The DRIFT Dark Matter Search

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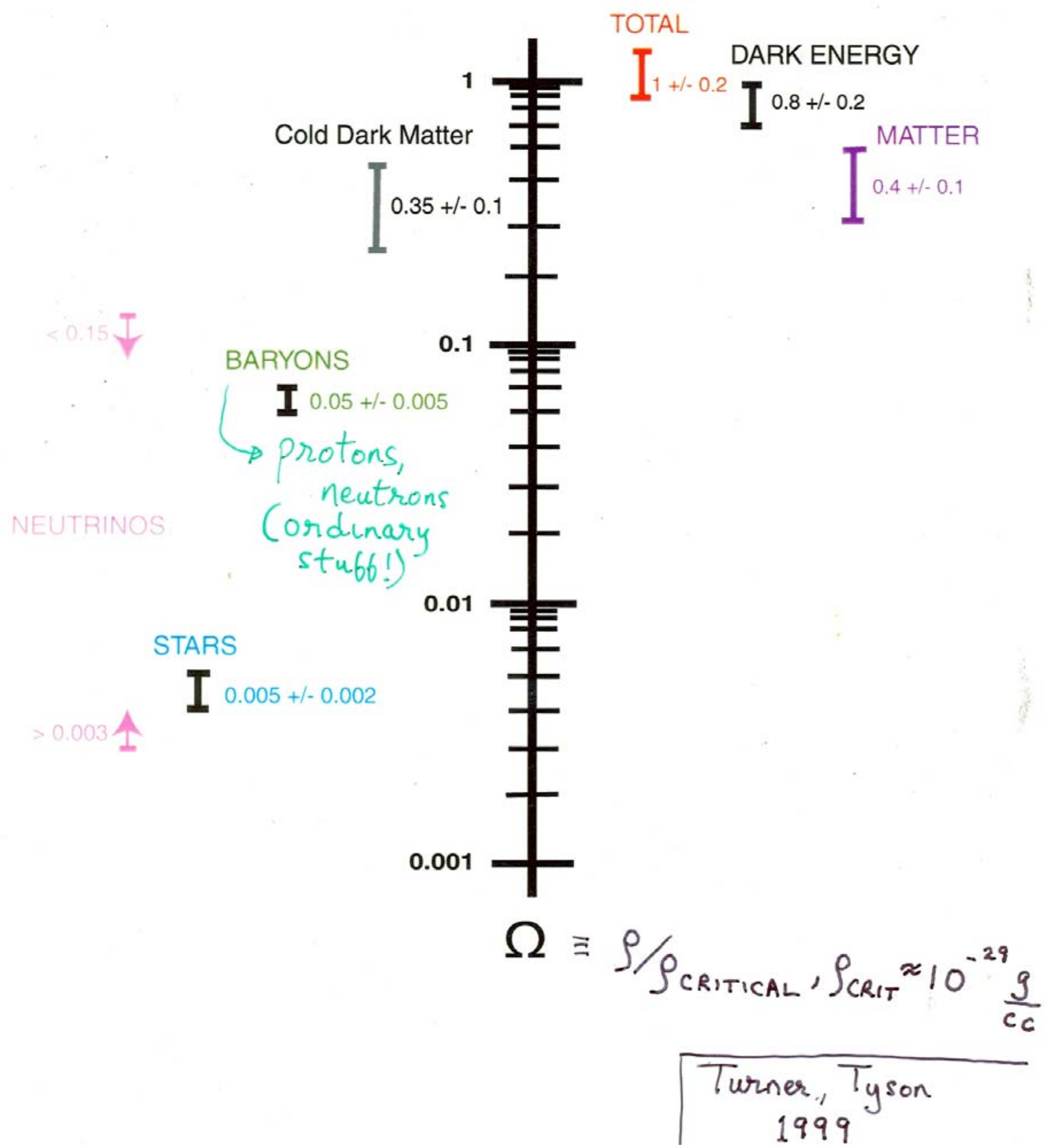
For the DRIFT collaboration
(Occidental, UNM, Sheffield, Edinburgh)

LBL INPA Feb 6, 2009

$$\Omega = \Omega_{\text{matter, radiation}} + \Omega_{\Lambda} = 1$$

$$\sim \frac{1}{3} + \frac{2}{3}$$

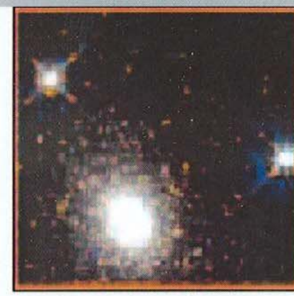
MATTER/ENERGY in the UNIVERSE



Post WMAP era ... Precision Cosmology! (~2003)

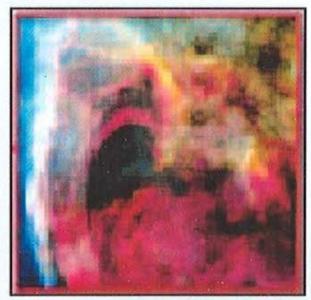
Knowing what we don't know! with great precision - matter and energy

heavy elements 0.03%

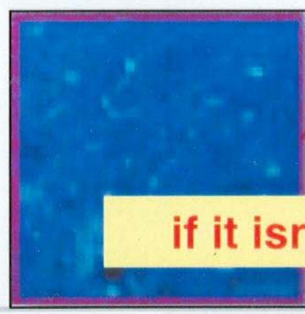


stars 0.5%

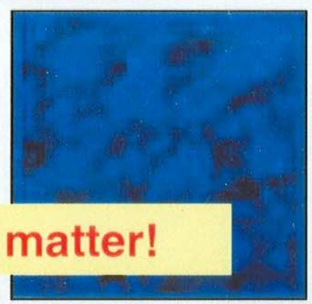
neutrinos 0.47%



free H and He 3.7%



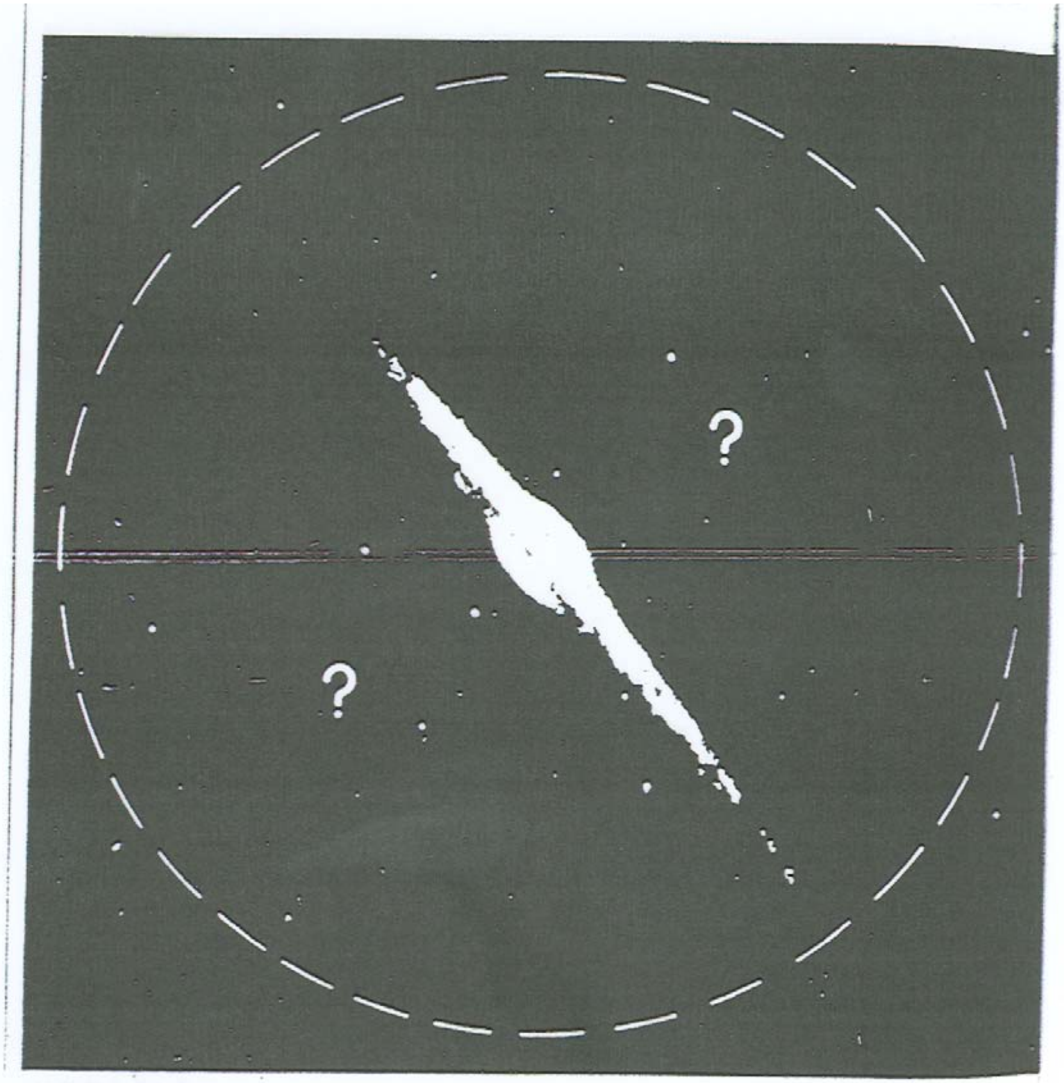
dark matter 24.3%



dark energy 71.0%

if it isn't dark it doesn't matter!

US0703 - all data shown is preliminary



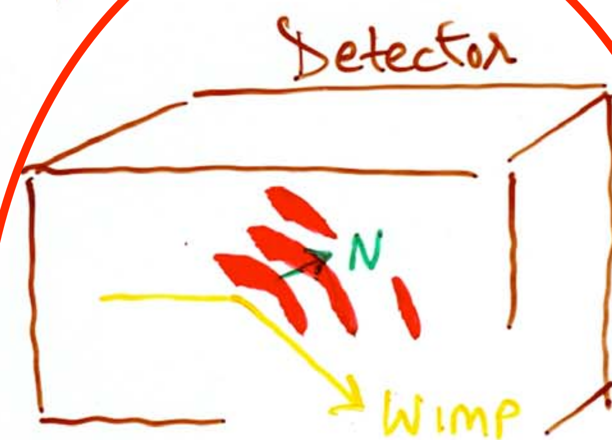
NGC4565

So, what is it??


Some (!) Candidates for DM
MACHOS
ν's
WIMPS
B-H's
Dwarfs
SIMPS²
axions
MOND
Xtra Dimensions!
Fuzzy DM
CHAMPS

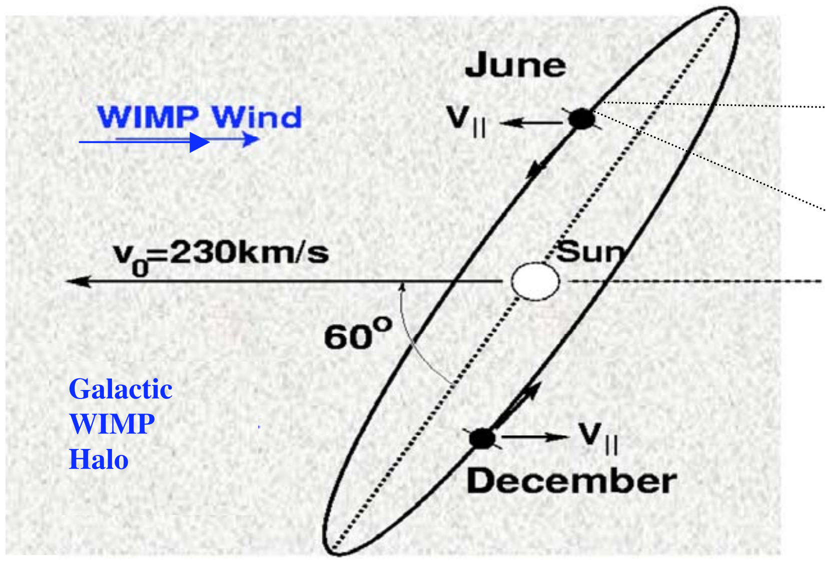
DRIFT exploits the other “textbook signature” for WIMP discovery

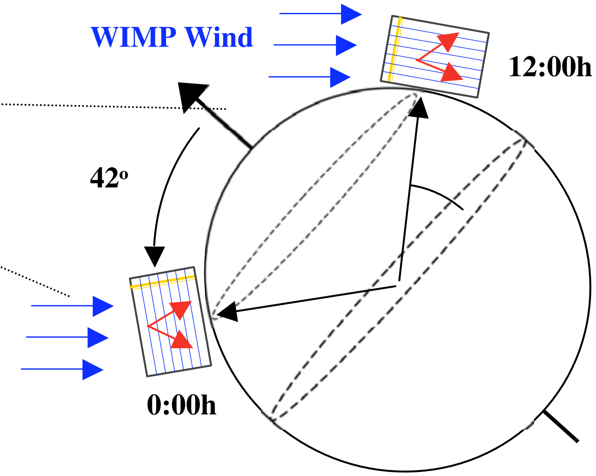
Annual modulation of the rate (e.g., DAMA)

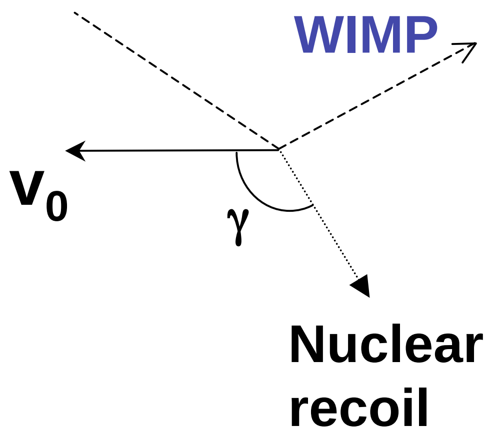


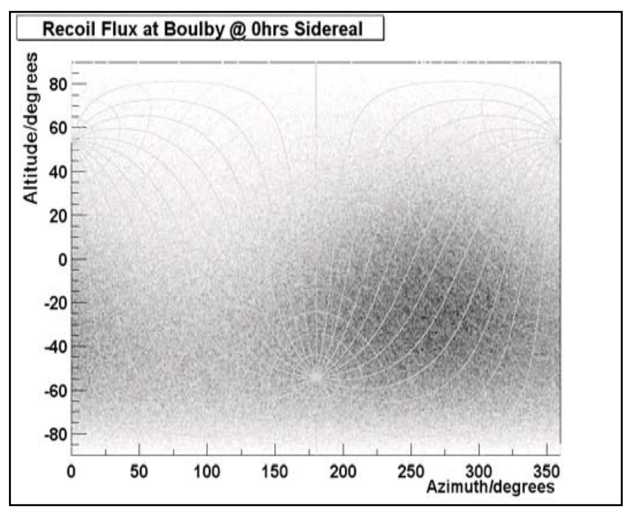
Diurnal modulation of the direction of nuclear recoils (e.g. DRIFT)

The WIMP directionality signature

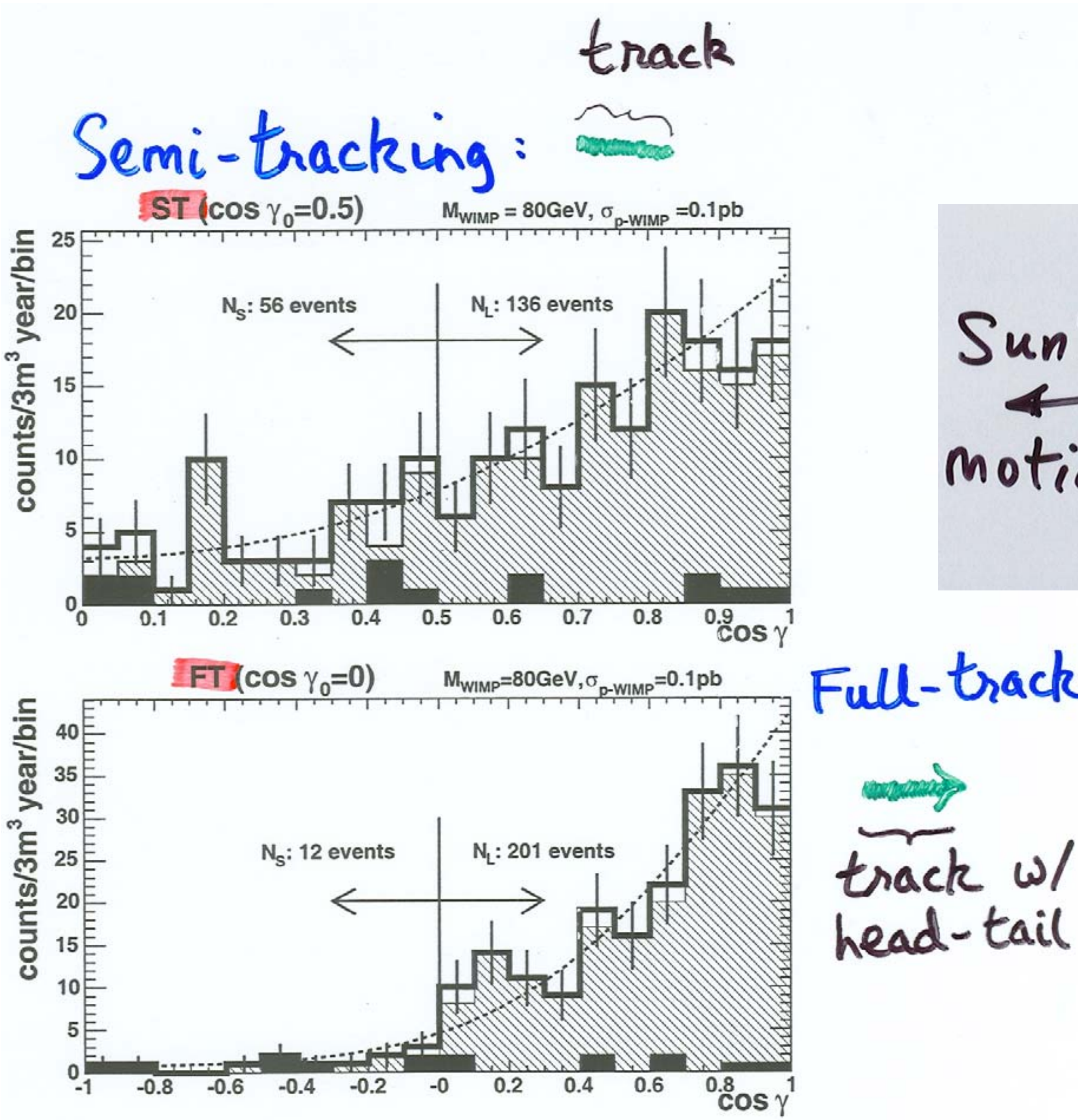


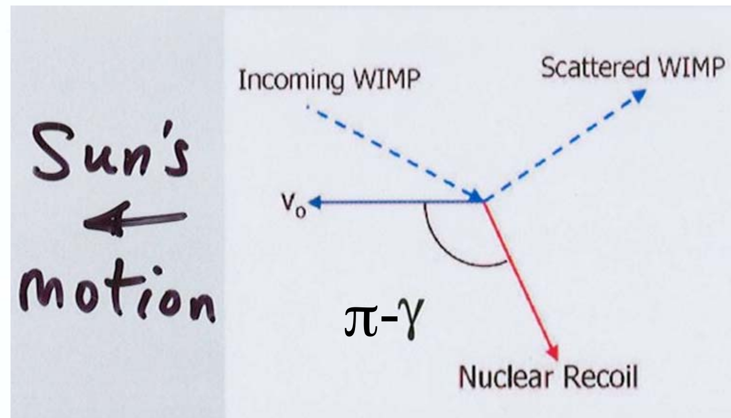






How many events do you need to claim a detection?

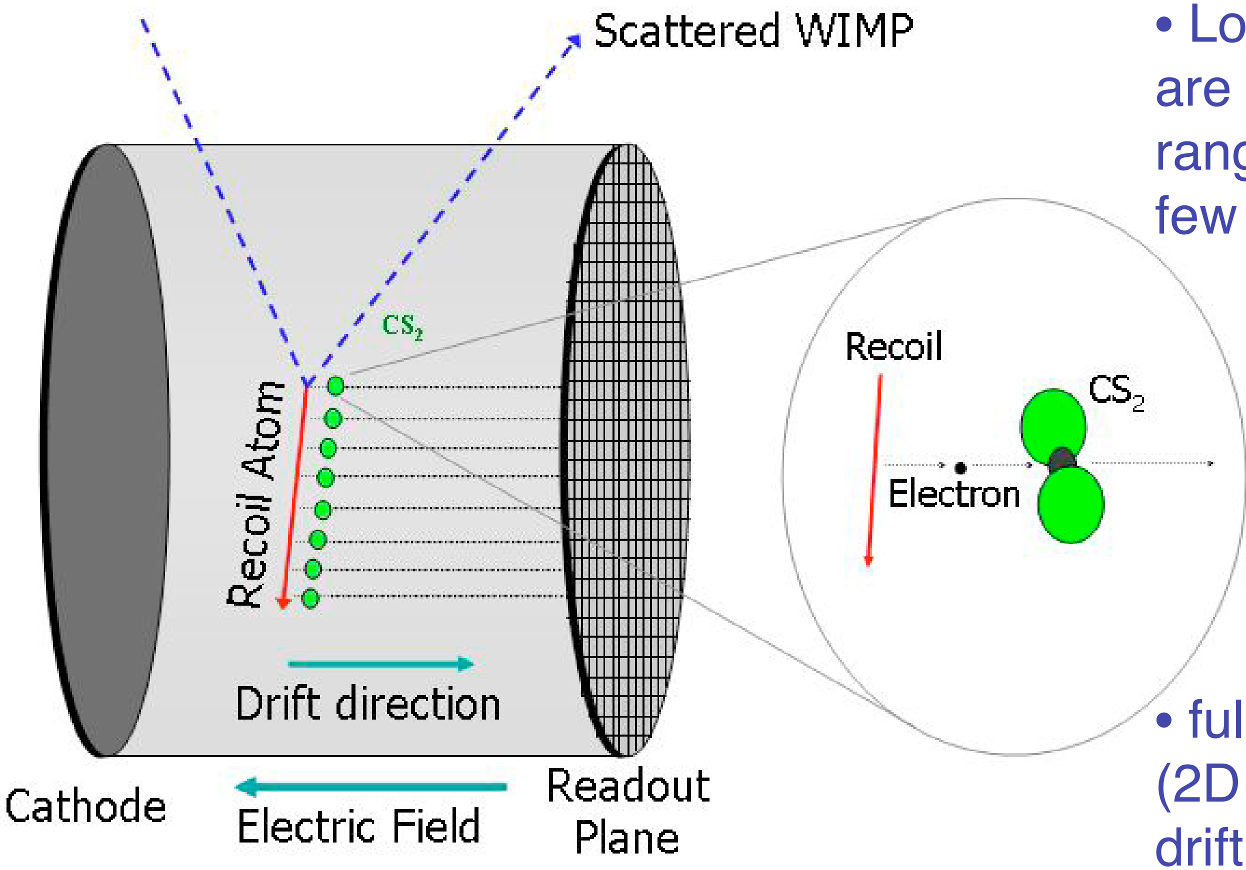




A few 10’s to a few 100’s!

Tanimori, et al Phys.Lett. B578 (2004)

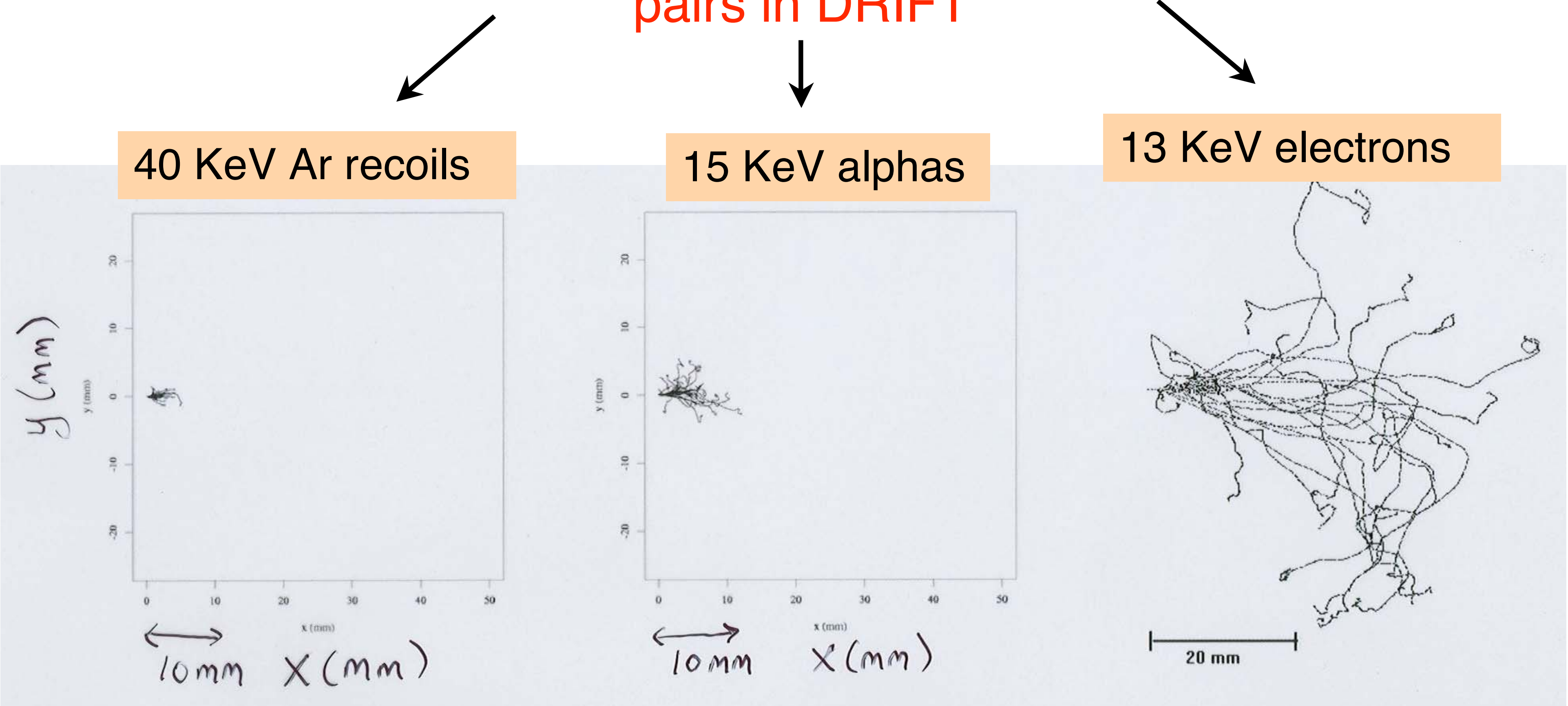
The DRIFT detector - a low pressure TPC



- Low pressures (<100 Torr) are required to extend range of nuclear recoils to a few mm
- full 3D track reconstruction (2D readout + timing along drift direction)
- low diffusion using negative ion drift (idea due to Jeff Martoff of Temple).

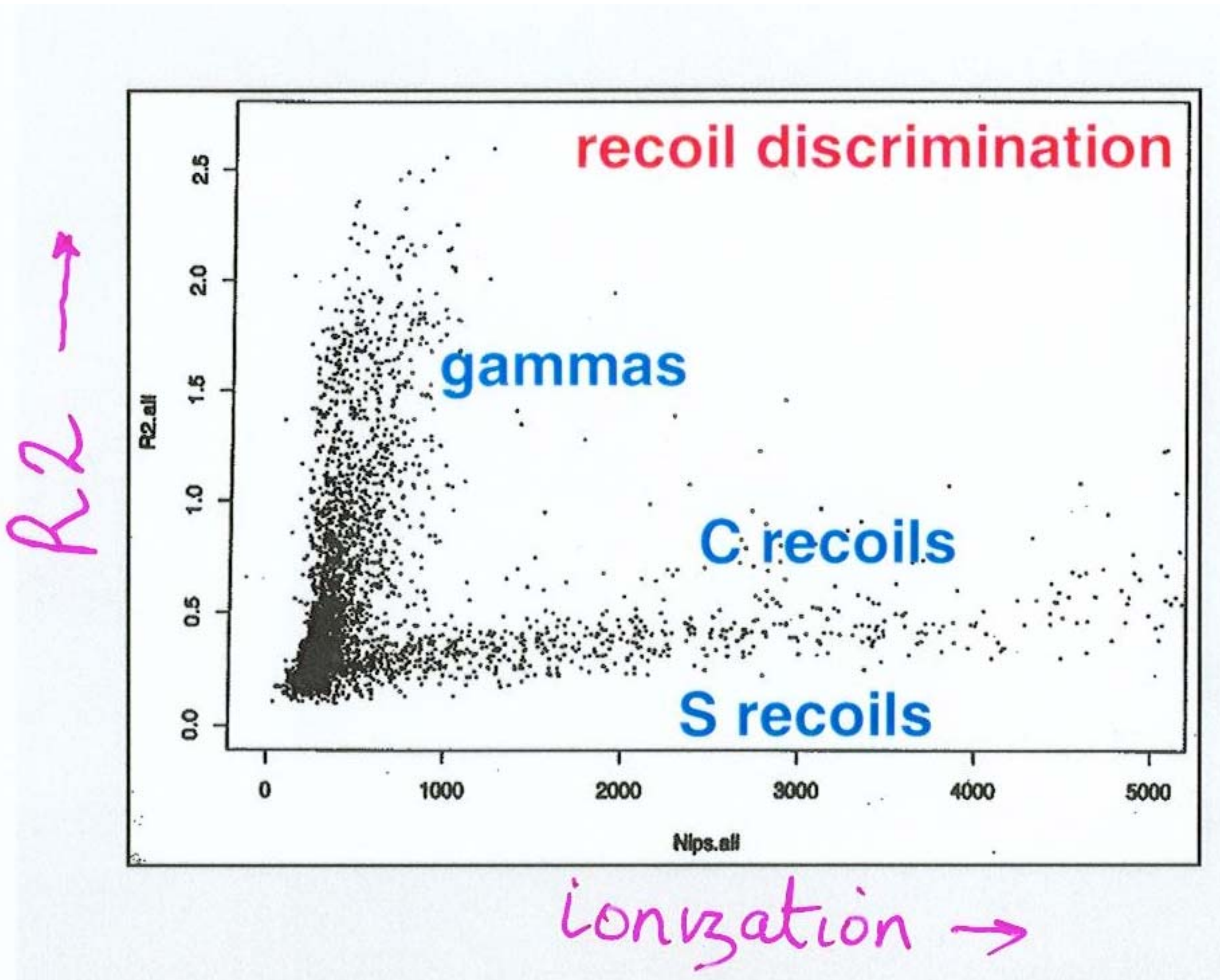
Background rejection also based on tracking: Range vs. Energy

Each produces 500 electron-ion pairs in DRIFT



Simulations from SRIM97

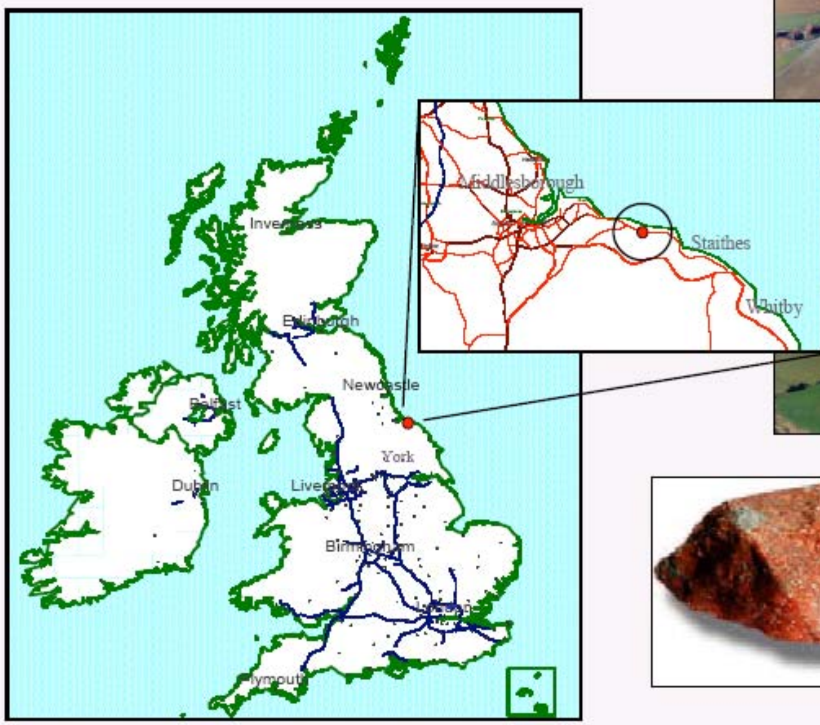
Demonstration with a ft^3 detector at Oxy in 2000



Snowden-Ifft et al IDM2000

DRIFT is located in the Boulby Mine

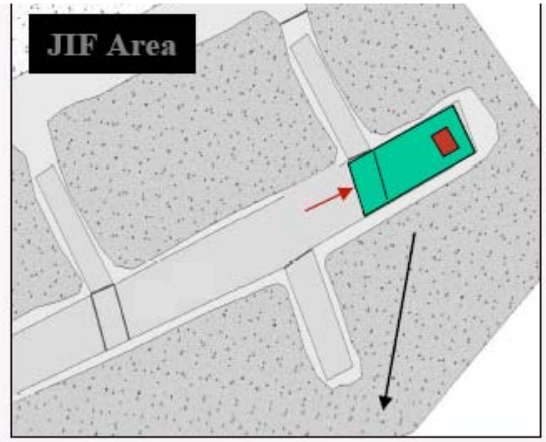
- Working Potash mine
- Deepest mine in Britain
- 850m to 1.3km deep



Sylvanite

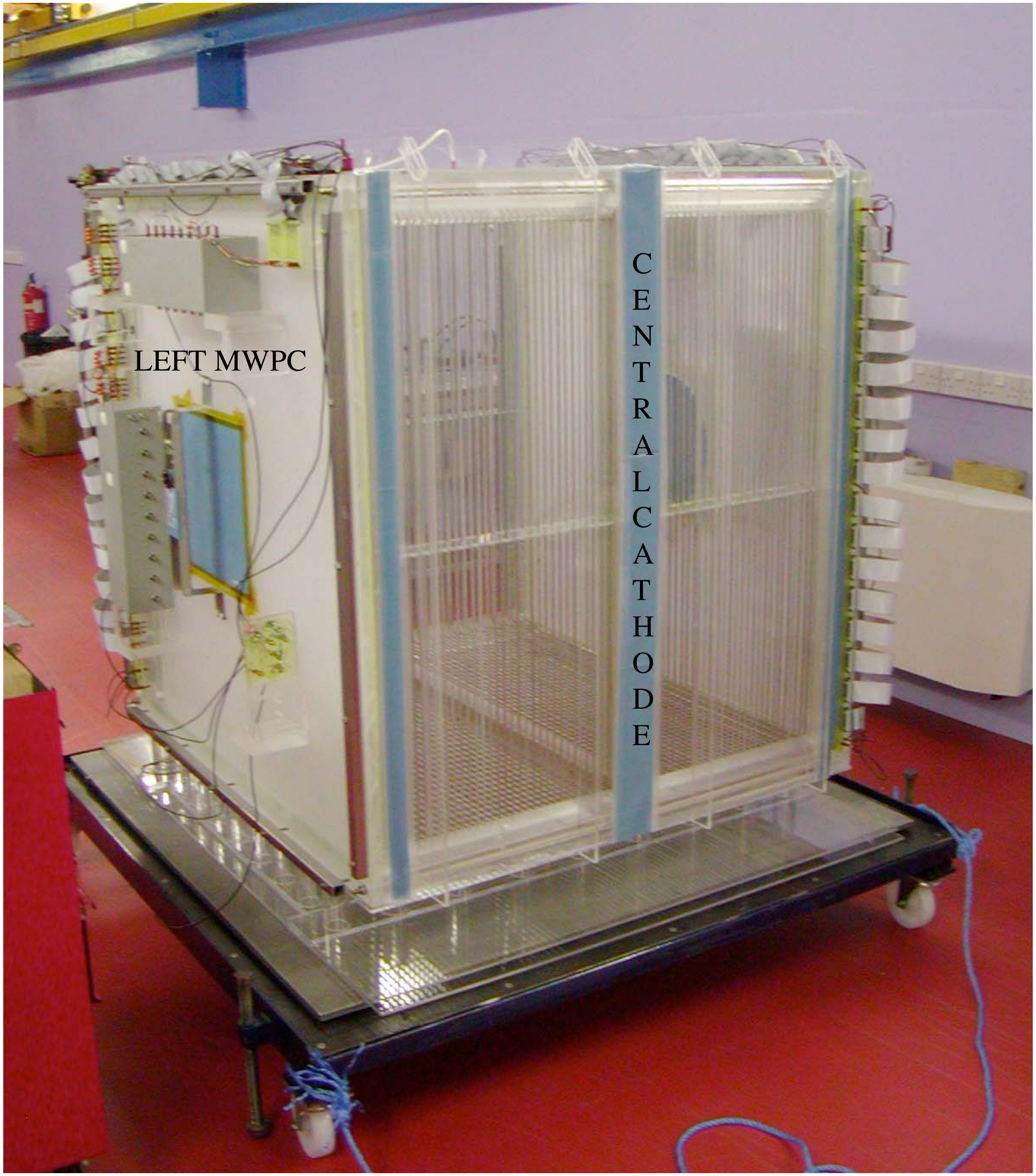
CLEVELAND POTASH

The JIF Laboratory



$1000m^2$ of supported lab space available for next generation Dark Matter experiments…

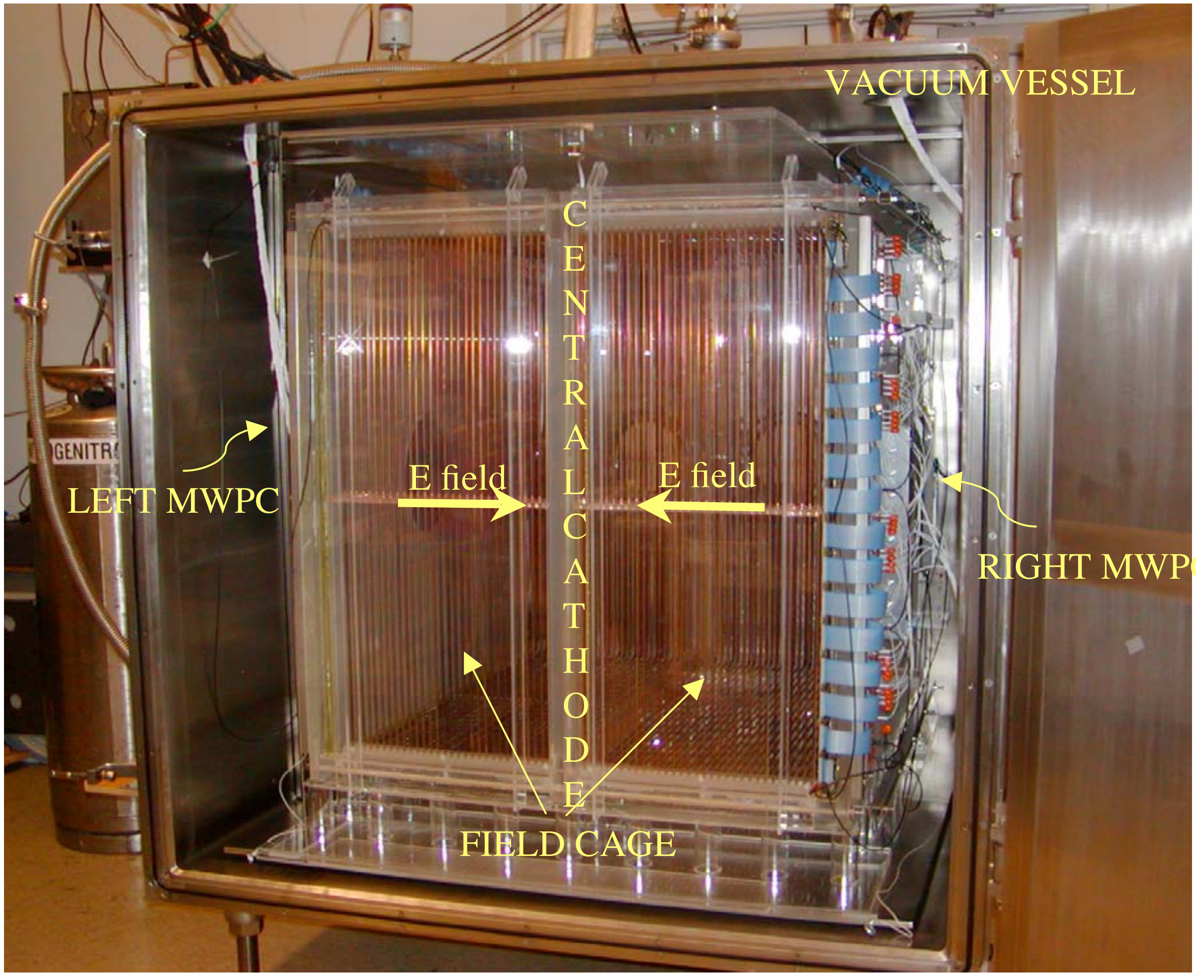
The DRIFT IIb detector in the Boulby Mine



Detector description

The detector volume is divided by the central cathode, each half has its own multi-wire proportional chamber (MWPC) readout.

1 m^3 fiducial volume, 40 Torr CS_2 --> 167 g

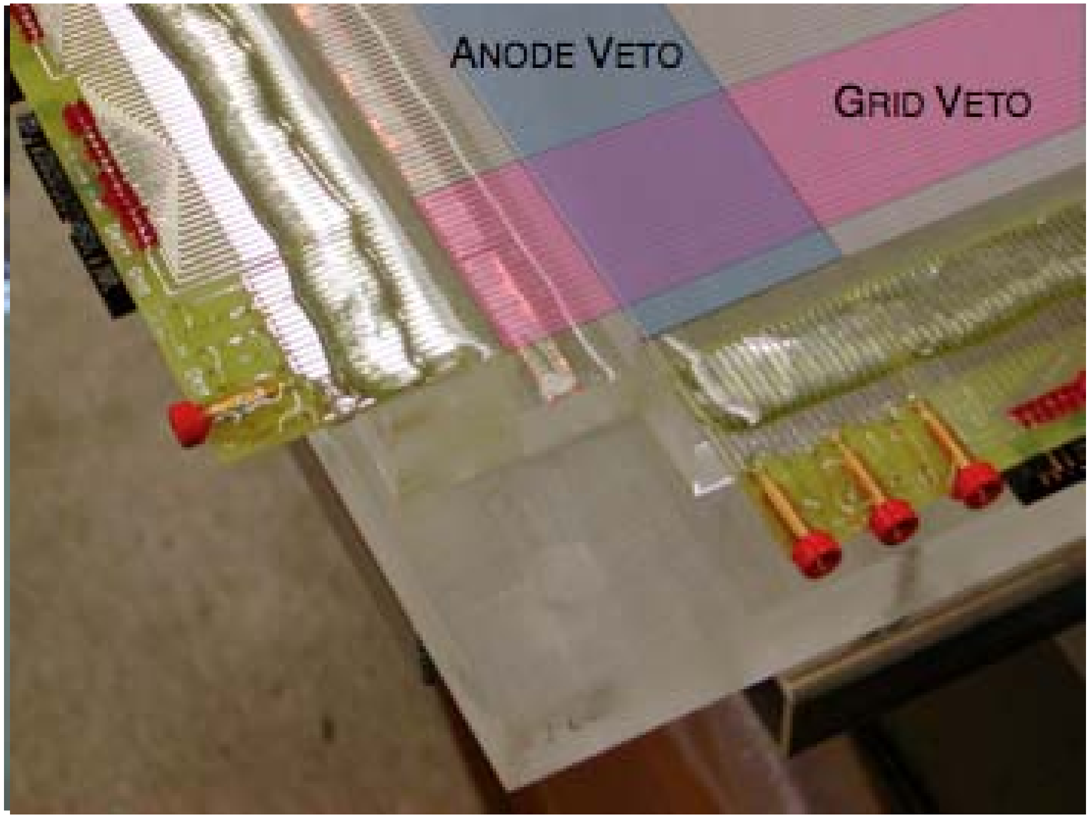


MWPC readouts

• 512 anode wires sandwiched between two grid planes, each with 512 wires. Each plane of wires are at 2mm pitch. --> x, y, Δx, Δy

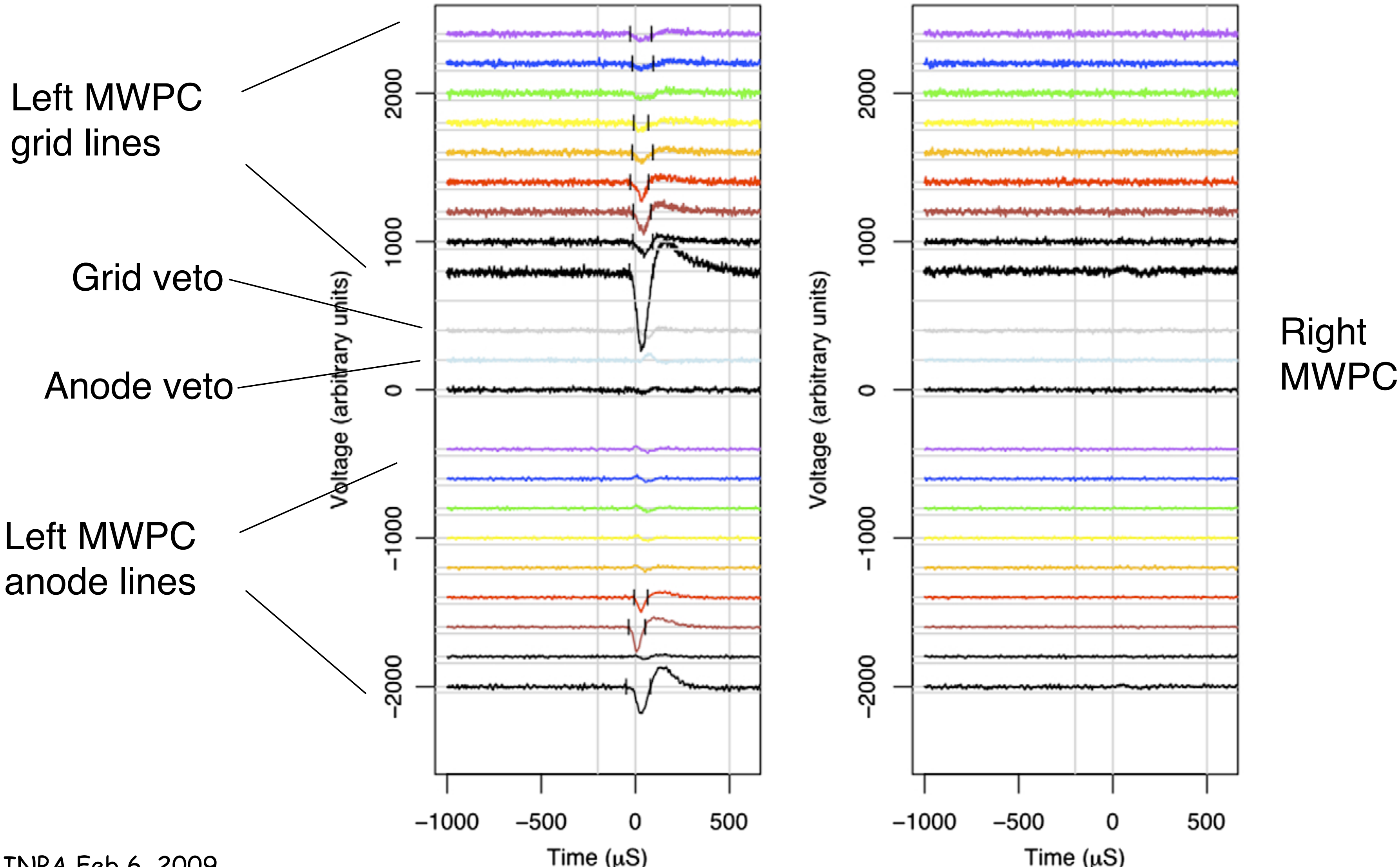
• digitization of signals at 1MHz, or 50 μm. --> Δz

• wires on boundary of anode & grid used for veto --> fiducialization in x, y



Signal waveforms

For each MWPC, anode and grid signals are separately grouped down to 8 lines, which are shaped, amplified and digitized.



Detector summary

- DRIFT has capability to measure full 3D tracks of low-energy nuclear recoils
- Background rejection < 3×10^{-6} against electrons/gammas (from Co-60)
- Each detector module consists of 1 m^3 fiducial volume, 40 Torr CS_2, 167 g of target mass
- Detector is currently fiducialized in x-y plane
- Event energy is measured and calibrated using Fe-55
- 1 detector costs ~$100K, which can be lowered by about half
- Detector is very robust: D-IIa ran for ~1 yr, D-IIb was installed in early 2005 and is still operating

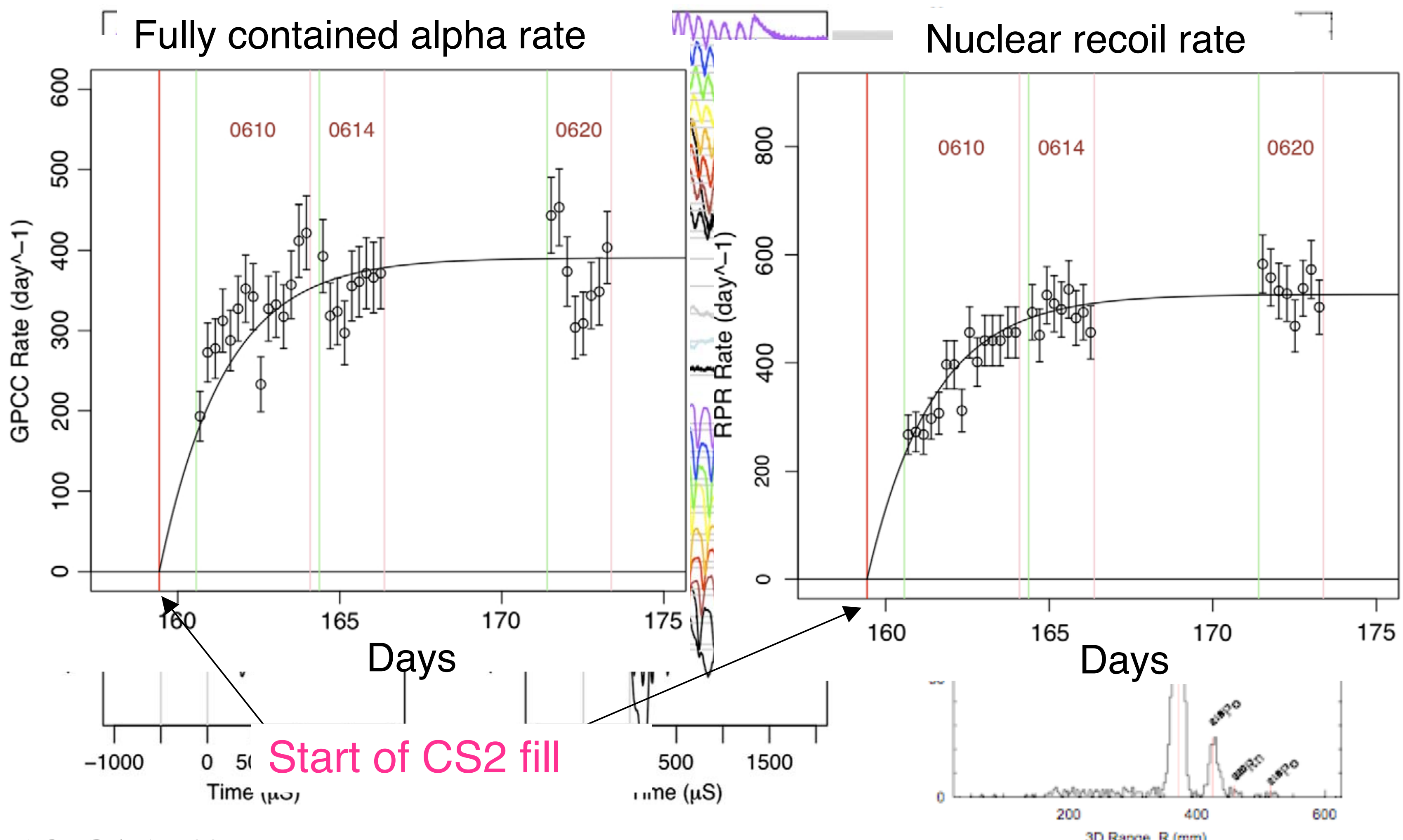
Recent progress

- Radon background
- Directionality signature

Radon background

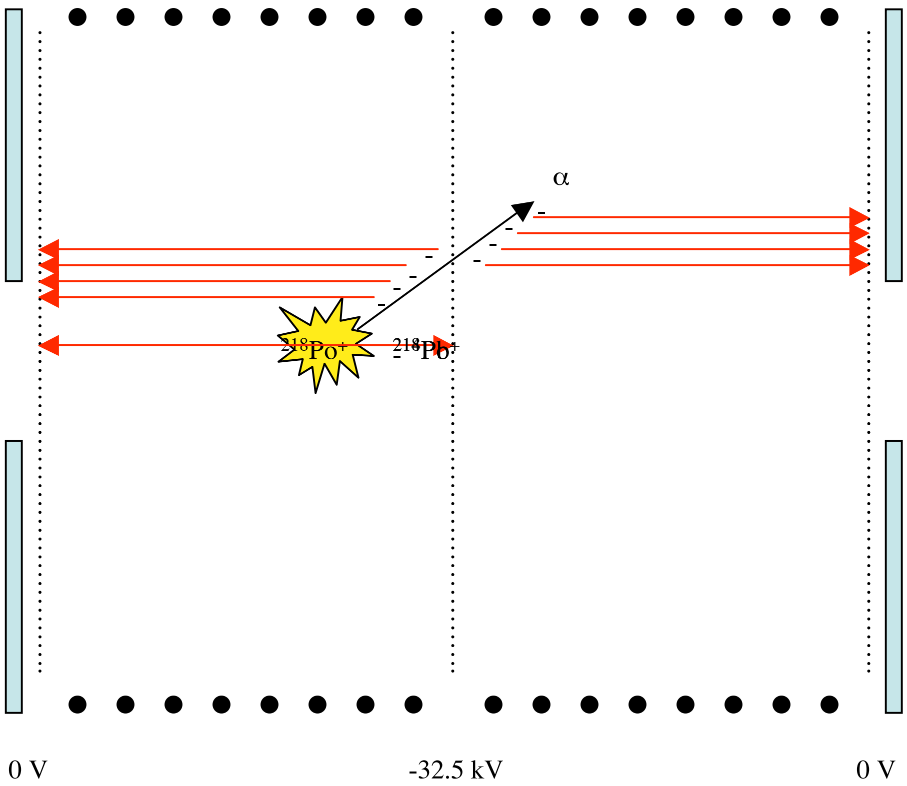
Correlation between fully contained alpha rates and nuclear recoil rates:

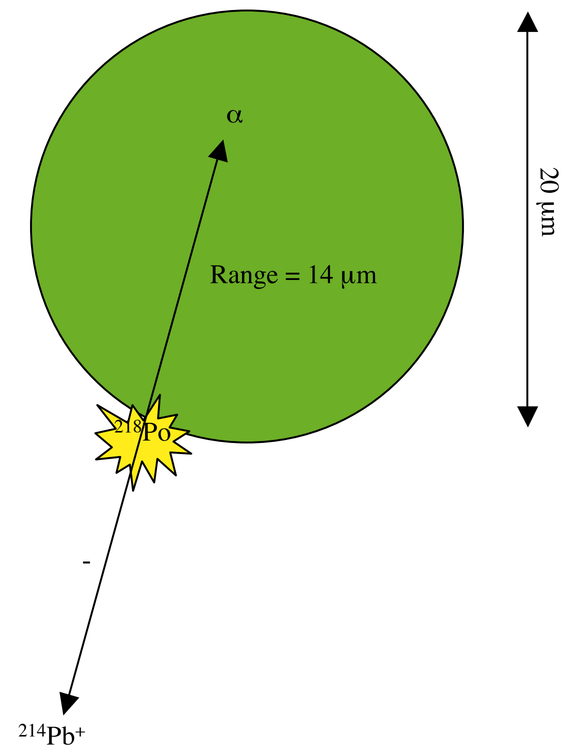
DRIFT-IIa dark matter runs revealed ~675 nuclear recoils/day:



Burgos, et al, NIM A584 (2008)

Radon Progeny Recoil (RPR) hypothesis





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D. Snowden-Ifft (Oxy), DMSAG (2006)

Steps taken to reduce RPRs

1) Reduce radon producing contaminants from vessel:

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

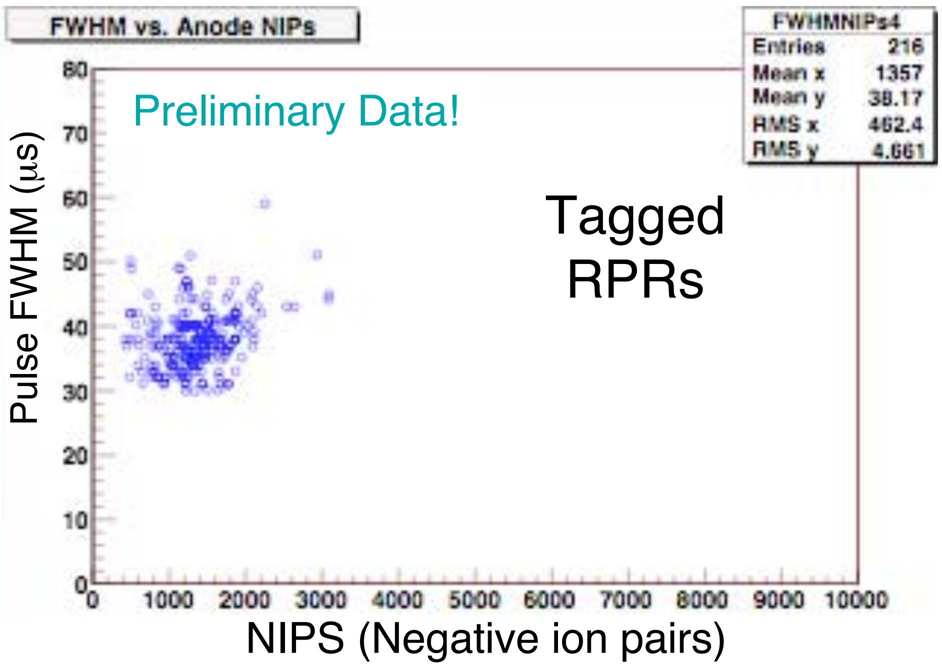
Sean Paling (Sheffield)

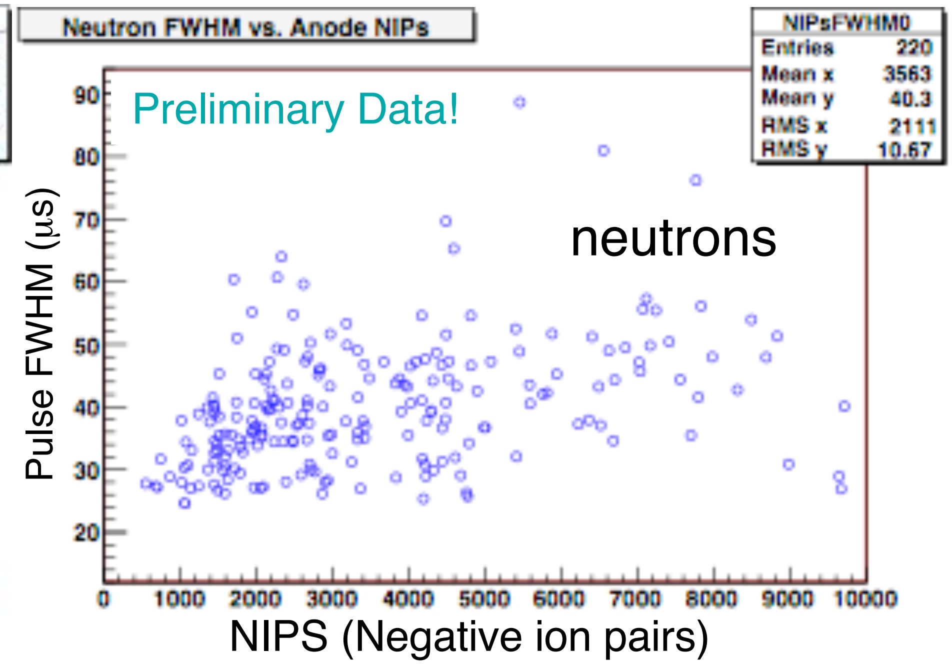
2) RPRs still produced from Pb isotopes plated out on cathode. Clean cathode with nitric acid:

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

J. Turk (UNM), PhD thesis (2008)

3) Residual RPRs may be removed in analysis:





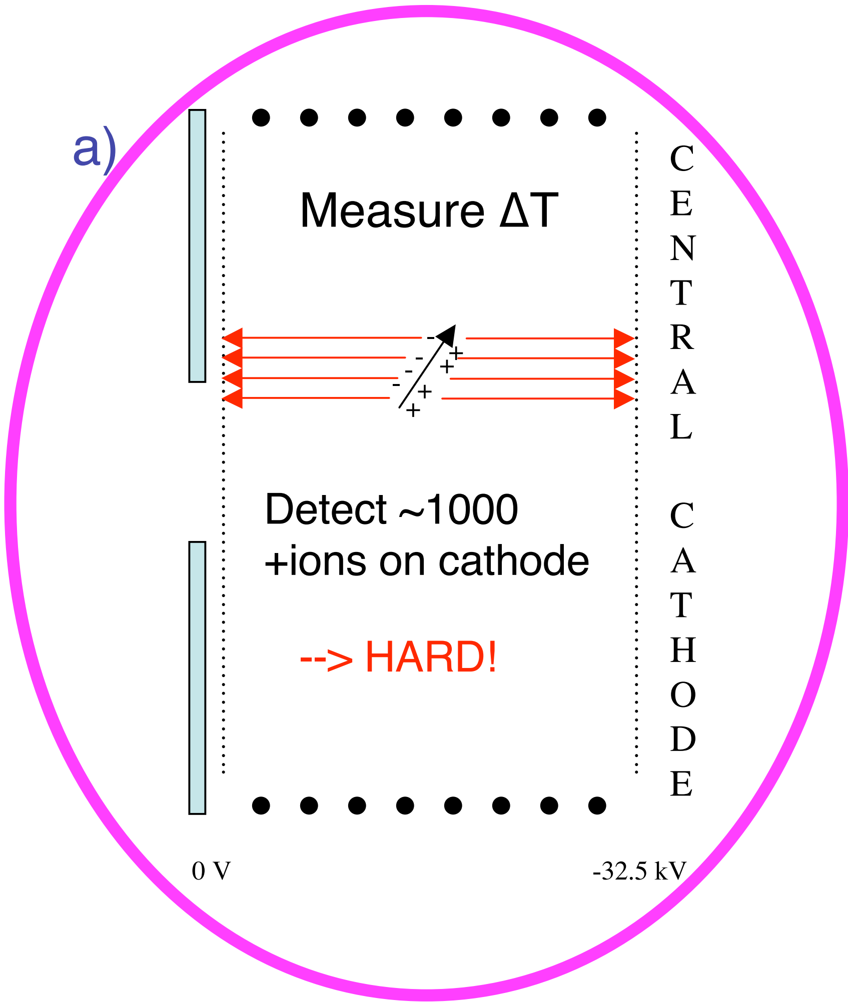
RPRs have large pulse-widths as expected from maximally diffused tracks drifting from cathode.

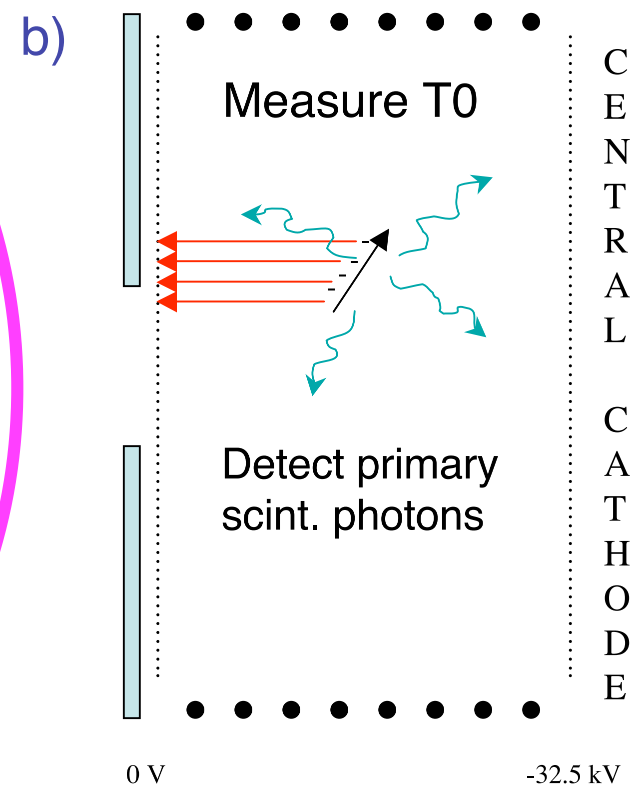
J. Turk (UNM), PhD thesis (2008)

- Steps taken to reduce RPRs have resulted in a current rate of <0.2/day
- In order to identify and veto the remaining RPRs we must fully fiducialize the DRIFT detector

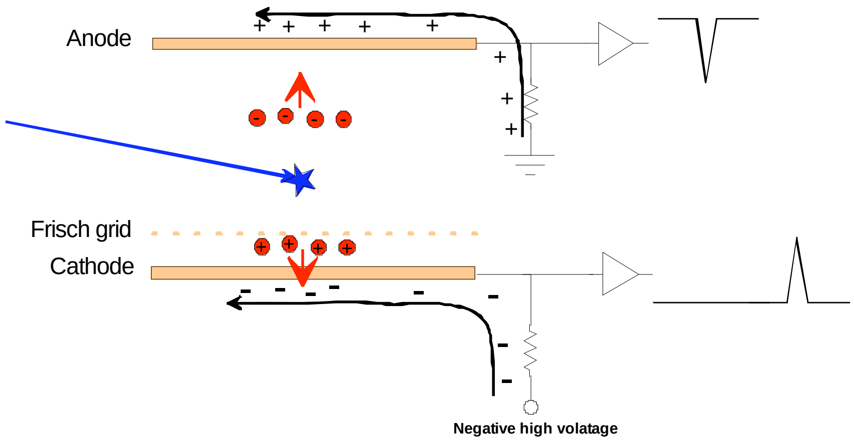
R&D to eliminate RPRs

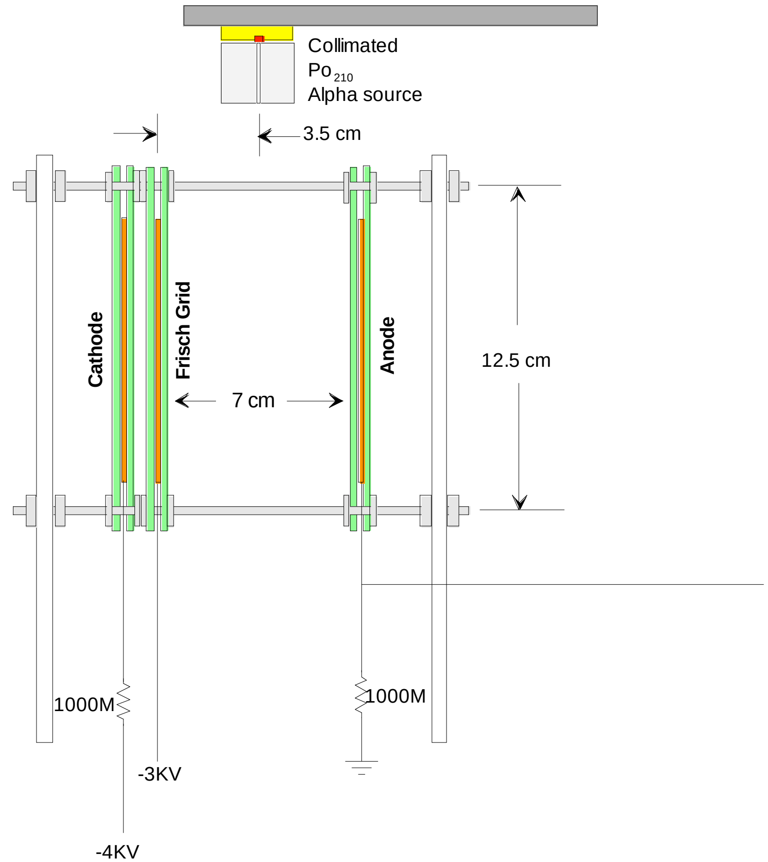
Ideas for z-fiducialization:





R&D Setup





Ion drift speed in 40 Torr CS_2 (cm/sec) = 9.8 x Drift field in volts/cm

DRIFT (-34 KV 620 volt/cm) Ion speed = 6100 cm/sec

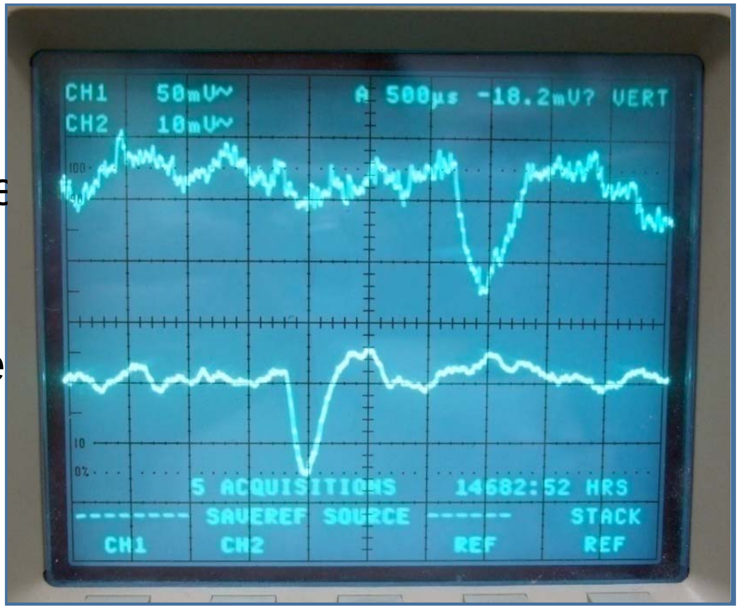
Our tests (-3 KV 429 volt/cm) Ion speed = 4200 cm/sec

Required frequency response is in the lower tens of KHz – audio band

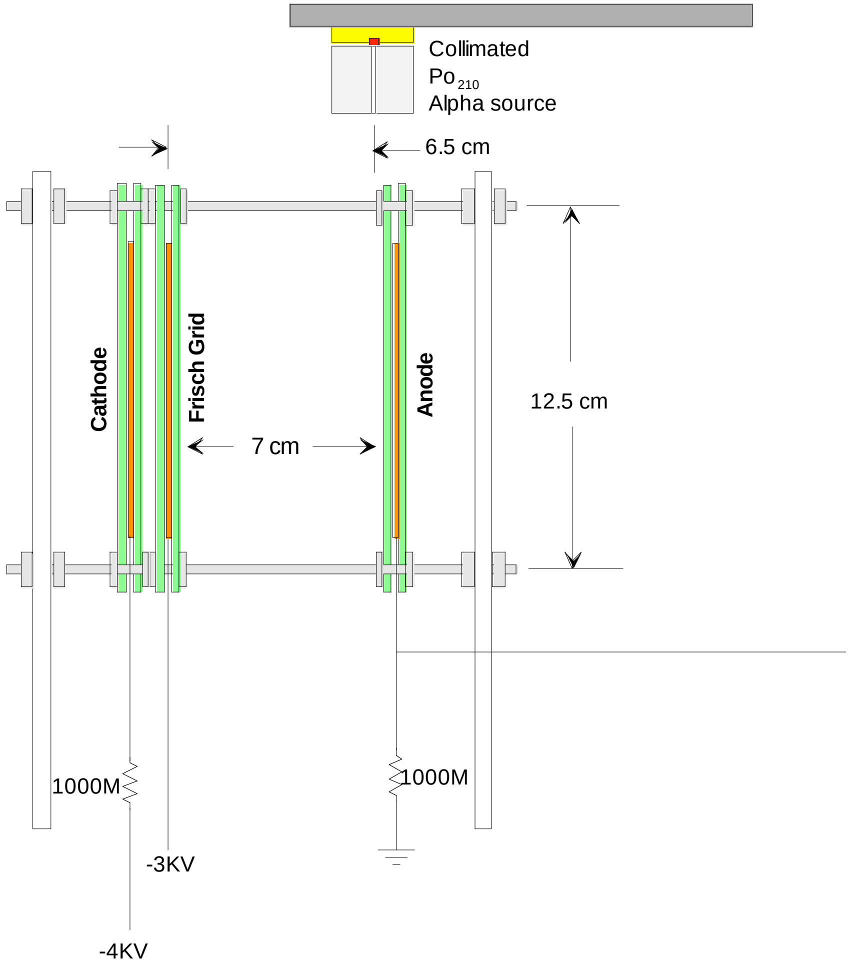
CS_2 – 40 Torr

Cathode

Anode



Expected delay = 1.5 milliseconds

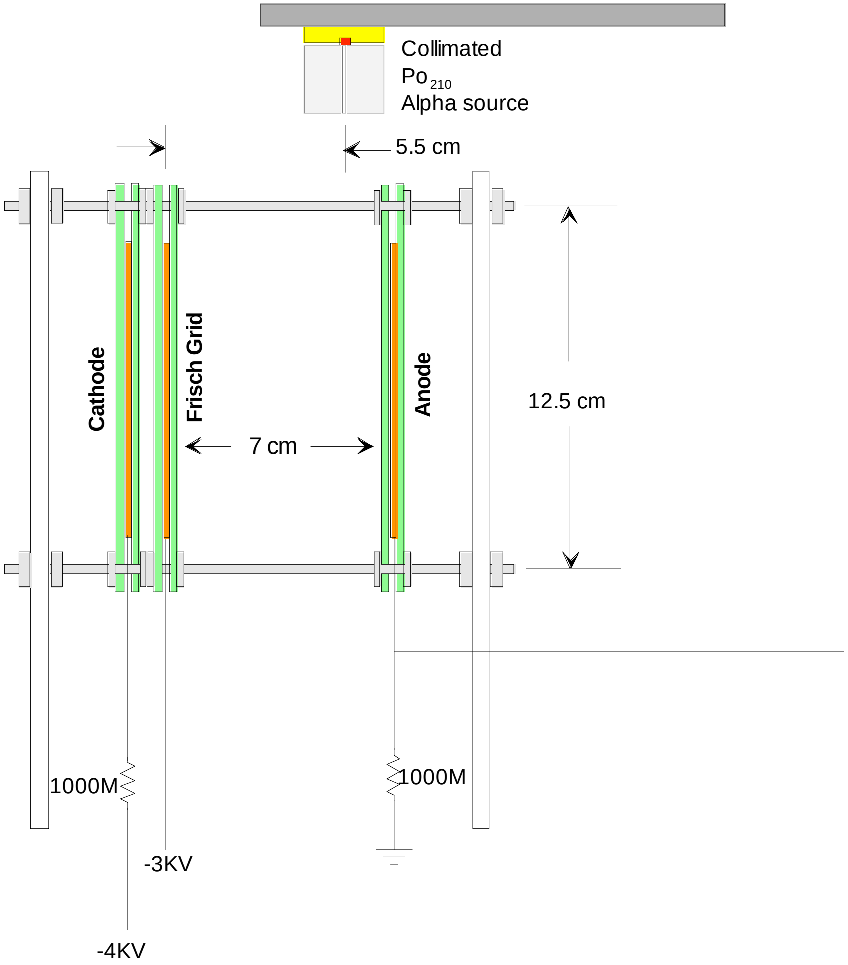


CS_2 – 40 Torr

Cathode

Anode

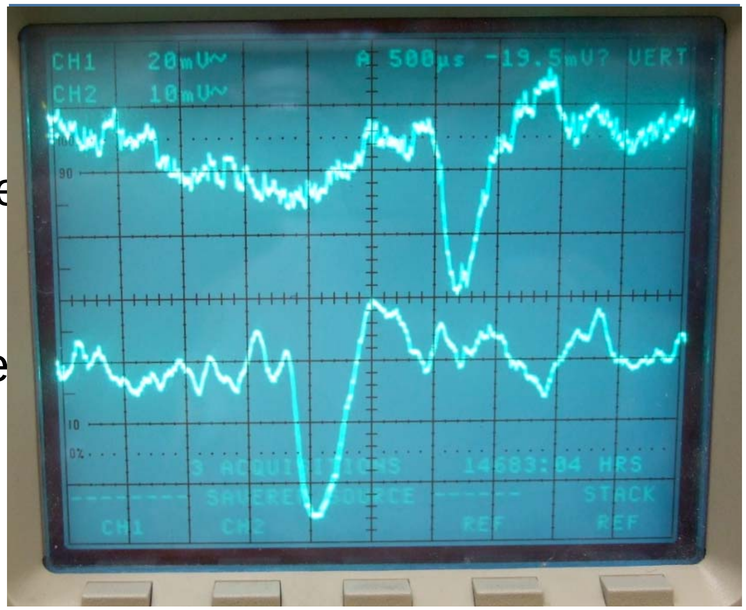
Expected delay = 1.3 milliseconds



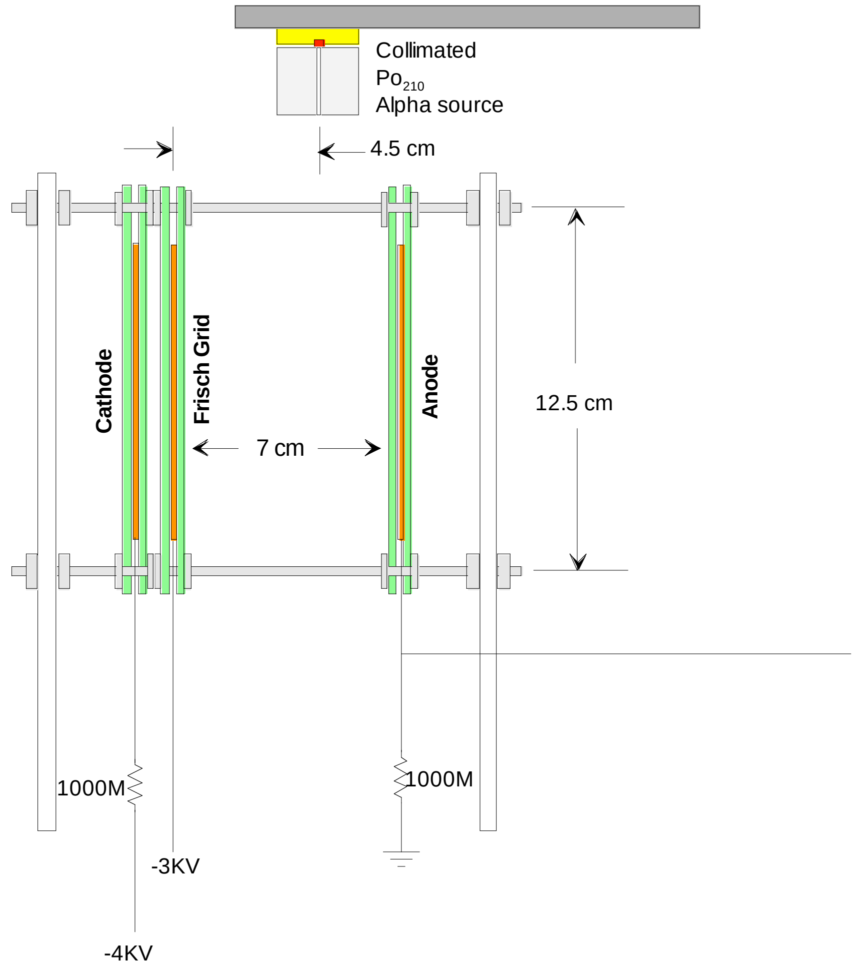
CS_2 – 40 Torr

Cathode

Anode



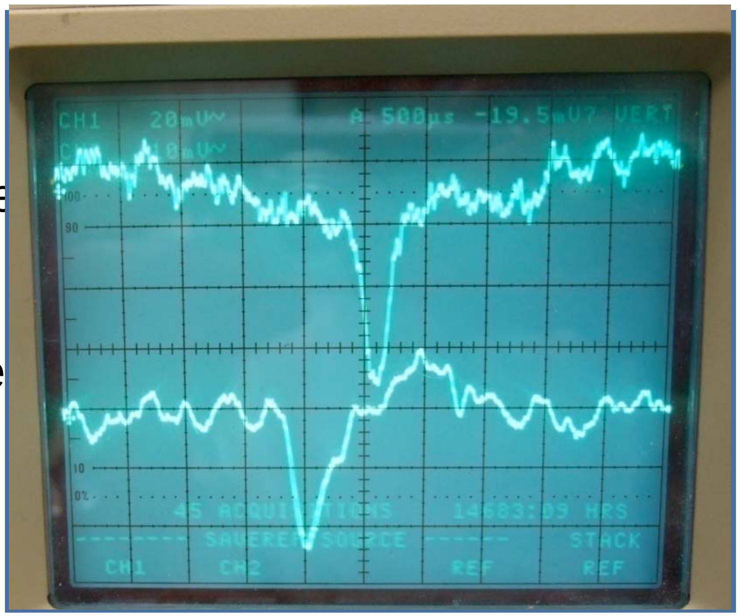
Expected delay = 1.1 milliseconds

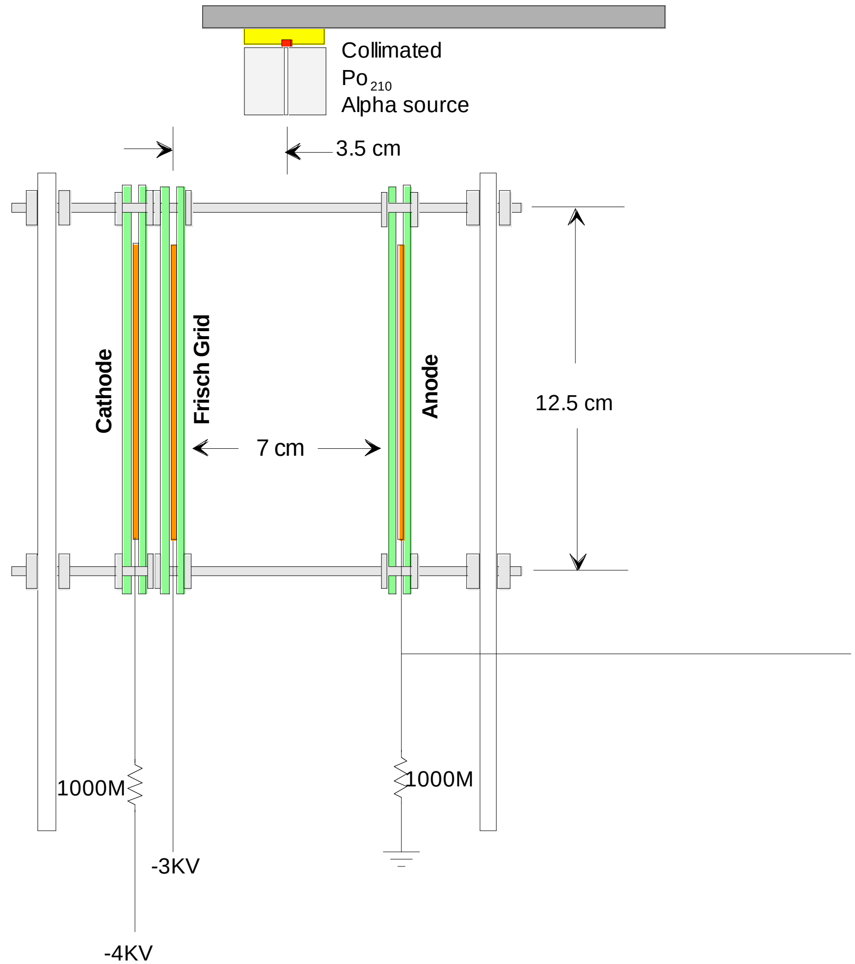


CS_2 – 40 Torr

Cathode

Anode



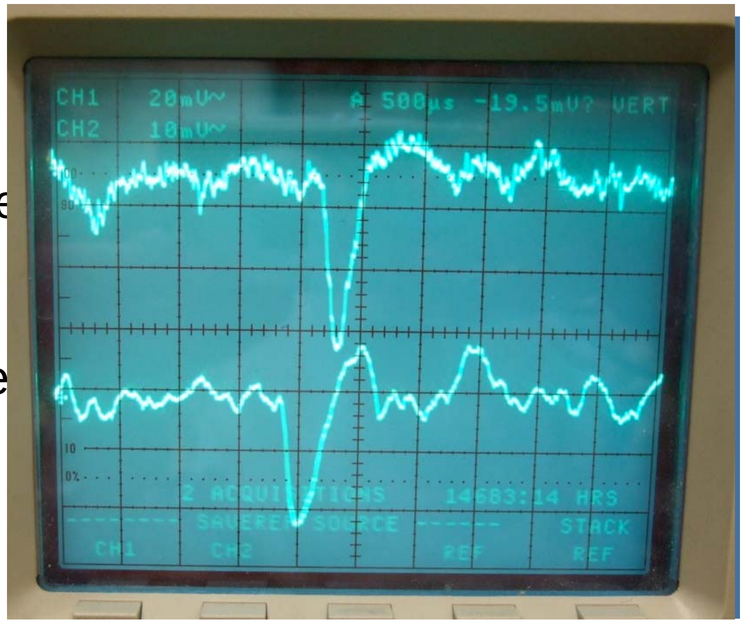


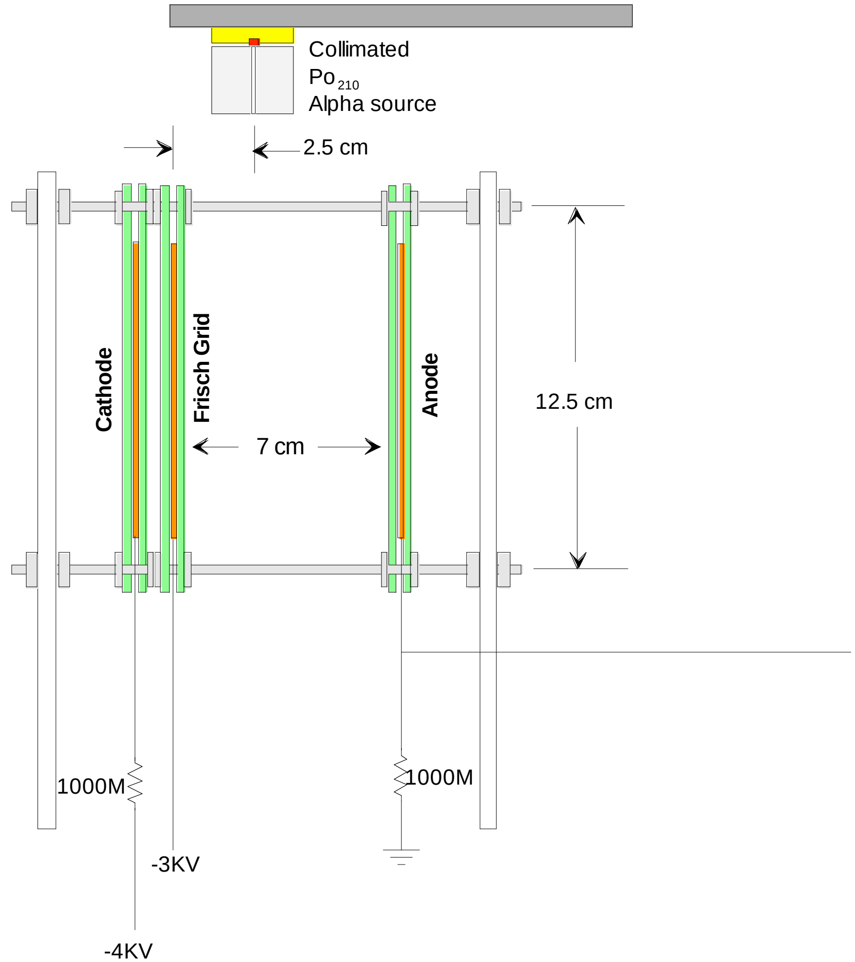
Expected delay = 0.8 milliseconds

CS_2 – 40 Torr

Cathode

Anode



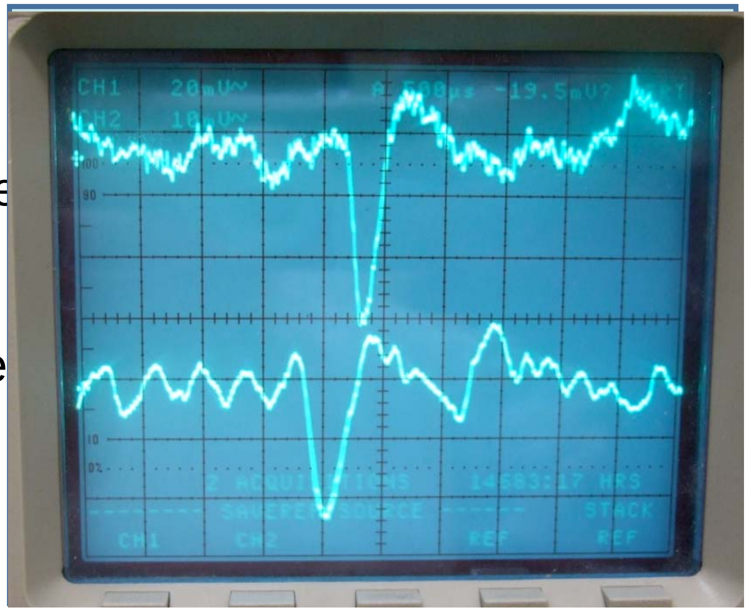


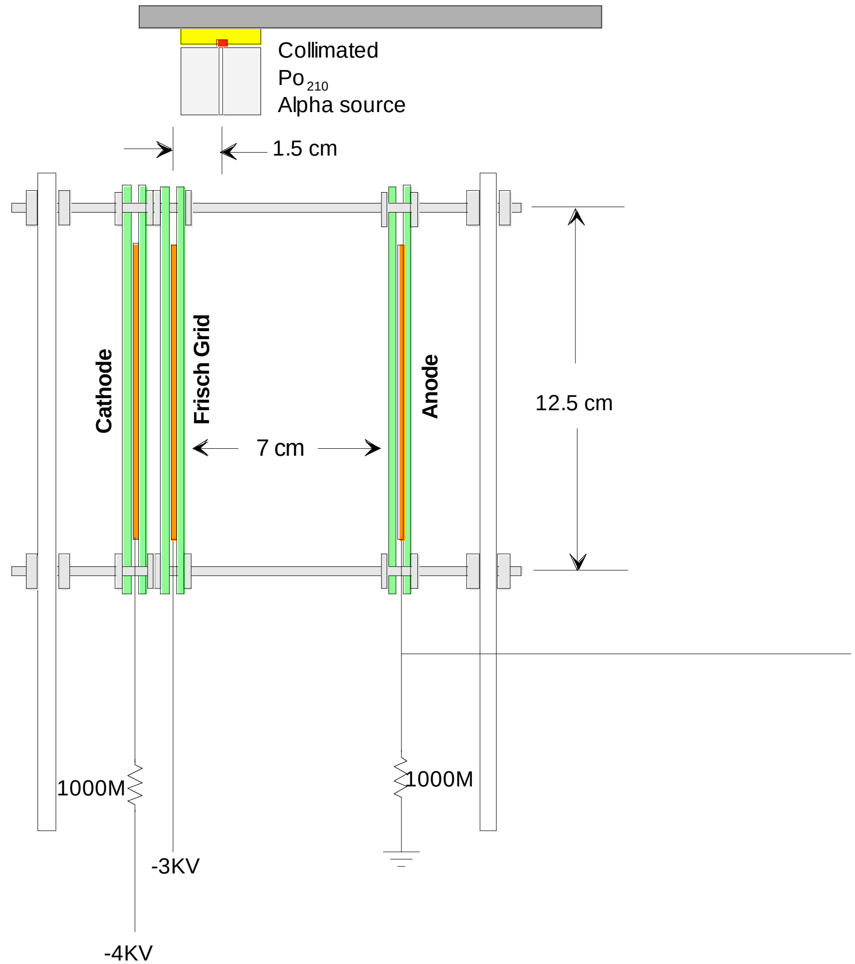
Expected delay = 0.6 milliseconds

CS_2 – 40 Torr

Cathode

Anode



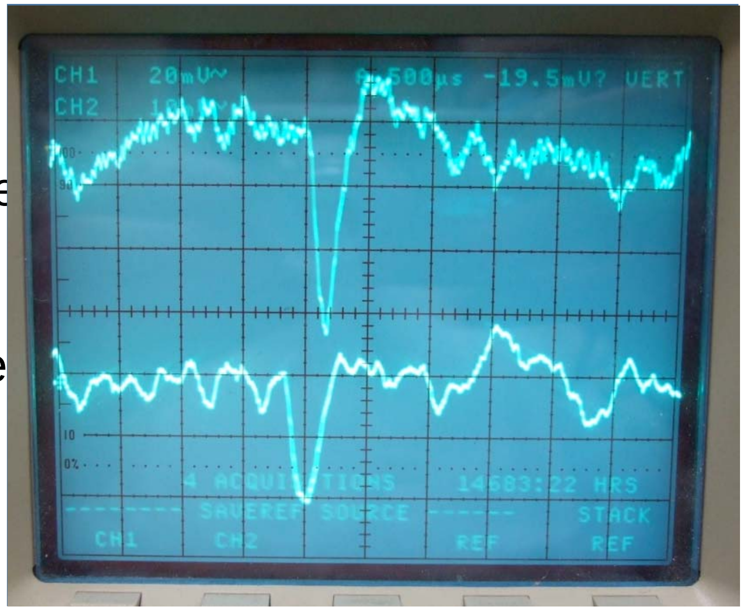


Expected delay = 0.4 milliseconds

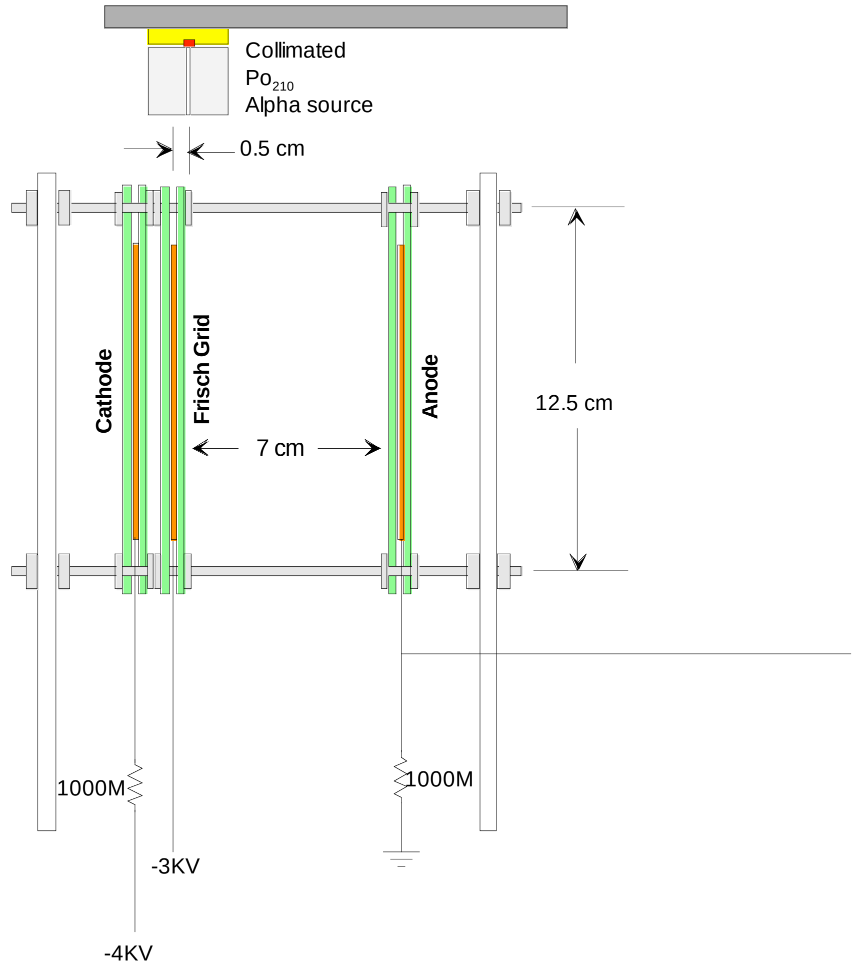
CS_2 – 40 Torr

Cathode

Anode



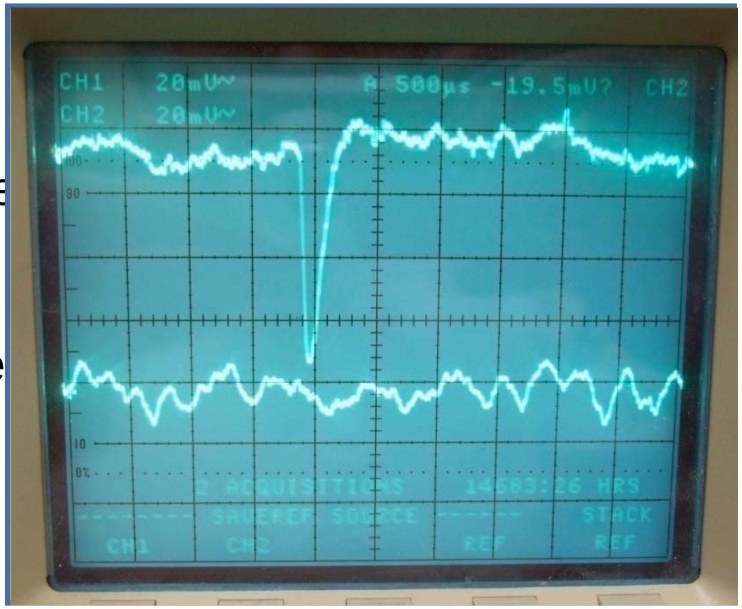
Expected delay = 0.1 milliseconds



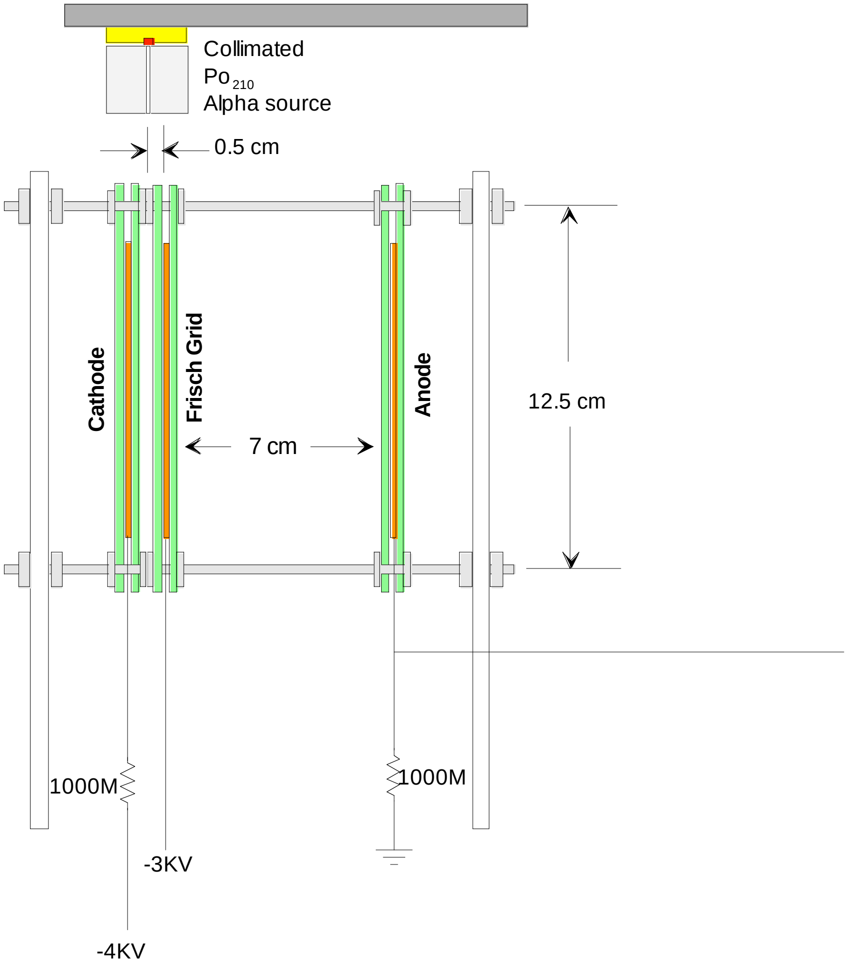
CS_2 – 40 Torr

Cathode

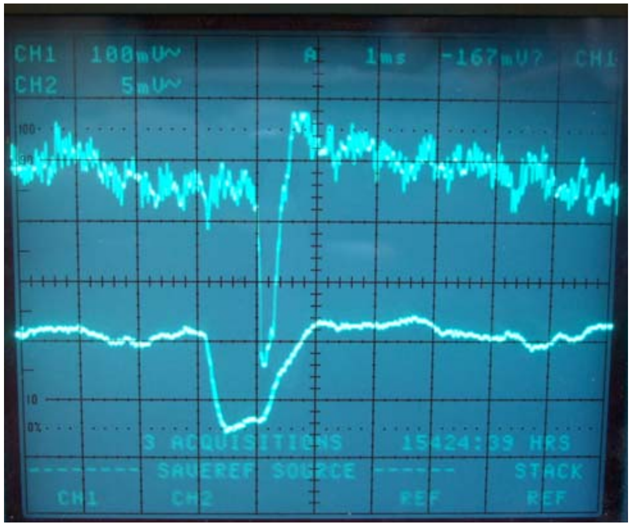
Anode



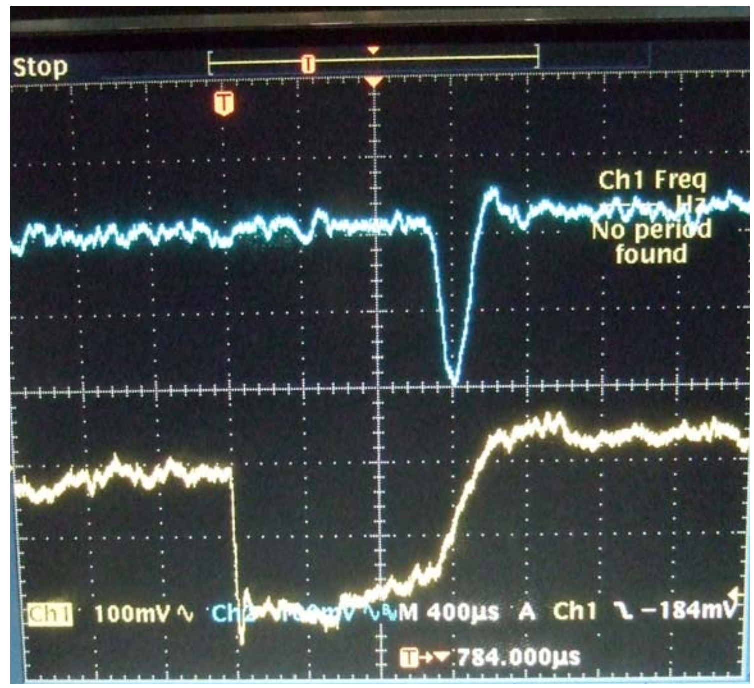
Expected delay = 0.0 milliseconds

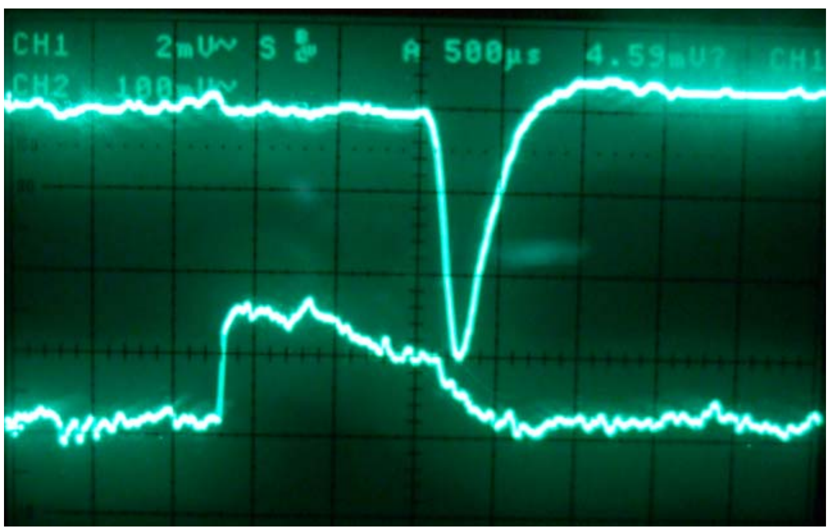


Progress on reducing noise



Top trace is cathode signal, bottom trace is anode signal





Next steps

• Currently we can detect ~4000-5000 +ions off HV cathode with high probability

• But, goal is to detect ~1000 +ions!

Possible solutions:

• Reduce noise (primarily microphonics)

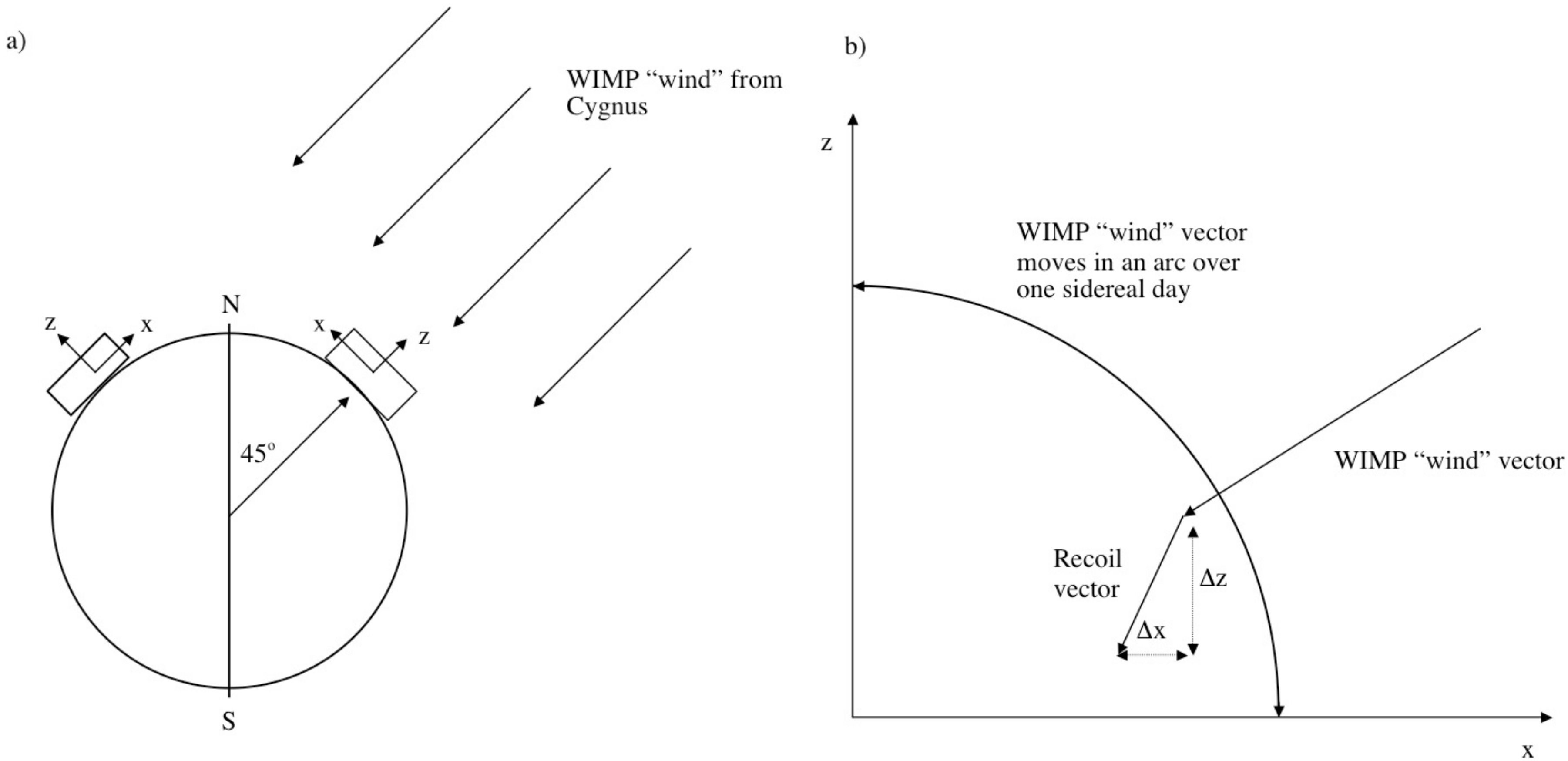
• Segment the cathode to reduce capacitance

• Algorithms (e.g., autocorrelation and matched filter) used for extracting known signals arriving in narrow windows of time. In principle, this has been demonstrated for signal-to-noise≤1

Recent progress

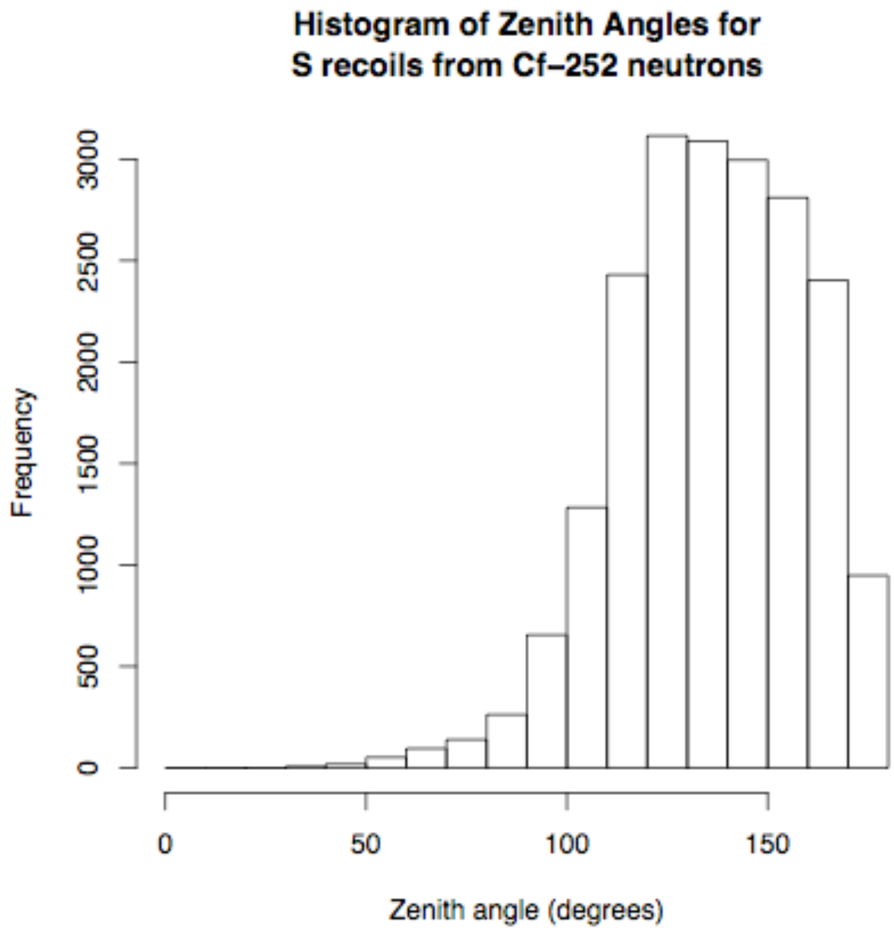
- Radon background
- Directionality signature

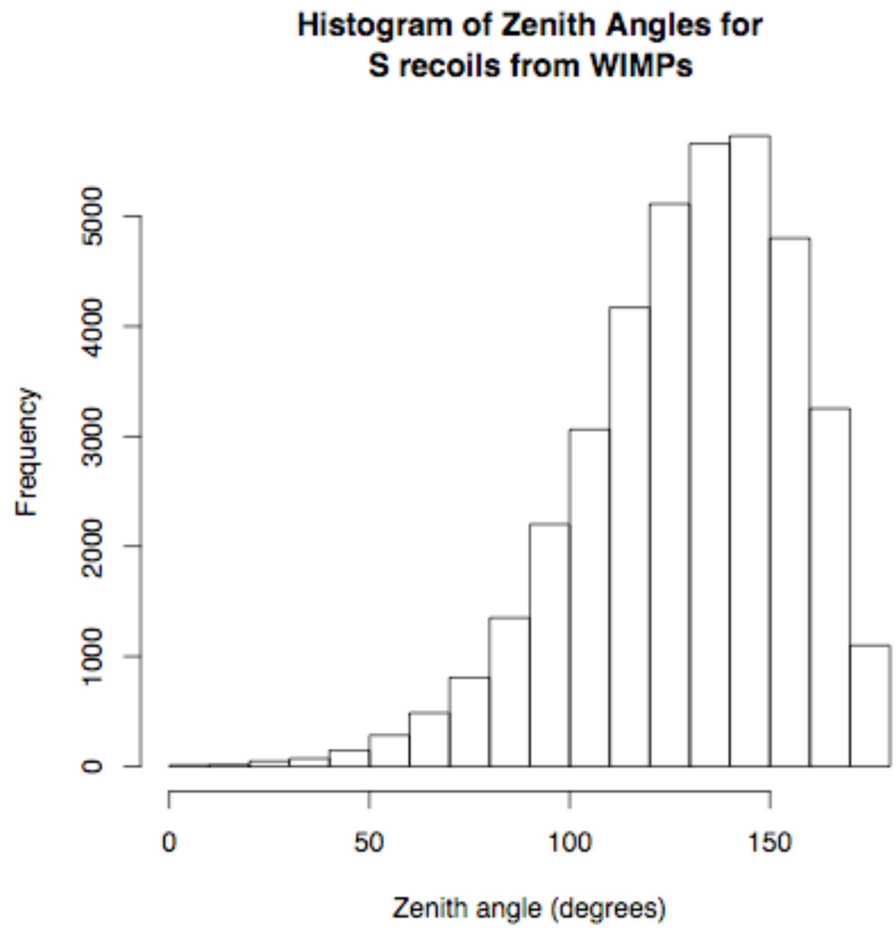
Directionality signature



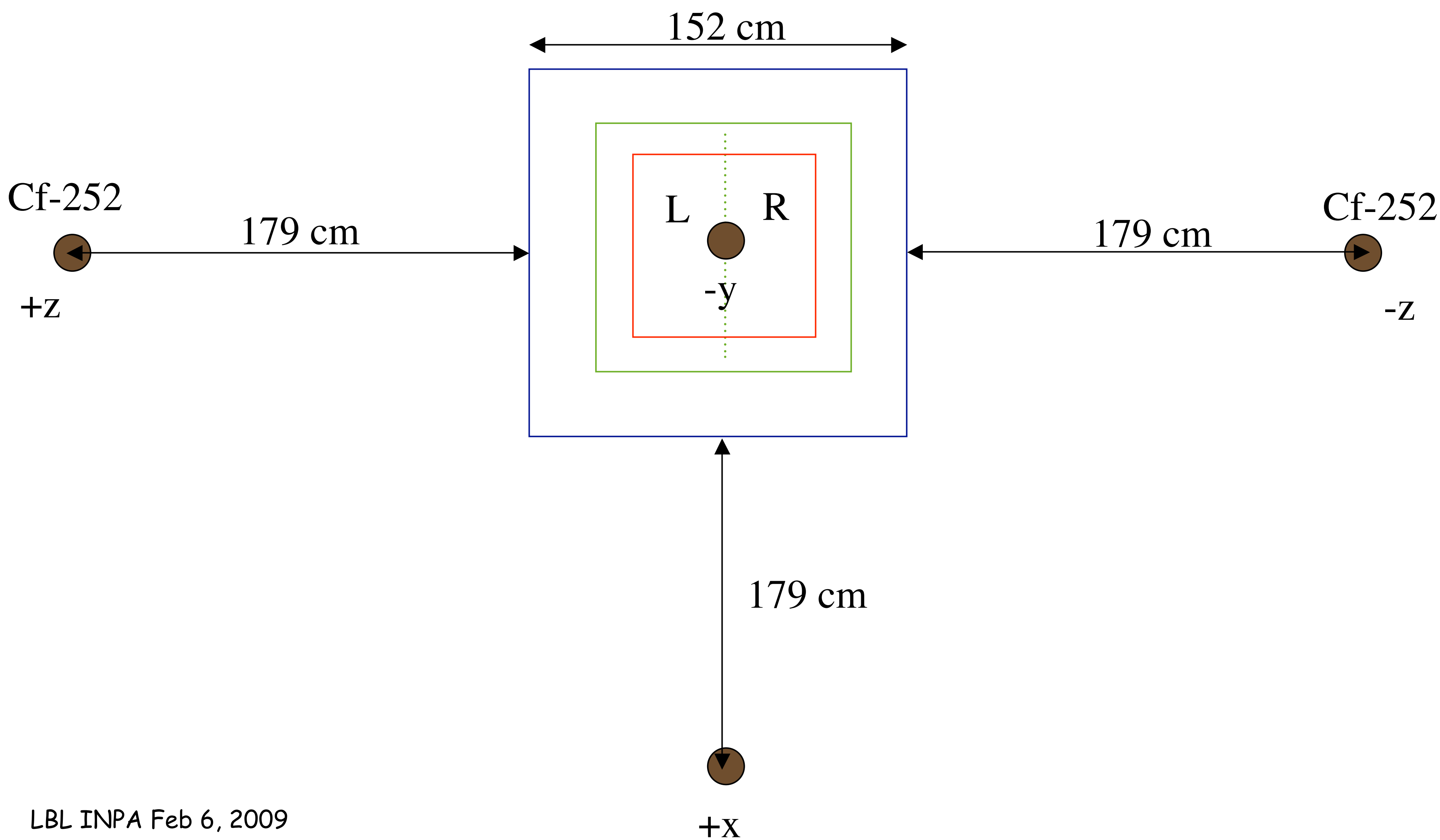
--> expect diurnal oscillation in $\Delta z/\Delta x$

Recoils from Cf-252 neutrons are a good approximation of those expected from WIMPs

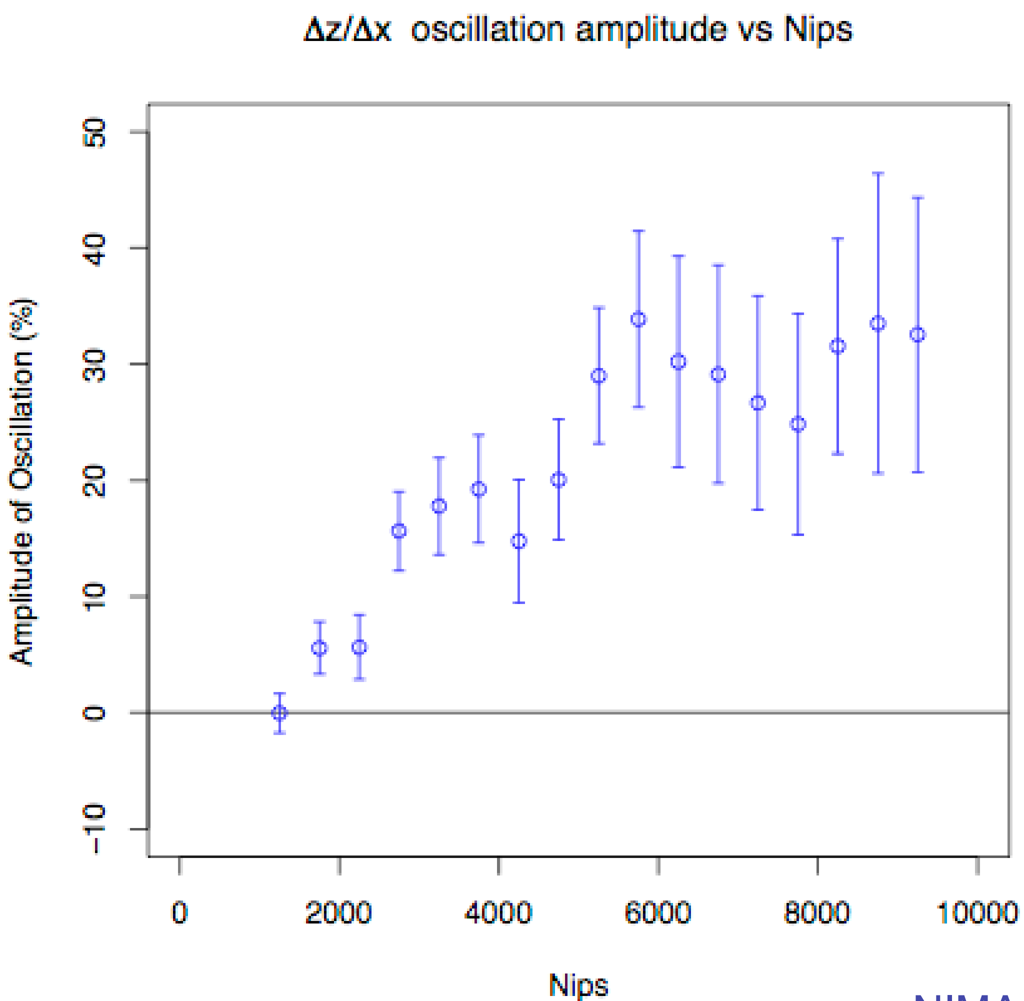




Geometry of Cf-252 neutron exposures



Results

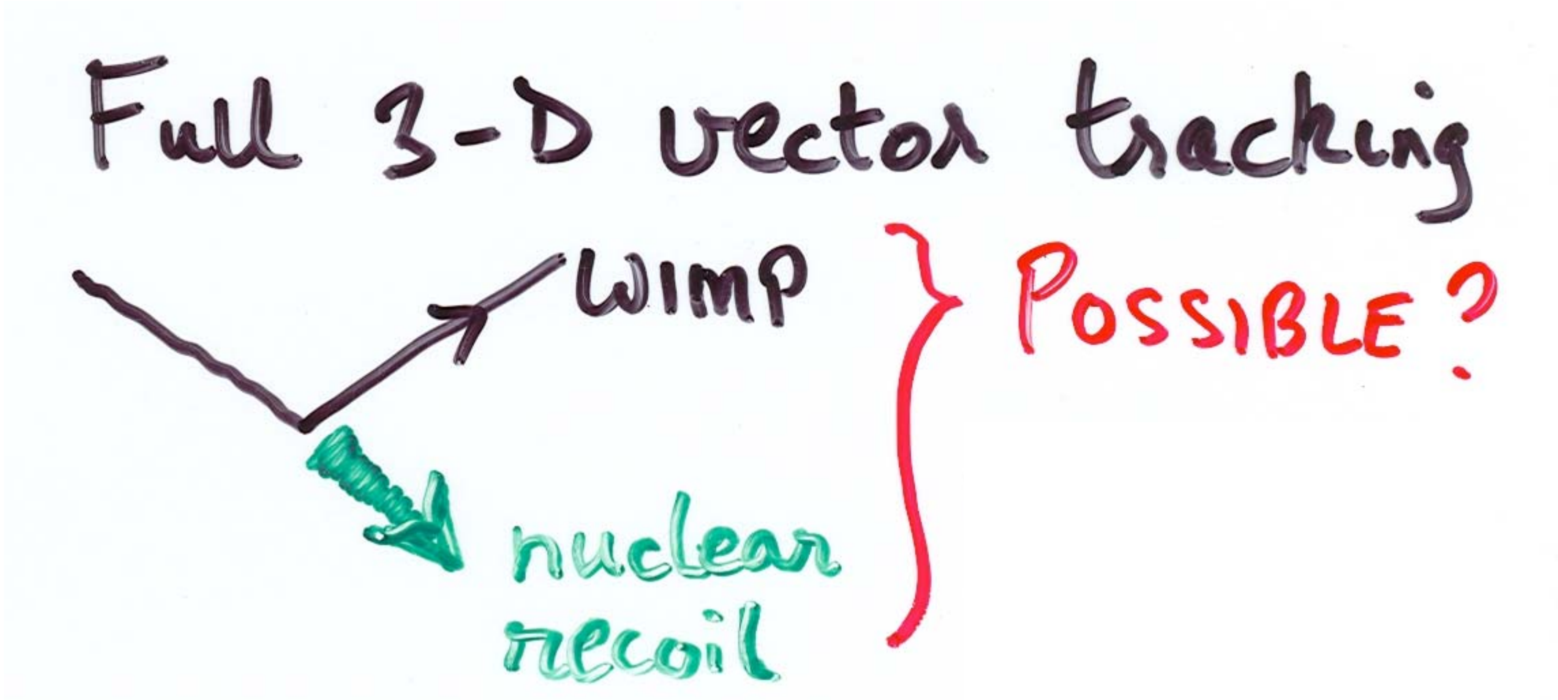


NIMA (in press)
arXiv:0807.3969

Summary on directionality:

- DRIFT detectors can sense recoil directions along all 3 axes, although the x and z directions are preferred.
- When properly oriented a DRIFT detector would see $\Delta z/\Delta x$ oscillate from a maximum when Cygnus is overhead to a minimum when Cygnus is to the North.
- Scaling the significance, we estimate ~160 events would be required for a 90% C.L. detection of WIMPs.

Head-Tail



Requires an asymmetry in the ionization dE/dx, e.g.:

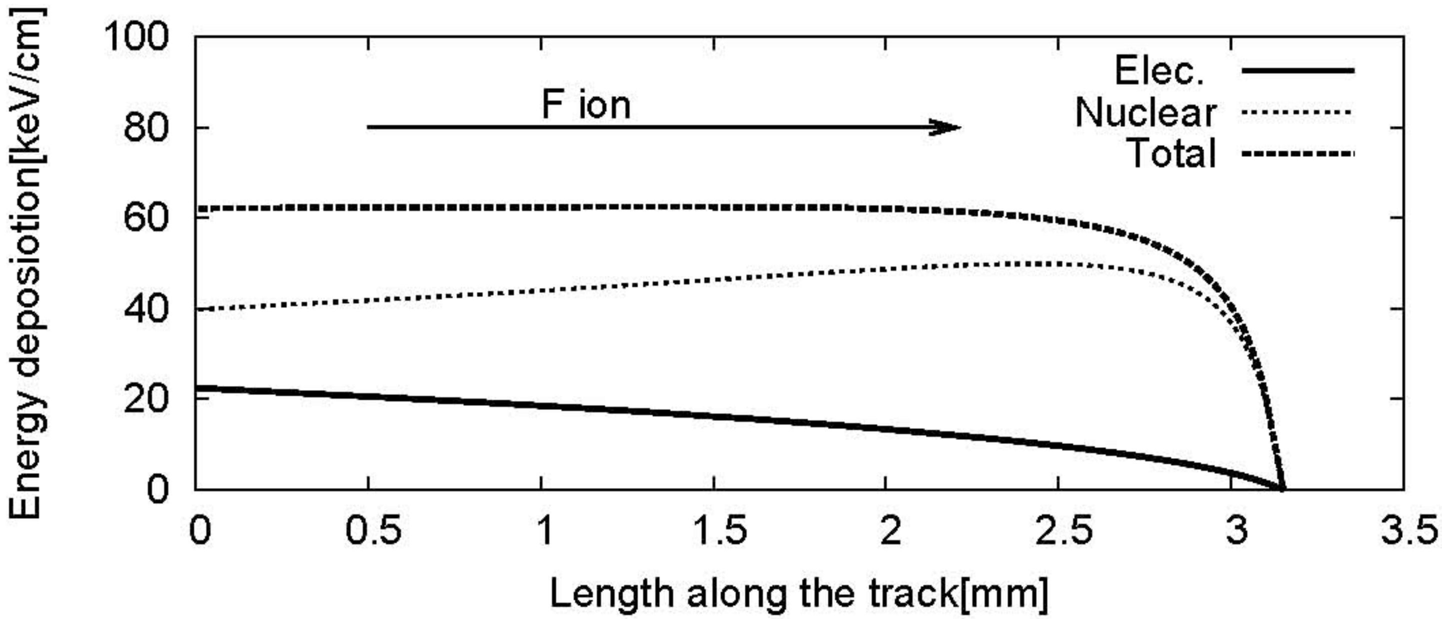
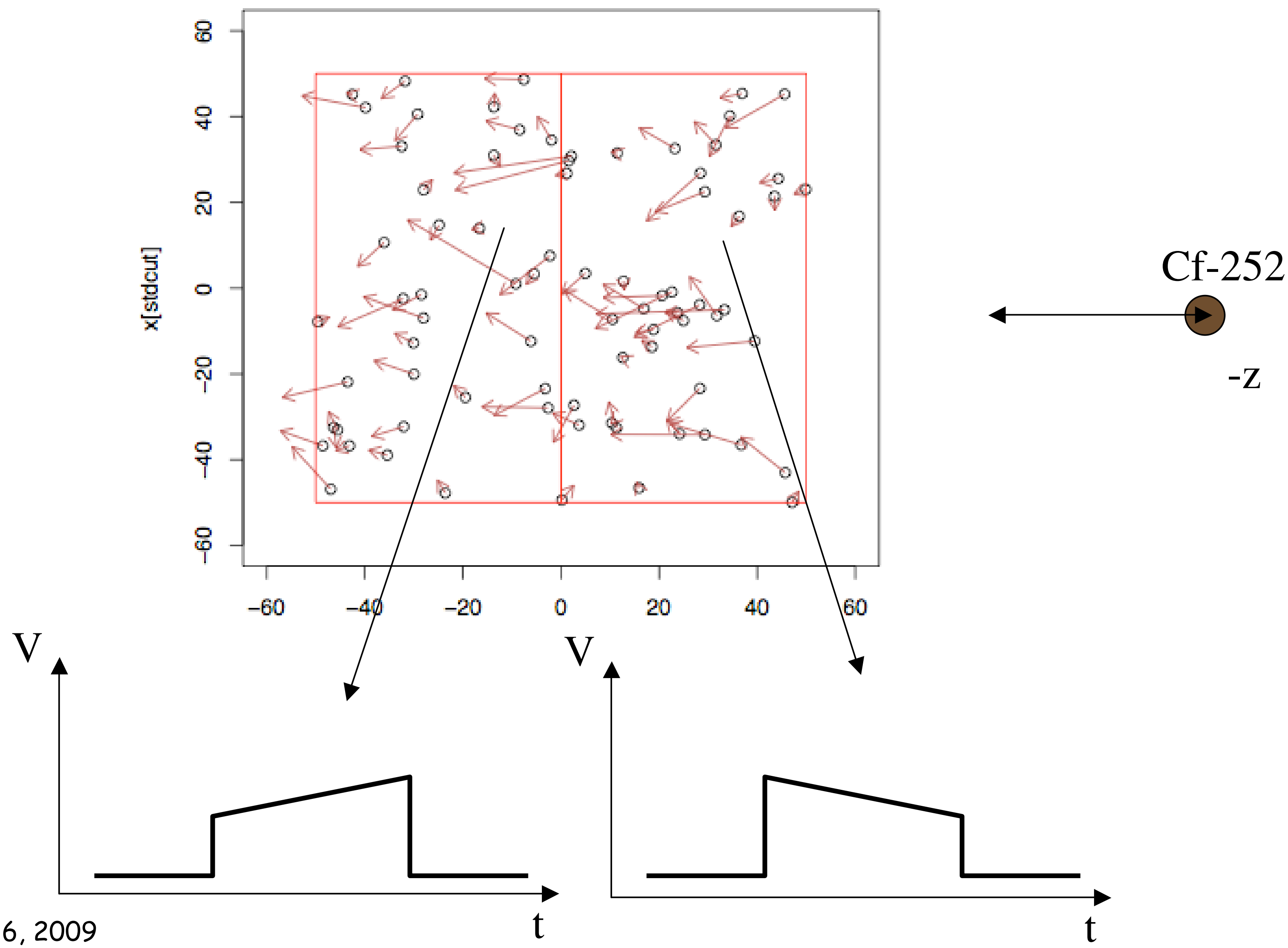


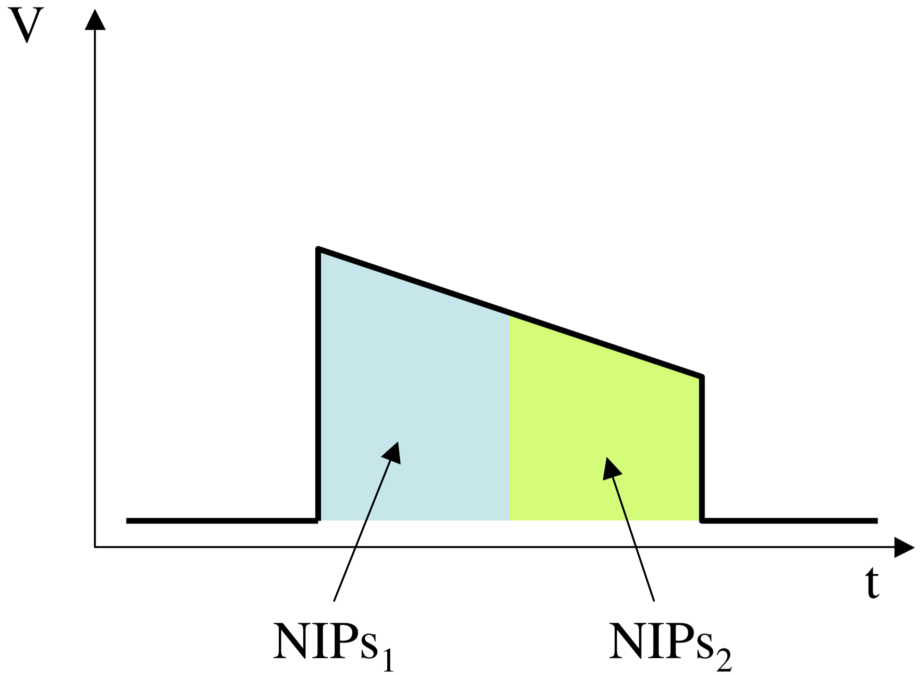
Fig. 2. Calculated energy loss of a F ion of 25 keV in 20 Torr CF_4 gas. The energy loss in the electron field, nuclear filed, and the total energy loss are shown by the solid, dotted, and dashed lines, respectively.

Tanimori, et al Phys.Lett. B578 (2004)

The principle of the measurement



Head-Tail Parameter

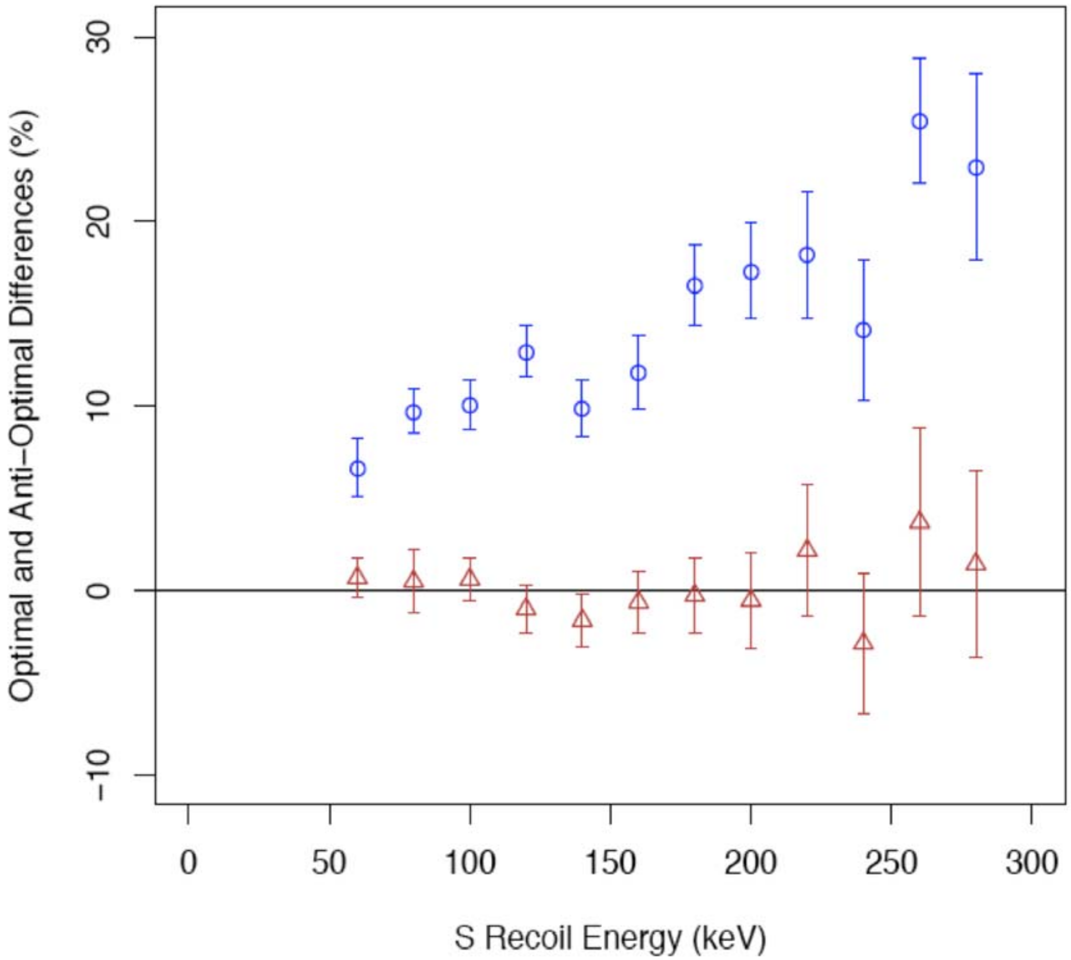


$$NipsRatio = \mathrm{Nips}_1 \,/\, \mathrm{Nips}_2$$

Left => $NipsRatio < 1$

Right => $NipsRatio > 1$

Results



Submitted to
AstroParticle Physics
(arXiv:0809.1831)

Summary on head-tail:

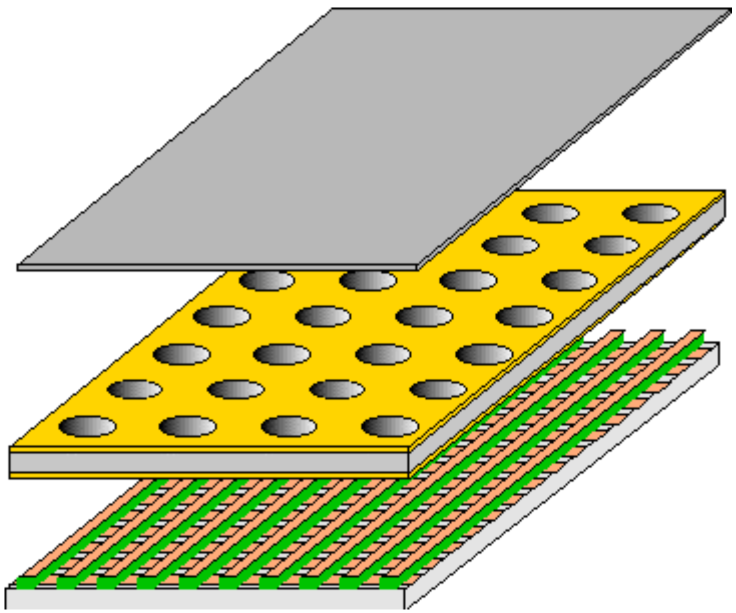
- We have found strong evidence for a head-tail effect in low energy Sulfur recoils.
- The effect produces more ionization at the beginning of the track than at the end.
- The difference of *NipsRatio* will oscillate from a maximum when Cygnus is overhead to a minimum when Cygnus is to the North.
- With similar statistics to $\Delta z/\Delta x$ the head-tail effect is 2x more significant.
- Scaling the significance shown in the previous plot, ~40 events would be required for a 90% C.L. detection of WIMPs.

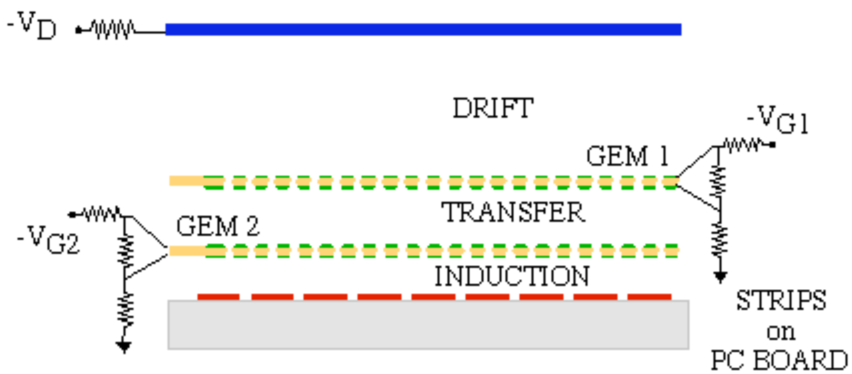
A combined analysis

- DRIFT has 2 directional signatures.
- They are independent of one and another.
- Combining these two directional signatures enable DRIFT to detect WIMPs with as few as 20 events at the 90% C.L.

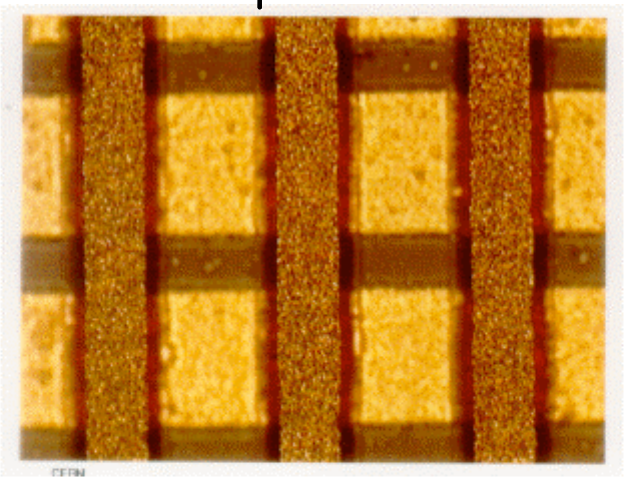
Detector R&D at UNM

Based on GEMs + 2D readout boards (from CERN)

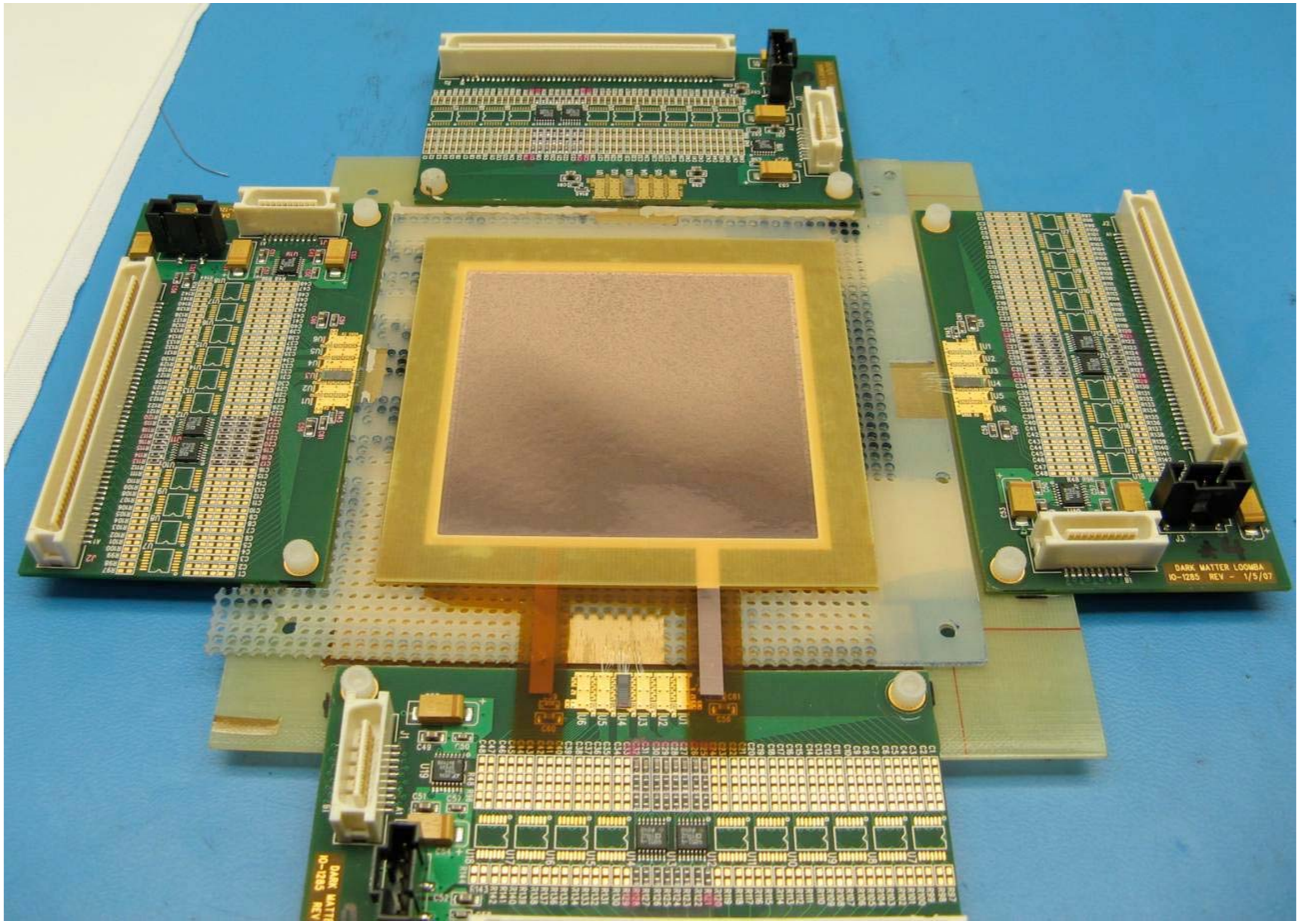




200 mm pitch

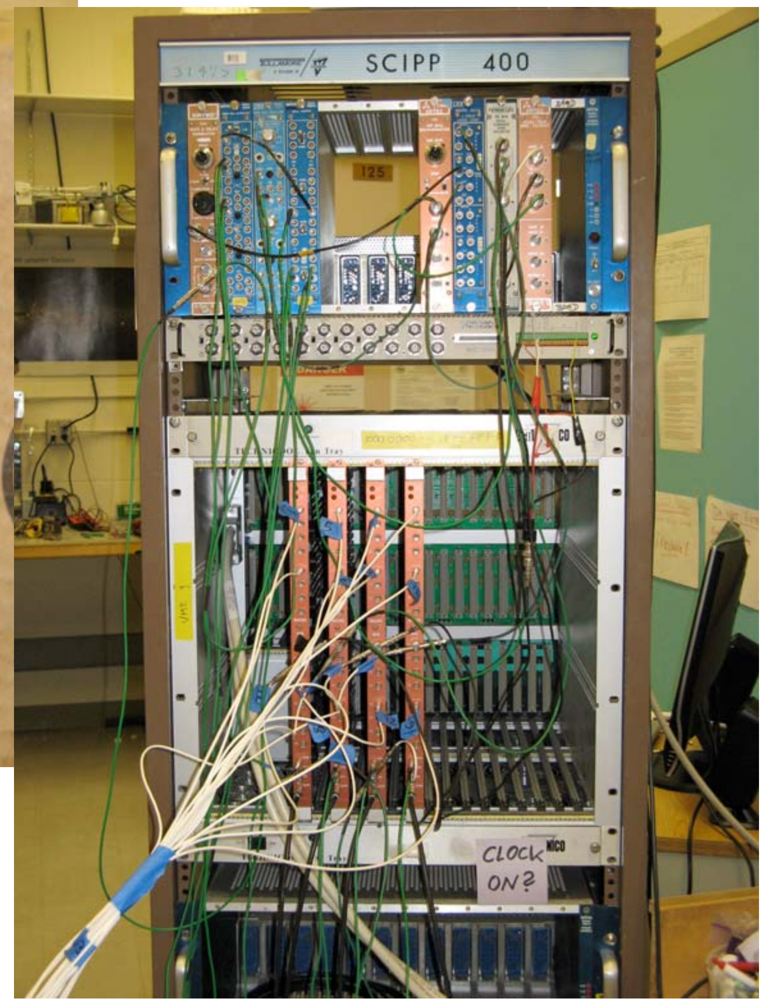


Detector



Measuring low energy nuclear recoils

Reading out 16 strips in 1D into 16 separate WFD channels giving us 200μm strip pitch

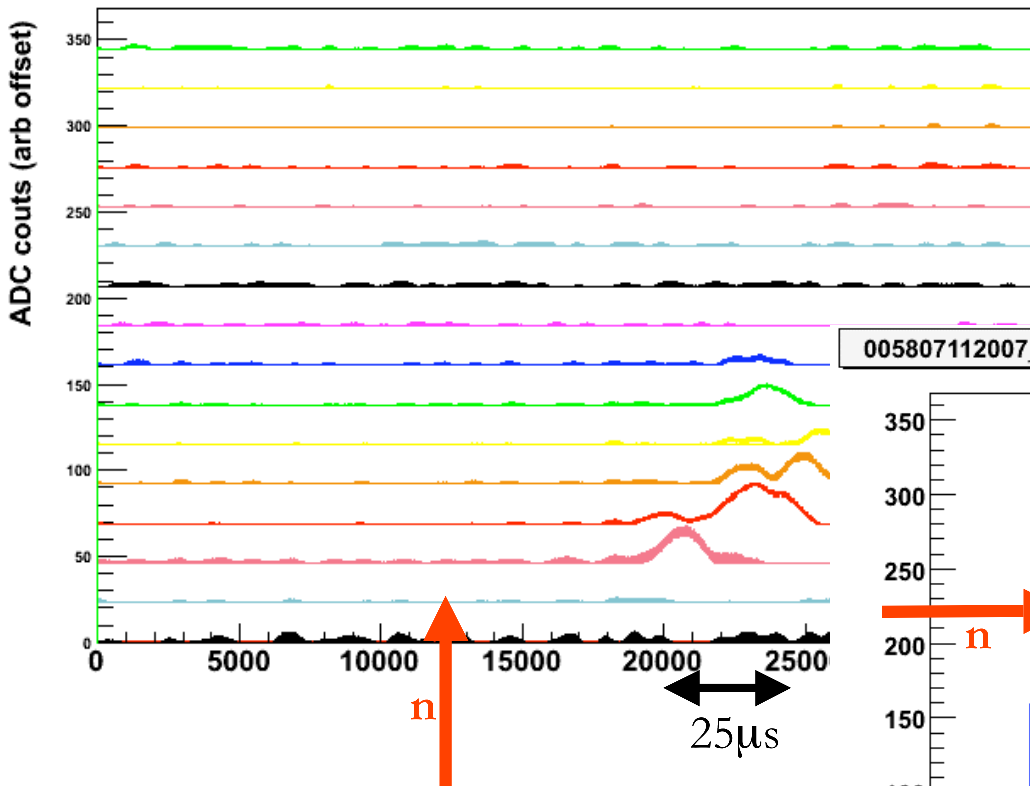


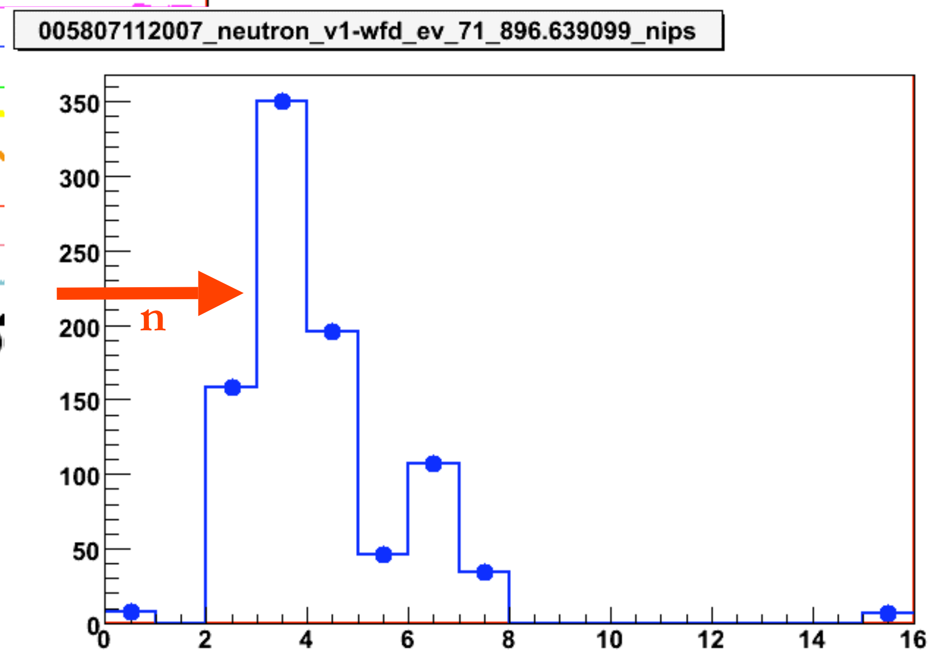
Digitizers have digitization rate of 200MHz and were designed and built for MACRO experiment;

on loan from Ed Kearns (Boston University)

EVENTS

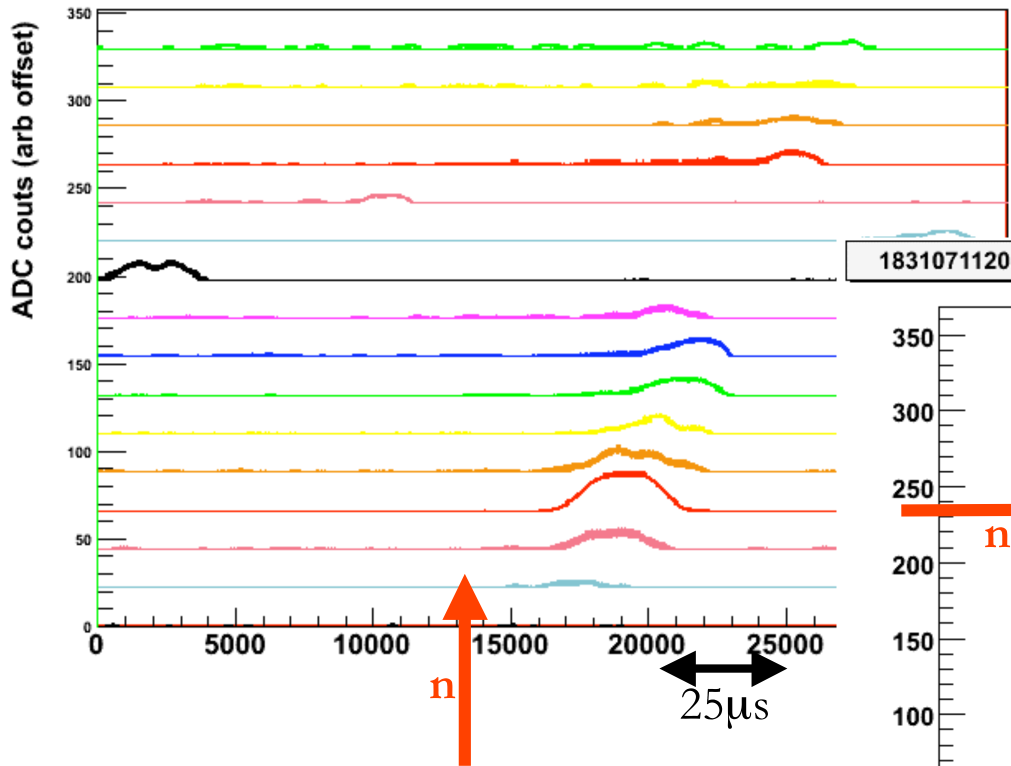
Event has ~900 NIPs
Δx ~ 1 mm
Δ z ~ 0.7mm
[25 - 30keV Carbon recoil]

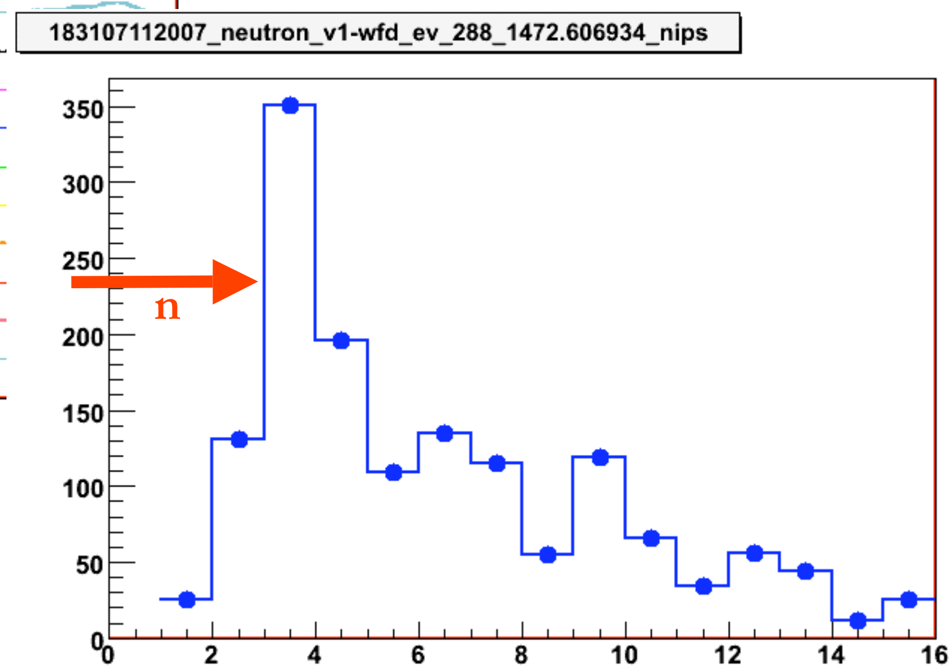




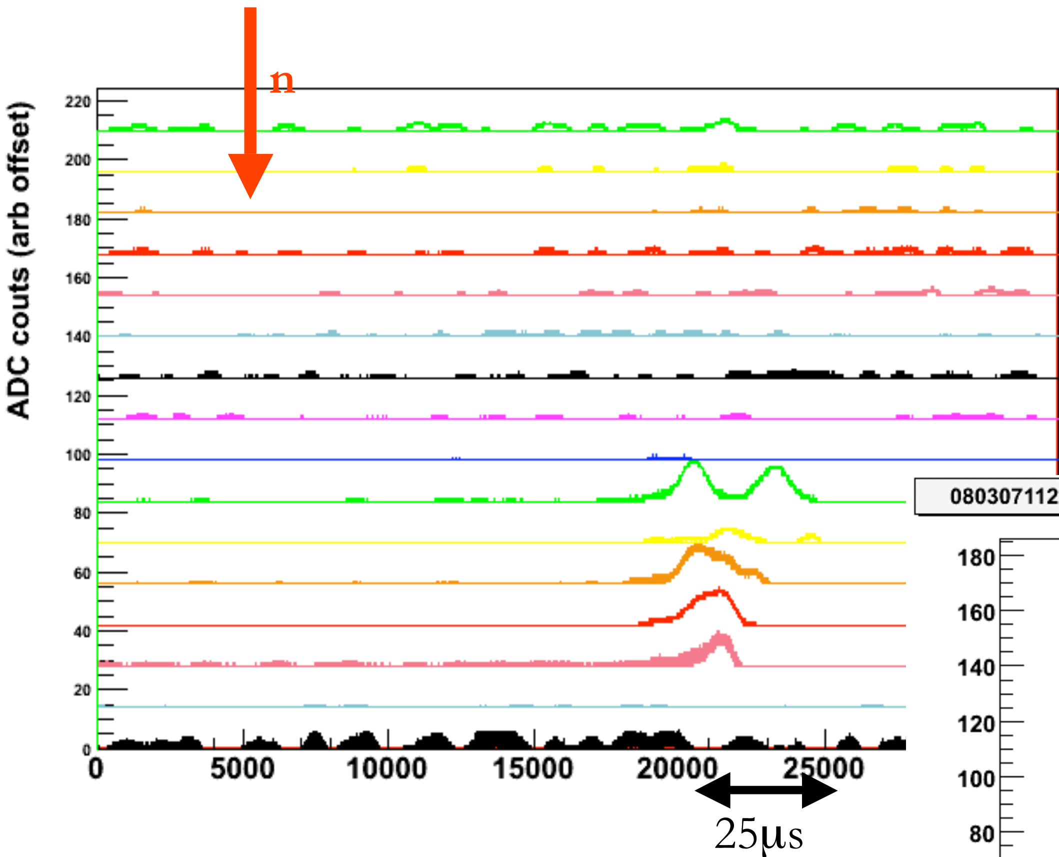
EVENTS

Event has ~1500 NIPs
Δ x ~1.2-1.4 mm
Δ z ~ 1.2mm
[40keV Carbon recoil]

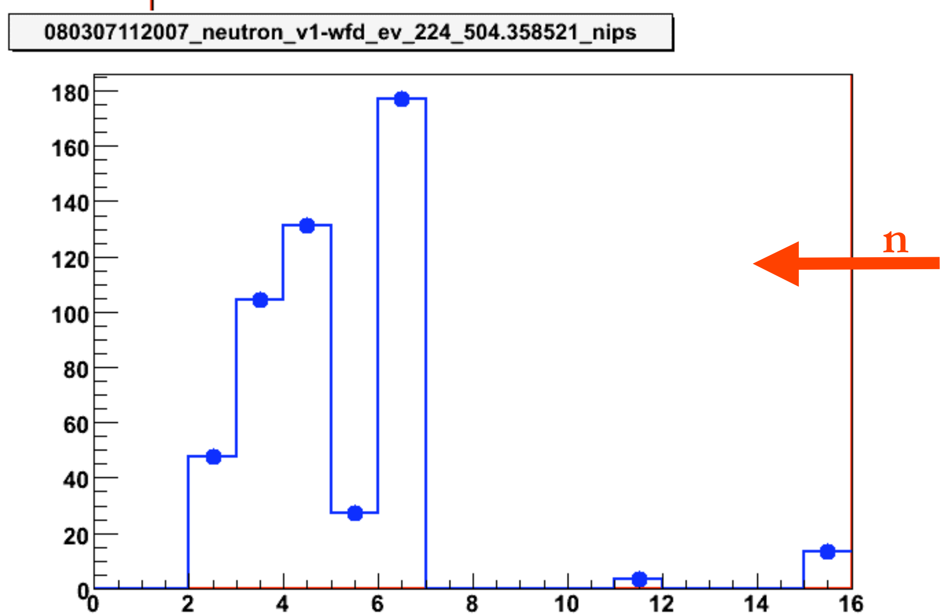




EVENTS



Event has ~500 NIPs
Δ x ~ 0.8 mm
Δ z ~ 0.5mm
[17keV Carbon recoil]



Combining the signatures

Combining the ΔZ/ΔX and Head-Tail signatures to determine the nuclear recoil direction:

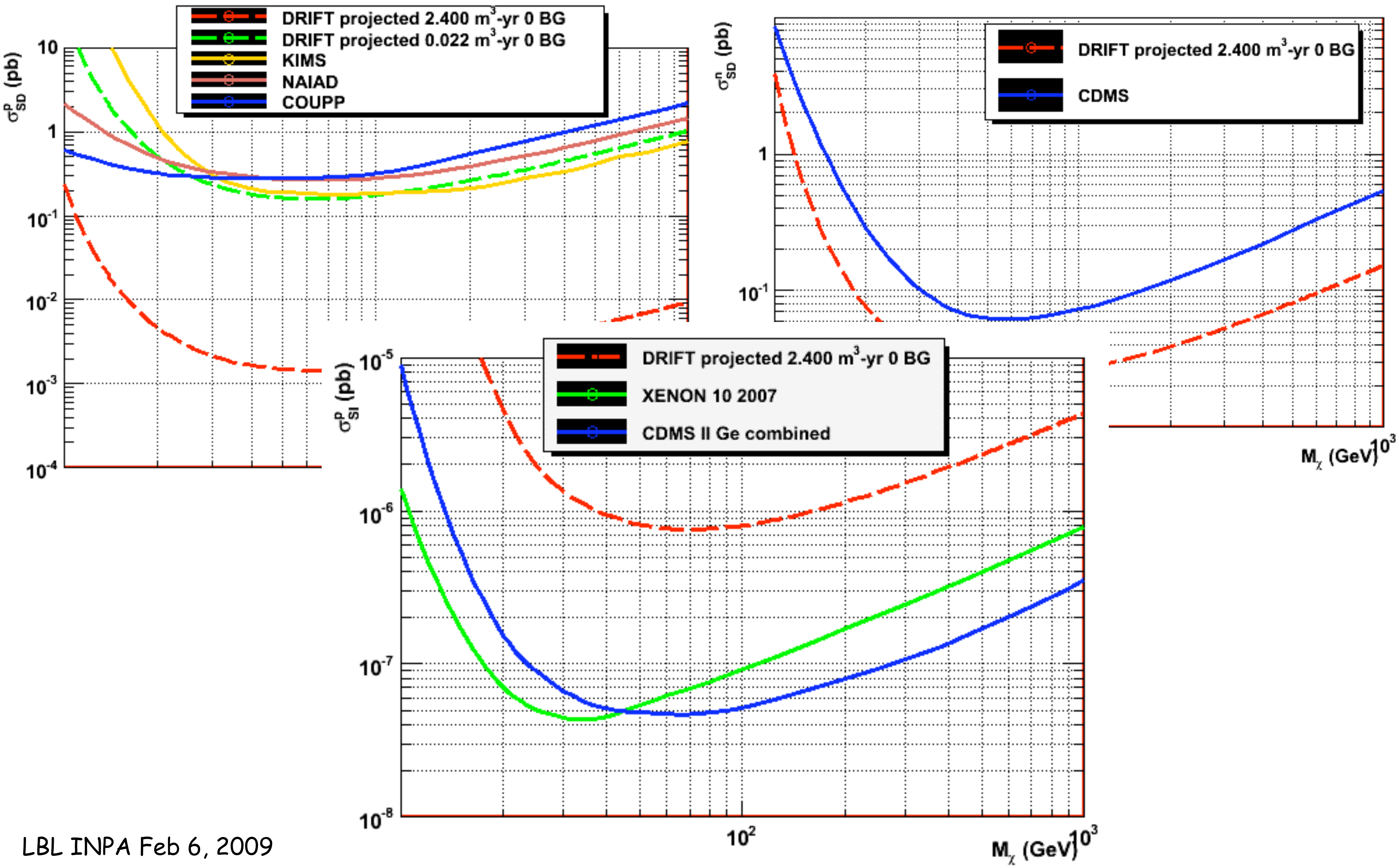
	Pressure	# events	CL $\frac{\Delta Z}{\Delta X}$	CL $track \rightarrow asym$	CCL
Xdir	80torr	32	86.2 %	31.9 %	90.6 %
	120torr	50	77.8 %	55.5 %	90.1 %
	Pressure	# events	CL $\frac{\Delta Z}{\Delta X}$	CL $track \rightarrow ZasymC$	CCL
Zdir	80torr	18	73.4 %	65.4 %	90.8 %
	120torr	25	61.2 %	74.5 %	90.1 %

The head-tail effect is seen down to 500 NIPs (e.g., 27 keV S recoils)

Conclusions

- Radon progeny recoils have been reduced down to <0.2/day
- R&D underway for z-fiducialization of the DRIFT detector. Looks promising and we hope to install hardware to veto the remaining RPRs, install shielding, and start data taking this summer
- DRIFT has two independent directional signatures, which enable the detection of WIMPs with as few as 20 events at the 90% C.L.
- R&D based on GEM-based readouts confirms directionality results and extends them to higher pressures and lower energy thresholds
- We will continue to investigate alternative readouts for future directional detectors

..and during the next year we will start running DRIFT with a 50/50 CF_4-CS_2 gas mixture for spin-dependent limits:



Future Goals: DUSEL S4

- Modular approach with each module consisting of 4kg target mass and a size approximately 3m by 6m
- Target will consist of 50/50 CS_2/CF_4
- Cost estimated at ~240K/module
- limits from 1 detector module, running for 3 years…

Future Goals: DUSEL S4
Zero-background limits