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LA-UR -86-2706

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TITLE e^+-e^- HADRONIC MULTIPLICITY DISTRIBUTIONS: NEGATIVE BINOMIAL OR POISSON?

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SUBMITTED TO Proceedings of the XVII International Symposium on Multiparticle Dynamics, Zeewinkle, Austria, June 13-23, 1986

e^+-e^- Hadronic Multiplicity Distributions Negative Binomial or Poisson?

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ABSTRACT

On the basis of fits to the multiplicity distributions for variable rapidity windows and the forward backward correlation for the 2 jet subset of e^+e^- data it is impossible to distinguish between a global negative binomial and its generalization, the partially coherent distribution It is suggested that intensity interferometry, especially the Bose-Einstein correlation, gives information which will discriminate among dynamical models

1 Recently great success has been obtained in fitting[1-4] hadronic multiplicity distributions arising from all types of colliding particles to the negative binomial distribution

$$P_n^{NB} = \frac{(n+k-1)!}{n!(k-1)!} \frac{(N/k)^n}{(1+N/k)^{n+k}} \quad (1)$$

where $N = \langle n \rangle$ is the mean charge multiplicity Data for symmetric rapidity windows of varying Δy are well described[3,5] by (1) for all measured Δy. Although it is tempting to regard (1) as a universal empirical "law" it is important to consider equally precise alternative phenomenological possibilities In particular we have considered the generalization of (1)

$$P_n^{PC} = \frac{(N/k)^n}{(1+N/k)^{n+k}} \exp\left(\frac{-S/N}{1+N/k}\right) L_n^{k-1}\left(\frac{-kS/N}{1+N/k}\right) \quad (2)$$

appropriate to partially coherent emission from k sources.[6,7] Here $\langle n \rangle = S+N$ where S is the strength of the coherent emission and N that of the (Gaussian) "noise" emission. Note that (2) contains both Eq. (1) and the Poisson distribution as limits when $S/N \to 0$ and $N/S \to 0$ respectively.

Regarding $\langle n \rangle$ as give by experiment, we parametrize Eq. (2) by the parameters k and $m \equiv (N/S)^{1/2}$, the magnitude of the noise to signal amplitude. Previously we have noted[8,9] that as an alternative to the very large and rapidly varying values of k resulting from fits to hadron-hadron data, we can obtain equally good χ^2 fits using (2) with small and slowly varying k; i.e. the narrowness associated with large k in the negative binomial can be equally well described by a small N/S ratio. The broadening of hadronic Koba, Nielson Olesen (KNO) plots[10] is then ascribed to a decreasing coherent emission as the energy is increased, a conclusion also reached by the Marburg group.[11] Detailed documentation can be found in our forthcoming review article.[4]

2. We have previously shown[7] that the narrow, KNO plots for e^+-$e^- \to$ hadrons can be explained by (2) with a very small N/S ratio (a few percent) and k chosen on physical grounds, specifically k = 1 for the 1 jet subset of events, k = 2 for the 2 jet subset etc. Although almost Poissonian, the "wings" of the distribution (2) are very sensitive to a small amount of noise. Chou and Yang[12] suggested that the e^+e^- multiplicities are purely Poisson. On the other hand Derrick et al.[3] showed that the new HRS data from SLAC are well fit by the negative binomial with k ranging from ~ 10^2 down to ~ 10 as the maximum accepted rapidity decreases from its maximum value down to unity. Figure 1 summarizes and compares the results of the two approaches. Clearly the statistical merit of either approach is equally good. For the indicated parameters both Eqs. 1 and 2 are nearly Poisson and difficult to distinguish.

3. The forward-backward correlation is sensitive to the difference (1) and (2) for moderate values of k, a fact we recently used[13]

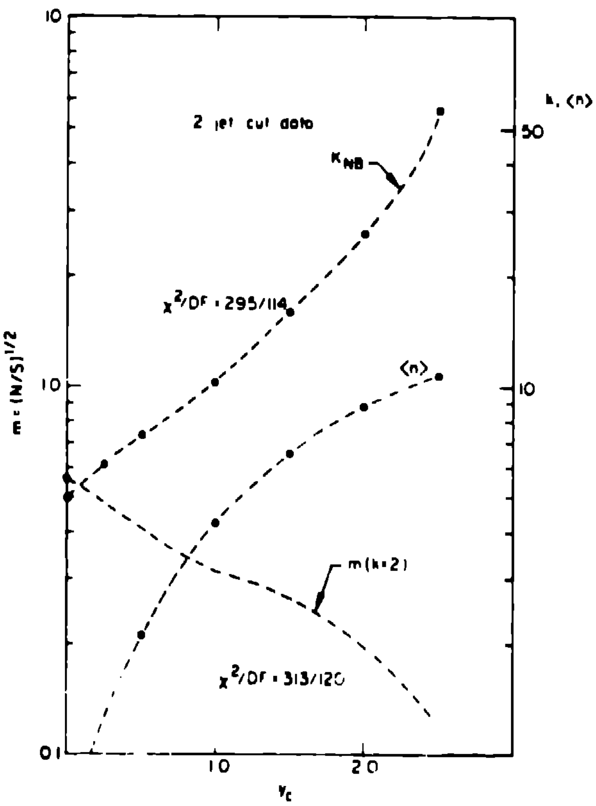

Fig. 1 The best-fit parameters to the limited-rapidity multiplicity distributions $-y_c<0<y_c$ are shown for the partially coherent distribution in Eq. 2 (i.e., the left hand ordinate gives $m = (N/S)^{1/2}$ as a function of y_c) and for the negative binomial formula Eq. 1 (i.e., the right hand ordinate gives k_{NB} (and $\langle n\rangle$) as a function of y_c).

to put a bound on N/S for hadron-hadron multiplicity distributions. For example if we partition the population n as $n = n_F + n_B$ and assume that the conditional probability $P(n|n_F)$ is binomial, (1) leads to a linear slope for the average of backward particles $\langle n_B\rangle_F$ as a function of n_F, while a Poisson global distribution has zero slope. In general, Eq. (2) leads to a curved $\langle n_B\rangle_F$ except that, for large k <u>or</u> small noise, linearity obtains with a small slope. Allowing for moving sources we write the joint probability as a composite of emissions from k sources whose probability of forward (backward) emission is $p_j(q_j)$ with $p_j + q_j = 1$.

$$P(n_F, n_B) = \prod_{j=1}^{k} P_j(n_{Fj}, n_{Bj}) \delta_{n_F, \sum_i n_{Fj}} \delta_{n_B, \sum_j n_{Bj}} \quad (3)$$

We apply this to the two-jet subset of the HRS data, taking $p_1 > q_1$, $q_2 = p_1$ and $p_2 = q_1$, writing P_j as the product of (1) or (2) with a binomial having parameters p_j, q_j. Similar proposals have been made recently by other authors.[14,15] (The p_i cannot be measured and are presently unavailable theoretically, so we vary them through a range of plausible choices.) Figure 2 compares the negative binomial with the

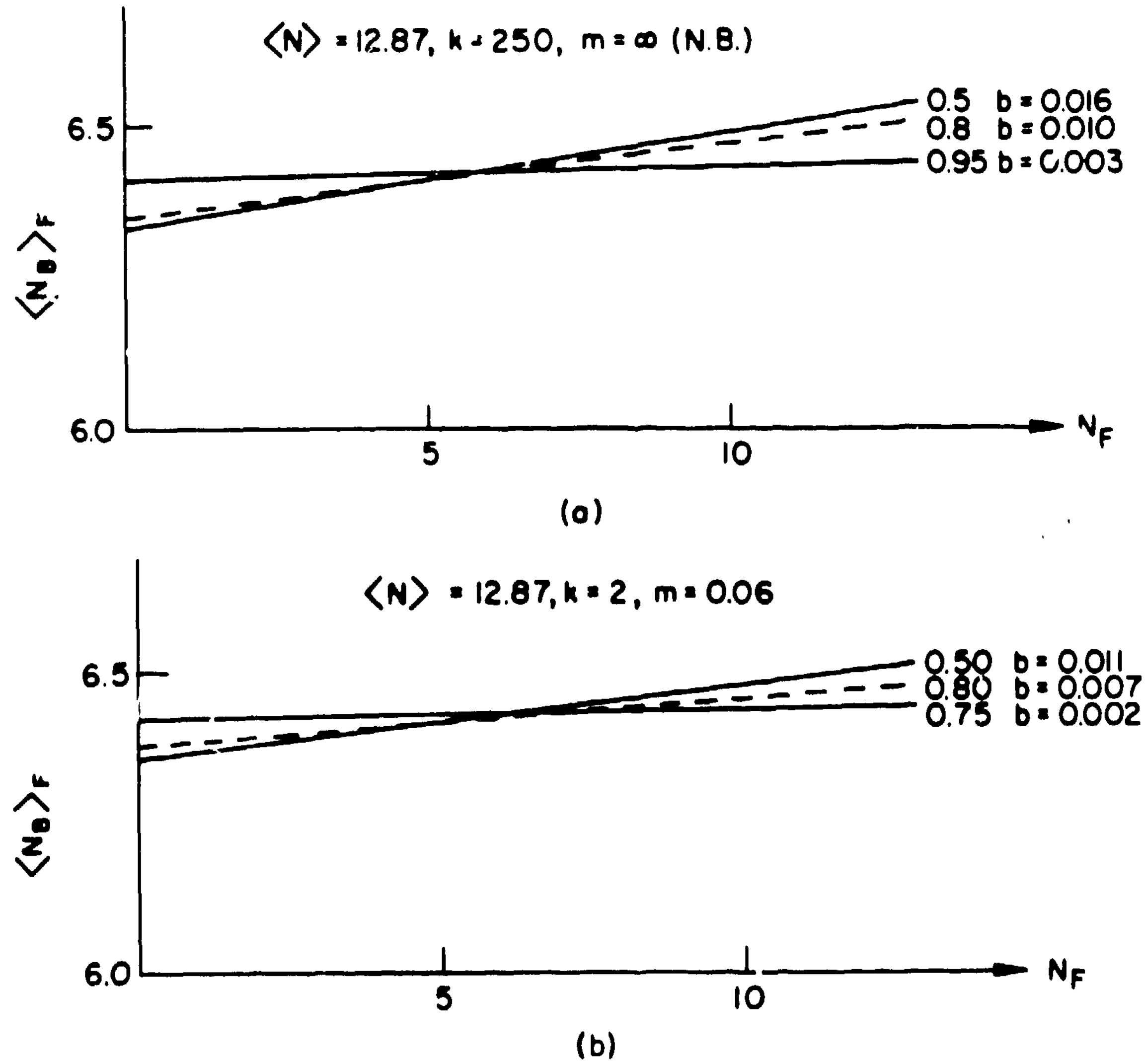

Fig. 2 The forward backward correlation as measured by the quantity $\langle n_B \rangle_F$ as a function of n_F is given for forward emission probabilities of the forward quark of $p = 0.5$, 0.80 and 0.95 for the negative binomial (top curve) and the partially coherent distributions.

partially coherent predictions. Noting that the experimental slope is $b \cong 0.006$ we see that although $p = 1/2$ is excluded, both (1) and (2) easily accommodate the data given all the uncertainties.

4. We have shown that neither the KNO plot nor the F/B correlation can discriminate between (1) and (2) for $e^+e^- \to$ hadrons. We can note however that P_n is merely the diagonal element of the density matrix, the latter having much more information (in particular phase information) in its off-diagonal elements. In order to learn about this phase information one needs to use higher order correlation information, in particular the Bose-Einstein correlations among like-sign particles. For a Gaussian ensemble of fields one expects a Hanbury-Brown Twiss intercept (zero detector separation) of 2 while for pure coherent it is one (no effect). If we accept the conjecture[16] of Fowler and Weiner that the correlation formulae of quantum optics can be adapted to particle physics by substituting rapidity for time, the apparent fact that the $Q^2 = 0$ intercept is small for e^+-$e^- \to$ hadrons than for hadron hadron $\to$ hadrons suggests more coherence in the e^+e^- case. According to our earlier speculation[7] the fast quark emits an approximate coherent state (which is not only nearly Poisson in counting statistics but has nearly perfect coherence).

Details of our analysis will be found in a paper submitted to the Physical Review. This research was supported in part by the U.S. Department of Energy and the U.S. National Science Foundation.

REFERENCES

1. UA5 Collaboration, Alner G. J. et al, Phys. Lett. 160B, 199 (1985).
2. NA22 Experiment, Van Hal P., (this conference).
3. Derrick M. et al., Phys. Lett. 168B, 299 (1986); Phys. Rev. D (to be published); Derrick M., to appear in Proceedings of the 2nd International Workshop on Local Equilibrium in Strong Interaction Physics, Santa Fe, NM, April 1986 (World Scientific, to be published); Sugano K., in Proceedings of XXI Recontre de Moriond, Les Arcs, France, March 1986 (to be published).

4. Carruthers P. and Shih C. C., J. Mod. Phys. A (to be published). Earlier work on the negative binomial and its uses may be found in this review.

5. UA5 Collaboration, Alner G. J. et al., Phys. Lett 160B 193 (1985).

6. Biyajima M., Prog. Theo. Phys. 69, 966 (1983); see also Carruthers P., in Proc. XIV International Symposium on Multiparticle Dynamics, ed. P. Yager and J. Gunion (Work Scientific, Singapore, 1983) p. 825.

7. Carruthers P. and Shih C. C., Phys. Lett. 137B, 425 (1984).

8. Carruthers P. and Shih C. C., in Proc. of XV International Symposium on Multiparticle Dynamics, eds. G. Gustafson and C. Peterson (World Scientific Singapore, 1984) p. 174.

9. Carruthers P., LA-UR-86-1540 to appear in the Proceedings of the XXI Recontre de Moriond, Les Arcs, France, March 1986.

10. Koba Z., Nielsen H., and Olesen, P., Nuc. Phys. B40, 317 (1972).

11. Fowler G. N., Friedlander E. M., Weiner R. M., Wilk G., Phys. Rev. Letters 56, 14 (1986).

12. Chou T. T., and Yang C. N., Phys. Lett, 167B 453 (1986).

13. Carruthers P. and Shih C. C., Phys. Lett. 165B, 209 (1985).

14. Xu Cai, Wei-qin Chao, Ta-chung Meng, and Chao-shang Huang, Phys. Rev. D 33 1287 (1986).

15. Fialkowski K., Phys. Lett. 173B, 197 (1986).

16. Fowler G. N. and Weiner R. M., Phys. Rev. D 17 3118 (1978).

A. ESKREYS

Did I understand you well, that given the ratio R_{BE} (of like pion pairs to the pairs from a reference sample) as defined by me a few days ago, its intercept at $Q^2 = 0$ measures the coherence of the pion source?

CARRUTHERS

Yes, under certain assumptions whose validity requires further study.

L. GUTAY (Purdue)

It is explicitly stated that the Kopylov Podgoretskii Hanbery-Brown Twiss correlation is an incoherent intensity correlation. How do we observe coherence with such a technique? Also, could you explain the measuring or consequences of coherence in $\bar{p}$-p collisions?

CARRUTHERS

It is known that incoherent starlight is involved in the original H-BT experiment. The experimental correlation is completely explained by assuming the radiation field to belong to an (incoherent) gaussian ensemble. For the hadronic correlation it is not a priori clear that the emitted fields lack a coherent emission component. The structure of the theory is unchanged but in particular the predicted intercept at zero momentum transfer is decreased in the presence of coherence. There are two immediate consequences of partial coherence of the hadronization fields in (non-annihilation) $p\bar{p}$ collisions. First of all the ratio intercept of like-sign pairs to all pairs should be less than two. Secondly, the forward-backward correlation will be smaller than those derived from the negative binomial, in a calculable way.