Scaling in electron-nucleus scattering in the Delta resonance region

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The concepts of scaling [1] and superscaling [2] in lepton-nucleus scattering have been extensively studied in the past decade, both as a testing ground for theoretical models of electron-nucleus cross sections [3] and as a starting point to build phenomenological models for neutrino-nucleus scattering starting from electron scattering data [4]. Past studies [2,3,5] have been focused mostly on the quasielastic (QE) scattering region and only recently they have been extended to the region of the Delta resonance [4].

In our work we are investigating the scaling properties of electron scattering cross sections beyond the QE region and up to the Delta resonance peak, exploring the possible origin of the observed scaling violations.

Following previous studies of superscaling[4,5], based on the relativistic Fermi gas (RFG) model, and in close connection with the procedures used for QE scattering, we have introduced a scaling variable

$$\psi_\Delta = \frac{1}{\sqrt{\xi_F}} \frac{\lambda - \tau\rho_\Delta}{\sqrt{(1+\lambda\rho_\Delta)\,\tau + \kappa\sqrt{\tau\,(1+\tau\rho_\Delta^2)}}}\,, \quad (1)$$

with

$$\rho_\Delta = 1 + \frac{\mu_\Delta^2 - 4\tau}{4\tau}\ ;\ \mu_\Delta = \frac{m_\Delta}{m_N} \quad (2)$$

and a scaling function

$$f_\Delta = k_F \frac{\frac{d\sigma}{d\epsilon' d\Omega'}}{S^\Delta}\,, \quad (3)$$

with

$$S^\Delta = \sigma_M\left[v_L G_L^\Delta + v_T G_T^\Delta\right] \quad (4)$$

$$G_L^\Delta = \frac{\kappa}{4\tau} A\left[\left(1+\tau\rho_\Delta^2+1\right) w_2^\Delta - w_1^\Delta\right] \quad (5)$$

$$G_T^\Delta = \frac{1}{2\kappa} A w_1^\Delta\,, \quad (6)$$

where $w_{1,2}^\Delta$ are the structure functions describing the free nucleon excitation of a stable Delta resonance, and $A = N + Z$ is the total number of nucleons. In the equations above $\xi_F = \sqrt{1+(k_F/m_N)^2} - 1$, k_F being the Fermi momentum, and the dimensionless variables $\kappa = q/2m_N$, $\lambda = \omega/2m_N$ and $\tau = \kappa^2 - \lambda^2$ have been used. The scaling function f_Δ depends in general on both the energy transfer ω and the momentum transfer q. If, for high enough values of q, it depends only on a combination of ω and q, that is the scaling variable ψ_Δ, it is said to scale (scaling of the first kind).

In order to obtain f_Δ from electron-nucleus scattering data, we have isolated the inelastic component of the experimental cross-sections by subtracting from them the QE contribution, reconstructed from the scaling functions obtained from QE scattering data[4]. We have then used these QE-subtracted cross sections in Eq. (3).

The results obtained using all available data for the ^{12}C nucleus having $q > 500$ MeV/c are shown in the upper panel of Fig. 1, together with an average parametrization of the scaling function itself. Reasonable scaling is present on the left of the Delta peak, while strong violations appear both at the right of the peak ($\psi_\Delta > 0$) and for $\psi_\Delta < -1$. The former are clearly due to the presence of higher inelastic contributions, which are also responsible of the weaker scaling violations observed for $-1 < \psi_\Delta < 0$. The latter, instead, are expected to be due to correlations and meson exchange currents (MEC) effects [6].

To investigate scale-breaking effects further, we have computed inelastic electron-nucleus cross sections using an extension of the RFG model[7], in which the inelastic nuclear response functions are written as

$$R_{L,T}^{inel} = \frac{1}{k_F}\int d\mu_X \mu_X f_{inel}(\psi_X) G_{L,T}^{inel}\,, \quad (7)$$

where ψ_X is obtained from Eqs. (1) and (2) for a generic invariant mass W_X of the final state reached by the nucleon, namely by replacing μ_Δ

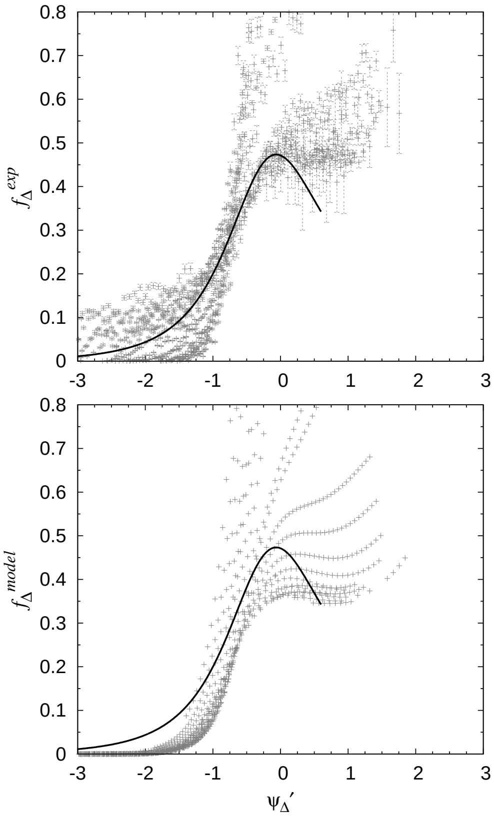

Figure 1. Upper panel: Delta scaling function obtained from all available data for ^{12}C having $q > 500$ MeV/c. Lower panel: Delta scaling function calculated according to the model described in the text for the same set of kinematics as in the upper panel. In both panels the solid line represents and average fit of the experimental f_Δ. The prime on the scaling variable indicates that a small energy-shift correction has been included to account for binding-energy/separation-energy effects [2,4,5].

with $\mu_X = W_X/m_N$, and the quantities $G^{inel}_{L,T}$ are given by

$$\begin{aligned} G_L^{inel} &= m_N \frac{\kappa}{2\tau} \left\{ Z \left[(1+\tau\rho_X^2)\tilde{w}_2^p - \tilde{w}_1^p \right] \right. \\ &\quad \left. + N \left[(1+\tau\rho_X^2)\tilde{w}_2^n - \tilde{w}_1^n \right] \right\} \qquad (8) \\ G_T^{inel} &= m_N \frac{1}{\kappa} \left\{ Z\tilde{w}_1^p + N\tilde{w}_1^n \right\} . \qquad (9) \end{aligned}$$

Here $\tilde{w}_{1,2}$ are the inelastic single-nucleon structure functions, for which we have used the very recent Bosted-Christy parametrization [8]. In Eq. (7) for $f_{inel}(\psi_X)$ we have used a phenomenological scaling function, which is assumed to be universal (*i.e.* the same for QE and inelastic scattering and the same for transverse and longitudinal response functions) and which is obtained from a fit of QE longitudinal experimental data[2].

Using the cross sections calculated within the model described above we have obtained the Delta scaling functions plotted in the lower panel of Fig. 1.

By comparing the upper and lower panels of the figure we can see that the model always underestimates the data, the discrepancy being much larger for large negative values of ψ_Δ.

The discrepancy at and close to the Delta peak may be, at least partially, due to the choice of the phenomenological $f_{inel}(\psi_X)$. Recent detailed studies of scaling in QE scattering [3] indicate, in fact, that a certain amount of scale-breaking is present even at relatively large values of q, and it should be included in our modeling. Work is progress along this line.

The complete discrepancy between theory and data for $\psi_\Delta < -1$ is due to the fact that the model does not contain any "non-impulsive" contribution, such as those due to MEC, which are expected to play a major role in this region [6]. Work is now in progress aimed at using our theoretical model, or an improved version of it, in order to subtract from the experimental cross sections the contributions coming from direct ("impulsive") inelastic scattering on bound nucleons., thus isolating the effects due to MEC and other correlations.

Finally, we mention that a more extended study of the region $-1 < \psi_\Delta < -0$, where, besides the discrepancy in normalization, the theoretical scaling function shows scale-breaking effects similar to those observed in the data, seems to confirm that the scaling violations observed in this region are mostly due to the presence in the data of contributions going beyond the Delta resonance.

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