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COMPARISON OF INCLUSIVE DISTRIBUTIONS IN pp AND $\bar{p}p$ INTERACTIONS

AT $\sqrt{s} = 53$ GeV

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ABSTRACT

Measurements are presented of inclusive distributions in pp and $\bar{p}p$ interactions at $\sqrt{s} = 53$ GeV. The data were obtained at the CERN ISR using the Split Field Magnet spectrometer with a minimum bias trigger. The inclusive distributions are analyzed as functions of the transverse momentum, the rapidity and the Feynman- x variable.

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Inclusive distributions in proton-proton interactions have been extensively studied in pp collisions at the CERN ISR [1]. The recent storage of antiprotons has made it possible to perform such studies also in $\bar{p}p$ interactions. Preliminary results have been presented at the Volendam and Santiago meetings [2,3].

In this letter we present a comparison of the inclusive distributions measured at the CERN ISR in pp and $\bar{p}p$ interactions at a c.m. energy $\sqrt{s} = 53$ GeV. The data are analyzed as functions of the transverse momentum, p_t , of the rapidity, y , and of the Feynman x variable. Multiplicity distributions for the central region are also given.

In the $\bar{p}p$ runs at the ISR at $\sqrt{s} = 53$ GeV the stored antiproton current was about 2 mA and the proton current was 10.5 A, resulting in a luminosity of approximately $7 \times 10^{26} \text{ cm}^{-2} \text{ s}^{-1}$. The pp runs were performed at a luminosity of about $7 \times 10^{29} \text{ cm}^{-2} \text{ s}^{-1}$.

Data were taken with the Split Field Magnet (SFM) spectrometer [4] and analysed with the SFM off-line program chain. The detector was used with a minimum bias trigger, which required at least one charged track candidate in the spectrometer. This trigger accepted about 95% of the inelastic cross section. For the $\bar{p}p$ data, only 2-3% of the triggers correspond to good events. This is due to the large background from beam-gas interactions present in runs with relatively low luminosities. In both pp and $\bar{p}p$ data the beam-gas background is eliminated after event reconstruction by requiring that the event vertex lie inside the known overlap region of the beams.

For the present analysis 12200 pp and 10000 $\bar{p}p$ minimum bias events were used. Each of these events was required to have a good vertex fit. The tracks belonging to identified V^0 particles (K_s^0 , Λ^0) were removed on the basis of the analysis performed in ref. [5]. The contamination of electrons from π^0 decay and subsequent γ conversions was estimated to be about 2% and was neglected. Tracks from the interaction vertex were used for the present study only if the relative error in their momentum determination was smaller than 30%. This insured that charge and momentum were correctly determined for each track.

The most important correction arises from the geometrical efficiency of the detector. In order to determine this efficiency, single tracks were generated with a Monte-Carlo program for all relevant values of y , p_t and azimuthal angle ϕ . The generated tracks were followed through the detector and hits in the proportional wire chambers were determined. These hits were then considered as the input for track reconstruction, using the same computer program employed for real events. For each bin in y , p_t and ϕ the ratio of events found to the events generated gives the efficiency for that particular y , p_t , ϕ combination. More than 120,000 Monte-Carlo tracks were generated for pp collisions and 50,000 for $\bar{p}p$ collisions for each charge configuration. The efficiencies were usually determined in bins of 18° in ϕ , 0.1 GeV/c in p_t and 0.5 units of rapidity. Data corrected for these inefficiencies are presented for the y and p_t distributions. The average correction factor was 1.3. Raw data are given for the x and multiplicity distributions.

The p_t dependence

In fig. 1 the quantity

$$f = \frac{1}{N_{in}} \frac{1}{2\pi p_t} \frac{\Delta N}{\Delta y \Delta p_t} = \frac{1}{\sigma_{in}} E \frac{d^3\sigma}{dp^3} \quad (1)$$

is plotted versus p_t for the central production ($|y| < 2$) of positive and negative particles in (a) $\bar{p}p$ and (b) pp interactions. N_{in} is the total number of inelastic events, while $(\Delta N/\Delta y \Delta p_t)$ is the number of tracks per unit rapidity and unit transverse momentum. It should be remembered that the positive particles are mostly π^+ , with some contamination of K^+ and p , while the negative particles are mostly π^- with some K^- and $\bar{p}$ contamination.

In $\bar{p}p$ interactions the p_t spectra of positive and negative particles are found to be equal within the experimental errors. At present this equality can be considered to represent only a qualitative test of the symmetry of the apparatus and of the acceptance corrections.

For pp interactions the data relative to the production of positive and negative particles at $y \approx 0$ are slightly different, with the data for negative particles having a larger slope. This has been known from

previous measurements [1,6-8]. Positive tracks contain a proton component of about 10%, while the antiproton component in the negative tracks is negligible ($\sim 0.1\%$).

The p_t dependence of the invariant cross section in the range $0.15 \text{ GeV}/c < p_t < 1.05 \text{ GeV}/c$ is essentially exponential:

$$f = A e^{-bp_t} \quad (2)$$

Deviations from an exponential start at larger values of p_t than accessible with the present statistics. Table 1 gives the results of fits of the data to the exponential form (2).

For an exponential form the average transverse momentum is related to the inverse of the slope. Under the assumption of factorization in y and p_t of the invariant cross section, one has: $\langle p_t \rangle = 2/b$, and this quantity is also given in table 1. The slopes found for pp interactions are in agreement with the values previously measured [6-8].

The rapidity dependence

Fig. 2 shows the rapidity distributions for the production of positive and negative particles in pp and $\bar{p}p$ collisions at $\sqrt{s} = 53 \text{ GeV}$. The pion mass was used to calculate the rapidity. This distorts somewhat the distribution for $|y| > 3.5$, but it does not affect the comparison of pp and $\bar{p}p$ interactions.

For pp, both the shape and the absolute value agree with previous measurements [7-9].

The shape of the rapidity distributions, with the approximate plateau for y around zero, is due to a complex mixture of contributions from particles coming from events of different multiplicities. Specifically, those events with small multiplicities tend to give diffractive-type distributions, while large multiplicities tend to produce a peaking near $y = 0$.

The absolute height of the central plateau integrated over p_t is of interest for the study of the energy dependence and for the comparison of pp data with $\bar{p}p$ data. We find that

$$\text{for } pp \quad \rho_{y=0} = \frac{1}{N_{inel}} \left(\frac{dN}{dy} \right)_{y=0} = 2.5 \pm 0.2, \quad \text{and} \quad (3)$$

$$\text{for } \bar{p}p \quad \rho_{y=0} = \frac{1}{N_{inel}} \left(\frac{dN}{dy} \right)_{y=0} = 2.7 \pm 0.3 \quad (4)$$

charged particles per unit of rapidity. In terms of pseudorapidity the values are about 20% lower.

Within the limits of the present statistics we find no difference between the rapidity distributions in pp and $\bar{p}p$ interactions apart from the obvious differences due to the difference in charge and baryon number [10-12].

The x-dependence

Some of the main qualitative features of particle production at high energies are readily observed in the x distributions for the production of positive and negative particles in $\bar{p}p$ collisions. Uncorrected raw data are shown in fig. 3, with elastic events removed. For $x > 0$, the distribution for positive particles contains two components: fragmentation products ($x \geq 0.3$) and centrally produced particles ($x < 0.3$). The distribution for negative particles on the other hand, has only one component which is typical of centrally produced particles, i.e. with a large concentration at $x = 0$ and rapid fall off at larger x , and with very few particles for $x > 0.3$. In the region for $x < 0$ the negative particles are leading, following the charge of the incident antiproton, while positive particles are the produced ones. For pp collisions the situation is symmetric around $x = 0$, and the distributions show leading effects for the positive particles.

The energy dependence

The comparison of the normalized cross section at $y = 0$ measured in this experiment with similar data at lower and higher energies indicates a typical $\ln s$ dependence. Within the experimental errors there are no differences between $\bar{p}p$ and pp collisions for c.m. energies larger than 20 GeV. The multiplicity per unit pseudorapidity, computed at $\eta = 0$, rises from (2.0 ± 0.2) at $\sqrt{s} = 30$ GeV to (3.1 ± 0.3) at $\sqrt{s} = 540$ GeV [13-16].

Multiplicity distribution

The multiplicity distribution for charged particles in high energy interactions contains information on the properties of the collision mechanism. For example, the energy dependence of the average multiplicity reflects the scaling properties of the collision dynamics, while the deviation of the distribution from a Poisson law reveals correlations between the produced particles.

Fig. 4 shows the charged multiplicity distribution in the Koba-Nielsen-Olesen (KNO) form, i.e. $P_n = \langle n \rangle \sigma_n / \sigma_{in}$ is plotted versus $z = n/\langle n \rangle$, for particles in the pseudo-rapidity range $|\eta| < 1.3$. It is seen that our pp and $\bar{p}p$ data follow the same pattern. The dashed line represents a fit performed at $\sqrt{s} = 540$ GeV to the pp data in the same η -interval [14]. Thus KNO scaling seems to apply up to $\sqrt{s} = 540$ GeV, at least in the limited η region considered.

In conclusion, the successful operation of the ISR with antiprotons has allowed us to study the inclusive distributions in $\bar{p}p$ collisions at $\sqrt{s} = 53$ GeV. We find all the typical features of $\ln s$ physics. The comparison of the spectra from pp and $\bar{p}p$ collisions at the same energy does not show any appreciable difference apart from the obvious differences due to electric charge and baryon number. The multiplicity of charged particles produced in the central region at $\sqrt{s} = 53$ GeV is about 50% lower than that observed at $\sqrt{s} = 540$ GeV [13].

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TABLE 1

Results of the fits to eq. (2) of the inclusive p_t distributions in the range 0.15 GeV/c to 1.05 GeV/c, and for $|y| < 2$. Quoted errors for b represent statistical errors only; the systematic as well as statistical uncertainty is quoted for A

	A	b (GeV/c) ⁻¹	$\frac{\chi^2}{\text{DoF}}$	$\langle p_t \rangle$ (GeV/c)
$\bar{p}p \rightarrow -$	5.7 ± 0.5	5.79 ± 0.10	1.5	0.345 ± 0.006
$\bar{p}p \rightarrow +$	5.7 ± 0.5	5.75 ± 0.10	1.2	0.348 ± 0.006
$pp \rightarrow -$	5.2 ± 0.3	5.84 ± 0.10	0.7	0.342 ± 0.006
$pp \rightarrow +$	4.7 ± 0.3	5.44 ± 0.09	0.9	0.368 ± 0.006

FIGURE CAPTIONS

- Fig. 1 p_t distributions for the production of positive and negative particles in (a) $\bar{p}p$ and (b) pp collisions at $\sqrt{s} = 53$ GeV.
- Fig. 2 Rapidity distributions for positive and negative particles produced inclusively in (a) $\bar{p}p$ and (b) pp interactions at $\sqrt{s} = 53$ GeV.
- Fig. 3 x -distributions of positive and negative particles produced in $\bar{p}p$ interactions at $\sqrt{s} = 53$ GeV. Only raw data with elastic events removed are presented. The slight differences between leading particles for $x > 0$ and $x < 0$ is due to the acceptance. The lines are only meant to guide the eye.
- Fig. 4 The observed charged multiplicity distributions in pp and $\bar{p}p$ collisions for $|\eta| < 1.3$ expressed in the KNO scaling form. The dashed line is a fit to the experimental data at $\sqrt{s} = 540$ GeV.

Fig. 1

Fig. 2

Fig. 3

Fig. 4