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
P. Majewski, D. Muna, D.P. Snowden-Ifft, N.J.C. Spooner (2009) arXiv:0902.4430

PI - D.P. Snowden-Ifft
PIs – D. Loomba and M. Gold
PIs - N.J.C. Spooner and E. Daw
PI - A.S. Murphy
PI – D. Santos

DRIFT

Progress with DRIFT
CYGNUS Cooperation

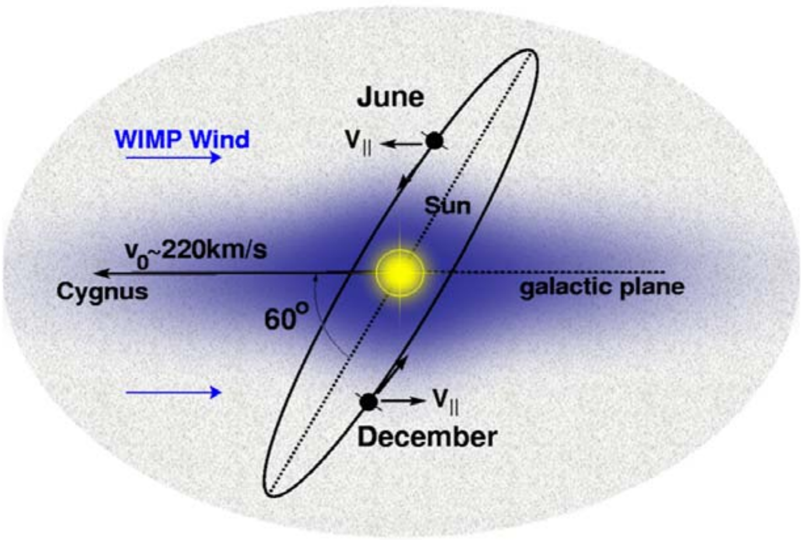
- old stuff
- new stuff

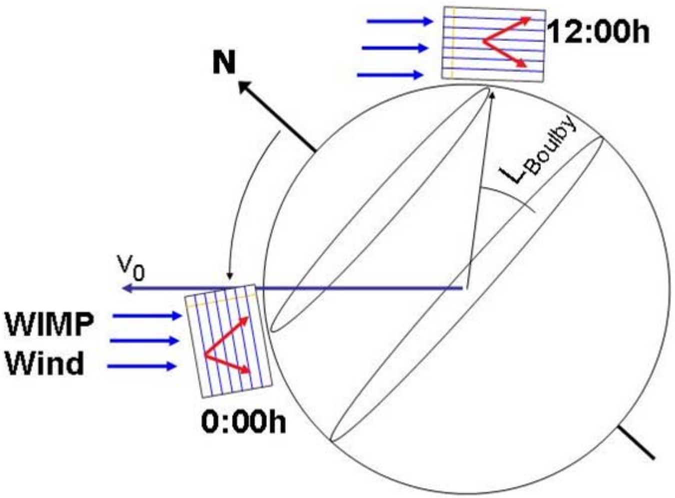
Neil Spooner

The University Of Sheffield.

Dark Matter Signals

- 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





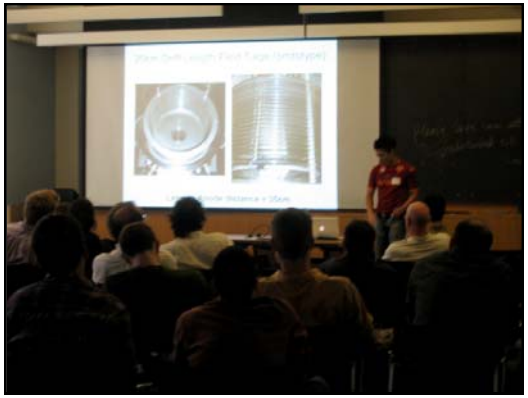
How Many People Needed?

CYGNUS Cooperation links most groups

- Interest in directional detection rapidly increasing
- DRIFT (US-UK), MIMAC (France), (CAST), NEWAGE (Japan), DMTPC (US), Emulsions (Japan)
- Theory groups....

CYGNUS2007 meeting
22-24 July 2007, Boulby, UK

CYGNUS2009
11-13 June 2009, Boston, USA

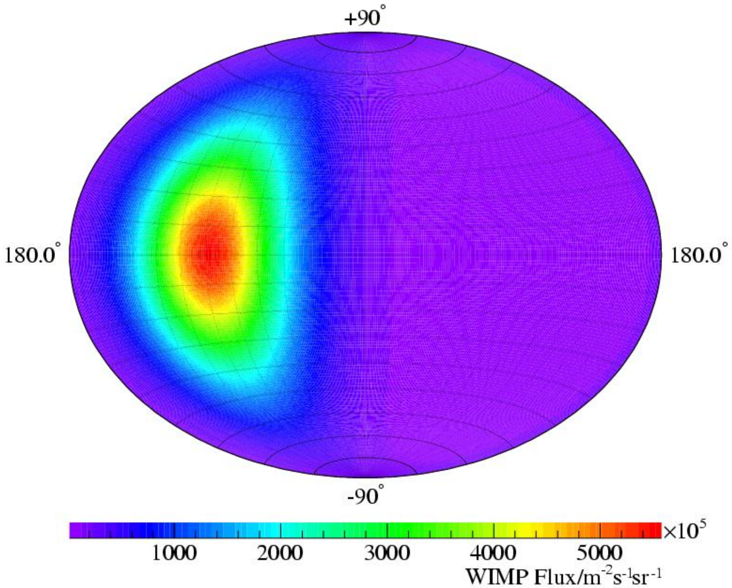


CYGNUS2010, Grenoble, France

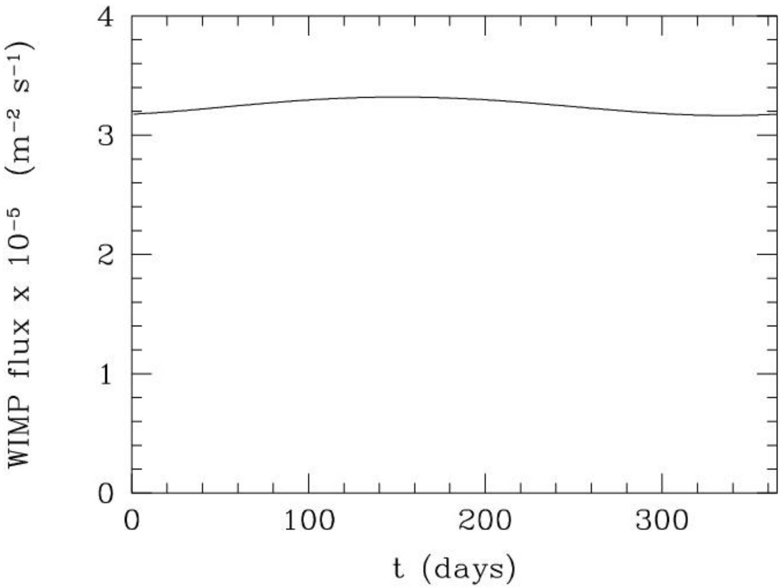
Cooperation on joint document towards scale-up

Directional Dependence v. Ann Mod

Directional signal



Annual modulation signal



Hard for a background to mimic the directional signal.
(anisotropic backgrounds in lab are isotropic in Galactic rest-frame)

A WIMP directional signal could ***(in principle)*** be detected with of order 10 events
[Copi, Heo & Krauss; Copi & Krauss; Lehner & Spooner et al.]

Towards WIMP Astronomy

How Many WIMPs Needed?

Dependence of number of events to reject isotropy (*and detect a WIMP signal*) at 90 (95)% c.l. in 90 (95)% of experiments, N_{90} (N_{95}), on detector capabilities:

difference from baseline configuration	N_{90}	N_{95}
none	7	11
$E_T = 0$ keV	13	21
no recoil reconstruction uncertainty	5	9
$E_T = 50$ keV	5	7
$E_T = 100$ keV	3	5
$S/N = 10$	8	14
$S/N = 1$	17	27
$S/N = 0.1$	99	170
3-d axial read-out	81	130
2-d vector read-out in optimal plane, raw angles	18	26
2-d axial read-out in optimal plane, raw angles	1100	1600
2-d vector read-out in optimal plane, reduced angles	12	18
2-d axial read-out in optimal plane, reduced angles	190	270

} upgraded and unrealistic

Green & Morgan 'PRD '08, arXiv:0711.2234
Green & Morgan, Astropart. Phys '07, astro-ph/0609115
Morgan & Green, PRD '06 ,astro-ph/0508134
Morgan, Green & Spooner, PRD '05, astro-ph/0408047

} assuming perfect angular resolution

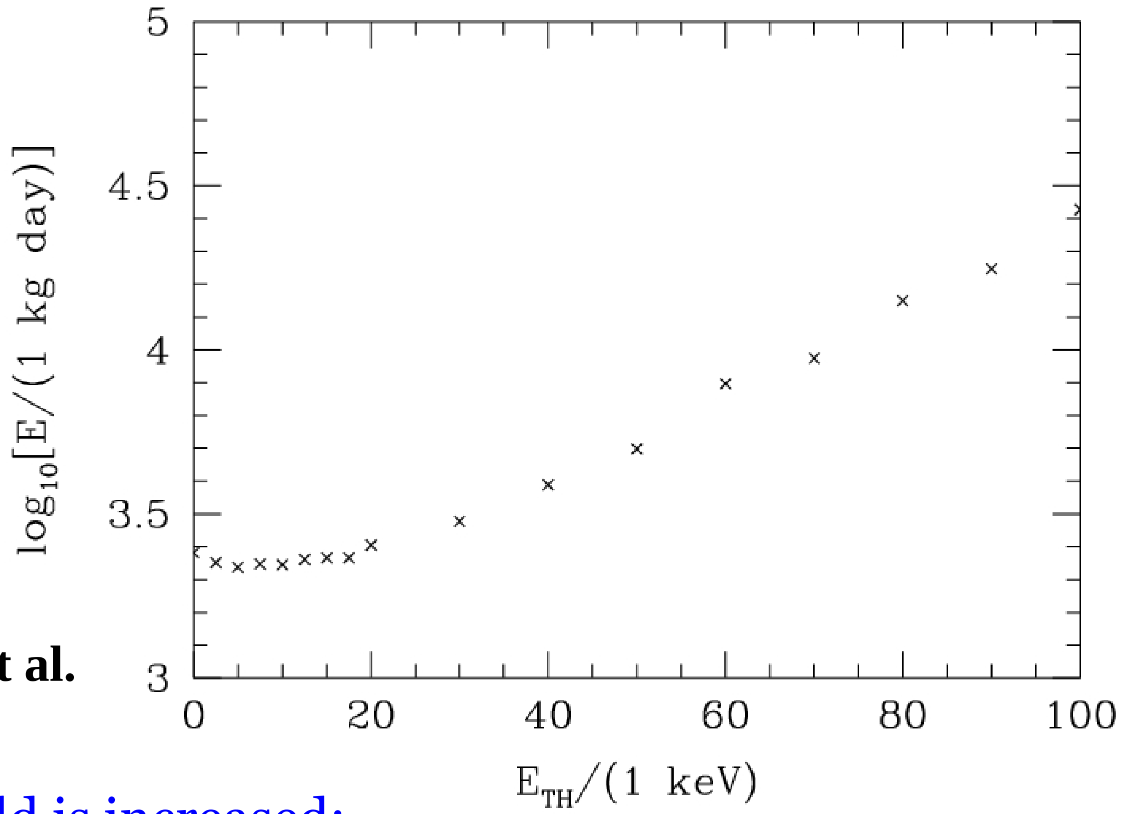
baseline configuration: 3-d vector read-out,
20 keV threshold,
zero background,
recoil reconstruction uncertainty taken into account

What Threshold Needed?

Exposure requires as a function of threshold energy to reach 10^{-7} pb:

Exposure vs. threshold

A. Green et al.

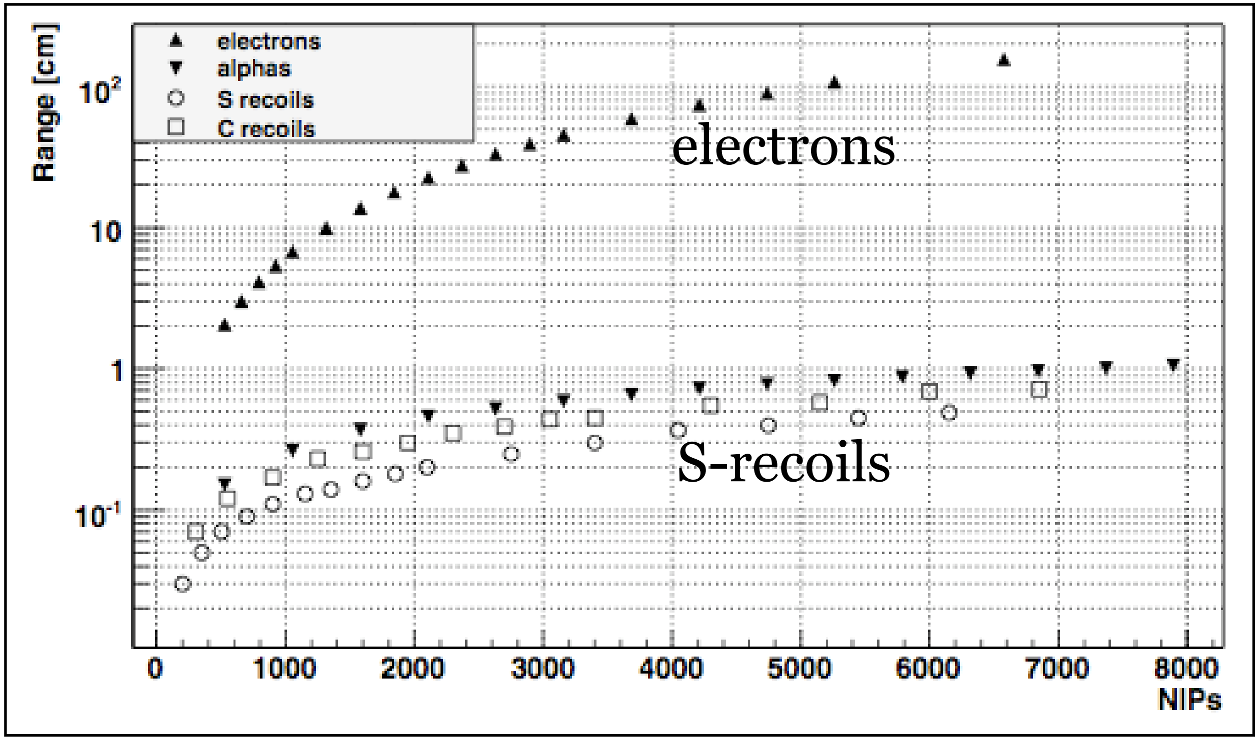


As energy threshold is increased:

anisotropy increases so number of events required decreases, but event rate also decreases. Net effect: exposure increases.

Range Discrimination

simulations



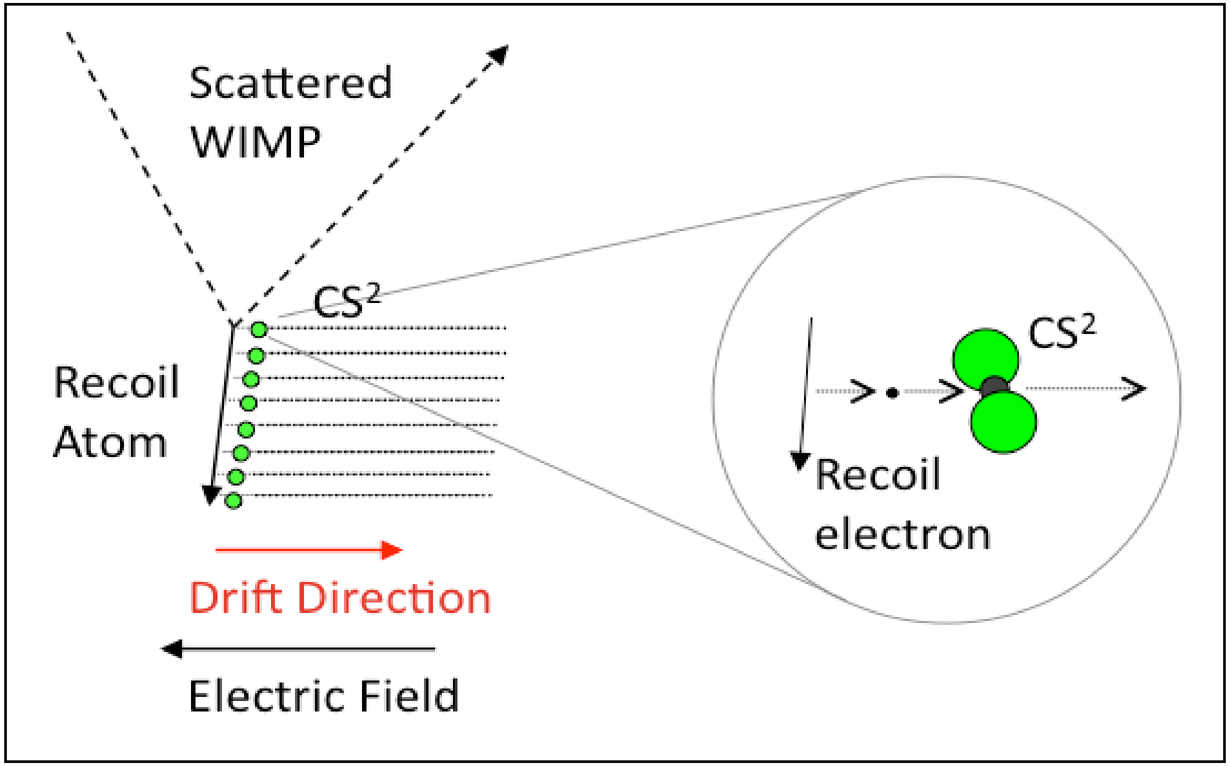
Key points: it's range discrimination - no doubt

$>10^6$ gamma rejection shown in DRIFT II

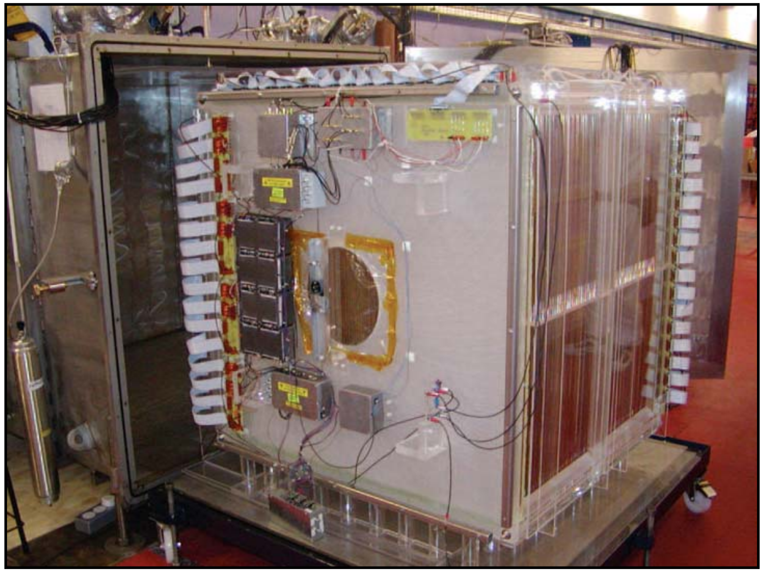
S. Burgos et al., Astropart. Phys. 28 (2007) 409

NI-TCP (negative ion time projection)

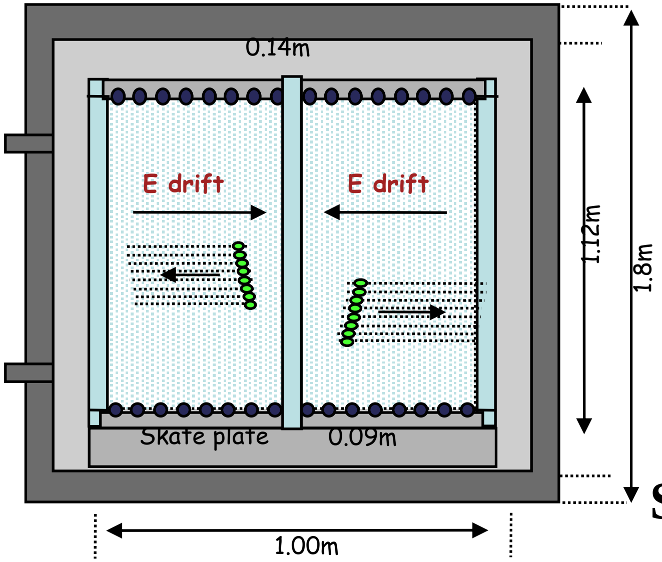
- NI-TPC uses electronegative CS_2 atoms to transport electrons to the MWPC readout plane with only thermal diffusion
- At the high field region near the MWPC the electrons are stripped from the negative ion and avalanche in the normal fashion
- Standard TPC – electrons at ~1000ms^{-1}
- NI TPC – ions at ~50ms^{-1}
- High spatial resolution

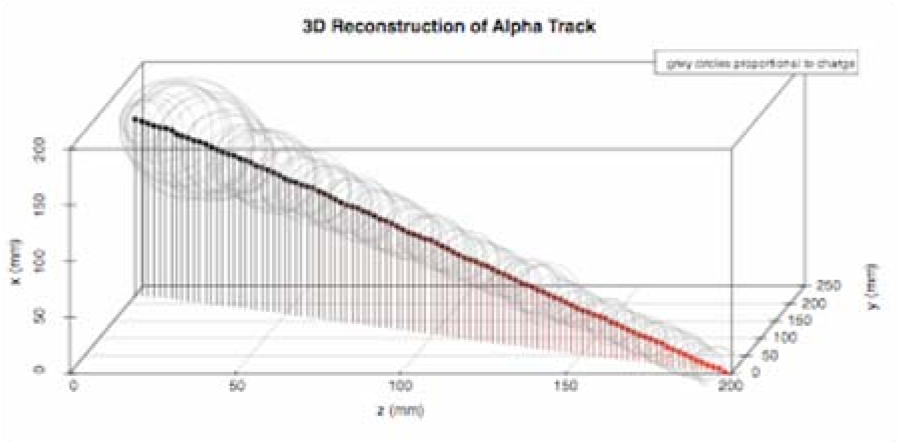


DRIFT IIa-d at Boulby mine



- 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

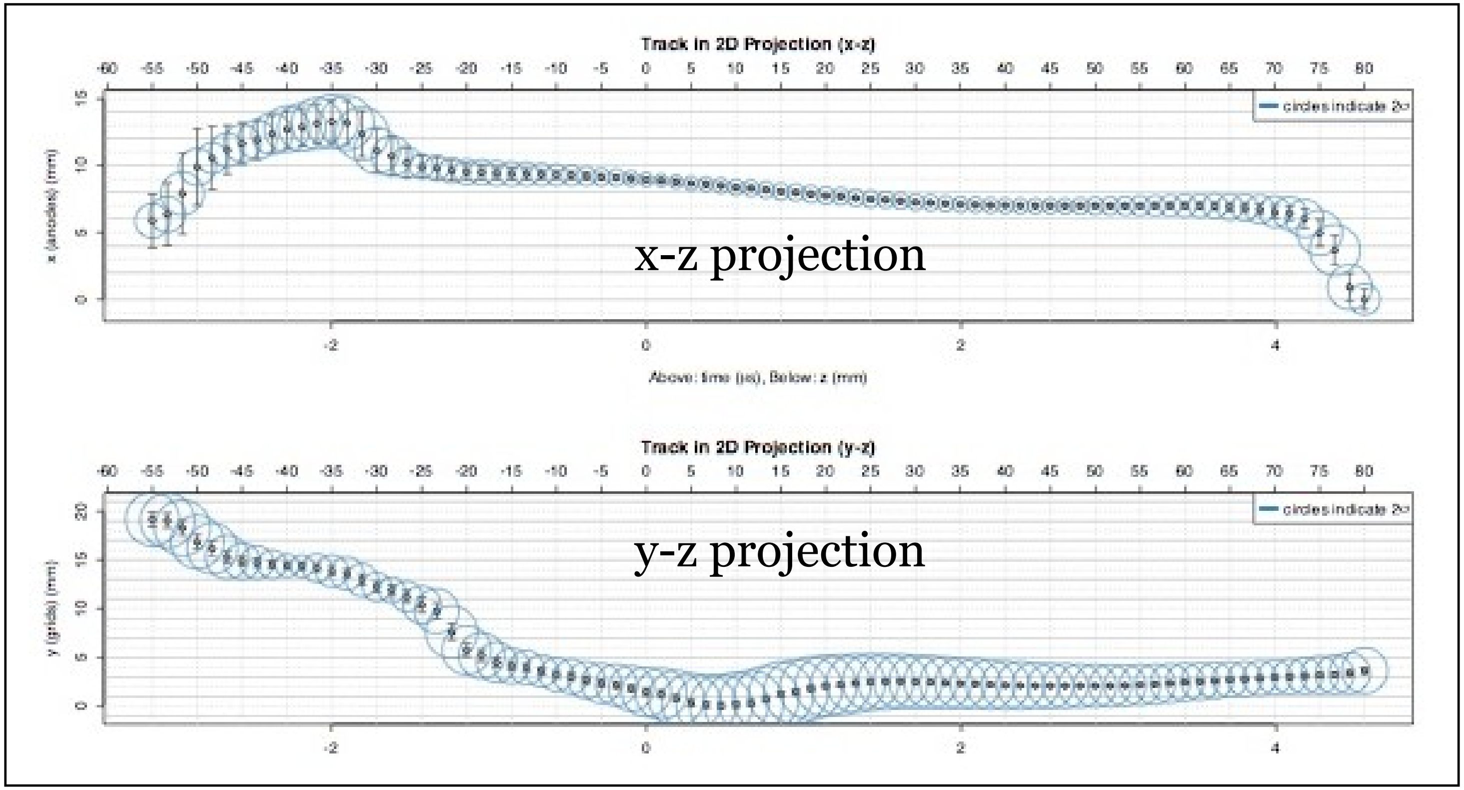




S. Burgos et al., Nucl. Instr. Meth. A 584, 114 (2008)

3D Track Reconstruction

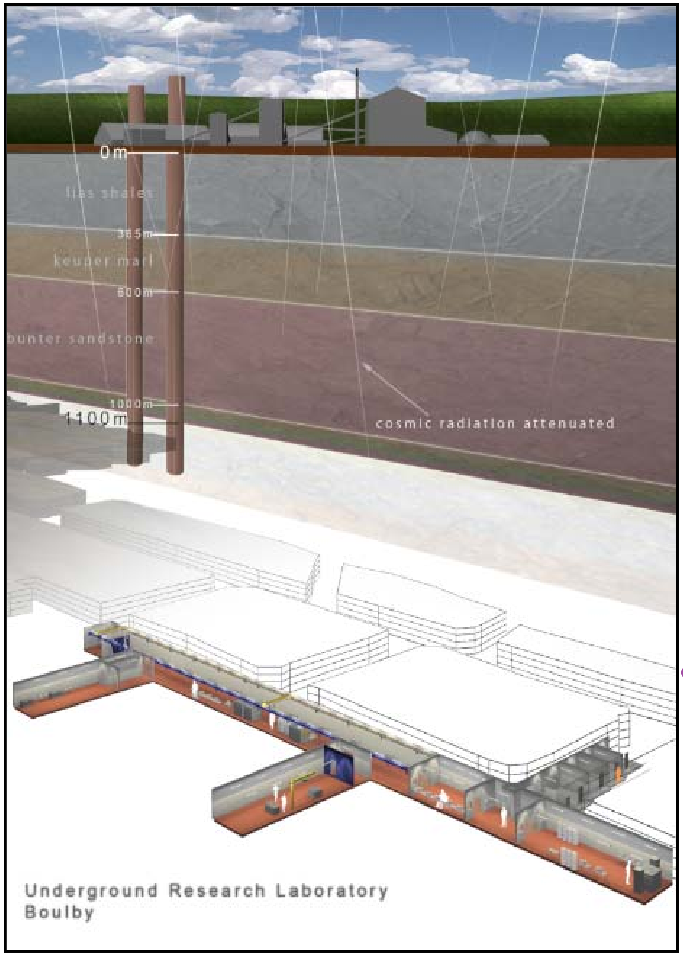
Example 3D reconstruction (x-z and y-z projections) of a ~100 keV S recoil in DRIFT IIb (size of circles is indicative of the size of charge deposited).



D. Muna Thesis, University of Sheffield (2008)

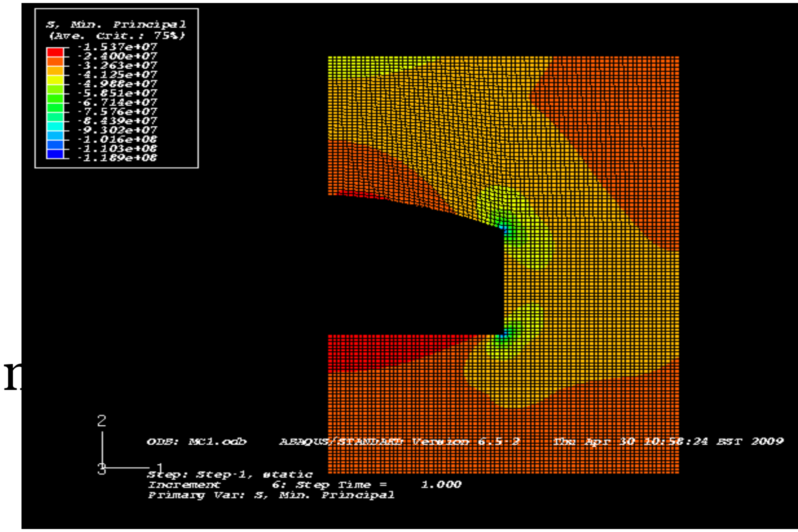
Boulby mine

- Current site (1.1 km deep) hosts dark matter experiments in salt rock
- But new excavation underway to deeper levels, hard dolomite rock
- Suitable for a large TPC!



expansion plans

- Geotechnical simulations indicate 40-80m spans feasible



Recent DRIFT Progress

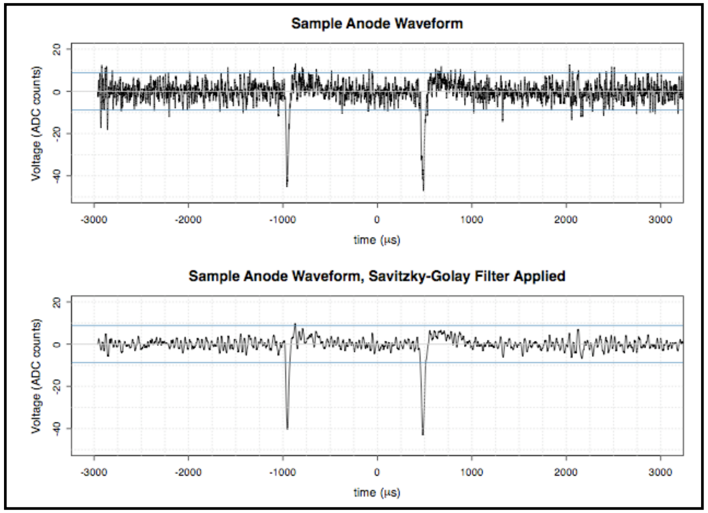
Recent papers from the DRIFT collaboration demonstrate:

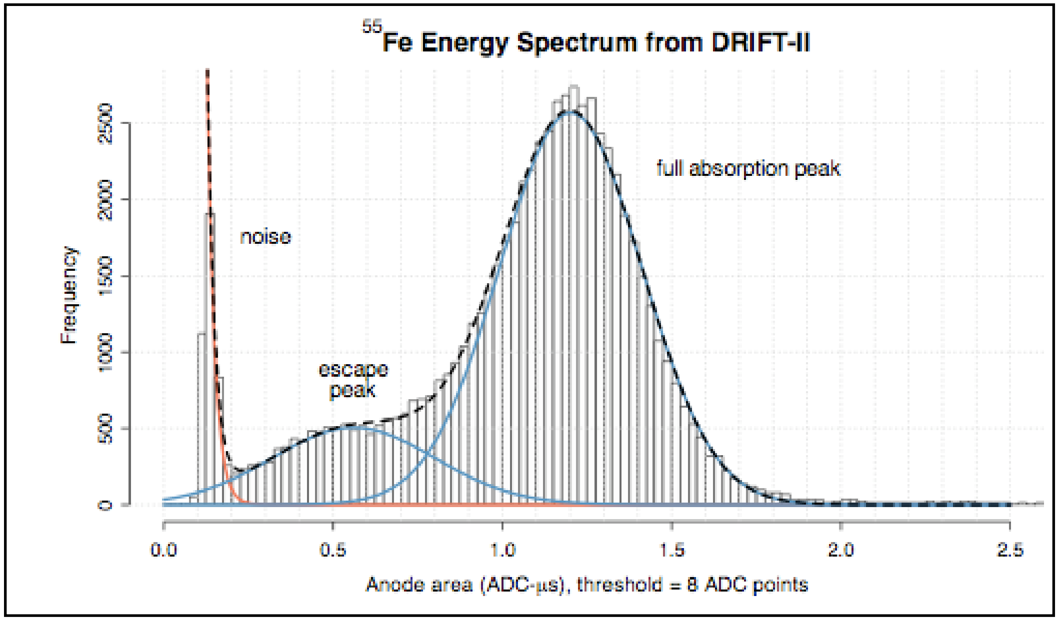
- 3-dimensional directionality - http://arxiv.org/abs/0807.3969
  - ^{252}Cf source produces S recoils similar to expected WIMP induced recoils
  - Demonstrated for the first time directional sensitivity to nuclear recoils in a large dark matter detector
- Head-tail discrimination - http://arxiv.org/abs/0809.1831v1
  - Demonstrated that neutron induced sulfur recoils in the DRIFT detector have a clear asymmetry.
  - Head-tail discrimination reduces no. of WIMP events required by an order of magnitude.
- Sensitivity to low energy events - http://arxiv.org/abs/0903.0326v2
  - Demonstrates the sensitivity of the DRIFT detector to detect sulfur recoils down to ~3keV
- Low background
  - Digital polynomial filtering
  - Solutions to radon RPR reduction
  - Latest background ~1 event per week

(1) Low Energy Result

S. Burgos et al., Astroparticle Physics 31 (2009) 261

use of Savitzky-Golay digital filter





^{55}Fe track reconstruction and digital polynomial smoothing - data fit to exponential decay(noise) plus Gaussians

Energy thresholds -->

Source of Track	Thres. Energy (keV)
Electron	1.23
Alpha	1.23
Carbon nuclear recoil	2.15
Sulphur nuclear recoil	3.46

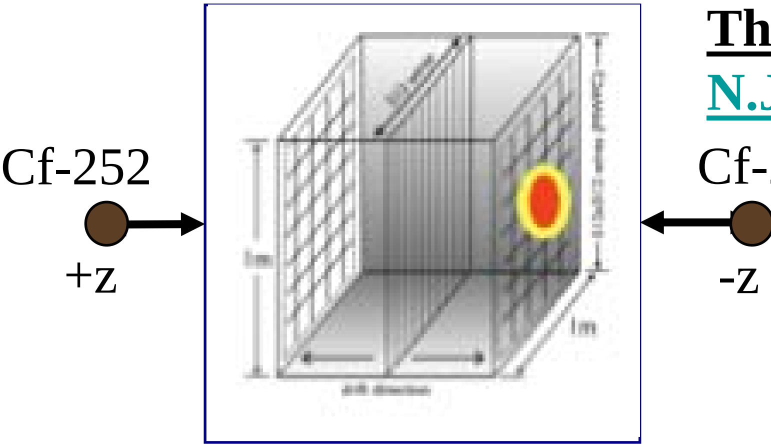
Note these are not the trigger thresholds yet

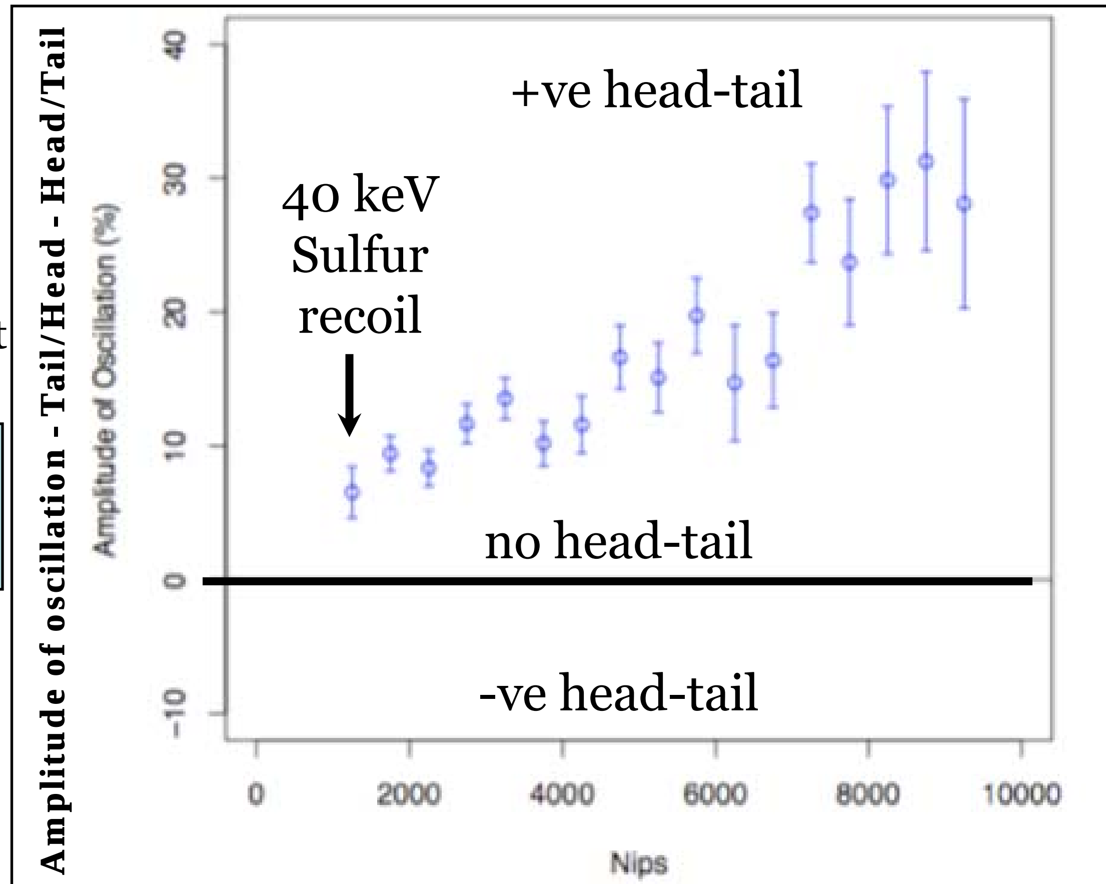
(2) Head-Tail Result

Experiment: S. Burgos et al., Astroparticle Physics 31 (2009) 261

Theory: P. Majewski, D. Muna, D.P. Snowden-Ifft, N.J.C. Spooner (2009) arXiv:0902.4430

Directed neutron runs (DRIFT IIc): +z, -z,+x, -y





Note: extrapolation indicates head-tail discrimination continues below current threshold

Clear head-tail discrimination (in 1 m^3 at low energy)!

Theory Conclusion:

- expect head-tail
- expect more ionization at start (near interaction)
- depends on W

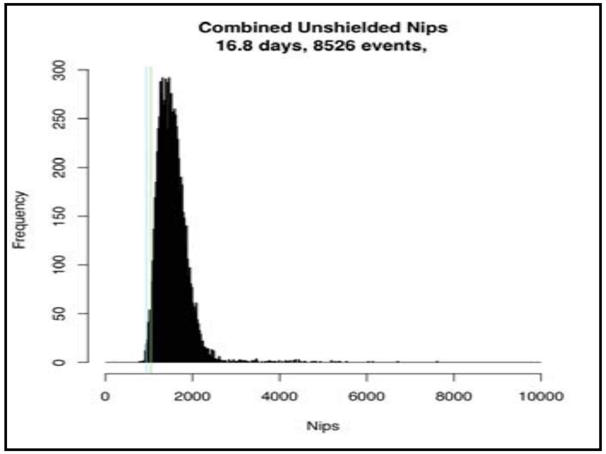
(3) Radon Progeny Result

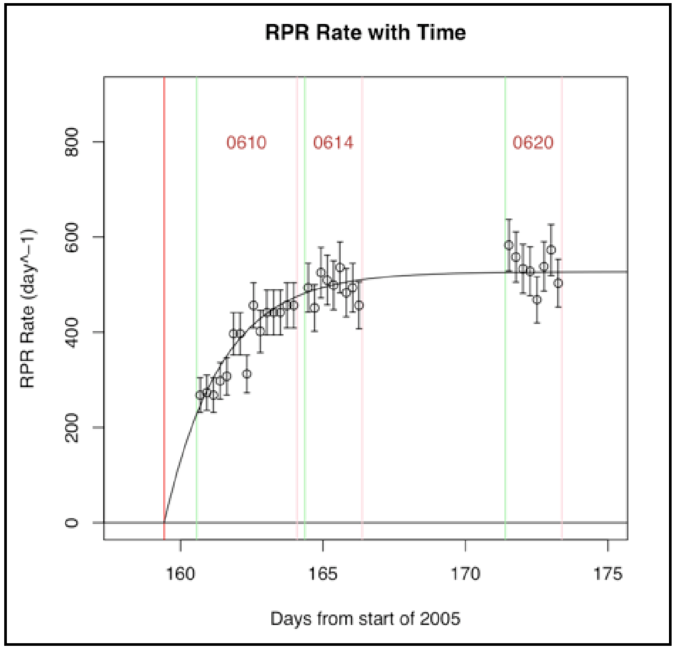
S. Burgos et al., Astropart. Phys. 28 (2007) 409

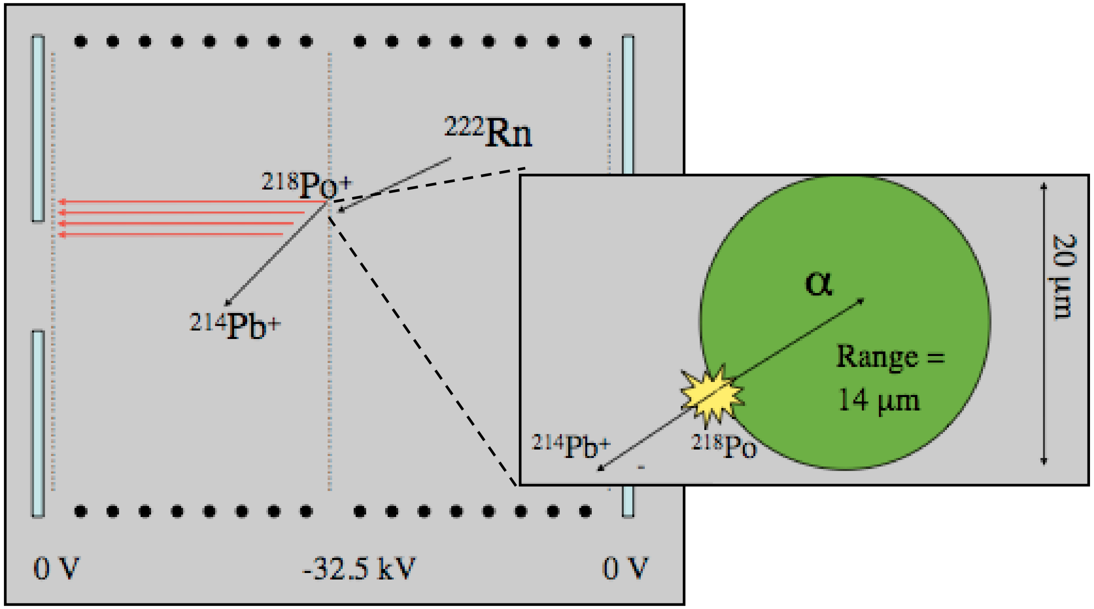
First low background runs of DRIFT-II see a recoil-like background ~200-600 / day (50-250 keV).

Increase with time consistent with Rn emanation.

Hypothesis: Recoil of radon progeny on central cathode - with alpha absorbed in wire.





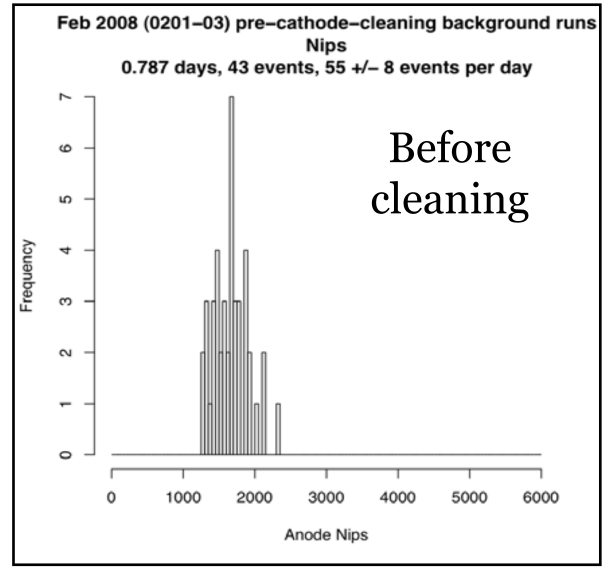


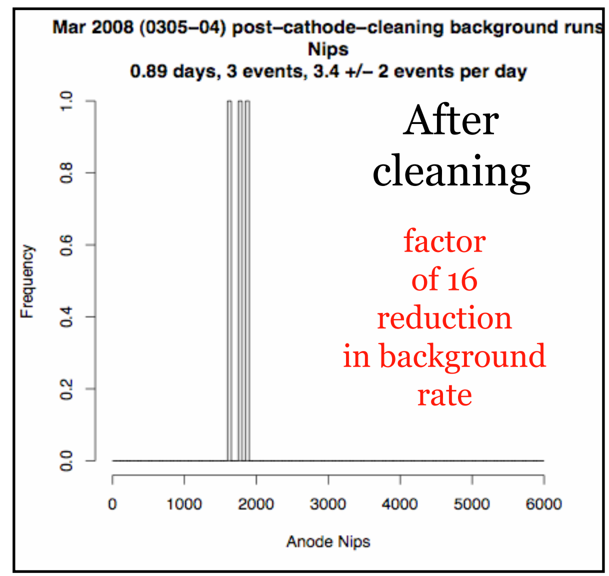
DRIFT II sees an excess of background events attributed to recoils of ^{210}Pb plated out on the detector. Likely region for build-up of ^{210}Pb is on the cathode wires.

Johanna Turk (University of New Mexico)

Mark Pipe (University of Sheffield)

Kirill Pushkin (Occidental College)





Now applied same cleaning procedure to the MWPC grid and anode wires.

RPR Reduction Results

Run	Detector configuration	Gas flow rate (chg/day)	GPCC rate (m^{-3}day^{-1})	RPR rate (day^{-1})
(1) DIIa June 2005	Original state	1	8000+/-1000	500+/-20
(2) DIIb Feb 2007	RG58, teflon cables removed and inner detector sealed	1	820+/-40	40+/-2
(3) DIIb July 2007	As above	10	110+/-30	51+/-4
(4) DIIb Feb 2008	As (2) (with slight cuts change)	1	-	55+/-8
(5) DIIb Mar 2008	As (4) but cathode nitric cleaned	1	-	3.4+/-2
(6) DIIb Aug 2008	After MWPC nitric clean	1	-	<1/week
(7) DIIb Mar 2009	After MWPC nitric clean	1	-	<1/week

- Big success in background reduction >x3000
- New work underway on fiducialisation and further passive reduction

Next - Spin Dependent Gas Mixtures

- DRIFT detector could be converted to a competitive spin dependent dark matter detector with the addition of CF_4
  - Dark matter signal contains both scalar and axial (spin independent, SI, and spin dependent SD) components
  - CF_4 is an attractive candidate
  - Can it work in DRIFT?
  - Can it work with CS_2 negative ion gas carrier but still preserve the low diffusion use of CS_2?
    - An ideal gas because
      - ☐Non toxic, non flammable (unlike CS_2)
      - ☐^{19}F has odd proton
      - ☐Natural abundance of 100% ^{19}F
      - ☐^{19}F has the best known spin figure of merit

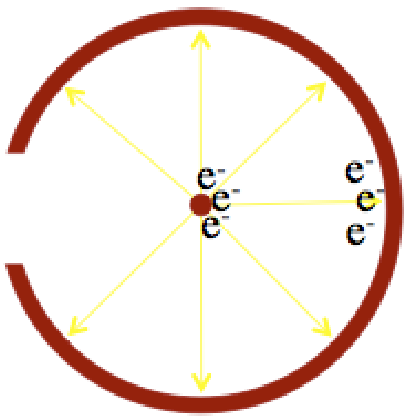
CS_2-CF_4 Gas Mixture Tests

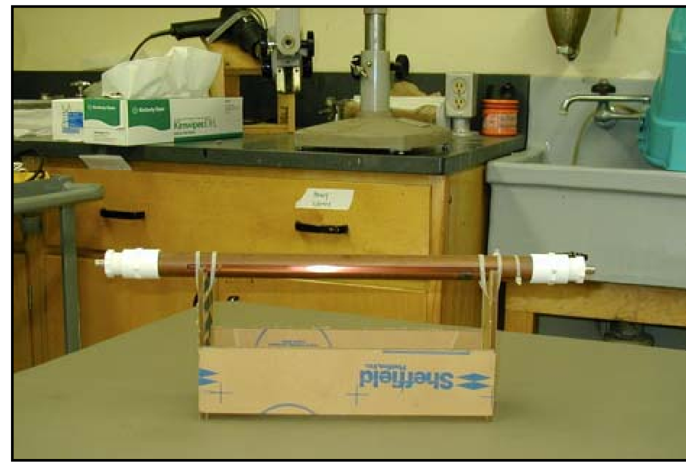
- The collaboration has explored various CS_2-CF_4 mixtures
- Sheffield studied sensitivity, Grenoble is studying quench factors

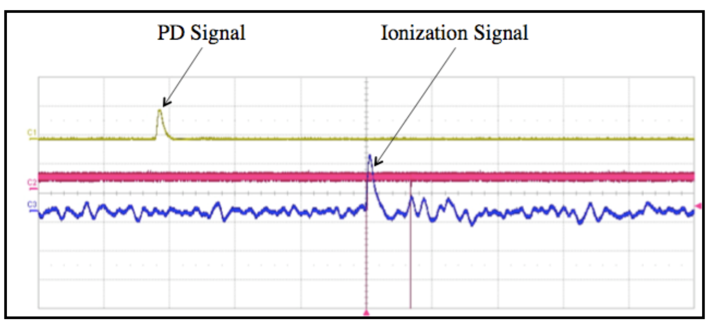
Tests at Occidental College

UV flash lamp

proportional counter







can measure size of single electron and drift time:

W
Mobility ←
Diffusion
Gain ←

Gas mixture tests - W value

Ionisation yield for a single electron, Y_{SE}

Size of event produced, $\langle\sum_{SE}\rangle$

Expose to ^{55}Fe x-rays to measure size of event $\langle\sum_{55}\rangle$

$$Y_{55} = \frac{\langle\Sigma_{55}\rangle}{\langle\Sigma_{SE}\rangle} Y_{SE} = \frac{\langle\Sigma_{55}\rangle}{\langle\Sigma_{SE}\rangle}$$

$$W = \frac{E_{55}}{Y_{55}}$$

Gases, (Torr)	Voltage, V	Ionization yield	W-value, eV	W-value, eV Pure CS_2 (other works)
Pure CS_2, (40)	1600	237 ± 7	24.9 ± 0.8	24.7±0.7[18] 26.0±0.5 [19]
CS_2-CF_4, (30-10)	1550	234 ± 6	25.2 ± 0.6	
CS_2-CF_4, (20-20)	1350	202 ± 7	29.2 ± 1.0	
CS_2-CF_4, (10-30)	1300	179 ± 5	33.0 ± 1.0	
CS_2-He, (35-5)	1550	249 ± 8	23.7 ± 0.8	
CS_2-Ne, (35-5)	1550	253 ± 8	23.1 ± 0.8	

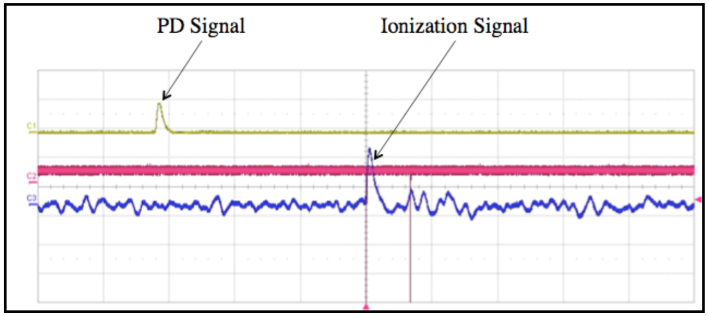
Preliminary

with thanks to Dan Snowden-Ifft

CS_2-CF_4 Gas Mobility

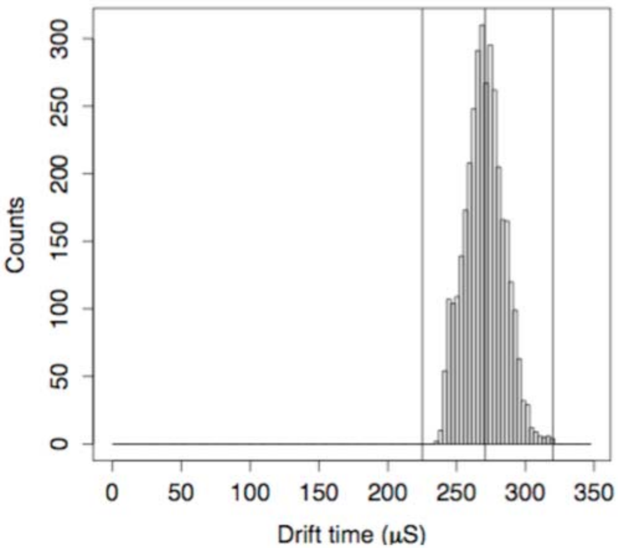
measure the drift time, using the laser start signal, and hence mobility:

$$v = \frac{\mu E}{p} \qquad \mu = \frac{p\ln(\frac{b}{a})}{2\Delta t \Delta V}(b^2 - a^2)$$



Gases, Torr	Voltage, V	Drift time, µs	Reduced mobility, $\mu, \frac{cm^2 atm}{Vs}$	Reduced mobility, $\mu, \frac{cm^2 atm}{Vs}$ (other works
Pure CS_2, (40)	1600	270.8±0.2	0.54 ± 0.02	0.52 ± 0.02 [5]
CS_2-CF_4, (30-10)	1550	250.1±0.2	0.60 ± 0.02	
CS_2-CF_4, (20-20)	1350	251.0±0.3	0.69±0.02	
CS_2-CF_4, (10-30)	1300	222.0±0.3	0.81±0.03	
CS_2-Ar, (35-5)	1550	257.4±0.2	0.59 ± 0.02	
CS_2-He, (35-5)	1550	252.0±0.3	0.60 ± 0.02	
CS_2-Ne, (35-5)	1550	248.2±0.3	0.61 ± 0.02	

Preliminary

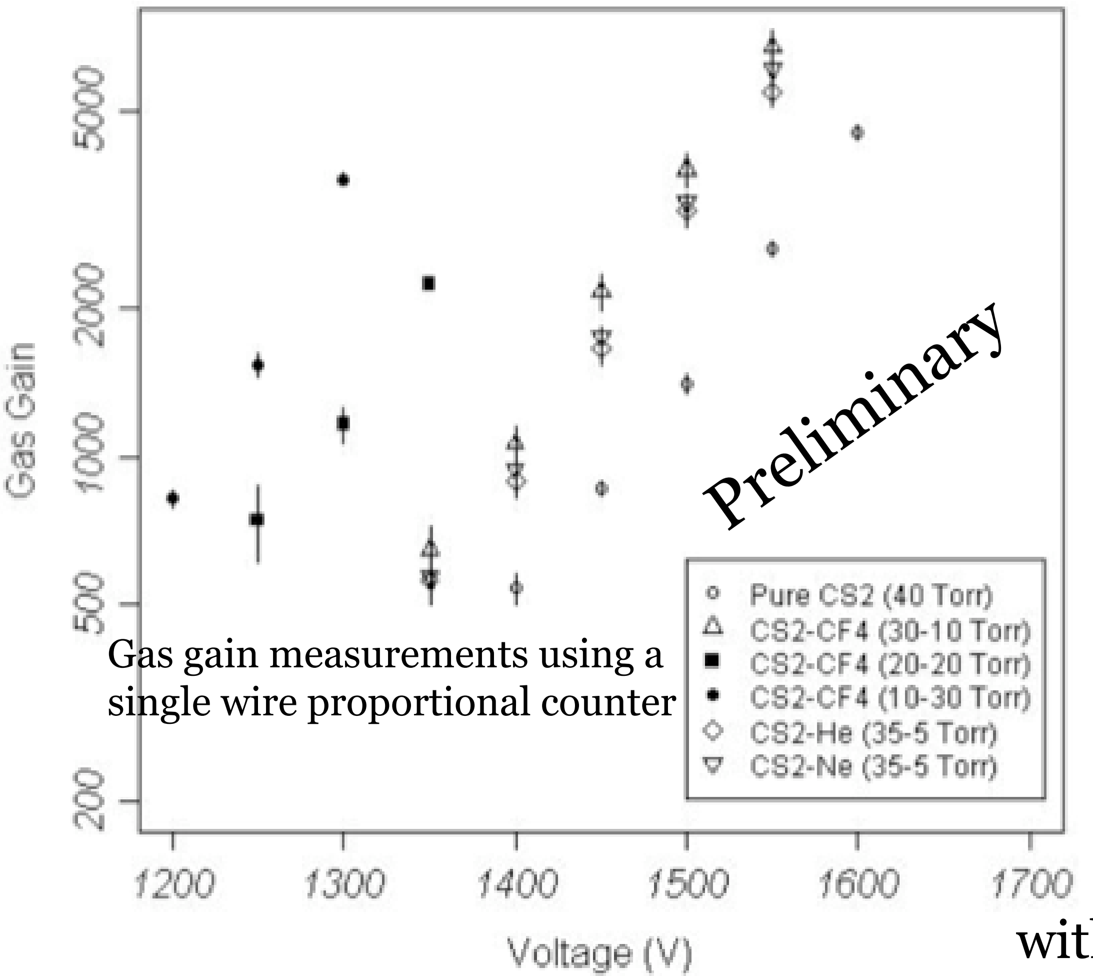


CONCLUSION:

negative ion works with F

Gas Mixture Tests - Gain

From the known gain of the amplifier chain and the size of events gives us the gain for a single electron



Gas gain measurements using a single wire proportional counter

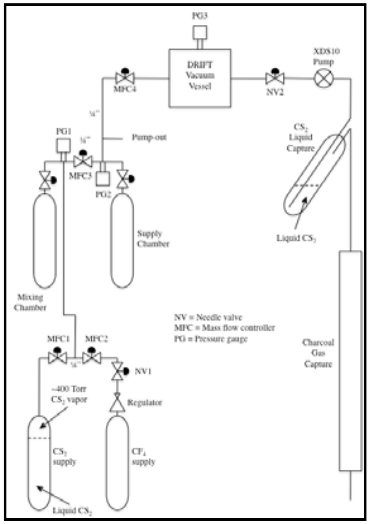
- All mixtures total 40 Torr
  - Gas gain increases for added CF_4
  - Stability decreases
  - High gas gains even with 75% CF_4
  - Best stability with 50:50 mix or lower CF4
- Need to run at lower voltages for stability of high voltage systems – lose MWPC gain
- Loss in MWPC gain is compensated for by improved gas gain.

with thanks to Dan Snowden-Ifft

Gas Mixing Installed - DRIFT IId

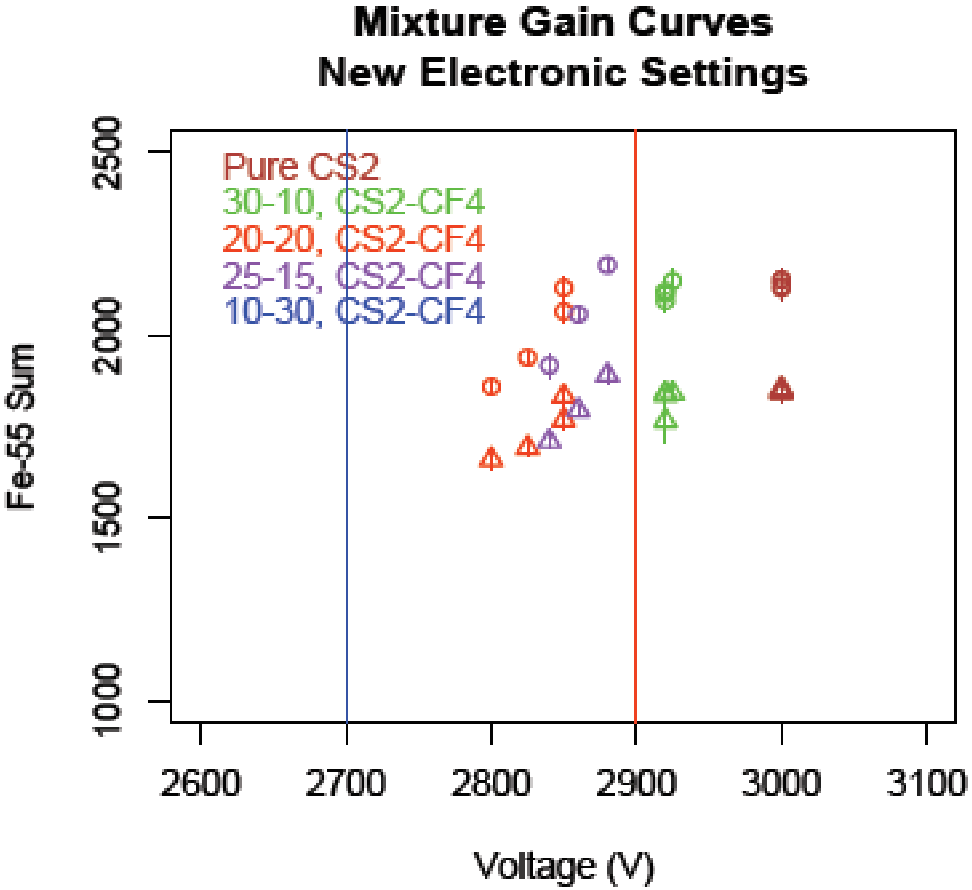
- Built a fully automated gas mixing system to supply a continuous flow of pre-mixed CS_2-CF_4 gas mixture to the vacuum vessel
- Designed by Oxy-Sheffield
- System of mass flow controllers and capacitance manometers to accurately control and monitor gas
- Fully automated and integrated into the current DRIFT slow control

- Installed at Boulby in May 2009
- Installed and working in 2 days
- Now taking CF_4 data



CS_2-CF_4 Gains in 1 m^3 Detector

- DRIFT detector concept works well with up to 75% CF_4
- Gas gain increases
- High voltage stability decreases
- MWPC voltages were chosen such that ^{55}Fe ionisation yield x gas gain is constant in each mixture
- Allows direct comparison of gas mixtures

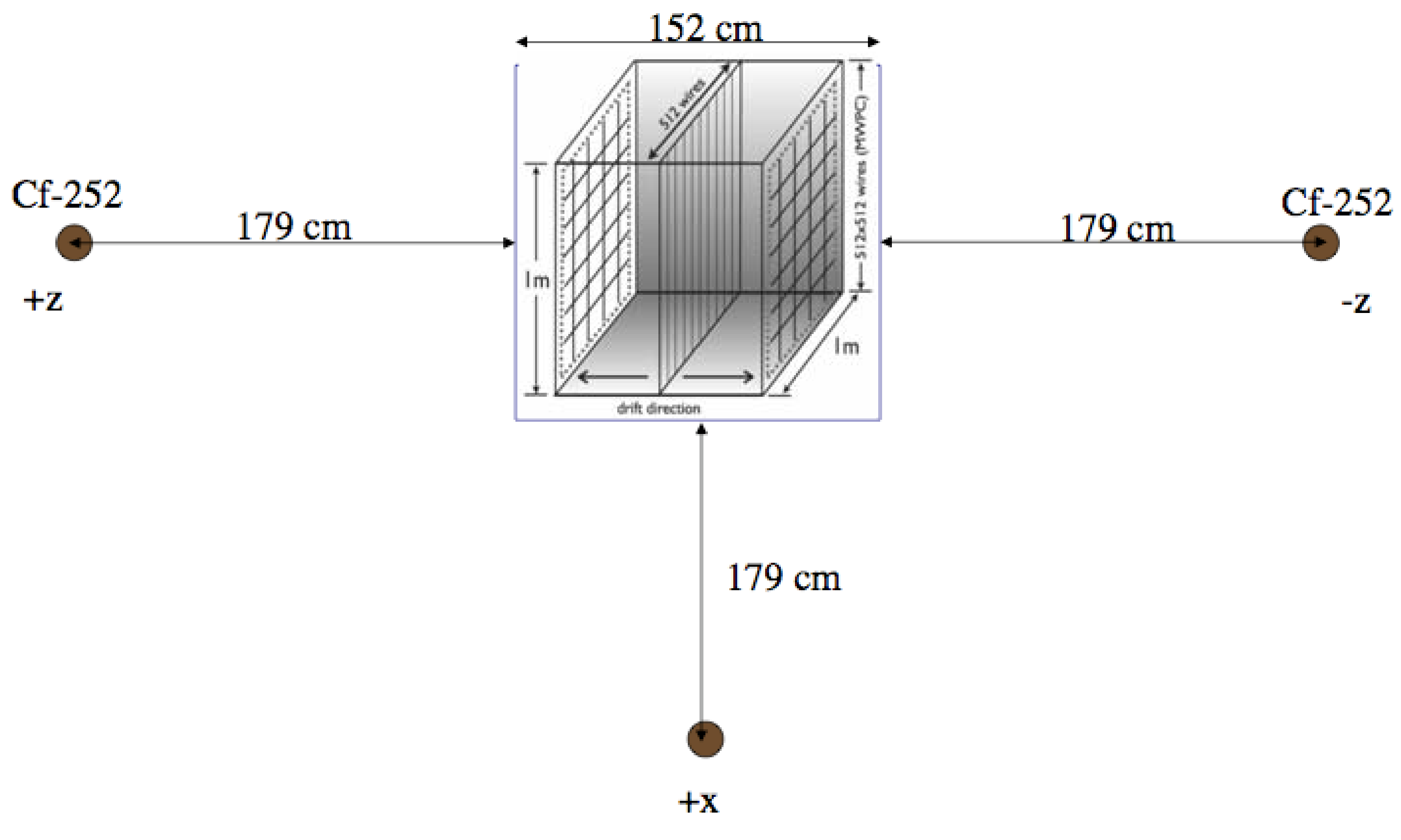


F Recoil Range and Rate Tests

pre-Boulby tests using ^{252}Cf

Expect n-event rate to increase with more CF4 (gains adjusted, same cuts)

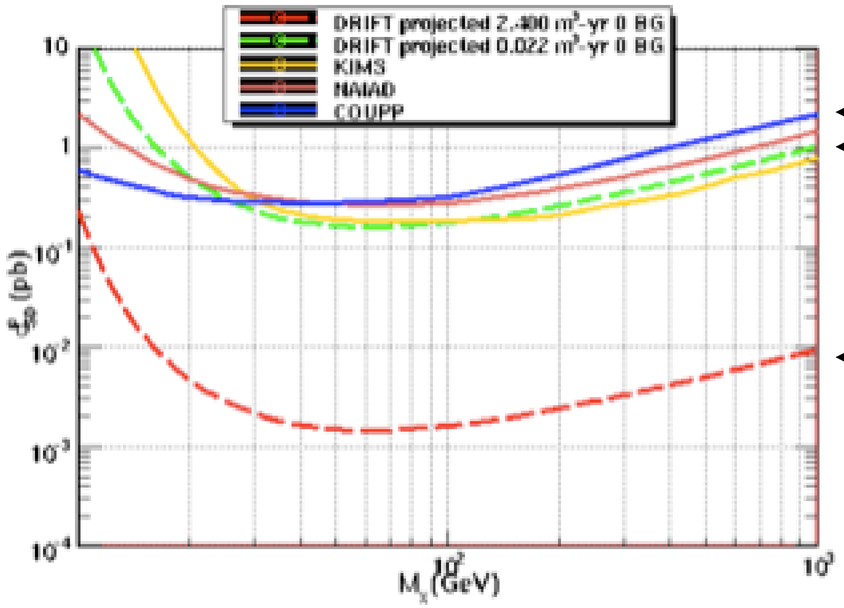
Expect F recoils to be longer than S recoils



SD Sensitivity of DRIFT IId

- Plan is to run for 2.4 m³-years of exposure (started)
- Simulations are in progress – understand the expected behavior in the mixed gas

Expected WIMP-proton spin dependent sensitivity



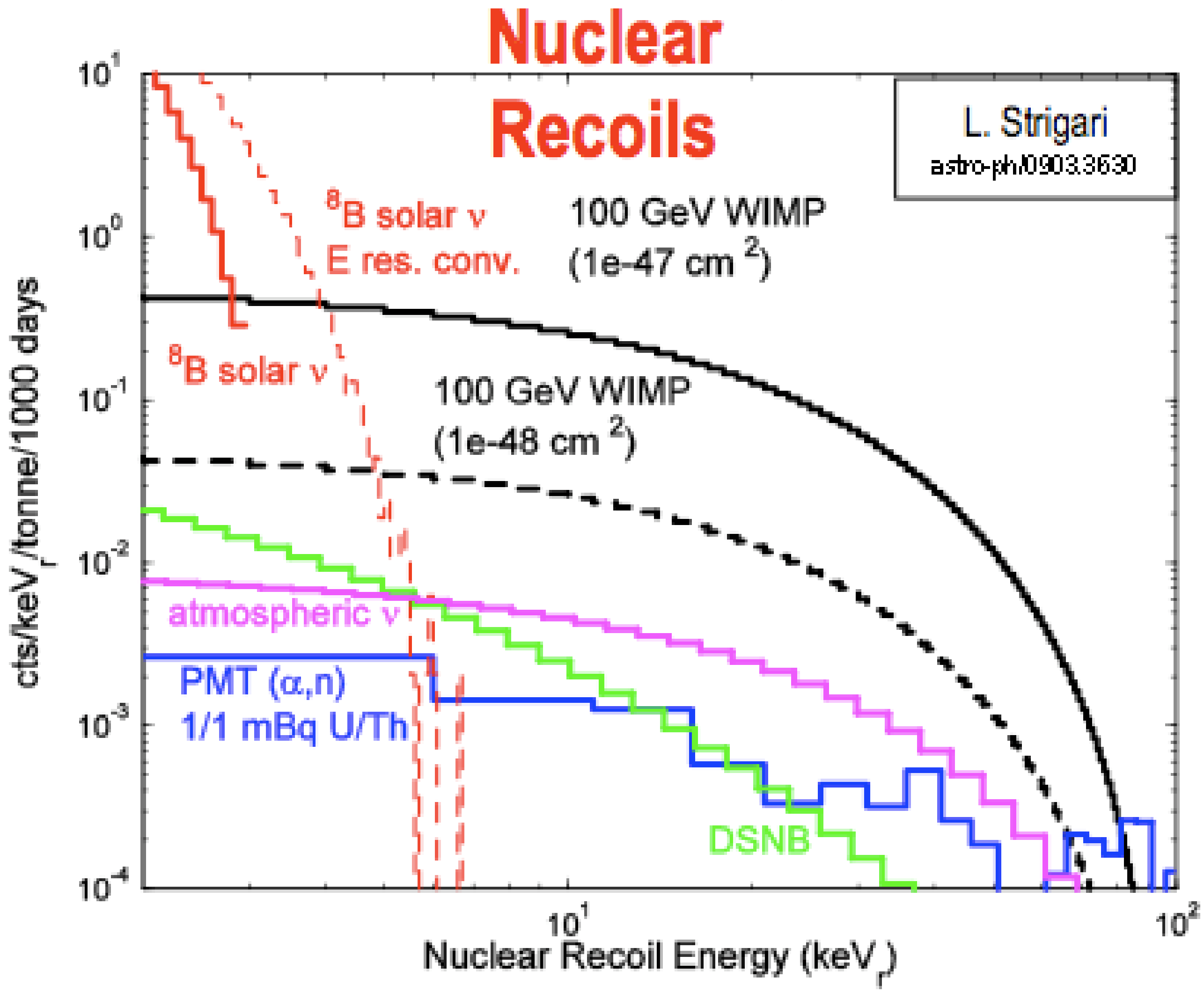
current limits

DRIFT IId - 10 day run, zero background

DRIFT IId - 2.4 m³-years, zero background

with directional capability

Ultimate limit for a non-directional detector is neutrinos (> tonne scale)



Scale-up Speculation (ultimate for SI)

1 tonne directional target:

- Charge readout option - ~10^6 channels (with grouping)
- CCD concept - ~ 10,000 CCD cameras and optics

SuperK size cavern device:

- 10 tonnes (40 Torr)
- 50 tonnes max

Ultimate - on scale of proton decay caverns:

- 400 - 2000 tonne directional target mass

Excavation not a cost driver: €20-50/m^3, €250K/tonne target

Cost extrapolation from DRIFT IId: €50K/m^3

$\Rightarrow$ ~€100M/tonne (with scale factors)

Conclusions

- Big progress in the last two years (published)
  - Event by event discrimination
  - Directional signals possible at 1 m^3 scale
  - Head-tail (sense) exists and is understood at 1 m^3 scale
  - Low recoil thresholds feasible (e.g. 2 keV S-recoil) at 1 m^3 scale
  - Negative ion (low diffusion) operation with other targets demonstrated, in particular Fluorine (CS_2-CF_4)
- More international activity
  - DM-TPC
  - NEWAGE
  - MIMAC, CAST

CYGNUS cooperation and conference series on directional dark matter successful and expanding

- Two scale-up design studies underway
  - DRIFT (US-UK) - CYGNUS (UK-France-Germany-Spain)

NSF bid

ASPERA bid