GENIE Tuning and Cross-Section Model for DUNE

Status report

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Genie Systematics

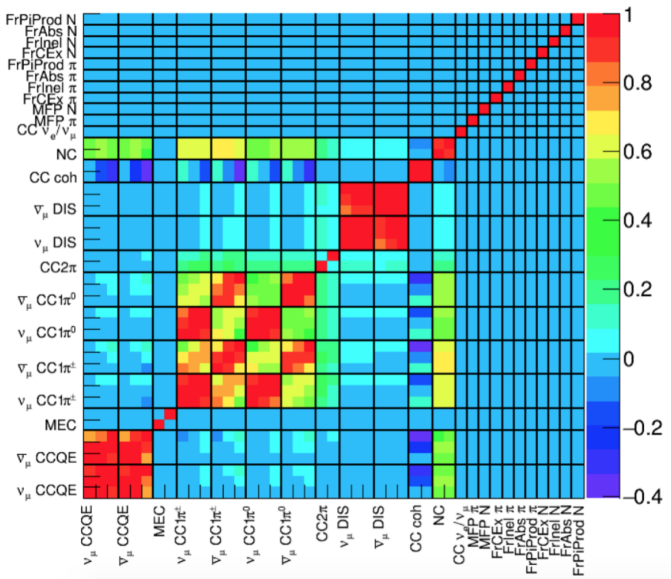
- Strong connection between GENIE and DUNE
  - cross-section model development / tuning and systematic error evaluation
  - ND and LBL analyses - VALOR in particular
- effort to characterise *prior* neutrino-interaction systematic uncertainties

Neutrino cross-section systematics:

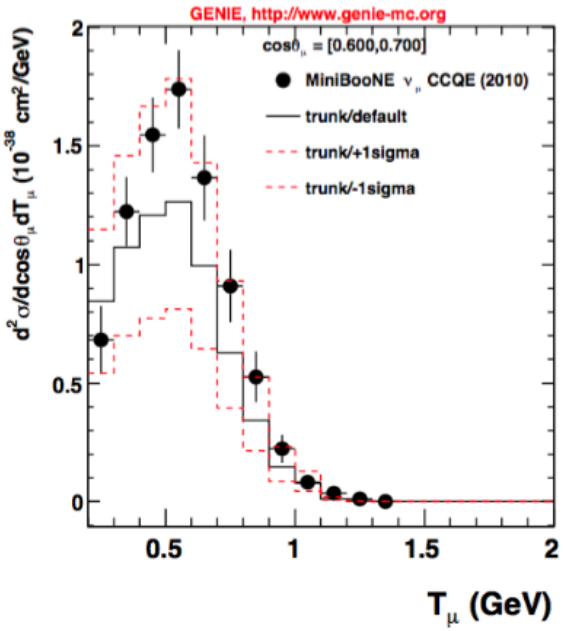
- 6 Q^2-dependent systematics for ν and $\bar{\nu}$ CC QE,
- 2 systematics for ν and $\bar{\nu}$ CC MEC,
- 6 Q^2-dependent systematics for ν and $\bar{\nu}$ CC $1\pi^{\pm}$,
- 6 Q^2-dependent systematics for ν and $\bar{\nu}$ CC $1\pi^0$,
- 2 systematics for ν and $\bar{\nu}$ CC 2π
- 6 energy-dependent systematics for ν and $\bar{\nu}$ CC DIS ($> 2\pi$)
- 2 systematics for ν and $\bar{\nu}$ CC coherent production of pions,
- 2 overall systematics for ν and $\bar{\nu}$ NC, and
- 1 ν_e/ν_μ cross-section ratio systematic.

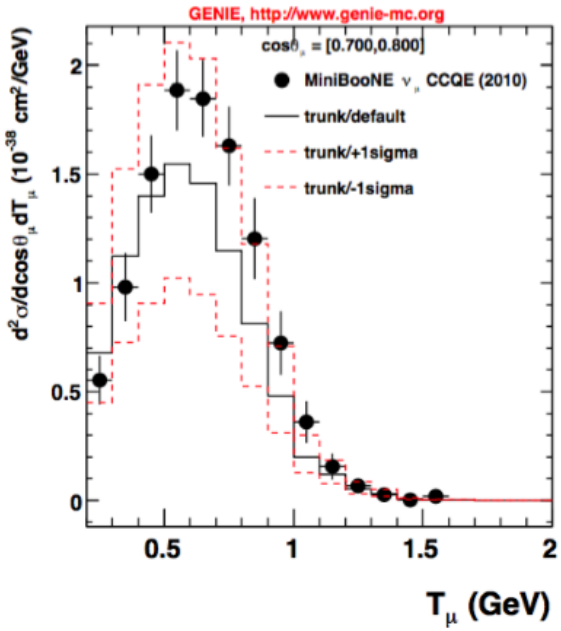
Hadronic re-interaction (FSI) systematics:

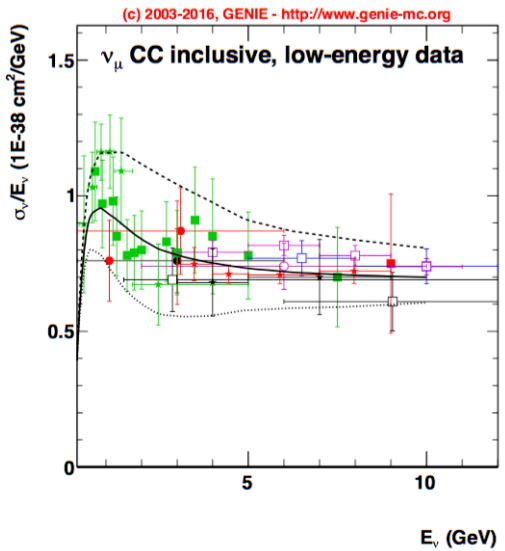
- 2 systematics on the overall re-interaction rate for pions and nucleons, and
- 8 systematics on the relative strength of different rescattering mechanisms (chg. exch., inelastic, absorption, pion production) for pions and nucleons.



Cross Section systematics







- Sytematics defined according to conservative approaches
- This large systematcs not fitted on xsec data
- Room for improvements in generators

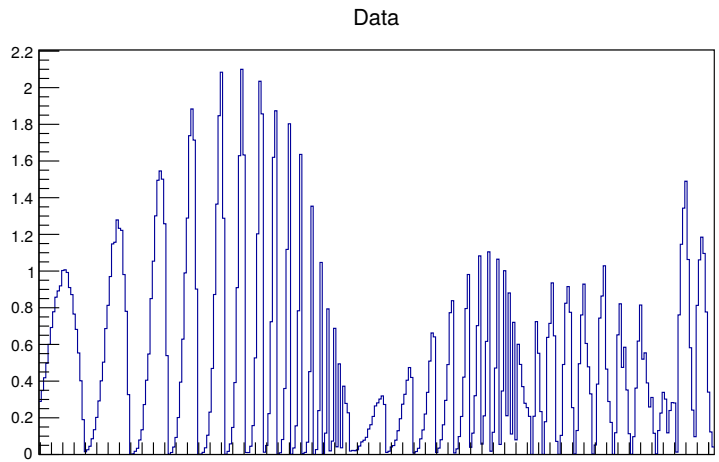
⇒ Data driven constraints

Genie Tuning

- new comprehensive configurations
  - better physics models
- machinery for a global fits
  - Using set of data/MC comparisons from GENIE validation tools
  - Professor tool used for general purpose MC tuning at the LHC
- Goal is a new generation of prior uncertainties used in the VALOR analysis
  - coming directly from the GENIE global fit
- right now we are working on the CC 0π tune

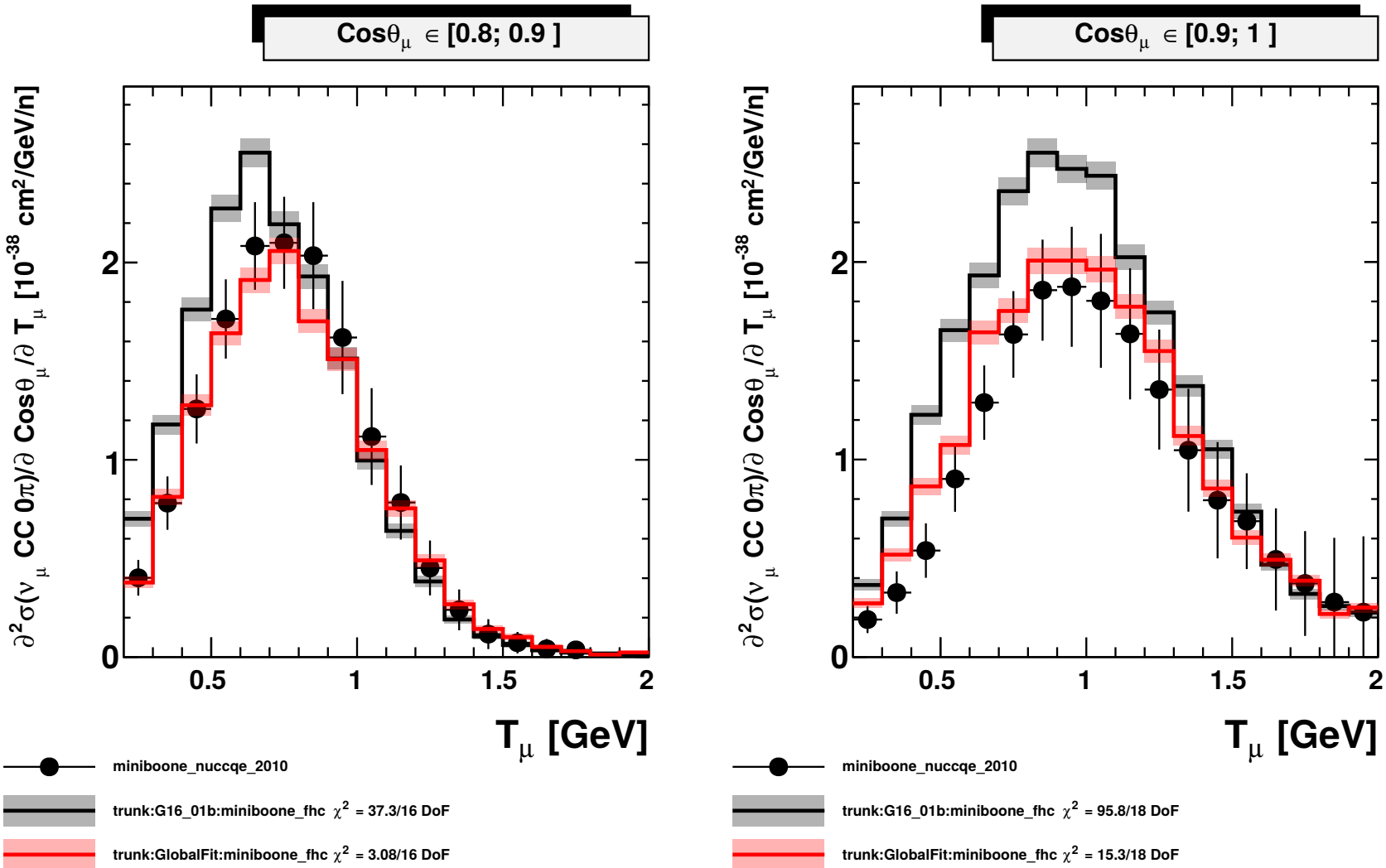
Tuning Example - CC 0π

- Input - 298 points
  - MiniBooNE
  - T2K
  - MINERvA
  - Correlations
  - Priors on parameters
  - ...
- Outputs
  - Parameters best fit
  - Prediction covariance
    - due to the propagation of the param. covariance
    - Tool to propagate systematics parameters
  - More details about the fit in backup slides



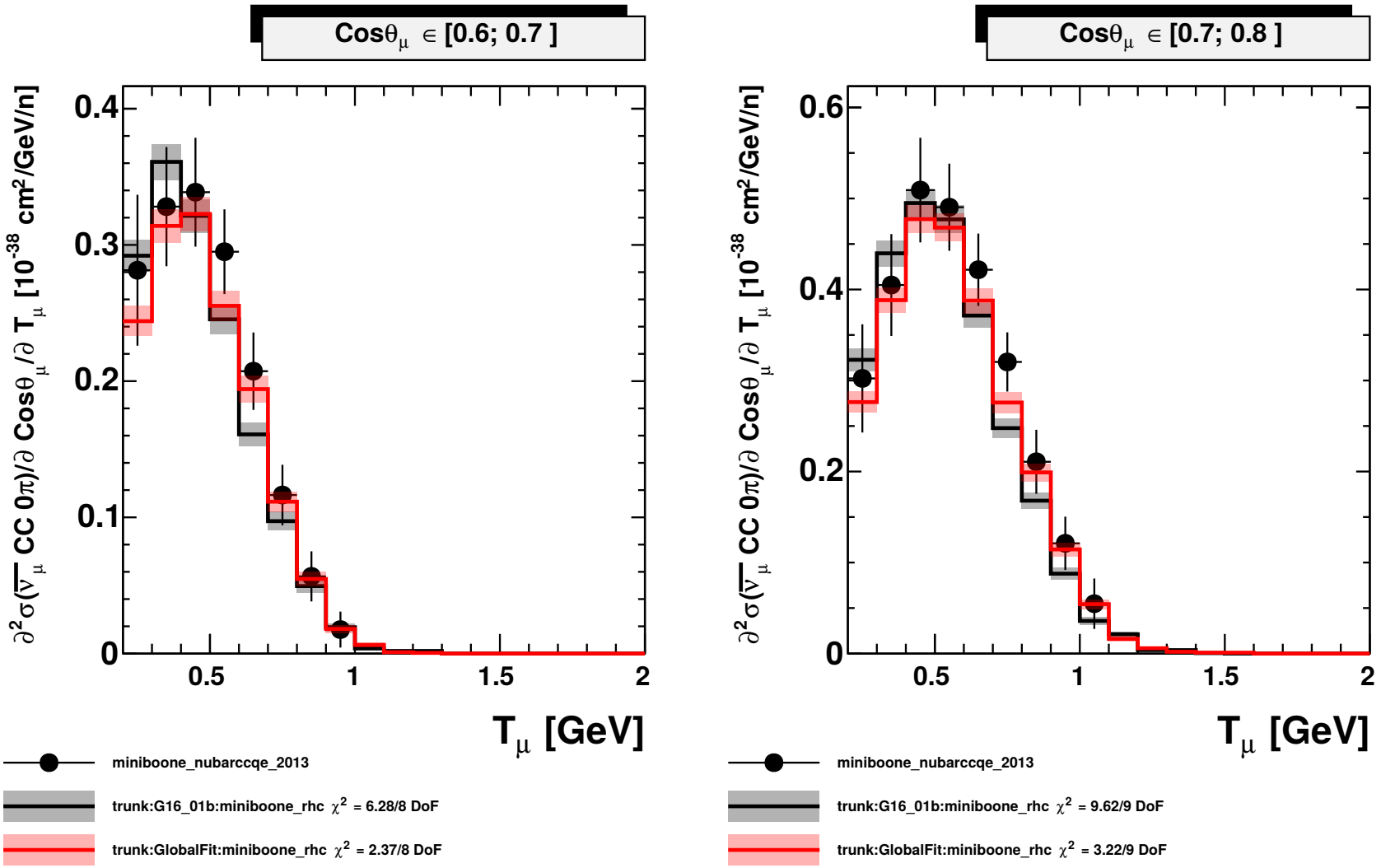
Parameter	Best fit	Nominal
M_A (GeV/c^2)	1.21 ± 0.02	0.99
QEL-CC-XSecScale	0.95 ± 0.02	1
RES-CC-XSecScale	1.02 ± 0.05	1
MEC-FracCCQE	0.53 ± 0.08	0.45
FSI-PionMFP-Scale	0.75 ± 0.04	1
FSI-PionAbs-Scale	0.87 ± 0.07	1

Best fit - MiniBooNE ν_μ CCQE



Fit has a big impact

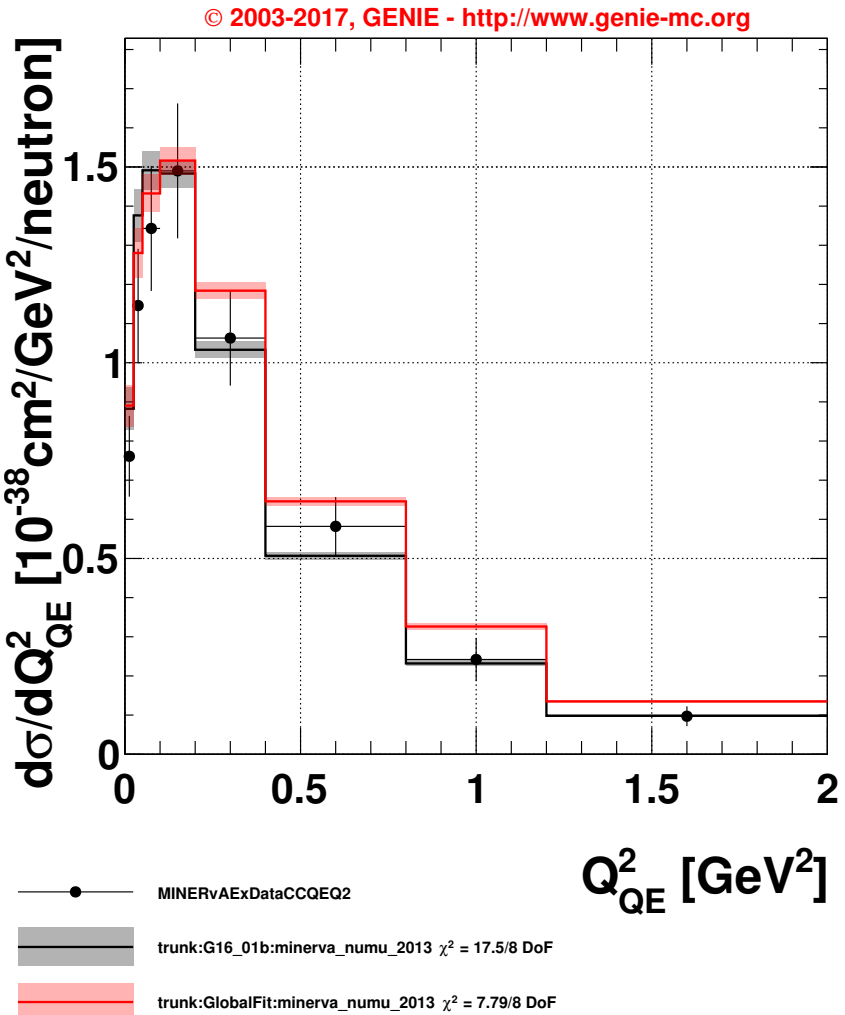
Best fit - MiniBooNE $\bar{\nu}_\mu$ CCQE



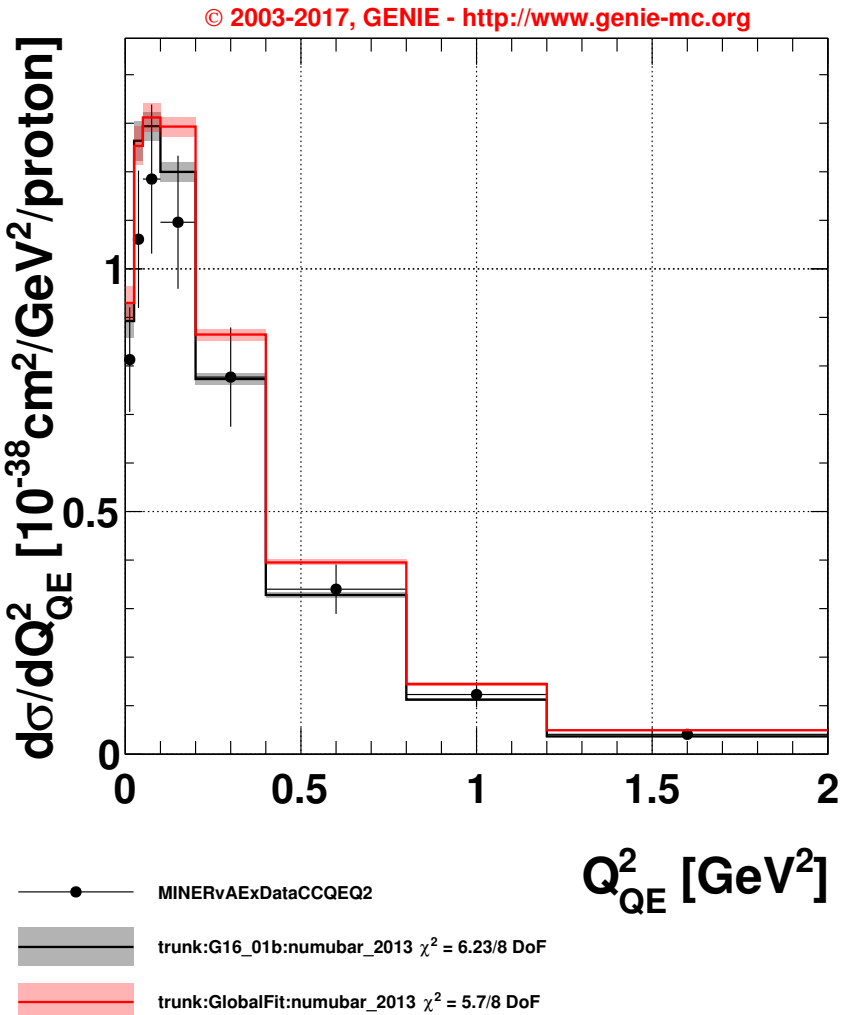
Improvement not really necessary in this case

Best fit - MINERvA

Neutrinos



Antineutrinos



⇒ "Eye evaluation" would prefer default model

Conclusion

- Major effort in quantitative characterisation of new GENIE comprehensive models
- First GENIE global fit of CC 0π tuning nearly complete
  - publication in late summer / early autumn
- Work on CC 1π tuning and hadronization will follow
- Close connection with VALOR:
  - new priors for the joint ND+FD analysis
  - well-motivated physics scenarios and fake datasets for studying the effects of model dependence

Backup slides

Sheer results

Parameter	Best fit	Nominal
M_A (GeV/c^2)	1.21 ± 0.02	0.99
QEL-CC-XSecScale	0.95 ± 0.02	1
RES-CC-XSecScale	1.02 ± 0.05	1
MEC-FracCCQE	0.53 ± 0.08	0.45
FSI-PionMFP-Scale	0.75 ± 0.04	1
FSI-PionAbs-Scale	0.87 ± 0.07	1

- M_A is reasonably low
- Scaling factors for single processes are compatible with nominal values
- You can find the complete comparisons plots in the indico page

Single datasets

Datasets were fitted separately

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

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

- M_A and cross section scale factors are in good agreement
- FSI parameters are not
- The agreement with data is reasonable
  - Better than original model

Single datasets - MiniBooNE

Parameter	Miniboone ν_μ fit	MiniBooNE $\bar{\nu}_\mu$	MiniBooNE Global fit
M_A (GeV/c^2)	1.10 ± 0.03	1.25 ± 0.03	1.17 ± 0.02
QEL-CC-XSecScale	1.12 ± 0.02	0.99 ± 0.03	1.05 ± 0.02
RES-CC-XSecScale	0.69 ± 0.06	0.9 ± 0.1	0.68 ± 0.06
MEC-FracCCQE	0.43 ± 0.07	0.63 ± 0.03	0.33 ± 0.08
FSI-PionMFP-Scale	0.95 ± 0.03	1.39 ± 0.04	0.99 ± 0.06
FSI-PionAbs-Scale	1.17 ± 0.07	0.8 ± 0.2	1.08 ± 0.09

Fit Results	Miniboone ν_μ fit	MiniBooNE $\bar{\nu}_\mu$ fit	MiniBooNE Global fitGlobal χ^2
Miniboone ν_μ χ^2	121 / 131	153 / 137	124 / 137
MiniBooNE $\bar{\nu}_\mu$ χ^2	60.4 / 78	29 / 72	40.3 / 78
T2K χ^2	298 / 67	279 / 67	271 / 67
MINERvA ν_μ χ^2	11.4 / 8	10.6 / 8	9.17 / 8
MINERvA $\bar{\nu}_\mu$ χ^2	16.3 / 8	11.7 / 8	10.4 / 8
Global dataset χ^2	507 / 292	483 / 292	455 / 292

Single datasets - T2K ND280 ν_μ 0π

Parameter	T2K fit	T2K fit - no corr	T2K fit with priors
M_A (GeV/c^2)	0.75 ± 0.04	1.03 ± 0.13	
QEL-CC-XSecScale	0.90 ± 0.02	1.11 ± 0.04	
RES-CC-XSecScale	1.2 ± 0.1	1.500 ± 0.001	
MEC-FracCCQE	0.36 ± 0.09	0.3 ± 0.1	
FSI-PionMFP-Scale	0.81 ± 0.05	1.1 ± 0.1	
FSI-PionAbs-Scale	1.1 ± 0.1	1.54 ± 0.08	

Fit Results	T2K fit	T2K fit - no corr
Miniboone ν_μ χ^2	1023 / 137	/ 137
MiniBooNE $\bar{\nu}_\mu$ χ^2	367 / 78	/ 72
T2K χ^2	127 / 61	/ 61
MINERvA ν_μ χ^2	26.1 / 8	/ 8
MINERvA $\bar{\nu}_\mu$ χ^2	23.5 / 8	/ 8
Global dataset χ^2	1567 / 292	/ 292

Single datasets - MINERvA

Parameter	MINERvA ν_μ fit	MINERvA $\bar{\nu}_\mu$	MINERvA Global fit
M_A (GeV/c^2)	1.16 ± 0.10	1.2 ± 0.1	1.20 ± 0.08
QEL-CC-XSecScale	0.81 ± 0.04	0.83 ± 0.03	0.84 ± 0.04
RES-CC-XSecScale	1.2 ± 0.2	0.7 ± 0.3	1.1 ± 0.1
MEC-FracCCQE	0.7 ± 0.2	0.07 ± 0.08	0.6 ± 0.1
FSI-PionMFP-Scale	1.3 ± 0.1	0.9 ± 0.3	1.2 ± 0.2
FSI-PionAbs-Scale	0.8 ± 0.2	1.2 ± 0.3	0.8 ± 0.3

Fit Results	MINERvA ν_μ fit	MINERvA $\bar{\nu}_\mu$ fit	MINERvA Global fit
Miniboone ν_μ χ^2	/ 131	/ 137	220 / 137
MiniBooNE $\bar{\nu}_\mu$ χ^2	/ 78	/ 72	97.2 / 78
T2K χ^2	/ 67	/ 67	184 / 67
MINERvA ν_μ χ^2	/ 2	/ 8	6.49 / 8
MINERvA $\bar{\nu}_\mu$ χ^2	/ 8	/ 2	3.26 / 8
Global dataset χ^2	/ 292	/ 292	511 / 292

T2K effect on the fit

- T2K ND280 data are complicated
  - Tensions
  - Correlations $\Rightarrow$ anti-intuitive

- T2K ND280 data can not even be fitted by their own with the current model

$\Rightarrow \chi^2 = 127/61$

- T2K fit results are not compatible with other dataset

$\Rightarrow \chi^2 = 1023/137$ vs MiniBooNE ν_μ CCQE

$\Rightarrow \chi^2 = 1567/292$ vs whole fitted dataset

- global fit can suffer from this
- Effect is clear
- discrepancy in low momentum muons
  - $T_\mu < 400$ MeV

- No reason to remove this dataset from the fit
  - Their effort on the error estimation should be praised