TCTracker Module

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Motivation & Approach

- TCTracker is the latest upgrade to TrajCluster
  - Now produces Track, TrajectoryPointFlags, TrackHitMeta and Track SpacePoint collections
- Led to improvements in 3D and 2D pattern recognition and track fitting
- Code developed using DUNE low energy protons, DUNE pdk MC, ArgoNeuT through-going muons and protoDUNE cosmics

- Many general improvements and new algorithms bundled into a meta-algorithm "NewCuts" – ON by default
  - Switch them OFF for evaluation

A Brief History

- TrajCluster based on the LineCluster idea
  - Construct a 2D seed trajectory from two nearby available hits
    - Step in a direction, add hits at the leading edge, fit leading edge hits, decide to continue/stop using position, kink angle and charge
    - Tracking strategy based a forecast of the hit environment ahead
    - Reverse propagate
  - Merge trajectories or make 2D vertices between them
  - Match 2D vertices in 3D
    - Split or merge 2D trajectories and 2D vertices using the presence or absence of a 3D vertex
  - Produce PFParticles with assns to 3D matched trajectories (clusters)
    - Requires using a track fitting module, e.g. PMAlgTrajFitter
- New: Produce recob::Track, TrackHitMeta data and SpacePoints

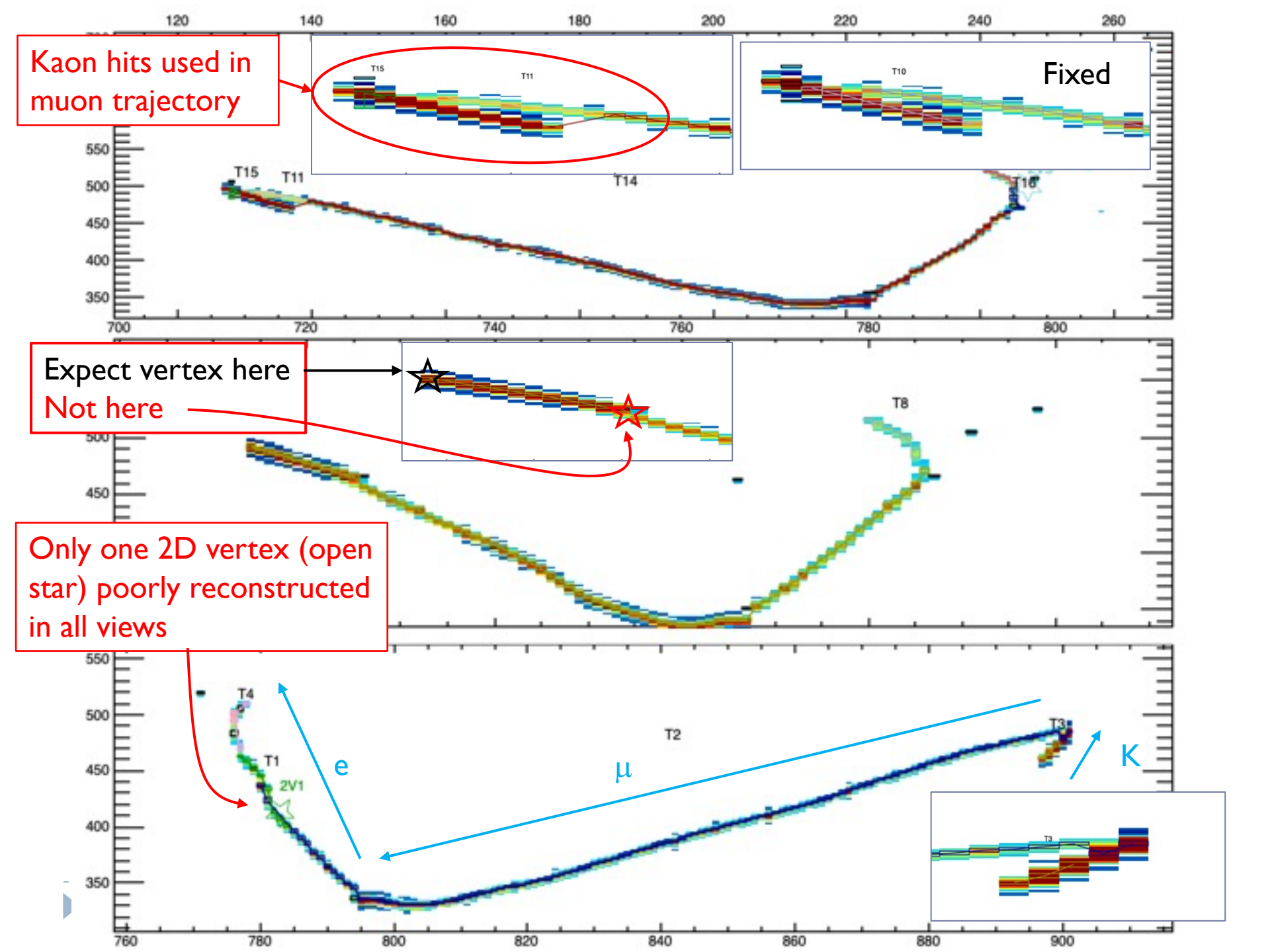
Measuring Performance
ClusterAna module revision

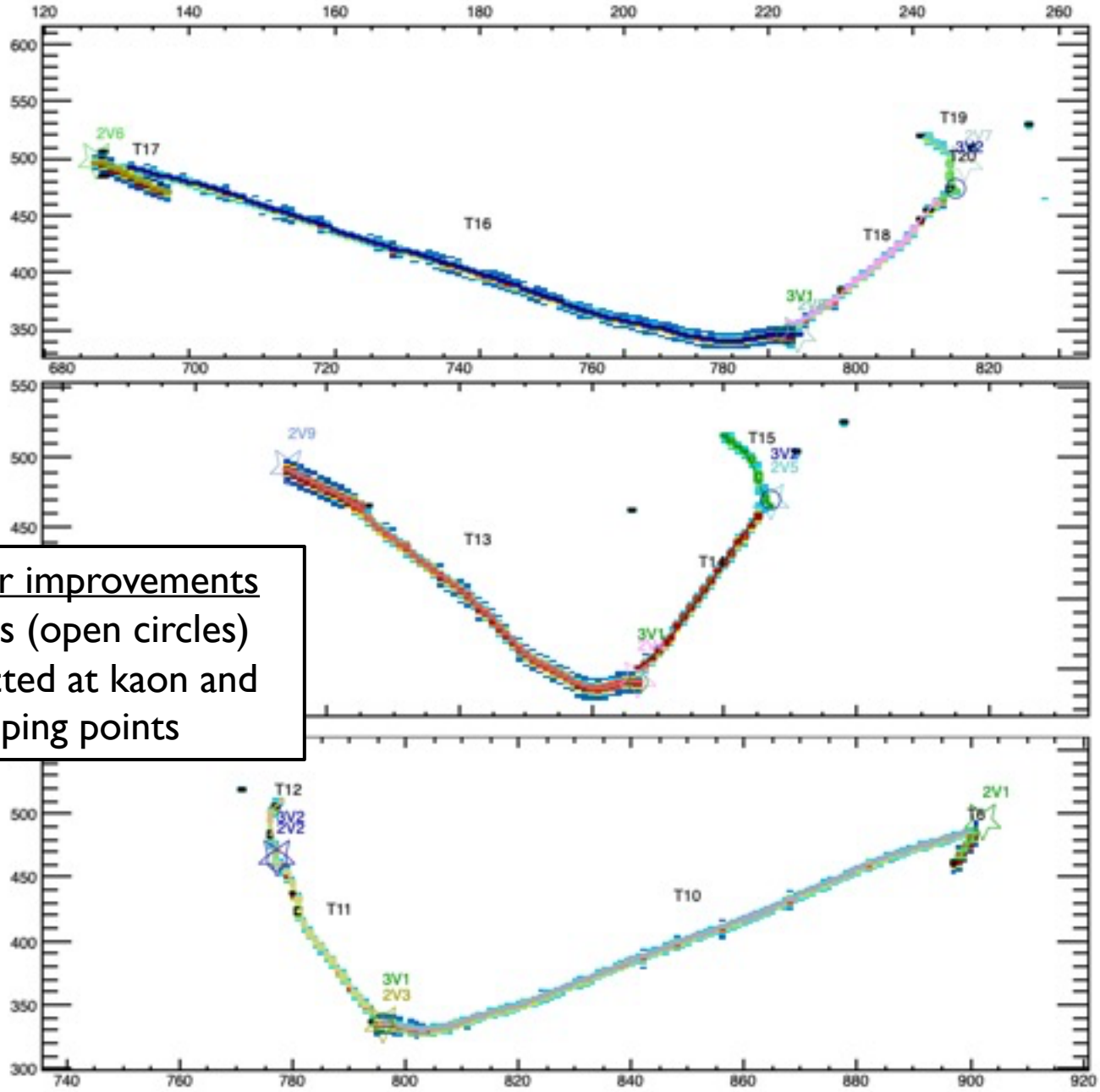
- Calculates efficiency (aka completeness) and purity separately for MCParticle electrons, muons, pions, kaons & protons
- A hit is matched to a MCParticle when it contributes to > 0.5 of the deposited energy
- Performance measured for cluster hits in each TPC and plane
  - Allows comparing 2D Cluster reco with 3D Track → 2D cluster reco
- Produces histograms and text report of Efficiency * Purity (EP)
  - EP = 1 → all hits correctly assigned to 2D (3D) objects
- Implicit weighting for short tracks – missing a single correct hit in a short track is far more important than missing one in a long track
- Proton decay 1K events (TDR sample)
  - 400 electrons with T > 50 MeV, <T> = 80 MeV
  - 2000 muons, <T> = 150 MeV
  - 800 pions, <T> = 85 MeV
  - 2500 kaons, <T> = 100 MeV
  - 500 protons, <T> = 60 MeV
- The TPC:Plane:Wire:Tick location of poorly reconstructed MCParticles is printed

Protons, kaons and muons stop with Bragg peaks and decay daughters – opportunities for reconstruction failures on each event and EACH PLANE

```
BadEP evt 1 kaon EP 0.00 true hit range 17:2:476:3694 - 17:2:478:3700 nTrueHits 6
```

The following slides show a sampling of reco failures and their resolution → Mostly due to failures in 2D reconstruction

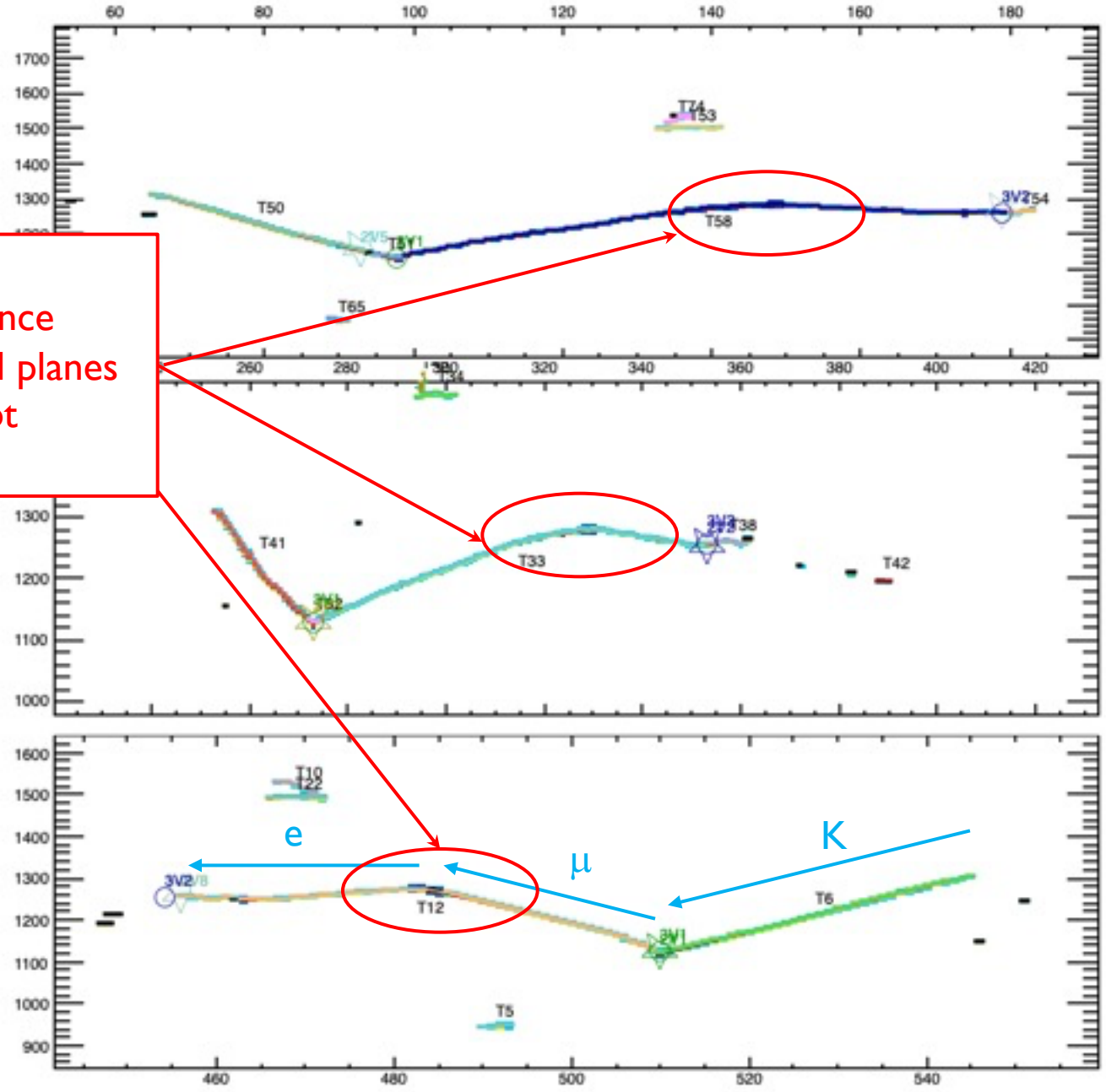

Kaon hits used in muon trajectory
Fixed
T15
T11
T14
T10
Expect vertex here
Not here
T8
Only one 2D vertex (open star) poorly reconstructed in all views
T4
T1
2V1
e
T2
μ
T3
K



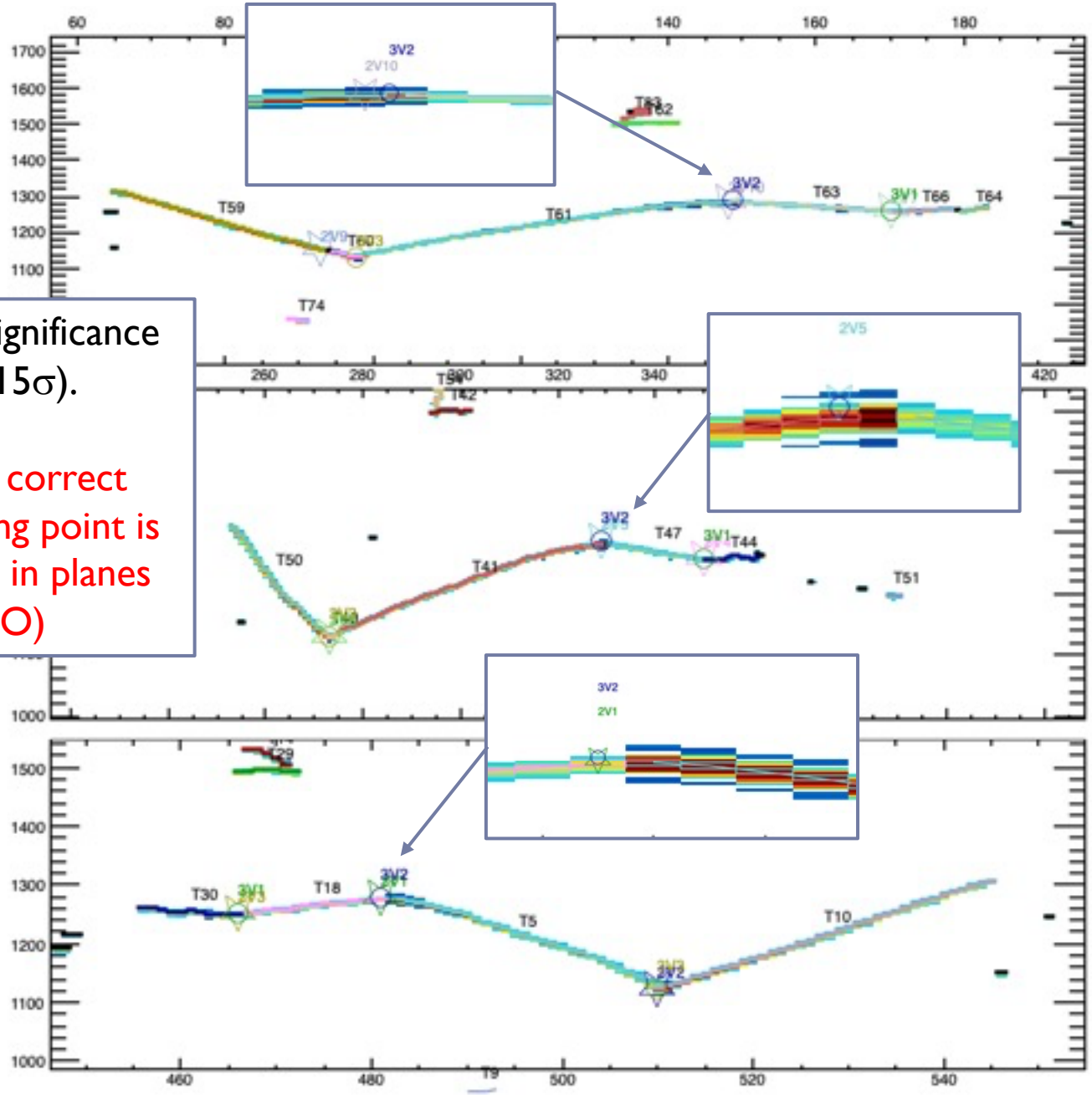
After other improvements
3D vertices (open circles) reconstructed at kaon and muon stopping points

Failures

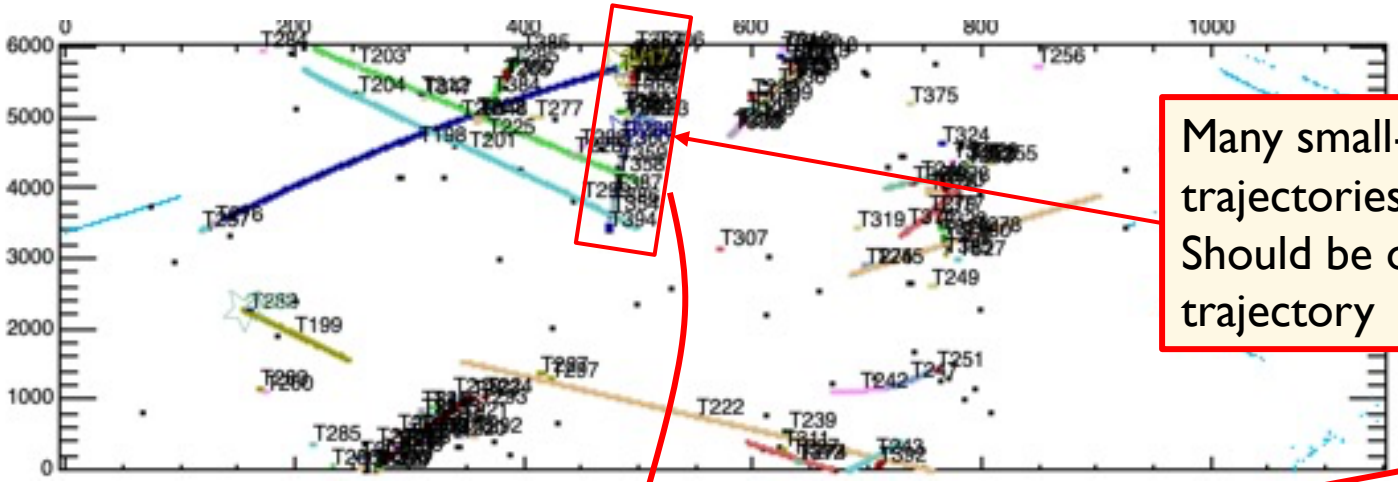
1) Local kink fit significance below threshold in all planes
2) Muon Bragg peaks not detected



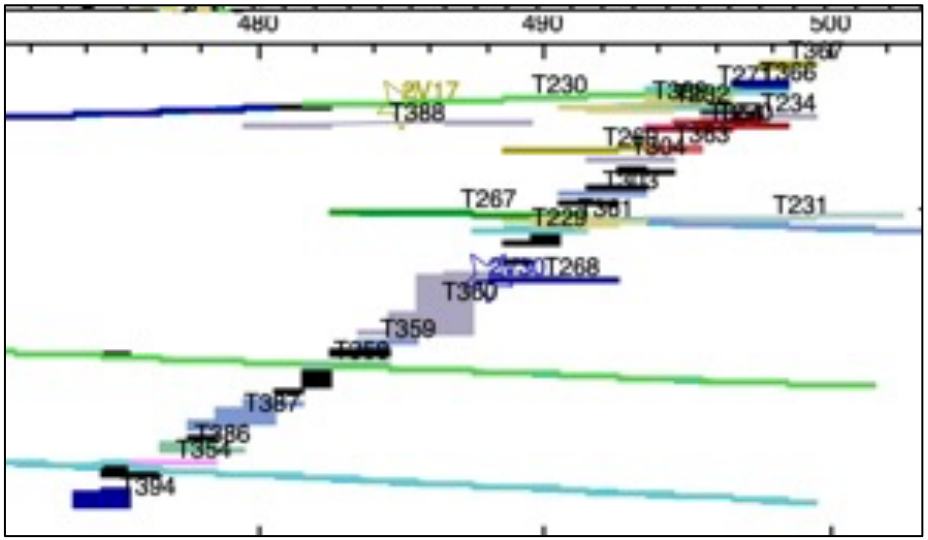
Default kink significance cut too high (15σ).
Set to 5σ.
Note that the correct cluster stopping point is off by ~1 wire in planes 1 and 2 (TODO)

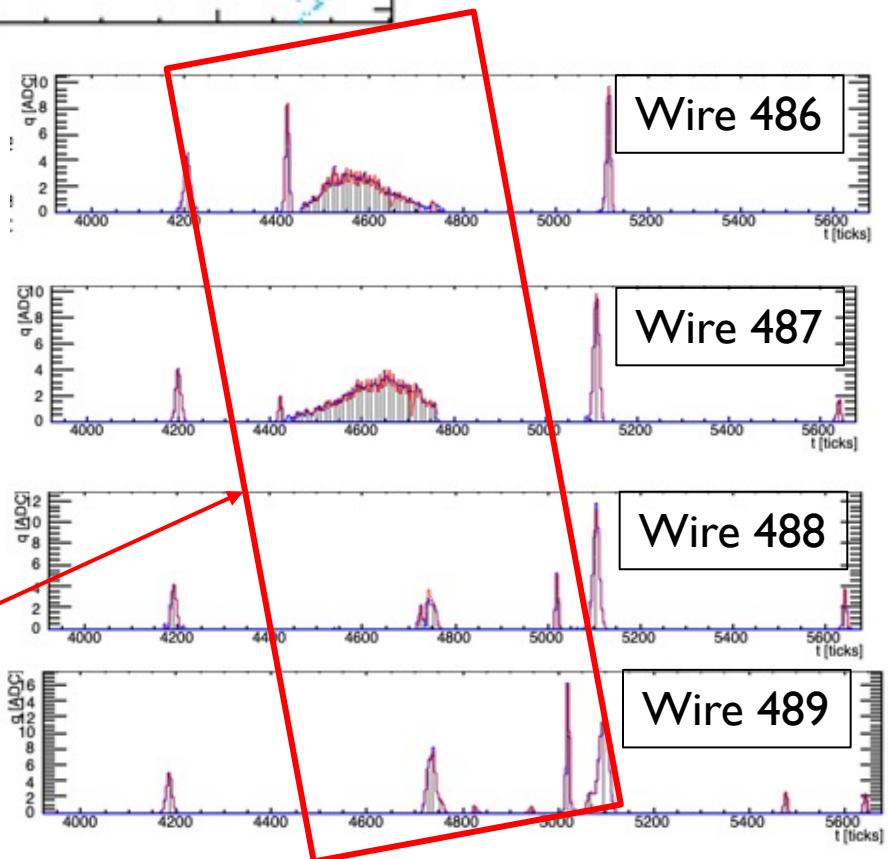


ProtoDUNE MC Cosmic – V Plane



Many small-angle trajectories reconstructed. Should be one large-angle trajectory





Making large-angle Trajectories: Requirement for hit time overlap on adjacent wires not always met on induction planes. Signal shaping problem?

Performance Summary – 2D Reconstruction

- 1K proton decay events
  - Baseline 2D reconstruction – NewCuts OFF

```
EP: elec 0.48 muon 0.52 pion 0.51 kaon 0.63 prot 0.55 Cnts: 376 1985 803 2509 471 All 0.56 nBad 3876
```

  - With improvements – NewCuts ON

```
EP: elec 0.55 muon 0.76 pion 0.61 kaon 0.71 prot 0.59 Cnts: 378 1987 807 2513 474 All 0.70 nBad 2543
```

25% overall improvement for all particle types

- 20 protoDUNE cosmic events
  - 4.1K muon MCParticle cluster entries + a few π's and p's
  - Baseline 2D reconstruction – NewCuts OFF

```
tctracker EP: muon 0.63 pion 0.57 proton 0.65 AveEP: 0.63 nBad/nMCPInPln 2074/4271
```

  - With improvements – NewCuts ON

```
tctracker EP: muon 0.71 pion 0.65 proton 0.76 AveEP: 0.71 nBad/nMCPInPln 1422/4271
```

12% overall improvement, ignoring δ-ray & shower electrons

3D Reconstruction

- Some of the 3D pattern recognition algorithms written to recover from 2D inefficiencies resulted in worse performance - removed
- The current strategy
  - Reconstruct 2D trajectories with high efficiency & high purity
  - Match trajectories in 3D and use simple pattern recognition algorithms to reconcile 2D – 3D conflicts
    - Primarily matching 2D vertices in 3D
  - Do linear 3D fits in track sections
  - Produce tracks, track trajectories, track hit meta data, track space points

TrackHitMeta & TrajectoryPointFlags

- What are these data products?
  - TrackHitMeta associates a Hit with a Track TrajectoryPoint
  - TrajectoryPointFlags identify hits that are Suspicious, Shared (with another trajectory) or have a DetectorIssue
    - These shouldn't be used for calorimetry, e.g. hits near a vertex in one or more views (see slide 6)
- TCTracker has had internal analogs of these concepts for some time
  - Now produces these data products
- The Calorimetry module needs to be updated

Summary

- Change in TrajCluster data products
  - Old: TrajCluster produced 3D matched 2D clusters requiring use of a track fitting module like PMAlgTrajFitter
  - New: TrajCluster (now TCTracker) produces 3D tracks with hit associations, SpacePoints and TrackHitMeta collections
- Significant improvement in K decay chain reconstruction
  - All due to 2D tracking improvements
  - Reconstruction of the correct stopping points in the decay chain is critical
    - Mis-assignment of a hit between a parent and daughter track has significant consequences
    - Needs improvement