Identifying “fat” cosmic ray tracks in CCDs

Theodore Grosson, Andrei Nomerotski
Physics Department, Brookhaven National Laboratory

Abstract

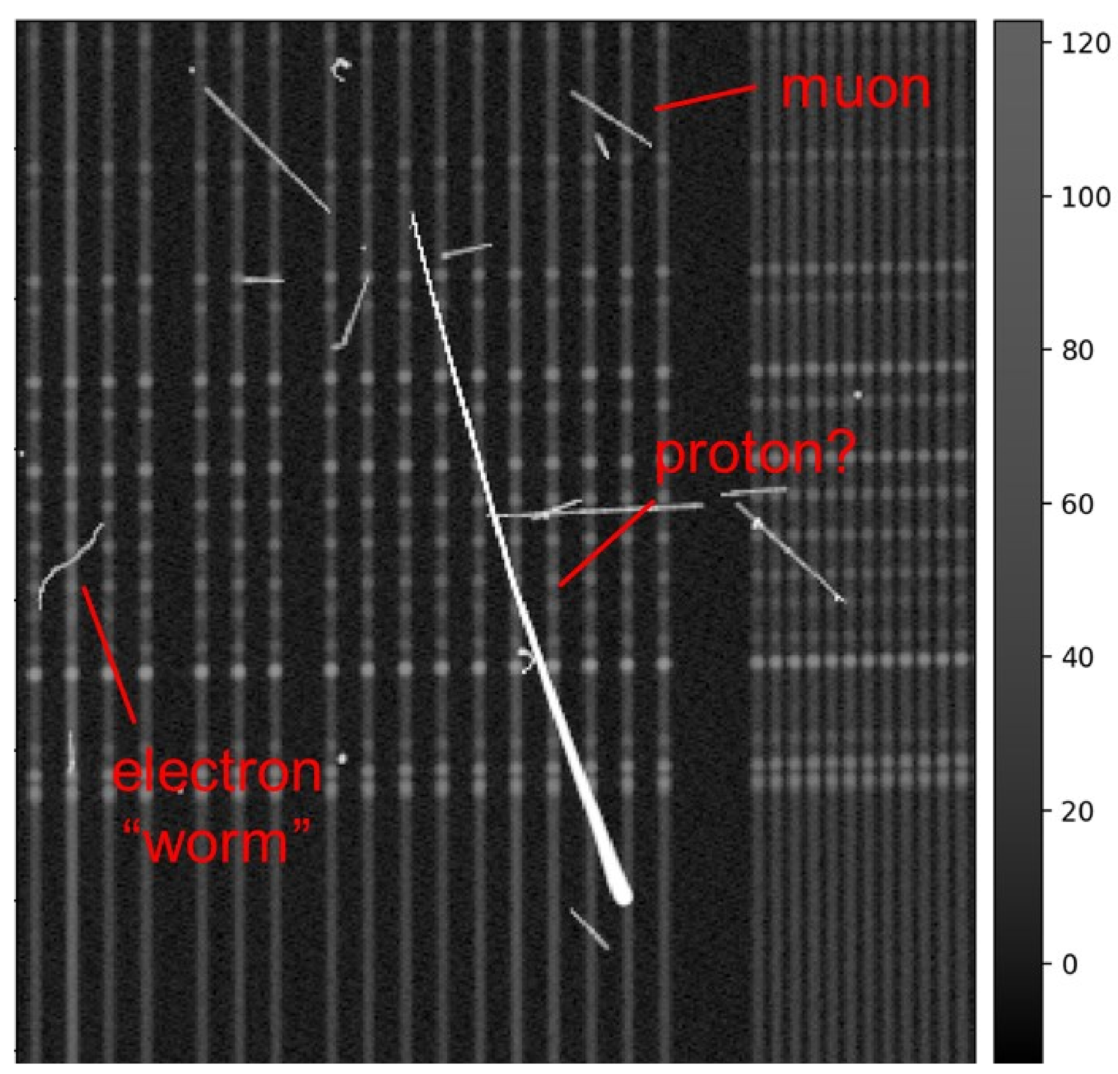
Cosmic rays are particles from the upper atmosphere which often leave bright spots and trails in images from telescope CCDs. We investigate so-called “fat” cosmic rays seen in images from the Subaru Telescope and Rubin Observatory. These tracks are both much brighter and much wider than typical cosmic ray tracks, and therefore are more capable of obscuring data in science images. It is important that we understand the cause of these tracks, so that we can remove them from our images. We propose that the origin of these tracks is cosmic ray protons, which deposit much greater charge in the CCDs than typical cosmic rays due to their lower velocities. The generated charges then repel each other, resulting in a track which is much wider than typical tracks.

Introduction

Cosmic rays (mostly muons from the upper atmosphere) are a pain for astronomers.

Typical muon tracks are removable, but what are “fat” tracks?

We ultimately want to make sure they are removable from images so they do not obscure data.

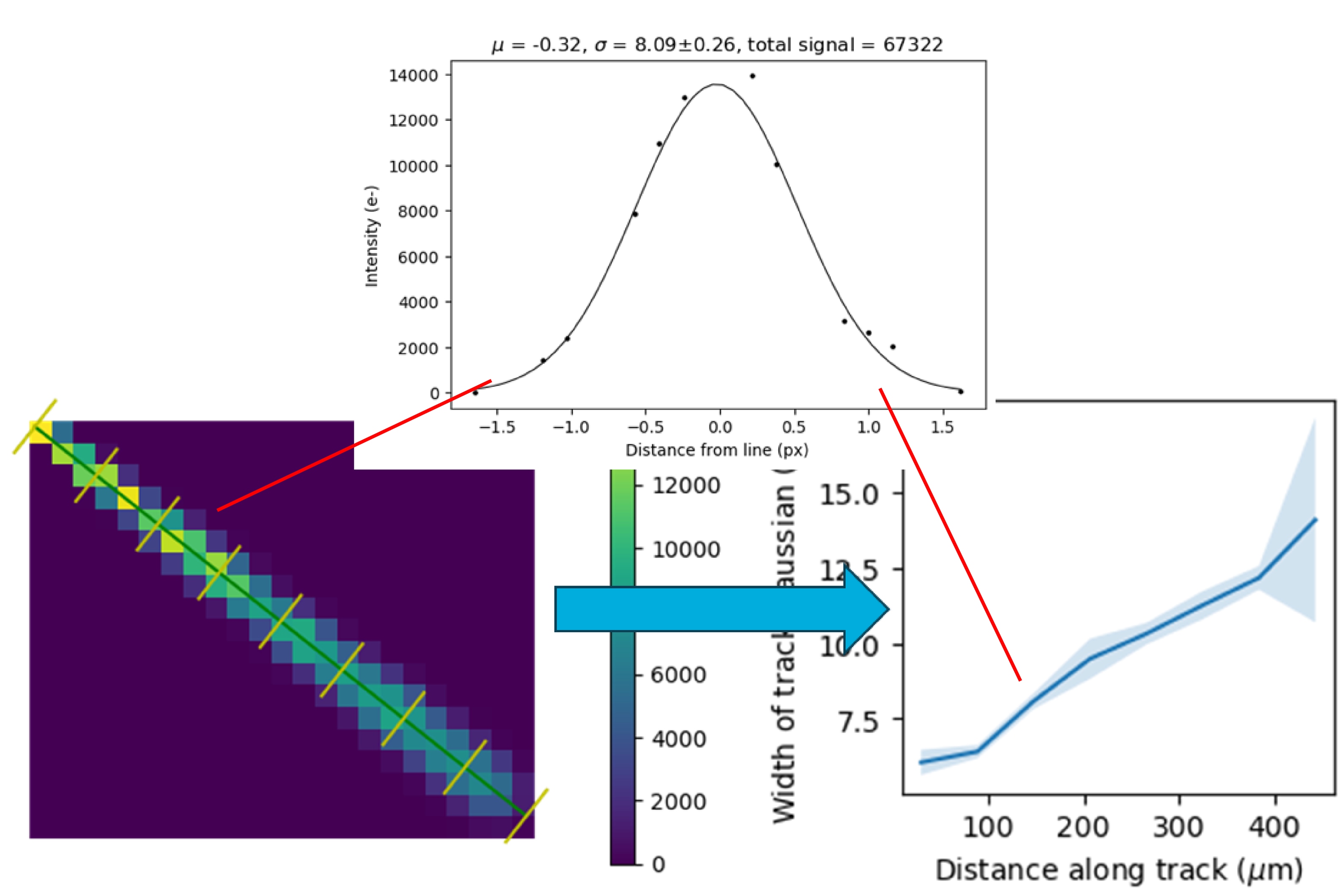


1200s dark exposure from Subaru Telescope featuring cosmic rays, including “fat” track in center. Image from Robert Lupton.

Methods

Measuring track properties:

1. Remove nonlinear tracks ($R^2 < 0.95$)
2. Fit line to track, measure dE/dx = sum of pixel values / track length
   - Tracks with dE/dx > 200 e-/μm are classified as “fat”
3. Divide track into segments, fit Gaussian to pixels in each segment
4. Gaussian widths describe how the track changes over its length

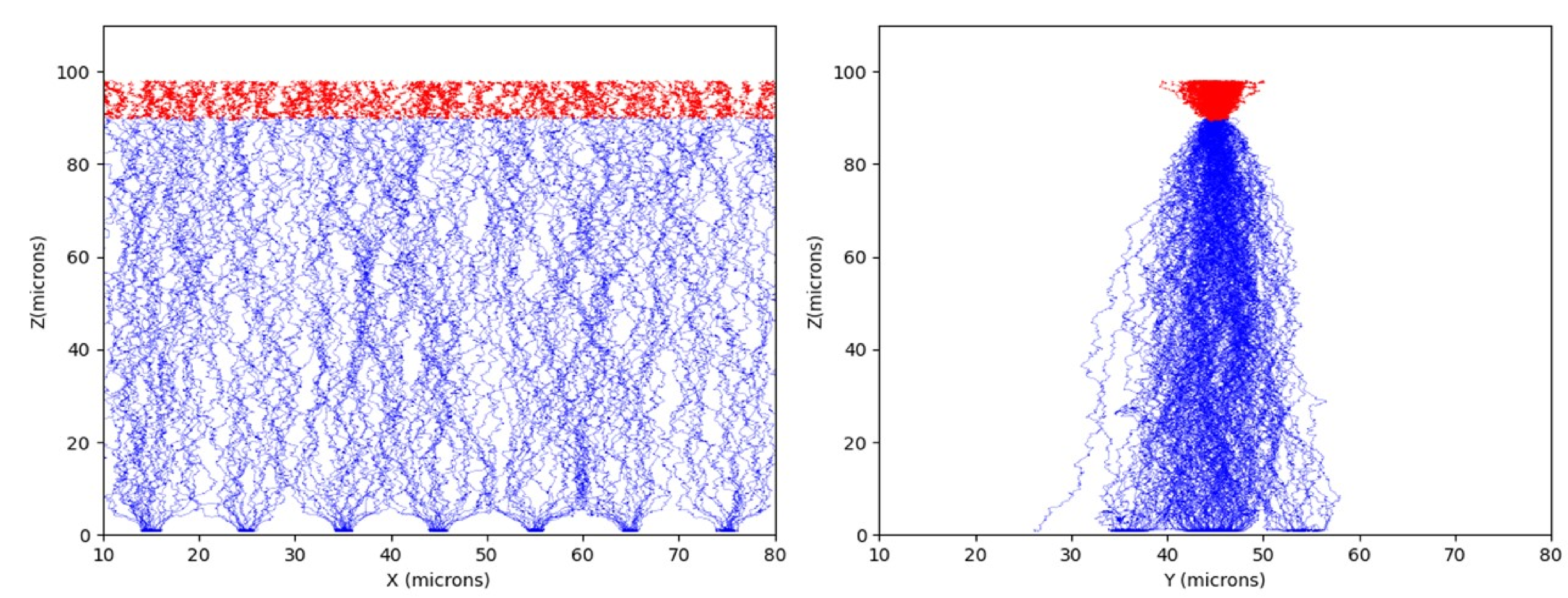


Process of fitting a line to a track and dividing into segments, measuring Gaussians in each segment, and characterizing width vs position for a track.

Methods, Cont’d

Compare measured tracks with simulations:

- Simulate paths of electrons in CCD caused by cosmic ray hit
- Simulate cosmic ray with varying dE/dx and height
- Expect greater dE/dx should result in wider tracks due to repulsion between electrons



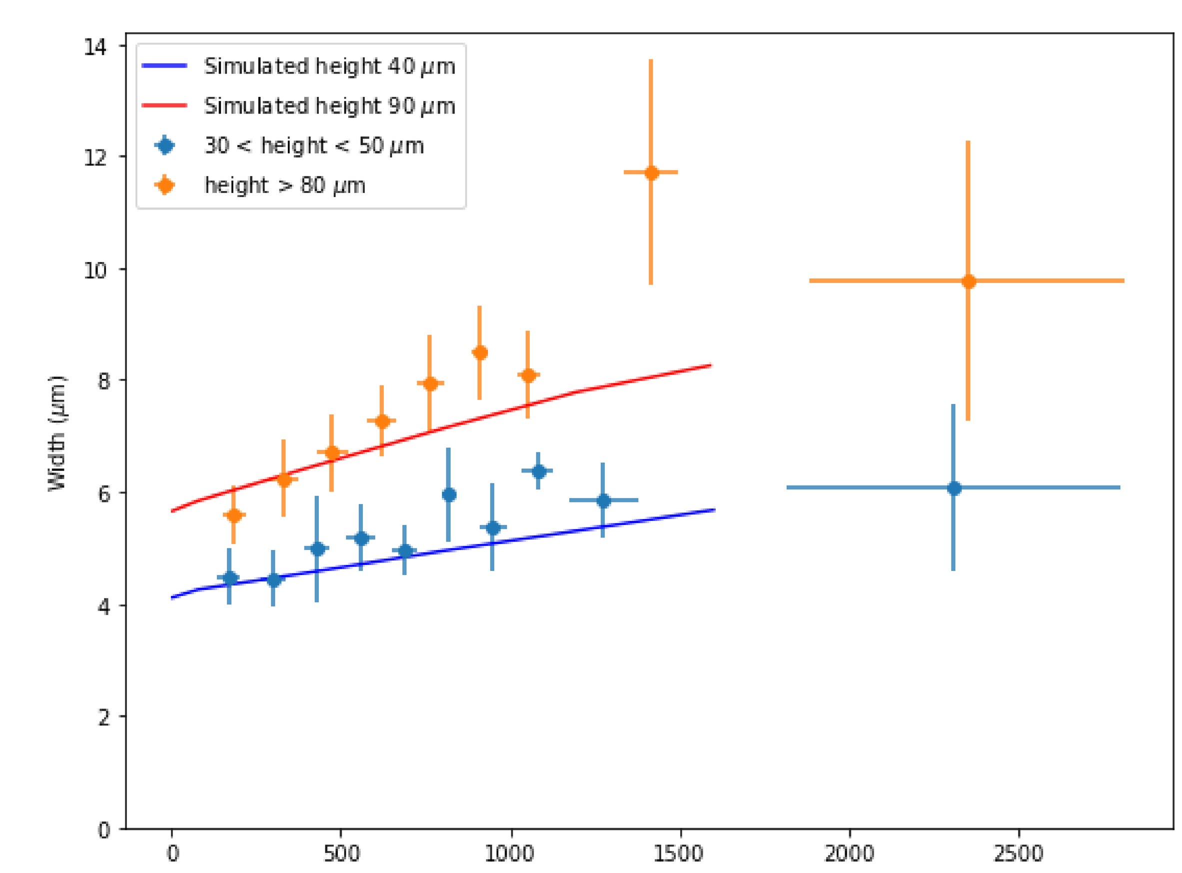
Simulated paths of electrons (blue) and holes (red) in a CCD generated by an 80 e-/μm cosmic ray.

Results

Broadening Mechanism:

Simulations do show increasing width with dE/dx.

Observations match simulations fairly well (red. χ^2=1.44).



Width vs brightness for fat tracks (binned by dE/dx) and simulated tracks at different heights.

Incident Particles:

Particle Data Group gives estimates of relative muon and proton abundances at different altitudes.

Compare these estimates to observed fat track abundances:

Camera / Location	PFS / Mauna Kea	ComCam / Cerro Pachon	LSSTCam / SLAC
Altitude	4.14 km	2.66 km	0.1 km
Ratio fat tracks/ total tracks	0.47%	0.18%	0.05%
Expected ratio	~10x sea level	~5x sea level	(sea level)

Matches expectations, but could use more detailed study.

Conclusions

Results suggest protons and electrostatic repulsion are primarily responsible for the appearance of fat tracks.

Delta-ray electrons were also considered as a broadening mechanism, but were found to be incapable of producing the observed tracks.

It would be worthwhile to investigate other mechanisms in future studies in order to fully understand cosmic ray appearances.

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