Improving multi-track reconstruction algorithms in the Mu2e experiment

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Target of the Mu2e Experiment

- The Mu2e experiment, under construction at Fermilab, will search for neutrinoless coherent $\mu^- N \to e^- N$ conversion in the field of Al nucleus by measuring

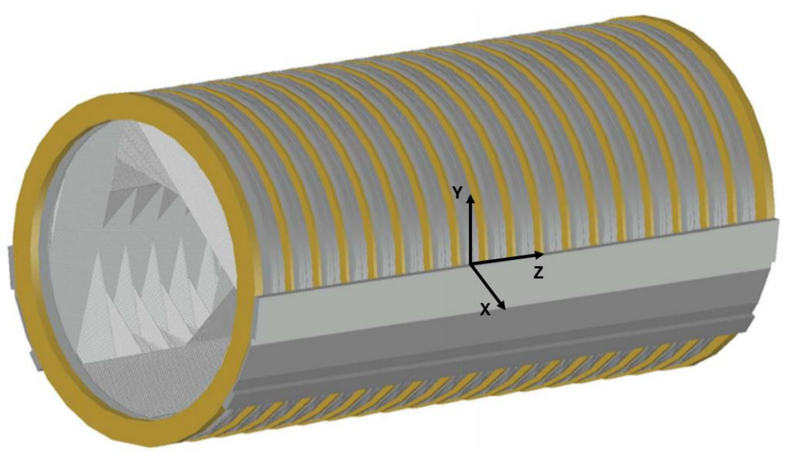
$$R_{\mu e} = \frac{\Gamma\left(\mu^- + N(Z,A) \to e^- + N(Z,A)\right)}{\Gamma\left(\mu^- + N(Z,A) \to \nu^- + N(Z-1,A)\right)}$$

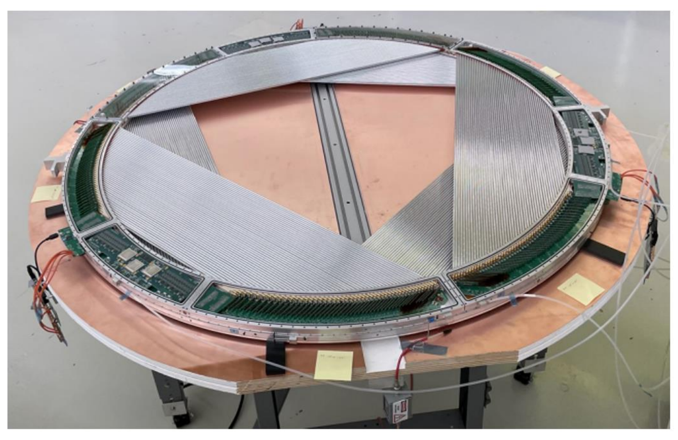
- The signature for muon conversion is a monochromatic e^- of 104.97 MeV/c.
- Mu2e Run I should be able to claim a 5σ discovery sensitivity: $R_{\mu e} = 1.2 \times 10^{-15}$. If no signal is observed, the upper limit is $R_{\mu e} < 6.2 \times 10^{-16}$ at 90% CL.

Source of multi-track events

- While the goal of the experiment is to observe an event with a single track, there is a strong motivation to develop an efficient tracking algorithm capable to reconstruct more simultaneous tracks. Among these:
  1) To constrain the background generated by pp̄-annihilation in Al target.
  2) To detect e^+e^- pairs from photon conversion.

Mu2e Tracker





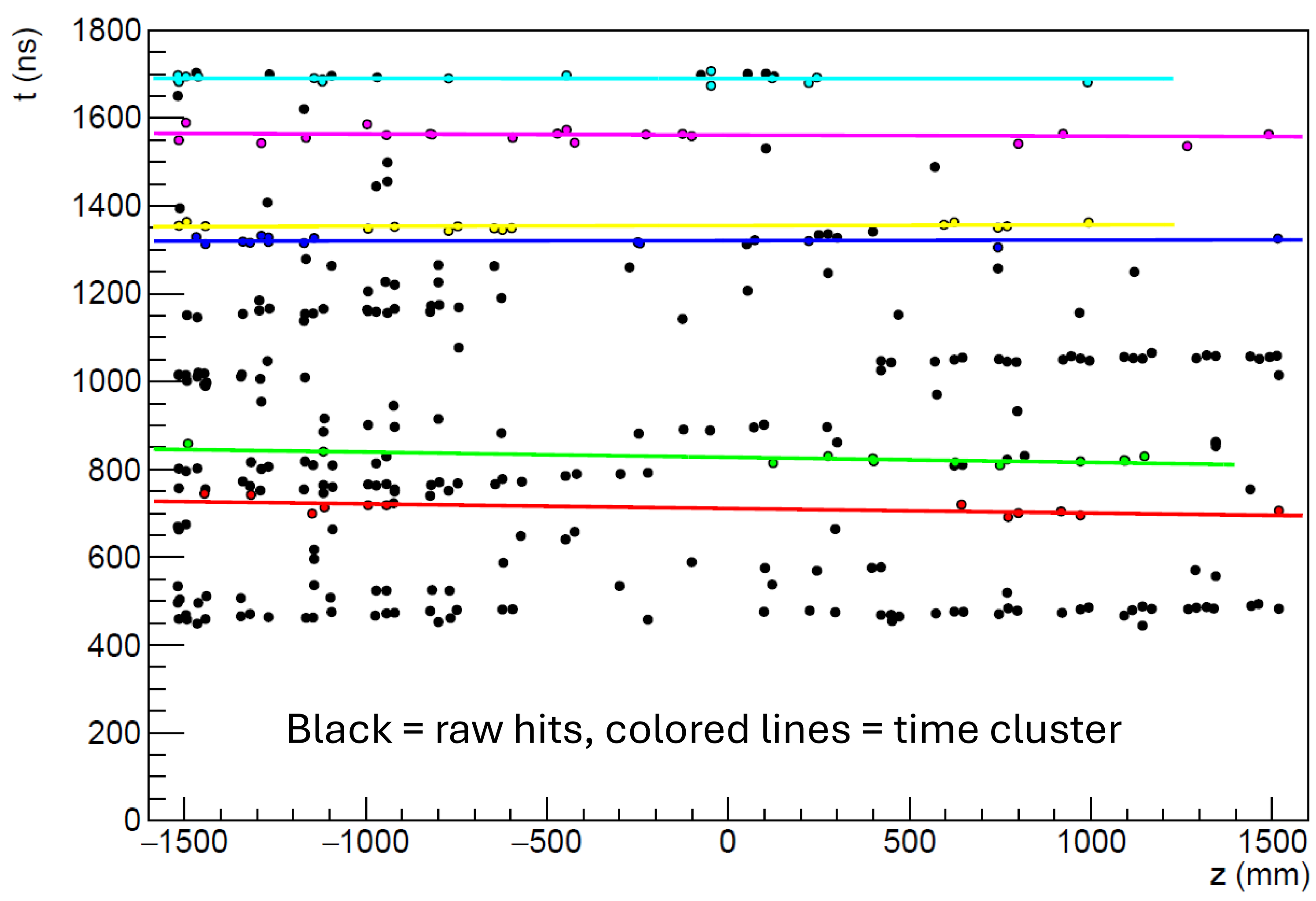
1) The straw-tube tracker is located in a 1T uniform magnetic field. It is approximately 3 m long and consists of 18 tracking stations with 1152 straws per station. The straws are filled with 80%: 20% $Ar: CO_2$ mixture.
2) Each straw is read from both ends, providing two timing measurements for each hit. The difference between the measured times is used to reconstruct the hit coordinate along the straw.

Track reconstruction algorithm

- Track reconstruction is divided in 4 sequential stages:
  1) Hit Reconstruction: raw current signals are converted into positional data and x, y, z, time, etc., are stored for each straw hit.
  2) Time Clustering: hits close in time to each other are grouped together to create time clusters.
  3) Helix Finding: using hits within time cluster one searches for a helical trajectory. Hits along a helix are grouped together to create helix seed.
  4) Final Track Fit: a Kalman filter is performed on the helix seed.

TZClusterFinder

- Time clustering algorithm can be improved by searching for lines in time vs z coordinate space, where z is the axis of the tracker.



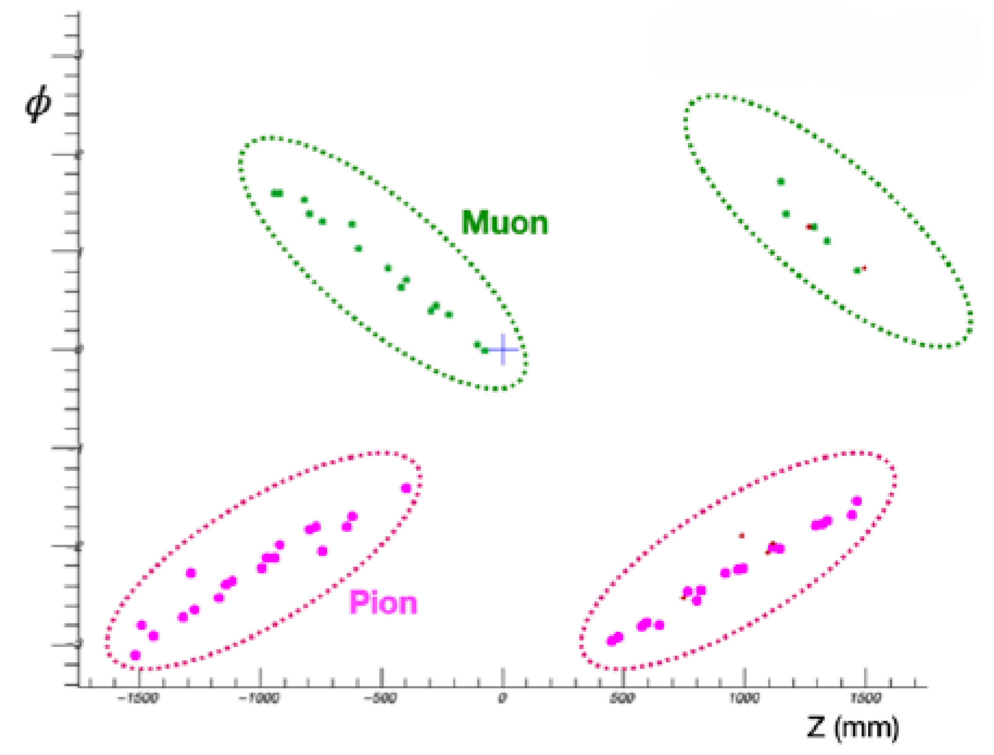
TZClusterFinder shortcomings

- New time clusters are inhomogeneous and contain hits of different particles.
- In many cases, they do not have well-reconstructable tracks.
- To reconstruct tracks of simultaneous particles, it is necessary to separate hits of different particles in different clusters.

TZClusterFilter

- Simultaneous tracks can be well separated in $\phi = \tan^{-1}(y/x)$.
- Different particles leave similar patterns inside the tracker.
- By searching for straight lines in ϕ vs z space, the new algorithm can recognize hits belonging to the same particle and select the time clusters with well-reconstructable tracks.
- At the same time, it can separate simultaneous tracks in different clusters before the helix finding.

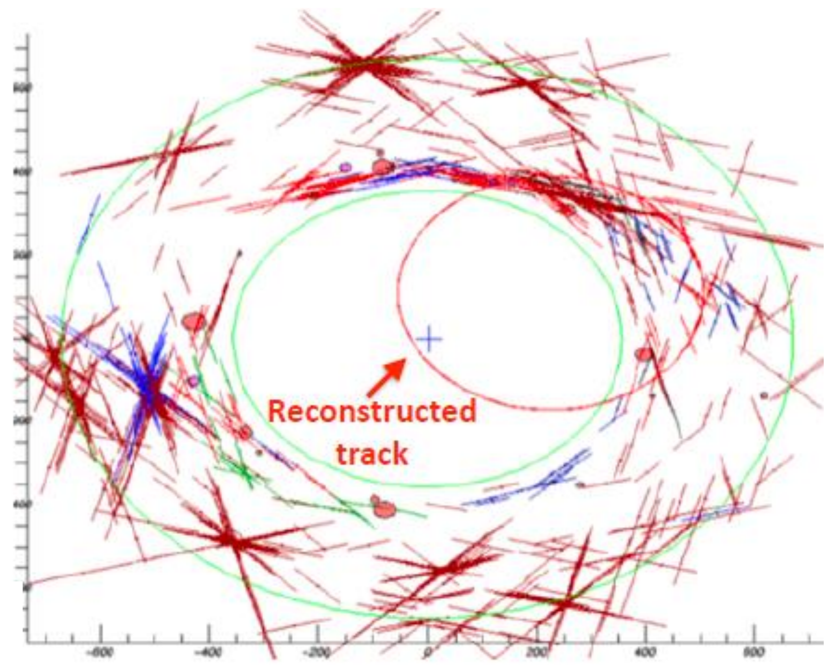
Example of hit separation in phi-z plane: hits coming from a muon and a pion produced from a $p\bar{p}$- annihilation

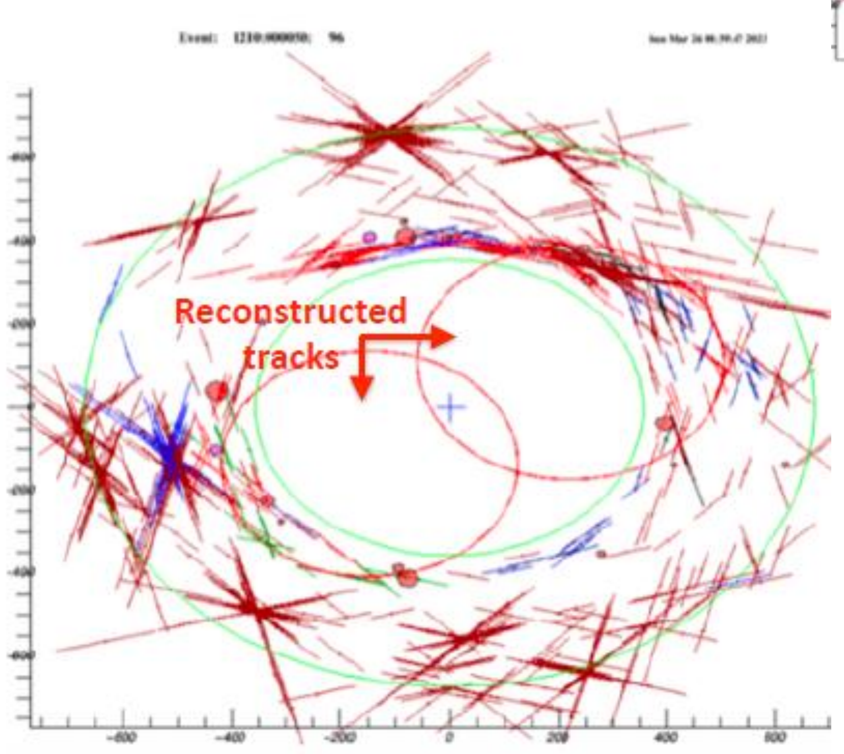


Results

The two pictures shows the same event of pp̄-annihilation in presence of the pileup hits produced by other beam particles. The standard clustering algorithm does not allow to reconstruct the second track that, in contrast, is well reconstructed using the new clustering algorithm.

Default Reconstruction





New Reconstruction

Conclusions

- We developed a new algorithm, TZClusterFilter, to recognize time clusters containing well-reconstructable tracks.
- We tested it with datasets containing the $\mu^- \to e^-$process and pp̄-annihilation mixed with background.
- The algorithm selects 99.2% of time clusters containing the $\mu^- \to e^-$process and 90% of time clusters containing pp̄-annihilation products.
- It rejects 77% of the time clusters which do not contain these processes.

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