Constraining Pion Secondary Interaction Systematics Uncertainties at T2K Using T2K Near Detector Data

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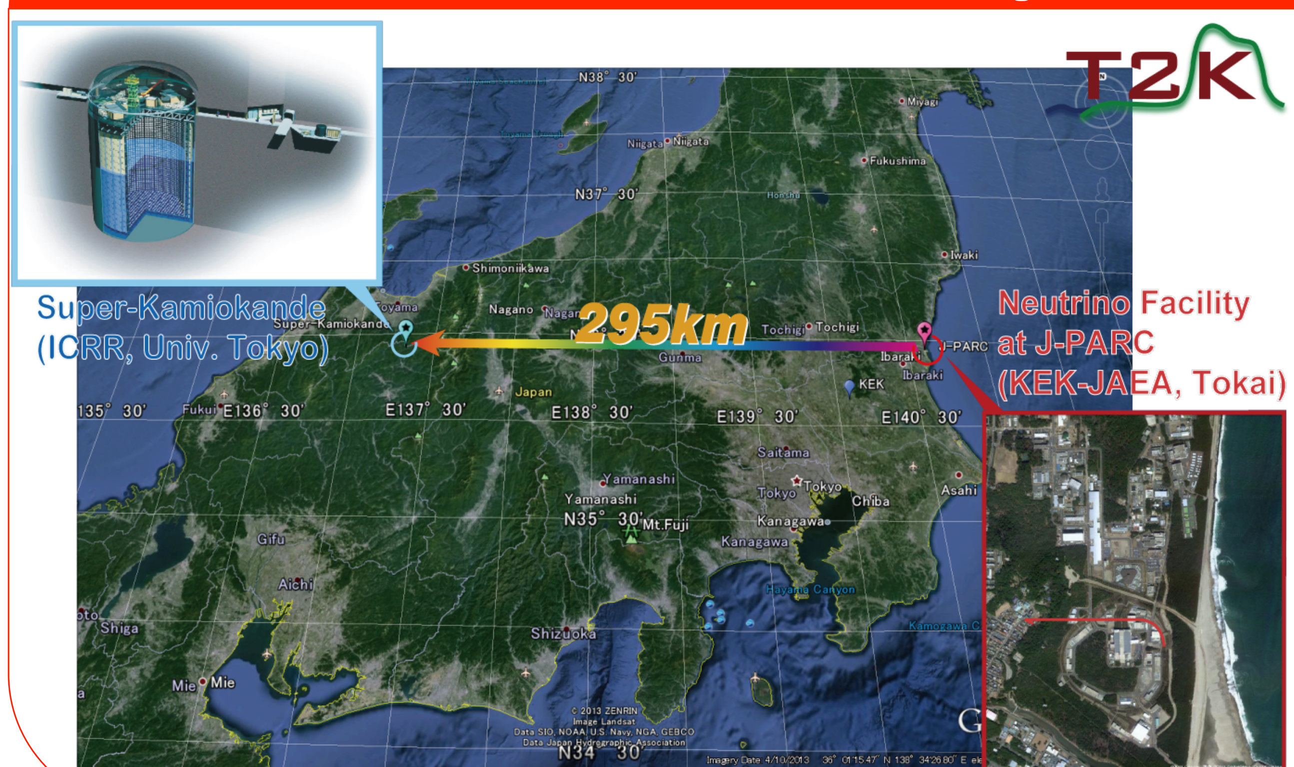
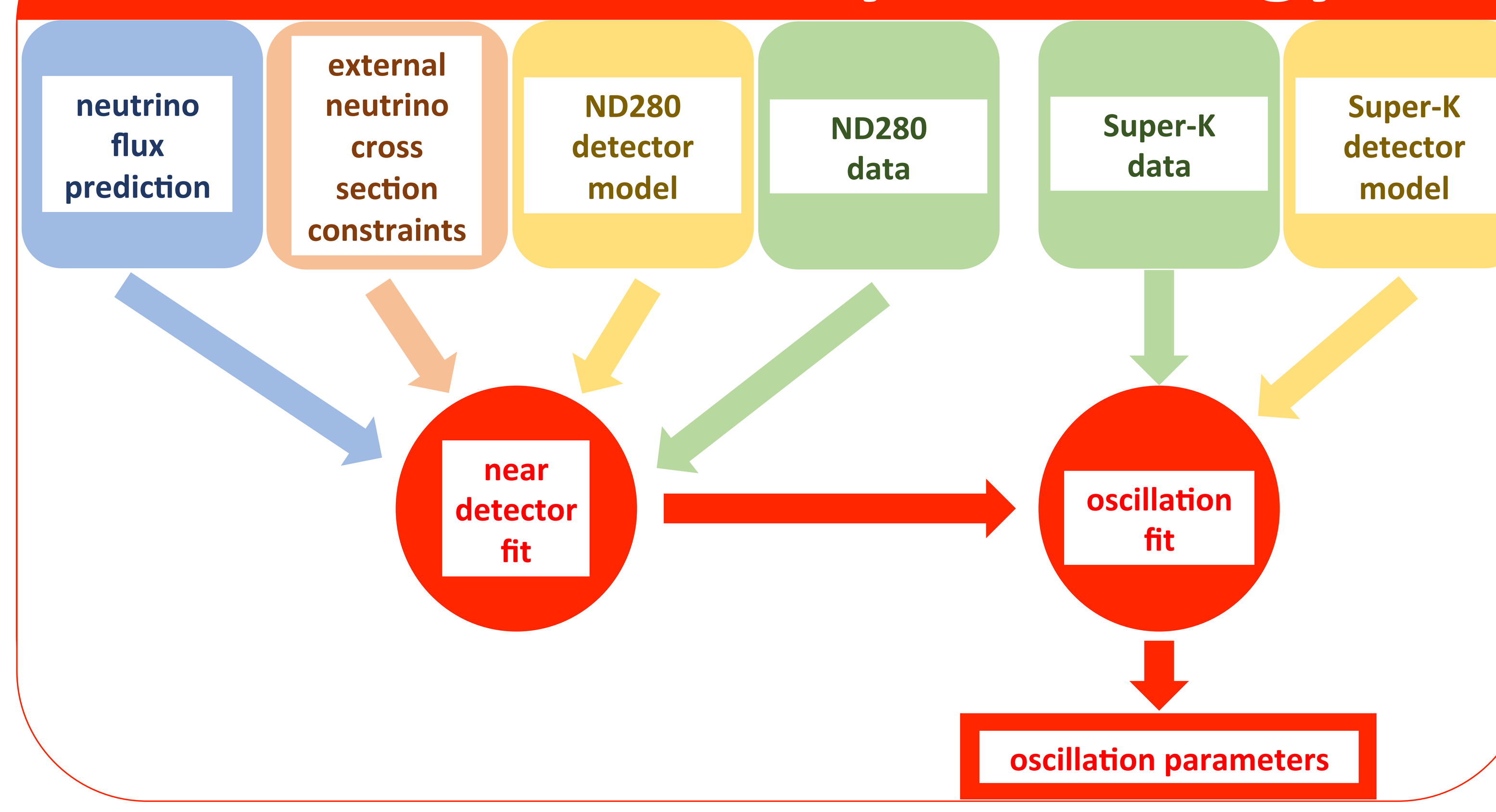
NuINT 2017
June 23-29, 2017
Toronto, Canada

The T2K Experiment[1][2]

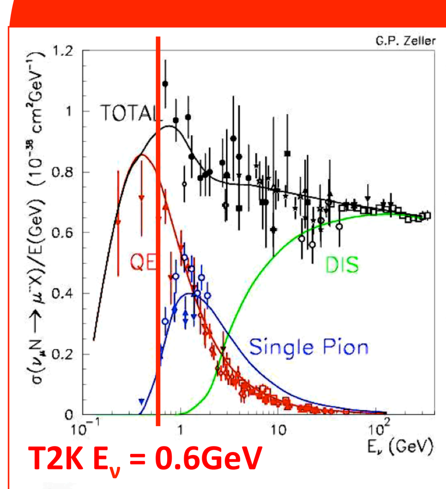


- The Tokai-to-Kamioka experiment (T2K) uses neutrino (antineutrino) beam produced by the collision between J-PARC's 30 GeV proton beam and a graphite target
- Near-far detector method to determine neutrino oscillation parameters
- Detectors placed at 2.5 degrees off-axis measuring neutrino beam peaked at 0.6 GeV

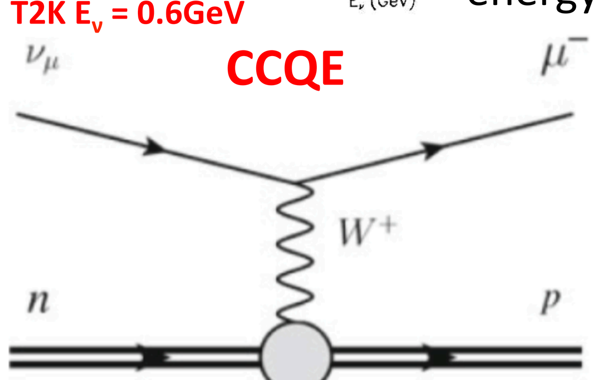
Oscillation Analysis Strategy



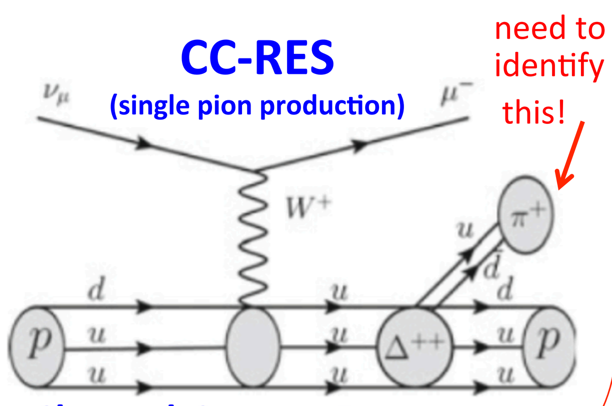
Neutrino Interactions



- CCQE and CC-RES are the dominant neutrino interaction modes for T2K
- CCQE: signal channel for neutrino detection
- CC-RES misidentified as CCQE: wrong neutrino event rate and reconstructed energy

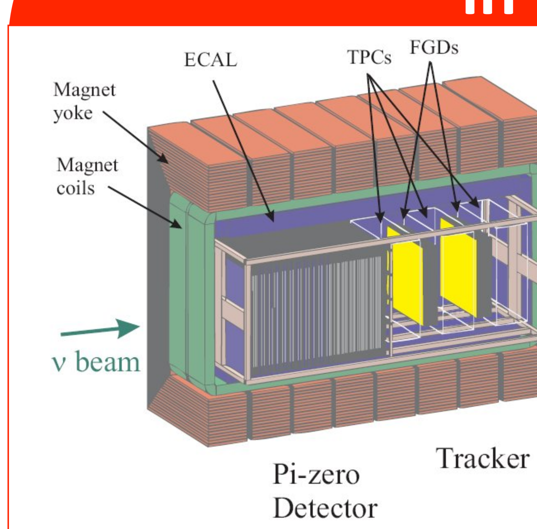


Charged-Current Quasi-Elastic

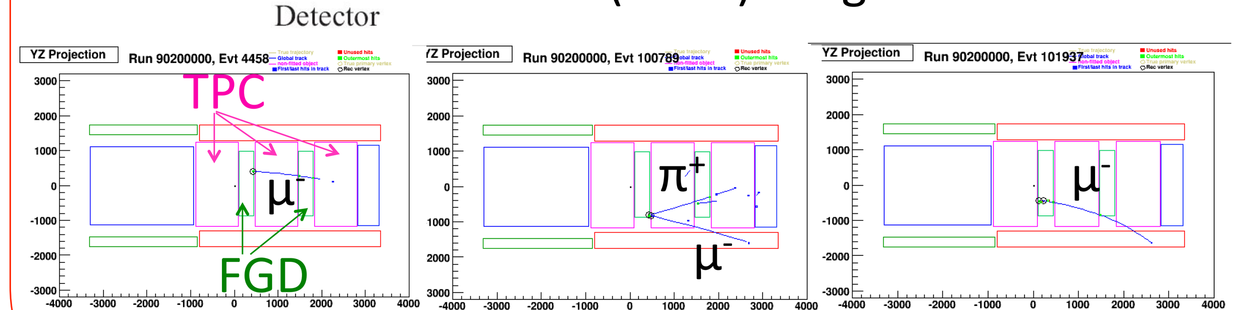


Charged-Current-Resonant-Pion-Production

Neutrino Interactions in ND280[1]



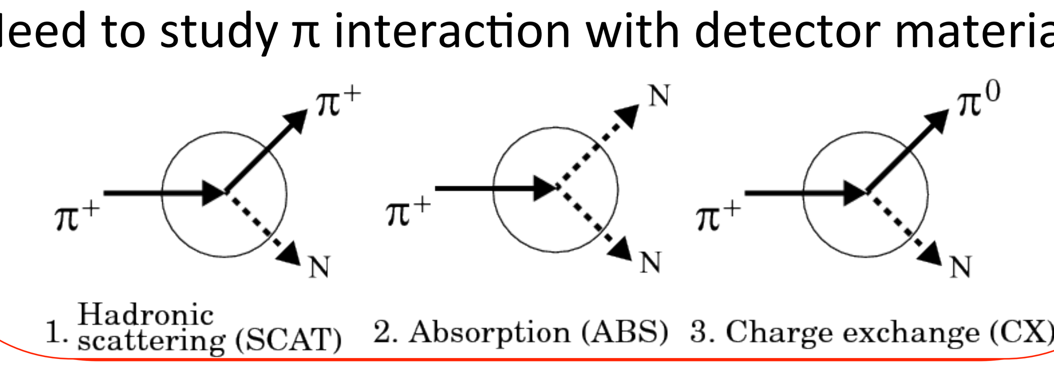
- Near detector (ND280) measures neutrino cross section & energy spectrum
- 3 time projection chambers (TPCs): dE/dx & track charge
- 2 fine-grained detectors (FGDs): target mass



CCQE | CC-RES | CCQE or CC-RES ?

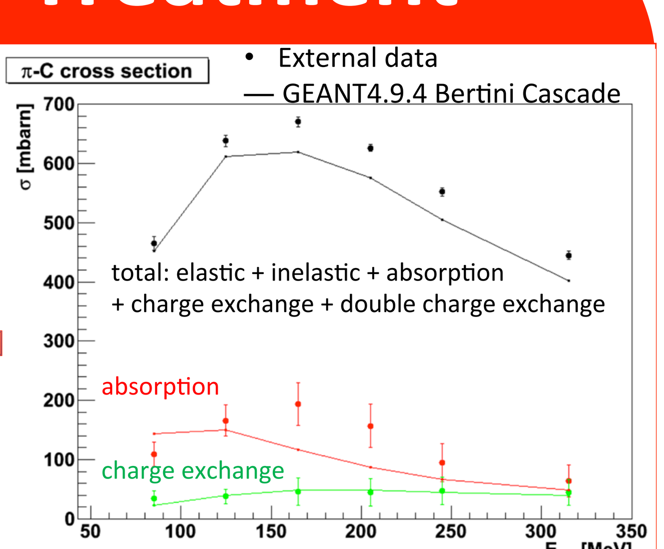
Pion Secondary Interactions

- Pion secondary interactions (SI): pion from neutrino interactions interacts with the detector materials
- Inelastic scattering: changes the pion kinematics
- Absorption or charge exchange: pion not detected
- Recall at T2K neutrino energy
  - 60% CCQE and 15% CC-RES events
  - Cannot ignore the CC-RES topology
- Need to study π interaction with detector materials



T2K Pion SI Treatment[3]

Systematic error	Normalization error (%)	Shape error (%)
TPC momentum scale	0.1	0.2–5.9
TPC momentum resolution	0.2	0.0–2.0
External background	1.3	0.4–8.9
Track reconstruction	0.6	0.7–2.1
TPC PID	0.02	0.0–0.7
Michel tagging	0.6	0.3–1.6
Sand interations	0.1	0.0–1.1
Pileup	0.4	0.3–1.6
Pion rescattering	1.4	0.5–4.7
Fiducial volume target mass	0.6	0.6



- Pion SI: largest systematics uncertainties for T2K
- Limited external data sets available
- GEANT 4 Monte Carlo does not describe external data sets well
- The near detector Monte Carlo (MC) is tuned by applying a weight for each pion SI

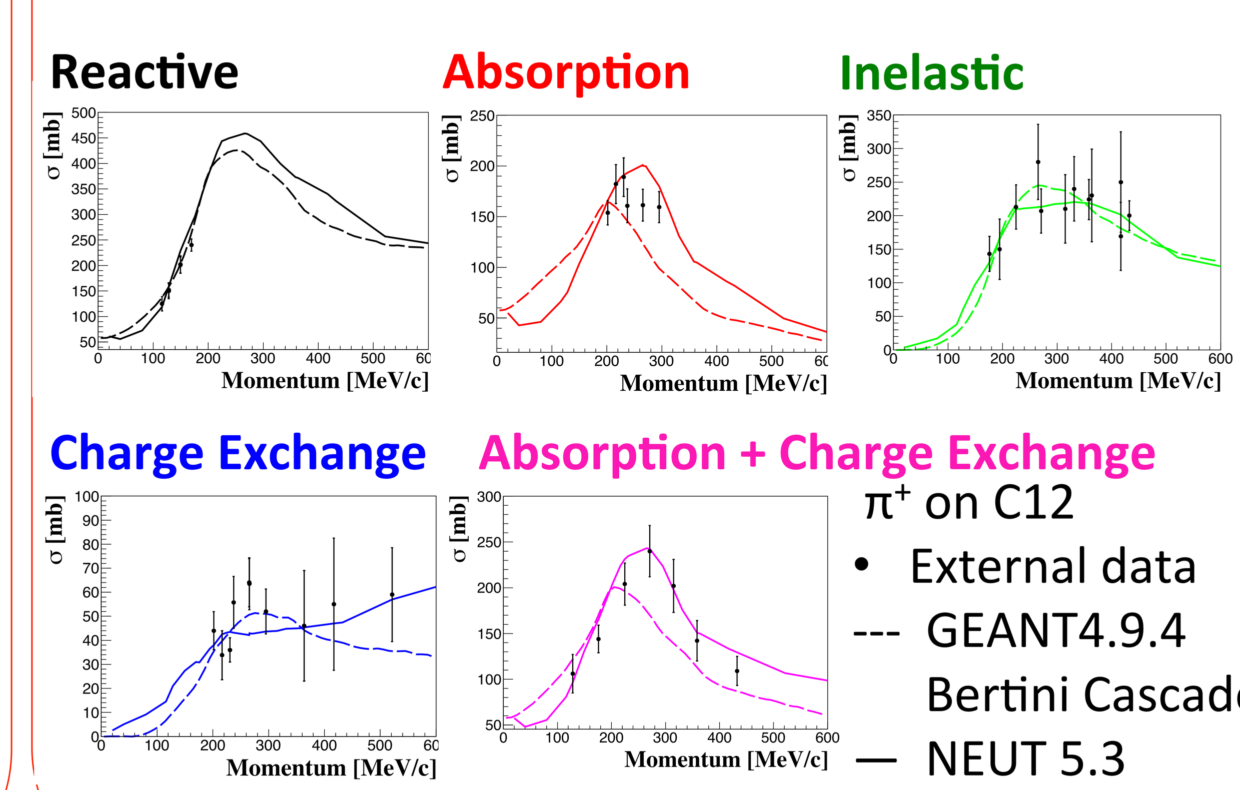
$$\mathrm{weight}(E^{\pi}_{kin}) = \frac{\text{external data}}{\text{MC GEANT4}}$$

Pion SI Improvements

- Use NEUT instead of GEANT4 for pion interactions modeling at the near detector
  - NEUT is T2K's neutrino event generator
- Using near detector data to further constrain the pion SI model
  - Lots of pions produced in the near detector
  - Select pions samples that enter the FGDs and study their interactions
    - Pion kinematics reconstructed by upstream TPC

$$\mathrm{weight}(E^{\pi}_{kin}) = \frac{\text{external data}}{\text{MC GEANT4}} \xrightarrow{\text{planned changes}} \mathrm{weight}(E^{\pi}_{kin}) = \frac{\text{ND280 data}}{\text{MC NEUT}}$$

Generator Comparison

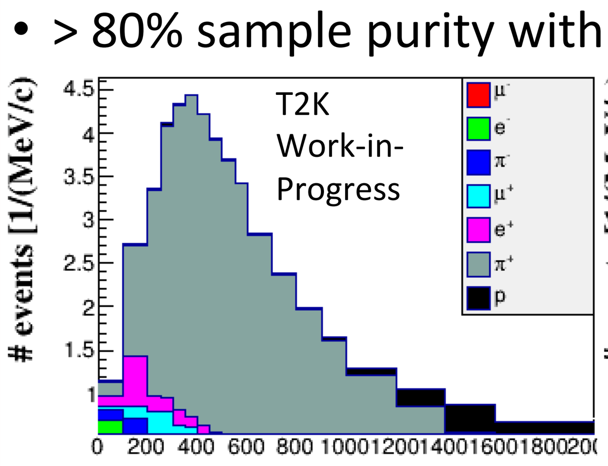


π^+ on C12
- • External data
- --- GEANT4.9.4 Bertini Cascade
- — NEUT 5.3

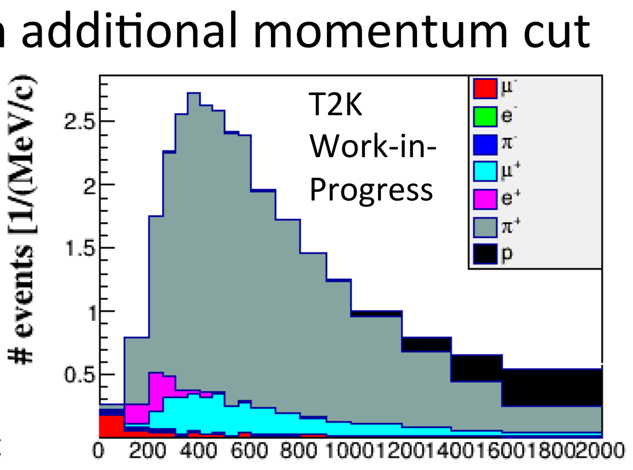
- NEUT: tuned to the external data sets

ND280 Pion Sample

- Selected 2 independent π^+ samples based on the reconstructed information
  - To study pion interactions in the near detector
- > 80% sample purity with additional momentum cut



Sample 1: TPC1 π^+ sample
- Enter FGD1 from TPC1



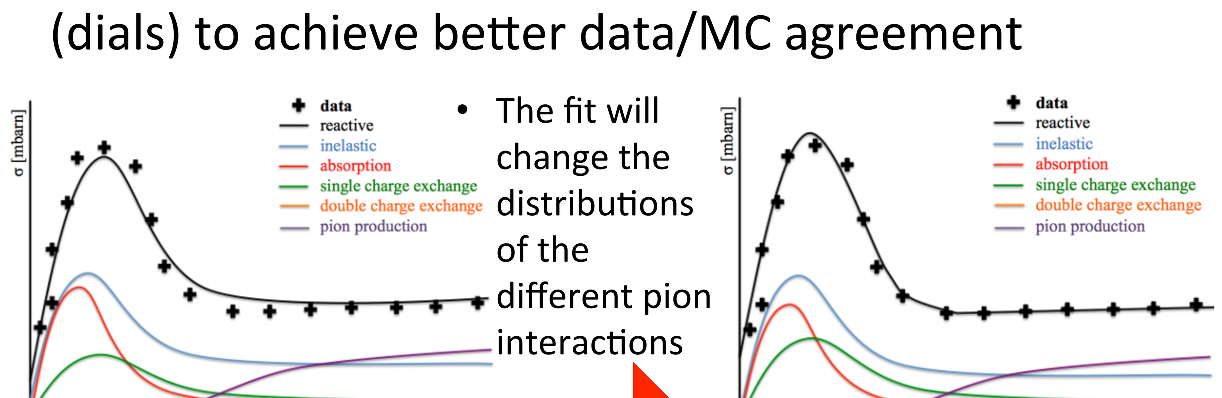
Sample 2: TPC2 π^+ sample
- Enter FGD2 from TPC2

Near Detector Fit

- Near detector fit: piecewise likelihood maximization method:

$$L_{tot}(\vec{b},\vec{x},\vec{o}) = L_{pbeam}(\vec{b}) * L_{NA61}(\vec{b}) * L_{ext-\nu}(\vec{x}) * L_{ND280}(\vec{b},\vec{x}) * L_{SK}(\vec{b},\vec{x},\vec{o})$$

- Using the available framework perform a fit to the SI parameters – the hadron-nucleon cross sections (dials) to achieve better data/MC agreement



- The fit will change the distributions of the different pion interactions

Summary

- Pion SI is the leading source of systematics uncertainties for T2K
- Improvements work-in-progress:
  - Neutrino interaction generator update
  - Inclusion of pion data from near detector
- This analysis strategy can also be used by other accelerator neutrino experiments to reduce pion SI systematics uncertainties

References

1. K. Abe et al. The T2K Experiment. Nucl. Instrum. Meth., A659:106–135, 2011
2. K. Abe et al. Precise Measurement of the Neutrino Mixing Parameter theta23 from Muon Neutrino Disappearance in an Off-axis Beam. http://arxiv.org/abs/1403.1532, 2014
3. K. Abe et al. Measurement of the ν_μ CCQE cross section with ND280 at T2K. Phys. Rev. D, 92:112003, 2015