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SHORT-RANGE CORRELATIONS IN HADRON PAIR PRODUCTION
AT $p_T \geq 2$ GeV/c

The WA77 Collaboration

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Abstract : Production of oppositely charged particle pairs at large p_T is studied, where both particles are in the central rapidity region within one unit of rapidity and nearby in azimuth. The data sample, which comes from $\pi^- Be$ interactions obtained using the CERN OMEGA spectrometer, contains events with a pair of oppositely charged particles having $p_T \geq 2$ GeV/c recoiling against a third one with $p_T \geq 1$ GeV/c. Our data provide new information on short range correlations involving the production of the nine possible pairs made from (π^+, K^+, p) and $(\pi^-, K^-, \bar{p})$. Comparison with Lund Monte Carlo predictions is made. Apart from proton yields, the model reproduces correctly our data. The main discrepancies observed with protons can be attributed to hard scattering of diquarks from the target nucleons.

Keywords : Correlations, quantum chromodynamics, string models, quark model.

Free keywords : high- p_T jets, diquarks.

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1 Introduction

It is now widely recognized that hadrons consist of pointlike partons (quarks and gluons) and that high- p_T hadron scattering occurs through the interaction of these constituents. The observed spectra follow from the partons coming out of the hard process through a fragmentation mechanism during which hadrons are generated. This parton picture which underlies QCD is complicated by possible diquarks which could exist inside baryons and undergo hard scattering, or could be produced pairwise in the course of the fragmentation process ; this is the standard picture to explain high- p_T baryons. A comprehensive review of this physics can be found in ref. [1].

As a consequence for all QCD based models, such as the Lund string model and subsequent Monte Carlo programs[2], it is important to collect information on the fragmentation scheme, which can be used in turn to tune the unavoidable free parameters in the simulations. A valuable source of information is provided by the study of correlations between particles produced nearby in azimuth and within a small rapidity interval ; in this case, pair production results from the fragmentation of the flux tubes drawn between coloured partons. One approach is to study how strangeness and baryon number (assumed to be connected to diquarks) are created at sufficiently large p_T and how the necessary compensation occurs. Baryonic number as well as strangeness must be conserved at the overall event level ; however, the present view of the fragmentation scheme implies that conservation laws could apply locally in the available phase space and this is subject to tests.

A large body of data is now available from e^+e^- , μN , $\nu(\bar{\nu})N$ collisions as well as hadron-hadron interactions. The main results on strangeness and baryonic quantum numbers compensation are summarized below.

Large values of Short Range Correlations (SRC) in producing K^+K^- , $K_S^0 K_S^0$ pairs or $K^\pm K_S^0$ are reported in e^+e^- annihilation experiments[3], high- p_T pp collisions[4][5] and μN deep inelastic scattering[6]. This indicates that $s\bar{s}$ quark pairs are created close together in the fragmentation process of high- p_T partons. SRC in rapidity have also been observed without any regard to the possible strangeness content of the hadrons involved in the fragmentation process[7][8]. Beside these large *positive* SRC reported in the production of K^+K^- , $K_S^0 K_S^0$, $\Lambda \bar{\Lambda}$ or $\bar{p} \Lambda$ pairs, it has also been found that SRC are *negative* for $\bar{p} \bar{p}$, $K^\pm K^\pm$, $\Lambda \Lambda$, $\bar{\Lambda} \bar{\Lambda}$ pairs. Within the framework of the Lund string model[2] for instance, this shows that $(s\bar{s})$ and diquark-antidiquark pairs are produced closer together than (ss) , $(\bar{s}\bar{s})$ or diquark-diquark pairs.

The ARGUS collaboration[9] has recently enlarged the field of correlation data in the baryon-antibaryon sector ($p\bar{p}$, $\Lambda\bar{\Lambda}$, $\Xi\bar{\Xi}$). To get simultaneous agreement between the Lund model on the one hand, and the observed correlations together with the measured ratio Ξ^-/Λ on the other hand, this collaboration suggests : (i) a nearly complete suppression of the local mode of producing baryon-antibaryon pairs in the so-called popcorn model[2], (ii) a much weaker suppression of the strange diquark (us) with respect to the non-strange one (ud) in the string fragmentation than the experiments already quoted[3-8].

This suggests a contradiction which needs to be analyzed further. It is therefore useful to get new experimental results.

We note that SRC for $p \bar{p}$ pairs can be shadowed by possible pre-existing diquarks inside protons in hadronic interactions[1] ; it has been found[1][10] that such an effect exists but is negligible at large cms scattering angles and large cms energy. At lower energy however, prompt protons coming from fragmenting these diquarks[11] give much larger rates, even at large cms angles.

SRC are understood as proving that flavour compensation – in terms of quarks and diquarks – is achieved inside the same jet. However, Long Range Correlations (LRC) in rapidity can also arise if flavour is compensated by a quantum number transfer between two jets (*i.e.* a high- p_T one and the forward one for instance)¹. Such information is available in the papers quoted above[4][5][6][10] ; ref.[12] finds a negative correlation between high- p_T protons and forward protons, while they get a positive correlation between a high- p_T K^+ and a forward Λ . This is in agreement with the common belief[1][4-6][10-13] that when protons are involved in any interaction, they split up mainly into u quarks and ud diquarks, thus favouring a $\bar{s}$ quark associated with u to give a K^+ and a s quark associated with ud to give a Λ .

We present the results obtained by the WA77 collaboration on SRC. An experiment on $\pi^- Be$ interactions at $p_{lab} = 300$ GeV/c has been performed with the main purpose of studying the prompt production mechanism of the ρ^0 meson at $p_T \geq 2$ GeV/c[14]. The trigger was designed to select events in which a pair of oppositely charged particles is produced in the central rapidity region ($Y_{lab} \simeq 3.23$) at $p_T \geq 2$ GeV/c, opposite in azimuth to a third one with $p_T \geq 1$ GeV/c. From geometrical reasons, these trigger particles come mainly from fragmenting high- p_T scattered partons with a negligible contamination of low- p_T remnants ; this has been confirmed by our comparison with a Lund simulation[14]. Our previous results[14][15] mainly deal with resonance signals, but here we shall be more interested by the particle pairs beneath them. Indeed, around 90% of our pairs do not come from resonances decaying into two charged particles and a large fraction of these pairs are leading fragments of high- p_T jets. This provides us with the opportunity to study short range correlations in the production of nine kinds of oppositely charged particle pairs, one being chosen from (π^+, K^+, p) , the other from $(\pi^-, K^-, \bar{p})$, with a good statistics ($\simeq 18,000$ events). There is presently little information available on most of the correlations which can be established from our data.

After a brief overview of the WA77 experiment (§2), we shall describe our data pair sample (§3). The way to correct the data for Cerenkov inefficiencies and particle misidentifications is described in section 4. We then outline the various contributions to the acceptance corrections applied to the pair yields (§5), and we focus on the p_T pair distributions. In section 6 we shall describe the correlation function which will be used in this study. In section 7 we discuss the correlations coming out of our experimental data. We finally compare our correlation results with those of a Lund Monte Carlo sample (§8). Section 9 is devoted to a

¹This can be achieved in the fragmentation process but it can also be produced at the hard process level.

summary of the main conclusions.

2 Overview of the WA77 experiment

The WA77 experiment has been performed using the CERN OMEGA spectrometer. Details of the layout (see figure 1(a)) and the trigger (see figure 1(b)) have been given in previous publications[14][16][17]. Our trigger selected events having three tracks with $p_T \geq 0.9$ GeV/c and cms rapidities $-1 \leq Y_{cms} \leq +1$. The trigger is sketched in figure 1(b) : a pair of oppositely charged particles at large p_T is produced opposite in azimuth to a third one. The opening angle of the pair in the plane tranverse to the beam is $\Phi \leq 45$ degrees. The trigger is expected to enhance pairs coming from high- p_T jets with a reduced contamination of spectator fragments from the beam and target. Thus our data are suitable to look for short range correlations in parton fragmentation.

Selecting events with a well reconstructed vertex leaves us with 209,654 triggers for which the pair and opposite particles fulfil the following conditions :

$$\left\{ \begin{array}{l} p_T^{trig.part.} \geq 1.0 \text{ GeV/c} \\ p_T^{pair} \geq 2.0 \text{ GeV/c} \\ -0.5 \leq Y_{cms}^{pair} \leq +0.5 \end{array} \right. , \quad (1)$$

using obvious notations.

In this sample we have signals corresponding to the two-body decays of the mesons ρ^0 , ϕ , K^{*0} , $\bar{K}^{*0}$ and $f_2(1270)$ which could affect the correlations we want to study. However, around 90% of our pairs do not come from two-body decays of these resonances. The acceptance for meson resonances decaying into more than two particles is small and their production rates are also expected to be small, so that this additional source of correlated pairs is negligible. Finally, no significant signal of the baryon resonances Δ^0 or $\bar{\Delta}^0$ is found in our data.

3 The data sample

Identification of the trigger particles is obtained by means of two multicell Cerenkov counters[16][17] (see figure 1(a)), the first one filled with freon 12, the second one with CO_2 , both at atmospheric pressure. The effective thresholds are given in table 1. These provide a common momentum range in which π , K , p can be identified by means of their Cerenkov response combination, in principle without ambiguity :

$$11.0 \leq |\vec{p}| \leq 17.0 \text{ GeV/c} . \quad (2)$$

We shall use in the following only those pairs for which both particles satisfy conditions

(1) and (2). The total number of pairs which survive these cuts is 25,206 (12.0% of the original sample). In this subsample, the number of pairs for which an unambiguous Cerenkov information is available is 18,117 (72% of the total); the remaining events are those for which at least one pair member falls outside the Cerenkov acceptance ($\simeq 15\%$) or those unidentified because of inefficiency ($\simeq 10\%$) of the scintillator hodoscopes HY1–HY3 (see figure 1(a)) or those for which the Cerenkov information is conflicting ($\simeq 3\%$). This last cause of rejection is due partly to the inefficiencies of our Cerenkov counters, partly to secondary interactions, and partly to the relatively large multiplicity environment we are dealing with (the mean number of charged tracks coming out of the target is $\simeq 15$).

	π	K	p
C_1	3.1	10.8	20.5
C_2	4.9	17.2	32.8

Table 1 : Cerenkov Threshold in GeV/c.

This high multiplicity environment leads us to check, for each pair assignment, the level of contamination due to misidentification. In order to make a qualitative estimate of this source of systematic errors, we use the signals of the ρ^0 - and ϕ -mesons which have been observed in our experiment[14][17], and compare the two-body mass spectra when the correct or wrong mass assignments are given to their decay products.

In figure (2) we have plotted effective mass spectra for the data subsamples identified by the Cerenkov counters as being $\pi^+\pi^-$, K^+K^- , π^+K^- , π^-K^+ pairs with the mass assignments $\pi^+\pi^-$ (leftside column) and K^+K^- (rightside column). In both subsamples of identified (π K) pairs, we clearly see the ϕ -meson signal and a small enhancement located at the ρ^0 mass. However, we observe a clear ρ^0 signal in the subsample of identified $\pi^+\pi^-$ pairs. The enhancements observed in the (π K) subsamples around 0.65 GeV/c (using the $\pi^+\pi^-$ mass assignment) and 1.10 GeV/c (using the K^+K^- mass assignments) are the expected reflections of the K^{*0} and $\bar{K}^{*0}$ signals. Finally, in the subsample of identified K^+K^- pairs, beside the ϕ signal, both the ρ^0 and K^{*0} reflections slightly emerge from the background.

This analysis leads us to conclude that the probability of misidentifying kaons as pions is larger than the converse. This feature can be attributed to the large number of produced particles which can provide light in the Cerenkov counters. Therefore the probability of having a non-trigger particle in the same Cerenkov cell as a trigger kaon is large.

On the other hand, we expect the contamination of p and $\bar{p}$ to be mainly due to misidentified kaons (because of C_1 inefficiency) and pions (because of combined C_1 and C_2 inefficiencies). This source of contamination is small (see §4 and appendix A).

To summarize this discussion, the main misidentification problem turns out to be the contamination of pions by both protons and kaons, and that of kaons by protons only. The reason already quoted is the large particle multiplicity in the Cerenkov counters. This is our main source of systematic errors.

4 Corrections for inefficiencies and misidentifications

In this section, we shall briefly describe the method used to correct the data for inefficiencies and misidentifications ; the detailed discussion is postponed to appendix A.

Let us denote N_{π}^{true} , N_K^{true} , N_p^{true} the true numbers of produced particles of given charge and kind. Let us also denote $N_{\pi}^{obs.}$, $N_K^{obs.}$, $N_p^{obs.}$ the corresponding observed ones as assigned by the Cerenkov information. The relation between both sets of numbers can be written in matrix notation :

$$\begin{pmatrix} N_{\pi}^{obs.} \\ N_K^{obs.} \\ N_p^{obs.} \end{pmatrix} = \begin{pmatrix} \varepsilon_{\pi} & f_{\pi K} & f_{\pi p} \\ f_{K\pi} & \varepsilon_K & f_{Kp} \\ f_{p\pi} & f_{pK} & \varepsilon_p \end{pmatrix} \begin{pmatrix} N_{\pi}^{true} \\ N_K^{true} \\ N_p^{true} \end{pmatrix} \quad (3)$$

The diagonal elements in this matrix are simply the efficiencies to assign correctly π , K , p respectively. The off-diagonal elements f_{ab} are the probabilities to misidentify a particle of kind b as being a particle of kind a . From the discussion above we expect $f_{\pi K}$, $f_{\pi p}$, f_{Kp} to be important, and $f_{K\pi}$, $f_{p\pi}$, f_{pK} to be rather small. To estimate the value of the f_{ab} and ε_a , we have used :

i) the efficiencies ε_1 and ε_2 of the Cerenkov counters C_1 and C_2 to provide light when it is physically expected,

ii) the probabilities c_1 and c_2 to get a fake signal in C_1 and C_2 respectively,

iii) the probability c_{12} to get a fake signal in C_1 and C_2 simultaneously.

Efficiencies ε_1 and ε_2 have been estimated using the probabilities to detect light for particles with momenta greater than 36 GeV/c (*i.e.* well above all thresholds, see table 1). Probabilities c_1 and c_2 have been deduced from the frequencies of signals in the Cerenkov cells adjacent to the corridor defined by means of the trigger particle hits in the scintillator hodoscopes HY1-HY3 (see figure 1(a)).

The probability c_{12} is not necessarily equal to the product $c_1 c_2$, because fake signals could be due to real particles accompanying the trigger ones. Therefore we have considered two cases : No correlation between fake signals in C_1 and C_2 ($c_{12} = c_1 c_2$) and full correlation between them ($c_{12} = \text{Min}[c_1, c_2]$). We shall always give the results corresponding to these two extreme assumptions. We have also considered the effect produced on the yields when varying ε_1 , ε_2 , c_1 and c_2 within their statistical errors. This effect has always been found negligible as compared to those produced when varying c_{12} in the quoted range.

The connection between ε_1 , ε_2 , c_1 , c_2 , c_{12} and the elements of the matrix in relation (3), together with their values, can be found in appendix A. Another estimate of the matrix in relation (3) can be deduced using the resonance signals observed in our data (ρ^0 , ϕ , K^0 , Λ , $\bar{\Lambda}$). These two independent estimates have been found to be in good agreement (see appendix A).

Inverting relation (3) allows to express the true number of each particle kind in terms of the observed yields. Let us notice that the sum of the probabilities in each column of the matrix in relation (3) is always slightly smaller than 1 because the probability to get an unphysical Cerenkov assignment (*i.e.* no light in C_1 , light in C_2) is non zero. We have also

checked that the yield of particles with unphysical assignment obtained by this method is in agreement with the experiment value.

As described above, this method applies to single particle yields of a given charge. It can be easily extended to particle pair yields as explained in appendix A.

In the following, we shall always give our numerical results in the form $a \div b$, where a refers to the “no correlation hypothesis” in having fake signals in C_1 and C_2 simultaneously, and b refers to the “full correlation hypothesis”. We consider the interval between these two numbers as the full range of our systematic errors (it is not a standard deviation).

To summarize, using this method we have been able to get the yields corrected for inefficiencies and misidentifications in both the pair and opposite sides of our trigger.

5 Acceptance corrections on yields

In order to analyze the correlations for our nine kinds of particle pairs, we need also to correct the pair yields for acceptance. Since we only deal with ratios, we can evaluate acceptances relative to any kind of pair chosen as reference and we choose $\pi^+\pi^-$.

5.1 Rapidity and mass distributions of pairs

We have found that relative acceptances for the possible kinds of pair depend only slightly on rapidity and invariant mass distributions of the particle pairs. We have used the following distribution for the pair rapidity in the πN centre-of-mass system :

$$f(Y_{cms}^{pair}) = \text{Constant} \quad , \quad -0.5 \leq Y_{cms}^{pair} \leq +0.5 \quad (4)$$

and the invariant mass distribution :

$$f(M) = \frac{q^*}{M} \exp[-0.33(M + M^2)] \quad (5)$$

for all kinds of pairs, where q^* is the momentum of each particle in the pair rest frame and M is the invariant mass of the pair expressed in GeV.

We have checked that distribution (4) describes our data and we have fixed the parameter in distribution (5) using fits of the background in the observed mass spectra. Notice that relation (5) shows the correct threshold behaviour and peaks in the low mass region for any particle pair. Our correlation results are weakly dependent on these distributions. In fact, using flat distributions for both rapidity and invariant mass produces effects below a 5% level.

5.2 p_T distributions of pairs

When integrated over the kinematical range we study, acceptance values are more sensitive to the p_T distributions of the pairs than to their invariant mass and rapidity distributions. Therefore we have computed them using p_T distributions fitted to our data.

In order to increase the statistics in the observed p_T -distributions, we have relaxed condition (2). The correction function which accounts for our experimental p_T acceptance has been obtained by generating events using distributions (4) and (5) and a flat distribution for the p_T of the pairs. We have assumed isotropic angular distribution of the particles in the rest frame of the pair. The p_T acceptance is represented in figure 3 and has been checked to be the same, regardless of the pair kind involved. It is very small below 2 GeV/c (as expected from our trigger conditions) and increases smoothly up to 5 GeV/c.

	Sample	$f(p_T) = (p_T - 2.)^b \exp[-a p_T]$		
		b	a	χ^2/NDF
1	$\pi^+ \pi^-$	0.26 ± 0.01	3.80 ± 0.03	71/58
2	$K^+ K^-$	0.37 ± 0.02	3.90 ± 0.06	47/45
3	$\pi^+ K^-$	0.28 ± 0.01	3.91 ± 0.04	63/53
4	$\pi^- K^+$	0.27 ± 0.01	3.88 ± 0.04	51/54
5	$p \pi^-$	0.25 ± 0.01	3.75 ± 0.04	43/56
6	$\bar{p} \pi^+$	0.26 ± 0.01	3.84 ± 0.04	51/55
7	$p K^-$	0.36 ± 0.02	3.50 ± 0.06	31/48
8	$\bar{p} K^+$	0.34 ± 0.02	3.67 ± 0.06	31/46
9	$p \bar{p}$	0.32 ± 0.02	3.20 ± 0.06	15/49

Table 2 : Fit of random pair p_T distributions

The experimental p_T -distributions, corrected for acceptance have been fitted in the range $p_T = 2 \div 5$ GeV/c, using the following expression :

$$f(p_T) = (p_T - 2.0)^b \exp(-ap_T) \quad (6)$$

The first factor in relation (6) allows for the difficulties of estimating correctly the p_T acceptance effects near our p_T threshold. This could be connected with the fact that the assumption of isotropic angular distribution of particles in the pair rest frame may not be correct in the lower p_T region.

We have also checked that :

$$f(p_T) = \exp(-ap_T) \quad (7)$$

with the same value for a as in relation (6) provides a good description of the region $p_T = 2.2 \div 5.0$ GeV/c with much better χ^2 for the corresponding pair. This indicates that the values of a coming from our fits are not affected by the threshold behaviour. Examples of fits are reproduced in figure 4 and the parameters are given in table 2. Pairs related by charge conjugation have parameters a and b nearly equal as expected. The observed variation of a in the range $3.2 \div 3.9$ would result in a change of $\simeq 10\%$ in the acceptance correction factor. Other functional shapes[18], have been tried but do not improve the fits.

5.3 Fully corrected pair yields

Acceptance corrections for the nine possible kinds of pairs have been computed by generating pairs using distributions (4), (5) and (6) and tracking the particles through a simulation of our setup. The acceptances normalized to that of $\pi^+\pi^-$ pairs are displayed in table 3 together with the raw yields.

	Pair	Raw yield	Acceptance	Acceptance corrected pair yields	Relative statistical error
1	$\pi^+\pi^-$	10392	1.	$9220 \div 8773$	1 %
2	$K^+ K^-$	1023	1.174	$1266 \div 1444$	3 %
3	$\pi^+ K^-$	1681	0.994	$1254 \div 1460$	3 %
4	$\pi^- K^+$	3018	0.994	$1956 \div 2691$	2 %
5	$p \pi^-$	1068	0.866	$3245 \div 2169$	3 %
6	$\bar{p} \pi^+$	336	0.866	$1033 \div 517$	6 %
7	$p K^-$	277	1.159	$231 \div 478$	6 %
8	$\bar{p} K^+$	169	1.159	$0 \div 191$	8 %
9	$p \bar{p}$	153	1.284	$1184 \div 579$	8 %

Table 3 : Pair yields corrected for acceptance, efficiency and misidentification

As already mentioned, the two corrected yields given here correspond to our full systematic error range. They account fully for Cerenkov inefficiencies, misidentifications and acceptance effects.

6 The pair correlators

We are interested in looking for possible short range correlations in pairs of oppositely charged particles produced at large p_T within a small distance in rapidity and azimuth. First

of all, we need to define the correlation function we plan to use. A variety of such functions or indicators is used in the literature[2-10][12][19], depending on the experimental conditions ; this makes difficult a quantitative comparison among the various conclusions. We intend to draw conclusions using our correlation indicators and comparing their values in our data sample and in a Lund simulation sample. We have chosen to analyze our data using the correlation function defined below. This correlation function is well adapted to our trigger ; its statistical meaning and some of its physical properties are illustrated in appendix B.

Let us denote X^+ or X^- any possible particle in our sample with charge +1 or -1 ; let us moreover denote $A^\pm, B^\pm, \dots$ any specified particle among (π, K, p) with the indicated charge. We shall denote $[A^+B^-]$ the yield of A^+B^- pairs and $[X^+X^-]$ the total number of pairs in the sample with both particles satisfying conditions (1) and (2).

If we approximate probabilities by frequencies, the probability to get a given pair A^+B^- can be written as :

$$\text{Prob}(A^+B^-) = \frac{[A^+B^-]}{[X^+X^-]} \quad , \quad (8)$$

the probability to get a pair with A^+ together with *any* negative particle X^- as :

$$\text{Prob}(A^+X^-) = \frac{[A^+\pi^-] + [A^+K^-] + [A^+\bar{p}]}{[X^+X^-]} \quad , \quad (9)$$

and the probability to get a pair with B^- together with *any* positive particle X^+ as :

$$\text{Prob}(X^+B^-) = \frac{[\pi^+B^-] + [K^+B^-] + [pB^-]}{[X^+X^-]} \quad . \quad (10)$$

Then we define the correlator of A^+ and B^- particles by :

$$\mathcal{C}(A^+B^-) = \frac{\text{Prob}(A^+B^-)}{\text{Prob}(A^+X^-)\text{Prob}(X^+B^-)} - 1 \quad (11)$$

The correlation indicator $\mathcal{C}(A^+B^-)$ has the property that $\mathcal{C}(A^+B^-) = 0$ if the production of A^+ and that of B^- are statistically independent. If $\mathcal{C}(A^+B^-) > 0$ the production of A^+ and that of B^- is enhanced by each other (*positive* SRC), while $\mathcal{C}(A^+B^-) < 0$ means that producing A^+ and B^- are partly exclusive of each other (*negative* SRC).

The properties of our correlator and its connection with the usual one are discussed in appendix B. Let us stress that the properties of correlators are tightly connected with the sample on which they are defined (see appendix B). For instance, our trigger conditions select events with oppositely charged particle pairs at large p_T .

As a consequence, some other kind of correlation cannot be revealed using our indicator (11) : even if a 2-particle correlation is expected to occur in a given mode ($\pi^+\pi^-$ for instance), if this mode is much more produced than all the other possible ones (this is the case with $\pi^+\pi^-$ pairs in our sample), it turns out from relations (8)–(10) that the corresponding correlator approaches zero. This is of course due to the definition of our sample.

7 Correlations in particle pair production

The pair yields corrected for Cerenkov inefficiencies, misidentifications and acceptance effects have been already given in table 3. They lead to the correlators given in table 4. In each case, the statistical error quoted is the average of the statistical errors of the correlators obtained in each of the two extreme cases described in section 4.

	Correlator $\mathcal{C}$	Values	Average statistical errors
1	$\mathcal{C}(\pi^+ \pi^-)$	$0.07 \div 0.10$	0.01
2	$\mathcal{C}(K^+ K^-)$	$1.81 \div 0.80$	0.05
3	$\mathcal{C}(\pi^+ K^-)$	$-0.23 \div -0.26$	0.02
4	$\mathcal{C}(\pi^- K^+)$	$-0.17 \div -0.16$	0.01
5	$\mathcal{C}(p \pi^-)$	$-0.07 \div -0.10$	0.02
6	$\mathcal{C}(\bar{p} \pi^+)$	$-0.20 \div -0.32$	0.04
7	$\mathcal{C}(p K^-)$	$-0.65 \div -0.20$	0.03
8	$\mathcal{C}(\bar{p} K^+)$	$-1.00 \div -0.37$	0.03
9	$\mathcal{C}(p \bar{p})$	$1.28 \div 1.55$	0.10

Table 4 : Fully corrected pair correlators

A general qualitative conclusion which can be drawn from our analysis is that all correlations are those expected on general grounds, simply assuming dominance of valence quarks inside the interacting hadrons (see the examples presented in appendix B). Of course, the precise absolute values of the correlators are model dependent, and therefore we shall make a comparison in the next section.

As expected, the possible correlation in $\pi^+ \pi^-$ production is small due to the dominance of the corresponding pair number, while large positive correlations are observed in producing $K^+ K^-$ as well as $p \bar{p}$ pairs .

There exist significant anticorrelations (*i.e.* *negative SRC*) in producing unlike sign (πK) pairs. Finally, producing baryon-meson pairs reveals only negative correlations, regardless of the possible strangeness content of the meson. Moreover, producing baryons together with kaons looks more suppressed than with pions.

8 Comparison with Lund Monte Carlo

All the results and conclusions described in the preceding paragraph are model independent. However, we can compare them with any model which reproduces most of the available

experimental data involving high- p_T scattering and parton fragmentation. We present a comparison with the Lund Monte Carlo[2] PYTHIA 5.3 using the version JETSET 7.2 for string fragmentation.

We have tuned the strange quark suppression factor s/u and the vector meson relative abundance with respect to the pseudoscalar ones $V/(V+PS)$ using the measurement of ϕ/π^- in proton-nucleus interaction at $p_{lab} = 400$ GeV/c[20] above $p_T = 2$ GeV/c. Using $s/u = 0.32$ and $V/(V+PS) = 0.30$, we obtain from the model $\phi/\pi^- = 0.44 \pm 0.01$ while the experimental value[20] in the same p_T range is 0.42 ± 0.04 . For the same values of s/u and $V/(V+PS)$, the ratio $\phi/\frac{1}{2}(\rho^0 + \omega)$ is found equal to 0.084 ± 0.010 while the corresponding experimental measurement[21] is 0.077 ± 0.046 . Our value of s/u is in agreement with most of the other estimates (see ref.[6] for instance).

We have also introduced tensor mesons because of the large $f_2(1270)$ signal found in our data[14]. In order to compare with string fragmentation, we have chosen to fix the ratio tensor/vector to $T/V = 0.15$ in agreement with the ratios $f_2(1270)/\rho^0$ and $K^{*0}(1430)/K^{*0}(890)$ found in e^+e^- collisions[22].

All other parameters connected with baryon production in the Monte Carlo have been set to their default values. For instance, the probability to get a diquark-antidiquark pair relative to quark-antiquark is thus 0.10 and the strange diquark suppression factor $(\frac{us}{ud})/(\frac{s}{d}) = 0.40$. Production of baryon-antibaryon pairs in the string fragmentation is done according to the popcorn model[2][23] half locally (it is the so-called $B\bar{B}$ configuration), half with one meson produced between the baryon and the antibaryon (it is the so-called $BM\bar{B}$ configuration); in this last configuration, there exist two more parameters which influence the sharing of strangeness[2]. Therefore, from the point of view of correlations involving baryon production, the Lund model depends on five tunable parameters.

The generated events have been tracked through the simulation of our apparatus and 115,829 events have been accepted by the trigger, out of which 13,247 events survive the cuts defined by conditions (1) and (2). This corresponds to a reduction rate of 11.4%, which is in good agreement with our data (12.0 %). Then the generated pair yields have been corrected for acceptance in the same way as the experimental ones.

8.1 Comparison of inclusive rates

In table 5 we give the inclusive rates on the pair side and on the opposite side of our trigger (see section 2). The main features of the data are well reproduced, with the noticeable exception of proton rates in both sides of our trigger. We have also compared our data with other available experimental results. Due to the particular conditions of our trigger, the only data with which comparison is possible are that of ref. [18], where the inclusive yields of $\pi^\pm$, $K^\pm$, p , $\bar{p}$ have been measured in π^-N interactions at $p_{lab} = 300$ GeV/c (in a kinematical range corresponding to our experiment). The relevance of this comparison relies on some hypotheses: the fragmentation of both high- p_T scattered partons in the hard process are independent of each other, so that we expect the yields in our opposite side to be comparable with that of an inclusive experiment.

	Pair side		Opposite side	
	Lund	Data	Lund	Data
π^+	34.4 %	$29.8 \div 29.3$ %	33.8 %	$31.4 \div 30.8$ %
π^-	39.5 %	$37.3 \div 37.2$ %	40.0 %	$39.5 \div 39.4$ %
K^+	9.2 %	$8.2 \div 11.8$ %	8.1 %	$7.4 \div 10.7$ %
K^-	6.1 %	$7.1 \div 9.3$ %	7.3 %	$6.0 \div 7.9$ %
p	6.4 %	$12.1 \div 8.8$ %	6.0 %	$10.8 \div 8.0$ %
$\bar{p}$	4.4 %	$5.6 \div 3.5$ %	4.8 %	$4.9 \div 3.3$ %

Table 5 : Inclusive yields in the pair and opposite sides

The only correction to be applied to our data in the opposite side is that for Cerenkov inefficiencies and misidentifications, because acceptances for single particles in our experiment are independent of the kind of particle.

	WA77 opposite side	Relative statistical errors	Inclusive yields from ref[18]	Lund opposite side
π^-/π^+	$1.26 \div 1.28$	1 %	1.21 [1 $\pm$ 0.03]	1.18 [1 $\pm$ 0.02]
K^-/K^+	$0.82 \div 0.73$	3 %	0.74 [1 $\pm$ 0.07]	0.90 [1 $\pm$ 0.03]
$\bar{p}/p$	$0.46 \div 0.41$	5 %	0.45 [1 $\pm$ 0.04]	0.80 [1 $\pm$ 0.04]
K^+/π^+	$0.24 \div 0.35$	2 %	0.29 [1 $\pm$ 0.04]	0.24 [1 $\pm$ 0.03]
K^-/π^-	$0.15 \div 0.20$	2 %	0.18 [1 $\pm$ 0.06]	0.18 [1 $\pm$ 0.03]
p/π^+	$0.34 \div 0.26$	2 %	0.33 [1 $\pm$ 0.06]	0.18 [1 $\pm$ 0.03]
$\bar{p}/\pi^-$	$0.13 \div 0.08$	4 %	0.13 [1 $\pm$ 0.04]	0.12 [1 $\pm$ 0.03]

Table 6 : Ratios of yields, comparison with ref.[18] and Lund Model

In table 6 we display ratios of yields coming from our data (opposite side), ref.[18] and the Lund model. We note the agreement between our results and the corresponding inclusive ones ; this is also true if we compare with the Lund model, except for the ratios involving protons for which the data reveal an excess of about a factor 2 with respect to Lund model predictions. As already mentioned this can be attributed to target nucleon diquarks scattered at large p_T , an effect not implemented into the Lund Monte Carlo. The possibility of scattering pre-existing diquarks from nucleons at large p_T has already been examined[1][10] with the conclusion that at large $\sqrt{s}$ scattering angles and at ISR energies they do not produce sizable effects. On the other hand, in pp scattering at Serpukhov (70 GeV/c), the rate of protons produced by this mechanism was found to be large[11]. Therefore it is useful to look for their effect in πN in the SPS energy range.

Dividing the ratio $\bar{p}/p$ in the Lund sample by the corresponding one in our data, we get the relative amount of protons η :

$$\eta = \frac{p_{WA77}}{p_{Lund}} = 1.74 \div 1.95 , \quad (12)$$

with a statistical accuracy of 5%.

If the discrepancy observed between the Lund model and both data sets is only due to the quoted reason, then about 45 % of the observed protons are generated by high- p_T diquarks scattered off target nucleons.

8.2 Comparison of pair rates and correlators

In table 7, we give the rates of the different pairs in our data and in the Lund sample. We observe that the rate of $\pi^+\pi^-$ pairs predicted by the Lund model is larger than that observed experimentally. This is the consequence of the excess of protons in the data with respect to the Lund model. It must be noticed that the excess protons in the pair side are mainly produced in association with mesons, since the relative abundances of $p\bar{p}$ pairs in the data and in the model are alike. This property implies that $p\bar{p}$ pairs produced at large p_T within a small rapidity gap are mainly due to the breaking of the colour string into a diquark-antidiquark pair.

	Pair	Lund	Data
1	$\pi^+ \pi^-$	59.9 %	47.7 $\div$ 47.8 %
2	$K^+ K^-$	5.5 %	6.5 $\div$ 7.9 %
3	$\pi^+ K^-$	6.2 %	6.5 $\div$ 8.0 %
4	$\pi^- K^+$	12.6 %	10.1 $\div$ 14.7 %
5	$p \pi^-$	6.5 %	16.8 $\div$ 11.9 %
6	$\bar{p} \pi^+$	2.6 %	5.3 $\div$ 2.8 %
7	$p K^-$	0.5 %	1.2 $\div$ 2.6 %
8	$\bar{p} K^+$	0.3 %	0.0 $\div$ 1.0 %
9	$p \bar{p}$	5.8 %	6.1 $\div$ 3.2 %

Table 7 : Relative abundances of pairs in the Lund model and in the data

The correlators have been computed as described above (including the acceptance corrections) and the results are displayed in table 8 together with the corresponding experimental values from table 4.

As a general remark, the signs of the Lund correlators are in agreement with the experimental ones, which means that enhancement and suppression effects in associated productions are well reproduced by the Lund model. As far as the values of correlators are concerned, we

observe sizable disagreements only for the $p\bar{p}$, $p\pi^-$, and $\bar{p}\pi^+$ correlators.

	Correlator $\mathcal{C}$	Value and error (stat.) Lund Model	Values Experimental data
1	$\mathcal{C}(\pi^+\pi^-)$	0.10 ± 0.01	$0.07 \div 0.10$
2	$\mathcal{C}(K^+K^-)$	1.42 ± 0.07	$1.81 \div 0.80$
3	$\mathcal{C}(\pi^+K^-)$	-0.26 ± 0.02	$-0.23 \div -0.26$
4	$\mathcal{C}(\pi^-K^+)$	-0.13 ± 0.01	$-0.17 \div -0.16$
5	$\mathcal{C}(p\pi^-)$	-0.36 ± 0.02	$-0.07 \div -0.10$
6	$\mathcal{C}(\bar{p}\pi^+)$	-0.57 ± 0.02	$-0.20 \div -0.32$
7	$\mathcal{C}(pK^-)$	-0.66 ± 0.04	$-0.65 \div -0.20$
8	$\mathcal{C}(\bar{p}K^+)$	-0.80 ± 0.03	$-1.00 \div -0.37$
9	$\mathcal{C}(p\bar{p})$	4.18 ± 0.14	$1.28 \div 1.55$

Table 8 : Correlators in a Lund Monte Carlo sample and in the data

Therefore, the question is whether these disagreements can be explained by the underestimation of proton yields in the model. To explore this possibility, we have to correct the Lund pair yields in such a way that the inclusive proton rate agrees with the experimental data. As already noted, this will tend to increase the number of $p\pi^-$ and pK^- pairs, leaving nearly untouched the number of $p\bar{p}$ pairs. A rough estimate of this correction is obtained assuming the number of $p\bar{p}$ pairs is fixed and increasing the number of $p\pi^-$ and pK^- pairs by the same factor. The factor λ by which the numbers of $p\pi^-$ and pK^- pairs has to be multiplied fulfils :

$$\lambda([p\pi^-] + [pK^-]) + [p\bar{p}] = \eta([p\pi^-] + [pK^-] + [p\bar{p}]) . \quad (13)$$

Using the values (12) of η , the extreme values of λ are :

$$\lambda = 2.35 \div 2.71. \quad (14)$$

Having corrected by this factor the proton-meson pair yields, we can estimate the Lund correlators corrected for hard scattering of nucleon diquarks. The results are given in table 9 together with the experimental results.

It can be seen that the agreement between experimental data and these corrected Lund correlators is highly improved in the proton sector. However, some disagreements remain. It is likely that they could be accounted for by decreasing the relative amount of local baryon-antibaryon production with respect to the non-local one[2][23]. A similar conclusion has been reached by ARGUS collaboration[9]. Qualitatively, this change will make the baryon-antibaryon correlation weaker while introducing positive contributions in the baryon-meson correlations.

	Correlator C	Lund value diquark corrected	Value Experimental data
1	$C(\pi^+ \pi^-)$	$0.09 \div 0.08$	$0.07 \div 0.10$
2	$C(K^+ K^-)$	$1.52 \div 1.54$	$1.81 \div 0.80$
3	$C(\pi^+ K^-)$	$-0.24 \div -0.23$	$-0.23 \div -0.26$
4	$C(\pi^- K^+)$	$-0.15 \div -0.15$	$-0.17 \div -0.16$
5	$C(p \pi^-)$	$-0.15 \div -0.12$	$-0.07 \div -0.10$
6	$C(\bar{p} \pi^+)$	$-0.52 \div -0.51$	$-0.20 \div -0.32$
7	$C(p K^-)$	$-0.52 \div -0.50$	$-0.65 \div -0.20$
8	$C(\bar{p} K^+)$	$-0.79 \div -0.78$	$-1.00 \div -0.37$
9	$C(p \bar{p})$	$2.25 \div 1.98$	$1.28 \div 1.55$

Table 9 : Correlators in a diquark corrected Lund sample and in the data

9 Discussion and Conclusions

The kinematical context of our data allows us to study the short range correlations between particle species expected to occur when fragmenting high- p_T scattered partons. We have measured the correlations involved when producing unlike sign pairs of particles (π, K, p). The main sources of systematic errors have been studied.

Comparison with other experiments[3–9][19] in this field is not easy quantitatively. The main reason is that the WA77 experiment was able to trigger on pairs unlike other experiments. As a result, we can treat both particles equally and use as correlation indicator the one given by relation (11) (see also appendix B). However, we agree qualitatively with all experiments reporting results on flavour correlations[3][6][9], *i.e.* with the existence of large positive SRC in K^+K^- and $p\bar{p}$ pair productions.

We have performed a model independent analysis of SRC. Small, but significant negative correlations are observed in producing unlike sign πK pairs. This is in good agreement with the Lund model. Positive SRC have been found in the production of K^+K^- and $p\bar{p}$.

We observe that the inclusive proton yield is larger than predicted by the Lund model. Assuming this discrepancy to be fully attributed to diquark scattering leads to an estimate of about 45 % for the amount of protons coming from diquarks scattered from nucleons at high- p_T and large cms angles in $p_{lab} = 300$ GeV/c π^-N interactions.

Apart from proton yields, the Lund Monte Carlo reproduces correctly our data : inclusive yields, pair yields, correlator values and signs. This means that enhancement and suppression effects in associated pair productions are well reproduced by the model. We have shown that the discrepancies observed in the baryon sector can be attributed to the absence in the Lund model of hard scattering of diquarks preexisting inside target nucleons.

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Appendix A : Estimation of particle identification efficiencies and faking

A1 The method

As described in section 4, we want to estimate the elements f_{ab} , ($a, b = \pi, K, p$) of the matrix which connects the true physical yields N_a^{true} and the observed yields $N_a^{obs.}$ obtained using the associated Cerenkov information :

$$\begin{pmatrix} N_{\pi}^{obs.} \\ N_K^{obs.} \\ N_p^{obs.} \end{pmatrix} = \begin{pmatrix} f_{\pi\pi} & f_{\pi K} & f_{\pi p} \\ f_{K\pi} & f_{KK} & f_{Kp} \\ f_{p\pi} & f_{pK} & f_{pp} \end{pmatrix} \begin{pmatrix} N_{\pi}^{true} \\ N_K^{true} \\ N_p^{true} \end{pmatrix} \quad (A.1)$$

The coefficients f_{ab} are the probabilities for a particle of kind b to be assigned as a particle of kind a when using the corresponding Cerenkov information. The probabilities f_{aa} are the efficiencies to detect a particle of kind a (in section 4 they have been denoted by ε_a). The probabilities f_{ab} (with $a \neq b$) are the probabilities to misidentify a particle of kind b as being a particle of kind a , because of wrong Cerenkov information.

The estimates of the f_{ab} have been computed separately for positive and negative particles. The procedure used to compute them is the following :

i) For each trigger particle, we associate a corridor (2 – 3 cells) in the Cerenkov counters C_1 and C_2 using the hits registered in the hodoscopes HY1-HY3 (see figure 1a). We define a positive response of the Cerenkov counters by a signal in at least one of the cells inside this corridor.

ii) We have also counted the number of events for which there is a signal in at least one of the two Cerenkov cells adjacent to the corridor (of course, when the corridor is on the edge of the Cerenkov detector, only one side cell is available). We have assumed that these Cerenkov hits are due to background, including particles accompanying the trigger particle. Moreover, we have assumed that the frequency of background signals inside the corridor can be approximated by the measured frequencies of background signals in the adjacent cells. Knowing the width of the corridor we can therefore compute the probabilities c_1 and c_2 to obtain a positive response in C_1 and C_2 respectively, due to the background (*i.e.* not produced by the trigger particle).

iii) Using the trigger particles with laboratory momenta above 36 GeV/c (to be well above all thresholds and to expect light in both C_1 and C_2) we have estimated the probabilities p_1 and p_2 to get a positive response from C_1 and C_2 respectively.

Because of fake signals, p_1 and p_2 are not the efficiencies of the Cerenkov counters C_1 and C_2 . Indeed these numbers must be corrected for fake signals. Using the probabilities to get fake signals, the Cerenkov efficiencies for high-momentum particles are respectively :

$$\varepsilon_1 = \frac{p_1 - c_1}{1 - c_1} \quad , \quad \varepsilon_2 = \frac{p_2 - c_2}{1 - c_2} \quad . \quad (A.2)$$

Assuming that the efficiencies well above thresholds do not depend on the particle momenta, we have approximated by ε_1 and ε_2 the probabilities that the positive responses from C_1 and C_2 respectively are produced by the particle which has to give the Cerenkov signals.

iv) Finally, we have to estimate the probabilities to obtain positive responses produced by the trigger particle or by any background in both Cerenkov counters simultaneously.

To compute the probability to get some combination of Cerenkov responses associated with the trigger particle, it is natural to assume the responses of C_1 and C_2 to be uncorrelated. In this case, the combined probability to get the correct Cerenkov information is just the product of ε_1 or $1 - \varepsilon_1$ with ε_2 or $1 - \varepsilon_2$, depending on the particle kind and momentum.

A problem arises when we want to determine the probability c_{12} to get simultaneously a positive response in both Cerenkov counters due to background. Since the main source of fake signals in the Cerenkov counters can be the existence of a large number of particles accompanying the trigger one in the same Cerenkov corridor, we expect a positive correlation between background signals in C_1 and C_2 . Therefore we shall use two extreme assumptions :

a) No correlation between background signals in C_1 and C_2 ; in this case, we have :

$$c_{12} = c_1 c_2 \quad (\text{A.3})$$

b) Full positive correlation between background signals in C_1 and C_2 , and then :

$$c_{12} = \text{Min}[c_1, c_2] \quad ; \quad (\text{A.4})$$

in this case $c_{12} = c_2$, since the level of background is lower in C_2 than in C_1 .

Using these probabilities and the above mentioned assumptions, the f_{ab} can be written :

$$\left\{ \begin{array}{l} f_{\pi\pi} = \varepsilon_1 \varepsilon_2 + \varepsilon_1 (1 - \varepsilon_2) c_2 + \varepsilon_2 (1 - \varepsilon_1) c_1 + (1 - \varepsilon_1) (1 - \varepsilon_2) c_{12} \\ f_{\pi K} = \varepsilon_1 c_2 + (1 - \varepsilon_1) c_{12} \\ f_{\pi p} = c_{12} \\ f_{K\pi} = \varepsilon_1 (1 - \varepsilon_2) (1 - c_2) + (1 - \varepsilon_1) (1 - \varepsilon_2) (c_1 - c_{12}) \\ f_{KK} = \varepsilon_1 (1 - c_2) + (1 - \varepsilon_1) (c_1 - c_{12}) \\ f_{Kp} = c_1 - c_{12} \\ f_{p\pi} = (1 - \varepsilon_1) (1 - \varepsilon_2) (1 - c_1 - c_2 + c_{12}) \\ f_{pK} = (1 - \varepsilon_1) (1 - c_1 - c_2 + c_{12}) \\ f_{pp} = (1 - c_1 - c_2 + c_{12}) \end{array} \right. \quad (\text{A.5})$$

We note that the sum of the probabilities to detect a particle of a given kind a as π , K and p , ($f_{\pi a} + f_{K a} + f_{p a}$) is slightly smaller than 1, because there exists a small probability to obtain the unphysical assignment (a positive response from C_2 with no response from C_1).

A2 Numerical estimates of the probabilities

We obtain the following estimates for positive particles from our experimental data :

$$\varepsilon_1 = 0.995 , \quad \varepsilon_2 = 0.970 , \quad c_1 = 0.520 , \quad c_2 = 0.286 , \quad (\text{A.6})$$

and for negative particles :

$$\varepsilon_1 = 0.960 , \quad \varepsilon_2 = 0.975 , \quad c_1 = 0.570 , \quad c_2 = 0.320 . \quad (\text{A.7})$$

The relative accuracy of all values in relations (A.6) and (A.7) is of the order 1%. Inserting these numerical values into expressions (A.5) we can deduce the matrix in relation (A.1). For positive particles we find :

$$F^+ = \begin{pmatrix} 0.976 \div 0.976 & 0.285 \div 0.286 & 0.150 \div 0.280 \\ 0.021 \div 0.021 & 0.712 \div 0.712 & 0.370 \div 0.240 \\ 0.000 \div 0.000 & 0.002 \div 0.002 & 0.344 \div 0.474 \end{pmatrix} \quad (\text{A.8})$$

and for negative particles :

$$F^- = \begin{pmatrix} 0.966 \div 0.966 & 0.324 \div 0.330 & 0.190 \div 0.320 \\ 0.016 \div 0.016 & 0.658 \div 0.653 & 0.380 \div 0.250 \\ 0.000 \div 0.000 & 0.012 \div 0.017 & 0.290 \div 0.420 \end{pmatrix} \quad (\text{A.9})$$

The two values given for each matrix element correspond to assumptions (A.3) and (A.4) respectively. We observe that the elements below the diagonal are much smaller than that which are above. This illustrates the fact that the probability to misidentify lower mass particles as higher mass particles is much smaller than the converse. Let us moreover remark that the systematic error range produced by the extreme hypotheses (A.3) and (A.4) mainly affects the efficiency to identify protons and the probabilities to misidentify protons as pions or kaons. This is a consequence of relations (A.5) and of the fact that the probabilities ε_1 and ε_2 are practically equal to 1.

A3 Checks using particle decays

In order to check the results (A.8) and (A.9), we have computed the efficiency matrix (A.1) using signals from resonances with small background : K^0 and ϕ mesons, Λ and $\bar{\Lambda}$ baryons.

Samples of K^0 , Λ and $\bar{\Lambda}$ have been extracted from our data, using criteria for a secondary vertex and effective mass cuts (with $\pi^+\pi^-$, $p\pi^-$ and $\bar{p}\pi^+$ mass assignment hypotheses respectively). Therefore, we have at our disposal small samples of well defined π^+ , π^- , p , $\bar{p}$; using those trigger particles which are in the acceptance of our Cerenkov counters, we can study the problems of inefficiencies and faking.

Thus, the subsamples of π give us new estimates of the first column elements of the matrix in relation (A.1), the p and $\bar{p}$ subsamples provide informations on the third column elements.

These estimates can then be compared with either of relations (A.8) and (A.9), depending on the electric charge of the particles.

An access to the second column elements of the same matrix is provided by the ϕ meson signal. Using the full sample of trigger pairs (*i.e.* without referring to the corresponding Cerenkov information) the total number of ϕ mesons N_ϕ can be obtained by fitting the effective mass spectrum with the K^+K^- hypothesis. The same procedure applies to the subsample of trigger pairs when we require a given assignment a from the Cerenkov counters and we get $N_{\phi a}$. Then the probabilities that kaons (of the chosen charge) are identified as particles of kind a (π , K , p) are :

$$f_{aK} = \frac{N_{\phi a}}{N_\phi} . \quad (A.10)$$

This method has been used separately for both particle charges (selecting the subsamples with one particle either positive or negative in the pair identified as being of kind a). For consistency, the estimates (A.10) has been checked by selecting all given pair assignments (a, b). Thus we have checked that there is no correlation between assignments for positive and negative tracks.

This second method has provided the following results for positive particles :

$$G^+ = \begin{pmatrix} 0.92 \pm 0.07 & 0.20 \pm 0.08 & 0.16 \pm 0.13 \\ 0.05 \pm 0.05 & 0.72 \pm 0.06 & 0.34 \pm 0.22 \\ 0.02 \pm 0.02 & 0.00 \pm 0.04 & 0.36 \pm 0.23 \end{pmatrix} \quad (A.11)$$

and for negative particles :

$$G^- = \begin{pmatrix} 0.95 \pm 0.05 & 0.37 \pm 0.08 & 0.38 \pm 0.23 \\ 0.04 \pm 0.03 & 0.60 \pm 0.05 & 0.25 \pm 0.19 \\ 0.01 \pm 0.01 & 0.00 \pm 0.03 & 0.31 \pm 0.22 \end{pmatrix} \quad (A.12)$$

Because of the smallness of our samples (142 π^+ , 142 π^- , 50 p , 16 $\bar{p}$), the accuracy of the matrix elements estimates in the third column is rather poor. By comparing relations (A.8) and (A.9) respectively with (A.11) and (A.12), we see however that the agreement is satisfactory. Another estimate of the first column in relations (A.11) and (A.12) can be obtained by treating the ρ^0 meson signal in the same way as that used for the ϕ meson. The results are compatible with those obtained by means of the K^0 meson signal.

To compute the corrected yields and correlators, we have used the probabilities given in relations (A.8) and (A.9) which cover our full interval of systematic errors.

The method as developed just above applies to correct single particle yields for inefficiencies and faking. Extension to particle pair yields is straightforward ; to this end we use the tensor product of the matrices (A.8) and (A.9). To be more precise, denoting $N_{a,b}^{true}$ and $N_{a,b}^{obs.}$, the pair yields for a particle pair of opposite charges, we have :

$$N_{a,b}^{obs.} = F_{ac}^+ F_{bd}^- N_{c,d}^{true} , \quad (A.13)$$

where summation is understood over $c (\pi^+, K^+, p)$ and $d (\pi^-, K^-, \bar{p})$. This matrix relation can easily be rewritten under a form which involves two vectors of nine components (the different kinds of pairs) and a 9×9 probability matrix. To obtain the true yields in terms of the observed ones, we invert this relation numerically.

As already mentioned, the sum of each column in relations (A.8) and (A.9) is slightly smaller than 1 ; therefore the total number of single particle and pair true yields are slightly greater than the corresponding raw yields. The differences between these sets of numbers account for the yields associated with the unphysical assignment quoted above. In all cases (single positive, single negative and pair yields) the observed rates associated with the unphysical assignment account for these excesses.

Appendix B : Correlations and Correlators

B1 Correlation indicator

The sample of events we are using consists of pairs of oppositely charged particles. In order to be self-contained, we repeat in this appendix the definitions given in section 6.

Let us denote by X^+ or X^- any possible particle with charge $+1$ or -1 ; let us moreover denote $A^\pm, B^\pm$ any specified particle among (π, K, p) with the indicated charge. We shall denote $[A^+B^-]$ the yield of A^+B^- pairs, and $[X^+X^-]$ the total number of pairs in our sample with both particles satisfying conditions (1) and (2).

If we approximate probabilities by frequencies, the probability to get a given pair A^+B^- can be written as :

$$\text{Prob}(A^+B^-) = \frac{[A^+B^-]}{[X^+X^-]}, \quad (\text{B.1})$$

the probability to get a pair with A^+ together with *any* negative particle X^- as :

$$\text{Prob}(A^+X^-) = \frac{[A^+\pi^-] + [A^+K^-] + [A^+\bar{p}]}{[X^+X^-]}, \quad (\text{B.2})$$

and that to get a pair with B^- together with *any* positive particle X^+ as :

$$\text{Prob}(X^+B^-) = \frac{[\pi^+B^-] + [K^+B^-] + [pB^-]}{[X^+X^-]}. \quad (\text{B.3})$$

Then we define the correlator of A^+ and B^- particles by :

$$C(A^+B^-) = \frac{\text{Prob}(A^+B^-)}{\text{Prob}(A^+X^-)\text{Prob}(X^+B^-)} - 1. \quad (\text{B.4})$$

As explained in section 6, we expect the sign of this correlation indicator to have a physical meaning : the positive sign expresses the fact that the production of A^+ and B^- are enhanced by each other, the negative one that the productions of A^+ and B^- are suppressed by each other. Finally if the production of both particles are statistically independent, this will appear through a zero value of the correlation indicator (B.4). The correlator (B.4) is never less than -1 (at -1.0 it is strictly impossible to get the corresponding pair of particles) ; the correlator values are not bounded from above.

Of course, the sign properties are intimately related with the sample on which this indicator is applied (oppositely charged particle pairs). We shall come back to this problem below.

B2 Physical illustrations

We now illustrate why working with our sample rather than minimum bias events gives an intuitive view of what is going on when fragmenting a parton.

In π^-N scattering, neglecting sea parton and gluon contributions, the possible 2-parton scatterings which contribute to the hard interaction are :

$$\bar{u} u, \quad \bar{u} d, \quad d u, \quad d d \quad . \quad (B.5)$$

Therefore the probabilities to get a high- p_T quark are in the following ratios :

$$\bar{u} : u : d = 1 : 1 : 2 . \quad (B.6)$$

Let us first consider the associated K^+K^- production. Here we always need to fragment the string with an $s\bar{s}$ pair. As sketched in figure 5, starting from scattered u or $\bar{u}$ quark, it is always possible to get K^+ and K^- as the two first rank fragments. When starting from a scattered d quark, the first rank fragment cannot be K^+ or K^- . Therefore, the production of K^+ as leading fragment enhances the probability to get K^- as second rank fragment, and conversely².

We have restricted our discussion here to the production of a pair as leading fragments. This case illustrates how a positive SRC occurs and its relation with the sign of our correlation indicator (B.4) is clear.

Another example is the associated π^+K^- production. Starting from the scattered $\bar{u}$ quark (see figure 6), we can get a leading K^- by a first breakup of the string with $s\bar{s}$; however the $\bar{s}$ which will enter the next fragment prevents a second rank π^+ . Starting now from the scattered u quark, by fragmenting the string into $d\bar{d}$, we obtain π^+ as leading fragment but the available d quark prevents to get a second rank K^- . Finally, a scattered d quark forbids both leading π^+ and leading K^- and does not contribute to the production. In this case the production of a leading π^+ suppresses the probability to get a second rank K^- and conversely³. This case illustrates how a negative SRC occurs in the sample of oppositely charged particle pairs.

In this sample, the sign of the correlation can generally be predicted correctly. There exists however a number of effects which can modify such simple predictions. First of all, the interplay of gluons and sea partons can spread out the correlation. Pairs of particles coming both from the same resonance can enhance² the value of the correlator (B.4) ; trigger pairs in which (at least) one of its member comes from the decay of a primary produced resonance can modify to some extent the magnitude of the corresponding correlator. Pre-existing valence diquarks inside the nucleon target can also decrease the value of $C(p, \bar{p})$ (since we can have diquarks without any need to break up the flux tube into diquark-antidiquark pairs).

As expressed in section 6, if a given kind of pair represents a very important fraction of the pair population (it is the case in our sample with $\pi^+\pi^-$ pairs), it turns out that all probabilities involving a π^+ and/or a π^- computed in this sample are $\simeq 1$ (see relations (B.1)-(B.3)) ; therefore in this case our correlator nearly vanishes. This property is not unexpected since it corresponds to an attempt to study the correlation of oppositely charged

²We do not take into account the possible production of vector mesons (K^* 's) because the final particles will have lower p_T unless we increase the scattered parton p_T ; this provides a suppression factor. In any way, this process will enhance the $K^+\pi^-$ associated production without suppressing the K^+K^- one.

³Of course, starting with an s -quark coming from the sea, the associated production of both is possible by fragmenting the string into $u\bar{u}$. This is obviously a non-leading contribution.

particles in a sample constituted of only $(+,-)$ pairs. In such a case, the very definition of the sample implies that the correlation must be zero. The case in which we are interested is to study flavour correlations between particles in associated production. This shows the connection between correlator values and the sample on which they are defined.

B3 Connection with the standard correlator

We discuss now the differences between our correlator and the most commonly used one[8], which can be written :

$$C'(A^+B^-) = \frac{\text{Prob}(A^+B^-)}{\text{Prob}(A^+)\text{Prob}(B^-)} - 1 \quad , \quad (\text{B.7})$$

where $\text{Prob}(A^+B^-)$ is now the probability to get the indicated pair in a given phase space window among all the inelastic events (in number N_{ev}). $\text{Prob}(A^+)$ (resp. $\text{Prob}(B^-)$) is the probability to get the particle A^+ (resp. B^-) in the corresponding window, regardless of any other possible particle in the same window (possibly nothing). Let us stress that the only difference between the correlators (B.4) and (B.7) lies in the samples on which they are defined. Using the same kind of notations as already defined, these probabilities are :

$$\text{Prob}(A^+B^-) = \frac{[A^+B^-]}{N_{ev}} \quad , \quad (\text{B.8})$$

$$\text{Prob}(A^+) = \frac{[A^+X^-] + [A^+ \text{ anything else}]}{N_{ev}} \quad , \quad (\text{B.9})$$

$$\text{Prob}(B^-) = \frac{[B^-X^+] + [B^- \text{ anything else}]}{N_{ev}} \quad . \quad (\text{B.10})$$

When the window is large enough that the number of particles inside is most probably 2, the dominant term in expressions (B.9)–(B.10) is the first one, because of local charge compensation. In this case, the connection between relations (A.4) and (A.7) is :

$$C'(A^+B^-) + 1 \simeq \frac{N_{ev}}{[X^+X^-]} (C(A^+B^-) + 1) \quad (\text{B.11})$$

In our sample, the correlator for $\pi^+\pi^-$ pairs tends to vanish as has been explained. If we extend the sample on which the correlator is defined to all inelastic events, the new correlator (relation (B.7)) becomes equal to $N_{ev}/[X^+X^-]$ which is a very large number. This illustrates the quoted dependence upon the sample under study.

The information obtained using the correlators (B.4) and (B.7) is the same. However, from the discussion and examples above, we conclude that the properties of 2-particle correlations are more transparent using our normalization $[X^+X^-]$ than the usual one N_{ev} .

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Figure Captions

Figure 1 : (a) Top view of the layout showing the trigger hodoscopes (HZ1–HZ2) and the hodoscopes (HY1–HY3) used to define roads to the cells of the Cerenkov counters (C_1 and C_2). (b) Perspective view of a reconstructed event showing the three trigger tracks (π_1, π_2, π_3) hitting the trigger hodoscopes. Hit slabs are dotted. These hodoscopes have a butterfly shape which prevents triggering on too low p_T (≤ 0.6 GeV/c) particles.

Figure 2 : $\pi^+\pi^-$, K^+K^- , π^+K^- and π^-K^+ pair subsample mass distributions represented with the mass assignments $\pi^+\pi^-$ (leftside column) and K^+K^- (rightside column).

Figure 3 : p_T acceptance of the pairs. This acceptance curve does not depend on the pair kind.

Figure 4 : Some examples of p_T distributions with the fitted curves provided by the function in equation (6) (see text).

Figure 5 : Enhanced associated production of K^+ and K^- pairs in u and $\bar{u}$ quark fragmentation.

Figure 6 : Suppression of associated production of π^+ and K^- in u and $\bar{u}$ quark fragmentation.

Fig.1a

Fig. 1 b

Fig. 2

arbitrary units

Fig. 3

events/50 MeV/c

Fig. 4

Fig. 5

Fig. 6