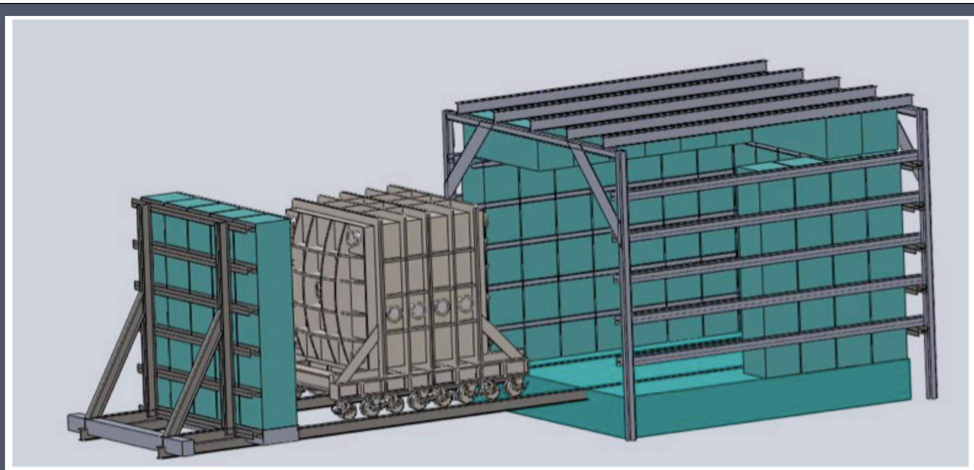
The DRIFT Directional Dark Matter Experiments....

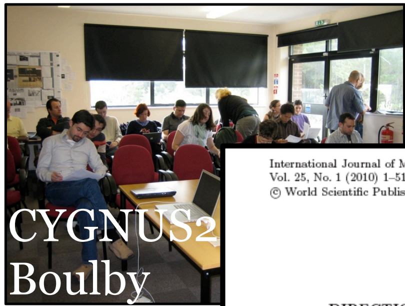


Neil Spooner, University of Sheffield
DRIFT collaboration, Boulby
(Occidental, UNM, USC, Sheffield, Edinburgh, STFC)

- Directionality
- DRIFT II backgrounds
- DRIFT II unblind and blind analysis
- DRIFT III and scale-up

for the collaboration - contributions from many →

CYGNUS Workshops



CYGNUS 2007

First Workshop on Directional Detection of Dark Matter

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…oratory, UK

…rs meeting

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THE CASE FOR A
DIRECTIONAL DARK MATTER DETECTOR AND
THE STATUS OF CURRENT EXPERIMENTAL EFFORTS

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White Paper
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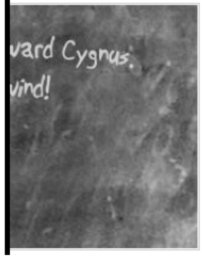
…tter Detection



…of Technology
… 11-13, 2009

…1

June 8-10, Aussois,
France

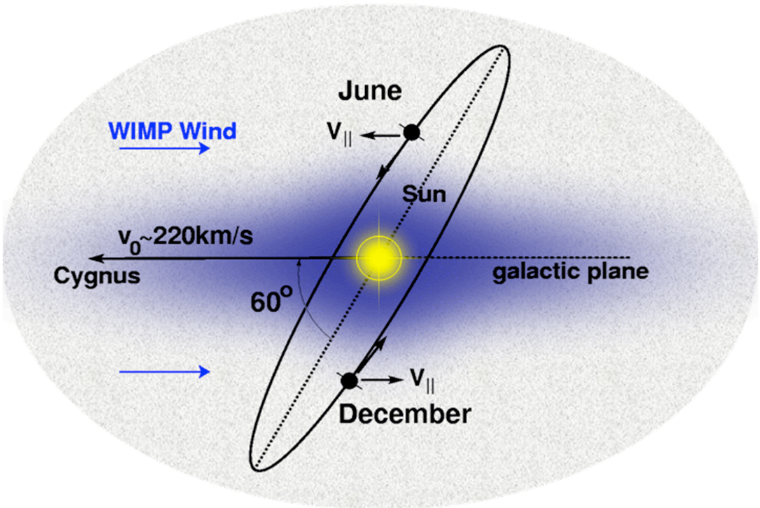
13 Directional R&D Challenges

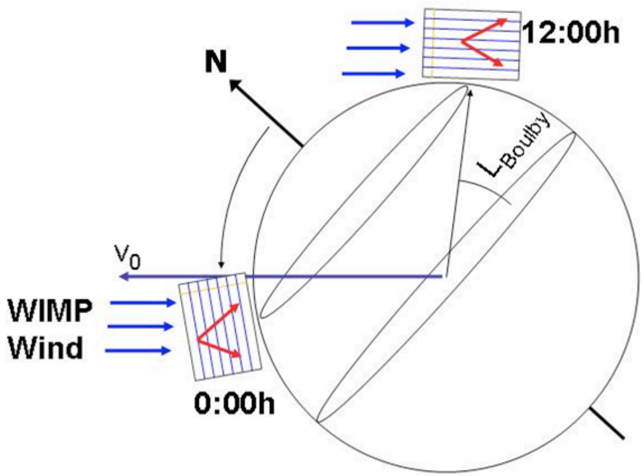
Techniques | Implementation | Theory

1. Development/demonstration of **directional sensitivity** for low energy nuclear recoils
2. Development/demonstration of **head/tail discrimination** for low energy nuclear recoils
3. Development/demonstration of **background discrimination** and **reduction**
4. Demonstration of **robustness and stability** for long-term operation
5. Selection/optimisation of **gases or gas mixtures** for SD and SI sensitivity
6. Determination of **gas parameters**, gains, sensivities, W and form factors
7. Development of **end-to-end simulations**
8. Development/optimisation of **readout techniques** and **instrumentation**
9. Optimisation of **gas pressure** (or pressures) for directional and non-directional operation.
10. Development/demonstration of **cost reduction** techniques for **scale-up**
11. Assessment of **infrastructure requirements** – size, depth, vetos?
12. Study of **halo / cosmology theory** and **likely science reach**.
13. Study of **wider applications**: KK axions? DAMA?

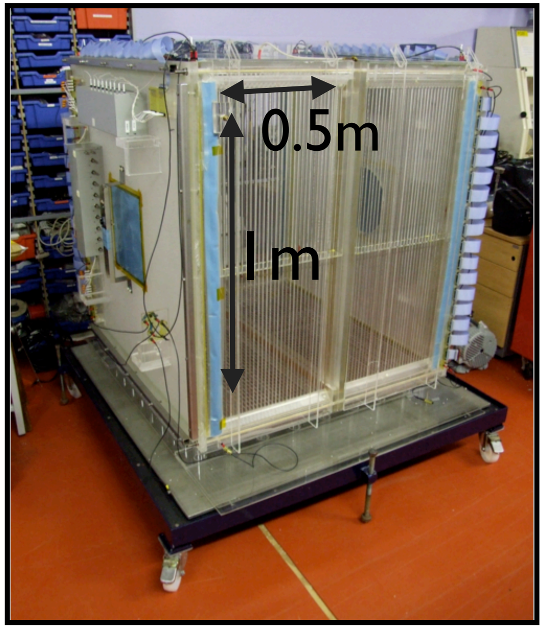
Dark Matter Signals
and directionality

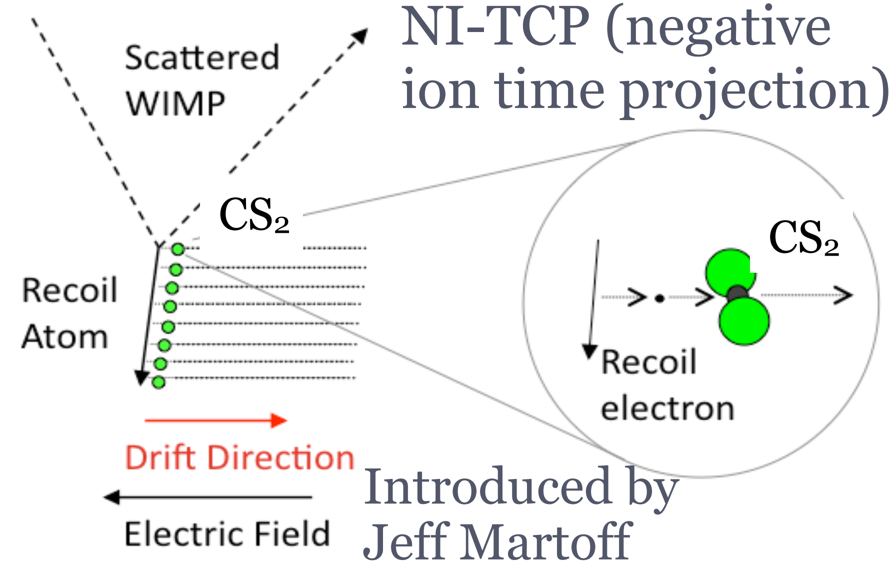
- Motion of the Earth through a static WIMP 'halo' -> Earth is subject to a 'wind' of WIMPs
- of average speed ~220kms^{-1} coming roughly from the direction of the constellation Cygnus.
- The Earths rotation relative to the WIMP wind -> Direction changes by ~90° every 12 hours





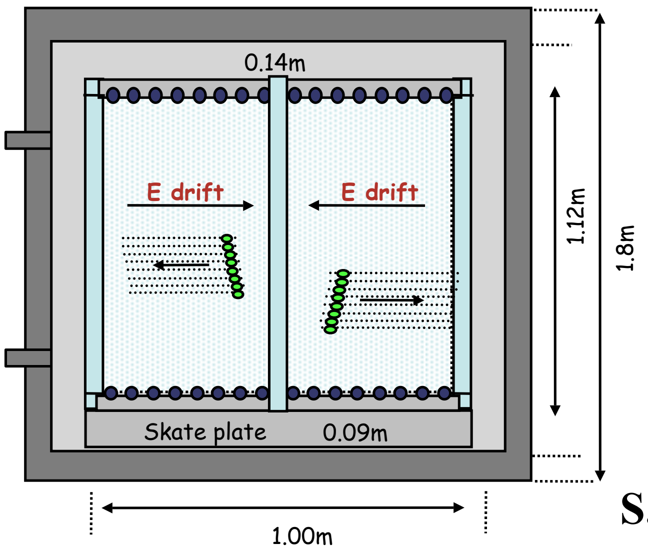
DRIFT II Concept





NI-TCP (negative ion time projection)

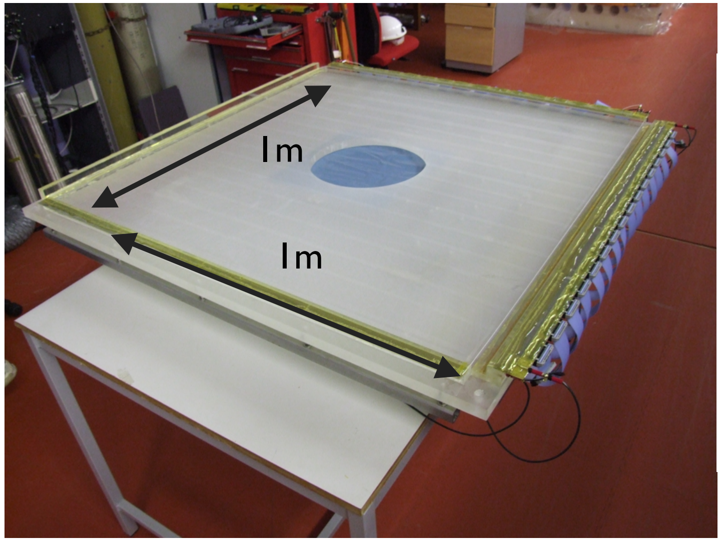
Introduced by Jeff Martoff

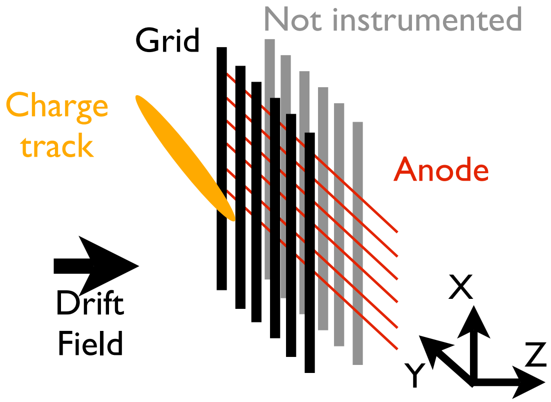


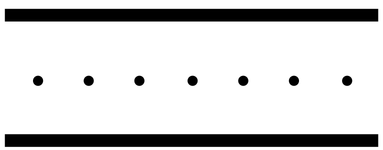
- 1 m^3 active volume - back to back MWPCs
- Gas fill 40 Torr CS_2 => 167 g of target gas
- 2 mm pitch anode wires left and right
- Grid wires read out for Δy measurement
- Veto regions around outside
- Central cathode made from 20 μm diameter wires at 2 mm pitch
- Drift field 624 V/cm
- Modular design for modest scale-up

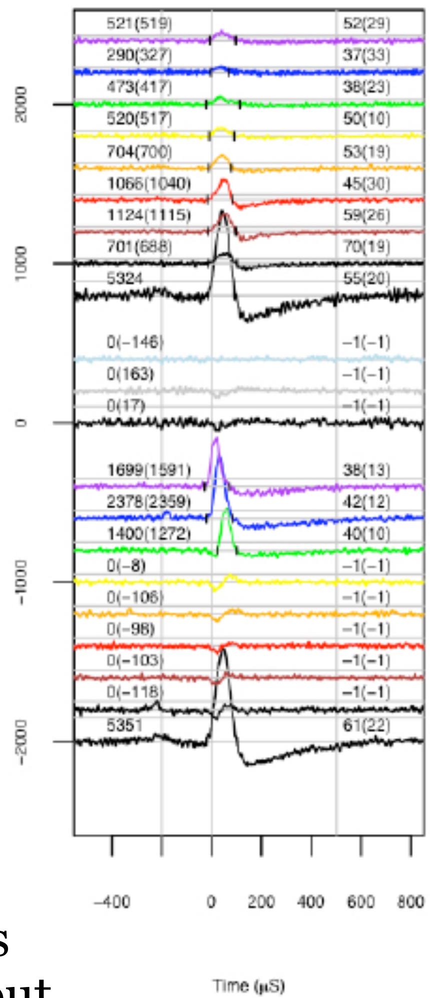
S. Burgos et al., Nucl. Instr. Meth. A 584, 114 (2008)

MWPC Readout









ΔX: Number of anode wires crossed
ΔY: Progression across grid wires
ΔZ: Drift time between start and end of track

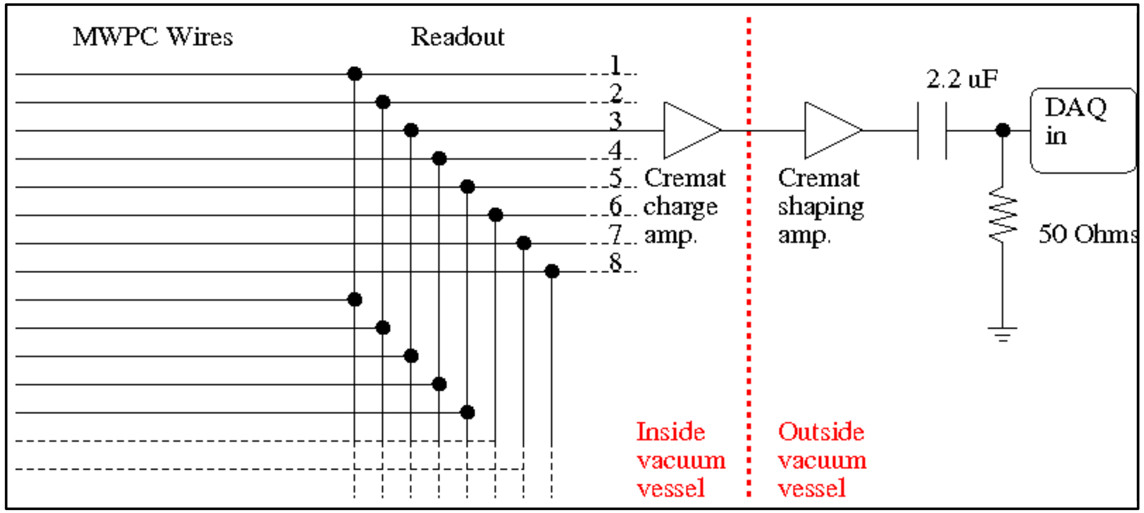
- Anode plane of 512 20μm wires with 2mm pitch
- 2 cathode planes of 512 100μm wires perpendicular to anode plane, 2mm pitch - one of which is read out

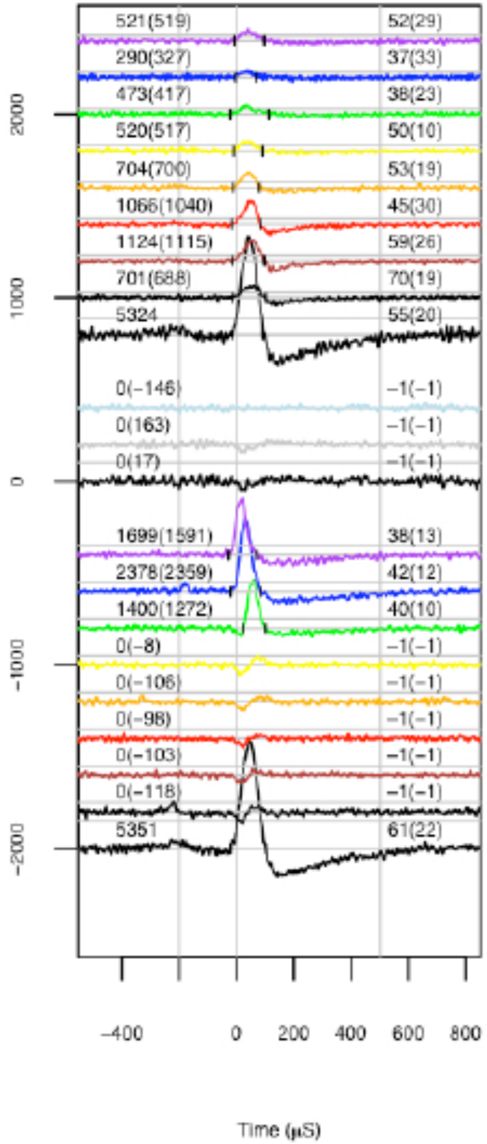
Multiplexed to 18 channels of digitised waveform output for 1m² readout plane

Simple, cheap & scalable

MWPC Readout

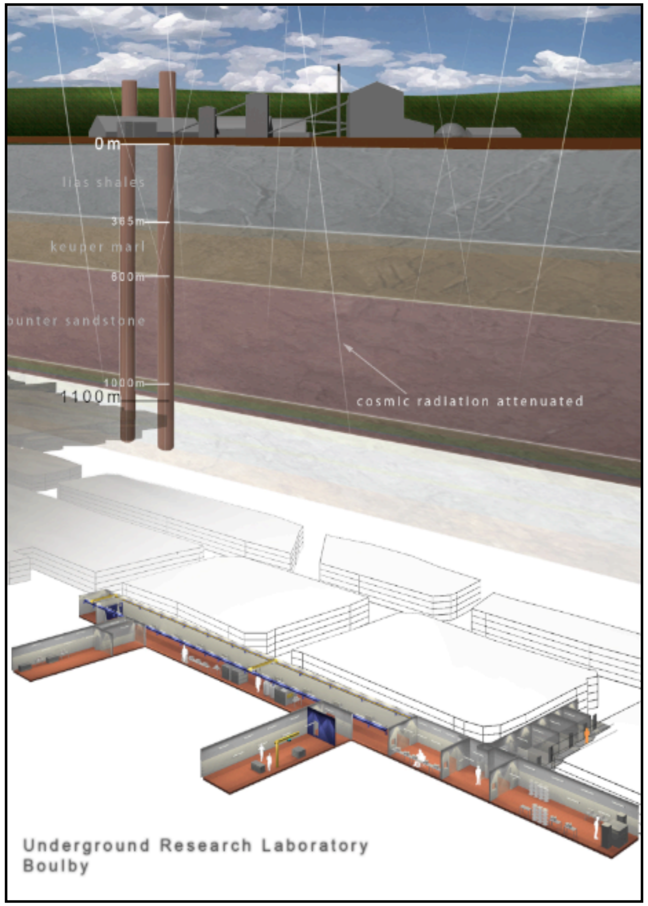
- Multiplexed to 8 lines of output per plane
- 1m² 2D readout - 18 ADC channels (8×anode, 8×grid, 2×veto)
- Cheap and scalable
- No absolute x-y position - only dx, dy





Boulby Mine (UK)

- Current site (1.1 km deep) in salt rock
- Deeper excavation underway in dolomite rock
- Suitable for a large TPC!



DRIFT II Shielding

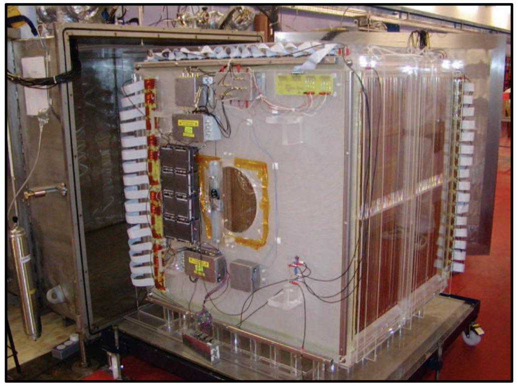
Simple and cheap poly pellet neutron shielding

- Lab at depth of 1100m (2800 m.w.e)
- Cosmic ray flux = 4.1×10^{-8} cm^{-2} s^{-1} [M. Robinson et. al, NIM A 511 (2003)]
- Polypropylene pellets of >67cm depth on all sides
- Equivalent to 40g/cm^2 solid hydrocarbon passive shielding
- Lead shielding not required due to detector's inherent insensitivity to electron recoil events

DRIFT II Summary

- Operational in the Boulby Mine since 2001
- DRIFT-I, DRIFT-IIa, DRIFT-IIb, DRIFT-IIc, DRIFT-IId
  - Low threshold potential (< 3 keV, S-recoil)
  - Directional signatures (and 3D reconstruction)
  - Head-tail (sense) is feasible, and verified by theory
  - Radon backgrounds (RPR) understood reduced
  - *Fiducialisation via +ve ions looks to work*
  - *Thin cathode works*
  - Neutron backgrounds understood
  - Stable and safe operation with CS_2 and CF_4
  - Competitive SD WIMP-P limits <u>with directionality</u>

BIG PROGRESS in the last 2 years

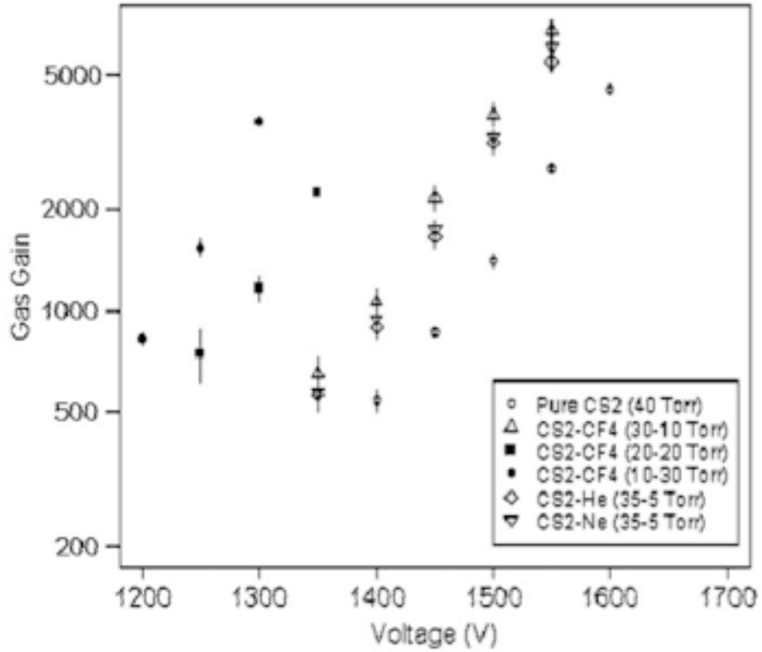


B. Morgan, A.M. Green and N.J.C. Spooner, Phys Rev D71 (2005) 103507
P. K. Lightfoot, N. J. C. Spooner et al., Astropart. Phys. 27 (2007) 490
S. Burgos et al., Astropart. Phys. 28 (2007) 409
N.J.C. Spooner, J. Phys. Soc. Japan, 76 (2007) 11101
E. Tziaferi et al., Astropart. Phys. 27 (2007) 326
K. Pushkin et al., (2008) arXiv:0811.4194
S. Burgos et al., Nucl. Instrum. and Meth. in Phys. Res. A 584 (2008) 114
S. Burgos et al., JINST 4 (2009) P04014
S. Burgos et al., Nucl. Instrum. and Meth. in Phys. Res. A600 (2009) 417
S. Burgos et al., Astroparticle Physics 31 (2009) 261
N.J.C. Spooner et al. Astroparticle Physics 34 (2010) 284
E. Daw et al, sub Astroparticle Physics (2011) - arXiv:1012.5967

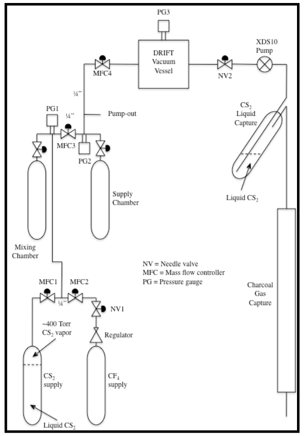
→ Ready for new experiment DRIFT III Module - $24m^3$

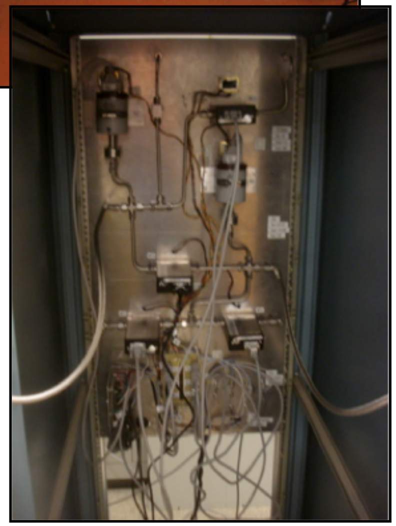
DRIFT IId - Gas Mixtures

- Recent emphasis on backgrounds and spin-dependent limits
- Measured ionization, gain, drift velocity and diffusion in various CS_2 gas mixtures **with CF_4**
- DRIFT-IId new set-up with CS_2/CF_4 (=DRIFT-IIb + gas mix system)



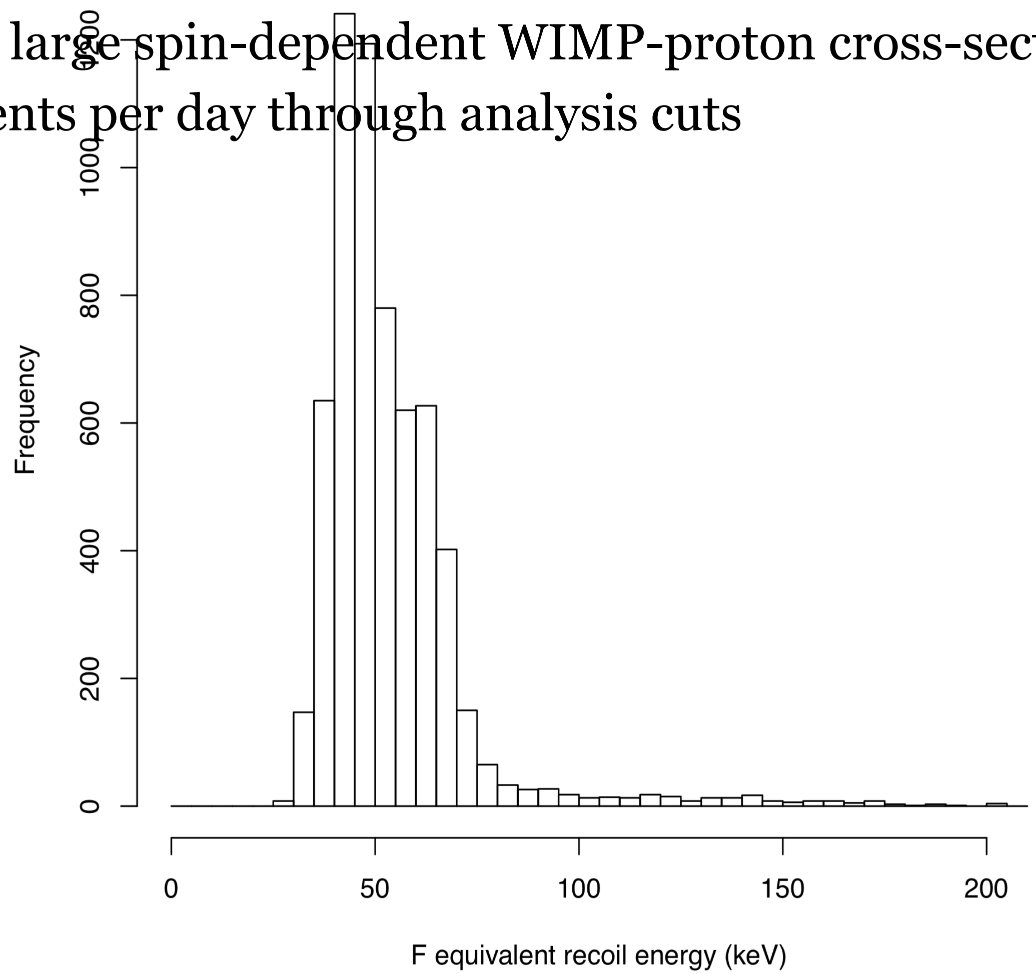
CS_2/CF_4 gain vs mixture





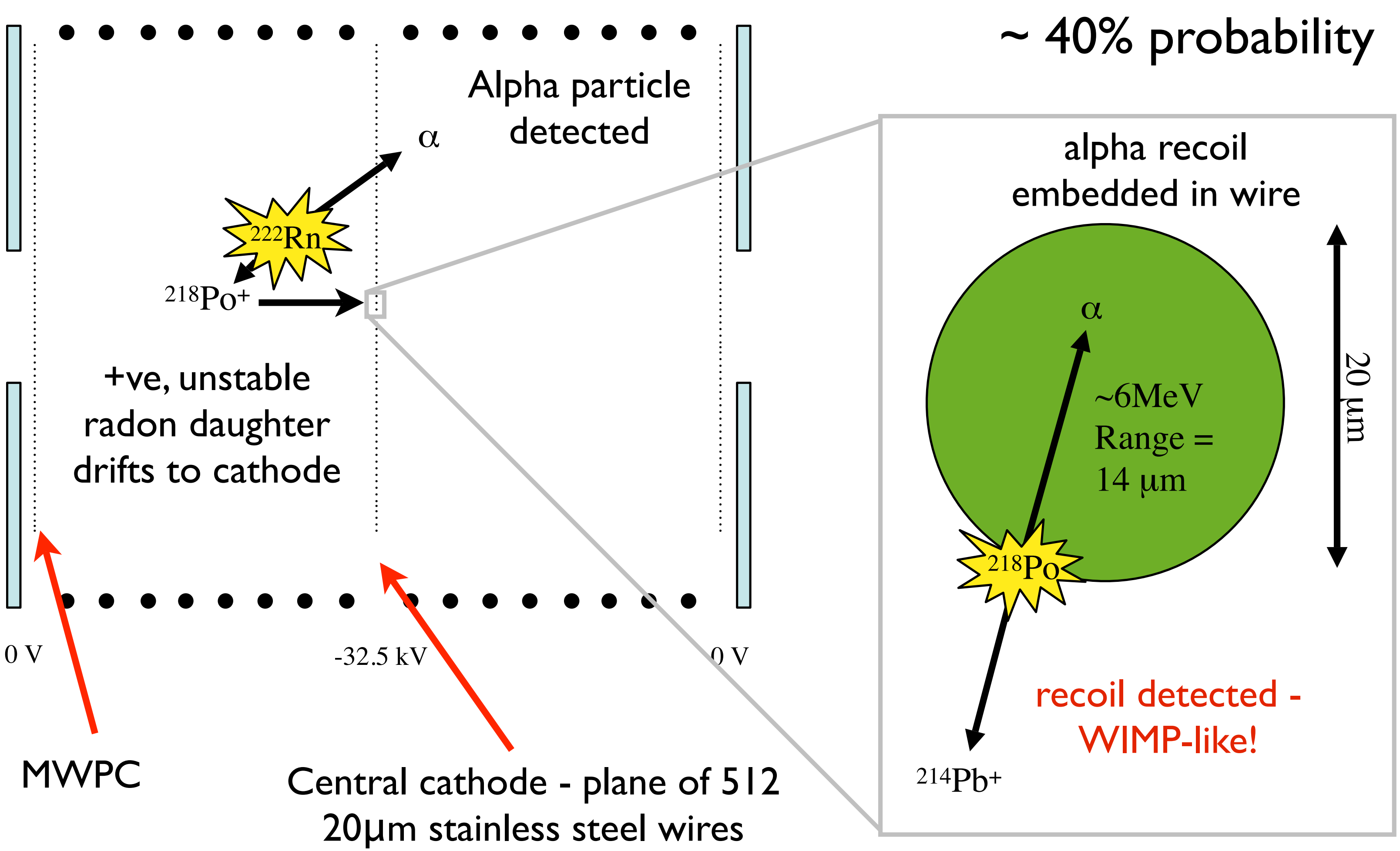
Dark Matter Runs with CS_2/CF_4

- 47.4 days of live time data collected in Winter 2009/2010
- Target was 30 Torr CS_2 + 10 Torr CF_4, 139 g of target mass
- F has a large spin-dependent WIMP-proton cross-section
- 130 events per day through analysis cuts

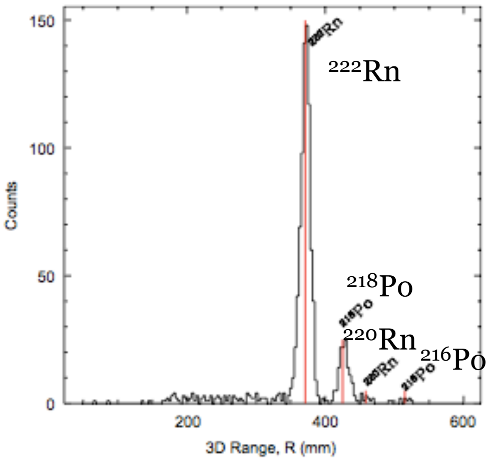


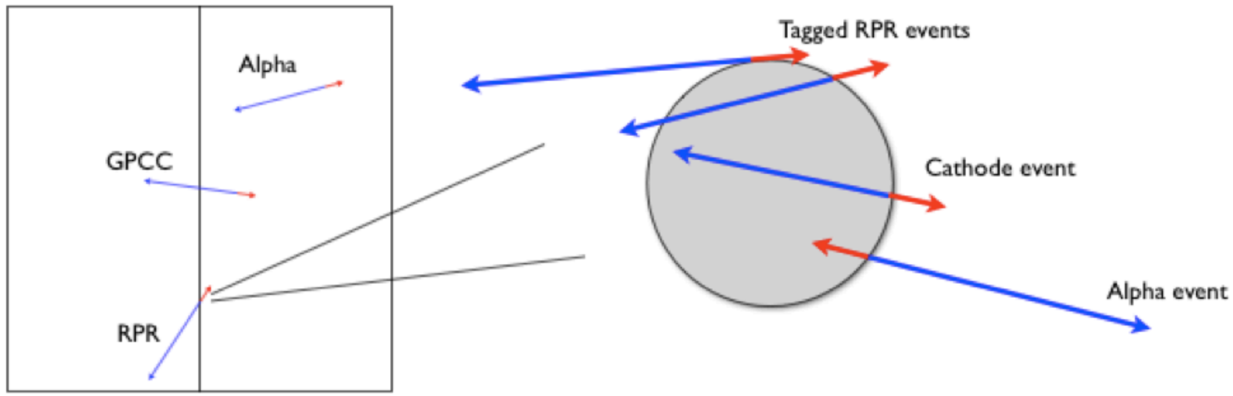
DRIFT II's dominating background

- The main background is from radon progenies (RPRs)



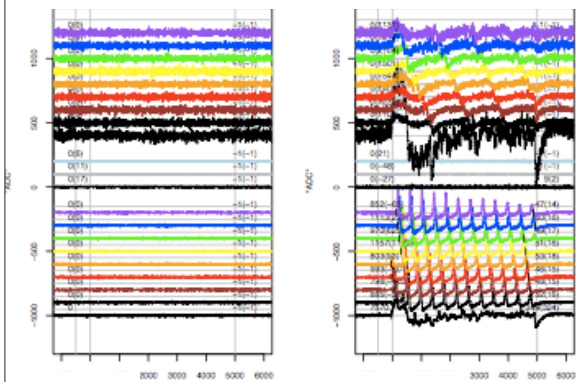
Separating out/reducing backgrounds





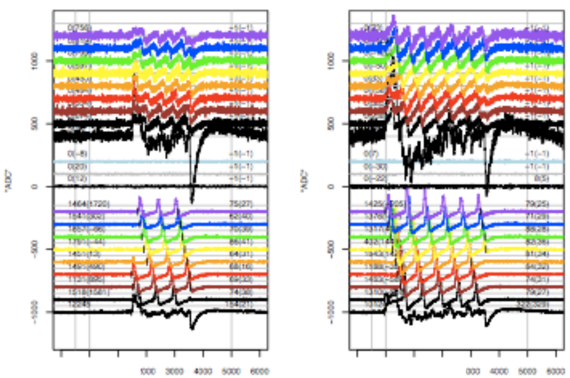
Tagged RPRs can be easily rejected....

contained alpha



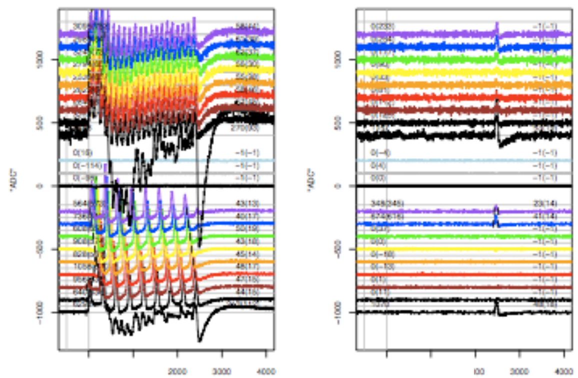
left right

cathode crossing alpha



left right

tagged RPR (+ alpha)

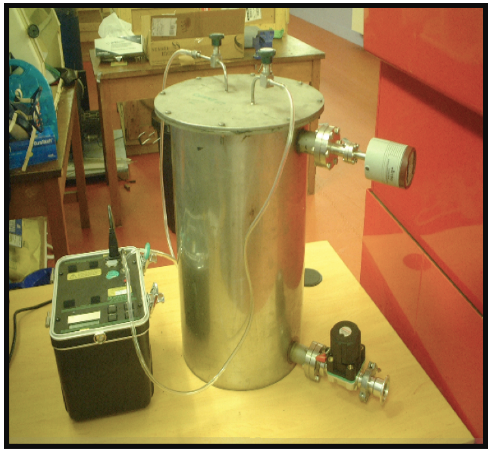


left right

RPR Reduction (PART 1)

- Reduce radon producing contaminants inside detector:

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



S. Sadler, S. Paling et al. (Sheffield)

- RPRs still produced from Pb isotopes plated out on cathode. Clean cathode with nitric acid

D. Snowden-Ifft, Oxy, J. Turk, UNM (PhD thesis 2008)

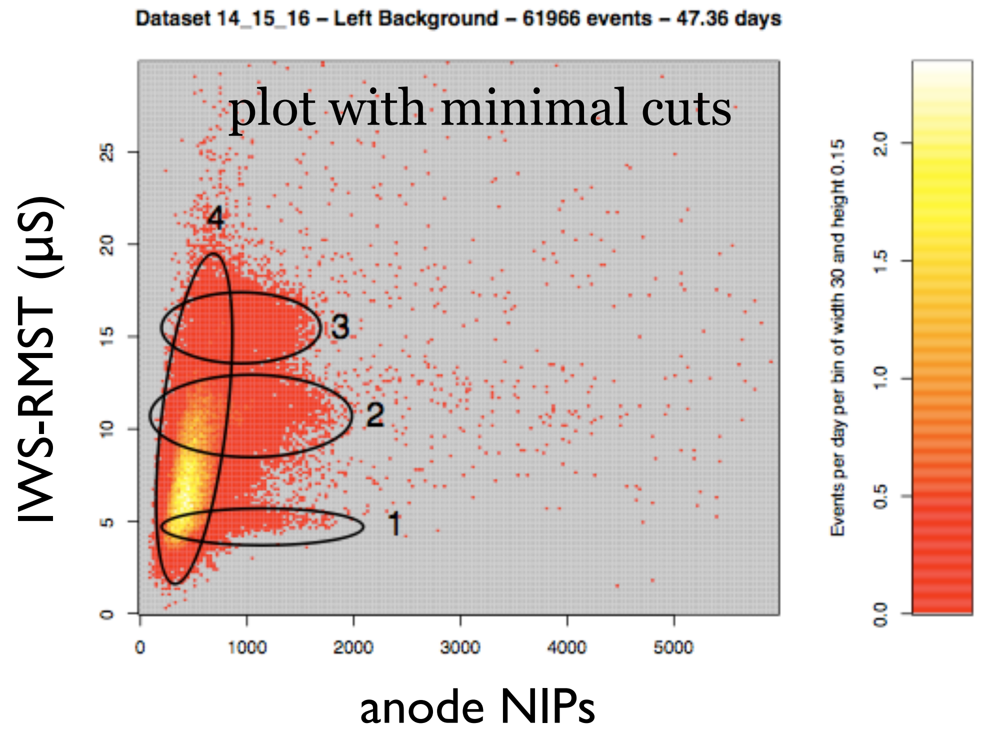
Together, these reduced the RPRs by 96% relative to D-IIa rate

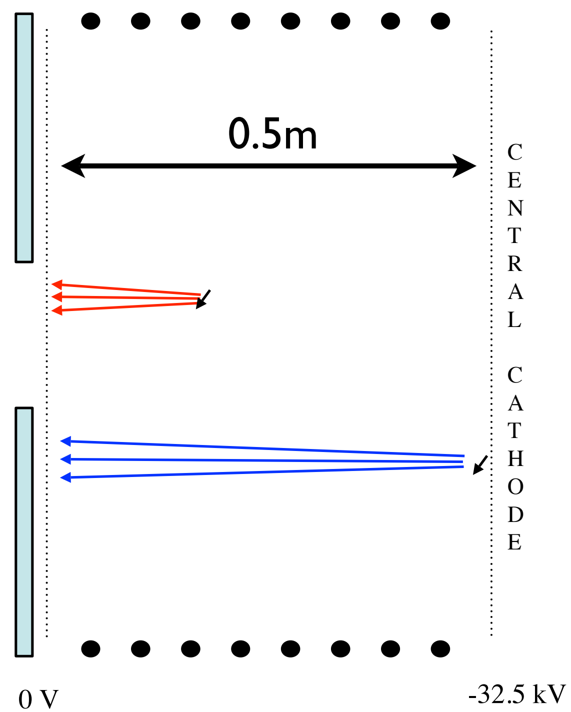

acid etching at Boulby

- Use pulse z-direction shape shape

Separating out/reducing backgrounds

- Neutrons occur throughout the detector volume
- RPRs come from the central cathode or MWPC and suffer different diffusion - on average cathode RPRs have higher width (IWS-RMST)

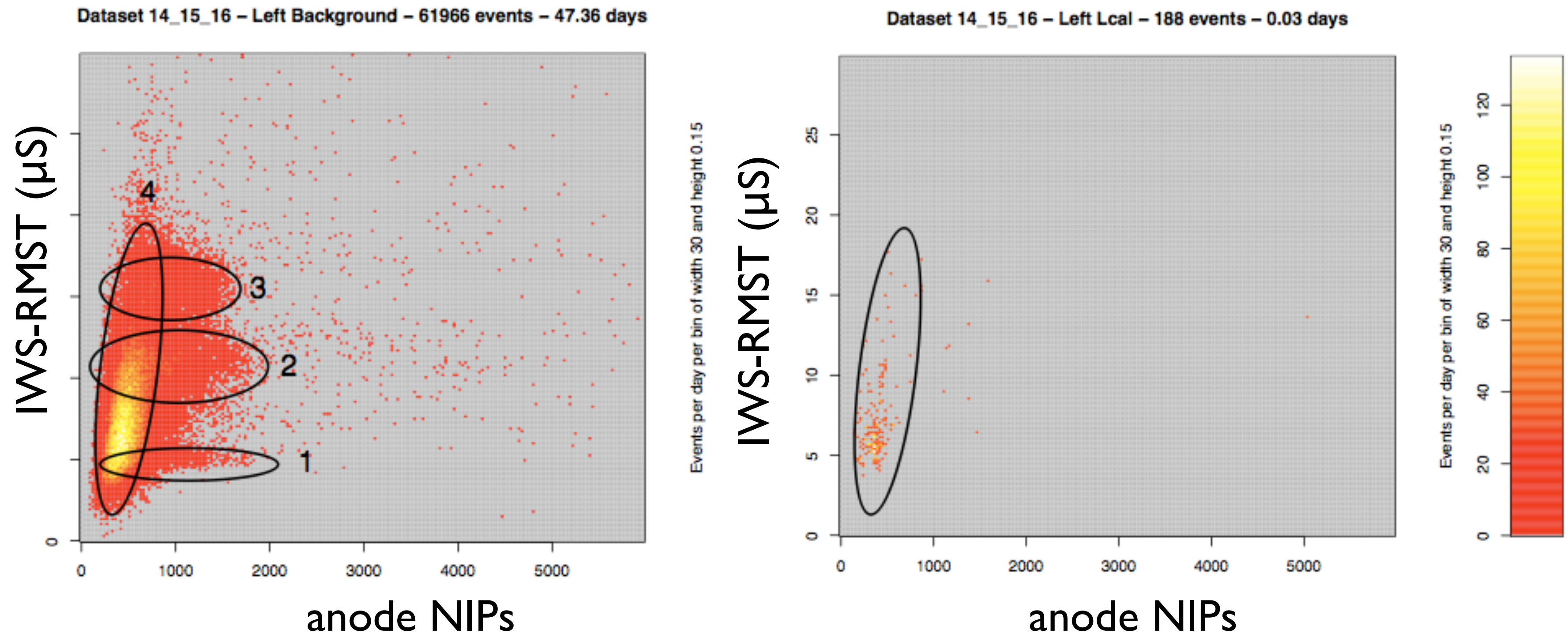




Plots with reduced cuts help explain various backgrounds at low recoil energy: (1) MWPC sparks, (2) MWPC RPRs (3) central cathode RPRs (4) betas

Separating out/reducing backgrounds

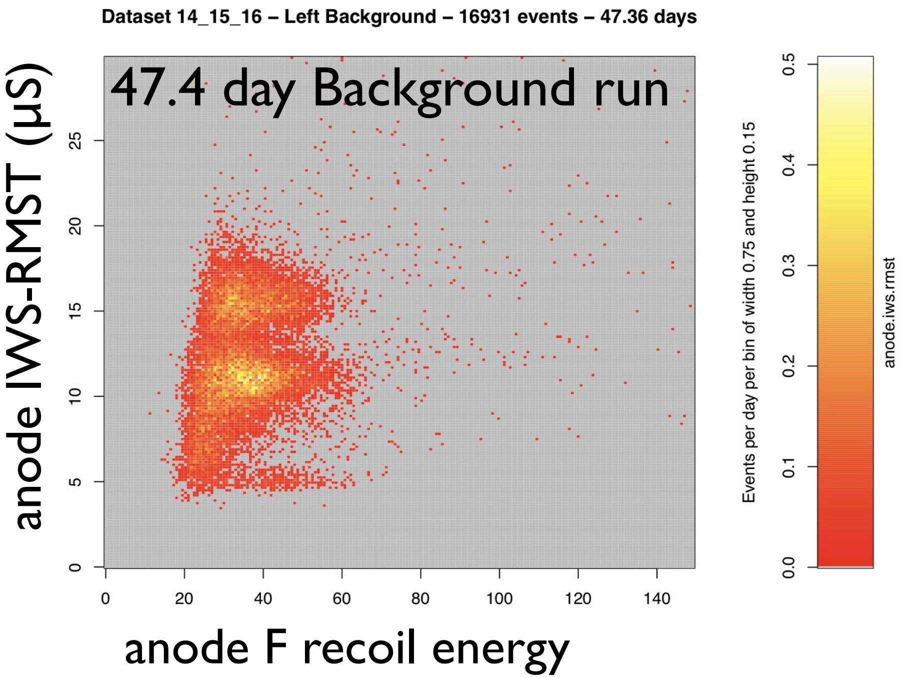
"WIMP" analysis of ^{55}Fe reveal some leakage of electron events at very low threshold (~500 NIPs)

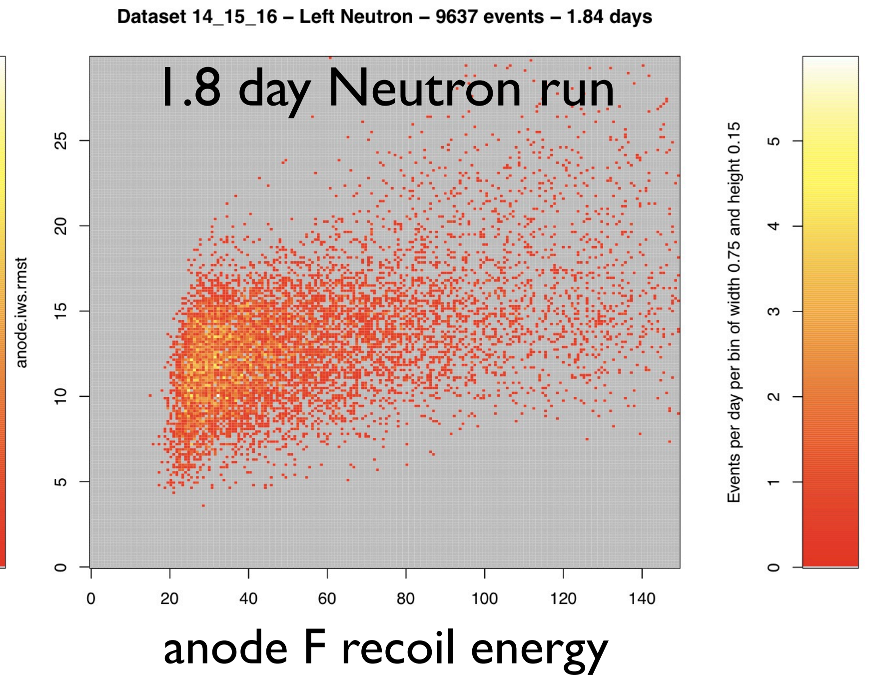


Backgrounds and neutron calibration

- X-axis - equivalent F recoil energy (keV)
- Y-axis - IWS-RMST - (Induced Waveform Subtracted - RMS Time) - measure of width of the track in the drift field (Z) dimension

- Three main background populations:
  - Low RMST - sparks consistent with shaping time of amplifiers
  - Mid RMST - events in the MWPC (RPRs?)
  - High RMST - RPRs coming from the central cathode





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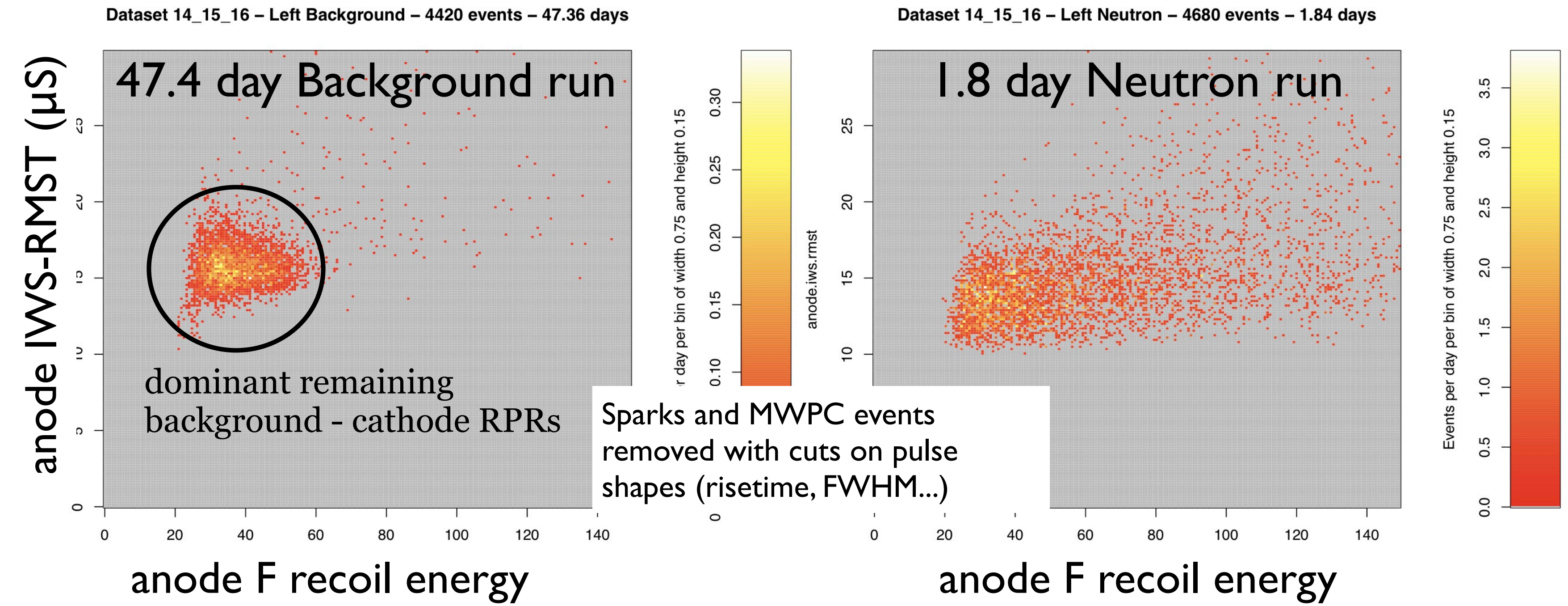
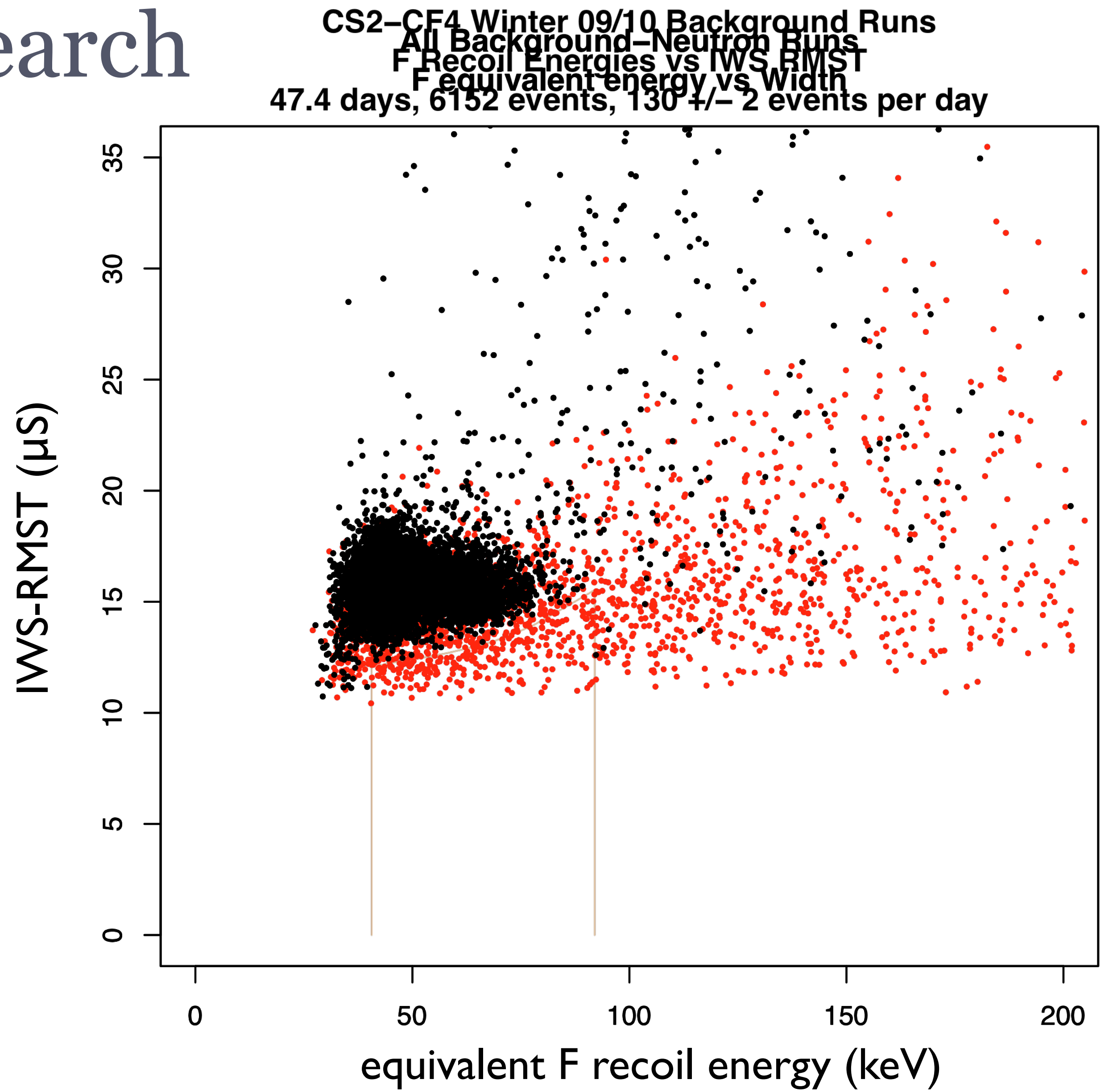
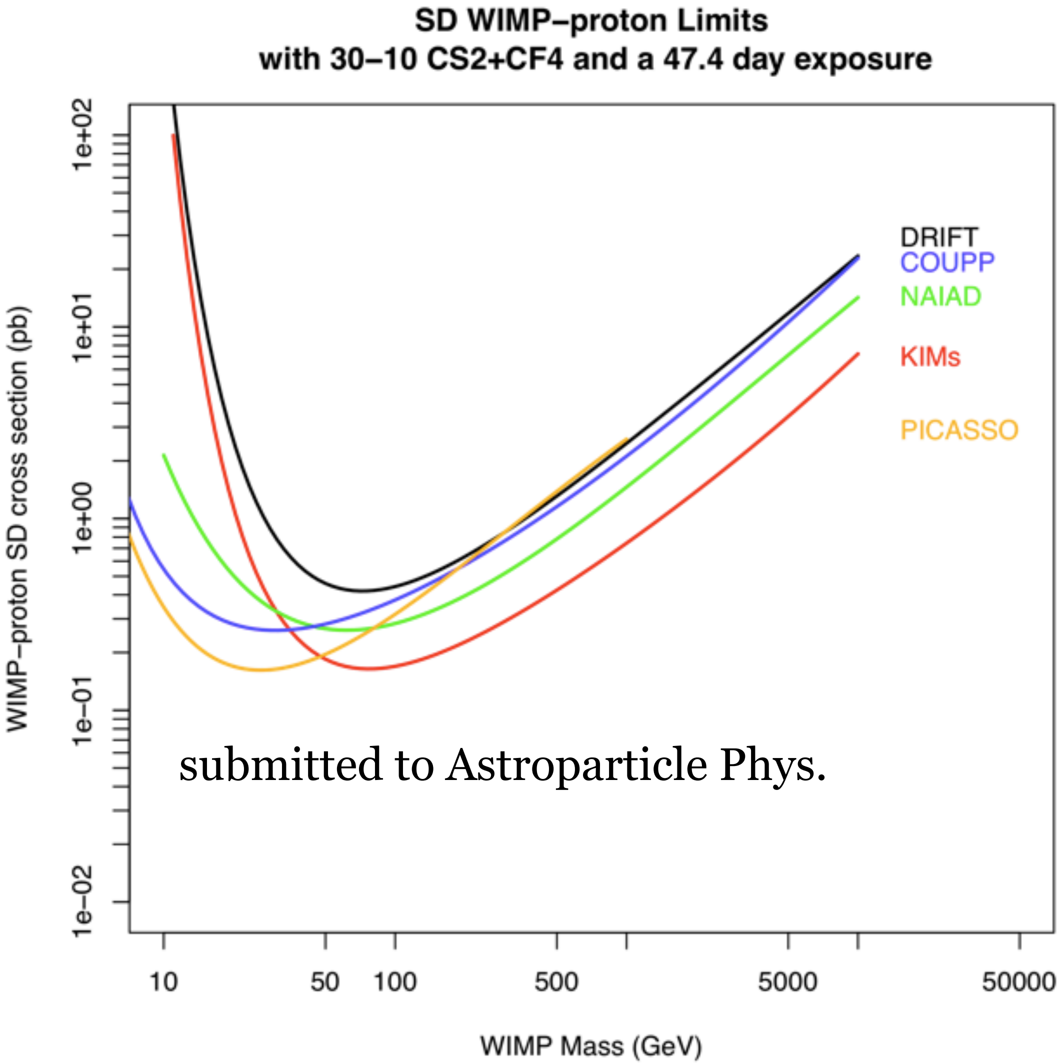


DM Search


CS2–CF4 Winter 09/10 Background Runs
All Background–Neutron Runs
F Recoil Energies vs IWS RMST
F equivalent energy vs Width
47.4 days, 6152 events, 130 +/– 2 events per day
IWS-RMST (μS)
0
5
10
15
20
25
30
35
0
50
100
150
200
equivalent F recoil energy (keV)

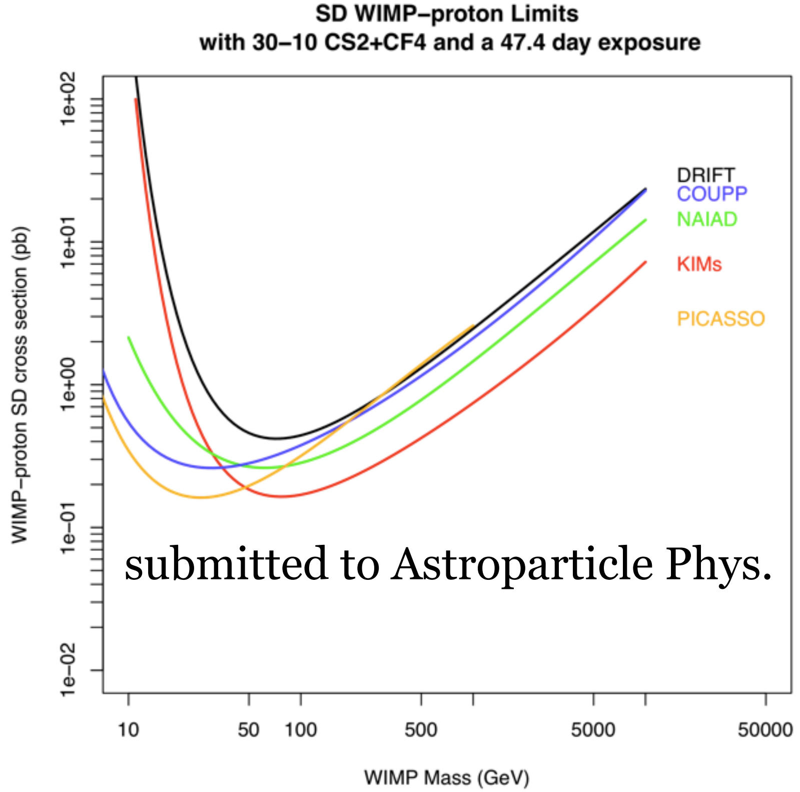
SD Limit from 47.2 days



DRIFT: 1.5 kg-days
COUPP: 28 kg-days
NAIAD: 12,500 kg-days
KIMS: 3,400 kg-days

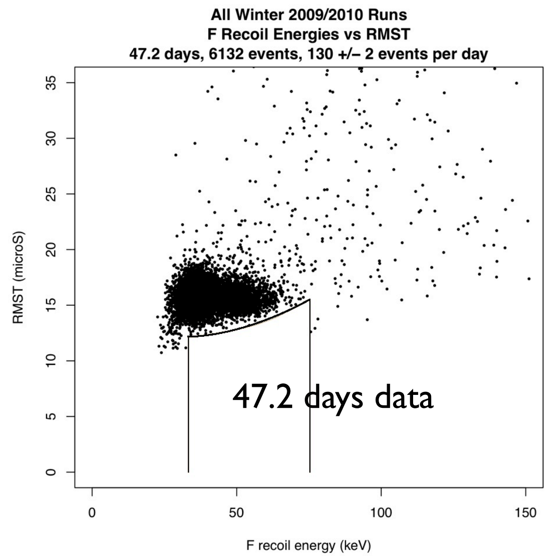
SD Limit from 47.2 days

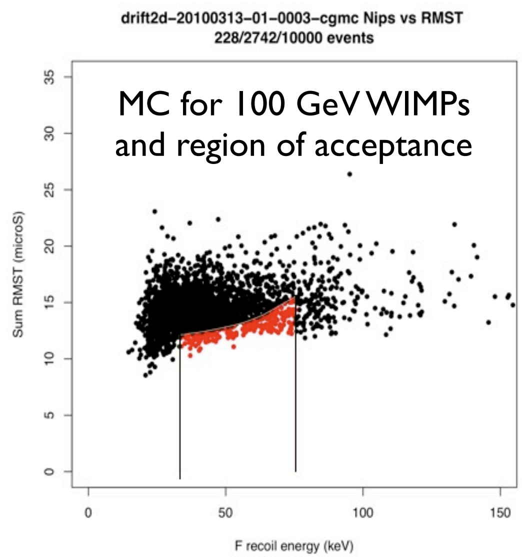
- 30 Torr -10 Torr CS2-CF4, 47.2 days background data = 1.5kg-days (^{19}F)
- MC simulation calibrated by neutron data
- No compromise on directional sensitivity
- Signal region chosen for zero events (unblind analysis)
- Further 53 days data on disk for a full blind analysis



Min. SD limits, directional detectors:
DRIFT: 1.8 pb
NEWAGE: 5400 pb
DM-TPC: 2400 pb

DRIFT: 1.5 kg-days
COUPP: 28 kg-days
NAIAD: 12,500 kg-days
KIMS: 3,400 kg-days

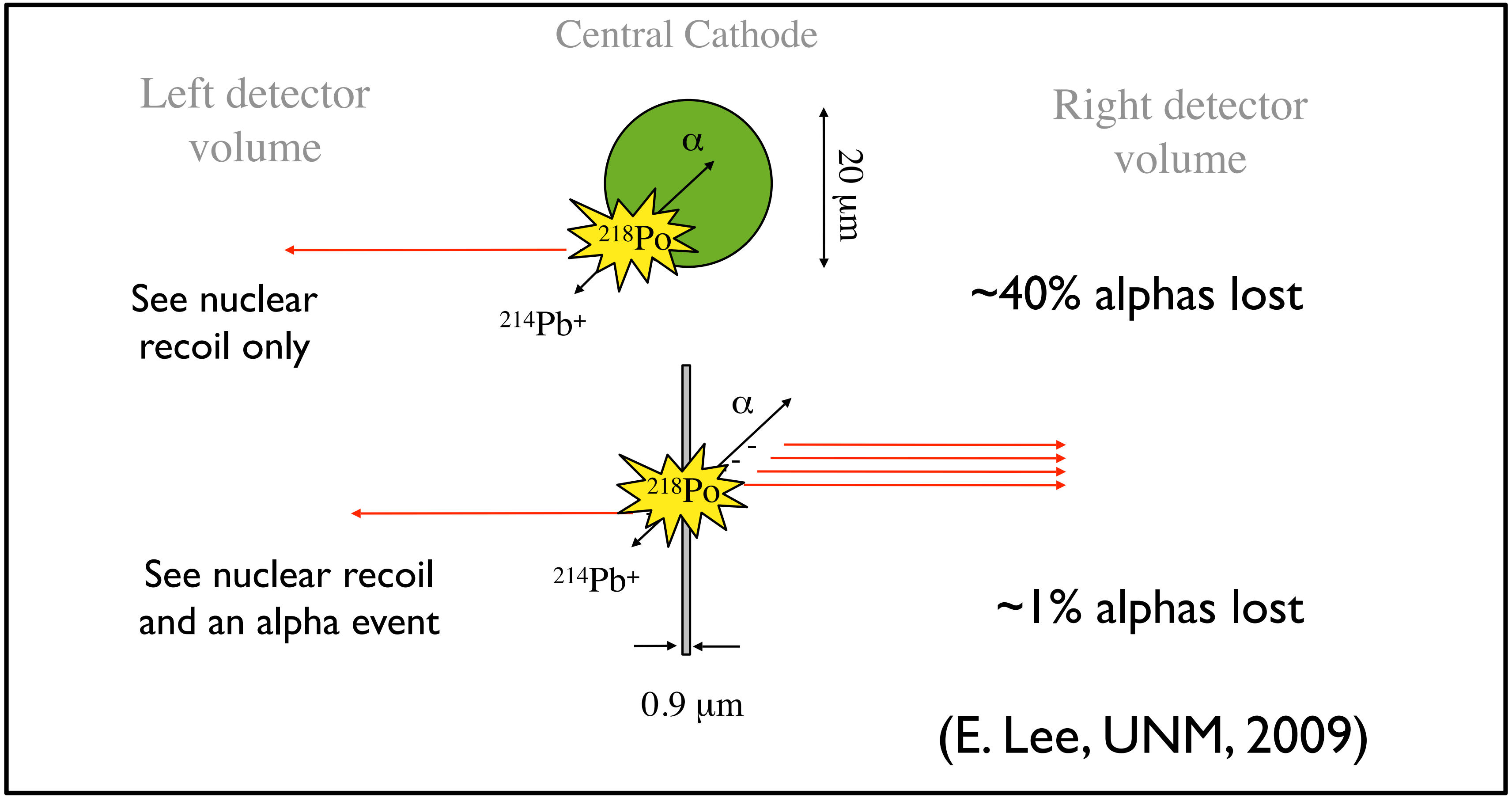




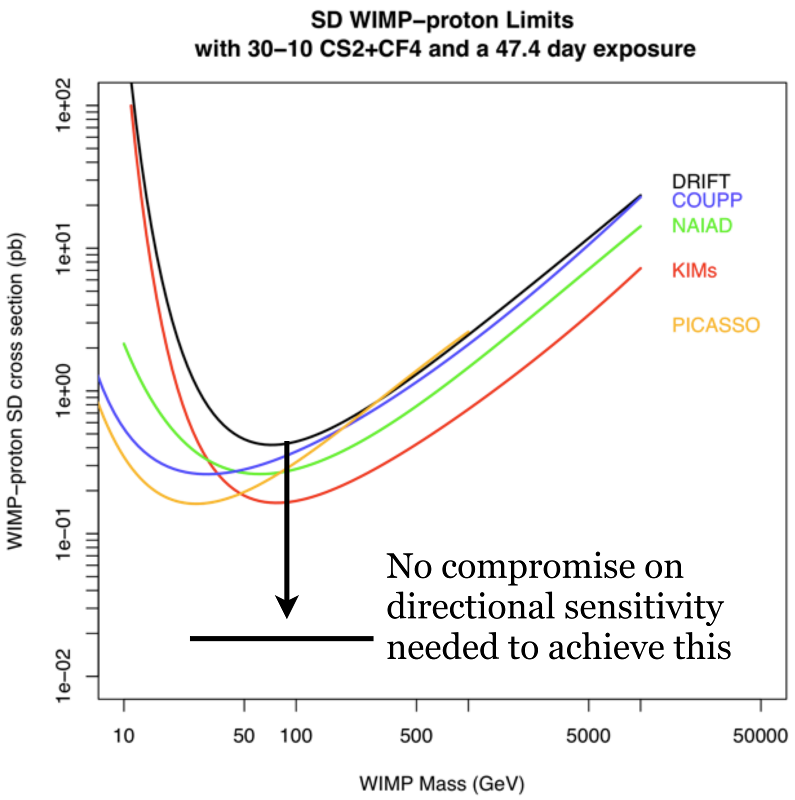
RPR Reduction (PART 2)

- Make central cathode transparent to alphas

A cathode highly transparent to α's from RPRs will provide a tag to veto events
Change from 20 μm wire to 0.9 μm thin film predicts x40 reduction in RPR



Thin cathode sensitivity Prediction

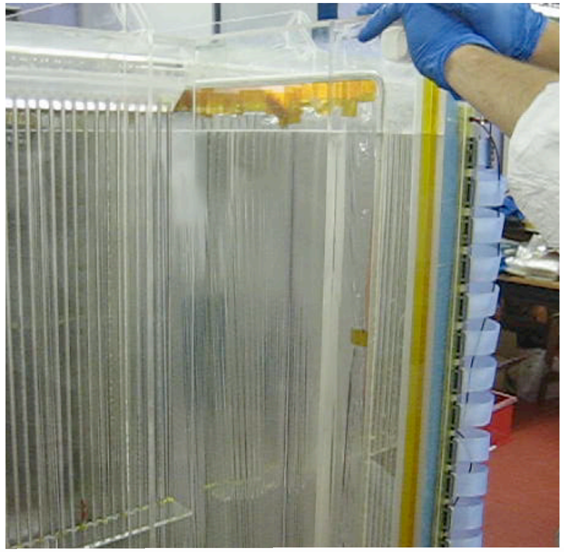


- ×40 reduction in RPR background expected
- 0.02pb limit projected assuming RPRs have same distribution
- ~2000 days live time required to achieve this
- DRIFT II is then volume limited not background limited

DRIFT IId 0.9μm cathode

Use of multi-panel 0.9μm thick DRIFT cathode

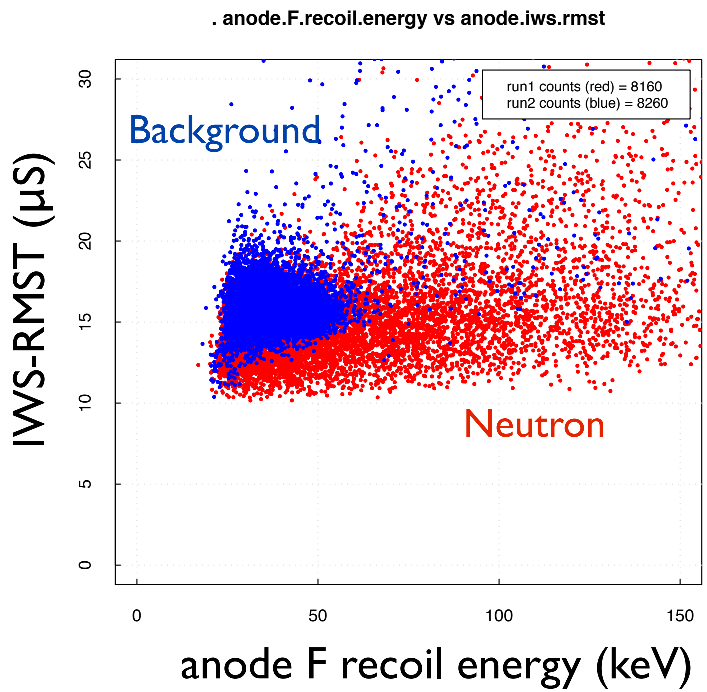
cathode tested at full voltage (32.5kV)



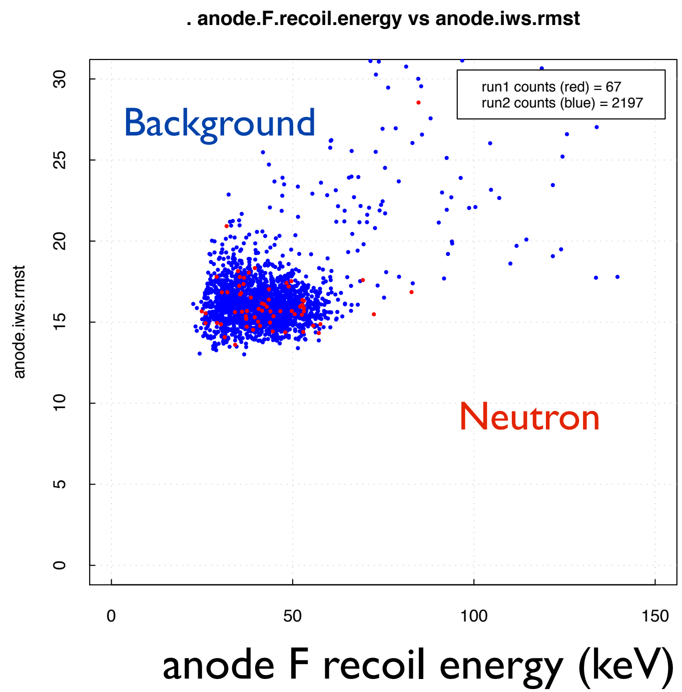
Running stably since installation
~65 days of live-time data collected and counting...

20 µm wire cathode

<u>Background events</u>
174 events/day



<u>Tagged RPRs</u>
47 events/day



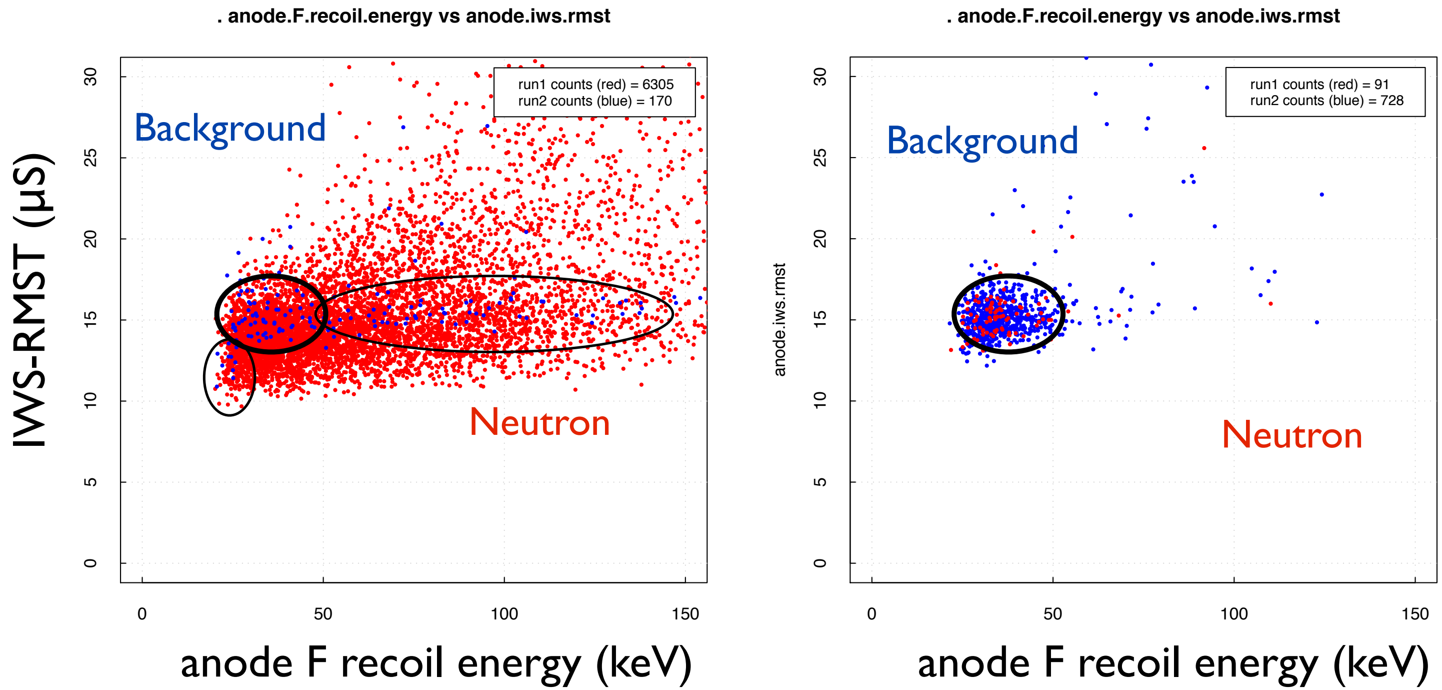
47.2 days data as used to set limit

0.3 tagged RPRs per background event

0.9 µm film cathode (new data)

<u>Background events</u>
14.7 events/day

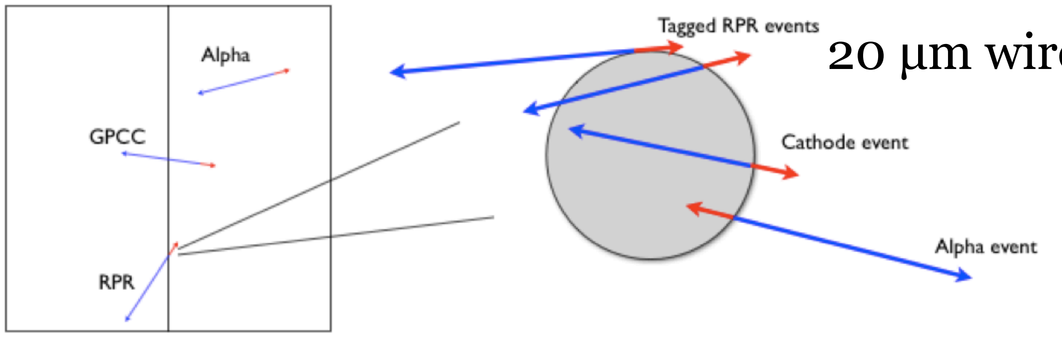
<u>Tagged RPRs</u>
63 events/day



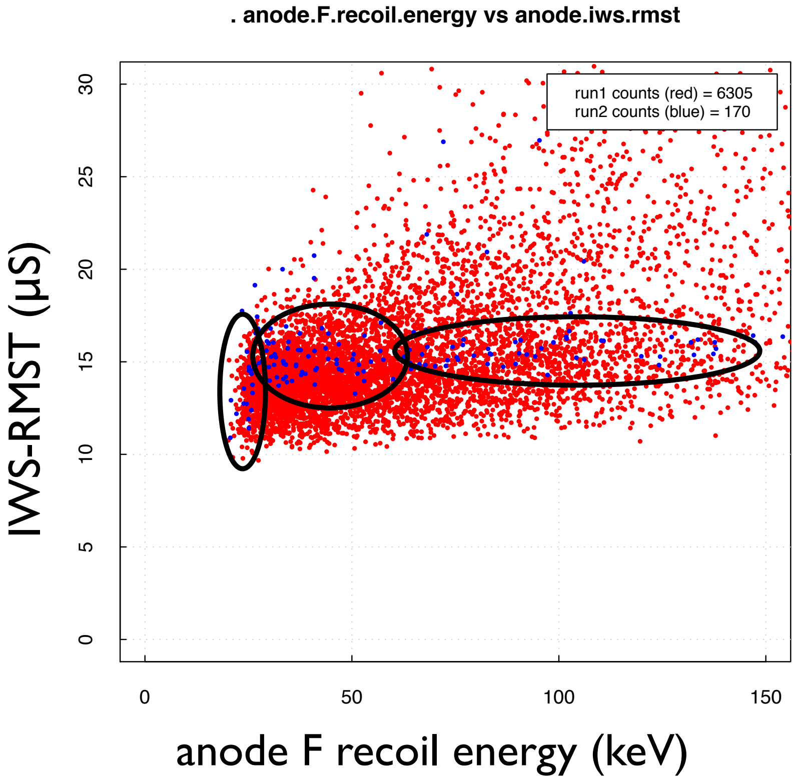
11.6 days - 53 days on disk ready for full blind analysis
4.3 tagged RPRs per background event = x 14 improvement

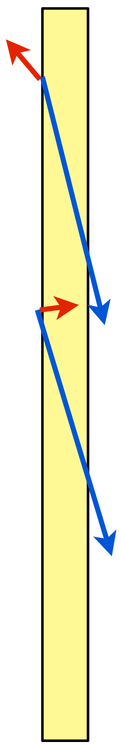
Other smaller backgrounds are now revealed that account for the lower difference seen compared to expectation of ~ x40
These are likely Low Energy Alphas (LEAs) and betas
Also shifts in the IWS-RMST distributions

Thin film backgrounds



20 µm wire





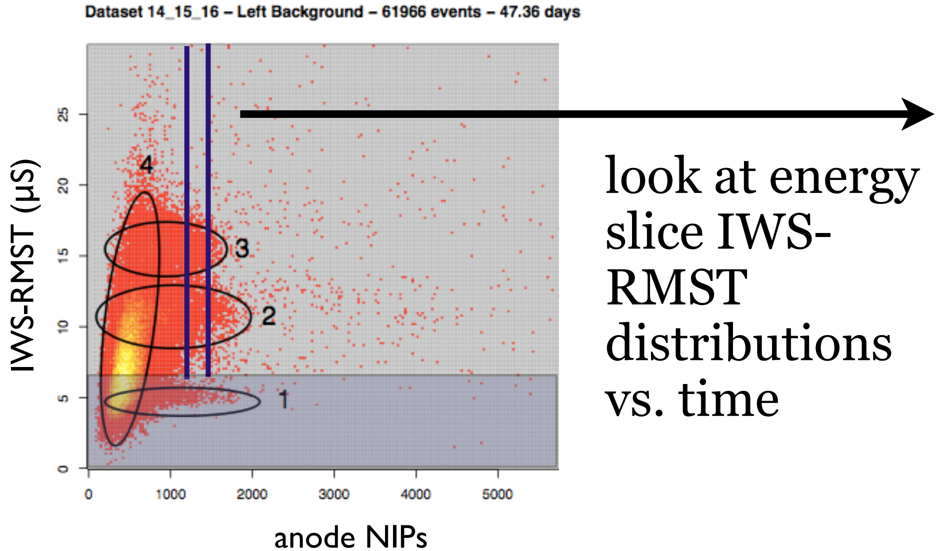
0.9 µm thin film

Background populations and rejection:

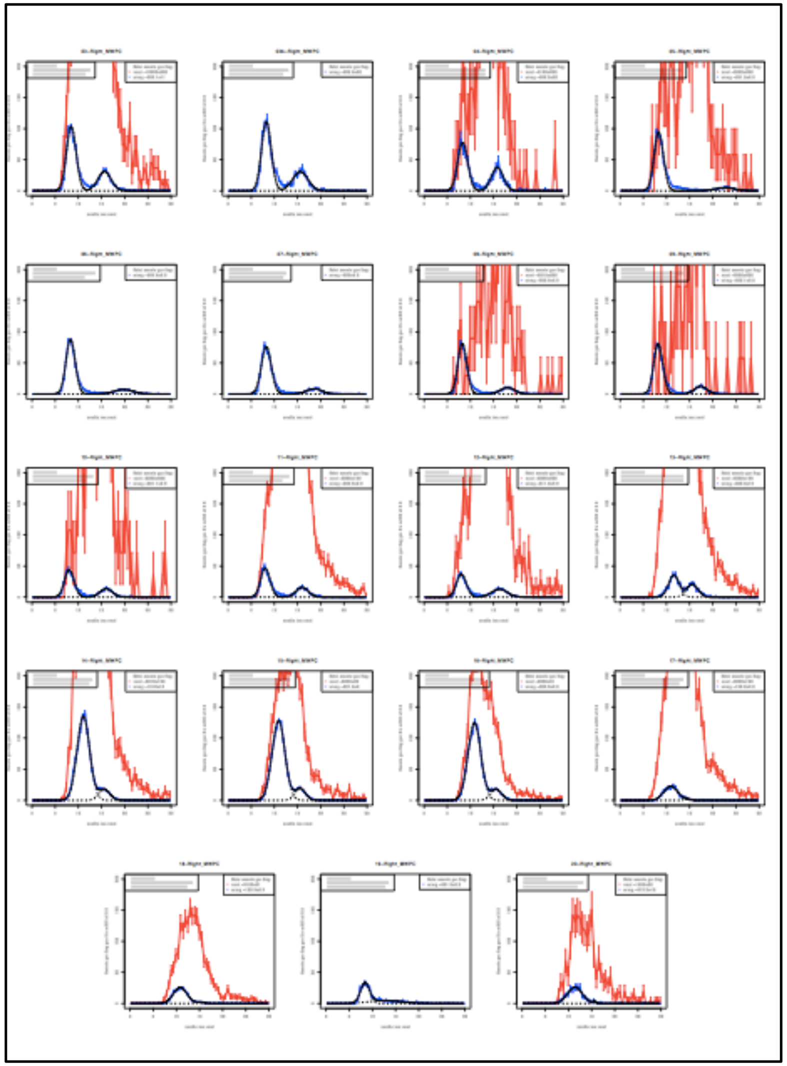
(i) RPR (standard)
(ii) double RPR - RPR plus low energy alpha
(iii) low energy alpha (straggling)
(iv) betas

Backgrounds RMST and rates vs. time

Lots of information on backgrounds by studying time changes over 1500 days



look at energy slice IWS-RMST distributions vs. time



Population changes in MWPC and cathode RPR events during evolution of the detector through radon reduction upgrades:

Position and rates changed by:

-cleaning of MWPCs

-cleaning of central cathode

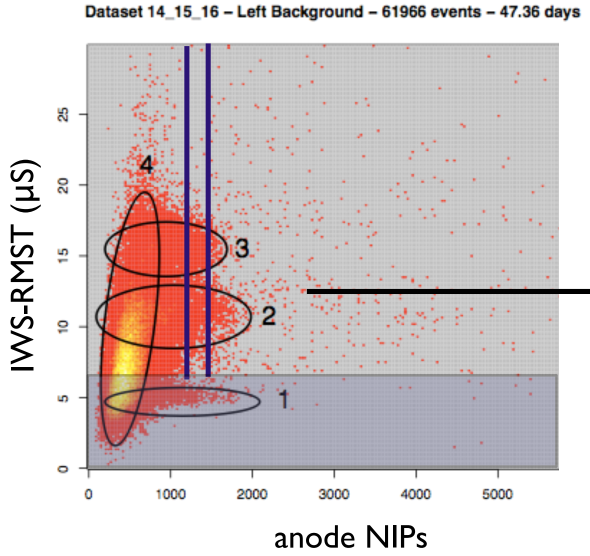
-addition of CF_4

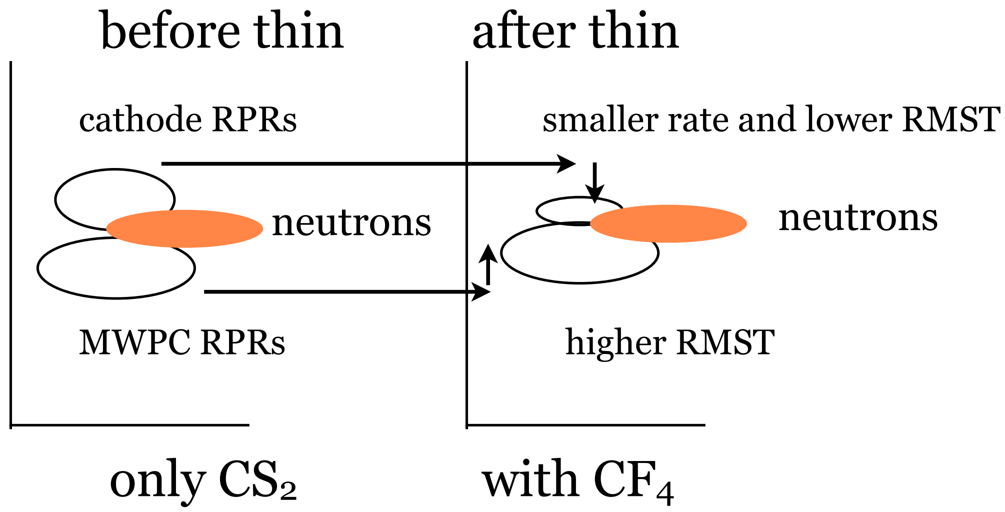
-gas flow

-change to thin cathode

Backgrounds RMST and rates vs. time

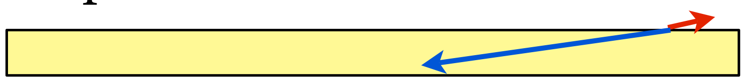
Lots of information on backgrounds by studying time changes over 1500 days





Conclusions:

The thin film successfully reduces the cathode RPRs. However, RMST factor reduces. This is most likely a geometric effect that untagged thin film RPRs are ejected more parallel to the film and so have smaller RMST



parallel RPR

Meanwhile on change to CF_4 the MWPC RPRs move up in RMST. This is most likely due to a longer free electron capture time cf pure CS_2

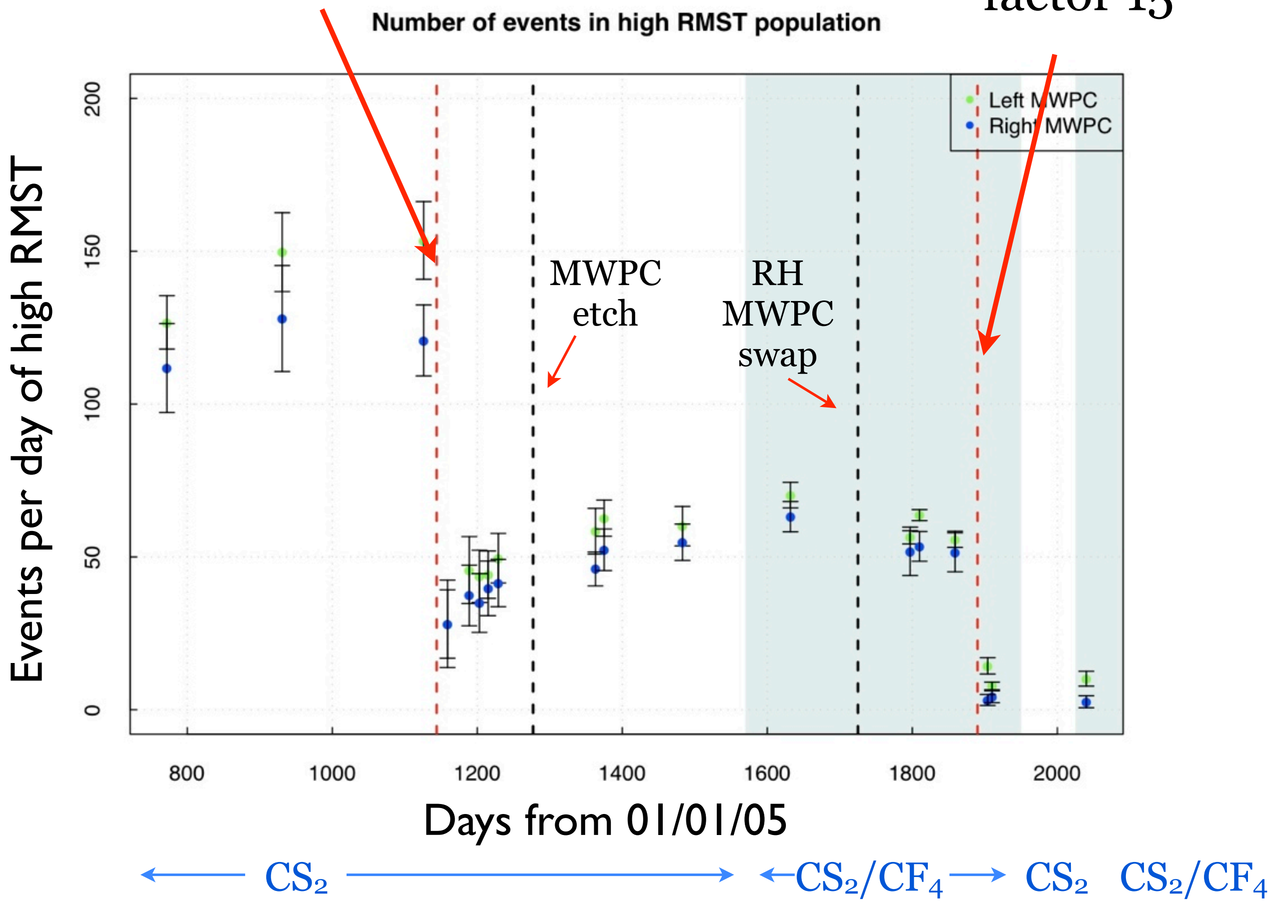
The result is that the signal (neutron) region gets squeezed.

Backgrounds rates vs. time

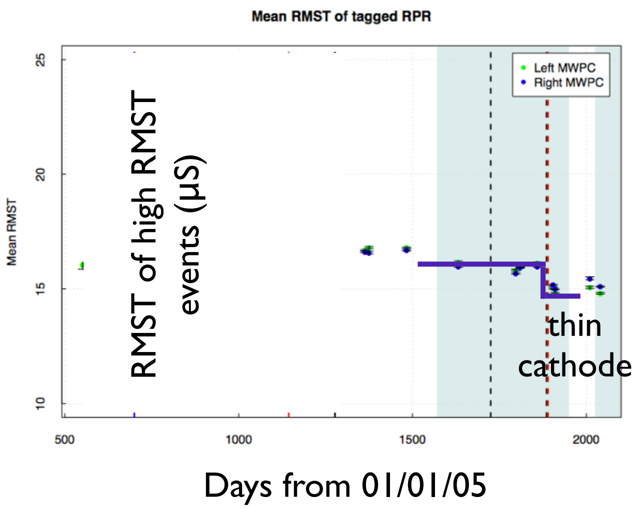
For instance cathode RPR region (higher IWS-RMST) vs. time

nitric acid etch of cathode reduced background by 5

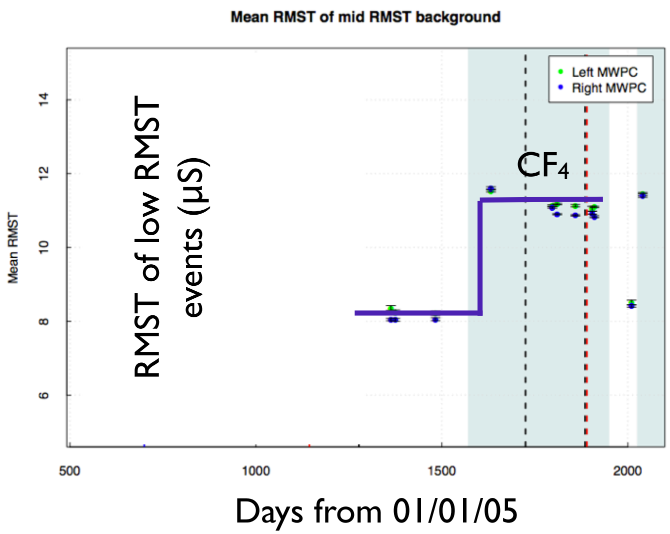
thin film cathode reduces by further factor 15



Backgrounds RMST and rates vs. time



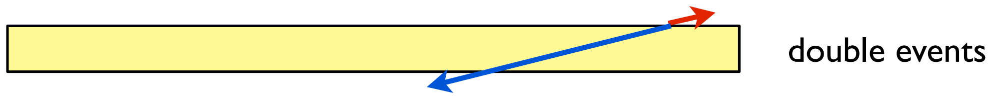
high RMST population



low RMST population

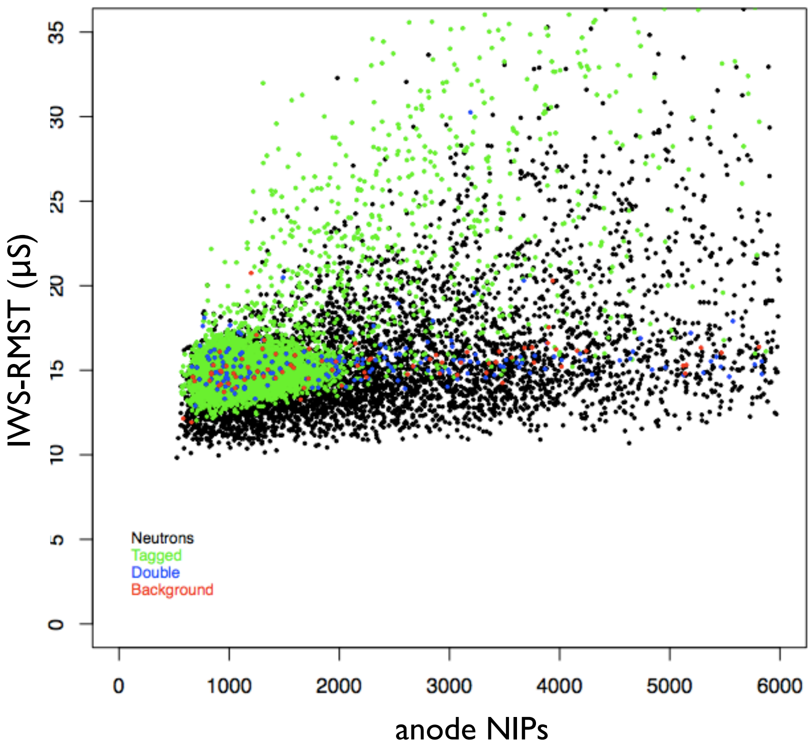
Towards new blind analysis

By relaxing cuts to see tagged RPRs and "doubles" we can produce "model" background events in the data that can be used to set the data box region for a full blind analysis

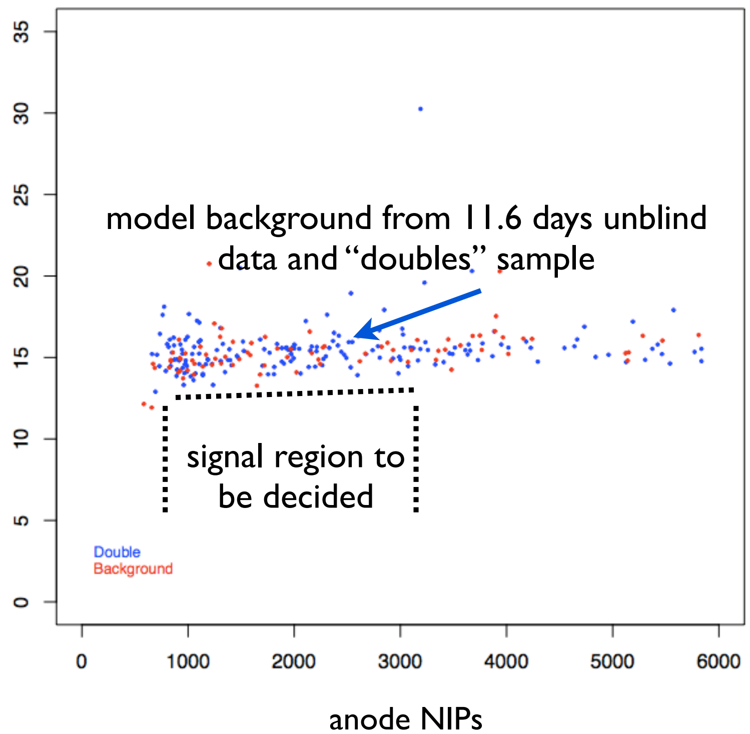


11.6 days unblinded and 53 days on disk ready for full blind analysis

all runs



unblind background and double recoil runs



Next with DRIFT II, towards DRIFT III

(1) Main thrust is RPR elimination:

(a) more reduction of intrinsic radon/RPR contamination

(b) improved PSD/position analysis and cuts

(c) further improvement to alpha-transparent cathode

(d) full z-fiducialisation via +ve ion

(2) Upgrade/streamlined electronics and gas system

(3) DRIFT III scale-up design

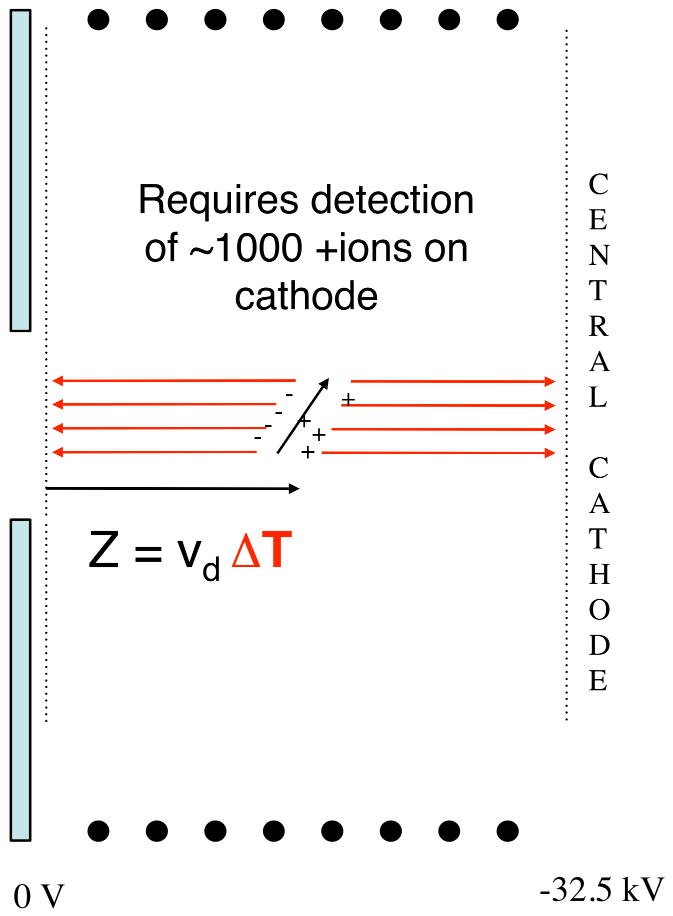
24 m^3

in 4 m^3 segments

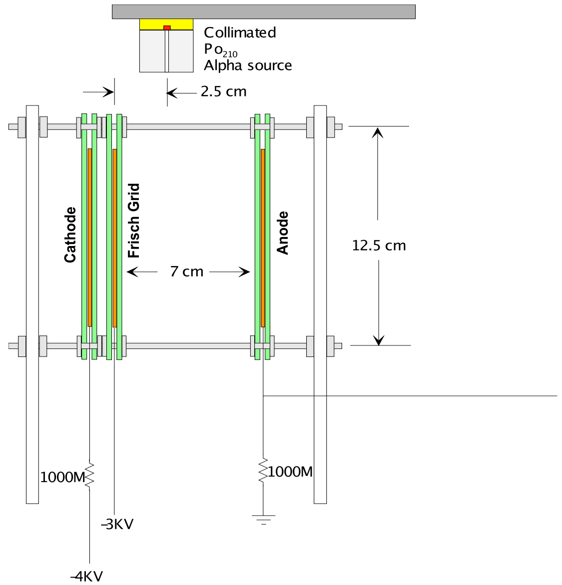
Z-fiducialisation

(E. Lee, D. Loomba et al., UNM)

Z-fiducialisation by +ve ion detection demonstrated to give **ΔT** measurement

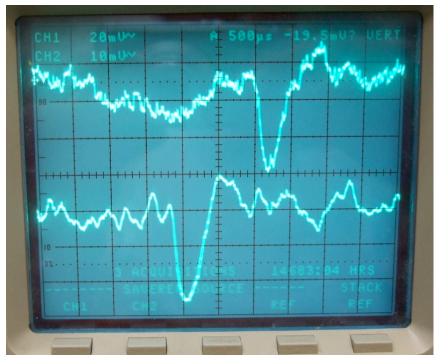


Eric Lee, UNM (2009)



Cathode

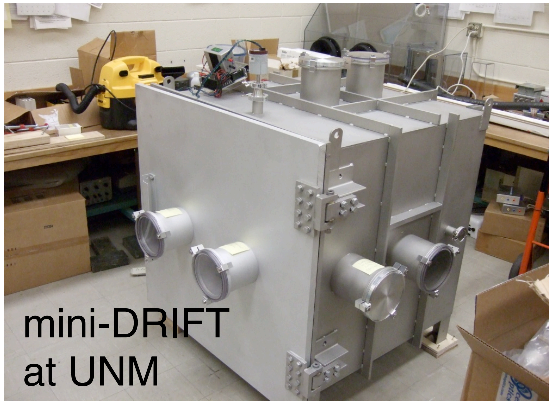
Anode

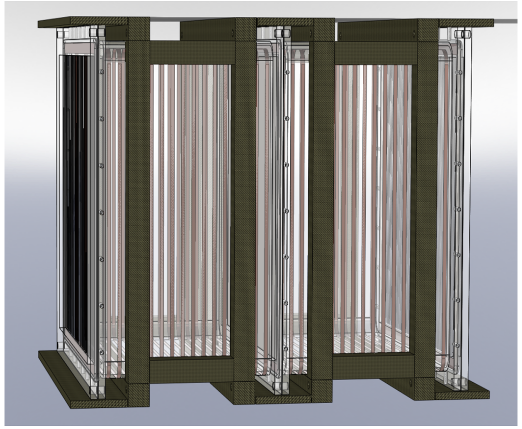


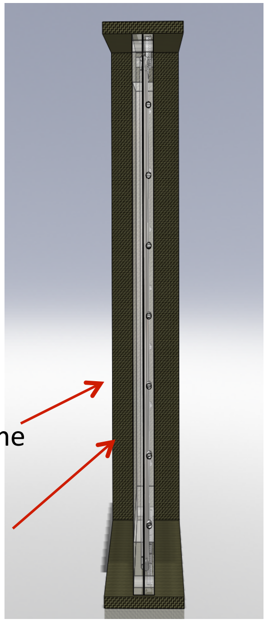
Z-fiducialisation scale-up

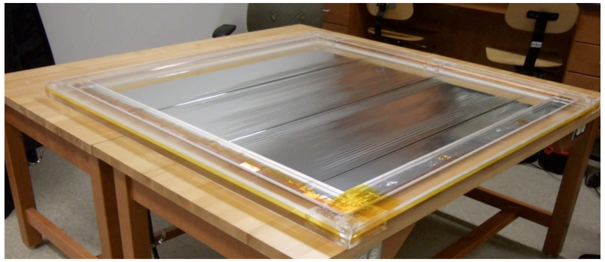
New mini-DRIFT test vessel at UNM to optimise z-fiducialisation design includes:

- Vibration suppression via acoustic shield and elastic suspension
- Lexan open ended box with Cu tape on inside for field cage with minimal HV coronal discharge and anti-vibration support
- I-beam design to maximise mechanical strength. Minimal dielectric (acrylic, polycarbonate) inner frame needed to maximize the open aperture area
- Then fit to DRIFT IIe









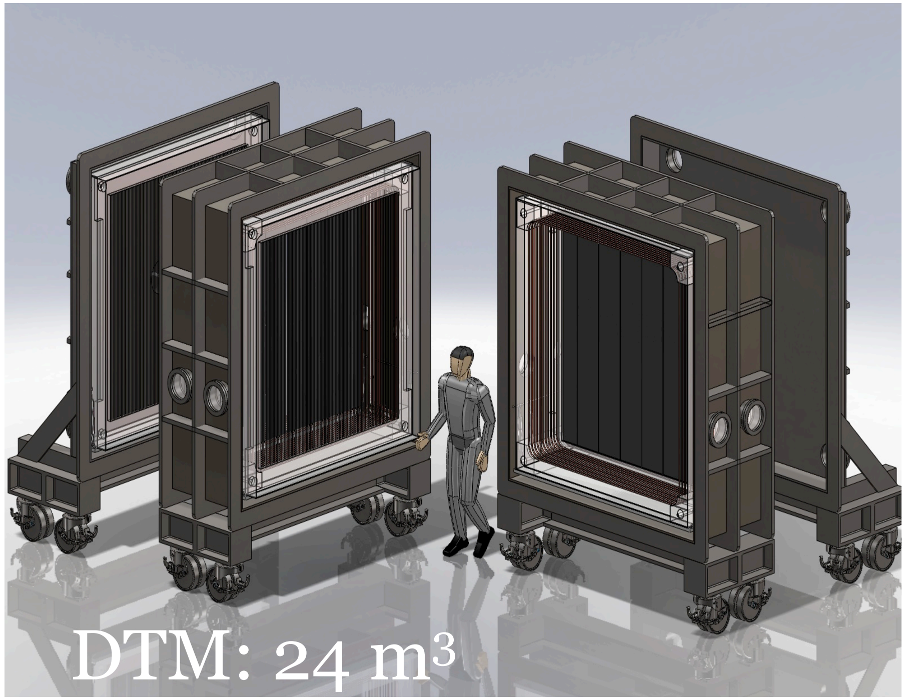
Bottom piece (MWPC frame) resting on bottom of vacuum vessel may be partly aluminum for internal electronics heat transfer.

DRIFT III Module (DTM) Concept

- Modular design to allow approach to ton-scale
- 4 kg target - 24 m^3

- One DTM well suited to Boulby
- Large number fits 30m x 150m DUSEL "Standard Lab Module" or new tunnel excavation at Boulby for 1 ton

Larger size with lower cost/m^3



- advantages of no cryogenics
- multiplexed electronics
- neutron shielding

cost split evenly:

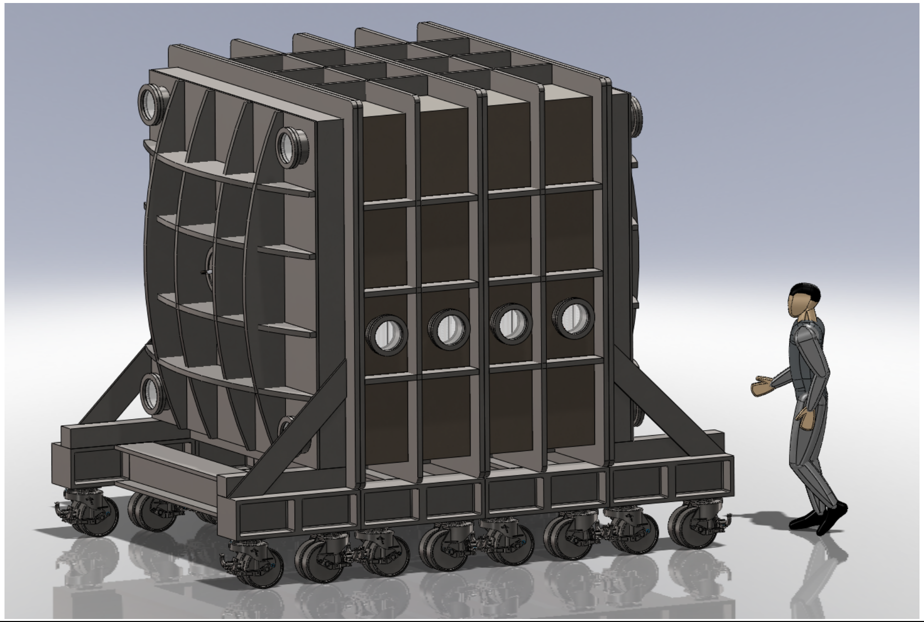
- vacuum vessel
- electronics
- gas system

NB: current cost of complete DRIFT II module (with shielding) ~ \$80K

Extrapolation gives ~\$250K for DTM (with shielding)

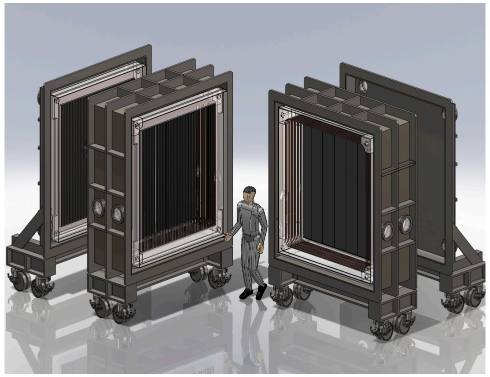
DTM Baseline Design <u>Subject to change</u>

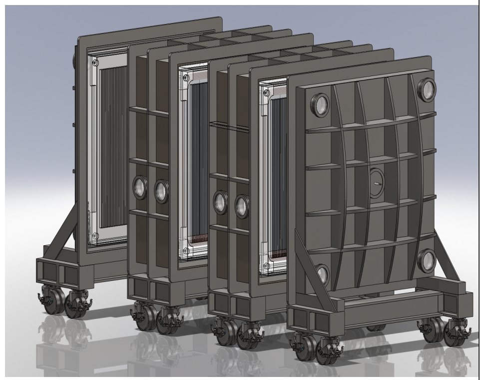
- 4kg fiducial mass, CS_2 -ve ion plus CF_4 (different target mixes)
- Thin low RPR central cathode (1 μm), partial segmentation
- Nitric acid process cleaning and radon emanation tests
- +ve ion detection for Z-fiducialisation
- 2 x 2m single plane anode with alternate grid wires, 1mm pitch reduced tension simplifies engineering (no strongback)
- Head-Tail sensitivity
- 2D readout but with 3D side veto using resistive wires
- neutron shielding
- No gamma shielding needed

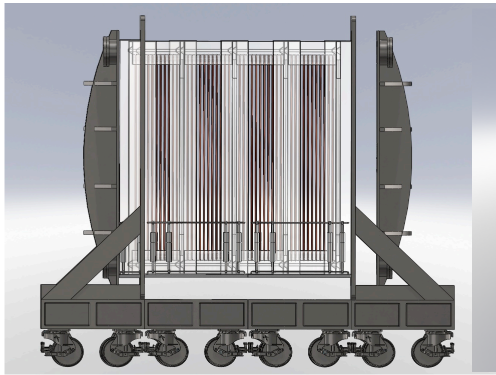


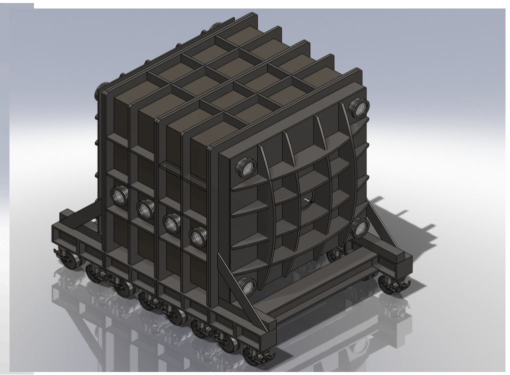
DTM Vessel

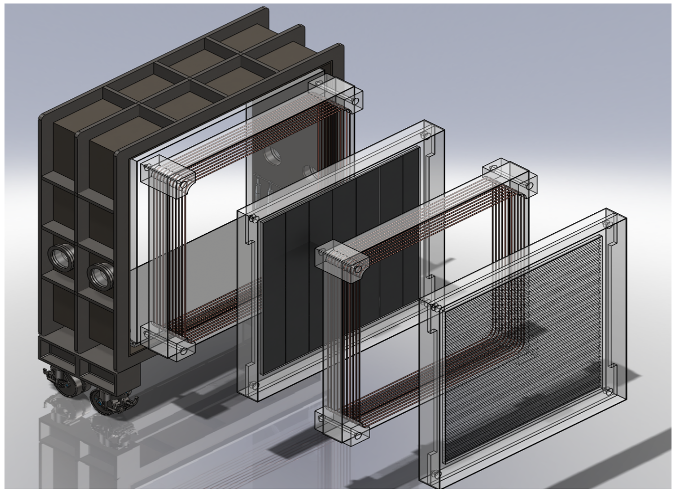
- One DTM vessel composed of 6 segments footprint ~6 m by 3 m.
- Each detector segment observes 4 m^3 of gas or, at 40 Torr of CS_2, 0.67 kg of target mass
- 250 of these 4 kg modules gives 1 ton and would fit into a standard DUSEL module or 500m tunnel at Boulby

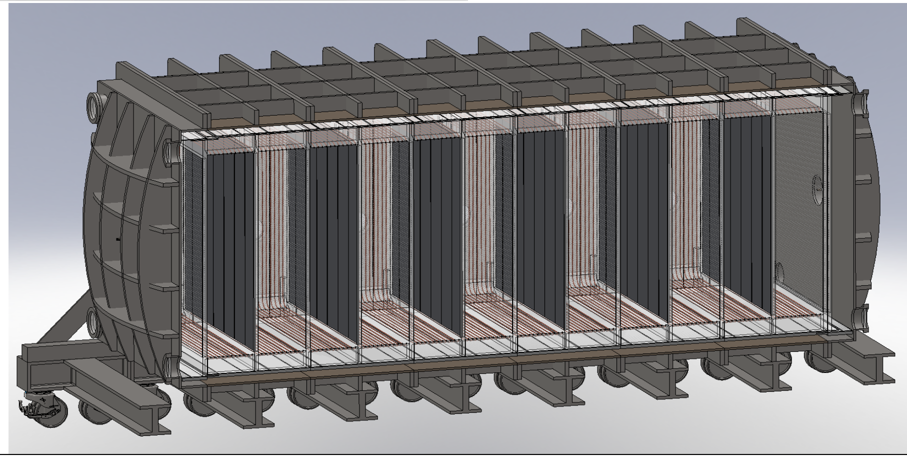










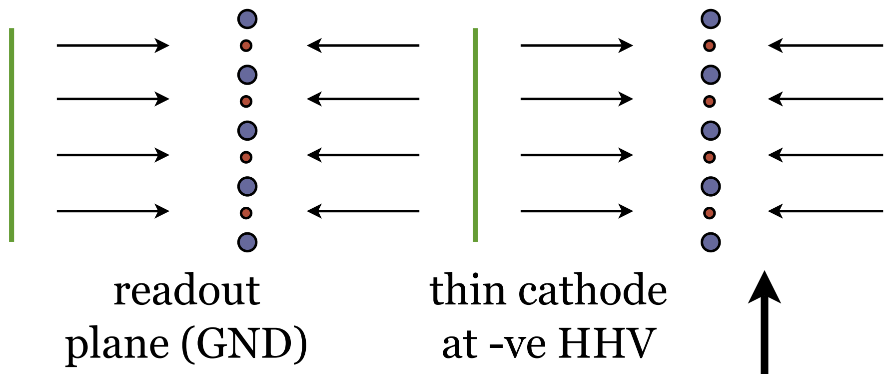


- Preference for CH-based material

DRIFT III Module Readout

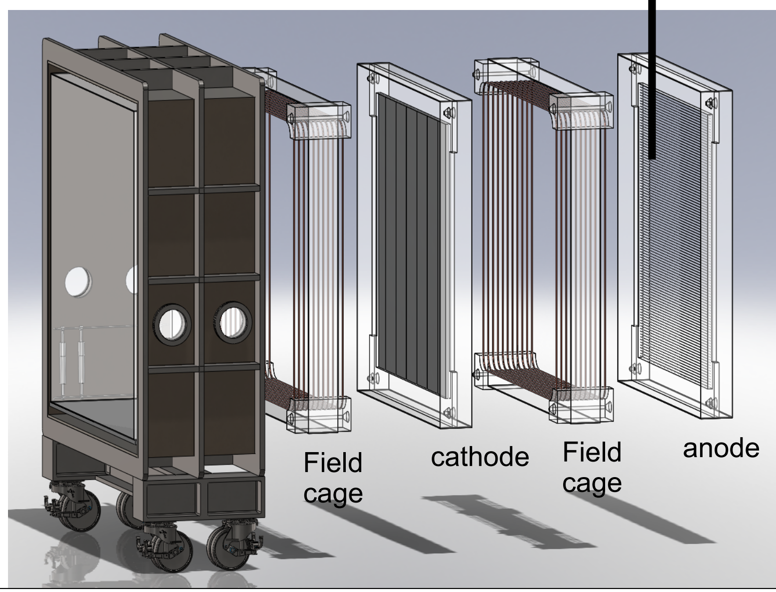
Sense plane

- Transparent readout plane to sense two sides (eliminates the mechanical support "strong back")
- 20 μm diameter stainless steel wires on a 2 mm pitch
- X-wires, Y-resistive wires



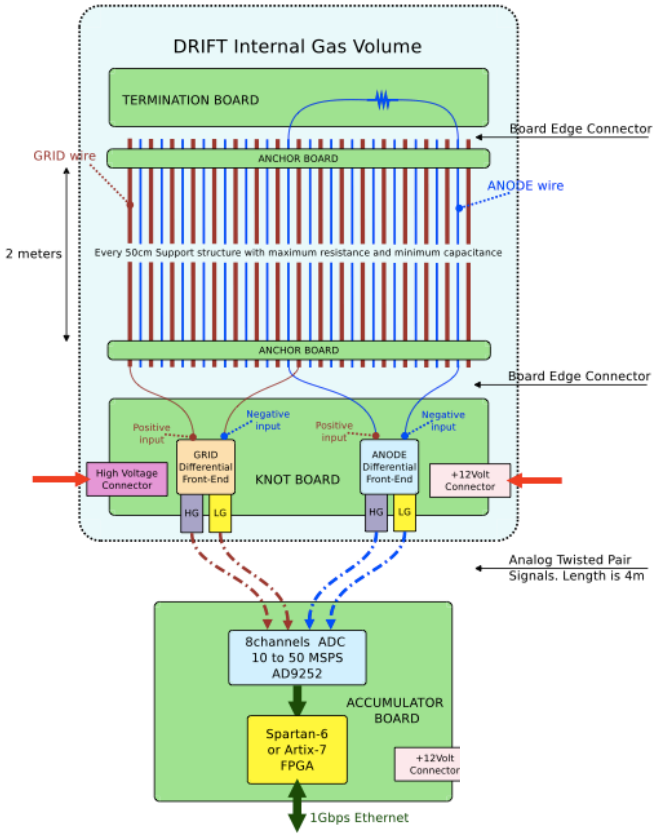
Cathode

- 70 kV with well-engineered field cage and high-voltage system; diffusion (reduced by 40% c.f. DRIFT II)
- +ve ion detection - segmented to reduce the input capacitance for Z fiducialisation
- Orientation perpendicular to anode wires to give more y dimension information



DRIFT III Module Electronics

(J. Harton et al., CSU)

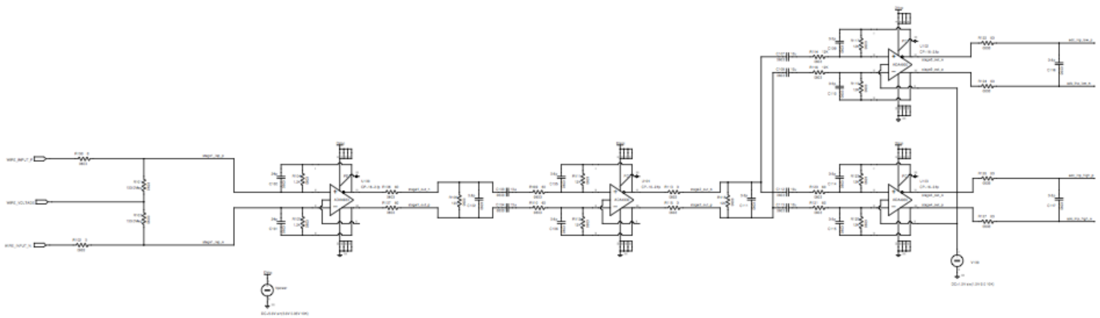


Anchor Board

Glued with epoxy to support frame.
Wires are soldered directly to the board.
Physically separates anodes from grids.

Termination Board

Plugs into Anchor Board through board edge connector.
Completes one side of the anode loop for resistive readout.
Every 9th anode is connected. Only one loop is shown for picture clarity.



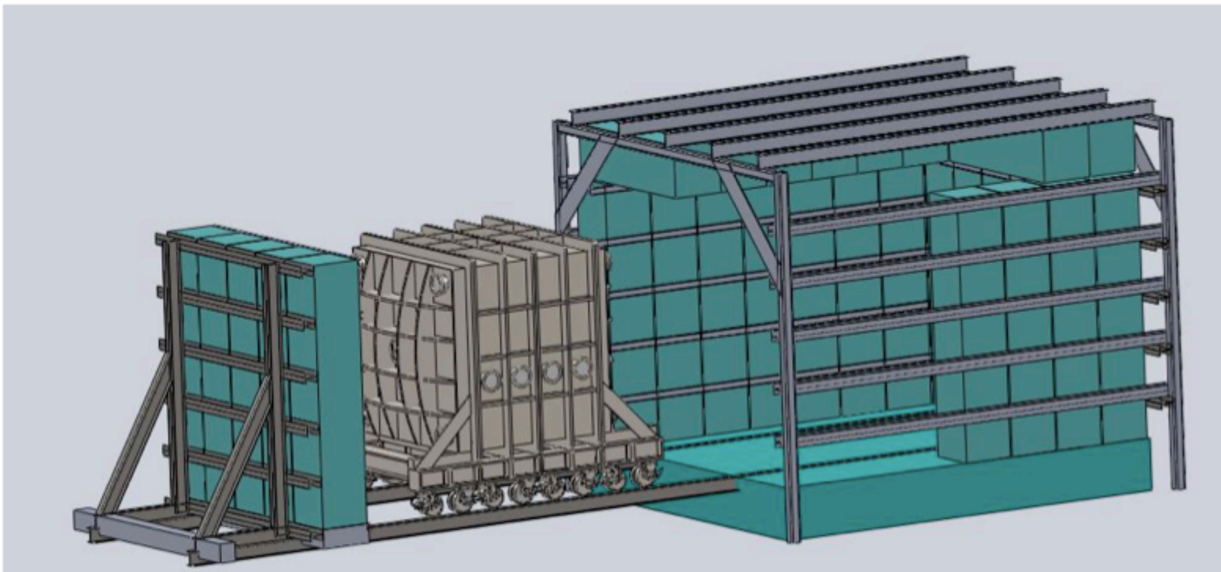
Anode Front End

More than 1GhZ Differential opamp: ADA4930. High Supply transient rejection rate, fully balanced input. Low and High gain channels (ratio is 200).

DTM Shielding

Simple and cheap poly pellet or water neutron shielding

DRIFT II

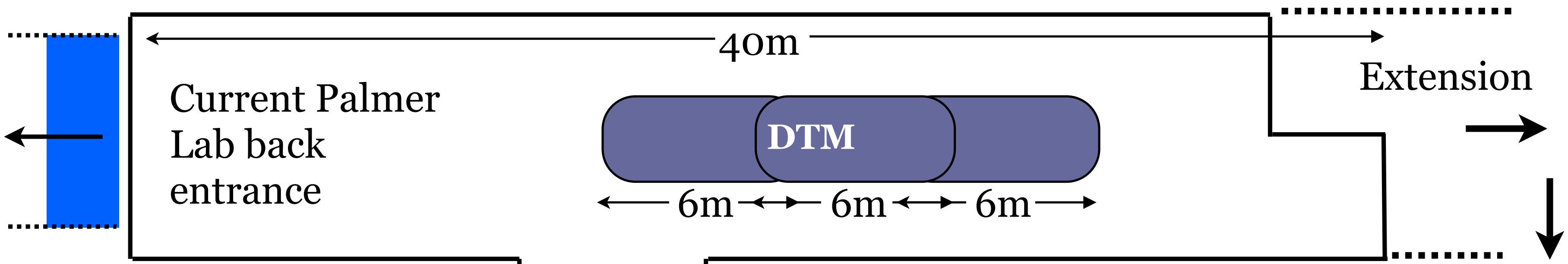


DTM

DRIFT III Module Site

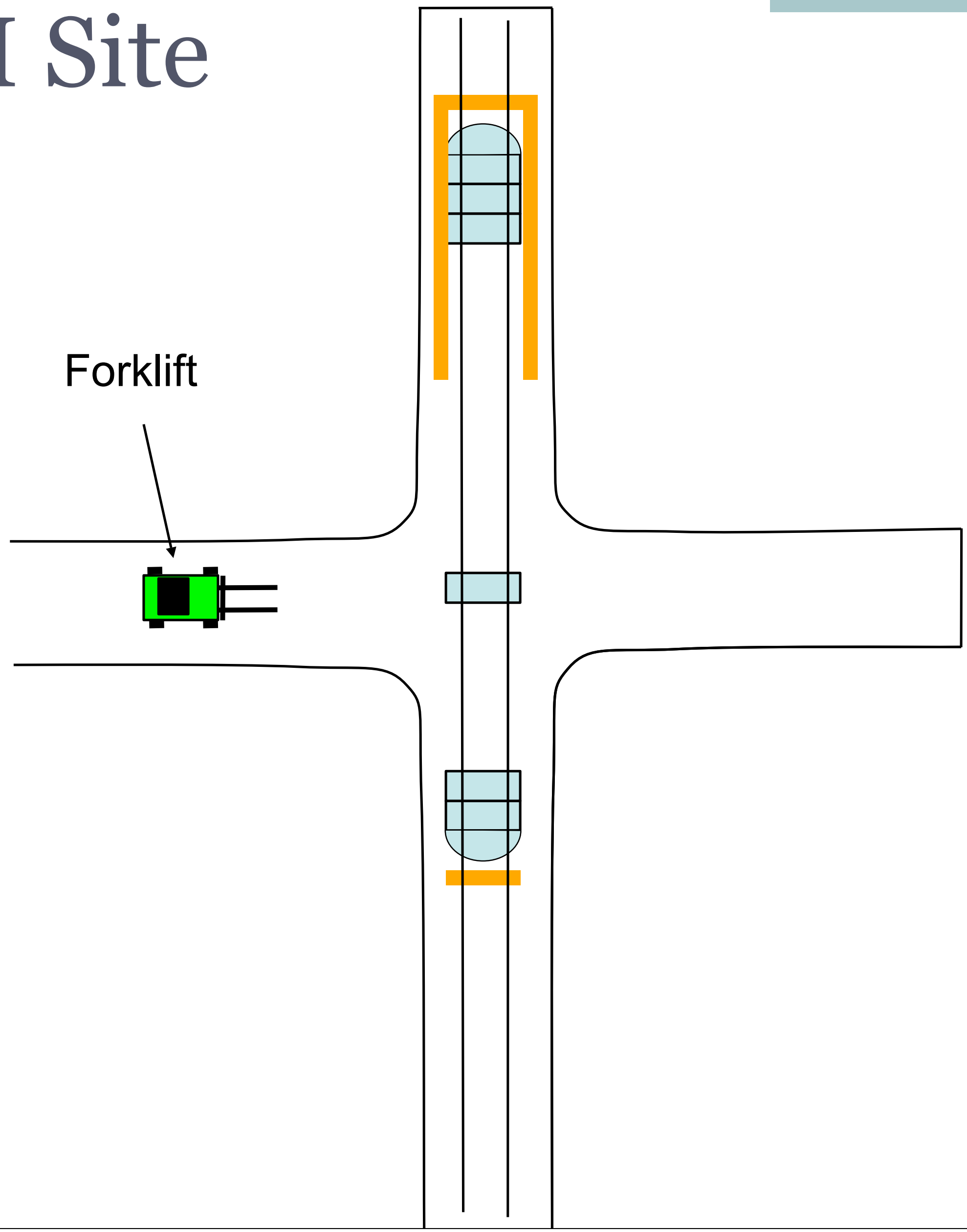
- Site for first DRIFT III module identified at Boulby
- CPL willing to excavate for DTM at "no charge"

scale drawing



only simple infrastructure needed to house the detector

DTM Site

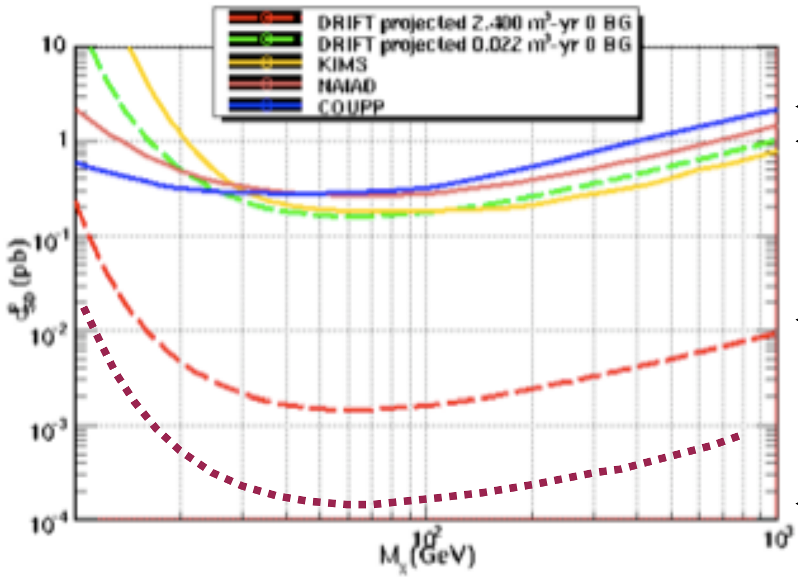


DRIFT III Module (DTM) Sensitivity

with directional capability SD Prediction

- Projected limits for a DTM (DRIFT III Module) (24 m³)
- With no compromise on directional sensitivity

Expected WIMP-proton spin dependent sensitivity



← current limits

← DRIFT IId - 10 day run, zero background prediction

← DRIFT IId - 2.4 m³-years, zero background prediction

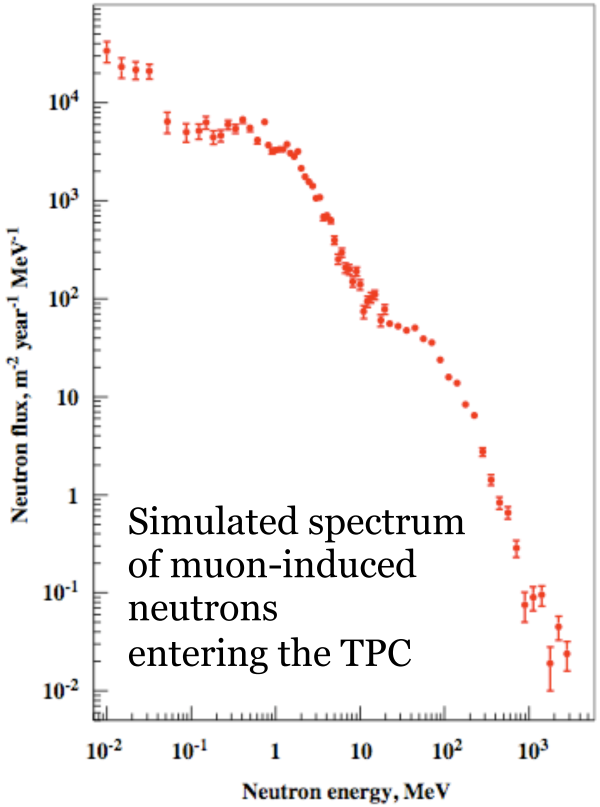
← DTM - 1 year run 4 kg.yr

Neutron Summary

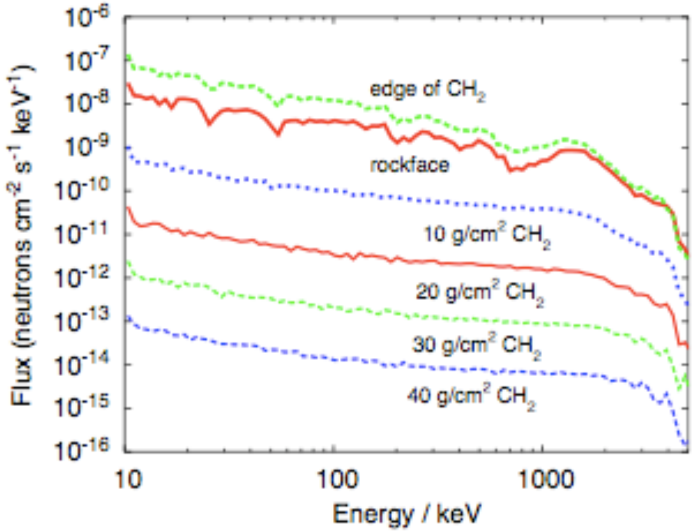
DRIFT II studies

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

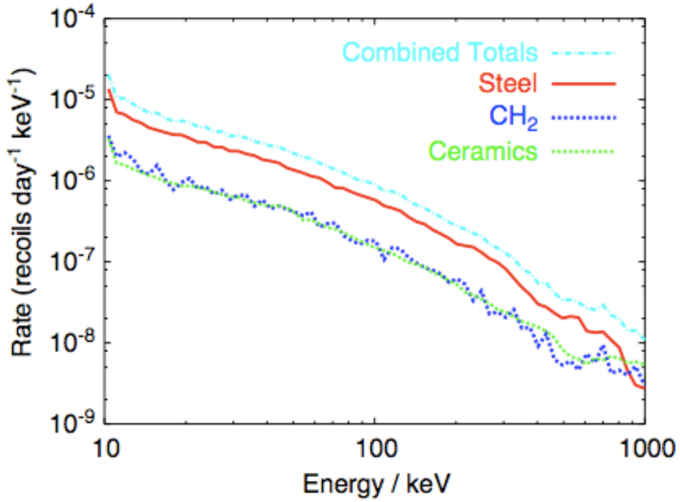
(1) Muon neutrons



(2) Rock neutrons



(3) Detector neutrons



Neutron Summary

Assumptions

Includes 40 g cm^{-2} CH_2 shielding against rock neutrons (estimates)

Result (prelim estimates for DTM)

see 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
DTM (as multiple DRIFT IIs)	4.00	0.24	2.88	1.56	4.68
DTM using steel, no muon veto	*4.00*	*0.20*	*2.00*	*1.50*	*3.70*
DTM acrylic, no muon veto	*4.00*	*0.20*	*<1.00*	*<1.00*	*<0.4*

Conclusion for <u>single</u> DTM (prelim):

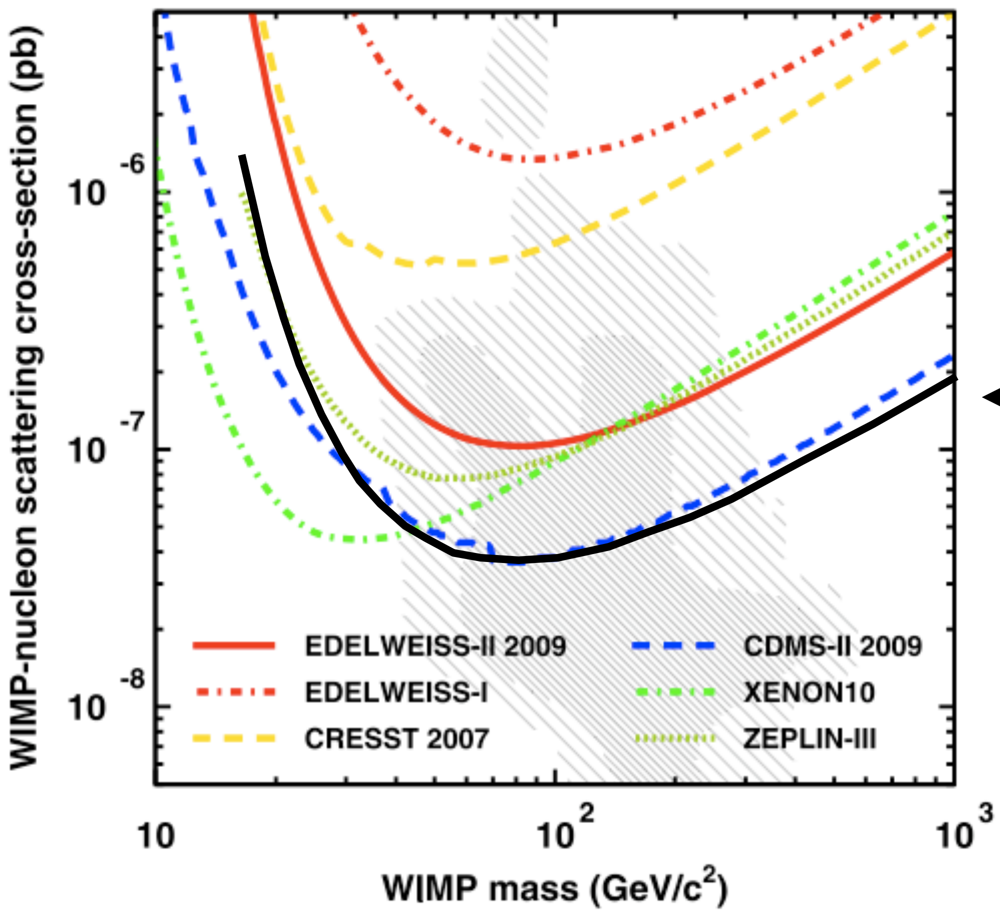
- Requires 40 gcm^{-2} CH neutron shielding (like DRIFT II)
- Steel construction just about alright
  optimization, selection, internal CH?
- No need for muon active veto at Boulby for single module

DTM Sensitivity

SI Prediction

with directional capability

- Projected limits for one DTM (4kg)
- With no compromise on directional sensitivity



← DTM - 1 year run (4 kg.yr)

thanks to EDELWEISS for the plot

Conclusion - a 24m³ directional detector

- New DRIFT IId WIMP-proton limits
- Blind analysis of further data with thin cathode soon
- Development from DRIFT II to DTM (x24) is now not a major technical leap; the main challenges are:
  - Vessel design (reduction of muon and detector neutrons)
  - Full implementation of z-fiducialisation (RPR reduction)
  - Gas recycling and handling underground
- CCDs, Micro-pix, Micromegas alternative readouts also possible