KNO SCALING AND MULTI-COMPONENT CLUSTER MODELS

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Within a multi-component cluster model including diffraction the presently observed KNO scaling is predicted to be real or transitory according to the energy-dependence of σ_{el}/σ_t. When no diffraction is included at most an extremely slow approach to scaling is predicted.

As is generally known (see e.g. Refs [1, 2]), multiparticle production in $p-p$ collisions is reasonably described by cluster models involving two or more components. The simplest one, the so-called two-component model, assumes a non-diffractive component and a diffractive one. Fiałkowski and Miettinen [1] suggested both components to be independent from each other. Białas and Kotański, on the contrary, showed [3] that the diffractive dissociation may be generated as a shadow of non-diffractive interactions. When the uncorrelated cluster emission model [4, 5] is used for this non-diffractive production, this approach predicts [6, 7] an absolute magnitude and a general behaviour of the diffractive cross-section which is in good agreement with experimental data, but a multiplicity distribution which fails badly.

Another approach based on the idea of splitting the distributions into simple components has been proposed by Benecke, Białas and de Groot [2]. Here the observed cross-section is represented as a sum over a number of component cross-sections, each of them satisfying the uncorrelated cluster emission model. With this assumption they obtain the peak-plateau structure of the leading particle spectrum within the KNO [8] limit. The multiplicity distribution [9] according to that model also seems to be a good approximation of the observed one.

Finally, we shall consider our approach [9] which combines Białas and Kotański's model with the one of Benecke et al. The idea of the last authors is assumed to be true for the non-diffractive production only. The diffractive cross-section, estimated by means of shadow calculations, and the multiplicity distribution appear to be fairly well described by this diffractive/non-diffractive (D/ND) multi-component model.

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From this brief description of the three cluster models we now know how multiplicity distribution agrees in each case with experimental data at present energies. In this paper we deepen the problem of the multiplicity distribution, more precisely of the KNO scaling, by extrapolating the predictions of the models up to very high energies. This will enable us to determine which features of the models are essential to ensure KNO scaling.

We remind that the KNO function [8] is defined by

$$\psi(z) = \langle n \rangle P_n, \tag{1}$$

where z is equal to $n/\langle n \rangle$, and where $\langle n \rangle$ is the average charged multiplicity and P_n the probability for producing n charged particles. Koba, Nielsen and Olesen have shown that Feynman scaling for all inclusive spectra implies scaling of the multiplicity distribution at infinite energies [8]. This means

$$\psi(z) \xrightarrow[s\to\infty]{} \psi_\infty(z), \tag{2}$$

where $\psi_\infty(z)$ is an energy-independent function. Such scaling can be expressed in terms of the moments of the multiplicity distribution by the following equation

$$C_q \equiv \langle n^q \rangle / \langle n \rangle^q = \text{constant} \qquad (q = 2, 3, \ldots) \tag{3}$$

which, however, is only equivalent to equation (2) asymptotically. By assuming the experimentally observed regularities

$$D/(\langle n \rangle - 1) = 0.576 \pm 0.008, \tag{4}$$

where D is given by $[\langle (n - \langle n \rangle)^2 \rangle]^{1/2}$, and

$$\langle (n - \langle n \rangle)^3 \rangle / D^3 = 2/3 \tag{5}$$

to hold at very high energies, Wróblewski has estimated that the moments C_2 and C_3 tend to the values 1.333 and 2.128, respectively [10].

What values for C_2 and C_3 do the three cluster models predict at very high energies and are these values constant? Before answering that question we have, however, to point out how we extrapolate the predictions of the models to energies that are higher than the present ones. Each model includes a certain number of parameters. Some are energy-independent such as the cluster mass which we take equal to 1.3 GeV [4]. This gives [11] the value of 0.3279 $(\text{GeV}/c)^2$ for the cluster average squared transverse momentum, if we assume each cluster to decay isotropically into 3 pions. Some other parameters are energy-dependent. So are the total and the elastic cross-section. For the total cross-section we use Amaldi's fit [12]:

$$\sigma_t(s) = 38.5 + 0.9(\ln s/200)^{1.8} \tag{6}$$

which is in agreement with the lower bound on $\sigma_t(s)$ given by cosmic ray experiments [13]. To get an estimate of the elastic cross-section, we assume the ratio ϱ, given by $\sigma_{el}(s)/\sigma_t(s)$, to be constant at higher energies than the ones investigated at present, as this seems to be experimentally confirmed at present energies. We take the value of 0.175 for ϱ [14]. This assumption implies that the models obey geometrical scaling [15].

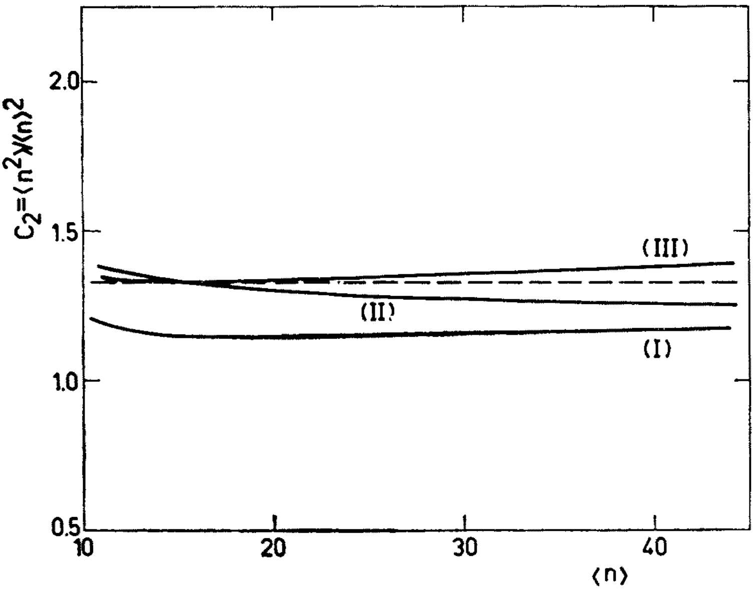

Fig. 1. Moment C_2 versus average charged multiplicity for (I): the model of Białas and Kotański, (II): the model of Benecke et al., (III): the D/ND multi-component model. Dashed line is Wróblewski's estimate [10]

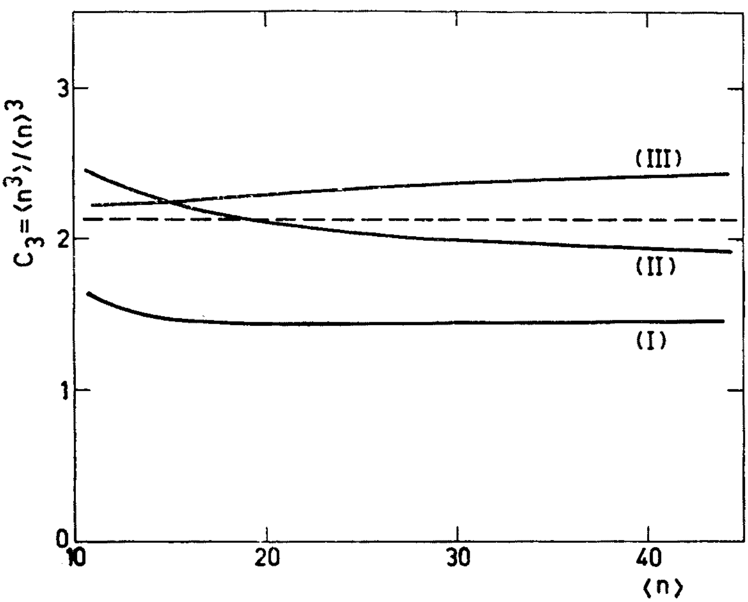

Fig. 2. Same as Fig. 1 for moment C_3

Let us now look at Figs 1 and 2 where we have plotted the moments C_2 and C_3 as functions of the average charged multiplicity $\langle n \rangle$. We have considered the three cluster models and compared their predictions with the ones of Wróblewski. We see that the model of Białas and Kotański is not good for describing the multiplicity distribution [7] because C_2 and C_3 at very high energies are much too small with respect to Wróblewski's values. They are in fact even smaller than the values obtained experimentally at low $\langle n \rangle$, i.e. at present energies. This clearly indicates that one should take as the input a superposition of coherent states and not just one of them [9]. One should assume the observed distributions to be a weighted average over several component distributions, as is done in the model of Benecke et al. and in the D/ND multi-component model. A property of these multi--component models is that skewness remains positive, on the contrary of what is predicted in the two-component approaches where it may become asymptotically negative [16].

If we now examine the moments obtained in both multi-component models, we see that in the model of Benecke et al. C_2 and C_3 decrease continuously with increasing energy. In the D/ND multi-component model C_2 first decreases with growing energy up to an energy of 10^5 GeV^2, then increases with it, while C_3, having a very similar behaviour, possesses a minimum value which is located at lower energies. At first sight none of both models seem to agree with KNO scaling. However, if we allow ourselves more freedom in the choice of ϱ, the ratio $\sigma_{el}(s)/\sigma_t(s)$, we shall see that KNO scaling, even early scaling may be described by the D/ND multi-component model. In case of the model of Benecke et al. such changes have no influence and so this model may just be compatible with an extremely slow approach to scaling or a complete lack of scaling. This would confirm what is suggested by the observation that no energy-independent plateau even for single particle spectra sets in until ISR energies, if at all.

For the D/ND multi-component model we note that the curves describing C_2 and C_3 as functions of $\langle n \rangle$ show minima, which is also the case for the model of Białas and Kotański, that also includes diffractive production. This is not seen in the model of Benecke et al., where there is no diffraction. The existence of the minima thus may be related to the addition of diffraction. By reducing the effect of it, i.e. by taking a lower value of ϱ, as in the model the total diffractive cross-section is proportional to the elastic one, the minimum values of C_2 and C_3 (similar to Wróblewski's estimates) only move to the right in Figs 1 and 2. Thus, in the context of the D/ND multi-component model, it seems that if the ratio ϱ goes down with growing energy, a true, rather early KNO scaling will occur. This is different from what is obtained with a semi-classical absorption model [17], where scaling is due to the constancy of ϱ. On the other hand, if ϱ remains constant with increasing energy, no real KNO scaling is predicted. The phenomena observed at present energies will be only transitory. Some indications of this may be found in Møller's experimental estimates of the moments C_2 and C_3 at different energies [18].

In the model of Benecke et al. as well as in the D/ND multi-component model the shape of the KNO functions does not seem to vary rapidly as the energy grows, as is shown in Figs 3 and 4. This may be due to the fact that a superposition of coherent states has been used as the input. Indeed, for the two-component model the KNO function is predicted to be asymptotically very different from the one observed at present energies [19].

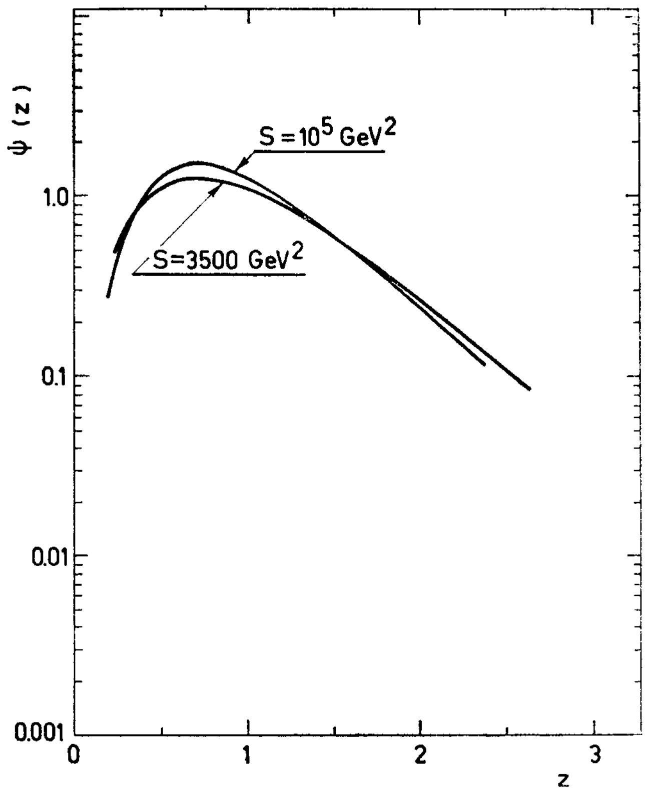

Fig. 3

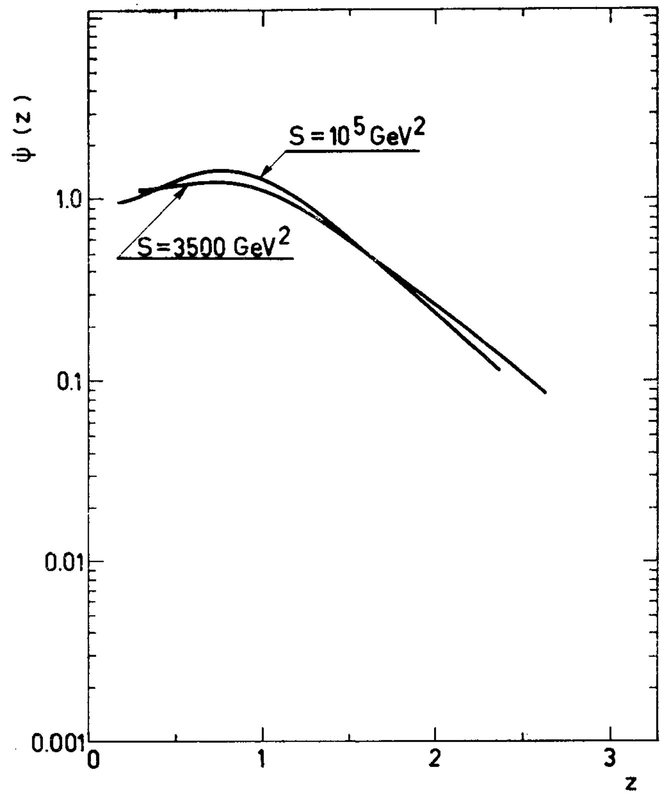

Fig. 4

Fig. 3. KNO function $\psi(z)$ at different energies for the D/ND multi-component model
Fig. 4. KNO function $\psi(z)$ at different energies for the model of Benecke et al.

If we now compare the KNO function obtained in the D/ND multi-component model (Fig. 3) with the one obtained in the model of Benecke et al. (Fig. 4), we see that the first model shows a flattening of the curve at low z values, which is not present in the second model. This is mainly due to the diffractive component. If ϱ is assumed to go down with increasing energy the contributions of diffractive production will be reduced. A curving down of the KNO function will then occur at small z, while a diffraction peak would develop if ϱ remained constant. If it appears that ϱ is constant and that experimentally no peak develops, then clearly the model of Benecke et al. seems better. In that case we may ask the question if the including of a shadow production is necessary, i.e. if one should really discriminate between diffractive and non-diffractive production mechanisms.

To summarize we may say that the two-component approach of Bialas and Kotański is not suited for the description of multiplicity distribution. The multi-component models, on the contrary, agree fairly well with it. They predict a skewness which remains positive and a KNO function which varies only slowly as the energy grows. The model of Benecke et al. seems to be compatible with an extremely slow approach to scaling or no scaling at all. A real early KNO scaling, on the other hand, may be obtained within the D/ND multi-component model if ϱ, the ratio $\sigma_{el}(s)/\sigma_t(s)$, goes down with increasing energy. If ϱ remains constant this last model predicts that the KNO scaling observed at present energies is only transitory and that a diffraction peak will develop in the KNO function.

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