FIRST RESULTS ON LOW MOMENTUM TRANSFER ELASTIC SCATTERING AT THE
CERN PROTON-ANTIPROTON COLLIDER

UA4 Collaboration

¹Amsterdam -²CERN -³Genova -⁴Napoli -⁵Pisa

R. Battiston⁵, M. Bozzo³, P.L. Braccini^{5(*)}, F. Carbonara⁴, R. Carrara⁵,
R. Castaldi⁵, F. Cervelli⁵, G. Chiefari⁴, E. Drago⁴, M. Haguenaue²,
B. Koene¹, L. Linssen¹, G. Matthiae⁴, L. Merola⁴, M. Napolitano⁴,
V. Palladino², G. Sanguinetti⁵, G. Sciacca⁴, G. Sette³, R. van Swol¹,
J. Timmermans¹, C. Vannini², 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 at a centre-of-mass energy of 540 GeV was measured in the four-momentum transfer range $0.05 < -t < 0.19 \text{ GeV}^2$. The t -distribution can be fitted by the exponential $\exp(bt)$ with $b = 17.2 \pm 1.0 \text{ GeV}^{-2}$. This result indicates a rapid decrease of the width of the diffraction peak between ISR and Collider energies.

Submitted to Physics Letters B

(*) Now at the University of Perugia (Italy).

0916P/MH/mk

During the first physics run of the CERN SPS Collider [1] proton-antiproton elastic scattering was measured in the four-momentum transfer range $0.05 < -t < 0.19 \text{ GeV}^2$ at a centre-of-mass energy $\sqrt{s} = 540 \text{ GeV}$. At these energies the typical value of the scattering angle in the region of the forward diffraction peak is of the order of one milliradian. The detection of elastic events at such small angles requires the use of a technique [2] similar to that employed at the ISR.

A side view of the experimental layout is shown schematically in fig. 1. Elastically scattered particles are detected by a system of four telescopes placed symmetrically above and below the SPS vacuum chamber at a distance of about 40 m from the $p\bar{p}$ crossing point. A telescope is composed of two detectors that are 6 m apart. Each detector, consisting of a wire chamber and a scintillation counter hodoscope, is placed in a movable section of the vacuum chamber ("pot") which is connected to the main body of the accelerator pipe by a bellow. Once stable beam conditions are reached, the "pots" are displaced vertically towards the beam. Particles leaving the crossing region after interaction traverse the quadrupoles of the machine lattice Q_L and Q_R , which in the vertical plane act as a defocussing and focussing lens respectively. The p and $\bar{p}$ trajectories for 1 mrad scattering angle in the vertical plane are also shown in fig. 1.

The wire chamber [3] in each "pot" contains four independent drift planes measuring the vertical coordinate of particle trajectories. Each plane is subdivided into three cells of 21 mm maximum drift length. The horizontal sense wires are suitably staggered as shown in fig. 1. The single-plane resolution, expressed as the r.m.s. deviation of the measured coordinate in the drift plane from the reconstructed track, was about 0.13 mm during actual data taking. The drift planes are followed by a proportional plane with high-resistivity anode wires. Charge-division read-out of these wires provides the horizontal coordinate of particle trajectories with an r.m.s. accuracy of 0.4 mm. The mechanical frame of the chambers is U-shaped, the side facing the beam being closed by a glass-epoxy plate of 0.8 mm thickness. A pattern of field-restoring strips on this plate ensured good detection efficiency down to a few tenths of a millimeter from the plate [3]. For each chamber, the distance to the nominal machine plane is known from the measured displacement of the "pot" and from the overall survey of the experiment with an accuracy of about

0.1 mm. Inside each "pot" the wire chamber is followed by a stack of eight vertical scintillators which is in turn backed by a trigger counter, 45 mm wide and 115 mm high, as shown in fig. 1. The calibration of the charge division electronics was monitored using the vertical scintillators. The "pots" are provided with 0.1 mm thick steel windows slightly larger than the active area of the detectors.

The present data were taken when the Collider was operating with a single antiproton bunch of a few times 10^9 particles colliding against a proton bunch of about 5×10^{10} particles. The machine optics in the intersection region was the same as for normal SPS operation. The nominal luminosity was of the order of $10^{26} \text{ cm}^{-2} \text{ s}^{-1}$. The total amount of running time was about 15 hours. Because of the asymmetric beam optics (fig. 1), the minimum detectable scattering angle was determined by the distance from the beam axis of the detectors on the proton side. On this side the active volume of the detectors started at about 18 mm from the beam axis, corresponding to a minimum value of the scattering angle of about 0.8 mrad. At this distance from the beam the chambers could be operated safely. The maximum accepted angle as determined by the aperture of the vacuum chamber is about 1.6 mrad. The trigger consisted of the logical OR of the two four-fold coincidences of the trigger counters in the two arms (up-left x down-right) + (down-left x up-right). The trigger rate was a few events per minute.

For track reconstruction within each telescope it was demanded that at least six out of the eight drift planes contribute a track point. An event was considered an elastic candidate if the track multiplicity per telescope was one or two, thus allowing for the possibility of an accompanying track due to a δ -ray. The track multiplicity distribution per telescope showed that the probability of δ -ray production within the narrow cone where it would lead to at least six track points is less than 1%. It was further checked that the candidate tracks in each of the two telescopes extrapolated backwards to the $p\bar{p}$ crossing region and that no tracks were simultaneously seen by the other pair of telescopes. About 40% of the triggers did not satisfy these selection criteria. Almost all of these events had a large number of tracks in several chambers and can be attributed to accidental coincidences of beam-gas or beam-wall interactions on the basis of the measured particle flux in the telescopes.

The measured vertical and horizontal displacements d_V and d_H of particle trajectories are proportional to the components θ_V and θ_H of the scattering angle, if the primary beam particles travel along the nominal machine axis and interact at the centre of the crossing region. One can write $d_{V(H)} = L_{V(H)} \theta_{V(H)}$, where L_V and L_H are the effective distances from the crossing point of the detector under consideration. L_V and L_H are accurately known from the machine optics. For the elastic candidates the values of θ_V of the two tracks in opposite telescopes were calculated from the measured vertical displacements. In the few cases where two tracks were recorded in a telescope, the track pair with the best match of the values of θ_V was chosen. The scatter plot of $\theta_V(p)$ versus $\theta_V(\bar{p})$ in fig. 2(a) clearly shows the ridge of elastic events, well identified by the collinearity requirement. The distribution of the quantity $\theta_V(\bar{p}) - \theta_V(p)$ has a standard deviation of about 0.05 mrad corresponding to a transverse momentum unbalance less than 15 MeV/c. The intrinsic vertical angular spread of both beams contributes ~ 0.03 mrad. The finite size of the crossing region together with alignment errors and the detector resolution further contribute to the width of the collinearity plot. A transverse displacement of the crossing region away from the machine axis can be derived from the observed coordinates of the scattered proton and antiproton. While the vertical offset turned out to be negligibly small, the horizontal shift of the interaction region was found to be about 4.5 mm. The horizontal components θ_H for p and $\bar{p}$ were corrected for this beam displacement. The asymmetry in the horizontal acceptance, as seen in the scatter plot of fig. 2(b), is a consequence of this offset. The distribution of $\theta_H(\bar{p}) - \theta_H(p)$ has a standard deviation of about 0.06 mrad to which the angular spread of the beams contributes ~ 0.035 mrad.

The sample of elastic events used in the analysis was obtained by applying a three-standard-deviation cut to both collinearity distributions. If the beam direction at the crossing region coincides with the machine axis, the true scattering angle would be given by $\theta = (\theta_V^2 + \theta_H^2)^{1/2}$ with values of θ_V obtained from $d_V(\bar{p}) + d_V(p) = (L_V(\bar{p}) + L_V(p))\theta_V$ and similarly for the horizontal component. However, the incoming beams actually formed an angle with the machine axis. This was shown by the different counting rates in the (up-left x down-right) and (down-left x

up-right) arms and the different apparent angular distributions in the two arms. The t -dependence of the data was described by the exponential form $\exp(bt)$. In order to extract the value of the slope parameter b , a fit of the two-dimensional (θ_V, θ_H) distribution was performed, simultaneously for both arms, leaving the beam angle as a free parameter.

The result of the fit is $b = 17.2 \pm 1.0 \text{ GeV}^{-2}$. The systematic uncertainty on the slope parameter b due to local chamber inefficiencies, alignment errors and acceptance calculations was estimated to be $\lesssim 0.5 \text{ GeV}^{-2}$. The vertical and horizontal components of the beam angle as determined from the fit, were $0.11 \pm 0.01 \text{ mrad}$ and $0.15 \pm 0.05 \text{ mrad}$ respectively. These values are consistent with those derived from direct measurements by beam position monitors placed upstream and downstream of the crossing region. It should be stressed that this procedure of using the information from both arms simultaneously eliminates systematic errors in the t -scale due to the beam angle. The acceptance corrected t -distribution is shown in fig. 3. The line represents the result of the fit described above. The acceptance of each arm, as obtained by a Monte-Carlo calculation, varies from 13% at $-t = 0.05 \text{ GeV}^2$ to 7% at $-t = 0.19 \text{ GeV}^2$.

In fig. 4 our result on the slope parameter b is plotted together with other measurements for proton-proton and proton-antiproton scattering. Data [4] were selected for which the t -range is at least partially overlapping with that of the present experiment. When data [5] were presented in a parametrization of the form $\exp(Bt + Ct^2)$, the points plotted in fig. 4 correspond to the local slope calculated at the middle of the t -range of this experiment. Although the selected set of data is not completely homogeneous because of the variation of the local slope with t , the compilation of fig. 4 should nevertheless be representative of the trend with energy at $-t \gtrsim 0.1 \text{ GeV}^2$.

The present measurement shows that the shrinkage of the forward diffraction peak persists into the new energy domain of the CERN $p\bar{p}$ Collider. Our result is compatible with a rise of the slope with at least the first power of $\log s$ between the lowest ISR energy and the Collider energy.

However, in spite of the sizeable error due to limited statistics, our result can hardly be accommodated by a recent fit with asymptotic $\log s$ behaviour [6] of slope values up to ISR energies, which predicted a slower increase of b with $\log s$. On the other hand, model approaches exist that indicate ranges of values encompassing our experimental result, like for instance, the prediction of $b \approx 17-18 \text{ GeV}^{-2}$ in our t -range which is obtained [7] when the scaling expression for the elastic amplitude in Reggeon Field Theory is fixed by a fit to ISR data.

Acknowledgements

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 (especially of the EA group) who took care of the design, installation and survey of the "pots". We highly appreciate the close involvement of A.N. Diddens with this experiment; at various stages his advice and support have been of great benefit to us. We are also very much indebted to R. Wojslaw for his contributions in the early stage of the experiment and to all technicians of the collaborating Institutes who participated in the preparation and setting-up of the experiment.

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FIGURE CAPTIONS

- Fig. 1 Sketch of the elastic scattering set up. A detail of the detector inside the "pot" is shown together with a perspective view.
- Fig. 2 Scatter plot and collinearity histograms for the elastic candidates in the vertical plane (a) and in the horizontal plane (b). The smooth line in the collinearity plots is a gaussian fit to the data.
- Fig. 3 t -distribution of elastic scattering events in the t -range from -0.05 to -0.19 GeV^2 .
- Fig. 4 Compilation of measured values of the slope parameter b for pp and $\bar{p}p$ elastic scattering in approximately the same t -range as this experiment.

ELASTIC SCATTERING LAYOUT

SIDE VIEW OF A POT

Fig. 1

Fig. 2

Fig. 3

Fig. 4