Detector R&D with Negative Ion Mixtures

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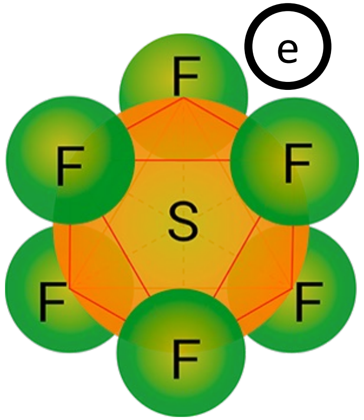
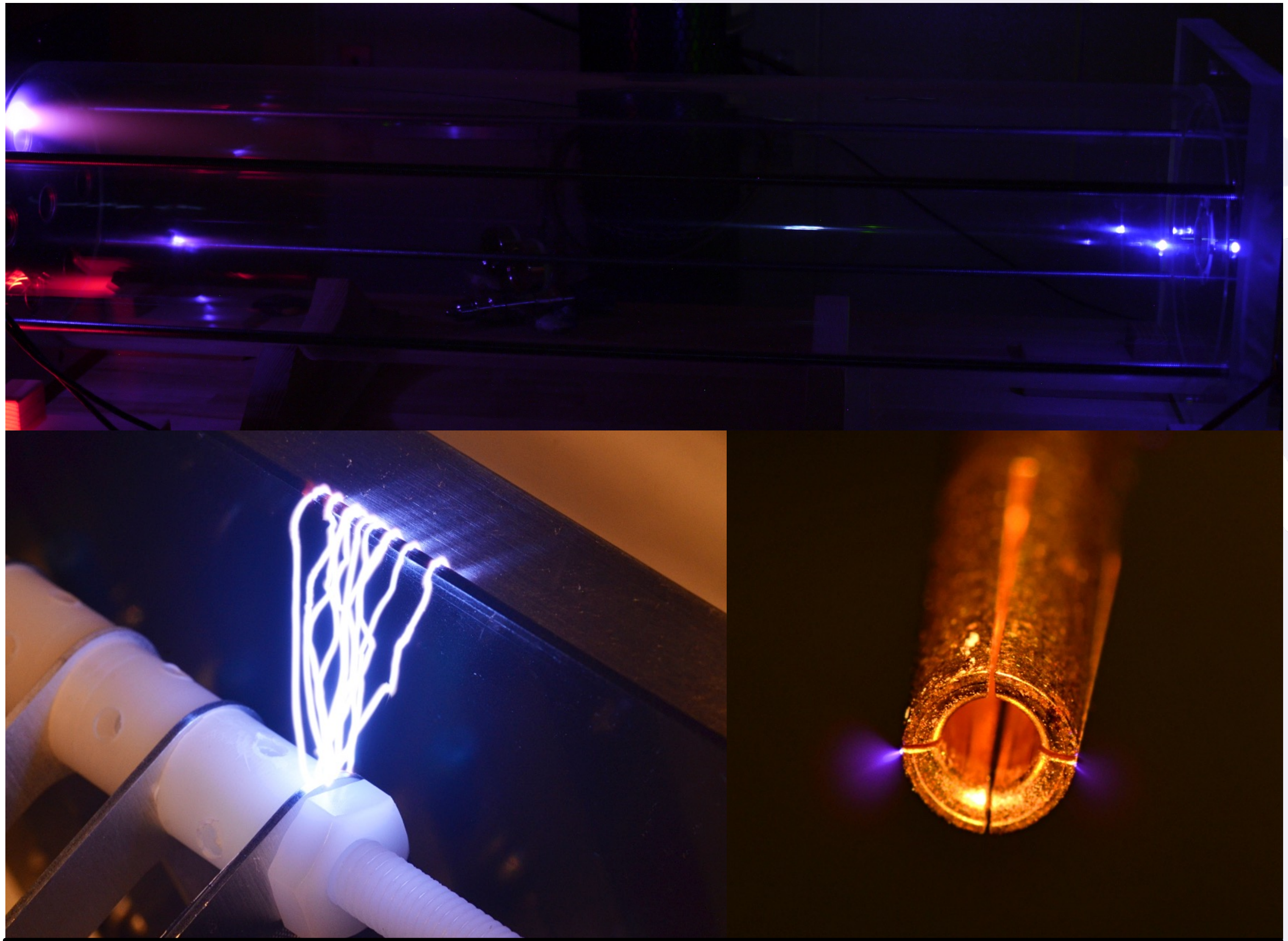
8th CYGNUS Workshop on Directional Recoil Detection – Sydney – 2023

Outline

- A motivation
  - Dual-phase TPC
- SF_6 measurements @ Hawaii
- SF_6 measurements @ CERN
- Argon-SF_6 measurements @ CERN
- Plans at LANL/UNM

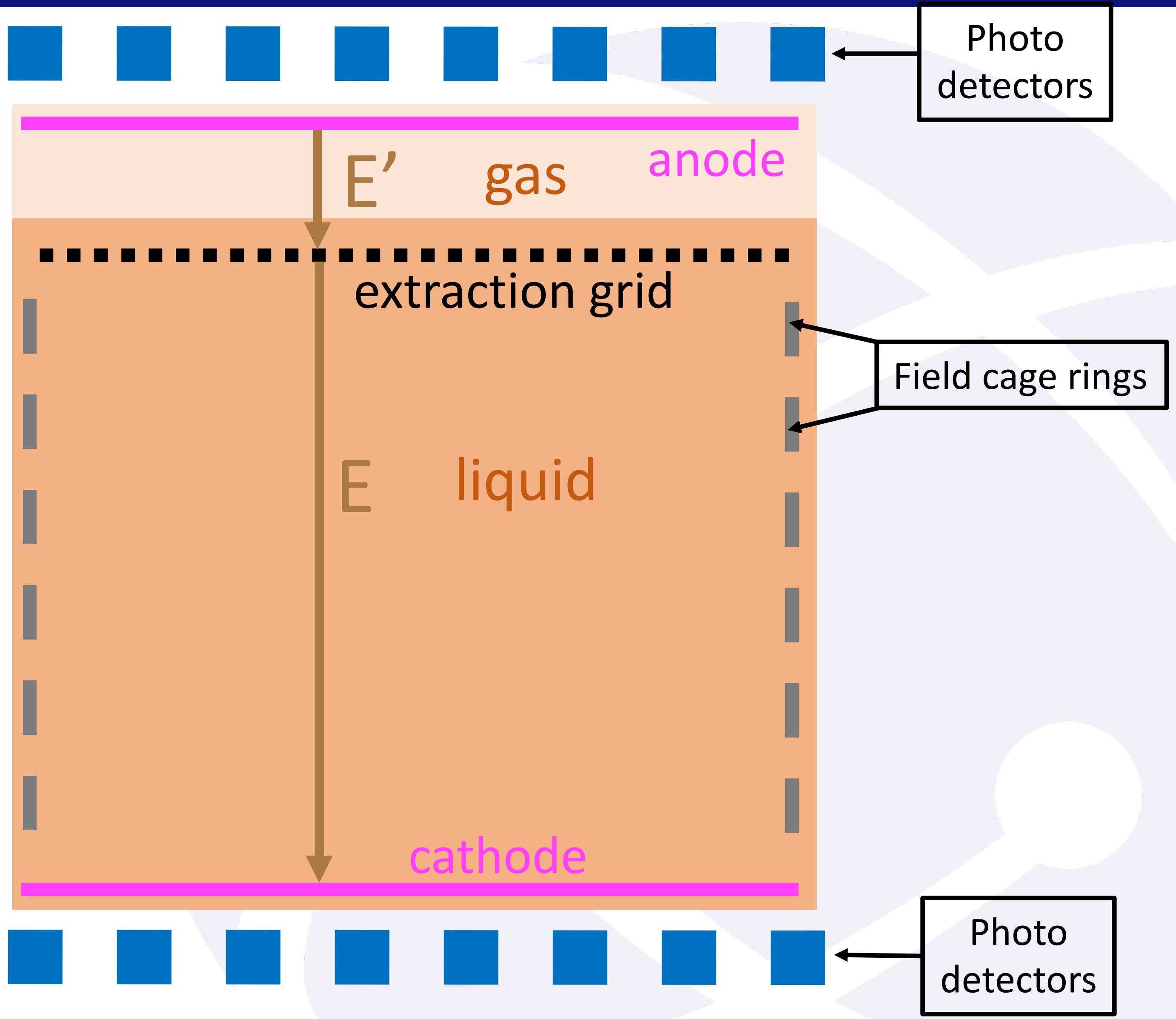




Sparking/corona discharge in Hawaii detectors

Dual-Phase Time Projection Chamber (TPC)

- Small gas pocket maintained above the liquid
- Higher electric field across gas pocket than liquid



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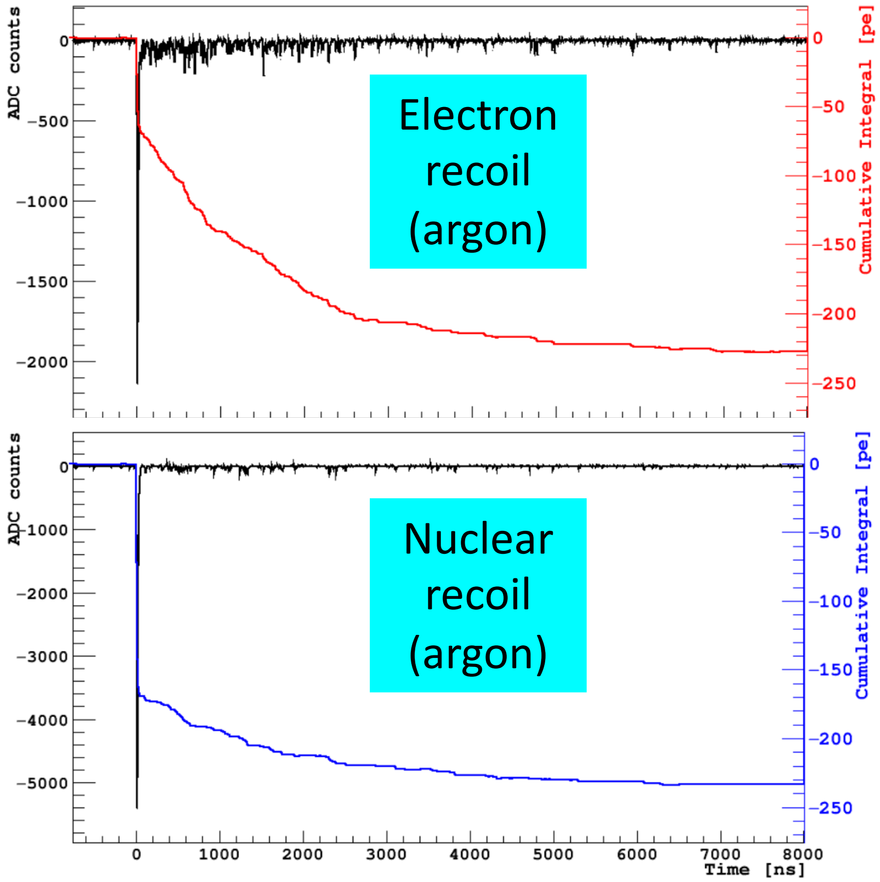
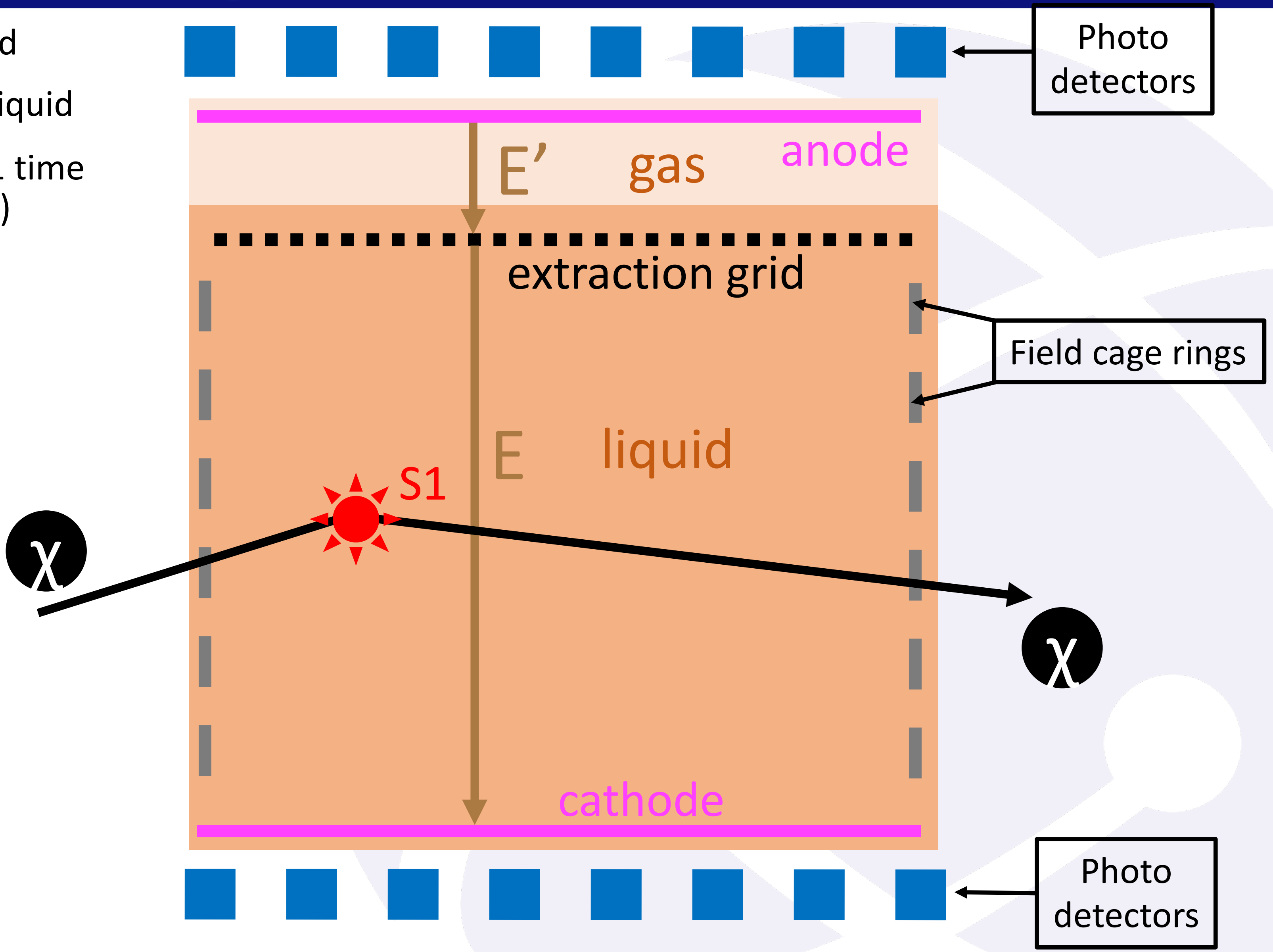
- Electron recoil discrimination exploits the S1 time signature – Pulse Shape Discrimination (PSD)





Dual-Phase Time Projection Chamber (TPC)

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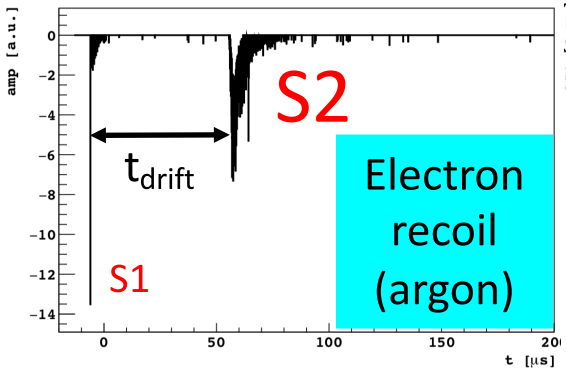
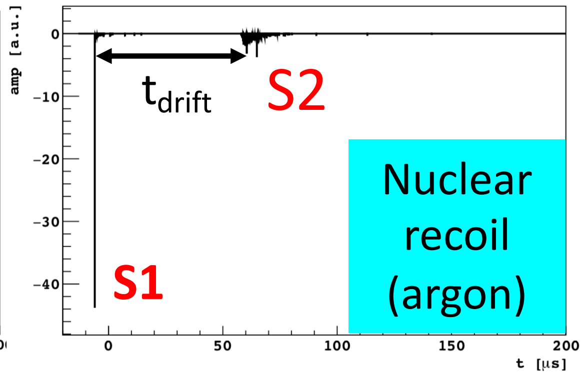
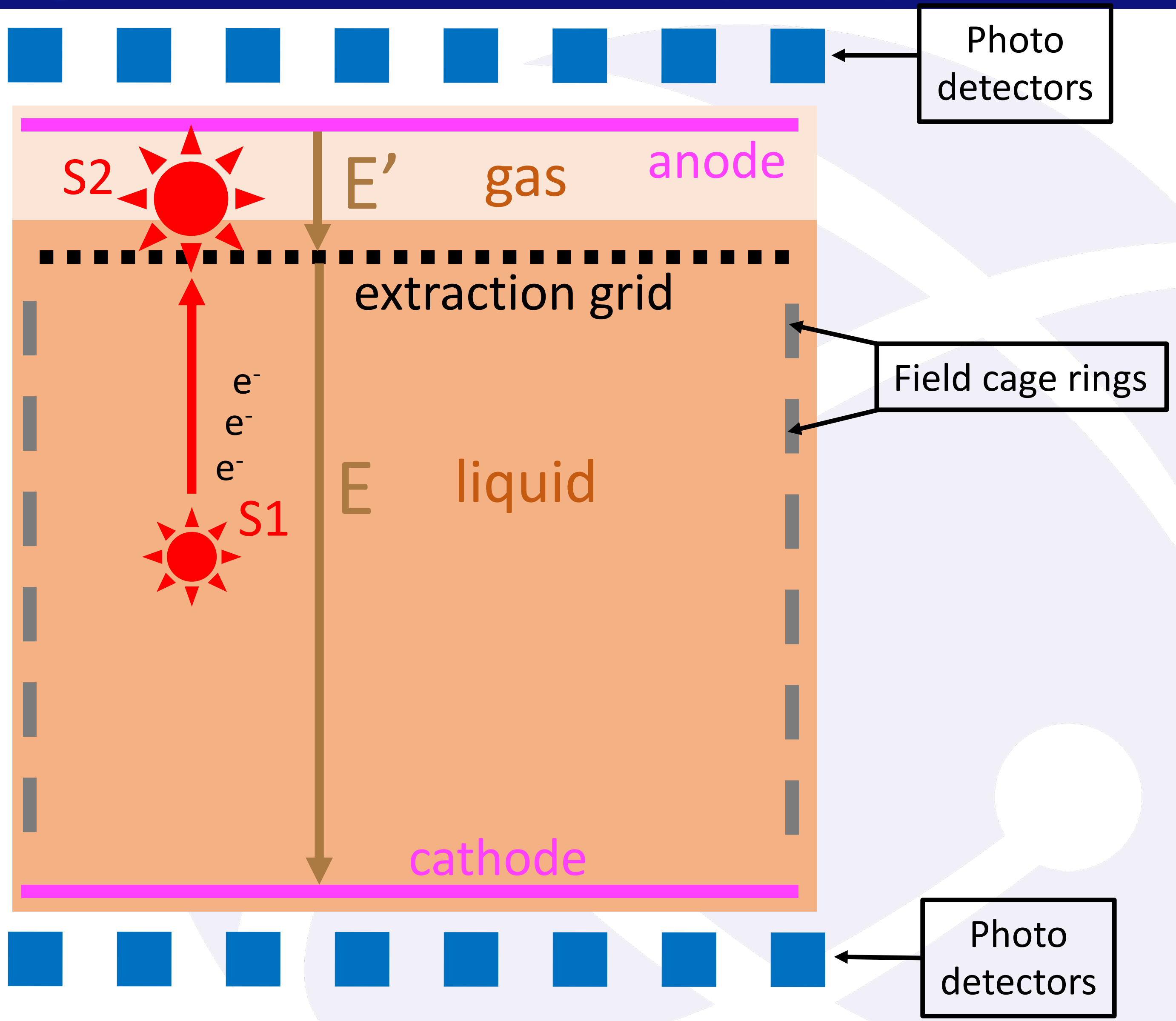
- Higher electric field across gas pocket than liquid
- Electron recoil discrimination exploits the S1 time signature – Pulse Shape Discrimination (PSD)
- Electrons drift to the extraction region
- X and Y are determined by localizing S2 with the top photo detector array
- Z is reconstructed via the arrival time difference between S2 and S1 (t_{drift})
- Suitable for low energy searches where only a few electrons are produced per event







Dual-Phase Time Projection Chamber (TPC)

- Small gas pocket maintained above the liquid
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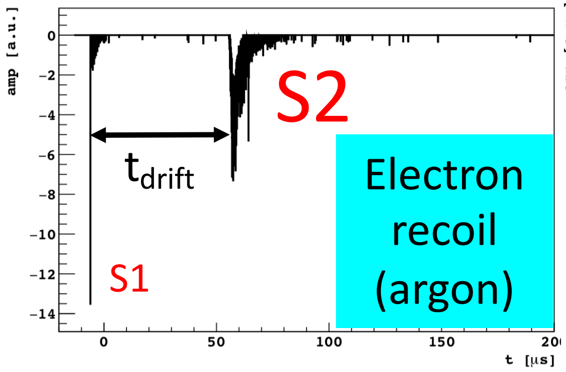
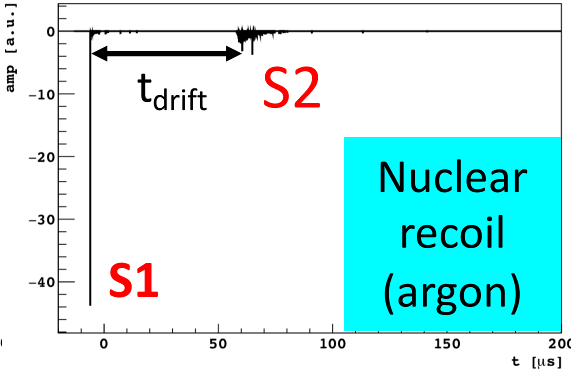
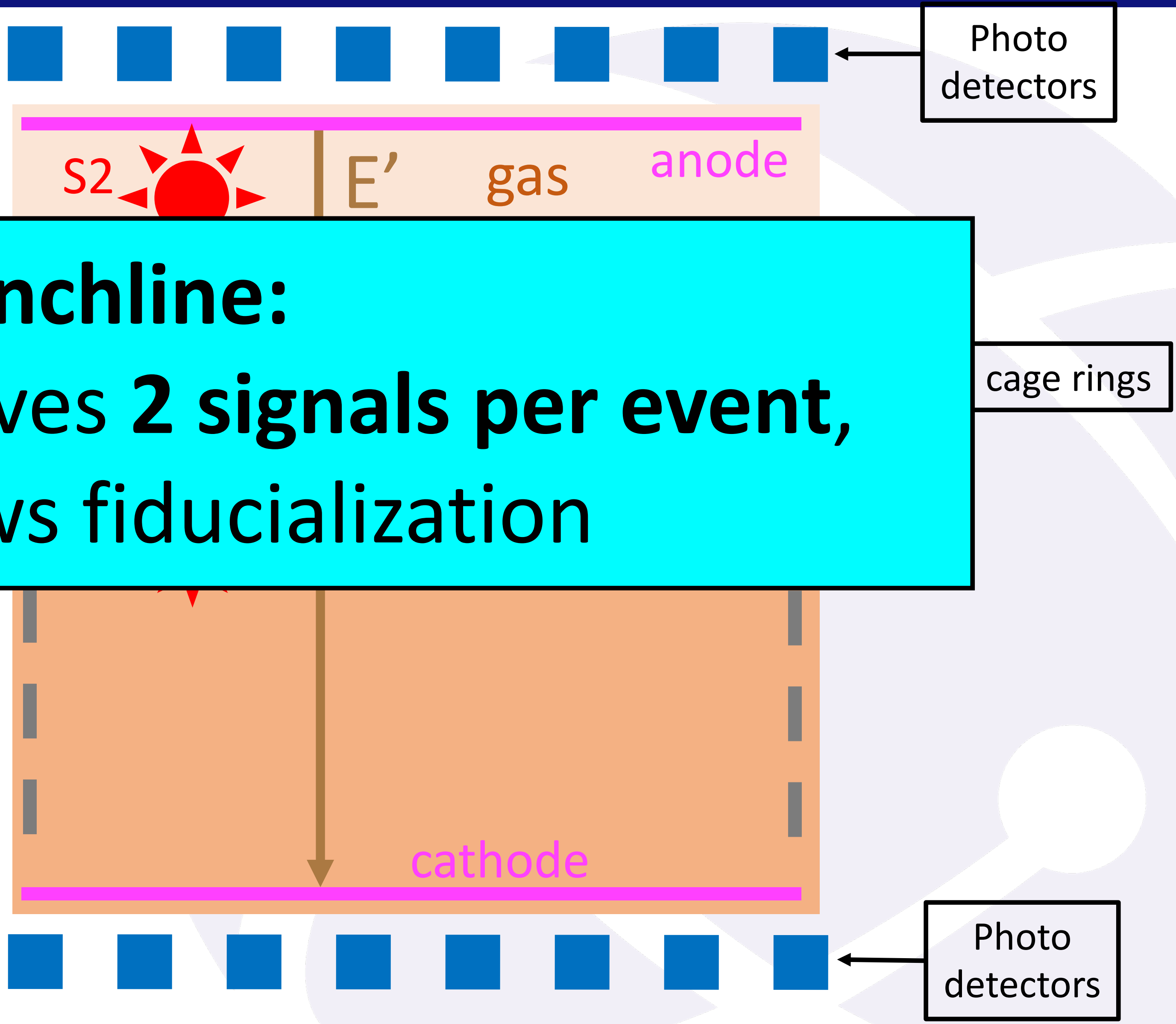
- Electron recoil discrimination exploits the S1 time signatur
- Electron
- X and Y top pho
- Z is reco betwee
- Suitable few electrons are produced per event

Punchline:
Dual-phase TPC gives **2 signals per event,** which allows fiducialization







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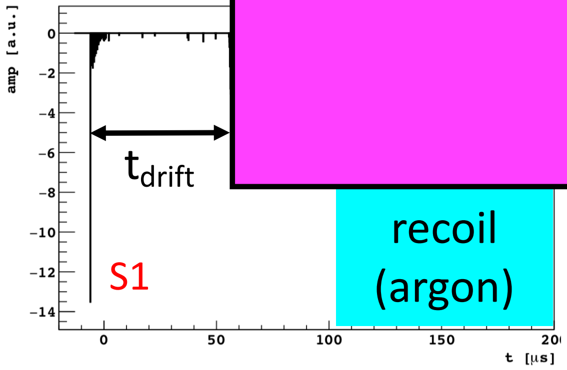
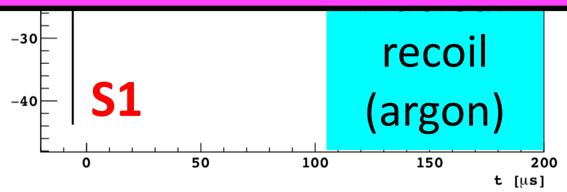
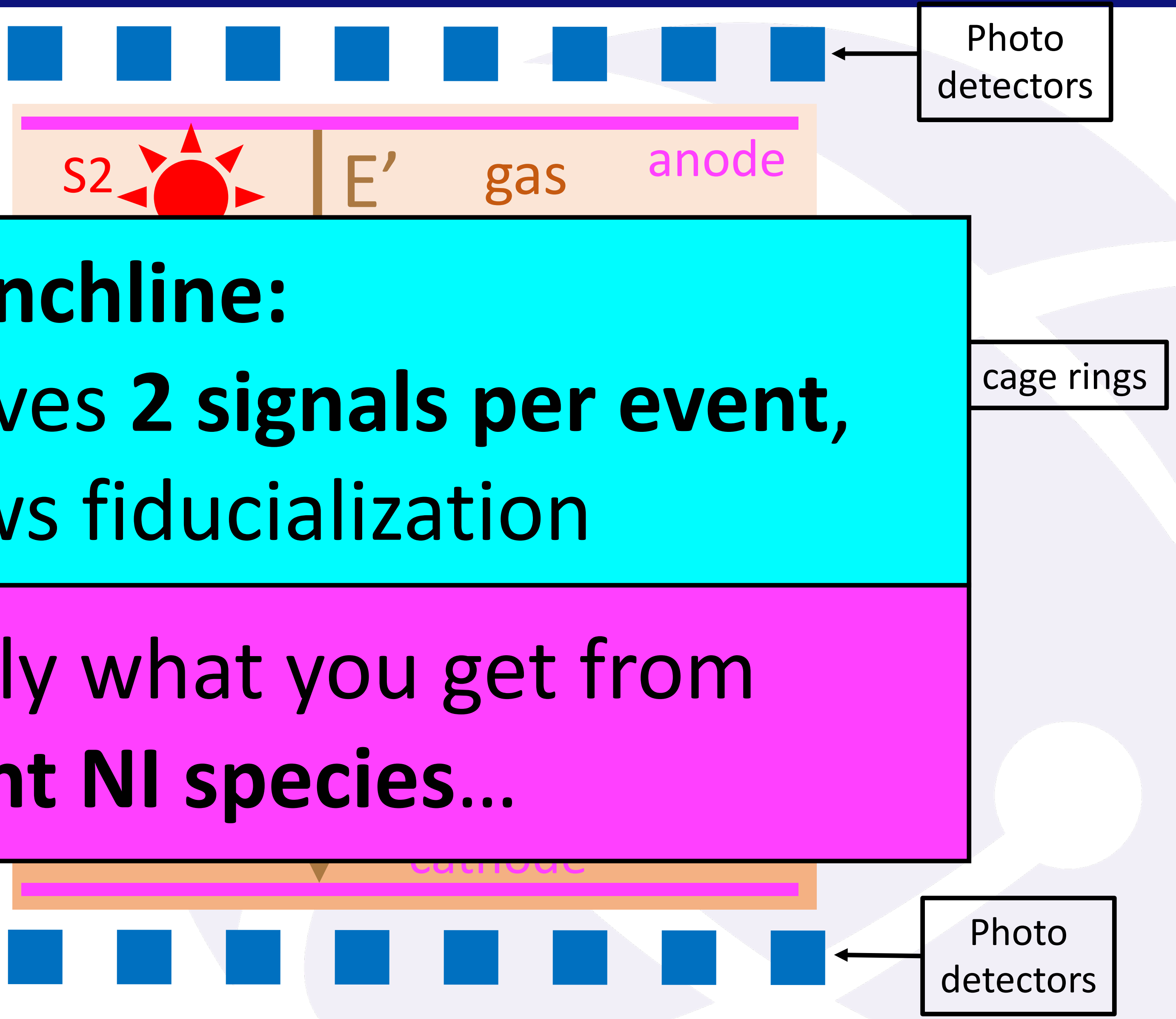




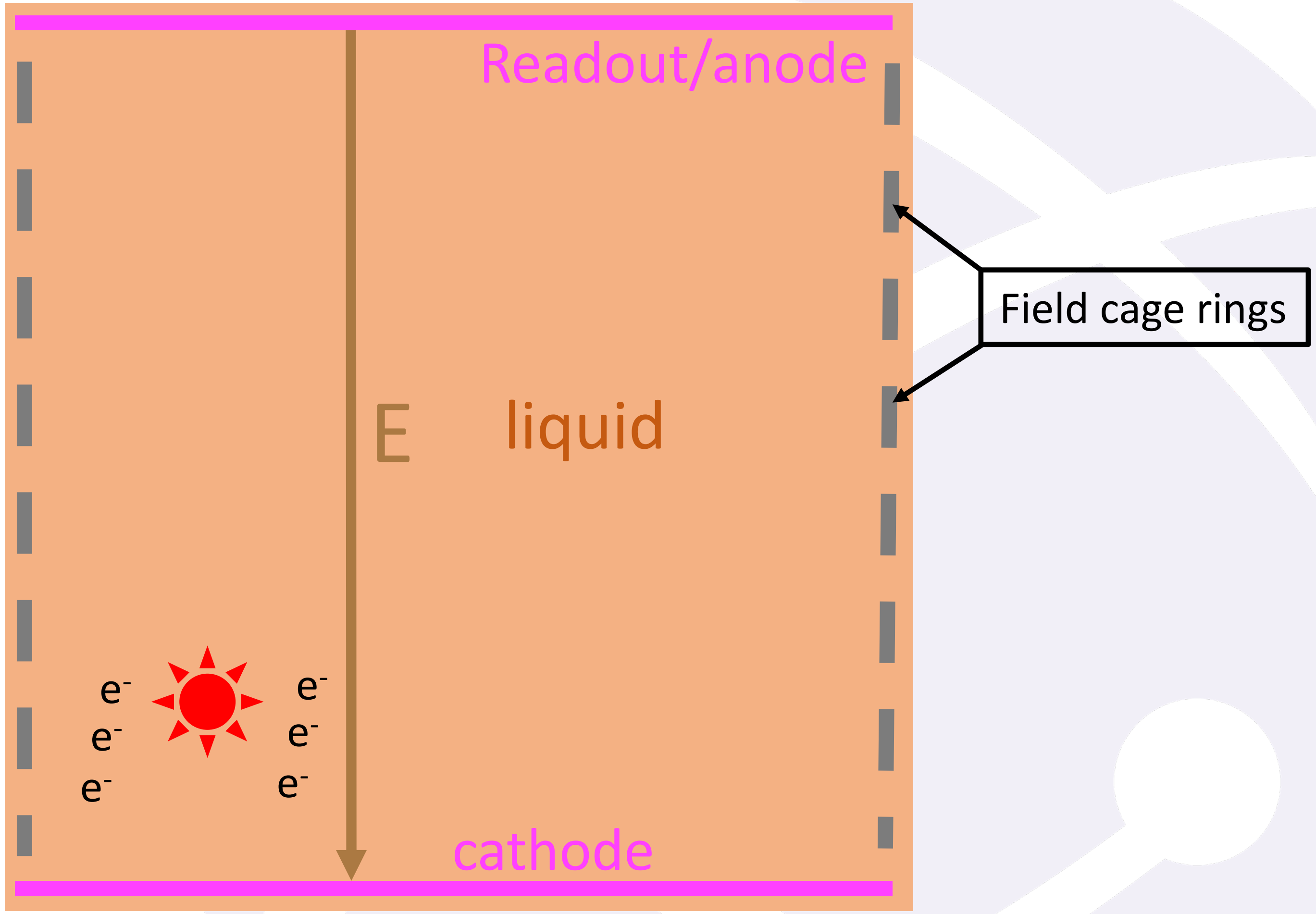


Punchline:

Dual-phase TPC gives **2 signals per event,** which allows fiducialization

But this is exactly what you get from **2 different NI species…**

Single-Phase TPC with Negative Ions



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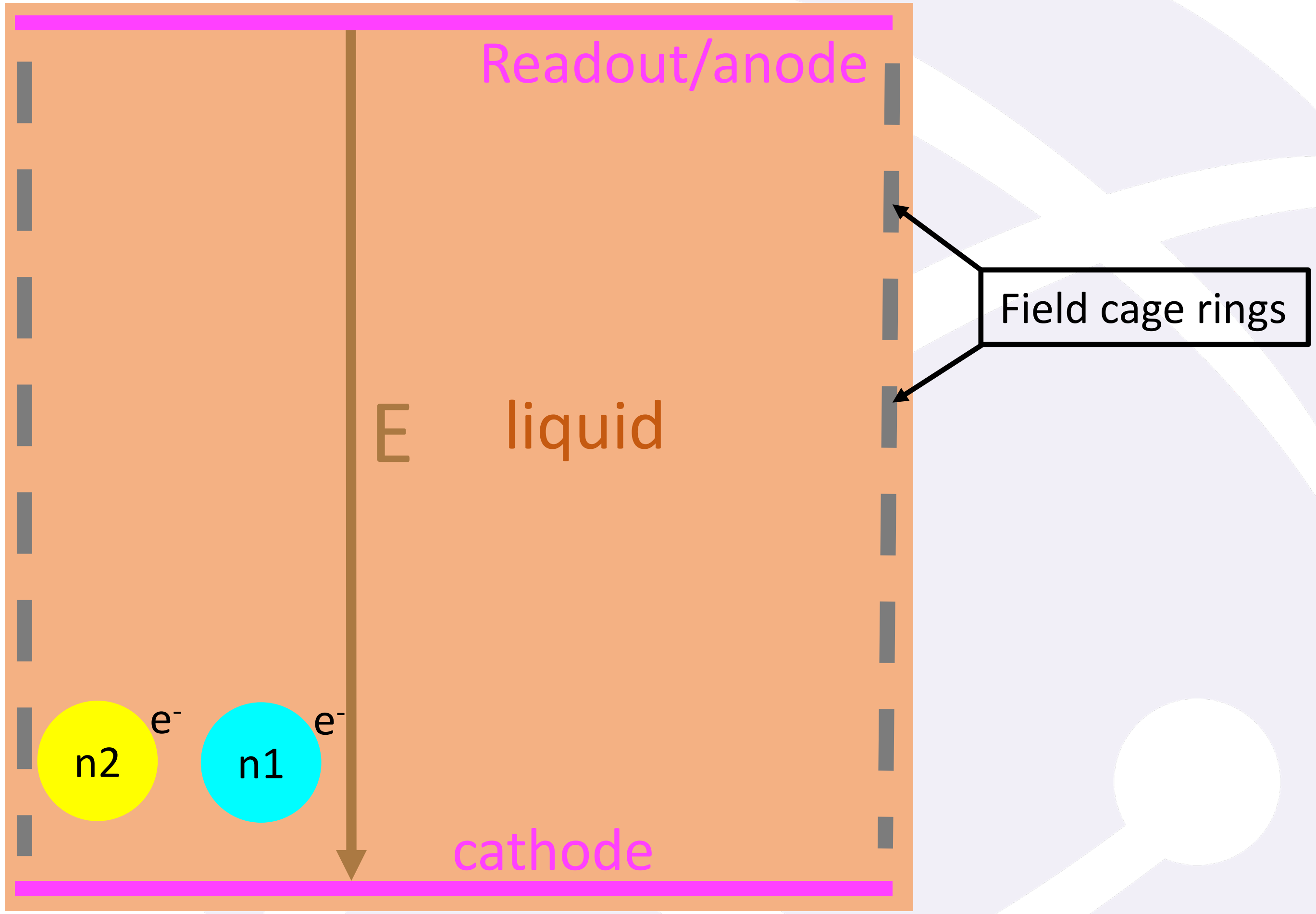
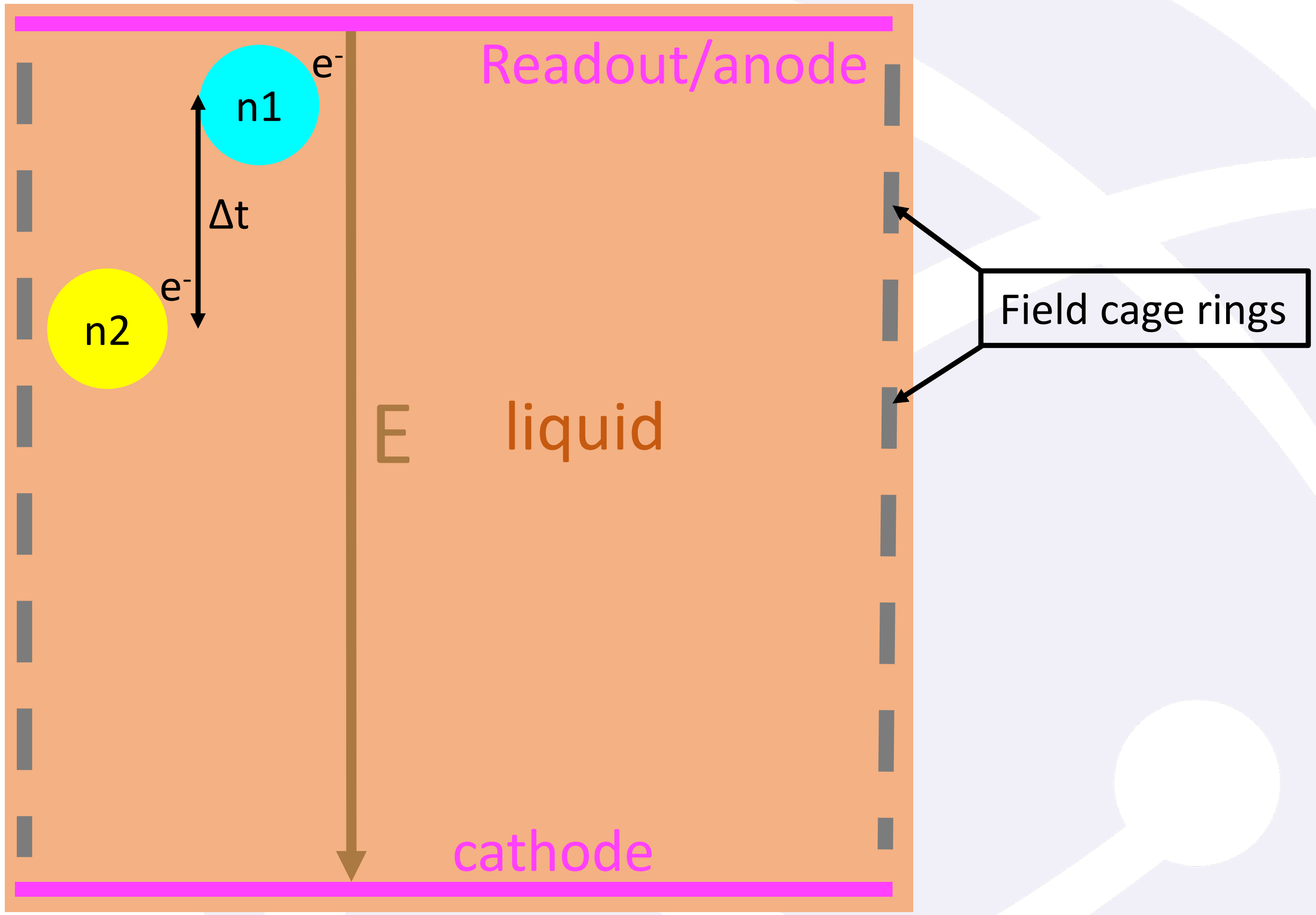


Single-Phase TPC with Negative Ions

- Removes need for gas pocket, along with complicated engineering as detectors become larger
- Fiducialize drift coordinate using 2 charge signals – Instead of S1 and S2, you have C1 and C2
- NIs typically kill scintillation yield – replace traditional light readout with charge readout
- “Cold” charge readouts would be adopted
- Start thinking about non-noble liquids as bulk, i.e. LN_2



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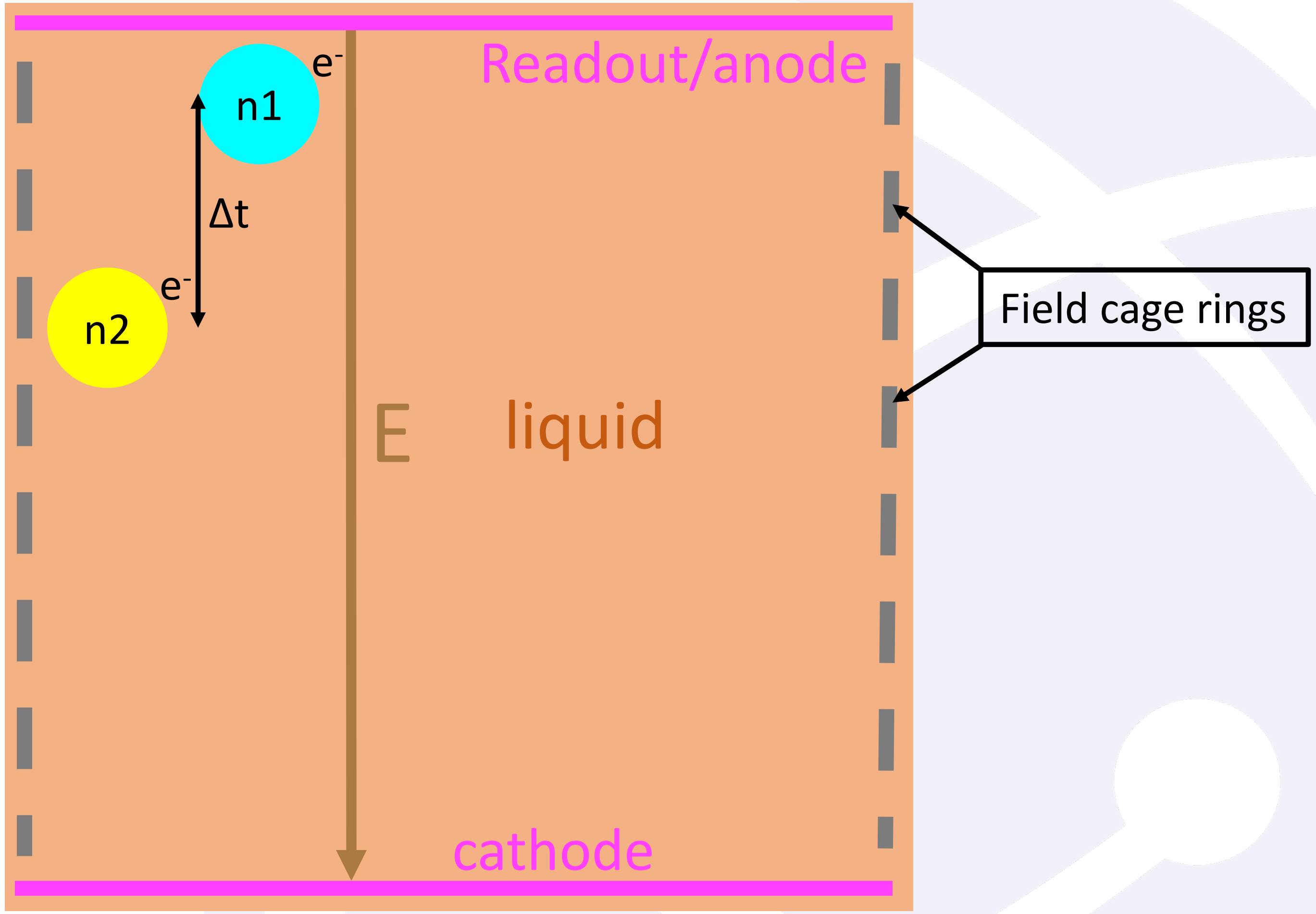
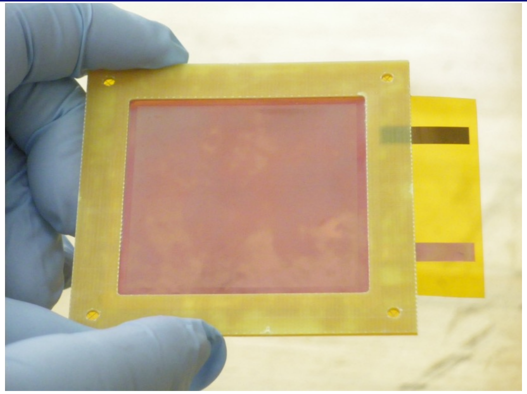


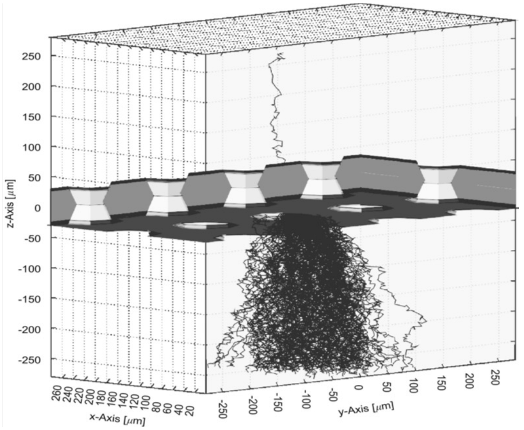
Punchline:
Single-phase liquid TPCs are **much** less complicated than dual-phase TPCs

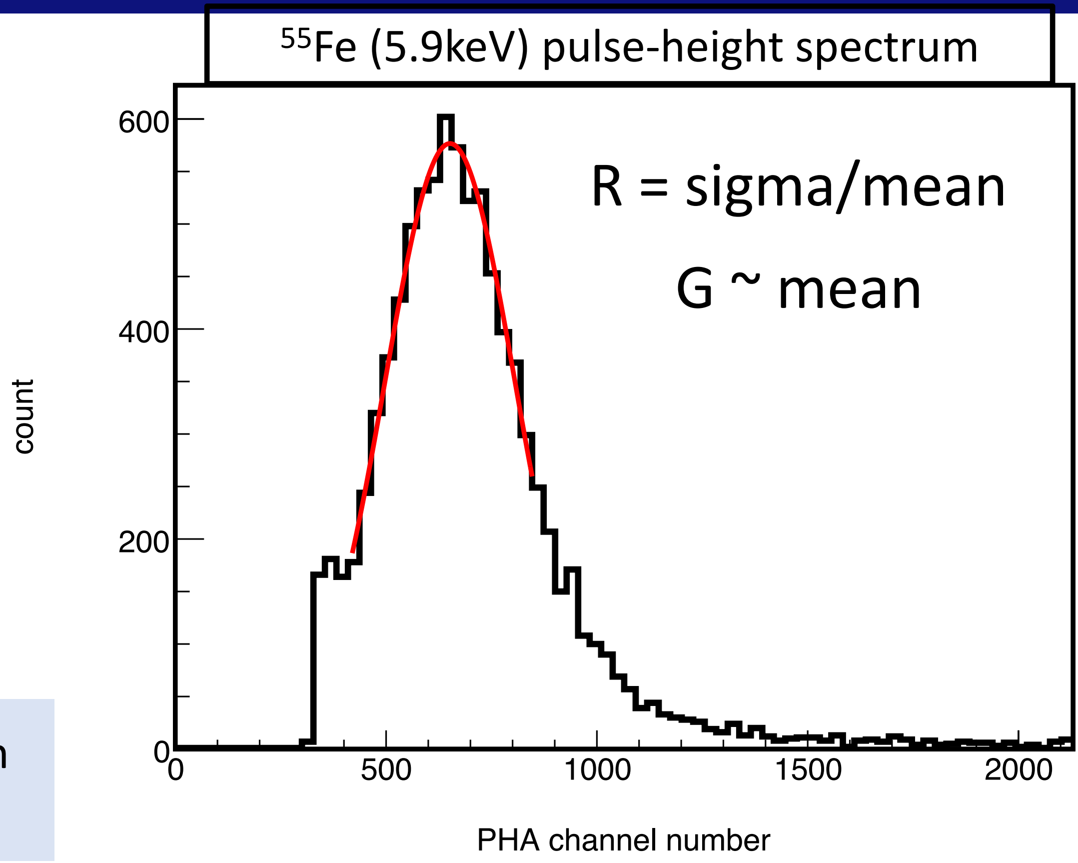
Propose line of R&D to study feasibility of **NIs in cryogenic liquid** TPCs

Measurements with Gaseous SF_6

Single Channel Avalanche Gain Measurement



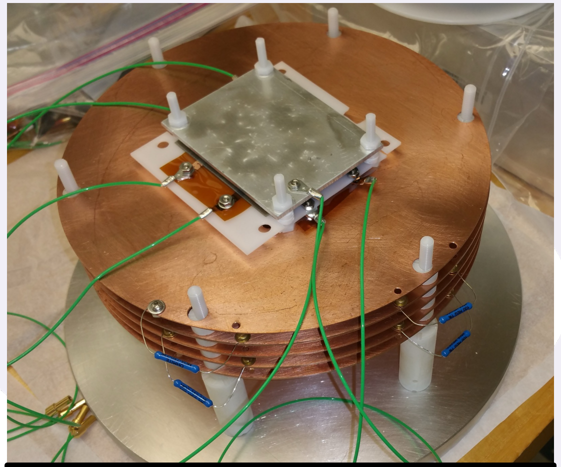




- V_G is the total voltage applied across all GEMs
- G is the 'effective' avalanche gain determined from the pulse-height spectrum
- V_G produces G
- R is the fractional resolution of pulse-height spectrum

Calibration pulser

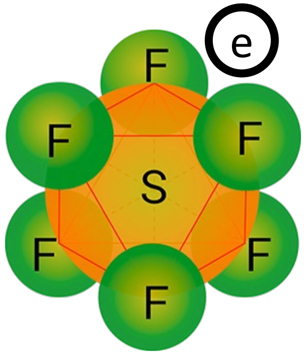
Charge collection plate → Charge integrating amplifier → Shaping amplifier → Pulse-height analyzer



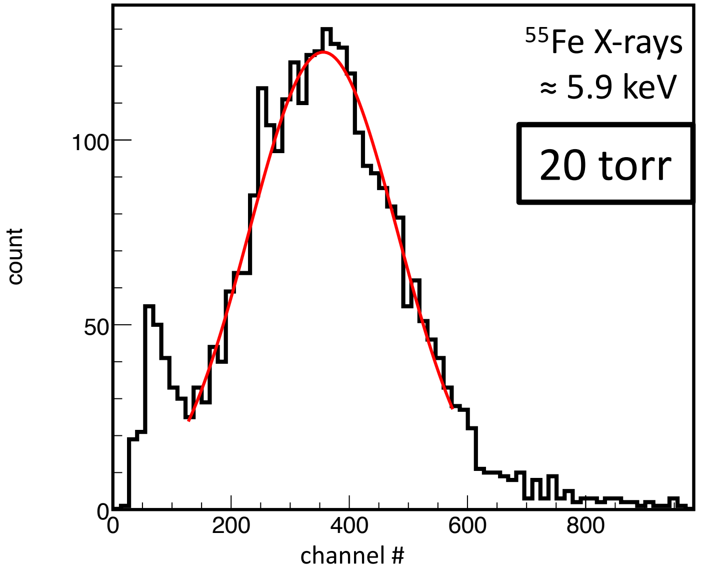
Hawaii detector

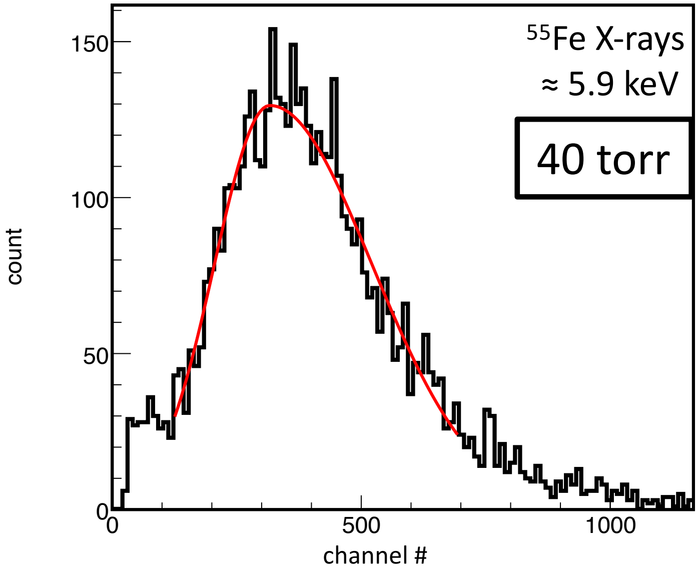
SF_6 - Avalanche Gain Measurements at U. Hawaii

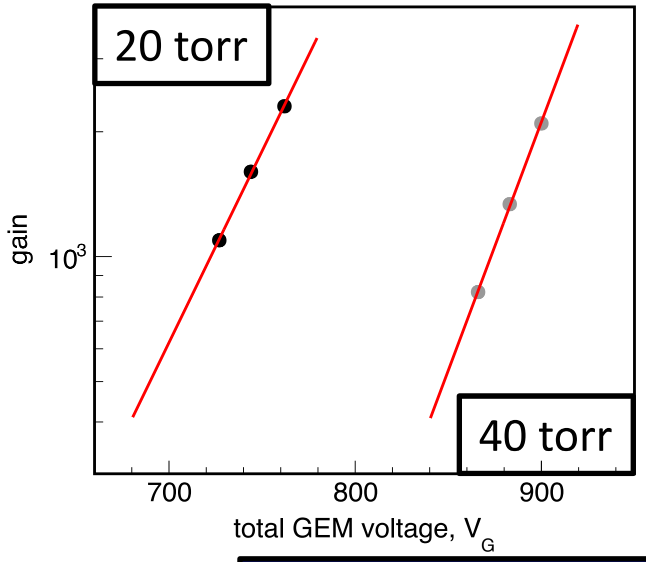
Why SF_6?

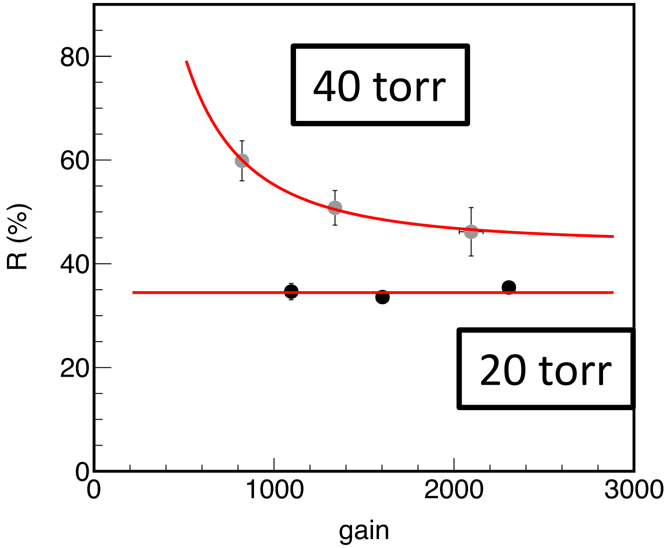


- High electron affinity
- Non-toxic, non-flammable
- Gaseous phase at STP
- Fluorine has un-paired spin
- Abundant literature from industry
- **Multiple species** have been identified
- **Diffusion** during drift is near **thermal limit**









Nucl.Instrum.Meth.A, Volume 1045, 167438 (2023)

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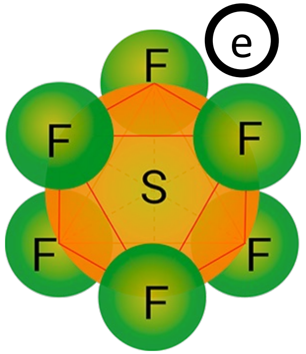

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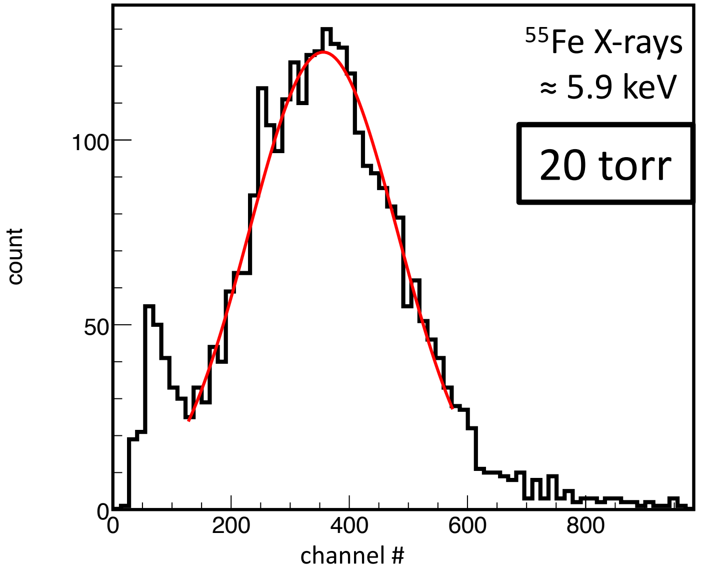
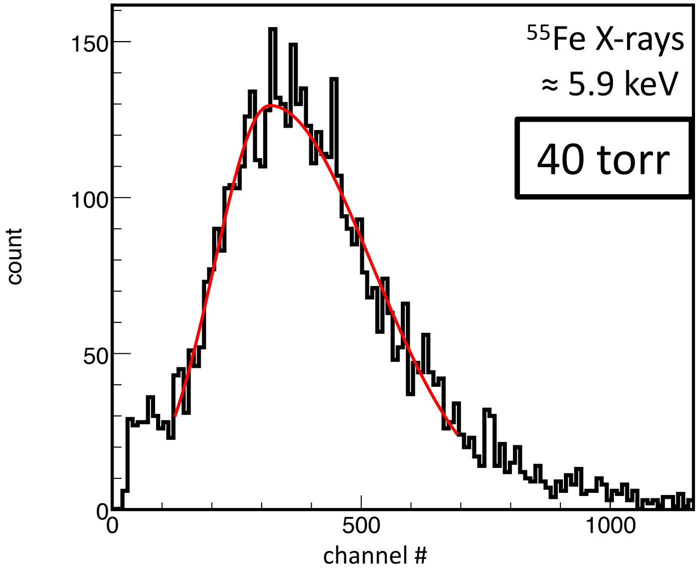
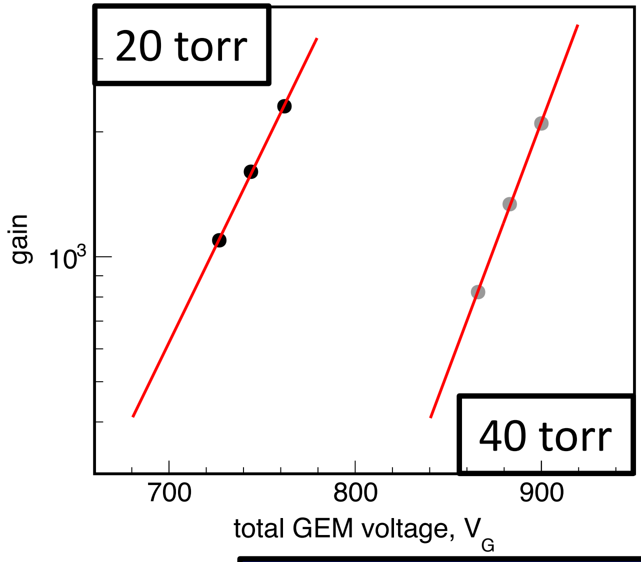
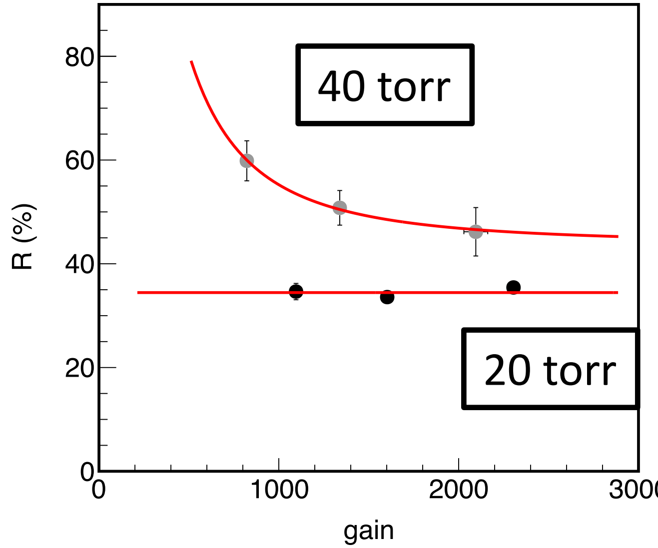
Punchline:
Avalanche gain and **energy resolution** worse than with electron-drift gas mixtures, but does function as a NI gas

N.S. Phan *et al* 2017 *JINST* **12** P02012









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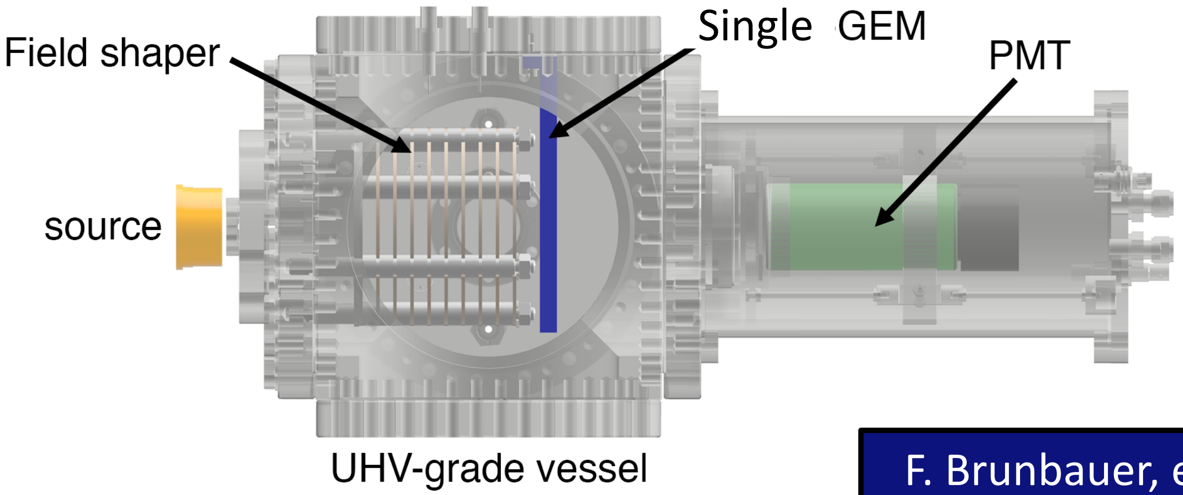
Studies with CERN GDD Group

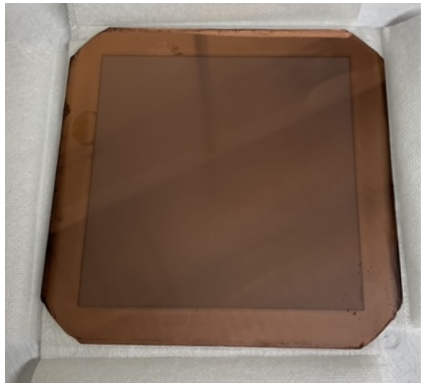
- Collaboration with CERN Gas Detector Development (GDD) to study doping noble gases with SF_6
- Possible exploitation of NI properties in noble elements
- Possible uses in existing experiments
- **Avalanche gain** and **drift velocity** measurements with SF_6 and argon-SF_6 mixtures
- Gain measurements done by monitoring the GEM current using an X-ray gun source

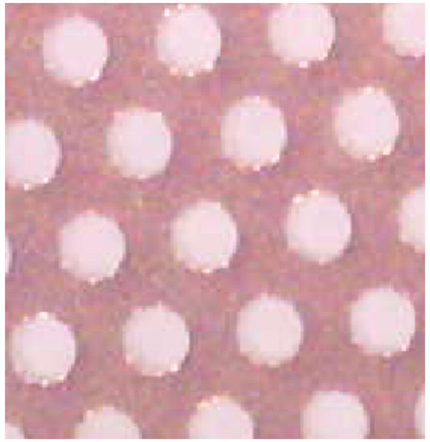


F. Brunbauer, et al

Glass GEM

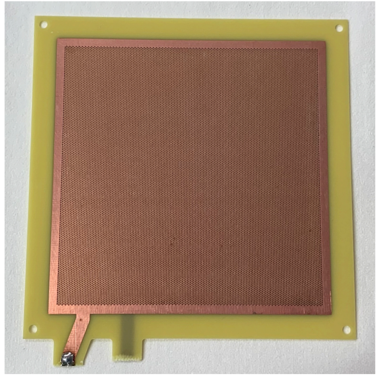
160-180μm diameter holes
280μm pitch
570μm or 680μm (old) thick glass

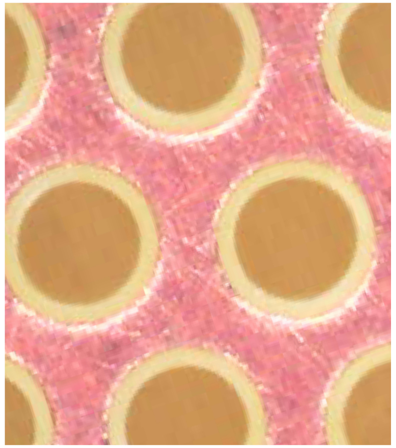




THGEM

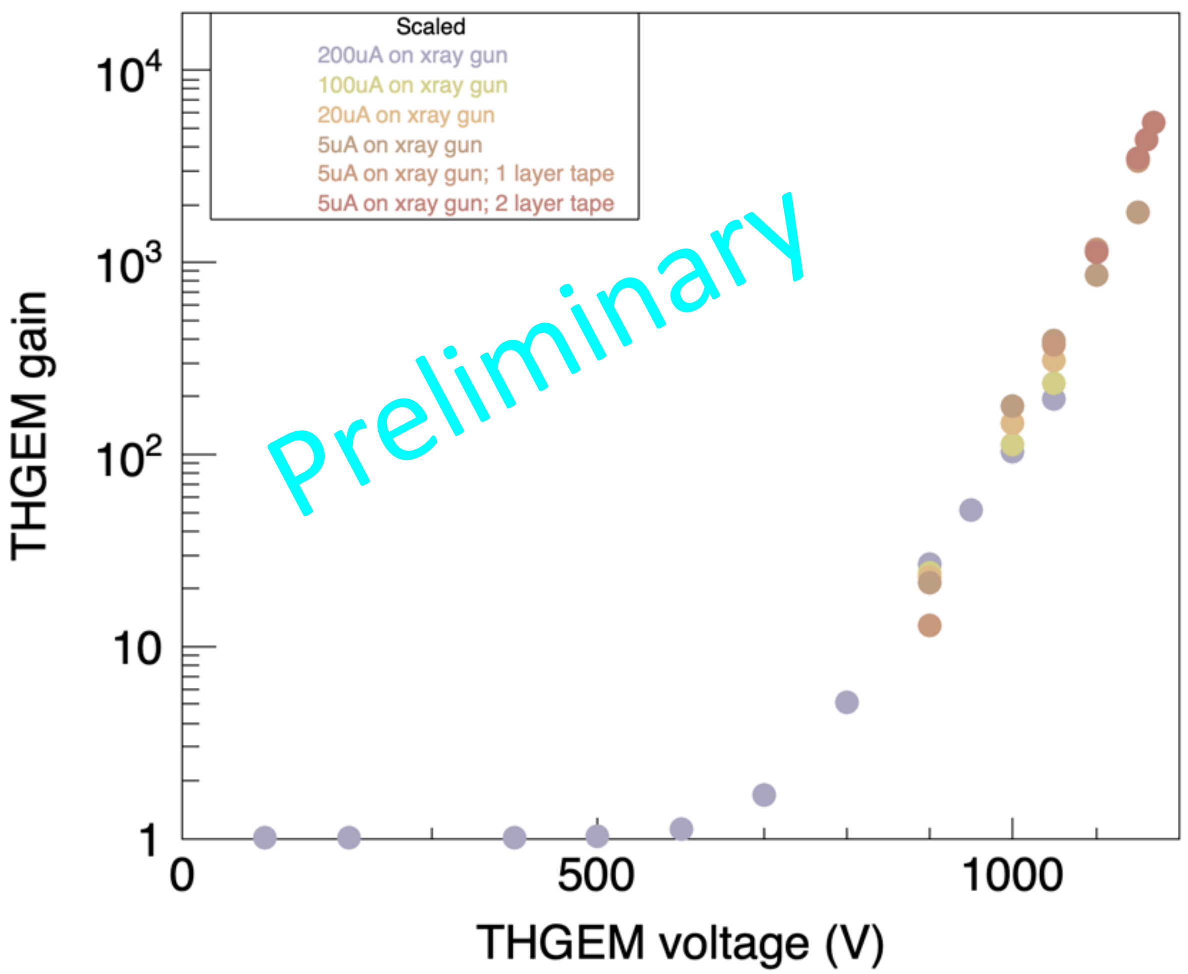
400μm diameter holes
700μm pitch
1mm thick FR4, 50μm rim



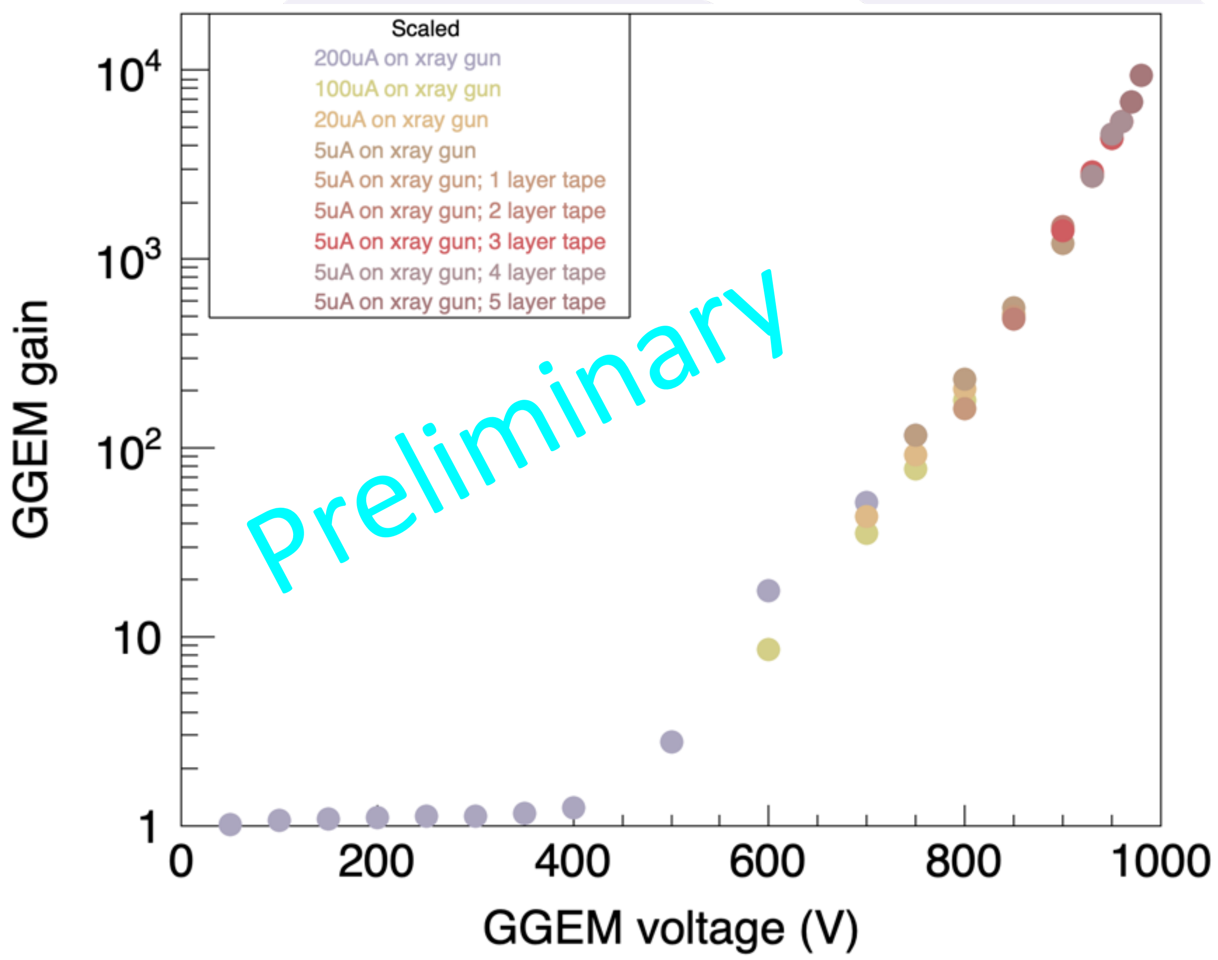


Avalanche Gain Results – 50 mbar SF_6

THGEM (1 mm)



Glass GEM (0.57 mm)



Avalanche Gain Results – 1 mm THGEM

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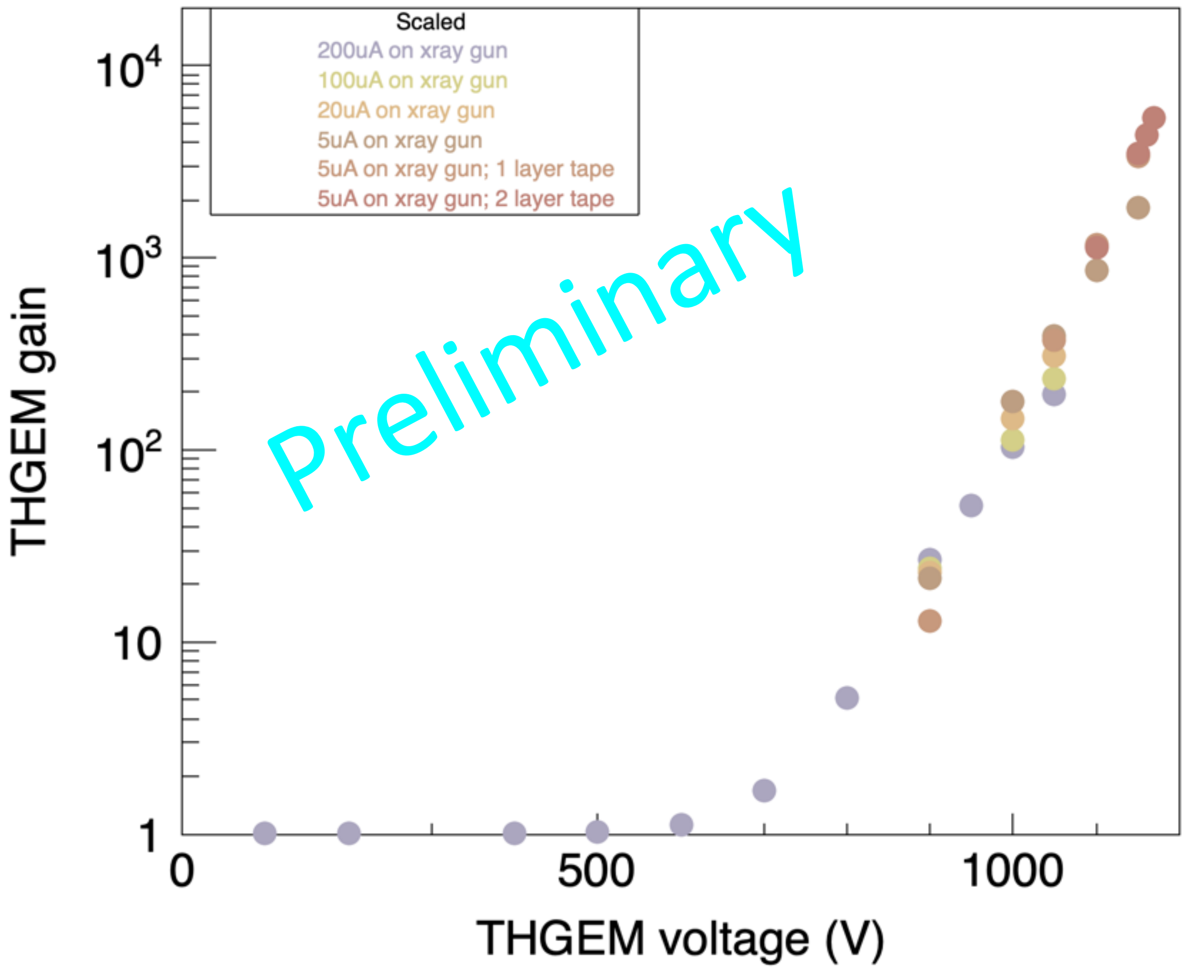
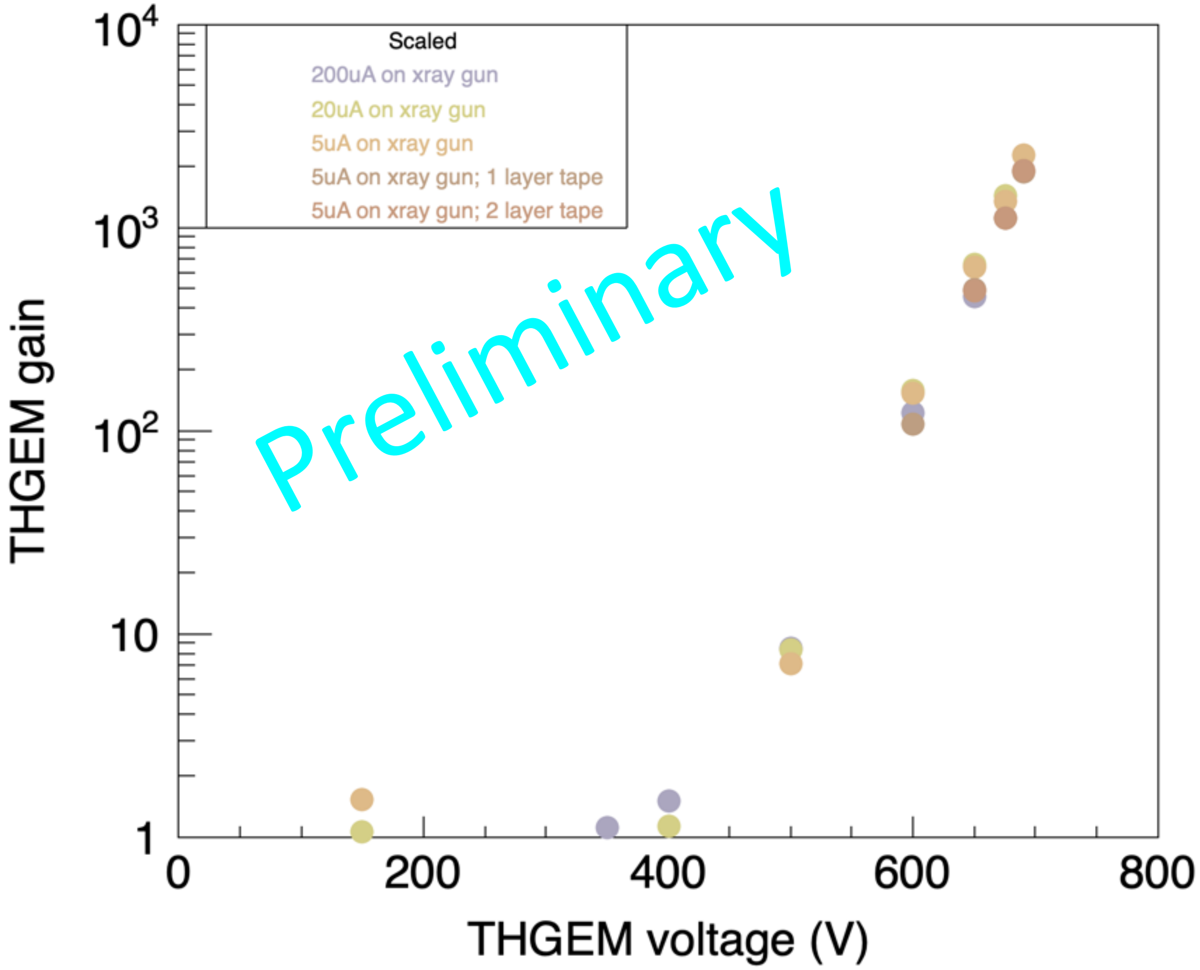
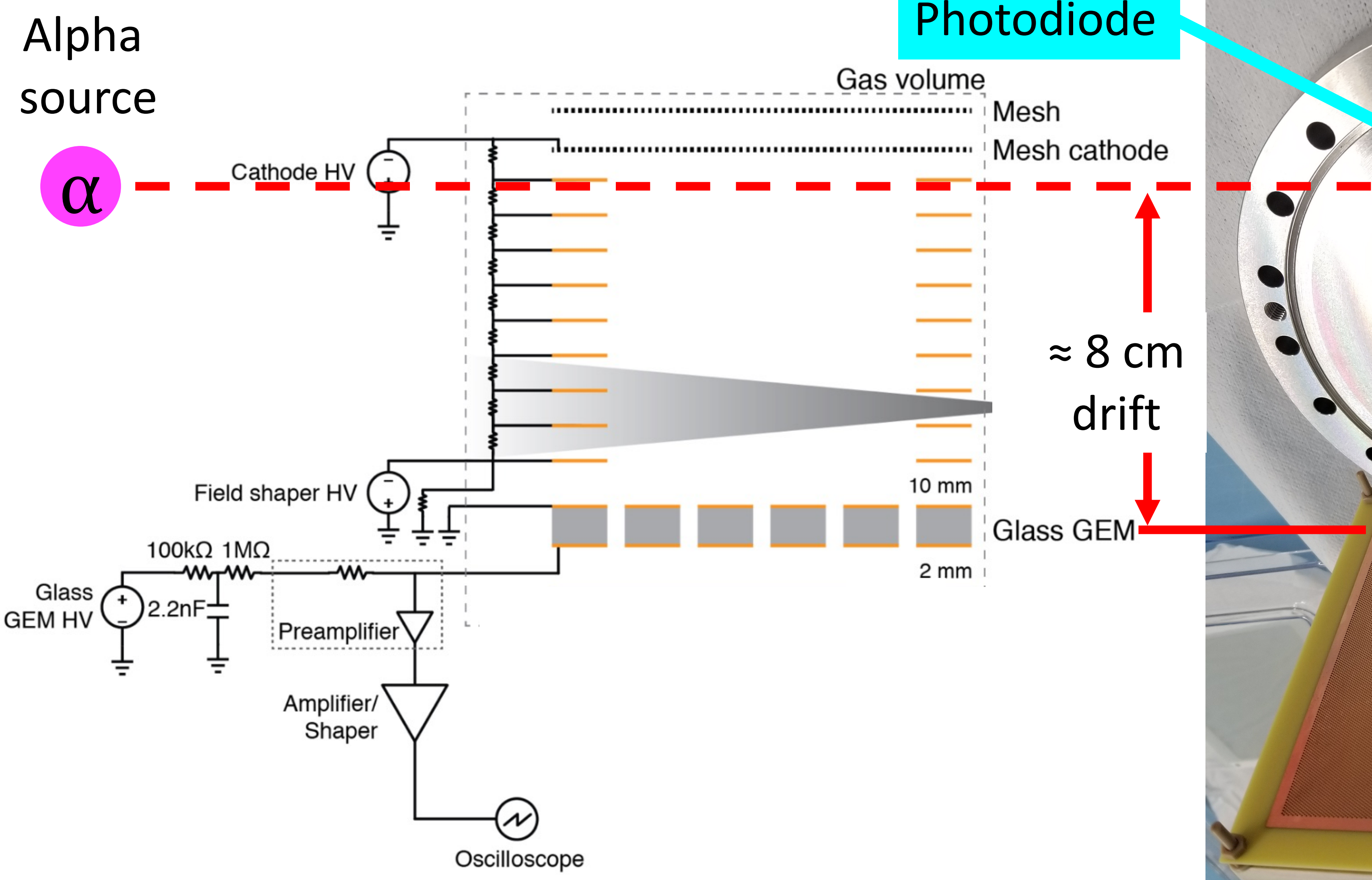
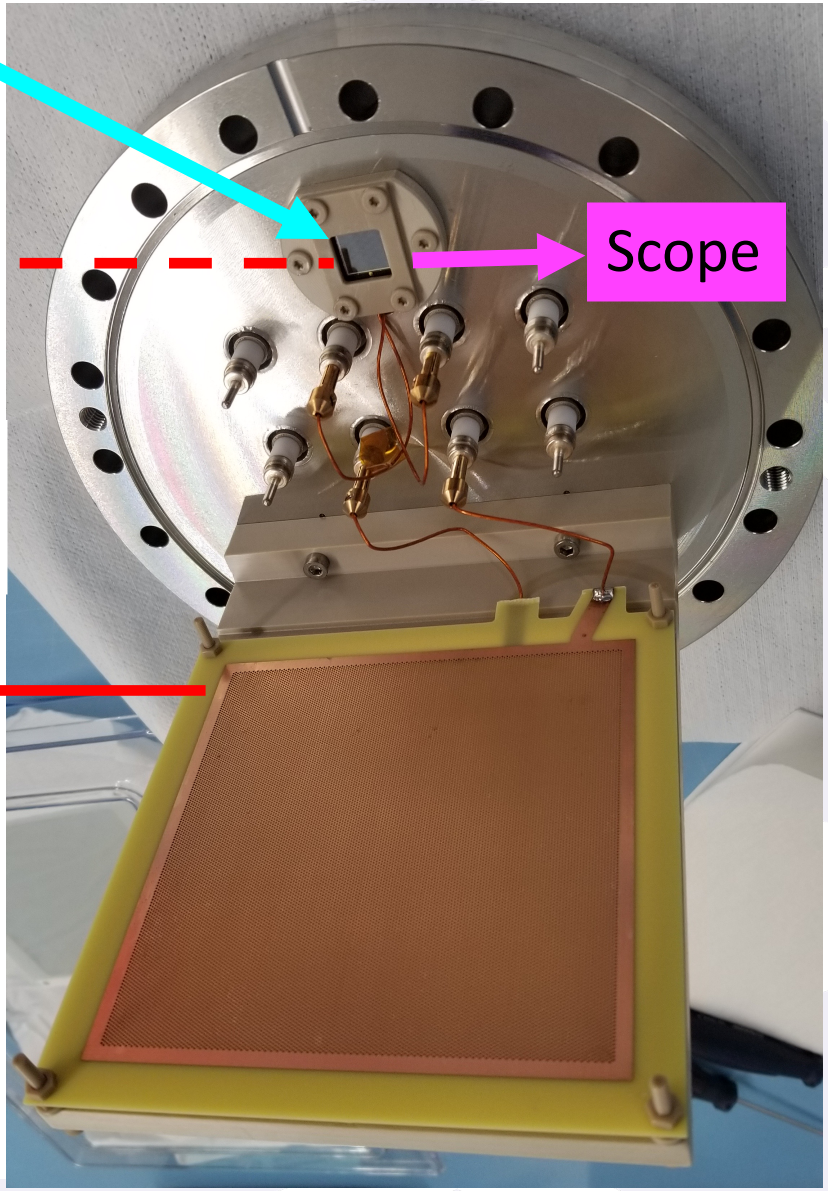


100 mbar argon + 1 mbar SF_6



Drift Velocity Measurement Setup

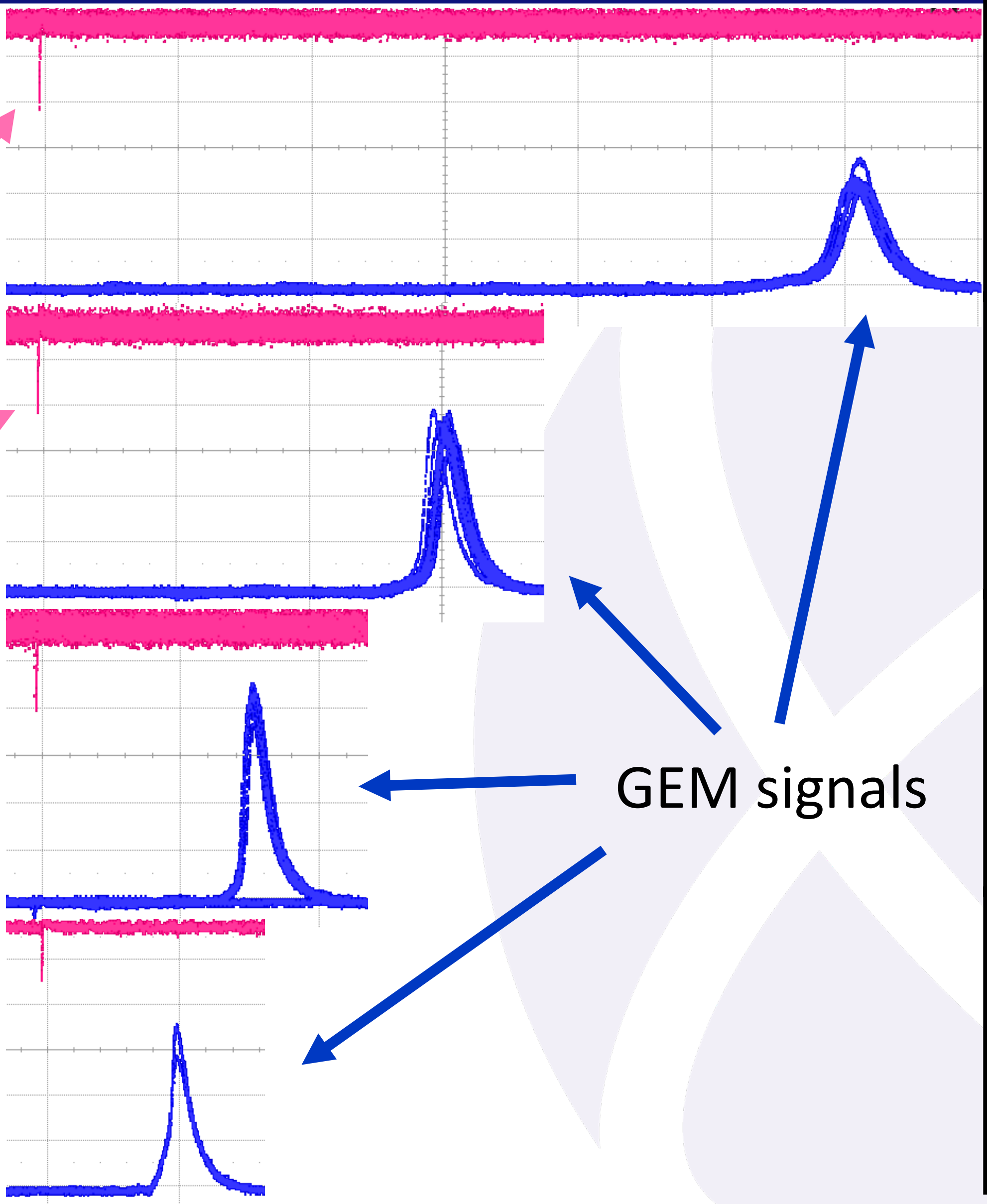




Visualizing the Drift Velocity Measurement

- Pure SF_6
- Drift length ≈ 8 cm
- Pressure ≈ 25 mbar
- Time scale is constant

Photodiode (t_0) signals



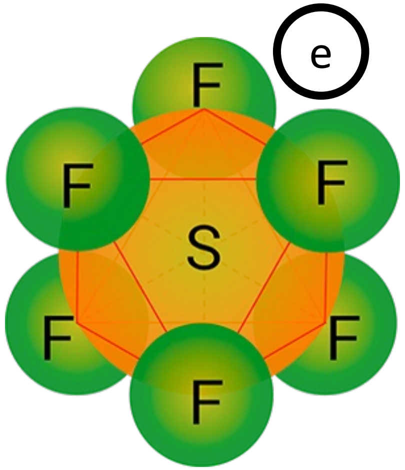
GEM signals

Drift ≈ 60V/cm
≈6*1ms/div = 6ms

Drift ≈ 120V/cm
≈3*1ms/div = 3ms

Drift ≈ 245V/cm
≈1.5*1ms/div = 1.5ms

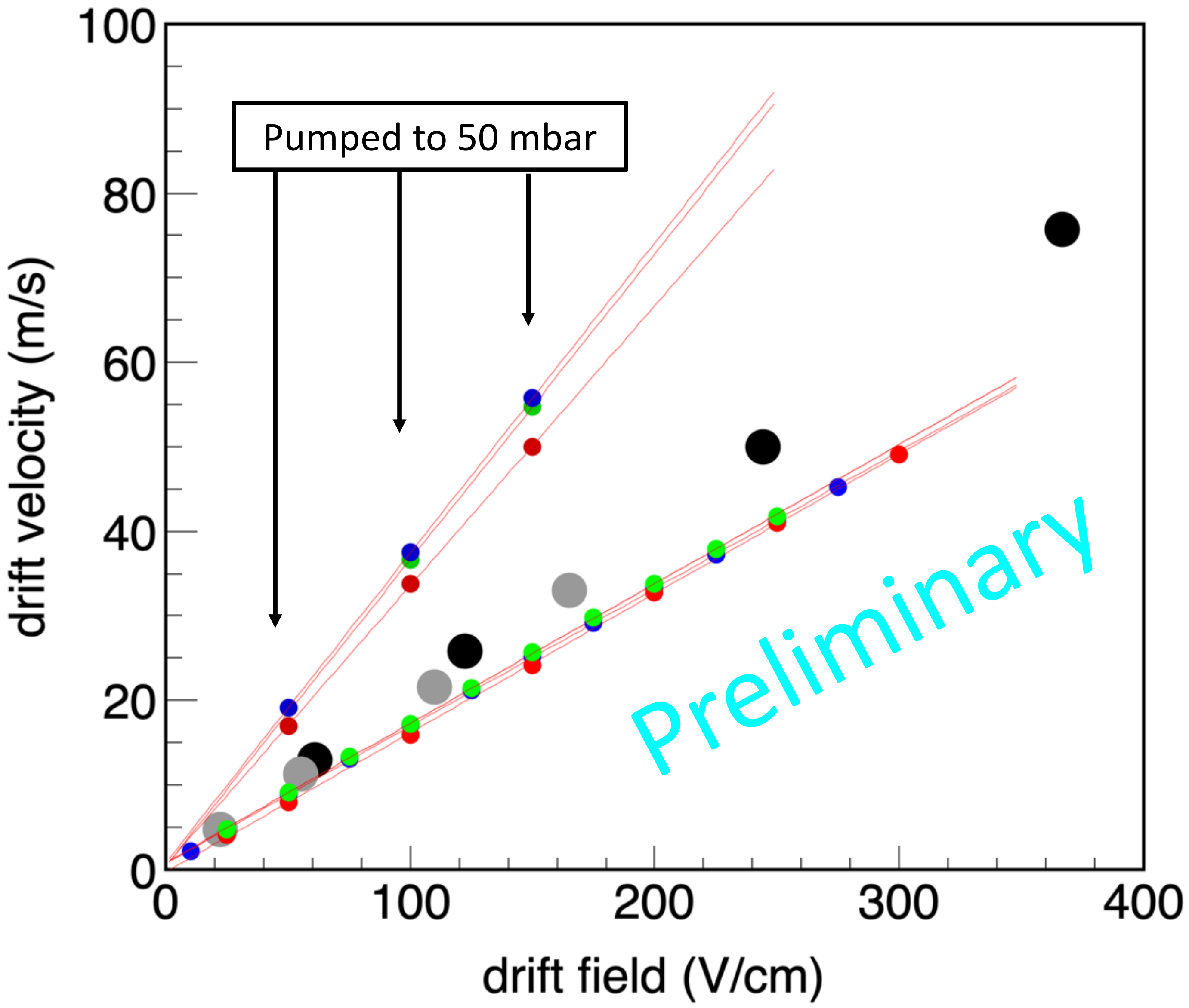
Drift ≈ 365V/cm
≈1*1ms/div = 1ms



Drift Velocities – First Attempts

25 mbar SF_6 (1st attempt)
100 mbar argon + 1 mbar SF_6 (1st attempt)
100 mbar argon + 1 mbar SF_6 (2nd)
100 mbar argon + 2 mbar SF_6
100 mbar argon + 5 mbar SF_6

- Don't expect the SF_6 content to affect the drift velocity other than the gas density
- Expect the slope of these lines to be inversely proportional to the gas pressure for a given mixture
- This is roughly observed



Reduced Mobilities – First Attempts

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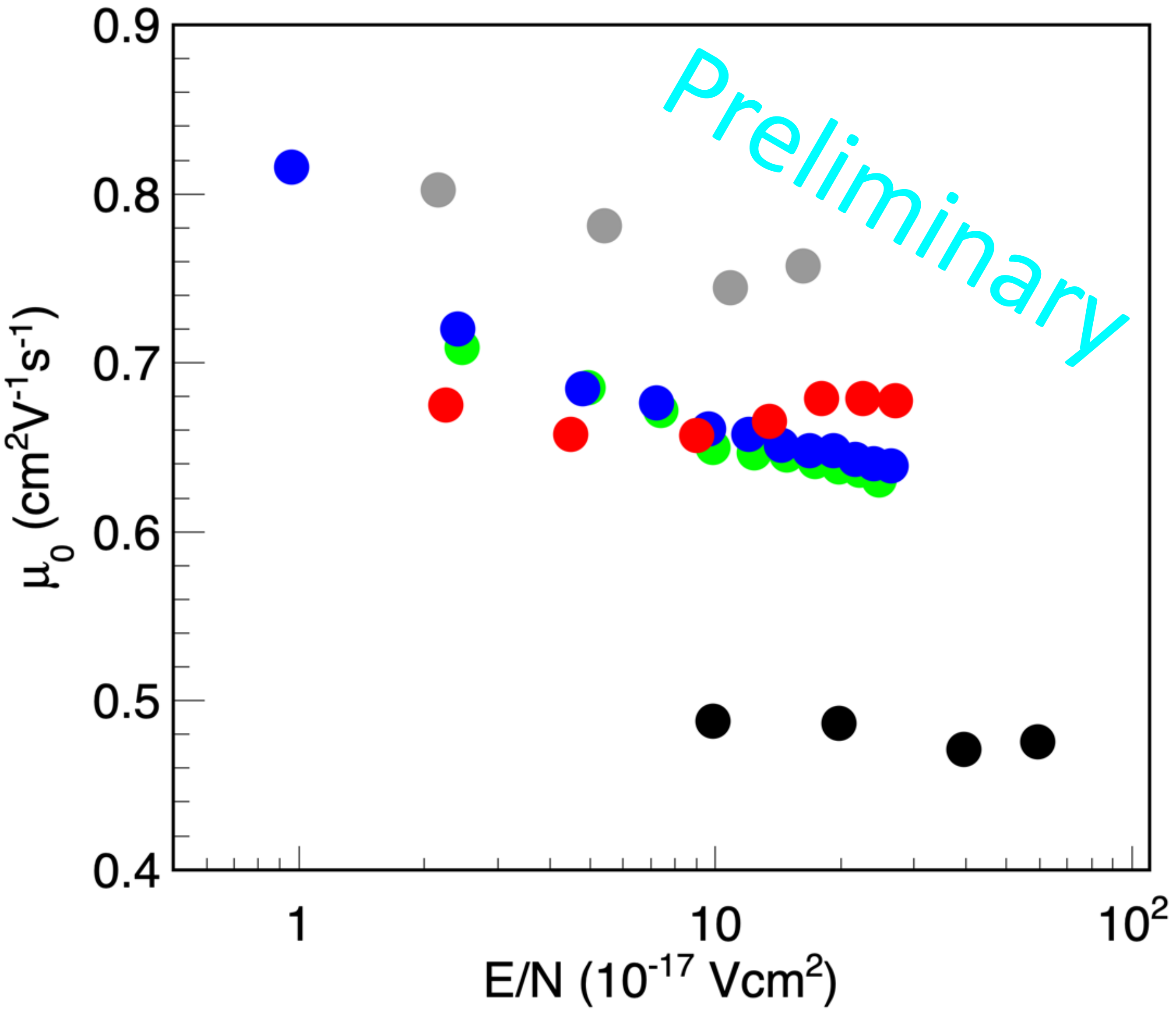

- At very low drift fields, a consistent divergence from constant is observed
- Dependent on how the charge arrival time is defined – GEM signals are not always Gaussian
- Carefully repeated data sets for a final result…

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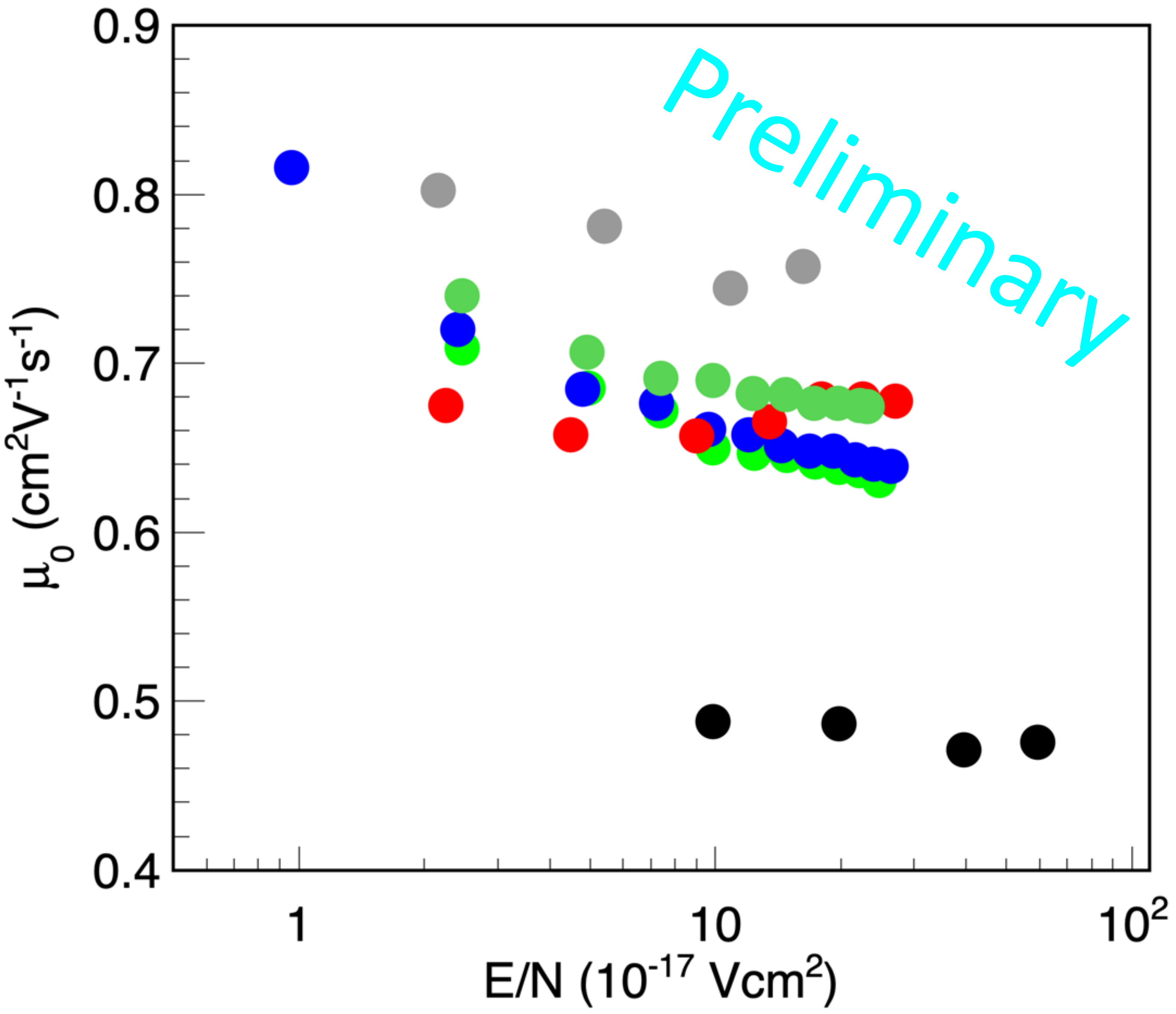
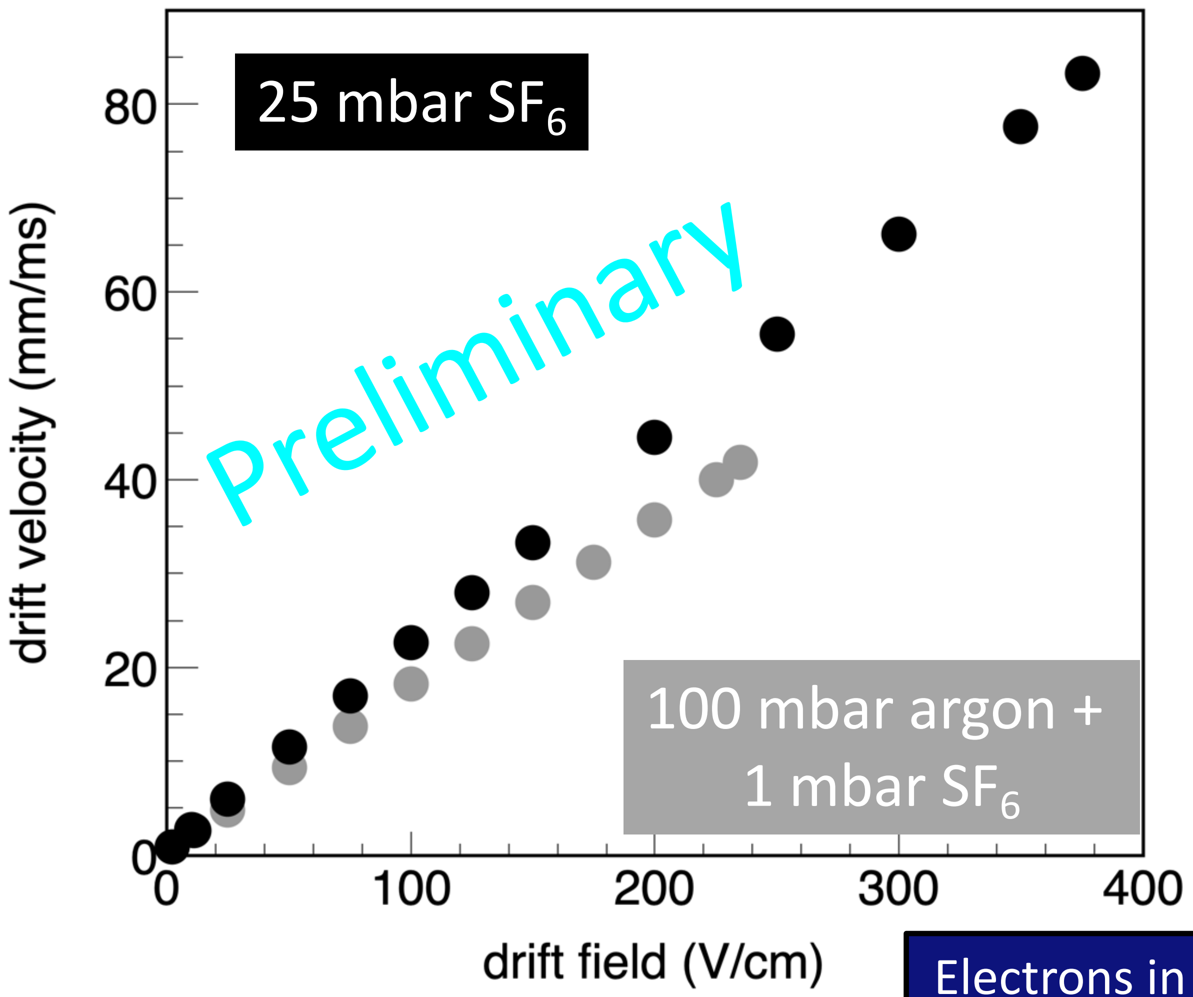
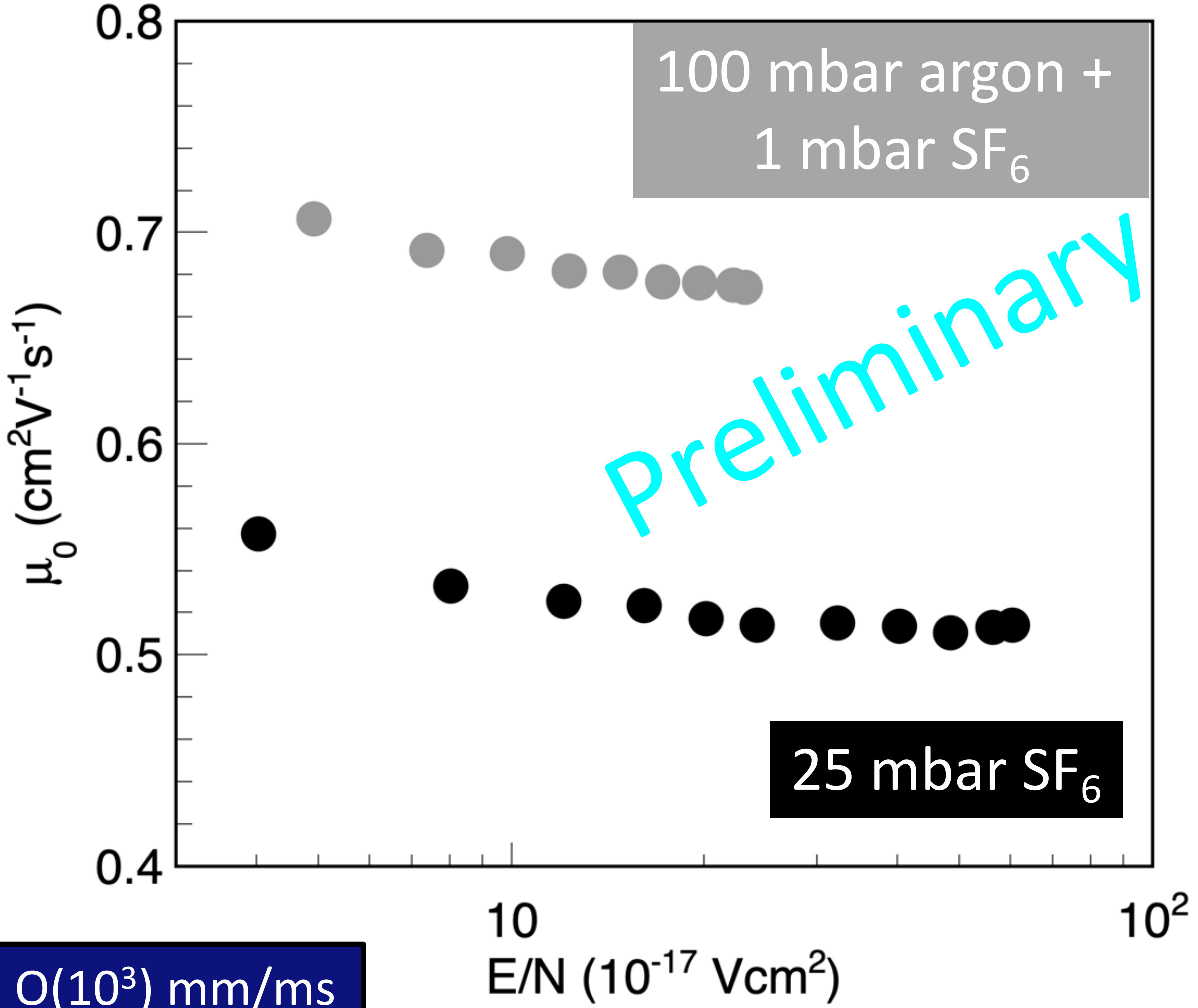


Drift Velocity and Mobility Results

Drift velocity vs. drift field



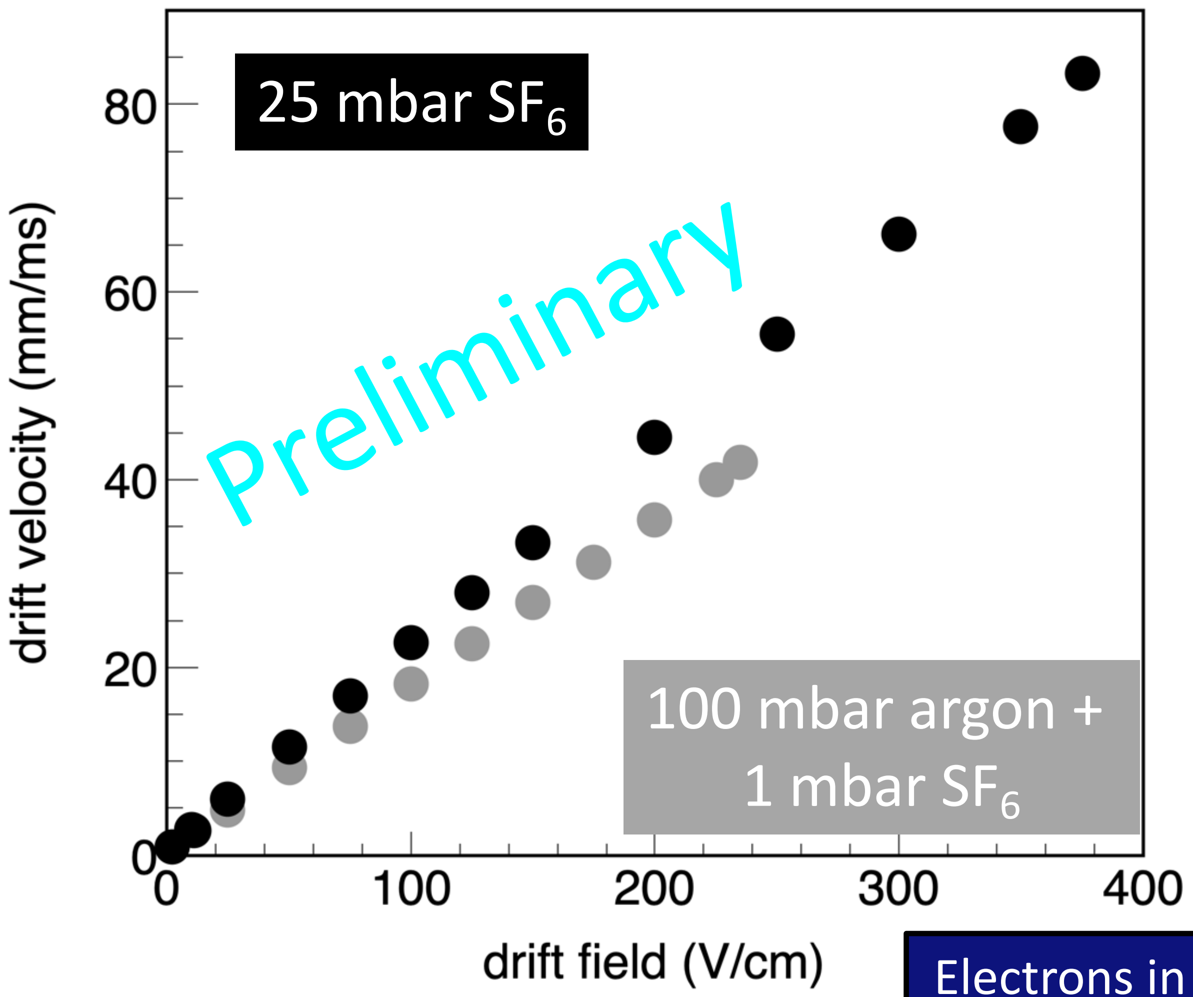
Reduced mobility vs. reduced drift field



Electrons in LAr ≈ O(10^3) mm/ms

Drift Velocity and Mobility Results

Drift velocity vs. drift field



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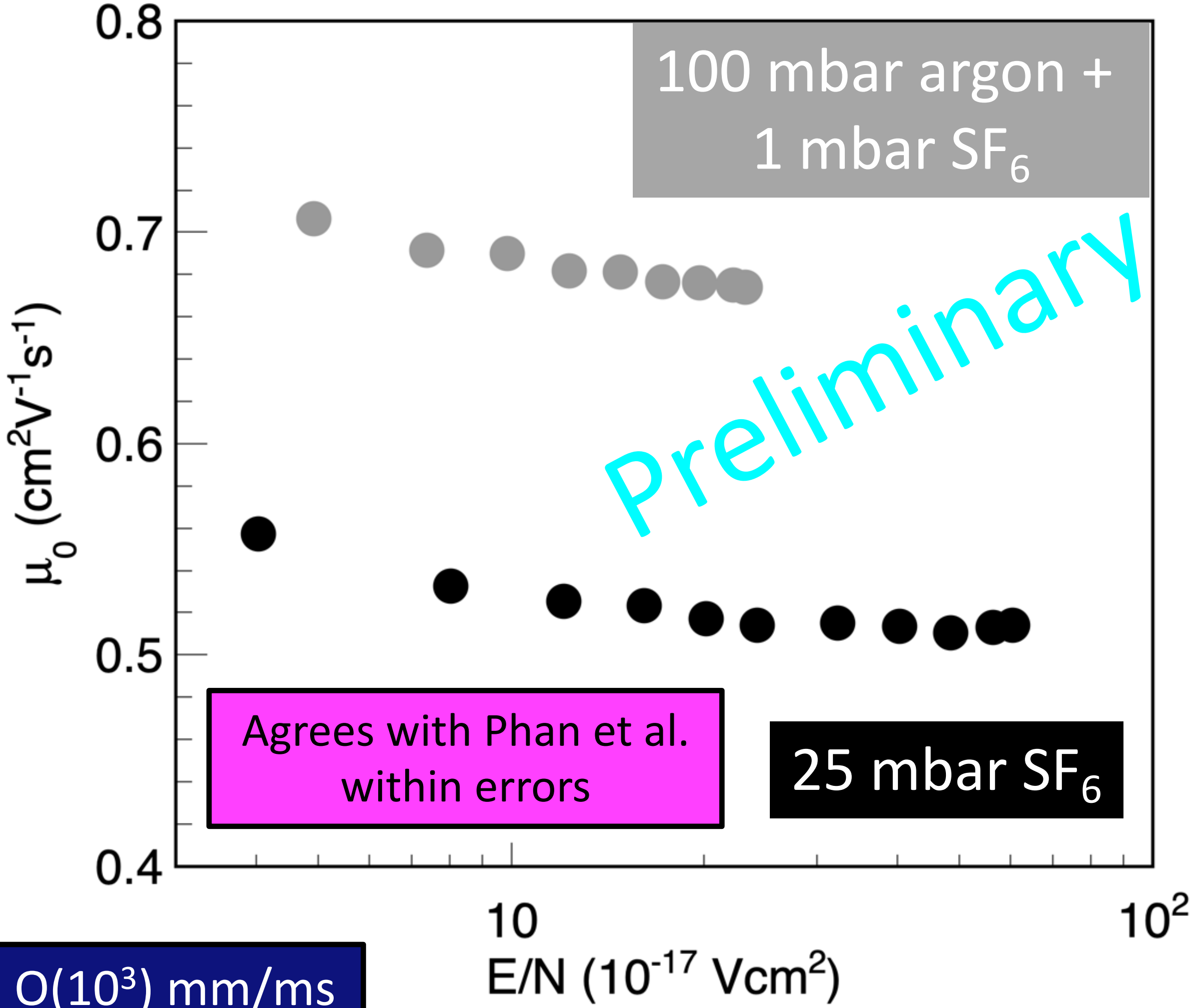
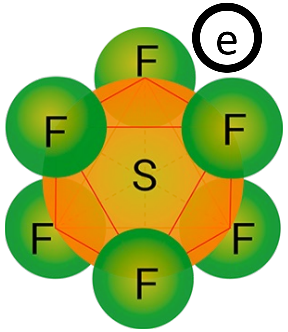


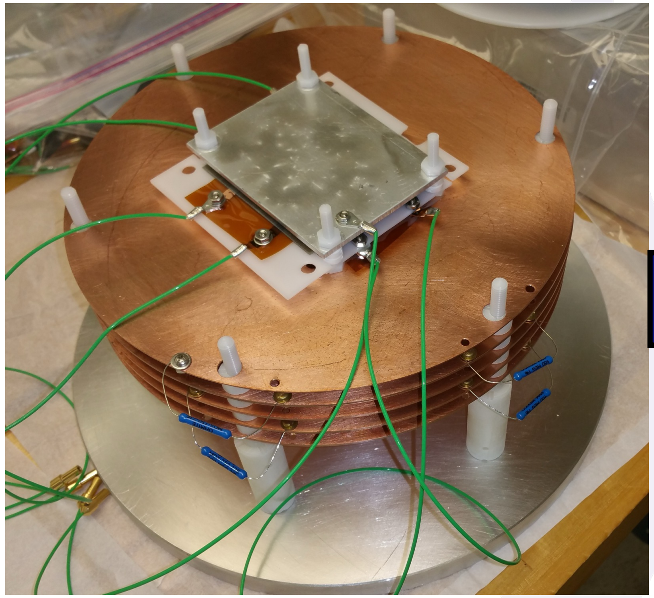
Electrons in LAr ≈ O(10^3) mm/ms

Plans in New Mexico

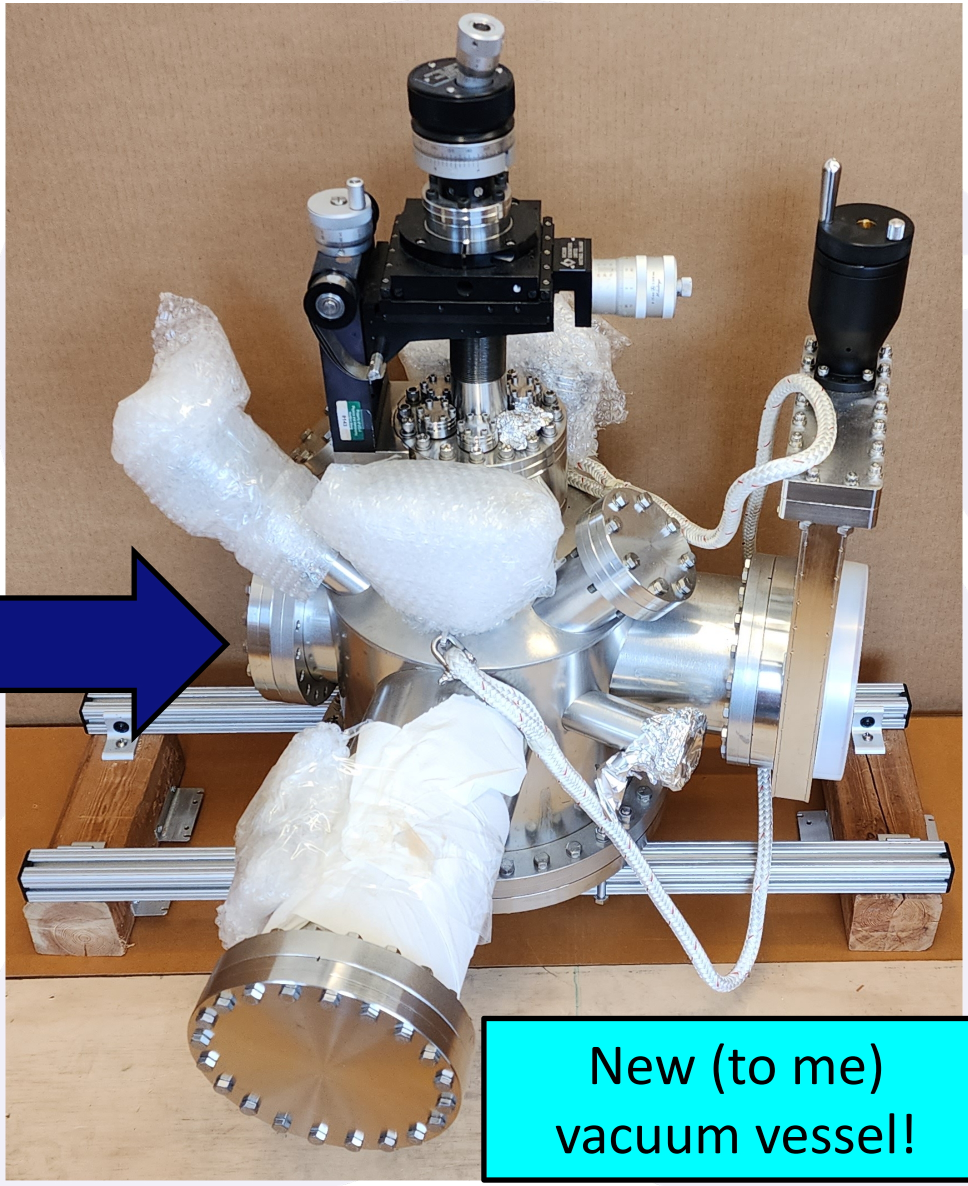
Gaseous Phase – NITPC at Los Alamos

- New vessel has 3D motion feedthrough with rotation (also used for gas pocket thickness control)
- Large viewing port
- Large gate valve
- Propose building a small TPC to continue noble gas doping studies started at CERN
- GEMs with charge readout
- Argon + SF_6 to start, but want to try other NI species
- Want to identify other promising NI gas mixtures





Need to design a small TPC with ≈ 10 cm drift

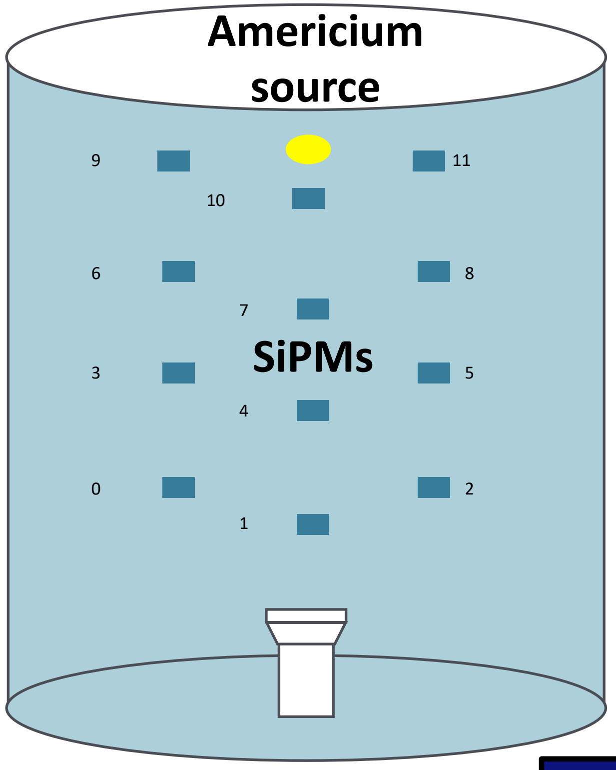


New (to me) vacuum vessel!

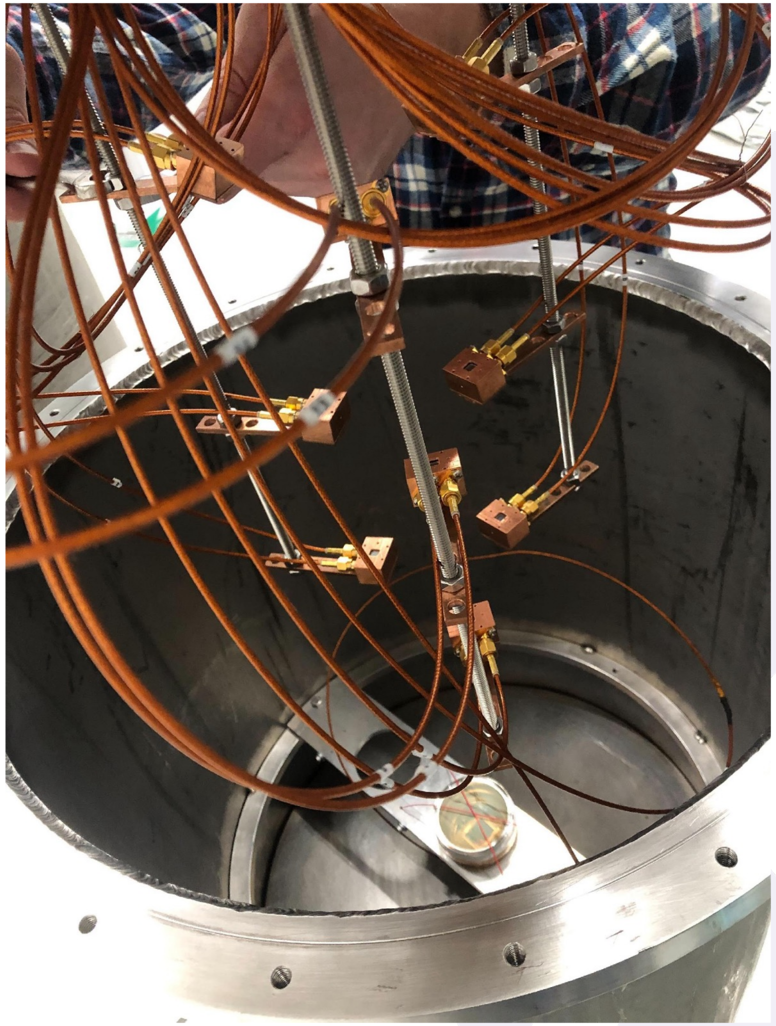
Liquid Phase – Scintillation (Light) Studies

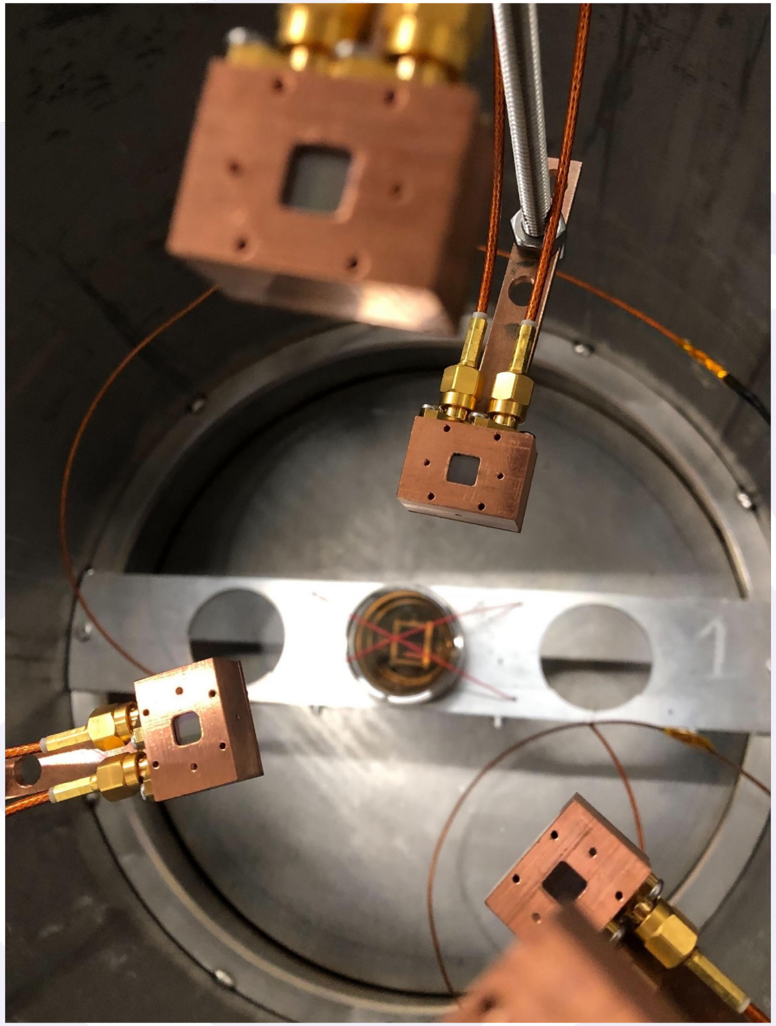
Link to LIDINE 2023 talk

Setup for studying xenon doping in liquid argon (LAr)



D. Fields, et al

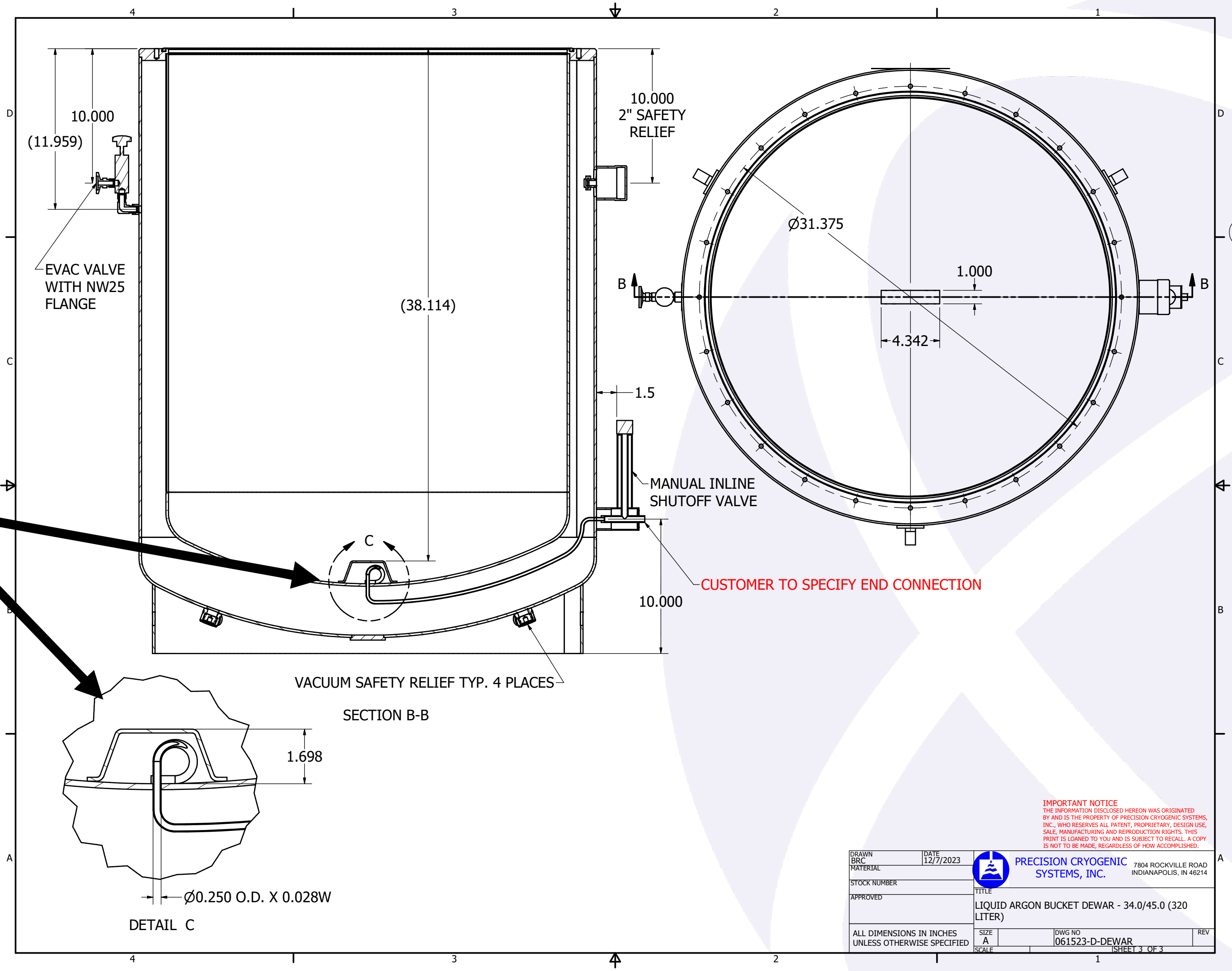


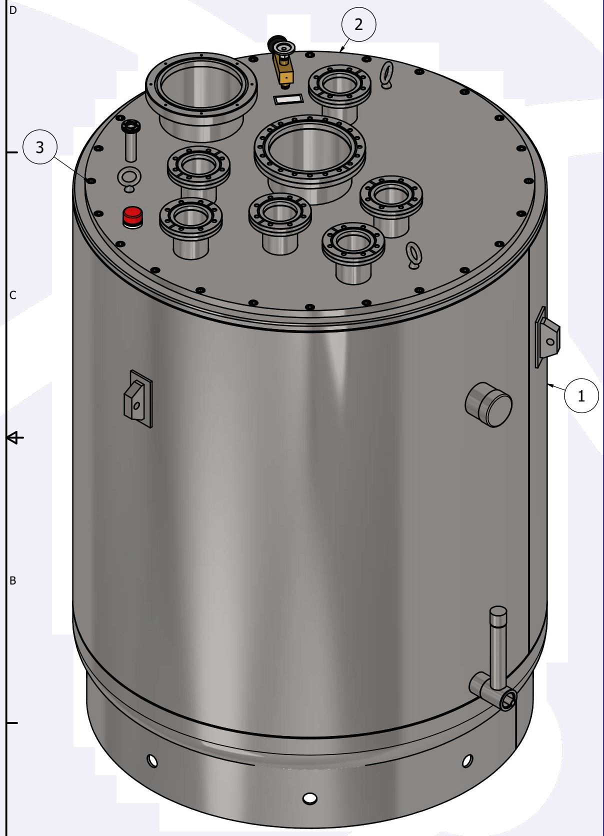


"BACoN" – Liquid Argon Cryostat @ UNM

BACoN Upgrade in Progress

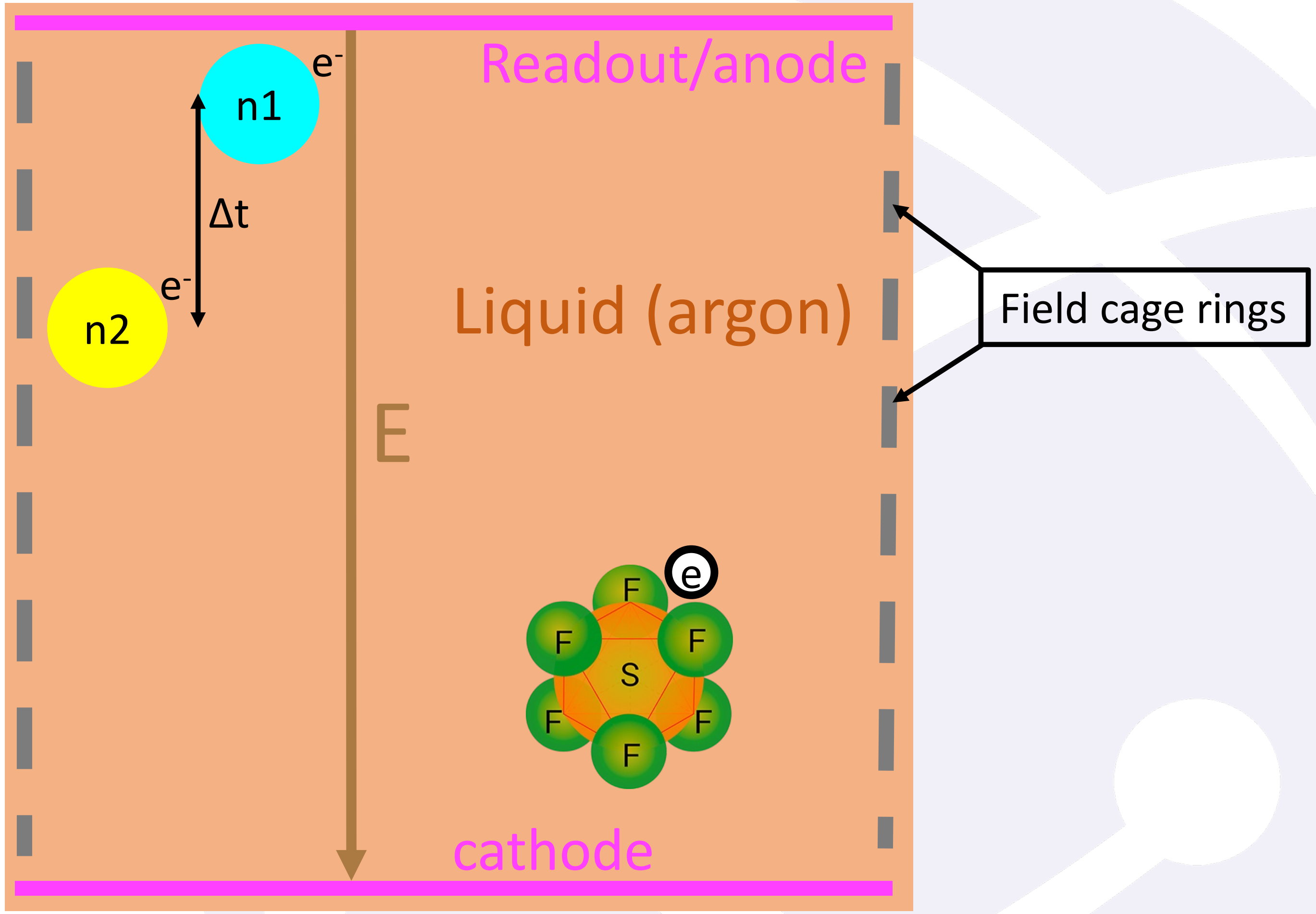
- Upgrading xenon doping setup – 320 liters with fast turnover
- Xenon concentration measurements are not consistent by sampling ullage volume
- Introducing a liquid sampling mechanism to help constrain possible causes
- System can also be used to dope gases besides xenon
- Will propose to dope SF_6 (NIs) into LAr to study the effects on light yield in detail





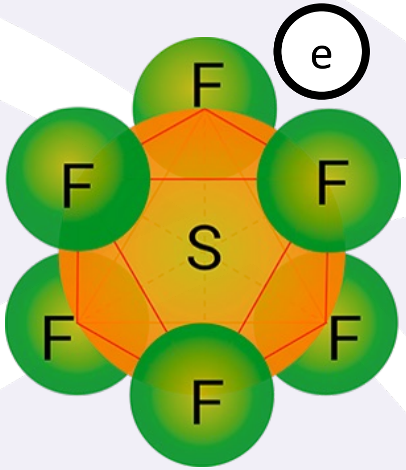
Single-Phase (LArTPC) – Charge Drifting Studies

- Final step is to build an NI-LArTPC in a cryogenic setup with doping capabilities
- Plan to submit a new LDRD (ER) proposal for this at LANL in January
- Study feasibility of charge drifting with NIs in liquid (argon)
- Anticipate building TPC with a long drift (> 50 cm) to ensure adequate separation of different NI species
- Readout not determined, needs to operate in cryogenic environment

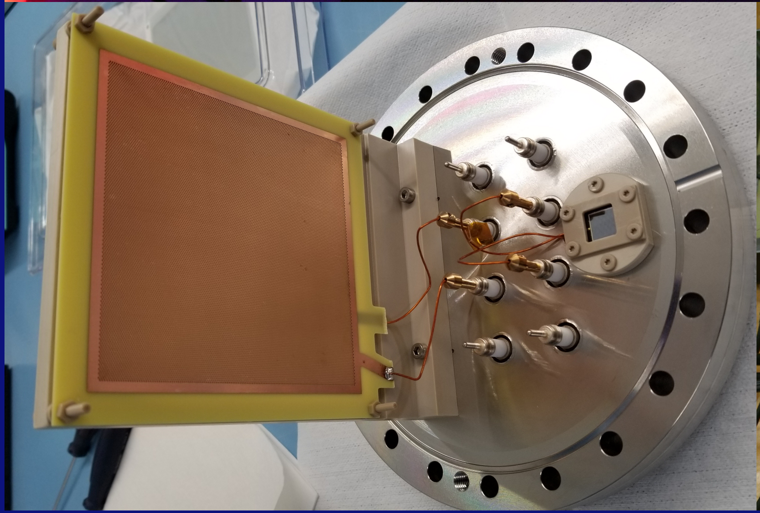


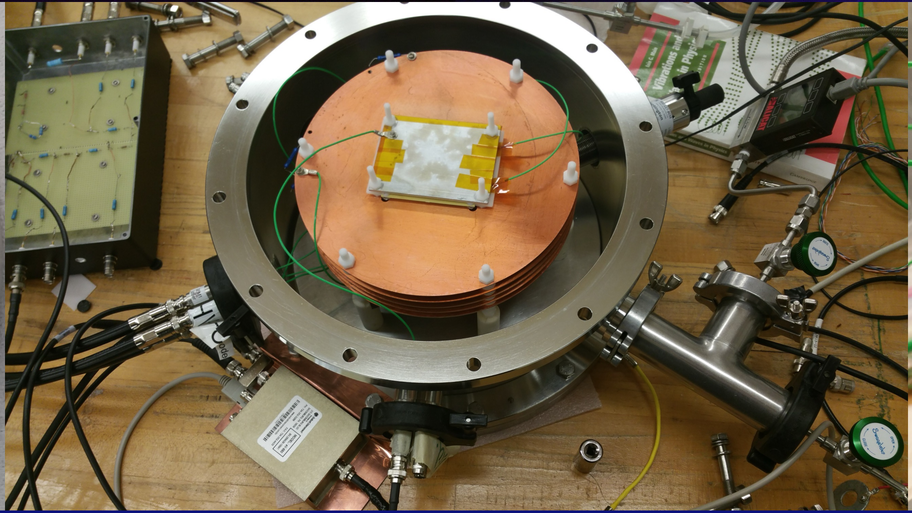
Summary

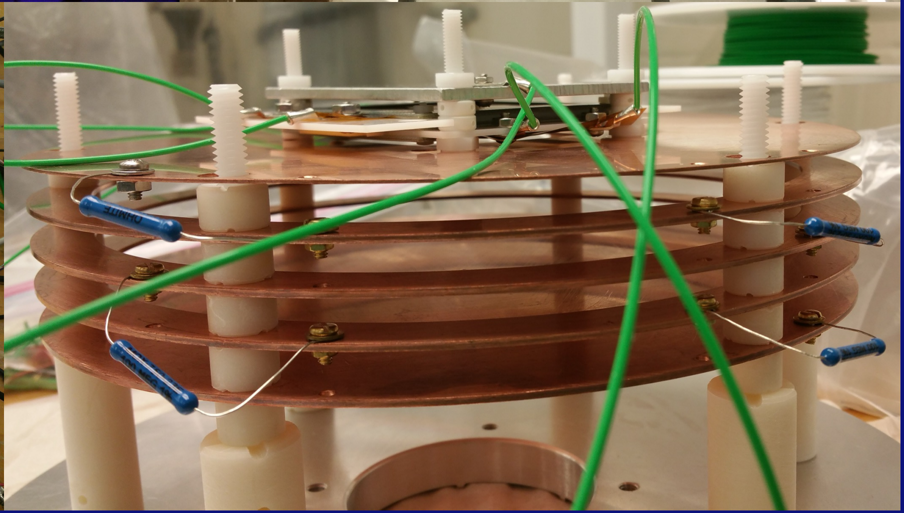
- Pure SF_6 negative ion behavior shown with Hawaii and CERN data
  - Agreement (along with gain data) with previously published results
- SF_6 (1%) – argon mixture gives gains of $O(10^3)$
- SF_6 (1-5%) – argon mixture shows NI drift velocity behavior
- Plans to further study different NI gaseous mixtures are in place
- Plans to study effect on light yield from doping NI in LAr are in place
- Plan to submit LDRD proposal for a NI-LArTPC early next year at LANL



Thank You

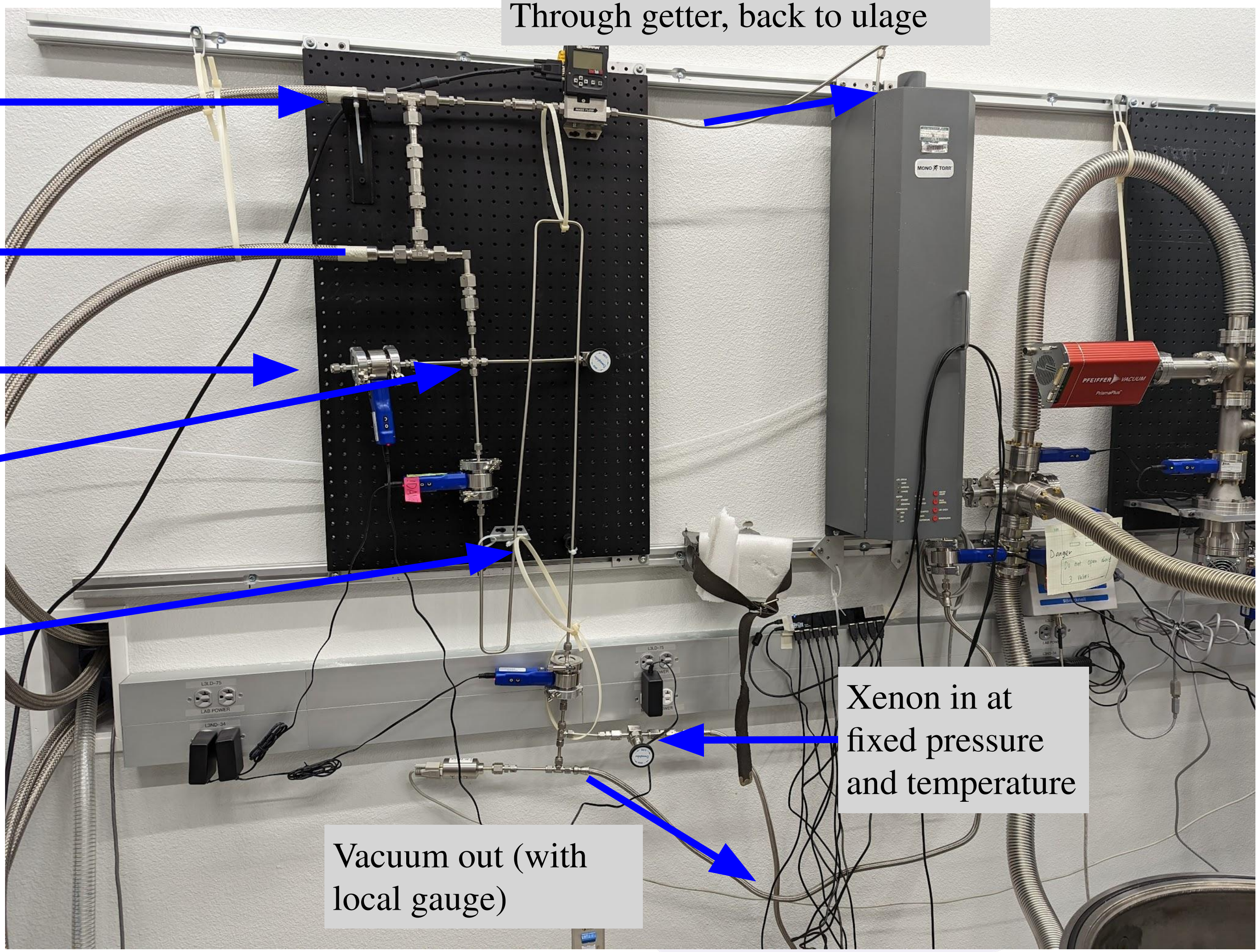






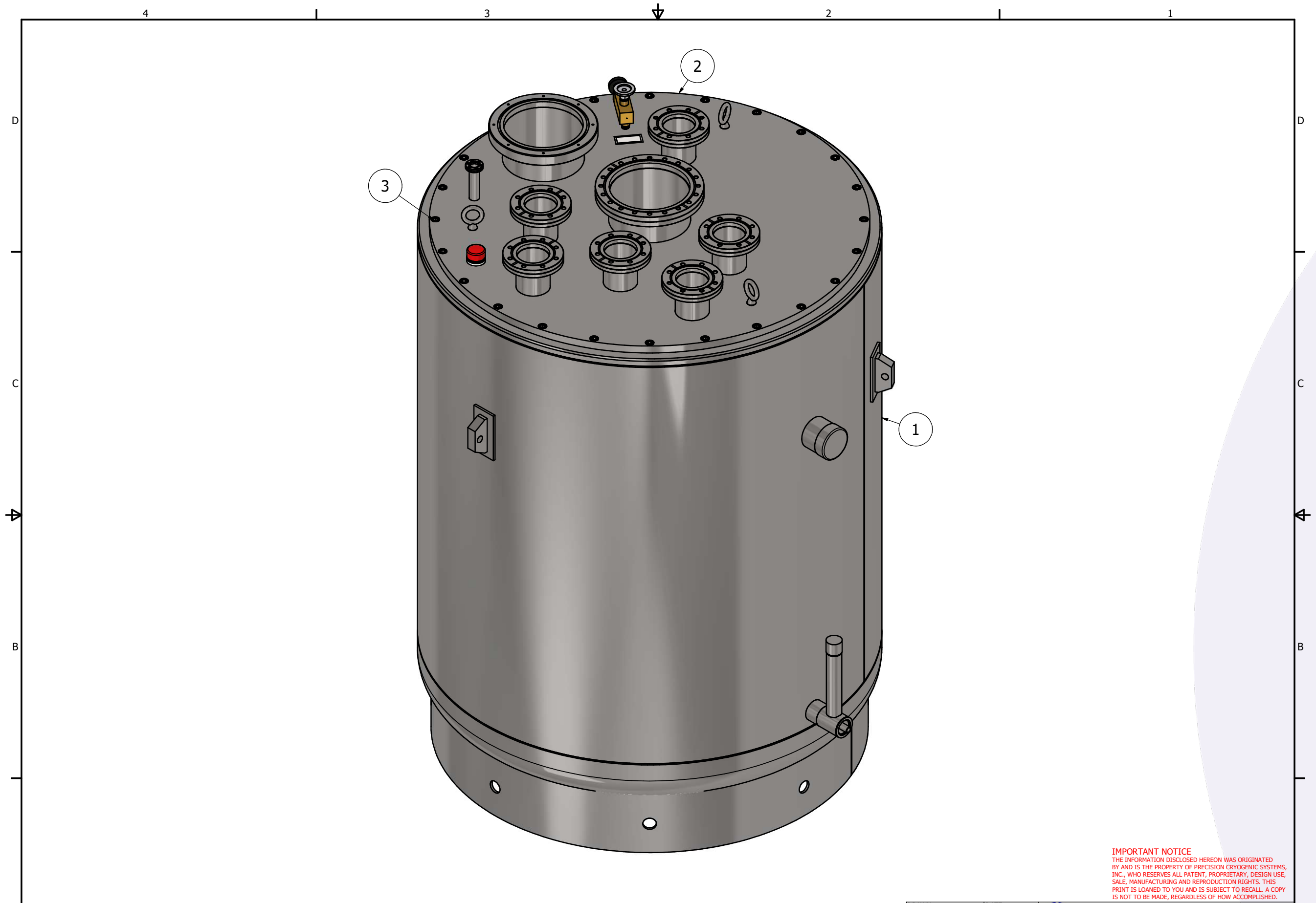
Backup

Doping Procedure



D. Fields, et. al.

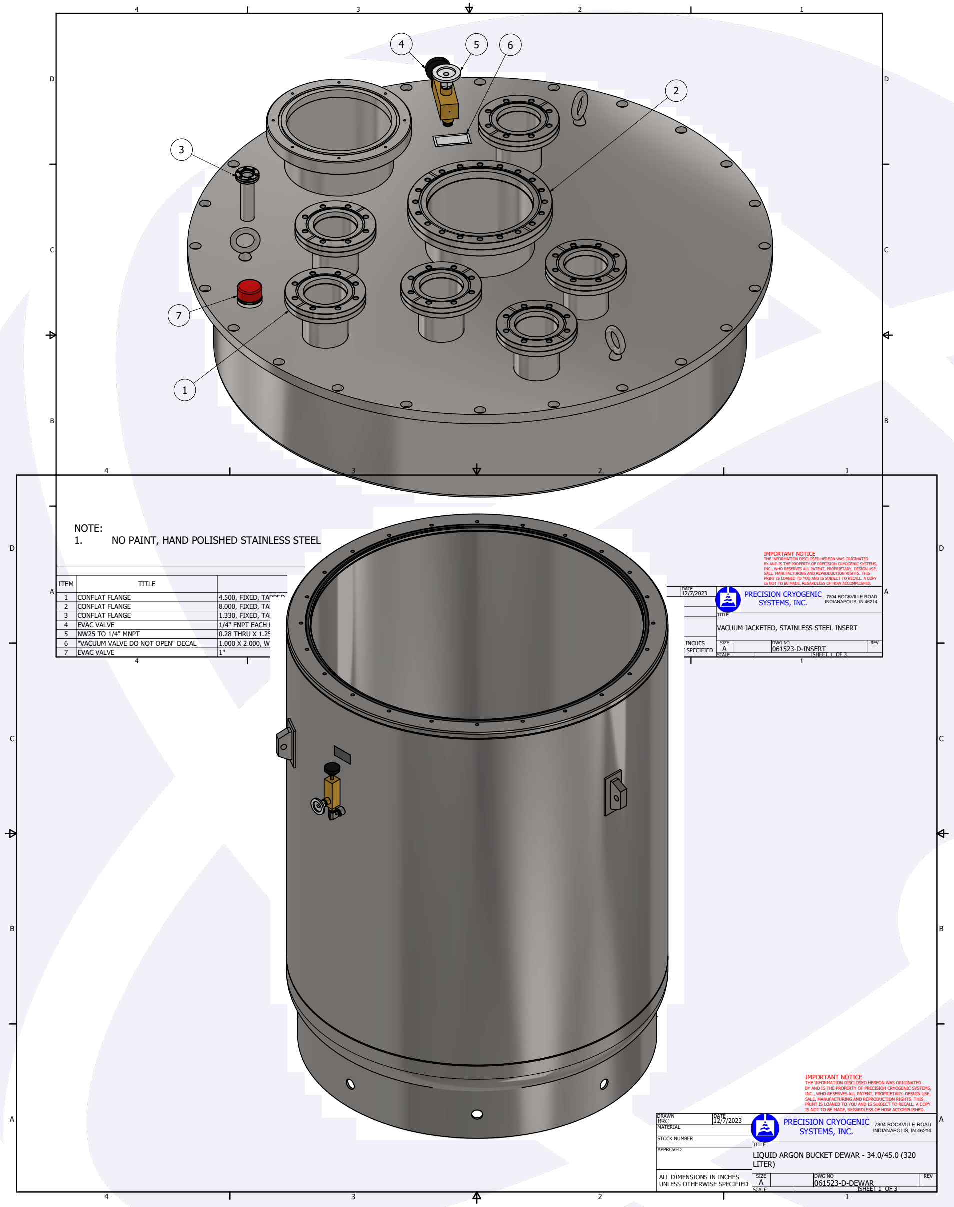
BACoN Upgrade - Cryostat



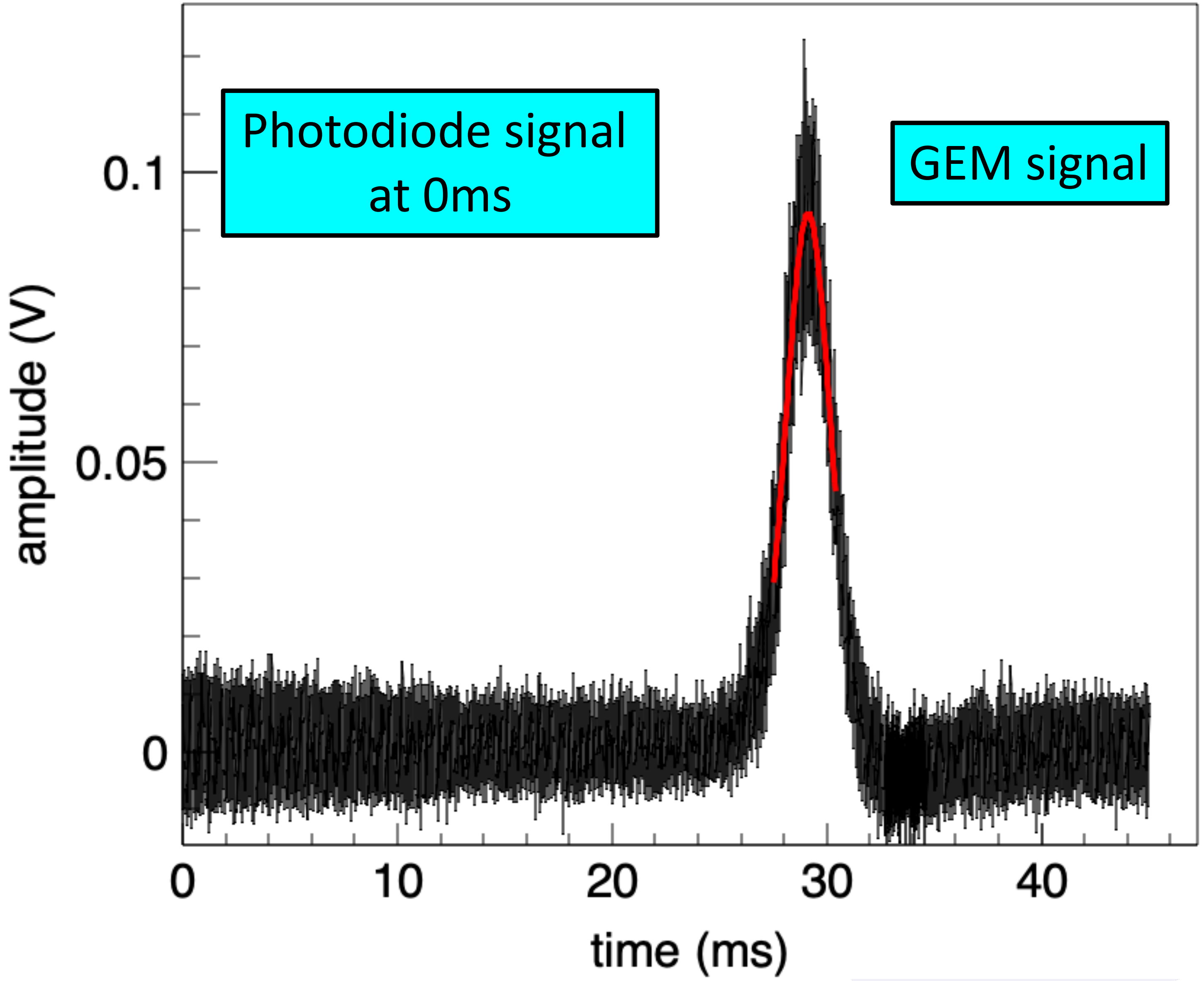
BILL OF MATERIALS

ITEM	PART NUMBER	TITLE	DESCRIPTION	QTY	U/M
1	061523-D-DEWAR	LIQUID ARGON BUCKET DEWAR - 34.0/45.0 (320 LITER)		1	EA
2	061523-D-INSERT	VACUUM JACKETED, STAINLESS STEEL INSERT		1	EA
3	12017	SCREW	3/8"-16 Thread Size, 7/8" Long	24	EA

DRAWN BRC DATE 12/7/2023
MATERIAL
STOCK NUMBER
APPROVED
ALL DIMENSIONS IN INCHES UNLESS OTHERWISE SPECIFIED
PRECISION CRYOGENIC SYSTEMS, INC. 7804 ROCKVILLE ROAD INDIANAPOLIS, IN 46214
TITLE LIQUID ARGON BUCKET DEWAR WITH VACUUM JACKETED INSERT
SIZE A DWG NO 061523-D REV
SCALE SHEET 1 OF 2



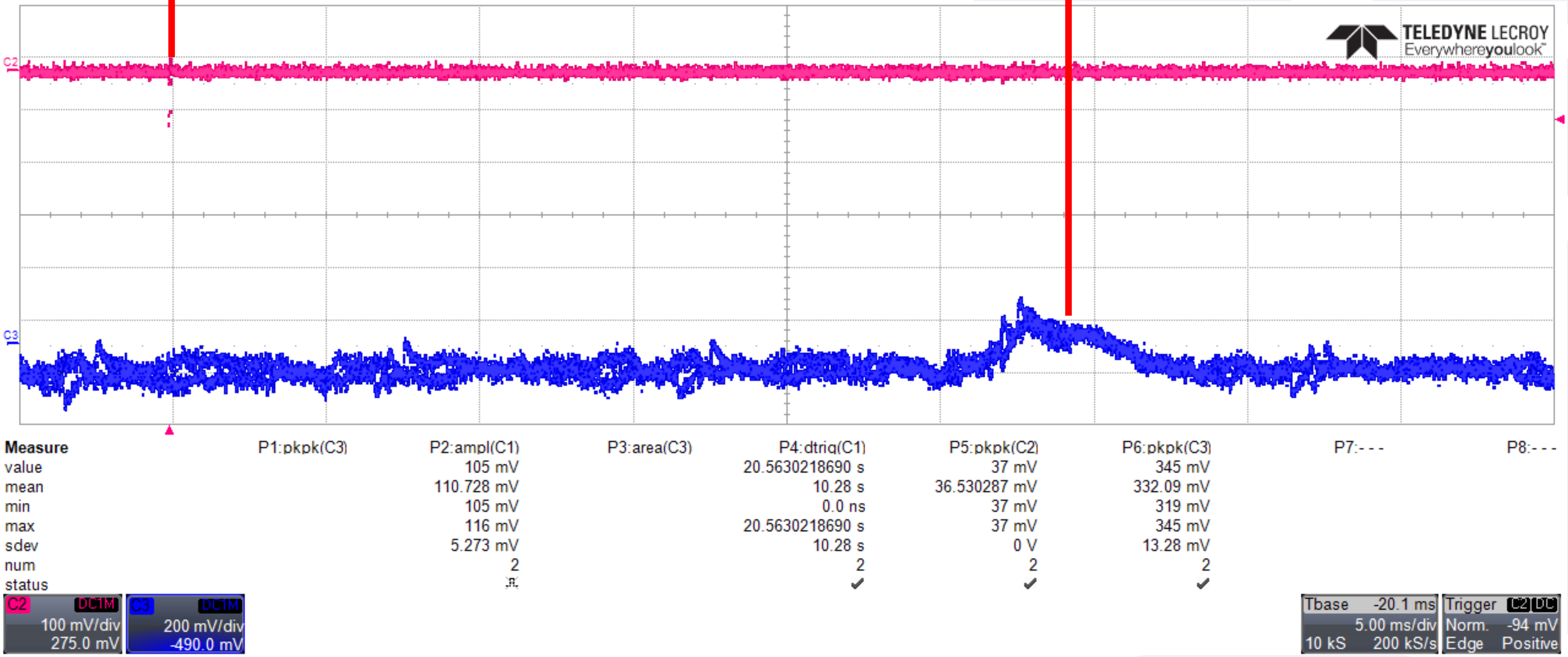
Long Drift Times with SF_6 - 10 V/cm Drift Field



SF_6 – 12 V/cm Drift Field

“Correct” drift time lines up with “second” peak

≈29ms



SF_6 Reduced Mobility – Phan et. al.