A COMPARISON OF $\bar{p}p$ AND pp INTERACTIONS
IN THE CENTRAL REGION AT $\sqrt{s} = 53$ GeV

T. Åkesson⁴, M.G. Albrow⁵, S. Almedh⁴, O. Benary⁶, H. Bøggild³, O. Botner²,
V. Burkert², A. di Ciaccio¹, D. Cockerill^{2,5}, S. Dagan⁶, E. Dahl-Jensen³,
I. Dahl-Jensen³, P. Dam³, G. Damgaard³, W.M. Evans^{2,5}, C.W. Fabjan², T. Ferbel²,
P. Frandsen², M.D. Gibson⁵, H. Gordon¹, A. Hallgren², K.H. Hansen³, B. Heck²,
S. Henning⁴, J.H. Hiddleston⁵, H.J. Hilke², R. Hogue¹, J.E. Hooper³, G. Jarlskog⁴,
P. Jeffreys², G. Kessler², T. Killian¹, J. v.d. Lans², J. Lindsay², D. Lissauer⁶,
E. Lohse³, B. Lörstad⁴, H.J. Lubatti², T. Ludlam¹, N.A. McCubbin⁵, A. Melin⁴,
U. Mjörnmark⁴, R. Möller³, W. Molzon², B.S. Nielsen², S.Ø. Nielsen³, A. Nilsson⁴,
L.H. Olsen³, Y. Oren⁶, L. Rosselet², E. Rosso², A. Rudge², R.H. Schindler²,
B. Schistad³, D.W. Wang^{*}, Ch.J. Wang^{*}, W.J. Willis², M. Winik¹,
W. Witzeling² and C. Woody¹

The Axial Field Spectrometer Collaboration

- 1) Brookhaven National Laboratory, USA
- 2) CERN, Geneva, Switzerland
- 3) Niels Bohr Institute, Copenhagen, Denmark
- 4) University of Lund, Sweden
- 5) Rutherford Appleton Laboratory, UK
- 6) University of Tel Aviv, Israel
- *) CERN: Visitor from Peking University, China

(Submitted to Physics Letters)

ABSTRACT

The inclusive production cross-sections of pions, kaons, protons, and antiprotons in $\bar{p}p$ and pp interactions at $\sqrt{s} = 53$ GeV are compared in the kinematic range $|y| < 0.8$ and $p_T < 1.5$ GeV/c.

We observe differences in the K^+/K^- and $\bar{p}/p$ ratios for the two data samples.

Although the bulk of the particles are produced with the same transverse momentum and rapidity distributions in $\bar{p}p$ and pp collisions, we observe differences in these distributions for produced protons and antiprotons.

This experiment was performed at the CERN Intersecting Storage Rings (ISR) using the Axial Field Spectrometer [1,2]. For the data reported here, the momentum measurements were made in a cylindrical drift chamber with multiple ionization sampling (dE/dx), which is used for particle identification. Good $\pi^\pm$, $K^\pm$, and $\bar{p}p$ discrimination is obtained for non-relativistic particles. Protons and antiprotons are identified in the range $200 < p_{lab} < 800$ MeV/c, and $K^\pm$ mesons in the range $100 < p_{lab} < 500$ MeV/c [2].

The vertex detector is a 1.4 m long drift chamber of the "bicycle wheel" configuration with 4° azimuthal segmentation. Each 4° sector contains 42 resistive sense wires that provide the coordinates in the transverse plane from drift time, and the position along the sense wire from charge division measurement.

The resolution in the chamber is $\sigma = 230$ μ m (r.m.s.) in drift distance and $\sigma = 1.5$ cm (r.m.s.) in the axial coordinate. For dE/dx measurements, the truncated mean (for > 30 pulse-height measurements) for minimum ionizing tracks has $\sigma_{rms}/mean = 11\%$.

The data described here consist of 25,000 $\bar{p}p$ events and 36,000 pp events at $\sqrt{s} = 53$ GeV. Both samples were obtained in ISR runs with low luminosity, spaced closely in time, and analysed with the same set of analysis programs. The trigger used was a minimum bias trigger, defined by a coincidence between scintillation counters surrounding the two beam pipes downstream of the intersection region. This trigger is sensitive to approximately 60% of the inelastic interactions. Background from beam-gas and beam-pipe interactions was measured by running with only the proton beam present, and processing the events accepted by our trigger through the off-line analysis program. We conclude that for both data samples this background is less than 1%.

We have determined that our acceptance is essentially uniform in the rapidity region $|y| < 0.8$ and in 76% of our azimuthal coverage. Thus all distributions presented will be for this region. The uncertainty in absolute normalization is approximately 10%; however, most results are presented as ratios of $\bar{p}p$ cross-sections relative to pp cross-sections.

In Fig. 1, the p_T spectrum of charged secondaries obtained in this experiment for pp collisions is shown together with the spectrum observed at 90° in previous experiments [3-5]. The distributions agree well, given that both distributions have absolute normalization uncertainties of 10%. Figure 2a shows the p_T spectra for $\bar{p}p$ and pp collisions, and the ratio of the distributions in Fig. 2b shows that there are no significant differences in the p_T distribution of charged secondaries up to approximately 1.5 GeV/c. An exponential fit $\exp(-ap_T)$ to the p_T spectra ($0.3 < p_T < 1.5$ GeV/c) gives $a = 3.70 \pm 0.03$ (GeV/c) $^{-1}$ for $\bar{p}p$ collisions and $a = 3.63 \pm 0.02$ (GeV/c) $^{-1}$ for pp collisions.

The charged particle multiplicity distributions in our acceptance for $\bar{p}p$ and pp collisions are shown together in Fig. 3a, and their ratio in Fig. 3b. The average charged multiplicity per unit rapidity in the region $|y| < 0.8$, is $\langle n_{ch} \rangle_{pp} = 2.31 \pm 0.01$ and $\langle n_{ch} \rangle_{\bar{p}p} = 2.30 \pm 0.01$, and the shapes of the distributions are also consistent with being identical, although there may be a surplus of high multiplicity events in $\bar{p}p$ interactions. The curves on Fig. 3b show the expected behaviour if the difference in $\bar{p}p$ and pp cross-section ($\Delta\sigma$) results from a component with a higher central multiplicity parametrized by $\langle n_{ch} \rangle_{\bar{p}p,a} = \langle n_{ch} \rangle_{pp} + \epsilon$, where $\Delta\sigma$ is estimated to be 0.9 mb and KNO scaling is used to determine the distribution of this component.

The ratio of the average multiplicity per unit rapidity interval in $\bar{p}p$ and pp collisions is shown as a function of y in Fig. 4 for all charged particles and for positive and negative particles separately. There are significantly more negative particles in $\bar{p}p$ collisions (than in pp) and fewer positive particles, which is to be expected since in $\bar{p}p$ collisions the $+/-$ ratio must equal 1.0 at $y = 0$ (we observe 0.98 ± 0.01), whilst in pp interactions it exceeds 1.0 by a few percent (we observe 1.03 ± 0.01 , and refs. 3, 4, and 5 find 1.06 ± 0.01). However, no y -dependence is observed within our range $|y| < 0.8$. The values of these ratios averaged over the range $|y| < 0.8$ are summarized in Table 1, where the corresponding values for $K^+ + K^-$ and $p + \bar{p}$ are also presented.

In the pp sample we observe a K^+/K^- ratio of 1.24 ± 0.06 , in good agreement with a previous measurement [5], where the value obtained at 90° is 1.18 ± 0.06 .

In the $\bar{p}p$ sample the K^+/K^- ratio is found to be 1.04 ± 0.07 , close to the expected value of 1.

From Table 1 we see that the total kaon production is the same, within errors, in $\bar{p}p$ and pp interactions. However, we note that there are $8 \pm 6\%$ more K^- and $10 \pm 5\%$ fewer K^+ emitted into the region $|y| < 0.8$ from $\bar{p}p$ interactions. Within errors this difference is independent of rapidity and transverse momentum.

These observations are in good agreement with the expected difference in (K,Y) associated production and with no change in the $(K,\bar{K})$ pair production. The contribution to the kaon production in our region from (K,Y) associated production is $\sim 20\%$, as measured by the K^+/K^- ratio in pp interactions. From this one would expect $\sim 10\%$ more K^- and $\sim 10\%$ less K^+ in $\bar{p}p$ than in pp collisions.

For proton and antiproton production we also observe a difference between $\bar{p}p$ and pp interactions. In this instance there is an indication of a difference in the p_T and y dependence of the ratio, as can be seen in Fig. 5. The broken lines in Fig. 5b are the estimates of the expected y -dependence obtained from the measured $pp \rightarrow pX$ and $pp \rightarrow \bar{p}X$ cross-sections [5] at $p_T = 0.6$ GeV/c, which are shown schematically in Fig. 6, curves (a) and (b). The difference between (a) and (b) gives the sum of the beam fragmentation distributions (c), which can be decomposed into the symmetric curves d_L and d_R by assuming that the beam fragmentation extends to $|y| = 1$ in the backward hemisphere^{*)}. Then the assumption that pair production of protons and antiprotons is identical in pp and $\bar{p}p$ interactions and that the beam fragmentation $p \rightarrow p$ and $\bar{p} \rightarrow \bar{p}$ has the same y and p_T distributions allows one to calculate the ratio shown in Fig. 5b.

We conclude that within the statistical errors of our event sample, distributions in charged particle multiplicity, rapidity, and transverse momentum in $\bar{p}p$ and pp interactions at $\sqrt{s} = 53$ GeV, $|y| < 0.8$, and $p_T < 1.5$ GeV/c are similar except for such changes in charge and baryon number flow, which can be understood as being consequences of the change in quantum numbers of one of the colliding particles. In particular, we have not observed any increase of the pair production

*) Precise data would enable the beam fragmentation distributions [curves (d)] to be extracted directly from the data. It is already clear from the modest y -variation of the data that the beam fragmentation distributions must extend significantly (approximately 1 unit in y) into the backward hemisphere.

of $K^\pm$ or protons and antiprotons in $\bar{p}p$ interactions, since the total production of kaons ($K^+ + K^-$) and of protons and antiprotons ($\bar{p} + p$) is the same for the two data samples. The observations reported here do not of course exclude differences between $\bar{p}p$ and pp collisions in rare final states.

Acknowledgements

These results were made possible by the fine achievements of the CERN Proton Synchrotron and Intersecting Storage Rings Divisions and the Antiproton Accumulator Group, in successfully producing, cooling, accelerating, and storing antiprotons in the ISR. We acknowledge with thanks the work of the CERN Experimental Facilities Division on the drift chamber construction, and that of the Experimental Support Group of the ISR Division who installed the experiment. A large number of people have worked on the construction of the Axial Field Spectrometer and we would like to thank them all. Support from the Research Councils in our home countries is gratefully acknowledged.

REFERENCES

- [1] D. Cockerill et al., Nucl. Instrum. Methods 176 (1980) 159.
- [2] O. Botner et al., Performance of the AFS Vertex Detector at the CERN ISR, CERN-EF/81-6. To appear in the proceedings of the INS International Symposium on Nuclear Radiation Detectors, Tokyo, Japan, March 1981.
- [3] K. Guettler et al., Nucl. Phys. B116 (1976) 77.
- [4] K. Guettler et al., Phys. Lett. 64B (1976) 111.
- [5] B. Alper et al., Nucl. Phys. B100 (1975) 237.

Table 1

Ratio of
average charged particle multiplicity
for $|y| < 0.8$

	$\langle n \rangle_{\bar{p}p} / \langle n \rangle_{pp}$
All ($\pm$)	1.00 ± 0.01
+	0.96 ± 0.01
-	1.03 ± 0.01
$K^+ + K^-$	0.98 ± 0.04
K^+	0.90 ± 0.05
K^-	1.08 ± 0.06
$p + \bar{p}$	1.05 ± 0.04
p	0.93 ± 0.04
$\bar{p}$	1.25 ± 0.07

Figure captions

Fig. 1 : Comparison of $(1/\sigma_{in})(d\sigma/dydp_T)$ versus p_T obtained in this experiment ($|y| < 0.8$) with results of refs. 3, 4, and 5.

Fig. 2 : a) $(1/\sigma_{in})(d\sigma/dydp_T)$ versus p_T for $\bar{p}p$ and pp collisions in the region $|y| < 0.8$. In cases of overlap the points have been displaced equally sideways.

b) Ratios of average multiplicity per unit p_T versus p_T .

Fig. 3 : a) Charged particle multiplicity of $\bar{p}p$ and pp collisions in the region $|y| < 0.8$ and 76% of azimuth. In cases of overlap the points have been displaced equally sideways.

b) $(1/\sigma_{in})(d\sigma/dn_{ch})|_{\bar{p}p} / (1/\sigma_{in})(d\sigma/dn_{ch})|_{pp}$. The curves are estimates of the ratio assuming that the $\bar{p}p$ annihilation events have

$$\langle n_{ch} \rangle_{\bar{p}p} = \langle n_{ch} \rangle_{pp} + \epsilon \text{ (see text).}$$

Fig. 4 : Ratio of the average charged particle multiplicity per unit y versus y .

Fig. 5 : Comparison of proton and antiproton production. The curves in (b) are the expected $\bar{p}$ (---) and p (---) y -dependence obtained from the measured $pp \rightarrow pX$ and $pp \rightarrow \bar{p}X$ cross-sections (see text).

Fig. 6 : Cross-sections used in obtaining the broken lines shown in Fig. 5b.

Curve a: $pp \rightarrow pX$; curve b: $pp \rightarrow \bar{p}X$; curve c: the difference between distributions a and b, which is equal to the distribution of protons from the beam fragmentation; curves d_L and d_R are the decomposition of curve c into left-moving and right-moving beam fragmentation distributions, respectively.

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6