BDX-DRIFT: A low-energy, low-background, directional search for LDMA

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May 27, 2017

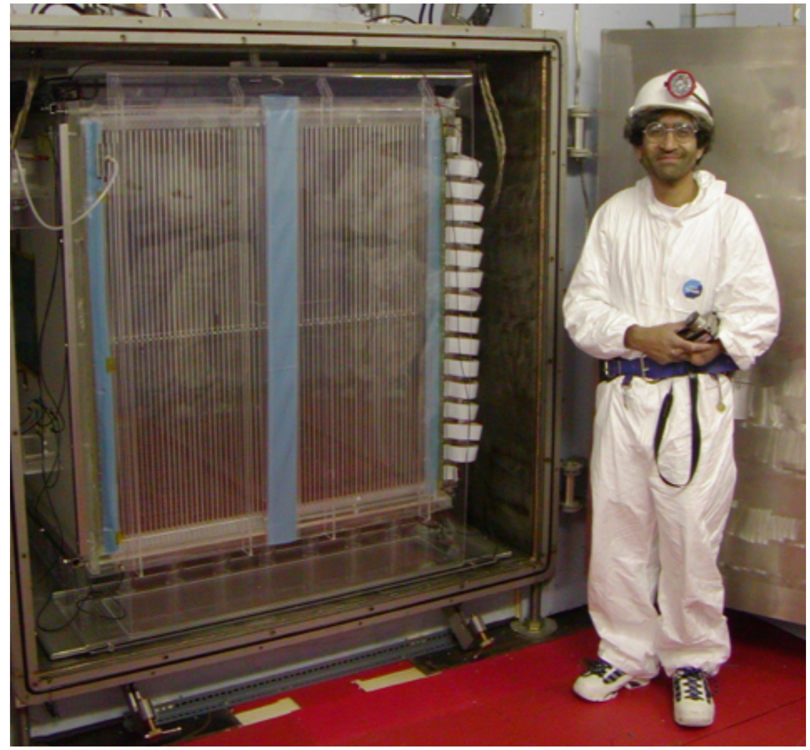
DRIFT lightning summary

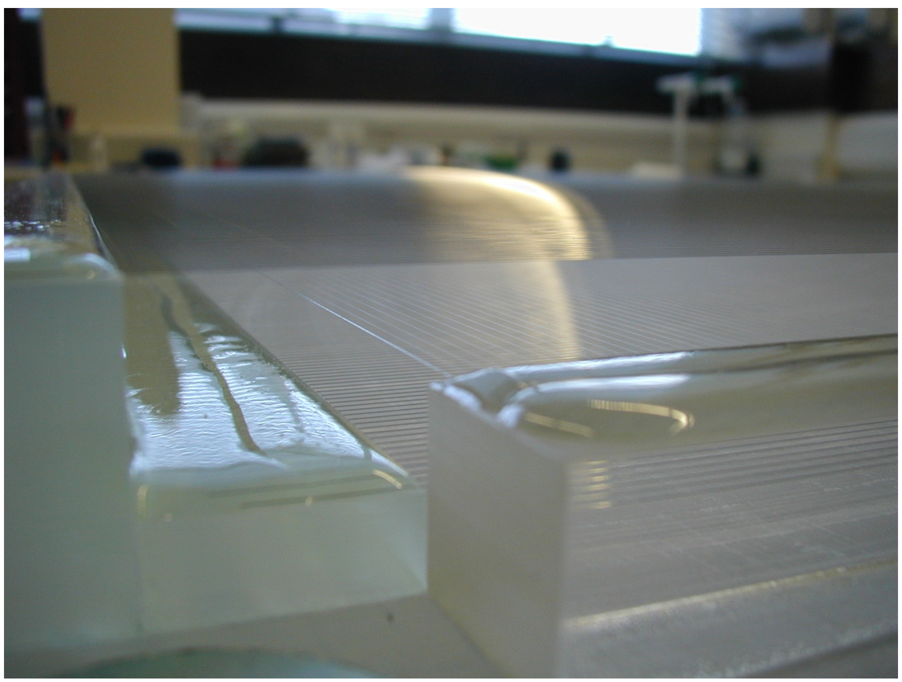
Started = 1998, US/UK

Directional WIMP dark matter detector

1/20 atm, 1 m^3 gaseous detector

Continuous R&D for 19 years





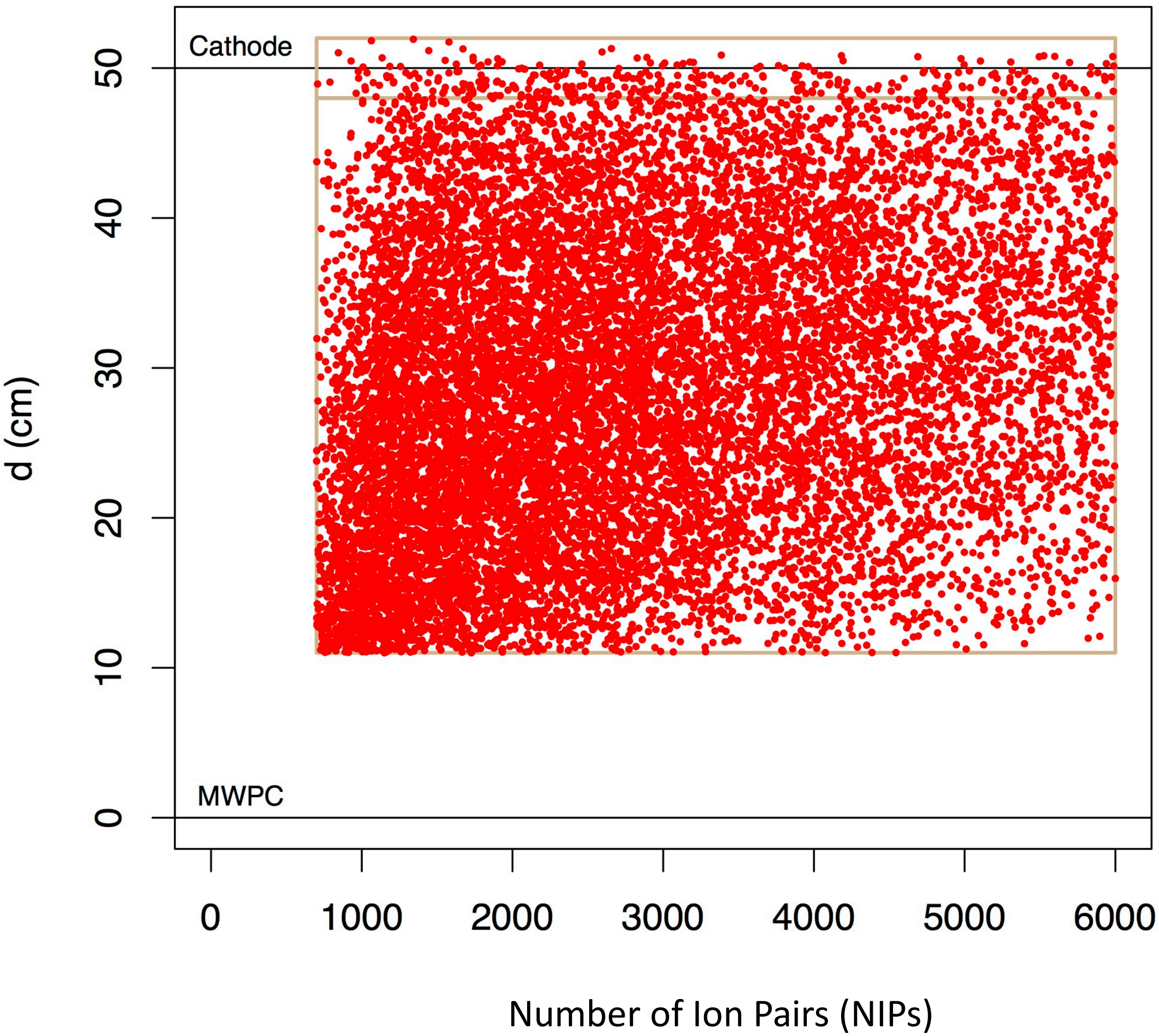
Unique and robust technology

Low energy (~35 keV) threshold for nuclear recoils

Low background

PRD, 61, 2000

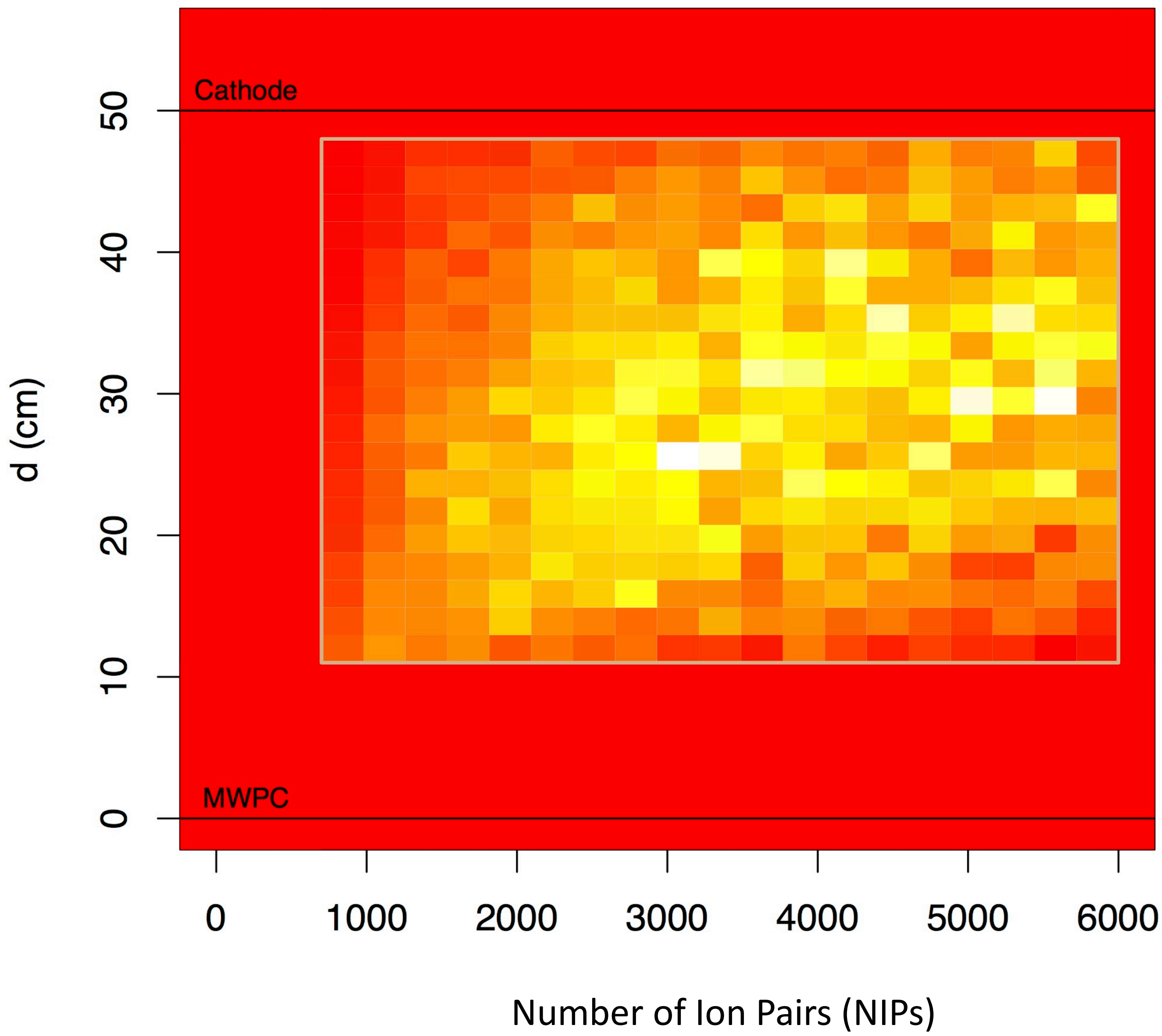
Calibration



Cf-252 neutron recoils

arXiv:1701.00171
AstroPle, 91, 2017

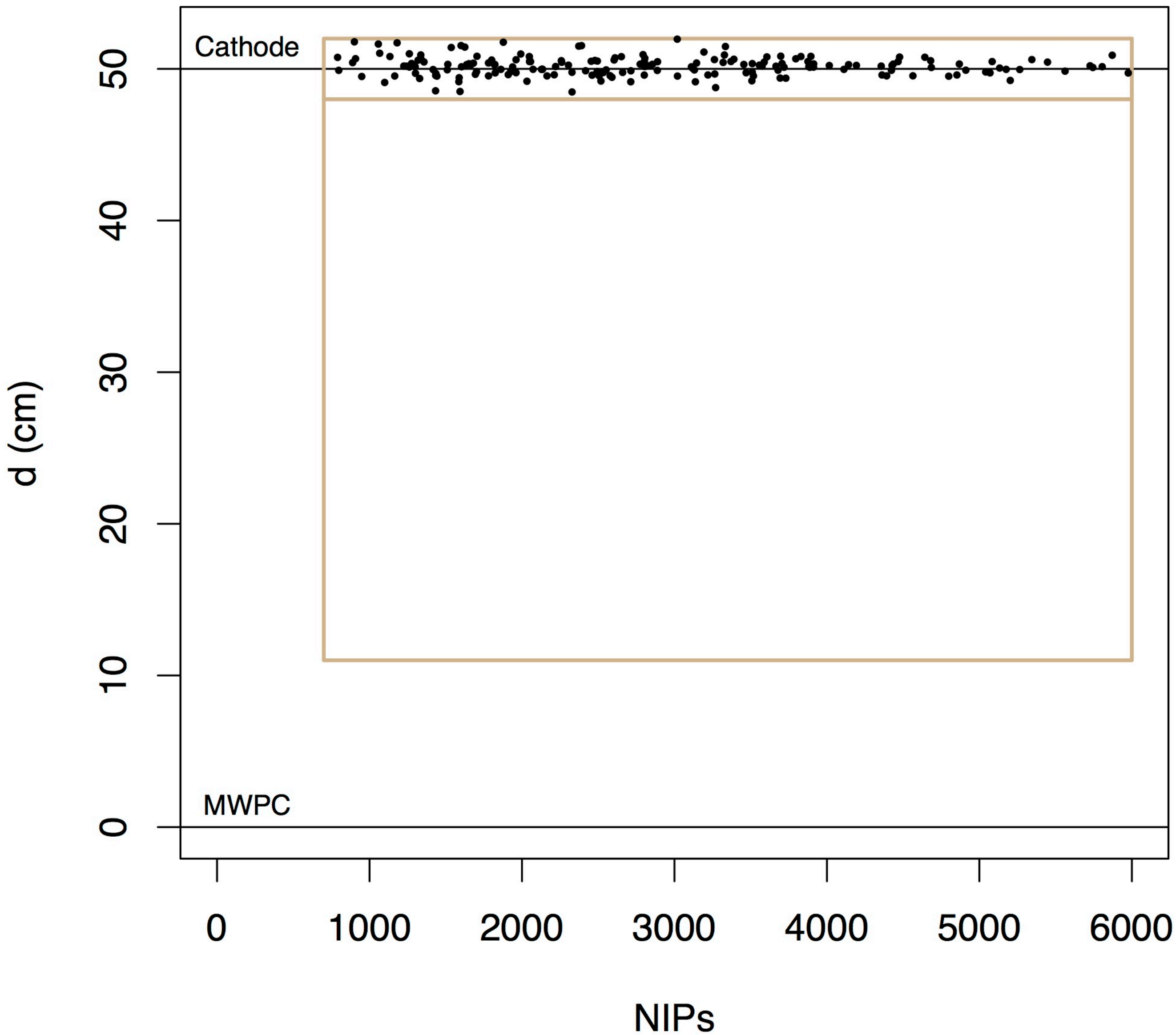
Calibration



Efficiency map

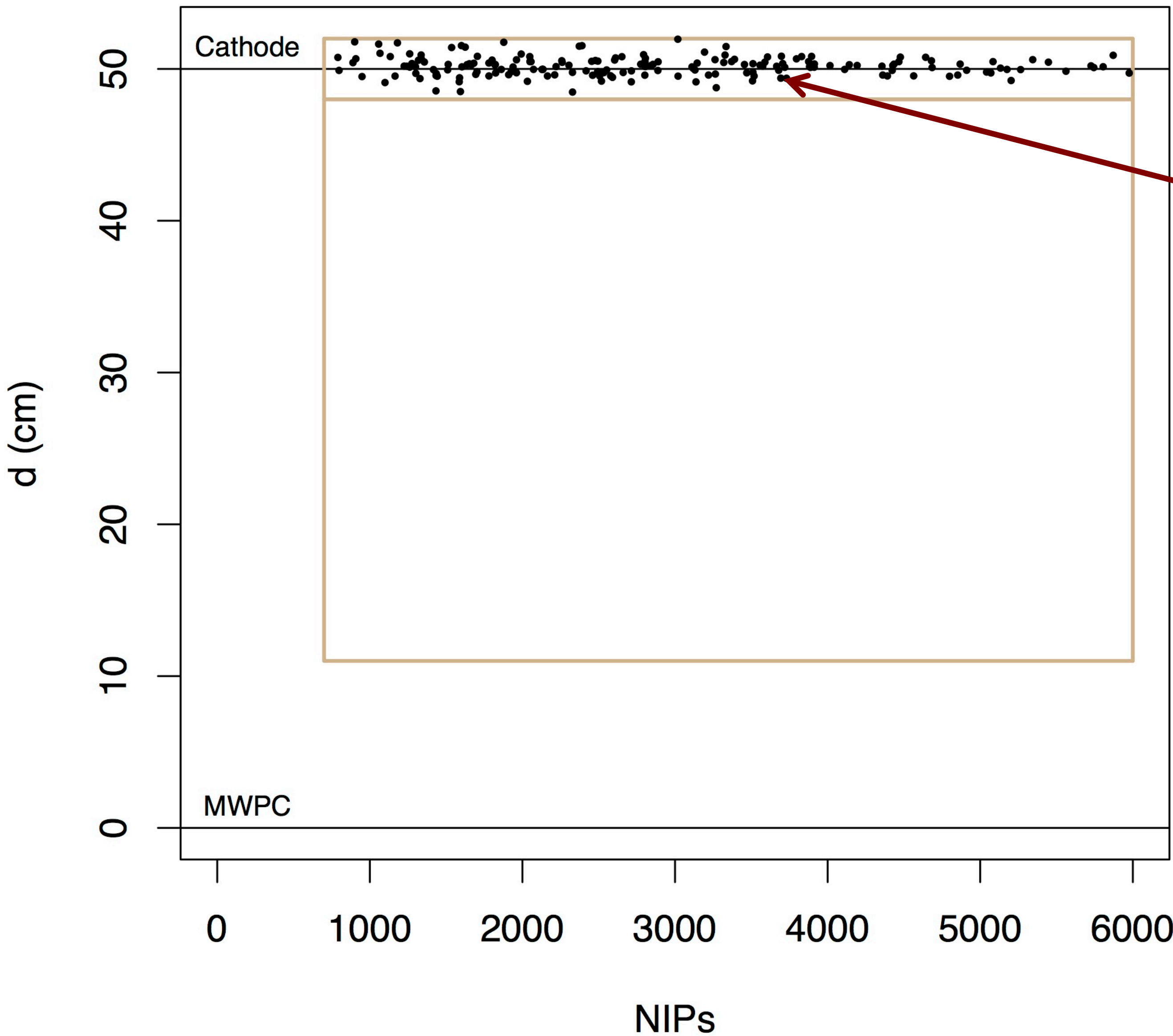
arXiv:1701.00171
AstroPle, 91, 2017

Shielded results – 55 days



arXiv:1701.00171
AstroPle, 91, 2017

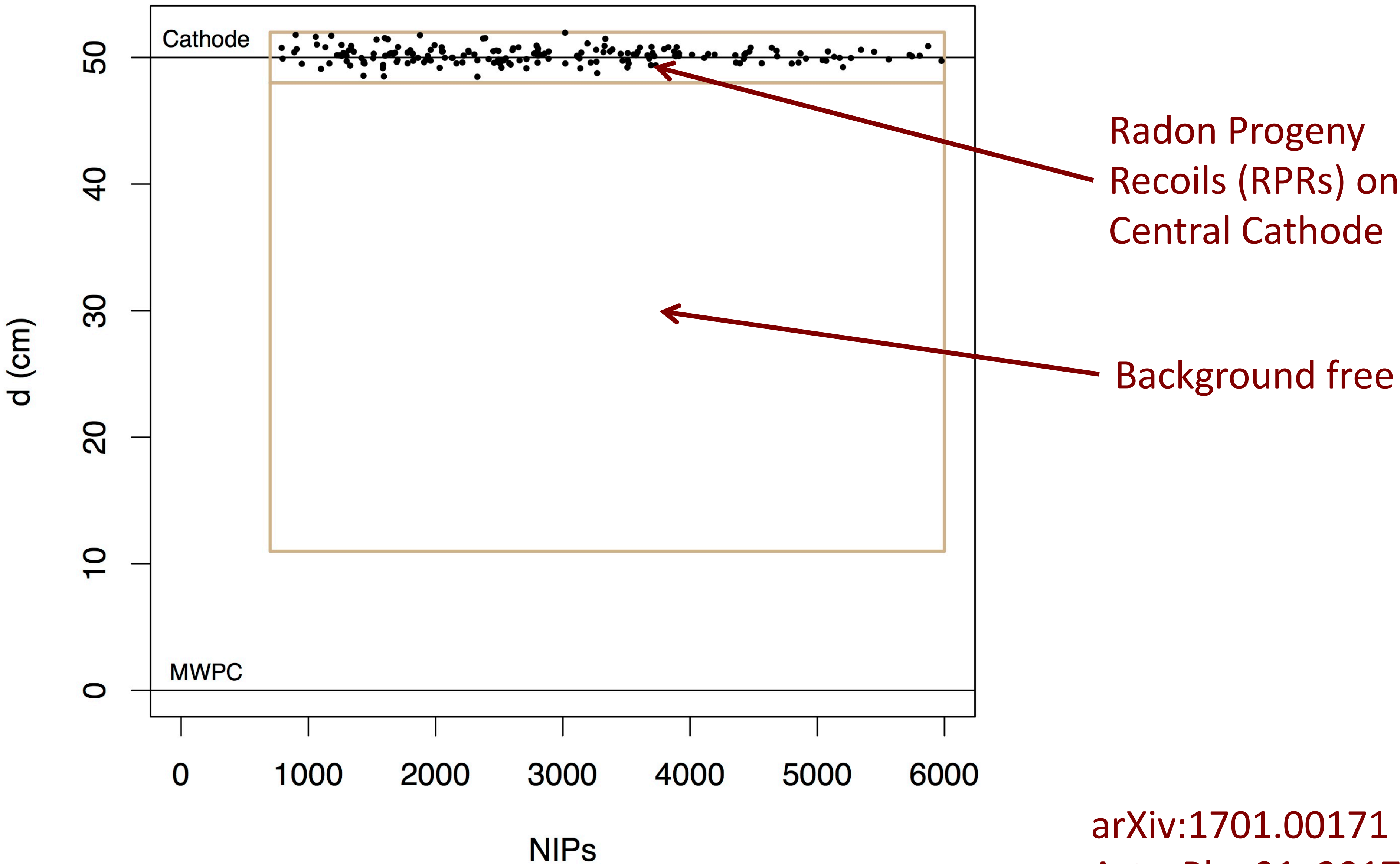
Shielded results – 55 days



Radon Progeny Recoils (RPRs) on Central Cathode

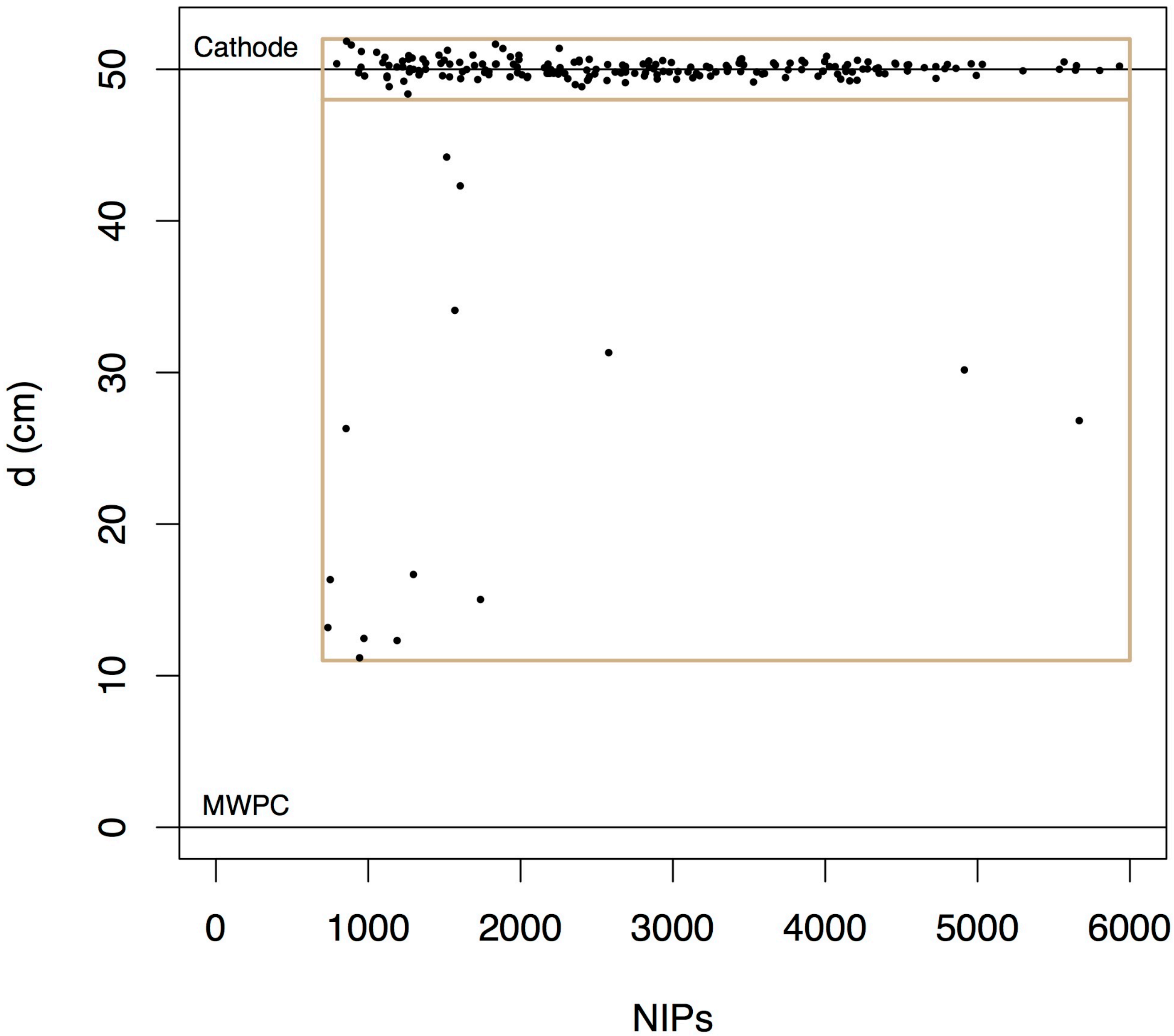
arXiv:1701.00171
AstroPle, 91, 2017

Shielded results – 55 days



arXiv:1701.00171
AstroPle, 91, 2017

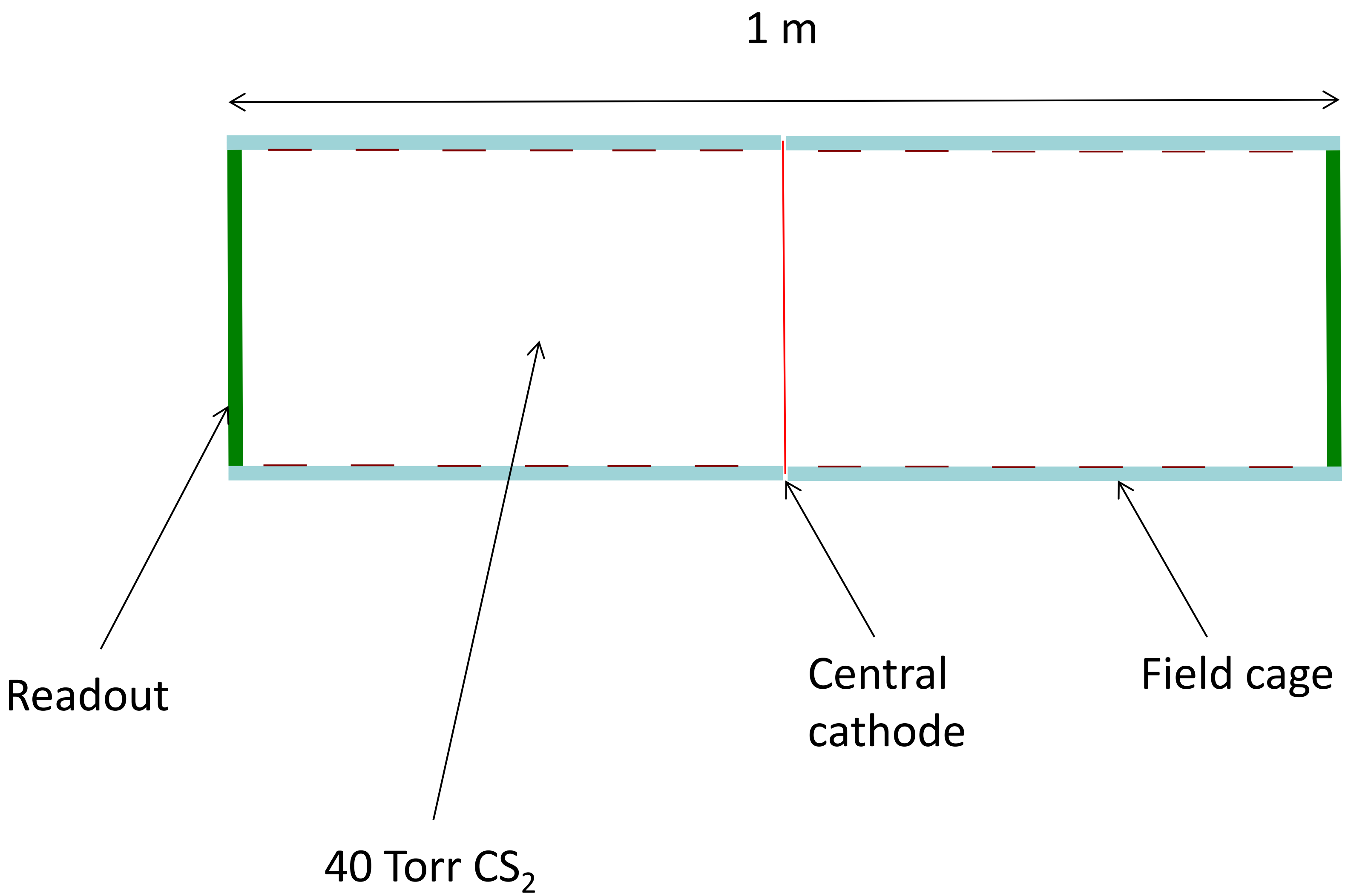
Un-shielded results – 45 days



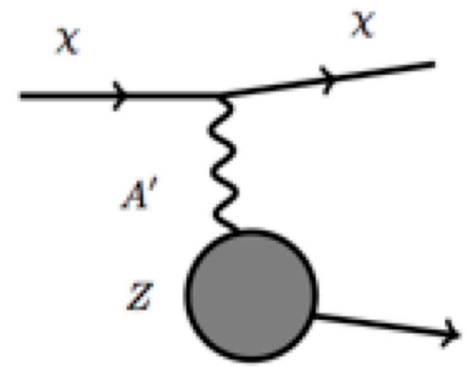
Ambient neutron background!

arXiv:1701.00171
AstroPle, 91, 2017

BDX-DRIFT-1m

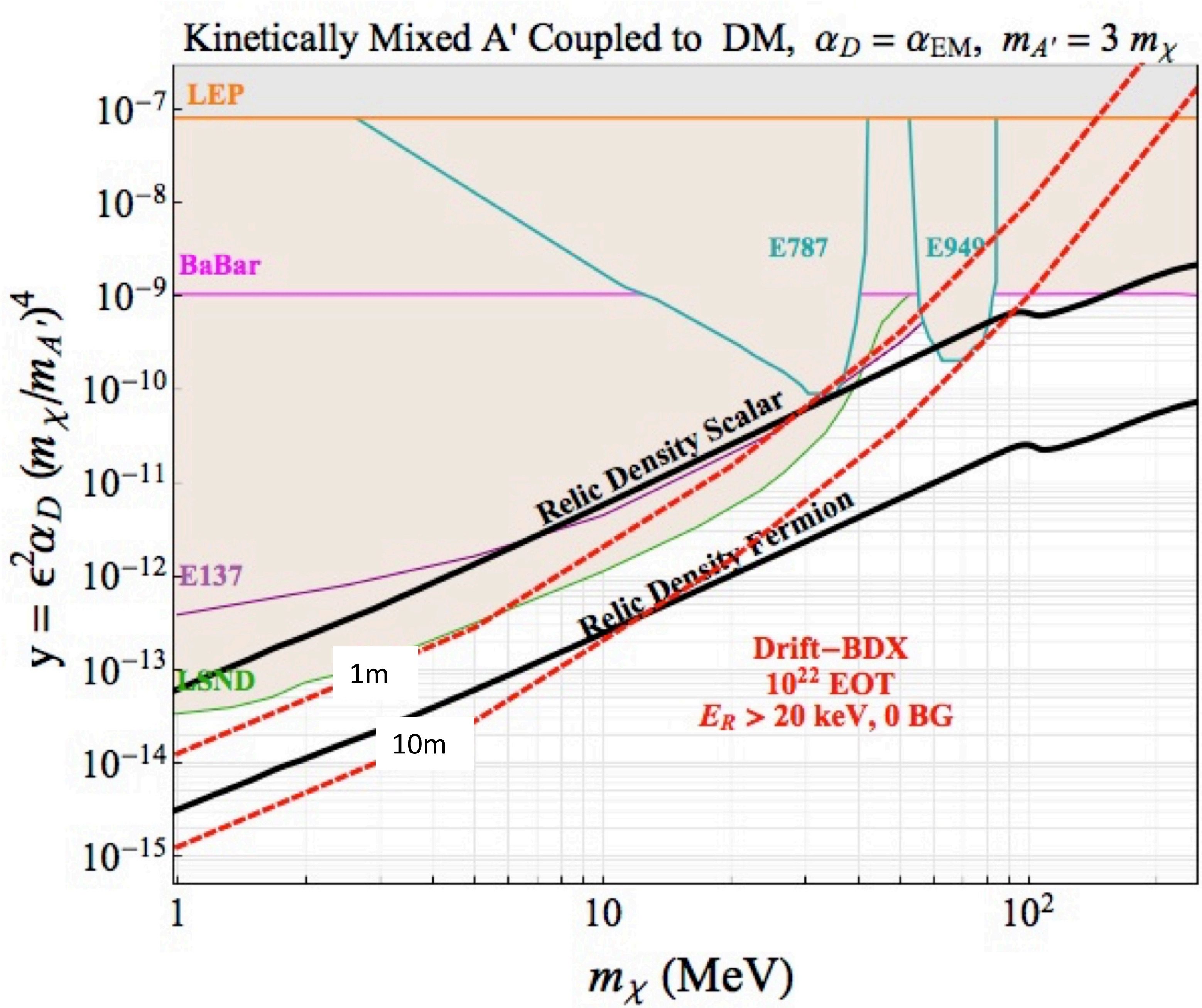


BDX-DRIFT - Signal

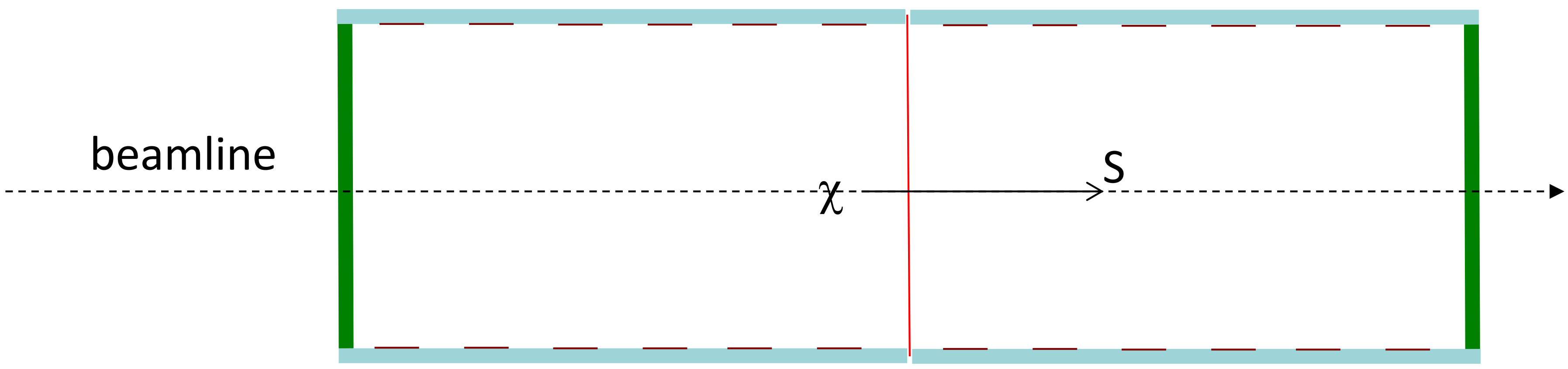


$$\frac{d\sigma}{dT} \cong \frac{8\pi\alpha\alpha_D\epsilon^2 Z^2 M}{(m_{A'}^2 + 2MT)^2}$$

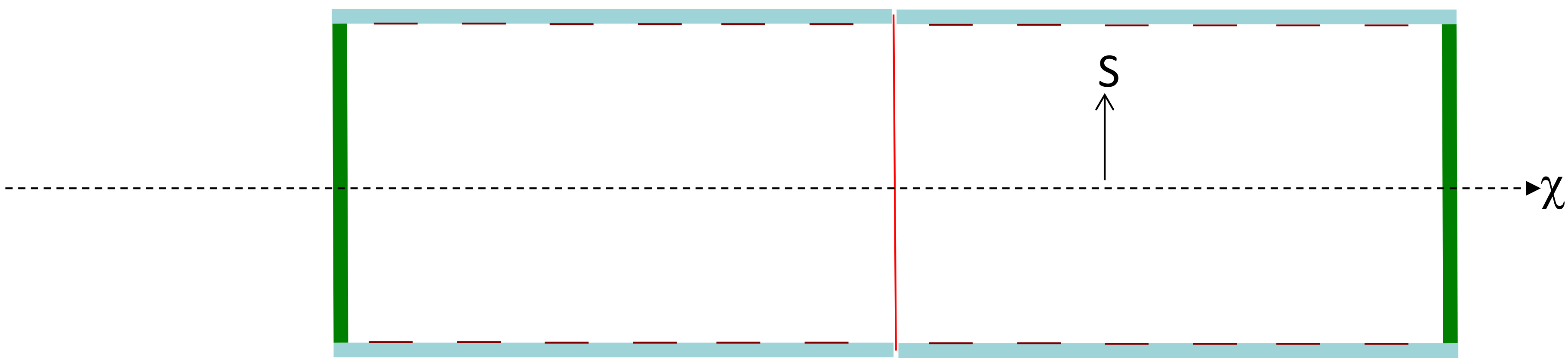
BDX-DRIFT - Limits



The Signature -



The Signature -



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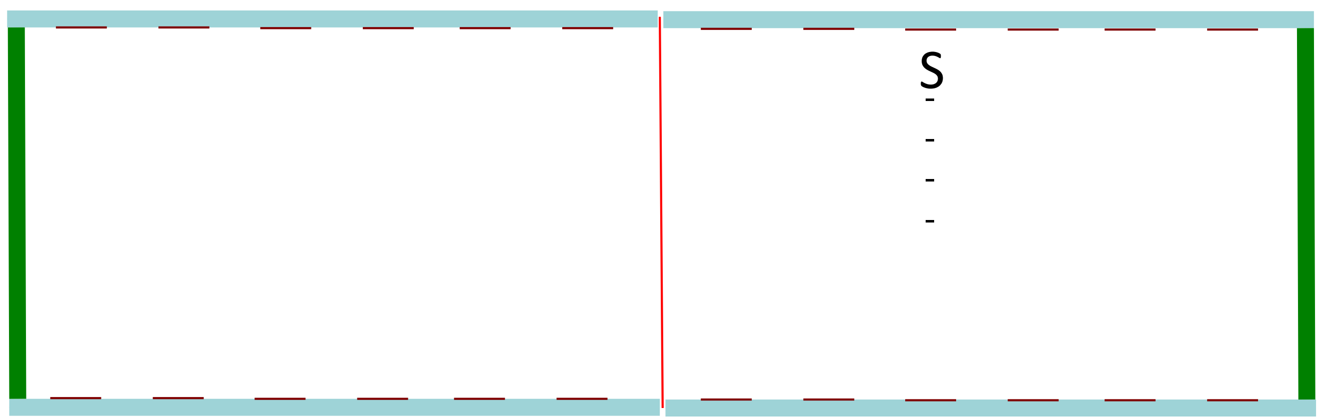

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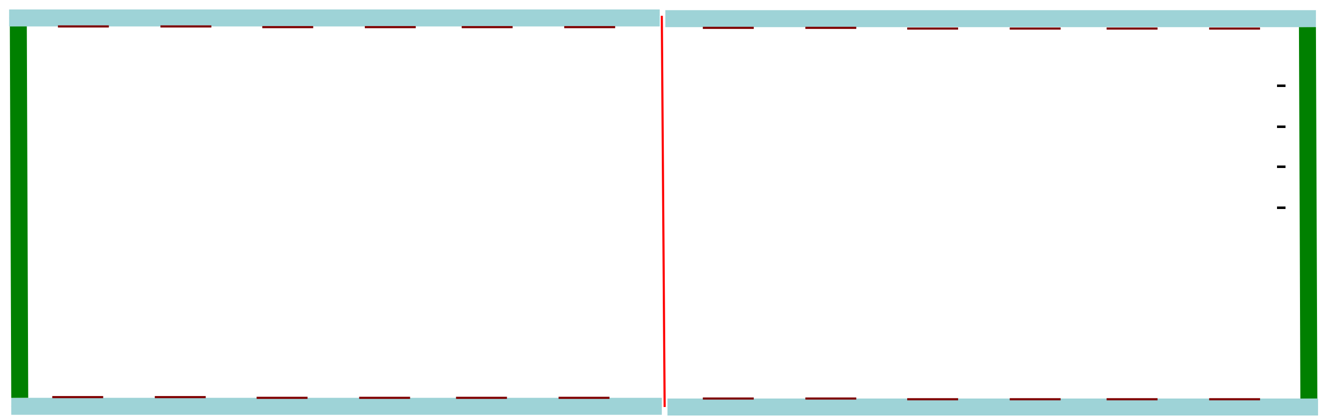
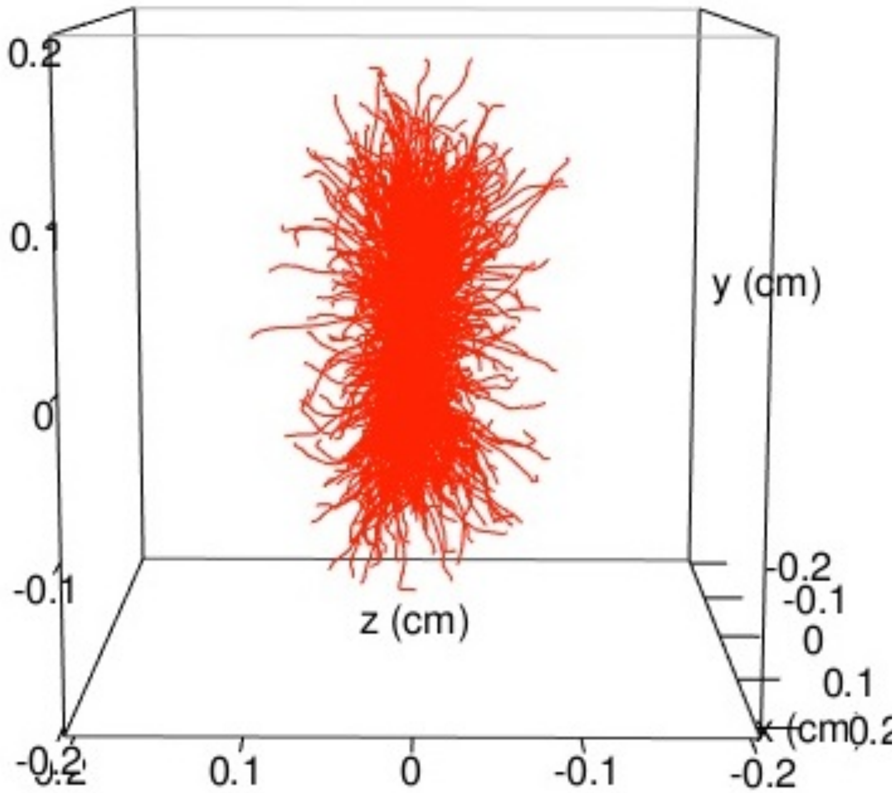
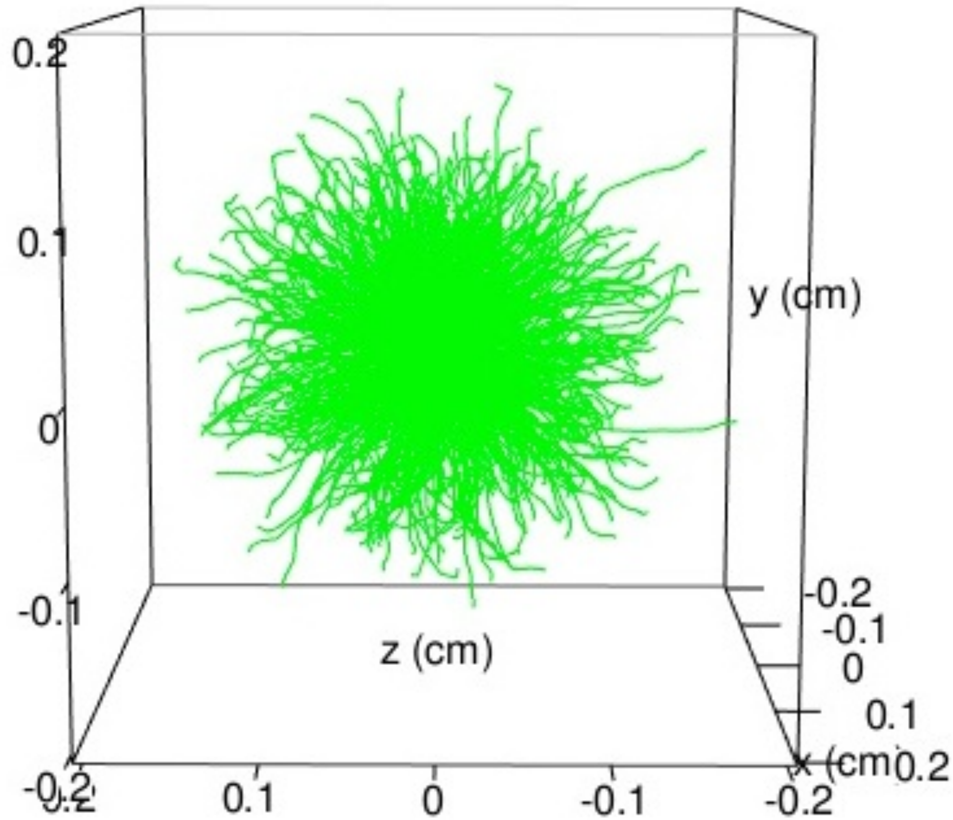


Directional Signal and Isotropic Background

1,000 50 keV
signal events

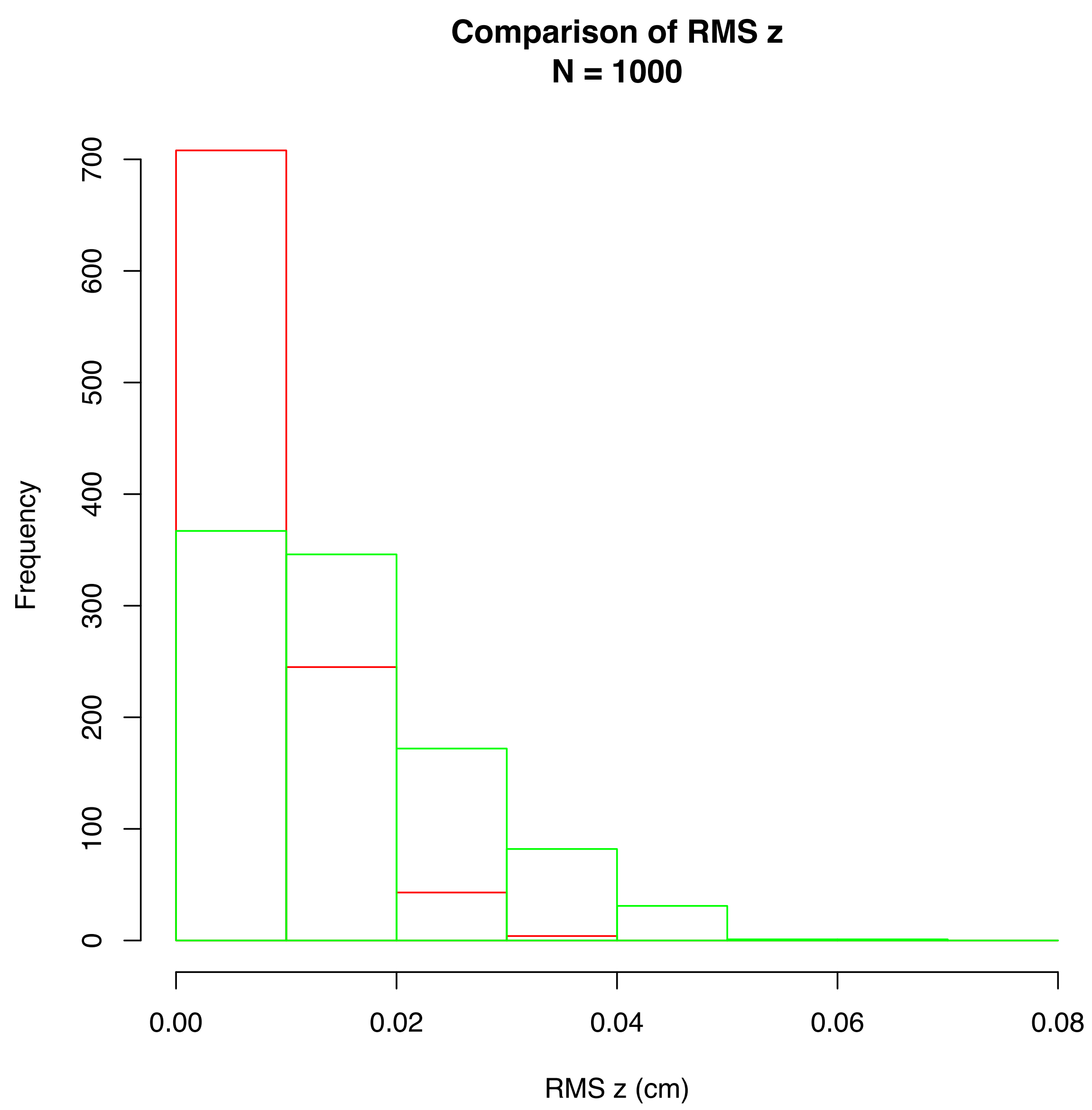


1,000 50 keV
background events



One of the easiest things to measure is the RMS in z.

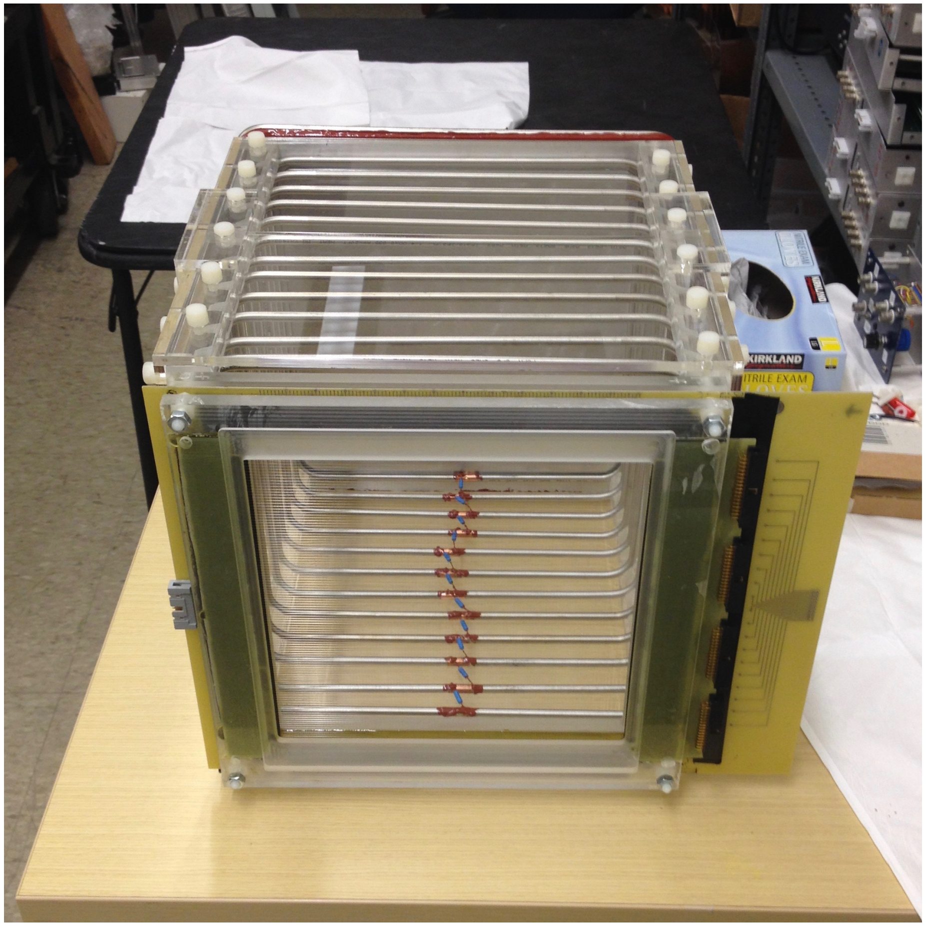
Directional Signal vs Isotropic Background



Directional Signal and Isotropic Background

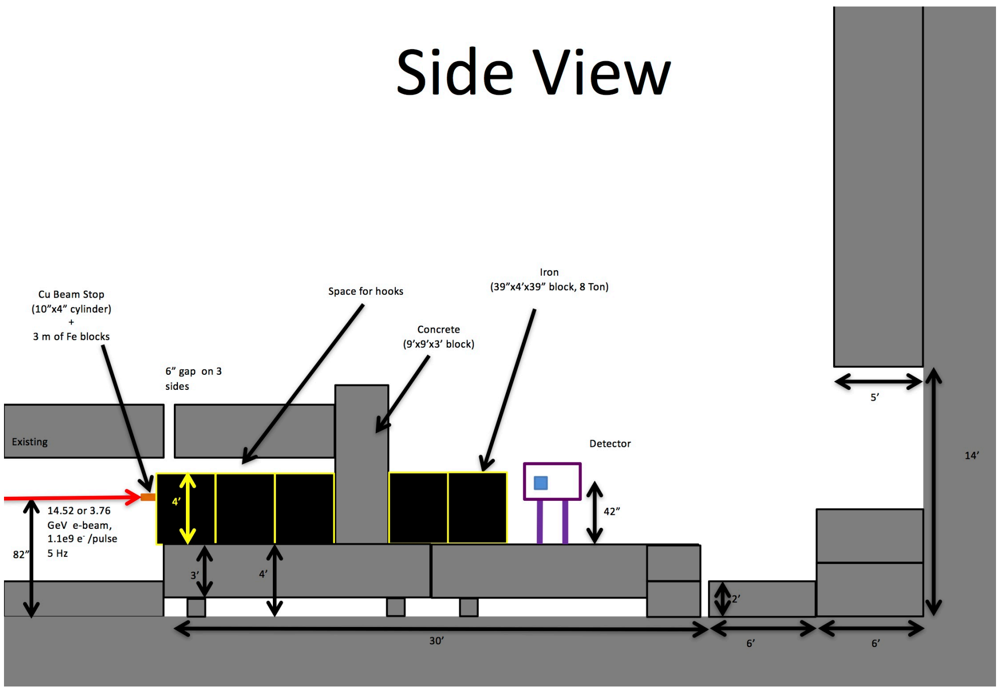
Detection (90% C.L.) after 16 events if no background and 50 keVr threshold.

Initial Tests - Background

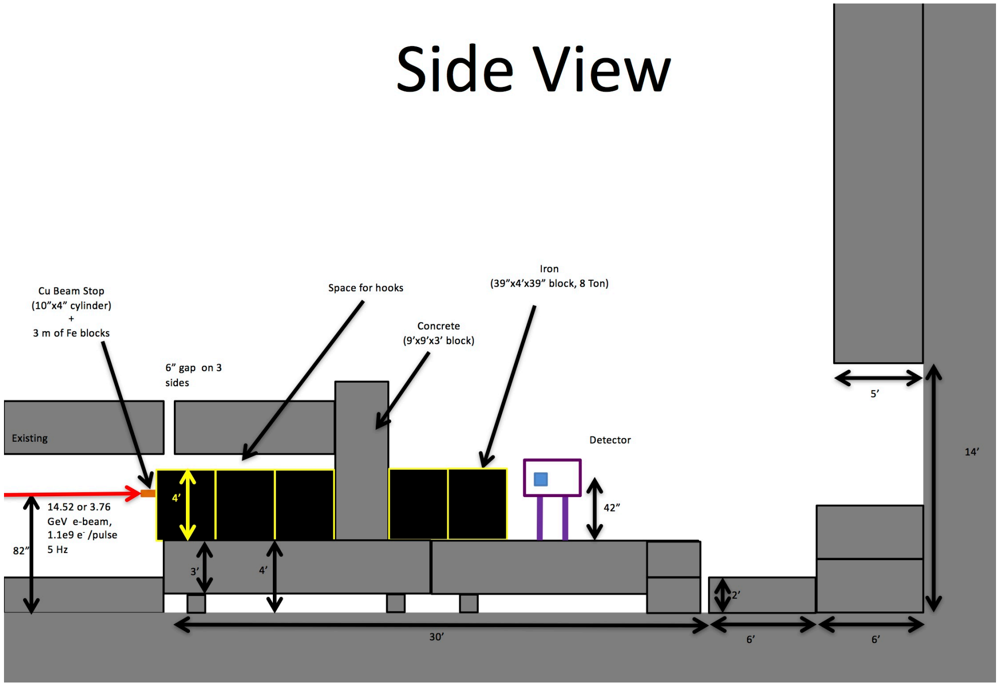


- Despite 4 Hz of cosmic ray muons passing through the fiducial volume of the detector the trigger rate is only 0.1 Hz. After nuclear recoil analysis we get ~1 event per day, roughly what we would expect from cosmic ray neutrons. *Backgrounds are low, even on the surface of the Earth.*

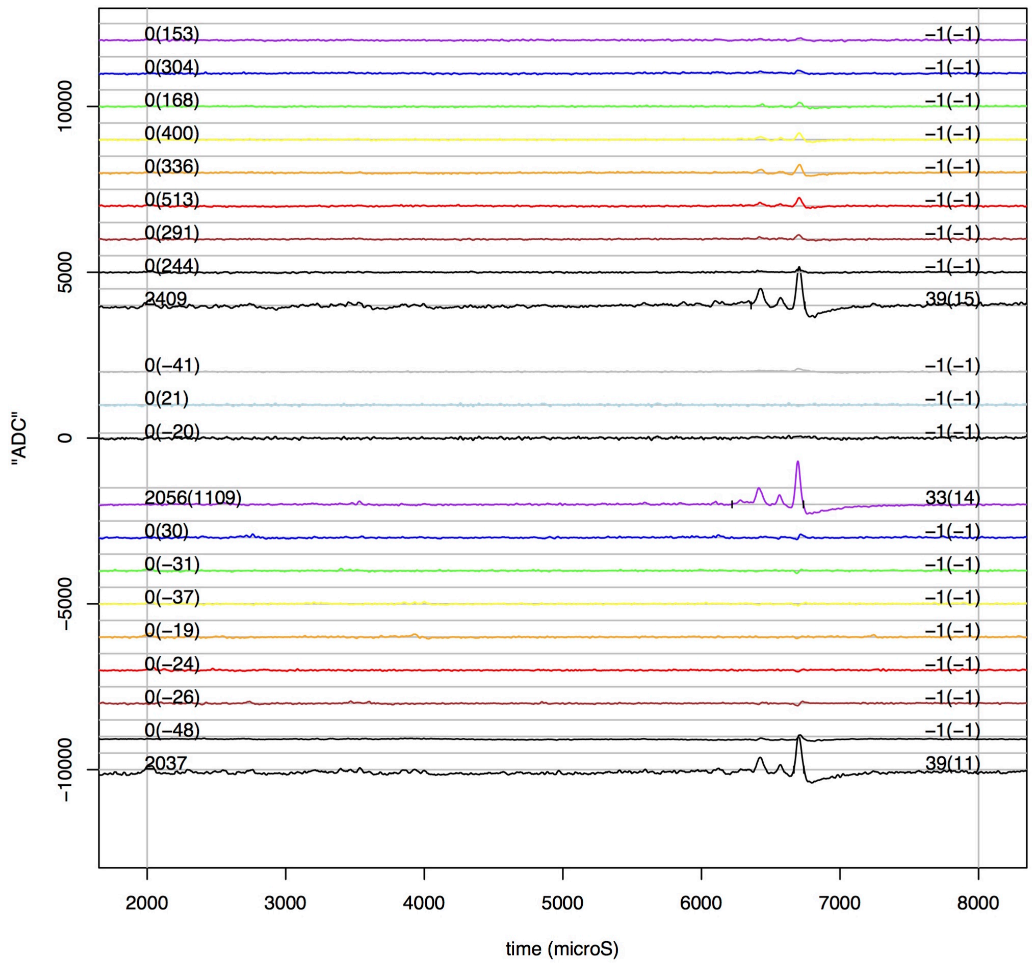
Initial Tests – SLAC Beam Run



Initial Tests – SLAC Beam Run



Initial Tests – SLAC Beam Run



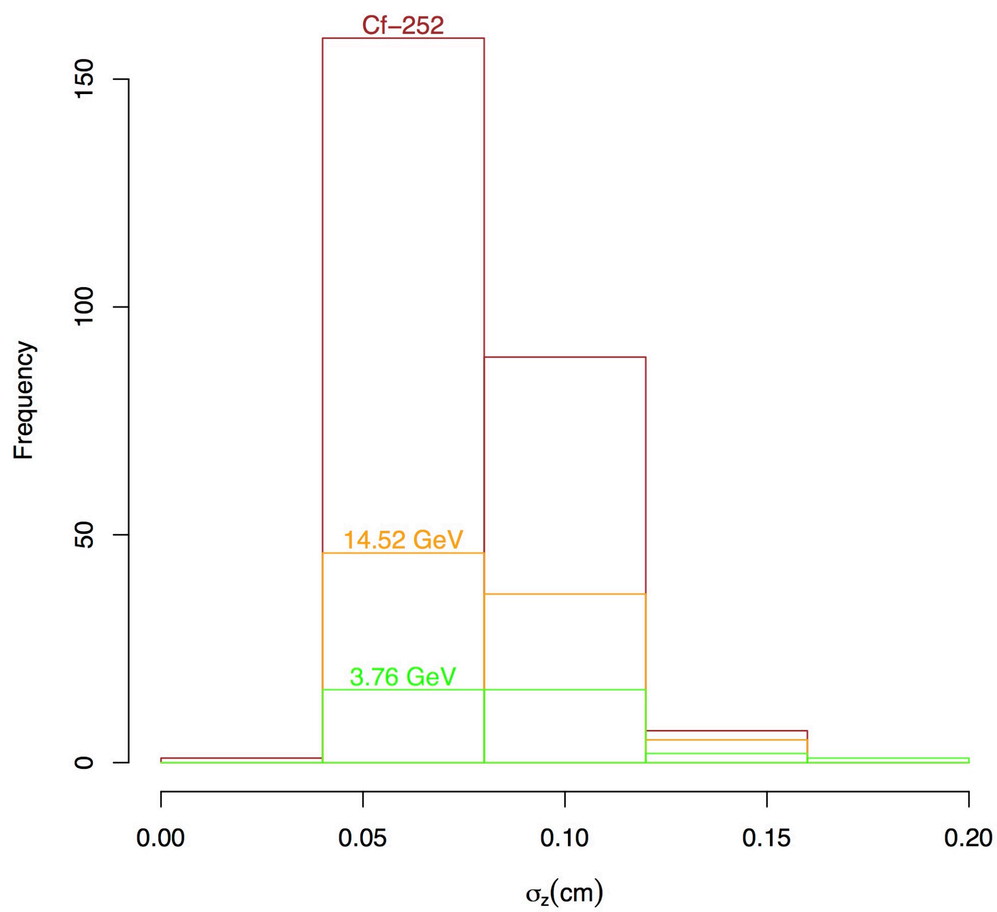
- Despite a crack in the shielding and an associated gammas flash, the performance of the detector was nominal. *You can operate a low-pressure TPC within 6 m of a beam-dump, even with poor shielding, at a nominal trigger rate.*

Initial Tests – GDR Neutrons

Number of EOT to produce one neutron through the detector		
Run Energy	GEANT4	Data
3.76 GeV	$(5.6 \pm 0.7)\times 10^6$	$(6.6 \pm 0.4)\times 10^6$
14.52 GeV	$(1.5 \pm 0.2)\times 10^6$	$(2.65 \pm 0.09)\times 10^6$

- Several hundred nuclear recoils were detected for each beam energy in agreement GDR neutron recoils from GEANT4 simulation. *Results agree with simulations.*

Initial Tests – Directionality Tests



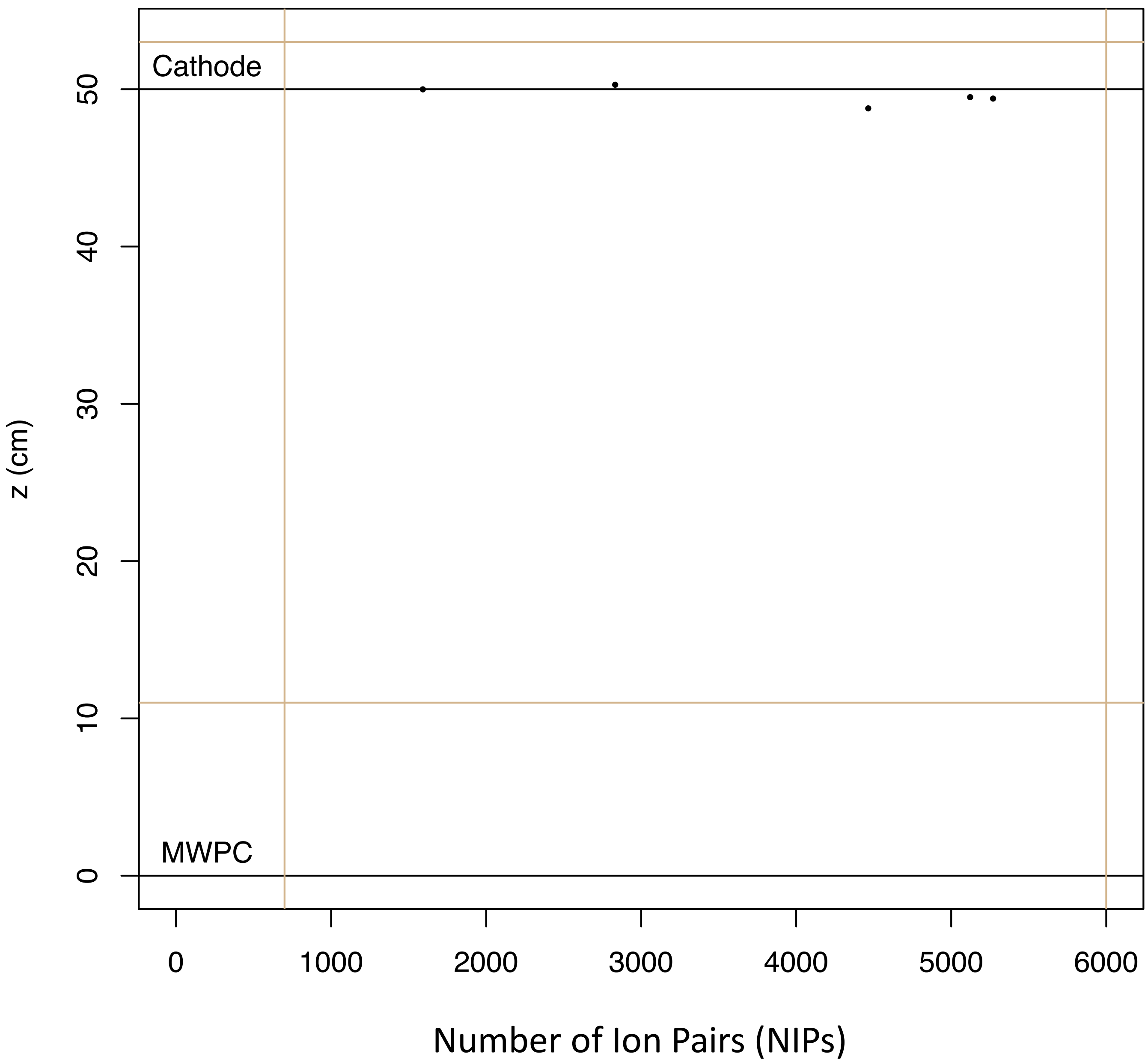
- The 2 GDR neutron distributions (3.76 GeV and 14.52 GeV) agree (KS test) with 96% confidence. They "agree" with the Cf-252 distribution with only 7% and 2% confidence. *The BDX-DRIFT detector has the expected directional capabilities.*

Conclusions

- High Z and low threshold gives a signal enhancement enough to make even a 1 m long BDX-DRIFT-1m detector competitive.
- Backgrounds are low, even on the surface of the Earth.
- You can operate a low-pressure TPC within 6 m of a beam-dump without undue trigger rate.
- GDR neutrons were detected and rate agrees with simulations establishing proof of principle.
- The BDX-DRIFT detector has directional capabilities.
- There is much more we would like to do.

Extra Slides

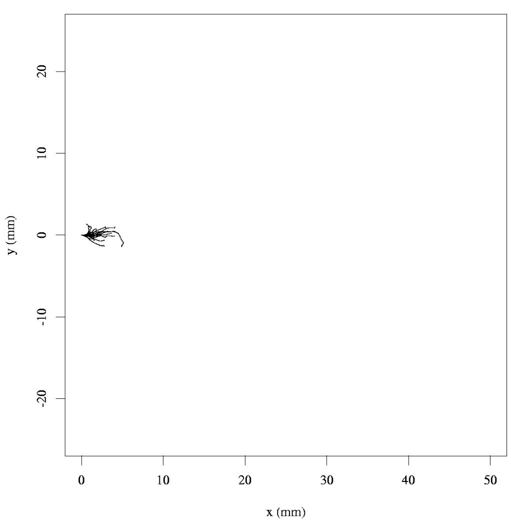
Background Co-60 shielded results – 24 days equivalent



Backgrounds

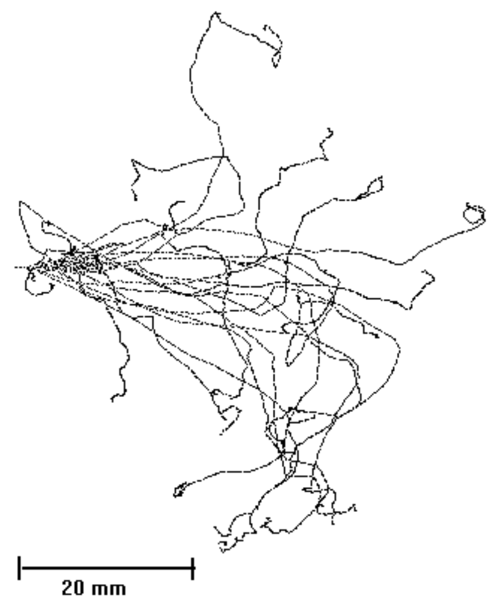
40 keV Ar recoils
from WIMPs
500 NIPs

SRIM97 - 40 keV Ar in 40 Torr Ar



13 keV e⁻s
from Compton
scatters
500 NIPs

EGS4/Presta - 13 keV e^- in 40 Torr Ar



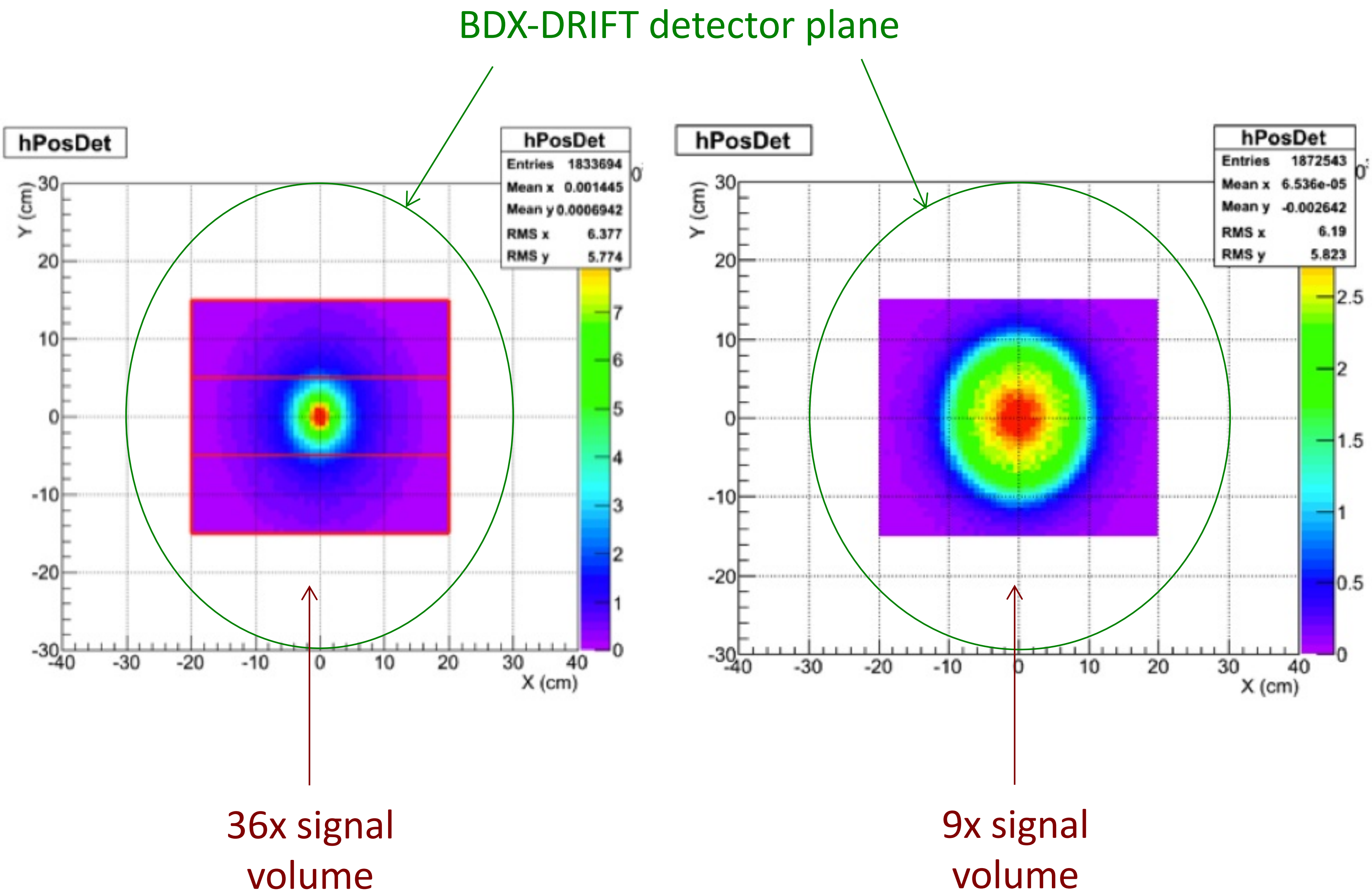
Negative Ion DRIFT

- CS_2 is highly electronegative
- CS_2^- drifts with minimal, thermal diffusion

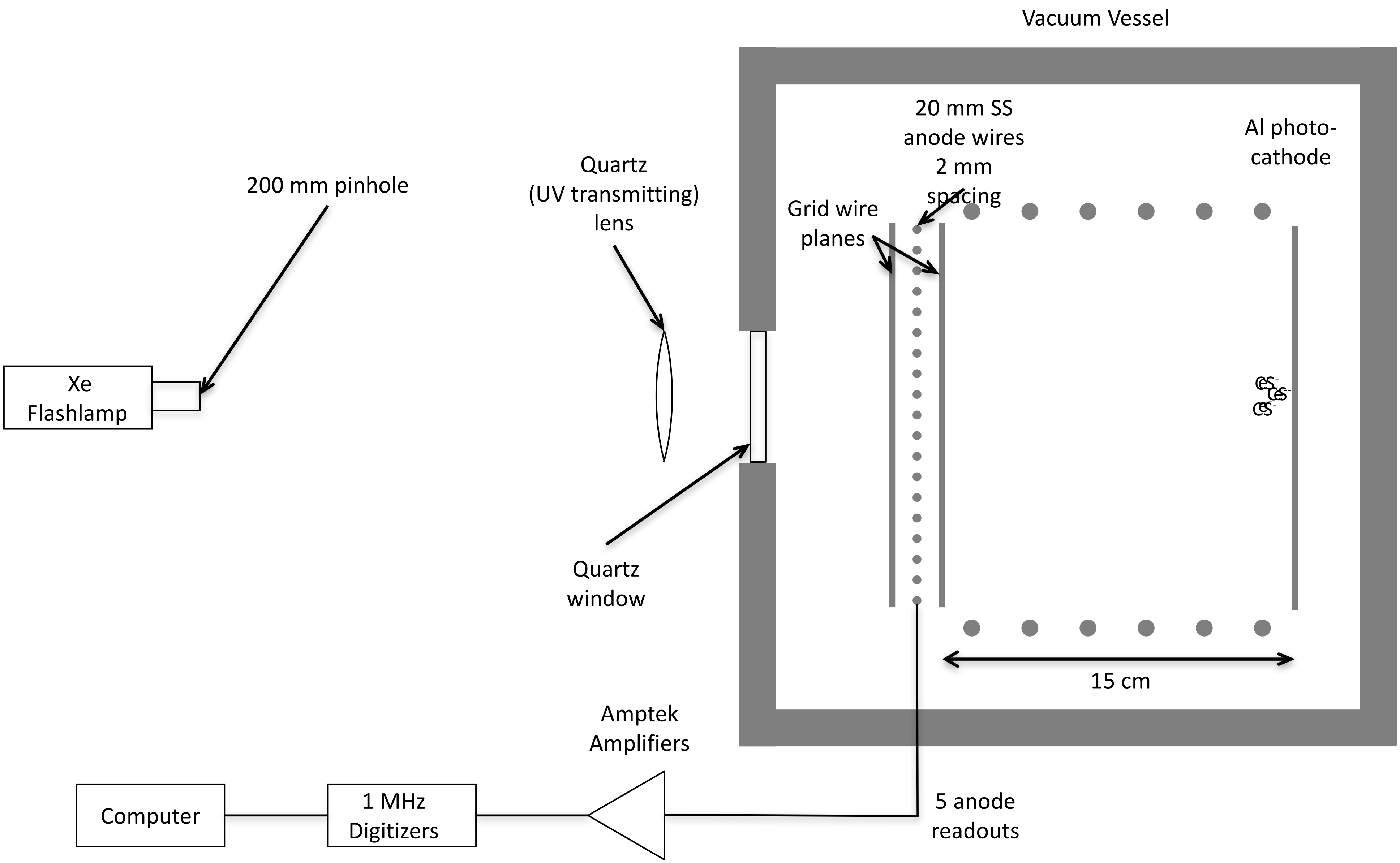
$$\sigma^2 = \frac{2kTL}{eE}$$

- e.g. rms = 0.65 mm over 50 cm drift
- After drift the negative ion releases its electron for a normal avalanche at the detector
- CS_2 also allows for fiducialization so thermal diffusion can be “subtracted” from observed diffusion

Scalable fiducial volume

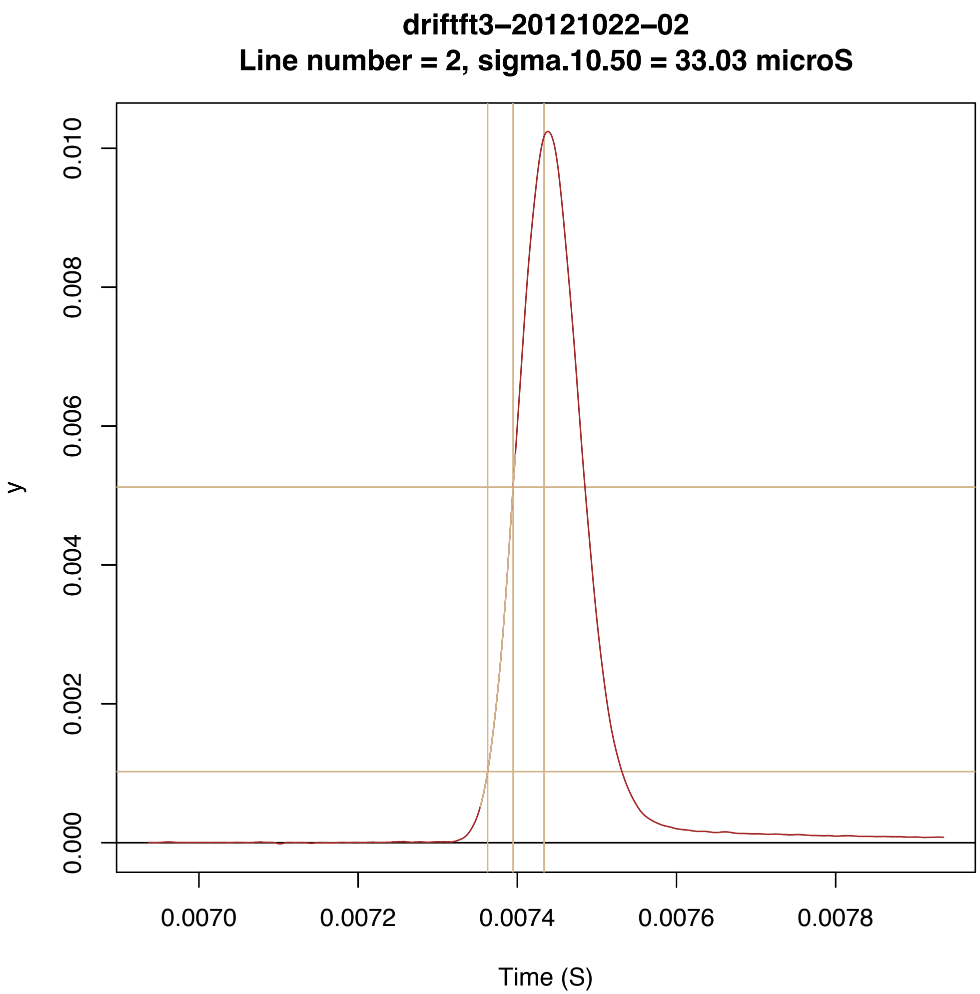


Mobility and Diffusion Experiment

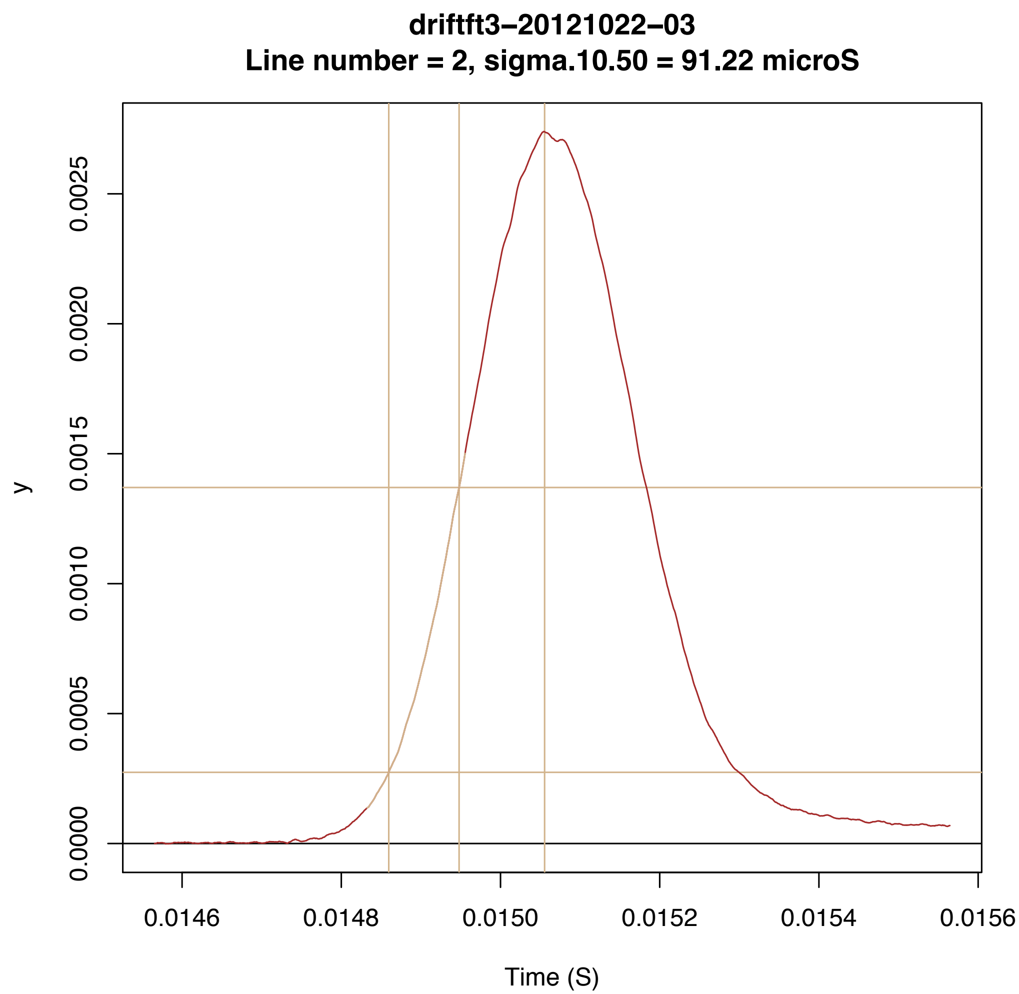


Longitudinal Diffusion Measurements

E = 239 V/cm



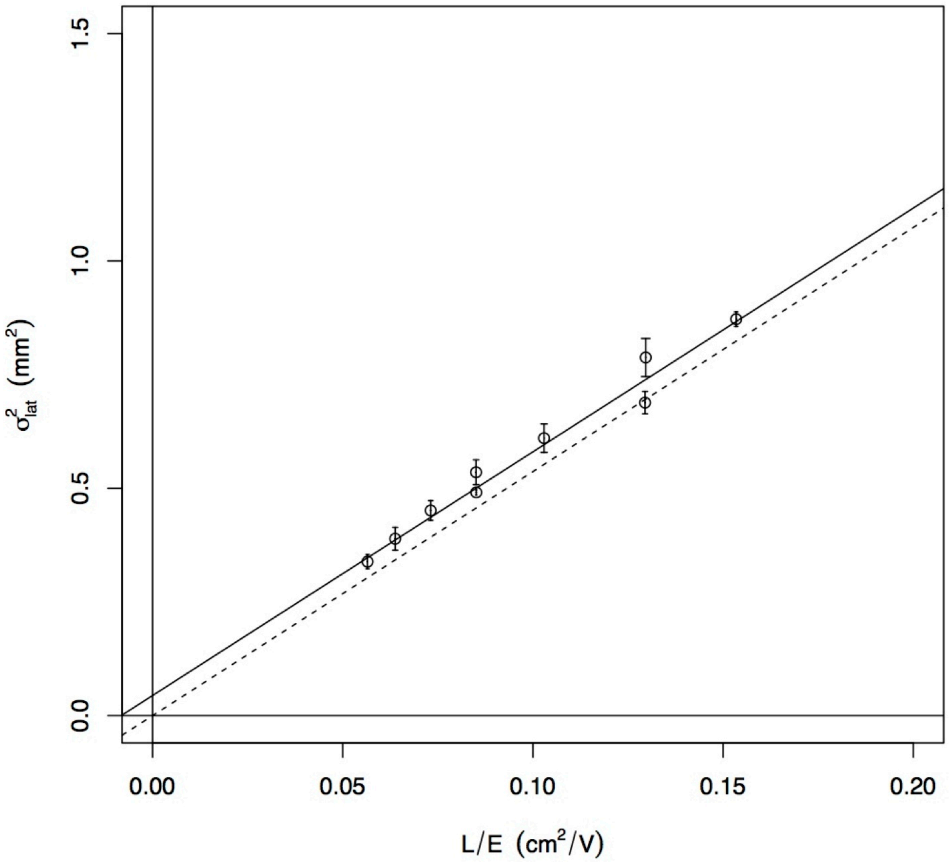
E = 118 V/cm



← t = 0 => flashlamp pulse

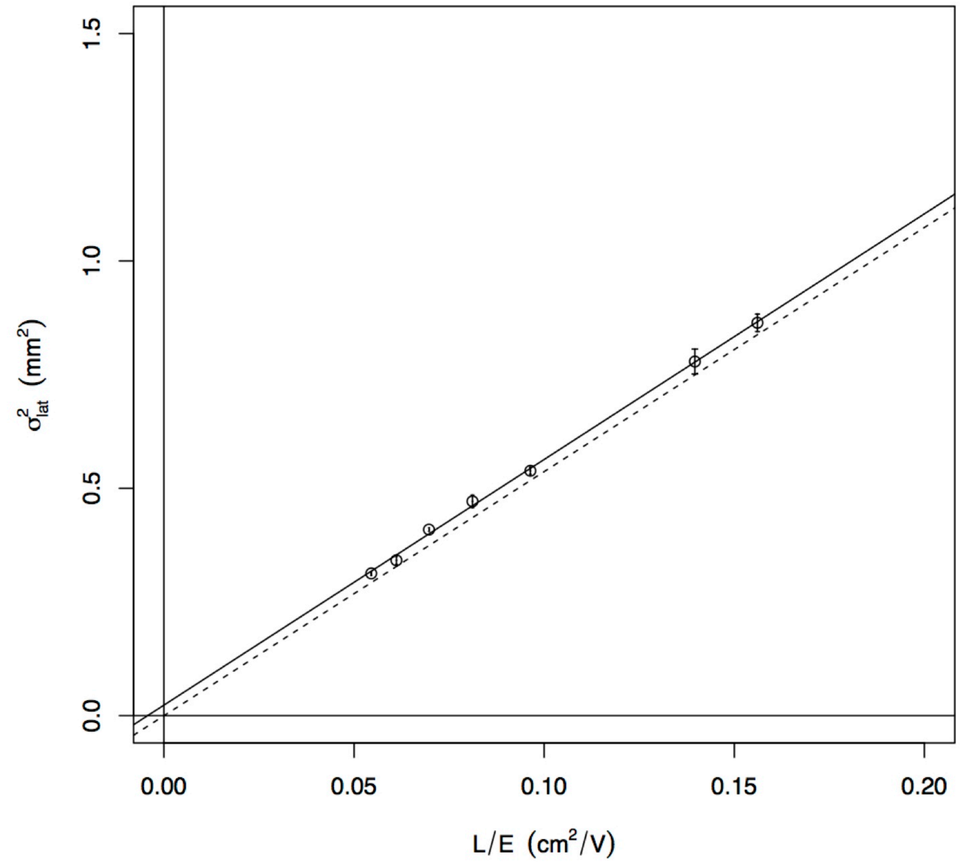
Results

40 Torr CS_2



T = 275 +/- 15 K

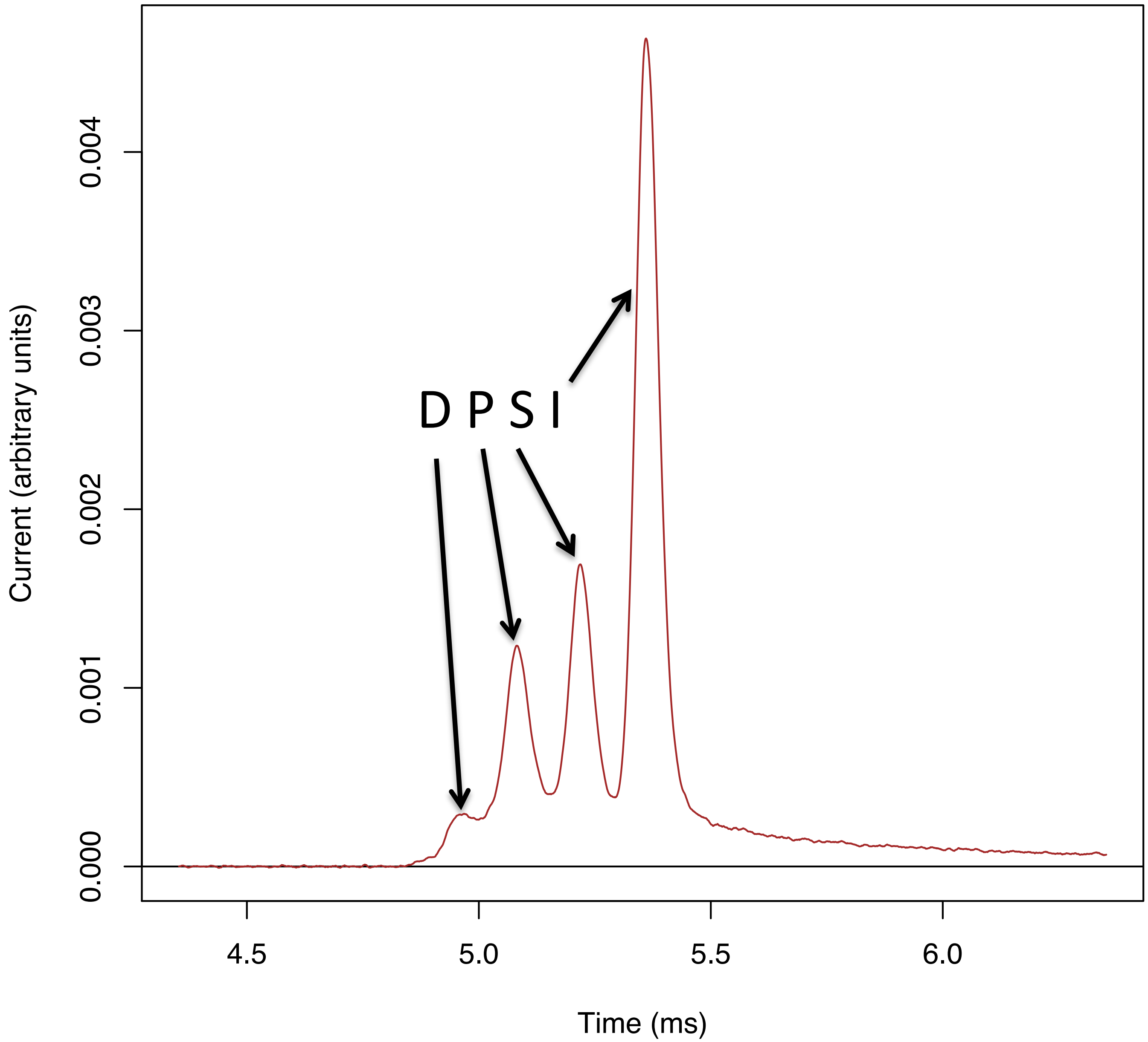
30-10 Torr CS_2+CF_4



T = 297 +/- 6 K

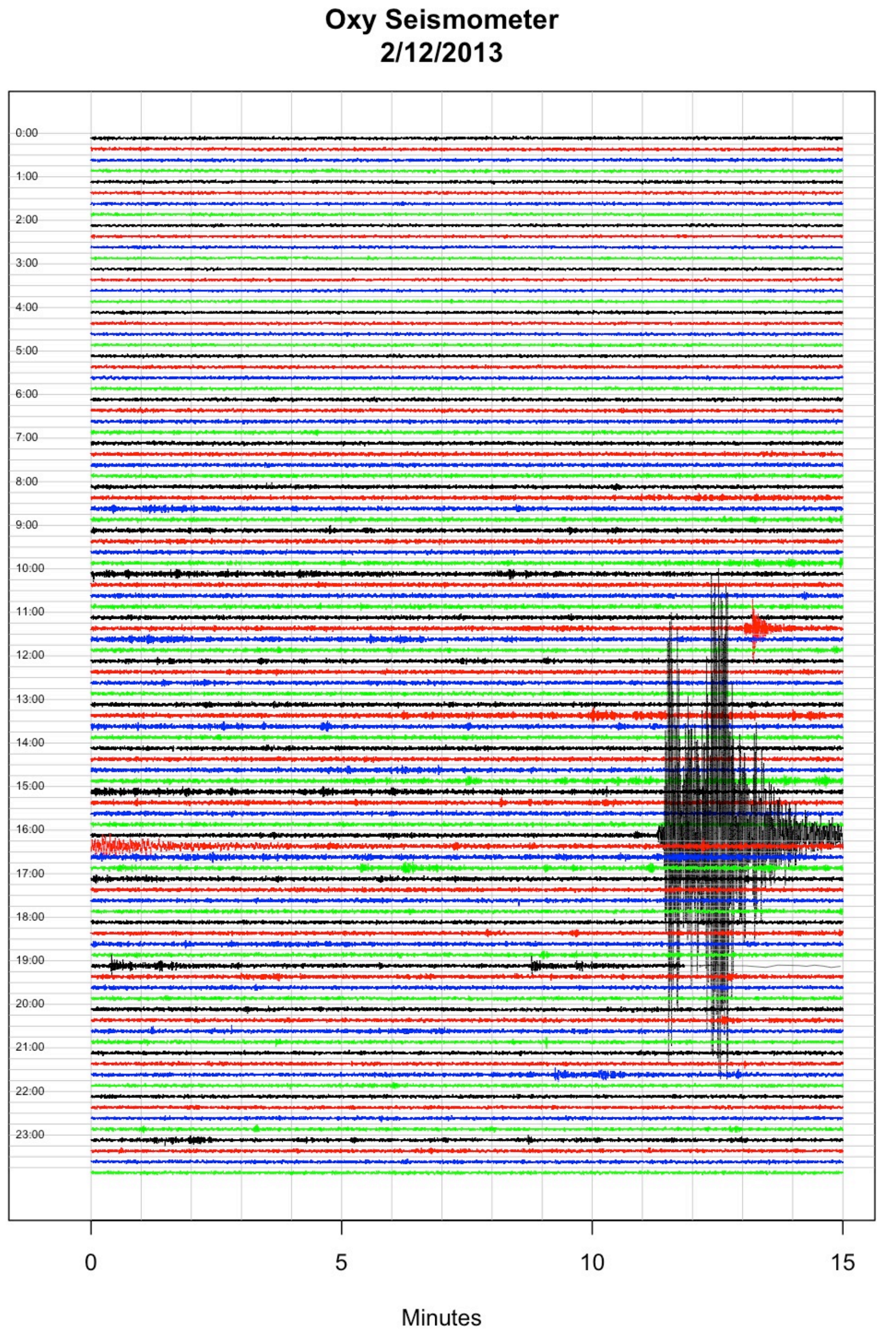
Rev. Sci. Inst., **84**, (2013) 1.

Discovery of Minority Carriers in Mixtures of CS_2 and O_2



Rev. Sci. Inst., **85**, (2014) 1.

Earthquake Fiducialization



Lightning summary of galactic directional, dark matter detection

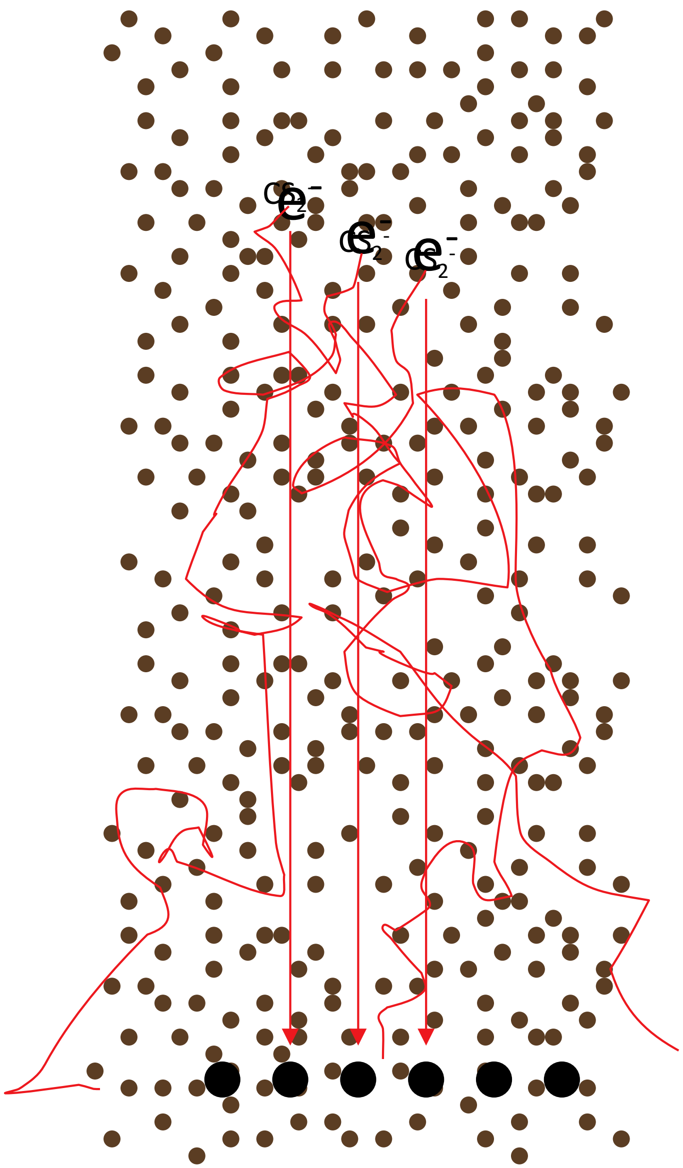
- The Milky Way's dark matter halo is supported by a thermal, RMS velocity of 281 km/s.
- Our solar system rotates through this halo with a velocity of 230 km/s creating a WIMP "wind."
- IF the dark matter is heavier than the target nuclei THEN ~1 keV/amu recoils are produced.
- Directed, on average, opposite our rotational velocity vector.
- To date the most successful directional detectors have been low pressure (~1/20 atm) TPCs.
- Directional Recoil Identification From Tracks (DRIFT)
- ~1 mm long tracks in 1,000,000,000 mm^3 volume
- Target density is $\sim 10^4$ times smaller so "How could a directional low pressure TPC possibly be competitive for LDMA searches?"

NIMA, **535**, (2004) 644.

Electron Diffusion

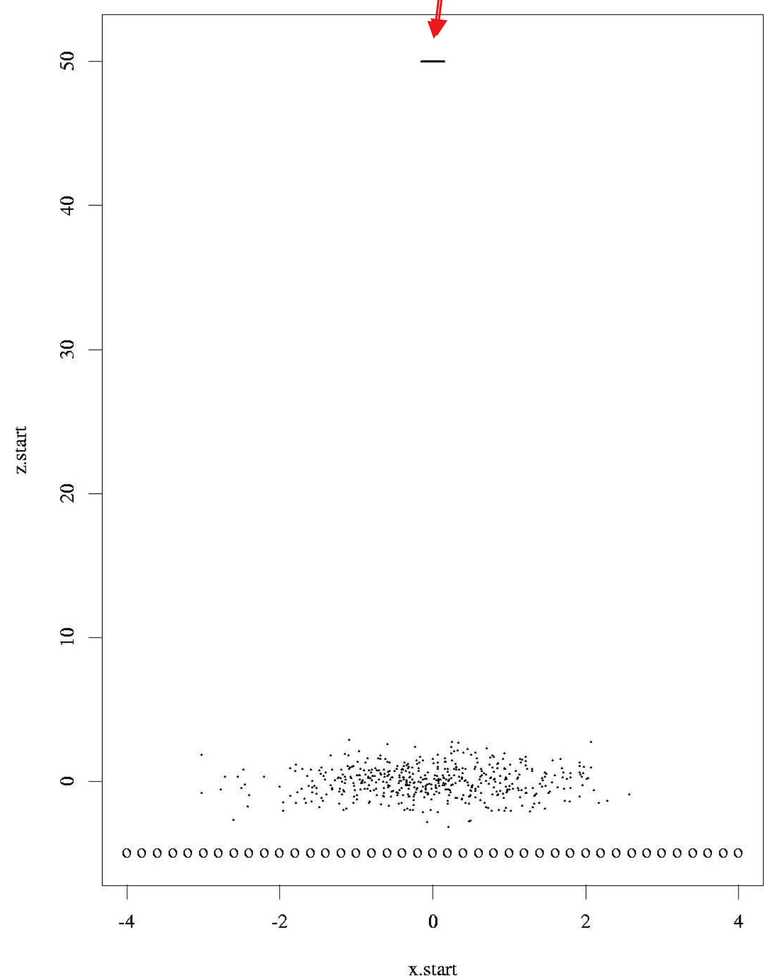
Electron diffusion is a limitation

Use an electronegative gas (CS_2) to limit diffusion

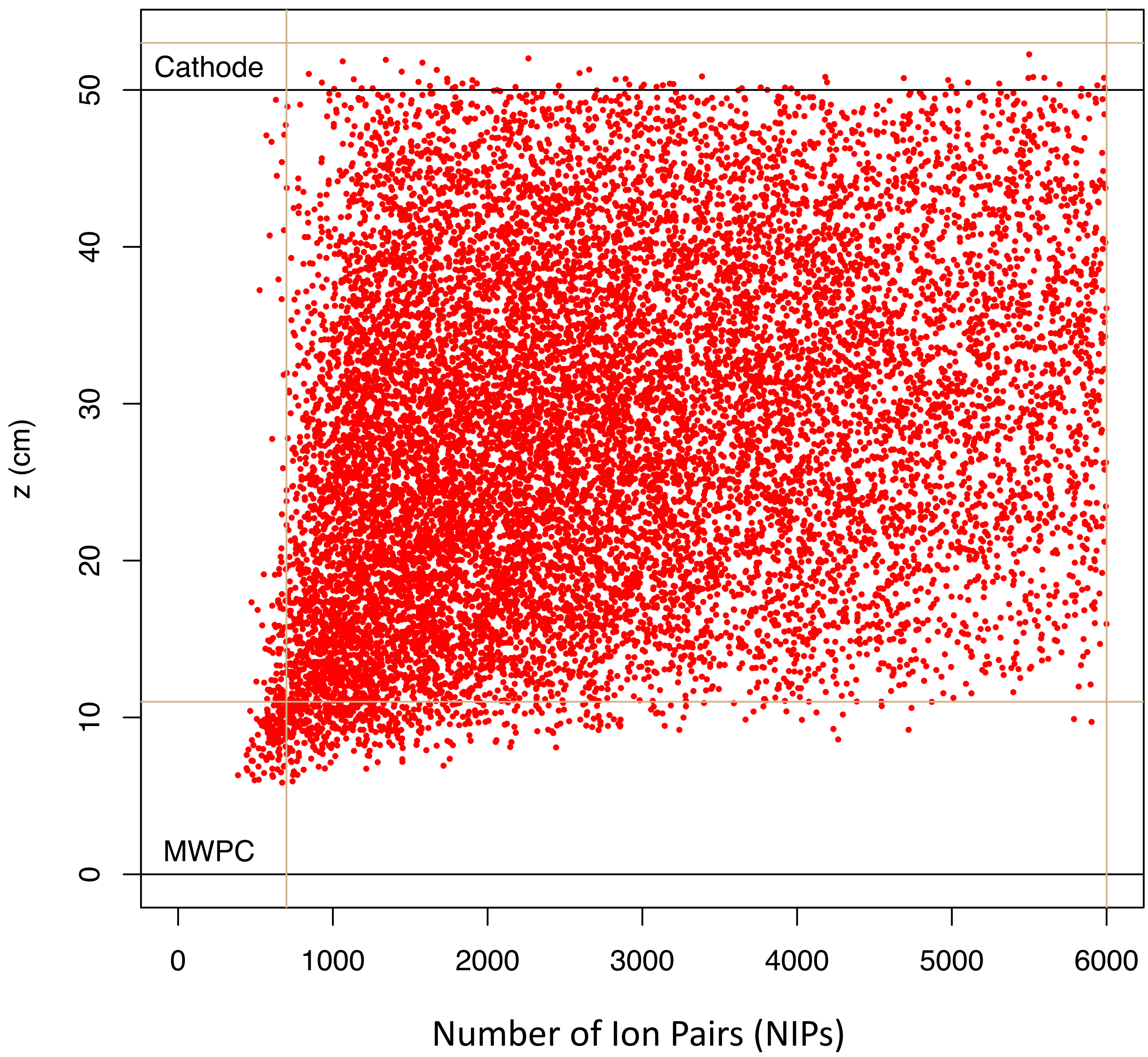


500 e^- spread over 3 mm

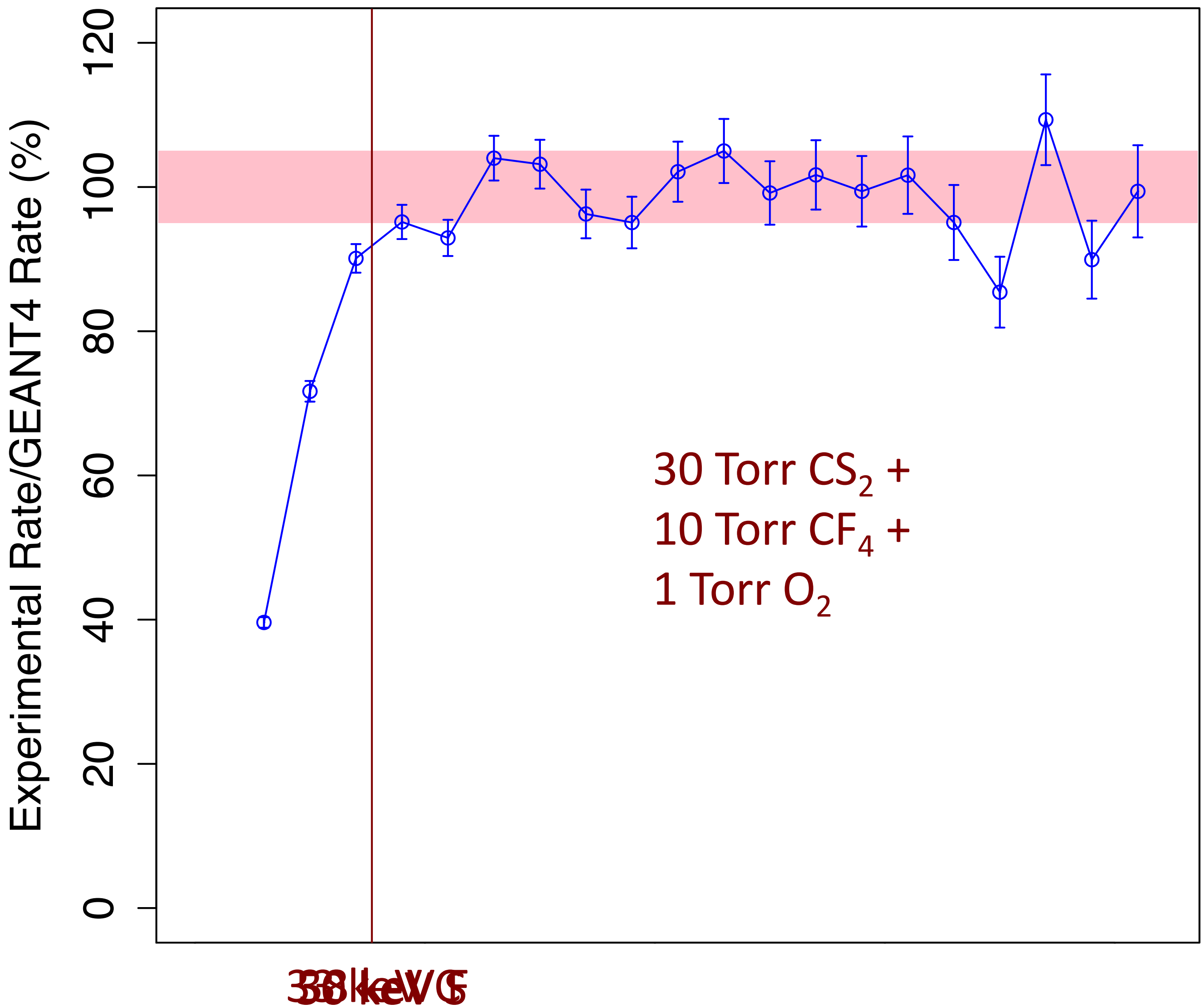
500 CS_2^- over 3 mm



Neutron recoil results –



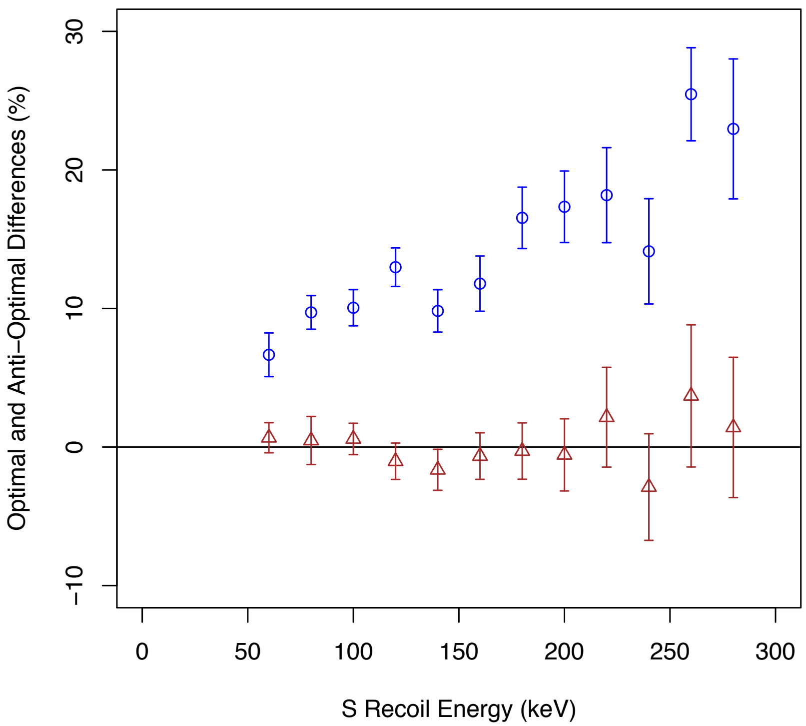
Detection efficiency after level 1 cuts



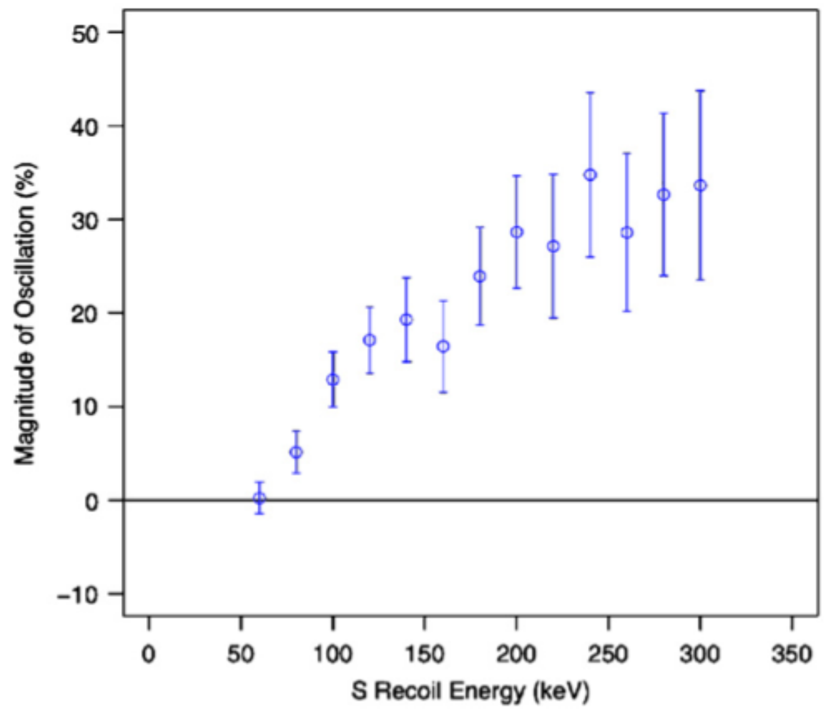
AstPle, **23**, (2007) 409.

DRIFT Directionality

DRIFT Head-Tail Results



DRIFT Range Results



AstPle, **31**, (2009) 261
NIMA, **600**, (2009) 417

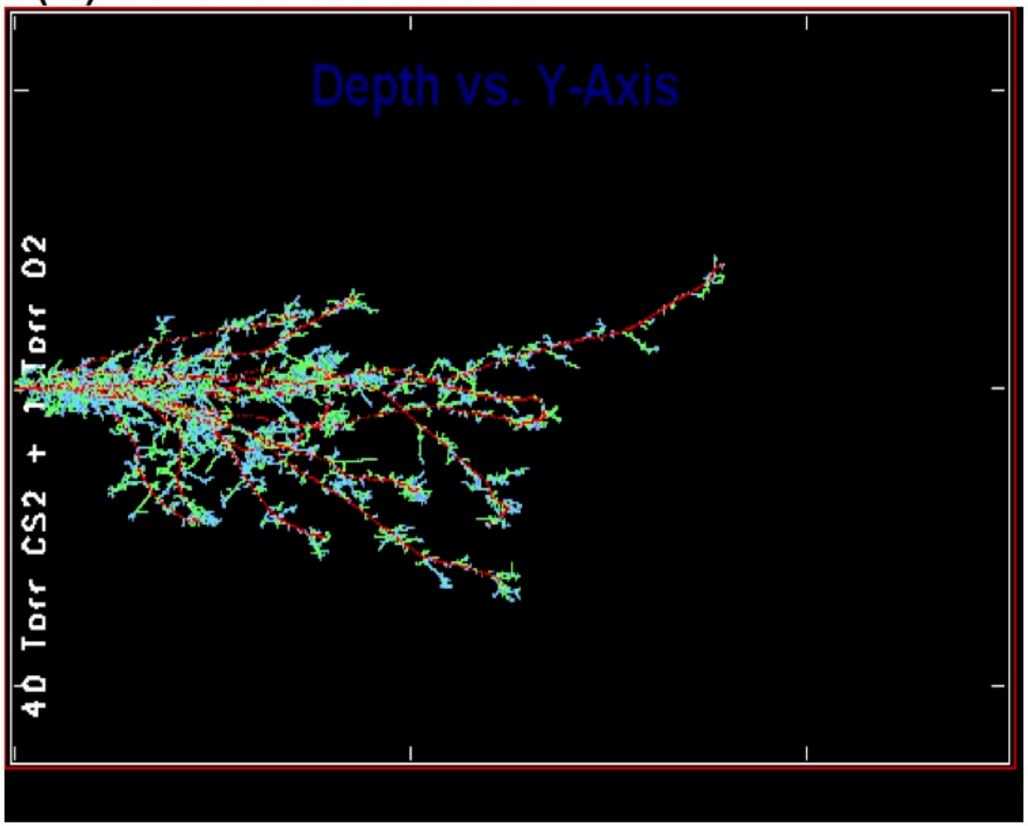
Summary of capabilities

- Stable operation of low pressure negative ion TPCs is demonstrated
- High sensitivity to low-energy, high-Z recoils e.g. 50 keV S recoils
- No known detector backgrounds
- Strong rejection ($<10^{-8}$) of betas, gammas and minimum ionizing particles
- Directionally sensitive

- Low cost
- Variable targets
- Some ability to distinguish target recoils

Straggling

S (50) into 40 Torr CS2 + 1 Torr O2



20 Ions Calculated

Ion Type = S
Ion Energy = 50 keV
Ion Angle = 0

SRIM-2008.04
June 20, 2015
www.SRIM.org

Calculation Parameters:

Backscattered Ions 0
Transmitted Ions 0
Vacancies/Ion 313.2

ION STATS	**Range**	**Straggle**
Longitudinal	996. um	353. um
Lateral Proj.	276. um	331. um
Radial	446. um	196. um

Type of Damage Calculation
Full Cascades

Stopping Power Version
SRIM-2008

% ENERGY LOSS	**Ions**	**Recoils**
Ionization	40.98	17.41
Vacancies	0.46	2.17
Phonons	1.81	37.17

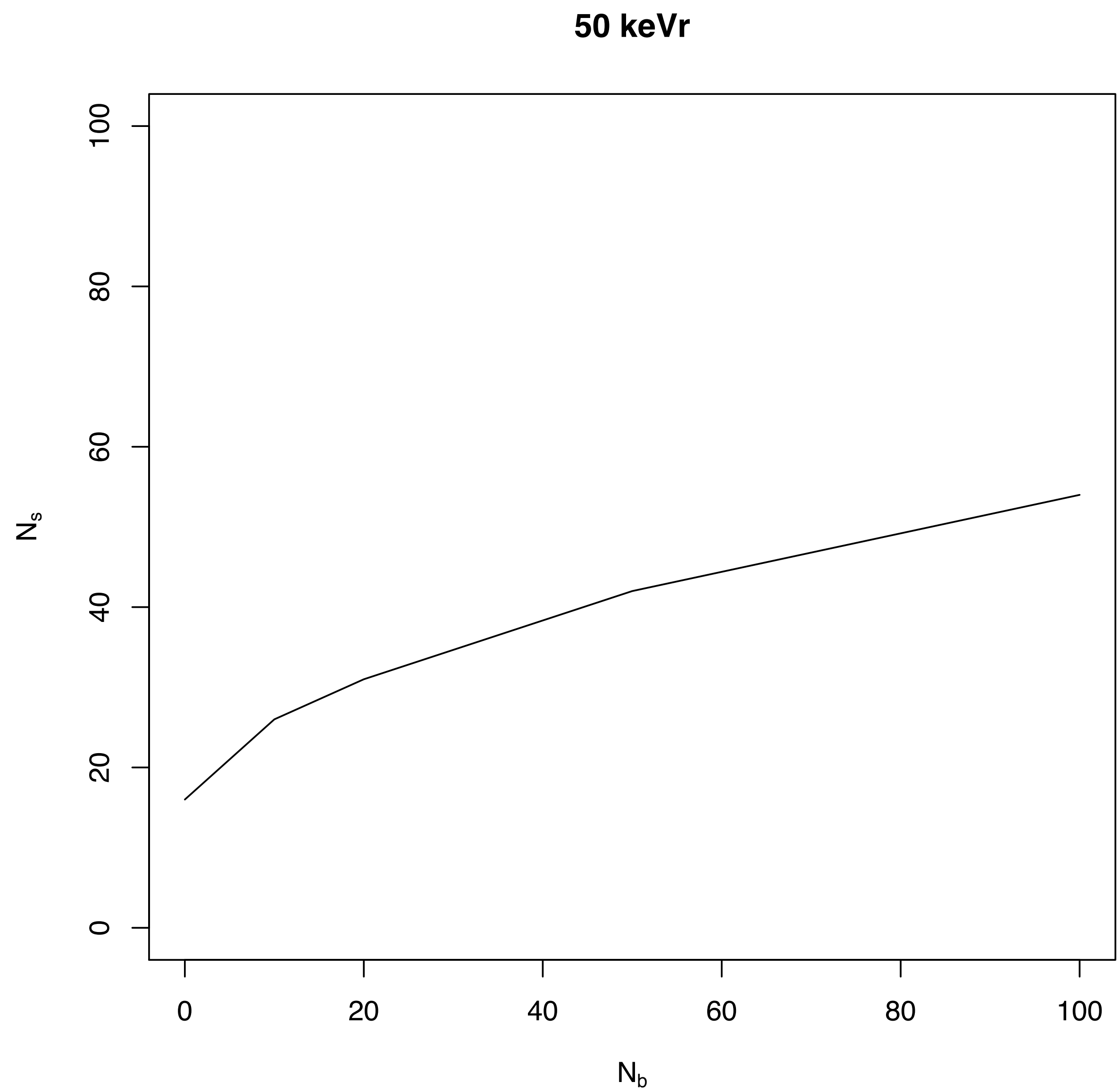
SPUTTERING YIELD

	Atoms/Ion	eV/Atom
TOTAL	0.100	
C	0.0500	47.69
S	0.0500	42.62
O	0.000000	0.00

Target layers:

		Moving atom colors ->						
		Stopped atom colors ->						
	Layer Name	Width (A)	Density	C (12.011)	S (32.066)	O (15.999)	Solid/Gas	Stop Corr.
1	40 Torr CS2 + 1 Torr O2	25000000	0.000166	0.32787	0.65574	0.01639	Gas	1
	Lattice Binding Energy			3	3	3		
	Surface Binding Energy			7.41	2.88	2		
	Displacement Energy			28	25	28		

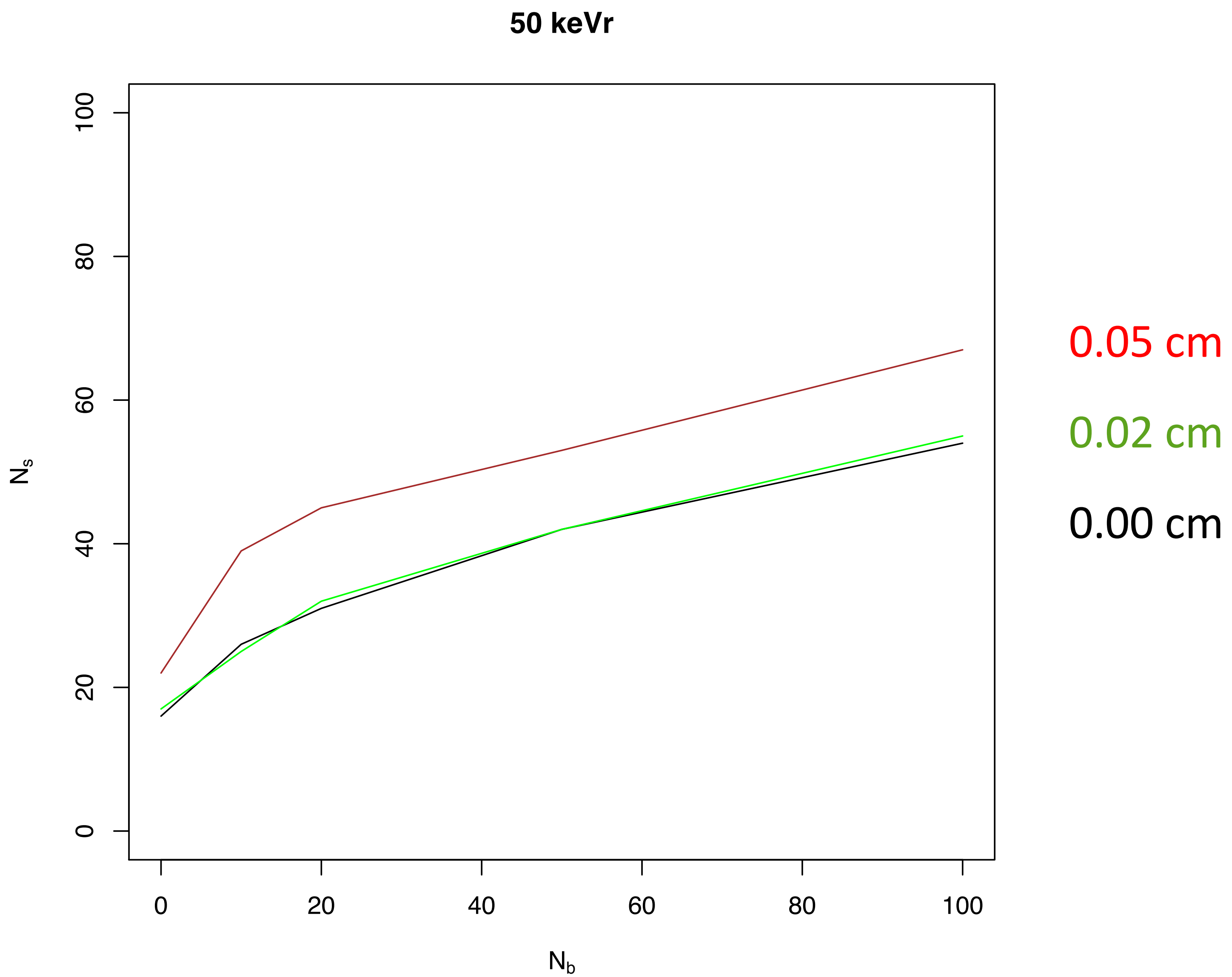
Directional Signal and Isotropic Background



Detector resolution

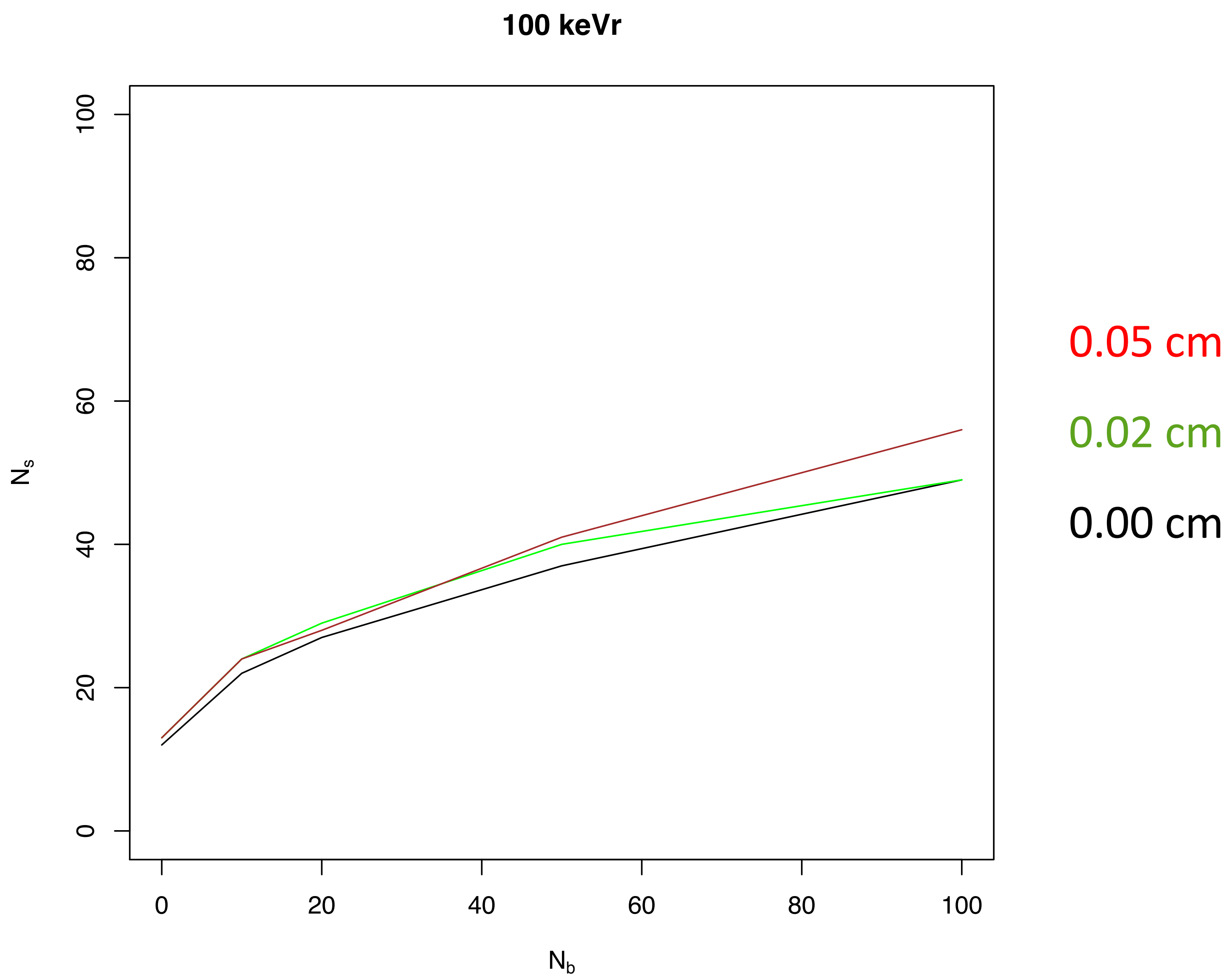
$$\sigma^2_{z,measured} = \frac{2kTL}{eE} + \sigma^2_{z,ionization} + \sigma^2_{z,smoothing} + \sigma^2_{z,path} + \sigma^2_{z,capture}$$

Directional Signal and Isotropic Background



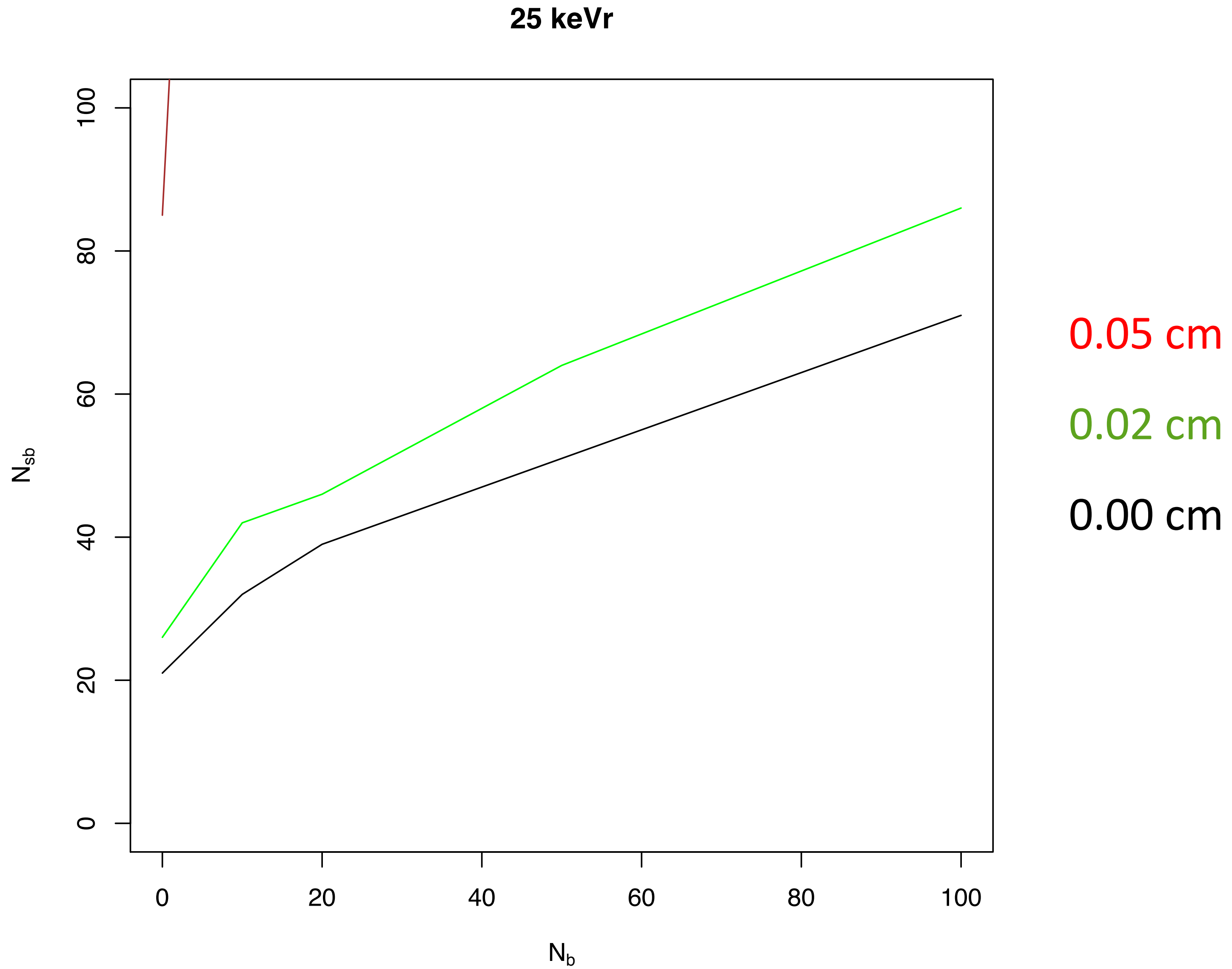
R(50 keVr S) = 0.086 cm

Directional Signal and Isotropic Background



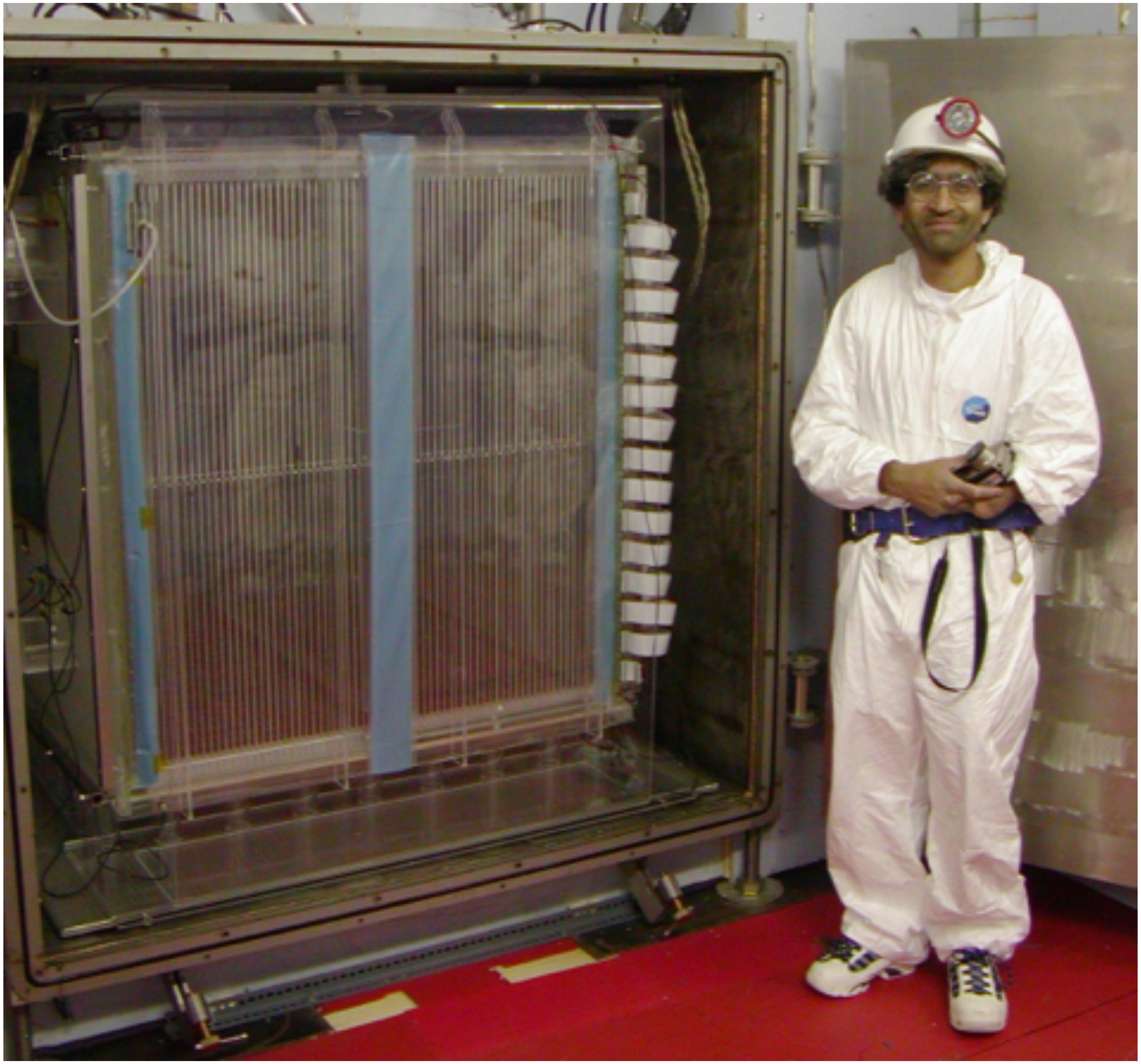
R(100 keVr S) = 0.170 cm

Directional Signal and Isotropic Background

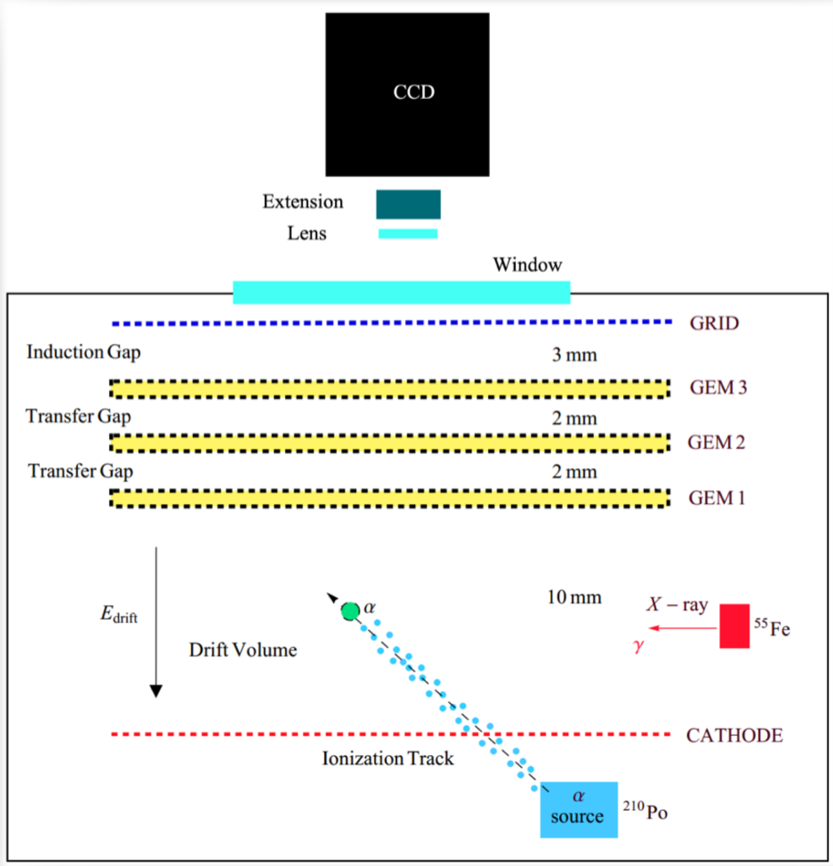


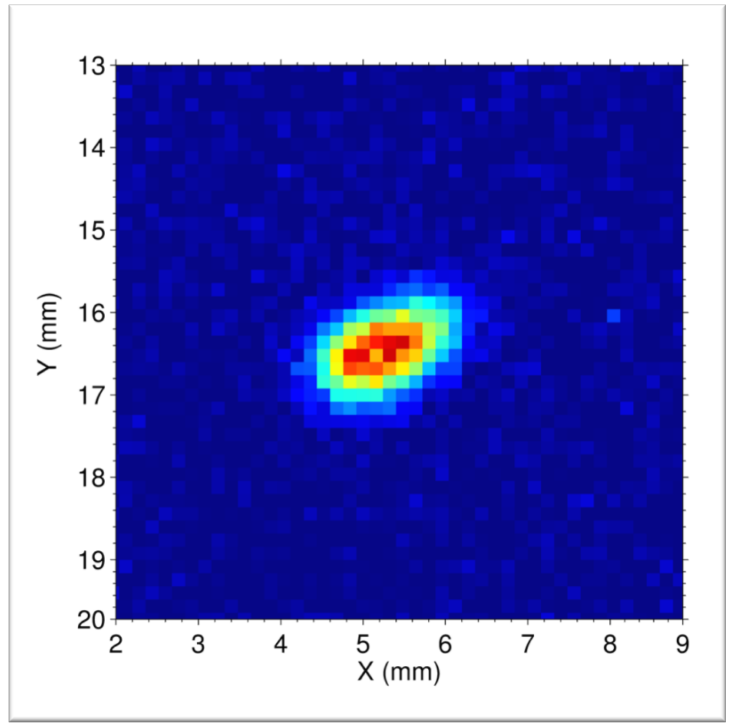
R(25 keVr S) = 0.046 cm

UNM Collaborator Dinesh Loomba



High Definition (HD) DRIFT detectors at UNM





- Triple GEM (gas electron multiplier) low pressure TPC with optical readout.
  - Three 7 cm x 7 cm CERN GEMs (140 µm pitch, 50-70 µm hole dia., ~ 50 µm thick)
  - FLI Back-illuminated CCD (13 µm pix., 1024 x 1024) + 58 mm F 1.2 Nikon lens.
  - 1 cm conversion gap, 3 cm x 3 cm imaging area.

- 104 keV F recoil in 100 Torr CF_4
- An approximation of a 50 keV S recoil in 40 Torr CS_2
- Working on 3D imaging of tracks at sub-mm resolution over large areas.
- Should improve particle ID, background rejection and threshold.