Diffraction in QCD

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Abstract

Results on soft and hard diffraction are briefly reviewed and placed in a QCD perspective using a parton model approach. Issues addressed include factorization, scaling properties, universality of rapidity gap formation, and unitarity. Predictions for differential cross sections of processes with multiple rapidity gaps are presented with examples for the Tevatron and the Large Hadron Collider. This paper is an expanded version of a paper delivered at "Snowmass-2001" [1].

1 Introduction

Experiments at $\bar{p}(p)$-p and e-p colliders have reported and characterized a class of events incorporating a hard (high transverse momentum) partonic scattering while carrying the characteristic signature of diffraction, namely a leading (anti)proton and/or a large "rapidity gap", defined as a region of pseudorapidity, $\eta \equiv -\ln(\tan\frac{\theta}{2})$, devoid of particles (see Figs. 1 and 2). The rapidity gap is a non-perturbative phenomenon presumed to be caused by the exchange of a Pomeron [2], whose generic QCD definition is a color-singlet[1] combination of quarks and/or gluons carrying the quantum numbers of the vacuum.

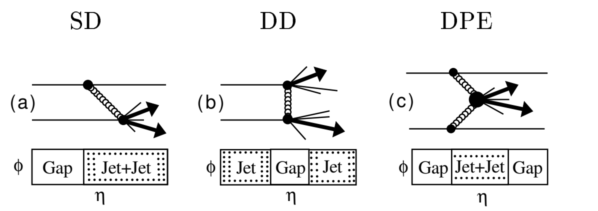

FIG. 1: Dijet production in $\bar{p}p$ single (a) and double (b) diffraction, and in double Pomeron exchange (c).

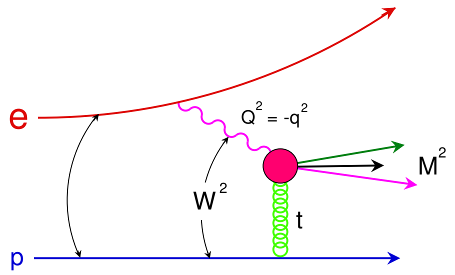

FIG. 2: Diagram for diffractive deep inelastic scattering at HERA.

The interplay between soft and hard processes in *hard diffraction* is of particular theoretical importance due to its potential for elucidating the transition from perturbative to nonperturbative QCD. Phenomenological models proposed for hard diffraction have been only partially successful in describing the data. A QCD-based theoretical description is still not available. This is not surprising, since diffraction invariably involves non-perturbative effects associated with the formation of rapidity gaps. The theoretical community has thus far paid very little attention to *soft* diffractive processes, i.e. those which do not have a hard partonic scattering. Yet, experiment has shown that soft processes have "a lot to say" about rapidity gap formation, which is key to understanding diffraction. In this paper, we examine the regularities observed in both soft and hard diffractive processes using a parton model approach, which places diffraction in a QCD perspective.

2 Rapidity gaps

The exchange of a gluon or a quark between two hadrons at high energies leads to events in which, in addition to whatever hard scattering may have occurred, the entire rapidity space is filled with soft (low transverse momentum) particles *(underlying event)*. The soft particle distribution is approximately flat in (pseudo)rapidity. The flat $dN/d\eta$ shape is the result of x-scaling [3] of the parton distribution functions of the incoming hadrons. Rapidity gaps can be formed in any inelastic non-diffractive (ND) event by multiplicity fluctuations. Assuming Poisson statistics, the probability for a gap of width $\Delta\eta$ within a ND event sample is given by

$$P_{gap}^{ND}(\Delta\eta) = \rho\, e^{-\rho\,\Delta\eta} \tag{1}$$

where ρ is the average particle density per unit η (the total probability for *any* gap is normalized to unity). As seen in (1), the probability for rapidity gaps formed my multiplicity fluctuations is exponentially suppressed. In contrast, since no radiation is emitted by the acceleration of vacuum quantum numbers, Pomeron exchange leads to large rapidity gaps whose probability is not exponentially dumped. Therefore, large rapidity gaps are an unmistakable diffractive signature and can be considered the *generic* definition of diffraction.

3 Soft diffraction

Soft diffraction has been traditionally treated theoretically in the framework of Regge theory. For large rapidity gaps ($\Delta\eta \geq 3$), the cross sections for $\bar{p}(p)$-p single and double (central) diffraction can be written as [4]

$$\frac{d^2\sigma_{SD}}{dtd\Delta\eta} = \left[\frac{\beta^2(t)}{16\pi}e^{2[\alpha(t)-1]\Delta\eta}\right]\left[\kappa\beta^2(0)\left(\frac{s'}{s_\circ}\right)^{\epsilon}\right], \quad \frac{d^3\sigma_{DD}}{dtd\Delta\eta d\eta_c} = \left[\frac{\kappa\beta^2(0)}{16\pi}e^{2[\alpha(t)-1]\Delta\eta}\right]\left[\kappa\beta^2(0)\left(\frac{s'}{s_\circ}\right)^{\epsilon}\right] \tag{2}$$

where $\alpha(t) = 1+\epsilon+\alpha' t$ is the Pomeron trajectory, $\beta(t)$ the coupling of the Pomeron to the (anti)proton, and $\kappa \equiv g(t)/\beta(0)$ the ratio of the triple-Pomeron to the Pomeron-proton couplings. The above two equations, which are based on factorization, are remarkably similar. In each case, there are two factors:

- the first, which is $\sim \{\exp[(\epsilon + \alpha' t)\Delta\eta]\}^2$ and thus depends on the rapidity gap,
- the second, which has the form $\sim (s')^{\epsilon}$ of a total cross section at c.m.s. energy squared s'.

In single diffraction (SD), the second factor is interpreted as the Pomeron-nucleon total cross section, while the first factor as the square of the elastic scattering amplitude between the diffractively excited nucleon state and the other nucleon. The similarity between the SD and double diffraction (DD) equations suggests an interpretation of the first factor in DD as the elastic scattering between the two diffractively dissociated nucleon states. However, the interpretation of the second factor in DD is not as straightforward as in SD, but does acquire a similar meaning in the parton model, as discussed in the next section. Since the second factors in (2) represent properly normalized cross sections, the first factors may be thought of as the rapidity gap probability and *renormalized* to unity. A model based on such a renormalization procedure [5, 6] has yielded predictions in excellent agreement with measured SD and DD cross sections, as seen in Figs. 3 and 4.

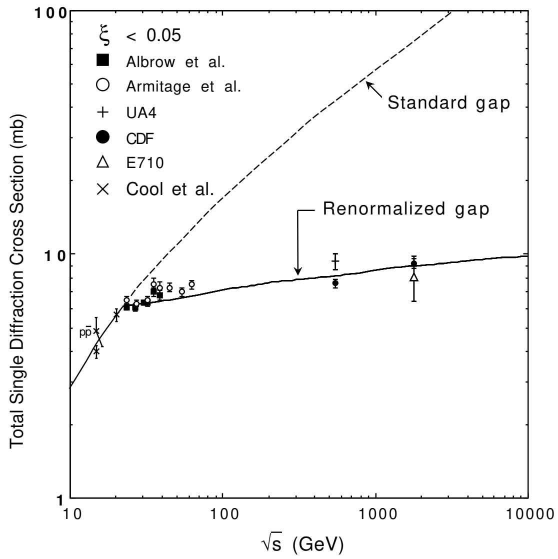

FIG. 3: The $\bar{p}p$ total SD cross section exhibits an s-dependence consistent with the renormalization procedure of Ref. [?], contrary to the $s^{2\epsilon}$ behaviour expected from Regge theory (figure from Ref. [?]).

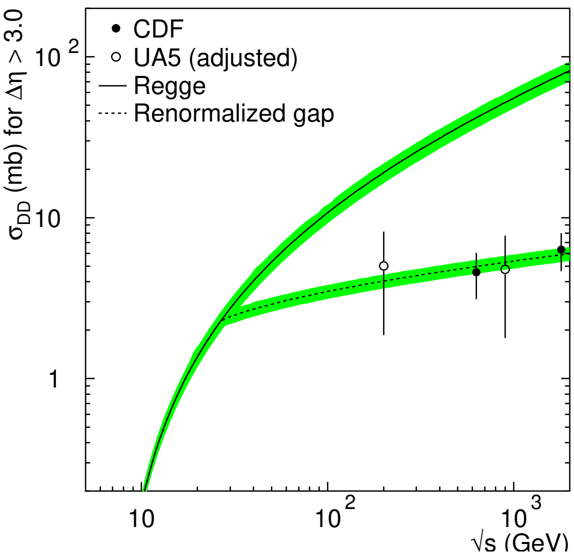

FIG. 4: The $\bar{p}p$ total DD (central gap) cross section agrees with the prediction of the *renormalized rapidity gap* model [?], contrary to the $s^{2\epsilon}$ expectation from Regge theory (figure from Ref. [?]).

4 Factorization, scaling and unitarity

The renormalized rapidity gap probability is by definition energy independent and thus represents a scaling behaviour, which is most prominently displayed in the form of the SD differential cross section in terms of the square of the mass of the diffractively excited nucleon state, M^2. The variable M^2 is related to $\Delta\eta$ and to the fractional momentum loss of the leading nucleon: $M^2 = s\xi = se^{-\Delta\eta}$. The unrenormalized SD cross section at $t = 0$ has the form $\frac{d\sigma_{SD}}{dM^2}|_{t=0} \propto \frac{s^{2\epsilon}}{(M^2)^{1+\epsilon}}$. This form leads to a total diffractive cross section $\sim s^{2\epsilon}$, which grows faster than the total nucleon-nucleon cross section ($\sim s^{\epsilon}$) and would exceed it at $\sqrt{s}$ $\approx$2 TeV violating unitarity (see Figs. 3 and 4). The renormalization procedure leads to the energy independent form $\frac{d\sigma_{SD}}{dM^2}|_{t=0} \propto \frac{1}{(M^2)^{1+\epsilon}}$, which avoids the violation of unitarity. This form is brilliantly supported by the data, as can be seen in Fig. 5. Thus, it appears that nature preserves unitarity by favoring "M^2-scaling" over factorization.

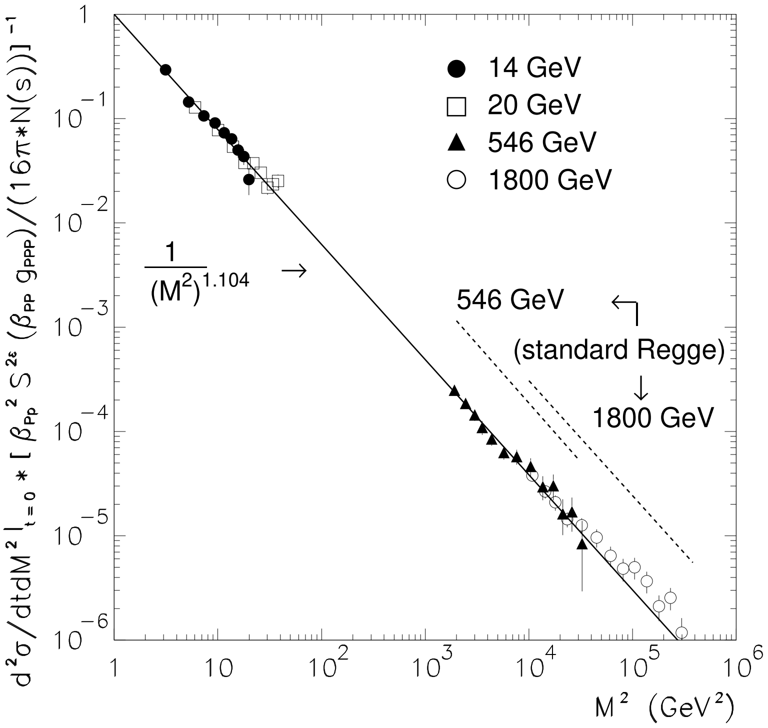

Fig. 5: Cross sections $d^2\sigma_{SD}/dM^2dt$ for $p + p(\bar{p}) \to p(\bar{p}) + X$ at $t = 0$ and $\sqrt{s} = 14$, 20, 546 and 1800 GeV, multiplied by $[\beta^2_{\mathbb{P}pp}\, s^{2\epsilon}(\beta_{\mathbb{P}pp} \cdot g_{\mathbb{P}\mathbb{P}\mathbb{P}})/(16\pi * N(s))]^{-1}$, where $N(s)$ is the integral of the rapidity gap probability, are compared with the renormalized gap prediction of $1/(M^2)^{1+\epsilon}$ using $\epsilon = 0.104$ [7]. The dashed curves show the standard Regge-theory predictions. The $t = 0$ data were obtained by extrapolation from their $t = -0.05$ GeV^2 values after subtracting the pion exchange contribution [8].

5 A parton model approach

In the parton model, the pp total cross section is basically proportional to the number of partons in the proton, integrated down to $x = s_\circ/s$, where $s_\circ$ is the energy scale for soft physics. The latter is of $\mathcal{O}(\langle M_T\rangle^2)$, where $\langle M_T\rangle \sim 1$ GeV is the average transverse mass of the particles in the final state. Expressing the parton density as a power law in $1/x$, which is an appropriate parameterization for the small x region responsible for the cross section rise at high energies, we obtain

$$\sigma_T \sim \int_{(s_\circ/s)}^{1} \frac{dx}{x^{1+n}} \sim \left(\frac{s}{s_\circ}\right)^n \tag{3}$$

The parameter n is identified as the $\epsilon = \alpha(0) - 1$ of the Pomeron trajectory [9].

According to the optical theorem, the form s^ϵ of the total cross section is that of the imaginary part of the forward ($t = 0$) elastic scattering amplitude. Note that $\ln s$ is the (pseudo)rapidity region $\Delta\eta$ in which there is particle production. The full parton model amplitude can be written as

$$\mathrm{Im}\,\mathrm{f}(t, \Delta y) \sim e^{(\epsilon + \alpha' t)\Delta y} \tag{4}$$

where we have added to ϵ the term $\alpha' t$ as a parameterization of the t-dependence of the amplitude.

One may now understand expressions (2) for the SD and DD cross sections as follows: the second term in brackets represents the nucleon-nucleon total cross section at a sub-energy squared s', multiplied by a factor κ, which may be interpreted as "the price to pay" for the color matching required to enable the formation of a rapidity gap, while the first term represents the amplitude squared of the elastic scattering between the diffractively dissociated nucleon and the other nucleon in SD, or between the two diffractively dissociated nucleons in DD. Since the cross section represented by the second term is properly normalized, the first term simply represents a rapidity gap probability distribution and should be normalized to unity. This result is equivalent to renormalizing the rapidity gap probability of the Regge model, as proposed in [5, 6].

6 Multiple rapidity gaps in diffraction

The parton model approach used above to calculate the SD and DD differential cross sections lends to easy generalization to events with multiple rapidity gaps. Here, we outline the procedure for calculating the differential cross section for a 4-gap event (see Fig. 6).

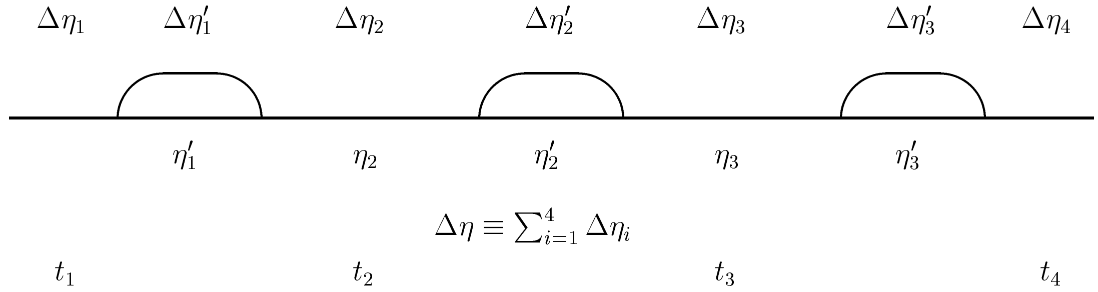

Fig. 6: Topology of a 4-gap event in pseudorapidity space.

The calculation of the differential cross section is based on the parton-model scattering amplitude of Eq. (4). For the rapidity regions $\Delta\eta'_i$, where there is particle production, the $t = 0$ parton model amplitude is used and the *sub-energy cross section* is $\sim e^{\epsilon\Delta\eta'}$. For rapidity gaps $\Delta\eta$ which can be considered as resulting from elastic scattering between diffractively excited states, the square of the full parton-model amplitude is used, $e^{2(\epsilon + \alpha' t_i)\Delta\eta_i}$, and the form factor $\beta^2(t)$ is included for a surviving nucleon. The *gap probability* (product of all rapidity gap terms) is then normalized to unity, and a *color matching factor* κ is included for each gap.

For the 4-gap example of Fig. 6, which has 10 independent variables V_i (shown below the figure), we have:

- $\frac{d^{10}\sigma}{\Pi_{i=1}^{10} dV_i} = P_{gap} \times \sigma(\mathrm{sub-energy})$
- $\sigma(\mathrm{sub-energy}) = \kappa^4 \left[\beta^2(0) \cdot e^{\epsilon \Delta y'}\right]$ $\qquad (\Delta y' = \sum_{i=1}^{3} \Delta\eta'_i)$
- $P_{gap} = N_{gap} \times \Pi_{i=1}^{4} \left[e^{(\epsilon+\alpha' t_i)\Delta\eta_i}\right]^2 \times [\beta(t_1)\beta(t_4)]^2 = N_{gap} \cdot e^{2\epsilon\Delta\eta} \cdot f(V_i)|_{i=1}^{10}$ $\quad (\Delta\eta = \sum_{i=1}^{4} \Delta\eta_i)$
  where N_{gap} is the factor that normalizes P_{gap} over all phase space to unity.

The last equation shows that the renormalization factor of the gap probability depends only on s (since $\Delta\eta_{max} = \ln s$) and not on the number of diffractive gaps. Thus, the ratio of two-gap to one-gap cross sections is expected to be $\approx \kappa$, with no additional energy dependent suppression for the second gap. Below, we discuss two specific two-gap processes which can be studied at the Tevatron. Studies of processes with more than two gaps will have to await the commissioning of the LHC.

6.1 Double Pomeron exchange (DPE)

The double Pomeron exchange process is shown below for $\bar{p}p$ collisions (we use rapidity y and pseudorapidity η interchangeably):

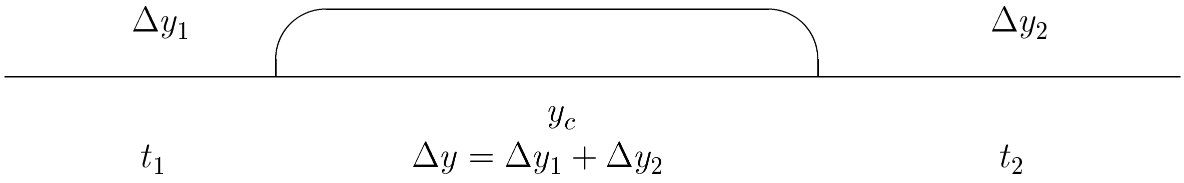

Fig. 7: $\bar{p} + p \to \bar{p} + \mathrm{GAP} + X + \mathrm{GAP} + p$

The Regge theory predictions for SD and DPE are:

$$\mathrm{SD:} \quad \frac{d^2\sigma}{dt\, d\Delta y} = \left[\frac{\beta(t)}{4\sqrt{\pi}}\, e^{[\alpha(t)-1]\Delta y}\right]^2 \kappa \left\{\beta^2(0)\left(\frac{s'}{s_\circ}\right)^{\alpha(0)-1}\right\}$$

$$\mathrm{DPE:} \quad \frac{d^4\sigma}{dt_1 dt_2 d\Delta y dy_c} = \Pi_i \left[\frac{\beta(t_i)}{4\sqrt{\pi}} e^{[\alpha(t_i)-1]\Delta y_i}\right]^2 \kappa^2 \left[\beta^2(0)\left(\frac{s'}{s_\circ}\right)^{\alpha(0)-1}\right]$$

$$\mathrm{Note:} \quad \Delta y_1 = \tfrac{1}{2}(\Delta y + y_c);\ \Delta y_2 = \tfrac{1}{2}(\Delta y - y_c)$$

Following the procedure outlined above, the DPE differential cross section can be written as

$$
\begin{aligned}
\frac{d^4\sigma}{dt_1\, dt_2\, d\Delta y\, dy_c} &= P_{gap}(t_1, t_2, \Delta y, y_c) \;\times\; \kappa^2 \sigma_{tot}(s') \\
P_{gap}(t_1, t_2, \Delta y, y_c) &= \frac{\beta(t_1)}{4\sqrt{\pi}} e^{\frac{1}{2}[\alpha(t_1)-1](\Delta y + y_c)} \times \frac{\beta(t_i)}{4\sqrt{\pi}} e^{\frac{1}{2}[\alpha(t_i)-1](\Delta y + y_c)} \\
\sigma_{tot}(s') &= \left[\beta^2(0)\left(\frac{s'}{s_0}\right)^{\alpha(0)-1}\right], \text{ where } \ln s' = \ln s - \Delta y \\
R_{SD}^{DPE}|_{\text{fixed }\xi(\bar{p})} &= \frac{N_{DPE}}{N_{SD}} \int_{t_p=0}^{\infty} \int_{\xi_p = M_0^2/(s\times\xi_{\bar{p}})}^{0.02} \frac{\beta^2(t_p)}{16\pi} \frac{\kappa}{\xi^{\alpha(0)+2\alpha' t_p}} dt_p d\xi_p
\end{aligned}
$$

The renormalization factor N_{DPE} is obtained by integrating the gap probability P_{gap} over $t_1, t_2, \Delta y, y_c$. The limits of integration are:
$0 < -t_1 < \infty$; $0 < -t_2 < \infty$
$2.3 < \Delta y < \ln(s/s_0)$, where $s_0 = 1$ GeV^2 and $\Delta y = 2.3$ corresponds to $\xi = 0.1$
$-\frac{1}{2}(\Delta y - 2.3) < y_c < \frac{1}{2}(\Delta y - 2.3)$
For SD, the gap probability is the first term in the SD equation and N_{SD} is obtained by integrating it over Δy within the region $2.3 < \Delta y < \ln(s/s_0)$.

For numerical evaluations we use [7, 8] $\alpha(t) = 1.104 + 0.25t$, $\beta(0) = 4.1$ mb$^{\frac{1}{2}}$ (6.57 GeV^{-1}) and $\kappa = 0.17$. The ratio of DPE to SD rates in $\bar{p}p$ collisions with a leading final state antiproton of fractional momentum loss $\xi_{\bar{p}} = 0.065$, the average value of the inclusive $\bar{p}$-triggered data samples in the CDF publications of Refs. [10, 11], and for $\xi_p > 0.02$ is predicted to be

$$\boxed{R_{SD}^{DPE}|_{\xi_{\bar{p}}=0.065,\,\xi_p>0.02} = 0.21\ (0.17)\ \pm 10\% \text{ at } 1800\ (630) \text{ GeV}}$$

where the error is due the the uncertainty on the factor κ. This ratio does not depend strongly on $\xi(\bar{p})$ within the range $0.035 < \xi(\bar{p}) < 0.95$ of the CDF event samples and therefore represents a realistic prediction.

6.2 Single diffraction with a second gap (SDD)

An interesting two-gap process is $\bar{p}p$ single diffraction with a leading final state antiproton and a rapidity gap within the rapidity space allocated to the diffraction dissociation products of the proton (see Fig. 7).

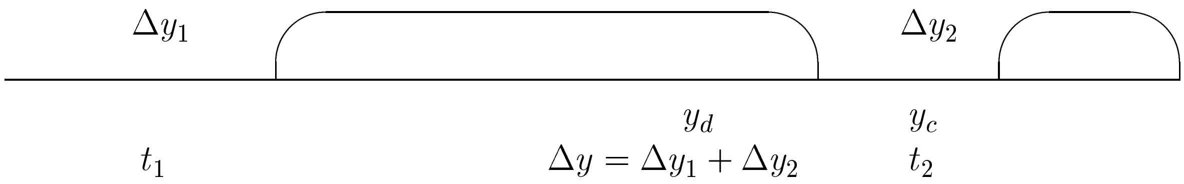

FIG. 8: $\bar{p} + p \to \bar{p} + \text{GAP}_1 + X + \text{GAP}_2 + Y$

The second gap, GAP$_2$, may be thought of as due to $I\!P$-p double diffraction. Thus, this process is a combination of single plus double diffraction and hence we represent it by "SDD".

To calculate the SDD cross section we start with the Regge predictions for SD, DD and SDD:

$$\text{SD:} \quad \frac{d^2\sigma}{dt\,d\Delta y} = \left[\frac{\beta(t)}{4\sqrt{\pi}}\,e^{[\alpha(t)-1]\Delta y}\right]^2 \kappa \left\{\beta^2(0)\left(\frac{s'}{s_\circ}\right)^{\alpha(0)-1}\right\}$$

$$\text{DD:} \quad \frac{d^3\sigma}{dt\,d\Delta y\,dy_c} = \kappa\left[\frac{\beta(0)}{4\sqrt{\pi}}e^{[\alpha(t)-1]\Delta y}\right]^2 \kappa \left[\beta^2(0)\left(\frac{s'}{s_\circ}\right)^{\alpha(0)-1}\right]$$

$$\text{SDD:} \quad \frac{d^5\sigma}{dt_1\,dt_2\,d\Delta y_1\,d\Delta y_2\,dy_c} = \left[\frac{\beta(t)}{4\sqrt{\pi}}\,e^{[\alpha(t_1)-1]\Delta y_1}\right]^2 \kappa\left\{\kappa\left[\frac{\beta(0)}{4\sqrt{\pi}}e^{[\alpha(t_2)-1]\Delta y_2}\right]^2 \kappa\left[\beta^2(0)\left(\frac{s''}{s_\circ}\right)^{\alpha(0)-1}\right]\right\}$$

Following the rules of the parton model approach, the SDD cross section may be written as

$$\frac{d^5\sigma}{dt_1\,dt_2\,d\Delta y_1\,d\Delta y_2\,dy_c} = P_{gap}(t_1,t_2,\Delta y_1,\Delta y_2,y_c) \times \kappa^2\sigma_{tot}(s'')$$

$$P_{gap}(t_1,t_2,\Delta y_1,\Delta y_2,y_c) = \left\{\left[\frac{\beta(t)}{4\sqrt{\pi}}\,e^{[\alpha(t_1)-1]\Delta y_1}\right]^2 \kappa\left[\frac{\beta(0)}{4\sqrt{\pi}}e^{[\alpha(t_2)-1]\Delta y_2}\right]^2\right\}$$

$$\sigma_{tot}(s'') = \left[\beta^2(0)\left(\frac{s''}{s_\circ}\right)^{\alpha(0)-1}\right], \text{ where } \ln s'' = \ln s - \Delta y_1 - \Delta y_2$$

Changing variables, $\Delta y_1,\ \Delta y_2 \Rightarrow \Delta y = \Delta y_1 + \Delta y_2,\ y_d$, where $y_d = \frac{1}{2}\Delta y_1$ is the center of the single diffractive cluster, the gap probability becomes

$$P_{gap}(t_1,t_2,\Delta y,y_d,y_c) = 2\kappa\left(\frac{\beta^2(0)}{16\pi}\right)^2 e^{2\epsilon\Delta y}\,F_1^2(t_1)\,e^{2\alpha'(2y_d)t_1}\,e^{2\alpha'(\Delta y-2y_d)t_2}$$

where $F_1(t_1)$ is the antiproton form factor [5]. Integrating P_{gap} over $t_1,t_2,y_c,y_d,\Delta y$ yields the renormalization factor N_{SDD}. The limits of integration are: $0<-t_1<\infty$; $e^{-(\Delta y-2y_d)}<-t_2<e^{\Delta y-2y_d}$; $-\ln\sqrt{s}+2y_d+\frac{1}{2}(\Delta y-2y_d)<y_c<\ln\sqrt{s}-\frac{1}{2}(\Delta y-2y_d)$; $0<y_d<\frac{1}{2}\Delta y$; $2.3<\Delta y<\ln\frac{s\,s_0}{(1.5\,\mathrm{GeV})^2}$, where $s_0 = 1\ \mathrm{GeV}^2$.

Experimentally, in order to be able to detect a large rapidity gap within a single-diffractive cluster of particles, the cluster must extend over a large part of the rapidity space covered by the detector. Therefore, we evaluate the SDD to SD fraction for events with a relatively large $\xi(\bar{p})$-value. For $\xi_{\bar{p}} = 0.075$, which for $\sqrt{s}$ =1800 (630) GeV corresponds to sub-energy $\sqrt{s'}\approx 500$ (170) GeV, the predicted SDD fraction for $\Delta y_2 > 3$ is

$$\boxed{R^{two-gap}_{one-gap}|_{\xi_{\bar{p}}=0.075,\,\Delta y_2>3} = 0.26\ (0.20)\ \pm 10\%\ \text{at}\ 1800\ (630)\ \text{GeV}}$$

where the error is due the the uncertainty on κ. This prediction can be compared with experiment using the existing CDF inclusive SD data of Refs. [10, 11].

7 Hard diffraction

The central issue in hard diffraction is the question of QCD factorization: can hard diffractive cross sections be obtained as a convolution of "diffractive structure functions" (DSF) with parton-level cross sections? This question was addressed decisively by a comparison [10] between the DSF measured by CDF in dijet production at the Tevatron and the prediction based on parton densities extracted from diffractive DIS at HERA. The DSF at the Tevatron was found to be suppressed relative to the prediction from HERA by a factor of ~ 10 (see Fig. 9). This result confirmed previous CDF results from diffractive W [12], dijet [13] and b-quark [14] production at $\sqrt{s}$=1800 GeV, and was corroborated by more recent CDF results on diffractive J/ψ [15] production at 1800 GeV and dijet production at 630 GeV [11].

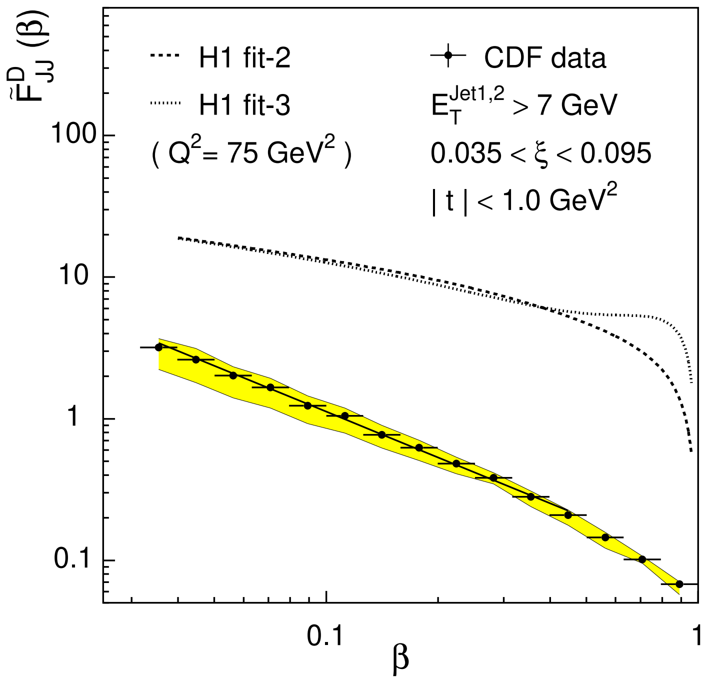

Fig. 9: The diffractive structure function $F_{jj}(\beta, Q^2)$, where β is the momentum fraction of the parton in the Pomeron, extracted from CDF diffractive dijet production data in $\bar{p}p$ collisions at $\sqrt{s}$ =1800 GeV at the Fermilab Tevatron, is compared with expectations from parton densities extracted from diffractive deep inelastic scattering by the H1 Collaboration at the DESY ep collider HERA (figure from Ref. [10]).

Although factorization breaks down severely between HERA and the Tevatron, it nevertheless holds within the HERA data and within the single-diffractive data at the Tevatron at the same center of mass collision energy. This is demonstrated by the fact that the gluon parton distribution function (PDF) derived from DIS adequately describes diffractive dijet production at HERA [16], while at the Tevatron a consistent gluon PDF is obtained from the measured rates of diffractive W, dijet, b-quark and J/ψ production [15].

Factorization was also tested at the Tevatron between the structure functions measured in single-diffractive and double-Pomeron exchange (DPE) dijet production at $\sqrt{s}$ =1800 GeV [17]. The ratio of the DPE to SD structure functions was found to be larger than that of the SD to ND ones by a factor of 5.3 ± 2.0. This result represents a breakdown of factorization within Tevatron data. However, we note that DPE is a two-gap process and, according to the parton model approach to diffraction that we have presented, should not be suppressed (except for kinematical edge effects) relative to SD. The above result, within the experimental uncertainty, confirms the prediction of the parton model approach.

Finally, CDF has reported that the β and ξ dependence of the diffractive structure function at $\sqrt{s} = 1800$ GeV in the region $0.035 < \xi < 0.095$ obeys β-ξ factorization for $\beta < 0.5$ The observed $\sim \xi^{-1}$ dependence shows that Pomeron-like behaviour extends to moderately high ξ values in diffractive dijet production. Such behaviour is expected in the parton model approach for hard diffraction, where the Pomeron emerges from the quark-gluon sea as a combination of two partonic exchanges, one on a hard scale that produces the dijet system and the other on a soft scale that neutralizes the color flow and forms the rapidity gap [18].

8 Conclusion

Soft hadronic processes have traditionally been treated theoretically in the framework of Regge theory. By postulating a Pomeron with a trajectory of intercept $\alpha(0) > 1$, Regge theory correctly predicts several features of soft physics including the rise of total cross sections with increasing energy, the shrinking of the forward elastic scattering peak, elastic to total cross section ratios, and the shape of the single diffraction differential cross section. However, the predicted $\sim s^{2\epsilon}$ rise of the single diffractive cross section is faster than the $\sim s^{\epsilon}$ rise of σ_T, so that if σ_{SD} is normalized to the experimental value at $\sqrt{s} \approx 22$ GeV the Regge prediction would exceed σ_T at $\sqrt{s} \approx 2$ TeV violating unitarity [5]. The violation of unitarity is averted by renormalizing the "Pomeron flux" [5] to unity, which is equivalent to renormalizing the rapidity gap probability of Eq. (2). This prescription leads to excellent agreement with data. It is interesting that the renormalization procedure, which violates Regge factorization, results in an energy independent $d\sigma_{SD}/dM^2$ cross section, which represents a scaling behaviour; moreover, it can also be applied to double-diffraction [6]. In the present paper, these results are obtained in a parton model approach, which has the added advantage that it can be generalized to describe processes with multiple rapidity gaps [1]. The most interesting conclusion from this approach is that in multigap events the renormalization factor depends only on the s-value of the collision, so that the same suppression factor, otherwise known as "gap survival probability", applies to a process regardless of the number of gaps it contains. The ratio of rates of two-gap to one-gap production in a diffractive process is predicted to be equal to the ratio of the $I\!\!P I\!\!P I\!\!P$ to $I\!\!P$-p couplings, neglecting phase space edge effects. Thus, this factor is interpreted as being the "price to pay" for the color-matching required to form a color-singlet with vacuum quantum numbers. The parton model approach can also be applied to hard diffraction (not discussed here for lack of space) and explains the breakdown of diffractive QCD factorization between HERA and the Tevatron [18].

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