DMTPC: A Directional Dark Matter Experiment

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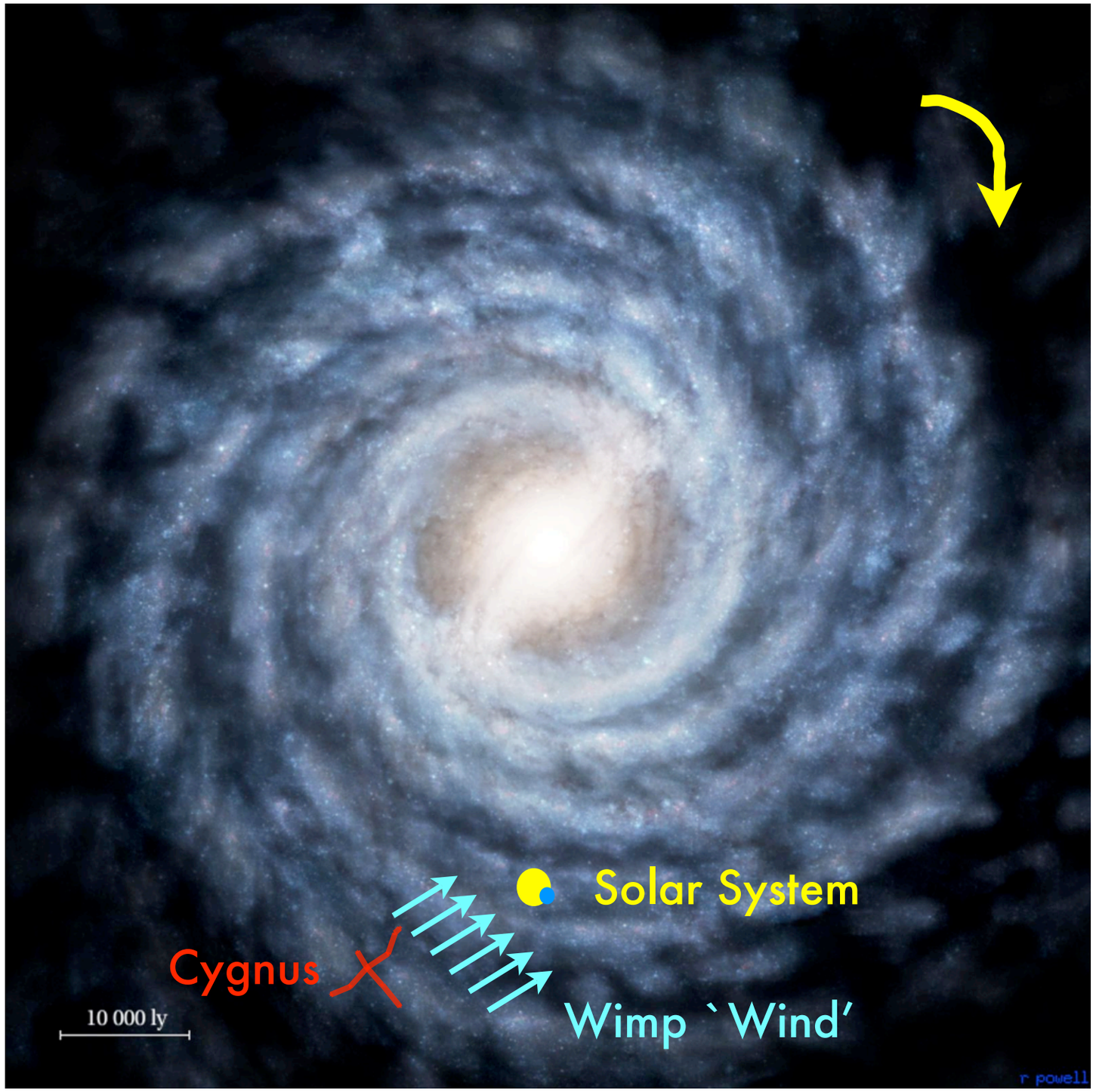
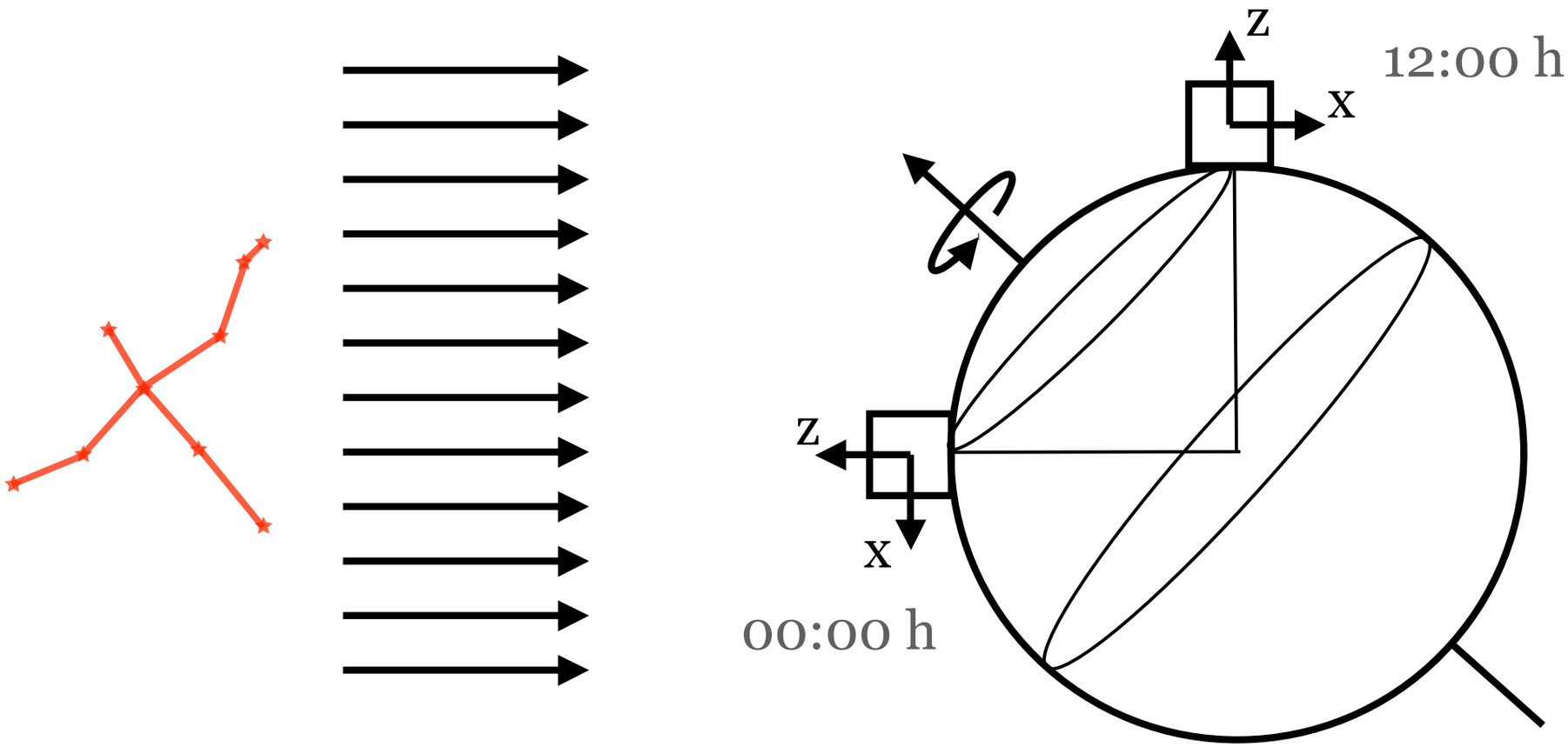
NDM, 1 Sept 2009

Why Directionality?



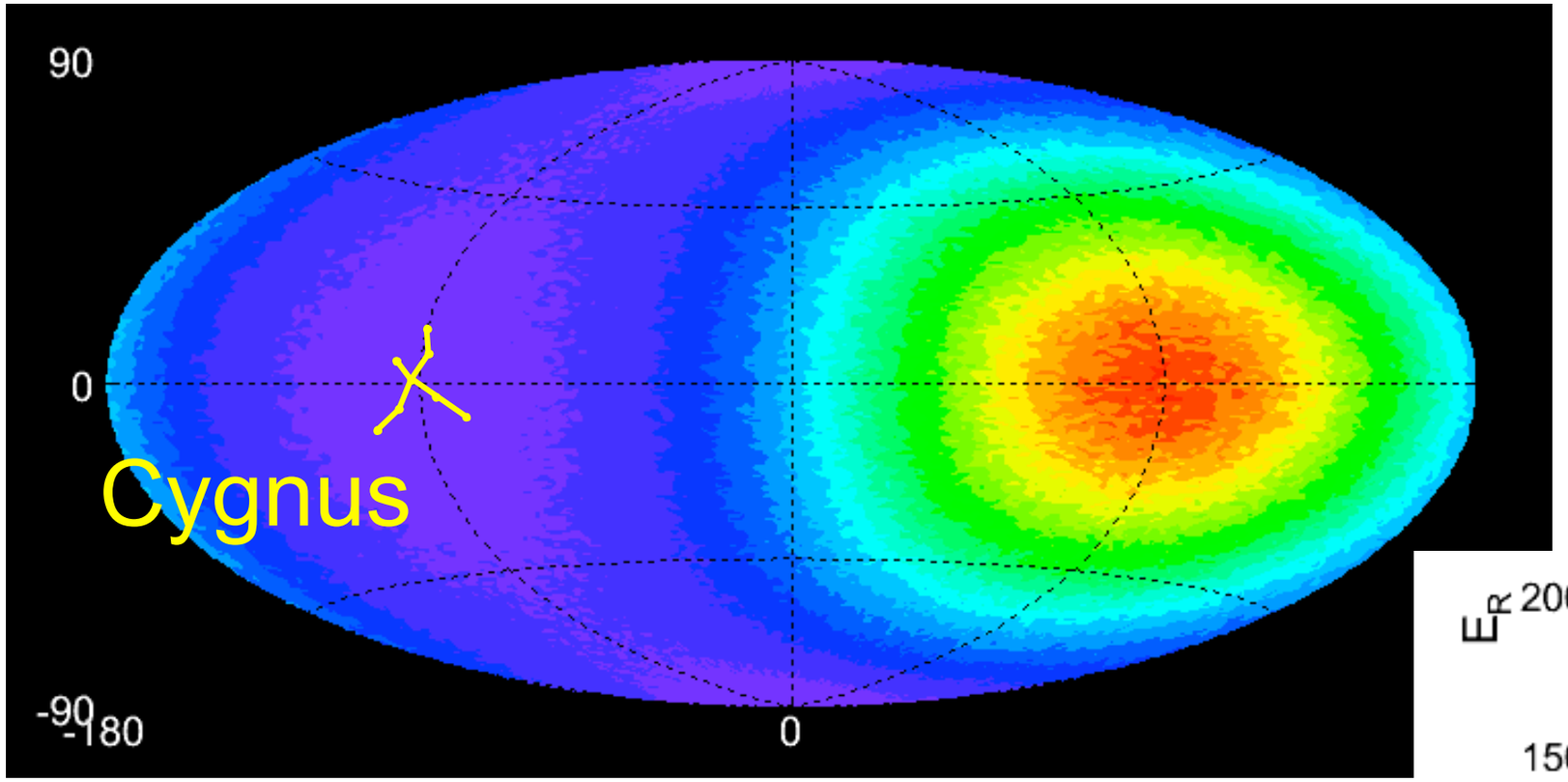
Signal Modulation

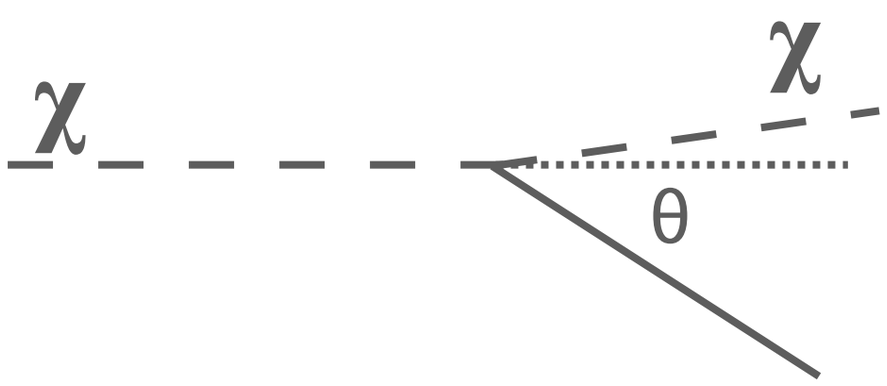


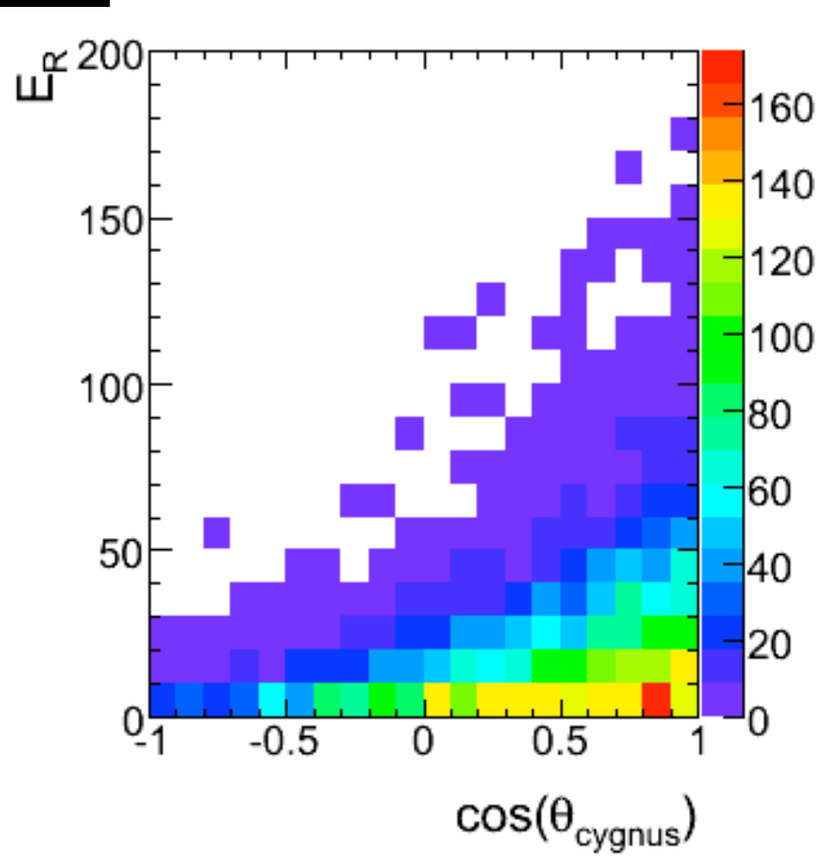
$$\frac{dR}{dE\ d\cos\gamma} \propto \exp\left[-\left(\frac{(v_E + v_\odot)\cos\gamma - v_{min}}{v_{halo}}\right)^2\right]$$

Spergel, Phys.Rev. D37 (1988) 1353

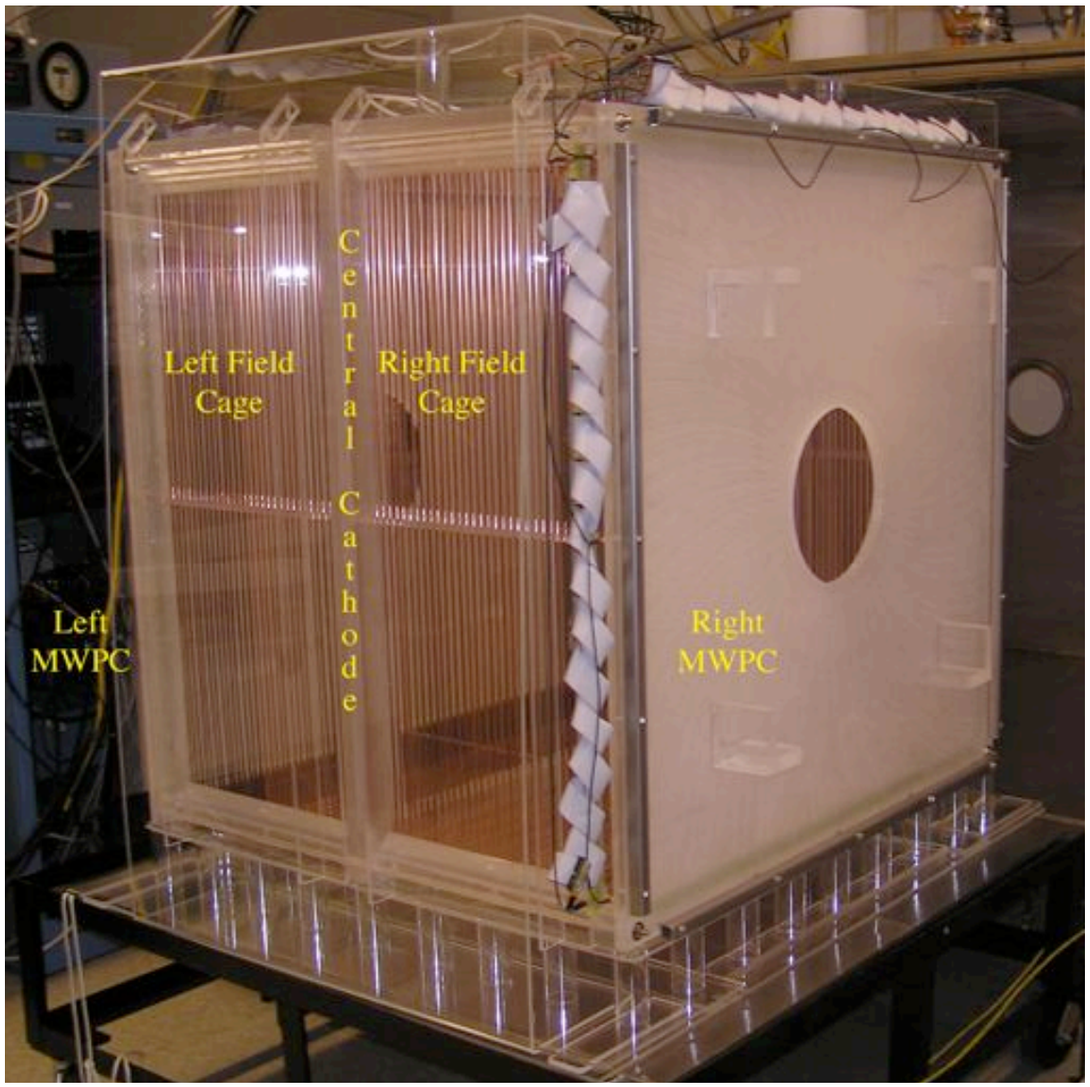
Dark Matter Recoils







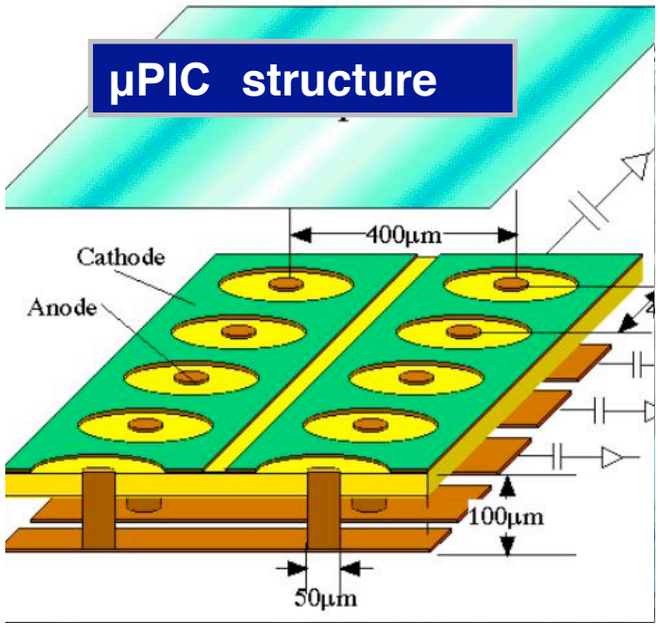
Wire TPCs
(DRIFT)

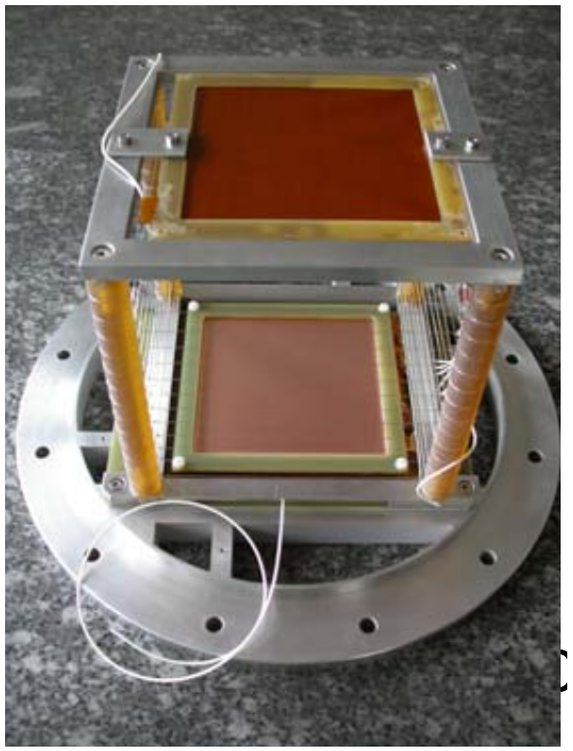


- `Grandfather' of directional experiments
- Uses negative ion drift with CS_2
- Has operated underground underground at Boulby in England for several years

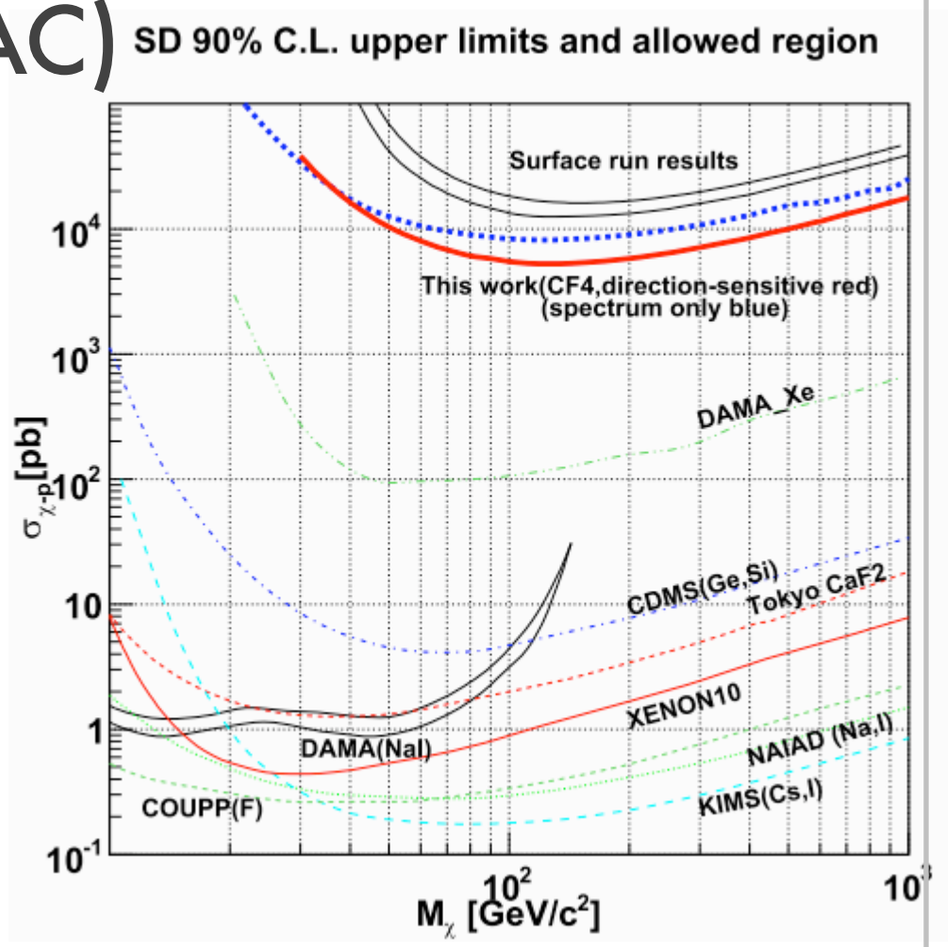
Micropattern Detectors

(NEWAGE, MIMAC)





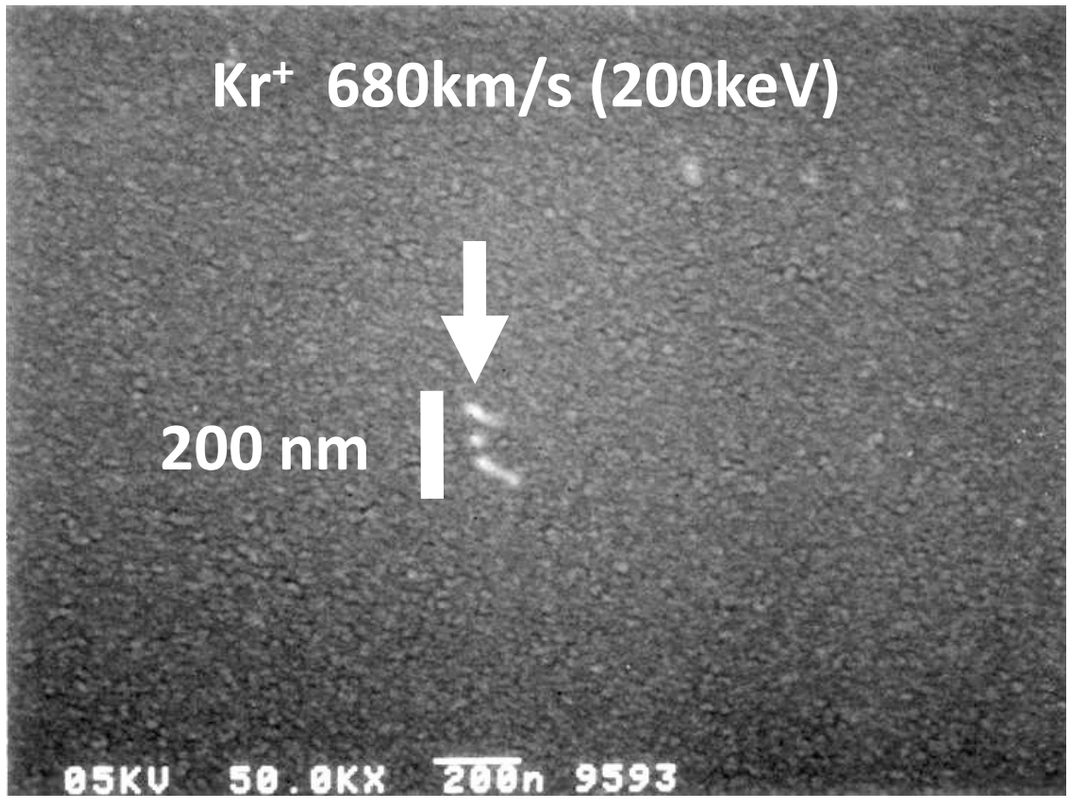
- Method is to use electronic readout of small pixels to reconstruct recoils
- NEWAGE uses μpics; MIMAC uses micromegas



- Small pixelization for excellent 3D-angle resolution
- Readout can be bulky and expensive

Emulsions

- Old technology repurposed for dark matter
- AgBr and gelatin emulsion with highly improved resolution
- Use emulsion expansion and optical microscope scanning for track recognition



DMTPC Collaboration

Boston University

S. Ahlen (PI) , A. Inglis, H. Tomita

Brandeis University

A. Dushkin, S. Goyal, F. Golub, B. N. Skvorodnev, H. Wellenstein (PI)

Massachusetts Institute of Technology

P. Fisher (PI), G. Sciolla, R. Yamamoto, D. Dujmic, R. Vanderspek, J. Battat, J. Monroe, S. Henderson, A. Kaboth, J. Lopez, T. Caldwell, A. Lee, T. Sahin, I. Wolfe, H. Yegorian

Detector Papers

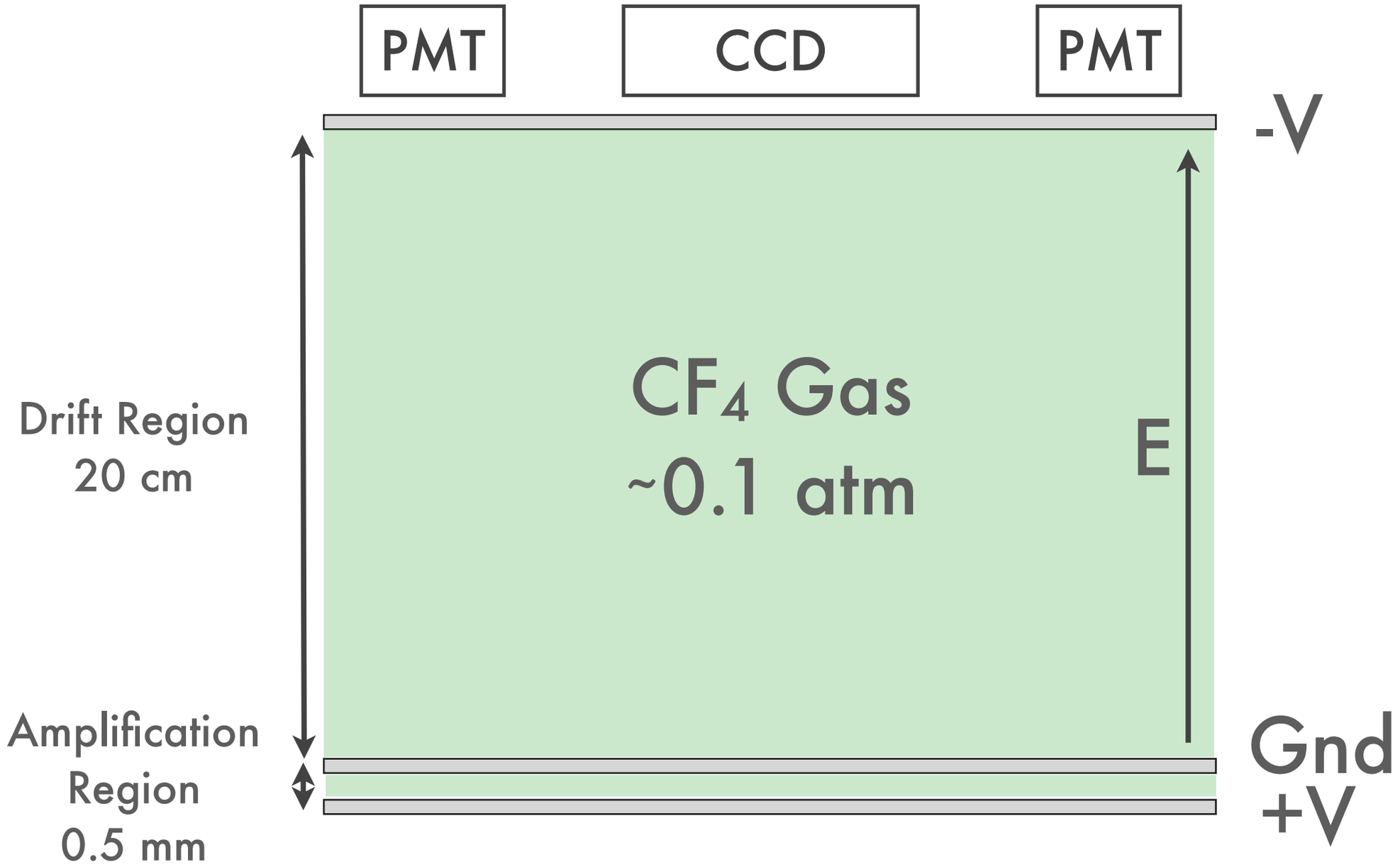
D. Dujmic et al. [DMTPC] NIMA 584 (2007)

A. Kaboth et al. [DMTPC] NIMA 592 (2008)

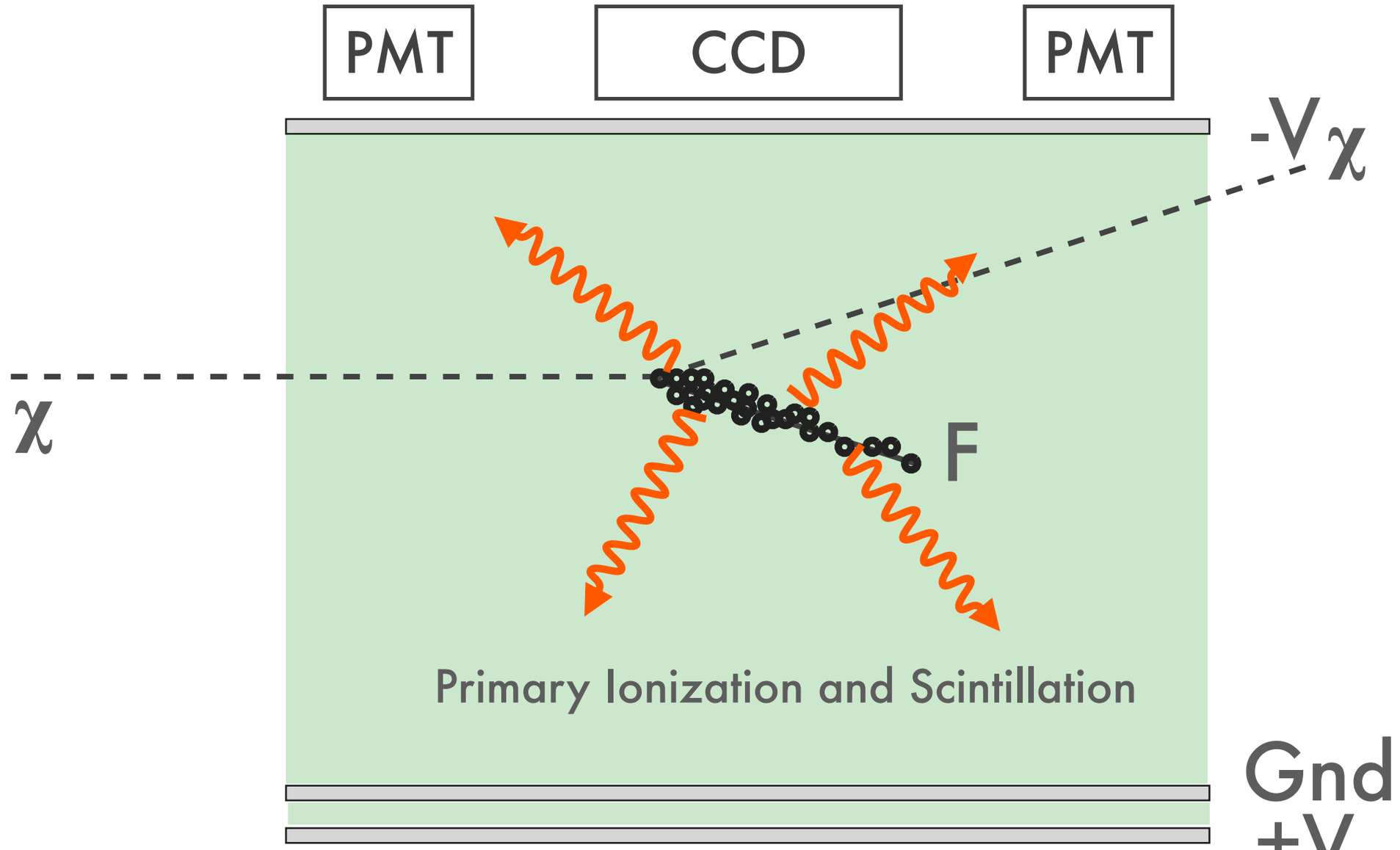
D. Dujmic et al. [DMTPC] Astropart. Phys 30 (2008)

T. Caldwell et al. [DMTPC] arXiv:0905.2549 (2009)

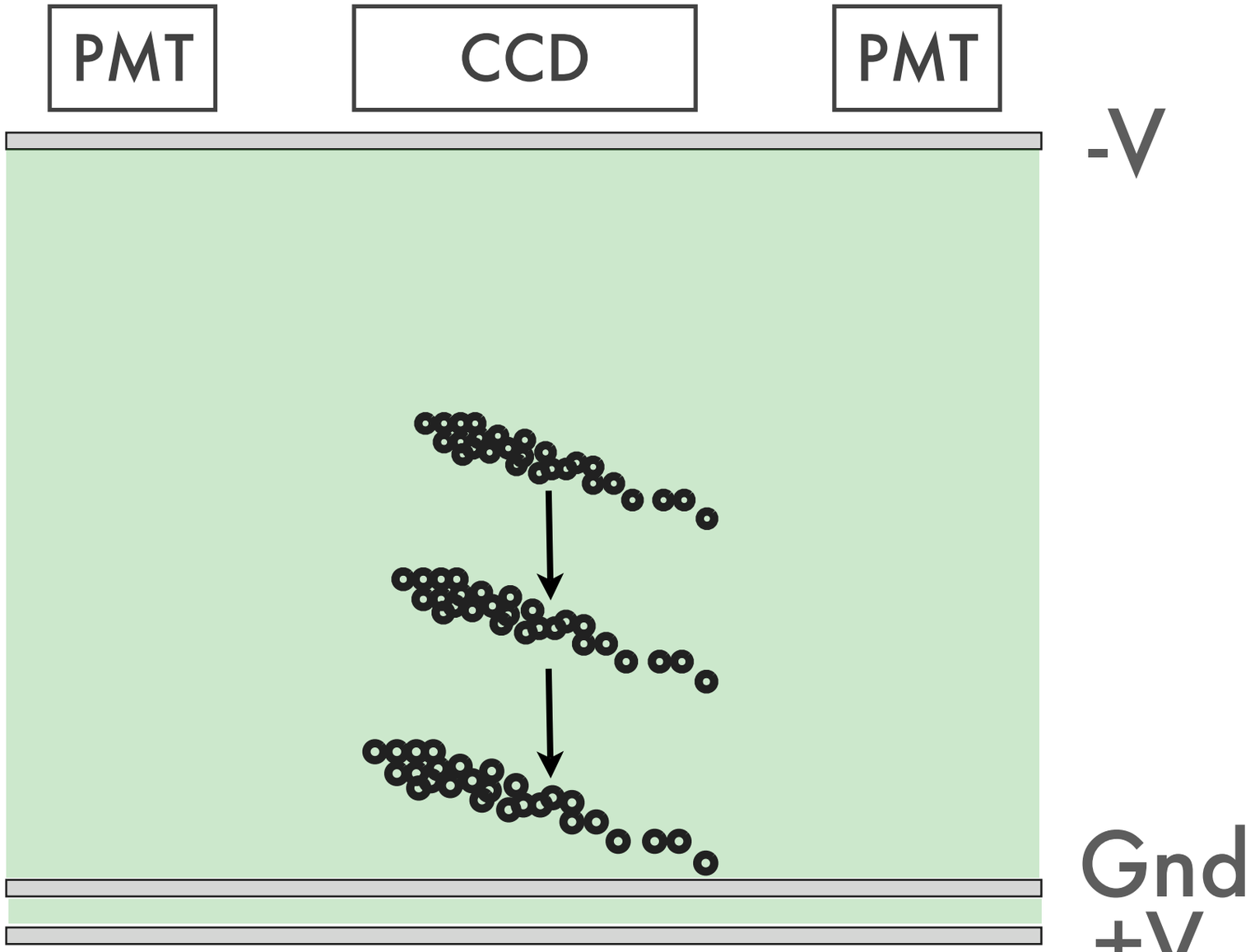
Detector Concept



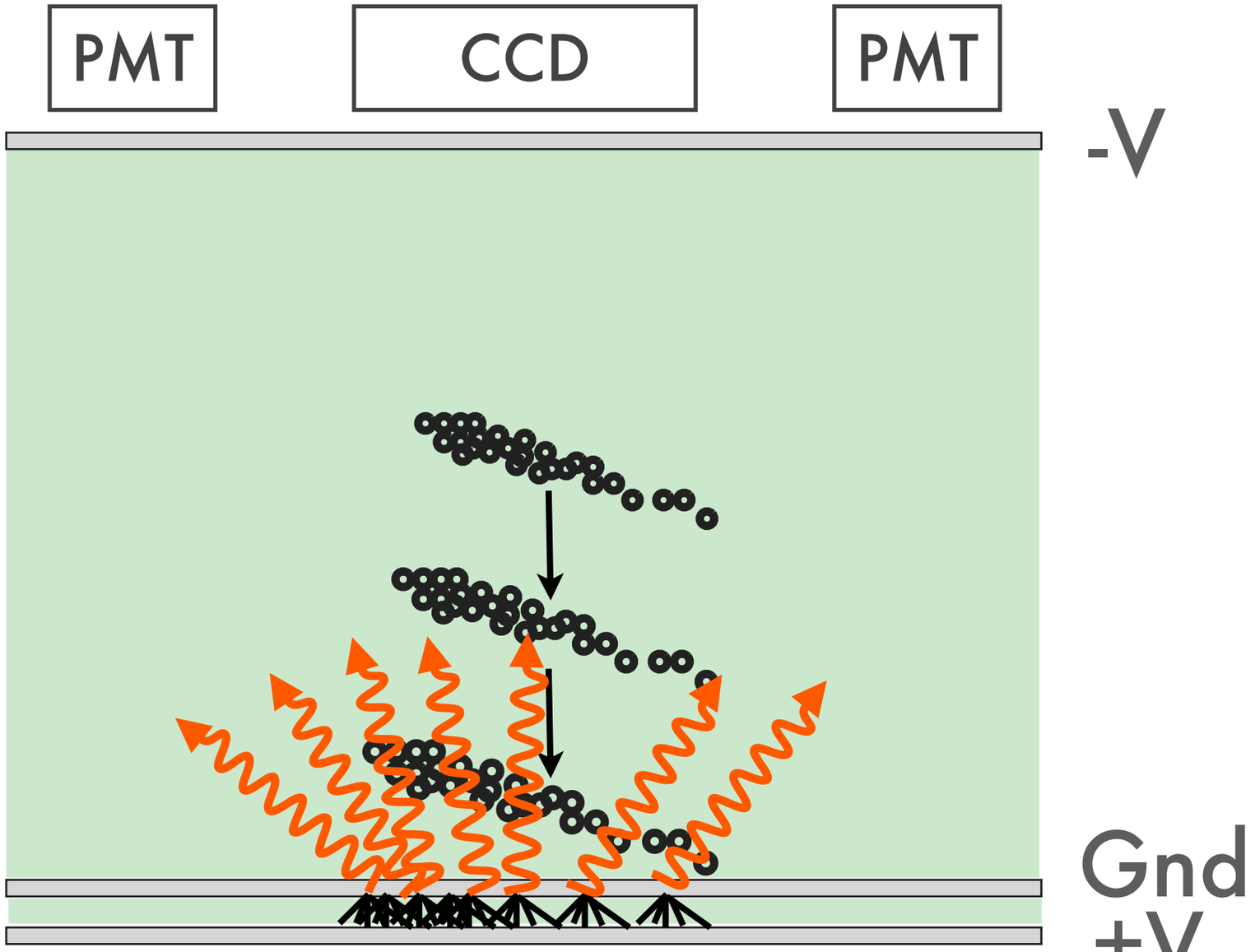
Detector Concept



Detector Concept



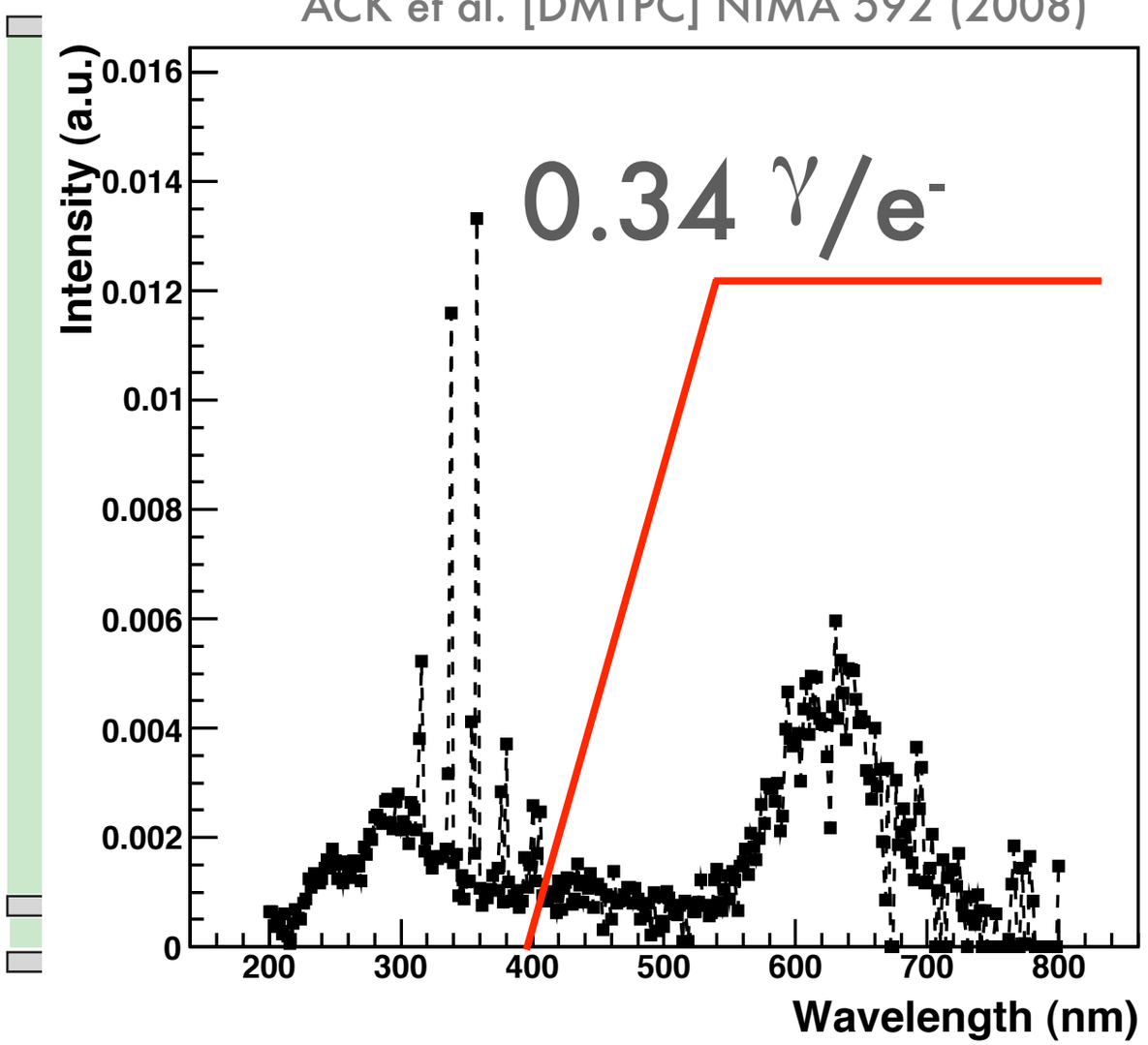
Detector Concept



Detector Concept

PMT CCD PMT

ACK et al. [DMTPC] NIMA 592 (2008)

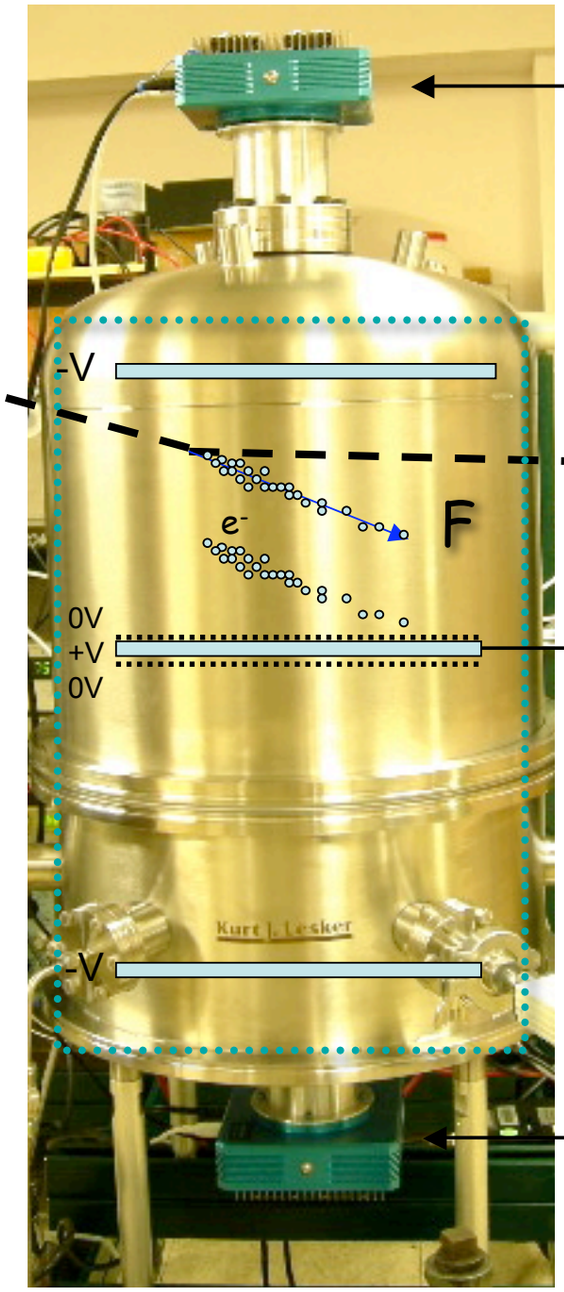


-V

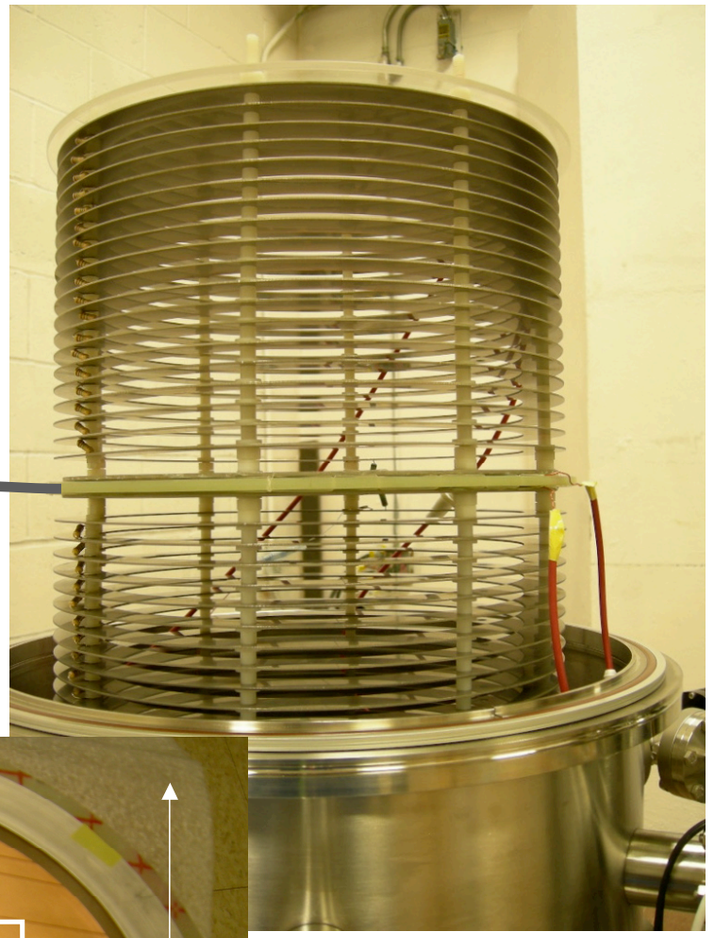
Gnd

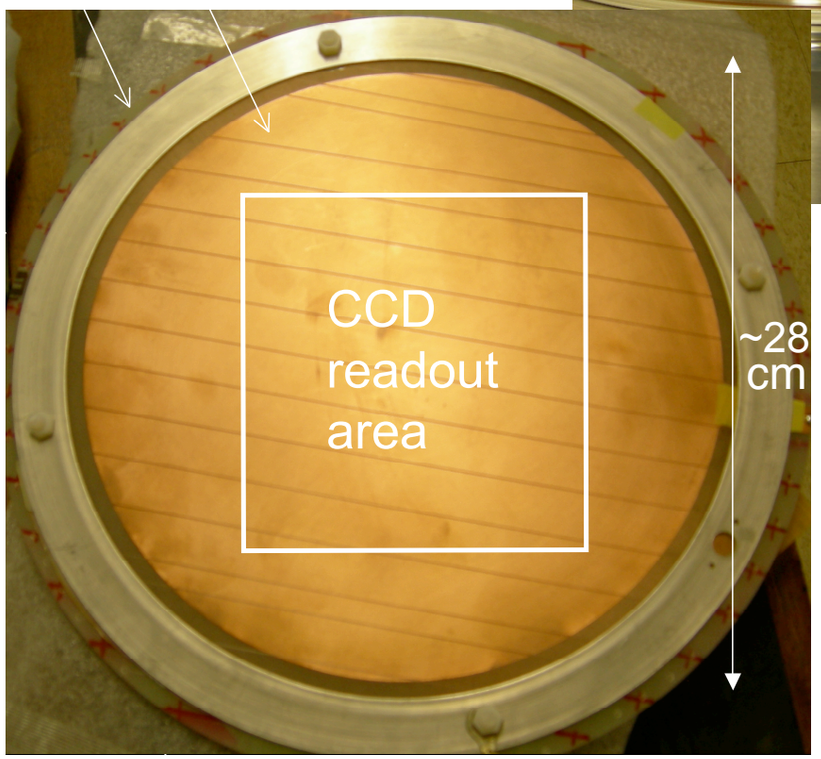
+V

Prototype Detector

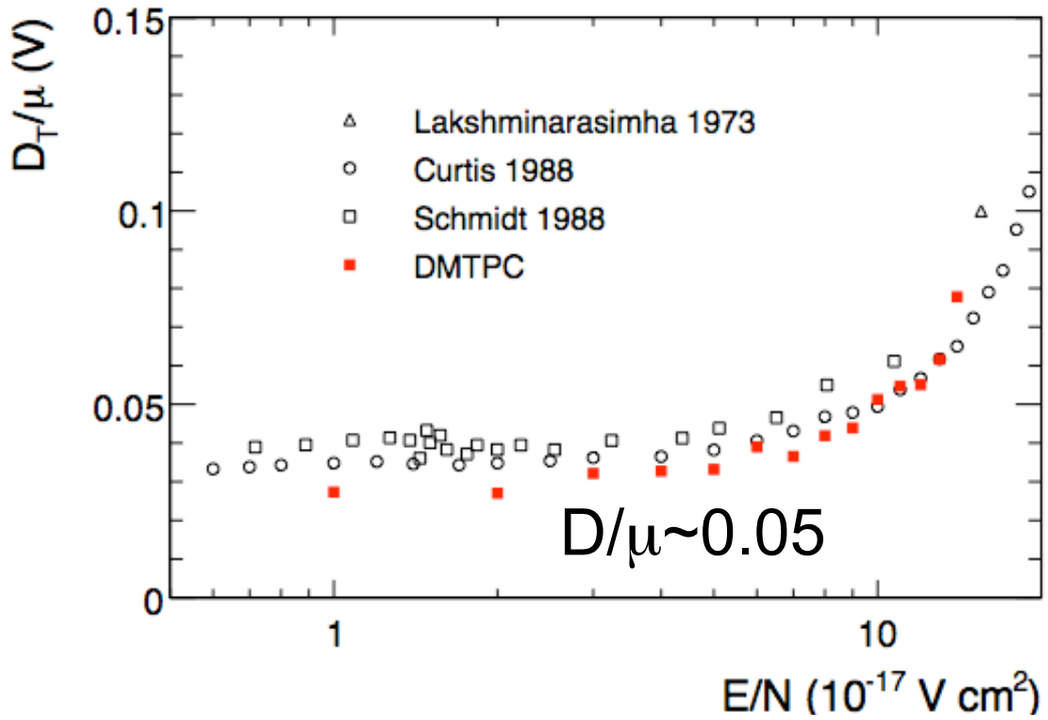


Minimal Materials:
copper, G10,
nylon, steel, fishing wire



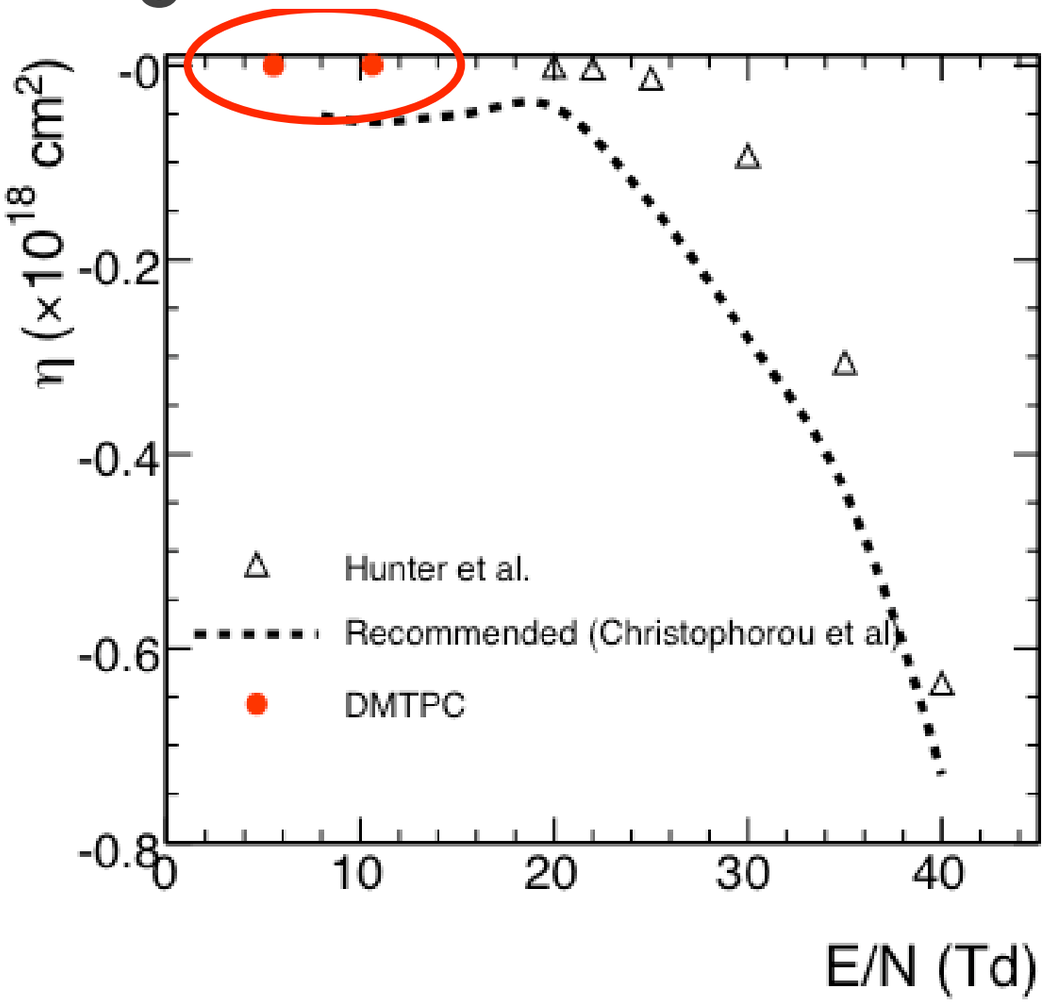


Gas Measurements with CF_4

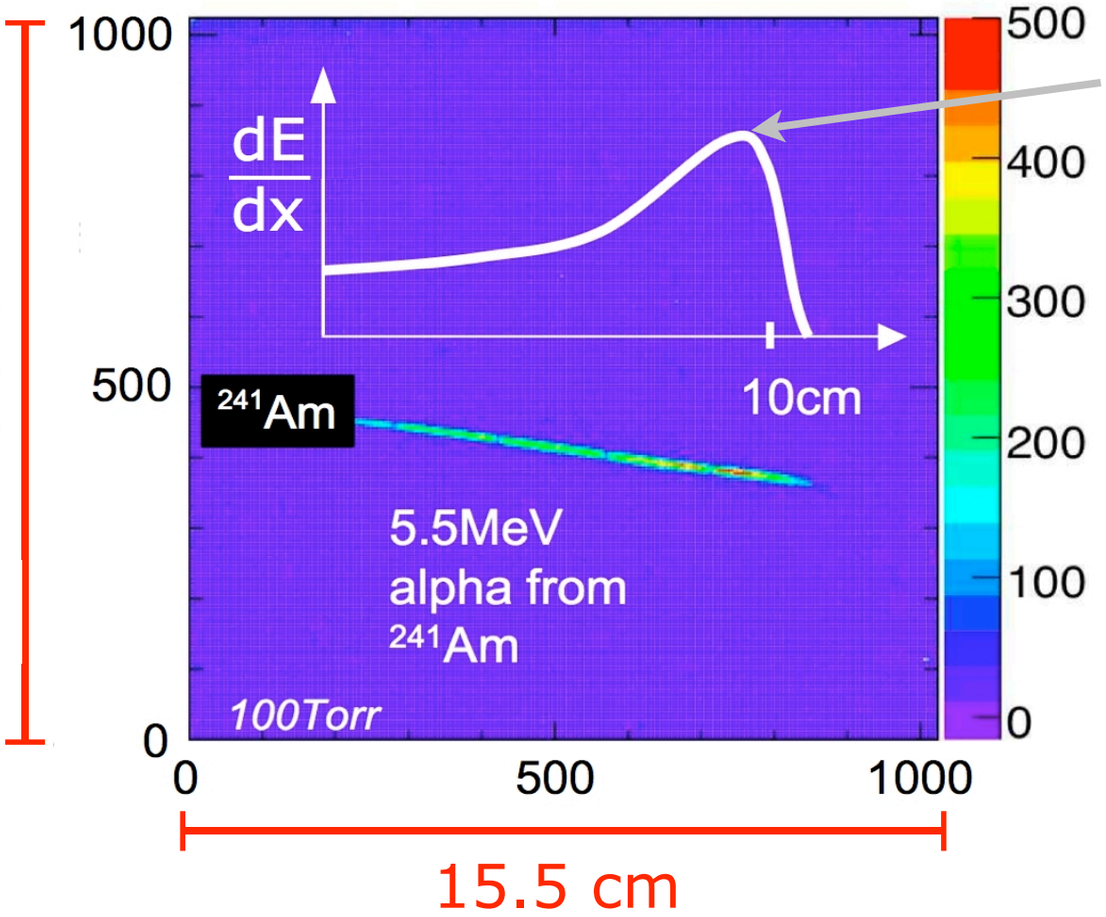


- Measure diffusion consistent with previous data
- Drift length of 20cm for 1mm diffusion
- No attenuation over 20 cm!

- Measure both diffusion and attenuation with varying height sources

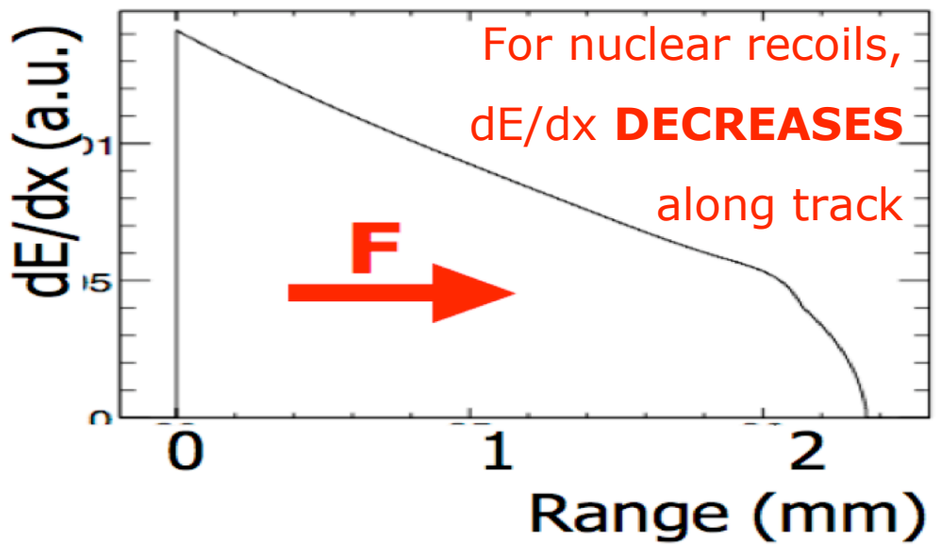


Directionality

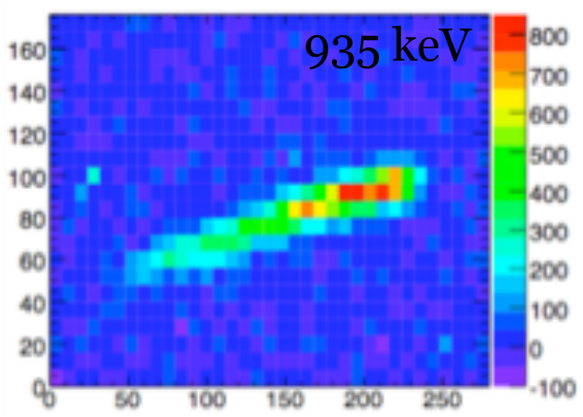


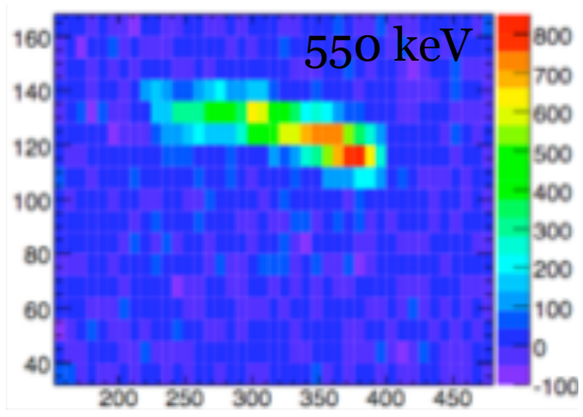
Angle and sense are given by knowledge of the energy deposition

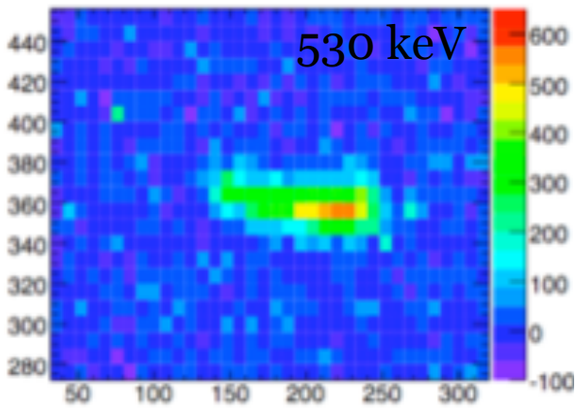
Total energy is given by amount of light deposited

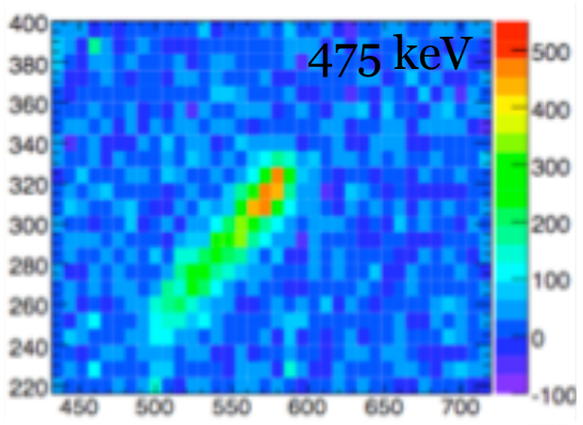


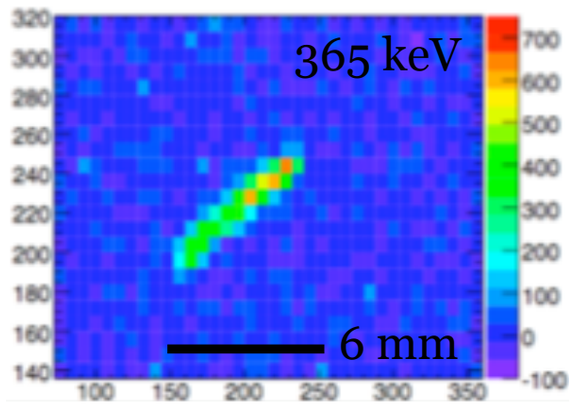
Nuclear Head-Tail

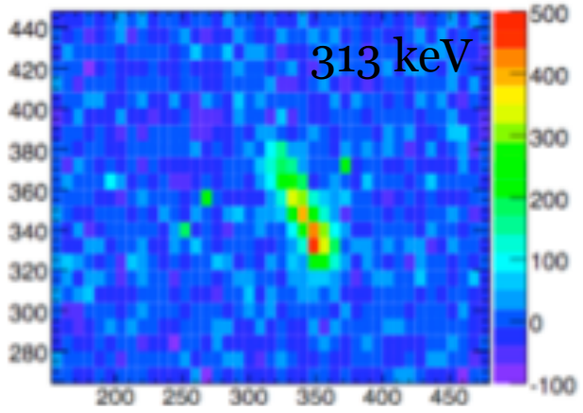


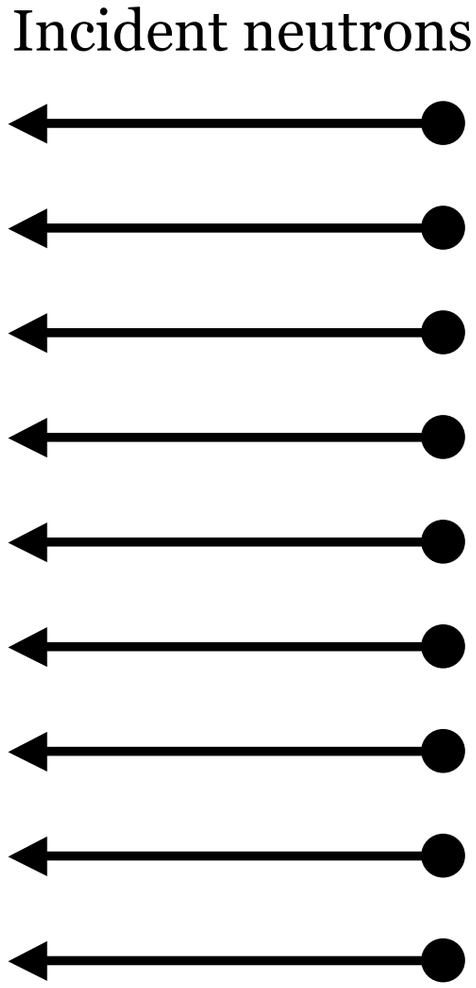






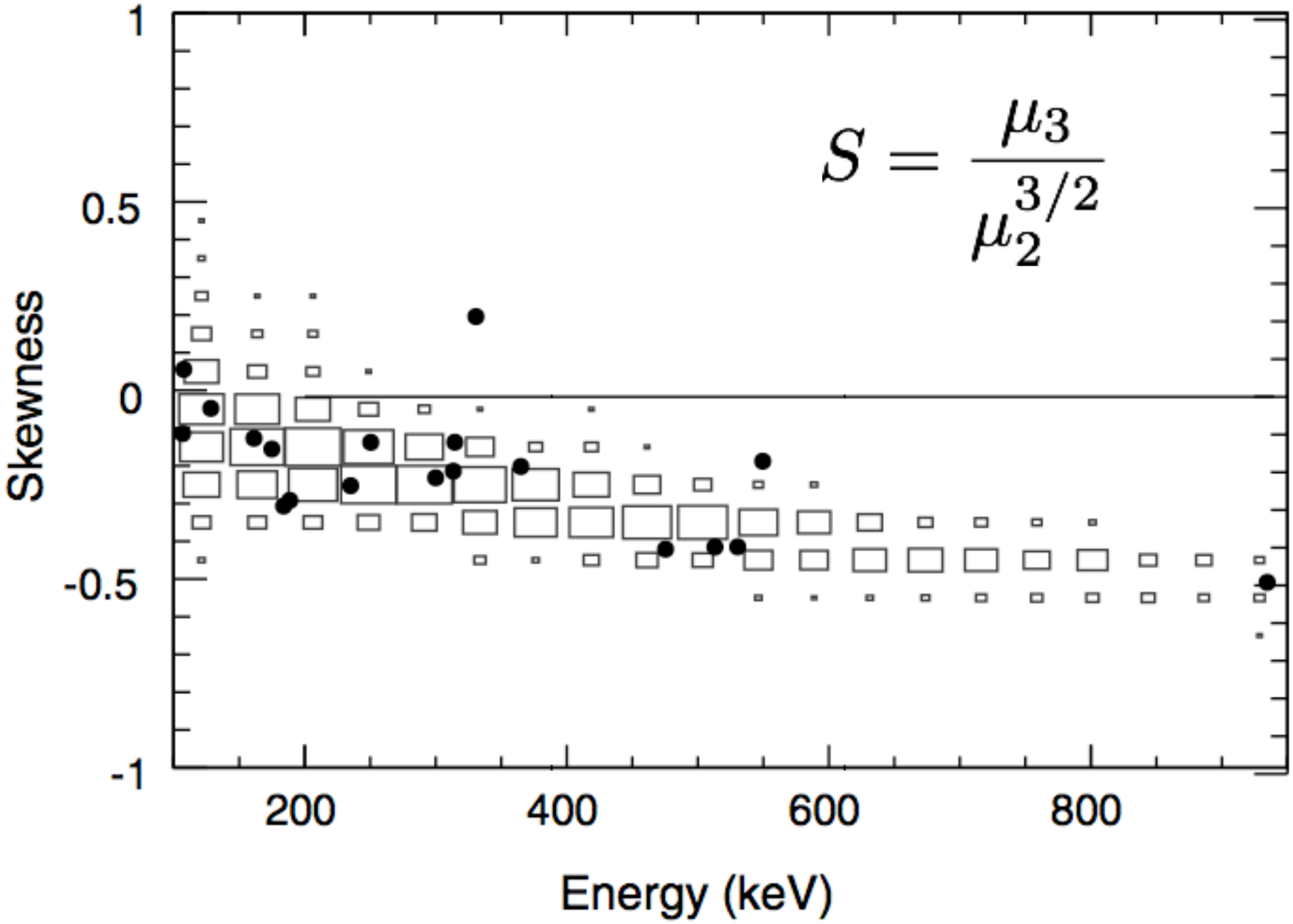




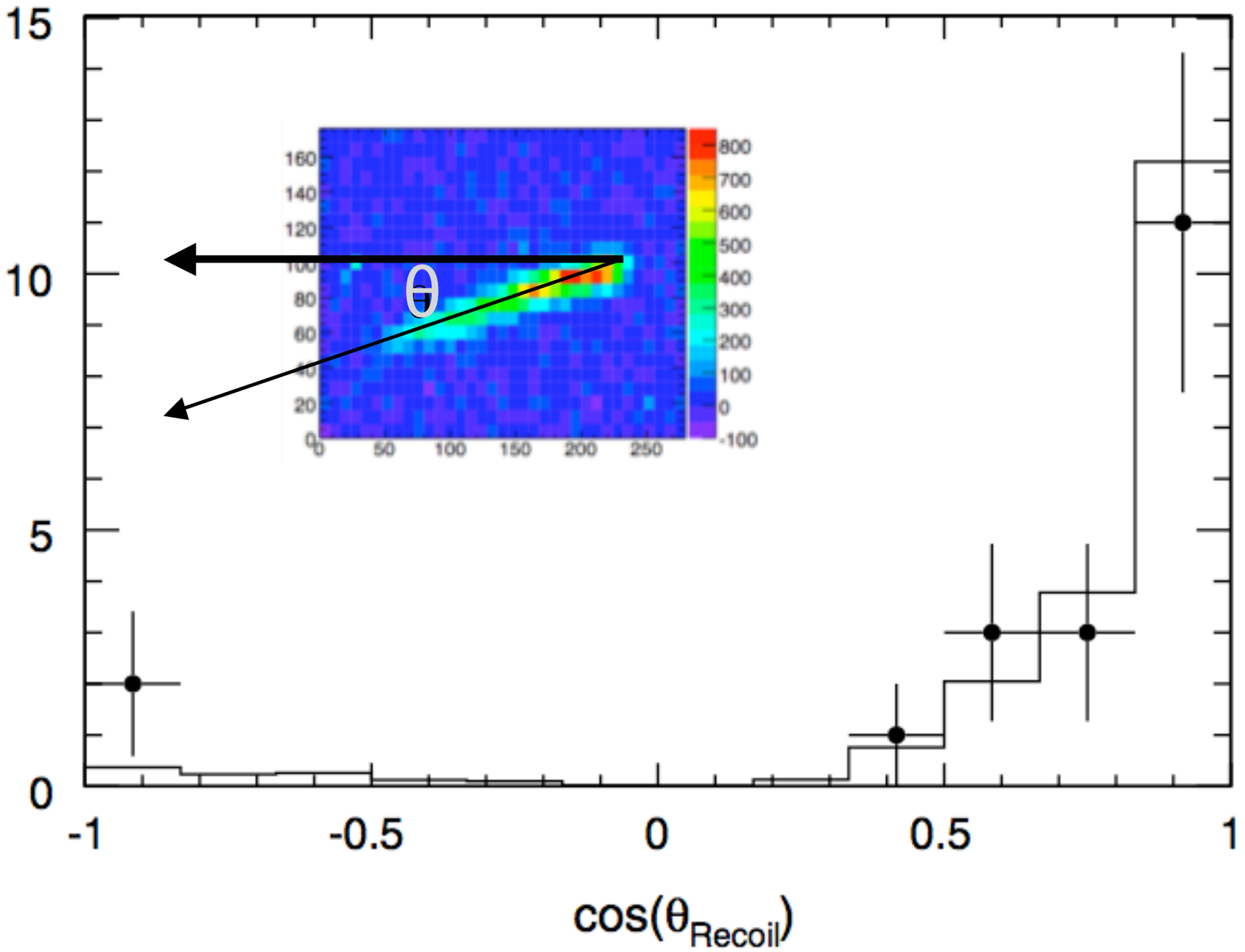


Dujmic et al. Astropart. Phys. 30 (2008) arXiv:0804.4827

Skewness

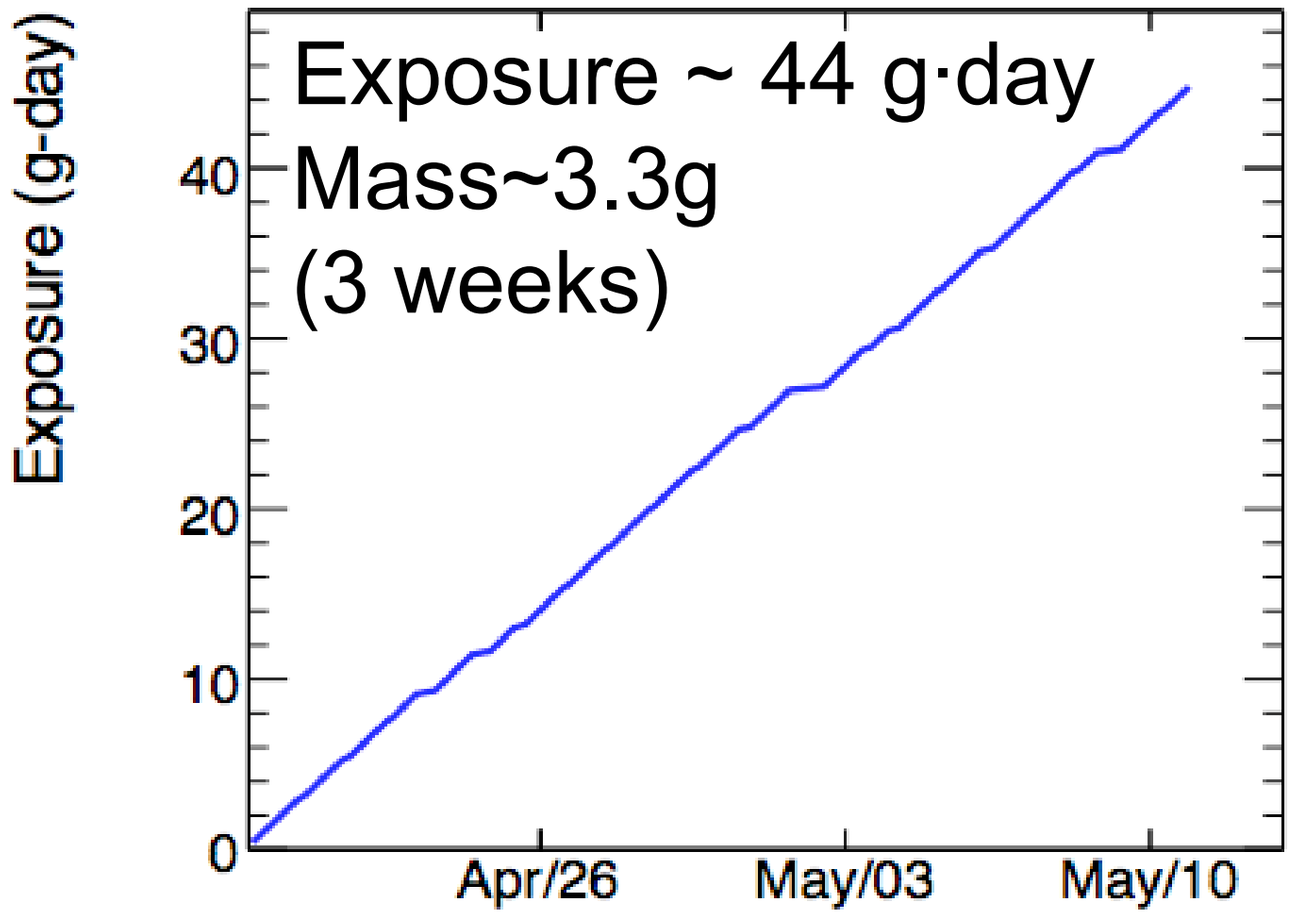


Recoil Distribution

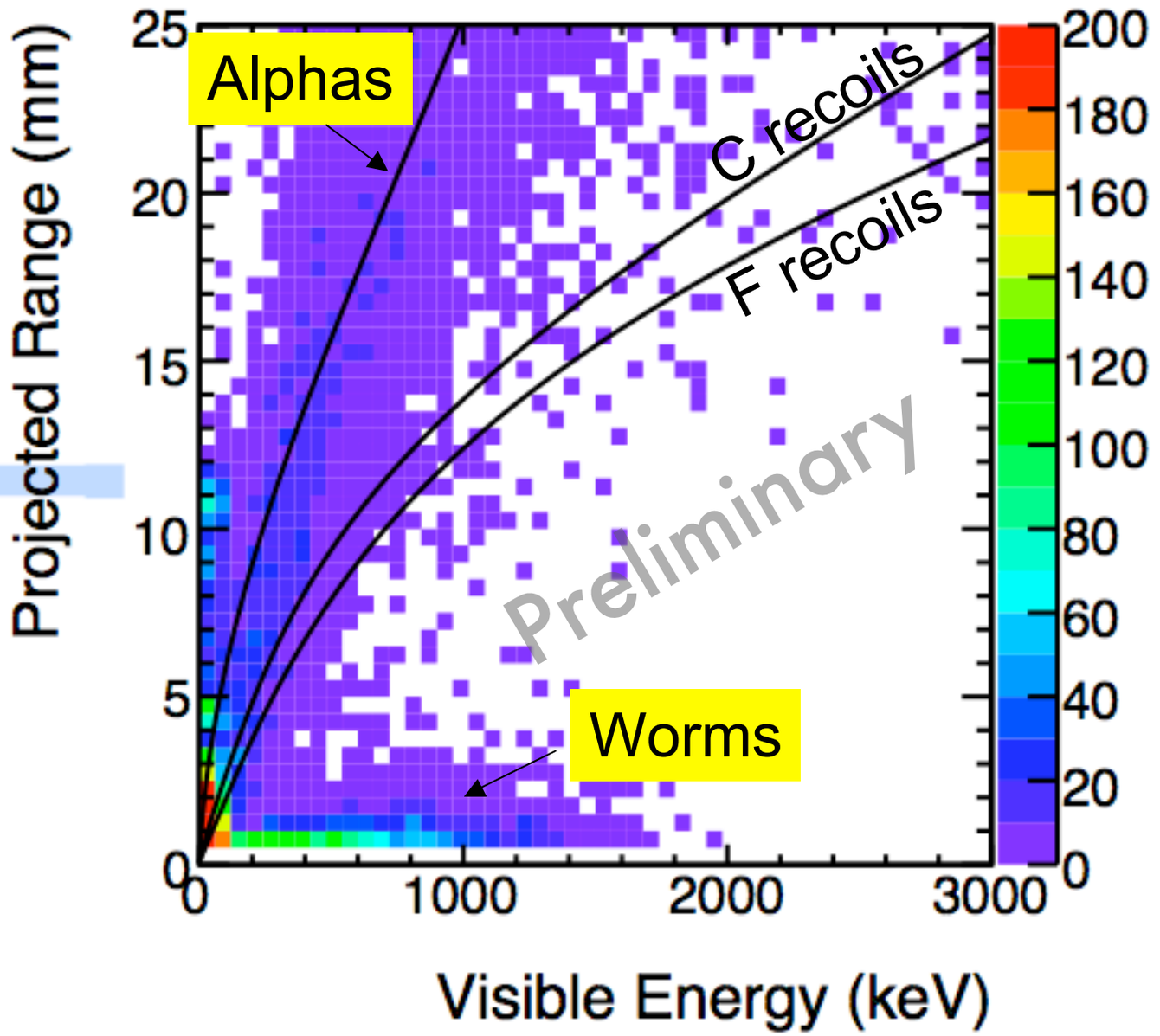


Surface Background Run

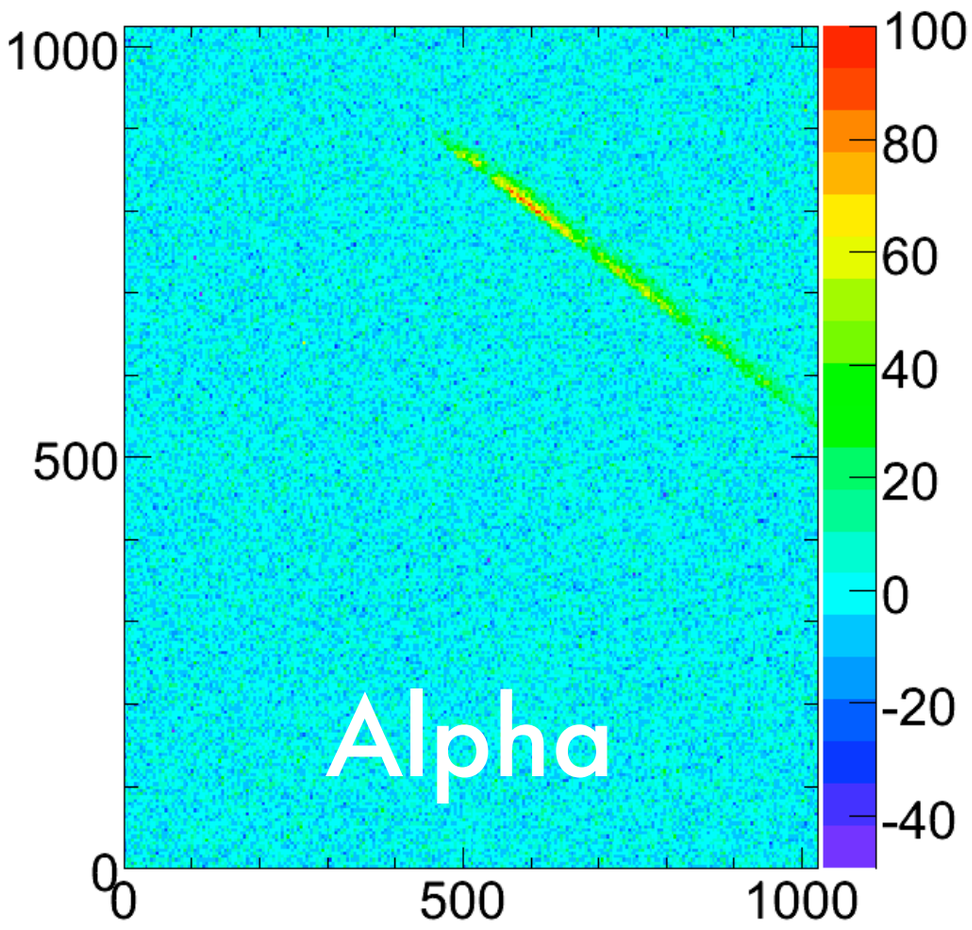
- Basement lab at MIT
- Triggerless, remote operation
- 5s CCD exposures
- Refill gas every 24 hours
- 70% live time
- 1% gain stability



Data Without Cuts



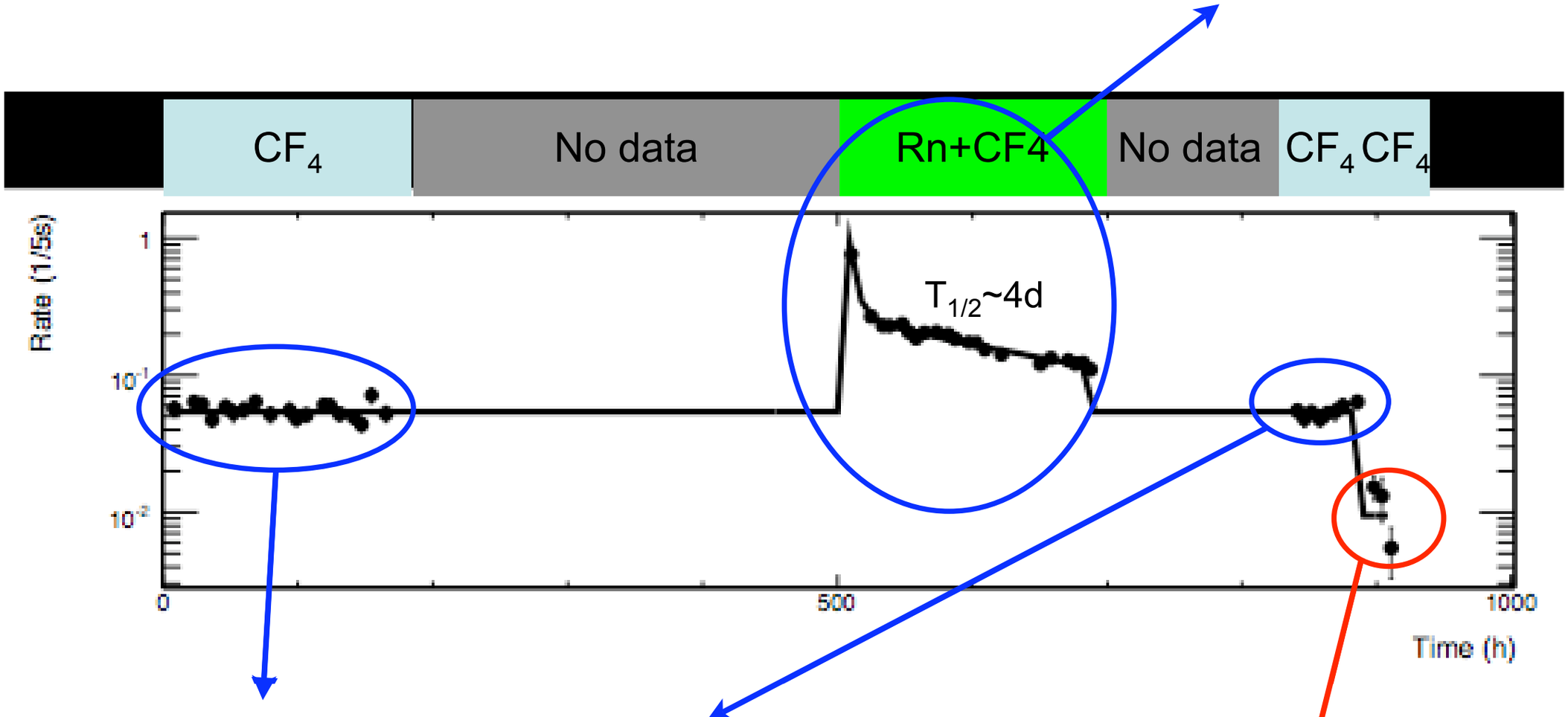
Alphas Background



- From U, Th decays in materials
- Efficiently remove with edge cuts, range/energy
- Reduce with radiopure materials

U/Th Decay and Radon

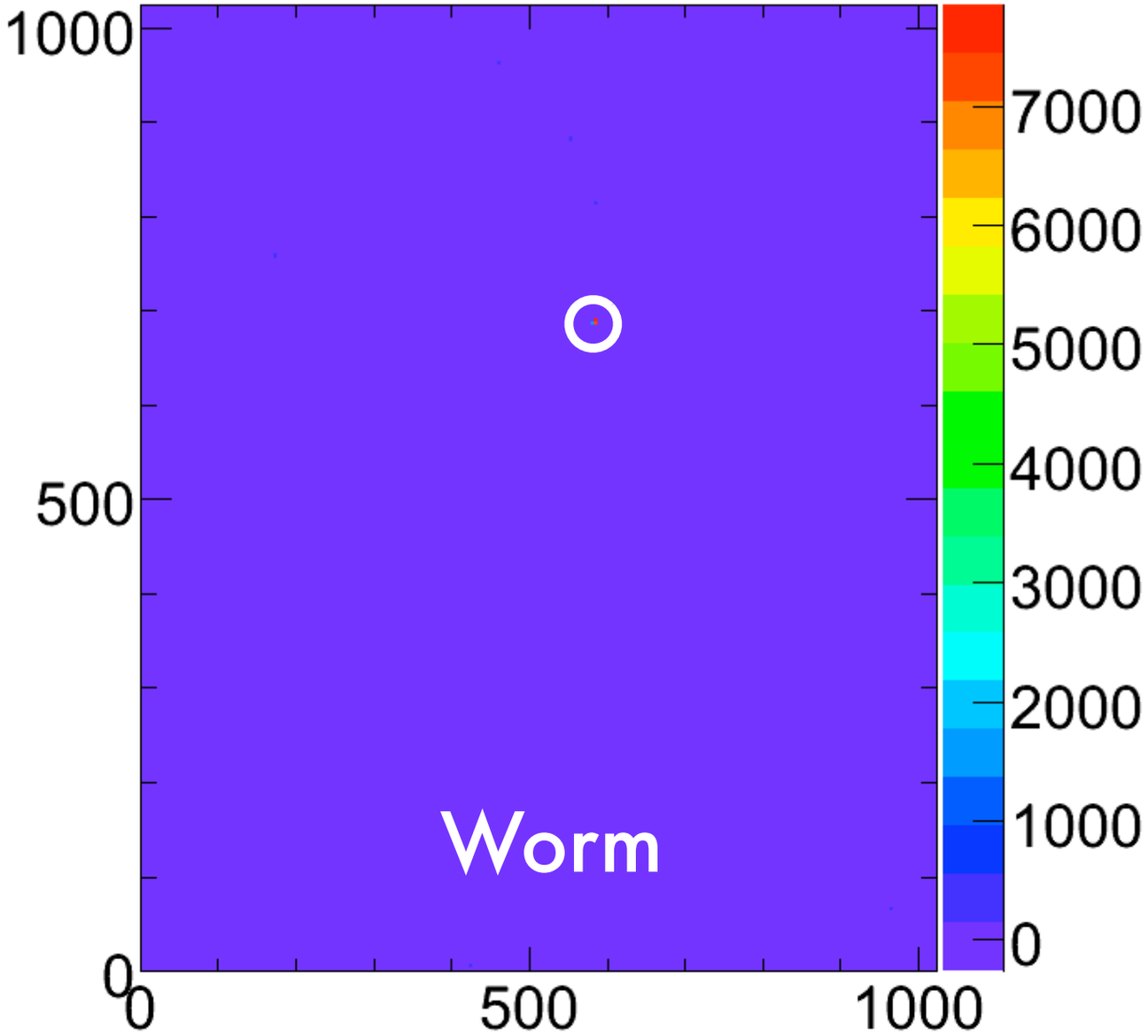
Radon introduced into chamber

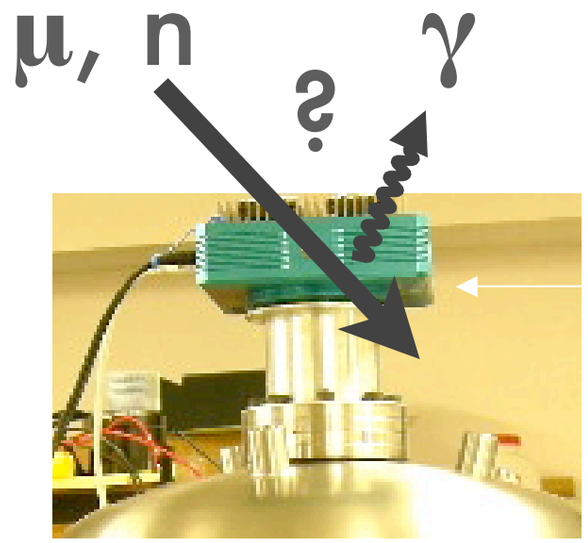


Constant 10 mHz rate from steel drift rings

5x reduced rate from Cu rings

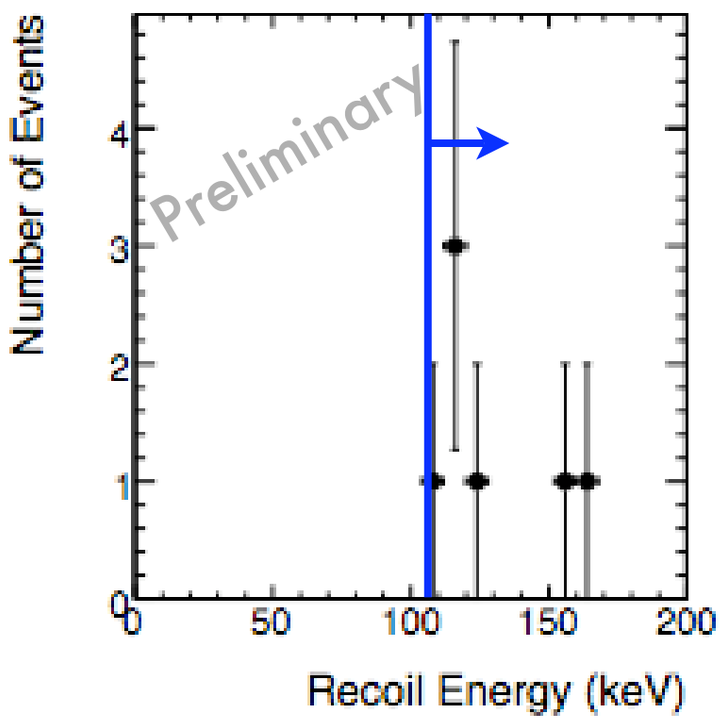
Worms

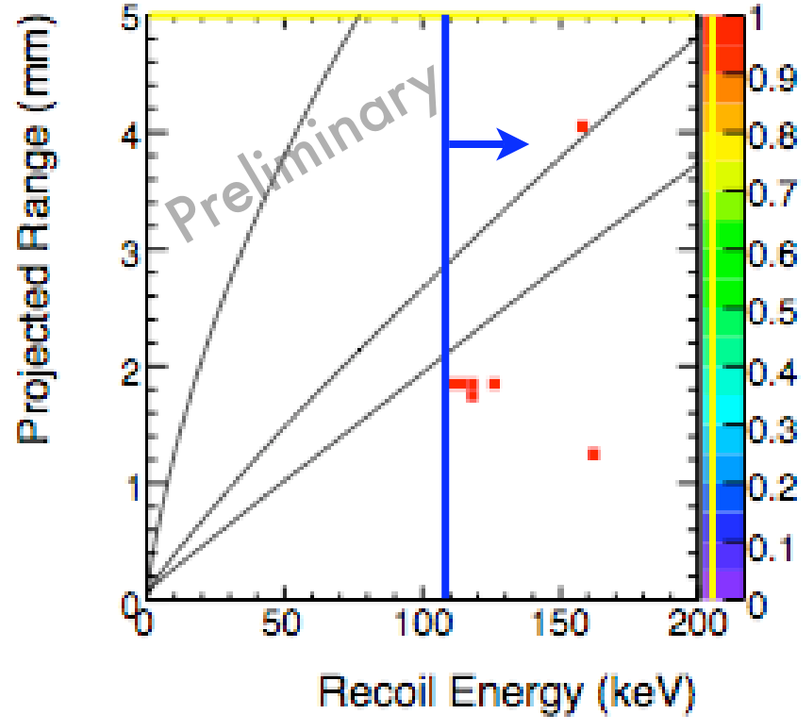




- CCD effect
- Remove most in software with energy density cut
- Reduce by going underground, new hardware

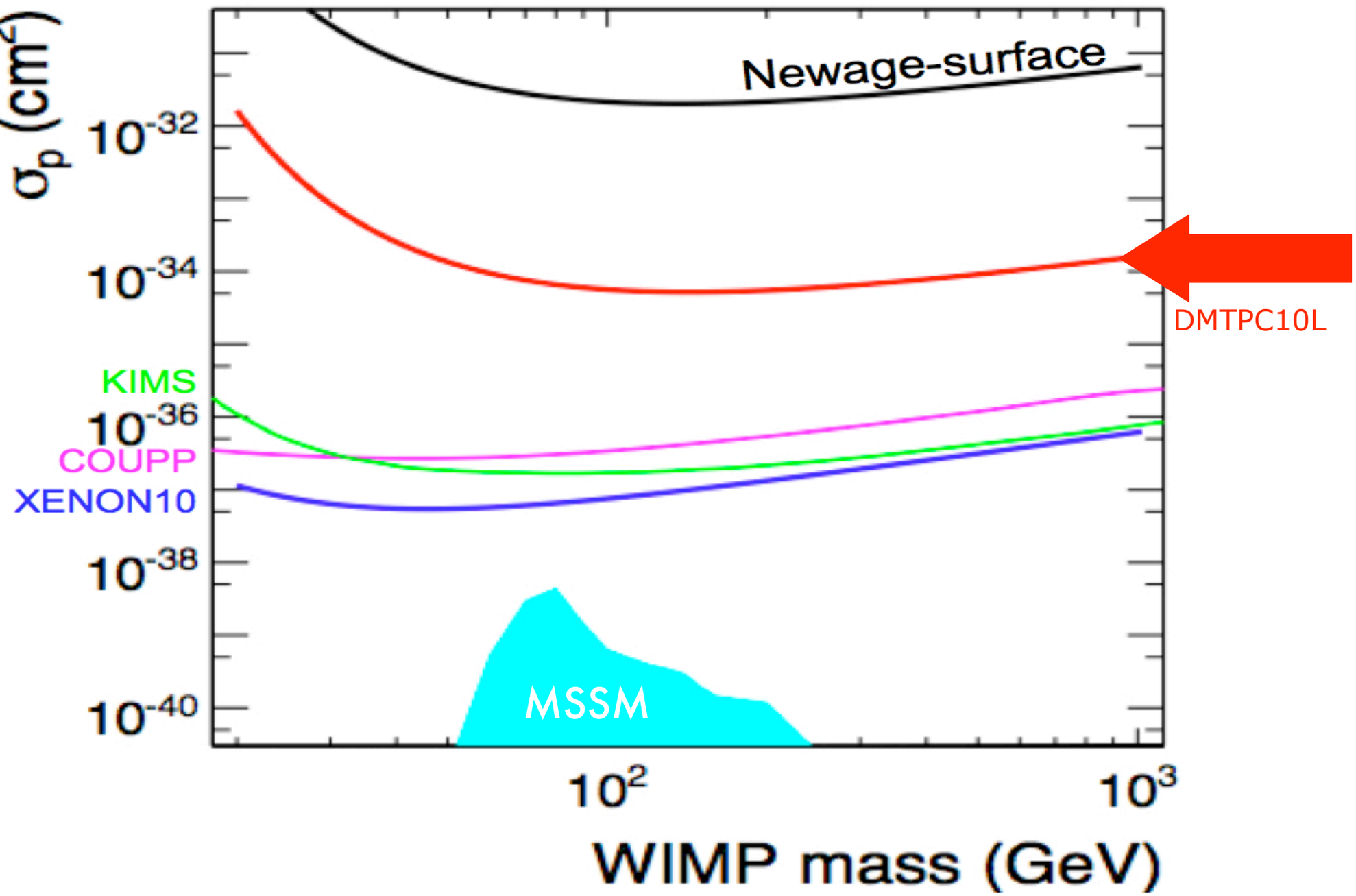
Preliminary Background Rate





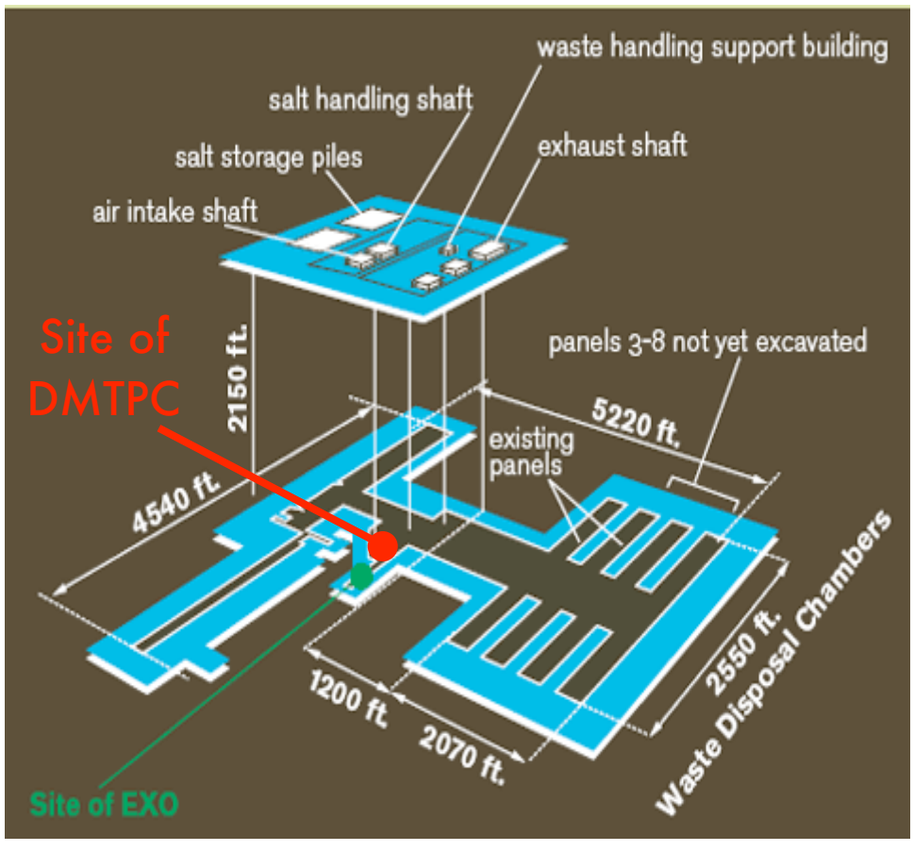
- Observe 7 recoil events in 110-200 keV range
- 10.8 day live-time
- 3.3 g detector mass

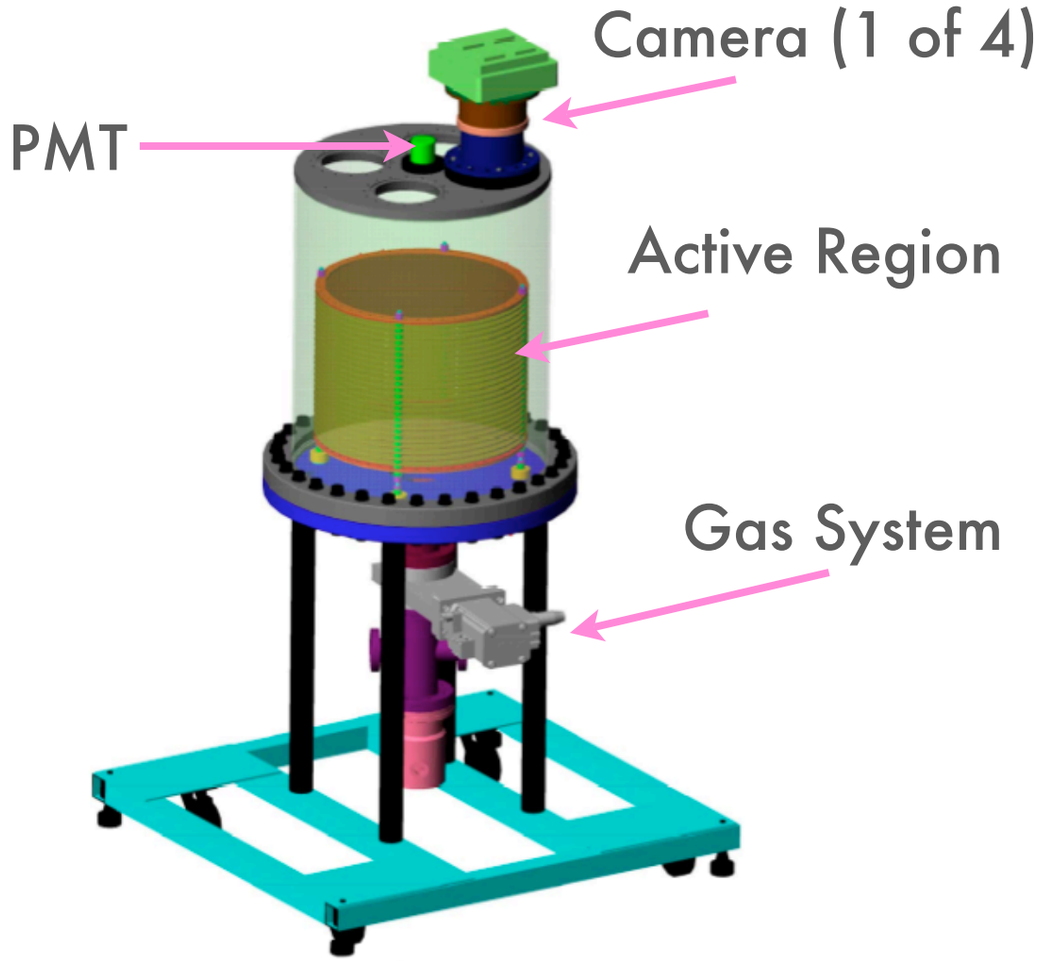
Expected Sensitivity



Going Underground

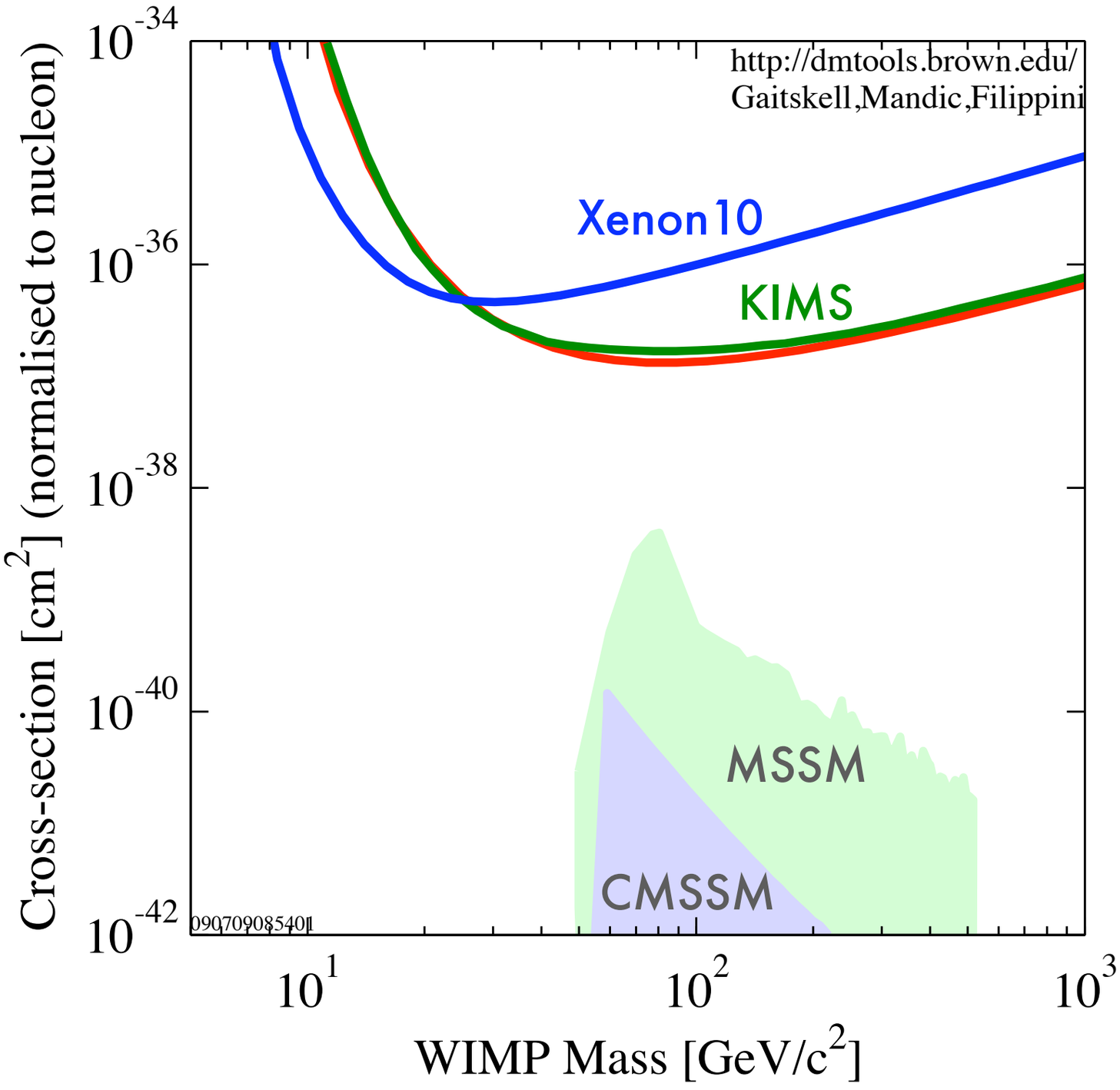
Waste Isolation Pilot Plant





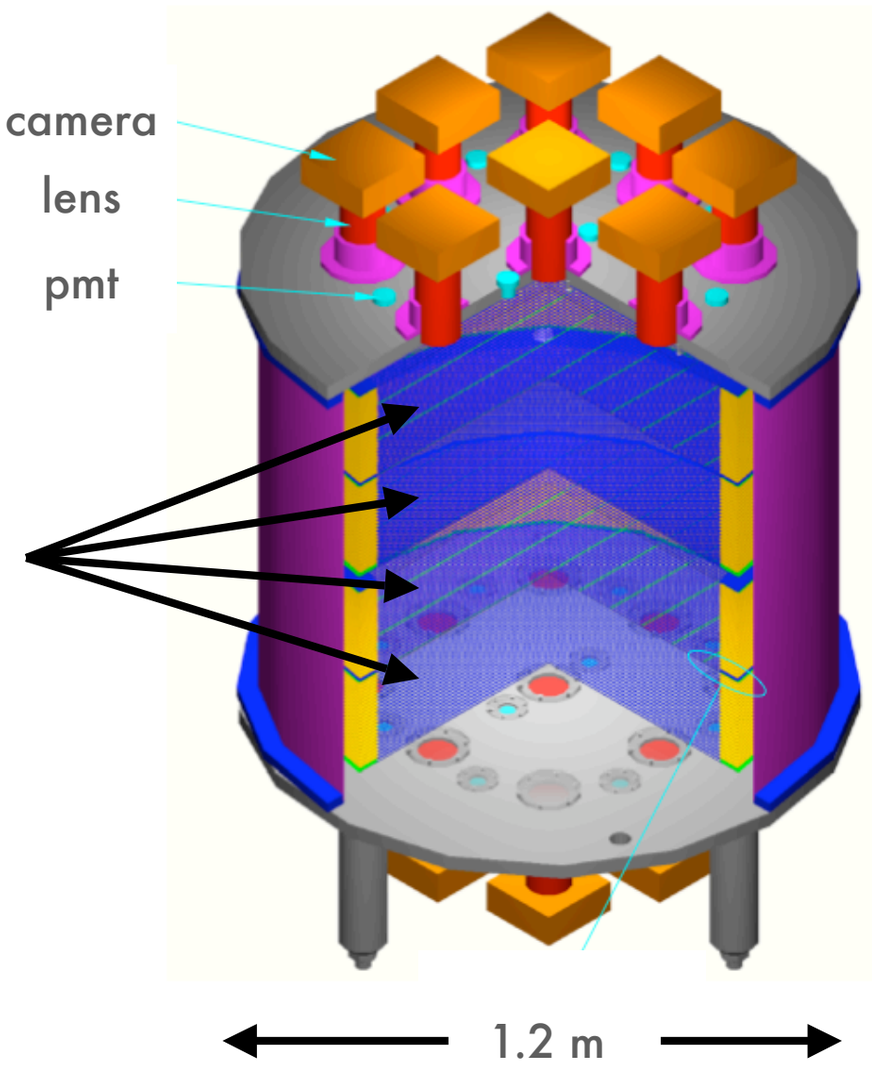
- New 10L detector with purer materials and four cameras
- ~1600 m.w.e passive shielding and active neutron monitoring
- Low radon contamination, < 7 Bq/m^3

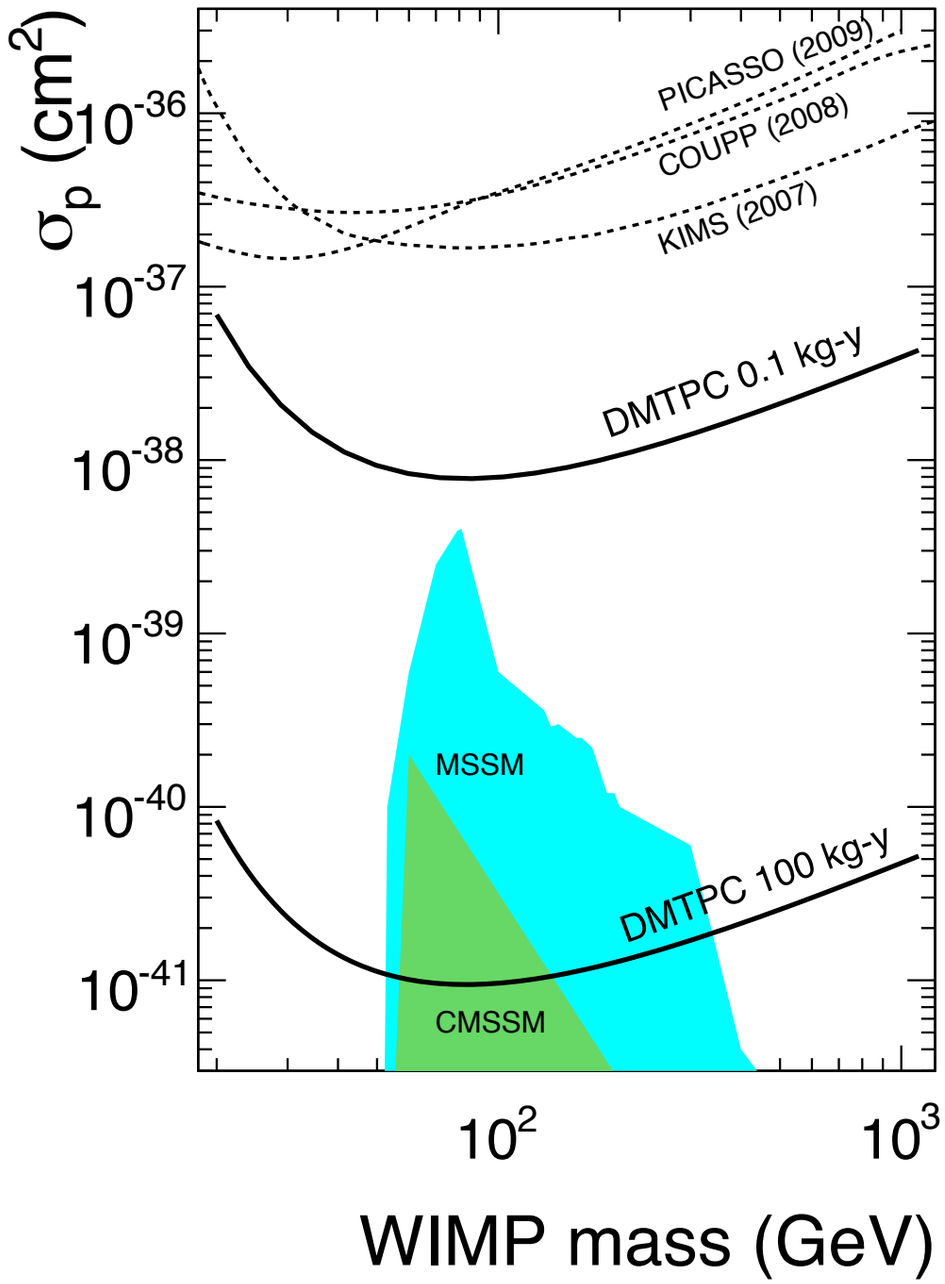
Projected Sensitivity



DMTPC 10 L with 50 keV threshold underground for 1 year at 100 torr

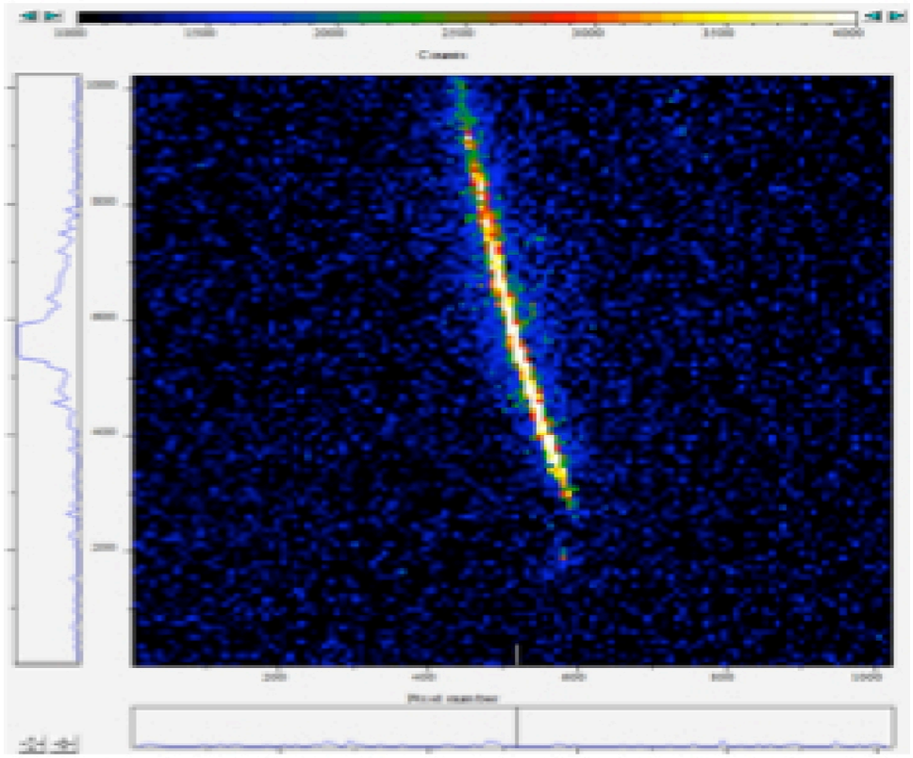
Scaling to 1 m^3





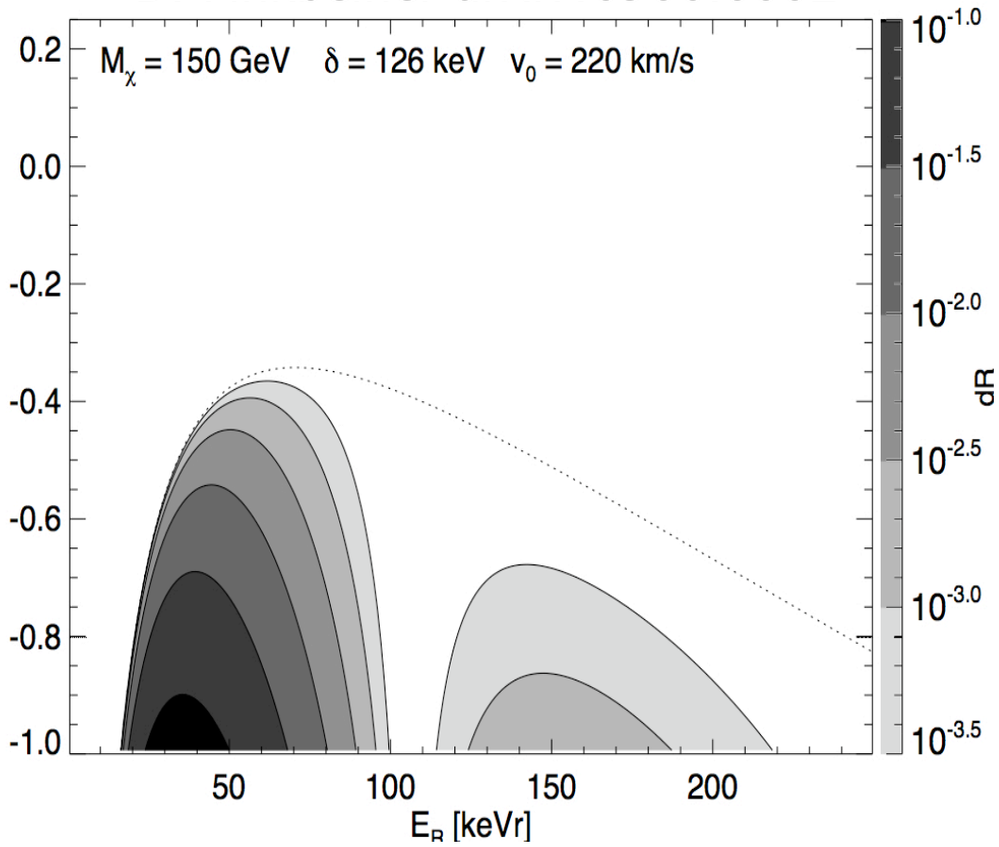
Ongoing and Future Work

- Use secondary detection (PMTs, charge readout) to improve reconstruction
- Different gas mixtures (e.g. Xe/CF_4 mixes)
- Incorporate inelastic dark matter models



(80torr Xe + 15torr CF_4)

D. Finkbeiner arXiv:0906.0002



Summary

- The field of directional dark matter is expanding quickly
- Demonstrated operation of a CCD-based gas detector with directional sensitivity
- Collected and analyzed surface run background data
- Plans for underground operation at WIPP