Inelastic neutrino-nucleus scattering in the superscaling model

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Introduction

- Quasielastic region.
- $2p$-$2h$ excitations.
- $\Delta$ resonance, other resonances and DIS.

Introduction, Model: $1\pi$-SuSAv2

Comparison between SuSAv2 and RFG scaling function.

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


SuSAv2 model comes from RMF.

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

In order to describe the $\Delta$ resonance region, a $\Delta$ pion production model [PRC 71, 015501 (2005)] is used with the SuSAv2 scaling function.

\[
[W^{\mu\nu}]^{\Delta} = \frac{1}{2} \Lambda_0 f_{\text{model}} U^{\mu\nu}
\]
Model: SuSAv2-inelastic


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

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

The limits of this integral are

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

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

BR and BC parametrizations (specially BC) work well. PDF gets closer at high $\omega$, but it is not suited to describe $\Delta$ region.
Model: SuSAv2-inelastic

\[ Q^2 = 0.14 \text{ GeV}^2/c^2 \quad Q^2 = 1.0 \text{ GeV}^2/c^2 \quad Q^2 = 5.0 \text{ GeV}^2/c^2 \]

- **Antiquarks distribution.**
  \[ F_2^{\nu N}(x) \approx \frac{18}{5} F_2^{eN}(x) \]

- **Bodek-Ritchie parametrization** [PRD 23, 1070 (1981)].

- **Parton Distribution Function.**
  \[ F_3(x) = F_2(x) - 2\bar{Q}(x) \]
  \[ xF_3^{\nu p}(n) = 2x(d + s - \bar{u}(\bar{d}) - \bar{c}) \]

- **Work in progress for neutrinos.**

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Results


**Preliminary Result.**

Using $1\pi$ – SuSAv2 and the SuSAv2-inelastic model (complete inel). At this kinematics (T2K) DIS does not have a great impact, at higher $\omega$ will be more relevant.

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

**T2K CC $\nu_e, <E_{\nu_e}> \sim 1.3 \ GeV$, inclusive data**
Conclusion

- It is necessary to include an analysis of the inelastic scattering to explain the neutrino cross section at certain kinematics.
- The model works well for electrons and it’s expected to work well for neutrinos, specially using BC parametrization in the full inelastic regime.
- In the SuSAv2-inelastic model, the contributions from $\Delta (\pi$ production) and other resonances can be removed, so this model can work alongside other resonance model.
- In the SuSAv2-inelastic model for neutrinos, the analysis of W3 inelastic structure function is a work in progress.
Thanks for your attention
Limits of the inelastic region

Kinematically allowed region, recoiling of the daughter nucleus

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

\[ \varepsilon_\infty(\theta) = m_N + \omega - \sqrt{W_X^2 + q^2 + p^2 + 2pq\cos\theta} \]

Considering that the mass of daughter nuclei is infinite

\[ m_N + m_\pi \leq W_X \leq m_N + \omega - E_S \]
W1, W2 and W3