Absorptive corrections to the one pion exchange and measurability of the small-$x$ pion structure function at HERA

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Abstract

We compare the absorptive corrections to the one pion exchange in $pp \rightarrow Xn$ and $ep \rightarrow e'Xn$ reactions. It is shown that the absorption is stronger in the case of $pp$ collision. The difference in strength of the absorption for the $pp \rightarrow Xn$ and $ep \rightarrow e'Xn$ reactions breaks the factorization peculiar to the pure one pion exchange. We evaluate the emerging model dependence of extraction of the small-$x$ pion structure function from an analysis of the HERA data on the neutron production at physical values of $t$. 
1 Introduction

The idea of using pions from the pion cloud of the proton as targets for measuring cross sections of interaction of different projectiles with pions goes back to Chew and Low [1]. For instance, the inclusive reaction $ap \rightarrow nX$ can be viewed as a breakup of the $\pi^-n$ Fock state of the physical nucleon when the projectile $a$ interacts with the $\pi^-$. It has been well established [2, 3, 4, 5] that the pion exchange of Fig. 1a is the dominant mechanism of this inclusive reaction in the region of small transverse momenta $p_\perp^2 \lesssim 0.2-0.3$ GeV$^2$ and $z \sim 0.7-0.9$, where $z = p_{z,m}^c/p_{max}$ is the neutron Feynman variable. The early discussions [6, 7, 8] of this reaction focused on the so-called triple-Regge formalism which is appropriate at high energies and large values of the Regge parameter, $\frac{1}{1-z} \gg 1$.

In terms of the inclusive structure function,

$$f(z, p^2) = \frac{z}{\pi} \frac{d\sigma}{dz dp^2},$$

the pion exchange contribution in the triple-Regge approach reads

$$f^a_\pi(z, p^2) = \frac{g_{pn\pi}^2}{2(2\pi)^3} \frac{|t|}{(t - m_\pi^2)^2} F^2(t)(1 - z)^{1 - 2\alpha'_\pi(t - m_\pi^2)} \sigma_{tot}^a(s_X).$$

Here $g_{pn\pi}^2/4\pi = 27.5$ [1], $\sigma_{tot}^a$ is the $a\pi$ total cross section, $s$ and $s_X = s(1 - z)$ is the $ap$ and $a\pi$ center of mass energy squared, $t$ is the pion momentum squared, $\alpha'_\pi$ is the slope of the pion Regge trajectory, $\alpha_\pi(t) = \alpha'_\pi(t - m_\pi^2)$, and $F(t)$ is the form factor taking into account the off-shell effects. If $s_X \gg 1$ GeV$^2$, i.e., if $\sigma_{tot}^{a\pi}(s_X)$ can be described by the pomeron exchange, then $f^a_\pi(z, p^2)$ is described by the triple-Regge diagram $\pi\pi P$ shown in Fig. 1b.

The salient feature of Eq. (1) is the factorization relation

$$\frac{f^a_\pi(z, p)}{f^{a_1}_\pi(z, p)} = \frac{\sigma^{a_1\pi}_{tot}}{\sigma^{a_2\pi}_{tot}},$$

which for $a_1 = \pi, K$ and $a_2 = p, n$ has been used in practice for determination of the $\pi\pi$ and $K\pi$ total cross sections [3]. As a matter of fact, the factorization relation (2) holds for both the reggeized pion exchange at $1 - z \ll 1$ and the elementary pion exchange at...
somewhat smaller $z$. On the other hand, because the $\pi N$ total cross sections are known from direct measurements, one can use the $pp \rightarrow Xn$ reaction to fix the magnitude and the $t$-dependence of the form factor $F(t)$. Then, this form factor $F(t)$ can be used to extract $\sigma_{tot}^{\pi(K)p}$ from the experimental data on the $\pi(K)p \rightarrow Xn$ reactions using (1). The crucial point about the factorization relation is that at fixed $s_X$ in the r.h.s., the l.h.s. of Eq. (2) must not depend on $z$.

By extension of the factorization relation (2) to the real and/or virtual photons, $a = \gamma, \gamma^*$, one may hope to determine the cross section of real and virtual photoabsorption on pions. In the latter case, there emerges a possibility of measuring the pion structure function $F_2^\pi(x_\pi,Q^2) = Q^2\sigma_{tot}^{\gamma\pi}(x_\pi,Q^2)/4\pi^2\alpha_{em}$, at very low $x_\pi = \frac{x_1}{1-z}$, unaccessible in the Drell-Yan experiments. The measurements of the semi-inclusive $ep \rightarrow e'Xn$ cross section are now in progress at HERA [11], and evaluation of the accuracy of the factorization relation (2) is called upon.

On of limitations on the accuracy of the factorization relation is backgrounds to the pion exchange. The background contributions connected with production of $\pi n$ states through the one pion exchange (Fig. 2) and heavy meson exchanges were estimated in the recent works [10, 12]. The results of Refs. [10, 12] show that in the region $z \sim 0.8$ and $p_\perp^2 \lesssim 0.2 - 0.3$ GeV$^2$ these mechanisms give a relatively small ($\sim 10 - 20\%$) background. This estimate is in a qualitative agreement with the earlier analysis [8], which gives $\sim 20\%$ background for $z \sim 0.8$ at $|t| \sim 0.1 - 0.2$ GeV$^2$. At high $s_X$ both the $\pi\pi P$ and background contributions are proportional to the $\gamma^*\gamma^* P$ coupling. For this reason, at HERA energies, even the 10-20% background will give only a negligible violation of the factorization relation (2). Therefore, one could have concluded that the uncertainties of the determination of the pion structure function from the semi-inclusive $ep \rightarrow e'Xn$ data will not exceed a few percent. This would have made the $ep \rightarrow e'Xn$ reaction competitive with the $\pi N$ Drell-Yan process, the interpretation of which presently involves theoretical uncertainties $\sim 10$ per cent because of the so-called K-factor [13].

Unfortunately, the real situation is more complicated due to the absorption corrections
to the pion exchange mechanism generated by the double reggeon pion-Pomeron exchange shown in Fig. 3. peculiar to the pure pion exchange mechanism. The diagram of Fig. 3 takes into account the initial and final state interaction effects. The absorption is known to suppress considerably the pion pole contribution in hadronic inclusive reactions. Typical estimates for the absorption factor are \( K_{abs} = (f_\pi + f_{abs})/f_\pi \sim 0.4 - 0.7 \), where \( f_{abs} \) is the absorptive correction [14, 15, 16, 17]. The important finding is that the absorption corrections are approximately the same for \( pp \) and \( \pi(K)p \) collisions. For the reference reaction \( p \rightarrow n \) reaction the effect of the absorptive \( K_{abs} \)-factor can be approximately included into the absorption-modified off-shell form factor, \( F_{abs}(t) \). Then, if one takes this absorption-modified form factor from the \( pp \) data, there will be only marginal corrections to the \( \pi(K)p \) cross section determinations based on the triple-Regge formula (1) [18]. However, as we shall argue in the present paper, one must expect substantial reduction of the absorption strength from hadrons to virtual photons. For this reason, one cannot use the effective form factor \( F(t) \) adjusted to the description of \( ap \rightarrow nX \) reactions for an analysis of the \( ep \rightarrow e'nX \), because the so obtained values of \( \sigma^{\gamma^*p}_{tot} \) will be overestimated by a factor \( R(\gamma^*/p) = K_{abs}(\gamma^*p \rightarrow Xn)/K_{abs}(pp \rightarrow Xn) \). In the present paper we perform comparative analysis of absorption in \( ap \rightarrow nX \) and \( ep \rightarrow e'nX \) reactions, and estimate the model dependence of the determinations of \( \sigma^{\gamma^*\pi}_{tot} \) because of the theoretical uncertainties in the absorptive corrections.

Evidently, absorption of the projectile hadron \( a \) and final state \( X \) is strong for impact parameters \( b \lesssim R_p \), where \( R_p \) is the proton radius. The size of the pion cloud around nucleon, \( \lesssim 1/m_\pi \), is comparable to the radius of the proton \( R_p \). Consequently, the pure pion exchange must be considerably modified by the absorption. Unfortunately, at present, a rigorous treatment of the absorptive effects generated by the diagram of the type in Fig. 3 is impossible. In the literature the absorptive effects in the triple-Regge region is commonly described in the framework of Reggeon calculus. The corresponding reggeon diagrams for the pion exchange mechanism are shown in Fig. 4. This approach is motivated by the generalization of the AGK cutting rules [19], derived within \( \lambda\phi^3 \) field theory,
to inclusive reaction in the triple-Regge regime[20]. A nontrivial consequence of the AGK rules is that, after summing over the final states, all the initial and final states interaction effects in the inclusive cross section can be described by the triple-Regge diagrams with additional Pomeron exchanges depicted in Fig. 4, and by the corresponding enhanced diagrams containing the triple-Pomeron coupling $r_{PPP}$. The latter are usually neglected due to smallness of the $r_{PPP}$. The major absorptive effect comes from the graphs of Figs. 4a,b, which correspond to interference of the $\pi$ (Fig. 1a) and $\pi P$ (Fig. 2) exchanges. The diagram of Fig. 4c related to the $\pi P$ exchange amplitude squared gives a relatively small positive contribution to the inclusive cross section.

For hadronic $ap \to Xn$ reaction the contribution of the graphs shown in Fig. 4 in the quasieikonal approximation is given by

$$f_{abs}^a(z, \vec{p}_\perp) = \frac{iC_1}{8\pi^2 s} \int d\vec{k} T_{ap}(\vec{k}) f_{\pi}^a(z, \vec{p}_\perp, \vec{k}),$$

$$f_{abs}^a(z, \vec{p}_\perp, \vec{k}_1, \vec{k}_2) = \frac{g_{\pi\pi P}}{2(2\pi)^3} \left|t_{min}\right| \frac{(\vec{p}_\perp - z\vec{k}_1)(\vec{p}_\perp - z\vec{k}_2)}{z} \left( \Lambda(t_1 - m_{\pi}^2) + \Lambda^*(t_2 - m_{\pi}^2) - \Lambda_{a\pi}(\vec{k}_1 - \vec{k}_2)^2 \right) a_{tot}^a(s_X),$$

where $T_{ap}$ stands for the amplitude of elastic $ap$ scattering (we use normalization $\text{Im} T_{ap}(\vec{k} = 0) = s\sigma_{tot}^{ap}$), $C_{1,2}$ are the shower coefficient for the diagrams of Figs. 4a,b and Fig. 4c, respectively. They are introduced to take into account the inelastic intermediate states in the $a \to a$ and $p \to n$ reggeon vertices. $C_{1,2} = 1$ in the eikonal approximation, when only elastic intermediate states are included. The generalized $\pi\pi P$ structure function $f_{\pi}^a(z, \vec{p}_\perp, \vec{k}_1, \vec{k}_2)$ for nonzero initial proton transverse momenta $\vec{k}_1, \vec{k}_2$ appearing in Eq. (3) is given by

$$f_{\pi}^a(z, \vec{p}_\perp, \vec{k}_1, \vec{k}_2) = \frac{g_{\pi\pi P}}{2(2\pi)^3} \left|t_{min}\right| \frac{(\vec{p}_\perp - z\vec{k}_1)(\vec{p}_\perp - z\vec{k}_2)}{z} \left( \Lambda(t_1 - m_{\pi}^2) + \Lambda^*(t_2 - m_{\pi}^2) - \Lambda_{a\pi}(\vec{k}_1 - \vec{k}_2)^2 \right) a_{tot}^a(s_X),$$

where

$$\Lambda = \alpha' \left[ \log \left( \frac{1}{1 - z} \right) - \frac{i\pi}{2} \right],$$

$$t_i = t_{min} - \frac{(\vec{p}_\perp - z\vec{k}_i)^2}{z},$$
In arriving at the formula (4) we have used the Gaussian parameterization of the amplitude of elastic $a\pi$ scattering, $\text{Im}T_{a\pi}(k) = s_X\sigma_{tot}^a\pi\exp(-\Lambda_{a\pi}k^2)$.

The numerical parameters for the $pp \to Xn$ reaction were fixed as follows. The shower coefficients $C_{1,2}$ can be written in the factorized form $C_1 = C_{PP}C_{P\pi}$ and $C_2 = C_{PPP}C_{P\pi}^2$. Here $C_{PP}(C_{PPP})$ and $C_{P\pi}$ are the shower coefficients for the $a \to a$ double-Pomeron (triple-Pomeron) and $p \to n$ pion-Pomeron blobs in Figs. 4, respectively. The shower coefficient $C_{PP}$ can be extracted from the data on the diffractive process $ap \to a^*p$. For the proton projectile, $a = p$, it has been found that $C_{PP} \approx 1.15$ [21]. The $C_{PPP}$ was estimated in the two-channel approximation, which yields $C_{PPP} \approx 1.09C_{PP}$ [17]. The mass of the $\pi_2(1670)$ meson suggests $\alpha'_{\pi} = 0.7 \text{ GeV}^{-2}$. For the elastic $pp$ scattering amplitude, which enters [3], we take the standard Gaussian approximation, $T_{pp}(k) = (i + \rho)s\sigma_{tot}\exp(-\Lambda_{pp}k^2)$. The useful parameterization for $\sigma_{tot}^a\pi^p(s_X)$ is found in [22], for a good compilation of the diffraction slope data see [23]. The real part of the $pp$ scattering amplitude is small, $\rho \ll 1$, and its impact on absorption corrections is negligible. We take the Gaussian parameterization for the off-shell form factor, $F(t) = \exp[R^2(t - m_{\pi}^2)]$. The two free parameters, $R^2$ and $C_{P\pi}$, were fitted to the experimental data on the $pp \to Xn$ and $pn \to Xp$ reactions. We have used the ISR data [2] on neutron production in $pp$ collision at $p_\perp = 0$, and the results of Refs. [3, 4, 5] on the $p_\perp^2$-integrated cross sections for the $pn \to Xp$ reaction. We included in the fit the experimental points in the interval $0.7 < z < 0.9$. The contribution of the background effects, which can give $\sim 10 - 30\%$ of the experimental cross section at $z \sim 0.8$ [8, 10, 12], is modeled scaling the pion exchange contribution up by the factor 1.2. We are fully aware that this procedure oversimplifies the description of the background. However, because the experimental errors are substantial and because the $z$ and $p_\perp$ dependence of the background is poorly known theoretically, going after more sophisticated parameterizations of the background contribution is not warranted.

A fit to the above described data gives $R^2 = -0.05 \pm 0.08$ and $C_{P\pi} = 0.67 \pm 0.1$, with
\( \chi^2/N \approx 1.65 \) Figs. 5, 6 show that the quality of the fit for in the region \( z \sim 0.7 - 0.9 \) is good. As described above, the theoretical curves calculated with the fitted parameters \( R^2 \) and \( C_{P\pi} \) are scaled up by the factor 1.2 to model the background contribution. The strength of absorption is seen in Fig. 7, in which we show by the \( K_{abs} \)-factor for \( pp \to Xn \) reaction, calculated for \( p_\perp^2 = 0, 0.1, 0.2, 0.3 \) GeV\(^2\) with the fitted parameters \( R^2 \) and \( C_{P\pi} \). Since the absorption only weakly depends on the energy, we show the results only for the incident proton momentum \( p_{lab} = 400 \) GeV/c. Fig. 7 shows that absorption is substantial and gets stronger for smaller \( z \), especially small \( p_\perp^2 \). This effect can be related to the decrease of the \( \pi N \) spatial separation in the impact parameter plane, \( R_{\pi N} \), with the decreasing \( z \). Indeed, the strength of the absorption is to a crude approximation proportional to the parameter \( \sigma_{tot}^m/(\Lambda_{pp} + R_{\pi N}^2) \). Because of non-vanishing \( t_{min} \), the pion propagator takes the form

\[
\frac{1}{t - m_{\pi}^2} = \frac{-z}{p_\perp^2 + zm_{\pi}^2 + m_{p}^2(1 - z)^2},
\]

which gives an estimate

\[
R_{\pi N}^2 \propto \frac{1}{zm_{\pi}^2 + m_{p}^2(1 - z)^2}.
\]

The \( K_{abs} \)-factor decreases with the increase of the transverse momentum, which is naturally related to stronger absorption at small impact parameters.

Strictly speaking, the applicability domain of the above triple-Regge is \( \log \frac{1}{1 - z} \gg 1 \). The elementary pion exchange is more appropriate for \( \log \frac{1}{1 - z} \ll 1 \). The considered region of \( z = 0.7 - 0.9 \) is on the boundary between the reggeized and elementary pion exchanges and, as a matter of fact, the reggeization effects are marginal. The transition from the triple-Regge formulas to the light cone treatment of the elementary pion exchange as expounded in [10,24] is achieved the replacement \( R^2 \to R^2/(1 - z) \) and by putting \( \alpha'_\pi = 0 \).

We checked that such a light cone formalism with \( R^2 = 0.19 \pm 0.07 \) GeV\(^{-2}\), \( C_{P\pi} = 0.75 \pm 0.1 \) provides an equally viable description of the \( pp \) and \( pn \) experimental data in the region \( 0.7 < z < 0.9 \) (\( \chi^2/N \approx 1.88 \)). Consequently, the specific Regge effects do not play any substantial role in this kinematical domain.
Let us now consider the $\gamma^* p \rightarrow Xn$ reaction. We will estimate the $K_{abs}$-factor for this case in two different ways. The first option is to extend to DIS the above outlined reggeon diagram approach. As we shall see, in this case absorption is weak and the contribution from the diagram of Fig. 4c, which is quadratic in the absorption amplitude of Fig. 3, can be neglected. We evaluate the diagrams of Figs. 4a,b assuming that the ratio of the coupling of the Pomeron to the pion and proton equals $\sigma_{\pi p}^{tot}/\sigma_{pp}^{tot} \approx 2/3$. Then, the two-Pomeron blob in Figs. 4a,b can be expressed through the $\gamma^* p \rightarrow Xp$ diffractive cross section, $d\sigma_D^{\gamma^* p}/dk^2$, and the absorptive correction to the pion exchange contribution can be written as

$$f_{abs}(z, \vec{p}_\perp) = -\frac{g_{\pi\pi}^2}{3\pi^3}c_{\pi}\Re e \int d\vec{k} \frac{d\sigma_D^{\gamma^* p}}{dk^2} \exp\left[-(\Lambda_{\pi p} - \Lambda_{pp})k^2\right]$$

$$\times \left[|t_{min}| + \frac{\vec{p}_\perp (\vec{p}_\perp - z\vec{k})}{z}\right] F(t) \exp\left[\Lambda(t - m_{\pi}^2)\right] \left(\frac{t}{t' - m_{\pi}^2}\right) ,$$

where

$$t' = t_{min} - \frac{(\vec{p}_\perp - z\vec{k})^2}{z} .$$

For the $\gamma^* p$ diffraction cross we use the conventional Gaussian parameterization,

$$d\sigma_D^{\gamma^* p}/dk^2 = \sigma_D^{\gamma^* p} B_D \exp(-Bk^2) ,$$

here $\sigma_D^{\gamma^* p}$ is the total diffraction cross section. We take $\sigma_D^{\gamma^* p} = \xi\sigma_{\gamma\gamma}^{tot}$ with $\xi = 0.07$, which correspond to the results of the H1 [25] and ZEUS [26] experiments in the region $Q^2 \sim 10 - 100$ GeV$^2$ and $x \sim 0.001$. For the diffraction slope we take $B_D = 7$ GeV$^{-2}$ according to the measurements performed by the ZEUS Collaboration [27].

The results for the $K_{abs}$-factor for this version of the absorption in the $\gamma^* p \rightarrow Xn$ reaction are shown in Fig. 7 by the dashed lines. The departure of the $K_{abs}$ from unity is much smaller that for the $pp \rightarrow nX$ reaction, which is better seen in Fig. 8 where we show the ratio $R(\gamma^* / p) = K_{abs}(\gamma^* p \rightarrow Xn)/K_{abs}(pp \rightarrow Xn)$. The departure of $R(\gamma^* p)$ from unity signals a strong factorization breaking. Weak absorption for $\gamma^* p \rightarrow Xn$ is predicted because in the reggeon calculus the combined effect of the initial and final state interactions effects is described by the rescattering of the initial particles. In DIS the strength of initial state rescattering is proportional to the small ratio $\xi = \sigma_D^{\gamma^* p}/\sigma_{\gamma\gamma}^{tot} \approx 0.07$. 

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The counterpart of this parameter for the projectile proton is the ratio $(\sigma_{el}^{pp} + \sigma_{D}^{pp})/\sigma_{tot}^{pp} \approx 0.25$, which is by a factor $\sim 3-4$ larger because of the contribution of elastic rescatterings.

The caveat of the above reggeon calculus estimate is that the status of the AGK rules in QCD remains open. Its applicability is especially questionable in the $\gamma^* p \to Xn$ reaction. In QCD one can expect that the final state interaction effects in this reaction will be approximately as strong as in the $pp \to Xn$ reaction, and now we comment more on this option. Indeed, the final state $X$, created in DIS after color exchange between the hadronic $q\bar{q}$ Fock component of the virtual photon and the pion, looks like a color octet-octet system, $X_{DIS} = (q\bar{q})_8(q\bar{q})_8$. In the $pp$ collision, similar color exchange between the proton and pion creates $X_{pp} = (qqq)_8(q\bar{q})_8$. The both color octet-octet states will have a similar transverse size, perhaps by a factor $\sim \sqrt{2}$ larger for the $X_{pp}$ state. Consequently, the strength of the final state interaction of the state $X_{DIS}$ with the spectator neutron will be as large as $\sim \frac{1}{2}$ of that of the state $X_{pp}$ in the $pp$ collision. The initial state interaction in the $\gamma^* p$ case for the most part comes from the well known asymmetric $q\bar{q}$ configurations in the virtual photon light-cone wave function [28], which dominate the leading twist photon diffraction cross section. Precisely as in the above reggeon calculus considerations, the absorptive effects for these $q\bar{q}$ configurations are suppressed by a factor $\sim 3-4$ as compared to those in the $pp$ collision. Thus, in QCD one can expect a significant enhancement of the absorptive effects in the $\gamma^* p \to Xn$ process as compared to prediction of the reggeon calculus. For the numerical estimate of the absorptive $K$-factor for the $\gamma^* p \to Xn$ reaction in this, QCD motivated, version one can use the formulas of the reggeon diagram approach for the $pp \to Xn$ reaction taking for the $C_{P\pi}$ a value two times smaller than that for the $pp \to Xn$ reaction. The results are presented in Figs. 7, 8 by the long-dashed lines and show weaker factorization breaking. The difference between the $R(\gamma^*/p)$ for the two versions of absorption, and especially variations of $R(\gamma^*/p)$ with $z$ and $p^2_\perp$, indicate the degree of model dependence of extraction of the pion structure function from the $\gamma^* p \to Xn$ data. Even in the region $z \sim 0.7-0.9$ and $p^2_\perp \lesssim 0.3 \text{ GeV}^2$, which is optimal from the point of view of the dominance of the pion exchange, the uncertainties
for the model dependence of absorption can be as large as \( \sim 20 \) per cent, exceeding the potential background corrections.

In principle, all the problems with the parameterization of the off-shell form factor and with the absorptive factor could have been eliminated if an extrapolation to the Chew-Low unphysical point \( t = m^2_\pi \) were possible. It is interesting to find out whether the determination of \( \sigma_{tot}^{\gamma^*\pi} \) by such a Chew-Low extrapolation is practically feasible. To this end we performed the following theoretical experiment. We approximate the \( t \)-dependence of the absorptive \( K \)-factor in the region \( p^2_\perp < 0.1 \text{ GeV}^2 \) by a polynomial \( K_{abs} = a_0 + a_1 t + a_2 t \). We checked that in the studied range of \( z \) an accuracy of such a parameterization is better than 1%. Then, making use of this parameterization we extrapolate the absorptive \( K_{abs} \)-factors from the physical scattering domain, \( t \leq t_{min} \), to the unphysical pion pole, \( t = m^2_\pi \). In the ideal case, the absorptive factor \( K_{abs} = (f_{\pi} + f_{abs})/f_{\pi} \) must extrapolate to unity at the pion pole. The results are shown in Fig. 9. The smaller is the \( z \), i.e., the larger is \( |t|_{min} \), the poorer is extrapolation. It is seen that in the case of the \( \gamma^*p \rightarrow Xn \) reaction the extrapolated \( K_{abs} \)-factor equals 0.9-0.95 at \( z \sim 0.8 \), while for the \( pp \rightarrow Xn \) reaction it is \( \sim 0.8 \). We conclude that the Chew-Low extrapolation is a very delicate procedure, and it hardly can be used in practice for a model independent extraction of \( \sigma_{tot}^{\gamma^*p} \).

The detection of neutrons from interaction of the proton beam with the residual gas in the HERA ring, \( pA \rightarrow nX \), provides a useful \textit{in situ} test of the performance of neutron detectors of ZEUS and H1 \cite{11}. However, because of the intranuclear absorption and intranuclear rescatterings of beam proton and produced neutrons, the effective form factor \( F_A(t) \) which one can deduce from the \( pA \rightarrow nX \), neither equals the form factor \( F(t) \) for the \( pp \) reaction, nor can it be used as an input in the analysis of the \( ep \rightarrow e' nX \) data. Consequently, the beam-gas interaction data cannot reduce the uncertainty in \( R(\gamma^*/p) \).

To summarize, with the present state of the theory of absorptive corrections, the above cited uncertainties in \( R(\gamma^*/p) \) and, consequently, in the absolute normalization of the extracted pion structure function, cannot be reduced. None the less, \( \gamma^*p \rightarrow nX \)
reaction will provide a useful information on the $x$ dependence of the pion structure function. For instance, if the $x$-dependence of the pion structure function $F_{2\pi}(x, Q^2)$ in the accessible region of $x \lesssim 10^{-4}$ is as strong as that of the proton structure function, then this $x$-dependence cannot be masked by the uncertainties in the evaluation of absorption corrections. On the large-$x_\pi$ end, $x_\pi \sim 0.1$, one can check a consistency with the Drell-Yan data [29].

Finally, a comment on the impact of absorption effects on evaluations [10, 24] of the mesonic corrections to the flavor content of the proton structure function is in order. In these calculations, the normalization of the form factor $F(t)$ has been deduced from the experimental data on $pp \rightarrow Xn$ reaction neglecting the absorption corrections. Because the absorption corrections are stronger for the proton projectile than in DIS, such a simplified analysis underestimates the effect of mesons in the proton structure function. If the allowance for absorption is made, then the mesonic contributions to the proton structure function will be enhanced by a factor $\sim R(\gamma^*/p)$. Here we wish to emphasize that because $t_{\min} = -(m_\Delta^2 - m_n^2)(1 - z) + m_n^2(1 - z)^2$ for the $pp \rightarrow \Delta X$ reaction is larger than for the $pp \rightarrow nX$ reaction, the absorption corrections in the $\pi\Delta$ state are stronger and the corresponding $R(\gamma^*/p)$ will be larger. This entails the larger contribution from the $\pi\Delta$ Fock state to the proton structure function than estimated before. This effect can be of great importance from the point of view of the Gottfried sum rule violation and the $\bar{u}-\bar{d}$ asymmetry in the proton, which are sensitive to delicate cancelation between the $\pi N$ and $\pi\Delta$ contributions [24]. An analysis of this problem with allowance for the absorption effects will be presented elsewhere.

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Figure Captions

Fig.1 The pion exchange amplitude for the $ap \rightarrow Xn$ reaction (a) and the corresponding triple-Regge diagram for the inclusive cross section (b).

Fig.2 The pion exchange mechanism for the background $ap \rightarrow X\pi n$ reaction with production of the $n\pi$ system.

Fig.3 The absorptive pion-Pomeron exchange amplitude for the $ap \rightarrow Xn$ reaction.

Fig.4 The reggeon diagrams for absorption corrections to the $\pi\pi P$ diagram of Fig. 1b for the inclusive cross section.

Fig.5 The $z$-distribution at $p_\perp = 0$ for the $pp \rightarrow Xn$ reaction. The theoretical curves correspond to the contribution from the absorption corrected pion exchange, scaled up by the factor 1.2 as described in the text. The experimental data from the ISR experiment [2].

Fig.6 The inclusive cross section for the $pn \rightarrow Xp$ reaction for different $|t|$ bins versus $z$ at:

(a) $p_{lab} = 100$ GeV/c [3] for $0.05 < |t| < 0.25$ GeV$^2$ (full circles) and $0.25 < |t| < 0.55$ GeV$^2$ (full quadrangles), (b) $p_{lab} = 195$ GeV/c [4] for $|t| < 1.4$ GeV$^2$, (c) $p_{lab} = 100$ GeV/c [3] for $|t| < 1$ GeV$^2$, (c) $p_{lab} = 400$ GeV/c [3] for $|t| < 1$ GeV$^2$. The theoretical curves are the same as in Fig. 6.

Fig.7 The absorptive $K_{abs}$-factor versus $z$ for $p_{\perp}^2 = 0$ (a), $p_{\perp}^2 = 0.1$ (b), $p_{\perp}^2 = 0.2$ (c) and $p_{\perp}^2 = 0.3$ (d) GeV$^2$. The solid lines correspond to the $pp \rightarrow Xn$ reaction at $p_{lab} = 400$ GeV. The dashed lines show the prediction of the reggeon calculus approach for the $\gamma^*p \rightarrow Xn$ reaction at HERA energies, the long-dashed ones correspond to estimate of the $K_{abs}(\gamma^*p \rightarrow Xn)$ for the QCD motivated version of the absorption discussed in the text.

Fig.8 The ratio $R = K_{abs}(\gamma^*p \rightarrow Xn)/K_{abs}(pp \rightarrow Xn)$ versus $z$. The legend of boxes, i.e., values of $p_{\perp}^2$, and the legend of curves are same as in Fig. 7.
Fig.9 The polynomial extrapolation of the absorptive $K_{abs}$-factor to the Chew-Low point $t = m^2_\pi$ versus $z$. The legend of curves the same as in Fig. 7.
\[ s^{1/2} = 30.6 \text{ GeV} \]

\[ \frac{E \mathrm{d}^3 \sigma}{d^3 \mathbf{p}}, \text{ mb/GeV}^2 \]
$K_{abs}(z,t=m^2_{\pi})$