

# The DMTPC Experiment

James Battat  
for the DMTPC Collaboration

Cygnus 2009

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# DMTPC Collaboration

Boston University

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Massachusetts Institute of Technology

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## 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)

**Graduate Students**

*Undergrads*

# Preview of DMTPC Talks

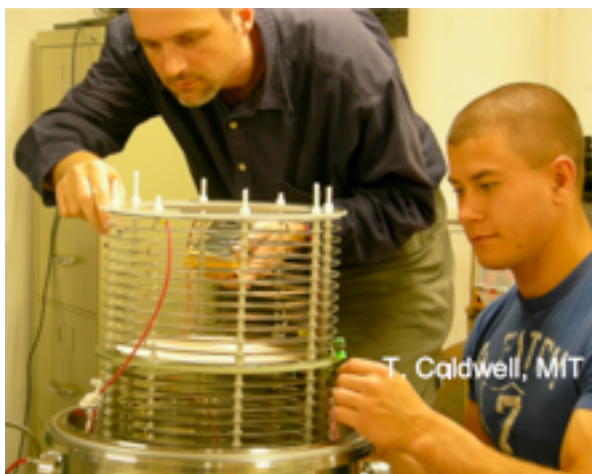
Neutrons and Xe  
Hidefumi Tomita



Track  
reconstruction  
Asher Kaboth



Detector R+D  
Denis Dujmic



MaxPatch  
Limit Setting  
Shawn Henderson



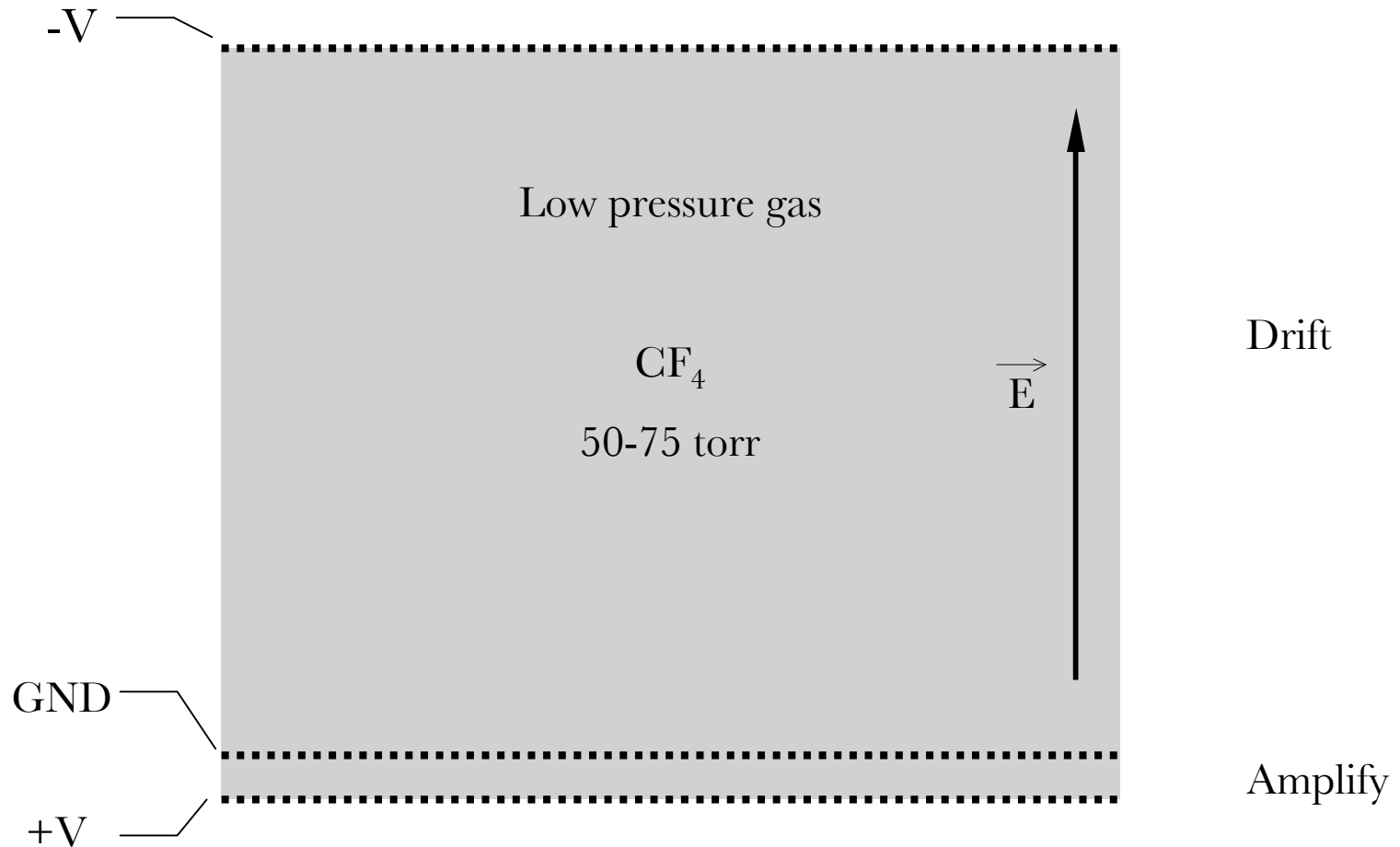
Detector  
backgrounds  
Tom Caldwell

# Outline

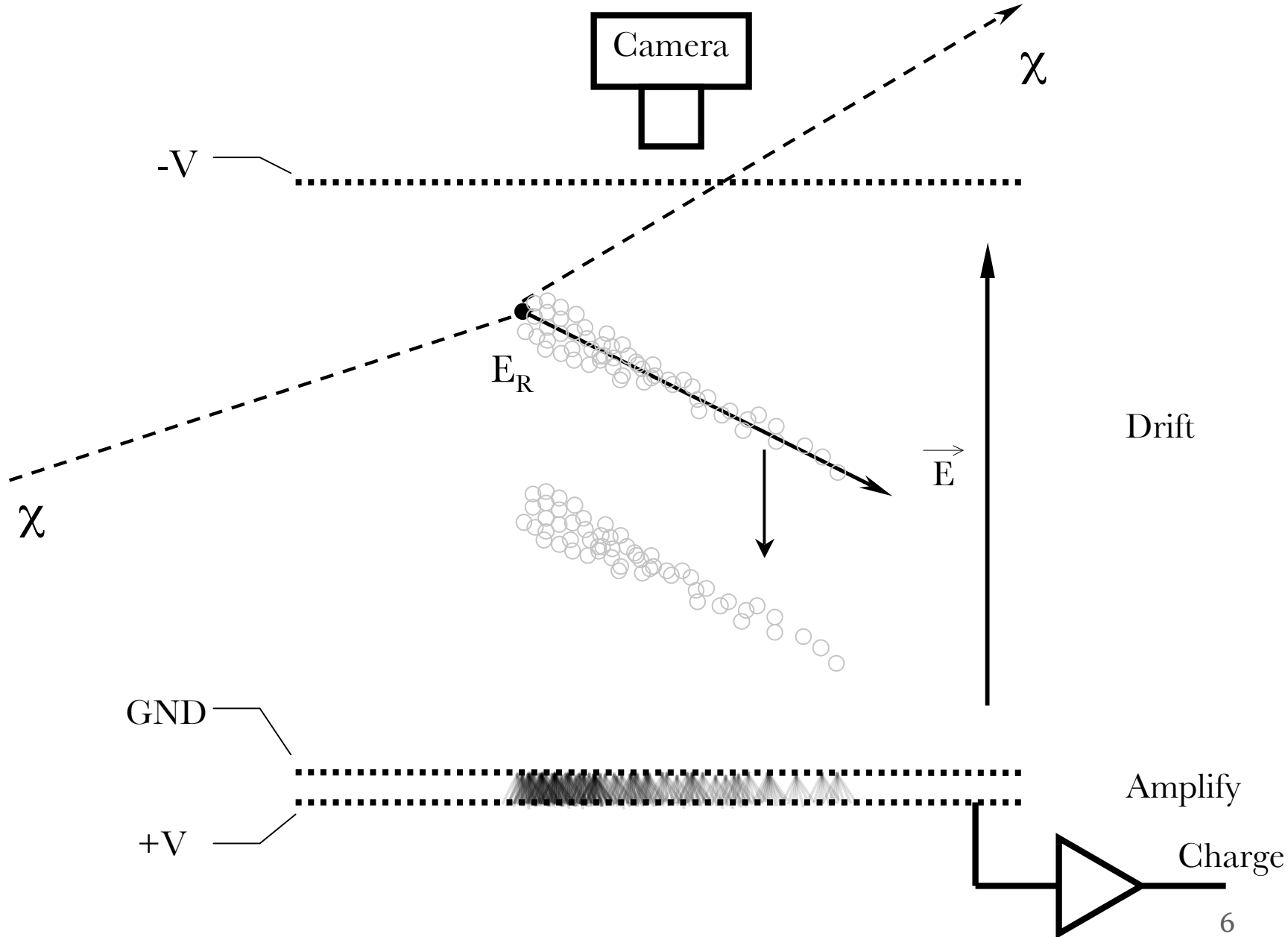
- Detector concept
- Progress since Cygnus 2007
- Current detector
- Head-tail measurements
- Going underground to WIPP
- Scaling up to larger mass

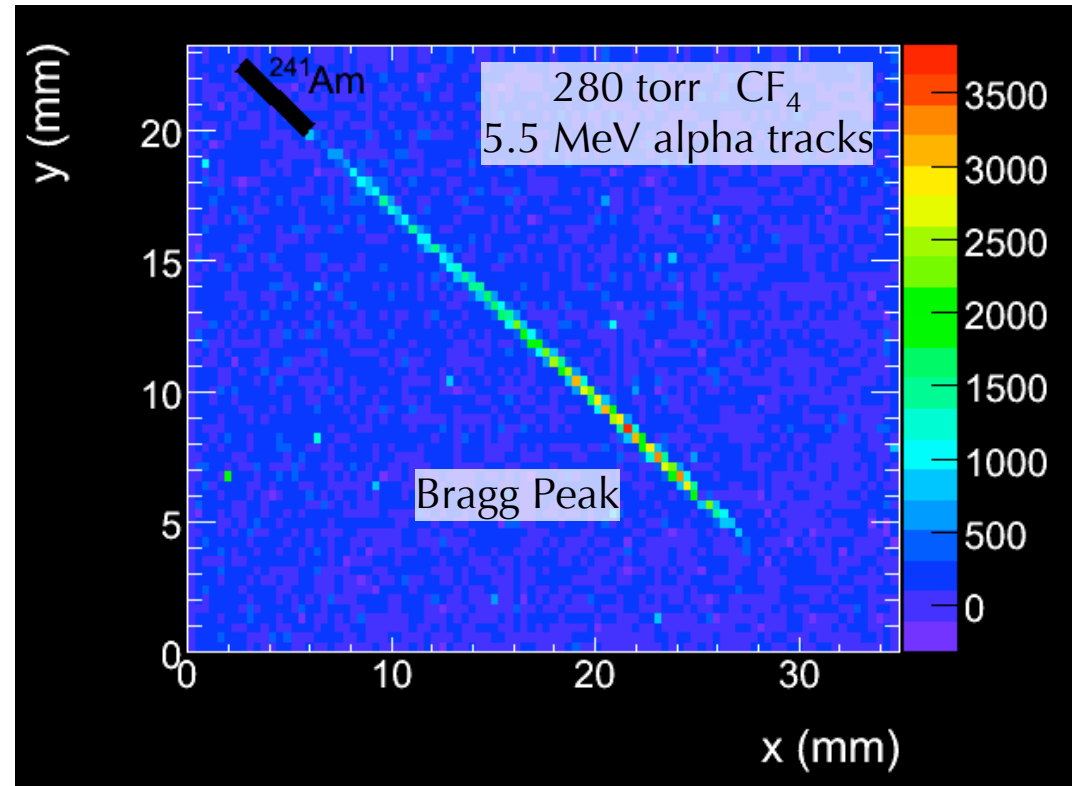
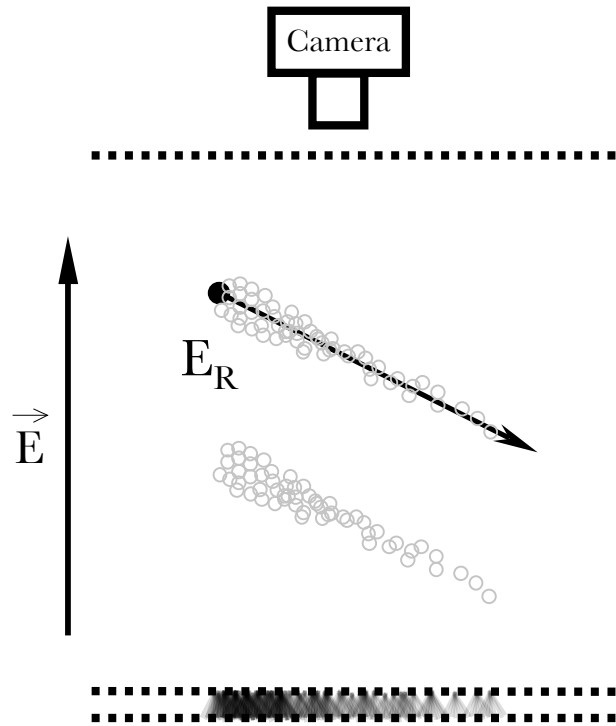


# Time Projection Chamber



Side view

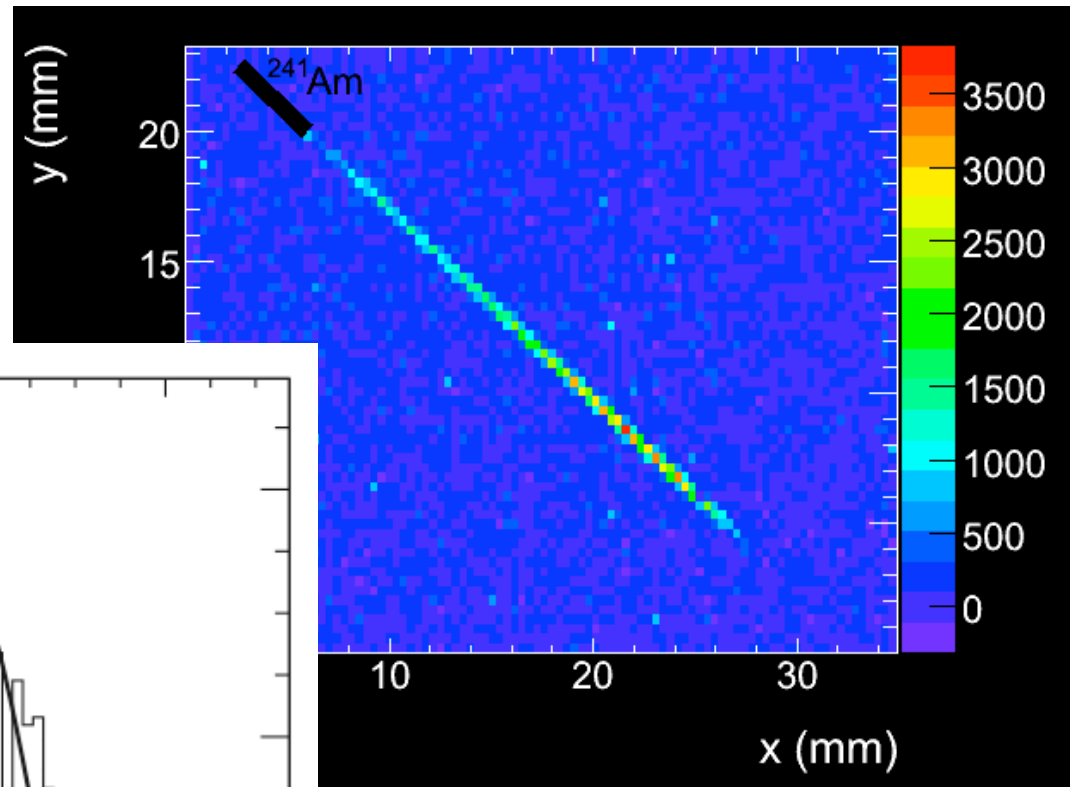
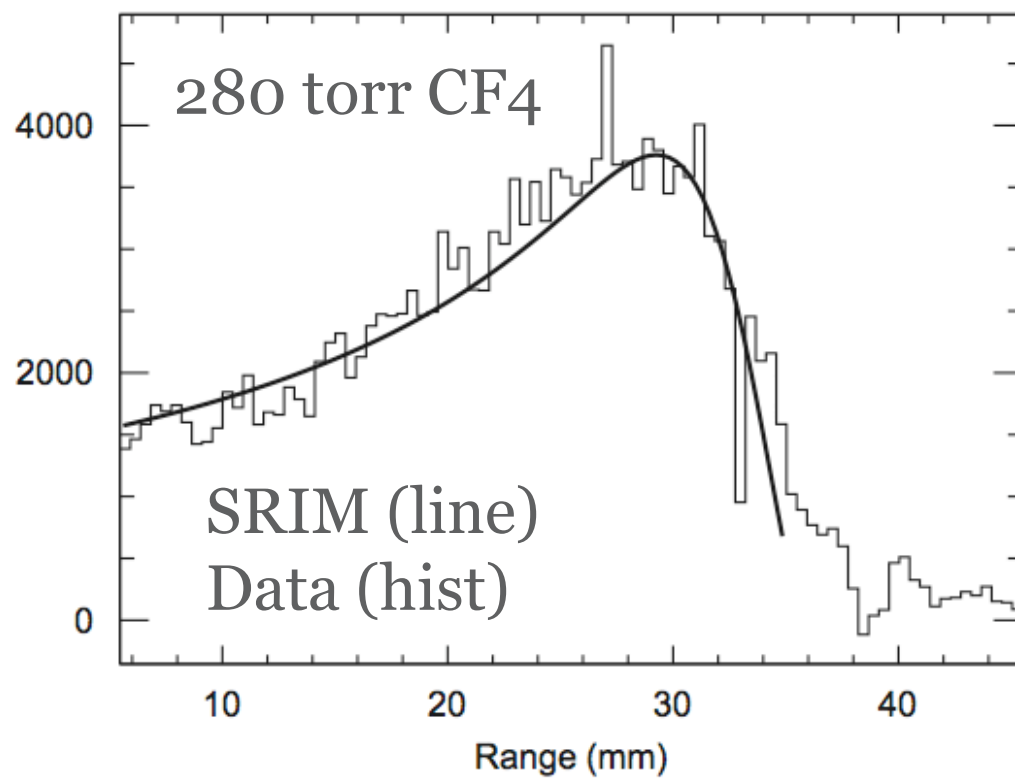




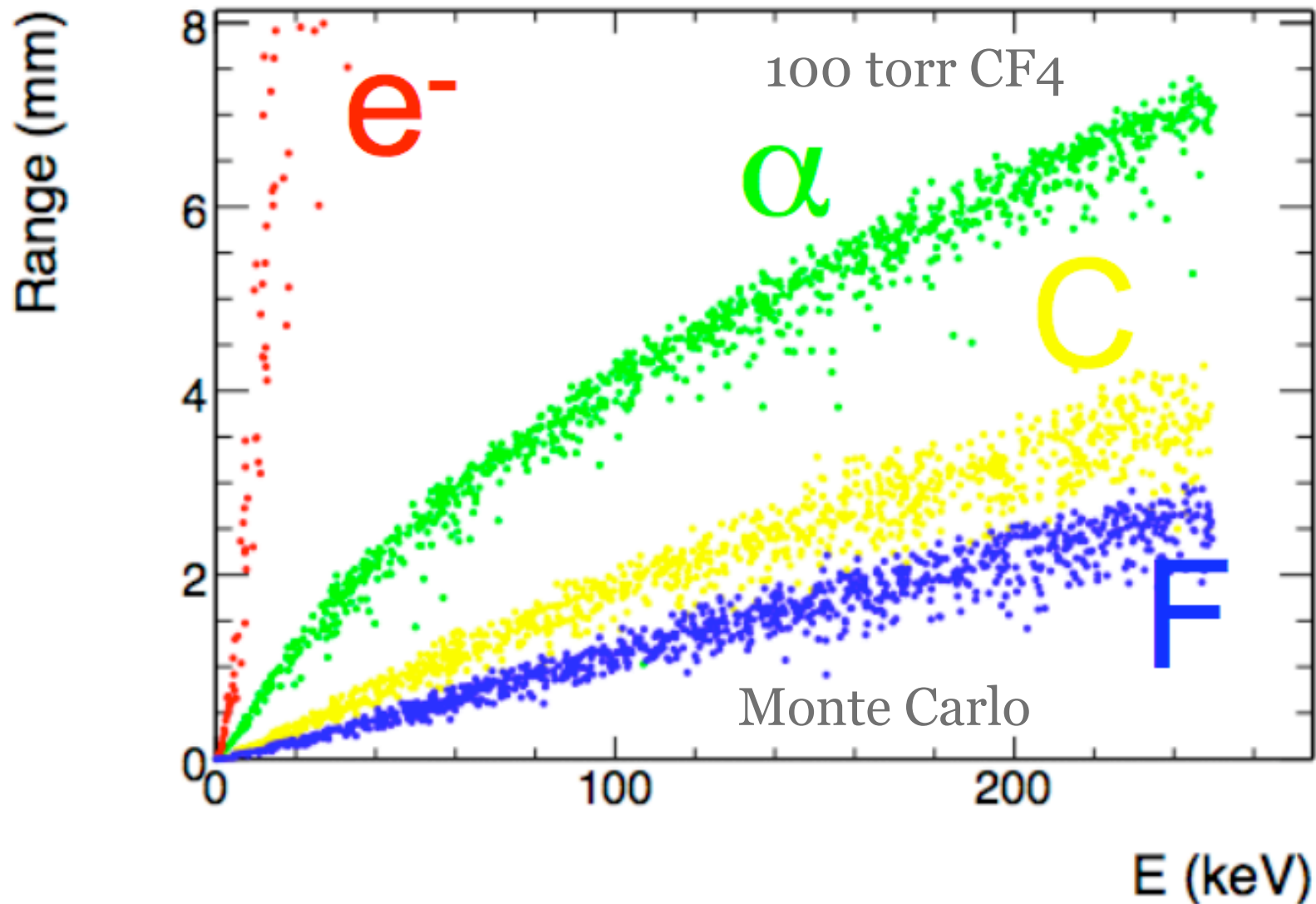
Track length

Energy (total light)

$dE/dx$



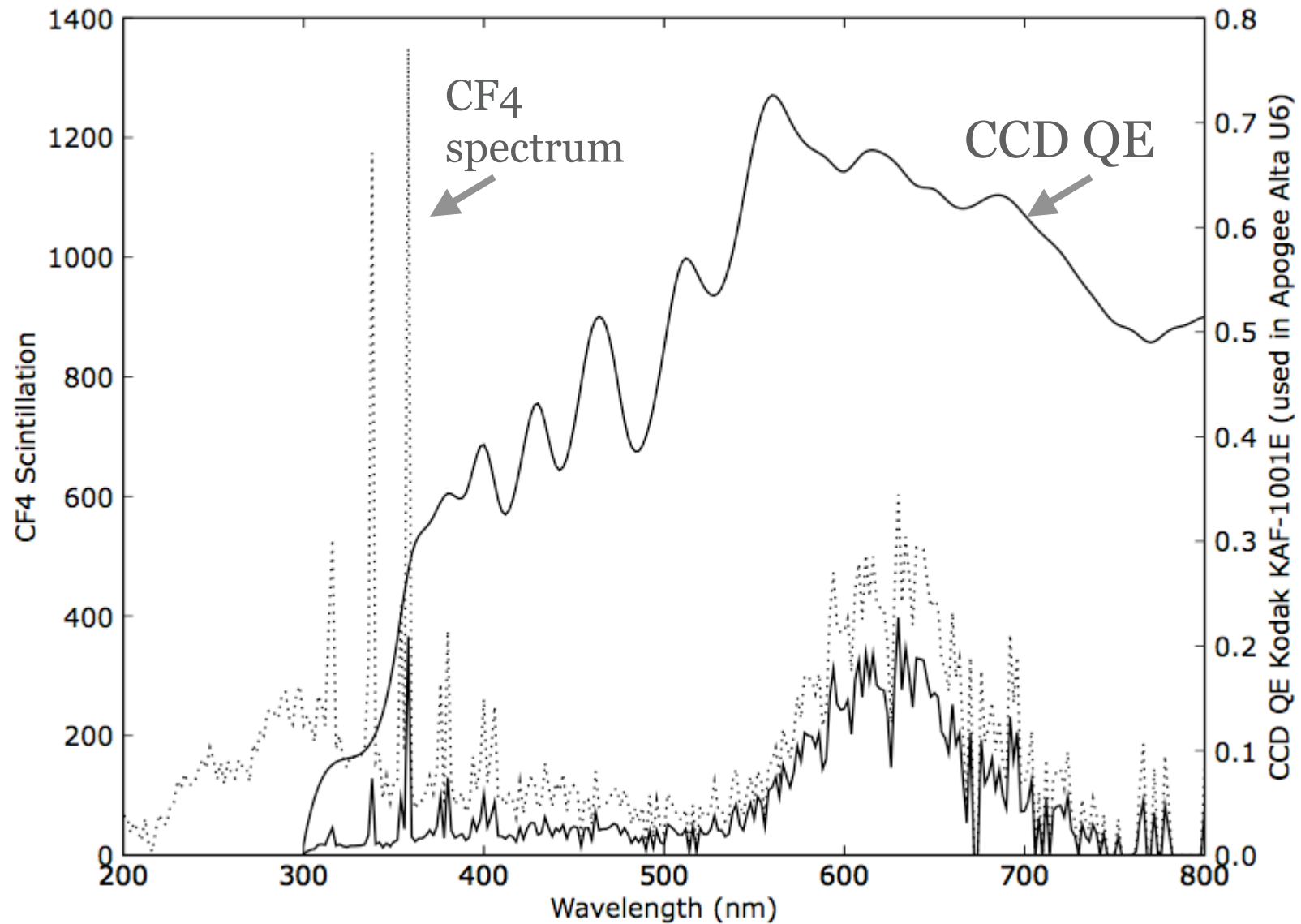
# Particle Identification



# CF<sub>4</sub> as a target gas

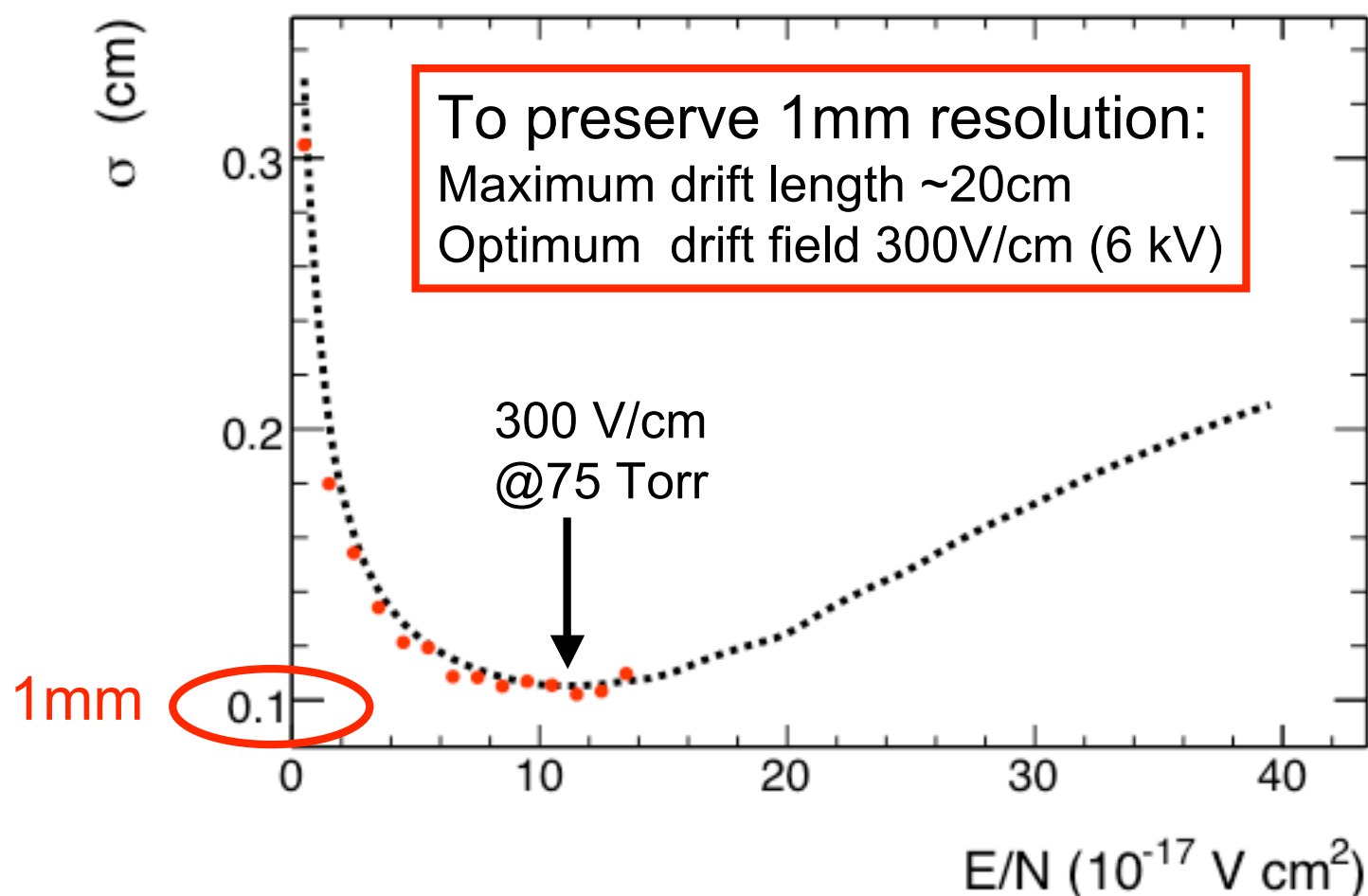
- Excellent sensitivity to spin dependent interactions
- Efficient scintillator
- Low electron diffusion
- Non-toxic, non-flammable

# CF<sub>4</sub> Scintillation Spectrum



*A. Kaboth, et al., NIM A 592:63-72 (2008)*

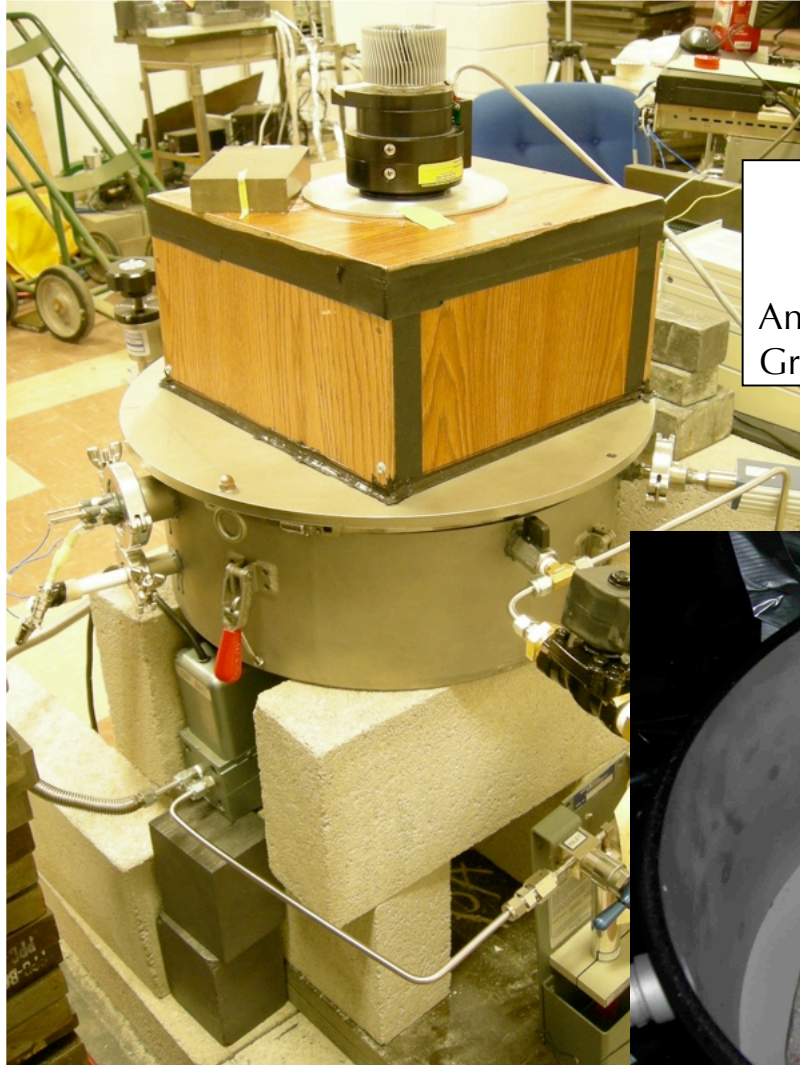
# Diffusion for 20 cm drift



See talk by Denis Dujmic

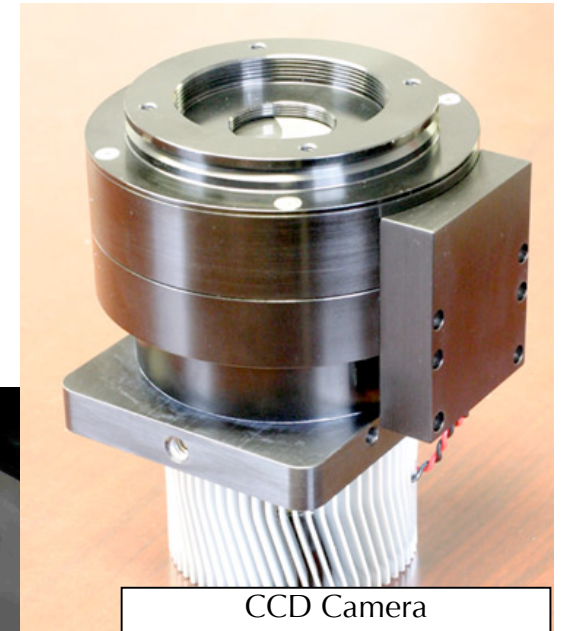
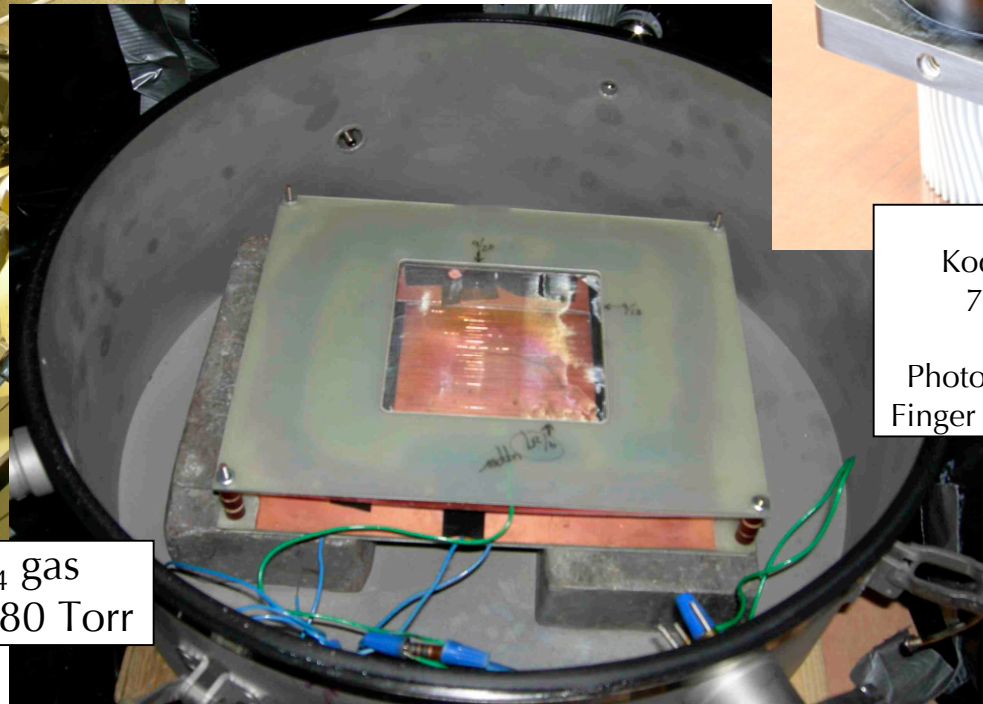


# First Prototype Detector (Cygnus 2007)



Drift region:  
2.6 cm,  $E=580$  V/cm  
Amplification region:  
Anode: 5mm pitch,  $100\text{ }\mu\text{m}$   
Ground: 2mm pitch,  $50\text{ }\mu\text{m}$

$\text{CF}_4$  gas  
100-380 Torr



CCD Camera  
Kodak KAF0401 chip  
768x512 ( $9\times 9\mu\text{m}$ )  
Cooled ( $-20^\circ\text{C}$ )  
Photographic lens (55mm)  
Finger Lakes Instrumentation

Field of view  
 $4.5 \times 3.2\text{ cm}^2$

# Since Cygnus 2007

- MWPC ---> Fine woven mesh
- Larger detector
- Improved CCD camera
- Head-tail measurement improvements
- Measurement of diffusion and attachment
- Long duration surface runs
- Remote operation
- Image analysis framework
- Going underground

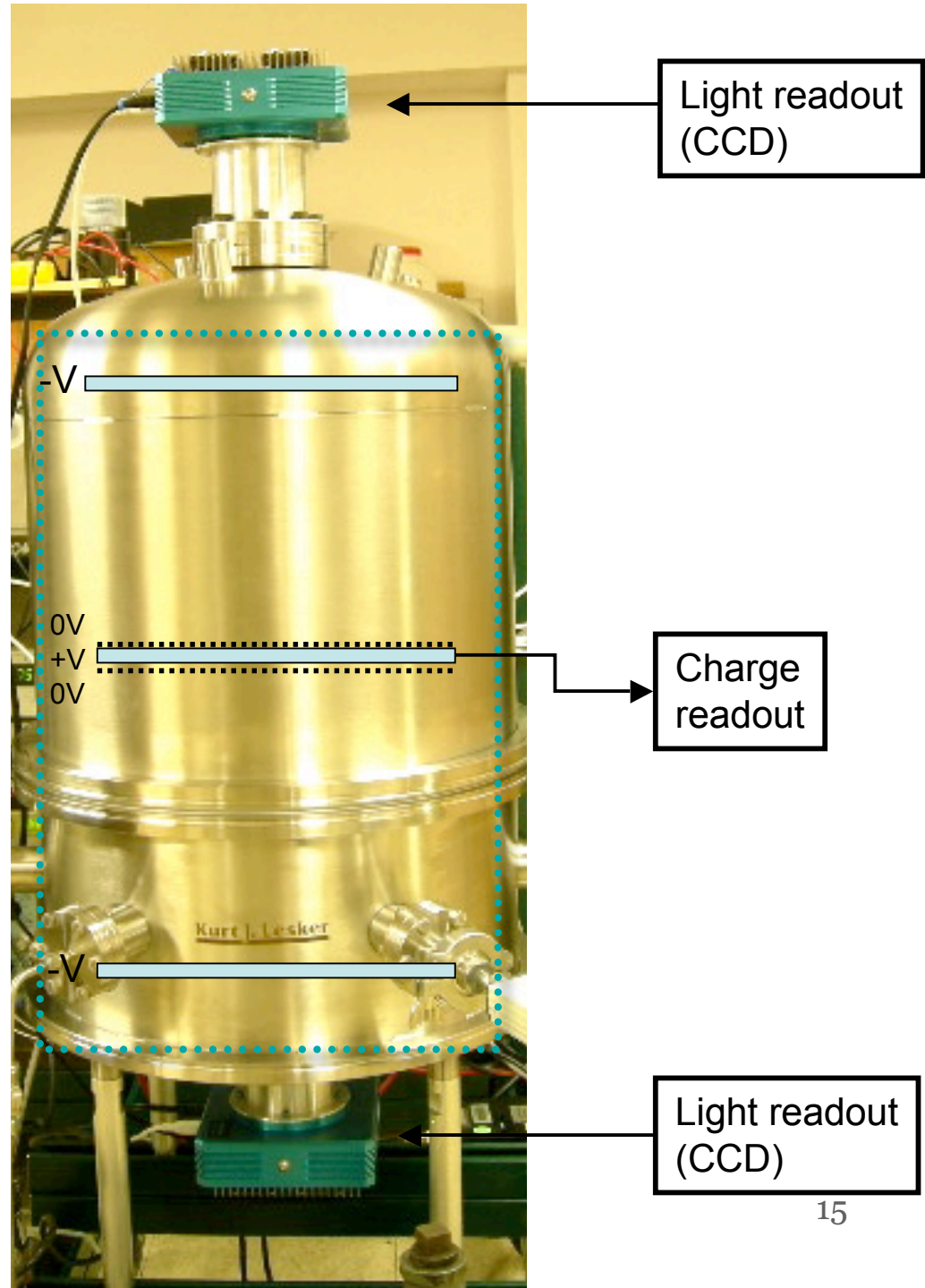
# DMTPC 10-Liter detector

Dual TPC

Mesh-amplification region  
(2-D imaging)

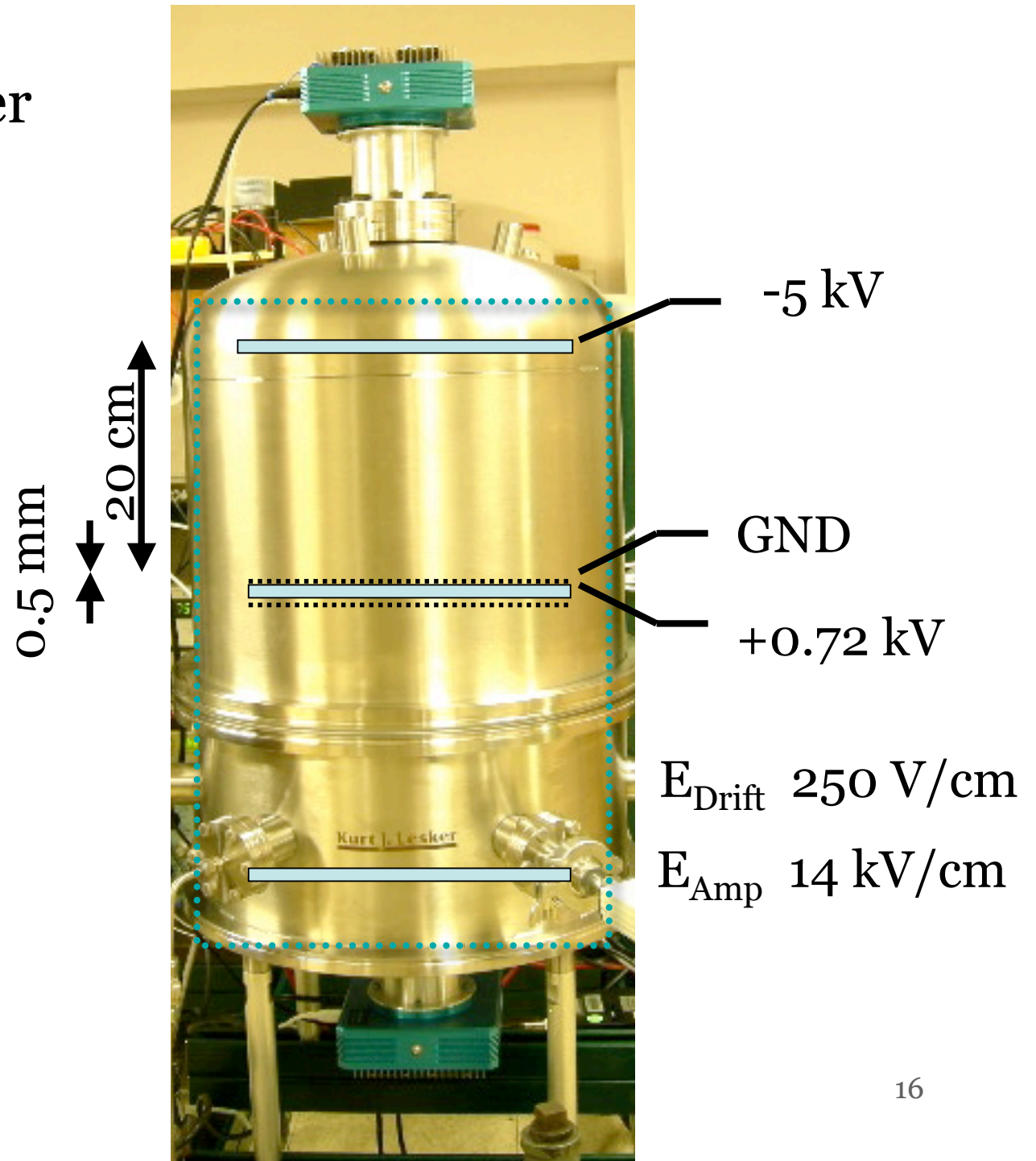
10 L fiducial volume  
20 cm drift  
3 g at 75 torr

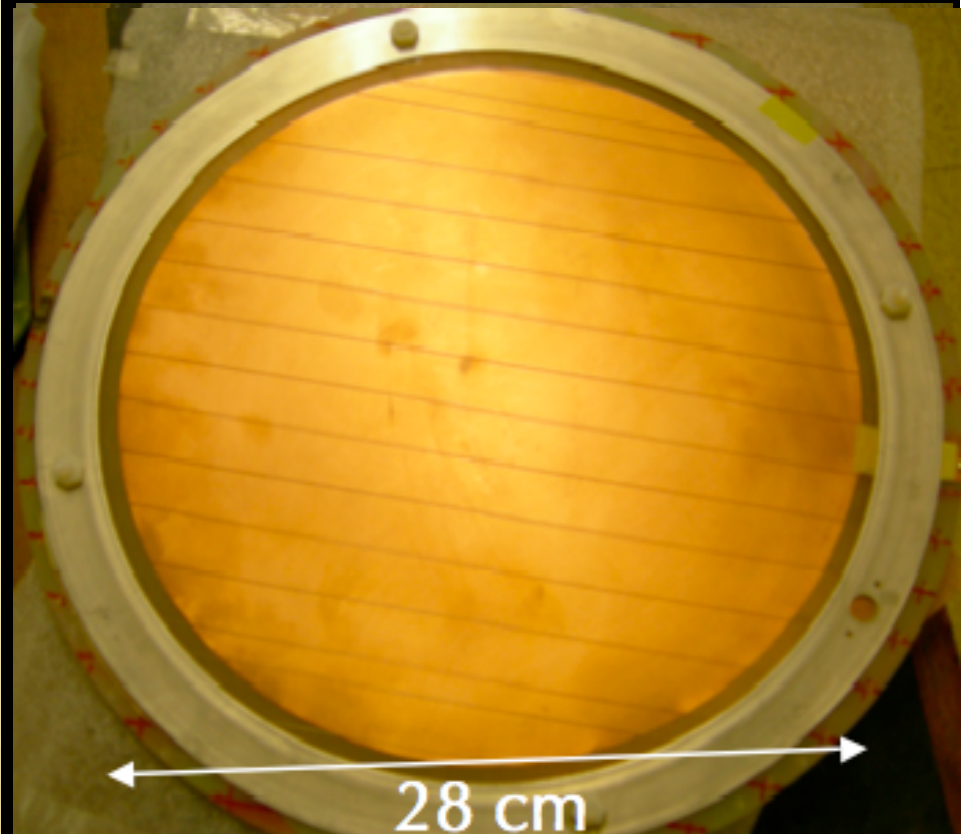
Charge and scintillation  
readout





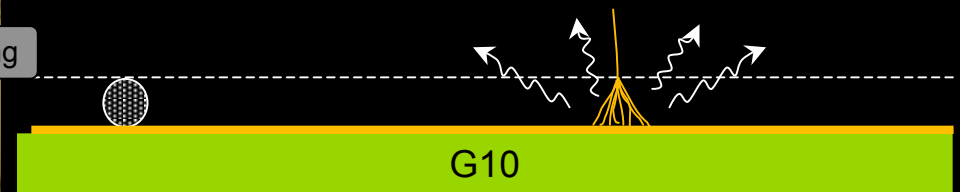
# DMTPC 10-Liter detector





*D. Dujmic et al., Astropart. Phys. 30 (2008)*

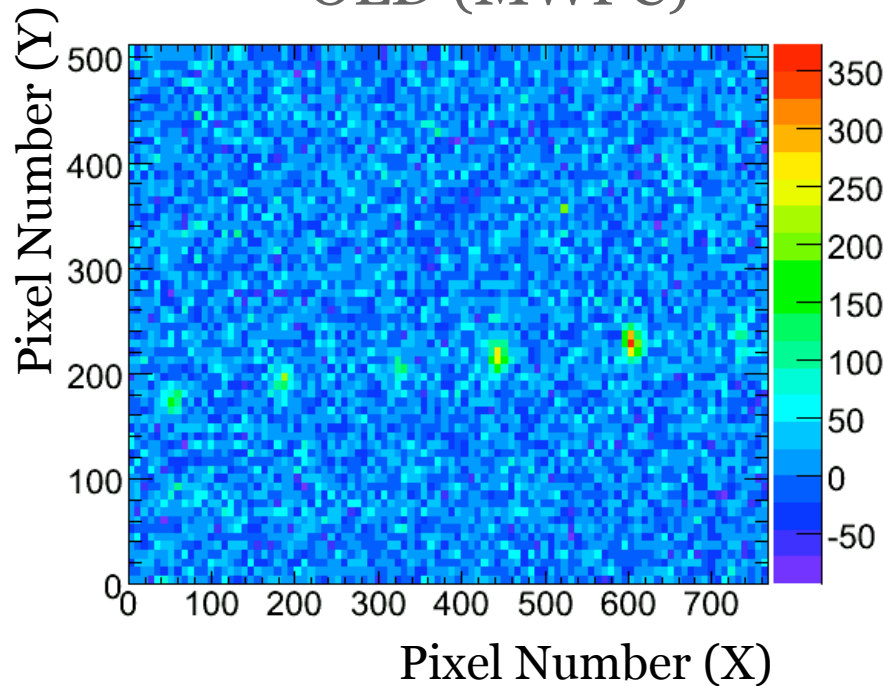
SS ring



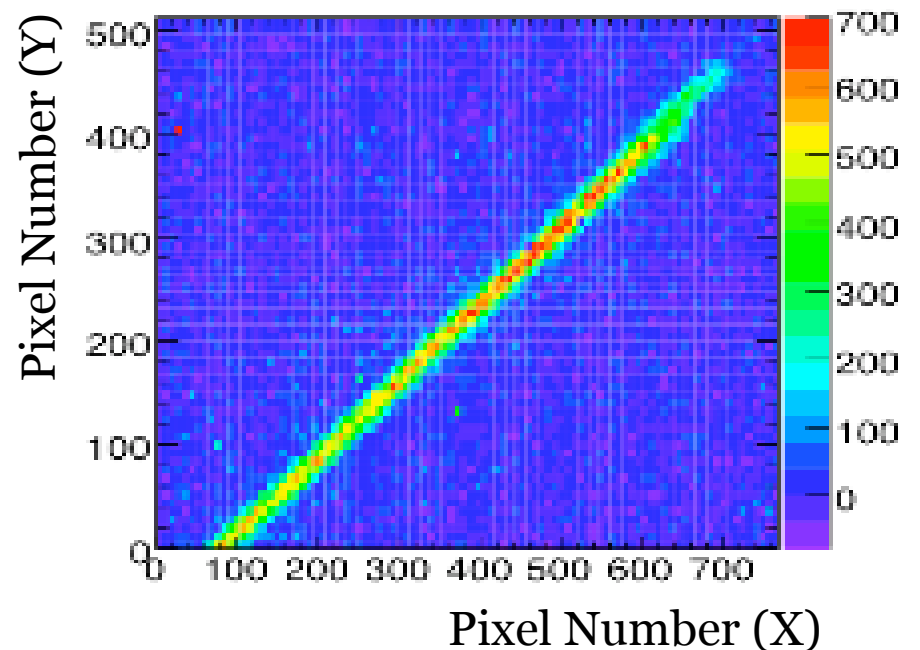
Resistive separators, dia=0.5mm, every 2 cm <sup>17</sup>

# Mesh-based Amplification

OLD (MWPC)



NEW (Mesh)



Mesh

256 um pitch

28 um wire

10x higher gain achieved

See talk by Denis Dujmic

# CCD Camera



Apogee Alta U6

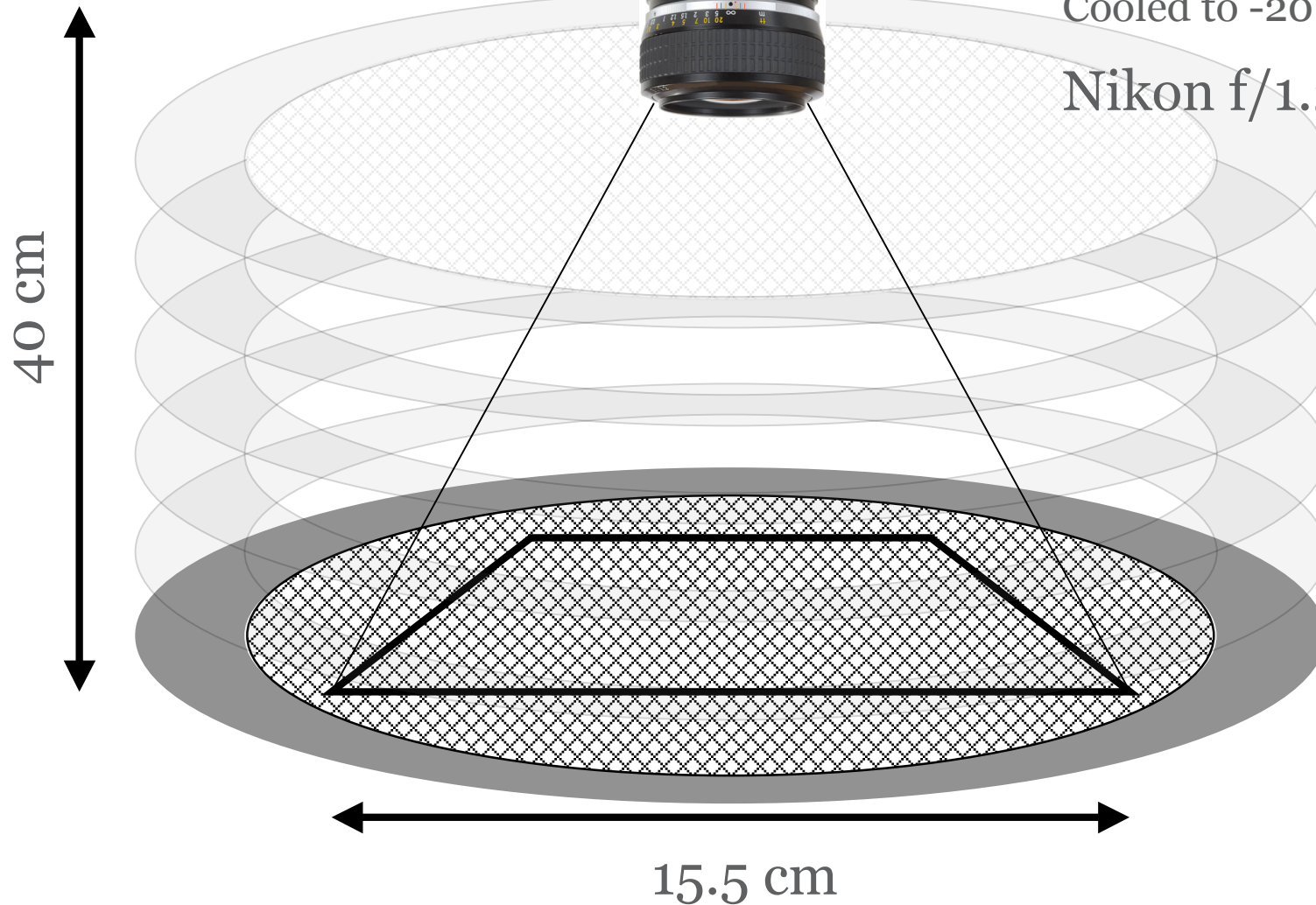
Kodak KAF-1001E

1024 x 1024 pixels

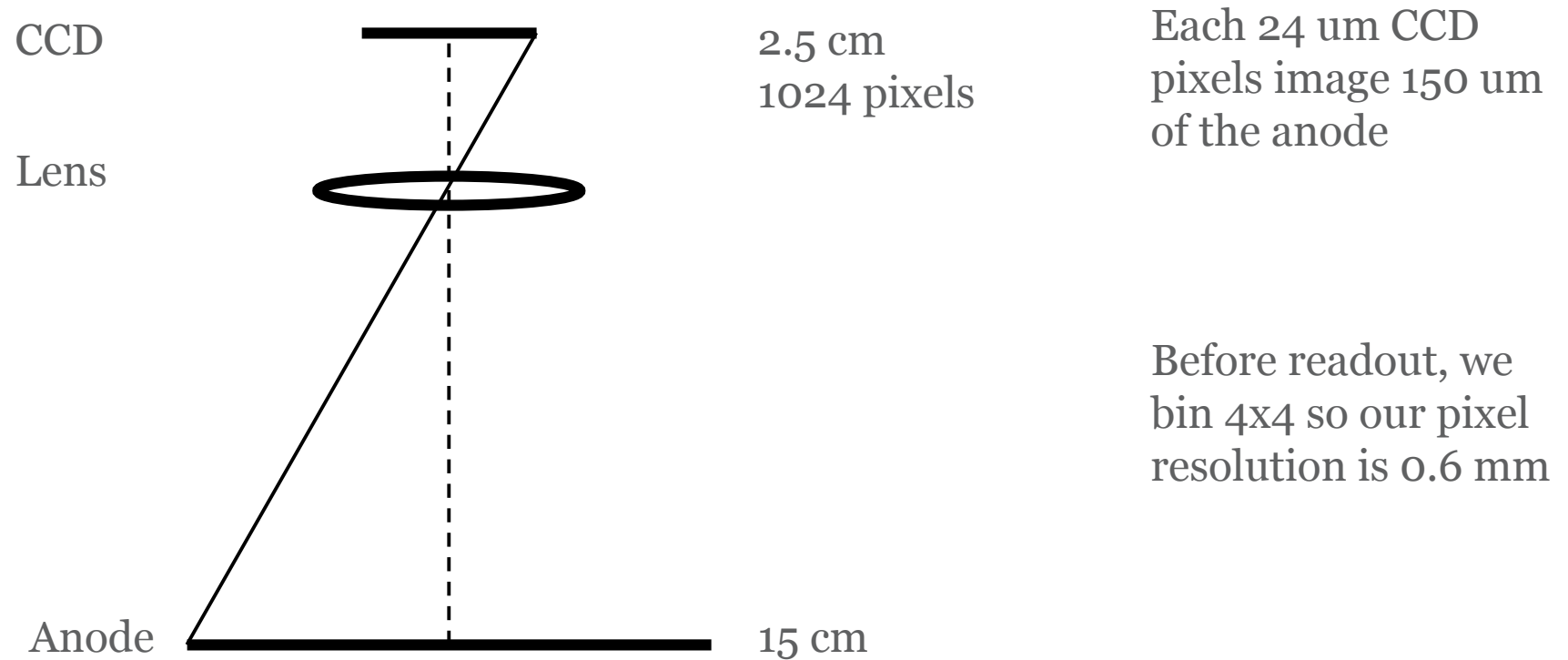
24 x 24  $\mu\text{m}^2$

Cooled to -20 C

Nikon f/1.2 55 mm

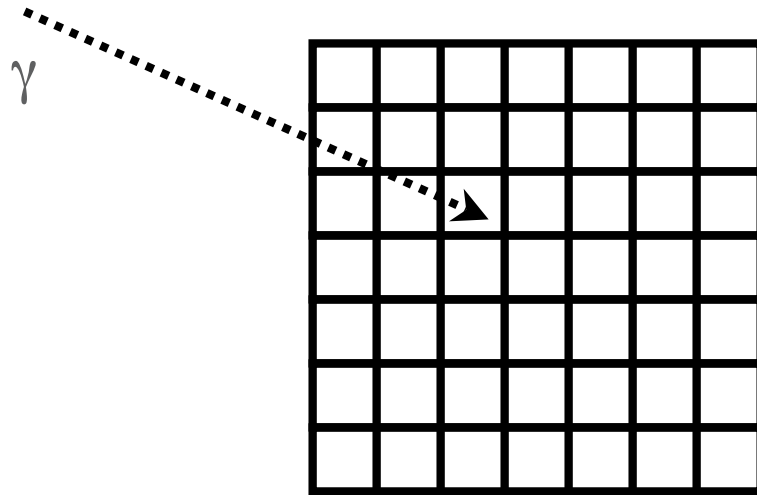


# Schematic of Optics



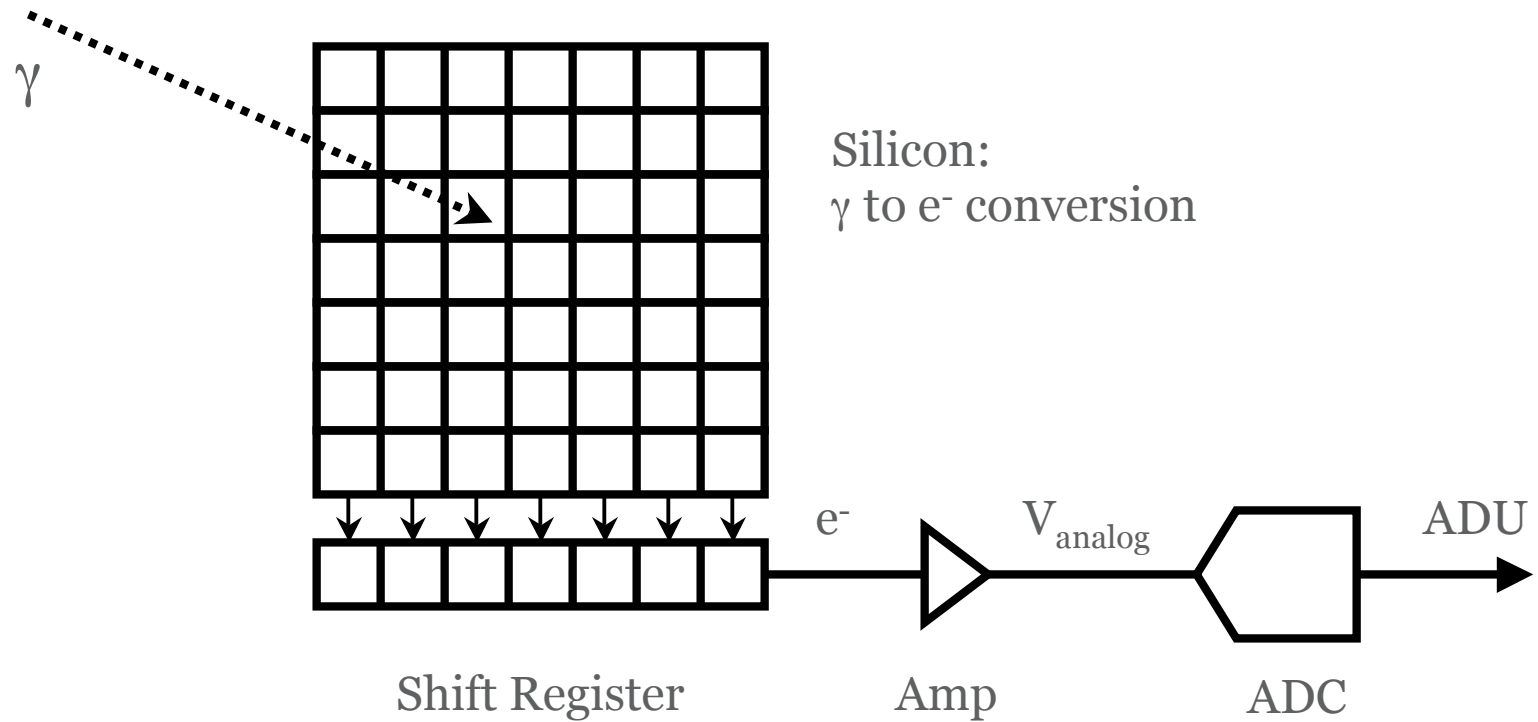


# CCD Readout

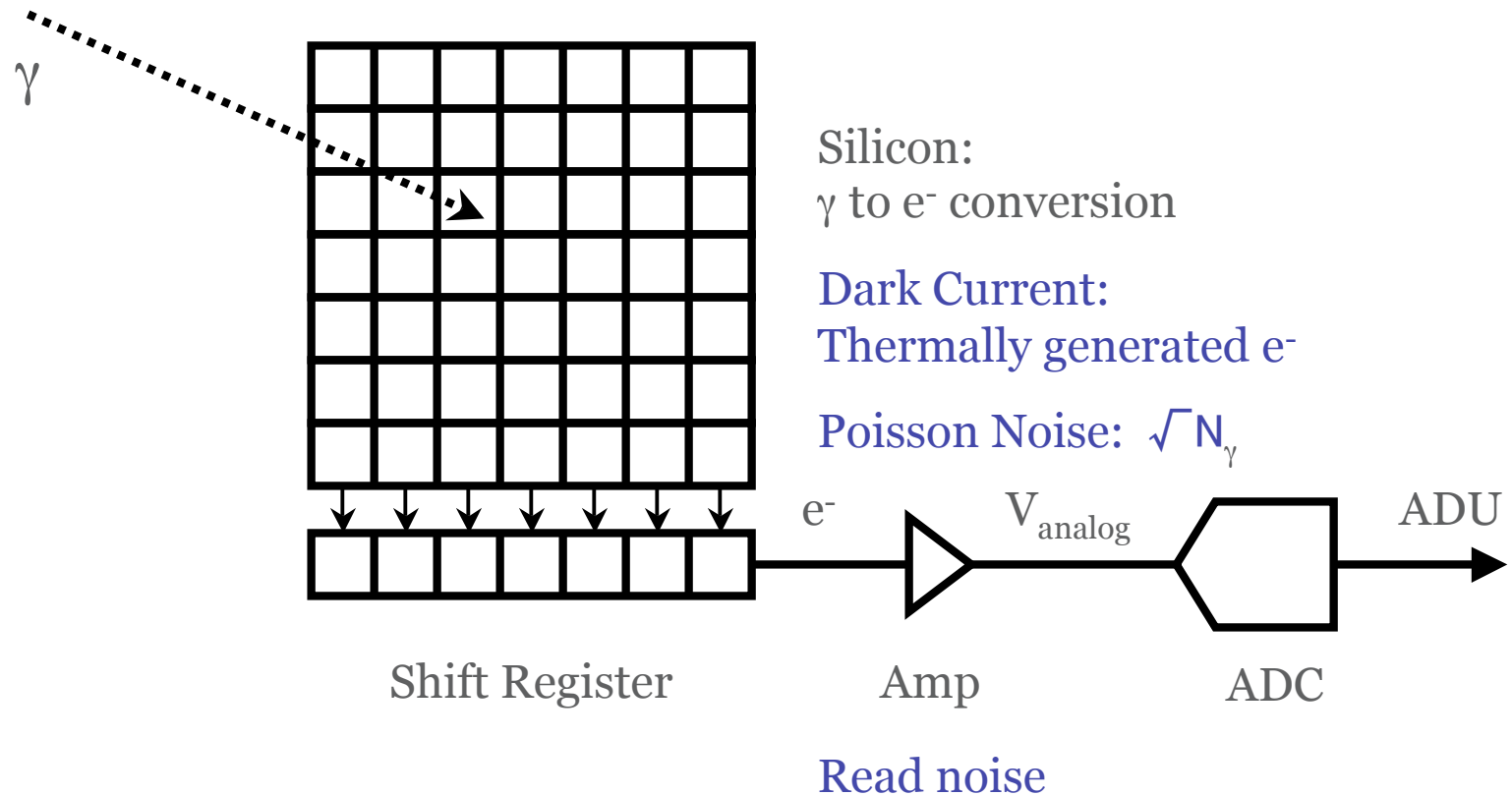


Silicon:  
 $\gamma$  to  $e^-$  conversion

# CCD Readout



# CCD Noise Sources



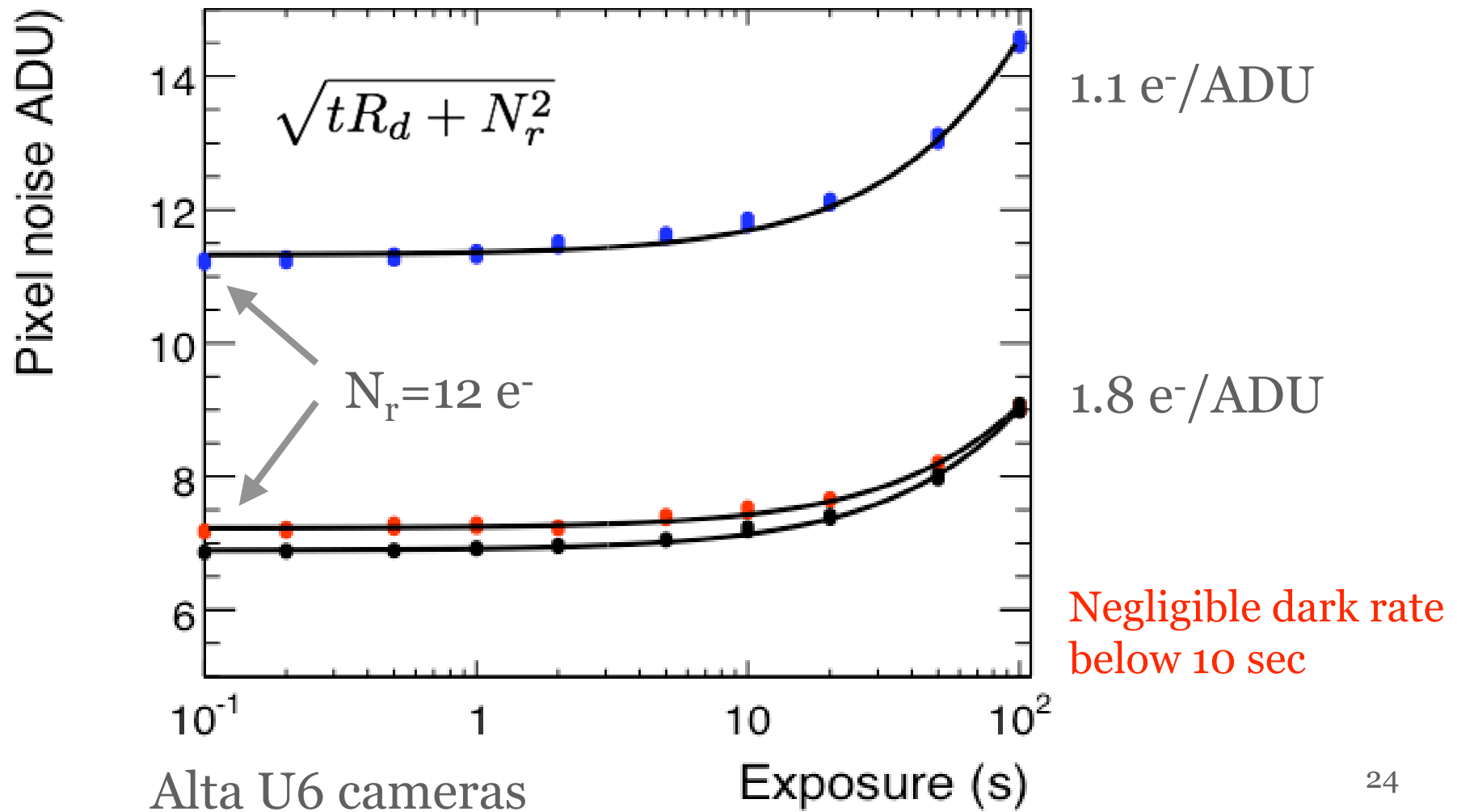
$$SNR = \frac{N_\gamma}{\sqrt{N_\gamma + N_d + N_r^2}}$$

$N_\gamma$  = # of detected photons

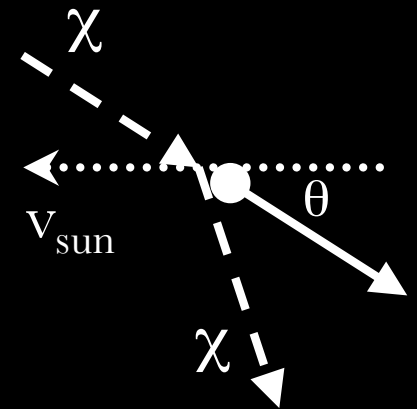
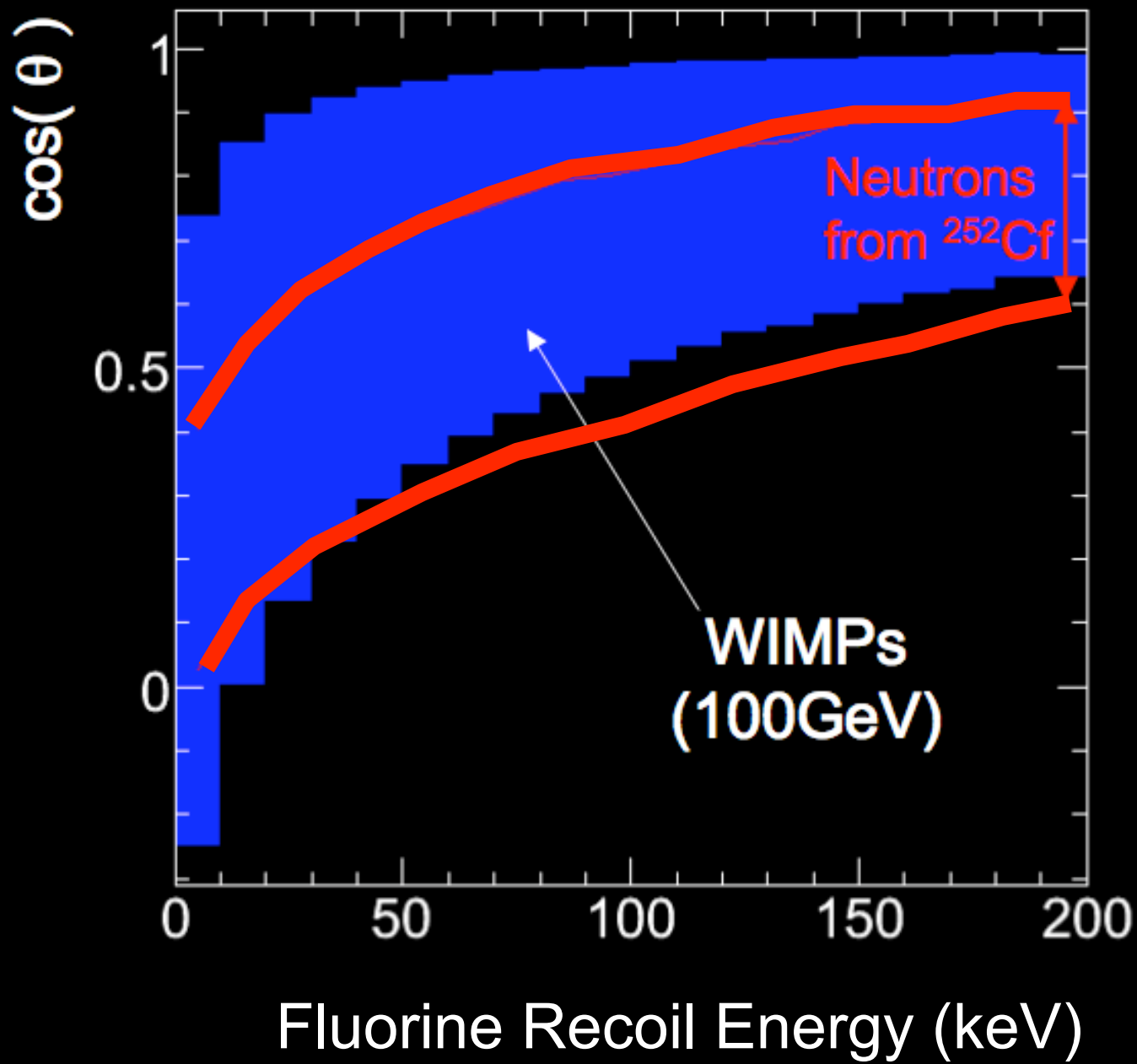
$N_d$  = dark noise

$N_r$  = read noise

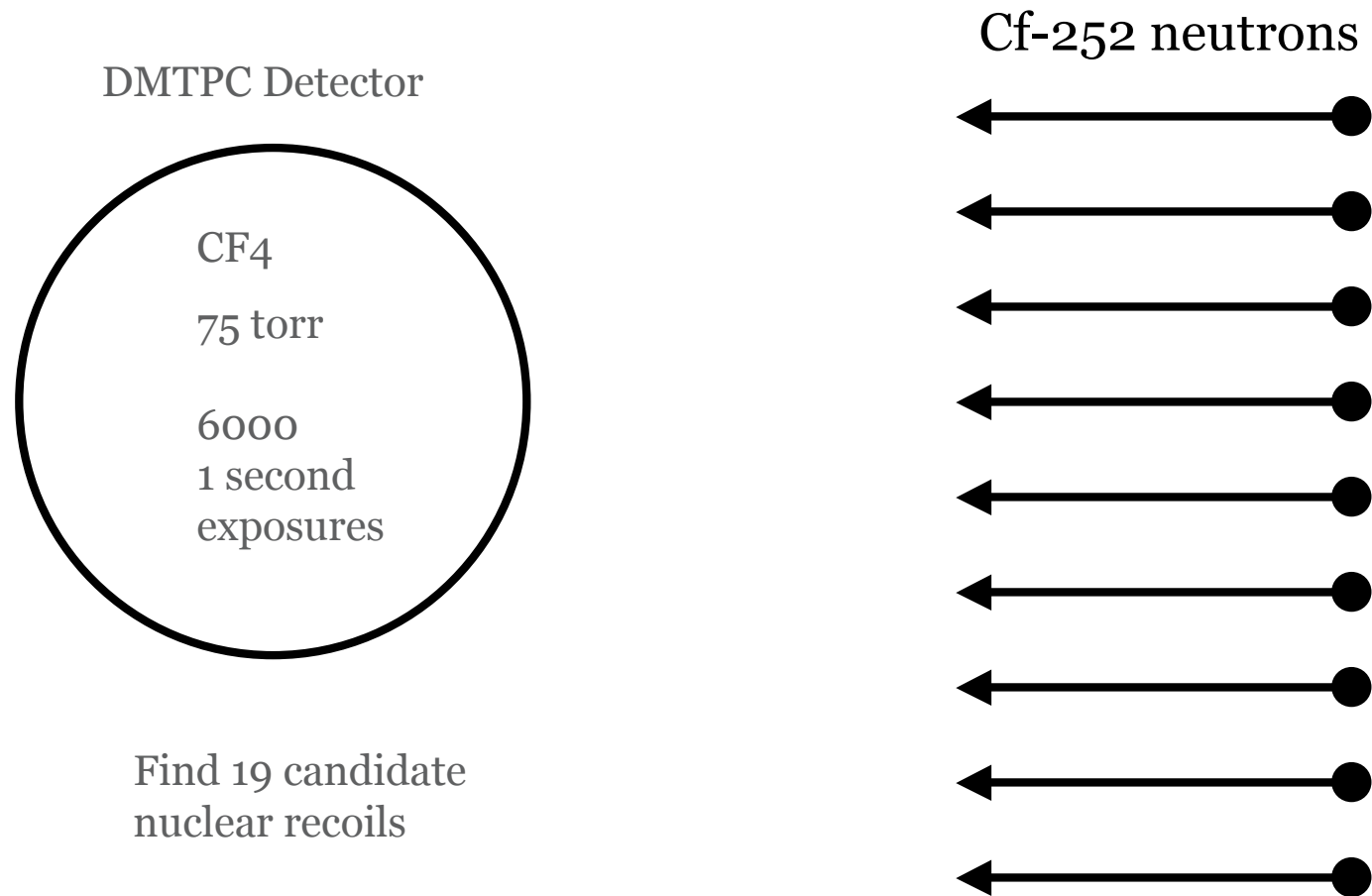
# CCD Camera Noise (shutter closed)



Head-tail for nuclear recoils



# Directionality and Head-Tail

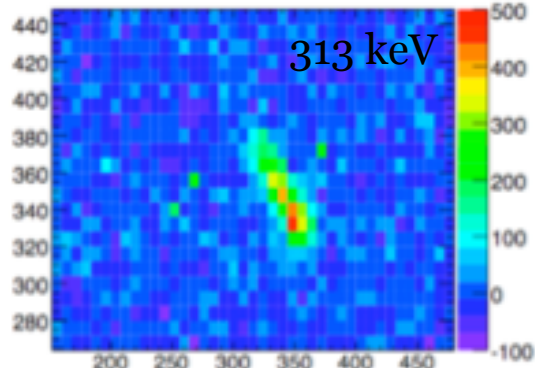
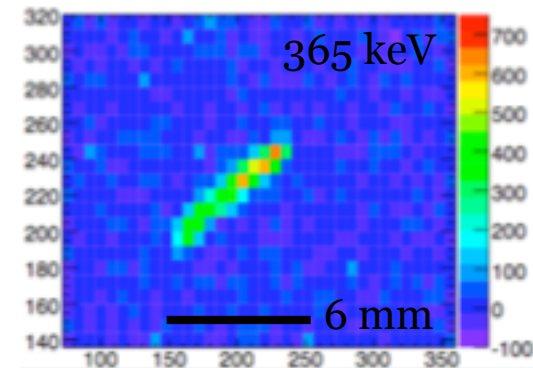
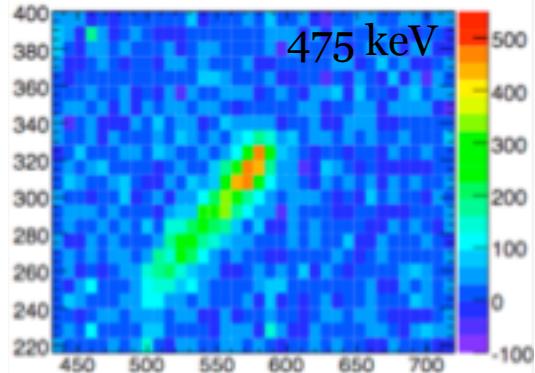
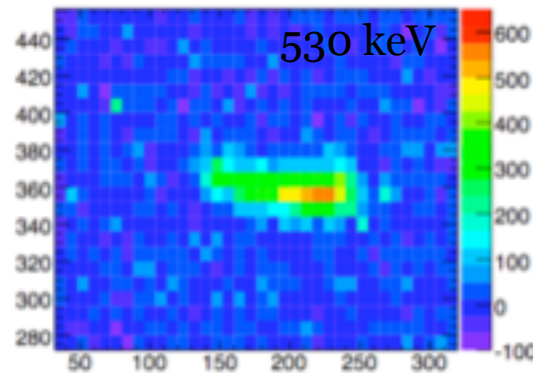
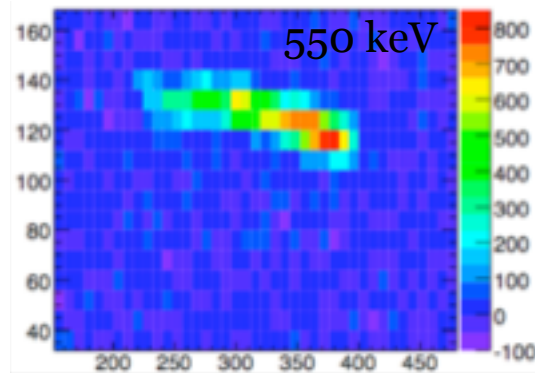
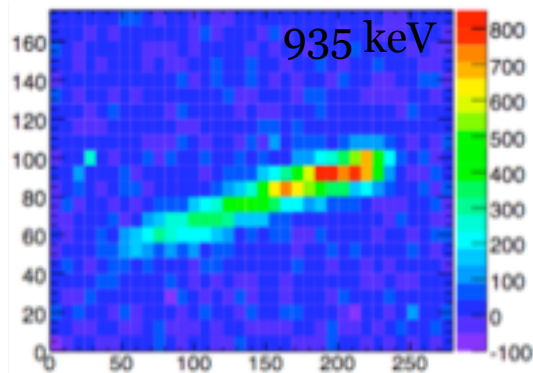


100 pixels = 6 mm

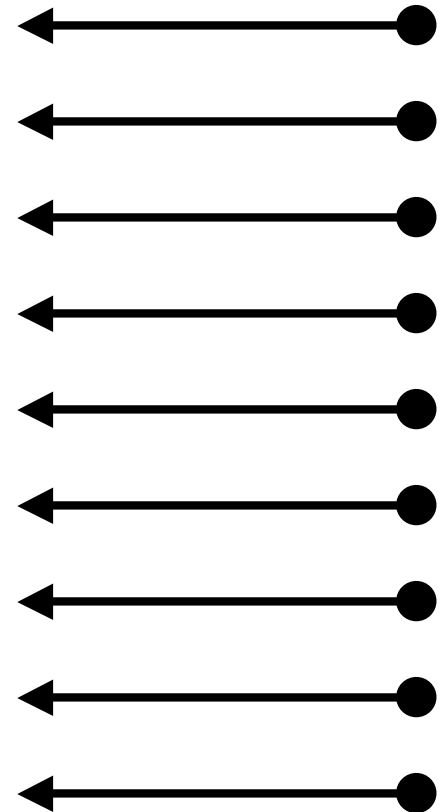
Dujmic et al. Astropart. Phys. 30 (2008) arXiv:0804.4827



# Directionality and Head-Tail



Cf-252 neutrons

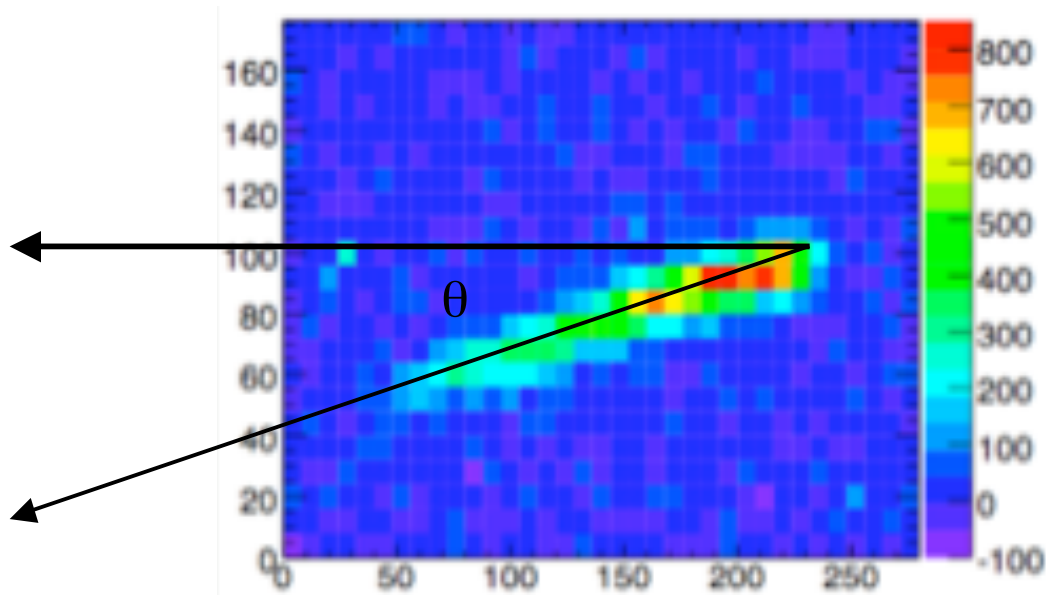


P = 75 torr

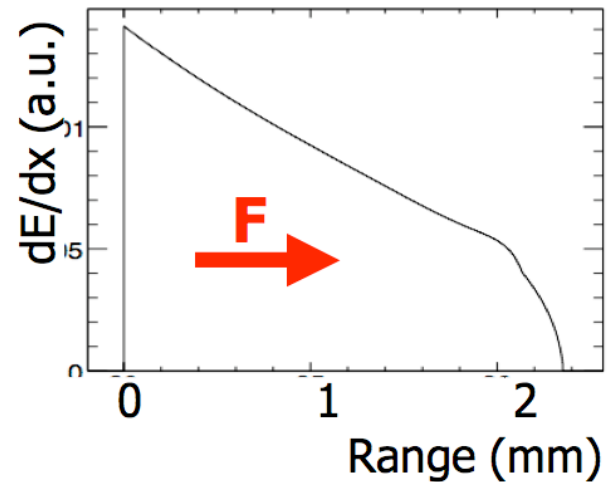
100 pixels = 6 mm

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

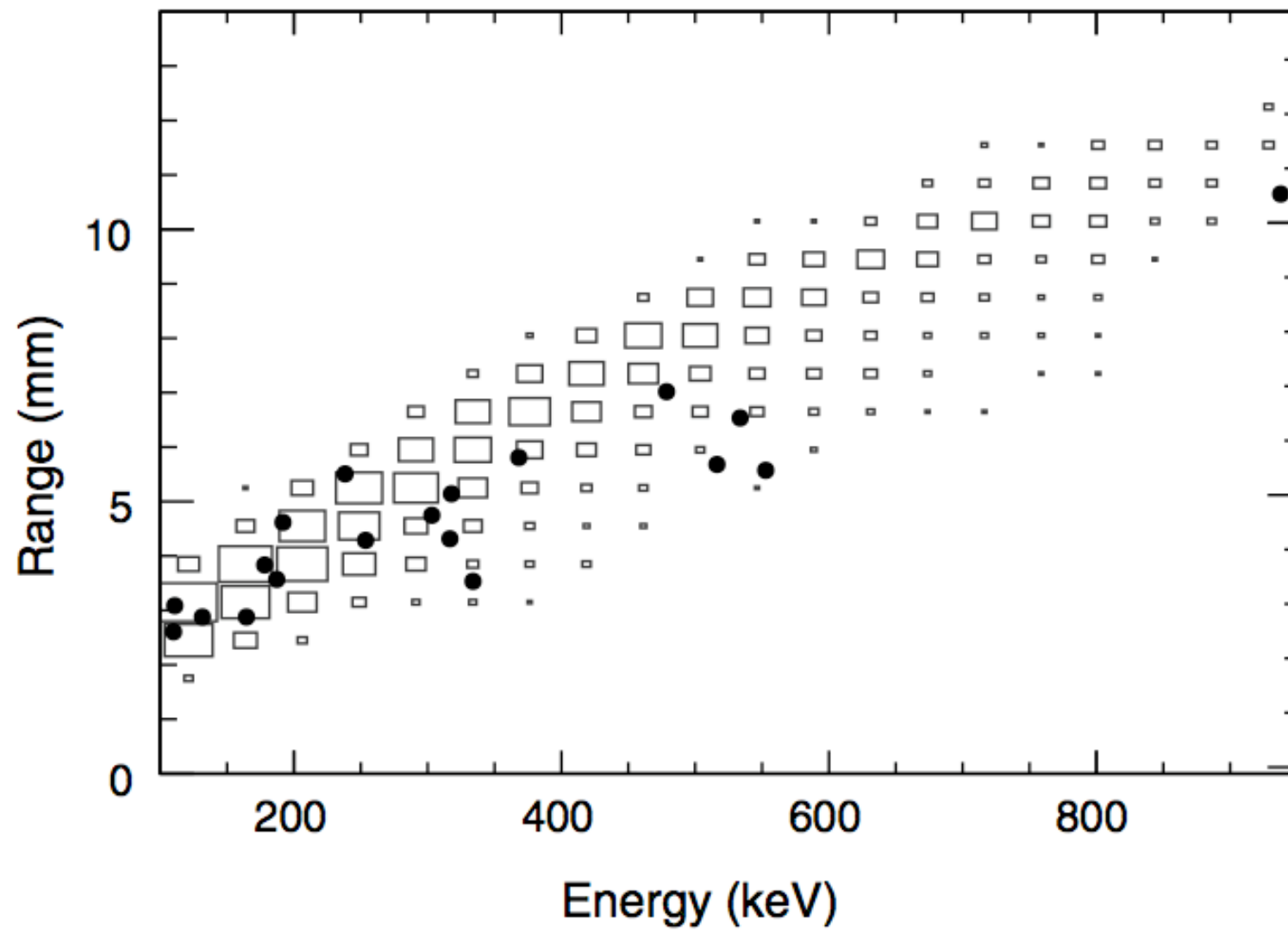
# Track Reconstruction

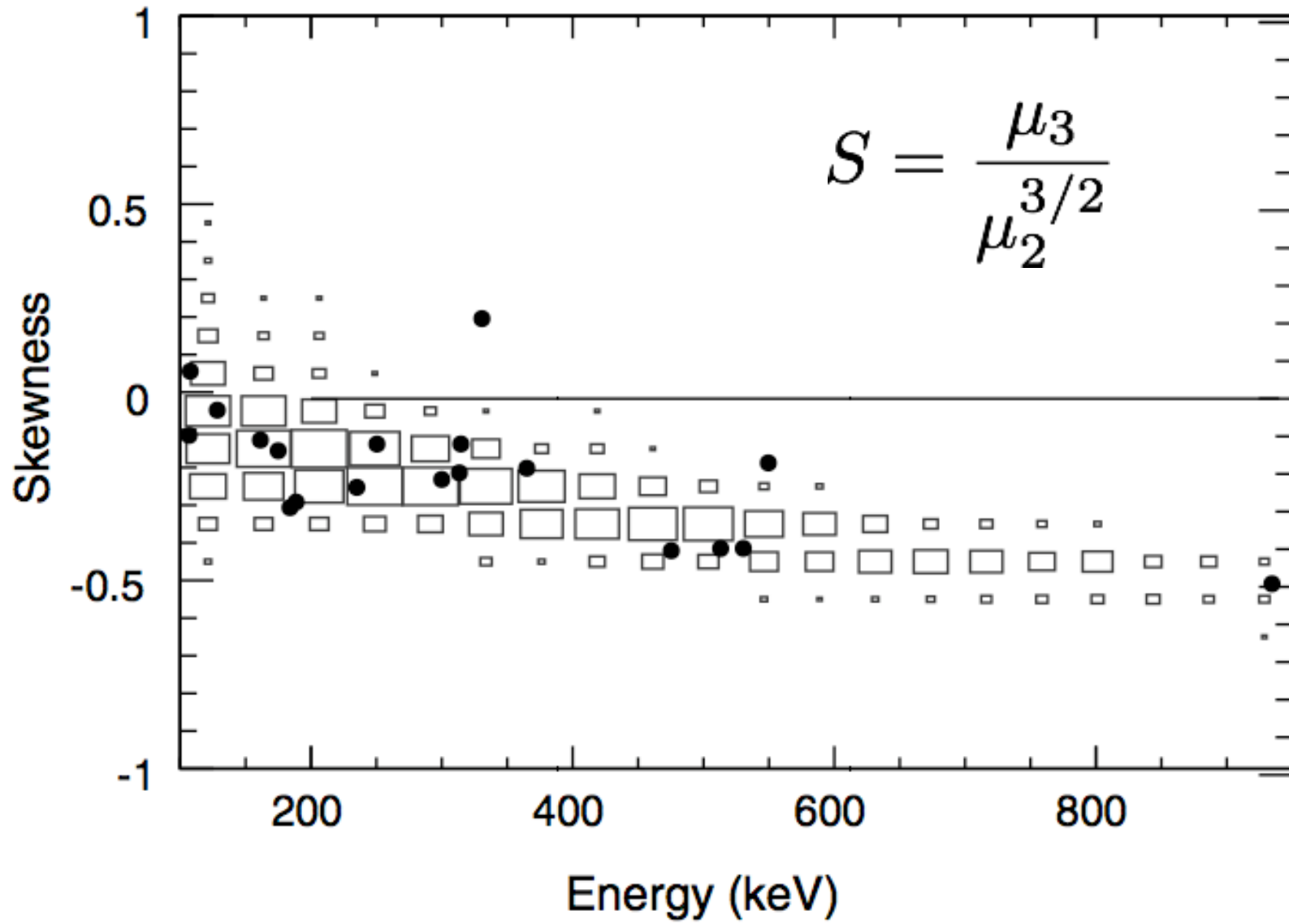


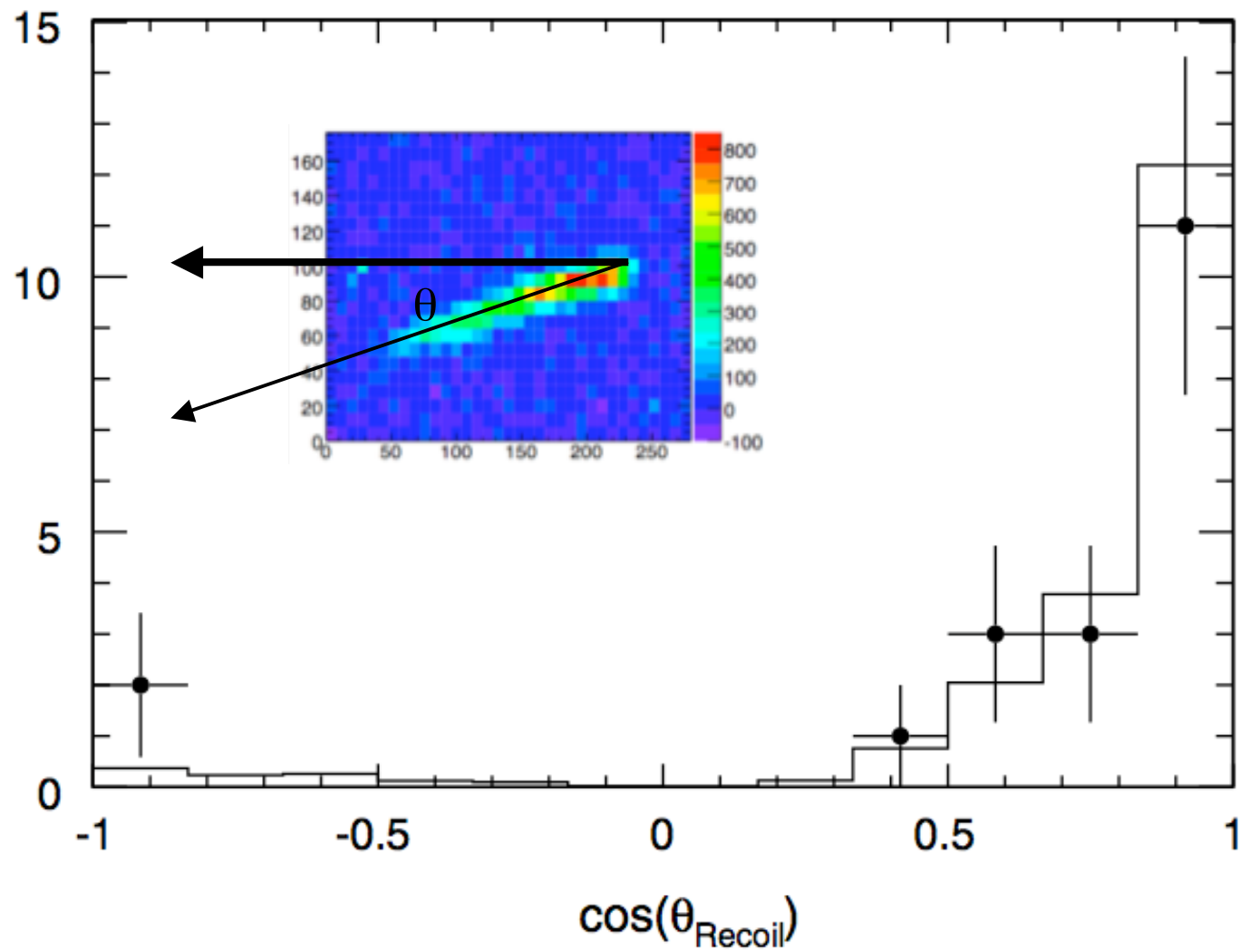
For image analysis discussion, see upcoming talk by Asher Kaboth



# Nuclear Recoils





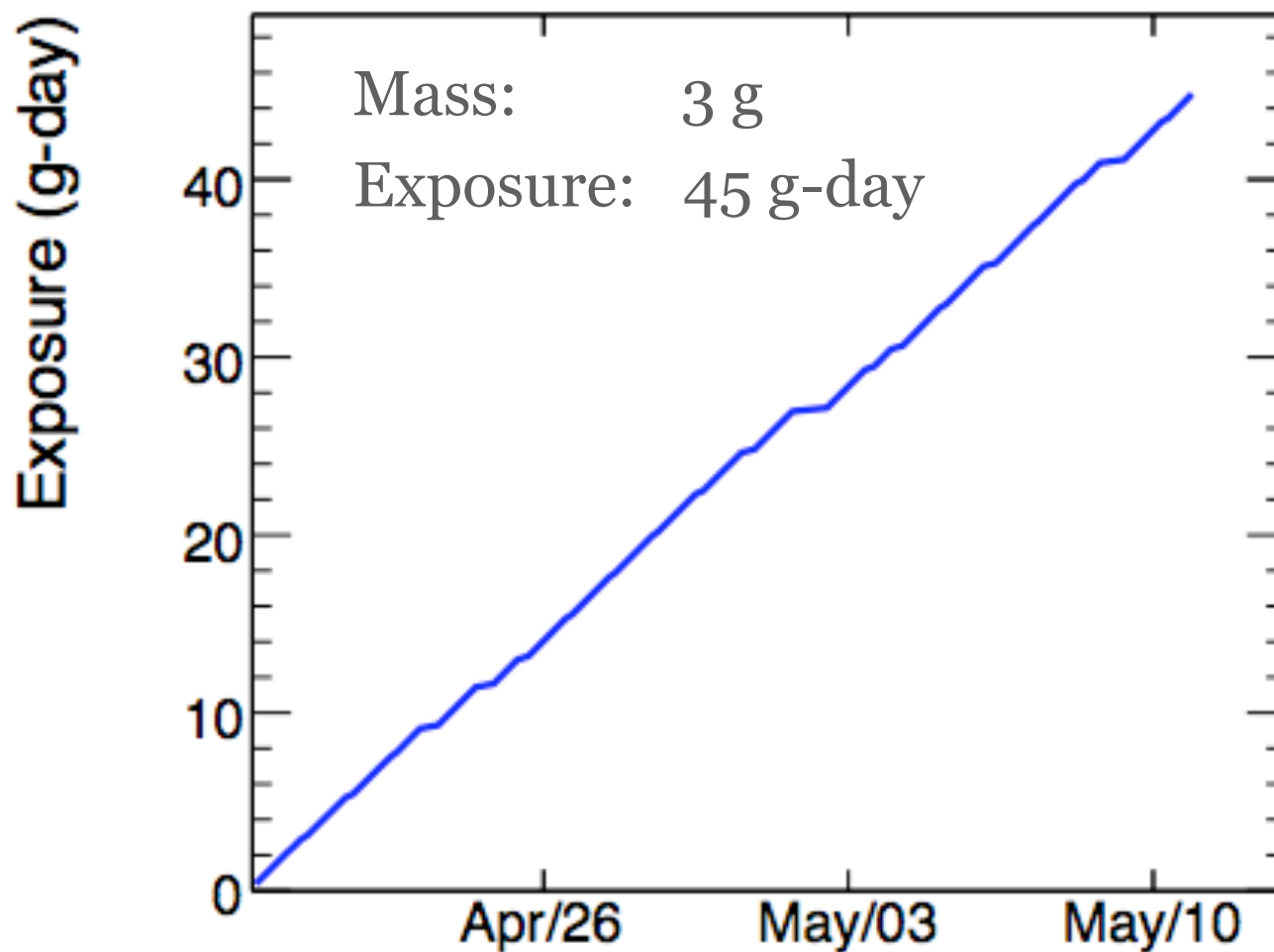


# Surface Run at MIT

- 10L prototype, dual TPC
- Run in a basement lab at MIT
- Remote operation
- 6 week & 3 week long datasets



# Surface Run at MIT



Dual TPC  
75 torr  
Untriggered  
Remote operation

~70% live-time  
Daily gas refill  
Operator  
CCD readout

# Surface Run Events

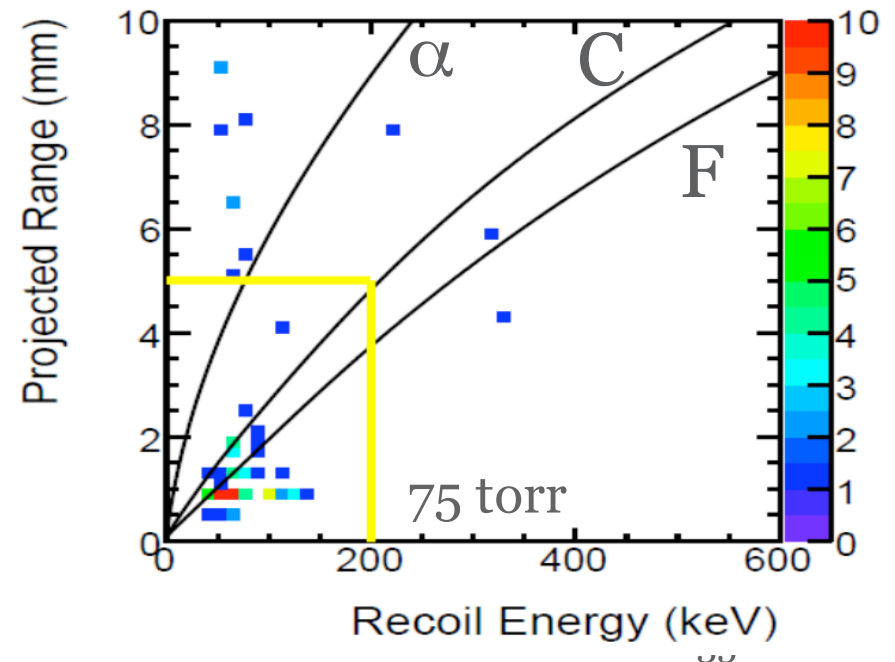
80 events remain:  $94 \mu\text{Hz}$

Range-energy is consistent  
with nuclear recoils

Monte Carlo studies show  
50% efficiency at 100 keV.  
Detect events down to 50 keV

For details of this analysis, see  
upcoming talk by Tom Caldwell.

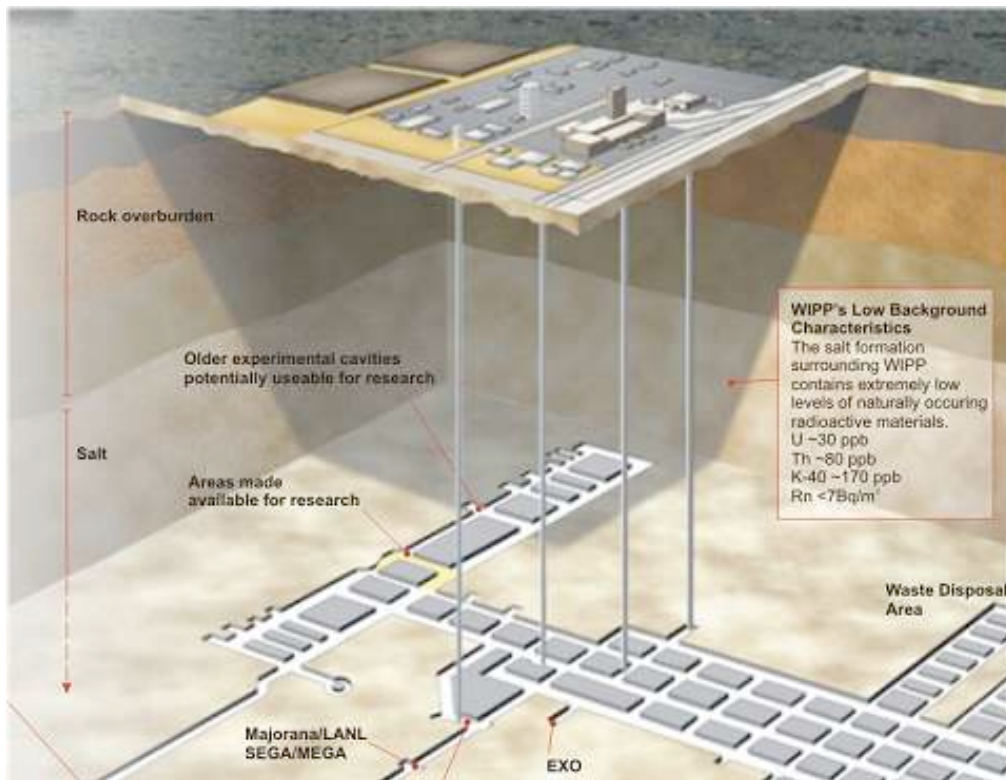
Non-spark, single track,  
non-edge crossing,  
not a worm (cosmic ray)  
Range < 5 mm  
Energy < 200 keV

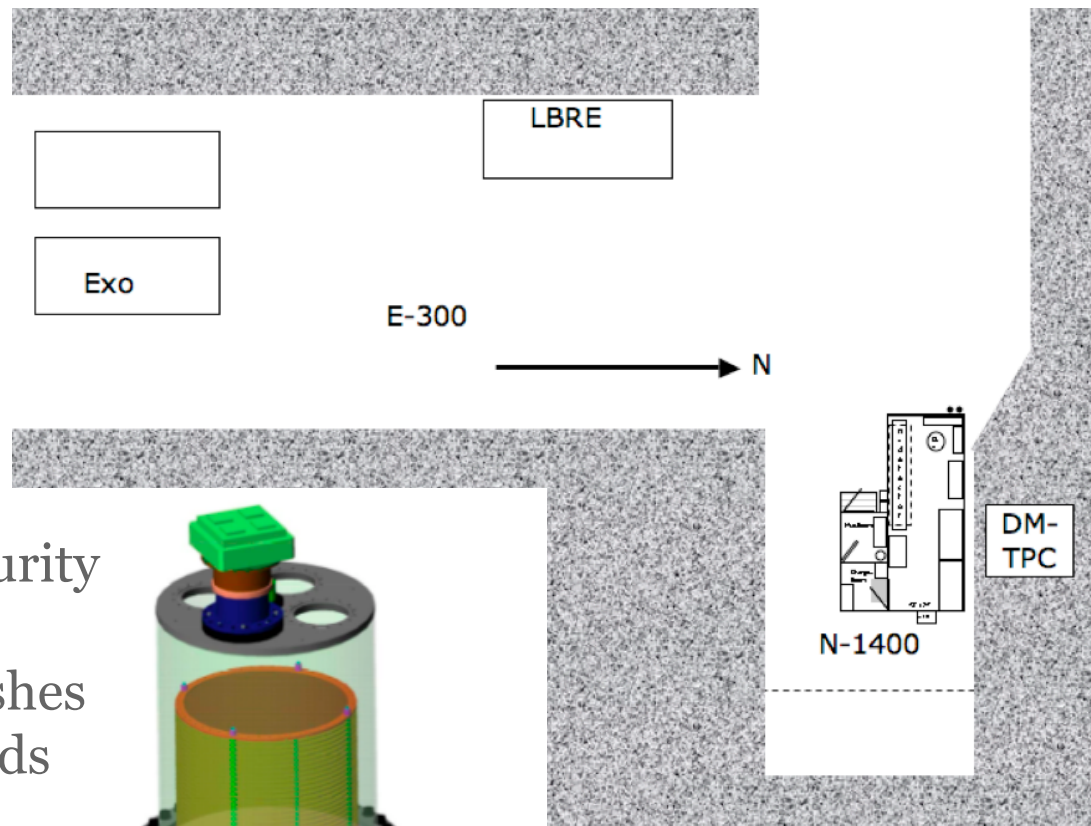




# Going underground to WIPP

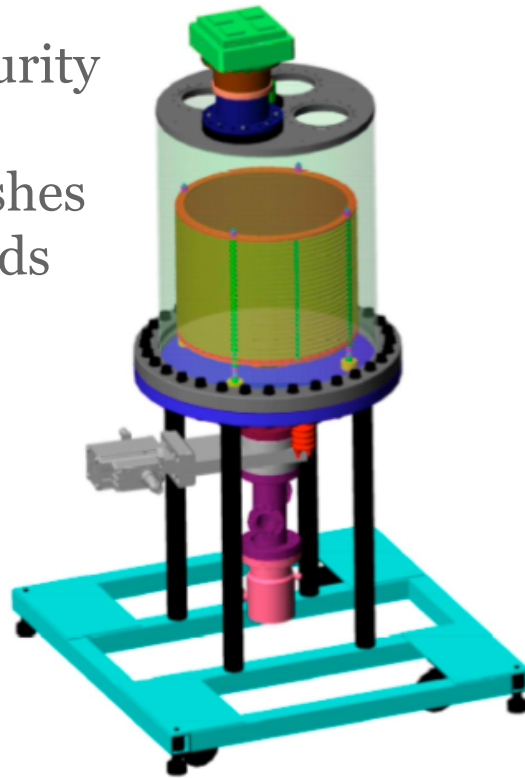
- Low radon level  $< 7 \text{ Bq/m}^3$
- 1.6 km water equivalent
- $< 1$  event/yr neutron background





Attention to radiopurity  
material selection  
OFHC copper meshes  
non-thoriated welds

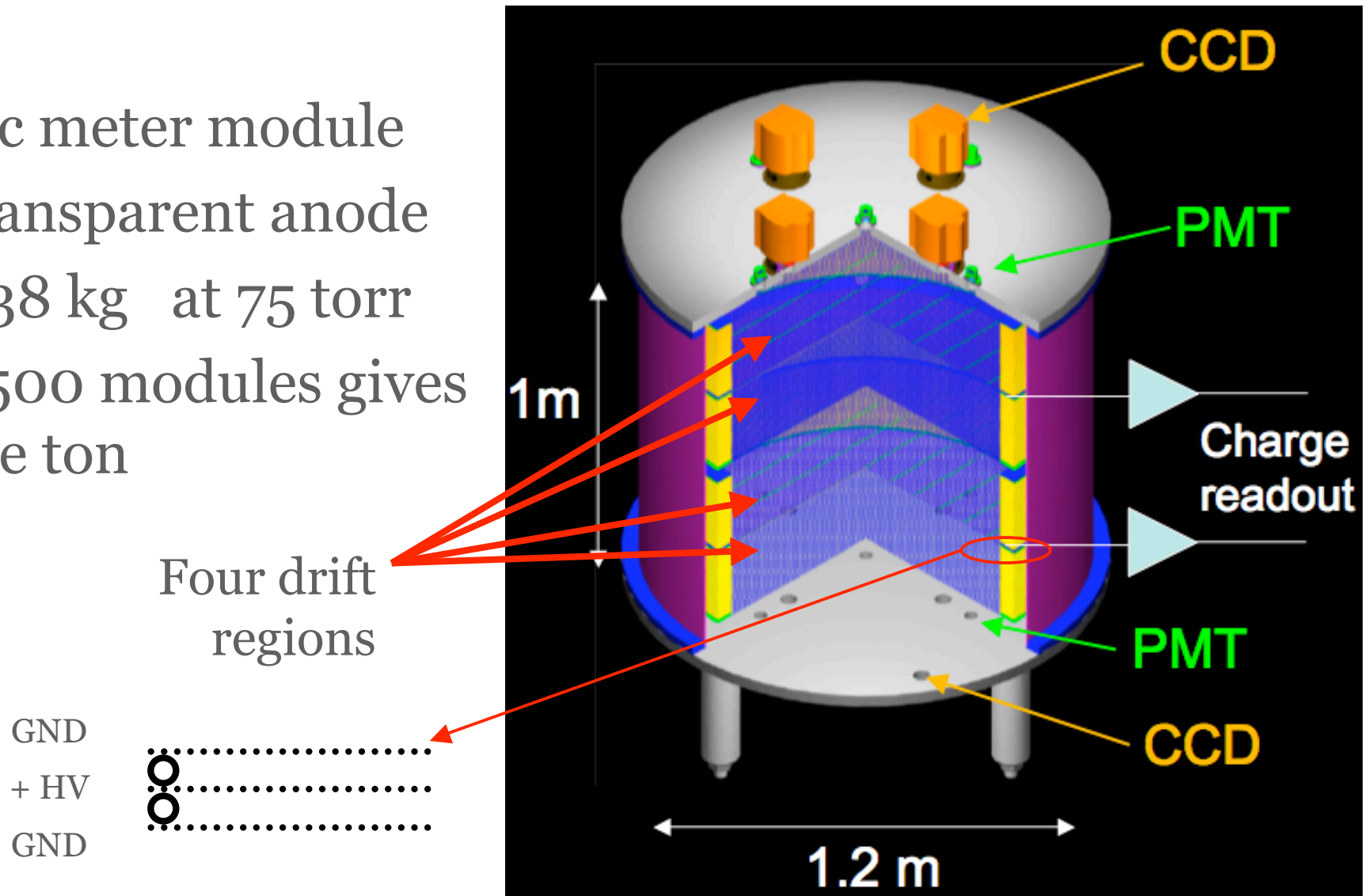
Higher vacuum  
more stable gain



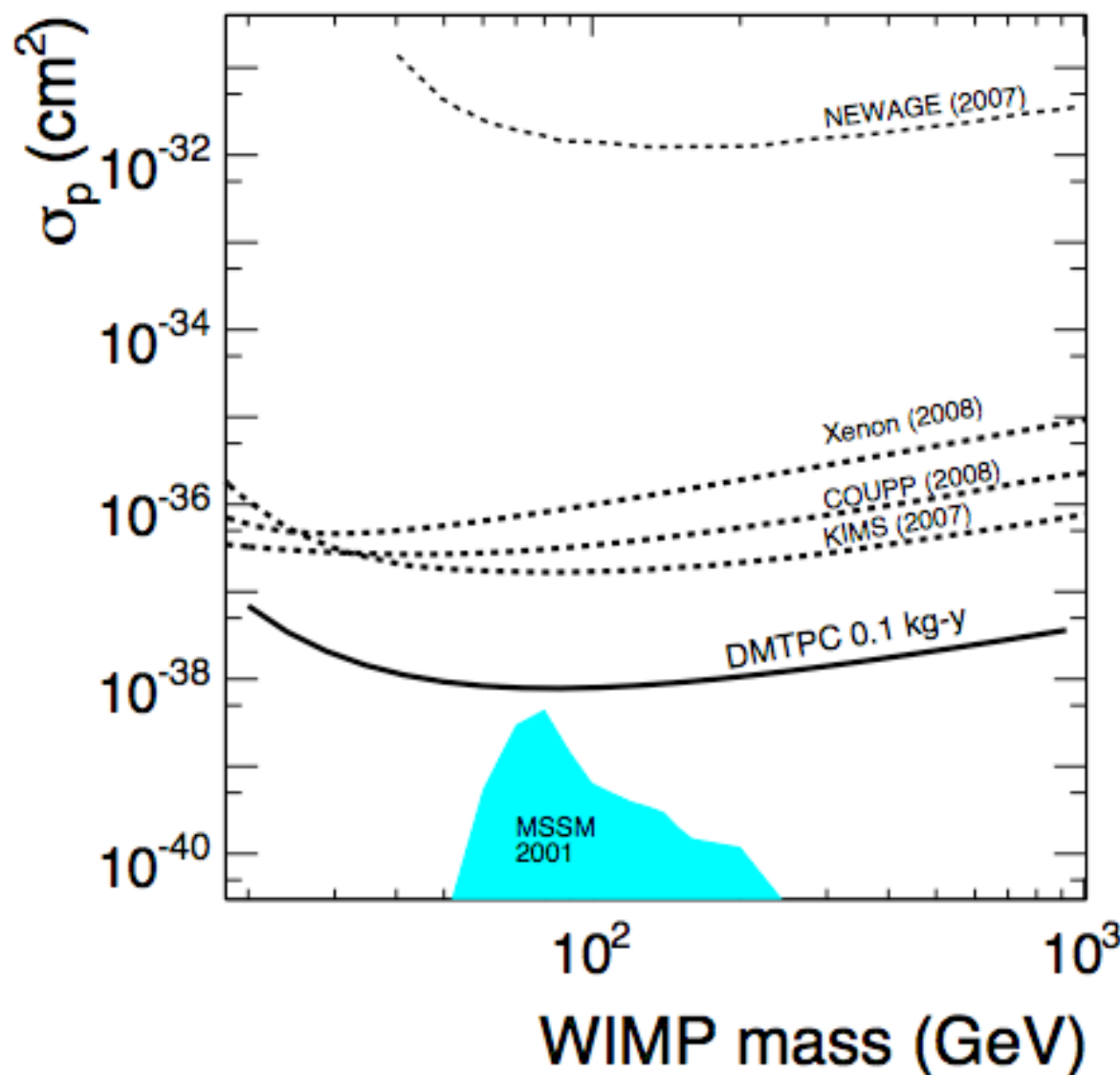
# Scaling to a cubic meter

Cubic meter module

- Transparent anode
- 0.38 kg at 75 torr
- 2,500 modules gives one ton



# DMTPC Physics Reach



1 m<sup>3</sup>

50 torr CF<sub>4</sub>

5 months live

No background

E = 50 keV - 150 keV



# Conclusions

- DMTPC has made great progress since Cygnus 2007
- Mesh-based detector allows 2D readout and higher gain
- Demonstrated head-tail discrimination on an event-by-event basis
- Surface run complete
- Remote, stable operation over months
- Preparing upgraded detector for WIPP

END

# Target Choice

$$\sigma_{\chi-N} = 4G_F^2 \mu_{\chi-N}^2 (C_N^{SI} + C_N^{SD})$$

$\mu_{\chi-N}$  = Reduced mass

$G_F$  = Fermi constant

## Spin independent

$$C_N^{SI} \propto A^2$$

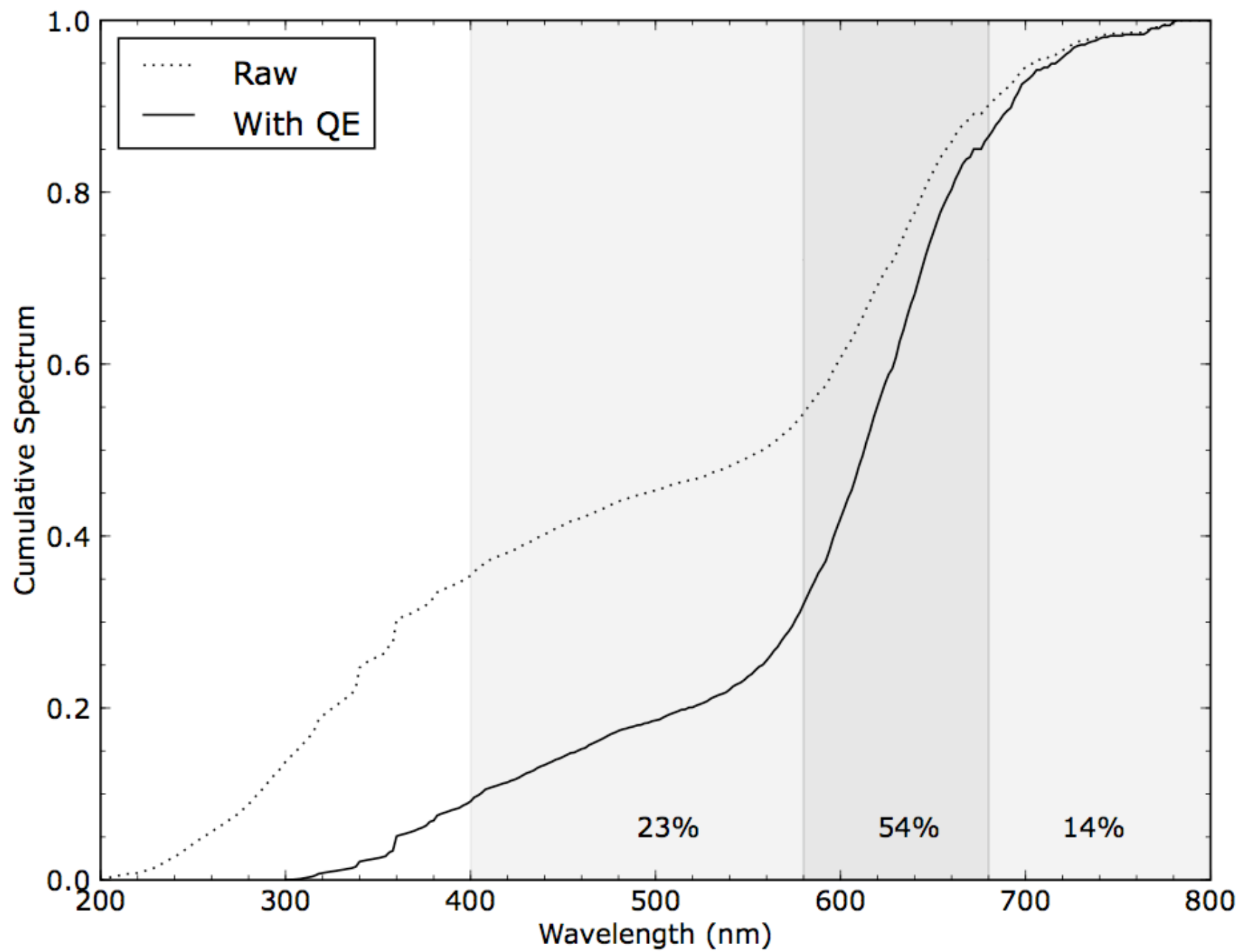
Constructive interference

Heavier targets favored:  
Liquid Xe, NaI

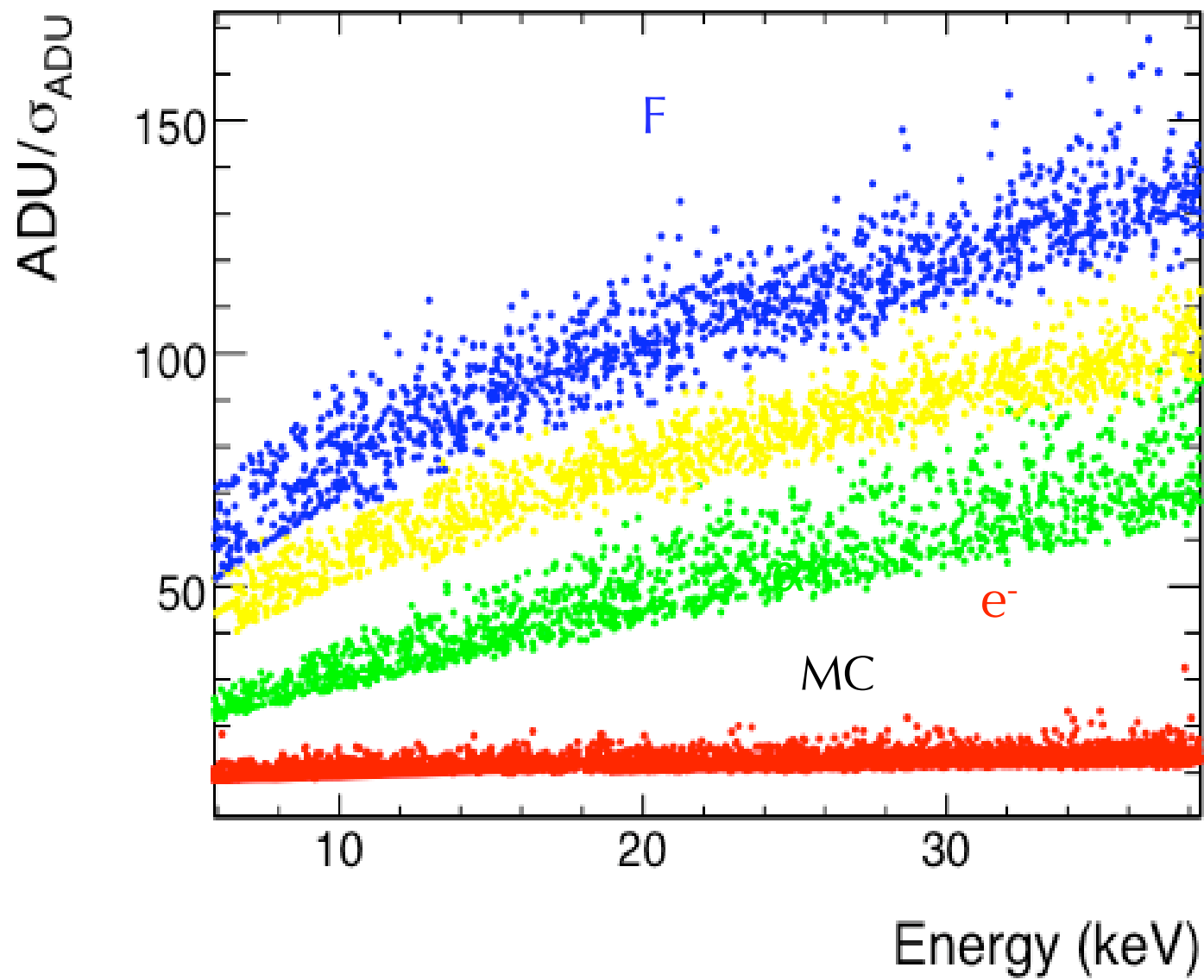
## Spin dependent

$$C_N^{SD} \propto \lambda^2 J(J+1)$$

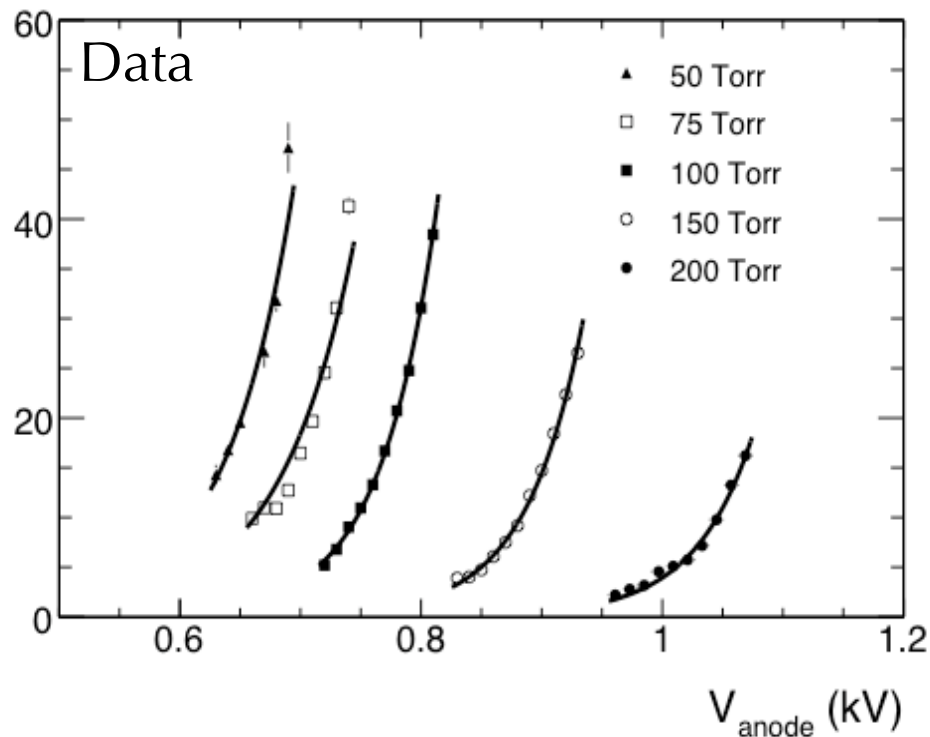
| Isotope           | unpaired | Abundance | $\lambda^2 J(J+1)$ |
|-------------------|----------|-----------|--------------------|
| $^1\text{H}$      | p        | 100%      | 0.750              |
| $^{19}\text{F}$   | p        | 100%      | 0.647              |
| $^{23}\text{Na}$  | p        | 100%      | 0.041              |
| $^3\text{He}$     | n        | 100%      | 0.928              |
| $^{129}\text{Xe}$ | n        | 26.4%     | 0.124              |





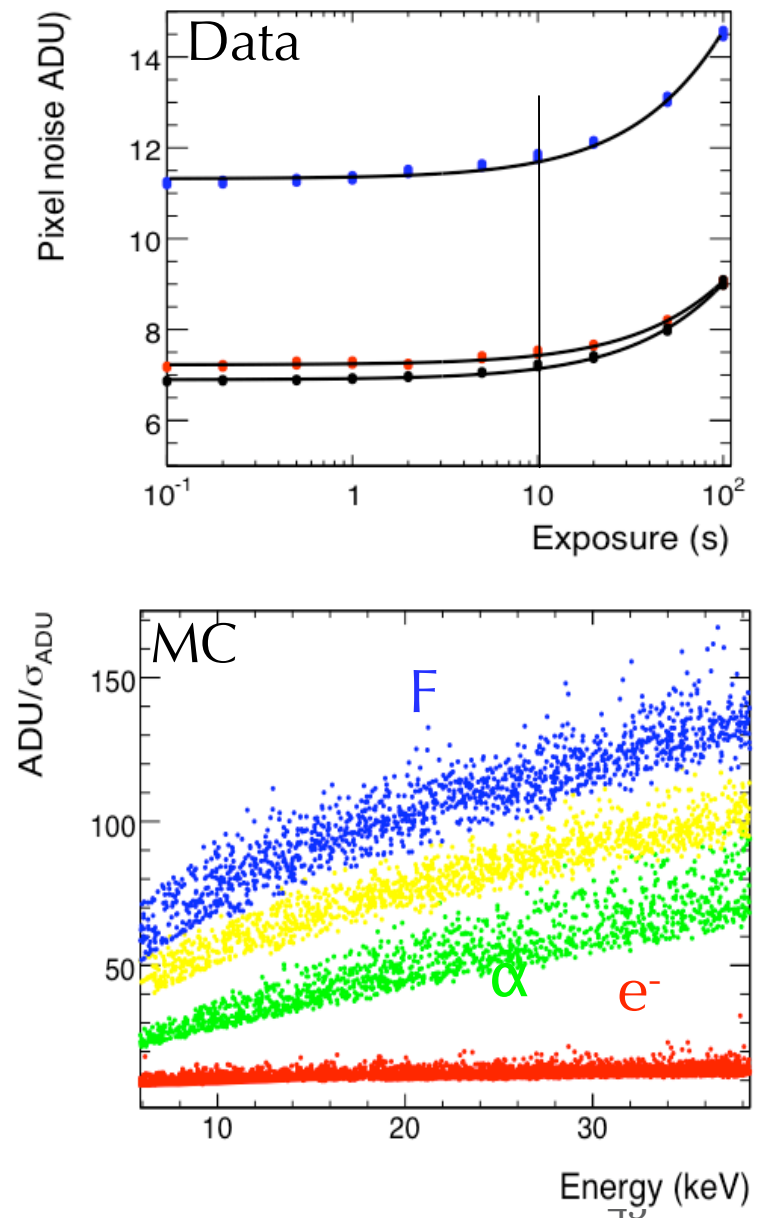


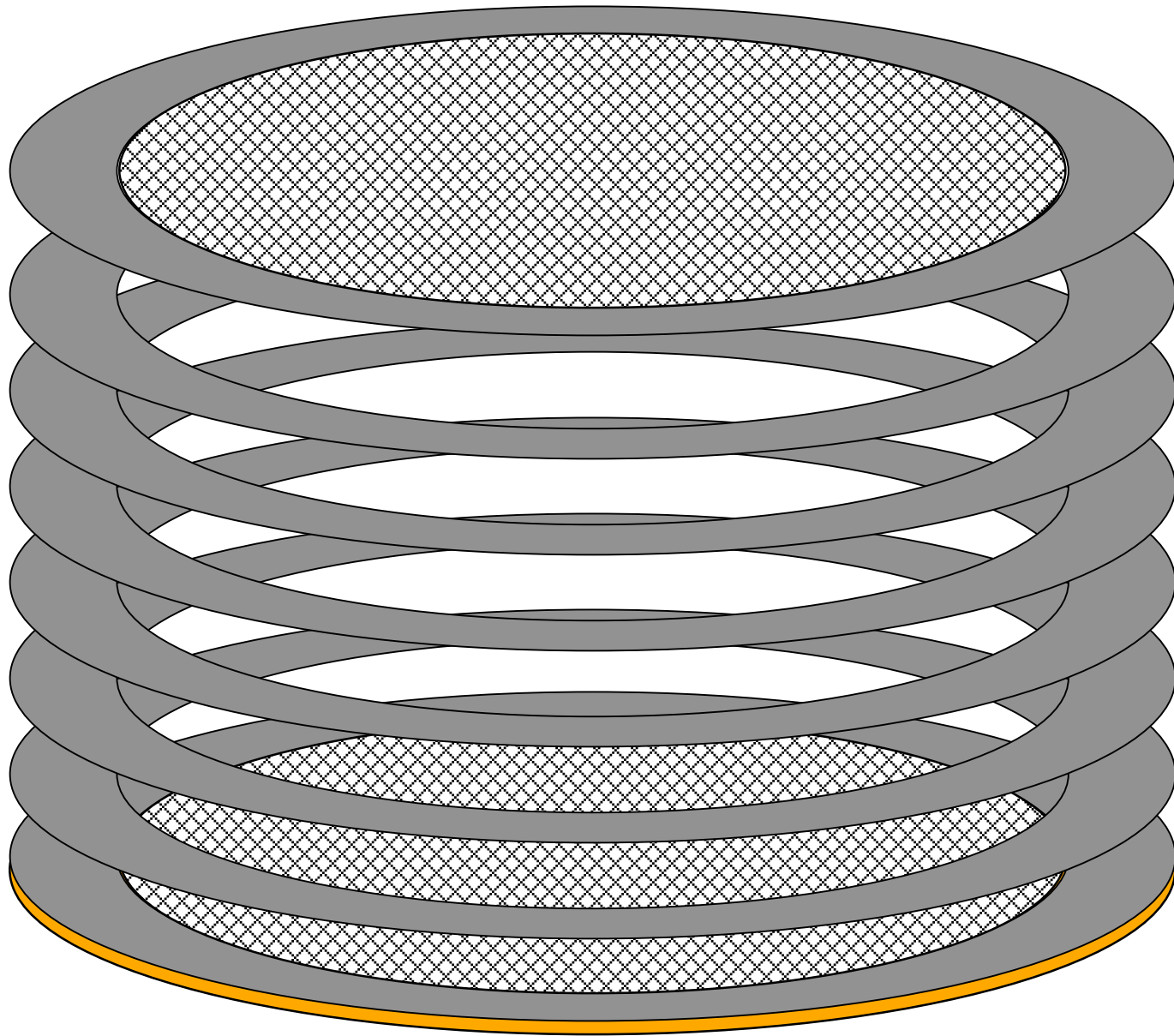
# CCD Readout



Increasing gain + track length with lower pressure, but decreasing mass!

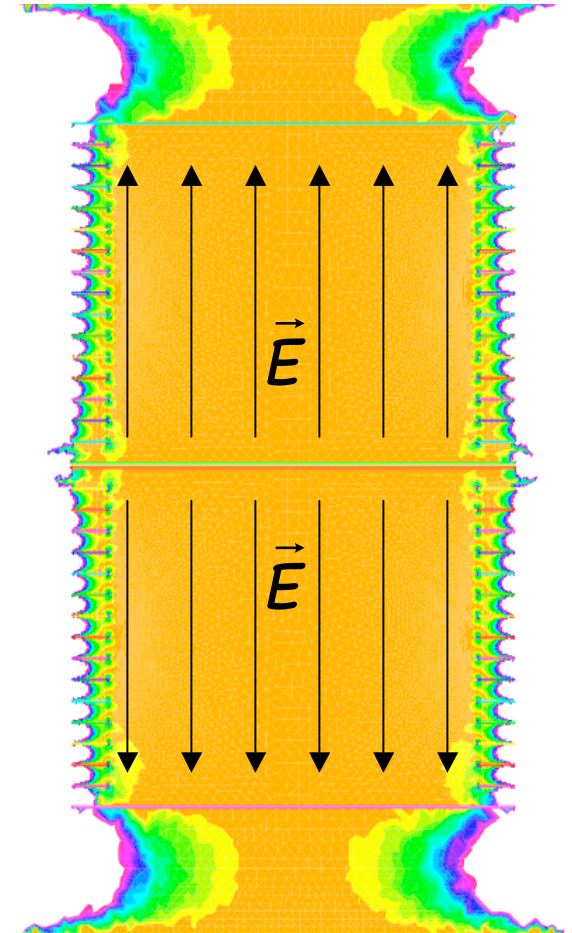
Energy threshold for finding track pixels depends strongly on CCD noise level



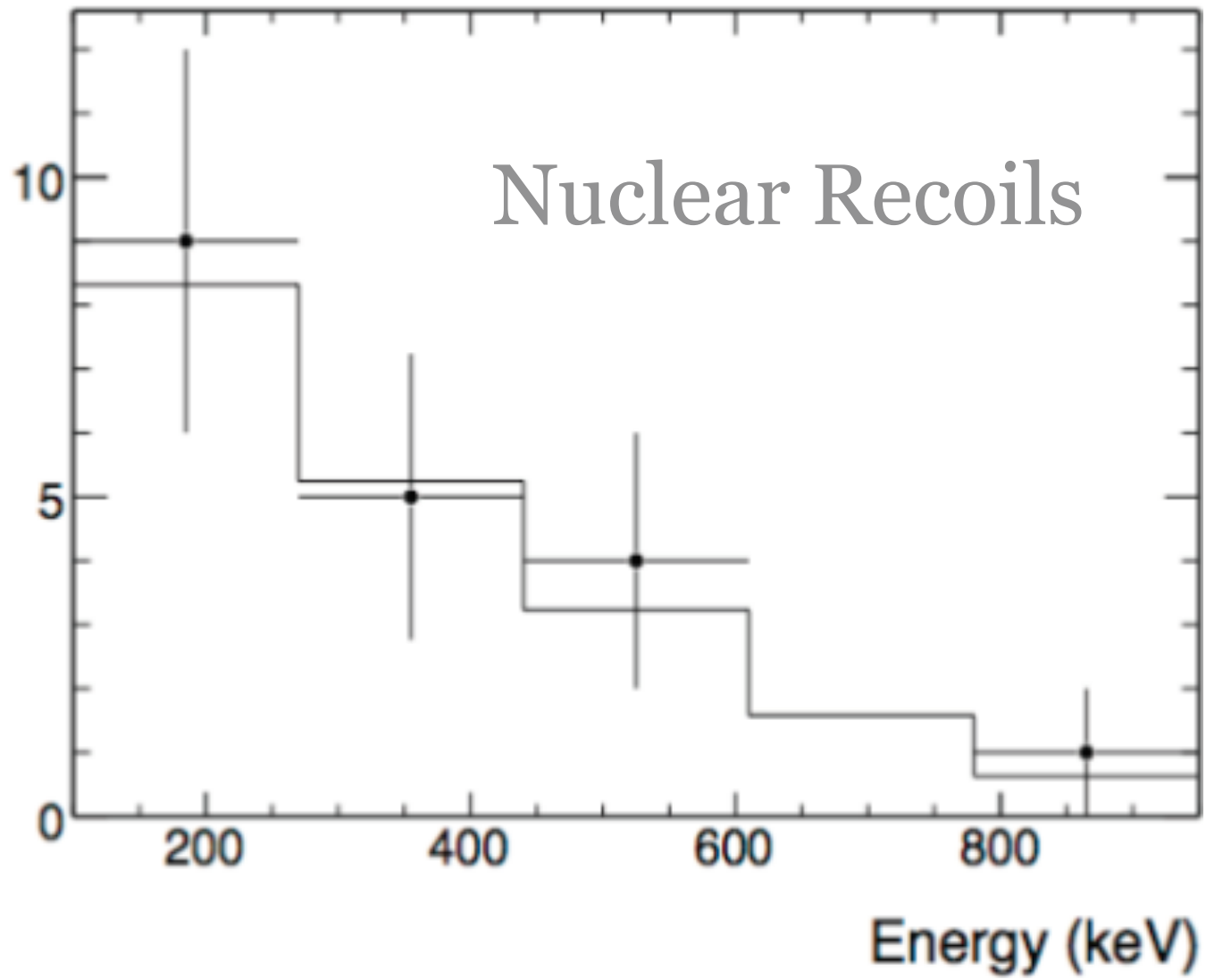


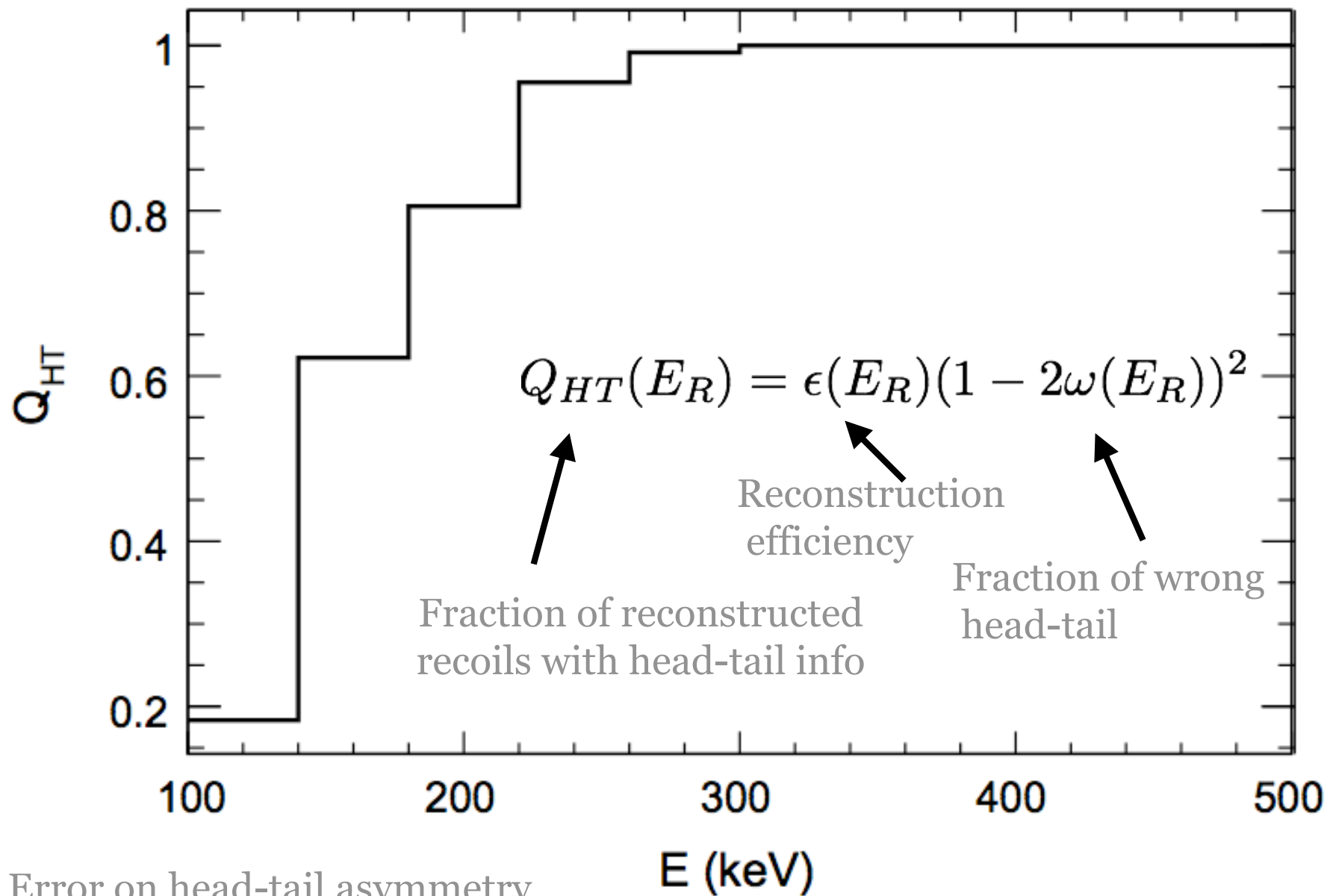


  $<1\% E_{\perp}/E$

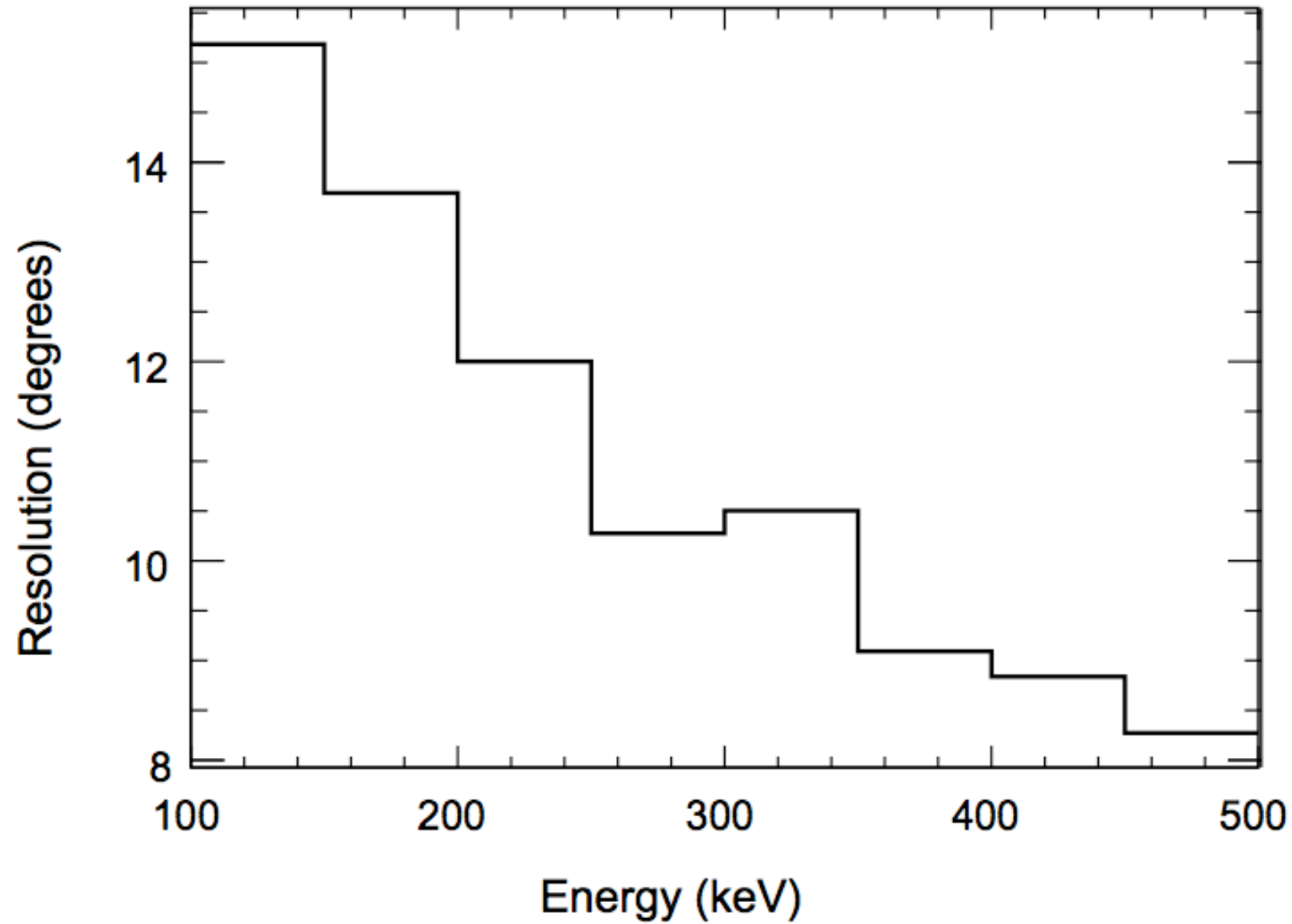


FEM calculation of  
 field uniformity  
 (H.Yegoryan)

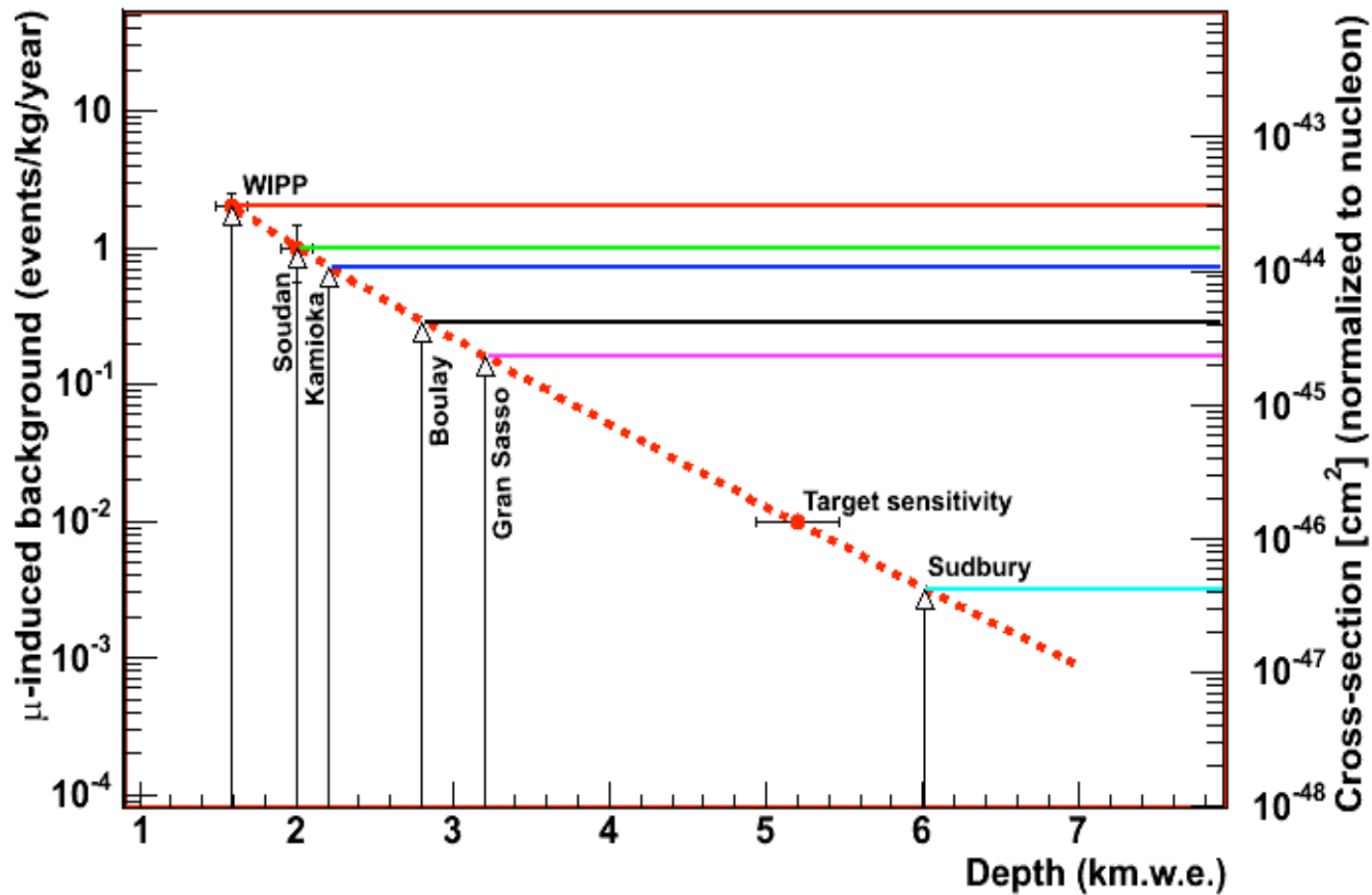




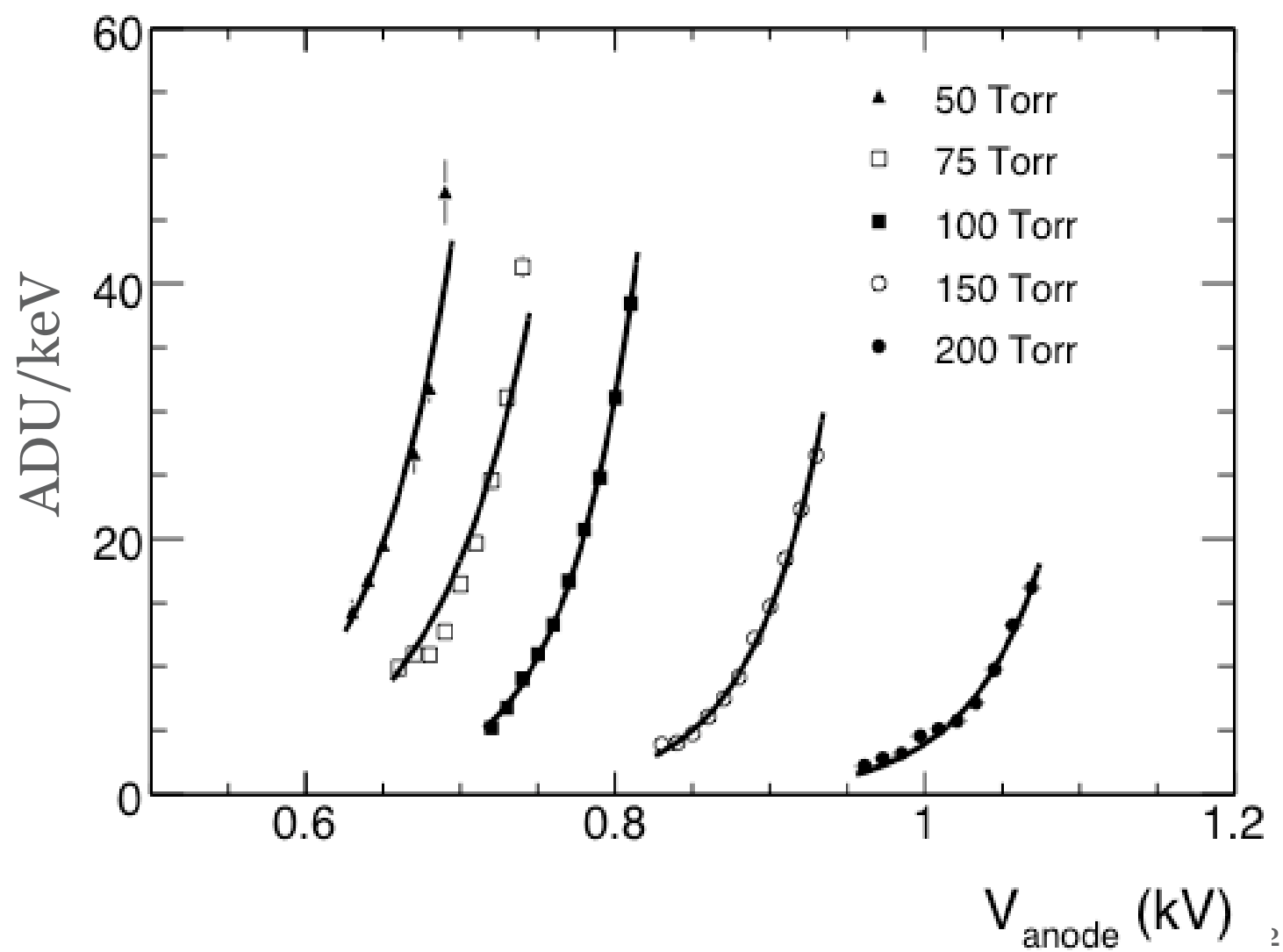
Error on head-tail asymmetry  
 scales as  $Q_{HT}^{-1/2}$



# Neutron backgrounds

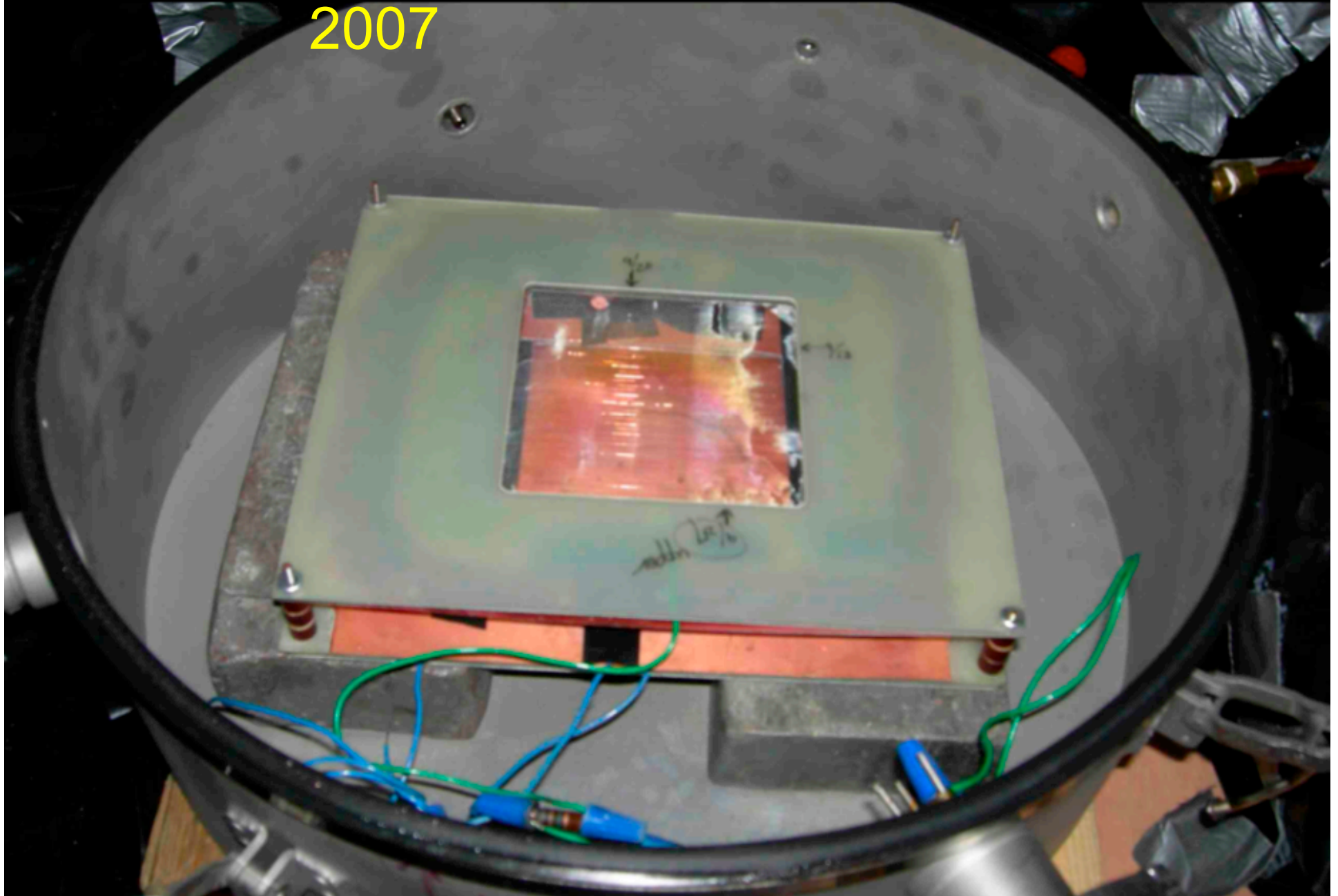






~~Current~~ prototype at MIT

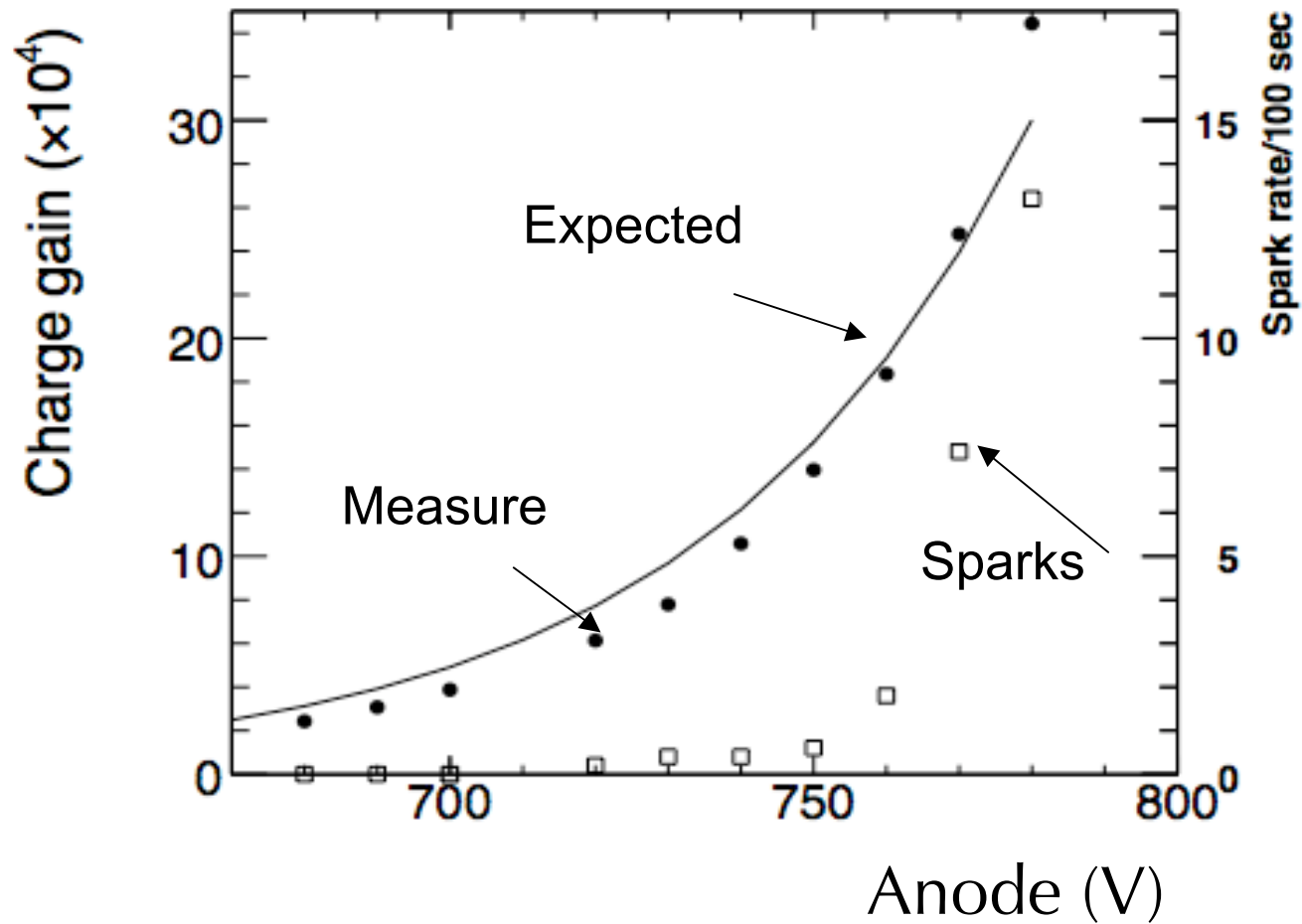
2007



# CF<sub>4</sub> Properties

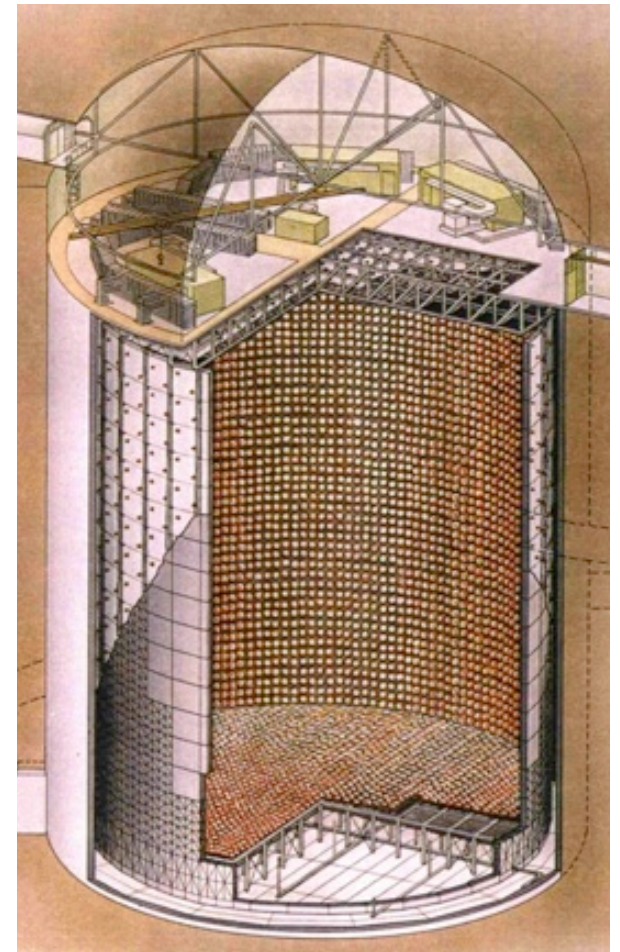
- 0.38 photons per electron (200-800 nm)
- 10,000 photons/MeV

# System Gain



# Scaling DMTPC to one ton

Super-K  
40 x 40 x 40 m<sup>3</sup>



SNO  
21 x 21 x 34 m<sup>3</sup>



DMTPC  
16 x 16 x 16 m<sup>3</sup>

CMS  
15 x 15 x 22 m<sup>3</sup>

1 ton of CF<sub>4</sub>  
@50Torr

