SMALL ANGLE ELASTIC SCATTERING AT THE CERN PROTON ANTIPROTON COLLIDERUA1 Collaboration, CERN, Geneva, Switzerland

G. Arnison¹⁰, A. Astbury¹⁰, B. Aubert², C. Bacci⁹, R. Bernabei⁹, A. Bézaguët⁴,
 R. Böck⁴, T.J.V. Bowcock⁶, M. Calvetti⁴, T. Carroll⁴, P. Catz², S. Centro⁴,
 F. Ceradini⁹, S. Cittolin⁴, A.M. Cnops⁴, C. Cochet¹¹, J. Colas²,
 M. Corden³, D. Dallman¹², S. D'Angelo⁹, M. DeBeer¹¹, M. Della Negra², M. Demoulin⁴,
 D. Denegri¹¹, R. Desalvo⁴, D. DiBitonto⁴, L. Dobrzynski⁷, J.D. Dowell³, M. Edwards³,
 K. Eggert¹, E. Eisenhandler⁶, N. Ellis³, P. Erhard¹, H. Faissner¹, G. Fontaine⁷,
 J.P. Fournier¹¹, R. Frey⁸, R. Frühwirth¹², J. Garvey³, S. Geer⁷, C. Ghesquière⁷,
 P. Ghez⁴, K.L. Giboni¹, W.R. Gibson⁶, Y. Giraud-Heraud⁷, A. Givernaud¹¹,
 A. Gonidec², G. Grayer¹⁰, P. Gutierrez⁸, R. Haidan⁴, T. Hansl-Kozanecka¹,
 W.J. Haynes¹⁰, L.O. Hertzberger^{*}, C. Hodges⁸, D. Hoffmann¹, H. Hoffmann⁴,
 G. von Holtey⁴, D.J. Holthuizen^{*}, R.J. Homer³, A. Honma⁶, W. Jank⁴, P.I.P. Kalmus⁶,
 V. Karimäki⁵, R. Keeler⁶, I. Kenyon³, A. Kernan⁸, R. Kinnunen⁵, H. Kowalski⁴,
 W. Kozanecki⁸, D. Kryn⁷, F. Lacava⁴, J.P. Laugier¹¹, J.P. Lees², H. Lehmann¹,
 R. Leuchs¹, A. Leveque¹¹, D. Linglin², E. Locci¹¹, T. Markiewicz⁴, G. Maurin⁴,
 T. McMahon³, J.P. Mendiburu⁷, M.N. Minard², K. Morgan⁸, M. Moricca⁹,
 F. Muller⁴, A.K. Nandi¹⁰, L. Naumann⁴, A. Norton⁴, A. Orkin-Lecourtois⁷,
 L. Paoluzi⁹, G. Piano Mortari⁴, M. Pimä⁵, A. Placci⁴, M. Rabany⁴, E. Radermacher¹,
 J. Ransdell⁸, H. Reithler¹, J. Rich¹¹, M. Rijssenbeek⁴, C. Roberts¹⁰,
 C. Rubbia⁴, B. Sadoulet⁴, G. Sajot⁷, G. Salvi⁶, G. Salvini⁹, J. Sass¹¹,
 J. Saudraix¹¹, A. Savoy-Navarro¹¹, D. Schinzel⁴, W. Scott¹⁰, T.P. Shah¹⁰,
 M. Spiro¹¹, J. Strauss¹², K. Sumorok³, F. Szoncso¹², C. Tao⁴, J. Timmer⁴,
 G. Thompson⁶, E. Tscheslog¹, J. Tuominiemi⁵, J.P. Vialle⁴, G. Vismara⁴, J. Vrana⁷,
 V. Vuillemin⁴, H. Wahl¹², P. Watkins³, J. Wilson³, M. Yvert², E. Zurfluh⁴

Aachen¹-Annecy (LAPP)²-Birmingham³-CERN⁴-Helsinki⁵-Queen Mary College, London⁶-Paris
 (Coll.de France)⁷-Riverside⁸-Roma⁹-Rutherford Appleton Lab.¹⁰-Saclay (CEN)¹¹-
 Vienna¹² Collaboration

To be submitted to Physics Letters

CERN LIBRARIES, GENEVA

Abstract

Proton-antiproton elastic scattering at cm energy 540 GeV has been studied in the t range $0.14 \leq -t \leq 0.26 \text{ GeV}^2$. The data is well fitted by an exponential form e^{bt} with $b=13.3 \pm 1.5 \text{ GeV}^{-2}$.

We report on a study of proton-antiproton elastic scattering at angles $\theta \leq 2$ mrad at the CERN Collider. The measurement was made with the precision drift chamber system which constitutes the elastic luminosity monitor for experiment UA1 and the SPS machine group.

Experimental Details

Figure 1 shows the magnetic elements of experiment UA1 [1] in Long Straight Section 5 (LSS5) of the CERN Super Proton Synchrotron (SPS). The elastic scattering apparatus was in "Roman Pots" symmetrically positioned at ± 23 m from the beam crossing point. Elastically scattered particles reached the detector after traversing the magnetic field of the UA1 detector dipole, the compensator dipole, and a pair of machine quadrupoles. The elastic detector (fig. 2) consisted of four pairs of drift chambers and triggering scintillators arranged so as to detect elastic scattering close to the vertical plane. Each drift chamber and companion scintillator was housed in a Roman pot, an insertion in the beam pipe by means of which the drift chambers can be moved vertically to within a few mm of the coasting beams. A detailed description of the apparatus is given in reference [2].

The scattered particle traverses four planes of sense wires in each chamber. The sense wires are staggered to eliminate vertical drift ambiguity between an elastic track ($\theta \leq 2$ mrad) and its "ghost" ($\theta \approx 9^\circ$). Each plane contains three sense wires; in this run elastically scattered particles were confined to the lower two rows of sense wires which are shown in fig. 2.

The readout electronics can record up to 16 hits per wire. In addition to drift time the orthogonal coordinate is obtained by charge division. The r.m.s. single wire resolution for drift time and charge division measurement in this run was 0.11 mm and 2.5 mm respectively. The corresponding resolution in t was always less than 0.01 GeV^2 .

The elastic scattering angular range accessible to the detector for this run

was $1.1 < \theta < 2.0$ mrad. The upper limit was set by the beam pipe aperture ; the lower limit was determined by the closest distance of approach of the drift chambers to the beam axis on the scattered proton side. The bottoms of the pots on the proton side were positioned at 1.9 cm vertical separation from the beam axis, corresponding to $12\sigma_v$ for the $\bar{p}$ beam where σ_v is the vertical r.m.s. beam size.

For this run the SPS machine was operated in the normal beta mode, i.e. the magnetic configuration of the machine was the same as for fixed target operation. The spatial and angular spreads of the $\bar{p}$ -p beams at the interaction point are given in Table 1. For normal beta the quadrupoles (fig. 1) are vertically focussing (defocussing) on the outgoing p($\bar{p}$) side (see fig. 2). The effect of the quadrupole field on elastically scattered particles can be expressed in terms of an "effective length" L for the vertical (v) and the horizontal (h) planes. Thus a proton scattered through θ_v in the vertical plane will have a vertical displacement relative to the beam of $L_v \theta_v$ at the elastic detector, where L_v is 18 m; the actual distance traversed in the beam direction is 23 m. The effective lengths on the proton side are 18 m (v) and 28 m (h), and on the antiproton side 28 m (v) and 18 m (h).

The elastic trigger was based upon a coincidence between an up telescope in one arm and a down telescope in the other arm, in time with a beam-beam crossing. The number of beam crossings per second was 43×10^3 . We simultaneously recorded up-up and down-down coincidences for background studies.

Data Analysis

A total of 5437 elastic triggers were recorded at an average rate of 0.2/sec in a 7.5 hour run. The luminosity averaged $10^{26} \text{ cm}^{-2} \text{ s}^{-1}$ and the luminosity lifetime was 18 hours. A visual scan of the drift chamber hit patterns revealed that elastic trigger events fell into two classes :

(1) events of elastic scattering topology with typically four wire hits per chamber as in fig.2. These constituted approximately 20% of triggers ;

2) events with large splashes (≥ 20 hits per chamber) in the p and/or $\bar{p}$ detectors. The accidental rate due to random left-right coincidence of secondaries from beam-gas and beam-vacuum tube interactions is 50%. The remaining 30% of the type (2) events are presumably associated with inelastic beam-beam interactions.

The first condition for elastic scattering events was that, for the appropriate combination of chambers, no single chamber had more than 8 hits. The minimal elastic configuration considered was a single left and right chamber with at least a 3-point track per chamber.

Fig. 3 shows $\theta_p - \theta_{\bar{p}}$ in (a) the vertical (drift) plane and (b) the horizontal (charge division) plane for candidate elastic scattering events. The width of the drift plane distribution ($\sigma = 0.08$ mrad) comes mainly from the vertical spread of the beams (0.06 mrad) and the beam angular divergence (0.03 mrad) at the crossing point. The width of the collinearity distribution in the charge division plane is dominated by measurement error.

The collinearity distributions in fig. 3 indicate that there is remarkably little background in the elastic scattering region. The final selection of elastic events was made with the criteria :

$$(i) \quad |\theta_v(p) - \theta_v(\bar{p})| \leq 0.3 \text{ mrad, (1029 events) and}$$

$$(ii) \quad |\phi| (\equiv \tan^{-1} \theta_h / \theta_v) \leq 20^\circ, (787 \text{ events})$$

The latter condition eliminated events with relatively low acceptance, and also, by restricting the range of the current division coordinate, ensured that the error in t was always less than 0.01 GeV^2 .

The scattering angle θ was obtained by averaging the measured proton and antiproton scattering angles θ_p and $\theta_{\bar{p}}$. This procedure eliminates possible error in θ and t due to displacement of the beam crossing point from

its nominal position in LSS5. The position of the vertex along the beam axis was measured directly with inelastic events recorded in the UA1 central detector during the same run ; it was found to be displaced from the centre by 11 cm in the outgoing $\bar{p}$ direction.

In order that systematic errors in the t distribution be small compared to statistical errors the drift chambers must be located relative to the vertex with accuracy ≤ 0.5 mm in the plane transverse to the beam. In the horizontal direction (x) the chamber acceptance is $-3 < x < 3$ cm and the required accuracy is easily achieved by using elastic tracks to align the chambers. In the vertical direction the separation of the two drift chambers, which are housed one above the other in a single structure containing two pots, is known to within 0.1 mm; the vertical pot movement has been measured to operate within a 25 μ m error limit. Elastic tracks were used to verify the relative vertical coordinates of the inner and outer chambers in the $\bar{p}$ and p detectors.

A vertical offset of the interaction vertex or of either elastic detector from the nominal beam trajectory give rise to differences between the elastic scattering distributions in the (down-up) $D_{\bar{p}} \cdot U_p$ and (up-down) $U_{\bar{p}} \cdot D_p$ configurations (fig. 4). In particular the minimum and maximum values of t and the relative number of events in the two distributions are sensitive functions of these offsets. The smooth curves in fig. 4 are Monte Carlo elastic scattering distributions calculated for a vertex displacement 0.6 mm above the nominal beam trajectory and a t distribution of the form e^{13t} . The assumed offset can account for the differing $t_{\min}$ and the different number of events (433 $D_{\bar{p}} \cdot U_p$ and 354 $U_{\bar{p}} \cdot D_p$) in the two distributions. The 0.6 mm vertex offset also accounts for the observed non-zero mean value (0.05 mrad) of the distribution in the vertical collinearity parameter $\theta_v(p) - \theta_v(\bar{p})$ (fig.3).

The Monte Carlo acceptance fails to account for the shape of the high t data in the $U_{\bar{p}} \cdot D_p$ distribution. A similar effect is seen in data recorded with the intermediate low beta scheme. A likely explanation is a 1 mm downward

displacement of the vacuum pipe at 14 m on the outgoing $\bar{p}$ side in the LSS5 area as indicated in fig. 4. The vacuum tube position is known with accuracy about 1 mm. It was also noted that during this run the vacuum tube at 8 m out in the $\bar{p}$ direction was displaced downward by 5 mm [3].

The final acceptance corrected t distribution in fig. 5 is based on the combined $D_{\bar{p}} \cdot U_p$ data for $0.14 < -t < 0.26 \text{ GeV}^2$ and $U_{\bar{p}} \cdot D_p$ data for $0.17 < -t < 0.23 \text{ GeV}^2$. The data is well fitted by the hypothesis $dN/dt \propto e^{bt}$ with slope parameter $b = 12.9 \pm 1.5 \text{ GeV}^{-2}$; after correction for smearing due to measurement errors and bin width the final value of the slope parameter is $b = 13.3 \pm 1.5 \text{ GeV}^{-2}$. The t -distribution is expressed as a differential cross-section using the measured integrated luminosity $2.6 \times 10^{30} \text{ cm}^{-2}$ and correcting for chamber efficiency (96%), inelastic background (5.5%) and azimuthal coverage (22%). The resulting differential cross-section $d\sigma/dt = (dN/dt) / \int L dt$ has a systematic uncertainty of 30% coming from the luminosity measurement [4]. The luminosity was calculated from the p , $\bar{p}$ currents and beam profiles measured by the SPS machine group. The beam profiles were obtained by the wire scan technique [5].

A comparison of the measured b value with the compilation of Burq et al. [6] in fig. 6 indicates that the forward elastic $\bar{p}p$ peak is shrinking over the ISR-Collider energy range.

Experiment UA4 [7] has recently measured $b = 17.2 \pm 1.0 \text{ GeV}^{-2}$ in elastic scattering at the $\bar{p}p$ collider for $|t| = 0.05 - 0.19 \text{ GeV}^2$. A simultaneous measurement of the total rate gave $\sigma_{el} = 13.2 \pm 1.3 \text{ mb}$ [8]. The UA4 elastic differential cross-section is given alongside the UA1 result in fig. 5. These preliminary collider results show that b increases with decreasing $|t|$ for $0.5 < |t| < 0.24 \text{ GeV}^2$; a similar $b(t)$ dependence in this t -range was noted in pp scattering at the ISR [9].

References

1. Aachen-Annecy (LAPP)-Birmingham-CERN-London (Queen Mary College)-Paris (Collège de France)-Riverside-Rutherford-Saclay (CEN)-Vienna Collaboration, "A 4π Solid-Angle Detector for the SPS Used as Proton-Antiproton Collider at a centre-of-mass energy of 540 GeV", Proposal CERN/SPSC/78-06/P92 (1978). G. Arnison et al., Phys. Lett. 107B (1981) 320.
2. P. Gutierrez, Ph.D. thesis, University of California, Riverside (1982).
3. B Angerth (SPS Vacuum Group), private communication.
4. G. Von Holtey, private communication.
5. A Barisy et al., A Transverse Beam Profile Monitor for $\bar{p}$ -p Studies, SPS/AC/LE/Imp. Rep. 173, March 1980.
6. J.P. Burq et al., Phys. Lett. 109B (1982) 124.
7. UA4 Collaboration, R. Battiston et al., Phys. Lett. 115B (1982) 333.
8. UA4 Collaboration, R. Batiston et al., Measurement of Elastic Scattering in Antiproton-Proton Elastic and Total Cross-Section at the Centre-of Mass Energy of 540 GeV, CERN/EP 82-111 (submitted to Phys. Lett. B).
9. G. Barbiellini et al., Phys. Lett. 39B (1972) 663.

Acknowledgements

We should like to thank the members of the CERN Accelerator Divisions for their work in commissioning the SPS Collider and providing the collisions which have yielded this physics. We are extremely grateful to the CERN management and staff who have supported the UA1 experiment so generously, and extend these warm thanks to the following external sources of financial support :

Fonds zur Forderung der Wissenschaftlichen Forschung, Austria.

Valtion luonnontieteellinen toimikunta, Finland.

Institut National de Physique Nucléaire et de Physique des Particules and
Institut de Recherche Fundamentale (CEA), France.

Bundesministerium fur Forschung und Technologie, Germany.

Istituto Nazionale di Fisica Nucleare, Italy.

Science and Engineering Research Council, United Kingdom.

Department of Energy, USA.

A great deal of understanding was demanded of all these bodies in order that we could realise the UA1 detector on the timescale required. Our technical and engineering colleagues in the collaborating institutions provided the untiring support needed to build UA1, and we gratefully acknowledge their work.

The special efforts of our SPS colleagues R. Maleyran, P. Dreesen and A. Manarin were indispensable in making the measurement reported here. And we thank R. Wojslaw for his early work in designing the luminosity chambers.

TABLE 1

Beam size and angular divergence of the p and $\bar{p}$ bunches
at the LSS5 crossing point

	σ_v (mm)	σ_h (mm)	$\Delta\theta_v$ (mrad)	$\Delta\theta_h$ (mrad)
p	0.77	1.00	0.016	0.020
$\bar{p}$	1.19	1.50	0.025	0.029

Figure Captions

1. UA1 and machine magnets and Roman pots at LSS5 of the $\bar{p}p$ collider.
2. Schematic of the four drift chamber telescopes (vertical plane). The display of the elastic scattering event shows the assymetry induced by the machine quadrupoles.
3. Collinearity plot in (a) the vertical and (b) horizontal planes for candidate elastic scattering events.
4. Measured t -distributions for elastic scattering events in the configuration (a) $\bar{p}$ (down)• p (up) and (b) $\bar{p}$ (up)• p (down). The broken lines are the corresponding Monte Carlo distributions normalised to the sum of events in both plots. The dot-dash curve in (b) shows the effect of a one mm vacuum pipe displacement of the limiting aperture.
5. Elastic differntial cross-section (545 events) ; the systematic uncertainty is $\pm 30\%$. The UA4 measurement is also shown [7].
6. Comparison of measured slope parameter b with the compilation of Burq et al., for $\langle t \rangle = 0.2 \text{ GeV}^2$ [6].

Fig.1

Fig.2

Fig.3

Fig.4

Fig.5

Fig.6