HIGH ENERGY QCD AND HARD DIFFRACTION AT HERA VERSUS TEVATRON

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We present and discuss two different topics where Tevatron and HERA data can be compared directly. A method allowing for a direct comparison of data with theoretical predictions is proposed for forward jet production at HERA. An application to the determination of the effective Pomeron intercept in the BFKL-LO parametrization from $d\sigma/dx$ data at HERA leads to a good fit with a significantly high effective intercept, $\alpha_P = 1.43 \pm 0.025(stat.) \pm 0.025(syst.)$. It is less than the value of the pomeron intercept using dijets with large rapidity intervals obtained at Tevatron. In a second part of this report, we make comparison between diffractive results at HERA and at Tevatron. We first give the parton distributions in the pomeron extracted from HERA data, and compare with hard single diffraction at Tevatron and diffractive dijets with a leading antiproton data.

1 Forward jets at HERA and Mueller-Navelet jets at Tevatron

1.1 Forward jets at HERA

The study of forward jets at ep colliders is considered as the milestone of QCD studies at high energies, since it provides a direct way of testing the perturbative resummations of soft gluon radiation. It is similar to the previous proposal of studying two jets separated by a large rapidity interval in hadronic colliders [1], for which preliminary results are available [2].

The cross-section for forward jet production at HERA in the dipole model reads [5]:

$$\frac{d^{(4)}\sigma}{dxdQ^2dx_Jdk_T^2d\Phi} = \frac{\pi N_C \alpha^2 \alpha_S(k_T^2)}{Q^4 k_T^2} \; f_{eff}(x,\mu_f^2) \; \Sigma e_Q^2 \int_{\frac{1}{2}-i\infty}^{\frac{1}{2}+i\infty} \frac{d\gamma}{2i\pi} \left(\frac{Q^2}{k_T^2}\right)^{\gamma} \times$$
$$\times \exp\{\epsilon(\gamma,0)Y\} \left[\frac{h_T(\gamma)+h_L(\gamma)}{\gamma}(1-y) + \frac{h_T(\gamma)}{\gamma}\frac{y^2}{2}\right] \quad (1)$$

where

$$Y = \ln \frac{x_J}{x} \quad (2)$$
$$\epsilon(\gamma,p) = \bar{\alpha}\left[2\psi(1) - \psi(p+1-\gamma) - \psi(p+\gamma)\right] \quad (3)$$
$$f_{eff}(x,\mu_f^2) = G(x,\mu_f^2) + \frac{4}{9}\Sigma(Q_f + \bar{Q_f}) \quad (4)$$

$$\mu_f^2 \sim k_T^2 \ , \tag{5}$$

are, respectively, Y the rapidity interval between the photon probe and the jet, $\epsilon(\gamma, p)$ the BFKL kernel eigenvalues, f_{eff} the effective structure function combination, and μ_f the corresponding factorization scale. The main BFKL parameter is $\bar{\alpha}$, which is the (fixed) value of the effective strong coupling constant in LO-BFKL formulae.

The so-called "impact factors" h_T and h_L are obtained from the k_T factorization properties [7] of the coupling of the BFKL amplitudes to external hard probes. The same factors can be related to the photon wave functions within the equivalent context of the QCD dipole model [8,9].

The main problem to solve is to investigate the effect of the experimental cuts on the determination of the integration variables leading to a prediction for $d\sigma/dx$ from the given theoretical formula for $d^{(4)}\sigma$ as given in formula (1). The effect appears as bin-per-bin *correction factors* to be multiplied to the theoretical cross-sections for average values of the kinematic variables for a given x-bin before comparing to data [10].

The experimental correction factors have been determined using a toy Monte-Carlo designed as follows. We generate flat distributions in the variables k_T^2/Q^2, $1/Q^2$, x_J, using reference intervals which include the whole of the experimental phase-space (we chose the variables which minimize the variation of the cross-section over the measured kinematical range. The correction factors are given in Reference [10]. We perform a fit to the H1 and ZEUS data with only two free parameters. these are the *effective* strong coupling constant in LO BFKL formulae $\bar{\alpha}$ corresponding to the *effective* Lipatov intercept $\alpha_P = 1 + 4 \log 2\bar{\alpha} N_C/\pi$, and the cross-section normalisation. The obtained values of the parameters and the χ^2 of the fit are given in Table **I** for a fit to the H1 and ZEUS data separately, and then to the H1 + ZEUS data together.

fit	$\bar{\alpha}$	Norm.	$\chi^2(/dof)$
H1	$0.17 \pm 0.02 \pm 0.01$	$29.4 \pm 4.8 \pm 5.2$	5.7 (/9)
ZEUS	$0.20 \pm 0.02 \pm 0.01$	$26.4 \pm 3.9 \pm 4.7$	2.0 (/2)
H1+ZEUS	$0.16 \pm 0.01 \pm 0.01$	$30.7 \pm 2.9 \pm 3.5$	12.0 (/13)

Table I- Fit results

1.2 Mueller Navelet Jets at Tevatron (D0)

It is fruitful to compare our results with the effective intercept we obtain from recent preliminary dijet data obtained by the D0 Collaboration at Tevatron [2]. The measurement consists in the ratio $R = \sigma_{1800}/\sigma_{630}$ where σ is the

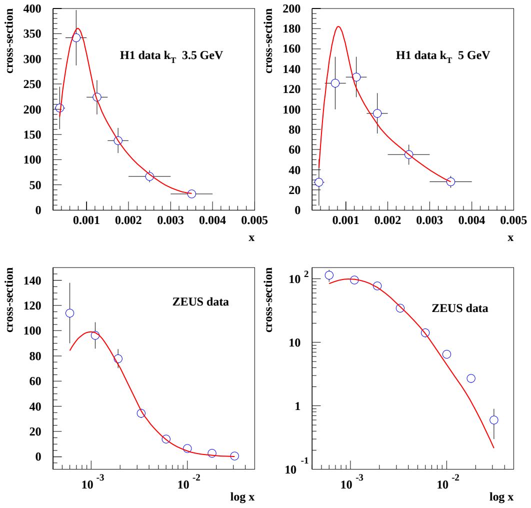

Figure 1. The H1 data ($k_T > 3.5$ GeV, $k_T > 5$ GeV), and the ZEUS data are compared with the result of the fit. ZEUS data are also displayed in logarithmic scales in vertical coordinates to show the discrepancy at high x values.

dijet cross-section at large rapidity interval $Y \sim \Delta\eta$ for two center-of-mass energies (630 and 1800 GeV), $\Delta\eta_{1800} = 4.6$, $\Delta\eta_{630} = 2.4$. The experimental measurement is $R = 2.9 \pm 0.3$ (stat.) ± 0.3 (syst.). Using the Mueller-Navelet formula [1], this measurement allows us to get a value of the effective intercept for this process. We get α_P=1.65 $\pm$ 0.05 (stat.) $\pm$ 0.05 (syst.), in agreement with the value obtained by D0 using a saddle-point approximation [2]. This intercept is higher than the one obtained in the forward jet study. The question arises to interpret the different values of the effective intercept. It could reasonably come from the differences in higher order QCD corrections for the BFKL kernel and/or in the impact factors depending on the initial probes [10].

2 Diffraction at HERA versus Tevatron

2.1 Diffraction at HERA

The data taken in 1992 by the H1 and ZEUS experiments showed some new interesting events with an interval of rapidity around the incident proton direction devoid of any hadronic activity. This means that a colourless exchange ("pomeron") must have occured since there is no colour connection between the remnant proton and the struck quark. The selection used to tag these events is mainly by asking a gap in rapidity in the forward proton direction [a]. These events represent about 10% of the total deep inelastic scattering events.

The statistics obtained in 1994 allowed a measurement of the proton diffractive structure function defined in analogy to the standard proton structure function in a wide kinematical domain [11]. The data accumulated between 1995 and 1997 allowed to extend the measurement to lower and higher Q^2. In addition to the usual deep inelastic variable x (the momentum fraction of the interacting quark), and Q^2 (the transfered energy squared between the electron and the interacting quark), two other kinematical variables are used, namely β, the momentum fraction of the colourless exchanged object, and $x_{\mathbb{P}} = x/\beta$, the momentum fraction of the parton inside this object if we assume it has a partonic structure.

The diffractive structure function $F_2^{D(3)}$ can be investigated in the framework of Regge phenomenology when both a leading ($\mathbb{P}$) and a sub-leading ($\mathbb{R}$) trajectory are considered, such that

$$F_2^{D(3)}(Q^2,\beta,x_{\mathbb{P}}) = f_{\mathbb{P}/p}(x_{\mathbb{P}})F_2^{\mathbb{P}}(Q^2,\beta) + f_{\mathbb{R}/p}(x_{\mathbb{P}})F_2^{\mathbb{R}}(Q^2,\beta) \ . \qquad (6)$$

In this parameterisation, $F_2^{\mathbb{P}}$ can be interpreted as the structure function of the pomeron. The values of $F_2^{\mathbb{R}}(Q^2,\beta)$ are taken from a parameterisation of the pion structure function [12], with a single free normalisation. The pomeron flux is assumed to follow a Regge behaviour with a linear trajectory $\alpha_{\mathbb{P}}(t) = \alpha_{\mathbb{P}}(0) + \alpha'_{\mathbb{P}}t$.

Using H1 1994 data [11], the resulting value of $\alpha_{\mathbb{P}}(0)$ is $\alpha_{\mathbb{P}}(0) = 1.20 \pm 0.09$ and is significantly larger than values extracted from soft hadronic data ($\alpha_{\mathbb{P}} \sim 1.08$). Also, we find $\alpha_{\mathbb{R}}(0) = 0.62 \pm 0.03$. Using ZEUS data [11], we find a pomeron intercept $\alpha_{\mathbb{P}} = 1.127 \pm 0.040$, lower than the H1 value [b].

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[a] There are other selection used by H1 and ZEUS collaborations, namely tagging a proton in the final state or using the M_X subtraction method [11].

[b] The selection of the diffractive sample in ZEUS is different from H1 and uses the so called M_X method [11].

The Q^2 evolution of the pomeron structure function may be understood in terms of parton dynamics and therefore perturbative QCD where parton densities are evolved according to DGLAP [3] equations. We assign parton distribution functions to the pomeron and to the reggeon. A simple prescription is adopted in which the parton distributions of both the pomeron and the reggeon are parameterised in terms of non-perturbative input distributions at some low scale $Q_0^2 = 3$ GeV^2 [13].

The resulting parton densities of the pomeron are presented in figure 2 as a function of z, the fractional momentum of the pomeron carried by the struck parton. We find one possible fit quoted here as fit 1. Fit 1 shows a large gluonic content. The quark contribution is much smaller compared to the gluon one. We also note that we find an other much less favoured fit quoted here as fit 2 with a peaked gluon at high β [?].

We have redone this QCD analysis with ZEUS 1994 diffractive cross-section measurements [11] applying the same cuts. The gluon density is found to be lower by about a factor 2, but the error bar on the ZEUS gluon density is large (about 50%) as only 30 data points are included in the fit. The quark component is found to be similar. This difference in the gluon density can however lead to differences in the charm structure function as it is very much sensible to the gluon structure function [13].

2.2 Diffraction at Tevatron

Diffractive events selection at Tevatron is basically the same as at HERA. A rapidity gap is asked, either between the proton (antiproton) direction and the jets inside the detector, or a rapidity central gap is asked between two jets inside the main part of the detector.

Hard single diffraction
D0 and CDF collaborations [14] have studied the fraction of central and forward jet events with rapidity gap at two different center-of-mass energies of 630 and 1800 GeV. The D0 results [c] are given in Table II and are compared to MC simulations with different pomeron structure functions (hard gluon, $f(\beta) = \beta(1-\beta)$, soft gluon, $f(\beta) = (1-\beta)^5$, and quarks). It can be first noticed that the gap fractions at 630 GeV are larger than the ones at 1800 GeV, and are much smaller than at HERA (about 1% to be compared with about 10% at HERA), which can be explained because there is no factorisation between both experiments [15]. The flat and hard gluon predictions are too high compared to the data, whereas the quark scenario could work (it has however

[c] CDF results [14] are compatible with the D0 ones.

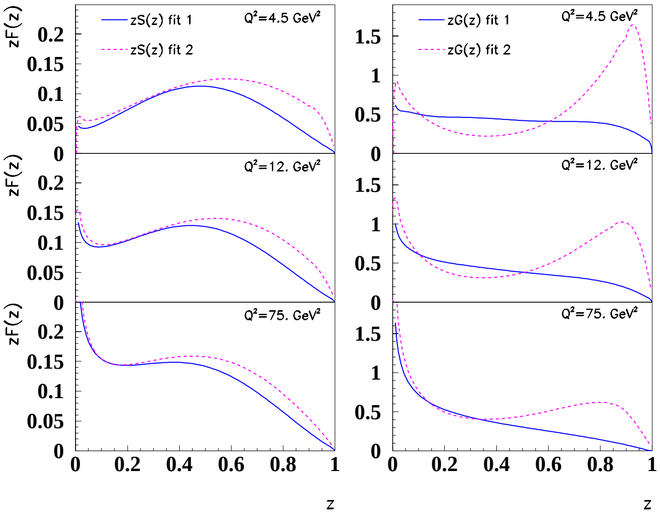

Figure 2. Quark flavour singlet (zS, left) and gluon (zG, right) distributions of the pomeron deduced as a function of z, the fractional momentum of the pomeron carried by the struck parton. The fit result is denoted here as fit 1. Another favourable fit is also given. ($\chi^2/ndf = 177.1/154 = 1.15$ for fit 1 and $\chi^2/ndf = 192.5/154 = 1.25$ for fit 2 with statistical errors only).

been shown that this would lead to predict an excesive rate of diffractive W production). A combination of soft and hard gluon could be possible to describe this measurement, whereas the HERA data have the tendency to favour the hard gluon scenario. The HERA and Tevatron kinematical domains in β and W are however different, and a more precise study including the QCD evolution of parton distributions measured at HERA in the Tevatron domain would be of great interest.

Sample	Data	Hard Gluon	Flat Gluon	Quark
1800 GeV $\lvert\eta\rvert > 1.6$	$(0.65 \pm 0.04)\%$	$(2.2 \pm 0.3)\%$	$(2.2 \pm 0.3)\%$	$(0.79 \pm 0.12)\%$
1800 GeV $\lvert\eta\rvert < 1.0$	$(0.22 \pm 0.05\%$	$(2.5 \pm 0.4)\%$	$(3.5 \pm 0.5)\%$	$(0.49 \pm 0.06)\%$
630 GeV $\lvert\eta\rvert > 1.6$	$(1.19 \pm 0.08)\%$	$(3.9 \pm 0.9)\%$	$(3.1 \pm 0.8)\%$	$(2.2 \pm 0.5)\%$
630 GeV $\lvert\eta\rvert < 1.0$	$(0.90 \pm 0.06)\%$	$(5.2 \pm 0.7)\%$	$(6.3 \pm 0.9)\%$	$(1.6 \pm 0.2)\%$

Table II- Measured and predicted gap fractions and their ratios (D0).

Hard color singlet exchange
At Tevatron (like at HERA), it is also possible to study events with a central rapidity gap between jets. This class of events could come from pomeron exchange at large momentum transfer $t >> 100$ GeV^2, compared to the previous measurement which was at low t ($t \sim 0$). The fraction of dijet events with a central rapidity gap is again about 1% [16], to be compared with 10% at HERA. An increase of gap fraction is observed with jet transverse energy and rapidity.

Diffractive dijets with a leading antiproton
The CDF collaboration installed roman-pot detectors allowing to tag $\bar{p}$ in the final state. They select a diffractive dijet subsample of it requiring two jets of an energy greater than 7 GeV [17].

Figure 3 shows the ratio of single diffractive events over the non diffractive ones, where the two data samples are normalised to the same luminosity, in six $x_{\mathbb{P}}$ bins (at Tevatron, $x_{\mathbb{P}}$ is called ξ). This ratio does not show any $x_{\mathbb{P}}$ dependence and the $x_{\mathbb{P}}$ dependence can be factorised out from the x one, which is similar to what has been found at HERA except at high $x_{\mathbb{P}}$ and low β where secondary reggeons are necessary to fit H1 data.

Knowing the ratio of diffarctive to non-diffractive events, it is quite easy to extract the pomeron structure function at Tevatron, by multiplying this ratio by the proton structure function. For this sake, the CDF collaboration chose to use the GRV parametrisation [17]. The result together with extrapolations of H1 fits is given in Figure 4. The results disagree both in normalisation and shapes. This disagreement represents a breaking of factorisation as expected [15]. It is quite challenging to analyze this breaking of factorisation which might be β dependent using run I and run II data. In run II, the D0 collaboration will have roman pots in both sides of the detector allowing to tag both proton and antiproton in the final state, it will be quite interesting to be able to test factorisation directly.

3 Conclusion

We have presented and discussed two related topics at HERA and Tevatron, namely forward jets and diffraction.

Using a new method to disantangle the effects of the kinematic cuts from the genuine dynamical values of the forward jet cross-sections at HERA, we find that the effective pomeron intercept is $\alpha_P = 1.43 \pm 0.025$ (stat.) ± 0.025

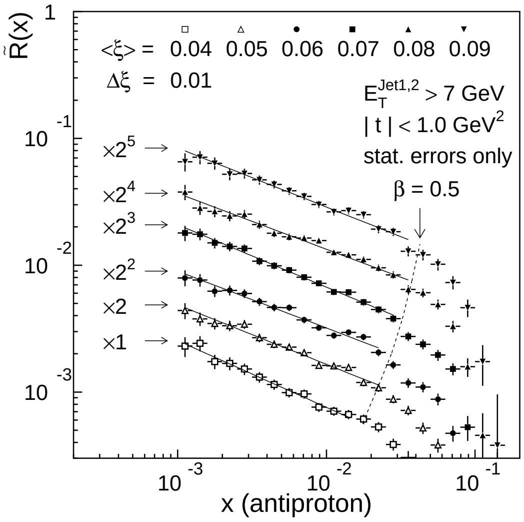

Figure 3. Ratio of diffractive to non-diffractive dijet events rates as a function of the momentum fraction of p carried by the tagged antiproton in the final state.

(syst.). It is much higher than the soft pomeron intercept, and, among those determined in hard processes, it is intermediate between $\gamma^*\gamma^*$ interactions at LEP [18] and dijet productions with large rapidity intervals at Tevatron.

Diffraction at HERA and Tevatron give quite different results. The D0 and CDF collaborations measure about 1% diffractive events whereas at HERA, it is close to 10%. QCD analysis of HERA data lead to a pomeron made of gluons, and a hard structure function is favored whereas the D0 collaboration showed that a combination of hard and soft structure functions is needed. The CDF collaboration was able to make for the first time a direct measurement of the antiproton diffractive structure function, allowing a direct comparison with HERA, by using their roman pot data. The data show large discrepancies both in shape and in normalisation. A QCD analysis of run I Tevatron data and run II data where D0 will have roman pot detectors on each side are quite challenging.

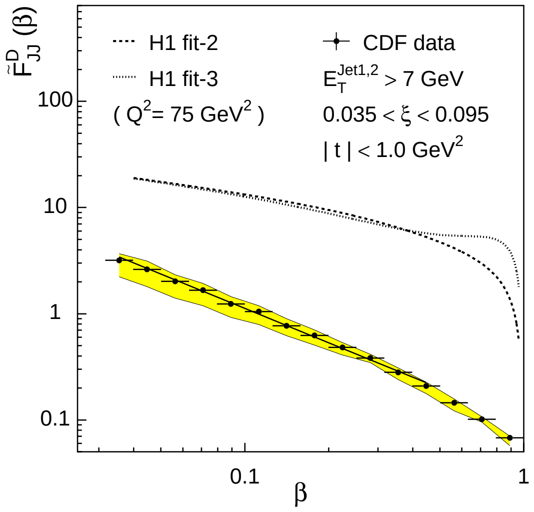

Figure 4. β distributions of CDF data compared with predictions coming from HERA fits. (fits 1 and 2 are designed respectively in this figure by H1-fit 2 and H1-fit 3).

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