BOSE-EINSTEIN CORRELATIONS IN K^+p AND π^+p COLLISIONS AT 250 GeV/c

EHS/NA22 Collaboration

Aachen- Antwerp/Brussels- Berlin (Zeuthen)- Helsinki- Krakow- Moscow -
Nijmegen- Rio de Janeiro- Serpukhov- Warsaw- Yerevan

M. ADAMUS[a], I.V. AJINENKO[b], Yu.A. BELOKOPYTOV[b], V.A. BEREZHNOY[b], H. BÖTTCHER[c], P.V. CHLIAPNIKOV[b], F. CRIJNS[d], A. DE ROECK[e1], E.A. DE WOLF[e2], K. DZIUNIKOWSKA[f], A.M.F. ENDLER[g], P.F. ERMOLOV[h], A. ESKREYS[f], H. GRAESSLER[i], R.Sh. HAKOBYAN[j], P. van HAL[d3], T. HAUPT[d4], L.P. KISHINEVSKAYA[j], W. KITTEL[d], A.I. KURNOSENKO[b], B.B. LEVCHENKO[h], J. MÄKELÄ[k], F. MEIJERS[d5], A.B. MICHAŁOWSKA[e], V.I. NIKOLAENKO[b], L.C.S. OLIVEIRA[g], K. OLKIEWICZ[f], E. RIIPINEN[k], H.F. ROLOFF[c], V.M. RONJIN[b], A.M. RYBIN[b], H.M.T. SAARIKKO[k], W. SCHMITZ[i], L. SCHOLTEN[d], J. STEPANIAK[a], O.G. TCHIKILEV[b], A.G. TOMARADZE[b6], V.A. UVAROV[b], F. VERBEURE[e], R. WISCHNEWSKI[c], S.A. ZOTKIN[h].

[a] University of Warsaw and Institute of Nuclear Problems, PL-00681 Warsaw, Poland (partially supported by grants from CPBP 01.06 and 01.09)
[b] Institute for High Energy Physics, SU-142284 Serpukhov, USSR
[c] Institut für Hochenergiephysik der Akademie der Wissenschaften der DDR, DDR-1615 Berlin-Zeuthen, German Dem. Rep.
[d] University of Nijmegen and NIKHEF-H, NL-6525 ED Nijmegen, The Netherlands
[e] Universitaire Instelling Antwerpen, B-2610 Wilrijk and Inter-University Institute for High Energies, VUB/ULB, B-1050 Brussels, Belgium
[f] Institute of Physics and Nuclear Techniques of the Academy of Mining and Metallurgy and Institute of Nuclear Physics, PL-30055 Krakow, Poland (partially supported by grants from CPBP 01.06 and 01.09)
[g] Centro Brasileiro de Pesquisas Fisicas, 22290 Rio de Janeiro, Brazil
[h] Moscow State University, SU-117234 Moscow, USSR
[i] III. Physikalisches Institut B, RWTH, D-5100 Aachen, Fed. Rep. Germany (partially funded by the German Federal Minister for Research and Technology (BMFT) under the contract number 053AC41P)
[j] Institute of Physics, SU-375036 Yerevan, USSR
[k] Department of High Energy Physics, Helsinki University, SF-00170 Helsinki, Finland

ABSTRACT

Two-pion correlations are studied for pions of like charge in K^+p and π^+p collisions at 250 GeV/c. An enhanced production is observed at small momentum difference and is attributed to Bose-Einstein interference between identical particles. A systematic study is presented on the influence of parametrization and reference sample. Interpreted in terms of the Kopylov-Podgoretskii parametrization a size of the emitting region $r_K \approx 1.4$ fm is found. The Lorentz invariant parametrization of Goldhaber gives $r_G \approx 0.8$ fm. With fixed parametrization, similarity is found for hadron-hadron, e^+e^- and lepton-hadron collisions. No multiplicity or angular dependence is found at our energy.

---

[1] Onderzoeker IIKW, Brussels, Belgium
[2] Bevoegdverklaard Navorser NFWO, Belgium
[3] Now with Ericsson Telecommunicatie B.V., Rijen, The Netherlands
[4] On leave from Institute of Nuclear Physics, Krakow
[5] Now at CERN, Geneva, Switzerland
[6] Visitor from Institute of High Energy Physics of Tbilisi State University, USSR

I. INTRODUCTION

As proposed by Hanbury Brown and Twiss [1] in 1954, the diameter of stars and radio sources in the universe is successfully determined by measuring the intensity correlations between separated telescopes. Likewise, in particle physics, one can in principle use Bose-Einstein correlations between identical bosons to measure the space-time structure of the region from which the particles originate [2,3].

The first experimental evidence for Bose-Einstein correlation in particle physics goes back to 1959 when, in $p\bar{p}$ annihilation at 1.05 GeV/c, Goldhaber, Goldhaber, Lee and Pais [4] observed an enhancement at small angles in like sign pion pairs not present for unlike sign pairs. More recently, Bose-Einstein correlations have been studied in hadron-hadron [5-22], hadron-nucleus [19,23], nucleus-nucleus [24-27], e^+e^- [28-31] and lepton-hadron collisions[32].

The radius of the particle emission source is determined to be of order 1 fm for particle collisions and up to several fm for nuclear collisions. In one nucleus-nucleus experiment [25] and in ISR experiments [20,21] the radius is found to increase with charge multiplicity. This increase is understood in the impact parameter model [33]. In general, the shape of the source is consistent with being spherical, but a possible elongation in the beam direction has been reported for the overall cms (see last refs.[21]). In most experiments, the effect has been studied for pions, but also kaons have been used [12,21].

Recently, Bose-Einstein correlations have also been introduced into string models [34,35]. In these models, an ordering in space-time exists for the hadron momenta within a jet. Therefore, bosons close in phase space are nearby in space-time and hence lead to a relatively small longitudinal dimension of the local pion emission region. These models can account well for most features of the e^+e^- data [30,31].

Here, we report on a study of the Bose-Einstein interference effect for pions produced in π^+p and K^+p collisions at 250 GeV/c. In the following section the relevant parametrizations of the interference effect are recalled. The data sample and the reconstruction procedure are described in sect.III. Results are presented in sect.IV and compared to those from other experiments in sect.V. Conclusions are summarized in sect.VI. The problem of the reference distributions is discussed in the appendix. More details are given in ref.[36].

II. THE PARAMETRIZATION

The normalized coincidence rate for simultaneous observation of two identical pions emitted incoherently from two sources positioned at $\bar{r}_1$ and $\bar{r}_2$ with momenta $\bar{p}_1$ and $\bar{p}_2$ is

$$R = 1 + cos(\bar{q}.\bar{r}) \tag{1}$$

with $\bar{q} = \bar{k}_1 - \bar{k}_2$ and $\bar{r} = \bar{r}_1 - \bar{r}_2$. Normalization is relative to the rate which would be observed without Bose-Einstein interference. In practice, the emitting pion sources will be distributed according to a certain density distribution, and the characteristic dimension r of this distribution will depend on the particular parametrization. We shall limit ourselves to the discussion of two parametrizations, one most commonly used in hadron-hadron, the other in e^+e^- and lepton-hadron experiments:

1. The Kopylov-Podgoretskii parametrization [2]

$$R(q_T, q_0) = 1 + [4J_1^2(q_T r_K)/(q_T r_K)^2] \cdot [1/(1+q_0\tau)^2] \quad , \tag{2}$$

   J_1 being the first-order Bessel function, $q_0 = |E_1 - E_2|$ and q_T the length of the component of the three-vector $\bar{q}$ transverse to $\bar{p}_1 + \bar{p}_2$. This parametrization corresponds to a radiating spherical surface of radius r_K with incoherent point-like oscillators of lifetime τ. The parametrization is not Lorentz-invariant. In general, the variables are calculated in the centre of mass of the initial collision.

2. The Lorentz invariant (Goldhaber) form [4,28]

$$R(Q^2) = 1 + exp(-r_G^2 Q^2) \quad with \tag{3}$$

$$Q^2 = -(p_1 - p_2)^2 = M^2 - 4M_\pi^2 \quad .$$

   where M is the invariant mass of the pion pair. It corresponds to a Gaussian shape of the source in the centre of mass of the pair, where $q_0 \equiv \Delta E = 0$.

Due to the different assumptions on the shape of the source, the spatial dimensions r_K and r_G used in the two parametrizations have a different meaning and are related via the exponential approximation of (2):

$$R \approx 1 + exp[-(r_K/2)^2 q_T^2 - \tau^2 q_0^2] \qquad .$$

In formulae (1) - (3) it is assumed that identical bosons are produced incoherently. For this case a maximum value of $R = 2$ is expected for $p_1 = p_2$, compared to $R = 1$ in the absence of interference effects. In most experiments, the maximum effect seen is smaller and one has to introduce a strength parameter λ. Since a coherent source gives no enhancement, the strength of the effect is often interpreted as a measure of the incoherence of the pion emitters [37]. On the other hand, there are also sources of biases in general leading to a decrease of the effect, physics induced (resonance production, local charge conservation, Coulomb repulsion) and detector induced (misidentification of the particles, wrong charge assignment, track losses). Furthermore, a large fraction of the observed pions are decay products of long-lived resonances, such as ω and η, resulting in a large effective radius of the pion sources [38]. For pairs including such a decay pion, the interference effects are relevant only in a very small Q (or q_T, q_0) range. However, the finite momentum resolution will smear out those pairs into Q ranges with much larger population and the effect becomes undetectable.

The physics induced biases can be reduced partly by the carefull antiselection of resonances and partly by Monte Carlo studies. The detector induced biases can be minimized by the careful selection of events and tracks and a proper choice of the reference sample.

Ideally, the reference sample is identical to that of the like pion pairs in all aspects, except for the interference effect itself. A number of suggestions have been proposed in the literature. In this paper we consider two approaches:

i) the reference sample is formed by a so-called "mixed event" technique, i.e. a pion from one event is combined with a pion randomly selected from a different event of the same multiplicity class (e.g. n=6-8, n=10, n=12, $n \geq 14$);

ii) the reference sample is formed from pairs of unlike charge pions in the same physical event and resonances like ρ^0 are excluded.

After carefull event and track selections, we find that the application of these two approaches leads to results consistent within statistical errors. A comparison of the two approaches to each other and to a third one are discussed in the appendix.

Accounting for the strength parameter λ and for a slow variation of R with q at large q, one fits the experimental distribution at fixed q_0 with the function

$$R(q_T) = \gamma[1 + 4\lambda J_1^2(\beta q_T)/(\beta q_T)^2](1 + \delta q_T) \tag{4}$$

in the Kopylov-Podgoretskii parametrization, and

$$R(Q^2) = \gamma(1 + \lambda e^{-\beta Q^2})(1 + \delta Q^2) \tag{5}$$

in the Goldhaber parametrization. The fit parameters are the normalization γ, the correlation strength λ, the spatial dimension of the pion source β ($r = 0.197\sqrt{\beta}$ fm) and the slow variation δ of the background.

III. DATA SAMPLE AND RECONSTRUCTION PROCEDURE

The data used in the present analysis come from the NA22 experiment performed at the CERN SPS with the help of the European Hybrid Spectrometer EHS.

The detector consists of an active vertex detector (Rapid Cycling Bubble Chamber) embedded in a 2T magnetic field and a downstream spectrometer. The spectrometer is built of a wire chamber, six drift chambers and an additional 1T magnet. Charged particle momenta are measured over the full solid angle with a resolution of $\Delta p/p \leq 2\%$ for all momenta. A more detailed description of the detector can be found in reference [39] and references given therein.

Events are accepted when scanned and reconstructed multiplicities n are consistent and charge balance is satisfied. Badly reconstructed tracks are rejected. Only events with $n \geq 6$ are accepted, the minimum required to yield a negative pair. The final data sample, accepted for the present analysis amounts to 25592 π^+p and 29307 K^+p events.

For the analysis presented in this paper two additional track cuts are applied:

1. the track momentum error is required to be below 4%;
2. each accepted track is required to have $|x_F| < 0.5$.

The latter selection minimises biases due to the violation of energy and momentum conservation, imminent to the "mixed event" technique. For positive tracks it, furthermore, reduces the contamination from particles other than pions. These two cuts reject additionally 15% and 2% of tracks, respectively, but improve the credibility of the final results. The resolution in Q^2 is estimated to be σ=12 (MeV/c)^2 at low Q^2.

The analysis of the Bose-Einstein correlations is performed on two samples:

1. All charged particles, except identified protons are assumed to have pion mass.
2. Only tracks identified as pions in the ionization sampling drift chamber ISIS are used in the analysis. (Due to the limited acceptance of ISIS, the number of pairs is reduced to 15% in this case).

In the first case both reference samples are used, in the second only the "mixed event" technique is applied (the unlike charge technique is unreliable in this case since ISIS acceptances depend on the particle charge). In all cases, our π^+p and K^+p samples are merged since no differences are observed between the two samples.

IV. RESULTS

IV.1 Pairs of Negative Particles

In Figs. 1 and 2 we show our data for negative particle pairs compared to fits of the Goldhaber (5) and the Kopylov-Podgoretskii parametrization (4), respectively. For the latter, the energy difference has been limited to $q_0 \leq 0.2$ GeV. Fits are shown with mixed event and unlike reference samples. In the unlike reference sample the range $0.36 < Q^2 < 0.60$ (GeV/c)^2 is contaminated by the ρ^0 decay products and excluded from the fit (Fig. 1b). In Fig. 2b the first point $q_T \leq 0.025$ GeV/c is biased by Dalitz pairs in the reference distribution and excluded from the data.

In all four plots, significant enhancements are seen for small values of Q^2 and q_T, respectively. For both parametrizations a small rise of the ratio R with Q^2 and q_T is observed. Fit parameters are given in Tables 1 and 2, for the latter case also with $\delta = 0$. No sizable differences are observed for the two reference samples.

The strength of the correlation λ varies between 0.3 and 0.45, hardly showing any dependence on the particular parametrization chosen. As expected, however, the spatial dimension of the particle source differs significantly in the two parametrizations. It is of order $r_G \approx 0.8$ fm for the Goldhaber and $r_K \approx 1.4$ fm for the Kopylov-Podgoretskii parametrizatio n.

IV.2 Identified Pions

Since Bose-Einstein interference applies to identical bosons, the effect will be stronger if identified pions are selected. In the following, results are presented for the pion sample identified with ISIS. As stated above the reference distribution is constructed with the mixed event technique.

To be able to see the effect of particle identification, we first consider the interference signal in the reduced sample without making use of the identification. The ratio R is shown as a function of Q^2 in Fig. 3a) and b) for all positive and all negative particle pairs, respectively. The results of the fits to these data with parametrization (5) are given in the first two lines of Table 3. Although the restriction to a smaller part of phase space may bias the effective shape of the particle source, the results for negatives are compatible with the values obtained for all pairs of unidentified particles given in Table 1. Positives give the same size of the source, but the parameter λ is a factor 2 smaller for positives than for negatives.

Next, the identification is 'switched on'. The ratios obtained are shown in Fig. 3c) and d) for pairs of positive and pairs of negative pions, respectively. Results of the fits are given in lines 3 and 4 of Table 3. As expected, the strength of the effect has increased, especially for positive particles where it has increased by almost a factor two. It is interesting to observe that also the quality of the fits has improved.

The availability of identification furthermore allows to check whether the interference effect is indeed absent for non-identical particles if these are treated as pions. Fig. 3e) and f) show the ratios for combinations of a pion with a kaon or (anti) proton, i.e. not a pion (note, however, that for the Lorentz boost and the calculation of Q^2 the pion mass is used). Although the errors are large, the data are indeed consistent with no effect. This lends support to the "mixed event" technique to form an uncorrelated reference sample.

IV.3 Charge Multiplicity Dependence

Following the indications observed in other studies of Bose-Einstein correlations concerning a possible dependence on the charge multiplicity [20,21], we have analysed also this aspect of the effect. The multiplicity dependence can, in principle, reveal an impact parameter dependence of the correlation effect [33].

In Fig. 4 the ratios R based on the "mixed event" technique are shown for 4 multiplicity classes of events. In Table 4 and Fig. 5 the results of the fits with parametrization (5) are given. No multiplicity dependence is observed at our energy. Similar results are obtained with the unlike reference sample and with parametrization (4).

IV.4 Angular Dependence

Because of relation (1), the Bose-Einstein effect can (in principle) be used to measure the extent of the source in the direction given by the momentum difference $\bar{q}$. Indeed, a possible dependence of r_K on the angle θ between $\bar{q}$ and the collision axis has recently been reported by the AFS Collaboration, if evaluated in the overall cms (last refs. 21). Fits to our data in three regions of $cos\theta$ in terms of parametrization (5) are given in Fig.6. The results are given in Table 5.

We conclude that no angular dependence of the Bose-Einstein correlations is observed at our energy.

V. COMPARISON TO OTHER ENERGIES AND OTHER TYPES OF COLLISION

In comparing the results obtained by different experiments, one should keep in mind that, in general, experimental conditions are different, different techniques are used in constructing the reference distributions and sometimes ad-hoc corrections are applied to make up for experimental shortcomings.

In hadron-hadron experiments, the enhancement is usually parametrized in terms of the Kopylov-Podgoretskii variables q_T and q_0. With this parametrization, our value for the size of the emitting region r_K is about 1.4 fm. Other hadron-hadron experiments [5-22] have found similar values. Most of the reported values are in the range 1.1-1.8 fm, a reasonable average seems to be 1.5 fm, and no clear energy dependence is seen [22] up to ISR energies. Also for e^+e^- annihilations such values (1.3±0.1 fm) have been reported [29,31] when using parametrization (4). The radius of the emitting region for collisions of two heavy nuclei, on the other hand, is found to be several fm [24-27].

The Lorentz invariant parametrization (5) is commonly used in e^+e^- annihilation experiments [28-31], which give values in the range $r_G = 0.7 - 0.9$ fm, in good agreement with our result of $r_G \approx 0.8$ fm. Furthermore, similar values (0.5-0.8 fm) are reported for lepton-hadron collisions [32]. We can conclude that the parameter r depends on the parametrization, but, within the systematical uncertainties, neither on the total energy, nor on the type of collision.

The strength of the effect is found to be $\lambda \approx 0.4$. Our value is comparabl e to the ones obtained by other hadron-hadron experiments when using reference distributions based on the mixed event or unlike reference techniques. Those values are in the range $\lambda = 0.3 - 0.5$. Significantly higher values are quoted when using a reference distribution based on the shuffling of transverse momenta. As shown in the addendum, this may be an artefact of this third technique. The strength found for e^+e^- annihilation is in the range $\lambda = 0.4 - 0.7$. Several authors [6,29-31] have pointed out that it is premature to associate a λ value smaller than the theoretical maximum of $\lambda = 1$ with the existence of coherent states.

In one nucleus-nucleus experiment at 1.8 GeV/A [25], the radius r_K was found to increase with charge multiplicity n. By relating r_K to the size of the overlapping region of the two colliding particles, this increase can be understood in terms of the geometrical model [33]: a large overlap should imply a large multiplicity. On the other hand, no evidence for a multiplicity dependence is found in hadron-nucleus collisions at 200 GeV/c [19].

After some time of confusion, the n dependence is now becoming clear for hadron-hadron collisions. At energies below $\sqrt{s} \approx 30$GeV (at $\sqrt{s} \approx 8$GeV [13] and 22 GeV in this experiment), no n-dependence is observed for r_K. At higher energies, (last ref.[20] and [21]) an n-dependence starts to set in and to grow with increasing energy.

As expected from the geometrical model, the results from e^+e^- experiments are (at least up to now) consistent with no multiplicity dependence.

We have found no significant evidence for a dependence of the emitting region on the angle between the collision axis and the event frame momentum difference of the pair. A similar conclusion has been reached for e^+e^- [31], lepton-hadron [32] and nucleus-nucleus collisions [26,27]. A possible elongation along the collision axis has been reported by the AFS collaboration [21] when evaluated in the overall cms. This elongation disappears in the two pion rest system, however.

VI. SUMMARY AND CONCLUSIONS

The study of the Bose-Einstein correlations in π^+p and K^+p interactions at 250 GeV/c with the help of the EHS spectrometer in the NA22 experiment reveals statistically significant correlation effects. These effects are observed as an enhancement of the number of the like charge pion pairs over that from uncorrelated samples, for small four-momentum difference of the pair. These effects are very similar for π^+p and K^+p data and therefore have been studied in the merged data.

Two choices of the reference sample of particles pairs were considered: the unlike charge particle pairs from the same physical event and combinations of the particles randomly chosen from different events of similar multiplicity. The results obtained are the same within statistical errors and yield a radius r_K=1.4 fm if the parametriation (4) is used and r_G=0.8 fm if (5) is used. For positive particles, the effect is strongly enhanced when the analysis is restricted to pairs of identified pions.

No multiplicity and no angular dependence of the correlation effects are observed at our energy.

APPENDIX A: REFERENCE DISTRIBUTIONS

In this appendix we comment on the reference samples used to normalize the interference effect. One way to investigate the effectiveness of the procedure to construct a reference distribution, is to apply this procedure to a sample of generated events not containing Bose-Einstein interference. Monte Carlo programs based on the Lund fragmentation scheme are well suited for this purpose, since this scheme includes a simulation of resonances and energy-momentum conservation effects, but does not include interference effects.

We have generated a sample of π^+p and K^+p events, 150000 events each, according to the two-string Dual Parton Model with Lund fragmentation [40]. The same cut on multiplicity ($n \geq 6$) and tracks ($|x_F| < 0.5$) is imposed on the generated events as on the data. All particles except slow protons are treated as pions.

The ratio predicted for negative particles is shown in Fig. 7 as a function of Q^2. Normalization is done to the a) mixed event and b) unlike reference sample. These ratios should be compared with the data in Fig. 1. No strong signal at low Q^2 is seen in the Monte Carlo events. The interpretation of the low Q^2 enhancement in the data in terms of Bose-Einstein interference is, therefore, supported.

However, some structure is seen in the ratio obtained from the Monte Carlo events and deserves comments. In case of normalisation with the mixed event reference sample, a small positive correlation at low Q^2 is observed. This can be attributed to resonance decays, dominantly $\eta' \to \pi^+\pi^-\eta$ followed by $\eta \to \pi^+\pi^-\pi^0$, producing two π^- from a small Q-value decay. A small negative correlation is seen for the unlike reference at low Q^2. This is caused dominantely by η, η' and ω decays in the reference distribution. In addition, a reflection of the ρ^0 is clearly seen at $Q^2 \sim 0.5$ (GeV/c)^2.

We have made no attempt to correct the data with the Monte Carlo ratios, since it is not known to what extent resonance production is correctly described by the Monte Carlo and it is not evident that the interference effect factorises with the other correlations. Furthermore, it is known that η' production is strongly overestimated in Lund

fragmentation [41].

The ratios obtained for the negative particles as a function of q_T (in the interval $q_0 \leq 0.2$ GeV) are shown in Fig. 8. These are to be compared with the data shown in Fig. 2. Also here, the two reference distributions are reasonably suited for the extraction of the interference effect.

Finally we want to comment on a third procedure to construct a reference distribution. Here, the momentum components transverse to the event axis are 'reshuffled'. One can then form the reference distribution by combining reshuffled unlike sign particles, or reshuffled like sign particles. In particular, this technique has been used in some experiments to obtain the ratio as a function of q_T [6,19,30].

Figure 9 shows the ratio obtained from the Monte Carlo events for the negative particles as a function of q_T (in the interval $q_0 \leq 0.2$ GeV). The exact procedure to obtain the reference distribution is the following. First, the two components of the transverse momentum are randomly and separately interchanged between the particles, irrespective of their charge. Combinations are formed between the unlike particles. Then the transformation to the overall centre of mass is done. From Fig. 9, it can be seen that this reference distribution causes an artifical enhancement at low q_T and, therefore, an unnaturally large λ. If one does reshuffling of the transverse components after the transformation to the overall centre of mass, which might be more natural intuitively, the enhancement becomes even stronger. This suggests that, at least for our energy, the shuffling technique is not well suited to construct a reference distribution. It is, therefore, not used in our analysis.

ACKNOWLEDGEMENTS

We are deeply indepted to the CERN SPS, beam and EHS crews for their support during preparation and runs of our experiment.

It is a pleasure to thank the scanning and measuring staff of our laboratories for their often tedious effort in scanning and measuring the RCBC film.

REFERENCES

[1] R. Hanbury Brown and R.Q. Twiss, Phil. Mag. **45**, 663 (1954); Nature **178**, 1046 (1956).
[2] G.I. Kopylov and M.I. Podgoretskii, Sov. J. Nucl. Phys. **15**, 219 (1972) and **18**, 336 (1974).
G.I. Kopylov, Phys. Lett. **B 50**, 472 (1974).
[3] E.V. Shuryak, Phys. Lett. **B 44**, 387 (1973).
G. Cocconi, Phys. Lett. **B 49**, 459 (1974).
M. Biyajima, Phys. Lett. **B 92**, 193 (1980).
[4] G. Goldhaber et al., Phys. Rev. Lett. **3**, 181 (1959); Phys. Rev. **120**, 300 (1960).
[5] F. Grard et al., Nucl. Phys. **B 102**, 221 (1976).
[6] M. Deutschmann et al., Nucl. Phys. **B 103**, 198 (1976) and **B 204**, 333 (1982).
[7] N.N. Biswas et al., Phys. Rev. Lett. **37**, 175 (1976).
[8] E. Calligarich et al., Lett. Nuovo Cim. **16**, 129 (1976).
[9] C. Ezell et al., Phys. Rev. Lett. **38**, 873 (1977).
[10] N. Angelov et al., Sov. J. Nucl. Phys. **26**, 419 (1977) and **33**, 671 (1981).
[11] E. De Wolf et al., Nucl. Phys. **B 132**, 383 (1978).
[12] A. M. Cooper et al., Nucl. Phys. **B 139**, 45 (1978).
[13] M. Goossens et al., Nuovo Cim. **48A**, 469 (1978).
[14] A. A. Loktionov et al., Sov. J. Nucl. Phys. **27**, 819 (1978).
[15] D. Drijard et al. (CCHK), Nucl. Phys. **B 155**, 269 (1979).
[16] V. G. Grishin et al., Uspekhi Fiz. Nauk **127**, 51 (1979).
[17] G. Borreani et al., Nuovo Cim. **61A**, 1 (1981).
[18] B. V. Batyunia et al., Czech. J. Phys. **31**, 475 (1981).
[19] C. de Marzo et al. (NA5), Phys. Rev. **D 29**, 363 (1984).
[20] A. Breakstone et al. (ABCDHW), Phys. Lett. **B 162**, 400 (1985) and Z. Phys. **C 33**, 333 (1987).
[21] T. Åkesson et al. (AFS), Phys. Lett. **B 129**, 269 (1983); **B 155**, 128 (1985); **B 187**, 420 (1987) and CERN-EP/87-142.
[22] R. Carlsson et al., Phys. Scr. **31**, 21 (1985).
[23] U. Becker et al., Nucl. Phys. **B 151**, 357 (1978).
[24] S. Y. Fung et al., Phys. Rev. Lett. **41**, 1592 (1978).
[25] J.J. Lu et al., Phys. Rev. Lett. **46**, 989 (1981).
[26] D. Beavis et al., Phys. Rev. **C 27**, 910 (1983).
[27] W.A. Zajc et al., Phys. Rev. **C 29**, 2173 (1984).
[28] Goldhaber, Proc. of Int. Conf. on High Energy Physics, Lisbon (1981) p.767.
[29] H. Aihara et al. (TPC), Phys. Rev. **D 31**, 996 (1985).
[30] P. Avery et al. (CLEO), Phys. Rev. **D 32**, 2294 (1986).
[31] M. Althoff et al. (TASSO), Z. Phys. **C 29**, 347 (1985) and **C 30**, 355 (1986).
[32] M. Arneodo et al. (EMC), Z. Phys **C 32**, 1 (1986).
[33] S. Barshay, Phys. Lett. **B 130**, 220 (1983).
[34] M.G. Bowler, Z. Phys. **C 29**, 617 (1985).
[35] B. Andersson and W. Hofmann, Phys. Lett. **B 169**, 364 (1986).
[36] F. Meijers, PhD. Thesis, Univ. of Nijmegen, May 1987.
[37] G.N. Fowler and R.M. Weiner, Phys. Lett. **B 70**, 201 (1977);
A. Giovannini and G. Veneziano, Nucl. Phys. **B 130**, 61 (1977);
M. Gyulassy et al., Phys. Rev. **C 20**, 2267 (1979);
M. Biyajima, Prog. Theor. Phys. **66**, 1378 (1981).
[38] P. Grassberger, Nucl. Phys. **B 120**, 231 (1977).
[39] M. Adamus et al. (NA22), Z. Phys. **C32**, 475 (1986).
[40] A. Capella, Proc. Europhysics Study Conf. on Partons and Soft Hadronic Processes, Erice (1981), ed. R.T. Van de Walle (World Scientific, Singapore) p.199.
E.A. De Wolf, Proc. XV-th Int. Symp. on Multiparticle Dynamics, Lund (1984), Ed. G. Gustafson (World Scientific, Singapore) p.2.
[41] A. Wróblewski, private communication.

Table 1: Fit results for eq. (5) to the ratio R as a function of Q^2. Data on negative particle pairs, shown in Fig. 1.

reference sample	λ	β $(\mathrm{GeV/c})^{-2}$	γ	δ $(\mathrm{GeV/c})^{-2}$	χ^2/NDF	r fm
mixed event	0.35±0.02	15.2±1.2	0.937±0.005	0.028±0.007	112/96	0.77±0.03
unlike	0.38±0.01	17.7±1.0	0.990±0.005	0.010±0.005	112/ 84	0.83±0.02

Table 2: Fit results for eq. (4) to the ratio R as a function of q_T. Data on negative particle pairs for $q_0 \leq 0.2$ GeV, shown in Fig. 2.

reference sample	λ	β $(\mathrm{GeV/c})^{-2}$	γ	δ $(\mathrm{GeV/c})^{-1}$	χ^2/NDF	r fm
mixed event	0.30±0.03	7.0±0.5	0.913±0.029	0.038±0.047	42/36	1.38±0.10
unlike	0.45±0.05	6.3±0.1	0.828±0.033	0.180±0.065	56/35	1.24±0.02
mixed event	0.28±0.02	7.3±0.4	0.937±0.005	fixed to 0	4 3/36	1.44±0.08
unlike	0.32±0.01	7.1±0.2	0.929±0.005	fixed to 0	6 5/36	1.40±0.04

Table 3: Fit results for eq. (5) to the ratio R as a function of Q^2. Data on pairs of particles with ISIS identification, shown in Fig. 3.

reference sample	λ	β $(\mathrm{GeV/c})^{-2}$	γ	δ $(\mathrm{GeV/c})^{-2}$	χ^2/NDF	r fm
all positives	0.17±0.03	21.2±7.3	0.97±0.01	0.01±0 .02	52/46	0.91±0.16
all negatives	0.35±0.05	20.9±4.7	0.96±0.02	-0.02±0 .03	44/46	0.90±0.10
$\pi^+\pi^+$	0.30±0.04	17.3±2.2	0.94±0.01	0.05± 0.03	33/46	0.82±0.05
$\pi^-\pi^-$	0.42±0.09	24.5±8.3	0.97±0.02	-0.07±0 .04	34/46	0.98±0.17

Table 4: Fit results for eq. (5) to the ratio R as a function of Q^2, for selections on the charge multiplicity n. Data on negative particle pairs, normalized by the mixed event reference sample, shown in Fig. 4.

n	λ	β $(\mathrm{GeV/c})^{-2}$	γ	δ $(\mathrm{GeV/c})^{-2}$	χ^2/NDF	r fm
6-8	0.42±0.07	20.9±5.2	0.982±0.012	-0.05±0.01	76/94	0.90±0.11
10	0.26±0.04	10.3±3.5	0.936±0.018	0.00±0.02	125/94	0.63±0.11
12	0.39±0.04	19.2±1.7	0.923±0.009	0.05±0.01	88/94	0.86±0.04
≥14	0.36±0.02	13.1±1.9	0.925±0.010	0.05±0. 01	134/94	0.71±0.05

Table 5: Fit results for eq. (5) of the ratio R as a function of Q^2, for selections on $|cos\theta|$ (see text). Data on negative particle pairs, normalized by the mixed event reference sample, shown in Fig. 6.

cut	λ	β $(\mathrm{GeV/c})^{-2}$	γ	δ $(\mathrm{GeV/c})^{-2}$	χ^2/NDF	r fm
$0.7 < \lvert cos\theta \rvert < 1$	0.39±0.03	16.0±2.3	0.924±0.007	0.037± 0.009	92/94	0.79±0.06
$0.3 < \lvert cos\theta \rvert < 0.7$	0.35±0.05	26.2±6.6	0.960±0.010	0.018±0.015	88/94	1.01±0.13
$0 < \lvert cos\theta \rvert < 0.3$	0.33±0.04	13.1±1.9	0.919±0.013	0.048 ±0.022	94/94	0.71±0.05

FIGURE CAPTIONS

Fig. 1: The ratio R as a function of Q^2, for negative particles, as obtained with the a) mixed event and b) unlike reference sample. The curves correspond to the best fit with parametrization (5).

Fig. 2: The ratio R as a function of q_T, for negative particles, as obtained with the a) mixed event and b) unlike reference sample. Pairs are in the interval $q_0 \leq 0.2$ GeV. The curves correspond to the best fits with parametrization (4).

Fig. 3: The ratio R as a function of Q^2, for positive (a,c,e) and negative (b,d,f) tracks with ISIS particle identification. The plots correspond to pairs of all positive and all negative particles (a,b), pairs of pions (c,d) and pairs of a pion with a particle identified as not being a pion (e,f). The curves in (a-d) correspond to the best fits with parametrization (5).

Fig. 4: The ratio R as a function of Q^2, for negative particles, with selections on the charge multiplicity n as indicated. Data are normalized by the mixed event reference sample. The curves correspond to the best fits with parametrization (5).

Fig. 5: The a) strength λ and b) size r_G, based on parametrization (5), as a function of the charge multiplicity n.

Fig. 6: The ratio R as a function of Q^2, for negative particles, with the $|cos\theta|$ selections as indicated. Data are normalized by the mixed event reference sample. The curves correspond to the best fits with parametrization (5).

Fig. 7: The ratio R as a function of Q^2, for negative particles, obtained from DPM Monte Carlo events. Normalization by the a) mixed event and b) unlike reference sample.

Fig. 8: The ratio R as a function of q_T, for negative particles, obtained from DPM Monte Carlo events. Normalization by the a) mixed event and b) unlike reference sample. Pairs are in the interval $q_0 \leq 0.2$ GeV.

Fig. 9: The ratio R as a function of q_T, for negative particles, obtained from DPM Monte Carlo events. Normalization by the shuffled reference sample. Pairs are in the interval $q_0 \leq 0.2$ GeV.