CERN-TH.5798/90

INTERMITTENCY EFFECTS IN A TWO-COMPONENT MODEL

N.G. Antoniou*)
CERN - Geneva

E.N. Argyres and C.G. Papadopoulos
Institute of Nuclear Physics, NRPS Demokritos
GR-15310 Athens, Greece

and

S.D.P. Vlassopulos
Department of Physics, National Technical University
GR-15773 Athens, Greece

CORRIGENDUM

Enclosed are the figures of this paper which were, by mistake, not printed with the text of the paper.

---

*) Also at Department of Physics, University of Athens, GR-15771 Athens, Greece.

CERN-TH.5798/90
July 1990

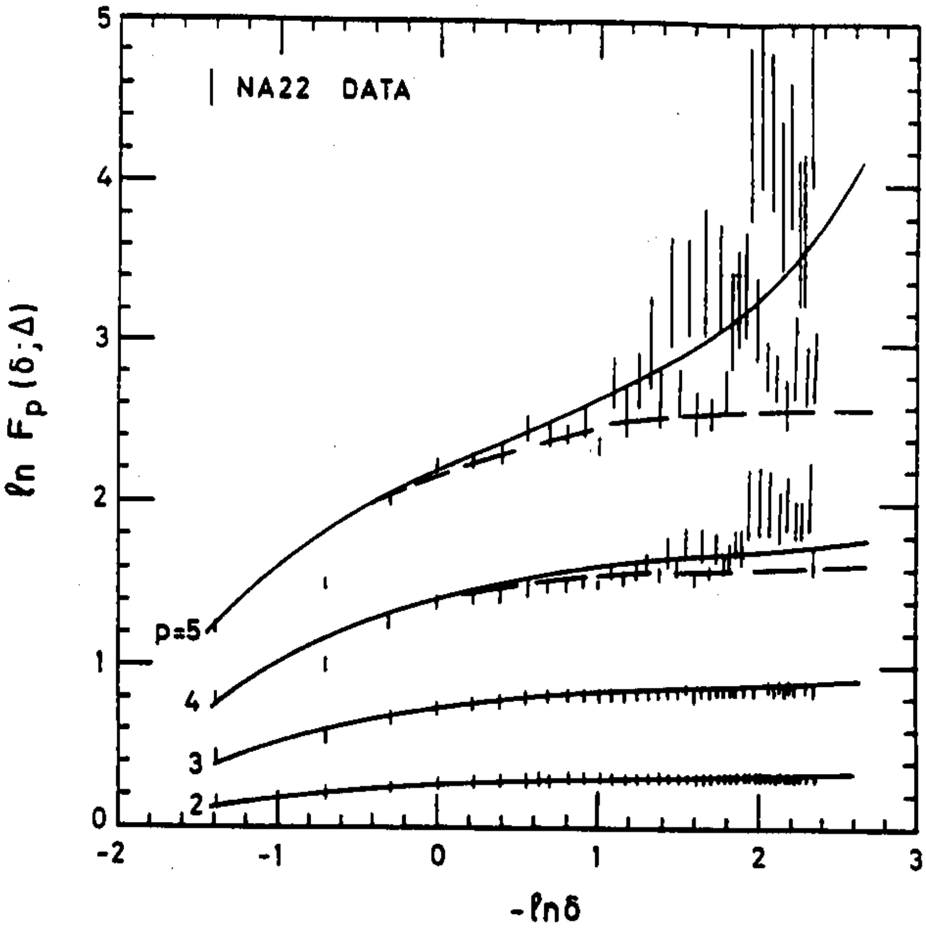
NA22 DATA
ln $F_p(\delta;\Delta)$
p=5
4
3
2
-ln δ

Fig. 1

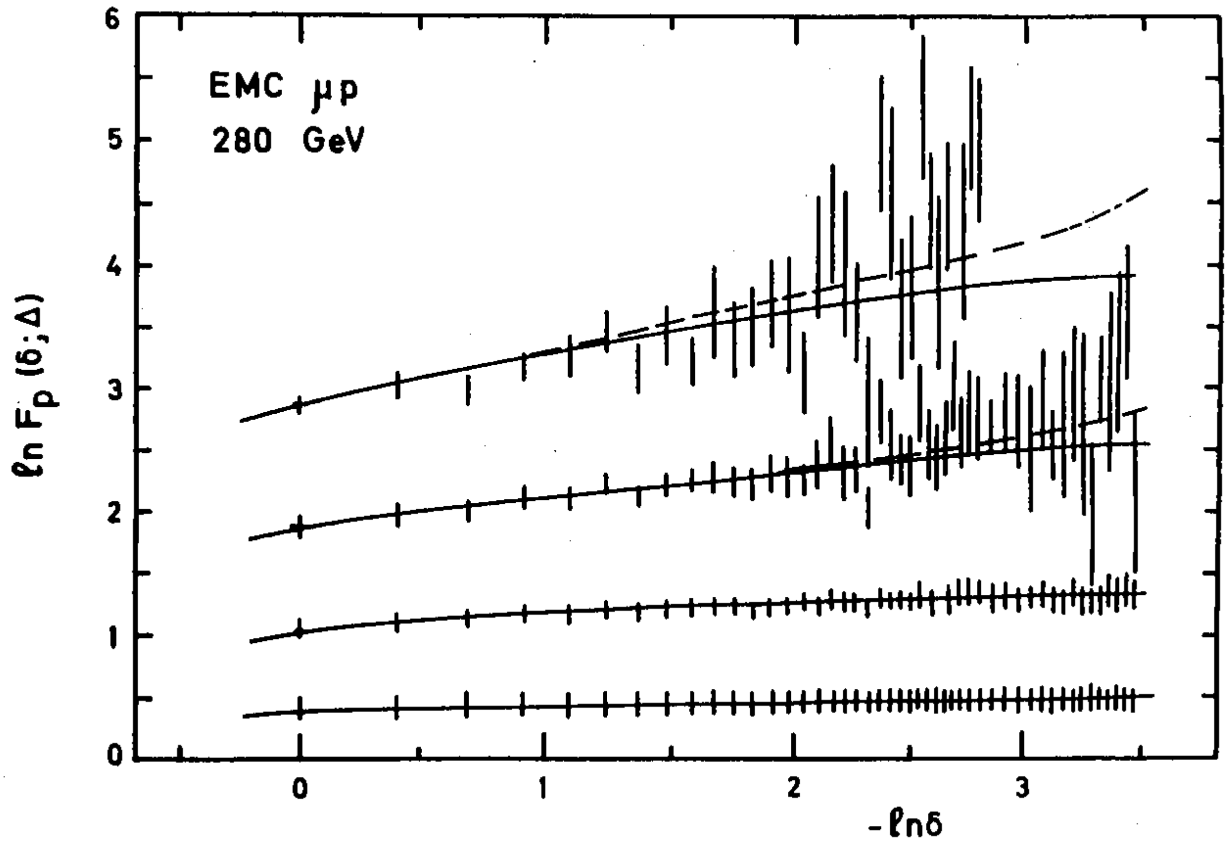
EMC μp
280 GeV
ln $F_p(\delta;\Delta)$
-ln δ

Fig. 2

CERN-TH.5798/90

INTERMITTENCY EFFECTS IN A TWO-COMPONENT MODEL

N.G. Antoniou*)
CERN - Geneva

E.N. Argyres and C.G. Papadopoulos
Institute of Nuclear Physics, NRPS Demokritos
GR-15310 Athens, Greece

and

S.D.P. Vlassopulos
Department of Physics, National Technical University
GR-15773 Athens, Greece

ABSTRACT

We study the intermittency phenomenon in high-energy collisions assuming that a new component in particle production processes, corresponding to a higher-order phase transition in the Feynman-Wilson fluid, coexists incoherently with a conventional production mechanism characterized by standard, finite-range correlations in rapidity space. The complementary effects of these two components are investigated and the origin of the power-law behaviour of the scaled factorial moments in present experiments is discussed.

---

*) Also at Department of Physics, University of Athens, GR-15771 Athens, Greece.

CERN-TH.5798/90
July 1990

1. - INTRODUCTION

A few years ago, Bialas and Peschanski suggested that the short-distance behaviour of many-particle correlations in a rapidity domain Δ can best be studied by means of the scaled factorial moments $F_p(\delta;\Delta)$ of the inclusive distribution, in small rapidity intervals δ [1]. This method can provide a sensitive probe for a class of exceptional events with large density fluctuations in rapidity, even if they occur with tiny cross-sections. Recently, a good deal of such moment measurements with increasing precision have become available in nucleus-nucleus, hadron-nucleus, hadron-hadron, lepton-hadron, as well as e+e- collisions [2-9], and a general experimental pattern, summarized by a power-law behaviour, $F_p \sim \delta^{-\phi_p}$, with $\phi_p > 0$, has emerged. Two general theoretical frameworks have been developed towards its understanding:

i) the pattern of the factorial moments is due to conventional events with finite-range correlations [10,11];

ii) a new phenomenon resulting in fractal or intermittent behaviour is responsible for the linear pattern [12-14]. $\left(\ln F_p \sim \phi_p \ln(1/\delta)\right)$.

In this work we adopt the point of view that the pattern observed experimentally is due to the incoherent coexistence of both types of events. We shall show that a few unusual events, with strong density fluctuations in rapidity, occurring only with a very small cross-section, as already hinted experimentally [3], can contribute significantly to the rise of the large-order factorial moments and help us to understand the observed behaviour. To be specific, we shall assume that the underlying dynamical mechanism for the exceptional events is a higher-order quark-hadron phase transition which takes place during the hadronization process [15]. This mechanism gives rise to strong fluctuations in a wide range of rapidity scales and leads to intermittency patterns in the corresponding Feynman-Wilson fluid [13].

To quantify this idea, we employ a two-component model where the inclusive densities $\rho(y_1,y_2,\dots,y_p)$ are built up by adding incoherently the inclusive densities $\rho_c(y_1,y_2,\dots,y_p)$ of the exceptional events to the densities $\rho_s(y_1,y_2,\dots,y_p)$ of the conventional events with finite-range correlations, namely

$$\rho(y_1,y_2,\dots,y_p) = \lambda_c \rho_c(y_1,y_2,\dots,y_p) + (1-\lambda_c)\rho_s(y_1,y_2,\dots,y_p) , \quad (1)$$

where $p = 1,2,\dots$ and $0 < \lambda_c < 1$. The corresponding factorial moments in a rapidity

interval δ, in the central region $|y| < \delta/2$, are written as follows:

$$F_p(\delta;\Delta) = \lambda_c \left[\frac{\rho_c(0)}{\rho(0)}\right]^p F_p^{(c)}(\delta;\Delta) + (1-\lambda_c)\left[\frac{\rho_s(0)}{\rho(0)}\right]^p F_p^{(s)}(\delta;\Delta), \quad (2)$$

where $F_p^{(c)}$ and $F_p^{(s)}$ are the two components of F_p corresponding to the densities ρ_c and ρ_s respectively. The term $F_p^{(c)}(\delta;\Delta)$ represents the collective effect due to the production of a critical Feynman-Wilson fluid with cross-section $\sigma_c = \lambda_c\sigma$, σ being the total cross-section of the collision. The other component, $F_p^{(s)}(\delta;\Delta)$, corresponds to a conventional production mechanism [10,11] with a finite correlation length ξ in rapidity. In present experiments we expect that $\rho_c(0) \gg \rho(0)$, and therefore the critical component $F_p^{(c)}$ may become dominant in Eq. (2) for large p, even if the cross-section σ_c is very small ($\lambda_c \ll 1$). On the contrary, the lowest moments (p = 2,3) are dominated, in the same limit $\lambda_c \ll 1$, by the conventional component $F_p^{(s)}$. This qualitative remark suggests that, independently of the detailed structure of the components $F_p^{(c)}$ and $F_p^{(s)}$, a genuine intermittency effect effect in present experiments is expected to appear at the level of higher-order moments ($p > 5$), whereas in the lowest moments ($p < 3$), this new, co-operative effect is likely to be masked by the conventional two-particle correlation mechanism. In order to compare Eq. (2) with experiments, we consider in the following two sections the specific forms of the components $F_p^{(c)}$ and $F_p^{(s)}$ as given in Refs. [13] and [10,11] respectively.

2. - THE CRITICAL COMPONENT $F_p^{(c)}(\delta;\Delta)$

The critical properties of the one-dimensional (in rapidity) Feynman-Wilson fluid are uniquely determined by Kadanoff scaling near the critical point [13]. The system has a fractal structure in the region $\delta_0 \ll \delta \ll \Delta$ of the rapidity space and the minimal scale δ_0 which, together with the critical exponent η, completely specifies the model, is connected with the particle density in rapidity, $\rho_c(0) \sim \delta_0^{\eta-1}$ ($0 < \eta < 1$). In the limit $\delta_0 \ll 1$ the system becomes intermittent with sufficiently high density $\rho_c(0)$, consistently with the requirement of a high-energy-density deposition in the central region, needed for a confinement-deconfinement phase transition. The pattern of the factorial moments in the fractality region is given by the following equation [13]:

$$F_p^{(c)}(\delta;\Delta) = \frac{p!\,[\Gamma(1-\eta)]^{p-1}}{\Gamma[1+\eta+(1-\eta)p]} \left(\frac{4\delta}{\Delta}\right)^{-\eta(p-1)} \qquad (\delta_0 << \delta << \Delta). \tag{3}$$

In the extended region, $\delta_0 << \delta < \Delta$, of the rapidity space, a more detailed form of the component $F_p^{(c)}$ is valid, as follows [13]:

$$F_p^{(c)}(\delta;\Delta) = \left(\frac{\delta}{\Delta}\right)^{\eta+(1-\eta)p} \left[B_{\frac{\Delta+\delta}{2\Delta}}(1-\eta,1-\eta) - B_{\frac{\Delta-\delta}{2\Delta}}(1-\eta,1-\eta) \right]^{-p}$$

$$\times \frac{p!\,[\Gamma(1-\eta)]^{p-1}}{\Gamma[1+\eta+(1-\eta)p]} \left(\frac{\Delta-\delta}{2\Delta}\right)^{-2\eta} F_3\left(\eta,\eta,1,1,1+\eta+(1-\eta)p,\frac{2\delta}{\delta-\Delta},\frac{2\delta}{\delta-\Delta}\right), \tag{4}$$

where B_x is the incomplete beta function and F_3 is a hypergeometric function of two variables.

3. - THE CONVENTIONAL COMPONENT $F_p^{(s)}(\delta;\Delta)$

Following the discussion in Refs. [10,11], we assume for the second moment $F_2^{(s)}(\delta;\Delta)$ the form:

$$F_2^{(s)}(\delta;\Delta) = 1 + \frac{\gamma\xi}{\delta}\left(1 - e^{-\delta/\xi}\right), \tag{5}$$

where ξ is the correlation length and γ the strength of the two-particle correlation. For the higher moments ($p > 2$) one may safely use the recursion formula,

$$F_p^{(s)}(\delta;\Delta) = F_{p-1}^{(s)}(\delta;\Delta)\left[1 + (p-1)\left(F_2^{(s)} - 1\right)\right], \tag{6}$$

which is derived by the negative binomial distribution [16]. It is of interest to note that in the limit $(F_2^{(s)}-1) << 1$, a simplified expression is obtained:

$$F_p^{(s)}(\delta;\Delta) = 1 + \frac{p(p-1)}{2}\left(F_2^{(s)} - 1\right) \qquad (p>2), \tag{7}$$

where terms of order $(F_2^{(s)}-1)^2$ have been neglected.

4. - COMPARISON WITH EXPERIMENTS

In comparing the two-component model with experiments we have used the detailed forms (4) and (6), but in order to reveal the complementary effects of $F_p^{(c)}$ and $F_p^{(s)}$ one may write, using Eqs. (3) and (7), a simplified expression for $F_p(\delta;\Delta)$ as follows:

$$F_p(\delta;\Delta) = \lambda_c\left(\frac{\rho_c}{\rho}\right)^p \frac{p!\,[\Gamma(1-\eta)]^{p-1}}{\Gamma[1+\eta+(1-\eta)p]}\left(\frac{4\delta}{\Delta}\right)^{-\eta(p-1)} + (1-\lambda_c)^{1-p}\left(1-\lambda_c\frac{\rho_c}{\rho}\right)^p\left[1+\tfrac{1}{2}\gamma p(p-1)\,G(\delta/\xi)\right] \tag{8}$$

where $\rho_c \equiv \rho_c(0)$, $\rho \equiv \rho(0)$ and $G(z) = z^{-1}(1-e^{-z})$. Equation (8) remains a good approximation in a wide range of δ. In the limit $\delta << 1$, the conventional component with $\xi > 1$ becomes a constant background on top of which an intermittency pattern, at the level of higher moments, emerges, even in the limit $\lambda_c << 1$, provided that $\rho << \rho_c$. In Fig. 1 the two-component model is compared with the NA22 measurements [4] in π^+p and K^+p collisions at 250 GeV/c. In this preliminary study we did not attempt any detailed, quantitative fit to the data; the choice of the parameters was simply guided by the experimental pattern and the existing studies of the conventional moments $F_p^{(s)}$ [10,11]. It is of interest to note that in this experiment (NA22) at least one unusual event has been measured, corresponding to a production cross-section of 0.2 μb and characterized by a local density of 100 particles per unit of rapidity [3]. If we associate the appearance of such exceptional events with the production of a critical hadronic system in a quark-hadron phase transition process, we may get, for this experiment, a phenomenological order-of-magnitude estimate of the mixing parameter λ_c in our two-component model, $\lambda_c \approx 10^{-5}$. In all our present comparisons we fix $\Delta = 4$, $\rho_c/\rho = 5$ and the rest of the parameters are given in the Table. In the conventional component, the values of the parameters γ,ξ are fixed close to the values used in Refs. [10,11]. We observe that the lowest moments ($p = 2,3$) are completely dominated by the conventional component (Fig. 1), the threshold of the intermittency pattern being shifted at the level of the fourth moment. For $p > 5$, a genuine intermittency effect, due to the critical component $F_p^{(c)}$, dominates the behaviour of the factorial moments in the limit $\delta << 1$. It may also be important to realize that a cut on the transverse momentum of the produced hadrons, $p_T > 0.3$ GeV/c, which can be argued as selecting events away from the critical temperature, removes the apparent rising trend of F_4 and F_5 for small δ [3].

Similarly, in Fig. 2 our two-component model is compared with measurements in muon-proton collisions at 280 GeV/c [5]. Again, for a very small value of the mixing parameter λ_c (see the Table), it is seen that the intermittency effect is non-negligible for $p > 5$, consistent with the trend of the data.

5. - CONCLUDING REMARKS

We have proposed a two-component model for studying intermittency effects in high-energy collisions, considering a superposition of the inclusive densities corresponding to a quark-hadron phase transition process and to a conventional production mechanism respectively. A qualitative comparison of this model with existing measurements leads to the following conclusions:

(a) the scaled factorial moments of lowest order ($p = 2,3$) are dominated by the conventional component.

(b) An intermittency pattern appears clearly in the higher factorial moments.

(c) The intermittency effect due to a quark-hadron phase transition may be significant even if the production cross-section for the critical system is very small ($\lambda_c \sim 10^{-5}$).

(d) The intermittency indices are likely to be much larger than the effective ones extracted from the data without taking into account the conventional component ($\eta > 0.2$).

(e) In the presence of the conventional component, a linear spectrum of the intermittency indices, $\phi_p = \eta(p-1)$, indicating a single fractal dimension in the critical process, may become consistent with the experimental measurements.

(f) Within the two-component model, the behaviour of the factorial moments in a multiparticle production process may be consistently associated with the presence of exceptional events in the sample, characterized by a strongly fluctuating rapidity density. One may conjecture that these events belong to a critical hadronic system which can be interpreted as a newly-hadronized quark-gluon plasma.

Our qualitative results about the relevance of the critical FW fluid model for the phenomenology of the intermittency patterns suggest a further investigation, taking into account in a two-component treatment all the existing experimental information on the behaviour of the factorial moments in various processes. Furthermore, systematic measurements in very small domains ($\delta \ll 0.1$) of the rapidity space are needed [17] in order to study the effect of the scale δ_0 which may lead to intermittency breaking in the region $\delta < 0.1$, at the level of sufficiently high moments [18]. Finally, in order to establish a firm connection between intermittency and a quark-hadron phase transition in present experiments by extracting from the data (i) the strength of the intermittency effect [19], (ii) the linearity

of the spectrum ϕ_p [14] and (iii) the universality of the critical exponent η, our two-component model suggests that one should take seriously into account the contribution of the conventional background to the scaled factorial moments. In future experiments, however, especially with relativistic heavy ions (RHIC, LHC), the probability of producing quark matter is expected to increase significantly and the role of the conventional component to become less important. Thus, in the extreme case, $\lambda_c \approx 1$, $\rho_c \approx \rho$, our model predicts a genuine intermittency pattern, given by Eq. (3), as a signal for quark-gluon plasma formation through a second-order quark-hadron phase transition.

ACKNOWLEDGEMENTS

One of us (N.G.A.) wishes to acknowledge very interesting discussions with A. Bialas and R. Peschanski. The authors are indebted to W. Kittel for supplying NA22 data.

	ξ	γ	λ_c	η
NA22	1.8	0.4	10^{-5}	0.3
EMC	1.0	0.7	10^{-4}	0.2

Table: Parameter values used in our calculations

REFERENCES

[1] A. Bialas and R. Peschanski, Nucl. Phys. B273 (1986) 703; B308 (1988) 857.

[2] W. Kittel and R. Peschanski, "Review on Intermittency in Particle Multiproduction", Proc. Europhys. Conf. on High Energy Physics 1989, to be published.

[3] W. Kittel, talk at the Santa Fé Workshop on Intermittency in High-Energy Collisions (1990);
M. Adamus et al. (NA22), Phys. Lett. B185 (1987) 200.

[4] I.V. Ajinenko et al. (NA22), Phys. Lett. B222 (1989) 306.

[5] I. Derado et al., "Investigation of Intermittency in Muon-Proton Scattering at 280 GeV", preprint MPI-PAE/Exp.El. 221 (1990).

[6] K. Sengupta et al., Phys. Lett. B236 (1990) 219.

[7] R. Holynski et al. (KLM), Phys. Rev. Lett. 62 (1989) 733.

[8] W. Braunschweig et al. (TASSO), Phys. Lett. B231 (1989) 548;
P. Abreu et al. (DELPHI), "A Study for Intermittency in Hadronic Z^0 Decays", preprint CERN-EP/90-78.

[9] C. Albajar et al. (UA1), "Intermittency Studies in $\bar{p}p$ Collisions at $\sqrt{s}$ = 630 GeV", preprint CERN-EP/90-56.

[10] P. Carruthers and I. Sarcevic, Phys. Rev. Lett. 63 (1989) 1562;
P. Carruthers et al., "Correlations and Intermittency in High-Energy Multihadron Distributions", preprint AZPH-TH/90-9.

[11] A. Capella, K. Fialkowski and A. Krzywicki, Phys. Lett. B230 (1989) 149;
A. Capella, K. Fialkowski and A. Krzywicki, "Intermittency Patterns in Hadron Production", Festschrift L. Van Hove, eds. A. Giovannini and W. Kittel (World Scientific, 1990), p. 413.

[12] R. Peschanski, Nucl. Phys. B327 (1989) 144.

[13] N.G. Antoniou, E.N. Argyres, A.P. Contogouris, C.G. Papadopoulos and S.D.P. Vlassopulos, "Intermittency, Kadanoff Scaling and Hadronization", Phys. Lett. B, to be published.

[14] A. Bialas and R.C. Hwa, "Intermittency Parameters as a Possible Signal for Quark-Gluon Plasma Formation", preprint CERN-TH.5754/90.

[15] N.G. Antoniou et al., Phys. Rev. D14 (1976) 3578; D18 (1978) 432.

[16] W. Ochs and J. Wosiek, Phys. Lett. B232 (1989) 271.

[17] E. Stenlund, Proceedings of "Quark Matter '90", Menton, France, May 1990, to be published.

[18] N.G. Antoniou, E.N. Argyres, A.P. Contogouris, C.G. Papadopoulos and S.D.P. Vlassopulos, in preparation.

[19] A. Bialas and J. Seixas, "Strong Intermittency in Momentum Space", preprint CERN-TH.5757/90.

FIGURE CAPTIONS

Fig. 1 : Comparison of our two-component model [Eq. (2)] with NA22 data (from Ref. [4]). The conventional component is given by the dashed lines.

Fig. 2 : Comparison of our two-component model [Eq. (2)] with EMC data (from Ref. [5]). The conventional component is given by the full lines.

Imprimé au CERN. Prix : 0.20 Fr.