PROTON-NUCLEUS AND NUCLEUS-NUCLEUS INTERACTIONS IN THE MULTI-CHAIN DUAL PARTON MODEL

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Abstract

After a short presentation of the multi-chain parton model description of proton-nucleus and nucleus-nucleus interactions at high energies and small p_T, we show the results of the model for p and $\bar{p}$ interactions on Argon and Xenon at 200 GeV/c as well as for α-α at ISR. We compare them with the experimental data presented by I. Derado and M. Faessler.

Après avoir présenté brièvement la description des interactions hadron-noyau et noyau-noyau à hautes énergies et petit p_T dans le cadre du modèle dual partonique à plusieurs chaînes, nous donnons les résultats du modèle pour les interactions p et $\bar{p}$ sur cible d' Argon et Xenon à 200 GeV et α-α aux ISR. Nous les comparons avec les données expérimentales présentées par I. Derado et M. Faessler.

POLONIUS : What do you read, my lord

HAMLET : Words, words, words.

We have heard, indeed many words on multihadron production in high energy hadron-nucleus and nucleus-nucleus collisions but, so far, the word "unitarity" has not been pronounced at all. This is amazing since unitarity is a key word in this field.

It follows essentially from unitarity that the ratio of p-A and A-B multiplicities to the p-p one is bounded, throughout the whole central region, by

$$R^{pA} \equiv \frac{N^{pA}}{N^{pp}} \lesssim \frac{A\sigma_{in}^{pp}}{\sigma_{in}^{pA}} \; ; \; R^{AB} \equiv \frac{N^{AB}}{N^{pp}} \lesssim \frac{AB\sigma_{in}^{pp}}{\sigma_{in}^{AB}} \qquad (1)$$

In these formulae the quantities in the r.h.s. correspond to the average number of inelastic collisions. The equality is obtained in the standard multiple-scattering models when energy-conservation effects are neglected. Due to the latter effects, the value in the r.h.s. is in fact an upper bound. In order to determine the exact values of these ratios and their dependence on the rapidity of the produced particle, one has to know the mechanism of particle production in h-A and A-B interactions. The model we are going to describe[1)] is of the multiple-scattering type[2)] with the hadron constituents explicitely taken into account. The general features of D.T.U.[3)] are used in order to reduce the complicated mechanism of multi-hadron production in these interactions to the "elementary" ones of q-$\bar{q}$ and q-(qq) color separation, suggested by confinement in Q.C.D.

In this model, in order to describe a low p_T high energy interaction involving hadrons, one has to consider an infinite sum of Fock states of the hadron wave function, namely

$$|M\rangle = |q_v,\bar{q}_v\rangle + \varepsilon\ |q_v,\bar{q}_v,q_s,\bar{q}_s\rangle + \ldots$$
$$|B\rangle = |q_v,(qq)_v\rangle + \varepsilon\ |q_v,(qq)_v,q_s,\bar{q}_s\rangle + \ldots \qquad (2)$$

for a meson and baryon respectively. For a meson, the simplest of these states is just formed by its two valence quarks whereas, in the case of a baryon, it is formed, according to D.T.U., by a quark and a diquark. The other states involve one or several extra q-$\bar{q}$ pairs from the sea. Note that these hadronic constituents are "dressed" i.e. the sum of the momentum fractions x_i carried by each constituent is equal to one.

The production of particles results from the hadronization of each of the (colored) hadron constituents involved. This hadronization takes place in the standard way : color flux tubes are stretched between two constituents (one from each colliding hadron) with complementary flavor quantum numbers. The color balance, (namely the color singlet nature of the pair of constituents stretching the color tube) which is necessary in order to obtain a chain or string of hadrons, is achieved via a complicated mechanism of gluon emission and absorption - which is also responsible for the interaction itself. This mechanism is very complex since we are in a large distance regime where perturbative QCD is not valid. It is this complexity which makes impossible, at present, to compute the corresponding cross-sections in QCD. One has to use instead the reggeon field theory in a S-matrix context. This is not at all in contradiction with QCD ; on the contrary a conceptual link exists[4] between reggeon field theory and gauge theories via the 1/N expansion in D.T.U. This expansion also provides the basis of the present approach[5].

For definiteness let us consider a proton-nucleus interaction. Two typical diagrams for particle production involving the two components of the proton wave function explicitely written down in eqs. (2) are shown in Fig. 1. Note that two chains or strings of particles are produced in each inelastic collision. The chains are either q-$\bar{q}$ or q-(qq) ones. These two types of chains are also produced in e^+e^- and ℓp deep inelastic scattering, respectively.

In order to compute physical quantities such as multiplicity distributions, rapidity distributions, etc, one has to know

a) the momentum distribution functions $\rho(x_1, x_2, x_3 \ldots)$ of the various hadron constituents ;

b) the relative weights of the various diagrams ;

c) the corresponding physical quantities for each type of chain.

The momentum distribution functions (normalized to one) can be obtained within the model from the dominance of Regge singularities in appropriate rapidity intervals[1]. One gets that the valence and sea quarks (and antiquarks) are slow in average (in $1/\sqrt{x}$ and $1/x$ respectively, i.e. the same $x \sim 0$ behaviour of the structure functions), whereas the diquark is fast in average (since $\sum_i x_i = 1$). The complete form of $\rho(x_1, x_2, \ldots)$ can be found in ref. 1). For the weights in b), we use the Glauber-Gribov formulae. However, many results are essentially independent of these weights (and in particular of the elastic rescattering approximation, involved in the standard Glauber formulae). Finally for the physical quantities of the chains we assume that they are the same obtained from hard scattering data (e^+e^- and ℓp interactions) in the scaling region (small p_T). (The large p_T tail, responsible for the scaling violations, is not to be considered). This universality assumption is very plausible since the hadronization mechanism has to do with the confinement and is presumably independent of the nature (hard or soft) of the interaction. However, one should realize that the present model would hold even if this assumption had to be modified.

We are now ready to understand all the qualitative feature of hadron production in p-A interaction. For instance, one can see from simple inspection of Figs. 1a and 1b that, since sea quarks and antiquarks are slow in average, all the excess of particles resulting from more than one inelastic collision within the nucleus, is mostly concentrated in the backward region. As a consequence, the ratio R^{pA} in eqs. (1) is smaller than the unitarity bound given by the r.h.s. of eqs. (1) - the difference between the actual value of this ratio and the unitarity bound depends, of course, on the rapidity of the produced particle. For a quantitative purpose it is quite straightforward to write down the exact formulae of the model for the multiplicity distributions, rapidity distributions, etc [1]. The generalization to nucleus-nucleus interactions is also very easy[6]. Note, that there is no adjustable parameter in the game. This talk being just a theoretical comment to the experimental talks by I. Derado and M. Faessler, I will restrict myself to a discussion of the results of the model concerning the data described in these two talks.

The rapidity distributions in proton-Argon and proton-Xenon interactions are shown in Fig. 2. The over-all agreement is quite good. For a very detailed comparison with the data one can see, as stressed by Derado, that the model tends to give a too large A-dependence of the multiplicities at $y^* = 0$ and a cross-over between the pA and pp rapidity curves slightly shifted to the left. However, the discrepancies are not too large (the cross-over is at $y_{lab} \sim 5$ instead of 5.5 [8] and the ratio N^{pXe}/N^{pAr} at $y^* = 0$ is 1.27 instead of the experimental value 1.21 ± 0.03). As far as the nucleus fragmentation region is concerned one can see that the theoretical curves are below the experimental ones for $y_{lab} < 1.5$. In this region there is intra-nuclear cascade, which is not included in the model. (Most theoretical estimates show, indeed, that the effect of intranuclear cascade is concentrated in the region $y_{lab} < 1.5$). A few comments are in order regarding the full curves in Fig. 2. They result from the A.Q.M. calculations in ref. 9) and contain four adjustable parameters. They also include the effect of intra-nuclear cascade with a scale of formation length given by the mass of the ρ meson. As a consequence of such a large scale the cascade extends up to $y^* \sim 0$ (without the effect of the cascade the A-dependence of the multiplicity at $y^* \sim 0$ would be much too small). We would like to stress that, on theoretical grounds, the only justification for such a large scale can be found within the additive quark model. In all other models the scale is taken to be much smaller. On the other hand, since the multiple scattering model gives a large enough A-dependence at $y^* \sim 0$, we conclude that there is no <u>experimental evidence whatsoever</u> for the effect of the cascade extending up to $y^* \sim 0$(*).

We turn next to the multiplicity distributions. Its first two moments are given in Table I and compared with the experimental data. As expected the theoretical values of the average multiplicities are slightly too small due again to the absence of intranuclear cascade in the model. However the D/<N> ratios are in excellent agreement with the data. In computing these ratios we have used as an input the corresponding ratio for e^+e^- and ℓp interactions and assumed that two different chains are uncorrelated. Note that the input D/<N> ratio for a chain is only 0.36. Thus a considerable broadening of the multiplicity distribution results from the structure of the model.

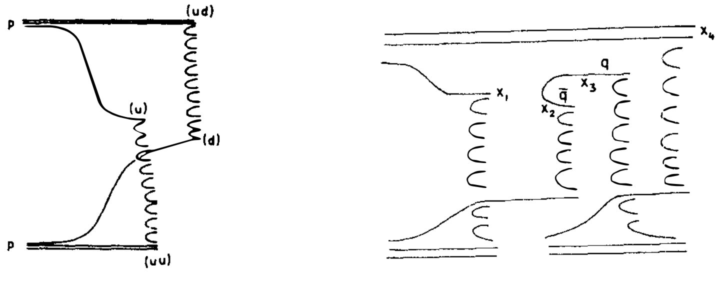
Finally, we consider α-α interactions at C. M. energy of $\sqrt{s}$ = 31 GeV (per nucleon-nucleon collision). The rapidity distributions[6)] are given in fig. 3. The agreement with experiment is quite satisfactory. One can also compute the mutliplicity distributions using, as before the e^+e^- and ℓp ones as an input. The (preliminary) calculations[13)] are shown in Table II. The ratio $D^-/\langle N^-\rangle$ is again in good agreement with experiment. Here the broadening of the multiplicity distribution resulting from the model is even stronger than in pAr and pXe in agreement with data. Experimentally, the $D^-/\langle N^-\rangle$ points in pAr and pXe are, within experimental errors, almost on top of the Wrobleski line for pp : D- = 0.288 (2 <N-> + 1), whereas the corresponding point in α-α is clearly above this line.

As mentioned in Faessler's talk, a calculation of the multiplicity distribution for α-α in another D.T.U. inspired model[11)] has been performed by Chao et Perner[12)]. They obtain a ratio D-/<N-> = 0.57 which is smaller than ours. The difference is probably due to both the effect of the chain fluctuations and the contribution of the short q-$\bar{q}$ chains, which were neglected in ref. 12).

(*) In a recent paper by B. B. Levchenki and N. N. Nikolaev[9)] extensive comments are given on the multiple-scattering models and in particular on those in refs. (1) and (2). This paper contains such gross misinterpretations and misleading remarks both on the theoretical foundations and the phenomenological aspects of those models that we feel obliged to refer the interested reader to the original publications.

In conclusion, the model that we have presented, features all the niceties of an s-matrix theory (in particular, unitarity is explicitely satisfied). D.T.U. ideas are used to reduce the complicated mechanism of particle production in high-energy hadron-nucleus and nucleus-nucleus collisions, to the "elementary" ones of $q-\bar{q}$ and q-(qq) color separation. A unified description of all low p_T interactions is thus achieved.

Fig. 1



Two (q-qq) chains. One nucleon of the target is interacting with the projectile.

Three (q-qq) chains and one q-$\bar{q}$ chain. Two nucleons of the target are interacting with the projectile.

The other nucleons are spectators.

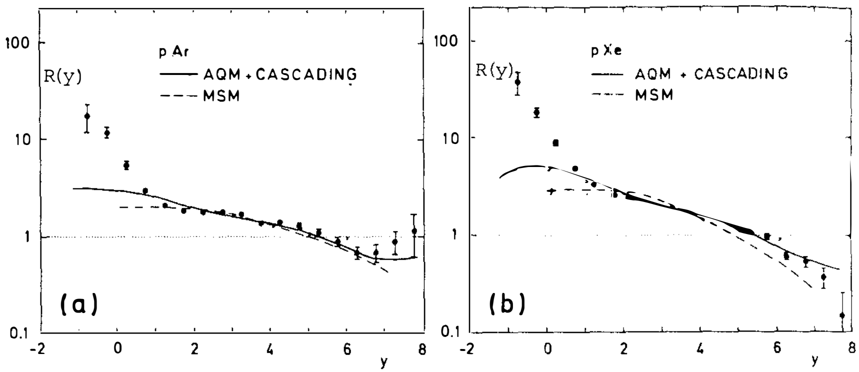


Fig. 2

The rapidity distributions for pAr and pXe at 200 GeV/c (divided by the pp ones) obtained in ref. 7). The curves are the theoretical calculations from refs. 1) and 9).

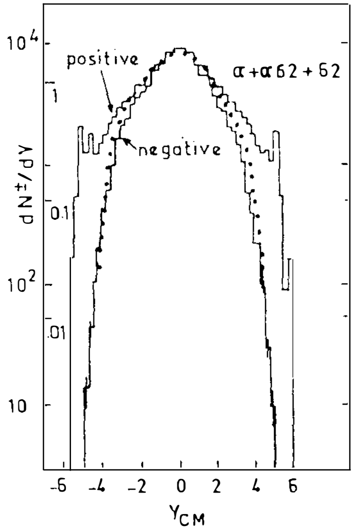


Fig. 3

Density distributions and negative particles in alpha-alpha collisions at ISR ($\sqrt{s}$ = 124 GeV). The dotted line is our calculation for negative particles [6].

T A B L E I

	Ar (theory)	Ar (exp.)	Xe (theory)	Xe (exp.)
<N>	12.2	13.31 ± 0.38	16.2	17.33 ± 0.31
D/<N>	0.58	0.58 ± 0.03	0.59	0.63 ± 0.03
D-/<N->	0.60	0.63 ± 0.04	0.61	0.64 ± 0.03

T A B L E II

	α-α (theory)	α-α (exp.)
<N->	6.3	6.80 ± 0.07
D-/<N->	0.70	0.73 ± 0.02

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