*THE DIFFRACTIVE COMPONENT OF PARTICLE PRODUCTION IN
THE DUAL MULTISTRING FRAGMENTATION MODEL*

J. Ranft*
CERN, Geneva

ABSTRACT

The single diffractive component is introduced in the dual Monte Carlo chain decay model of soft particle production. The diffractively excited multiparticle states in this model arise from the fragmentation of two chains formed out of the valence quarks and antiquarks (or diquarks) of the diffractively excited hadron and a sea quark-antiquark pair of the Pomeron, considered to be a gluonic object. In this way the excited clusters behave in a way quite similar to multiparticle states formed in nondiffractive meson-hadron collisions. The calculated multiparticle states agree quite well with recent data from the UA4-SPS collider collaboration and with recent data on strange particle production in diffractive photon-proton collisions.

Submitted to Z. Phys. C

* Permanent address:
Sektion Physik, Karl-Marx-Universität, Leipzig, DDR

1. INTRODUCTION

The experiments performed at the CERN SPS collider have brought, in addition to the data on gauge boson production and hard hadronic scattering, a renaissance of the study of multiparticle production in soft hadron-hadron collisions. The results from the UA1 [1] and UA5 [2] collaborations indicate that properties of multiparticle production are no longer true which were considered 10-15 years ago as well established.

The dual multichain quark fragmentation models have become in the last years quite successful in describing all aspects of soft multiparticle production. Those models exist in different forms which differ not as much in the underlying physical model as in the formulation. Originally at Orsay [3] and ITEP, Moscow [4] the model was formulated in an analytical way. It turned out, however, that this model can also be very efficiently formulated in the form of a Monte Carlo multichain fragmentation model. This version of the model was studied and applied extensively [5,6,7] and shown to agree with essentially all properties of multiparticle production, like non-KNO scaling, rise of the rapidity plateau, and transverse momentum-multiplicity correlations [8]. This is the formulation of the model, which we will also use in the present paper.

One component of multiparticle production which has so far not been studied in detail in these models is the single diffractive particle production in hadronic events. The understanding of diffractive events is hampered largely due to the missing theoretical understanding of the Pomeron, the object exchanged in these reactions, within QCD or even the quark-parton model.

In the present paper we follow the ideas of Low and Nussinov [9] that the Pomeron is an object composed of glue, and Donnachie and Landshoff [10] that the Pomeron interacts like a photon, and we propose a way to represent diffractive events in the dual multistring model. This will be described in Section 2. In Section 3 we test this model comparing with data from the UA4-SPS collider collaboration [11,12] and other experiments on diffractive particle production.

2. SINGLE DIFFRACTIVE PARTICLE PRODUCTION AND THE DUAL CHAIN FRAGMENTATION MODEL

Diffraction interactions of hadrons at high energies have been studied experimentally in each new energy region accessible. An essentially up-to-date review is given by Goulianos [13]. In a single diffractive process one of the primary particles will be excited in the collision.

$$h_1 + h_2 \rightarrow h_1 + X \quad (1)$$

The system X decays subsequently into hadrons. The cross-section for such processes is usually described in terms of the momentum transfer t to the system X and M_X , the invariant mass of the system X , which is produced in the hemisphere opposite to the quasi-elastically scattered particle h_1 .

In the language of the Regge theory [14] diffractive processes are described by Pomeron exchange. A deeper theoretical understanding of diffractive processes from the gauge theory of strong interaction, QCD, is missing since we do not know how the Pomeron is to be described in QCD. A rather old proposal is due to Low and Nussinov [9]. According to this the Pomeron is an object composed mainly of gluons. Indeed, the elastic proton-proton scattering at large t can be described rather well by

$$\frac{d\sigma}{dt} \propto t^{-8} \quad (2)$$

an expression predicted by three gluon exchange [15].

Donnachie and Landshoff [10] describe single diffraction processes rather successfully in a model based on the similarity of Pomeron exchange in single diffractive processes and photon exchange in deep inelastic scattering processes (see Fig. 1). Using this similarity they describe the cross-section for single diffractive excitation with the help of the proton form factor at the upper proton-Pomeron vertex and the inelastic structure functions at the lower vertex. A Monte Carlo model following these lines is proposed by Ingelman [16]. In this model the excited system X has properties similar to the excited hadronic system in deep inelastic collisions,

i.e. it is a quark-diquark jet. No actual comparison of the results of such a model with data on diffractive particle production was however given. In any case, in this model the diffractive state X is an elongated object, not an isotropically decaying one.

The rather interesting field of hard Pomeron-hadron scattering with production of large $P_{\perp}$ jets is explored in some recent papers. The energies available at the proton-antiproton colliders allow the study of this question also experimentally. Ingelman and Schlein [17] calculate the jet structure expected in high mass single diffractive scattering assuming the Pomeron consisting mainly of gluons to be described by hadronic structure functions. Also the diffractive production of heavy quarks in hard diffractive collisions has been studied recently [18].

Here we are interested in the bulk of diffractive production at high mass of the excited system X . High mass means in this context that X should not be a well defined hadron resonance. There is obviously no large momentum transfer in such collisions. Therefore it seems doubtful that the production of the hadronic system should be described similar to a deep inelastic collision.

We use the Pomeron-photon similarity according to Fig. 1. At low momentum transfer we rather expect that the Pomeron interacts hadronically similar to the photon as described by the vector dominance model, i.e. as a mesonic state composed of quark-antiquark pairs. Therefore we translate the analogy according to Fig. 1 in our model in a way as expressed in Fig. 2. The Pomeron is emitted from the hadron at the upper vertex as an object composed of two, three or several gluons and interacts at the lower vertex like a $q\bar{q}$ state composed in the actual calculations of $u\bar{u}$, $d\bar{d}$ and with reduced probability $s\bar{s}$ quark-antiquark pairs.

In the spirit of the multichain fragmentation model we select the Pomeron at the upper vertex by sampling its momentum fraction as the sum of the x -values of two or three gluons, sampled out of typical distributions, which are adequate for a soft process

$$g(x) \propto \frac{1}{x} (1 - x)^n \quad (3)$$

where the exponent n is used as $n = 2$ or $n = 3$. Furthermore we give intrinsic transverse momenta to the gluons (and therefore the Pomeron) in the same way as this is done for all valence and sea quarks in the Monte Carlo version of the dual multichain fragmentation model [6,7]. At the lower vertex the Pomeron interacts with the second hadron in the same way as does a $q\bar{q}$ meson.

From this construction it is clear that in our model the excited system X is a longitudinally and not isotropically decaying object, very similar to the systems formed in soft meson-hadron collisions. In detail, since in our model as seen from Fig. 2 we have two quark-antiquark or quark-diquark chains fragmenting, the predictions of the model should differ from the model which follows directly from the deep inelastic scattering analogy [16]. As indicated in Fig. 2 the model is well defined not only in proton-proton and proton-antiproton collisions but also in all hadron-hadron collisions including meson-baryon and hadronic photon-baryon interactions.

3. PROPERTIES OF DIFFRACTIVE PRODUCTION IN THE MULTISTRING FRAGMENTATION MODEL

The pseudo rapidity distributions of the final states produced in diffractive processes:

$$p + p \rightarrow X + p \quad (4)$$

were recently measured by the UA4 collaboration at the CERN SPS proton-antiproton collider [12]. These data show very clearly a longitudinally decaying system. The length of the pseudo rapidity distributions grows with the mass of the excited system X produced.

In Fig. 3 we compare these data with the results obtained from our model. We are indeed able to reproduce the shape of the distributions and the change of the width of the curves with growing mass of the diffractive system. Of course the errors of the experimental data are quite big and there are also some fluctuations in the Monte Carlo results. We should look forward to seeing more precise data and also information on the particle composition of the excited state.

Our calculation gives not only the momentum, rapidity, or pseudo rapidity distributions of the hadrons produced, but we also calculate in the form of a histogram the distribution in the momentum transfer t and excitation mass M_X in the form $d^2N/dt dM_X^2$.

In terms of the momentum transfer this distribution shows an exponential $dN/dt \propto \exp(bt)$ and we determine the slope parameter as a function of the mass M_X as given in Fig. 4. The slope fluctuates around $b \approx 6 \text{ GeV}^{-2}$.

The M_X^2 dependence of the cross-section $d^2\sigma/dt dM_X^2$ was determined by the UA4 collaboration [11] and found to behave rather well as $1/M_X^2$. In Fig. 5 we plot the histograms obtained in our calculation for three momentum transfer bins and find also a behaviour consistent with $1/M_X^2$. We conclude that the diffractive cross-section in the model behaves like

$$\frac{d^2\sigma}{dt dM_X^2} \propto \frac{1}{M_X^2} e^{bt} \quad (5)$$

We should however stress that, owing to the nature of the Monte Carlo calculation, we are able to determine this distribution only in the range up to about $t = -1 \text{ GeV}^2$ and $M \approx 150 \text{ GeV}/c$. There is no indication for a change of the slope parameter b with growing mass M_X . Certainly the model, by changing the input distributions, i.e. the x and transverse momentum distributions of the gluons sampled at the beginning, is able to modify the shape of the diffractive cross-section $d^2\sigma/dt dM_X^2$.

In Table 1 we give for diffractive photon-proton reactions the calculated multiplicities of diffractively produced particles in the forward going diffractive cluster (photon fragmentation region) as a function of the mass of the diffractive system at three photon energies. The hadronic interaction of the photon is described in the model by the vector meson dominance model [21]. The multiplicities of neutral strange particles produced in diffractive photon-proton interactions was recently measured [20]. In Fig. 6 we compare the calculated multiplicities from Table 1 with the data [20]. Except at the lowest mass bin we find very good agreement of our model with the data.

The diffractive component is also very important to obtain the correct leading particle behaviour of the inclusive particle distributions, especially in reactions with meson beams. In Fig. 7 we compare the longitudinal momentum distributions of π^+ , π^- and K^- mesons produced in 58 GeV/c π^- proton collisions with recent data of the ACCMOR collaboration [22]. The calculated histograms are obtained from the full model including the nondiffractive compound [6] and the diffractive component described here.

The same leading particle effect can be seen in Fig. 8, where we compare Feynman-x distributions in pion-proton collisions calculated according to our model. We compare these distributions also with data known for a very long time [23].

We conclude: a single diffractive component can be defined in the dual multichain fragmentation model. This component agrees well with recent data from the UA4 collaboration [12] which show very clearly that the diffractively produced states decay not as an isotropic fireball but in a longitudinal way similar to particle production in meson-proton collisions at a c.m.s. energy corresponding to the mass of the excited cluster. This feature is very well described by the model. The model is also consistent with the momentum transfer and mass dependence of the diffractive cross-section.

Finally we demonstrate, comparing the diffractive particle production in photon-hadron collisions with data, that also the particle composition predicted by the model agrees well with the data.

While finishing the present paper, I learned about a paper of Innocenti et al. [24] where also the UA4 data are analysed with a similar model but formulated differently, and where the same conclusions were reached.

ACKNOWLEDGEMENTS

The author acknowledges the hospitality, August to November 1985, in the Radiation Physics Group of SLAC, where the major part of the results reported were obtained, and of the Radiation Protection Group at CERN where the paper was completed.

REFERENCES

1. G. Arnison et al., UA1 Collaboration, Phys. Lett. 118B (1982), 167; Phys. Lett. 123B (1983), 108.
2. K. Alpgard et al., UA5 Collaboration, Phys. Lett. 112B (1982), 183; Phys. Lett. 121B (1983), 209.
3. A. Capella et al., Phys. Lett. 81B (1979), 68;
A. Capella and J. Tran Thanh Van, Z. Phys. 18 (1983), 85.
4. A.B. Kaidalov, Phys. Lett. 116B (1982), 459.
5. P. Aurenche and F.W. Bopp, Nucl. Phys. B 91 (1977), 445;
Phys. Lett. 114B (1982), 363.
6. J. Ranft and S. Ritter, Z. Phys. C 20 (1983), 347; Z. Phys. C 27 (1985), 413; Z. Phys. C 27 (1985), 569.
7. P. Aurenche, F.W. Bopp and J. Ranft, Z. Phys. C 26 (1984), 279. Z. Phys. C 23 (1974), 67; Phys. Lett. 147B (1984), 212.
8. F.W. Bopp, P. Aurenche and J. Ranft, Annecy Preprint LAPP-TH-141 (1985).
9. F.E. Low, Phys. Rev. D 12 (1975), 163;
S. Nussinov, Phys. Rev. Lett. 34 (1975), 1286; Phys. Rev. D 14 (1976), 246.
10. A. Donnachie and P.V. Landshoff, Nucl. Phys. B 244 (1984), 322.
11. M. Bozzo et al, UA4 Collaboration, Phys. Lett. 136B (1984), 217.
12. D. Bernard et al., UA4 Collaboration, CERN Preprint CERN/EP 85-155 (1985).
13. K. Goulianos, Phys. Rep. 101 (1983), 169.
14. See P.D.B. Collins, An Introduction to Regge Theory, Cambridge University Press (1977).
15. A. Donnachie and P.V. Landshoff, Z. Phys. C 2 (1979), 5.
16. G. Ingelman, CERN preprint CERN-EP/85-159 (1985), to be published in Proc. of Workshop on Elastic and Diffractive Scattering at the Collider and beyond, Chateau de Blois (1985).
17. G. Ingelman and P.E. Schlein, Phys. Lett. 152B (1985), 256.
18. J.C. Collins, D.E. Soper and G. Sterman, Nucl. Phys. B 263 (1986), 37; E.L. Berger, J.C. Collins, D. E. Soper and G. Sterman, Argonne National Laboratory preprint ANL-HEP-CP-86-12 (1986).

19. M.G. Albrow et al., Nucl. Phys. B 108 (1976), 1.
20. K. Abe et al., Phys. Rev. D 32 (1985), 2869.
S. Bhadra et al., preprint Colo-HEP-104 (1985), submitted to
Phys. Rev. Lett.
21. See T.H. Bauer, R.N. Spital, D.R. Yennie and F.M. Pipkin,
Rev. Mod. Phys. 50 (1978), 261.
22. F. Pauß et al, ACCMOR Collaboration, Z. Physik C 27 (1985), 211.
23. W.D. Shephard et al. Phys. Rev. Lett. 27 (1972), 1164.
24. V. Innocenti, A. Capella, A.V. Ramallo and J. Tran Thanh Van,
Orsay preprint 85/40, Dec. 1985.

FIGURE CAPTIONS

- Fig. 1. The similarity of Pomeron exchange in single diffractive processes and photon exchange in deep inelastic collisions.
- Fig. 2. Single diffractive excitation as described in the present paper in the dual multichain fragmentation model.
- Fig. 3. Comparison of the calculated pseudo rapidity distributions as a function of the mass M of the diffractively produced state (histogram) with the data of the UA4 Collaboration [12] (points).
- Fig. 4. Slope parameters b as a function of the mass M_x of the diffractive state. Result of the Monte Carlo calculation with the described model.
- Fig. 5. Histogram of the calculated distributions $d^2/N/dt dM^2$ for three t -bins as a function of M^2 . The straight lines correspond to M^{-2} .
- Fig. 6. Multiplicities of Λ , Λ and K_S^0 particles produced in the photon fragmentation region of diffractive photon-proton collisions. Plotted are the particle multiplicities as a function of the mass of the diffractive cluster in the forward region. The data are from Abe et al. [20].
- Fig. 7. Single inclusive distributions in the reaction $\pi^- p \rightarrow h + X$ plotted as a function of the longitudinal variables in the laboratory frame $x = P_{||}/P_{lab}$. The experimental points [22] are compared with the histograms according to the Monte Carlo calculation of our model.
- Fig. 8. Inclusive particle production in pion-proton collisions described in the c.m. system in the form of the Feynman- x distribution $F(x)$, a) experimental data [23], b) calculations according to the dual multichain fragmentation model including the diffractive component.

TABLE 1

Particle multiplicities in diffractively produced clusters in γ -p interactions, calculated using the dual multi-chain fragmentation model

P_γ (GeV/c)	M_F (GeV/c ²)	Multiplicities								
		p	$\bar{p}$	π^+	π^-	K^+	K^-	Λ	$\bar{\Lambda}$	K_S^0
50	1-3	0.0009	0.0007	1.12	1.11	0.057	0.060	-	-	0.024
	3-5	0.016	0.017	1.79	1.80	0.145	0.141	0.0028	0.0020	0.110
	5-7	0.038	0.033	2.25	2.25	0.20	0.21	0.0034	0.014	0.167
	7-9	0.051	0.051	2.76	2.68	0.27	0.36	0.0169	0.0169	0.203
100	1-3	0.0012	0.0015	1.12	1.12	0.061	0.064	-	-	0.025
	3-5	0.016	0.016	1.79	1.80	0.142	0.135	0.0047	0.0029	0.106
	5-7	0.044	0.033	2.28	2.29	0.20	0.21	0.0134	0.0141	0.176
	7-9	0.054	0.062	2.56	2.56	0.28	0.27	0.0202	0.0080	0.246
	9-11	0.070	0.063	2.98	2.97	0.29	0.29	0.031	0.023	0.255
150	1-3	0.0011	0.0012	1.13	1.12	0.064	0.065	0.0001	0.0003	0.026
	3-5	0.022	0.023	1.78	1.79	0.14	0.13	0.0035	0.0029	0.109
	5-7	0.043	0.039	2.28	2.27	0.19	0.20	0.0086	0.0126	0.167
	7-9	0.051	0.045	2.79	2.76	0.25	0.28	0.0147	0.0168	0.224
	9-11	0.077	0.060	3.16	3.18	0.32	0.32	0.0219	0.0247	0.289
	11-13	0.13	0.13	3.26	3.30	0.38	0.33	0.0307	0.0231	0.319
	13-15	-	-	3.80	3.76	0.40	0.48	0.040	0.040	0.280

FIG. 1

FIG. 2

FIG. 3

FIG. 4

FIG. 5

FIG. 6

FIG. 7

FIG. 8