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ANTIPROTON-PROTON TOTAL AND ELASTIC CROSS-SECTIONS

AT THE CERN ISR AND THE SPS COLLIDER

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ABSTRACT

Three experiments, currently running at CERN, are devoted to the measurement of total and elastic cross-sections in antiproton-proton collisions: Experiments R210 and R211 at the ISR, and Experiment UA4 at the SPS Collider. The various experimental techniques and setups are briefly described, and the most recent results obtained are reported. The combined centre-of-mass energy range of the three experiments is $31 < \sqrt{s} < 540$ GeV. In this range the $\bar{p}p$ total cross-section is found to rise approximately like $(\ln s)^2$, as does the pp total cross-section, and the difference, $\sigma_{\text{tot}}(\bar{p}p) - \sigma_{\text{tot}}(pp)$, tends to zero as $s^{\alpha-1}$, with $\alpha \approx \frac{1}{2}$.

INTRODUCTION

The experiments whose results I shall be presenting are R210 and R211 at the ISR, which have data at $\sqrt{s} = 31, 53$, and 63 GeV, and UA4 at the SPS Collider with data at $\sqrt{s} = 540$ GeV. All three experiments have measured the total $\bar{p}p$ cross-section, $\sigma_{\text{tot}}(\bar{p}p)$, and the $\bar{p}p$ differential elastic cross-section, $d\sigma_{\text{el}}/dt$, at small angles in various ranges of the momentum-transfer-squared t . The ISR experiments have also measured the corresponding parameters for the pp reaction. The institutions and people participating in each experiment are listed in Table I.

My talk is organized as follows:

- an outline of the antiproton program at CERN,
- a brief discussion of the experimental methods,
- a brief description of the experimental setups,
- presentation of the results and comparison with existing data,
- a short discussion of the significance of the measurements, and
- a mention of future prospects.

ANTIPROTONS AT CERN

The antiproton program at CERN is based on the Antiproton Accumulator (AA), which supplies the SPS Collider, the ISR, and eventually the low-energy ring LEAR with antiprotons for $\bar{p}p$ colliding-beam physics.

A 26-GeV/c proton beam from the PS (10^{13} p/pulse every 2.4 s) impinges on the AA target, and $\bar{p}$'s produced with 3.5 GeV/c momentum

Table I List of Participants	
Experiment R210	
CERN:	D. Lloyd Owen and F. Schiavo
Napoli:	M. Ambrosio, G. Barbarino, G. Paternoster, and S. Patricelli
Pisa:	G. Carboni, V. Cavasinni, T. Del Prete, M. Morganti, and M. Valdata-Nappi
Stony Brook:	G. Anzivino and P.D. Grannis
Experiment R211	
Louvain:	D. Favart, P. Lipnik, P. Macq, J.P. Matheys, and J. Debaisieux
Northwestern:	N. Amos, M. Block, C. Leroy, D. Miller, and S. Zucchelli
CERN:	G. Bobbink, K. Potter, and C. Vander Velde-Wilquet
Utrecht	M. Botje and F. Linde
Experiment UA4	
Amsterdam:	B. Koene, L. Linssen, R. Vanswol, and J. Timmermans
CERN:	M. Haguenauer, V. Palladino, C. Vannini, and J. Velasco
Genova:	M. Bozzo and G. Sette
Napoli:	F. Carbonara, G. Chiefari, E. Drago, G. Matthiae, L. Merola, M. Napolitano, G. Sciacca, and F. Visco
Pisa:	R. Battiston, P.L. Braccini, R. Castaldi, F. Cervelli, and G. Sanguinetti

are captured in the AA ($2.5 \cdot 10^7$ $\bar{p}$ /PS pulse or $2 \cdot 10^{10}$ $\bar{p}$ /day). The accumulated beam in the AA cooled stochastically and injected back into the PS, circulating the "wrong" way around. The PS then accelerates the $\bar{p}$'s to the standard energies for injection into the ISR or to 26 GeV/c for injection into the Collider and subsequent acceleration to 270 GeV/c. A diagram of the machines involved and the interconnecting beam lines is shown in Fig. 1 (the heavily shaded lines indicate the specially constructed $\bar{p}$ transfer tunnels).

At the ISR, $\bar{p}$ currents of 4 mA (10^{11} $\bar{p}$'s) were obtained in mid-1982, which, in collision with p beams of 10 A, gave luminosities of about 10^{27} $\text{cm}^{-2}\text{s}^{-1}$. In the Collider at the time of writing, a top luminosity of $\sim 2 \cdot 10^{28}$ $\text{cm}^{-2}\text{s}^{-1}$ has been achieved with three bunches of $\bar{p}$'s (10^{10} $\bar{p}$ /bunch) circulating against three of p's (10^{11} p/bunch).

Fig. 1 Layout of the CERN Machines and Their Interconnections

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METHODS OF MEASURING σ_{tot}

In the experiments under discussion, three different methods have been used to measure the total cross-section:

Direct Method: The first technique is to measure the total interaction rate R_{tot} while simultaneously measuring the machine luminosity L . The σ_{tot} total cross-section is then

$$\sigma_{\text{tot}} = R_{\text{tot}}/L \quad (1)$$

Measuring R_{tot} implies a 4π coverage of the solid angle around the interaction source. In practice, there have to be holes in the detector for the beam lines, and the observed rate needs to be correct for small, mainly elastic losses.

Indirect Method: An alternative is to measure the differential elastic rate dR_{el}/dt at small t , again while measuring L . For $-t < 0.05 \text{ GeV}$, nuclear elastic scattering has an exponential dependence on t , and by extrapolation one can obtain the zero intercept $dR_{\text{el}}/dt|_0$. Then, invoking the optical theorem, one has:

$$\sigma_{\text{tot}} = \sqrt{\frac{16\pi(\hbar c)^2}{1 + \rho^2} \left. \frac{dR_{\text{el}}}{dt} \right|_0 \frac{1}{L}} \quad (2)$$

To extrapolate accurately to the intercept, one has to measure the elastic rate at quite small t , and -- since $-t = p^2 \theta^2$ -- this requires an accurate position detector at increasingly smaller angles at higher beam momenta p .

The quantity ρ in eq. (2) is the ratio of the real to the imaginary part of the forward nuclear scattering amplitude. This can be extracted from a fit to the elastic cross-section in the region of nuclear-Coulomb interference ($-t \sim 10^{-3} \text{ GeV}^2$) if one has high enough statistics.

Combination Method: Finally, if R_{tot} and dR_{el}/dt are measured simultaneously, σ_{tot} can be obtained in a luminosity-independent manner. Combining eqs. (1) and (2), we have:

$$\sigma_{\text{tot}} = \frac{16\pi(\hbar c)^2}{1 + \rho^2} \left. \frac{dR_{\text{el}}}{dt} \right|_0 \frac{1}{R_{\text{tot}}} \quad (3)$$

The quantities measured by the three experiments are noted in Table II.

Table II Quantities Measured			
Experiment	R_{tot}	dR_{el}/dt	L
R210	95%	$-t > 0.01$ (b only)	YES ($\pm < 1\%$)
R211	NO	$-t > 0.001$ (b and ρ)	YES ($\pm 1\%$)
UA4	98% R_{inel}	$-t > 0.05$ (b only)	NO

Expt. R210 can measure σ_{tot} by the direct method or, independently, by either of the other methods, if a value for ρ is assumed. Expt. R211 uses the indirect method, and Expt. UA4, assuming a value for ρ , uses the combination method.

THE ELASTIC MEASUREMENT

In the analysis of elastic data, a candidate sample is prepared by vetoing on secondary production at large angles and by requiring an appropriate trigger configuration, i.e. UP_{left}·DOWN_{right} or vice versa. True elastic events are then selected by imposing a collinearity requirement. The resulting distribution is shown schematically in Fig. 2.

Fig.2 The t Dependence of Elastic Scattering

The cross-section is composed of two amplitudes -- Coulomb and nuclear:

$$\frac{d\sigma}{dt}el = \pi |f_C + f_N|^2, \quad f_C = -2\alpha \frac{G^2(t)}{|t|} e^{i\alpha\phi} \quad (4)$$

$$f_N = \frac{i + \rho}{4\pi} \sigma_{tot} e^{\frac{1}{2}bt}$$

The Coulomb contribution is significant only at very small t ; at larger (but still small) t , one finds a simple exponential dependence of the nuclear amplitude on t . In the expression for the Coulomb amplitude in eq.(4), $G(t) = 1 - 2.94|t|$ is the (anti)proton electromagnetic form factor, and $\phi(t) = \ln \{0.08/|t|\} - 0.577$ is the Coulomb phase factor. (The expression given is that for pp scattering -- for the $\bar{p}p$ case, reverse the sign of the fine-structure constant α .)

The t ranges accessible to the experiments are shown approximately in Fig. 2.

THE LUMINOSITY MEASUREMENT

The measurement of the ISR luminosity is relatively straightforward because the colliding beams can be steered independently in the vertical direction and because the beams cross at a finite angle so that only the vertical current density is of significance.

Neither of these conditions obtains at the Collider, and so no direct measurement of the luminosity is possible.

The definition of the ISR luminosity is indicated in Fig. 3.

Fig. 3 Definition of the ISR Luminosity

A luminosity monitor -- a coincidence of counters with inclusive cross-section σ_M -- is chosen, ideally with the following properties: a) independence of source position, b) insensitivity to background, and c) relatively large σ_M . The monitor rate R_M is given by:

$$R_M(\delta) = \sigma_M L(\delta) \quad (5)$$

The standard Van der Meer technique consists in steering the beams vertically in small, precise steps, thus performing the integral:

$$\int R_M(\delta) d\delta = K \sigma_M \int i_1(z) dz \int i_2(z+\delta) d\delta = K \sigma_M I_1 I_2 \quad (6)$$

in which σ_M is the only unknown. At any subsequent time, the instantaneous luminosity can be determined from the monitor rate via eq.(5). Figure 4 is an example of such a luminosity curve. The luminosity data were taken by Expt. R210 in an early pp run with poorer than average conditions -- nevertheless, a high-quality curve was obtained.

The ISR experiments have benefitted from the installation in Intersection 2 of high-precision beam scrapers, which have been used to calibrate the vertical beam-displacement scale. The true scale was found to be 2% larger than the nominal, calculated one.

Fig. 4 An Example of a Luminosity Curve. The data were taken in an early $\bar{p}p$ run with a $\bar{p}$ current of only 0.306 mA.

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THE EXPERIMENTAL SETUPS

Experiment R210: The total-rate detector consists of sets of scintillation-counter hodoscopes surrounding the interaction region and possessing a left/right symmetry (Fig. 5). Each hodoscope comprises two planes of trigger counters operated in coincidence, and the fully inclusive trigger:

$$T = \text{Hit}_L \cdot \text{Hit}_R, \text{ where} \quad (7)$$

$$\text{Hit} = (\text{TB}_a \cdot \text{TB}_b + \text{H5}_a \cdot \text{H5}_b + \text{H4} \cdot \text{H3} + \text{H2} \cdot \text{H1} + \text{CO} \cdot \text{CI})$$

is sensitive to 99% of inelastic events. The relative timings of each hodoscope relative to the trigger are recorded, and this information is used to discriminate against background. The TB hodoscopes contain the elastic detector: two planes of twelve 1-cm drift tubes both above and below the beam pipe, used in conjunction with finger counters to localize particles horizontally. Each of the H hodoscopes has an additional plane of annular scintillators to measure the polar angles of secondaries.

A trigger loss of $\leq 5\%$ of R_{tot} is due to elastic or singly diffractive events in which a $^{\text{tot}}$ (quasi)elastically scattered particle passes through the hole ($2 \cdot 10^{-4}$ sr) in a TB hodoscope. This

Fig. 5 Layout of Experiment R210

loss is estimated by extrapolating an experimental distribution and integrating it over the region of the holes. In the case of the elastic loss, the distribution is differential elastic cross-section; in the case of the diffractive loss, it is the maximum-angle distribution in one arm when a large-angle secondary is detected in the other arm.

Experiment R211: The elastic detectors of Expt. R211 are located 8.7 m from the I2 crossing point, between R210 hodoscopes H5 and TB (see Fig.5). Each detector hodoscope (Fig. 6) consists of a vertical stack of twenty-four 2-mm scintillators and a horizontal array of seven 4-mm finger counters, backed by a trigger counter. The hodoscopes are located in "Roman Pots" (so-called for the CERN-Rome Collaboration that pioneered the technique at the ISR), which are movable indentations in the vacuum chamber. The Roman Pots are

Fig. 6 The Elastic Detector of Experiment R211

remotely controlled, and are moved to within about 8 mm ($\theta_{\min} \approx 1$ mrad) of the beam centroids (with an accuracy in the detector position of ± 0.1 mm) once the beams have been stabilized.

All counters are equipped with pulse-height analysis, information which is used to discriminate between elastic events with a secondary interaction and inelastic events in those cases when a hodoscope registered more than one hit. The relative timings of the trigger counters are also recorded, and used to subtract single-beam and accidental background.

To improve the definition of t , the ISR was operated with so-called Terwilliger optics, reducing the size of the beams in the even-numbered intersections at the cost of the odd-numbered intersections. In this mode, the vertical and horizontal extensions of the beams are 1.5 - 3 mm and 4 - 7 mm respectively, giving a source length of about 3 cm (cf. 40 cm for the other intersection regions).

Experiment UA4: For their elastic measurement, Expt. UA4 also uses the Roman-Pot technique (Fig. 7). Two pots, 6 m apart, are located in each arm about 40 m from the crossing point. Each pot contains (see Fig. 8) 4 planes of drift chambers (single-plane r.m.s. accuracy of 0.13 mm) measuring the vertical coordinate; a multi-wire proportional plane with high-resistivity anode wires measuring the horizontal coordinate (r.m.s. accuracy of 0.4 mm) by charge division; a stack of 8 finger scintillators to calibrate the charge-division electronics; and a trigger counter. When stable beam conditions are achieved, the pots are moved to within about 18 mm of the beams with an accuracy of 0.1 mm, this position corresponding to a minimum scattering angle of 0.8 mrad.

The detectors view the source through two machine quadrupoles Q_L and Q_R , which vertically defocus the elastically scattered p 's and focus the $\bar{p}$'s. The minimum accessible t ($t_{\min} = 0.05 \text{ GeV}^2$) is thus determined by the proton arm, while the maximum ($t_{\max} = 0.19 \text{ GeV}^2$) is determined by the aperture of the vacuum chamber in the antiproton arm.

In the track reconstruction, six out of eight drift planes in

Fig. 7 The Elastic Layout of Experiment UA4

each arm are required to contribute a point. A cut is placed on the reconstructed vertex, and the track multiplicity in a telescope has to be one or two (to allow for an accompanying δ -ray). These requirements remove about 40% of triggers, and the surviving candidate sample is refined by a cut in collinearity.

UA4's inelastic detector (Fig. 9) consists of trigger counters ($T_1 - T_3$) and drift-chamber telescopes ($D_1 - D_3$) for track reconstruction. While the polar angle coverage of the system appears small ($0.5^\circ < \theta < 10^\circ$), the pseudorapidity range is quite large ($3.0 < |\eta| < 5.6$), and, by using single-arm as well as double arm triggers, 98% of inelastic events are detected. Background events are removed using the timing information of the trigger counters as a first step, and then by reconstructing the vertex as a second step. The small inelastic losses at small and large angles are estimated by extrapolating and integrating maximum- and minimum-angle distributions of secondary particles.

Fig. 8 UA4 Elastic Telescope

Fig. 9 The Inelastic Detector of Experiment UA4

RUNNING CONDITIONS

The ISR results come from the three stacks described in Table III. The results of Expt. UA4 come from 8 hours of running time with a $\bar{p}$ bunch of $5 \cdot 10^9$ particles circulating a bunch of 10^{11} p's, giving a luminosity of about $10^{26} \text{ cm}^{-2} \text{ s}^{-1}$.

Table III ISR Running Conditions					
Date	$I_{\bar{p}}$ (A)	I_p (mA)	L ($\text{cm}^{-2} \text{ s}^{-1}$)	$L \text{ dt}$ (cm^{-2})	$\sqrt{s}$ (GeV)
19/9/81	10.	2.	$4 \cdot 10^{26}$	$4 \cdot 10^{32}$	53
6/4/82	12.	3.4	10^{27}	$4 \cdot 10^{32}$	63
25/5/82	11.	4.2	10^{27}	$7 \cdot 10^{32}$	31

THE RESULTS

The data of Expt. UA4 are obviously very preliminary, since they have had so little running time to date. Their elastic data (Fig. 10) are fitted with an exponential with slope parameter $b = 17.2 \pm 1.0 \text{ GeV}^{-2}$. Extrapolating this slope and combining the elastic and inelastic data, the total cross-section obtained is:

$$\sigma_{\text{tot}} = 66 \pm 7 \text{ mb}, \quad \sqrt{s} = 540 \text{ GeV}$$

The ratio of the integrated elastic to the total cross-section is $\sigma_{\text{el}}/\sigma_{\text{tot}} = 0.20 \pm 0.02$. The ratio of the real to the imaginary part of the forward amplitude was assumed to be zero. An error of 1 GeV^{-2} in b or an error of 5% in the inelastic rate would lead to a change in σ_{tot} of 3 mb.

Fig. 10 $\bar{p}p$ Differential Elastic Cross-Section (UA4)

The members of Expt. R211 have not completed the analysis of their $\sqrt{s} = 63 \text{ GeV}$ data, so I shall only present their results at 31 and 53 GeV. Figures 11(a) and 11(b) show the high quality of

Fig. 11 $\bar{p}p$ and pp elastic cross-sections at 31 GeV (R211)

their $\bar{p}p$ and pp data, in this case at 31 GeV. To obtain their results they perform a simultaneous fit to the $\bar{p}p$ and pp differential cross-sections. As input to this fit, they use an average value of $\sigma_{\text{tot}}(pp)$ compiled from earlier ISR data, and, at $\sqrt{s} = 31$ GeV where the t range does not extend far enough beyond the Coulomb region, they also input values for the slope parameters. The results of the fits are listed in Table IV. Experiment R211 also calculate the geometrical-scaling ratio $R = \sigma_{\text{el}}/\sigma_{\text{tot}}$ by integrating the differential cross-section to obtain:

$$\sigma_{\text{el}} = \frac{1}{16\pi(hc)^2} \frac{1 + \rho^2}{b} \sigma_{\text{tot}}^2 \quad (8)$$

Table IV Results of R211 Fits to $d\sigma_{el}/dt$		
parameter	31 GeV	53 GeV
INPUT		
$\sigma_{tot}(pp)$ mb	40.14±0.17	42.67±0.20
$b(pp)$ GeV ⁻²	12.6±0.3	-
$b(\bar{p}p)$ GeV ⁻²	12.2±0.2	-
OUTPUT		
$\sigma_{tot}(\bar{p}p)$ mb	41.70±0.50	43.68±0.41
$\Delta\sigma_{tot}$ mb	1.50±0.50	0.98±0.36
σ_{av} mb	40.90±0.30	43.16±0.26
$\rho(\bar{p}p)$	0.031±0.021	0.101±0.018
$\rho(pp)$	0.040±0.005	0.060±0.006
$\Delta\rho$	-0.01±0.02	0.042±0.020
ρ_{av}	0.036±0.011	0.081±0.010
$b(\bar{p}p)$ GeV ⁻²	-	13.36±0.53
$b(pp)$ GeV ⁻²	-	12.85±0.12
Δb GeV ⁻²	-	0.51±0.54
b_{av} GeV ⁻²	-	13.10±0.28

The values they obtain are:

$$\sqrt{s} = 31 \text{ GeV}$$

$$R(\bar{p}p) = 0.169 \pm 0.007$$

$$R(pp) = 0.170 \pm 0.002$$

$$\sqrt{s} = 53 \text{ GeV}$$

$$R(\bar{p}p) = 0.169 \pm 0.005$$

$$R(pp) = 0.168 \pm 0.003$$

The results of the R210 total-cross-section measurement using the total-rate technique are listed in Table V.

Table V R210 Total Cross-sections (mb)			
$\sqrt{s}$ (GeV)	$\sigma_{tot}(\bar{p}p)$	$\sigma_{tot}(pp)$	$\Delta\sigma_{tot}$
31	42.33 ± 0.30	40.04 ± 0.20	2.29 ± 0.30
53	44.70 ± 0.40	43.26 ± 0.20	1.44 ± 0.44
63	45.25 ± 0.30	44.68 ± 0.22	0.57 ± 0.30

We have completed the small-angle elastic analysis at 53 GeV, but not at the other energies. Both the $\bar{p}p$ and pp data are shown in Fig. 12 along with fits of the form of eq.(4).

Fig. 12 $\bar{p}p$ and pp Elastic Cross-sections at $\sqrt{s} = 53$ GeV (R210)

The slope parameters found are $b(\bar{p}p) = 13.92 \pm 0.5 \text{ GeV}^{-2}$ and $b(pp) = 13.09 \pm 0.5 \text{ GeV}^{-2}$. Applying the optical theorem and assuming that $\rho(\bar{p}p) = 0.1$ and $\rho(pp) = 0.078$, we obtained the following total cross-sections:

$$\left. \begin{aligned} \sigma_{\text{tot}}(\bar{p}p) &= 44.86 \pm 0.50 \\ \sigma_{\text{tot}}(pp) &= 43.34 \pm 0.40 \end{aligned} \right\} \quad \left\{ \begin{array}{l} \sqrt{s} = 53 \text{ GeV} \\ \text{optical theorem} \end{array} \right.$$

The direct and indirect methods give good agreement. Combining the three quantities -- the total rate, the elastic intercept, and the luminosity -- into a single, "maximum-likelihood" estimate of the total cross-section, we obtain $\sigma_{\text{tot}}(\bar{p}p) = 44.77 \pm 0.48$ mb and $\sigma_{\text{tot}}(pp) = 43.28 \pm 0.30$ mb.

In R210, we also measure elastic scattering in the t range $0.1 < -t < 0.7$ GeV². The cross-section in this region (Fig. 13) is still exponential in t , but with a gentler slope -- $b = 10.68 \pm 0.26$ GeV⁻² for $\bar{p}p$ and $b = 10.34 \pm 0.25$ GeV⁻² for pp at $\sqrt{s} = 53$ GeV. The change in slope occurs somewhere in the region $0.05 < -t < 0.1$ GeV², in the gap between the t ranges of the two elastic detectors. Assuming the change in slope occurs at $t = 0.1$ GeV and integrating the two slopes, one obtains for the elastic cross-section the following values:

$$\begin{aligned}\sigma_{\text{el}}(\bar{p}p) &= 7.89 \pm 0.28 \text{ mb} \\ \sigma_{\text{el}}(pp) &= 7.79 \pm 0.24 \text{ mb}.\end{aligned}$$

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Let us now consider the energy dependence of these results, comparing them with earlier data.

First, the total cross-section. Figure 14 shows the $\bar{p}p$ point of UA4 and the three $\bar{p}p$ and pp points of R210; the lower-energy points are those of Carroll et al. (Fermilab, 1976-79). The data of Carroll et al. and R210, together with the earlier pp results of Amaldi et al. at the ISR, are replotted on a larger scale in Fig. 15. Shown in both figures is a simultaneous fit to both the pp and $\bar{p}p$ data of the form:

$$\begin{aligned}\sigma_{\text{tot}}(pp) &= \sigma_0 + \kappa (\ln s/s_0)^2 \\ \sigma_{\text{tot}}(\bar{p}p) &= \sigma_{\text{tot}}(pp) + \kappa' s^{\alpha-1}\end{aligned}\tag{9}$$

The fit is in pretty good agreement with the data, and indicates that the two cross-sections are rising faster than would be expected from the earlier ISR data. (As far as the discrepancy between the earlier ISR data and those of R210 goes, all I can say is that the operation of the ISR has improved continuously and the machine is now operating better than ever before. In particular, we can now

Fig. 13 The $\bar{p}p$ elastic cross-section in the larger t region at $\sqrt{s} = 53$ GeV

Fig. 14 $\bar{p}p$ and pp Total Cross-sections as a Function of Energy

routinely obtain such quiet proton beams that even the detector of Expt. R210, which is very sensitive to background, sees virtually no single-beam events. Furthermore, we are fortunate in I2 in that the beam-displacement scale, fundamental to the luminosity measurement, has been measured since 1981 to a very high accuracy, $\pm 0.2\%$. We are, nevertheless, still checking these data and in the process of analyzing new data to be certain of our results.)

Turning now to the difference in the $\bar{p}p$ and pp cross-sections, we see that this difference is positive, tending to zero as a small inverse power of s . The results of R210 and R211 and lower-energy data on the difference are plotted in Fig. 16. The new data are in good agreement with an extrapolation of the lower-energy trend.

The fit (eq. [9]) in the three figures is the same one, and corresponds to the parameter values:

$$\sigma_0 = 38.3 \text{ mb} \quad \kappa = .50 \text{ mb} \quad s_0 = 117 \text{ GeV} \quad \kappa' = 79 \text{ mb} \quad \alpha = .42$$

Fig. 15 The Energy Dependence of the $\bar{p}p$ and pp Total Cross-sections

Fig. 16 Energy Dependence of $\Delta\sigma$

The form of the difference term in eq.(9) is motivated by Regge phenomenology: the difference amplitude which is odd under charge conjugation should be composed of simple poles like the ω , the ρ , and the ϕ ; amplitudes even under charge conjugation, including the pomeron, can be ignored. These poles give the $s^{\alpha-1}$ dependence, where α is the intercept. Both the ω and ρ intercepts have values $\alpha \approx \frac{1}{2}$, while $\alpha_\phi \approx 0$: as might be expected the ϕ , consisting of strange quarks, couples weakly to nucleons. The ω and ρ intercepts have been extracted from fits to $p\bar{d}$, $K\bar{d}$, and π^+p data (in which only one or the other pole contributes) by Carroll et al, and found to be $\alpha_\omega = 0.40 \pm 0.02$ and $\alpha_\rho = 0.55 \pm 0.03$. The new fit thus supports the conclusion that in the ($p\bar{p}$ - pp) cross-section difference it is ω exchange that dominates.

The fit, having been obtained, can be used to evaluate the s dependence of ρ , the ratio of the real to the imaginary parts of the forward scattering amplitude, using dispersion relations. In Fig. 17, this prediction is compared with the existing $p\bar{p}$ and pp data. The calculation is in good agreement with the data, and

Fig. 17 Dispersion-relation calculation of ρ (dotted lines) for $p\bar{p}$ and pp compared with data.

indicates that ρ tends to about 0.2 at high energy for both $p\bar{p}$ and pp .

Turning briefly to the elastic results, the ratios σ_{el}/σ_{tot} and b/σ_{tot} for the $p\bar{p}$ reaction found by R210 and R211 are in agreement with the values found for pp , indicating that geometrical scaling has the same validity in $p\bar{p}$ as it does in pp . Since the ratios are constant in s , the numerators show the same $(\ln s)^2$ behaviour as σ_{tot} .

FUTURE PROSPECTS

Experiment UA4 have just begun their data-taking and the results I have presented from them are very preliminary. In the

future, they will run with a high- β scheme, which, because of the machine quadrupoles between their detector and the source, will reduce their minimum t to 0.006 GeV^2 instead of 0.05 GeV^2 . They will also benefit from the larger-angle coverage of Expt. UA2 for the inelastic measurement. Ultimately, they aim for a precision of $\pm 2\%$ in the total cross-section.

The fates of Expts. R210 and R211 are different: the ISR will close for good at the end of 1983, and only one month of $\bar{p}p$ operation is foreseen for next year. Both experiments have more analysis work still to do, however, and will soon have more and preciser results than those that I have spoken about.

ACKNOWLEDGEMENTS

I would like to thank the members of Experiments R211 and UA4 for providing me not only with their latest results but also with many of the transparencies that I have used. I am especially grateful to Claude Leroy (R211) and Rino Castaldi (UA4) for many clarifying discussions.