

Introduction to the Pomeron Structure Function

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Abstract

In many ways the pomeron is like the photon, but there are important differences. Factorisation allows us to define a pomeron structure function, even though the pomeron is not a particle. Although we have a model for the light-quark content of the pomeron, which led to the prediction that a surprisingly large fraction of events at HERA would have an extremely-fast final-state proton, its charm and gluon content will have to be got from experiment. Because the pomeron is not a particle, we cannot derive a momentum sum rule.

Résumé

A bien des égards le pomeron est comme le photon, mais il y a d'importantes différences. La factorisation nous permet de définir une fonction de structure du pomeron, même si le pomeron n'est pas une particule. Bien que nous ayons un modèle du contenu en quarks légers du pomeron, qui a conduit à la prédiction qu'une étonnamment grande fraction des événements à HERA aurait un proton dans l'état final extrêmement rapide, son contenu en gluon et en quarks charmés devra être obtenu à partir des expériences. Parce que le pomeron n'est pas une particule, nous ne pouvons pas dériver une règle de sommation des impulsions.

1. Definition of the Pomeron Structure Function

This introduction to the pomeron structure function applies to the soft pomeron, whose exchange is responsible for the $s^{0.08}$ rise in total cross-sections [3]. See for example figure 1, which shows the γp cross-section: the curve is the sum of an $s^{0.08}$ term corresponding to the soft pomeron and an $s^{-0.45}$ term corresponding to (ρ, ω, f_2, a_2) exchange. I do not know to what extent my discussion may apply to any other pomeron, whether it be a less soft one [4][5] or a hard one. The data for elastic scattering and diffraction dissociation in pp and $\bar{p}p$ collisions are described extremely well[6] by supposing that soft pomeron

exchange is similar to photon exchange. For photon exchange between a pair of quarks, the amplitude is

$$\gamma \cdot \gamma e^2 \left[\frac{1}{t} \right] \quad (1a)$$

while for soft pomeron exchange it is

$$\gamma \cdot \gamma \beta_0^2 \left[(\alpha' s)^{\alpha(t)-1} \xi_{\alpha(t)} \right] \quad (1b)$$

Thus the charge e is replaced by a constant pomeron coupling $\beta_0 \approx 2\text{GeV}^{-1}$, and the photon propagator is replaced by the expression in square brackets which is something like a pomeron propagator. Here

$$\alpha(t) = 1 + \epsilon + \alpha' t \epsilon \approx 0.08 \quad \alpha' = 0.25\text{GeV}^{-2} \quad (2)$$

and ξ_{α} is a phase factor $-e^{\frac{1}{2}i\pi\alpha}$.

Although photon and pomeron exchange have similarities, there is a crucial difference. The photon

* Based on talks given in April 1995 at Photon '95(Sheffield) and DIS '95(Paris)

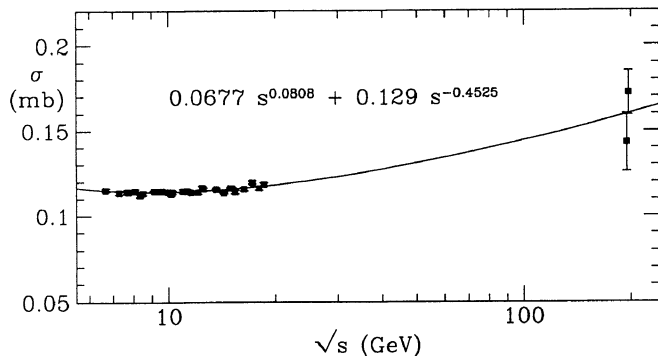


Figure 1. γp total cross-section

propagator has a pole at $t = 0$ because there is a real zero-mass photon, but there is no pole at $t = 0$ in the pomeron propagator because the pomeron is not a particle. We do expect to find a 2^{++} particle, probably a glueball, with mass m such that $\alpha(m^2) = 2$, but this particle would have $m \approx 1.9$ GeV and so it has no direct influence on the properties of pomeron exchange near $t = 0$. (However, it is interesting that the WA91 collaboration has reported a 2^{++} glueball candidate with just this mass[7][6].)

Consider now the proton structure function F_2^{proton} . Being related to the total $\gamma^* p$ cross-section, it corresponds to a sum over all possible final states. In some small fraction of events, there is an extremely fast proton in the final state[1]. Such events contribute to $F_2^{\text{proton}}(x, Q^2)$ a part which we call $F_2^{\text{diffractive}}(x, Q^2)$. In order to define this we must decide what we mean by an “extremely fast” proton, that is we must specify the maximum fraction ξ of its longitudinal momentum we allow it to lose to include the event. Alternatively, rather than summing over ξ up to some maximum value, we may introduce ξ as an extra variable into $F_2^{\text{diffractive}}$, and in fact it is useful to introduce also the momentum transfer t between the initial and final protons: $F_2^{\text{diffractive}} = F_2^{\text{diffractive}}(x, Q^2, \xi, t)$.

This definition of $F_2^{\text{diffractive}}$ does not mention the pomeron. By interpreting it in terms of pomeron exchange we find that it has some simple properties: it

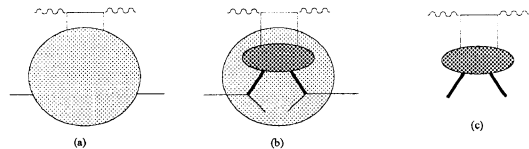


Figure 2. The parton model: (a) F_2^{proton} (b) $F_2^{\text{diffractive}}$ and (c) F_2^{pomeron} . The black lines represent the pomeron.

is leading twist (and so varies only slowly with Q^2), and it factorises[8]. In the simple parton model[13], which is a good approximation at not-too-large Q^2 , F_2^{proton} corresponds to the diagram in figure 2a. The lower bubble is the amplitude that gives the probability of finding a quark in the proton. It includes all possible nonperturbative contributions. In drawing figure 2a I have used the optical theorem: if we cut the diagram down the middle we reveal the final states. A part of the bubble corresponds to those final states that contain an extremely fast proton, and if we take that part we obtain the diagram of figure 2b. As I have said, this part is leading twist.

The thick lines represent the pomeron. The momentum it carries away from the proton is just $\xi p + \dots$. In recognition of this it is nowadays usual to rename ξ and instead call it x_P . Soft pomeron exchange has a factorisation property, which yields

$$\begin{aligned} \frac{d^2}{dt dx_P} F_2^{\text{diffractive}}(x, Q^2, x_P, t) &= F_{P/p}(t, x_P) F_2^{\text{pomeron}}(\beta, Q^2, t) \\ \beta &= x/x_P \\ F_{P/p}(t, x_P) &= \frac{9\beta_0^2}{4\pi^2} [F_1(t)]^2 x_P^{1-2\alpha(t)} \end{aligned} \quad (3)$$

Here F_1 is the Dirac elastic form factor of the proton.

2. Momentum sum rule

We may regard $F_{P/p}(t, x_P)$ as the flux of pomerons emitted by the proton, and F_2^{pomeron} as the structure function of the pomeron. In the parton model, F_2^{pomeron} is just the upper part of figure 2b, drawn in figure 2c. Figure 2c looks just like figure 2a, with the initial-state proton apparently replaced by an initial-state pomeron. However, there is no *particle* called the pomeron; figure 2c rather makes sense because of the factorisation property (3).

In fact, because there is no pomeron particle near $t = 0$, this factorisation is not uniquely defined. I think that (3) is the most natural way to define it[8], but we could just as well multiply one of the factors in (3) by any number N and the other by $1/N$. Indeed, the choice

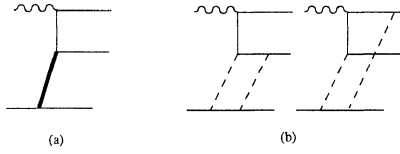


Figure 3. (a) box contribution to F_2^{pomeron} . The black lines represent the pomeron. (b) the equivalent when pomeron exchange is modelled by two-gluon exchange.

$N = \frac{1}{2}\pi$ is found in the literature[9][4]. Because of this ambiguity, one cannot derive a momentum sum rule for F_2^{pomeron} : if such a sum rule were to be satisfied for some choice of N , obviously it would not be for any other choice. One cannot derive a momentum sum rule because the pomeron is not a particle.

3. Simple model for the pomeron structure function

I have said that the pomeron in some ways resembles the photon, and so one expects that it has a quark structure function something like that of the photon, in that it consists of two pieces at not-too-large Q^2 : one that can be calculated from a simple box diagram and another that is not calculable and is most important at small β .

The box contribution corresponds to figure 3a. The simplest model for pomeron exchange is that it corresponds to the exchange of a pair of nonperturbative gluons[10]. Then figure 3a becomes the sum of the two diagrams in figure 3b. Together these give[8][11]

$$\beta q^{\text{pomeron}}(\beta) = C\beta(1 - \beta) \quad (5)$$

where $C \approx 0.2$ for each light quark and each light antiquark. This formula provided the remarkable prediction, nearly 10 years ago[8], that some 10% of HERA events would have a very fast final-state proton.

The other piece[8] of the pomeron quark structure function resembles the ρ -like contribution to the photon structure function, and so is most important for small β , where it behaves as $\beta^{-\epsilon}$. If β is not too small, one expects that $\epsilon = 0.08$, as for the proton structure function[12]. But for extremely small β one would expect the same to happen as with F_2^{proton} , and see a marked increase in the effective value of ϵ .

4. Scaling violation and related issues

Even though the pomeron is not a particle, the factorisation that leads to figure 2c makes it

natural[8][14] to write an evolution equation for F_2^{pomeron} similar to that for F_2^{proton} , as if the pomeron were the initial state. For this, one needs an input gluon distribution $g^{\text{pomeron}}(\beta)$ at some initial Q^2 value. One might guess that its shape is not too different from that of $q^{\text{pomeron}}(\beta)$, but this is just a guess. Further, we have no model that tells us how large it is. Experiment will be important here, for example high- p_T jet production in real-photon diffractive events, the analogue of the UA8 experiment at the CERN $\bar{p}p$ collider[2].

We also need to know what is the initial charmed-quark content of the pomeron. Again we have no reliable model, and so experiment will be important. The coupling of the pomeron to quarks could be rather flavour-blind, so that the c -quark content might be quite large even at quite small Q^2 , but even if the coupling is flavour-blind there may be a suppression because of the mass[11]. We do not know.

Acknowledgements

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