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S. Belforte
For the CDF Collaboration

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

Istituto Nazionale di Fisica Nucleare
Pisa, Italy

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MEASUREMENT OF THE ELASTIC, TOTAL AND DIFFRACTION CROSS SECTIONS AT TEVATRON ENERGIES

STEFANO BELFORTE
Istituto Nazionale di Fisica Nucleare, Pisa, Italy
for the CDF Collaboration

ABSTRACT

The CDF collaboration has measured the differential elastic cross section $d\sigma_{el}/dt$, the single diffraction dissociation double differential cross section $d^2\sigma_{sd}/dM^2dt$ and the total inelastic cross section for antiproton-proton collisions at center of mass energies $\sqrt{s}$=546 and 1800 GeV. Data for this measurement have been collected in short dedicated runs during the 1988-1989 data taking period of CDF. The elastic scattering slope is 15.28 ± 0.58 (16.98 ± 0.25) GeV^{-2} at $\sqrt{s} = 546$ (1800) GeV. Using the luminosity independent method $(1+\rho^2)\sigma_T$ is measured to be 62.64 ± 0.95 (81.83 ± 2.29) mb at $\sqrt{s} = 546$ (1800) GeV. Assuming $\rho = 0.15$ the elastic, total and single diffraction cross sections are $\sigma_{el} = 12.87 \pm 0.30$, $\sigma_T = 61.26 \pm 0.93$ and $\sigma_{sd} = 7.89 \pm 0.33$ mb ($\sigma_{el} = 19.70 \pm 0.85$, $\sigma_T = 80.03 \pm 2.24$ and $\sigma_{sd} = 9.46 \pm 0.44$ mb) at $\sqrt{s} = 546$ (1800) GeV.

Experimental Method

The luminosity-independent method is based on the simultaneous measurement of dR_{el}/dt, the elastic scattering rate as a function of the four-momentum transfer-squared (t), and of the total inelastic rate R_{in}. The total cross section is then derived as $\sigma_T = \frac{16\pi(\hbar c)^2}{1+\rho^2} \cdot \frac{dR_{el}/dt|_{t=0}}{R_{el}+R_{in}}$ where ρ is the ratio of the real to imaginary part of the forward elastic scattering amplitude.

The CDF detector has been described in detail in[1]. For this measurement, the CDF tracking system was supplemented with a small angle magnetic spectrometer in the accelerator tunnel and forward telescopes close to the central detector. The spectrometer provided detection and angle measurement of elastically scattered p and $\bar{p}$, and momentum analysis of the recoiling $\bar{p}$ The telescopes extended the detector acceptance for inelastic fragments to $|\eta| \leq 6.7$. The trigger covered $3.2 \leq |\eta| \leq 6.7$ on each side of the interaction region (*East* and *West*). A complete description of the apparatus and of the data analysis can be found in[2].

Elastic Scattering

A first selection removed triggers due to satellite bunches and high multiplicity events due to beam losses and interactions in the beam pipe. Since trajectories on each side were measured in more then one detector, multiple tracks ambiguities could be resolved by choosing the pair with best collinearity. The final sample was obtained applying $\sim 4\sigma$ cuts on the track impact parameters and collinearity. The residual background contamination ($\sim$ 0.5%) was statistically subtracted from the data dR_{el}/dt distribution. The elastic slope b_{el} and the optical point $A = dR_{el}/dt|_{t=0}$ were derived by fitting to the data the exponential form $A \cdot e^{b_{el}t}$. The fit yielded $b_{el} = 15.28 \pm 0.58$ (16.98 ± 0.24) GeV^{-2} at $\sqrt{s} = 546$ (1800) GeV. In order to obtain the A and R_{el}, data at $\sqrt{s} = 546$ GeV have been refitted with the additional requirement $b_{el} = 15.35 \pm 0.20$ GeV^{-2}, as indicated by the more precise UA4 and UA4/2 measurements[3]. The statistical error on A was 1.2% (3.0%) at $\sqrt{s} = 546$ (1800) GeV. The various sources of systematical errors contributed a total additional 0.5% uncertainty on A and 0.3% on b_{el} at both energies. Assuming an s-dependence of the slope $b_{el} = b_0' + 2\alpha' \ln(s/s_0)$, the data at $\sqrt{s}$=546 and 1800 GeV yield α'=0.34±0.07. A fit including also the ISR data yields α'=0.26±0.02.

Inelastic Non-Diffractive cross section

The total inelastic rate has been obtained by measuring separately its diffractive and non-diffractive components. Inelastic non-diffractive events were triggered by the *West* $\cdot$ *East* coincidence, which detected more than 98% of the inelastic non-diffractive events and the high-mass tail of the single diffraction dissociation. Most background was removed with time of flight cuts and by using the CDF vertex chamber to tag particle showers originating upstream of the interaction region. In the remaining events, tracks and trigger counter timing information were combined to obtain the z-distribution of the event vertices. Comparison of this distribution with those from Monte Carlo simulation and from a sample of tagged background showed no residual background at $\sqrt{s} = 546$ GeV, and a small contamination ($\sim$ 10%) at 1800 GeV, which was statistically subtracted. The simulation was also used to estimate the corrections for events without a valid vertex (< 0.5%) or lost due to the partial angular coverage of the trigger ($\simeq$ 1%).

Single Diffractive Dissociation

Single diffractive events are characterized by the presence of a quasi-elastic recoil antiproton with a differential distribution sharply peaked at both small angles and small diffracted masses $M_x \approx \sqrt{s \cdot (1-x)}$ with $x = p_{\bar{p}}/p_{beam}$. These events were triggered by the coincidence of proton fragments on the East side of the interaction region and of an antiproton on the West side of the spectrometer. Good events were selected as in the elastic and inelastic non-diffractive triggers, by requiring the validation of both the antiproton trajectory and the event vertex. The background contamination ($\ll 1\%$ at $\sqrt{s} = 546$ GeV, $\sim 1\%$ at 1800 GeV) was statistically subtracted from the recoil d^2N/dM_x^2dt distribution.

The single diffraction dissociation contribution was estimated by fitting the d^2N/dM_x^2dt distribution of the data with the standard triple-Pomeron Regge formula. Assuming a linear Pomeron trajectory, $\alpha_P(t) = 1 + \epsilon + \alpha' t$, the PPP form becomes $d^2\sigma_{sd}/dM_x^2dt = G(0) \cdot (s/s_0)^\epsilon \cdot e^{(b_0+2\alpha' ln(s/M_x^2))t} \cdot (s/M_x^2)^{1+\epsilon}$. In order to account for the non-diffractive contribution at $x \geq 0.85$, the empirical term $d^2\sigma_{nd}/dxdt = I \cdot (1-x)^\gamma \cdot e^{b' t}$ was added. The total single diffractive rate was obtained by integrating the fitted distribution over the full momentum transfer in the diffraction region 1.5 GeV^2 $< M_x^2 < 0.15s$, and multiplying by a factor of two to account for the dissociation of the antiproton. The contribution to the total inelastic rate, R_{in}, was integrated after removing the events which also gave a $West \cdot East$ trigger. In the fit we assumed α'=0.25 GeV^{-2} in order to reduce the number of free parameters. Fit results are listed in Table 1. The Regge form of the diffractive slope

Table 1: Fit results

$\sqrt{s}$ (GeV)	546	1800
σ_{sd} (mb)	7.89±0.33	9.46±0.44
$G(0)(s/s_0)^\epsilon$ (mb/GeV^2)	3.55±0.35	2.53±0.43
ϵ	0.121±0.011	0.129±0.022
b_0 (GeV^{-2})	7.7±0.6	4.2±0.5
σ_{nd} (mb)	1.2±0.2	2.5±0.5
I (mb/GeV^2)	537^{+498}_{-280}	162^{+160}_{-85}
b' (GeV^{-2})	10.2±1.5	7.3±1.0
γ	0.71±0.22	0.10±0.16

$b_{sd} = b_0 + 0.5$ GeV$^{-2} \cdot \ln(s/M_x^2)$ fits well our data at each energy, but with different b_0's. This could be a consequence of the fact that low masses ($M_x^2 \leq 6$ GeV^2) have steeper slopes than those given by such formula. By taking into account a possible ±0.1 GeV^{-2} uncertainty on α', and possible contributions from trajectories other than the Pomeron, final systematic errors on ϵ and b_0 are obtained: $\delta\epsilon = \pm 0.011$ and $\delta b_0 = \pm 1.5$ GeV^{-2} at both energies. The overall systematical error on σ_{sd} due to uncertainties on ϵ and on α' is $< 1\%$.

Conclusion

Combining the elastic and inelastic rates, we obtain $(1+\rho^2)\cdot\sigma_T$= 62.64±0.95 and 81.83±2.29 mb at $\sqrt{s}$=546 and 1800 GeV, respectively. Assuming ρ=0.15, our results for the total cross section are 61.26±0.93 mb at $\sqrt{s}$=546 and 80.03±2.24 mb at $\sqrt{s}$=1800 GeV.

The elastic scattering cross sections are 12.87 ± 0.30 (19.70 ± 0.85) mb at $\sqrt{s}$=546 (1800) GeV. From the elastic and total cross section values we derive the ratio $r = \sigma_{el}/\sigma_T = 0.210 \pm 0.002$ (0.246 ± 0.004). The continuing rise of r up to $\sqrt{s}$=1800 GeV is in qualitative agreement with optical models predictions, but still far below the asymptotic regime of black-disk maximum absorption at which r=0.5. However, the central opaqueness of the nucleon, has increased from 0.36 at the ISR to 0.492±0.008 at $\sqrt{s}$=1800 GeV and is close to the unitarity bound of 0.5 corresponding to complete absorption at zero impact parameter.

The total inelastic cross sections are measured to be 48.39±0.66 (60.33±1.40) mb at $\sqrt{s}$=546 (1800) GeV. Single diffraction dissociation contributes with 7.89 ± 0.33 (9.46 ± 0.44) mb. In terms of single-Pomeron exchange, the $\bar{p}p$ total cross section, σ_T, behaves at high energies as $s^{\alpha_P(0)-1} = s^\epsilon$. From our measurements of σ_T at $\sqrt{s}$=546 and $\sqrt{s}$=1800 we derive $\epsilon = 0.112 \pm 0.013$. In good agreement with the average ϵ-value 0.125±0.010±0.011 obtained from the single diffraction M_x^2-dependence at our two energies. In terms of triple-Pomeron exchange, when using $\epsilon = 0.112 \pm 0.013$ (from the rise of σ_T) and b_0 = 6.0 GeV^{-2} (average over our two energies), the value of σ_{sd}=7.89±0.33 mb measured at $\sqrt{s}$=546 extrapolates to σ_{sd} = 13.9±0.9 at $\sqrt{s}$=1800, where we measure $\sigma_{sd} = 9.46 \pm 0.44$ mb. This indicates that large screening corrections have to be introduced in order to save the traditional supercritical Pomeron model.

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