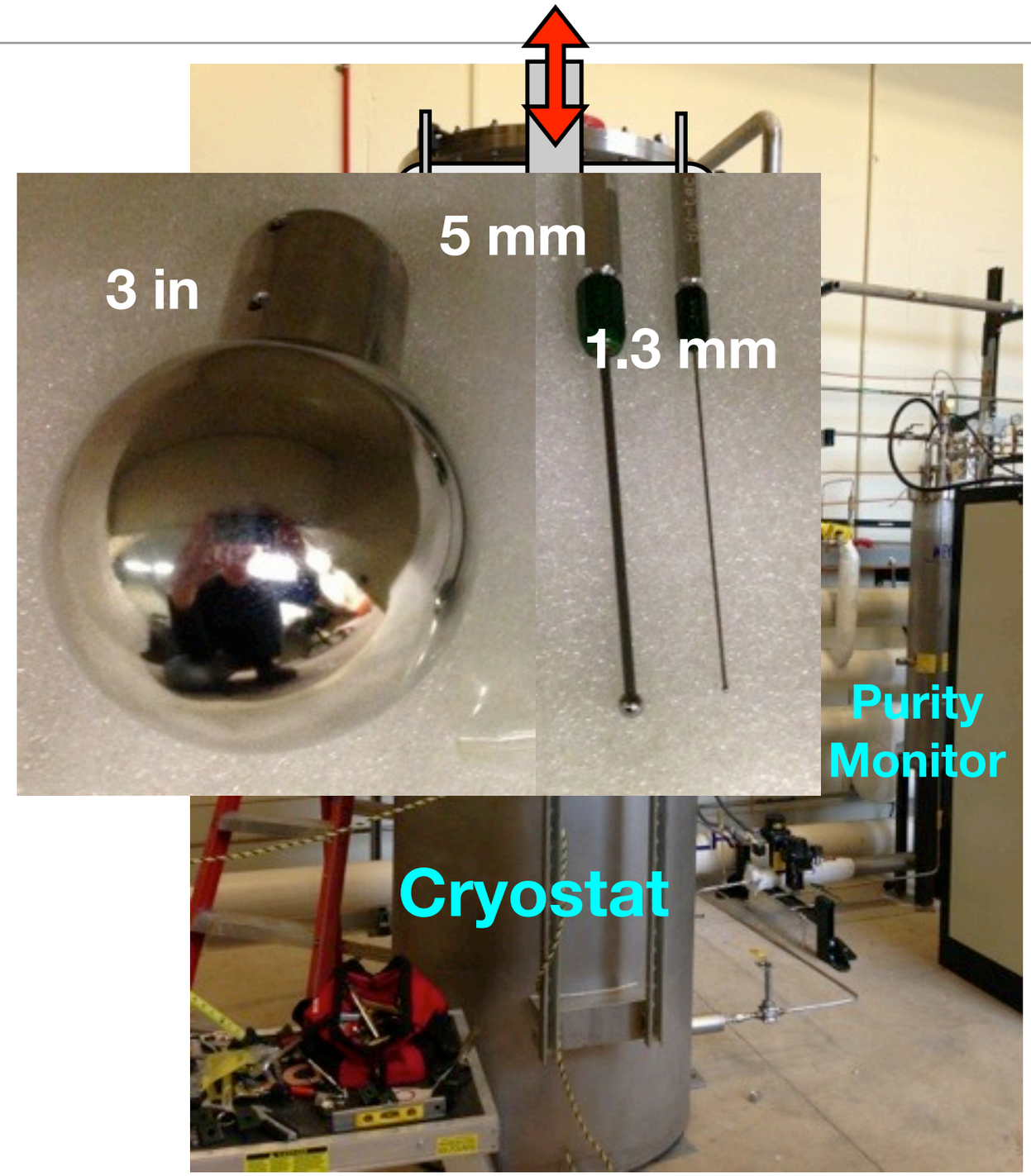

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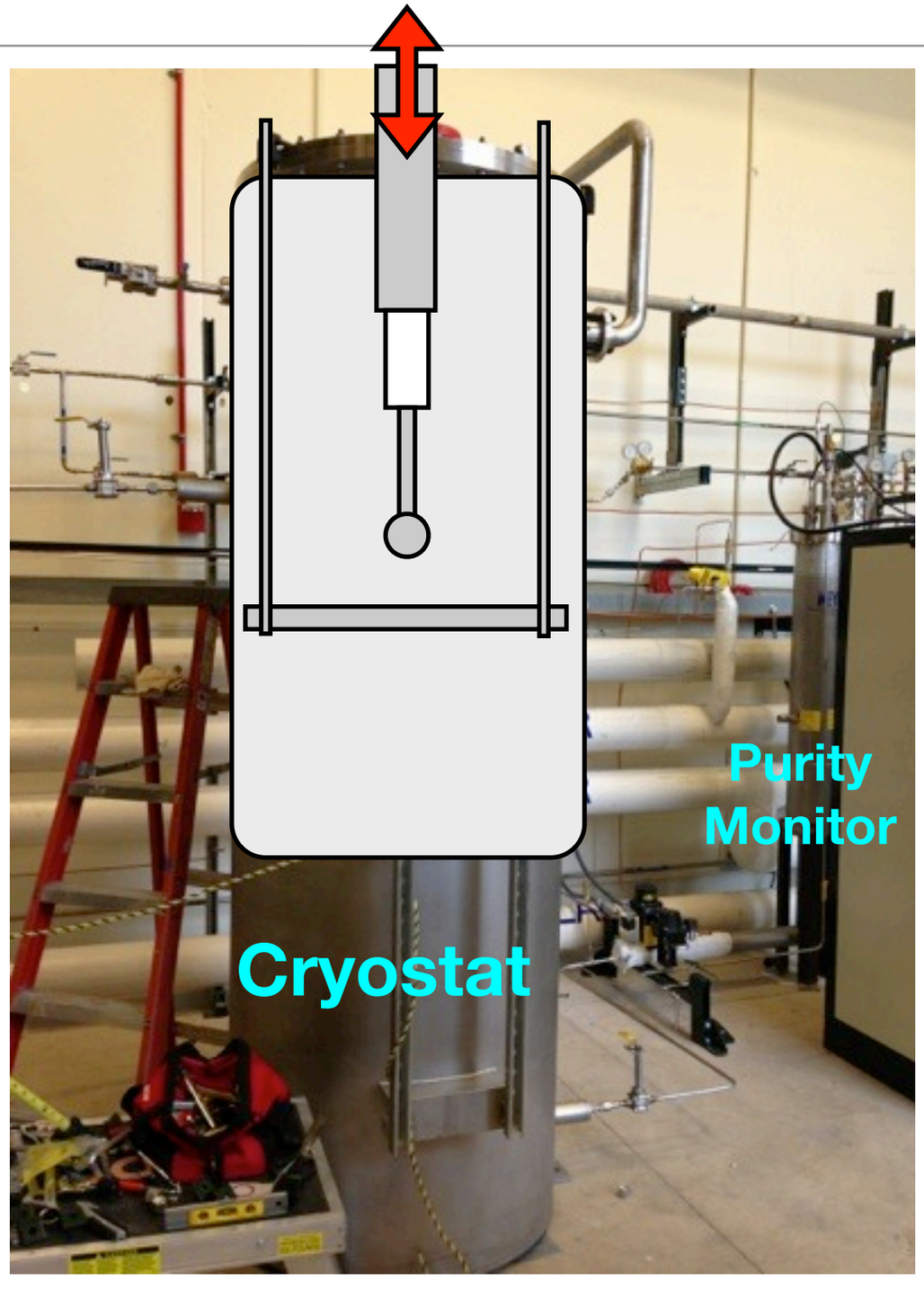

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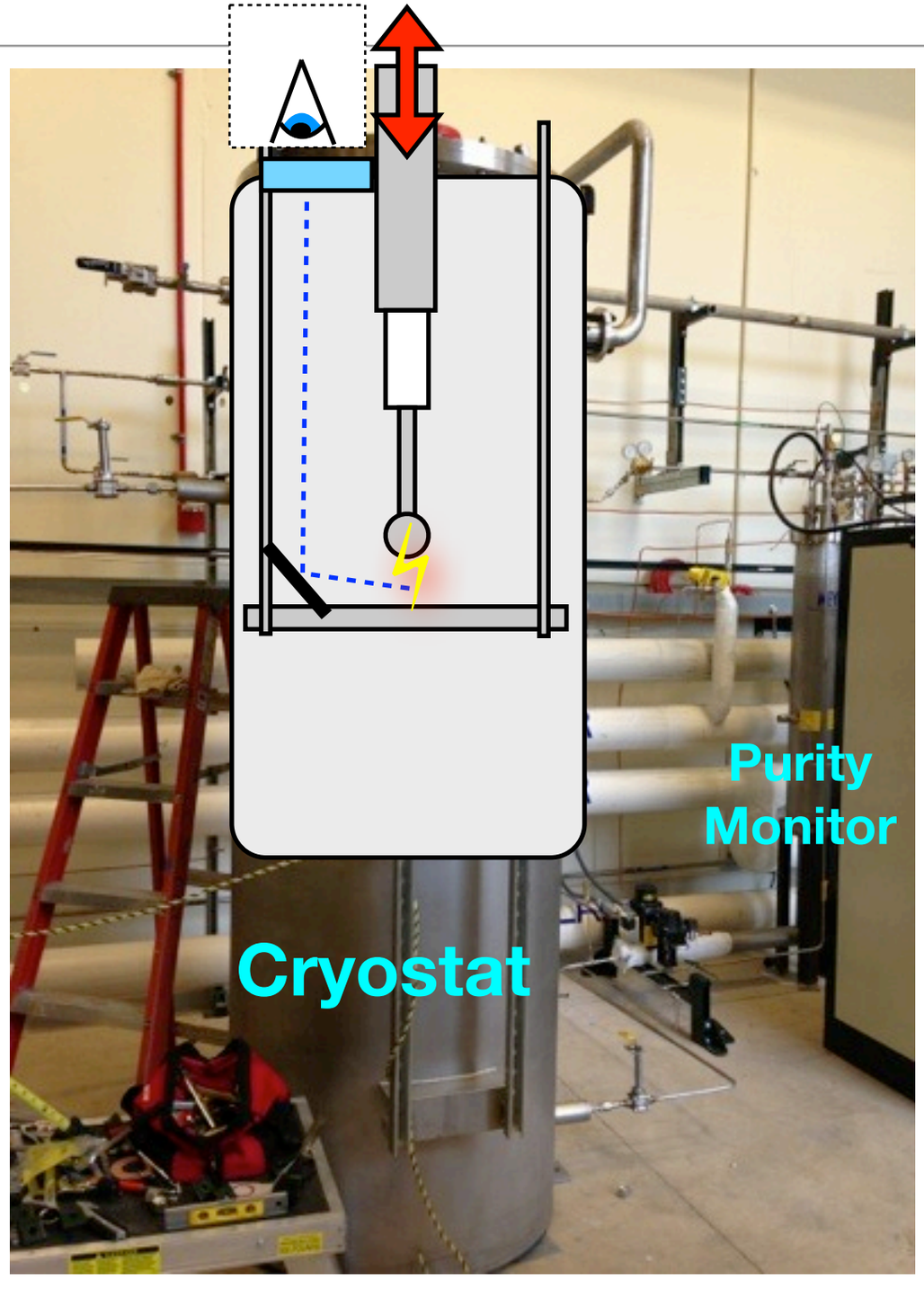

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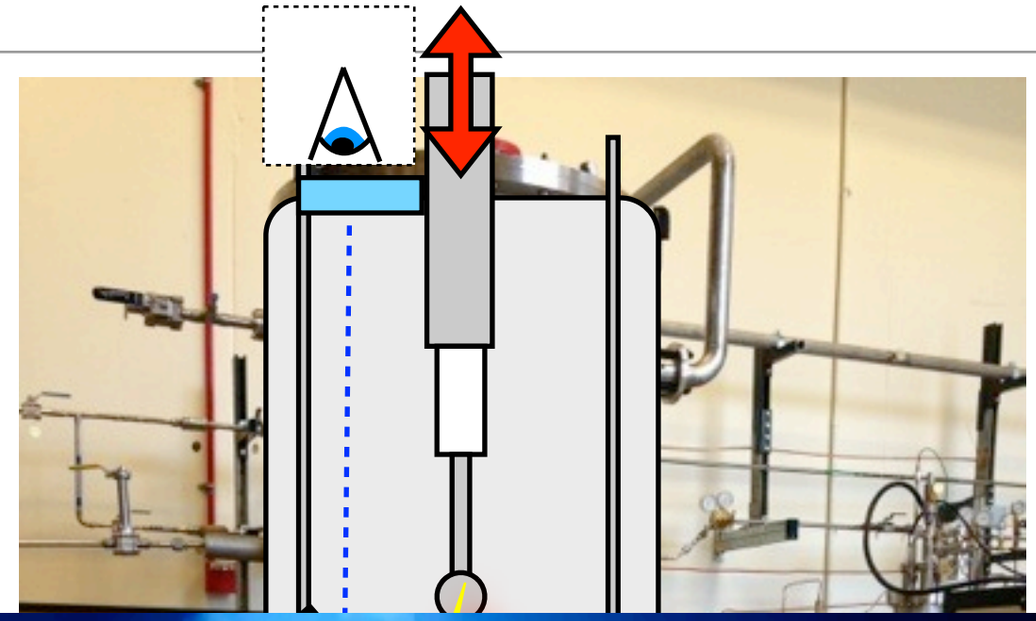

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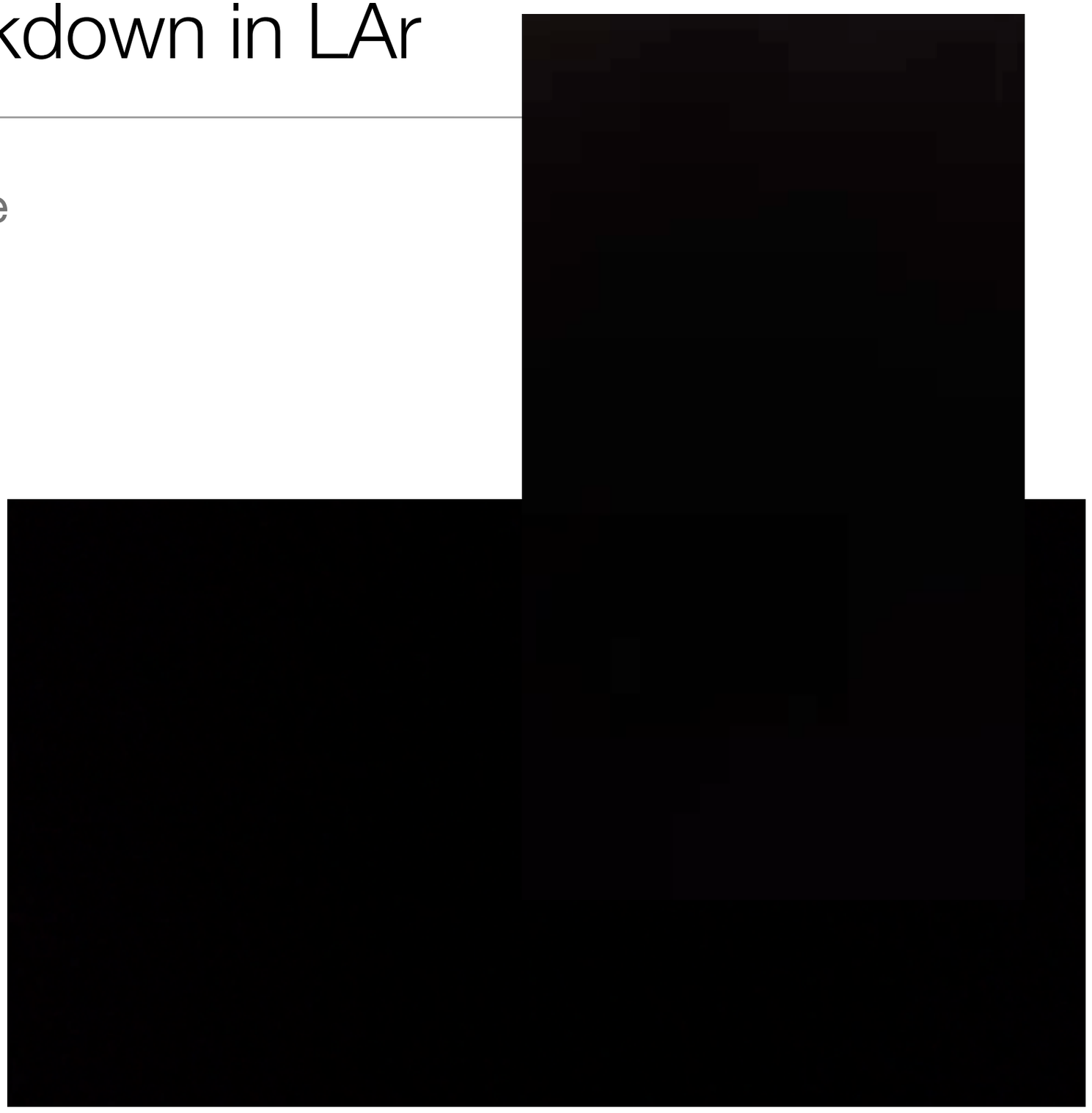

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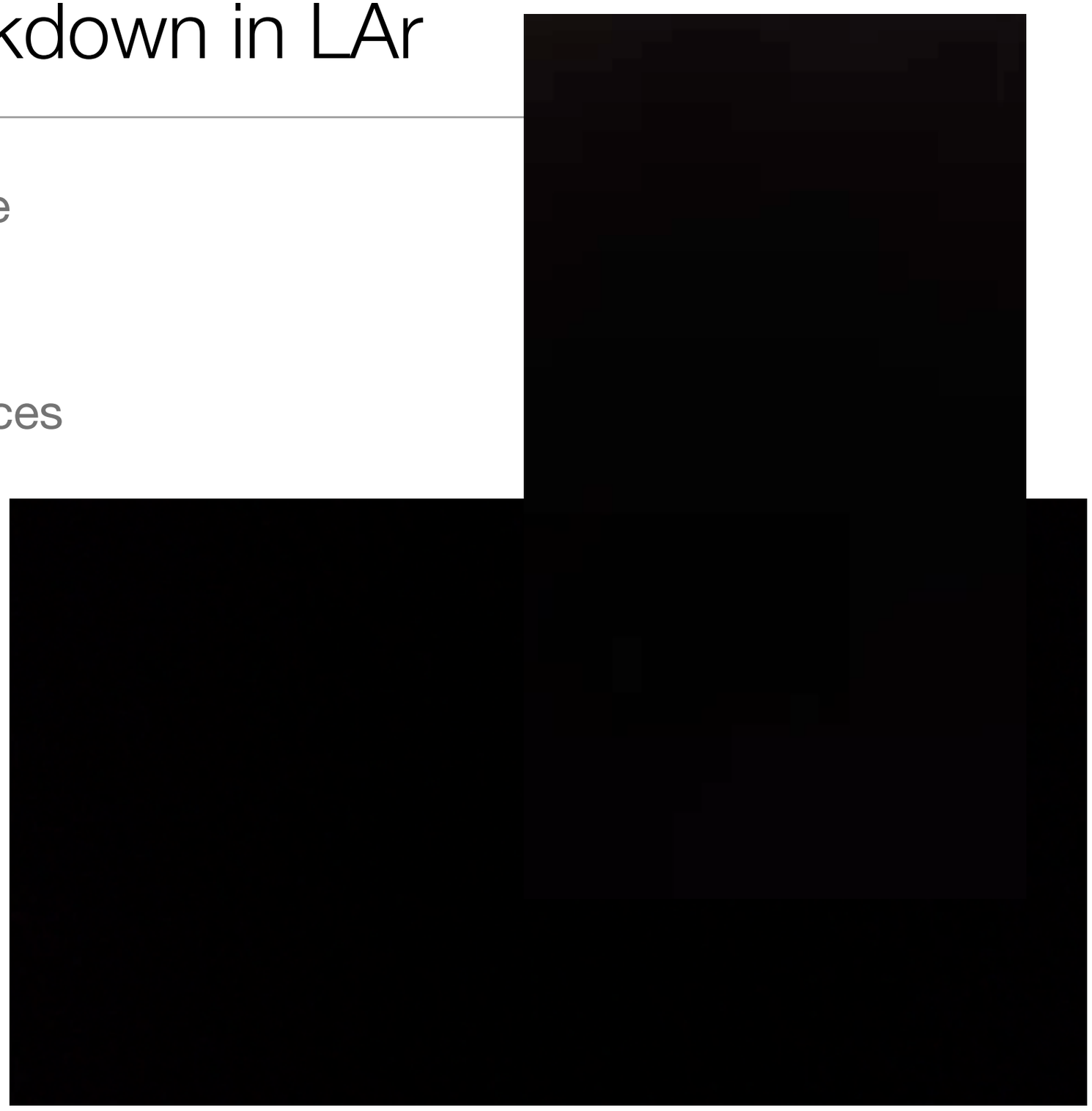

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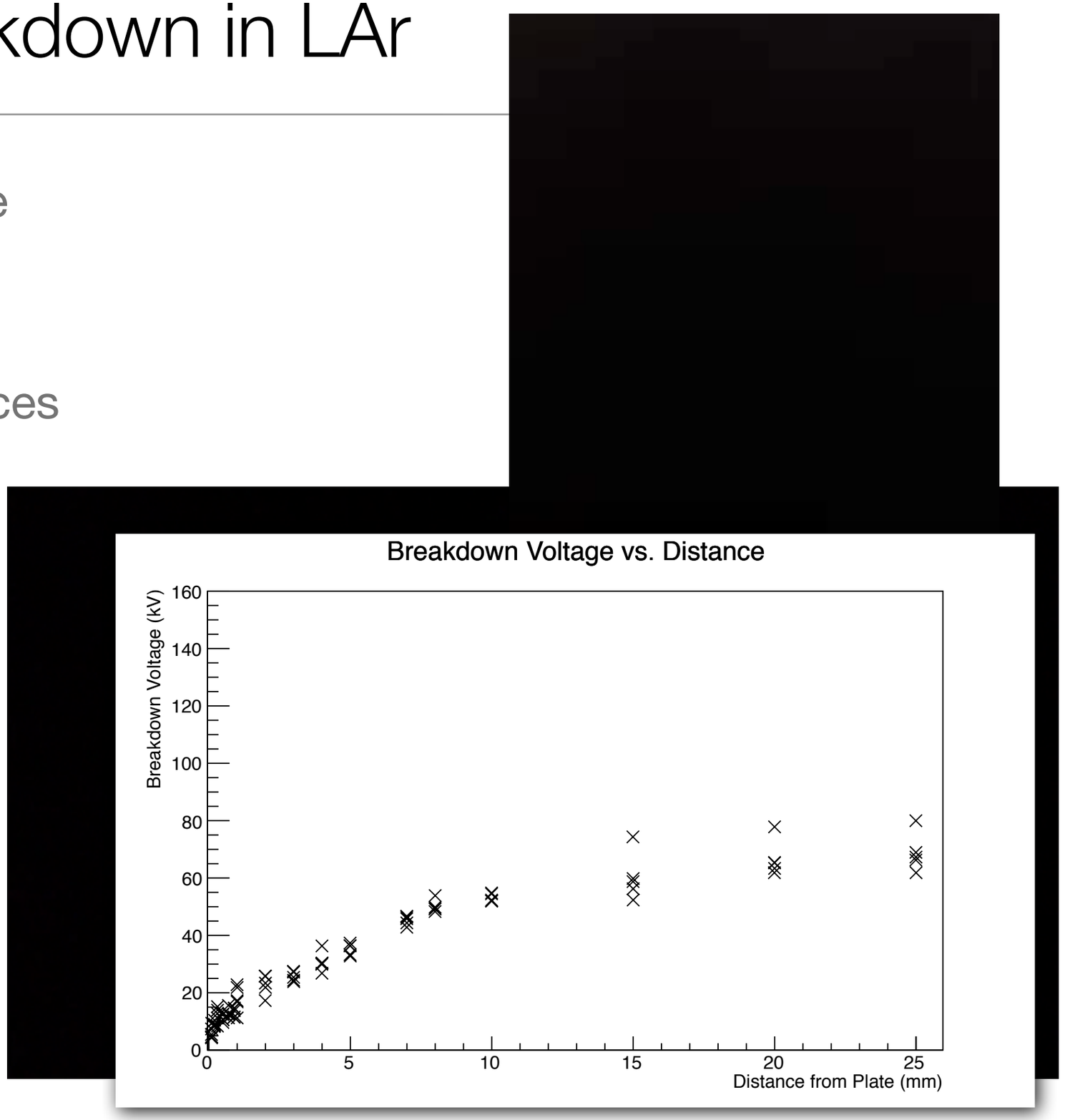

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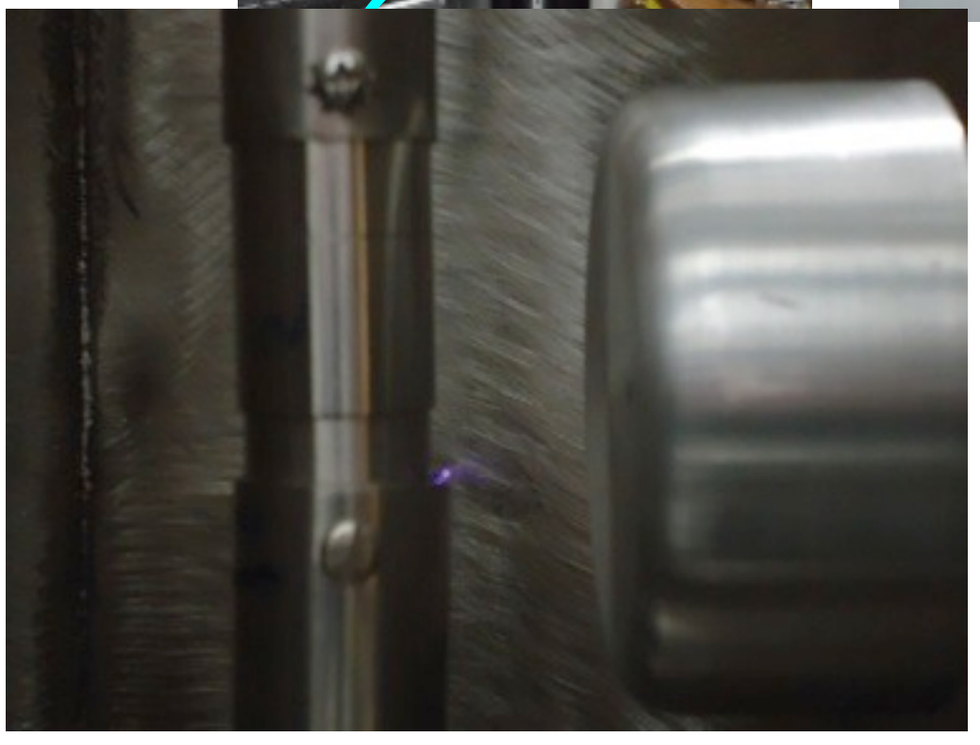

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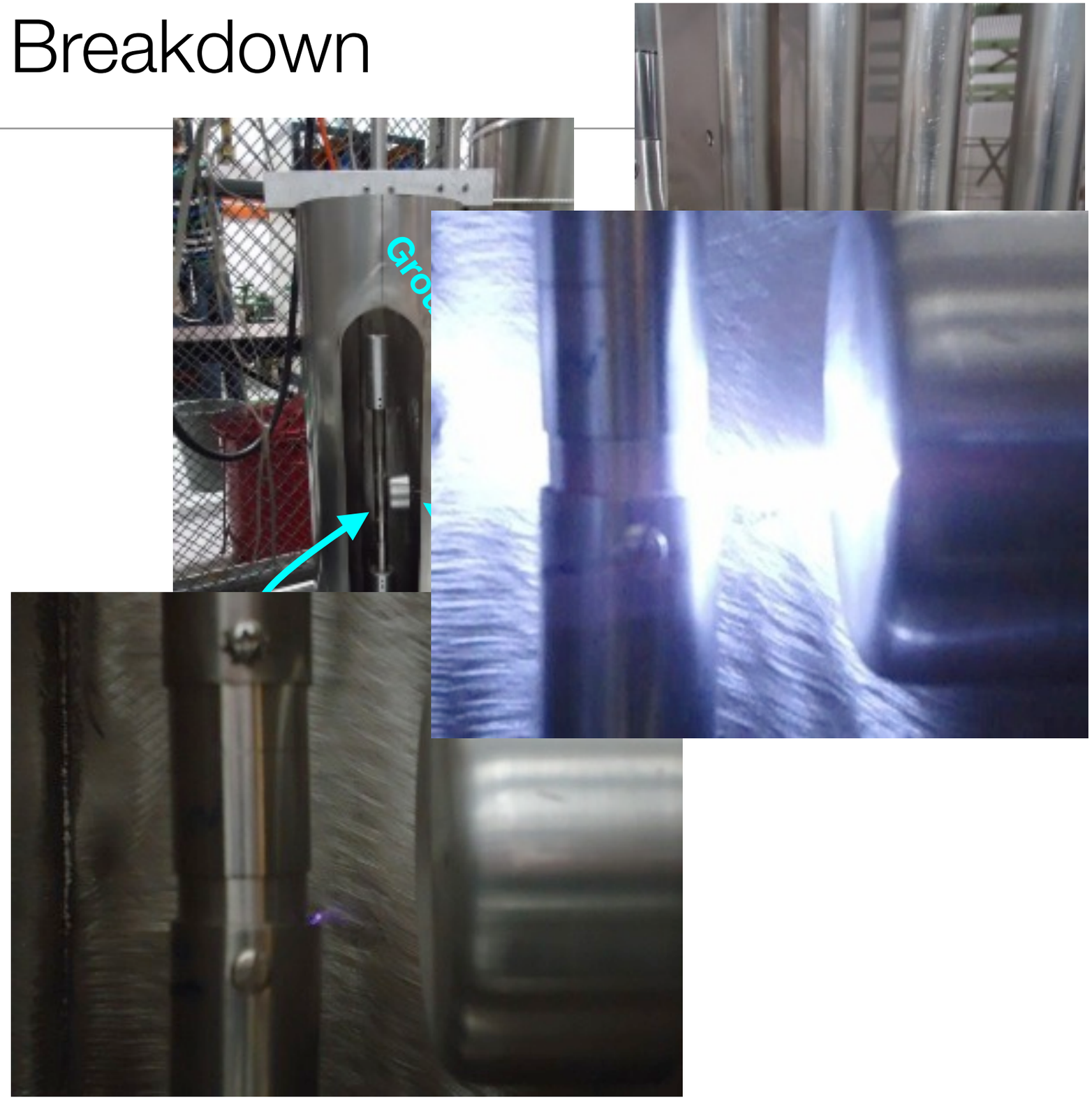

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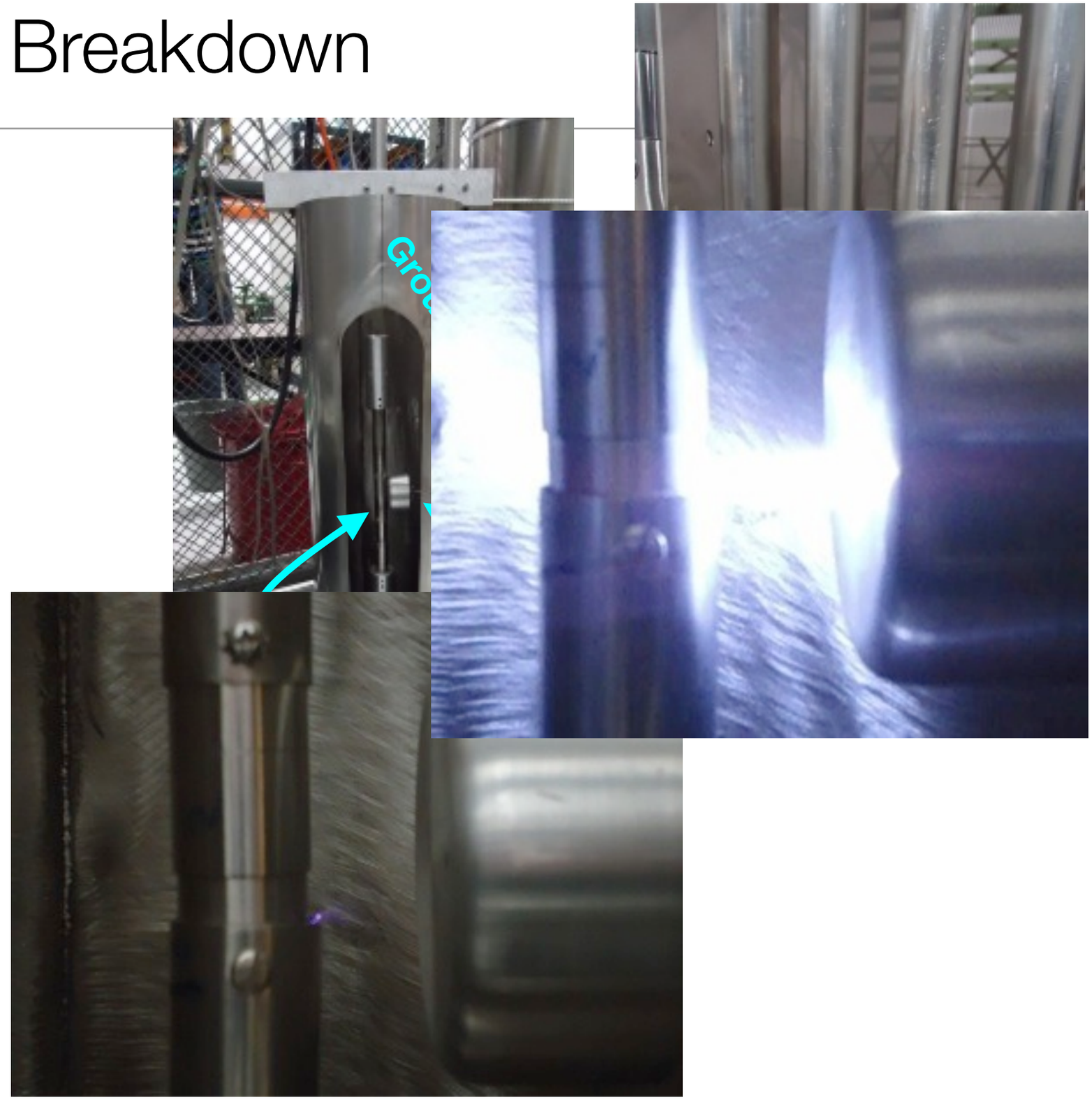
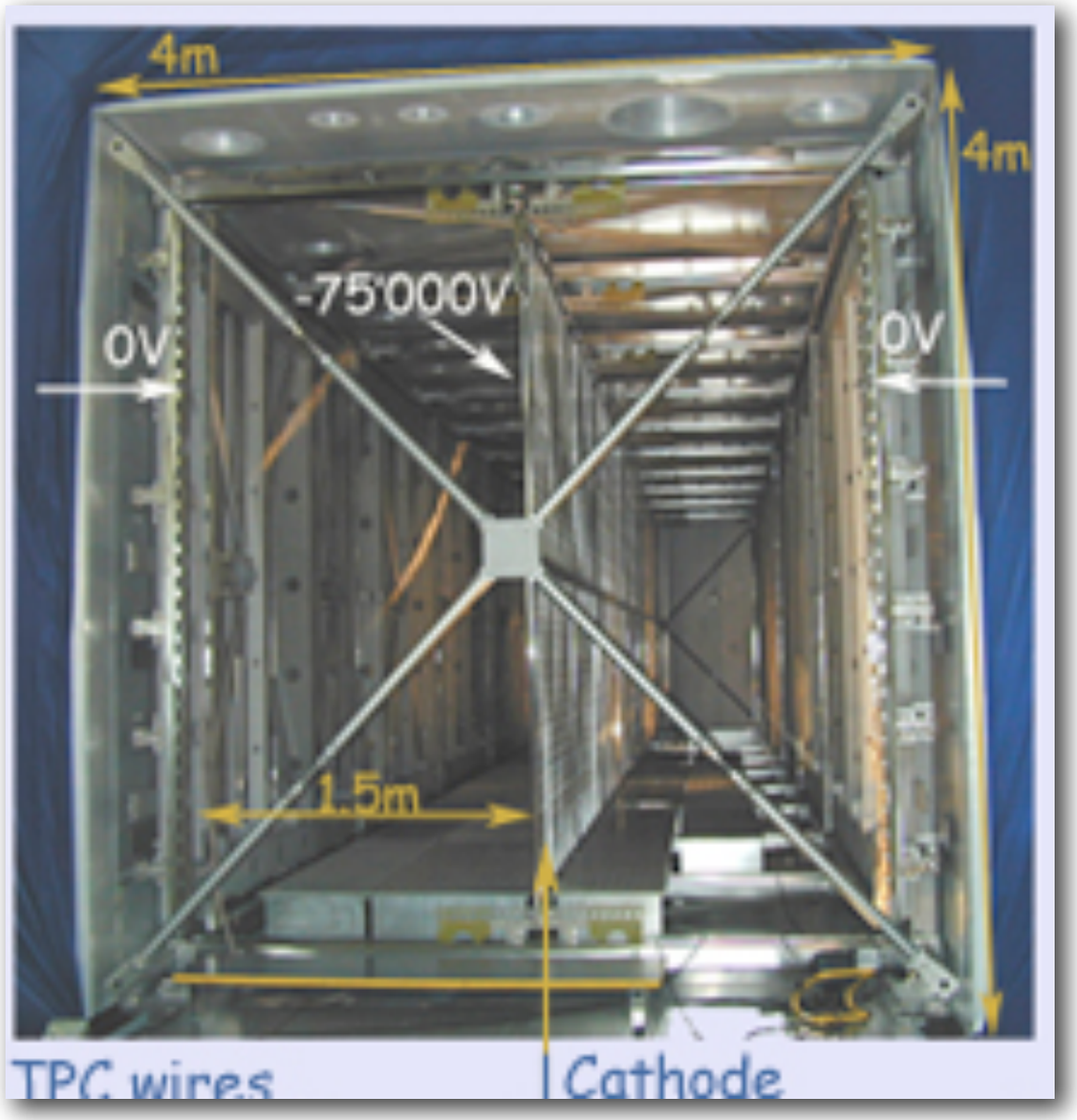


Experiments

ICARUS

- Pioneer in the field
  - Proposed by C. Rubbia in 1977
- ICARUS T600
  - 2001 Pavia: 100 days on surface
  - 2010-2013 Gran Sasso: filled with 760 tons LAr (477 t)
  - 1.5 m drift; 75 kV on cathode



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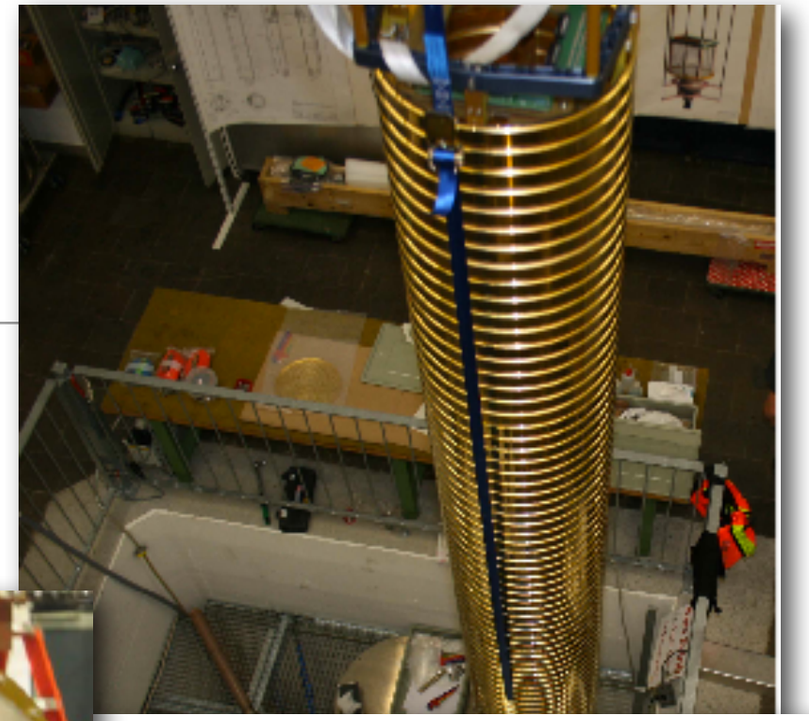

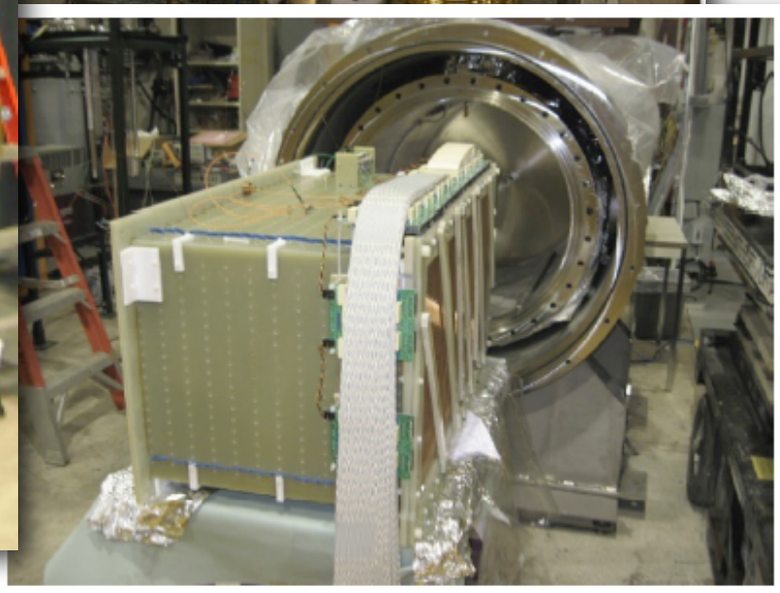

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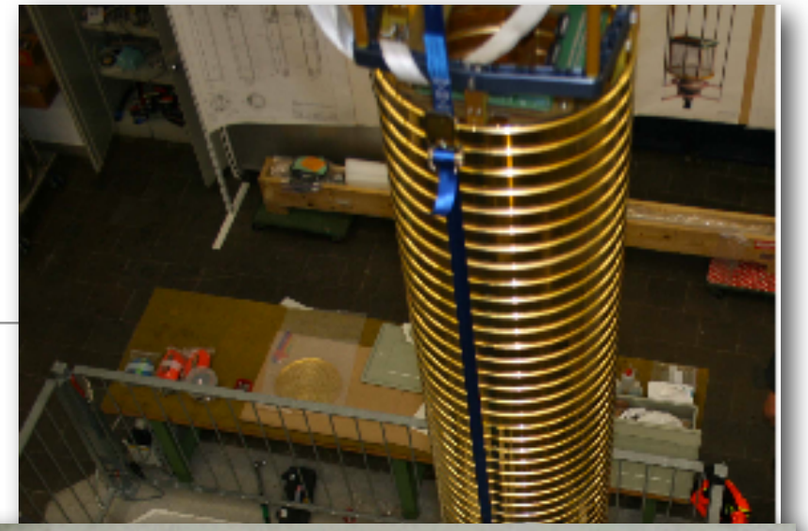

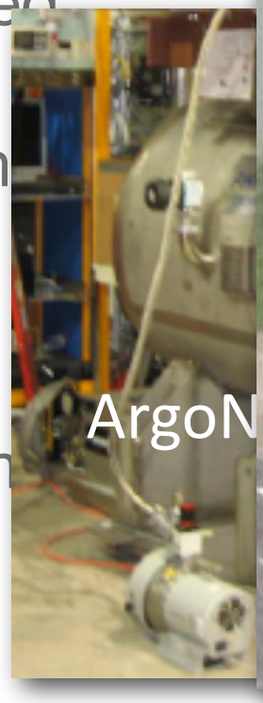

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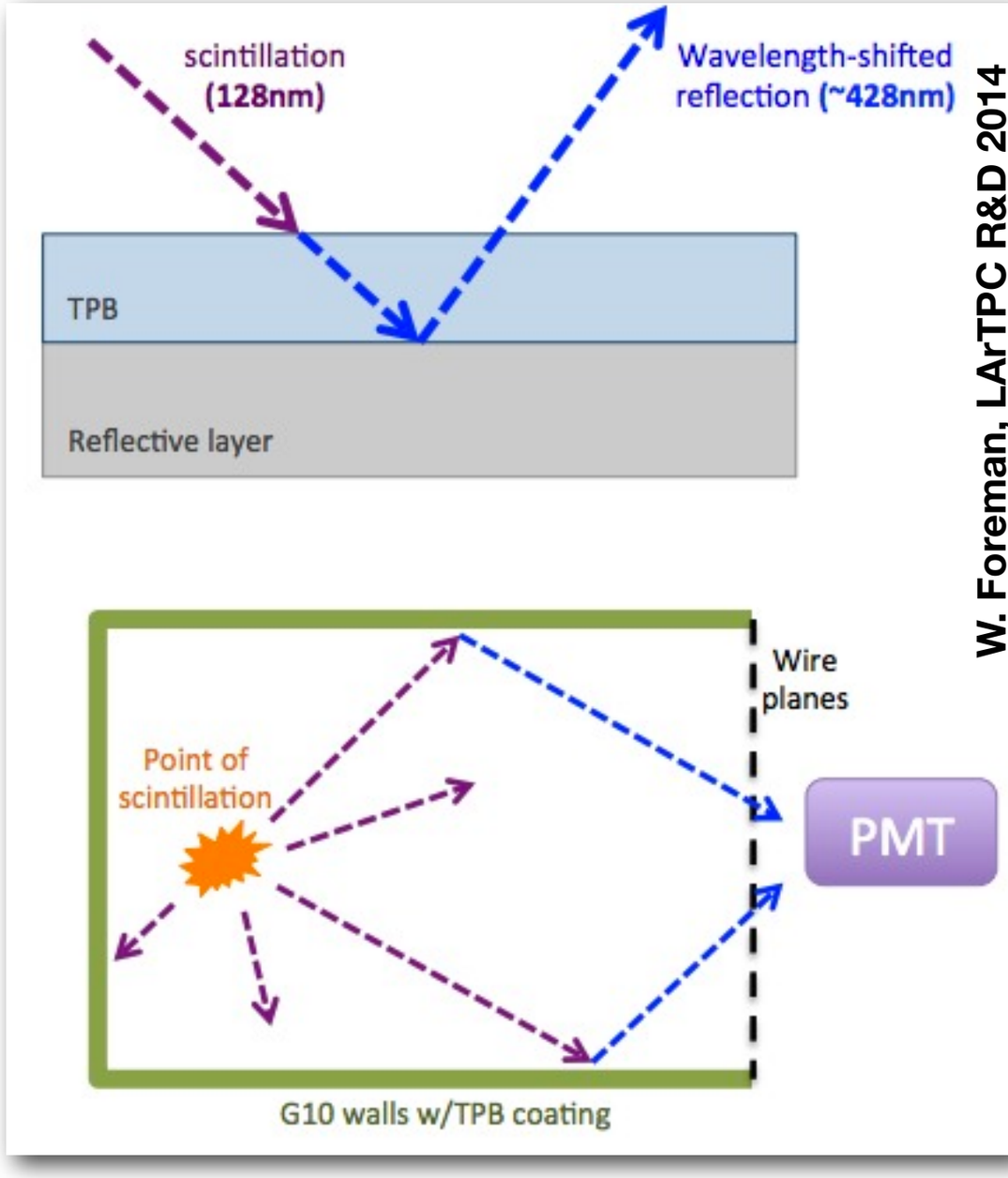
- CAPTAIN (Los Alamos): Idea is to have a mobile cryostat. 0.3 m^3; L_d=1m

A Few Words on LArIAT

- Resurrected Argoneut -- but better!
- Going in a test beam
  - (Not looking for neutrinos or specifically looking at cosmic rays)
  - Will improve our understanding of how charged particles interact in LAr
- Light collection is different
  - Walls of TPC have the wavelength-shifting coating
  - Want to increase light yield --> improve energy resolution
- Start running by the end of the year



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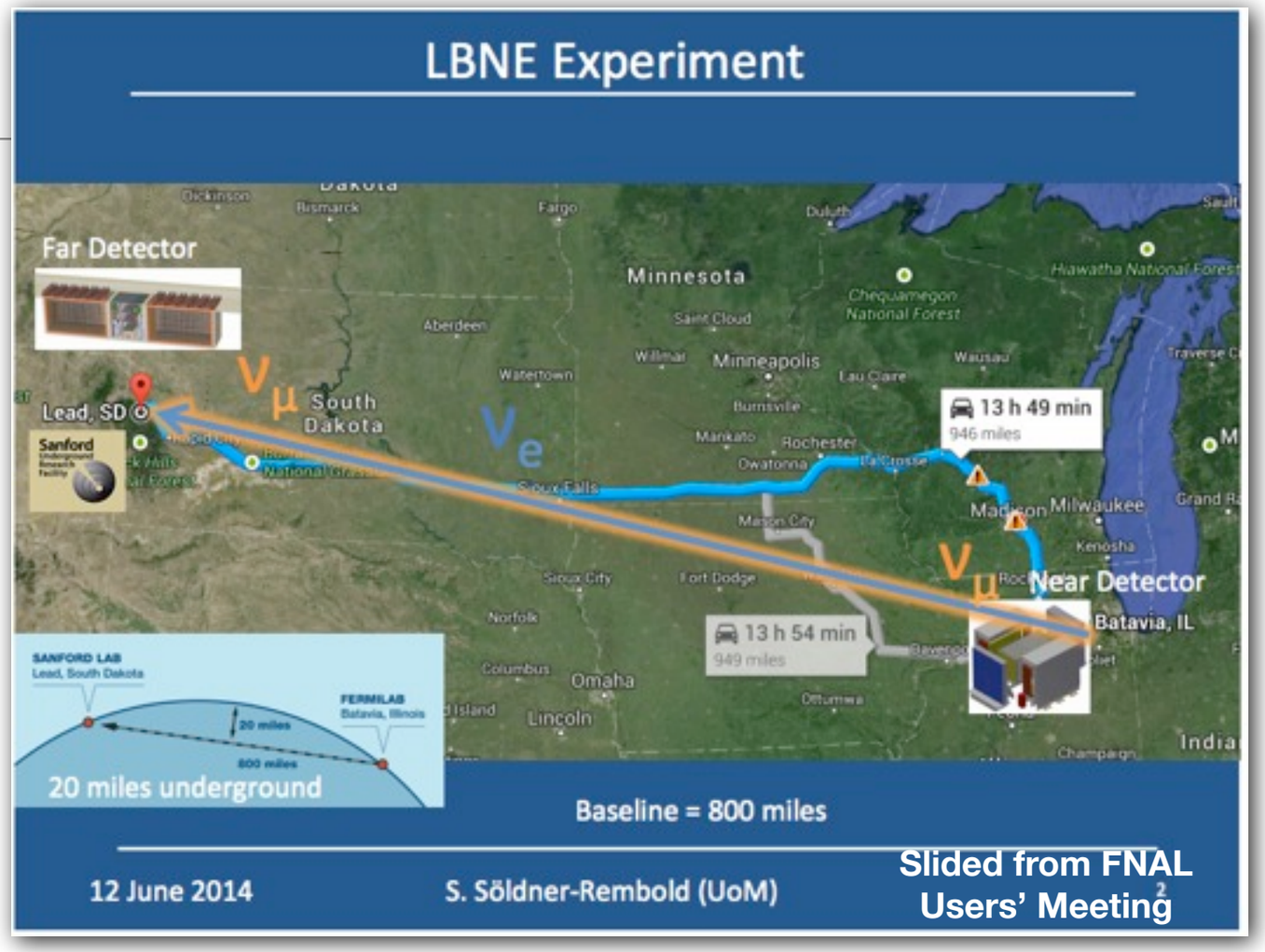

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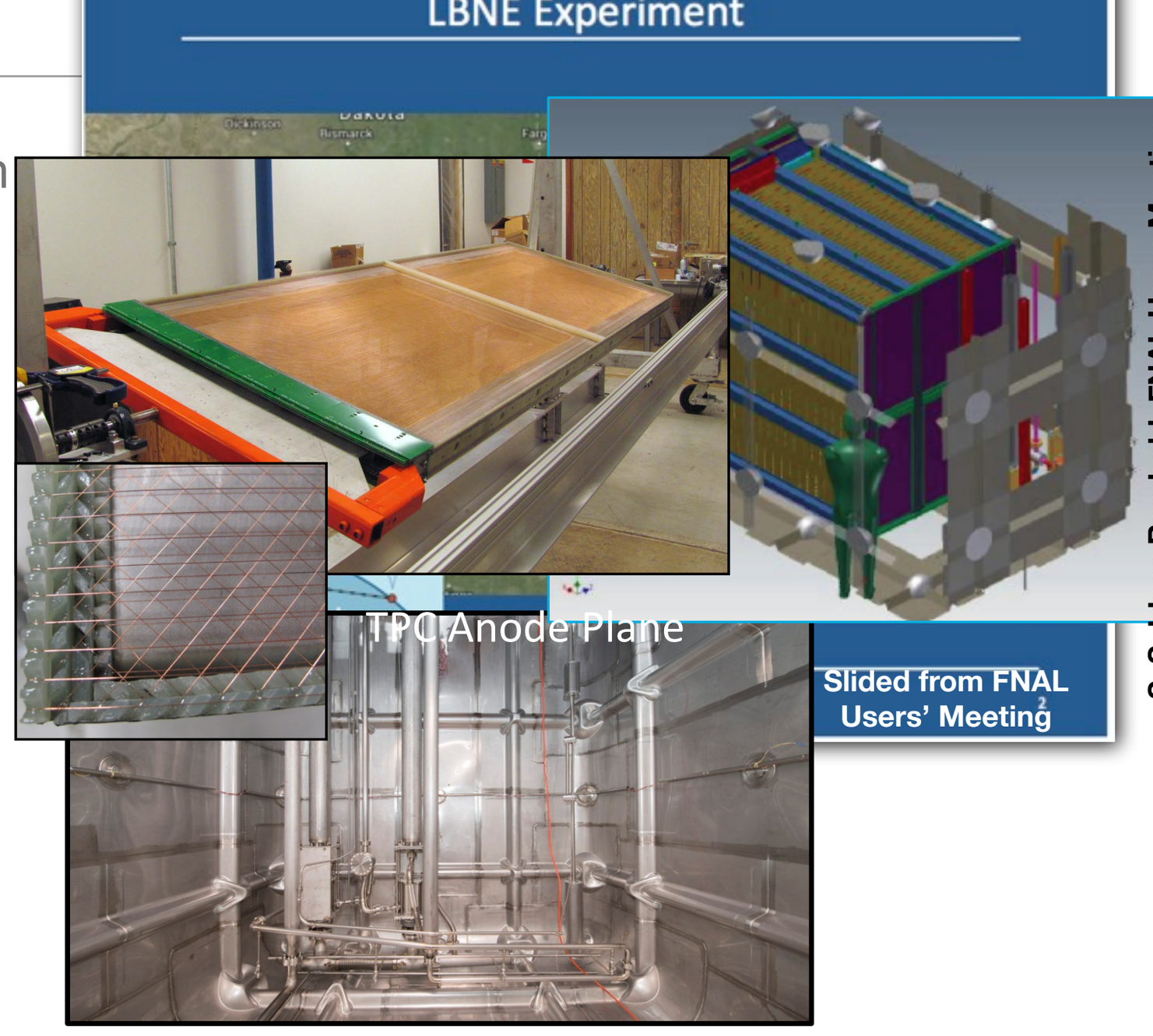

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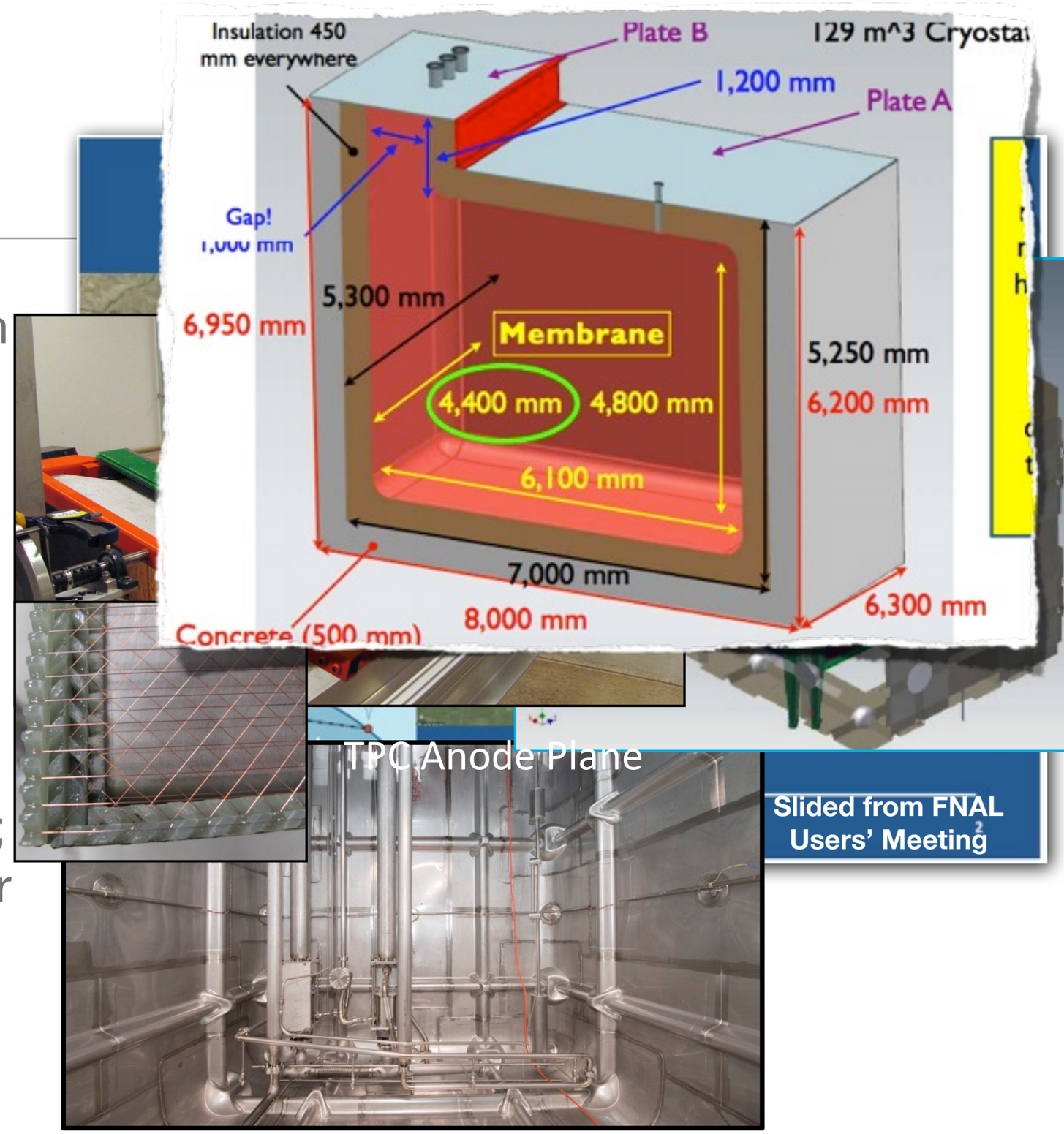

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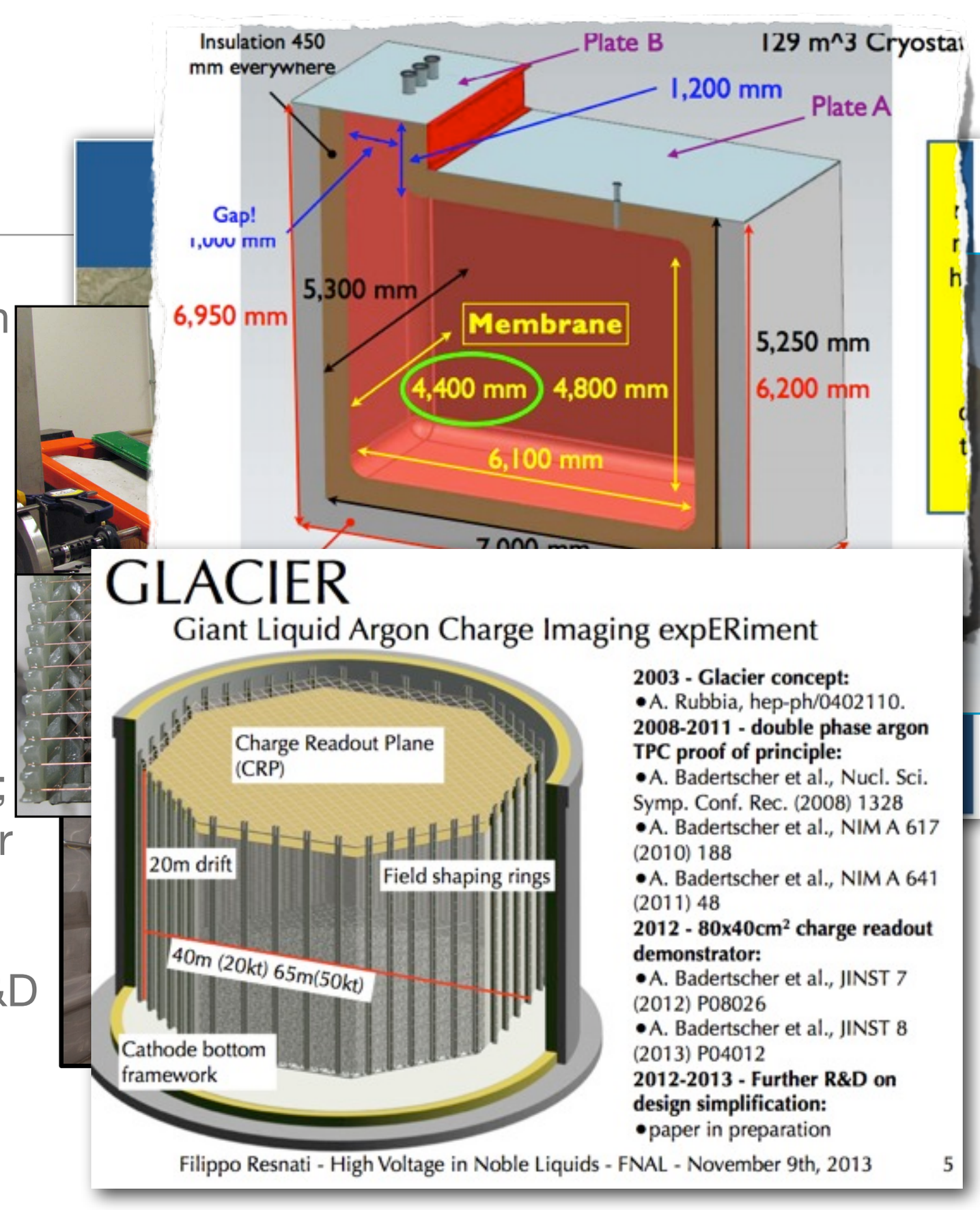
- GLACIER: European effort; R&D stages; 20 m drift, 20-50 kt; cathode HV at the **MV scale**

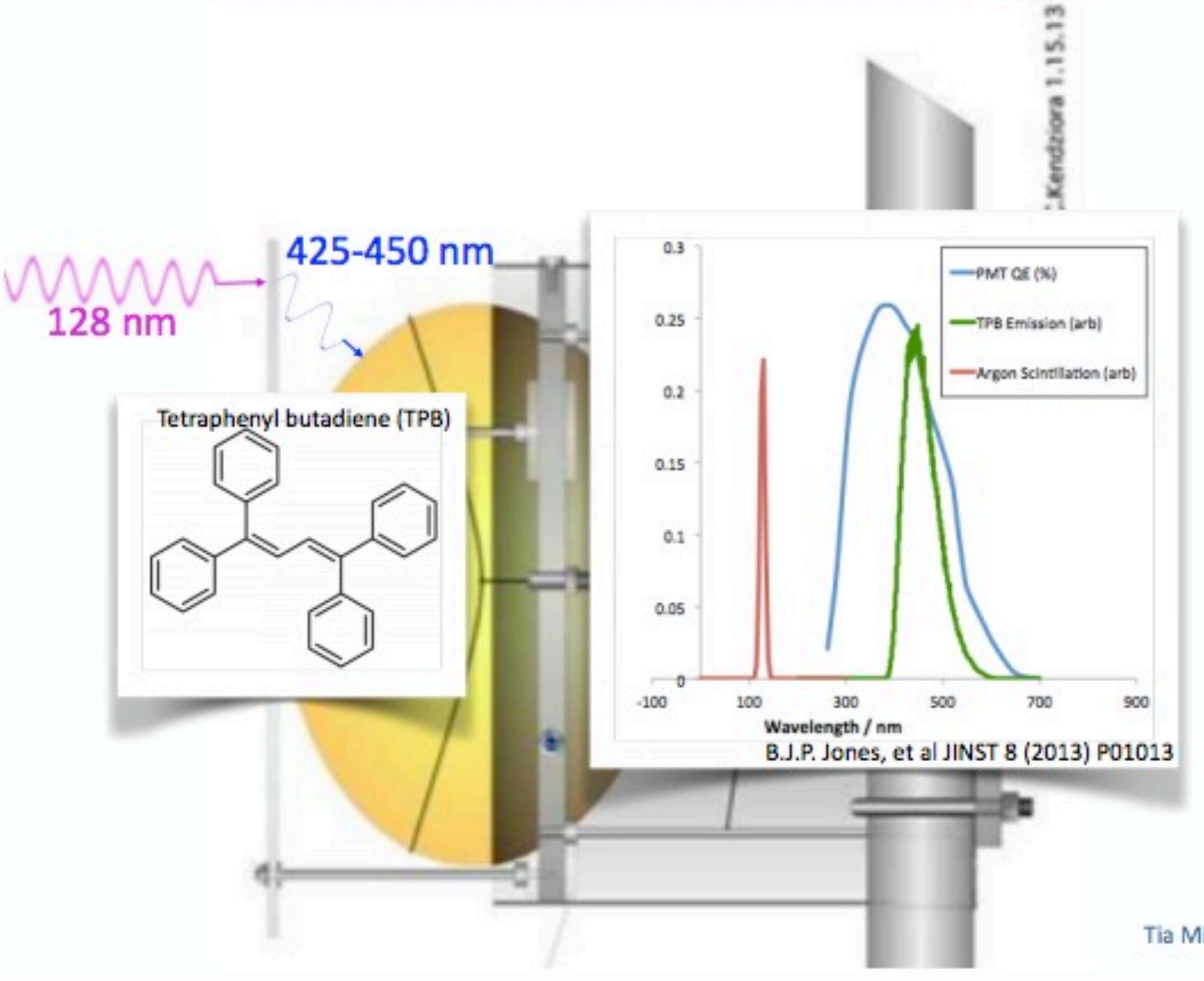


Closing Thoughts...

- I did not cover
  - Physics potential & event reconstruction efforts
  - Dual phase LArTPCs (used in dark matter searches)
    - My apologies if I forgot your favorite LArTPC in the review (feel free to tell me about it)
- LArTPCs are a rich area of research right now -- lots of physics on the horizon & (fun) R&D taking place!

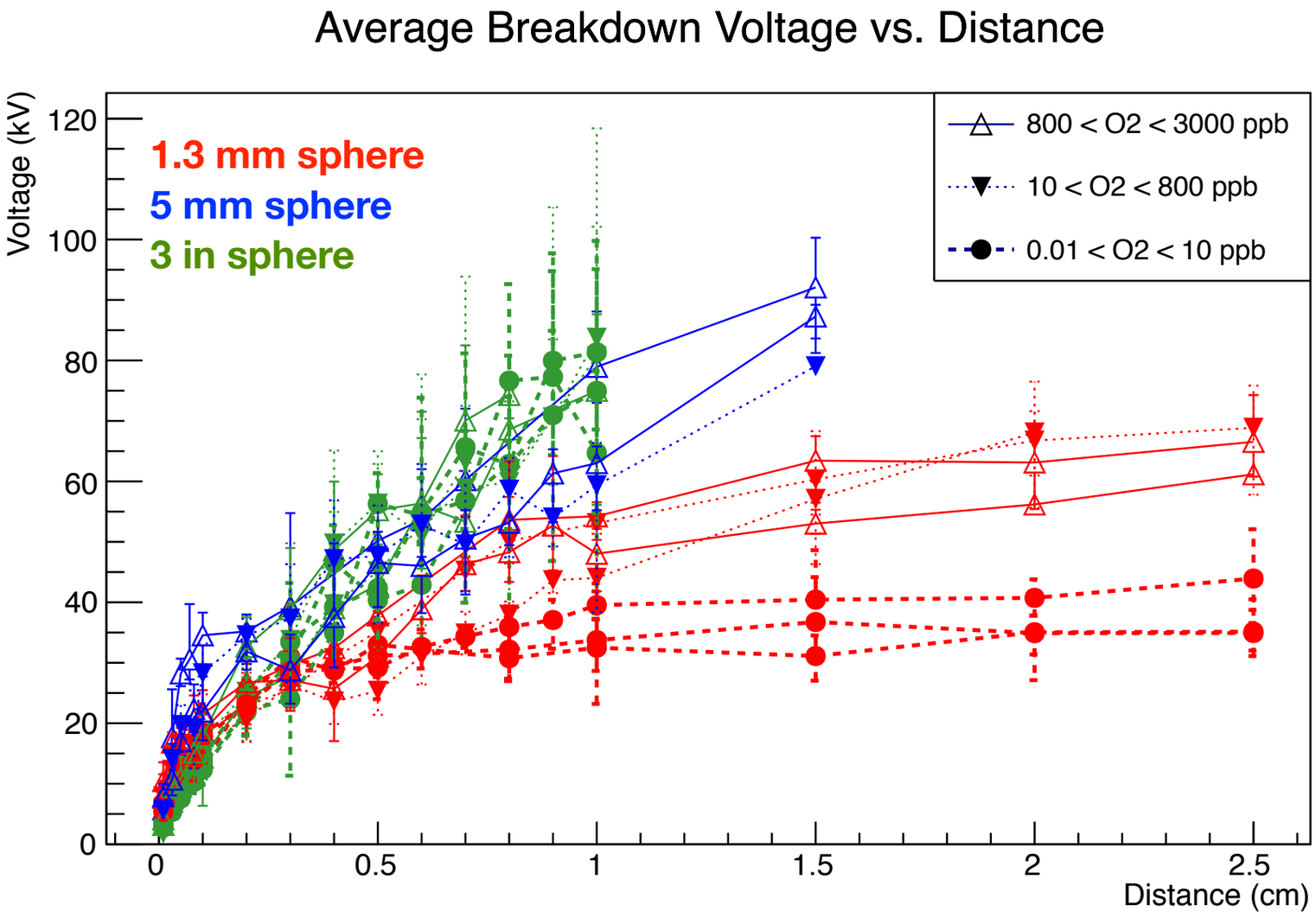
Back Up Slides

Detecting scintillation light



$V_{Breakdown}$ vs. Distance

- Plotted average V_{bd} at a given distance for a given date's data (specific purity and probe)



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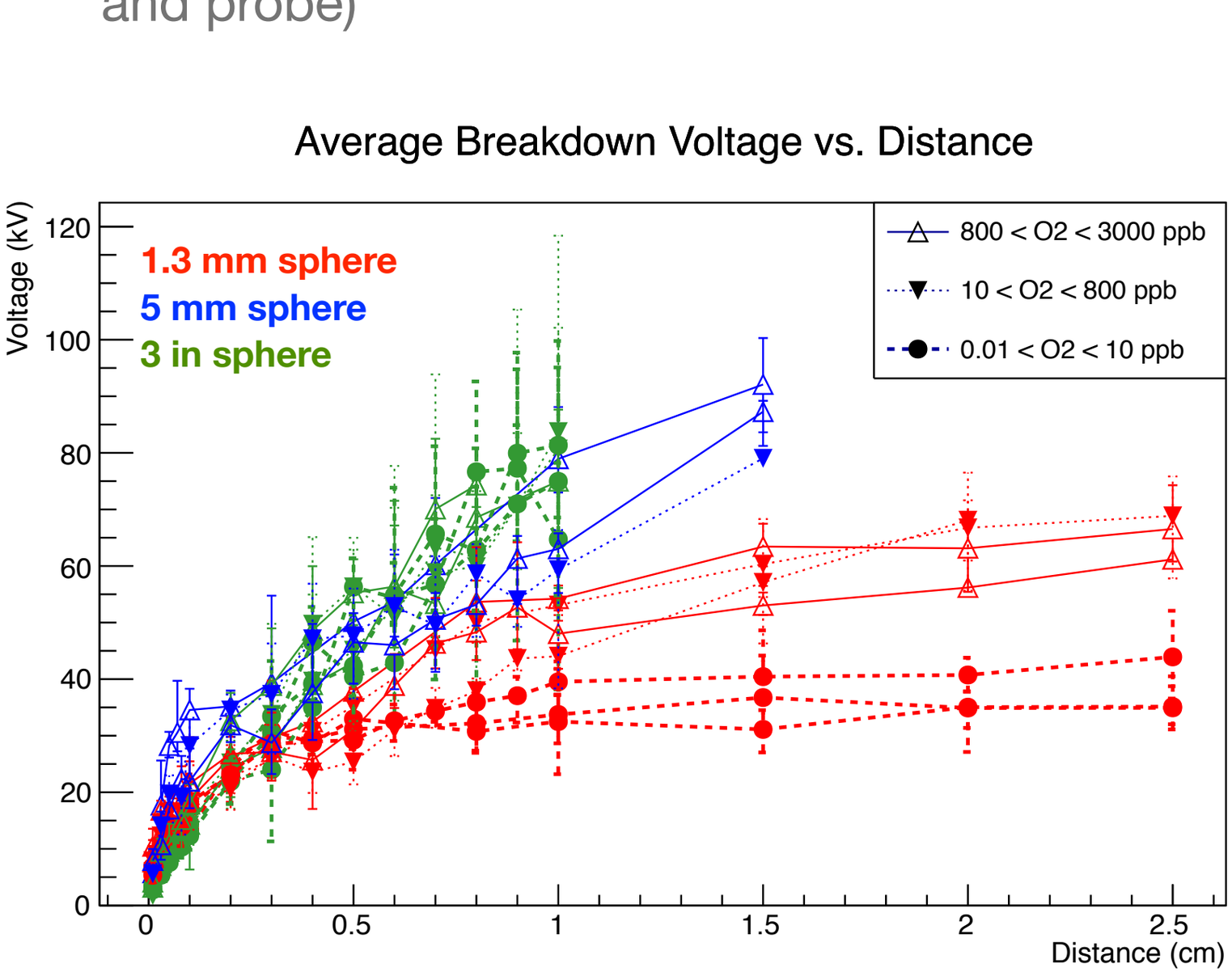

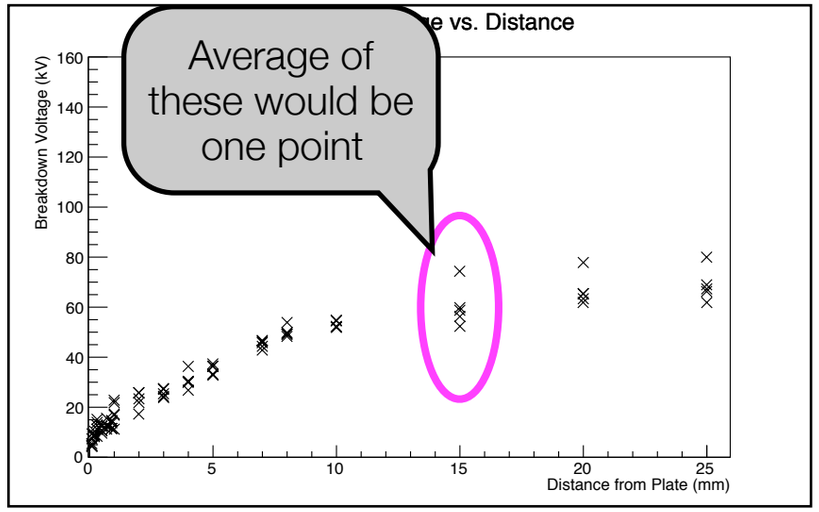

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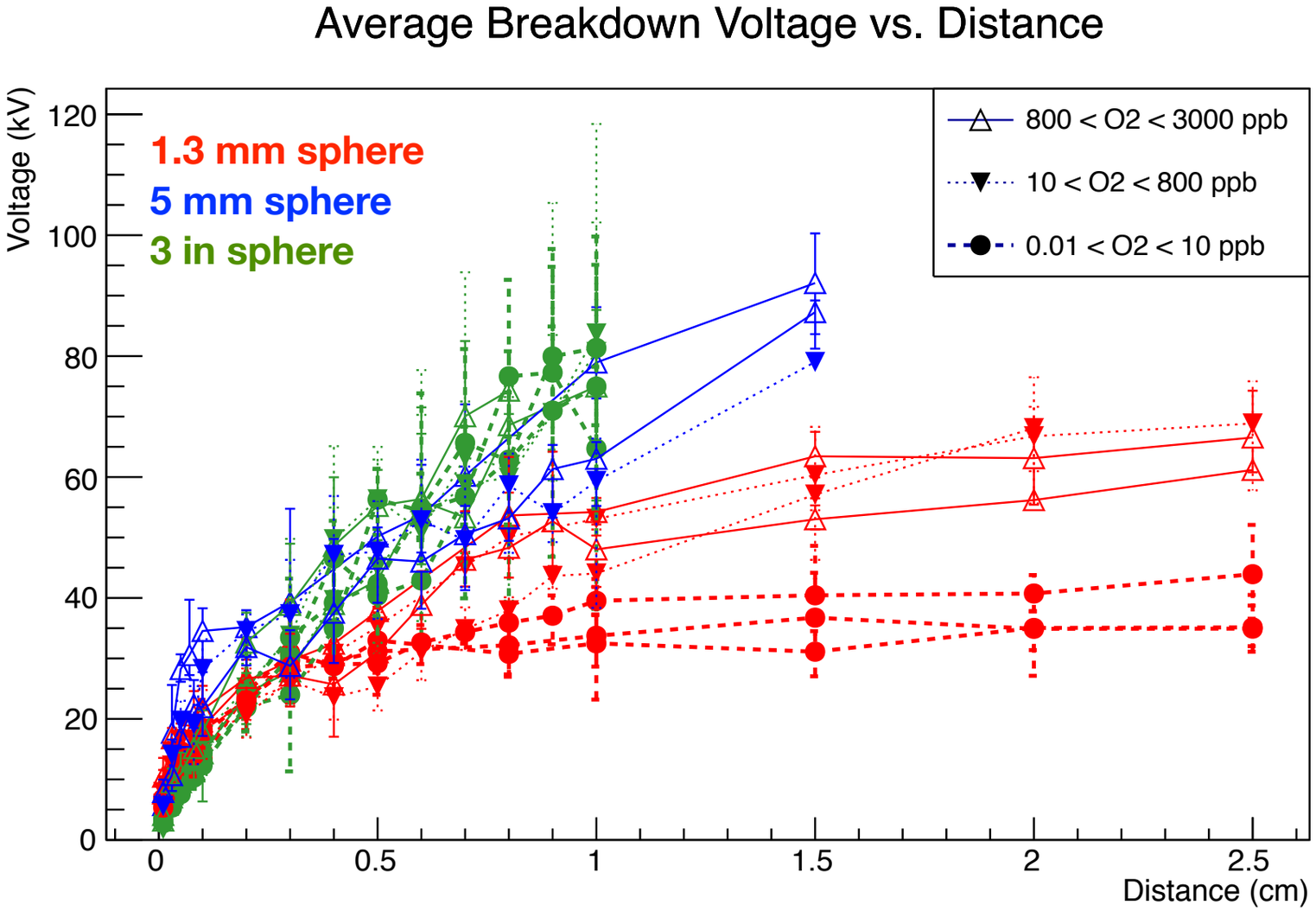
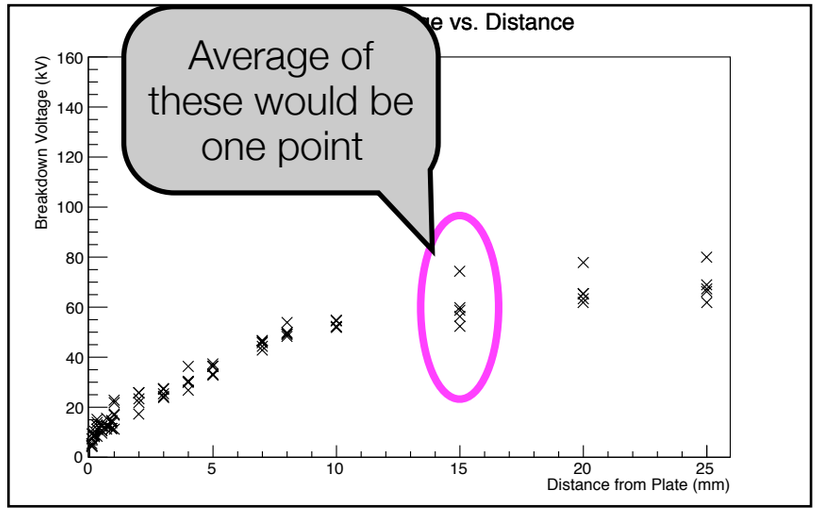


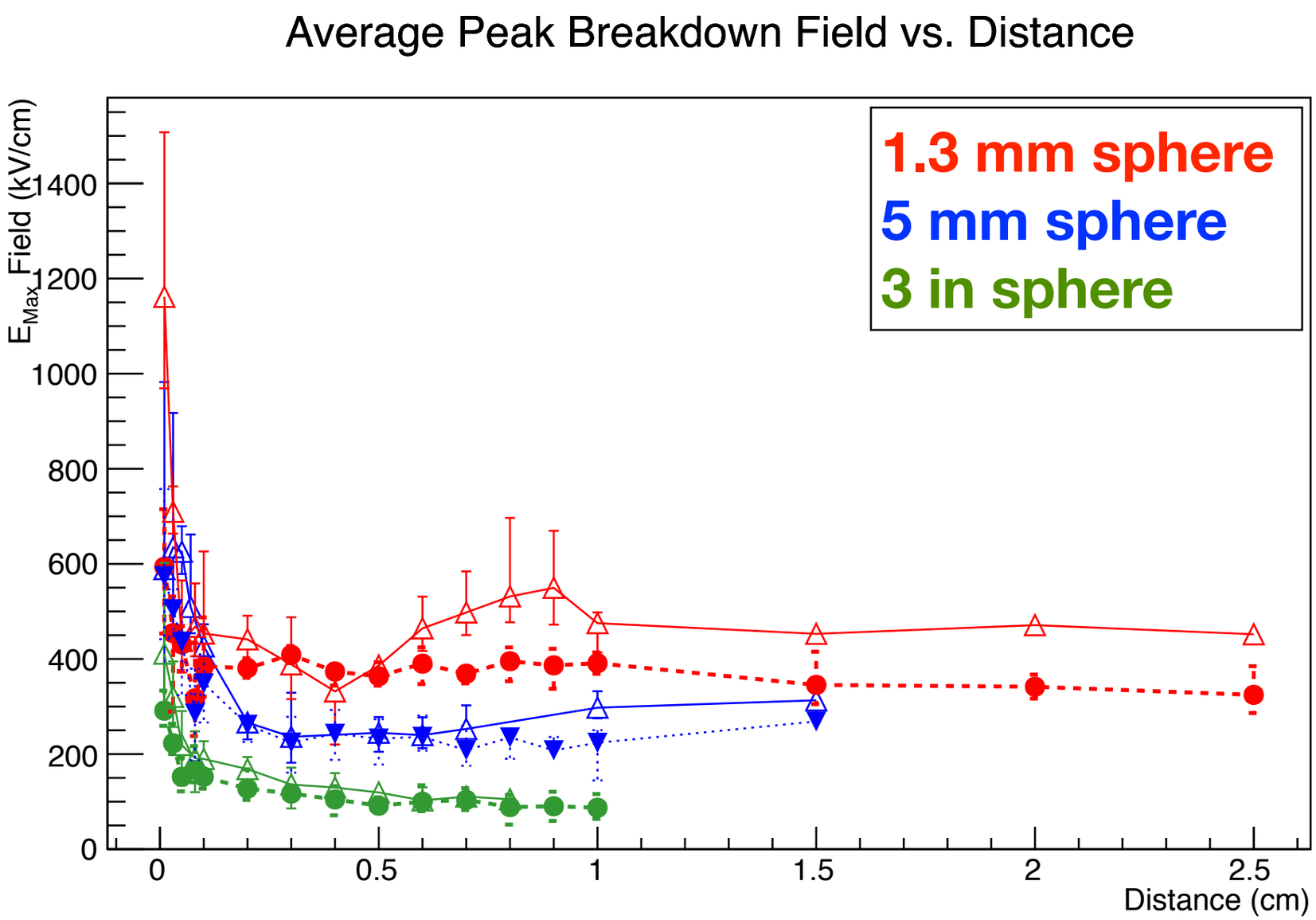


10-1400 ppb O_2

0.29-1.8 ppb O_2

E_{Max} vs Distance

- Doesn't appear to be just E_{max}



Other Quantities of Interest

Gerhold *et al.*, Cryogenics (1994)

Area effect

The impact of an area effect on LHe breakdown has been recognized by several authors. It is generally accepted that LHe breakdown is triggered at weak-links adjacent to the cathode, i.e. protrusions. The area

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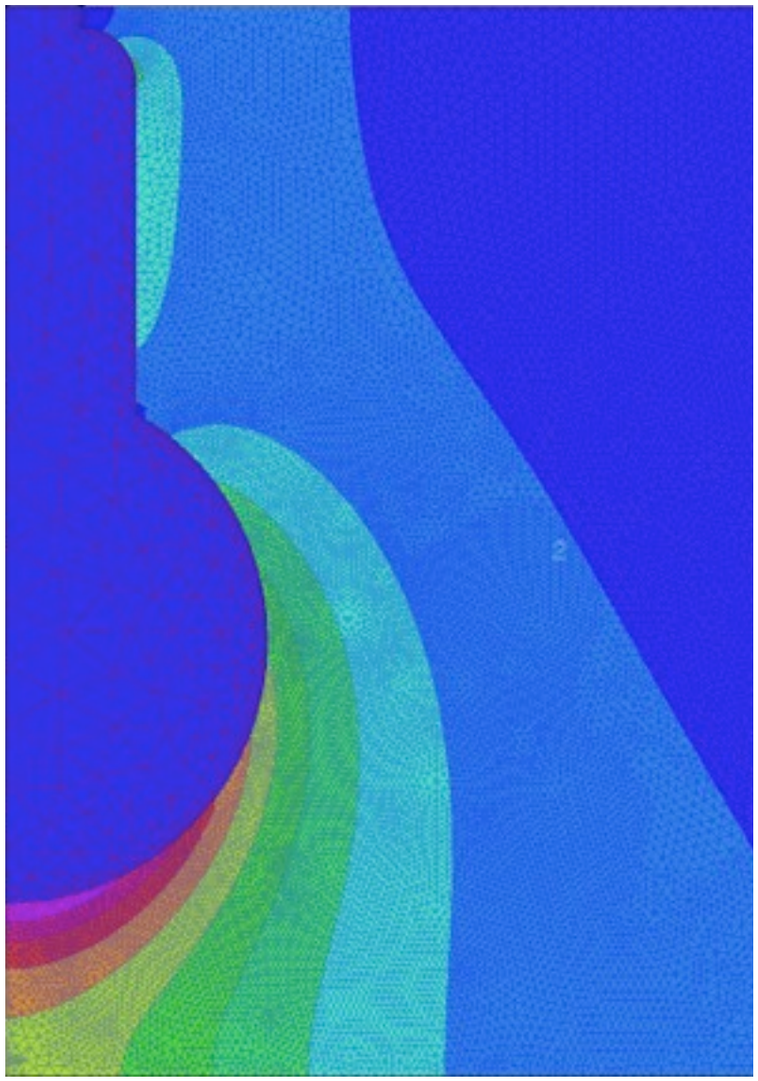

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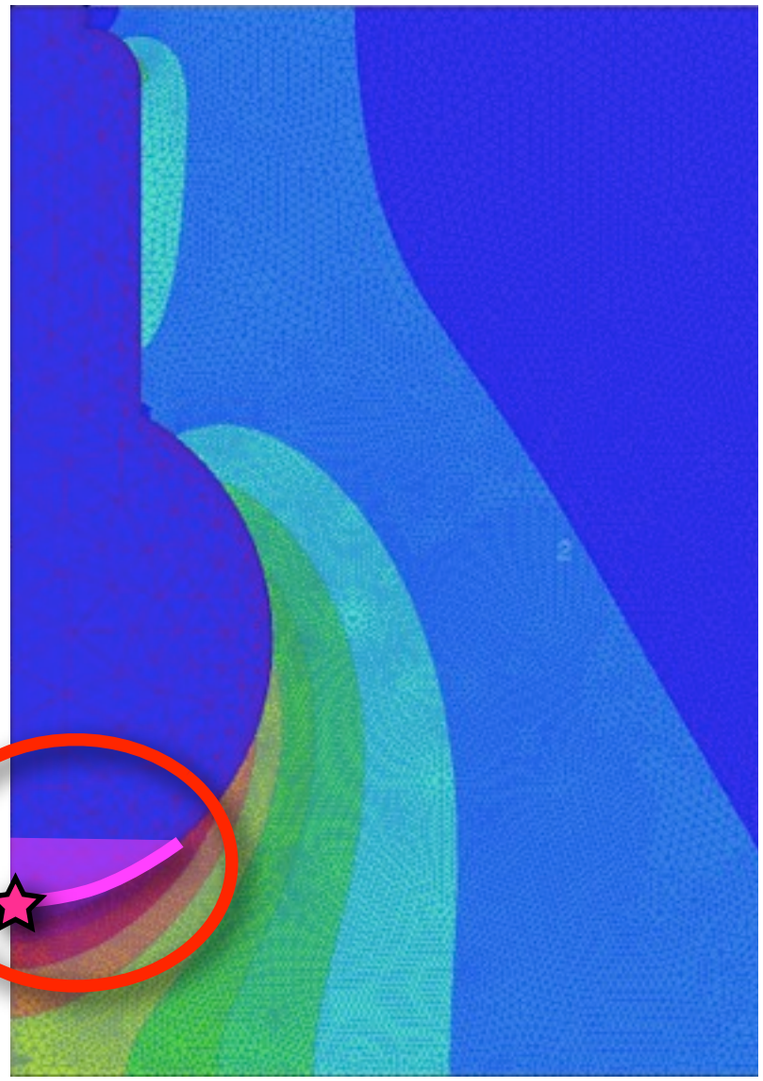
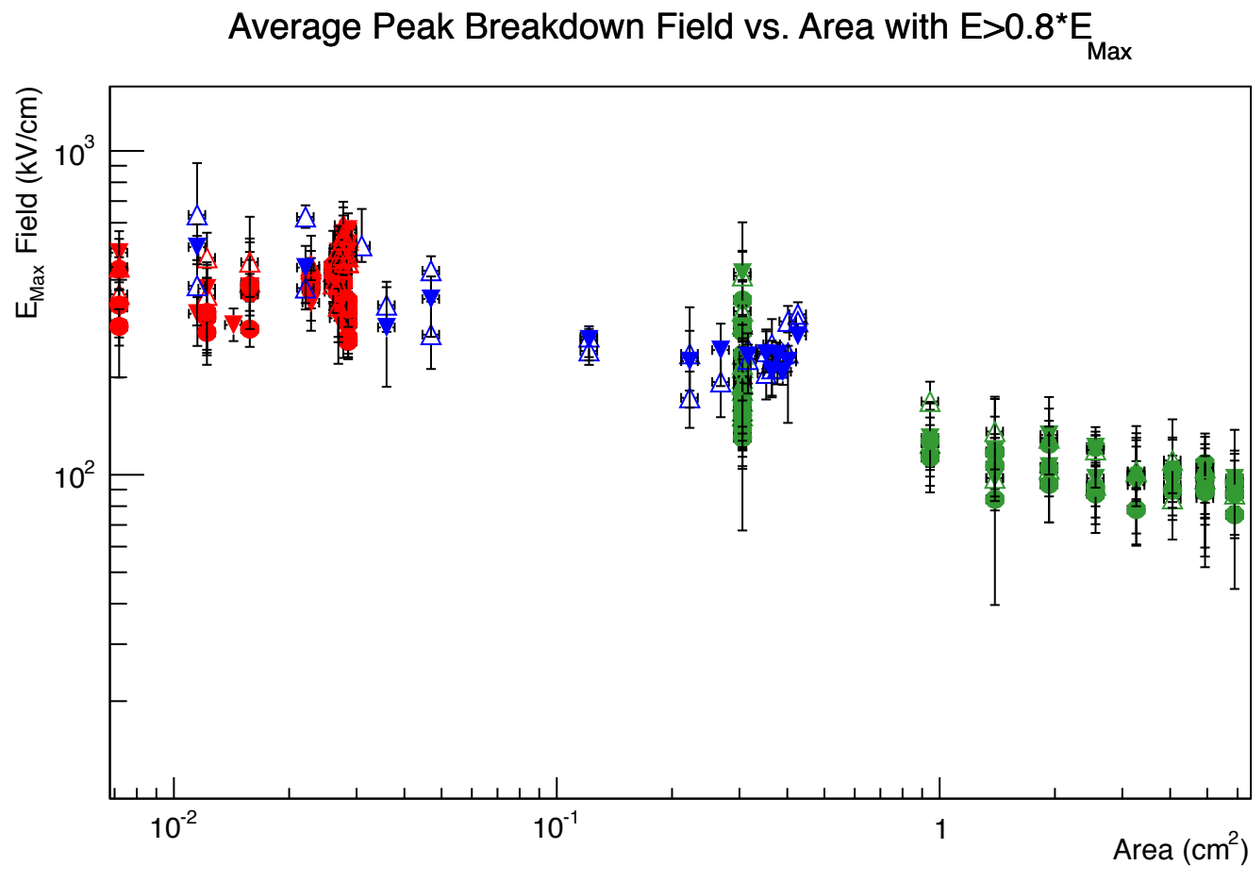
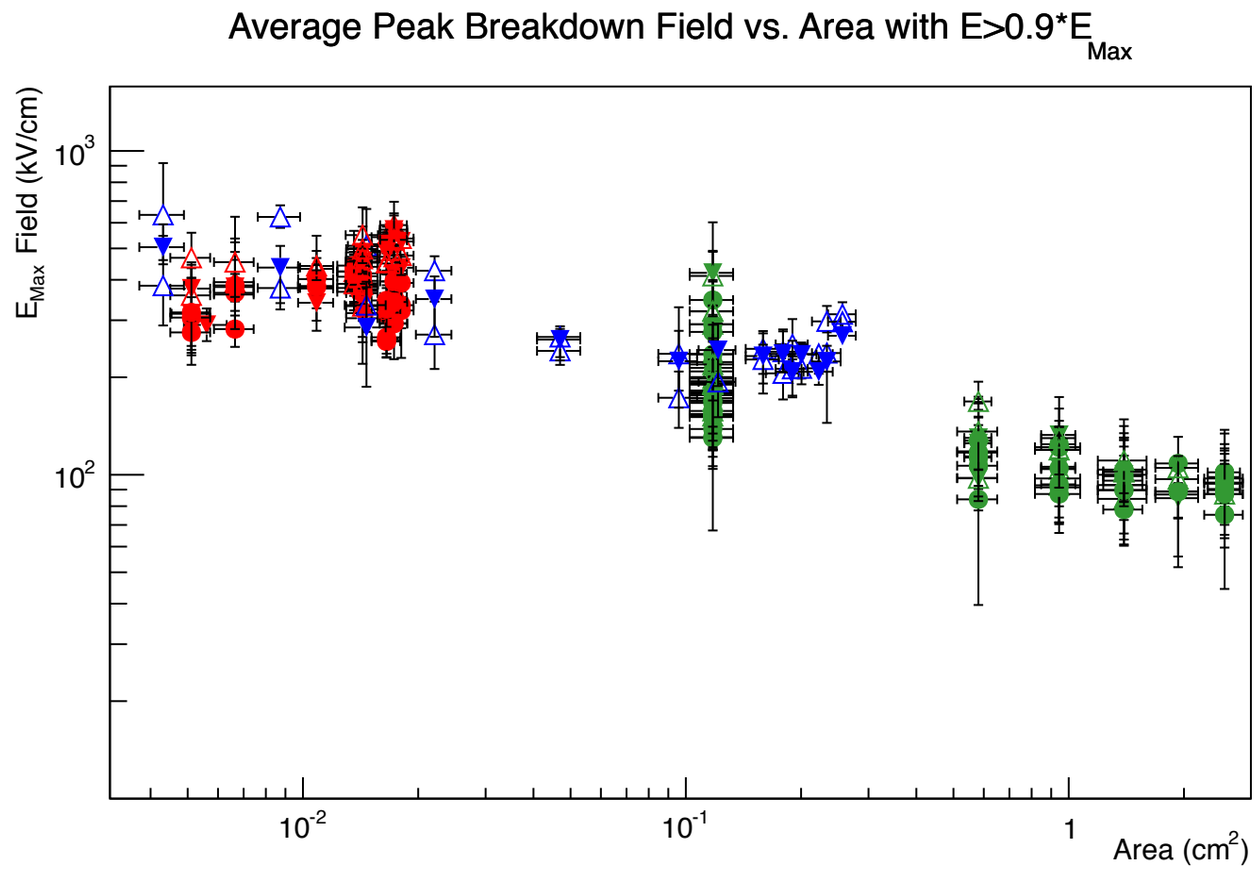


Stressed area, peak field is at the star, shaded pink has $E>80\%*E_{max}$

Other Quantities of Interest

- E_{max} vs Area (80% E_{max} left; 90% right)





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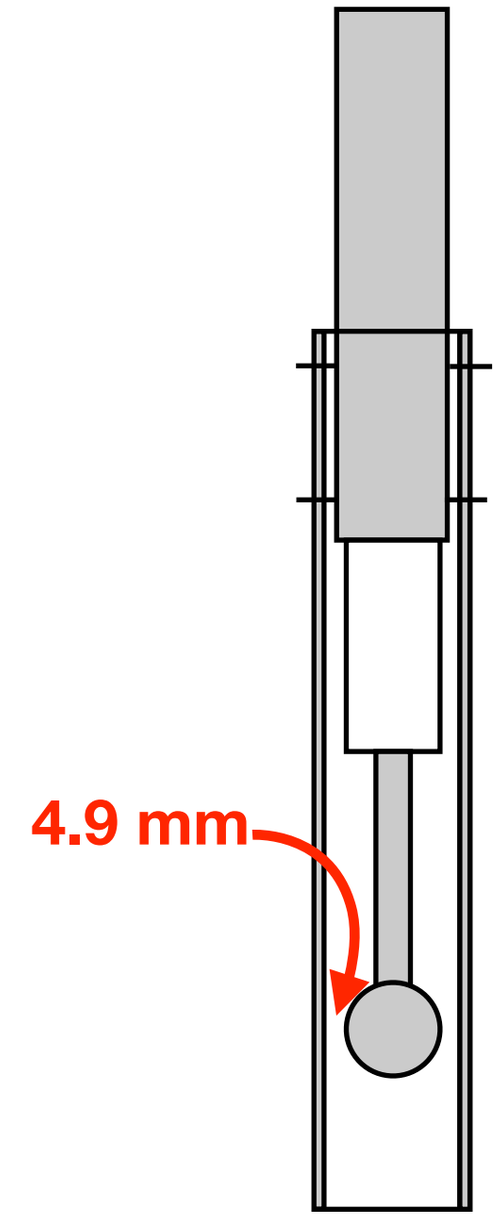

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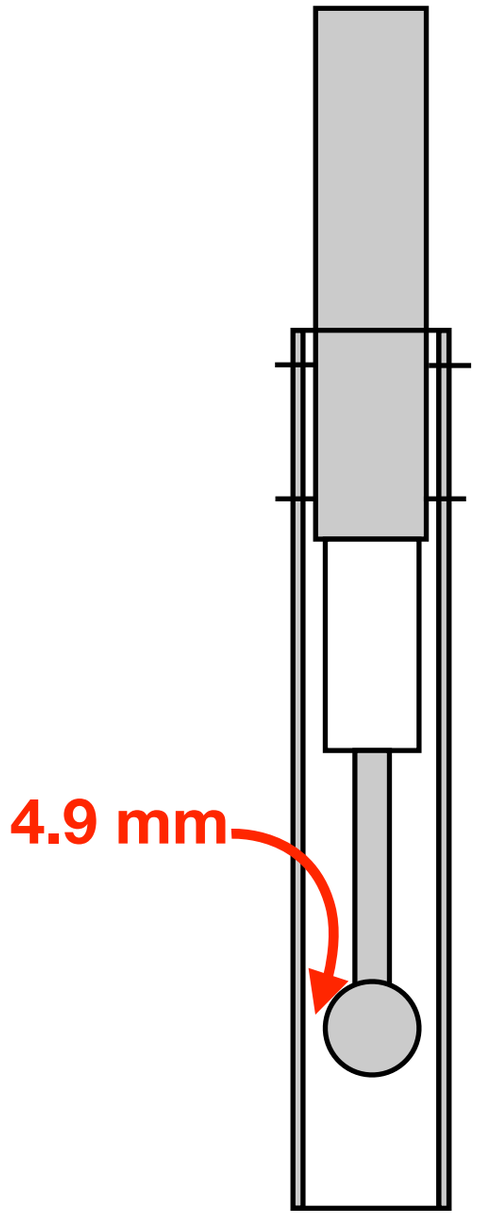

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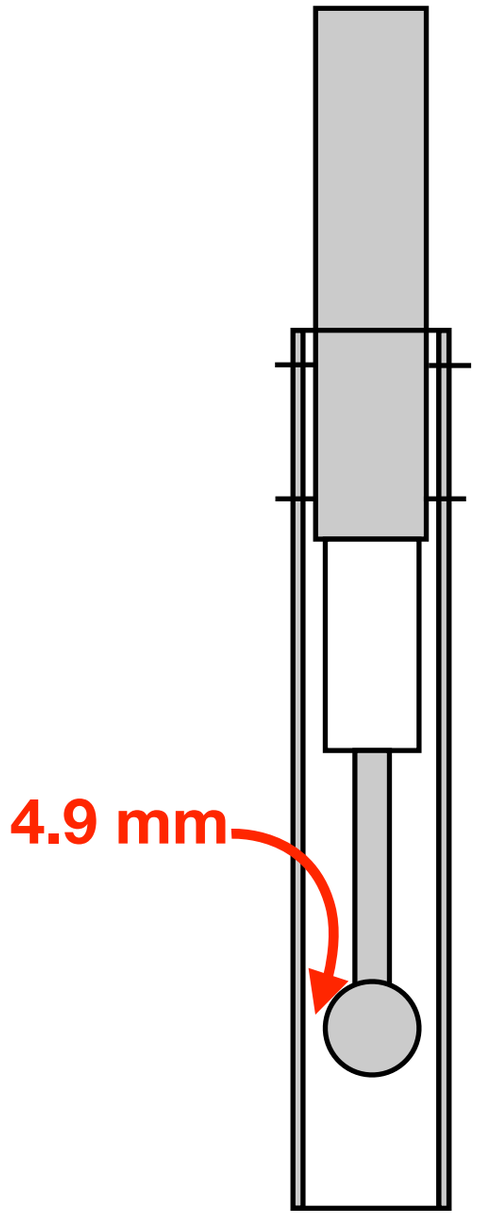
  - (so we likely will not publish this)



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- (80%: 37.6 cm^2, 90%: 24.7 cm^2; E_{max}: ~52 kV/cm)