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Abstract

Following a suggestion of Ingelman and Schlein, we examine the possibility of investigating the pomeron's quark structure through a deep inelastic electroproduction measurement performed at an ep collider such as HERA, using a tagging device for protons scattered very close to 0° and with small relative energy loss.

Résumé

Suivant une suggestion d'Ingelman et Schlein, nous examinons la possibilité d'étudier la structure en quarks du poméron dans une expérience d'électroproduction profondément inélastique, réalisée auprès d'un collisionneur ep tel que HERA, où l'on utiliserait un système d'étiquetage pour les protons diffusés à un angle très voisin de 0° et avec une faible perte relative d'énergie.

Following a suggestion of Ingelman and Schlein [1], we recently examined the possibility of probing the gluonic structure of the pomeron with quasi-real photons, i.e. through the process $ep \rightarrow ep + 2$ jets + X taking place at an ep collider such as HERA [2]. We assumed that tagging of the proton scattered very close to 0° can be realized at the collider [3]. A tagging device of that kind, selecting elastically scattered protons should indeed allow one to use the incident proton either as a generator of quasi-real photons, thus measuring various QED reactions, such as $\gamma e \rightarrow \gamma e$ or $\gamma e \rightarrow \ell^+ \ell^- e$, which might in particular be used for calibration; or as a pomeron generator, in order to investigate electron-pomeron collisions leading to multihadron production. The latter variant is obviously the more promising one.

We here consider (Fig. 1) the configuration involving deep inelastic electron-pomeron scattering, i.e. the exchange of a virtual photon with high Q^2 in order to probe the pomeron's quark structure. Let us remark that, while a number of theoretical models favour a multigluon structure of the pomeron [4], the latter may be assumed to contain quarks as well, at least virtually through its gluon constituents.

The mechanism shown in Fig. 1 is analogous to the one used for determination of the photon's structure function at e^+e^- colliders. The differential cross section is computed similarly:

$$d\sigma^{ep \rightarrow epX} = f_{\mathbb{P}/p}(z)\,dz \sum_q \left[f_{q/\mathbb{P}}(x,Q^2) + f_{\bar{q}/\mathbb{P}}(x,Q^2) \right] dx \, \frac{d\hat{\sigma}^{eq \rightarrow eq}}{dQ^2}(\hat{s},Q^2)\, dQ^2$$

where z is the fractional momentum of the pomeron in the proton; x is the usual scaling parameter, i.e. $x = Q^2/(W^2 + Q^2)$, where W is the total hadronic invariant mass produced in the $\gamma^* \mathbb{P}$ collision; $f_{\mathbb{P}/p}(z)$ describes the pomeron distribution in the proton, while $f_{q/\mathbb{P}}(x,Q^2)$ (resp. $f_{\bar{q}/\mathbb{P}}(x,Q^2)$) defines the quark (resp. antiquark) distribution in the pomeron; $\hat{s} = z \times s$, where $s^{1/2}$ is the total c.m. energy of the ep collider; finally $\sum_q$ means summing over quark flavors. One easily gets (with massless quarks, and neglecting the contribution of Z° exchange):

$$\frac{d\hat{\sigma}^{eq \rightarrow eq}}{dQ^2}(\hat{s},Q^2) = \frac{4\pi\alpha^2 e_q^2}{Q^4}\left(1 - y + \frac{y^2}{2}\right)$$

defining $y = Q^2/\hat{s}$. One thus obtains

$$\frac{d\sigma^{ep\to epX}}{dz\,dx\,dy} = f_{\mathbb{P}/p}(z)\; F_2^{\mathbb{P}}(x,Q^2)\; \frac{4\pi\alpha^2 s}{Q^4}\left(1-y+\frac{y^2}{2}\right)$$

where $F_2^{\mathbb{P}}(x,Q^2) = x\sum_q e_q^2\left[f_{q/\mathbb{P}}(x,Q^2) + f_{\bar{q}/\mathbb{P}}(x,Q^2)\right]$

Provided $f_{\mathbb{P}/p}(z)$ is known, the pomeron's structure function $F_2^{\mathbb{P}}(x,Q^2)$ can thus be extracted from the measurement. An empirical expression of $f_{\mathbb{P}/p}(z)$ may be taken from Ref. 1:

$$f_{\mathbb{P}/p}(z) = \frac{3.4}{z}\int_{t_{min}}^{t_{max}}\left(e^{-5.6\,t} + 0.04\,e^{-2t}\right)A(z,t)\,dt,$$

where t is the absolute value (in GeV^2) of the proton's four-momentum transfer squared, and A(z,t) is the acceptance factor of the proton tagging system.

In a multigluon model the quark (resp. antiquark) distribution in the pomeron is given by convolution, i.e.

$$f_{q/\mathbb{P}}(x,Q^2) = \int^1 f_{g/\mathbb{P}}(u,Q^2)\, f_{q/g}(x/u,Q^2)\,\frac{du}{u}$$

(resp. a similar expression for $f_{\bar{q}/\mathbb{P}}(x,Q^2)$). [a]

For $f_{g/\mathbb{P}}(u,Q^2)$ we shall use the two scale-invariant models proposed in Ref. 1, i.e.

"hard" $\quad f_{g/\mathbb{P}}(u) = 6(1-u)$

"soft" $\quad f_{g/\mathbb{P}}(u) = \frac{6}{u}(1-u)^5$

Taking $f_{q/g}(x/u,Q^2)$ and $f_{\bar{q}/g}(x/u,Q^2)$ as given by lowest-order QCD (the box diagram), i.e.

$$f_{q/g}(v,Q^2) = f_{\bar{q}/g}(v,Q^2) \simeq \frac{\alpha_s}{4\pi}\left[v^2+(1-v)^2\right]\ln\frac{Q^2}{\Lambda^2} \simeq \frac{3}{33-2n_f}\left[v^2+(1-v)^2\right]$$

and summing over u, d, s, c quark flavors, we get the scale-invariant structure function $F_2^{\mathbb{P}}(x)$ shown in Fig. 2 for both pomeron models.

In addition we have computed the integrated cross section, using the above-written formulas and assuming the following values for the total energy, the tagging parameters and additional experimental cut-offs: $s = 10^5$ GeV^2; $t_{min} = 0$; $t_{max} = 0.2$; $z_{min} = 0.01$; $z_{max} = 0.1$; $A(z,t) = 1$; $Q^2_{min} = 25$ GeV^2; $W^2_{min} = 25$ GeV^2. With the two pomeron models considered, we obtain the predictions:

"hard" $\sigma^{ep\to epX} = 3.1$ nb

"soft" $\sigma^{ep\to epX} = 7.6$ nb

Fairly high counting rates may thus be expected, except if there are drastic additional restrictions on experimental acceptance, or of course if our theoretical assumptions based on Ref. 1 are wrong. It should also be noticed that in such an experiment all final state particles could be measured, except for hadrons escaping along the beam axis; it results that, in particular, the W (resp. x) distribution can be obtained in two different ways: either through the inclusive measurement of W or, as in F_2^{γ} measurements [5], by unfolding from the W_{vis} (resp. x_{vis}) distribution.

A similar investigation of the pomeron's structure may be performed using a charged vector boson, instead of the photon, as a probe (Fig. 3). Experimentally, events produced by that mechanism would be characterized by a large missing transverse momentum. We may assume that, using unfolding techniques, it should be possible to derive the (x,y) distributions from the measurement of the visible parameters of the hadron system produced.

With the same notations as above, one here gets

$$d\sigma^{ep\to\nu pX} = f_{\mathbb{P}/p}(z)\,dz\Big[\sum_q \hat{f}_{q/\mathbb{P}}(x,Q^2)\,dx\,\frac{d\sigma^{eq\to\nu q'}}{dQ^2}(\hat{s},Q^2)\,dQ^2 + \sum_{\bar{q}} f_{\bar{q}/\mathbb{P}}(x,Q^2)\,dx\,\frac{d\sigma^{e\bar{q}\to\nu\bar{q}'}}{dQ^2}(\hat{s},Q^2)\,dQ^2\Big]$$

where the sums are taken over q = u, c and $\bar{q} = \bar{d}, \bar{s}$. From

$$\frac{d\sigma^{eq\to\nu q'}}{dQ^2}(\hat{s},Q^2) = \frac{16\pi\alpha_W^2}{(m_W^2+Q^2)^2}$$

$$\frac{d\sigma^{e\bar{q}\to\nu\bar{q}'}}{dQ^2}(\hat{s},Q^2) = \frac{16\pi\alpha_W^2}{(m_W^2+Q^2)^2}(1-y)^2$$

where m_W is the mass of the $W^{\pm}$ boson, while the epW coupling constant is defined as $e_W = (4\pi\alpha_W)^{1/2}$, we obtain

$$\frac{d\sigma^{ep\to\nu pX}}{dz\,dx\,dy} = z\,f_{\mathbb{P}/p}(z)\Big[x\sum_q f_{q/\mathbb{P}}(x,Q^2) + (1-y)^2 x\sum_{\bar{q}} f_{\bar{q}/\mathbb{P}}(x,Q^2)\Big]\frac{16\pi\alpha_W^2 s}{(m_W^2+Q^2)^2}$$

$$= z\,f_{\mathbb{P}/p}(z)\Big[\Big(1-y+\frac{y^2}{2}\Big)\tilde{F}_2^{\mathbb{P}}(x,Q^2) + \Big(y-\frac{y^2}{2}\Big)x\,\tilde{F}_3^{\mathbb{P}}(x,Q^2)\Big]\frac{8\pi\alpha_W^2 s}{(m_W^2+Q^2)^2}$$

where we define the pomeron's weak-interaction structure functions (in analogy with e.g. the proton's structure functions determined from deep inelastic νp, $\bar{\nu} p$ scattering) as

$$\tilde{F}_2^{I\!P}(x,Q^2) = 2x\left[\sum_q f_{q/I\!P}(x,Q^2) + \sum_{\bar{q}} f_{\bar{q}/I\!P}(x,Q^2)\right]$$
$$\tilde{F}_3^{I\!P}(x,Q^2) = 2\left[\sum_q f_{q/I\!P}(x,Q^2) - \sum_{\bar{q}} f_{\bar{q}/I\!P}(x,Q^2)\right]$$

On the basis of a multigluon model, and actually of any reasonable model for the pomeron, one should expect to find: $\tilde{F}_2(x,Q^2) = F_2(x,Q^2)/(\sum_q e_q^2)$; $\tilde{F}_3(x,Q^2) = 0$.

With the same models and numerical assumptions as above, one here obtains for the integrated cross section:

"hard" $\sigma^{ep \to \nu pX} = 1.02$ pb

"soft" $\sigma^{ep \to \nu pX} = 0.94$ pb

The corresponding yields may still be sufficient to justify a measurement of the process considered.

To finish, let us emphasize that, while of course our calculations are model dependent, the suggestion presented is not based on any theoretical pre-assumption regarding the pomeron. We simply consider that it may be interesting to investigate the quark structure of the object, whatever it is, that bears the quantum numbers of the vacuum and is exchanged in the elastic scattering of a proton in strong-interaction processes.

Footnote

a We implicitly assume that the pomeron interacts via one of its gluon constituents, while the other(s) play the role of spectator(s). There are other theoretical models in the literature, where a multigluonic pomeron interacts as a whole [6].

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Figure captions

Fig. 1. Feynman graph for the reaction $ep \rightarrow epX$ involving deep inelastic $e\mathcal{P}$ scattering, mediated by a virtual photon.

Fig. 2. The function $F_2^{\mathcal{P}}(x)$ defining the pomeron's quark structure, as computed on the basis of the "hard" and "soft" multigluon models of Ref. 1 and by using lowest-order QCD to describe the quark content of a gluon. Solid line: "hard"; dash-dotted line: "soft".

Fig. 3. Feynamn graph for the reaction $ep \rightarrow \nu pX$ involving deep inelastic $e\mathcal{P}$ scattering, mediated by a W^- vector boson.

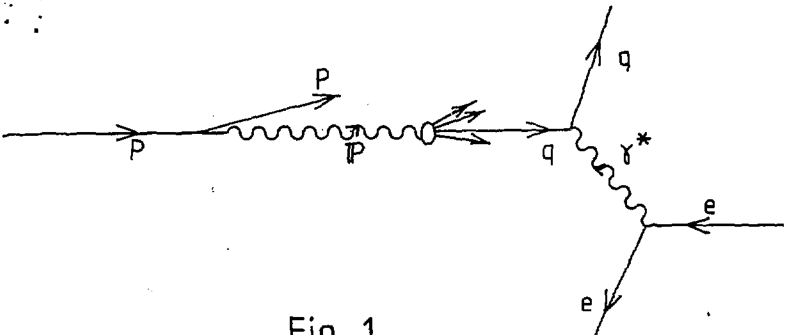

Fig. 1

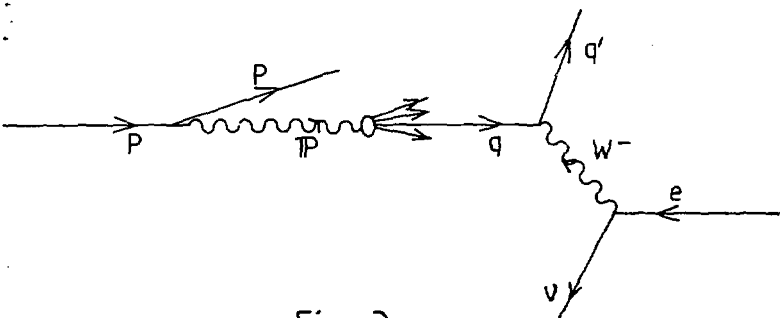

Fig. 3

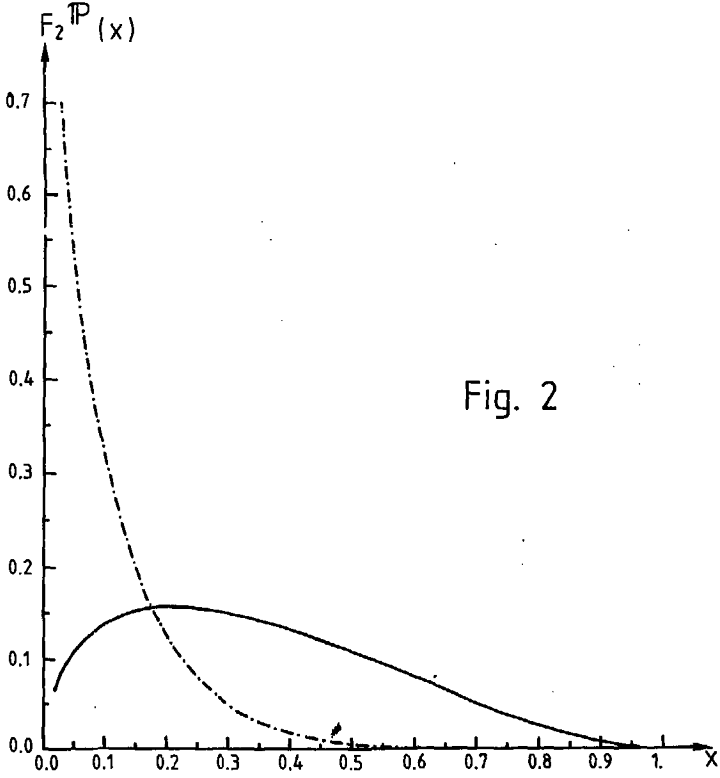

Fig. 2