Minority Carriers: A Revolution for Low Background TPC Work

Dan Snowden-Ifft

7th Symposium on Large TPCs for Low Energy Rare Event Detection

December 16, 2014
Directional Recoil Identification From Tracks (DRIFT)

Sheffield University
Neil Spooner – PI
Matt Robinson
Dan Walker
Stephen Sadler
Sam Tefler
Andrew Scarff
Anthony Ezeribe
Frederic Mouton
Trevor Gamble

Occidental College
Dan Snowden-Ifft - PI
Jean-Luc Gauvreau
Chuck Oravec
Alex Lumnah
Chongmo Tang

Colorado State University
John Harton – PI
Jeff Brack
Dave Warner
Alexei Dorofeev
Fred Shuckman II

University of New Mexico
Dinesh Loomba - PI
Michael Gold – PI
John Matthews - PI
Eric Lee
Eric Miller
Nguyen Phan
Randy Lafler

The University of Edinburgh
Alex Murphy – PI

Wellesley College
James Battat – PI

University of Hawaii
Sven Vahsen – PI
Tom Thorped

Boulby Mine
Sean Paling – PI
Emma Meehan
Louise Yeoman
Introduction to DRIFT

- DRIFT has been operating in Boulby since 2001.
- DRIFT-I -> DRIFT-II (a-e).
- DRIFT-IId volume = 0.8 m³, ~40 Torr gas.
- Negative CS₂ anion drift to limit diffusion (PRD, 61 (2000) 1).
- Phenomenal Compton background rejection (AstroPle, 28 (2007) 409).
- Many gas mixtures possible.
- DRIFT-IId used a 30-10 Torr of CS₂-CF₄ to optimize for spin-dependent limits, 139 g target mass. (AstroPle, 35 (2007) 397).
- Relatively cheap, clean, stable and scalable technology.
DRIFT-IIId Data

CS2–CF4 Winter 09/10 Background Runs
47.4 days, 6152 events, 130 events per day

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

Radon Progeny Recoils

\[ ^{222}\text{Rn} \rightarrow ^{218}\text{Po} + ^{4}\text{He} \] 
\[ ^{218}\text{Po} \rightarrow ^{214}\text{Pb} + ^{4}\text{He} \]

Range = 12 µm

DRIFT-IIId Data

- Diffusion of the RPRs from the central cathode increases their width
- So used width as a crude discrimination parameter
- Black = Background
- Red = Neutron recoils

DRIFT-IIId Data

CS2–CF4 Winter 09/10 Background Runs
F Recoil Energies vs IWS RMST
47.4 days, 6152 events, 130 +/- 2 events per day

- Select an signal window
- For 100 GeV WIMPs the signal window gives only 8% efficiency for events passing the cuts

DRIFT-IIId Spin-Dependent WIMP Limits
Mobility and Diffusion Experiment

Xe Flashlamp

200 μm pinhole

Quartz (UV transmitting) lens

Quartz window

20 μm SS anode wires
2 mm spacing

Grid wire planes

15 cm

Vacuum Vessel

Al photocathode

Amptek Amplifiers

Computer

1 MHz Digitizers

5 anode readouts
Lateral Diffusion Measurements

**Average Sum vs position**

\( E = 219 \text{ V/cm} \)

- Mean: 1.2464 ± 4e-04, Sigma: 0.0639 ± 6e-04
- Mean: 1.047 ± 3e-04, Sigma: 0.0645 ± 5e-04
- Mean: 0.8428 ± 4e-04, Sigma: 0.0656 ± 6e-04
- Mean: 0.6433 ± 4e-04, Sigma: 0.0649 ± 6e-04
- Mean: 0.4394 ± 3e-04, Sigma: 0.0649 ± 5e-04
Diffusion Theory

\[ 2 = \frac{2kTL}{eE} \]
Lateral Diffusion Results

40 Torr $\text{CS}_2$

30-10 Torr $\text{CS}_2 + \text{CF}_4$

Longitudinal Diffusion Measurements

\[ E = 239 \text{ V/cm} \]

\[ E = 118 \text{ V/cm} \]

\[ \text{driftft3-20121022-02} \]

Line number = 2, \( \sigma.10.50 = 33.03 \text{ microS} \)

\[ \text{driftft3-20121022-03} \]

Line number = 2, \( \sigma.10.50 = 91.22 \text{ microS} \)

\[ t = 0 \implies \text{flashlamp pulse} \]

Longitudinal Diffusion Results

40 Torr CS$_2$

30-10 Torr CS$_2$+CF$_4$

As discussed here in 2012:

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.

BUT...
Discovery of Minority Carriers in Mixtures of CS₂ and O₂

Earthquake Fiducialization
Discovery of Minority Carriers in Mixtures of CS$_2$ and O$_2$

Fall 2013 DRIFT-IIId Results with 30-10-1 Torr CS$_2$-CF$_4$-O$_2$
DRIFT-IId Results with 30-10-1 Torr CS$_2$-CF$_4$-O$_2$
Fall 2014 DRIFT-IId Results with 30-10-1 Torr CS$_2$-CF$_4$-O$_2$

Neutron calibration (3.2 days)

Neutrons 20141016−02 422

3.71 days, 2962 events, 798 ± 10 events per day
Deconvolution of Tracks

- Knowledge of the drift distance allows us to precisely calculate the diffusion (the PSF) of the ionization.
- Therefore we should be able to, like astronomers, deconvolve the observed track to get better knowledge of the actual track.
- Here is a theoretical (20 cm drift) simulation.

Figure 7 – Simulation results for deconvolution of a 49.4 keVr F recoil track in 100 Torr CF$_4$. Left: the original, undiffused image; Middle: the image with the same S/N, diffusion ($\sigma \sim 0.4\text{mm}$) and pixelization as seen by Phan's R&D detector; and Right: deconvolution result of the middle image. The deconvolved image correctly reconstructs the energy to within 5%, the track direction to 3.6 degrees and the head-tail asymmetry to within 8%. In the middle 'detector' image the asymmetry is almost washed out.
Deconvolution of Tracks

- Here is some real data taken with a GEM-Optical readout TPC
Conclusion

- The addition of $O_2$ to mixtures containing $CS_2$ produces abundant minority carriers.
- The minority carriers allow us to accurately measure the drift distance of segments of ionization.
- Fiducialization has revolutionized DRIFT’s background rejection capabilities because our only known backgrounds come from the central cathode.
- New limits have been set and data for better limits are being taken now.
- Knowledge of the diffusion should allow DRIFT to deconvolve tracks to obtain better directional information.
- Vive la Révolution!
Thanks
Extra Slides
Alpha + $O_2$

![Graph showing current as a function of time for Alpha + O2 reaction.](image-url)
Triggerless Fiducialization

The problem

The 6 MeV Po-218 alpha can hide in central cathode wires.
Thin film

Give the alphas few places to hide in an aluminized Mylar thin film.
Thin Film

Of course some alphas will find a way to hide
Thin Film

Give the alphas even less places to hide in a texturized aluminized Mylar thin film.
Miraculously the guys at UNM have managed to create a texturized 0.9 micron thin film.

This has been deployed on DRIFT-Illd in Boulby.

Preliminary results indicate a drop from 130 events per day down to ~1 event per day.

Further improvements are expected with the deployment of DRIFT-Ille this spring.