Measurement of muon neutrino CC0π cross sections on Oxygen and Carbon at the T2K near detector

M. BUIZZA AVANZINI[a], L. MARET[b] on behalf of the T2K Collaboration

[a]CNRS/IN2P3/LLR, Palaiseau, France; [b]University of Geneva, Switzerland

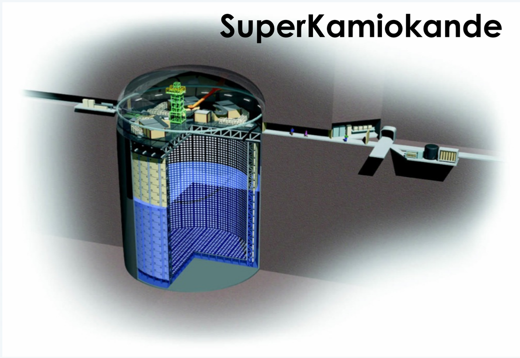
NEUTRINO 2018, 4-9 June, Heidelberg

1. Motivations (FAQ)

Understanding neutrino-nucleus interactions is essential for the precise measurement of neutrino (ν) oscillations at long-baseline experiments, such as T2K.

Why the oxygen target?

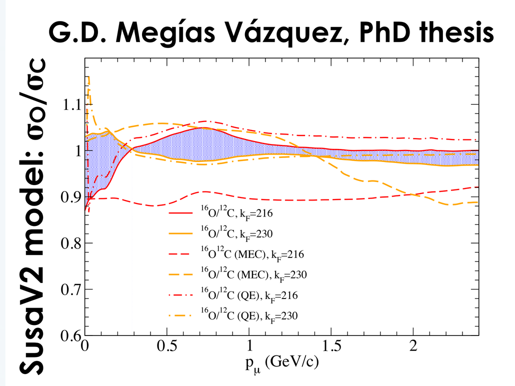
The T2K far detector, Super-Kamiokande, and future Hyper-Kamiokande use water: measurement of ν cross sections on oxygen required!



Why the O/C ratio?

The T2K near detector (ND280) has scintillator and water targets.

O/C ratio could help to discriminate theoretical models and to compare with external measurements.

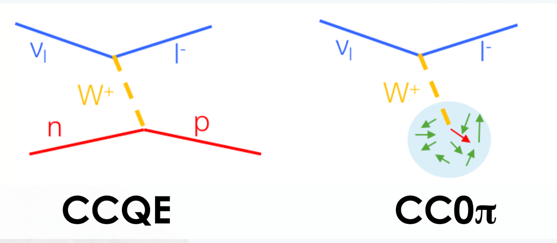


Why CC0π interactions?

CCQE interactions dominant at T2K.

Not possible to identify them event-by-event (nuclear effects!).

Reduce model dependance by defining the signal based on the final state topology: Charged Current without pions in the final state (**CC0π**).

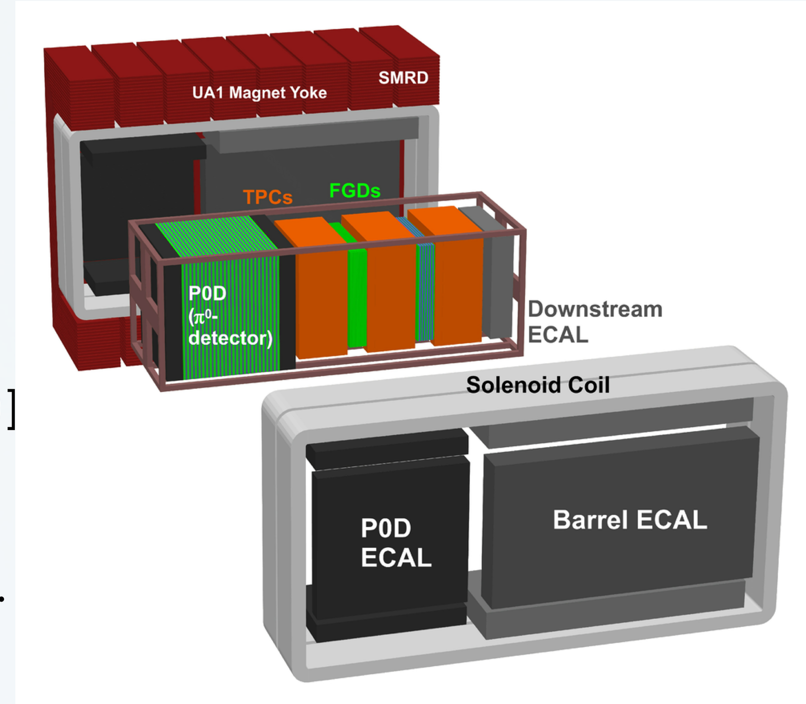


2. The T2K near detector: ND280

Near Detector complex (ND280) located at 280m from the production target, 2.5° off-axis as Super-Kamiokande.

For this analysis we use:

- 3 Time Projection Chambers (**TPCs**) for momentum reconstruction and particle identification [NIMA 637, 25 (2011)]
- 2 Fine-Grained Detectors (**FGD1 and FGD2**) as a target [NIMA 696, 1 (2012)]. Both are made of **C_8H_8 scintillator bars** alternately oriented in the x and y directions for a 3D tracking. FGD2 also contains **water modules** alternating with scintillator layers

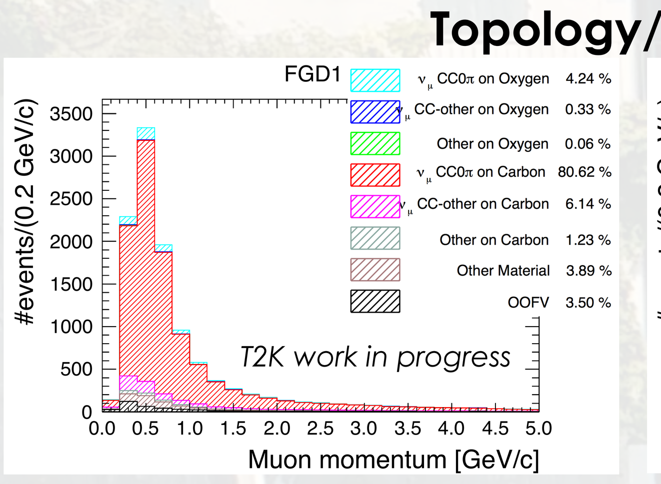


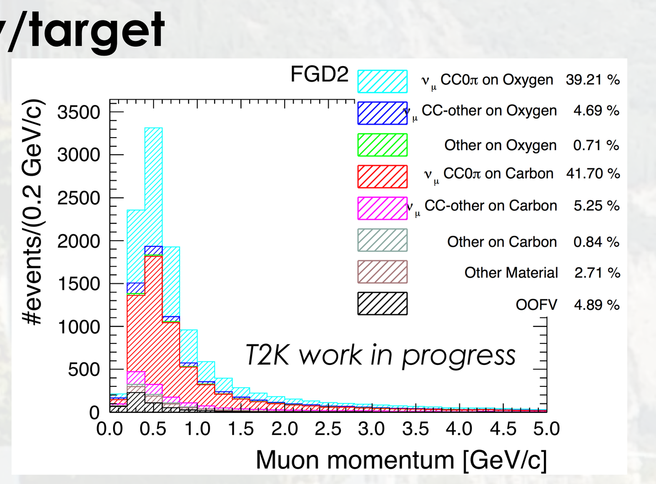
3. Event Selection

Select CC0π interactions for ν_μ.

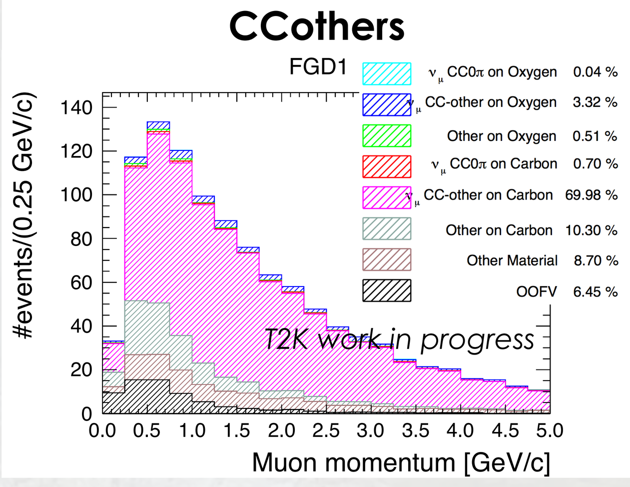
Signal samples : 1μ + 0π + 0, 1 or more protons

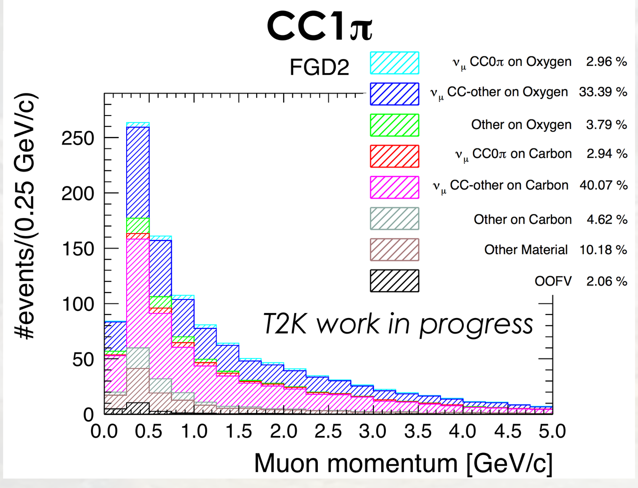
Topology/target





Control samples : to constrain the background



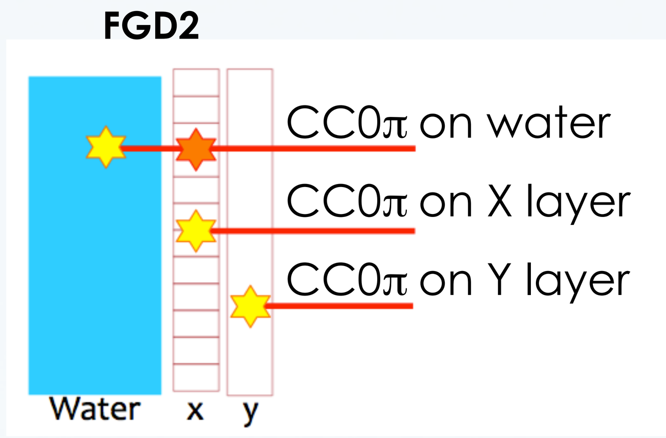


4. Simultaneous extraction of O and C cross sections

For the first time we **combine FGD1 and FGD2 data to simultaneously extract the O and C double differential flux integrated cross sections** as a function of the muon kinematics ($\cos\theta_\mu$, p_μ)

Base concept of the analysis:

1. samples reconstructed in **FGD2-X** layers are **oxygen-enhanced**
2. samples reconstructed in **FGD2-Y** layers and **FGD1** are **carbon-enhanced**



Fraction	CC0π oxygen	CC0π carbon
FGD1	~ 4%	~ 80%
FGD2-X	~ 50%	~ 35%
FGD2-Y	~ 15%	~ 60%

Binned likelihood fit

Via a binned likelihood fit, **carbon and oxygen interactions are simultaneously fitted** to the number of selected events, in all the signal and background samples

Fit parameters of interest for C; Fit parameters of interest for O

$$N_i^{CC0\pi} = c_i N_i^{MC,\,CC0\pi,C} + o_i N_i^{MC,\,CC0\pi,O}$$

i = ($\cos\theta_\mu$, p_μ) bin (29 in total)

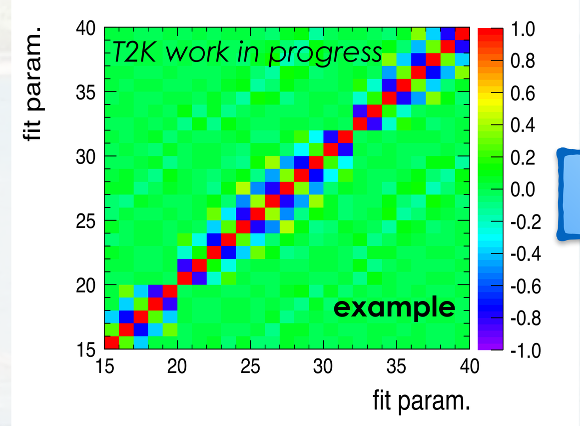
Key features

- **Unconstrained fit parameters** that estimate the signal in each bin -> minimize the model dependence!
- Detector-related and theoretical parameters included as **nuisance parameters** -> reduce the systematics!
- **FGD1** samples effectively **constrain Carbon interactions ->** reduce the anti-correlation O-C and the related uncertainties!
- **Data-driven regularization** [arXiv:1802.05078] **->** minimize the anti-correlation between adjacent bins (optional)!

Strong anti-correlation between adjacent bins and O and C

FGD2 only

fit parameters correlation matrix

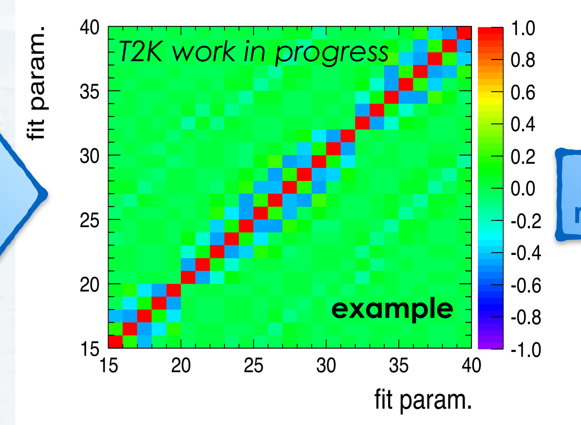


adding FGD1 samples

Reduced anti-correlation between c_i and o_i !

FGD2+FGD1

fit parameters correlation matrix

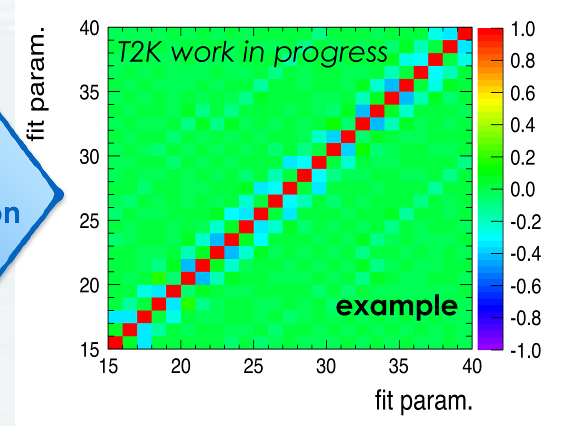


adding regularization

Reduced anti-correlation c_i-c_{i+1} and o_i-o_{i+1} !

FGD2+FGD1+regularization

fit parameters correlation matrix



even parameters: o_i, odd parameters: c_i, 58 parameters in total, above just showing some of them

5. Blind analysis: fit validation and pseudo data studies

Uncertainties estimation

- Nominal Monte Carlo is **NEUT** (5.3.2).
- Detector, vertex migration, flux and model systematic errors are evaluated via **toy experiments**. Toys are used to vary priors -> same technique will be used also for data.
- The final cross section is the mean value obtained over N_{toys} and the standard deviation is taken as an uncertainty.

* considering detector, flux, model and statistical uncertainties

Fit validation

- Done using different sets of pseudo data.
- Here we show some examples using **GENIE** (below) **and NEUT** (right) **as pseudo data**.
- Example for the GENIE (2.8.0) sample. Goodness of fit*(χ^2)
- Preference for pseudo data, i.e. **no bias from prior!**

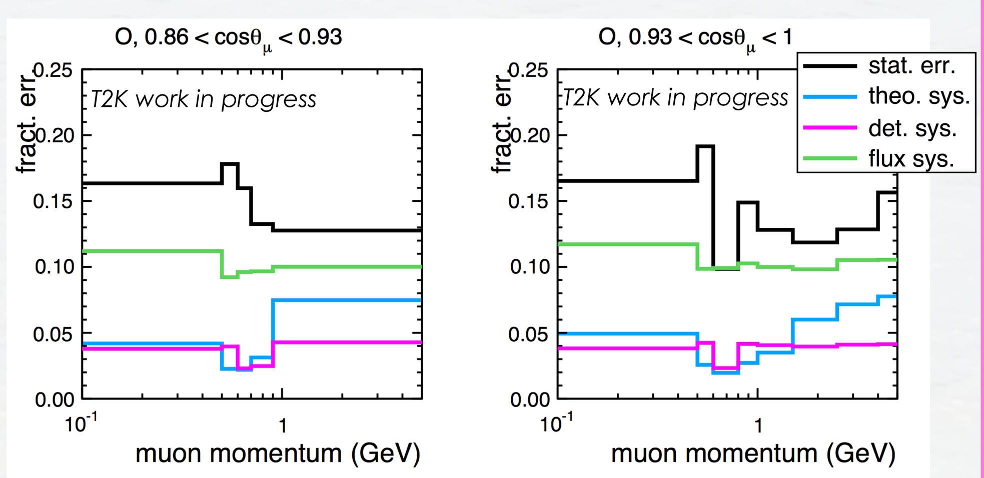
χ (Model - Fit)	NEUT (prior)	GENIE (pseudo data)
Fit result	45	24

$$\chi^2 = \sum_i^{N_{bins}}\sum_j^{N_{bins}}\left(\frac{d\sigma_i}{dx_i}^{Model} - \frac{d\sigma_i}{dx_i}^{Fit}\right)\left(V_{ij}^{cov}\right)^{-1}\left(\frac{d\sigma_j}{dx_j}^{Model} - \frac{d\sigma_j}{dx_j}^{Fit}\right)$$

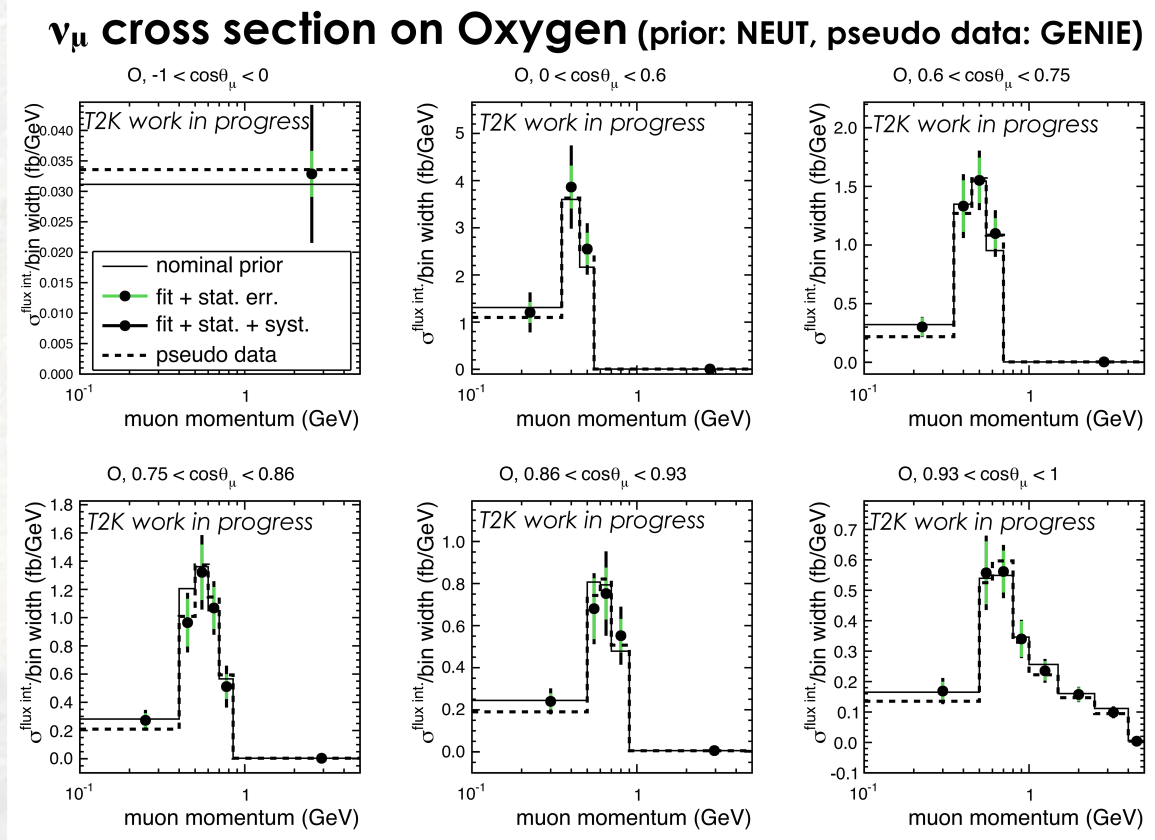
Uncertainty summary

Example for Oxygen

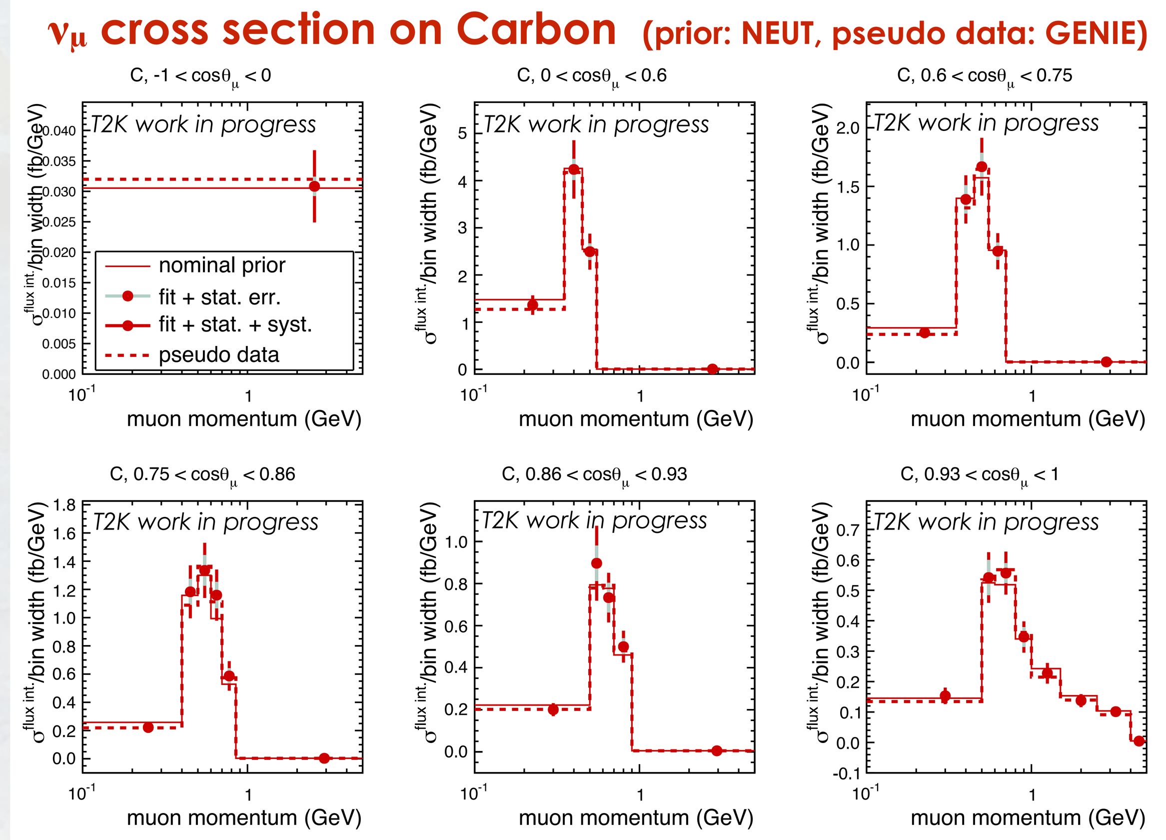
Prior: NEUT, Pseudo data: NEUT



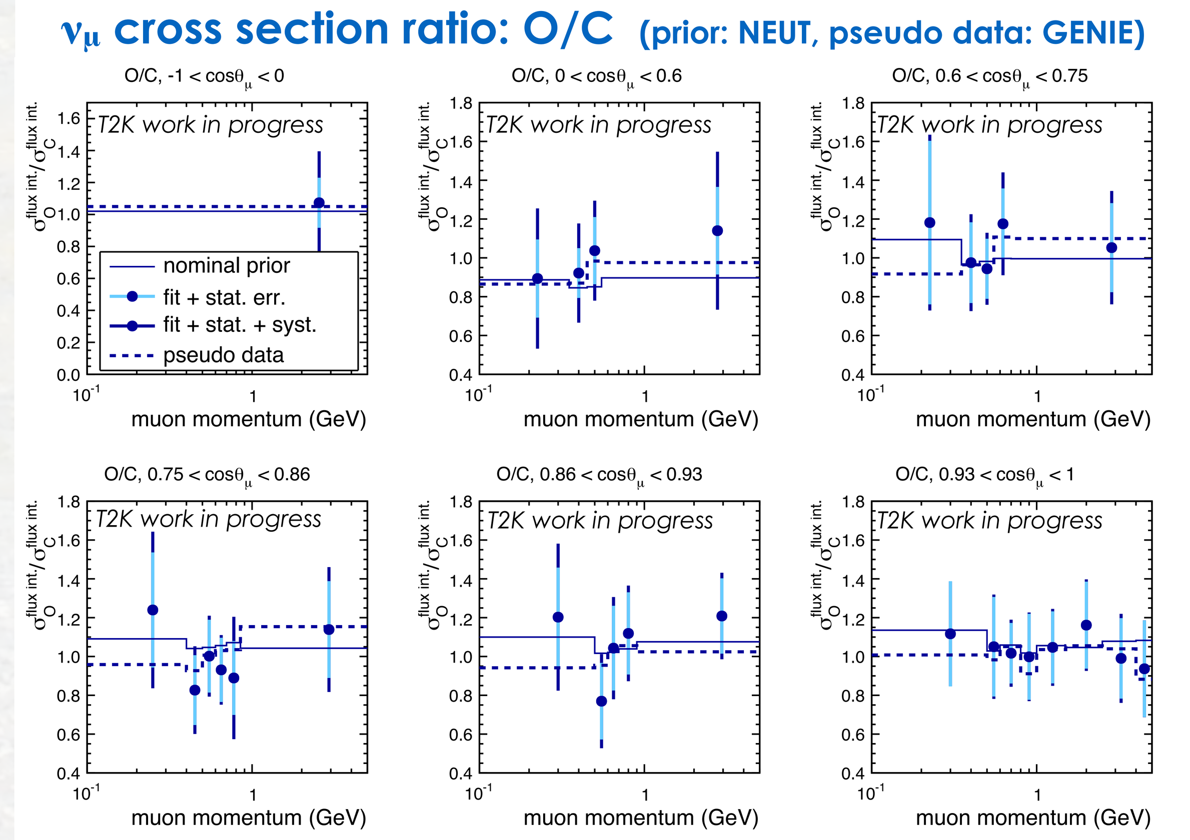
ν_μ cross section on Oxygen (prior: NEUT, pseudo data: GENIE)



ν_μ cross section on Carbon (prior: NEUT, pseudo data: GENIE)



ν_μ cross section ratio: O/C (prior: NEUT, pseudo data: GENIE)



Conclusions: **Fitter works correctly → unblind soon! Stay tuned!**