Towards Measuring the ν_μ Charged Current Quasielastic Cross Section on Water using T2K's Near Detector

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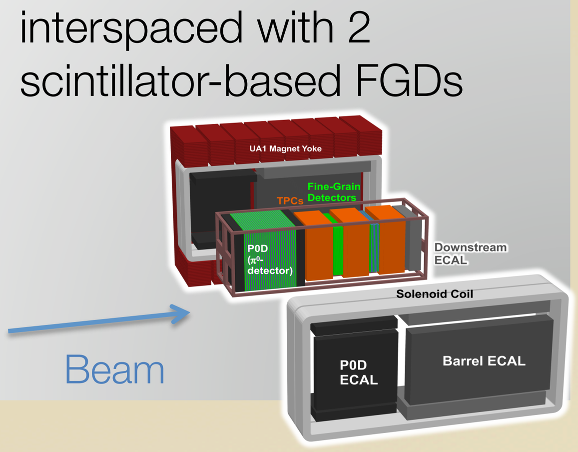
Abstract

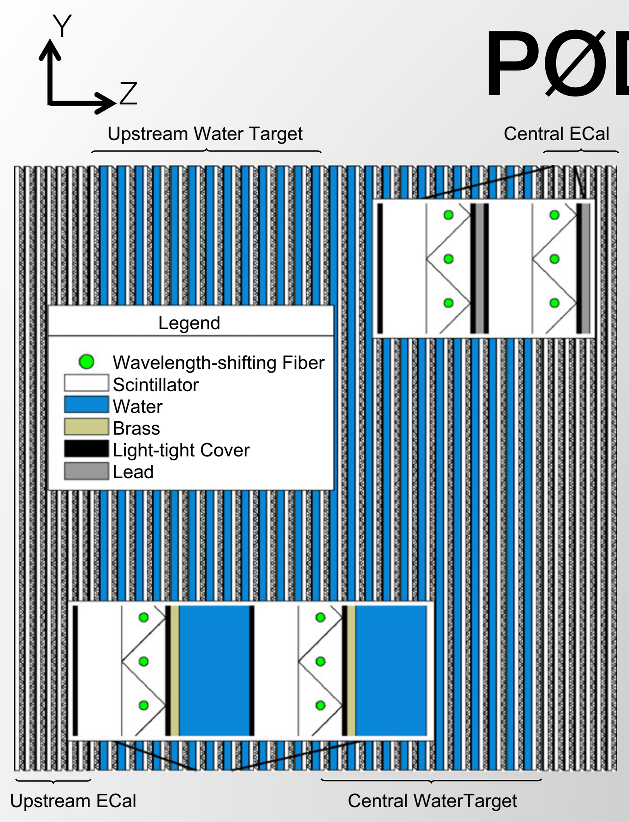
A measurement of the ν_μ charged current quasielastic cross section on water would provide additional constraints for T2K's oscillation analysis and serve to guide future neutrino-nuclear interaction models. We present a selection of ν_μ charged current events using the Pi-Zero Detector (PØD) and the Tracker of T2K's near detector. An analysis that includes Data/MC comparisons and several systematic uncertainties has been completed. In addition, by separating the data sets into time periods when the PØD is filled with water and when it is empty, we propose a subtraction method that can provide an isolated sample of ν_μ interactions on water only. In this way, we plan to provide a measurement of the ν_μ CCQE cross section on water.

ND280

- Near detector of T2K
- Pi-zero detector (PØD) upstream of tracker is a scintillator-based detector
- Tracker consists of 3 argon-based TPCs interspaced with 2 scintillator-based FGDs



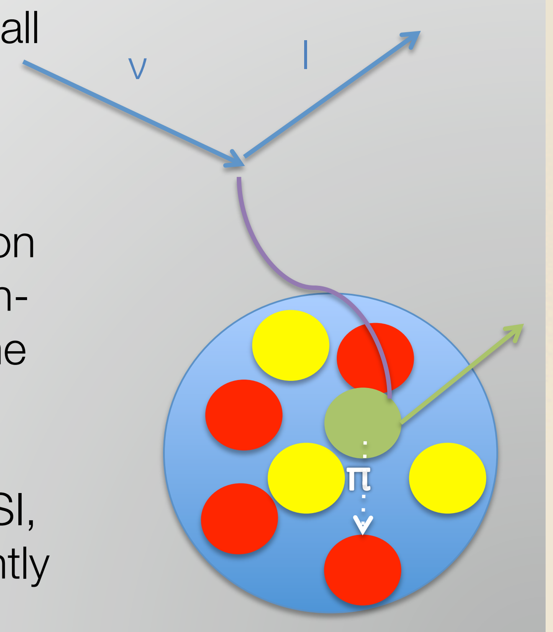
PØD



- PØDECals consist of alternating layers of scintillator and lead
- WT consists of alternating layers of scintillator, brass, and water
- Scintillation measured with wavelength-shifting fiber, readout via MPPCs

Cross Section Definition

- Observables of experiment all after FSI, which means the true reaction information is lost.
- For example, pion absorption inside nucleus causes a non-CCQE interaction to become CCQE-like.
- Therefore, we claim to measure a topology after FSI, **CC0π**, which is predominantly from CCQE.



Pion absorption

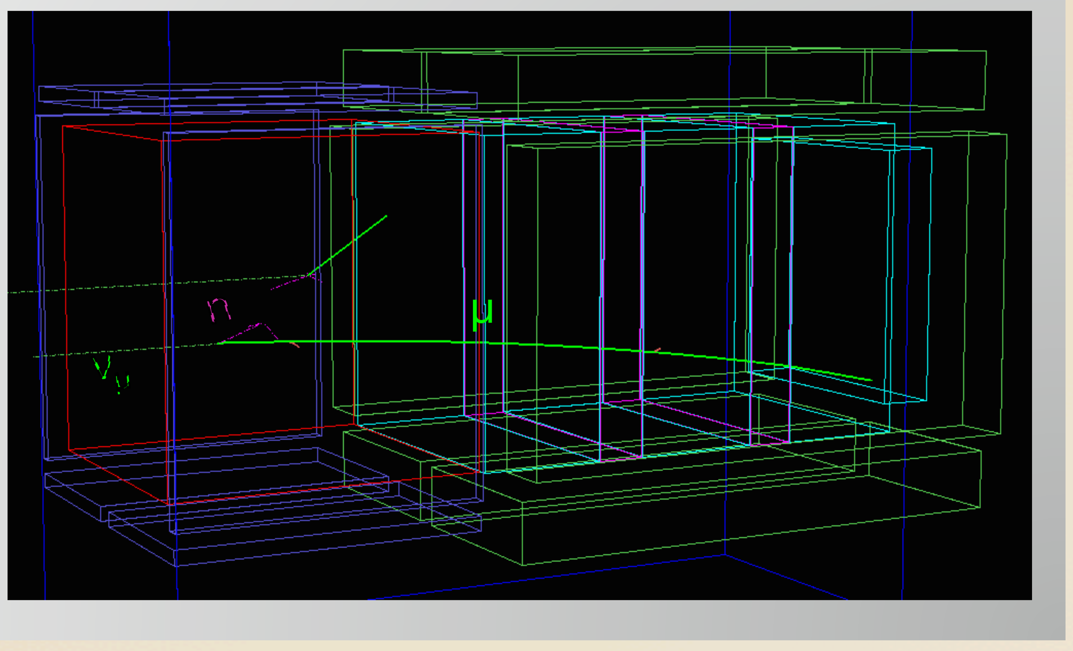
CC0π

- Requires an outgoing μ, zero π's, and allows for any number of outgoing nucleons.
- CC0π has been measured on ^{12}C but not H_2O, although a fit to M_A using water data has been done (PhysRevD.74.05200 2)
- **Goal**: measure a flux-averaged, double-differential, ν_μ CC0π cross section on O

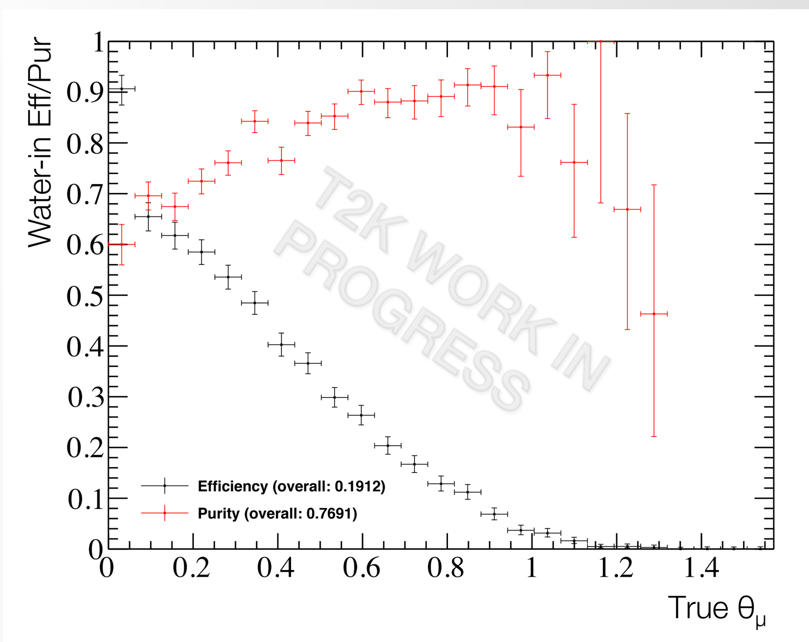
Event Selection

1. Data Quality (Not applicable for MC)
2. PØD Fiducial Volume (~25 cm from XY edges, Z between midpoints of first and last water-PØDule)
3. Track enters tracker
4. Select highest momentum negative track in bunch
5. Single PØD reconstructed object per bunch

MC-Truth CC0π Event



Selection Efficiency and Purity

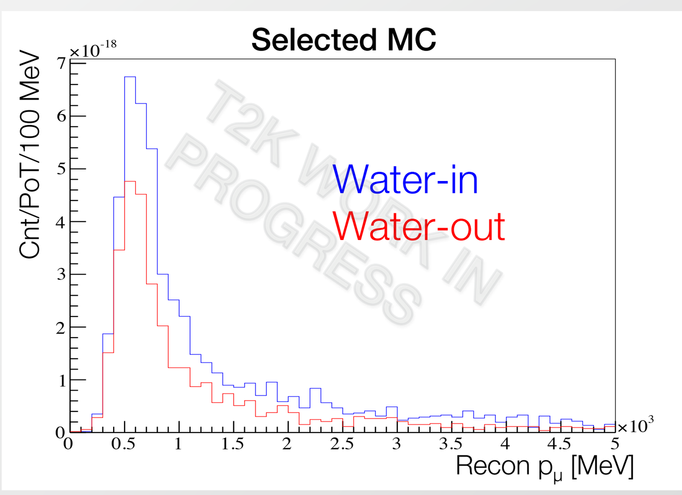


- The requirement for a track to enter the Tracker is needed to ensure accurate momentum reconstruction but affects our selection efficiency.
- We are able to select low-angle tracks with higher efficiency than high-angle tracks, and as θ_μ approaches π/2 our selection efficiency drops to zero.
- This limits our ability to sample the double differential phase space of θ_μ-p_μ and low efficiency regions are more dependent on MC

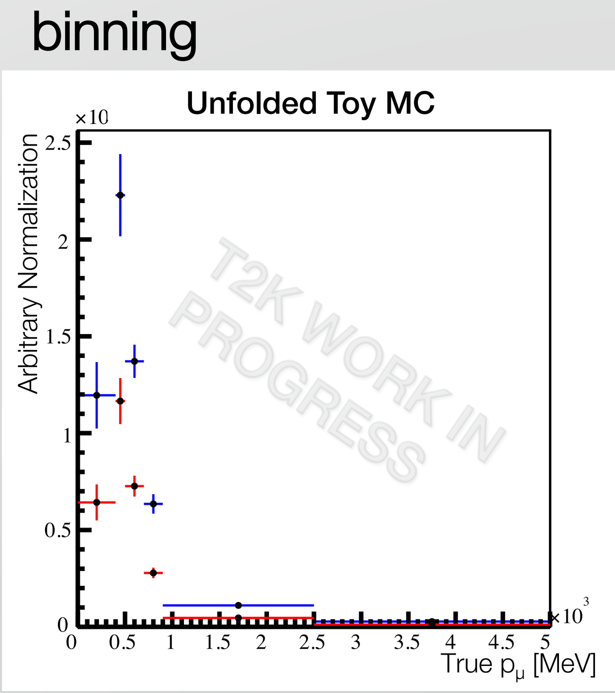
Method

- The PØD is the only detector in ND280 that has run periods in two different configurations: water-in and water-out. We take advantage of this fact!
- Our method is as follows:

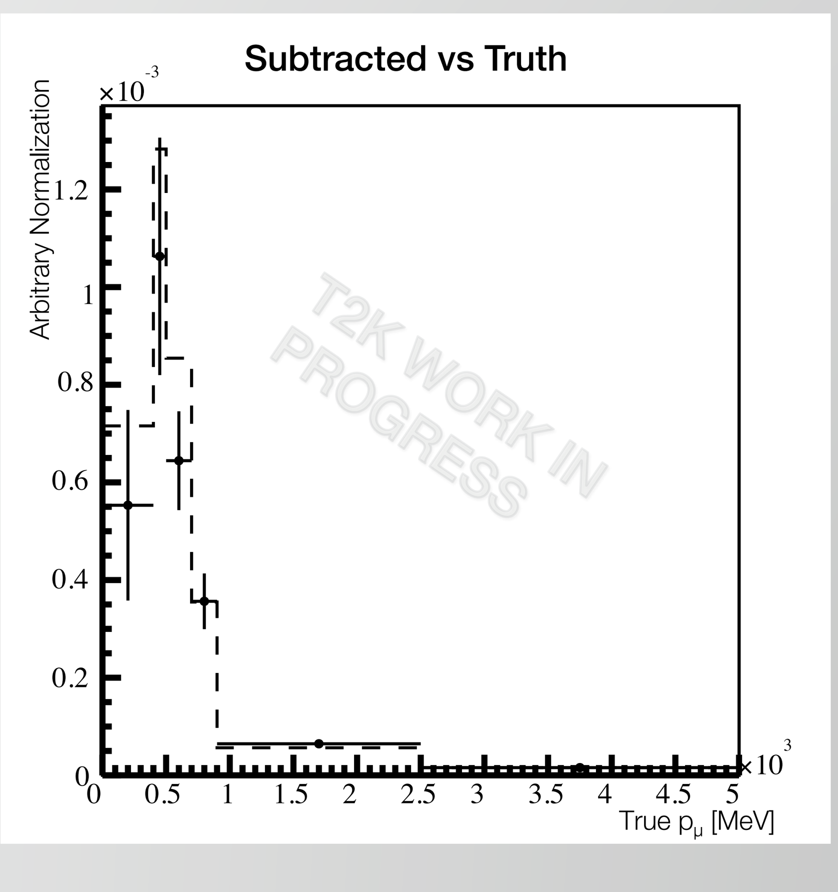
1. Separate samples into water-in and water-out



2. Iterative Bayesian unfold from reconstructed to true binning



3. Subtract the two unfolded samples to extract a measurement on oxygen



The number of events on oxygen is given by:

$$N_i^O = \frac{U_{ij}^w N_j^w}{\varepsilon_i^w} - R\frac{U_{ij}^a N_j^a}{\varepsilon_i^a}.$$

The indices *i* and *j* indicate true and recon bins, *N* is the number of events in the bin, *R* the flux normalization ratio between water-in and water-out samples, ε the selection efficiency, and *U* is the unfolding matrix. Then the cross section is:

$$d\sigma_i = \frac{N_i^O}{F^w N_n D_i},$$

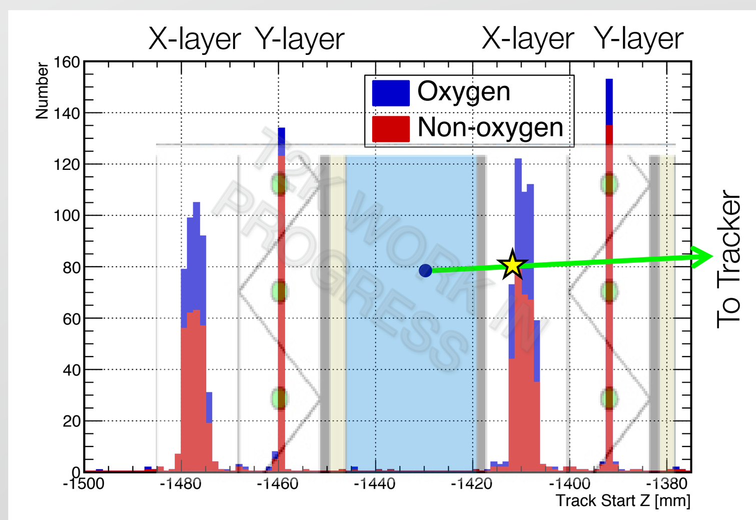
where F is the integrated flux, N_n the number of nucleons, and D_i the bin width

Statistical Error Reduction

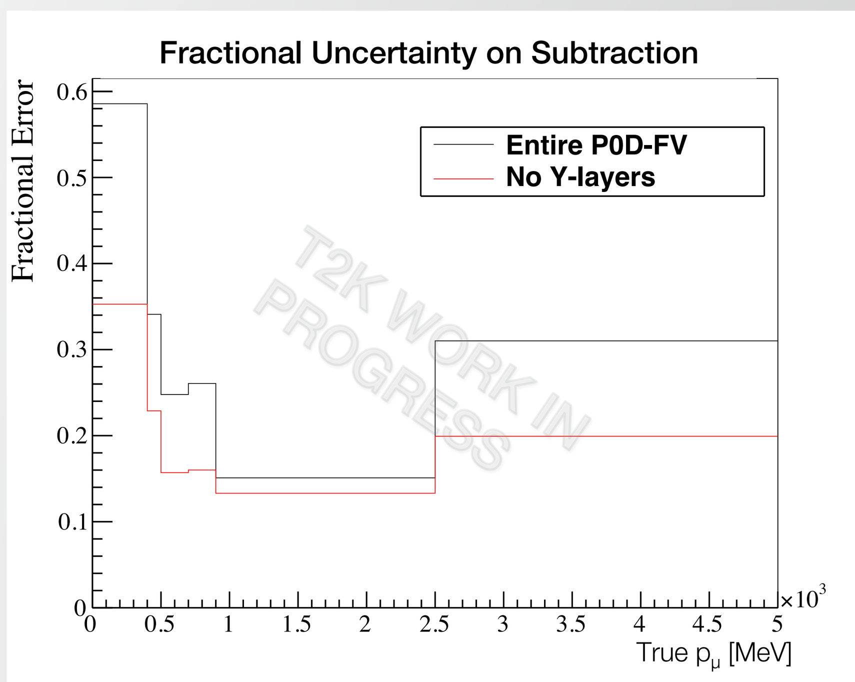
- Assuming water-in/water-out samples are statistically independent, the variance on their difference is a sum of their individual variances.
- The statistical uncertainty on subtracted distribution is approx:

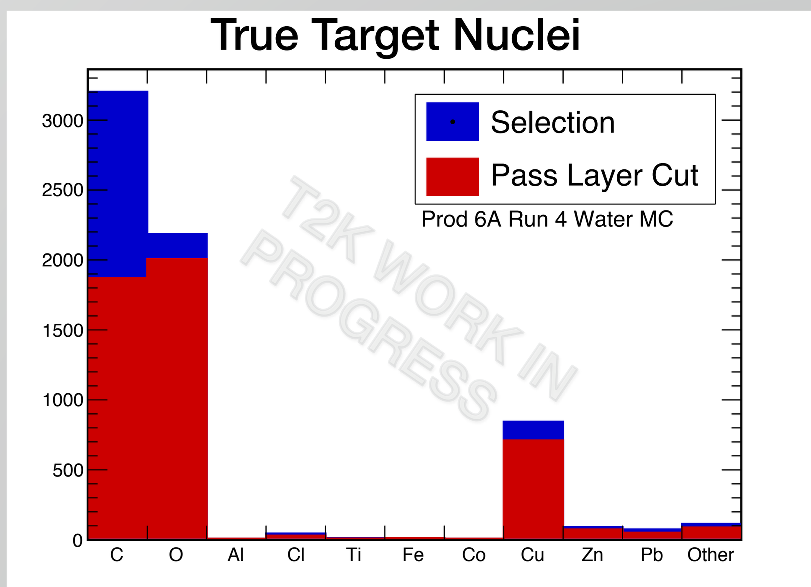
$$\frac{\sigma(N_O)}{N_O} \approx \frac{1}{\sqrt{N_O}}\sqrt{1+(1+R)\frac{N_{nonO}}{N_O}}$$

- Here N_{nonO} are interactions that occurred on a non-oxygen target
- Can reduce the fractional uncertainty by **reducing the non-oxygen background!**



Events occurring on O are more likely to reconstruct in X-layer





Cutting out the Y-layer reduces a large fraction of C background without losing many O events

Systematics and Outlook

- The three major contributions to our systematics are beam flux, interaction modeling and detector systematics. Reweighting methods exist to help give handle on first two, we need to focus on detector systematics related to our measurement. For example, fiducial volume and mass uncertainties, energy reconstruction differences and track matching all need to be understood.
- Lots of work to be done!

References

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The T2K Collaboration. Precise Measurement of the Neutrino Mixing Parameter θ_{23} from Muon Neutrino Disappearance in an Off-axis Beam. arXiv: 1403.1532, 2014.

Melody Ravonel. *Measurement of the Inclusive ν_μ Charged Current Cross Section in the Near Detector of the T2K Experiment*. PhD Thesis, University of Geneva, 2012.