ν_τ containment studies

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ν_τ and high-energy beam tune meeting

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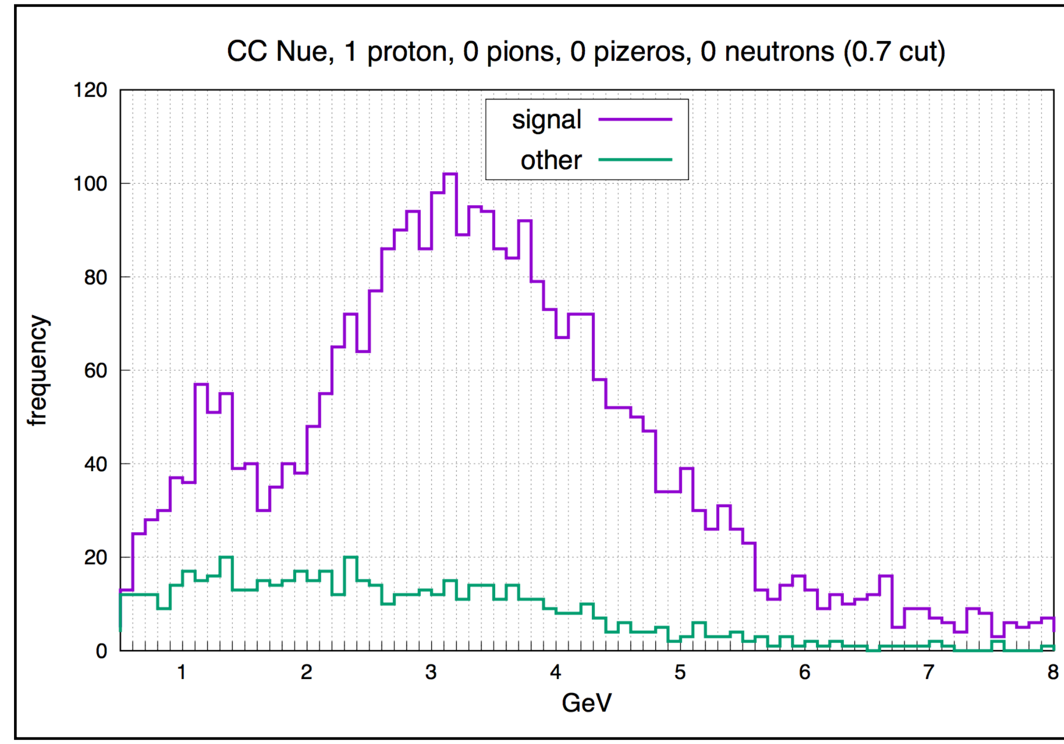
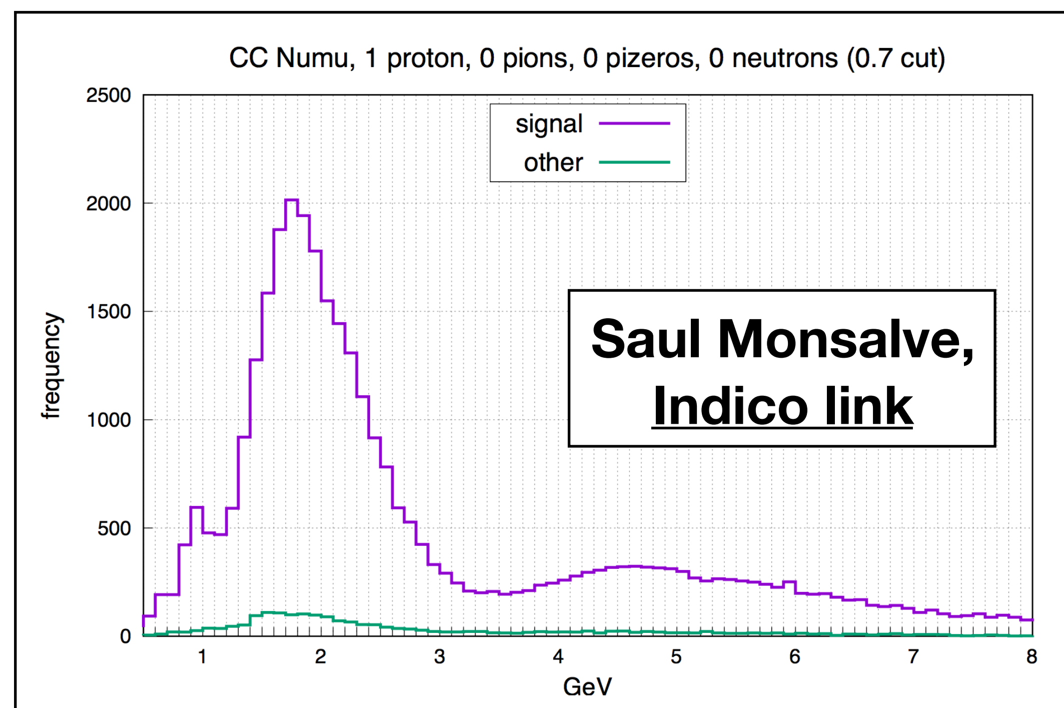
Introduction

- Looking at ν_τ interactions using a full simulation and reconstruction chain:
  - ν events simulated using GENIE.
  - GEANT4 propagates MC particles through detector.
  - Detector simulation to convert these particles into signals on wires.
  - Reconstruction chain:
    - Wire processing.
    - Hit finding & clustering.
    - Object reconstruction (tracks, showers).
    - Neutrino energy reconstruction.

Motivation

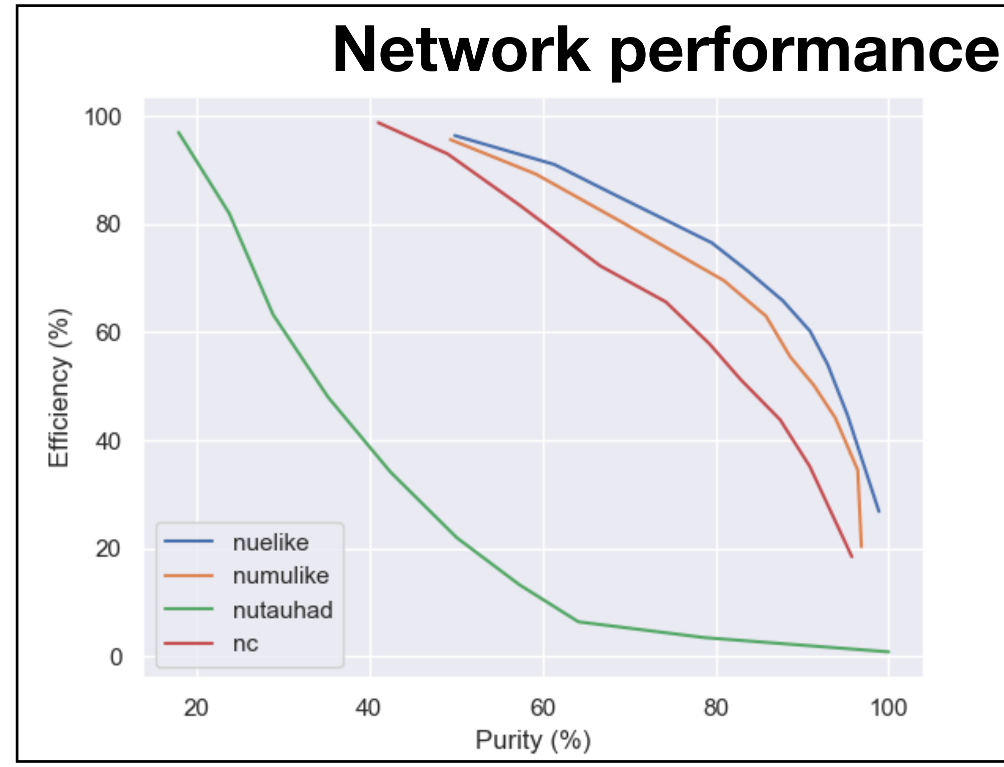
- Studies by Saul Monsalve, Leigh Whitehead, Alex Radovic et al. show great promise for CVN (convolutional visual network).
- Given its success at identifying ν_e and ν_μ events, how effective is CVN at identifying ν_τ interactions?
- Their model performed poorly on ν_τ events due to a severe lack of MC statistics on which to train the network.
- Produced an enriched ν_τ MC sample to add to their dataset, but this introduced new problems.
    - Now at higher energies, ν_τ events over-represented in training sample.
    - Network classifies any high-energy neutrino interaction as a ν_τ.

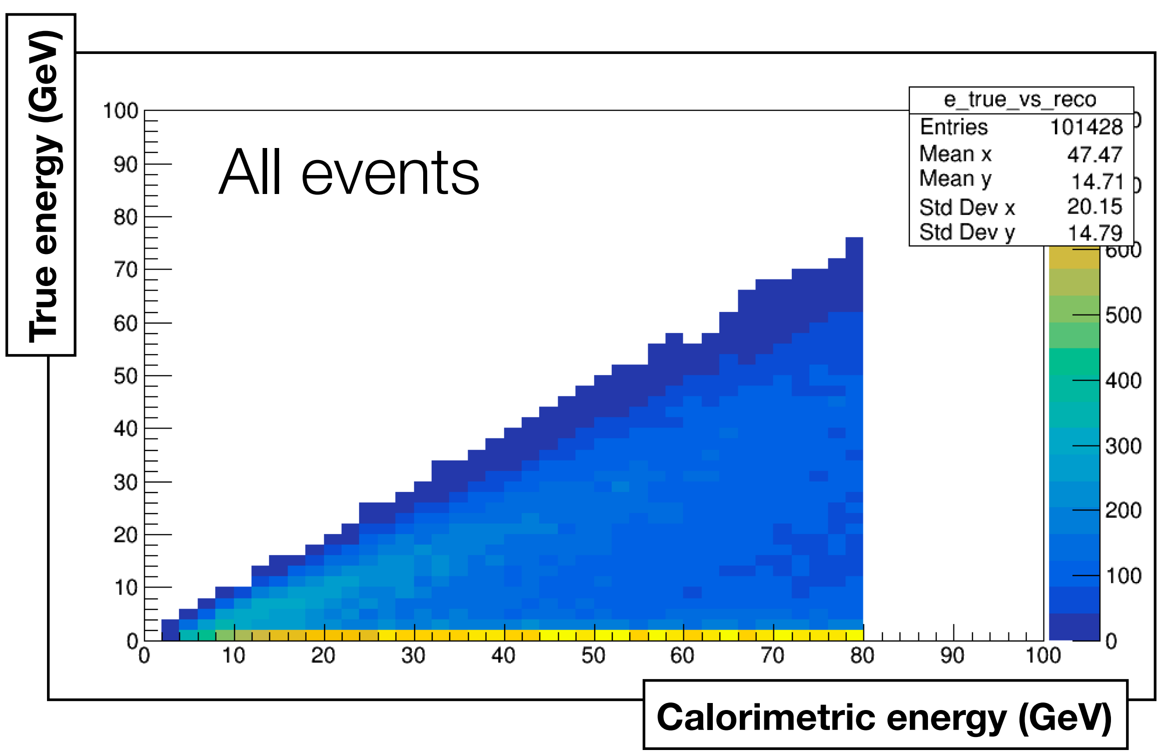


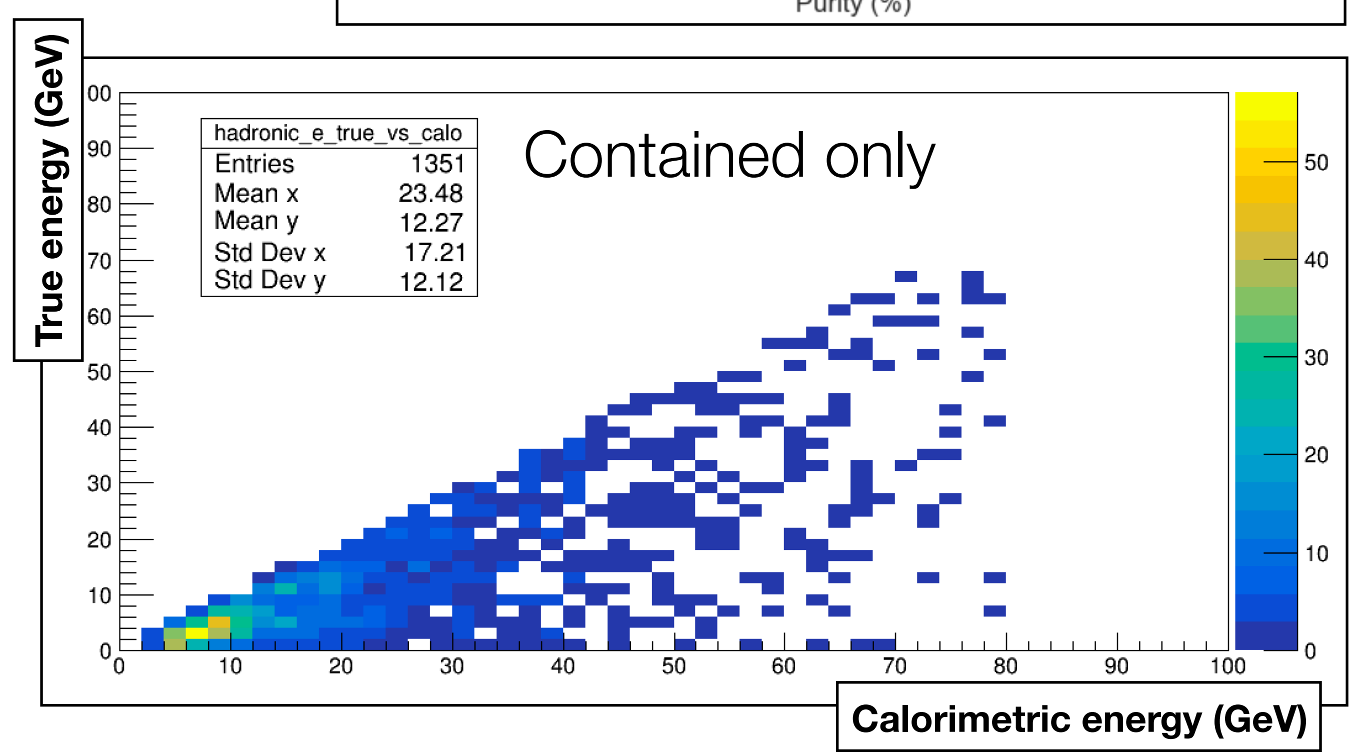


Training samples

- Produced high-stats (~800k total) simulation samples for six neutrino types (ν_e, ν_μ, ν_τ, $\bar{\nu}_e$, $\bar{\nu}_\mu$, $\bar{\nu}_\tau$) with an event rate approximately flat in true neutrino energy between 3.5 and 80 GeV.
- Trained a ResNet network, but accuracy for ν_τ events significantly worse than other neutrino flavours.
- The small 1x2x2 workspace geometry used meant the majority of ν_τ events were uncontained.

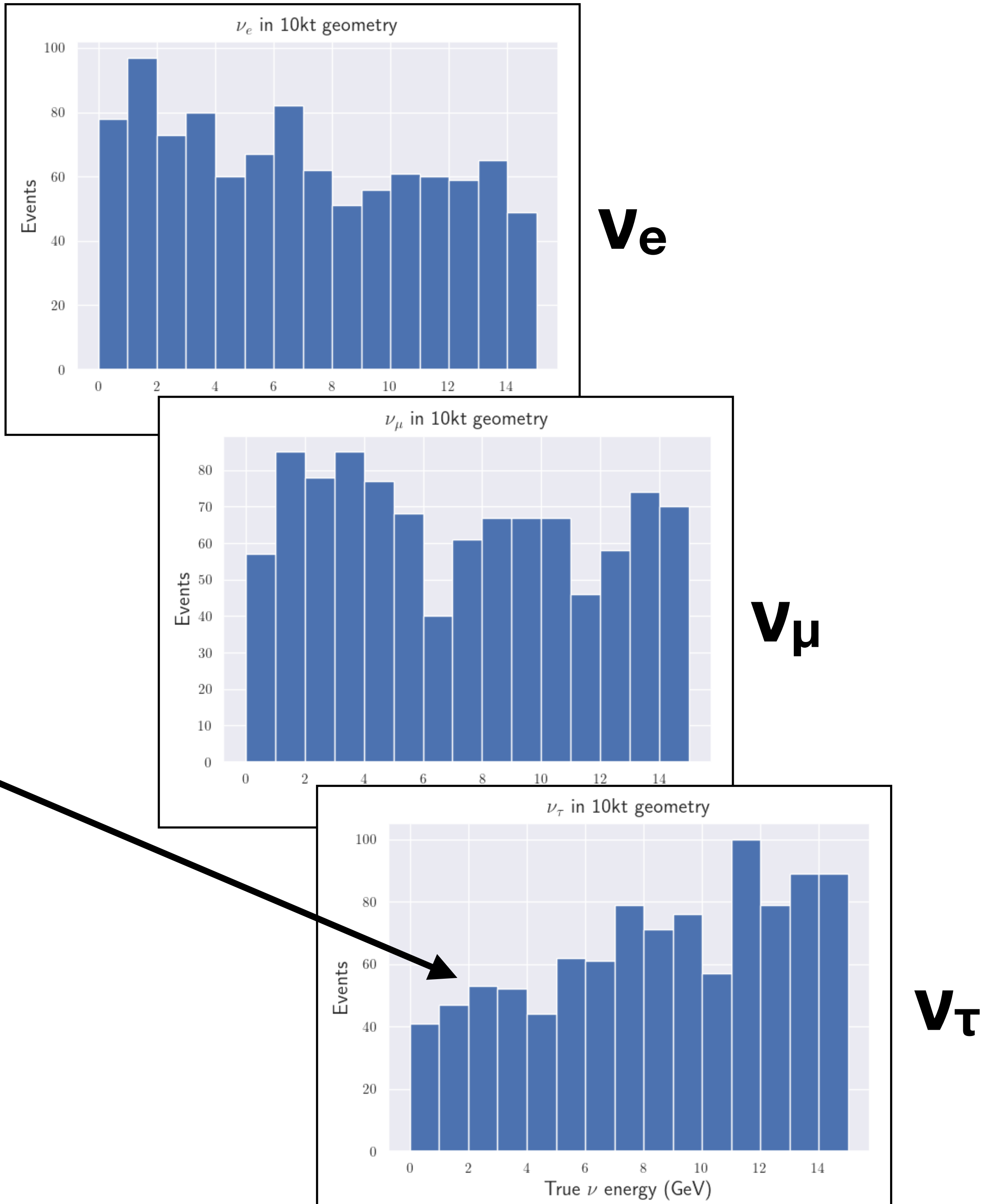






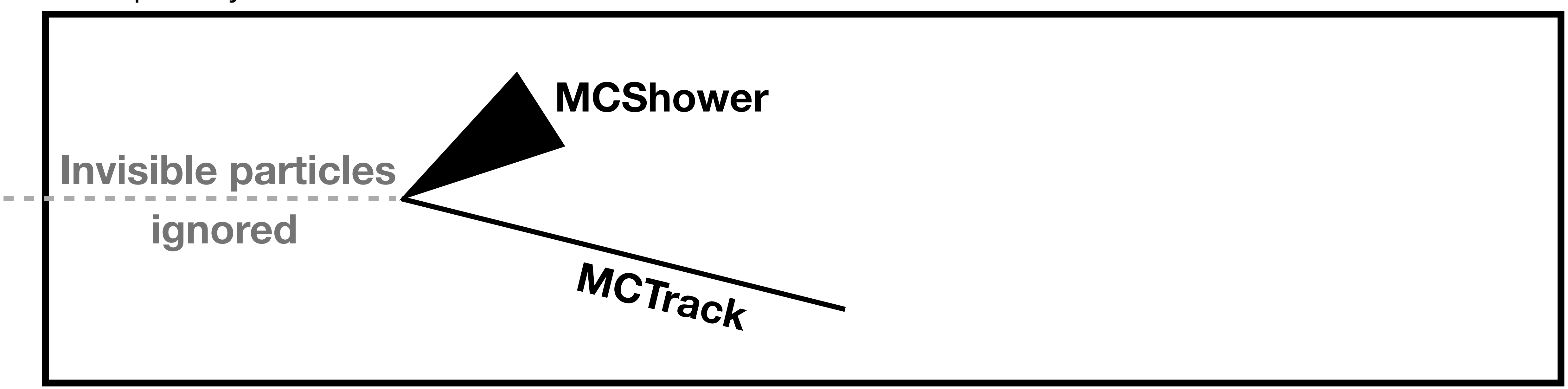
Containment studies

- Examining how well-contained events are in each available geometry before beginning another round of high-stats MC production.
- Clearly workspace is too small, but 1x2x6 and 10kt are both candidates.
- Use new lower-energy warped flux (150 MeV - 15 GeV).
- Produced low-stats (~1000) samples for ν_e, ν_μ, ν_τ in both detector geometries.
- Flux warping to approximate event rate flat in energy is less accurate for ν_τs, likely because of lower cross-sections at lower energies.
    - Should produce separate warped flux for ν_τ events to correct for this.

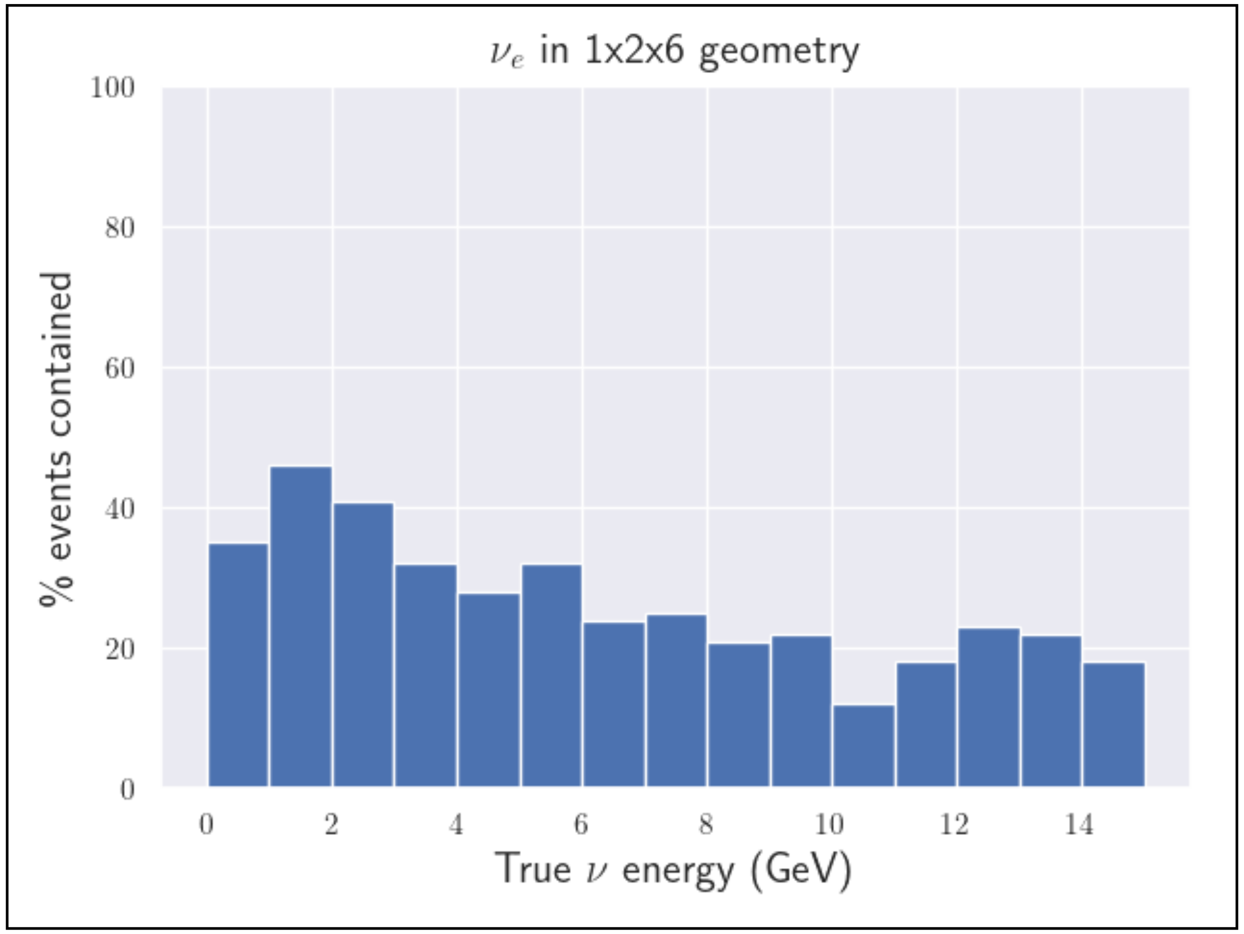


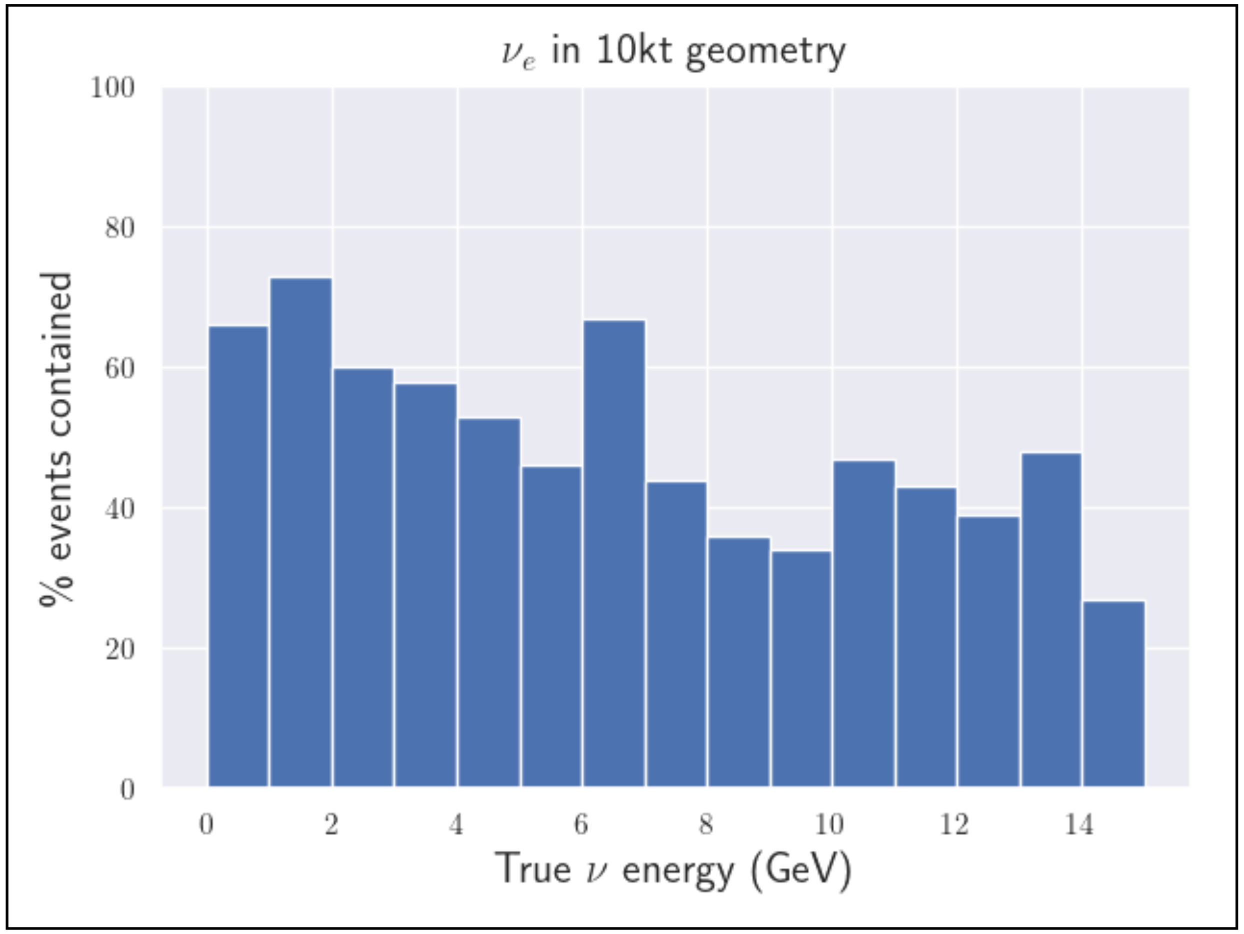
Containment definition

- Simulation provides "MC reconstructed" objects based on simulated ionization electrons.
  - Construct "MC showers" and "MC tracks" for particles which are above thresholds and visible in the detector.
  - A version of MC truth information which describes what we *see* in the detector.
- Require all MC reco objects have a start and end point inside the fiducial volume.
- Strict definition of containment — *every* particle visible in the detector must be completely contained.

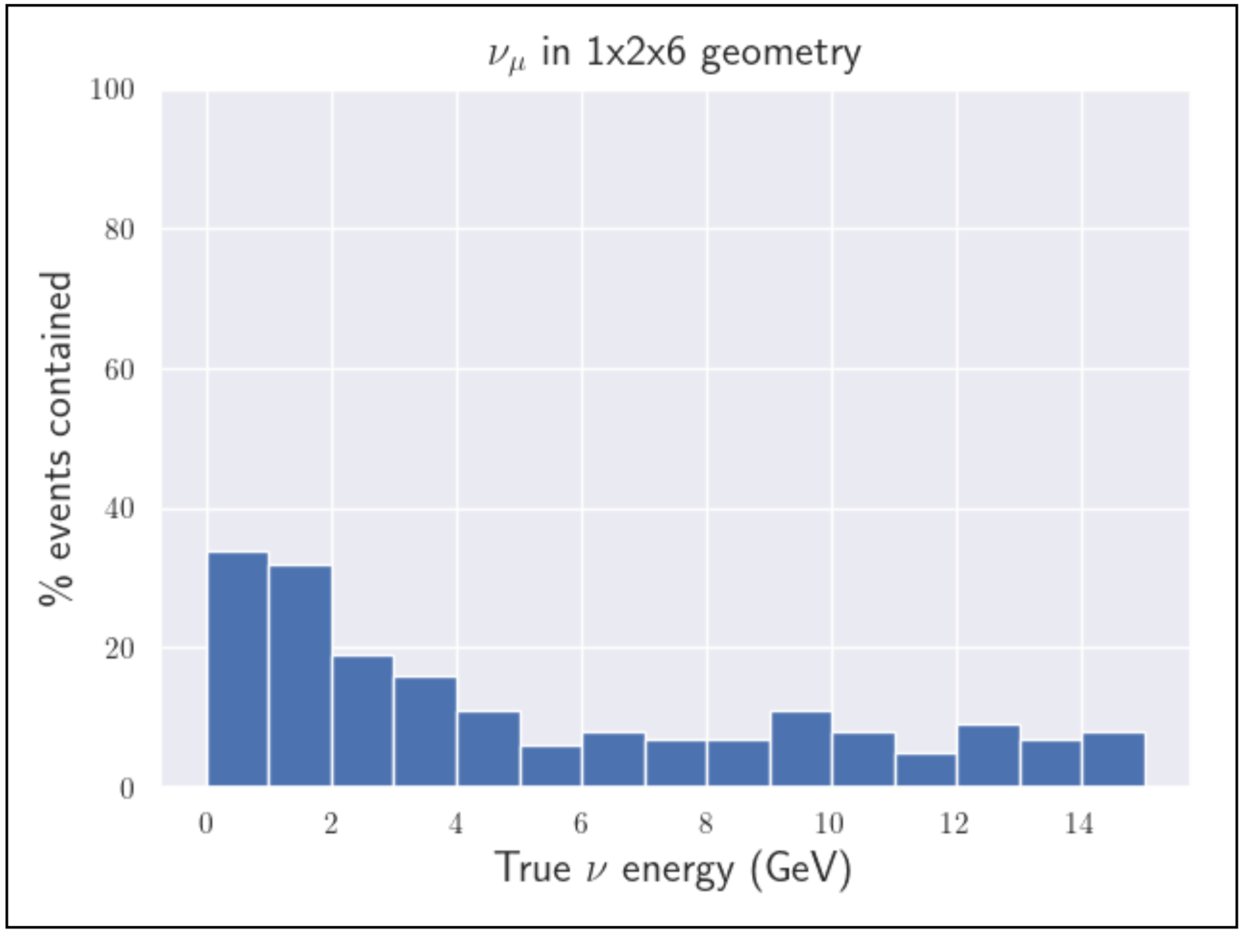


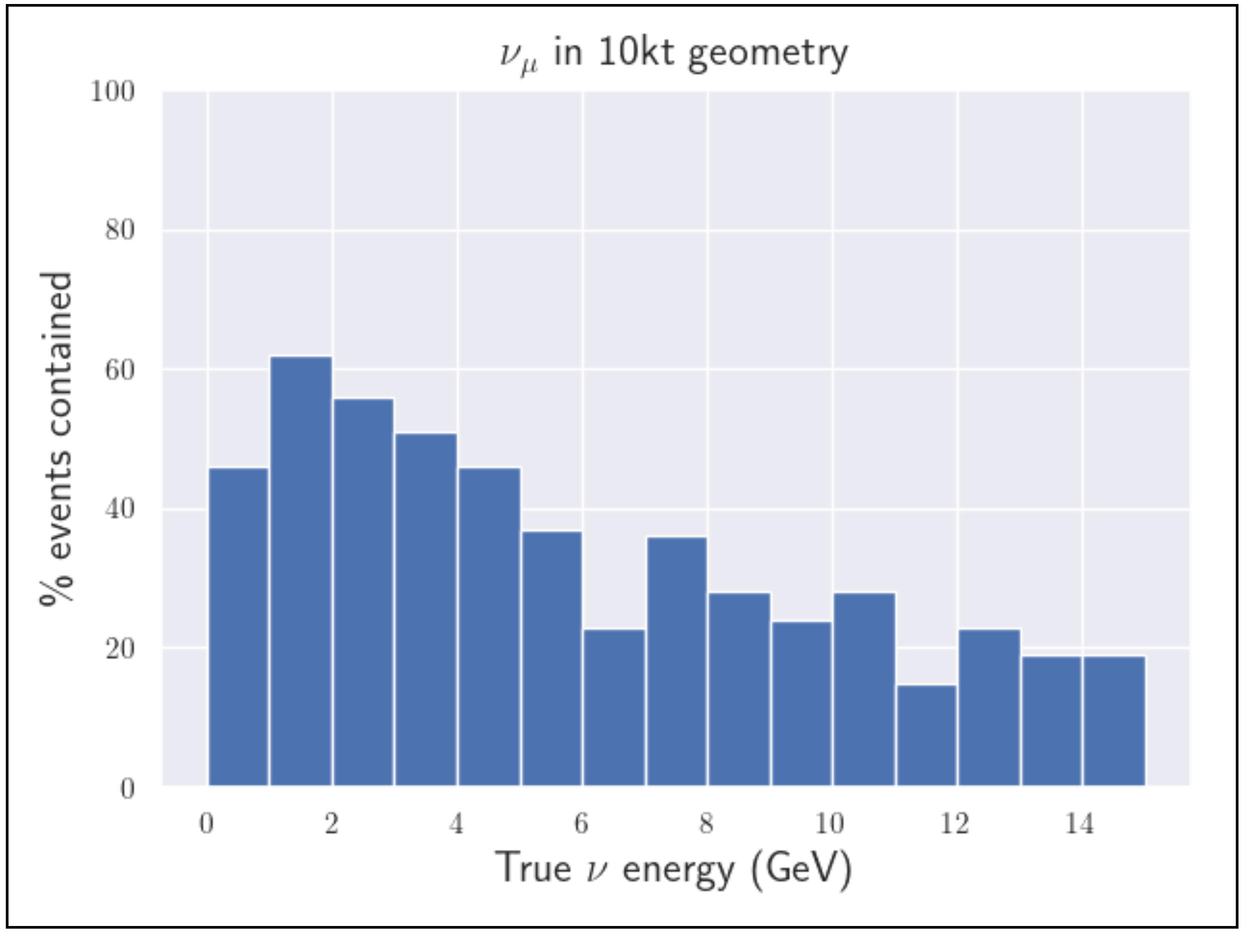
ν_e containment



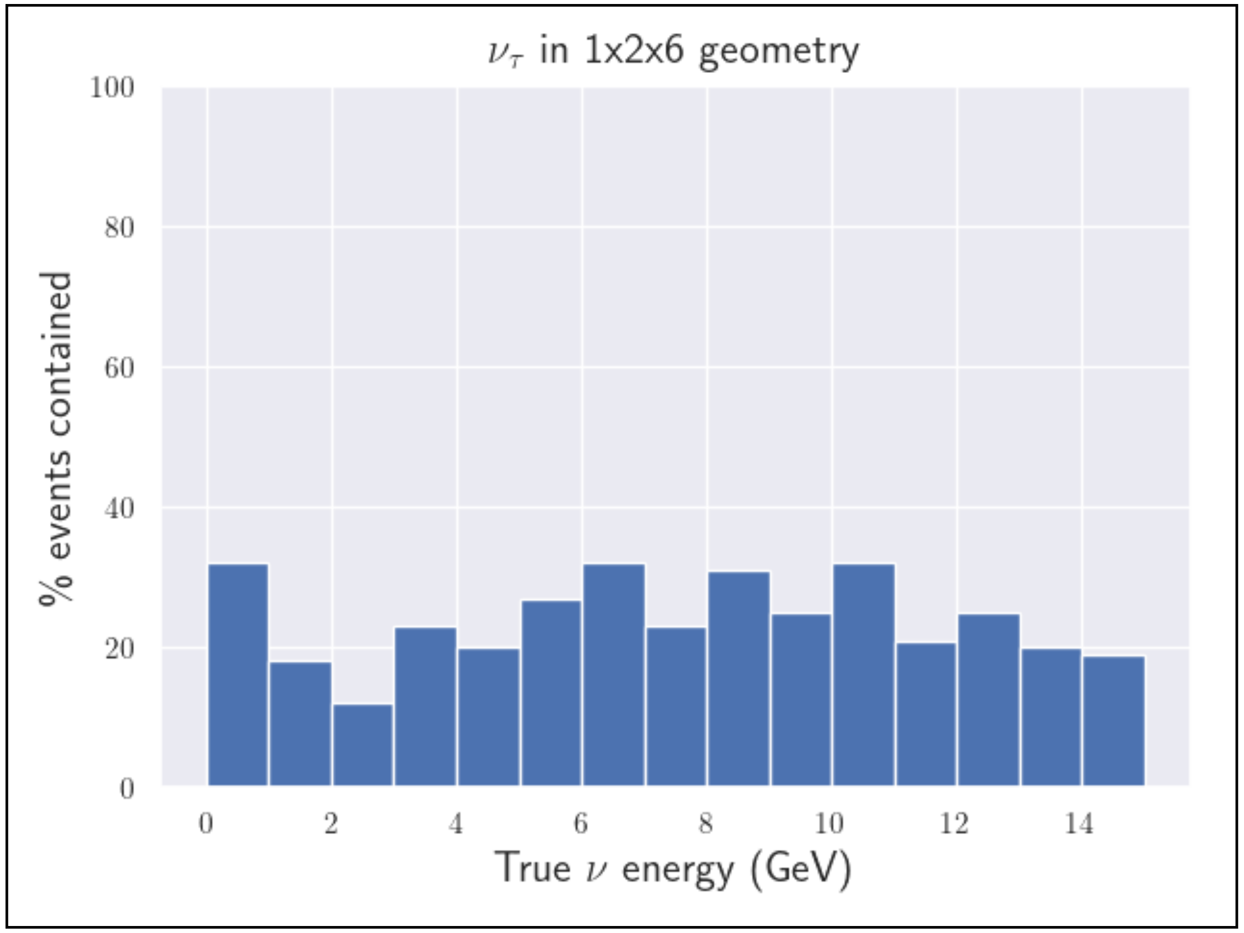


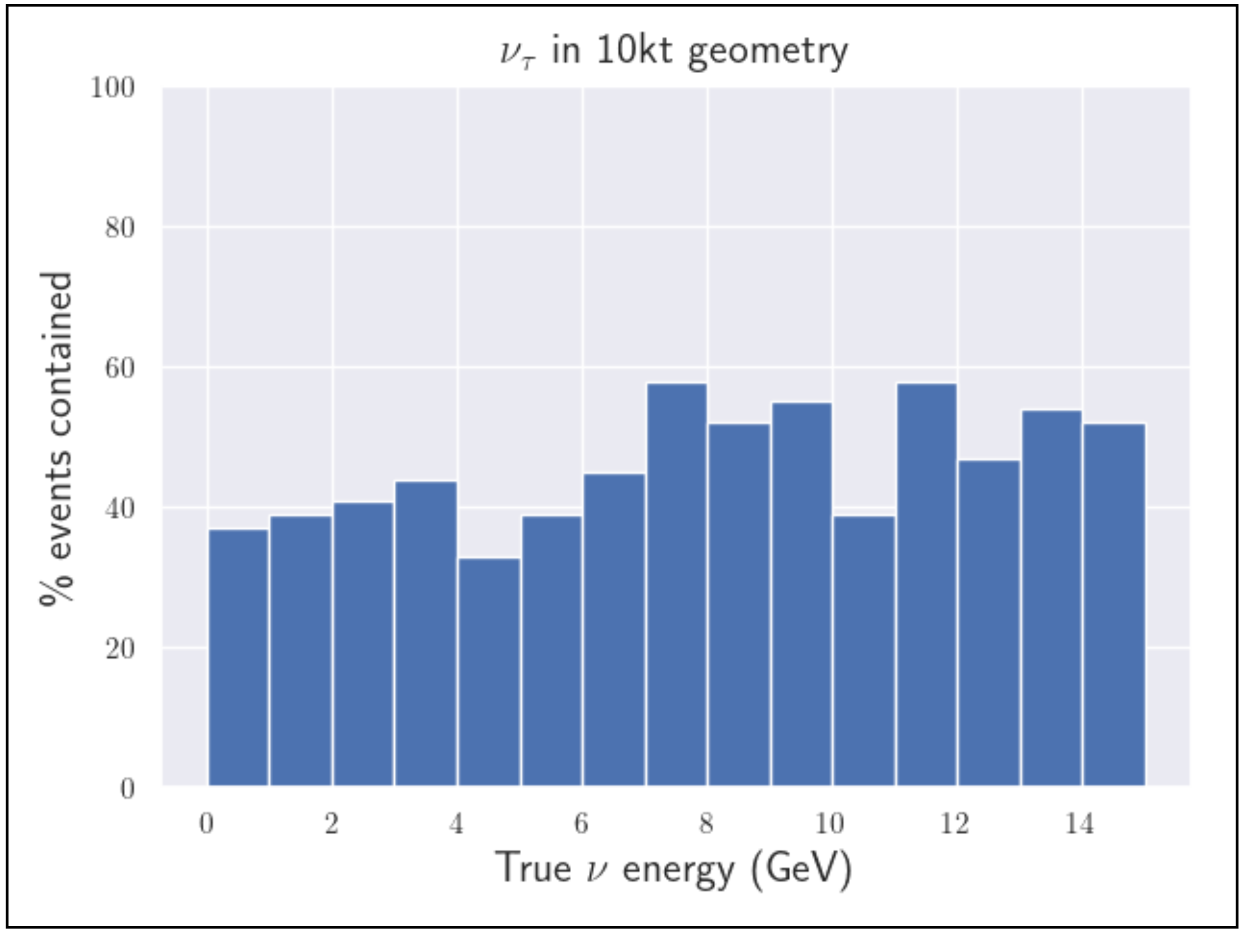
ν_μ containment





ν_τ containment

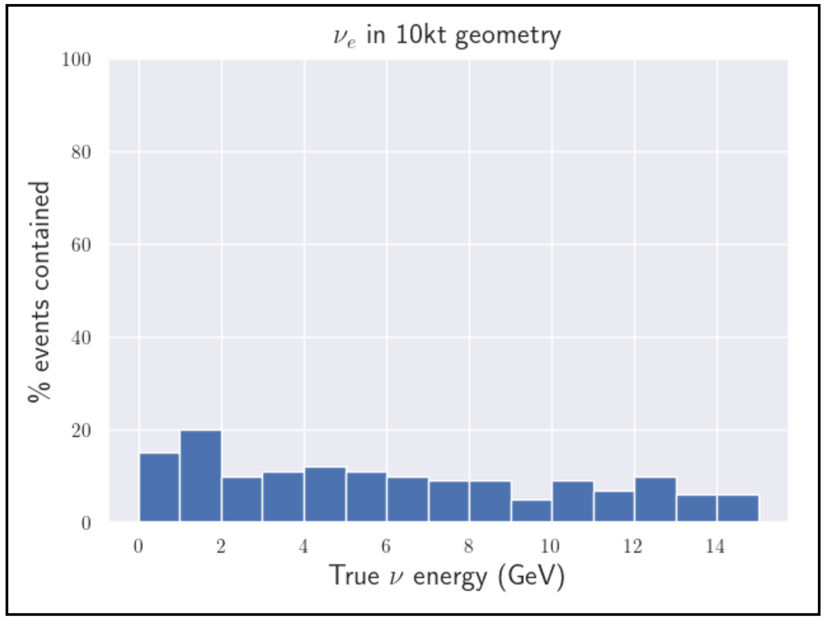


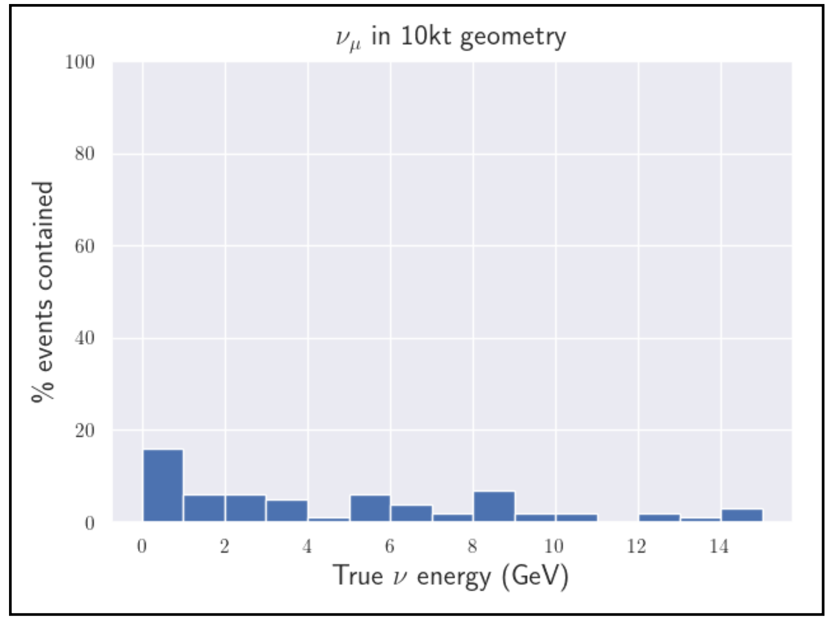


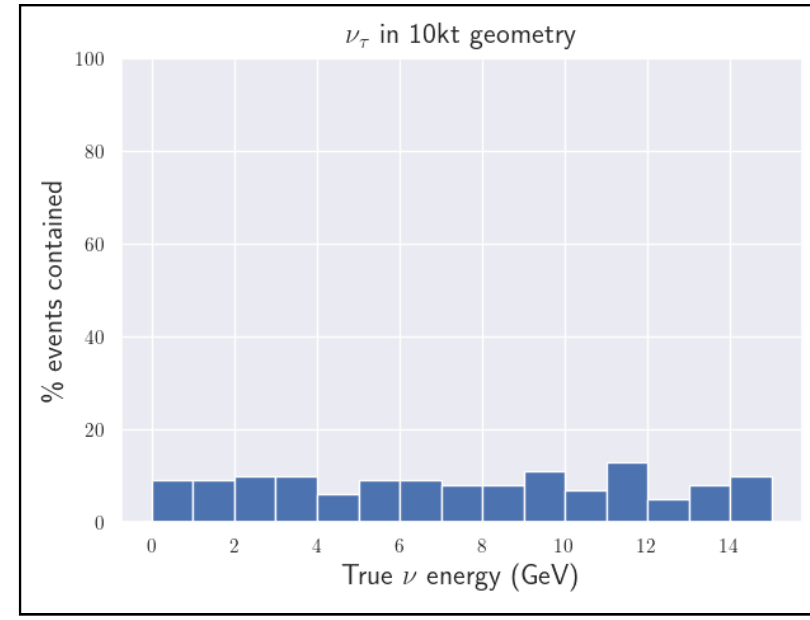
Atmospheric containment

- We have an MC sample of beam neutrinos with an event rate ~flat in energy. What can this tell us about atmospheric neutrinos?
- Downward-going neutrinos only have ~12m of detector in which to stop.
- Define a 12x12x12 subset of the detector, and see what % of events with a vertex inside this volume are contained within it.

Containment







- Containment in 12x12x12 volume generally very poor.
- ν_μ containment in CDR is ~75%, but this only considers the muon containment, whereas we consider *everything*.

Table 4.3: Atmospheric neutrino event rates including oscillations in 350 kt · year with a LArTPC, fully or partially contained in the detector fiducial volume.

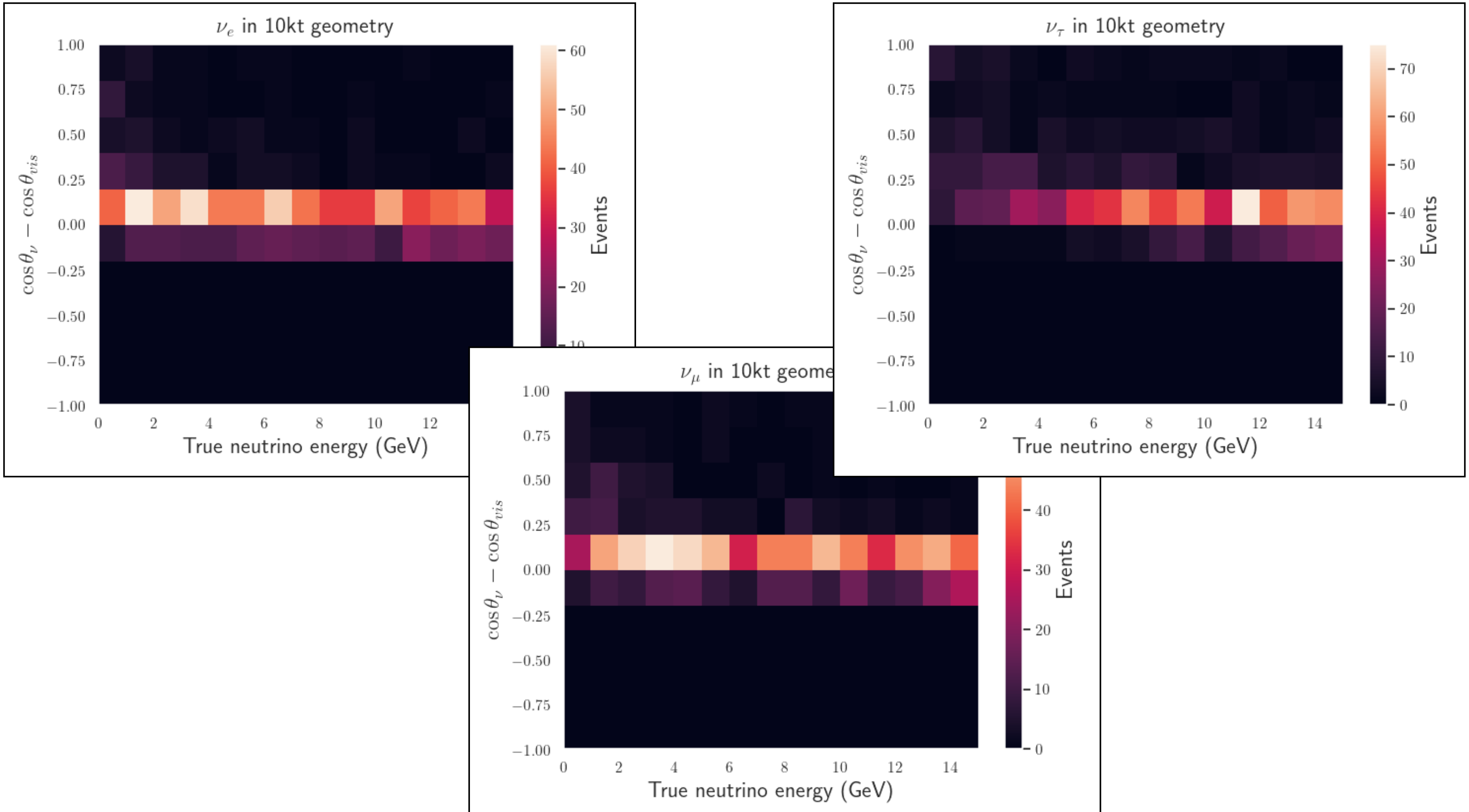
Sample	Event Rate
fully contained electron-like sample	14,053
fully contained muon-like sample	20,853
partially contained muon-like sample	6,871

- Would be interesting to do this study for simulated atmospherics in full detector.

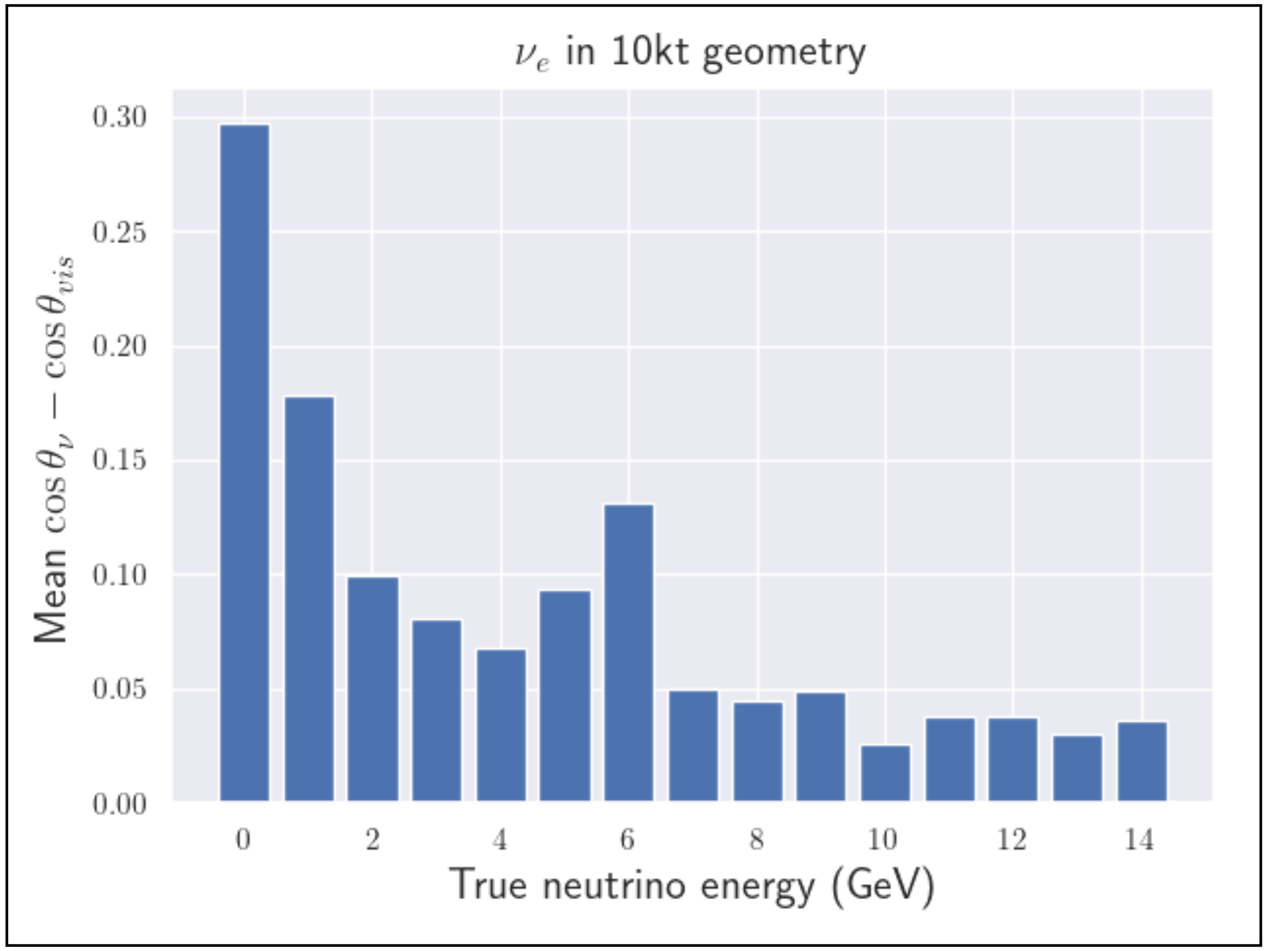
Angular resolution

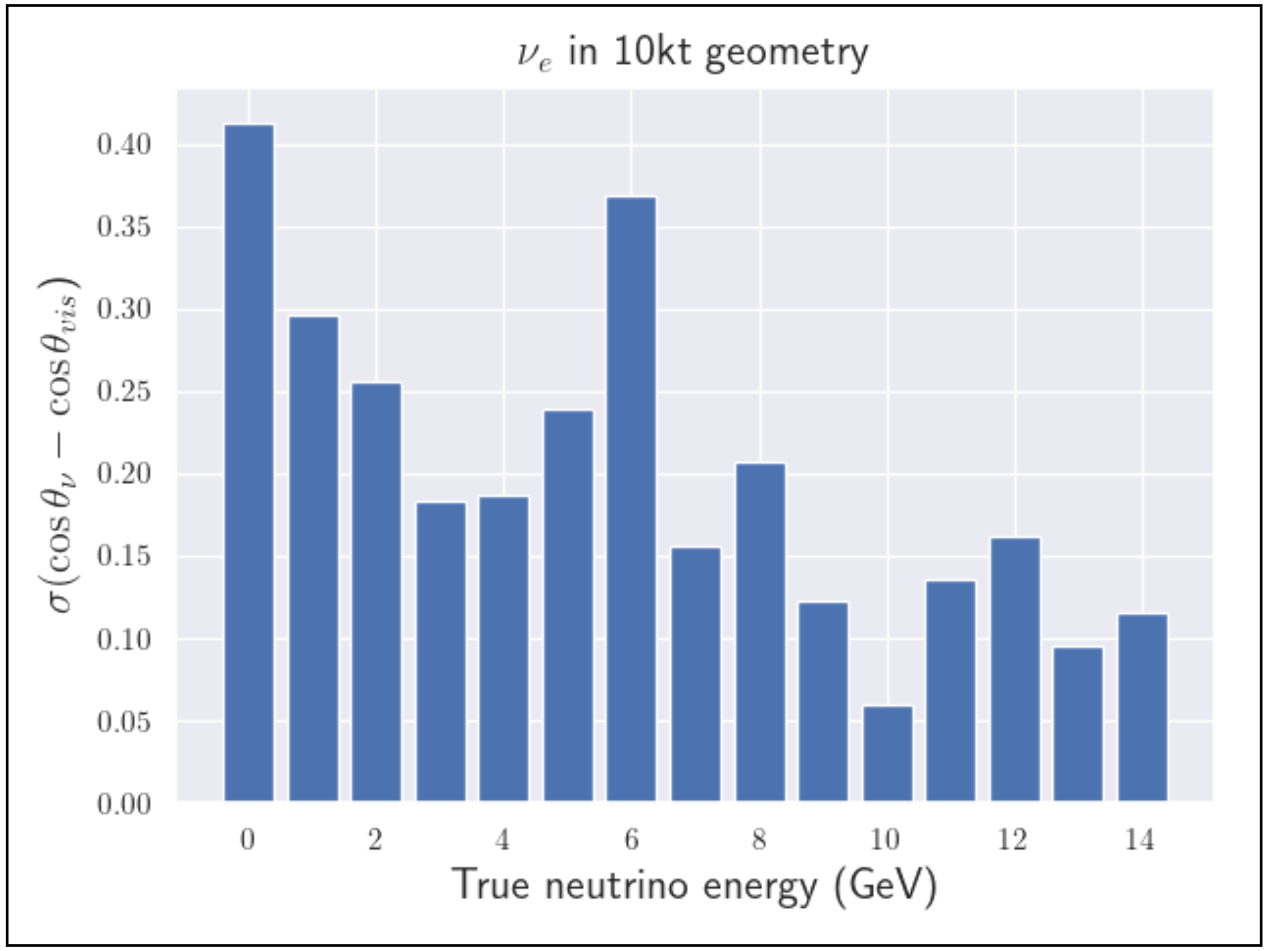
- First-pass look at angular resolution:
  - Calculate cos θ_{ν} between true neutrino direction and beam direction.
  - Calculate cos θ_{vis} between directionality of visible system and beam direction.
    - Direction of visible system is calculated from the directions of all MC reco particles, weighted by momentum.
  - Take the difference between these two to calculate angular resolution.
  - Look at the mean and spread in these as a function of true neutrino energy.

Angular resolution — all events

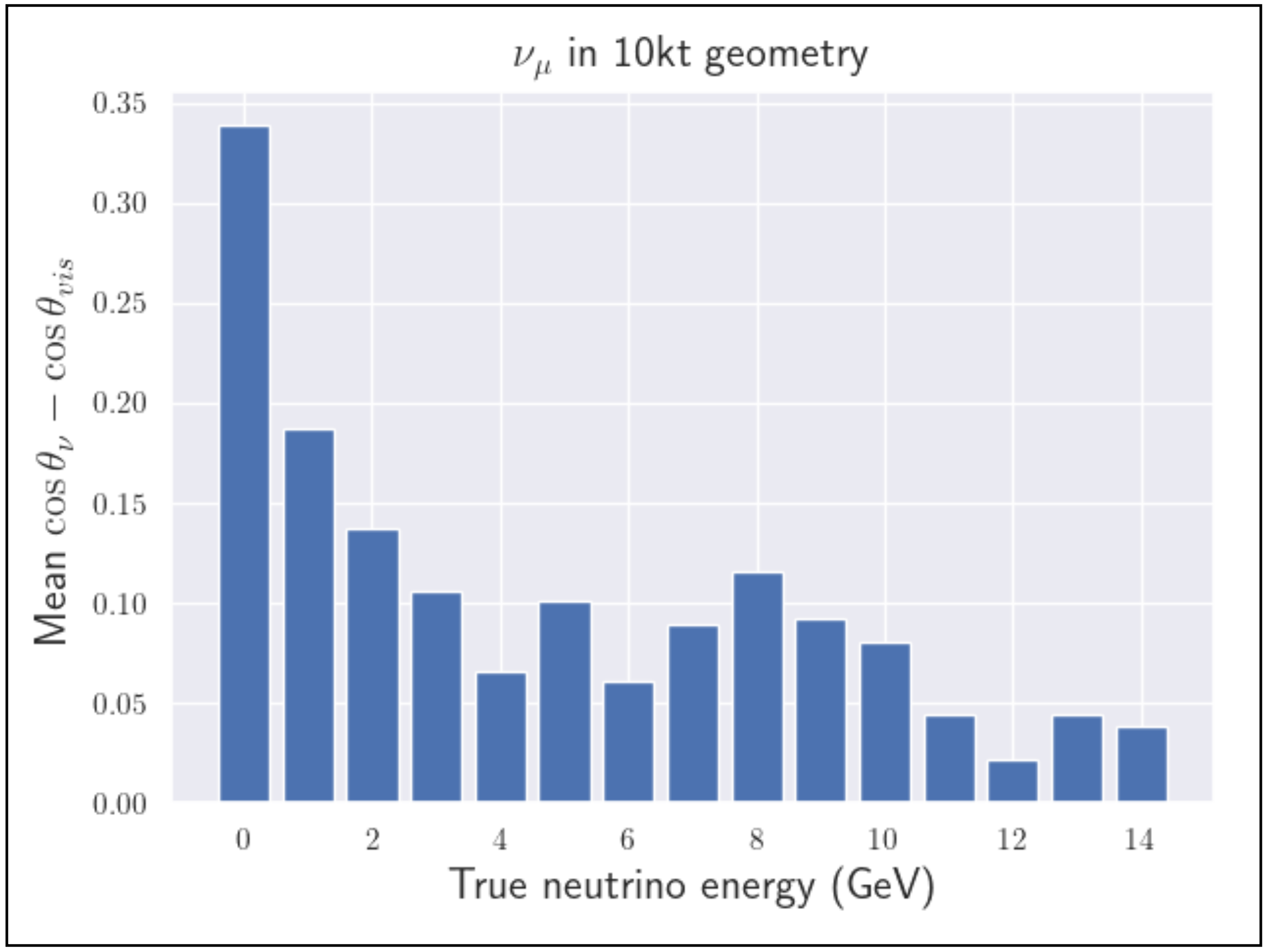


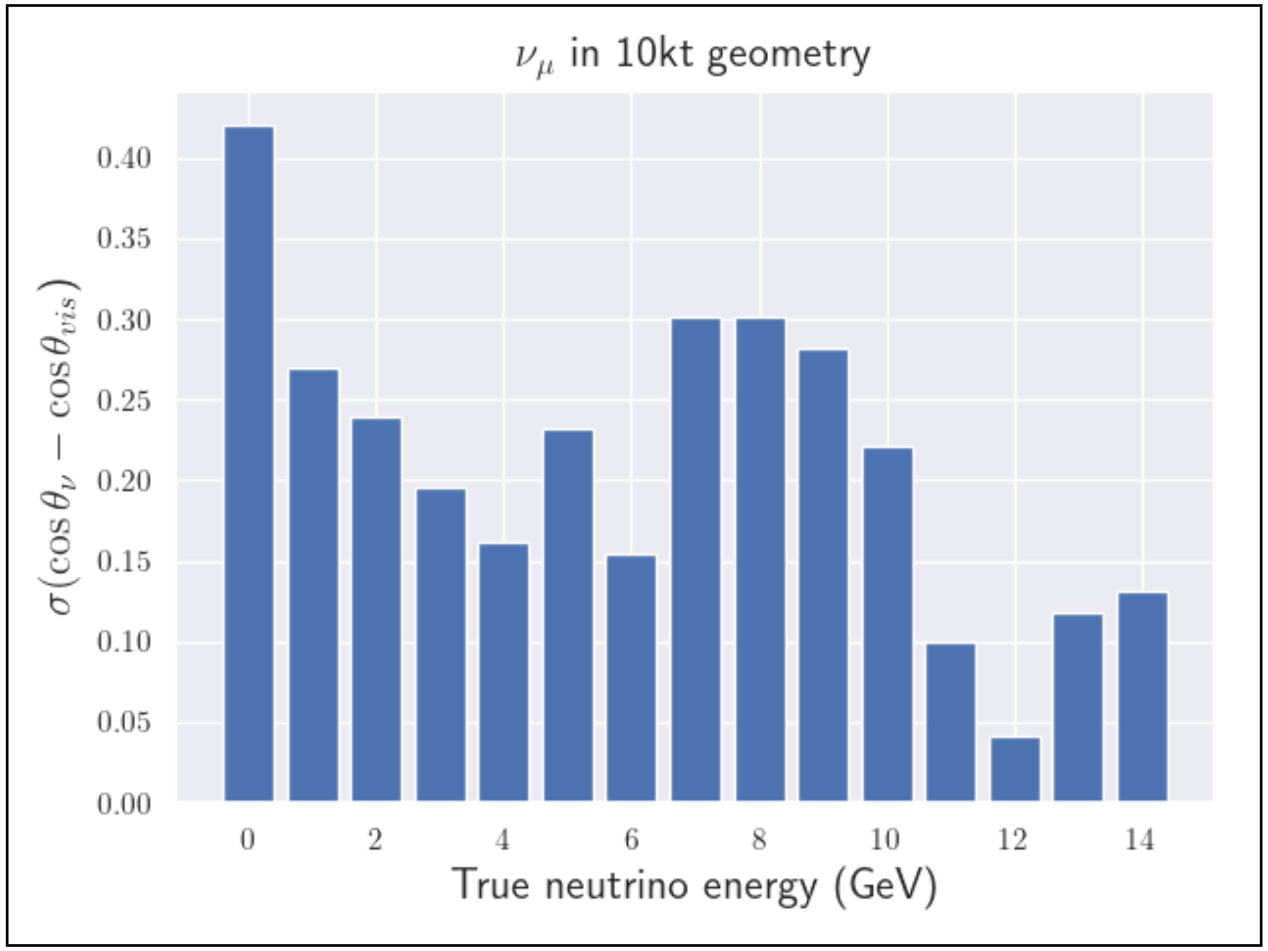
Angular resolution — all ν_e events



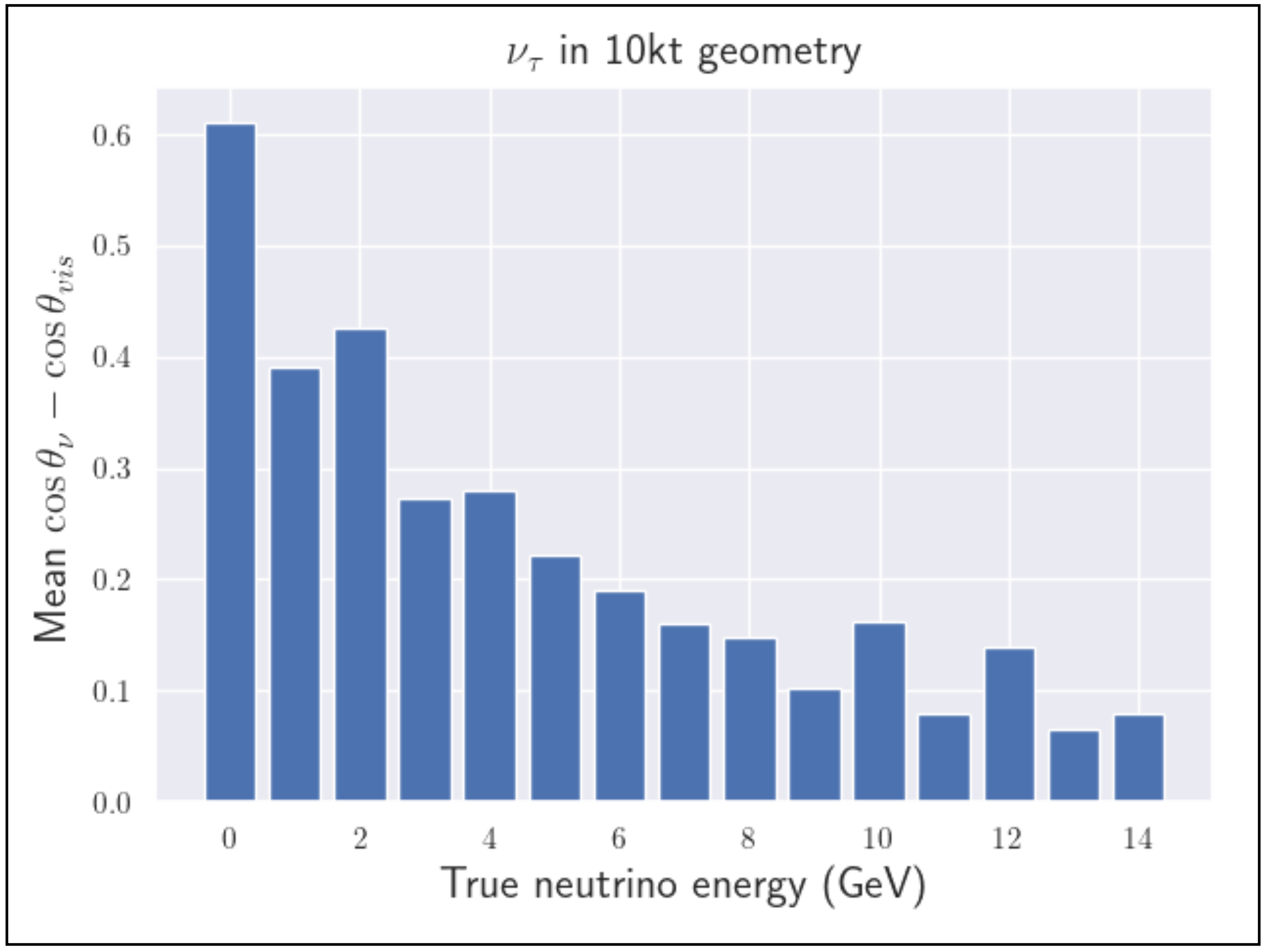


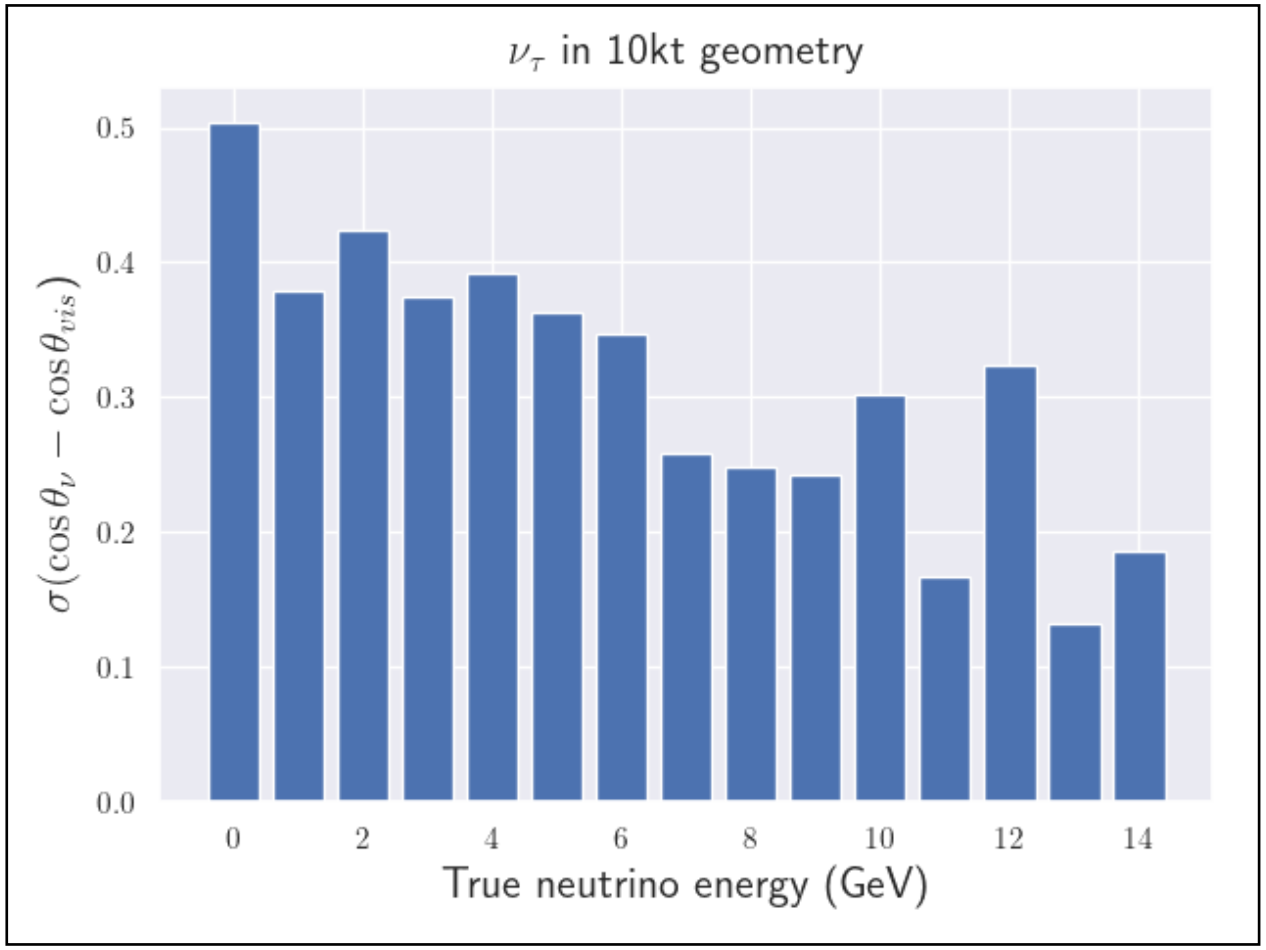
Angular resolution — all ν_μ events





Angular resolution — all ν_τ events





Conclusions

- Containment is an issue even for the larger "reduced" detector 1x2x6 geometry.
    - Gives us motivation to produce MC in the full DUNE 10kt geometry for our next round.
- We are able to:
    - Produce migration matrices for true ν energy vs calorimetric energy for contained events.
    - Make statements on what proportion of interactions we expect to be contained.
    - Any other useful inputs for sensitivity studies?