DRIFT

Latest Results from a Search for Spin-Dependent WIMP Interactions using the DRIFT-II Directional Sensitive Detector

Daniel Walker

The University Of Sheffield.

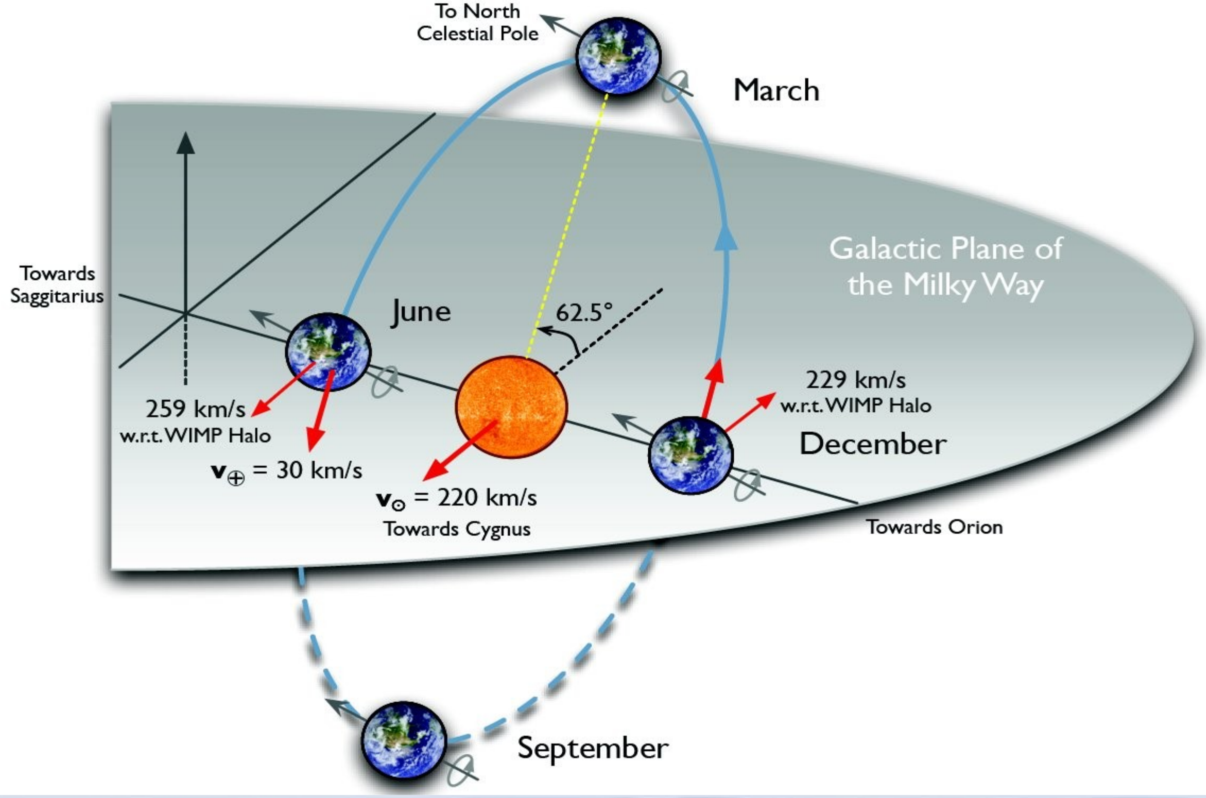
Colorado State University

Introduction

- WIMP Signatures
- DRIFT-IId Detector Overview
- Boulby Mine Overview
- Detector Features
- Radon Progeny Recoils
- Gas Mixture (CS_2 - CF_4)
- Spin dependent Limit – Preliminary Results
- Background reduction – Central Cathode Replacement
- Next steps – Z Fiducialisation
- DRIFT-III Design

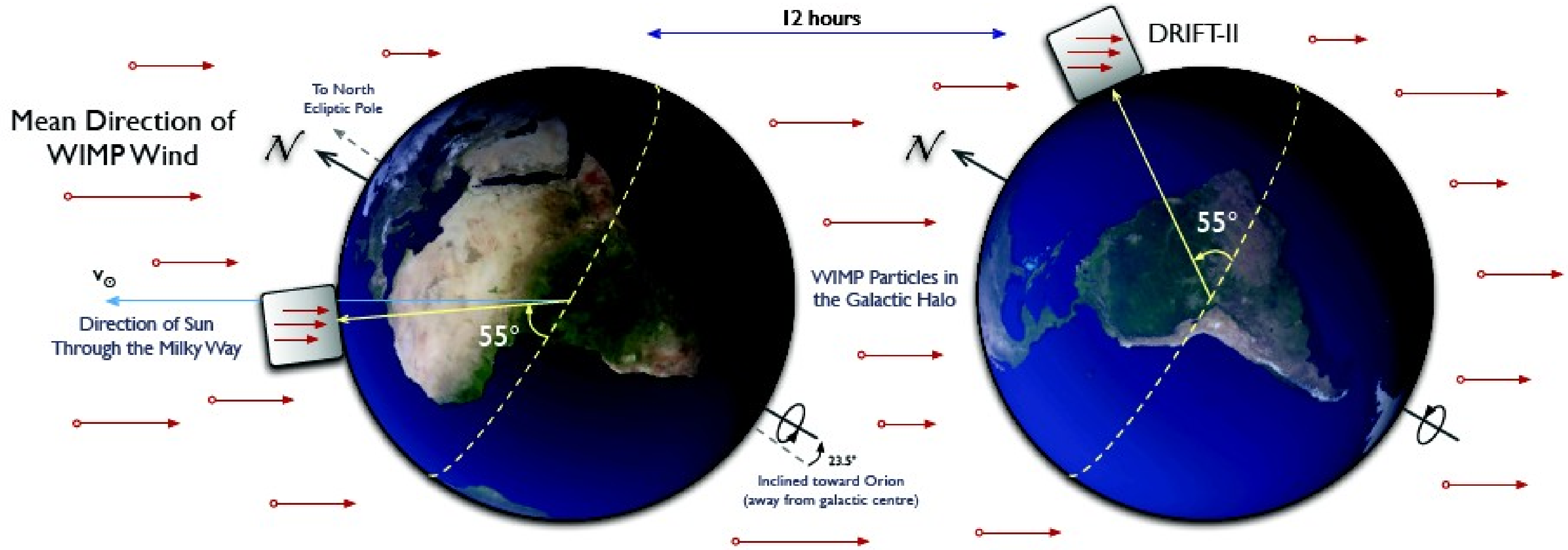
WIMP Wind

- 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



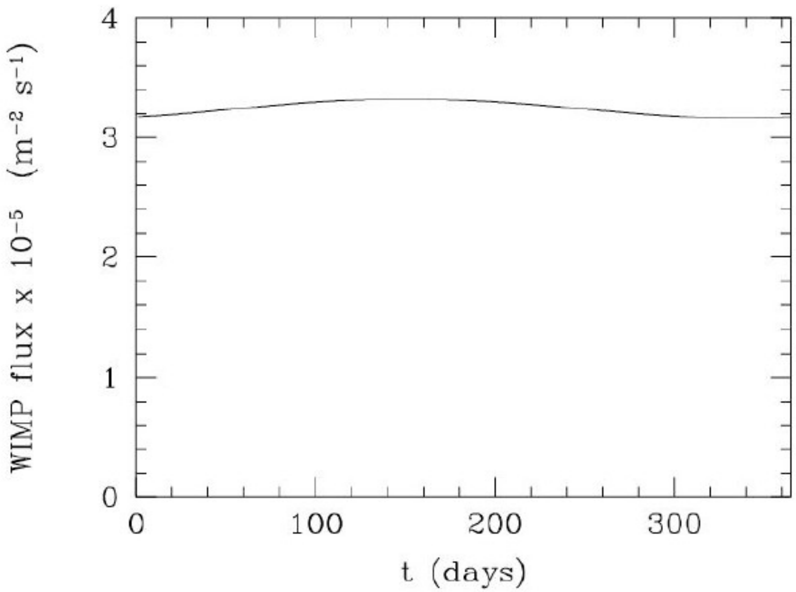
WIMP Wind

- 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.

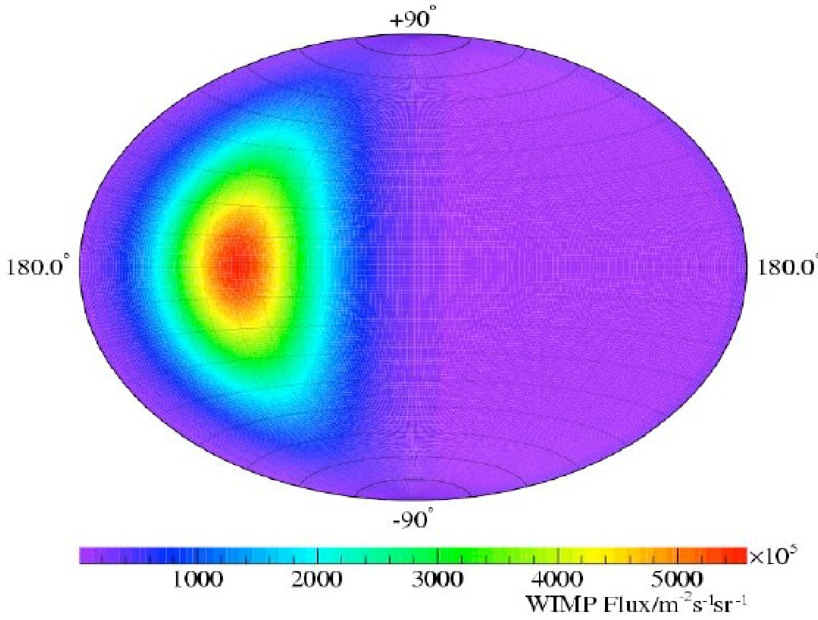


WIMP Signatures

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

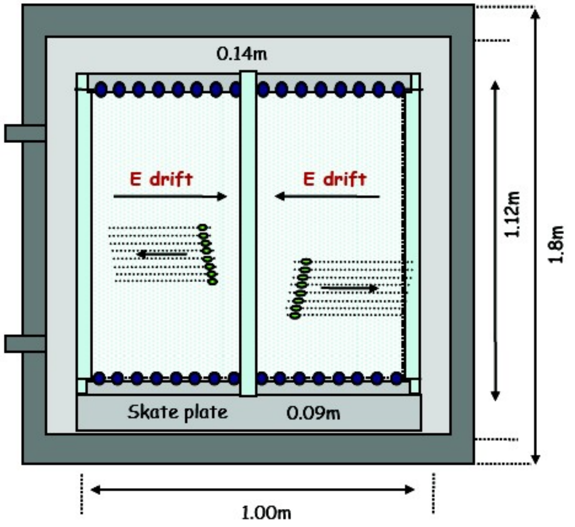


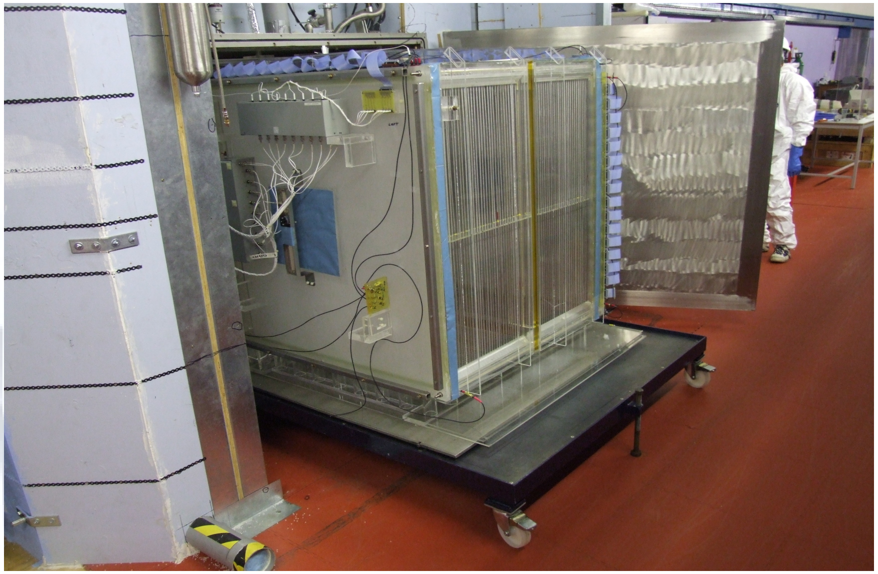
- Directional Dependence
- Nuclear recoils from WIMP collisions will be biased in the direction of the WIMP wind.
- Strong signature, originating from the Earth's motion through the WIMP wind. Terrestrial source not be able to produce such a signal.

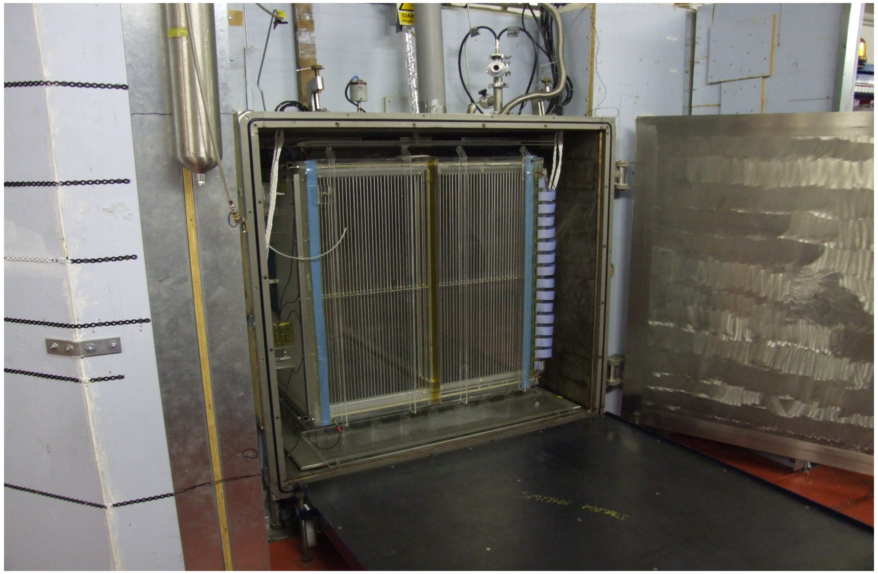


DRIFT IId Overview

- 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)

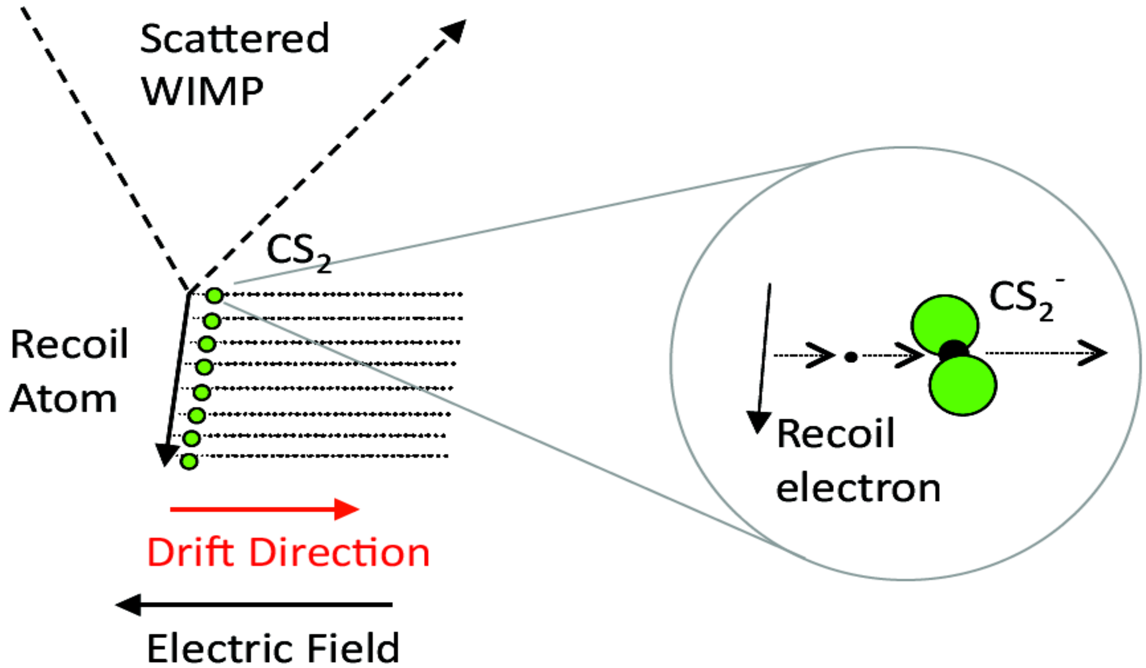






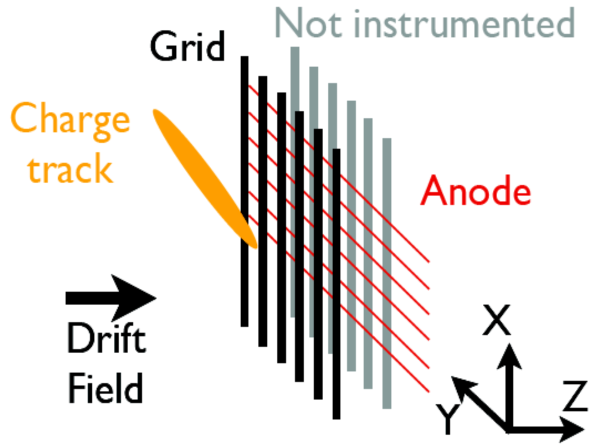
Negative Ion Drift

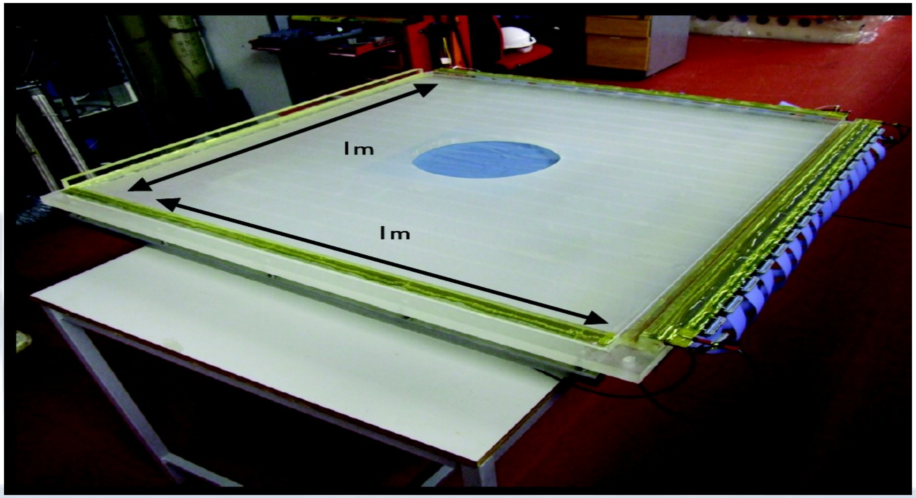
- WIMP interaction causes ionisation track of few mm.
- In a large volume detector, the drifted track undergoes diffusion, leading to the loss of directional information.
- CS_2 is electronegative, so negative CS_2^- anions are drifted rather than free electrons. Massive ions suffer only thermal diffusion.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

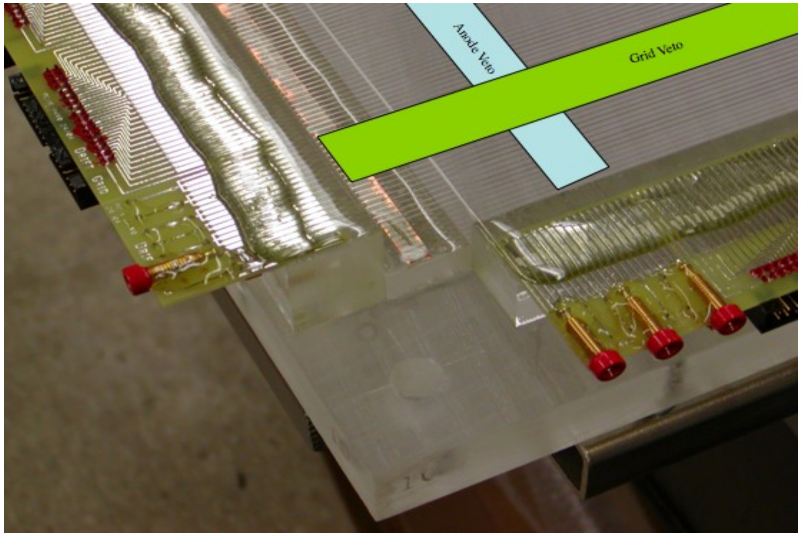


MWPC Readout

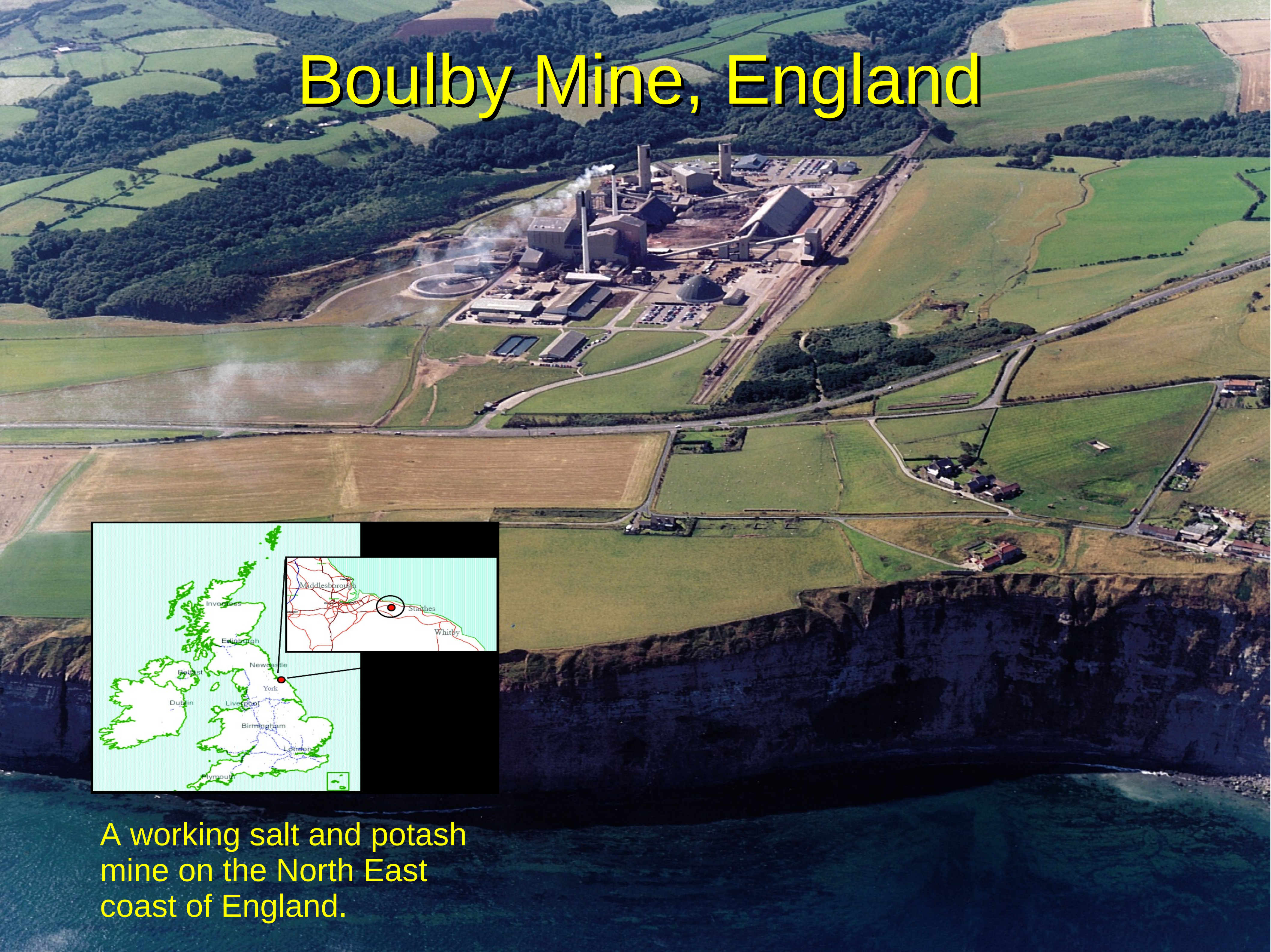
- MWPCs each consist of a central anode plane of 512 20μm diameter stainless steel wires and two perpendicular grid planes of 512 100μm wires.
- The wire-plane separation is 10mm and wire separation within each plane is 2mm.
- Δx: Progression across anode wires
- Δy: Progression across grid wires
- Δz: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







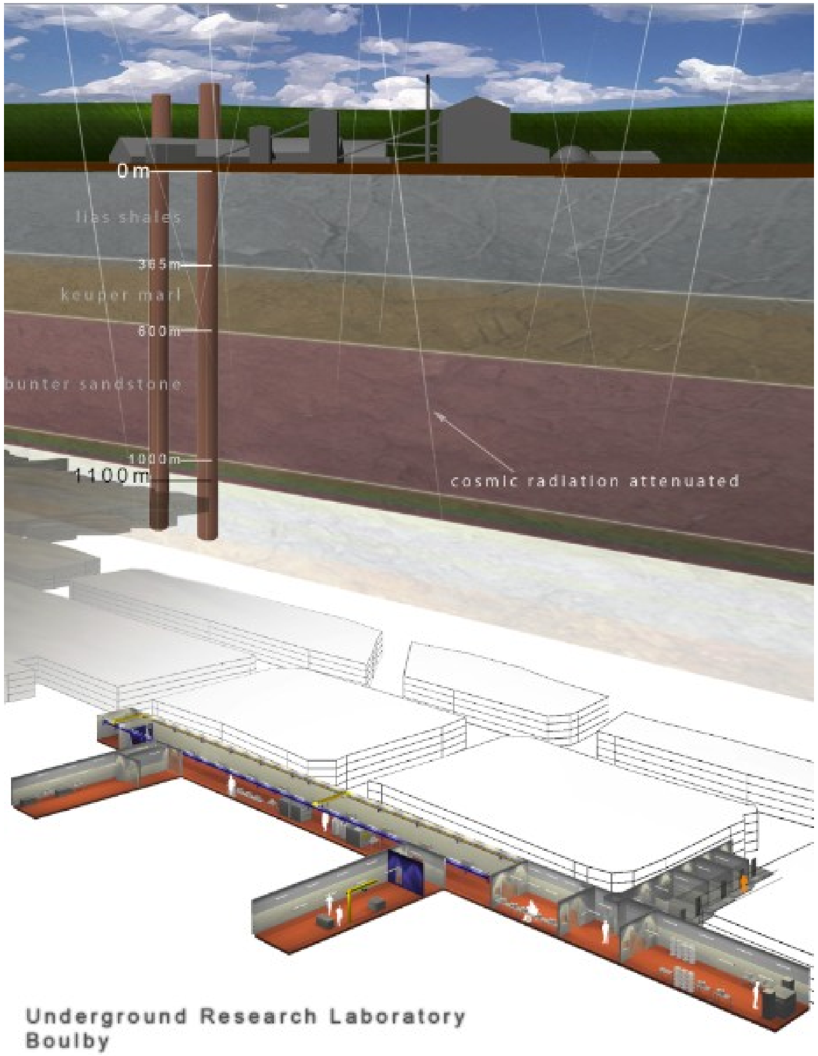
Boulby Mine, England



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 $\sim 10^6$.
- 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.

Gas Mixture

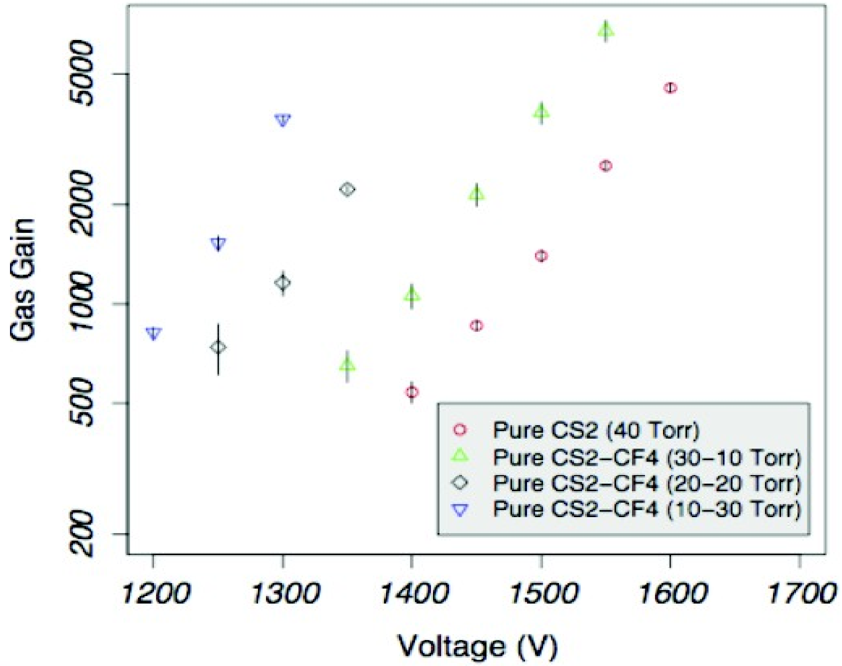
- Initial target gas was 40 Torr CS_2, required due to its electronegative property leading to low diffusion. However, it is not sensitive to spin dependent (SD) interactions.
- CF_4 (^{19}F) is a good choice for SD measurements, but we still require CS_2
- Single wire proportional counter measurements of gas gain, W-value and mobility in CS_2-CF_4 mixtures.

Mobility – Negative ion drift preserved up to 75% CF_4.

Gas Mixture CS_2 – CF_4 (Torr)	Reduced mobility, μ (cm^2 atm/Vs)	W-value eV
40-00	0.54±0.02	24.9±0.8
30-10	0.60±0.02	25.2±0.6
20-20	0.69±0.02	29.2±1.0
10-30	0.81±0.03	33.0±1.0

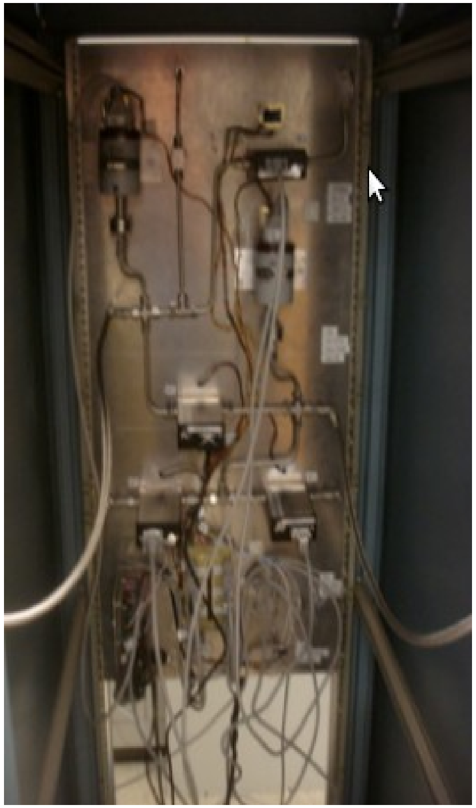
[K.Pushkin, NIM A 606 (2009) 569]

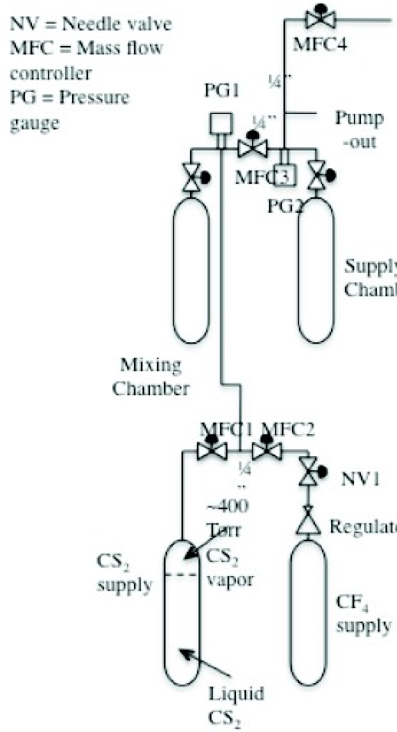
Gas Gain increases with CF_4 concentration



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 in 2009 and now operating with 30 Torr – 10 Torr CS_2-CF_4 with ~1 year of stable running.

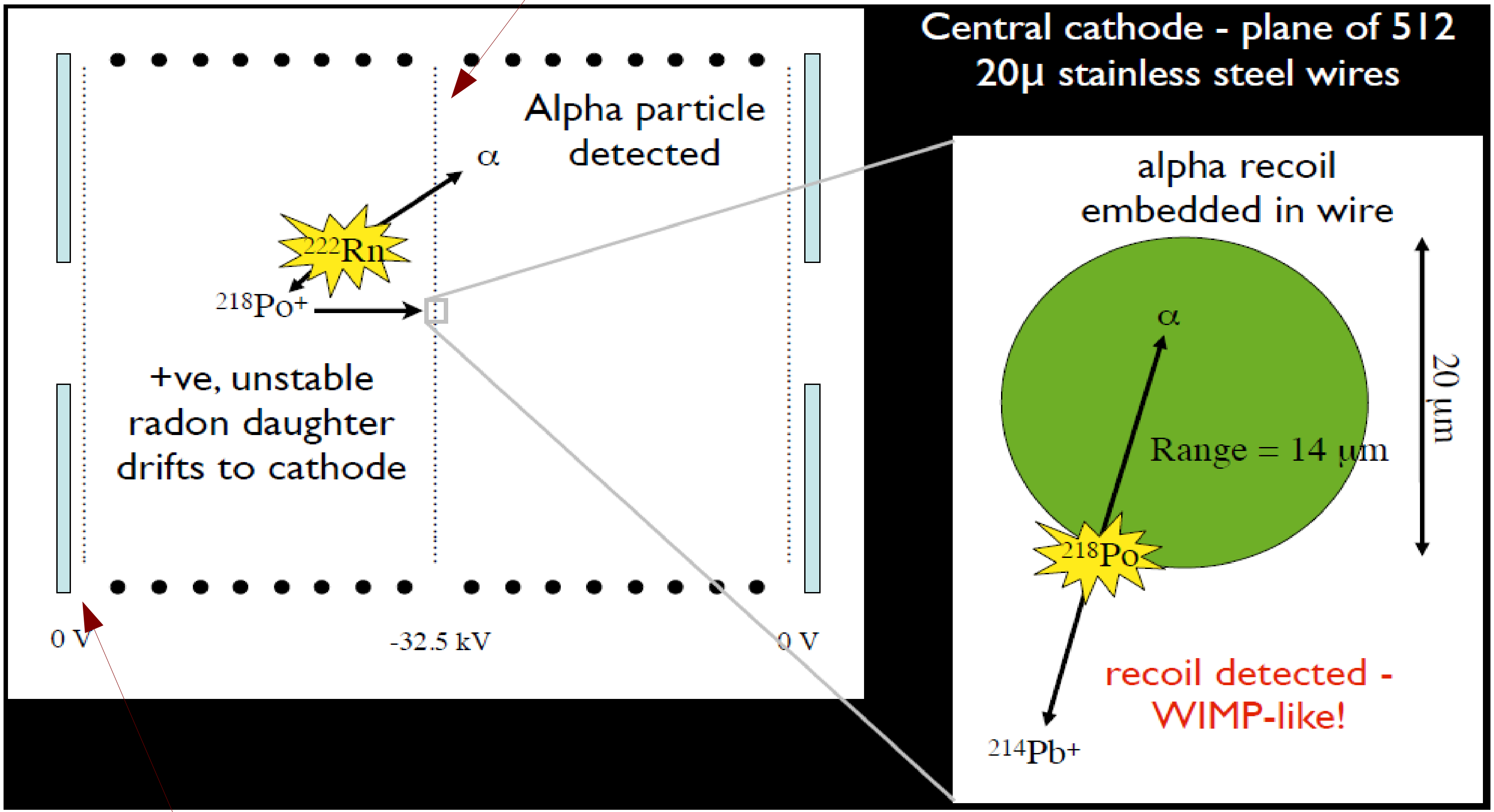




(Mark Pipe, Sheffield)

Dominant Background – Radon Progeny Recoils (RPRs)

Central cathode – plane of 512 20µm stainless steel wires



MWPC

~ 40% probability

RPR Reduction

1) 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

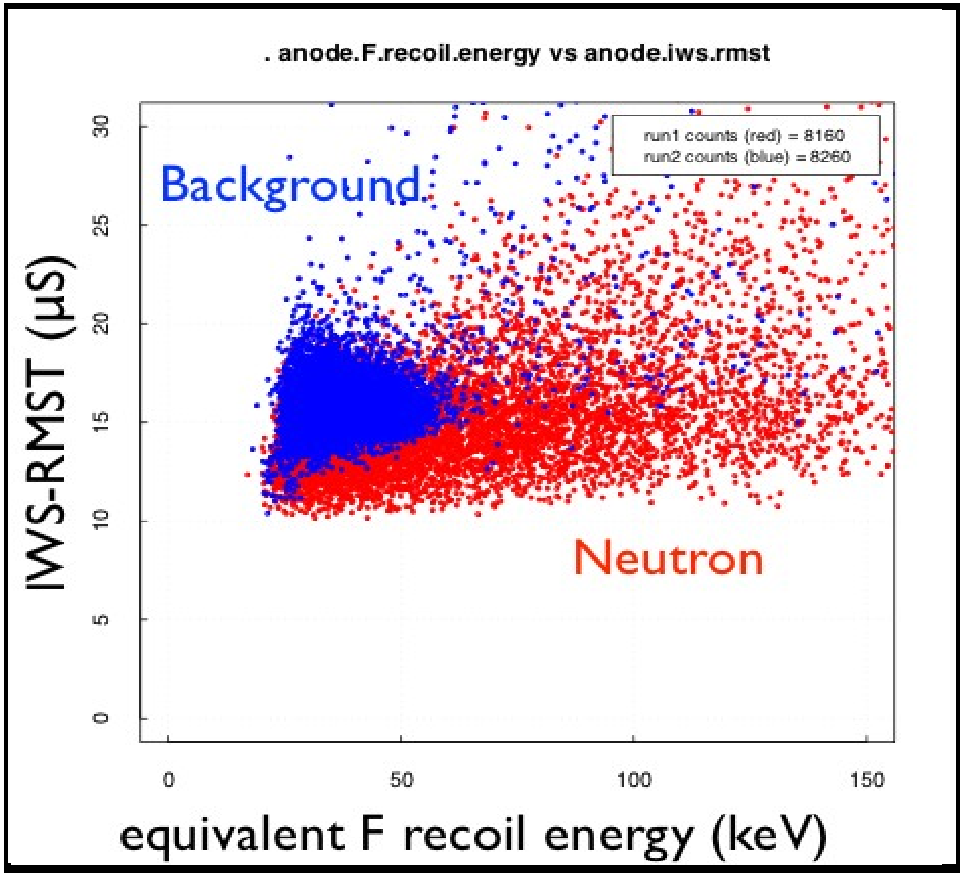
2) The plated out ^{210}Pb ($\tau_{1/2}$~22yrs) was cleaned from the cathode using nitric acid →

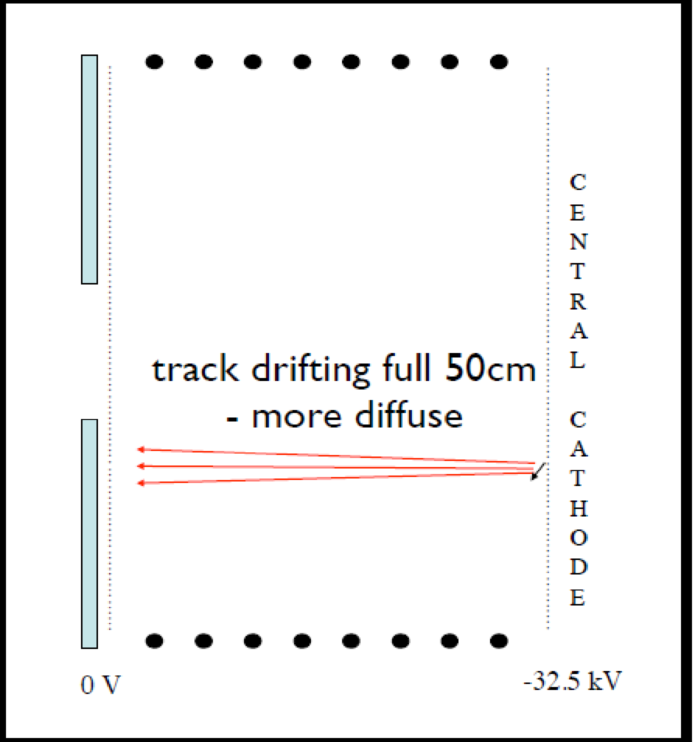
- Together these reduced the RPR rate by 96% (compared with D-IIa rate)

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

RPR Reduction

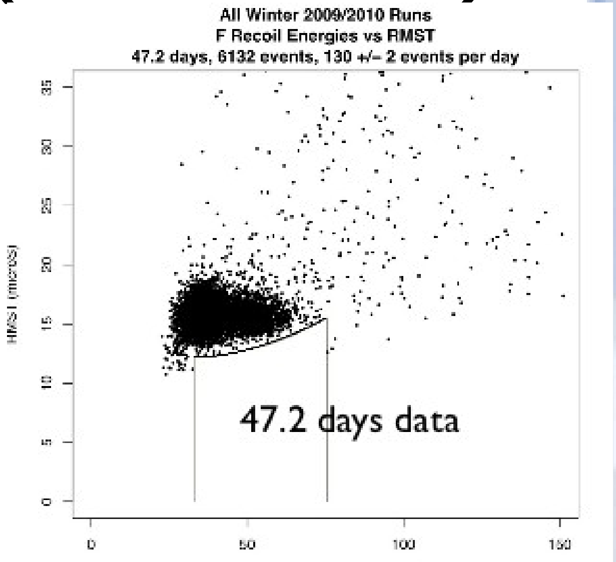
- In addition, pulse shape information can be used to remove events that originate on the central cathode, these events will have drifted the full 50cm and so will be more diffuse. On average have higher IWS-RMST (Induced waveform subtracted – RMS time) - measure of width of the track in the drift field (Z) dimension.
- Disadvantage is loss of signal (neutron) efficiency.

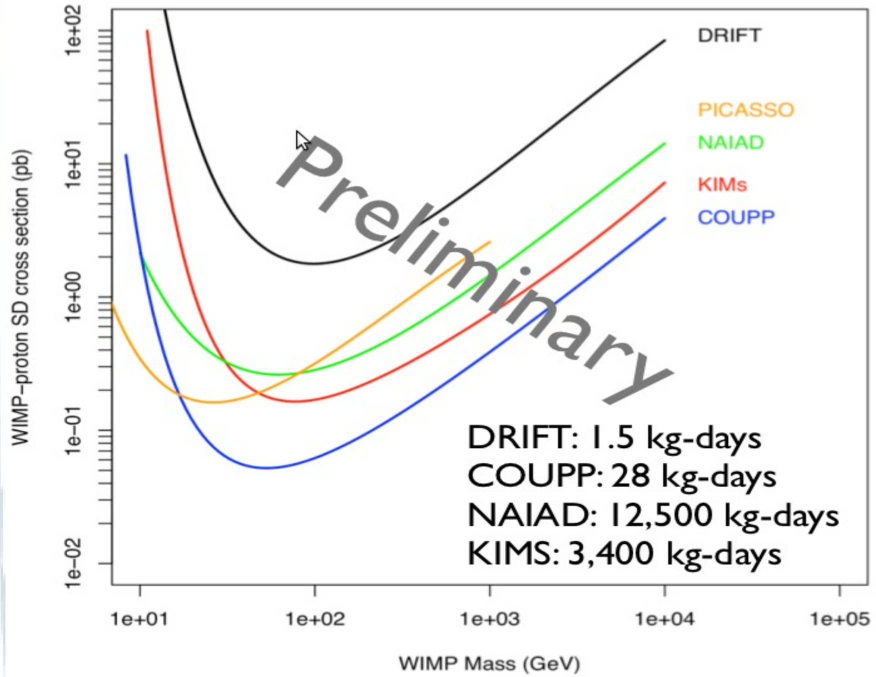




SD Limit from 47.2 days (not blind)

- 30-10 Torr CS_2-CF_4 47.2 days background data = 1.5kg-days (^{19}F)
- MC simulation calibrated by neutron data
- Signal region chosen by eye for zero events (not a blind analysis)
- Further 53 days data on disk for a full blind analysis



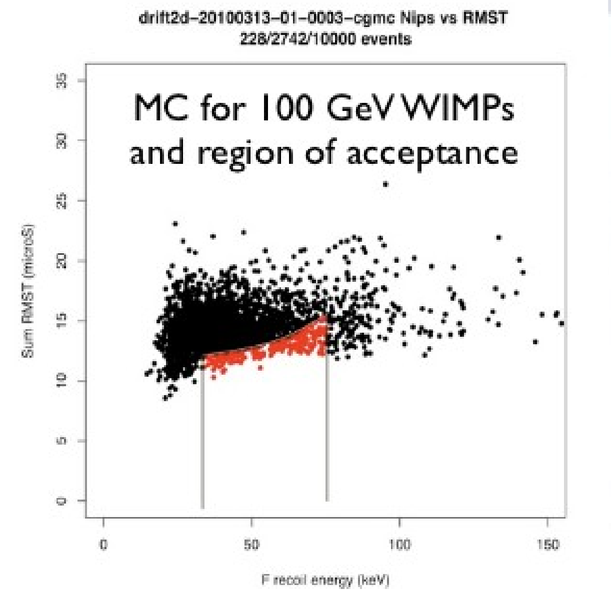


Min. SD limits for directional detectors:

DRIFT: 1.8pb

NEWAGE: 5400pb

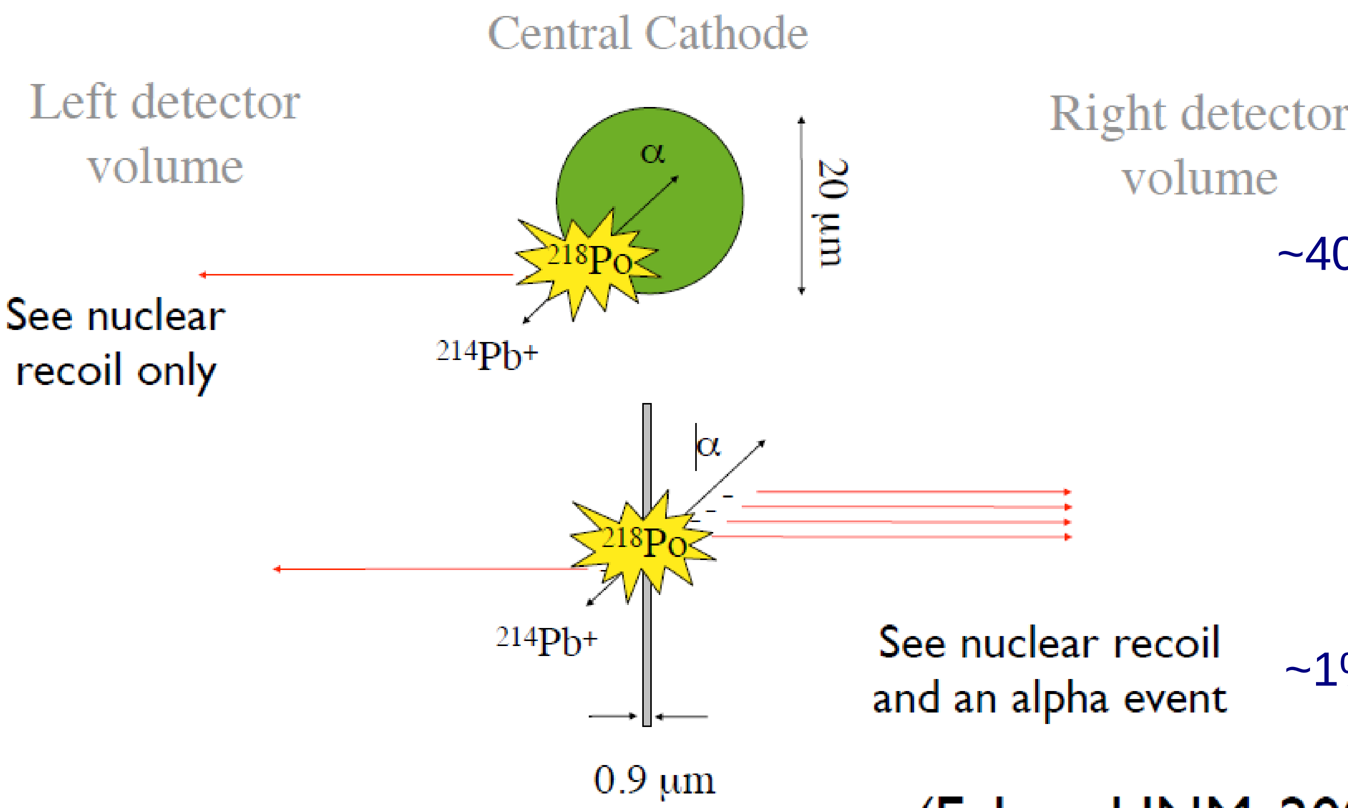
DM-TPC: 2400pb



Submitted to Astroparticle Phys.
E. Daw et. al. arXiv:1010.3027

Further RPR Reduction

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



~40% alphas lost

~1% alphas lost

(E. Lee, UNM, 2009)

Thin Film Cathode

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

Wire cathode

Factor ~40 reduction in RPRs expected

- With a cathode of 0.9μm thickness the RPR rates should drop by a factor of ~40

(E. Lee, E. Miller, UNM, 2009)

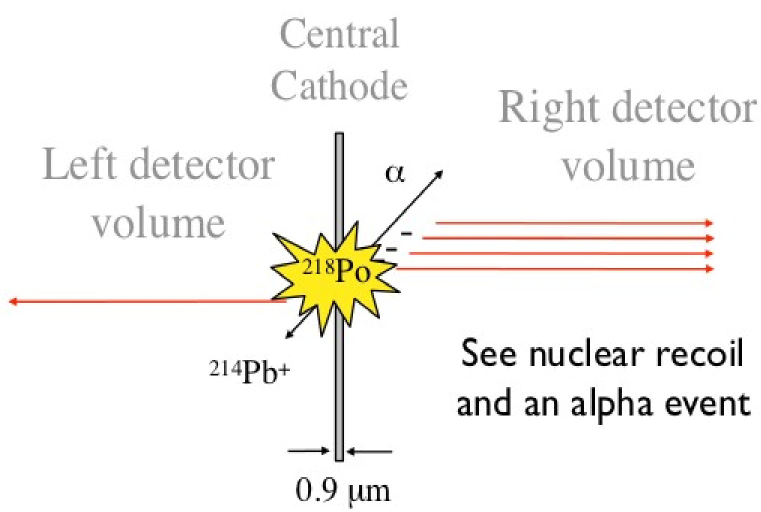
Thin film cathode

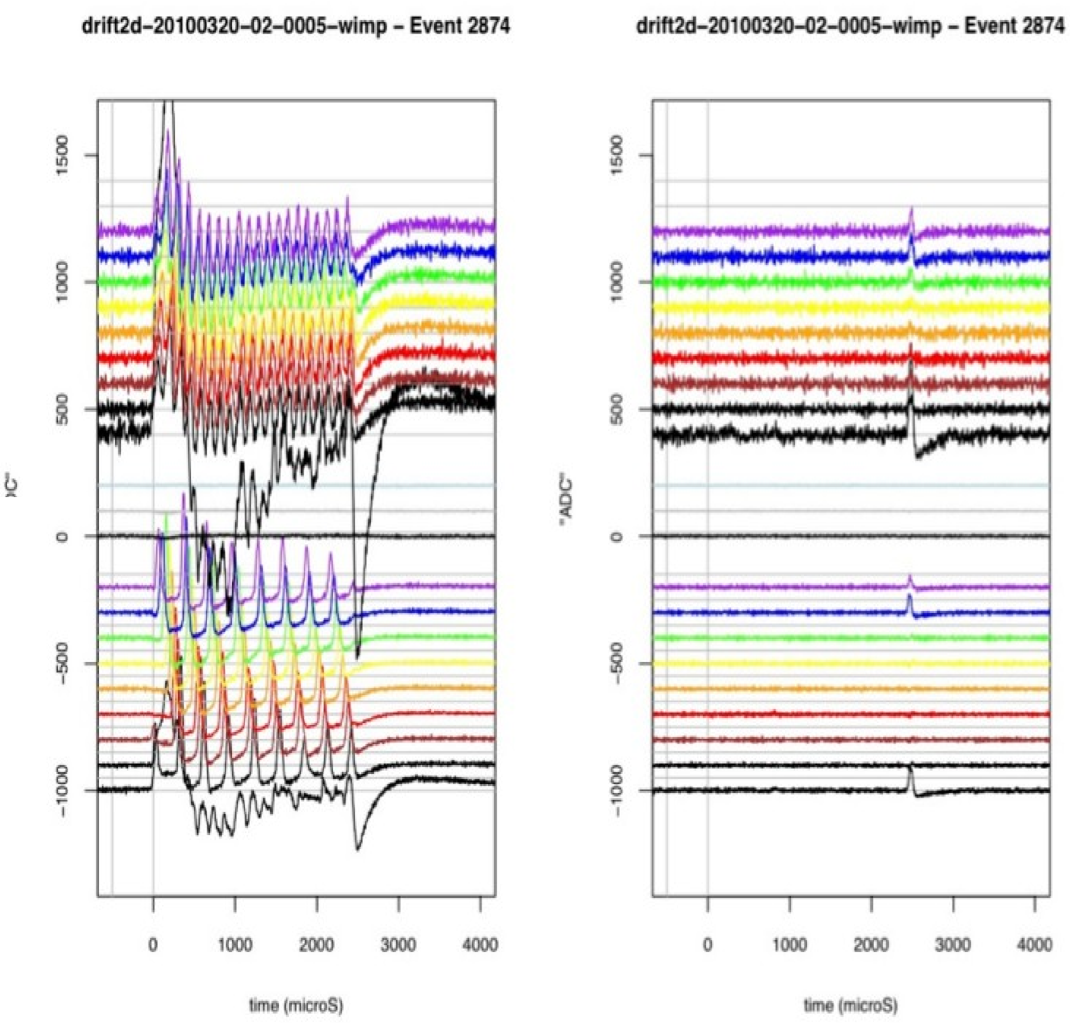
- The 0.9µm mylar sheet central cathode was installed on DRIFT-II at the Boulby Mine in March 2010. Successful operation began a week after installation and is still running stably.

Tagged RPRs

Tagged Radon Progeny Recoil

- Alpha on one side, WIMP-like event on the other
- With the thin film data we expect less WIMP-like background, more tagged RPRs

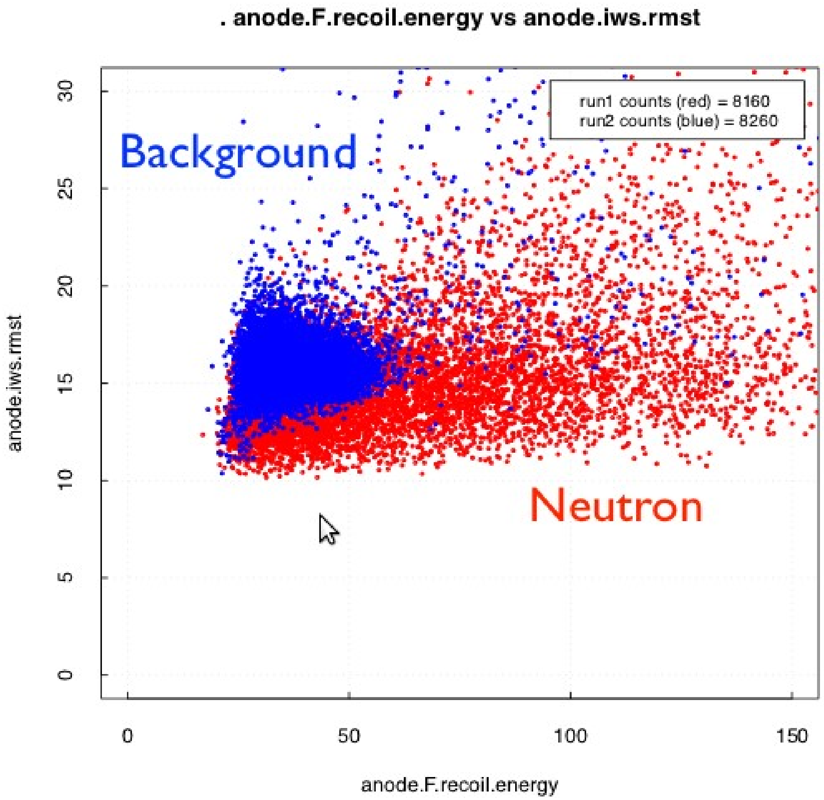




20µm wire central cathode

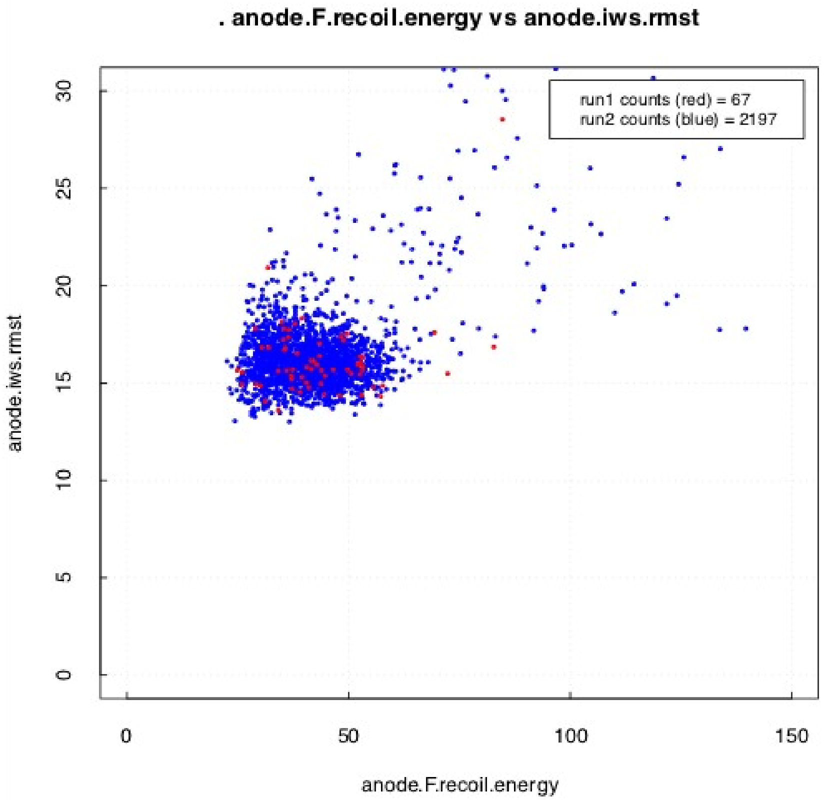
<u>Background events</u>

174 events / day



<u>Tagged RPRs</u>

47 events / day

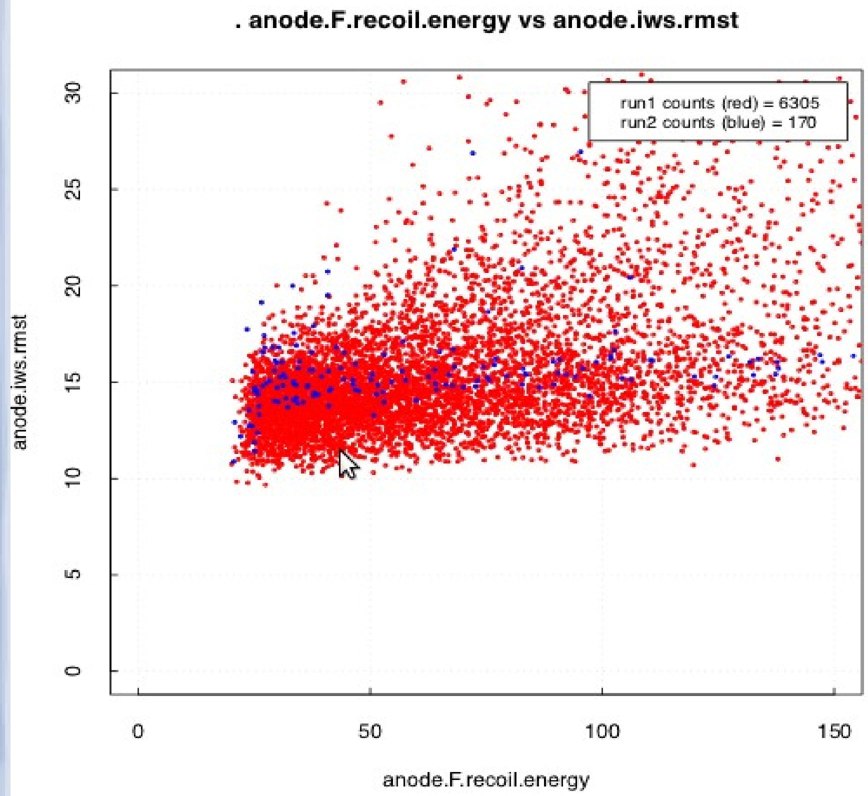


- 0.3 tagged RPRs per background event
- 47.2 days data used to set limit

0.9µm thin film central cathode

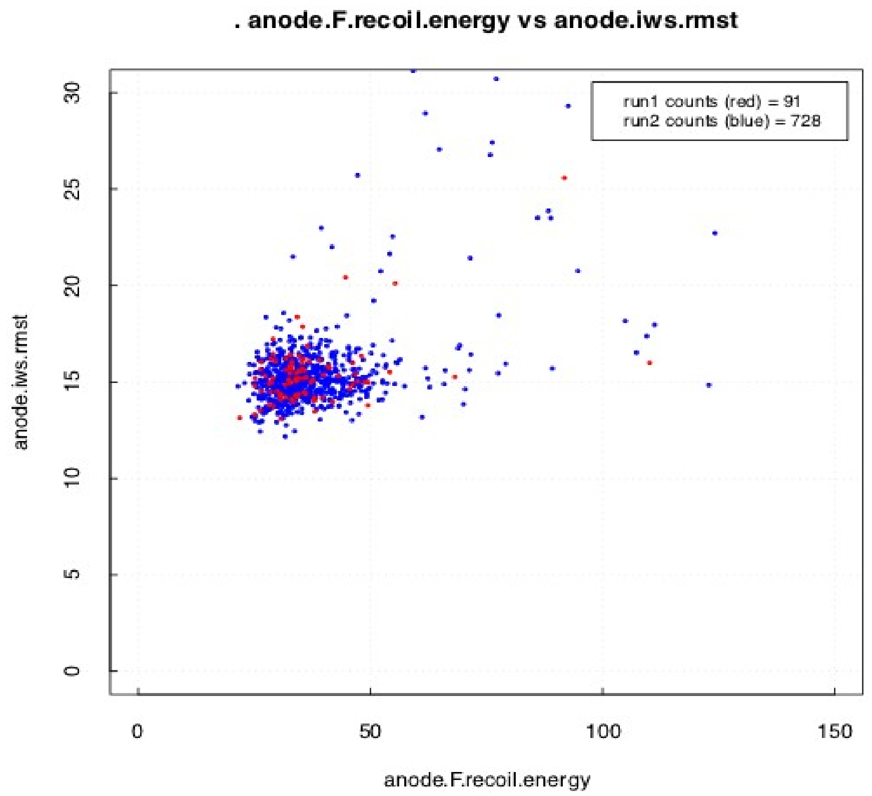
Background events

14.7 events / day



Tagged RPRs

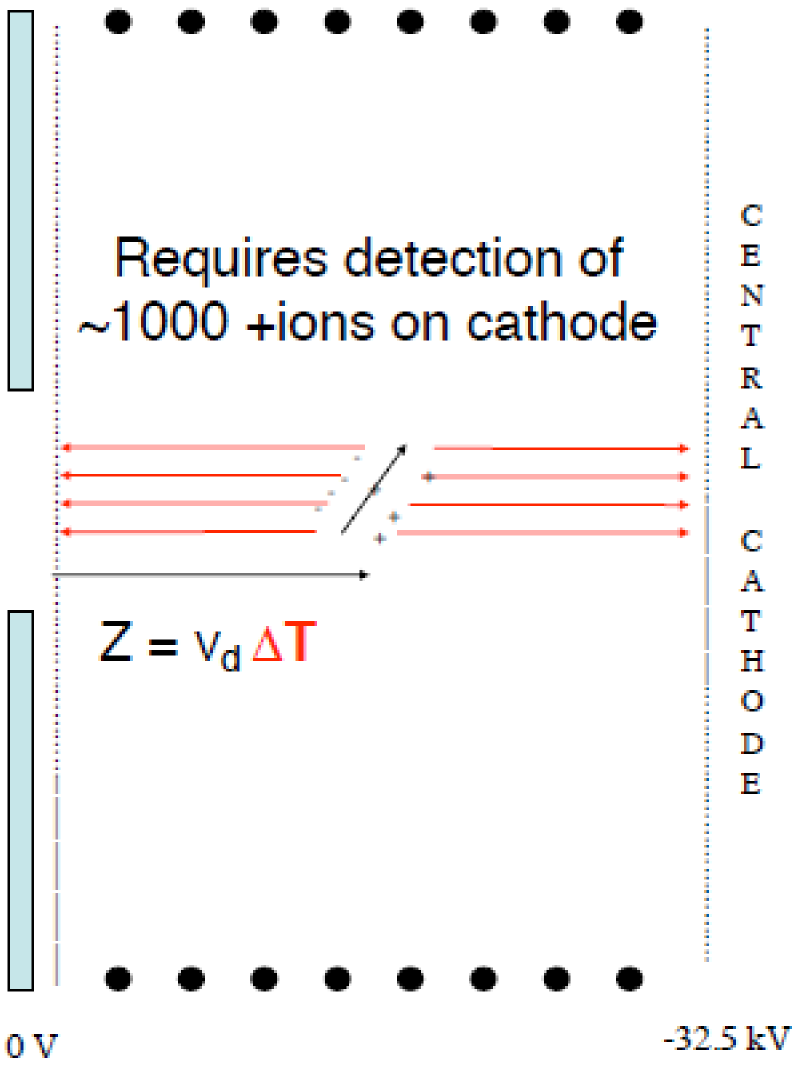
63 events / day



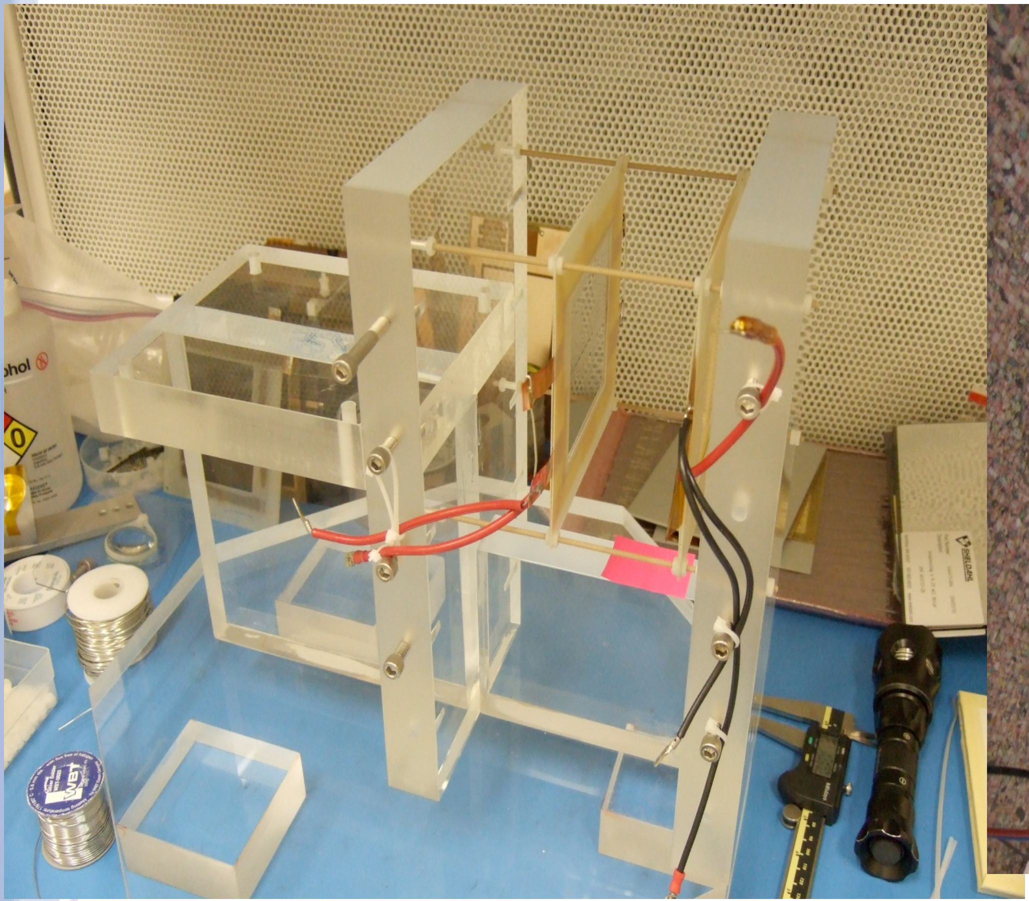
- 4.3 tagged RPRs per background event
- 11.6 days – we have > 50 days on disk with full blind analysis in progress.

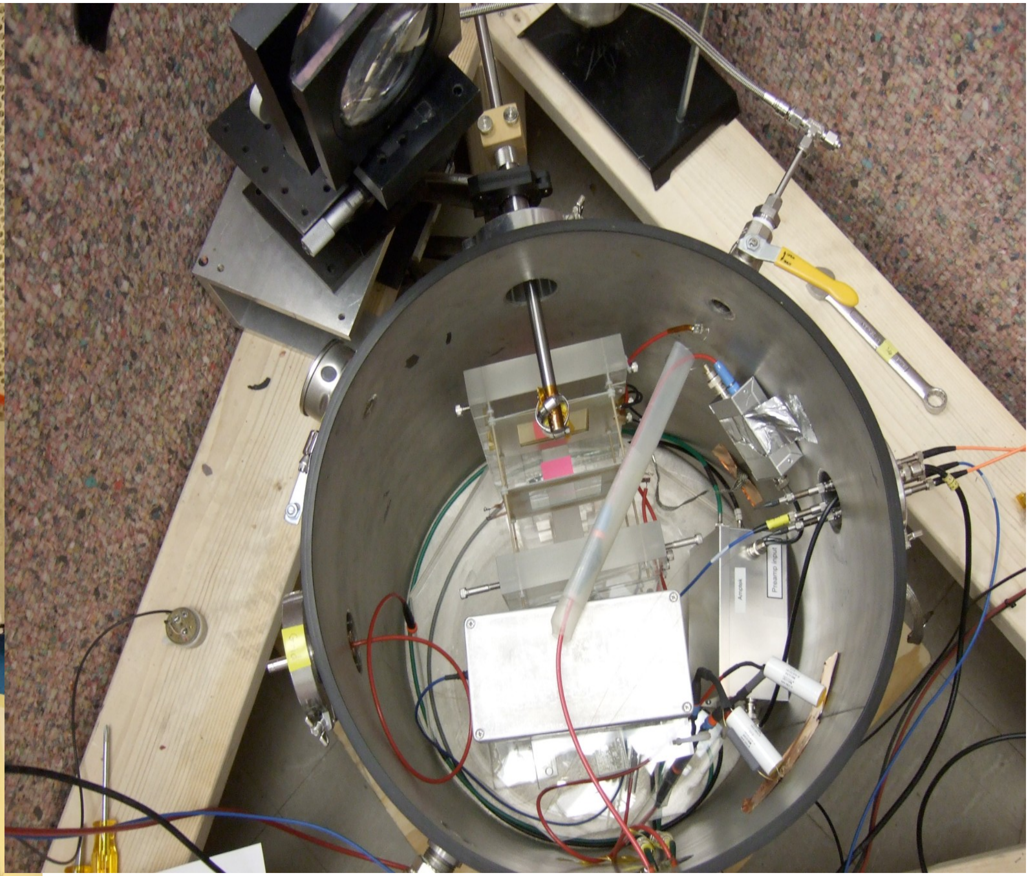
Future - Z-fiducialisation

- 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

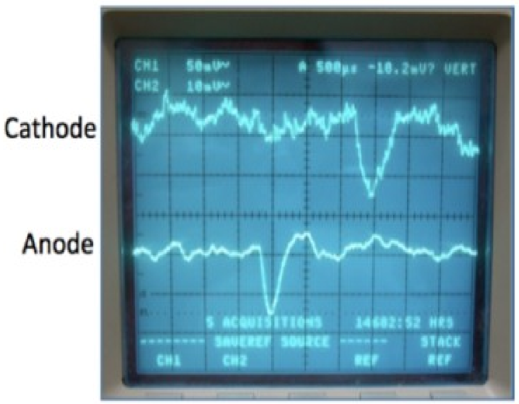


Fiducialisation Test Chamber

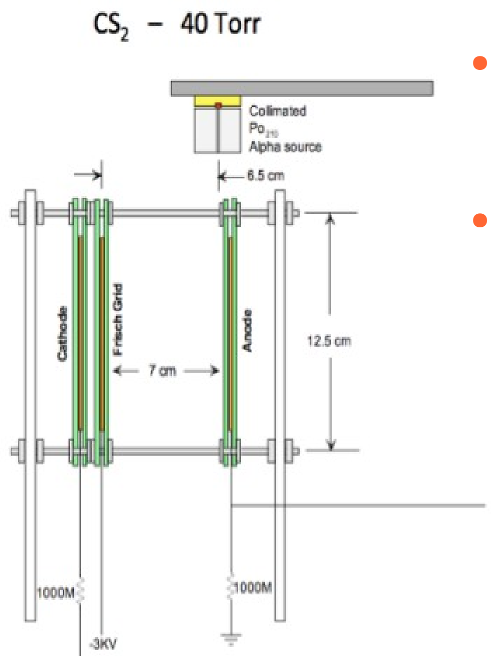




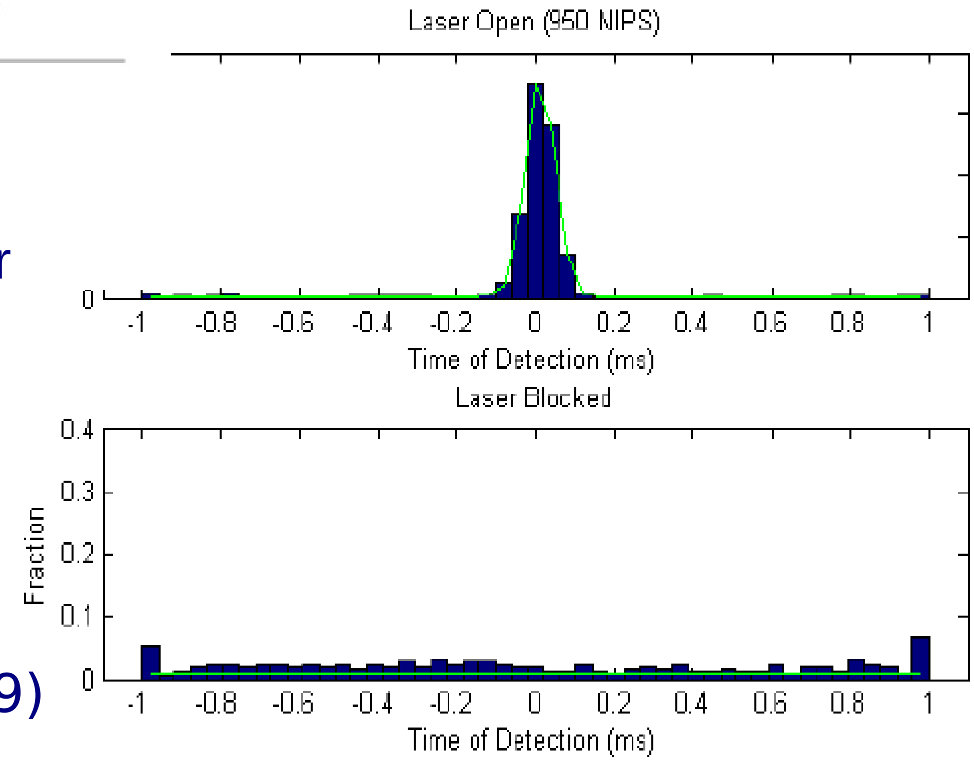
Future - Z-fiducialisation



Expected delay = 1.5 milliseconds



- Demonstrated in a test rig with similar conditions to DRIFT
- Test rig ion drift velocity = 42 ms^{-1}. 1m^3 DRIFT detector = 61 ms^{-1}.



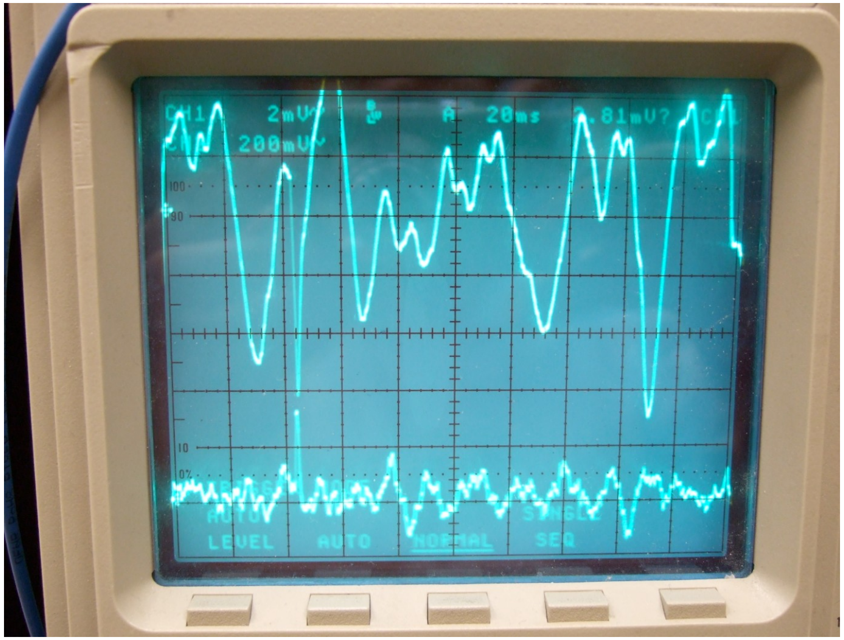
- ~950 + ions created with N$_2$ laser
- Point of ionisation correctly determined to within ±8mm for 84% of events
- Working towards scaling to m^3

(E. Lee, E. Miller UNM, 2009)

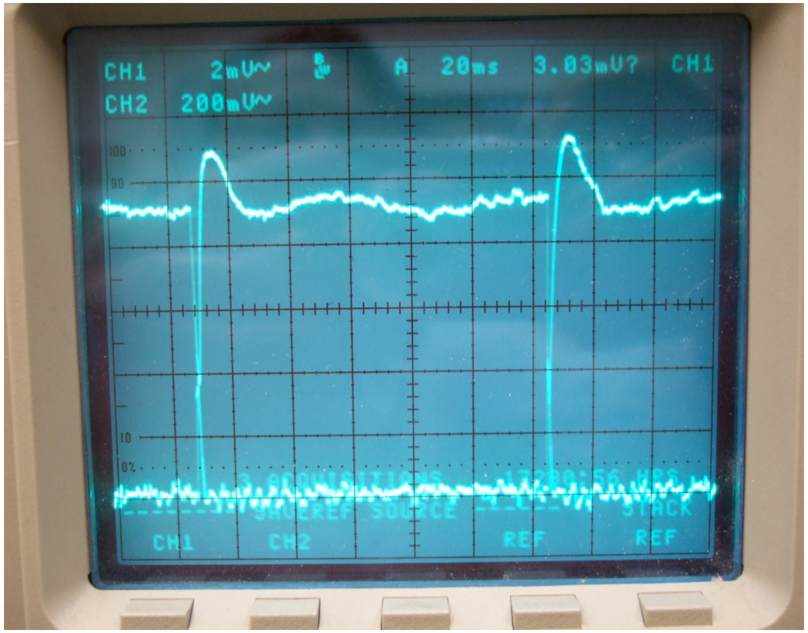
Effect of Isolation

- The frequency range of the signals lie in the 100's – 1000's Hz, which is dominated by microphonic noise from both seismic and audio sources.
- The detector was isolated from microphonics leading to a reduction in noise.

Before Isolation



After Isolation

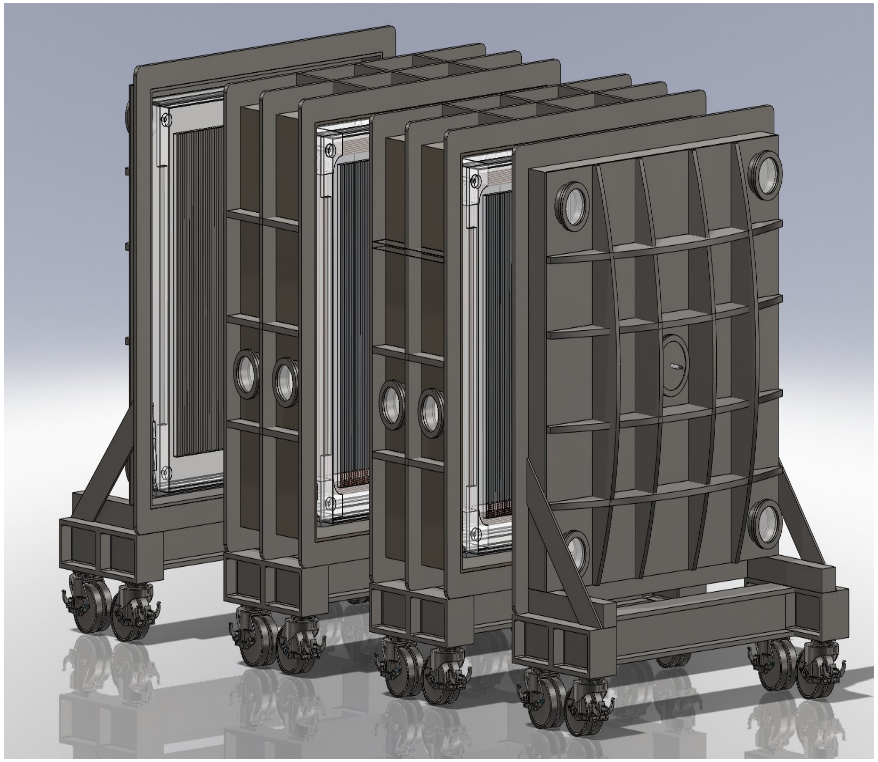


DRIFT-III Concept

- DRIFT is now volume limited. Need for larger volumes.
- DRIFT-III module of 4 kg – 24m^3

  (*DRIFT-II: 0.8 m^3, 0.13 kg CS_2/m^3*)

- Designed to be built up in segments and thus be scalable to large sizes.
- Relatively low cost per fiducial mass.
- One DRIFT-III module (6 independent segments) is well suited to Boulby

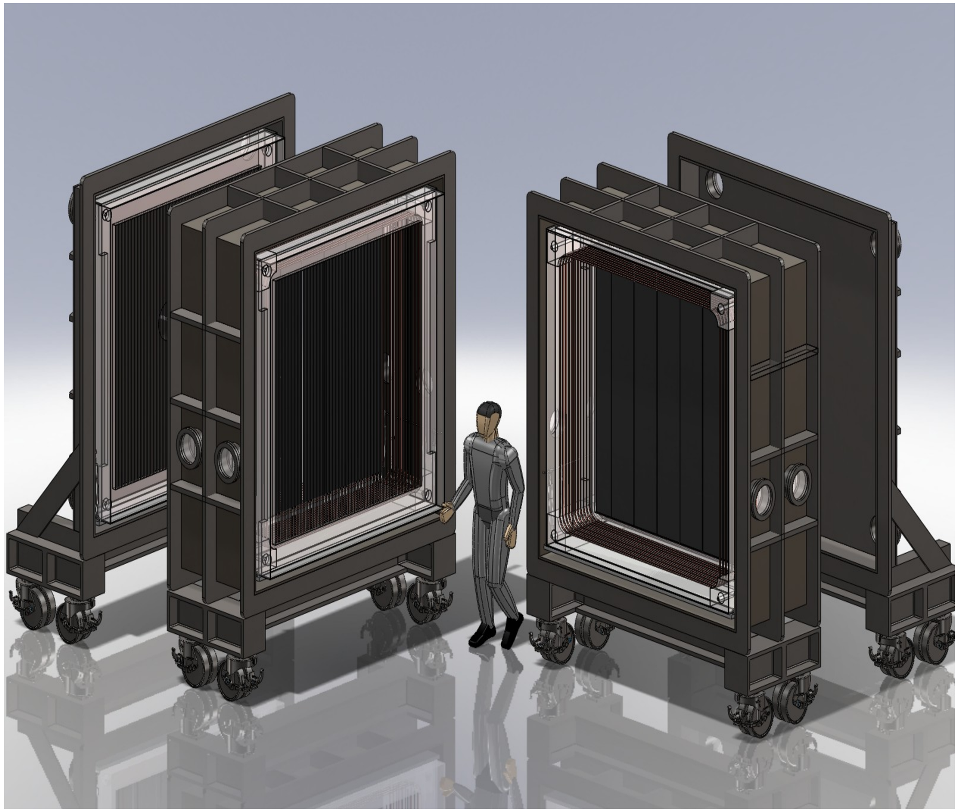


DRIFT-III segments
6 segments = 1 module = 24m^3

DRIFT-III Concept

Key features:

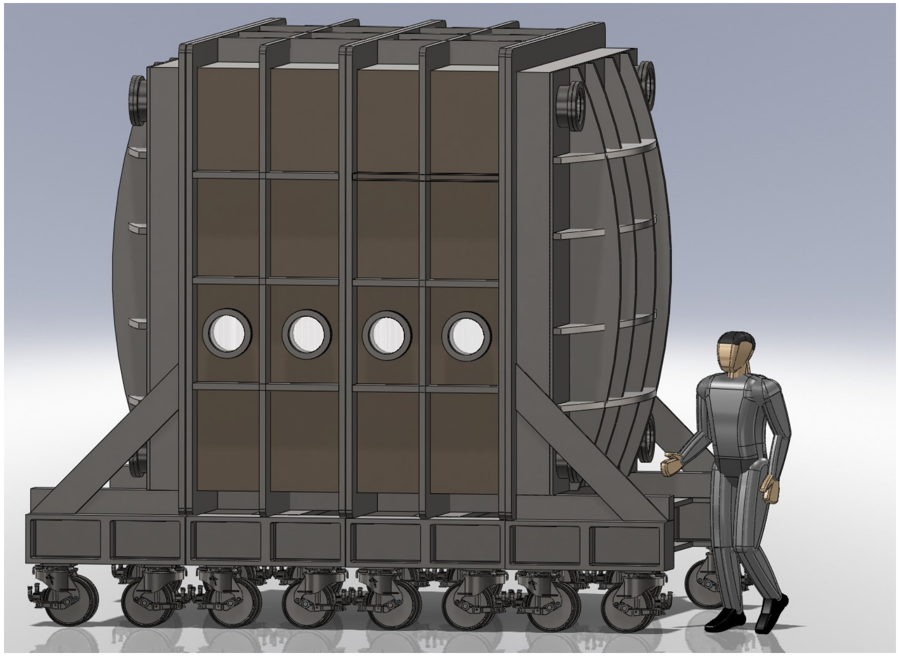
- Directional capability will be maintained
- advantages of no cryogenics
- multiplexed electronics
- neutron shielding



DRIFT-III Design

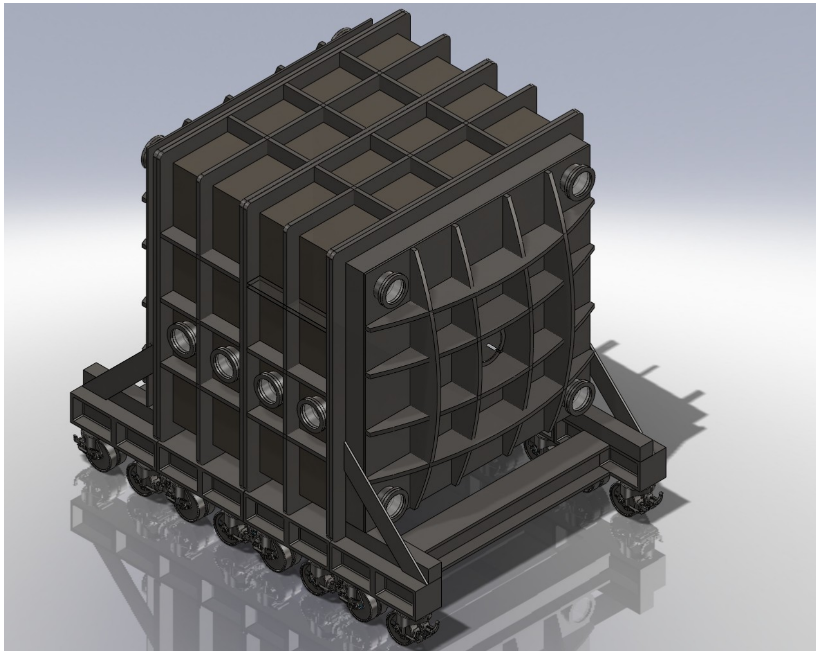
- 4kg fiducial mass, CS_2 -ve ion plus CF_4 (different target mixes)
- Thin low RPR central cathode (~1 μm)
- Nitric acid process cleaning and radon emanation tests
- +ve ion detection for Z-fiducialization
- 2 x 2m single plane anode with alternate grid wires. Reduced tension simplifies engineering (no strongback)

- Water shielding within plastic containers surrounded by a steel frame.
- No gamma shielding needed



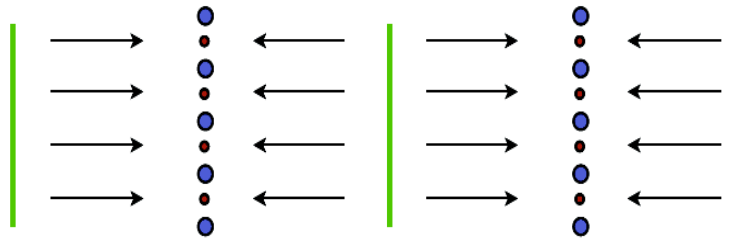
DRIFT-III Vessel

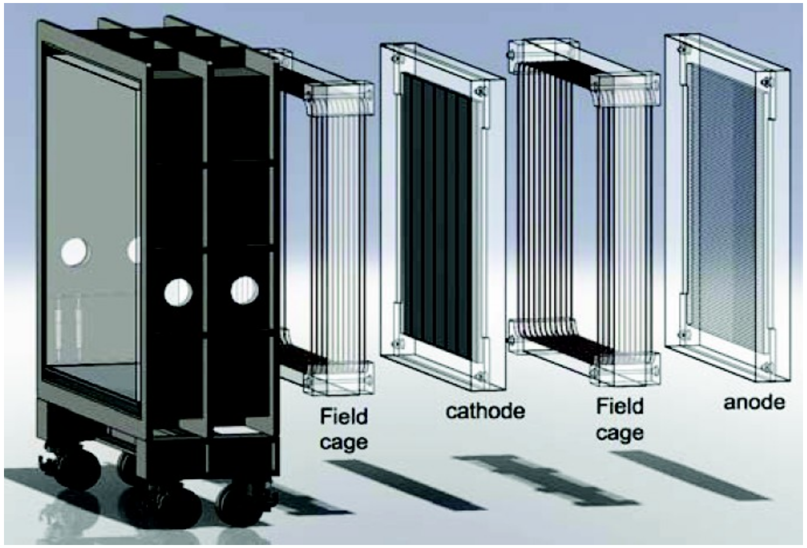
- Each DRIFT-III module built up of segments --> scalable.
- Each detector segment observes 4 m^3 of gas or, at 40 Torr of CS_2 - CF_4 mixture: 0.67 kg of target mass



DRIFT-III Readout

- Alternating 100 µm and 20 µm stainless steel wires on a 2mm pitch. 1000 wires of each.
- All readout wires are on a single plane, capable of reading events on either side, thus lowering the cost (e.g. for construction and DAQ). Also eliminates the need for a strongback support.
- Single plane largely removes torque issues with orthogonal wire planes
- Propose raising the electric field in the drift region (~70kV) to either lower diffusion or to increase the drift distance (larger volume means reduced cost).
- Anode wires read on both ends to enable position measurement along the resistive wire.
- Full readout DAQ – Currently the DAQ groups the wires into 8 channels for both the grid and anode. New DAQ proposed to recover absolute positional information, approx. precision of 2mm.





A single segment

DRIFT-III Gas and Safety

- Multiple targets possible with no change to detector (C, F, S...)
- CS_2 + CF_4 mixing system as demonstrated in DRIFT II
- Works with up to ~1% contamination (oxygen)
- Gas flow for removal of contamination and radon emanation control (R&D tasks)
- Handling and disposal of CS_2 (flammable toxic gas) and CF_4 is understood (e.g. at Boulby)
- Recirculation and cleaning with a closed system is a R&D topic

Summary

- DRIFT-IId at the Boulby Underground Laboratory (UK) now running with CS_2- CF_4 gas mixture for SD sensitivity.
- Unblind analysis of 47.2 days produced SD limit of ~1.8pb (100 GeV WIMP). No compromise on directionality.
- Thin film cathode installed and analysis shows large reductions (factor > 15) in RPR background from cathode.
- >50 days of unanalysed data with thin film cathode is on disk – full blind analysis underway.
- Progress is being made on Z-fiducialisation with the aim of eliminating backgrounds from the central cathode.
- A scale up to DRIFT-III, 24 m^3 target volume is planned, initial design stages underway.