# DI-JET PRODUCTION BY DOUBLE POMERON EXCHANGE IN CDF

Michael G. Albrow
*FermiLab, USA*

For the CDF Collaboration
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We have studied events with a high-$x_F$ antiproton and two central jets with $E_T > 7$ GeV in CDF, in $p\bar{p}$ collisions at $\sqrt{s} = 1800$ GeV. We find an excess of events with a rapidity gap at least 3.5 units wide in the proton direction, which we interpret as di-jet production in double pomeron exchange events.

## I. INTRODUCTION

Double pomeron exchange, DPE, events [1] contain two large rapidity gaps, where by "large" is meant not exponentially damped on a scale of order one unit of rapidity. A region $\Delta\eta$ (or better $\Delta y$) as large as (say) 4 units with no hadrons is dominated by pomeron exchange in the t-channel, with little background from other processes (non-diffractive or reggeon exchange). For a region $\Delta\eta$ only 2 units wide reggeon exchange dominates. One cannot distinguish these processes on an event-by-event basis, only on the basis of multi-event distributions. The Feynman-$x$, $x_F = \frac{p_{z,out}}{p_{z,in}} = 1 - \xi$, distribution of leading particles of identical type to the incoming particle (e.g. $\bar{p} \rightarrow \bar{p}$) shows a flat or falling spectrum due to reggeon exchanges and a distinct peak for $x_F > 0.95$ (approximately) due to pomeron exchange. Also, if one selects a large (e.g. 4 units) region of rapidity and counts the hadrons, the multiplicity $n$ distribution sometimes shows two distinct components: One is like a negative binomial distribution (nbd) and represents non-diffractive events (and some diffractive events where the pomeron did not span the whole $\Delta\eta$ region), the other a peak at $n$=0. In the measurements reported here we used both methods; we triggered on a high $x_F$ $\bar{p}$ and observed the two-component $n$ distribution on the opposite side.

The total rapidity range of a $p\bar{p}$ collision is $\Delta y = ln\frac{s}{m_p^2}$, which was 8.4 at the CERN ISR ($\sqrt{s} = 63$ GeV), 13.0 at the $Sp\bar{p}S$ ($\sqrt{s} = 630$ GeV), and is 15.1 at the Tevatron ($\sqrt{s} = 1800$ GeV). Requiring two forward rapidity gaps of at least 3 units is approximately equivalent to requiring the beam particles to both have $x_F > 0.95$, and that limits the central masses to 3 GeV at the ISR, 30 GeV at the $Sp\bar{p}S$ and 90 GeV at the Tevatron. Of course this is merely a rule of thumb, there is no hard limit, just a smaller and smaller signal÷background if you push the mass higher. The DPE process was discovered at the ISR and used there [2] for glueball searching; if pomerons are predominantly gluonic at low $Q^2$ this should be an ideal hunting ground; furthermore the central system has tightly constrained quantum numbers ($I^{GPC} = 0^{+++}$) as the pomeron has vacuum quantum numbers.

At the $Sp\bar{p}S$ UA1 [3] made a study of events triggered on two forward rapidity gaps ($3 < |\eta| < 6$) together with a localised central energy deposition (either $E_T > 1.2$ GeV in an electromagnetic cluster or $E_T > 3$ GeV in an electromagnetic + hadronic sum). Unfortunately one cannot derive from this data the relative amounts of DPE signal and background; it was lacking the control samples which did *not* require forward gaps.

The data presented here from CDF benefit greatly from the higher $\sqrt{s}$, the detection of the forward $\bar{p}$ and the study of forward multiplicities without any trigger requirements. Experiment DØ [4] also presented at this meeting evidence for jets in DPE, triggering on a rapidity gap on one side, central jets and observing the two-component multiplicity distribution (zeros + nbd) on the other side.

## II. APPARATUS AND POT TRACKING

The Collider Detector at Fermilab (CDF) 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 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 $0.05 < \xi < 0.1$ are bent into the pot detectors by the traversed dipole field. Three pots are placed 98.5 cm apart to measure the deflected track in scintillating fiber trackers. Some details of these detectors, their use in triggering and reconstructing forward tracks are given in another talk at this meeting [5]. Data were taken for this study with a "pot-inclusive" trigger (pot track together with a beam crossing, **PX**).

The active edge of the pot detectors was about 12 mm from the beams. The acceptance region is 100% at $t = 0$ from $\xi = 0.05$ to 0.10; this $\xi$ range shrinks as $t$ increases out to about 1.5 GeV$^2$. Outside this region the acceptance drops due to the restricted $\phi$ coverage. The acceptance drops rapidly at $\xi = 0.1$; 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 $\frac{\Delta p}{p} \approx 10^{-3}$.

## III. 1800 GEV POT+DIJETS DATA SAMPLE

For this study we used 3,255K events triggered on a coincidence of the 3 pot trigger scintillators with a beam crossing, **PX**. Of these, we selected 2,337K with exactly one reconstructed vertex with $|z_{vertex}| < 60$ cm. We then required that the pulse heights of the pot trigger counters are consistent with a single m.i.p., and that we reconstruct a single track with 3 x and 3 y hits; 1,777K events survive. After some minor clean-up cuts we have 1,698K good **PX** events of which 26,997 **PJJ** have at least two jets with $E_T > 7$ GeV. The $\xi$ of the pot track using the central vertex as origin is reconstructed; no cut is applied but nearly all events have $0.05 < \xi < 0.10$ and $|t| < 1$ GeV$^2$.

We then required low multiplicity $N_{BBC}(west) \leq 6$ in the 16-element Beam-beam counters (BBC) with $3.2 < \eta < 5.9$ on the same (west) side as the pots, as well as a signal consistent with no particles in a small angle "microplug" calorimeter with $4.4 < \eta < 5.4$ in the same region. The above selections leave us with 22,304 **PJJ** events with $E_T$ above 7 GeV for each of the two jets.

A similar dijet selection (**JJ** events) was made on a minimum bias data sample, with of course no selection on forward tracks or multiplicity. As noted in [5] for dijets above 15 GeV, the $E_T$ spectra are very similar. The $\Delta\phi$ distribution between the two leading jets is slightly more peaked back-to-back in the **PJJ** than in the **JJ** events. The jets are shifted in rapidity away from the pot track. One expects a shift first because of the moving c.m. of the pomeron-proton collision, together with any effect due to the $\beta$-distribution of the partons in the pomeron, which is expected to be harder than the $x_{Bjorken}$ distribution of the partons in the proton. These two effect tend to cancel, which could explain the similar $E_T$ spectra of the jets. However if the cancellation were complete, then of course the mean $\eta$ of the jets would also be the same, so it is only partial.

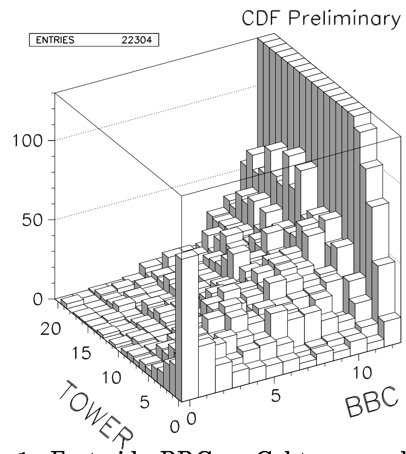


FIG. 1. East side BBC vs Cal.tower multiplicity distribution for $PJJ$ events, 7 GeV di-jets.

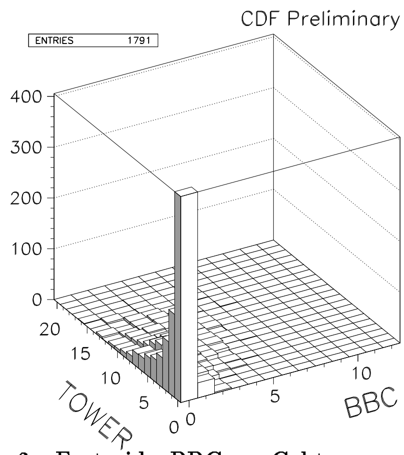


FIG. 2. East side BBC vs Cal.tower multiplicity distribution for Monte Carlo Double Pomeron (POMPOMPYT) with a flat-$\beta$ distribution.

## IV. DOUBLE POMERON SIGNAL

We now look on the opposite (east) side to the pot track for events with a rapidity gap, over and above what would be expected from downward fluctuations in multiplicity. Fig 1(data) shows $N_{BBC}(east)$ vs $N_{tower}(east)$ for these **PJJ(7)** events; the BBC counters cover $3.2 < \eta < 5.9$ and the calorimeter towers are in the region $2.4 < \eta < 4.2$. The $E_T$ cut on the towers was chosen to be $\eta$-dependent to minimize noise while maximizing sensitivity to particles. The empirical formula for the cut was (GeV) 0.579 - 0.143$|\eta|$ for $2.3 < |\eta| < 3.0$ and 0.3375 - 0.0625$|\eta|$ for $|\eta| > 3.0$. There can still be some noise hits among all the towers in the search region. The data show a spike in the (0,0) bin not explicable in terms of an extrapolation of the bulk of the (SDE) events. There are 90 events in that bin, out of the 22,304 in the whole sample, where the surrounding bins have about 20 events.

The shape of the distribution in Fig.1, and how to extract a signal and background, can be understood with the help of a Monte Carlo simulation. For this we modified the program POMPYT, which was made to include single diffraction in PYTHIA, to simulate DPE (POMPOMPYT). Each incident beam particle can emit a pomeron with a defined flux and defined structure functions, and the pomeron-pomeron collision is treated like a hadron-hadron collision to produce jets. The resulting simulation of Fig.1, for a pomeron with a flat-gluon $\beta$-distribution, is shown in Fig.2. We note the strong signal in the (0,0) bin, but actually only 24% (28%) of the DPE events with $\xi < 0.10$ for 7 GeV (10 GeV) dijets are in this bin.

The lack of MC events along the diagonal of the $N_{BBC} - N_{tower}$ plot beyond the first two bins leads us to use this distribution extrapolated to (0,0) as a reasonable estimate of the background to DPE, but to put a generous systematic uncertainty on it. The plot is shown in Fig.2, and we take 70 events for the DPE signal and $20 \pm 10$ events for the background in this bin. The statistical significance of the signal is clearly overwhelming. If we select dijets above 10 GeV rather than 7 GeV, the diagonal entries are : 14, 3, 4, 4, 2, 3,... from a total number of 4237 events in the **PJJ(10)** sample.

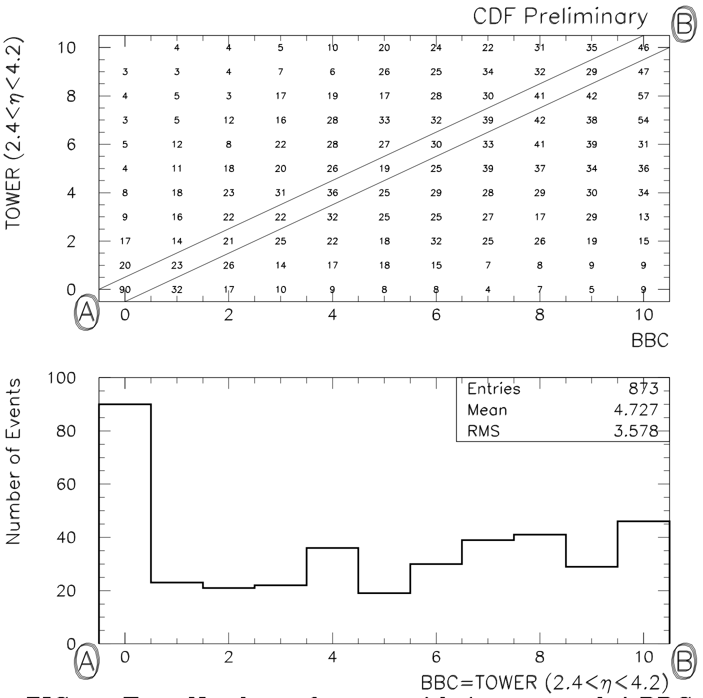


FIG. 3. Top: Numbers of events with $i$ towers and $j$ BBC counters occupied, where $i$ ($j$) is the vertical (horizontal) axis, on the east side (opposite the high-$x_F$ antiproton). Bottom: Distribution along the diagonal $i = j$ showing the DPE signal in the first bin.

Taking the fraction of **JJP** events with a (0,0) gap, **PJJG**, and considering the (19%) difference in correcting for events rejected because they have an additional fake vertex, we find a ratio:

$$R(\frac{PJJG}{PJJ}) = [0.26 \pm 0.05(stat) \pm 0.05(syst)]\%$$

where $\mathbf{G}$ = gap (i.e. no detected particles[1]) for $2.4 < \eta < 5.9$, the two jets are above 7 GeV in $E_T$, and **P** means a pot track with $0.05 < \xi < 0.10$.

Note that if the gap on the east side extends all the way from $\eta = 2.4$ to the unobserved beam proton, the latter should have, from $\Delta\eta = -ln\xi$, $\xi_p \approx 0.006$. Further considerations such as fluctuations in the rapidity gap edge, detector efficiency effects and $\eta \neq y$ etc. allow higher values of $\xi_p$. Monte Carlo studies lead to values of $\xi$ typically

[1]Particles above the $\eta$-dependent $E_T$ thresholds described above in the tower region; the BBC counters are inefficient for $\gamma, n, K^\circ$.

0.015 - 0.035. Central masses are given by $\xi_1\xi_2 = \frac{M^2}{s}$, allowing a range from 50 GeV to 100 GeV for the present studies. We are at present studying this calorimetrically.

Note also that the above fraction is **not** the same as the ratio $\frac{DPE}{SDE}$. Firstly, POMPOMPYT predicts that only 24% of all the DPE events will be in the (0,0) signal bin, with a flat gluon pomeron (we are now studying the effect of other pomeron structures). Secondly we are not yet ready to say what fraction of the **PJJ** events are due to pomeron exchange, although we believe that it is large. POMPOMPYT as a phenomenological model, has the incoming protons emitting pomerons with a certain flux and they have an input partonic structure. The acceptance for DPE **PJJ** events depends on the pomeron's structure. In CDF we previously measured **JJG** [6] and diffractive-$W$ [7] **WG** events. By comparing these rates we extracted the fraction $\frac{g}{g+q}$ in the pomeron, finding 70 $\pm$ 20 %, similar to the slightly lower fraction found at HERA [8]. However we find fewer diffractive events than the HERA data lead us to expect (together with the pomeron = quasiparticle paradigm, including factorisation in the calculations) by a "Discrepancy factor" $D = 0.18 \pm 0.04$. In order for POMPOMPYT to agree with our measured ratio (0.26% in the (0,0) bin) we need to apply a factor $D^2$; then the agreement is good, with POMPOMPYT predicting 0.25%.

The cross section for events at $\sqrt{s} = 1800$ GeV with a $\bar{p}$ with $0.05 < \xi < 0.10$, two jets above 7 GeV $E_T$ and a gap (just counting the excess 70 events) on the $p$ side $2.4 < \eta < 5.9$ is $13.6 \pm 2.8 \pm 2.0$ nb.

## V. KINEMATICS

Taking the 90 events in the (0,0) signal bin, we see no appreciable difference in the $\xi$ or $t$ distributions when compared with the SDE events, i.e. those with medium or even high multiplicity on the east side. Fig.4 shows a comparison between the leading jet $E_T$ distributions, $<\eta>_{Dijet}$ and $\Delta\phi$ distributions for the DPE candidates, single diffractive events and non-diffractive events.

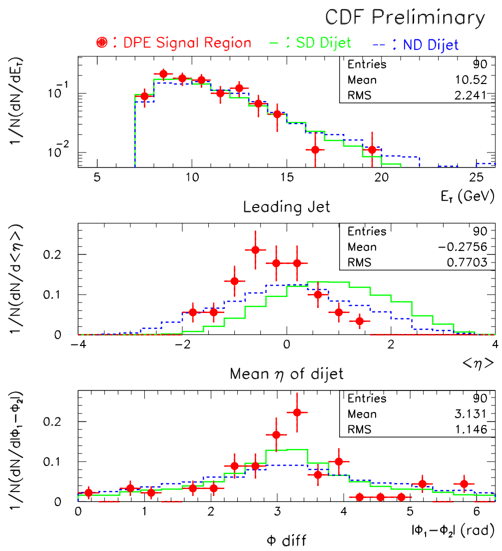


FIG. 4. Top: $E_T$ jet spectra for leading jet, DPE compared with SDE and non-diffractive events. Middle: DPE/SDE/ND comparison for $\eta$ distributions. Bottom: DPE/SDE/ND comparison for $\Delta\phi$ distributions

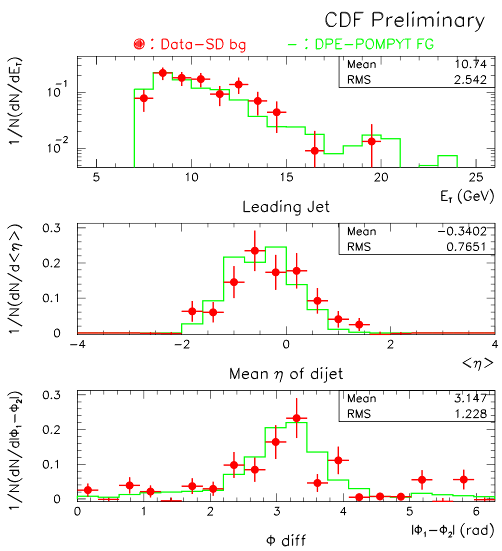


FIG. 5. Top: $E_T$ jet spectra for leading jet, DPE compared with POMPOMPYT. Middle: DPE Data-POMPYT comparison for $\eta$ distributions. Bottom: DPE Data-POMPYT comparison for $\Delta\phi$ distributions

The $E_T$ distributions are equal, the $\eta$-distributions show the expected boosts (symmetric about $\eta = 0$ for non-diffractive, pushed to positive $\eta$ for **PJJ**, and pushed back to slightly negative $\eta$ for **PJJG**), and the $\Delta\phi$ distribution shows that the DPE events are even more peaked back-to-back. POMPOMPYT with a flat gluon $\beta$-distribution for the pomeron reproduces well, see Fig.5, the shapes of the $E_T$, $\eta$ and $\Delta\phi$ plots.

## VI. CONCLUSIONS

In a sample of $\sqrt{s} = 1800$ GeV $p\bar{p}$ collisions with a high $x_F$ $\bar{p}$ track ($x_F > 0.90$) and two jets with $E_T > 7$ GeV, we have observed a clear excess of events with a rapidity gap from 2.4 - 5.9 on the $p$ side. About 0.26% of the **PJJ** events are in this **PJJG** class.

We developed a DPE version of POMPYT to understand the signal÷background levels in the data. According to this Monte Carlo, if the pomeron structure is flat-gluonic, 0.24% of the DPE events with $0.90 < x_F(\bar{p}) < 0.95$ and $0.9 < x_F(p) < 1.0$ fall in this (0,0) bin. The rate of events is consistent with having to apply the previously determined discrepancy factor between diffraction in $pp$ and $ep$ collisions [9] $D = 0.18$ twice, $D^2$, to get the correct rate. This is expected with the renormalized flux hypothesis of Goulianos [10].

The jets have the same $E_T$ spectrum as SDE and non-diffractive jets; they are however more back-to-back in $\Delta\phi$, following a systematic trend. Perhaps simply the more of the rapidity range of an event is taken by gaps, the less additional jet activity is allowed. The jet $\eta$ distributions show the expected boosts.

Finally, we would like to note that these data were taken in the last four weeks of the last Collider run, with triggers that were heavily down-scaled and not optimum for this physics. In Run II, starting in the year 2000, factors of $10^3$ in statistics with higher $E_T$ jets should be possible.

## VII. ACKNOWLEDGEMENTS

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[1] See e.g. M.G.Albrow, Double Pomeron Exchange from the ISR to the SSC, Nucl.Phys.B (Proc.Supp.) **12**, 291 (1990) and references therein.
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