DRIFT

Status and Spin Dependent Limits from DRIFT -
a directionally sensitive dark matter detector

Daniel Walker

Introduction

- WIMP Wind
- DRIFT-IId Detector Overview
- Boulby Mine Overview
- Detector Features
- Dominant Backgrounds
- Gas Mixture (CS_2 - CF_4)
- Spin dependent Limit – Preliminary Results
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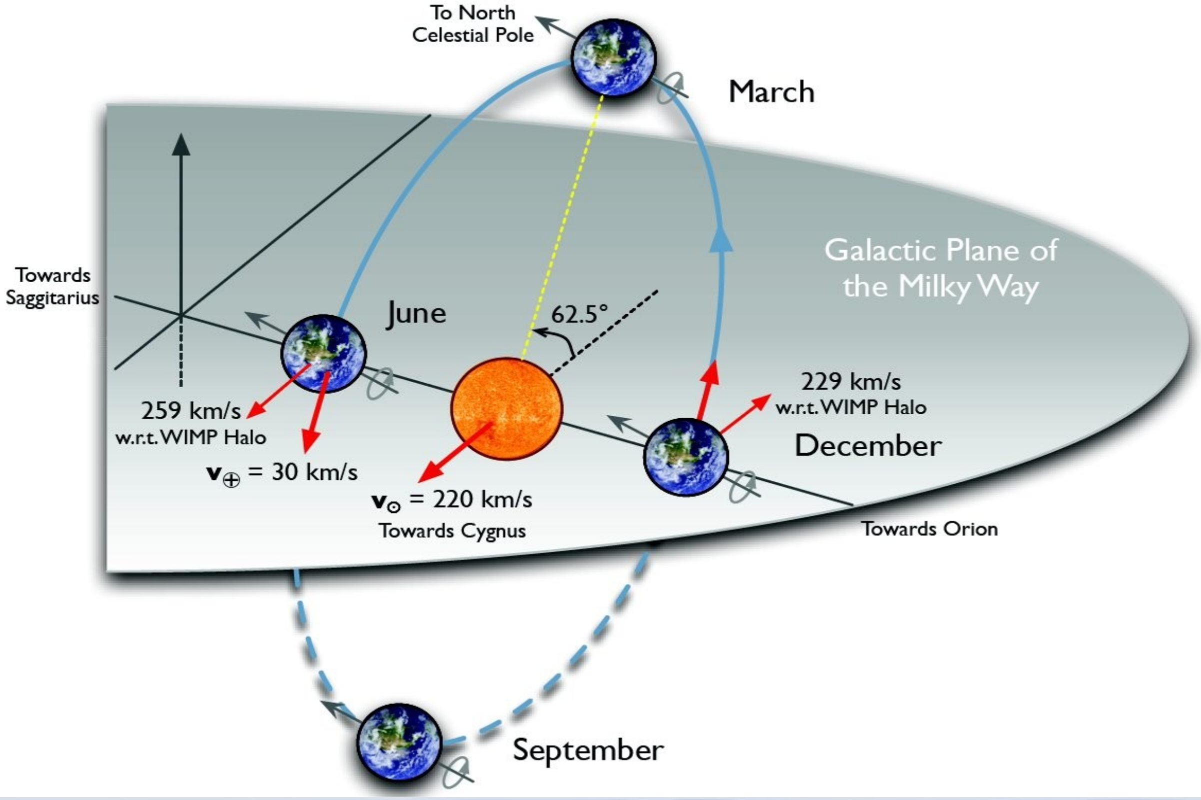
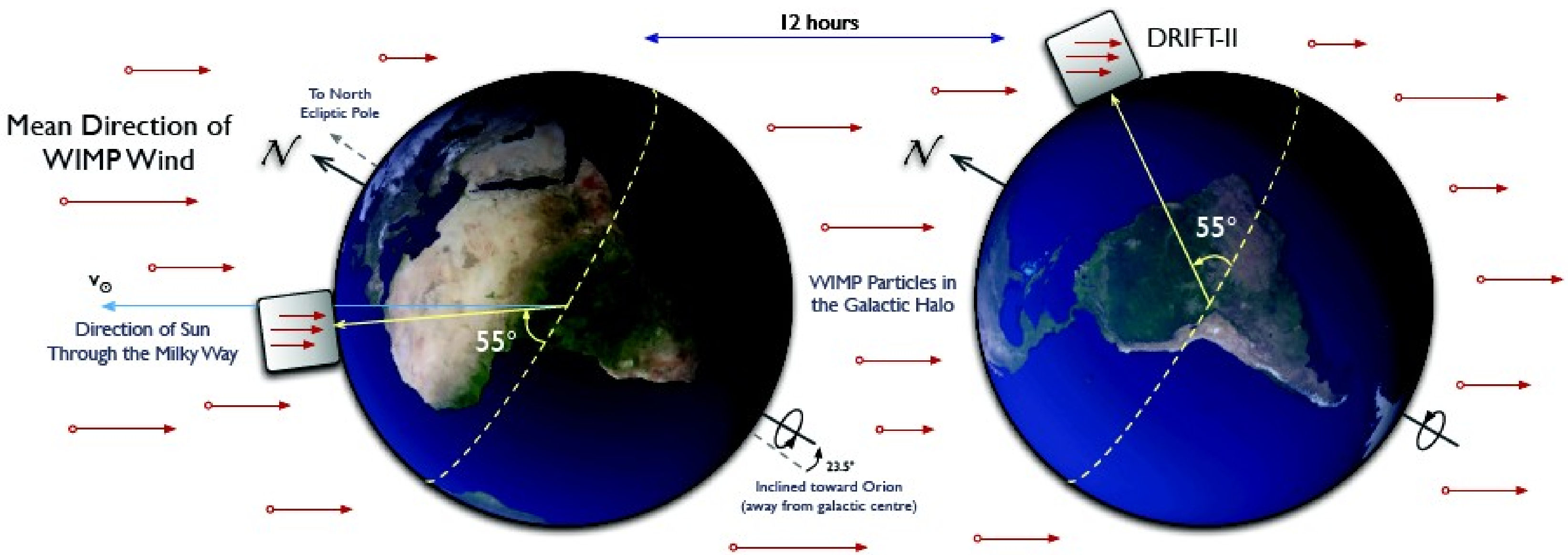
WIMP Wind

- Galaxy thought to be within an isotropic halo of static WIMPs
- An apparent WIMP wind is created from the Earth's path through this halo
- Mean velocity ~220 kms^{-1} from the constellation Cygnus – orbit of the Sun around the galactic centre.
- ~15kms^{-1} annual modulation in the WIMP wind due to the Earth orbiting the Sun



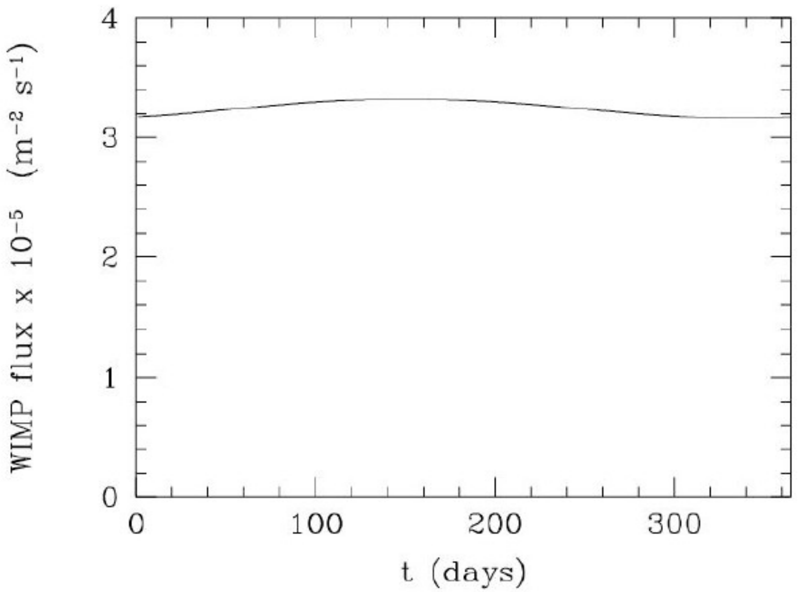
WIMP Wind

- Also a modulation in the direction of the WIMP wind as the Earth spins on its axis - a ~90^{o} modulation over the course of a sidereal day
- 1 sidereal day (measured relative to fixed stars) = 23 hrs 56 mins.

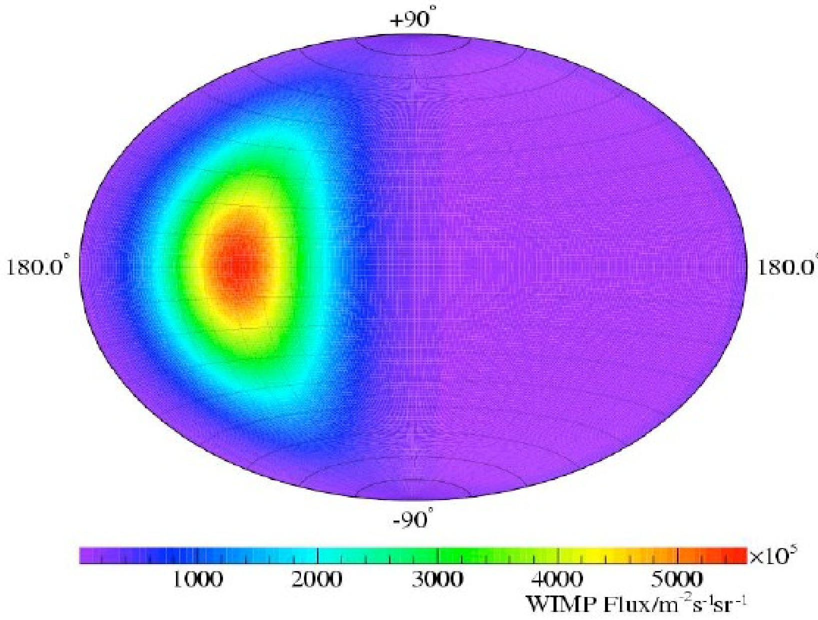


WIMP Signatures

- Annual modulation – WIMP-nucleon event rate and energy spectrum module with WIMP velocity.
- A small effect (~5%)
- Hard to eliminate seasonal backgrounds.
- Variation dependent on halo model and WIMP particle characteristics

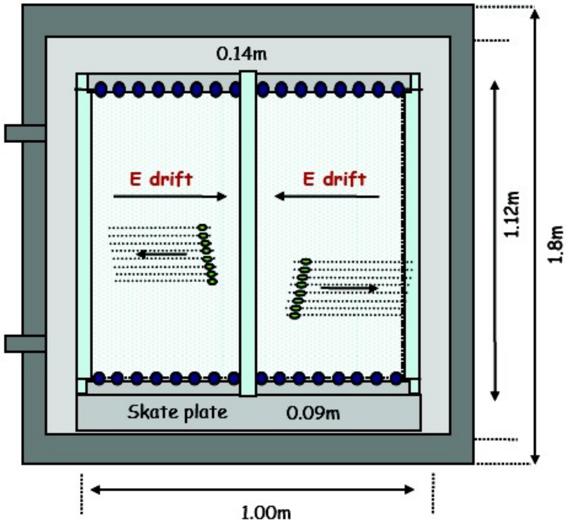


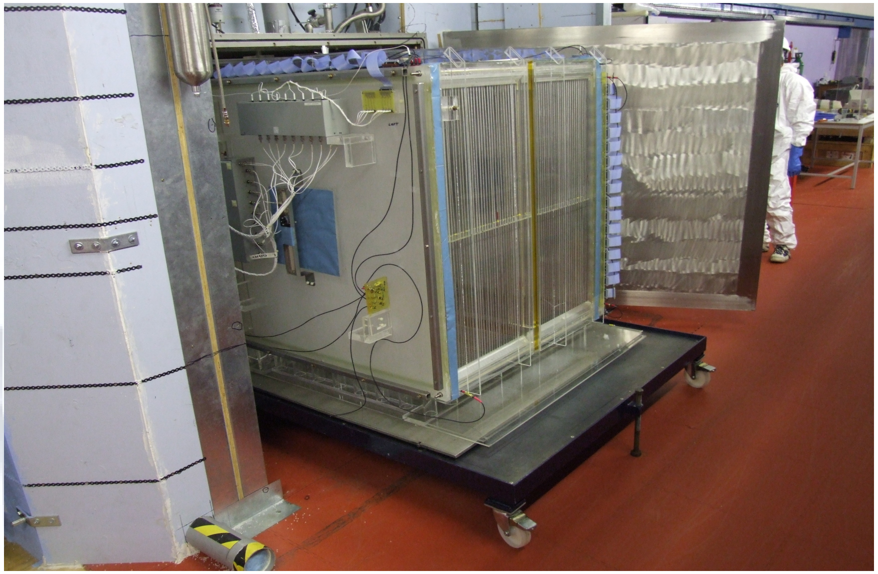
- Directional Dependence
- Nuclear recoils from WIMP collisions will be biased in the direction of the WIMP wind.
- Strong signature, originating from the Earth's motion through the WIMP wind. Terrestrial source not be able to produce such a signal.

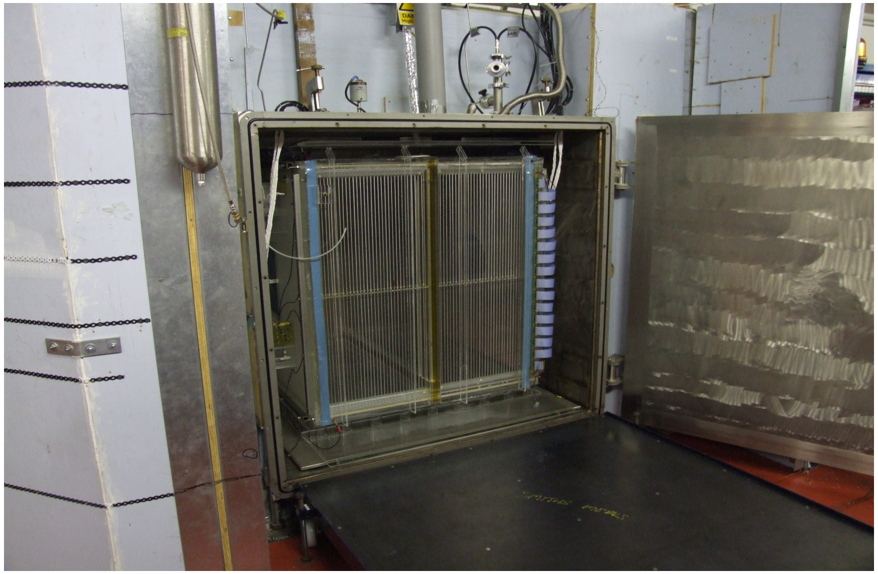


DRIFT IId Overview

- Consists of two back-to-back low pressure gas TPCs
- $1m^2$ central cathode, $1m^2$ MWPC readout planes
- 0.5m drift region
- Vacuum vessel made from low-background stainless steel, approx 7mm thick. Access via a hinged door. Filled with a low pressure target gas (eg 40 Torr CS_2)
- Fiducial volume = $0.8m^3$ (134g CS_2)

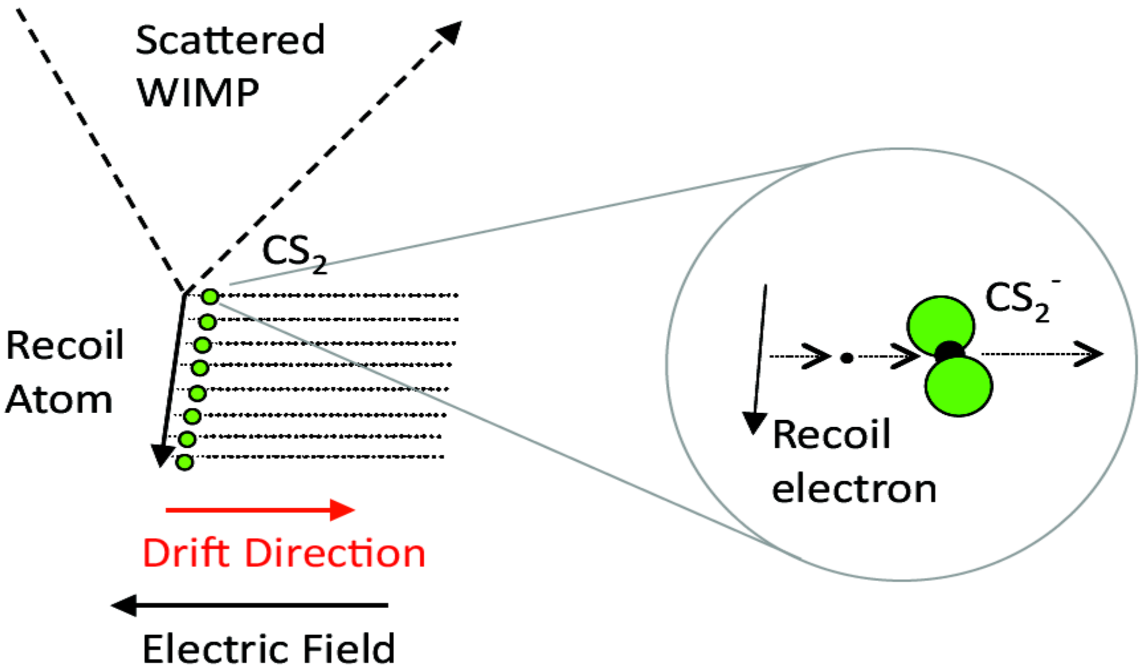






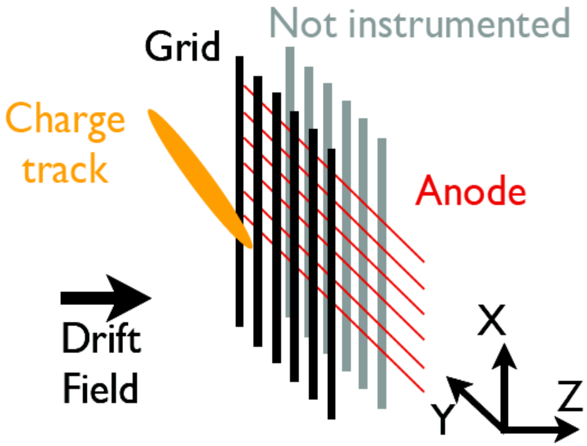
Negative Ion Drift

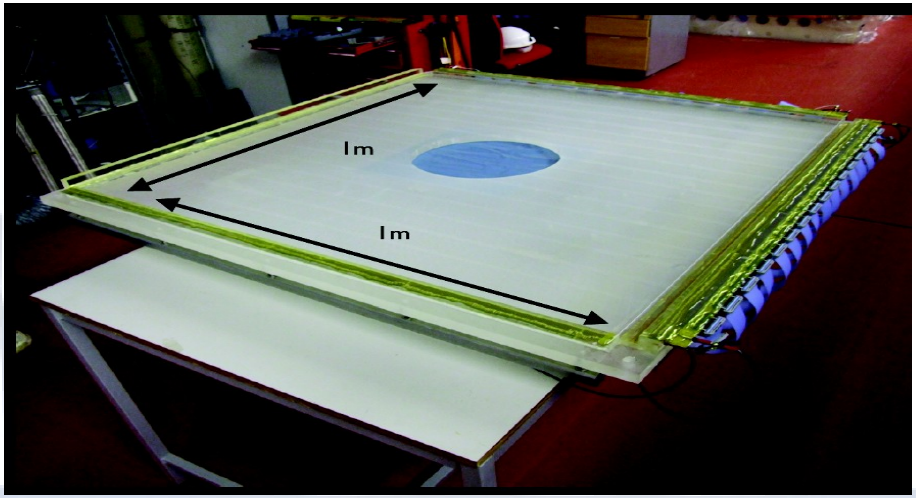
- In a large volume detector, the drifted track undergoes diffusion, leading to the loss of directional information.
- CS_2 is electronegative, so negative CS_2^- anions are drifted rather than free electrons. This drastically reduces diffusion of the charged track as the massive ions suffer only thermal diffusion.
- This maintains fine detail features in three dimensions until the track's arrival at the readout plane.

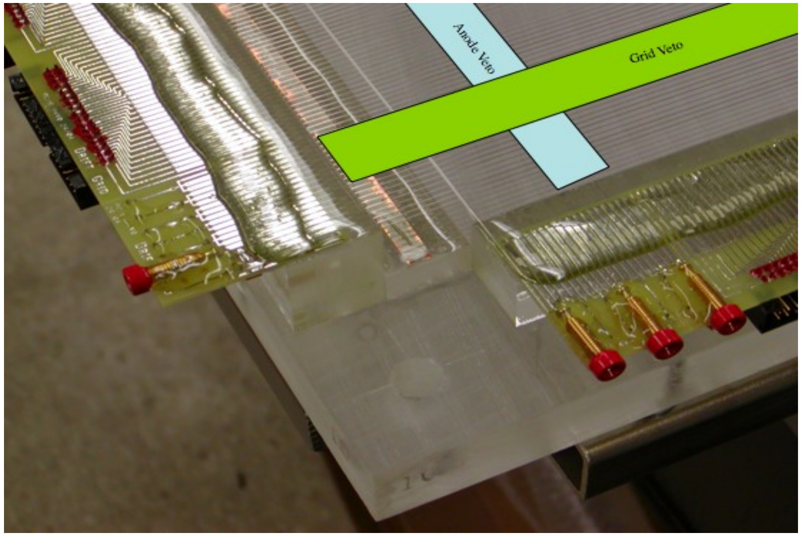


MWPC Readout

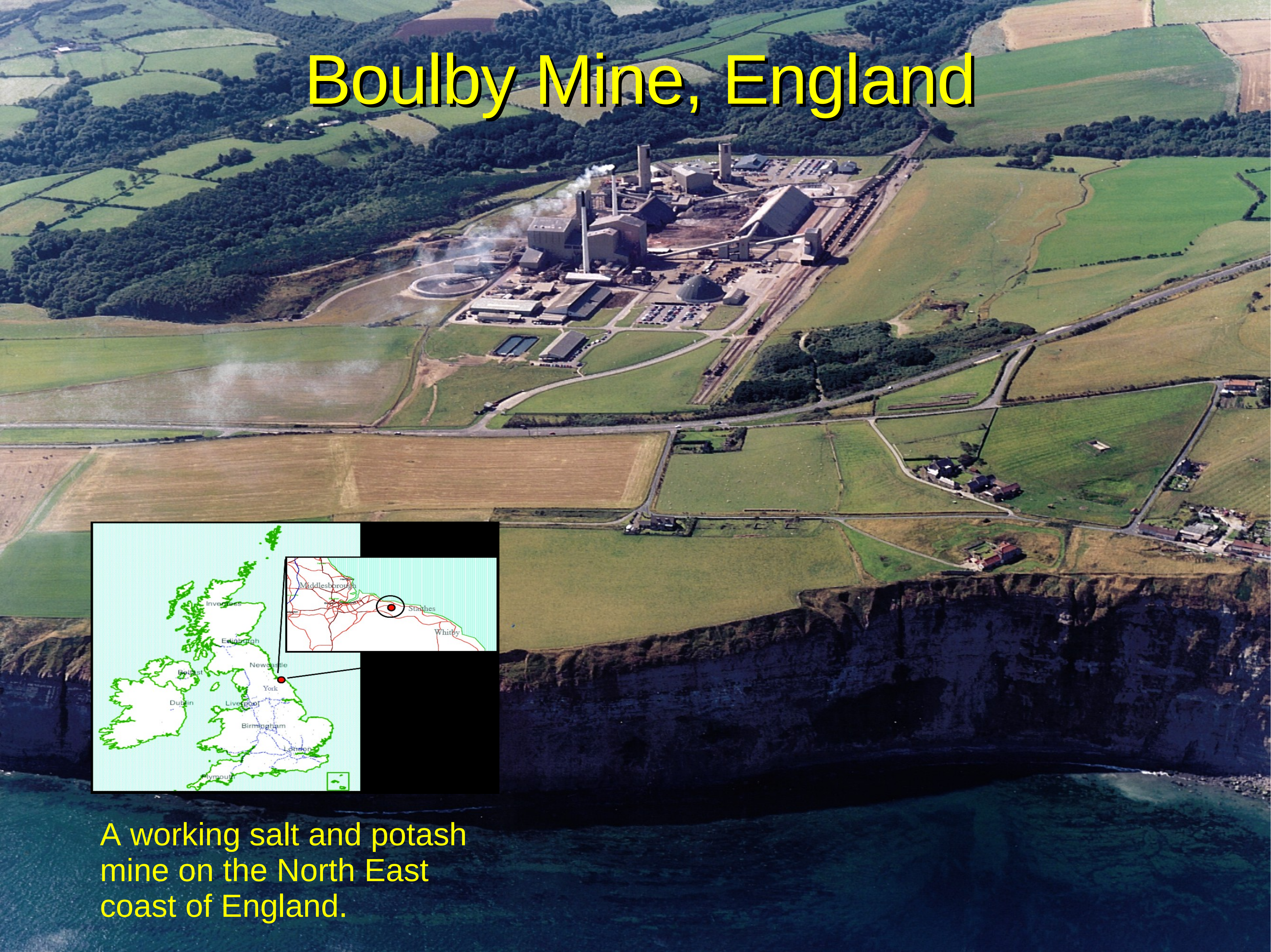
- MWPCs each consist of a central anode plane of 512 20μm diameter stainless steel wires and two perpendicular grid planes of 512 100μm wires.
- The wire-plane separation is 10mm and wire separation within each plane is 2mm.
- Δx: Progression across anode wires
- Δy: Progression across grid wires
- Δz: Drift time between start and end of track (digitised at 1MHz).
- The wires are multiplexed to 18 channels. This is *simple, cheap* and *scalable*.







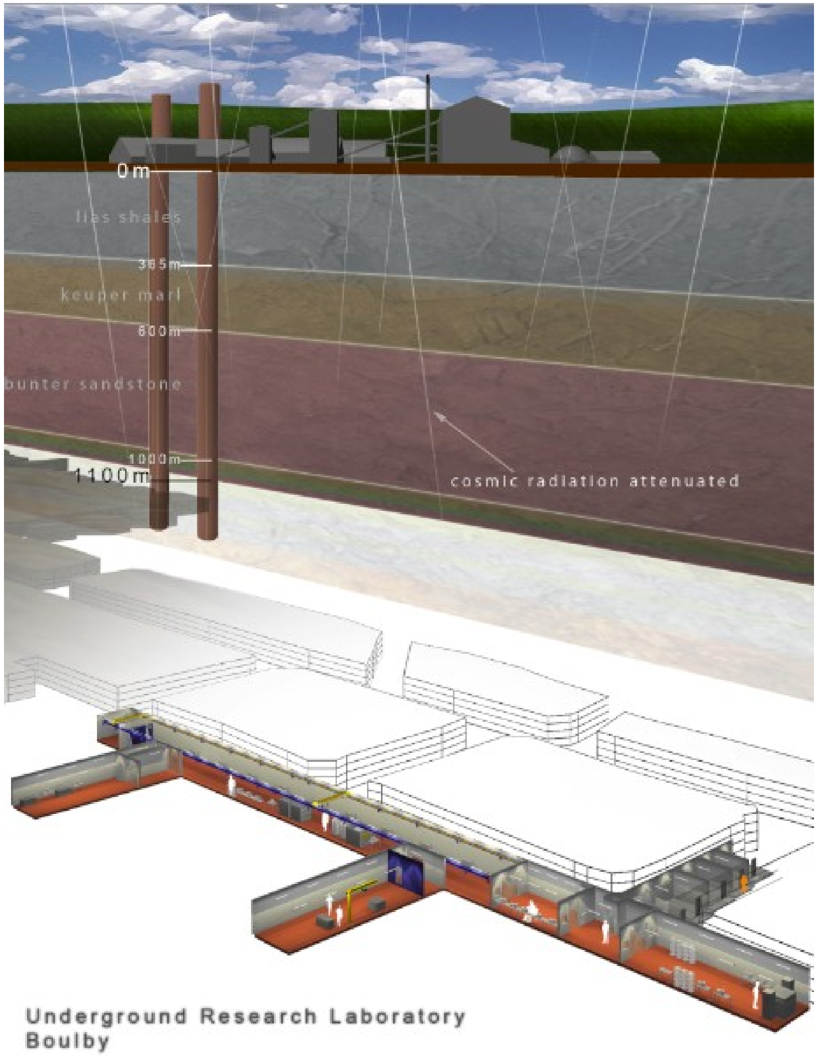
Boulby Mine, England



A working salt and potash mine on the North East coast of England.

Boulby Underground Laboratory

- Located at a depth of 1.1km (2805 m.w.e.)
- Cosmic rays are attenuated by a factor of ~10^6, measured to be 4.1 x 10^{-8} cm^{-2} s^{-1}. [M.Robinson et.al, NIM A 511 (2003)]
- The rocksalt is low in Uranium (U) and Thorium (Th) contaminants

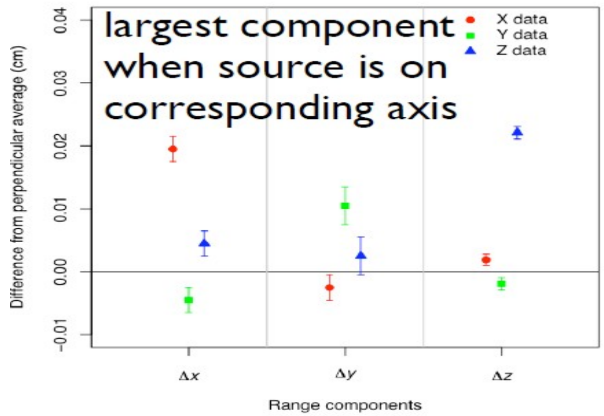


DRIFT Underground

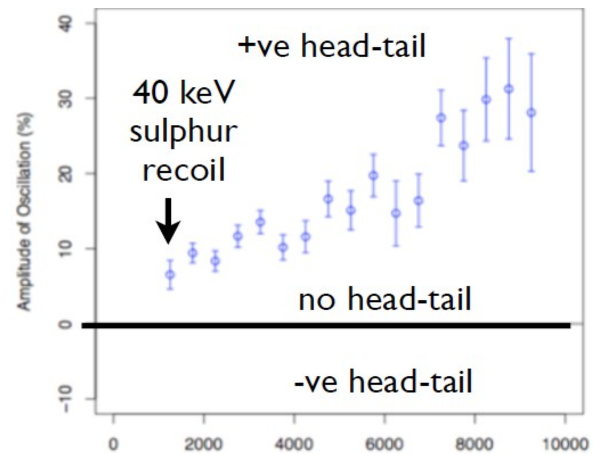
- DRIFT is shielded using polypropylene (CH_2) pellets up to a depth of 67 cm on all sides.
- Lead shielding is not necessary, due to the detector being insensitive to electron recoils. These have a long range and lower ionisation density relative to nuclear recoils and are not triggered on.

Recent publications

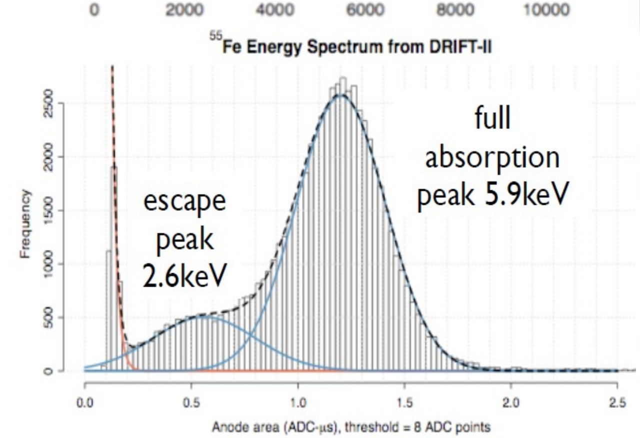
- 1. Directional Sensitivity [S. Burgos et al., NIM A 600 (2009) 417] Demonstrated directional sensitivity in all dimensions to nuclear recoils at energy thresholds (~1 keV/amu), relevant to dark matter searches.



- 2. Head-Tail discrimination [S.Burgos et al. Astropart. Phys. 31 (2009) 261]. Demo nstrates a clear asymmetry in neutron induced sulphur recoils in the DRIFT detector down to 1.5 keV/amu. *Head-tail discrimination can reduce number of WIMP events required by an order of magnitude.*

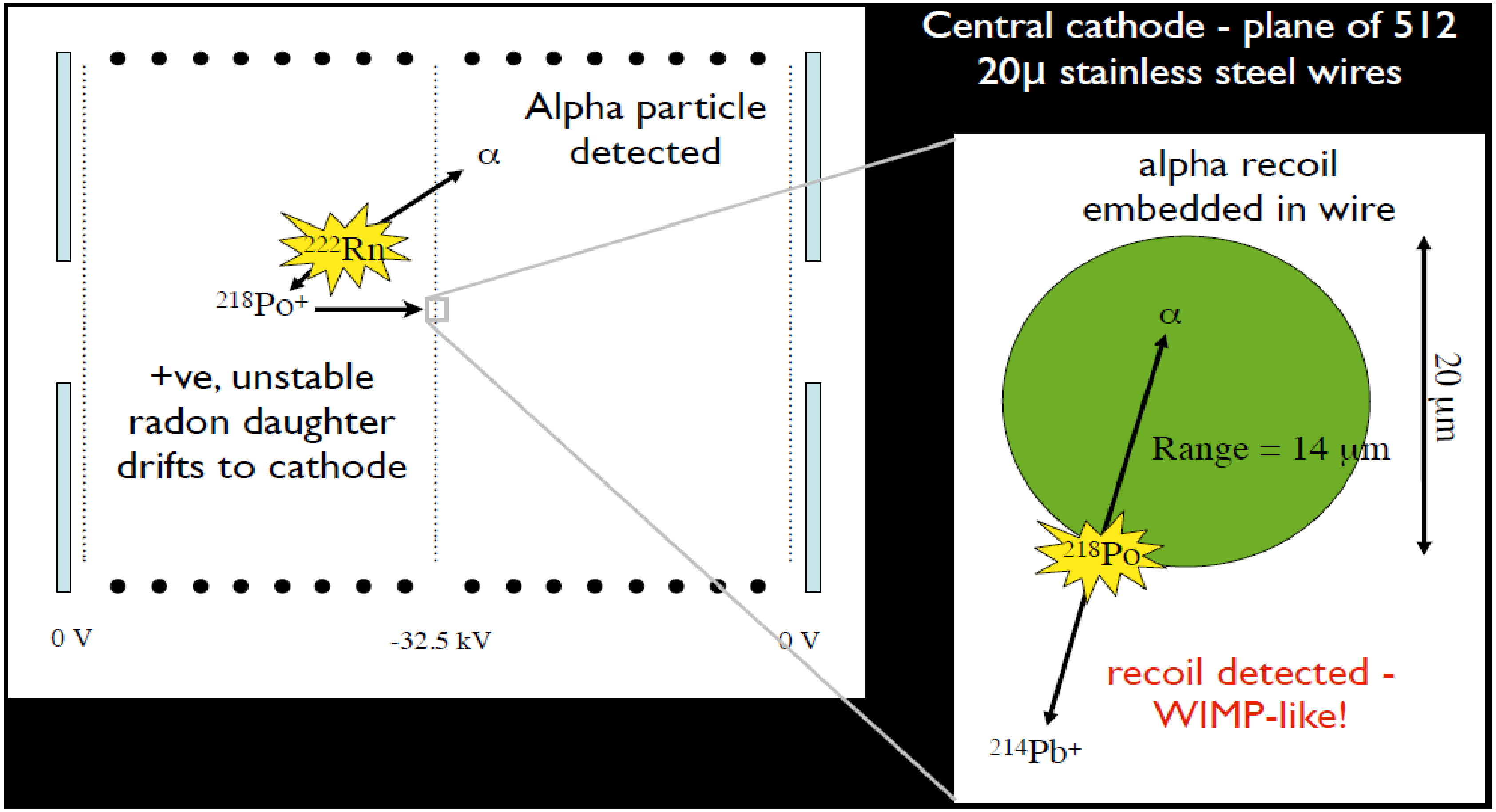


- 3. Low energy events [S. Burgos et al., JINST 4 (2009) P04014] . Demonstrates the potential of DRIFT to detect sulphur recoils down to ~4 keV using digital polynomial filtering to produce ^{55}Fe spectra with a visible escape peak.



Dominant Background – Radon Progeny Recoils (RPRs)

- Central cathode – plane of 512 20μm stainless steel wires



- ^{218}Po+ $\tau_{1/2}$ = 3.1mins (alpha decay)
- ^{214}Pb+ $\tau_{1/2}$ = 27 mins (beta decay)

RPR Reduction

- Aim is to reduce the amount of radon in the detector. Samples were studied to determine amount of radon present and remove radon emitting components (S.Paling, Sheffield):

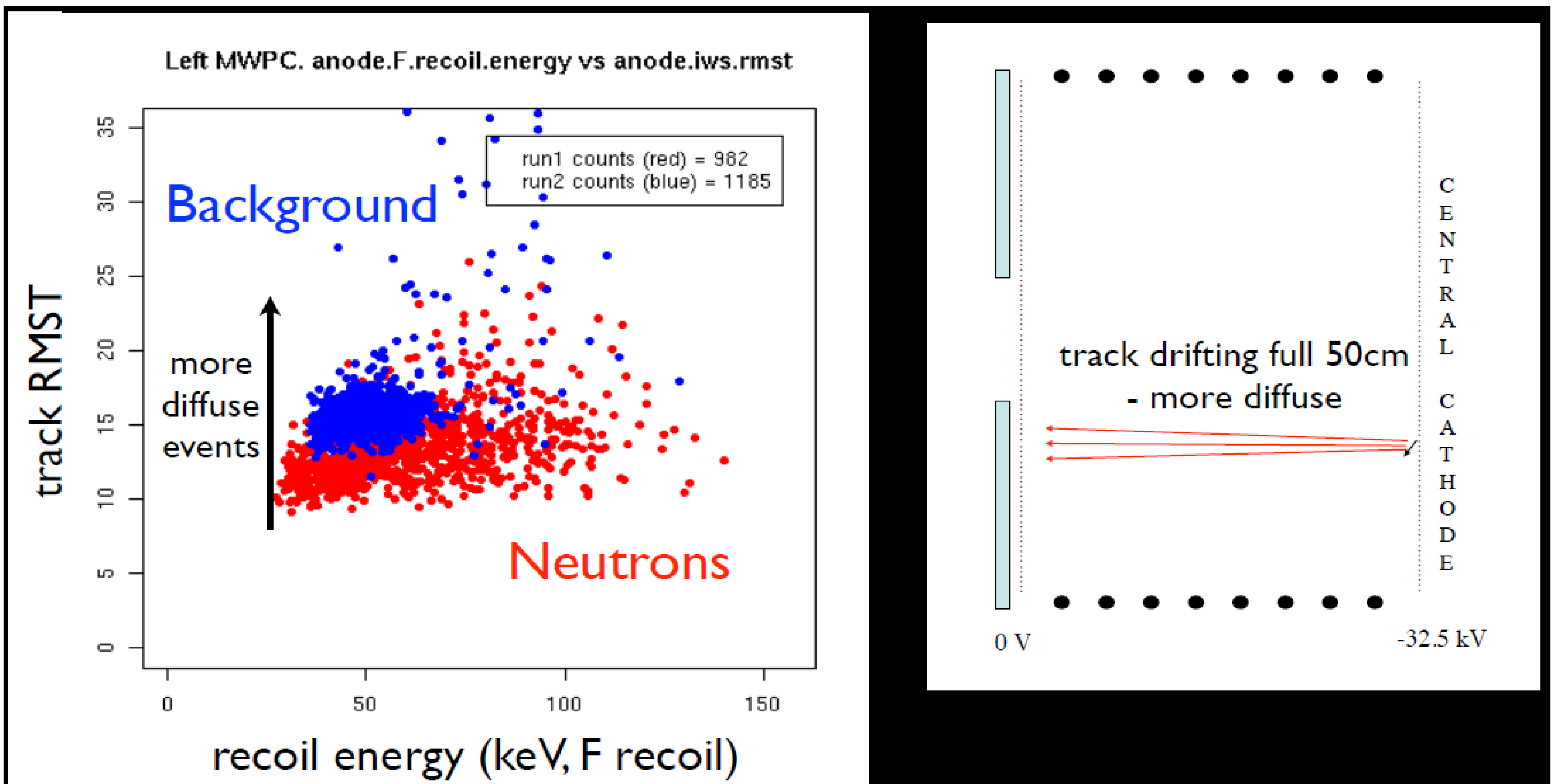
Sample (Emanating into vacuum)	Fill gas	Emanation time (days)	Humidity (%)	Raw result (Bq/m^3)	Adjusted result (Rn atoms.s^{-1})
RG58 coax cables (72m)	Dry N2	12.5	24	9.4 +/- 0.7	0.36 +/- 0.03
Electronics boxes	Dry N2	12	37	1.5 +/- 0.3	0.05 +/- 0.02
Ribbon cables	Dry N2	6.5	23	10.1 +/- 0.7	0.50 +/- 0.04
Electronics & PCBs	Dry N2	10	37	0.3 +/- 0.2	<0.02 *
Single core & thin coax cables	Dry N2	7	19	1.3 +/- 0.3	0.04 +/- 0.02
Field cage parts	Dry N2	7	33.3	0.6 +/- 0.2	<0.03 *
				Total	0.95 +/- 0.5

- The plated out ^{210}Pb ($\tau_{1/2}$~22yrs) was cleaned from the cathode using nitric acid -> Together these reduced the RPR rate by 96% (compared with D-IIa rate)

  [D. Snowden-Ifft, Oxy, J. Turk, UNM, PhD thesis 2008]

RPR Reduction

- In addition, pulse shape information can be used to remove events that originate on the central cathode, these events will have drifted the full 50cm and so will be more diffuse. Disadvantage is loss of signal (neutron) efficiency.



Gas Mixture

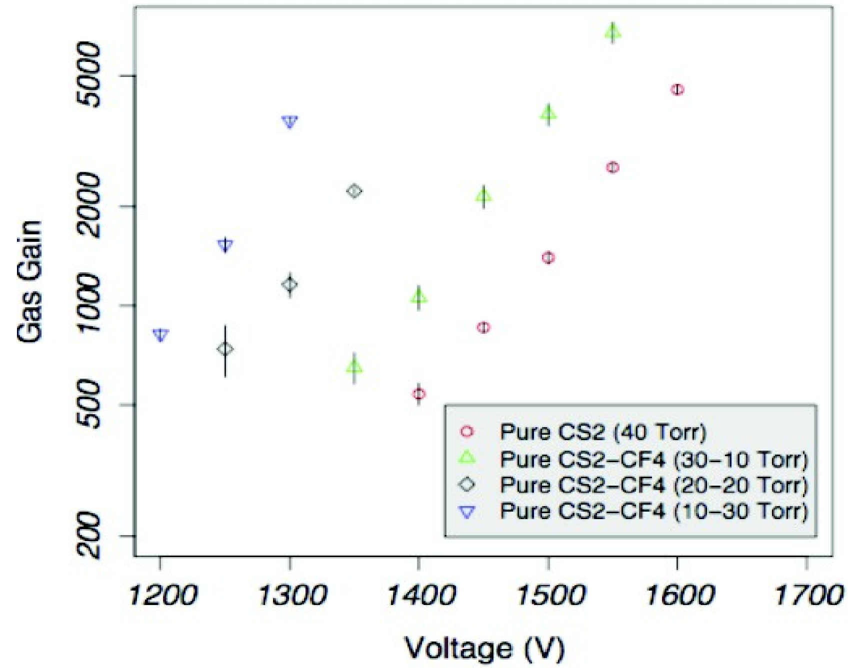
- Initial target gas was 40 Torr CS_2, required due to its electronegative property leading to low diffusion. However, it is not sensitive to spin dependent (SD) interactions.
- CF_4 is a good choice for SD measurements, but we still require CS_2

Mobility - Negative ion drift preserved up to 75% CF_4

Gas Mixture CS_2 – CF_4 (Torr)	Reduced mobility, μ (cm^2 atm/Vs)
40-00	0.54±0.02
30-10	0.60±0.02
20-20	0.69±0.02
10-30	0.81±0.03

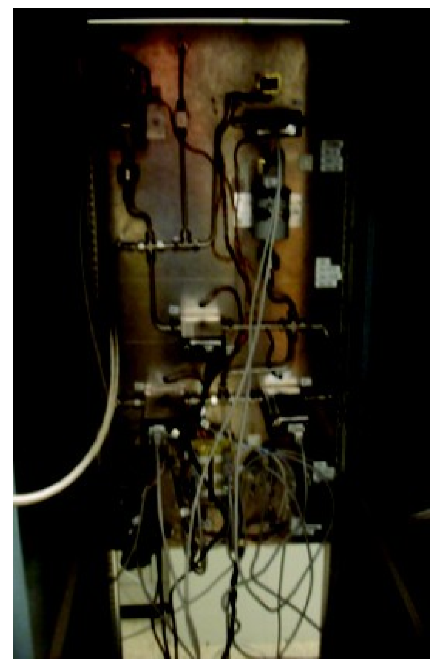
[K.Pushkin, NIM A 606 (2009) 569]

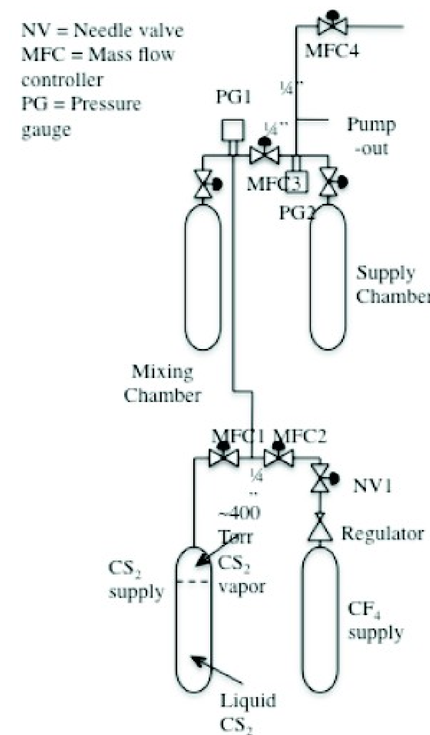
Gas Gain increases with CF_4 concentration



Gas Mixing System

- Periodically prepares a defined mixture of CS_2-CF_4 to maintain the pressure inside the vessel at 40 Torr
- Installed underground at Boulby last year and now operating with 30 Torr – 10 Torr CS_2-CF_4 with over 100 days of stable running.

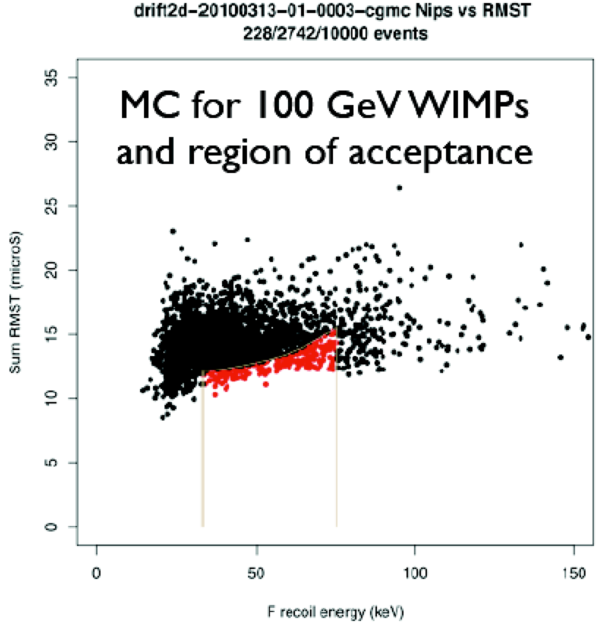


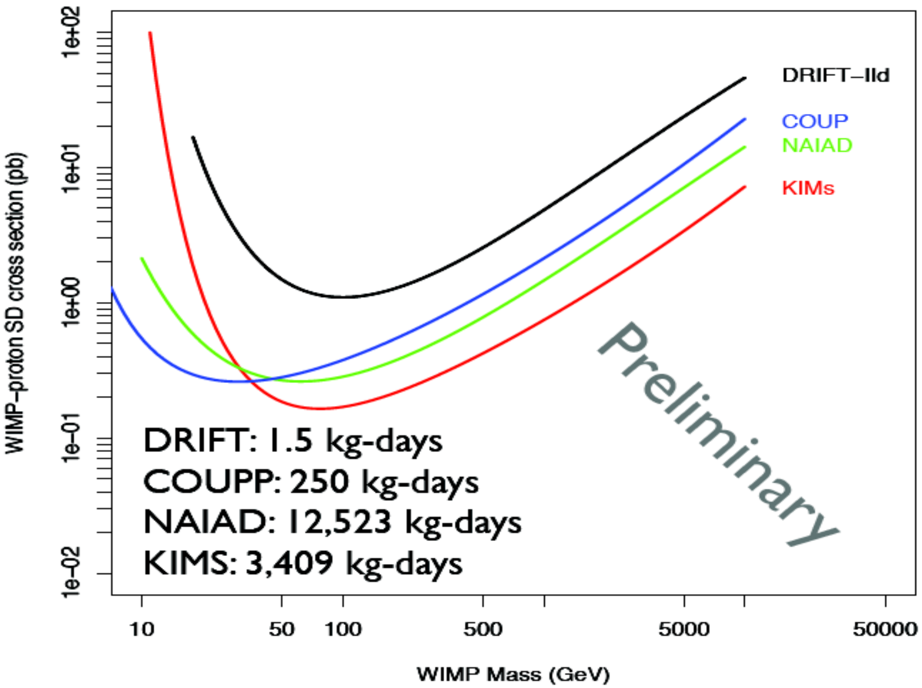


(Mark Pipe, Sheffield)

SD Limit from 47.2 days (not blind)

- 30-10 Torr CS_2-CF_4 47.2 days background data, 130±2 nuclear recoils per day
- 1.5 kg-days (CF_4) with no compromise on directional sensitivity, 35 keV threshold
- Signal region chosen for zero events (not a blind analysis)



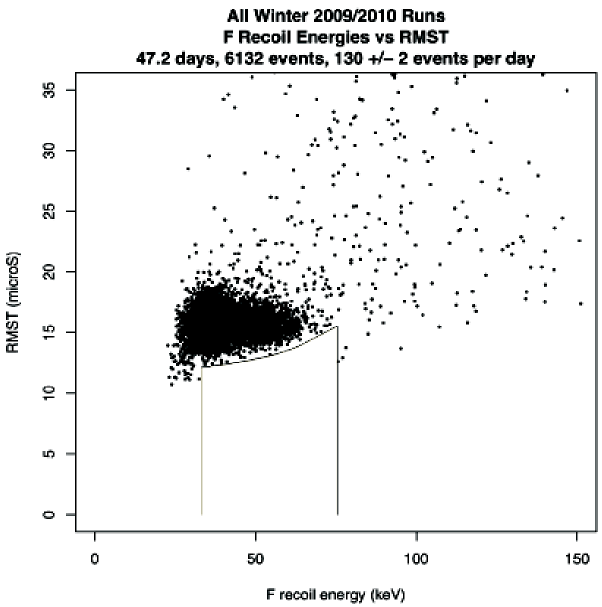


Min. SD limits for directional detectors:

DRIFT: 1.2pb

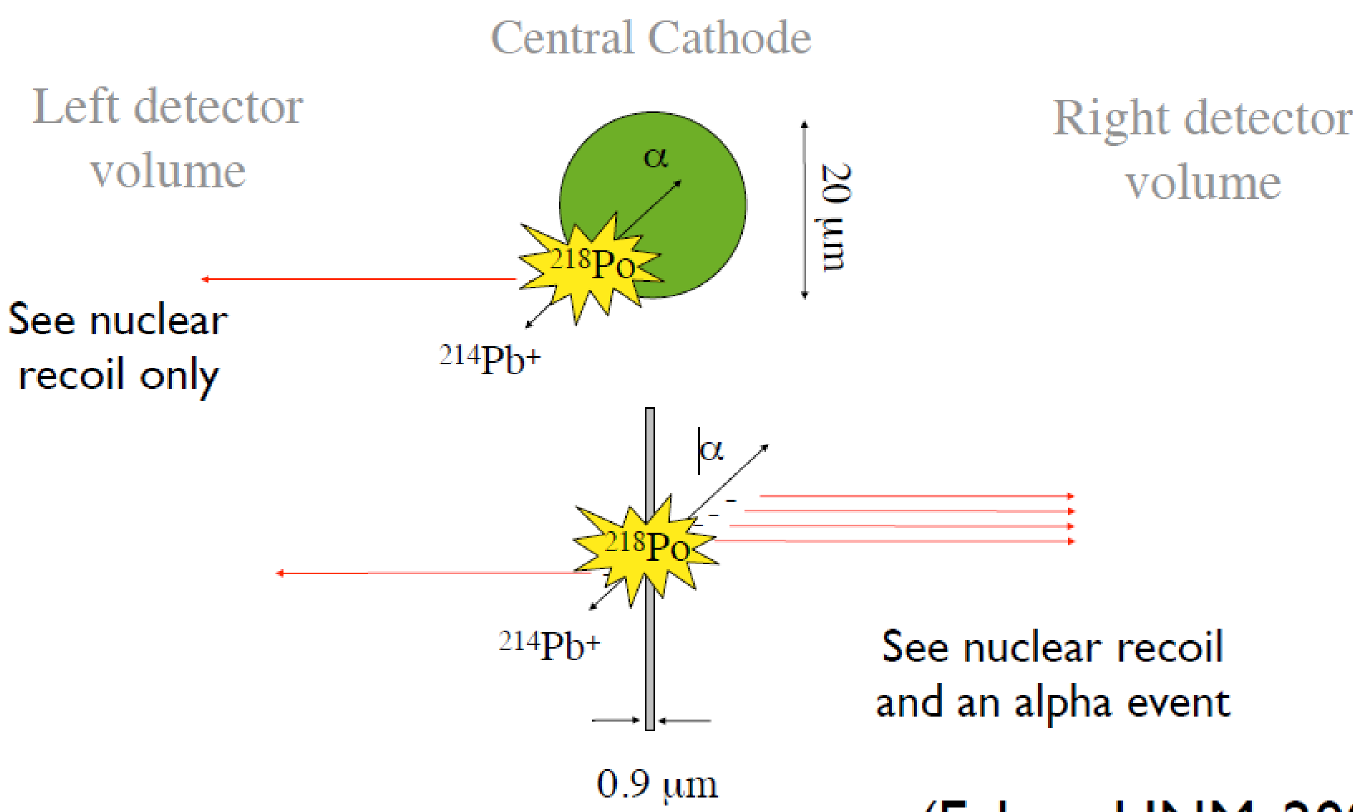
NEWAGE: 5400pb

DM-TPC: ~50pb



Further RPR Reduction

- It is possible to veto α's from RPRs, via the use of a thin film cathode which is transparent to α's.



(E. Lee, UNM, 2009)

Thin Film Cathode

current

Factor ~40 reduction in RPRs expected

Cathode Type	Fraction Lost (%) Po 214 (7.69 MeV)	Fraction Lost (%) Po 218 (6 MeV)
20 micron steel wire	37	41
20 micron quartz fiber	8.6	14
8.2 micron quartz fiber	3.4	5.1
6.5 micron quartz fiber	2.6	4.1
10 micron mylar sheet	9.1	13
2 micron mylar sheet	1.8 (1.6)	2.7 (2.5)
1.5 micron mylar sheet	1.4	2.0
0.9 micron mylar sheet	0.8	1.2

- With a cathode of 0.9µm thickness the projected RPR rates would drop from the current rate of 138/day to < 4 /day.

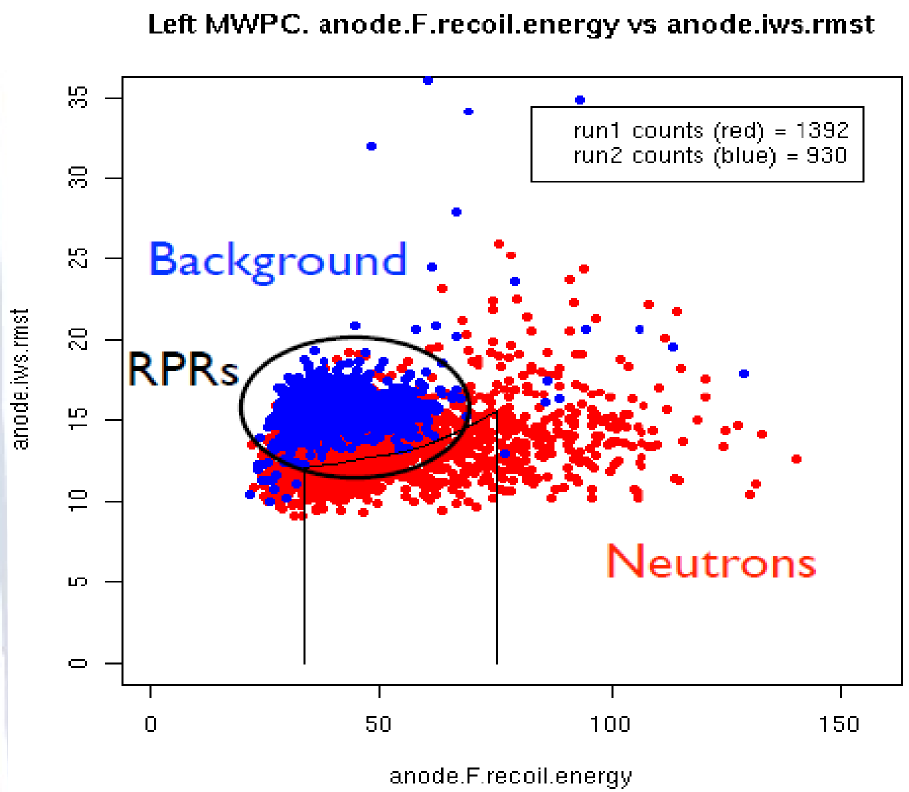
(Eric Lee, UNM)

Thin film cathode

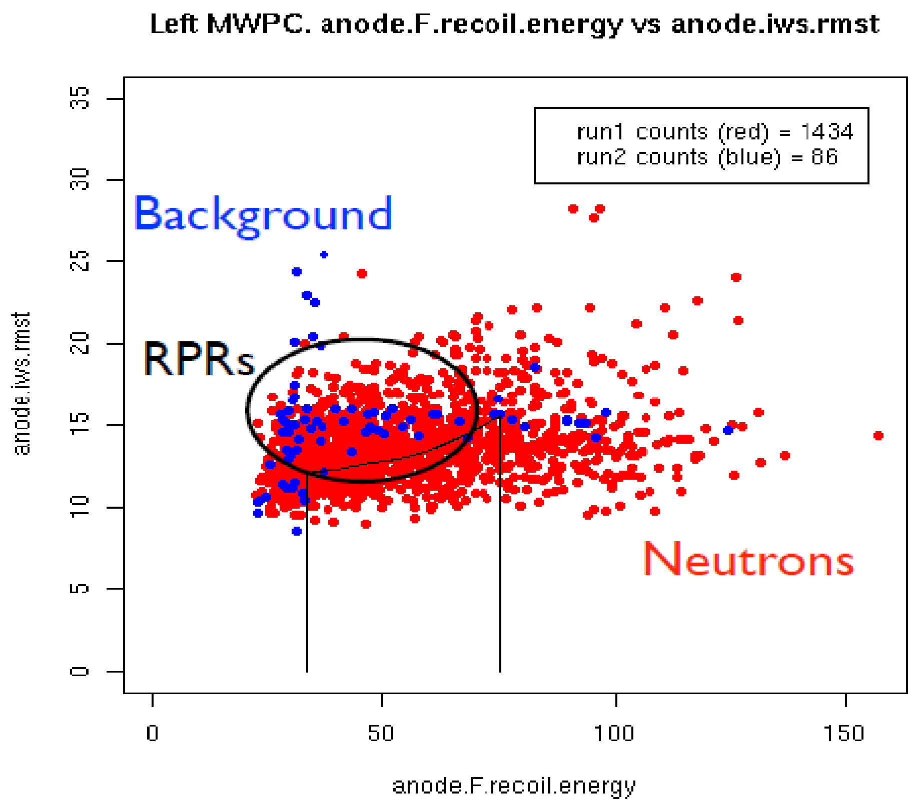
- The 0.9μm mylar sheet central cathode was installed on DRIFT-II at the Boulby Mine in March 2010. Successful operation began a week after installation.

Preliminary Results

<u>20µm wire central cathode</u> – 12.25 days background on 0.43 days neutron. 898 RPR events.



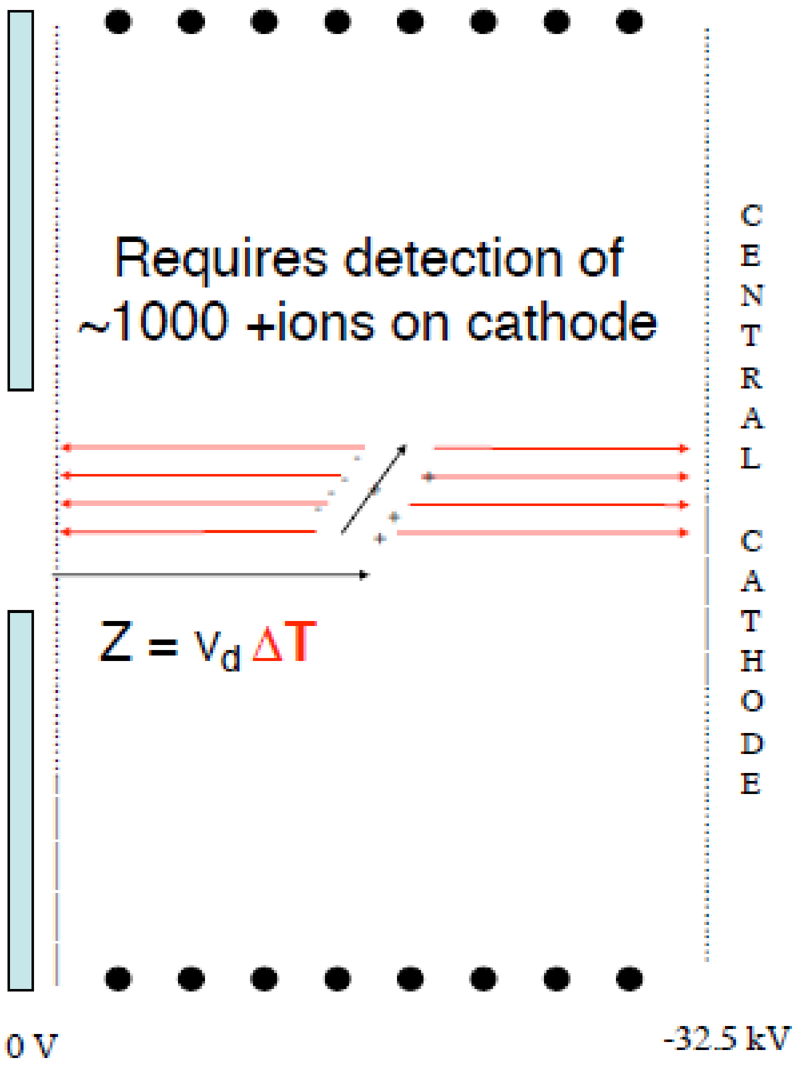
<u>0.9µm thin film central cathode</u> – 12.22 days background on 0.44 days neutron. 60 RPR events.



- Reduction of ~15 observed in RPR background
- Full analysis of tagged RPRs is now underway.

DRIFT's next goal - Z-fiducialisation

- Determine absolute Z position by detecting positive ions arriving at the central cathode
- Eliminate RPRs with significant improvement in neutron efficiency by replacing crude cuts that use diffusion information from pulse shape

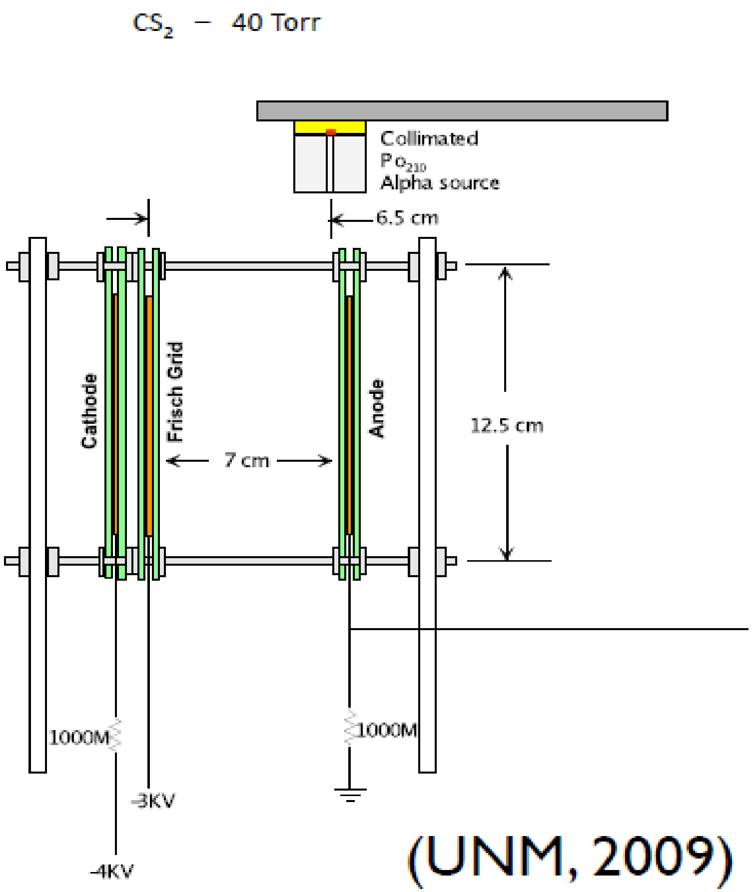


Z-fiducialisation – R&D Setup

- DRIFT (-34 kV 620 V/cm)

  Ion speed = 6100cm/s
- Test setup (-3 kV 429 V/cm)

  Ion speed = 4200 cm/s
- Alpha source produces events of ~950 ion pairs (equivalent F recoil energy = 38keV)



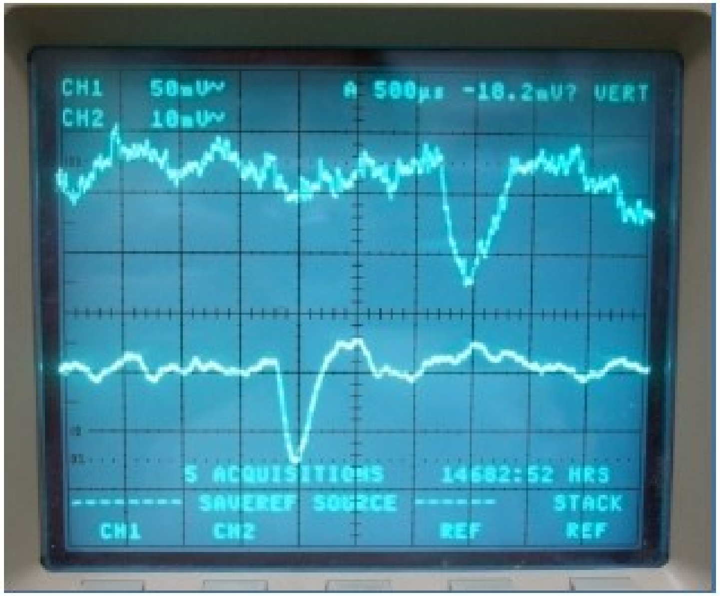
(UNM, 2009)

Z-fiducialisation

- Move the source from the anode to the cathode to test the effectiveness of the cathode readout

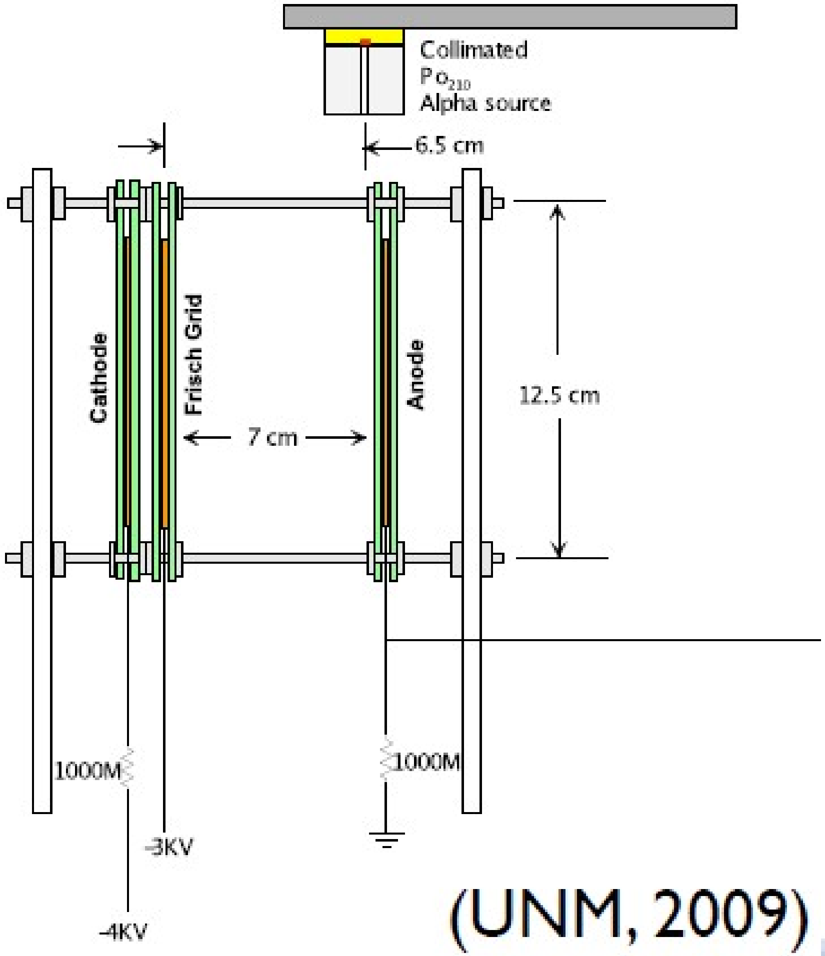
Cathode

Anode



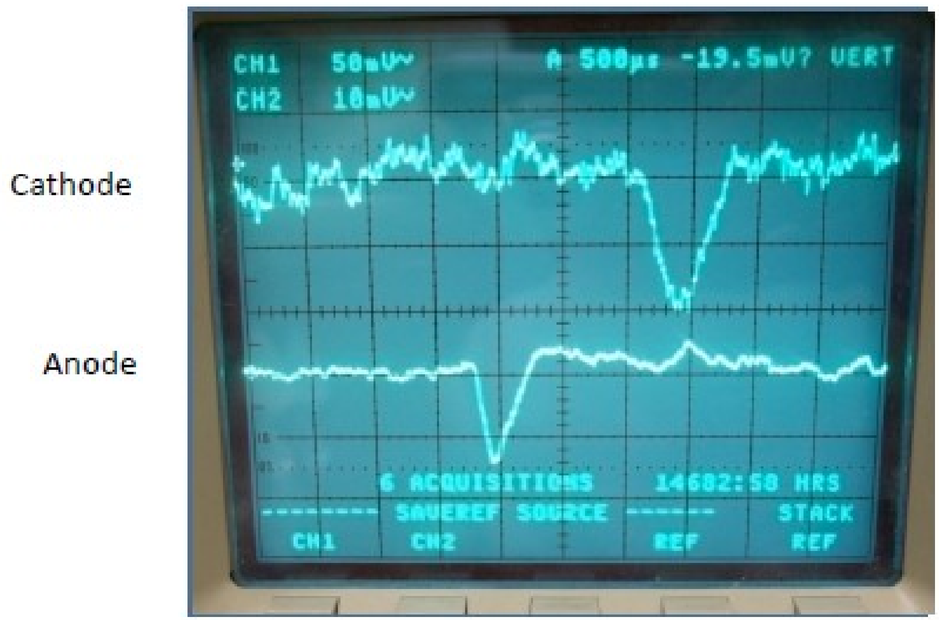
Expected delay = 1.5 milliseconds

CS_2 – 40 Torr



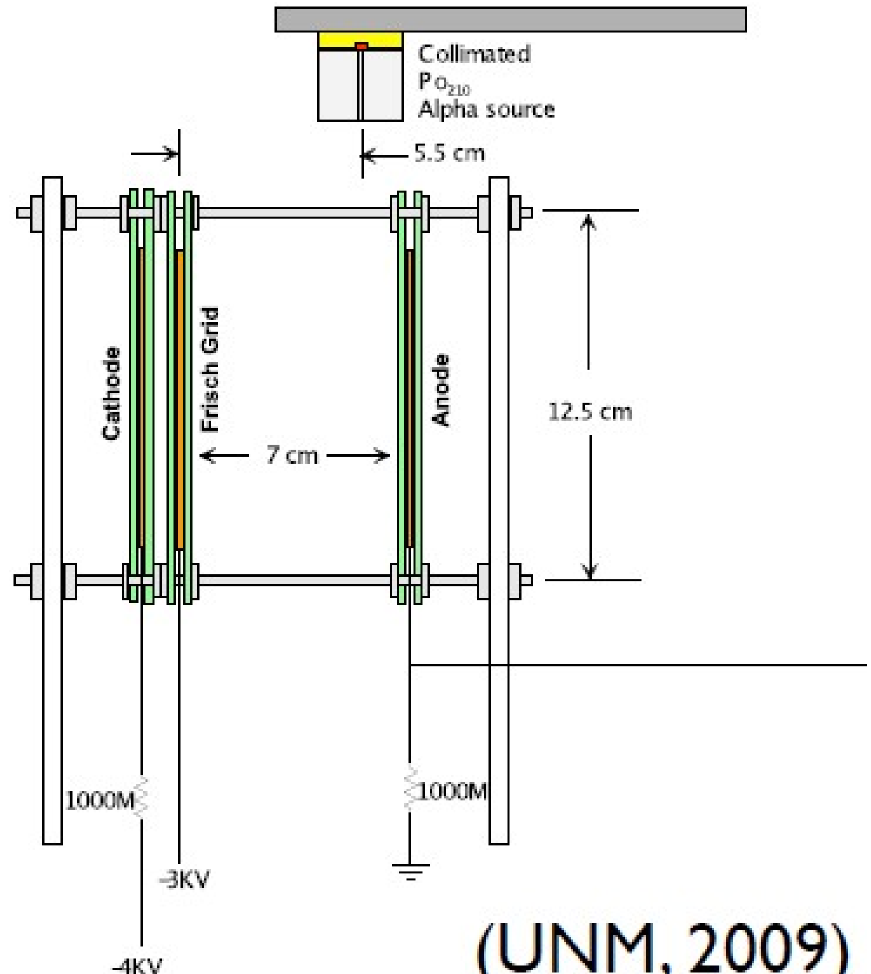
(UNM, 2009)

Z-fiducialisation



Expected delay = 1.3 milliseconds

CS_2 – 40 Torr

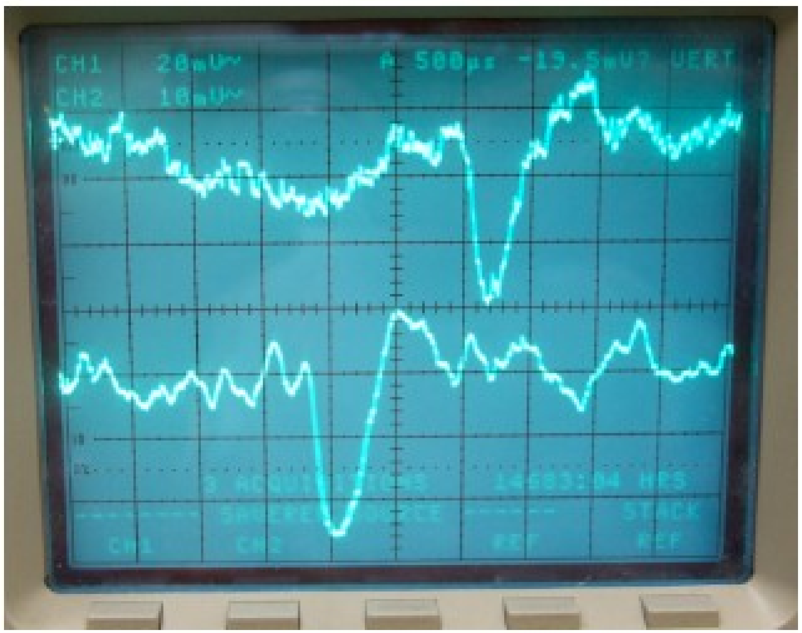


(UNM, 2009)

Z-fiducialisation

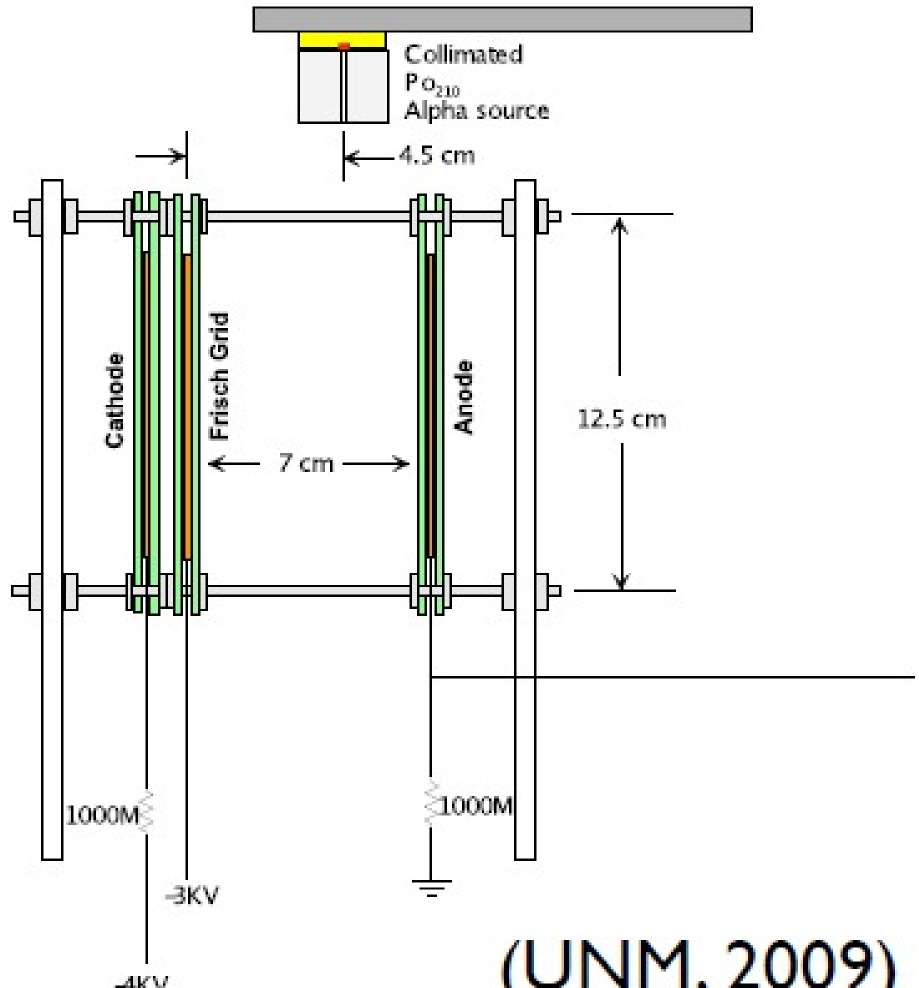
Cathode

Anode



Expected delay = 1.1 milliseconds

CS_2 – 40 Torr

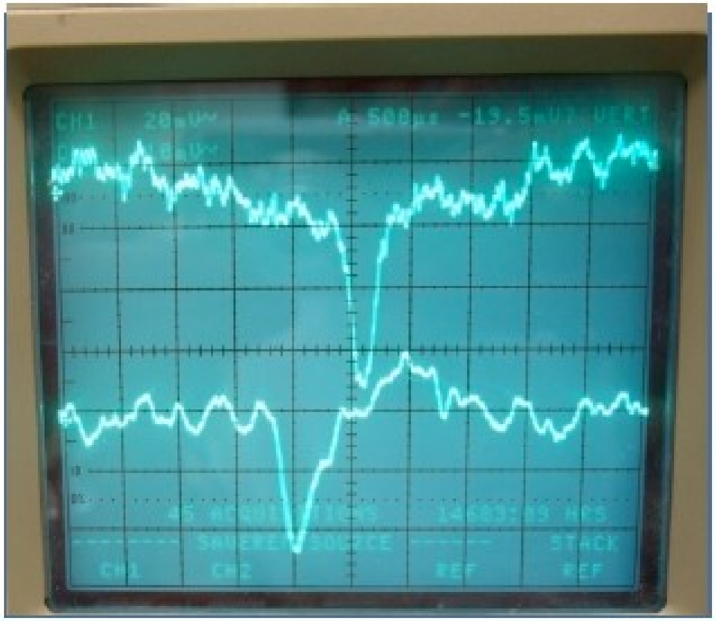


(UNM, 2009)

Z-fiducialisation

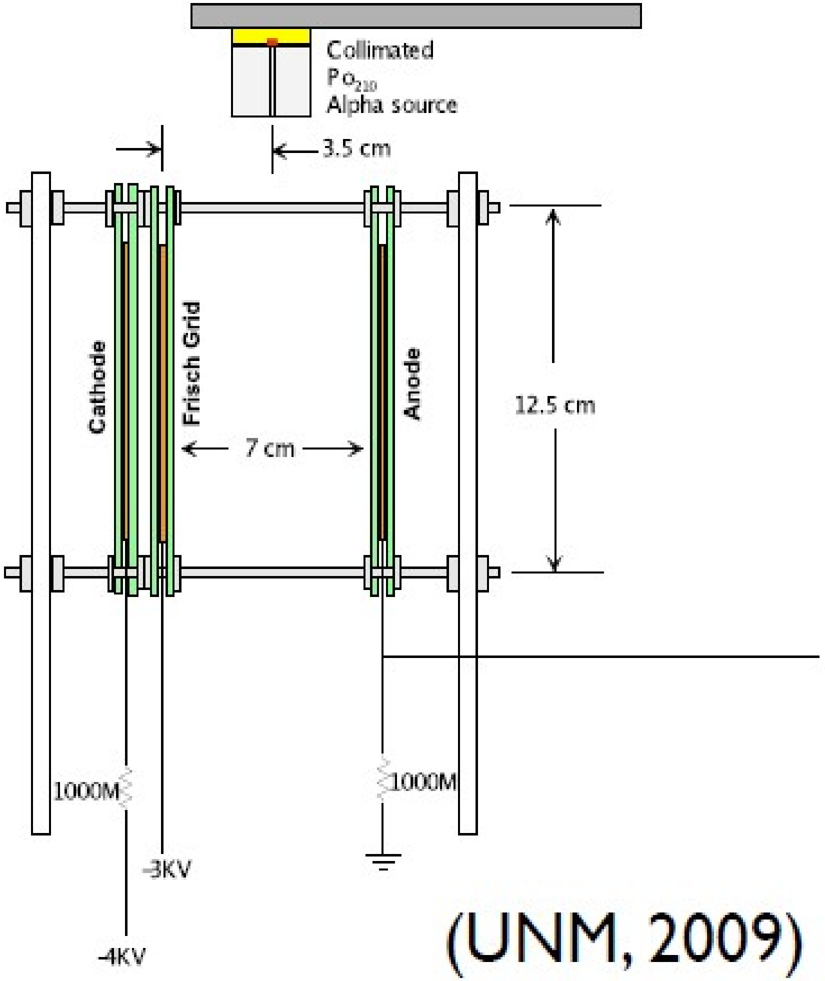
Cathode

Anode



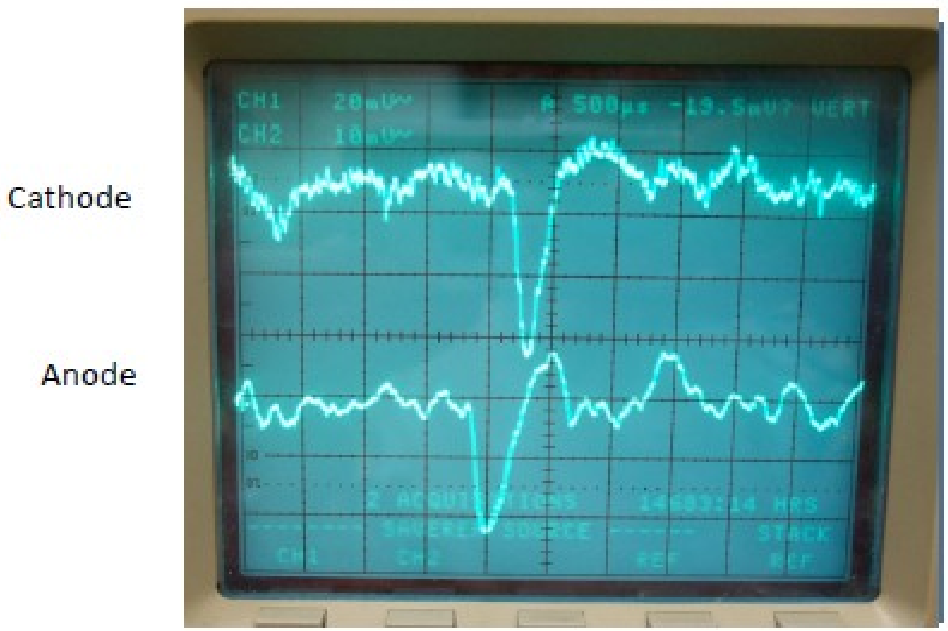
Expected delay = 0.8 milliseconds

CS_2 – 40 Torr

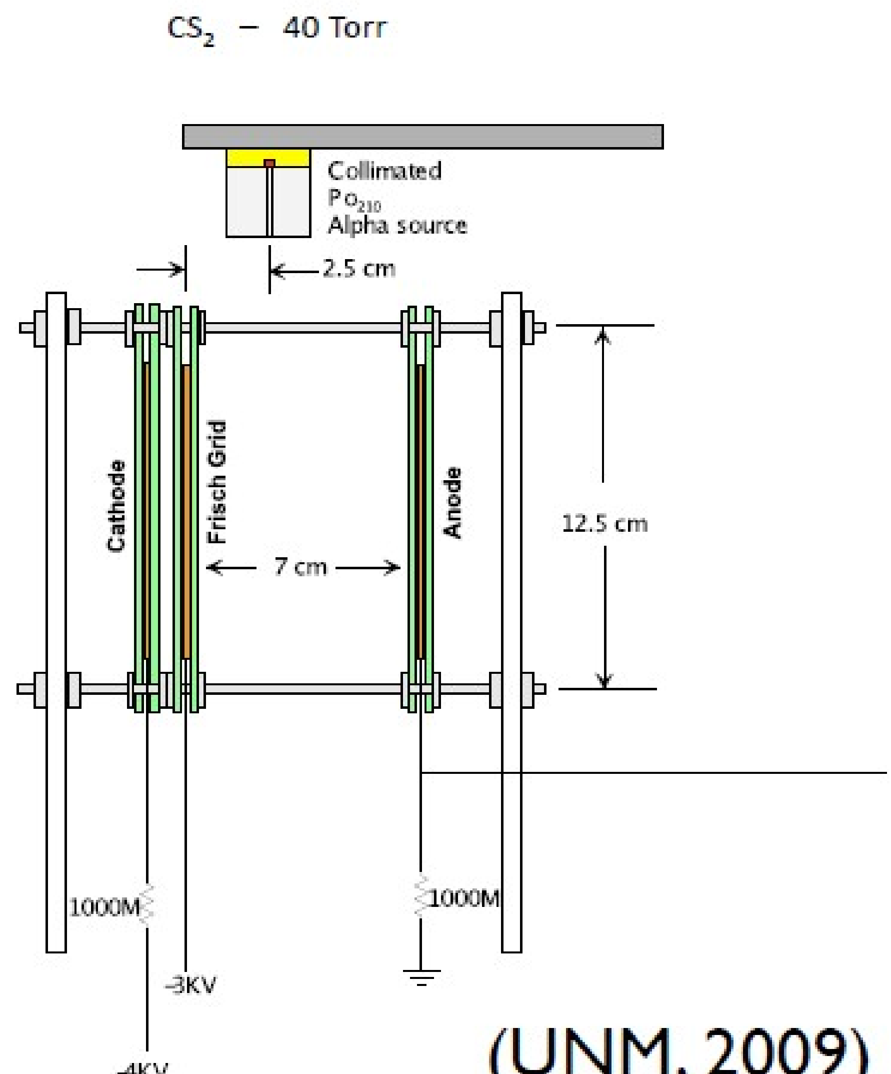


(UNM, 2009)

Z-fiducialisation



Expected delay = 0.6 milliseconds

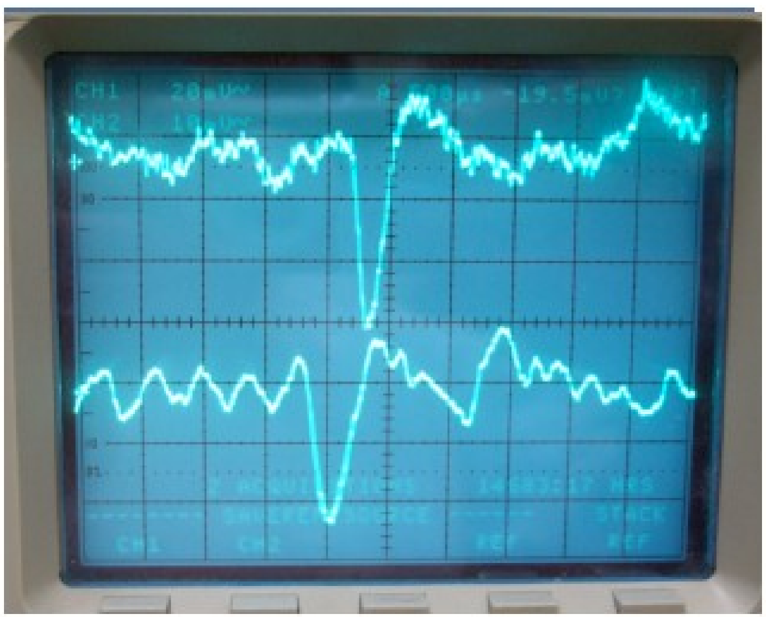


(UNM, 2009)

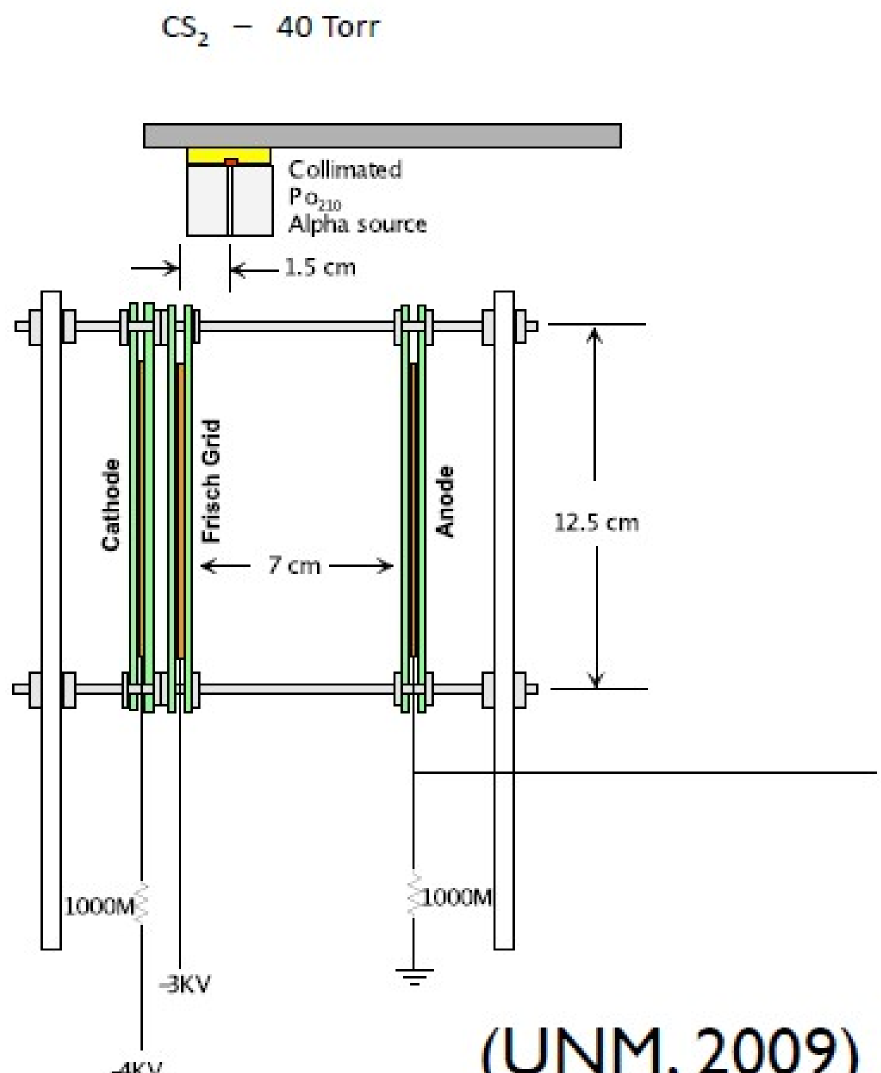
Z-fiducialisation

Cathode

Anode



Expected delay = 0.4 milliseconds

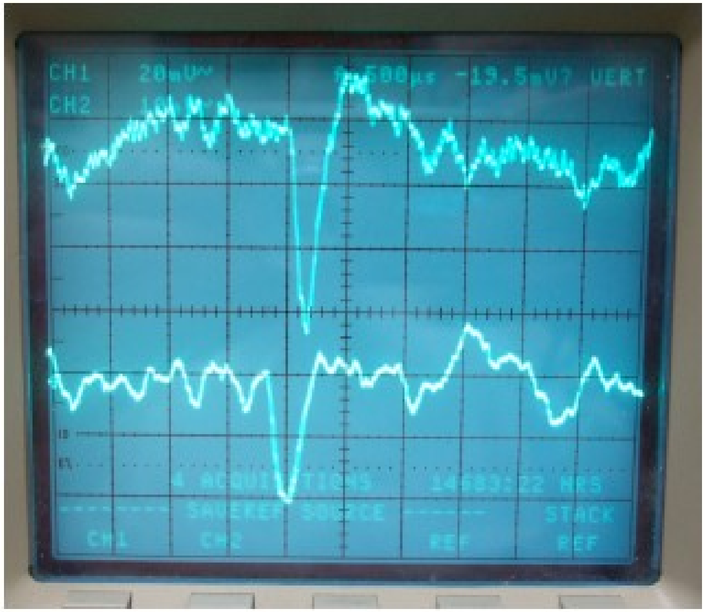


(UNM, 2009)

Z-fiducialisation

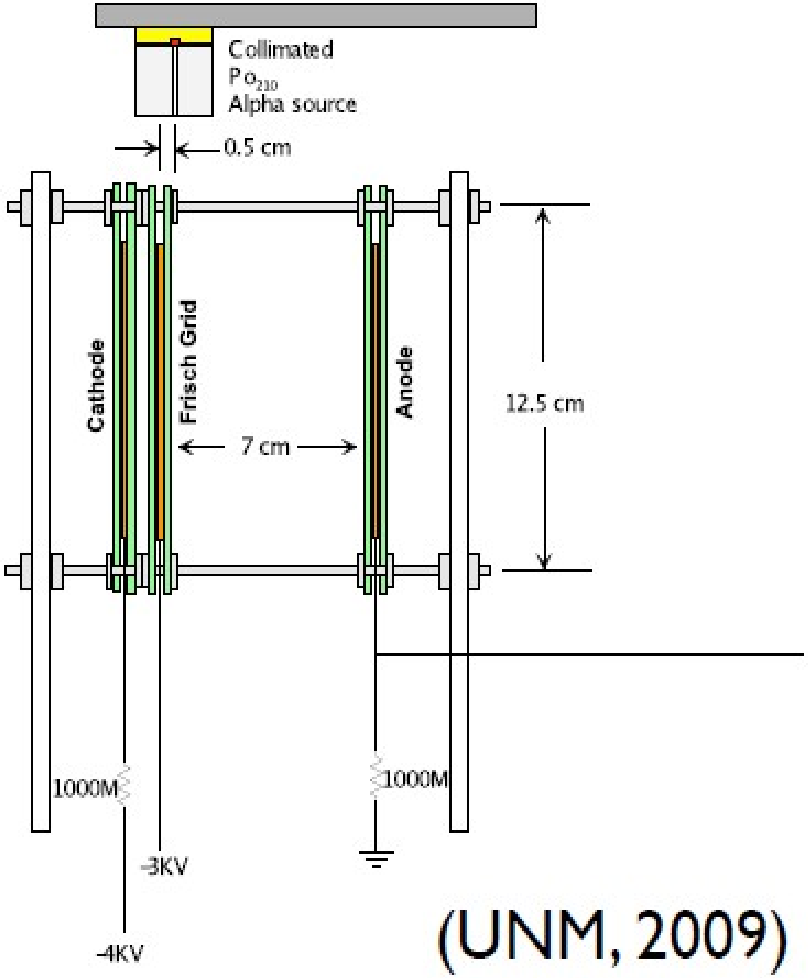
Cathode

Anode



Expected delay = 0.1 milliseconds

CS_2 – 40 Torr



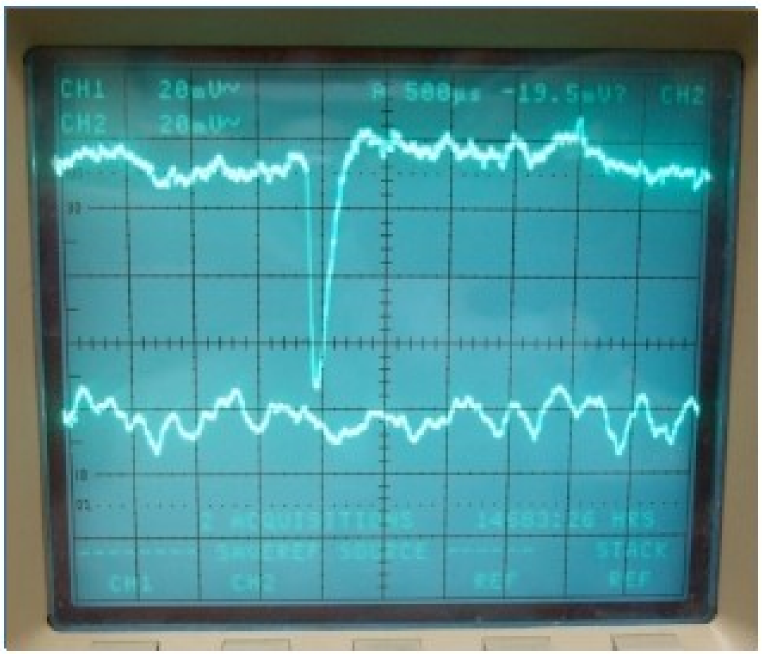
(UNM, 2009)

Z-fiducialisation

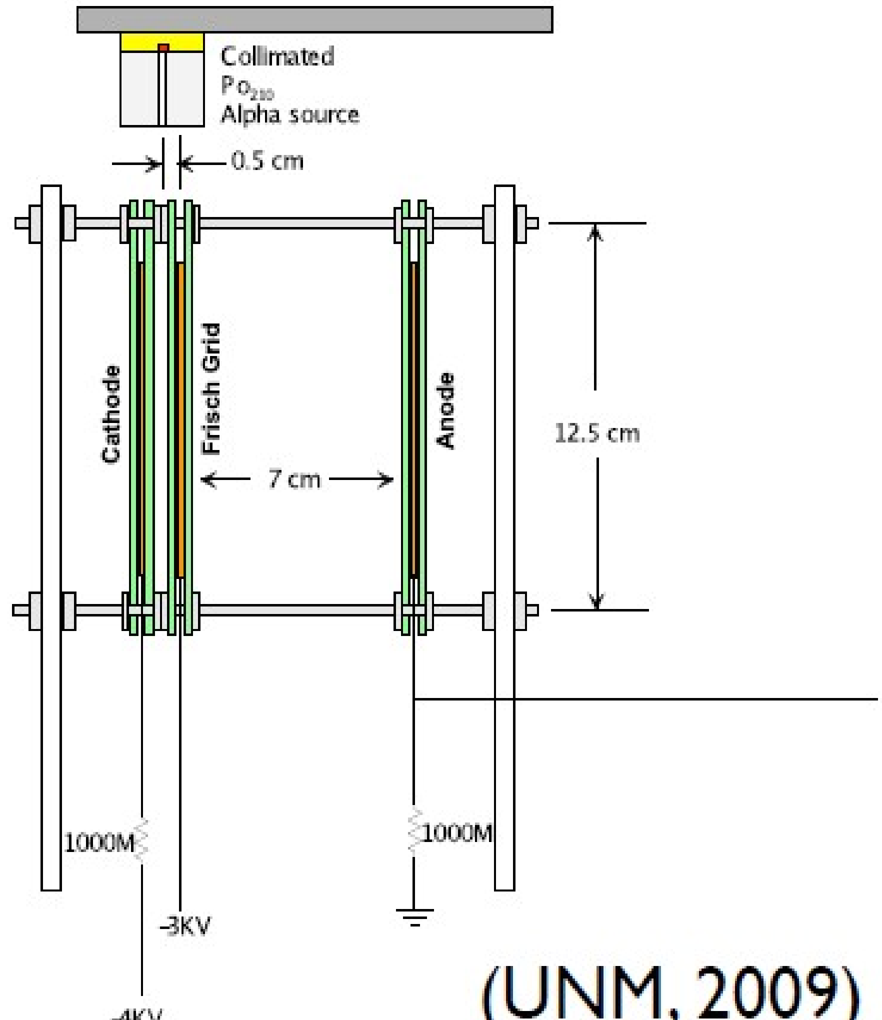
CS_2 – 40 Torr

Cathode

Anode



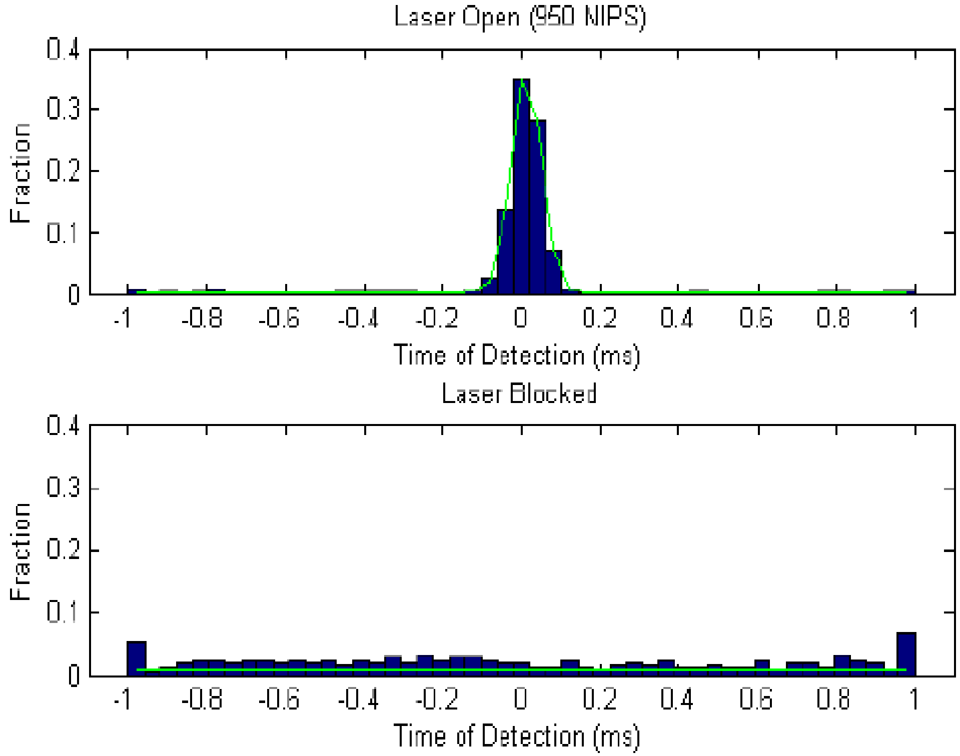
Expected delay = 0.0 milliseconds



(UNM, 2009)

Z-fiducialisation

- Detection of ~950 +ions (F recoil energy = 38 keV) at 84%



- Detection of ~500 ions (F recoil energy = 23 keV) at 54% has now been achieved.
- <u>Full 1m^2 version to be tested in DRIFT detector this summer</u>

Summary

- Directionality, head-tail sensitivity and energy threshold potential demonstrated via the publication of three papers last year.
- ~100 days of stable running so far with the CS_2-CF_4 mixture in the Boulby Underground Laboratory
- Spin dependent limit set at ~1.2pb with an energy threshold of ~35 keV F recoil with no compromise on directionality
- Large reductions in RPR background observed after installation of thin film cathode
- Z-fiducialisation progress