TWO-BODY CORRELATIONS
IN HIGH-ENERGY PROTON-PROTON INTERACTIONS

M. Basile, G. Cararomeo, L. Cifarelli, P. Giusti,
T. Massam, F. Palmonari, G. Valenti and A. Zichichi

CERN, Geneva, Switzerland

Istituto Nazionale di Fisica Nucleare, Bologna, Italy

Istituto di Fisica dell'Università, Bologna, Italy

ABSTRACT

A study of about 10^5 proton-proton interactions at $\sqrt{s} = 52.5$ GeV was performed using the ISR Split Field Magnet. Correlations between particles pairs, with like and unlike charges, were studied in terms of six variables. The main conclusions are: i) the difference in the azimuthal asymmetry parameter between unlike and like charge pairs shows up at invariant masses between 500 and 1200 MeV, i.e. in the region of the well-known resonances; ii) a supershort ($\Delta y \leq 0.5$) correlation effect exists for unlike as well as for like charge pairs; iii) the azimuthal asymmetry parameter remains positive (back-to-back configurations are preferred) even for very large values of the rapidity variables, independent of the charge configurations.

The 10^5 interactions represent a high statistical sample of events without any sort of trigger bias, such as high p_T , multiplicity, or energy.

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1. INTRODUCTION

A way to understand the dynamics underlying the multiparticle production processes in hadronic interactions is the study of two-particle correlations¹⁾. Extensive studies in this field have been done at proton accelerators²⁻⁷⁾, and at the ISR⁸⁻¹¹⁾.

The purpose of this work is to report on a study based on a high statistics sample ($\sim 10^5$) of "normal" or "unbiased" interactions, i.e. interactions without a trigger condition on high p_T , multiplicity, or energy. This study has been focused on the two-body azimuthal correlations of like and unlike charge pairs over a range of variables, related to the *pair* and to the *event*. More precisely, the variable i) azimuthal angle between pairs of particles of equal and opposite charge, has been studied as a function of: ii) the rapidity difference, iii) the transverse momentum difference, iv) the mean transverse momentum, v) the invariant mass of the *pair*; and vi) the charged multiplicity of the *event*.

The reaction studied is:

$$p + p \rightarrow \text{two charged particles} + \text{anything}$$

at the total centre-of-mass energy $\sqrt{s} = 52.5$ GeV.

2. DATA-TAKING AND ANALYSIS

The experiment was performed at the ISR Split Field Magnet (SFM) using the CERN-Bologna apparatus, which was built to search for quarks¹²⁾ and consisted of scintillation counter hodoscopes matching the acceptance of the SFM detector (Fig. 1).

The trigger required a unit-charge particle on one side of the apparatus in coincidence with an apparently fractionally charged particle on the other side. At the hardware level, the fractional charge requirement was a low pulse-height selection made on sets of eight counters within the hodoscopes. This selection produced a factor of 10^{-4} reduction in the trigger rate, but since it was due to effects such as low-energy showers accompanying the event, the selection has a negligible energy bias. The absence of biases in the trigger was checked as follows:

- i) The trigger rate was found to be proportional to the beam-beam rate. This shows that the selected sample was due to (pp) interactions and not to beam-gas or to other background sources.
- ii) After correction for the acceptance of the apparatus, the inclusive distributions of charged particles agree with those obtained in previous experiments¹³⁻¹⁵⁾.

The analysis has been developed using pairs of particles in: i) the "good-good" regions, and this permits the study of pairs with $\Delta y < 1.5$ ^{†)} and $3.0 \leq \Delta y < 6.0$; ii) the "good-difficult" regions, corresponding to pairs with $1.5 \leq \Delta y < 3.0$. However, the conclusions of the present work are based on the "good-good" pairs, the "good-difficult" ones being used only to check that nothing wrong happens in between the short-range ($\Delta y < 1.5$) and the long-range ($\Delta y \geq 3.0$) regions.

Let ϕ_1^* and ϕ_2^* be the centre-of-mass azimuthal angles of a pair of particles; the azimuthal correlation angle Φ (Fig. 2) is defined as $\Phi = |\phi_1^* - \phi_2^*|$ and the asymmetry parameter B as:

$$B = \frac{\int_{90^\circ}^{180^\circ} (dN/d\Phi) d\Phi - \int_{0^\circ}^{90^\circ} (dN/d\Phi) d\Phi}{\int_{90^\circ}^{180^\circ} (dN/d\Phi) d\Phi + \int_{0^\circ}^{90^\circ} (dN/d\Phi) d\Phi}.$$

The definition of $(dN/d\Phi)$ differs from case to case, since it is the number of pairs with an azimuthal angle difference in the interval Φ to $\Phi + d\Phi$ integrated over the various kinematic regions and configurations described below. Corrections for the variations of the single-particle ϕ^* acceptance in the different kinematic regions have been made as follows. Pairs of particles were generated uniformly in ϕ^* by a Monte Carlo program, and the corresponding distribution, weighted by the product of the two single-particle ϕ^* acceptances, was used to correct the experimental distribution. In the "good" regions the corrections to be applied were always smaller than $\pm 5\%$ per point in the Φ distributions and of the order of $\pm 1\%$ in the asymmetry parameter B; in the "difficult" regions these figures could be four times higher.

3. RESULTS

The analysis of the data has been developed on a set of six variables, each one related to a pair of particles, and on the possible dependence of the azimuthal correlation angle of a pair on the other variables. In events with more than two observed charged particles, every possible pair of particles from the event is entered in the distributions.

^{†)} $\Delta y = |y_1^* - y_2^*|$.

The short-range pairs show a clear enhancement of B for decreasing multiplicity, both for like and unlike pairs. This enhancement is not present for the long-range pairs of any charge state. We interpret this low multiplicity effect as being due to a residual of leading particle processes mentioned above. This can be eliminated with a multiplicity $n_c \geq 6$ cut. These x and n_c cuts thus provide a sample of events with negligible leading particle phenomena.

3.3 The azimuthal asymmetry parameter versus Δp_T

The azimuthal asymmetry parameter has also been studied as a function of the transverse momentum difference of the pair:

$$\Delta p_T = |p_{T1}^* - p_{T2}^*|.$$

The results for $\Delta y < 1.5$ are shown in Fig. 9a; the main features are as follows. The B -value for the unlike pairs stays constantly above the value for the like pairs for $\Delta p_T \lesssim 0.6$ GeV/c. The B -values become indistinguishable for the two cases when $\Delta p_T \gtrsim 0.65$ GeV/c.

The B -parameter for $\Delta p_T < 0.2$ GeV/c increases for the unlike pairs, while decreasing for the like pairs. This behaviour can be understood in terms of the well-known "Bose effect" acting on the like charge pairs¹⁶⁾; in fact, for small values of Δp_T , the positive value of B is depressed¹⁷⁾:

The B -dependence versus Δp_T for "long-range" Δy pairs is shown in Fig. 9b; the value of B is nearly constant over the Δp_T range investigated and there is no significant difference between like and unlike pairs.

3.4 The azimuthal asymmetry parameter versus the invariant mass of the pair

In order to make a Bose-Einstein-effect independent comparison between like and unlike pairs, we have determined the Δy region, where this effect is important. The values of B for $\Delta y < 0.8$ are quite different for unlike and like pairs, the latter being systematically lower. As expected for $\Delta y > 0.8$ the difference disappears.

In the remaining analysis we have excluded events which have charged multiplicity $n_c < 6$, or a positively charged particle with $|x| > 0.5$. In the sample left, particle pairs have been rejected if they have simultaneously $\Delta p_T < 0.2$ GeV/c and $\Delta y < 0.8$. The values of B are given in Table 2.

The effect of the cuts on B is negligible for the "long-range" pairs, and the value of B for unlike pairs remains slightly lower than for like pairs.

We emphasize that this "super-short-range" correlation cannot be due to Bose effects, or to leading particle effects, or to known resonances; it is a sort of super-clustering of hadronic matter.

3.7 Super-long-range correlations for like and unlike pairs

The values of B as a function of Δy in the range $\Delta y \geq 3.0$ are shown in Figs. 13a and b for the unlike and like charge pairs.

The azimuthal asymmetry parameter B remains significantly above zero, at a level of a few per cent, even for $\Delta y \geq 3.5$, for like as well as for unlike charge pairs, an effect already reported at lower energies²⁾.

In order to complete this study, we have analysed the intermediate Δy range; it can only be done if the "good-difficult" pairs are used. This is done with the purpose of examining a possible pathological behaviour of B in the intermediate range of Δy .

As shown in Figs. 14a and b the two ranges of Δy join together very well, and this is the proof that our corrections in the "difficult" SFM solid angle range are satisfactory.

The data reported in Figs. 14a and b, where all ranges of Δy are presented in a compressed scale, demonstrate the smoothness of the B behaviour along the complete range of Δy and confirm the effects reported above.

4. CONCLUSIONS

The results of the present analysis allow us to conclude that two-particle correlations effects, both for like and unlike charge pairs, are present at this very high energy in inelastic interactions after the removal of leading particle effects and of Bose-Einstein statistics effects. The most relevant features of our study can be summarized as follows:

- i) The difference in the azimuthal asymmetry parameter between unlike and like charge pairs is due to well-known resonances.
- ii) A super-short-range ($\Delta y \leq 0.5$) correlation with positive value for the azimuthal asymmetry parameter exists for unlike as well as for like charge pairs. This correlation cannot be due to Bose effects, or to leading particle phenomena, or to known resonances. It is a sort of super-clustering of hadronic matter.
- iii) The super-long-range ($\Delta y \geq 3.5$) correlation, already observed at lower energies, for unlike and like charge pairs with positive value of the azimuthal asymmetry parameter, is still present at this very high energy with the same magnitude.

REFERENCES

- 1) For a review of the experimental data, see:
P. Darriulat, Proc. 6th Internat. Colloquium on Multiparticle Reactions, Oxford, 1975 (Rutherford Laboratory, Didcot, UK, 1975), p. 1.
T. Del Prete, Rivista del Nuovo Cimento 5, 532 (1975).
N.A. McCubbin, Proc. EPS Internat. Conf. on High-Energy Physics, Palermo, 1975 (Editrice Compositori, Bologna, 1976), p. 821.
P. Darriulat, Large transverse momentum hadronic processes, to be published in Proc. 18th Internat. Conf. on High-Energy Physics, Tiflis, 1976.
G. Ranft, Azimuthal correlations in particle production at low p_T , to be published in Proc. 14th Course of the Erice Internat. School of Subnuclear Physics, Erice, 1976.
- 2) T. Ferbel, Proc. 5th Internat. Symposium on Many-Particle Production, Leipzig, 1974, p. 385.
- 3) C.M. Bromberg, D. Chaney, D. Cohen, T. Ferbel, P. Slattery, J.W. Chapman, J.W. Cooper, N. Green, A.A. Seidl and J.C. Vander Velde, Phys. Rev. D 9, 1864 (1974).
- 4) M. Pratap, R. Engelmann, T. Kafka, Y. Cho, T.H. Fields, L.G. Hyman, R. Singer, L. Voyvodic, R. Walker and J. Whitmore, Phys. Rev. Letters 33, 797 (1974).
- 5) J. Erwin, W. Ko, R.L. Lander, D.E. Pellett, P.M. Yager and M. Alston-Garnjost, Phys. Rev. Letters 33, 1443 (1974).
- 6) B.Y. Oh, W. Morris, D.L. Parker, G.A. Smith, J. Whitmore, R.J. Miller, J.J. Phelan, P.F. Schultz, L. Voyvodic, R. Walker, R. Yaari, E.W. Anderson, H.B. Crawley, W.J. Kernan, F. Ogino, R.G. Glasser, D.G. Hill, G. McClellan, H.L. Price, B. Sechi-Zorn, G.A. Snow and F. Svrcek, Phys. Letters 56B, 400 (1975).
- 7) C. Bromberg, T. Ferbel, P. Slattery, A. Seidl and J.C. Vander Velde, Rapidity correlations in pp collisions at 102 and 400 GeV/c, submitted to Phys. Rev., 1976.
- 8) H. Dibon, G. Flügge, Ch. Gottfried, B.M.K. Nefkens, G. Neuhofer, F. Niebergall, M. Regler, W. Schmidt-Parzefall, K.R. Schubert, P.E. Schumacher and K. Winter, Phys. Letters 44B, 313 (1973).
- 9) K. Eggert, H. Frenzel, W. Thomé, B. Betev, P. Darriulat, P. Dittmann, M. Holder, K.T. McDonald, T. Modis, H.G. Pugh, K. Tittel, I. Derado, V. Eckardt, H.J. Gebauer, R. Meinke, O.R. Sander and P. Seyboth, Nuclear Phys. B86, 201 (1975).
- 10) S.R. Amendolia, G. Bellettini, L. Bosisio, P.L. Braccini, C. Bradaschia, R. Castaldi, V. Cavasinni, C. Cerri, T. Del Prete, L. Foà, P. Giromini, P. Laurelli, A. Menzione, L. Ristori, G. Sanguinetti and M. Valdata, Nuovo Cimento 31A, 17 (1976).
- 11) M.G. Albrow, B. Alper, J. Armitage, D. Aston, P. Benz, G.J. Bobbink, B. Bošnjaković, A.G. Clark, F.C. Erne, W.M. Evans, C.N.P. Gee, E.S. Groves, L.E. Holloway, J.N. Jackson, G. Jarlskog, H. Jensen, P. Kooijman, F.K. Loebinger, A.A. Macbeth, N.A. McCubbin, H.E. Montgomery, J.V. Morris, P.G. Murphy, H. Ogren, R.J. Ott, D. Radojicic, S. Rock, A. Rudge, J.C. Sens, A.L. Sessoms, J. Singh, D. Stork, P. Strolin and J. Timmer, Correlations between two identified charged hadrons at the CERN ISR, submitted to Phys. Letters, 1976.

Figure captions

- Fig. 1 : Top view of the SFM, showing the Charpak Chambers and the CERN-Bologna-hodoscope layout.
- Fig. 2 : Definition of the azimuthal angle ϕ^* of a track and of the azimuthal correlation Φ angle, in the pp centre-of-mass system. z is parallel to the magnetic field direction in the laboratory system. The centre-of-mass motion is along the x -axis (antiparallel to it).
- Fig. 3 : The SFM detector acceptance in the $y^*-\phi^*$ plane for: a) all charged particles, b) all positive particles, c) all negative particles.
- Fig. 4 : Total track multiplicity distribution of the events with at least two tracks in the rapidity range $1.5 \leq |y^*| < 3.0$, and momentum error less than 15%.
- Fig. 5 : Azimuthal angle distribution of all tracks in the rapidity range $1.5 \leq |y^*| < 3.0$, and with momentum error less than 15%.
- Fig. 6a,b,c: Azimuthal correlation angle distributions of all pairs for the different charge configurations ($^{+-}$, $--$, $++$) in the two Δy intervals. The factor $1/\pi N$, where N is the total number of pair combinations, normalizes the area under the curve to unity.
- Fig. 7 : Ratio of the number of events with a "leading particle" to the total number of events, as a function of the charged multiplicity, for different values of x_0 . The dashed lines are arbitrary smooth curves to show the trend of the data.
- Fig. 8a,b : Asymmetry parameter B as a function of the total track multiplicity for unlike and like pairs in the two Δy intervals: a) $\Delta y < 1.5$; the dashed lines are the best fits with arbitrary functions. b) $\Delta y \geq 3.0$; the horizontal lines show the average B values for like and unlike pairs.
- Fig. 9 : a) Asymmetry parameter as a function of the transverse momentum difference of the two particles, for like and unlike pairs with $\Delta y < 1.5$. The shaded area shows the range of Δp_T values above the cut, discussed in the text. b) Same as in (a) but for pairs with $\Delta y \geq 3.0$. The horizontal band shows the range of B values for like and unlike pairs, obtained from the two average values.
- Fig. 10 : Asymmetry parameter difference between opposite charge and same charge pairs as a function of the invariant mass of the pairs.

Fig. 1

Fig. 3

Fig. 5

Fig. 7

Fig. 9

Fig. 11

Fig. 13