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PROTON-ANTIPROTON ELASTIC SCATTERING AT FOUR-MOMENTUM TRANSFER
UP TO 0.5 GeV² AT THE CERN SPS COLLIDER

UA4 Collaboration

Amsterdam¹-CERN²-Genova³-Napoli⁴-Pisa⁵

R. Battiston⁵(*), M. Bozzo³(**), P.L. Braccini⁵(***), F. Carbonara⁴,
R. Carrara⁵, R. Castaldi⁵, F. Cervelli⁵, G. Chiefari⁴, E. Drago⁴,
M. Haguenaue², B. Koene¹, G. Matthiae⁴, L. Merola⁴, M. Napolitano⁴,
V. Palladino⁴, G. Sanguinetti⁵, G. Sciacca⁴, G. Sette³, R. van Swol¹,
J. Timmermans¹, C. Vannini⁵, J. Velasco² and F. Visco⁴

¹ NIKHEF-H, Amsterdam, The Netherlands

² CERN, European Organization for Nuclear Research, Geneva, Switzerland

³ Istituto di Fisica dell'Università e Sezione INFN, Genova, Italy

⁴ Istituto di Fisica Sperimentale dell'Università e Sezione INFN,
Napoli, Italy

⁵ Istituto di Fisica dell'Università e Sezione INFN, Pisa, Italy

ABSTRACT

Proton-antiproton elastic scattering was measured at a centre of mass energy $\sqrt{s} = 540$ GeV. In the four-momentum transfer range $0.21 < -t < 0.50$ GeV² the t -distribution of about 7000 events is well represented by the exponential shape $\exp(bt)$ with slope parameter $b = 13.7 \pm 0.3$ GeV⁻². A new measurement of the slope for $-t \leq 0.19$ GeV² confirms our earlier result [1], giving evidence for a change of slope of about 4 GeV⁻² around $-t \approx 0.15$ GeV².

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(*) Also at Scuola Normale Superiore, Pisa, Italy.

(**) At present CERN Research Associate.

(***) Also at University of Perugia, Italy.

We report the result of a measurement of proton-antiproton elastic scattering at the CERN SPS Collider in the four-momentum range $0.21 < -t < 0.50 \text{ GeV}^2$ at a nominal centre of mass energy $\sqrt{s} = 540 \text{ GeV}$. The experimental technique is the same as in an earlier measurement [1] of elastic scattering at lower values of t . A sketch of the experimental apparatus is shown in fig. 1. Elastic scattering events are observed by means of detectors placed inside movable sections of the SPS vacuum chamber ("pots"). Each detector consists of a counter hodoscope and a wire chamber which provides a point measurement with resolutions of 0.07 mm and 0.4 mm in the vertical and horizontal coordinates, respectively [2]. The "pots" were arranged in a system of four telescopes placed symmetrically at a distance of about 25 m from the crossing point above and below the machine plane. The present data were collected in a few days of running time at an average luminosity of about $1.5 \times 10^{27} \text{ cm}^{-2} \text{ s}^{-1}$. The Collider was operated in the so-called medium β mode, where the betatron function at the crossing point has the values 7.0 m and 3.5 m in the horizontal and vertical planes, respectively. Scattered particles leaving the interaction region traverse quadrupoles of the machine lattice which act in the vertical plane as focussing lenses. The p and $\bar{p}$ trajectories for a scattering angle of 2.0 mrad in the vertical plane are also shown in fig. 1. The vertical and horizontal components of the production angle, θ_V and θ_H , of proton and antiproton are calculated from the measured track points by use of the transfer matrices from the crossing point to the detectors. The four-momentum transfer t is calculated from the measured angles using the nominal value of the beam momentum $270 \text{ GeV}/c^{(*)}$.

The trigger and the procedures for track reconstruction and for selection of elastic events were the same as discussed in ref. [1]. The fraction of elastic candidates in the trigger was about 40%. The distribution of the candidate events in the collinearity variables $\theta_V(\bar{p}) - \theta_V(p)$ and $\theta_H(\bar{p}) - \theta_H(p)$ is shown in fig. 2. The width of the collinearity distribution is almost the same in the vertical and

(*) However, preliminary calibrations [7] of the SPS Collider seem to indicate that the actual beam momentum is about 1.5% higher. In that case the values of the slope parameter b given in this paper and in refs [1,3] should be scaled down by about 3%.

horizontal projections, about 0.12 mrad at one standard deviation. It is essentially determined by the intrinsic angular spread of the beams, which is known from the measured value of the beam emittances. Elastic events were selected by three-standard-deviation cuts on the two collinearity projections. Background was assumed to be linear in the collinearity distributions and was subtracted using as control regions the intervals between 6 and 9 standard deviations away from the centre. The level of the background varies smoothly from less than 1% at $-t \approx 0.2 \text{ GeV}^2$ up to 6% at $-t \approx 0.5 \text{ GeV}^2$. The low level of the inelastic background is partly due to the analyzing power of the quadrupoles.

The scattering angle is obtained by averaging the observed production angles of the proton and antiproton. The resulting resolution in t varies from 0.015 GeV^2 at $-t = 0.21 \text{ GeV}^2$ to 0.023 GeV^2 at $-t = 0.5 \text{ GeV}^2$. The t -dependence of the data - about 7000 elastic events - was described by the exponential form $\exp(bt)$. The value of the slope parameter b was determined by fitting the two-dimensional event distribution in θ_V and θ_H , simultaneously for the two detection arms (up-left x down-right) and (down-left x up-right), leaving the angle of the incoming beams as a free parameter. This procedure was chosen since comparison of the observed angular distributions and counting rates in the individual arms showed that the direction of the incoming beams was slightly off from the nominal machine axis. The result of the fit, which also takes into account the effect of experimental t -smearing, is $b = 13.7 \pm 0.2 \text{ GeV}^{-2}$. The χ^2 value of the fit is 0.8 per degree of freedom, showing that the data are very well represented by an exponential shape with constant slope parameter. Various systematic uncertainties may slightly alter the shape of the t -distribution. Uncertainties on the t -dependence of the acceptance, on the absolute position of the detectors and on the subtraction of the inelastic background were estimated to affect the measured value of the slope by less than 0.2 GeV^{-2} . We therefore quote as the result of our measurement of the slope parameter in the range $0.21 < -t < 0.50 \text{ GeV}^2$, the value $b = 13.7 \pm 0.3 \text{ GeV}^{-2}$. The t -distribution is shown in fig. 3 together with the result of the fit.

Low-statistics data from the first Collider run were reported by the UA1 Collaboration [3] ($b = 13.3 \pm 1.5 \text{ GeV}^{-2}$ in the interval $0.14 < -t < 0.26 \text{ GeV}^2$) and by the present authors [1] ($b = 17.2 \pm 1.0 \text{ GeV}^{-2}$ for $0.05 < -t < 0.19 \text{ GeV}^2$). These data suggested that the change of the slope parameter observed in pp scattering at the ISR [4] at $-t \approx 0.15 \text{ GeV}^2$ is also present at the Collider energy for $\bar{p}p$ at about the same value of t . Besides obtaining the result discussed above, we have also remeasured the t -distribution at lower t -values. Since this angular range is not accessible at the usual machine optics, it could only be re-explored during a special run of limited integrated luminosity with high- β optics. The result, $b = 17.6 \pm 1.0 \text{ GeV}^{-2}$ in the range $0.03 < -t < 0.19 \text{ GeV}^2$, confirms our earlier measurement [1]. Our new data for $-t < 0.19 \text{ GeV}^2$ are shown in the inset in fig. 3. We conclude that a change of the slope parameter by about 4 GeV^{-2} does indeed occur in the t -region around 0.15 GeV^2 . Clearly, the statistics is at present still insufficient for a precise localization in t of the change in slope.

The measurement at $0.21 < -t < 0.50 \text{ GeV}^2$ establishes the rate of shrinkage with energy of the diffraction peak in this t -range. The differential cross section in this interval of t is well described by an exponential shape also at ISR energies. A compilation of published data [3,5,6] on the slope parameter b for $\bar{p}p$ elastic scattering for $\sqrt{s} \gtrsim 10 \text{ GeV}$ in the range $0.2 \lesssim -t \lesssim 0.5 \text{ GeV}^2$ is shown in fig. 4 together with the present result. Recent ISR data [6] have shown that the $\bar{p}p$ slope approaches the value for pp scattering quite closely already at $\sqrt{s} = 53 \text{ GeV}$. In this range of t the shrinkage of the diffraction peak from $\sqrt{s} = 53 \text{ GeV}$ to $\sqrt{s} = 540 \text{ GeV}$ amounts to $\Delta b \approx 3 \text{ GeV}^{-2}$.

We wish to express our gratitude to the staff of the CERN Accelerator Divisions for the so successful operation of the SPS Collider. Special thanks go to the members of the SPS Division who took care of the design, installation and survey of the "pots".

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FIGURE CAPTIONS

- Fig. 1 Sketch of the elastic scattering set-up. The detectors are placed inside the "pots".
- Fig. 2 Collinearity histograms in the vertical and horizontal projections for the elastic candidates. These distributions are not centred because of a slight offset of the beam position.
- Fig. 3 t -distribution of the elastic scattering events in the range $0.21 < -t < 0.50 \text{ GeV}^2$. The newly measured distribution for $0.03 < -t < 0.19 \text{ GeV}^2$ is shown in the inset.
- Fig. 4 The present result on the slope parameter b in the range $0.21 < -t < 0.50 \text{ GeV}^2$ is shown together with published data for $\bar{p}p$ scattering in the same t -range.

ELASTIC SCATTERING LAYOUT

Fig. 1

Fig. 2

$p\bar{p}$ ELASTIC SCATTERING

$\sqrt{s} = 540 \text{ GeV}$

Fig. 3

SLOPE OF $p\bar{p}$ ELASTIC SCATTERING $0.2 \lesssim -t \lesssim 0.5 \text{ GeV}^2$

Fig. 4