First+ Studies of SF_6 in a TPC

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(UPDATE ON CYGNUS2015 LA TALK)

Electron vs. Negative Ion Drift Gases

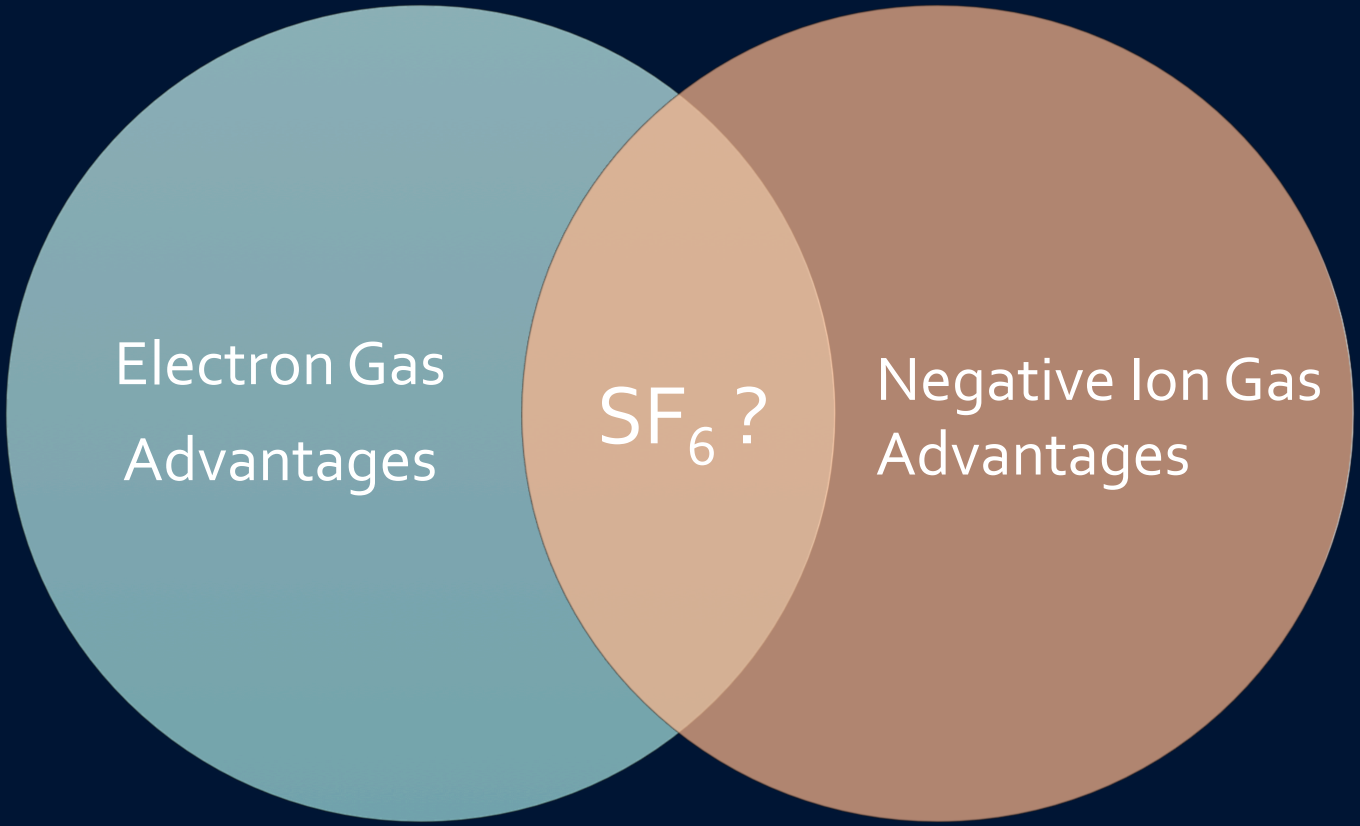
Electron Drift

- Example: CF_4
  - Larger diffusion -> smaller detector length
  - Spin target -> no sacrifice of volume -> higher target density at same pressure -> can operate at shorter drift lengths.
  - Benign
  - Good scintillator -> allows for optical readouts
  - Fiducialization?

Negative Ion Drift

- Example: CS_2
  - Low diffusion -> large detector length
  - Good high voltage operation at low pressures
  - Demonstrated fiducialization
  - Lack spin-dependent content -> sacrifice detector volume to enable negative ion operation with a spin target
  - Toxic

Motivation



SF_6 Properties and Applications

Properties

- Non-toxic, non-volatile, colorless, odorless
- Electronegative gas,
- e- affinity = 1.1 eV
- High vapor pressure:
- ~ 15,000 Torr at room temperature

Industrial Uses

- Insulation for high voltage power devices
- Semi-conductors fabrication
- Metal casting
- Numerous other applications

Research

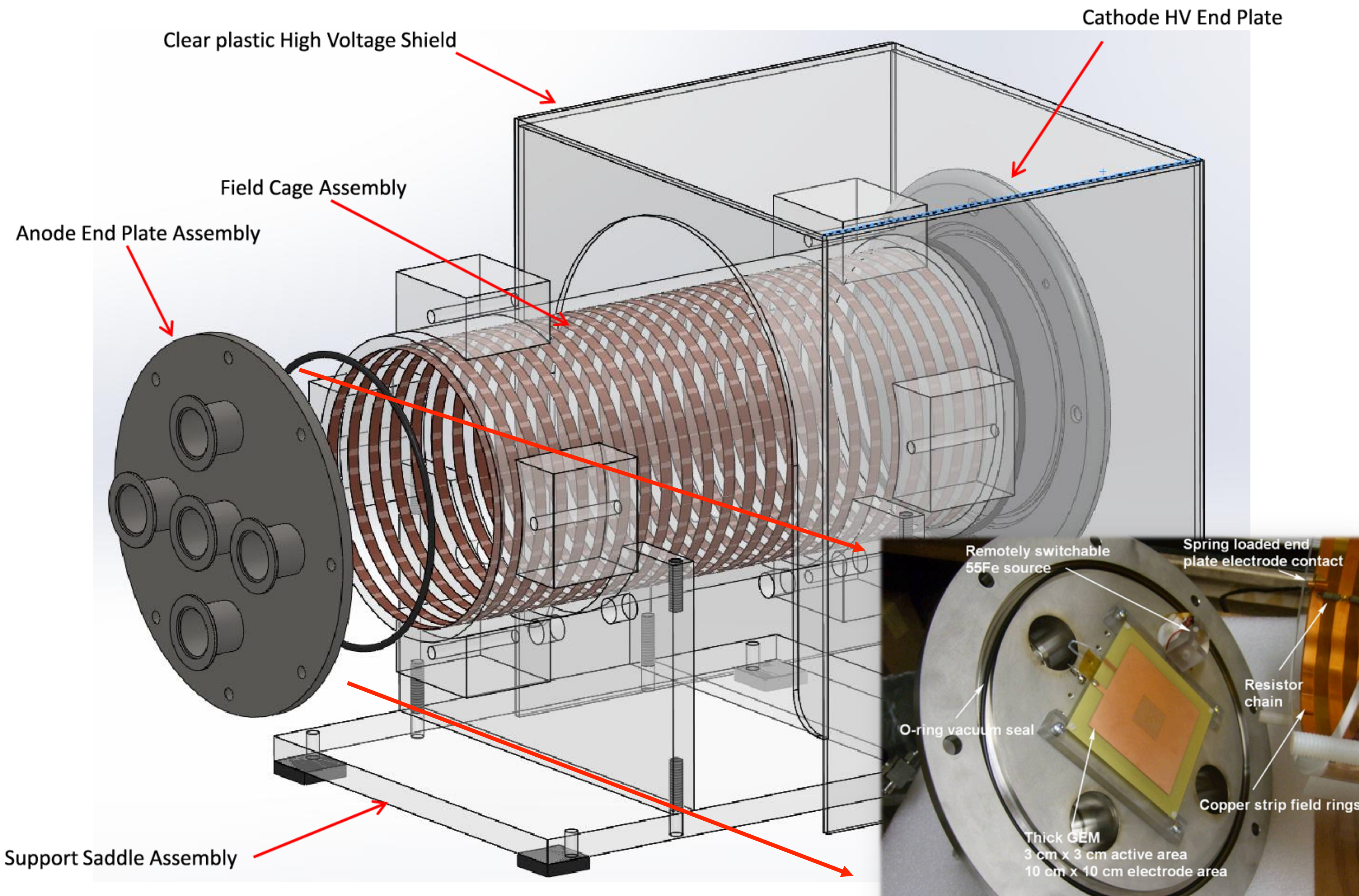
- Quencher in resistive plate chambers (RPCs) (as trace gas, not the primary)

Questions

- Is it possible to avalanche in SF_6 primary gas detector?
- What gas gain is achievable and how does it depend on pressure?
- What is the diffusion behavior of SF_6 and how does it compare to CS_2 ?
- Is fiducialization of events in the drift dimension attainable in SF_6 mixtures, and if so, under what conditions?
- Potential applications besides dark matter?

Experimental Apparatus

Designed by Eric Lee at UNM

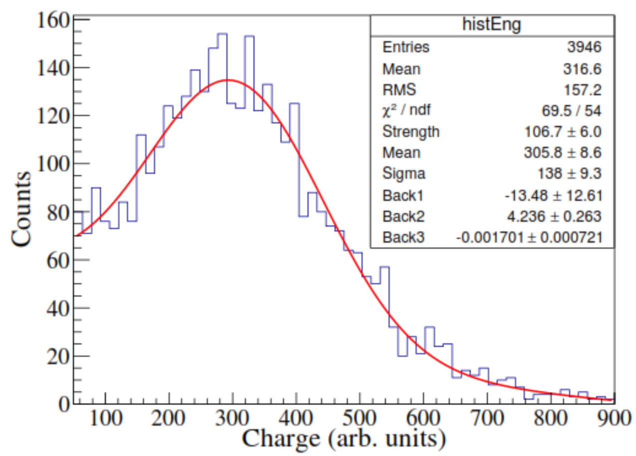


SF_6 Measurements

- Pressure: 20 Torr – 100 Torr
- Drift Field: 0 – 1 kV/cm over a drift length = 60 cm
- All measurements currently made with THGEMs
- Ionization generated at cathode with N_2 laser (3.5 ns pulse width), trigger from laser.
- Fe-55 X-ray and Cf-252 neutron exposures
- CS_2 measurements at 20 and 40 Torr for comparison (identical setup used for SF_6)

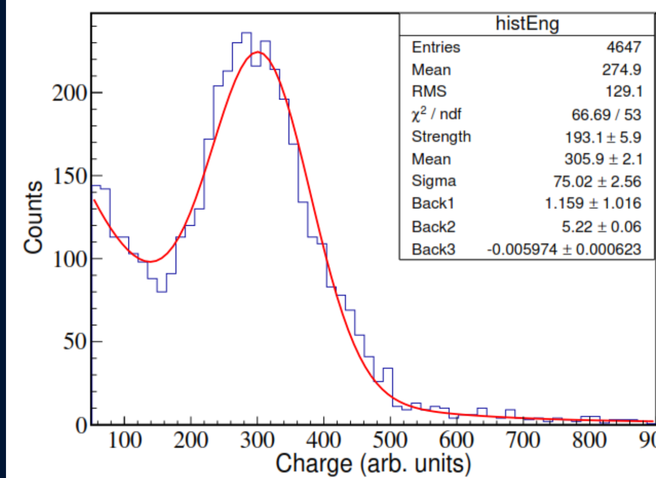
SF_6 Gas Gain

30 Torr SF6 (1.0 mm THGEM)



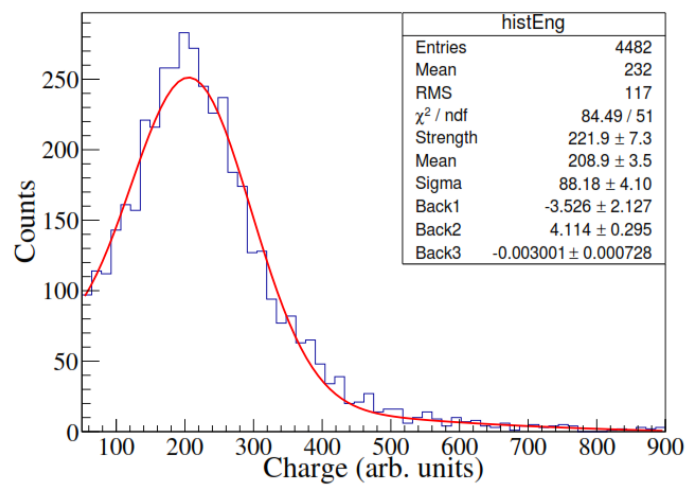
(a) ^{55}Fe energy spectrum in 30 Torr SF_6 using 1 mm THGEM

30 Torr SF6 (0.4 mm THGEM)



(a) ^{55}Fe energy spectrum in 30 Torr SF_6 using 0.4 mm THGEM

40 Torr SF6 (0.4 mm THGEM)



(a) ^{55}Fe energy spectrum in 40 Torr SF_6 using 0.4 mm THGEM

First Fe-55 spectrum in SF6 bulk gas TPC??

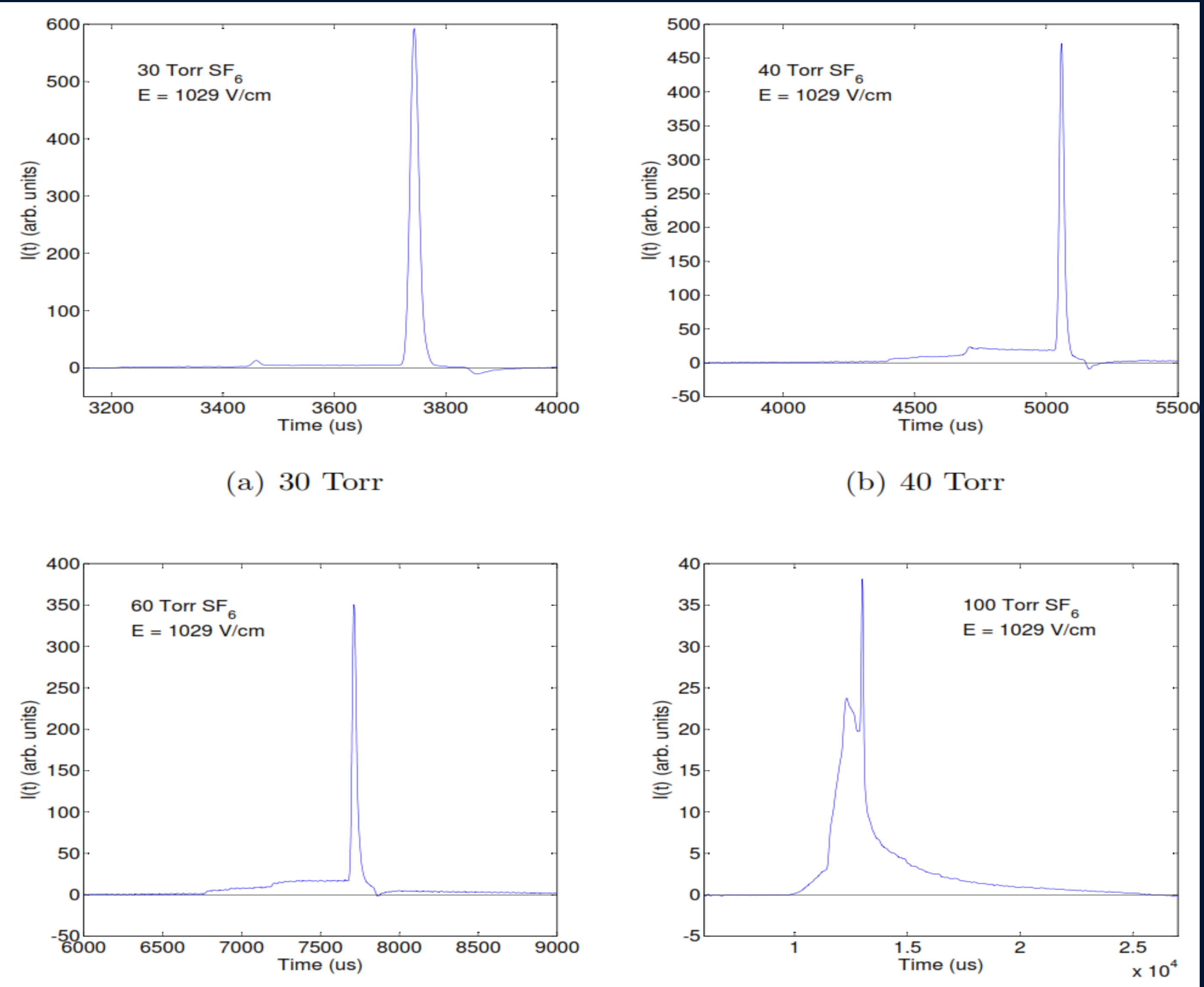
Gain ~ few 1000's

Gas Gain

- Energy resolution appears to worsen with lower E/p inside the amplification region.   to > 50%
- What other amplification devices can get gain in SF_6 (thin GEMs, micromegas, MWPCs, micro-channel plates, etc)?
- Can we get any gain at higher pressure (~ 1 atm)? Could be important for other applications. For example, if SF6 then why not SeF6 (Se for double-beta searches)?

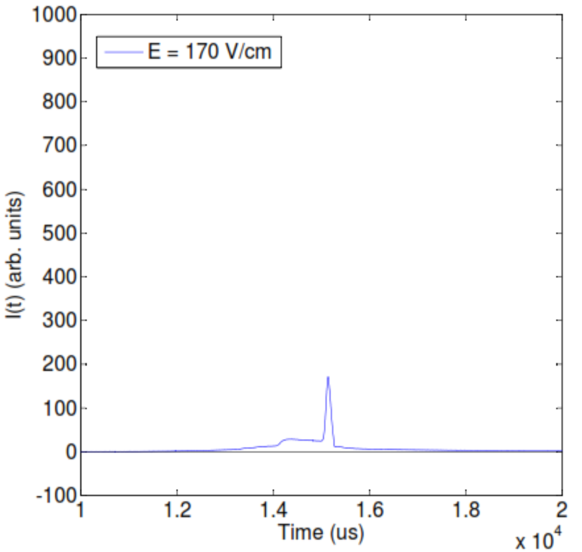
Waveforms shown at CYGNUS2015

Waveform Features (2015 data)

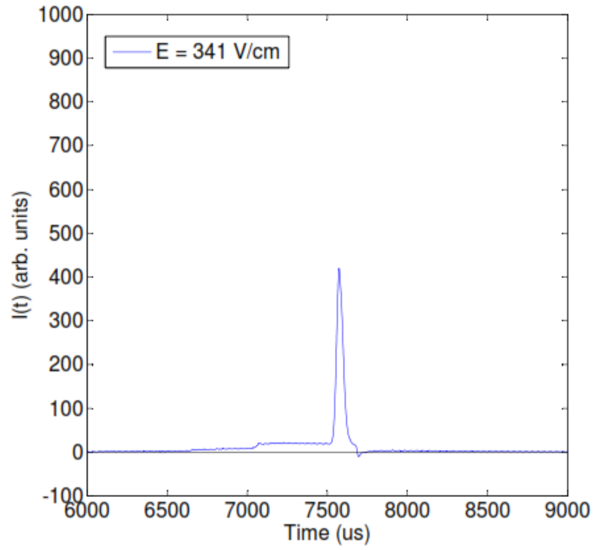


(a) 30 Torr (b) 40 Torr

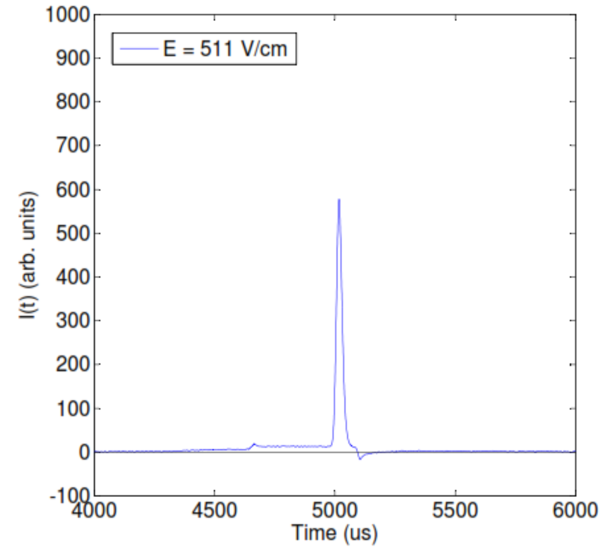
(c) 60 Torr (d) 100 Torr



(a) 10 kV

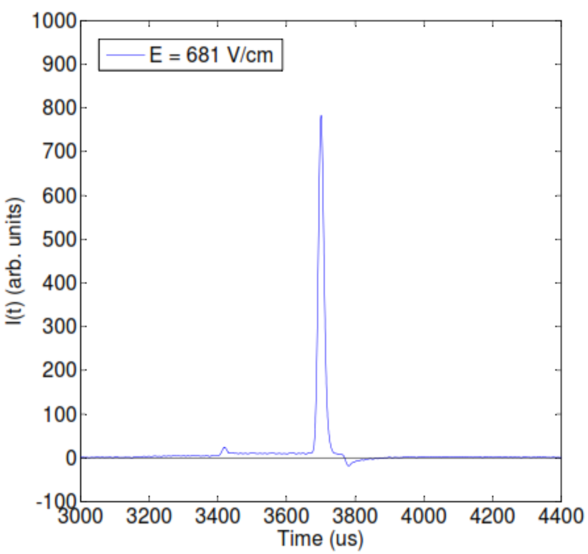


(b) 20 kV

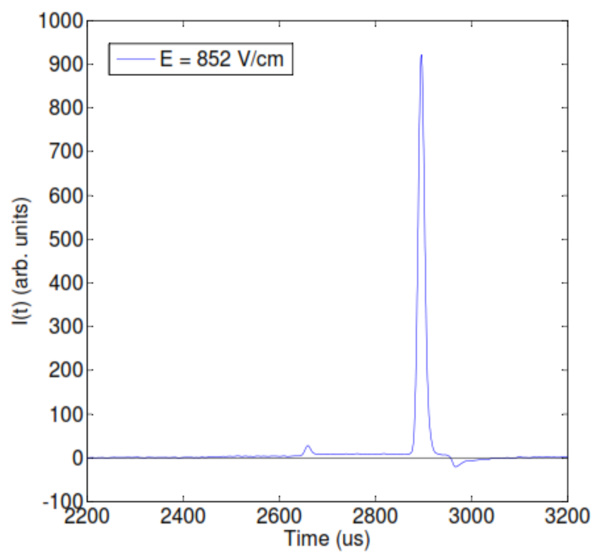


(c) 30 kV

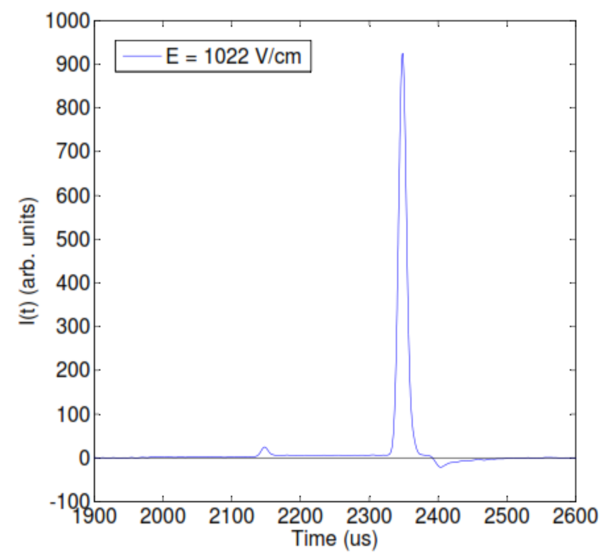
20 Torr SF_6 waveforms



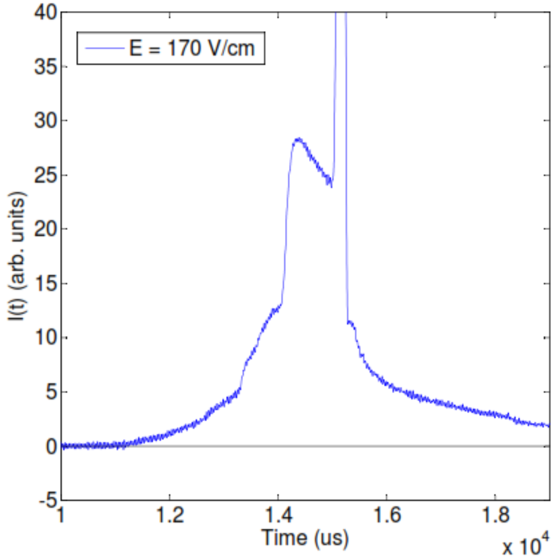
(d) 40 kV



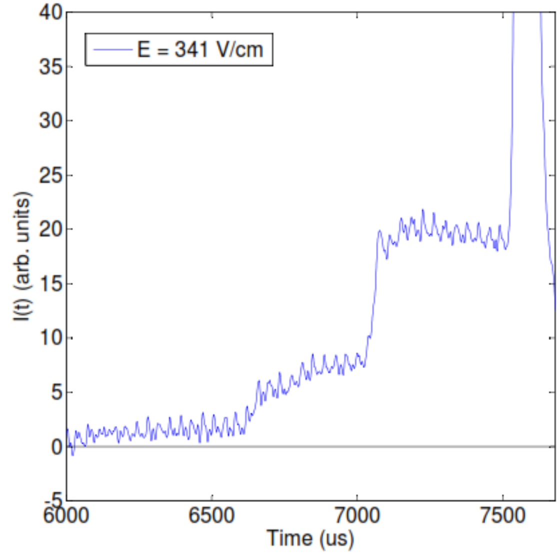
(e) 50 kV



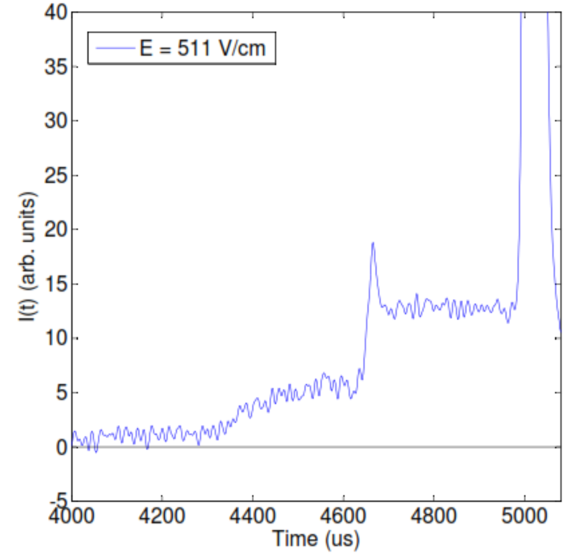
(f) 60 kV



(a) 10 kV

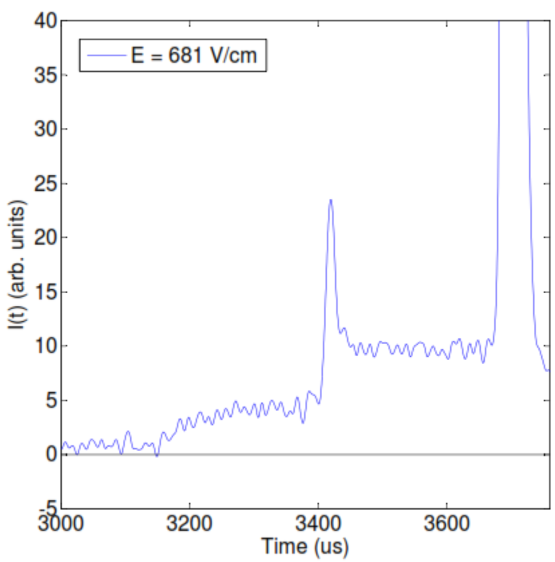


(b) 20 kV

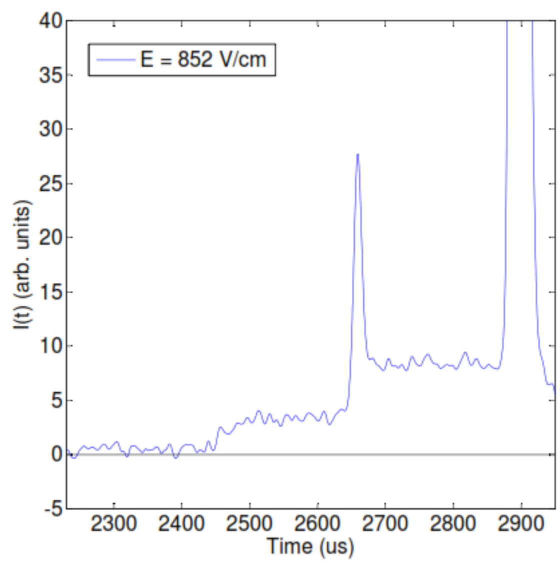


(c) 30 kV

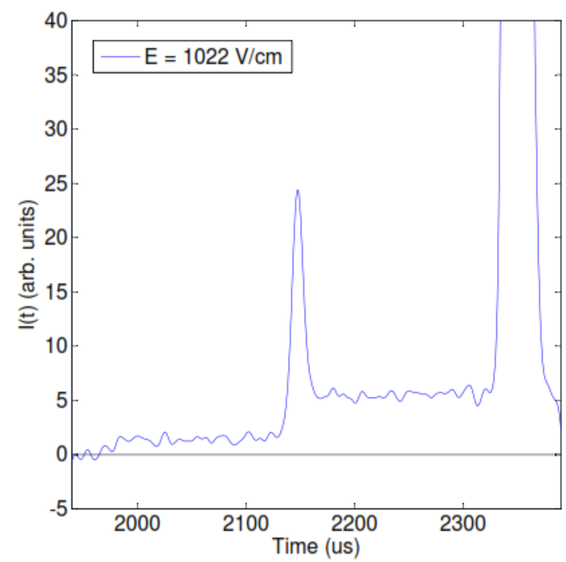
20 Torr SF_6 zoomed in views of previous waveforms



(d) 40 kV



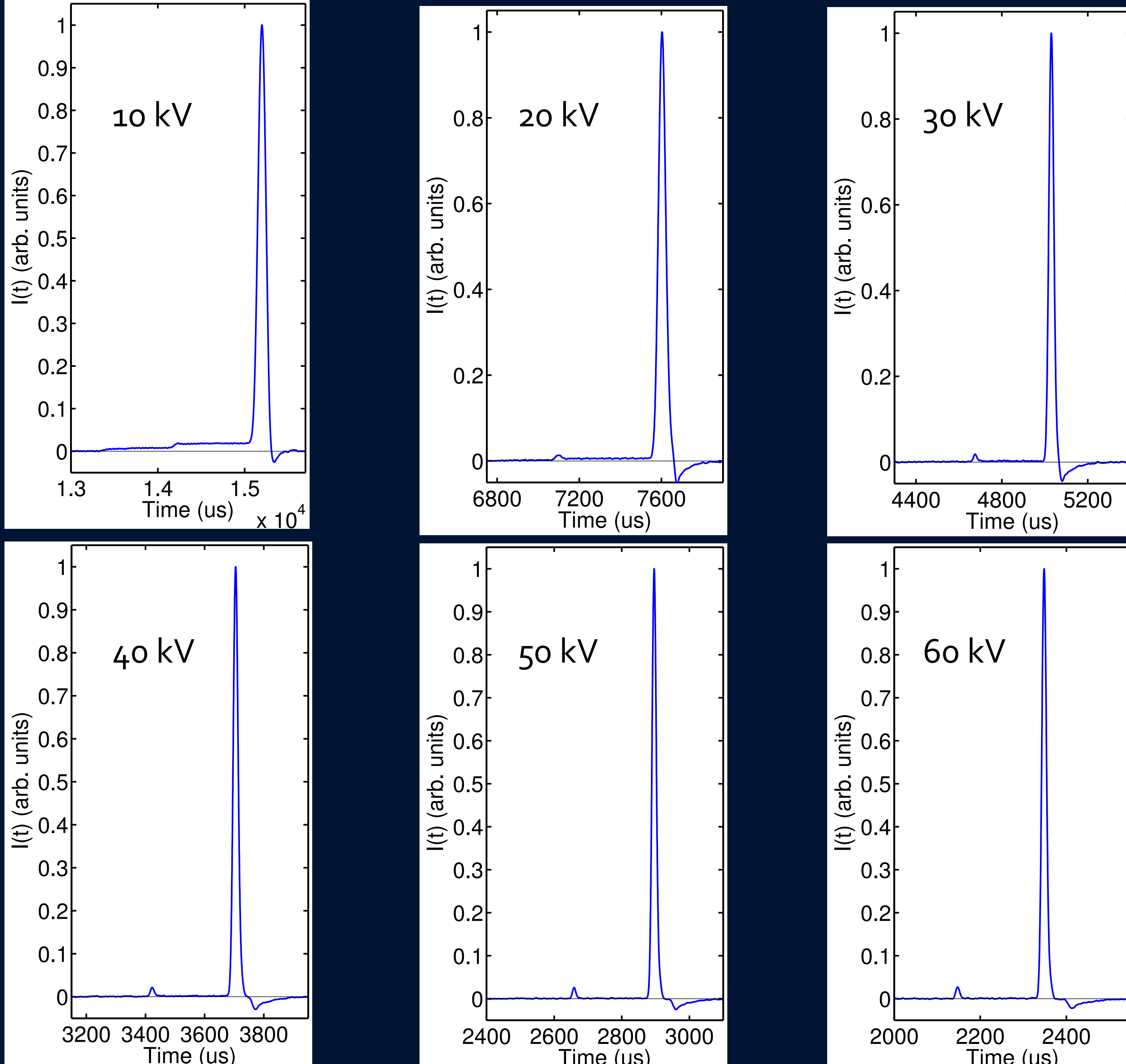
(e) 50 kV

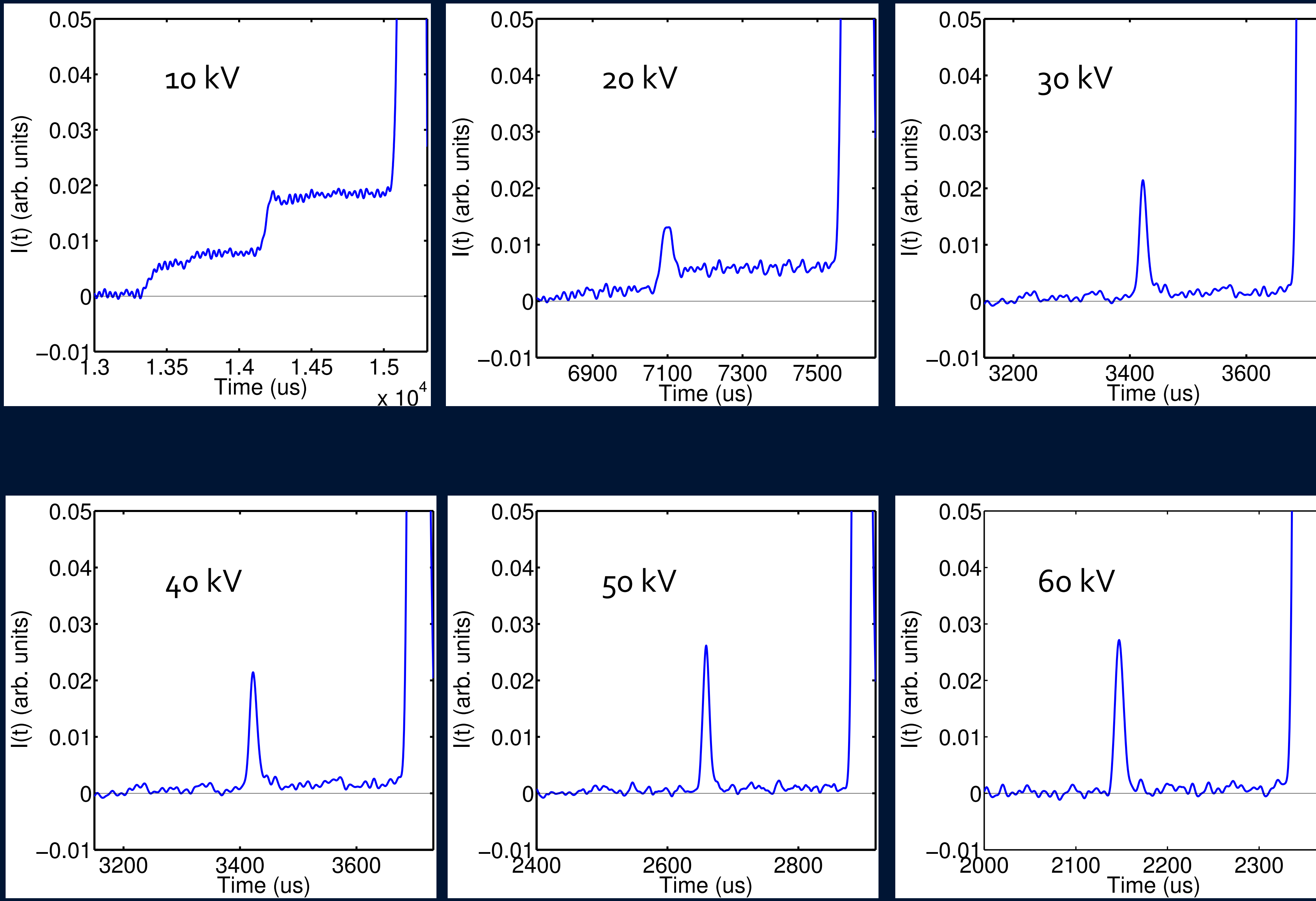


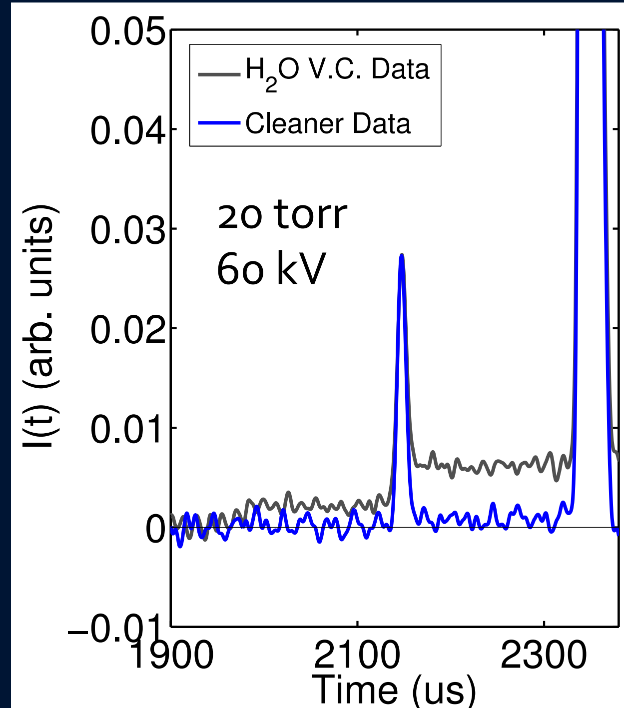
(f) 60 kV

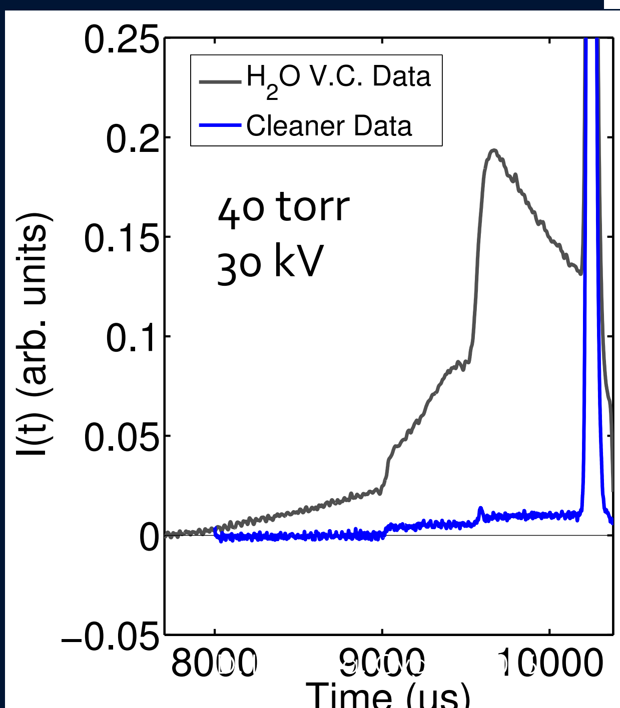
Waveforms show 2 peaks, identified as SF5- and SF6-, but what is all the structure?

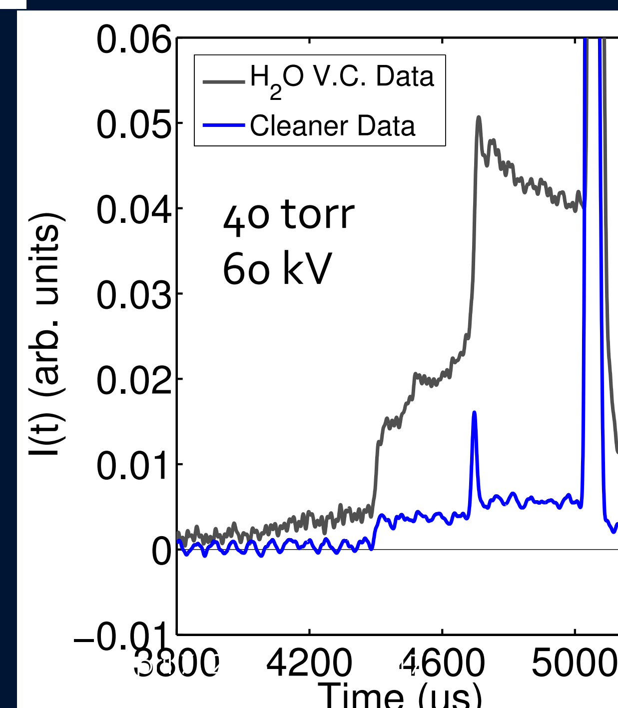
- It disappears at high E/P.
- The structure is not independent of the peaks: there is one amplitude between the SF5- and SF6- peaks, and a lower amplitude left of (faster than) SF5-
- Chemistry of drifting SF5- and SF6-? Something to do with attachment/detachment?
- We recently discovered it was contamination…the following data (2016) is at 20 Torr with the contamination mostly gone:


10 kV
20 kV
30 kV
40 kV
50 kV
60 kV
I(t) (arb. units)
Time (us)
x 10^4


10 kV
20 kV
30 kV
40 kV
50 kV
60 kV
I(t) (arb. units)
Time (us)
x 10^4
0.05
0.04
0.03
0.02
0.01
0
−0.01
1.3
1.35
1.4
1.45
1.5
6900
7100
7300
7500
3200
3400
3600
2400
2600
2800
2000
2100
2200
2300


H2O V.C. Data
Cleaner Data
20 torr
60 kV
I(t) (arb. units)
Time (us)
0.05
0.04
0.03
0.02
0.01
0
−0.01
1900
2100
2300

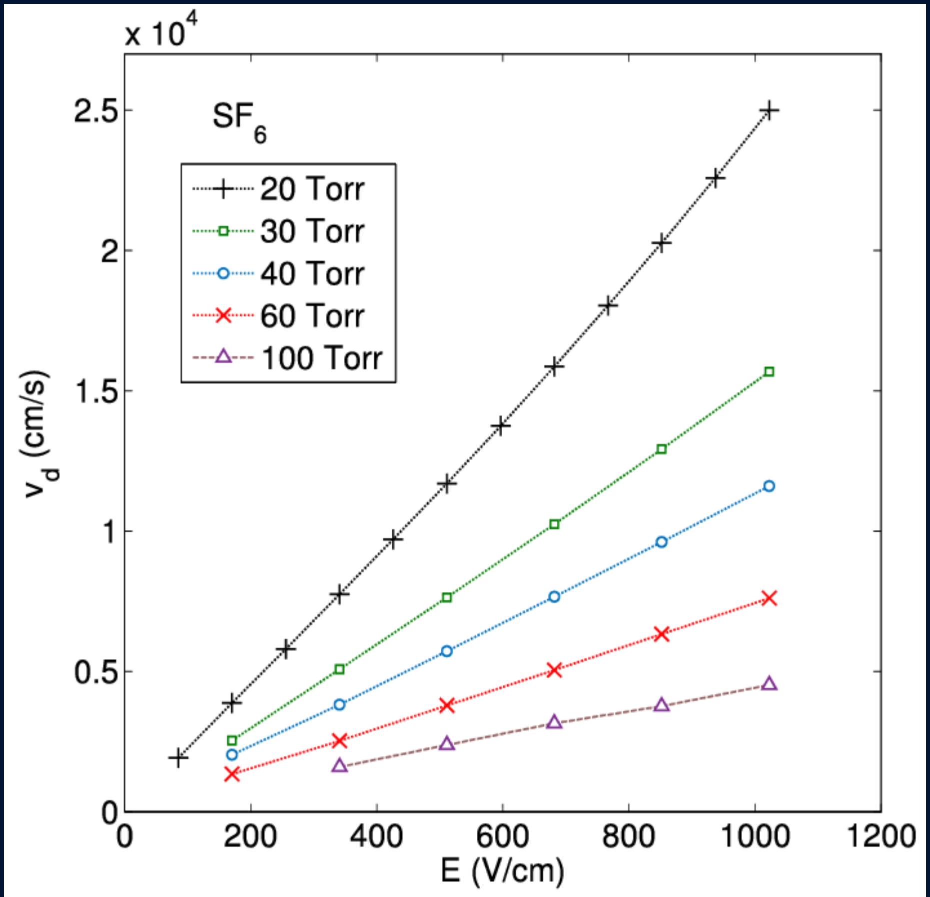

H2O V.C. Data
Cleaner Data
40 torr
30 kV
I(t) (arb. units)
Time (us)
0.25
0.2
0.15
0.1
0.05
0
−0.05
8000
9000
10000

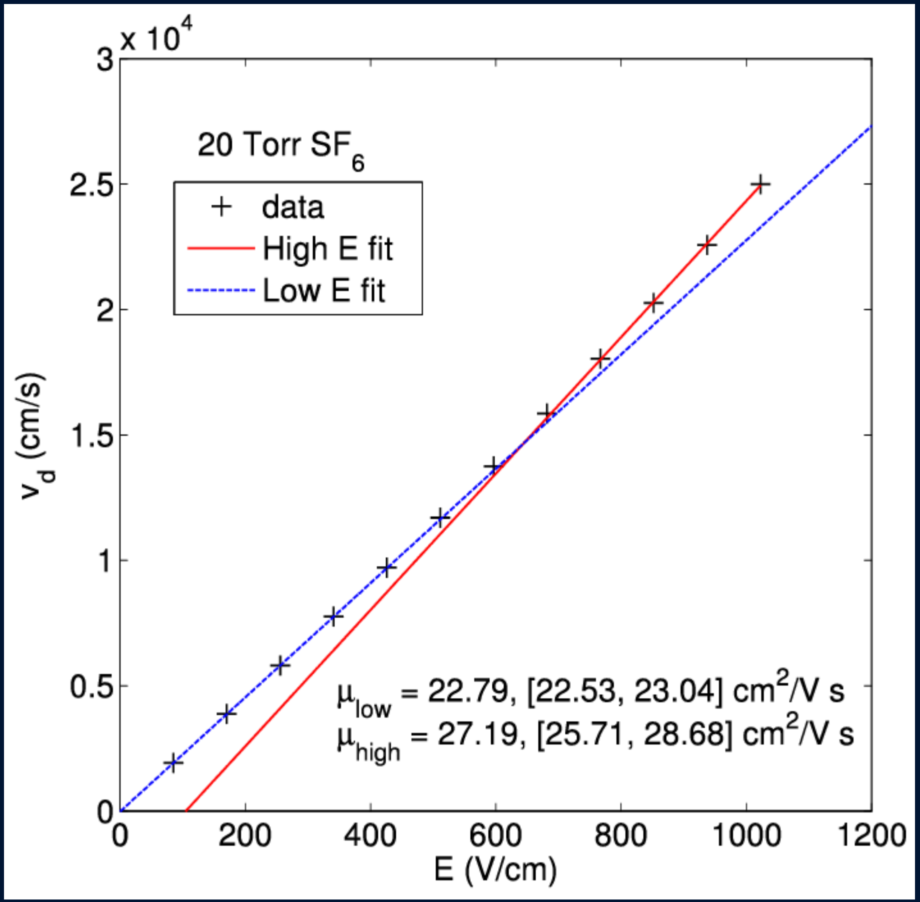

H2O V.C. Data
Cleaner Data
40 torr
60 kV
I(t) (arb. units)
Time (us)
0.06
0.05
0.04
0.03
0.02
0.01
0
−0.01
3800
4200
4600
5000

Its water vapor!

- It has practically no effect on the mobilities of the SF5- or SF6-, gain, etc.
- With it mostly gone we are able to see the SF5- peak at much lower E/p.
- The level of contamination that caused the effect? We believe it was around 0.1% – 0.5% but its difficult to quantify.
- Most of the CF4-based directional experiments take care to use high purity gas, and they flow/circulate/filter, so perhaps that will be sufficient.
- One concern is to watch for outgassing, especially if there is plastic in the vessel!

Drift Speed *(preliminary)*





- Ions in noble gases: at low fields , at high fields

Mobilities *(preliminary)*

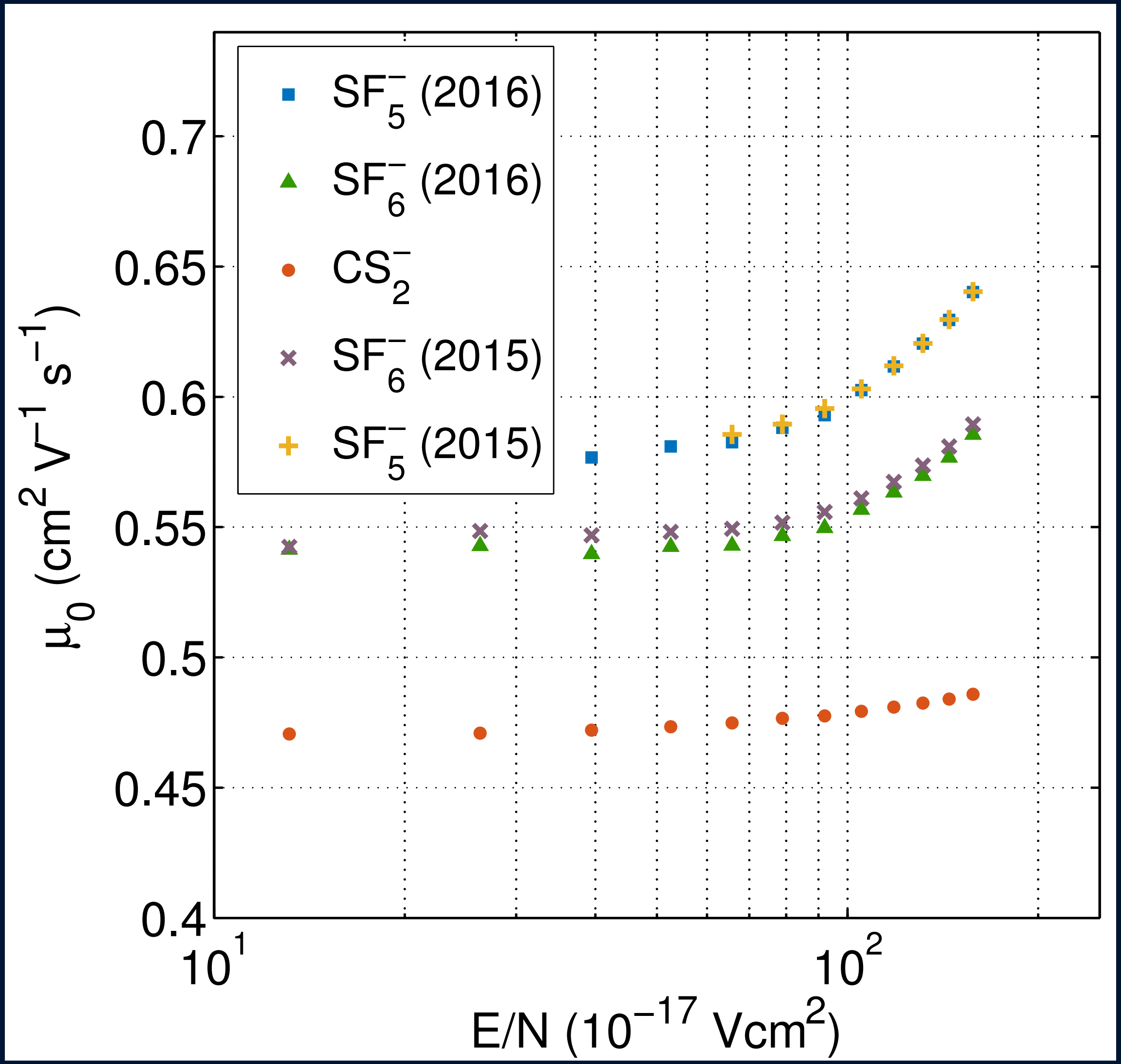
$$v_d = \mu \cdot E$$

μ: mobility, v: drift speed, E: electric field

Gas	Pressure (Torr)	Low Field Mobility ($cm^2V^{--1}\ s^{-1}$)	High Field Mobility ($cm^2V^{--1}\ s^{-1}$)
SF_6	20	22.79 +- 0.25	27.19 +- 0.50
CS2	20	19.80 +- 0.15	20.91 +- 0.3

SF6 15% higher mobility than CS2 in low field but 30% higher in high field.
SF6 mobility is 19% higher in high field than low field.

Mobilities Update *(preliminary)*

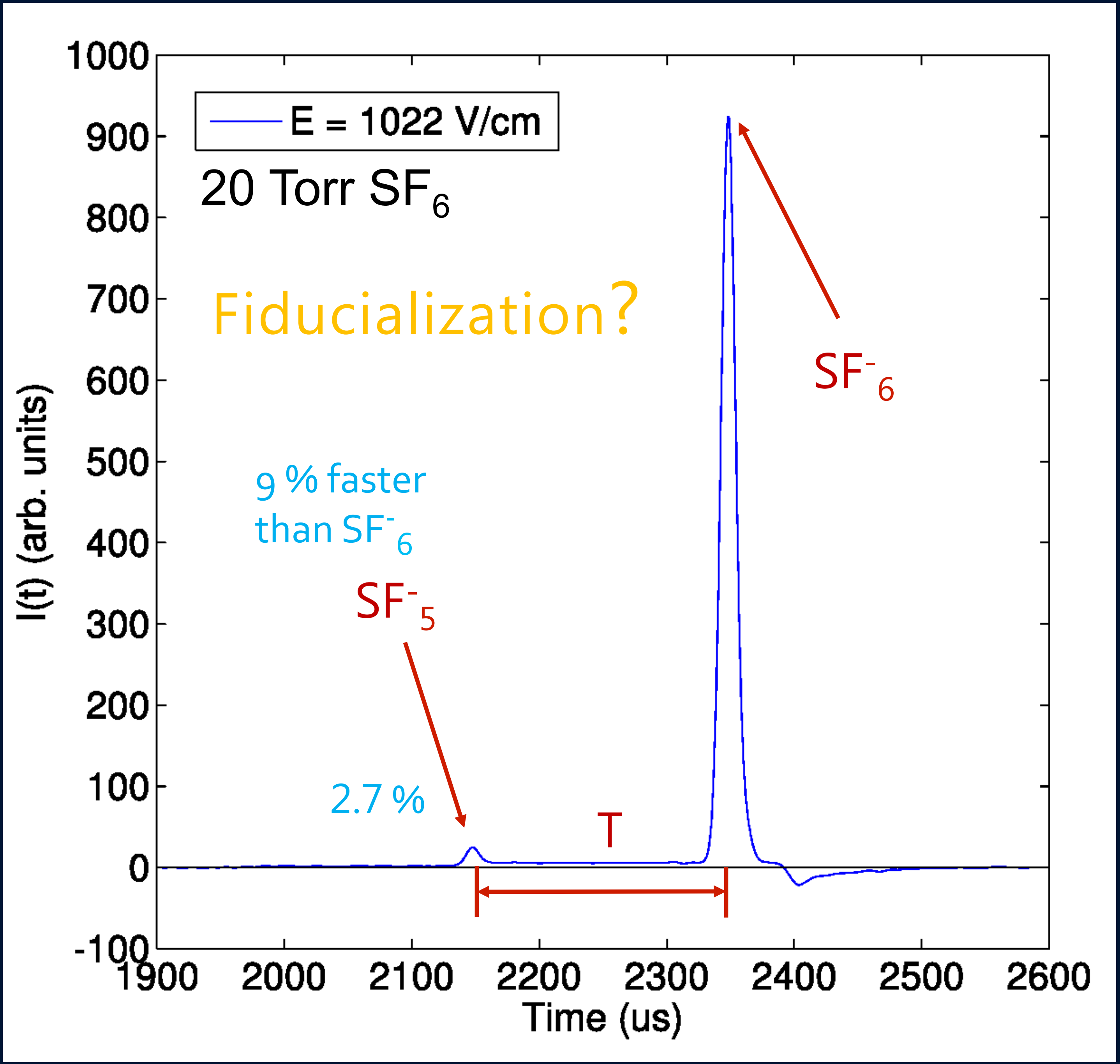


Mobilities

- Both the SF5- and SF6- mobility data agree with the literature, as does the CS2 data.
- There is a rise in mobilities for all 3 -ion species at high E/P.
- It is a steeper rise for SF5/SF6 than CS2.
- This is probably indicative of non-thermal behavior.

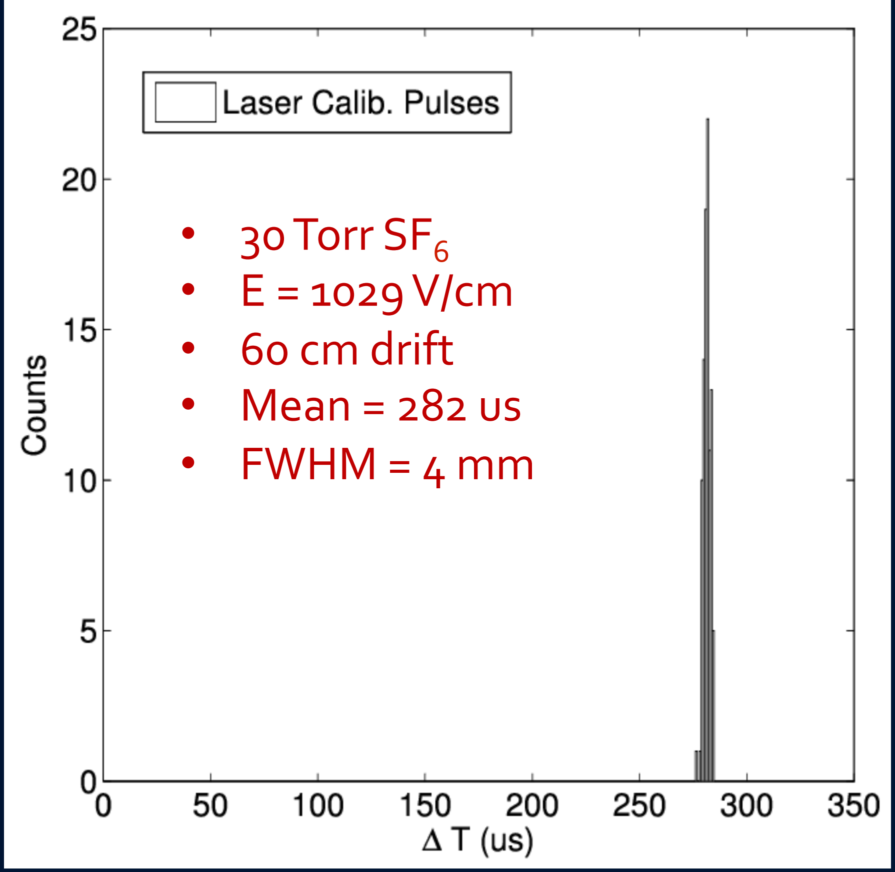
Fiducialzation?

- With two peaks, SF_5^- and SF_6^-, the obvious question is whether we can fiducialize along the drift axis (z).
- This is an absolutely critical tool for eliminating the radon progeny backgrounds that appear at the cathode/anode surfaces.
- DRIFT has used this z-fiducialization capability to go from many/day to ZERO backgrounds in over 50 days (see DRIFT talk by D. Snowden-Ifft)


E = 1022 V/cm
20 Torr SF6
Fiducialization?
SF-6
9 % faster
than SF-6
SF-5
2.7 %
T
I(t) (arb. units)
Time (us)
1000
900
800
700
600
500
400
300
200
100
0
-100
1900
2000
2100
2200
2300
2400
2500
2600

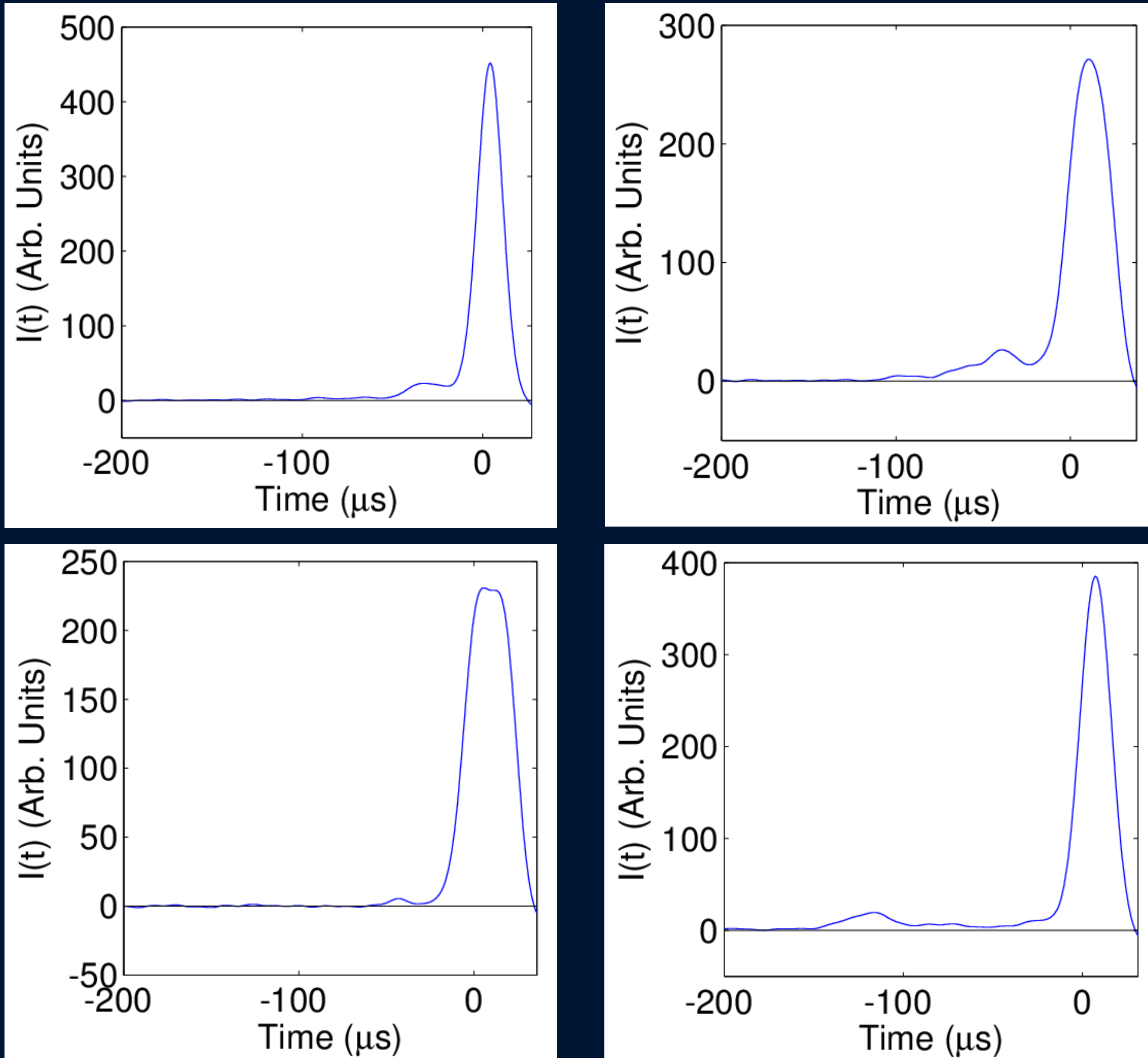
Fiducialization: Laser Generated Cathode Events

- Distribution of time difference for laser generated cathode events (60 cm drift).
- Calibration for absolute z for events with different

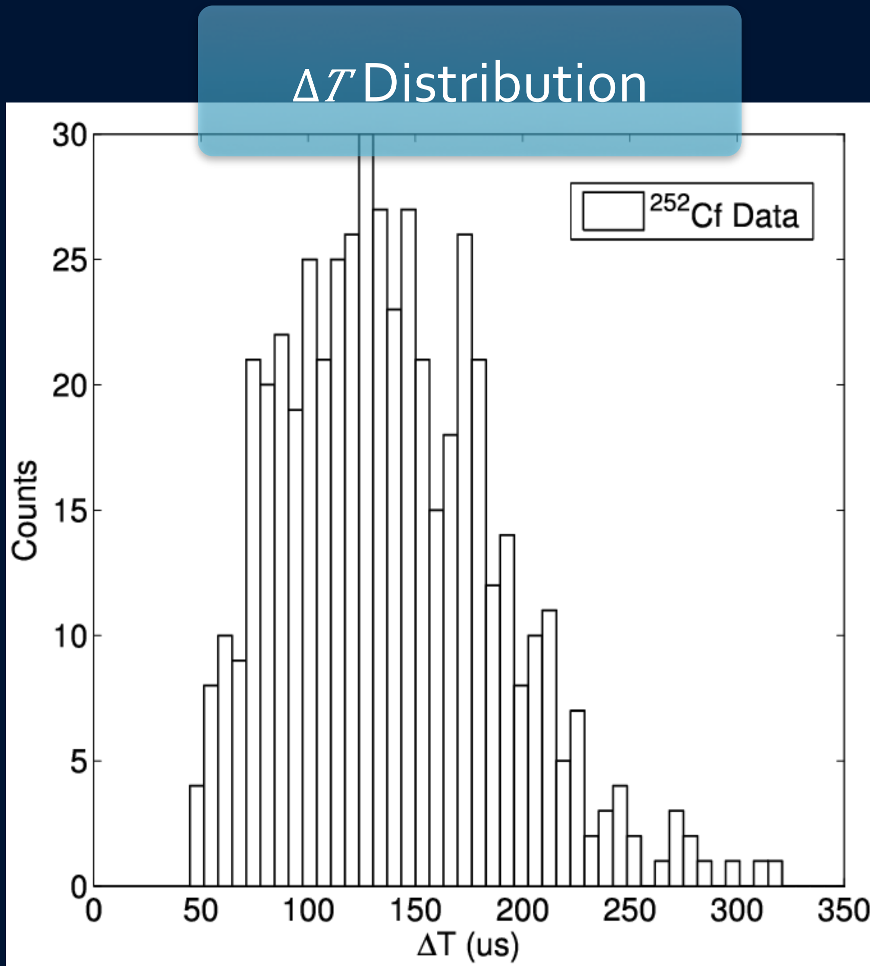


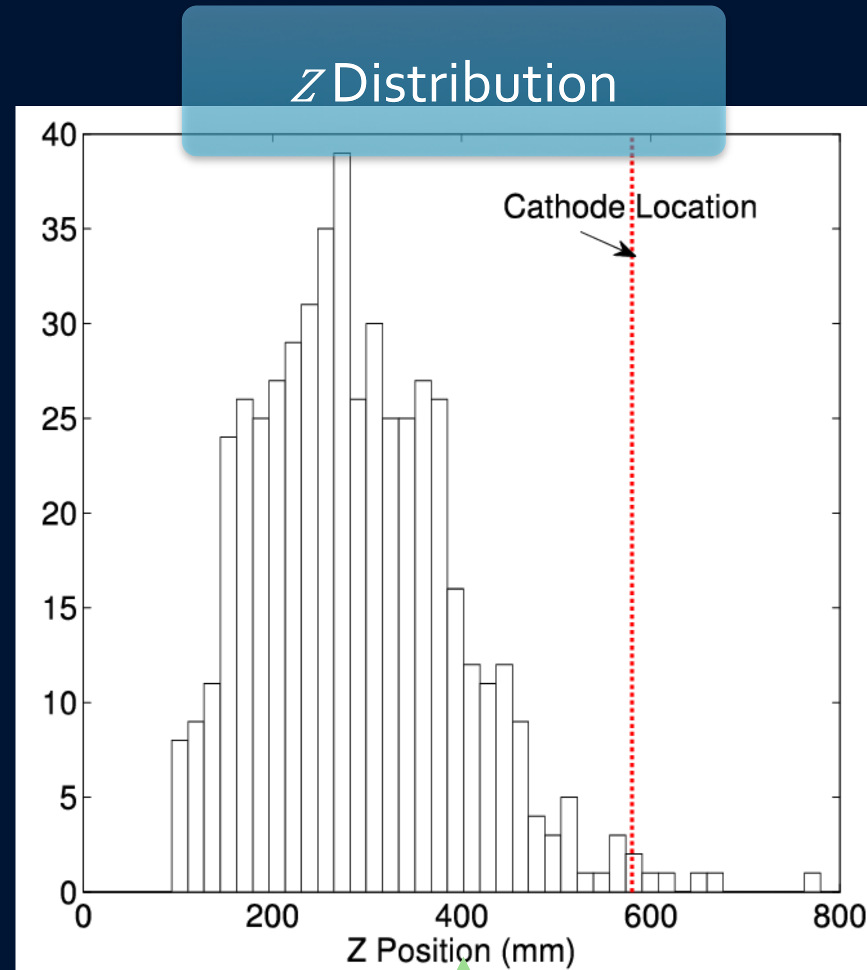
Generate events at various Z positions with a Cf-252 source.

^{252}Cf events



Fiducialization: ^{252}Cf Data *(preliminary)*





^{252}Cf source location

- Events from 252Cf data run > 60 keVee
- Peaks found through automated process

Thermal Diffusion?

- mm expected for thermal diffusion (60 cm drift, E = 1 kV/cm)
- We clearly observe thermal behavior, as expected from -ion gas
- We see comparable widths in SF6 and CS2 in 40 Torr at E = 1 kV/cm
- Deviations from thermal begin at >700 kV/cm @ 40 Torr BUT diffusion still decreases with E, just not as expected for thermal
- Width increases at lower pressures – due to longer capture length, detachment?
- Stay tuned…

Conclusions

- Gain is achieved in SF_6 bulk gas TPC and ^{55}Fe signals detected.
- Poor energy resolution at high pressures/ low E/p. Inefficient stripping of electrons from anions? Re-attachment in THGEM holes? Other amplification devices (e.g. micromegas, thin GEMs, MWPCs)?
- Detection of secondary peak at high reduced fields – most likely SF^-_5 . Fiducialization works using this feature.
- Diffusion appears thermal, similar to CS_2, but requires further study.

Many new mysteries but also new opportunities for further studies.

Next steps

- Finish the diffusion studies
- Thin GEMs – we are undertaking a study gas gain in SF6 using a double or triple thin GEM detector
- Using the same detector/vessel as described here, we have started directionality studies in 20 Torr SF6. For the nuclear recoils we will use ~2.2 MeV neutrons from a recently obtained DD generator