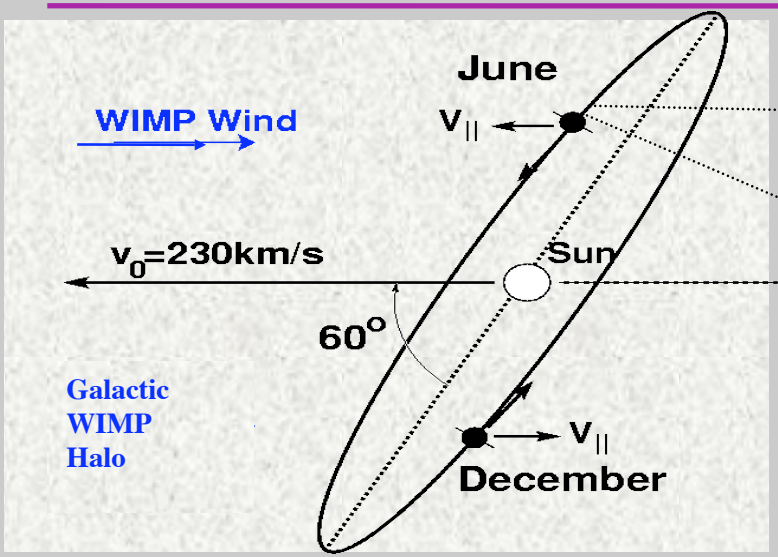
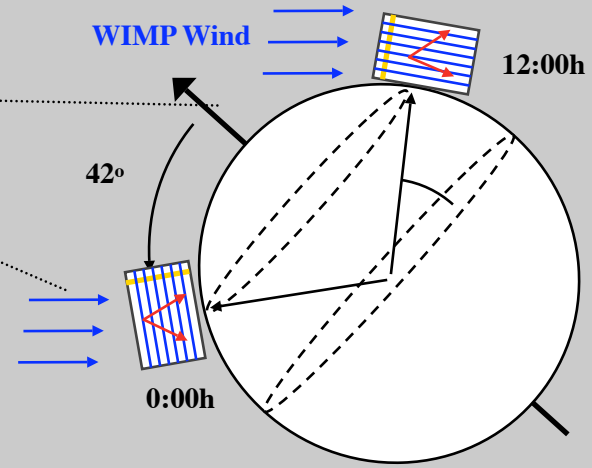
Dark Matter Directional Detection

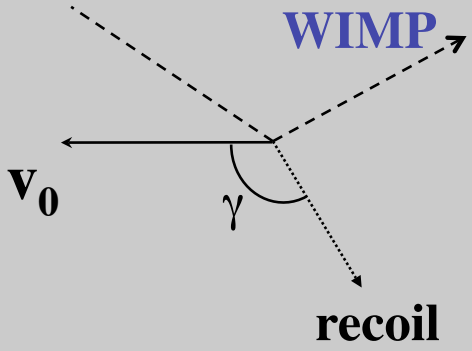
Neil Spooner - on behalf of the DRIFT collaboration

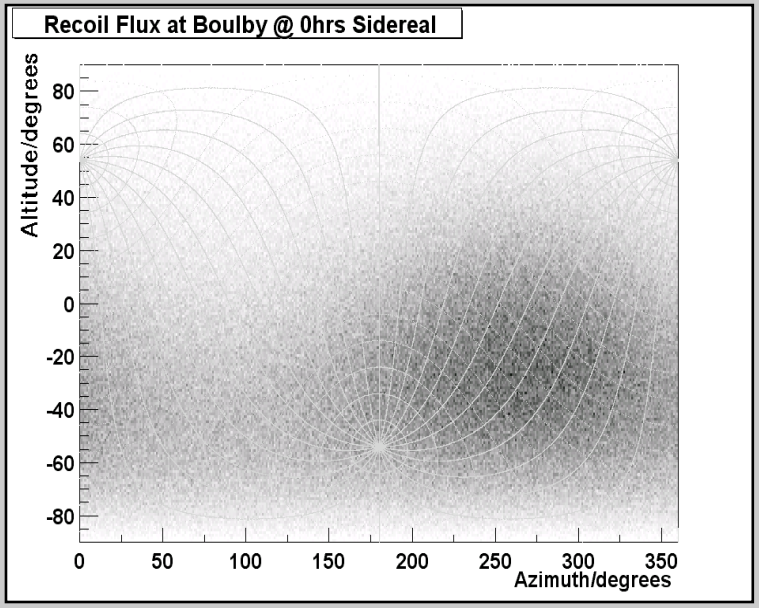


Directional Motivation









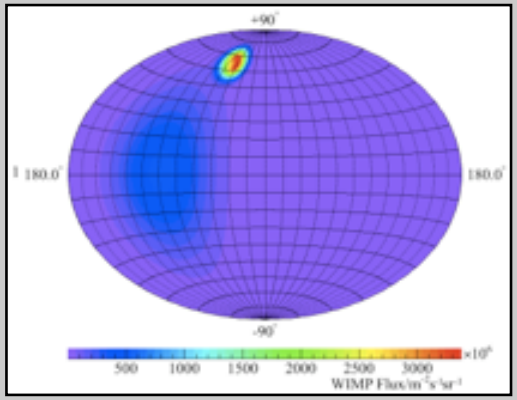
A WIMP telescope?

Results for various halos

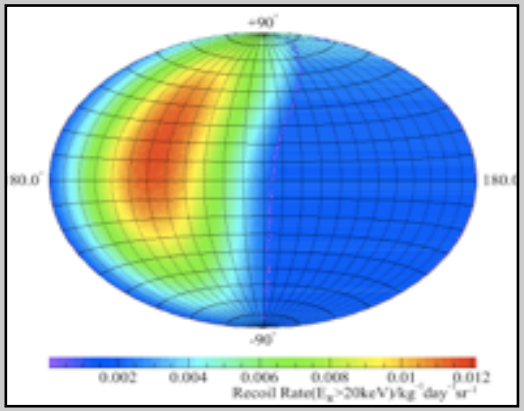
Our predictions for TPC-type detector with 200 μm resolution

B. Morgan et al., Phys. Rev. D71 (2005) 103507

input WIMPs



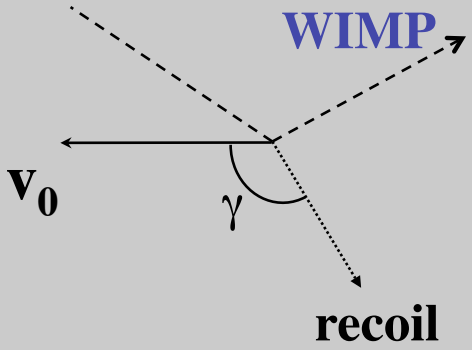
output recoils



Halo Model	$N_{\rm iso}$ for $(R_c, A_c) = (0.90, 0.90)$						
	Vectorial Statistics				Axial Statistics		
	$\mathcal{W}^*$	$\mathcal{A}$	$\mathcal{F}$	$\langle\cos\theta\rangle$	$\mathcal{B}^*$	$\mathcal{G}$	$\langle\lvert\cos\theta\rvert\rangle$
1	12	12	13	7	167	168	104
2	12	12	12	7	112	114	73
3	14	14	15	8	156	157	121
4	13	12	13	7	148	150	96
5	15	15	15	8	215	215	150
6	11	11	11	6	67	68	47
7	14	14	14	8	89	88	74
8	13	13	13	7	176	177	112
9	15	15	16	9	264	265	188
10	15	15	15	8	278	281	194
11	12	12	12	7	126	128	81
12	16	16	17	9	233	234	210
	$N_{\rm iso}$ for $(R_c, A_c) = (0.95, 0.95)$						
1	18	18	19	11	235	235	131
1 (no)	16	16	17	9	128	129	65
2	17	17	18	10	162	162	93
3	20	20	21	12	226	226	152
4	18	18	19	11	212	213	120
5	21	21	22	12	309	312	199
6	16	16	16	10	96	96	59
7	19	20	20	12	125	126	94
8	18	18	19	11	248	249	142
9	21	21	22	13	376	379	237
10	21	21	21	12	395	399	244
11	17	17	17	10	180	180	102
12	20	20	20	15	326	327	276

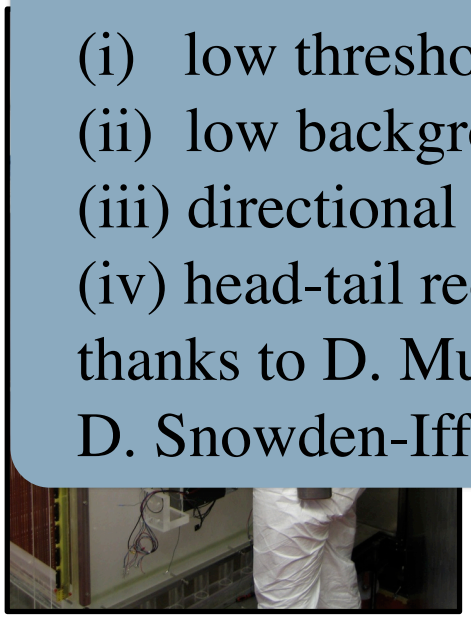
~100s detected WIMPs needed to identify halo model

~x10 fewer needed if there is head-tail sensitivity



A SIGNAL!
but can it be true?
but is it galactic?

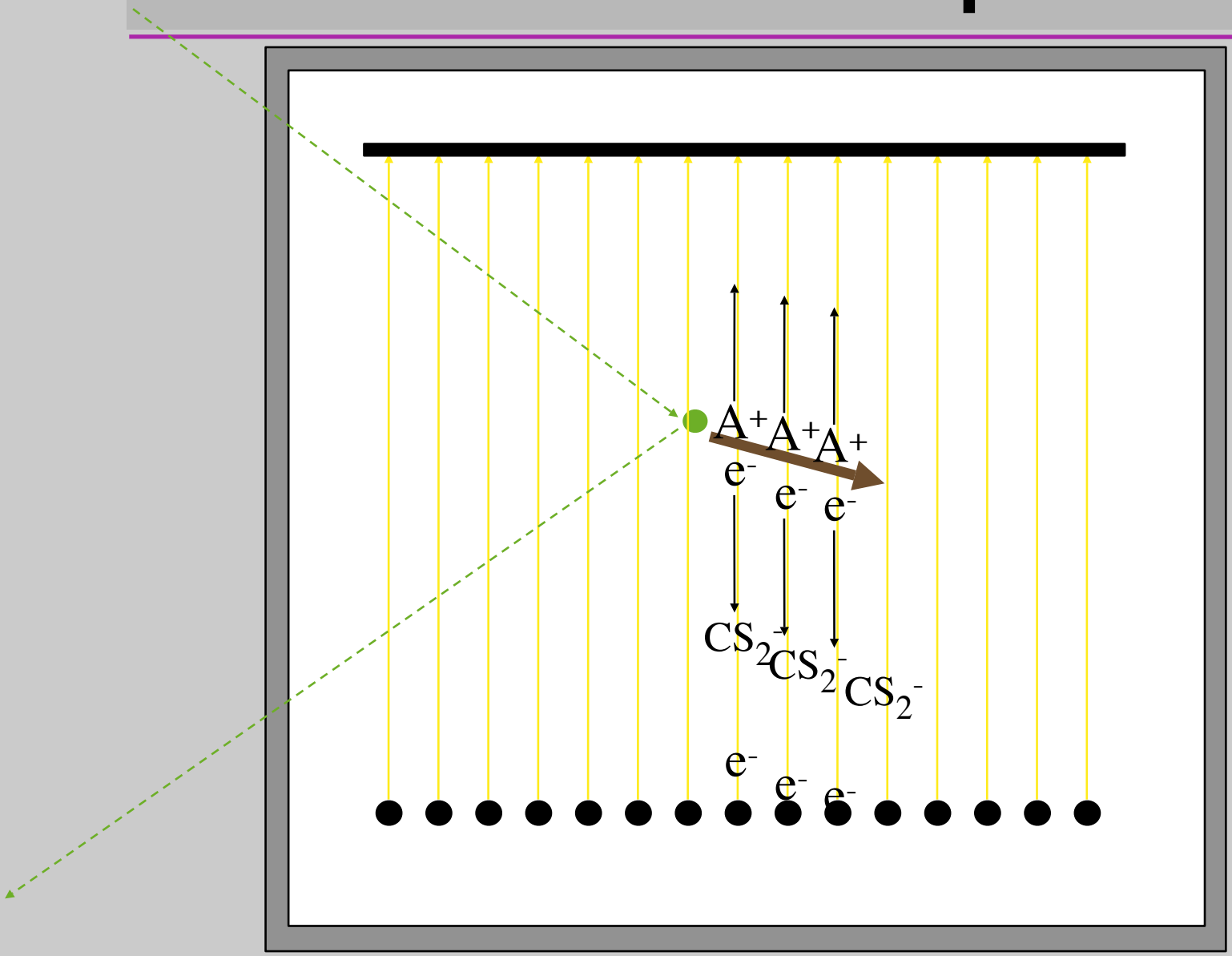
Recent work here (4 papers in preparation):
(i) low threshold - use for axions searches
(ii) low background - radon progeny background
(iii) directional signals
(iv) head-tail recoil vector discrimination
thanks to D. Muna, S. Paling, P. Majewski (USFD), D. Snowden-Ifft (Oxy)



DRIFT

Burgos et al, arXiv:0707.1488 (sub Astrop.Phys, 2007) - first DII data
Burgos et al, arXiv:0707.1758 (sub Astrop.Phys, 2007) - DII alpha results
Spooner, Majewski et al, arXiv:1107..- head-tail simulations DARK2007
Lightfoot et al., Astrop Phys, 27 (2007) 490
Tziaferi et al., Astroparticle Physics 27 (2007) 326
Spooner. J, Phys. Soc. Japan http://arxiv.org/abs/0705.3345
Alner et al., Nucl. Instrum. and Meth. in Phys. Res. A555 (2005) 173
Alner et al., Nucl. Instrum. and Meth. in Phys. Res. A 535 (2004) 644

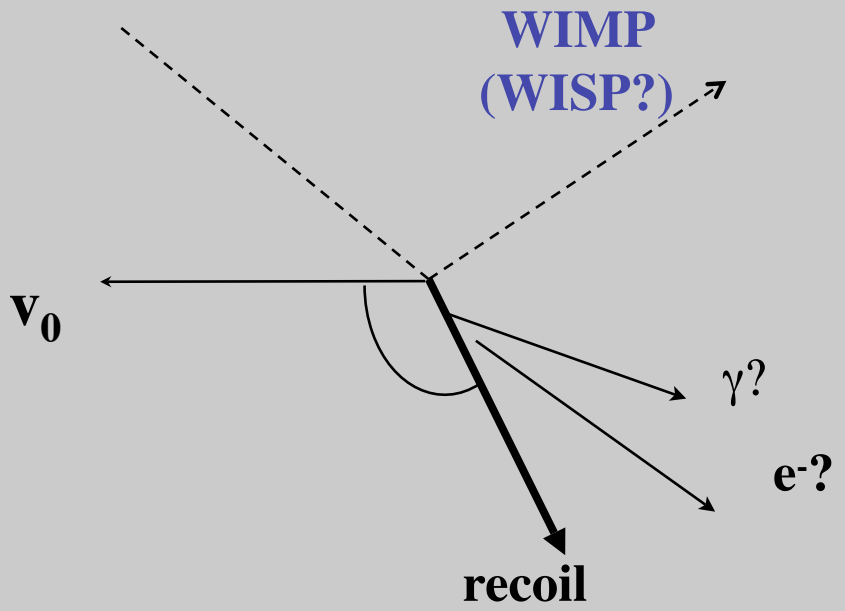
DRIFT concept



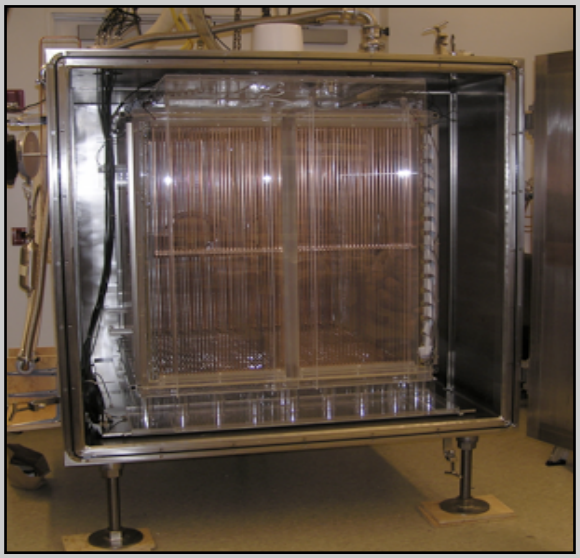
Negative
Ion
Time
Projection
Chamber

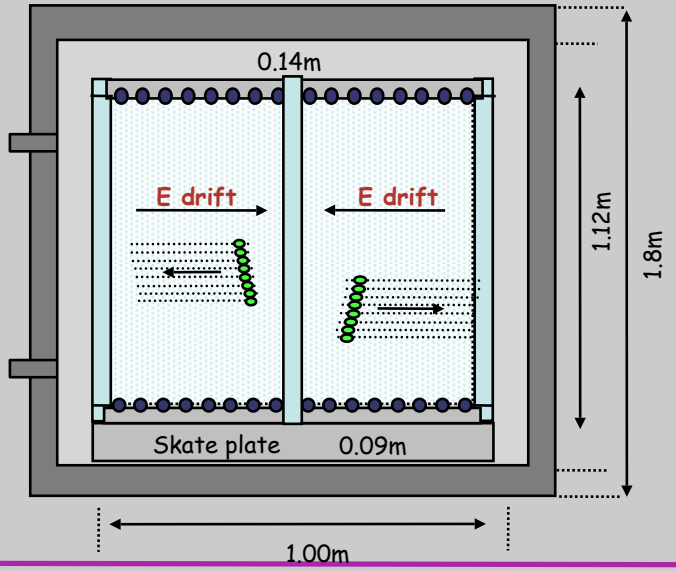
AIM

- gamma, electron, recoil tracking in space
- gamma, electron, recoil tracking in time
- at low threshold >1 keV
- multi-target - F, S, C, Xe... (SD and SI)
- maximum information on events
- including sense direction of recoils

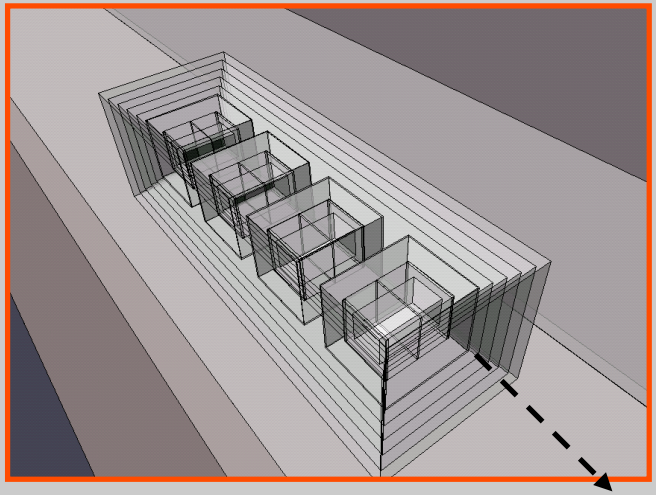


DRIFT IIa design & dimensions





- 1 m³ 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



Range/track discrimination

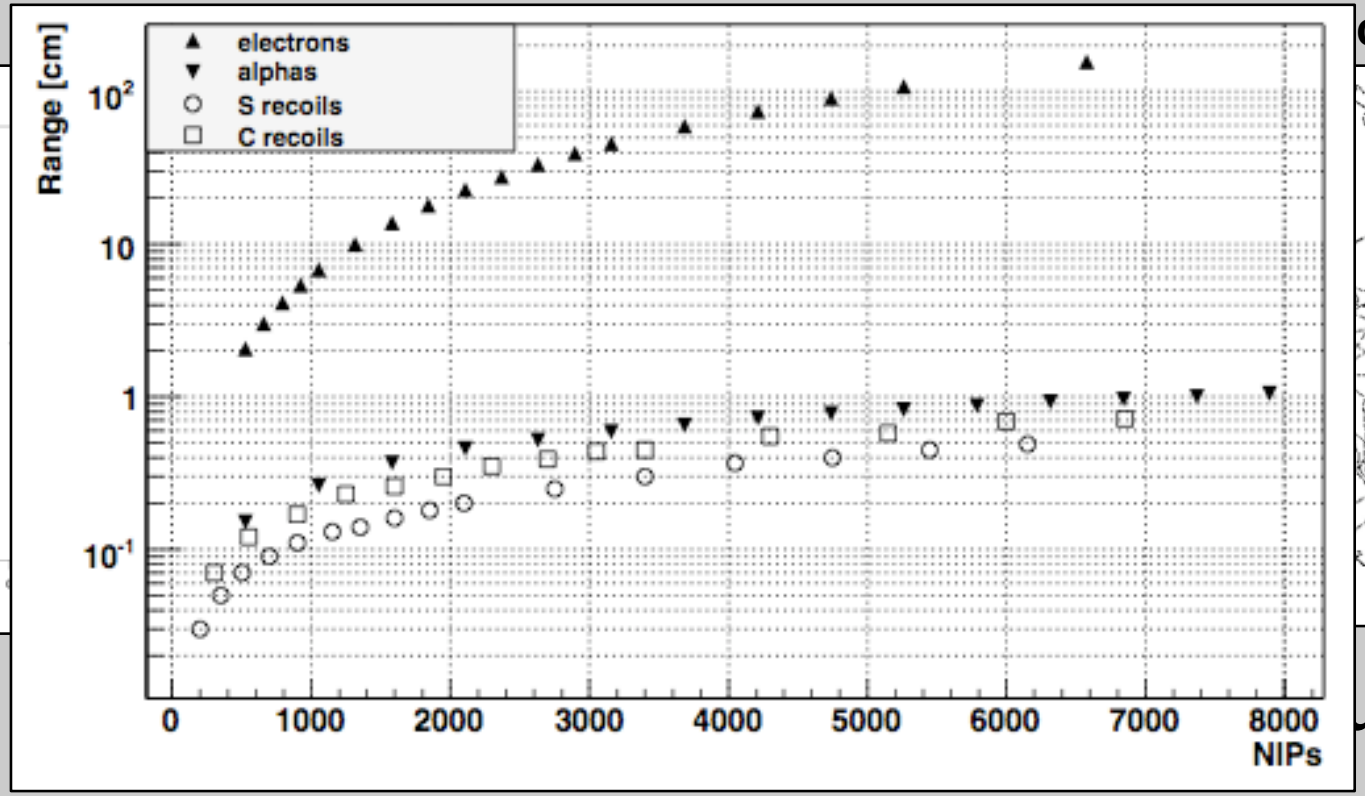
simulation

RECOIL: keV Ar recoils from WIMPs

ALPHA: 15 keV alpha as

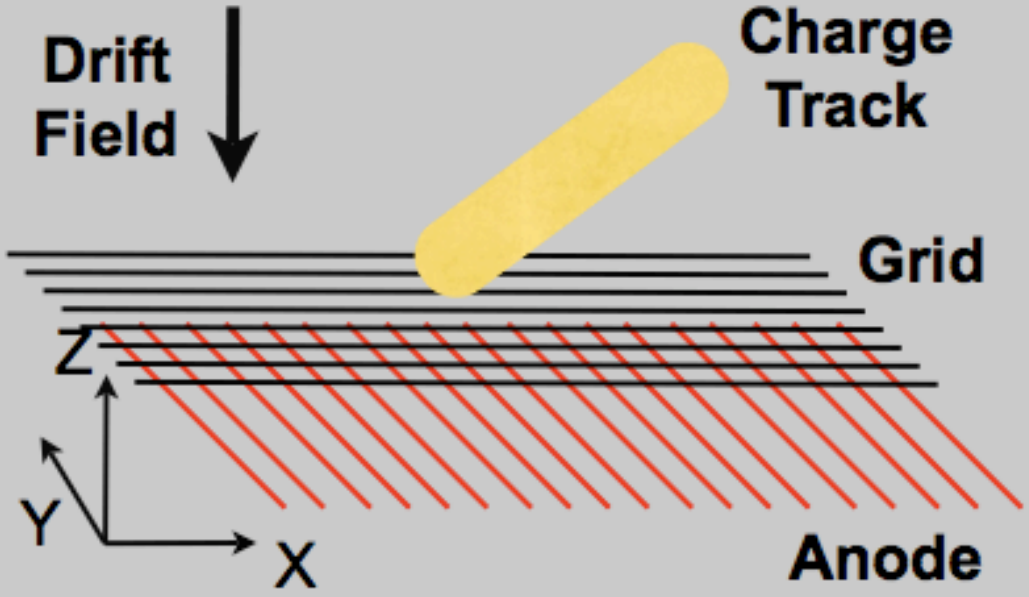
ELECTRON: 13 keV e-s

ctivity

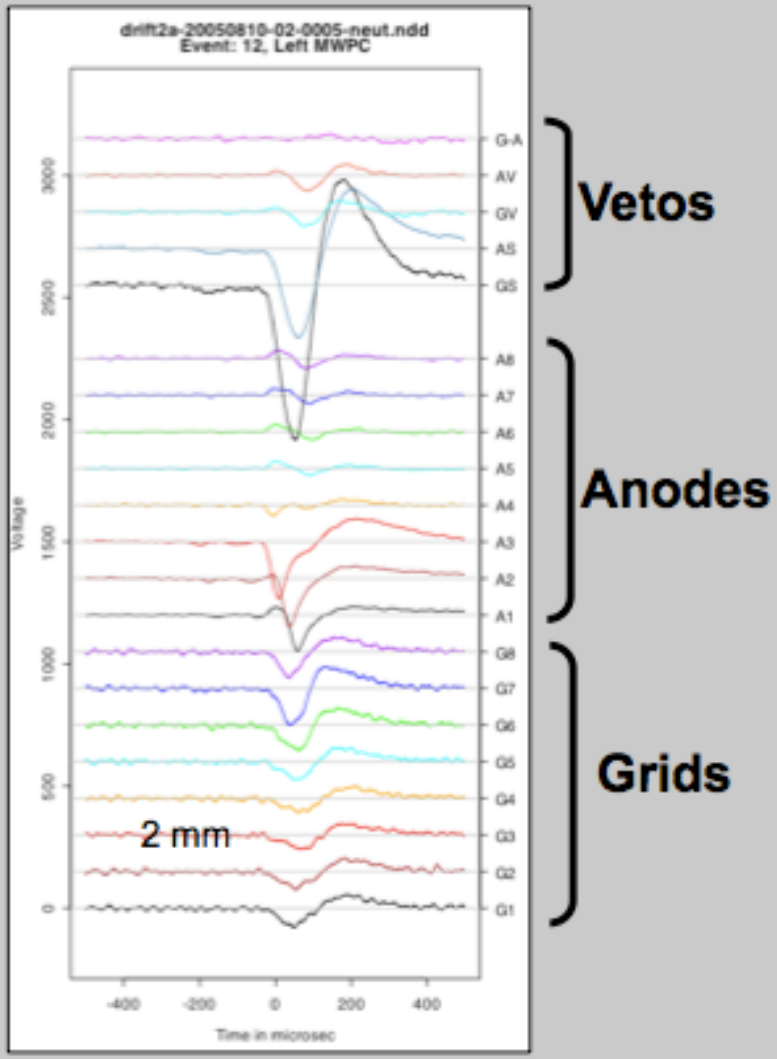


ubt

Track reconstruction, R2, R3

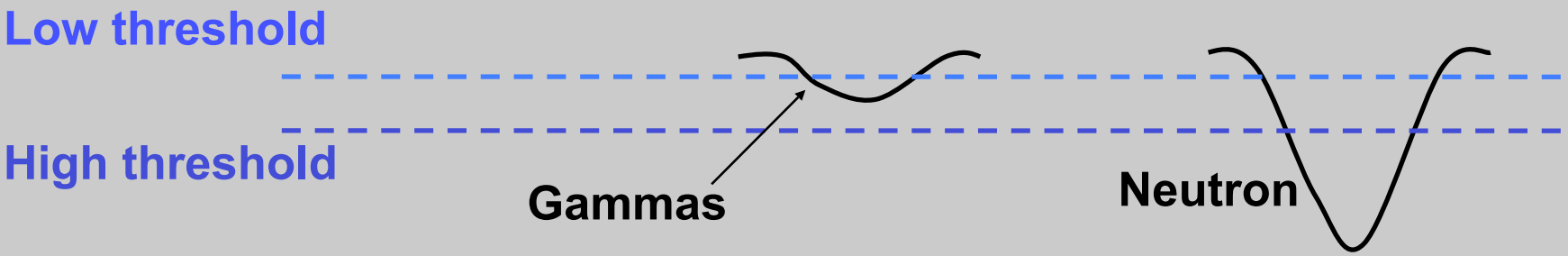


ΔX: Number of Anode Wires Crossed
ΔY: Progression across Grid Wires
ΔZ: Drift Time difference between start and end of track



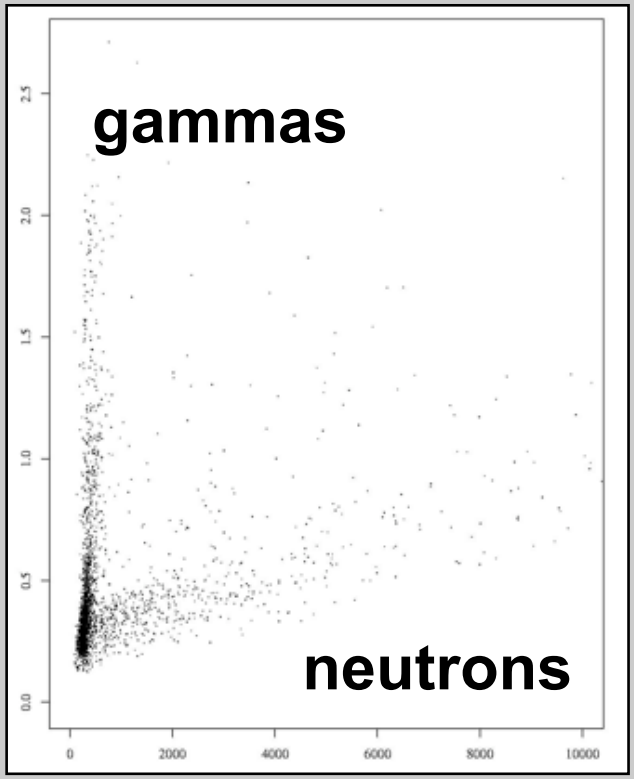
dE/dx Discrimination

- e.g. Test with 1 ft^3 detector at Occidental



dE/dX discrimination

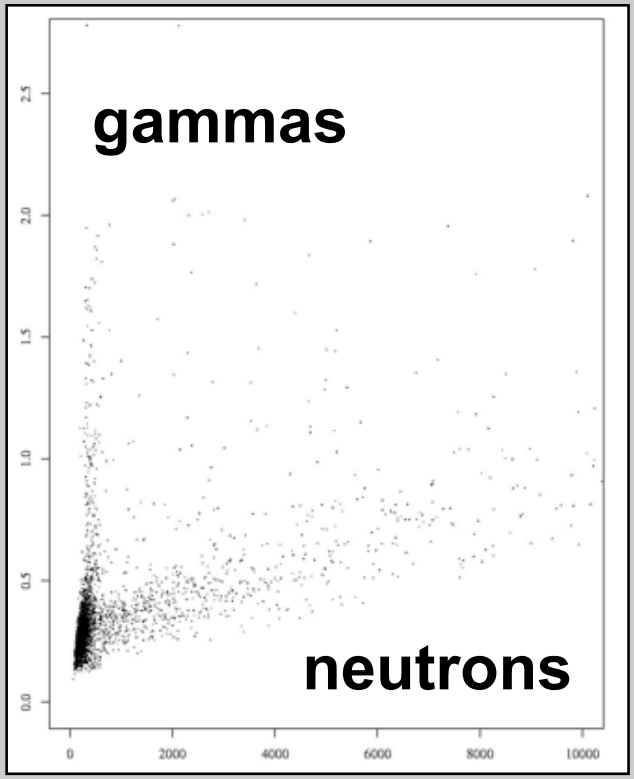
Old 1ft^3 data



Threshold

dE/dX discrimination

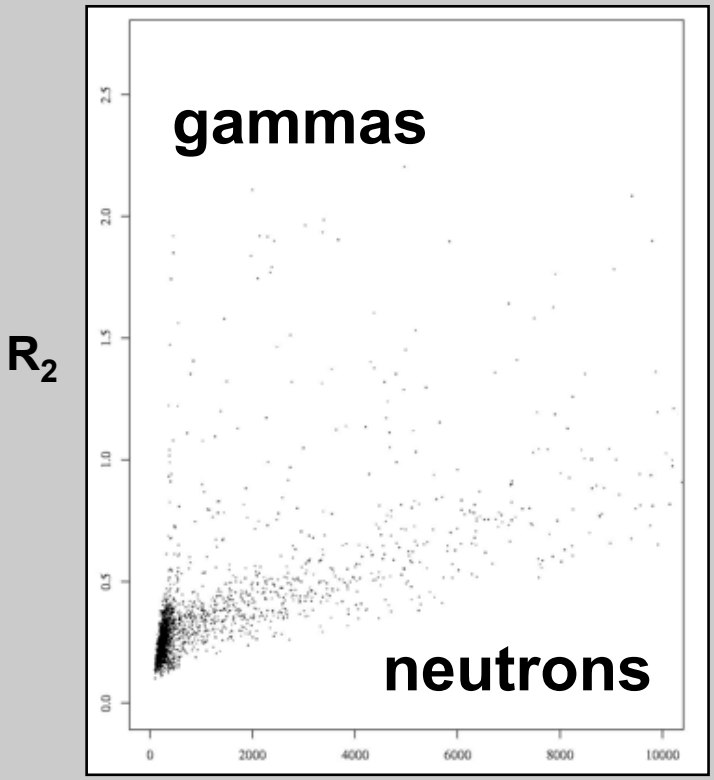
Old 1ft^3 data



Threshold

dE/dX discrimination

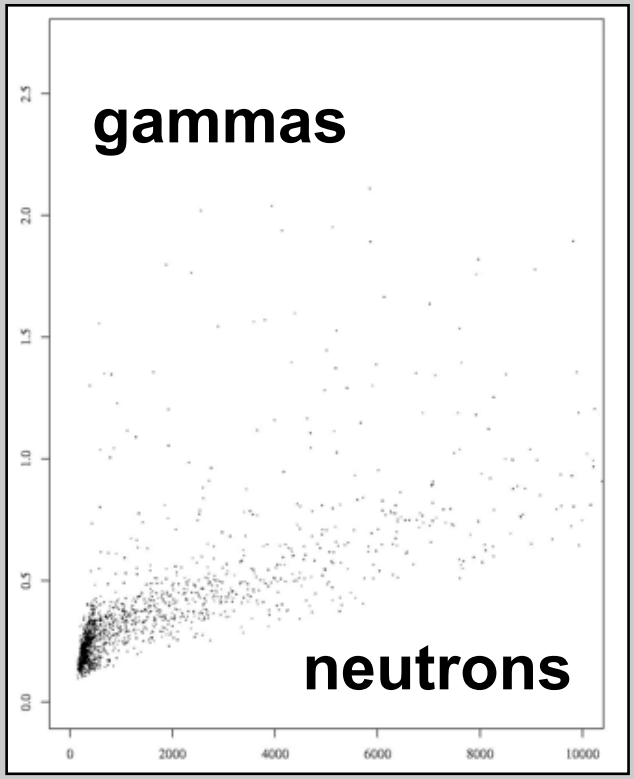
Old $1ft^3$ data



Threshold

dE/dX discrimination

Old 1ft^3 data



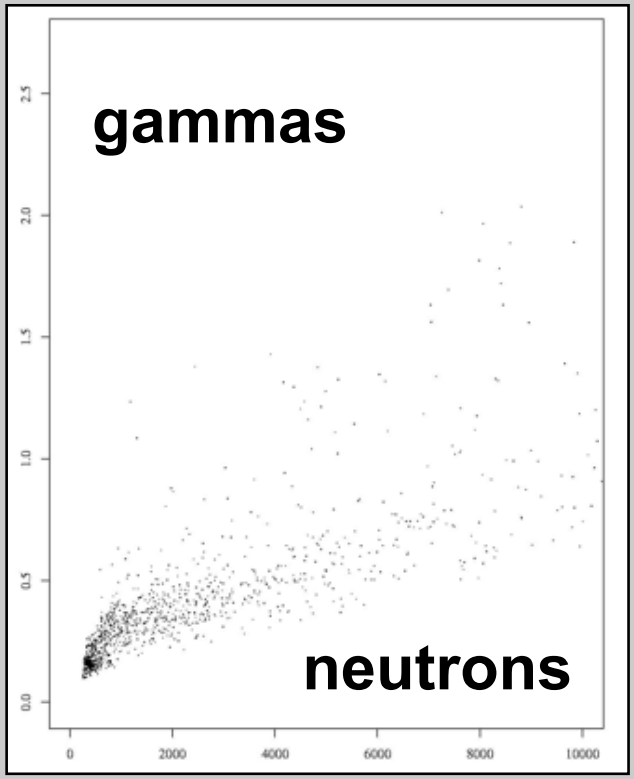
R_2

NIPS

Threshold

dE/dX discrimination

Old 1ft^3 data



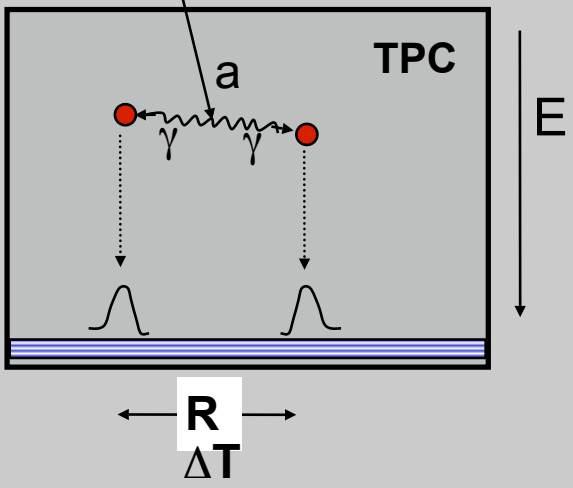
R_2

NIPS

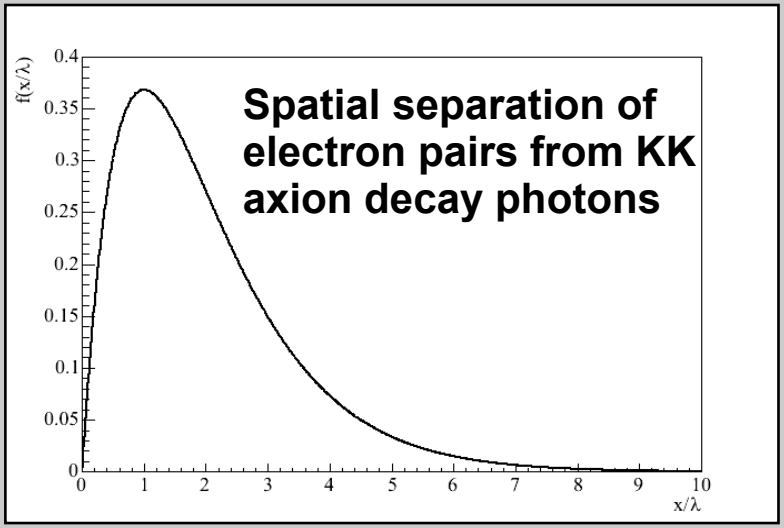
Threshold

(KeV) gamma ID - KK axions

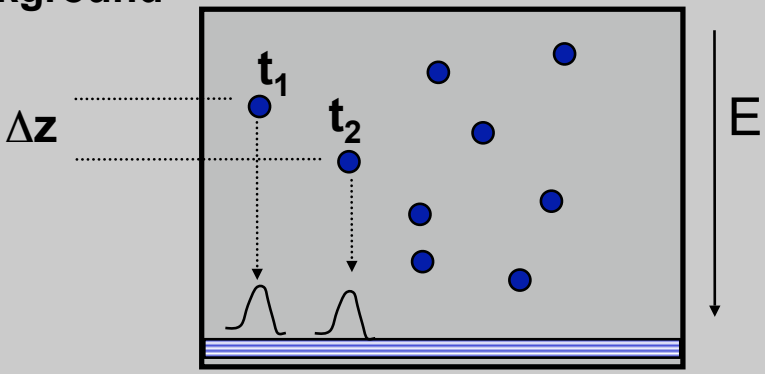
Signal



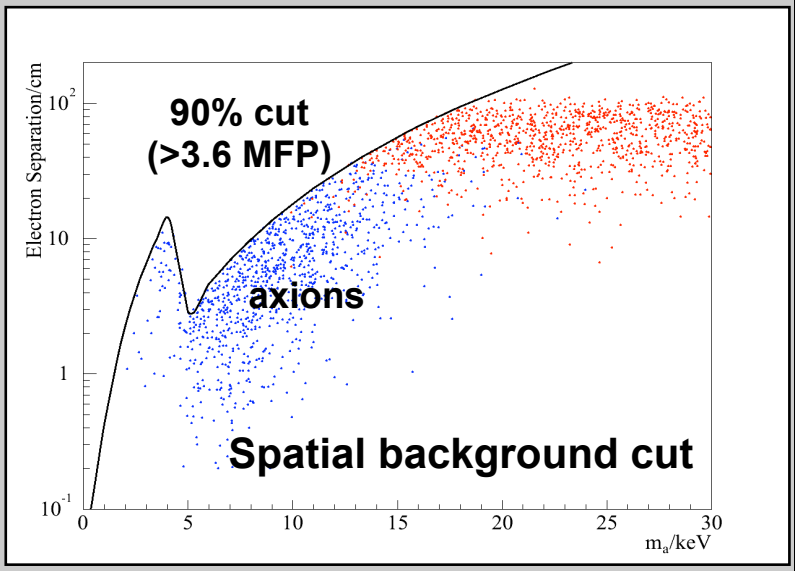
Photon mean free path



Background



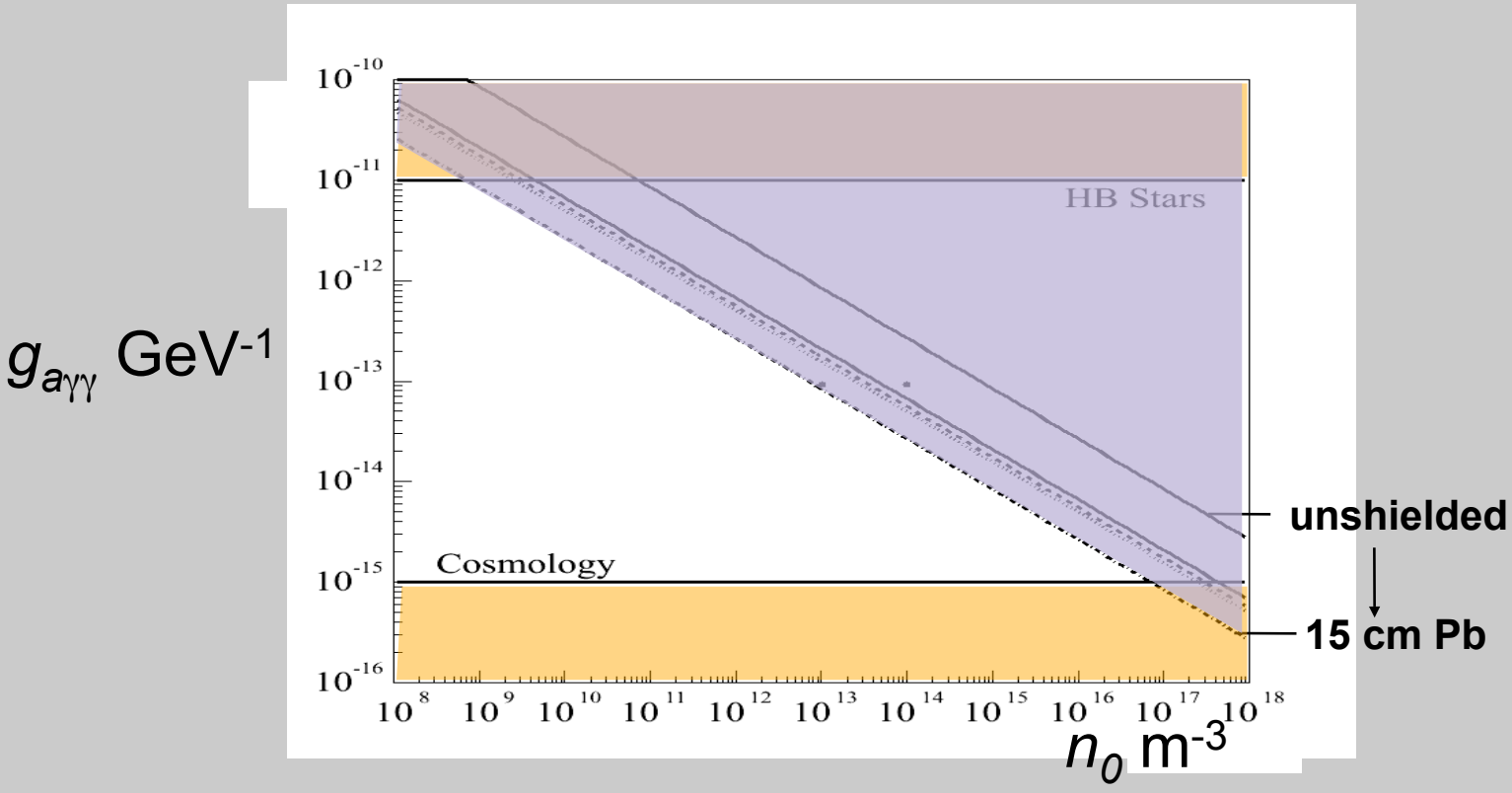
$\Delta T=(|t_1-t_2|)+\Delta z/V_{dif}$



KK axion limit prediction (preliminary)

BASIC LIMIT - Add Pb shielding until vessel background dominates (10 cm for 1 ppb)

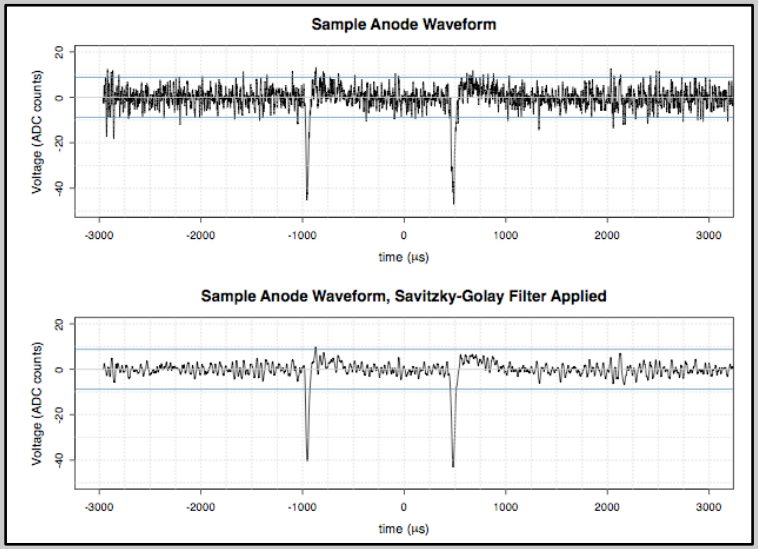
[1 m^3yr, CS_2, 160 Torr, m_a = 6-20 keV, 1 ppbU/Th in vessel]

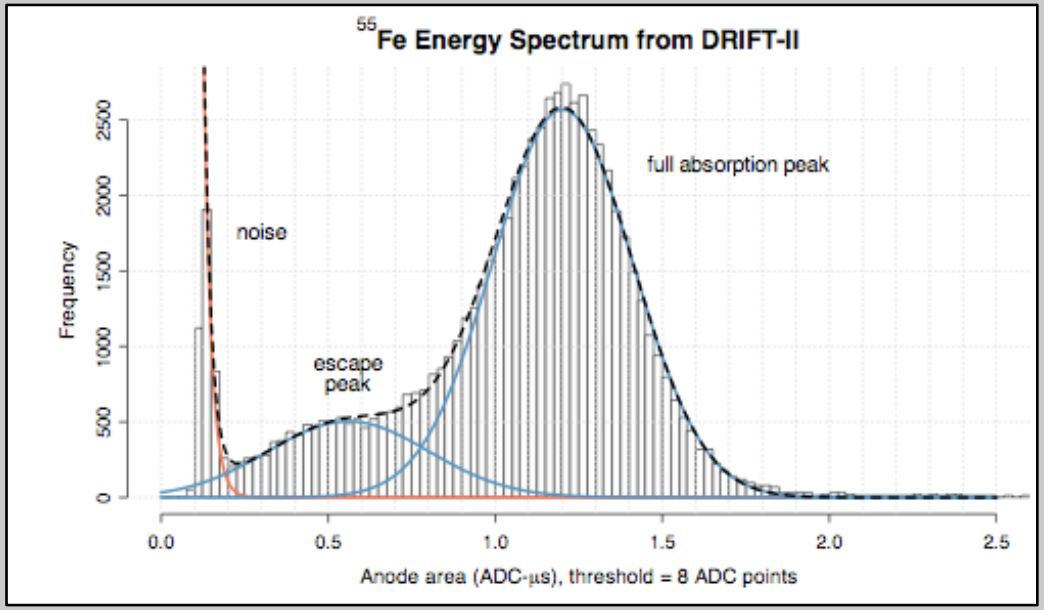


B. Morgan et al. Astrop. Phys 23 (2005) 287,

Energy Threshold - new analysis

use of Savitzky-Golay digital filter





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

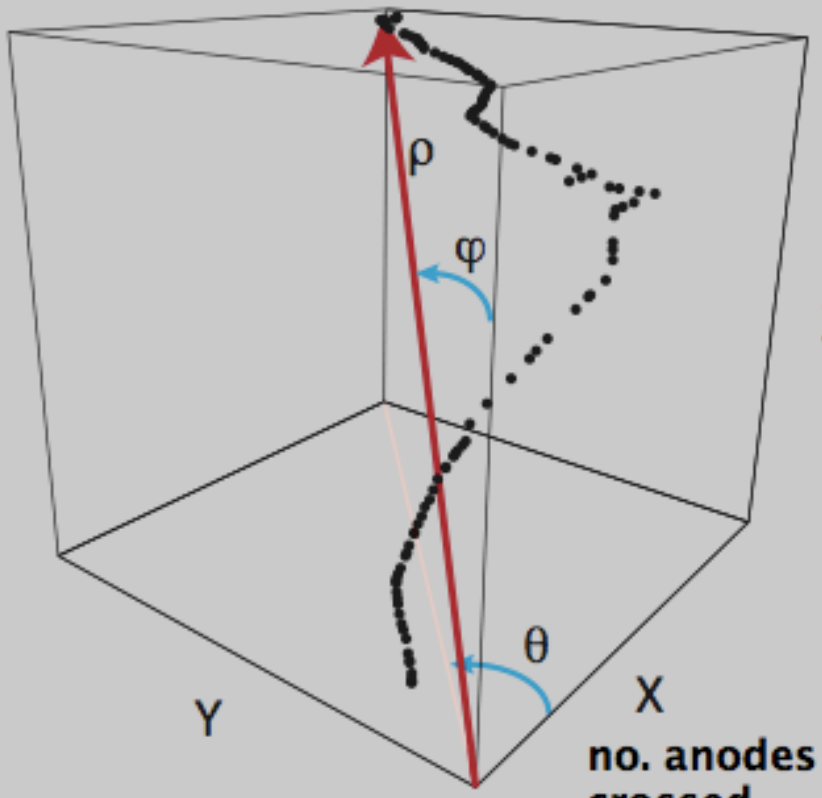
Energy thresholds -->

Source of Track	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

Paper in preparation - D. Muna

Track reconstruction



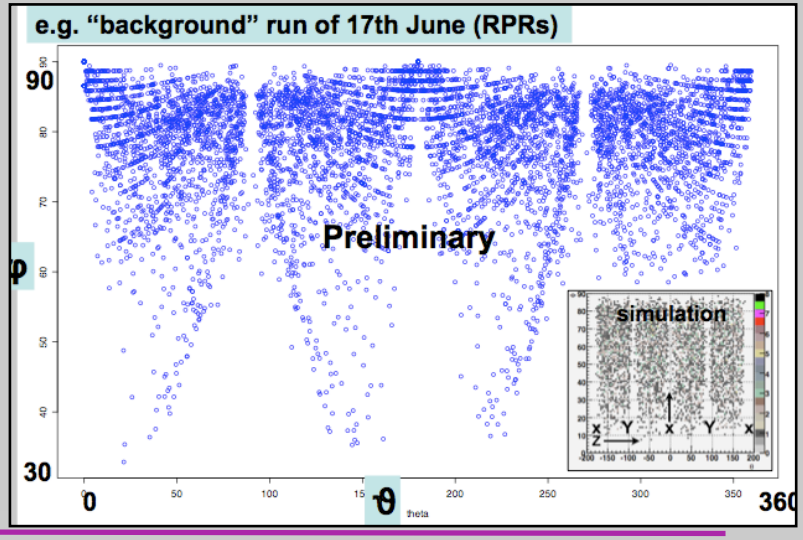
x, y, z

ϑ, φ

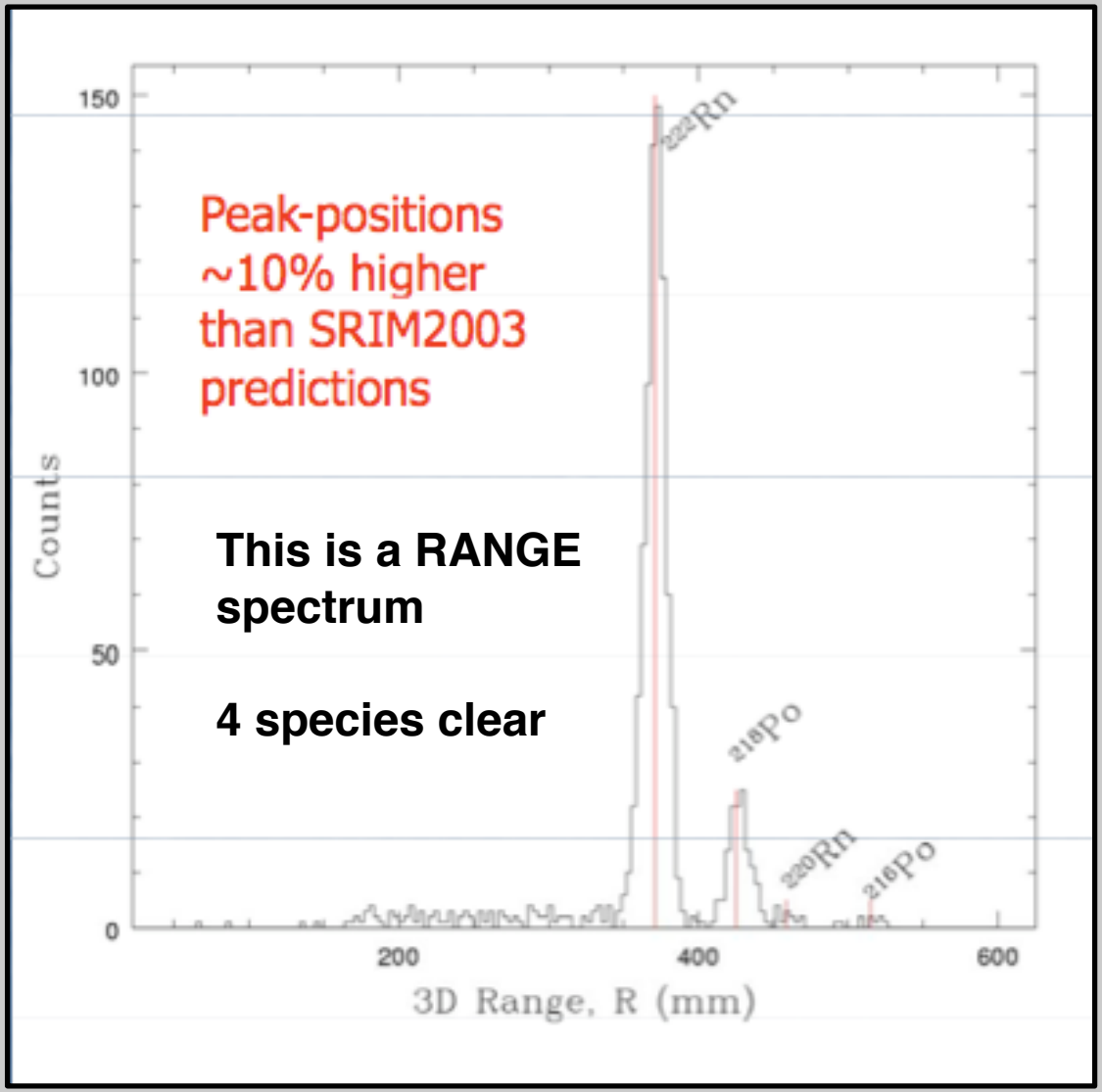
no. anodes crossed

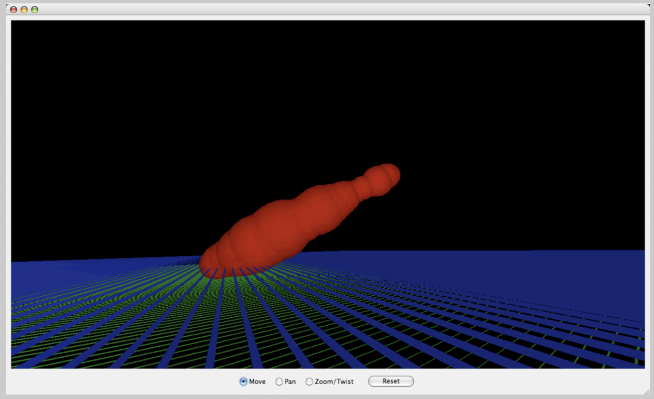
$\theta = \mathrm{atan2}(y/x)$

$\varphi = \mathrm{acos}(z/\rho)$



Alpha range data





Reconstructed 3D ranges of contained alphas

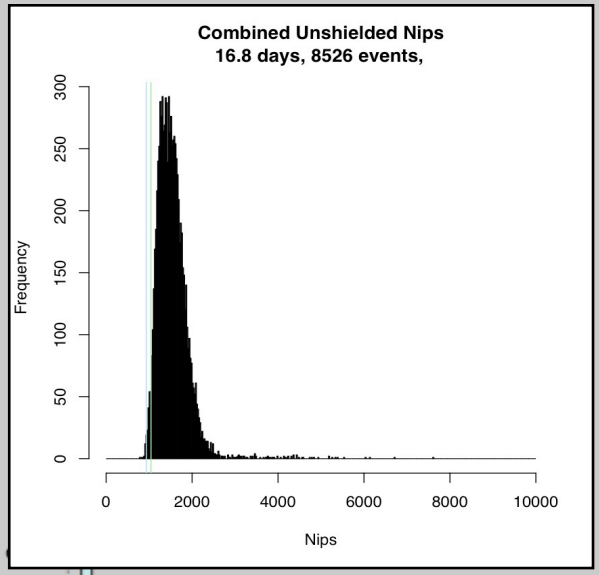
S. Burgos et al., Nucl. Instr. Meth. A 584, 114 (2008)

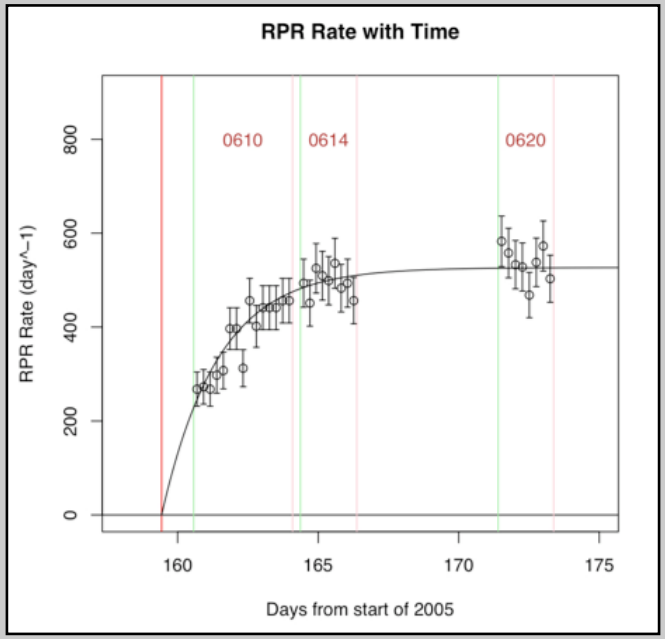
Radon Progeny Recoils (RPRs)

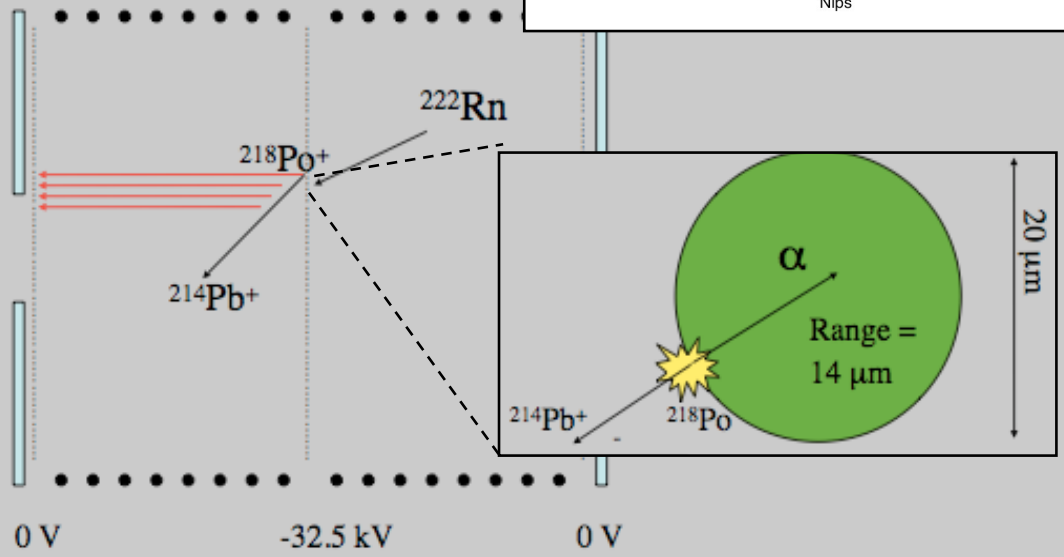
A recoil-like background ~200-600 / day (50-250 keV).

Increase with time consistent with Rn emanation.

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





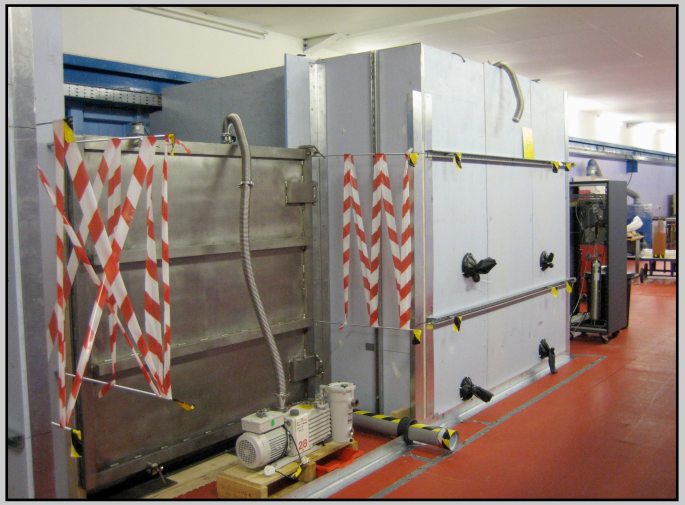


DIla WIMP run - background

For typical analysis run - 4.36 days background, neutron run 0.97 hours (2005/6)

calibrated recoil efficiencies

Nips	Rate (Hz)	Efficiency (%)
1000 - 5000	0.075 ± 0.005	39 ± 3
2000 - 5000	0.066 ± 0.004	60 ± 7
2500 -5000	0.055 ± 0.004	70 ± 11



remaining rates

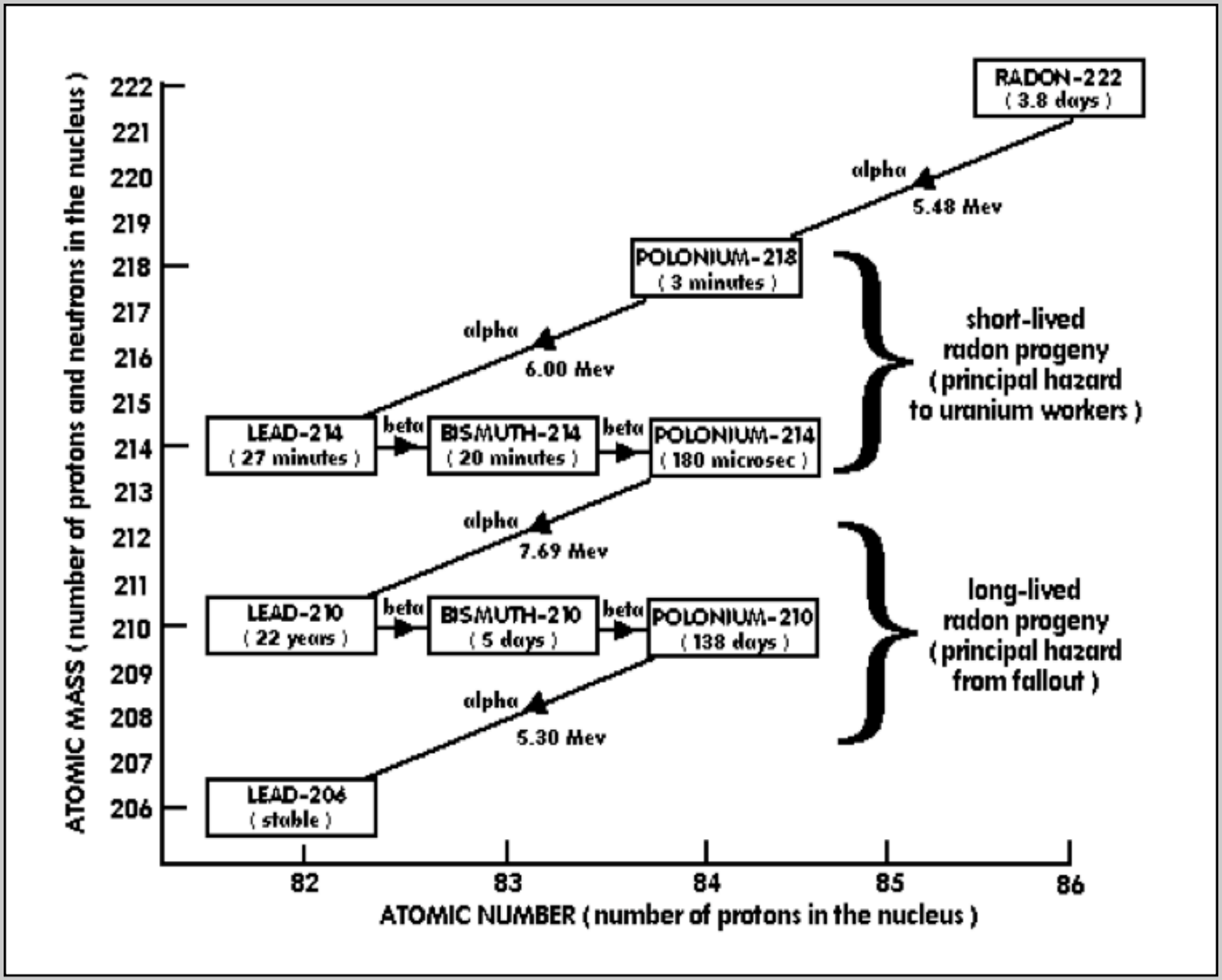
47 keV S recoil

Nips	Rate (/day)
1000 - 5000	20 ± 2
2000 - 5000	15 ± 2
2500 -5000	7 ± 1

remaining events are <u>recoils</u>
identified as radon progeny recoils (RPR)

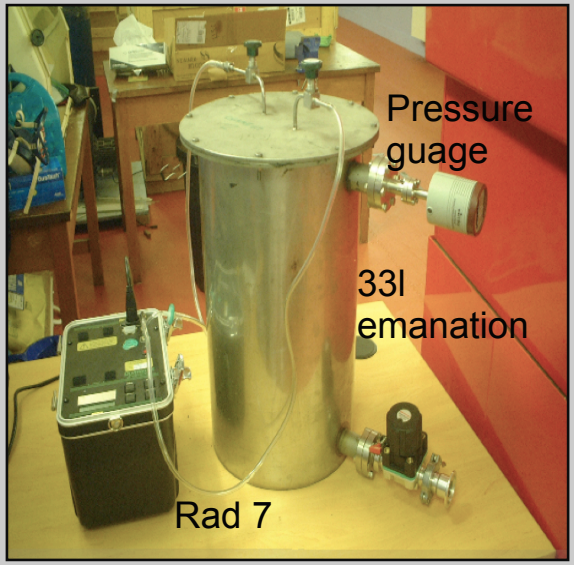
LIMIT published in Tziaferi thesis

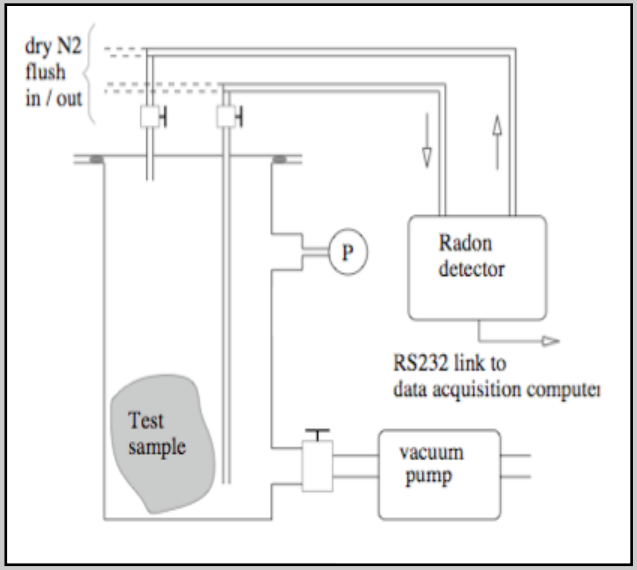
Rn decay chain

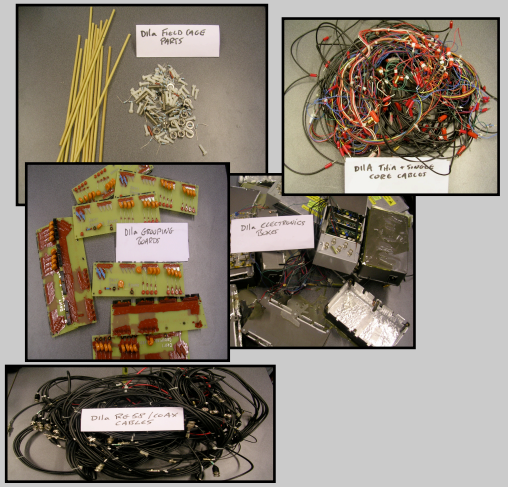


- Gaseous element in Uranium decay chain
- Rn222 half life = 3.8 days
- 4 alpha decays before reach stable Pb-206
- Radon levels at Boulby are actually very low! (~3 Bq/m^3)

Rn Emanation Facility - ^{218}Po







DIIa samples:

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 +/- 0.01
Ribbon cables	Dry N2	6.5	23	10.1 +/- 0.7	0.50 +/- 0.03
Grouping Boards	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 +/- 0.05

* The limit of sensitivity of the method (see above)

DRIFTIIa: July 2005
390 events / day

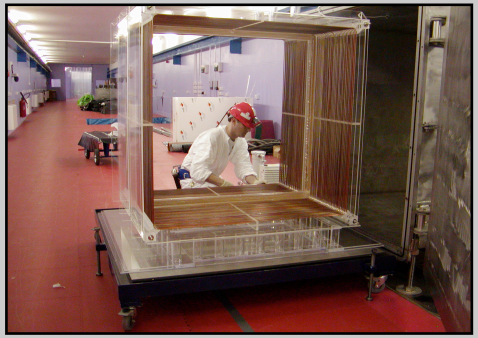
DRIFTIIb: June 2006
31.3 events / day

DRIFTIIb(refit 2): July 2007 expected.....

- **Main offenders = Ribbon cables and Coax. cables**
- **Total of items measured = 0.95 +/- 0.05 Rn atoms.s^{-1}:**

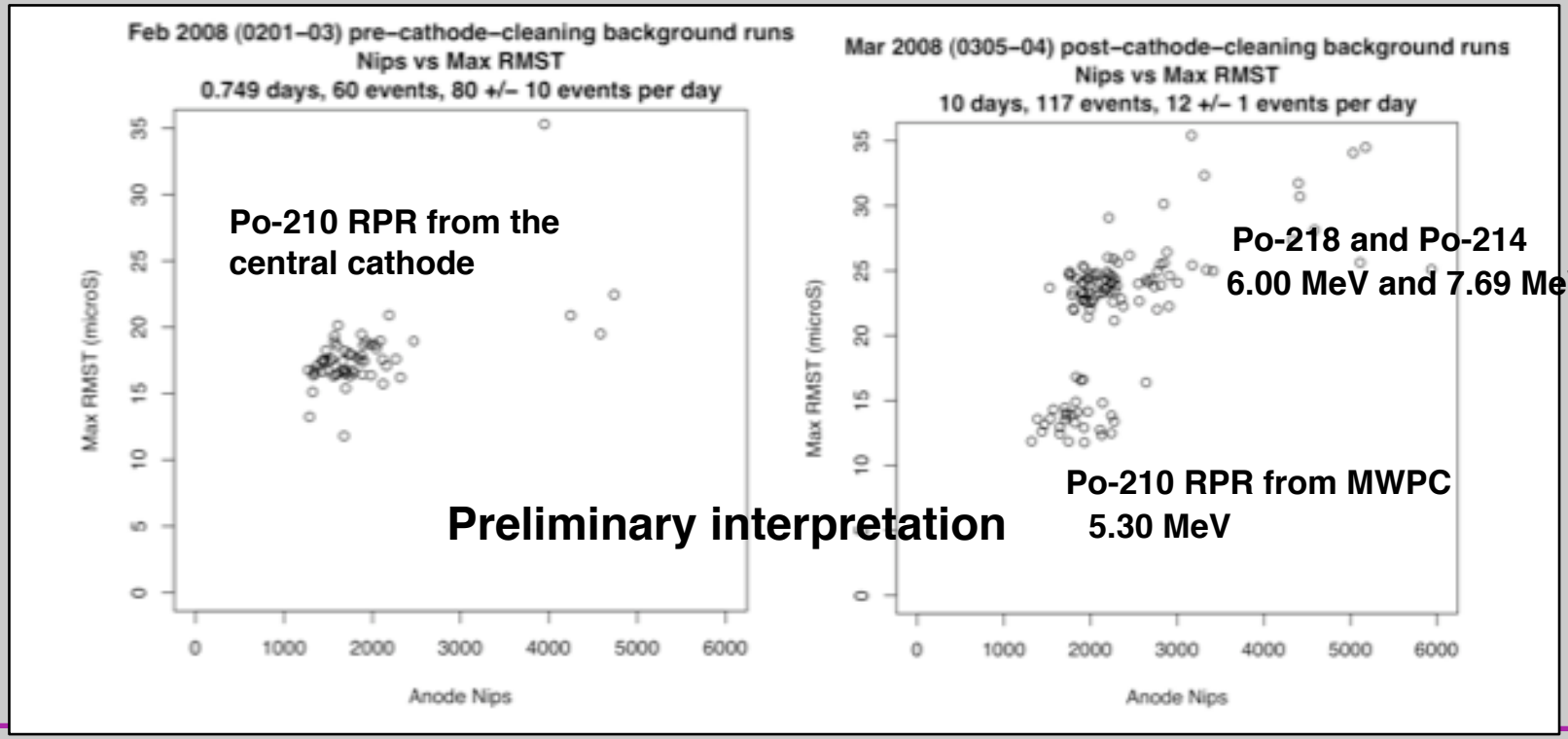
Central Cathode Cleaning

Central Cathode plane (512 wires) cleaned with nitric acid process



before cleaning

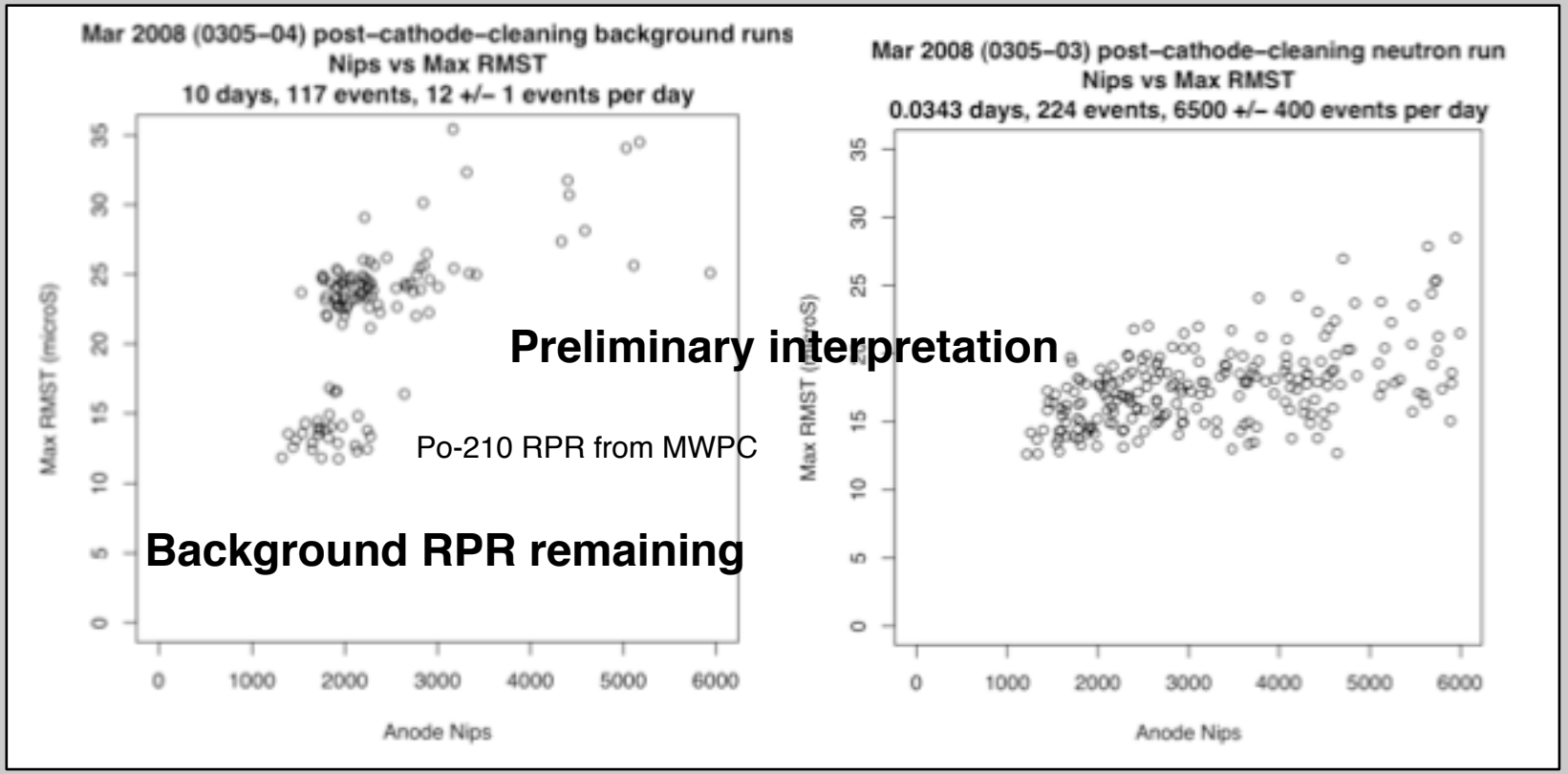
after cleaning (x13 more stats)



Central Cathode Cleaning

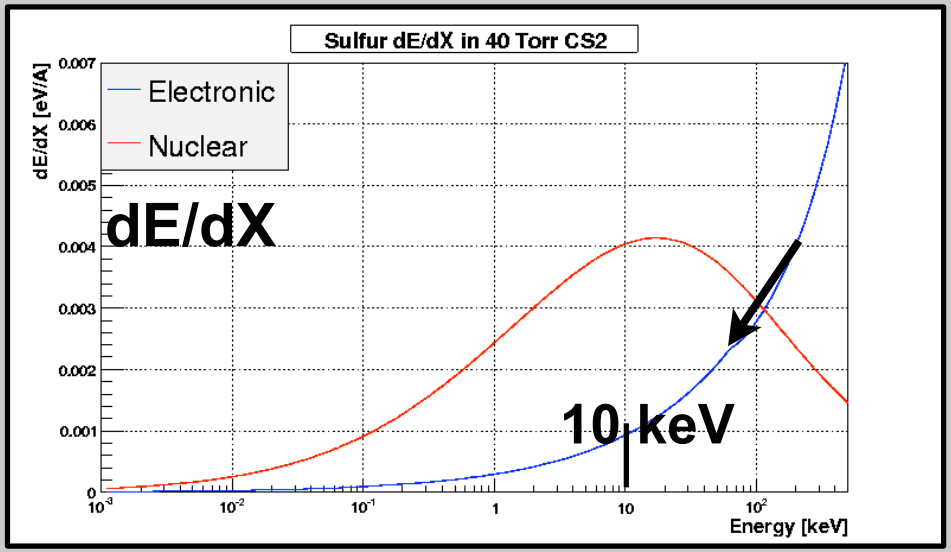
Background RPRs vs neutrons

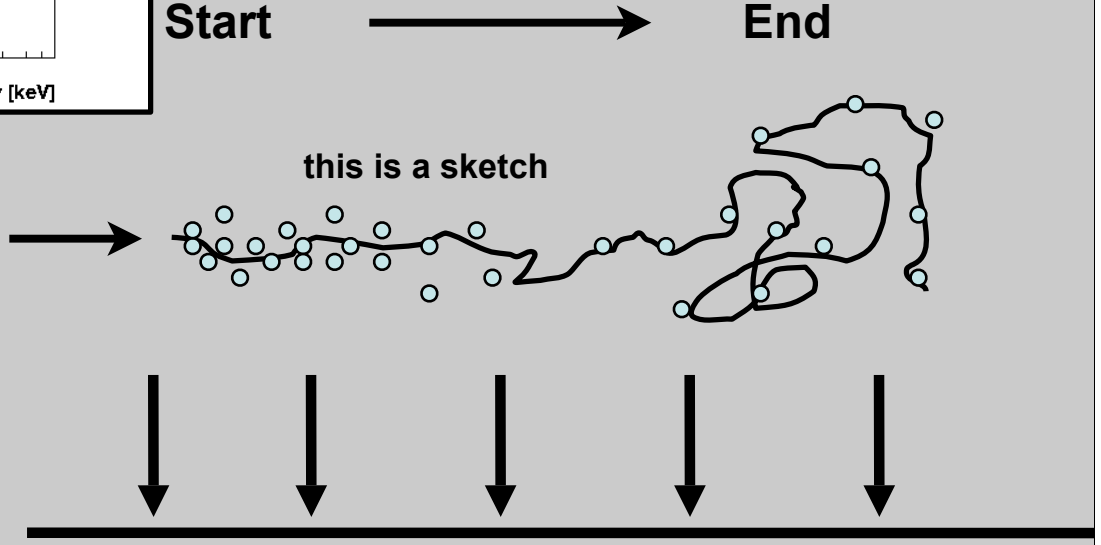
neutron calibration (S recoils)



Preliminary interpretation: (i) remaining short-life cathode RPRs can be cut and reduced by flushing, (ii) remaining MWPC RPRs (~1/day)

Head-Tail discrimination theory





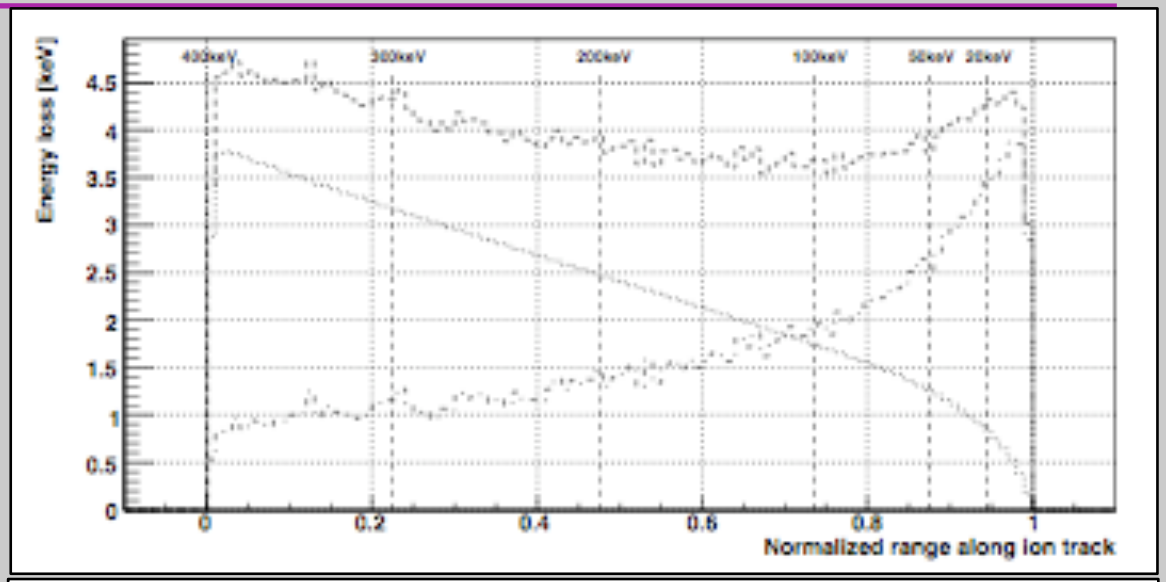
project track for readout

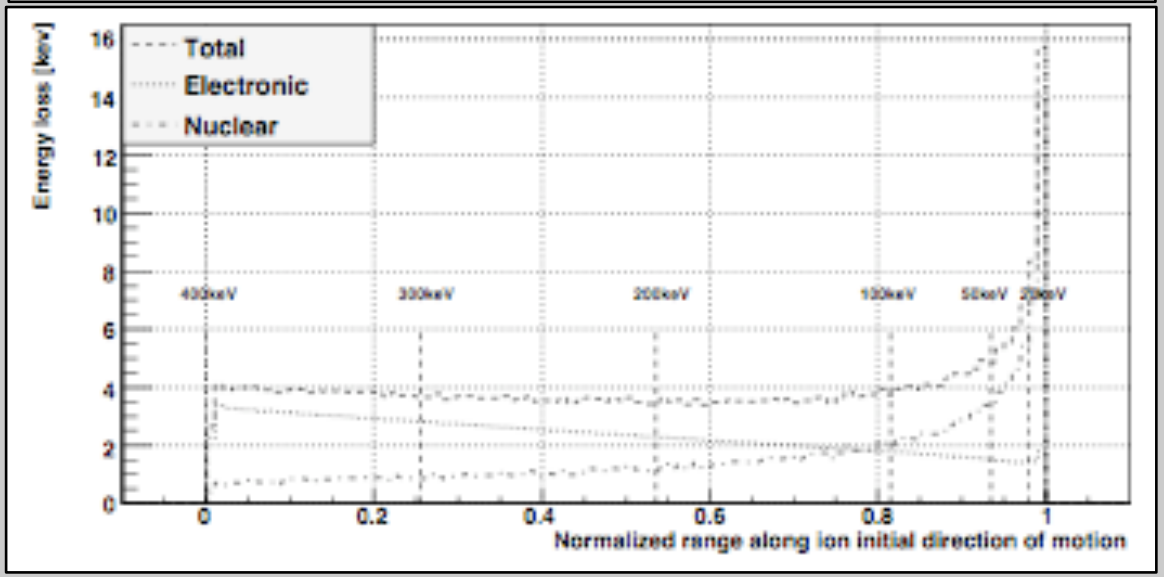
Understanding Head-Tail

Example of energy loss distributions for 400keV Sulfur ion

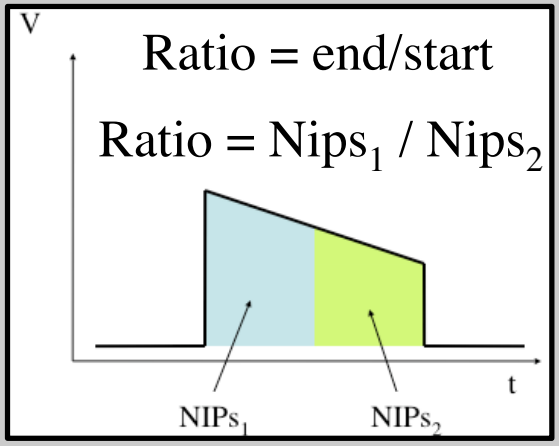
distribution normalized along the track (like 3D reconstruction)

distribution normalized along initial ion direction (like 1D reconstruction)





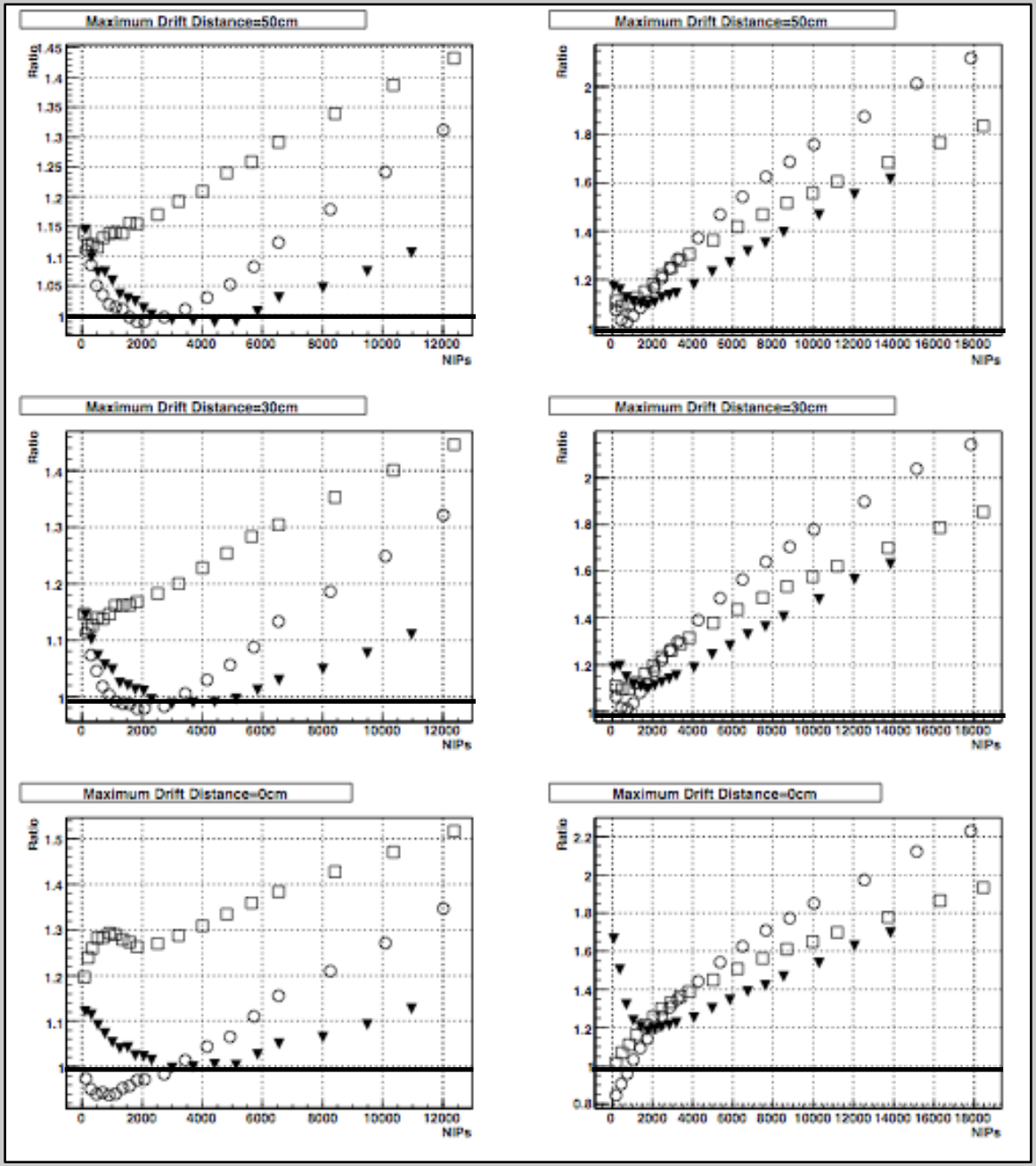
Take simple end/start ratio



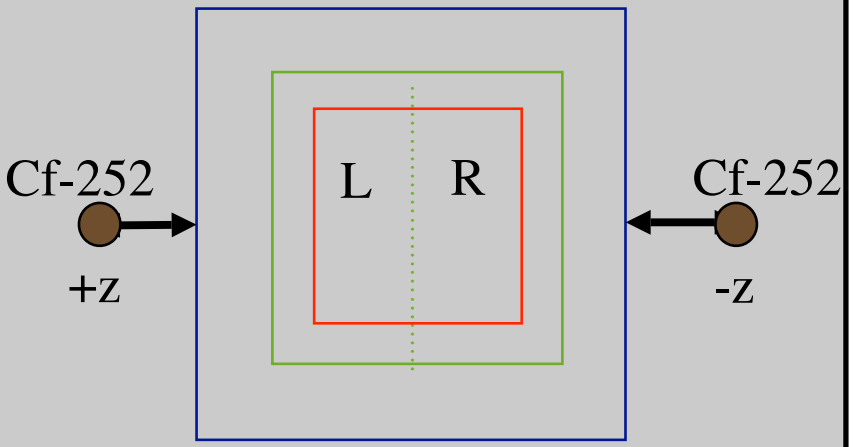
Position of mean of charge distribution along track

diffusion of 10cm, 30cm and 50cm

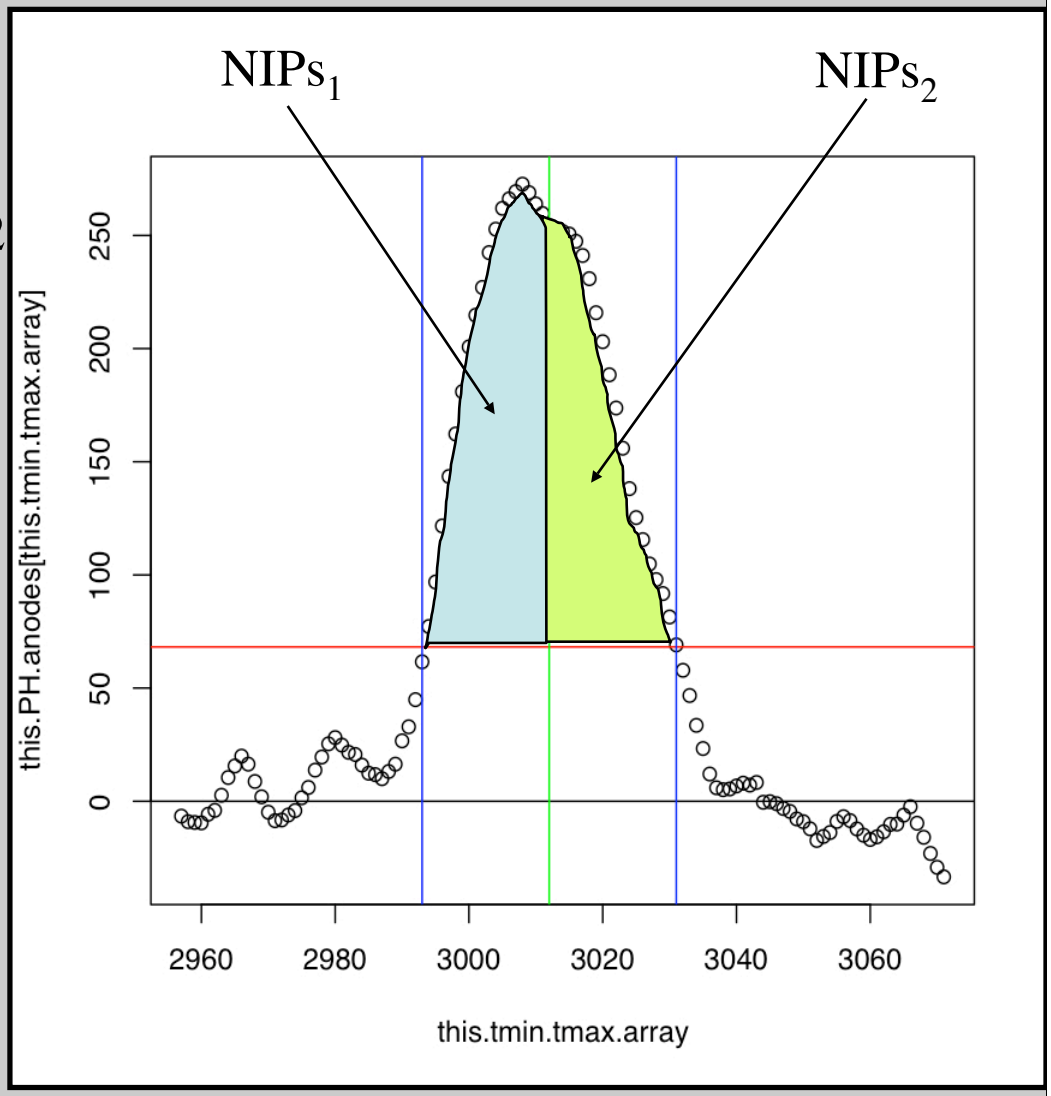
1 D projection case



Head-Tail DRIFT II data analysis

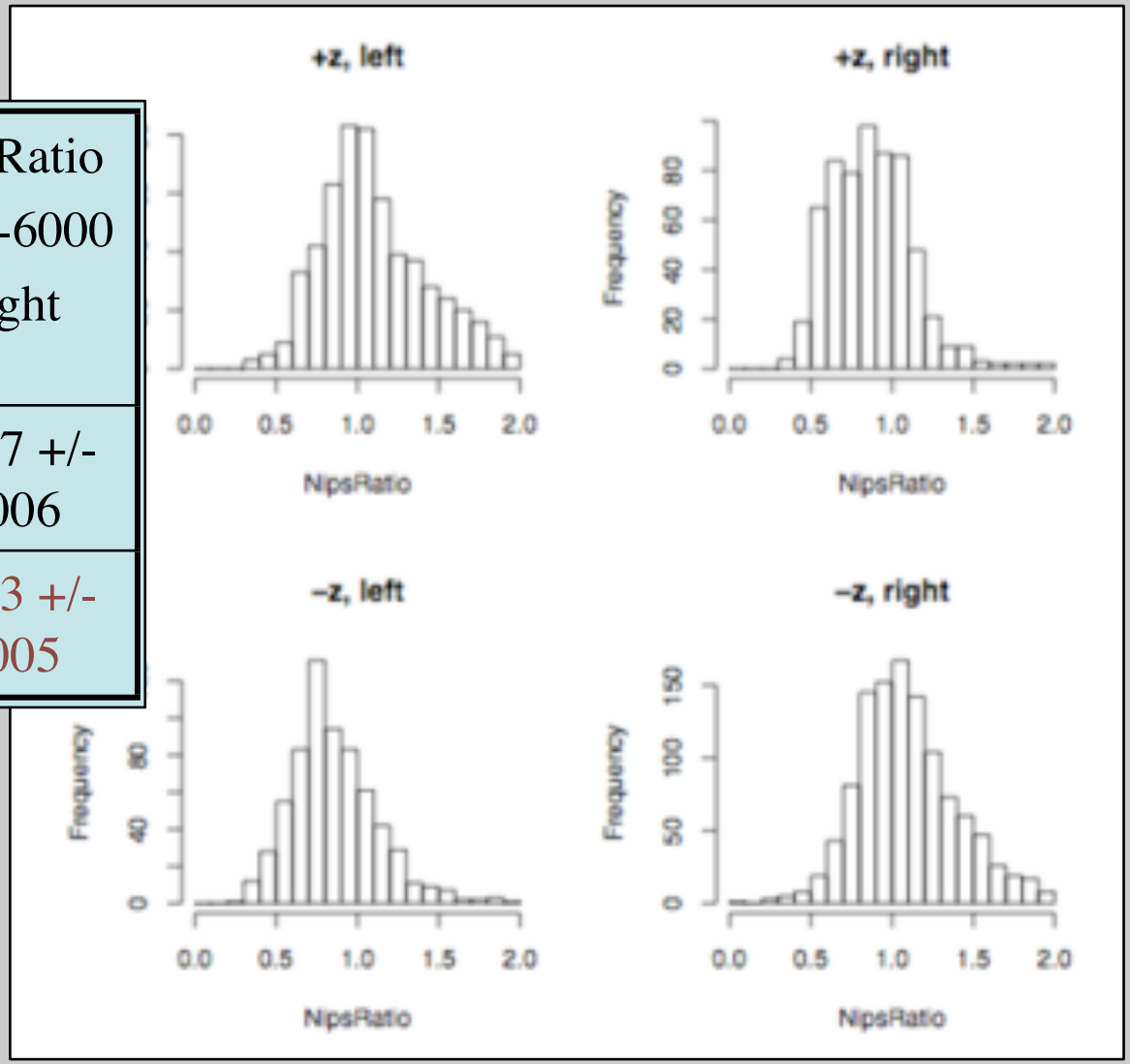


Directed neutron runs (DRIFT IIc): +z, -z,+x, -y



Head-Tail analysis

Nips Ratio 1000-6000 Left	Nip Ratio 1000-6000 Right
1.145 +/- 0.009	1.007 +/- 0.006
0.995 +/- 0.006	1.143 +/- 0.005



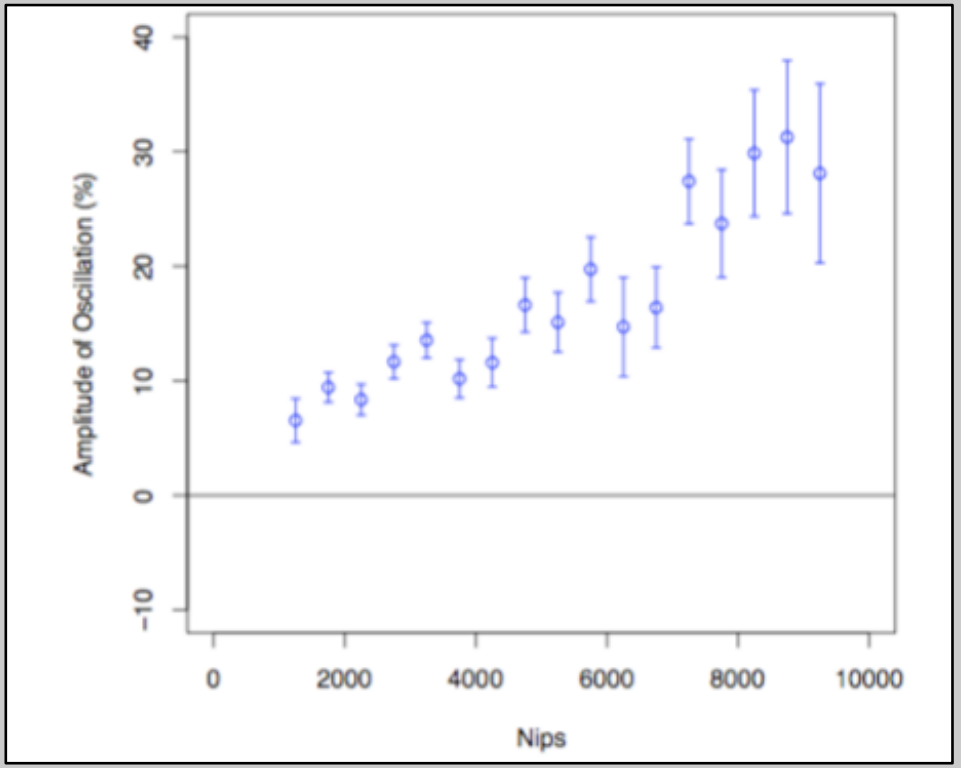
Head-Tail analysis

Run	N	Left	Right	Left-Right	S
+x	8673	1.074 ± 0.008	1.069 ± 0.004	0.005 ± 0.009	0.549
-y	5859	1.082 ± 0.006	1.083 ± 0.006	-0.001 ± 0.009	-0.121
+z	5829	1.145 ± 0.009	1.007 ± 0.006	0.14 ± 0.01	13.4
-z	8755	0.995 ± 0.006	1.143 ± 0.005	-0.147 ± 0.008	-19.2
-	-	-	-	Tail/Head-Head/Tail	-
Optimal (+z and -z)	14458	-	-	0.143 ± 0.006	23.8
Anti-optimal (+x and -y)	14397	-	-	0.005 ± 0.006	0.756

Amplitude of oscillation - Tail/Head - Head/Tail

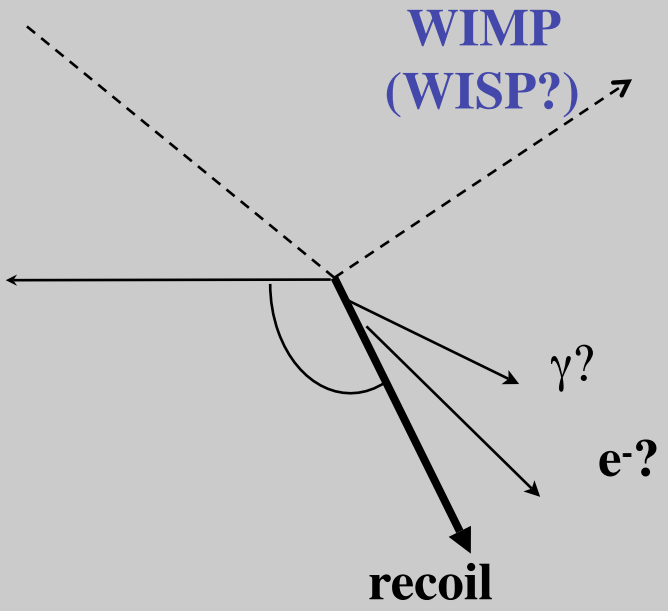
Note: extrapolation indicates head-tail discrimination continues below current threshold

Clear head-tail discrimination!



Conclusion

Comment: we will need the maximum information on events to show definitively that WIMPs exist in the galactic halo!



Low pressure TPC (1m^3 DRIFT) has:

- low energy threshold
- recoil tracking - 3D
- dE/dx discrimination
- range discrimination
- head-tail sense discrimination
- ability to identify multi-prong events
  (double-gamma - KK axion; recoil+gamma - DAMA?)