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Inclusive Two-Particle Rapidity Correlations in 205 GeV/c pp Interactions

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Using the 30-inch bubble chamber at NAL, we have analyzed an inclusive sample of ~2,500 inelastic pp interactions. Two-particle rapidity correlations are presented for charged-charged, --, ++, and +- particles. The results are compared with a simple model which incorporates the observed multiplicity distribution and semi-inclusive single particle spectra. In the central region, the data lie consistently above the model predictions indicating the presence of correlation effects not included in the model.

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A considerable amount of data on multiplicities and inclusive single particle distributions has been published during the past two years. However, several kinds of phenomenological models for high energy multiparticle production processes are able to accommodate such results. Further information, which is expected to be more definitive in discriminating among models,[1] can be obtained from the study of inclusive two-particle distributions. Such correlation data have already been presented from several National Accelerator Laboratory (NAL) and CERN Intersecting Storage Rings (ISR) experiments,[2-6] mostly in preliminary form, and have been interpreted[1] as showing strong evidence for short range correlation effects. In this Letter, we present new correlation results and indicate the complexities associated with isolating such effects.

We report experimental values for the inclusive correlation functions

$$R(y_1, y_2) = [\sigma_{inel} \frac{d^2\sigma}{dy_1 dy_2} / \frac{d\sigma}{dy_1} \frac{d\sigma}{dy_2}] - 1 \tag{1}$$

$$C(y_1, y_2) = [\frac{1}{\sigma_{inel}^2} \frac{d\sigma}{dy_1} \frac{d\sigma}{dy_2}] R(y_1, y_2) \tag{2}$$

(where y is the CM longitudinal rapidity) for secondary charged particles produced in inelastic pp collisions at 205 GeV/c. The data, from the 30-inch hydrogen bubble chamber at NAL, consist of an unbiased inclusive sample of ~ 2,500 inelastic events[7] for which all of the charged tracks have been measured.

Many of the technical aspects concerning the momentum measurements

and their accuracy are described elsewhere.[8] To calculate the longitudinal CM rapidity, y, for each outgoing particle requires that its mass be known. In the absence of such knowledge, we have assumed all negative tracks to be π^-, positive tracks with momentum greater than 120 GeV/c to be protons (resulting in less than a 5% misidentification of pions as protons), and the remainder of the positive tracks (except for identified slow proton tracks, with momentum less than 1.4 GeV/c) to be pions. We have verified that our results are insensitive to these mass assumptions. In fact, even the use of the approximation $y_{lab} \approx \eta_{lab} = -\ln \tan [\theta_{lab}/2]$ (which is equivalent to the assumption that $m \ll p_T$) has little effect on R in the central region.[9]

Table I lists our results for R for all charged particles where, because of CM symmetry, the data have been folded and averaged about y = 0. Fig. 1 is a contour plot based on the data of Table I. Two of the interesting features of this plot are the contours, in the central region, elongated along the direction $y_1 = y_2$, and the large regions of near zero values (even going positive again) in the upper left and lower right corners. These features are similar to those seen at other energies.[2, 4]

In Fig. 2(a-d) are plotted values of R as a function of $y_2 - y_1$ when y_1 is near zero, i.e. at 90° CM, or near -1, i.e. near the end of the rapidity plateau.[8] The figures correspond to the cases when: (a) all charged particles are included (R_{cc}), (b) only negatives are included (R_{--}), (c) only positives (R_{++}), and (d) one is positive and the other is negative (R_{+-}). The

curves are the results of a Monte Carlo calculation based on a simple physical model to be discussed below. Table II gives our values of C(0, 0) and R(0, 0). We give in Table III values for the single particle densities so that one can convert from R to C.

From these experimental results we conclude that:

(1) $R_{cc}(0, 0)$ is equal within errors to preliminary values found[2, 4] at 102, 291, and 2067 GeV/c. The possible absence of s dependence in the experimental values of $C_{cc}(0, 0)$ has been considered to be a failure of fragmentation models.[1] $R_{--}(0, 0)$ also appears to be independent of energy, based on preliminary data at 102 and 303 GeV/c.[4, 6] Our $R_{++}(0, 0)$ is slightly lower than that obtained at 102 GeV/c.[4] $R_{+-}(0, 0)$ is equal to the 102 GeV/c result.[4]

(2) Invariance of R with respect to translations in rapidity (i.e. dependence on only $|y_2 - y_1|$ and not y_1) in the central region holds within the errors for all charge combinations.

(3) Within the region for which translation invariance is satisfied, there is a falloff as a function of $|y_2 - y_1|$, which is consistent with the forms $\exp[-(y_2 - y_1)^2/\lambda^2]$ or $\exp[-|y_2 - y_1|/\lambda]$, with a correlation length $\lambda \approx 2 \pm 1$. (Such a falloff has been interpreted[1] as evidence for short range correlations.) However, since these forms cannot fit negative values of R, and are not expected[1] to hold for small Δy, it is difficult to attach physical significance to fitted values of λ.

Despite the existence of several interesting theoretical models, the optimum method for extracting clear-cut dynamical conclusions from these results is far from clear. In an attempt to understand better how to interpret the measured values of the correlation function, we have constructed a simple physical model, which includes no explicit short range correlations as input. This model incorporates the following assumptions: (a) The rapidity distribution, $d\sigma/dy$, for pions is that observed in the experimental data,[8] and narrows as the multiplicity increases. (b) The transverse momentum spectrum of secondaries has a gaussian shape.[8] (c) Energy and momentum are conserved in each event. (d) The multiplicity distribution is that determined by experiment.[10] Note that this constrains the model to yield the experimental value of $f_2^{cc} = 7.44 \pm 0.72$. This means that an average positive correlation is contained within the model, since f_2 is equal to an integral of R over the entire y_1, y_2 plane,

$$f_2 = \frac{1}{\sigma_{inel}^2} \iint \frac{d\sigma}{dy_1} \frac{d\sigma}{dy_2} R(y_1, y_2)\, dy_1 dy_2 \quad . \tag{3}$$

(e) For each multiplicity one-fourth of the events have two protons, one-fourth have two neutrons and one-half have one neutron and one proton.[11] (f) For a given topology, the number of π^o is gaussian distributed with the peak at the average number of π^+ and π^- and width of about $3\pi^o$'s.[12]

By comparing the data to the curves resulting from the model,[13] the following points may be noted:

(1) The data at $y_1 \approx y_2 \approx 0$ are consistently above the model curves, indicative of correlations not included in the model.

(2) A clear difference between the model and data is the translational invariance exhibited by the data in the central region but not by the model. The model predicts that the strongest correlation occurs when one of the particles is at $y = 0$. The data, however, indicate that the strongest correlation occurs when $y_1 = y_2$, again indicative of correlations not contained in the model.

(3) The decreasing behavior of R outside the central region is well represented by this model.

As mentioned above, input to the model includes the experimental value of f_2. Also, the narrowing of the rapidity distribution as the prong number increases is model input. These are presumably dynamical correlation effects, and they do influence the shape of R. To minimize these complications and to further investigate correlation effects, one can study the values of R for semi-inclusive data, i. e., for events with a fixed number of prongs. This is done in the following paper.[14]

We thank R. Arnold and G. Thomas for valuable discussions on the mysteries of correlations.

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results were presented on $\pi^-\pi^-$ correlations at 205 and 303 GeV/c using data obtained by the hybrid bubble chamber wide gap spark chamber experiment at NAL.

7. All inelastic two- and four-prong events (599 and 1191, respectively) plus an unbiased sample of ~ 1,600 events with six or more prongs have been measured. After weighting, this corresponds to an inclusive sample of ~ 2,500 events.

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9. The use of η_{lab} affects the distributions markedly in the end regions. Use of η_{CM} causes still larger distortions in the end regions, as well as some distortions in the central region.

10. G. Charlton et al., Phys. Rev. Letters 29, 515 (1972).

11. Using the data of S. J. Barish et al., Phys. Rev. Letters 31, 1080 (1973), we estimate an average of ~ 1.1 protons per inelastic collision.

12. G. Charlton et al., Phys. Rev. Letters 29, 1759 (1972).

13. In Ref. 4 a similar model which yields comparable results is described.

14. Following Phys. Rev. Letter.

Table I

Measured Values[a] for R_{cc}

y_2	y_1 = -3.5	-3.0	-2.5	-2.0	-1.5	-1.0	-0.5	0.0
-3.5	-0.43 ± 0.17	-0.71	-0.45	-0.33	-0.22	-0.20	-0.17	-0.18
-3.0	-0.71 ± 0.06	-0.61	-0.53	-0.43	-0.48	-0.47	-0.42	-0.37
-2.5	-0.45 ± 0.07	-0.53	-0.36	-0.16	-0.14	-0.11	-0.09	-0.06
-2.0	-0.33 ± 0.09	-0.43	-0.16	0.12	0.14	0.14	0.08	0.03
-1.5	-0.22 ± 0.09	-0.48	-0.14	0.14	0.36	0.45	0.37	0.22
-1.0	-0.20 ± 0.08	-0.47	-0.11	0.14	0.45	0.51	0.51	0.32
-0.5	-0.17 ± 0.08	-0.42	-0.09	0.08	0.37	0.51	0.57	0.45
0.0	-0.18 ± 0.08	-0.37	-0.06	0.03	0.22	0.32	0.45	0.50
0.5	-0.07 ± 0.09	-0.31	-0.08	0.02	0.27	0.31	0.45	0.45
1.0	-0.14 ± 0.09	-0.25	-0.04	0.06	0.18	0.23	0.31	0.32
1.5	+0.08 ± 0.11	-0.27	-0.01	0.01	0.09	0.18	0.27	0.22
2.0	-0.03 ± 0.10	-0.07	-0.02	0.01	0.01	0.06	0.02	0.03
2.5	-0.10 ± 0.10	+0.01	+0.01	-0.02	-0.01	-0.04	-0.08	-0.06
3.0	-0.04 ± 0.11	+0.19	+0.01	-0.07	-0.27	-0.25	-0.31	-0.37
3.5	-0.64 ± 0.24	-0.04	-0.10	-0.03	+0.08	-0.14	-0.07	-0.18

[a] To the left of the line, statistical errors are given for the first column of values and are approximately 0.04 for the remaining columns. To the right of the line, the values are obtained by using pp CM symmetry. Values to the left of the line for $|y_2| \geq 3.0$ should be assigned an additional systematic error of ~ 0.05 to account for momentum uncertainties in fast tracks.

Table II

Correlation Functions at $y_1 \approx y_2 \approx 0$[a]

Charge	R(0, 0)	C(0, 0)
cc	0.50 ± 0.05	1.38 ± 0.16
--	0.38 ± 0.06	0.21 ± 0.04
++	0.25 ± 0.05	0.22 ± 0.04
+-	0.67 ± 0.06	0.47 ± 0.04

[a]For cc we use the interval $-0.25 < y < 0.25$. For the other charge combinations, the interval is $-0.5 < y < 0.5$. Note that these differ from intervals used in Refs. 2-6.

Table III

Inclusive Single Particle Densities

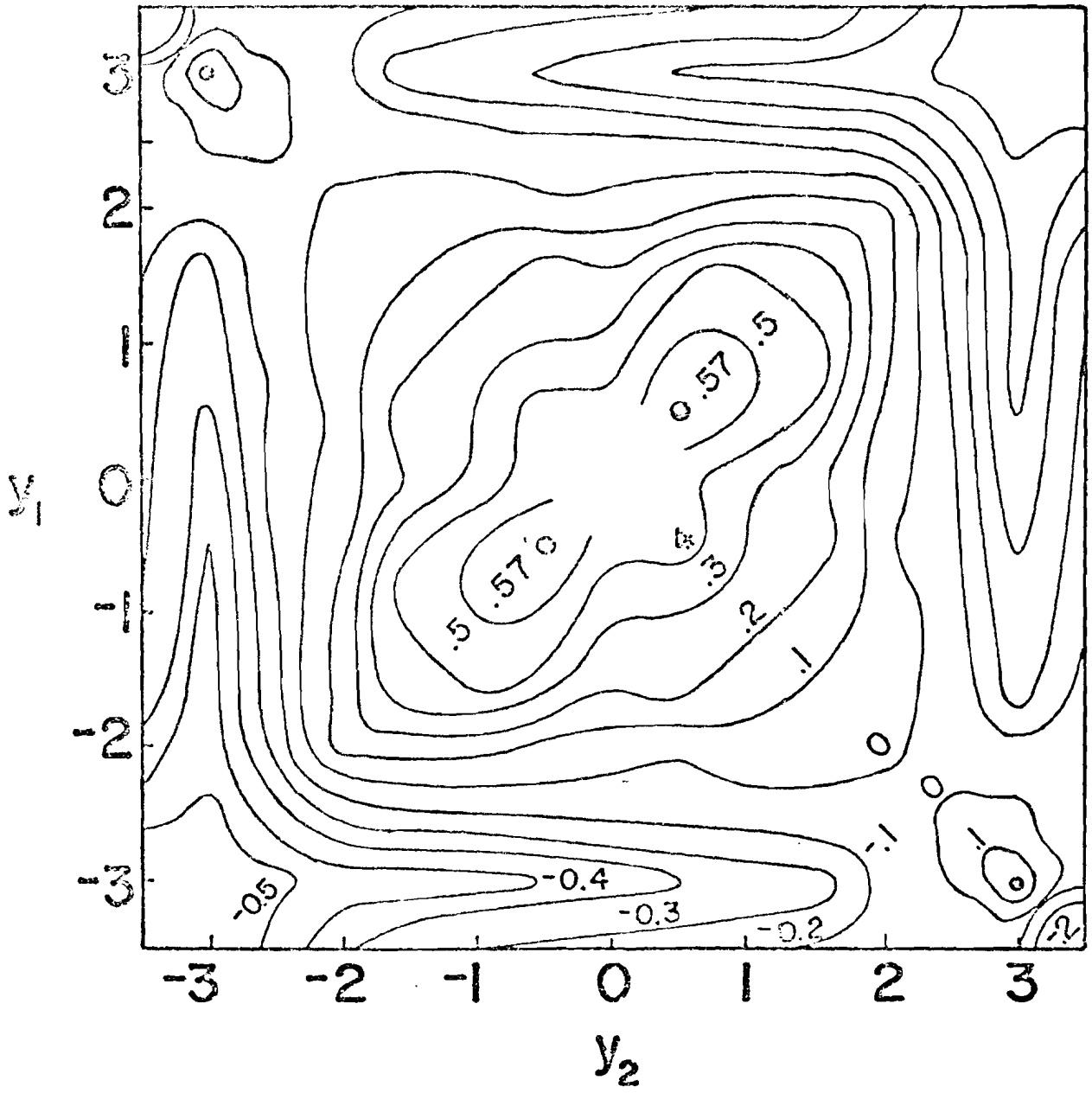
y	$\frac{1}{\sigma_{inel}} \frac{d\sigma_c}{dy}$	$\frac{1}{\sigma_{inel}} \frac{d\sigma_-}{dy}$	$\frac{1}{\sigma_{inel}} \frac{d\sigma_+}{dy}$
0.0	1.66	0.75	0.95
-0.5	1.66		
-1.0	1.54	0.64	0.89
-1.5	1.24		
-2.0	0.94	0.32	0.68
-2.5	0.88		
-3.0	0.46	0.06	0.42
-3.5	0.09		

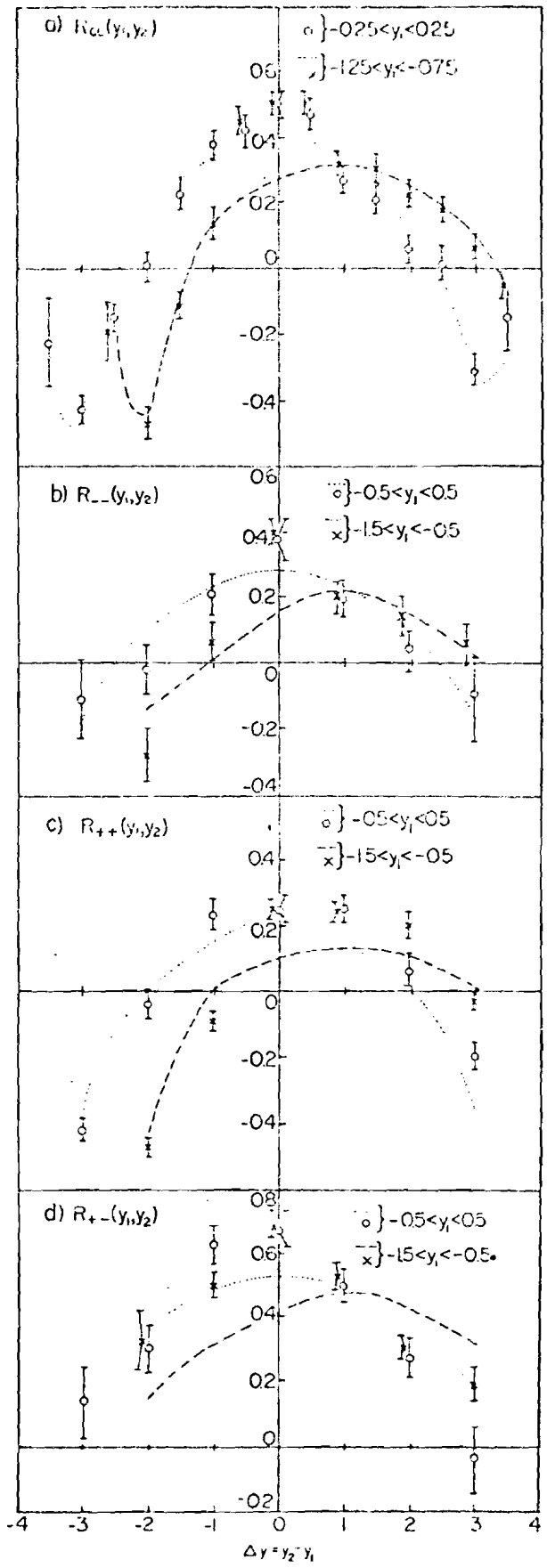
Figure Captions

Fig. 1 Contour plot of $R_{cc}(y_1, y_2)$ as obtained from Table I. Some of the detailed structure is of uncertain significance as can be judged from the statistical errors given in Table I.

Fig. 2 $R(y_1, y_2)$ versus $y_2 - y_1$ for fixed y_1. (a) R_{cc}, (b) R_{--}, (c) R_{++}, (d) R_{+-}. The curves are results of the model described in the text.

R_{cc} FOR 205 GeV/c pp





a) $R_{cc}(y_1,y_2)$
o } -0.25<y_1<0.25
x } -1.25<y_1<-0.75
b) $R_{--}(y_1,y_2)$
o } -0.5<y_1<0.5
x } -1.5<y_1<-0.5
c) $R_{++}(y_1,y_2)$
o } -0.5<y_1<0.5
x } -1.5<y_1<-0.5
d) $R_{+-}(y_1,y_2)$
o } -0.5<y_1<0.5
x } -1.5<y_1<-0.5
$\Delta y = y_2 - y_1$