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Antiproton-Proton Elastic Scattering at $\sqrt{s}$ = 1.8 TeV from $|t|$ = 0.034 to 0.65 (GeV/c)^2 *

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Abstract

The differential cross section for elastic antiproton-proton scattering at $\sqrt{s}$ = 1.8 TeV has been measured over the t range $0.034 \leq |t| \leq 0.65$ $(GeV/c)^2$. A logarithmic slope parameter, B, of 16.3 ± 0.3 $(GeV/c)^{-2}$ is obtained. In contrast to lower energy experiments, no change in slope is observed over this t range.

The shape of the pp and $\bar{p}p$ differential elastic scattering in the diffraction peak ($|t| \lesssim 1$)[1] has been previously studied at lower energies in fixed target experiments[2,3,4] and at the ISR[5-8] and SPS[9] colliders. These measurements show that the distribution is approximately exponential in form, with logarithmic slope parameter $B = \frac{d}{dt}\left(\ln \frac{d\sigma}{dt}\right)$, which can be function of both t and energy, increasing with increasing energy. At $|t| \sim 1$, structure appears -- a dip or break followed at larger $|t|$ by a cross section varying more slowly with $|t|$; the value of $|t|$ at which the structure appears varies with energy, and the detailed distribution in that region differs between pp and $\bar{p}p$ scattering.[10-16]

The elastic scattering distribution in the t range between the coulomb region ($|t| \lesssim 0.001$) and the onset of the above structure, when measured with high statistics, has been observed to be more complex than a simple exponential. It has been fit by two exponentials, one in the range $|t| \lesssim 0.15$ and the other in the range $0.15 \lesssim |t| \lesssim 0.4$. The latter region has a value of B lower than that of the former by about 2 $(GeV/c)^{-2}$. This has been seen for incident fixed target momenta above ~20 GeV/c up through SPS collider energies, and was first observed about two decades ago.[17] Some experiments find that satisfactory fits are obtained with the form $d\sigma/dt = a \exp(bt+ct^2)$; other, more complex, forms have also been used.

The data reported here, covering the t range $0.10 \lesssim |t| \lesssim 0.65$, were taken during the Fermilab Tevatron Collider running for the CDF detector; our experiment was located at the E0 interaction point, 180° around the Collider from CDF. For this data, we used the inner "Roman Pots", located 25m from the interaction point (see the layout in Reference 18). At the time, drift chambers with 3 active wires each were working in two of the pots, one to record scattered protons and the other conjugate scattered antiprotons. There were 16 runs of about two hours duration each, with the drift chamber's closest approach to the beam center varying from 7.5mm to 12mm for individual runs; the smallest $|t|$ value reached was 0·10.

The hardware trigger was a 2-fold coincidence of scintillation counters in the 2 Roman Pots used in the analysis, with scintillation counters in the other inner Pots in veto. A total of 1.2×10^6 triggers was obtained. In the analysis,

events were first rejected where scintillation counters in the vicinity of the interaction region (see Figure 1 of Reference 18) recorded an inelastic event, leaving 388K events. To reduce backgrounds further, we required 3 hits out of 3 in one chamber and 2 hits out of 3 in the other to be in straight lines parallel to the circulating beams (within 600μm) in the vertical (scattering) plane. Although the combined efficiency of this was only ~20%, it was determined accurately by measuring individual wire efficiencies. At this point, 38K events remained. We then made a horizontal cut of ±3mm around the beam axis at the detectors in order to have fiducial regions that were sufficiently far from the edge of Tevatron injection magnets located between the interaction point and the Roman Pots; the upper limit of the $|t|$ acceptance used was 0.65 for the same reason. After the fiducial cuts, we were left with 26K events. The drift chamber horizontal coordinate readouts (based on charge division) were known with substantially less accuracy than the vertical readout (drift time), so we integrated over the horizontal coordinate and only used the vertical (y) coordinate in the subsequent analysis.

The correlation between the y coordinates in the two chambers of the events which remained at this stage in the analysis showed a strong band of elastic events with little background; there were 23K total events in the elastic event region. Figure 1 shows the y-y correlation plot for one of the runs. The background remaining under the signal was determined from the shape of the background outside the elastic region and was negligible except in the four lowest $|t|$ bins, where in the worst case it was 5%; the data were corrected for this.

To extend the data obtained here to smaller values of $|t|$, we used our results of Reference 19 for $0.034 \leq |t| \leq 0.083$ (with slight changes due to later analysis) and our total cross section obtained in Reference 20. We normalized the large $|t|$ data reported here to the earlier data by requiring that in any of the fits discussed below, the fit to the small $|t|$ data and the fit to the large $|t|$ data gave the same value at $t = 0$. This led to a renormalization by 0.87±0.16 of the large $|t|$ data compared to the value obtained from our own luminosity monitor. Our data are shown in Figure 2. As seen in the figure, we observe no evidence for a dip or other structure over the t range studied here. We have fit the data over the three regions $0.034 \leq |t| \leq 0.083$, $0.10 \leq |t| \leq 0.65$, and $0.034 \leq |t| \leq 0.65$, using the two forms (i) $d\sigma/dt = A \exp(Bt)$ and (ii) $d\sigma/dt = a \exp(bt+ct^2)$. The results are given

with statistical errors only in Table 1. We see that the form (ii) does not give a better fit than form (i), and the coefficient c is always consistent with zero; in what follows we will therefore only consider fit (i). From the Table, it can be seen that the value of B obtained for each of the three $|t|$ ranges is the same within errors, which is in contrast to the case at lower energies, where the B value using form (i) is a function of t. We quote as the result of this experiment the value of B given by the fit over the range $0.034 \leq |t| \leq 0.65$, namely, $B = 16.3 \pm 0.1$ $(GeV/c)^{-2}$ where the error is statistical. We estimate the systematic uncertainty to be ± 0.3 $(GeV/c)^{-2}$, arising from uncertainties in the absolute positions of the Roman Pots with respect to the beam, and from the uncertainty in the drift chamber distance calibrations. This leads to our final value

$$B = 16.3 \pm 0.3\ (GeV/c)^{-2}.$$

We noted earlier that lower energy data shows that $B(|t| \lesssim 0.15)$ is always greater than $B(0.15 \lesssim |t| \lesssim 0.4)$. As an example, the UA4 experiment[9] at the SPS Collider at $\sqrt{s} = 546$ GeV found $B = 15.2 \pm 0.2$ $(GeV/c)^{-2}$ for $0.03 \leq |t| \leq 0.15$, and $B = 13.4 \pm 0.3$ $(GeV/c)^{-2}$ for $0.21 \leq |t| \leq 0.5$. Thus our results show a qualitative change in the picture of elastic scattering. One explanation is that from References 19 and 20 σ_{el}/σ_T is becoming larger with increasing energy, which can be interpreted as the nucleon becoming blacker. For scattering from a uniform black (or grey) disc of radius R, the differential cross section is proportional to

$$\left[\frac{J_1\left(R\sqrt{|t|}\right)}{R\sqrt{|t|}}\right]^2,$$

which has B increasing as $|t|$ increases towards the first diffraction minimum. Thus, as energy increases, there must be a change from the low energy behavior where empirically B decreases with increasing $|t|$, to the high energy (black disc) behavior, where B increases with increasing $|t|$. At some intermediate energy, then, B should be independent of t. A model for elastic $\bar{p}p$ scattering was proposed some time ago[21, 22] which contained the above ideas, and which predicted that B should be independent of t at Tevatron Collider energies.

In summary, we have measured $\bar{p}p$ elastic scattering at $\sqrt{s} = 1.8$ TeV over the range $0.034 \leq |t| \leq 0.65$. In this t range we see no structure in the cross section,

and find that the logarithmic slope parameter is constant. This is in contrast to the situation at lower energies where a change in slope is observed at $|t| \sim 0.15$.

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TABLE 1.

Results of fits described in the text.

(Statistical errors only are shown)

			t Range		
			$0{\cdot}034 \leq \lvert t \rvert \leq 0{\cdot}083$	$0{\cdot}10 \leq \lvert t \rvert \leq 0{\cdot}65$	$0{\cdot}034 \leq \lvert t \rvert \leq 0{\cdot}65$
(i)	e^{Bt}	$B(GeV/c)^{-2}$	16·37±0·45	16·40±0·12	16·30±0·06
		$\chi^2/DF=$	0·66	0·48	0·57
(ii)	e^{bt+ct^2}	$b(GeV/c)^{-2}$	20·65±3·84	16·87±0·57	16·25±0·23
		$c(GeV/c)^{-4}$	38·62±34·05	1·08±1·27	-0·14±0·70
		χ^2/DF	0·65	0·47	0·58

FIGURE CAPTIONS

Figure 1. Correlation between the y coordinates of the chambers recording the scattered proton and antiproton for each event, for one run; y_p and $y_{\bar{p}}$ are the distances of the scattered proton and antiproton respectively from the center of the circulating beams.

Figure 2. Elastic scattering distribution from this experiment ($0{\cdot}10 \leq |t| \leq 0{\cdot}65$), together with our earlier data of Reference 19 with slight changes due to later analysis ($0{\cdot}034 \leq |t| \leq 0{\cdot}083$). The line shown is the fit of the form A exp (Bt) to the range $0{\cdot}034 \leq |t| \leq 0{\cdot}65$.

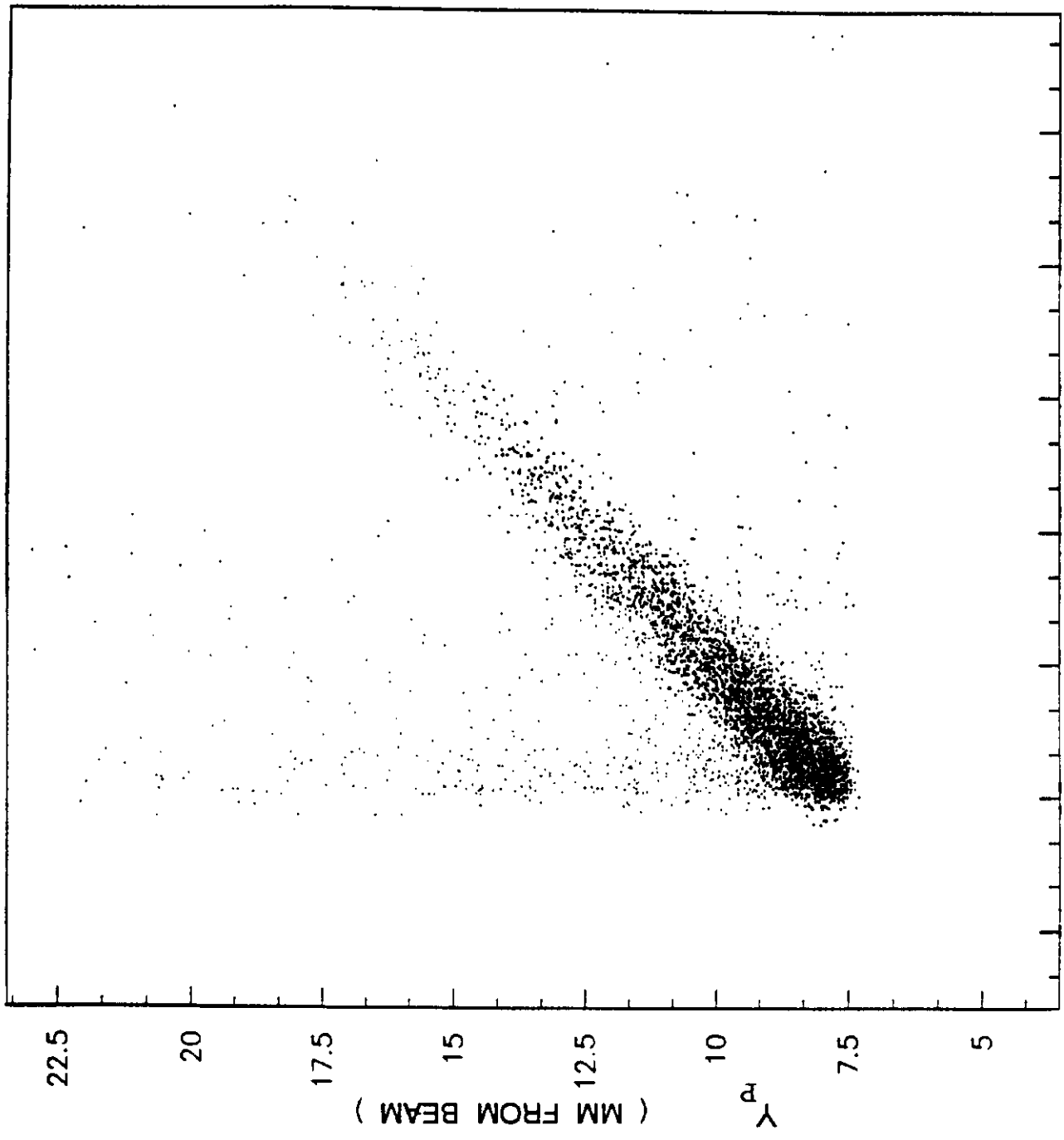
22.5
20
17.5
15
12.5
10
7.5
5
Y_p (MM FROM BEAM)
5
7.5
10
12.5
15
17.5
20
$Y_{\overline{p}}$ (MM FROM BEAM)

Figure 1

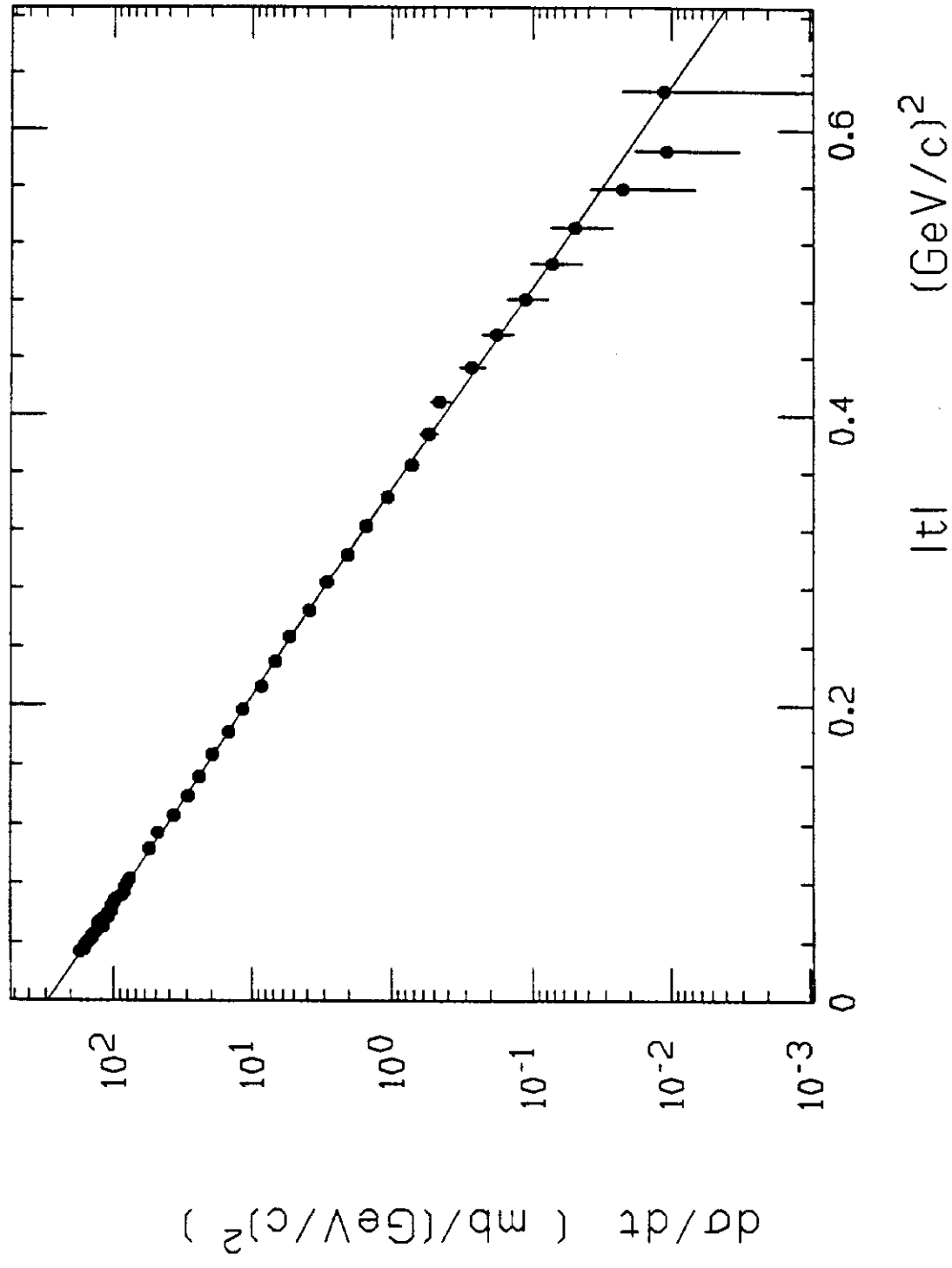

Figure 2