SuSAv2 model for inelastic neutrino-nucleus scattering

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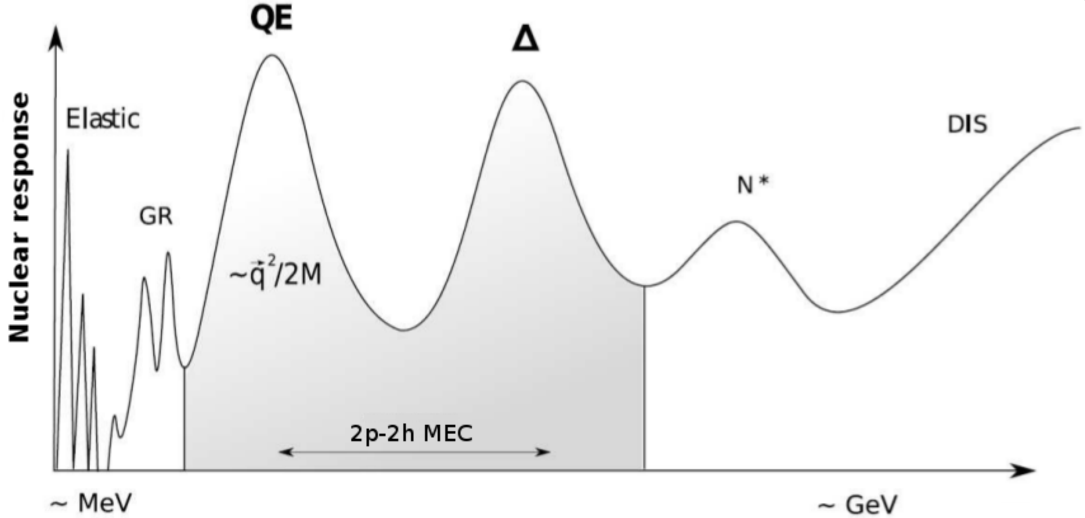
Outline

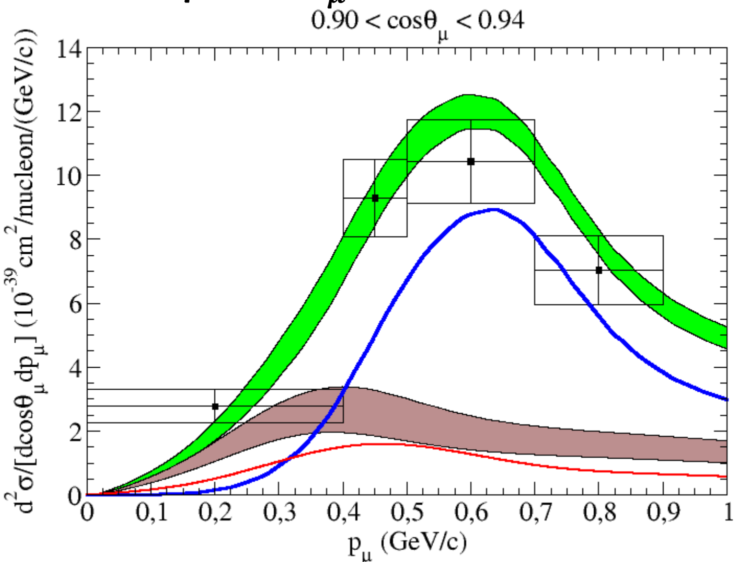
- Introduction
- Model:
  - SuSAv2-Δ
  - SuSAv2-inelastic
- Results:
  - Electron scattering
  - Neutrino scattering
- Conclusion

Introduction

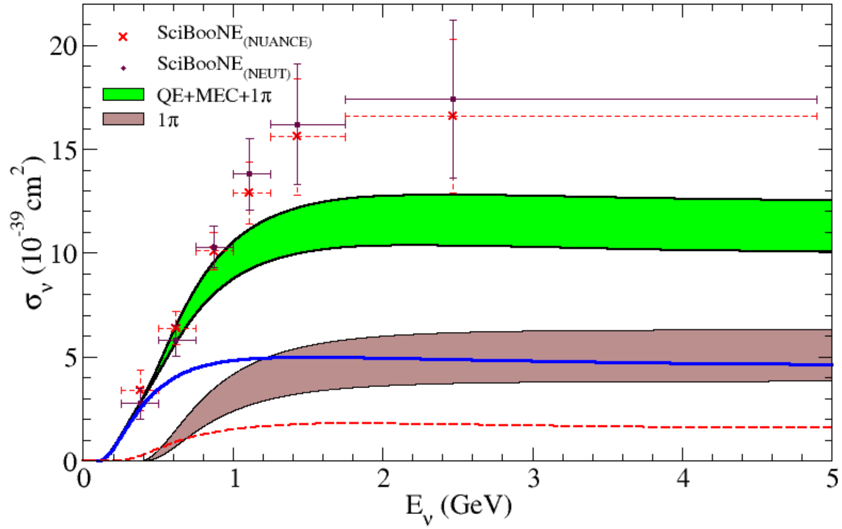


- Quasielastic region.
- 2p-2h excitations.
- **Δ** resonance, other resonances and DIS.

T2K CC $\nu_\mu, < E_{\nu_\mu} > \sim 0.8\ GeV$, inclusive data



Total Inclusive Cross Section

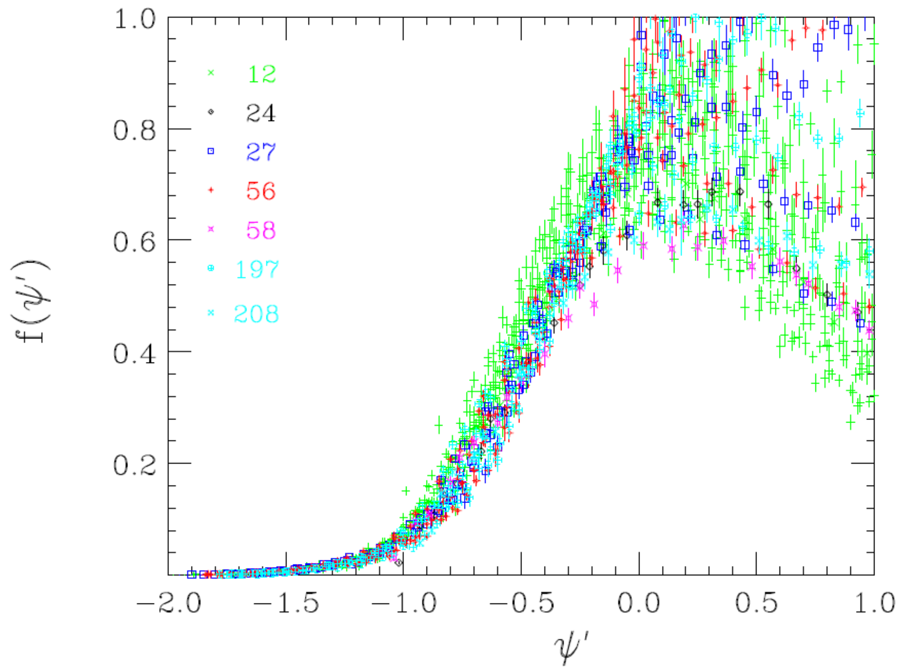


Superscaling model with QE + 2p2h + 1π [M.V Ivanov et al., J. Phys. G 43, 045101 (2016)].

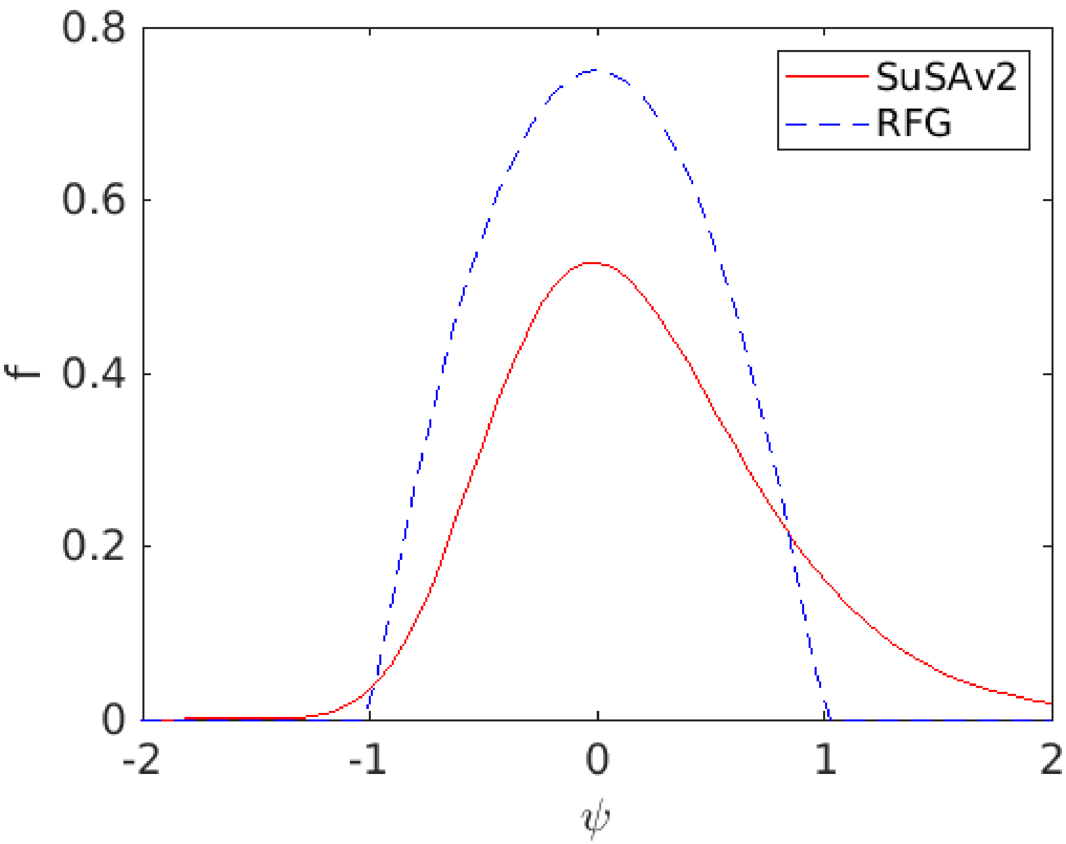
Introduction

The scaling function does not depend explicitly on the transferred momentum or the nuclear species [J. E. Amaro et al., J. Phys. G 47, 124001 (2020), G. D. Megias, PhD Thesis (2017)].

$$f(\psi) = k_F \frac{\left(\frac{d^2\sigma}{d\Omega dw}\right)}{\left(\frac{d^2\sigma}{d\Omega dw}\right)_{s.n}}$$



Introduction



Comparison between SuSAv2-QE and Relativistic Fermi Gas (RFG) scaling function.

SuSAv2 model provides a more accurate description of nuclear dynamics as it is based of RMF theory.

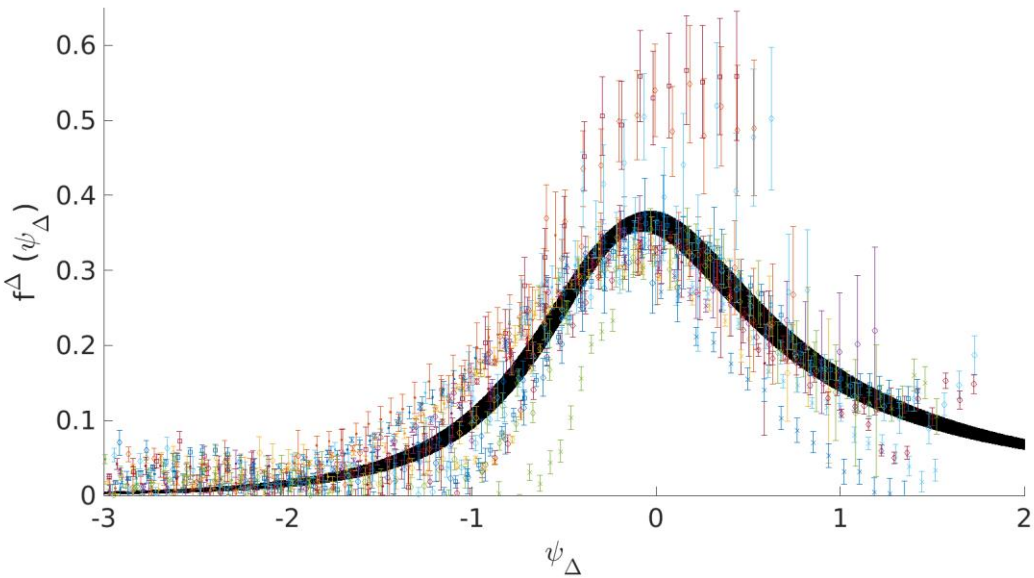
SuSAv2-QE scaling function is going to be implemented in the inelastic regime.

Model: SuSAv2-Δ

In order to describe Δ resonance region, a Δ pion production model [J. E. Amaro et al., Phys. Rev. C 71, 015501 (2005)] is used with a phenomenological scaling function.

$$[W^{\mu\nu}]^{\Delta} = \frac{1}{2}\Lambda_0 f^{model} U^{\mu\nu}$$

$$\left(\frac{d^2\sigma}{d\Omega d\omega}\right)^{\Delta} = \left(\frac{d^2\sigma}{d\Omega d\omega}\right)^{exp} - \left(\frac{d^2\sigma}{d\Omega d\omega}\right)^{QE} - \left(\frac{d^2\sigma}{d\Omega d\omega}\right)^{2p2h} - \left(\frac{d^2\sigma}{d\Omega d\omega}\right)^{HR+DIS}$$

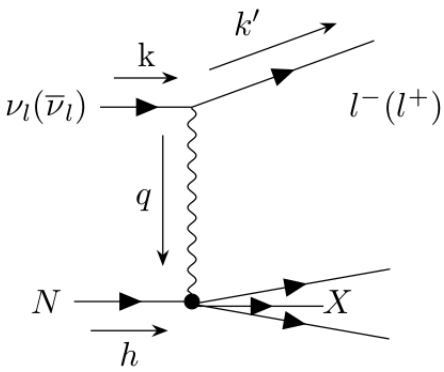


$$f^{\Delta}(\psi_{\Delta}) = k_F \frac{\left(\frac{d^2\sigma}{d\Omega d\omega}\right)^{\Delta}}{\sigma_{Mott}(v_L G_L^{\Delta} + v_T G_T^{\Delta})}$$

The results are published in J. Gonzalez-Rosa et al., Phys. Rev. D 105, 093009 (2022).

Model: SuSAv2-inelastic

SuSAv2-inelastic model describes the full inelastic spectrum (Δ, other res. And DIS)[G. D. Megias, PhD Thesis (2017), M. B. Barbaro et al., Phys. Rev. C 69, 035502 (2004), J. Gonzalez-Rosa et al., Phys. Rev. D 105, 093009 (2022)]. Good agreement with (e,e') data.



Inelastic Feynmann Diagram

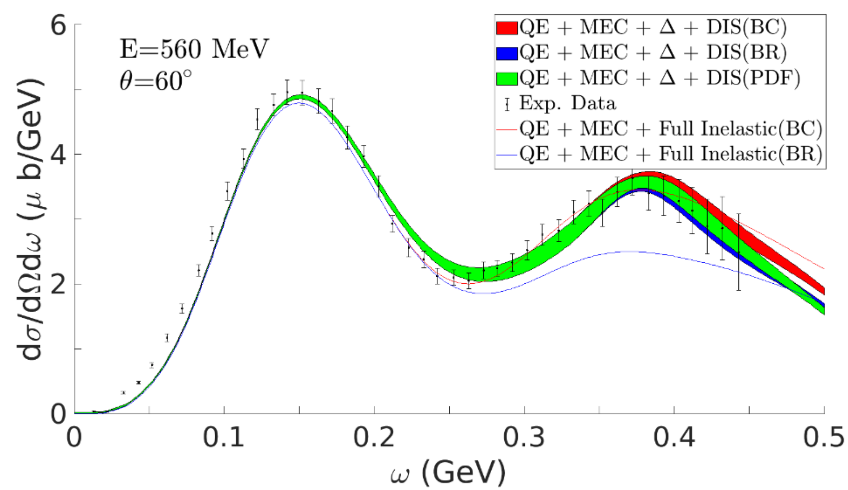
$$R^K_{inel}(\kappa,\tau) = \frac{N}{\eta_F^2 \kappa}\xi_F \int_{\mu_X^{min}}^{\mu_X^{max}} d\mu_X f^{model}(\psi'_X) U^k$$

The hadronic response is given by an integration of the single-nucleon tensor over the invariant mass.

Limits of this integral are

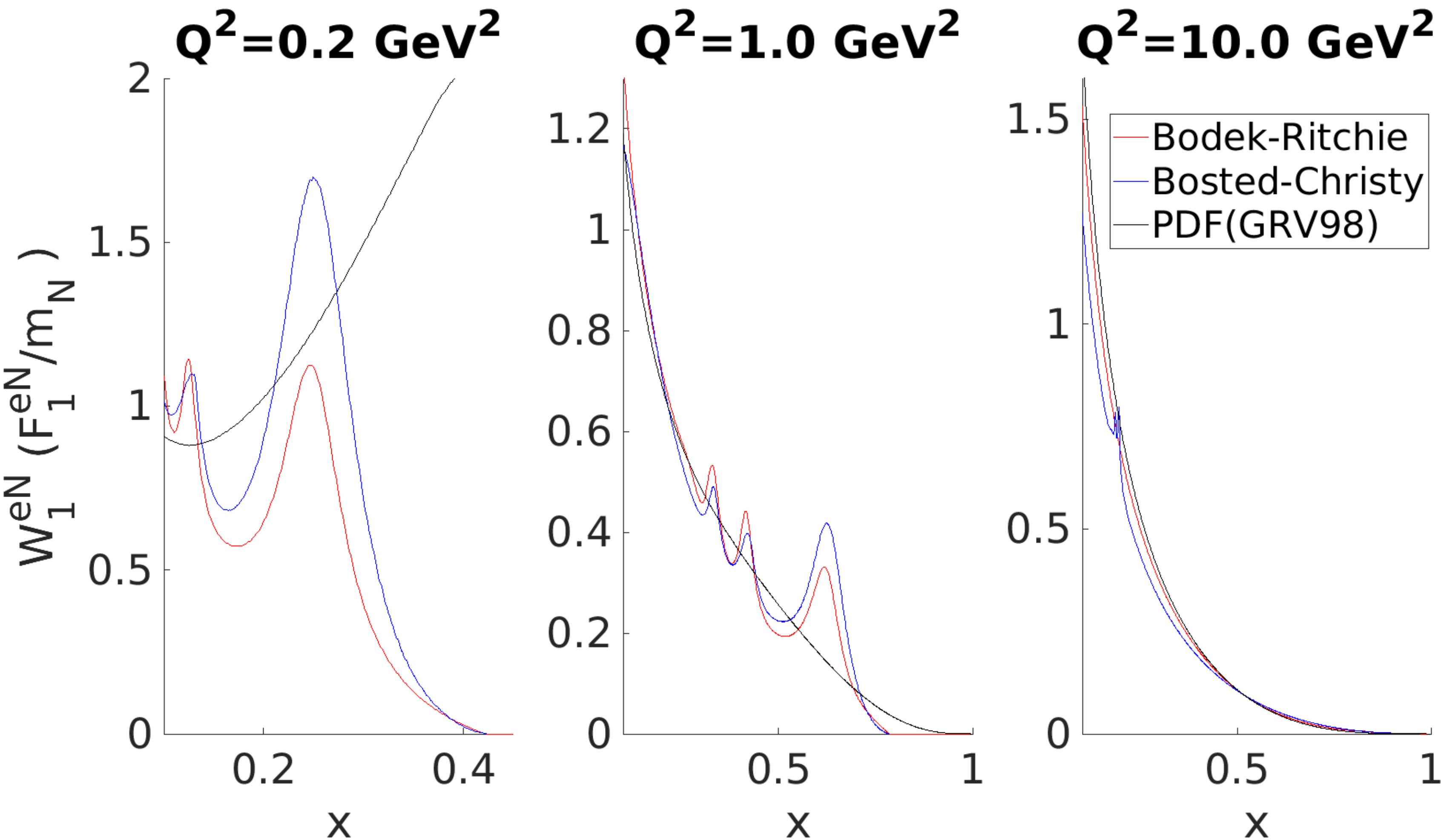
$$\mu_X^{min} = 1 + \frac{m_\pi}{M_N},\ \mu_X^{max} = 1 + 2\lambda - \frac{E_S}{M_N}$$

This limits can be changed to work alongside a resonance model.



Bodek-Ritchie and Bosted-Christy parametrizations (specially BC) on their own and alongside SuSAv2-Δ work well.

Model: SuSAv2-inelastic



Model: SuSAv2-inelastic

Inelastic Structure Function [M. Sajjad Athar and J. G. Morfín, J. Phys. G 48, 034001 (2021)].

$$F_2^{eN} = \frac{5x}{18}(u(x) + \bar{u}(x) + d(x) + \bar{d}(x))$$

$$F_2^{\nu N} = \upsilon W_2^{\upsilon} = Q + \bar{Q} = x(u(x) + d(x) + \bar{u}(x) + \bar{d}(x))$$

$$F_{1,2}^{\nu N}(x) \approx \frac{18}{5} F_{1,2}^{eN}(x)$$

Regarding the vector-axial inelastic structure function:

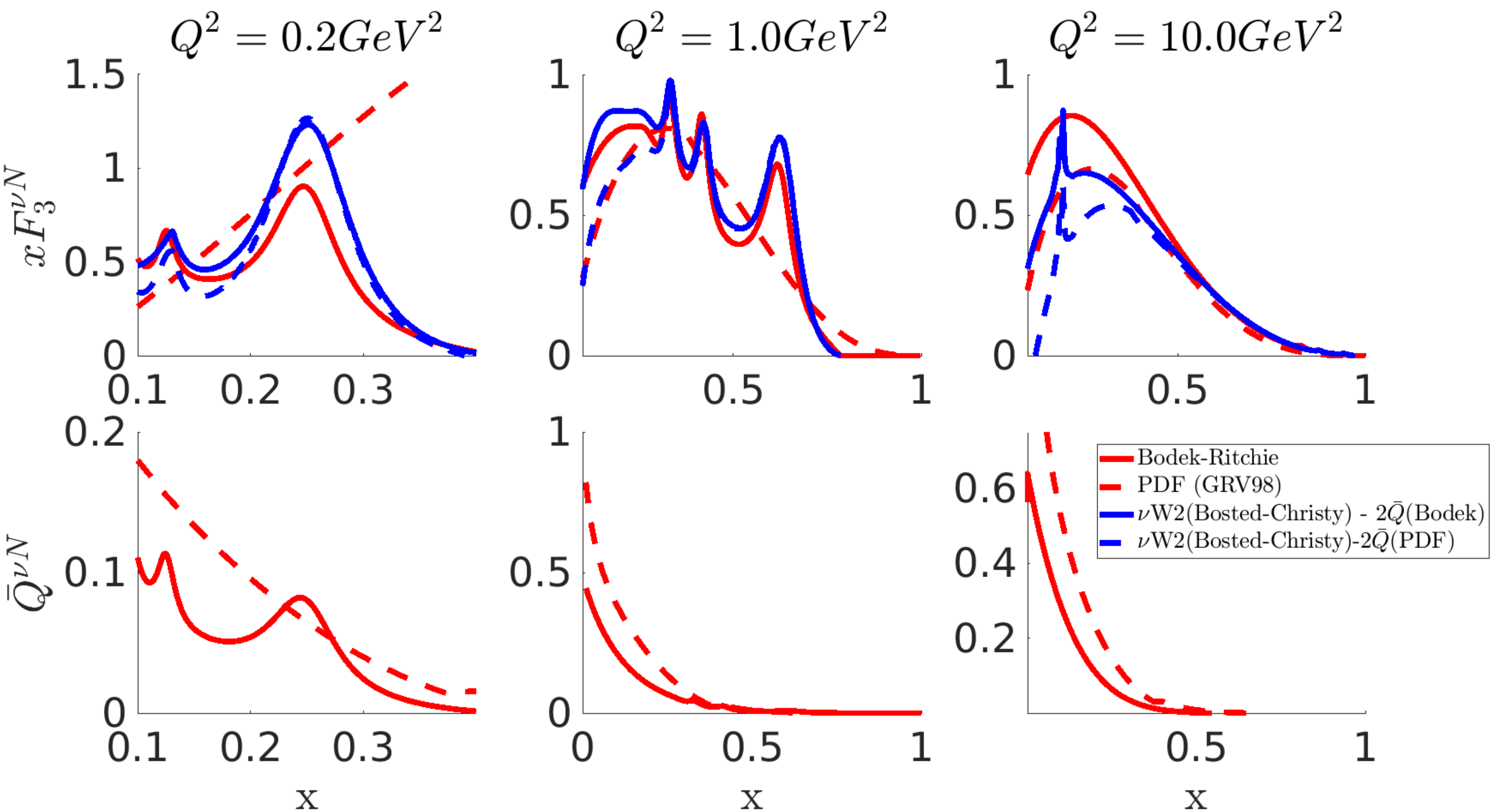
- Bodek-Ritchie parametrization [A. Bodek and J. L. Ritchie, Phys. Rev. D 23, 1070 (1981)].

$$xF_3 = F_2 - 2\bar{Q} \longrightarrow \text{Antiquarks distribution.}$$

- Parton Distribution Function [M. Sajjad Athar and J. G. Morfín, J. Phys. G 48, 034001 (2021)].

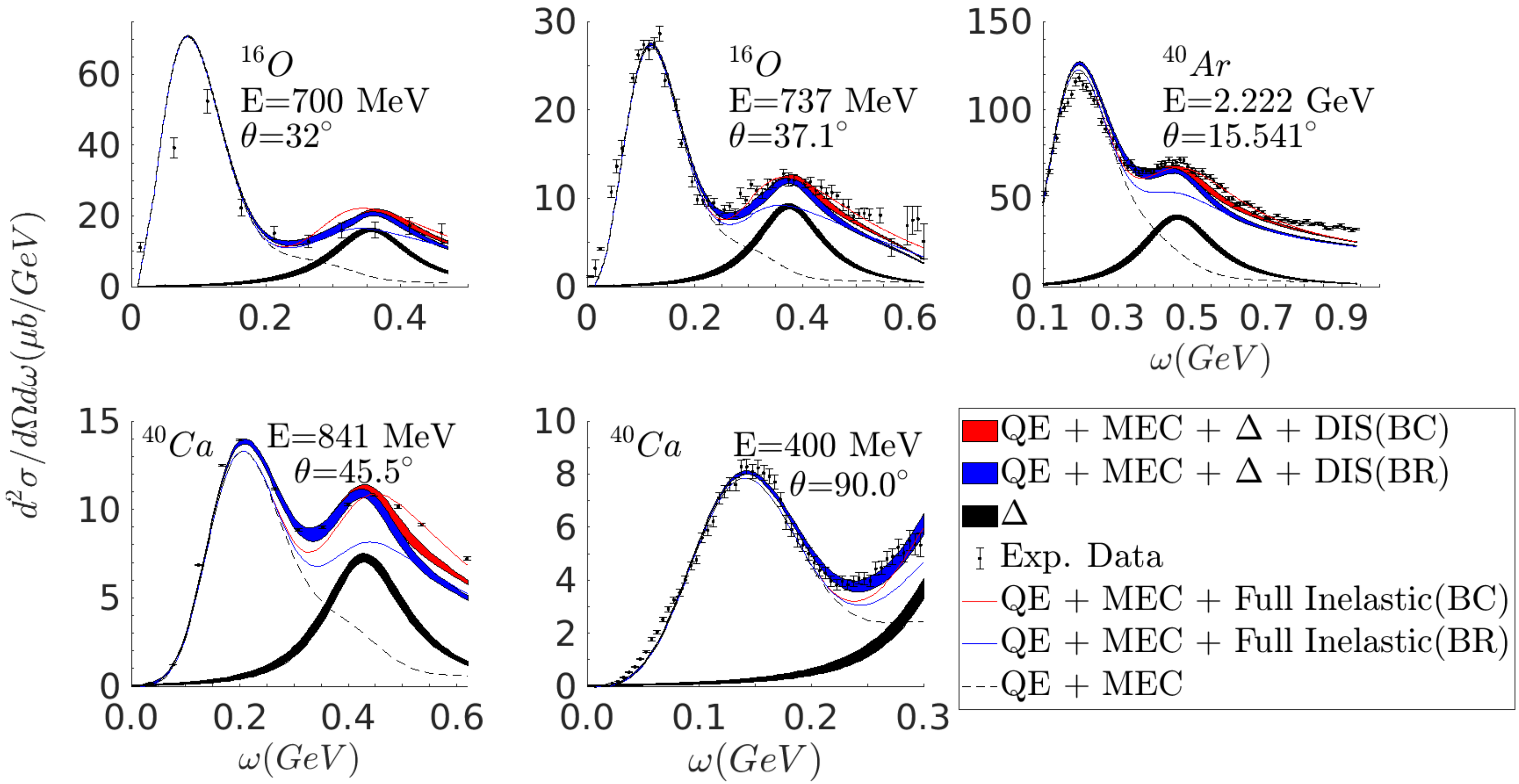
$$xF_3^{\upsilon p(n)} = 2x(d(u) + s - \bar{u}(\bar{d}) - \bar{c})$$

Model: SuSAv2-inelastic

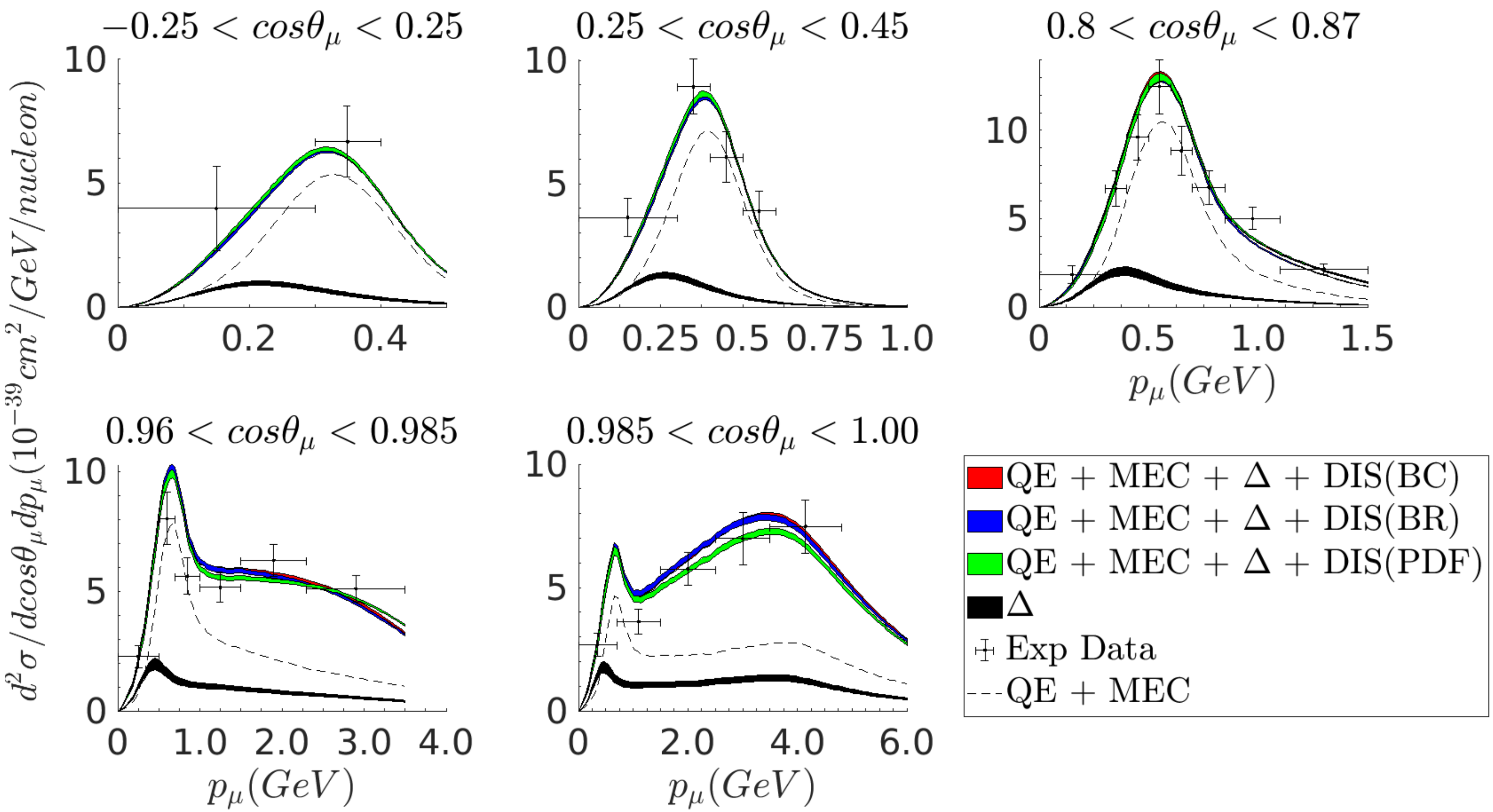


The following results are published in J. Gonzalez-Rosa et al., Phys. Rev. D 105, 093009 (2022).

Results: Electron scattering.

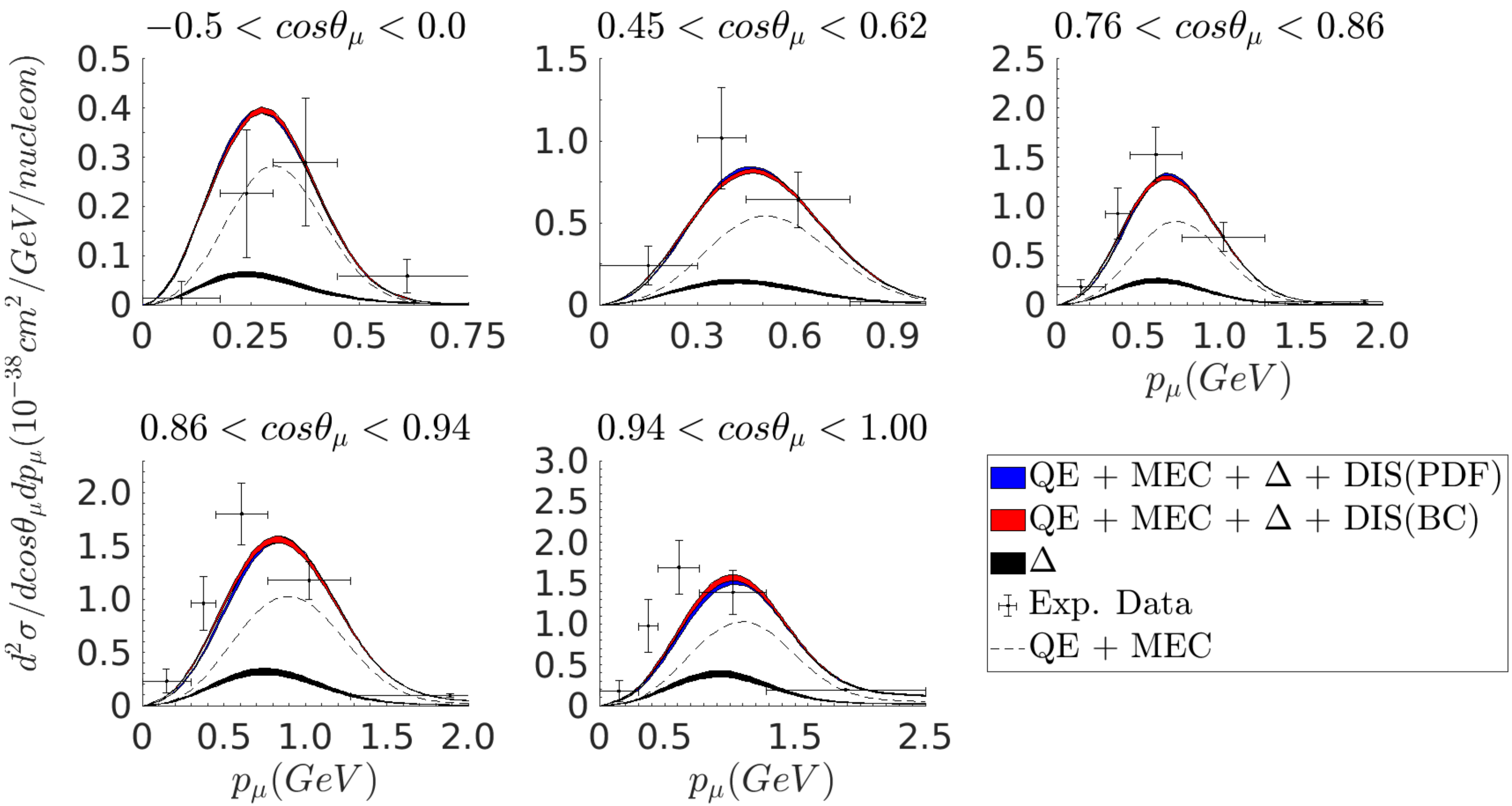


Results: Neutrino scattering.



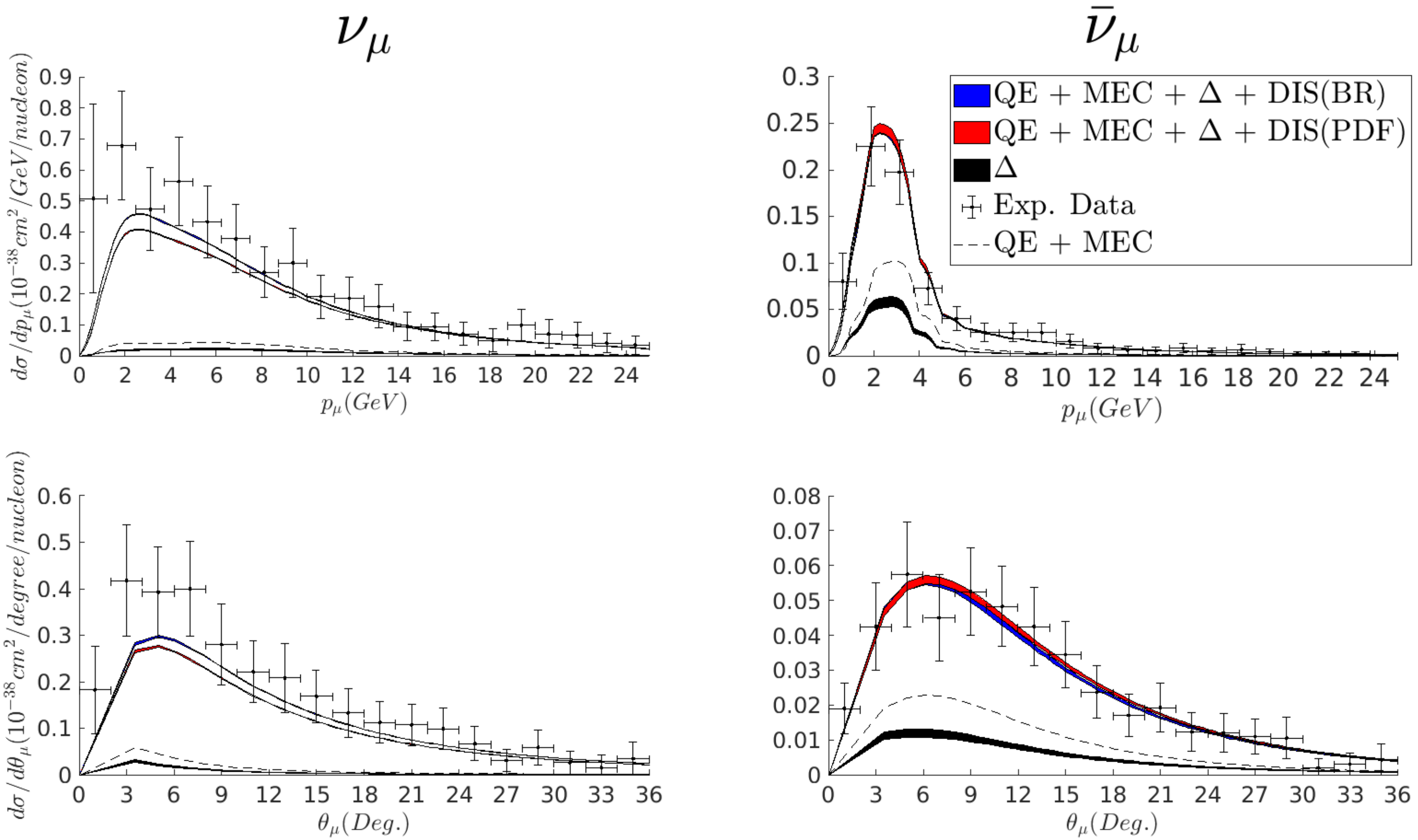
T2K CC ν_μ, $< E_{\nu_\mu} > \sim 0.6\ GeV$

Results: Neutrino scattering.



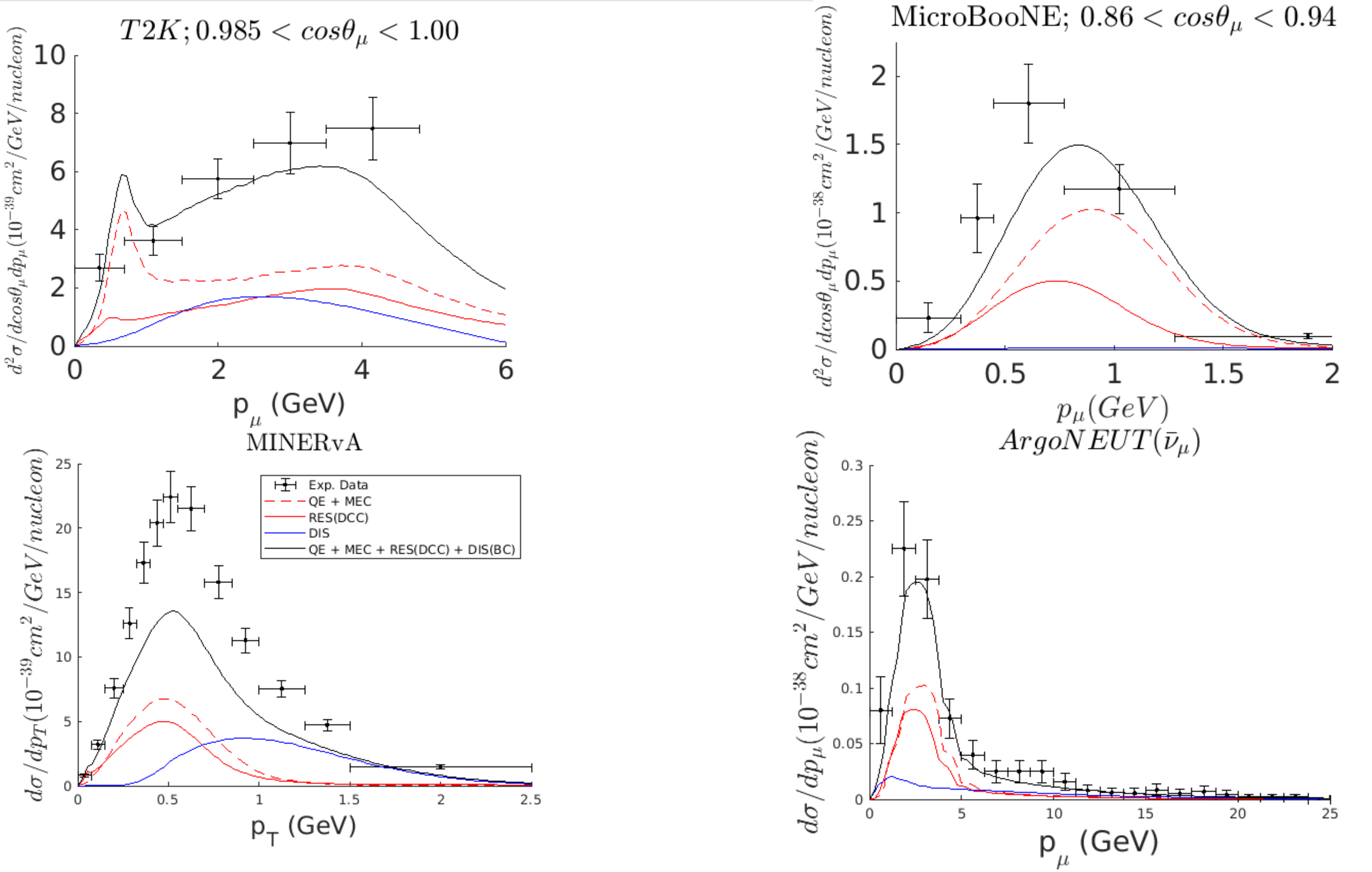
MicroBooNE CC ν_μ, $< E_{\nu_\mu} > \sim 0.8\ GeV$

Results: Neutrino scattering.



ArgoNEUT CC $\nu_\mu, < E_{\nu_\mu} > \sim 9.6\ GeV$; **CC**$\bar{\nu}_\mu, < E_{\nu_\mu} > \sim 3.6\ GeV$

Future studies: DCC model- Preliminary results



Dynamical coupled-channels (DCC) model [Phys. Rev. D 92, 074024 (2015)] determines the interference pattern between resonance and non-resonance amplitudes.

Conclusion

- The superscaling model was tested and reproduced well electron scattering data across the whole energy spectrum.
- The superscaling model for neutrinos has been extended to the inelastic regime for the first time. Weak inelastic structure functions were obtained by using relationships among the electromagnetic inelastic structure functions given by QCD. This description fails at intermediate-high energies. Therefore, the former SuSAv2-Δ approach is more appropriate at these kinematics.
- Our predictions have been compared with available data for charged current muon neutrino-nucleus reactions from T2K and ArgoNEUT experiments.

Conclusion

- For T2K and MicroBooNE, QE channel dominates in most of kinematical situations. At forward angles, the contribution of DIS gets larger and becomes crucial to explain the experiment.
- In the case of neutrinos for ArgoNEUT, the predictions are below the data in the region where the cross sections reach their maxima. The description of ArgoNEUT data for antineutrinos is excellent. This is mainly due to the different energy distribution of neutrino and antineutrinos fluxes.
- The present study shows clearly the applicability of these models to describe weak processes. Further studies are needed with new models for the elementary process implemented.

Thanks for your attention

Limits of the inelastic region

Kinematically allowed region, recoiling of the daughter nucleus

$$\max[\varepsilon(0), 0] \leq \varepsilon \leq \varepsilon(\pi)$$

Considering that the mass of daughter nuclei is infinite

$$\varepsilon_{\infty}(\theta) = m_N + \omega - \sqrt{W_X^2 + q^2 + p^2 + 2pqcos\theta}$$

Considering the limits

$$m_N + m_\pi \leq W_X \leq m_N + \omega - E_S$$