

# Comparing the T2K and NOvA interaction model

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# Overview



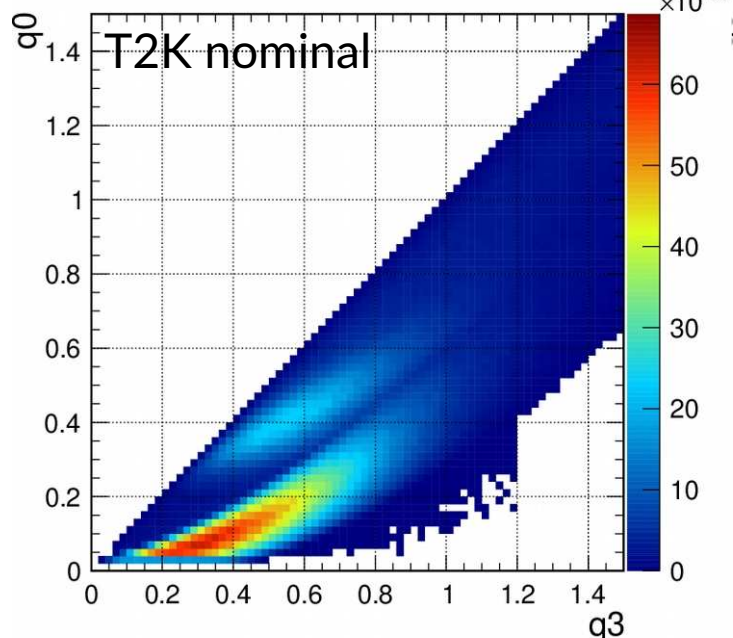
- One of the large challenges of the joint fit will be unifying systematics
- The interaction systematics should be largely correlated
  - Neutrino interactions, e.g. CC0/ $1\pi$ , 2p2h, FSI models...
  - Secondary interactions of pions or nucleons
- Interaction systematics have a large impact on the error budget at both experiments
  - Wrong evaluation  $\rightarrow$  Bias in central value and/or uncertainty
- Crucial to study these for success of joint fit!
- Could not convince NEUT to generate on NOvA target; only showing T2K CH target with ND280 flux today
- Previous talks by Callum, Luke, Hayato-san, Jeremy and me

# Tuning at T2K and NOvA

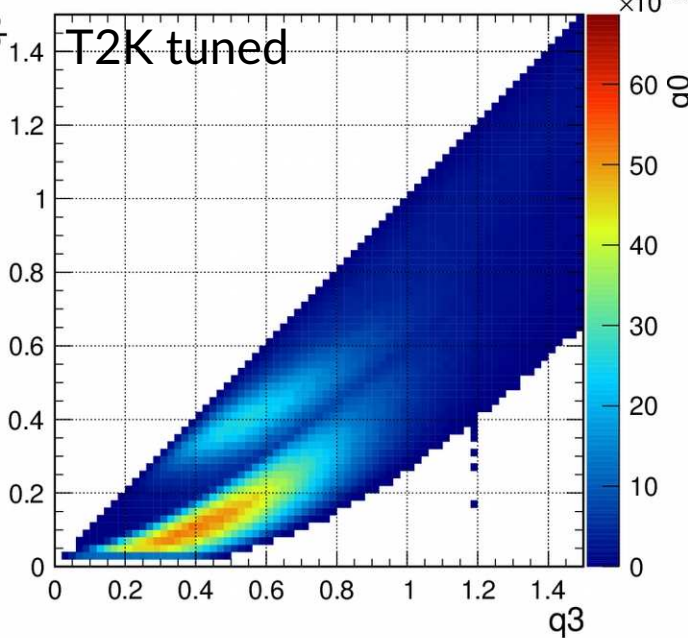
- T2K: NEUT 5.3.3 with model changes from fit to ND280
  - 2p2h shape parameter shifts to mostly Nieves Delta-like
  - 2p2h normalisation for neutrinos up by 50%
  - RPA shape changed much from Nieves
  - Single pion production tuning away from bubble chamber...
  - ... long list (see backup and last meeting for details)
- NOvA: GENIE 2.10.2 with model changes from tune to ND
  - 2p2h tuning of Empirical MEC to CC-inclusive events
  - CCQE RPA tuning from R. Gran et al.
  - $1\pi$  non-resonant background tuning from P. Rodrigues et al.
  - “RPA resonant” tuning using CCQE RPA parameters
  - Small CCQE  $M_A^{\text{QE}}$  tuning
  - Multi- $\pi$ /DIS tuning
- See November 2017 NOvA-T2K meeting \*

# CC-inclusive

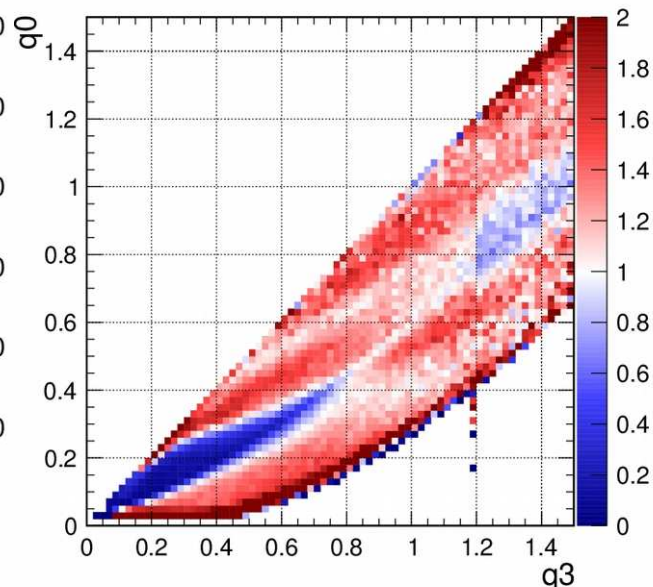
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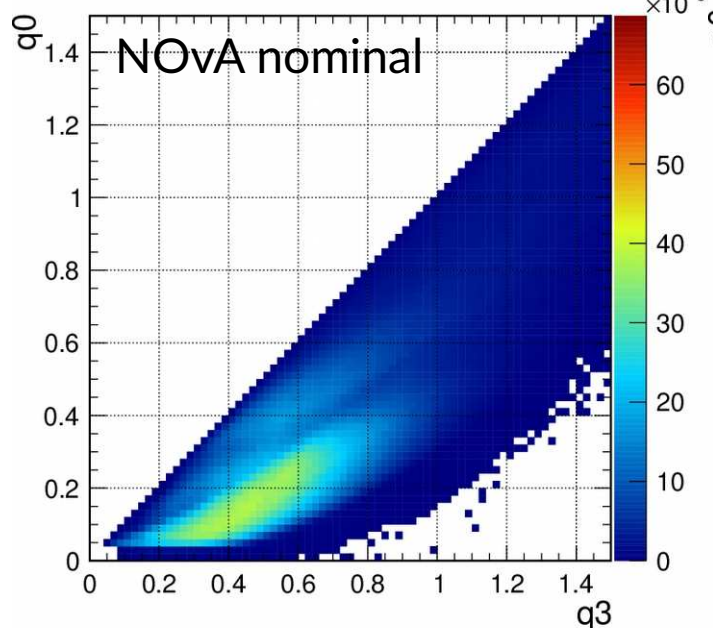
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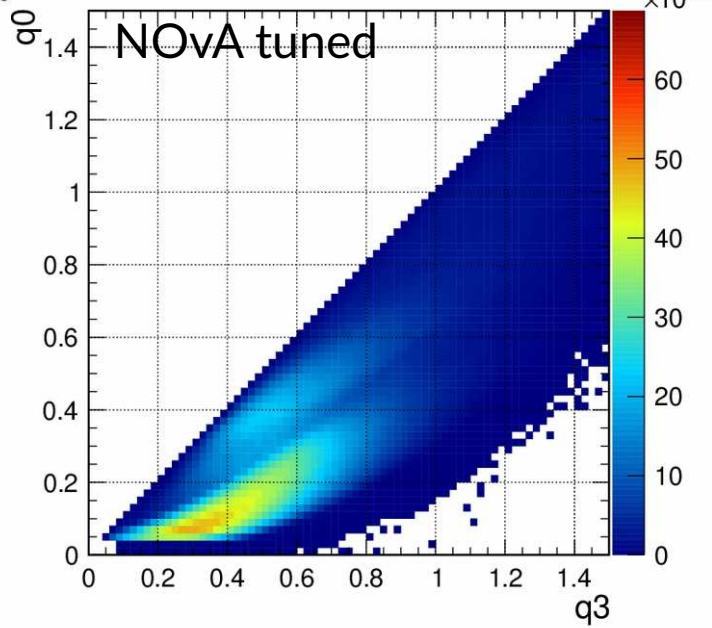
(T2K tuned/NOvA tuned) CC-Inclusive



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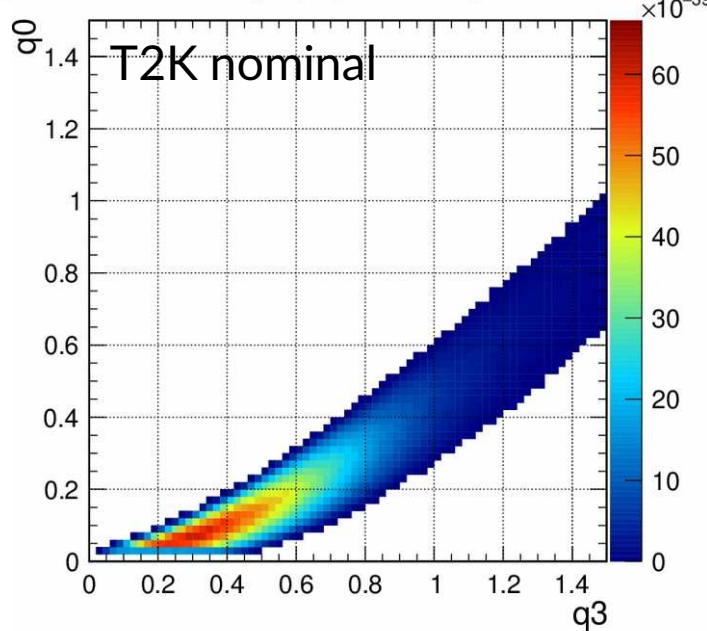
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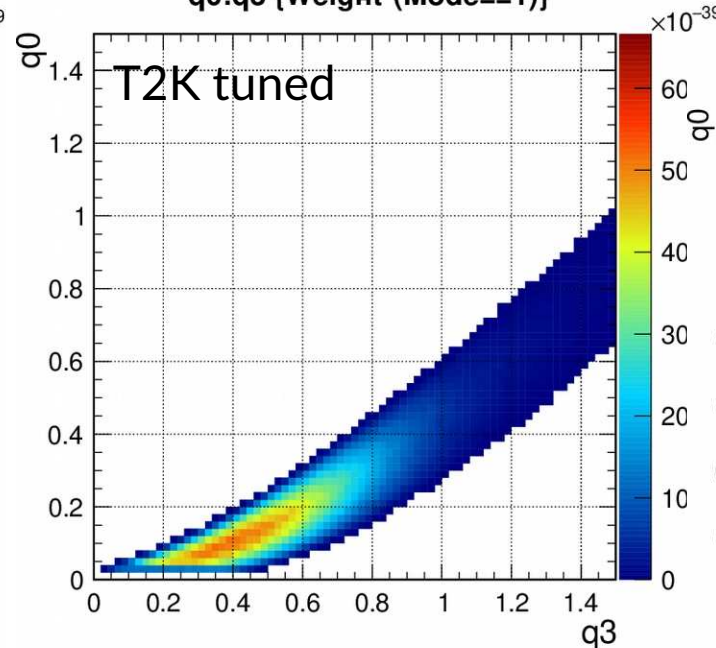
- Complicated differences
- Indicates CCQE, 2p2h, single pions and multi- $\pi$  all different
- T2K has larger cross-section over most phase space except 2p2h

# CCQE

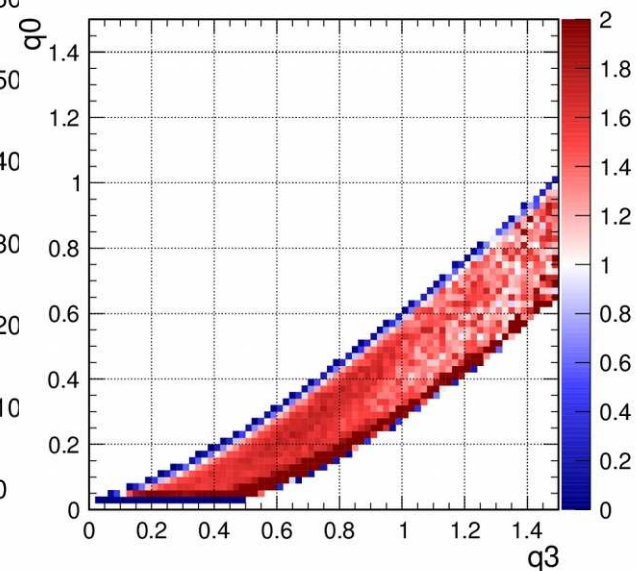
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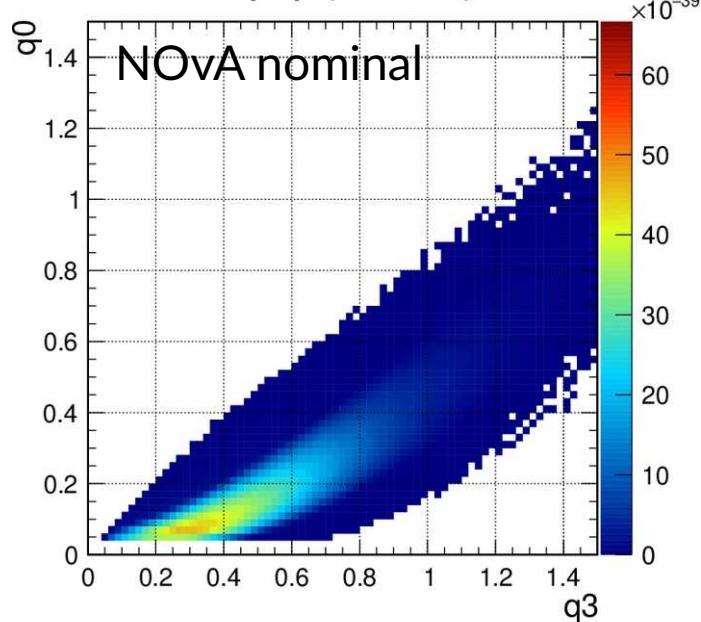
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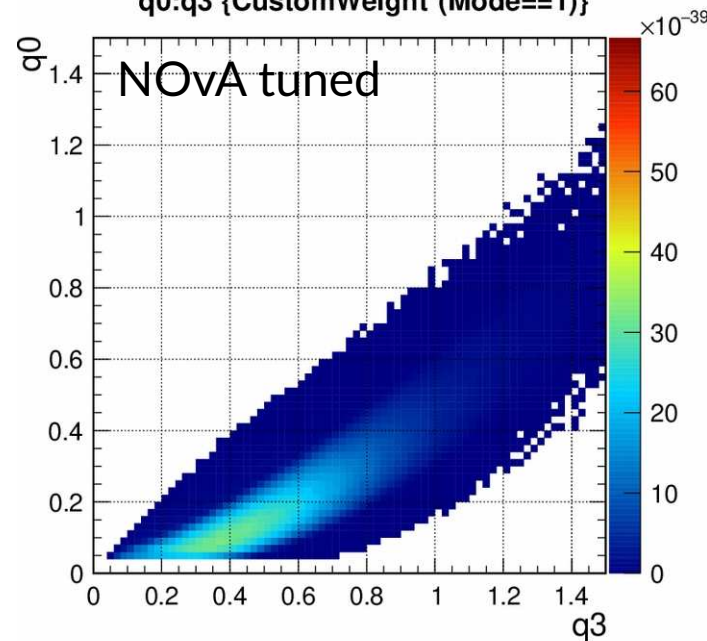
(T2K tuned/NOvA tuned) CCQE



q0:q3 {Mode==1}



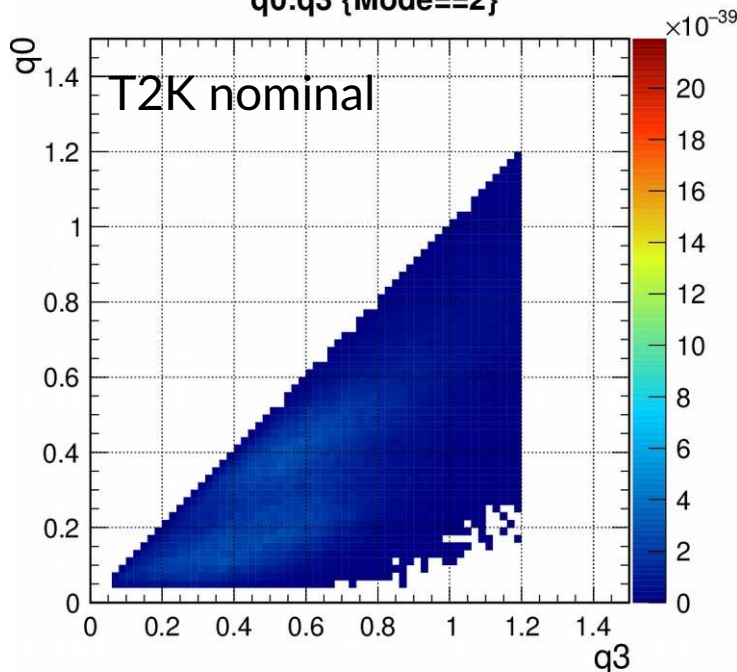
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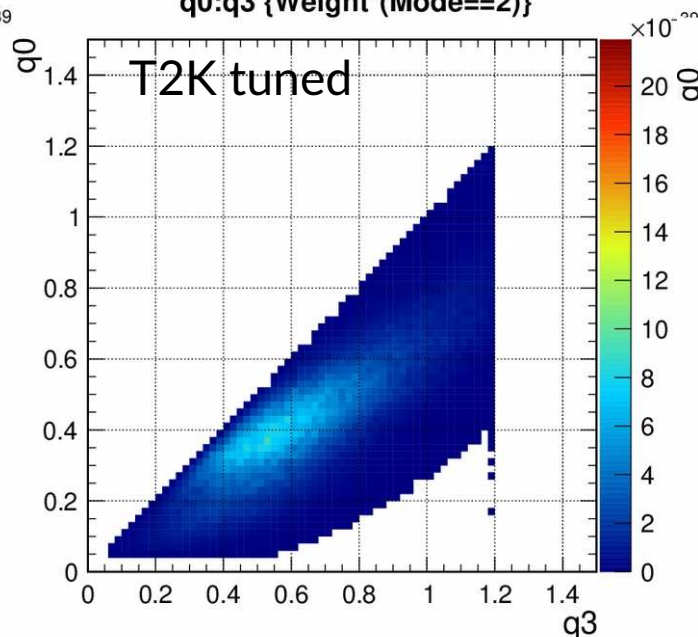
- T2K cross-section larger
- Primarily  $M_A^{\text{QE}}$  and tuned BeRPA at play
- Pre-tuned BeRPA is very similar to RikRPA

# 2p2h

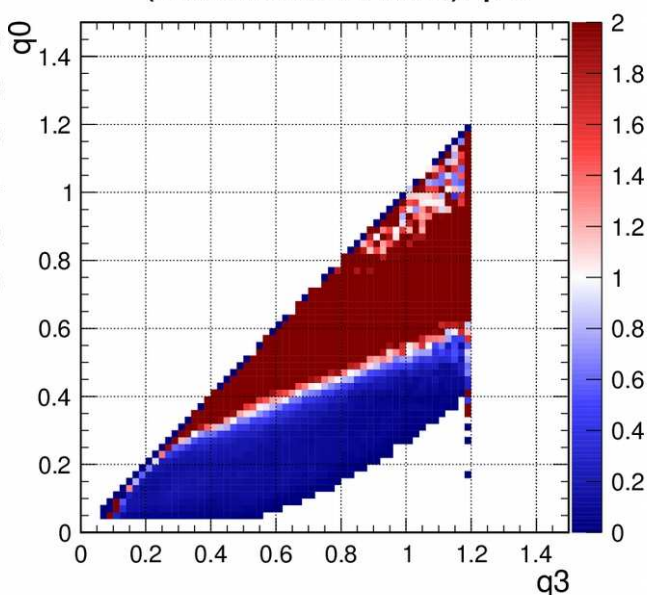
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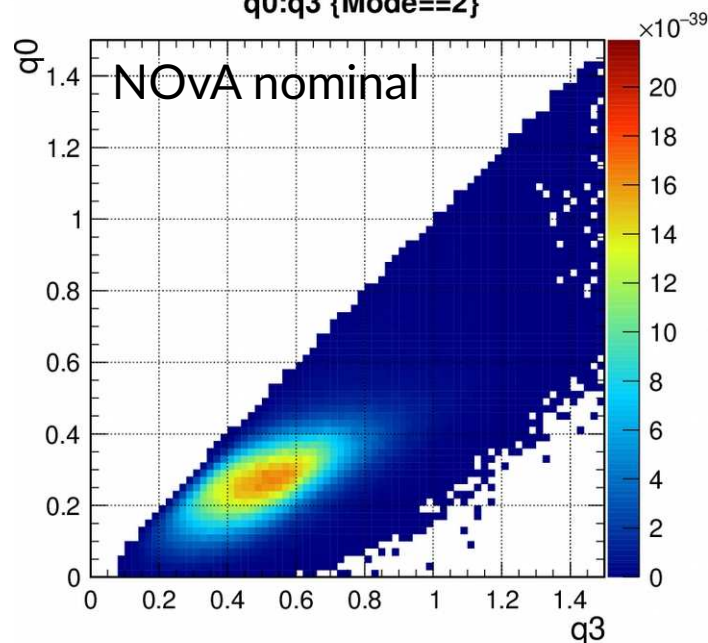
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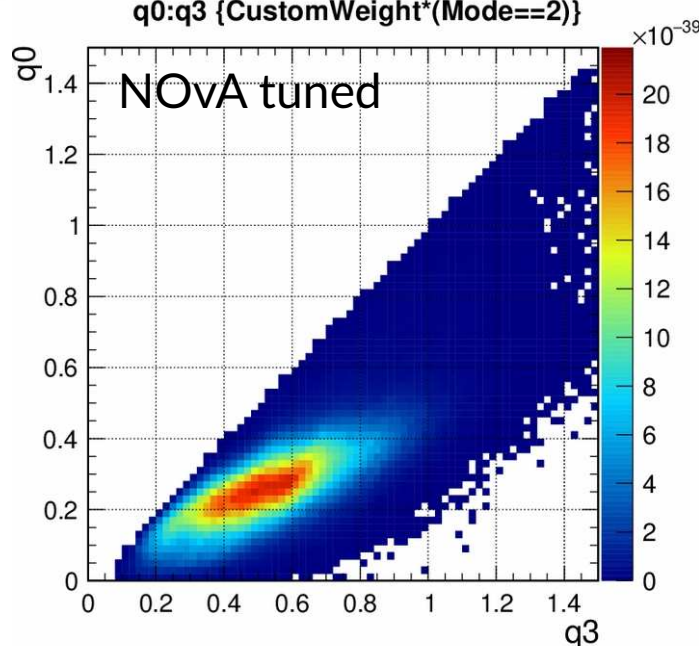
(T2K tuned/NOvA tuned) 2p2h



q0:q3 {Mode==2}

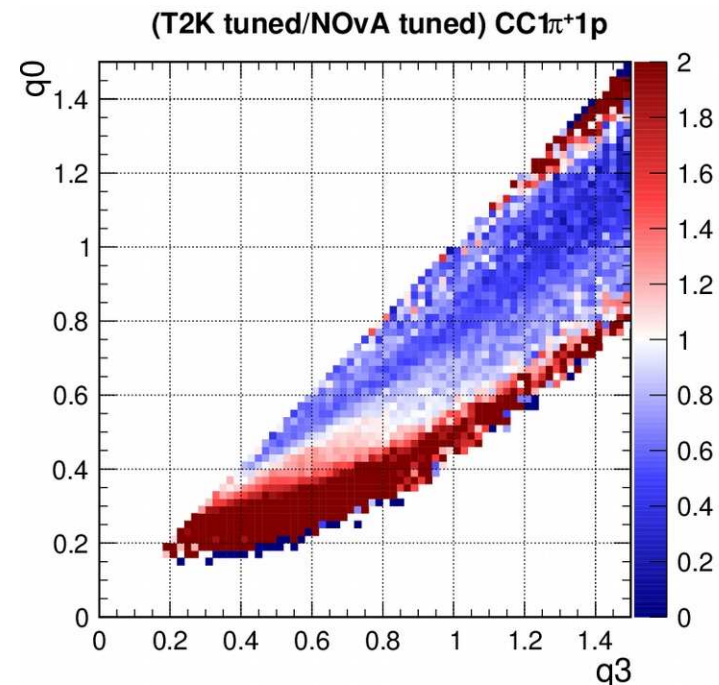
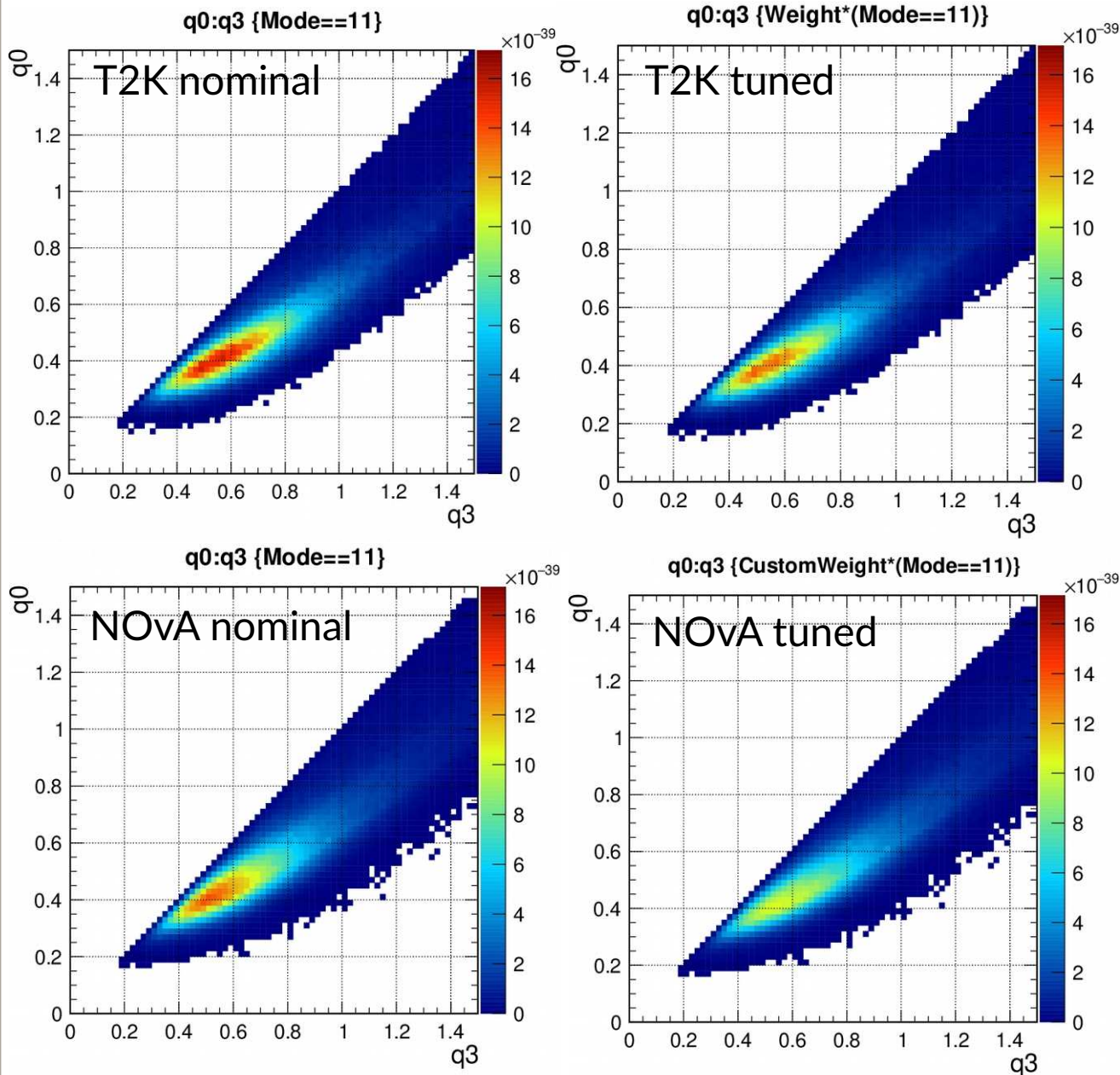


q0:q3 {CustomWeight\*(Mode==2)}



- Large difference in 2p2h pre and post-tune at both experiments
- Post-tune has very small region with same cross-section
  - Sharp cliffs on either side

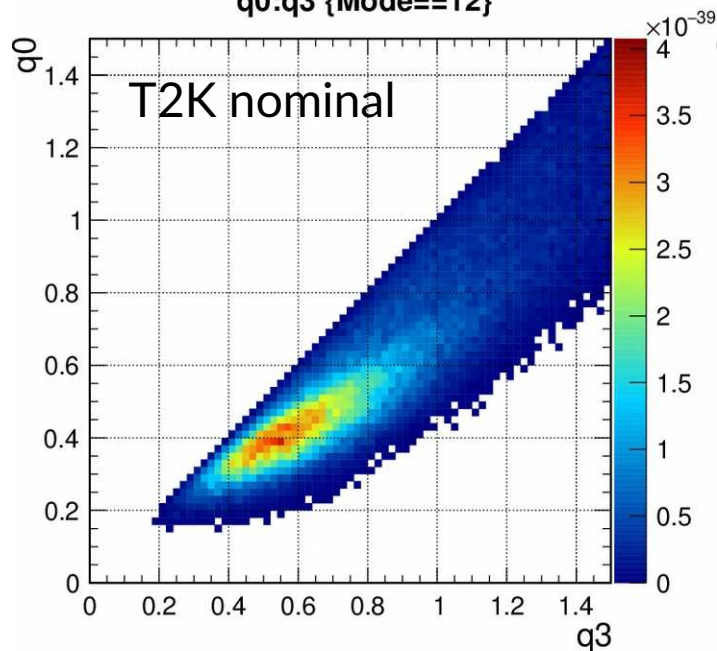
# CC1 $\pi^+$ 1p



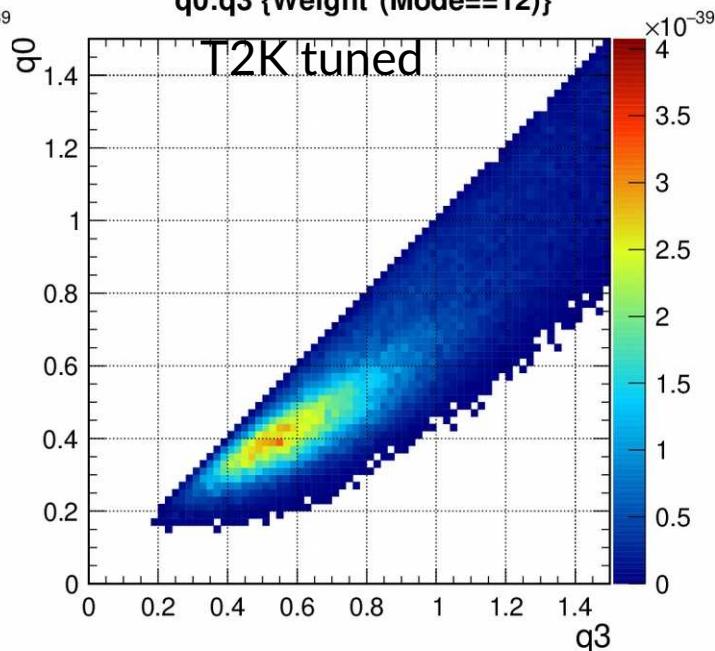
- NOvA tune has larger effect than T2K tune
  - Bubble chamber tune
  - Resonant RPA
- T2K “lobe” stretches further than NovA
  - Resonances? FSI?

# CC1 $\pi^0$

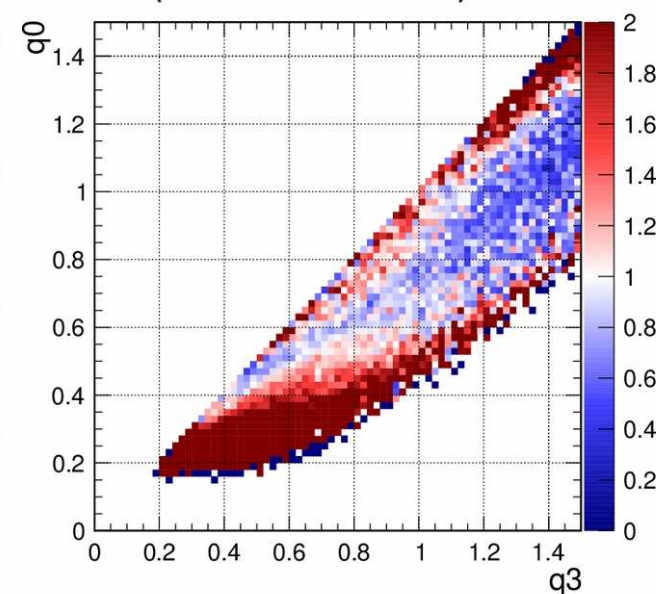
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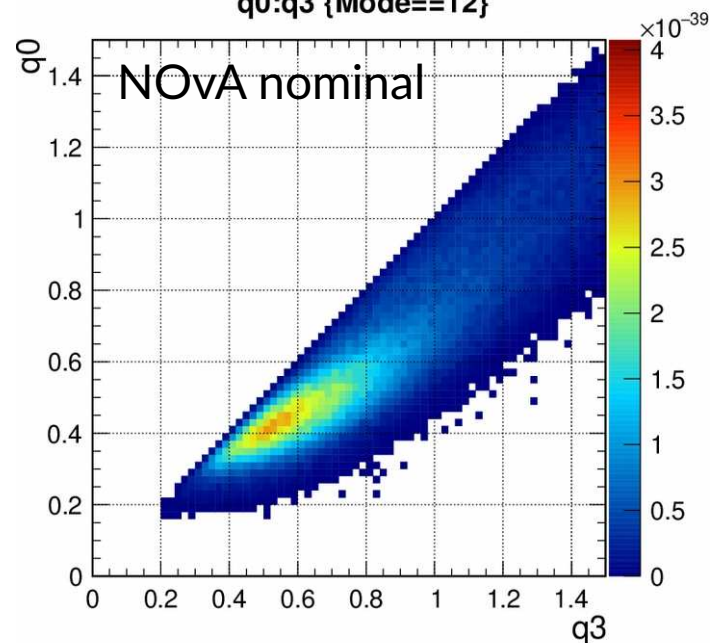
q0:q3 {Weight\*(Mode==12)}



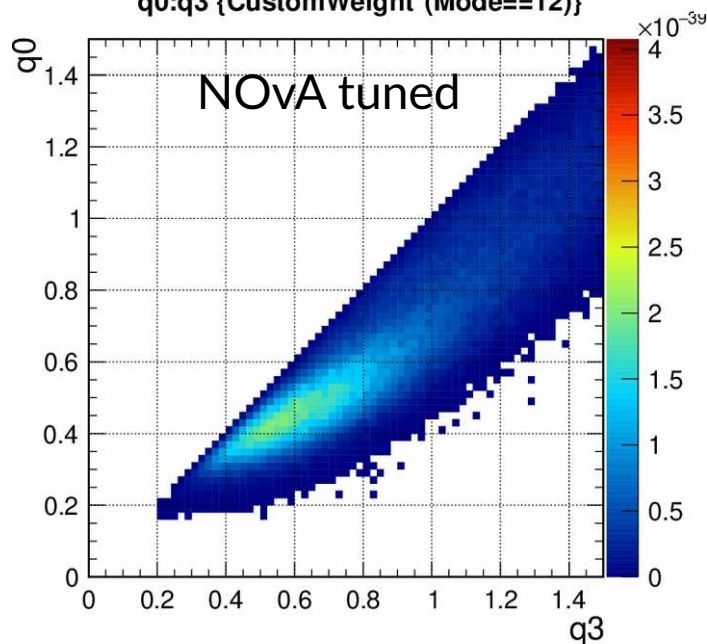
(T2K tuned/NOvA tuned) CC1 $\pi^0$



q0:q3 {Mode==12}



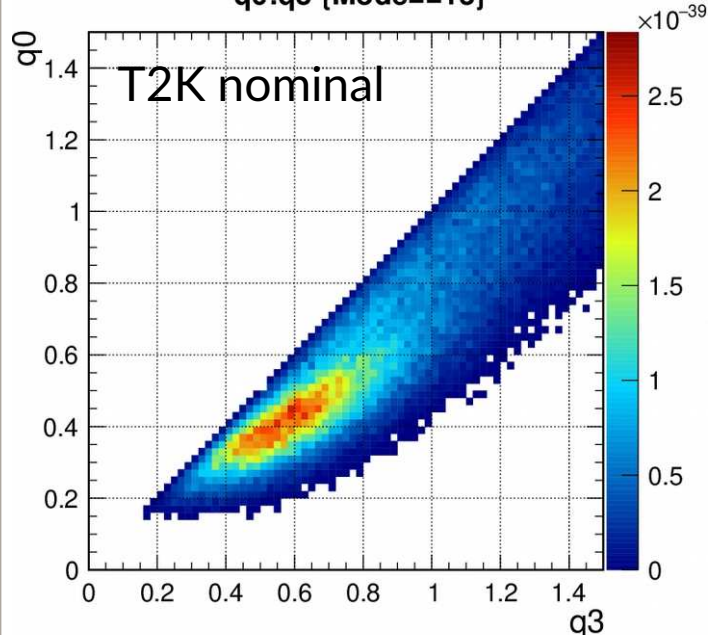
q0:q3 {CustomWeight\*(Mode==12)}



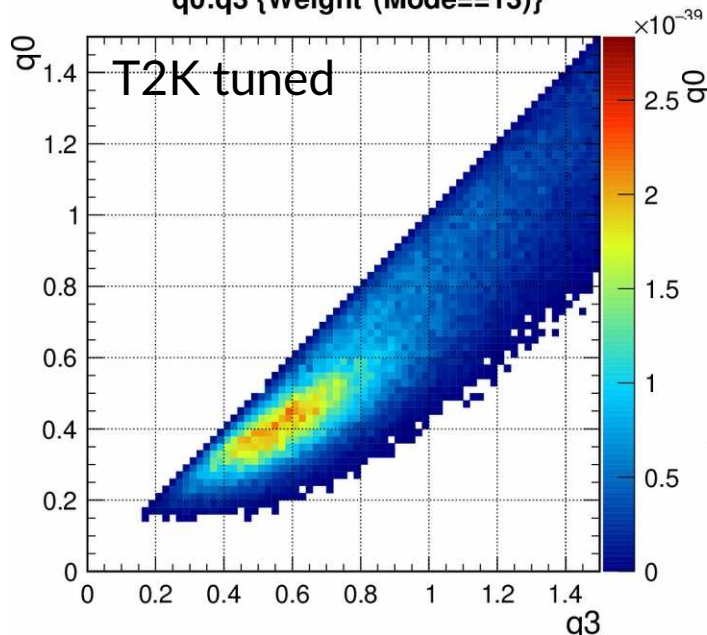
- Similar decrease in cross-section after tune to CC1 $\pi^+1p$
- T2K cross-section notably larger except high  $q_0$  and  $q_3$

# CC1 $\pi^+$ 1n

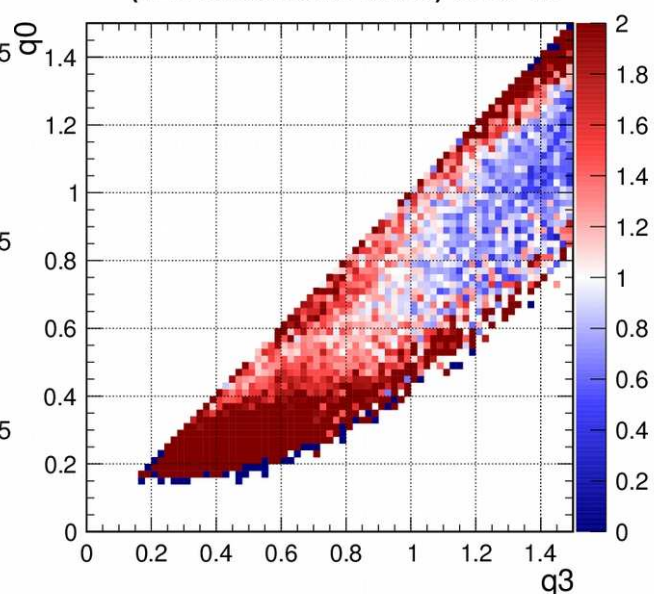
q0:q3 {Mode==13}



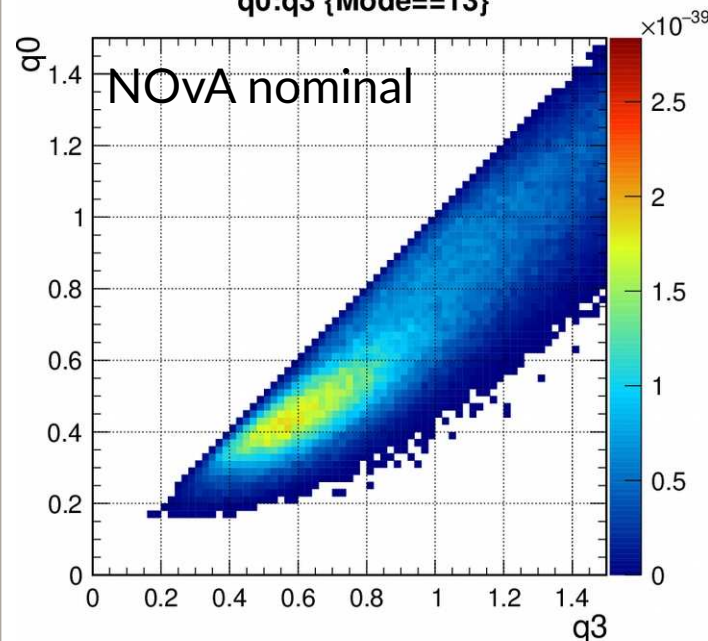
q0:q3 {Weight\*(Mode==13)}



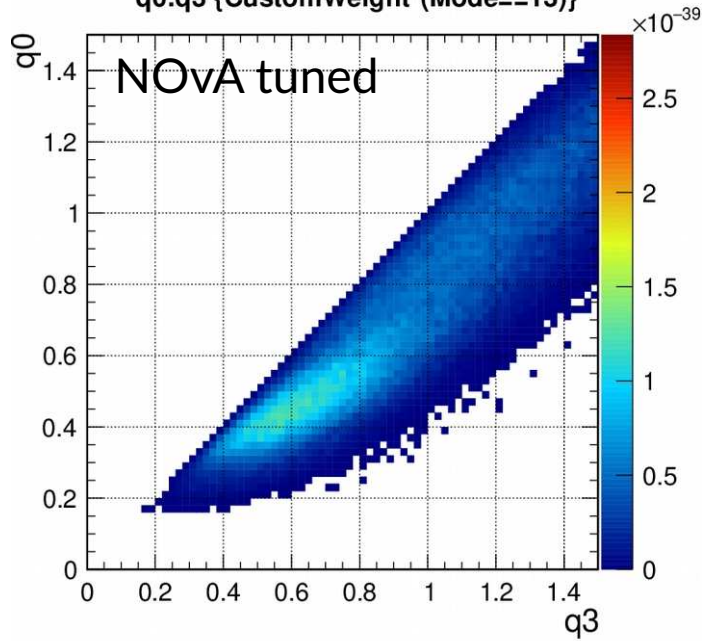
(T2K tuned/NOvA tuned) CC1 $\pi^+$ 1n



q0:q3 {Mode==13}



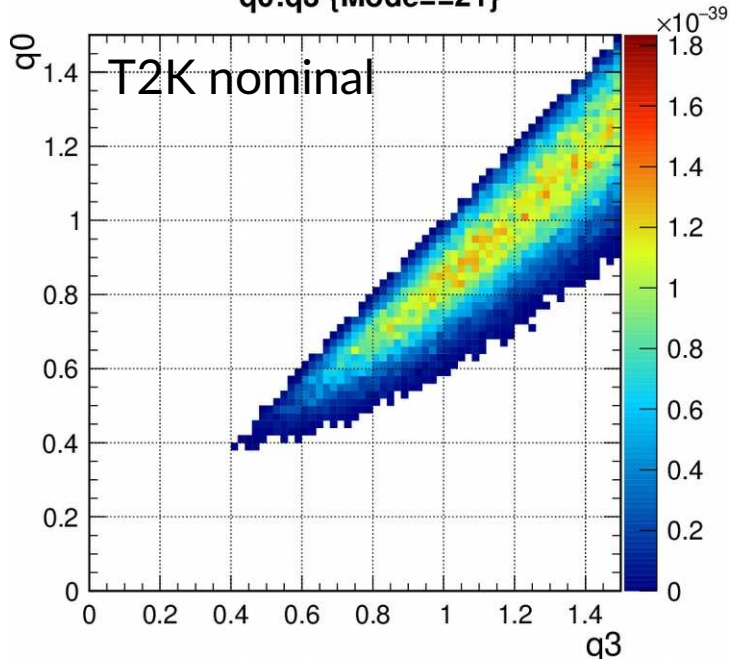
q0:q3 {CustomWeight\*(Mode==13)}



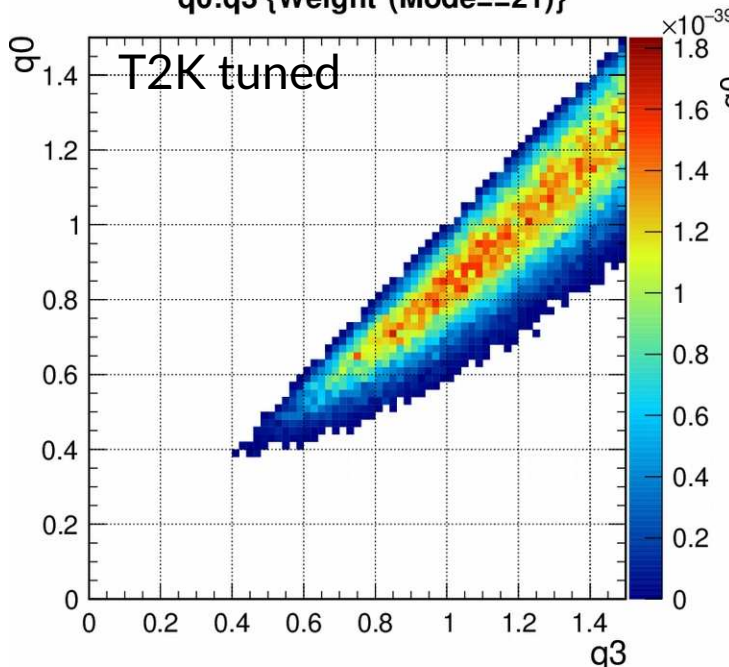
- Implemented physics is similar in CC1 $\pi^+$ 1n and CC1 $\pi^0$  for both NEUT and GENIE
- Neither experiment tune pion channels independently

# CC multi- $\pi$ (trans)

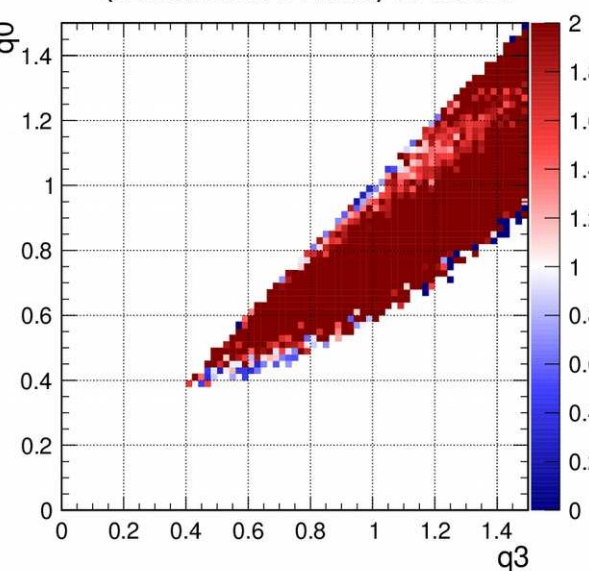
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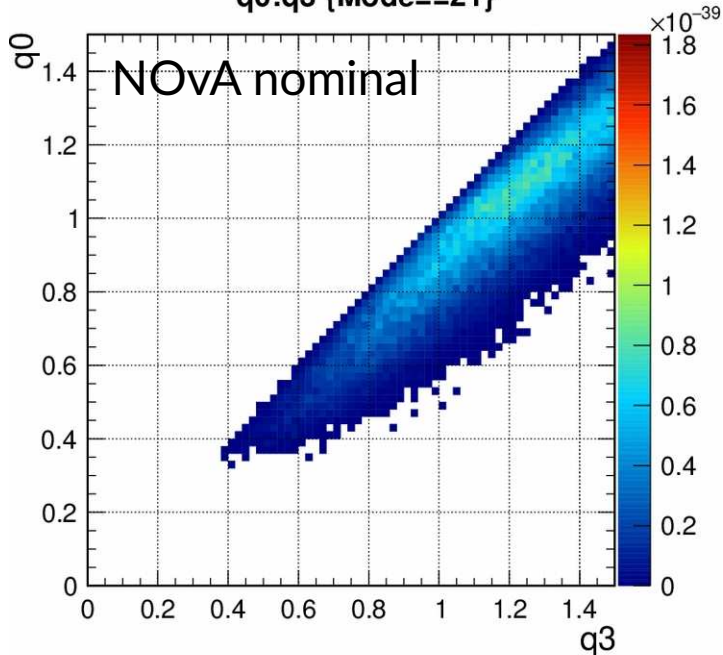
q0:q3 {Weight\*(Mode==21)}



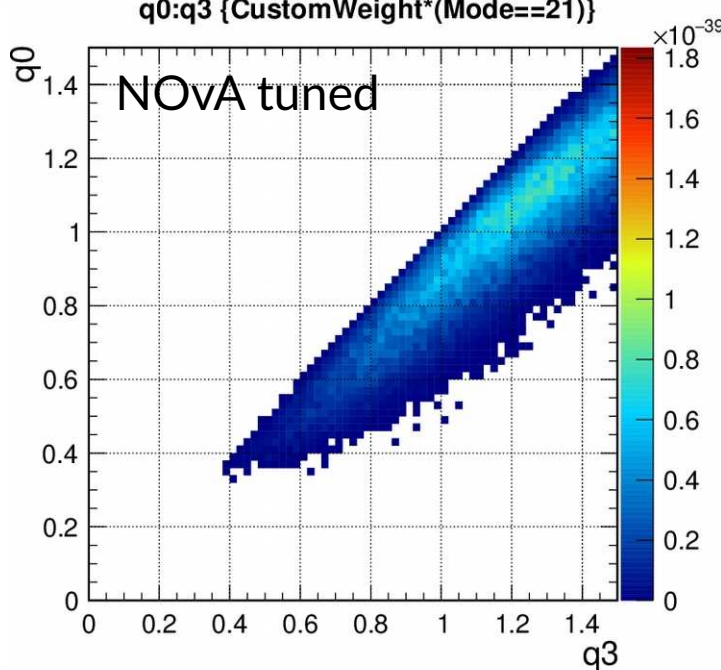
(T2K tuned/NOvA tuned) CC Multi- $\pi$



q0:q3 {Mode==21}



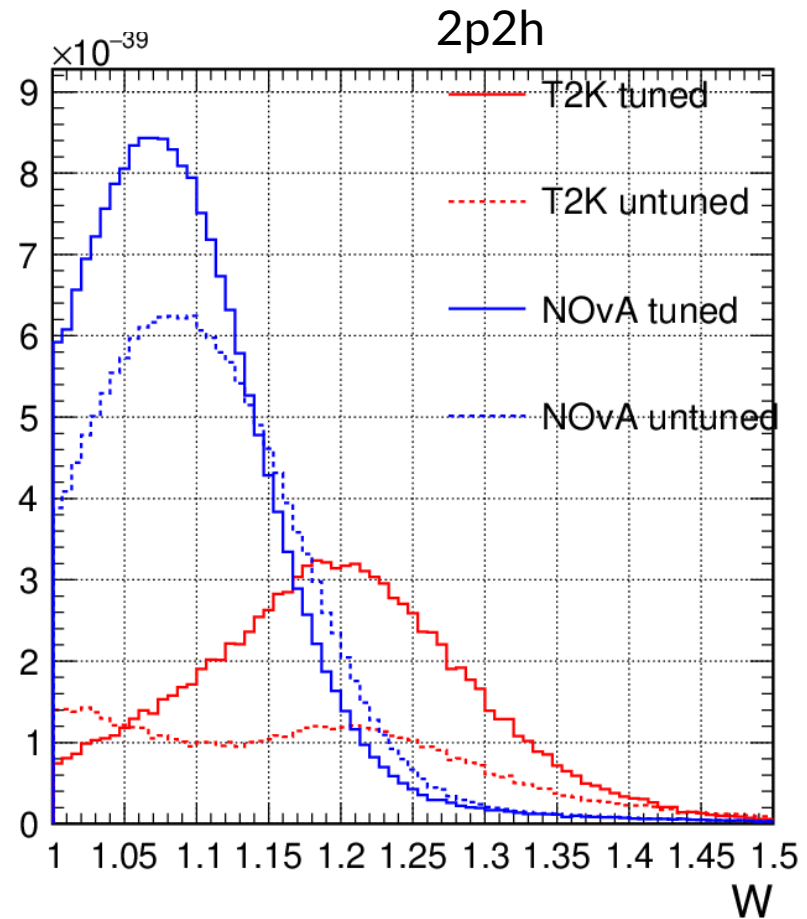
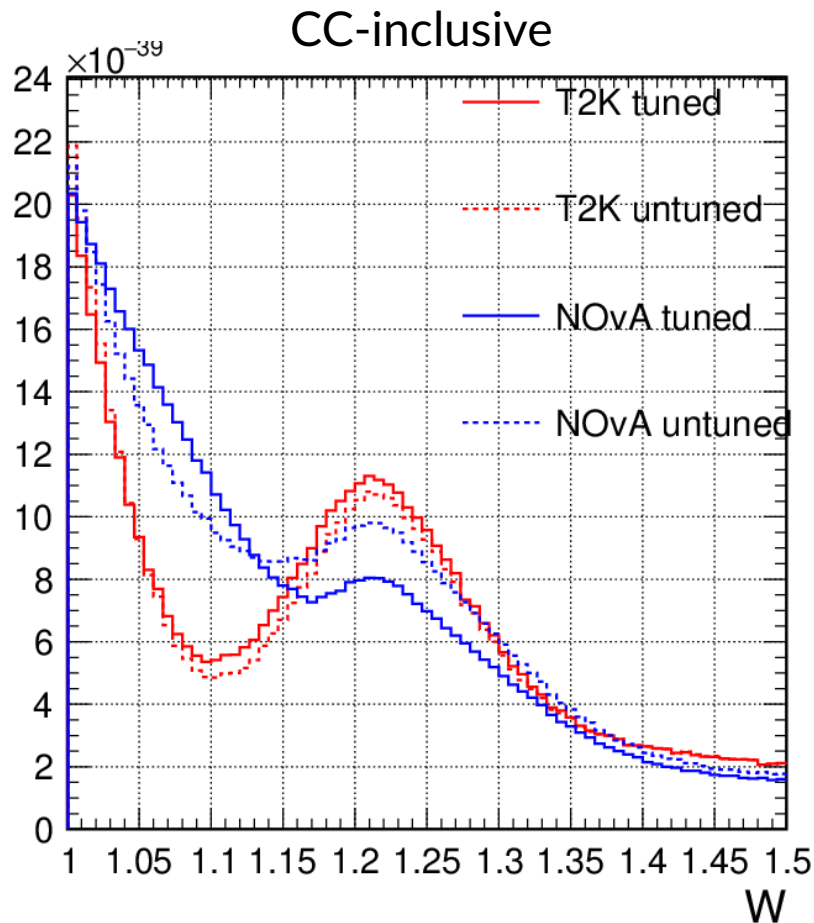
q0:q3 {CustomWeight\*(Mode==21)}



- Distinctly different transition region
- Less important for T2K, but important for NOvA ( $\sim 1/3$  of cross-section)

# W “reconstructed”

Assume struck nucleon at rest,  
reconstruct W from q

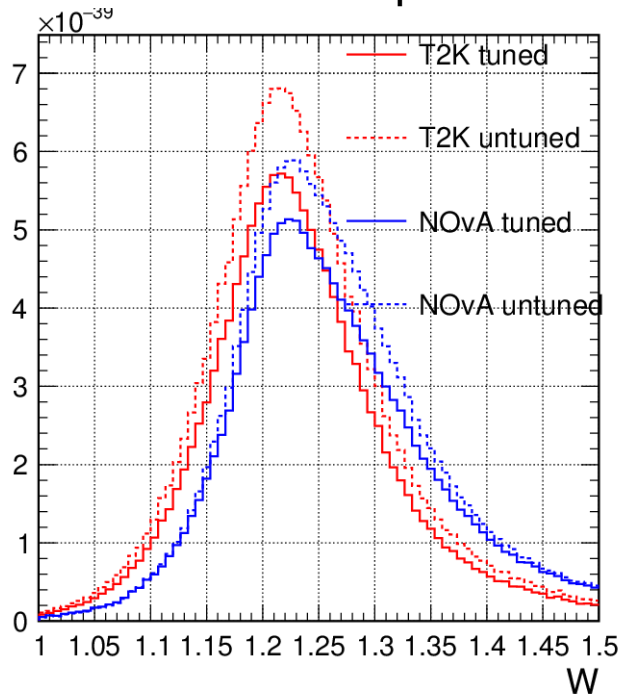


- Different shape in CC-inclusive at T2K energies above CCQE peak is largely from 2p2h model

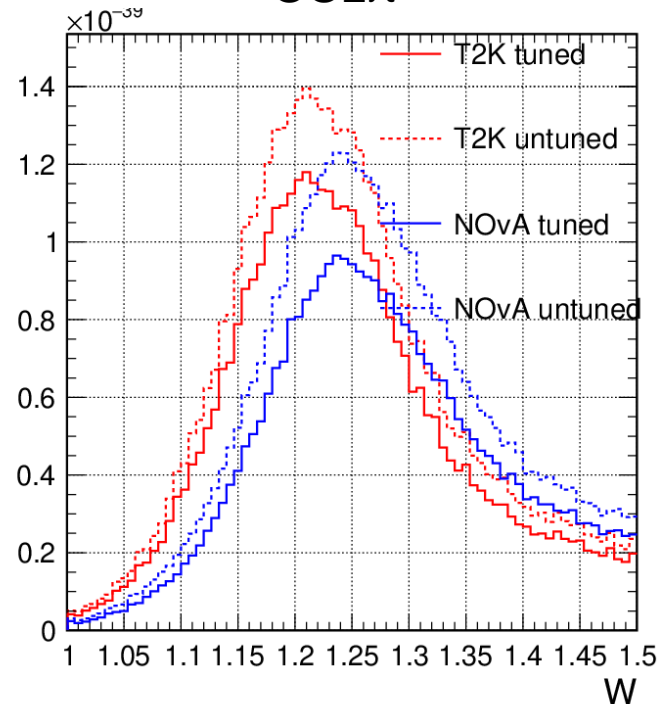
# W “reconstructed”

Assume struck nucleon at rest,  
reconstruct W from  $q$

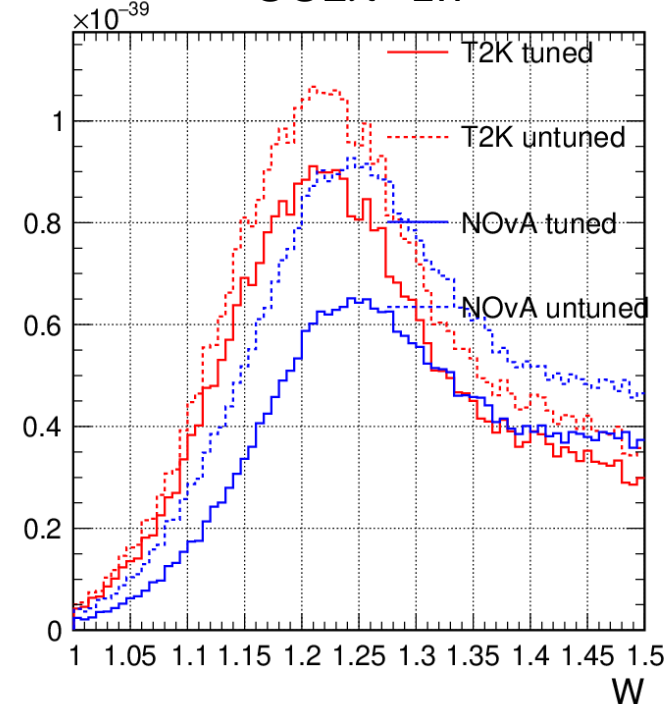
CC1 $\pi$ +1p



CC1 $\pi^0$



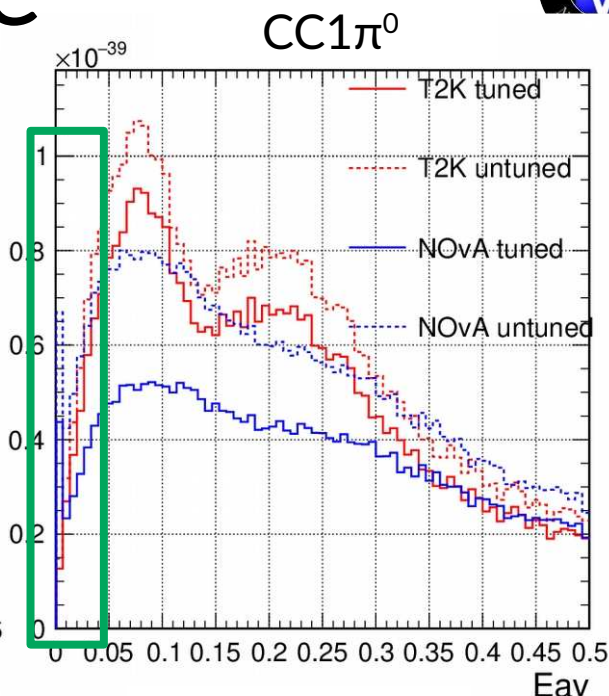
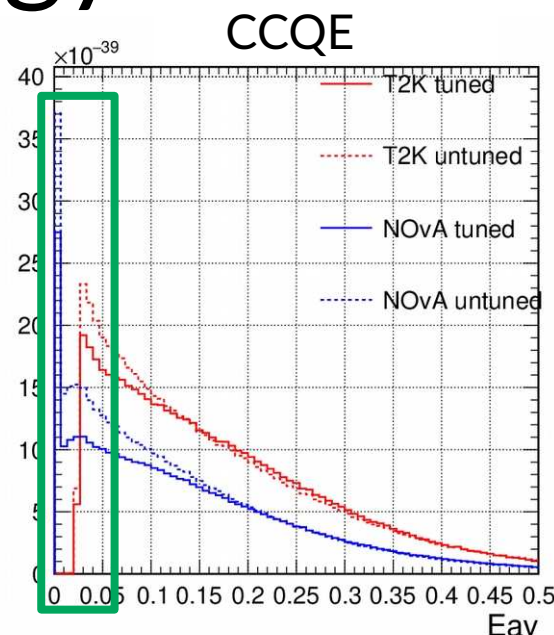
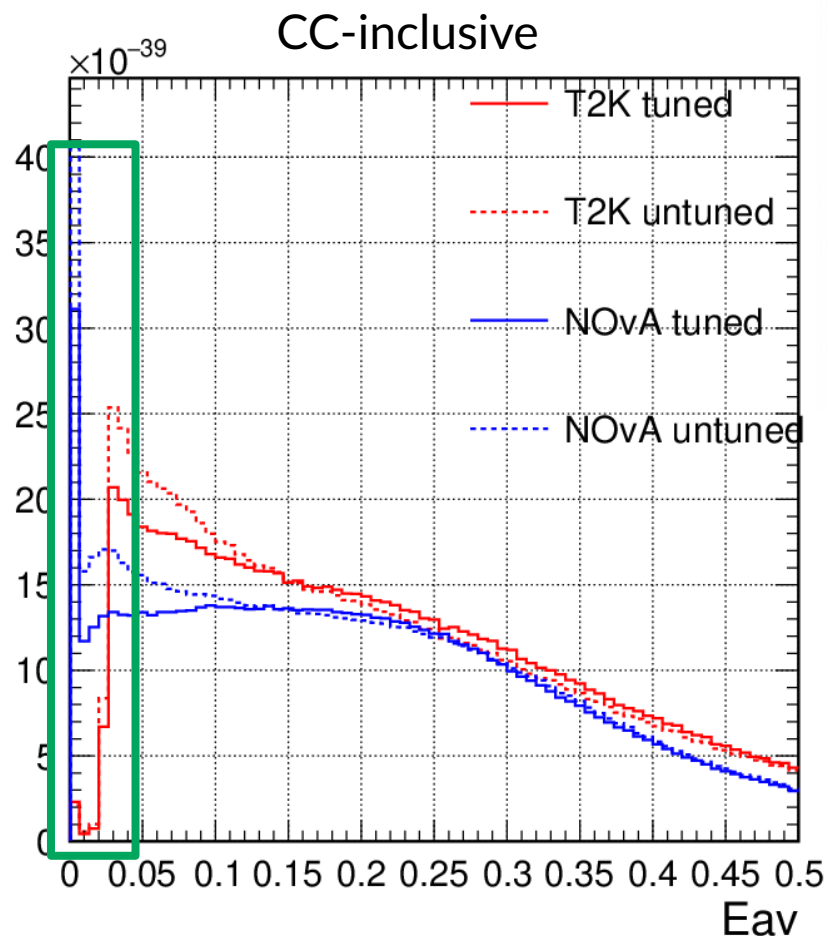
CC1 $\pi$ +1n



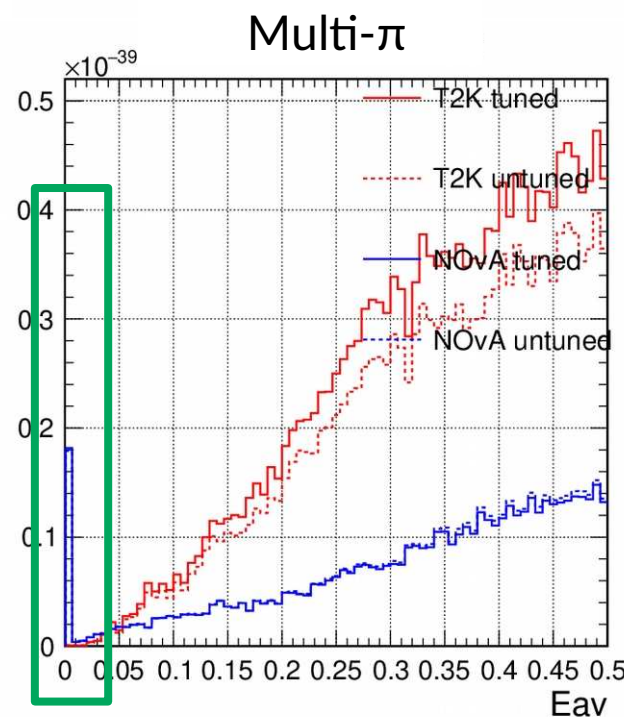
- Single pion production see similar decrease in cross-section across all the interaction channels
- NOvA model resonance shifted upwards in W
  - Non-resonant background implementation?
  - Resonance-resonance interference (ignored in GENIE)?

# Energy available

- $E_{av}$  = KE of protons and  $\pi^\pm$  + Total energy of  $\pi^0$ , electrons and  $\gamma$
- Rough measure of visible energy detected



- Very large differences at low  $E_{av}$
- Coming primarily from CCQE
- $CC1\pi^0$  and multi- $\pi$  see similar



- Effect of GENIE's ambitious nucleon and pion FSI? Important for calorimetric reconstruction?

# Summary

- Expanded on Luke's comparisons of NOvA vs T2K model, now including post-fit parameter values
- Modelling is notably different for 2p2h and multi- $\pi$ 
  - Stems largely from physics/implementation choices
- CCQE and resonant are similar, but not in  $E_{\text{available}}$ 
  - Similar physics/implementation choices
  - Tuned model parameters are different: T2K larger cross-section
- Project still has some distance to cover:
  - Include acceptances
  - NEUT on NOvA target
  - External data comparisons
  - MINERvA tune for good measure?
- Would appreciate help, either working group or individuals



# Thanks

# T2K post-fit details

<i>Parameter</i>	<i>PreFit</i>	<i>PostFit</i>
FSI_INEL_LO	$0.0 \pm 0.41$	$-0.32332 \pm 0.081129$
FSI_INEL_HI	$0.0 \pm 0.34$	$-0.0086159 \pm 0.12846$
FSI_PI_PROD	$0.0 \pm 0.5$	$0.040936 \pm 0.18706$
FSI_PI_ABS	$0.0 \pm 0.41$	$-0.34771 \pm 0.14731$
FSI_CEX_LO	$0.0 \pm 0.57$	$-0.088986 \pm 0.30907$
FSI_CEX_HI	$0.0 \pm 0.28$	$0.022924 \pm 0.10475$

Pion  
FSI

CCQE  
and  
2p2h

MAQE (GeV/c <sup>2</sup> )	$1.2 \pm 0.03$	$1.1314 \pm 0.079024$
pF_C (MeV/c)	$217.0 \pm 13.0$	$224.16 \pm 13.295$
pF_0 (MeV/c)	$225.0 \pm 13.0$	$204.98 \pm 15.083$
2p2h_norm_nu	$1.0 \pm 1.0$	$1.5018 \pm 0.1955$
2p2h_norm_nubar	$1.0 \pm 1.0$	$0.726 \pm 0.23125$
2p2h_normCto0	$1.0 \pm 0.2$	$0.96392 \pm 0.16657$
2p2h_shape_C (%)	$100.0 \pm 300.0$	$200.22 \pm 20.606$
2p2h_shape_0 (%)	$100.0 \pm 300.0$	$199.71 \pm 34.746$

CA5	$0.96 \pm 0.15$	$0.97601 \pm 0.064304$
MARES (GeV/c <sup>2</sup> )	$1.07 \pm 0.15$	$0.806 \pm 0.044916$
ISO_BKG	$0.96 \pm 0.4$	$1.3147 \pm 0.25594$
nue_numu	$1.0 \pm 0.028284$	$1.0 \pm 0.028284$
nuebar_numubar	$1.0 \pm 0.028284$	$1.0 \pm 0.028284$
CC_DIS	$0.0 \pm 0.4$	$0.38541 \pm 0.19726$

Single  
pion

RPA

$\nu_e/\nu_\mu$   
DIS

BeRPA_A	$0.59 \pm 0.118$	$0.6878 \pm 0.057308$
BeRPA_B	$1.05 \pm 0.21$	$1.5993 \pm 0.11727$
BeRPA_D	$1.13 \pm 0.1695$	$0.96248 \pm 0.13445$
BeRPA_E	$0.88 \pm 0.352$	$0.8749 \pm 0.35332$
BeRPA_U	$1.2 \pm 0.1$	$1.2 \pm 0.1$

CC_Coh_C	$1.0 \pm 0.3$	$0.87408 \pm 0.28178$
CC_Coh_0	$1.0 \pm 0.3$	$0.87406 \pm 0.28179$
NC_Coh	$1.0 \pm 0.3$	$0.93795 \pm 0.29744$
NC_1gamma	$1.0 \pm 1.0$	$1.0 \pm 1.0$
NC_other_near	$1.0 \pm 0.3$	$1.208 \pm 0.25613$
NC_other_far	$1.0 \pm 0.3$	$1.0 \pm 0.3$

Small  
cross-  
sections

# Mode breakdown

Mode {(Mode<30)}

