QCD analysis of the diffractive structure functions measured at HERA and factorisation breaking at Tevatron

C. Royon [a]

[a]DAPNIA/SPP, Commissariat à l'Energie Atomique, Saclay,
F-91191 Gif-sur-Yvette Cedex

The 1994 data published by the H1 collaboration are compared with models based on Regge phenomenology. The $x_{I\!P}$ dependence of the data can be described in a model based on the exchange of a dominant diffractive (pomeron) trajectory with additional sub-leading reggeon contributions. The dynamics of the Pomeron structure is studied within the framework of perturbative QCD and new parton distributions are obtained. These parton distributions will allow a direct test of factorisation breaking at Tevatron.

1. Regge parametrization

The 1994 data are first investigated in the framework of a Regge phenomenological model [1]. The 1994 data are subjected to a fit in which a single factorisable trajectory ($I\!P$) is exchanged such that:

$$F_2^{D(3)}(Q^2,\beta,x_{I\!P}) = f_{I\!P/p}(x_{I\!P}) F_2^{I\!P}(Q^2,\beta) \ . \qquad (1)$$

In this parameterization, $F_2^{I\!P}$ can be interpreted as the structure function of the pomeron [4]. The value of $F_2^{I\!P}$ is treated as a free parameter at each point in β and Q^2. The pomeron flux takes a Regge form with a linear trajectory $\alpha_{I\!P}(t) = \alpha_{I\!P}(0) + \alpha'_{I\!P} t$, such that

$$f_{I\!P/p}(x_{I\!P}) = \int_{t_{cut}}^{t_{min}} \frac{e^{B_{I\!P} t}}{x_{I\!P}^{2\alpha_{I\!P}(t)-1}} \mathrm{d}t \ , \qquad (2)$$

where $|t_{min}|$ is the minimum kinematically allowed value of $|t|$ and $t_{cut} = -1$ GeV^2 is the limit of the measurement. The value of $\alpha_{I\!P}(0)$ is a free parameter and $B_{I\!P}$ and $\alpha'_{I\!P}$ are taken from hadron-hadron data [1]. The fit with a single trajectory does not give a good description of the data in the same way as it is observed at $Q^2 = 0$ [2] that secondary trajectories in addition to the pomeron are required to describe diffractive ep data.

A much better fit is obtained when both a leading ($I\!P$) and a sub-leading ($I\!R$) trajectory are considered in the same way as in formula (1), where the values of $F_2^{I\!P}$ and $F_2^{I\!R}$ are treated as free parameters at each point in β and Q^2, $\alpha_{I\!P}(0)$ and $\alpha_{I\!R}(0)$ being two free parameters. The flux factor for the secondary trajectory takes the same form as equation (2), with $B_{I\!R}$, and $\alpha'_{I\!R}$ again taken from hadron-hadron data [1]. This fit yields to the following value of $\alpha_{I\!P}(0) = 1.203 \pm 0.020$ (stat.) $\pm$ 0.013 (syst.)$^{+0.030}_{-0.035}$ (model) [1] and is significantly larger than values extracted from soft hadronic data ($\alpha_{I\!P} \sim$ 1.08). The quality of the fit is similar if interference between the two trajectories is introduced.

2. QCD fits and the structure of the Pomeron

It has been suggested that the Q^2 evolution of the Pomeron structure function may be understood in terms of parton dynamics from perturbative QCD where parton densities are evolved according to DGLAP [3] equations [4,1], using the GRV parametrization for $F_2^{I\!R}$ [5].

For the pomeron, a quark flavour singlet distribution ($zS_q(z,Q^2) = u+\bar{u}+d+\bar{d}+s+\bar{s}$) and a gluon distribution ($zG(z,Q^2)$) are parameterized in terms of coefficients $C_j^{(S)}$ and $C_j^{(G)}$ at $Q_0^2 = 3$ GeV^2 such that :

$$zS(z,Q^2=Q_0^2) \left[\sum_{j=1}^{n} C_j^{(S)} \cdot P_j(2z-1) \right]^2 \cdot e^{\frac{a}{z-1}} \qquad (3)$$

$$zG(z,Q^2=Q_0^2) \left[\sum_{j=1}^{n} C_j^{(G)} \cdot P_j(2z-1) \right]^2 \cdot e^{\frac{a}{z-1}} \qquad (4)$$

where $z = x_{i/I\!P}$ is the fractional momentum of the pomeron carried by the struck parton, $P_j(\zeta)$ is the j^{th} member in a set of Chebyshev polynomials, which are chosen such that $P_1 = 1$, $P_2 = \zeta$ and $P_{j+1}(\zeta) = 2\zeta P_j(\zeta) - P_{j-1}(\zeta)$. Some details about the fits can be found in Reference [7].

A sum of $n = 3$ orthonormal polynomials is used so that the input distributions are free to adopt a large range of forms for a given number of parameters. The exponential factor is needed to ensure a correct convergence close to z=1.

The trajectory intercepts are fixed to $\alpha_{I\!P} = 1.20$ and $\alpha_{I\!R} = 0.62$. Only data points of H1 with $\beta \leq 0.65$, $M_X > 2$ GeV and $y \leq 0.45$ are included in the fit in order to avoid large higher twist effects and the region that may be most strongly affected by a non zero value of R, the longitudinal to transverse cross-section ratio.

3. Results of the QCD fits

The resulting parton densities of the Pomeron are presented in figure 1. As it was noticed in the 1994 F_2^D paper [1], we find two possible fits quoted here as fit 1 and fit 2. Each fit shows a large gluonic content. The quark contribution is quite similar for both fits, but the gluon distribution tends to be quite different at high values of z. This can be easily explained as no data above $z = 0.65$ are included in the fits. Thus there is no constraint from the data at high z. The quark densities is on the contrary more constrained in this region with the DGLAP evolution. Both fits show similar χ^2 (the χ^2 per degree of freedom is about 1.2) [1]. Adding the 1995 data points into the fits also allows to get a better constraint on initial parton densities at $Q_0^2 = 3$ GeV^2 compared to the fits performed with 1994 data points alone. For the gluon density presented in figure 1, we have determined that $\frac{\delta G}{G} \simeq 25\%$ for z below 0.6.

The result of the fit is presented in figure 2 together with the experimental values for 1994 data points ; we see on this figure the good agreement of the QCD prediction and the data points, which supports the validity of description of the Pomeron in terms of partons following a QCD dynamics.

We have also tried to extend the QCD fits to lower Q^2 (below 3 GeV^2) using the 1995 F_2^D measurement. The χ^2 of the fit turns out to increase ($\chi^2/ndf = 1.6$, adding 35 low Q^2 points to the 171 points) [8]. This can be illustrated in figure 2 of Reference [8] where changes of slopes of scaling violations for Q^2 below and above 3 GeV^2 can be seen. It may indicate that breaking of perturbative QCD has already occured in this region.

The idea would then to use these parton distributions and to compare with the measurements at Tevatron in order to study factorisation breaking. The roman pots which will be available in the D0 experiment at Run II will allow a direct comparison with the results obtained from the HERA parton distributions. It will be possible to know where factorisation breaking takes place at Tevatron, e.g. is it at low or high β?

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[1]Fit 2 is a bit disfavoured compared to fit 1 (its χ^2 by degree of freedom is 1.3 compared to 1.2 for fit 1) and is quite instable: changing a little the parameters modifies the gluon distribution at high z.

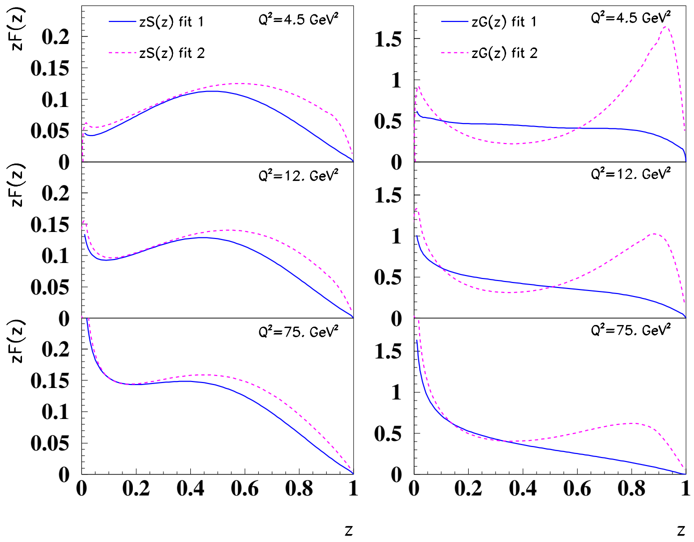

Figure 1. Quark flavour singlet (zS, left) and gluon (zG, right) distributions of the pomeron deduced as a function of z, the fractional momentum of the pomeron carried by the struck parton, from the fit on 1994 data points with $Q^2 \geq 4$ GeV^2. Two possible fits labelled as fit 1 and fit 2 are found ($\chi^2/ndf = 1.2$ for fit 1,and $\chi^2/ndf = 1.3$ for fit 2 with statistical errors only).

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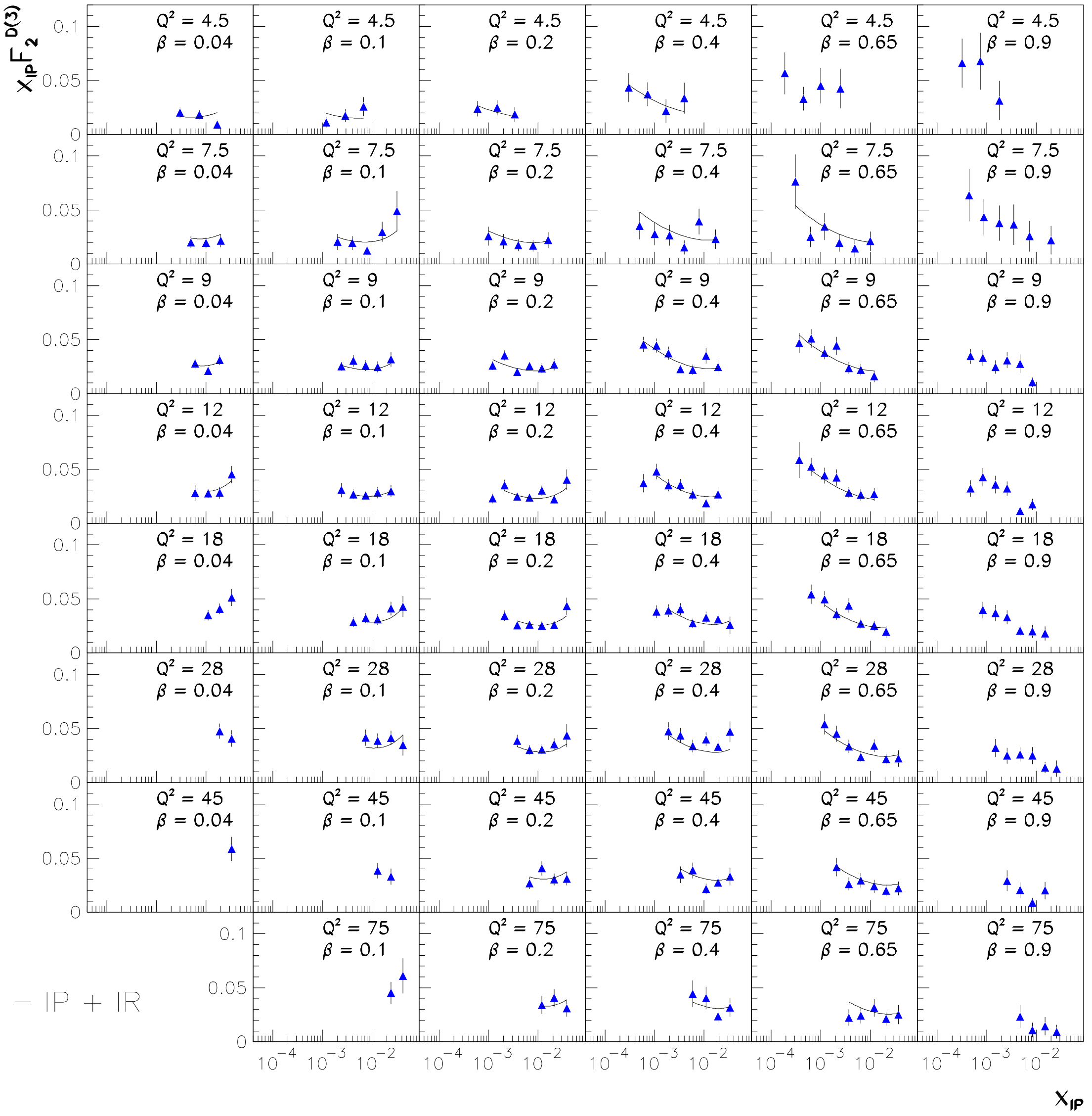

Figure 2. The H1 data points on $x_{I\!P} F_2^{D(3)}$ (1994) are shown with the result of the QCD fit described in the text; the result of the fit is drawn only in bins included in the minimization procedure.