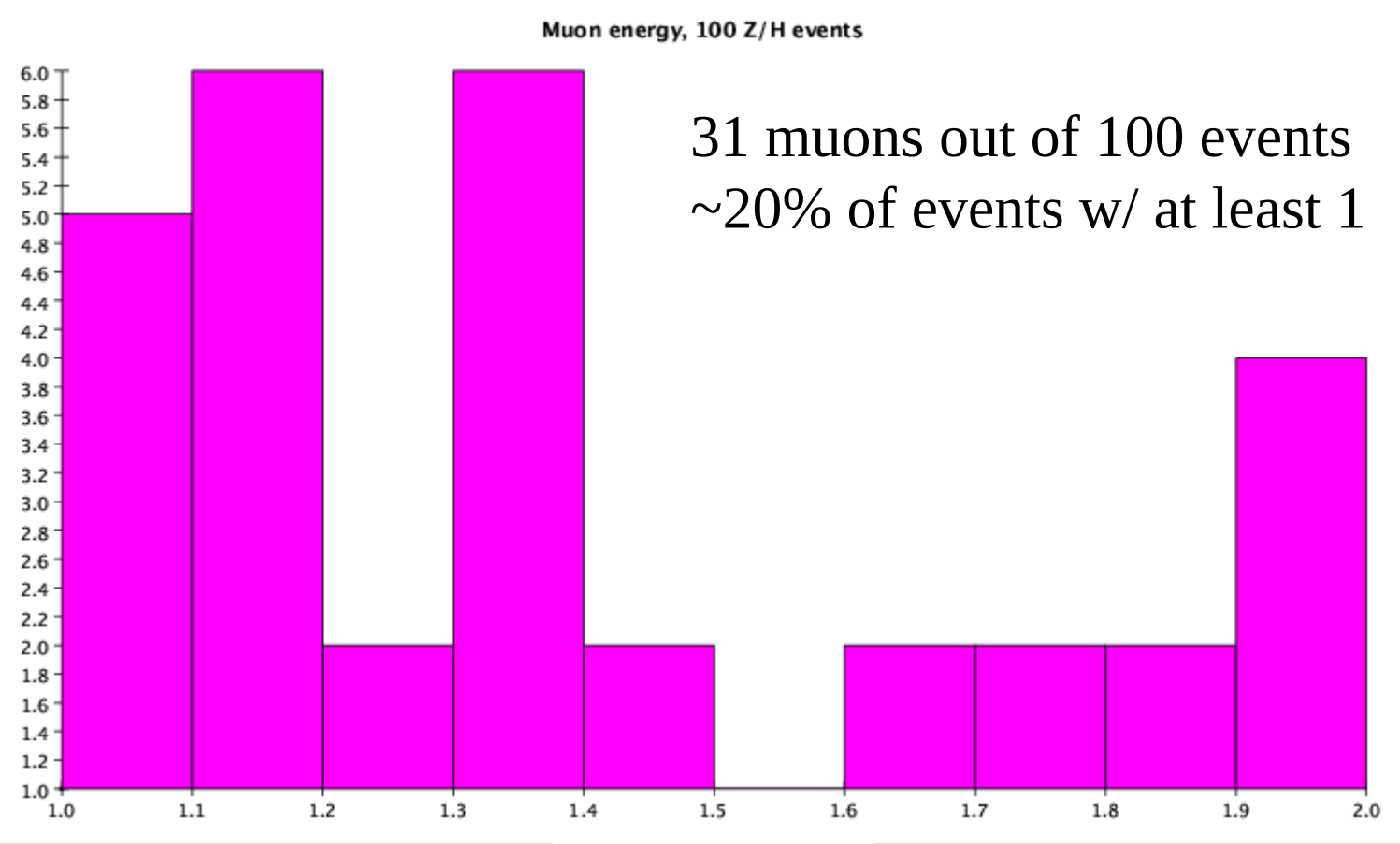
Tracking Low-Energy Muons

Overview

- Goal:
  - Reconstruct low-energy (1-2 GeV) muons, associating them with the calorimeter hits they leave behind
  - Remove these hits from the event
- Problem:
  - Muons at this energy can loop inside the EM calorimeter, leaving several distinct clusters. Must correctly associate all clusters with the single muon.
  - Multiple scattering and energy loss greatly affect the position of clusters

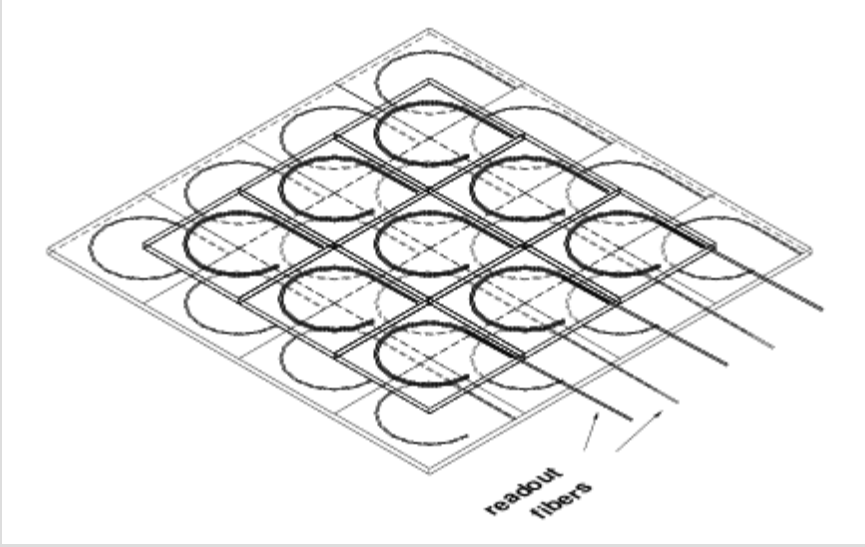
How often do these occur?



31 muons out of 100 events
~20% of events w/ at least 1

Note on Geometry

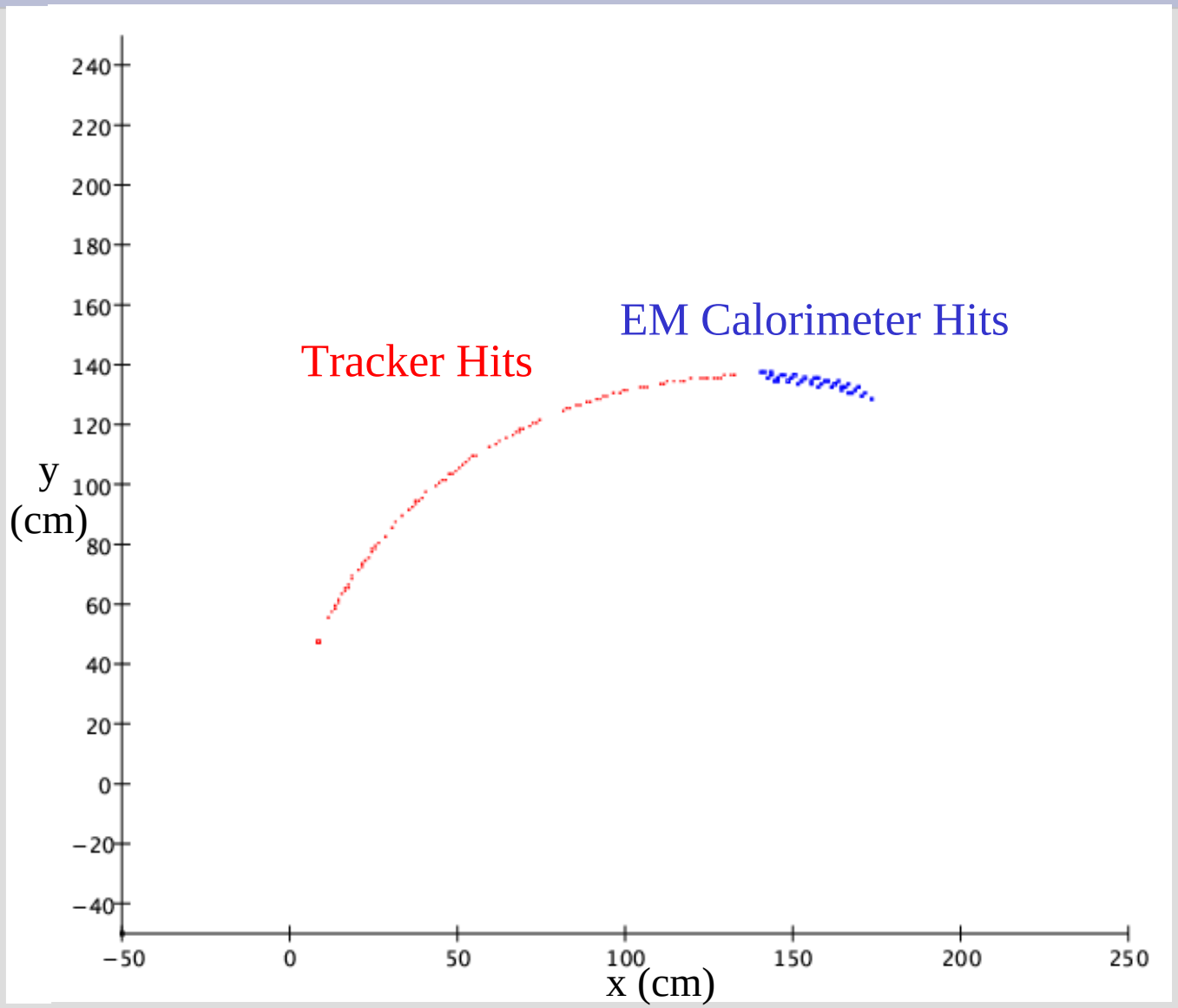
- Using CU's geometry, a variation on the LDC
- TPC tracker
- EM calorimeter has 40 layers of tungsten and scintillator, inner radius of 196cm
- 3T magnetic field
- 5cm x 5cm offset tiles, projective geometry



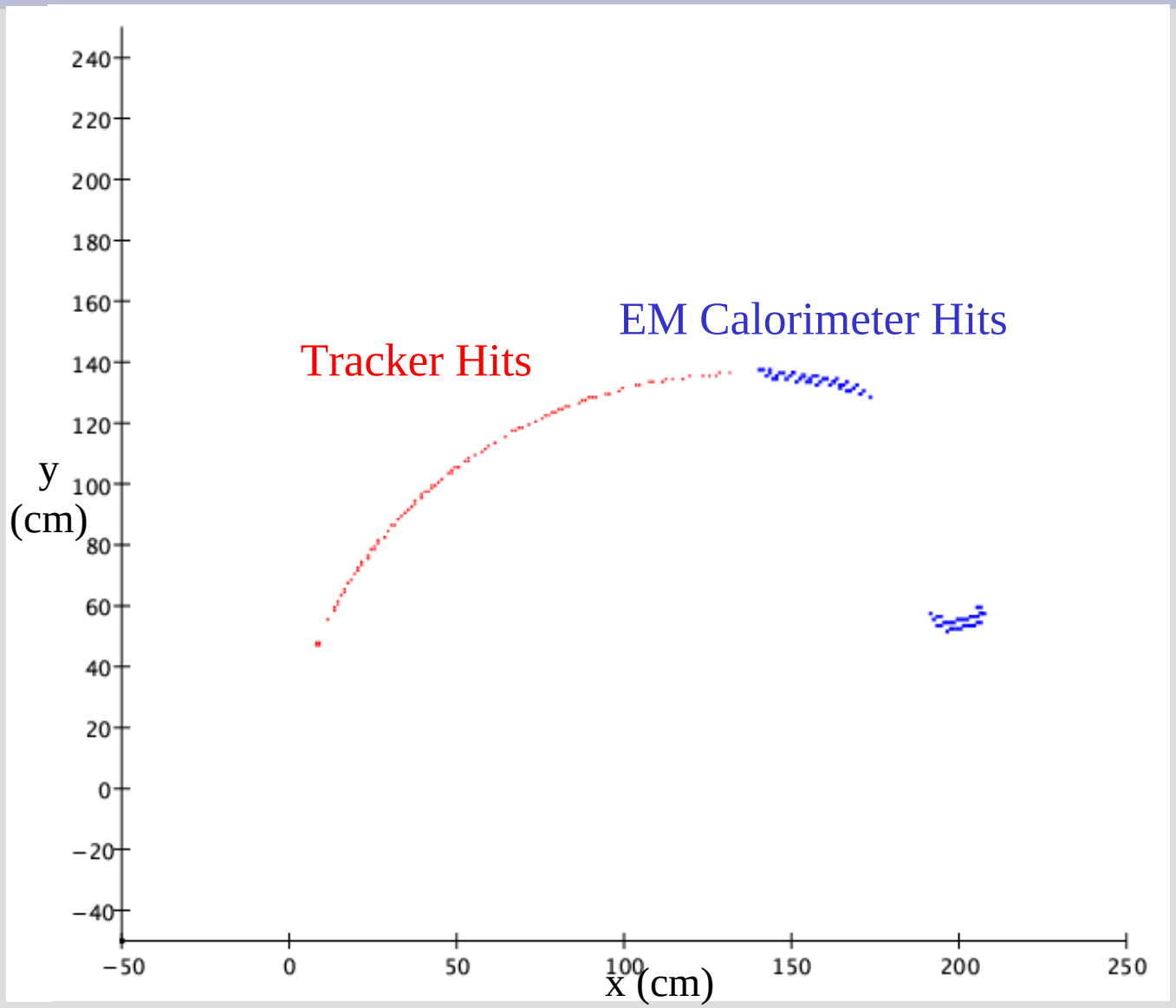
Data to Analyze

- Generated single mu+ and mu- events with the LCDG4 gun
- Fired with 1.2 GeV straight along the y-axis (no z momentum)
- Randomness in multiple scattering and dE/dx means these identical muons can leave very different clusters
- Muon can leave a single cluster, 2 clusters, or 3 clusters

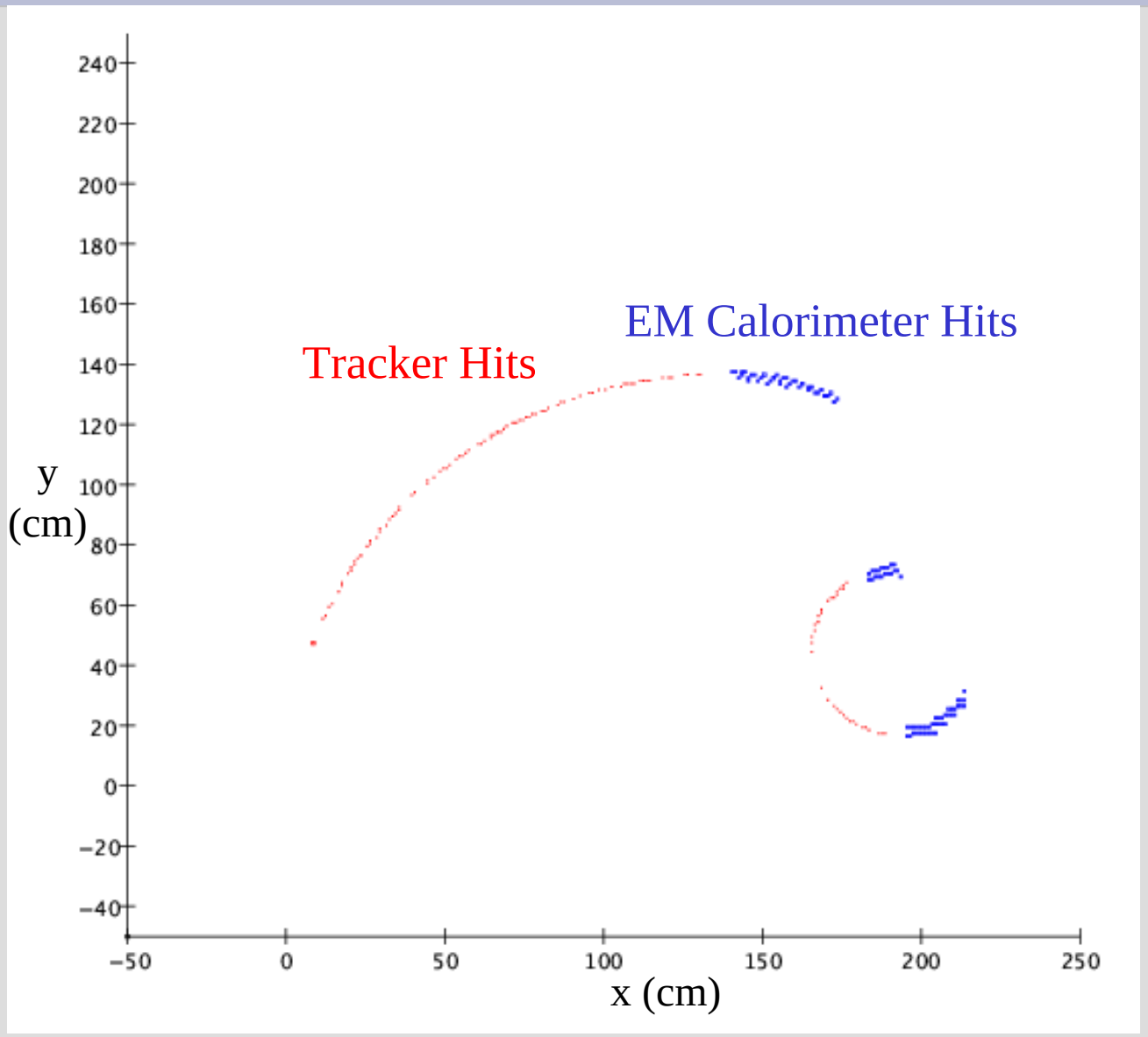
Single Cluster



Double Cluster



Triple Cluster



Method

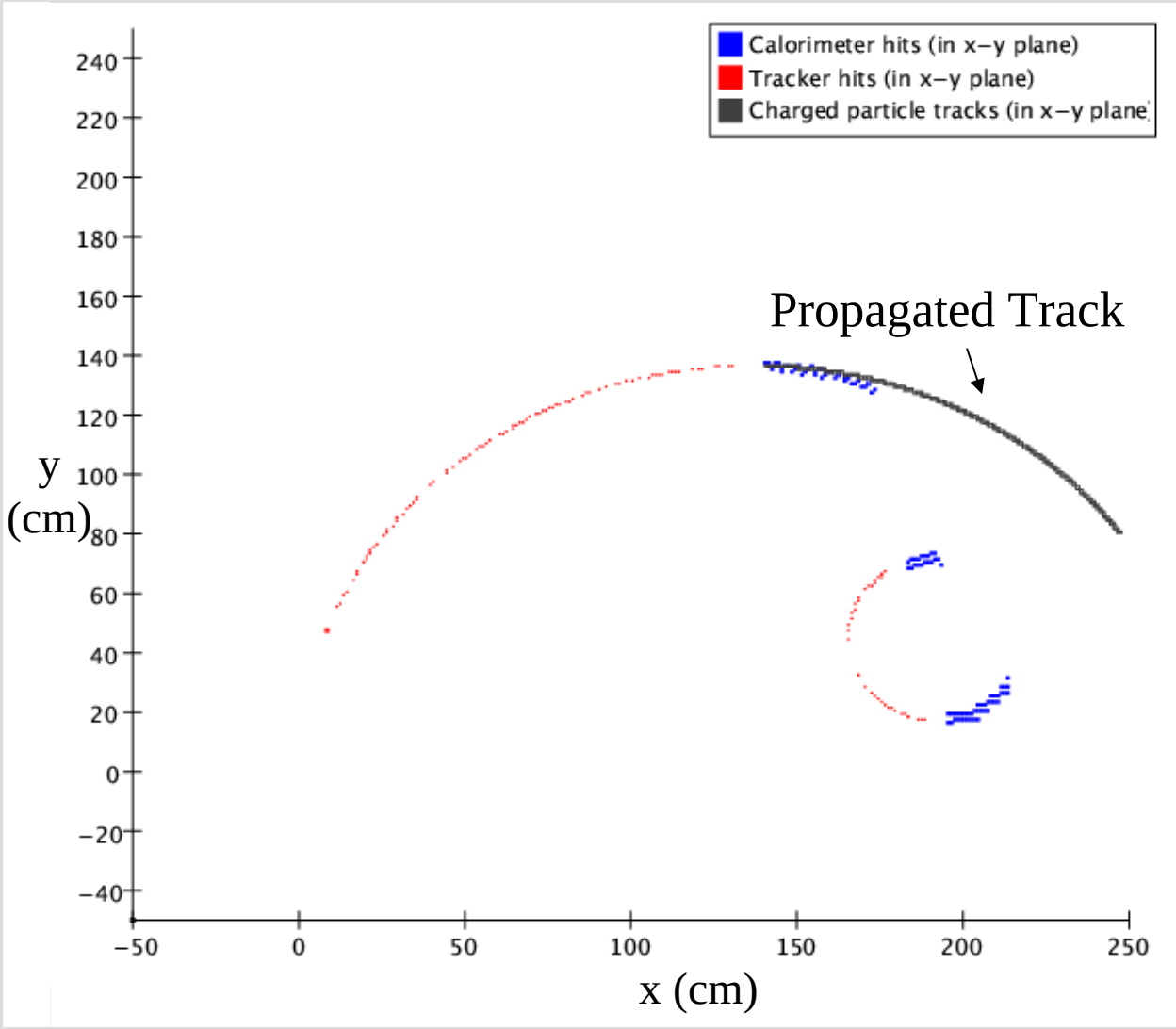
- Using the muon's starting position and momentum, step through the path it makes as it curves in a B-field
  - Move the muon some small length along the direction of its momentum, adjust the momentum according to

$$d\mathbf{p}/dt = q(\mathbf{v} \times \mathbf{B})$$

  - Repeat until the muon leaves the calorimeter
- Find clusters this track intersects; associate them with the muon; remove them from the event

No Correction

If energy loss and multiple scattering are not corrected for, the track does not properly loop

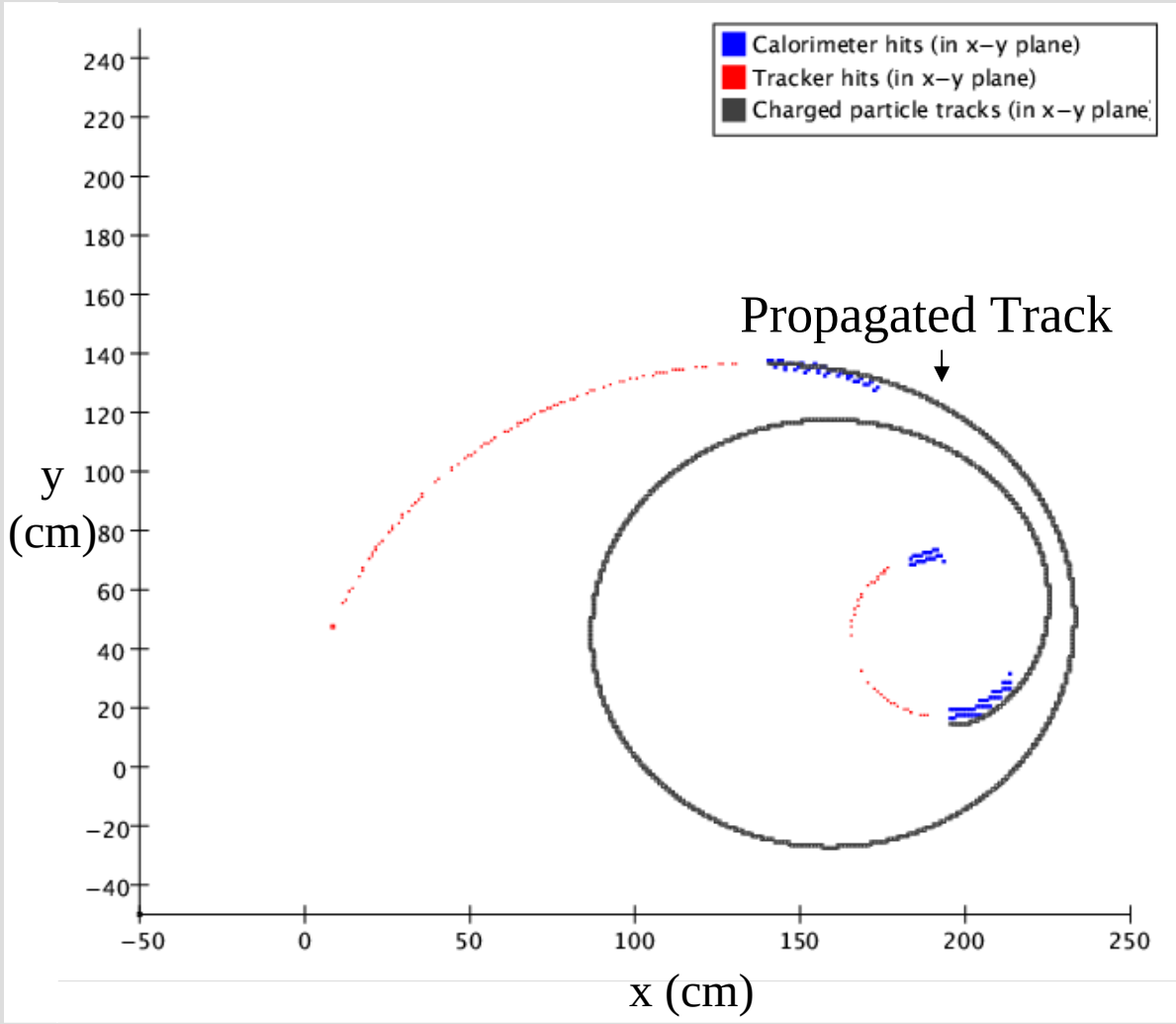


Energy Loss Correction

- Energy Loss
  - Lost energy in aluminum support structure before and after EM calorimeter
  - Lost energy in tungsten and scintillator tiles
  - Leads to much tighter helix
- Correction
  - Remove energy from track when it is in the supports based on average dE/dx of a MIP through aluminum
  - Remove energy deposited in calorimeter tiles, scaling to account for E loss in tungsten

Effect of E loss Correction

- Makes the track loop around, but not enough to hit the second cluster
- Without seeing this cluster's energy to remove, the track does not curve as much as it needs to

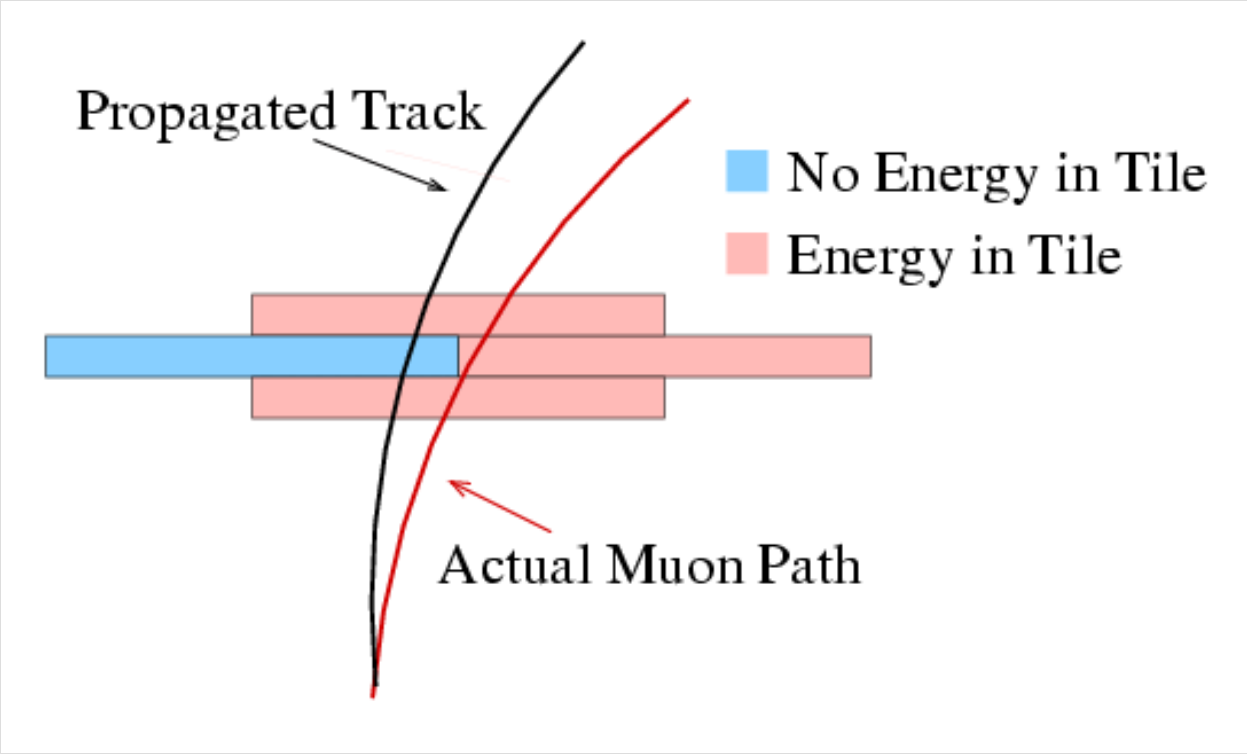


Multiple Scattering Correction

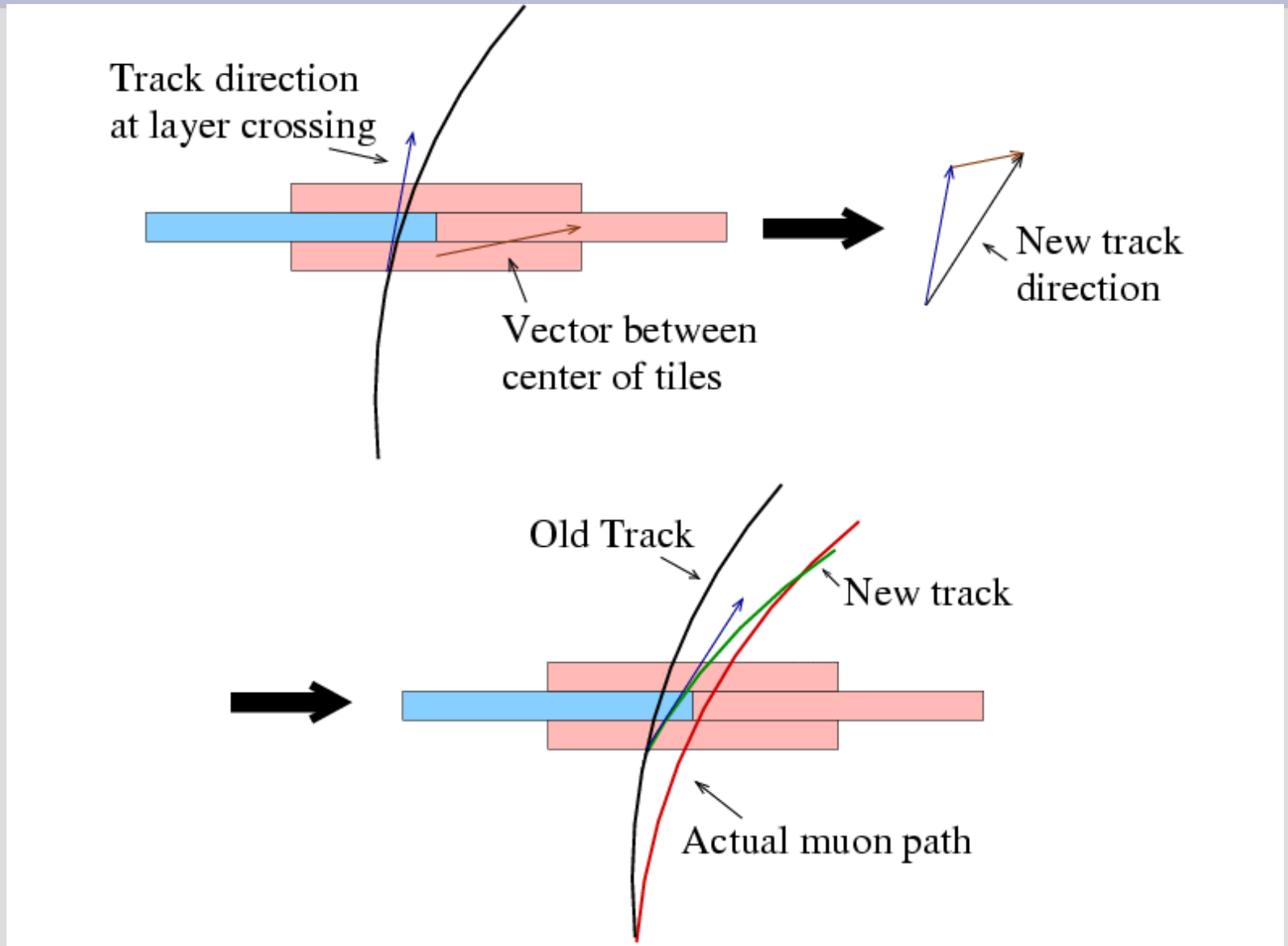
- Multiple Scattering
  - Coulomb deflections off nuclei change direction of muon
  - Changes transverse momentum, altering the radius of curvature
  - Much harder to correct for than energy loss due to unpredictability
  - Only information usable for correction is location of calorimeter tiles

Correction Method

If track hits a tile without energy but an adjacent tile has energy, then the track missed

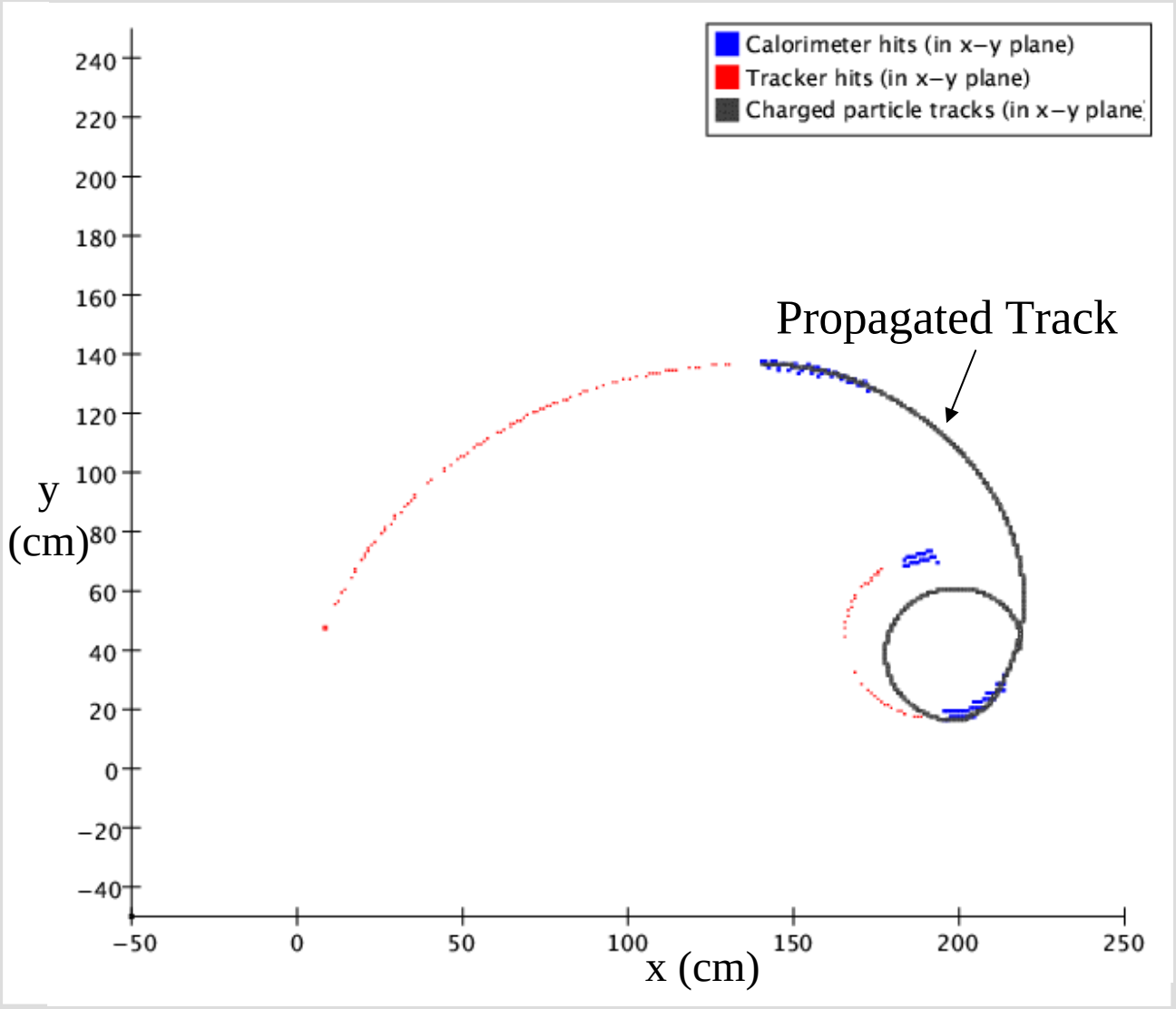


Correction Method



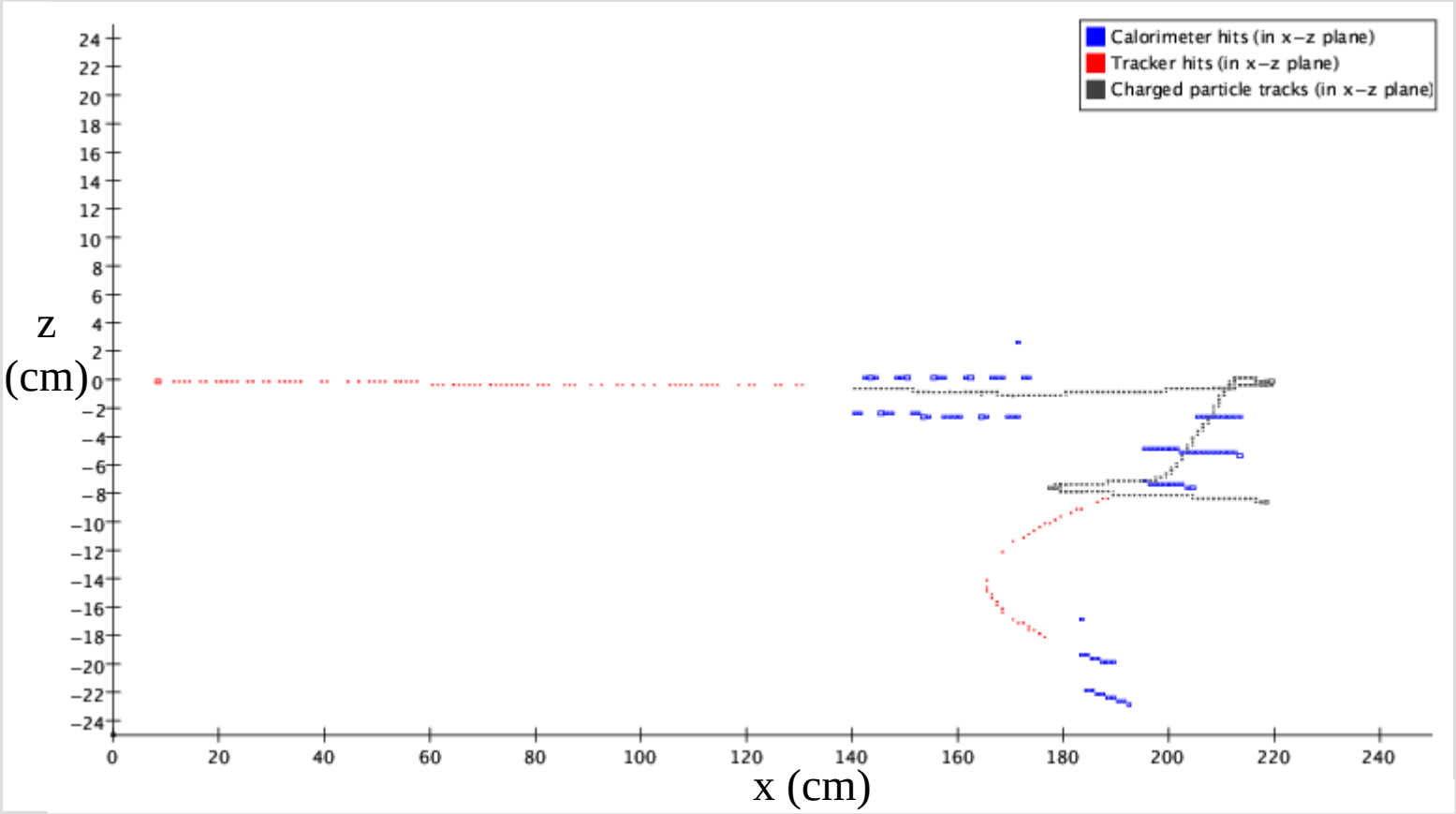
Propagated Track with Both Corrections

- Successfully intersects the first two clusters
- Still misses the third cluster



x-z Projection

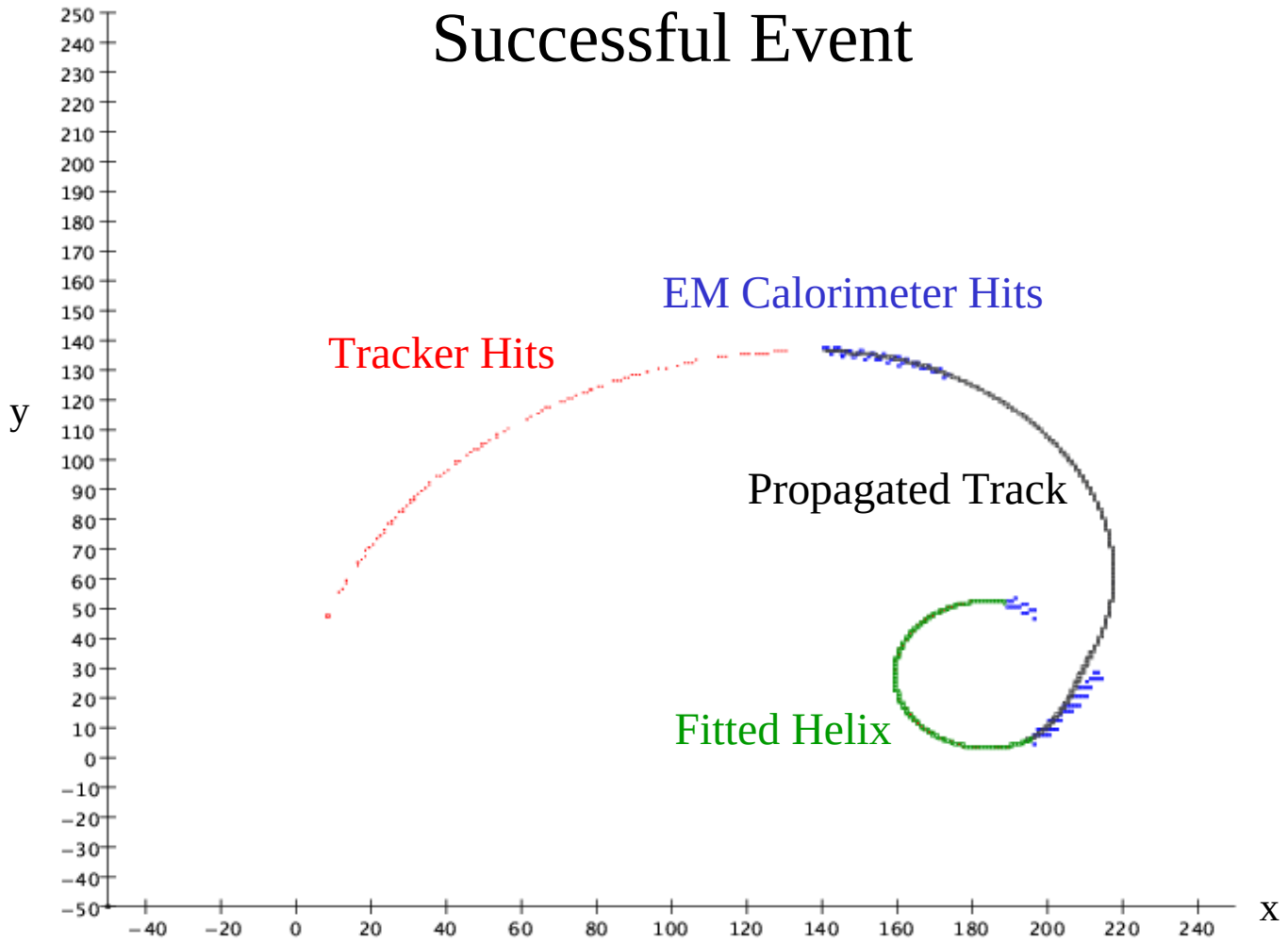
Additional clusters can be scattered substantially in z, difficult to properly track given only center of tiles

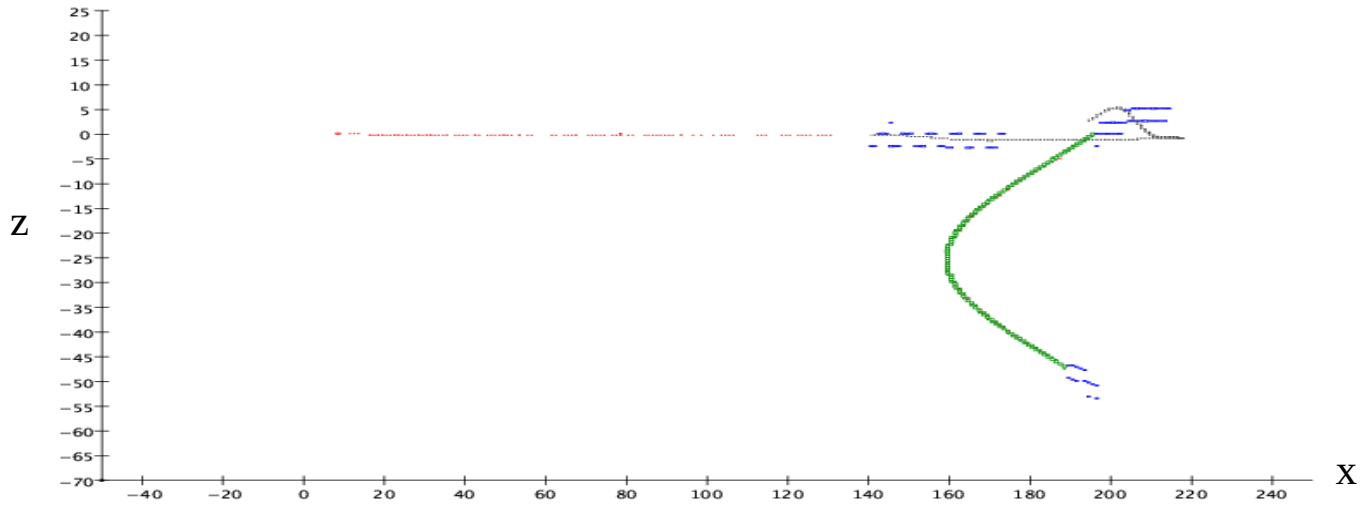


Using tracker hits

- Instead of finding third cluster with propagated track, use tracker hits
- Tracker hits make a clear helix, leading from the second cluster into the third cluster
  - Fit the tracker hits using Joe Proulx's helix fitting code, find which clusters helix intercepts
- Can use propagated track to associate first and second clusters, then tracker hits to associate second and third clusters
  - Clusters determined by any clustering algorithm, such as nearest-neighbors (i.e. Tony Johnson's SimpleClusterBuilder)

Successful Event

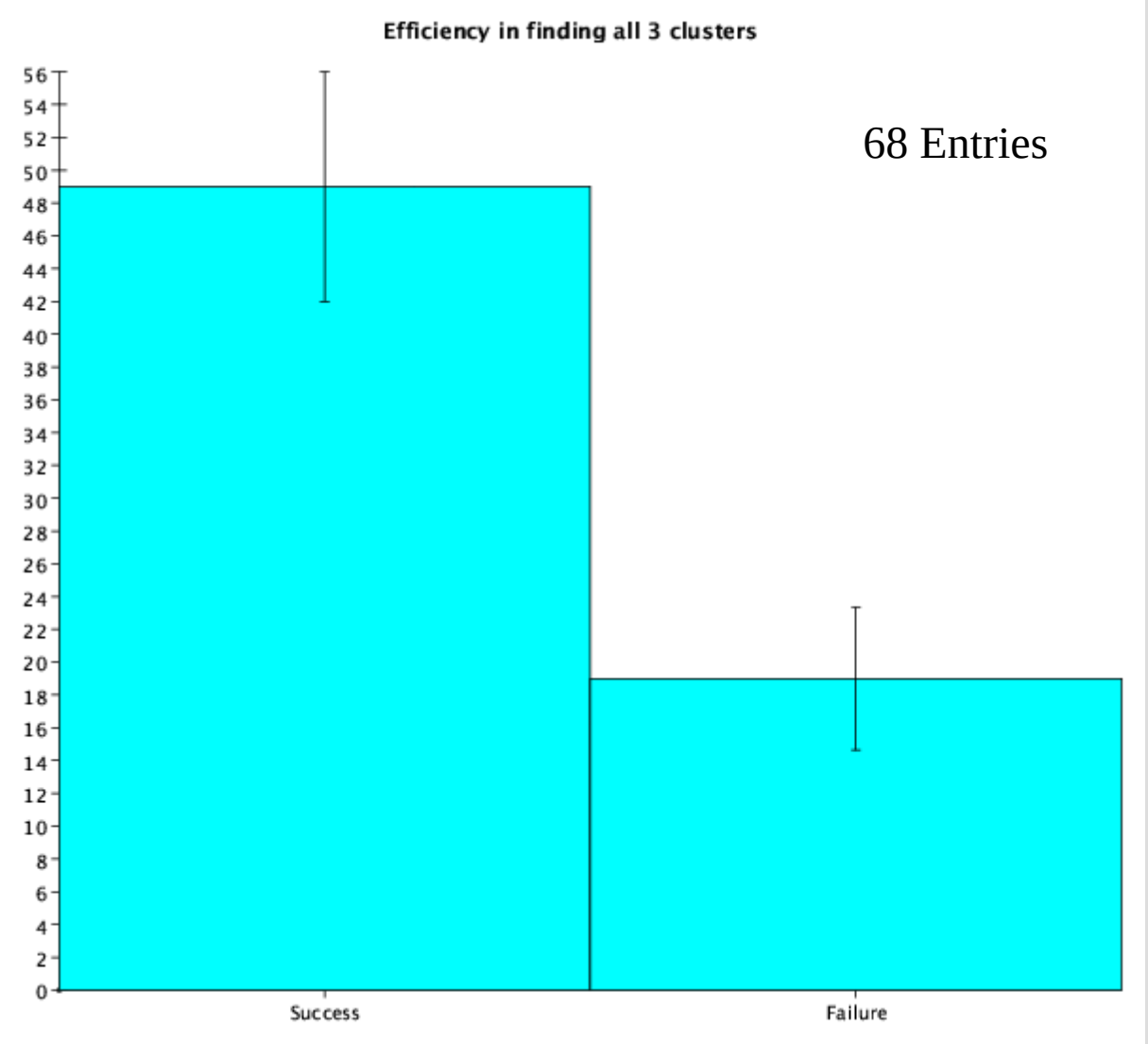




Efficiency

49 out of 68 events found all three clusters successfully

Implies
~72% efficiency



Work to be done

- Several improvements to make:
  - Improve multiple scattering correction (Kalman Fitter?)
  - Take delta rays into account for energy loss
  - Find out why helix fit doesn’t always work
  - Include hadronic calorimeter hits, when applicable
- Find out how effective this method is in a full event (not single muons)

Conclusion

- Want to identify all calorimeter hits left by a looping muon
- Must correct for energy loss and scattering
  - Good enough to find first and second clusters
- Can use tracker hits to find third cluster
- Achieves 72% efficiency in a single muon event, can be improved
- Determine efficiency in full events