DIFFRACTIVE AND EXCLUSIVE MEASUREMENTS AT CDF

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Experimental results from the CDF experiment at the Tevatron in $p\bar{p}$ collisions at $\sqrt{s}$=1.96 TeV are presented on the diffractive structure function at different values of the exchanged momentum transfer squared in the range $0 < Q^2 < 10,000$ GeV^2, on the four-momentum transfer $|t|$ distribution in the region $0 < |t| < 1$ GeV^2 for both soft and hard diffractive events up to $Q^2 \approx 4,500$ GeV^2, and on the first experimental evidence of exclusive production in both dijet and diphoton events. A novel technique to align the Roman Pot detectors is also presented.

1. Quantum Chromodynamics and diffraction

Diffractive processes have been studied by tagging events with either a rapidity gap or a leading hadron. The traditional "pomeron" can be defined within the framework of Quantum Chromodynamics (QCD) and can be described as a composite entity of quarks and gluons[1]. The goal of the CDF diffractive studies is two-fold: (a) to obtain results which can help decipher the QCD nature of the Pomeron, such as the measurement of the diffractive structure function and $|t|$ distributions, and (b) to measure exclusive production rates (dijet, χ_c^0, $\gamma\gamma$), which could be used to establish benchmark calibrations for exclusive Higgs production at the LHC experiments[2].

2. Diffractive structure functions

The gluon and quark content of the interacting partons can be investigated by comparing single diffractive (SD) and non-diffractive (ND) events. SD events are triggered on a leading antiproton in the Roman Pot Spectrometer (RPS)[3] and at least one jet, while the ND trigger requires only a jet in the calorimeters. The ratio of SD to ND dijet production rates (N_{jj}) is proportional to the ratio of the corresponding structure functions, and can be measured as a function of the Bjorken scaling variable $x \equiv x_{Bj}$[4]. In the ratio, many uncertainties cancel

*Representing the CDF collaboration.

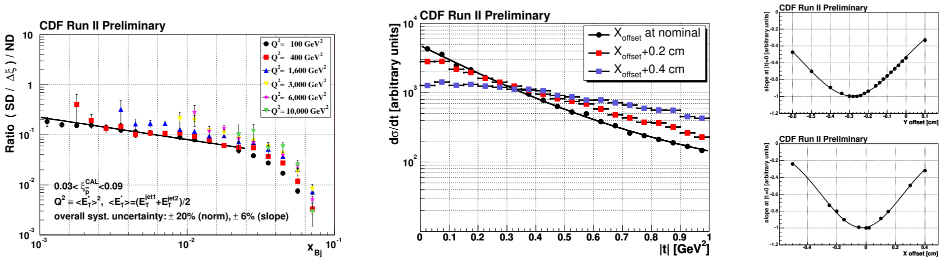

Figure 1. *Left*: Ratio of diffractive to non-diffractive dijet event rates as a function of x_{Bj} (momentum fraction of struck parton in the antiproton) for different values of $E_T{}^2 \equiv Q^2$; *Center*: t-distribution of reconstructed RPS tracks for positive $X_{\rm offset}$ shifts; *Right*: $|b|$ slope versus Y (*top*) and X (*bottom*) offsets.

out. Results are consistent with those of Run I[5], hence confirming a breakdown of factorization. In Run II, the jet E_T spectrum extends to $E_T^{\rm jet} \approx 100$ GeV. Results indicate that the ratio does not strongly depend on $E_T^2 \equiv Q^2$ in the range $100 < Q^2 < 10,000$ GeV^2 (Fig. 1, left). The relative normalization uncertainty cancels out in the ratio, and the results indicate that the Q^2 evolution, mostly sensitive to the gluon density, is similar for the proton and the pomeron.

3. Measurement of $|t|$ distributions

Dynamic alignment of Roman Pot detectors: The antiproton fractional momentum loss, ξ, and four-momentum transfer squared, t, of SD events can be determined from tracks reconstructed in the RPS and the position of the event vertex at the Interaction Point (IP) using the beam transport matrix between the IP and RPS. Crucial for this measurement is the determination of the detector alignment with respect to the beam. The RPS detectors can be aligned by seeking a maximum of the $d\sigma/dt$ distribution at $t = 0$ for SD events (Fig. 1, center). Offsets in both the X and Y coordinates of the RPS detectors with respect to the beam are adjusted until a maximum for $|d\sigma/dt|$ is found at $t = 0$, when the RPS fiber tracker is correctly aligned with respect to the beam (Fig. 1, right). This innovative method is very precise and quite general, and can be used to accurately calibrate the RPS detector position with respect to the beam in CDF using current data or in future experiments at the LHC. The accuracy of the RPS alignment at CDF is ΔX $\approx \pm 30$ μm and ΔY $\approx \pm 30$ μm, respectively.
$|t|$ distributions: SD events studied contain both soft and hard diffractive interactions. An exponential fit with a slope b and arbitrary normalization agrees well with the data in the region $0 < |t| < 1$ GeV^2 for different data samples in which the mean dijet transverse energy is increasingly larger (Fig. 2, left). The measured $|t|$ distribution does not show diffractive minima or "dips", which could have been caused by the interference terms of imaginary and real parts of the interacting partons. When comparing soft and hard diffractive events, results

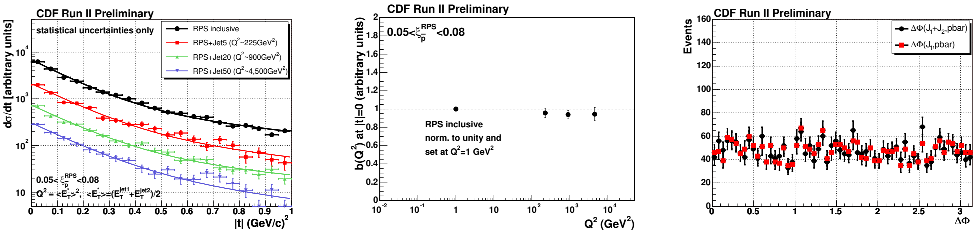

Figure 2. *Left*: $|t|$-distribution measurement for soft and hard SD events; *Center*: b-slope at different Q^2 values (slope of RPS inclusive data is normalized to $b = 1$); *Right*: Azimuthal angle difference between the jets and the outgoing antiproton in the RP+J5 sample. The jet angle is that of the leading jet (red squares) or the average of the angles of the two leading jets (black circles).

show that the b parameter is equal within uncertainties up to $Q^2 \approx 4,500$ GeV^2 (Fig. 2, center). The azimuthal angle difference, $\Delta\Phi$, between the jets and the outgoing antiproton is a flat distribution without any correlation (Fig. 2, right).

4. Exclusive dijet and diphoton production

Exclusive dijet production at the Tevatron can be used as a benchmark to establish predictions on exclusive diffractive Higgs production, a process with a much smaller cross section[6]. The characteristic signature of this type of events is a leading nucleon and/or a rapidity gap on both forward regions, and it results in an exclusive dijet final state produced together with both the leading proton and anti-proton surviving the interaction and escaping in the very forward region. The CDF RPS spectrometer can tag the anti-proton, while the proton is inferred by the presence of an adjacent large ($\Delta\eta > 3$) rapidity gap. The dijet mass fraction (R_{jj}), defined as the dijet invariant mass (M_{jj}) divided by the mass of the entire system, $M_X = \sqrt{\xi_{\overline{p}} \cdot \xi_p \cdot s}$, is calculated using all available energy in the calorimeter. If jets are produced exclusively, R_{jj} should be equal to one. Owing to hadronization effects, underlying event energy spilling out of the jet reconstruction cone, and radiation from the jets, the sharp peak from exclusive production is smeared out to a wider distribution. The search is performed by comparing data with MC expectations. At large R_{jj} values, the excess of events in the data with respect to inclusive DPE dijet production, which is described by POMWIG[7] MC, is well accounted for by the DPEMC[8] (or equivalently ExHuME[9]) MC sample of exclusive events (Fig. 3, left). The quark/gluon composition of dijet final states can be used to provide additional information on exclusive dijet production. At leading order (LO) $gg \to gg$ process is dominant while $gg \to q\overline{q}$ is strongly suppressed. This “suppression” mechanism can be used to improve the sensitivity to exclusive production. Thanks to high tagging efficiency of heavy flavor jets and low mistag rate, b/c-quarks are selected. The

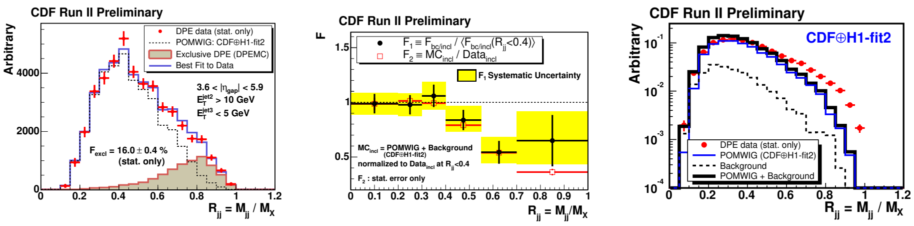

Figure 3. *Left*: dijet mass fraction in DPE data (points) and best fit (solid) obtained from POMWIG MC events (dashed) and exclusive dijet MC events (shaded); *Center*: normalized ratio of heavy flavor jets to all jets as a function of dijet mass fraction. *Right*: R_{jj} distribution for the data (points) and POMWIG MC prediction (thick histogram), composed of DPE dijet events (thin) and non-DPE events (dashed).

ratio ($F_{\mathrm{bc/incl}}$) of heavy flavor tagged jets divided by all inclusive jet events is measured as a function of R_{jj} and is normalized to the weighted average in the region $R_{jj} < 0.4$. In the large mass fraction region ($R_{jj} > 0.6$) a significant "dip" is observed in the data, indicating a contribution due to exclusive production (Fig. 3, center). The result is compared with the ratio of the inclusive MC events to the data, for inclusive dijets (Fig. 3, right).

Another process which can be used as "standard candle" is exclusive diphoton events, $p\overline{p} \to p\gamma\gamma\overline{p}$. The final state is cleaner than in exclusive dijet production as hadronization effects are absent, but the expected cross section is smaller. CDF has performed a search in this channel by requiring nothing else except two electromagnetic (EM) calorimeter towers above threshold in the final selection. Three exclusive $\gamma\gamma$ candidate events with $E_T > 5$ GeV are found with no tracks pointing at the clusters, with a small expected background. The purely QED $p\overline{p} \to pe^+e^-\overline{p}$ process is mediated through $\gamma\gamma \to e^+e^-$ scattering and constitutes a good control sample: 16 exclusive e^+e^- candidate events are selected in the data with a small background of $2.1^{+0.7}_{-0.3}$ events. The cross sections measured, $\sigma(\gamma\gamma) = 0.14^{+0.14}_{-0.04}(\mathrm{stat}) \pm 0.03(\mathrm{syst})$ pb and $\sigma(e^+e^-) = 1.6^{+0.5}_{-0.3}(\mathrm{stat}) \pm 0.3(\mathrm{syst})$ pb, are in agreement with expectations from exclusive ExHuMe and QED LPAIR MCs, respectively.

References

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