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Diffractive and nondiffractive components of the multiplicity distribution in pp collisions

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Abstract. Topological cross sections for diffractive and nondiffractive components in pp collisions are deduced on the basis of a dynamical model proposed earlier to explain the multiplicity distribution of charged particles. The model has an important prediction for the angular and momentum distributions of charged particles in diffractive events.

Keywords. pp collisions; topological cross sections; diffractive and nondiffractive components.

Several authors (Koba *et al* 1972, Harari and Rabinovici 1973, Van Hove 1973, Fiabkowski and Micttinen 1973, Lach and Malamud 1973) have attempted to explain the prong multiplicity distribution of charged particles in pp collisions by different approaches. Surveying these attempts, one finds that the prong multiplicity distribution is rather a gross feature of multiparticle production that can be fitted in many ways and not restrictive enough to lead to definite conclusions regarding the pattern of multiparticle production. However, Dao *et al* (1973) have recently reported measurements on the topological cross sections of a more restrictive type, which put strong constraints on the dynamical models which could be compatible with these results. In the new measurements, one makes a selection of events in which there is a slow moving proton. Dao *et al* have given explicitly the values of the topological cross sections for events corresponding to $|t| < 0\cdot25\ \mathrm{GeV}^2$, where t is the four momentum transfer between the target and the detected proton. From the histograms presented in their paper, one can also deduce the topological cross sections for events corresponding to $|t| < 0\cdot125\ \mathrm{GeV}^2$ and $|t| < 0\cdot5\ \mathrm{GeV}^2$. Further the missing mass squared M_x^2, recoiling from the detected proton, has been obtained as a function of the number n_c of charged particles for the different $|t|$ cuts, $0\cdot125$, $0\cdot25$ and $0\cdot5\ \mathrm{GeV}^2$.

The topological cross sections $\sigma_{nc}{}^{d}$, corresponding to the events in the cut $|t| < 0\cdot25\ \mathrm{GeV}^2$, have been identified by Dao *et al* as the diffractive component and the difference $\sigma_{nc} - \sigma_{nc}{}^{d} \equiv \sigma_{nc}{}^{n.d}$ as the nondiffractive component, where σ_{nc} is the usual topological cross sections without any $|t|$ cut. The arbitrariness in the $|t|$ cut in specifying the diffractive component has been justified by citing that the cross sections do not change much when the $|t|$ cut is increased from $0\cdot25$ to $0\cdot5\ \mathrm{GeV}^2$.

The importance of the new results, in confronting the predictions of specific dynamical models to a test, has been noted. The nova models (Hwa 1970) which predict $\sigma_{n_c}{}^{d} \sim 1/n_c{}^2$ are seen to be in disagreement with the date. Further the diffractive dissociation models with isotropic decay distribution and a cut off in the momentum in the nova frame, would predict a peaking in the effective mass plot for all charge topologies. Experimentally no such peaking is seen for $n_c \geqslant 6$. It has already been noted by Vander Velde (1972) at the Chicago Conference, on the basis of data at 100 and 200 GeV, that only about 25% of $\sigma_4{}^d$ and a smaller percentage (if any) of $\sigma_{n_c}{}^d$ ($n_c \geqslant 6$) could be attributed to single diffraction dissociation. A nova type of model with anisotropic angular distribution, motivated by simple multiperipheral arguments, has been constructed recently by Kajantie and Ruuskanen (1973). Though the disagreement with the effective mass plots associated with usual nova models may be eliminated, the diffractive multiplicity distribution at 303 GeV given in their paper seem to be in poor agreement with the data, as $\sigma_{n_c}{}^d$ falls too fast as $\exp\{-(n_c - 2)/2\}$.

Recently Chaudhary *et al* (1973) have proposed a model to explain the pattern of multiplicity distribution in the entire energy range 5–300 GeV. In this model, the multiplicity distribution is composed of a " specific " mixture of Poisson distributions. The individual components of this mixture would roughly correspond to different $|t|$ cuts. The first component corresponds to the smallest $|t|$ cut but its value cannot be fixed on the basis of the model. If one makes the identification that the first component roughly corresponds to the $|t|$ cut at 0·5 GeV^2, one can compare the predictions of the model for prong multiplicity distribution for diffractive and non-diffractive components with the experimental data of Dao *et al.*

We find that, in spite of the arbitrariness in the $|t|$ cut, the theoretical results for $\sigma_{n_c}{}^d$ and $\sigma_{n_c}{}^{n.d}$ are in reasonable agreement with experiment. The shape of the distribution of $n_c{}^2 \times \sigma_{n_c}{}^d$ as predicted by the model, compares well with the experimental curve. Though the effective mass plots cannot be predicted straight away from the model, rough bounds on the missing mass for different charge topologies can be inferred. These bounds are seen to be compatible with experiment. Moreover, one does not expect, on the basis of the present model, sharp peakings in the effective mass plots except for $n_c = 2$ and possibly $n_c = 4$.

We first briefly outline the model to the extent necessary for the present paper and give relevant theoretical expressions. The results are then compared with the experimental data. Finally we present the dynamical implications of our model of diffraction and some theoretical ideas leading to such a dynamical picture.

According to the model of Chaudhary *et al* (1973) there are two groups of particles produced in each collision, which are characterized by different number distributions. One group of particles, called non-leading particles, may be identified with the central component or pionization and their distribution is a Poisson in the number of charged pairs. The other group of particles, referred to as leading particles, arise in the decay of two fast moving (in the CM system) baryon-like excited objects. In the energy range which includes ISR energies, the masses of these excited objects need not exceed a few GeV. The leading particles at any given energy would have a variation between 2 and some maximum value $2R$, where R would be a function of energy. The number distribution of leading charged particles is assumed to be a geometric distribution with R terms. Further the emission of leading and non-leading particles is assumed to be uncorrelated. The probability P_{nc} of having a total of n_c charged particles in an event can be written as:

$$P_{nc} = \sum_{r=1}^{n_c/2} a_r \bar{P}_{\frac{n_c}{2}-r} \qquad \text{if } \frac{n_c}{2} < R$$

$$= \sum_{r=1}^{R} a_r \bar{P}_{\frac{n_c}{2}-r} \qquad \text{if } \frac{n_c}{2} > R \tag{1}$$

where $\bar{P}_m$ is the probability of having $2m$ charged non-leading particles and a_r is the probability of having $2r$ charged leading particles in an event. By our assumptions regarding the number distributions of leading and non-leading particles, one can write,

$$\bar{P}_m = \exp\left(- \langle n_{\text{N.L}} \rangle/2\right) \left[\langle n_{\text{N.L}} \rangle/2\right]^m/m\,! \tag{2}$$

$$a_r = \frac{1-q}{1-q^{\text{R}}} q^{r-1} \tag{3}$$

and

$$\langle n_{\text{L}} \rangle = \frac{2}{1-q} - \frac{2\text{R}q^{\text{R}}}{1-q^{\text{R}}} \tag{4}$$

where $\langle n_{\text{L}} \rangle$ and $\langle n_{\text{N.L}} \rangle$ are the average numbers of leading and non-leading charged particles. Further $\langle n_c \rangle = \langle n_{\text{L}} \rangle + \langle n_{\text{N.L}} \rangle$ where $\langle n_c \rangle$ is the averege number of charged particles. According to our earlier discussion, the first term on the R.H.S. of (1) is identified with diffraction and the sum of the remaining terms with nondiffraction. The topological cross sections $\sigma_{nc}{}^{\text{d}}$ and $\sigma_{nc}{}^{\text{n.d}}$ can then be written as:

$$\sigma_{nc}{}^{\text{d}} = \sigma_{\text{in}}\, a_1 \bar{P}_{\frac{n_c}{2}-r} \tag{5}$$

$$\sigma_{nc}{}^{\text{n.d}} = \sigma_{\text{in}} \sum_{r=2}^{n_c/2} a_r \bar{P}_{\frac{n_c}{2}-r} \qquad \text{if } \frac{n_c}{2} \leqslant R$$

$$= \sigma_{\text{in}} \sum_{r=2}^{R} a_r \bar{P}_{\frac{n_c}{2}-r} \qquad \text{if } \frac{n_c}{2} > R \tag{6}$$

where σ_{in} is the total inelastic cross section. The topological cross sections $\sigma_{nc}{}^{\text{d}}$ and $\sigma_{nc}{}^{\text{n.d}}$ are completely determined by eqs (2) to (6) if one knows the break up of the average number $\langle n_c \rangle$ of the charged particles as a sum $\langle n_{\text{L}} \rangle$ and $\langle n_{\text{N.L}} \rangle$ and the value of R. One can give a parametrization of $\langle n_{\text{L}} \rangle$, $\langle n_{\text{N.L}} \rangle$ and R as functions of energy or alternatively treat them as free parameters to be fixed at each energy so as to obtain a minimum χ^2 fit to the experimental data of P_{nc}. Table (1) in the paper of Chaudhary *et al* (1973) has been computed by the latter procedure. We make use of that table to compute the values of $\sigma_{nc}{}^{\text{d}}$ and $\sigma_{nc}{}^{\text{n.d}}$ according to (5) and (6). The results at 303 GeV for $\sigma_{nc}{}^{\text{d}}$, $\sigma_{nc}{}^{\text{n.d}}$ and $n_c{}^2\,\sigma_{nc}{}^{\text{d}}$ are shown in figures 1, 2 and 3 respectively and compared with the experimental cross sections corresponding to the cut $|t| < 0{\cdot}5$ GeV^2. Results for $\sigma_{nc}{}^{\text{d}}$ at other energies are given

Table 1. Calculated diffractive charged particle cross sections (in mb) and the charged multiplicity. The numbers in brackets are experimental values deduced from the histograms given by Vander Velde (1972)

	P_{lab} (GeV/c)			
	19	69	102	200
d 2	9·08	5·07	4·76	2·81
d 4	4·66	5·87	5·35 (6±0·46)	4·00 (3·73±0·33)
d 6	1·20	3·39	3·00 (2·74±0·5)	2·91
d 8	0·20	1·31	1·12 (2·1±0·49)	1·39
d 10	0·026	0·38	0·32	0·50
d 12	0·0027	0·087	0·070	0·14
d 14		0·017	0·013	0·035
d 16		0·003	0·002	0·007
d 18		0·0003	0·0003	0·001
d 20				0·0003

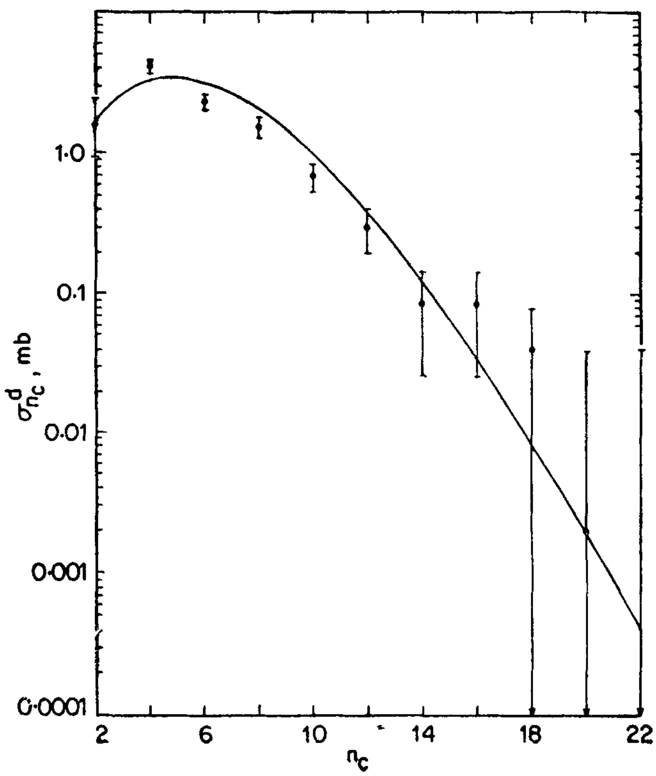

Figure 1. Diffractive cross section $\sigma_{n_e}{}^d$ versus n_e = the number of charged particles in the collision. The experimental points are cross sections corresponding to the cut $|t| < 0·5$, deduced from the histograms of Dao *et al.* (1973).

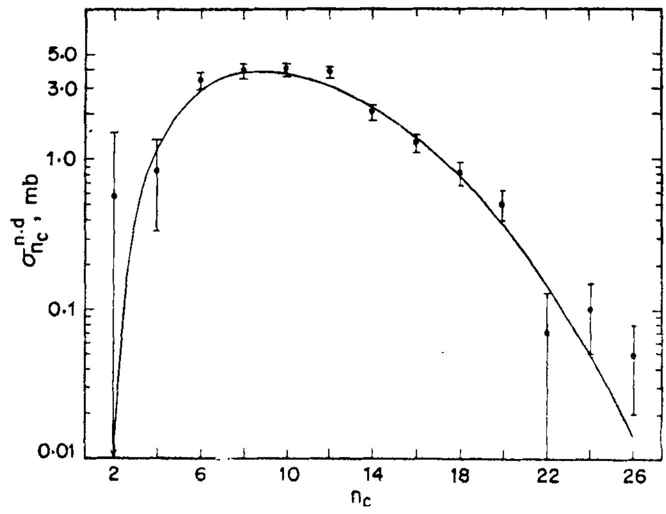

Figure 2. Nondiffractive cross sections $\sigma_{nc}{}^{\mathrm{n.d}}$ versus n_c. The experimental points correspond to the cut $|t| < 0{\cdot}5$.

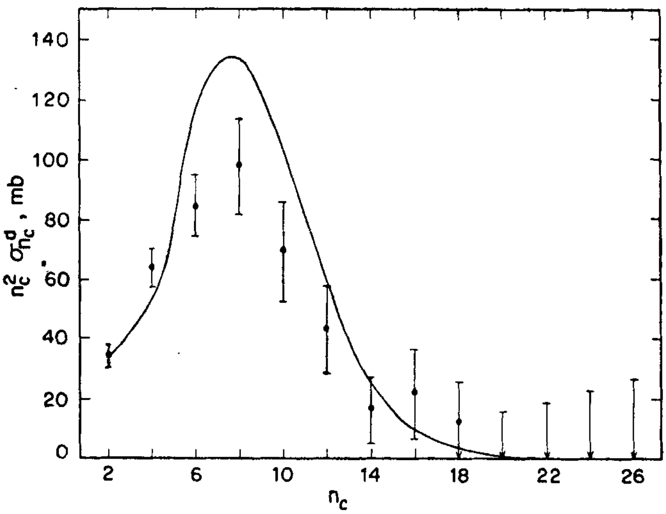

Figure 3. $n_c{}^2\,\sigma_{nc}{}^{\mathrm{d}}$ versus n_c.

in table 1. It may be noted that the distribution in (5) is not a Poisson distribution even though $\bar{P}_m$ is a Poisson distribution.

According to our model of diffraction outlined above, diffractive events are those in which there are just two leading charged particles and some poinization. We assume that in these events only one of the incident protons is excited at a time and the events detected in the cut $|t| < 0{\cdot}5$ GeV^2 correspond to the projectile excitation. Events corresponding to the target excitation would have much larger missing masses and one may assume that they go out of the $|t|$ cut. The situation is represented in figure 4. Using the notation of figure 4, the square of the missing mass is $M_x{}^2 = (P_a{}^* + \Sigma_i K_i)^2$ where the sum over i is taken for both charged and neutral particles. Since the momenta K_i refer to pionization, it is reasonable to assume that $\Sigma_i K_i = 0$. Moreover, as the values of M^* are not expected to be much larger than the mass M of the proton, one can approximate $E_a{}^* \simeq E_b{}' \simeq \frac{1}{2}(\sqrt{S} - \Sigma_i\, \omega_i)$ where $E_a{}^*$, E_b and ω_i are the energy components of $P_a{}^*$, $P_b{}'$ and K_i in the CM system. With these approximations one gets

$$M_x{}^2 \simeq M^{*2} + \sqrt{S}\,(\sum_i \omega_i) \tag{7}$$

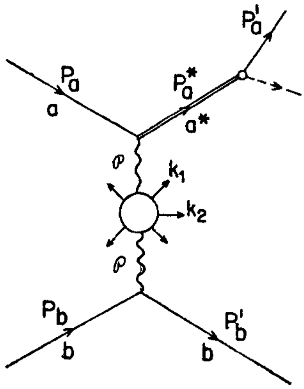

Figure 4. Schematic representation for the dynamics of a diffractive event.

In a two-prong event there can be no charged non-leading particles and the excited object a^* (figure 4) would emit one or more neutral particles. According to experiment (Dao *et al* 1973), the number of neutral particles in a two-prong event is ~ 1. This would imply that the emission of neutral non-leading particles should be rare in two prong events. One then finds that $M_x^2 \sim M^{*2}$ and as the values of M^* are limited, one gets a peaked distribution for M_x^2 in two-prong inelastic events. The situation would change somewhat for 4-prong events but the peaking may be expected to be still seen in four-prong events. For $n_c \geqslant 6$, there would be considerable fluctuation both in the number of neutral pionization particles and the total energy carried by all the pionization particles. This would give a broad spread to the values of M_x^2. A rough lower bound on the value of M_x^2 can be obtained if one assumes that no neutral particles are emitted in the central component and that the charged particles in it are all pions with energies not much larger than the pion mass m_π. This gives according to (7), the inequality

$$M_x^2 > [\langle M^{*2} \rangle + \sqrt{S}\,(n_c - 2)\, m_\pi] \tag{8}$$

Similarly a rough upper bound can be obtained if one assumes that in the pionization, the number of neutral particles is half the number of charged particles and that there are very few pionization particles with energies greater than, say, $2\langle P_\perp \rangle$ where $\langle P_\perp \rangle$ is the average transverse momentum of such particles. This gives

$$M_x^2 < [\langle M^{*2} \rangle + 3\sqrt{S}\,(n_c - 2) \langle P_\perp \rangle] \tag{9}$$

Taking $\langle M^{*2} \rangle \sim 4\ \text{GeV}^2$, $\langle P_\perp \rangle \sim 0{\cdot}3\ \text{GeV}/c$, one finds at 303 GeV that, in 4-prong events $11 < M_x^2 < 47$, in 6-prong events $17 < M_x^2 < 90\ \text{GeV}^2$ and in 8-prong events $24 < M_x^2 < 133$. These rough lower and upper bounds on the values of M_x^2 are consistent with the observed distribution of M_x^2.

If the model described in this paper for diffraction is valid, it has an important experimental consequence, namely, that all the charged particles excepting the two leading ones are due to pionization. They have small momenta and an angular distribution nearly isotropic in the CM system. This unexpected feature of the model is amenable to experimental test using the ISR machine. This can be achieved simply by triggering for events in which there is a leading proton within a given $|t|$ cut, say $|t| > 0{\cdot}5\ \text{GeV}^2$. One then looks at the angular and momentum distribution of the other charged particles. Contrary to what one expects from the usual models of diffraction, one would find, on the basis of the present model, a considerable fraction of particles, particularly in high multiplicity events, to be emitted at large angles and with small momenta.

While specifying the pattern of diffraction according to the present model, the physical ideas associated with the origin of such a pattern has not been discussed. A possible mechanism for the realization of the present model is the one represented in figure 4 in which two Pomerons are exchanged leading to, besides an excited baryon, a Pomeron-Pomeron interaction resulting in a low mass cluster which decays into a number of pion pairs. A different mechanism is provided, at a classical level, by the model of random fragmentation (Narayan 1971) proposed by the author to explain the features of multiparticle production. One has to refer to the original paper for details. We would like to point out, here, some crude resemblance between the physical ideas underlying the above model with those of the parton model (Feynman 1969). In the spirit of the parton model, the proton may be regarded as composed of a heavy parton having the quantum numbers of a proton and a sea of light partons. What has been referred to as core-cloud collision in the fragmentation model would correspond to the interaction of a heavy parton with a light parton, giving rise to a baryon-like excited object. The cloud-cloud interaction leads always to pionization. This unexpected and surprising result is attributed to a new aspect of physics which is postulated to emerge at high energies. Due to the Lorentz contraction of the hadrons and the extremely short duration of the time of interaction in the CM system, the interaction gets localized to small cells which keep contracting with energy in such a way that the energy per cell remains roughly constant. This localization may be compared to point-like interactions in the parton picture. In the latter model, it is, however, difficult to see how the collision of two light partons always leads to pionization, except for the collision of so-called " wee " partons. As a matter of speculation, one may imagine that when two light-partons in a cell interact to emit a pair of pions, the energy involved in the interaction is just the energy contained in the cell which is small, while the cell itself is nearly at rest in the CM system.

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