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Diffractive Component in *pp* Collisions at 102 and 405 GeV*

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We study the diffractive component in *pp* collisions at 102 and 405 GeV and examine its energy dependence in M^2 and x variables. The total cross section for $|x| > 0.9$ remains approximately constant: 6.6 ± 0.5 and 6.8 ± 0.7 mb at the two energies. However, both $d\sigma/dx$ and $d\sigma/dM^2$ show strong energy dependence within the $|x| > 0.9$ region. The energy and M^2 dependences of $d\sigma/dM^2$ do not have the characteristics of a triple-Pomeron term for $0.90 < |x| < 0.99$.

Recent studies of the recoil-proton spectrum observed in *pp* collisions at high energies have provided evidence for the presence of a sizable inelastic diffractive component in the data.[1] Furthermore, the universal aspect of diffractive production in hadronic collisions has been revealed through investigations utilizing πp incident channels.[2] In this paper we discuss our complete results at 102 GeV pertaining to diffractive production in the reaction

$$p + p \rightarrow p + \text{anything}. \quad (1)$$

We also present our preliminary findings for this inclusive process at 405 GeV.

Our data are from the 30-in. hydrogen bubble chamber at the National Accelerator Laboratory (NAL): a 30 000-picture exposure at 102 GeV/c and an initial 12 000-picture exposure at 405 GeV/c, yielding 124 and 65 events/mb, respectively. The film was scanned three times for events having a possible proton with bubble density greater than 1.5 times the minimum. All such candidate tracks were measured, reconstructed, and subsequently reexamined to identify protons through their predicted ionization. This identification is reliable up to a lab momentum of about 1.3 GeV/c, consequently a final cut at 1.2 GeV/c was imposed on the data. Because of the sharp transverse-momentum (P_T) dependence of Reaction (1), this cut does not cause any significant bias in the data we present for values of $x < -0.5$. (x is defined as $P_{\parallel}/P_{\text{incident}}$ in the c.m. system.)

Two-prong inelastic events were separated from elastic events by a kinematic fitting procedure.[3] Elastic background was further reduced by requiring the square of the missing mass (M) recoiling from the proton in Reaction (1) to be greater than 1 and -1 GeV^2 at 102 and 405 GeV, respectively. (The average resolution in M^2 is ± 0.7 and ± 2.8 GeV^2, corresponding to $\delta x = \pm 0.0035$ at the two beam energies.) Small corrections were applied to the two-prong events to account for the resulting losses. Scanning-loss corrections, based on the loss found for elastic events, were also applied to the two-prong data for short protons with $|t| < 0.04$ GeV^2. Small corrections were also applied for a few $\geqslant$4-prong events which had protons too short to see and/or mea-

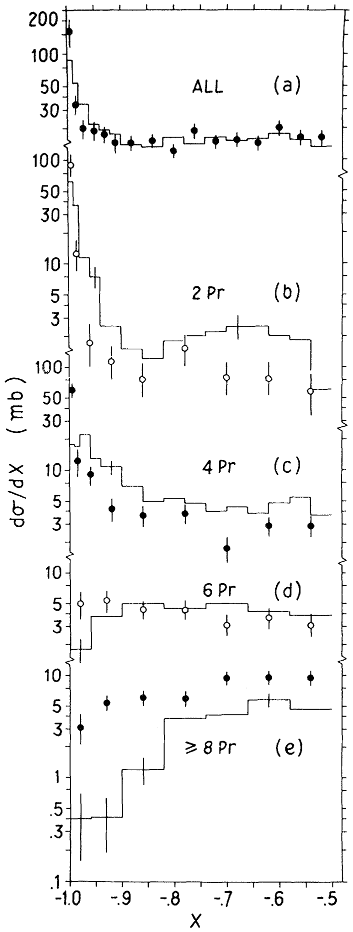

FIG. 1. x distributions for various charged-particle topologies. Histograms are 102-GeV data; closed and open circles are 405-GeV data. Where the cross sections are equal, the 102-GeV error bars are ~0.7 times the 405-GeV error bars. Events with $x<-1$ have been put into the first bin in each histogram. These events appear with $M^2 \lesssim 1$ GeV^2 in Fig. 2.

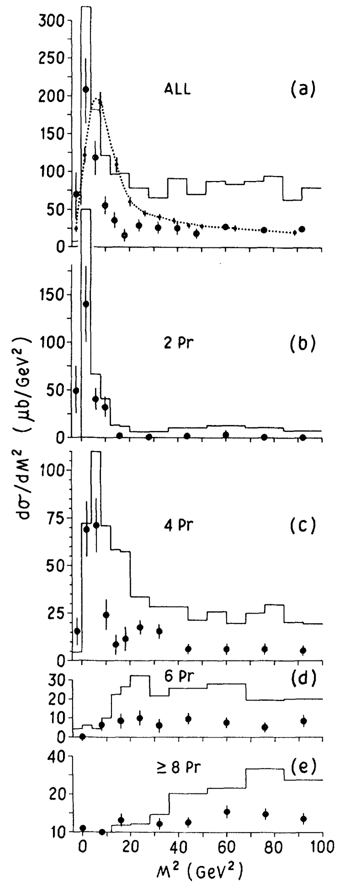

FIG. 2. M^2 distributions for various topologies. Histograms are 102-GeV data; closed circles are 405-GeV data. The dotted durve in (a) represents the ISR data for the doubly differential invariant cross section at $P_T^2=0.275$ (GeV/c)^2, $s=930$ GeV^2, arbitrarily normalized to our 405-GeV data at $M^2=75$ GeV^2.

sure. Uncertainties in all these corrections do not materially affect the conclusions we draw from the data.

In Figure 1 we show $d\sigma/dx$ distributions for various topologies at both energies. [Our slow-proton restriction cuts off the data at $P_T^2=0.36$ (GeV/c)^2 for $x=-0.5$ and at $P_T^2=1.1$ (GeV/c)^2 for $x=-1.0$, but because of the sharp P_T^2 dependence in the data the cross sections we show represent essentially the complete P_T^2 range.] We note the following features of the $d\sigma/dx$ distributions.

(1) There is a general rise in the cross section for $x \lesssim -0.9$. A similar rise is seen at $|x| \approx 0.9$, for specific P_T^2 values, measured at the CERN intersecting storage rings (ISR) [1] and NAL[4] using counters.

(2) An estimate of the total diffractive inelastic cross section can be obtained by assuming it approximately equals the observed cross section for $x<-0.9$.[5] The cross sections we obtain for $x<-0.9$ are 3.3 ± 0.25 and 3.4 ± 0.35 mb at 102 and 405 GeV, so that what we call the total single diffractive cross section (twice these values) shows little energy dependence over the NAL range.

(3) In the range $-0.95<x<-0.90$ there may be a slow decrease of $d\sigma/dx$ with energy. We obtain 20 ± 2 and 16 ± 2 mb for the average value of $d\sigma/dx$ in this region at our two energies.

(4) There is a dramatic increase of $d\sigma/dx$ with energy near the kinematic boundary. The com-

bination of this effect with the one above is such as to keep the total cross section for $x < -0.9$ approximately constant.

(5) Cross sections for the higher topologies rise in the $x < -0.9$ region as the beam energy increases, giving a rapid energy dependence to the multiplicity associated with a proton at a fixed x in this region. This agrees with the observation[6] that the associated multiplicity is an s-independent, increasing function of M^2. The growth at fixed x comes about, therefore, because $M^2 \approx s(1-|x|)$.

In Fig. 2 we plot $d\sigma/dM^2$ for these same data. The diffractive region, $x < -0.9$, corresponds to $M^2 < 77$ GeV^2 for the 405-GeV and $M^2 < 20$ GeV^2 for the 102-GeV data.

(1) We consider first the region in which both M^2 and s/M^2 are "large," where triple-Regge behavior[7] should be applicable. This extends from $M^2 \approx 10$ GeV^2 up to $M^2 \approx 20$ and 80 GeV^2 at our two s values of 193 and 763 GeV^2, respectively. If a pure triple-Pomeron (PPP) term dominated the production process in this mass region, $d\sigma/dM^2$ would be proportional to $1/M^2$ and independent of s (up to ln$s$ terms). The fact that $d\sigma/dM^2$ falls approximately like s^{-1} and, at 405 GeV, is definitely not proportional to $1/M^2$ rules out PPP behavior as the dominant mechanism at NAL energies for the t-integrated cross section in the region $0.90 < |x| < 0.99$.

The high-P_T^2 data at the ISR ($s = 930$ GeV^2) show a wider and somewhat shifted peak in M^2 [dotted curve, Fig. 2(a)] and are in agreement with PPP dominance out to $M^2 \approx 60$ GeV^2 (Foà, Ref. 7). The apparent disagreement between our 405-GeV data and the ISR data in the M^2 shapes would suggest that the M^2 and P_T^2 dependences are correlated.

(2) The $M^2 < 10$ region shows an entirely different behavior: $d\sigma/dM^2$ is approximately independent of s. (The events at negative M^2 are due to experimental resolution and should be added into the peaks in making this comparison.) This $M^2 < 10$ region may be related to "diffraction dissociation" processes, observed at lower energies, which have $d\sigma/dM^2$ independent of s but not necessarily proportional to $1/M^2$. It is this $M^2 < 10$ region that produces the sharp peaks in

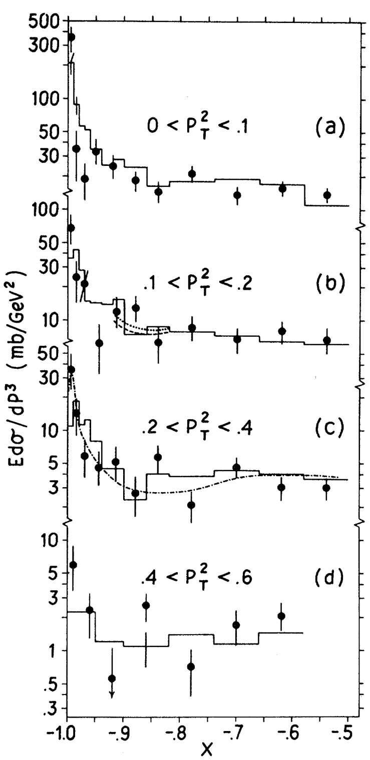

FIG. 3. Invariant cross section versus x for various P_T^2 slices of the data (all topologies). Histograms are 102-GeV data, closed circles are 405-GeV data. The curves in (b) are from Ref. 4 and have ±15% normalization uncertainty. Dotted (dashed) curve is $s = 213$ (752), both at $P_T^2 \approx 0.135$. These data have been converted for us from fixed t to fixed P_T^2 by the authors of Ref. 4. The curve in (c) is ISR data (Ref. 9), $s = 930$, $P_T^2 \approx 0.275$, and has ±10% normalization uncertainty.

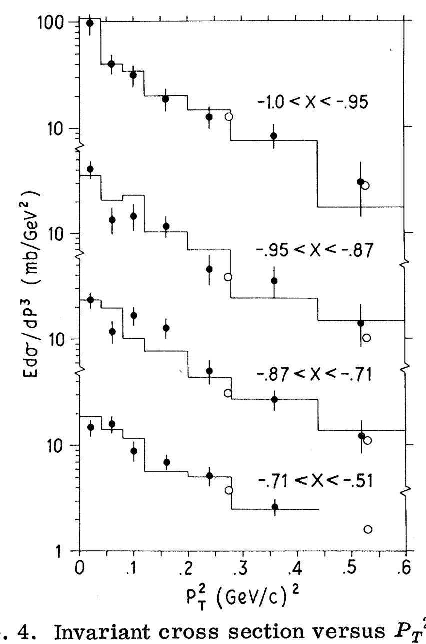

FIG. 4. Invariant cross section versus P_T^2 averaged over various x slices of the data (all topologies). Histograms are 102-GeV data, closed circles are 405-GeV data. Open circles are ISR data from Ref. 9, averaged over the same x intervals.

Fig. 1.

(3) The cross sections at 102 and 405 GeV for $M^2 < 10$ GeV^2 are, respectively, 4.5 ± 0.4 and 3.5 ± 0.5 mb (after multiplying by 2).[8] Taking into account differences in background we conclude that this low-mass diffraction-dissociation region contributes about half of the total "diffractive" component of 6–7 mb.

In Fig. 3 we show the invariant cross section versus x for various P_T^2 slices of the data. Where possible we have made comparison with the NAL[4] and IST[9] counter data and find good agreement within the limited statistical accuracy.

In Fig. 4 we show the invariant cross section versus P_T^2 for various x slices of the data. The P_T^2 dependences do not show any marked variation with x or s. In the P_T^2 region where our data overlap the ISR data the agreement is good. We see no evidence for turnovers or dips at small P_T^2.

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[3]We estimate the overall systematic uncertainties in the cross sections for the inelastic two-pronged channels in the region $x < -0.99$ to be $\pm 10\%$ at 102 GeV and $\pm 25\%$ at 405 GeV. The separation between elastic and inelastic events is particularly questionable for momentum transfers below 200 MeV/c. See C. Bromberg *et al.*, University of Michigan–University of Rochester Report No. UMBC 73-18 and UR-459 (to be published).

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Evidence for the $\omega\pi\pi$ Decay Modes of the A_2 and $\omega(1675)$

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We present evidence for the decay $A_2^0 \rightarrow \omega\pi^+\pi^-$ with a branching ratio $\Gamma(A_2 \rightarrow \omega\pi\pi)/\Gamma(A_2 \rightarrow \rho\pi) = 0.28 \pm 0.09$ and for the decay $\omega(1675) \rightarrow \omega\pi^+\pi^-$ with a branching ratio $\Gamma(\omega(1975) \rightarrow \omega\pi^+\pi^-)/\Gamma(\omega(1675) \rightarrow \rho\pi) = 0.47 \pm 0.18$. Evidence is given for an intermediate $B(1235)\pi$ state in the $\omega(1675)$ decay.

We present evidence for enhancements in the $\omega\pi^+\pi^-$ mass spectrum in the 1.3- and 1.65-GeV regions, which we identify as decay modes of the A_2 and the $\omega(1675)$, respectively. Enhancements in these regions have been reported in several experiments.[1-6] In addition, we give evidence