Background Rejection with the DMTPC Dark Matter Search Using Charge Signals

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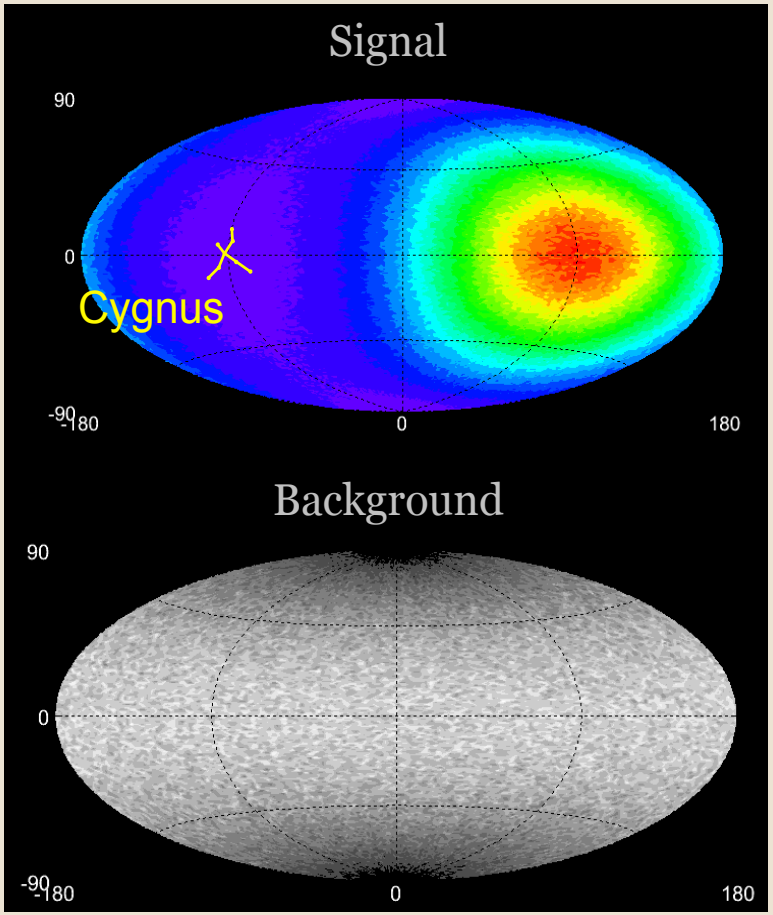
For the DMTPC Collaboration

DPF Meeting, 12 Aug. 2011

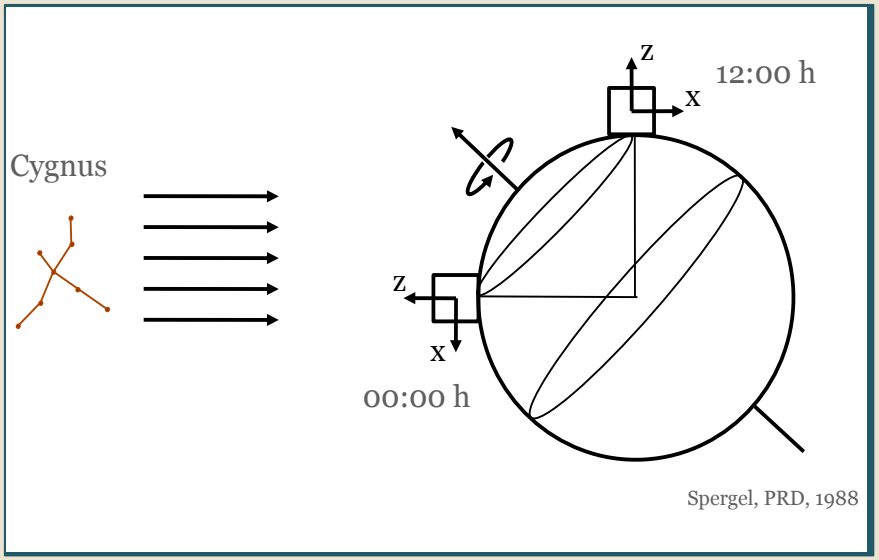
Outline

1. Directional Detection of Dark Matter
2. The DMTPC Experiment
3. Charge Readout and Background Rejection
4. Conclusions and Outlook

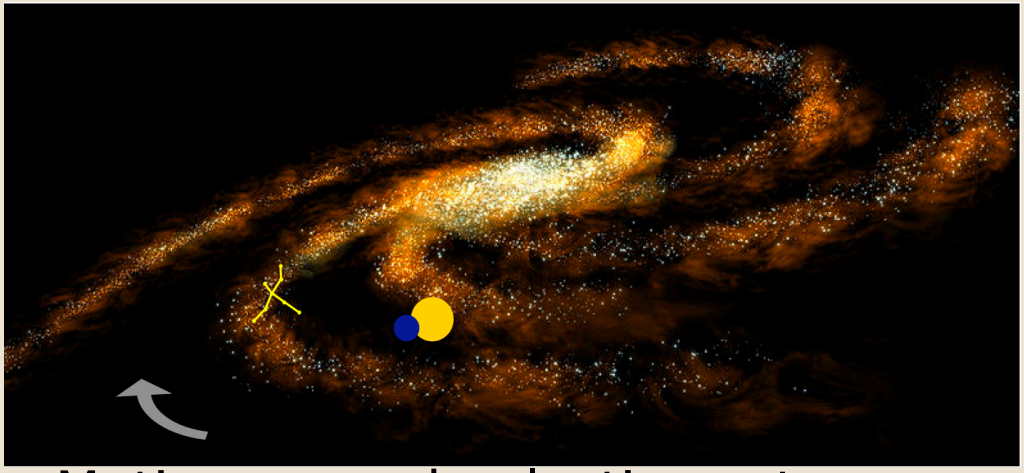
The Directional Signal of WIMP-Induced Recoils



Sky map of nuclear recoils & backgrounds



Sidereal modulation of recoil directions



Motion around galactic center

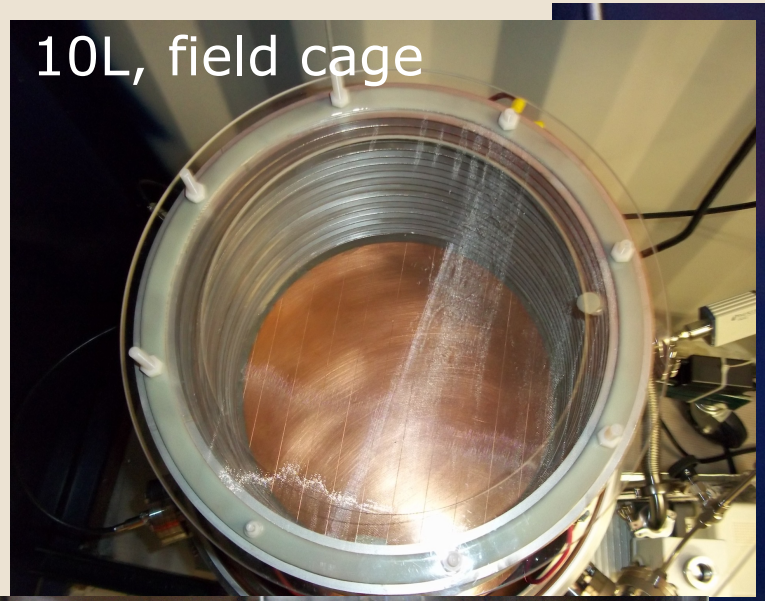
The DMTPC Collaboration

Dark Matter Time Projection Chamber

- Boston University
  - S. Ahlen, M. Chernikoff, A. Inglis, H. Tomita
- Brandeis University
  - A. Dushkin, L. Kirsch, H. Ouyang, G. Sciolla, H. Wellenstein
- Bryn Mawr College
  - J.B.R. Battat
- MIT
  - T. Caldwell, C. Deaconu, D. Dujmic, W. Fedus, P. Fisher, S. Henderson, A. Kaboth, G. Kohse, J. Lopez, E. Nardoni, T. Sahin, A. Strandberg, R. Vanderspek, I. Wolfe, R. Yamamoto, H. Yegoryan
- RHUL
  - R. Eggleston, J. Monroe

- Low-pressure gas TPC
- CCD readout of light from electron avalanches for sub-mm spatial resolution on readout plane

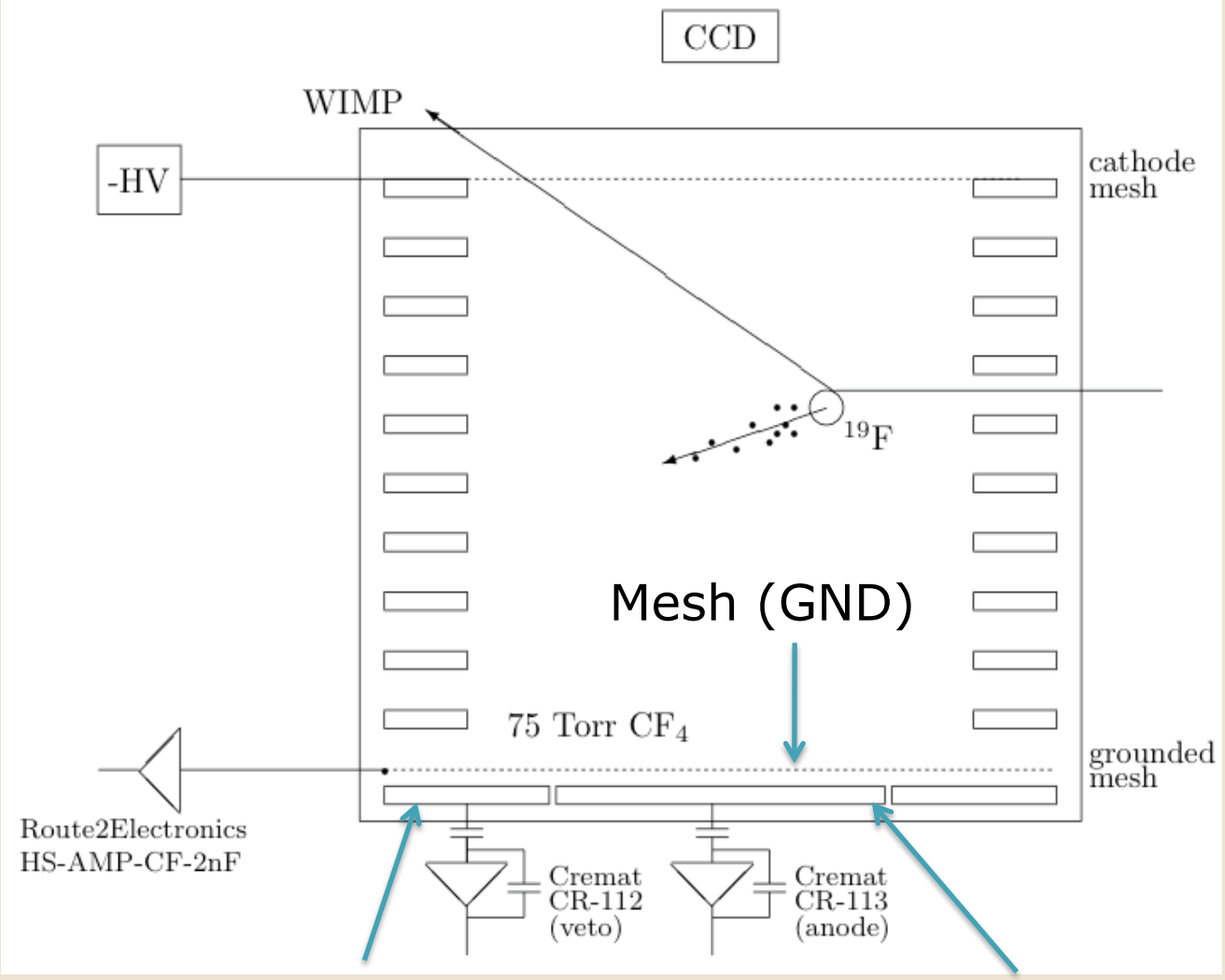
DMTPC Detectors



+several others

Used in this talk

Schematic



Veto Ring (+HV) Central Anode (+HV)

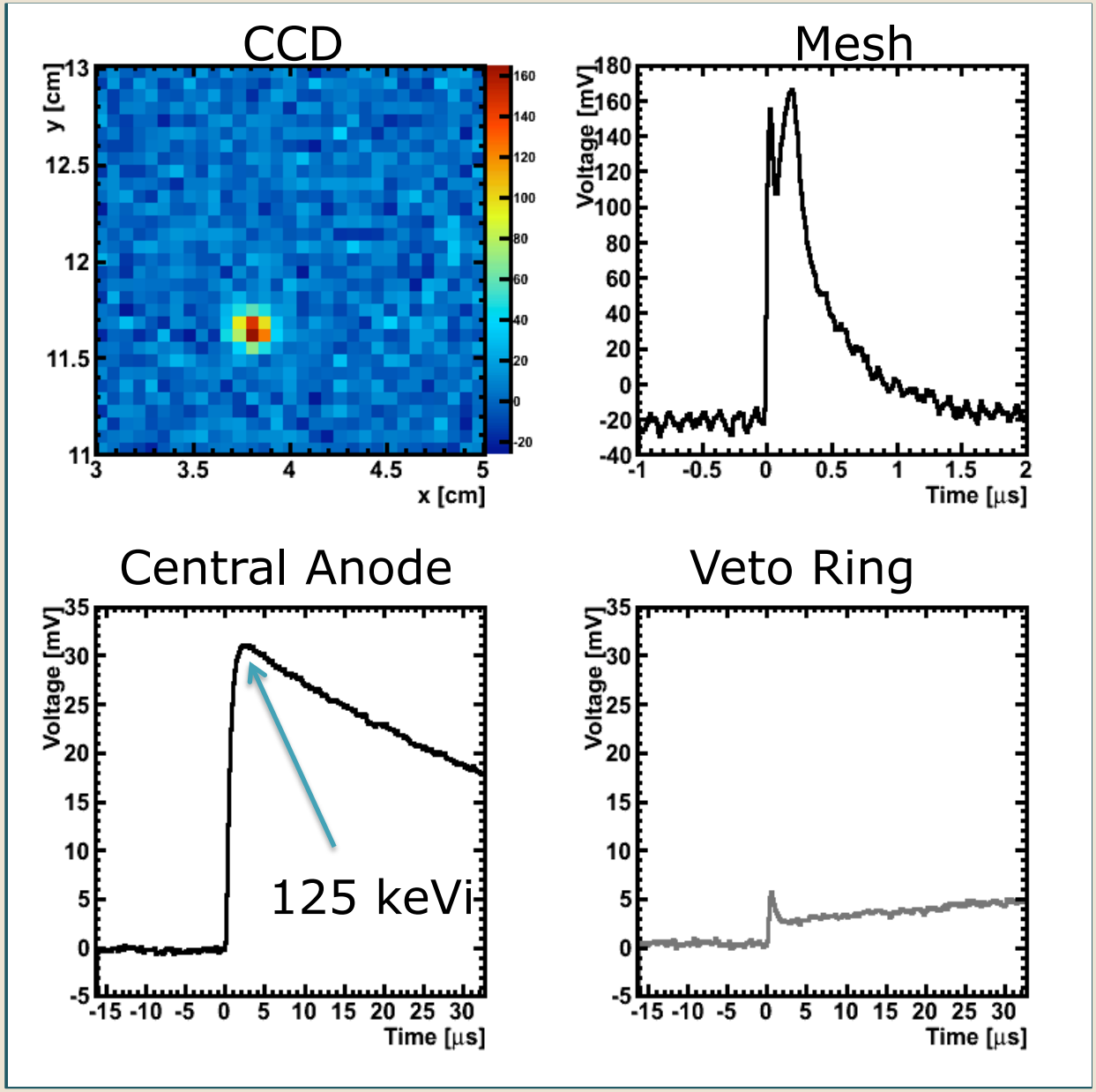
CF_4: χF elastic scattering -SD cross section

Channels:

Charge readout:
- 1 s exposure/event
- 4 ns samples
- Save triggered pulses
- Mesh: Current signal
- Anode/Veto: Integrated charge

CCD:
- 1 s + readout (0.3 s)) exposure / event
- No shutter used
- Tracks during readout appear shifted in position: must reject

Example Event



Nuclear recoil candidate in R&D vessel during a surface run at MIT.

Note: In this talk, keVi = electron-equivalent ionization yield.

Region of amplification plane Near field cage rings. Small signal→No ionization near edge of field cage.

Pulses smoothed with Gaussian convolution

Potential Backgrounds

- Electronic Recoils
  - Invisible to CCD: Low pressure → Low ΔE / Volume, pixel noise > signal.
  - Measured in charge signals.
  - Use charge pulse shape discrimination.
- CCD Artifacts
  - Use redundant measurements, track shape parameters.
- Radon Progeny Recoils
- Cosmogenic Nuclear Recoils

Rejection of Electronic Recoils

1. How blind is the CCD to these?
2. How well can we discriminate between charge signals from nuclei and electrons?

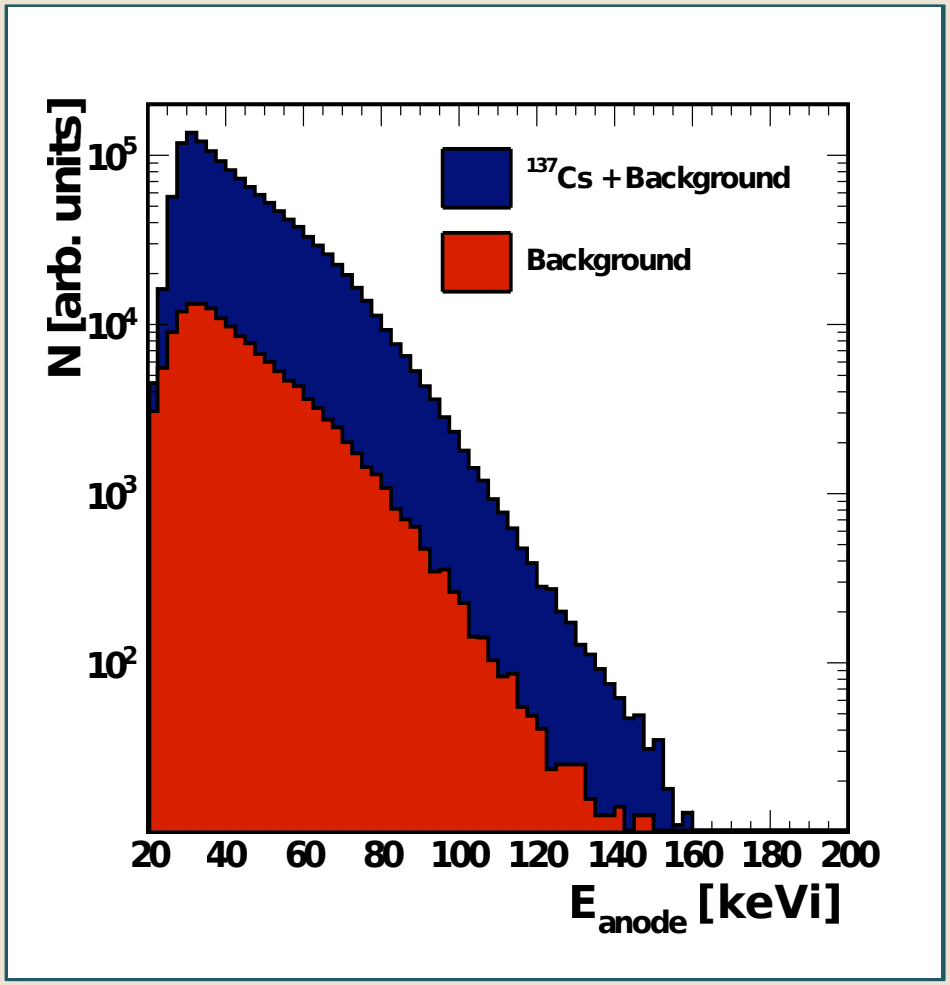
Place ^{137}Cs source inside detector:

- Generate ~25 e^- recoils (E>30 keVi) per 1 s exposure.
- Get light pileup in CCD, no pileup in charge.

In this run:

Monte Carlo studies: CCD efficiency 90% or better for E>40 keVi (for nuclear recoils).

From trigger level for charge: expect near 100% charge readout efficiency for E>30 keVi.



CCD Rejection of Electronic Recoils

Cuts Used

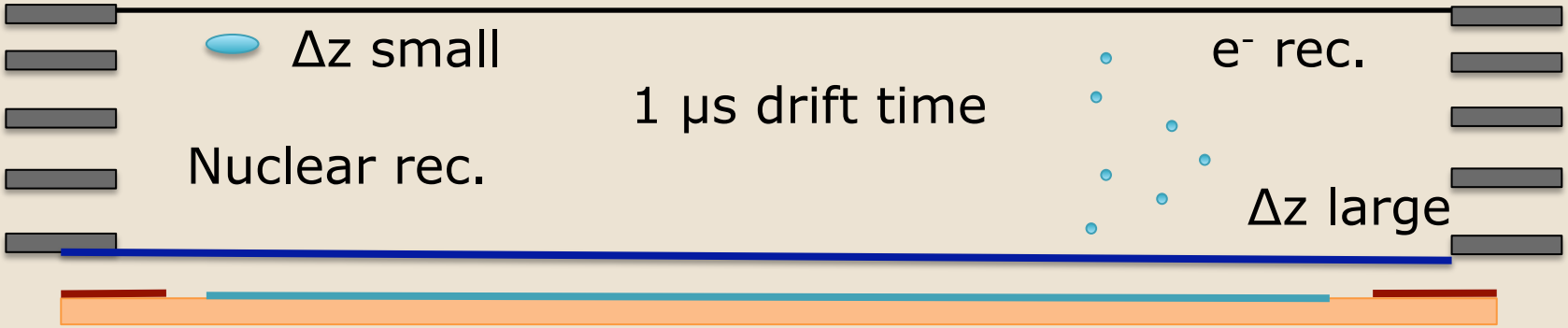
- No tracks on edge of image.
- Peak pixel value must be small compared to total light, large enough to be like a nuclear recoil.
- Range is short.
- Multiple tracks don't appear in same position throughout a run.

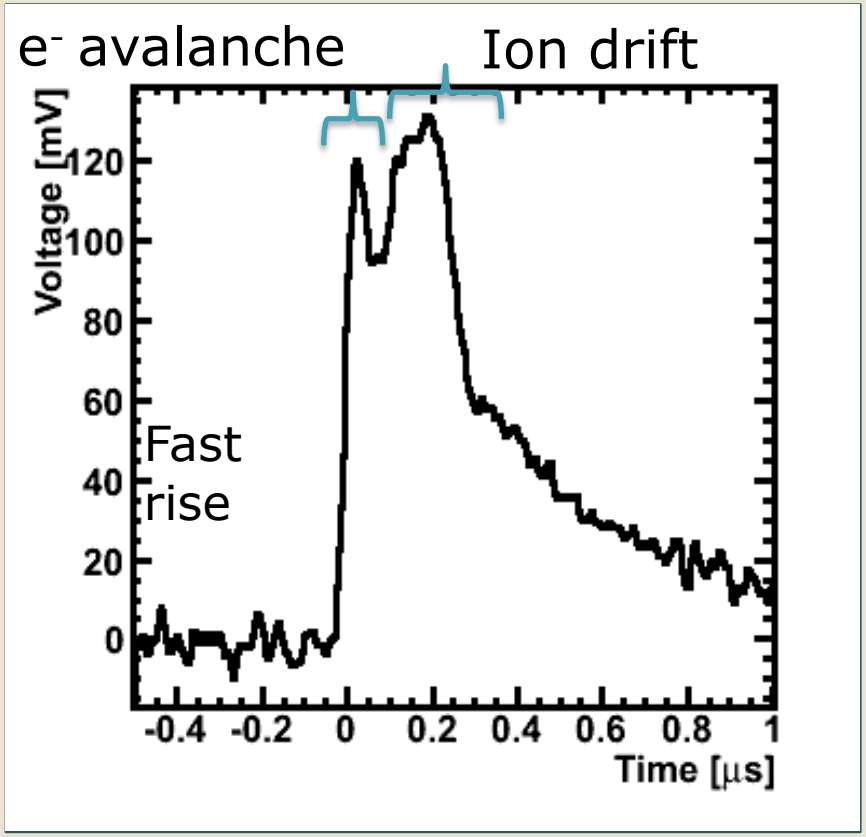
- Much more restrictive cuts are used in WIMP searches.

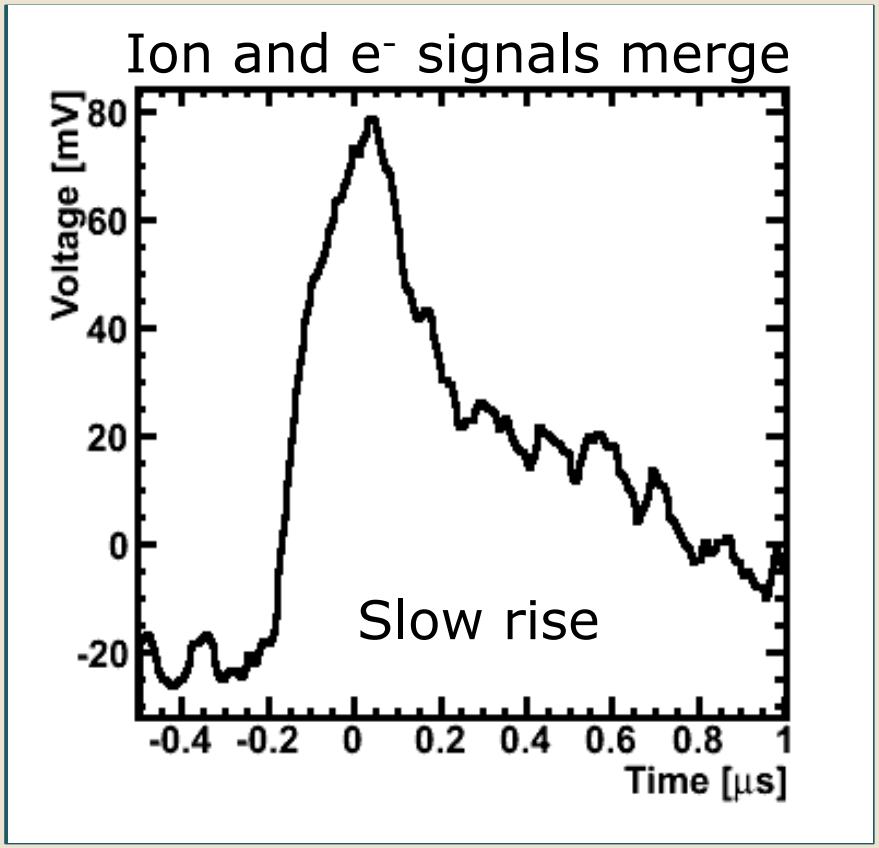
Calculation of CCD Rejection of e- Tracks

- Can measure # of e^- events with charge signals.
- Compare to total # of excess (compared to source-free run) tracks found.
- e- rejection of $3x10^{-5}$ (40-250 keVi)

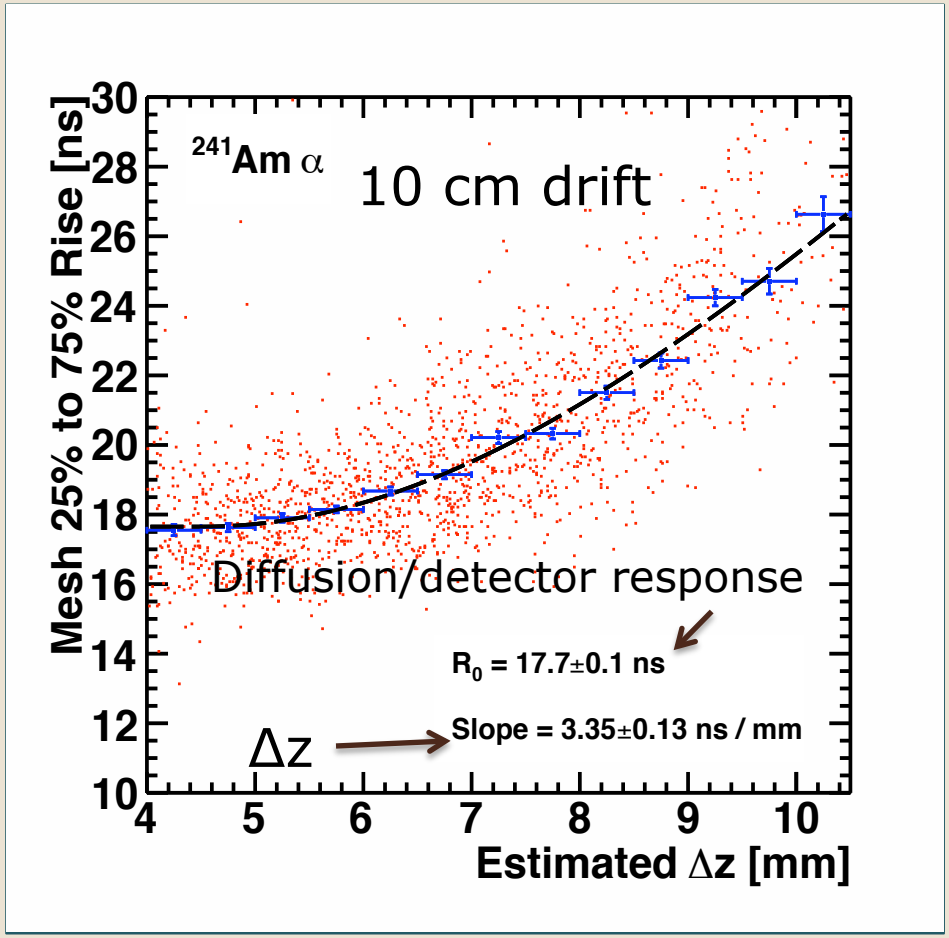
Nuclear vs Electronic Recoils



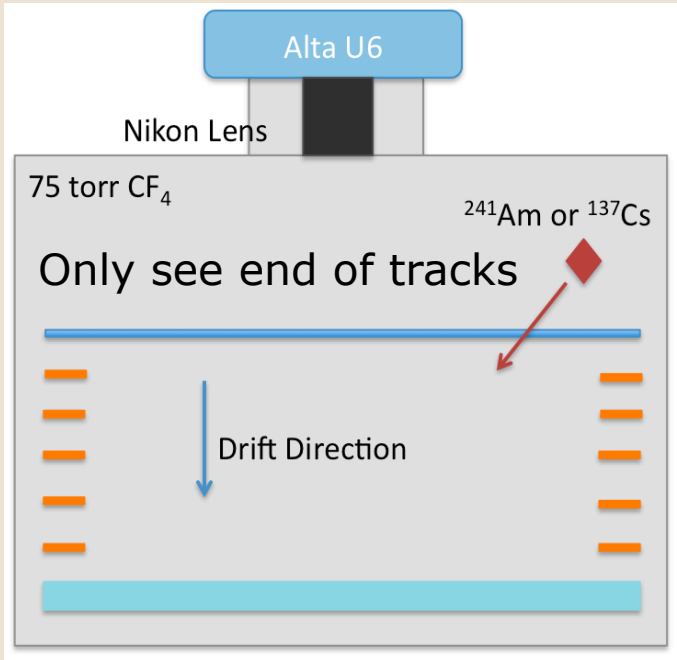




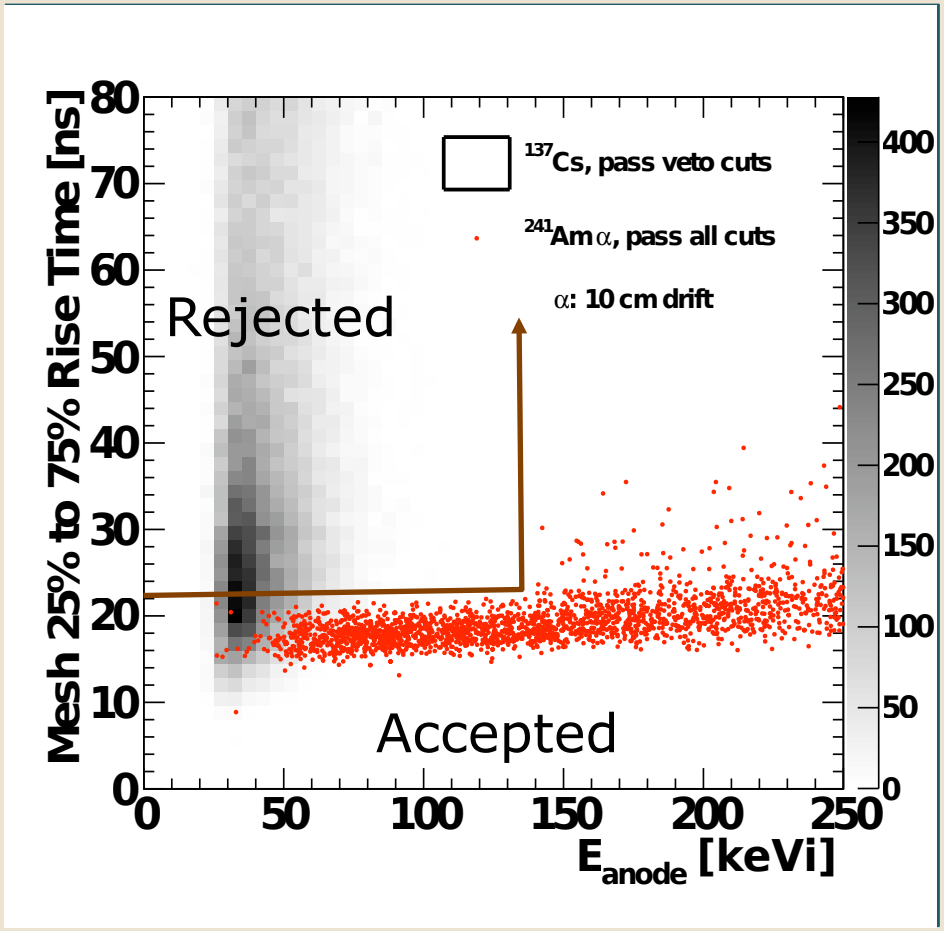
Measurement of Track Δz

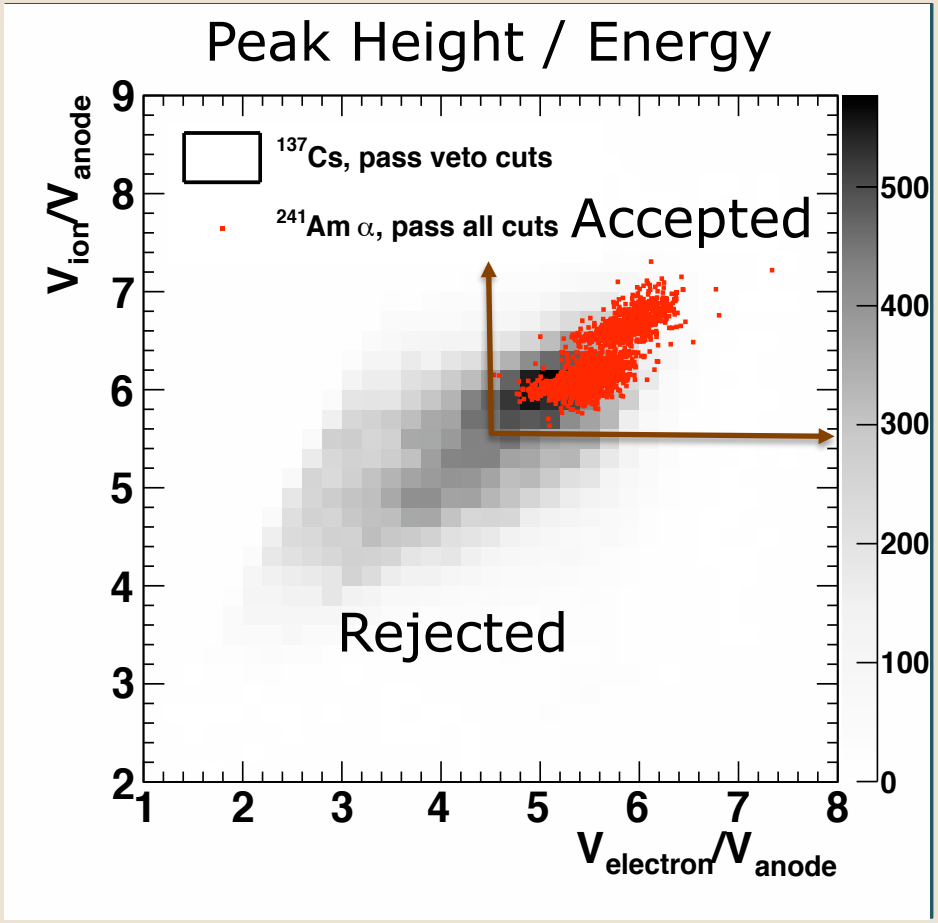


- Compare measured E, 2D range to SRIM estimated 3D range to get Δz.
- Look at mesh pulse rise time.
- Low (120 V/cm) drift field → much diffusion.



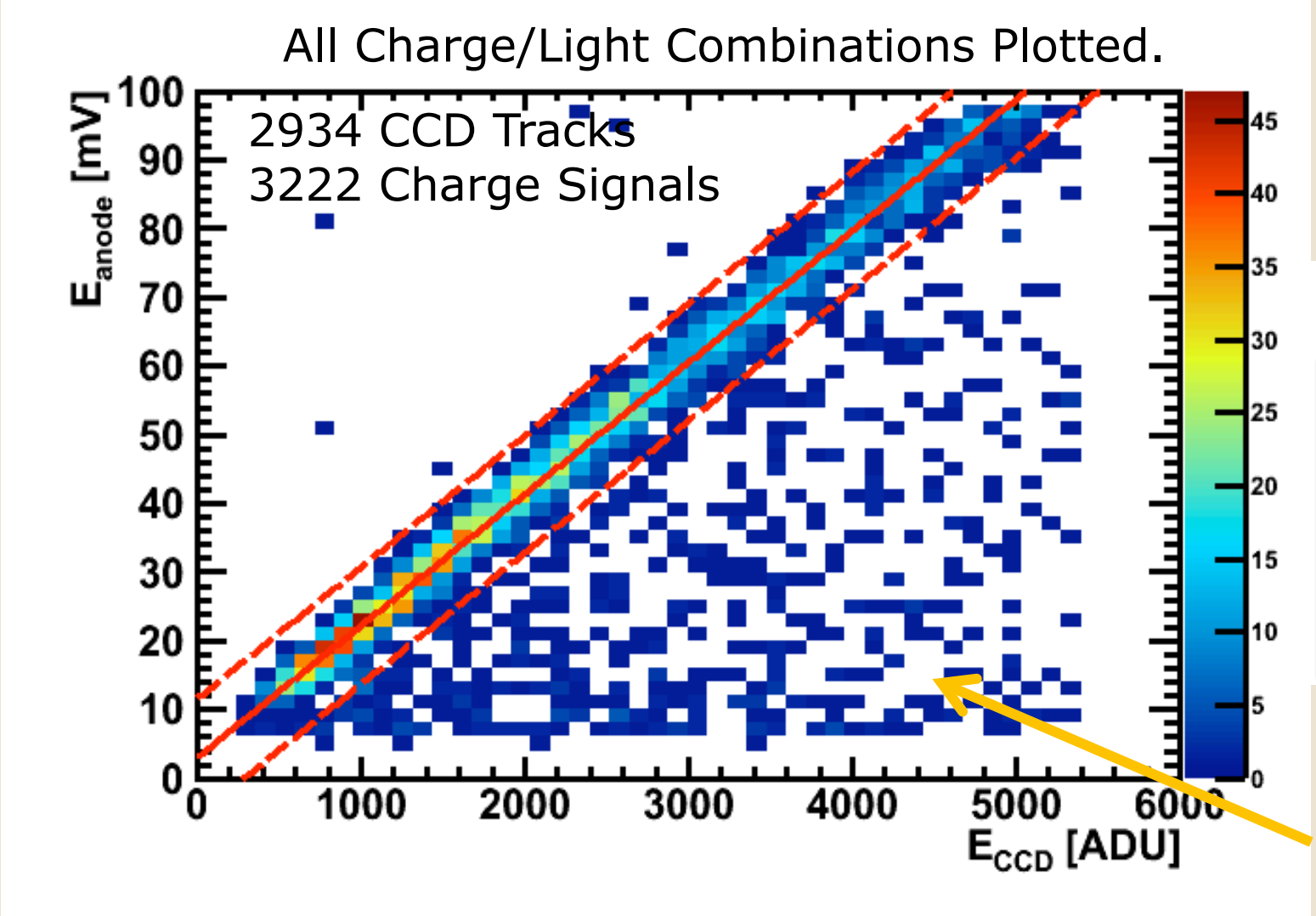
Pulse Shape Analysis



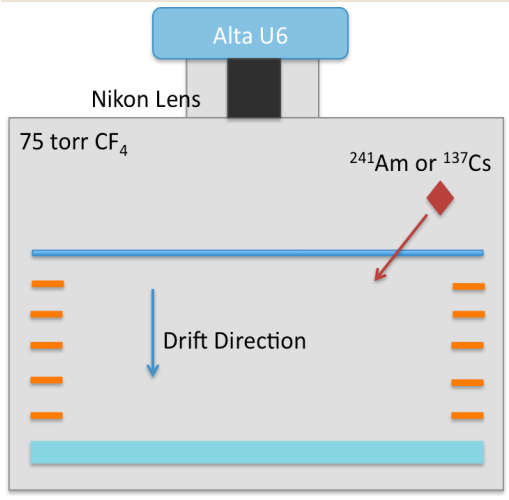


Cuts	Rejection	Total Rejection
Veto (fiducialization)	0.054	0.054
Pulse shape	0.0061	3×10^{-4}

Charge-Light Energy Matching



Solid Line: Best fit.
Dashed Lines: Define acceptance region (3.5σ from best fit).



Incorrect matches: Tracks during readout, Overlapping tracks (from collimated source), multiple passing charge signals etc.

^{241}Am source, positioned so only last O(100 keV) is measured.
Compare all passing CCD tracks to all passing charge signals.
Incorrect matches appear away from main band.

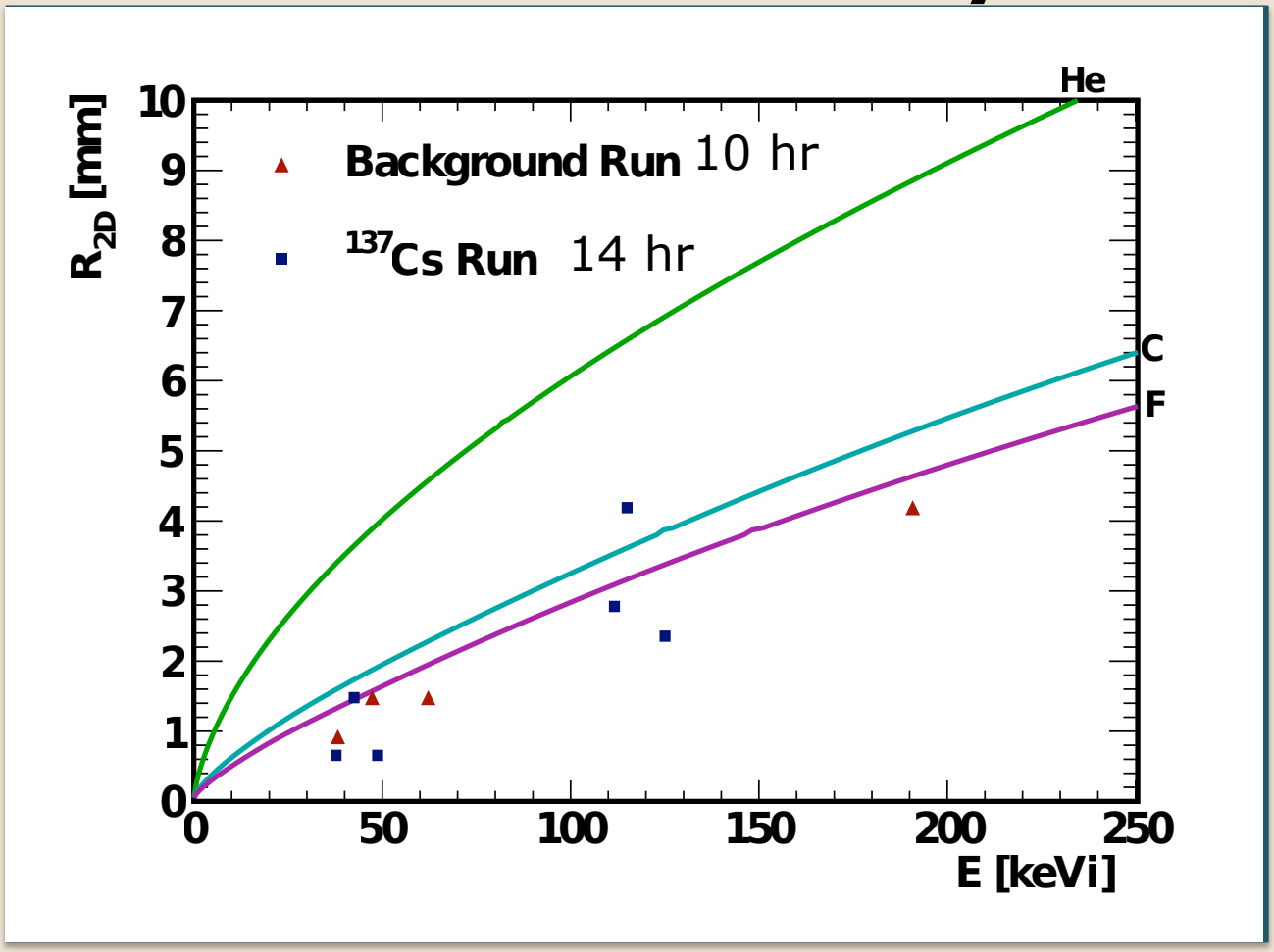
Final Results from e$^-$ Discrimination Study

Results are conservative: CCD rejection will improve in source-free running (no pileup)

Lines: SRIM 3D range prediction

Points: Data 2D range measurement

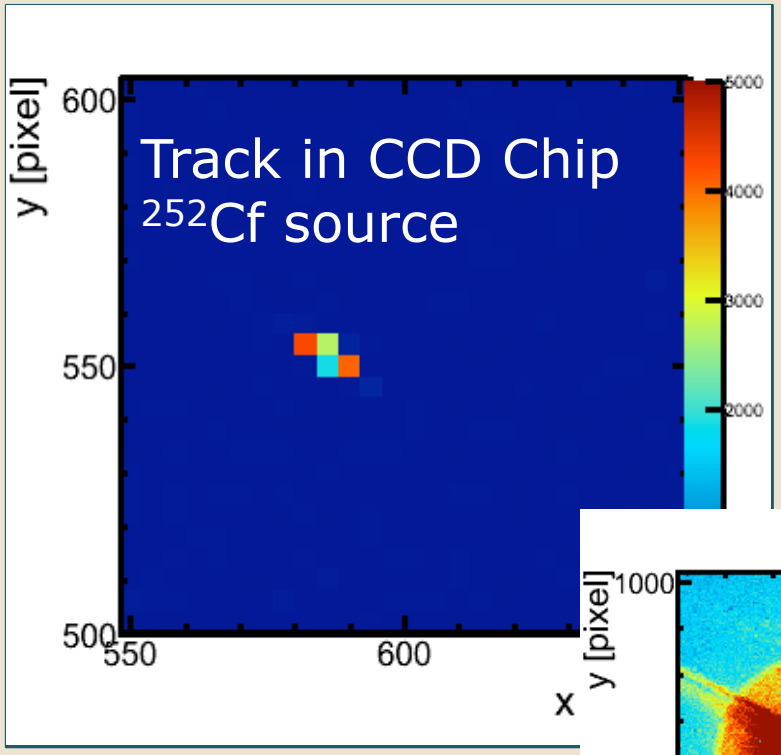
Consistent with nuclear recoils



For 40-250 keVi

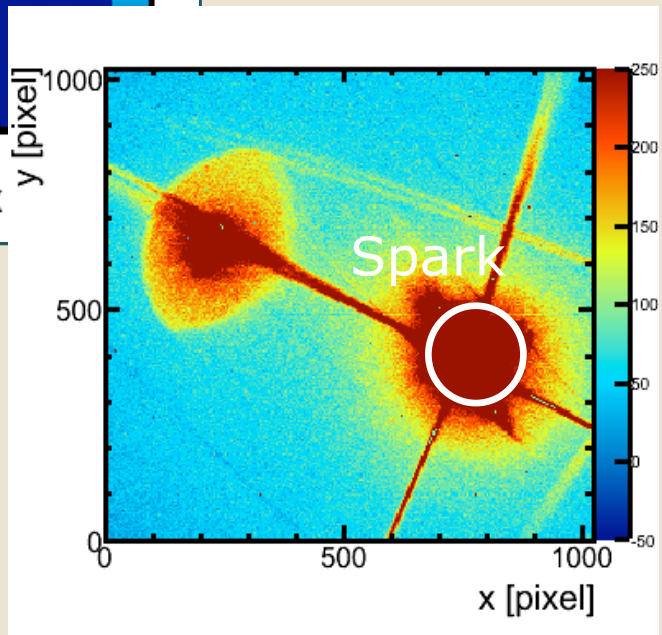
- Charge (pulse shape+veto): 3×10^{-4} rejection
- CCD: 3×10^{-5} rejection
- Combined: 90% C.L. $<6\times10^{-6}$ rejection
- Combined result is statistics-limited

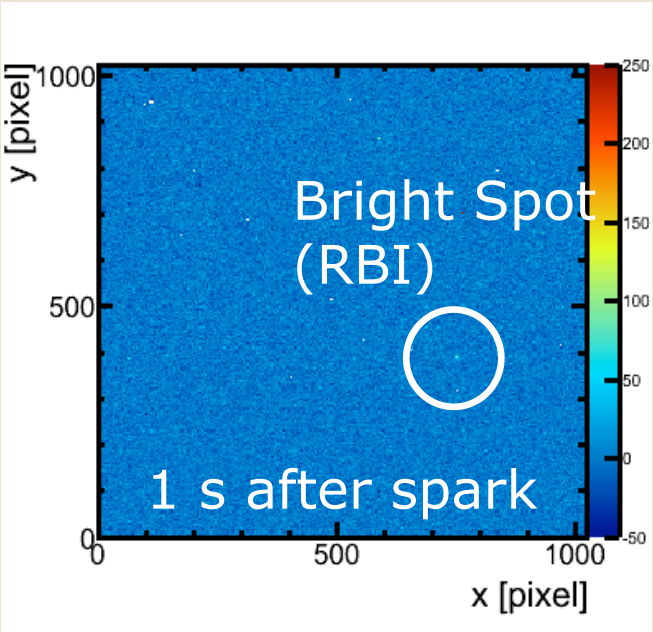
CCD Backgrounds



- Tracks in CCD Si (μ,α,β)
- Hot pixels, noise fluctuations
- Shifted tracks
- Residual bulk images

No corresponding charge signal!





CCD Artifact Rejection

Background	Cuts on CCD Only	CCD Track Finding + Cuts Only on Charge	Combined
RBI	1320	9	0
Hot pixel/CCD Si track/Noise	1287	9	0
Section of Background Alpha	15	0	0
Track	14	5	5

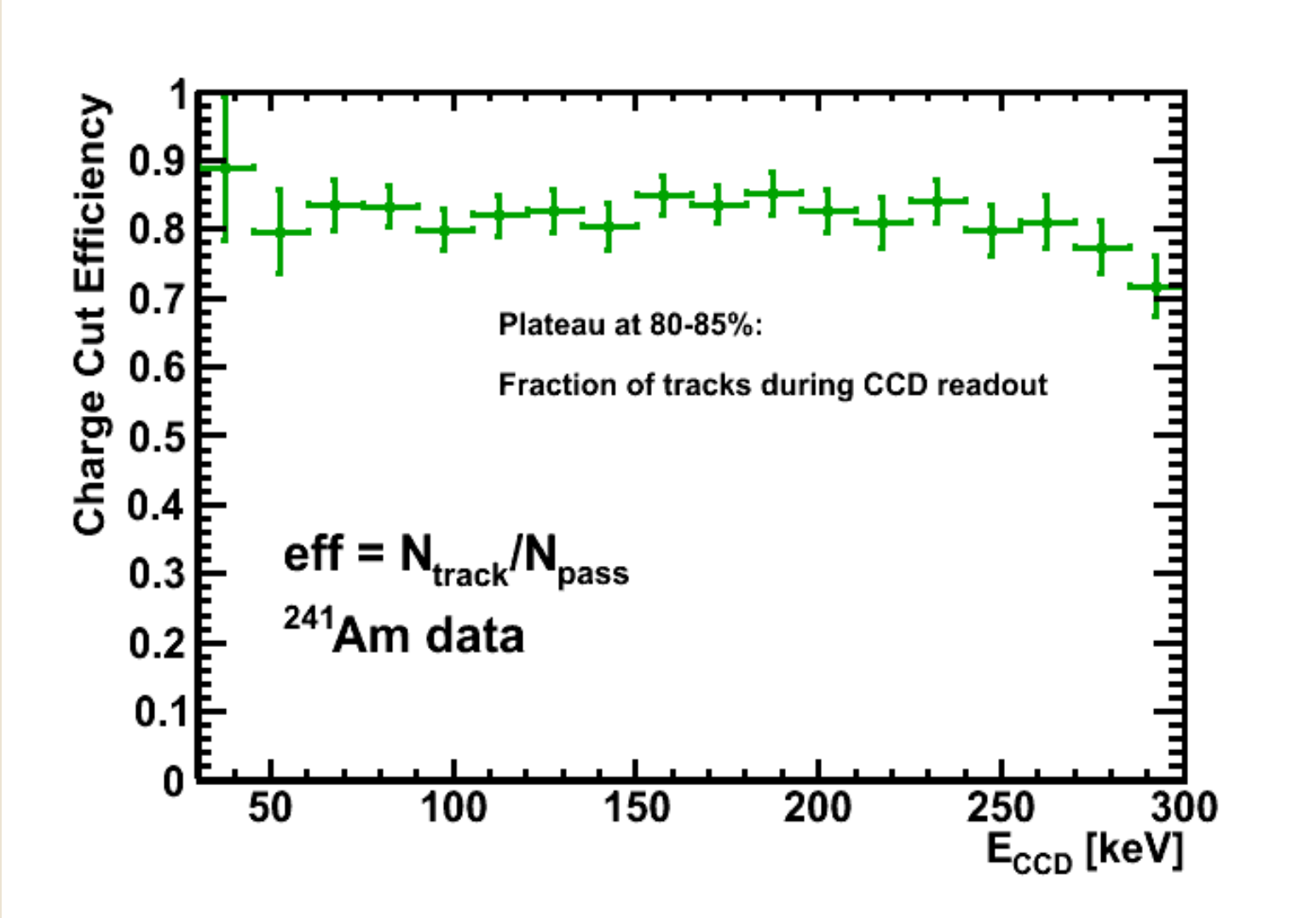
10 hr run at surface, no sources
Look for coincidence between charge signals and various classes of CCD tracks and artifacts
Can reduce CCD artifacts by 10^{-2} before applying CCD cuts!

Conclusions and Outlook

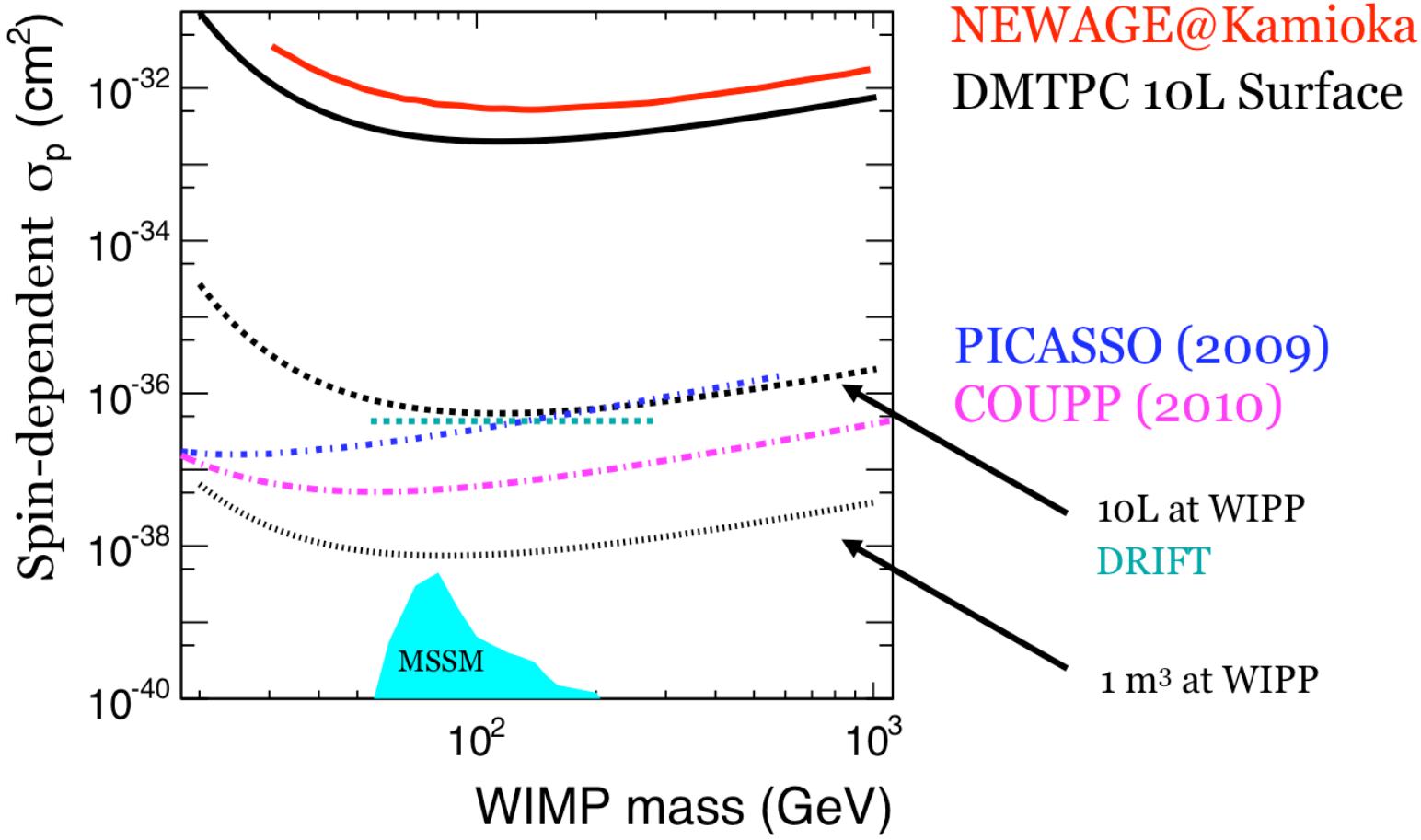
- Can reduce electronic backgrounds by at least (40 keVi<E<250 keVi):
  - $3x10^{-5}$ with CCD analysis
  - $3x10^{-4}$ with charge analysis
  - $6x10^{-6}$ combined (90% C.L., statistics limited)
- Get additional 10^{-2} reduction of CCD artifacts with charge analysis.
- Can now eliminate shifted tracks occurring during CCD readout.
- Charge readout implemented on detectors for underground operation.

Thank You!

Charge Efficiency



Future Sensitivity



From J. Battat

WIPP

- Nuclear waste repository near Carlsbad, NM, USA.
- 650 m depth (1600 mwe)
- Built into salt (NaCl) deposits.
- <<1 cosmogenic n / year
- Low radon backgrounds.
- Summer 2010: set up lab underground
- Fall 2010: shipped 10L detector
- Winter 2010/11: 10L commissioning
- Spring/Summer 2011: AmBe and WIMP data taking
- Future: Move 4shooter to WIPP, plan for m^3 detector