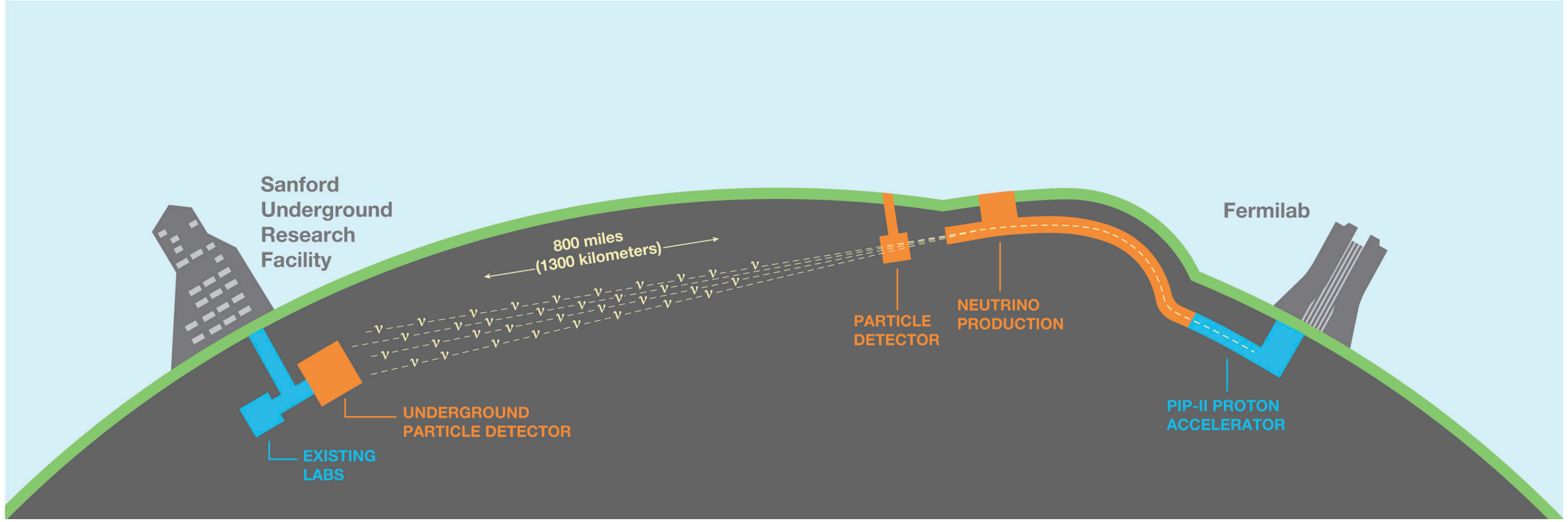
Particle Identification in DUNE Using Multiple Coulomb Scattering

By Harry Mayrhofer

The Neutrino & DUNE

- The Neutrino - incredibly small, chargeless particles that interact very weakly with matter
- Really hard to detect, but they have the potential to lead to new physics
- DUNE – Deep Underground Neutrino Experiment
- LArTPC – Liquid Argon Time Projection Chamber
- ProtoDUNE – DUNE's prototype



[1]

Neutrino interactions

- Fire a lot of neutrinos into a lot of liquid argon
- Particles created ionize electrons

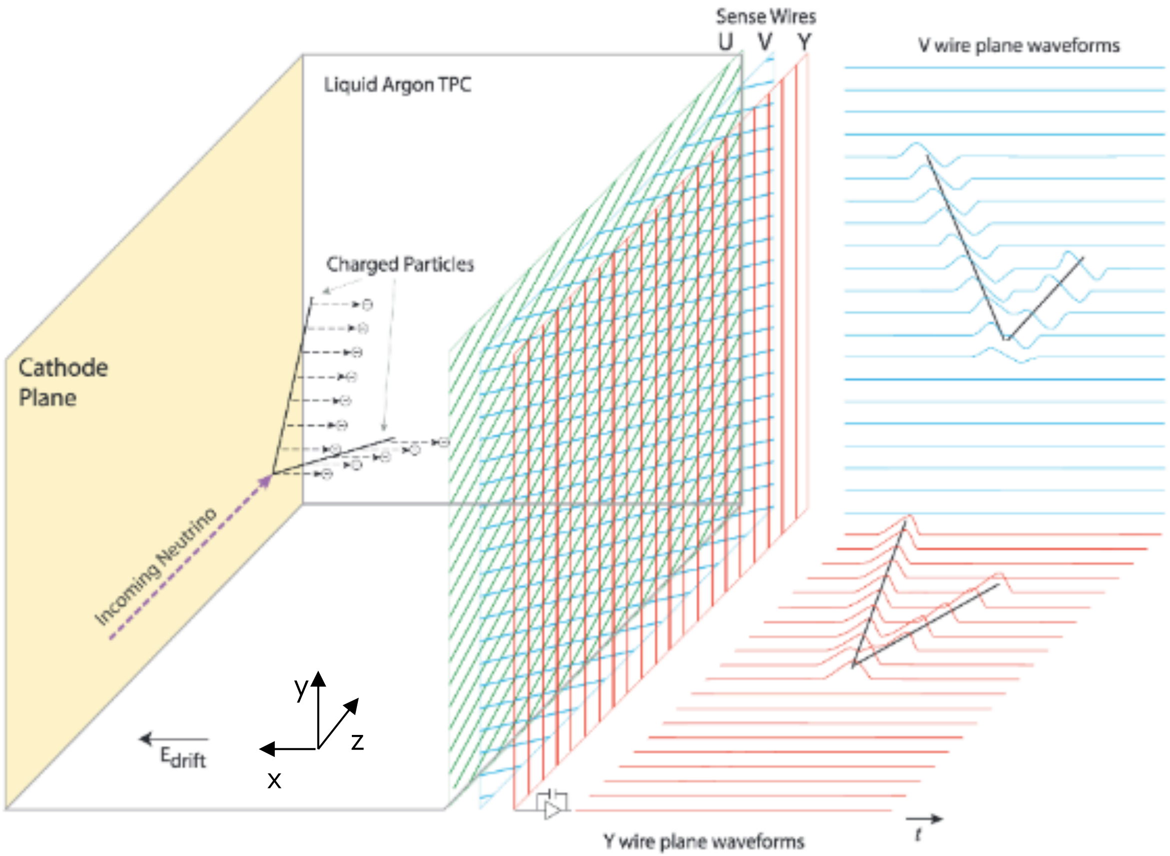
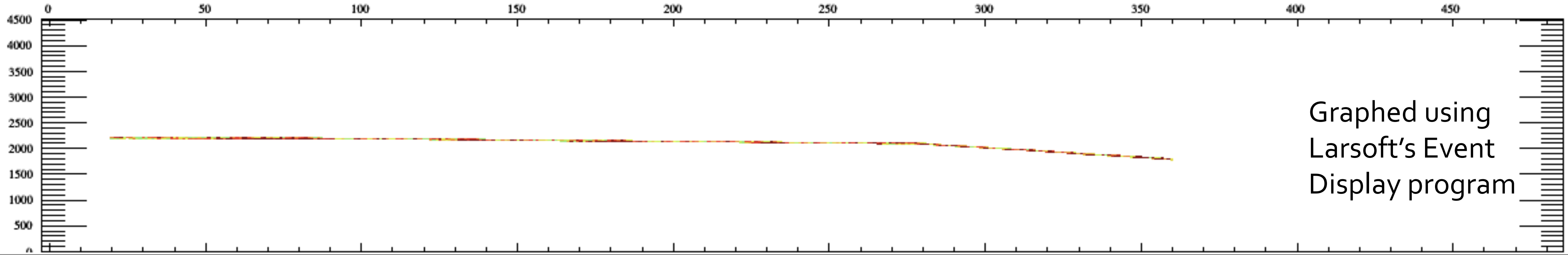


Fig 1 in [3], coordinate axis added

Wire number (z axis)

Drift Time (x axis)



Graphed using Larsoft's Event Display program

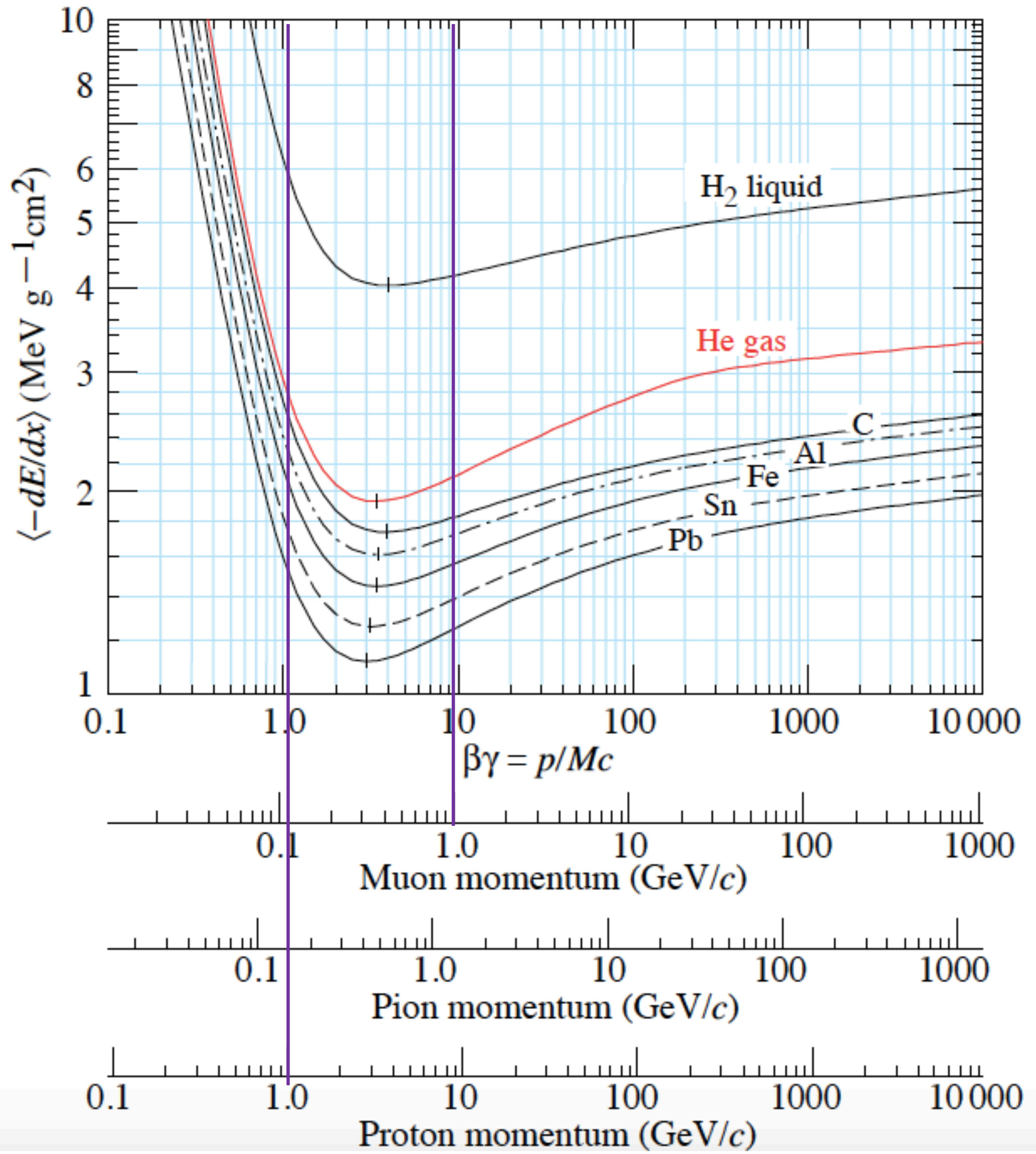
Particle Identification (PID)

- What particles come flying off, and what are their energies and momenta?
- Primary Candidate particles:
  - Proton
  - Muon
  - Pion (π^+)

Have similar rest mass, but behave differently as they pass through matter

PID Methods

- As a particle travels through Argon, it collides with electrons, losing energy at a mean rate $\left\langle \frac{dE}{dx} \right\rangle$ as described by Hans Bethe
- In general, muons will lose energy more slowly and make longer tracks than protons
- However, a muon and a proton can make similar length tracks if the proton has a much larger momentum than the muon



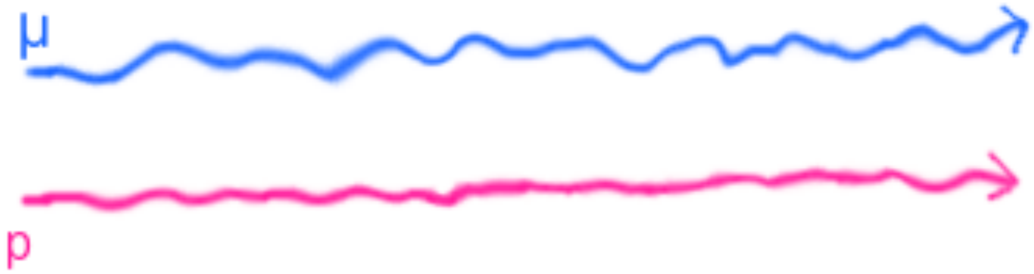
From [2], fig 33.2

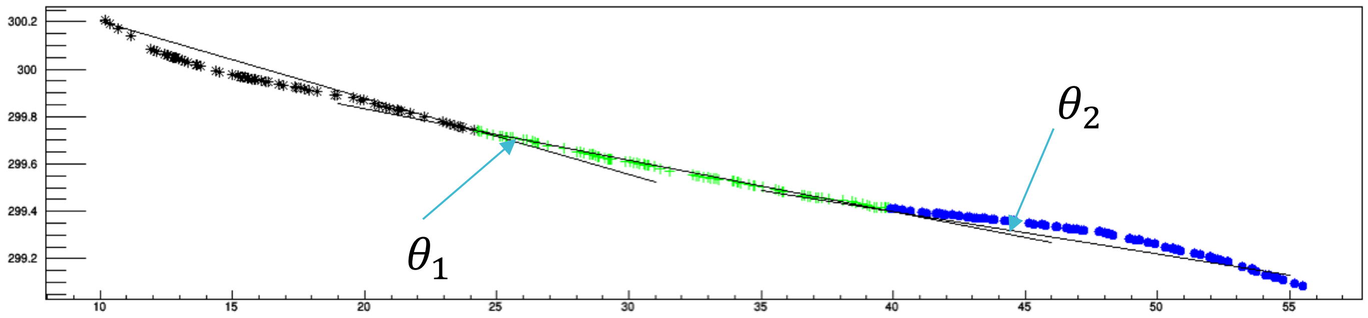
Multiple Coulomb Scattering (MCS)

- An incident particle interacting with argon nuclei by Coulombic forces replicates nearly elastic collisions that cause the particle to change direction
- A stochastic process around a Gaussian distribution, where

$$\theta_{RMS} \sim \frac{1}{\beta p} = \frac{\sqrt{m^2+p^2}}{p^2} \text{ [3]}$$

- In order for a proton and a muon to create similar track lengths, the proton would need to have a higher momentum than a muon





Applying Theory of MCS

- Based on an algorithm designed by the MicroBooNE collaboration [3]
- On some given track with some pattern of scattering angles, calculate the likelihood L that a particle scatters through those angles for a range of starting momenta. Return the highest likelihood & its associated momentum.
- The algorithm requires a hypothesis about the mass of the particle that made the fitted track
- Let $\mathscr{L}$ be the negative log-likelihood of an outcome; that is,

$$\mathscr{L} = -\ln(L),$$

where L is the likelihood of an outcome.

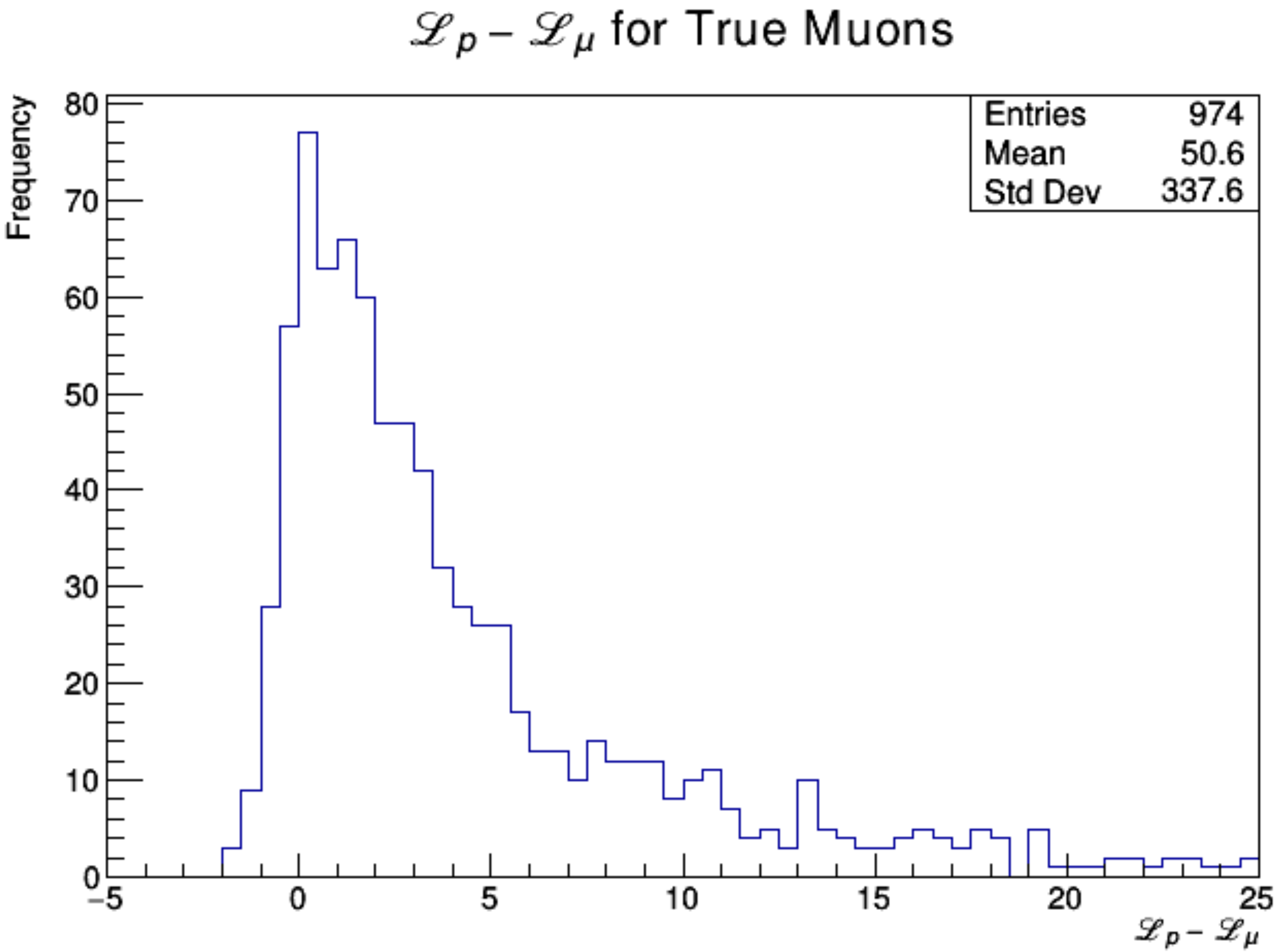
Minimizing $\mathscr{L}$ is equivalent to maximizing L

Results

From a simulation of 1000 muon events (p = 0.3 GeV/c) sent at a direction where $\theta = \varphi = 0$ and run in DUNE's geometry.

Position information was collected from recob Track data using the Pandora module.

The data at the right represents all events that produced tracks with length greater than 70 cm

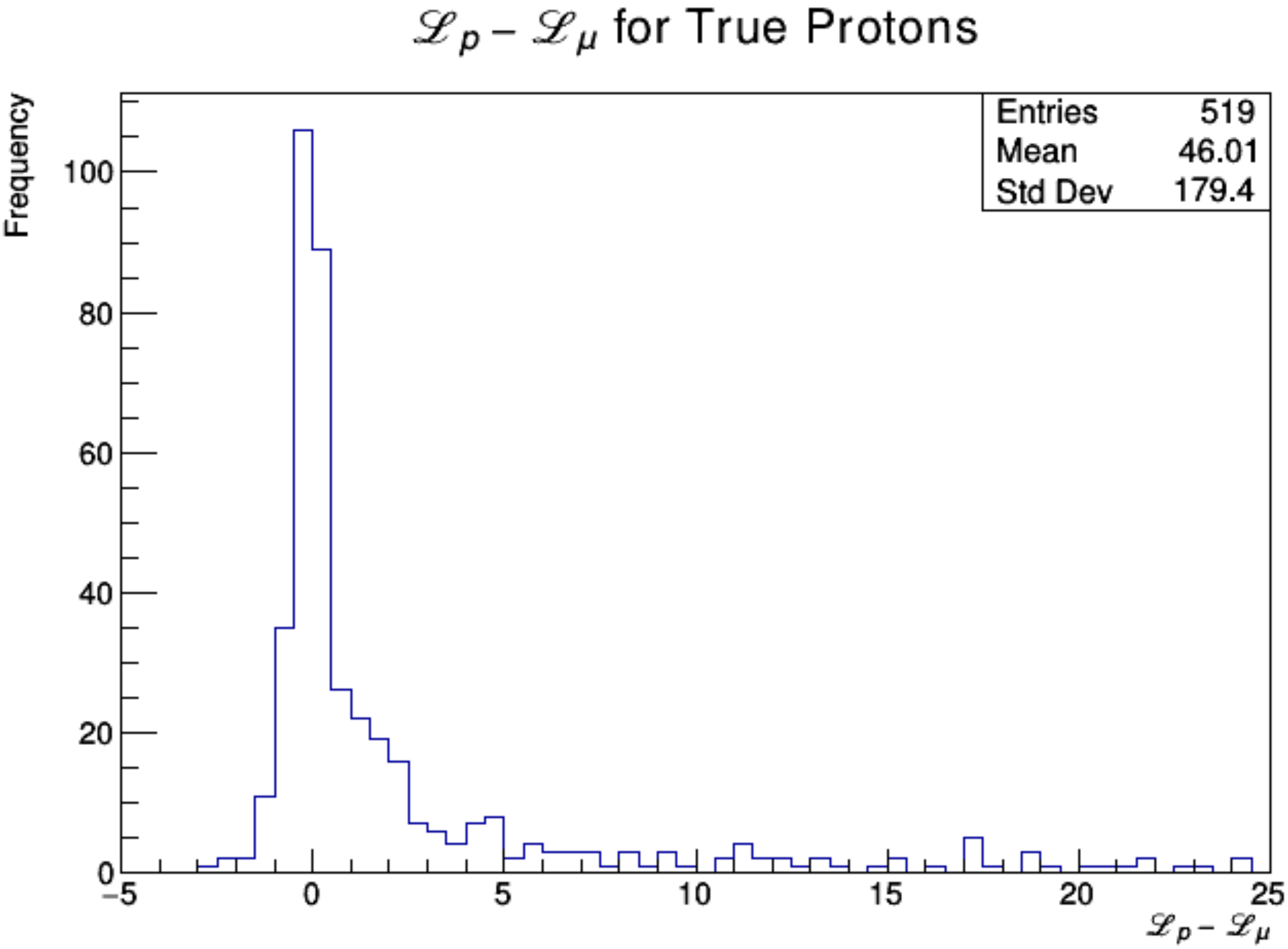


Results

From a simulation of 1000 proton events (p = 1.0 GeV/c) sent at a direction where $\theta = \varphi = 0$ and run in DUNE's geometry.

Position information was collected from recob Track data using the Pandora module.

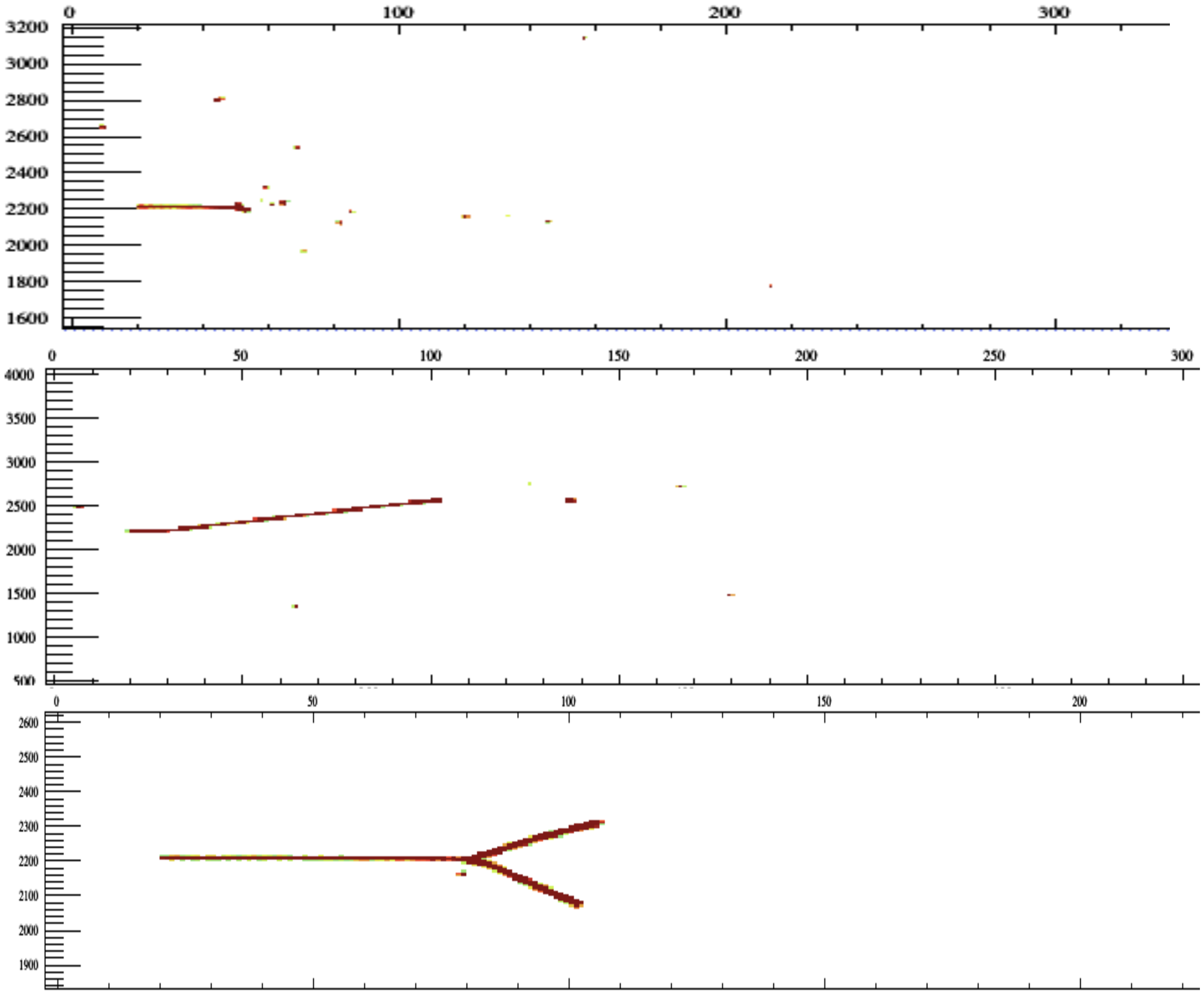
The data at the right represents all events that produced tracks with length greater than 70 cm



Proton Interactions

Protons can interact by the strong nuclear force.

If a proton undergoes an inelastic collision or a hard scatter, then it will deflect more than Multiple Coulomb Scattering predicts



Further investigation

- Figure out how to account for strong interactions in the multiple Coulomb scattering algorithm
- One potential avenue of study is figuring out when hard scatters are being observed in the detector

Acknowledgements

- Dr. Glenn Horton-Smith
- Dr. Tim Bolton
- Isabella Ginnett
- Norman Martinez
- National Science Foundation
- Kansas State University
- Fermilab & the MicroBooNE collaboration

References

[1] https://www.dunescience.org/

[2] P. Abratenko *et al* [MicroBooNE collaboration] Determination of muon momentum in the MicroBooNE LArTPC using an improved model of multiple Coulomb scattering 2017 *JINST* **12** P10010

[3] M. Tanabashiet al.[Particle Data Group] Passage of Particles Through Matter, Phys. Rev. D98, 030001 (2018)

Equations

$$\theta_{RMS} = \frac{\kappa(p)}{\beta p}\sqrt{\frac{l}{X_0}}\left(1 + \epsilon * \ln\left(\frac{l}{X_0}\right)\right),$$

$$\kappa(p) = \frac{0.105MeV}{p^2} + 11.004MeV$$

$$\epsilon = 0.038$$

$$p = m\beta\gamma = \frac{m\beta}{\sqrt{1-\beta^2}}$$

$$p^2 = \frac{(m\beta)^2}{1-\beta^2}$$

$$p^2(1-\beta^2) = m^2\beta^2$$

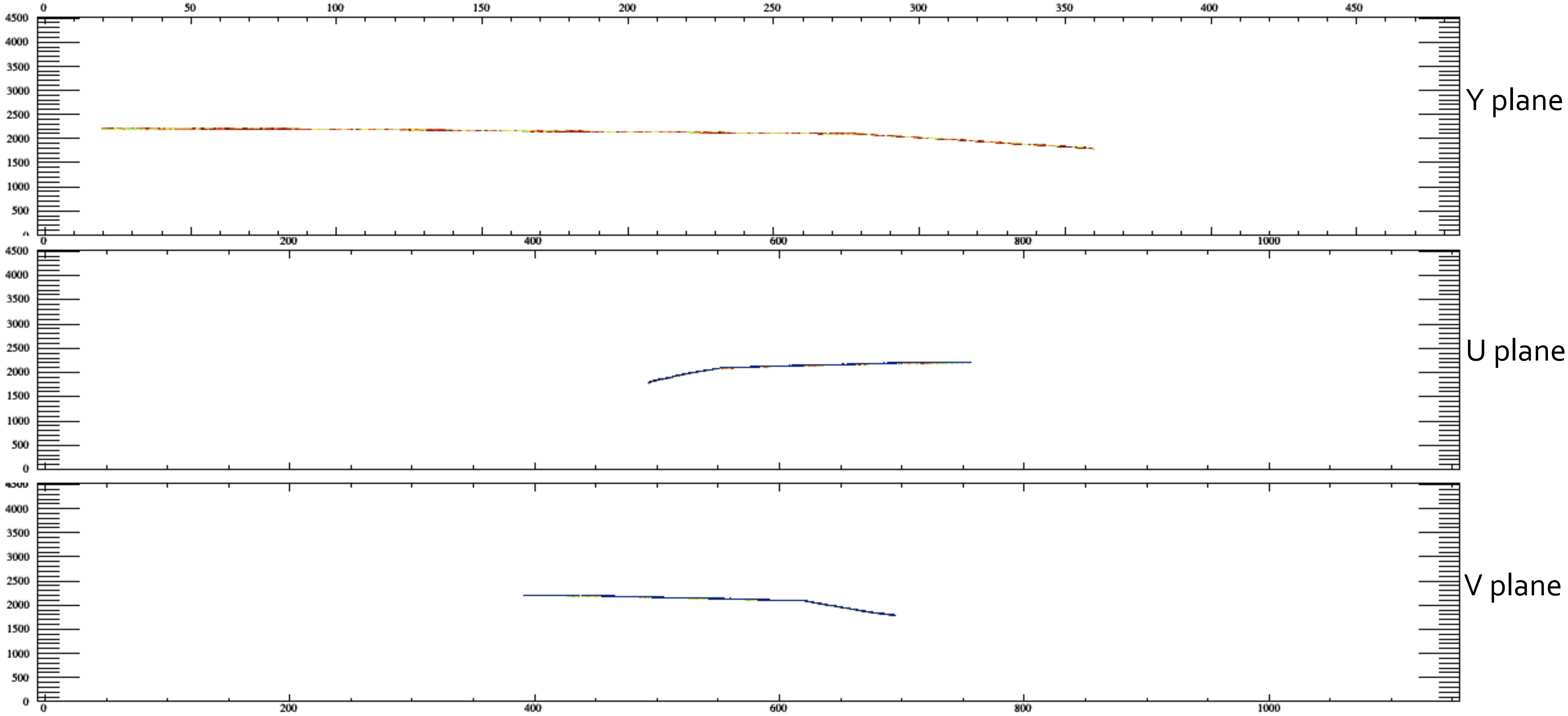
$$p^2 = \beta^2(m^2 + p^2)$$

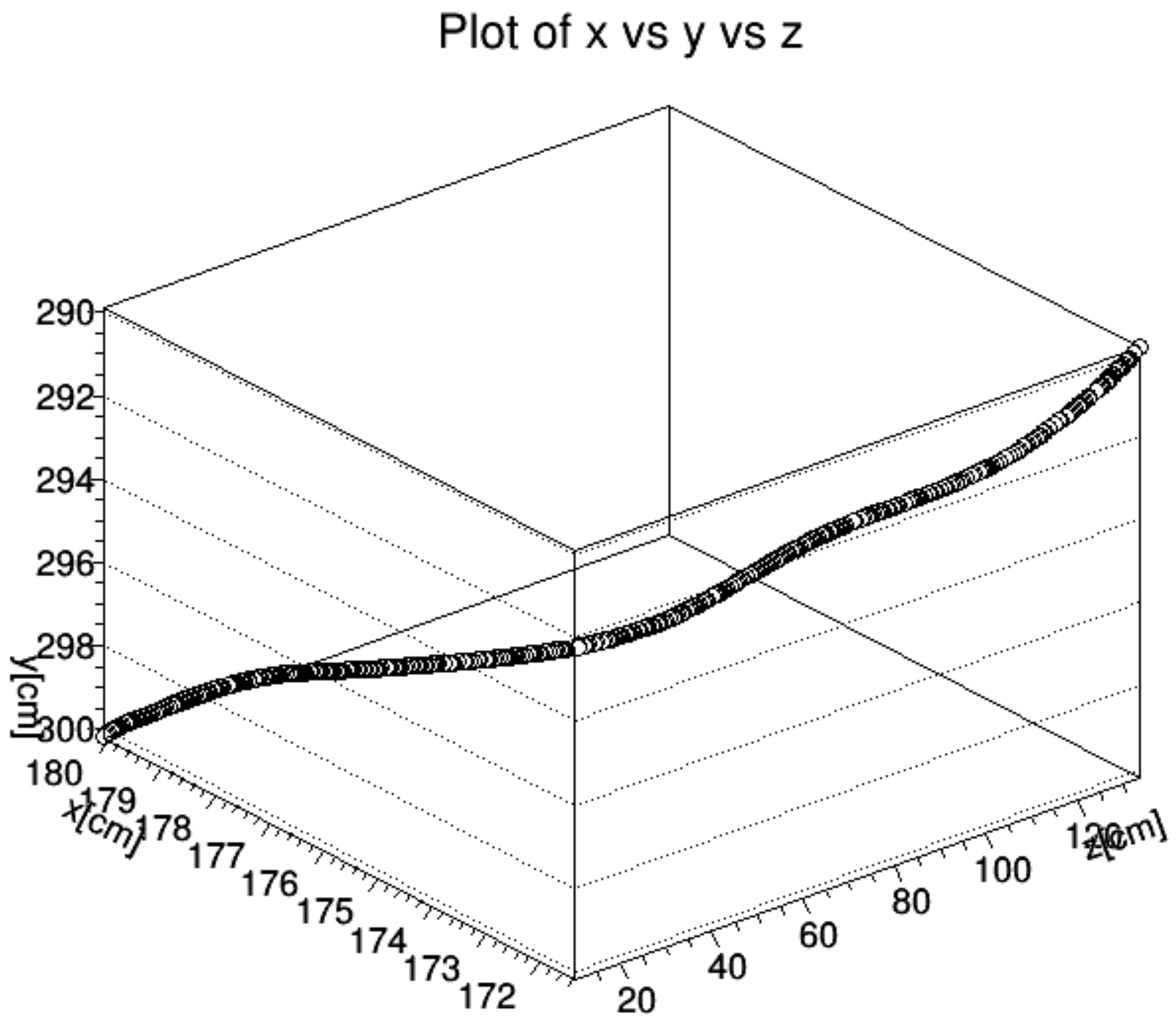
$$\beta^2 = \frac{p^2}{m^2 + p^2}$$

$$\beta = \frac{p}{\sqrt{m^2 + p^2}}$$

$$\beta p = \frac{p^2}{\sqrt{m^2 + p^2}}$$

$$\frac{1}{\beta p} = \frac{\sqrt{m^2 + p^2}}{p^2}$$

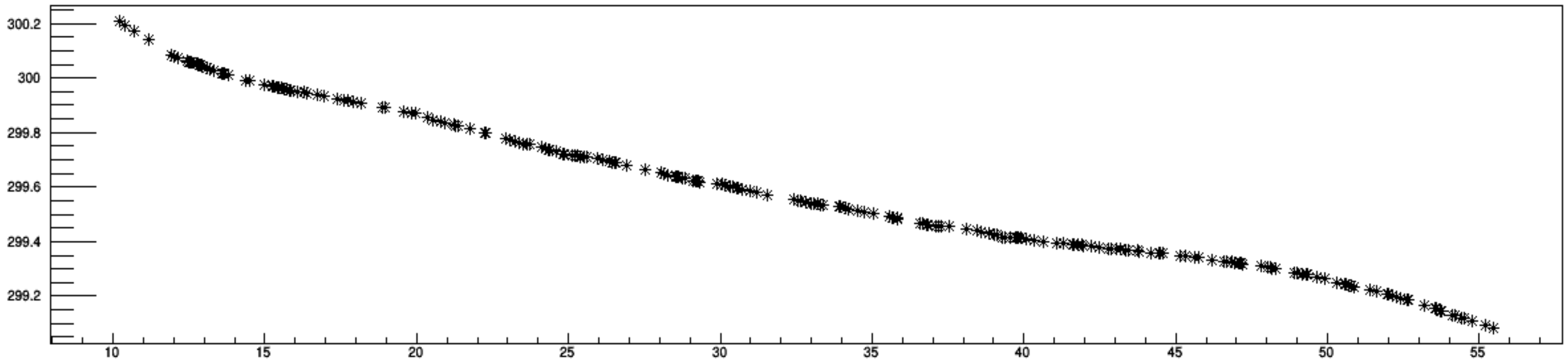

Y plane
U plane
V plane



Graphed using ROOT

1) Break the track up into several line segments fit to linear regressions

Multiple Coulomb Scatter fitting



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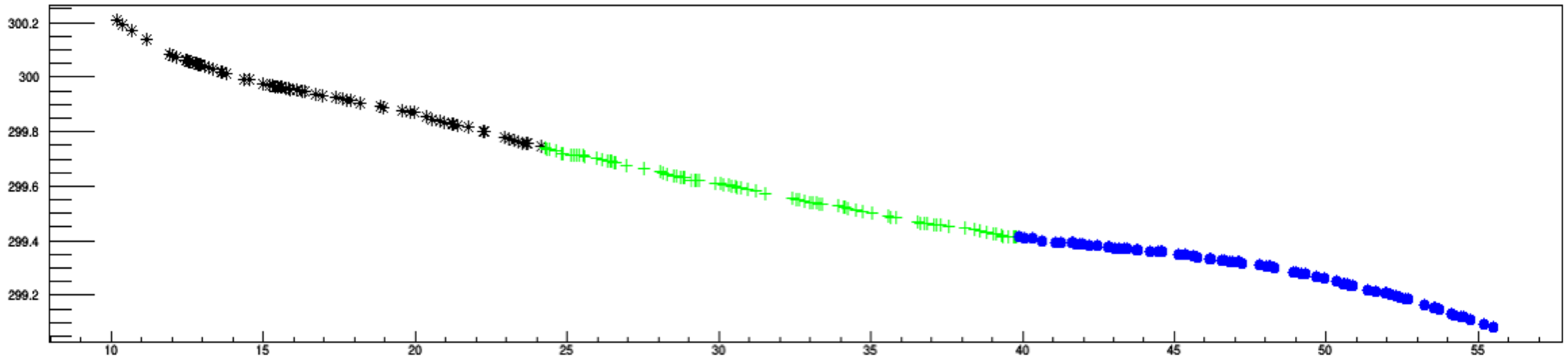
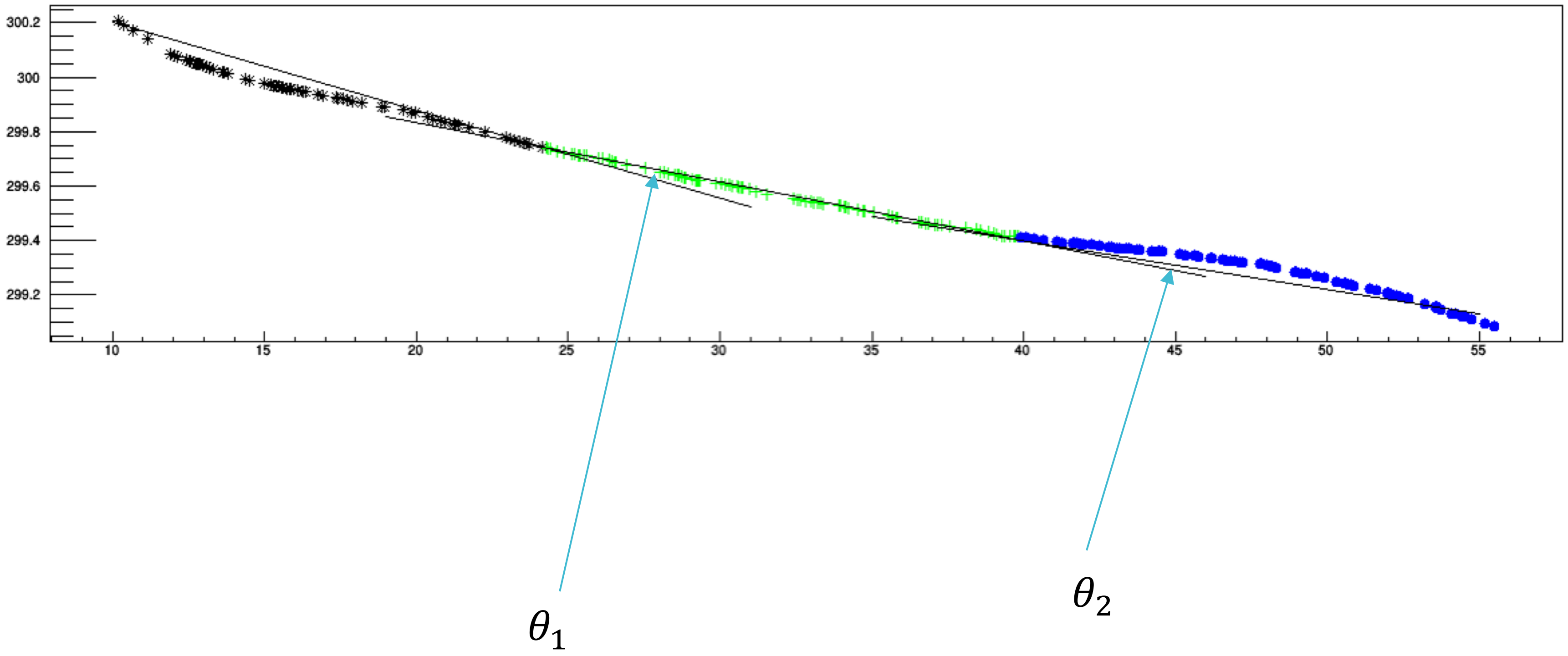


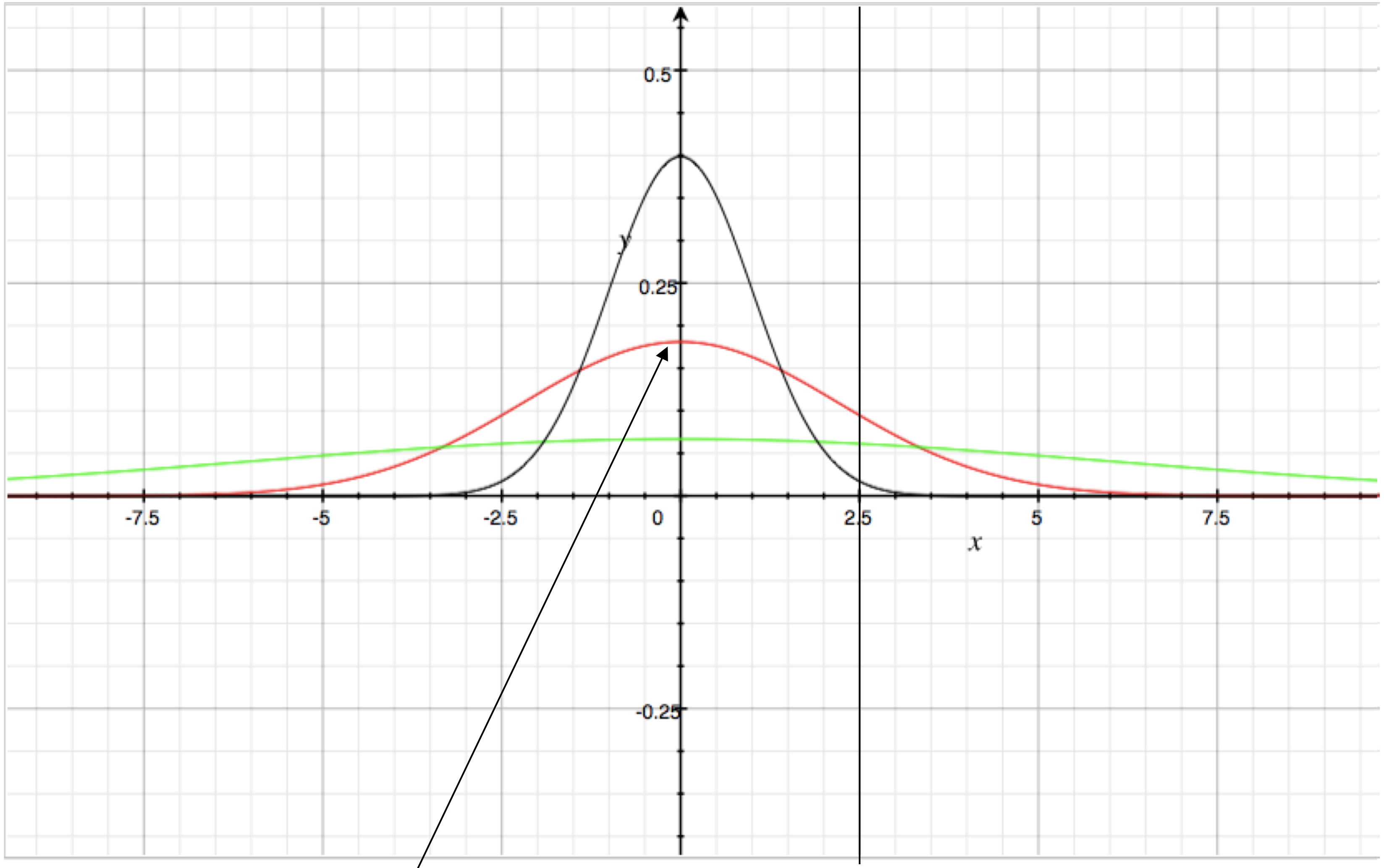
2) Find the deflection angles between each pair of segments

Multiple Coulomb Scatter fitting



3) Figure out the momentum that is most likely to have generated the track that was detected

Multiple Coulomb Scatter fitting



Use momentum associated
with this gaussian distribution

θ_1