Detection of Head-Tail of Nuclear Recoils

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BU-MIT-Brandeis Collaboration

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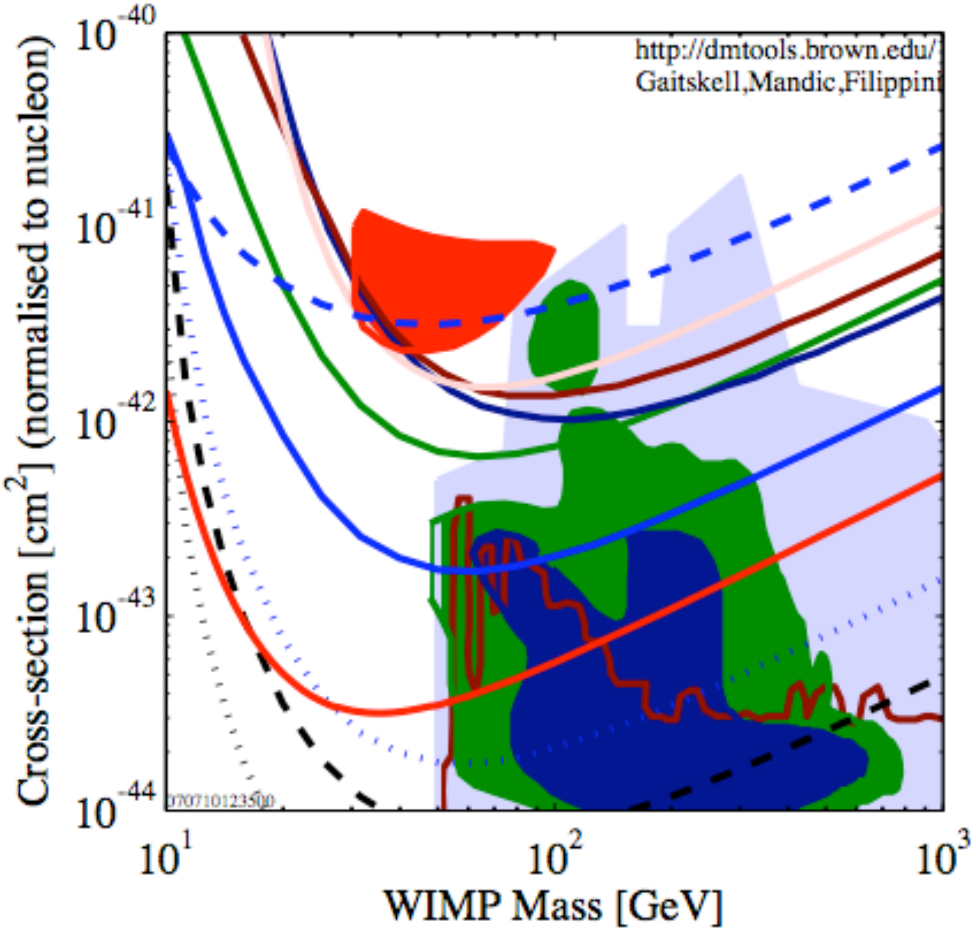
Current Limits

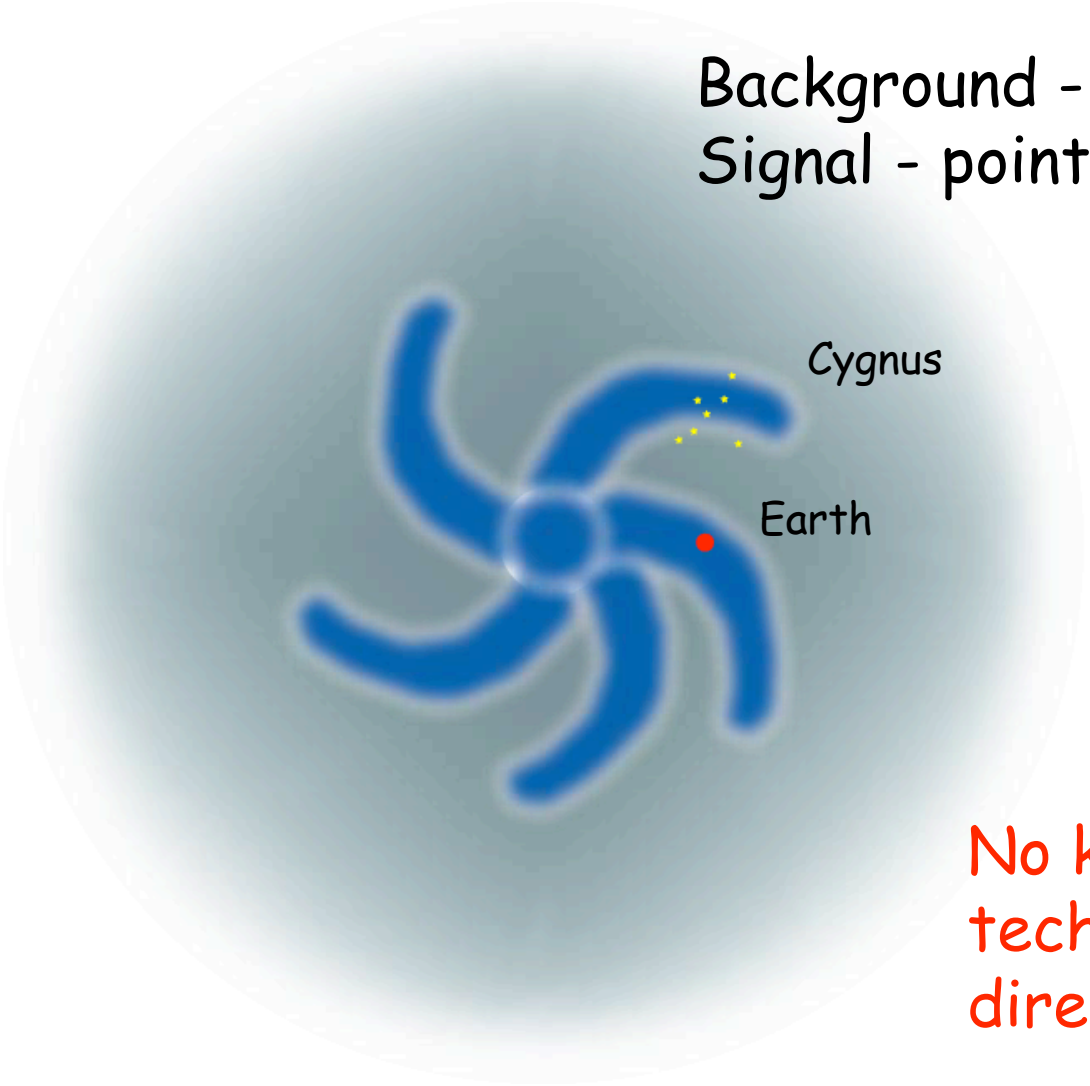


For $\sigma \sim 10^{-46}$ cm^2 zero-background analysis hard (e.g. due to coherent scattering from solar neutrinos [Monroe,Fisher, arXiv:0706.3019])

Directional measurements (head/tail) may be the only way to unambiguously detect dark matter using correlation with astrophysics phenomena

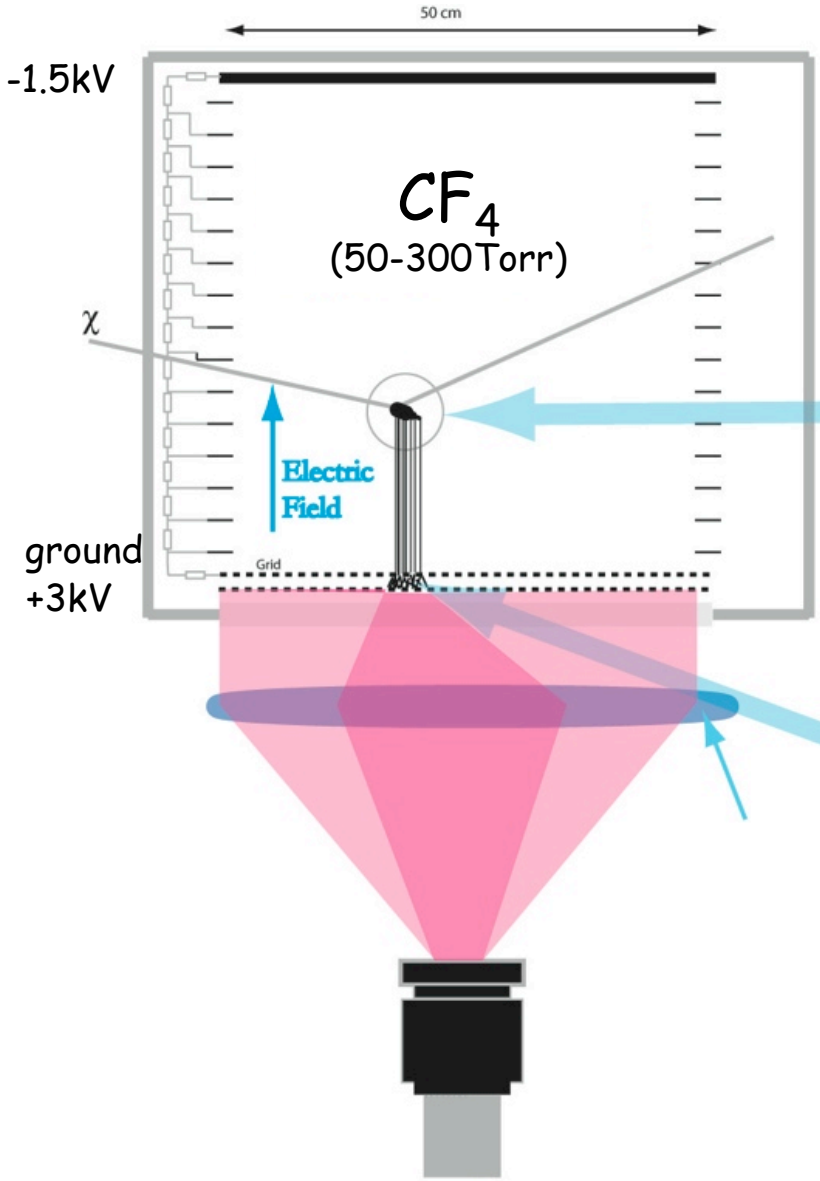
Dark Matter Direction

Background - not pointing to Cygnus
Signal - pointing to Cygnus

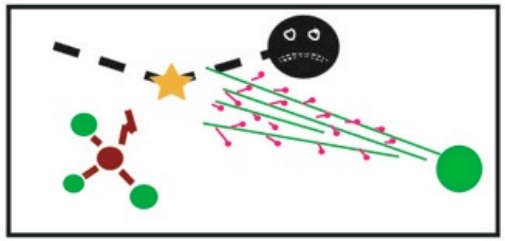


No known experimental technique can reconstruct direction of WIMPs!

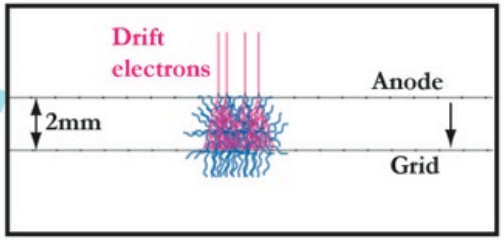
Detection Principle



Elastic recoil on gas nucleus
Recoiling track (~mm) ionizes gas:

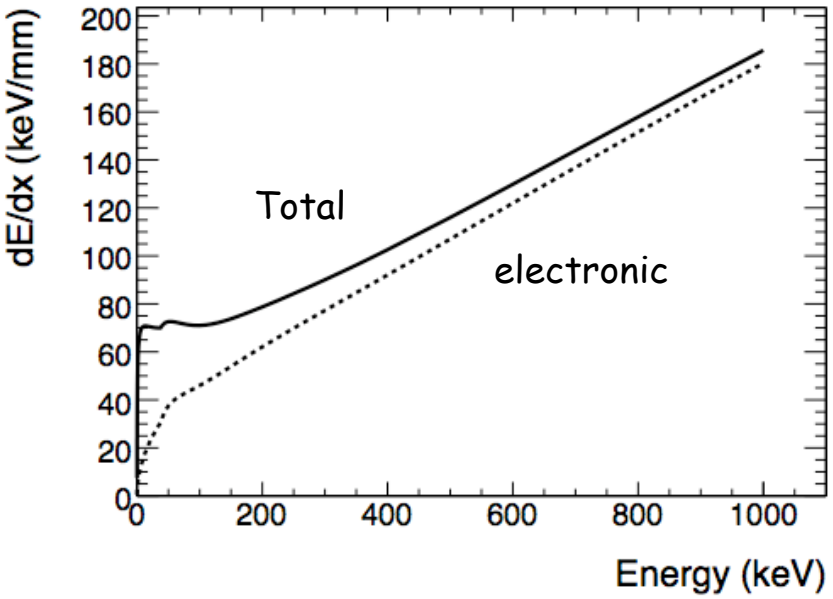


Charge multiplication and scintillation:

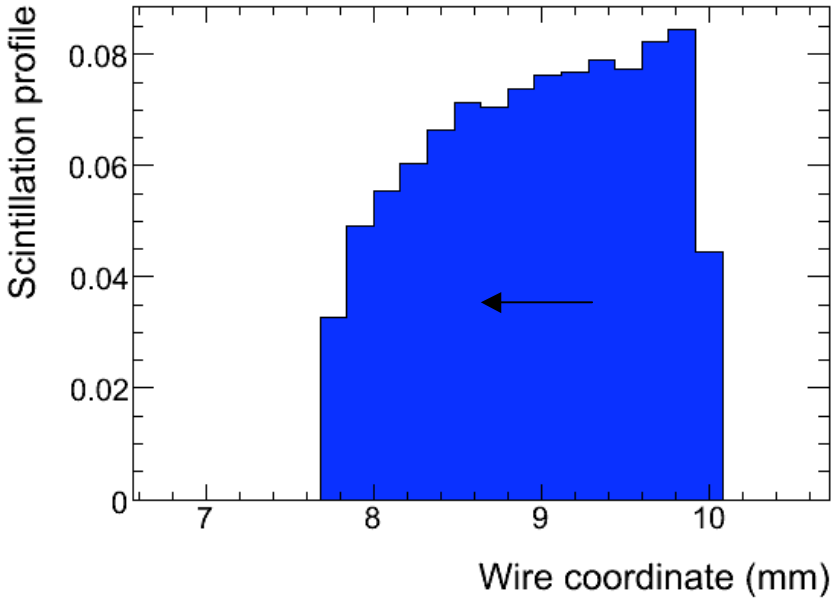


Head-Tail Effect

Predicted dE/dx of recoiling fluorine nucleus*



Asymmetry in scintillation profile along wire**:



stopping power and straggling from SRIM

**Recoil from 200GeV WIMP; Diffusion effects not included*

Direction of fluorine recoil determined from scintillation profile

Detector Prototype

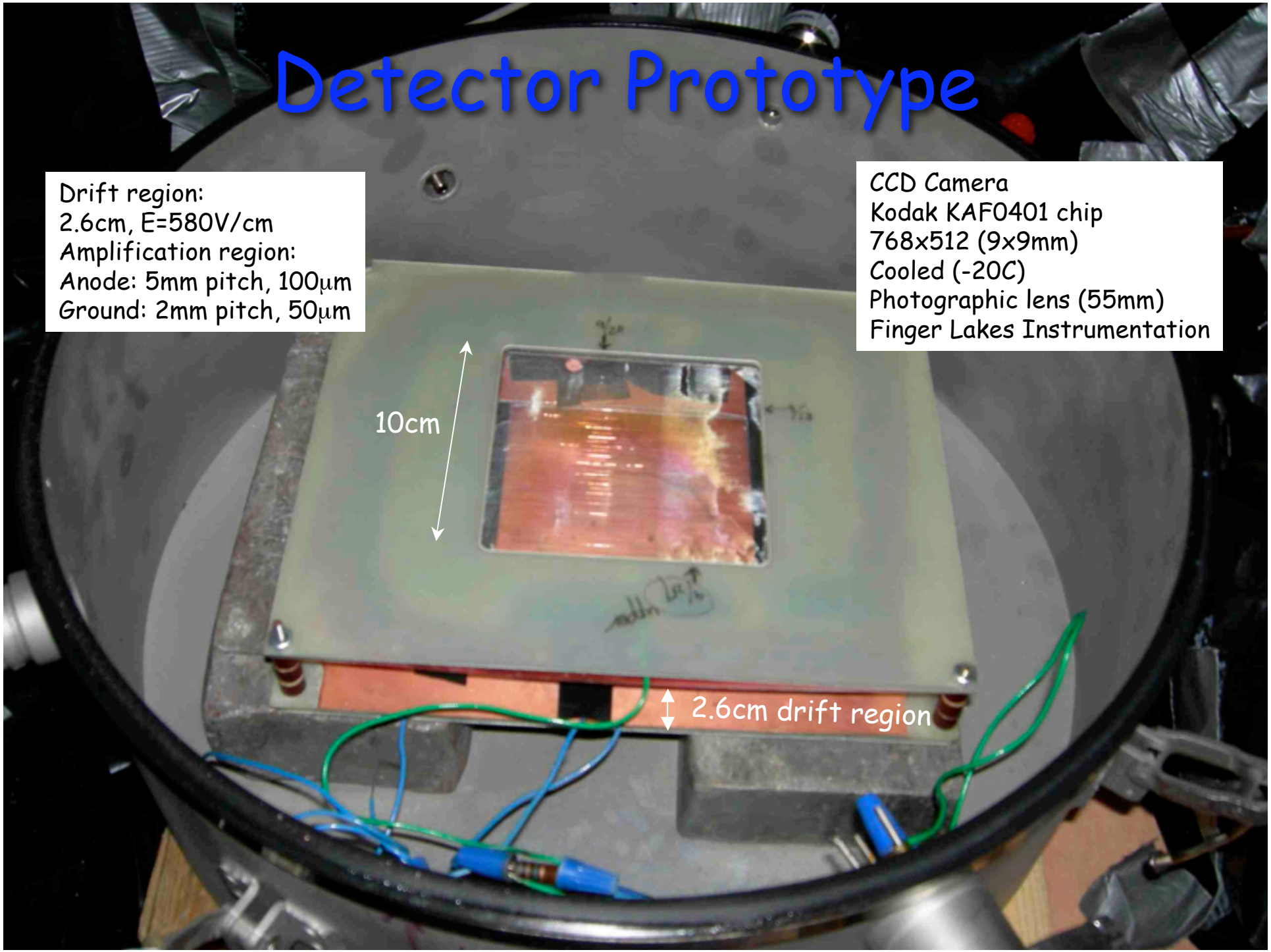
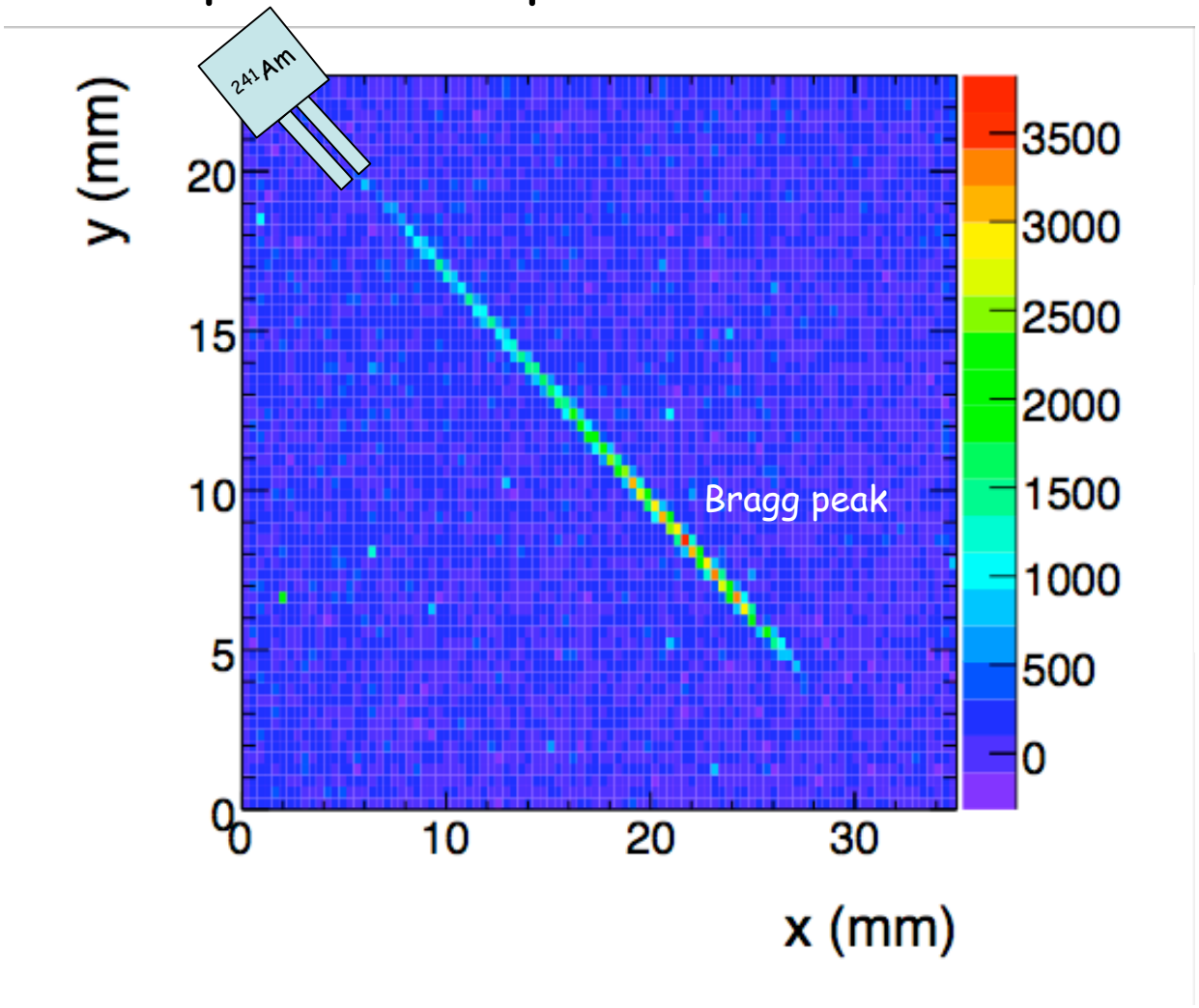
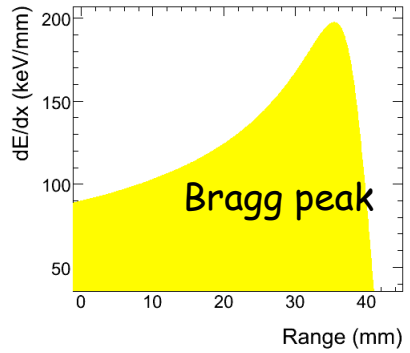


Image of Alpha Tracks

5.5MeV alpha tracks parallel with anode wires:

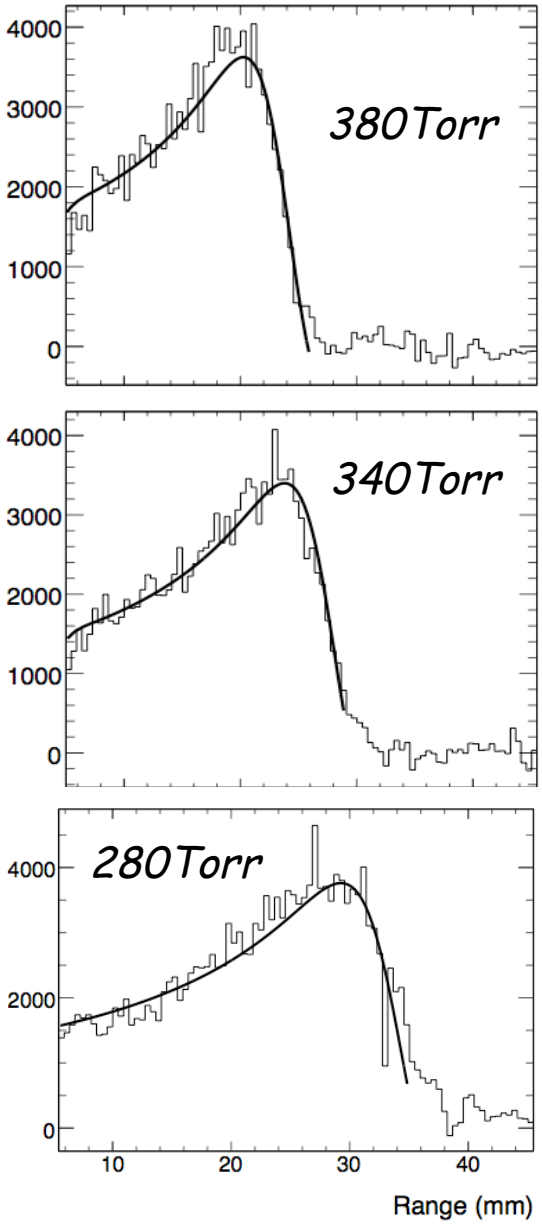


280Torr of CF_4

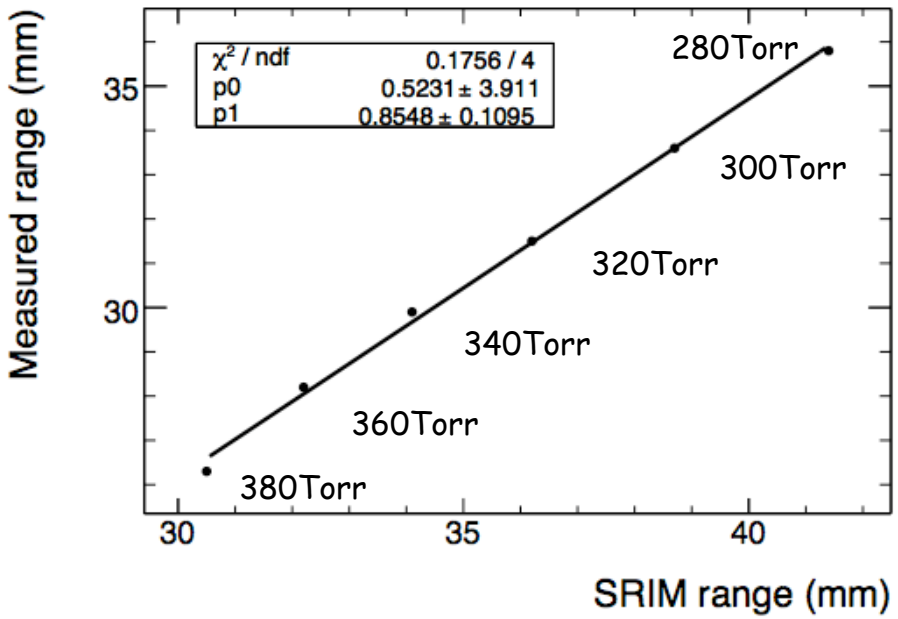


dE/dx profile from SRIM simulation

Scintillation Profile of α Track



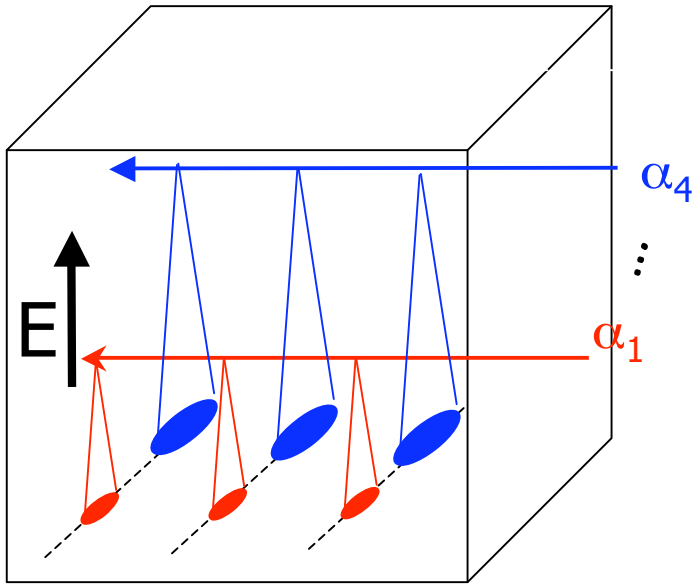
Data + fit dE/dx from SRIM



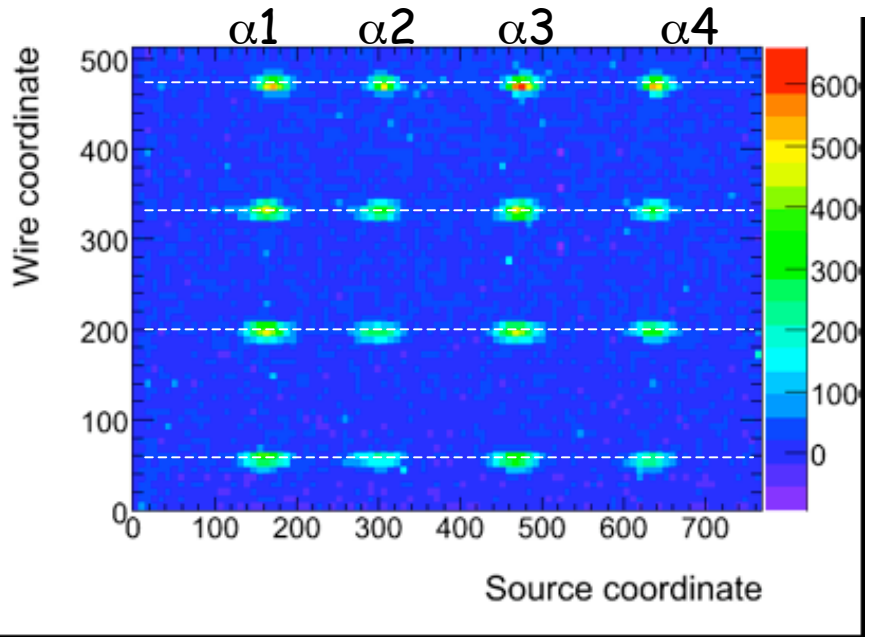
Assume dE/dx ~ scintillation

Diffusion Along Wire

Four alpha sources at different heights in drift region (Δz)
Critical parameter: range for nuclear recoils ~ mm

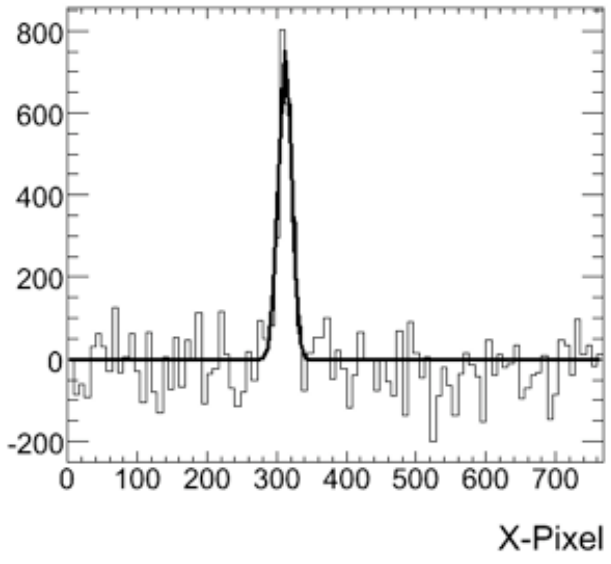


Accumulated image of 250 tracks:

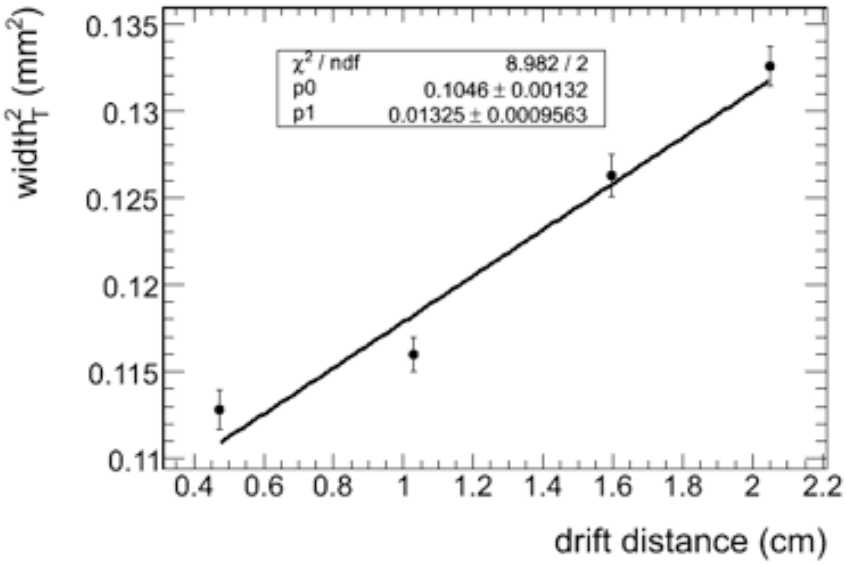


Diffusion Along Wire

Profile along wire



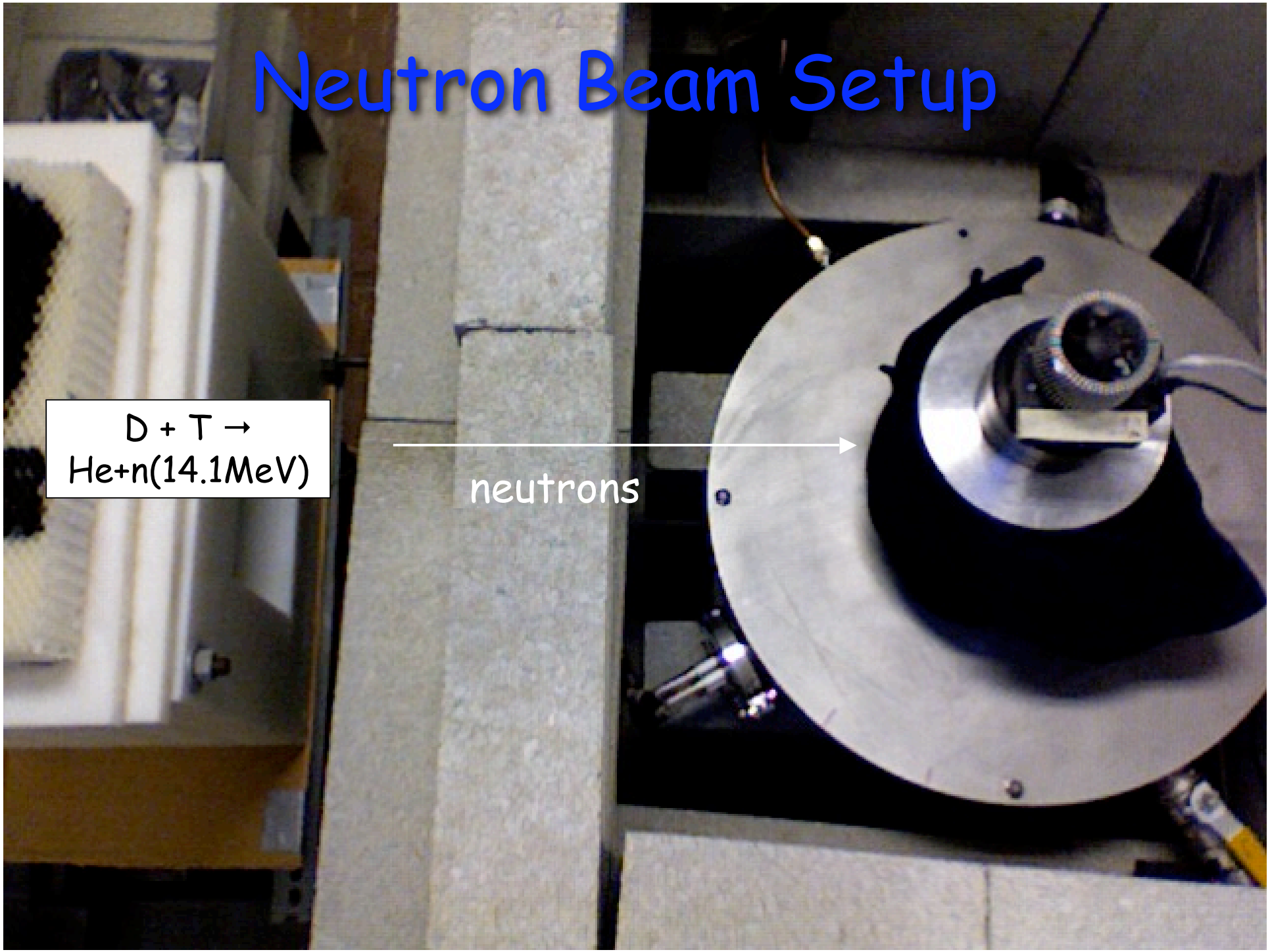
Signal width for different sources (Δz positions)



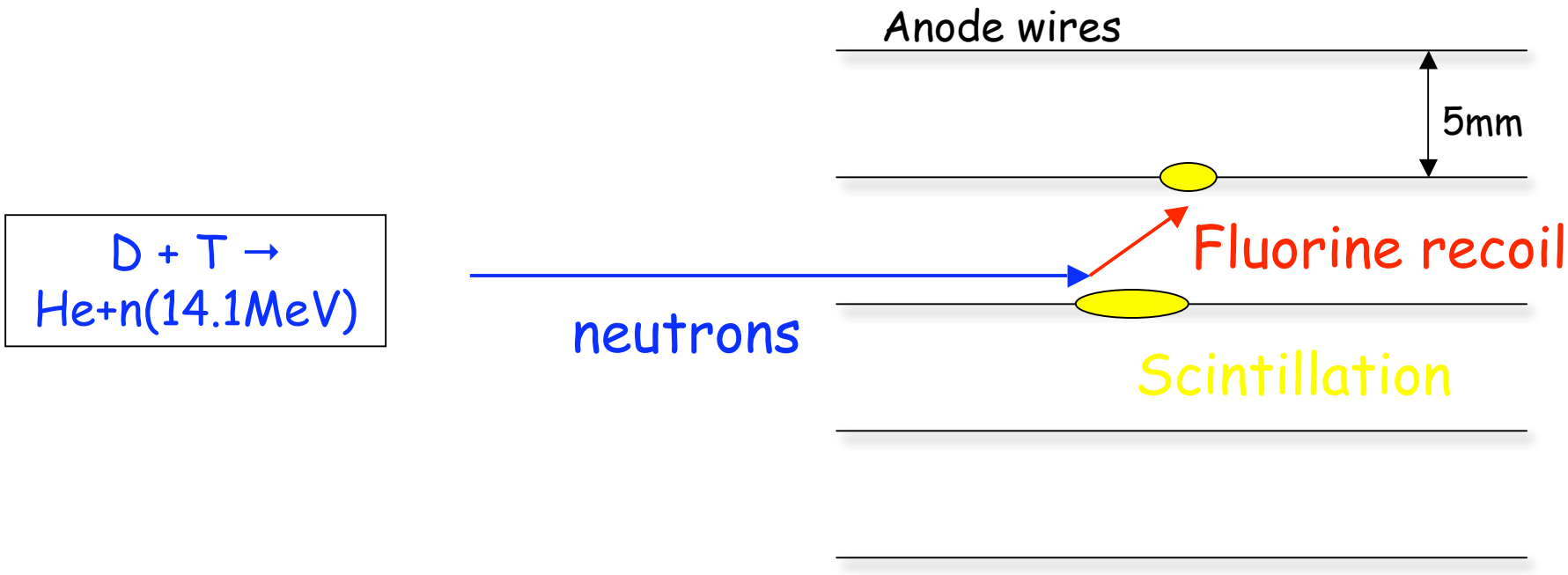
$$\sigma[\mu m] = 324 \oplus 36\sqrt{\Delta z}$$

340μm for Δz=1cm
670μm for Δz=25cm

Neutron Beam Setup



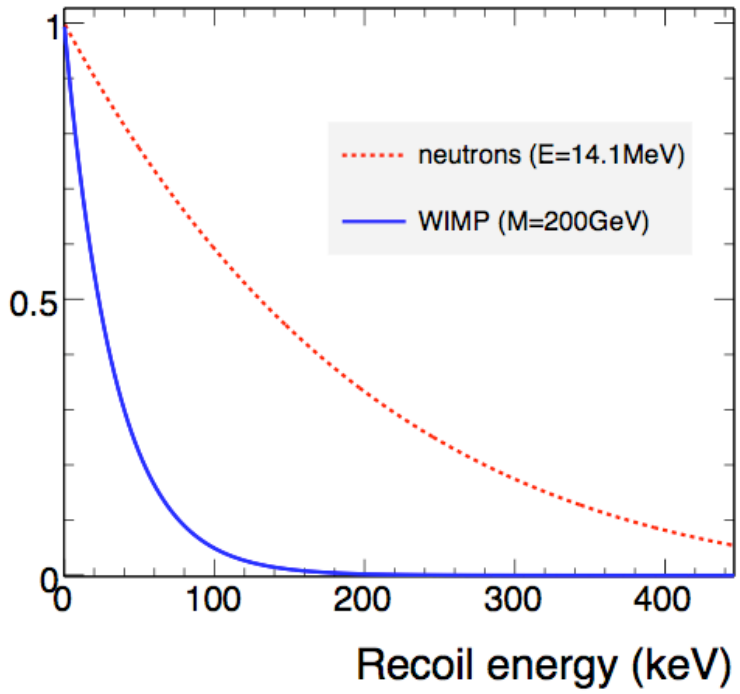
Recoils in Neutron Beam



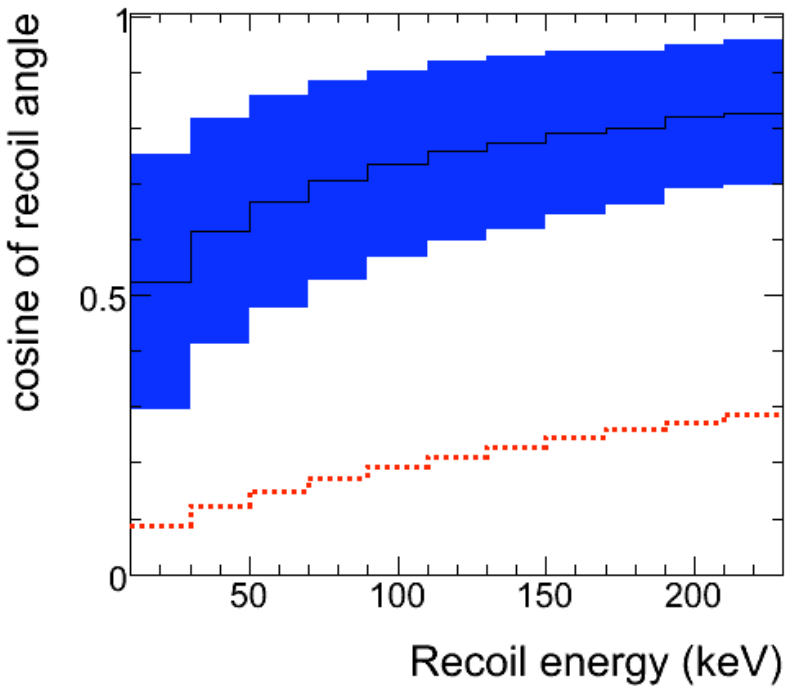
Neutrons vs. WIMPs

- Neutron elastic scattering mimics dark matter recoils

Fluorine recoil energy



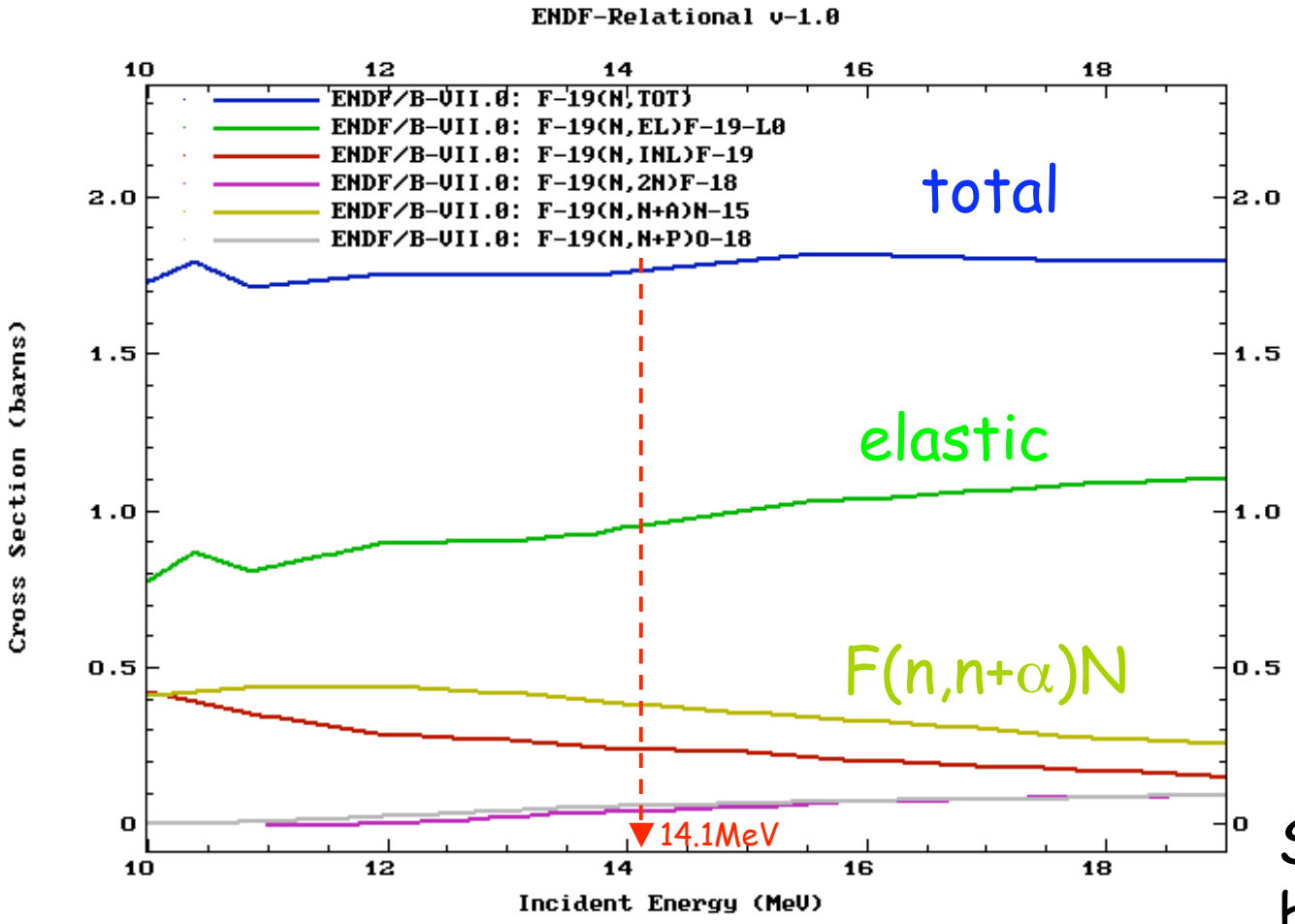
Fluorine recoil angle wrt wires



Fluorine recoil momentum better aligned with WIMP direction

Cross Sections

Predicted neutron scattering cross sections (ENDF-B/VII.0)



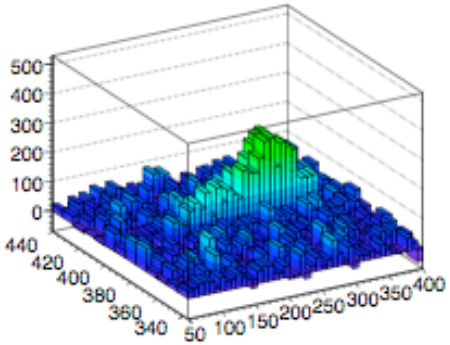
45% of F between 100-800keV

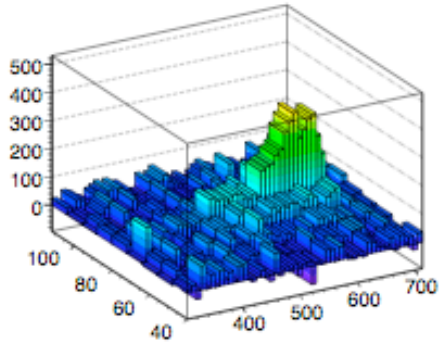
7% of a, 17% of N between 100-800keV

Sample dominated by elastic recoils of fluorine

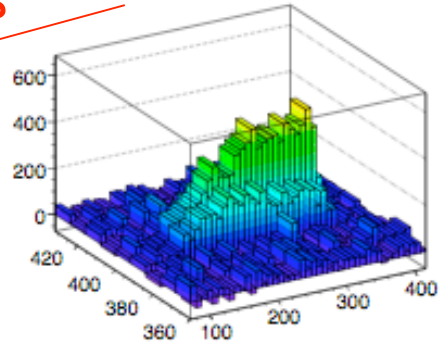
Event Images

Wires at 0 deg:

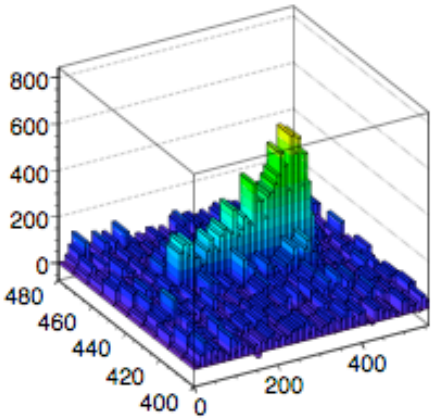


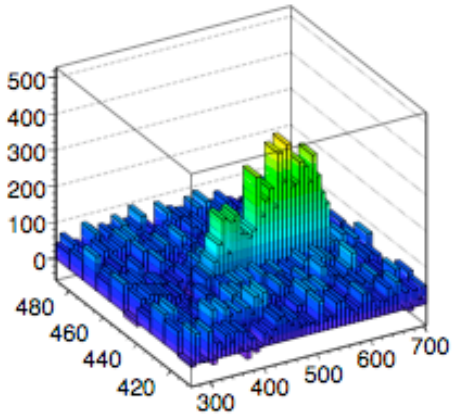


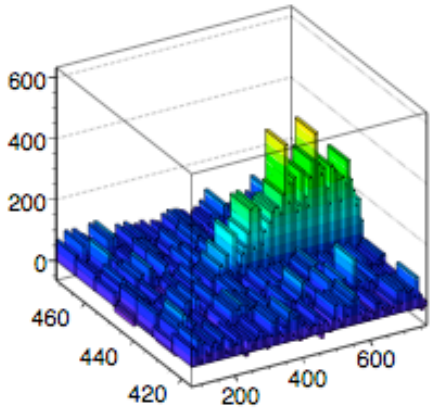
Direction of neutrons



Wires at 180 deg:

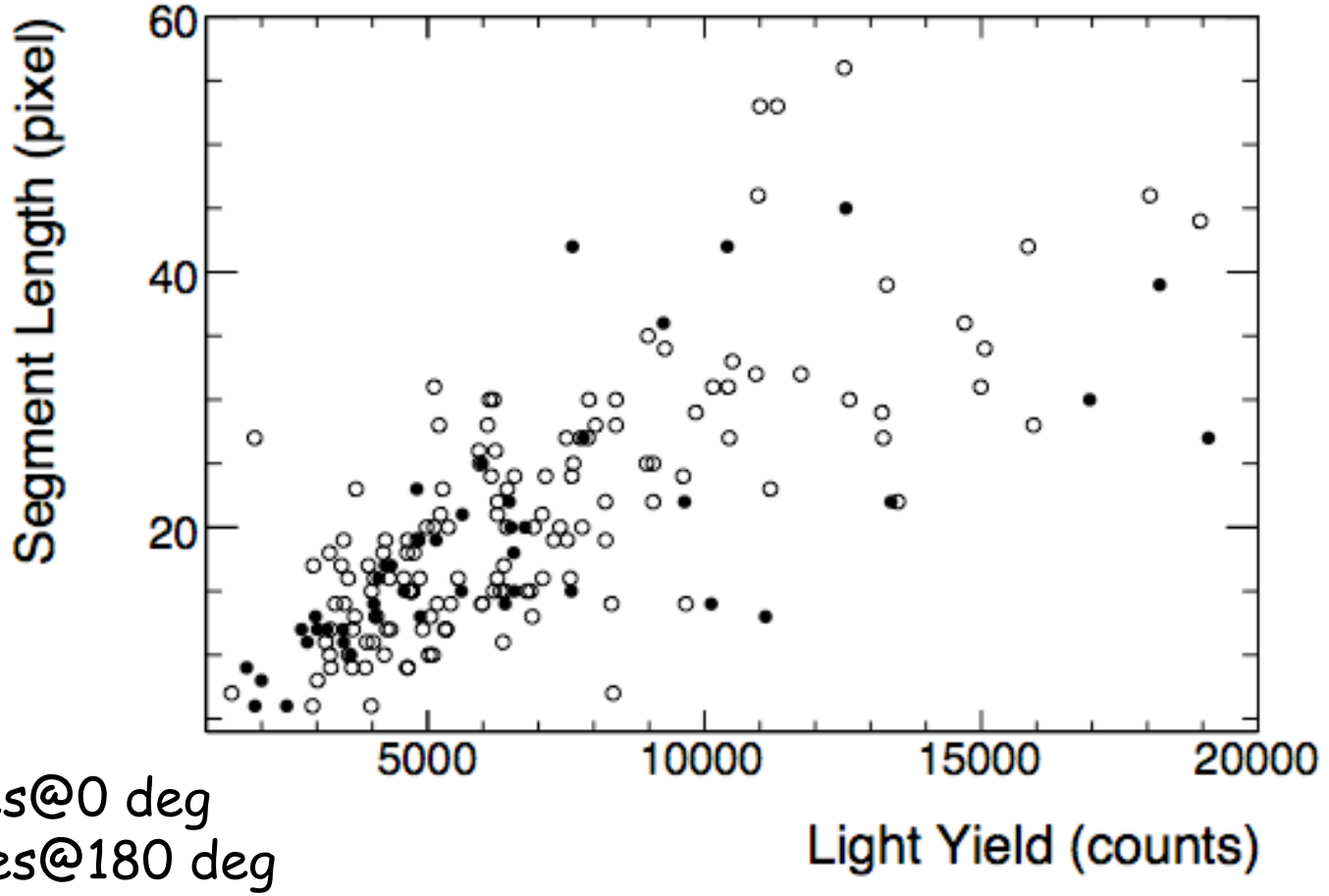






Energy vs. Range

Correlation between energy (ADC counts) and range (CCD pixels):

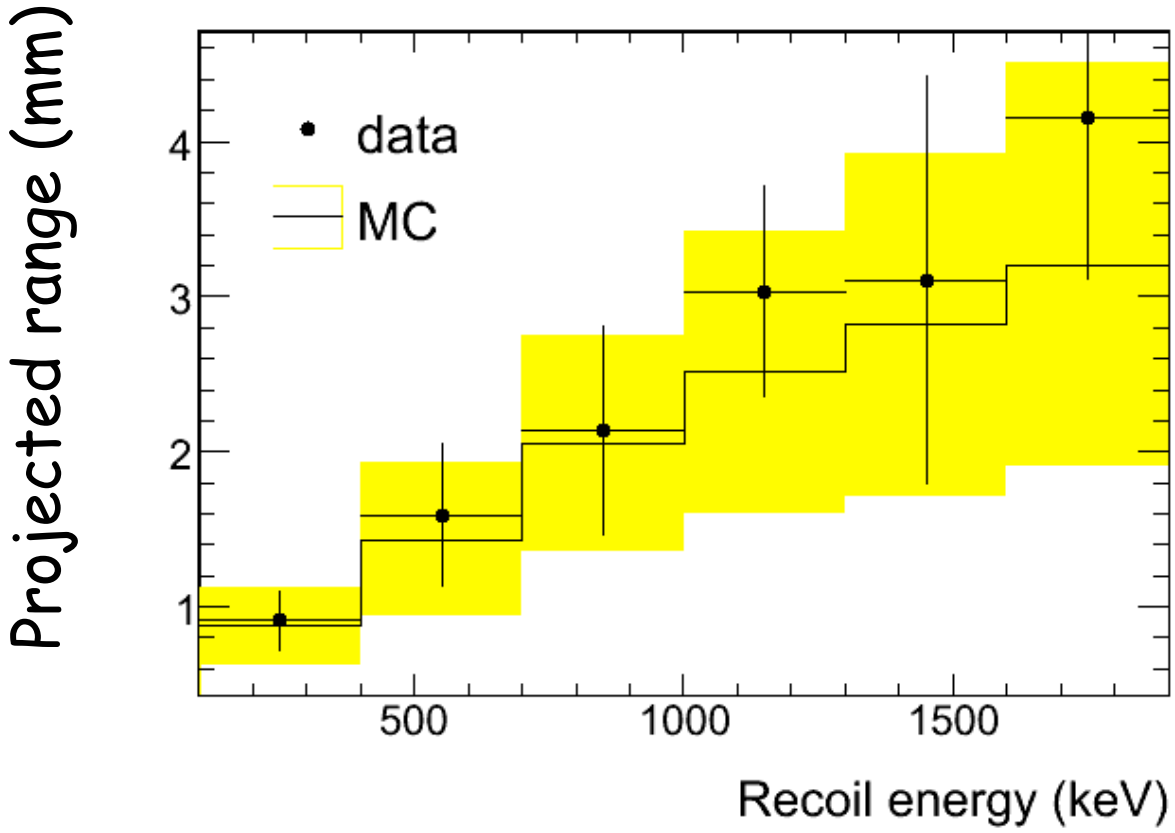


Filled - wires@0 deg
Hollow- wires@180 deg

(Slope proportional to stopping power)

Energy vs. Range

Comparison with MC (±1σ spread is indicated):



8counts/100keV
8.25bins/mm
~220Torr

Error on range ~ 20%
Error on energy ~ 50% (pressure, wire gain)

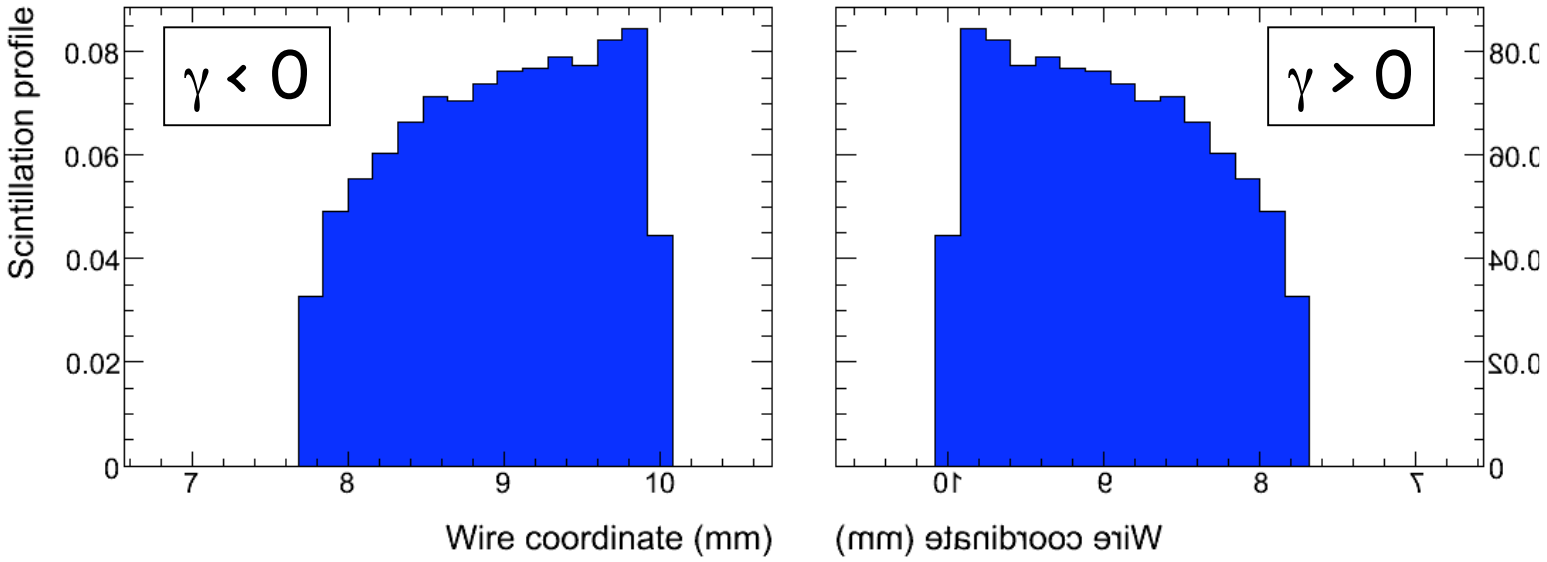
Measure of Head-Tail Effect

Skewness of light asymmetry along segment:

$$\gamma(x) = \frac{\mu_3}{\mu_2^{3/2}} = \frac{\langle (x - \langle x \rangle)^3 \rangle}{\langle (x - \langle x \rangle)^2 \rangle^{3/2}}$$

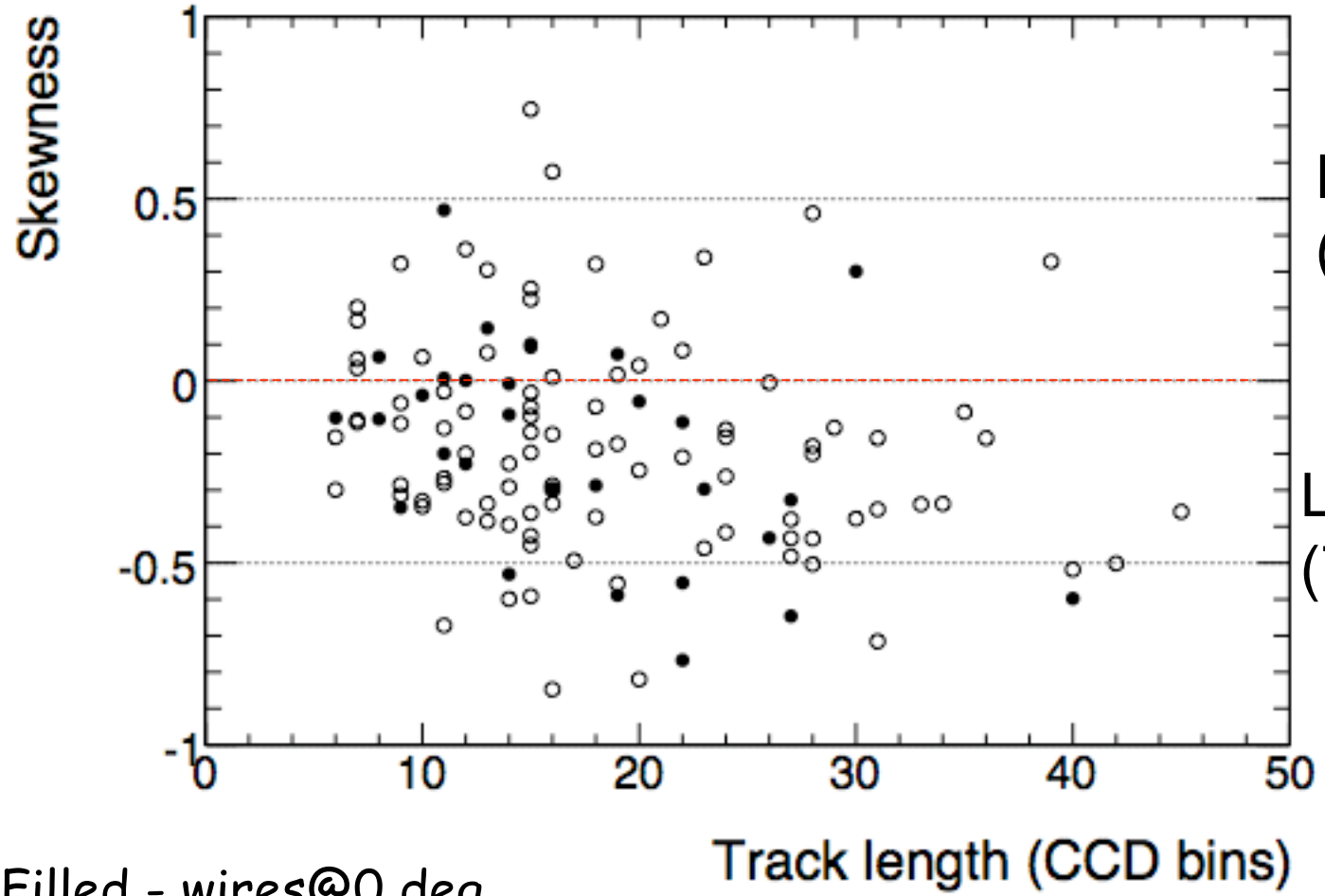
(dimensionless!)

Head-tail of track direction:



Skewness Results

Recoil direction (neutrons toward left):



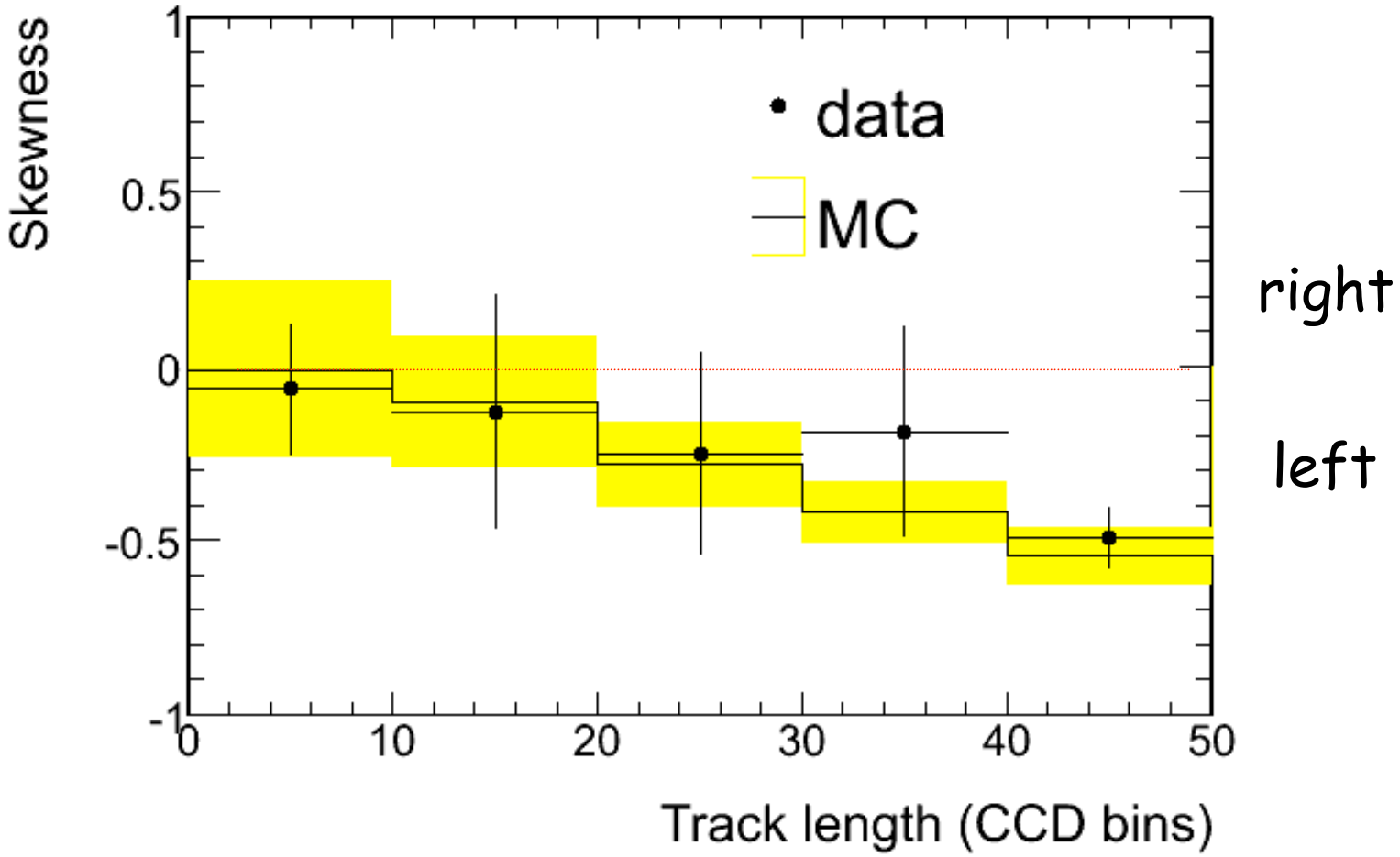
Right
(24±3)%

Left
(76±3)%

Filled - wires@0 deg
Hollow- wires@180 deg

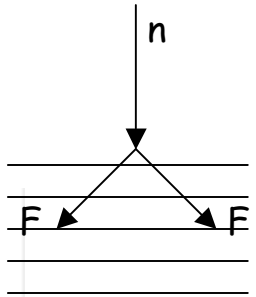
Skewness MC

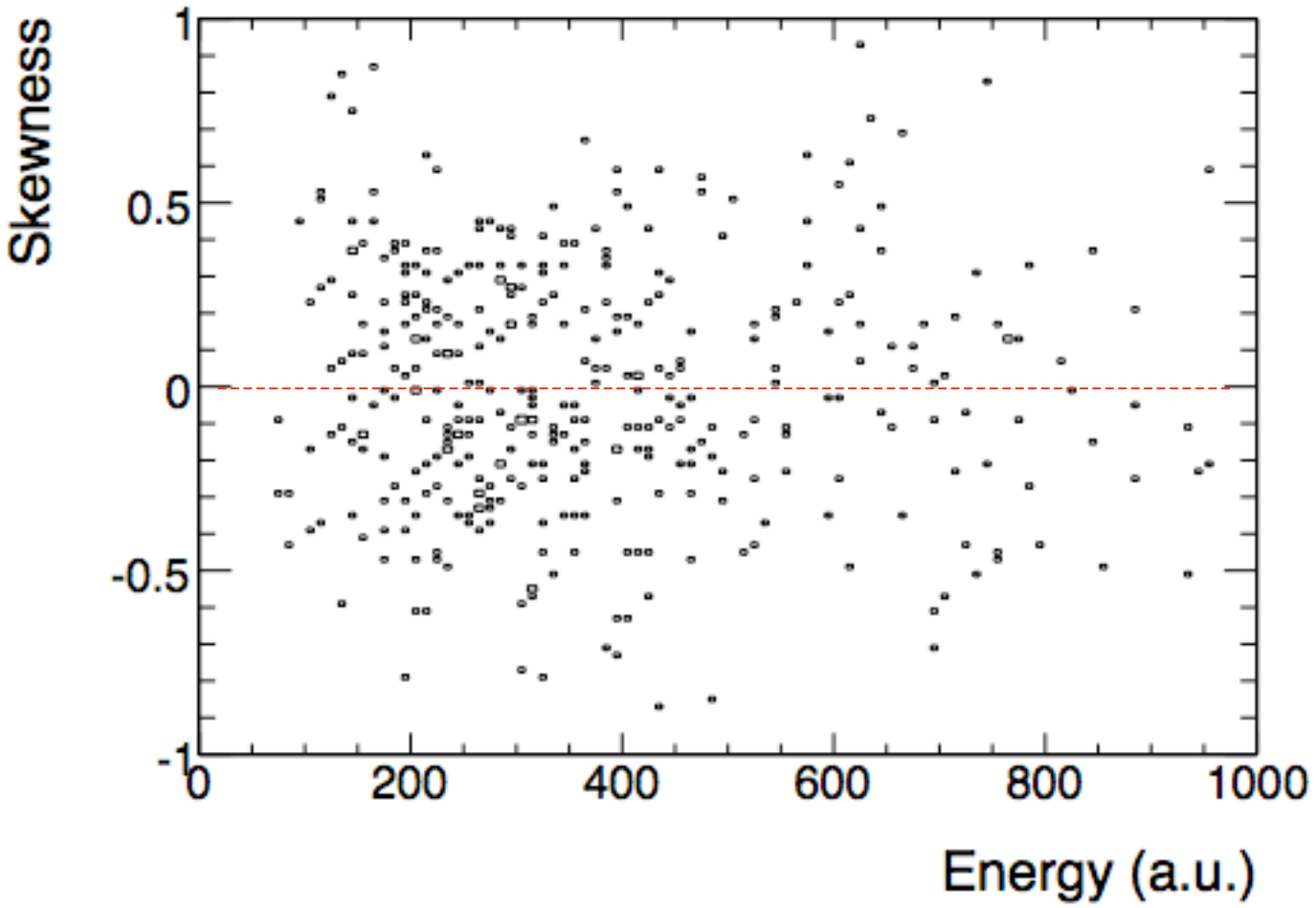
±1σ spread in data (points), MC (dashed,shaded)



Control Sample: n ⊥ Wires

Null test with neutrons @ 90deg to wires
Same # of recoils to left, right

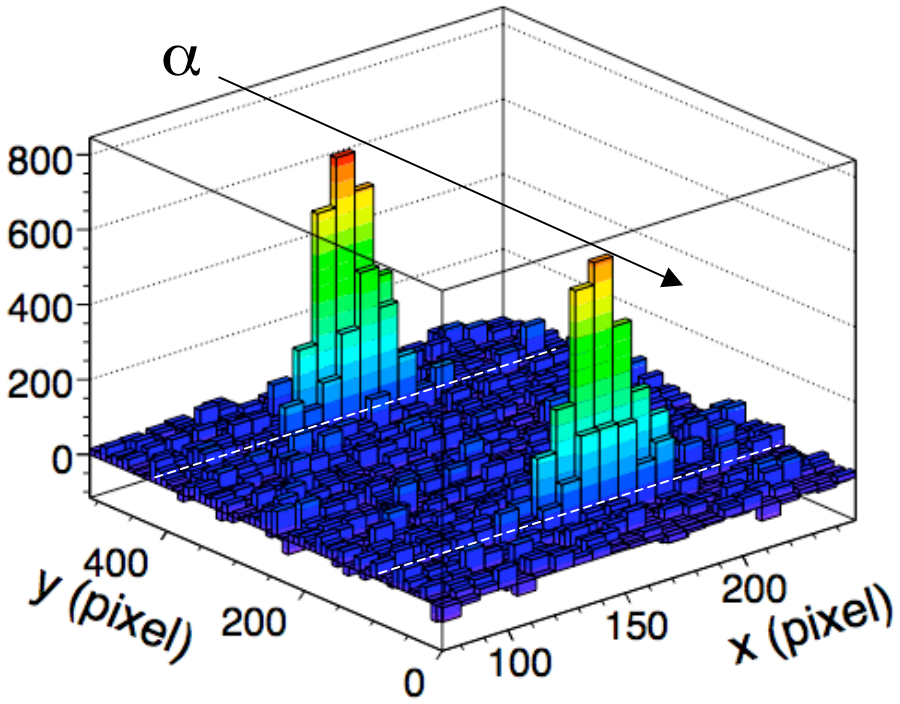




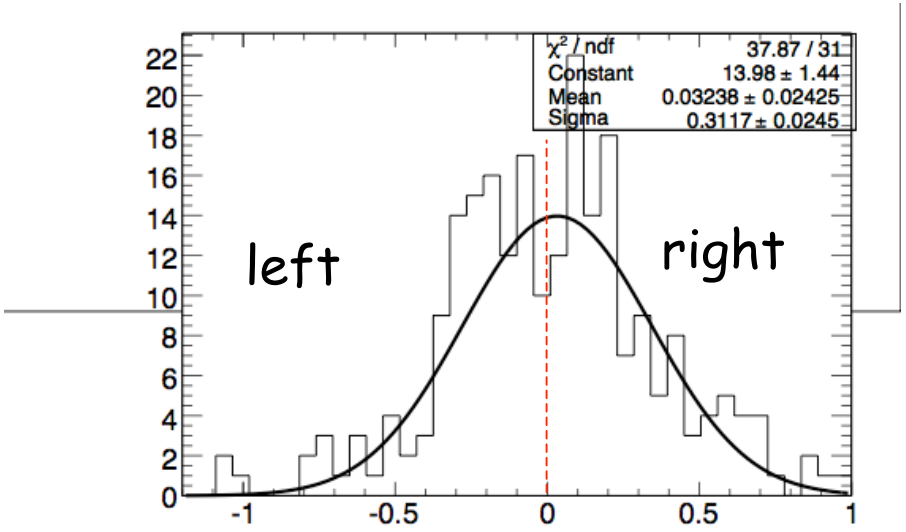
Right
(47.3±2.5%)

Left
(52.7±2.5%)

Control Sample: $\alpha \perp$ wires



Skewness:
0.032+/- 0.024



Summary

For the *first time*, we demonstrated technique to measure head-tail of nuclear recoils:
- observed asymmetry in direction of recoils
- and correlation between energy and range,
- both consistent with MC expectation;
- Sanity checks ok.

Critical parameters for dark matter search:
- *length of recoil along wire*: 5x longer scintillation profile than in neutron scattering (for same energy)
- *photon yield*: detector performance with higher gain under study

A Year from Now

	Current	2008
Pressure (Torr)	200	100
Wire diameter (μm)	100	30
Viewfield area (cmxcm)	1x1	100x100
Drift length (cm)	2.6	25

Longer track

Better gain

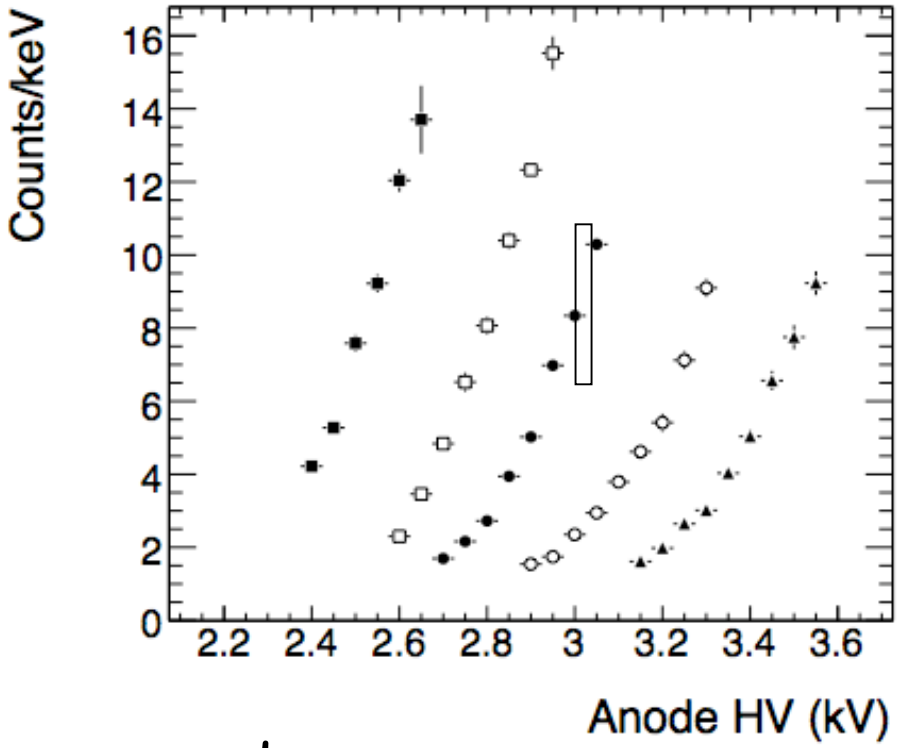
Bigger sensitive region

Set limit on cross section with few months of data

Backup

Energy Calibration

1) Use light emitted from alpha tracks, dE/dx from SRIM

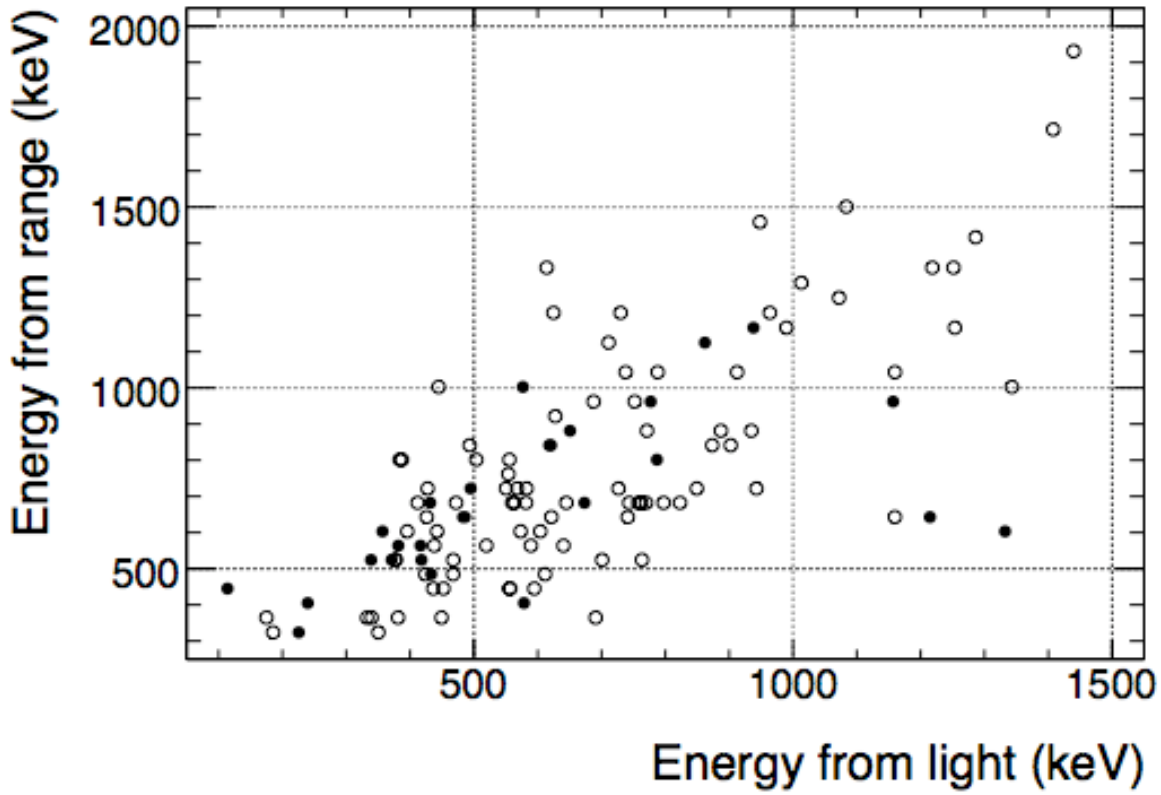


Needs improvements:
- pressure calibration
- non-uniform wire gain
- gain stability

2) Use measured range

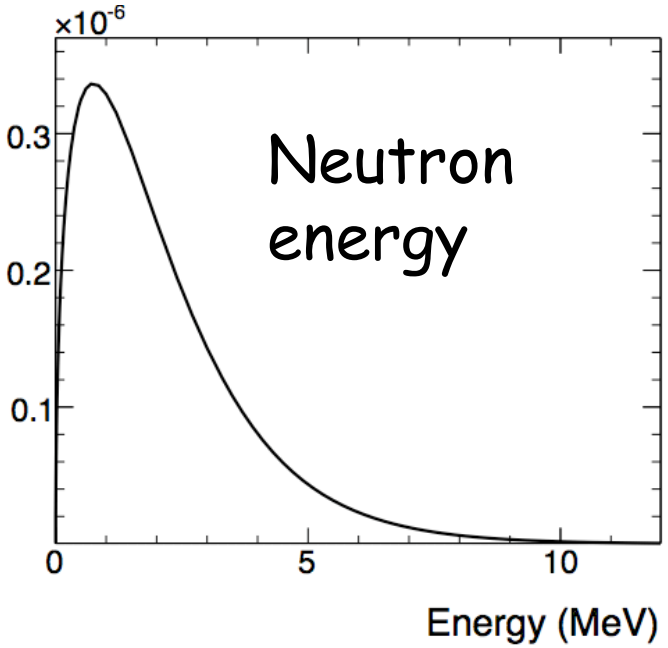
3) Use both measured range, light profile

Energy Calibration

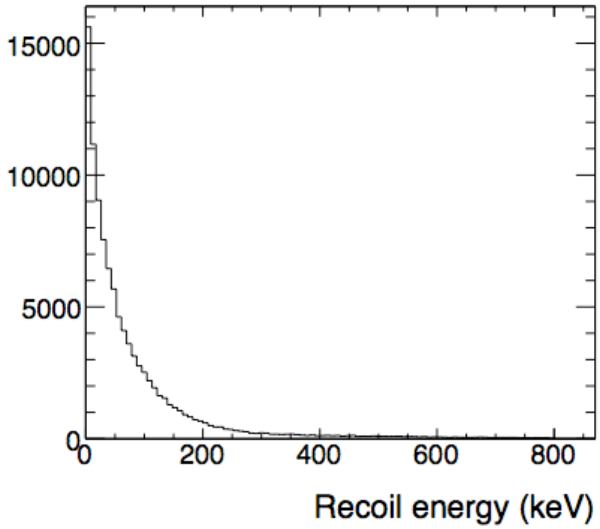


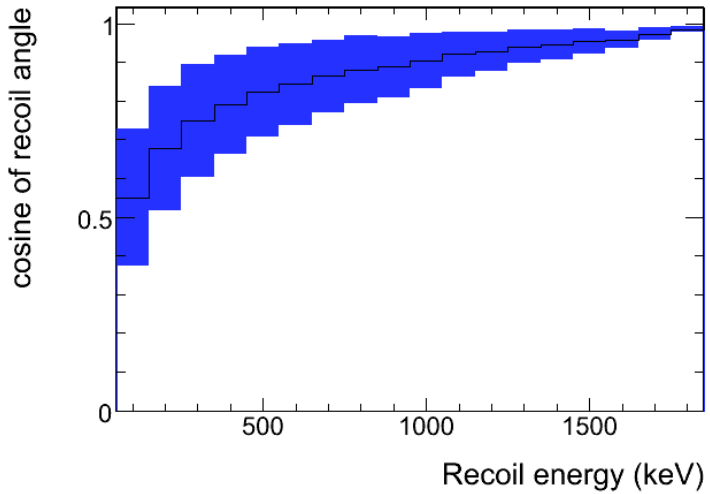
Cf-252

Most of neutrons below threshold for alpha production (~4MeV)

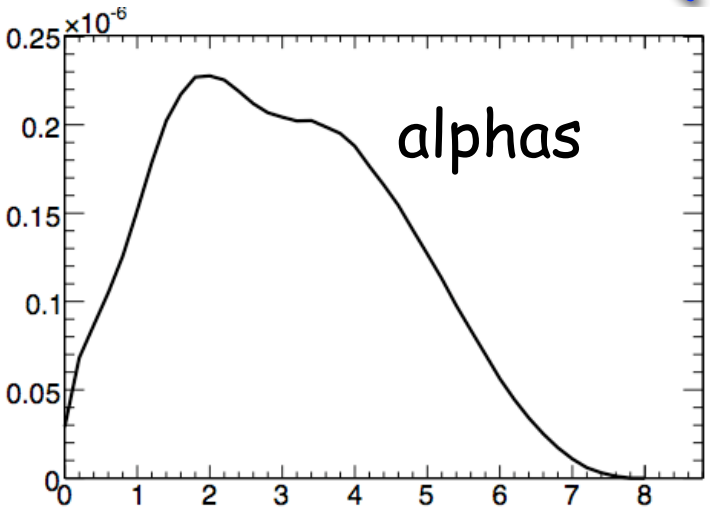


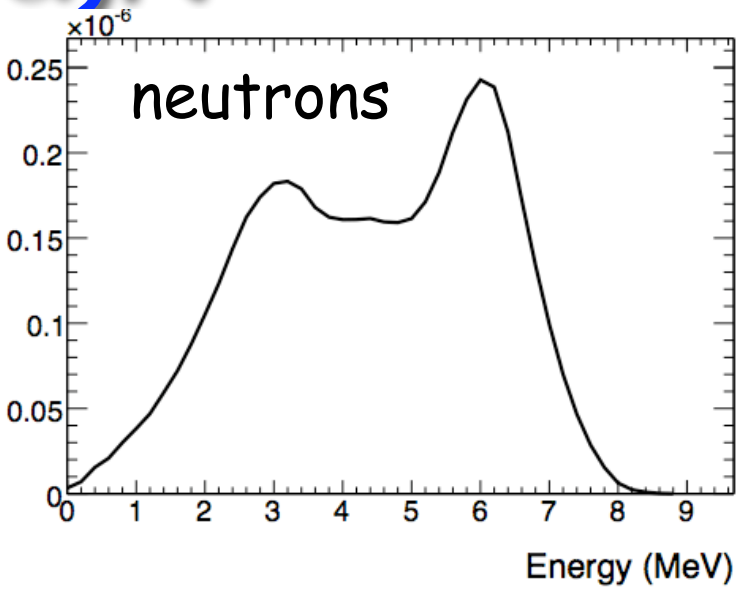
Energy, angular distribution similar to DM recoils

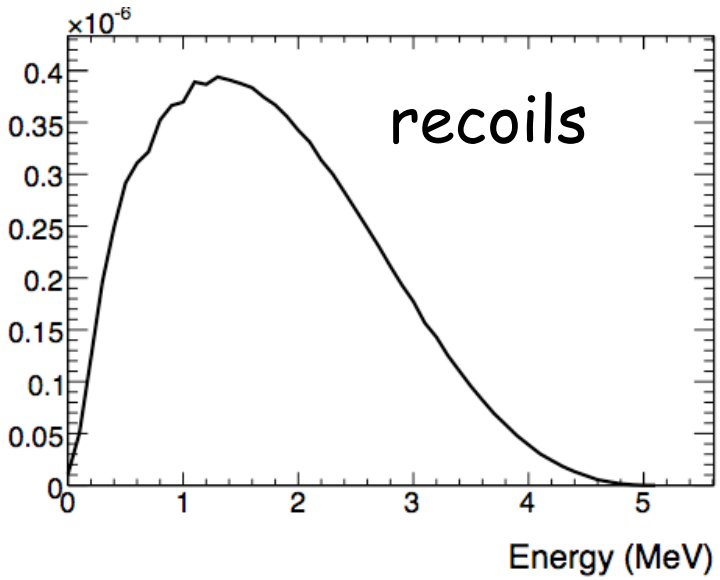




F(n,n+α)N







Dark Matter Direction