MULTIPARTICLE AND LOW MASS DIMUON PRODUCTION IN A SIMPLE QUARK PARTON MODEL

By V. Černy, P. Lichard and J. Pišút

Department of Theoretical Physics, Comenius University, Bratislava*

(Presented at the XVIII Cracow School of Theoretical Physics, Zakopane, 26 May — 8 June, 1978)

We describe our Monte Carlo quark-parton model of multiparticle production. The model is based on the following assumptions: mesons and baryons in the final state are originated by the recombination of quarks and antiquarks, the recombination is of a short range in rapidity and the valence quarks keep large momentum fractions during the collision. Low mass dimuons are supposed to arise from the annihilation of quarks and antiquarks (most of them created during the collision). Good qualitative agreement with data on low mass dimuon production is obtained if constraints following from the space-time evolution of the interaction are taken into account.

Multiparticle production in hadronic collisions (and more generally in reactions where hadronic jets are formed) is a process with rather complicated dynamics. It is therefore not surprising that a more profound information about the structure of hadrons was obtained from studies of other reactions, like deep inelastic lepton-nucleon scattering, Drell-Yan production of large mass dimuons, etc. Still, we believe that multiple production might bring some additional information, provided that the data are interpreted within the same quark-parton model framework. It seems however that there is an important practical difference between phenomenological studies of deep inelastic processes and of the multiple production. In the former a single piece of data can provide a valuable information, whereas in the latter, it seems, a qualitative understanding of many pieces of data is of much larger value than a good quantitative fit of an isolated piece of data. This indicates that Monte Carlo models are probably an efficient way (or an inavoidable nuisance) in studying multiple production.

We shall now describe an attempt [1] to construct such a Monte Carlo model. Some ideas implemented in the model have much in common with previous work [2–4] and in what concerns the technical part of the problem we found Jadach's generator [5] of the cylindrical phase space very useful. In our model we assume that a hadronic collision

* Address: Department of Theoretical Physics, Comenius University, 81631 Bratislava–Mlýnska Dolina, Czechoslovakia.

proceeds in a few stages: the process is initiated by the interaction of wee partons at $y = 0$, then the excitation from the region around $y = 0$ proceeds to larger values of the c. m. s. rapidity. During the excitation of a particular rapidity region gluons are supposed to be converted to quarks and antiquarks (Q's and $\overline{\text{Q}}$'s) and finally recombinations of neighbouring (in rapidity) $\text{Q}\overline{\text{Q}}$ pairs and QQQ and $\overline{\text{QQQ}}$ triplets give rise to mesons, baryons and antibaryons.

In our model we do not try to describe the whole process and instead we just generate the distribution of Q's and $\overline{\text{Q}}$'s before the recombination. This distribution of Q's and $\overline{\text{Q}}$'s has to satisfy the following general constraints

— energy-momentum conservation,

— transverse momentum cut-off,

— relationship to deep inelastic (in a process initiated by wee partons and governed by the dynamics which is of a short range in rapidity the valence partons have to keep large momentum fractions).

The distribution of Q's and $\overline{\text{Q}}$'s in the hadronic system formed in, say, proton-proton collision is given by the following Ansatz

$$dP_N(\vec{p}_1, \vec{p}_2, \cdots, \vec{p}_N) \sim W_{\text{id}} G^n \delta(\sum_1^N \vec{p}_i)\delta(\sum_1^N E_i - \sqrt{s}) \exp(-\sum_1^N p_{\text{T}i}^2/R_{\text{T}}^2)$$

$$V(x_1, \cdots, x_6) \prod_1^N dy_i d^2 p_{\text{T}i}. \tag{1}$$

Here N denotes the total number of Q's and $\overline{\text{Q}}$'s, $N = 2n+6$ (in a particular event), where 6 stands for 6 valence quarks present in a proton-proton collision and we have n additional $\text{Q}\overline{\text{Q}}$ pairs (most of them created during the collision by the "conversion" of gluons). The factor W_{id} takes into account the identity of Q's and $\overline{\text{Q}}$'s, G is a "coupling constant" regulating the average multiplicity of Q's and $\overline{\text{Q}}$'s (and thereby also the average multiplicity of final state hadrons), factors for p_{T} cut-off, four-momentum conservation and for the Lorentz invariant phase space are self-explanatory and the factor $V(x_1, \ldots x_6)$ depending on longitudinal momentum fractions of the valence quarks has to be chosen in such a way that valence quarks keep large momentum fractions. In our calculations we have used a simple Kuti-Weisskopf [6] factor $V(x_1, \ldots, x_6) = \prod_1^6 \sqrt{|x_i|}$. This form is probably oversimplified and one should perhaps insert into Eq. (1) also factors which push non-valence Q's ans $\overline{\text{Q}}$'s to smaller values of x (see the recent work by DeGrand and Miettinen [7]).

The expression (1) contains two free parameters: G and R_{T}, in the course of calculations there appears also the third parameter λ which specifies the phenomenological suppression of the production of strange Q's and $\overline{\text{Q}}$'s.

The whole calculation proceeds as follows (all the relevant details are given in Ref. [1]). One starts with generating an exclusive configuration of Q's and $\overline{\text{Q}}$'s. This configuration is assigned the weight according to Eq. (1). Then one assigns quantum numbers to non--valence partons. In the next step rapidity neighbours are recombined to mesons, baryons and antibaryons following the prescriptions given by the SU(6) scheme (only the production of the 35-plet of mesons and 56-plets of baryons and antibaryons is taken into account). Unstable hadrons then decay with branching ratios summarized by Particle Data Group.

The net result then looks similar as a data summary tape from an experiment. We have a set of events and in each of them we know the momenta and types of particles in the final state. The results can then be plotted in any desirable way. In Fig. 1 we show

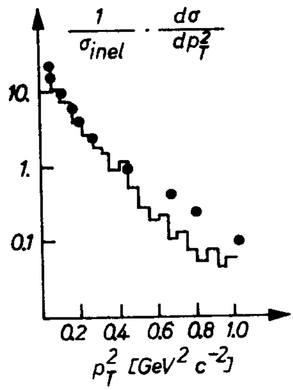

Fig. 1. The distribution of negative particles in p_T^2 for pp collisions at 150 GeV/c (our calculation — histogram, data — full circles)

the p_T distribution of negative particles produced in pp collision at 150 GeV/c and in Fig. 2 we compare average multiplicities as calculated within the present model with the data. In fact the comparison in Fig. 1 served for the determination of the parameter R_T in Eq. (1) (p_T cut-off). In what concerns the data in Fig. 2 the relative abundance of kaons is put in by hand at one energy (150 GeV/c) and the total multiplicity at this energy

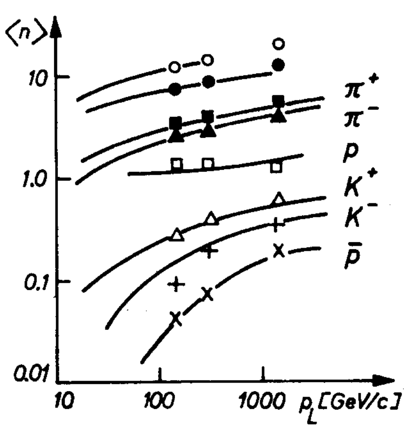

Fig. 2. The dependence of average multiplicities on p_{Lab}. Curves represent the data, other symbols show our results at 150, 300 and 1500 GeV/c

is fixed by specifying the value of G. The rest of the agreement with the data (in particular p/π, $\bar{p}/p$ ratios and the energy dependence of average multiplicities) is non-trivial. Particle ratios depend, of course, on the prescription [1] for the recombination of rapidity neighbours.

We have also studied single particle spectra and these results can be roughly summarized as follows: for pions, kaons, protons and antiprotons the agreement with the data is reasonably good, perhaps with the exception of the large x region where results of our Monte Carlo program fluctuate too much.

It seems to us that the uncertain features of the model (the exact shape of $V(x_1, \ldots, x_6)$, possible factors for pushing non-valence partons to small x, etc.) can be specified by comparing Monte Carlo results with various pieces of data on multiparticle production. However, before trying to do that it is most useful to have a look on such data which can shed some light on the underlying physical picture. In our opinion the production of low mass (LM) dimuon continuum observed in the Chicago-Princeton experiment [8] provides a possible check of the assumed physical picture of the collision. The short-range character

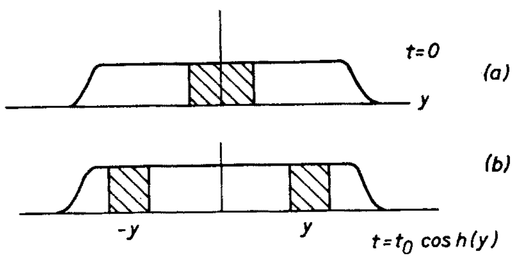

Fig. 3. A rough scheme of the space-time evolution of the hadronic collision. At the beginning of the collision only a region with $\Delta y \sim 1$ around $y = 0$ is excited (a), at $t = t_0 \cosh(y)$, $t_0 \approx 1$ fermi/c the two regions around $\pm y$ are excited (b)

of the recombination process (built in explicitly into our model) is closely connected with the whole Bjorken-Gribov picture [9] of the space-time evolution of hadronic collisions. This picture is shown in Fig. 3. By itself the picture does not say much about the relationship between the LM dimuon and hadron productions. However if one assumes that hadrons are formed by the recombination of Q's and $\bar{Q}$'s the situation changes. If the recombination is the dominant mechanism of hadron production it means that when a particular rapidity region gets excited the gluons are relatively soon converted to Q's and $\bar{Q}$'s and these exist for some time in the excited region before recombining to hadrons. During the existence of Q's and $\bar{Q}$'s in the excited region a $Q\bar{Q}$ pair has also a possibility to annihilate to a dimuon. The rate is easy to calculate if one knows the density of Q's and $\bar{Q}$'s in the excited region, the spatial extension of that region, the duration of the excitation and the dimension of the excited region in rapidity. Such a calculation was performed in Ref. [10], where we have used the distribution of Q's and $\bar{Q}$'s taken directly from our Monte Carlo model of multiparticle production[1].

[1] The annihilation of Q's and $\bar{Q}$'s created during the collision was first considered by Bjorken and Weisberg [11].

The results depend on two parameters, the first is related to the space-time extension of the excited region and the second gives the extension of that region in rapidity. It is clear that some features of the LM dimuon production can be reproduced if one takes suitable values of these parameters. It is however less trivial that a good qualitative agreement is obtained [10] if these parameters are assigned values expected on physical grounds.

Moreover there is one feature of the data which is in this picture predicted independently of technicalities or of the choice of parameters. If LM dimuons are originated by annihilations and directly produced mesons by recombinations of Q's and $\bar{Q}$'s separated by small rapidity intervals, then p_T and x_F spectra of (directly produced) mesons and of LM dimuons have to be quite similar. In fact just this behaviour of LM dimuons was observed in the Chicago-Princeton experiment [8].

On a qualitative level this argument can be extended also to other processes in which hadronic jets are formed. A classical example is the e^+e^- annihilation. According to Casher, Kogut and Susskind [12], Bjorken [9] and Feynman [13] the e^+e^- annihilation starts with the creation of a $Q\bar{Q}$ pair and then proceeds via the inside-outside cascade. Assuming that this cascade behaves similarly as the central region in hadronic collisions one can use the model of Ref. [1] also for processes where a quark initiated jet is formed. These topics are discussed in Refs. [14] and [15].

Of particular interest here will be undoubtly the recent data of the CDHS group [16] at the CERN SPS on the production of trimuons in neutrino interactions. It seems [16] that one out of the three muons in the final state is created in the primary weak interaction and a considerable part of the additional two muons comes from the space-time evolution of the quark-initiated jet.

In general it seems that many features of particle and low mass dimuon production can be understood (at least on a qualitative level) in models which, apart of general constraints, have explicitly built in the short range (in rapidity) character of the interaction and the space-time evolution of hadronic collisions and quark initiated jets.

Gribov [9] has shown that this space-time evolution is valid in the φ^3 theory. It would be important to show that the same conclusions are valid also in QCD. Naively this seems quite plausible since the QCD leads to strong interactions at low relative momenta (small distances in rapidity) and to weaker interactions at large relative momenta.

Finally, one of the authors (J. P.) would like to thank Andrzej Białas, Andrzej Kotański, Romek Wit and Kacper Zalewski for the hospitality at Zakopane and to Elżbieta Białas and Maria Czyż for creating the unforgettable atmosphere of this School.

REFERENCES

[1] V. Černý, P. Lichard, J. Pišút, *Phys. Rev.* **D16**, 2822 (1977) and to be published in *Phys. Rev.* D.
[2] V. V. Anisovich, V. M. Shekhter, *Nucl. Phys.* **B55**, 455 (1973); V. V. Anisovich et al., *Nucl. Phys.* **B55**, 474 (1973).
[3] J. D. Bjorken, G. R. Farrar, *Phys. Rev.* **D9**, 1449 (1974).
[4] S. Pokorski, L. Van Hove, *Acta Phys. Pol.* **B5**, 229 (1974); *Nucl. Phys.* **B86**, 243 (1975); L. Van Hove, *Acta Phys. Pol.* **B7**, 339 (1976); L. Van Hove, K. Fiałkowski, *Nucl. Phys.* **B107**, 211 (1976).
[5] S. Jadach, *Comput. Phys. Commun.* **9**, 297 (1975).

[6] J. Kuti, V. F. Weisskopf, *Phys. Rev.* **D4**, 3418 (1970).
[7] T. A. DeGrand, H. I. Miettinen, *Phys. Rev. Lett.* **50**, 435 (1978).
[8] K. J. Anderson et al., *Phys. Rev. Lett.* **37**, 799 and 803 (1976).
[9] J. D. Bjorken, *Current Induced Reactions*, Lecture Notes in Physics, Vol. 56, p. 93, editors J. G. Koerner, G. Kramer, D. Schildknecht, Springer Verlag 1976; V. N. Gribov, *Elementary Particles*, Vol. I, p. 65; First ITEP School on Theoretical Physics, Atomizdat, Moscow 1973.
[10] V. Černý, P. Lichard, J. Pišút, *Phys. Lett.* **70B**, 61 (1977).
[11] J. D. Bjorken, H. Weisberg, *Phys. Rev.* **D13**, 1405 (1976).
[12] A. Casher, J. Kogut, L. Susskind, *Phys. Rev. Lett.* **31**, 792 (1973).
[13] R. P. Feynman, *Photon-Hadron Interactions*, W. A. Benjamin, 1972.
[14] V. Černý, P. Lichard, J. Pišût, *Acta Phys. Pol.* **B9**, 269 (1978).
[15] V. Černý et al., Bratislava preprint 1978.
[16] M. Holder, Talk at the XVIII School of Theoretical Physics at Zakopane, May 26th — June 6th, 1978.