TARGET FRAGMENTATION OF THE NUCLEON AT HIGH ENERGIES

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We calculate target fragmentation in $pp \rightarrow nX$ and $\gamma p \rightarrow nX$ reactions in the meson cloud picture of the nucleon. The $pp \rightarrow nX$ reaction is used to fix the $pn\pi^+$ form factor for two different models. We take into account the possible destruction of the residual neutron by the projectile. Using the form factor from the hadronic reaction we calculate photoproduction and small $x$ Bj electroproduction of forward neutrons at HERA. In photoproduction we observe slightly less absorption than in the hadronic reaction. For deep inelastic events ($Q^2 > 10$ GeV$^2$) screening is weaker but still present at large $Q^2$. The signature for this absorptive rescattering is a shift of the $d\sigma/dE_n$ distribution to higher neutron energies for photofragmentation.

1 Introduction

In the one pion exchange model the differential cross section for a general reaction leading to neutron production i.e. $ap \rightarrow n(z, p_t)X$ reads:

$$E_n \frac{d^3\sigma}{d^3p_n} = \frac{2g^2}{16\pi^2} \frac{|t|}{(t - m^2_\pi)^2} (1 - z)^{1-2\alpha_\pi(t)} |G(z, p_t)|^2 \sigma_{tot}^{a\pi},$$

where the first factor is the splitting probability of a proton into a neutron-pion system (including the reggeization of the pion in a covariant approach), $G(z, p_t) = \exp[-R_c^2(t - m^2_\pi)]$ is the $pn\pi$ form factor, and $\sigma_{tot}^{a\pi}$ is the total $a\pi$ cross section. To get the lightcone formula one has to set $\alpha_\pi(t) = 0$ and to replace $R_c^2$ by $R_{lc}^2/(1 - z)$.

The usual procedure to extract the pion structure function $\Delta F_2^\pi$ is to fix the relevant parameters entering the flux factor from the data of leading neutron production in proton-proton ($a = p$) collisions and then apply eq.(1) for virtual photon scattering ($a = e^+$) in DIS.

Recently a first study of absorptive corrections in the Regge formalism has appeared. These absorptive effects depend on the projectile and are a source of factorization breaking. Applying high-energy Glauber theory, we will investigate the relevance of absorptive corrections in detail in order to

\footnote{Supported by TMR programme, EU-Project FMRX-CT96-0008.}
\footnote{Hereafter $z$ is the neutron longitudinal momentum fraction, $p_t$ its transverse momentum and $t$ the momentum transfer.}
understand the one pion exchange mechanism and the extraction of the pion structure function.

2 Estimate of absorptive corrections in \( pp \rightarrow nX \)

We consider the target fragmentation reaction as a stripping reaction where the projectile proton strips a \( \pi^+ \) from the the target proton, leaving behind a neutron. This picture is reliable when the pion and the neutron in the target proton are well separated (as in the case of large \( z \)) but becomes questionable at intermediate values of \( z \) when the rescattering of the projectile on the neutron and its subsequent screening can be important. We treat the target proton as a pion-neutron system (\( \phi_0 \)) undergoing a transition to an excited state (\( \phi_\alpha \)) and sum over all excited states, excluding the elastic contribution. The differential cross section reads

\[
\frac{d\sigma}{dz} = \int d^2b \int d^2b_{rel} \rho_{\pi n}(z, b_{rel}) 2Re\Gamma_{\pi\pi}(b - s_\pi)[1 - 2Re\Gamma_{pn}(b - s_n)],
\]

(2)

where \( b \) is the impact parameter, \( s_\pi = -zb_{rel} \) and \( s_n = (1-z)b_{rel} \) are the coordinates\(^2\) of the pion and the neutron in the impact parameter plane, and \( b_{rel} \) is the relative distance between the pion and the neutron. For the profile functions we use \( \Gamma_{ab}(b) = \sigma_{tot}^{ab}/(4\pi)\Lambda_{ab}^2 \exp[-b^2\Lambda_{ab}^2/2] \). The density factor \( \rho_{\pi n}(z, b_{rel}) \) is the probability to find the pion and the neutron at relative distance \( b_{rel} \) and fixed momentum fraction \( z \).

We calculate the invariant differential cross section assuming that the final state interaction does not modify the transverse momentum distribution of the fragments. We adjust the radius parameters \( R_{lc} \) and \( R_c \) in the light-cone and in the covariant form factors respectively to the experimental data at \( p_t = 0 \).\(^3\) The additional background is included rescaling the pion exchange contribution by a factor 1.2. We find reasonable agreement with the data for a radius squared \( R_{lc}^2 = 0.2 \text{ GeV}^{-2} \) and \( R_c^2 = 0.05 \text{ GeV}^{-2} \), (see fig. \( \square \)). The screening effect can be clearly seen in the same figure, where we plot the \( K \)-factor, i.e. the ratio of the differential cross section with and without absorptive corrections.

3 Cross sections for \( \gamma^*p \rightarrow nX \) and \( \gamma p \rightarrow nX \)

We limit ourselves to forward neutrons in photon induced reactions at small \( x_{Bj} \), as studied at HERA. For small \( x_{Bj} \), we consider the photon as a quark-antiquark state which materializes long before the proton and interacts with

\(^2\)These last relations come from the center-of-mass constraint.
the pion and neutron in the proton wave function. Schematically, we get the inelastic cross section in a form similar to the proton induced cross section

$$\frac{d\sigma}{dz} = \int d^2b_{rel} \rho_{n\pi}(z, b_{rel}) \int dw d^2r |\Psi_{q\bar{q}}(w, r)|^2 \sigma_{tot}^{q\bar{q}\pi}(r)$$

$$\left\{ 1 - \Lambda^2_{eff} \sigma_{tot}^{q\bar{q}n}(r) \frac{\sigma_{tot}^{q\bar{q}\pi}}{2\pi} \exp \left[ - \frac{\Lambda^2_{eff} b_{rel}^2}{2} \right] \right\} \Lambda^2_{eff} = \frac{\Lambda^2_{q\bar{q}\pi} + \Lambda^2_{q\bar{q}n}}{\Lambda^2_{q\bar{q}\pi}}. \quad (3)$$

Here the \(q\bar{q}\) pair wave function is represented by \(|\Psi_{q\bar{q}}(w, r)|^2\) with \(w\) as the momentum fraction of the quark and \(r\) as the \(q\bar{q}\) transverse separation. Note that it does not enter in the magnitude of the screening correction with the same weight as in the direct term. Screening is a strong interaction effect which is a function of \(r\). Eq. (3) can be recast as

$$\frac{d\sigma}{dz} = \int d^2b_{rel} \rho_{n\pi}(z, b_{rel}) \sigma_{tot}^{\gamma^*\pi^+}(1 - \Lambda^2_{eff} \frac{\sigma_{tot}^{q\bar{q}n}}{2\pi} \exp \left[ - \frac{\Lambda^2_{eff} b_{rel}^2}{2} \right]), \quad (4)$$

with \(\sigma_{eff} \equiv \langle \sigma_{tot}^{q\bar{q}n} \sigma_{tot}^{q\bar{q}\pi} / \langle \sigma_{tot}^{q\bar{q}\pi} \rangle = N_0 \frac{1}{F_{p}^2(x_{\pi})} \left( \frac{1}{x_{\pi}} \right)^{\Delta_{eff}} \left( \frac{1}{x_{n}} \right)^{\Delta_{eff}} \). \quad (5)

where we have included the proper scaling variable dependence. We use \(N_0 = 2\) GeV\(^{-2}\) and \(\Delta_{eff} = 0.15\). The low value for \(\Delta_{eff}\) comes from the fact that diffraction and therefore shadowing are dominated by soft processes. For real photons we use \(\sigma_{eff}|_{Q^2=0} \approx 20\) mb. In fig. 3 we plot the integrated photoproduction and deep inelastic energy distributions applying the ZEUS cuts. A shift of the peak to a 50 GeV lower energy in the \(dN/dE_{n}\) for DIS neutron production is visible. This comes from the effective screening in the photoproduction, which
eats up cross section at smaller $z$, making the peak appear at higher energies. At large $Q^2$ screening is reduced but still non negligible. The $K$-factors for $\gamma p \rightarrow nX$ and $ep \rightarrow e'nX$ are shown in fig. 2.

4 Discussion of fragmentation results and validity of the factorization hypothesis

Finally, we compare the screening corrections for the three different cases of proton, real and DIS photon induced semi-inclusive fragmentation reactions. Both proton induced and real photon induced cross sections have $K$-factors differing by about 30% from unity for $z < 0.85$, while for highly virtual photons this effect is reduced. This makes a model-independent extraction of the pion structure function difficult for these $z$-values. Thus semi-inclusive neutron fragmentation, even on the nucleon, seems to be a new channel available for the study of final-state interactions of virtual partons.

References

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