Minority Carrier Fiducialization in DRIFT

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Cygnus 2013

4th Workshop on Directional Detection of Dark Matter

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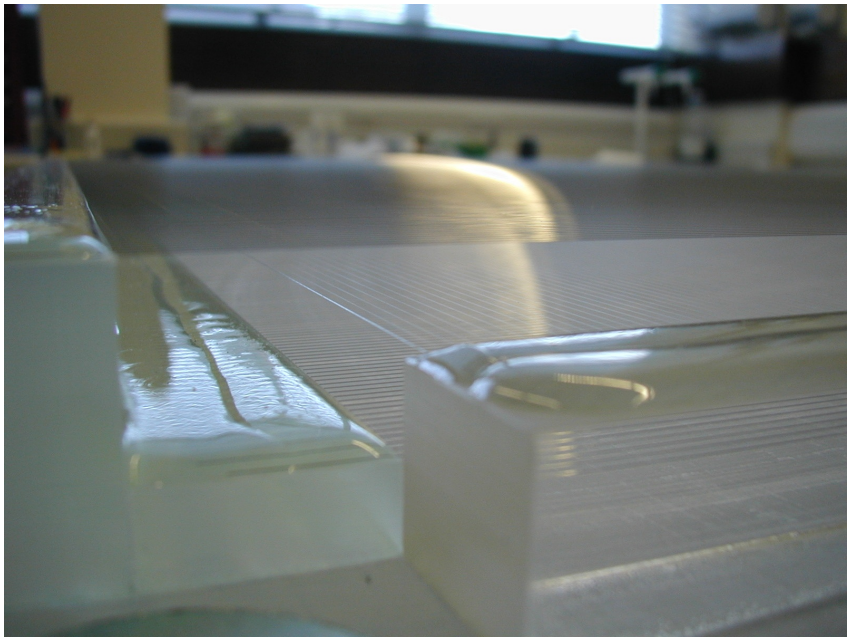
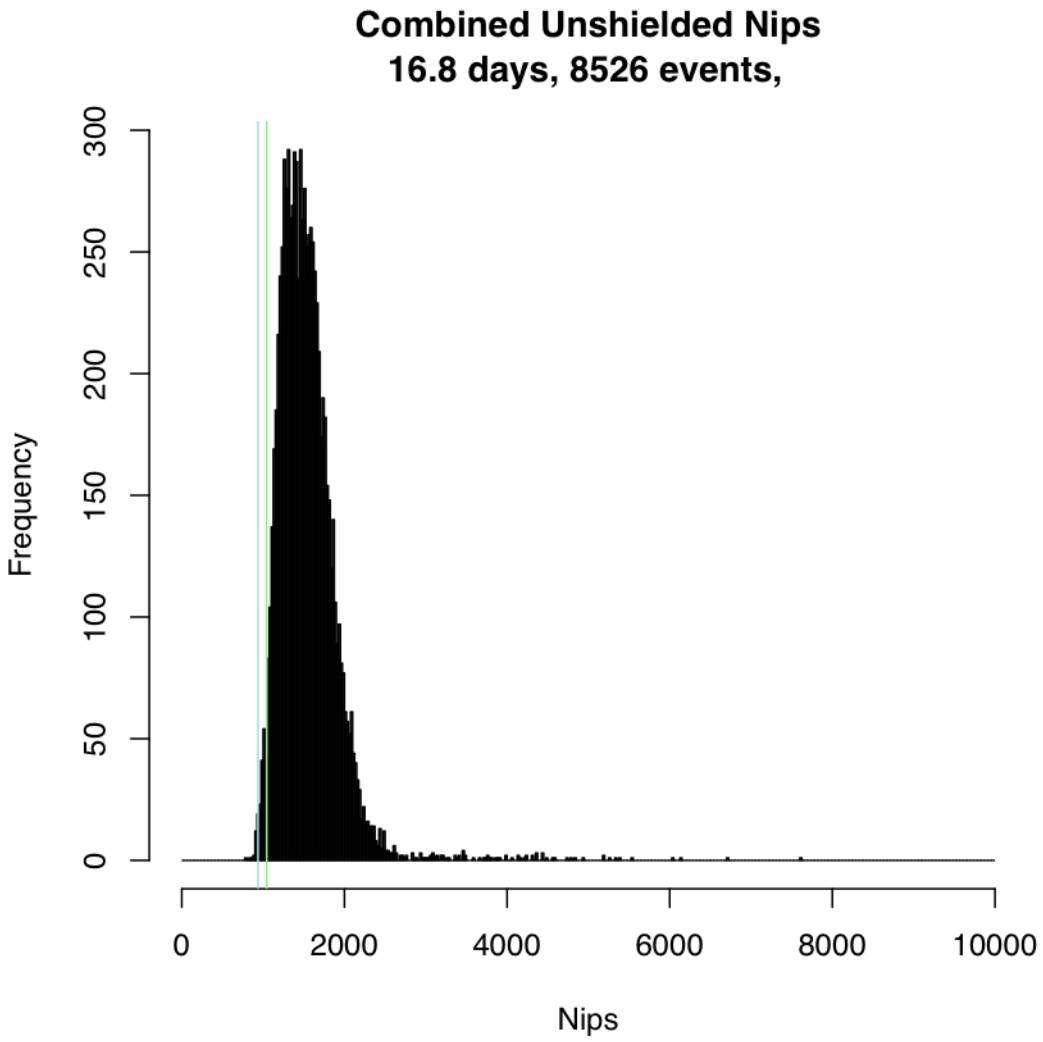
DRIFT – Directional Recoil Identification From Tracks

Started = 1998, US/UK
Underground in Boulby, England in 2001
Current operating detector = DRIFT-IId
Technology = Negative ion TPC with
MWPC wire readout



xyz resolution = 2 mm, ~<2mm, 0.2 mm, no absolute
Target = 30 Torr CS_2 + 10 Torr CF_4
Fiducial volume = 800 liters
F mass = 33.3 g
Limit setting threshold = 20 keVr

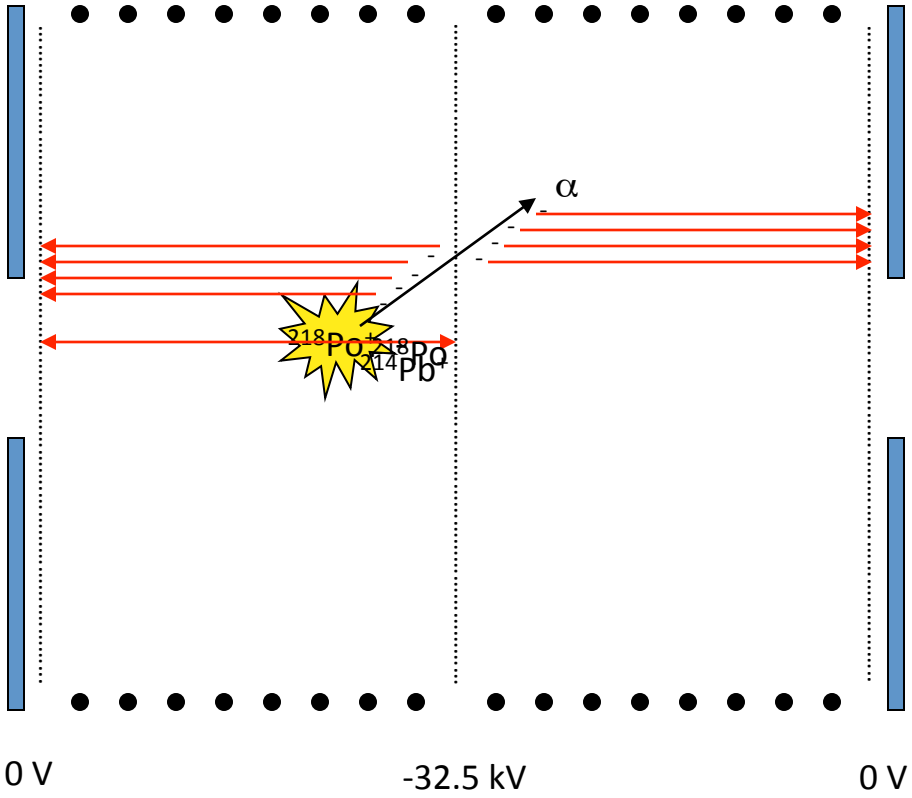
DRIFT-IIa Data

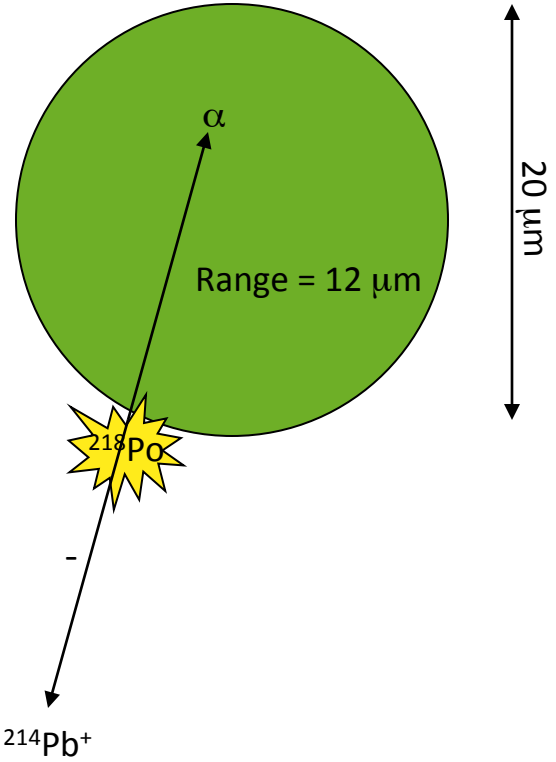


- 508 events per day observed
- Annoying because they are right where the WIMP-recoil signal should be
- Proved that these were Radon Progeny Recoils (RPRs)

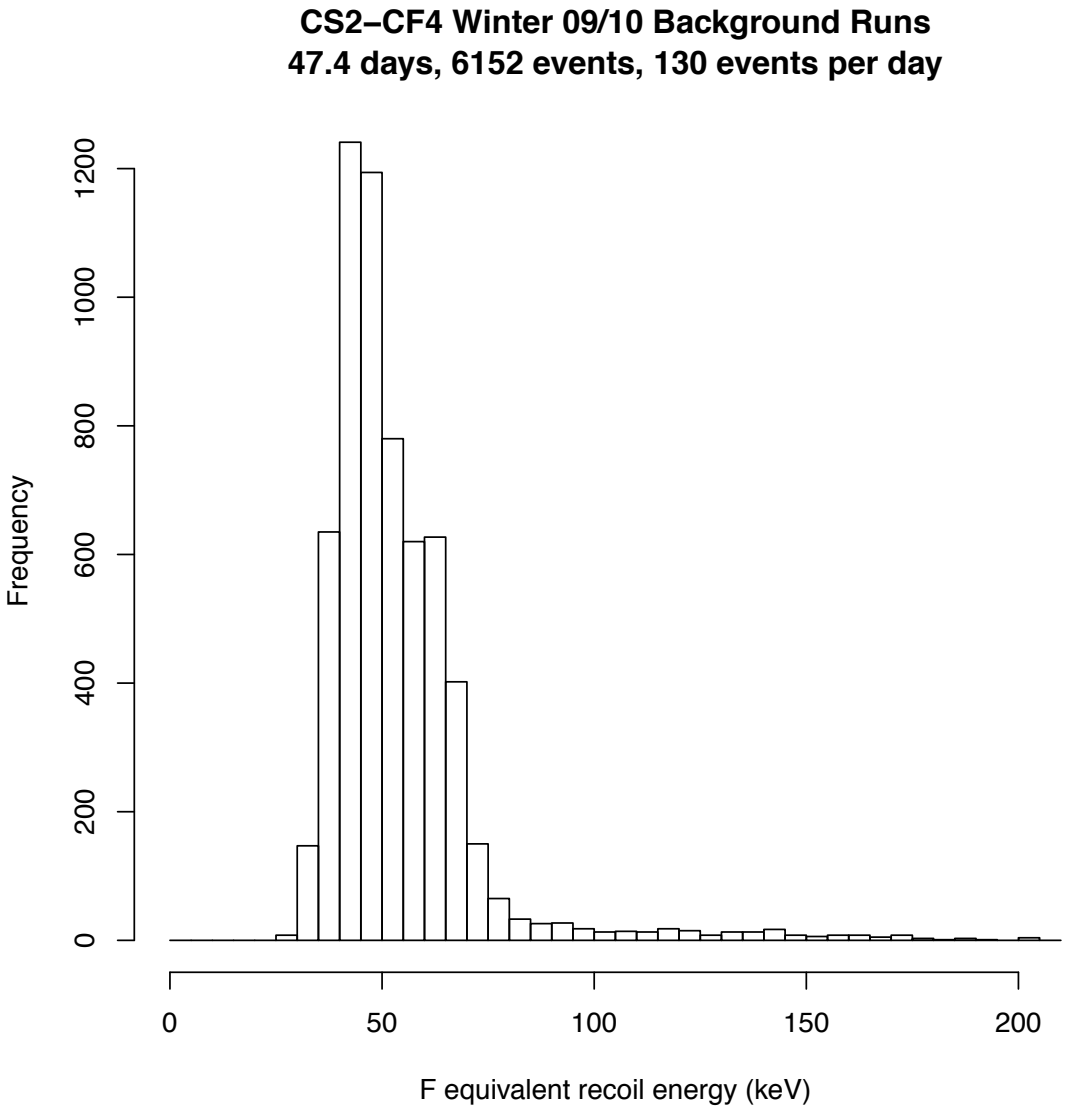
AstroPle, **28**, (2007) 409.

Radon Progeny Recoils (RPRs)





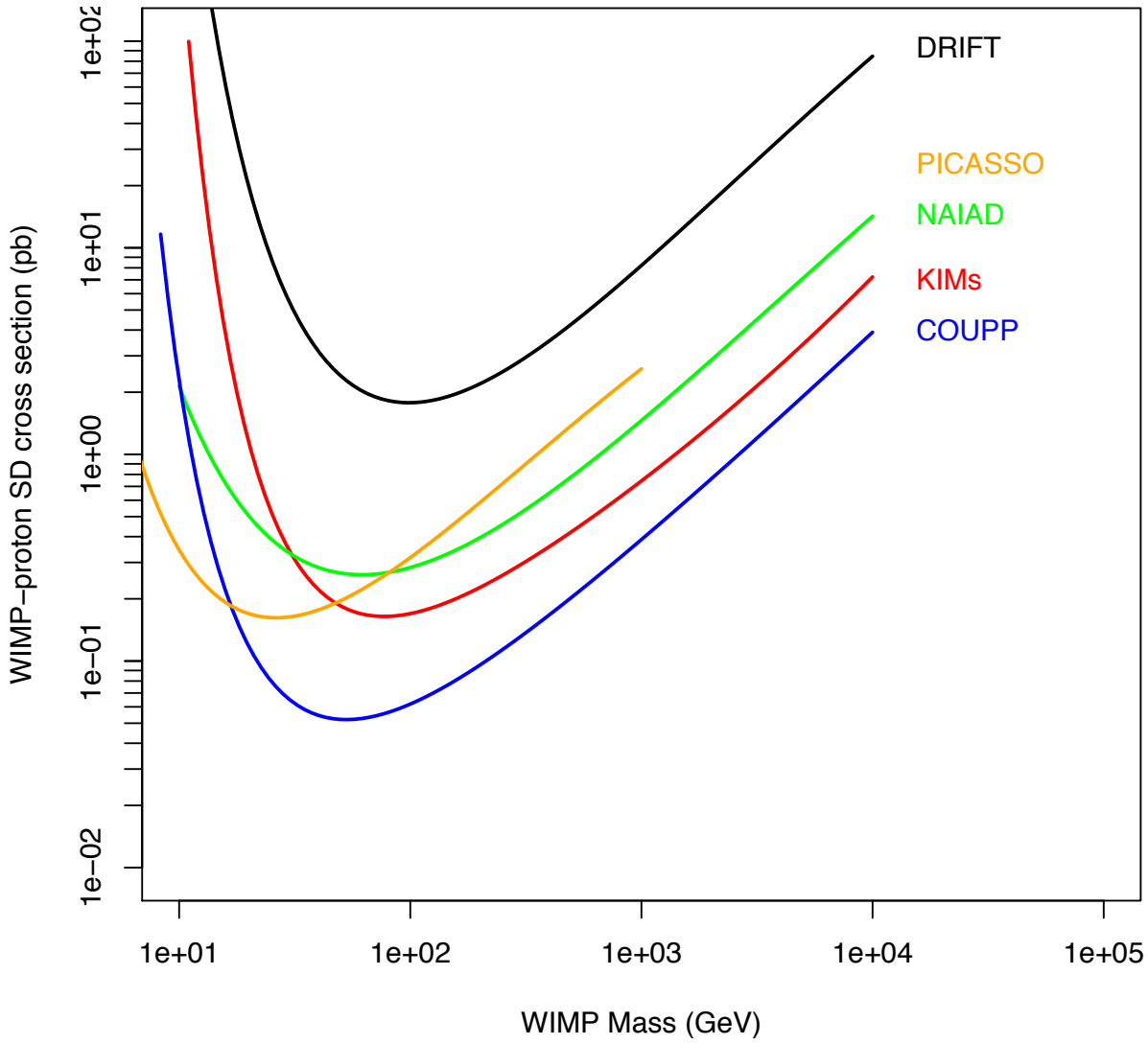
DRIFT-IId - Data



- 47.4 days of live time recorded
- A background of 130 events per day found

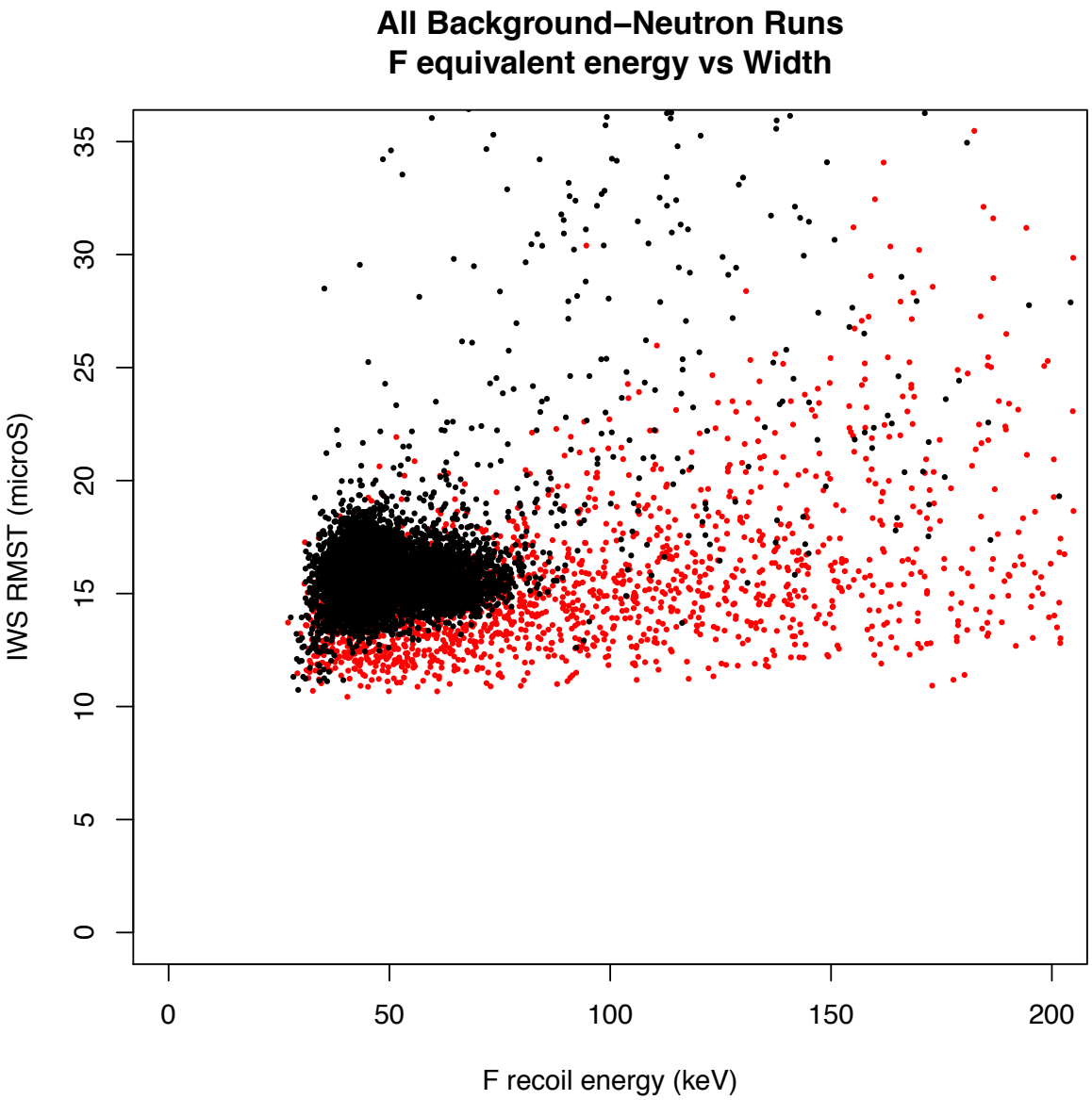
AstroPle, **35**, (2012) 397.

DRIFT-IId Spin-Dependent Limits



AstroPle, **35**, (2012) 397.

DRIFT-IId Fiducialization



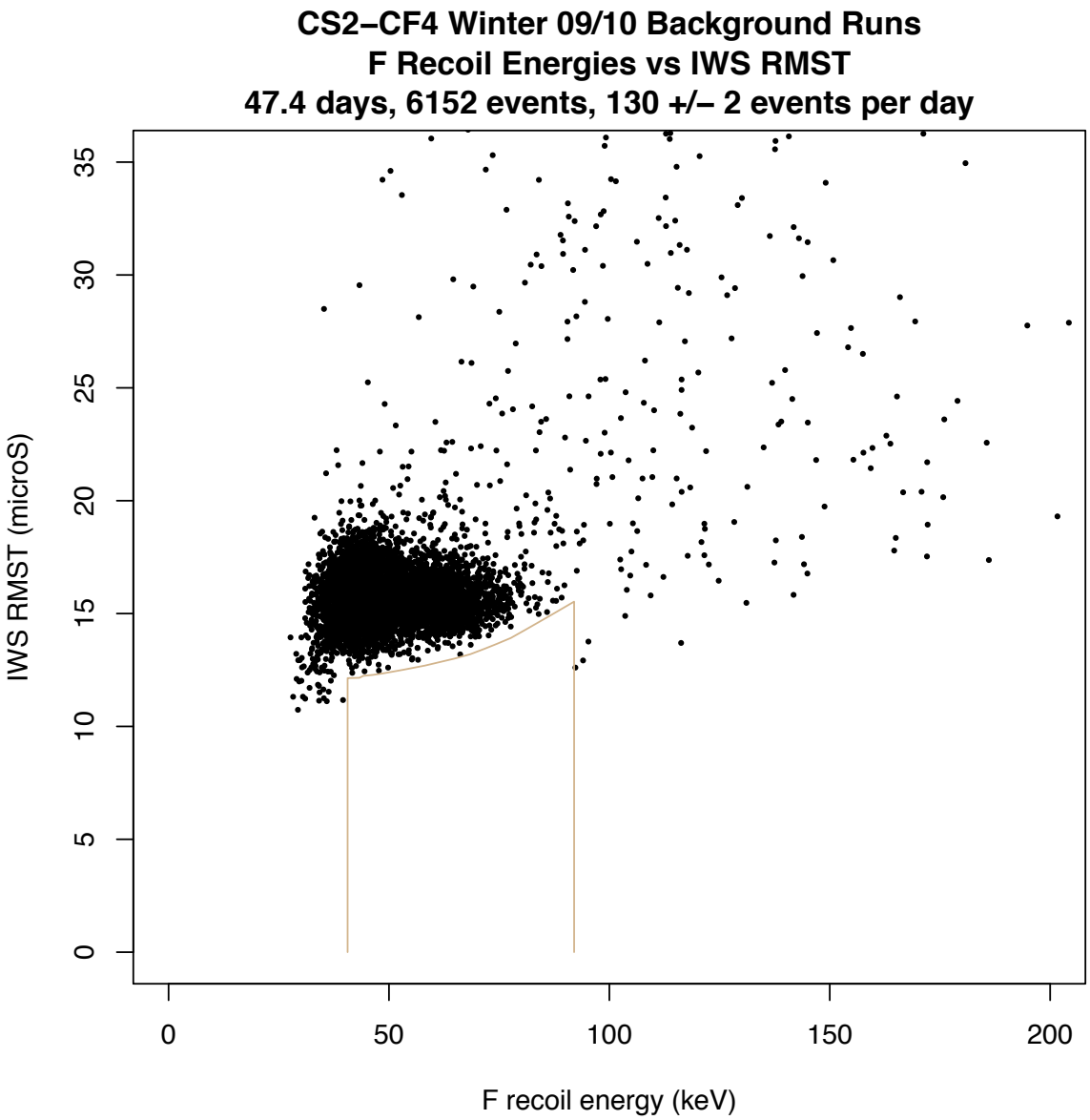
- Diffusion of the RPRs from the central cathode increases their width
- Use width as a crude discrimination parameter

$$\sigma^2 = \frac{2kTz}{eE}$$

- Black = Background
- Red = Neutron recoils

AstroPle, **35**, (2012) 397.

DRIFT-IId Signal Window

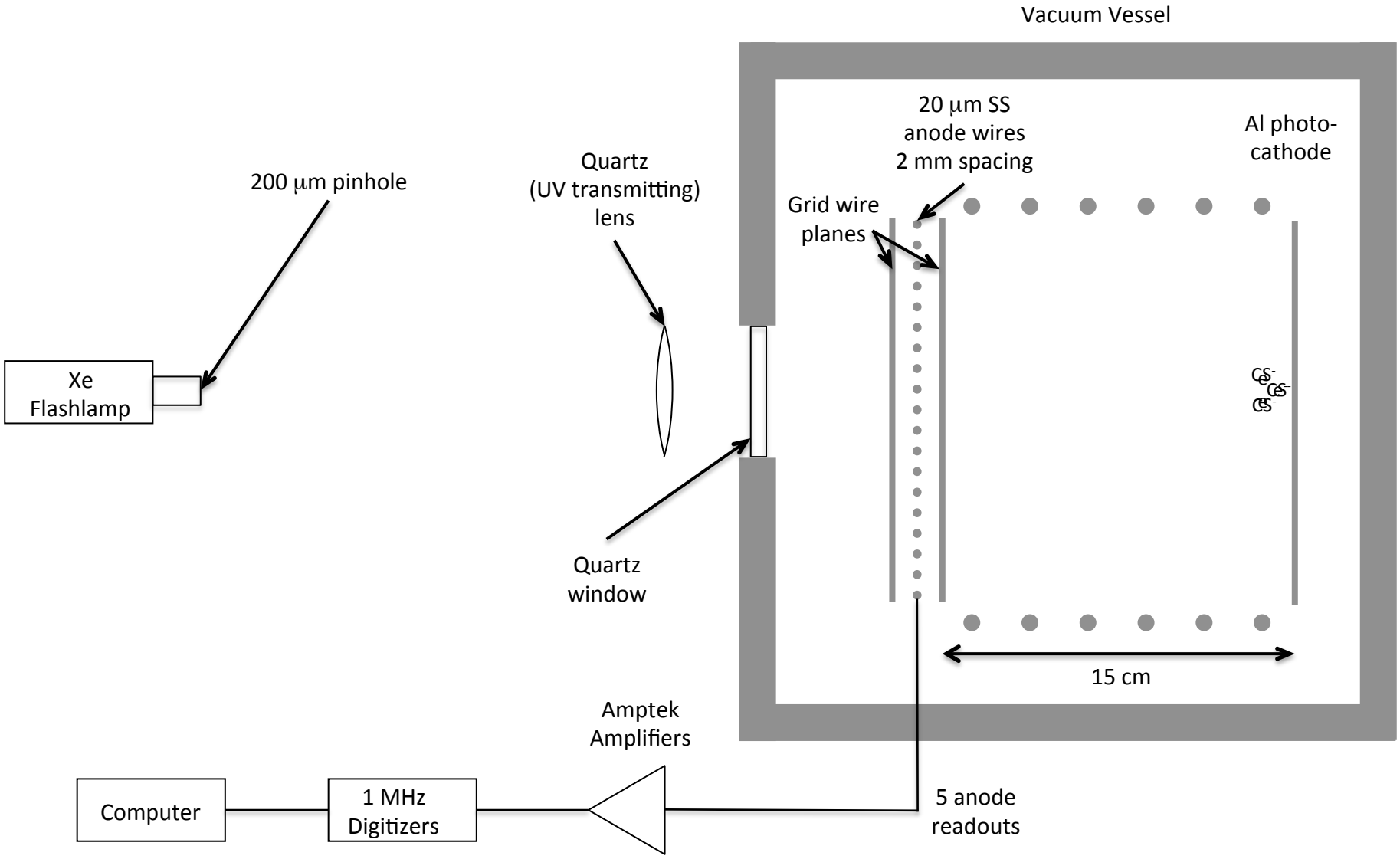


- Select an signal window
- Only ~4% of 100 GeV WIMPs above threshold would appear in the analysis window.
- Having 0 background would therefore improve our signal by a factor ~25.

AstroPle, **35**, (2012) 397.

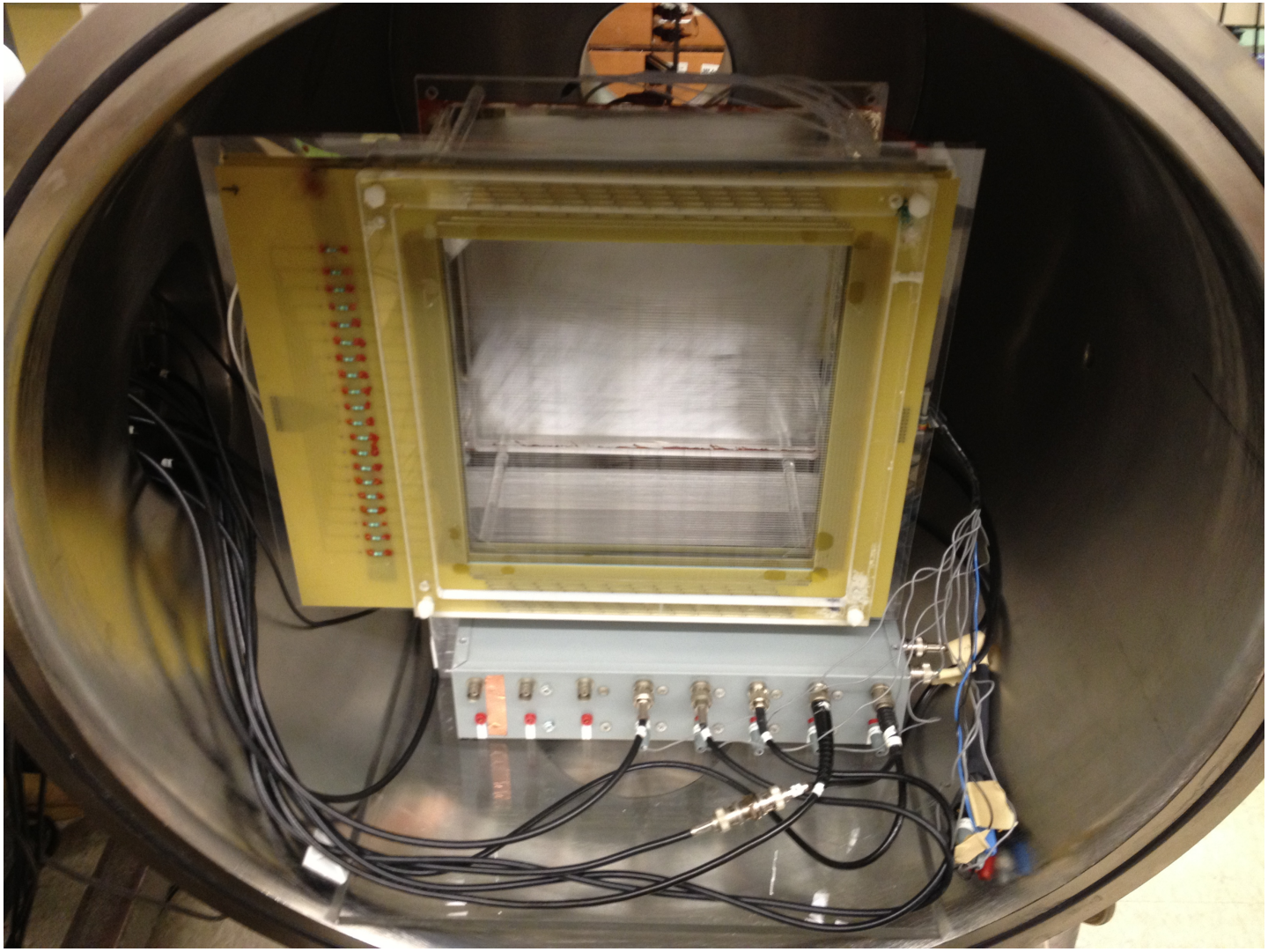
“Fiducialization is the Holy Grail of the DRIFT project.”

Schematic

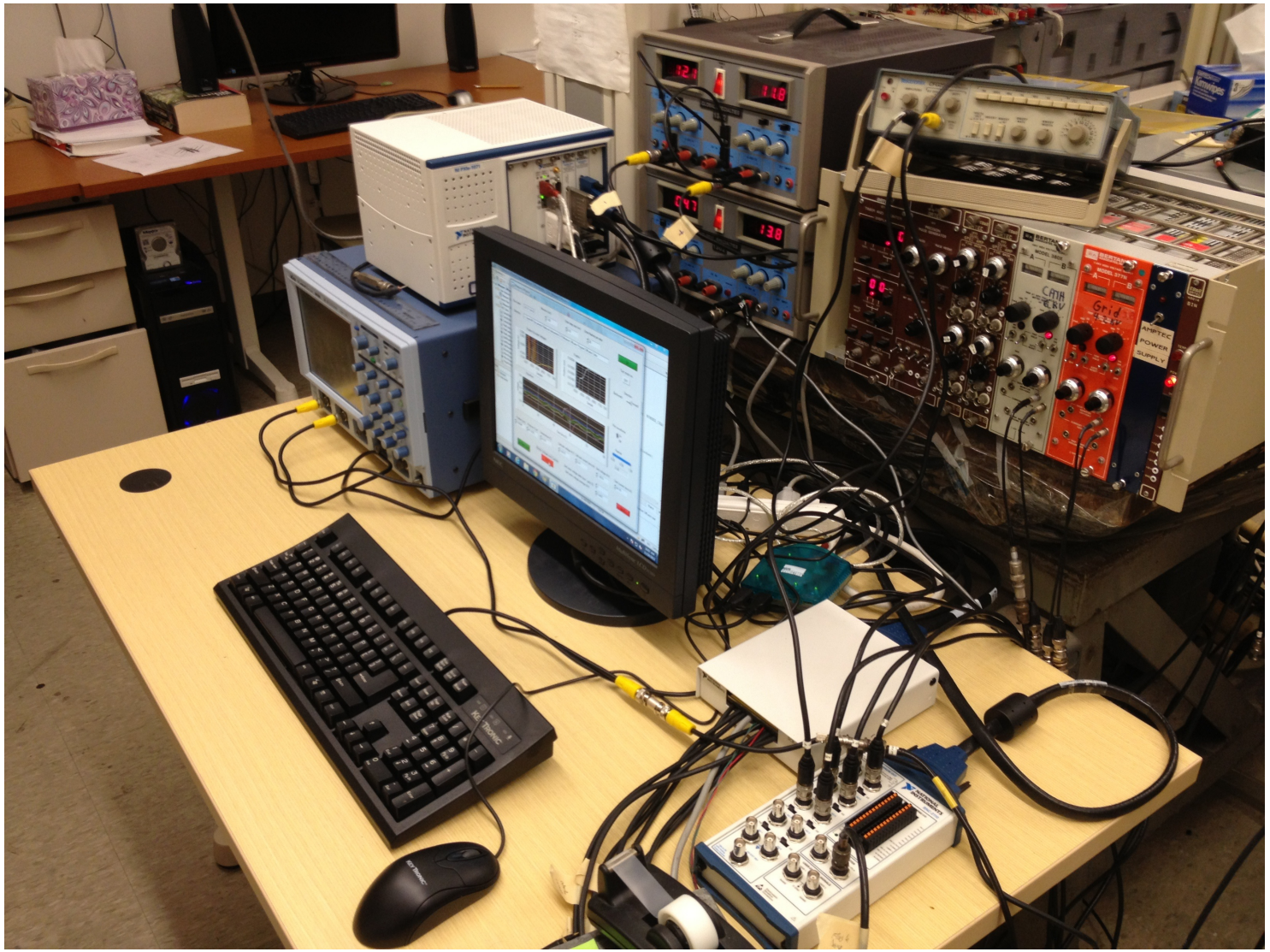

Vacuum Vessel
20 μm SS
anode wires
2 mm spacing
Al photo-
cathode
200 μm pinhole
Quartz
(UV transmitting)
lens
Grid wire
planes
Xe
Flashlamp
Quartz
window
15 cm
Amptek
Amplifiers
Computer
1 MHz
Digitizers
5 anode
readouts

Hardware

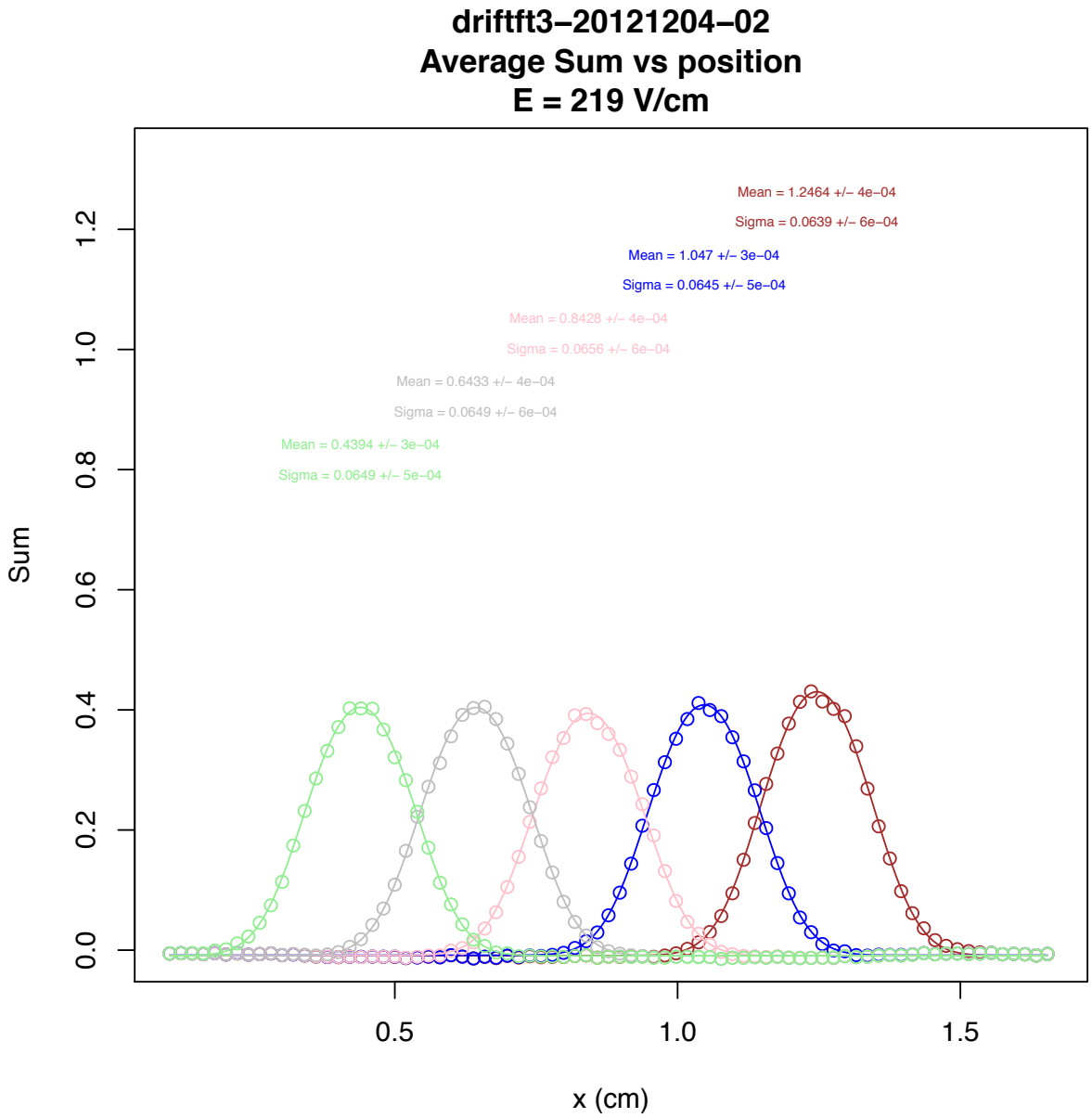
Hardware



Computer

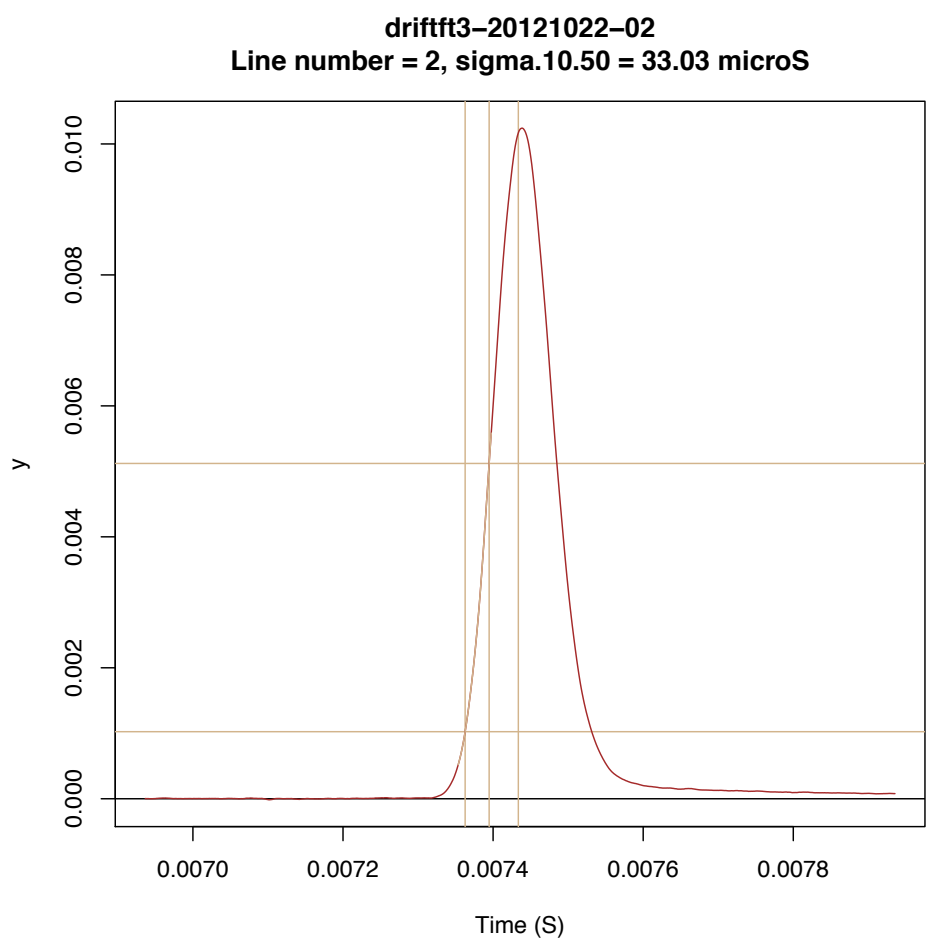


Lateral Diffusion

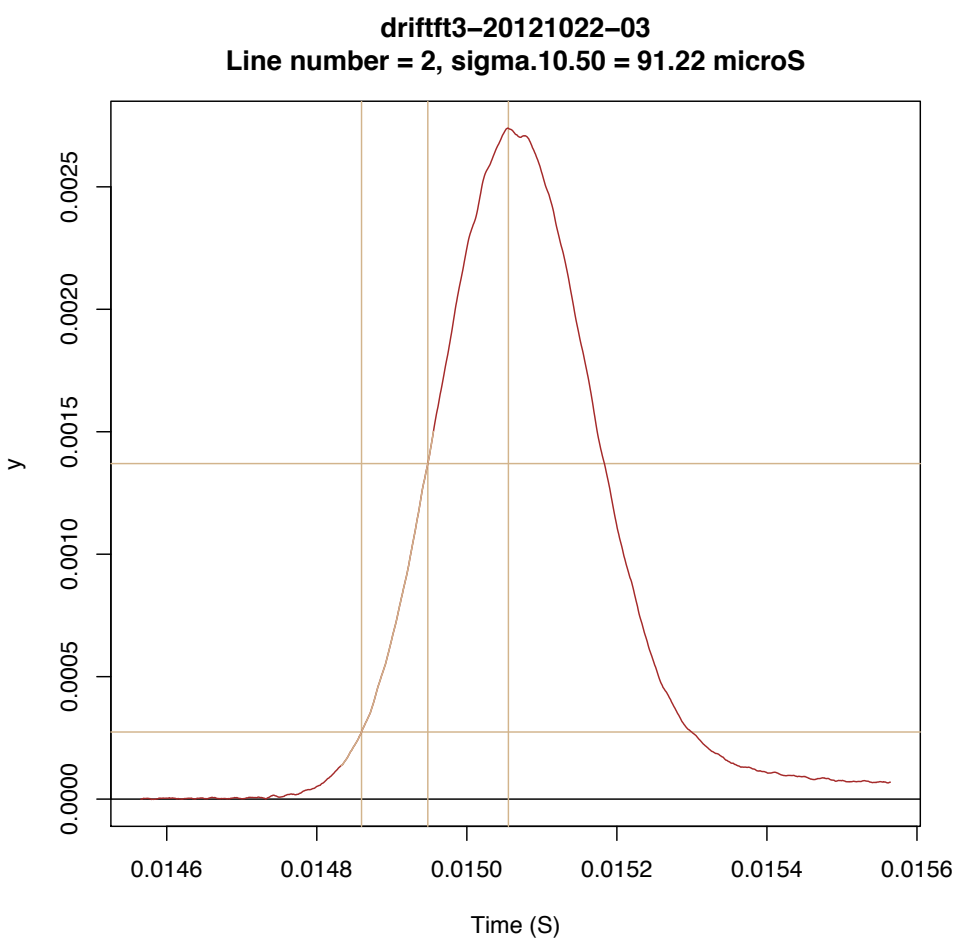


Longitudinal Diffusion

E = 239 V/cm



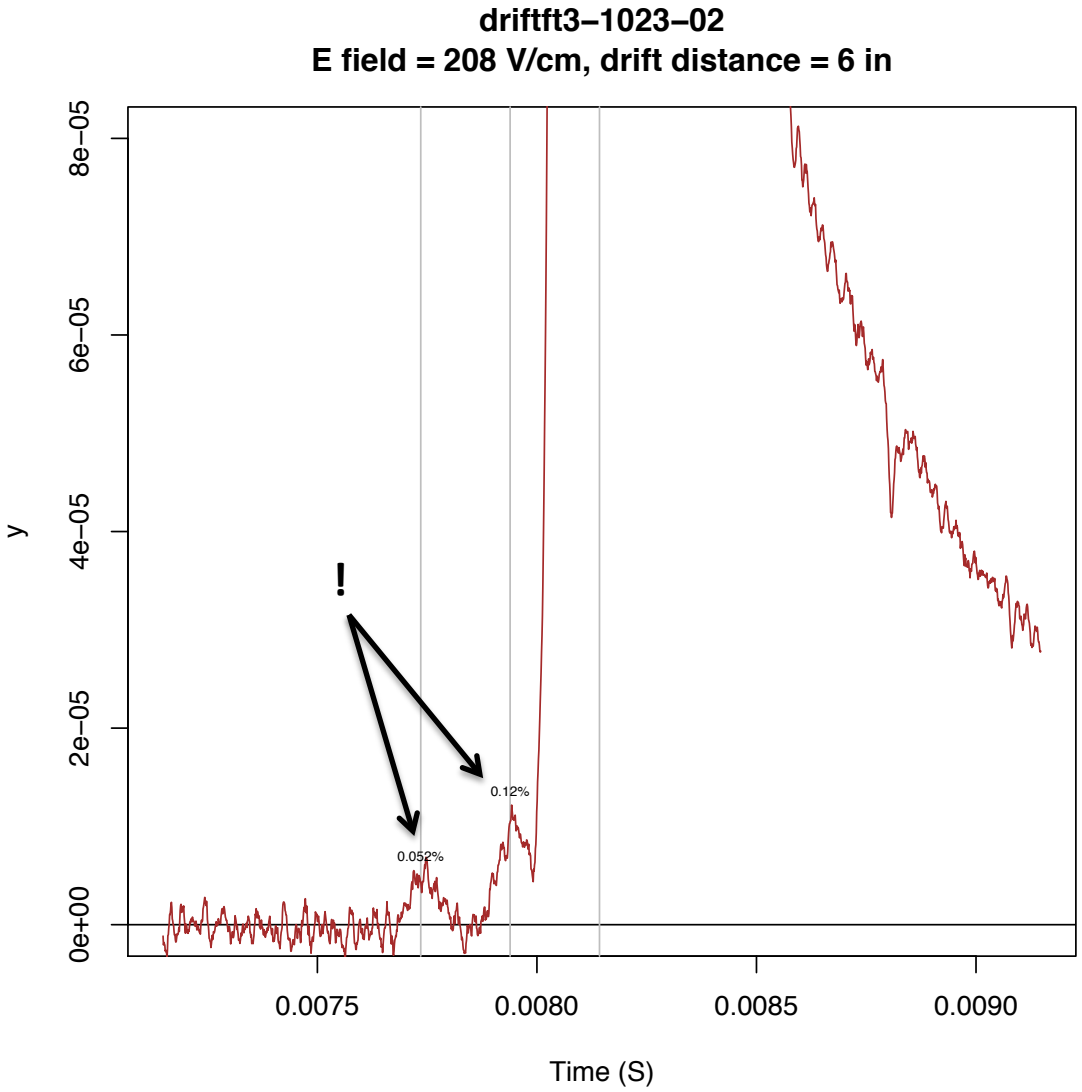
E = 118 V/cm



⟵ t = 0 => flashlamp pulse

RSI, **84**, (2013) 053304-3

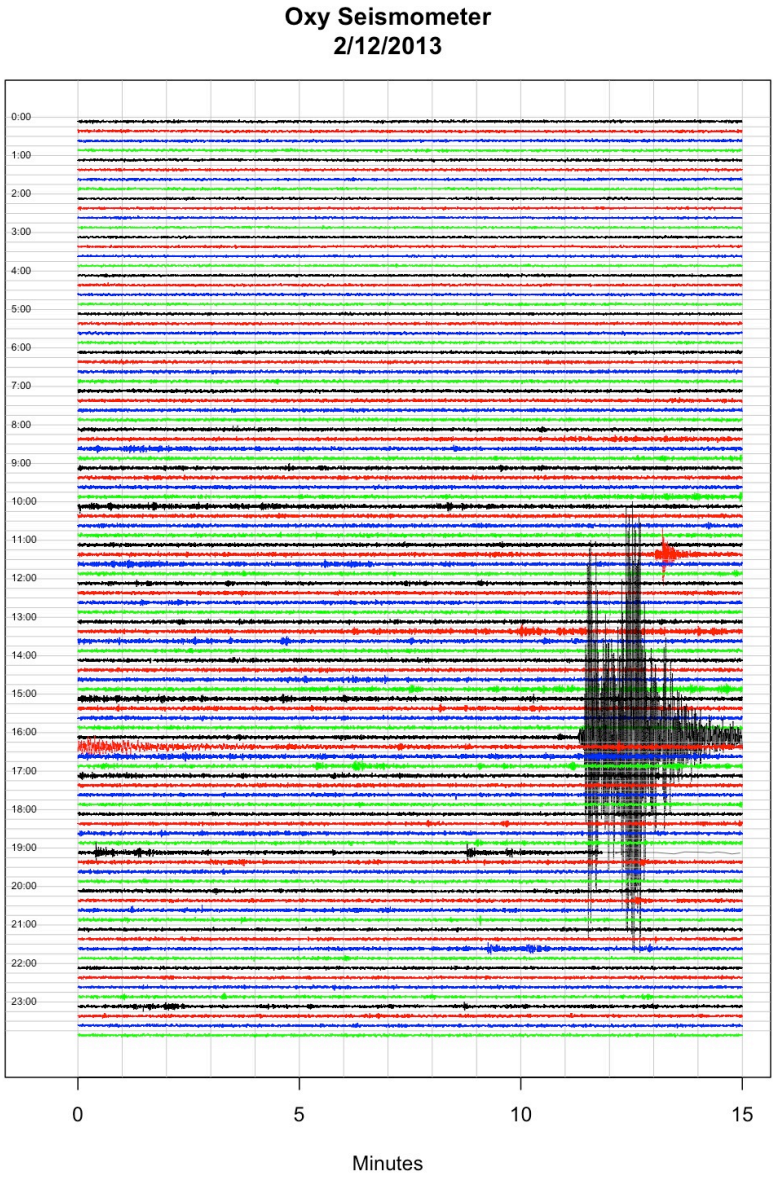
Minority Carriers



- Separate peaks in the data indicate that other carriers, **minority carriers,** are generated at the site of the ionization and carry their charge **with different velocity** to the readout plane.
- An interesting puzzle but of little impact to negative ion drift detectors because of their tiny size.

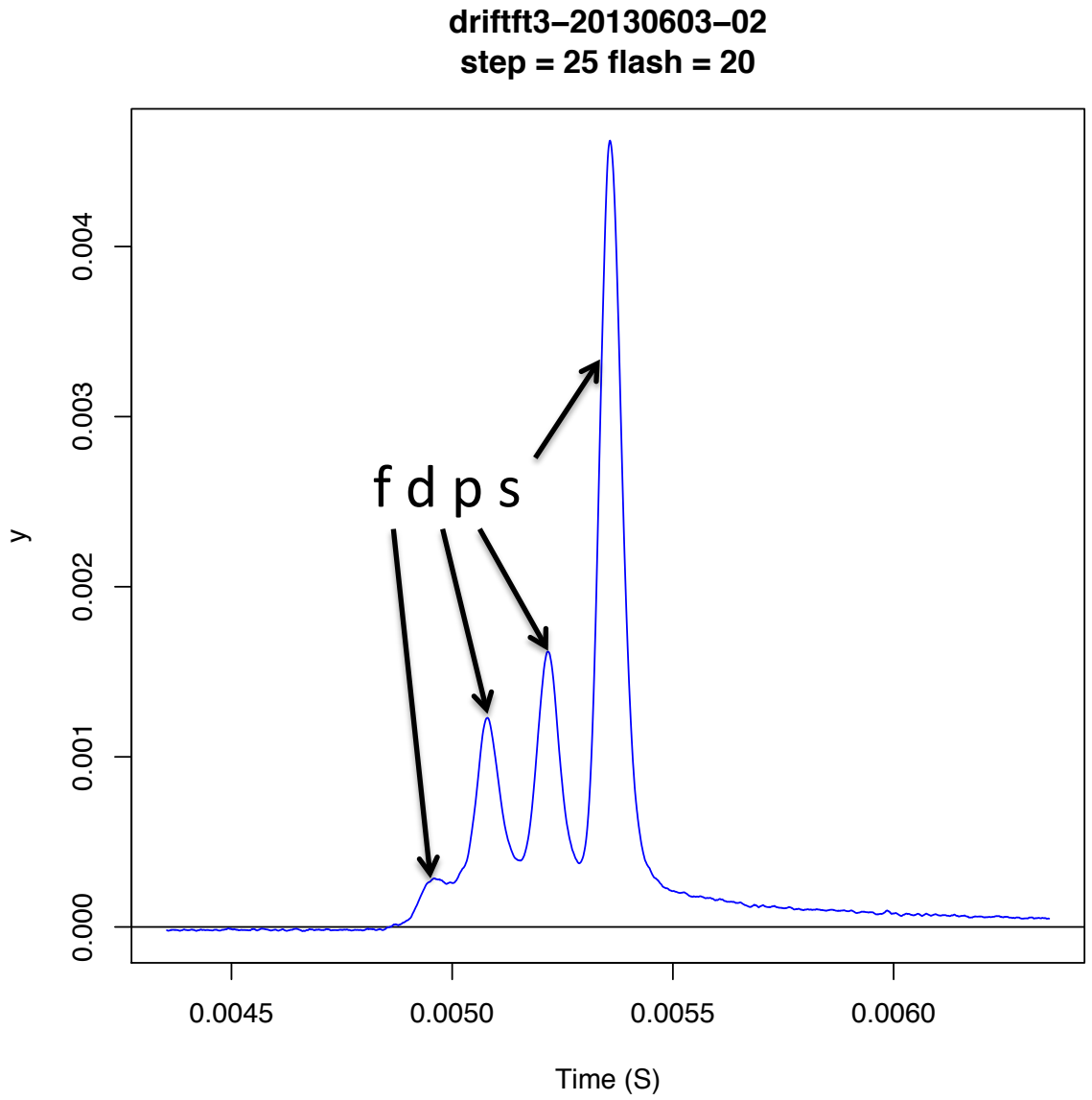
Earthquake Fiducialization

- But for their small size the minority carriers provide an amazingly useful method of fiducialization.
- Similar to “fiducializing” earthquakes.
- The revelation of the minority carriers is that one can have two species of negative ions in the gas **at the same time**, something we have long held as impossible in DRIFT.
- I reasoned that if minority carriers could exist in in the gas separate from the majority CS_2 carriers then I could, perhaps, add my own.
- Following Adam Bernstein and Mike Heffner at LLNL I thought adding electronegative O_2 to the gas mix might provide another carrier I could control.



“You can't always get what you want, but if you try sometimes, you might find, you get what you need.” - Mick Jagger

30 Torr CS_2 + 10 Torr CF_4 + 1 Torr O_2



- I added 1 Torr of O_2 to the nominal DRIFT-IId mixture.
- Instead of creating a separate O_2 peak the addition of just 2.5% O_2 increased the size of the minority peaks by a factor of 250!
- I now think the tiny minority peaks I was observing before were due to air contamination.

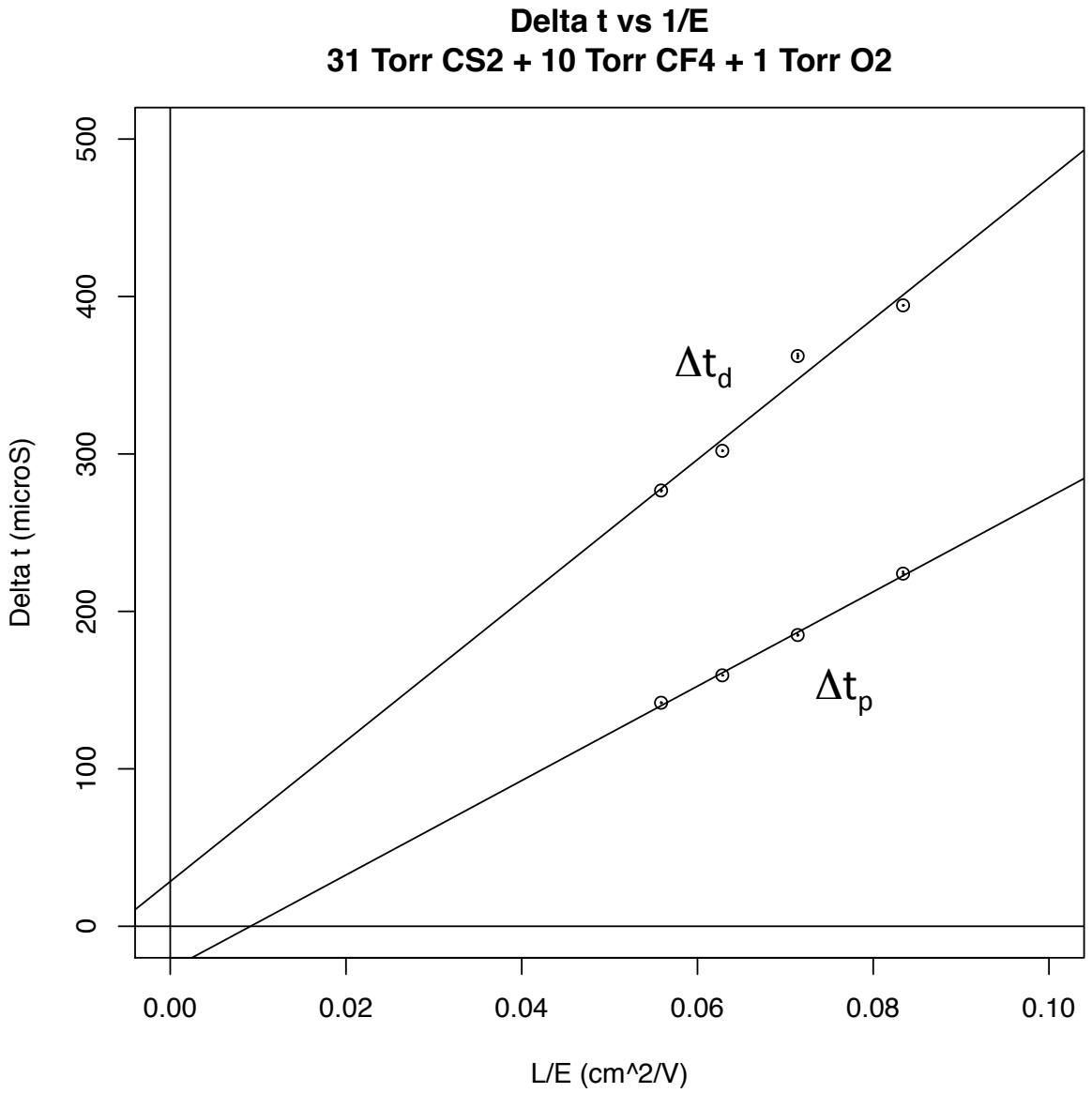
Minority Peak Equations

$$t_s - t_p = \frac{z}{v_s} - \frac{z}{v_p}$$

$$v \equiv \mu \frac{E}{p}$$

$$\Delta t_p \equiv t_s - t_p = \frac{p}{\mu_s}\left(1 - \frac{\mu_s}{\mu_p}\right)\left(\frac{z}{E}\right)$$

Minority Peak Flashlamp Results

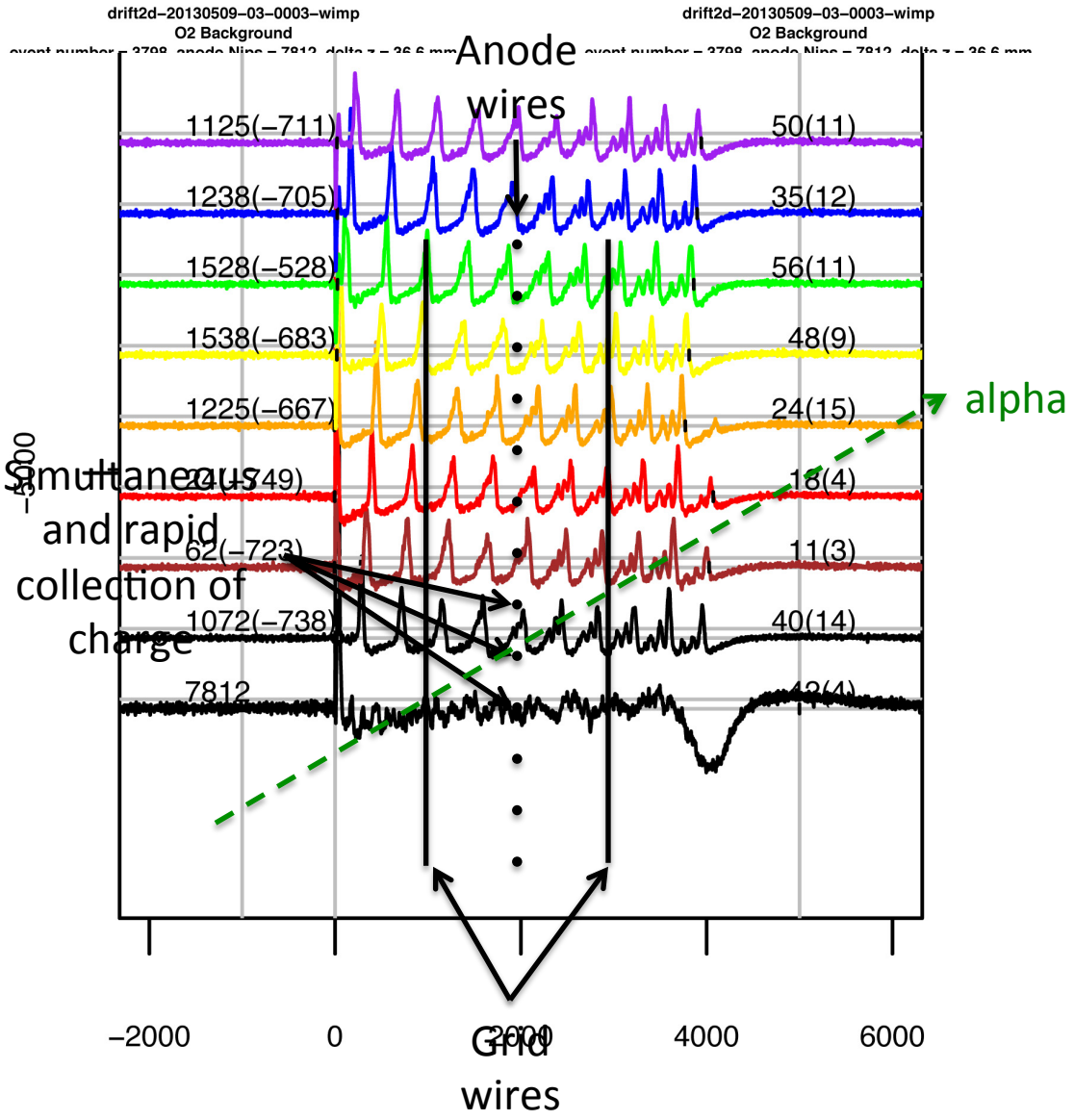


- The arrival time of the s, p and d peaks were measured and the s-p and s-d time differences plotted vs 1/E.
- The data are consistent with straight lines with zero offset.
- This confirms that minority peaks travel with velocity proportional to E.
- The next step is therefore to look for fiducialization data, i.e. $\Delta t \propto z$
- The flashlamp setup had no method of changing z so we looked to DRIFT-IId.

Minority Peaks in DRIFT-IId in Boulby

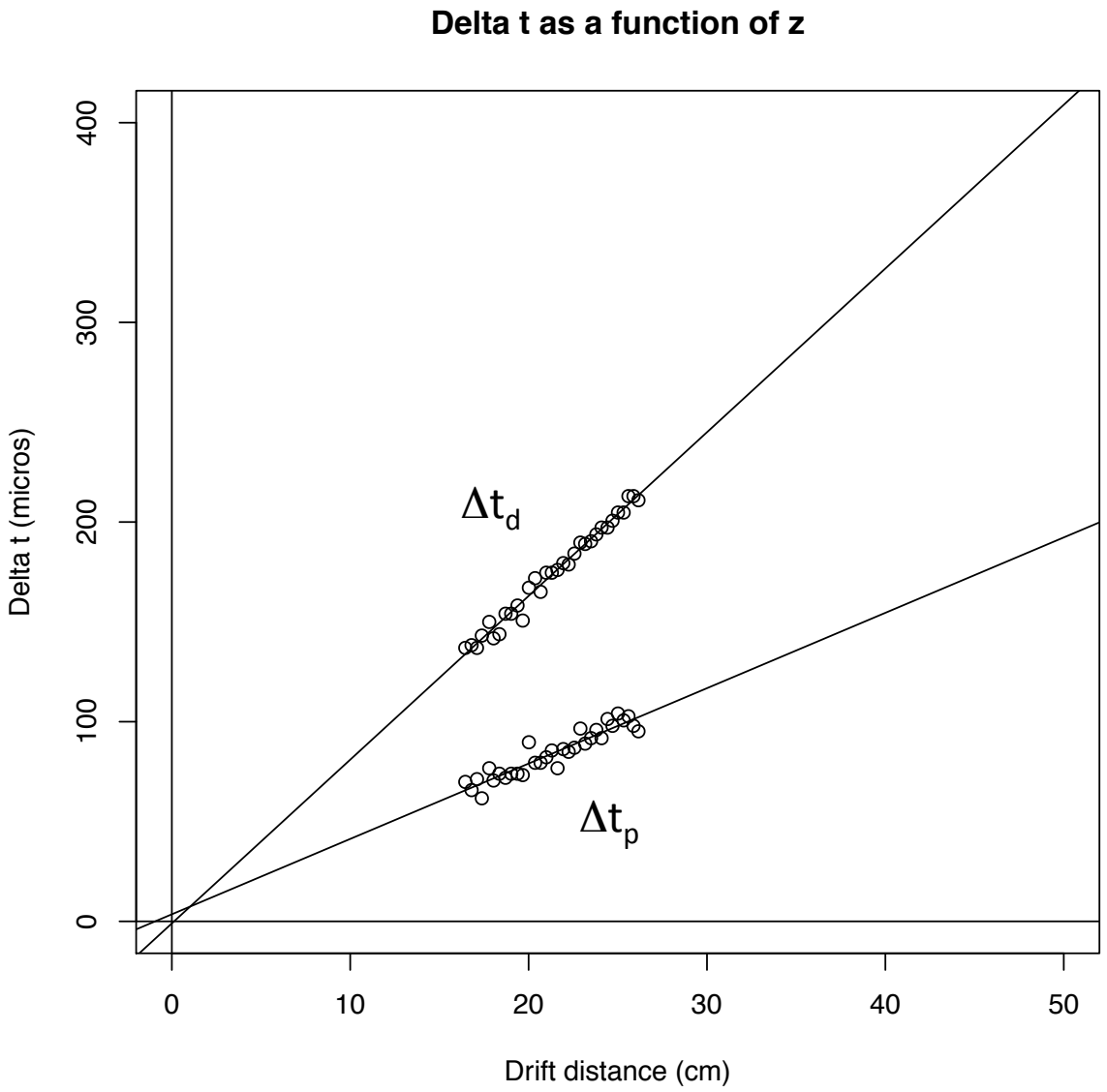
- 1 Torr of O_2 was added to the normal 30 Torr CS_2 and 10 Torr CF_4 mixture in Boulby.
- 3.5 hours of background and 1 hour of neutron data have been analyzed so far.

Minority Peaks in DRIFT-IId



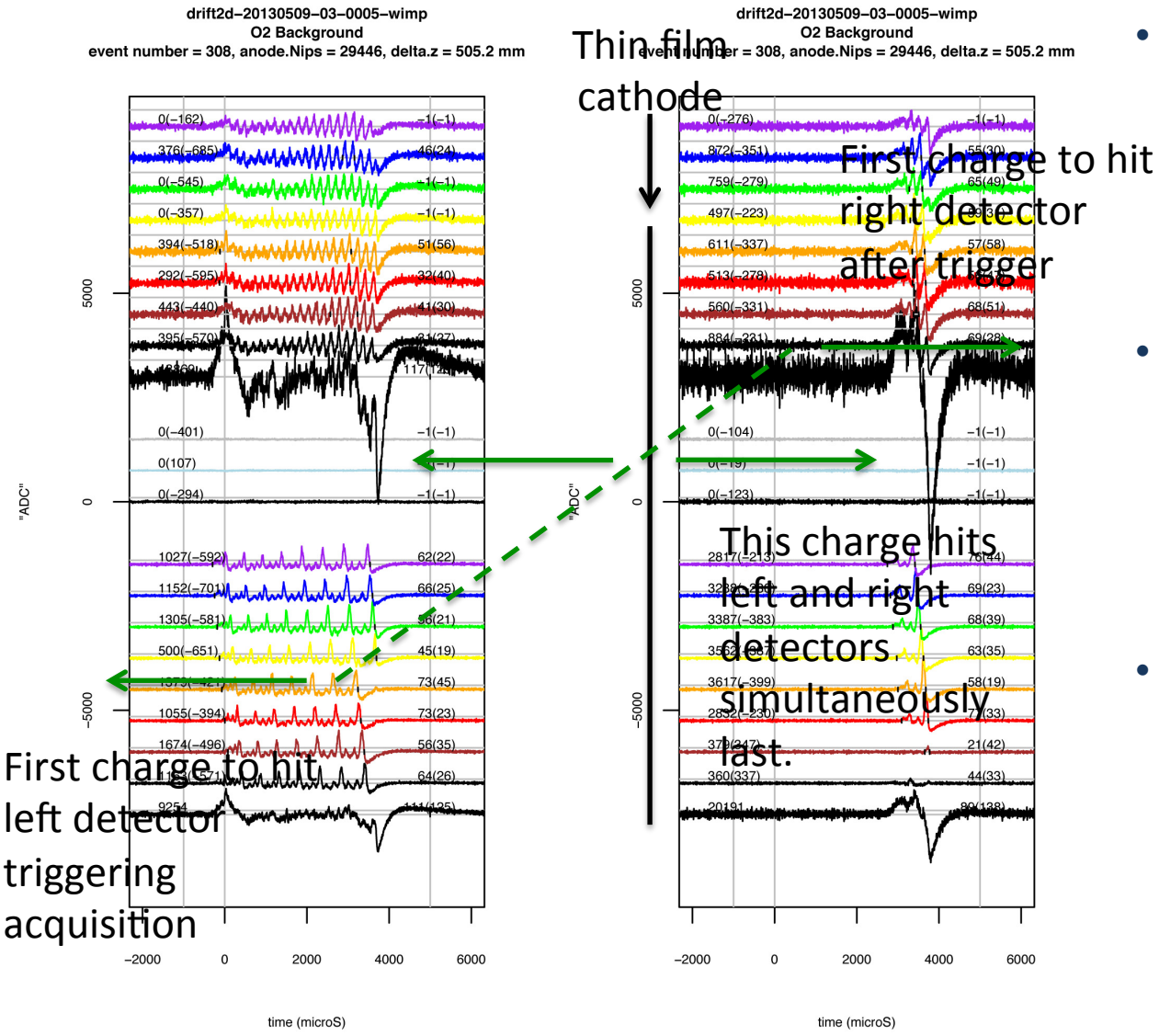
- This alpha crossed the MWPC as evidenced by the simultaneous peaks at t = 0 from rapid collection of charge in the MWPC.
- The t = 0 part of this track is therefore "fiducialized" to the MWPC, i.e. z = 0.
- We can get z for each s peak from the mobility measurement.
- Measuring Δt vs z should therefore give us a straight line.

Fiducialization in DRIFT-IId



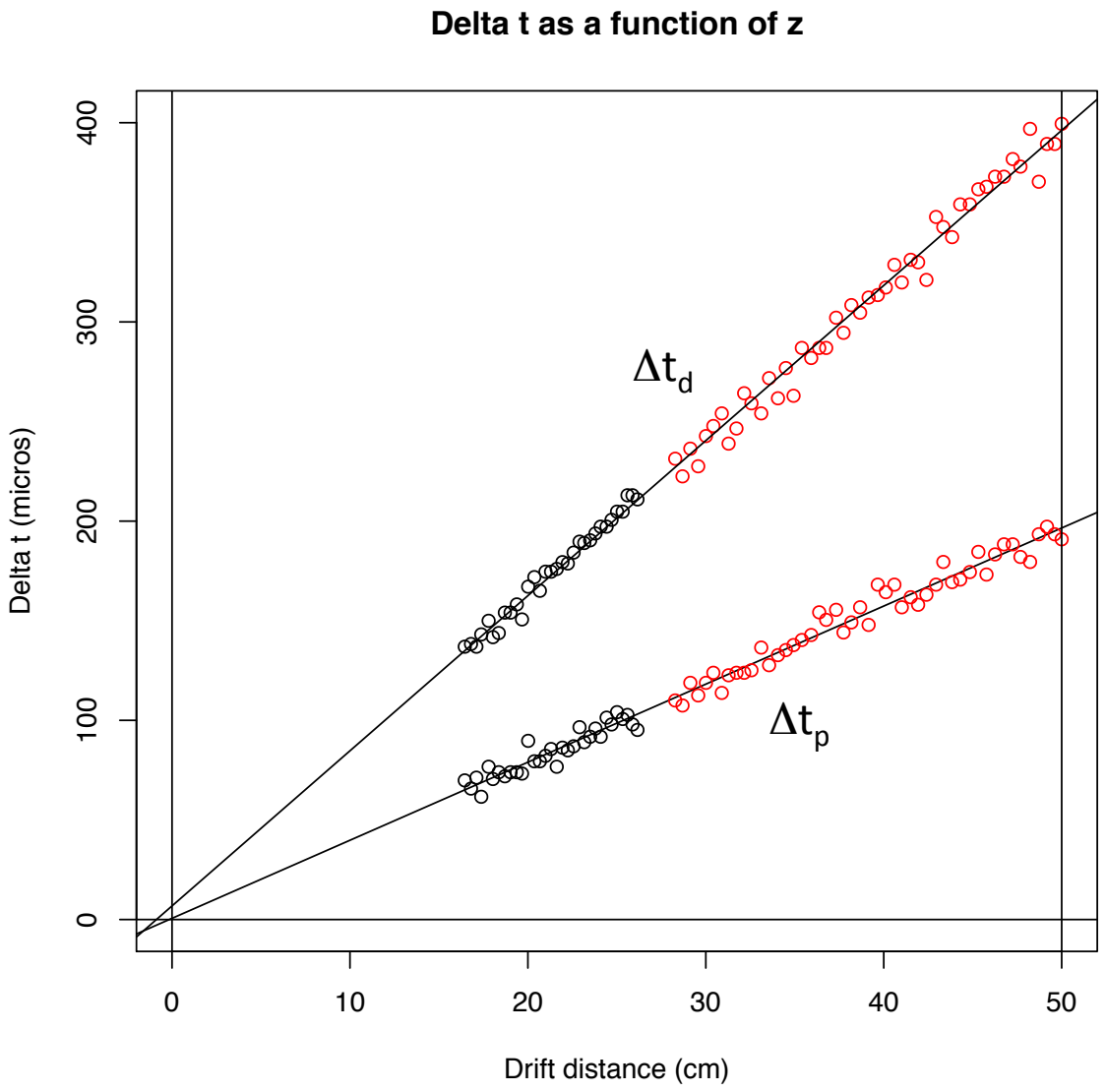
- The linear dependence and zero intercept show that z fiducialization via minority carriers works.
- The most important region, though, is the central cathode at z = 50 cm.

Cathode Crossing Alpha



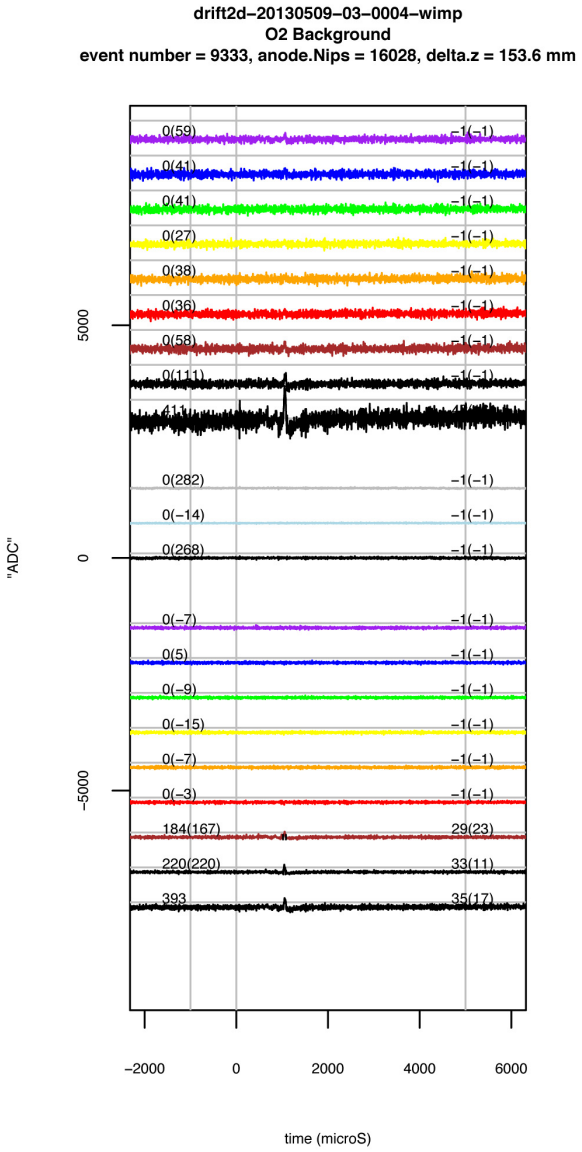
- The last (to the right) peaks on each side to reach the detector must have originated at the central cathode, 50 cm from the detector.
- The time difference from this last peak and previous peaks tells you how far away the ionization was from the central cathode.
- This data therefore allows us to extend our data from the previous plot.

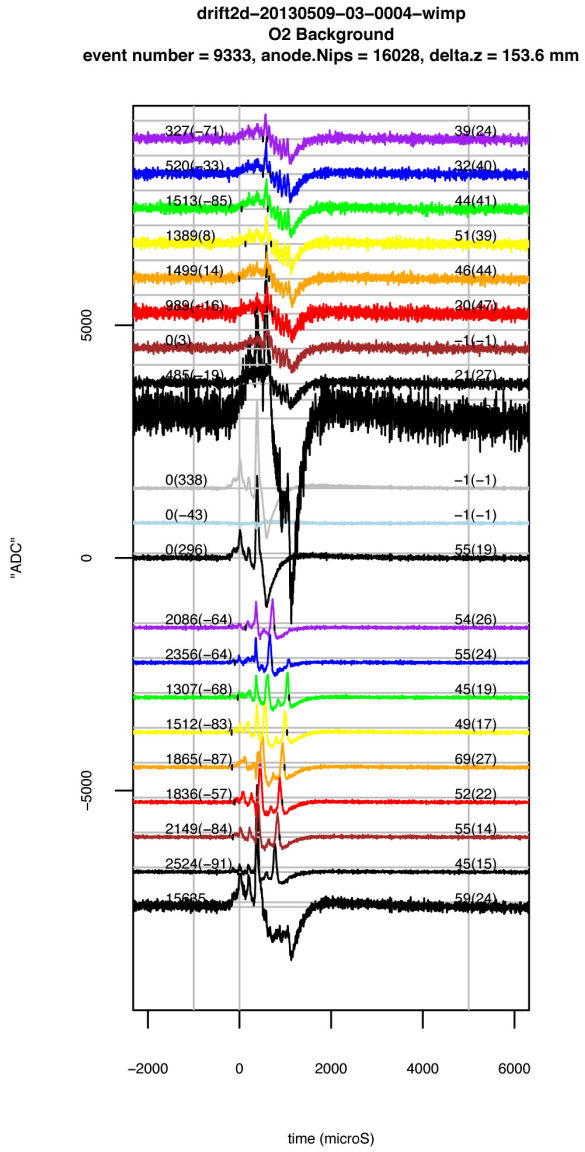
Fiducialization in DRIFT-IId



- Black = MWPC crossing alpha
- Red = Cathode crossing alpha
- These lines were not forced to zero.
- The linear dependence and zero intercept show that z fiducialization via minority carriers works.
- Δt_d = 397 μs and Δt_p = 197 μs @ z = 50 cm

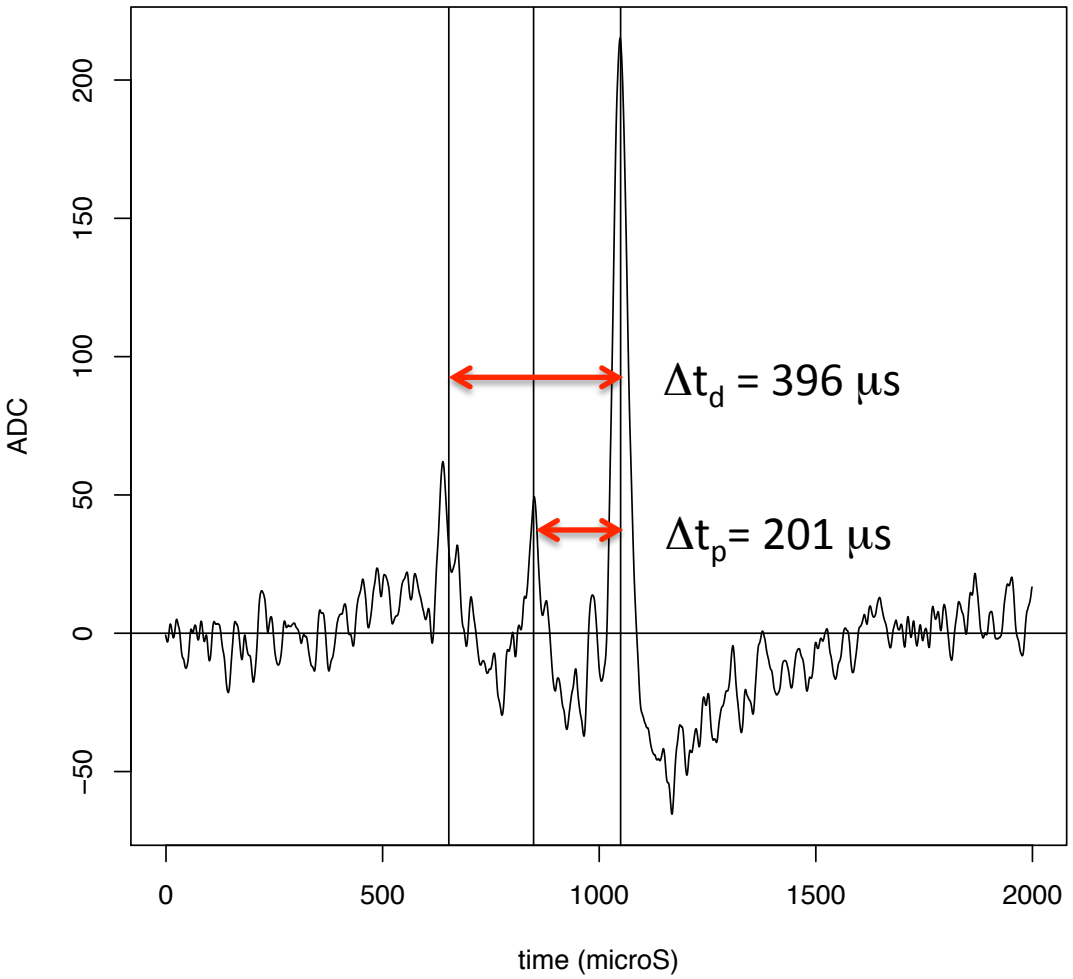
Tagged RPR in DRIFT-IId





- Tagged RPRs are quite frequent with the thin film. In this event and alpha on the left side of the thin film traveled through the thin film and out into the right detector, hitting the veto. An RPR recoiled on the left.

Tagged RPR Measurements



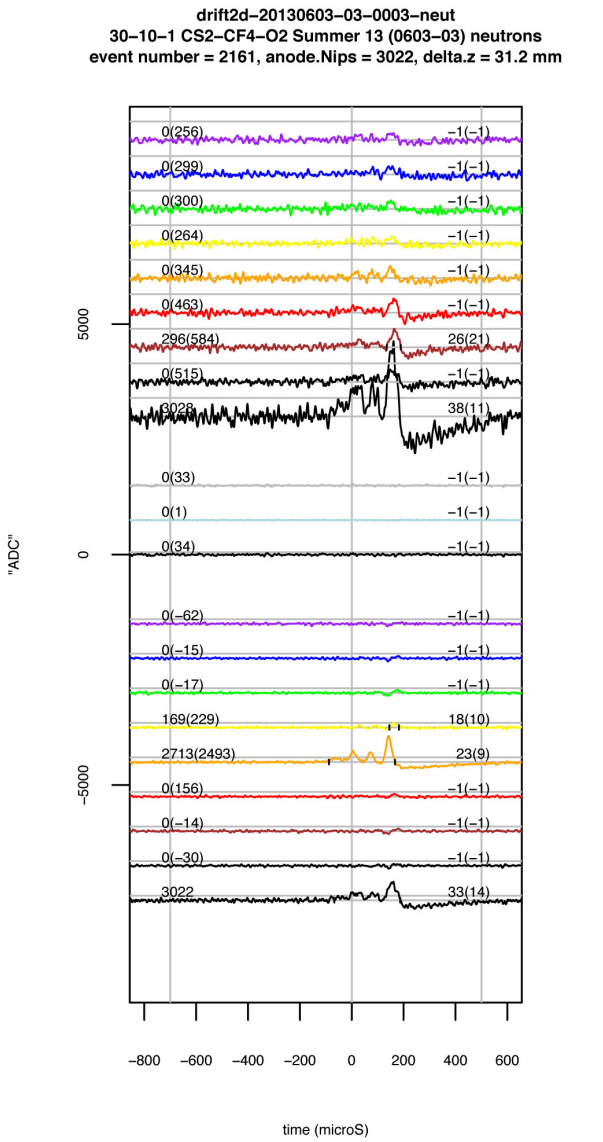
- This event from the central cathode has the predicted Δts to within a few %.
- This also shows that nuclear recoils possess the minority peak signature.
- Overshoot in the electronics poses an analysis challenge for us.
- $\frac{\Delta t_p}{\sigma_s} = 11.5$ @ 50 cm!

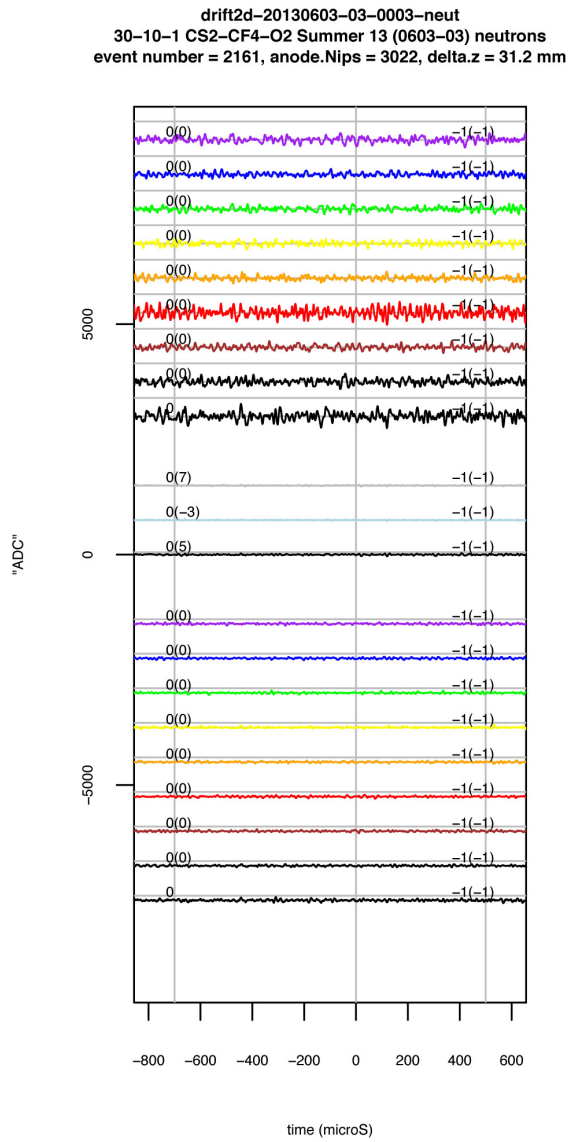
Tagged RPR Measurements

$$\sigma^2 = \frac{2kTz}{eE}$$

$$\frac{\Delta t_p}{\sigma_t} = \sqrt{\frac{e}{2kT}}\left(1 - \frac{\mu_s}{\mu_p}\right)\sqrt{Ez} \propto \sqrt{V}$$

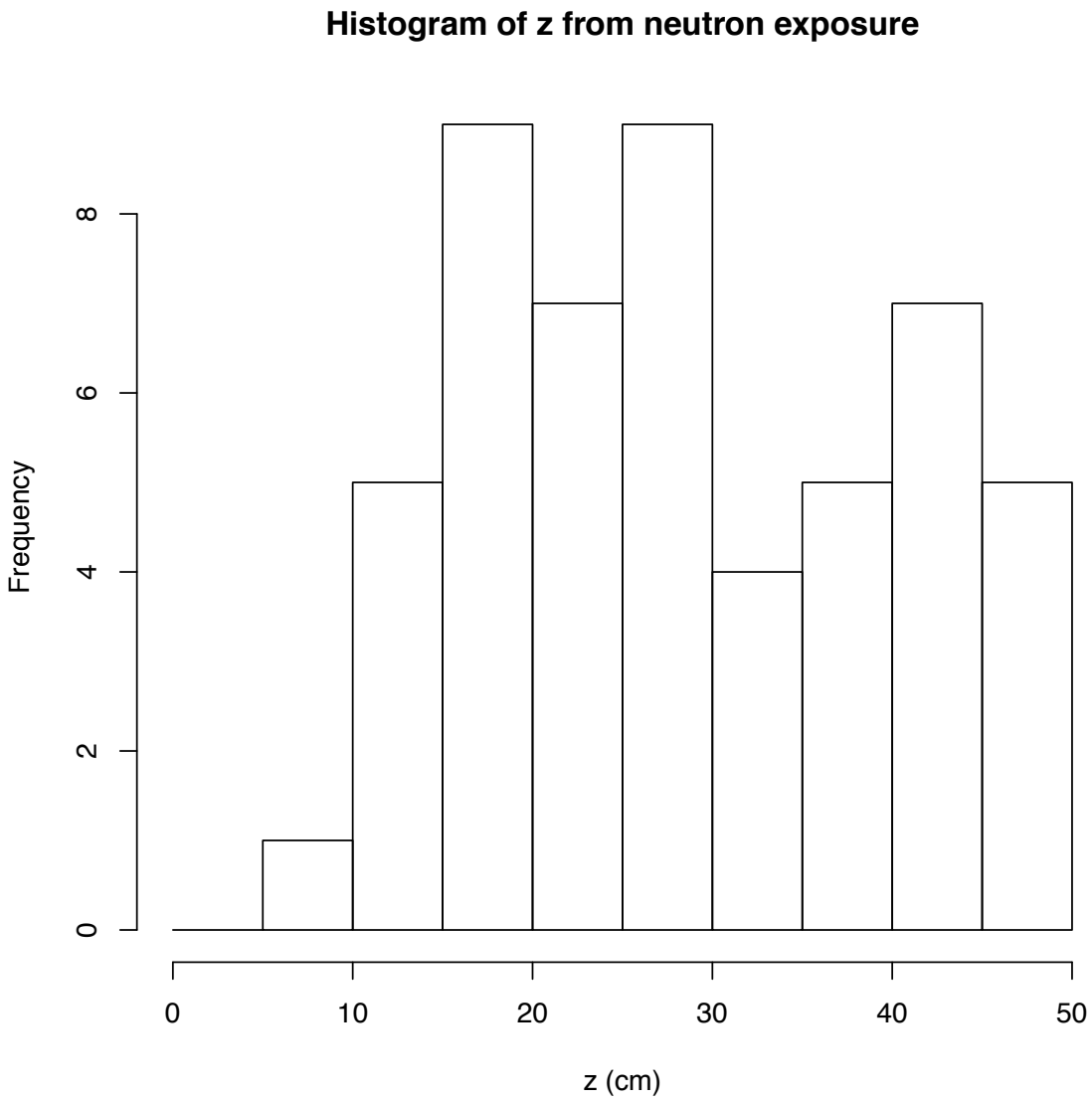
Neutron Recoil in DRIFT-IId





- Neutron recoil in DRIFT-IId
- This one was 16.9 cm from the detector based on the Δt_d measurement.

Distribution of measured z



- This is the distribution of recoil distances from the neutron exposure.
- It is basically flat.
- Perhaps there is a small rise towards the detector (small z) but the source was a point source near the cubic detector and partially shielded.
- There appears to be a limit of about 12 cm, 24% of detector volume.
- Again a peak finding algorithm will help us move that border closer to zero.

Plans for the Future

- After several test runs we are now poised to run DRIFT-IId with a texturized central cathode and O_2 for fiducialization.
- There is every reason to expect zero background.
- In two days of running we should therefore be able to equal our previous limit.

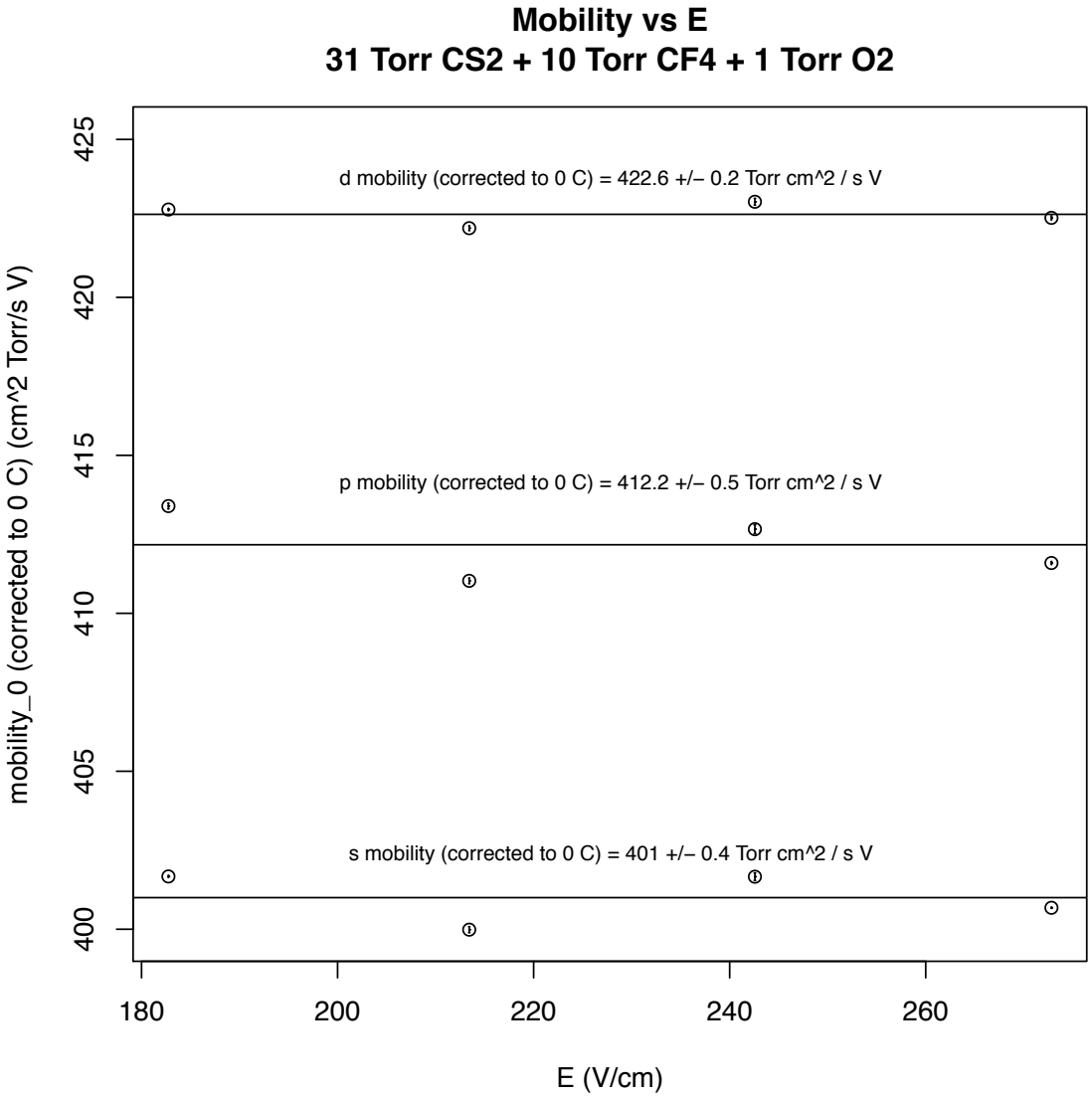
What are they?

Basic facts -

1. There are at least 3 minority carriers which are enhanced by the addition of O_2 in mixtures with CS_2 + CF_4 and CS_2.
2. CS_2 and CS_2 + CF_4 do not produce minority carriers.
3. The more O_2 the bigger the minority peaks.
4. Minority carriers are produced by the flashlamp, alphas, RPRs, Fe-55 X-rays and neutron recoils, basically any ionizing event.
5. Minority carriers travel at different velocities.
6. The minority carriers travel *faster* than the s peak.
7. The increments in speed s->p, p->d, d->f are nearly the same, 2.7% each.

Extra Slides

Minority Peak Mobility Plot



Mobility's Formula

$$\mu = \sqrt{\frac{2kT}{3m}}\frac{e}{\sigma}$$

“Isotopes” of CS2

[1,]	"75.9451 amu"	"89%"
[2,]	"76.9445 amu"	"1.4%"
[3,]	"76.9485 amu"	"1%"
[4,]	"77.9409 amu"	"8%"
[5,]	"77.9439 amu"	"0.005%"
[6,]	"77.9479 amu"	"0.016%"
[7,]	"78.9403 amu"	"0.063%"
[8,]	"78.9443 amu"	"0.091%"
[9,]	"79.9367 amu"	"0.18%"
[10,]	"79.9402 amu"	"0.037%"
[11,]	"79.9437 amu"	"8e-04%"
[12,]	"80.9396 amu"	"1e-04%"
[13,]	"80.9401 amu"	"0.0023%"
[14,]	"80.9435 amu"	"1e-04%"
[15,]	"81.9360 amu"	"0.0017%"
[16,]	"82.9393 amu"	"1e-04%"