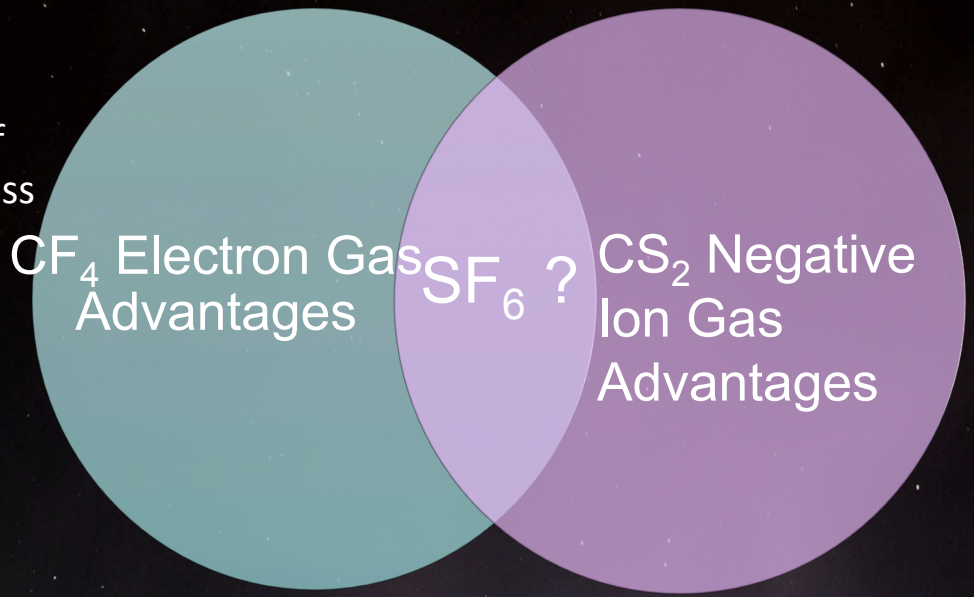
Why not CS_2?

- Lacks spin-dependent target (e.g. DRIFT uses a mixture with only 20% target).
- Why not adjust mixture? At low pressures, need a lot of CS_2 to ensure electrical stability.
- Highly toxic. Can be explosive with high O_2 concentration and spark.
- Detector maintenance & operation issues: no re-circulation system, surface absorption.
- Reduces light yield (optical readouts not necessarily excluded but more challenging).

How about SF_6?

78% of SF_6 mass is spin target.

Recall: only 20% of DRIFT detector mass is spin target.



N. S. Phan et al., "THE NOVEL PROPERTIES OF SF_6 FOR DIRECTIONAL DARK MATTER EXPERIMENTS," (manuscript in preparation).

SF_6 Properties & Applications

Properties

- Non-toxic, non-volatile, colorless, odorless
- Electronegative gas with electron affinity : 1.1 eV
- High vapor pressure: 15,000 Torr at room temperature
- Good high voltage behavior

Industrial Uses

- Insulation for high voltage power devices
- Semi-conductor fabrication
- Metal casting
- Many other uses

Research

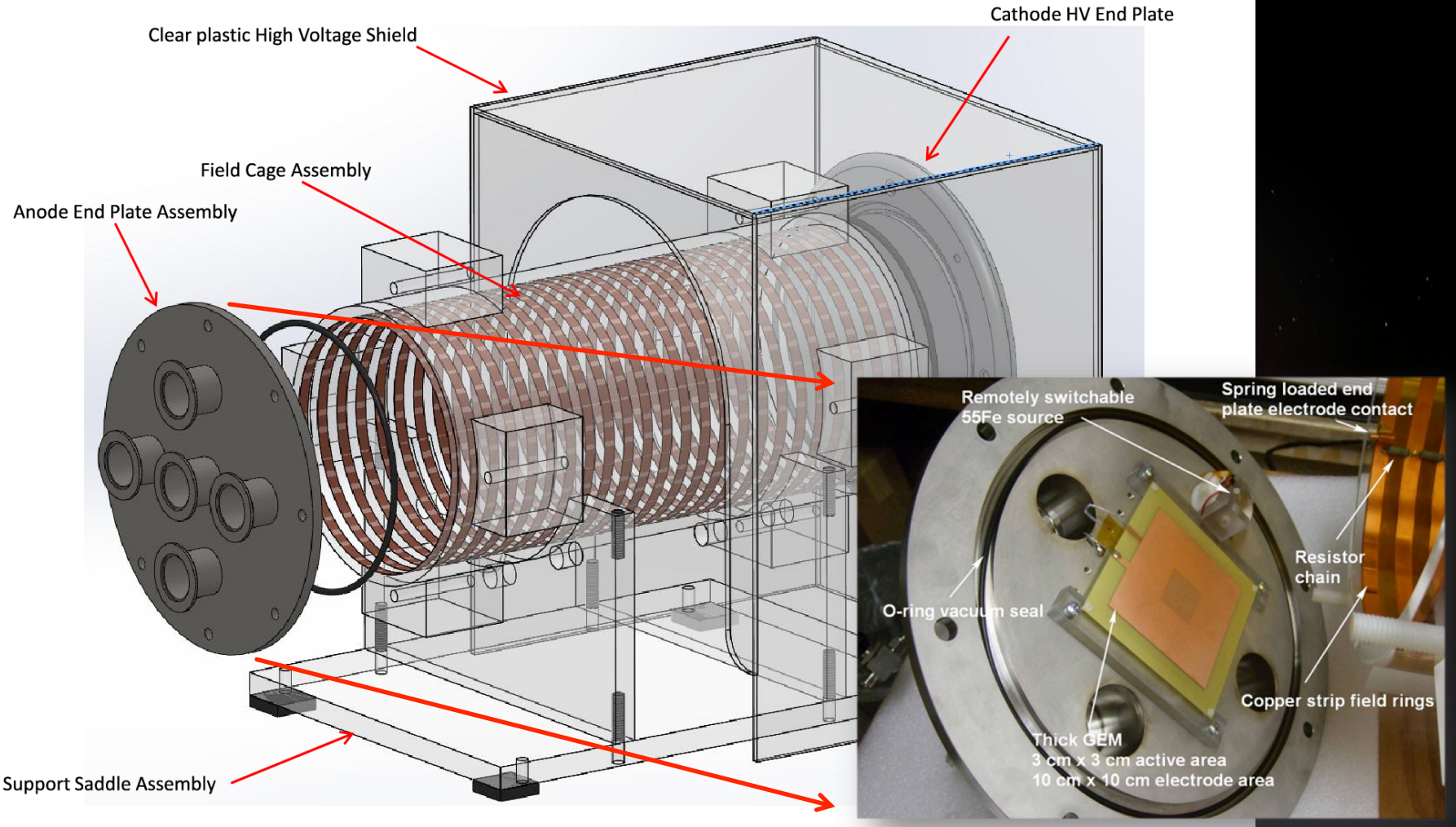
- Quencher in Resistive Plate Chambers (RPCs) (trace gas, not primary)

Questions

- Is it possible to produce avalanche in SF_6 gas? This requires stripping the electron from SF_6^- in gain stage.
- What gas gain is achievable and how does it depend on pressure?
- What is the diffusion characteristic 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?
- Other potential applications besides dark matter? Double-beta decay (SeF_6)?

Experimental Apparatus

Designed by Eric R. Lee at UNM



SF_6 Measurements

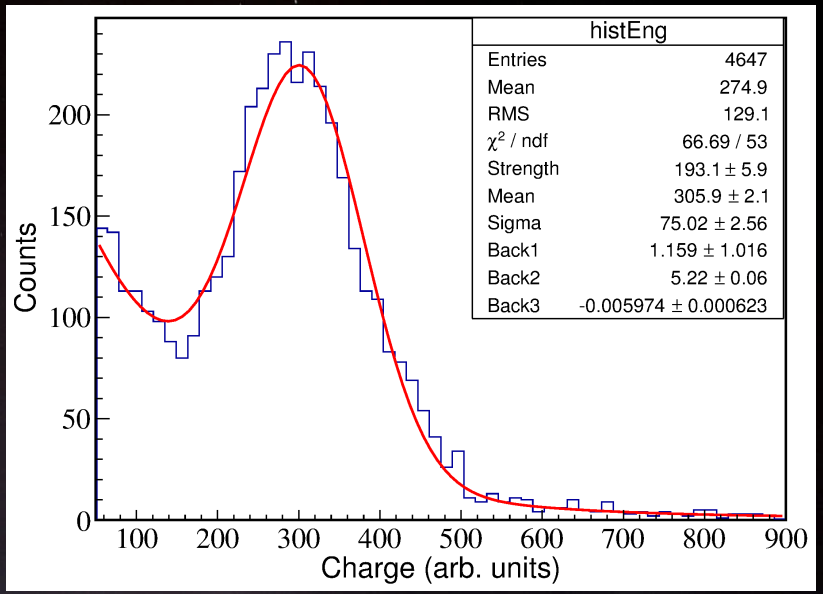
- Pressure: 20 - 100 Torr pure SF_6
- Drift field: 0 - 1 kV/cm (60 kV, 60 cm drift)
- Ionization generated with nitrogen laser (3.5 ns pulse width), trigger from laser, or ^{55}Fe source for gain measurements.
- Single 0.4 mm THGEM for amplification.
- Single channel charge readout to measure charge cloud Z-profile.

^{55}Fe Energy Spectrum

Wγ = 34.0 eV (average energy to create electron-ion pair in SF_6).

^{55}Fe (5.9 keV) -> 173 e^-

- Gains: up to 3000 w/ single THGEM.
- Energy resolution (σ/E): 25-45% (appears to depend on reduced field).
- Can we get gain at higher pressure (e.g. ~ 1 atm.)?
- Other amplification devices?



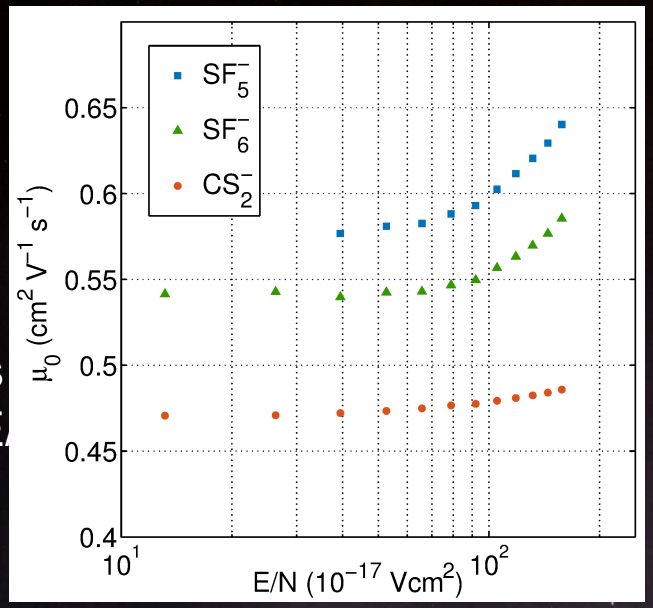
^{55}Fe energy spectrum in 30 Torr SF_6 using 0.4 mm THGEM

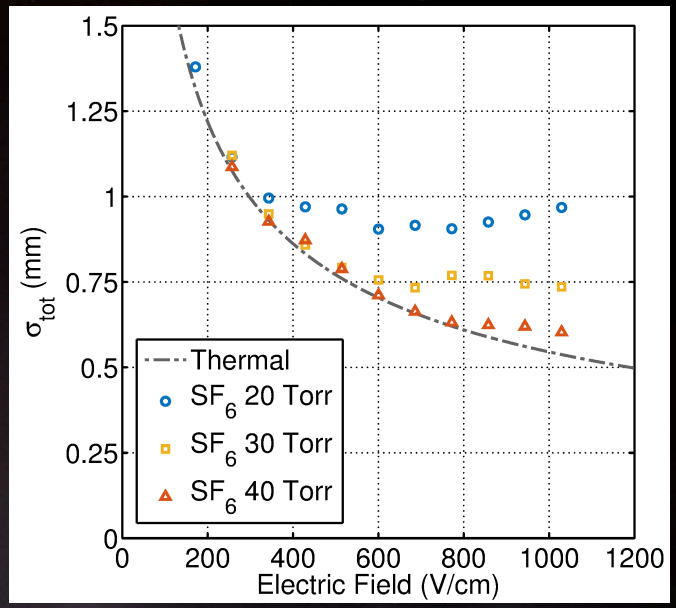
Reduced Mobility and Diffusion

* CF_4 at 20 Torr & 58 cm drift length: σ = 3 mm!

Using nitrogen laser

- SF^-_6 drift speed: 19 - 248 um/us
- SF^-_5 ~ 9% faster than SF^-_6
- Diffusion deviates from thermal at E/N ~ 61 Td.





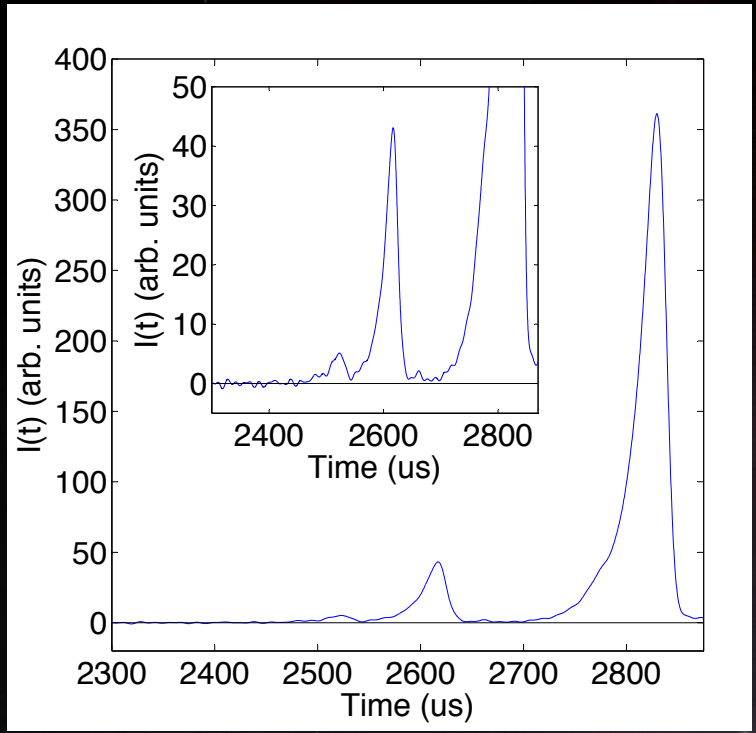
Reduced Mobility:

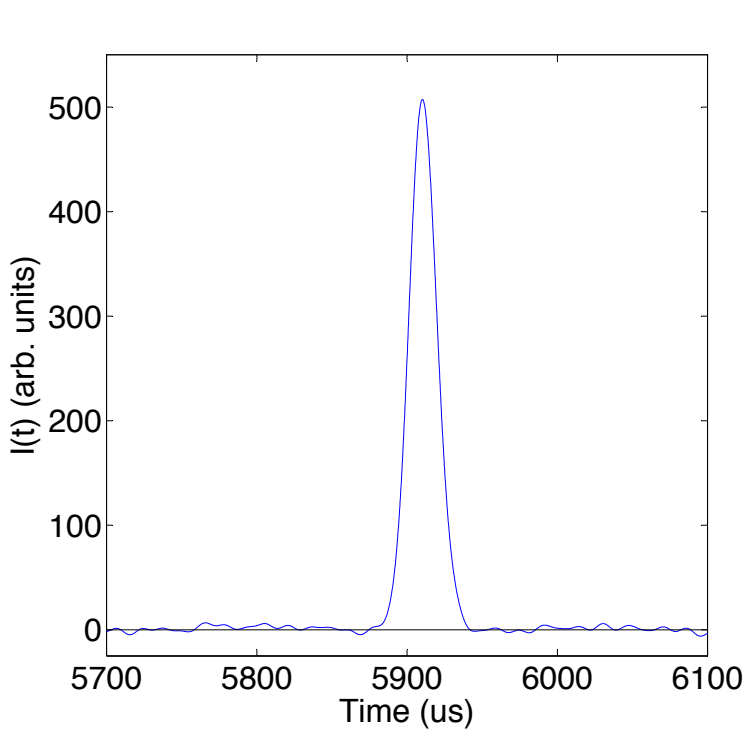
$$\mu_0 = \frac{v_d}{E}\frac{N}{N_0}$$

Thermal Diffusion:

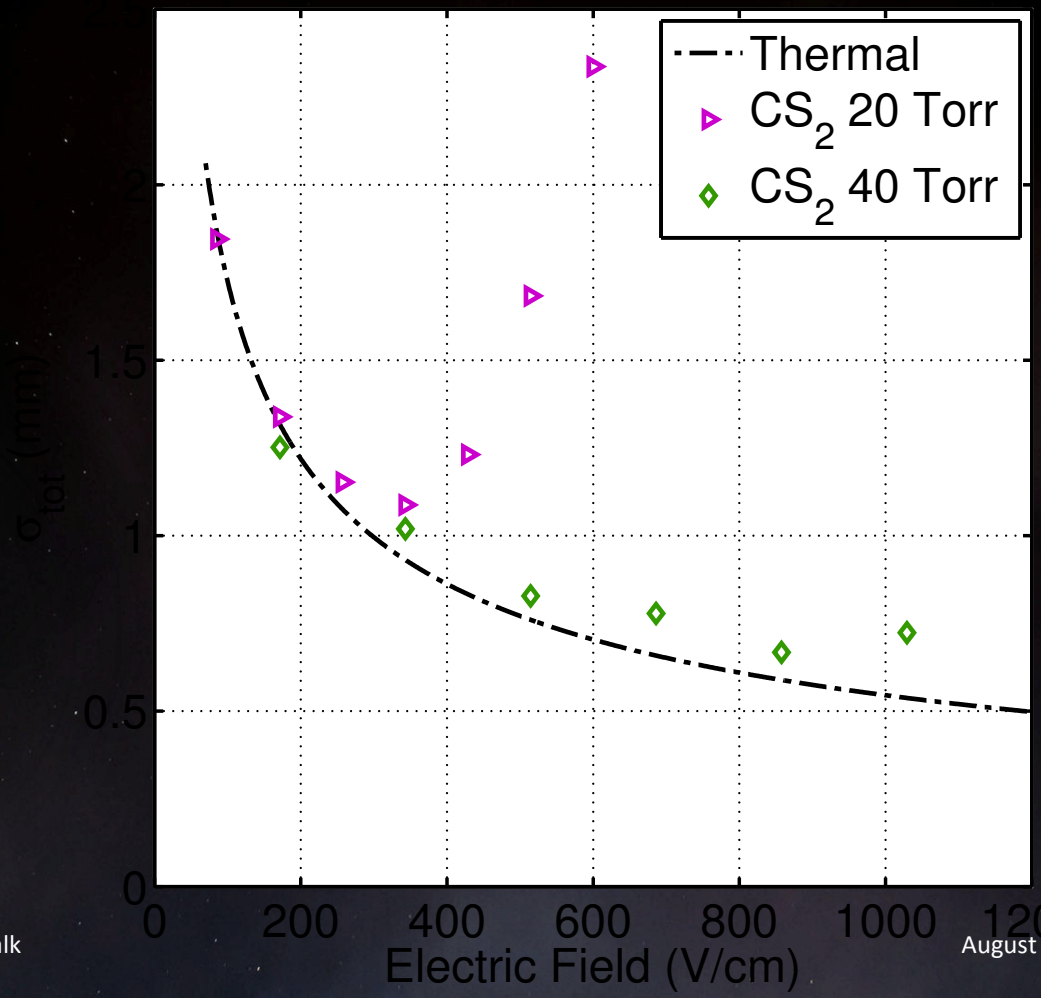
$$\sigma_z^2 = 2D_L t = \frac{2kTL}{eE}$$

CS2: what's happening??



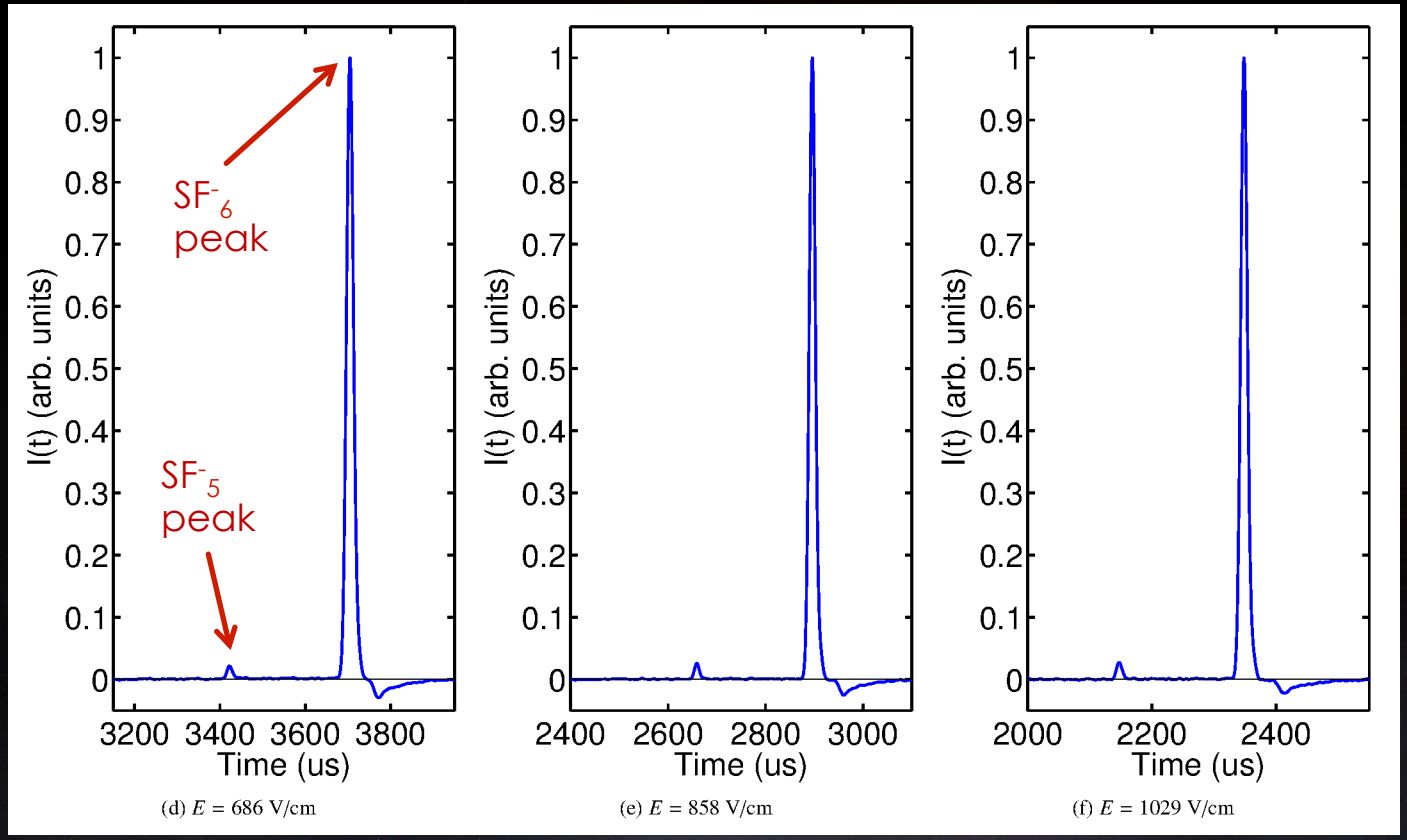


CS2 Diffusion:

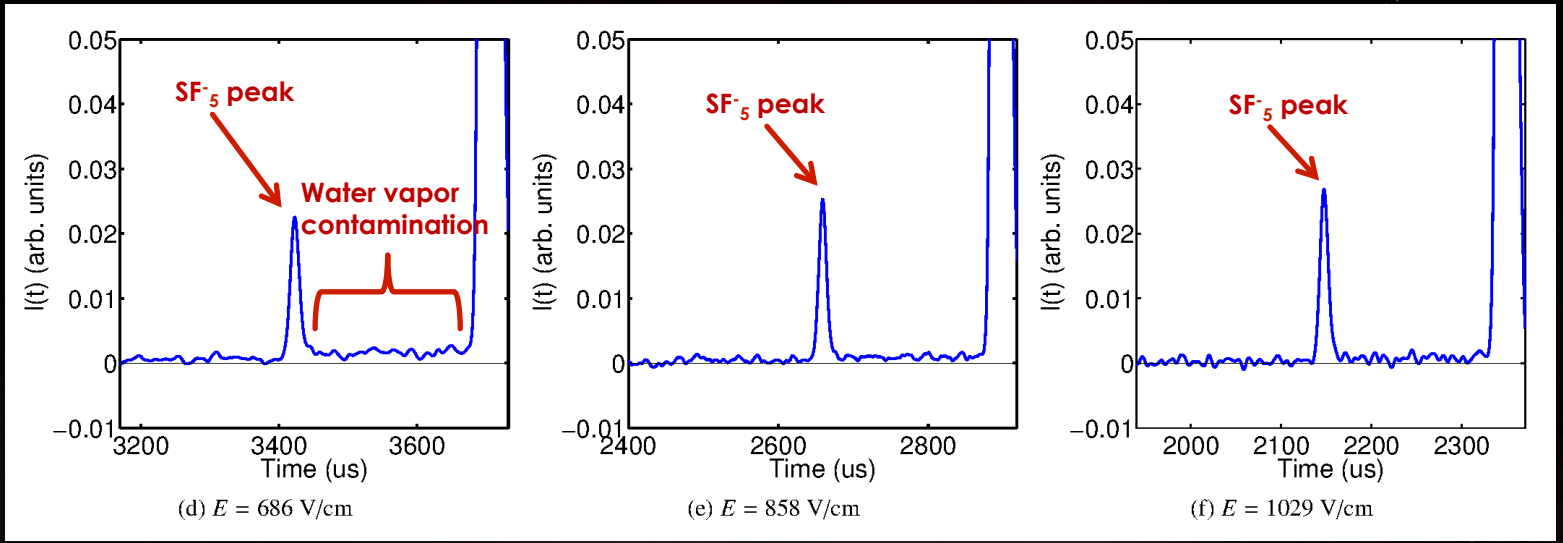


Waveform Features: Multiple Peaks

*Charge generated with nitrogen laser.



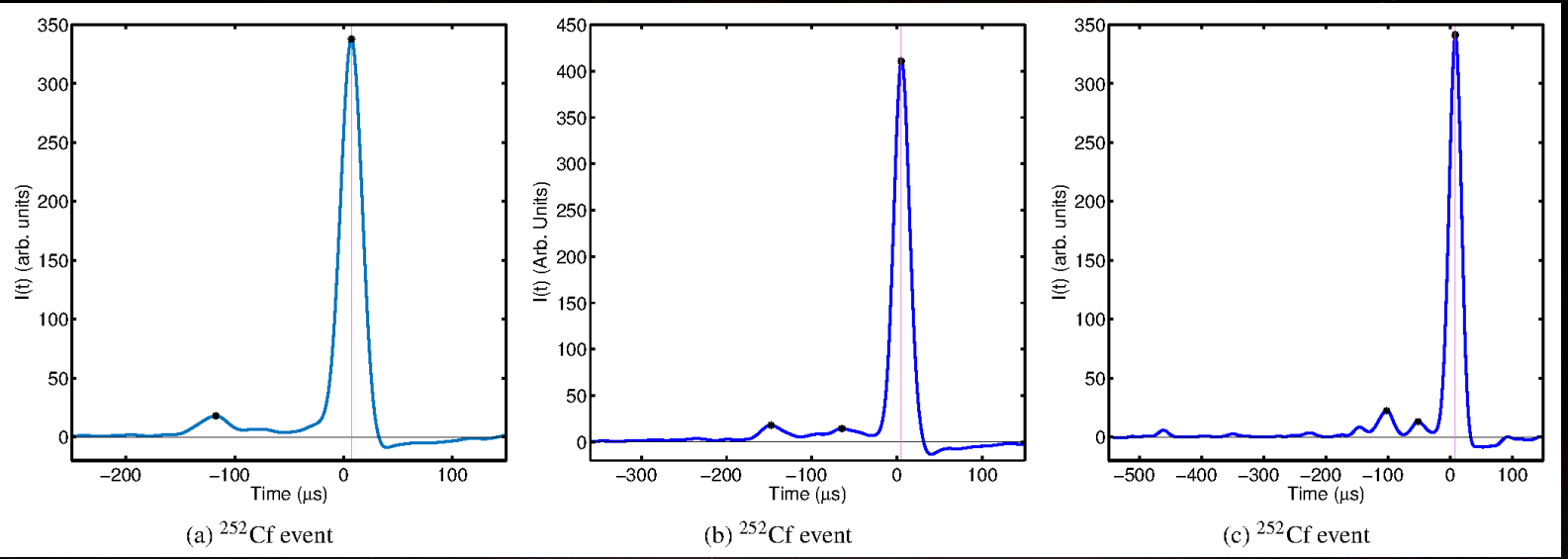
Waveform Features: SF^-_5 Peak



- SF^-_5 peak grows with electric field (~ 2.8% of primary SF^-_6 at 1 kV/cm, 20 Torr).
- Multiple drift species enables Z-fiducialization: $Z = \frac{v_s \cdot v_p}{v_s - v_p} \Delta T$

Fiducialization in SF_6

*Nuclear recoils



- Waveforms of recoils from ^{252}Cf in 30 Torr SF_6 at E = 1029 V/cm.
- Additional peaks besides SF^-_5 and SF^-_6 are present. Could be F^- and SF^-_4 ? Or something related to water contamination?
- Z-fiducialization resolution: σ = 4 mm.

Prospects for SF_6 in TPCs

- SF_6 has properties that make it ideal for directional dark matter searches:
  - High fluorine content for spin-dependent searches.
  - Low, thermal diffusion over large drift distance -> detector *Z* scaling.
  - Multiple charge carriers for full event fiducialization.
  - Good high voltage behavior at low pressures, non-toxic, gas gain.

Scaling in the X-Y Dimensions

- After sensitivity has been maximized per unit volume.
  - Low discrimination & directional thresholds (CCD detector)
  - Increased target density with SF_6
- Scale detector in Z (SF_6).
- Finally, scale in X-Y dimensions.

Novel 2D readout.

A low-cost readout with similar resolution to CCD detector for X-Y detector scaling.