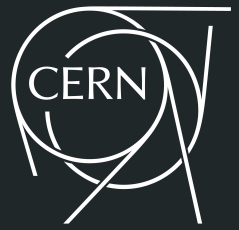
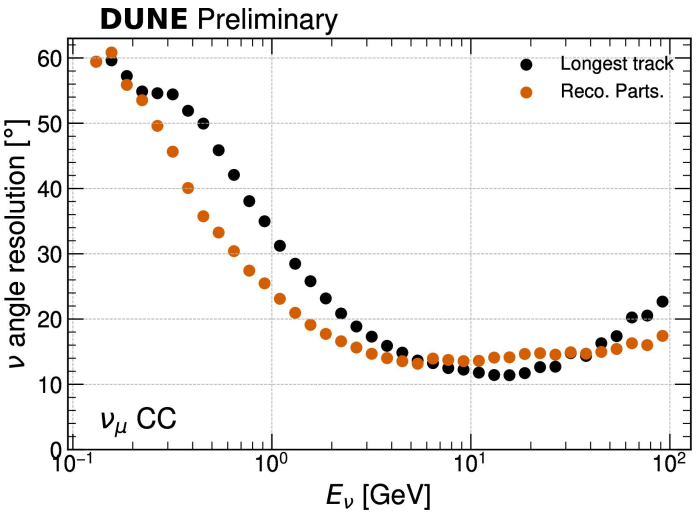
# Implementing an additional neutrino direction reconstruction method using the 2D hits

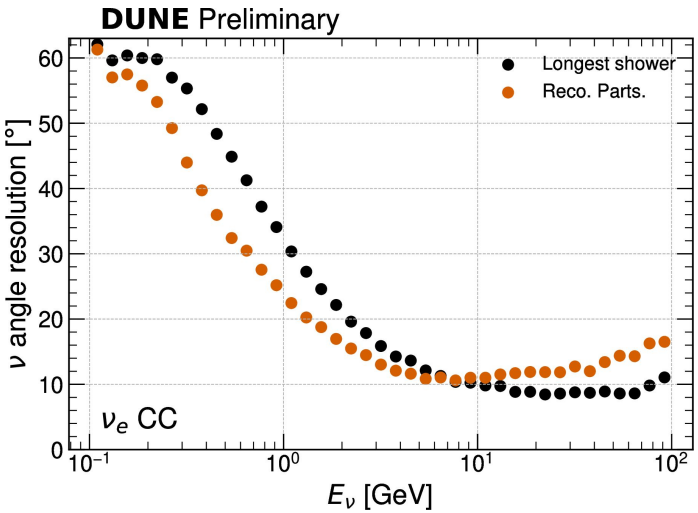
P. Granger - CERN



# Recap of previous studies

- Relying on the Pandora reconstructed PFPs
- Different methods available




- Low-Energy performance are not great (mostly due to Fermi motion)
- Loss of resolution $\gtrsim$ 4GeV because of reconstruction issues
- No reconstruction when no PFP available

# Trying an additional method

Trying out an additional naive method:

- Calorimetric only: using only the 2d hits information
- Also using the reconstructed vertex

Idea:

- Use the hits in each of the 2D reco planes (U, V, W) to get an average projected 2D direction and merge the information to obtain a reconstructed 3D direction

Hopes:

- Does not depend on particle reconstruction at High-Energy -> should improve
- At Low-Energy all the reconstructed hits might provide some info -> might improve

Cons:

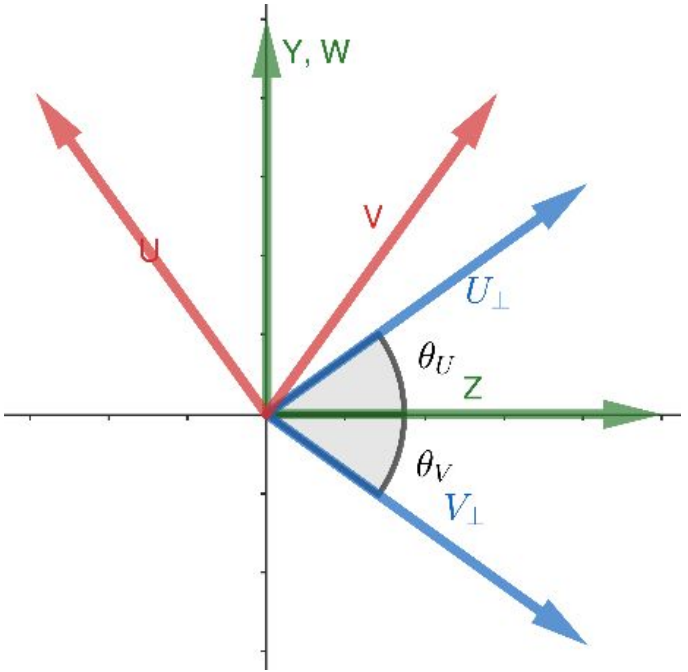
- We approximate KE to momentum and don’t use any PID info

# Using the recob::Hit objects

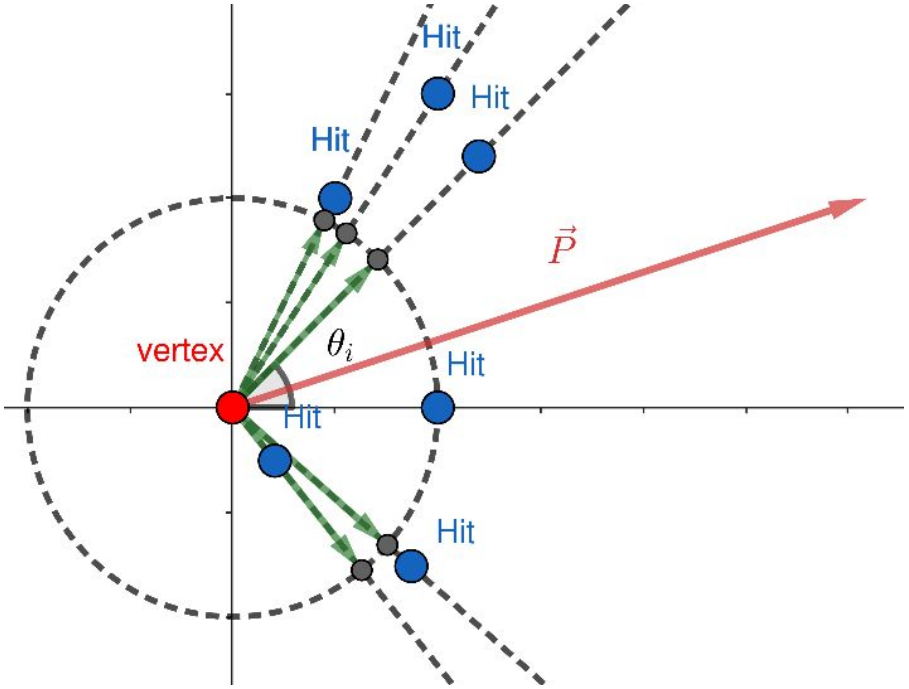
- All the recob::Hit objects are sorted in the 3 views (U, V, W) and put back in the view coordinate system
  (with V- = U+ and U- = V+)

$$\begin{pmatrix} \vec{e_{U_\perp}} \\ \vec{e_{V_\perp}} \end{pmatrix} = \begin{pmatrix} -\sin\theta_U & \cos\theta_U \\ -\sin\theta_V & \cos\theta_V \end{pmatrix} \begin{pmatrix} \vec{e_y} \\ \vec{e_z} \end{pmatrix}$$

- The coordinates are shifted so that the vertex lies at (0, 0) in all the views.



# Method itself




$$\vec{P} = \sum_i \left( w_i \frac{x_i \vec{e_x} + y_i \vec{e_y}}{\sqrt{x_i^2 + y_i^2}} \right) = \sum_i w_i e^{j\theta_i}$$

*'y' here is the view direction, not the real 'y'*

Hits $(x_i, y_i, w_i)$:

- $x_i$ is the time position
- $y_i$ is the view we consider
- $w_i$ is the number of ADCs of the hit

<u>Method:</u>

- We get the direction of all the hits with respect to the vertex. We sum all of them weighted by the number of ADCs.
- Should give the average KE vector in this view

# Combining the 2D infos back to 3D

- We measure $\vec{P}_{\text{view}} = P_{\text{view}} e^{i\theta_{\text{view}}}$ for each view.
- We only use the $\theta_{\text{view}}$ information, which should be the only relevant for the direction (and allows to not care about views calibration)

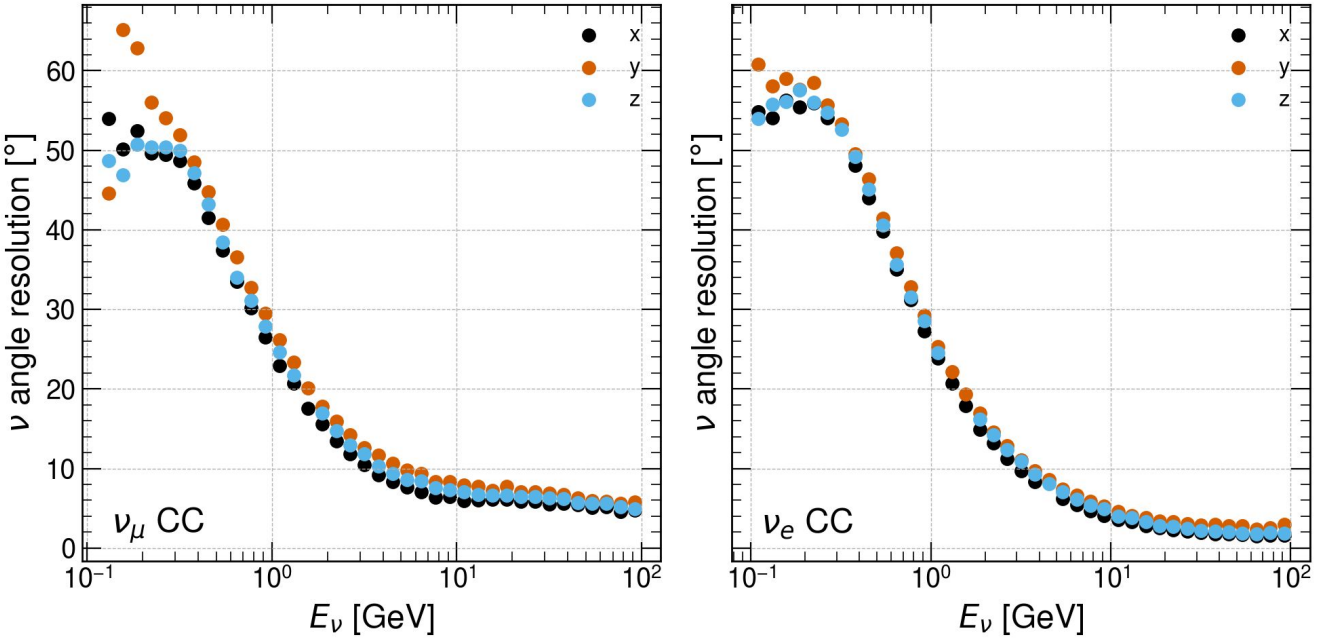
- We have an excess of measurements with respect to what we want to reconstruct. We make a fit in spherical coordinates to use all of them:

$$\chi^2 = \sum_{\text{view}} \left( \theta^{obs}_{\text{view}} - \theta^{fit}_{\text{view}} \right)$$

$$\vec{P}_{\text{fit}} = \begin{pmatrix} \sin\theta\cos\phi \\ \sin\theta\sin\phi \\ \cos\theta \end{pmatrix}$$

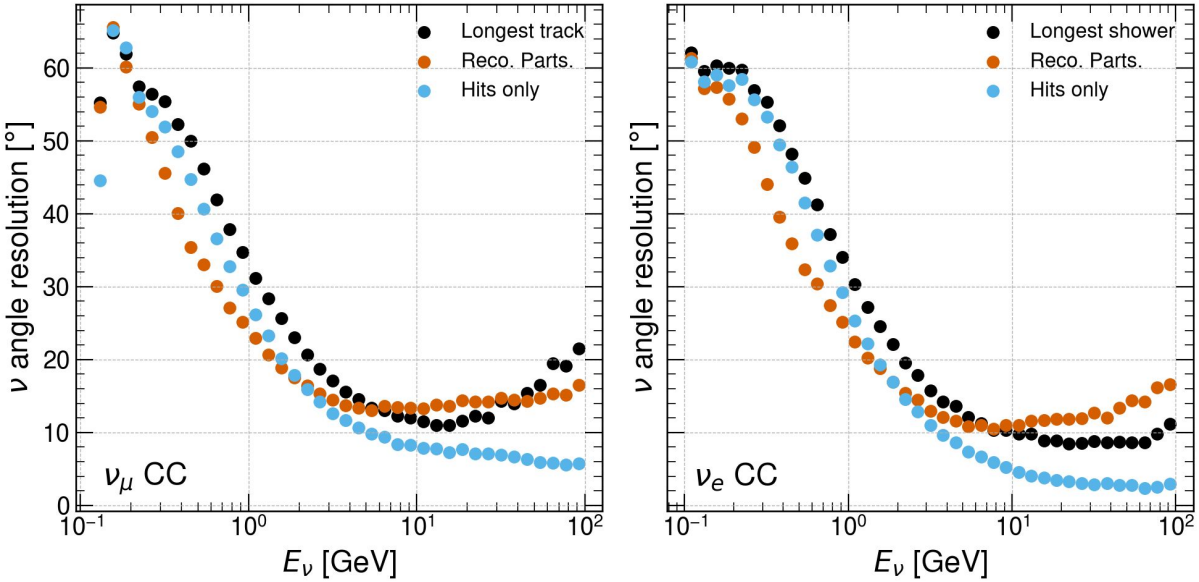
e.g. $\theta^{\text{fit}}_{W} = \arctan 2(\cos\theta, \sin\theta\cos\phi)$

# Reconstruction of different directions



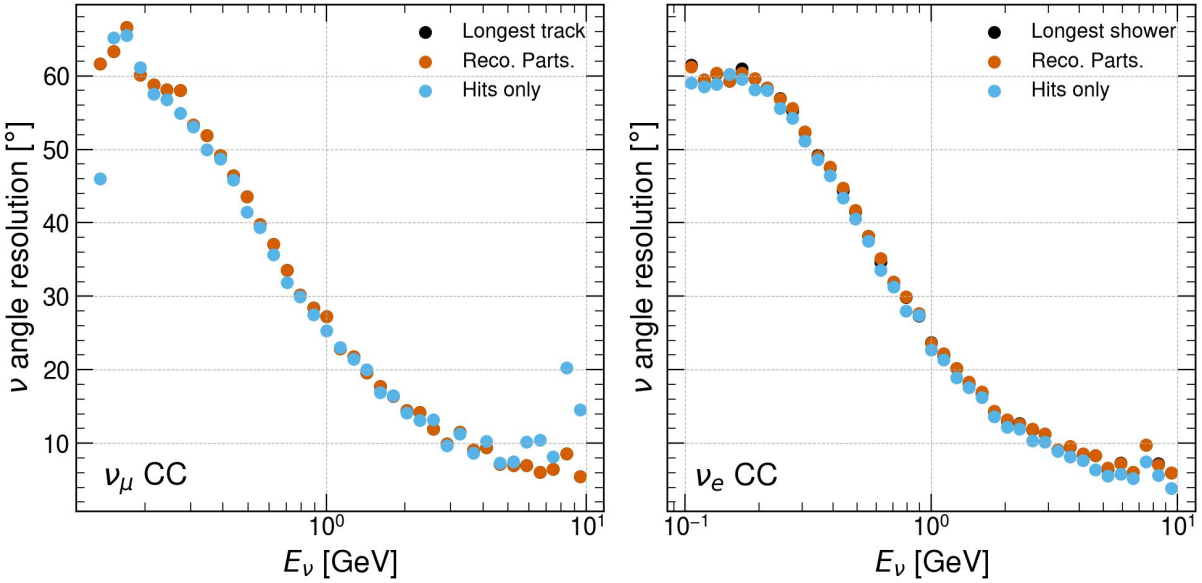

- Best resolution on x, then z and finally y
- Due to the orientations of wires. Sadly we are more interested in y here.
- **Only looking at y in the next slides**

# Reconstruction of direction along y




- Improvements at higher energies (>2-3GeV)
- Worse performance at low-energies

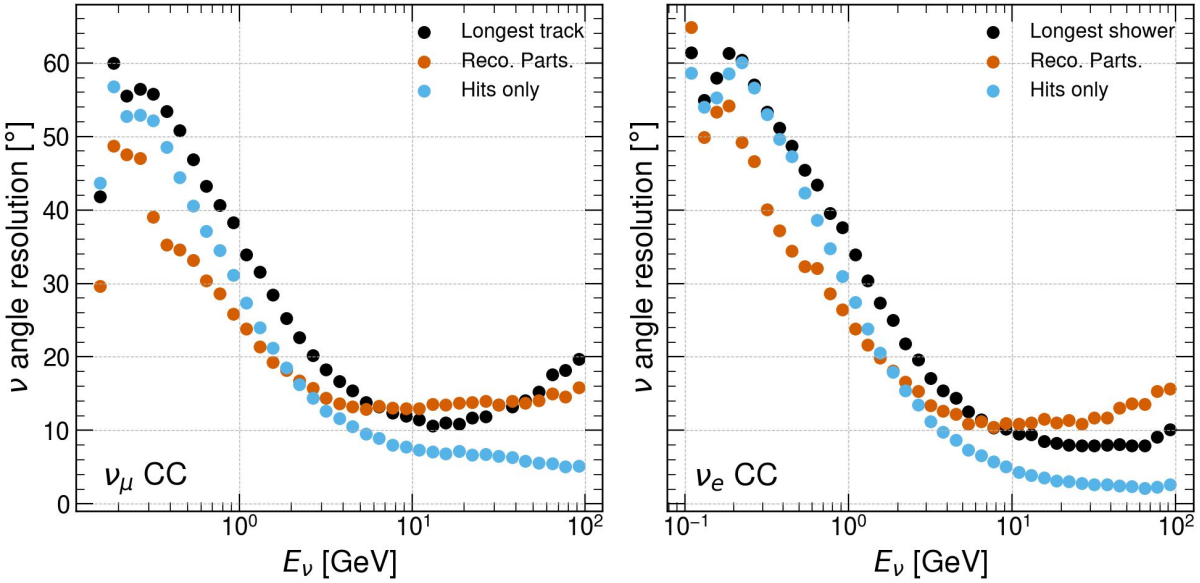
# Reconstruction of direction along y




**Events with single reco PFP**

- Performs slightly better on events with single reco PPF
- Possibly because it adds up a bit of the isolated hits information

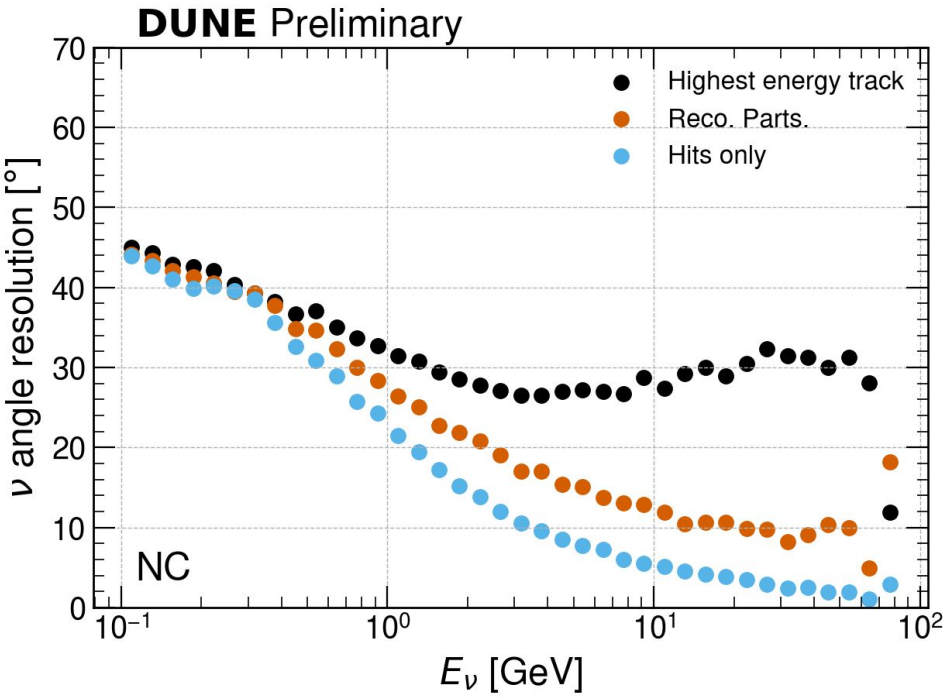
# Reconstruction of direction along y




**Events with multiple reco PFPs**

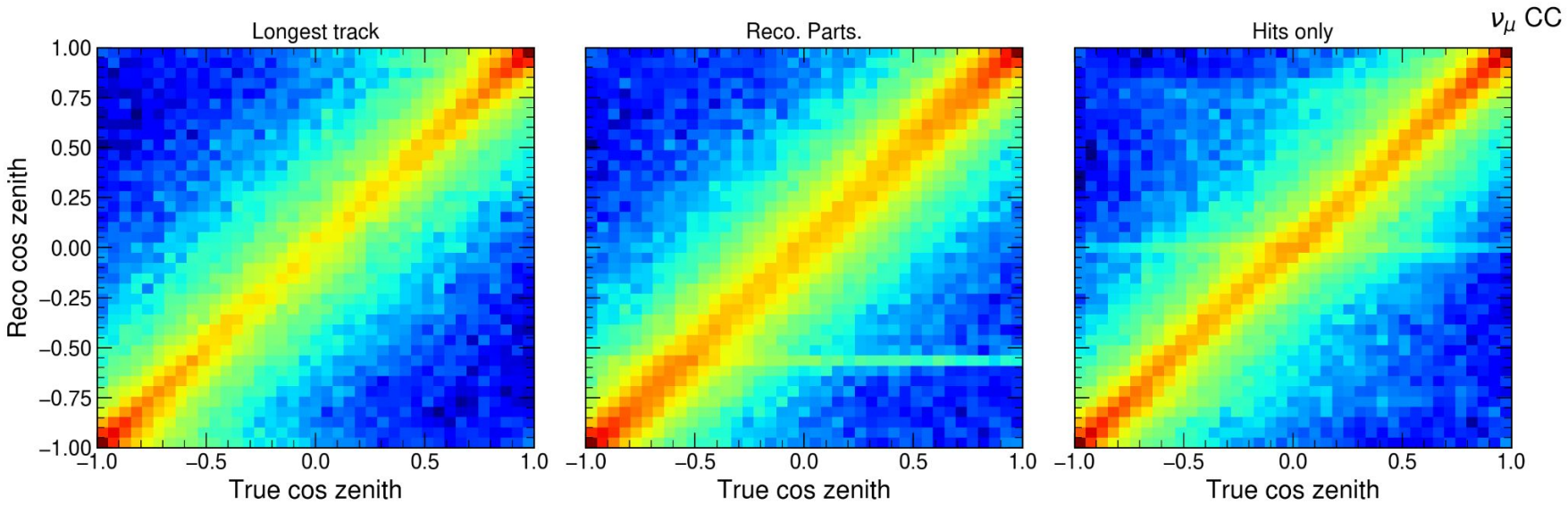
- Performs worse at lower energies, because we lose the PID info
- Performs better at higher energies because the tracking becomes harder

# NC improvement




- This method improves the resolution on NC events
- Not critical for OA, but could improve the flux normalization

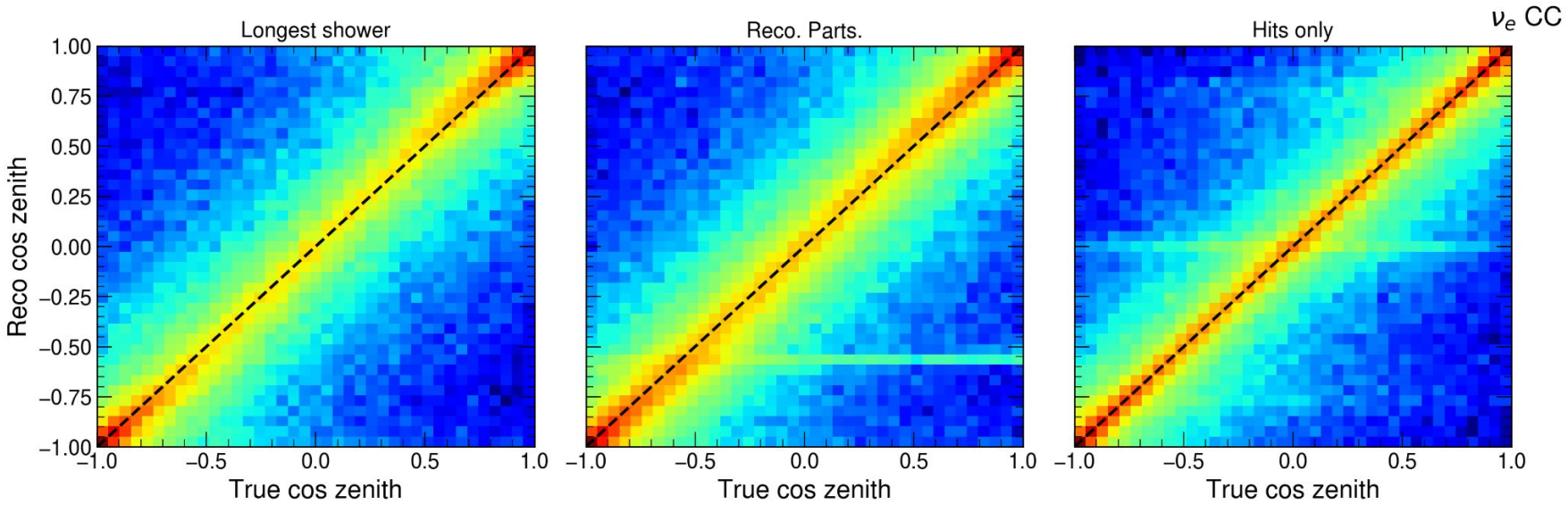
# Response uniformity




*Log coloring*

- Performance look rather uniform across the directions
- No visible skew

# Response uniformity

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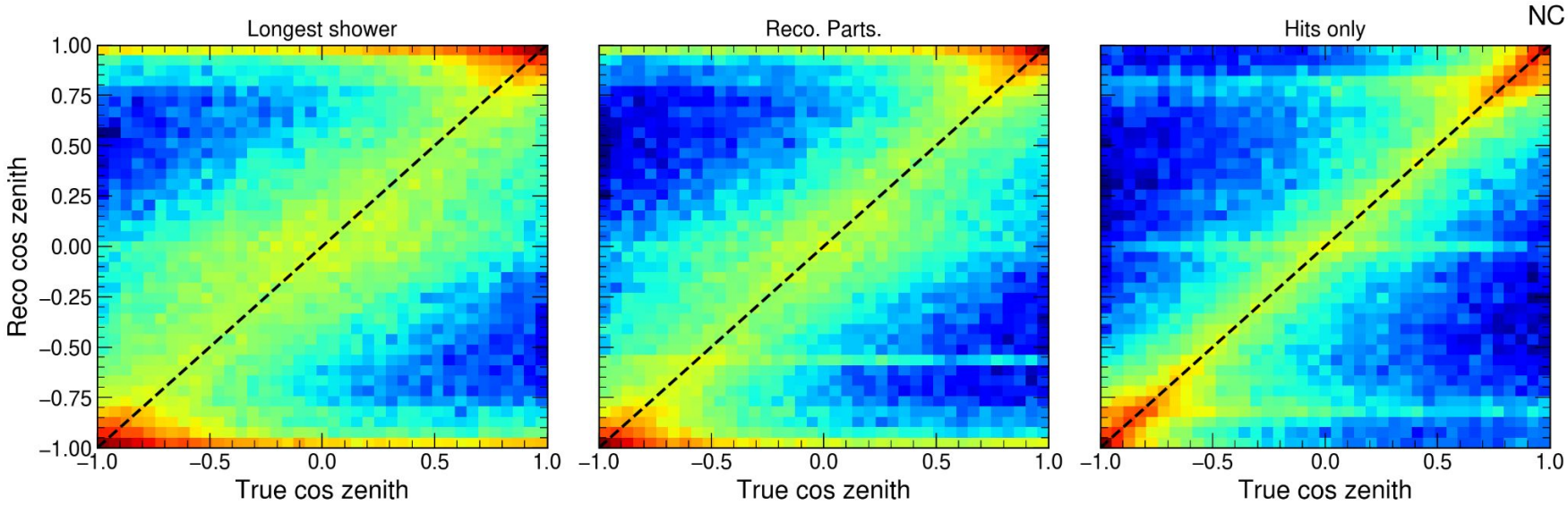


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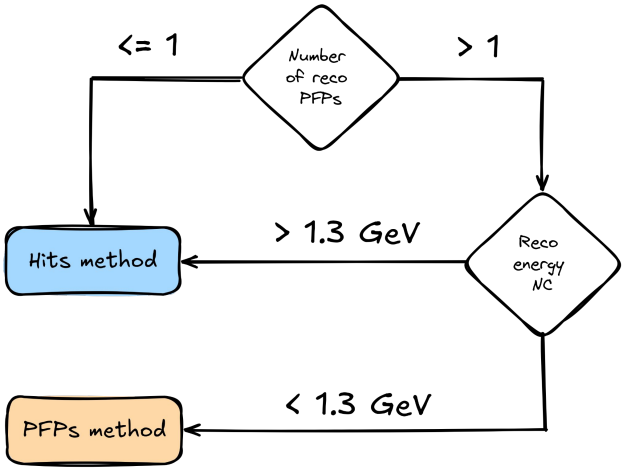
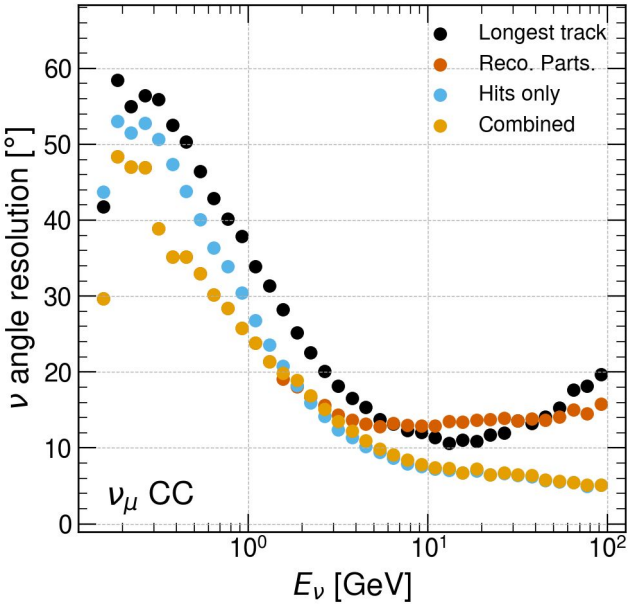
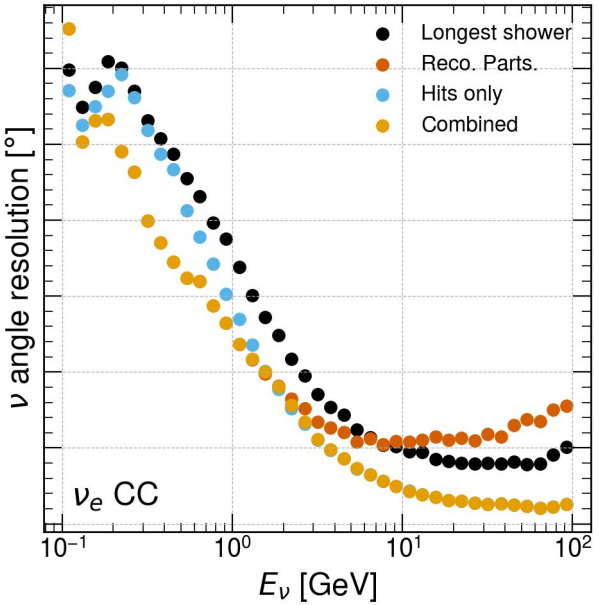
# Combining methods




- Combining the methods on different energy ranges seems to work

# Summary

- The implementation of an additional direction reconstruction method in LArSoft seems to work (still no open PR for it)
- This calorimetric only method performs well at “high-energy” (> 2GeV) and when there is one or less reconstructed PFPs by Pandora
- We now have quite complementary methods for the direction reconstruction and combining these methods seems to work correctly

<u>Going further:</u>

- Looking at the differences between methods event by event might give during the analysis might provide some useful information
- Trying to use a ML framework (investigated by Aaron I think)