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The Pandora multi-algorithm approach to automated pattern recognition of cosmic-ray muon and test beam events in the ProtoDUNE-SP detector

First Author · Second Author

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1 Introduction

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2 ProtoDUNE-SP

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3 Pattern Recognition

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3.1 Algorithm Chains

3.1.1 Pandora Test Beam

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3.1.2 Pandora Cosmic

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3.2 Consolidated Reconstruction

The consolidated reconstruction is a framework designed to reconstruct test beam particles in the presence of cosmic ray backgrounds. The process utilises both the Pandora Teat Beam and Cosmic algorithm chains in order to apply the optimal pattern recognition logic to any given scenario.

The consolidated reconstruction begins by running the Pandora Cosmic algorithm chain that reconstructs all particles under the cosmic ray particle hypothesis. The reconstructed particles are then examined in order to determine if they are clear cosmic rays. Two distinct methods are used for identifying clear cosmic rays:

- If the hits for the reconstructed particle fall outside the expected read out time window for the target test beam particle.
- If it the reconstructed particle enters the detector through the top face and exists the lower face.

Reconstructed particles identified as clear cosmic rays are then set aside to form one part of the reconstructed event output and what remains int he event is analysed further. These remaining hits are then put through a slicing produced that is designed to group hits together across all three views into regions that contain a single parent particle. Slicing involves running a reduced version of the full reconstruction, where particles are reconstructed up to 3D, but the finesse of particle hierarchies is not considered. By reconstructing the particles up to 3D, correlations across the three input views are considered when dividing up the event into separate regions, or slices, which is more powerful than dividing up each view independently. Each slice is then dissolved back into input hits and the Pandora Test Beam and Cosmic algorithm chains applied.

At this stage each slice has two possible reconstructed outputs, based on the test beam and cosmic hypotheses respectively, that are compared in order to determine the most appropriate output to persist. In ProtoDUNE a Boosted Decision Tree (BDT) is used for this decision. The following features are used as inputs to the boosted decision tree:

- The distance of the closest 3D LArTPC hit to the beam spot.
- The direction and angle of a spatial fit to the reconstructed 3D hits with respect to the beam line.
- The eigenvalues of the covariance matrix of the spatial position of the 3D LArTPC hits.
- The vertical distance of the reconstructed 3D LArTPC hit closest to the top of the detector.
- The number of reconstructed particles.

The distribution of the output BDT scores for signal, true beam particles, and background, cosmic rays, is shown in figure BLAH. Any slice reconstructed with a BDT score greater than -0.225 is classified as a teat beam particle and the Pandora Test Beam reconstruction output is persisted. All other slices are reconstructed as cosmic rays with the Pandora Cosmic hypothesis persisted.

4 Assessment of Pattern Recognition

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4.1 Monte-Carlo

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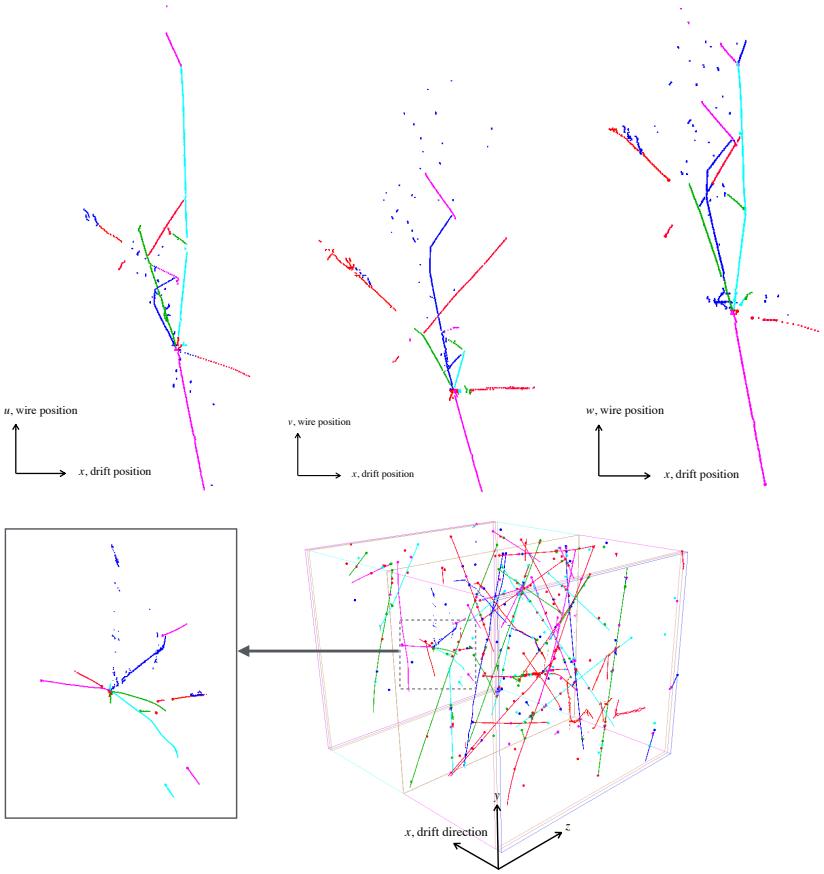

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4.1.1 Test Beam Metrics

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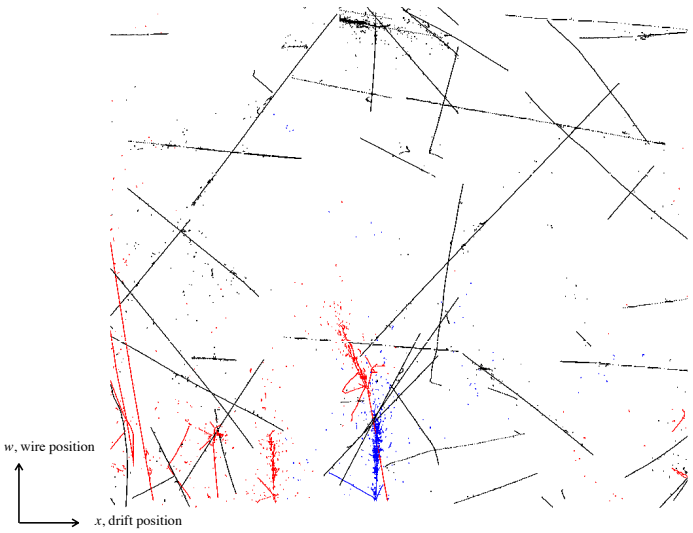

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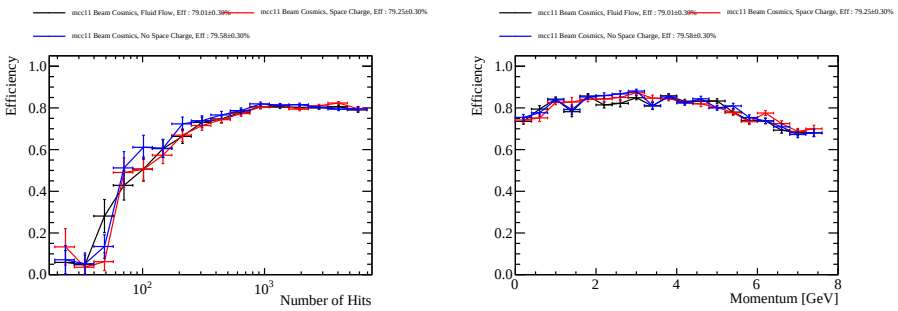

Fig. 3 The test beam particle reconstruction efficiency as a function of the number of hits in the test beam particle and the test beam particle momentum.

Table 1 The reconstruction efficiency for the test beam particle in MC as a function of beam momenta.

Beam Momenta [GeV]	Reconstructed Efficiency
1	87.5±0.8
2	91.0±0.7
3	92.7±0.6
4	89.8±0.5
5	89.0±0.5
6	82.1±0.7
7	75.4±0.7

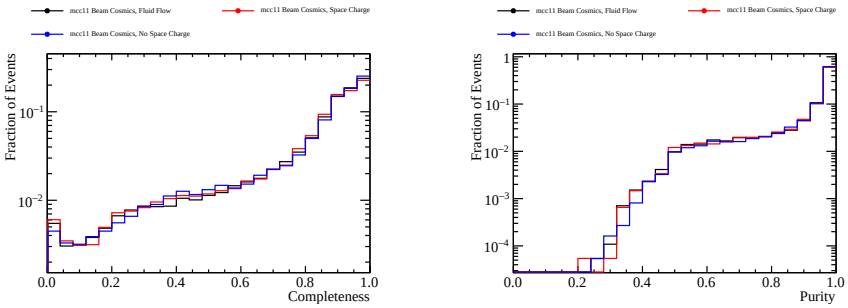

Fig. 4 The purity and completeness of reconstructed test beam particles in MC.

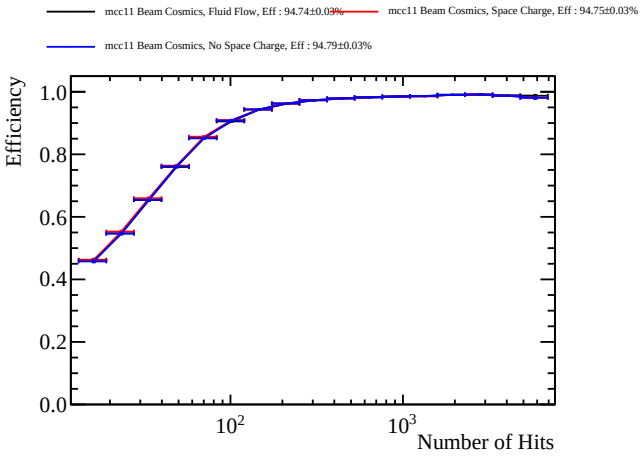

Fig. 5 The reconstruction efficiency for cosmic rays in MC as a function of number of hits.

4.1.2 Cosmic Ray Metrics

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4.2 Data

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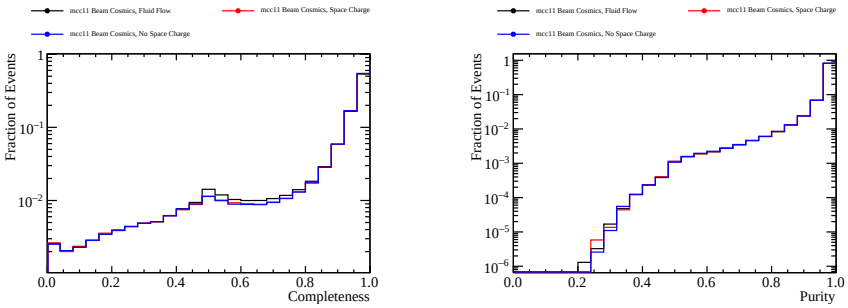

Fig. 6 The purity and completeness of reconstructed cosmic ray particles in MC.

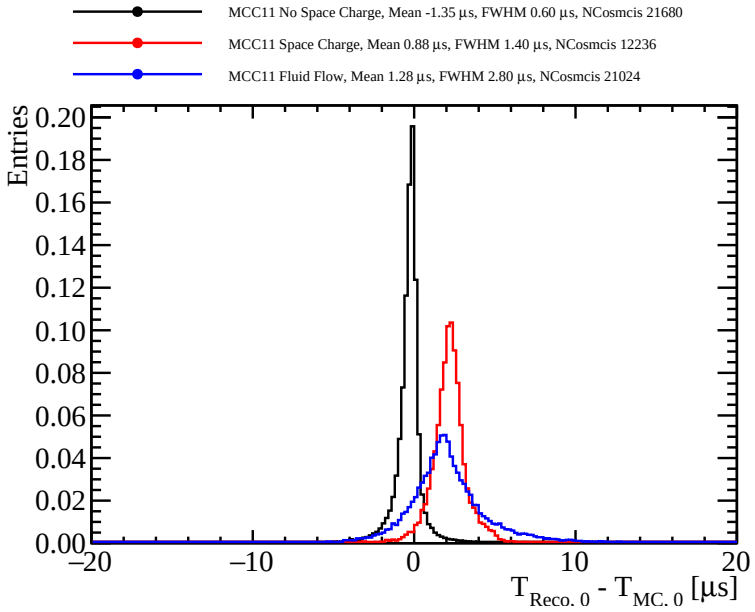

Fig. 7 The resolution purity and completeness of reconstructed cosmic ray particles.

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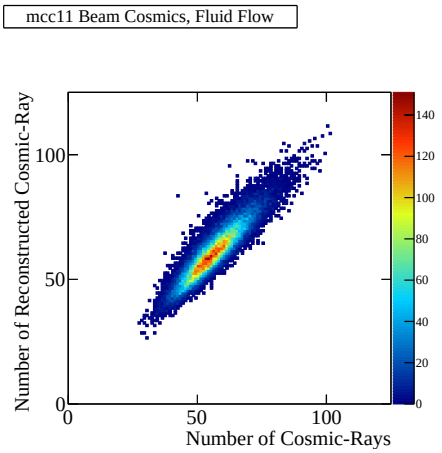

Fig. 8 Please write your figure caption here

Table 2 The reconstruction efficiency for the test beam particle in data as a function of beam momenta.

Beam Momenta [GeV]	Reconstructed Efficiency
0.3	43.2±0.3
0.5	55.4±0.2
1	70.6±0.3
2	84.2±0.3
3	86.8±0.2
6	85.2±0.2
7	83.7±0.2

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4.2.1 Test Beam Metrics

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4.2.2 Cosmic Ray Metrics

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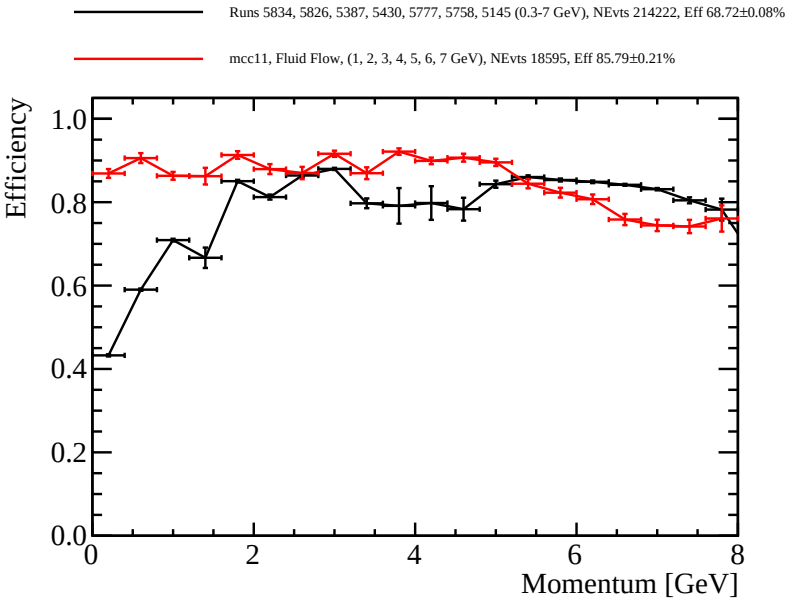

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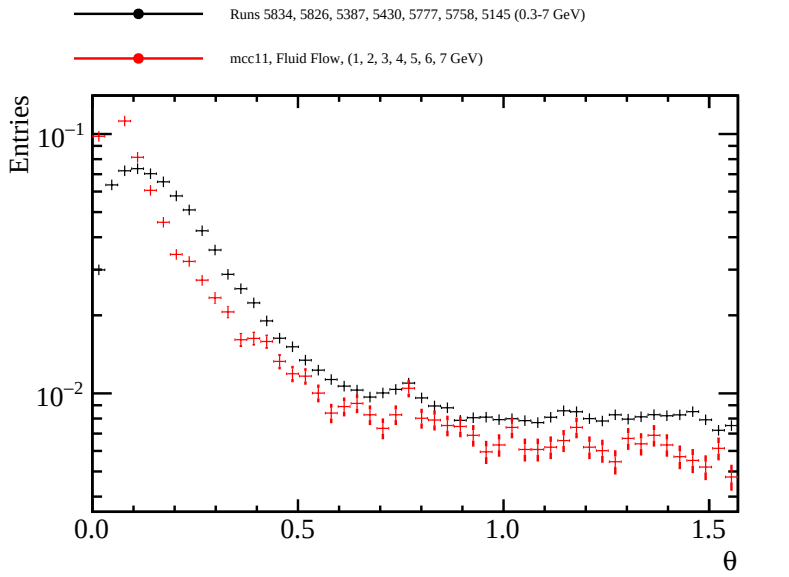

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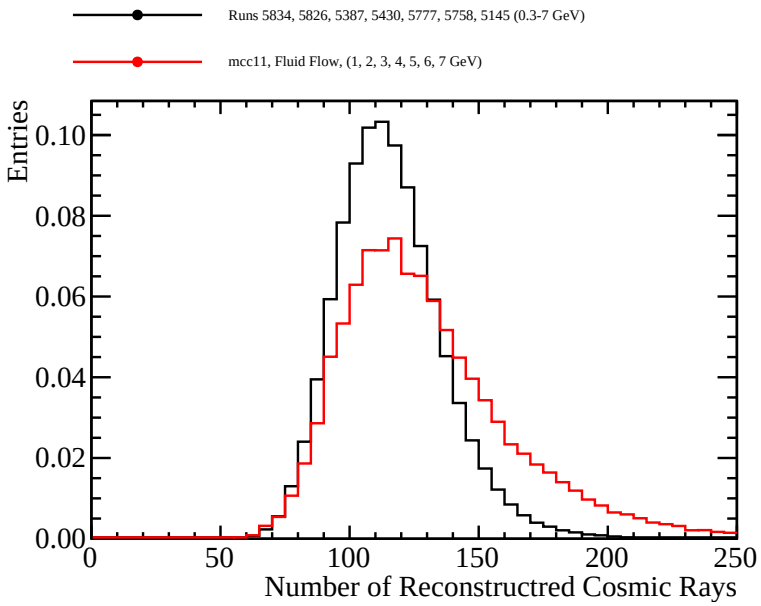

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5 Conclusions

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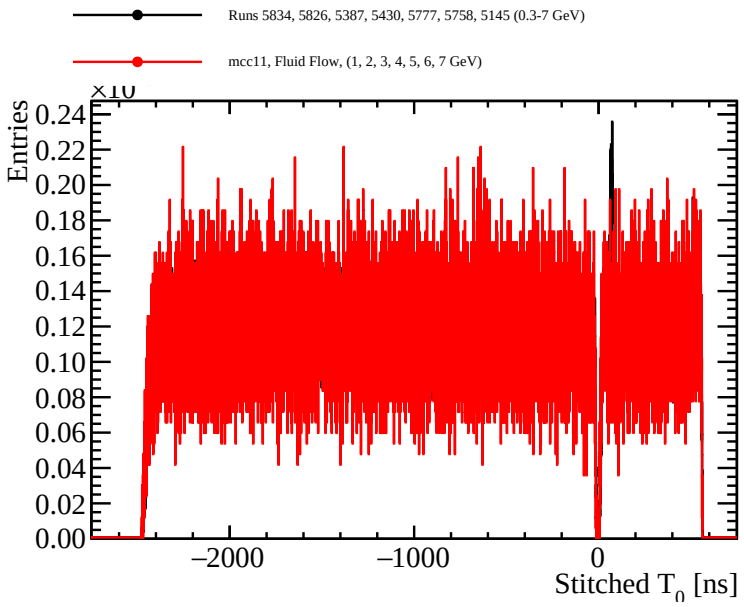

Fig. 12 Please write your figure caption here

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1. Author, Article title, Journal, Volume, page numbers (year)
2. Author, Book title, page numbers. Publisher, place (year)