Charged current interactions on carbon with a single positively charged pion in the final state at the T2K off-axis near detector with 4π solid angle acceptance

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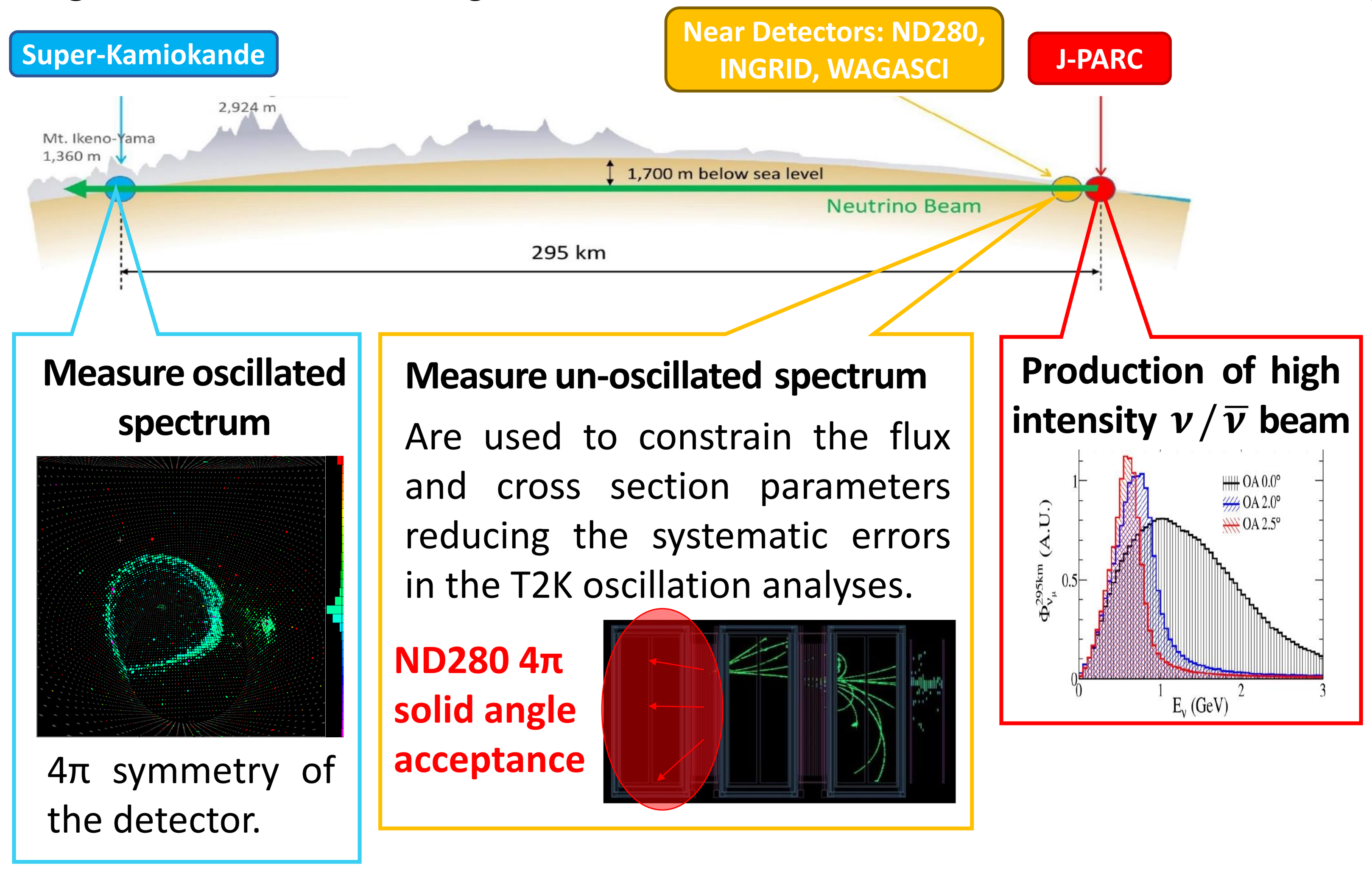
1. Motivation

- $CC1\pi^+$ constitutes the main background for the muon neutrino disappearance measurement when the charged pion is not observed.
- The aim of the distributions presented here is to provide results in a model independent way, to make their comparison to other experiments easier and to contribute to the improvement of current models.
- The $CC1\pi^+$ cross section will be extracted using the present event selection (with 4π solid angle acceptance).
- We can study the nuclear effects, FSI and Fermi momentum by computing and comparing the Adler angles.

Figure 1: T2K baseline diagram.



2. T2K experiment

- T2K is a long-baseline neutrino oscillation experiment.
- Goal: make precise measurements of oscillation parameters via observation of $\bar{\nu}_\mu/\nu_\mu$ disappearance and $\bar{\nu}_e/\nu_e$ appearance.

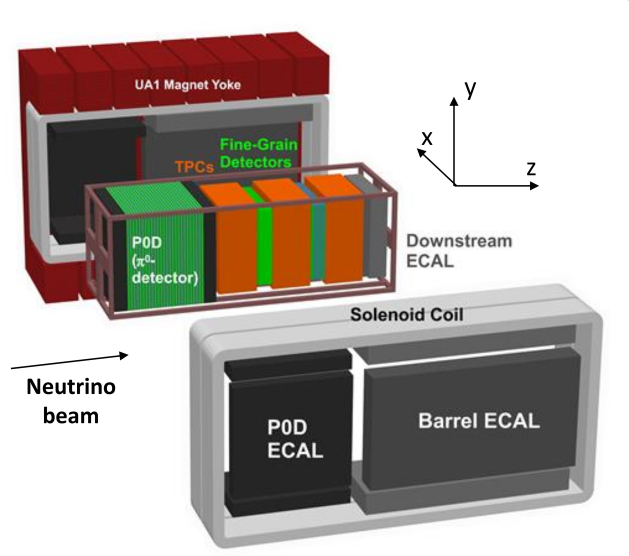


Figure 2: Schematic view of ND280 off-axis near detector.

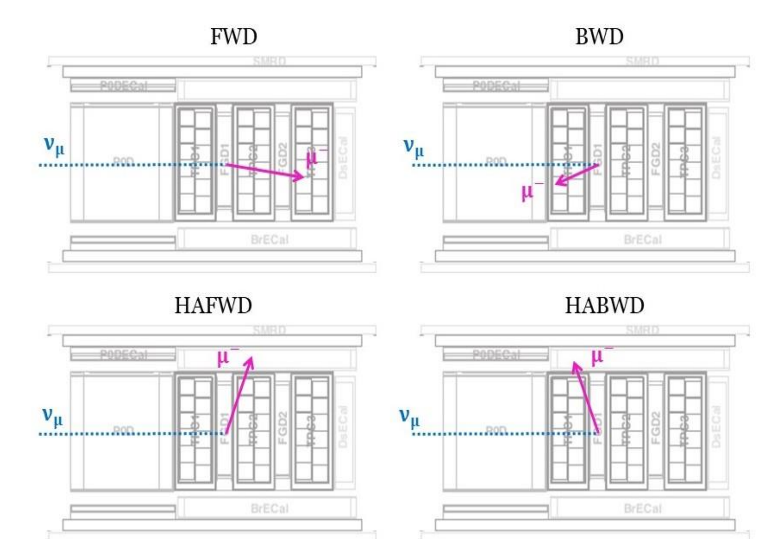
3. Off-axis ND280 detector

- 0.2 T magnetized tracking detector
- π^0 detector (P0D)
- Electromagnetic calorimeters (ECals)
- Side Muon Range Detectors (SMRD)
- The tracker (located downstream of the P0D) is made up of :
  - 3 gas Time Projection Chambers (TPCs)
  - 2 Fine Grained Detectors (FGDs)

4. Event selection

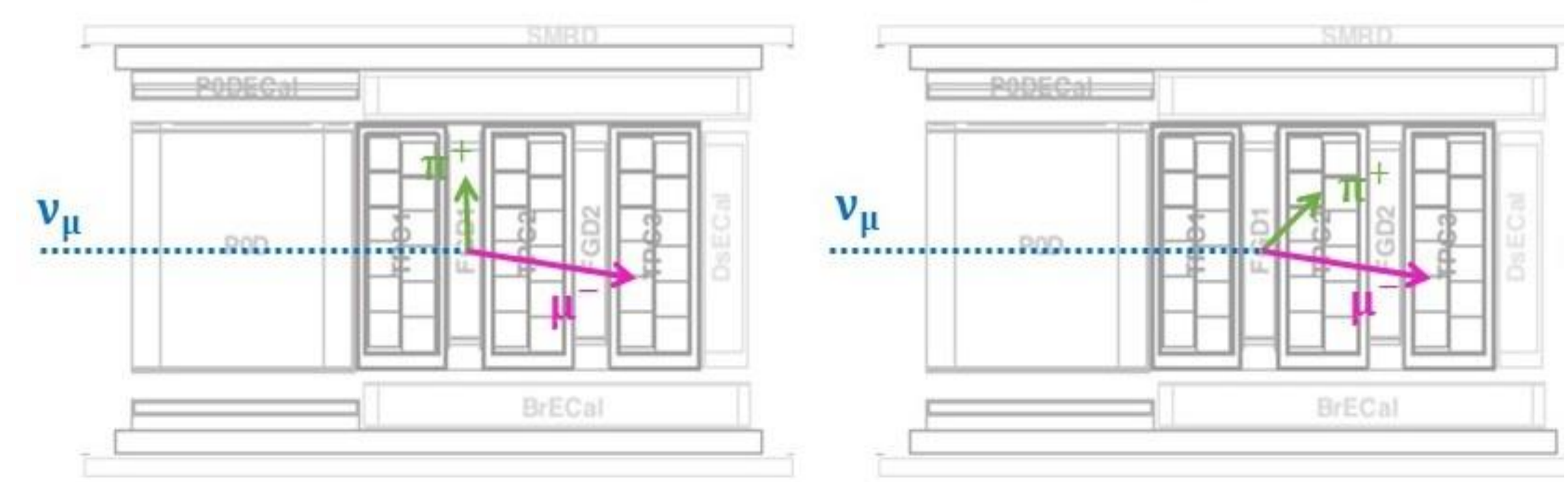
- Pion production is dominated by resonant interactions in the T2K energy range.
- The signal is defined in terms of the experimentally observable particles exiting the nucleus.
- Is composted by a muon and a positive pion.

ND280 4π solid angle acceptance



IsoFGD Pion

TPC Pion



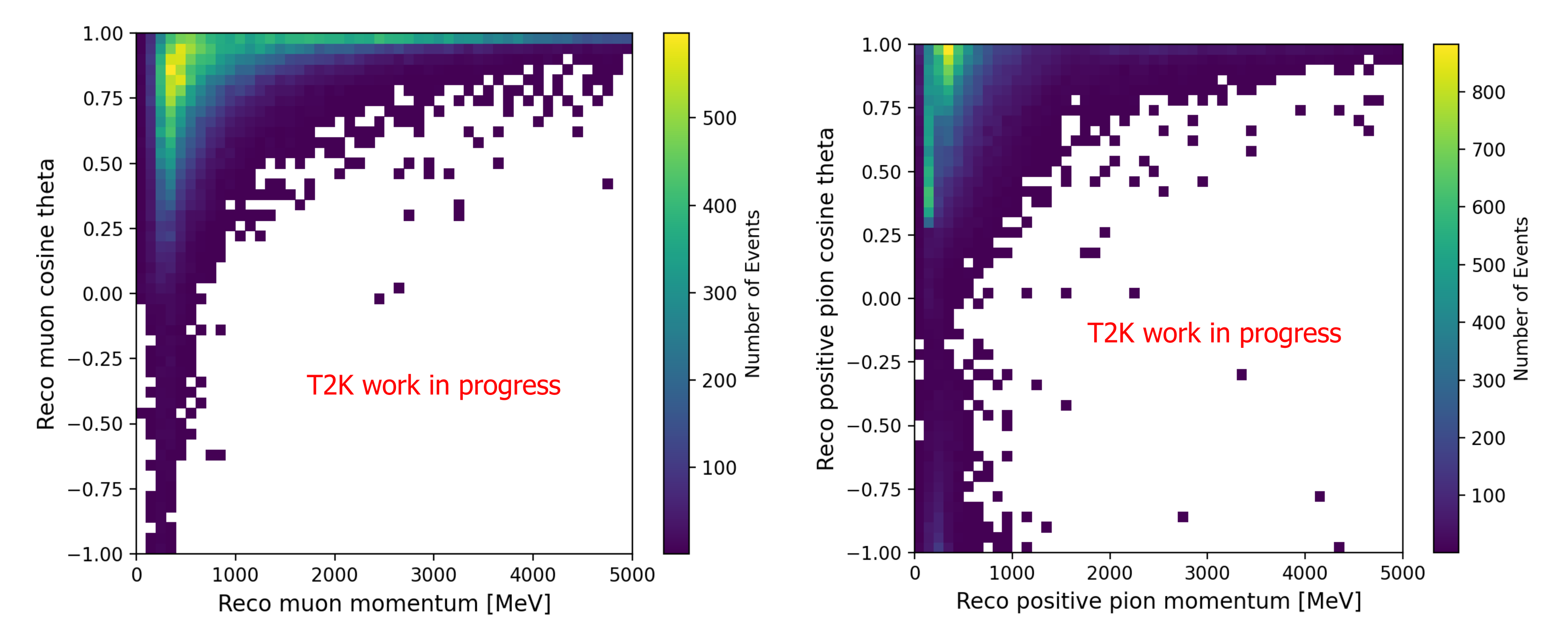
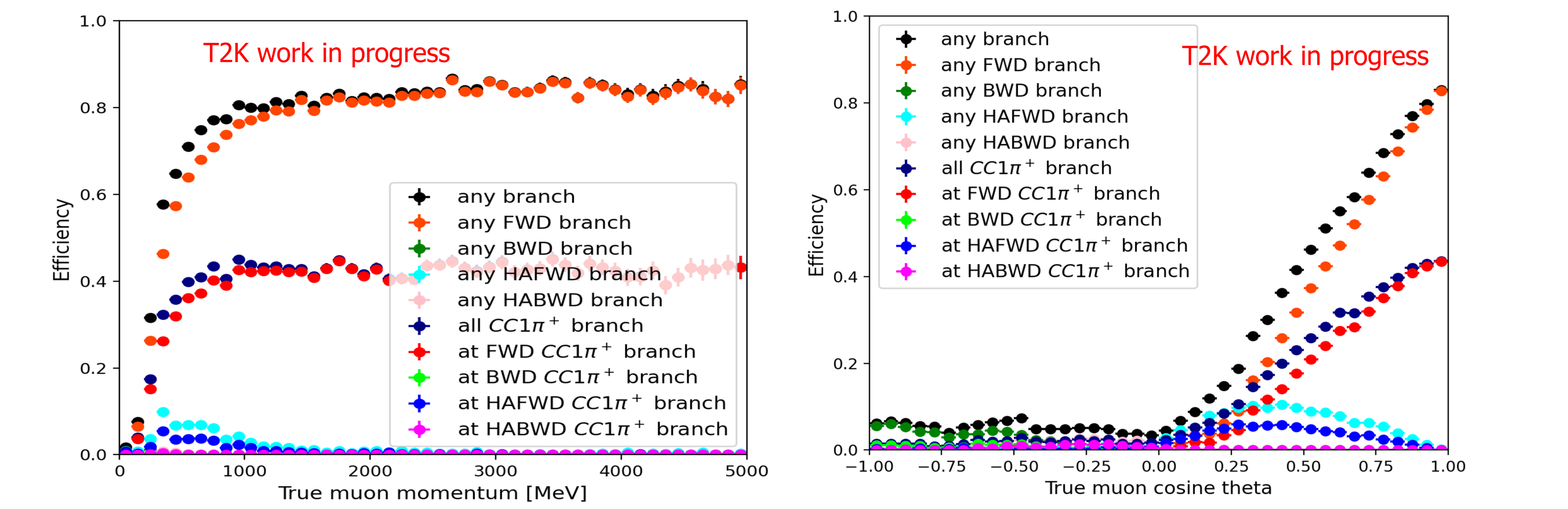


Figure 4: $CC1\pi^+$ reconstructed kinematic variables, cosine of the angle vs. momentum: for muons (left) and positive pions (right)

7. Conclusion

- Using NEUT as the default MC generator we observe a purity of the $CC1\pi^+$ signal of ~63%. CCother events being the main contamination.
- This sample will allow us to reduce the systematic errors for the oscillation analyses in SK and more important now that new pion samples are being added (already in use with Michel electron and more to come with multiring).
- Next steps are in terms of both inclusion of these selections in the ND fits and in terms of cross section extraction.
- We have presented the Adler angles observables that will be most useful for comparison with neutrino interaction models.
  - This is the second time those angles are measured in interactions of neutrinos on heavy nuclei (first time was also in ND280, 2 years ago in a constrained phase space and with less statistics).
- Negative values of the cos θ_{planar} correspond to pions with low momentum after the boost. We are missing low momentum pions in the reconstruction due to nuclear effects.
- The Adler angles can be used to improve our interaction models.

Figure 3: $CC1\pi^+$ efficiency vs. muon momentum (left) and muon cos theta (right) with 4π solid angle acceptance for FGD1 sample.



5. Reconstructed neutrino energy

The neutrino energy is reconstructed using energy-momentum conservation:

$$E_{\nu_{reco}} = \frac{m_p^2 - (m_p - E_{bind} - E_\mu - E_\pi)^2 + |\vec{P}_\mu + \vec{P}_\pi|^2}{2\{m_p - E_{bind} - E_\mu - E_\pi + \hat{k}_\nu(\vec{P}_\mu + \vec{P}_\pi)\}}$$

Were $(E_\mu, \vec{P}_\mu)$ and $(E_\pi, \vec{P}_\pi)$ are the four-momenta of the muon and the pion, $\hat{k}_\nu$ is the neutrino direction, E_{bind} is the target nucleon binding energy (~25 MeV) and m_p is the free proton mass. This definition of the neutrino energy assumes that the target nucleon is at rest.

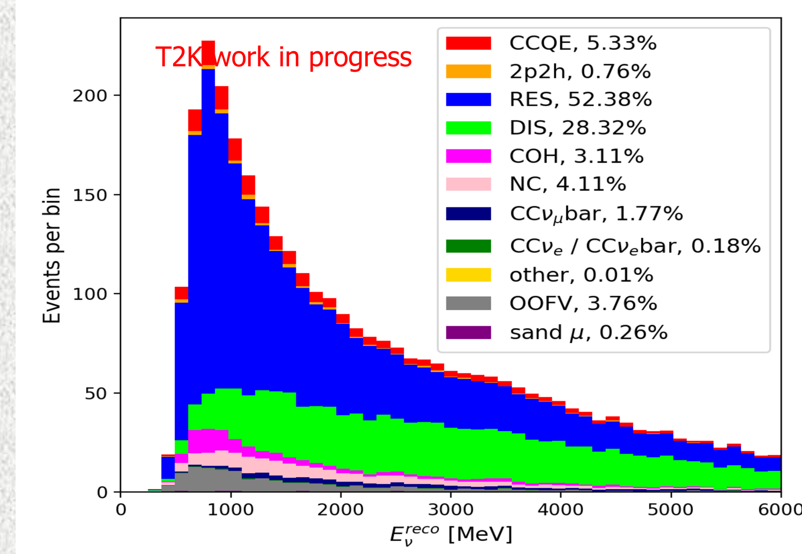


Figure 5: Reconstructed neutrino energy using events $CC1\pi^+$ (only using TPC pions)

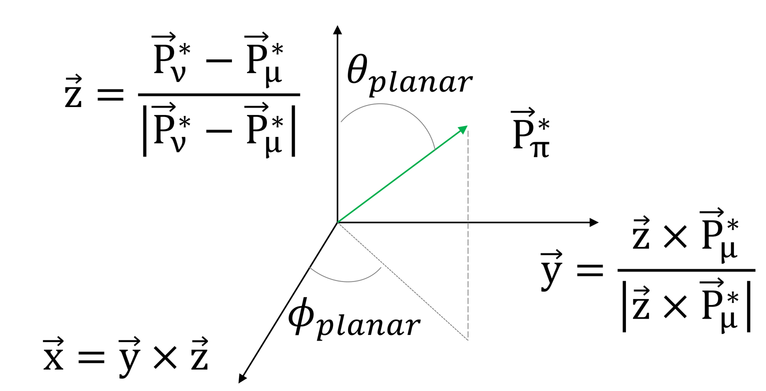
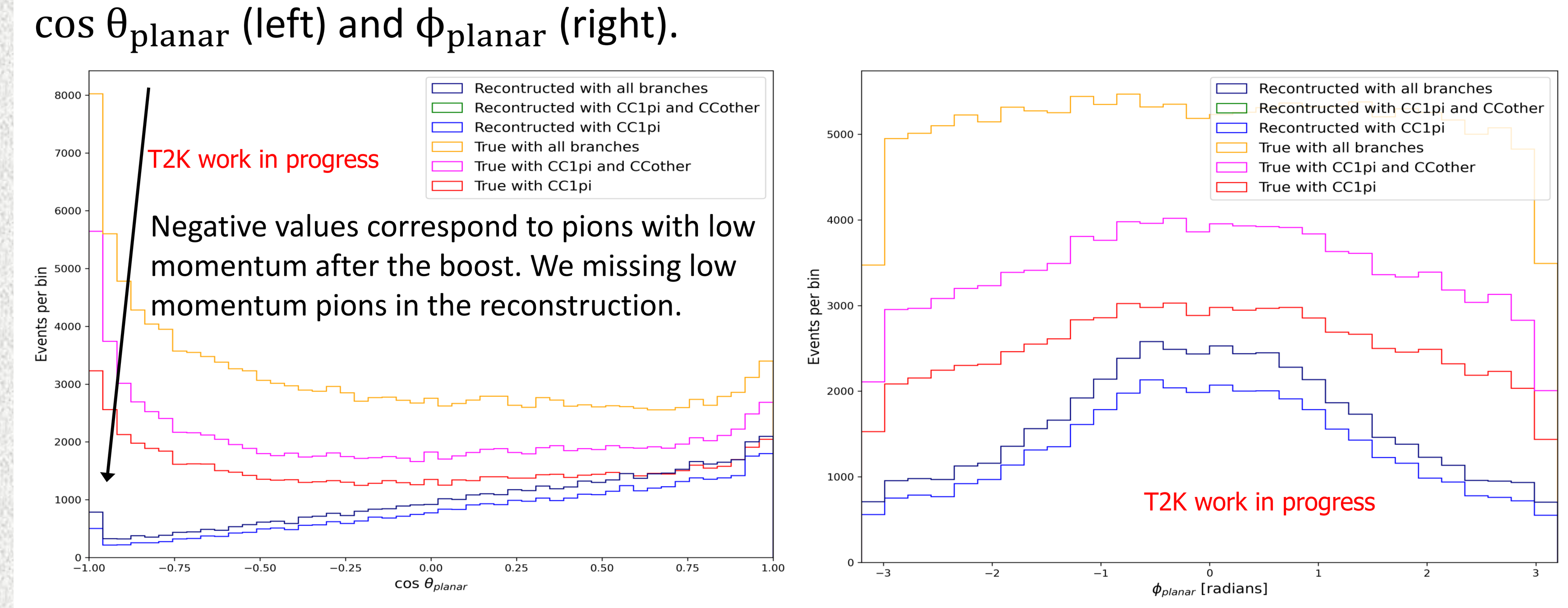


Figure 6: Definition of the Adler's Angles at the nuclear level. The momenta of the particles are defined in the rest frame $\vec{q} = \vec{p}_\nu - \vec{p}_\mu$.

6. Adler angles

- The angles θ_{planar} and ϕ_{planar} define the direction of the pion in the Adler system ($p - \pi^+$ final state in the Δ reference system).
- Are computed with particles leaving the nucleus.
- Carry information about the polarization of the Δ resonance, the interference with non resonant single pion production.

Figure 7: Comparison between reconstructed and true Adler angles distributions cos θ_{planar} (left) and ϕ_{planar} (right).



8. References

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[2] K. Abe et al., Phys. Rev. D 101, 012007 (2020)
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9. Acknowledgements

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