COMPARISON OF SHORT RANGE RAPIDITY CORRELATIONS
IN \( \bar{p}p \) AND \( pp \) INTERACTIONS AT \( \sqrt{s} = 53 \text{ GeV} \)

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ABSTRACT

Measurements are presented of two-particle rapidity correlations in \( \bar{p}p \)
and \( pp \) at \( \sqrt{s} = 53 \text{ GeV} \). The data were recorded at the CERN-ISR using the
Split Field Magnet spectrometer with a minimum bias trigger. Short range
correlations in normal inelastic events with measured charged multiplicities \( n_{\text{ch}} \geq 4 \) are observed for pairs of charged particles in all charge
combinations. Within the experimental errors no differences are observed
between the analogous correlations in \( pp \) and \( \bar{p}p \) interactions.

Submitted to Physics Letters B
One of the prominent features of multiparticle production in high energy interactions is the presence of two-particle short range correlations in rapidity. These correlations are usually interpreted in the framework of cluster models. Short range correlations of charged hadron pairs produced in proton-proton interactions have been extensively studied at the CERN-ISR [1-4]. The recent storage of antiprotons in the ISR has made it possible for the first time to perform such studies also with \( \bar{p}p \) events.

This letter presents results on short range, two-particle rapidity correlations in low transverse momentum \( \bar{p}p \) and pp interactions at \( \sqrt{s} = 53 \text{ GeV} \). The correlations studied involve pairs of charged particles in all charge combinations.

In the \( \bar{p}p \) runs the stored antiproton current was 2 mA, while the proton current was 10.5 A. This resulted in a luminosity of approximately \( 7 \times 10^{24} \text{ cm}^{-2}\text{s}^{-1} \). The pp runs were performed at a luminosity of \( 7 \times 10^{29} \text{ cm}^{-2}\text{s}^{-1} \).

Data were taken with the Split Field Magnet (SFM) spectrometer [5] and analysed with the SFM off-line program chain. The detector was used with a minimum bias trigger, which requires at least one charged track candidate in the spectrometer. This trigger accepts \( \approx 95\% \) of the inelastic cross section. For the pp data 90\% of the triggers are good events (beam-beam interactions), but for the \( \bar{p}p \) data only 2-3\% of the triggers are good events due to the large background (percentage wise) of beam-gas interactions present in runs with relatively low luminosities. In both cases the beam-gas background is eliminated after event reconstruction by requiring the vertex to lie inside the known overlap region of the beams.

For this analysis we considered 12,200 pp and 9,300 \( \bar{p}p \) minimum bias events. Each event was required to have a good vertex fit within the intersection region. The tracks belonging to identified \( V^0 \) particles (\( K^0_s, \Lambda^0 \)) were removed on the basis of the analysis performed in ref. [6]. The contamination of electrons from \( \pi^0 \) and \( \gamma \) conversions was estimated to be about 2\% [7] and was neglected. Vertex tracks were used for the correlation studies if the error in their curvatures was smaller than 100\%.
This insured that the charge was correctly determined for each track. No other corrections, such as for acceptance, were made. This is possible because the acceptance corrections essentially drop out from the correlation coefficients which we are studying; that is, the two-track acceptance is very close to the product of one-track acceptances. The residual acceptance term is negligible since, for this detector, the acceptance corrections represent a small effect.

For the reaction

\[ \bar{p}p + h_1 + h_2 + X \]  

(1)

where \( h_1 \), \( h_2 \) are observed charged hadrons, one defines the two-particle correlation function as

\[ R_2(y_1, y_2) = \frac{\rho_2(y_1, y_2)}{\rho_1(y_1) \rho_1(y_2)} - 1 \]  

(2)

\[ = \frac{(d^2\sigma/dy_1 dy_2)}{\sigma_{\text{in}} (d\sigma/dy_1)(d\sigma/dy_2)} \]  

(3)

where

\[ \rho_1(y) = \frac{1}{\sigma_{\text{in}}} \frac{d\sigma}{dy} \]  

(4)

is the single particle density distribution, and

\[ \rho_2(y_1, y_2) = \frac{1}{\sigma_{\text{in}}} \frac{d^2\sigma}{dy_1 dy_2} \]  

(5)

is the two-particle density distribution. \( \sigma_{\text{in}} \) is the inelastic cross section, and \( y_1 \) and \( y_2 \) are the rapidities of hadrons \( h_1 \) and \( h_2 \), respectively.

If hadrons \( h_1 \) and \( h_2 \) were emitted independently, \( \rho_2(y_1, y_2) \) would be the product of the two single particle distribution functions \( \rho_1(y_1) \rho_1(y_2) \), and \( R_2(y_1, y_2) \) would be zero. Values of \( R_2 \) different from zero indicate the existence of correlations between hadrons \( h_1 \) and \( h_2 \).

In practice we used the functions

\[ R_2(y_1, y_2) = N \frac{N_2(y_1, y_2)}{N_1(y_1) N_1(y_2)} - 1 \]  

(6)
where, in a sample of $N$ events, $N_t(y)$ tracks are observed at rapidity $y$
within $\Delta y$ and $N_t(y_1, y_2)$ pairs are observed at rapidities $y_1, y_2$
within $\Delta y_1, \Delta y_2$. Selection criteria, e.g. multiplicity, affect both $N_t$ and $N_t$.

The ability of the SFM detector to measure the momentum and charge of
each produced charged particle allows us to study the correlations $R^{-+}$,
$R^{++}$ and $R^{--}$, in addition to $R^{CC}$. The superscripts on $R$ give the
charges of hadrons $h_1$ and $h_2$. $R^{CC}$ is the correlation function for all
charged-charged pairs.

Fig. 1 shows the correlation function $R^{CC}(y_1, y_2)$ versus $y_1$ for four
different values of $y_2$ ($y_2 = -1, 0, +1$ and $+2$). The figure contains
data for both pp (black points) and $\bar{p}p$ (open circles) interactions with
observed charged particle multiplicities $n_{ch} \geq 8$. The maxima at $y_1 = y_3$ are
evidence for short range correlations between charged pairs of hadrons.
The dashed curved in fig. 1(d) indicates qualitatively the symmetric
correlation trend observed for $y_2 = -2$.

The pp correlation data of fig. 1 are in good agreement with those of
previous ISR experiments [1,2]. We conclude from fig. 1 that there are no
differences between the correlation functions for pp and $\bar{p}p$ events.

In fig. 2 are shown the correlation data at $y_2 = 0$ for the production
of pairs of charged hadrons for all charge combinations. As in fig. 1 the
data are for both pp and $\bar{p}p$ interactions with observed charged hadron
multiplicities $n_{ch} \geq 8$. For all combinations there is a peak at $y_1 = 0$.
The maximum value of the correlation function is different for the
different charge combinations: it is largest for $R^{--}$ and smallest for
$R^{++}$ and $R^{--}$. Within errors we find $R^{++} = R^{--}$ and no differences
between pp and $\bar{p}p$ interactions.

Fig. 3 shows $R^{CC}$, $R^{+}$, $R^{++}$ and $R^{--}$ for $y_3 = 0$ and for observed
charged hadron multiplicities $n_{ch} \geq 4$. One finds the same trends observed
in fig. 2, but the maximum values of the corresponding correlation
functions are considerably larger. Such a decrease in the maximum for
higher multiplicities has been seen previously in other experiments, for
ever example, see ref. [8].
Even though the distributions are not shown for lack of space we observe that the maximum values of $R_2^{++}$ and $R_2^{--}$ decrease significantly for $|y_2| > 2$ while the maximum value of $R_2^{+-}$ remains approximately constant.

Our results on $R_2^{+-}$, $R_2^{++}$, and $R_2^{--}$ in pp interactions can be compared with results from bubble chamber experiments at lower energies [3,9] and from a previous ISR experiment [2]. The trends are all the same within errors, thus excluding any strong energy dependence between $\sqrt{s} = 13.8$ GeV and ISR energies.

These correlation data in the central region can be described in the framework of a model which incorporates independent emission of charged clusters. In this model one cluster with an average mass of about 1.3 GeV is produced per unit of rapidity and, on the average, each cluster decays into 1.8 charged particles [2]. The evidence for correlations between like charges (figs 2 and 3) indicates that either doubly charged clusters or clusters of more than two charged particles are formed.

In conclusion, the successful operation of the ISR with antiprotons has allowed us to study short range correlations in pp interactions with observed charged multiplicities $n_{ch} > 4$. We find in $\bar{p}p$ clear evidence for strong short range correlations, which are equal to those found in pp interactions. The analysis of the correlation coefficients $R_2^{++}$, $R_2^{+-}$, $R_2^{++}$ and $R_2^{--}$ indicates that $R_2^{--}$ is larger than $R_2^{++} = R_2^{--}$ in both pp and $\bar{p}p$ interactions. The correlation coefficients for pp interactions are essentially energy independent.

Acknowledgements

We are especially grateful for the support provided by the SFM detector group and the ISR Experimental Support group. We would also like to thank R. Messerli, U. Schlüpmann and G.P. Siroli for their assistance. The Ames group was supported by the Department of Energy under contract W-7405-eng-82. The Dortmund and the Heidelberg groups were supported by a grant from the Bundesministerium für Wissenschaft und Forschung of the Federal Republic of Germany.
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FIGURE CAPTIONS

Fig. 1  The correlation function $R_2(y_1, y_2)$ for charged hadron pairs as a function of $y_1$ for different values of $y_2$ ($y_2 = -1, 0, +1, +2$). The pp(\overline{p}p) data are plotted with black points (open circles). The data are for $\sqrt{s} = 53$ GeV and $n_{ch} \geq 8$. The value and bin size (0.5) of $y_2$ is indicated in each graph. The dashed line in the graph for $y_2 = +2$ indicates the trend of $R_2(y_1, y_2 = -2)$. For clarity, error bars are included for only a few representative points.

Fig. 2  The correlation function $R_2(y_1, y_2 = 0)$ for the production of $\pi^+, \pi^-, \pi^0$ and charged-charged hadron pairs in pp and \overline{p}p collisions at $\sqrt{s} = 53$ GeV with $n_{ch} \geq 8$. The value and bin size (0.5) of $y_2$ is indicated in each graph. The data are plotted in the same way as in fig. 1.

Fig. 3  The same as in fig. 2, but with $n_{ch} \geq 4$. 