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DIFFRACTIVE DISSOCIATION AND THE pp MULTIPLICITY DISTRIBUTION

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Multiplicity distributions from proton-proton interactions are analysed in the framework of two-component model. The asymptotic relations between the dispersion and average multiplicity are discussed using the new data on single proton diffraction at ISR energies. An incompatibility is indicated between the asymptotic stability of relevant phenomenological parameters and the universality of jet parameters for hadron- and lepton--induced processes.

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One of the major difficulties in testing models of soft hadron interactions is the presence of inelastic diffractive component in the inclusive data. This component should be added to the model predictions (usually available for nondiffractive production) to get a meaningful comparison with data. Therefore the separation of two components is important for any model investigations. Unfortunately, it is very difficult to perform such a separation in the model-independent way. In particular, it remains an open question to what extent the observed features of multiplicity distributions reflect just the two-component structure, and how they are related to the non-diffractive distributions.

Recently, new improved data on single proton diffraction at ISR energies have been published [1]. They show the scaling behaviour suggesting the development of an energy--independent $1/M^2$ tail in the diffractive spectrum

$$\frac{d\sigma}{dM^2}(s, M^2) \simeq \frac{\alpha}{M^2}\,(M_0^2 \leqslant M^2 \leqslant 0.05 \cdot s). \tag{1}$$

The data are compatible with constant ratio of the integrated single diffractive cross--section to the total cross-section in the whole ISR energy range

$$\frac{\sigma_{SD}}{\sigma_t} \simeq \bar{c} = 0.17 \pm 0.01, \tag{2}$$

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where a symmetry factor of 2 is included. Both cross-sections rise in this energy range by about 10%.

In this note we show that these data allow to reanalyse the two-component model interpretation of multiplicity distributions [2, 3]. The results are still model-dependent, but they suggest some disagreement between the "universality" assumptions relating the hadron collisions directly [4, 5] or indirectly [6, 7] to the lepton-hadron collisions, and the "early asymptotics" of relevant parameters. A model-independent separation of non--diffractive term would require at least a reliable estimate of diffractive average multiplicity at ISR energies.

Let us note first that the value of $\bar{c}$ quoted above allows us to estimate the basic two--component model parameter α, which is the ratio of total diffractive cross-section to the total inelastic cross-section

$$\alpha = \frac{\sigma_{\mathrm{D}}}{\sigma_{\mathrm{inel}}}. \tag{3}$$

Using the ratio of elastic-to-total cross-sections of 0.17, as measured at ISR [8] and applying the factorization theorem to estimate the double diffraction we find easily

$$\alpha \simeq 0.25 \pm 0.03. \tag{4}$$

It should be noted that the naive factorization rule used here, $\sigma_{\mathrm{DD}} = \sigma_{\mathrm{SD}}^2/\sigma_{\mathrm{el}}$, seems to underestimate some values quoted from pp experiments [9]. This suggests that the upper error limit in (4) may be a better estimate of α than the quoted value. Such a correction does not influence seriously any of our results. We will comment at the end of this note on the conclusions resulting from significantly higher estimates of α suggested by some earlier experiments [9].

The first parameters describing the multiplicity distributions are the average multiplicity $\bar{n}$ and the dispersion D. Here and in the following we denote always by n the number of negative particles produced in the pp interactions. In the two-component model one finds [2]

$$\bar{n} = \alpha \bar{n}_{\mathrm{D}} + (1-\alpha)\bar{n}_{\mathrm{ND}}, \tag{5}$$

$$D^2 = \alpha D_{\mathrm{D}}^2 + (1-\alpha) D_{\mathrm{ND}}^2 + \alpha(1-\alpha)(\bar{n}_{\mathrm{ND}} - \bar{n}_{\mathrm{D}})^2, \tag{6}$$

where the indices D and ND refer to the diffractive and non-diffractive distributions, respectively.

Since we do not have reliable estimates of the global diffractive multiplicity distributions at ISR energies, we cannot perform the simple separation of multiplicity distributions, although many diffractive channels are well indentified. We will show, however, how some simple assumptions on diffractive average multiplicity reflect in the estimates of non--diffractive parameters via formulae (5) and (6).

We use the well-established empirical relation between the dispersion and average multiplicity [10]

$$D \simeq A(\bar{n} + \tfrac{1}{2}) \tag{7}$$

which describes all the pp data with $A = 0.576 \pm 0.005$. We take this value as a good estimate of the asymptotic $D/\bar{n}$ ratio. We assume also that the value of α obtained above will not change at asymptotic energies.

Now we may note that the value of α agrees exactly with an estimate obtained from the value of A in the simplest version of tw-component model. Indeed, let us assume [3] that the diffractive parameters are energy independent (or vary more slowly than the corresponding non-diffractive parameters) so that we have

$$\lim_{\bar{n}\to\infty} \frac{\bar{n}_D}{\bar{n}} = 0, \tag{8}$$

$$\lim_{\bar{n}\to\infty} \frac{D_D^2}{\bar{n}^2} = 0 \tag{9}$$

and that no long-range correlations appear in the separated non-diffractive term

$$\lim_{\bar{n}\to\infty} \frac{D_{ND}^2}{\bar{n}^2} = 0. \tag{10}$$

Then we find from formula (6) asymptotically

$$\frac{\alpha}{1-\alpha} = \lim_{\bar{n}\to\infty} \frac{D^2}{\bar{n}^2} = A^2 \simeq \tfrac{1}{3} \tag{11}$$

in perfect agreement with the value of α estimated above.

However, the assumptions (8)–(10) lead inevitably to the singular two-maximum shape of the asymptotic KNO curve [11], which seems an unlikely development, although the data do not rule out really definitely this possibility [12]. Thus it is generally believed that the success of relation (11) is accidental and due to the cancellations in (6) between the increase of second term (long-range correlations in the non-diffractive part) and the reduction of the third term (non-negligible average diffractive multiplicity). This conjecture seems now to be strongly supported by the observation of an increasing tail of the diffractive mass spectrum (1). Indeed, if the average diffractive multiplicity increases (as expected) with mass, it is natural to assume that (8) is wrong and

$$\lim_{\bar{n}\to\infty} \frac{\bar{n}_D}{\bar{n}} = \varepsilon \neq 0. \tag{12}$$

We will see later that this result can be derived in some simple models, resulting in the estimates of non-diffractive parameters contradicting (10).

It is now rather obvious that assumption (10) should be abandoned if we want to fit asymptotically Eq. (6) with non-zero ε and values of A and α satisfying relation (11).

In fact, we can use formula (6) to estimate the asymptotic $D_{ND}/\bar{n}_{ND}$ ratio as a function of ε, assuming the values of A and α as estimated above. We get

$$\lim_{\bar{n}_{ND}\to\infty} \frac{D_{ND}}{\bar{n}_{ND}} = \frac{\sqrt{1-\alpha}}{1-\varepsilon\alpha}\left[A^2 - \alpha\varepsilon^2 \lim_{\bar{n}_D\to\infty} \frac{D_D^2}{\bar{n}_D^2} - \frac{\alpha}{1-\alpha}(1-\varepsilon)^2\right]^{1/2}. \tag{13}$$

For calculations we need still the asymptotic ratio of $D_D/\bar{n}_D$. The results, however, do not depend too strongly on this value. In Fig. 1 we show the asymptotic $D_{ND}/\bar{n}_{ND}$ ratio calculated for $D_D/\bar{n}_D = 0$ and for $D_D/\bar{n}_D = A$ in the ε range $0 < \varepsilon < 1$. For comparison, the experimental $D/\bar{n}$ values for pp and νp data are indicated. We see that already at small ε quite a large estimate of asymptotic non-diffractive ratio $D_{ND}/\bar{n}_{ND}$ follows from two-component model formula (6) with non-zero ε.

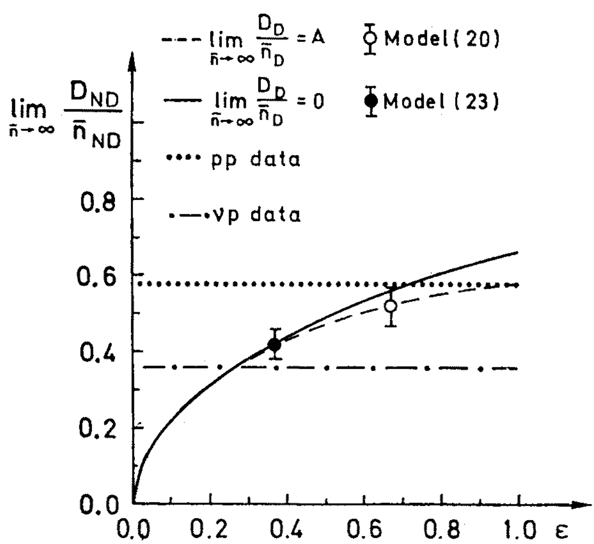

Fig. 1. The assumed estimate of non-diffractive asymptotic $D_{ND}/\bar{n}_{ND}$ ratio as a function of $\varepsilon = \bar{n}_D/\bar{n}$. The curve is calculated for $D_D/\bar{n}_D = 0$ (solid line) and $D_D/\bar{n}_D = A$ (broken line). The experimental values of $D/\bar{n}$ in pp and νp data are indicated for comparison as horizontal dash-dotted and dotted line, respectively. Two points correspond to models considered in the text

Unfortunately, no reliable estimate of ε is possible from the existing data. The NAL diffractive cross-sections collected in Ref. [13] suggest the value of $\varepsilon \simeq 0.2 \div 0.3$, whereas different methods of separating the diffractive component result in the value of 0.4 or even 0.7 in the same energy range [14]. In all cases double diffraction has been neglected. Thus, in the following, we have to use simple models predicting a definite value of ε.

As a first example, let us assume that the average single diffractive multiplicity grows asymptotically with mass squared in the same way as the non-diffractive multiplicity grows with s. This is supported by phenomenological fits [15]. In particular, let us assume asymptotically

$$\bar{n}_{SD}(s, M^2) = \gamma \ln M^2 + \beta + O\left(\frac{1}{M^2}\right), \tag{14}$$

$$\bar{n}_{ND}(s) = \gamma \ln s + \beta' + O\left(\frac{1}{s}\right), \tag{15}$$

where $\beta \neq \beta'$ may reflect the reduction of the "effective s", due to the leading baryon effect. Then integrating over M^2 according to (1) we find

$$\lim_{\bar{n}\to\infty} \frac{\bar{n}_{SD}}{\bar{n}_{ND}} = \tfrac{1}{2}. \tag{16}$$

If we include the double diffractive term with weight $\sigma_{DD}/\sigma_D \simeq \frac{1}{5}$ and $\bar{n}_{DD} = \bar{n}_{SD}\times 2$, as suggested by factorization, and use the α value of $\frac{1}{4}$ as above, we find

$$\varepsilon \simeq \tfrac{2}{3}. \tag{17}$$

The dispersion of diffractive distribution can be also estimated assuming the linear relation analogous to (7) for high M^2

$$D_{SD}(s, M^2) = A'\bar{n}_{SD}(s, M^2) + O(\sqrt{\bar{n}_{SD}}). \tag{18}$$

Integrating over M^2 and adding again the double diffraction we obtain

$$\lim_{\bar{n}_D\to\infty} \frac{D_D}{\bar{n}_D} \simeq \left(\tfrac{10}{9}A'^2 + \tfrac{7}{18}\right)^{1/2} \tag{19}$$

which fortunately does not depend crucially on the poorly known value of A'. Assuming $0 \leqslant A' \leqslant 0.5$ (the last value being the corresponding estimate for pion diffractive dissociation [16], we may now calculate from (13) the asymptotic nondiffractive ratio of dispersion to the average multiplicity (shown in Fig. 1 as open point)

$$\lim_{\bar{n}_{ND}\to\infty} \frac{D_{ND}}{\bar{n}_{ND}} \simeq 0.52 \pm 0.05. \tag{20}$$

The obtained value is far from zero and does not differ significantly from the value of A found experimentally in the full multiplicity distribution. It is also compatible with A', as suggested by the assumed similarity of diffractive and non-diffractive jets. The value (20) is, however, significantly higher than the analoqous ratio for νp interactions, where the value of $c = 0.36 \pm 0.02$ was found in the fit [17]

$$D_{\gamma p} = c\bar{n}_{\gamma p} + d. \tag{21}$$

Note that such value of c fits also well the e^+e^- data [18]. Thus, assuming that the diffractive and non-diffractive jets from hadron collisions are similar, we find that their estimated dispersion is significantly larger than in lepton-induced jets. This may reflect the composite structure of hadrons (impact parameter profile [19]).

Note that our result does not contradict the similarity of non-diffractive jets at fixed inelasticity and e^+e^- jets at corresponding s in the present energy range [4, 5]. The inelasticity fluctuations contribute significantly to the dispersion at present energies and the full inelastic distribution may be much broader then distributions at given inelasticity. Asymptotically, however, the $D/\bar{n}$ ratio should be the same in both cases and the similarity of lepton- and hadron-induced jets may survive only if some of our parameters (A, α, ε, c) are still far from their true asymptotic values.

The second model which we will consider here is the two-chain model of non-diffractive pp collisions [6, 7]. Assuming the analogous parametrization of a diffractive and non-diffractive chain we should replace now (15) by

$$\bar{n}_{\mathrm{ND}} = 2\gamma \ln s + \beta'' + O\left(\frac{1}{s}\right) \tag{22}$$

from which we obtain after calculations analogous to those presented above a value of $\varepsilon = 4/11$ and the resulting asymptotic ratio, shown in Fig. 1 as a black dot, reads

$$\lim_{\bar{n}_{\mathrm{ND}} \to \infty} \frac{D_{\mathrm{ND}}}{\bar{n}_{\mathrm{ND}}} \simeq 0.42 \pm 0.04. \tag{23}$$

This corresponds to the analogous ratio for a single chain of

$$\lim_{\bar{n}_1 \to \infty} \frac{D_1}{\bar{n}_1} = \sqrt{2}\,(0.42 \pm 0.04) \simeq 0.59 \pm 0.06. \tag{24}$$

Again, we conclude that the parameters for a non-diffractive chain may agree with those assumed for a single diffractive chain, but the value of $D_1/\bar{n}_1$ ratio exceeds significantly the corresponding value of c fitted to the νp data. This seems to be even more embarassing than the other asymptotic prediction of this model, $\bar{n}_{\mathrm{ND}}/\bar{n}_{\nu p} \to 2$, (also not confirmed by trends observed in data) since the $D/\bar{n}$ ratios are supposedly much less affected by sub-asymptotic effects.

Note also that our results do not contradict the successes of two-chain model (with νp data used to parametrize single chain) in describing $\bar{n}$ and D for pp collisions up to the ISR energies [20]. In this energy range the chain energy spread increases significantly the dispersion, making possible the correct description of pp data with very conservative estimate of diffractive term ($\alpha = 0.18$, as in Ref. [13]). This effect, however, is asymptotically negligible. We have therefore to abandon either the assumption of equivalence of hadron- and lepton-induced chains, or the belief in the asymptotic stability of phenomenological parameters (as listed above) in the framework of this model.

We should stress here that our remarks concern the two-chain model only, and not the dual model with the unitarity corrections, where the average number of chains in pp collision exceeds two and the effect of extra chains increases with energy. In the latter model the "early asymptotics" of the $D/\bar{n}$ ratio in pp collisions is quite compatible with fits to the νp and e⁺e⁻ data [21], since the pp dispersion is asymptotically enhanced by the fluctuations in the number of chains.

We add now a few more remarks. First, let us note that the non-vanishing $\bar{n}_D/\bar{n}$ ratio follows from the $1/M^2$ distribution (1) and from the proportionality of leading terms in diffractive and non-diffractive multiplicities not only for the logarithmic formulae (13), (14). Indeed, let us assume more generally

$$\bar{n}_{SD}(s, M^2) = \gamma \ln^k M^2 + O(\ln^{k-1} M^2), \tag{25}$$

$$\bar{n}_{ND}(s) = \bar{\gamma} \ln^k s + O(\ln^{k-1} s). \tag{26}$$

We find then after integration (for α and double diffraction estimated as above)

$$\varepsilon = \frac{8\gamma k}{2\gamma k + 5\bar{\gamma}(k+1)} \tag{27}$$

which for $k = 1$ and $\gamma = \bar{\gamma}$ reduces obviously to (17). We have checked that assuming $k = 2$ we do not change qualitatively our results as compared to those presented above. It should be noted, however, that for $\bar{n}$ increasing faster than any power of logarithm (assuming again the same M^2 dependence of $\bar{n}_{SD}$ and s dependence of $\bar{n}_{ND}$) we find $\varepsilon = 0$ and recover the result (10). On the other hand, if we abandon the relation between the single diffraction and non-diffractive production, we cannot predict ε value and the early KNO scaling becomes an accident.

Second, we should note that even for negligible correlations between the diffractively produced particles at given mass of diffractive state ($A' = 0$) we obtain a KNO scaling curve of non-zero width for the integrated diffractive multiplicity distribution. In fact, neglecting for simplicity double diffraction and using $A' = 0$ and the logarithmic parametrization (14) we find that the diffractive part of KNO distribution is asymptotically a step function

$$\psi_D(z) = \frac{1}{2\varepsilon}\, \theta(2\varepsilon - z) \tag{28}$$

where

$$\psi(z) = \alpha\psi_D(z) + (1-\alpha)\psi_{ND}(z) \tag{29}$$

defines the separation of KNO function [11] into the diffractive and non-diffractive part. Since the non-diffractive part in both models discussed for $\varepsilon \neq 0$ is characterized by quite large values of $D/\bar{n}$, we conclude that the early KNO scaling to the curve of the shape as seen experimentally [10] is quite natural for such models, being the sum of "nearly flat" and "nearly Gaussian" contributions.

Finally, we comment on the approach to the asymptotic values of $D/\bar{n}$ ratios. Let us compare the case of constant diffraction and no long-range correlations in non-diffractive component (8)–(10) with models with constant ε and large $D_{ND}/\bar{n}_{ND}$ ratio. It is easy to show that both pictures can account for the success of linear fit (7). Indeed, let us compare the results for the two following parametrizations:

$$\bar{n}_D = D_D^2 = 1; \quad D_{ND}^2 = \bar{n}_{ND} - \tfrac{1}{3}; \quad \alpha = \tfrac{1}{4} \tag{30}$$

which is an example of simplest two-component model parametrization, and

$$\bar{n}_D = \tfrac{1}{2}\bar{n} - \tfrac{1}{4}; \quad D_D^2 = \tfrac{3}{13}(n_D + \tfrac{1}{2})^2; \quad D_{ND}^2 = \tfrac{3}{13}(\bar{n}_{ND} + \tfrac{1}{2})^2; \quad \alpha = \tfrac{1}{4} \tag{31}$$

where the value of $\varepsilon = \frac{1}{2}$ (intermediate between two models considered) has been assumed, and the remaining parameters were suitably adjusted. Using (5) and (6) one can check that in both examples we reproduce *exactly* (7) with $A^2 = \frac{1}{3}$, as seen in data. Moreover, the diffractive parameters in both cases agree quite well with quoted NAL data [13], where $\bar{n}$ is around 3. However, the non-diffractive dispersion assumed is very different already in the available energy range (note that $\bar{n}$ exceeds 5 at top ISR energy), as shown in Fig. 2. Therefore our examples show that one cannot estimate the non-diffractive parameters in the model-independent way from data on D and $\bar{n}$ alone, even for diffractive parameters constrained to agree roughly with NAL data. The existence of long-range

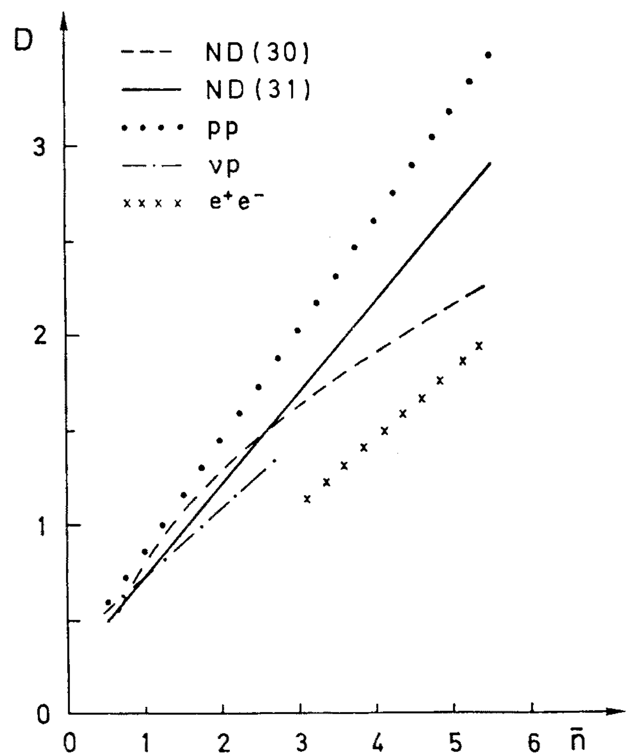

Fig. 2. Two examples of parametrizations for non-diffractive dispersion as a function of average multiplicity in pp collisions. The full line corresponds to the parametrization (31) and the broken line to (30). For comparison, fits to the experimental pp, νp and e^+e^- data are shown as dotted, dash-dotted and crossed line, respectively

correlations in non-diffractive component can be demonstrated only if we assume that the diffractive average multiplicity is asymptotically non-negligible as compared with global average multiplicity ($\varepsilon \neq 0$). The arbitrariness of ε is therefore embarassing for any efforts of model-independent estimates of non-diffractive distributions. A good measurement of $\bar{n}_{SD}$ as the function of M^2 at ISR energies would be very helpful in separating the non--diffractive component.

Let us repeat now once more that all our results presented above depend on the estimate of diffractive cross-section (4). Some earlier experiments [9] suggest the higher values of single diffractive cross-sections and much higher values for double diffraction, resulting in the saturation of Pumplin bound [22] at top ISR energies.

$$\sigma_{el}+\sigma_D \simeq \frac{1}{2}\sigma_t.$$

This corresponds to the value of $\alpha \simeq 0.4$. For such a value of α the relation (11) is violated and a non-zero limit of $\bar{n}_D/\bar{n}$ ratio, $\varepsilon > 0.3$ is necessary to explain the value of A in fit (7) for any asymptotic value of $D_{ND}/\bar{n}_{ND}$ ratio in the two-component model. We have checked that the limit of $D_{ND}/\bar{n}_{ND}$ estimated from formula (13) with $\alpha \simeq 0.4$ is significantly reduced in all the relevant ε range, $0.3 < \varepsilon < 1$, changing our conclusions. In particular, the two-chain model with each chain parametrized according to the νp data is then compatible with the experimental value of A. Thus a confirmation or correction of the value of α used here (4) is very important for our results.

Summarizing, let us conclude that although the new data have confirmed the possibility to explain the observed $D/\bar{n}$ ratio in pp interactions without long-range correlations in the non-diffractive component, they strongly suggest the non-vanishing asymptotic value of the ratio of average diffractive and non-diffractive multiplicities. This, in turn, suggests that the non-diffractive pp collisions results in the multiplicity distributions broader than those observed in νp or e^+e^- interactions. It may reflect the impact parameter profile of proton or, in another language, the necessity of unitarity corrections to the simplest dual picture.

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