Fermi National Accelerator Laboratory

FERMILAB-Conf-98/134-E
CDF

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Michael G. Albrow
For the CDF Collaboration

Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510

April 1998

Presented at *LAFEX International School on High Energy Physics (Lishep98), Workshop on Diffractive Physics*, Rio de Janeiro, Brazil, February 10-20, 1998

Operated by Universities Research Association Inc. under Contract No. DE-AC02-76CH03000 with the United States Department of Energy

DIFFRACTIVE DI-JET PRODUCTION IN CDF

Michael G. Albrow
FermiLab, USA

For the CDF Collaboration
(April 17, 1998)

We have studied events with a high-x_F antiproton and two central jets in CDF, with $p\bar{p}$ collisions at $\sqrt{s} = 630$ and 1800 GeV. These events are expected to be dominated by diffraction (pomeron exchange). The jet E_T spectra are very similar to those of non-diffractively produced jets but slightly steeper; their azimuthal difference $\Delta\phi$ is more peaked at 180°.

I. INTRODUCTION

In the era before QCD interactions among hadrons were described by "Regge Theory", which was based on sound principles such as unitarity (probabilities ≤ 1.0), scattering amplitudes being analytic in continuous variables (e.g. 4-momenta-squared s,t,u) and being symmetric under "crossing" (this latter relates processes like $\pi^- p \to \pi^\circ n$ to $p\bar{n} \to \pi^+\pi^\circ$). Hadron scattering processes were described by the exchange of sums or "towers" of virtual hadrons in the t-channel (Regge trajectories with spin $\alpha(t)$), giving the s- and t-dependences of the data. The total cross sections and elastic scattering of pp and $p\bar{p}$ (related through the Optical Theorem) can be well described by the exchange of just two dominant effective trajectories. One corresponds to ρ, ω, f, A_2 exchange and has an intercept $\alpha(0) \approx 0.5$ and a slope $\frac{d\alpha}{dt} \approx 1.0$ GeV^{-2}. The contribution of this to the total cross section dies away with energy like $s^{-0.5}$ [1]. The other is the *pomeron*, the subject of this Conference, associated with a rise of the total cross sections like s^ϵ with $\epsilon \approx 0.1$. The slope $\frac{d\alpha}{d|t|}$ of the pomeron is much less than that of the mesons, namely about 0.25 GeV^{-2}. The nature of the pomeron was not known, but it is worth emphasizing that it carries *vacuum quantum numbers* $I^{GPC} = 0^{+++}$.

In the late 1970s and early 1980s QCD became well established as the theory of strong interactions. Attention moved away from low-Q^2 processes (which no-one knew how to describe in QCD since the coupling $\alpha_s(Q^2)$ ... not to be confused with trajectories $\alpha(t)$ ...becomes too large for perturbation theory calculations) to large-Q^2 processes where the quarks and gluons become manifest as partons. F.Low [2] and S.Nussinov [3] suggested that the pomeron corresponds to the exchange of two gluons. Twenty years later, after a long period of inattention, this is still a good qualitative, first order picture. The flatter slope of the pomeron trajectory compared to all the other Reggeon ($q\bar{q}$) exchanges then corresponds to the gg force (or "string tension") being stronger than the $q\bar{q}$ force. If at low Q^2 the pomeron is predominantly gg, as Q^2 increases its structure would soften if it behaves like a hadron with the evolution of $q, \bar{q}$ and more g. In 1985 Ingelman and Schlein suggested [4] that the partonic structure of the pomeron could be studied by looking for high E_T jets in single diffractive excitation, SDE, i.e. the process $\bar{p}p \to \bar{p} + X$. When the Feynman-x ($x_F = \frac{p_{z,out}}{p_{z,in}}$ in the c.m, z is the collision axis) exceeds about 0.9, or better 0.95, pomeron exchange in the t-channel dominates this process. Defining $\xi = 1 - x_F$ as the fractional momentum of the exchanged object, a rule of thumb is that pomeron exchange dominates for ξ below about 0.05 and Reggeon exchange (non-diffractive collisions) is relatively more important for larger ξ. This statement is s-dependent; in fact according to the fits of CDF inclusive high-x_F data at $\sqrt{s} = 546$ GeV and 1800 GeV [5] the cross over (diffractive = non-diffractive) occurs at $\xi = 0.06$ at 546 GeV and only 0.03 at 1800 GeV. The relative amounts should depend on whether the event is soft or contains high E_T jets. At the CERN S$p\bar{p}$S Collider UA8 observed diffractive jet production [6] and claimed a hard pomeron structure, i.e. its partons tend to have large momentum fractions β ($\beta = \frac{p_{parton}}{p_{pomeron}}$). A "superhard" component with $\beta \approx 0.9$ was also suggested. Data from HERA also suggest a hard structure, with a rather flat β-distribution. If this is the case events with jets will have a higher pomeron component than soft inclusive events of the same ξ, t. Our experiment was done to study these issues, and eventually to measure the β-distribution and compare it with HERA data. In this paper we do not attempt to distinguish between pomeron and other Reggeon exchanges, but we use a high-x_F track to select a subset of high E_T jet events with a leading particle and tag the t-channel exchange kinematics.

II. APPARATUS AND POT TRACKING

The Collider Detector at Fermilab (CDF) [7] consists of a large central detector with tracking in a solenoidal field and calorimetry over $-4.2 < \eta < 4.2$ to measure jets. For the last two months of the last Collider Run (Ic, which finished in February 1996) we installed (just in time!) three Roman Pot detectors to detect quasi-elastically scattered antiprotons. These were placed on the inside of the Tevatron ring 56 m. from the intersection point. Antiprotons with $\xi > 0$ (or $\xi = 0$ and large $|t|$) are bent into the pot detectors by the 73 T.m dipole field traversed. Three pots are placed 98.5 cm apart to measure the deflected track in scintillating fiber trackers. These have an area of 2.1 cm $\times$ 2.1 cm and a resolution in x and y of approximately 100 μm. A small square scintillator in each pot provided an input to a 3-fold coincidence making a "pot-trigger"; these also had pulse-height information and off-line we have selected signals consistent with a single minimum ionizing particle. Most of these have a clean 3-point track in $x-z$ and $y-z$ views. Data were taken both with a "pot-inclusive" trigger (**PX**, pot track together with a beam crossing) and with a "pot-dijet" trigger (**PJJ**).

After the beams had been accelerated and cleaned the pots were moved in to about 12 mm distance. The acceptance region for the pot detectors is 100% at $t = 0$ from $\xi = 0.05$ to 0.10; this ξ range shrinks as t increases out to about 1.5 GeV^2. Outside this region the acceptance drops due to the restricted ϕ coverage; it drops rapidly for $\xi \geq 0.1$; particles with smaller momentum hit the beam pipe upstream and shower. Together with a primary vertex measured in the CDF central detector we have a resolution $\frac{\Delta p}{p} \approx 10^{-3}$ [8].

We generated by Monte Carlo (POMPYT) antiprotons with ξ, t distributions given by ref [5], as measured by CDF in 1989-91 with an earlier set of Roman Pots. The simulated distributions of x and y, dx/dz and dy/dz agree well with the measured pot hit and track distributions. So do the ξ distribution and the $|t|$ distribution to 1 GeV^2, which is beyond where the previous measurements were made. We therefore believe we have a good understanding of the track reconstruction.

III. 1800 GEV DATA, NON-DIFFRACTIVE DIJETS AND POT+DIJETS

In this talk for the 1800 GeV data I will only compare dijets measured in events taken with a pot + dijet trigger (**PJJ**) with dijets found in minimum bias events, called non-diffractive (**JJ**) events. Without going into details of the triggering and event selection, for both samples we required exactly one good vertex with $|z_{vertex}| < 60$ cm, at least two jets with E_T after corrections above 15 GeV, and a missing $\not{E}_T$ less than 20 GeV and missing $\not{E}_T$ significance $\sqrt{\Sigma E_T}$ less than 3. The latter clean-up cuts remove cosmic ray and beam halo junk events. The pot track had to have 3 x-hits and 3 y-hits making a good recoil $\bar{p}$ track and the three pot scintillators had to have pulse heights consistent with one m.i.p. The ξ of the pot track using the central vertex as origin must be reconstructed and we cut on 0.04 $< \xi <$ 0.095 and $|t| < 1$ GeV^2. For these events we then looked at the multiplicity in the 16-element Beam-Beam Counters (BBC) with $3.2 < \eta < 5.9$ on the same (west) side as the pots. There is a small component piling up at high N_{BBC} indistinguishable from that seen in typical (ND) dijet events, together with a broad low multiplicity distribution which is quite different. This demonstrates both that most of the events do indeed have the pot track and the jets coming from the same collision, but that there is still a small contamination which can be pile-up, with the pot track unassociated with the jets. It could be from a coincident soft diffractive collision or beam halo; it does not matter, these events are easily removed with a cut requiring $N_{BBC}(west) < 6$. Note that we do not expect to see any spike in this distribution in bin 0, because that would imply a rapidity gap extending as far from the beam as 4.3 units, considerably longer than expected from the minimum ξ of 0.04 (through the approximate relation $\Delta\eta \approx ln\frac{1}{\xi}$). The above selections leave us with 1314 **PJJ** events with E_T above 15 GeV.

A similar dijet selection was run on a minimum bias data sample, with of course no selection on forward track or multiplicity. This left only 695 events (out of an initial sample of about 1.5M minimum bias events).

We now compare the distributions of the jets in the **PJJ** data and the **JJ** data. The E_T distributions of the leading jets, from 15 GeV to about 60 GeV where the statistics become marginal, are indistiguishable. The same is true for the second jet, although we can only make the comparison up to 40-50 GeV. A difference is however seen in the third jet E_T spectrum, if there is one above 10 GeV in the events, which is steeper in the **PJJ** events than in the **JJ** events. The fraction of events in the sample with a third jet above 10 GeV is $(44 \pm 2(stat))\%$ and $(27 \pm 1(stat))\%$ in the **JJ** and **PJJ** cases respectively.

The azimuthal difference $\Delta\phi$ between the two leading jets is more peaked back-to-back in the **PJJ** events than in the **JJ** events. This reflects their lower activity, as seen also in the fewer and softer third jets.

Where the largest difference between the two samples shows up is, not surprisingly, in the pseudorapidity distributions of the jets. The mean rapidity of the two leading jets is (trivially) 0.0 in the **JJ** sample but +0.63 in the **PJJ** sample, the dijet system recoiling against the (-ve η) antiproton.

IV. 630 GEV DATA, NON-DIFFRACTIVE DIJETS AND POT+DIJETS

We have made similar studies from data taken at $\sqrt{s} = 630$ GeV during a short run when the pots were newly installed. For this we did not use a **PJJ** trigger but simply a pot inclusive trigger **PX**, with 1.36 million events. The luminosity was low, typically $10^{30} cm^{-2} s^{-1}$. After applying similar cuts to those described above for 1800 GeV, but without any central dijet requirement, we had 189,400 clean single pot-inclusive events, of which 904 contained two jets with $E_T > 7$ GeV and 109 had two jets with $E_T > 10$ GeV. In this case we took a larger sample of minimum bias data, and out of 2.54 million events found 57,179 with two jets above 7 GeV and 9,015 with two jets above 10 GeV.

The acceptance of the pot system in the $t - \xi$ plane is essentially the same as at 1800 GeV except for the very important point that the acceptance in t scales like p_{beam}^2! Therefore at small $\xi \approx 0.01$ we accept down to $|t| \approx 0.15$ GeV^2 rather than about 1 GeV^2, giving access to much larger cross sections and hence larger rates. The t, ξ distributions of the inclusive data agree well with equations derived from the data in Ref [5]. We mostly use the region $0.05 \leq \xi \leq 0.10$, $|t| \leq 0.2$ GeV^2 where the acceptance is high, and require again N_{BBC} (West) ≤ 6. The t distributions are exponential starting from a kinematic t_{min} which grows with ξ; $t_{min} \approx \xi \times m_p^2$.

The 2-dimensional plot of the BBC ($-5.9 < \eta < -3.2$) multiplicity and calorimeter tower ($-4.2 < \eta < -2.0$) multiplicity on the west (pot) side shows a peak in the (0,0) bin falling off in both directions, quite different from non-diffractive (min-bias) events which peak at high values. We selected BBC(W) ≤ 6 which removes some background (overlaps). The same plot for the opposite (east) side peaks at high multiplities for both pot and min-bias data in a very similar way.

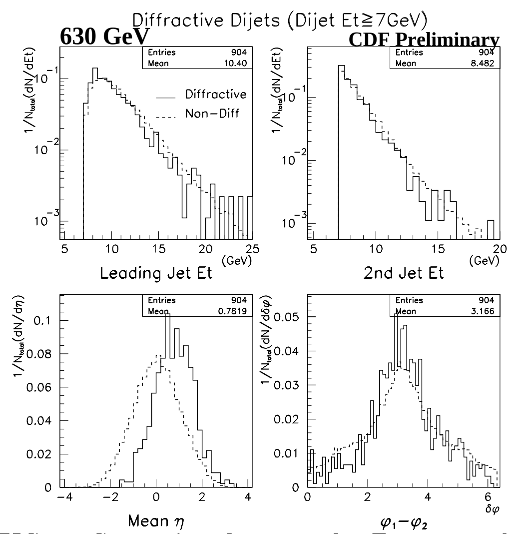

FIG. 1. Comparison between the E_T spectra for the two leading jets, the mean η and the $\Delta\phi$ distribution

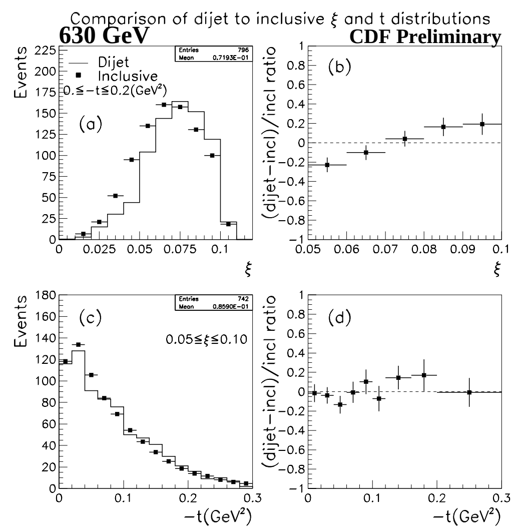

FIG. 2. Comparison between the ξ and the t distributions for **PX** events and **PJJ** events.

In Fig.1 we compare the E_T distributions of the leading and second jets in the "diffractive" (= **PJJ**) and non-diffractive (= **JJ**) samples. We see that they are very similar, as at 1800 GeV, with a slight tendency to be steeper in the diffractive sample. The mean η of the jets recoils to positive values, and the $\Delta\phi$ distribution between the leading jets is slightly more peaked back-to-back. All these conclusions were noted above for the 1800 GeV sample. We show in Fig.2 the ξ and t distributions, comparing the inclusive **PX** data with the **PJJ** data. Not surprisingly, requiring jets gives a bias to higher $\xi = \frac{M^2}{s}$. No t-dependence is seen although the range is small, but this is the first such data down to t_{min} which might have been "special"; apparently it is not. The lego plot of BBC(W) vs. N_{tower} is more peaked at (0,0) for the dijet sample than the inclusive sample; showing less forward activity. Perhaps it is natural that for events with a $\bar{p}$ taking (93$\pm$3)% of the beam energy away, requiring central jets leaves less forward activity alongside the $\bar{p}$. We are studying this effect in simulations.

V. RATIOS

We can derive some interesting ratios which are free of most systematic errors. The cross section for an inelastic collision producing a $\bar{p}$ in the bin $-0.20 < t < 0.0$ GeV^2 , $0.05 < \xi < 0.10$ at $\sqrt{s} = 630$ GeV is approximately 0.5

mb. The fraction of these events which have at least two jets above 7 GeV E_T is $f_7^{POT} = [0.52 \pm 0.02(\text{stat})]\%$. We measure the fraction of min-bias events with at least two jets above 7 GeV to be $f_7^{MB} = [3.32 \pm 0.02(\text{stat})]\%$. The ratio of these two fractions:

$$\frac{f_7^{POT}}{f_7^{MB}} = [15.7 \pm 0.6(stat)]\%$$

showing that pomeron-proton collisions with $\sqrt{s}$ = 150-200 GeV are less likely to have jets than 630 GeV pp collisions. This qualitatively matches the observation that the diffractive E_T spectra are steeper, but modestly, reflecting a harder partonic structure of pomerons than protons. For 10 GeV dijets at 1800 GeV the "ratio of ratios" is at a similar level.

VI. CONCLUSIONS

We are analyzing data at $\sqrt{s} = 630$ GeV and 1800 GeV with a high-x_F antiproton measured in roman pots, which tags a t-channel exchange believed to have a large pomeron component. The ξ and t distributions are consistent with expectations from previous Tevatron experiments. The multiplicity on the $\bar{p}$ side is low.

High E_T jet pairs are observed in these events, with similar (but slightly steeper) E_T distributions to those in non-diffractive collisions, however the fraction of pot events containing jets is lower by a factor 6-10 than the fraction of min-bias events containing jets. The dijets recoil in η away from the $\bar{p}$, and they are more peaked at $\Delta\phi = 180^\circ$ than in min-bias events. At $\sqrt{s} = 630$ GeV the jet events tend to have larger ξ and lower associated multiplicity on the $\bar{p}$ side than **PX** events, but the same t-distribution from t_{min} to -0.3 GeV^2.

We are now using the POMPYT Monte Carlo and studying the relative amounts of pomeron and reggeon exchange (or non-t-channel processes) and using the event kinematics to derive the parton distribution functions in the t-channel.

VII. ACKNOWLEDGEMENTS

I thank the Fermilab staff, especially C. Moore, and the technical staffs of the participating institutions in CDF for their vital contributions. This was a supplementary program (E876) within CDF and additional support from the U.S. Department of Energy and the Ministry of Education, Science and Culture of Japan is gratefully acknowledged.

[1] A.Donnachie and P.V.Landshoff, Nucl.Phys.B **267**, 690 (1986).
[2] F.Low, Phys.Rev.D **12**, 163 (1975).
[3] S.Nussinov, Phys Rev D **14**, 246 (1976).
[4] G.Ingelman and P.Schlein, Phys.Lett. B **152**, 256 (1985).
[5] F.Abe et al., Phys.Rev D **50**, 5535 (1994).
[6] R.Bonino et al. (UA8), Phys.Lett. B **211**, 239 (1988).
[7] F.Abe et al., Nucl.Inst.Methods **A271** 387 (1988).
[8] C.Moore, these proceedings.