Backgrounds in DMTPC

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DMTPC Collaboration

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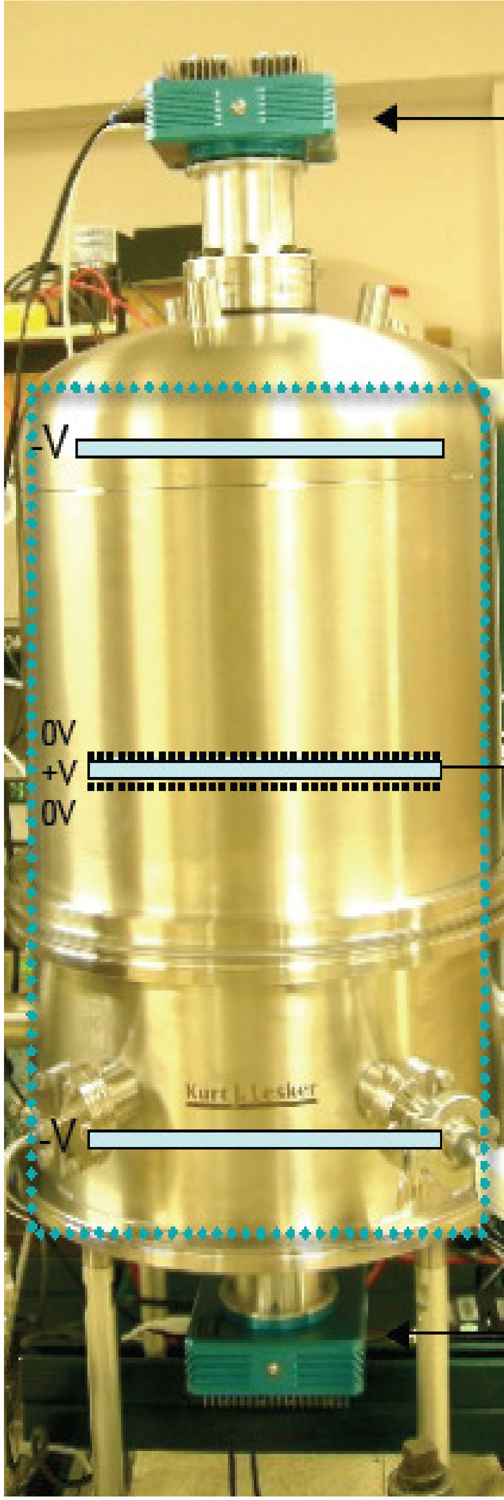
Outline

- Expected backgrounds for surface run
- Detector operation
- Characteristics of surface run
- ^{252}Cf calibration neutron data
- Data from DMTPC's second WIMP run



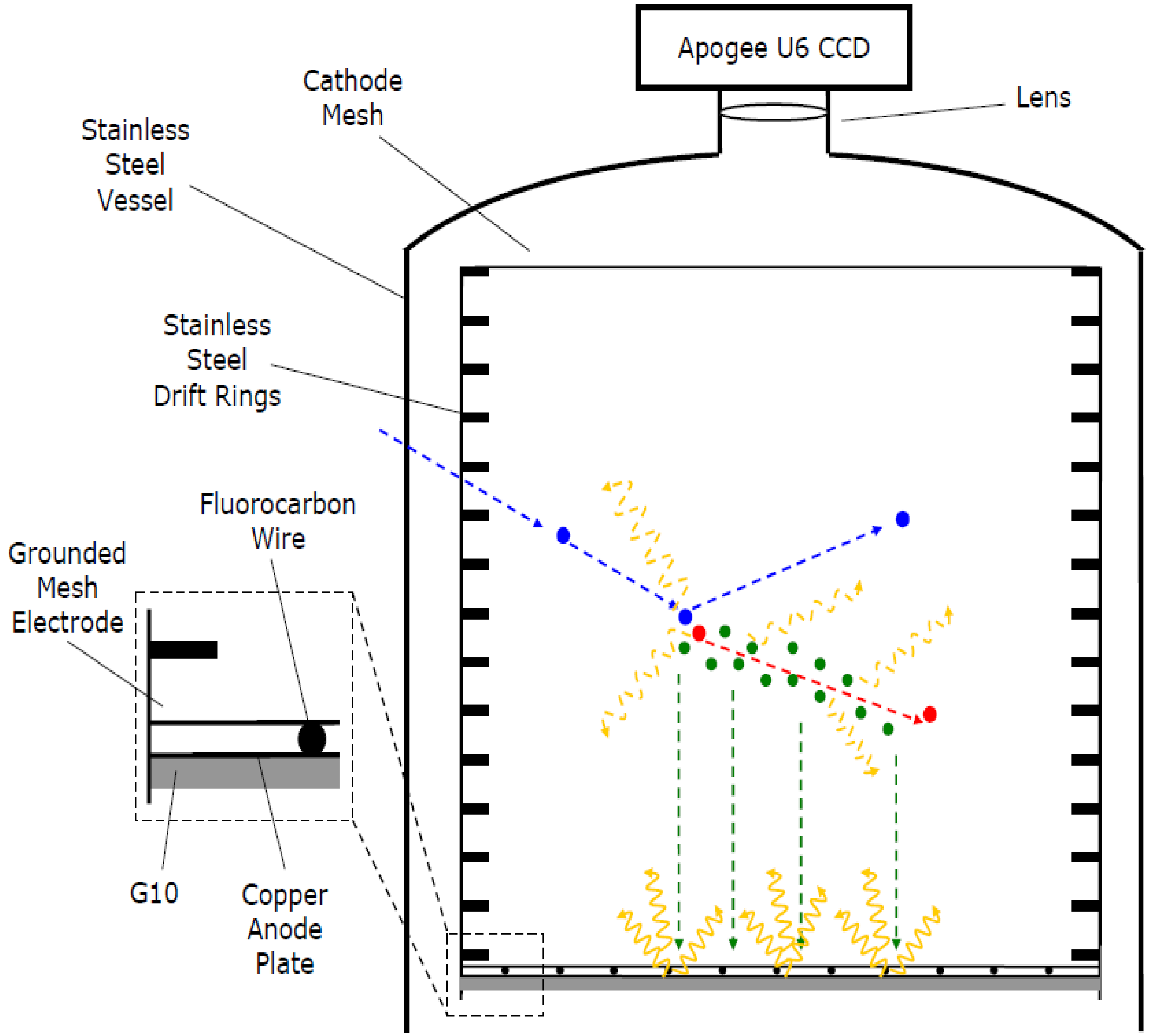
Introduction

- Current DMTPC prototype uses optical readout of 2 back-to-back TPCs

- Data taken with high rate ^{252}Cf neutron source

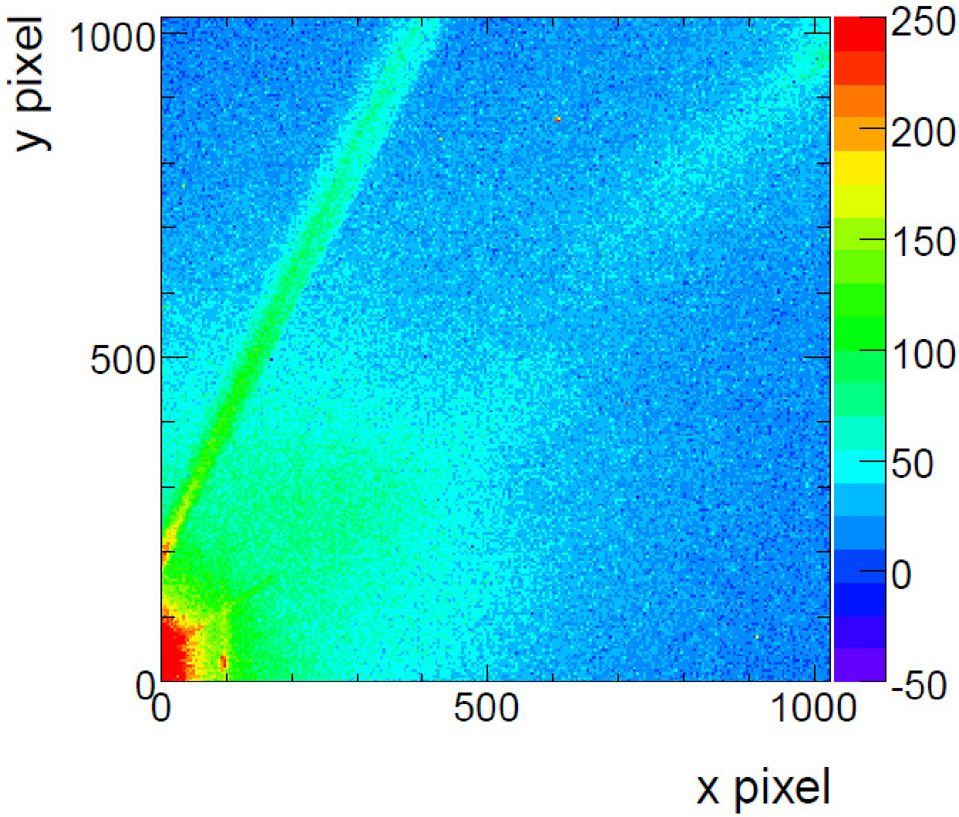
- Use neutron data to understand detector's response to nuclear recoils and to determine signal cuts

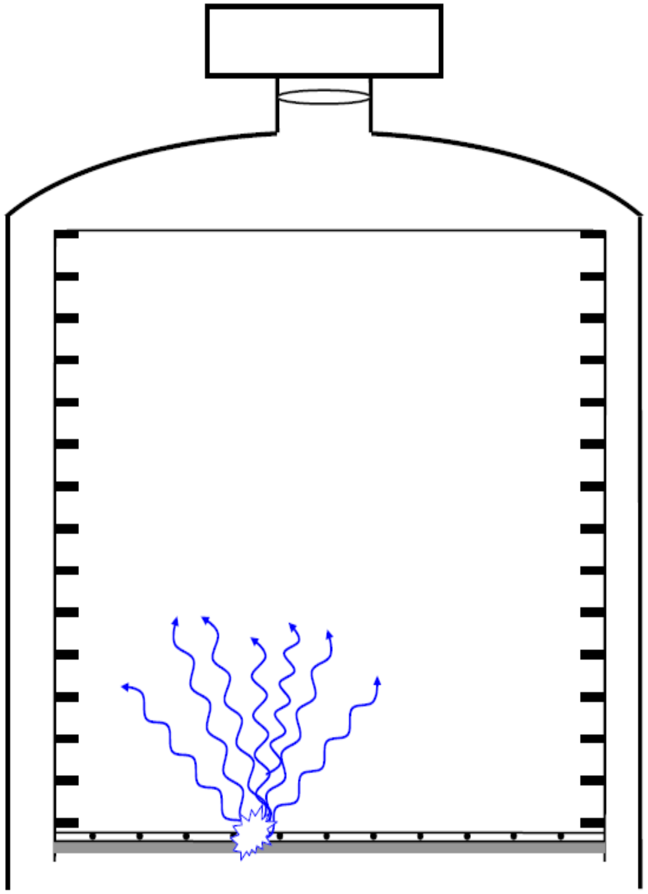
- Data then acquired for 13.3 days live time (3 weeks real time) at surface to understand background events and determine detector sensitivity



Expected Backgrounds – Sparks

- Electrical discharge within detector floods CCD with light
- Higher voltages gives higher gain, but increases spark rate

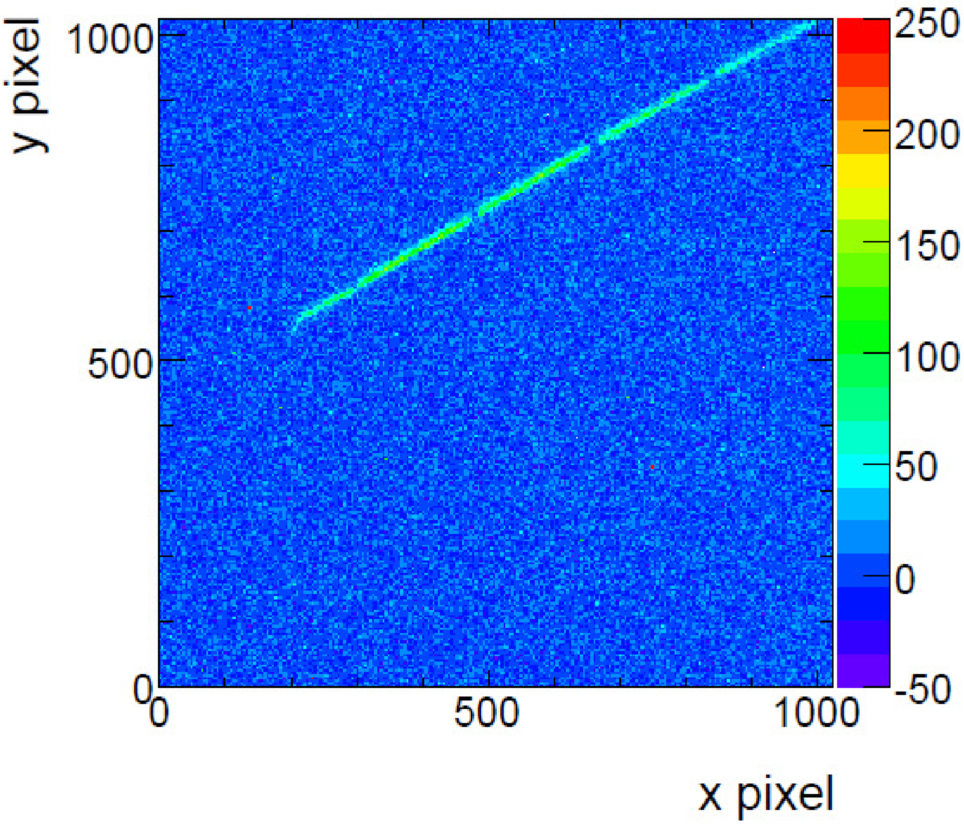


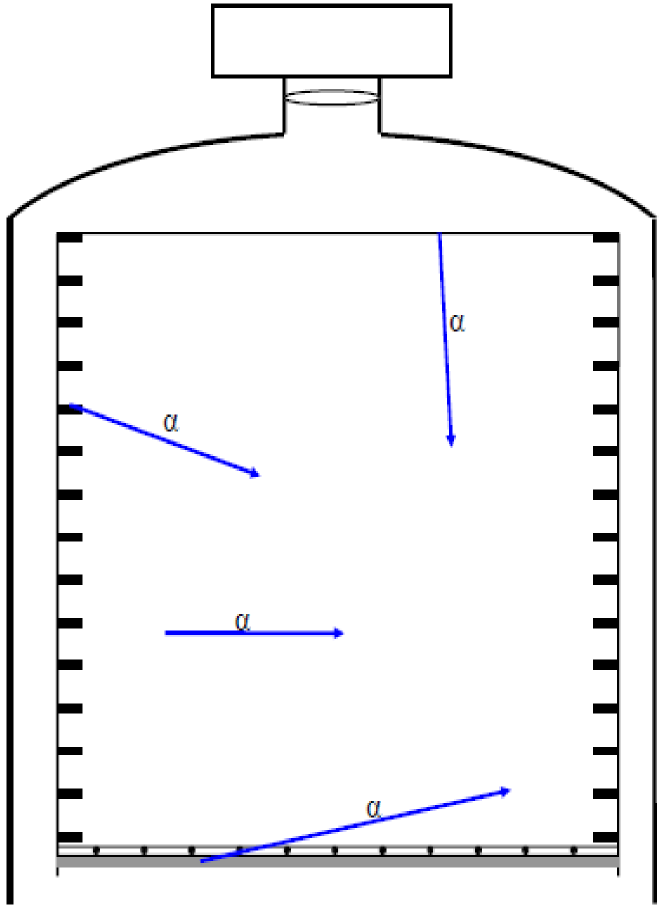


- Sparks are easy to identify by very large light yield
- However, must throw out spark events (~25 mHz), reducing live time

Expected Backgrounds – Alpha Particles

- Radon daughters primarily on detector materials emit alphas
- Particularly large source of bg in this prototype since materials are not radiopure

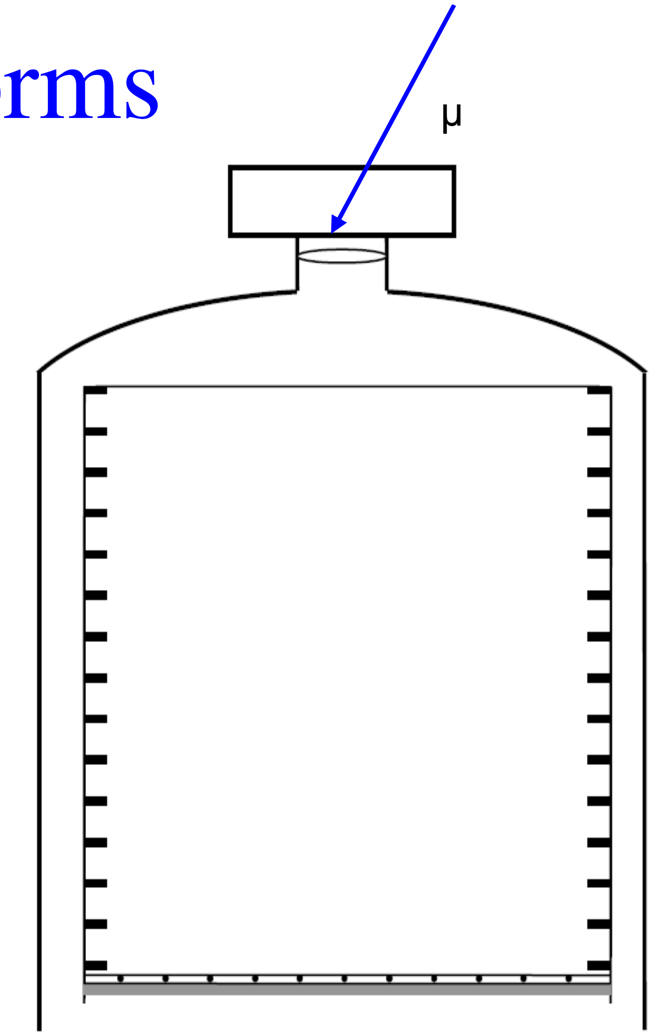


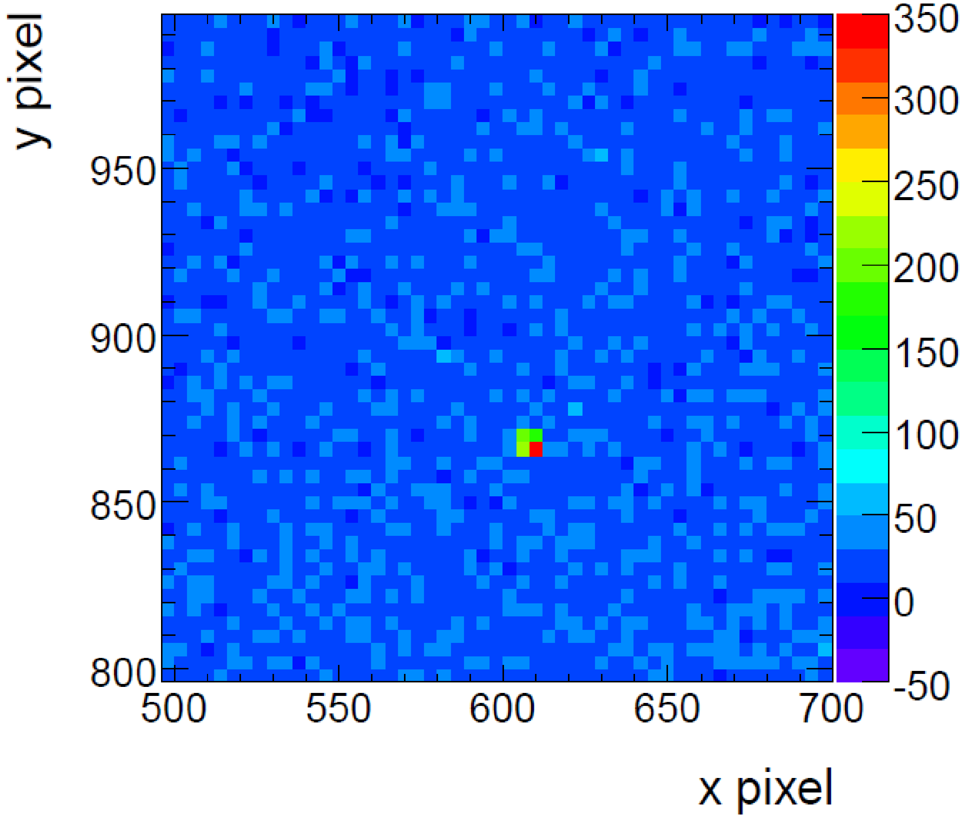


- Most alphas come from sides; these identified by edge crossing
- Some alphas contained in view field; cut by range vs. energy discrimination

Expected Backgrounds – Worms

- Interactions of particles with CCD chip itself; from cosmic rays for example
- We refer to worms as any event with one or a few localized very bright pixels



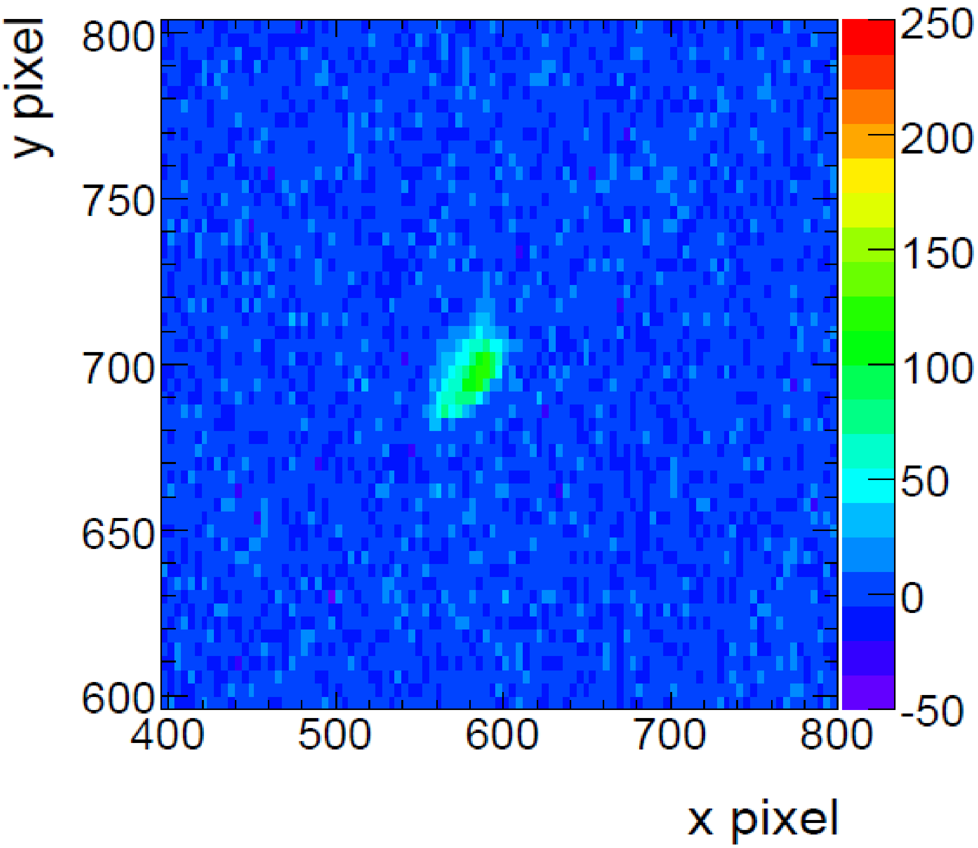


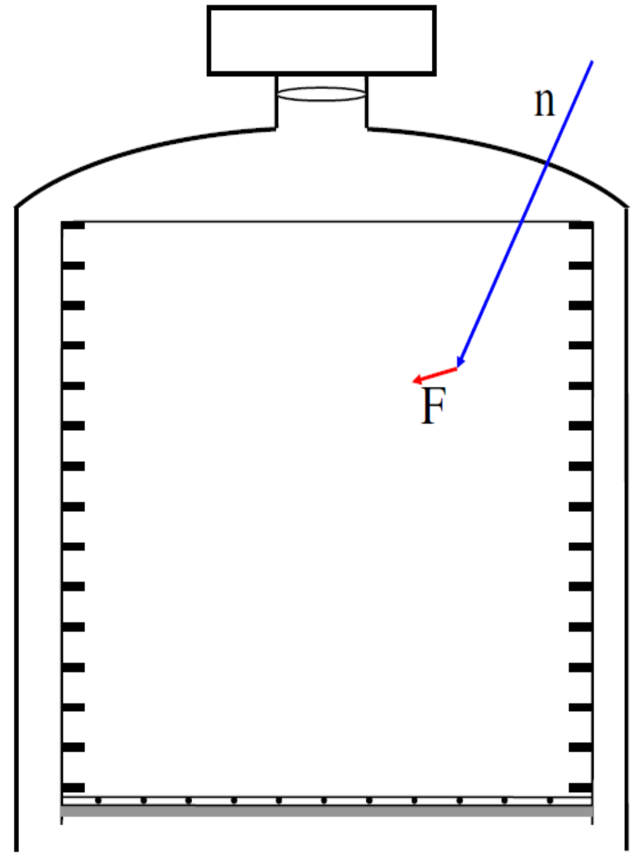
- Identify worms by large energy density
- Sometimes two worm-like events are separated by short distance; identify by cluster characteristics

Expected Backgrounds – Neutrons

- Neutron induced nuclear recoils, primarily from ambient neutrons
- Expect roughly 2 events/day from surface neutron flux

T. Nakamura et al. JNST 42 (2005)

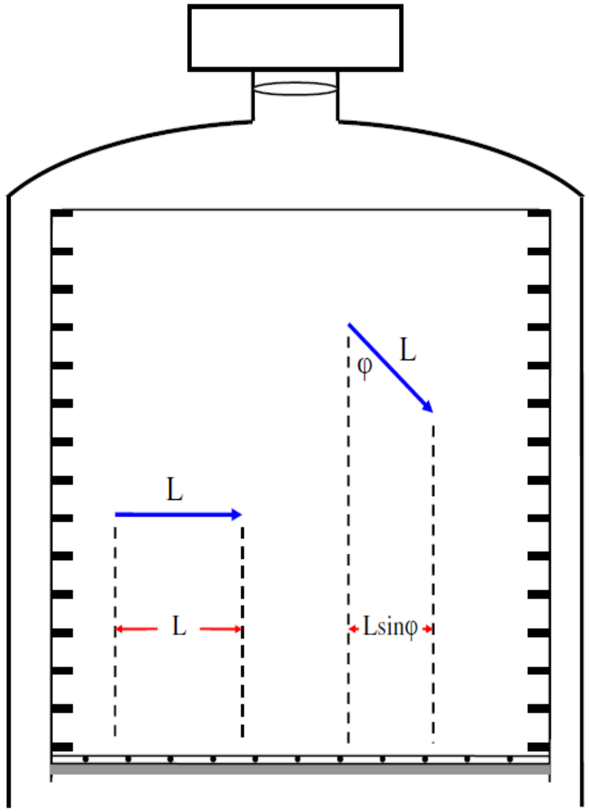


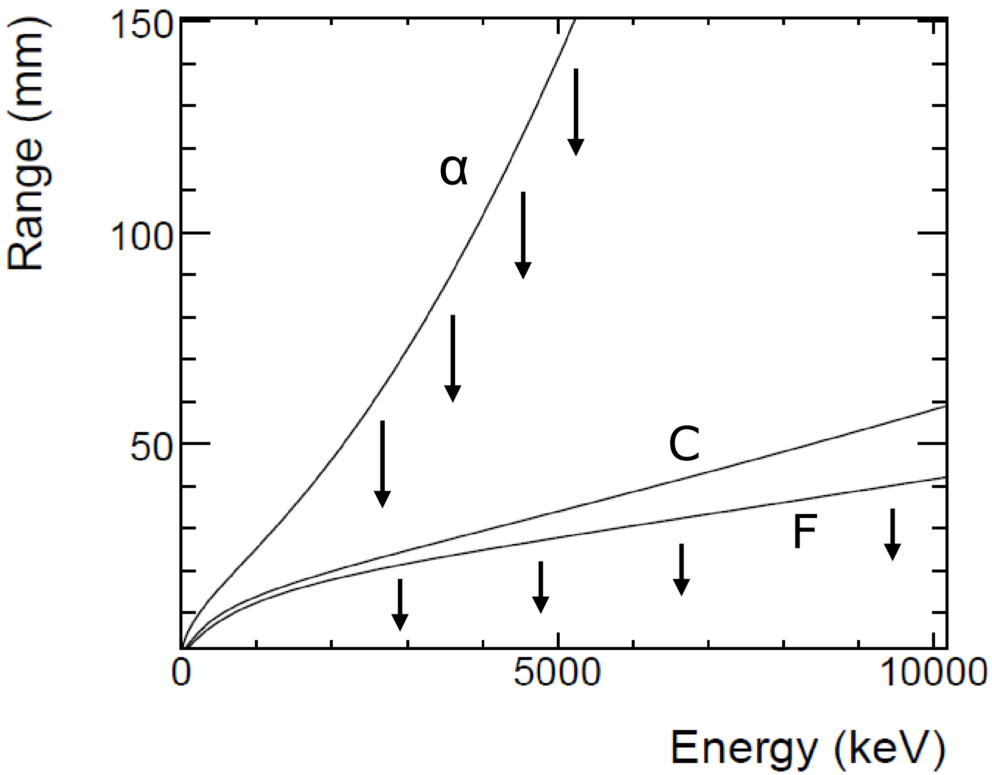


- Low energy neutron induced nuclear recoils mock dark matter signal
- Go underground to reduce the rate of these events

Projected Range and Comparing to SRIM

- We reconstruct the range projected onto the image plane
- Subsequent plots use SRIM prediction of range versus energy for various particles
- However, this is the range in 3-dimensions, not the projected range

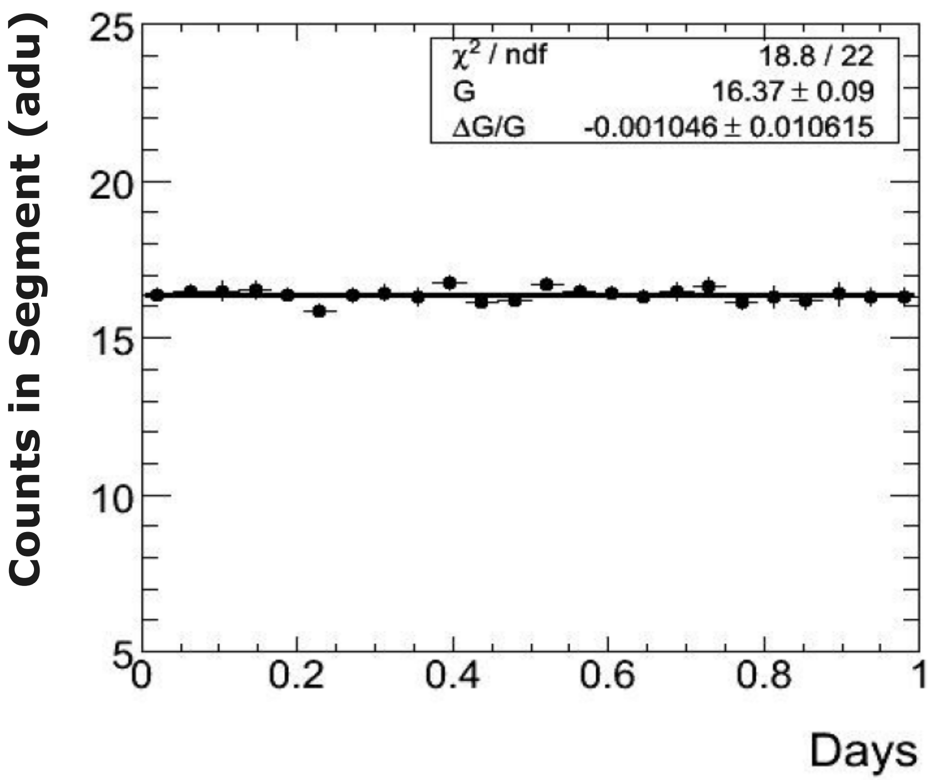


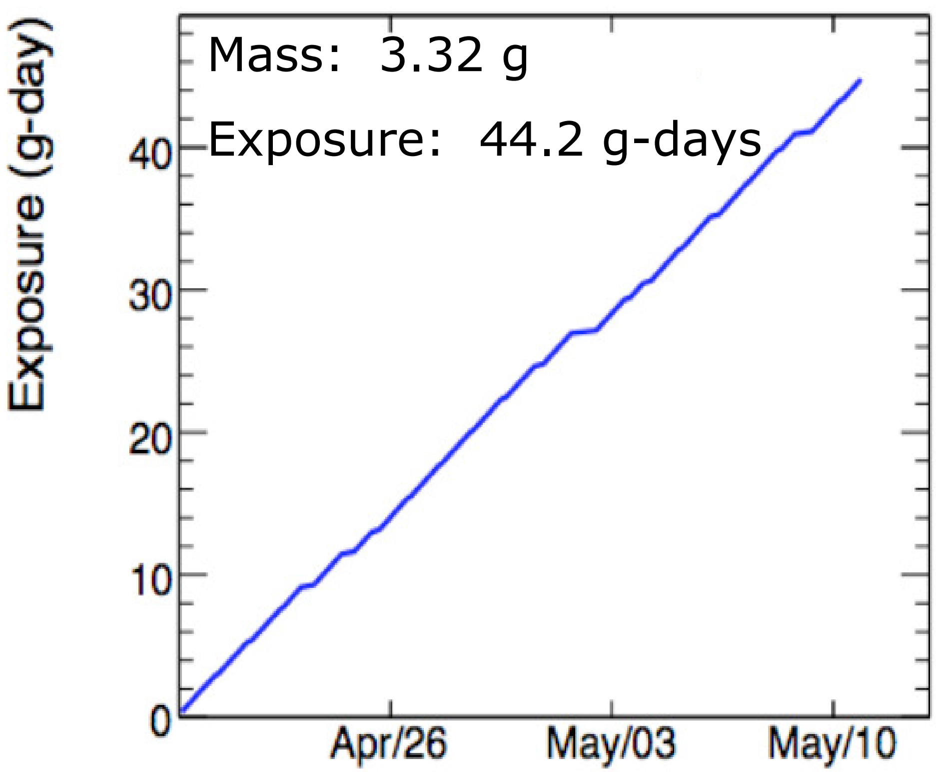


- Tracks parallel to the image plane should lie on this curve, but those at an angle will lie below the curve
- So, the SRIM curves are meant to be the predicted upper limit for the distribution of tracks in range vs. energy

Detector Operation

- Operate at 75 Torr CF_4 pressure
- 5 kV drift voltage (250 V/cm), 0.72 kV amplification voltage (14.4 kV/cm)
- Refill gas approximately every 24 hours to maintain ~1% stability in effective gain
- 5 second exposures without trigger, then readout without shutter
- 1024 x 1024 pixels binned 4 x 4 by cameras
- Detector operated remotely during 3 week run





Background Analysis

Calibration

- Use alpha calibration data from ^{241}Am source to determine length and energy calibrations
- 1 pixel = 0.143mm x 0.143mm

Camera Characteristics

- Top camera:
  - 9.3 +/- 1.7 keV/adu
  - 7.3 adu rms noise
- Bottom camera
  - 12.1 +/- 2.0 keV/adu
  - 11.0 adu rms noise

Monte Carlo and Neutron Data

- Monte Carlo studies give at least 50% efficiency at and above 100 keV
- Events seen as low as ~50 keV
- Acquired data with 2 mCi ^{252}Cf source a few meters from detector in order to define cuts

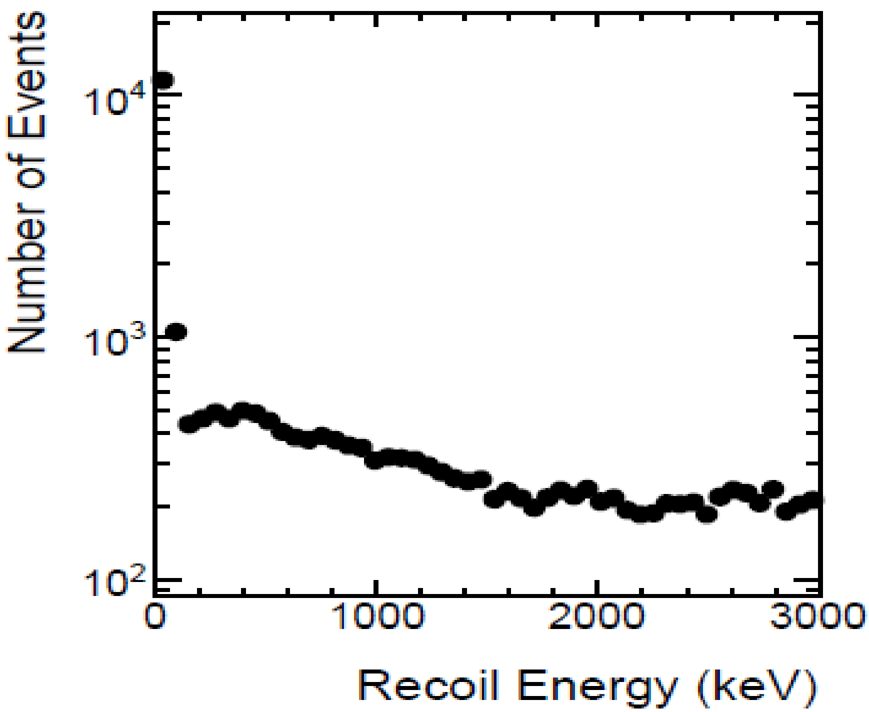
Background Rate

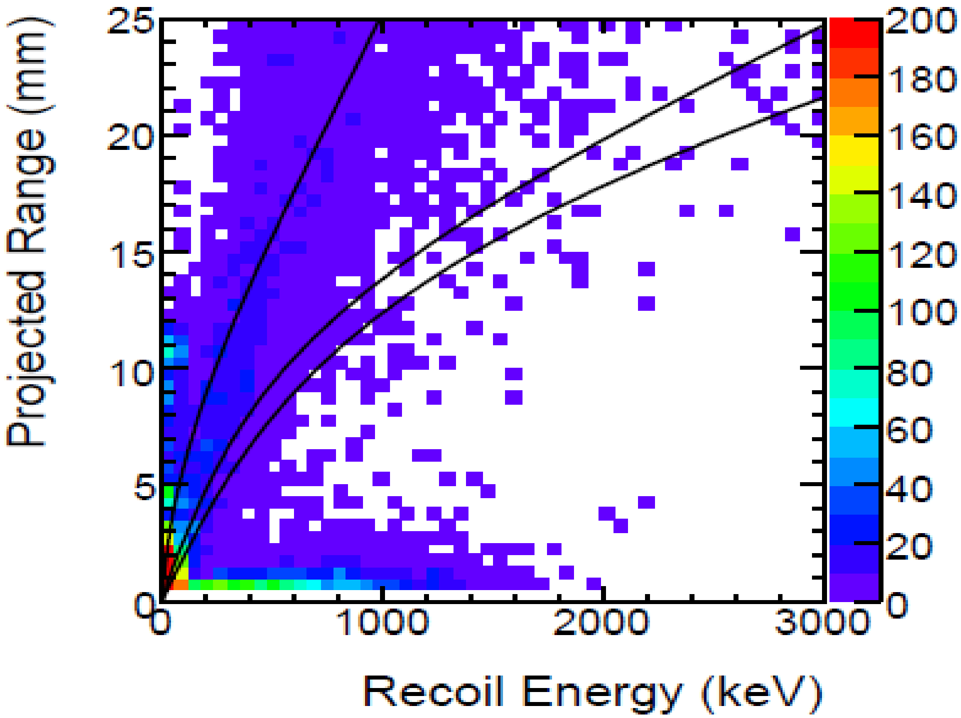
- Apply cuts to "WIMP" data (9.8 days live time)
- Measurement of surface background rate
- Test of detector sensitivity

WIMP Surface Run Data

- In 850,000 total events, 329,446 tracks were found above threshold requirements
- Alphas and worms dominate

Cut	Remaining Events	Efficiency of Cut
No Cuts	329446	1.000
Spark	308295	0.936
Tracks	32071	0.097
Edge	14139	0.043
Worm	150	0.005
Range	81	0.002
Energy	80	0.002





WIMP Surface Run Data

- Require that images contain only one track
- Eliminate alphas from edges by excluding tracks which cross the edge
- Eliminate worms based on cluster characteristics (cluster pixel rms > 100, 80< maximum pixel value < 500, neighbors around maximum >2)

Cut	Remaining Events	Efficiency of Cut
No Cuts	329446	1.000
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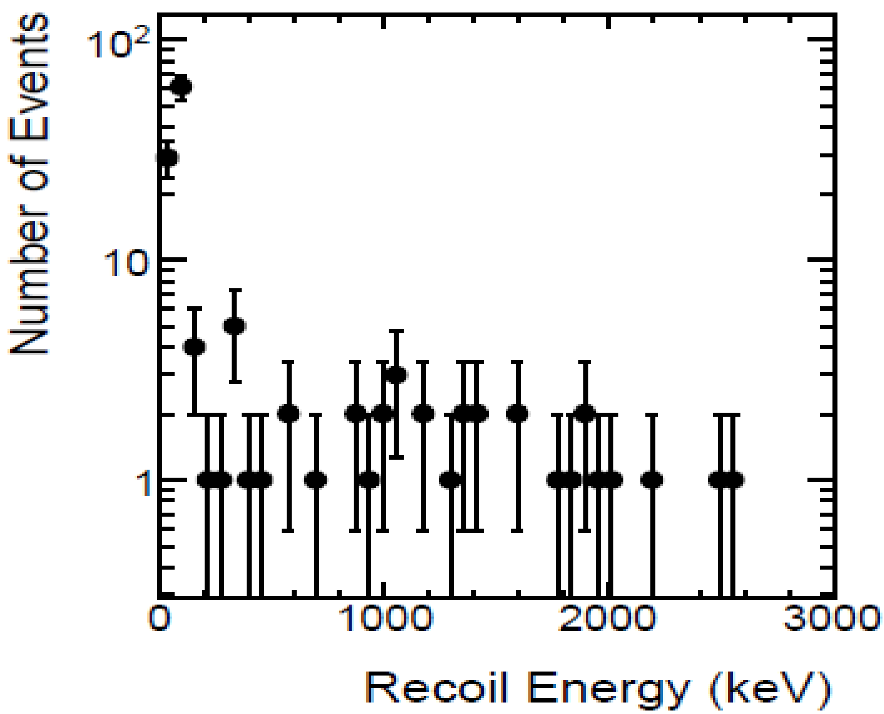
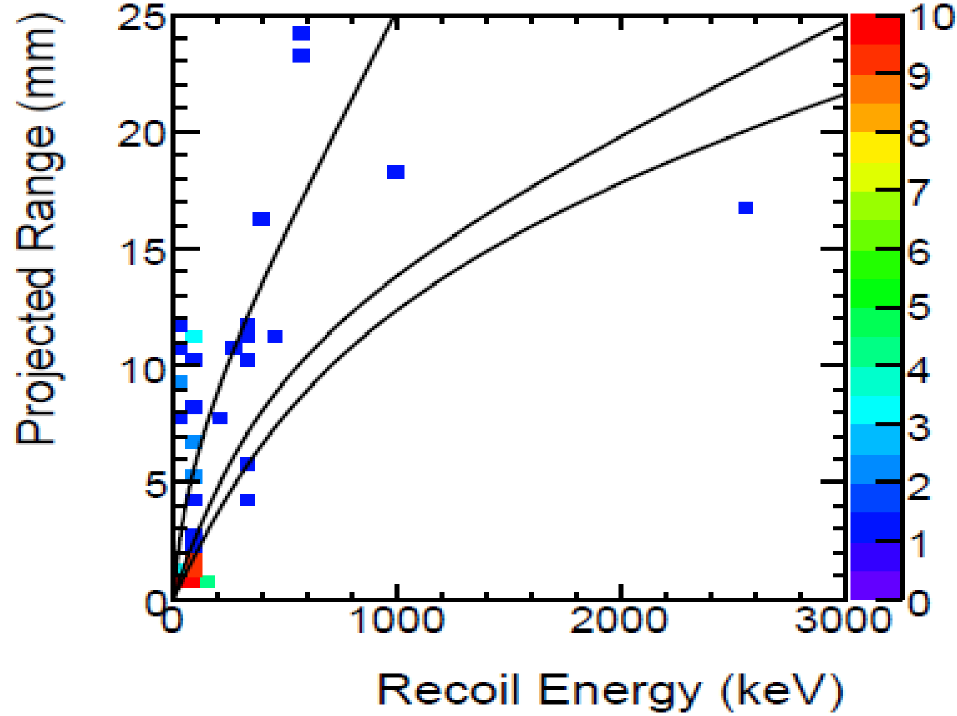
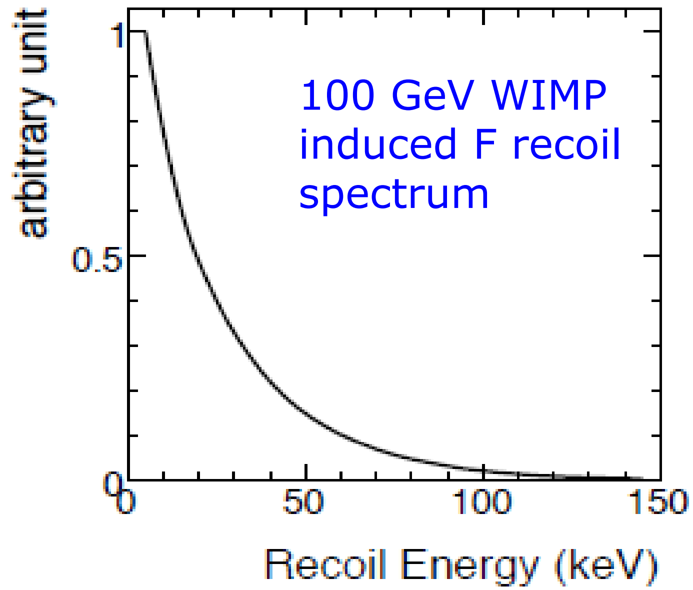
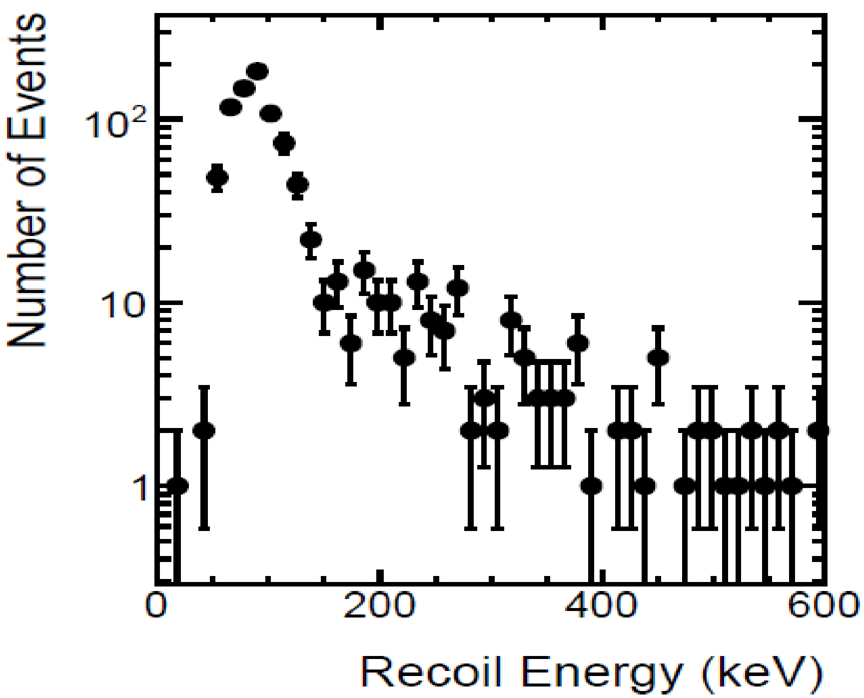


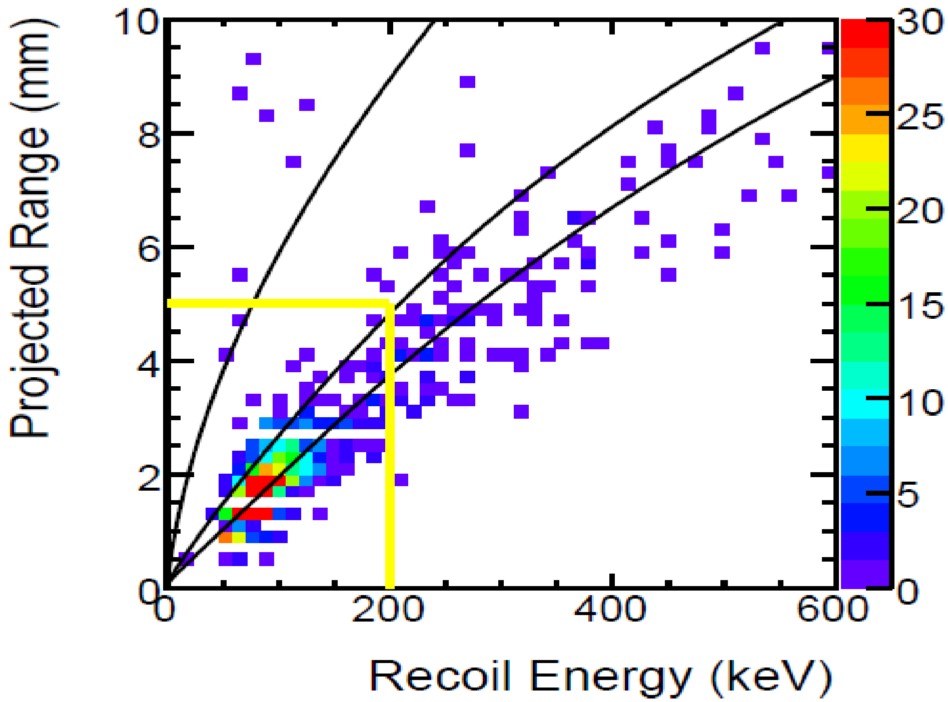


^{252}Cf Neutron Data

- For comparison, neutron data is shown below with the data cleaning cuts
- Population appears to be consistent with SRIM predictions
- Also shown are the cuts on range versus energy which were determined from WIMP Monte Carlo
- These cuts keep the region of low energy nuclear recoils but eliminate contained alpha tracks







WIMP Surface Run Data

- Shown is the data after all data cleaning cuts in the low energy region of interest
- The cuts on range < 5 mm and energy < 200 keV are also shown
- With 80 background events, this gives a background rate of 94.1 μHz

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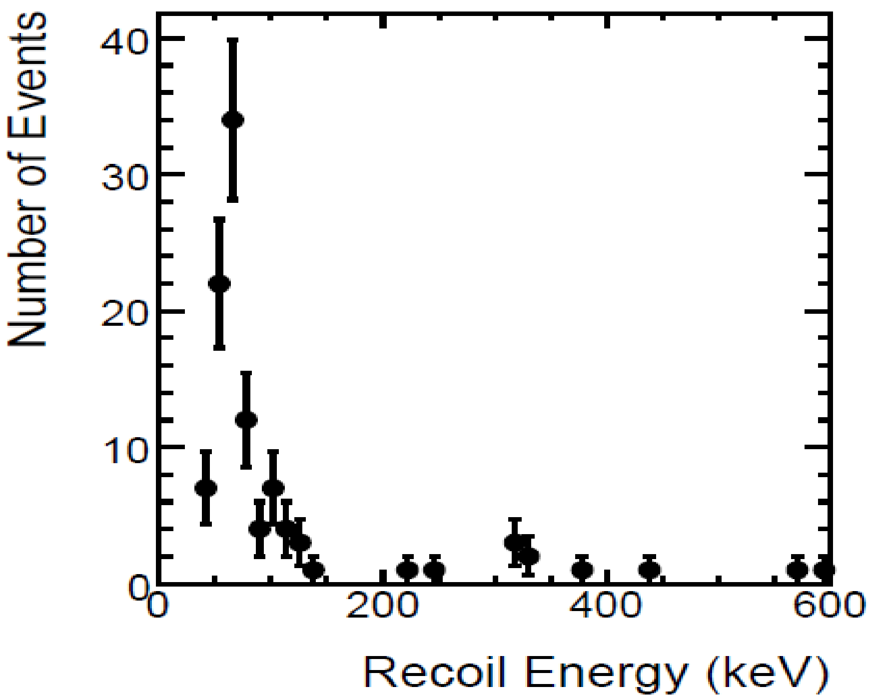
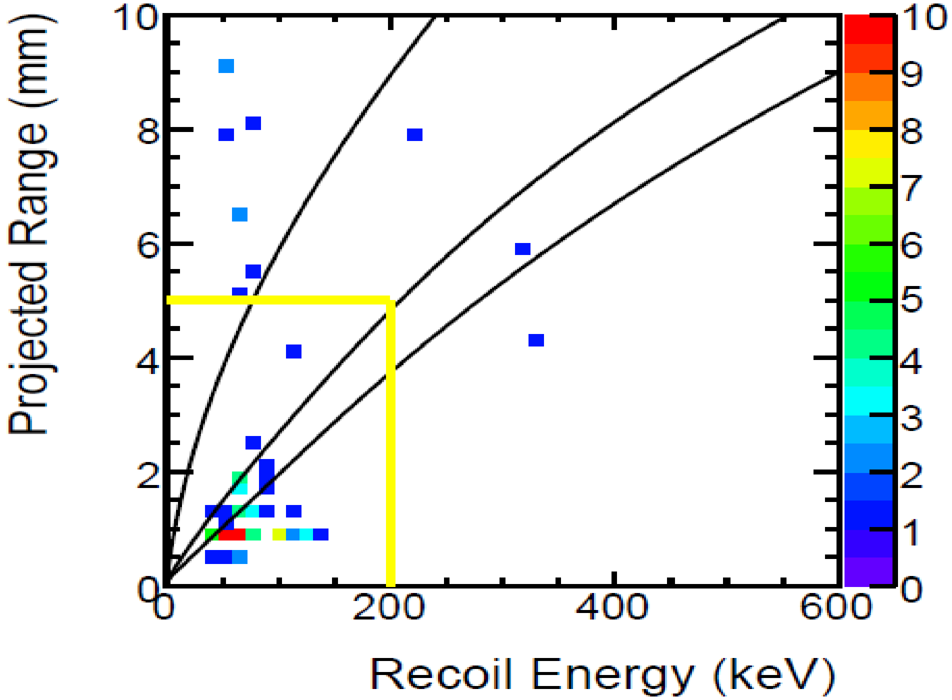




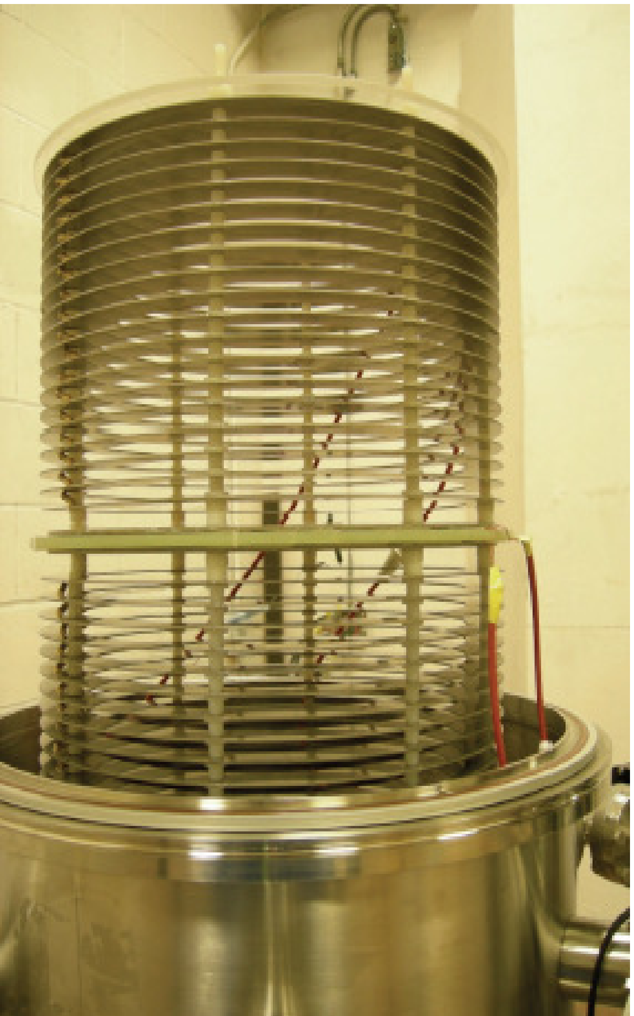
Conclusions

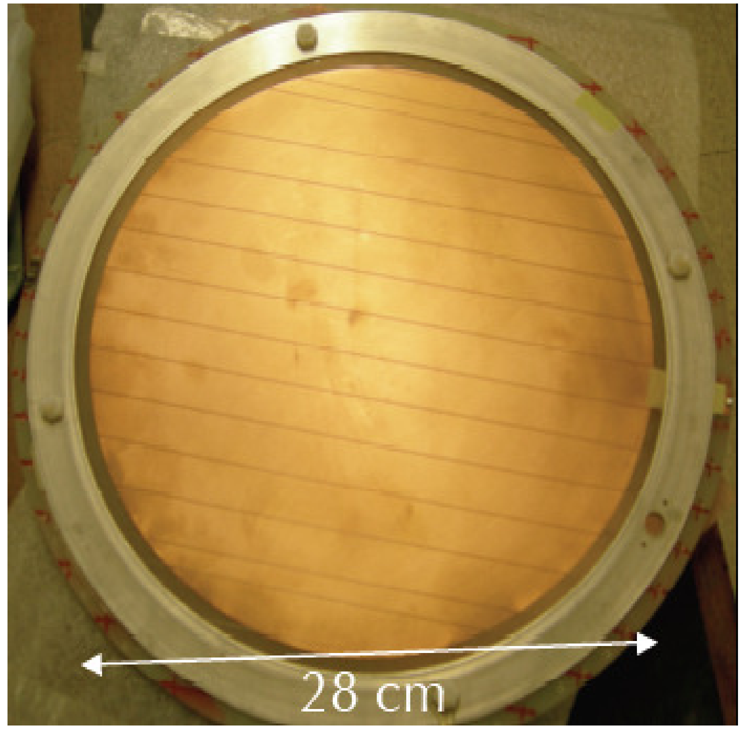
- 3 week surface run achieved background rate of 94.1 μHz with exposure of 44.2 g-days
- Use neutron data to define cuts, and we see events at ~50 keV with at least 50% efficiency at 100 keV
- Remaining events appear to be consistent with neutron induced nuclear recoils
- Also identified a somewhat unexpectedly large worm background

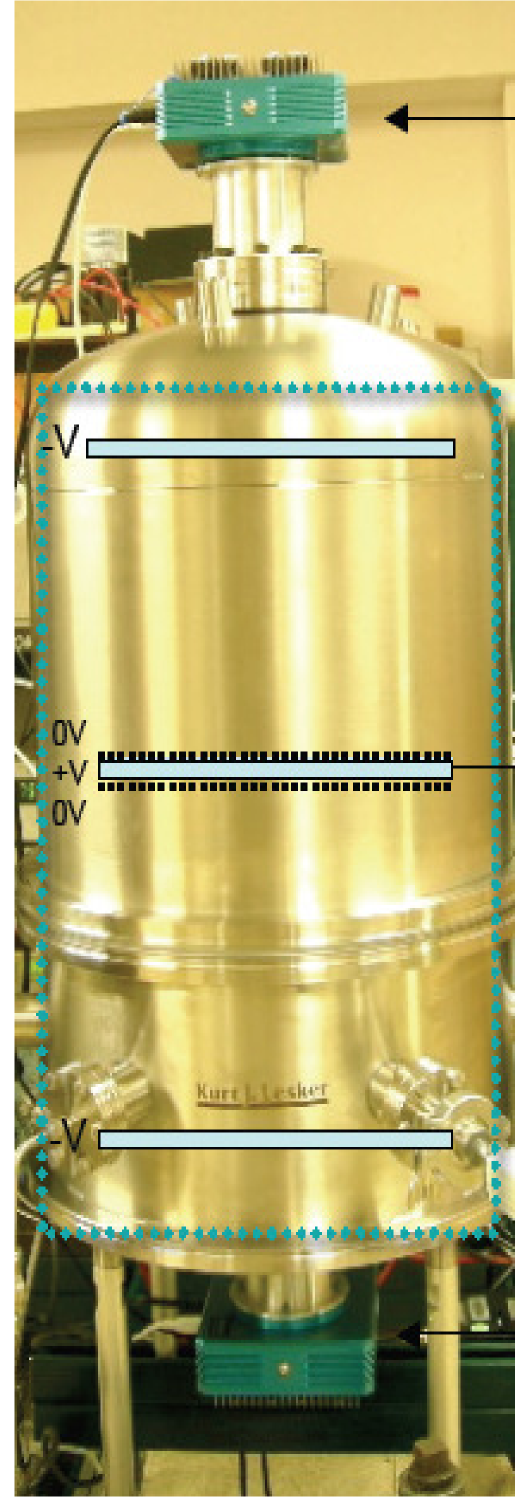
Future Improvements

- Future detector made of radiopure materials in clean environment
- Underground detector reduces cosmic ray neutron flux and other worm events
- Improved angle reconstruction to allow discrimination based on WIMP distribution

DMTPC Detector Prototype







WIMP Surface Run Data (1)

- < 55000 pixels above threshold

Cut	Remaining Events	Efficiency of Cut
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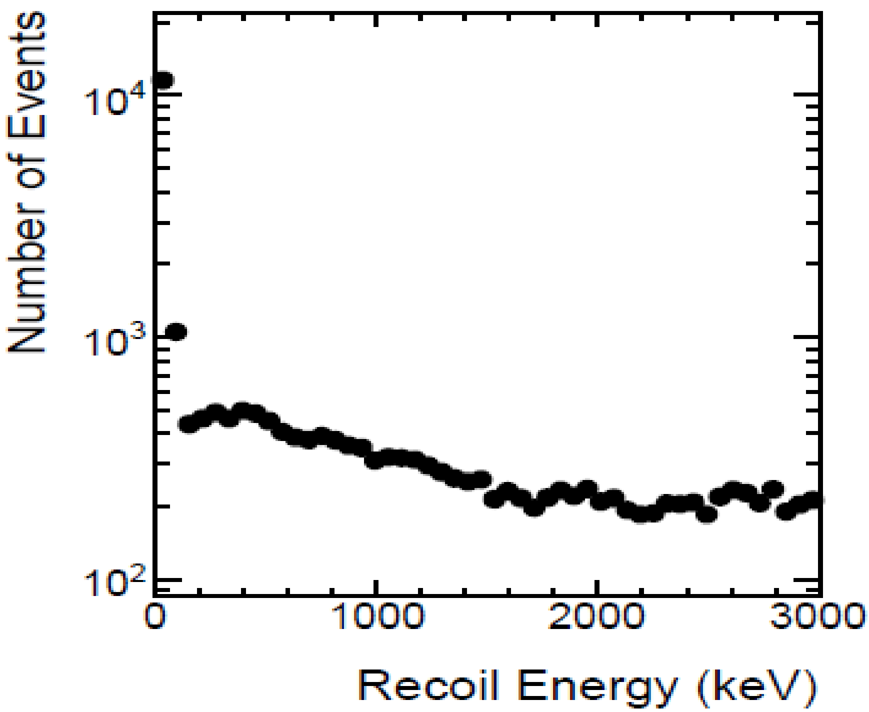

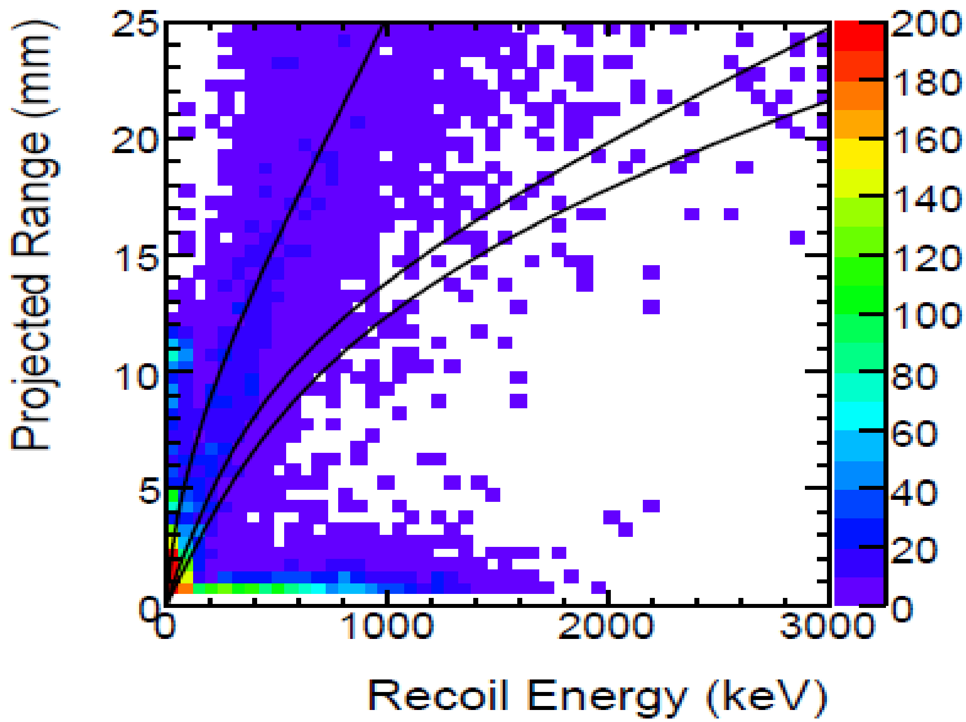

WIMP Surface Run Data (2)

- < 55000 pixels above threshold
- Only 1 track in image

Cut	Remaining Events	Efficiency of Cut
No Cuts	329446	1.000
Spark	308295	0.936
Tracks	32071	0.097
Edge	14139	0.043
Worm	150	0.005
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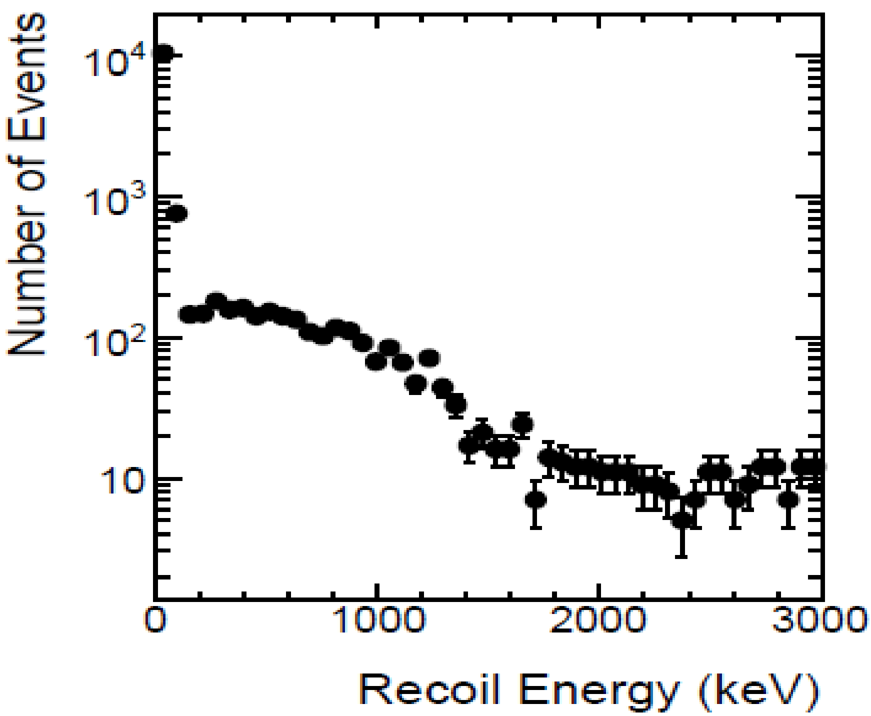

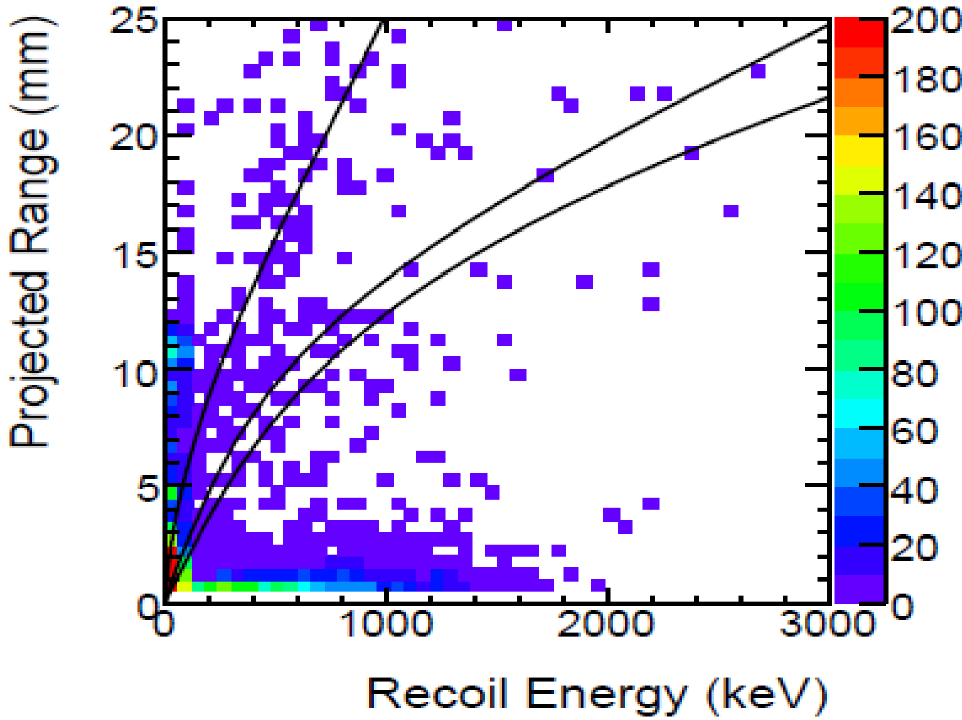

WIMP Surface Run Data (3)

- < 55000 pixels above threshold
- Only 1 track in image
- No pixel in track < 40 pixels from edge

Cut	Remaining Events	Efficiency of Cut
No Cuts	329446	1.000
Spark	308295	0.936
Tracks	32071	0.097
Edge	14139	0.043
Worm	150	0.005
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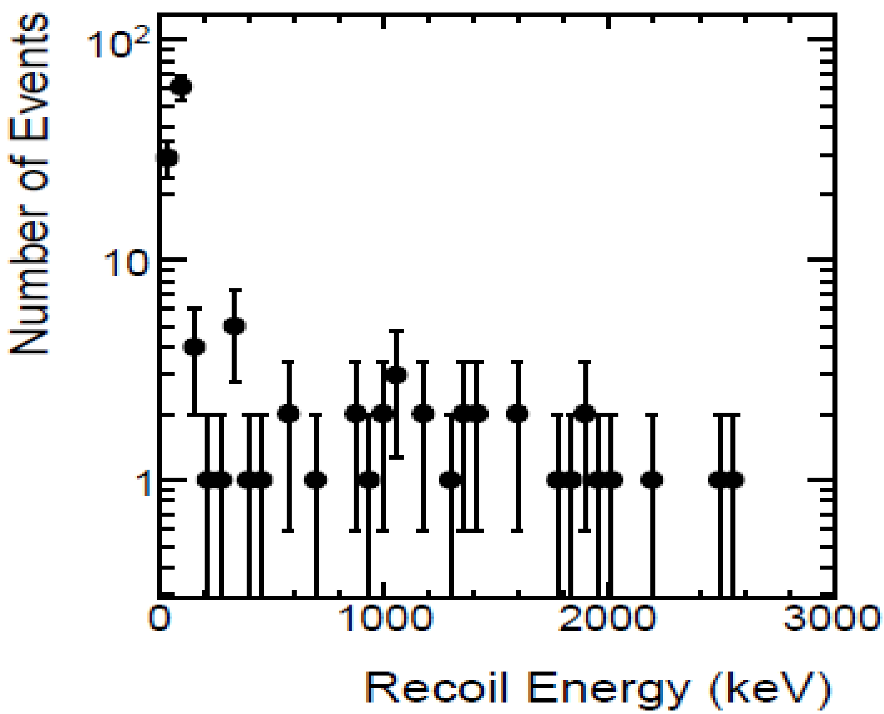

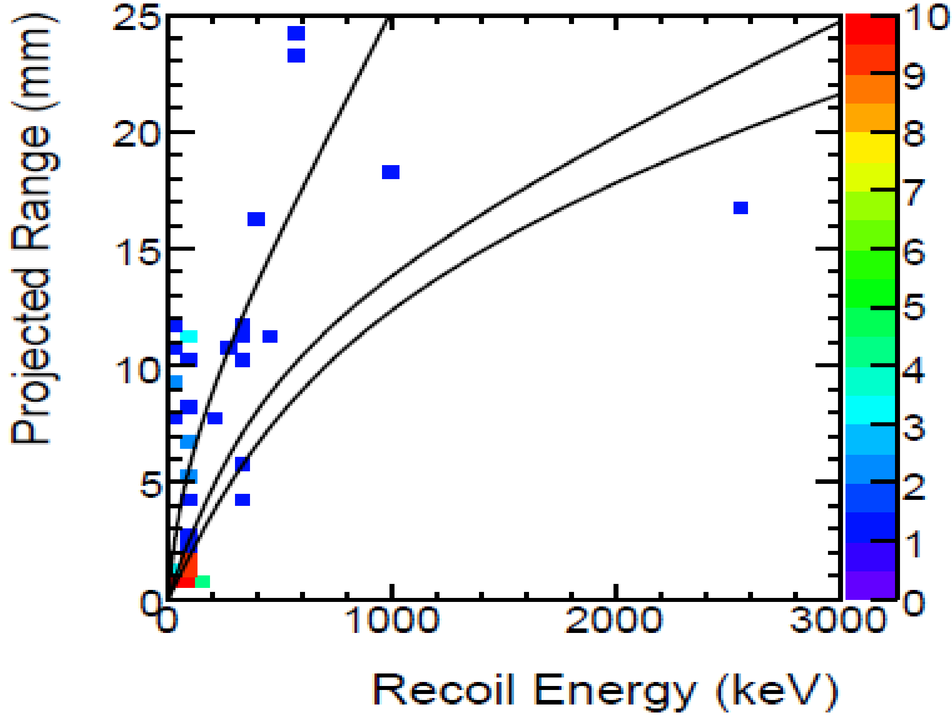

WIMP Surface Run Data (4)

- < 55000 pixels above threshold
- Only 1 track in image
- No pixel in track < 40 pixels from edge
- Max. bin in cluster has at least 2 neighboring pixels above threshold
- 80 < max. pixel value < 200 counts
- RMS of pixel in cluster < 100 counts

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Tracks	32071	0.097
Edge	14139	0.043
Worm	150	0.005
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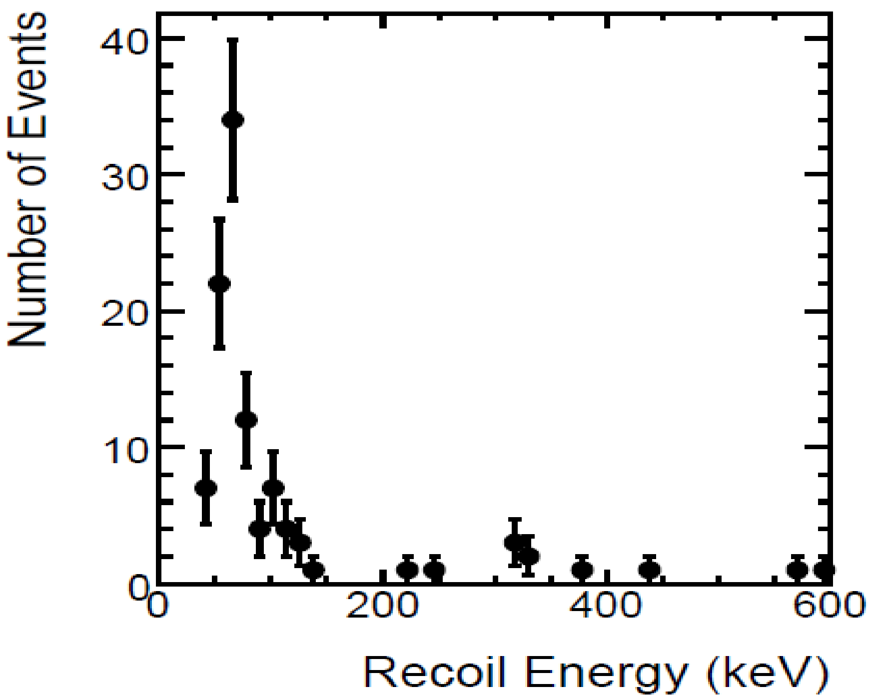

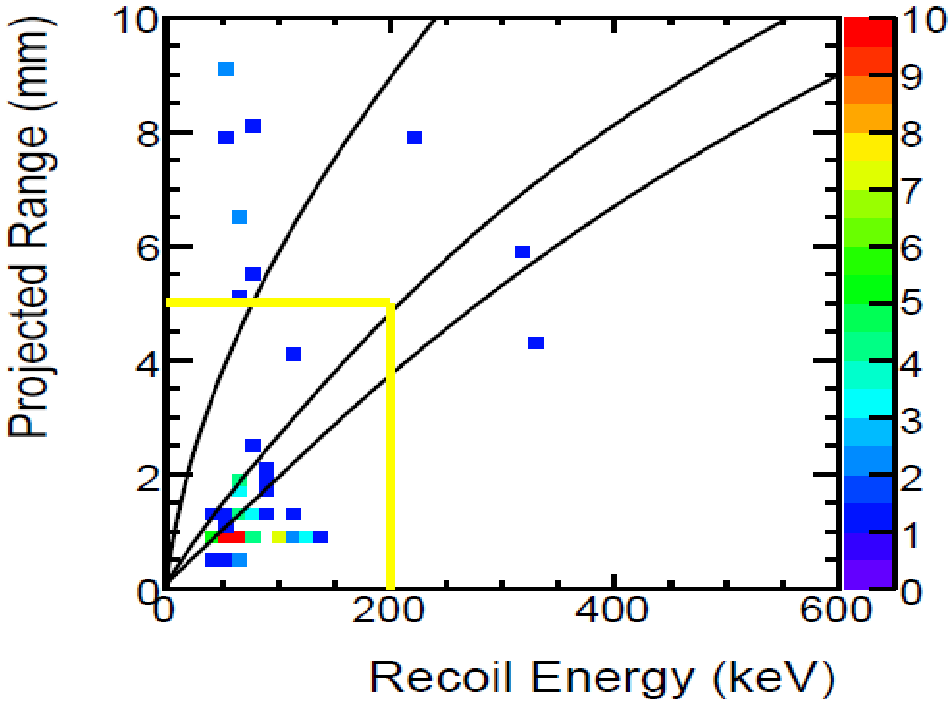

WIMP Surface Run Data (5)

- < 55000 pixels above threshold
- Only 1 track in image
- No pixel in track < 40 pixels from edge
- Max. bin in cluster has at least 2 neighboring pixels above threshold
- 80 < max. pixel value < 200 counts
- RMS of pixel in cluster < 100 counts
- Projected range < 5 mm
- Reconstructed recoil energy < 200 keV

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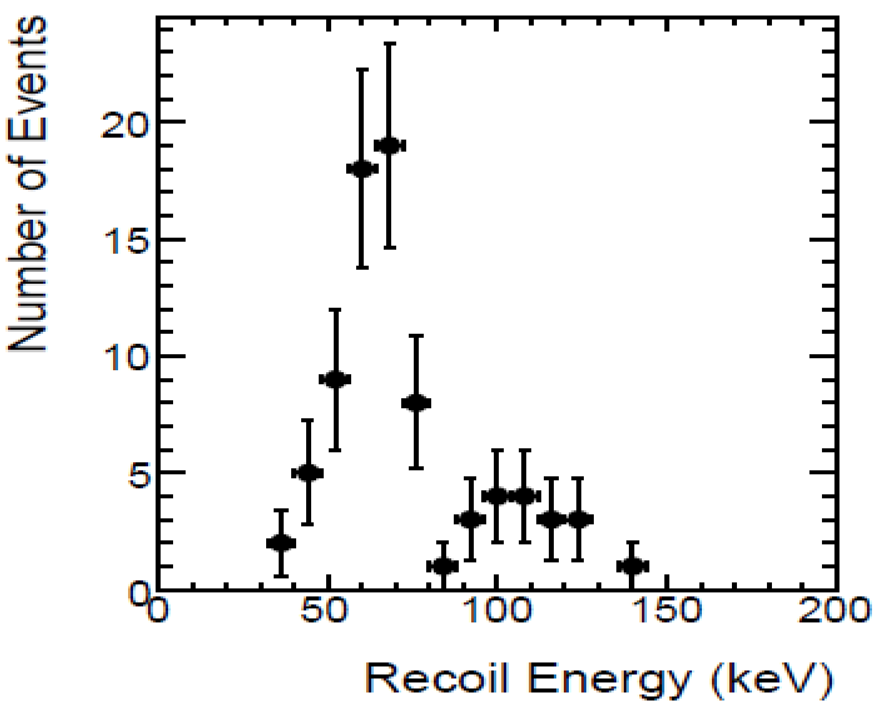
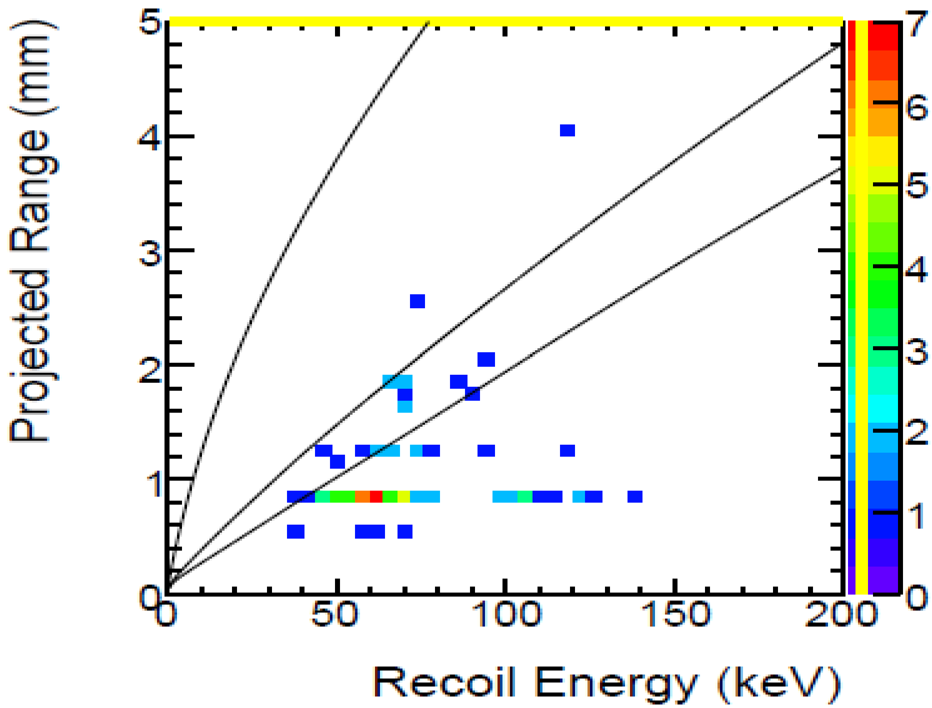
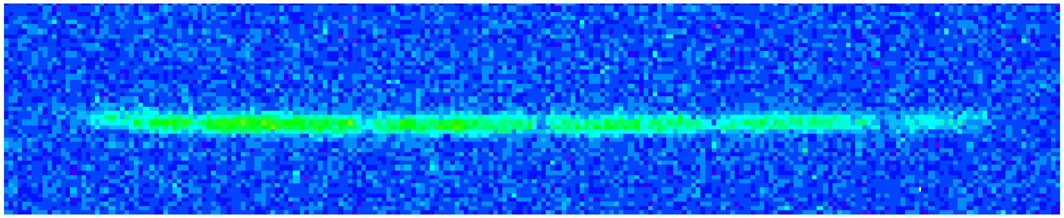
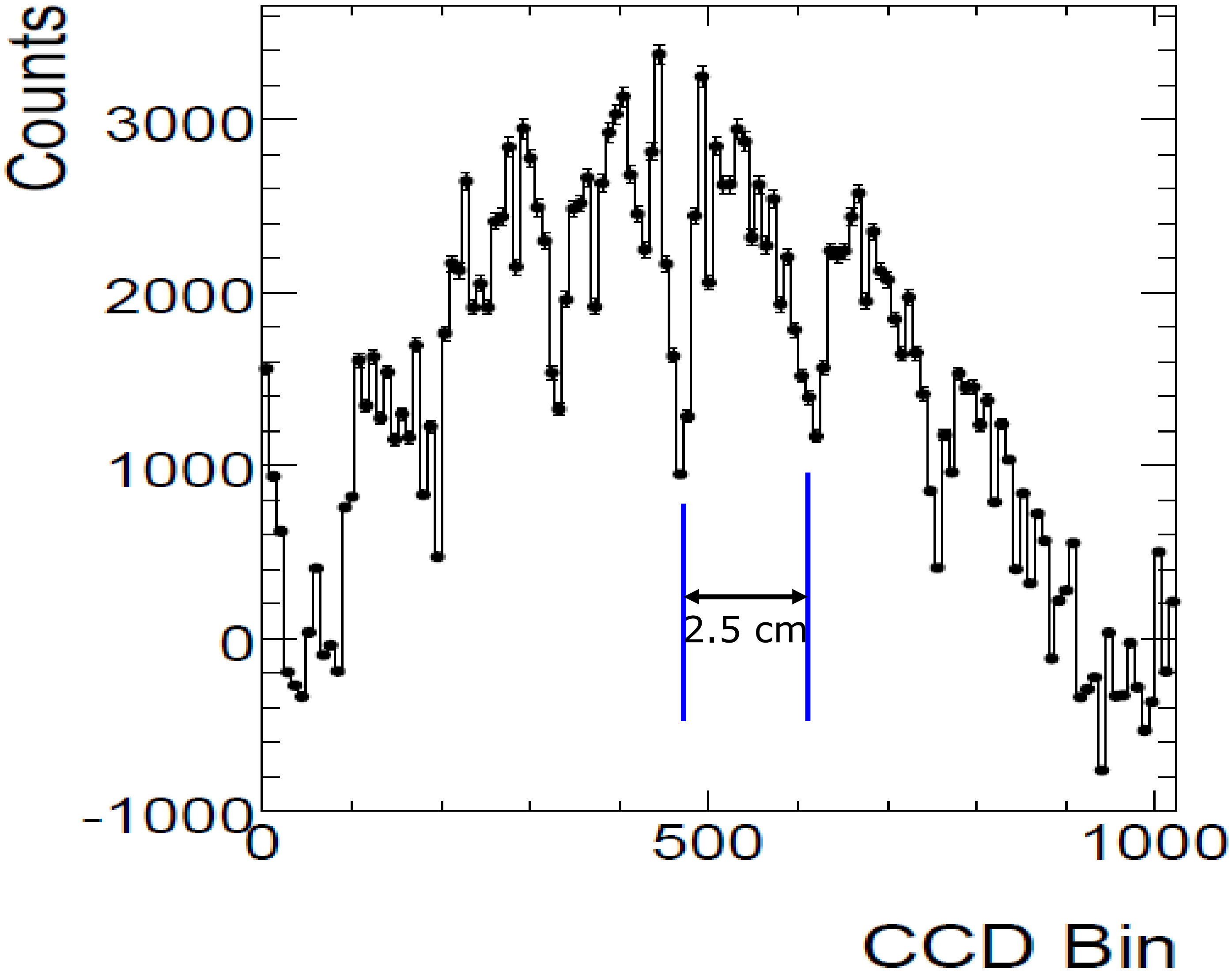




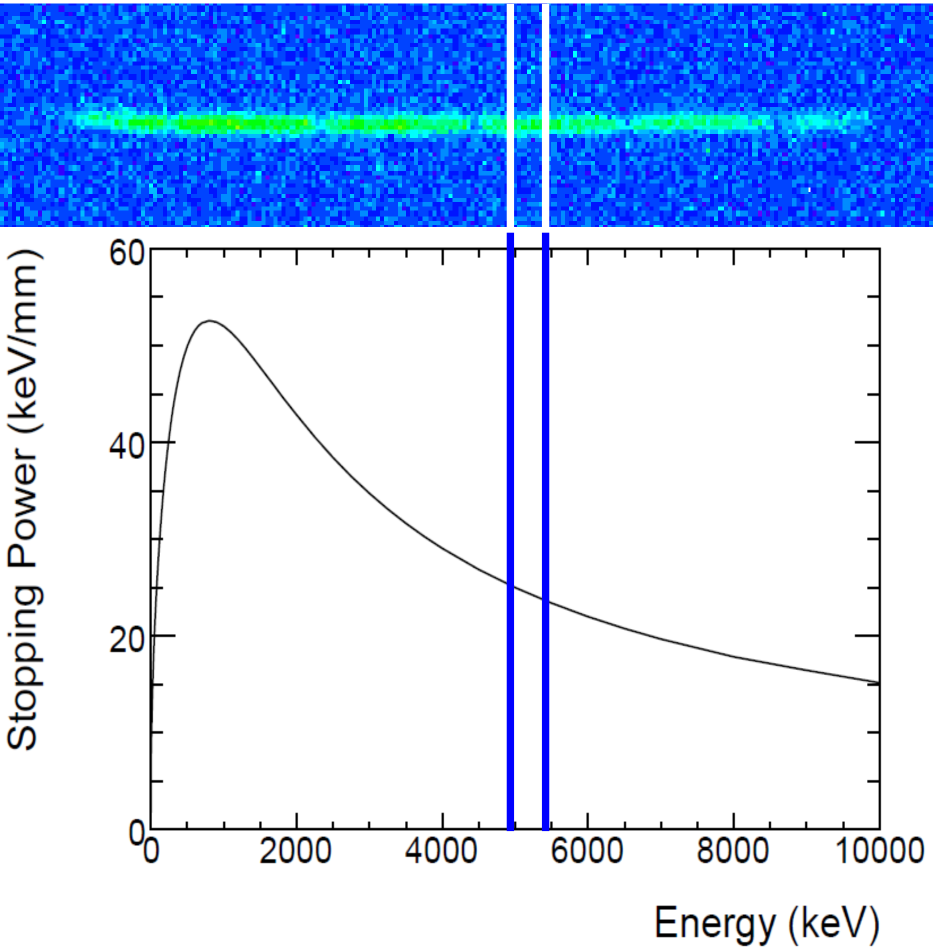
Length Calibration



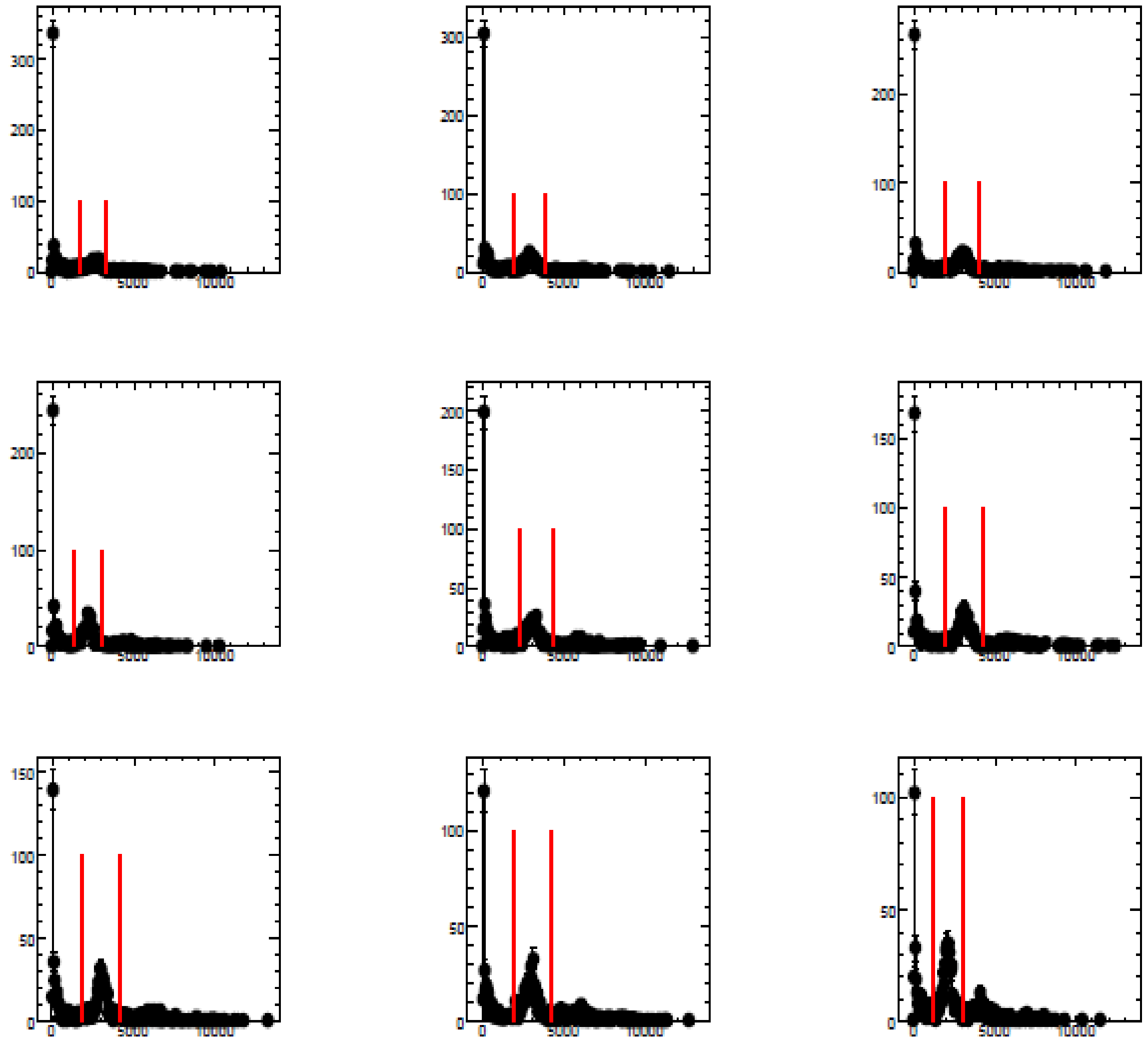


- Project many straight tracks onto axis perpendicular to spacers
- Observe minima caused by spacers which are separated by 2.5+/0.1 cm
- Average over locations of the minima

Energy Calibration



- Take 9 ten bin segments of track (avoiding spacer gaps)
- Select only straight tracks and integrate track segment
- Divide mean of segment integral by corresponding SRIM prediction



Integral of Counts in Segment (adu)