Factorization Breaking in Diffraction

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Factorization breaking in diffraction has been experimentally observed in soft and hard pp and $\bar{p}p$ processes, as well as in photoproduction and in low Q^2 deep inelastic scattering. In this paper, relevant experimental results are presented and phenomenologically connected through a *common thread* provided by the renormalization model of hadronic diffraction.

1 Introduction

Factorization breaking in diffraction has been a topic of interest in high energy physics since the observation of a breakdown of factorization in diffractive dijet production in $\bar{p}p$ collisions at $\sqrt{s} = 630$ GeV by the UA8 collaboration published in 1992 [1]. A suppression of a factor ~ 4 was reported relative to theoretical expectations based on parton densities extracted from diffractive deep inelastic scattering (DDIS) at HERA. This result was later confirmed by the CDF collaboration [2], where a suppression of $\mathcal{O}(10)$ was found at $\sqrt{s} = 1800$ GeV. Equally important is a 1994 CDF result of a breakdown of factorization in soft diffraction: the total $\bar{p}p$ diffractive cross section at $\sqrt{s} = 540$ GeV [$\sqrt{s} = 1800$ GeV] was found to be suppressed by a factor of ~ 4 [factor of $\mathcal{O}(10)$] relative to Regge theory expectations [3].

The similarity of the suppression between soft and hard processes is in contrast with diffractive photon dissociation results [4] and DDIS, where only a $\sim 30\%$ suppression is seen in γp but no suppresion was seen in high-Q^2 DDIS. Recently, HERA experiments reported factorization breaking in γp and $\gamma^* p$ processes, including vector meson production and dijet production (see HERA talks in these proceedings). The breakdown generally occurs at low Q^2 with a magnitude dependant on scale, such as the mass of the vector meson or the dijet mass.

We review relevant experimental data from the Tevatron and from HERA, and offer a phenomenological interpretation based on renormalizing the *rapidity gap probability* to unity, which effectively removes overlapping rapidity gaps generally appearing in other models as multi-Pomeron exchanges (see [5]). The renormalization model (RENORM) is briefly discussed in Sect. 4. By removing potential contributions from overlapping rapidity gaps, RENORM leads to a scaling behaviour in single-diffraction and an asymptotically constant total cross section, $\sigma_t^{SD} \stackrel{s\to\infty}{\rightarrow}$ constant [6].

The paper is organized in five sections:

1. Introduction
2. pp and $\bar{p}p$ results
3. γp and $\gamma^* p$ results
4. RENORM: *the common thread*
5. Summary and conclusions

2 pp and $\bar{p}p$ Results

Figure 1 shows the soft and hard diffractive $\bar{p}p$ processes studied at CDF.

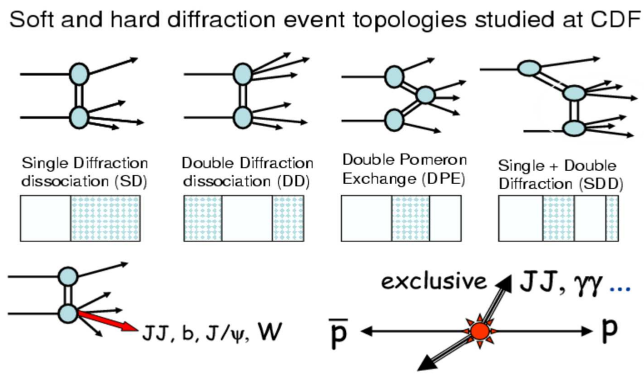

Figure 1: Event topologies of processes studied in $\bar{p}p$ collisions at CDF.

2.1 Soft Single-Diffraction

The first result on factorization breaking was the discovery that the total single-diffractive cross section did not exhibit the $s^{2\epsilon}$ dependence expected by Regge factorization but was suppressed by a factor of $\mathcal{O}(10)$ at $\sqrt{s} = 1800$ GeV, as shown in Fig. 2 (left). In contrast, $d^2\sigma_t^{SD}/dt\,dM^2|_{t=0.05}$ which was expected to vary as $s^{2\epsilon}$ was found to have no explicit s-dependence – see Fig. 2 (right). This $\boldsymbol{M^2}$**-scaling** behaviour leads to an asymptotically constant σ_t^{SD} as $s \to \infty$ and forms the basis of the RENORM model, which is used in predicting the ratio of the intercept of the Pomeron trajectory to its slope [7] and the total cross section at the LHC [6].

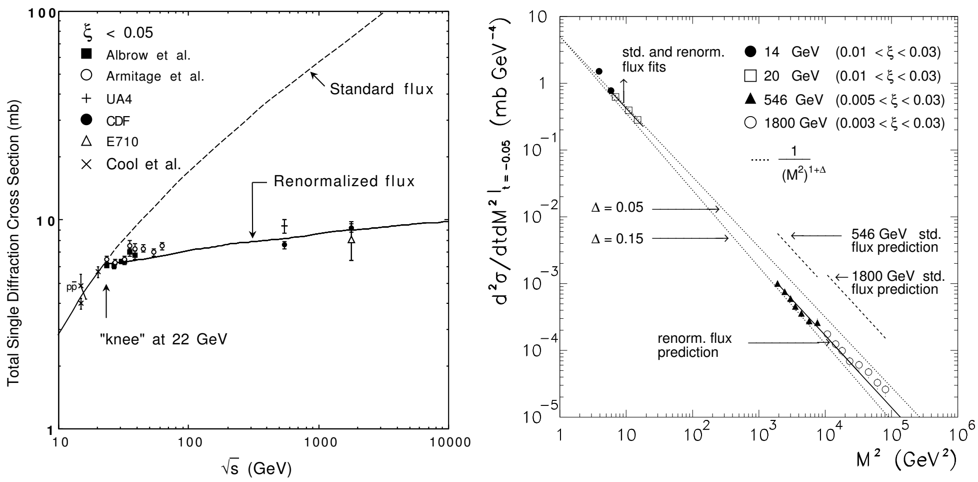

Figure 2: *(left)* σ_t^{SD} vs. $\sqrt{s}$; *(right)* $d^2\sigma_t^{SD}/dt\,dM^2|_{t=0.05}$ compared with Regge predictions.

2.2 Soft Double and Multi-Gap Diffraction

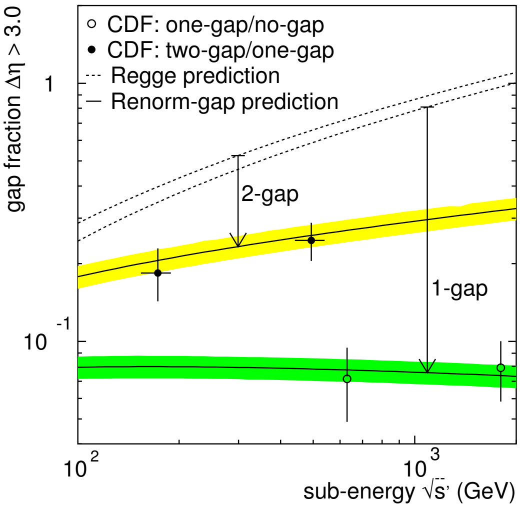

Figure 3: Ratios of two-gap (SDD) to one-gap (SD) rates (solid) and one-gap DD to no-gap (total cross section) vs. $\sqrt{s}_{I\!P-p}$ and $\sqrt{s}_{\bar{p}p}$, respectively.

An important input to deciphering the mechanism of factorization breaking in diffraction is provided by the study of processes with multiple diffractive rapidity gaps. Two such processes were studied by CDF, DPE and SDD (see Fig 1). The η-range available at the Tevatron is not large enough to observe multi-gap events with more than two rapidity gaps, but the lessons learnt from two-gap diffraction studies can be used to pave the way to multi-gap diffraction studies at the LHC.

Classified by the number of rapidity gaps in an event, the following soft diffraction processes were studied at CDF:

- 0-gap: total cross section,
- 1-gap: SD and DD, and
- 2-gap: DPE and SDD.

It was found that while factorization breaking of the same magnitude is observed in the 1-gap to no-gap ratios, the 2-gap to 1-gap ratios are much less suppressed.

2.3 Hard Diffraction

As shown in Fig. 1, CDF has obtained results for several single diffractive hard processes involving JJ, b-quark, J/ψ and W production (and also Z production in Run II). Two types of results have been extracted from the data: diffractive fractions (ratios of diffractive to total production rates) and diffractive structure functions. The general features of the Run I results are summarized below.

- *Diffractive fractions:* at the same collision energy, all measured diffractive fractions are approximately equal; at $\sqrt{s} = 1800$ GeV the fractions are $\approx 1\%$; differences among the measured fractions can be attributed to kinematics.
- *Diffractive structure functions:* the most precise structure functions were extracted from dijet production in SD [2] and in DPE [11]; results are shown in Fig. 4.

The following conclusions were drawn:

(a) *factorization breaking:* a factorization breaking of $\mathcal{O}(10)$ relative to expectations from diffractive parton densities extracted from DDIS at HERA was found, which is similar to that observed in soft diffraction relative to Regge expectations.

(b) *restoration of factorization:* the 2-gap to 1-gap ratio is not as strongly suppressed, just as in soft diffraction.

In addition to the results obtained in Run I, there are also several results obtained in Run II at $\sqrt{s} = 1960$ GeV. The factorization breakdown in the diffractive structure function from SD dijets was confirmed, but there are other results that show the relationship between the

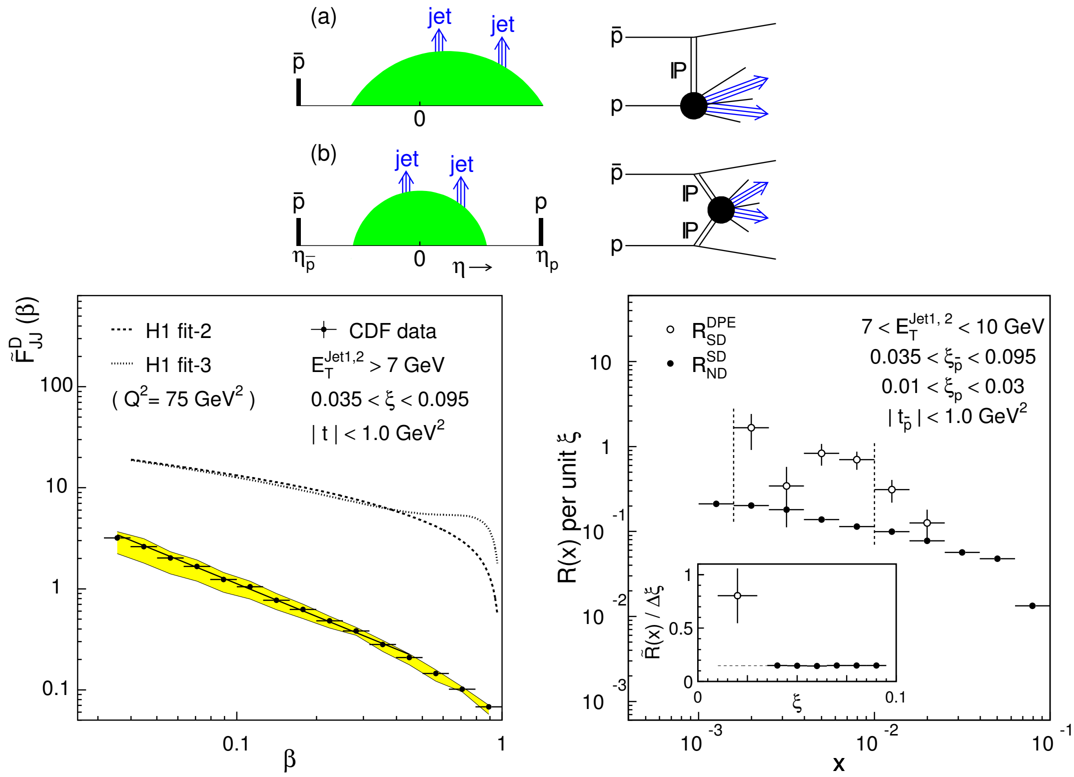

Figure 4: Dijet production in (a) SD and (b) DPD; *(left)* $F^D_{JJ}(\beta)$ vs. β; *(right)* ratios of DPE to SD and SD to ND rates per unit ξ vs. x-Bjorken.

diffractive and non-diffractive structure functions and point to a saturation of the rapidity gap probability as the main controlling factor of the factorization breakdown.

The following Run II results from diffractive events (SD) triggered by the Roman Pot Spectrometer (RPS) and non-diffractive ones (ND) triggered by a dijet event with a calorimeter tower above 5 GeV (Jet5 sample) illustrate the scale *independence* of the suppression factor in dijet production:

- Dijet $E^*_T = (E^{jet1}_T + E^{jet2}_T)/2$ distributions,
- x-Bjorken distributions, and
- t-distributions.

These results are presented in Figs. 5 and 6.

$\longrightarrow$ Figure 5 shows the E^*_T distribution for SD and ND events. The two distributions are practically identical.

$\longrightarrow$ Figure 6 (left) shows the SD to ND ratio as a function of Bjorken-x for different Q^2 values. In the range of 10^2-10^4 in Q^2, within which E^*_T varies by a factor of 100, this ratio varies by less that a factor of two.

→ Figure 6 (right) displays the slope of the diffractive t distribution over the Q^2 range of the RPS triggered data normalized to the value from inclusive RPS triggered data which are dominated by soft diffraction. As seen, there is no scale dependence in the slope of the t distribution in the range $\sim 1\,\mathrm{GeV}^2 < Q^2 < 10^4\,\mathrm{GeV}^2$.

The above results suggest that SD interactions have the same QCD origin as non-diffractive ones, *i.e.* originate from the *proton* low-x parton densities. The suppression in rate relative to theoretical expectations is due to the colour constraint imposed by the requirement of exchanging another parton that forms a colour-singlet with vacuum quantum numbers, commonly referred to as *Pomeron*. This picture is reinforced by the CDF finding that the final state event topologies, namely pseudorapidity and ET distributions, are very similar for SD and ND events when compared at the same $I\!P - p$ collision energy $\sqrt{s}'$ as for $\bar{p}p$ collisions at $\sqrt{s}$. This is further discussed in Sect. 3.

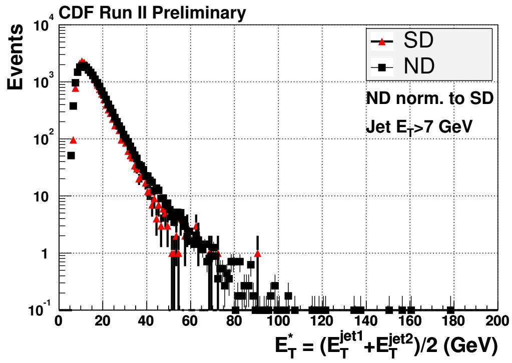

Figure 5: Mean dijet transverse energy distribution for SD and ND events.

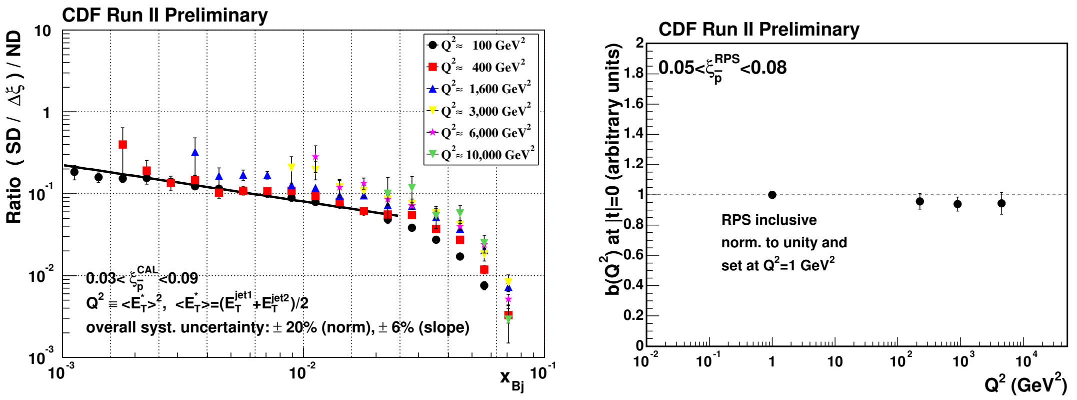

Figure 6: (left) Ratio of diffractive to non-diffractive dijet event rates as a function of x_{Bj} (momentum fraction of parton in the antiproton) for different Q^2 values; (right) the slope parameter of the t distribution b_1 near $t = 0$ vs. Q^2 (normalized to RPS inclusive data sample)

3 γp and $\gamma^* p$ Results

Diffractive photoproduction and DDIS results have been presented at this conference (see [12, 13] and references therein). Below, we present selected results pertaining to factorization breaking, and in the next section we relate the magnitude of the observed effect to that found in $\bar{p}p$ collisions at the Tevatron.

The processes we discuss are vector meson production in γp and $\gamma^* p$ and dijet photoproduction. Of particular interest is the dependence of the factorization breakdown effect on scale, such as the vector meson mass and the jet E_T. Since no scale dependence is observed at the Tevatron, the observation of such dependence at HERA could provide clues for the source of the mechanism of the breakdown.

a) Diffractive vector meson production:

1. W^{Δ}*-dependence on* M_{VM}: Δ increases (*) with M_{VM}.
2. b-slope *of* t*-distribution:* b increases (*) with M_{VM}.

b) Diffractive dijet production:

1. *direct and resolved processes:* violation observed in both components.
2. E_T^{jet}*-dependence:* violation increases with E_T^{jet}.

(*) The effect could be a suppression at low M_{VM} in (1) or with decreasing E_T^{jet} in (2).

In all cases, the maximum factorization breaking effect observed is up to $\sim 50\%$.

4 RENORM: *the Common Thread*

The renormalization model for hadronic diffraction was introduced in [14] and was later extended to a model of renormalizing the *gap probability* to include DD and multi-gap diffractive processes. RENORM is inspired by the Regge description of diffraction, in which the differential cross section factorizes into two parts, one depending on the pseudorapidity space in which particles are produced and the other on the space occupied by rapidity gaps. This second part is interpreted as the rapidity gap probability and should saturate when it reaches unity.

The collision energy at which saturation occurs can be *read off* from Fig. 2 as $\sqrt{s} = 22$ GeV, which corresponds to a rapidity span of $\ln s = 2 \times \ln 22 = 6.2$ units. For any process where the rapidity span in which particles can be produced exceeds 6.2 units, saturation will occur expressed as a suppression of the cross section. The magnitude of the effect can be determined from Fig. 2 as the ratio of the values of the cross section represented by the *renormalized flux* (solid) to *standard flux* (dashed) curves. All CDF results presented here are all in agreement with RENORM predictions (see listed references). In each case, care was taken to asses the rapidity span available for particle production.

Renormalization can equally well be applied to γp and $\gamma^* p$ collisions at HERA. The HERA data were taken at a c.m.s. ep collision energy of 320 GeV, which corresponds to a rapidity span of 11.5 units. In DDIS and in processes with a hard scale in the final state, rapidity space occupied by this scale becomes unavailable for particle production reducing the probability of overlaps and thereby the suppression factor.

In soft diffraction, the entire rapidity span is available for particle production, and therefore from Fig. 2 a suppression of a factor ~ 3 would be expected at this energy, in agreement with the data.

In vector meson production, rapidity space occupied by the vector meson mass ($\ln M_{VM}^2$) and by the $|t|$ scale of the recoil proton ($\ln |t|$) must be subtracted from the value of 11.5 before evaluating the suppression factor. Therefore, one would expect the suppression to increase as the M_{VM} and $|t|$ decrease. This is precisely what is observed in the data: as the $\ln Q^2$ decreases, including contributions from any hard scale present in the final state, the suppression increases.

In diffractive dijet photoproduction, hard scales are introduced my E_T^{jet} and $|t|$. For the data samples studied, a suppression factor of ~ 2 would be expected, both for the **direct** and **resolved** components.

5 Summary and Conclusions

Results from the Tevatron on factorization breaking in soft and hard diffraction in $\bar{p}p$ collisions obtained by the CDF collaboration have been presented, including single-gap and multi-gap processes. Factorization breaking in diffractive vector meson and dijet production at HERA has also been discussed and compared with the Tevatron results. The renormalization model *RENORM*, which handles double-counting caused by overlapping rapidity gaps was offered as a *common-thread* to explain under the same principle both the Tevatron and HERA results.

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