An improved muon neutrino charged-current single positive pion cross section on water using Michel electron reconstruction in the T2K near detector

New Directions in Neutrino-Nucleus Scattering, NuSTEC

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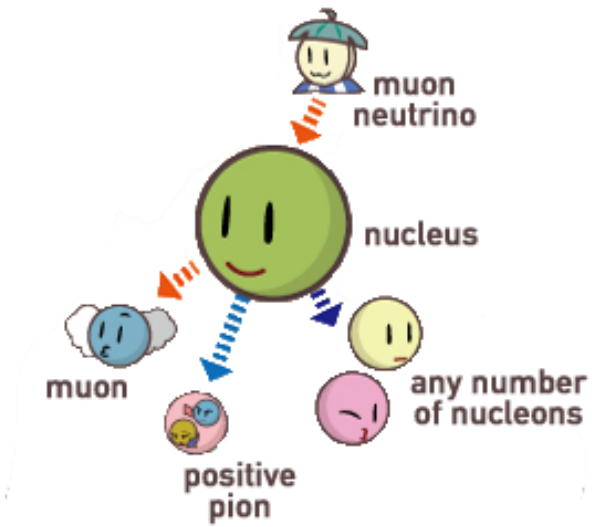
ν_μCC1π^+ on water and hydrocarbon

- Signal: CC1π^+ events in ND280 FGD1 (CH target) or FGD2 (CH + O layered target)
  - ND280 details: A. Cudd - *Recent Results and Future Prospects from the T2K Experiment*

$$\nu_\mu + N \rightarrow \mu^- + \pi^+ + X$$



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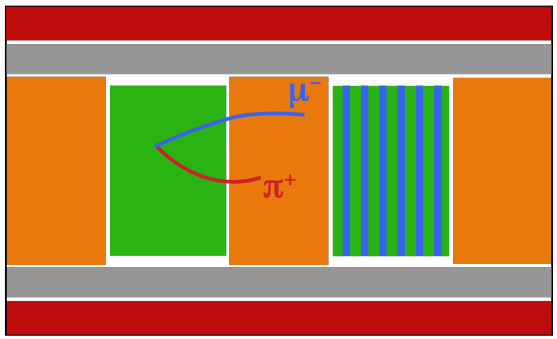
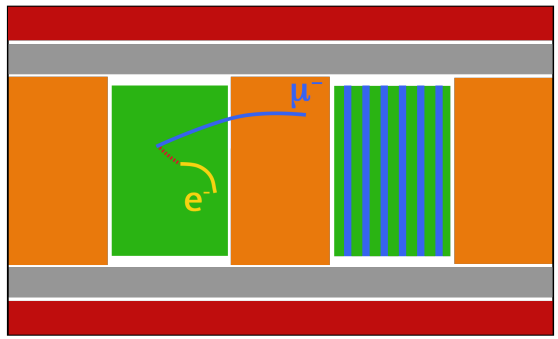
- 4D differential measurement in muon and pion momentum and cos θ
- Major background to CCQE dominated oscillation analysis.
- Pion kinematics of particular interest - no current measurements including these!

Signal Selection

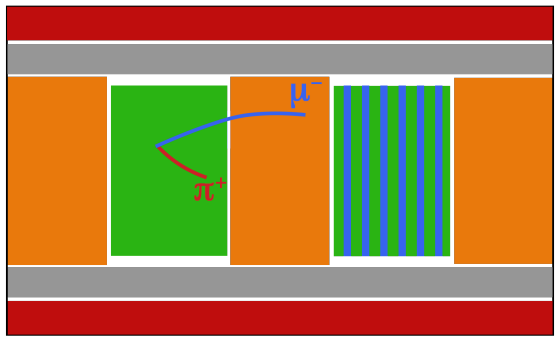
- Signal split into three samples based on how the pion is detected in ND280:
  - Pion detected in TPC (left)
  - Stopping pion in FGD detected from Michel electron (mid)
  - Isolated pion-like track in FGD (right)
- Each of these also split by detector - FGD1, FGD2x (∼water), FGD2y (∼carbon)
- Also 3 control samples based on major backgrounds



TPC

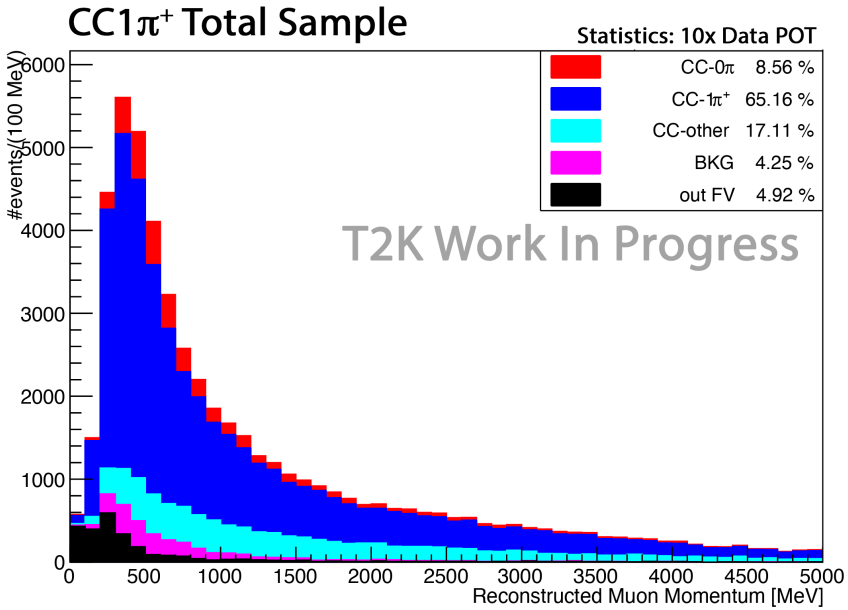


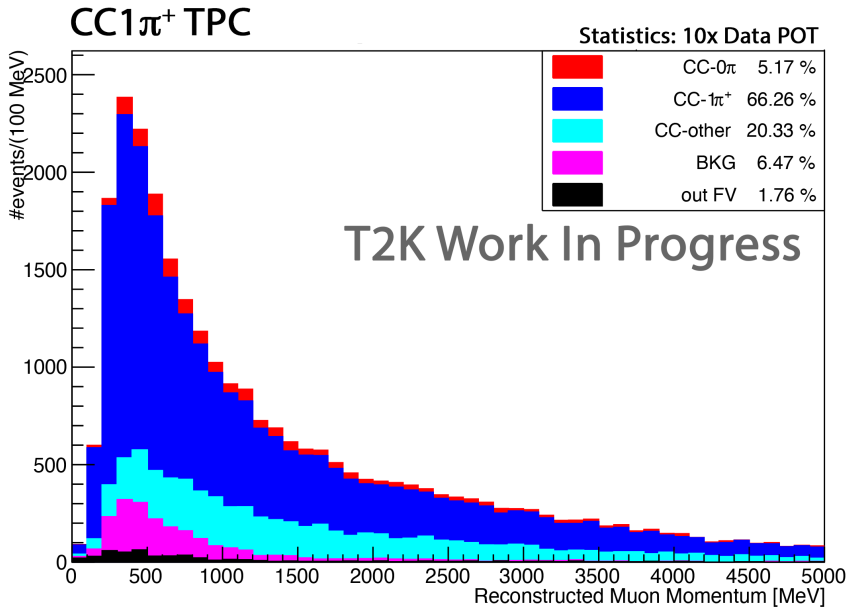
ME

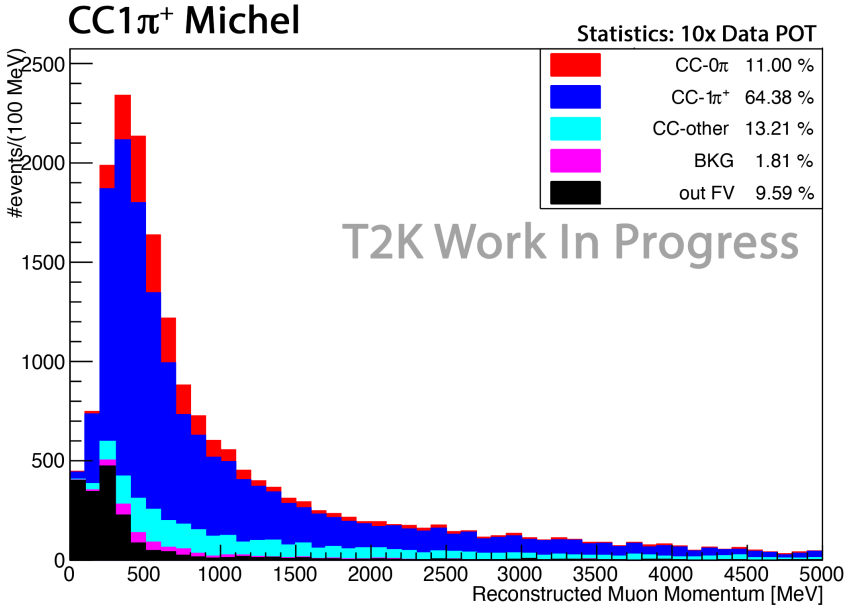


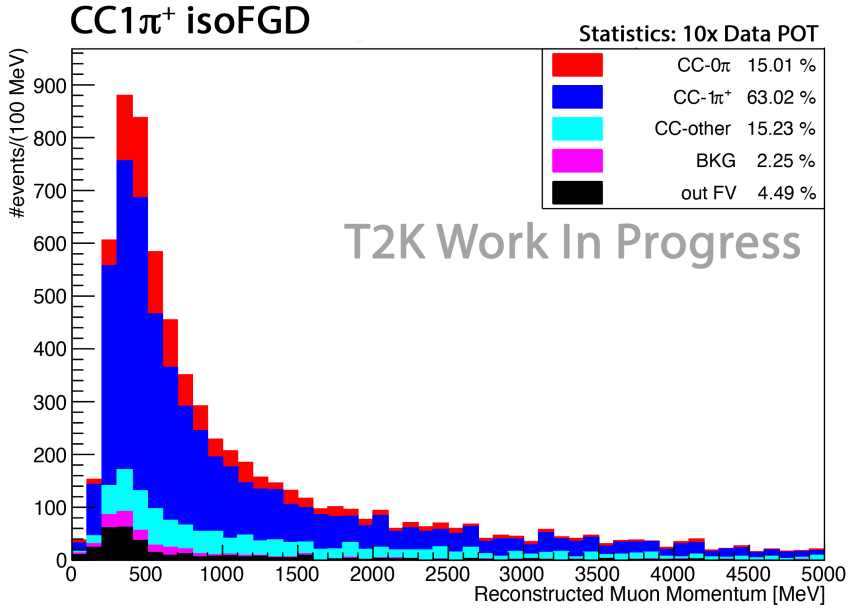
FGD

Muon Momentum FGD1



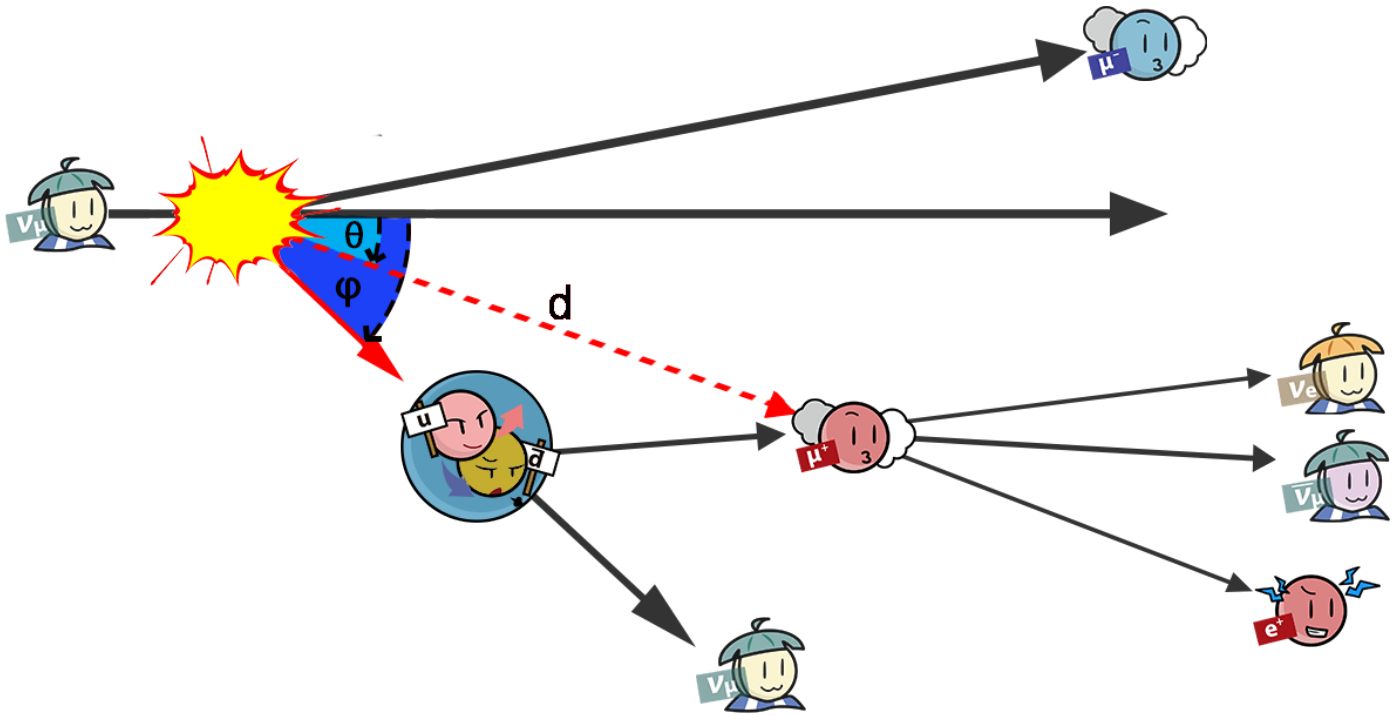






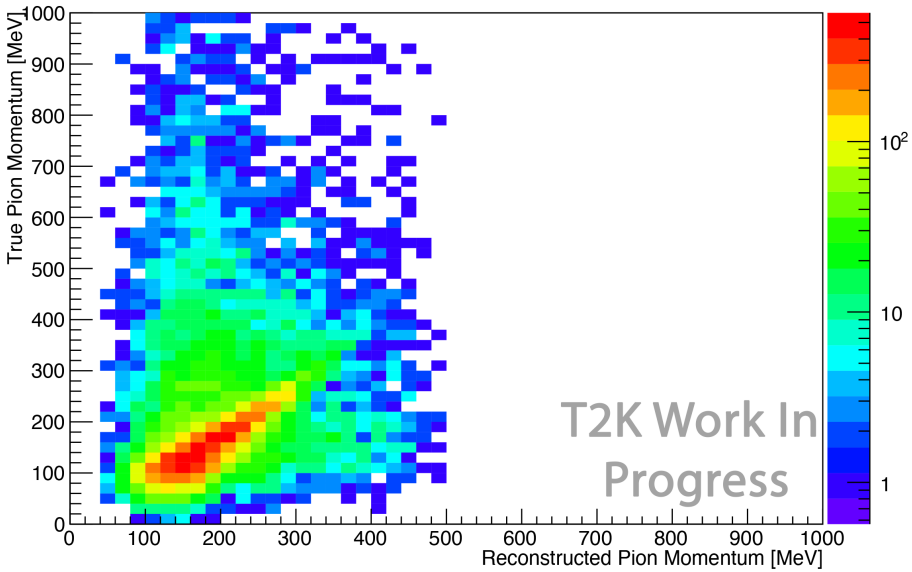
Michel electron reconstruction

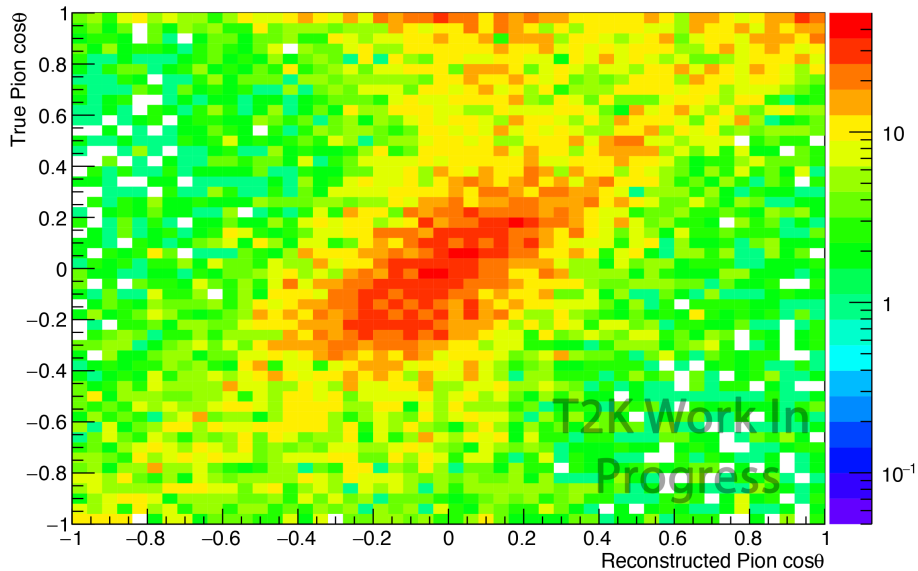
- Roughly 35% of selected sample has pions identified via Michel electrons - kinematics not currently reconstructed
- Estimate pion momentum by range to ME vertex, and pion angle from angle between ME vertex and ν direction!



Pion Kinematic Reconstruction

- Good correlations found in truth between pion kinematics and ME geometry
- Reconstruction limited by FGD bar structure - each FGD hit has only x OR y coordinate, not both $\rightarrow$ SuperFGD will do this much better
- FGD1 reconstructed mom (left), cos θ (right):





A simplified cross section extraction

- Extraction will be done with a binned template likelihood fit, as with previous T2K Xsec analyses
- Simultaneous extraction on both carbon and oxygen:

$$N_i^{\text{C, signal}} = c_i N_{i,\text{ MC}}^{\text{C, signal}}$$
$$N_i^{\text{O, signal}} = o_i N_{i,\text{ MC}}^{\text{O, signal}}$$

N_i^{signal} - Number of events in true variable bin
$N_{i,\text{ MC}}^{\text{signal}}$ - Number of MC events in true variable bin
c_i / o_i - Free template parameters

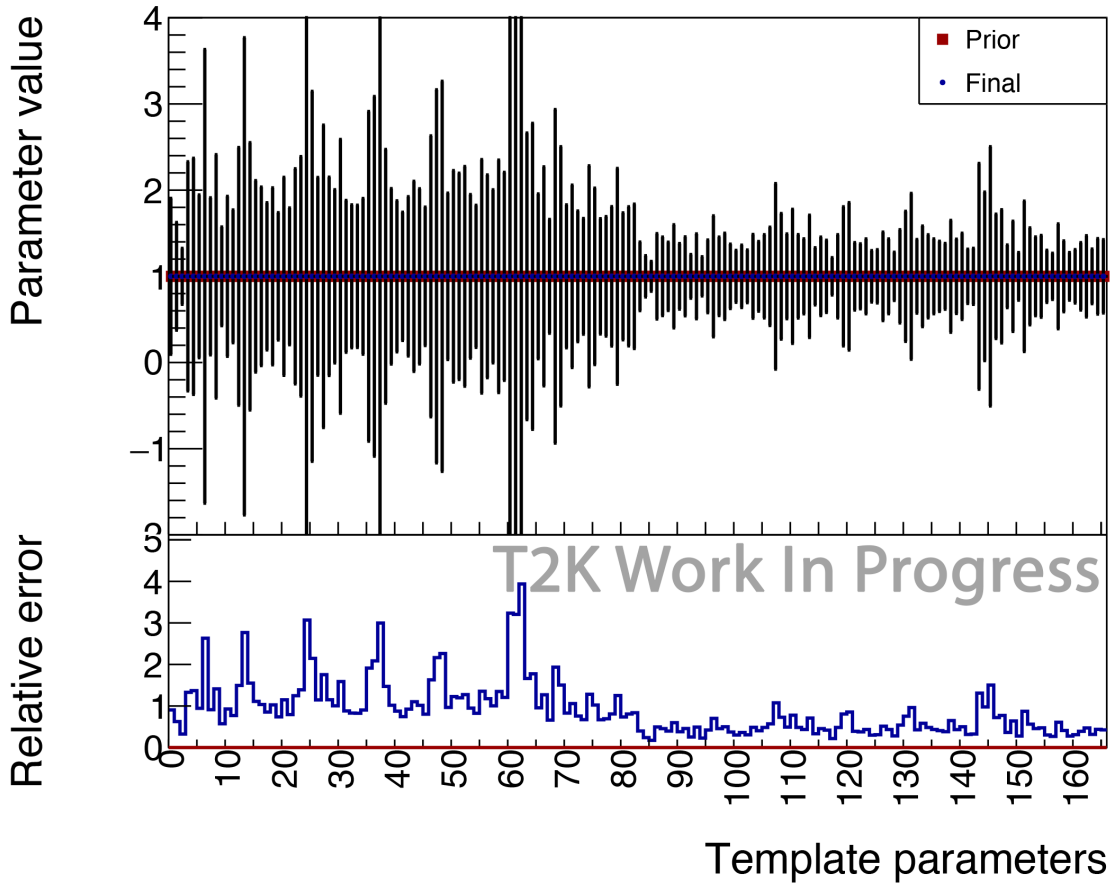
- MC is fit to data by minimising the log likelihood, in order to obtain unfolded result

$$\left(\frac{d\sigma}{dx}\right)_i = \frac{N_{i,true}^{sig}}{\epsilon_i \Phi T \Delta x_i}$$

where ϵ is efficiency, Δx_i is bin width, Φ is integrated flux and T is number of targets.

Asimov fits

- Fit machinery tested using Asimov fit - detector, cross section and flux uncertainties to be added!
- Plan to extract in fine bins for efficiency correction, collapse to reduce statistical error



Summary

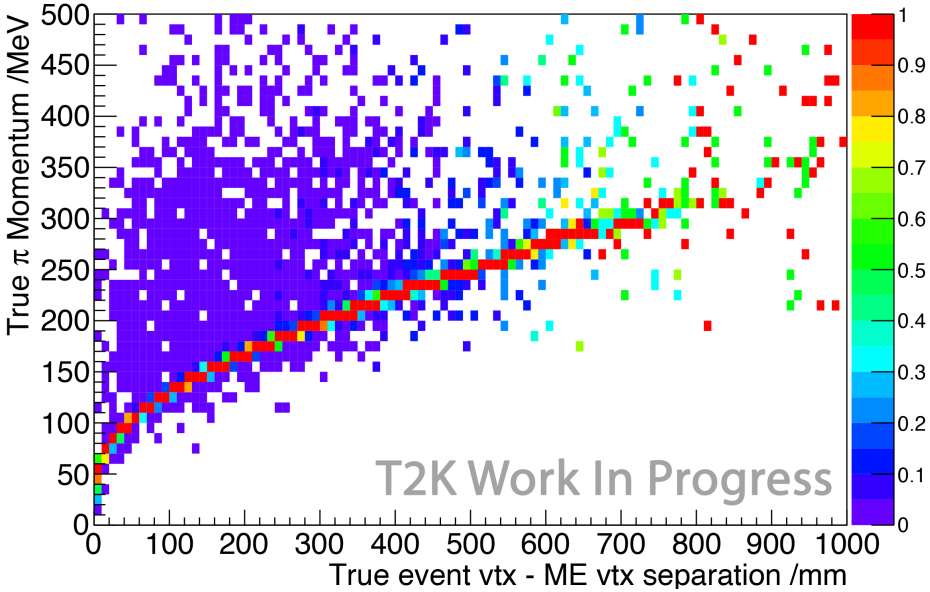
- ν_μCC1π^+ selection developed - 3 signal samples, 3 sideband samples, each split by detector layer
- Ability to estimate pion kinematics from Michel electron chain geometry
  - Reconstruction limited by FGD design
  - Proof of concept for method
  - SuperFGD would make better use of this!
- Cross section to be extracted using binned likelihood fit
- Fitter machinery in place and tested, uncertainty inputs soon to be added

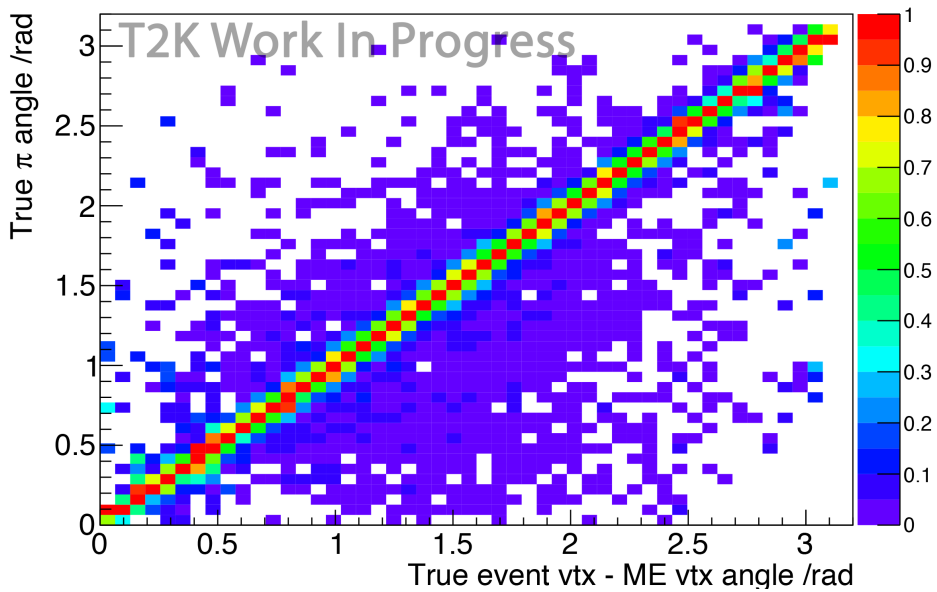
Thanks for listening!

Questions?

Backup

Pion mom vs ME geometry truth distributions





- Columns are normalised to highest bin content
- Both plots show good correlation between pion kinematics and ME geometry in truth
- Angle can be taken as one-to-one correlation, momentum is fitted to find relationship - done separately for FGD1 and 2