

Measurement of the proton-antiproton total cross section at the S \bar{p} pS collider by a luminosity dependent method

UA4/2 Collaboration

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Abstract

The proton-antiproton total cross section was measured at the center-of-mass energy of $\sqrt{s} = 541$ GeV at the S \bar{p} pS at CERN using a luminosity dependent method. The result $\sigma_{tot} = 63.0 \pm 2.1$ mb is in agreement with the luminosity independent measurement performed earlier by the UA4 collaboration.

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The $p\bar{p}$ total cross section was measured years ago at the CERN SPS Collider ($\sqrt{s} = 546$ GeV) by the UA4 collaboration [1] using the luminosity independent method. The result was $(1 + \rho^2)\sigma_{tot} = 63.3 \pm 1.5$ mb. In the luminosity independent method, σ_{tot} comes out to be proportional to the differential elastic rate dN/dt extrapolated to the forward direction. In this paper, we present a new result on σ_{tot} derived from a measurement of the machine luminosity. In this case σ_{tot} is found to be proportional to the square root of dN/dt at $t = 0$. Systematic effects due to the extrapolation are therefore reduced.

1. The experimental method

The total cross section is related, via the optical theorem, to the forward differential nuclear elastic rate by

$$\sigma_{tot}^2 = \frac{16\pi (\hbar c)^2}{1 + \rho^2} \frac{1}{L} \left. \frac{dN_{el}}{dt} \right|_{t=0} \quad (1)$$

where $\rho = 0.135 \pm 0.015$ [2] is the ratio of the real to the imaginary parts of the elastic scattering amplitude. The differential elastic rate at the optical point $dN_{el}/dt|_{t=0}$ is obtained from the extrapolation of the elastic differential distribution measured by our collaboration at $\sqrt{s} = 541$ GeV and previously reported [2]. The ratio L' between the instantaneous machine luminosity and the inelastic rate in luminosity counters placed around the interaction point was measured at different time intervals. The luminosity L is obtained by integrating the ratio L' over the inelastic counts for the considered period of data taking.

2. The luminosity measurement

The machine luminosity is obtained using the standard expression:

$$L = \sum_i L_i = \sum_i \frac{f_0}{2\pi} \frac{N_{p_i} N_{\bar{p}_i}}{\sqrt{\sigma_{V_{p_i}}^2 + \sigma_{V_{\bar{p}_i}}^2} \sqrt{\sigma_{H_{p_i}}^2 + \sigma_{H_{\bar{p}_i}}^2}} \quad (2)$$

where ($i = 1, 2, 3$) corresponds to the three bunch crossings, $f_0 = 43375$ Hz is the revolution frequency of the S \bar{p} pS Collider, N_{p_i} and $N_{\bar{p}_i}$ are the number of particles and sigmas characterize the vertical and horizontal profiles for each individual proton and antiproton bunches.

A precise measurement of the horizontal and vertical beam profiles and positions for each of 3 p and 3 \bar{p} bunches was obtained by a wire scan system [3] placed at the crossing point. Two data sets were recorded for each bunch corresponding to the two traversals in opposite directions of the wire through the beam. The resulting profiles have gaussian shape (Fig. 1). The r.m.s. for the horizontal plane σ_H obtained by gaussian fit of the beam profile varies from 4.5 ± 0.08 mm to 6.9 ± 0.08 mm for the different data samples, In the vertical plane, σ_V varies from 0.90 ± 0.03 mm to 1.31 ± 0.03 mm.

The number of particles in each bunch was measured by synchronous RF receivers [4] placed at various places around the accelerator. The absolute calibration is known to within $\pm 3\%$.

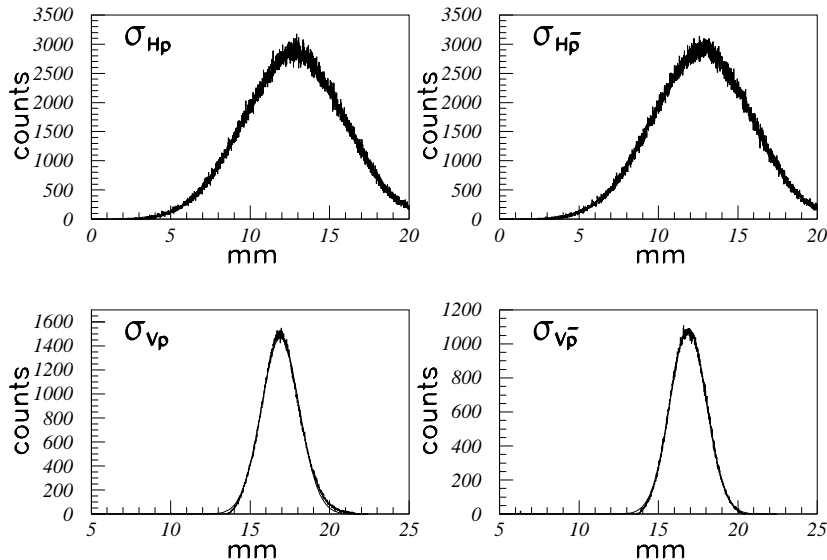


Figure 1: *Beam profile from the wire scan measurements.*

The luminosity monitoring system is composed of four hodoscopes LA1, LA2, LP1, LP2 as shown in Fig. 2. They are symmetrically placed on both sides of the interaction point at distances of 10.2 m (LA1,LP1) and 15.2m (LA2,LP2). The number of inelastic interactions is related to the number of coincidences in all four hodoscopes (LA1×LA2×LP1×LP2). This configuration allow us to monitor, as a function of time, the inelastic counting rate in a limited kinematic region $4.6 \lesssim \eta \lesssim 5.5$. Measurements done in a test beam showed an efficiency higher than 99.7% for each hodoscope for minimum ionizing particles.

The background of random coincidences associated to the observed inelastic rate was measured by monitoring the delayed coincidences of LA1×LA2 with respect to LP1×LP2. This background was found to be $\sim 3\%$ in average and subtracted.

The ratio L' was calculated for each of the 12 wire scan measurements spread through all data taking period. Its mean value is

$$L' = 99 \pm 6 \text{ barn}^{-1}/\text{inelastic count} \quad (3)$$

3. The forward extrapolated rate

The differential elastic distributions taken to evaluate the elastic rate at the optical point are those obtained in the measurement of the real part of the scattering amplitude and already presented in ref.[2]. It is worth recalling that these distributions were obtained from the elastic events collected in thirteen independent runs of the SppS Collider.

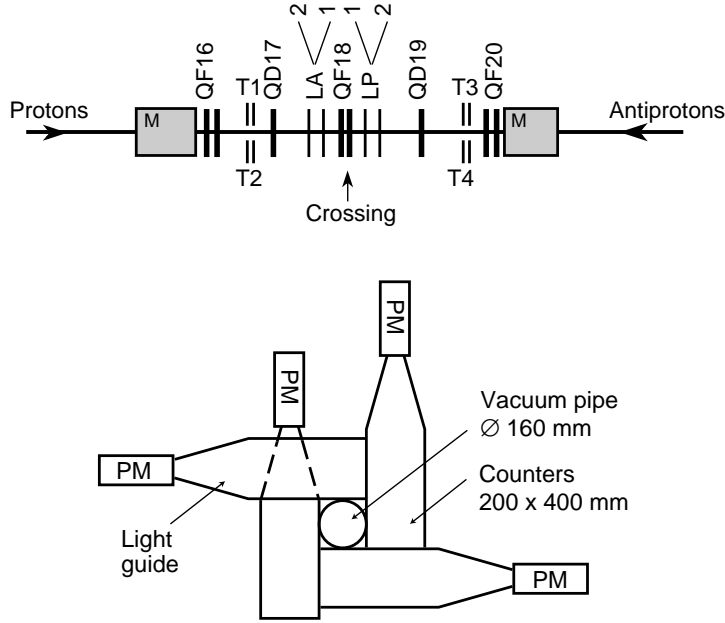


Figure 2: *The luminosity monitor of UA4/2 experiment. T1 to T4 are the elastic scattering detectors.*

Data inside the interval $3 \times 10^{-3} < |t| < 0.12 \text{ GeV}^2$, where strong interaction gives the most important contribution, were fitted by a maximum likelihood method, representing the differential cross section with the standard expression used in ref. [2]. The extrapolated forward rate was found to be independent (within 0.1%) of the selected lower limit of the t interval and for our thirteen runs it is determined with an average statistical error of 0.3%.

For the same t interval we investigated the possible presence of a quadratic term inside the exponential fall off of the strong interaction $e^{-B|t| + Ct^2}$. The fit gave a C value compatible with zero, while the forward rate value was found to be on the average $(0.3 \pm 0.3)\%$ higher than the one obtained in the "linear" fit case.

The observed forward rate was corrected for the following losses at data taking and analysis stage (for details about the selection procedure and the detectors, please refer to [2] and [5]):

- events with additional hits in the opposite "Roman pot" combination or in one of the luminosity counters are rejected at the trigger stage. The relative amount was estimated by removing the vetoing conditions in part of the data sample. The loss, evaluated with a relatively high uncertainty, amounts to $(4 \pm 2)\%$.
- the selection criteria reject also part of the events where one of the scattered particle was interacting in the detectors. This loss was estimated by studying the reconstructed rates in both telescopes and in the two "Roman pots" of each telescope. A global loss of 6.2% was

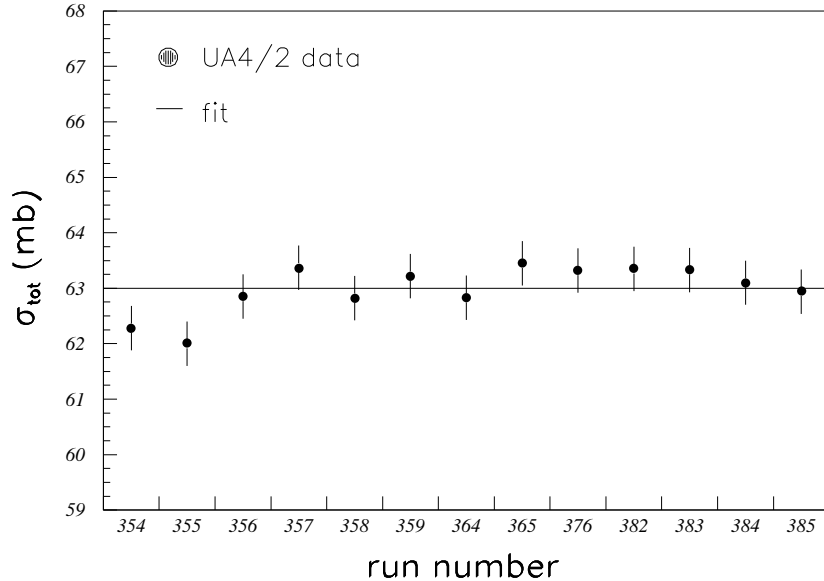


Figure 3: Measured σ_{tot} values for each of our 13 runs. The quoted errors are statistical only

estimated.

- the inefficiency of 1.0% of the drift chambers due to high voltage trip off was estimated by recording the rates as a function of a time.
- the data were also corrected for a 0.6% loss due to the collinearity cuts between the two scattered protons and antiprotons.

The total cross section value is proportional to the square root of the forward extrapolated rate, thus the global correction factor CF to be applied to σ_{tot} is 1.06 ± 0.015 .

4. Total cross section

After evaluation of both integrated luminosity and forward elastic rate, the total cross section values are extracted from Eq. (1) for each of our thirteen data taking runs. The time stability is demonstrated in Fig. 3 where the total cross section values with their statistical errors are shown. As a final result for our luminosity dependent total cross section measurement, we get

$$\sigma_{tot} = 63.0 \pm 2.1 \text{ mb} \quad (4)$$

The quoted error is mostly dominated by the uncertainty on the intensity in each particle bunch. The very accurate S \bar{p} pS beam momentum measurement [6] gives rise to a negligible contribution of the beam momentum uncertainty in the final total cross section error. Total cross section values computed by allowing ρ to vary by one standard deviation were used in order to extract the existing correlation between σ_{tot} and ρ . The resulting

value is $\delta\sigma/\delta\rho = -3.48$ mb. In varying the nuclear slope B , a similar procedure was performed in order to extract the correlation between total cross section and B . Its value is $\delta\sigma/\delta B = 1.35$ mb GeV².

By integrating the elastic rate over t in Eq. (1), the ratio between the elastic and total cross section can also be obtained:

$$\sigma_{el}/\sigma_{tot} = 0.208 \pm 0.007 \quad (5)$$

The extrapolations outside the presently measured t -interval were performed assuming a constant diffractive slope up to $t=0$ and the contribution from higher t 's using the measured shape in [7].

Conclusion

Despite the relatively high value of the systematic error caused by the dominating uncertainty on the absolute intensity of bunches, the precision on the present luminosity dependent measurement is comparable to that one obtained with different methods. The present value agrees with the luminosity independent result obtained by the UA4 collaboration [1] and the preliminary value of the CDF collaboration [8] at 546 GeV center-of-mass energy.

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