

MEASUREMENT OF TOTAL CROSS-SECTION IN PROTON-PROTON
AND PROTON-ANTIPROTON COLLISIONS AT ISR ENERGIES

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ABSTRACT

The results of Experiment R210 on the measurement of the total cross-section in $\bar{p}p$ and pp collisions at the CERN ISR are summarized. Fits to the data, using various parametrizations, are discussed. The status of the data on $\sigma_{\text{tot}}(pp)$ at ISR energies is also mentioned.

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In an experiment performed at the CERN ISR we measured the total cross-section in $p\bar{p}$ and pp collisions at $\sqrt{s} = 31, 53$, and 63 GeV. The total cross-sections $\sigma_{\text{tot}}(p\bar{p})$ and $\sigma_{\text{tot}}(pp)$ were measured using the total-rate method^{1,2}). The method consists of the simultaneous measurement of the total interaction rate (R_{tot}) and the ISR luminosity (L), providing the total cross-section via:

$$\sigma_{\text{tot}} = R_{\text{tot}}/L.$$

The experimental apparatus (Fig. 1) has been fully described elsewhere^{3,4}). Briefly, it consisted of large scintillation-counter hodoscopes covering the entire solid angle (C1-C0, H1-H2, H3-H4, H5_A-H5_B, TB_A-TB_B), except for two narrow cones (1.9×10^{-4} sr in total), which accommodated the beam pipes. The system was supplemented by finely divided scintillation-counter hodoscopes located directly behind the trigger counters, which were used to measure the polar and azimuthal coordinates of charged secondaries. The two arms of the detector were mirror images of each other.

The trigger required the presence of hits in the left and in the right arm of the detector. For each event the timing of each hodoscope pair with respect to the trigger was recorded, together with the live time of the experiment, and the presence of hits in all the cells of all hodoscopes. The rate R_{obs} measured by the detector differed from the total rate R_{tot} because of the incomplete coverage at small angles. The great majority of the events lost at small angle were elastic or single-diffractive events. The corrections for losses were calculated from the data by extrapolating the appropriate measured angular distribution over the regions of the holes.

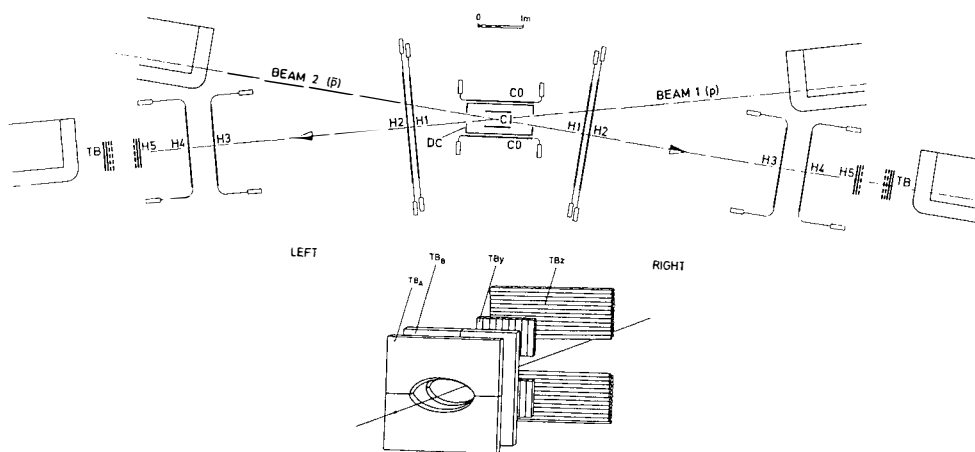


Fig. 1 Layout of Experiment R210.

The measurement of the ISR luminosity was achieved using the van der Meer method³⁻⁵⁾ of vertically displacing the beams in special runs interleaved with data taking. The vertical displacements were calibrated by precision scrapers specially installed in our intersection region. In this way, the absolute scale error on the luminosity, a plague of early ISR experiments, was reduced to about $\pm 0.3\%$.

The main source of background resulted from the upstream interactions of either beam with the residual gas in the vacuum chamber or with the vacuum chamber itself, interactions that produced jets of particles entering the apparatus from the sides and which were distinguished from beam-beam events using the relative timing of left- and right-arm hodoscopes. This background was virtually absent in the pp runs, owing to the very good conditions in which the ISR is currently operated, but was an important problem in the $p\bar{p}$ runs, owing to the large imbalance of current ($I_p = 10$ A, $I_{\bar{p}} = 2-4$ mA) necessary to obtain a decent luminosity ($L = 10^{27} \text{ cm}^{-2} \text{ s}^{-1}$) given the limited antiproton current. The ratio of background to beam-beam events, at the trigger level, was typically 10:1 in $p\bar{p}$ runs. With this severe background, the left-right time information was not sufficient to remove all "single-beam" events and a subtraction was needed. For this purpose, we varied the ISR luminosity, taking many pairs of runs with beams at full overlap (recording beam-beam and background events) and with beams completely separated (only background events were recorded). We then subtracted and averaged⁴⁾.

Total cross-section results are shown in Fig. 2, together with FNAL^{6,7)} and previous ISR data²⁾, and prove that $\sigma_{\text{tot}}(p\bar{p})$ rises with energy in the ISR energy range, asymptotically approaching $\sigma_{\text{tot}}(pp)$ from above. The same data are replotted on Fig. 3 over a broader energy scale, including the point of UA4⁸⁾. In both figures, we show a simultaneous fit to the pp and the $p\bar{p}$ data of the form:

$$\begin{aligned}\sigma_{\text{tot}}(pp) &= \sigma_0 + \gamma_+ \ln^2(s/s_+) \\ \sigma_{\text{tot}}(p\bar{p}) &= \sigma_{\text{tot}}(pp) + \beta_R s^{\alpha-1}.\end{aligned}$$

The results of the fit are presented in Table 1 (Fit A).

The difference in the $p\bar{p}$ and pp cross-sections is shown in Fig. 4 including data down to very low energies and measurements of the annihilation cross-section.

Table 1

Results of fits to $\sigma_{\text{tot}}(p\bar{p})$ and $\sigma_{\text{tot}}(pp)$

	χ^2/DOF	σ_0	γ_+	s_+	β	α	γ_-	s_-
FIT A	1.44	38.3 ± 0.02	0.50 ± 0.02	117 ± 3.0	78.3 ± 6.0	0.425 ± 0.02	-	-
FIT B	1.33	38.3 ± 0.02	0.49 ± 0.02	115 ± 3.0	80.1 ± 6.0	0.42 ± 0.02	$(-1.0 \pm 0.3) \times 10^{-3}$	0.01 ± 0.1

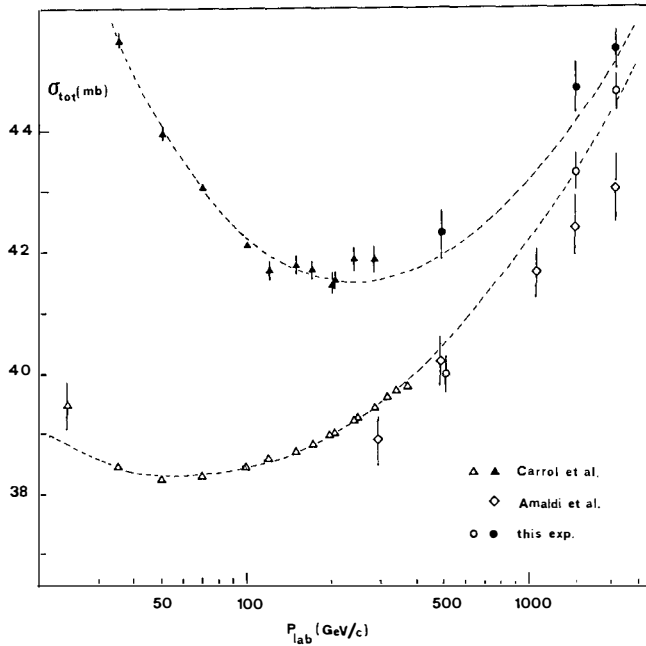


Fig. 2 The energy dependence of $\sigma_{\text{tot}}(p\bar{p})$ and $\sigma_{\text{tot}}(pp)$. The dashed lines are the fit to the data discussed in the text.

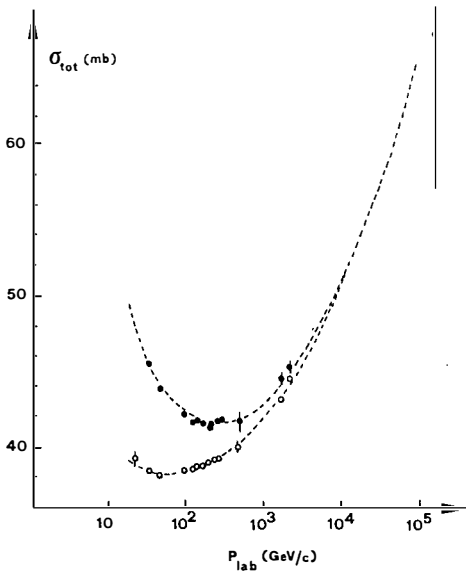


Fig. 3 The high-energy behaviour of $\sigma_{\text{tot}}(p\bar{p})$ and $\sigma_{\text{tot}}(pp)$.

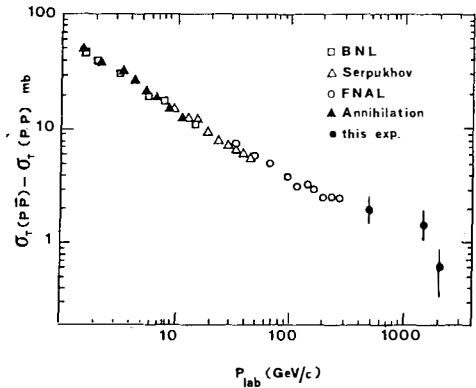


Fig. 4 The energy dependence of the difference in the $p\bar{p}$ and pp total cross-sections.

The new data, in good agreement with extrapolation from lower energy, show that the two cross-sections converge in a way compatible with the power law expected in Regge theory. This convergence is not demanded *a priori* by any theoretical constraint. The Pomeranchuk theorem, for instance, states that for asymptotically rising cross-sections, the ratio $\sigma_{\text{tot}}(p\bar{p})/\sigma_{\text{tot}}(pp)$ tends toward unity, but still allows the difference, in absolute value, to increase with the energy. Models along these lines have been developed, introducing "odderon" terms, i.e. asymptotic terms odd under crossing^{9,10}). We have analysed the data including in the previous fit an "odderon" term⁹):

$$\sigma_{\text{tot}}(pp) = \sigma_0 + \gamma_+ \ln^2(s/s_+) + \gamma \ln(s/s_-)$$

$$\sigma_{\text{tot}}(p\bar{p}) = \sigma_{\text{tot}}(pp) + \beta_R s^{\alpha-1} - \gamma_- \ln(s/s_-) .$$

To constrain better the fit, FNAL and ISR data on ρ (the ratio of the real to imaginary part of the forward nuclear elastic scattering amplitude) both for pp and $p\bar{p}$ scattering were taken into account, by exploiting dispersion relations¹¹). Preliminary results are reported in Table 1 (Fit B). The two fits virtually coincide, leading to the conclusion that any "odderon" contribution to the cross-section is less than 1% of the Regge term, up to ISR energies.

A final comment is needed on the differences amongst the values of $\sigma_{\text{tot}}(pp)$ as measured by this experiment and by previous ISR experiments^{2,4,12-14}). Figure 5 shows a compilation of all existing results. Some of the experiments^{2,12}) performed

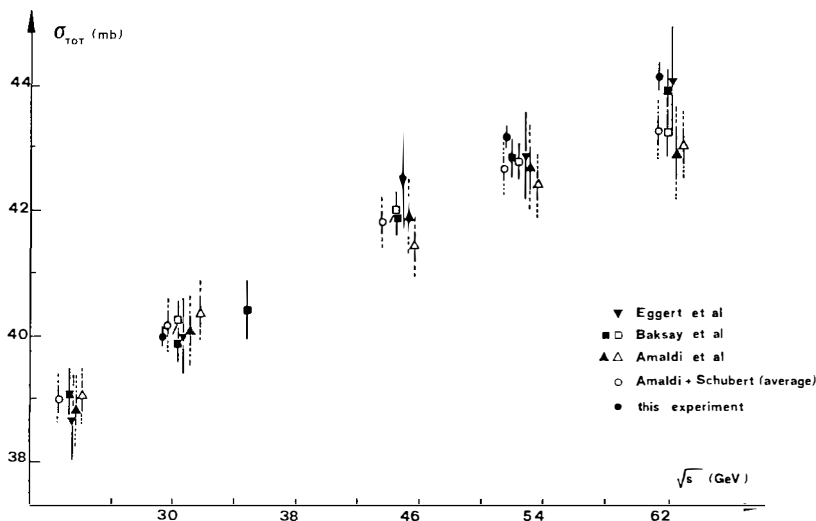


Fig. 5 Compilation of all available data on $\sigma_{\text{tot}}(pp)$ at the ISR. The open points are obtained with the optical-theorem method, the full points are obtained with the total-rate method. The dashed part of the error bars are scale errors.

the measurement of $\sigma_{\text{tot}}(\text{pp})$ both by the total-rate method and by the optical-theorem method (extrapolating the nuclear elastic scattering cross-section to $t = 0$ and invoking the optical theorem). In Fig. 5, no inconsistency appears in the data, at a one-standard-deviation level. However, a careful investigation shows that at $\sqrt{s} = 63$ GeV, the results obtained by the optical-theorem method are systematically lower than those found by the total-rate method. Since the former have a higher statistical weight, they pull down the "best average"¹⁴⁾ cross-section, which is then statistically inconsistent with our point. To make the argument more explicit, we have plotted in Fig. 6 the difference in $\sigma_{\text{tot}}(\text{pp})$ as measured in two experiments^{2,12)} by the two methods: $\Delta\sigma = \sigma_{\text{pp}}(\text{tot. rate}) - \sigma_{\text{pp}}(\text{opt. theor.})$. Some energy dependence may be present in these data at the limit of statistical significance: three negative points below $\sqrt{s} = 40$ GeV and four positive and two negative above. This suggests that the two methods might systematically disagree -- at a 1% level -- at the top ISR energy.

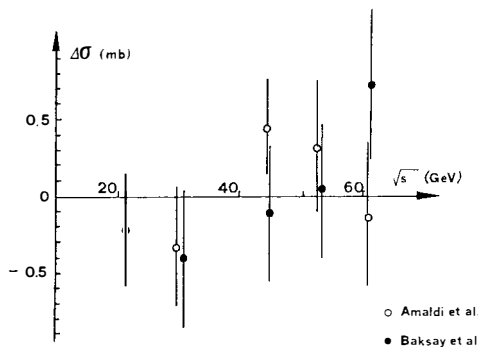


Fig. 6 Difference in the pp total cross-section as measured via total-rate and optical-theorem methods.

It is very important to resolve this question and, in particular, to place on solid grounds the value of $\sigma_{\text{tot}}(\text{pp})$ at $\sqrt{s} = 63$ GeV. For this reason, we plan to remeasure, in the forthcoming months, the pp total cross-section with high precision (better than $\pm 0.5\%$). Both the total-rate and the optical-theorem methods will be employed, with the aim of resolving the present inconsistencies by cross-checking the results.

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