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SCALING DISTRIBUTION OF LARGE TRANSVERSE MOMENTA

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ABSTRACT

We compute the structure function of large k_T scaling law in the framework of a multiperipheral or parton model. This function depends on two scaling variables. We show that recent NAL data are in perfect agreement with the same $1/k_T^8$ law observed at ISR. The observed apparent change of the scaling power is faked by the neglect of the dependence on one of the scaling variables.

Scaling is, in our point of view, a very important concept. Its breaking would imply the discovery of a new parameter (scale) which would dictate a change of regime. The importance of such a finding imposes a careful analysis of experimental data in terms of the scaling (dimensionless) variables. For the case of large k_T inclusive distributions in $p_a + p_b \rightarrow k + \text{everything}$, the natural scaling variables that arise in parton ¹⁾ of multiperipheral ²⁾ models are

$$x = \frac{k \cdot p_a}{p_a \cdot p_b} \quad ; \quad y = \frac{k \cdot p_b}{p_a \cdot p_b}$$

For a comparison with experimental data, it is more convenient to introduce as independent scaling variables

$$x_T = 2 (xy)^{1/2} \simeq \frac{2k_T}{\sqrt{s}} \quad ; \quad \eta^2 = \frac{x}{y} = \frac{1 - \cos \theta}{1 + \cos \theta}$$

where θ is the centre-of-mass angle of particle k , and, as usual, $s = (p_a + p_b)^2$ is the square of the total centre-of-mass energy. If scaling holds, one can find a value of p such that

$$E \frac{d^3\sigma}{d^3p} = (k_T)^{-p} G(x_T, \eta) \quad (1)$$

independently of s .

Of course, scaling should be checked by changing k_T and s at fixed x_T and η . For any fixed value of θ , and therefore also for an integral over a finite s independent range of θ like the one performed by the counters of an ISR experiment, x_T is the proper scaling variable, and indeed the ISR results ³⁾ indicate that (1) holds with $p \simeq 8$. If, however, the two scaling variables are varied simultaneously in an experimental set-up, the omission of one of them implies to smuggle in a fake energy dependence and, therefore, an apparent scaling breaking. This is what happens in the set-up of a recent experiment ⁴⁾ in which the energy is varied at fixed laboratory angle ($\theta_{\text{lab}} = 0.077$) of particle k .

It is easy to show that under these circumstances $\eta^2 = (s \theta_{\text{lab}}^2)/4m^2$, and the value of η^2 changes from 0.62 to 0.93 when the incident momentum is increased from 200 GeV/c to 300 GeV/c.

The results of the aforementioned experiment are at variance with property (1) if one neglects the η dependence of G . They would seem to suggest that scaling is broken in the sense that the value of p depends on x_T , and ranges from $p \simeq 8$ at $x_T \simeq 0.2$ (the region explored by ISR experiments) to $p \simeq 11$ at x_T larger than 0.4. We want to understand if this apparent breaking of scaling can be due to the neglect of the η variation in their set-up. We will indeed show that a quantitative evaluation of $G(x_T, \eta)$ inspired in a multiperipheral or parton model gives on the one hand a very good x_T dependence at fixed η and, on the other hand, an η dependence which in the fixed Θ_{lab} set-up of Ref. 4) explains their apparent departure from scaling.

The inclusive large k_T spectrum in the multiperipheral model was calculated in Ref. 2). Let us recall our motivations to look for such a model and the results obtained.

In the multiperipheral model small and large p_T are given by the same dynamics. This fact is a necessary condition for a model if one thinks, as we do, that scaling comes from losing the scales that determine the low values of the variable in question (k_T in our case) and not from a new ad hoc dynamics.

The multiperipheral model (in the $\lambda\phi^3$ version) has the correct two-dimensional scaling law in the language of Ref. 5), i.e., reggeization, strong scaling, Bjorken scaling in deep inelastic lepton scattering. When also k_T is large (three-dimensional scaling) we found ²⁾ the scaling law of Eq. (1) with $p = 2\lambda + \alpha + 1$ where λ is related to the dimension of the field ($\lambda = 1$ for scalars) and α is the intercept of the leading Regge (Pomeron) trajectory. If $\lambda = 1$ (pure $\lambda\phi^3$ theory) and $\alpha = 1$, $p = 8$. Using these values, the structure function $G(x, y)$ obtained in Ref. 2) reads ^{*)} in terms of the variables x_T and η :

$$G(x_T, \eta) = P(x_T, \eta) + F(x_T, \eta) \quad (2)$$

$$P(x_T, \eta) = \int_{\frac{x_T \eta}{2}}^{1 - x_T/2\eta} d\omega \, \omega(1-\omega) [\omega^2 + (1-\omega)^2] \times \left(\frac{2\omega}{x_T \eta} \right) \times \left(\frac{2(1-\omega)\eta}{x_T} \right) \quad (3)$$

*) Equations (2)-(4), as well as the subsequent Eq. (5), are not a consequence of the only multiperipheral model. Indeed, it can be obtained in the framework of parton-like approaches. We would say that it is a general characteristics of models which assigns large p_T to an elementary process (hard structure).

$$F(x_T, \eta) = \frac{1}{8} \left(1 - \eta x_T - \frac{x_T}{\eta} \right) x_T^4 \left[\frac{1}{\eta^4} \chi \left(\frac{2}{\eta x_T} - \frac{1}{\eta^2} \right) + \eta \leftrightarrow \frac{1}{\eta} \right] \quad (4)$$

The term P represents the distribution of large p_T particles coming from the internal steps of the MP chain, whereas F is the contribution of the first and last particles, which is negligible for moderate x_T and $\eta \simeq 1$ [and was therefore neglected in Ref. 2)], but becomes obviously dominant in the regions of large x_T or of η very different from 1.

The function $\chi(\omega)$ is determined by the eigenfunction of the multiperipheral integral equation. It is the structure function of a deep inelastic process induced by a field and it determines, in the model, the electromagnetic deep inelastic structure function. We expect for it similar properties as W_1 or $\sqrt{W_2}$ at SLAC, i.e., a power increase at $\omega \sim 1$, related to the asymptotic behaviour of form factors, and a monotonic increase towards 1 for $\omega \sim \infty$. In the following, we will tentatively consider $\chi(\omega)$ to be given strictly by $\sqrt{W_2(\omega)}/\sqrt{W_2(\infty)}$, and obtain in this way surprisingly good quantitative results ⁶⁾.

Equation (2) was derived in a multiperipheral model in which the particles produced, as well as those exchanged, are elementary. As discussed in Refs. 6) and 7), the results remain substantially unchanged if we substitute elementary particles with composite ones (described themselves by ladders) as long as the large k_T particle remains an elementary constituent coming from breaking a composite one. This is again common to parton descriptions of scaling phenomena. Both for large k_T as for deep inelastic lepton scattering it must be argued, with essentially hand-waving arguments, that somehow this elementary constituent should recombine without spoiling scaling.

Let us stress that in the models in which the hard structure seen electromagnetically at SLAC is the same responsible for large k_T production, we can recast the expression of G in terms of measurable quantities. Indeed if $f(\omega, R)$ is the inclusive distribution of fast hadrons in deep inelastic scattering $\gamma(Q) + p \rightarrow k + X$ (assumed scaling), and $R = (k \cdot p)/(Q \cdot p)$, $G(x_T, \eta)$ takes the form :

$$G(x_T, \eta) = \int_0^1 dR \, R^{-8} \int_{\frac{x_T \eta}{2R}}^{1 - \frac{x_T}{2\eta R}} d\omega \, \omega(1-\omega) [\omega^2(1-\omega)^2] f\left(\frac{2\omega R}{x_T}, R\right) \chi\left(\frac{2(1-\omega)R\eta}{x_T}\right) \quad (5)$$

and the problem of parton recombination is shifted to the understanding of f . Unfortunately f is not known, and we are forced to make some crude assumption of how the momentum of the parton is shared among physical particles. A sensible choice seems to be

$$f(w, R) = X(w) (1-R)^p \quad (6)$$

whence

$$G^{\text{physical}}(x_T, \eta) = \int_0^1 dR R^8 (1-R)^p G^{\text{parton}}\left(\frac{x_T}{R}, \eta\right) \quad (7)$$

and we choose $p=3$ motivated by the form factor behaviour. The specific form (6) turns out, however, not to have too much relevance in the quantitative evaluations that follow. What matters is that the physical particle takes a fraction (of the order of $2/3$, it turns out) of the transverse momentum of the parton.

The function $G(x_T, \eta)$ obtained in (7) is shown in Fig. 1. The crosses indicate the points for which the F and P contributions in Eq. (2) are equal : above the dashed line P is dominant, below F takes over. As expected $G(x_T, \eta)$ is a rapidly decreasing function of x_T , that at $\eta=1$ can be parametrized as e^{-8x_T} for $x_T \lesssim 0.7$.

The x_T distribution obtained using (7) at the appropriate value $\eta^2 = 0.93$ is compared with the results of Ref. 4) at $p_{\text{lab}} = 300 \text{ GeV}/c$ in Fig. 2. The agreement is impressive, and gives us confidence that also the η dependence can be reasonably estimated using (7). As a function of η , $G(x_T, \eta)$ is essentially constant at small x_T (as expected), while it has an increasing η^2 dependence as x_T becomes ~ 0.5 .

In Fig. 3 we show with a solid line the calculated value of

$$R = G(x_T, \eta^2 = .62) / G(x_T, \eta^2 = .93)$$

The points shown in the same graph are the ratio of the experimentally measured distributions, scaled with an s^{-4} factor. We see that, even quantitatively, the η dependence of R reproduces the experimental results and fakes an $s^{-5.5}$ dependence for $0.4 < x_T < 0.6$.

Let us try to understand why $G(x_T, \eta)$ has the shape shown in Fig. 1. When we move away from 90° the P component typically decreases, whereas the F component increases for x_T not too close to 1. Since at large x_T (~ 0.5)

the latter component is dominant, the over-all yield increases, moving away from $\eta^2 = 1$. If this physical picture is correct, one would expect an increase of the p/π^+ ratio associated with a taking over of F over P, and therefore associated with the apparent breaking of scaling. The results of Ref. 4) shown in Fig. 3 seem indeed to indicate that this is the case.

We conclude therefore that we can well understand the data of Ref. 4), together with the ISR data, in a scaling theory with $p=8$. Let us remark, however, that we could not accommodate in this framework a persistence of an $s^{-5.5}$ law at large x_T in the same apparatus for $p_{lab} = 400$ GeV/c, as some preliminary results of the same group seem to indicate ⁸⁾.

Our aim in writing this note was not to fit the data in a model rather than another, but to understand if there is indeed evidence of breaking of scaling. Scaling has nothing sacred, but its holding or breaking is an important piece of information which has to be established with great care.

R E F E R E N C E S

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FIGURE CAPTIONS

- Figure 1 : The function $G(x_T, \eta)$. The dashed line separates the regions in which the pionization or the fragmentation component dominates.
- Figure 2 : The data of Ref. 4) at $p_{lab} = 300$ GeV compared with our calculated values.
- Figure 3 : The apparent breaking of p_T^{-8} scaling induced by the η dependence.

FIG. 1

FIG. 2

FIG. 3