T2K analyses (just 3 of them)

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Neutrino group meeting

Jan. 31st 2020

Reminder

- ν_μ&ν_μ-paper (i.e. Ciro's analysis): 2nd round of comments from the coll. finishing next Monday (I still have to read the second version!)

https://www.t2k.org/comm/pubboard/JournalPapers/CC0pinuanu/

- O&C paper (i.e. Margherita's analysis): received comments from the 1st round… It will take time to introduce all of them!

https://www.t2k.org/comm/pubboard/JournalPapers/CC0piOCfgd1fgd2

- Water and scintillator CC0pi0p in ~Wagasci (i.e. Chikuma-san's analysis – proton+water+ingrid modules): final round of comments ending next Monday

https://www.t2k.org/comm/pubboard/JournalPapers/CC0pi0pnunubarinWagasci

(Non-) Common points between O&C and nu& anu analysis

Common points:

- Both analyses use the same neutrino CC0π selection in the FGD1
- They extract a double differential xsec in muon kinematics (momentum and angle)
- Both analyses use a joint fits

➔ Thus the O&C paper will refer to the nu/anu paper for the description of the selection and the detector systematics

Specificities:

- For the O&C analysis, we fit at the same time FGD1 and FGD2 samples. We present both regularized and unregularized results.
- For the nu&anu analysis, we fit at the same time nu and anu (specific selection!) samples. No regularization applied.
- For the O&C analysis we can extract the O/C ratio with proper correlation
- For the nu and anu analysis, we can extract the sum, the difference and the asymmetry to look for 2p2h effects [Phys Rev C 91 035501,2015]

Joint fit strategy

Details about the analyses have already been shown many times (nu/anu paper already passed the first round of comments)

- TN 337 https://www.t2k.org/docs/technotes/337
- TN 338 https://www.t2k.org/docs/technotes/338

Basic idea: we use the num. of events in the reconstructed bin j, to disantangle the O and C (or the nu and anu) contribution. c_i and o_i (or c_i and $\bar{c}_i$) are **free parameters** in the fit!!

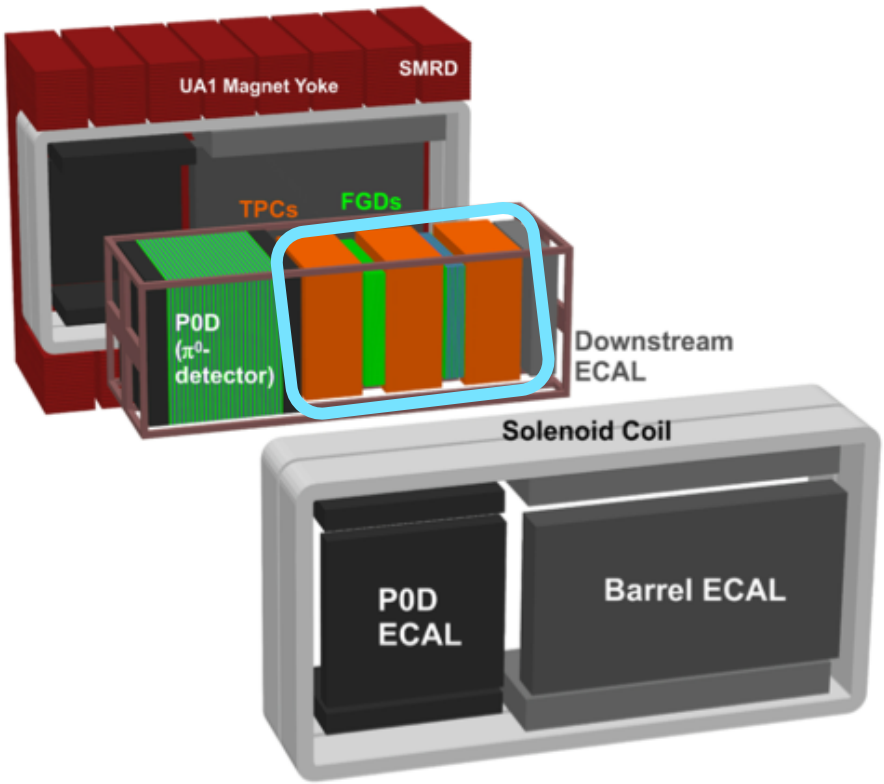
$$N_j = \sum_{i}^{\text{true bins}} \left[c_i w_i^{\text{sig-C}} N_i^{\text{sig-C}} + o_i w_i^{\text{sig-O}} N_i^{\text{sig-O}} + w_i^{\text{bkg}} N_i^{\text{bkg}} \right] U_{ij}$$

Free parameters

Effect of the systematics

O&C paper

Targets and detectors



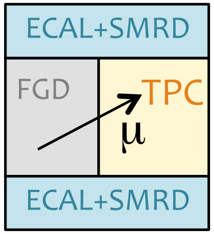
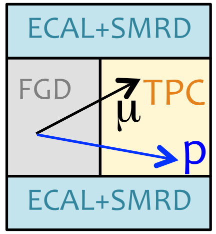
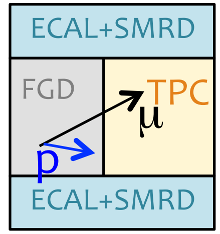
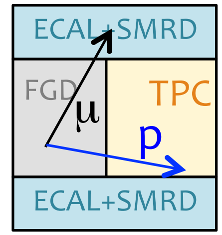
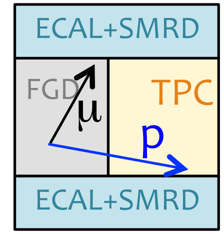
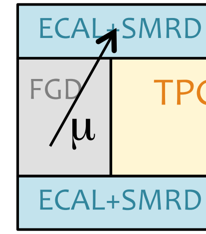
For this analysis we use:

- 3 Time Projection Chambers (**TPCs**) for momentum reconstruction and particle identification
- 2 Fine-Grained Detectors (**FGD1 and FGD2**) as a target.

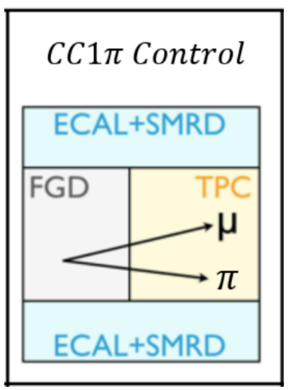
FGD1: made of **C_8H_8 scintillator bars** alternately oriented in the x and y directions for a 3D tracking -> **Carbon target**!

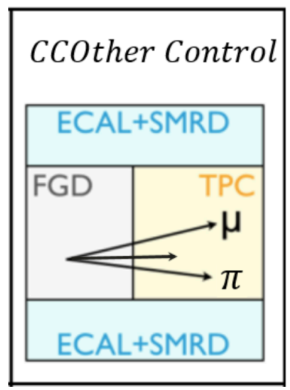
FGD2: also contains **water modules** alternating with scintillator layers -> **Carbon & Oxygen targets**

Event selections

	(1)	(2)	(3)	(4a)	(4b)	(5)
CC0π samples						
Sample description	▪ μ_{TPC} ▪ p not reconstructed	$\mu_{TPC}+p_{TPC}$	▪ $\mu_{TPC}+p_{FGD}$ ▪ μ_{TPC}+Np	▪ $\mu_{FGD}+p_{TPC}$ ▪ $\mu_{FGD}+p_{TPC}$ + Np ▪ μ_{FGD} + Np		▪ μ_{FGD} not fully contained ▪ p not reconstructed

Control samples





NumuCCZeroPiAnalysis v2r0, using Highland2 v2r7

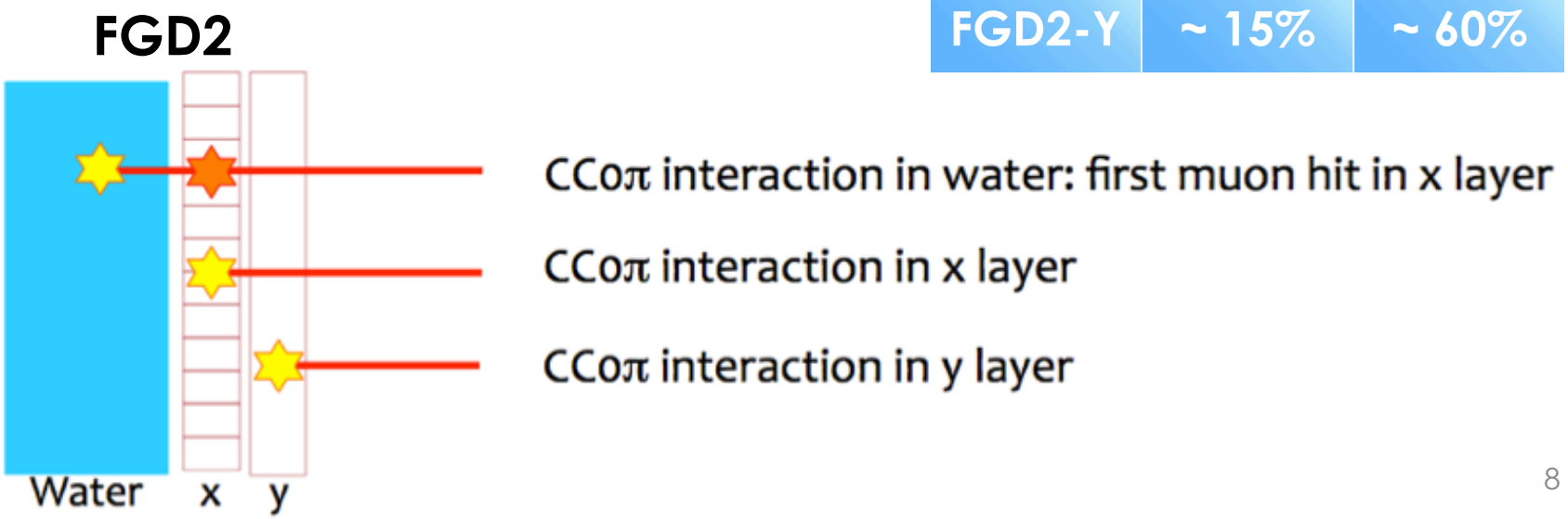
Selecting interactions on O and C

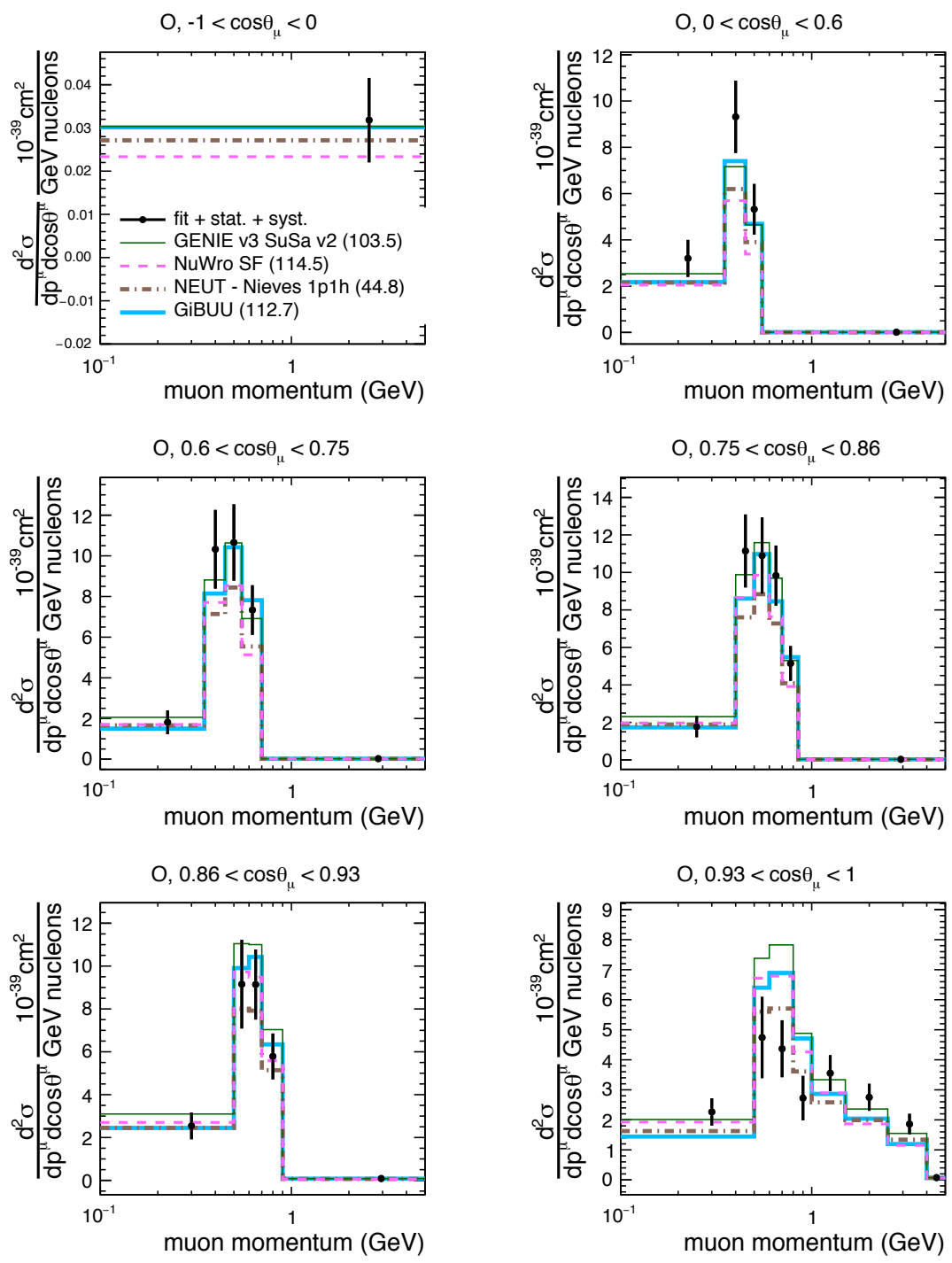
For the first time we **combine FGD1 and FGD2 data to simultaneously extract the O and C double differential flux integrated cross sections** as a function of the muon kinematics ($\cos\theta_\mu$, p_μ)

Base concept of the analysis:

- samples with the track starting point in FGD2-X layers are oxygen-enhanced
- samples with the track starting point 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%





Oxygen

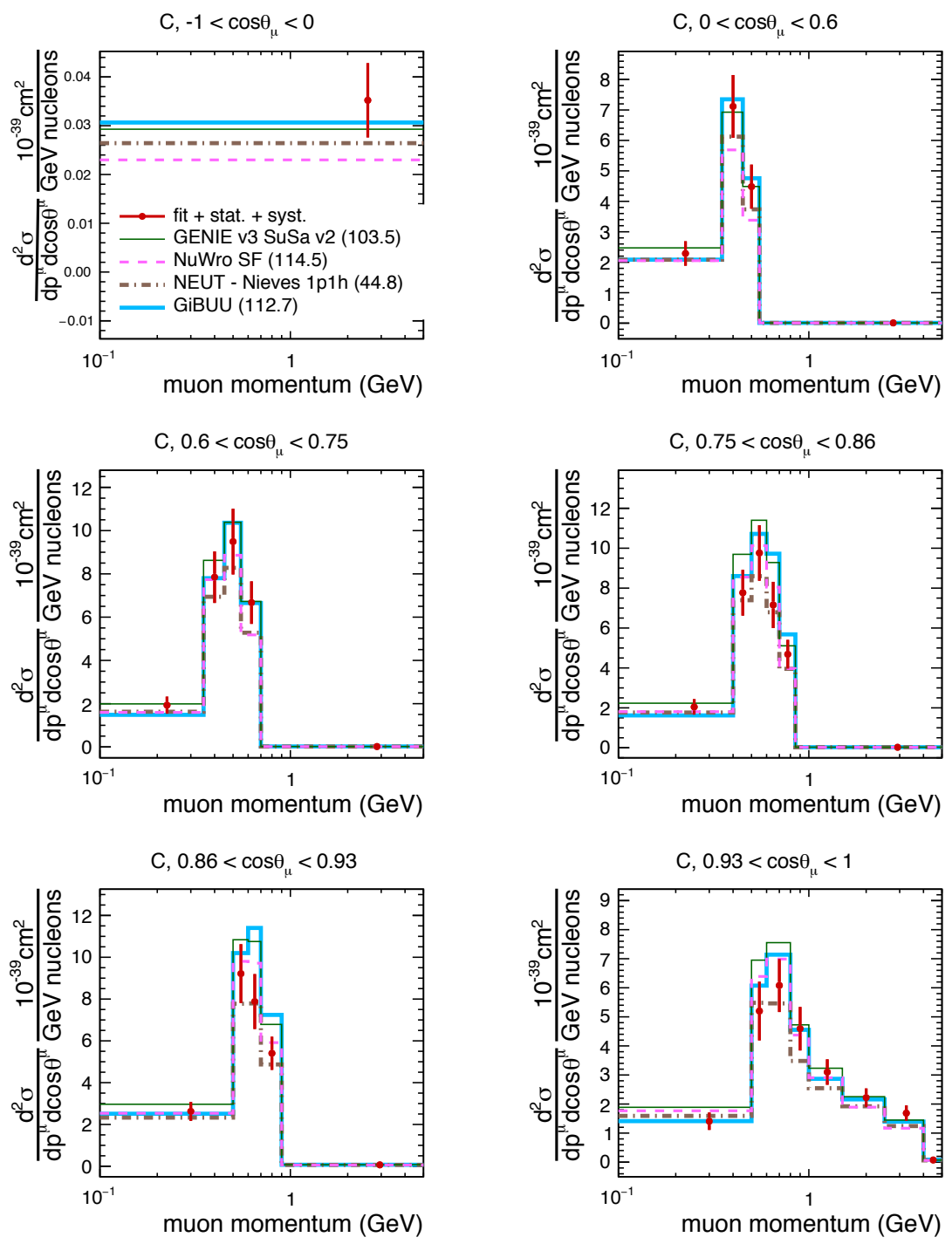
Compared with different 1p1h models:

- Spectral Function (Nuwro 18.2)
- LFG - Nieves 1p1h (NEUT 5.4)
- Susav2 (GENIE 3)
- GiBUU

The chi2 corresponds to the total measurement O&C.

Clear preference for LFG

Ndof = 58



Carbon

Compared with different 1p1h models:

- Spectral Function (Nuwro 18.2)
- LFG - Nieves 1p1h (NEUT 5.4)
- Susav2 (GENIE 3)
- GiBUU

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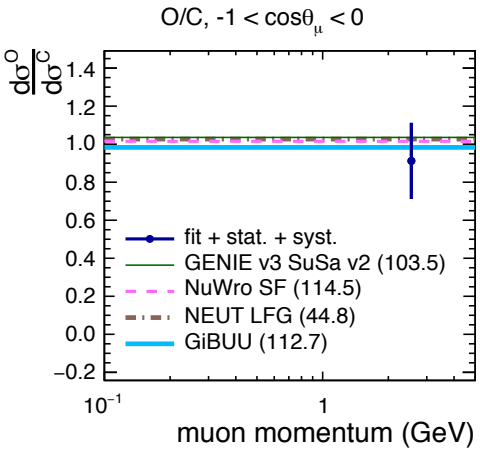
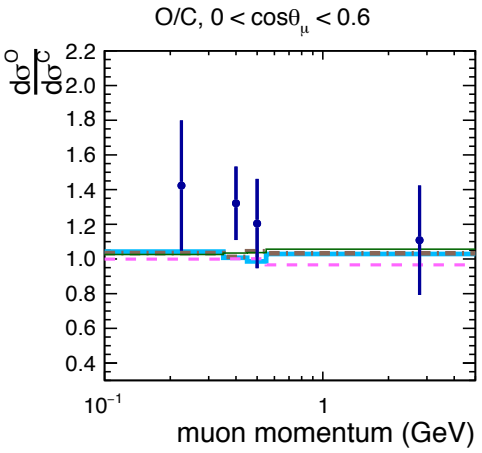
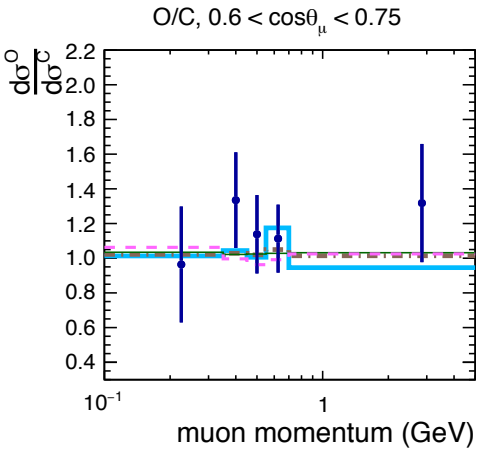
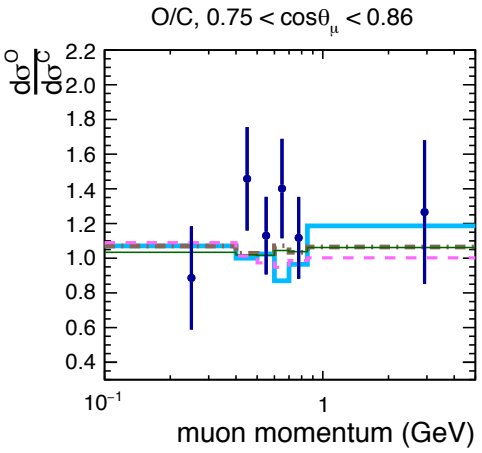
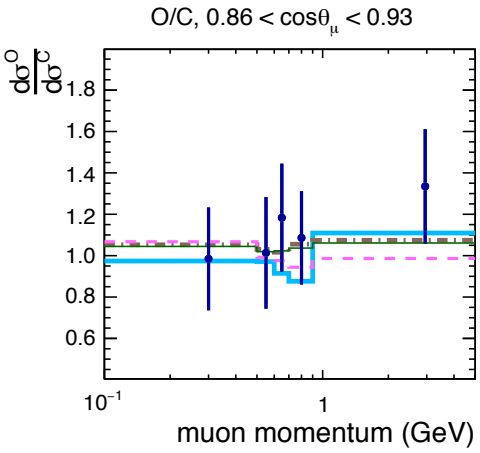
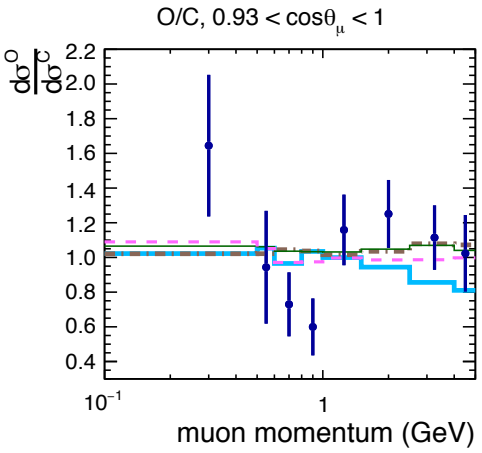












O/C ratio

Compared with different 1p1h models:

- Spectral Function (Nuwro 18.2)
- LFG – Nieves 1p1h (NEUT 5.4)
- Susav2 (GENIE 3)
- GiBUU

The chi2 corresponds to the total measurement O&C.

Clear preference for LFG

Ndof = 58

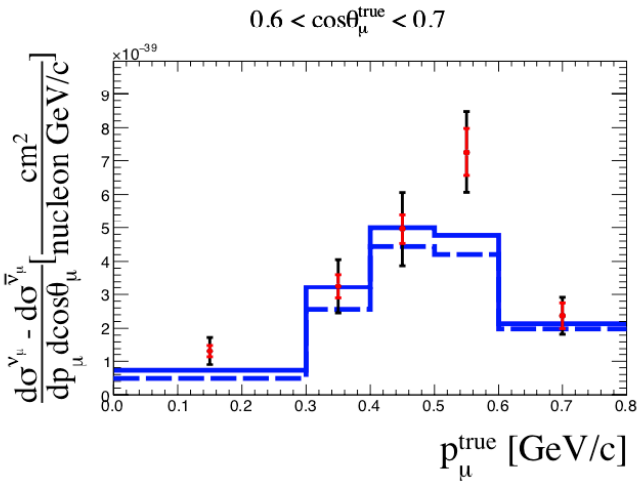
χ^2 table summary

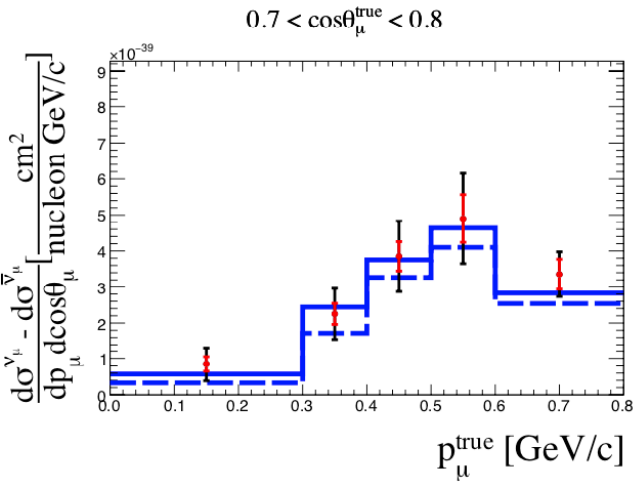
Generator	result	Total χ^2 (shape only)	χ^2 excluding last cosθ bin	only O χ^2	only C χ^2	O/C ratio χ^2
NEUT 5.4.1 LFG	reg.	44.8 (58.6)	17.9 (21.1)	26.0 (34.5)	15.2 (20.1)	30.8
	unreg.	44.4 (62.3)	17.3 (22.5)	26.4 (39.1)	14.0 (19.4)	30.6
NEUT 5.4.0 SF	reg.	111.0 (156.8)	45.3 (69.0)	50.0 (77.6)	40.1 (58.3)	31.7
	unreg.	116.8 (166.7)	45.1 (70.1)	53.7 (86.5)	38.6 (56.2)	32.2
NuWro 18.2 LFG	reg.	64.7 (83.7)	21.0 (30.5)	31.9 (45.0)	23.5 (31.5)	33.1
	unreg.	66.8 (88.7)	21.1 (32.1)	32.9 (49.9)	22.6 (30.6)	33.5
NuWro 18.2 SF	reg.	114.5 (180.1)	50.2 (80.9)	50.1 (86.1)	44.8 (70.3)	34.2
	unreg.	119.2 (189.0)	48.7 (80.9)	52.7 (94.8)	42.6 (67.4)	33.9
Genie 3 LFG hN	reg.	48.9 (58.5)	22.3 (24.6)	24.9 (32.1)	18.4 (22.3)	33.5
	unreg.	46.6 (60.0)	20.1 (23.8)	24.7 (35.6)	16.3 (20.4)	34.0
Genie 3 LFG hA	reg.	55.4 (62.0)	22.9 (25.5)	27.8 (34.3)	19.8 (22.3)	32.3
	unreg.	52.9 (62.0)	21.0 (24.5)	27.7 (37.0)	17.7 (20.4)	32.6
Genie 3 SusaV2	reg.	103.5 (105.4)	39.0 (44.7)	50.6 (57.3)	35.8 (36.8)	29.8
	unreg.	110.3 (111.3)	40.3 (45.6)	55.4 (62.8)	35.1 (35.5)	30.1
RMF (1p1h) + SusaV2 (2p2h)	reg.	90.6 (97.5)	48.2 (60.5)	31.4 (37.8)	43.9 (51.3)	31.3
	unreg.	95.8 (102.2)	49.3 (60.7)	34.0 (42.1)	41.9 (48.1)	30.7
GiBUU	reg.	112.7 (117.0)	47.2 (50.6)	46.8 (58.0)	46.6 (46.1)	39.3
	unreg.	107.5 (112.2)	41.7 (46.8)	43.5 (56.0)	41.0 (41.2)	37.0

TABLE V. χ^2_{tot} (χ^2_{shape}) calculated as in Eq. 9 (10) for the full measurement of oxygen and carbon cross sections (number of degrees of freedom: 58), for oxygen and carbon neglecting the last cosθ bin (ndof: 50), for oxygen only (ndof: 29), for carbon only (ndof: 29) and for the O/C ratio (ndof: 29).

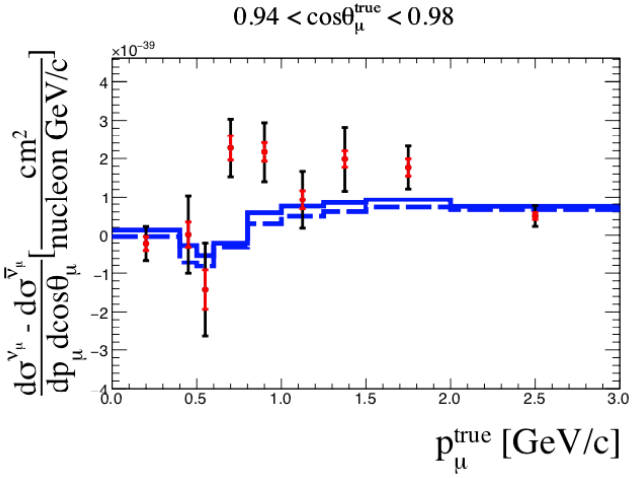
Nu&anu paper

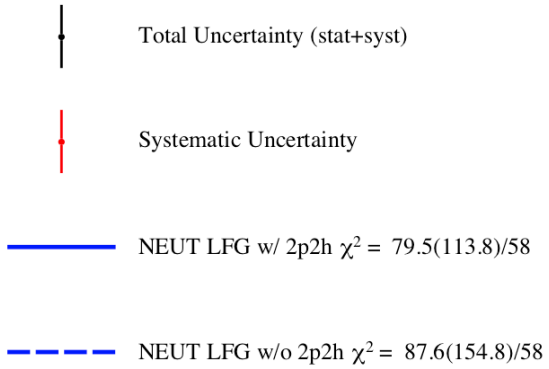
nu – anu difference





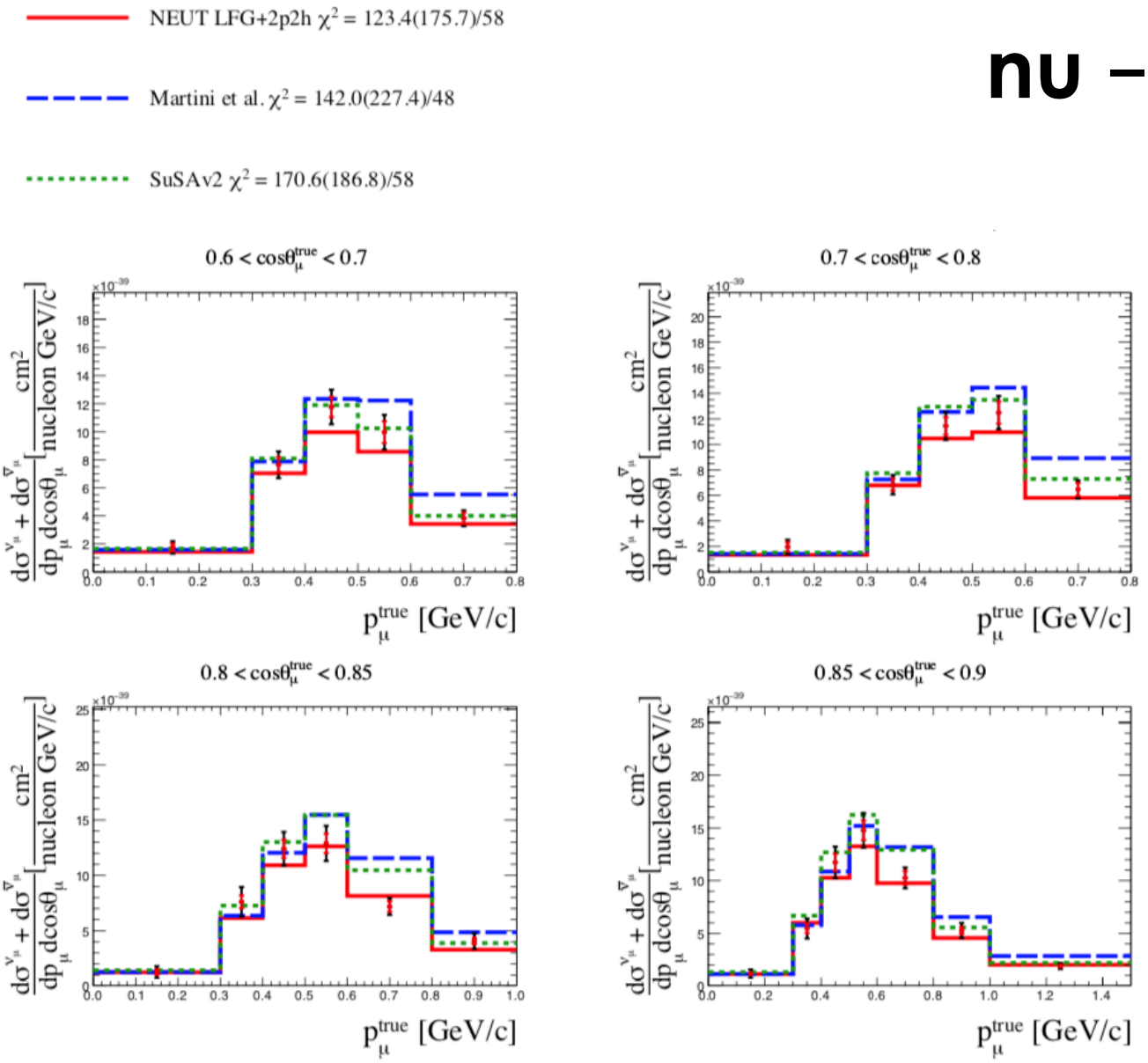
Compared with NEUT LFG w/ and w/o 2p2h





Preference for w/ 2p2h in the high angle region
Disagreement in the forward region

nu – anu sum



Compared with different 2p2h models:

- Nieves et al (NEUT LFG)
- Martini et al. (NEUT LFG)
- SusaV2 (for 1p1h and 2p2h)

No perfect model

χ^2 table summary

TABLE III. χ^2 values for different generators and models. The number of degrees of freedom is 116 for the combined χ^2 (96 for Martini *et al.*) and 58 for the sum, difference and asymmetry (48 for Martini *et al.*).

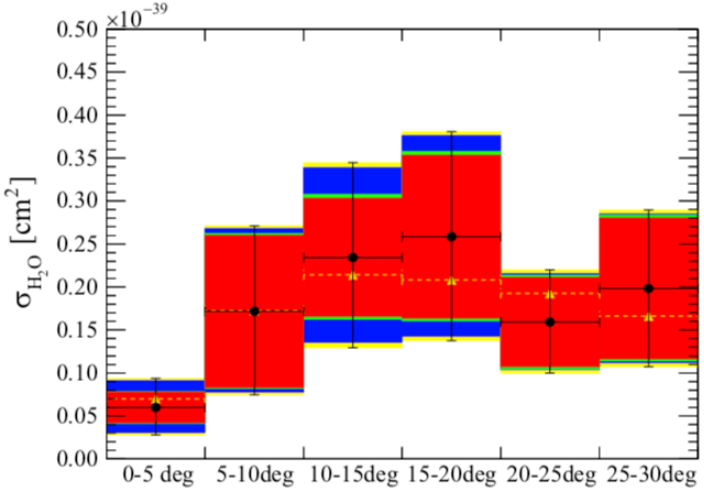
Generator/model	Cross section		Sum		Difference		Asymmetry	
	Full χ^2	Shape-only χ^2	Full χ^2	Shape-only χ^2	Full χ^2	Shape-only χ^2	Full χ^2	Shape-only χ^2
GENIE LFG w/ 2p2h	333.1	444.7	101.3	141.3	76.2	102.0	143.6	134.4
NEUT LFG w/ 2p2h	366.7	459.1	123.4	175.7	79.5	113.8	150.5	147.8
NEUT LFG w/o 2p2h	236.7	388.7	82.5	126.5	87.6	154.8	160.0	169.4
NUWRO LFG w/ 2p2h	408.9	481.5	122.2	158.1	87.0	121.6	162.9	142.4
NUWRO SF w/ 2p2h	650.0	838.8	233.5	358.1	97.6	149.7	170.6	185.0
GIBUU	488.2	474.3	133.5	136.3	120.1	140.1	157.7	148.0
Martini *et al.*	368.6	573.4	142.0	227.4	119.6	289.8	93.9	131.2
SUSAV2	565.9	563.1	170.6	186.8	119.2	137.9	152.6	146.3

No model able to simultaneously describe nu and anu xsec.

Nice feature shown by the difference (but more stat. needed)

~WAGASCI paper

anu


×10⁻³⁹
σ_H2O [cm²]
0.50
0.45
0.40
0.35
0.30
0.25
0.20
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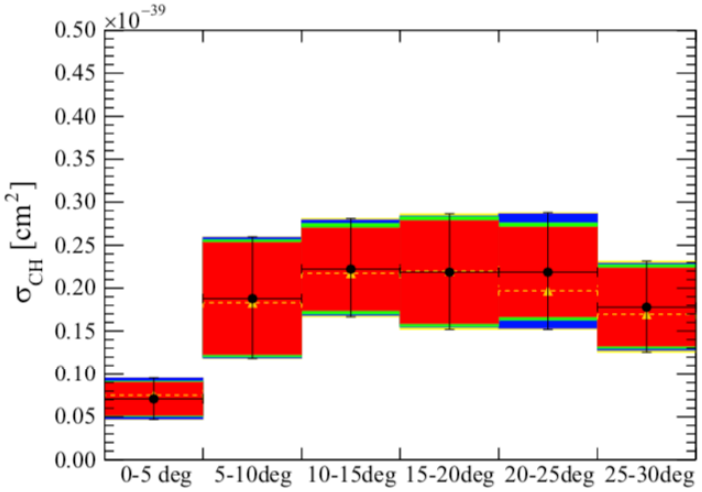
10-15deg
15-20deg
20-25deg
25-30deg


×10⁻³⁹
σ_CH [cm²]
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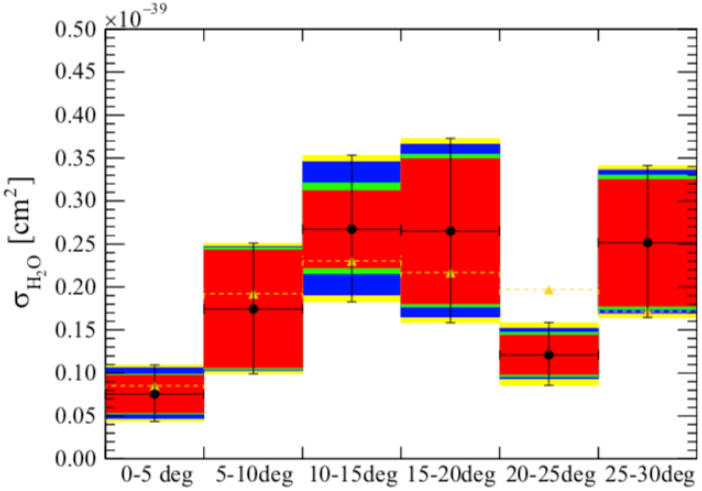
10-15deg
15-20deg
20-25deg
25-30deg

nu+anu


×10⁻³⁹
σ_H2O [cm²]
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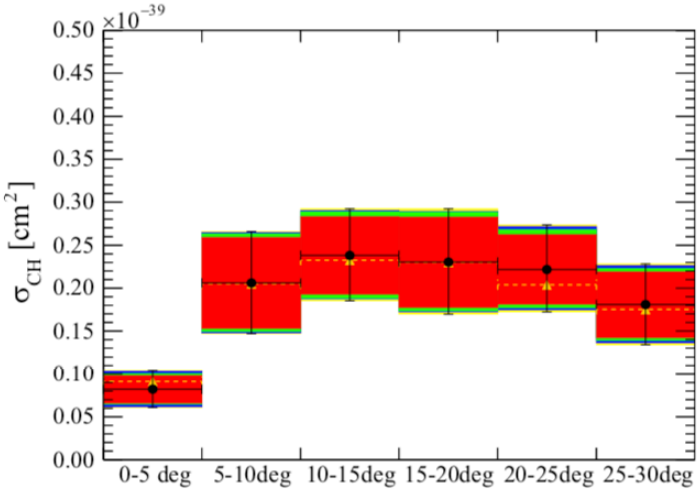
×10⁻³⁹
σ_CH [cm²]
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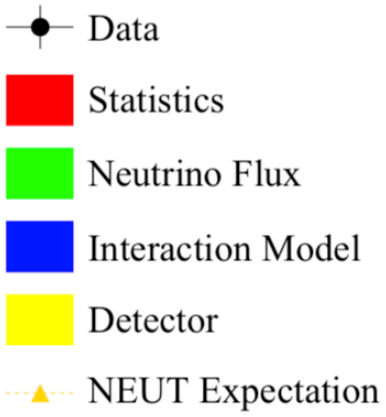
15-20deg
20-25deg
25-30deg


Data
Statistics
Neutrino Flux
Interaction Model
Detector
NEUT Expectation

For the future: ND280upgrade (Jaafar)

Create a working group with the young manpower

LLR (Jaafar)

+ CEA (Alice+PhD theoricien)

+ LPNHE (1 post doc, 1 PhD)

to integrate the superFGD in the oscillation analysis:

1. study the new available variables (protons and neutron kinematics)
2. Look at the sensitivity with a simple 2D fitter (Jaafar+alice stage)
3. Adapt the current xsec fitter and create a new (better!) BANFF (help also from Laura, 2nd year PhD from CEA)
4. Add also standard FGD1 and FGD2