The 3DST Reconstruction

CubeRecon Status

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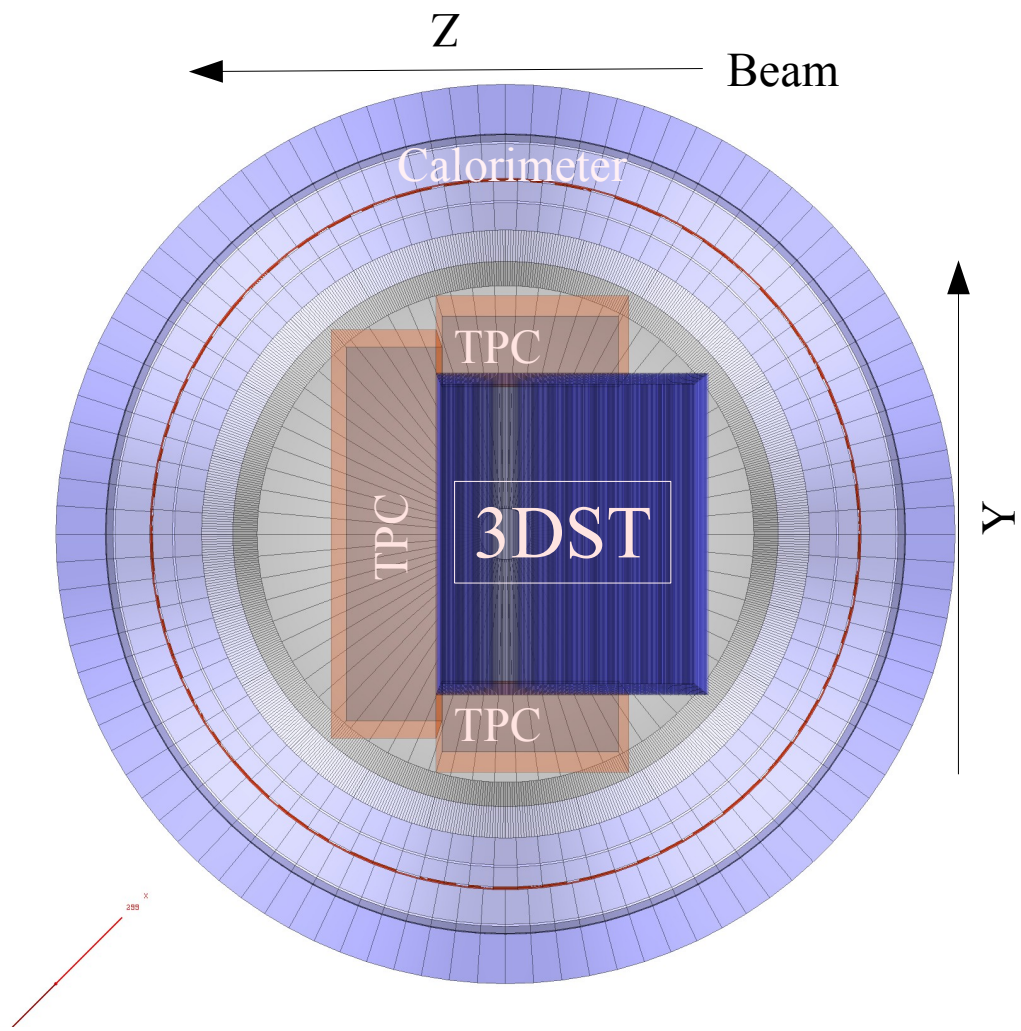
- Track pattern recognition details
- Muon efficiency relative to other tracks

TL;DR

- The simulation and reconstruction follows the lead of the SuperFGD
  - Response based on a beam test done at CERN (arxiv.ins-det:2008.08861)
    - Full "microscopic" simulation from energy deposition through electronics.
  - Event reconstruction applied to simulated events
- Reconstruction outputs
  - Position (x, y, z, t)
  - Direction (for longer tracks it's chosen based on time-of-flight)
  - Energy Deposition (both total and local)
  - Exception: very small energy deposits only provide positions, times and energy deposition (with a threshold of approximately 100 KeV)
- Current tracking efficiency
  - Muons: >99% for isolated tracks
  - Pion: 85% to 90% over 100 MeV/c
  - Proton: about 90% over 400 MeV/c, 50% at 350 MeV/c
- Vertex resolution (not in this presentation)
  - Multi-track: 5.4 mm (average)
  - Single-track: 8.2 mm (average)
  - Time resolution: 0.52 ns (excluding tails)

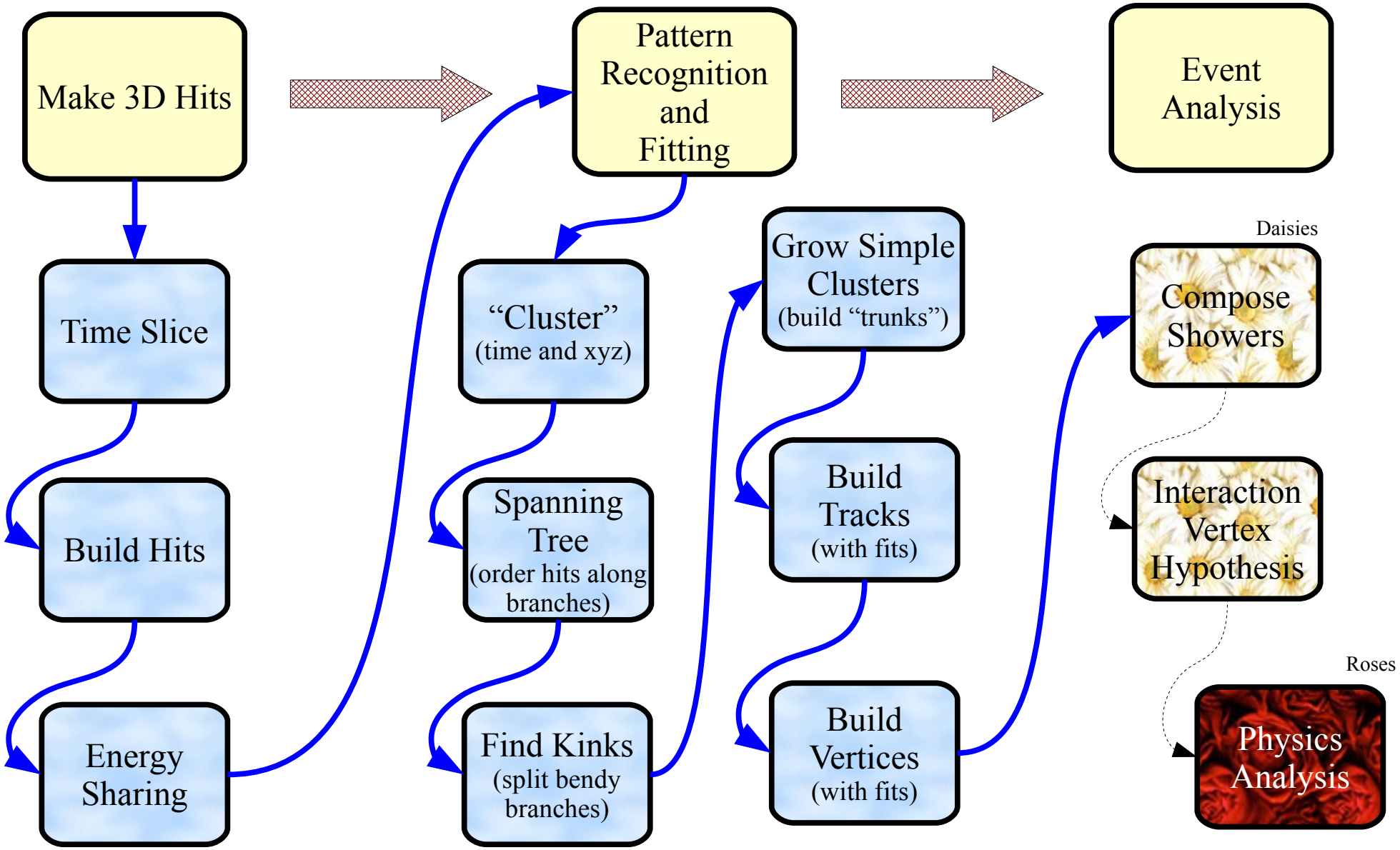
Geometry for 3DST, TPC, Calorimeter & Magnet

- All geometry is taken from DUNE ND-GGD
  - Software uses the input geometry, so it's insensitive to updates
- 3DST Geometry
  - Cube size: 10mm x 10 mm x 10 mm
  - Cubes: 252 x 236 x 200 (11.8944 M)
  - Channels: 157072
    - 59472 xy + 50400 xz + 47200 yz
  - Mass: 12.49 tons
- TPC
  - Based on Resistive MicroMEGAs
- Calorimeter
  - KLOE calorimeter installed with magnet
- Magnet: 0.4 Tesla



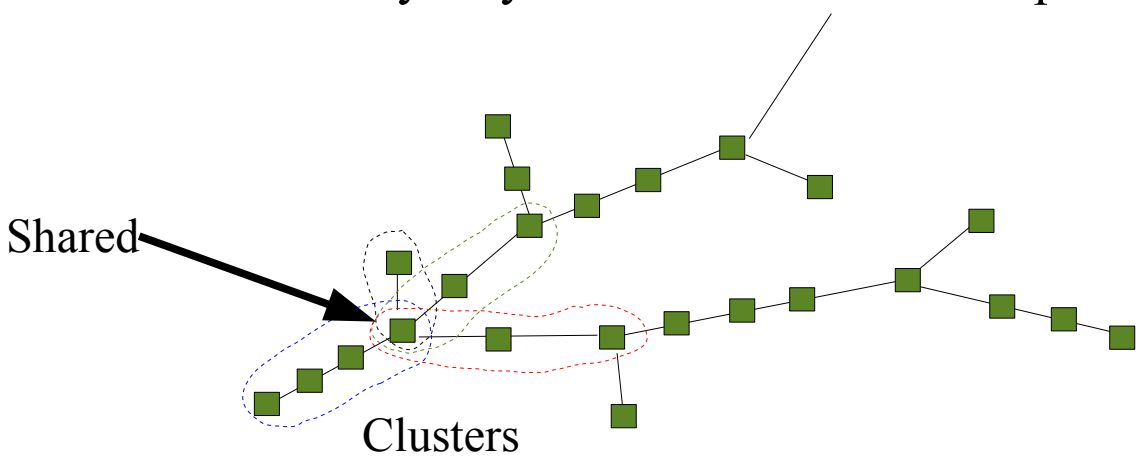
SAND Geometry v.13

The Flow of the Reconstruction



Clusters produced by the MST

- The order of the hits in the cluster is significant
  - A slight misuse of the TClusterRecon object
- The tree is built from branches, and each branch is a sequence of hits
  - Each cluster represents one branch
  - The hits in the cluster are ordered from "first" to "last"
    - Choice between which is "first" and which is "last" is arbitrary
      - Upstream is "first", downstream is "last" (mostly...)
- The "first" and "last" hits in a cluster are usually shared with another cluster
  - This is how the connections between the branches are saved.
    - Side note: there are easy ways to find and remove duplicates.



Cluster Growth

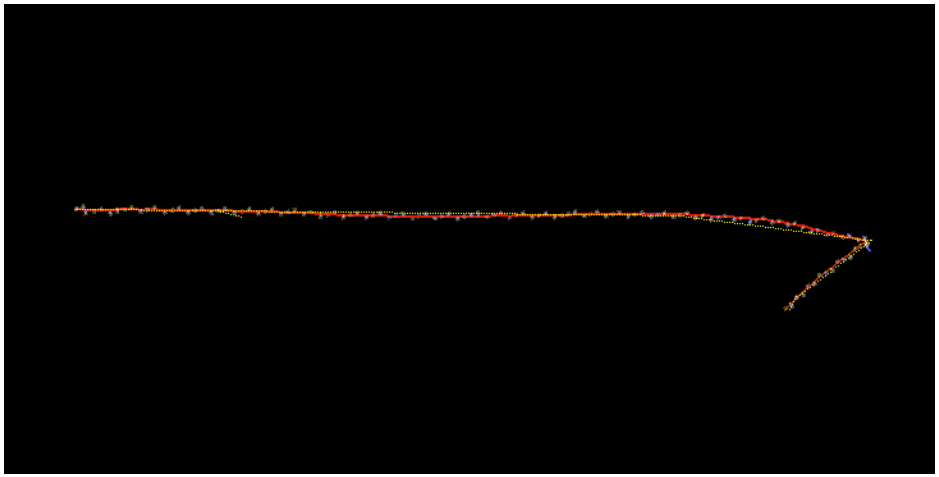
- The track segments found by the minimal spanning tree are combined into longer segments
- Possibly combine clusters sharing a single hit (i.e. they are neighbors)
  - Choose best pair of clusters based on
    - Product of the number of hits in each cluster (prefer more)
    - Product of the minimum charge in each cluster (prefer larger)
    - Change in χ^2 to a line ($\Delta\chi^2 = \chi^2_{1+2} - \chi^2_1 - \chi^2_2$)
  - If the best pair meets the goodness criteria, then combine
  - Criteria assumes that tracks are locally straight
    - Misses a "Y" when a pair of track segments are almost colinear
- Continue until there are no more candidates that can be combined.

Combine Short into Long Tracks (Cube::GrowTracks)

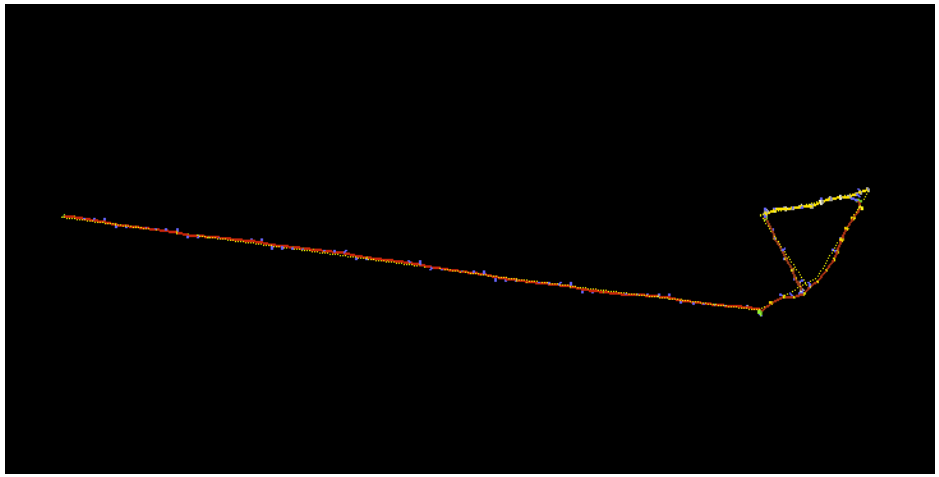
- Combine pairs of tracks that have a good match between the end points and directions.
- General algorithm:
  - Queue the tracks based on the number of nodes
    - Longest track first
    - Number of nodes is equivalent to the number of hits
  - For the front of the queue (longest first), compare with remaining tracks.
    - Don't match if the ends are far apart (default > 5 cm)
    - Don't match if the directions are consistent with a kink (default: > 30°)
    - Do match if the χ^2 between the end states is good enough (default: $\chi^2 < 16$)
    - Do match if the changes in direction and projected "miss" distance are small (default: < 10° and < 15 mm)
      - This manages the case where the fitted covariance is underestimated due to the discreet cube positions.
  - When a match is found
    - Remove both tracks from the queue
    - Combine the tracks and put the combined track at the front of the queue
      - It will be the longest track
  - If no match is found
    - Put the track into the output object container.

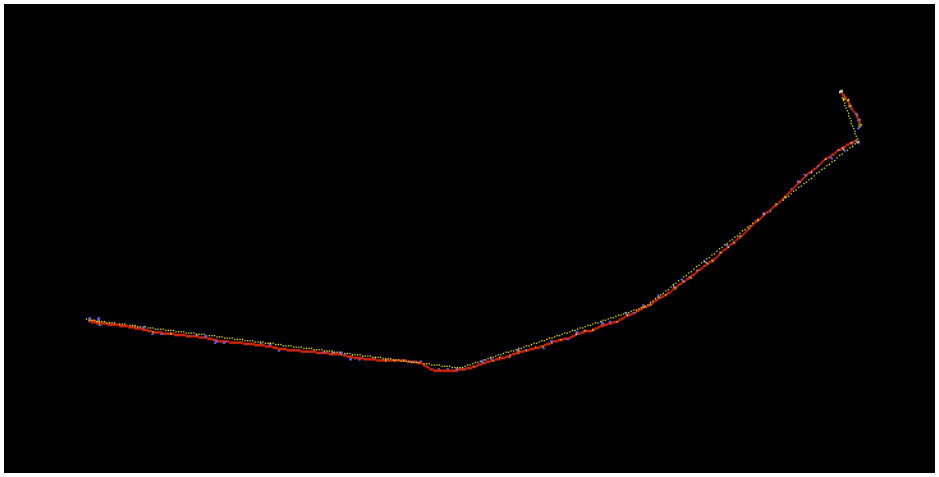
First Four 640 MeV π^+ Particle Gun Events as Reconstructed

Decay at rest to muon (electron is visible)

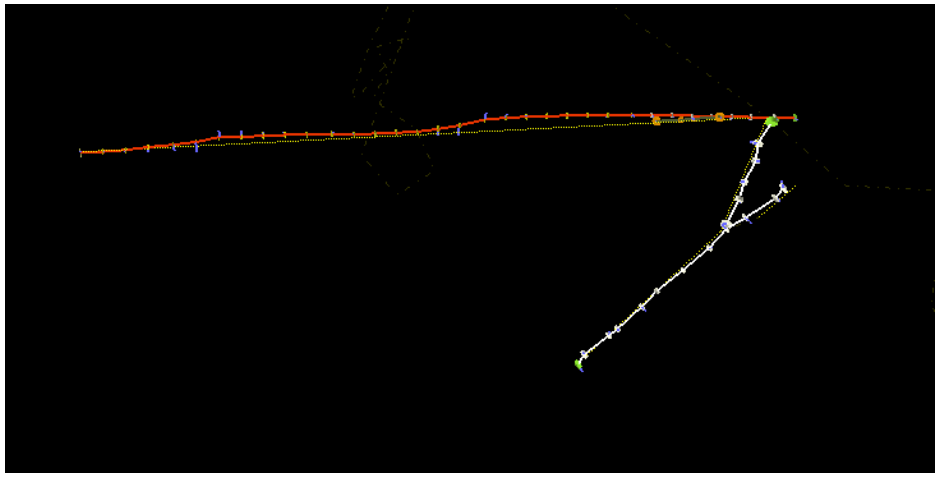


Hard secondary scatter followed by decay at rest





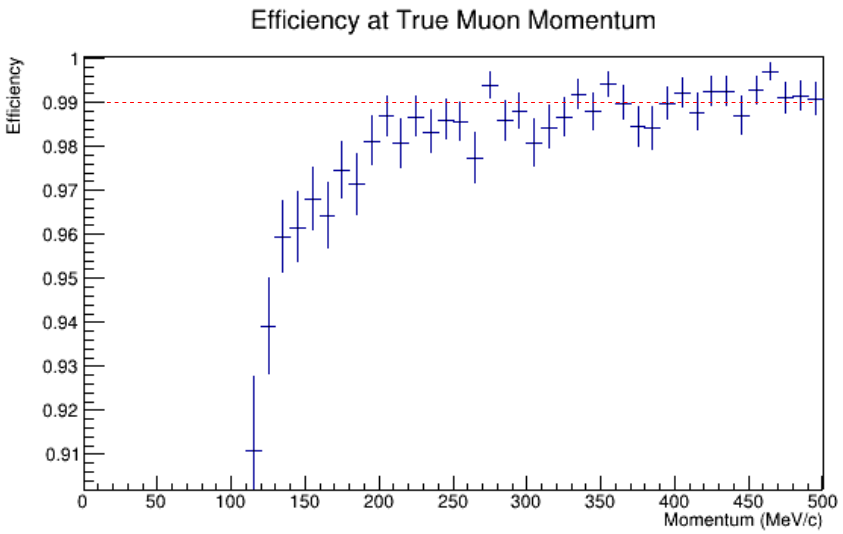
Hard scatter followed by decay in flight



Hard scatter to $\pi \rightarrow \pi$ (250 MeV) $\rightarrow$ p + p

Track Reconstruction Efficiency (10/5)

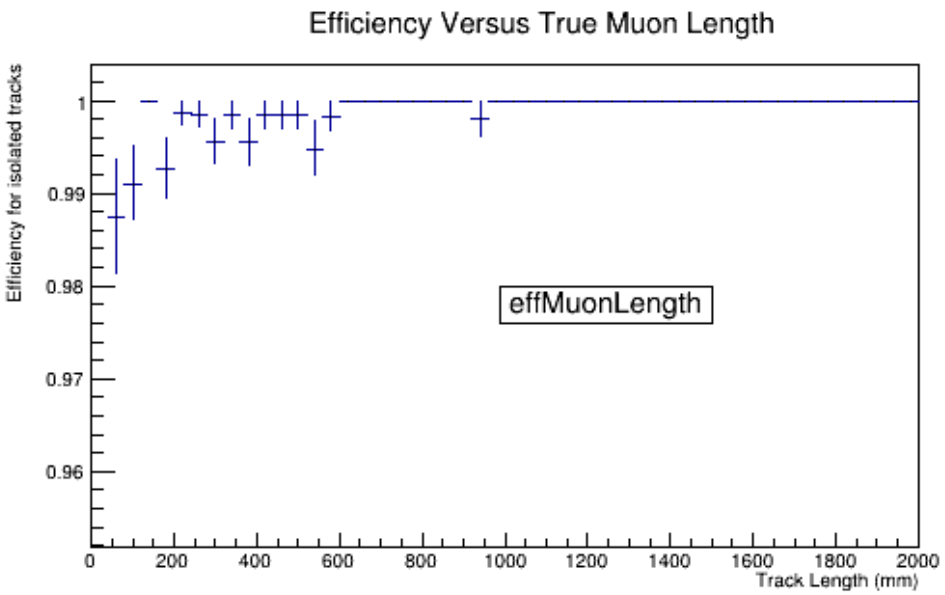
- The reconstruction efficiency is studied with a "particle bomb"
  - Muon 100 – 700 MeV/c (30 degree forward cone)
  - Proton 100 – 600 MeV/c (isotropic)
  - Pion 100 – 700 MeV/c (isotropic)
- CubeRecon, Oct 5, 2019 version
  - 1,000,000 generated events (40,000 used so far)
- Efficiency (same for μ, π^+, and p)
  - Reco: Reconstructed track associated with primary particle
    - > 90% of length from primary
  - True: Primary particle
    - starting point more than 5 cubes from the edge

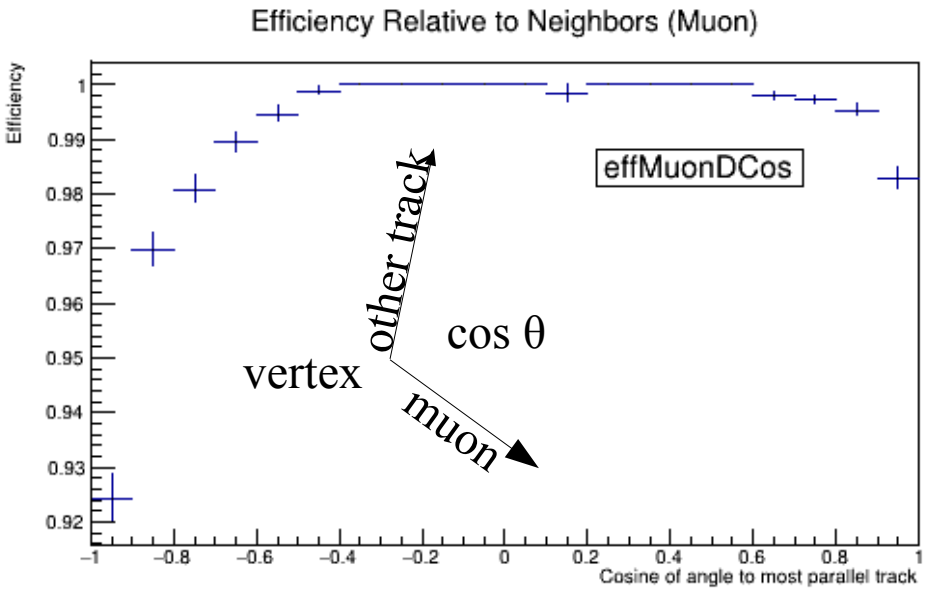


- Muon efficiency ~ 99% above 200 MeV/c
  - Note suppressed zero!
  - Inefficiency due to parallel and overlapping tracks
    - Depends on the phase space of the test sample

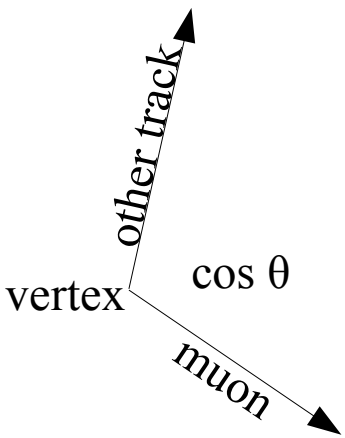
Muon Efficiency for Sub-samples

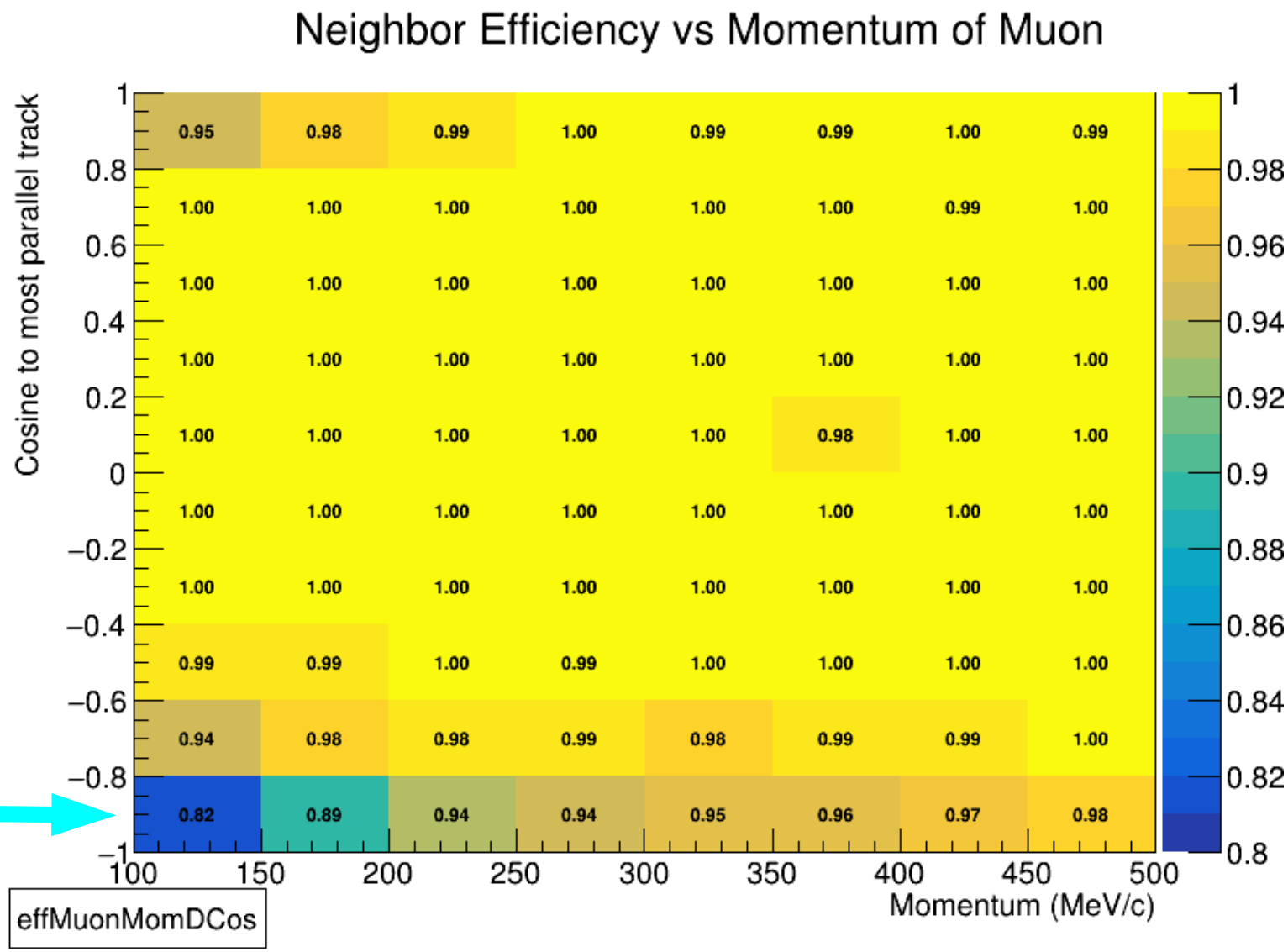
- Efficiency for non-parallel muons
  - Only includes tracks where the primary is doesn't have another track with a similar direction
    - Angle to nearest neighbor is between 25 and 120 degrees
- Efficiency versus angle to neighboring tracks
  - The angle to the closest (most parallel) track from the same vertex
  - There is a third track, but it is at a wider angle.





Muon Efficiency vs Cosine of Angle to Nearest Track

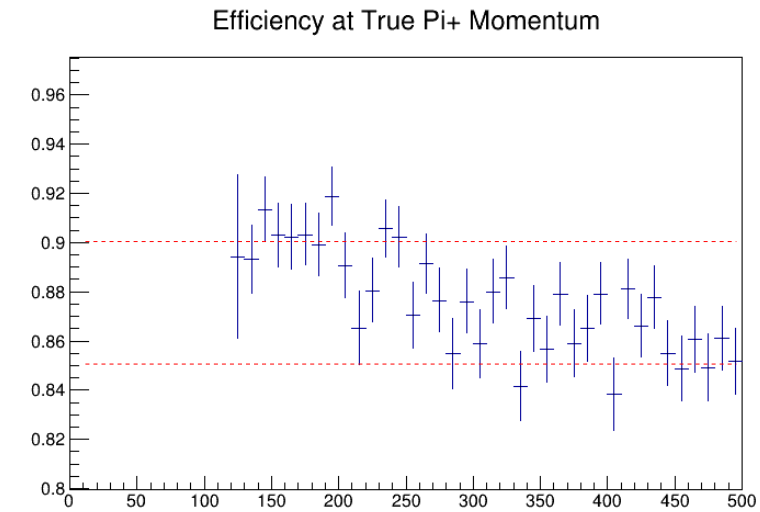


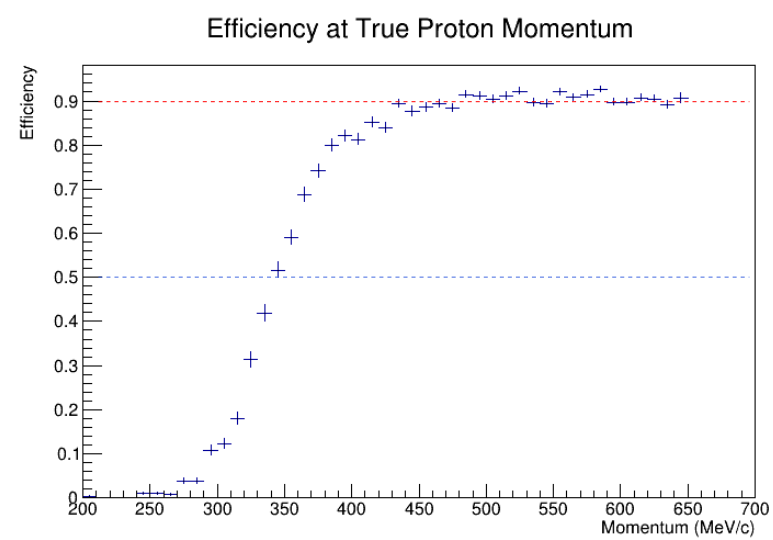


Vertex between tracks is being interpreted as a kink

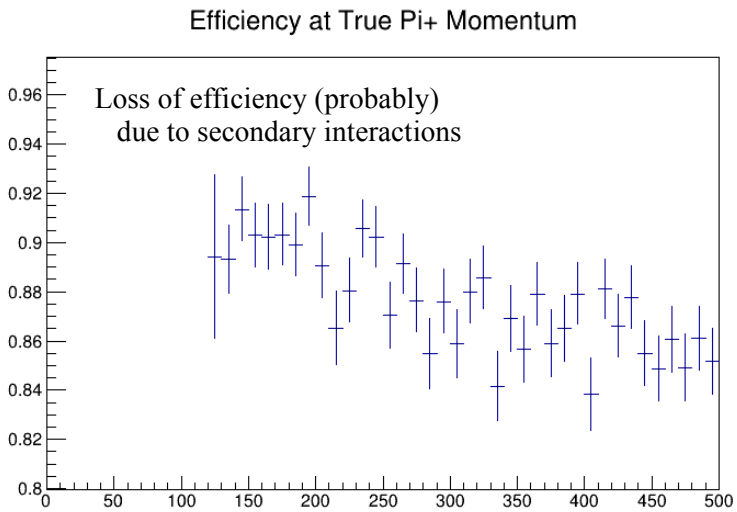
Proton and Pion Tracking Efficiency

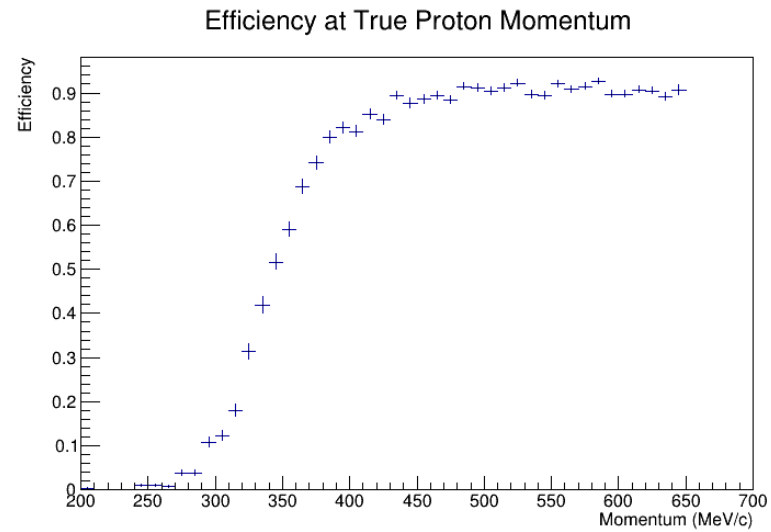
- Integrated over isotropic "4π" distribution
  - Events have a muon (forward-going), pion and a proton
- Tracks that are "anti-parallel" to muon are treated as a kink in the muon tracks (~5% of tracks)
  - A kink of less than about 20°
- Inelastic hadronic interactions contribute to inefficiency
  - Changes the direction of the track, or truncates the track
  - Causes ~5% inefficiency
- Proton momentum threshold (350 MeV/c)
  - Tracks must have 4 cubes, implies track longer than 3 cm

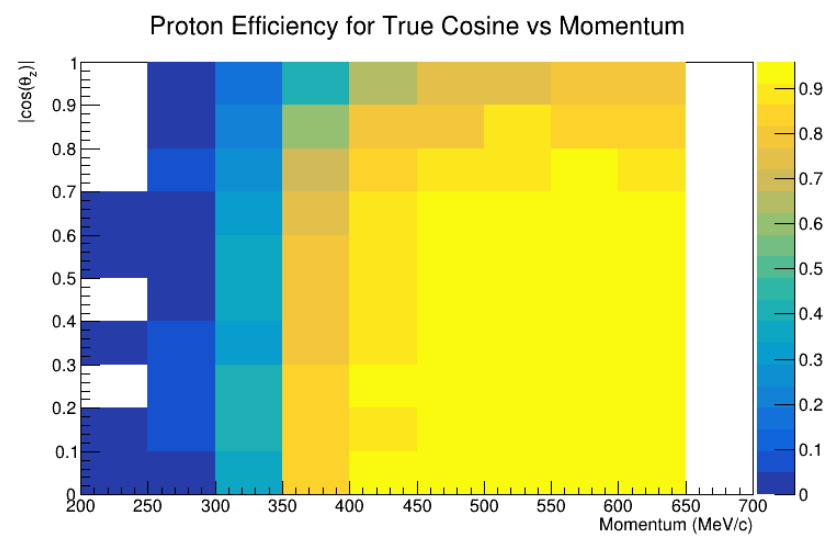




Tracking Efficiency (charged pion and proton)







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