GENIE global fits of neutrino scattering data

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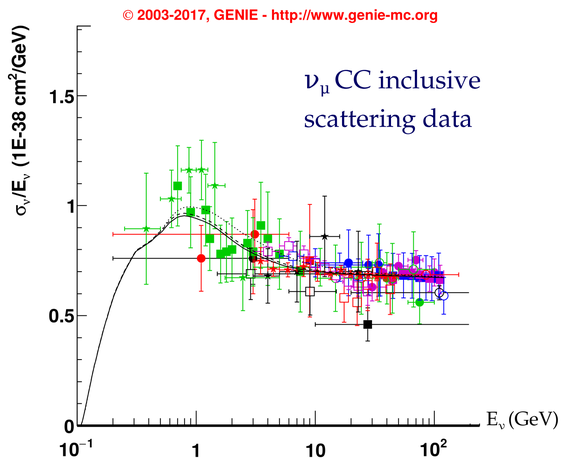
Introduction

The understanding (and improved modeling) of the neutrino interactions is crucial for precision measurements in the neutrino sector, such as high precision future experiments like DUNE.

The GENIE collaboration has developed a framework for global fits of neutrino (and anti-neutrino) scattering data. The fitting framework can accommodate any combination of observables and datasets, while properly handling possible correlations. The machinery is based on the Professor software suite which is actively used for general purpose MC tuning at the LHC.

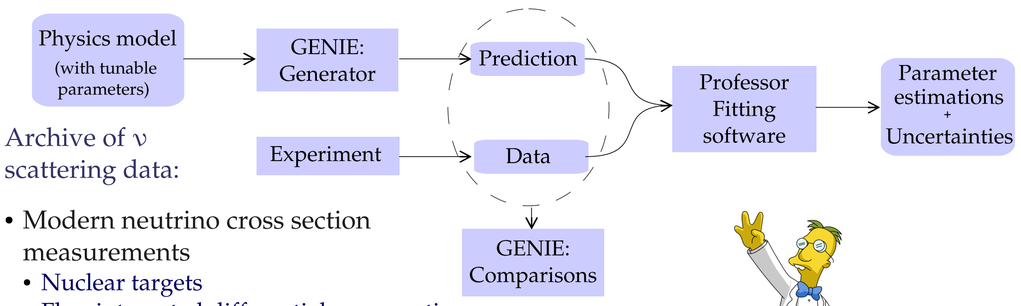
GENIE

GENIE simulates neutrino events using predictions constructed from theoretical models which incorporate the dominant scattering mechanisms from several MeV to several hundred GeV.
Emphasis is given to the few-GeV energy range since this is the challenging boundary between the non-perturbative and perturbative regimes which is relevant for the current and near future long-baseline neutrino experiments.



www.genie-mc.org

GENIE fitting framework



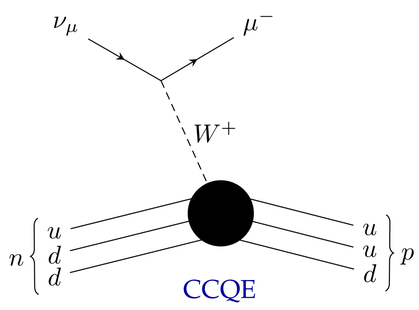
Archive of ν scattering data:

- Modern neutrino cross section measurements
  - Nuclear targets
  - Flux-integrated differential cross-sections
  - MiniBooNE, T2K, MINERvA
- Historical neutrino cross section measurements
  - Bubble chamber experiments
- Neutrino-induced hadronic system characteristics
- Hadron-nucleon and hadron-nucleus event characteristics
- Semi-inclusive electron scattering data
- World data on F2 and xF3

http://professor.hepforge.org

"Fundamentally, the idea of Professor is to reduce the exponentially expensive process of brute-force tuning to a scaling closer to a power law in the number of parameters, while allowing for massive parallelisation and systematically improving the scan results by use of a deterministic parameterisation of the generator's response to changes in the steering parameters."

Quasi-elastic puzzle and MEC



CCQE

Quasi-elastic (QE) scattering is modeled using an implementation of the Llewellyn-Smith model. In this model the hadronic weak current is expressed in terms of the most general Lorentz-invariant form factors.

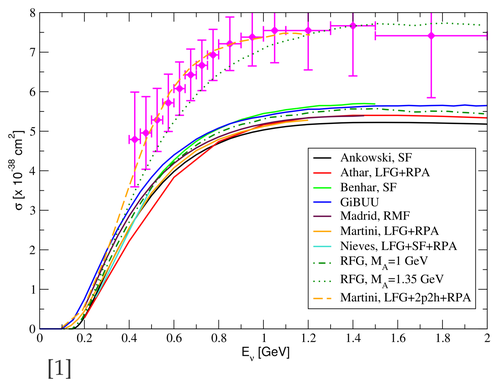
The CCQE interaction on free nucleons is well understood theoretically.
However, complications occur due to the QE puzzle:

The inability to explain nuclear data based on models built on the free-nucleon cross-section and the impulse approximation.

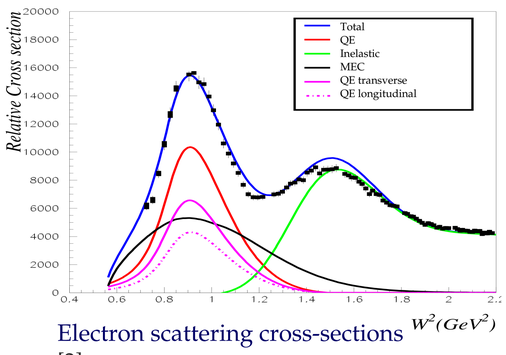
- Pions may be produced and absorbed before ever escaping the nucleus
- Multiple nucleons may be involved in the scattering (2p-2h)
- Detectors cannot observe what occurs within the nucleus

It is therefore crucial to correctly distinguish between definitions of an observed CC0π interaction, and a 'true' CCQE interaction.

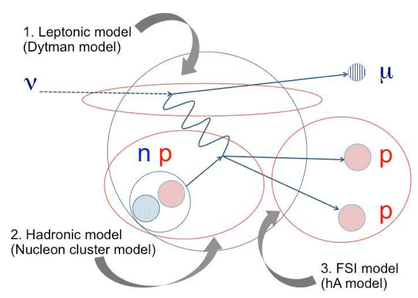
CCQE on ^{12}C



[1]



Electron scattering cross-sections [2]



MEC 2p2h [3]

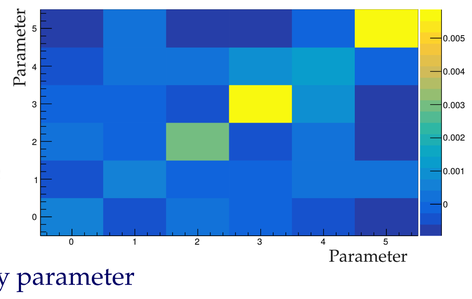
The 2-particle 2-hole effect, dominated by the Meson Exchange Current (MEC), is thought to be responsible for recent neutrino experiment's observation of an excess of electron scattering events.
MEC is also thought to explain the 'dip region' which separates the QE and Resonant scattering peaks in the electron scattering inclusive cross section distribution.
Understanding and correctly modeling MEC is a crucial issue for neutrino generators.

CC0π tuning results

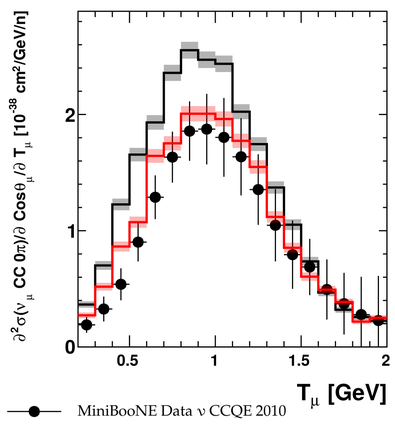
Tuned model: Default+MEC – G16_01b

- Includes Empirical MEC
- CCQE process is Llewellyn-Smith Model
- Dipole Axial Form Factor - Depending on M_A= 0.99 GeV
- Nuclear model: Fermi Gas Model - Bodek, Ritchie

Covariance between parameters



MiniBooNE opening angle slice Fit results



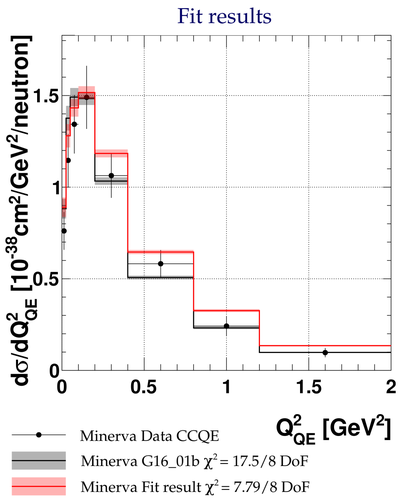
Fit results by parameter

	Parameter	Neutrino fit	Anti-neutrino fit	Global fit	Nominal value
0)	M_A (GeV/c^2)	1.17 ± 0.02	1.26 ± 0.03	1.21 ± 0.02	0.99
1)	QEL-CC-XSecScale	0.93 ± 0.01	0.97 ± 0.02	0.95 ± 0.02	1
2)	RES-CC-XSecScale	0.86 ± 0.05	0.98 ± 0.09	1.02 ± 0.05	1
3)	MEC-FracCCQE	0.85 ± 0.03	0.7 ± 0.1	0.53 ± 0.08	0.45
4)	FSI-PionMFP-Scale	0.87 ± 0.02	1.39 ± 0.03	0.75 ± 0.04	1
5)	FSI-PionAbs-Scale	1.51 ± 0.03	0.7 ± 0.1	0.87 ± 0.07	1

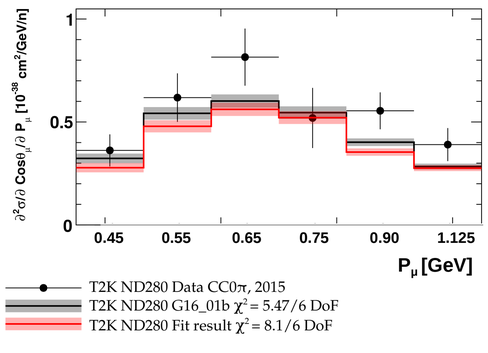
Fit results by experiment

Fit Results	Neutrino fit	Anti-neutrino fit	Global fit	Nominal Values
Miniboone ν_μ χ^2	152 / 137	171 / 137	138 / 137	441 / 137
MiniBooNE $\bar{\nu}_\mu$ χ^2	60 / 78	32.4 / 78	36.2 / 78	50.4 / 78
T2K χ^2	237 / 67	276 / 67	252 / 67	135 / 67
MINERvA ν_μ χ^2	6.11 / 8	8.07 / 8	7.79 / 8	17.5 / 8
MINERvA $\bar{\nu}_\mu$ χ^2	8.19 / 8	11.5 / 8	5.7 / 8	6.23 / 8
Global dataset χ^2	463 / 292	499 / 292	440 / 292	650 / 298

Minerva momentum transfer Fit results



T2K ND280 opening angle slice, Fit results



Conclusions

The global fit resulted in a drastic improvement to the model agreement with data and the nominal parameter values, though there still exist tensions in some of the individual experimental outcomes, like T2K.

Neutrino interaction uncertainties will be one of the dominant systematics for DUNE and this work could improve the understanding of one of the major ingredients for the CP violation search.

[1] L. Alvarez-Ruso, arXiv:1012.3871 [neutrino 2010]
[2] A. Bodek, et. al. arXiv:1106.0340 [hep-ph]
[3] T. Katori, arXiv:1304.6014 [nucl-th]