

Systematic uncertainties in the neutrino interaction model for T2K (update)

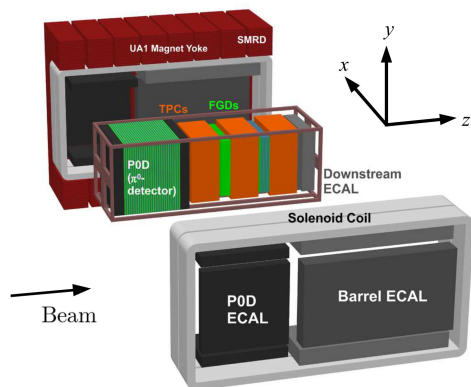
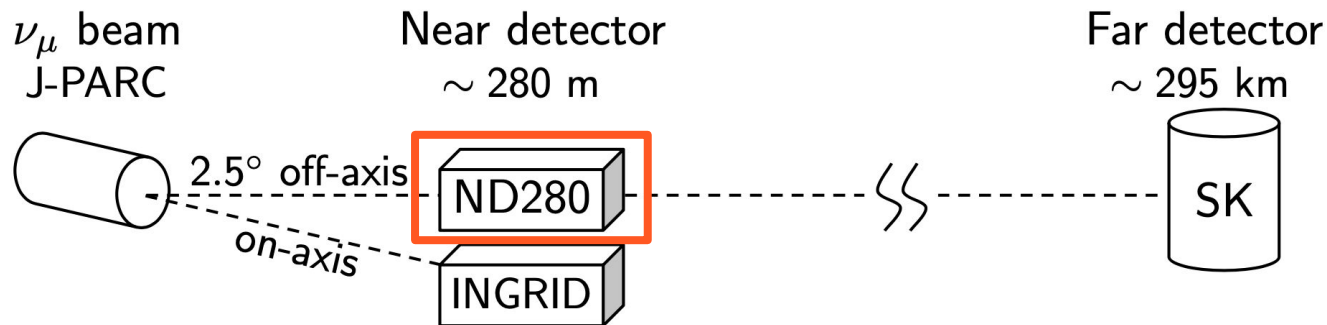
Jaafar Chakrani
EP-NU Group Meeting - 24/09/2020

Outline

- Introduction
- First fit results
- Summary and next steps

Introduction

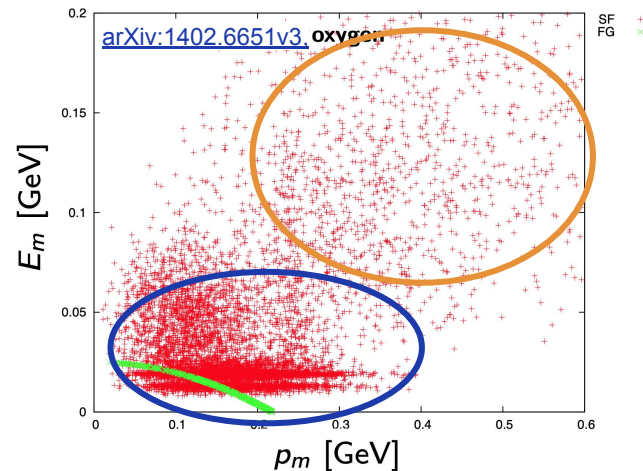
T2K experiment



- Neutrinos interact with carbon and oxygen
- Dominant interaction channel is CCQE:
$$\nu_\mu + n \rightarrow \mu^- + p$$
$$\bar{\nu}_\mu + p \rightarrow \mu^+ + n$$
- Nuclear effects present a major source of systematic uncertainties in the oscillation analysis
⇒ Need a good nuclear model

Nuclear models

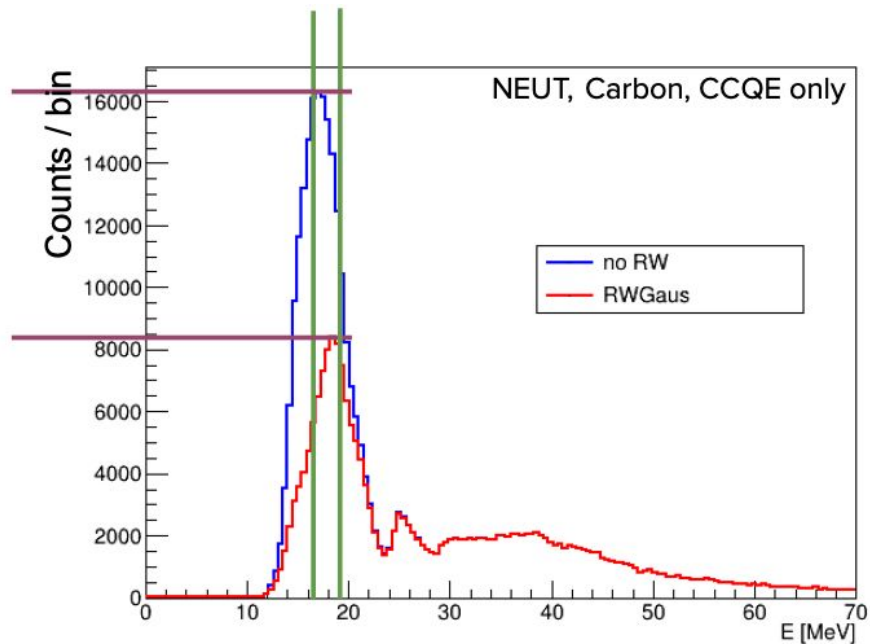
- Nuclear models give the energy and the momentum of nucleons inside the nucleus
- Different nuclear models:
 - Fermi-gas based models (**RFG**, LFG)
 - Constant binding energy
 - Stat. corr. between fermions only
 - Spectral Function (**SF**) model
 - **Nuclear shell model**
 - **Short-range correlations (SRC)**



New dials

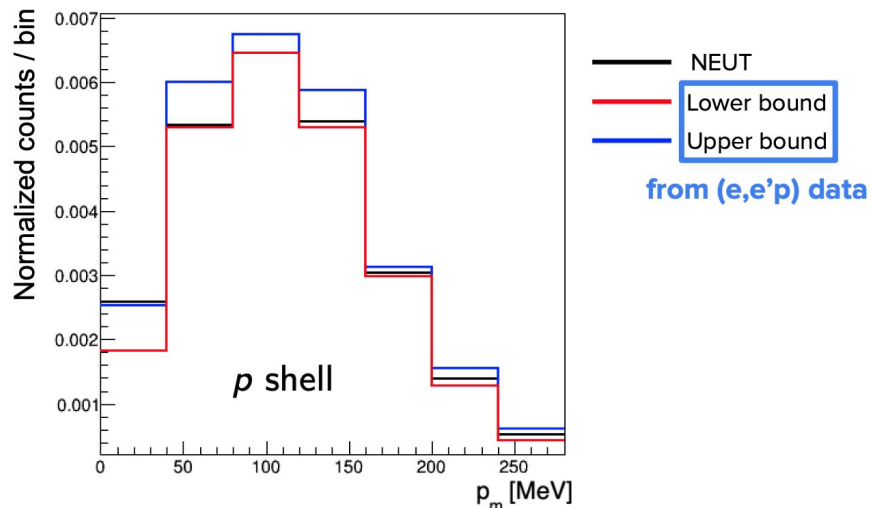
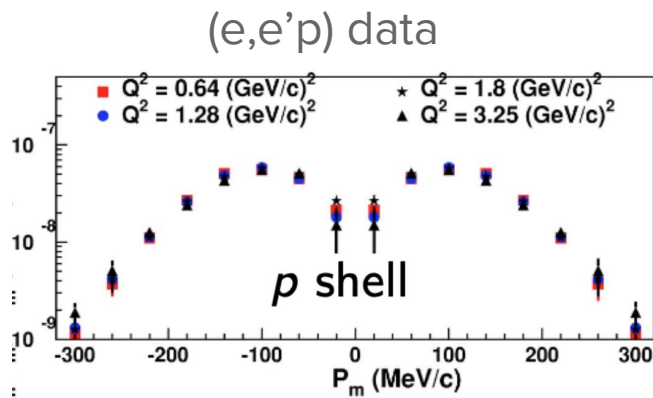
New dials

- Missing energy: 3 parameters per shell => **6 parameters**



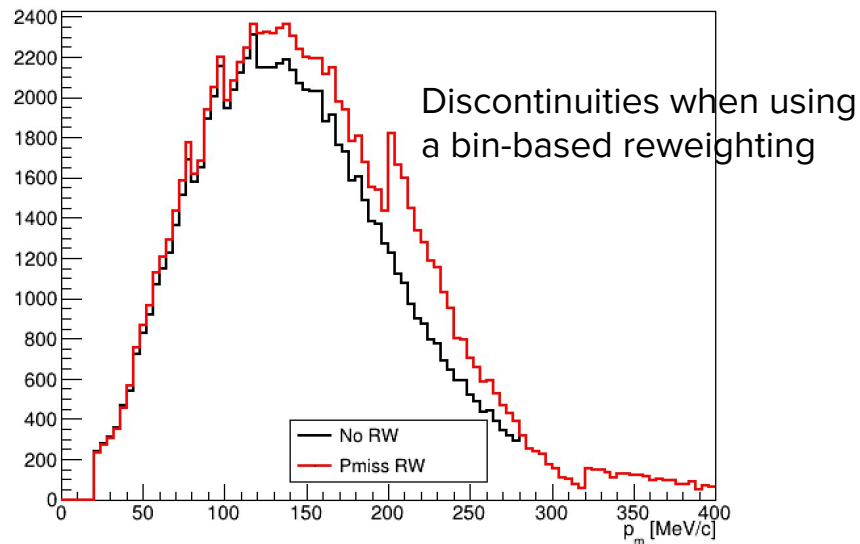
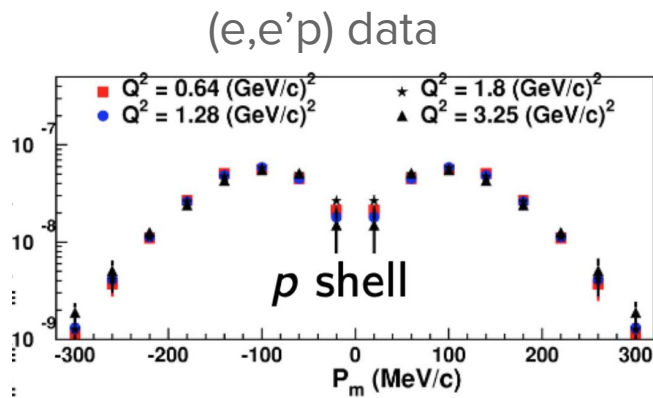
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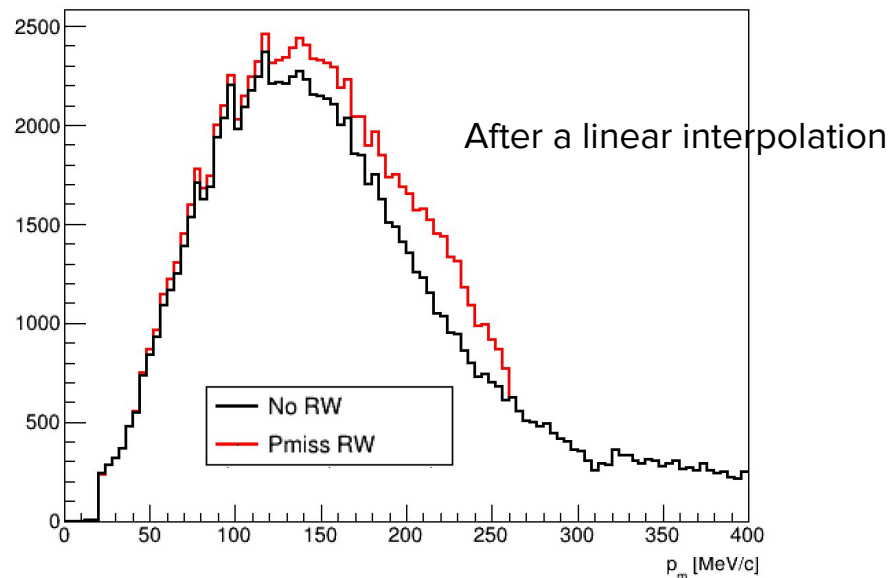
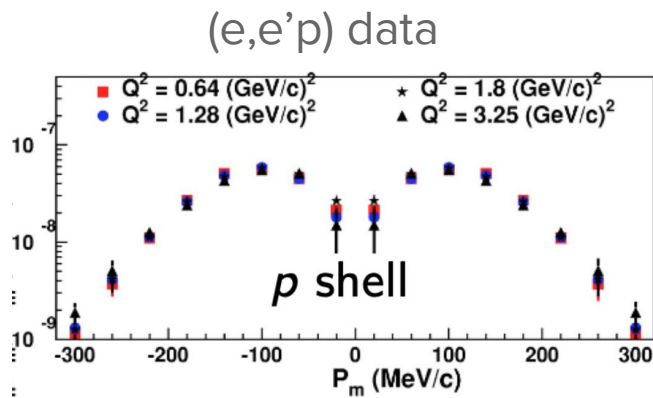
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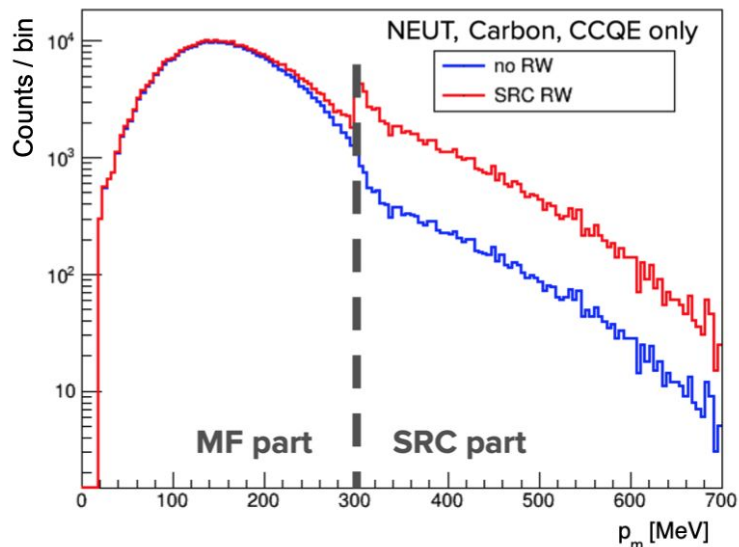
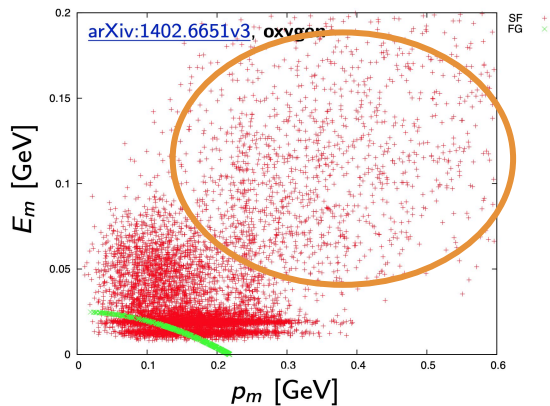
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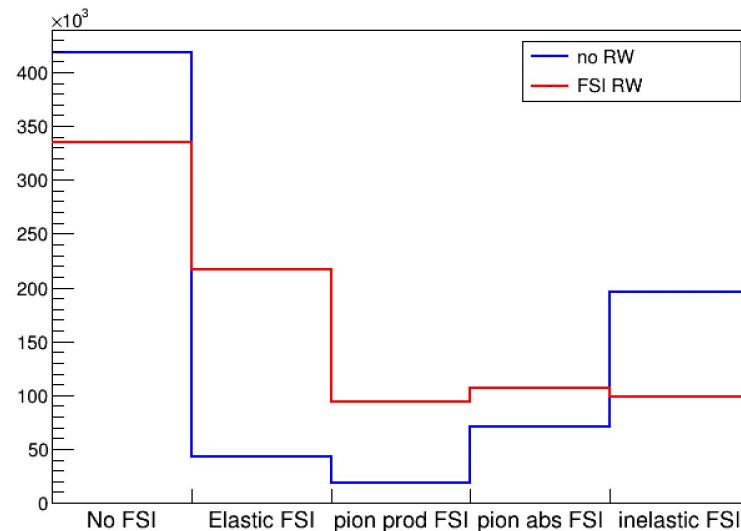
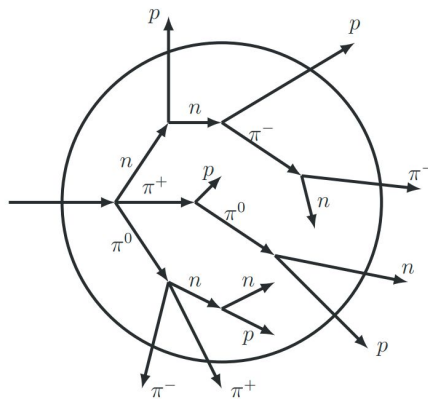
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New dials

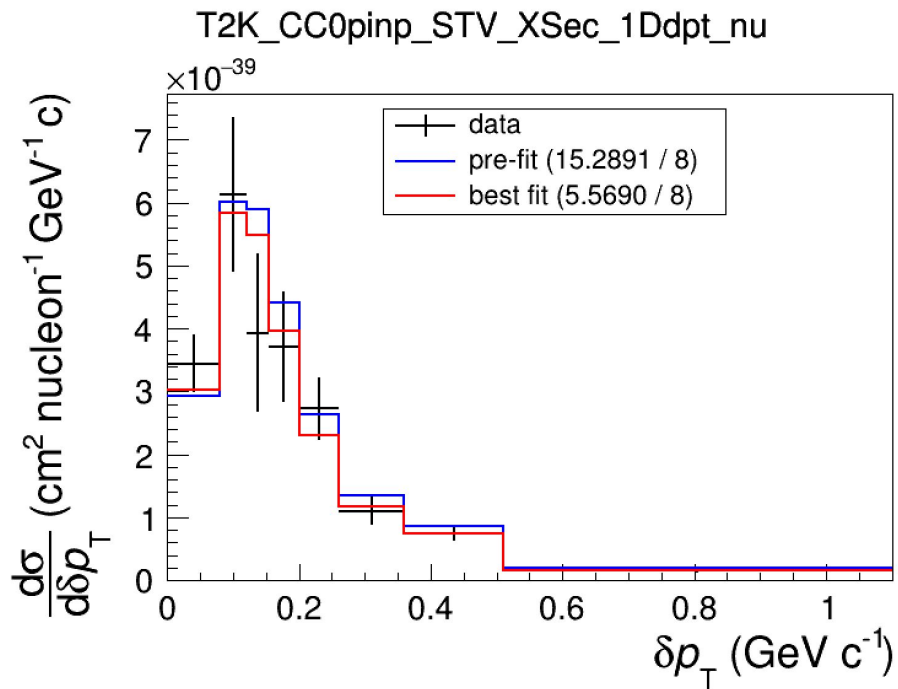
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→ What's missing:

- ◆ 2p2h shape variation
- ◆ Pion production dials

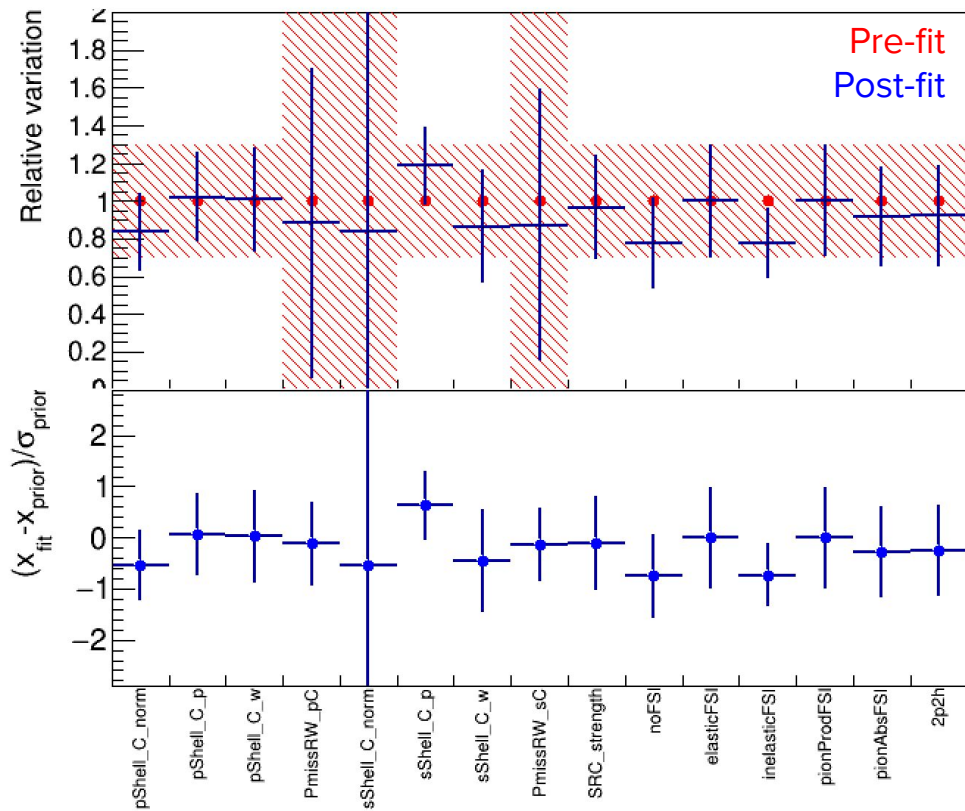
Fit results

Fitting T2K dpt data



Fitting T2K dpt data

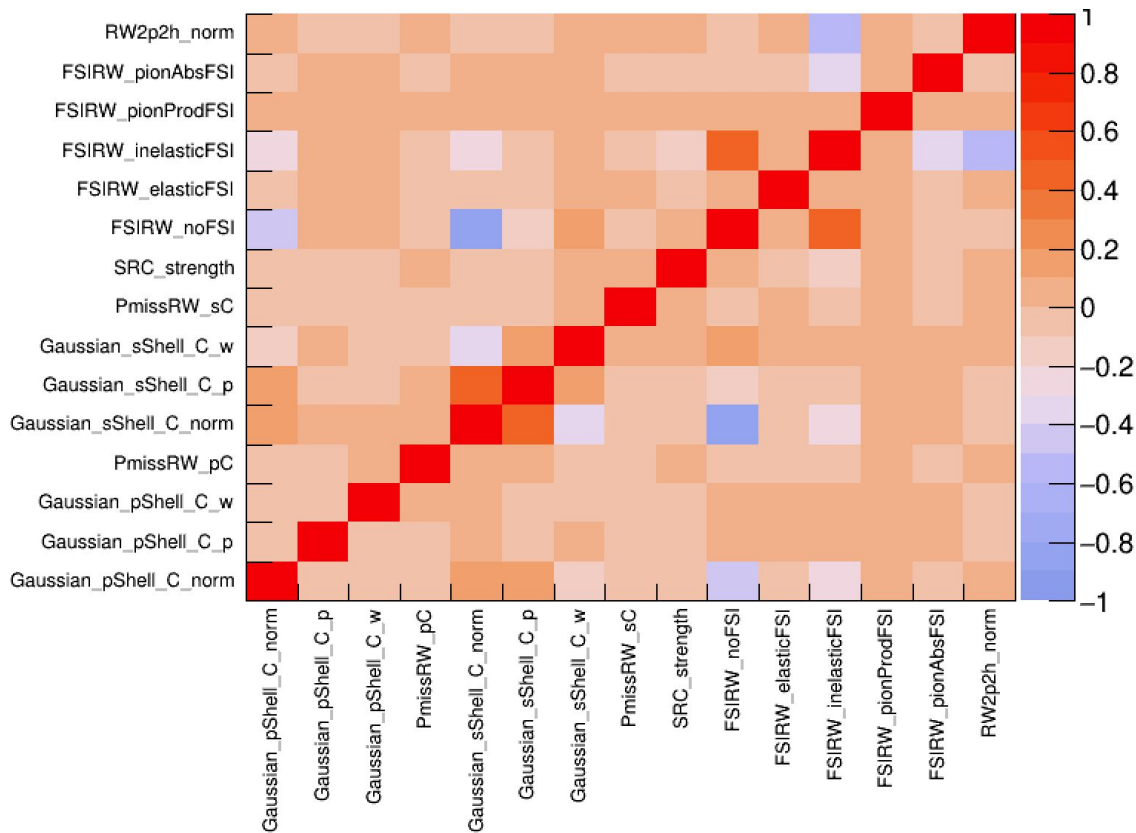
Pre-fit vs. post-fit parameters



- Weak constraints on the parameters: fitting 8 bins with 15 parameters!
- Largest changes are small shifts in the normalization parameters
- The fit changes mainly:
 - The shape of the s-shell
 - noFSI and inelasticFSI

Fitting T2K dpt data

Correlation matrix



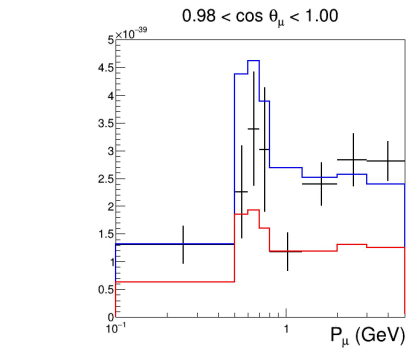
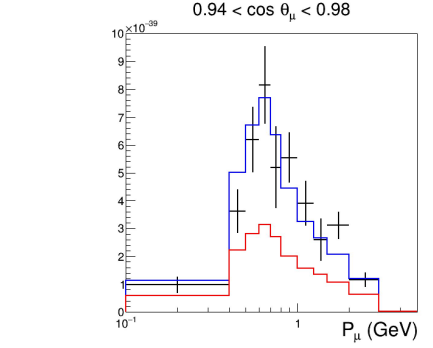
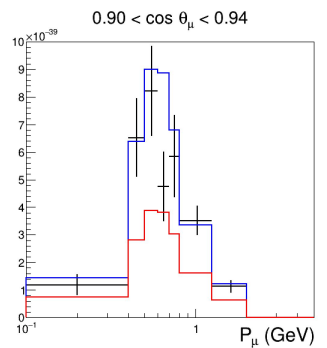
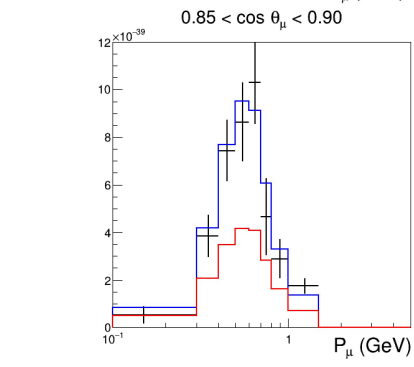
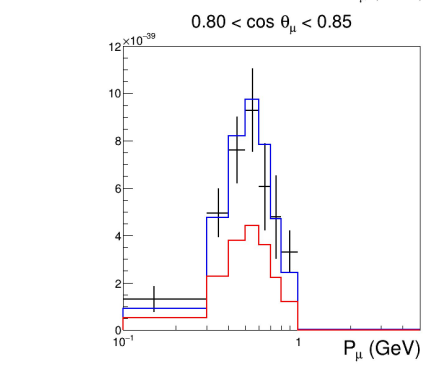
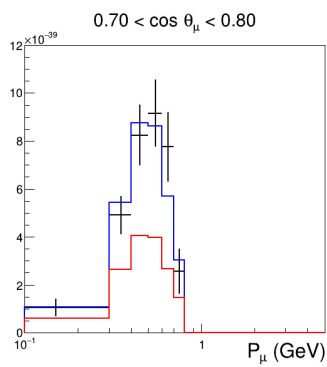
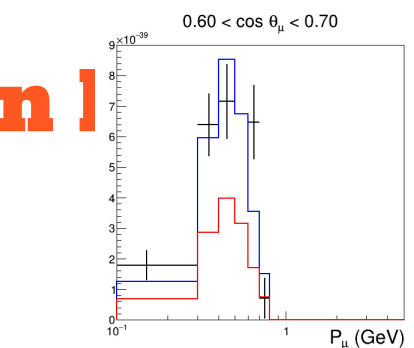
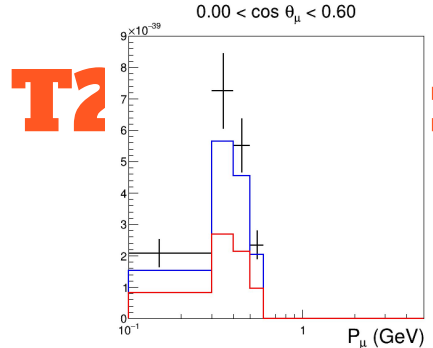
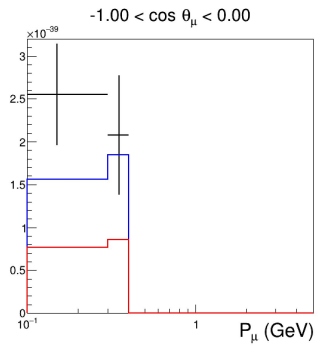
→ General weak correlations indicate weak constraints from the data

→ Strong anti-correlations between parameters that can significantly alter the normalization

Fitting T2K lepton kinematics data

- Not as directly sensitive to nuclear effects as STV data, but has more statistics and bins

T2 n1 tics data



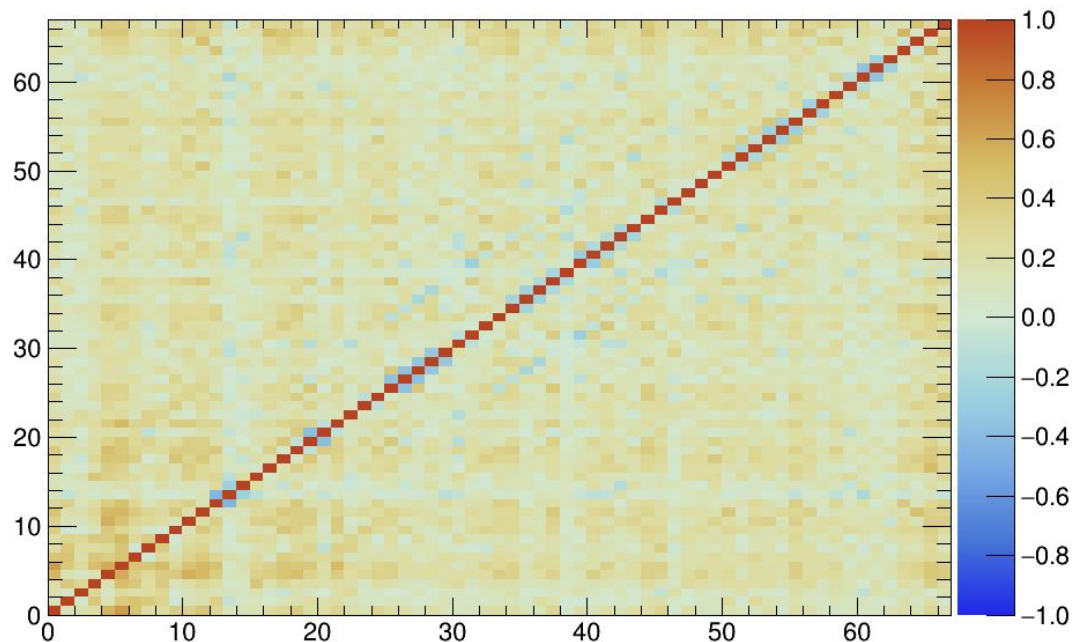
+ data
 — pre-fit 228.2410 / 67
 — best fit 73.4021 / 67

The shape of the post-fit model does not match well the data: χ^2 smallest for MC with low normalization

→ Peelle's Pertinent Puzzle (PPP)

Fitting T2K lepton kinematics data

Data correlation matrix



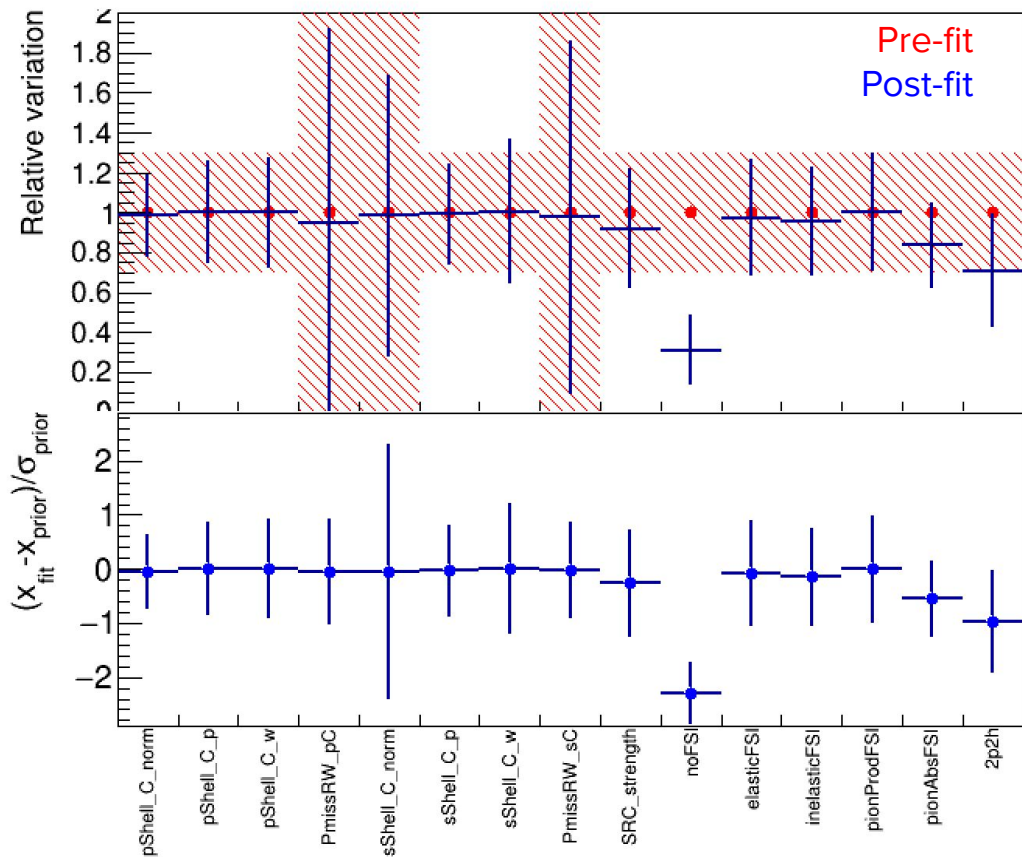
PPP problem:

Due to strong correlations between the bins (coming mainly from flux systematics)

→ One way to avoid this is performing “shape-only” fits

Fitting T2K lepton kinematics data

Pre-fit vs. post-fit parameters

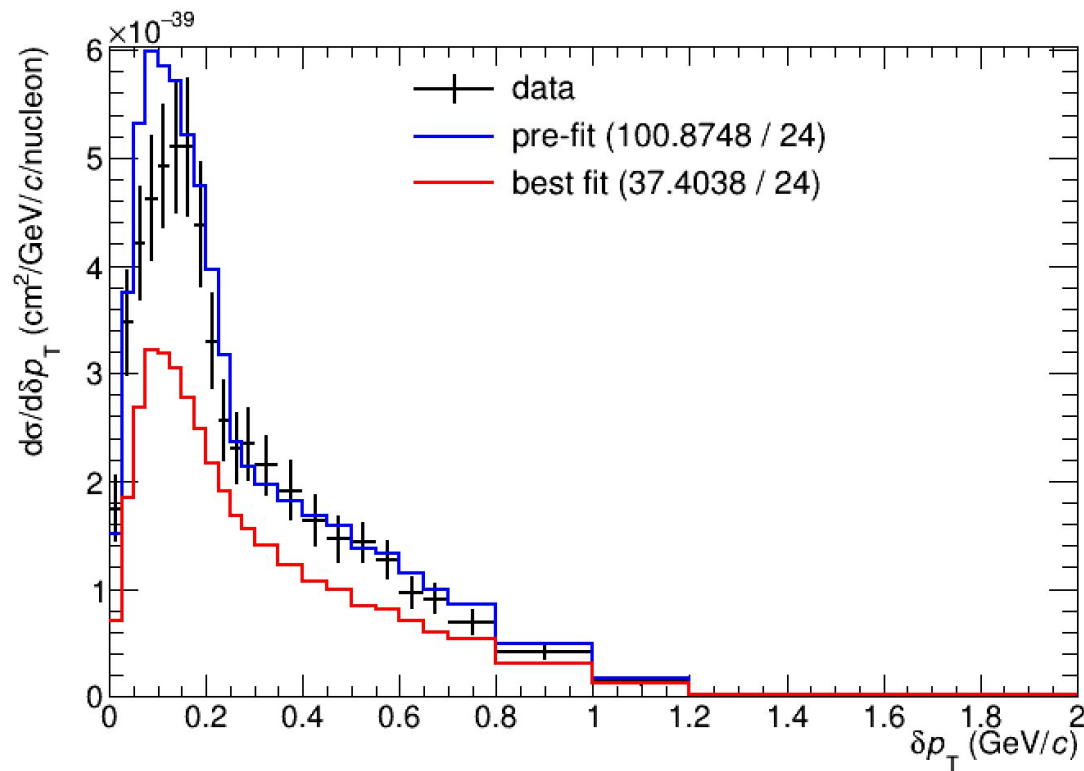


Limitation of our FSI dials:

Very large variation to the “noFSI” dial
(~420,000 events → ~160,000 events)

→ Causes significant change to the total cross section, which it shouldn't be able to

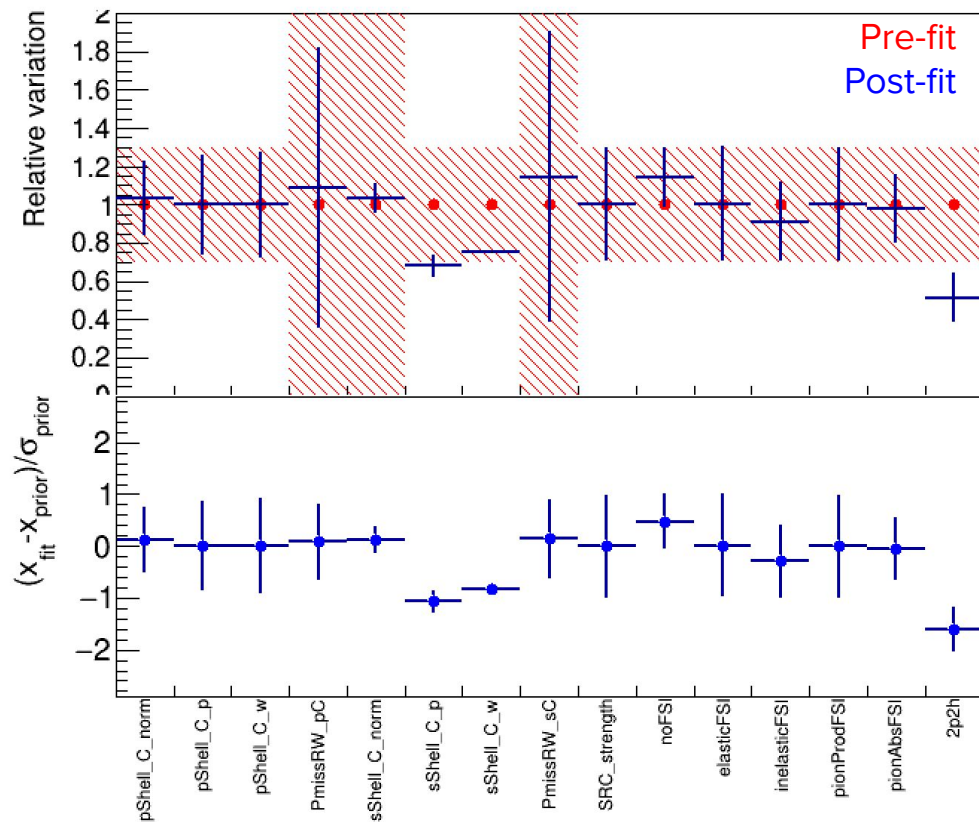
Fitting MINERvA dpt data



→ Similar issue (PPP): the post-fit model underestimates the cross section

Fitting MINERvA dpt data

Pre-fit vs. post-fit parameters



How to address the ESI dials limitation?

- Introduce *cushions* terms: choose one parameter that we don't fit, but rather modify such that the total cross section remains the same
 - Problems when using fitters with standard methods

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- Introduce *cushions* terms: choose one parameter that we don't fit, but rather modify such that the total cross section remains the same
 - Problems when using fitters with standard methods
- Introduce a penalty term in the χ^2 of the fit: penalises large variations of the cross section

$$\chi_{pen}^2 = p \left(\frac{\sigma_{reweighed} - \sigma_{pre-fit}}{\sigma_{pre-fit}} \right)^2$$

Summary and next steps

Summary and next steps

- The new dials allow to parameterize systematic uncertainties on the missing energy and the missing momentum in the SF model as well as on FSI processes in order to fit neutrino data
- The encountered PPP problem can be mitigated by shape-only fits
- When fitting FSI dials, they cause significant alterations to the total cross section. This could be fixed by introducing a penalty terms accordingly
- A more precise definition of the prior uncertainties on the dials from electron scattering data