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

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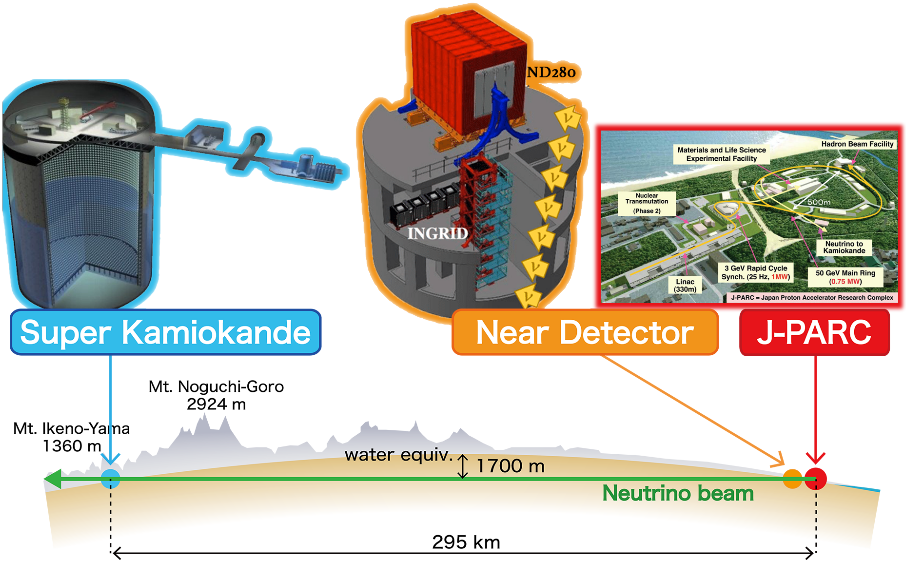
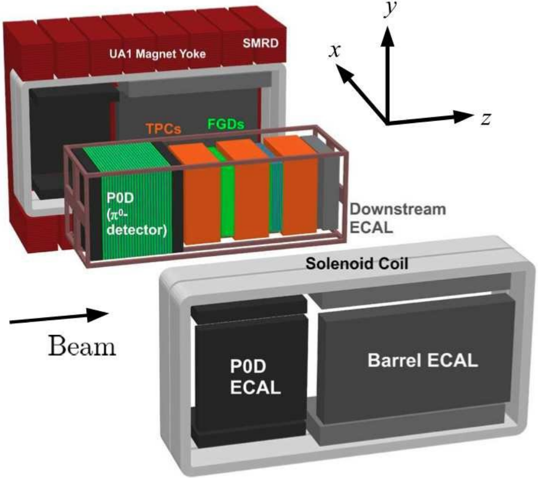
The T2K Experiment



ND280 Near Detector

- 2.5°off-axis magnetised tracking detector
- Time Projection Chambers (TPCs)
  - Gaseous tracking detector
  - Particle ID
  - Charged particle momentum
- Fine Grained Detectors (FGDs)
  - Plastic scintillator tracker
  - FGD1 and 2 hydrocarbon targets
  - FGD2 interleaved water target layers
- Monitors beam composition, and observes different neutrino interaction rates → neutrino cross-section measurements!



Cross Section Measurements

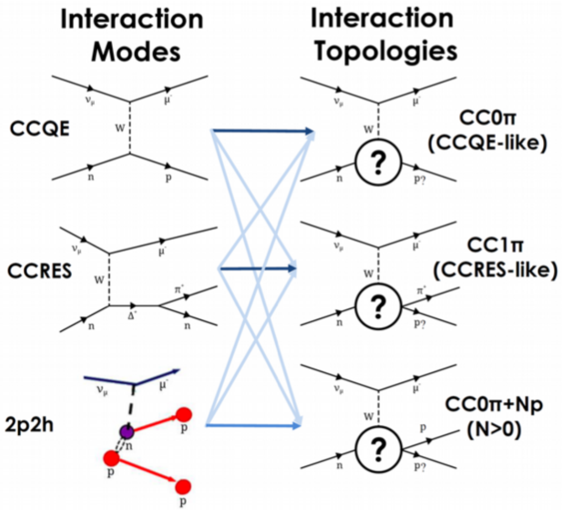


Image from S. Dolan

General rate:

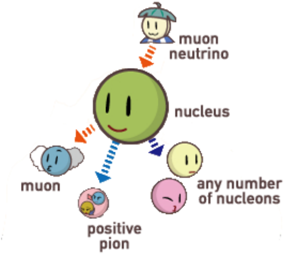
$$R(\vec{x}) = \phi(E_\nu) \times \sigma(E_\nu, \vec{x}) \times \epsilon(\vec{x}) \times P(\nu_A \rightarrow \nu_B)$$

- Can't detect nucleon-level processes due to final state interactions, additional smearing from detector effects
- Instead define signal by the final state we observe in the detector (known as topology eg. CC1π)
- Avoids a large amount of dependency on the generator model used

$\nu_\mu CC1\pi^+$ on water and hydrocarbon

- Signal: $CC1\pi^+$ events in ND280 FGD1 (CH target) or FGD2 (CH + H_2O layered target)

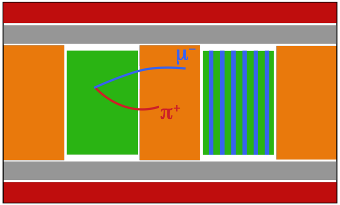
$$\nu_\mu + N \rightarrow \mu^- + \pi^+ + X$$



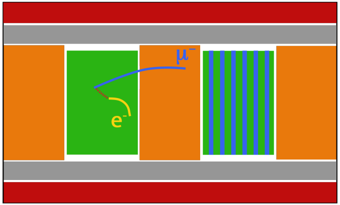
- 4D differential measurement in muon and pion momentum and $\cos\theta$
- Major background to CCQE dominated oscillation analysis.
- Pion kinematics of particular interest - no current measurements including both of these!

CC1π^+ Signal Selection

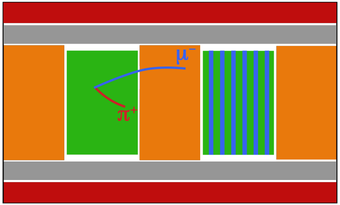
- Signal split into three samples based on how the pion is detected in ND280:
  - Pion detected in TPC (left)
  - Stopping pion in FGD detected from Michel electron (ME) (centre)
  - Isolated pion-like track in FGD (right)
- Each of these also split by detector - FGD1, FGD2x (~water), FGD2y (~hydrocarbon)
- Also 3 control samples based on major backgrounds
  - Multiple charged pions
  - Neutral pions
  - Pion-proton misID in FGDs



TPC



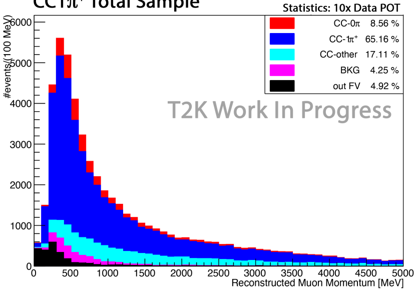
ME



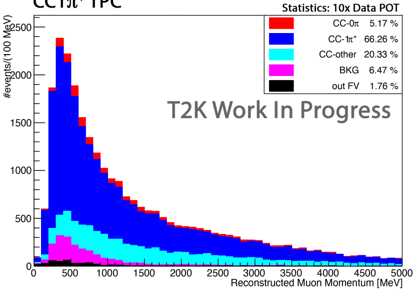
FGD

Muon Momentum FGD1

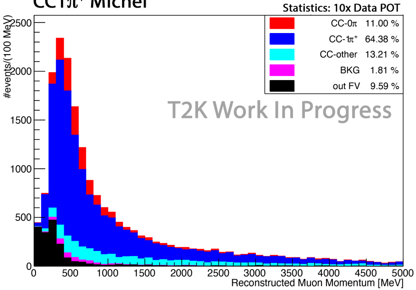
CC1π^+ Total Sample



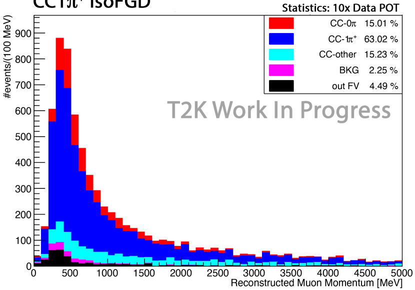
CC1π^+ TPC



CC1π^+ Michel

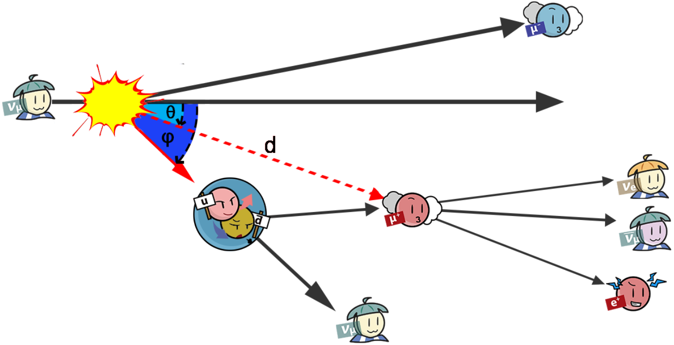


CC1π^+ isoFGD



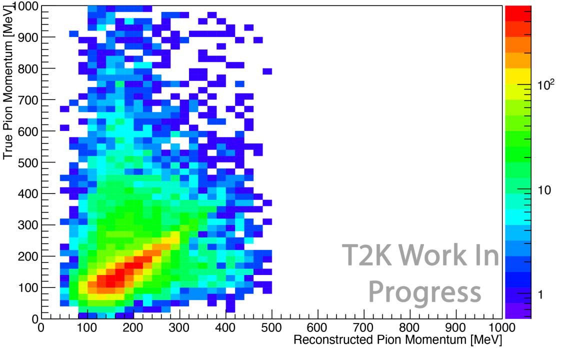
Michel electron reconstruction

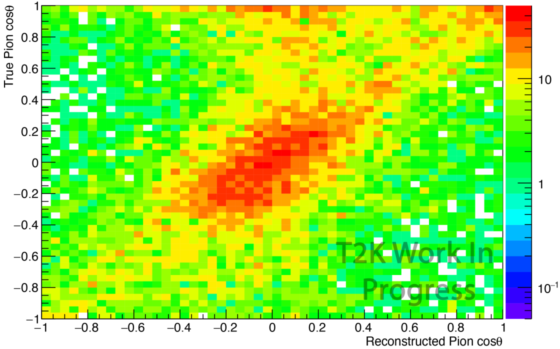
- Roughly 35% of selected sample has pions identified via Michel electrons - kinematics not currently reconstructed
- Estimate pion momentum by range to ME vertex, and pion angle from angle between ME vertex and ν direction!



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), $\cos\theta$ (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 hydrocarbon and water:

$$N_i^{\text{CH, signal}} = c_i N_{i,\text{ MC}}^{\text{CH, signal}}$$
$$N_i^{\text{H}_2\text{O, signal}} = o_i N_{i,\text{ MC}}^{\text{H}_2\text{O, signal}}$$

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

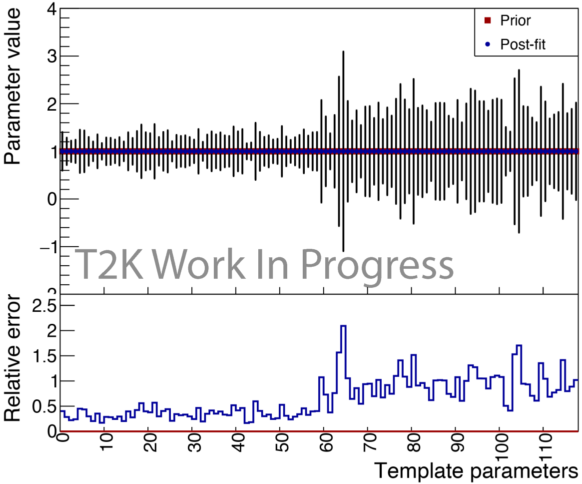
- MC is fit to data by minimising the log likelihood, in order to obtain unfolded result

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

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

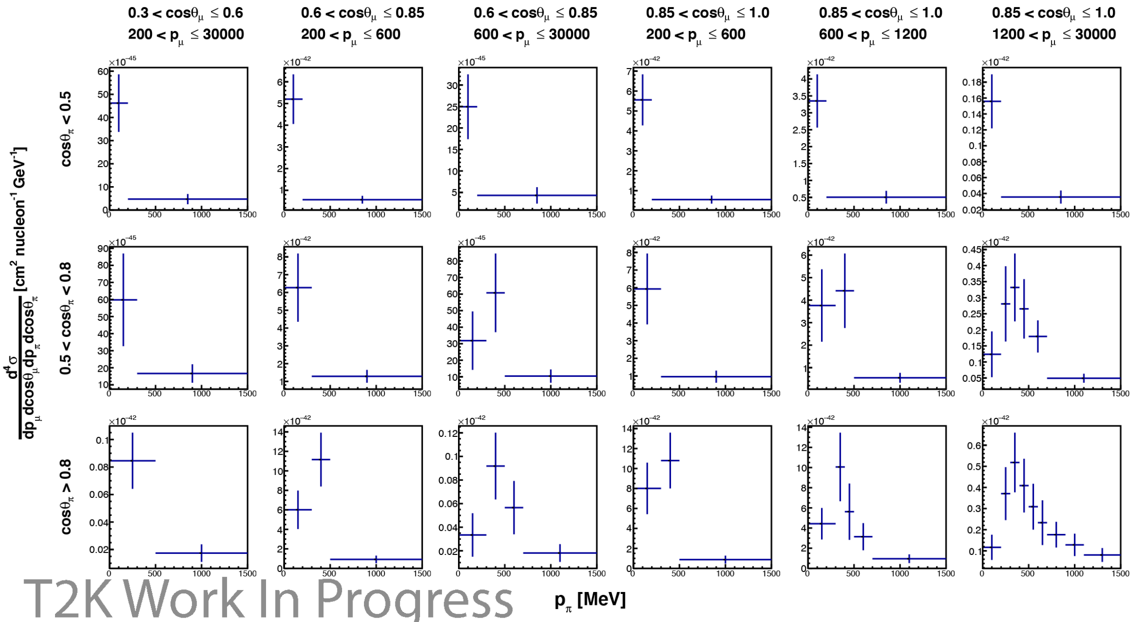
Asimov fits

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



- First 59 params CH, second 59 H_2O
- Can be reported as full 4D cross section before collapsing to interesting lower-dimensional regions

Preliminary Asimov result - MC (NEUT) only (CH)



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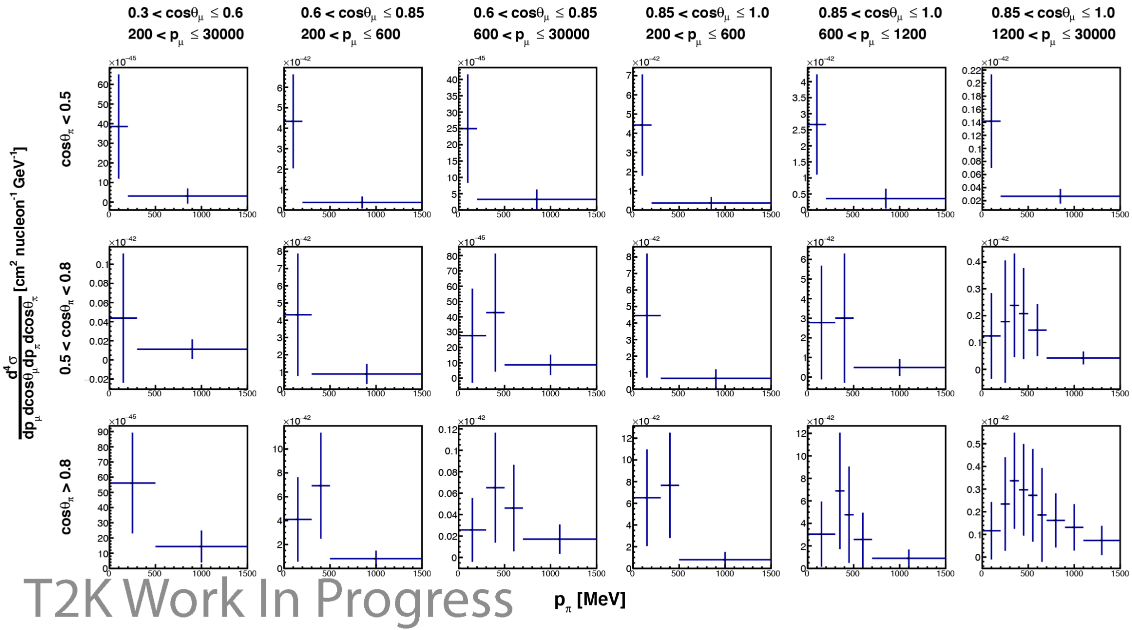


Summary

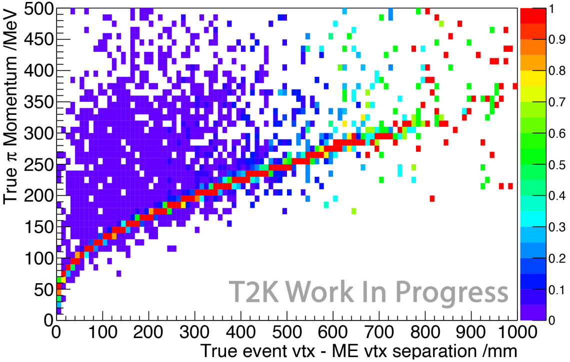
- $\nu_\mu CC1\pi^+$ selection developed - 3 signal samples, 3 control samples, each split by detector layer
- Ability to estimate pion kinematics from Michel electron chain geometry
  - Reconstruction limited by FGD design
  - Proof of concept for method
  - SuperFGD would make better use of this!
- Cross section to be extracted using binned likelihood fit - well used method in T2K analyses
- Fitter machinery in place and tested
- Preliminary Asimov measurement with NEUT simulation done
  - Series of fake data fits planned before using data

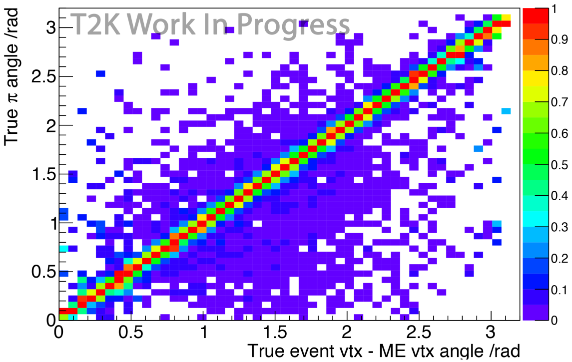
Thanks for listening!

Questions?

Backup

Pion mom vs ME geometry truth distributions

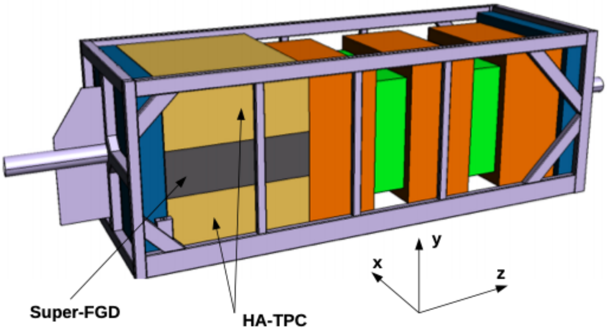




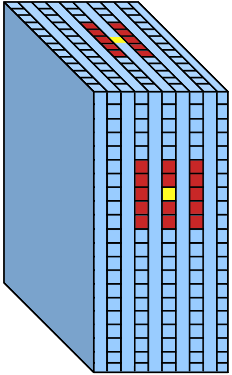
- Columns are normalised to highest bin content
- Both plots show good correlation between pion kinematics and ME geometry in truth
- Angle can be taken as one-to-one correlation, momentum is fitted to find relationship - done separately for FGD1 and 2

ND280 Upgrade

- Remove PØD
- Replace with High Angle TPCs and SuperFGD
- Surrounded by ToF detectors

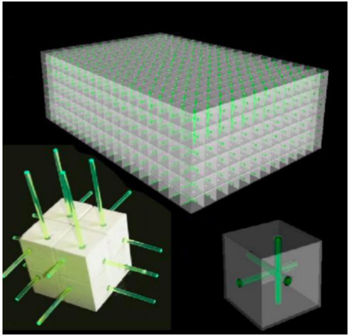


FGD vs. SuperFGD



FGD

- Layered bar structure
- Single hit gives x OR y coordinate



SuperFGD

- Full 3D tracking
- Single hit gives x AND y coordinate