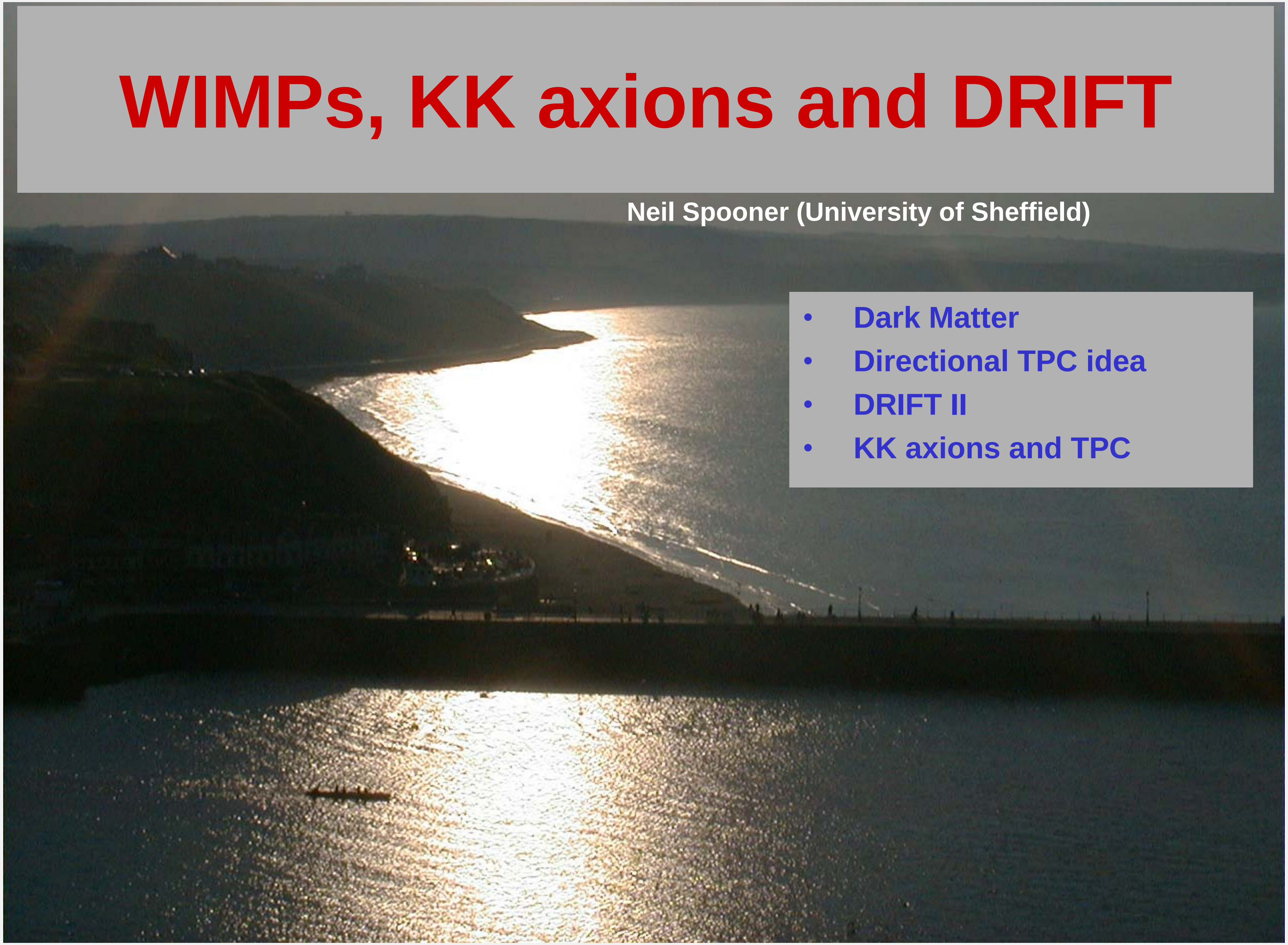
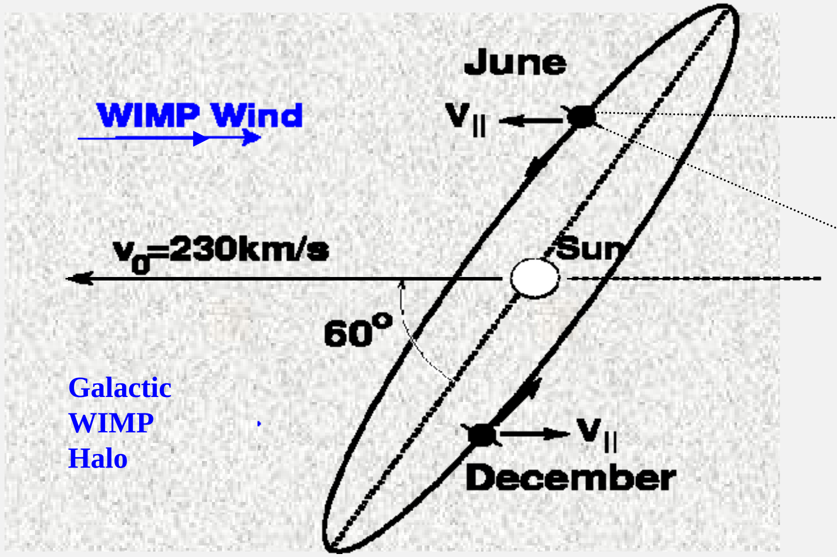
WIMPs, KK axions and DRIFT

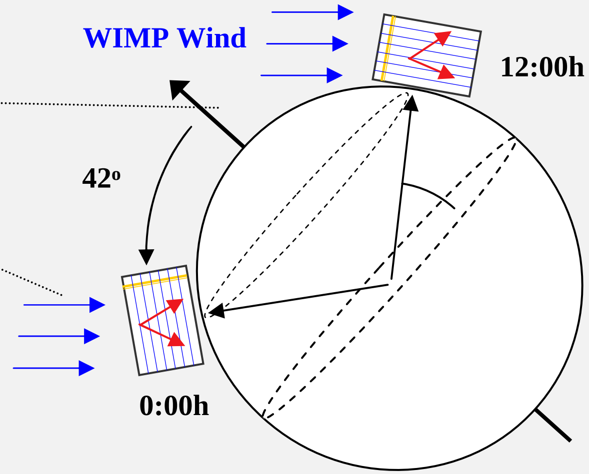
Neil Spooner (University of Sheffield)

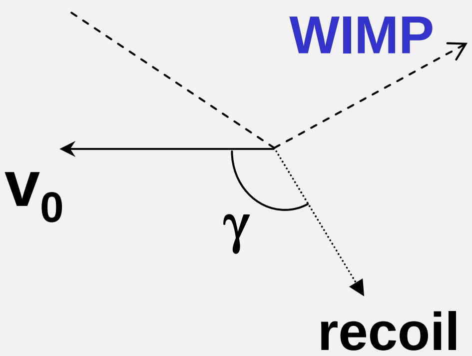
- Dark Matter
- Directional TPC idea
- DRIFT II
- KK axions and TPC

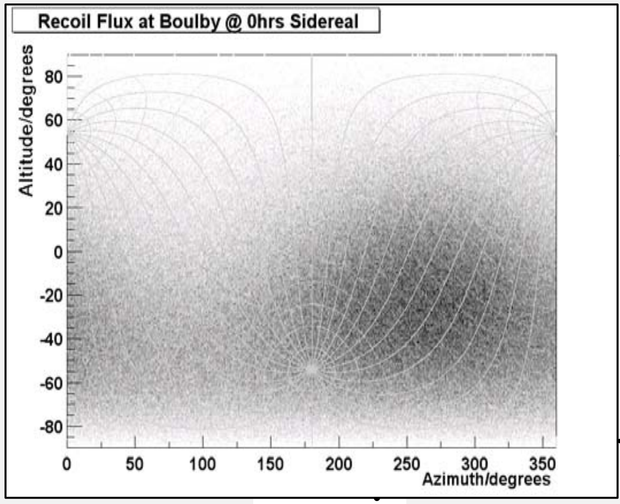


Direction sensitive WIMP detectors







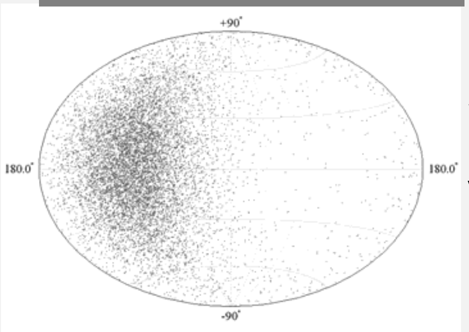


Determine galactic origin

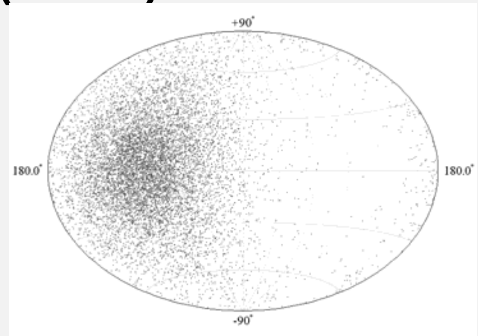
WIMP astrophysics?

Determining Halos (galactic co.)

WIMP flux inputs - assume all S (32GeV) recoils with 100GeV WIMPs.

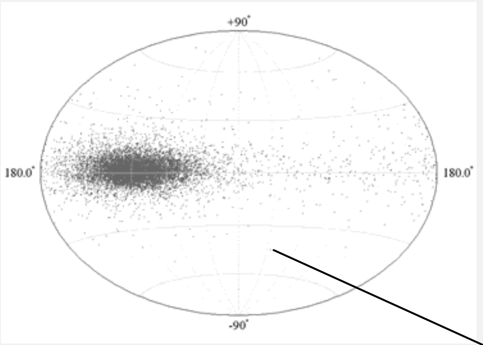


Standard Maxwellian halo, v_0=220kms^{-1}.

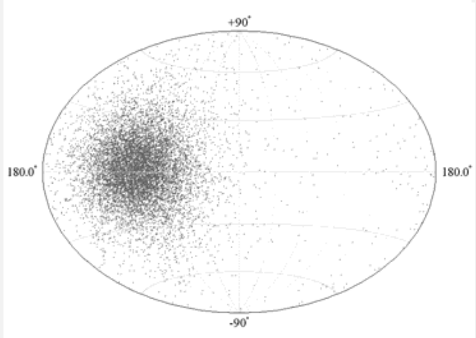


N-body simulations also suggest mild radial orbit bias.

$$\beta(r) = 1 - \frac{\langle v_\theta^2 \rangle - \langle v_\phi^2 \rangle}{2\langle v_r^2 \rangle}$$

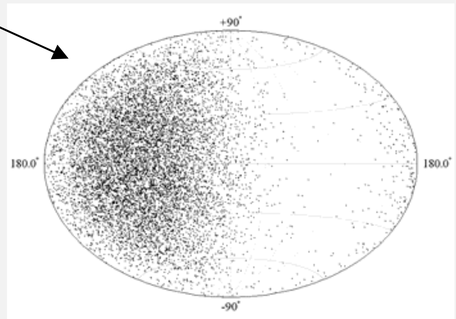


Triaxial - rather extreme case: p=0.72, q=0.7



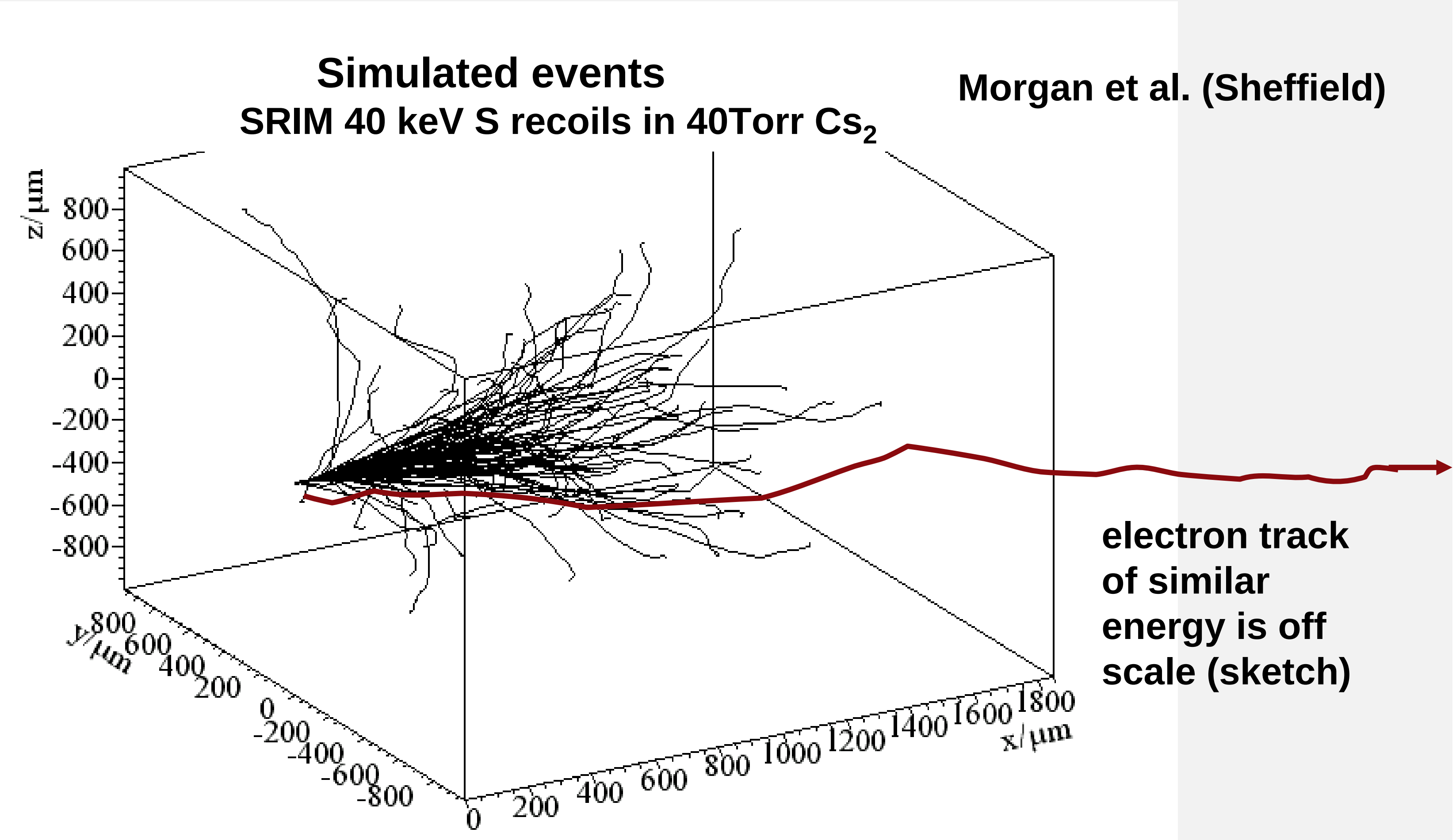
Triaxial halo with p=0.9, q=0.8.

Example detector outputs



Low background low pressure TPC

Morgan et al. (Sheffield)



electron track of similar energy is off scale (sketch)

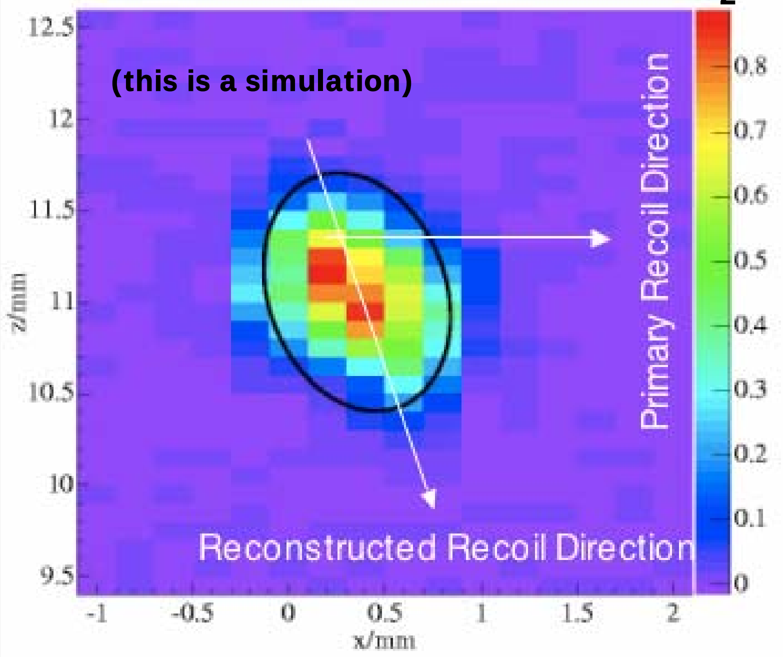
negative ion drift with CS_2 rediscovered by Jeff Martoff (Temple)

How many WIMPs to see the halo

AIM: how many WIMPs to see the halo?

[B. Morgan, A. Green, N. Spooner - Astro-ph/040804]

40 keV S recoil in 40 Torr CS_2



Model for realistic (advanced) detectors

- 40 Torr CS_2
- 1 $kVcm^{-1}$ drift field
- 200 μm resolution
- 10 cm drift
- ***SRIM2003 - recoil scattering and diffusion***

Vectorial Statistics:

Axial Statistics:

Recoil directions estimated as principal axis ±**r** of ***moment analysis of pixel signals***.

Recoil sense known(unknown): ***10-20(100-400) events needed to reject isotropy at 95% confidence in 95% of experiments***.

primary limitations: ***(1) recoil scattering and diffusion***
(2) head-tail

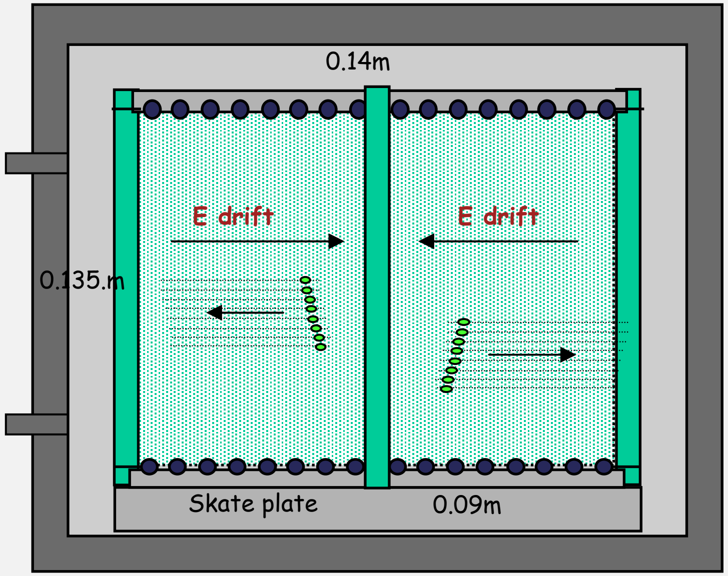
DRIFT II (a,b,c....) - multi-module

first steps to cheap modules

- **Aim**

WIMP sensitivity of 10^{-6} pb per module per year

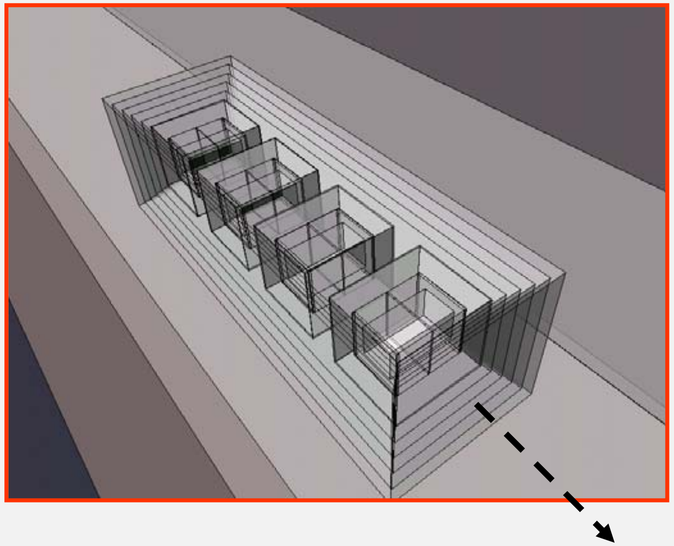
1m³



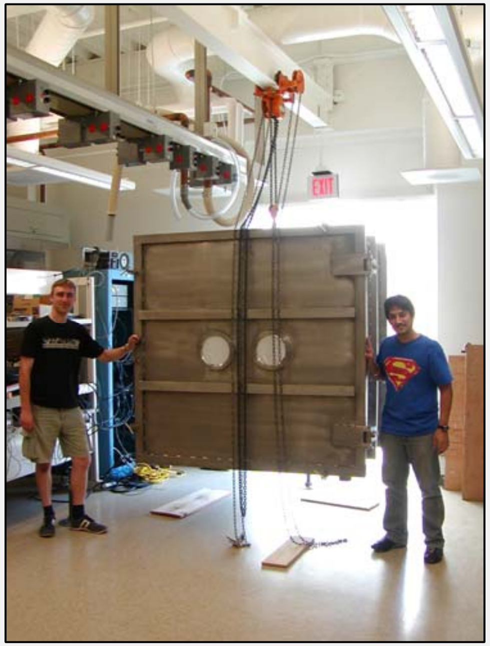
- **Basic Design**

Modular… n (3-4) × 1m³ fiducial vol, NITPCs

- Back-to-back drift vols & dual MWPC readout
- Vertical planes, warp adjust strongback MWPCs
- **3d track reconstruction (anode, grid and z-drift) (resolution: Δx = 2mm, Δ y = 0.1mm, Δ z = 0.1mm)**
- Low noise DAQ (few keV S-recoil threshold)
- low leak vessel design (<10^{-5}T.L.s^{-1}) .
- Simple gas system (various pressure & gas mixtures)

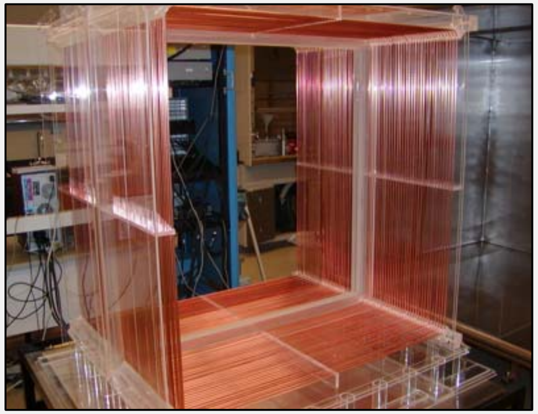


DRIFT IIa construction

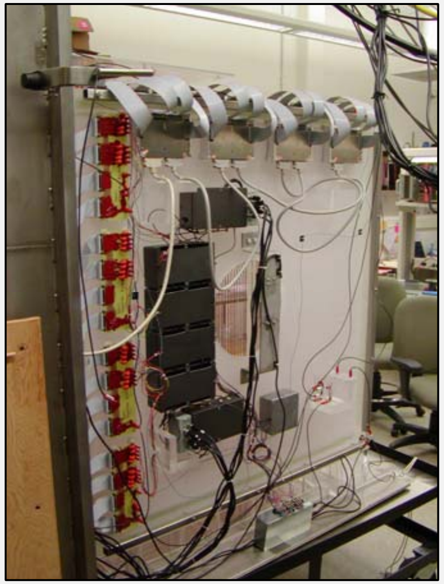


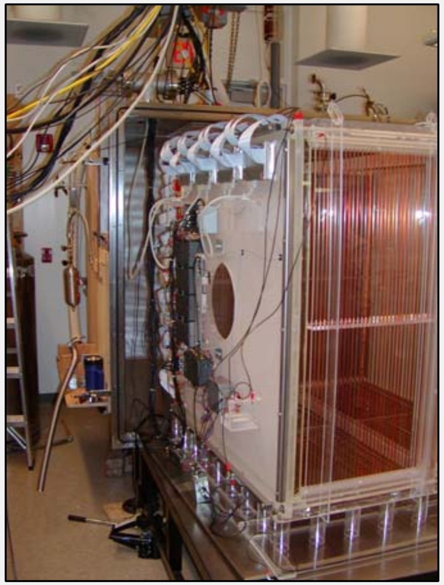
vacuum vessel

MWPC, 1m^2



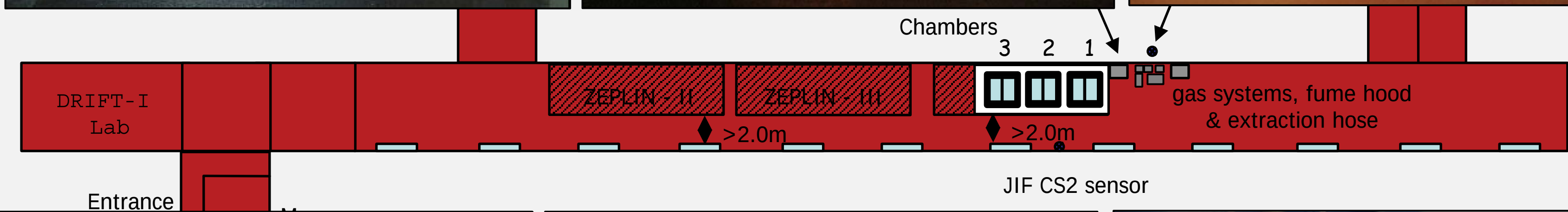
assembly of field cage





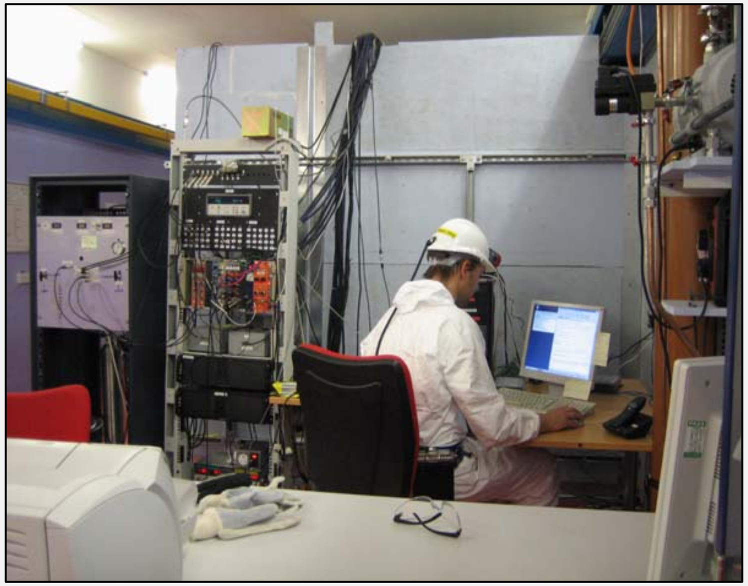
DAQ

DRIFT IIa installation at Boulby (1.1km depth)



DRIFT II shielded and running

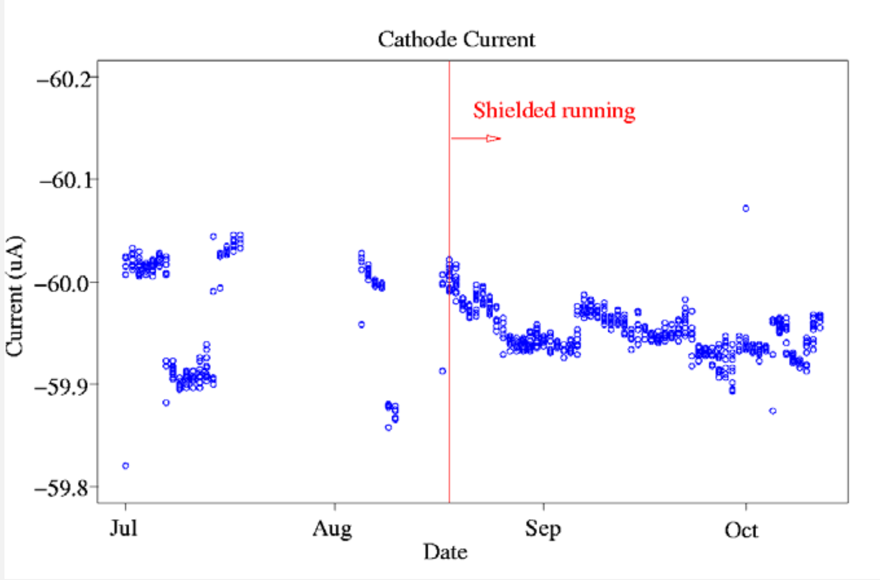
Aug-Nov 2005

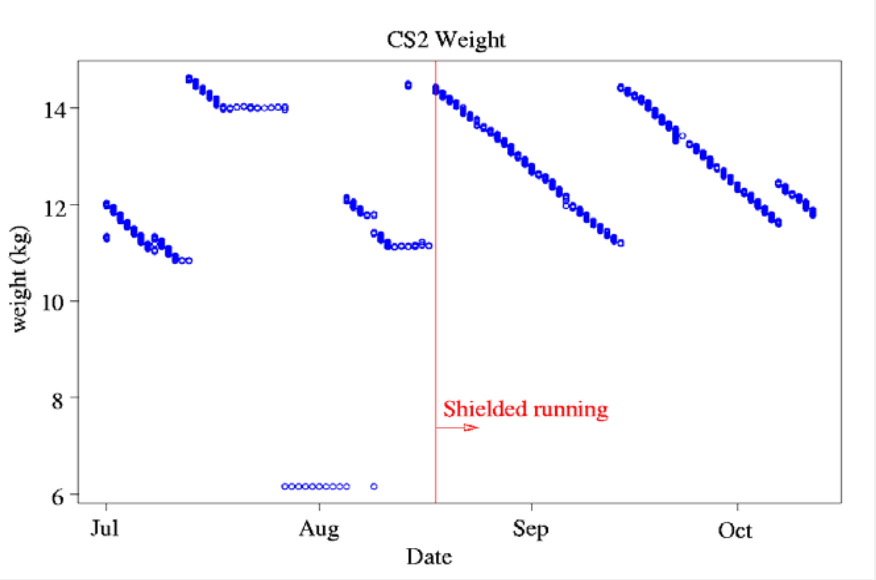


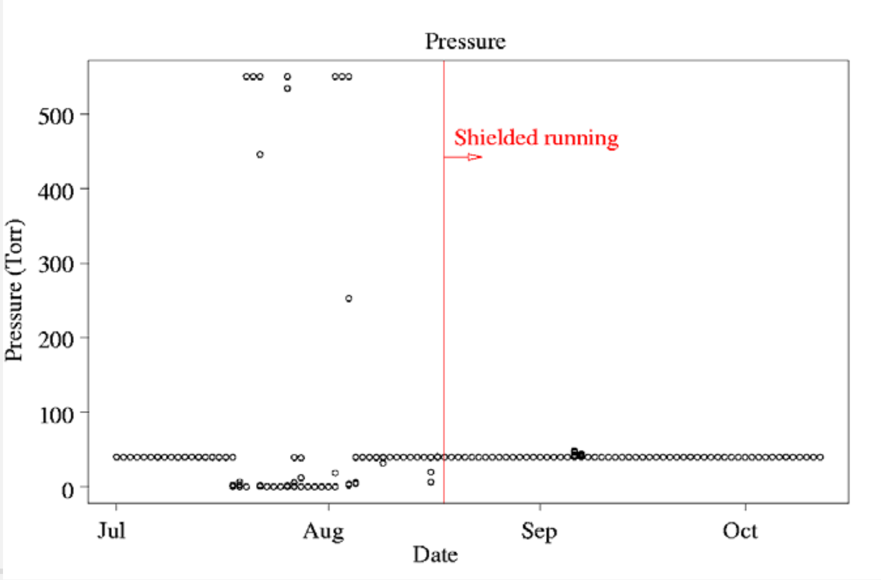
Continuous, stable, shielded operation since Aug 17th 05.

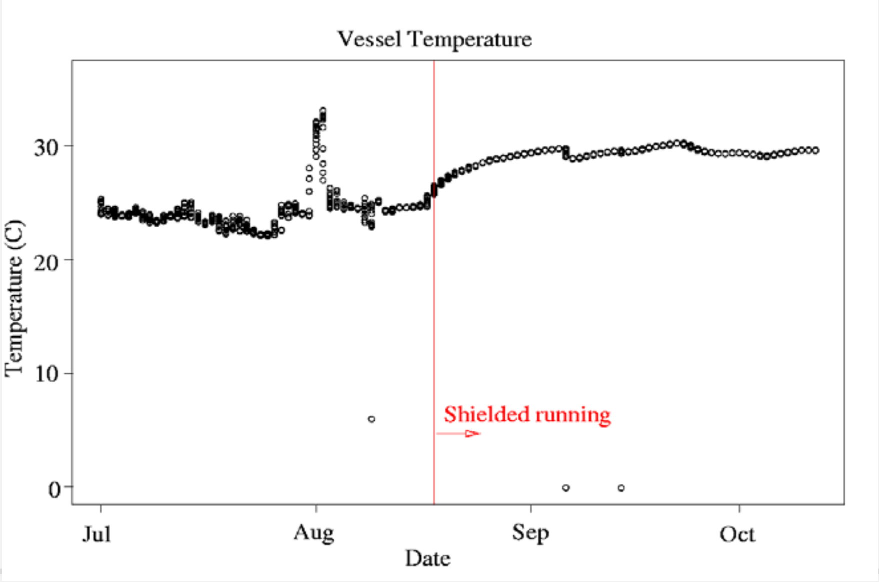
- 6 kg.days of unshielded data from engineering runs with ~3 kg.days partially-shielded.
- 12 kg.days of shielded data so far (~80 days continuous operation at 90% live time).

Long-term running and detector stability

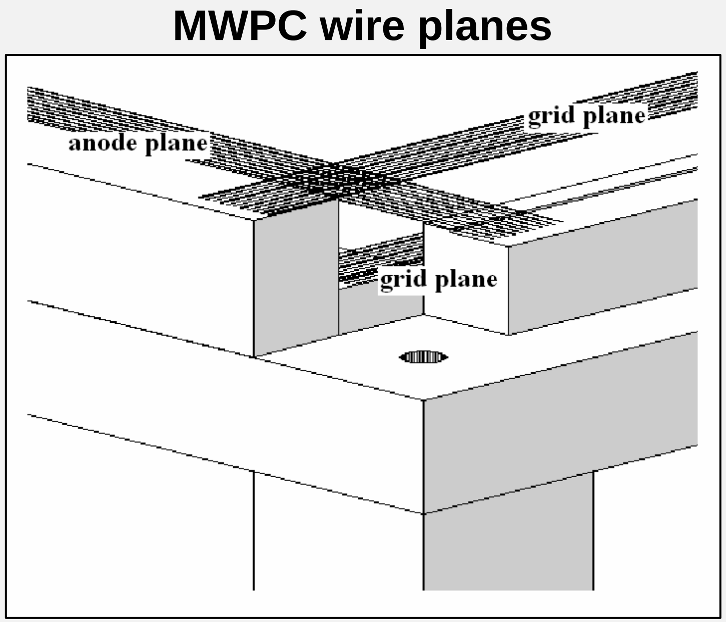


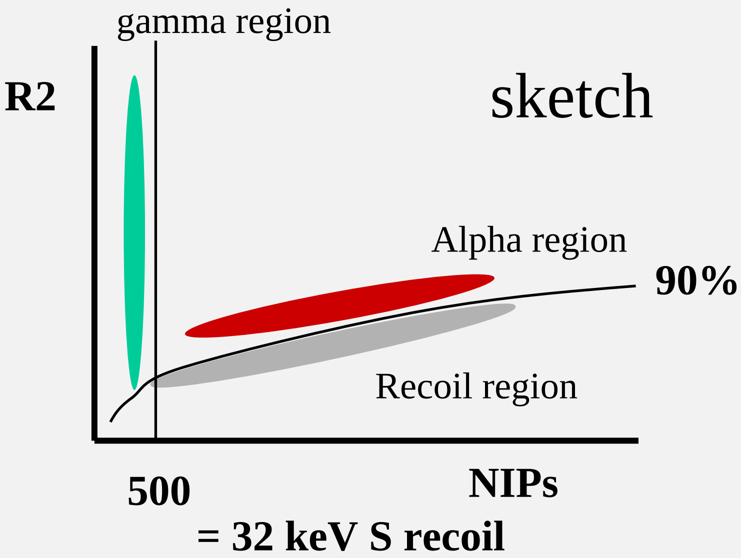


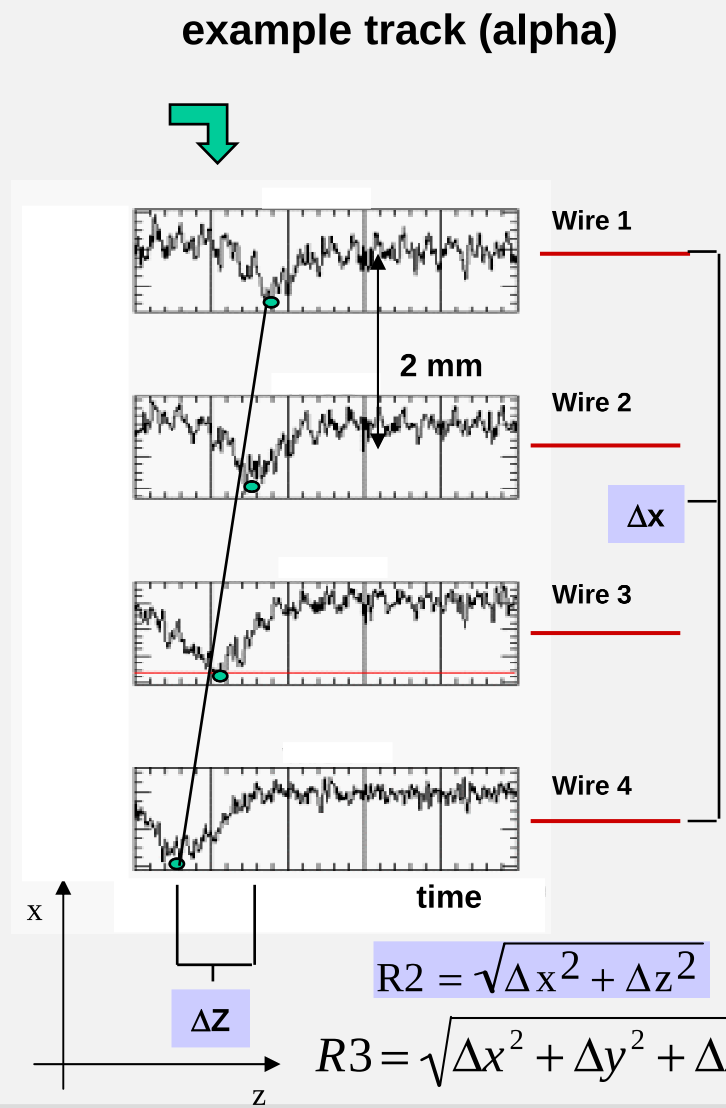




Track analysis





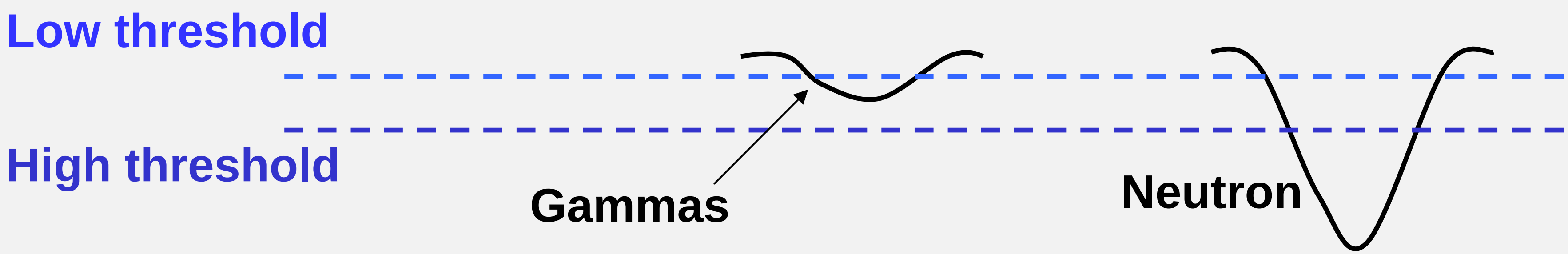


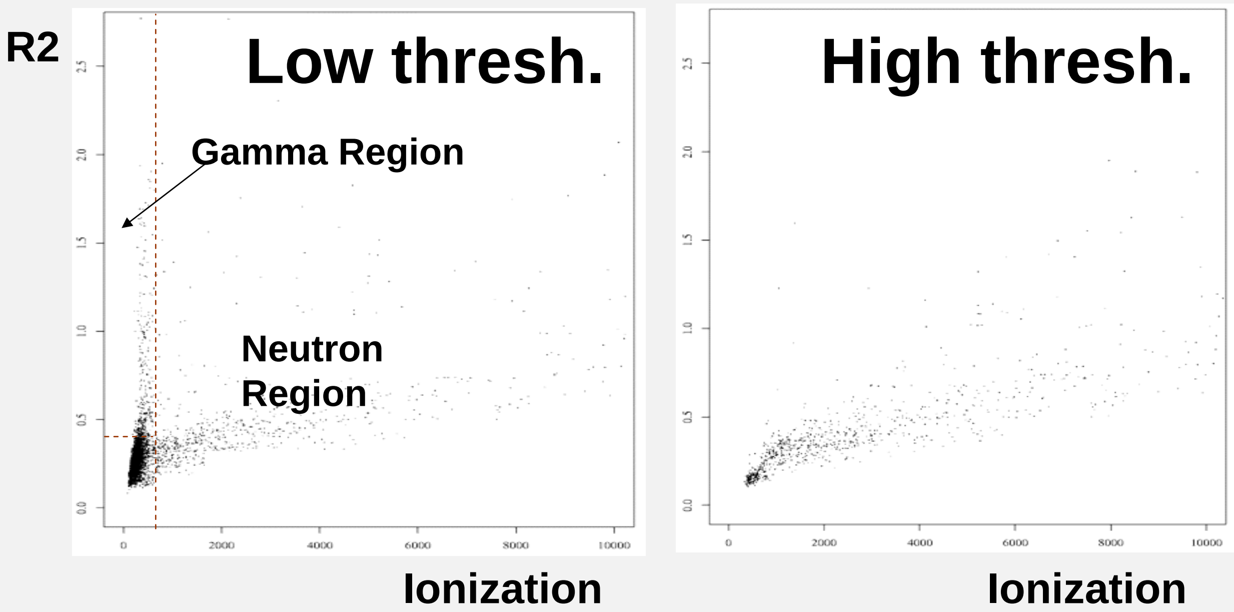
$$R2 = \sqrt{\Delta x^2 + \Delta z^2}$$

$$R3 = \sqrt{\Delta x^2 + \Delta y^2 + \Delta z^2}$$

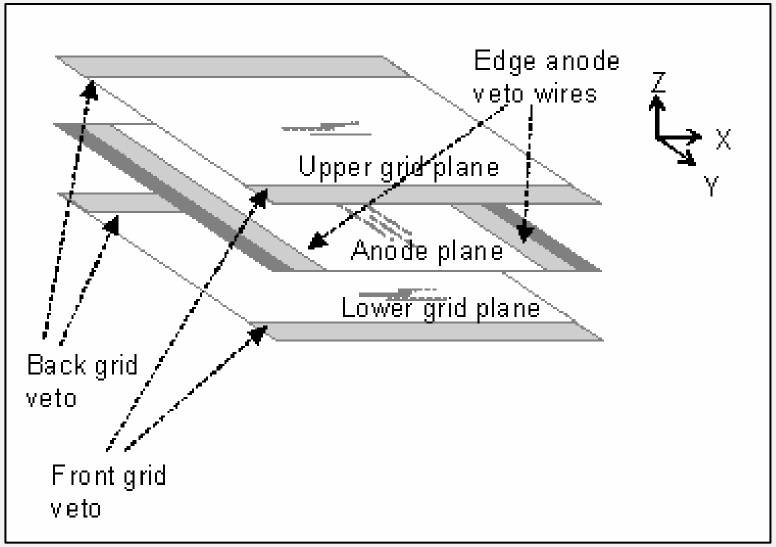
Gammas rejection basics

- Test with 1 ft^3 detector at Occidental





1000 Wires grouped down to 8 Channels



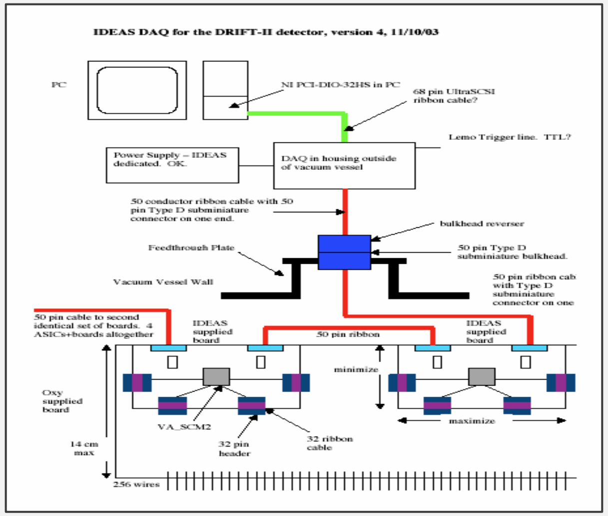
GRID: 12bit 5MHz sampling PCI ADCs.

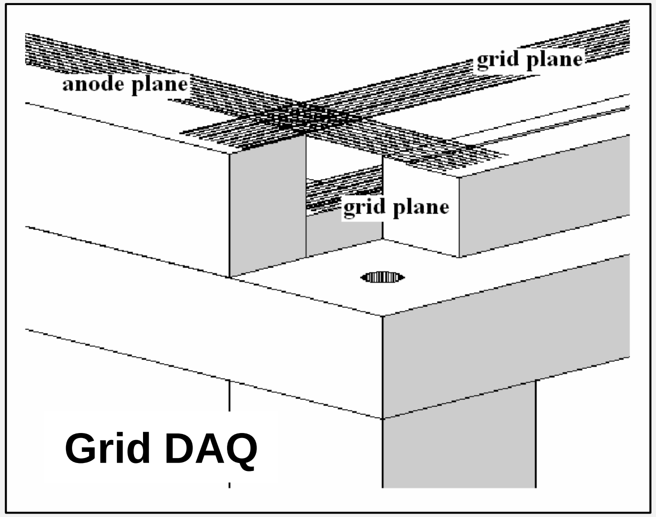
Internal 64 fold grouping & Amptek pre-amplification - 8 channels per MWPC

X & Y alpha vetos read into GRID DAQ

ANODE: ditto

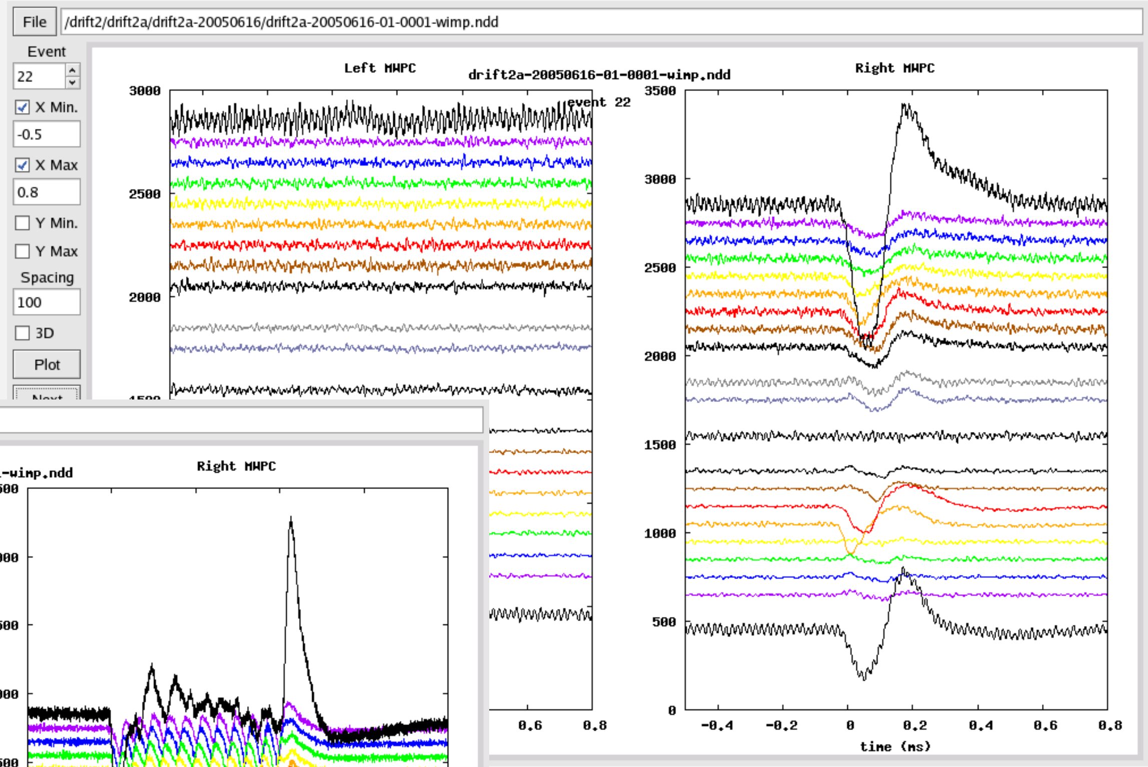
Slow Control: 120 chan Agilent data acq unit.

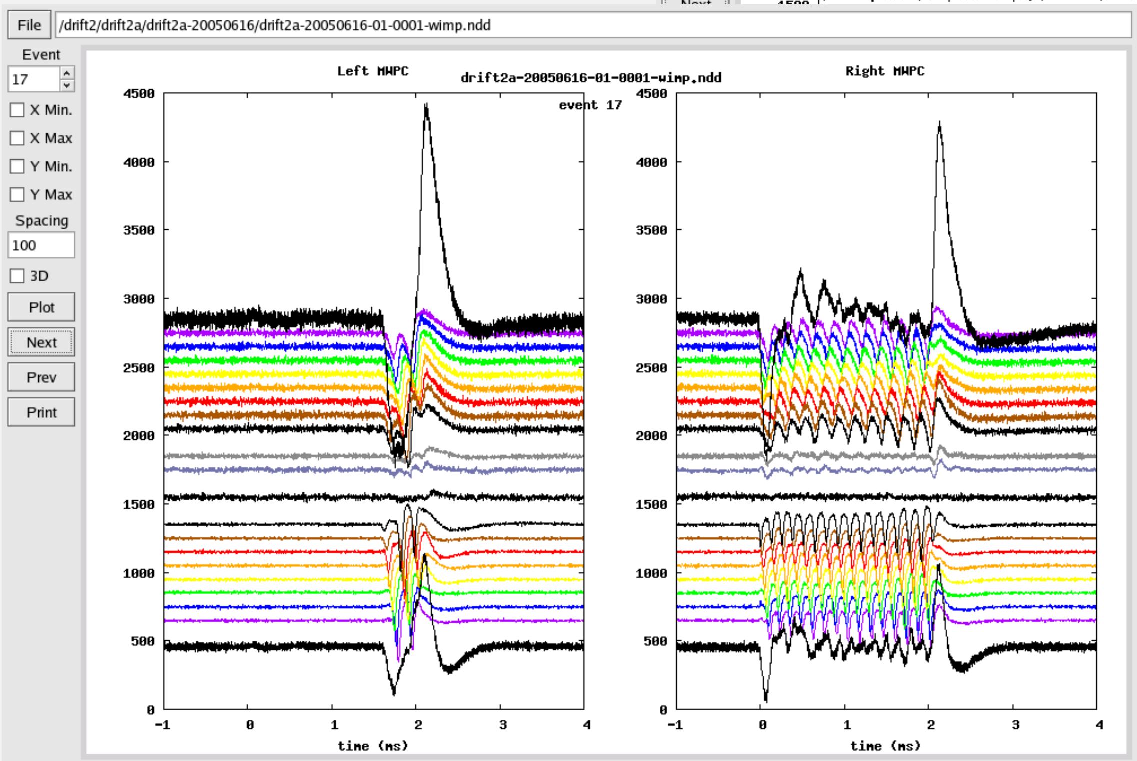




DRIFT IIa underground data

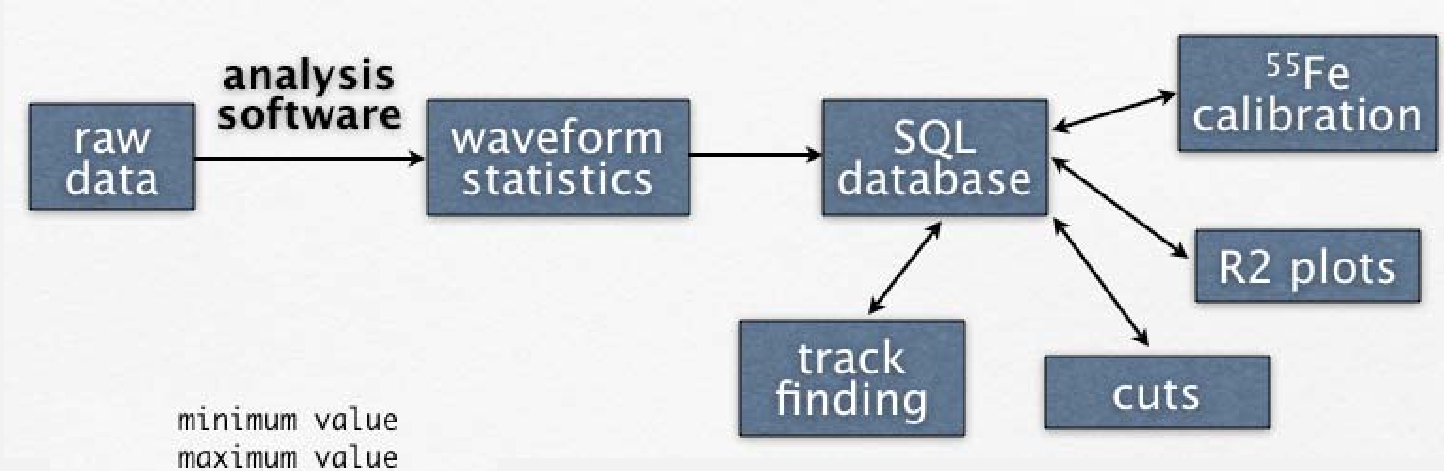
Typical neutron calibration event in right detector:



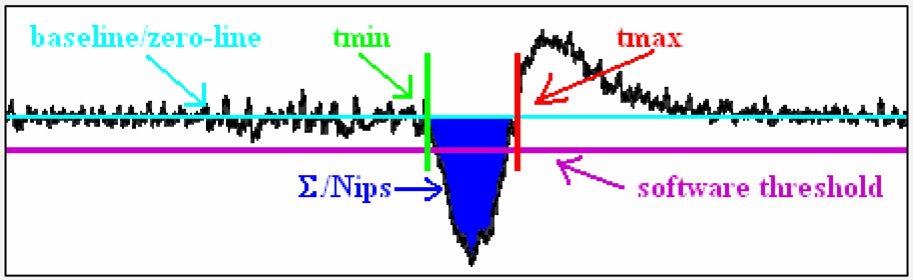


Background alpha crossing central drift-cathode (parts of track detected by both MWPCs).

DRIFT IIa data analysis



minimum value
maximum value
fwhm
width (time)
width (samples)
integrated area
timestamp
polarity
signal profile index
event number
polarity
voltage weighted time
minimum value index
maximum value index
start time/index
end time/index
baseline offset
height to width ratio



Solar Kaluza-Klein axions

- Axions arise from Peccei-Quinn solution to strong CP problem in QCD (see other talks….)
- In theories with *n* extra dimensions, axions may be able to propagate and acquire so-called Kaluza-Klein excitations
- Such Kaluza-Klein axions produced in the Sun may be trapped into Earth-crossing orbits
- Decay of these trapped Kaluza-Klein axions to pairs of back-back photons may be observable in a suitable detector such as a Time Projection Chamber (TPC) like DRIFT
- Prospects for such a detection are determined by:

- Axion-photon coupling constant $g_{a\gamma\gamma}$
- The local axions number density n_0
- Volume of detector (m^3)
- Background gammas (1-10 keV)

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

KK axion lifetime

standard electromagnetic coupling

Axion couples to two photons: $g_{\alpha\gamma\gamma} = \frac{\alpha_{EM}}{\pi} \frac{C_a}{f_{PQ}}$

axion model factor ~1

symmetry breaking energy scale

This implies decay to two photons with mean lifetime: $\tau = \frac{64\pi}{g_{a\gamma\gamma}^2 m_a^3}$

However, astrophysical constraints imply τ too long to observe:

$$10^9 GeV \le f_{PQ} \le 10^{12} GeV; 10^{30} \le t \le 10^{45} days$$

But propagation in extra dimensions allows shorter, observable, lifetime

$$m_a = m_{an} \sim \frac{n}{R}$$

Solar KK axion mass spectrum

Basis for an experimental search:

B. Morgan, N. Spooner et al, D. Hoffmann et al., K. Zioutas...

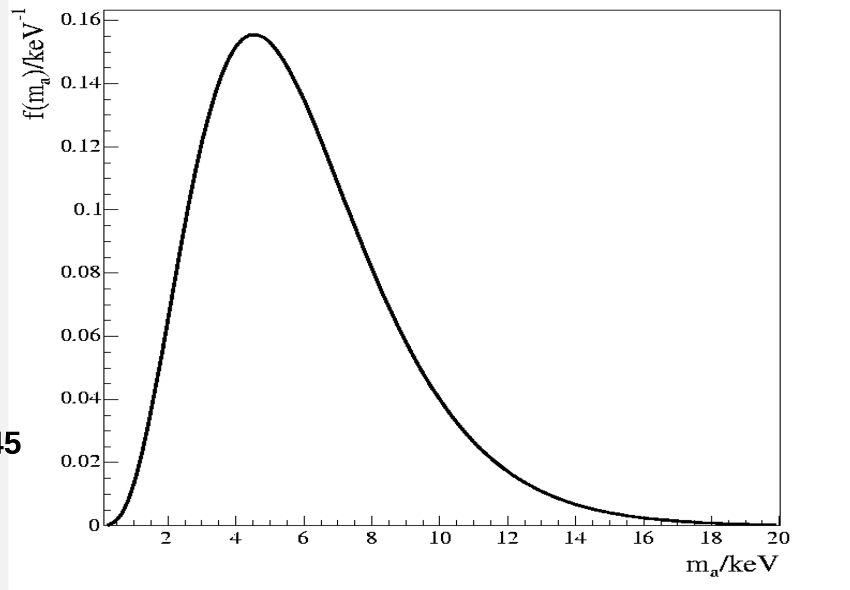
B. Morgan et al. Astrop. Phys 23 (2005) 287,

- **Leads to differential decay spectrum:** $$\frac{dR}{dm_a} = \frac{g_{a\gamma\gamma}^2}{64\pi} n_0 m_a^3 f(m_a)$$

$$R = (2.5\times10^{11} m^{-3} day^{-1}) \left(\frac{g_{a\gamma\gamma}}{GeV^{-1}}\right)^2 \left(\frac{n_0}{m^{-3}}\right)$$

→ **Typical rate ~ 1 m^{-3} day^{-1} (~keV events)**

Result for trapped axions in orbits around Sun $g_{a\gamma\gamma} = 9.2\times10^{-14} GeV^{-1}$ $n_0 = 10^{14} m^{-3}$
(local number density depends on $g_{a\gamma\gamma}$)



Mass spectrum for solar axions trapped in orbits around the sun

L. Di Lella and K. Zioutas, Astrop. Phys., 19 (2003) 145

Low pressure TPC is ideal

Decay in space so best to have large volume ~ m^3

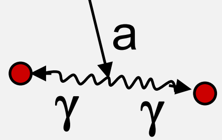
Low pressure allows separation of back to back gammas

(1) spatial cut

$$P(s:m_a) = \frac{s}{\lambda^2(m_a/2)} e^{-\frac{s}{\lambda(m_a/2)}}$$

Spatial separation between photoelectrons from axion decay of mass m_a

Photon mean free path in the gas



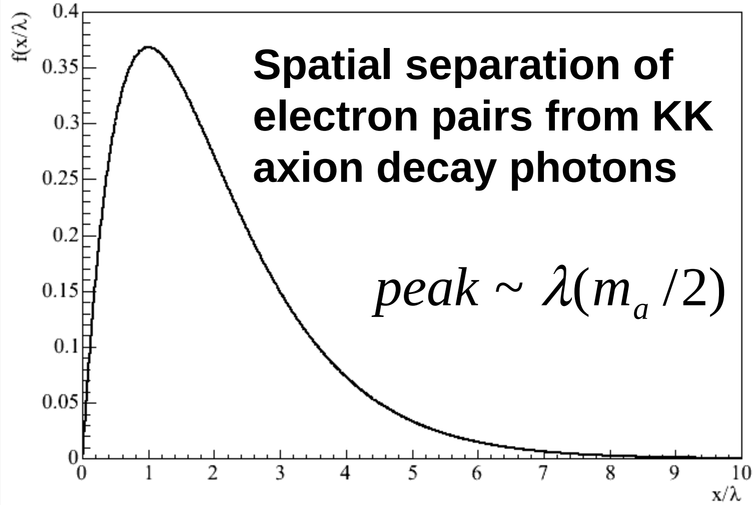
(2) energy cut

Energy resolution

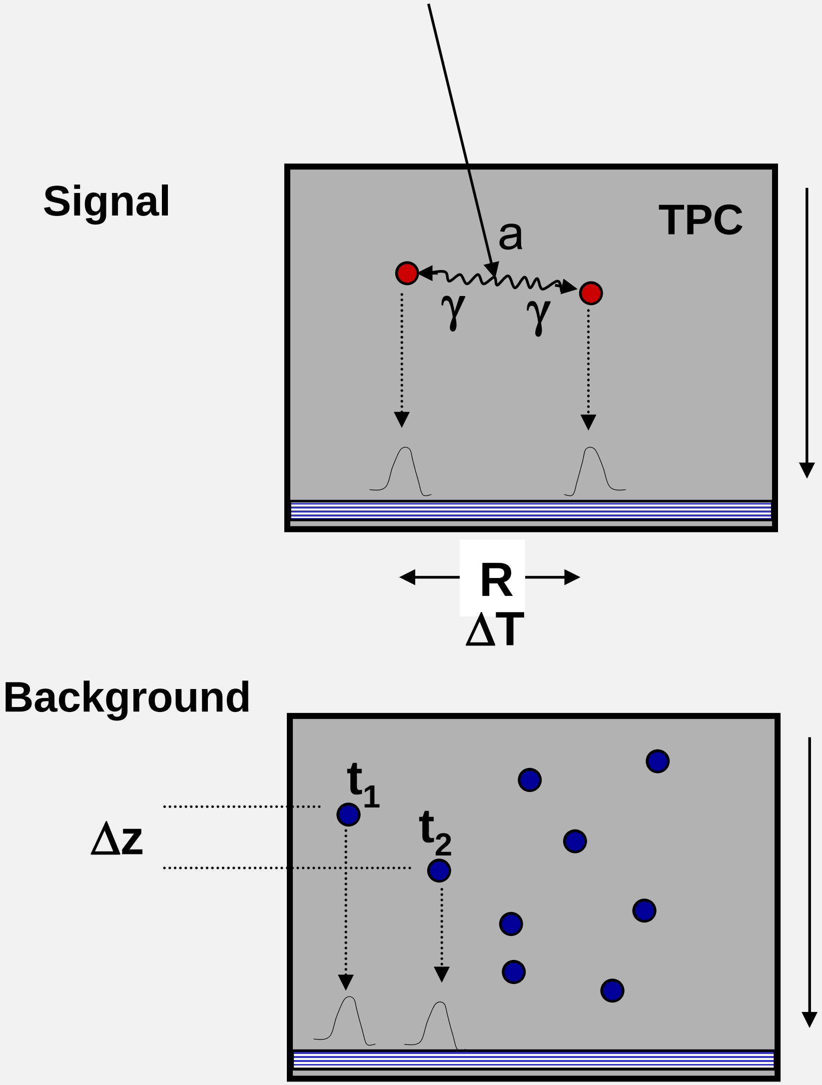
$$|E_1 - E_2| > \sqrt{2}\, x\, \sigma_p(\bar{E})$$

90% at 1.64

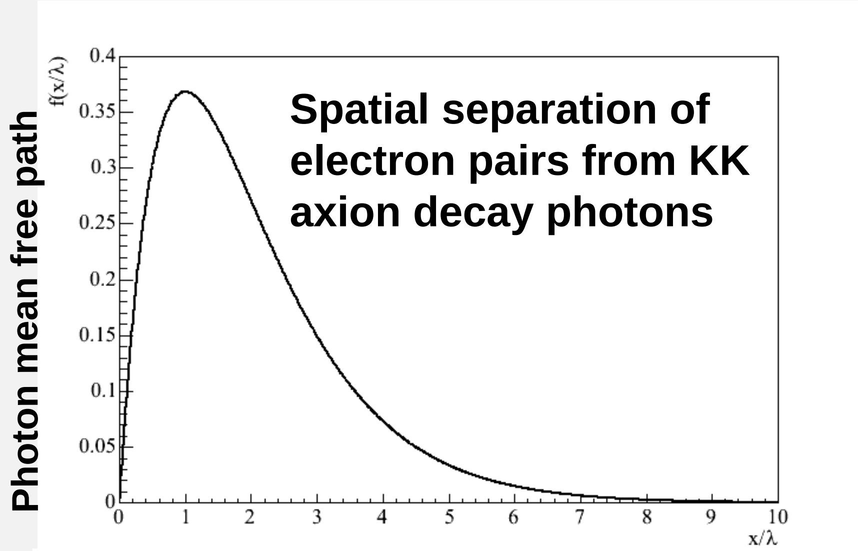
(3) time cut

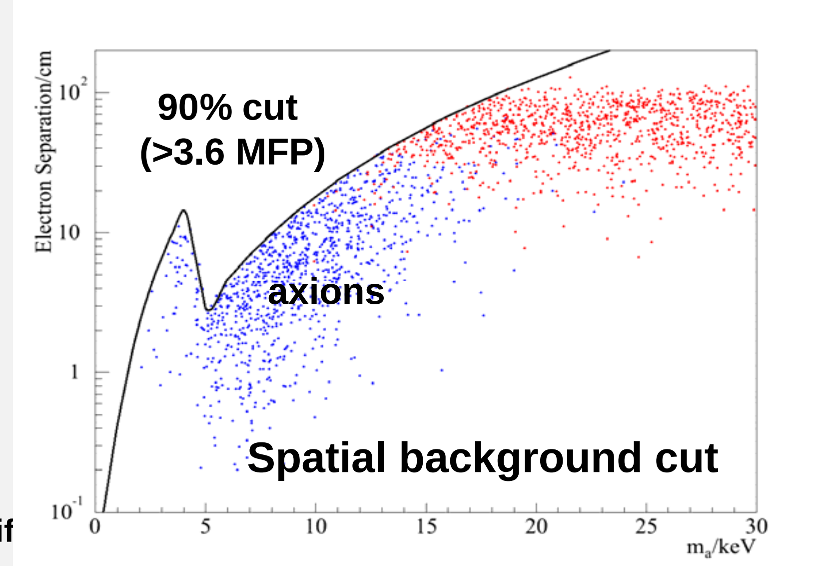


Signal and γ background MCs



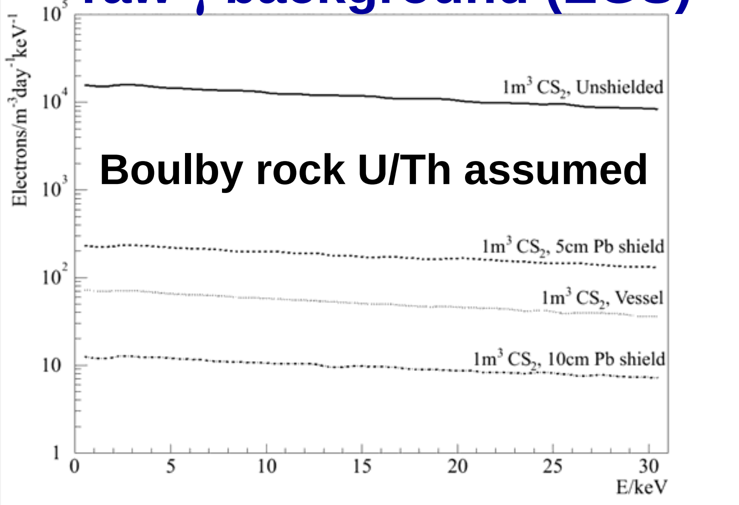
$\Delta T=(|t_1-t_2|)+\Delta z/V_{dif}$



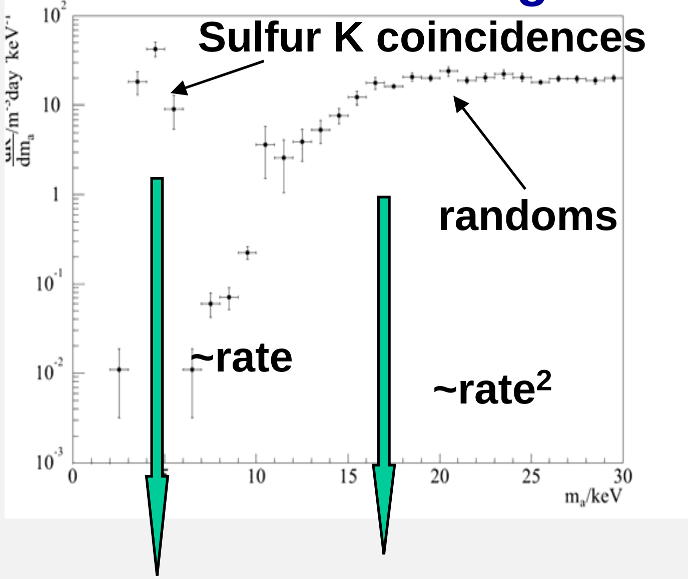


γ background prediction (DRIFT, 160 Torr CS_2)

raw γ background (EGS)



unshielded cut background



Issues

Random gamma coincidences
Coincident backgrounds:
Compton scatters
~2 keV S K-shell x-ray

CS_2 conclusion

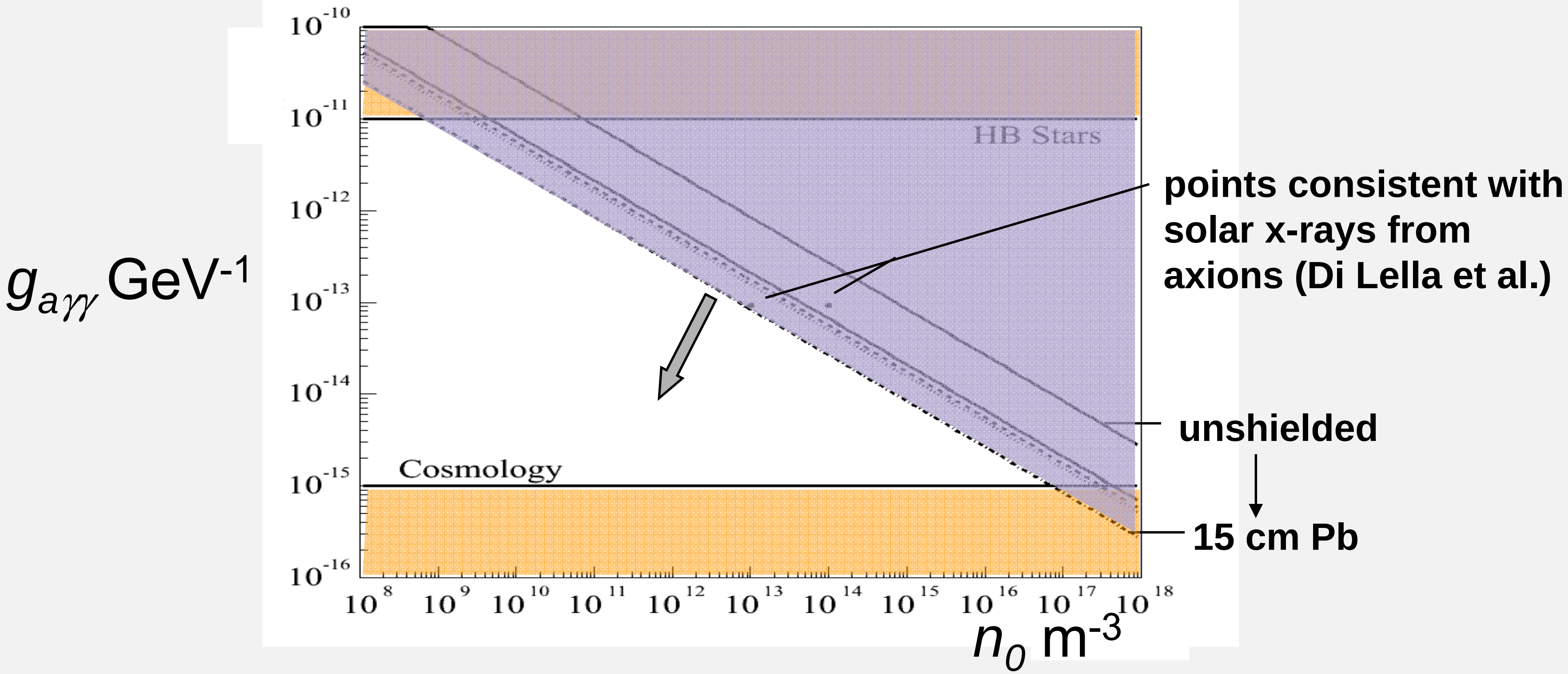
- Good resolution on R (low diffusion)
- Good low gamma sensitivity
- Poor ΔT (gas is slow)
- Poor K - pair background

Nevertheless background rates ~0.1 m^{-3} day^{-1} are possible for m_a of 6-20 keV several orders of magnitude less than for solid state detectors

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]



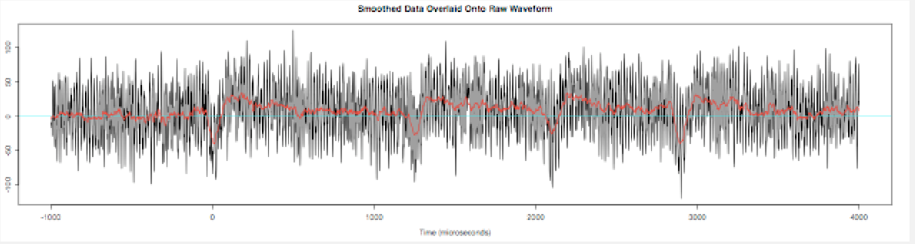
POSSIBLE IMPROVEMENT (lots of ideas)

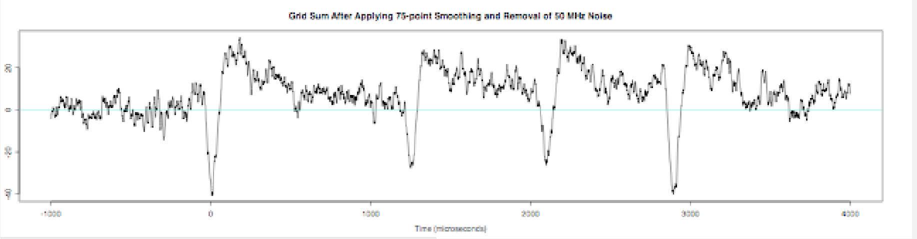
- **alternative gases to avoid K- events: (a) P10 - but poor R, (b) CF_4 - but longer MFPs…**
- **larger volumes, higher pressure, purer materials, better analysis**

Is DRIFT sensitive enough to the x-rays?

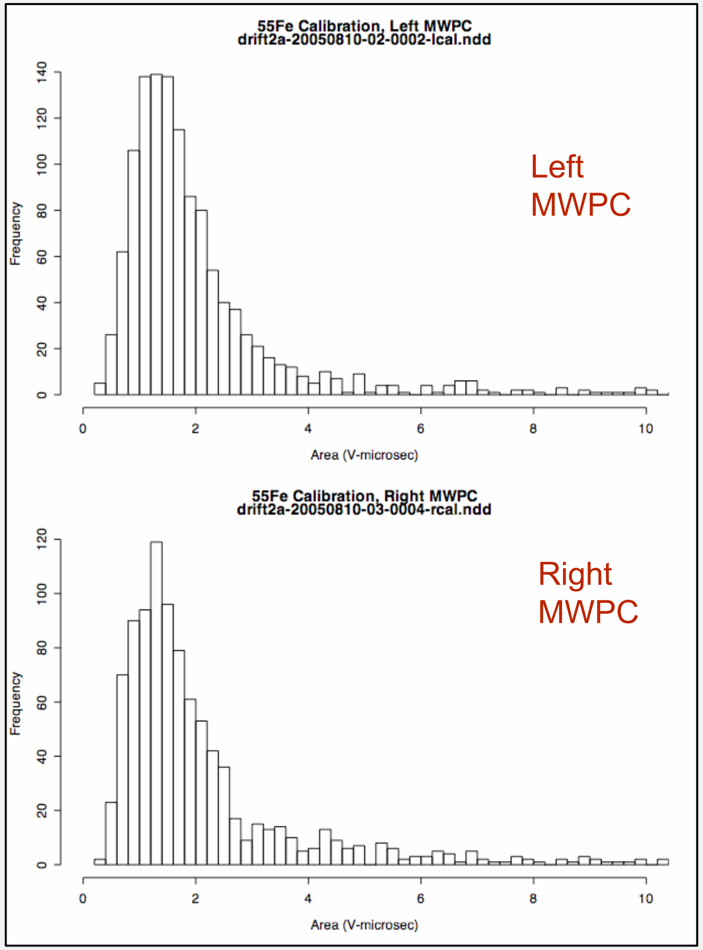
Energy calibration performed using automated Fe55 exposures.

Noise reduction using Fourier transform & box-car smoothing





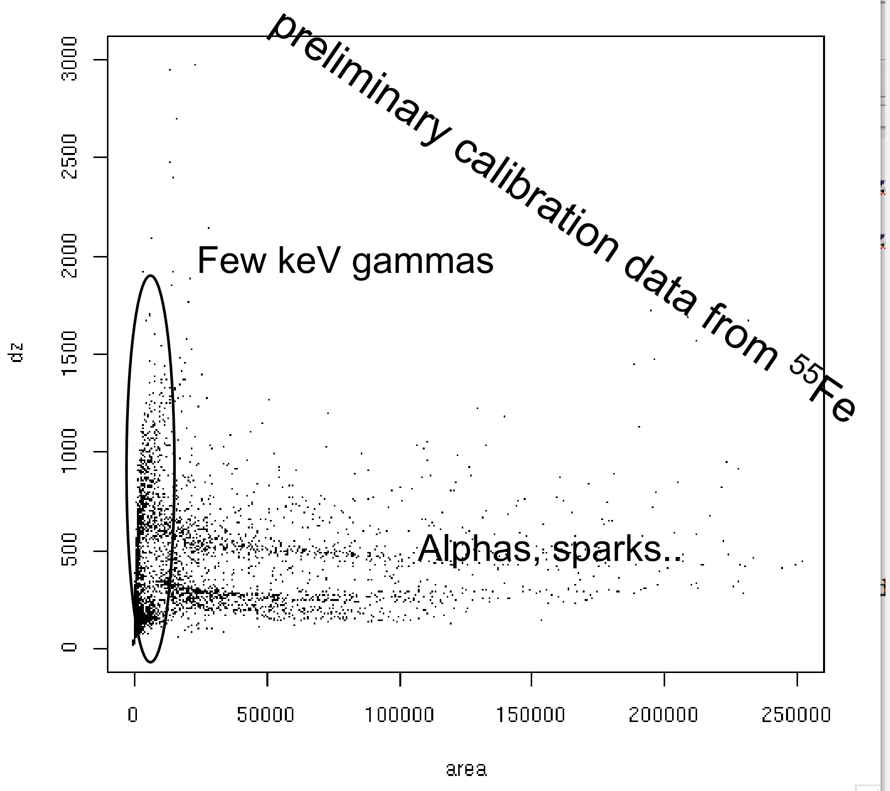
Individual Fe55 (5.9keV) events on the grid sum



Probably yes

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

e.g. uncut low threshold data (1000 events)



But, grouped readout limits spatial sensitivity to projection on the xy plane

Conclusion - next steps - DRIFT II b, c..

DRIFT IIa running for WIMPs!

Low energy threshold and spatial resolution may allow identification of back to back gammas from KK axions

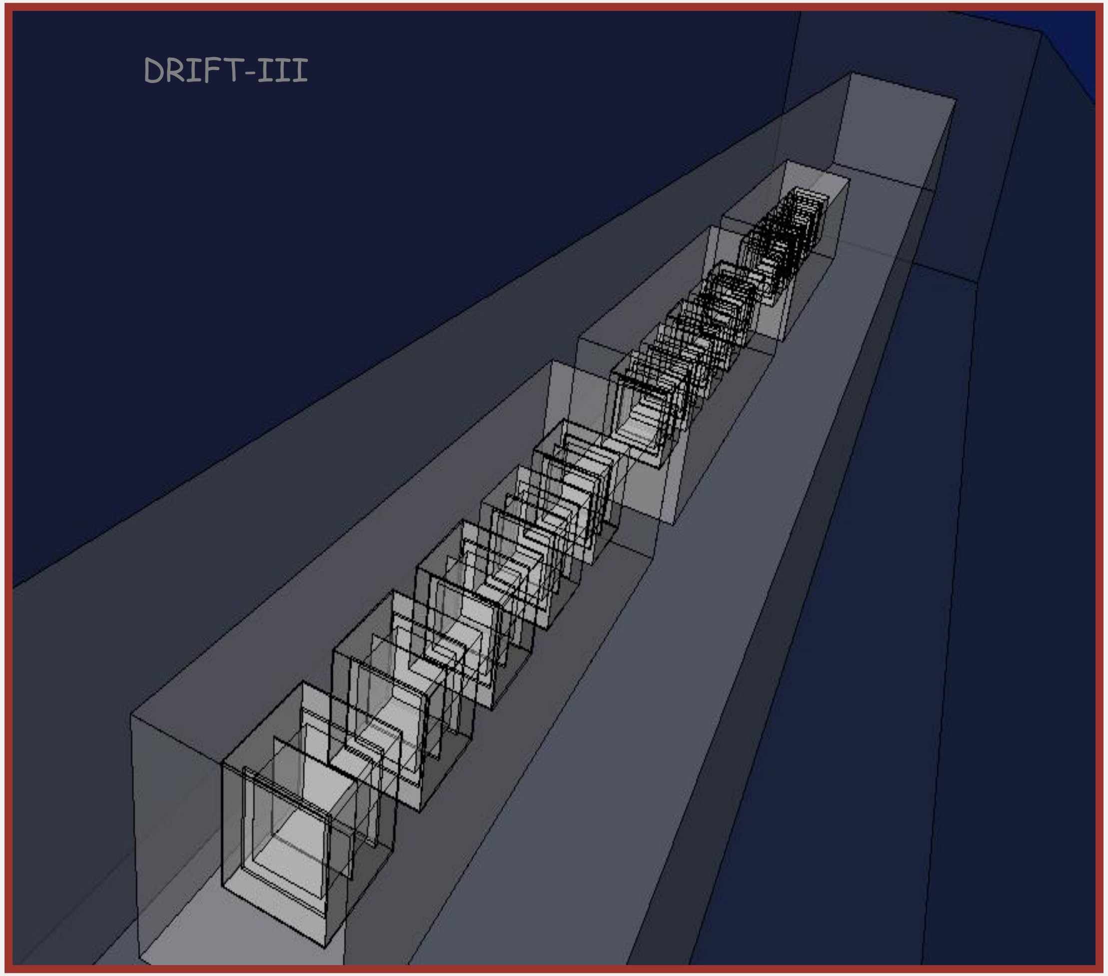
Needs upgrade:

gamma shielding

<u>**less channel grouping**</u>

Meanwhile DRIFT IIb due for U/G installation Feb 2006:

-triggerless DAQ
-lower threshold
-lower-cost



Bulk micromegas provides route to better PSD…