INCLUSIVE PRODUCTION OF FORWARD NEUTRONS AND THE PIONIC CONTENT OF THE NUCLEON*

W. Schäfer, N. Nikolaev, J. Speth

Institut für Kernphysik, Forschungszentrum Jülich GmbH
D-52425 Jülich, Germany

and A. Szczurek

H. Niewodnicanski Institute for Nuclear Physics
Radzikowskiego 152, 31-342 Kraków, Poland

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We discuss a model for the inclusive production of forward neutrons in high energy hadronic and deep inelastic reactions based on Regge phenomenology. The model includes pion and rho exchange as well as a contribution from the decay of Δ-resonances. The π, ρ-exchanges are taken in the reggeized form. A good description of the reaction $pp \to nX$ is achieved. The application to deep inelastic scattering is discussed.

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Recent experiments on inclusive production of forward baryons in deep inelastic scattering at HERA, utilizing the forward particle spectrometers of the ZEUS and H1 collaborations [1–3], have brought back some attention to soft peripheral production mechanisms in high energy scattering (for a recent review see [4]). In fact, semi-inclusive production in deep inelastic scattering $\gamma^* p \to hX$ $(h = p, n, \Delta)$, calls for the inclusion of non-perturbative production mechanisms. This is based on the simple point, that the QCD hardness scale gradually decreases from Q^2 in the current (γ^*) fragmentation region down to a soft, hadronic scale in the proton fragmentation region. Quite naturally, there must emerge a similarity of the inclusive baryon spectra in hadronic and deep inelastic reactions. Such high energy inclusive processes dominated by soft, nonperturbative interactions are successfully described

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by Regge phenomenology, for a review see for instance [5]. Evidently, the charge exchange channel $p \to n$ contains a contribution from t-channel pion exchange, which is expected to dominate in a certain kinematic range. These observations suggest a simple strategy: the contributions from the relevant exchanges are fixed from data on inclusive neutron production in pp collisions, and can then be used to predict the corresponding cross sections in deep inelastic scattering.

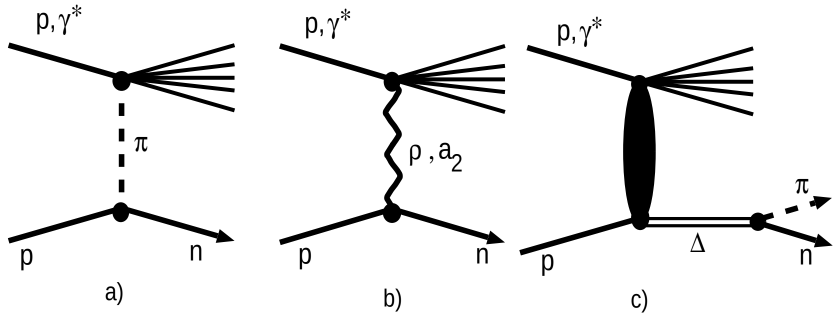

Fig. 1. The mechanisms for inclusive production of forward neutrons. a) pion exchange, b) background from (reggeized) ρ, a_2 exchanges, c) neutrons originating from the decay of an intermediate Δ-resonance.

We first give a brief description of forward neutron production in pp collisions. We take three production mechanisms into account: the dominant pion exchange, background contribution from the isovector exchanges ρ, a_2, and, finally, the production of neutrons from the decay of an intermediate Δ-resonance (see Fig. 1). We incorporate the distortion of the incoming proton waves by the standard methods of the generalized eikonal approximation [6]. As it was argued in [6], we apply the absorptive corrections only in pp scattering, they can be neglected in the $\gamma^* p$-case. In view of a possibly large Regge parameter $s/M_X^2 \sim 1/(1-z) \gg 1$ (here M_X^2 is the invariant mass squared of the inclusive system X, z is the fraction of the initial proton's momentum carried by the forward baryon), the proper description must involve a Regge treatment [7]. In Fig. 2 we show the $p_\perp$-integrated spectrum of forward baryons together with the experimental data as analyzed in [8], and find a good agreement. We clearly observe the peak due to pion exchange for $0.7 \lesssim z \lesssim 0.9$. The background contribution from the two step process $p \to \Delta \to n$ is sizeable only for $z \lesssim 0.8$, whereas ρ exchange takes over for $z \gtrsim 0.95$. This is predicted by Regge theory and reflects the fact that the intercept of the ρ trajectory is higher than the one of the pion. A caveat is in order: an exchange of a reggeized ρ trajectory should by no means be confused with a spin-one particle exchange. We remind the reader that Regge

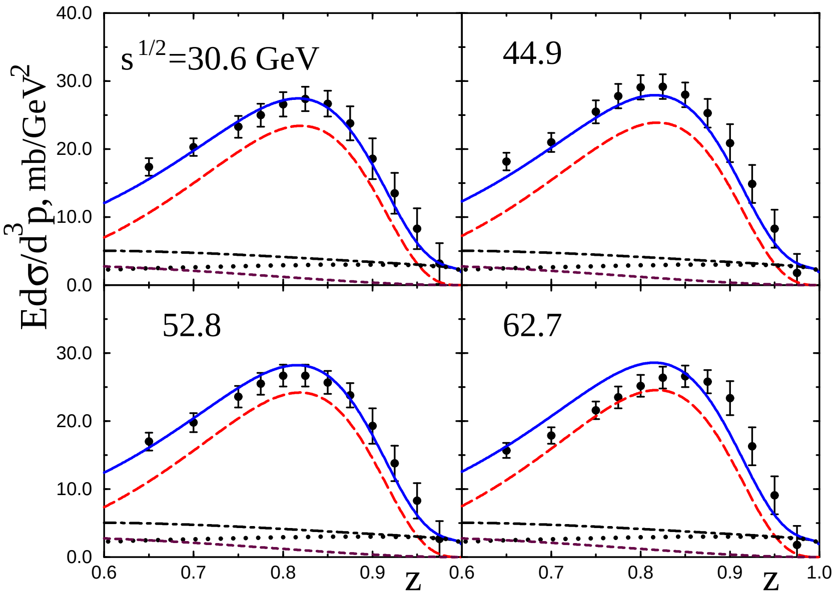

Fig. 2. Invariant cross section for the reaction $pp \to nX$ as a function of z for $p_\perp^2 = 0$. The long dashed curve shows the contribution from the pion exchange; the dotted curve is the ρ, a_2-exchange contribution, and the dashed curve shows the contribution from the two-step process $p \to \Delta \to n$. In addition we present the sum of the two background contributions as the dot-dashed line. The solid curve represents the sum of all components. The experimental data are taken from [8].

phenomenology makes use of the asymptotic form of scattering amplitudes in the kinematic region $s/M_X^2 \gg 1\,, s/|t| \gg 1$. Please remember, that in this limit, and after analytic continuation from the ρ-meson pole at $t = m_\rho^2$ to the physical region of negative t, the Regge amplitude differs quite strongly from the amplitude for the spin-one particle exchange (see for instance the textbook [9]). Indeed, one of the firm predictions of Regge theory is a t-dependent phase of the amplitude, which leads to important consequences when we want to infer the contribution of a certain inclusive production mechanism to the total cross section. While the inclusive cross section is proportional to the amplitude squared, $|A|^2$, it is the product of two amplitudes, $A \cdot A$, that enters the evaluation of the total cross section. For ρ-exchange the phase of the amplitude is such, that the contribution to the total cross section vanishes [11]. For pion exchange, on the other hand, Reggeization effects are negligible: due to the proximity of the pion pole, the departure of $\alpha_\pi(t) = \alpha'(t - m_\pi^2)\,, \alpha' \approx 0.7$ GeV^{-2} from $J_\pi = 0$ is small, and the real pion exchange amplitude squared *enhances* the total cross section. The pion exchange mechanism is thus consistently interpreted in terms of the πN-

Fock state decomposition of the (lightcone-)wave function of the interacting nucleon (see [10] and Refs therein). Such an interpretation is apparently meaningless for the reggeized ρ exchange. In the practical calculation we use form factors of the type $F^2_{\pi NN}(t) = \exp[-(R^2(t-m_\pi^2))^2]\,, R^2 = 1.5\ \mathrm{GeV}^{-2}$, different choices of the functional form are discussed in [11]. We note in passing that the parameters of our model are further constrained by forward neutron cross sections differential in $p_\perp$ as well as by forward pion production data.

Very recently preliminary data taken by the ZEUS with their forward neutron spectrometer collaboration [3] have become available. They further confirm the relevance of the pion exchange in this particular reaction. The experimental data show all the factorization properties typical of the particle exchange [3]. Our model correctly predicts an increase of the $p_\perp^2$ slope with increasing z. For $z = 0.625$ we obtain $B = 6\ \mathrm{GeV}^{-2}$, in good agreement with the preliminary experimental value $B = 6 \pm 1.5\ \mathrm{GeV}^{-2}$, for $z = 0.8$ we get $B = 7\ \mathrm{GeV}^{-2}$ theoretically, and $B = 8.5 \pm 1\ \mathrm{GeV}^{-2}$ from experiment. At large z however the model seems to underpredict the slope by $20 \div 25\,\%$.

We finally wish to point out, that the pionic content of the nucleon as inferred from our model is consistent [11] with the findings on the violation of the Gottfried sum-rule [12] and gives a good description of the recent Drell–Yan determination of the $\bar{d} - \bar{u}$-asymmetry by the E866 collaboration at Fermilab [13].

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