The DRIFT Directional WIMP Detectors

Improved Limits and Progress to Scale-up

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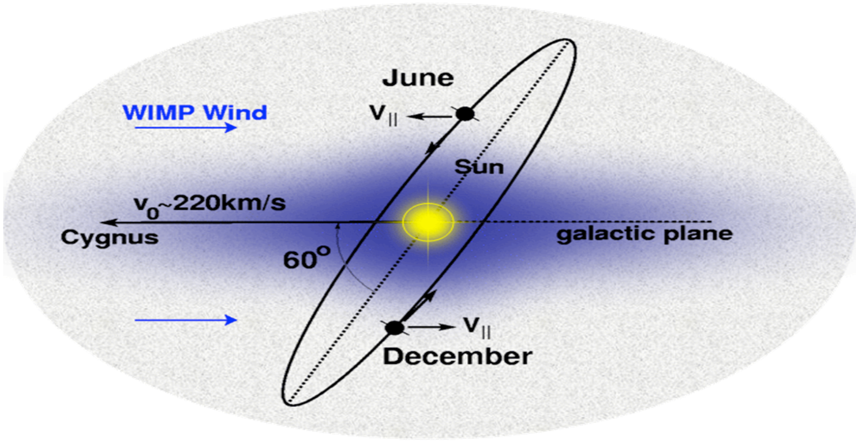
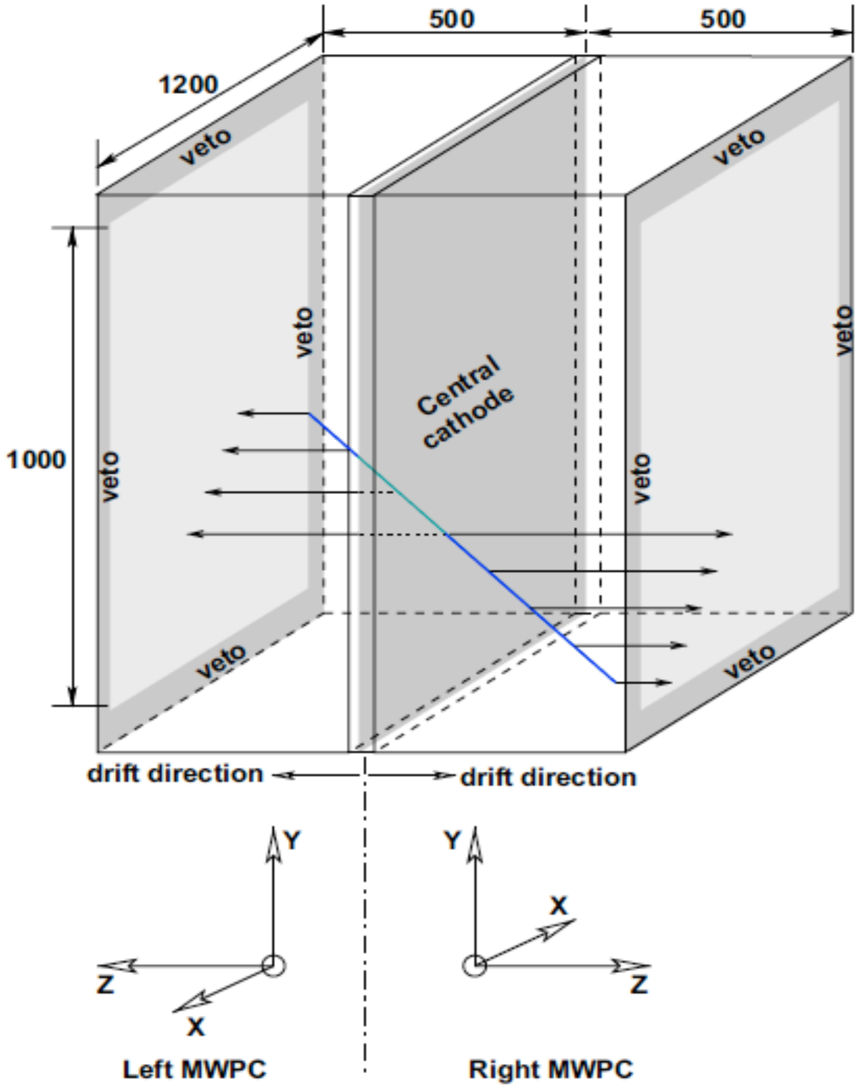


advert:
Workshop on Directional Detection of WIMPs

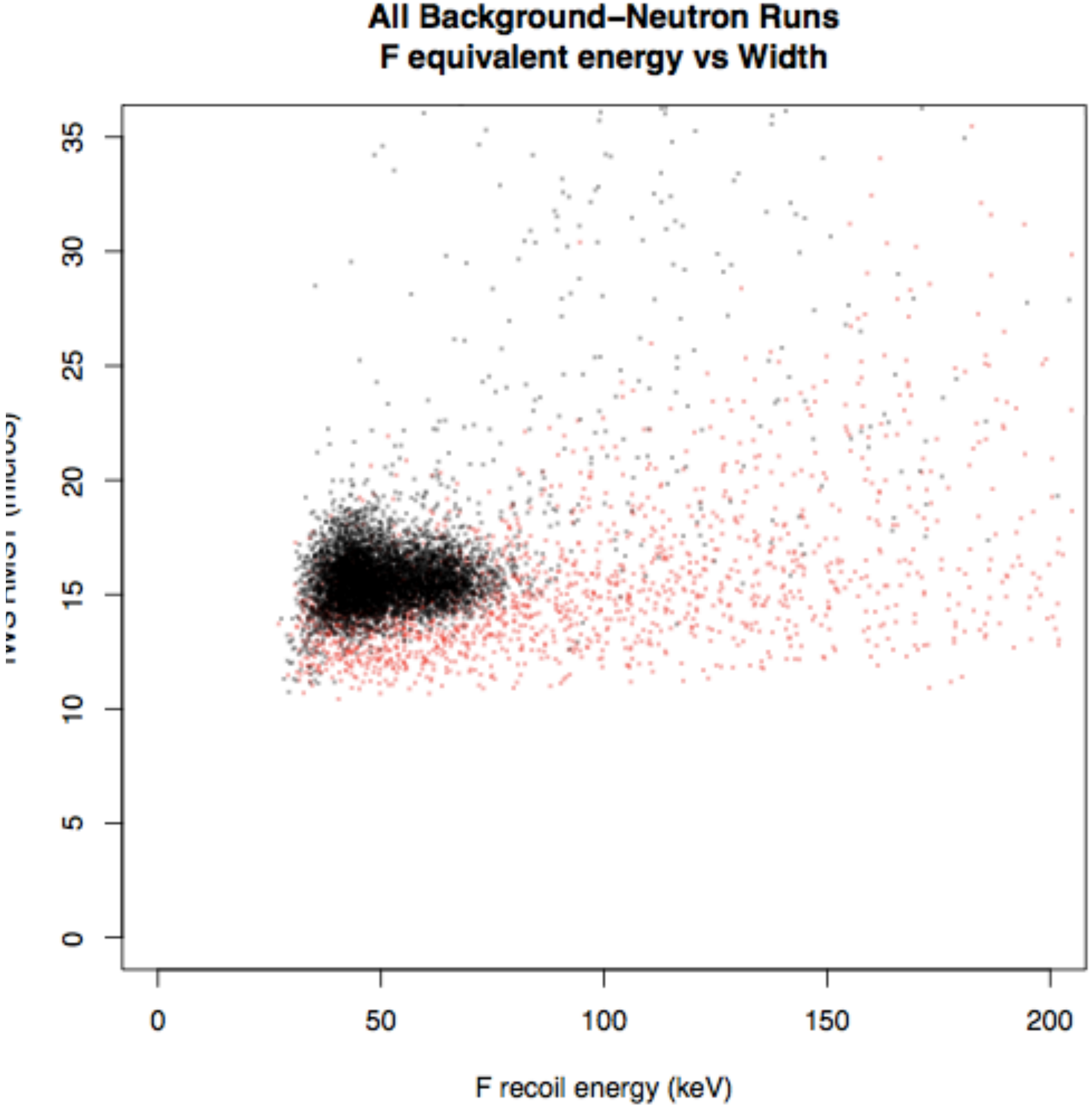
DRIFT Concept

Technology evolution - DRIFT IIa, b, c, d...e, DRIFT III



- 1 m^3 Negative ion TPC read out by two MWPCs.
- Electronegative drift gas (CS_2) with J=1/2 target gas (CF_4) to probe SD interactions whilst maintaining low diffusion.
- The shared central cathode defines two 624 V/cm drift regions.
- Every 8^{th} wire grouped.
- > 67 cm polypropylene pellet neutron shielding on all sides.
- Current iteration: DRIFT-IId is running at Boulby Mine in Cleveland, UK.
- Next iteration: DRIFT-IIe being installed, with first data coming later this year.

DRIFT IId old data



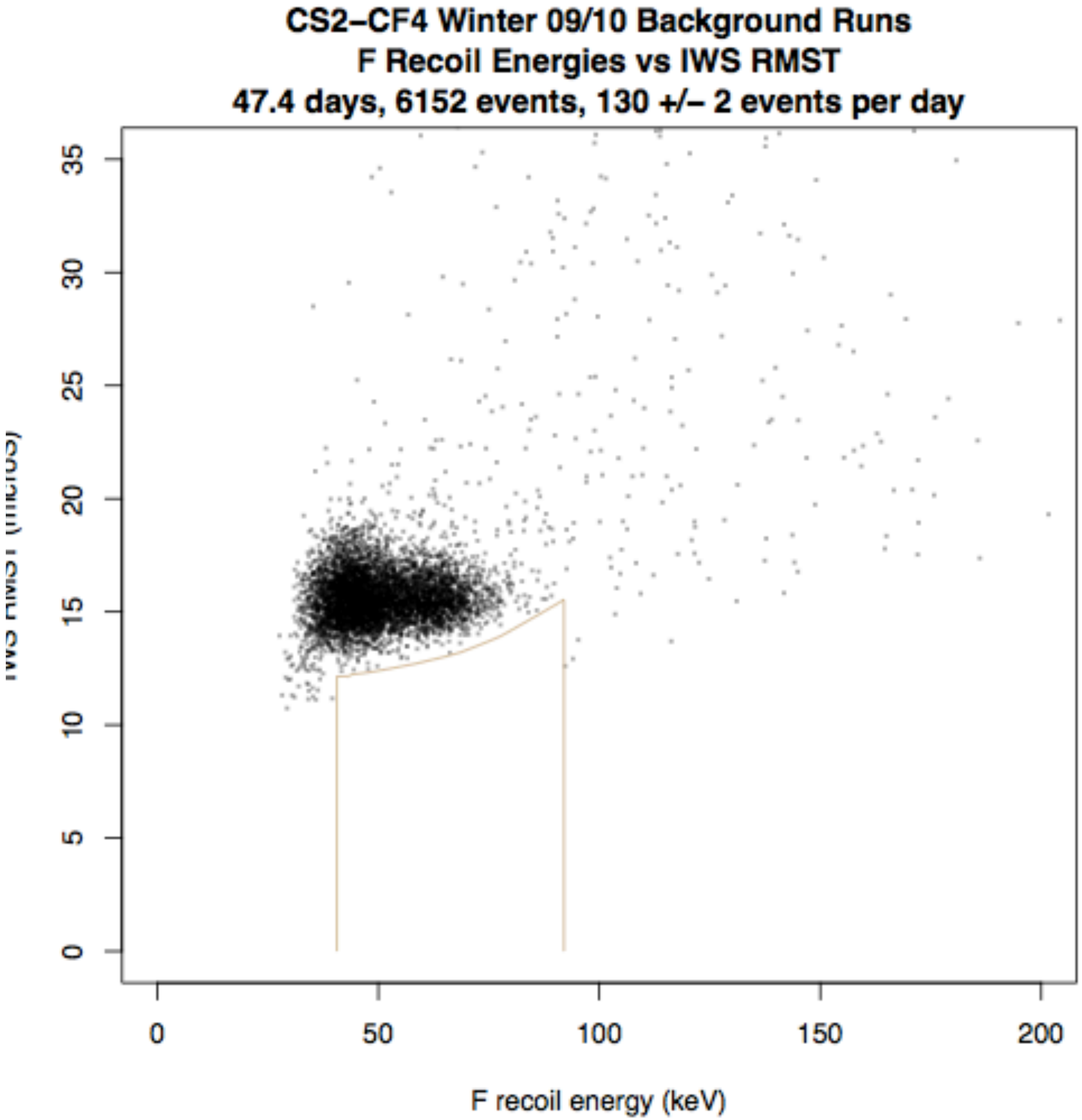
- Diffusion of the RPRs from the central cathode increases their width
- Use width as crude discrimination parameter

Black = Background

Red = Nuclear Recoils

AstroPart. **35** (2012) 397

DRIFT IId old data



- Select a signal window
- Unfortunately for 100 GeV WIMPs the signal window gives only ~8% efficiency of events passing the cuts

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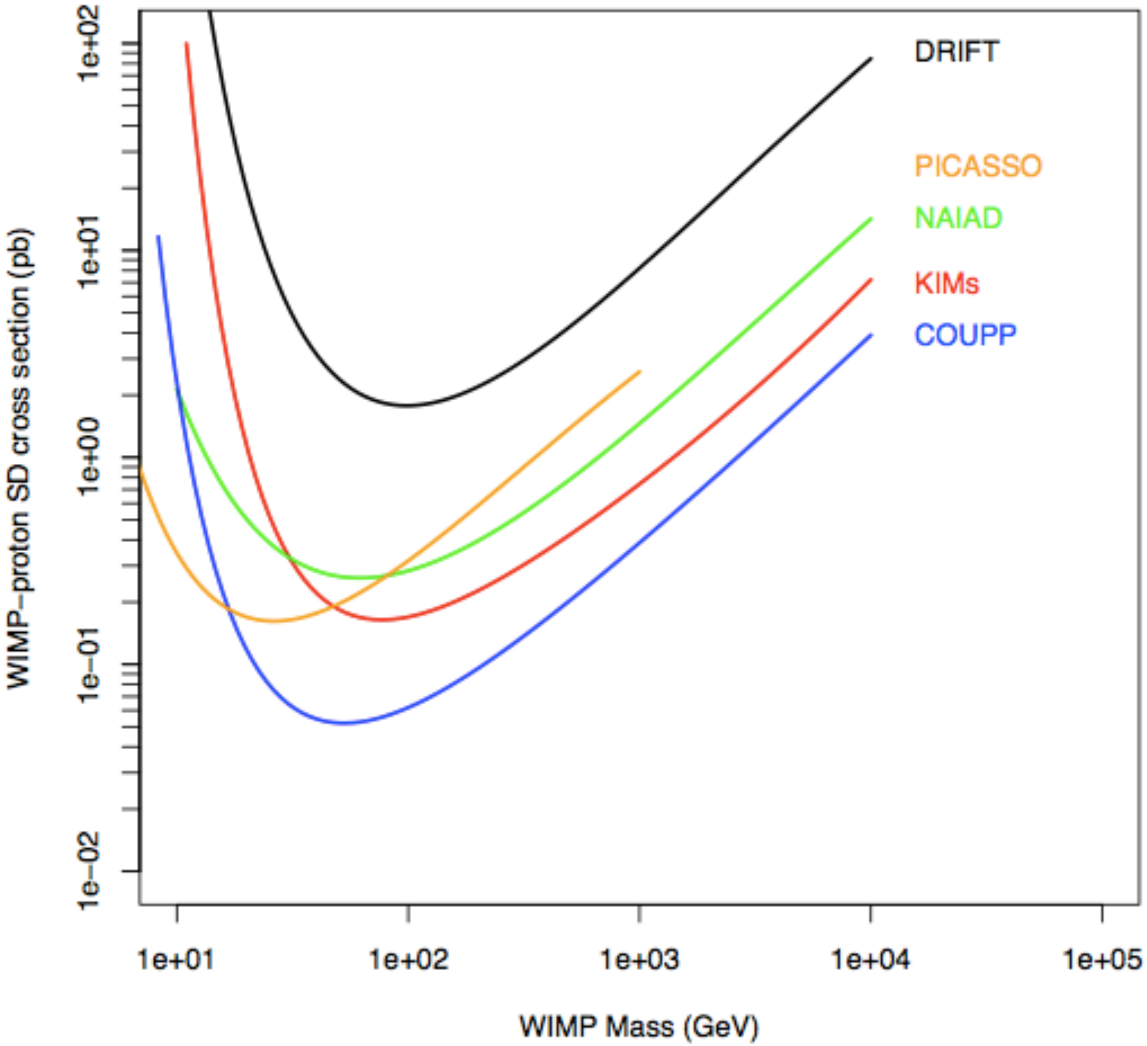
DRIFT IId WIMP-SD Limits (2012)



- Subsequent blind analysis of new data confirmed this result (thesis publication only)

AstroPart. **35** (2012) 397

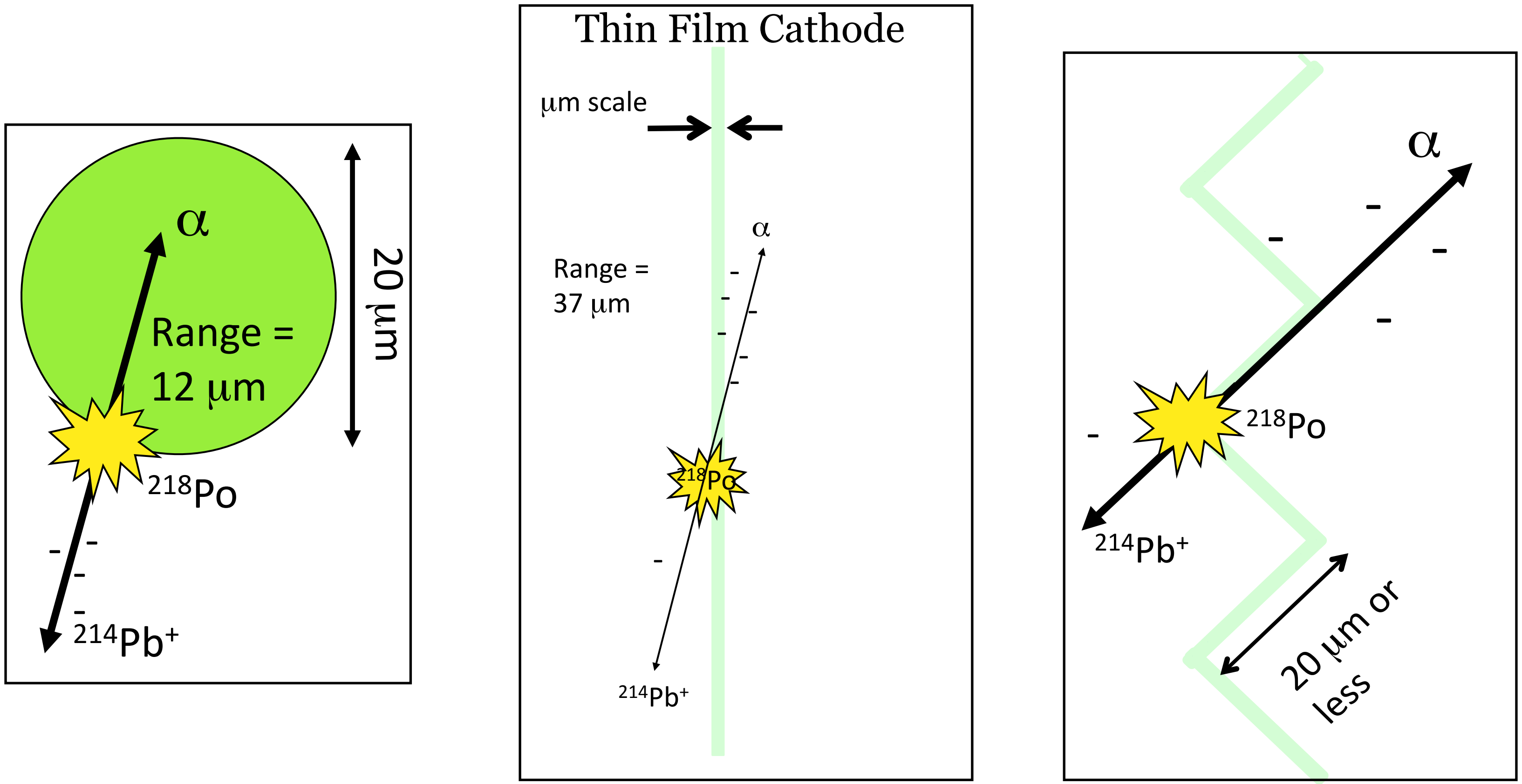
DRIFT IId Upgrades: Texturised Cathode

Wire Cathode → Thin Cathode → Thin Texturised Cathode

~600 RPRs/day ~130 RPRs/day (with nitric etch) ~1 RPRs/day

Wire Cathode

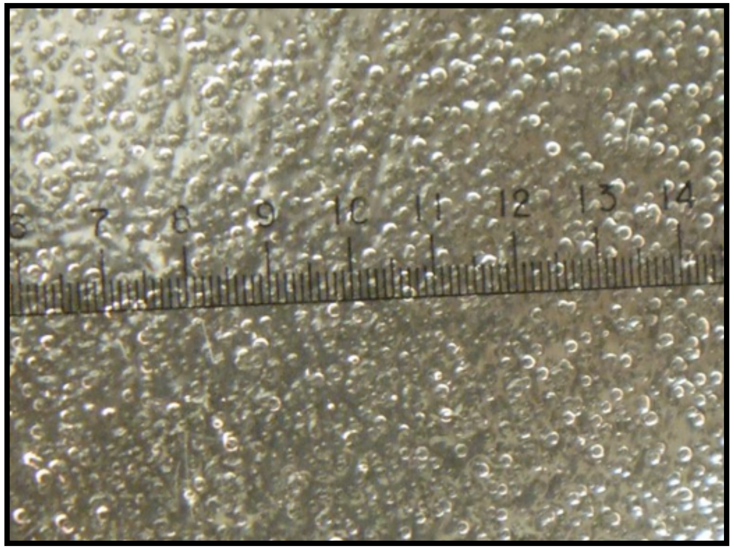
Texturised Cathode



The concept:
Give the alphas **no** place to hide in a **texturized** aluminized Mylar thin film

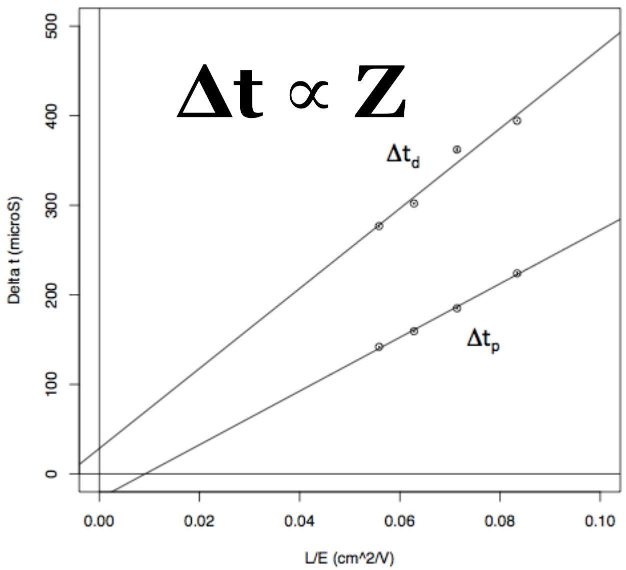
DRIFT IId Upgrades: Texturised Cathode

- Texturized 0.9 micron thin film is really difficult to fabrucate but UNM group managed it
- This was deployed on DRIFT-IId at Boulby in May 2013
- Results indiacte a drop from 130 events per day to ~1 event per day
- Further improvements are expected with the deployment of DRIFT-IIe in 2014



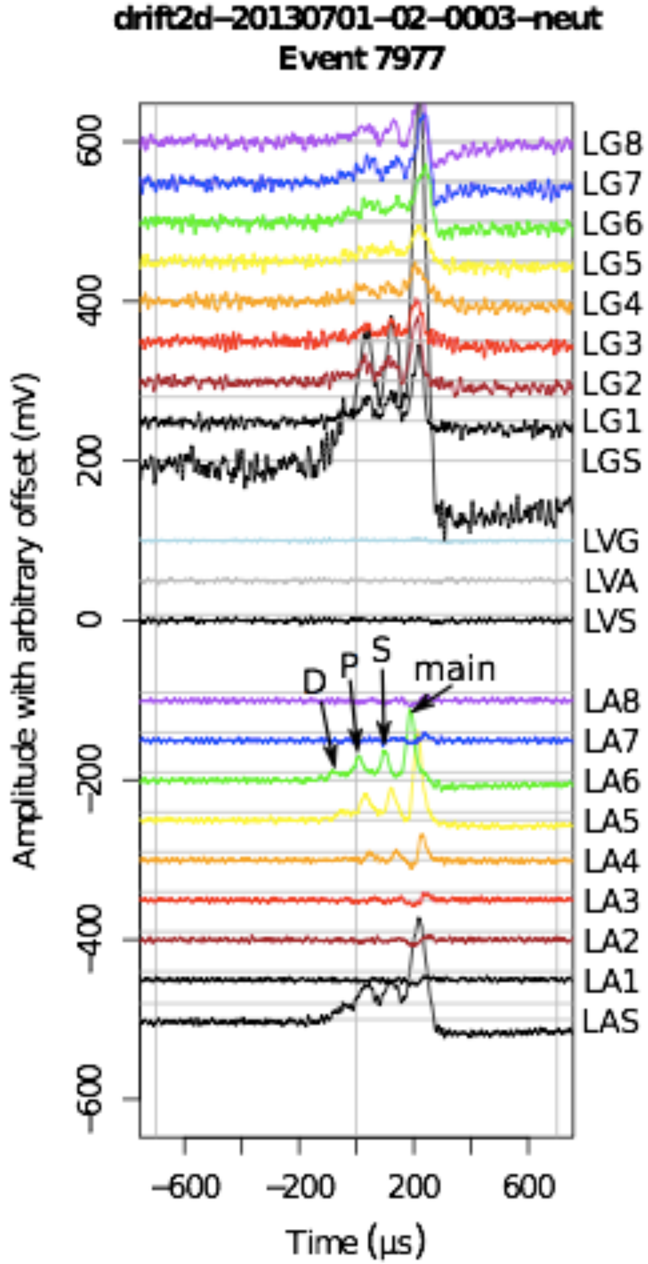
DRIFT IId Upgrades: Z Fiducialisation

- **1% oxygen** added to normal 30:10 Torr CS_2: CF_4 mixture
- Appearance of "minority carrier" peaks **earlier** than the "majority" peak, carrying ~1/2 of the total charge (see Snowden-Ifft Rev. Sci. Instr. 85 (2014))
- Timing between main peak and minority peaks gives **absolute Z information** on events
- This allows rejection of RPR events that originate near the cathode at z = 50 cm or MWPC planes at z = 0 cm

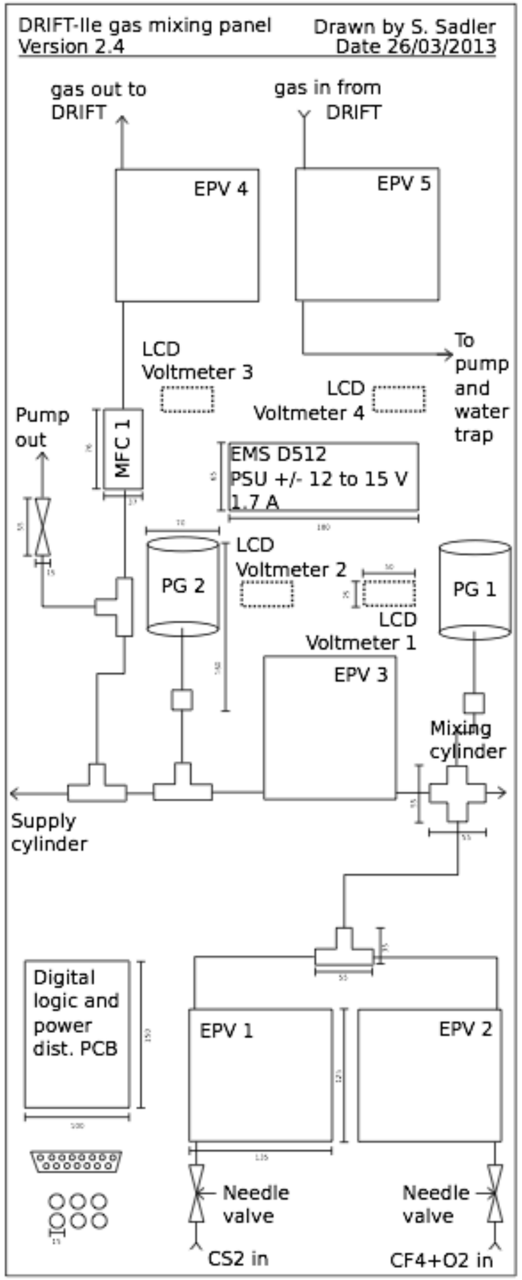


$$z = (t_m - t_p)\frac{v^m_{drift} v^p_{drift}}{v^m_{drift} - v^p_{drift}}$$

Example event display from minority carrier data. The main peak and the earlier 'S', 'P' and 'D' minority peaks can be seen on LA 3, 4, 5 and 6.

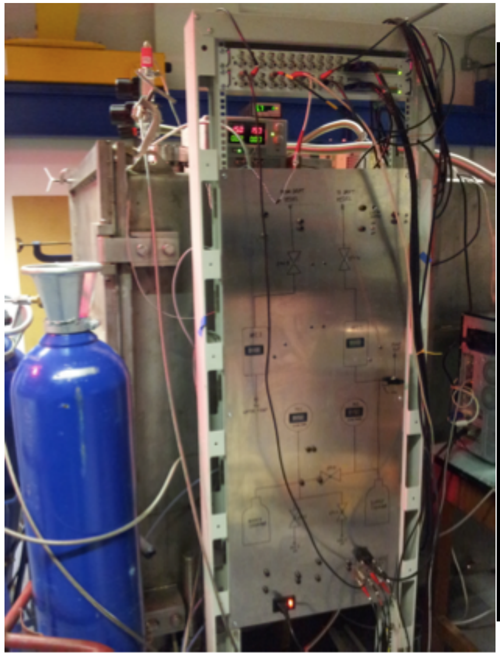


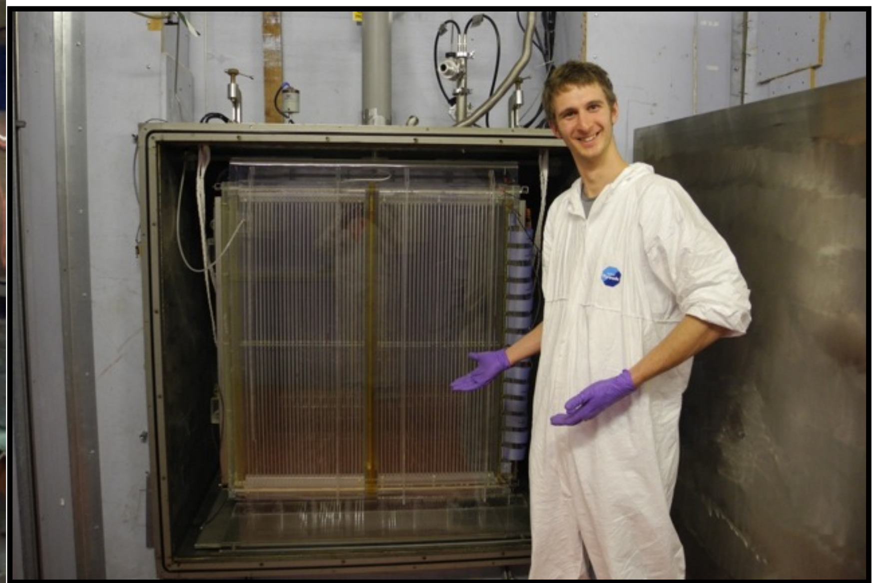
DRIFT IId Upgrades: Z Fiducialisation



The magic gas mixing system

$CS_2 : CF_4 : O_2$ 30 : 10 : 1



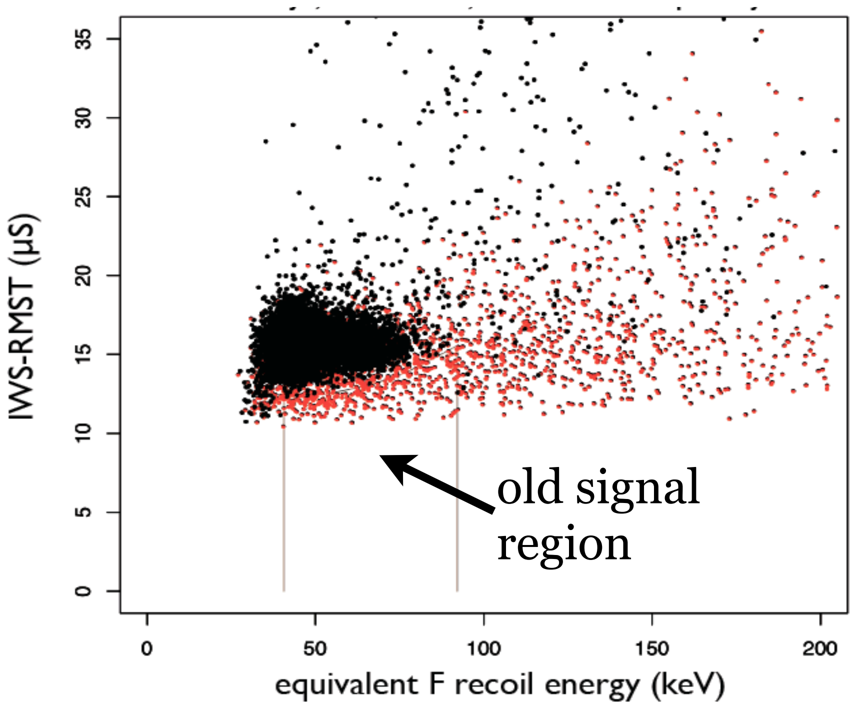


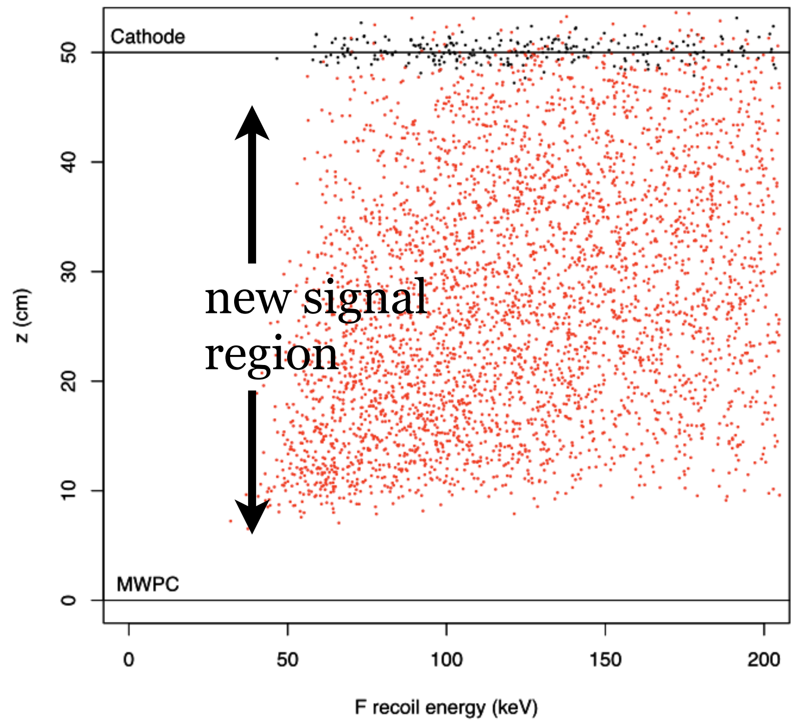
DRIFT IId Upgrades: New Analysis Paths

New z-fiducialisation means big changes to analysis underway:

- New more powerful cuts being developed
- Ability to keep events in the bulk and reject background from edge electrodes
- Introduce **mp.ratio** cut: ratio of charge in minority peaks to that in the main peak

Initial results using by-eye analysis:

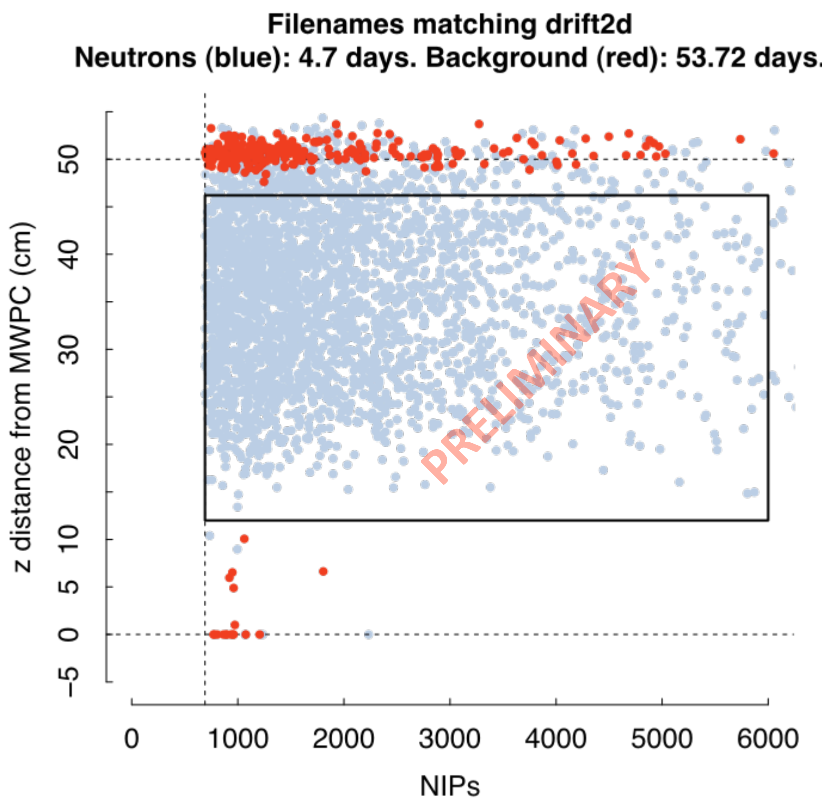




- Efficiency drop at low z due to minority peaks overlapping
- Simplified cuts and larger signal region yield improvement in ^{252}Cf calibration neutron (red points) efficiency, whilst preserving background rejection (black).

DRIFT IId First Automated Z-Analysis

First preliminary limit using automated minority carrier analysis:

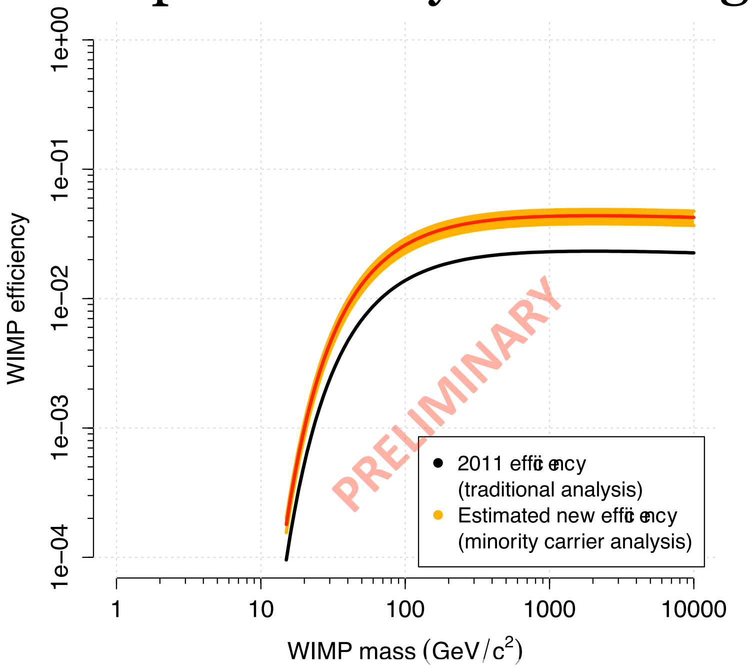


Data collected with no gas flow and a high effective threshold. Currently running with gas flow for improved oxygen stability, and a lower threshold.

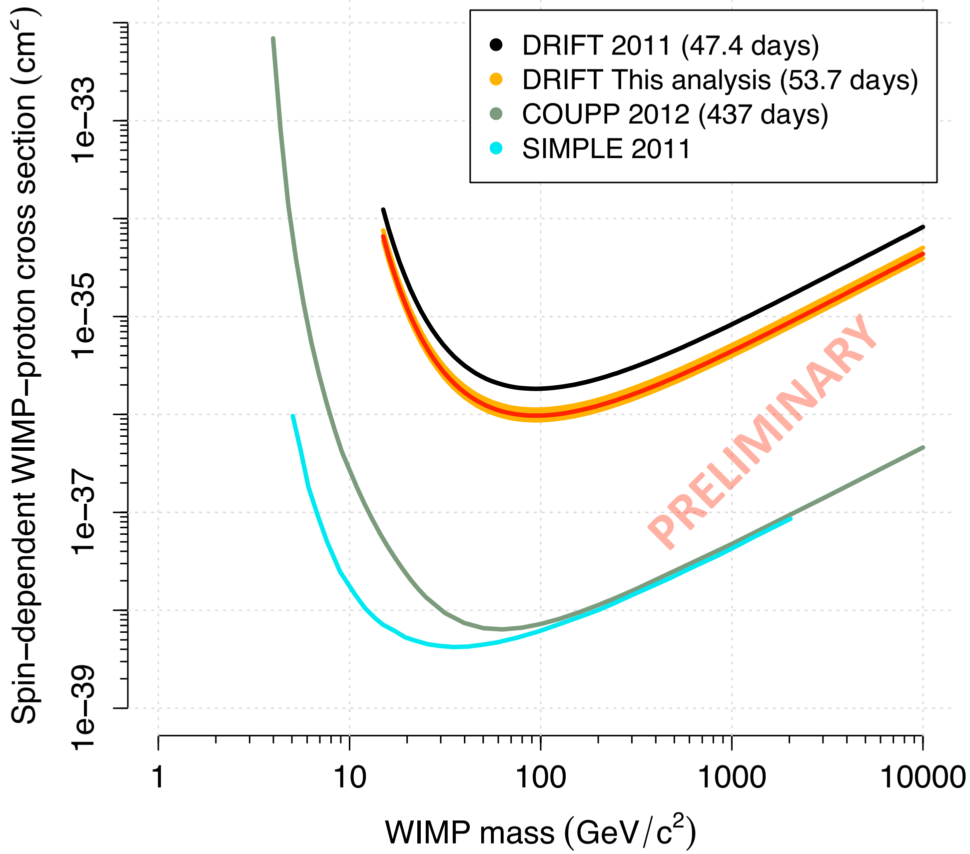
- Peak-finding algorithm developed to pick out minority carrier events in data.
- Acceptance rate ‘by eye’: 789+/- 10 events/d
- Algorithm acceptance rate: ≈ 530 events/d
- Efficiency loss at low z, where peaks are closely spaced, and high z, where S peak is suppressed.
- Cuts to remove residual background: ratio of P to main peak charge, and anode to grid charge ratio.
- Calculate **efficiency improvement factor:** ratio of neutron acceptance rate in ‘minority carrier’ data to that in ‘traditional’ data.
- Combine with 53.7 days’ bg-free livetime to estimate limits on SD WIMP-proton x section.

DRIFT IId Automated Z-Analysis Limit

First preliminary limit using automated minority carrier analysis:

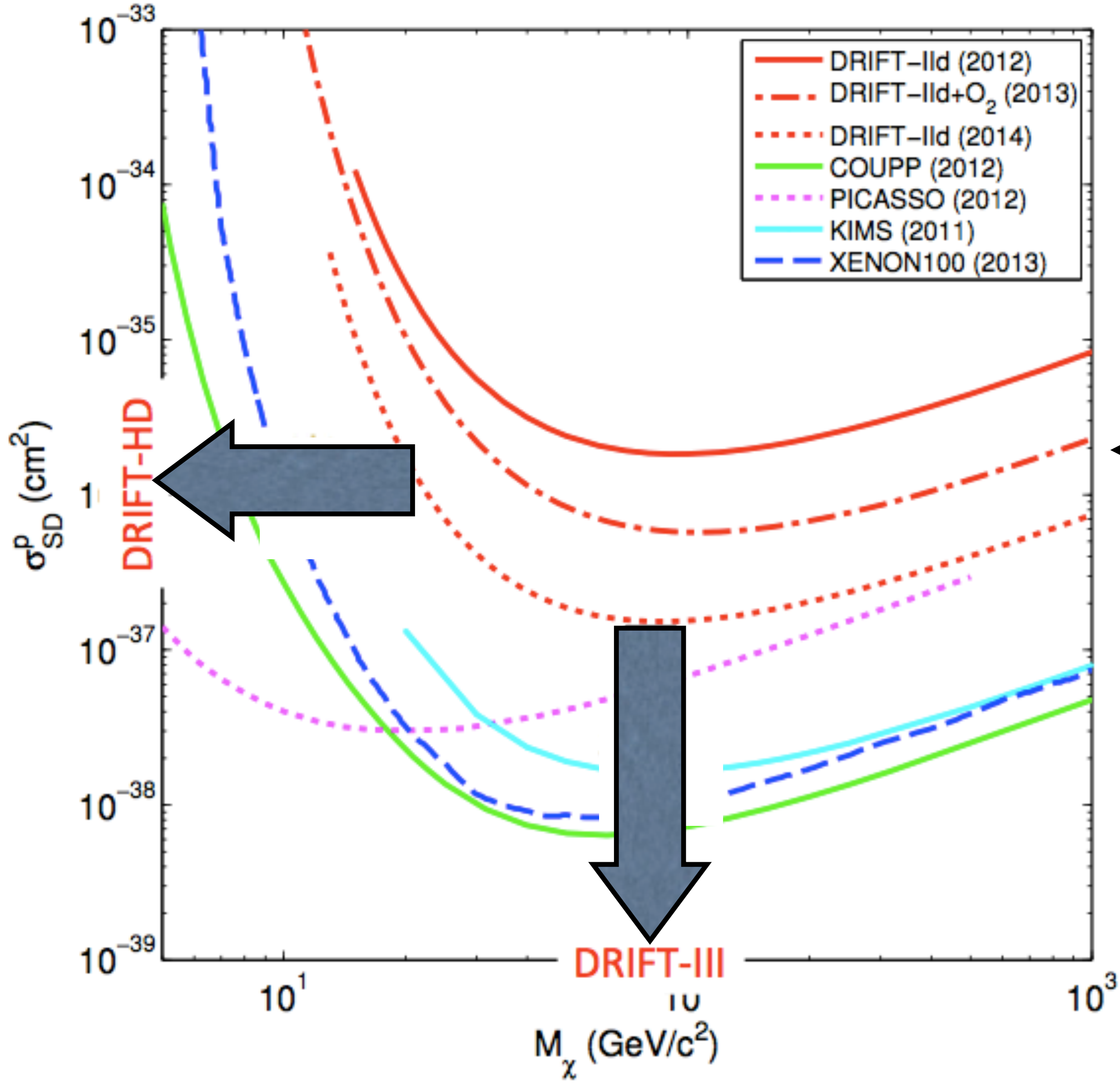


- WIMP efficiency from previous work (Daw et al. AstroPart. 35 (2012)).
- Scale up by ratio of neutron acceptance with 'traditional' and 'minority carrier' analyses
- Orange bands due to uncertainty in the neutron acceptance used to calculate the improvement factor.



Analysis inefficiencies caused by reduced trigger threshold due to reduced charge in the "majority" peak - work in progress

DRIFT IId Status and DRIFTIII prospects



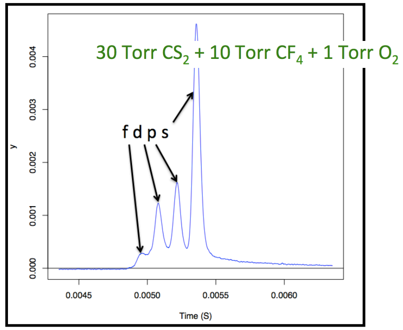
← Z-fiducialisation "by-eye" analysis

DRIFT-IId is currently background limited

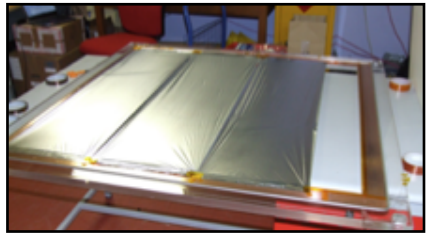
Scale-up - Is it Feasible

Many important technical advances made (DRIFT IIa-d)

- x-y-**Z** fiducialisation solved (using minority carriers)
- texturised cathode technology; intrinsic radon control works
- head-tail directionality shown
- multiple gas technology and control works
- scale-up electronics - on-going
- lower electronic noise by x5
- alternatives to MWPCs feasible
- space is not an issue



Z-fiducialistion

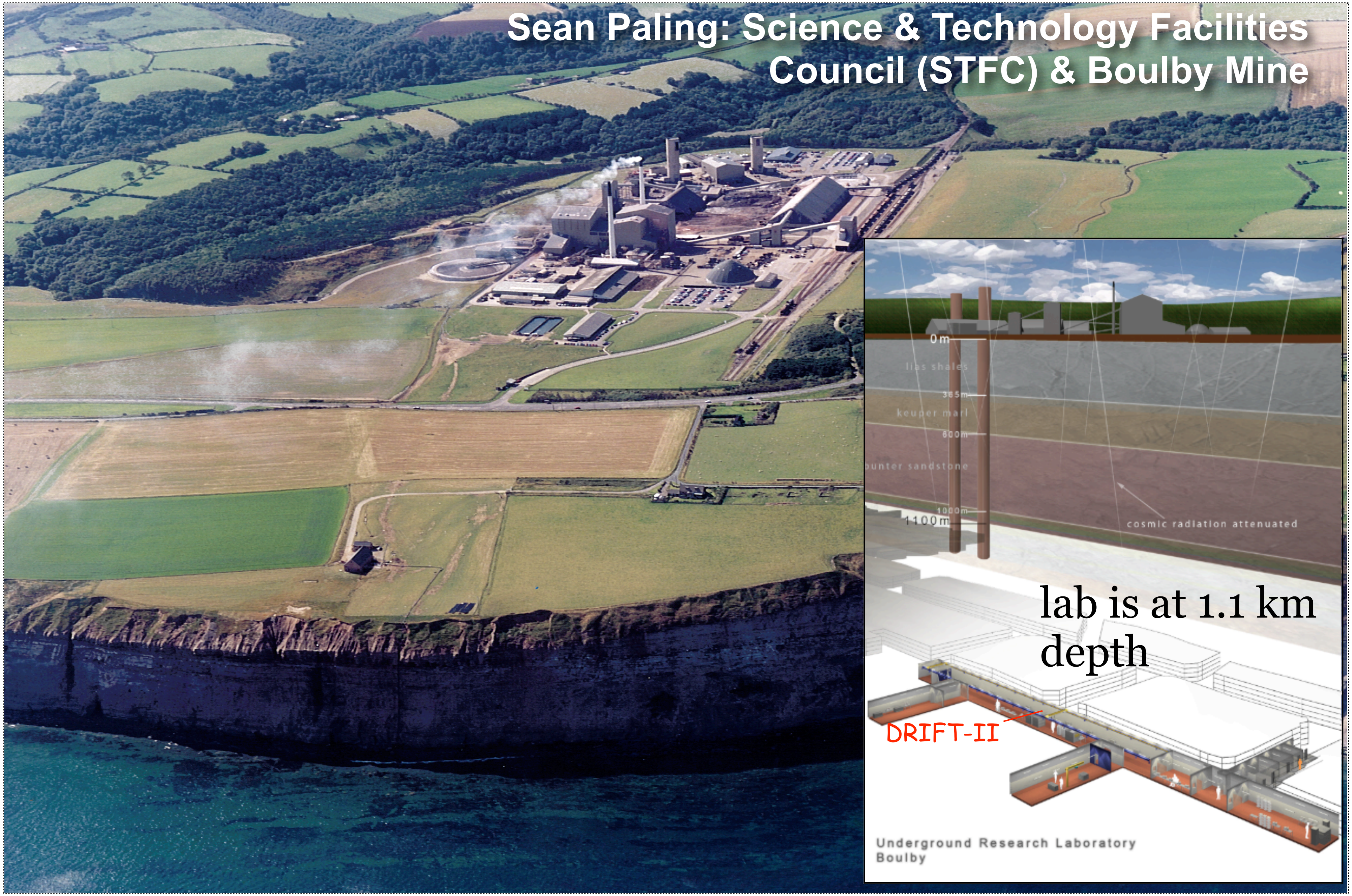


RPR redcution

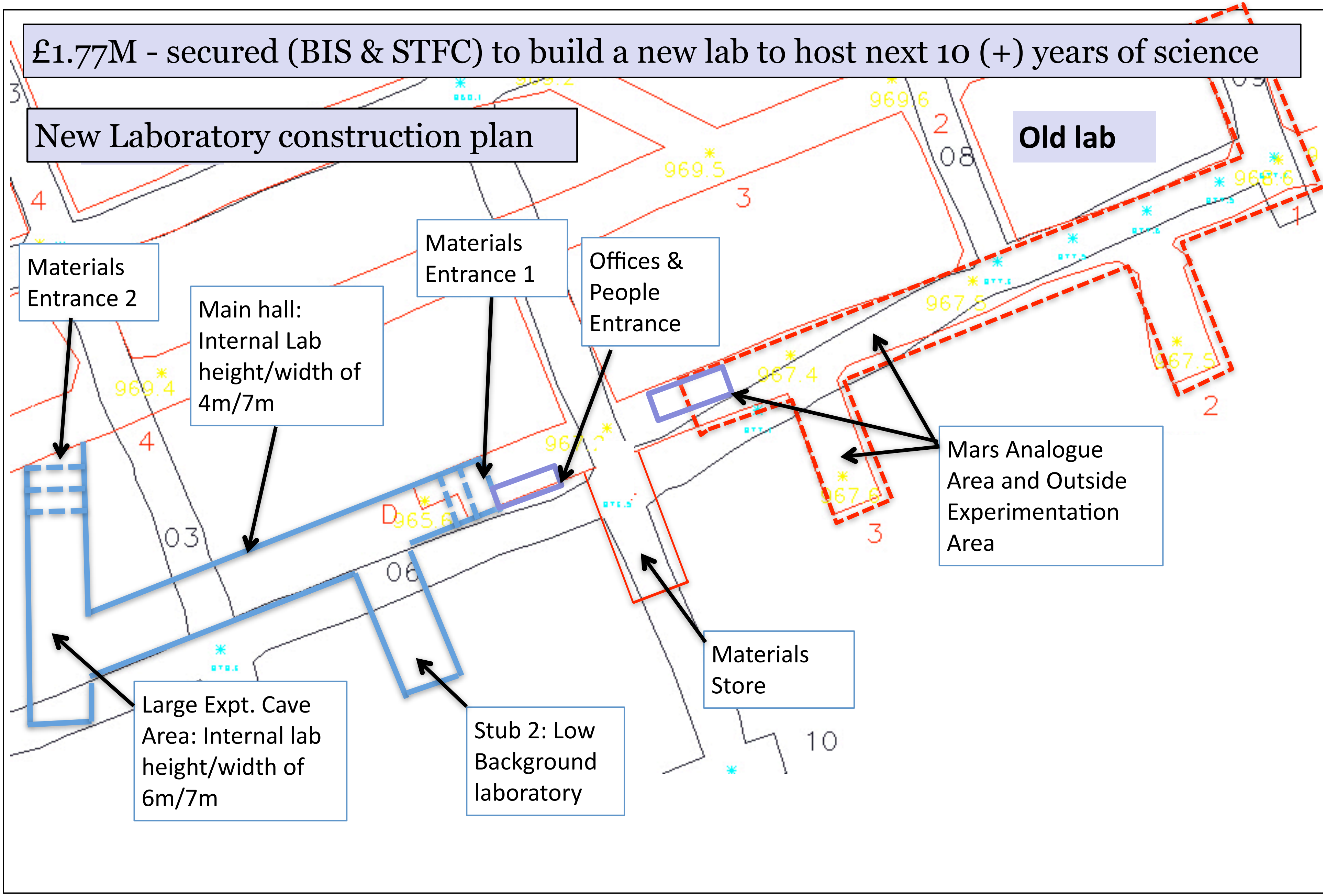
DRIFT III Specifications - 24m^3

- <1 background event/year/24m^3 (neutron, gamma, Rn control)
- directional threshold <40 keV$_{recoil}$
- head-tail sensitivity
- 1 mm wire separation in single plane - Δx and Δz < 200 μm
- full fiducialisation and all wires read out

Space for DRIFT III solved

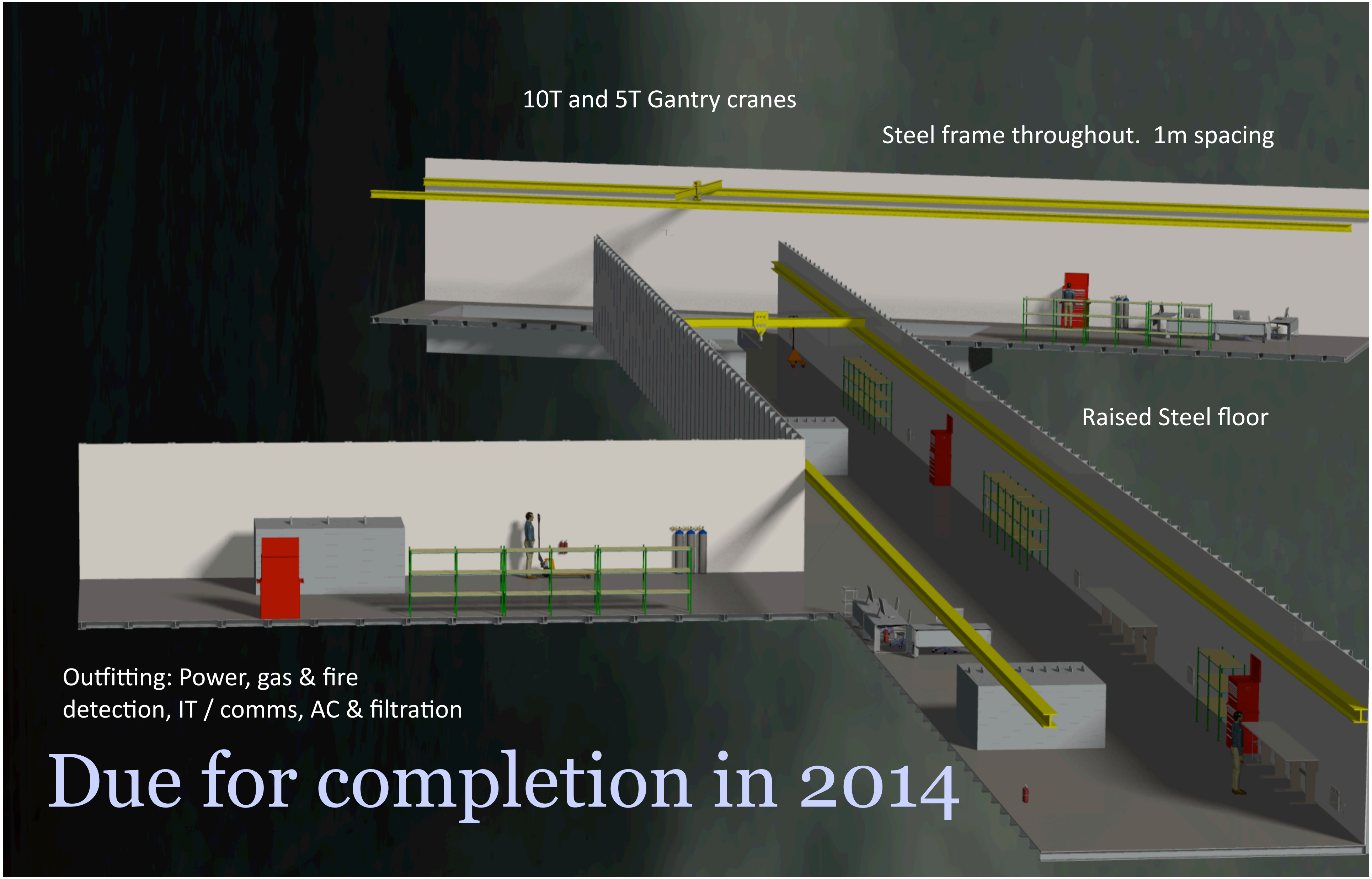


Space for DRIFT III solved



New Laboratory Details

- Large Experiments Cavern (6 x 7 m internal H x W)
- Main Hall (4 x 7 m H x W)



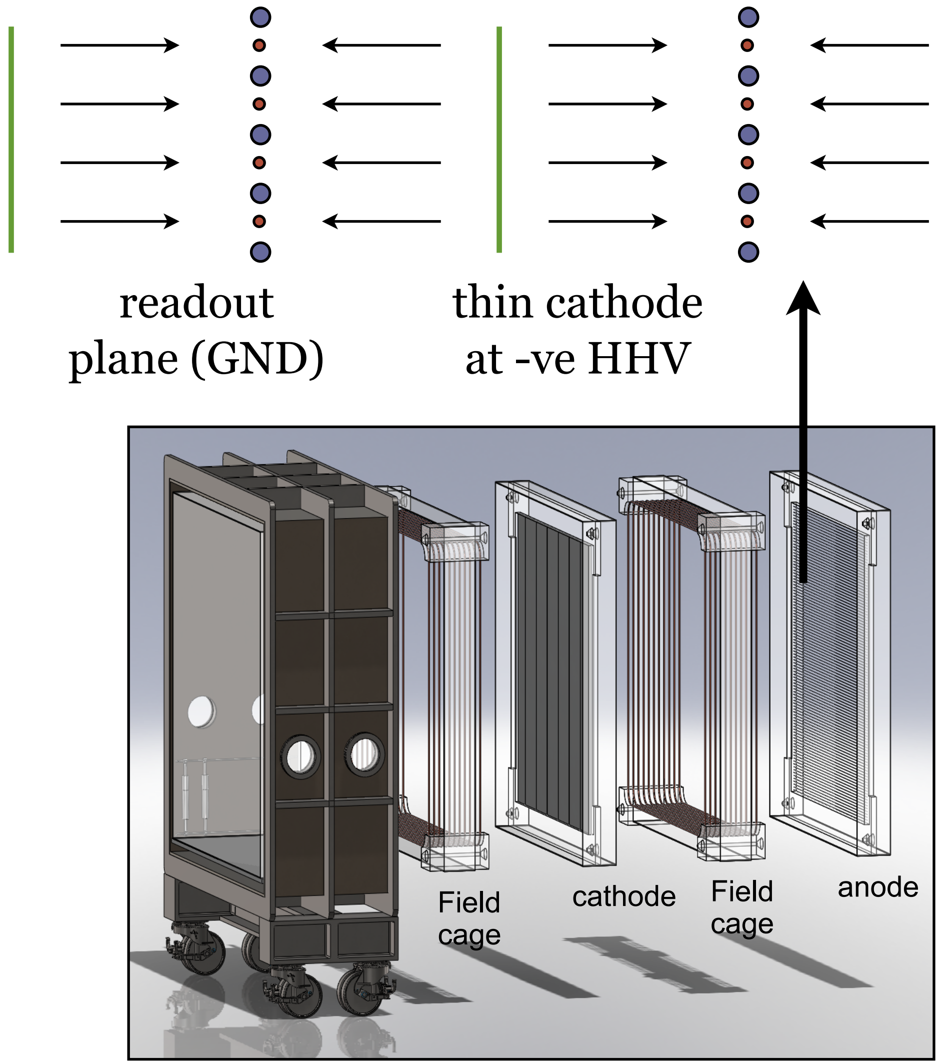
Excavation Started in January 2014

Stand well clear....

DRIFT III Readout

Sense plane 2m x 2m

- Transparent readout plane to sense two sides (eliminates the mechanical support "strong back")
- 20 µm anode (50 µm grid) diameter stainless steel wires on a 1 mm pitch
- X-wires, Y-veto strip
- Head-Tail sensitivity
- 2D readout but with 3D side veto

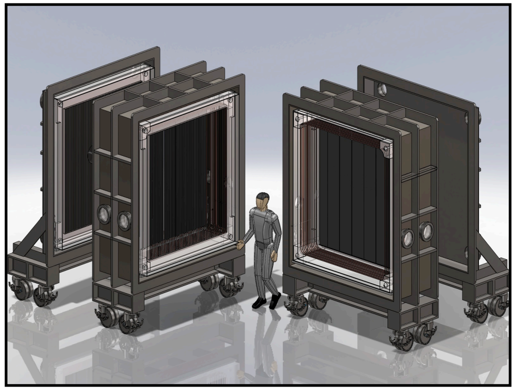


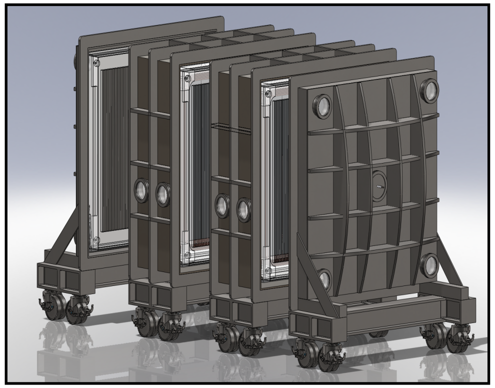
Cathode

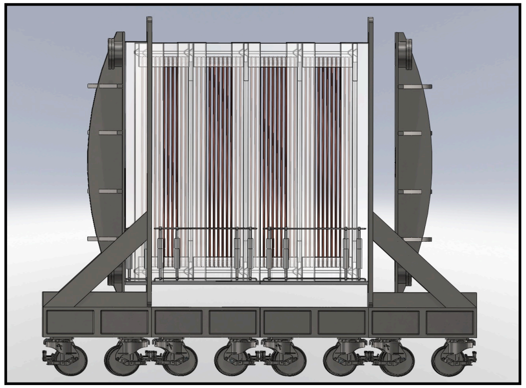
- 35 kV with well-engineered field cage and high-voltage system
- Texturised thin film
- Partial segmentation

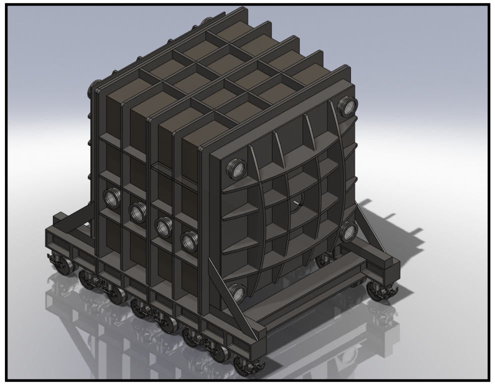
DRIFT III Unit Design and Modularity

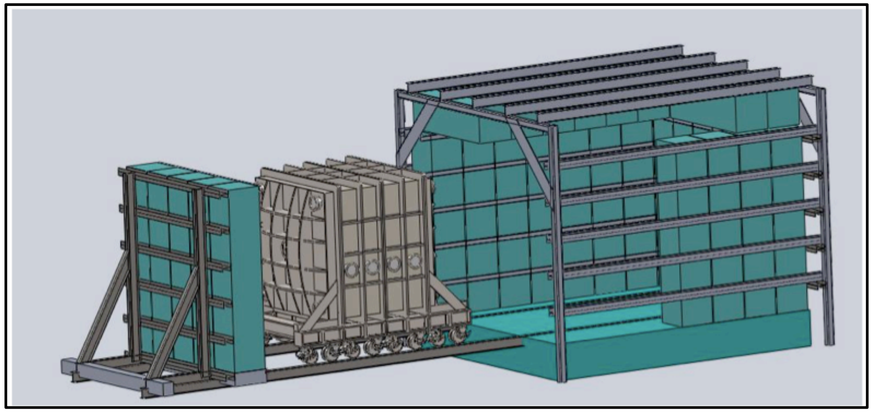
- Unit cell of 8 m^3
- Modular design, 3 unit cells to give 4 kg target - 24 m^3
- 250 of 4 kg modules gives 1 ton would fit into a standard DUSEL module or 500m tunnel at Boulby
- Water shield

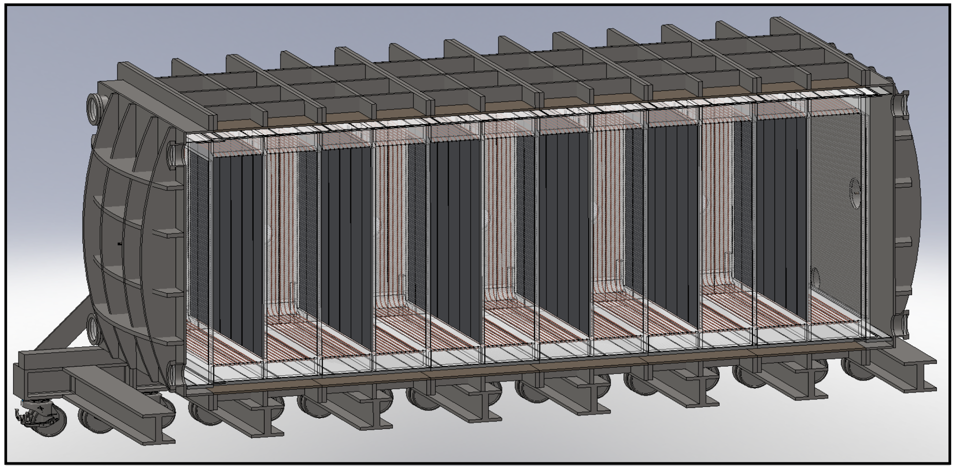












Backgrounds: Radon/RPR Control

Requirements to achieve <1 RPR event/year/24m³ feasible now

- Lower intrinsic Rn rate likely still needed by up to ~x 10-50 depending on fiducialisation efficiency

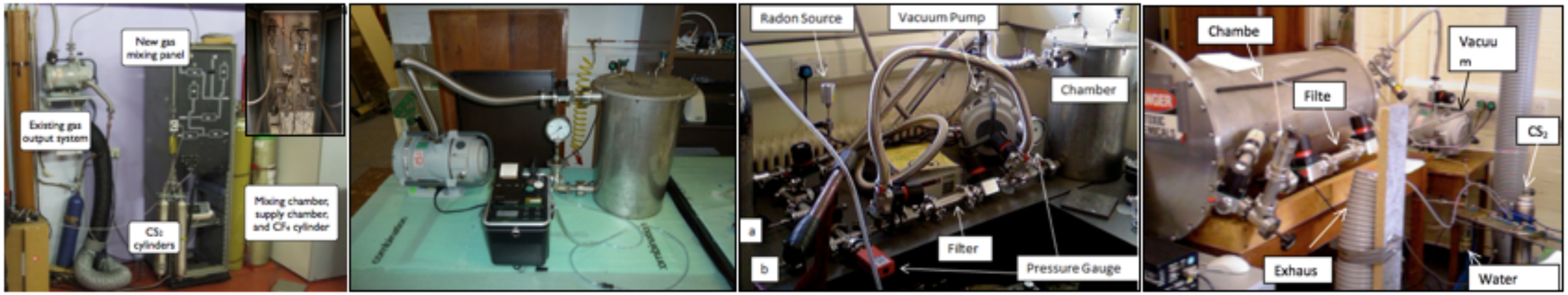
Sample	Dimensions	Vessel	E. time (days)	RH (%)	Rn emanation (atoms/s)
Example background	N/A	2	21	23	0.021 ± 0.007
Standard ribbon cables	2.56 ± 7 kg	2	6.5	23	0.50 ± 0.03
Low-Pb ribbon cables	$\sim 2.56 \pm 7$ kg	2	12	17	0.14 ± 0.01
FEP ribbon cables	$\sim 2.56 \pm 7$ kg	1	12.5	24	0.00 ± 0.02
Electronics Boxes	-	1	12	37	0.05 ± 0.01
DRIFT-IIb Grouping boards	-	1	10	37	< 0.02
DRIFT-IIb Field cage parts	-	1	7	33	< 0.03
HV and misc. cables (standard insulation)	-	2	7	19	0.04 ± 0.02
RG58 signal cables (standard insulation)	l: 72 m	2	12.5	24	0.36 ± 0.03
RG58 signal cables (PTFE insulation)	l: 72 m	1	20	23	0.00 ± 0.02
Nitrile O-ring (DRIFT vessel door seal)	ID: 6.42 m. D: 9.5 mm	1	15	33	0.09 ± 0.01
Example background	N/A	S	8.24	28.4	0.0206 ± 0.0023
Example background	N/A	2	8.30	11.6	0.0201 ± 0.0053
Nitrile O-ring	ID: 6.42 m. D: 9.5 mm	2	8.7	26.2	0.1204 ± 0.0136
HV cables (standard insulation)	25 m. D: 3.0 ± 0.5 mm	2	9.3	14.6	0.1069 ± 0.0134
Standard ribbon cables	2.56 ± 7 kg	2	9.1	18.2	0.4036 ± 0.0293
10 rubber bungs (truncated cones)	D1: 16 mm. D2: 12 mm. h: 25 mm	S	7.6	38.5	0.0464 ± 0.0033
Aluminized 0.9 µm Mylar sheet	0.59 g	S	10.36	21.9	0.0045 ± 0.0018
Teflon-encapsulated O-ring (half full length)	ID: 3.2 m. D: 10 mm	S	8.0	25.5	0.0052 ± 0.0025
20 Silicone bungs	D1: 16 mm. D2: 12 mm. h: 25 mm	S	17.4	27.0	0.0166 ± 0.0017
HV cables (Teflon-coated)	l: 25 m. D: 3.0 ± 0.5 mm	S	9.2	45.5	0.0053 ± 0.0019
4 two-layer PCBs (made from FR-4)	$150 \times 100 \times 1.5$ mm	S	7.2	20.6	0.0011 ± 0.0025
4 Kapton-insulated traces w/plastic plugs	Each 365×65 mm	S	9.2	26.9	0.0111 ± 0.0021
Thermoplastic (TPE) ribbon cable roll	l: 30 m. Wound roll V: 2.23 L	2	9.4	12.6	0.0074 ± 0.0073
DRIFT-IId - complete detector	N/A	1	8.41	68.8	0.2694 ± 0.019
DRIFT-IId (zero emanation time)	N/A	1	0.00	76	0.0126 ± 0.0114

← radon emanation results

Radon/RPR strategy:

- x-y-**Z** fiducialisation
- texturised cathode
- material selection
- acid etch of MWPC/CPA
- new radon scrub and gas recirc.

- DRIFT intrinsic radon emanation and control becoming well understood



R&D on gas recirculation and radon scrubbing with carbon filters

Backgrounds: Neutron Control

Requirements to achieve <1 neutron event/year/24m³ feasible now

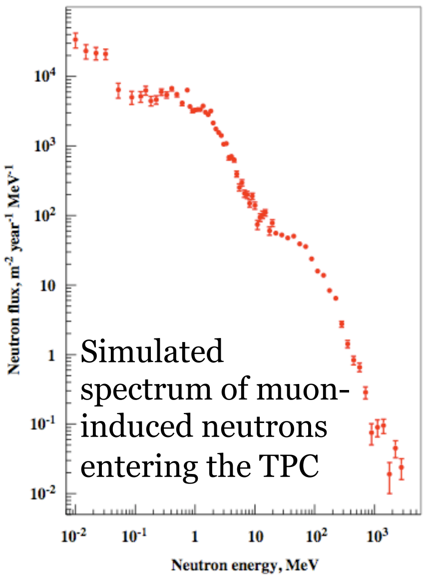
- 40 g cm^{-2} water/CH_2 shielding against rock neutrons (estimates)
- Assumes nominal selected steel U, Th, and no muon veto (internal or external)

M.J. Carson et al NIM A 546 (2005) 509–522

Estimated neutron backgrounds per year at 10-50 keV recoil energies

		kg	Rock	Muons	Detector	Total
	DRIFT II	0.167	0.01	0.12	0.06	0.19
	24 m³ (as multiple DRIFT IIs)	4.00	0.24	2.88	1.56	4.68
DRIFT III	24 m³ using steel, no muon veto	*4.00*	*0.20*	*2.00*	*1.50*	*3.70*
DRIFT III	24 m³ acrylic, no muon veto	*4.00*	*0.20*	*<1.00*	*<1.00*	*0.2-2.0*

PRELIMINARY



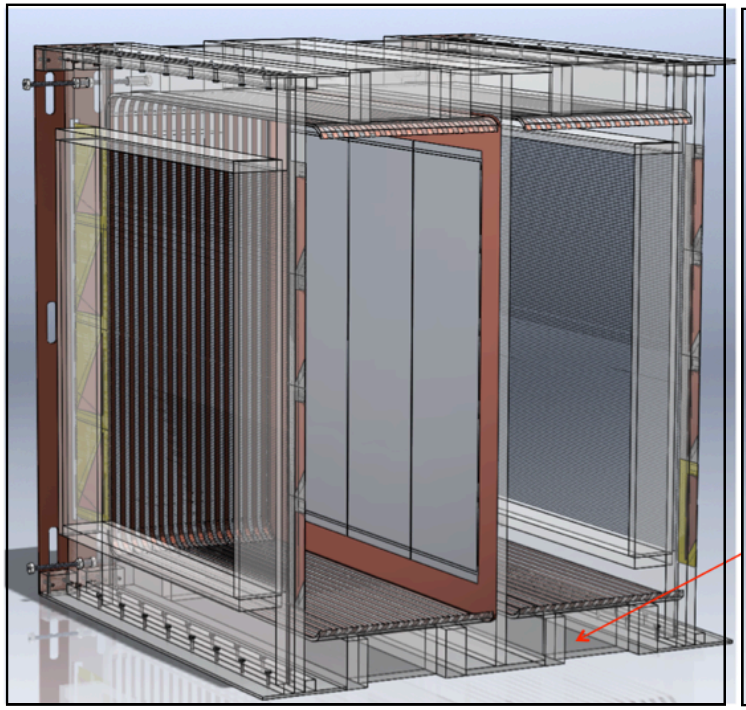
Conclusion for DRIFT III.1 module (prelim):

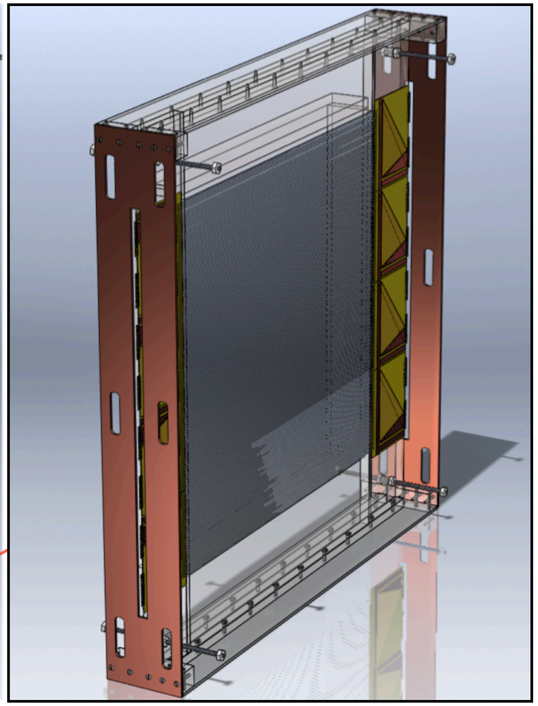
- Requires 40 gcm^{-2} H_2O/CH_2 neutron shield (like DRIFT II)
- Steel construction just about alright, will need careful selection for U, Th *optimization, selection, internal CH?*
- No need for muon active veto at Boulby for single module but likely for 24 m³

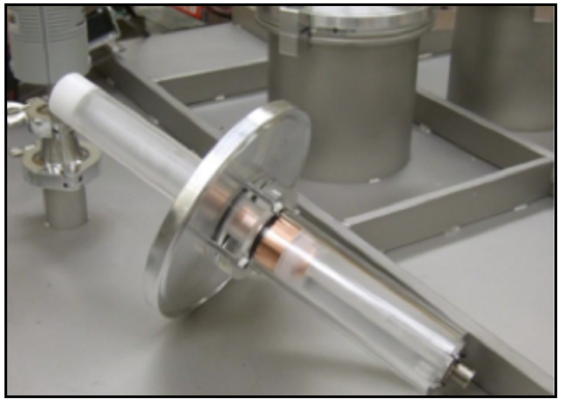
DRIFT IIe - a Test-Bed for DRIFT III

New DRIFT IIe will test all the new technologies needed for DRIFT III

- Minority carrier 3D fiducialisation and texturised thin cathode
- Robust, low radon MWPC cage and cathode engineered suitable for 2 x 2m
- New vessel with reduced outgassing and leaks
- New simpler gas control system with automated multiple new gases
- Test of gas recirculation and radon scrubbing
- New electronics allows all wire readout

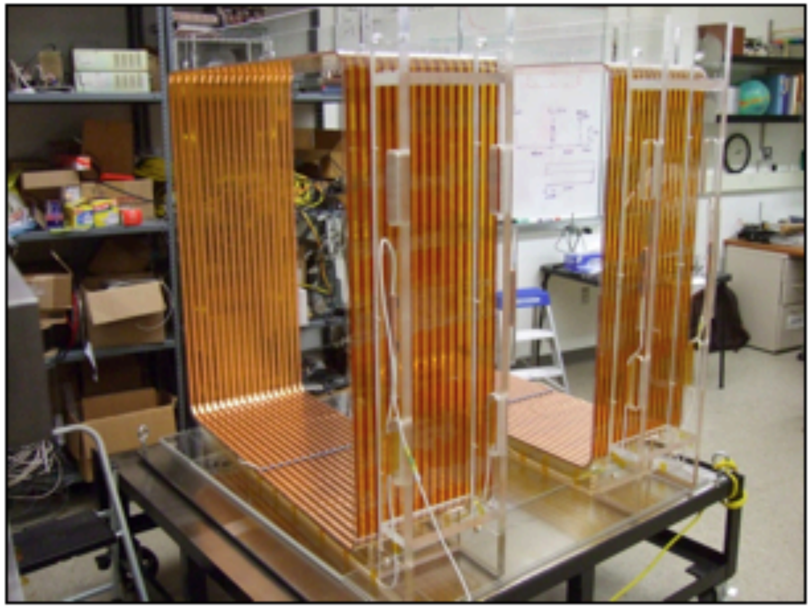
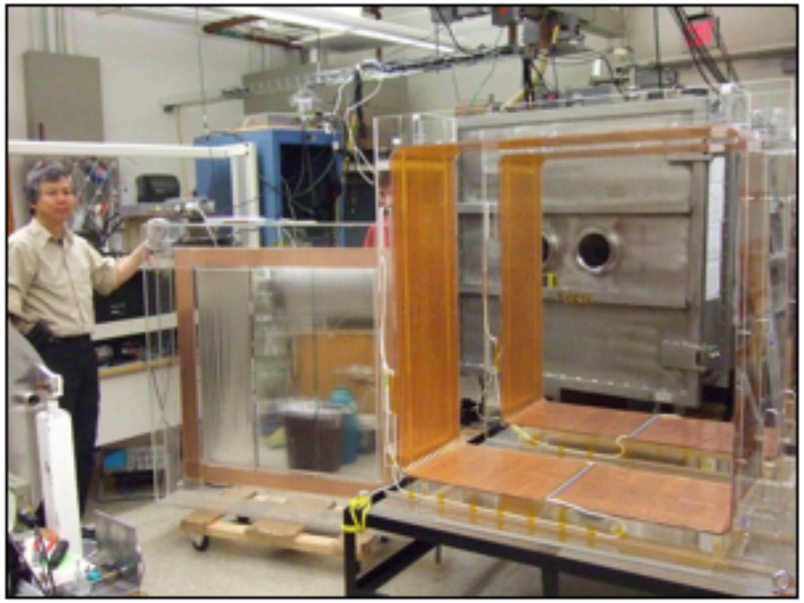
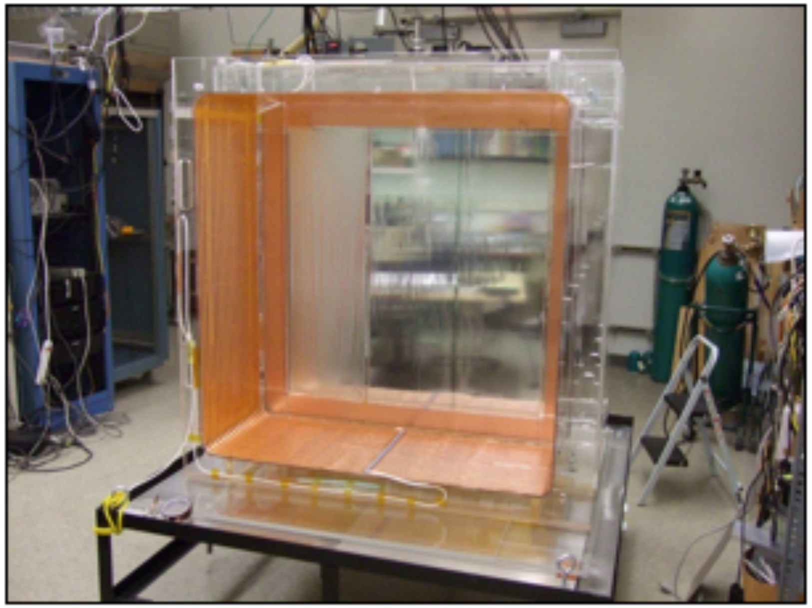
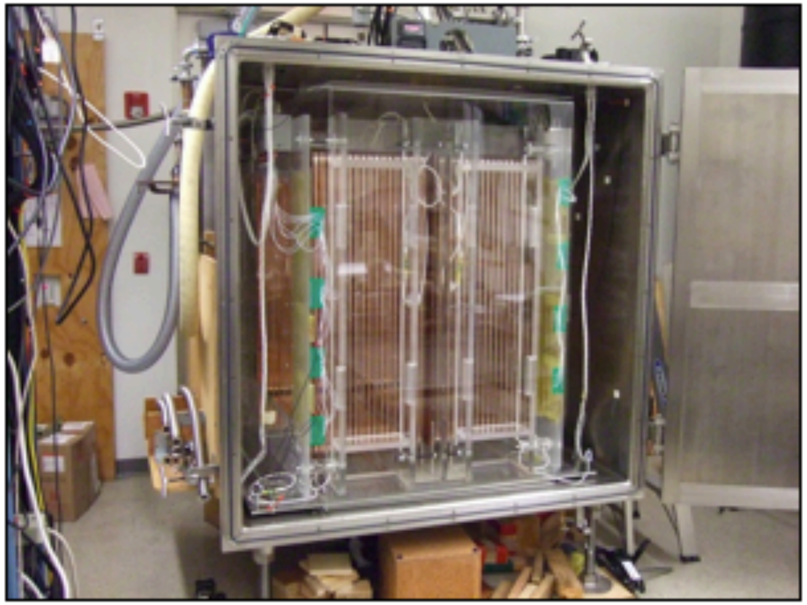






DRIFT IIe - a Test-Bed for DRIFT III

New DRIFT IIe final construction

DRIFT IIe - a Test-Bed for DRIFT III

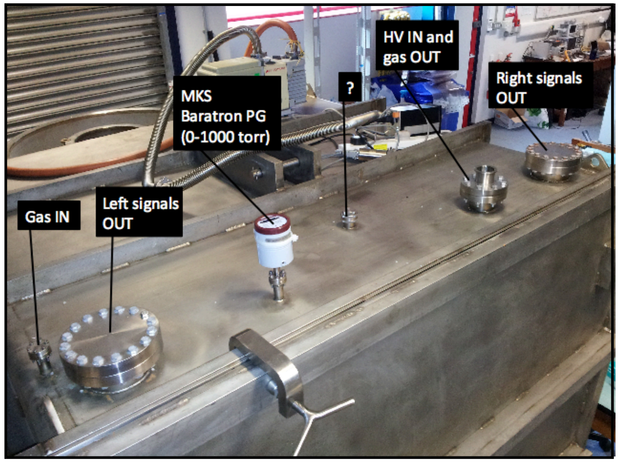
- Leaves Sheffield

- Arrives underground

- Arrives underground

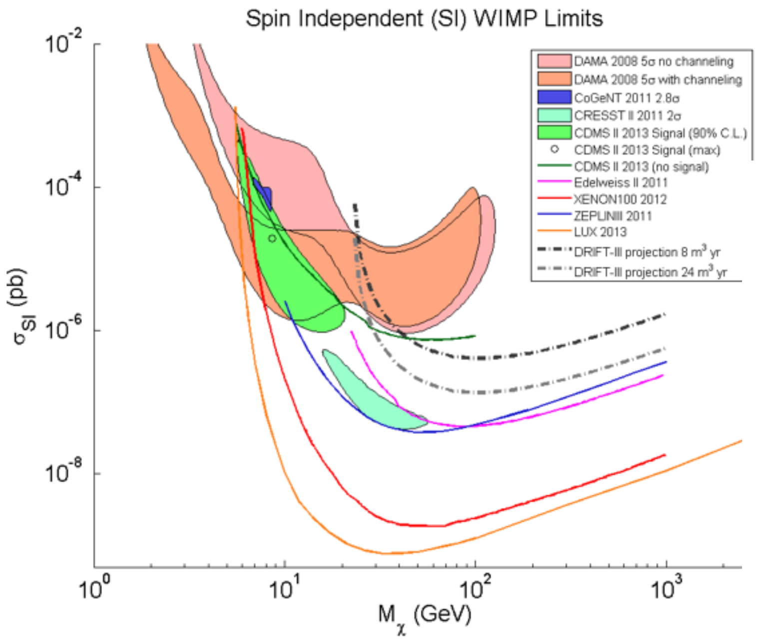
- Installed in shielding March 2012

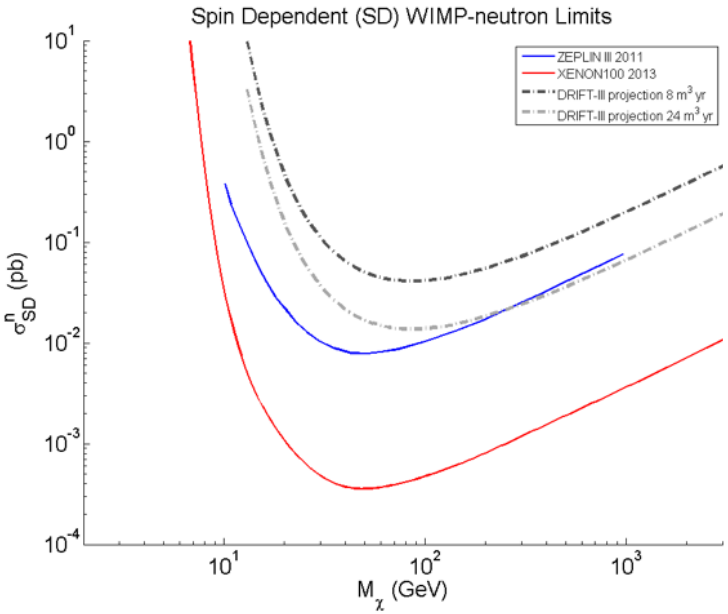
- Installed in shielding March 2012



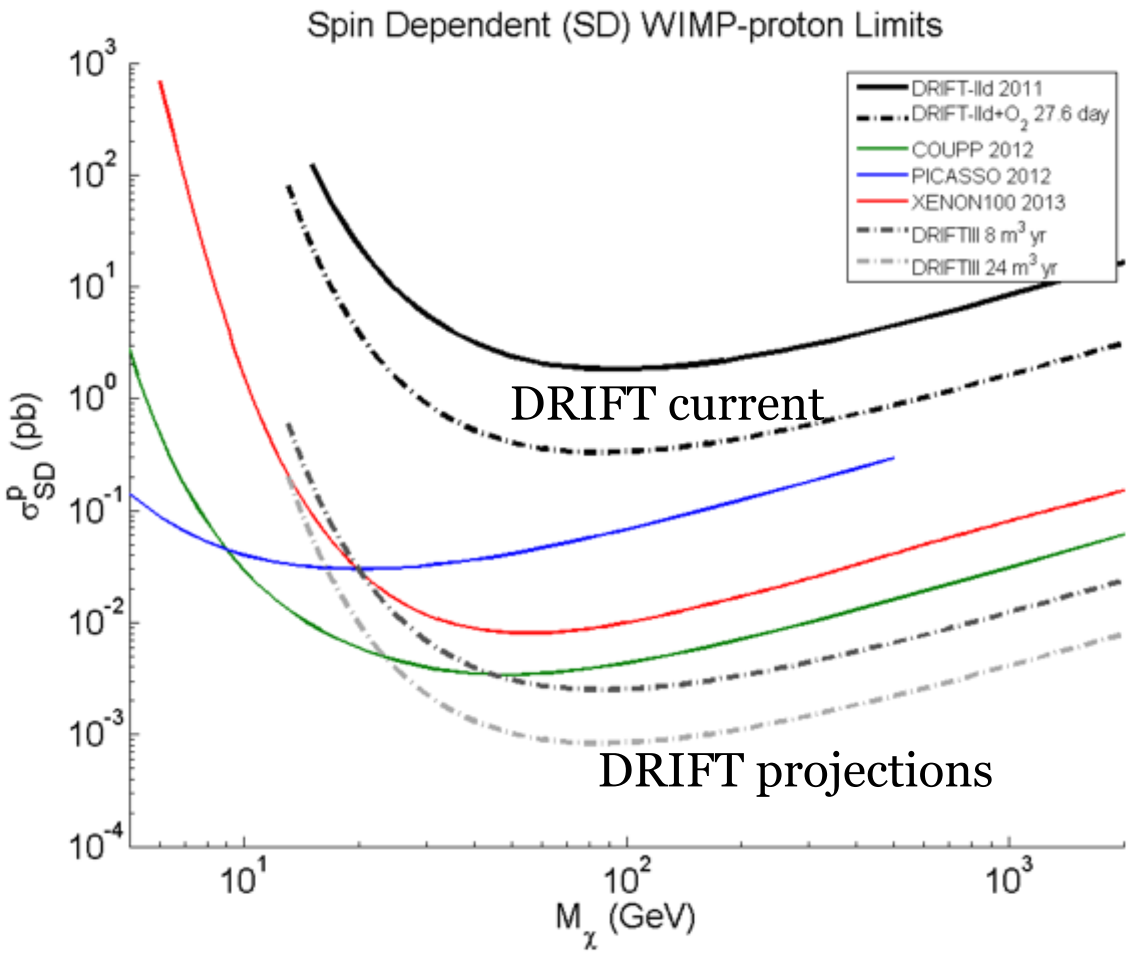
- Top plate details

DRIFT IIe/III goals





Note: only DRIFT has directional sensitivity on these plots



- Apology - not all latest results included yet

Conclusions

- DRIFT is the ultimate WIMP experiment because it seeks a SIGNAL
- It's directional so in principle no known background, <u>not even solar neutrinos</u>?
- Introduction of minority carrier Z-fiducialisation and RPR reduction means DRIFT II is now background limited
    - Initial by-eye and first automated analysis of 54.4 live days has yielded improved limits by a factor ~x3
    - Limitation by high threshold and poor gas control has now been rectified so expect further improvement
- DRIFT II/III is competitive with non-directional expts for WIMP-SD
- DRIFT III is the next step - upgrade in sensitivity by ~x30
- DRIFT IIe will check all new techniques needed for DRIFT III
- Ultimate volumes for directionality are tough but not absurd nor necessarily unaffordable