Vertical drift detector optimisation studies

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LBNC Review

10th May 2021

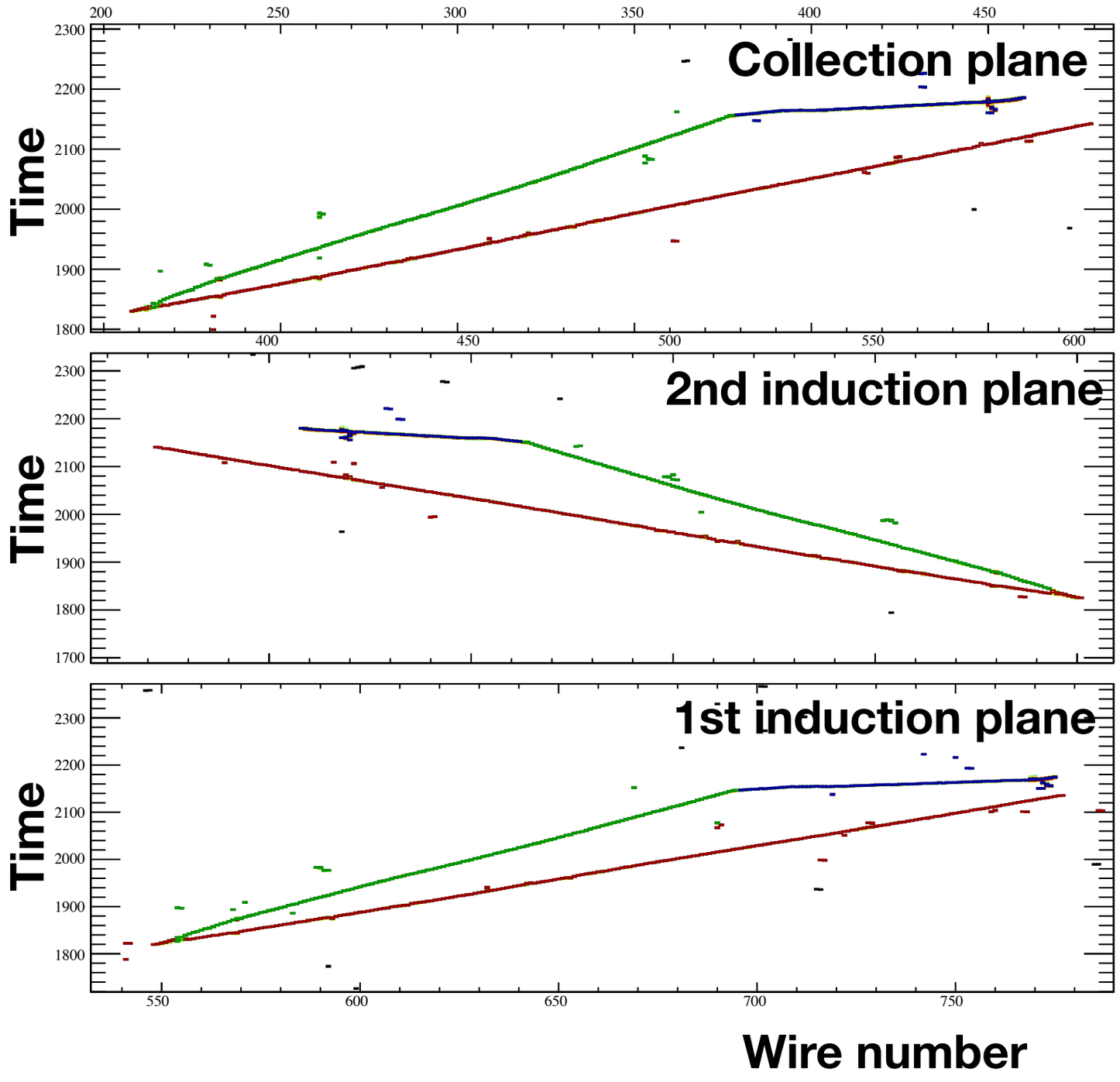
Vertical drift detector optimisation studies

- The reference design of the CRP-based vertical drift detector includes different features to the horizontal drift design
    - Longer drift length
    - A larger pitch in the collection plane
    - Induction plane orientation, including one plane parallel to the beam direction
- Alternative designs feature 2 readout views, and induction planes that are non-parallel to the beam direction

- As the vertical drift simulation is currently being configured, all ongoing optimisation studies use the simulation and reconstruction in the horizontal drift detector
- The initial studies largely focus on the reconstruction impact of a 2 view detector, featured in the alternative design. Those studies broadly investigate the impact on:
    1. Full 3D reconstruction, using the Pandora recognition suite
    2. Event-level neutrino flavour ID, using a Convolution Visual Network (as was used in the DUNE TDR oscillation analysis)

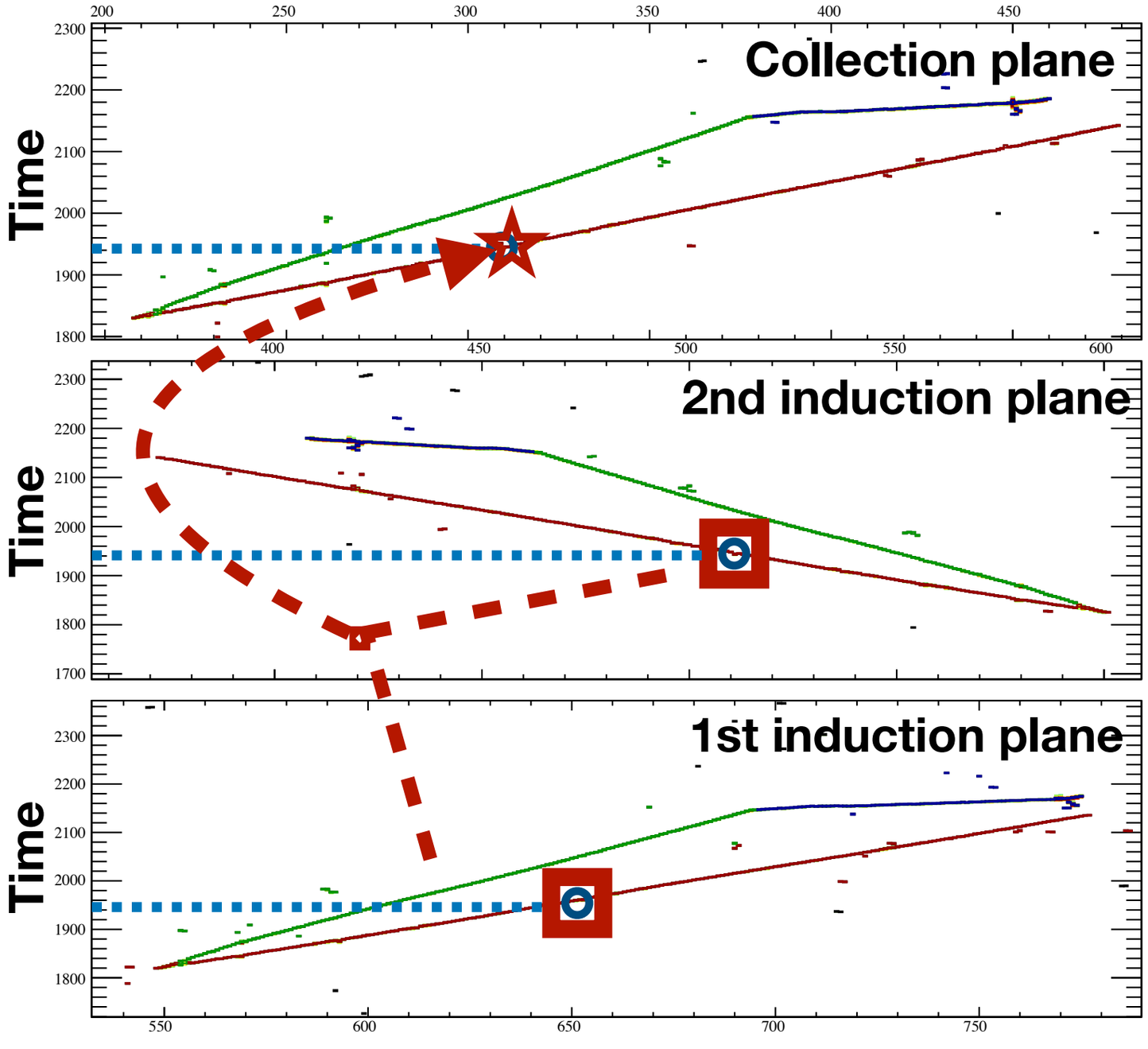
Vertical drift detector optimisation studies using Pandora

- Pandora is a pattern recognition suite used by DUNE's horizontal drift detectors
- Inputs are reconstructed 2D hits
- Outputs are fully 3D, reconstructed particles arranged into parent/child hierarchies
- All 2D stages of the pattern recognition should be largely unaffected by the number of available readout views
- The impact of 2 available views would be largest during the 2D->3D matching stage
    - Where the 2D clusters are matched across views to make 3D particles
- Pandora provides a suite of dedicated 2D->3D matching algorithms



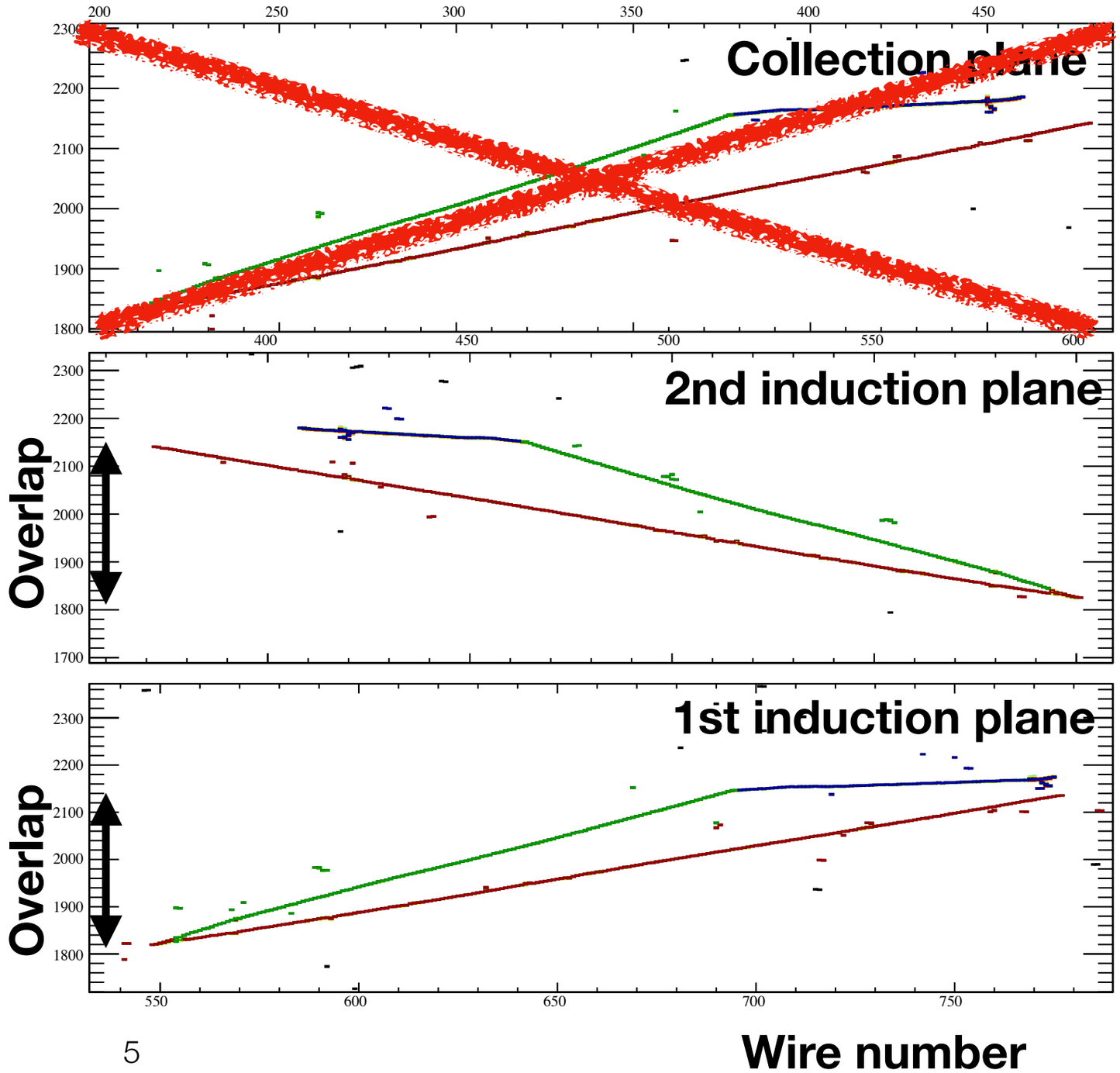
Pandora's 3 view 2D->3D matching using geometry

- Matches 2D cluster triplets across views to make a 3D particle
- Compares equivalent positions in time on each of the clusters in the matching triplet
- Two clusters in each triplet are used to infer positions in the opposing view (e.g. U:V -> W)
- Repeatedly finding a good match between inferred and measured positions indicates a good match



Pandora's 2 view 2D->3D matching using geometry

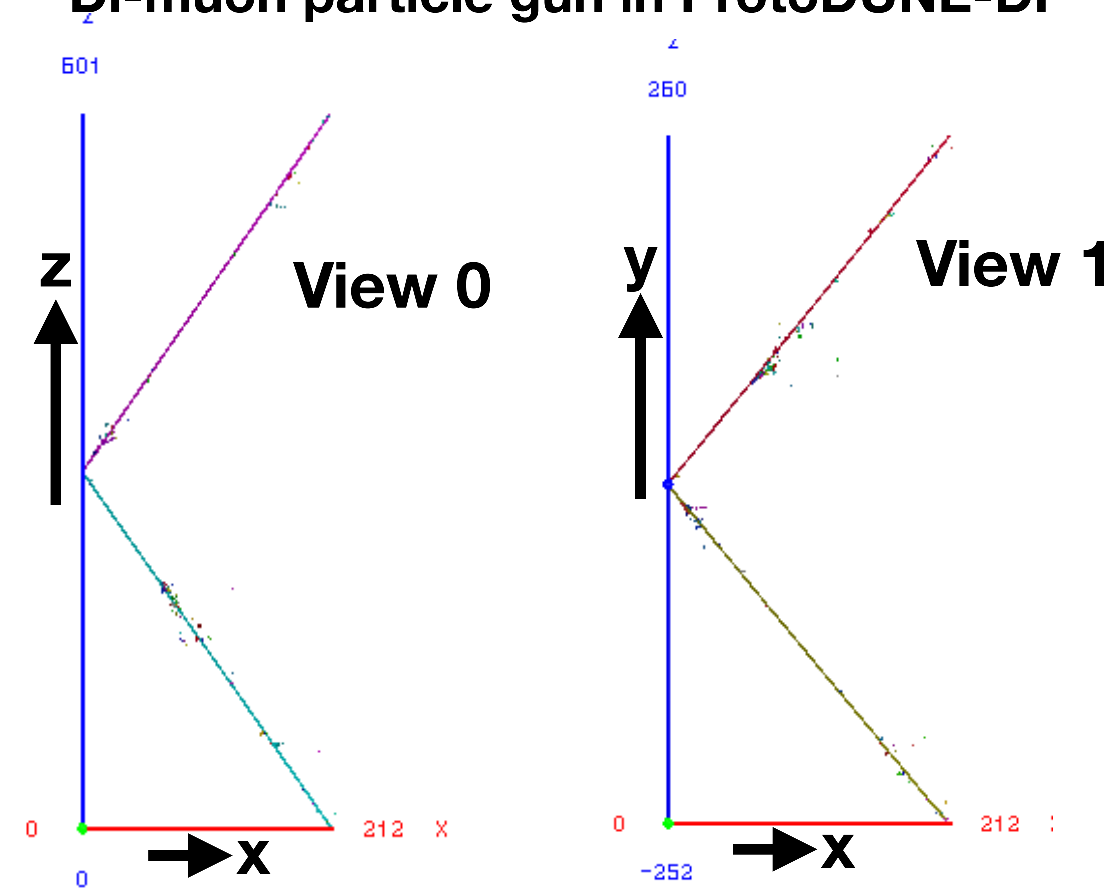
- A lot less to work with when considering geometry alone
- Algorithm measures the overlap/end point proximity of two clusters
- Two clusters end points being in close proximity indicates a good match

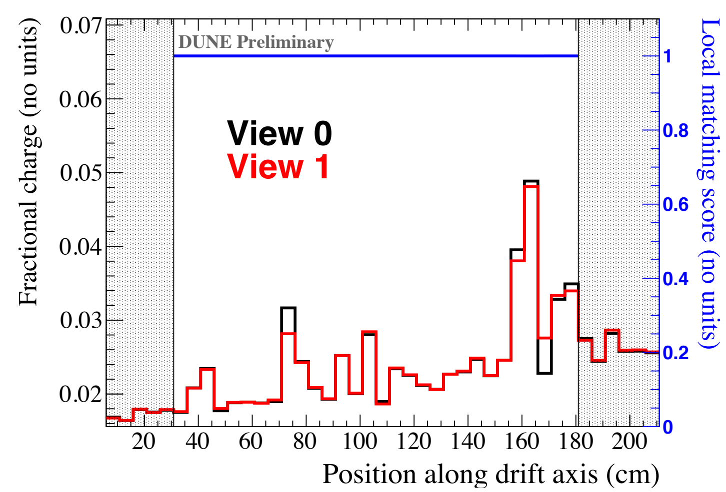


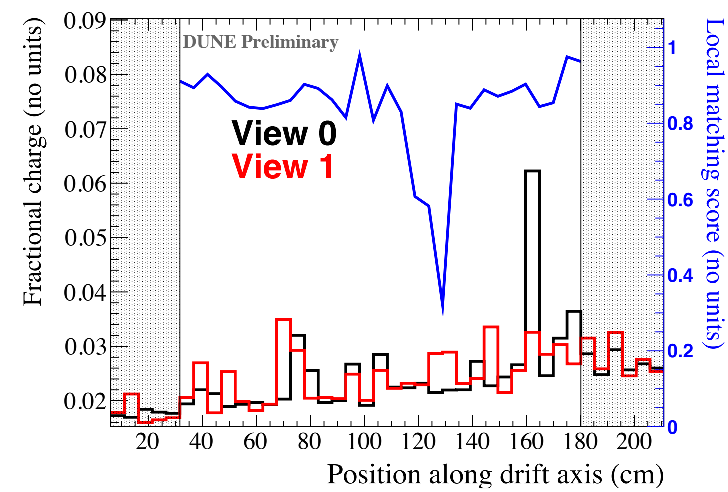
Pandora's 2 view 2D->3D matching using calorimetry

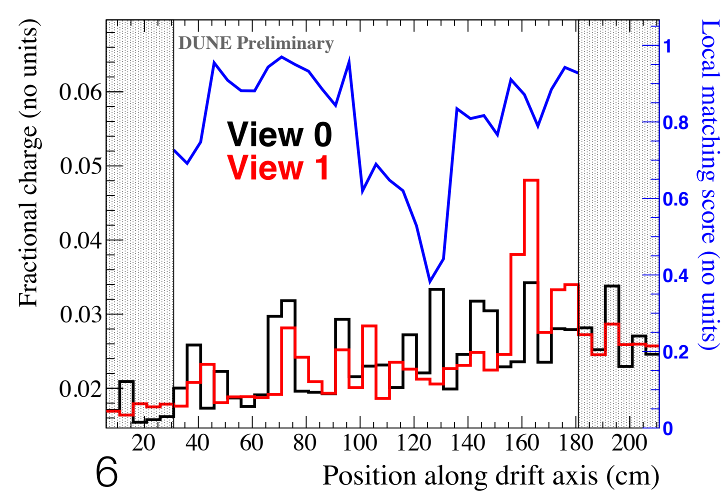
- A new matching algorithm, originally developed for ProtoDUNE-DP (a 2 view LAr TPC)
- Algorithm exploits similarity of energy deposition profiles between views to enhance the 2D->3D matching performance
- Compare fractional charge profiles for 2D cluster pairs where they overlap in time (red and black histograms)
- For each cluster comparison, calculate:
    - Global matching score*
    - Local matching scores* for regions of the overlap (blue curves)
- A high score (global or local) indicates a good match

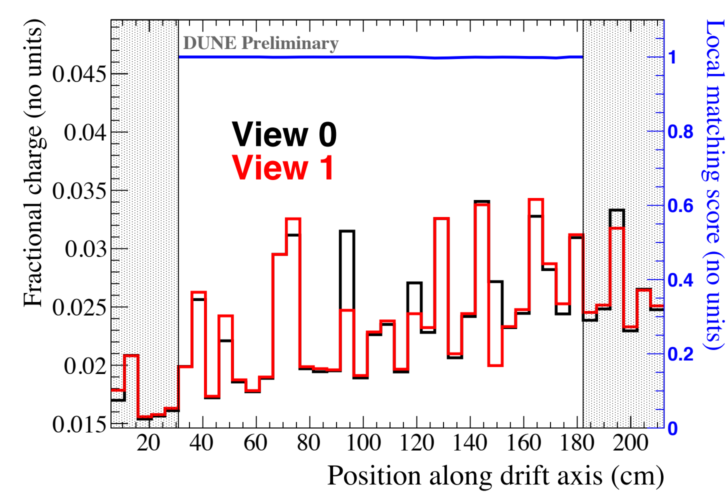
Di-muon particle gun in ProtoDUNE-DP











***Score based on correlation coefficient p-value**

Testing the 2D->3D matching performance of a 2 view/3 view detector

- The studies have been carried out using two versions of the **horizontal drift far detector**
  - The nominal design: induction planes are ~±36 degrees to the vertical
  - The alternative design: induction planes are ~±45 degrees to the vertical

- The studies involve two separate Monte Carlo samples simulated in the horizontal drift far detector
  - ‘Di-muon’ particle gun events
  - Charged current ν_μ interactions simulated using GENIE

- The studies assess three iterations of 3D reconstruction provided by Pandora
  1. **The standard pandora reconstruction workflow for the horizontal drift detector**
     - 3 view and 2 view geometric 2D->3D matching
  2. **Iteration 1 with the collection plane missing**
     - 2 view geometric 2D->3D matching-only
  3. **Iteration 2 with the calorimetry-based 2D->3D matching**

Di-muon reconstruction efficiency (particle gun simulation)

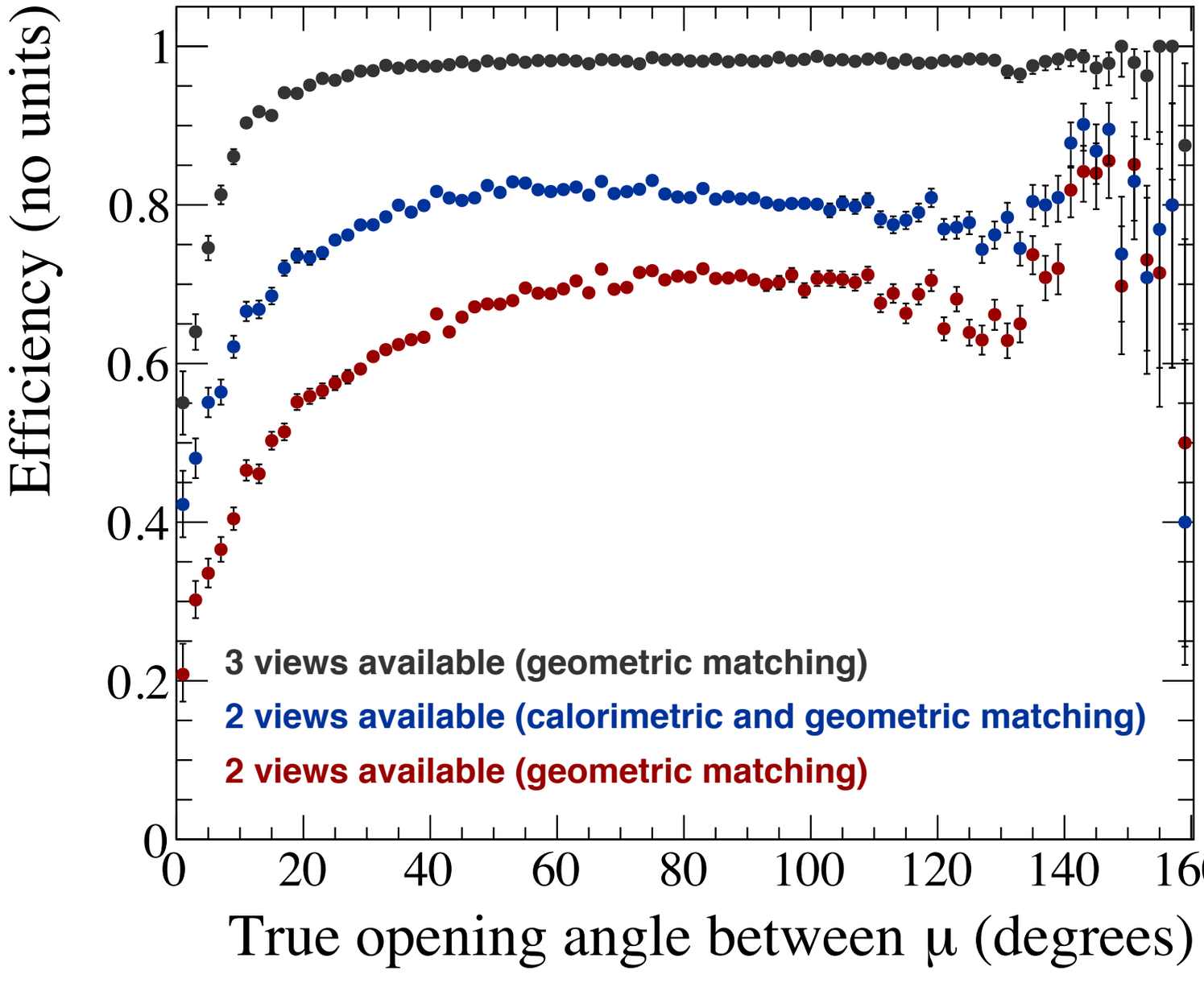
- Di-muon particle gun simulation:
  - Two muons fired from the same location
  - Both muons are roughly forward going

- Di-muons are simulated in the alternative horizontal drift detector design
  - Induction planes are ±45 degrees to the vertical

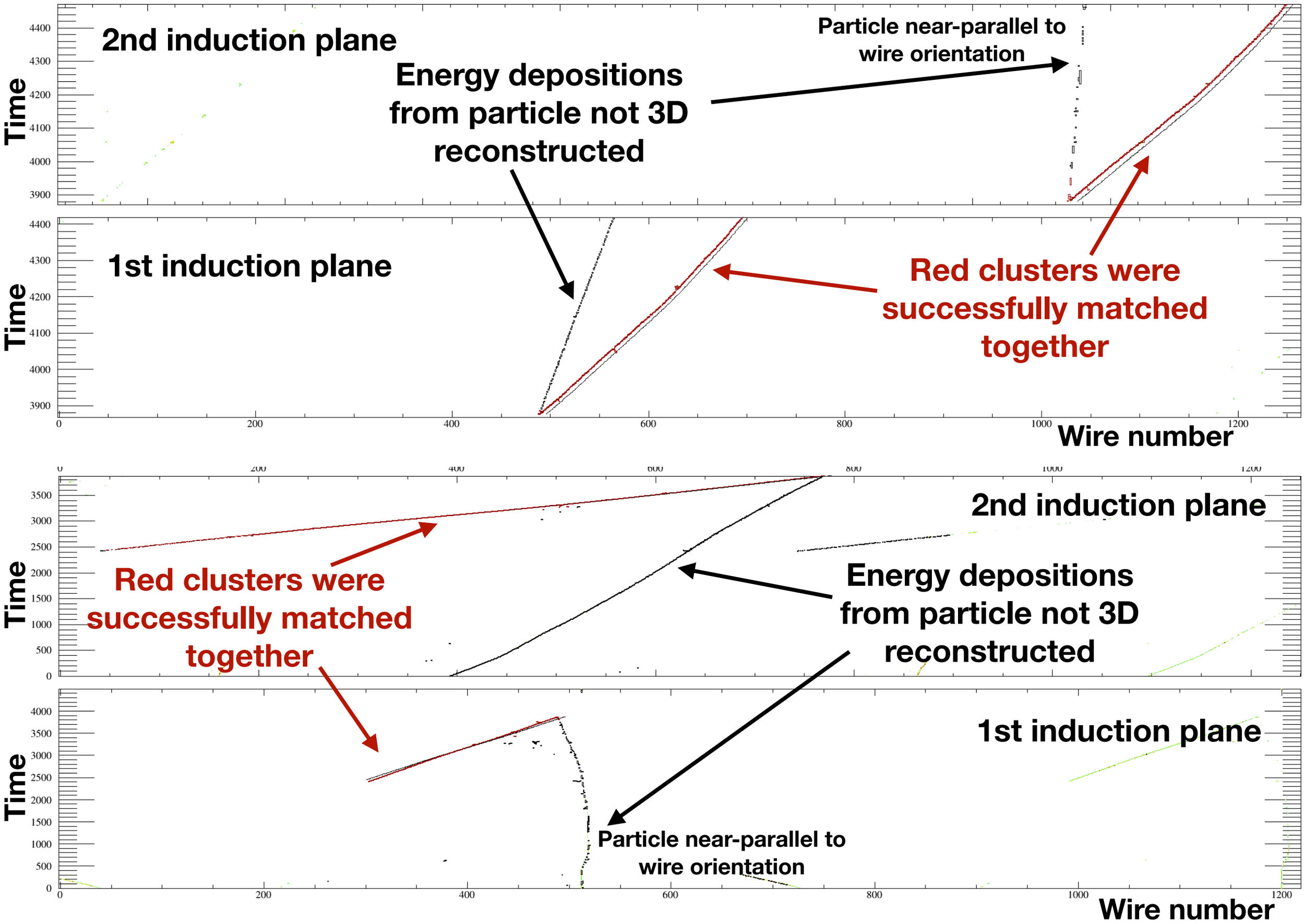
- RHS plot shows the di-muon event reconstruction efficiency vs the true opening angle between the di-muon pair

- The di-muon event is counted as reconstructed if:
  - Both muons truth match to at least one reconstructed particle
  - The contributing views of the reconstructed particle all match the same true muon

- 2 view 2D->3D matching performance can be partially recovered by the calorimetric matching
  - It should be noted that the calorimetric matching is a very new and ongoing development

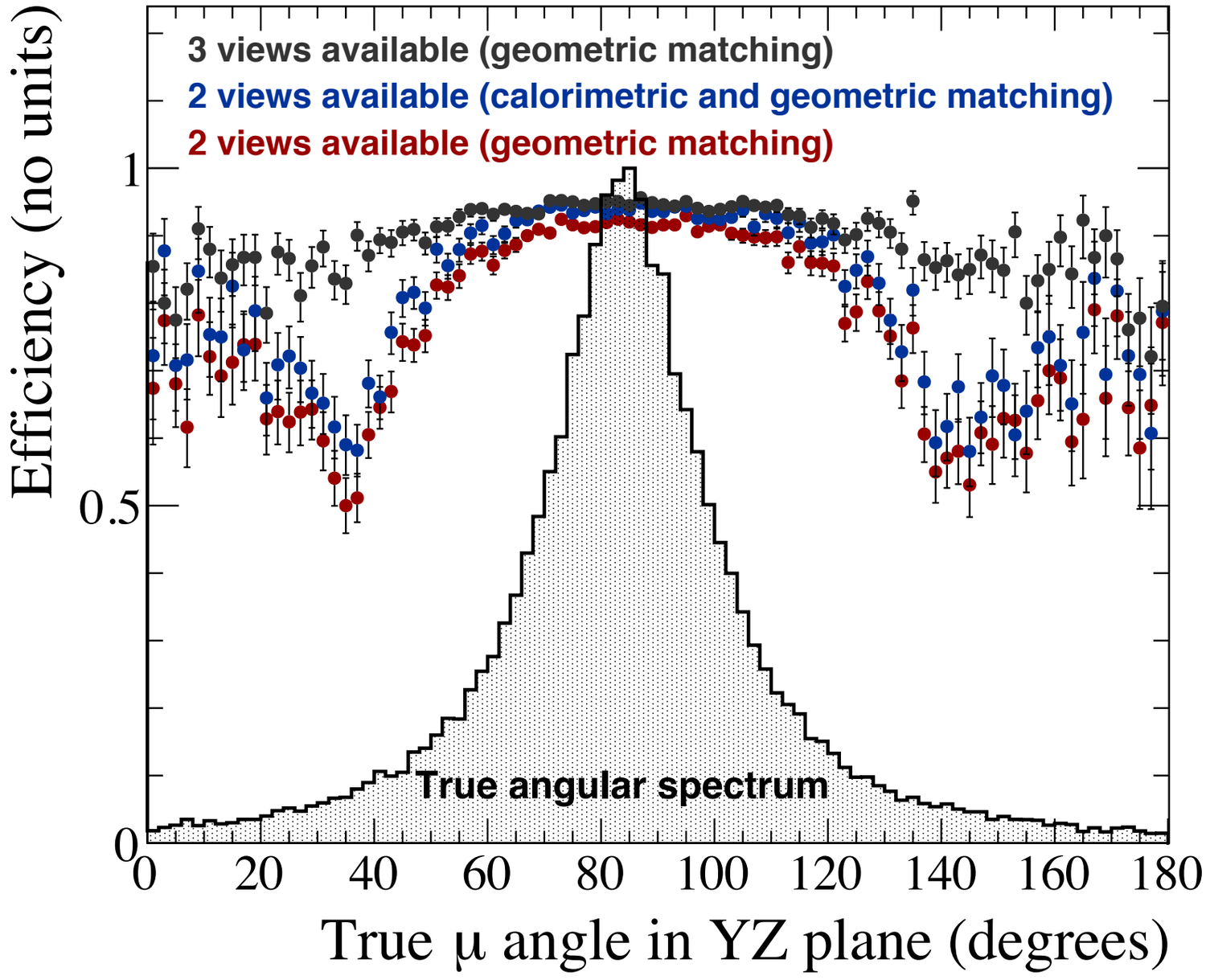


Event displays showing calorimetric 2D->3D matching failures



Muon reconstruction efficiency (neutrino simulation)

- Simulated charged current ν_μ interactions in the nominal single phase far detector
    - Induction planes are ~±36 degrees to the vertical
- RHS plot shows final-state muon reconstruction efficiency vs its angle in the YZ plane
- The muon is counted as reconstructed if:
    - The muon truth matches to at least one reconstructed particle
    - The muon truth matches to all of the reconstructed particle's contributing views
- The calorimetric 2D->3D matching partially recovers the performance when the muon is not near-parallel to the wire orientation
- When 3 views are available, the reconstruction efficiency is largely impervious to the muon inclination

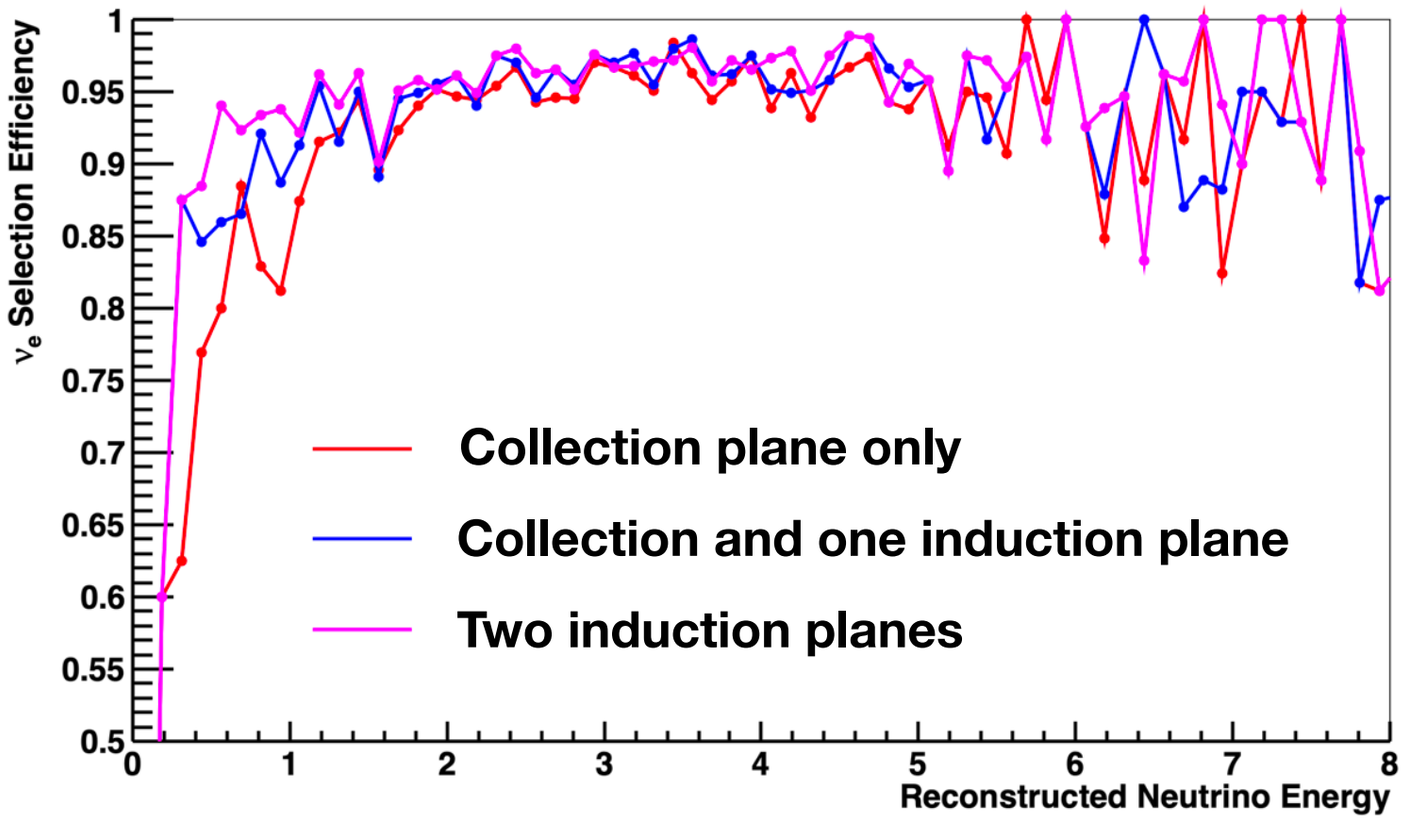


Neutrino flavour identification efficiency using a CVN

Taken from vertical drift detector proposal

Configuration		ν_e CC purity @ efficiency	ν_μ CC purity @ efficiency
DUNE CVN	(3 views)	0.92 @ 0.89	0.97 @ 0.94
Collection plane only	(1 view)	0.87 @ 0.81	0.96 @ 0.88
Two induction planes	(2 views)	0.85 @ 0.85	0.96 @ 0.91
Collection and one induction plane	(2 views)	0.86 @ 0.84	0.96 @ 0.91

- Reminder: Convolution Visual Network (CVN) used as the sole neutrino flavour ID algorithm for the far detector oscillation analysis in the TDR
    - CVN assesses reconstructed energy depositions in all available readout views simultaneously
- The CVN was exposed to different combinatorics of readout views to assess performance impact
- The nominal horizontal drift far detector geometry was used for each test
- Neutrino flavour identification performance weakly depends on the number of available views



Vertical drift reconstruction timeline

- Vertical drift particle and detector response simulation is nearing completion

- We will then begin mechanically configuring the full reconstruction workflow for the vertical drift detector
  - Expected to take ~2 months

- After configuration, the reconstruction workflow would need to be tuned and validated. Optimisation studies using the vertical drift reconstruction would be part of that procedure
  - Expected to take ~6 months

Summary

- Initial vertical drift optimisation studies have begun
  - The studies so far solely use the horizontal drift detector
  - The studies primarily focus on the impact of the alternative 2 view vertical drift design

- Two broad areas of the reconstruction are being assessed
  - 3D reconstruction using the Pandora pattern recognition suite
  - Event-level neutrino flavour identification using a CVN

- The evolving findings for the 3D reconstruction are that the 2D->3D matching performance is lower for a 2 view detector:
  - The 2D->3D matching performance can be bolstered, but so far not completely recovered, by employing calorimetry
- The CVN's neutrino flavour identification performance weakly depends on the number of available readout views

- The ongoing studies will transition to using the full vertical drift detector reconstruction as it comes online in the next few months