FR9901035

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A UNIFIED TREATMENT OF HIGH ENERGY INTERACTIONS

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Rapport Interne SUBATECH 99-03

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A Unified Treatment of High Energy Interactions

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Abstract

It is well known that high energy interactions as different as electron-positron annihilation, deep inelastic lepton-nucleon scattering, proton-proton interactions, and nucleus-nucleus collisions have many features in common. Based upon this observation, ~~we construct~~ a model for all these interactions, is constructed which relies on the fundamental hypothesis that the behavior of high energy interactions is universal.

1 The Universality Hypothesis

Our ultimate goal is the construction of a model for interactions of two nuclei in the energy range between several tens of GeV up to several TeV per nucleon in the center-of-mass system. Such nuclear collisions are very complex, being composed of many components, and therefore some strategy is needed to construct a reliable model. The central point of our approach is the hypothesis, that the behavior of high energy interactions is universal (universality hypothesis). So, for example, the hadronization of partons in nuclear interactions follows the same rules as the one in electron-positron annihilation; the radiation of off-shell partons in nuclear collisions is based on the same principles as the one in deep inelastic scattering.

The structure of nucleus-nucleus scattering is expected to be as follows: there are elementary interactions between individual nucleons, realized via parton ladders, where the same nucleon may participate in several of these elementary interactions. Although such diagrams can be calculated in the framework of perturbative QCD, there are quite a few problems : important cut–offs have to be chosen, one has to choose the appropriate evolution variables, one may question the validity of the "leading logarithmic approximation", the coupling of the parton ladder to the nucleon is not known, the hadronization procedure is not calculable from first principles and so on. So there are still many unknowns, and a more detailed study is needed.

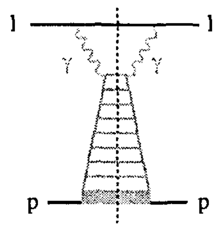

Figure 1: The diagram representing deep inelastic lepton-proton scattering.

Our starting point is the universality-hypothesis, saying that *the behavior of high-energy interactions is universal* [wer97]. In this case all the details of nuclear interactions can be determined by studying simple systems in connection with using a modular structure for modeling nuclear scattering. One might think of proton-proton scattering representing a simple system, but this is already quite complicated considering the fact that we have in general already several "elementary interactions".

2 The semihard Pomeron

Let us call an elementary interaction in proton-proton scattering at high energies "semihard Pomeron". In order to investigate the structure of the semihard Pomeron, we turn to an even simpler system, namely deep inelastic lepton-nucleon scattering (DIS). In figure 1 we show the cut diagram representing lepton-proton scattering: a photon is exchanged between the lepton and a quark of the proton, where this quark represents the last one in a "cascade" of partons emitted from the nucleon. So the hadronic part of the diagram is essentially a parton ladder. In the leading logarithmic approximation (LLA) the virtualities of the partons are ordered such that the largest one is close to the photon [rey81, alt82].

Let us first investigate the so-called structure function F_2, representing the hadronic part of the DIS cross section, i.e. the diagram of fig. 1 but without the lepton and photon lines. In DGLAP approximation, we may write F_2 as

$$F_2(x, Q^2) = \sum_j e_j^2\, x\, f^j(x, Q^2) \qquad (1)$$

with

$$f^j = \sum_i \varphi^i \otimes E_{\mathrm{QCD}}^{ij}.$$

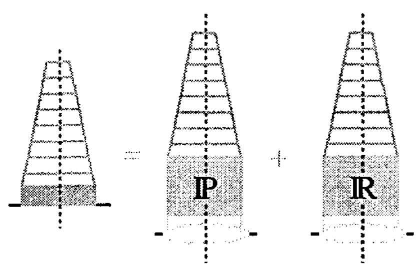

Figure 2: The total contribution, being the sum of IP-contribution and IR-contribution.

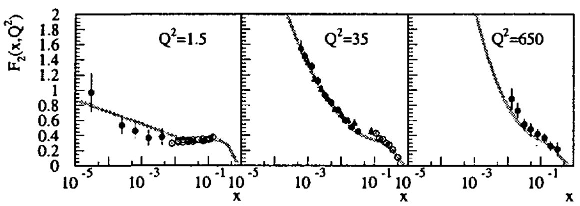

Figure 3: The structure function $F_2$for different values of Q^2 together with experimental data from H1 [h1-96a], ZEUS [zeus96]and NMC [nmc95].

Here, $E^{ij}_{\rm QCD}(x, Q_0^2, Q^2)$ is the QCD evolution function, representing the evolution of a parton cascade from scale Q_0^2 to Q^2, being calculated based on the DGLAP evolution equation. We solve this equation numericly in an iterative fashion. The function φ^i is the initial parton distribution (at scale Q_0^2), assumed to be of the form

$$\varphi^i = C_{\rm I\!P} \otimes E^i_{\rm soft I\!P} + C_{\rm I\!R} \otimes E^i_{\rm soft I\!R}.$$

So we have two contributions, represented by a soft Pomeron and a Reggeon respectively. In any case we adopt a form $C \otimes E_{\rm soft}$, where $E_{\rm soft}$ represents the soft Pomeron/Reggeon, and where C is the coupling between the Pomeron/Reggeon and the nucleon. So the parton ladder is coupled to the nucleon via a soft Pomeron or Reggeon, see fig. 2. Here, we regard the soft Pomeron (Reggeon) as an effective description of a parton cascade in the region, where perturbative methods are inapplicable. A similar construction was proposed in [tan94, lan94], where a t-channel iteration of soft and perturbative Pomerons was considered. We call $E_{\rm soft}$ also the soft evolution, to indicate that we consider this as simply a continuation of the QCD evolution, however, in a region where perturbative techniques do not apply any more. Some results of our calculations for $F_2(x, Q^2)$ are shown in fig. 3 together with experimental data from H1 [h1-96a], ZEUS [zeus96] and NMC [nmc95]. We are now in a position to write down the expression $G_{\rm semi}$ for a *cut semihard Pomeron*, representing an elementary inelastic interaction in pp scattering. We can divide the corresponding diagram into three parts: we have the process involving the highest parton virtuality in the middle, and the upper and lower part representing each an ordered parton ladder coupled to the nucleon. According to the universality hypothesis, the two latter parts are known from studying deep inelastic scattering, representing each the hadronic part of the DIS diagram, as shown in fig. 4. For given impact parameter b and given energy squared s, the complete diagram is therefore given as

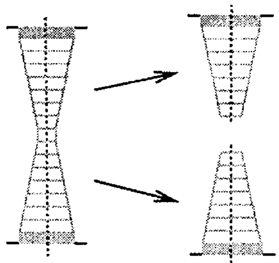

Figure 4: The universality hypothesis implies that the upper and the lower part of the Pomeron diagram are identical to the hadronic part of the diagram for DIS.

$$\int dx^+ dx^- \, G_{\rm semi}(x^+, x^-), \tag{2}$$

with

$$\begin{aligned} &G_{\rm semi}(x^+, x^-) = \\ &\sum_{IJ} C_I(x^+)\, C_J(x^-) \\ &\sum_{ijkl} \int du^+ du^- dQ^2 \, [E^k_{{\rm soft}\, I} \otimes E^{ki}_{\rm QCD}](u^+) \\ &[E^l_{{\rm soft}\, J} \otimes E^{lj}_{\rm QCD}](u^-)\, \frac{d\sigma^{ij}_{\rm Born}}{dQ^2}(u^+u^-x^+x^-s, Q^2). \end{aligned} \tag{3}$$

The variables I and J may take the values $\rm I\!P$ and $\rm I\!R$. This is the expression corresponding to a *semihard Pomeron*.

In addition to the semihard Pomeron, one has to consider the expression representing the purely soft contribution $G_{\rm soft}$ [hla98]. The complete contribution is then the sum $G = G_{\rm semi} + G_{\rm soft}$.

3 Multiple Scattering in Nucleus-Nucleus collisions

We define a consistent multiple scattering theory for nucleus-nucleus scattering (including proton-proton) as follows:

- Any pair of nucleons may interact via the exchange of any number of cut or uncut Pomerons of any kind (Reggeons, soft Pomerons, semihard Pomerons).
- The total cross section is the sum of all such "Pomeron configurations".

As usual, cut Pomerons represent contributions of partial nucleon-nucleon interactions into real particle production, whereas uncut ones are the corresponding virtual

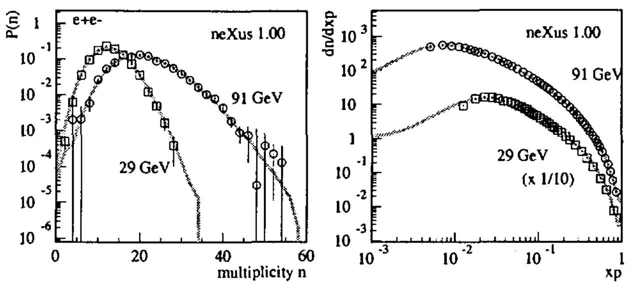

Figure 5: Multiplicity (left) and x_p distributions (right) at 29 GeV (lower curves) and 91 GeV (upper curves). The 29 GeV results have been divided by ten, to separate the two curves.

processes (screening corrections) [agk73, wer93]. With each cut Pomeron contributing a factor G, each uncut one a factor $(-G)$(the Pomeron amplitude is assumed to be imaginary), and each remnant contributing a factor F_{proj} or F_{targ}, one gets

$$\sigma_{\text{inel}} = \int dT_{AB} \sum_{m_1 l_1} \cdots \sum_{m_{AB} l_{AB}} \prod_{k=1}^{AB} \left\{ \frac{1}{m_k!} \frac{1}{l_k!} \right\} \int dX$$
$$\prod_{k=1}^{AB} \left\{ \prod_{\mu=1}^{m_k} G(x^+_{k,\mu}, x^-_{k,\mu}) \prod_{\lambda=1}^{l_k} -G(\tilde{x}^+_{k,\lambda}, \tilde{x}^-_{k,\lambda}) \right\}$$
$$\prod_{i=1}^{A} F_{\text{proj}} \left(x_i^{\text{R}+}\right) \prod_{j=1}^{B} F_{\text{targ}} \left(x_j^{\text{R}-}\right) \quad (4)$$

where $\int dT_{AB}$ represents the integration over impact parameters of projectile and target nucleons with the appropriate weight given by the so-called thickness functions, $\int dX$ represents the integration over all momentum fraction variables, and $x_i^{\text{R}+}$and $x_j^{\text{R}-}$represent remnant momentum fractions. Equation (4) should be considered symbolic, in reality, there appear also transverse momentum variables and one has to take into account the fact that the case of zero cut Pomerons is somewhat complicated: one has elastic and diffractive interactions as well as cuts between nucleons. All this is taken into account in the numerical calculations [hla98]. Eq. (4) is the basic formula of our approach, it serves not only to generate Pomeron configurations (how many Pomerons of which type are exchanged), it serves also as basis to generate partons. The final step amounts to transform partons into hadrons (hadronization). This is done according to the so-called kinky string method, which has been tested very extensively for electron-positron annihilation. As an example, we present in fig. 5 multiplicity and x_p distributions at 29 and 91 GeV together with data from [der86] and [ale96], where x_p is the momentum fraction of a particle. In a similar fashion, we reproduce data concerning inclusive spectra for individual hadrons.

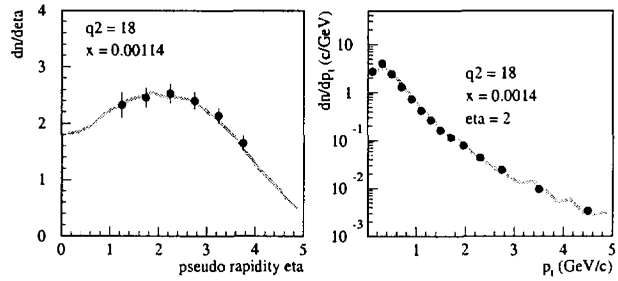

Figure 6: Pseudo-rapidity distributions in DIS for charged particles (left) or for charged particles with $p_t > 1$ GeV (right). Data are from [h1-96b].

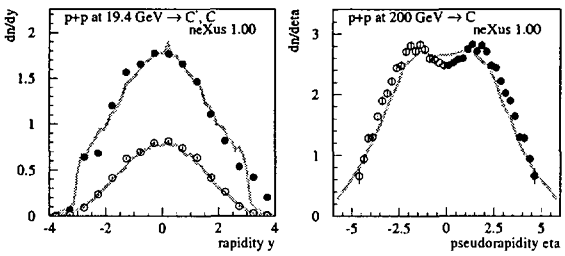

Figure 7: Rapidity or pseudorapidity distributions at 19.4 and 200 GeV. The data are from [dem82, UA5-86]

4 Results

Let us now discuss some results concerning particle production, first in deep inelastic lepton-nucleon scattering. In fig. 6, we present pseudo-rapidity distributions and transverse momentum spectra for $1.5 < \eta < 2.5$. We compare our simulations (lines) with H1 data (points). We applied the same acceptance cuts as done in the experiment.

We are now going to discuss a few results for pp scattering. In fig. 7, we present on the left-hand-side rapidity spectra of charged particles (upper curve) and negatively charged particles (lower curve) at a center-of-mass energy of 19.4 GeV. On the right-hand-side, we show pseudorapidity spectra of charged particles at 200 GeV.

In order to treat nucleus-nucleus collisions, one needs to include secondary interactions. This cannot be done

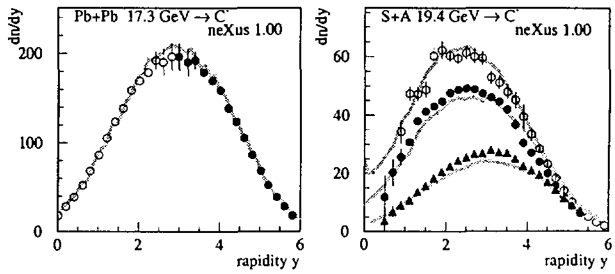

Figure 8: Rapidity distribution of negatives for Pb+Pb (left) and S+S, S+Ag, S+Au (right). The data are from [NA49-98, NA35-94]

within the theoretical framework discussed for far. So we proceed in two steps:

- We first treat the "primary interactions", according to the procedures discussed above. This is a consistent multiple scattering approach, fully compatible with proton-proton scattering and deep inelastic lepton-nucleon scattering.
- We then reconsider the event, to perform the "secondary interactions", i.e. to check whether at least three particles are close to each other to form droplets, or if two particles are close to each other to perform a hadron-hadron interaction.

It goes beyond the scope of this paper to discuss the details of "secondary scattering", this will be left to a future publication, where we also are going to present a detailed comparison with data. In fig. 8, we show rapidity distributions of negatives for Pb+Pb and for S+S, S+Ag, S+Au at SPS. In general, we obtain an agreement with the data on the level of 5 - 10 %.

5 Summary

Based on the universality hypothesis, we constructed a theoretically consistent approach to high energy interactions as different as deep inelastic lepton-nucleon scattering, proton-proton scattering and nucleus-nucleus scattering. Both, interactions of nucleons or nuclei, are complex in the sense that the cut Feynman diagrams contributing to the total cross section are composed of "subdiagrams" representing elementary interactions between nucleons. These subdiagrams are called semihard Pomerons, they are parton ladders coupled to the nucleons. Each subdiagram can be divided into two parts, each one representing a diagram, which can be studied via deep inelastic lepton-nucleon scattering. This is very important, because in this way we can study the soft coupling of the parton ladder to the nucleon, not being known from QCD calculations, fit the parameters of parameterizations by comparing to lepton scattering data, and have in this way no freedom any more in proton-proton or nucleus-nucleus scattering.

This work has been funded in part by the IN2P3/CNRS (PICS 580) and the Russian Foundation of Fundamental Research (RFFI-98-02-22024).

References

[agk73] V.A. Abramovskii, V.N. Gribov, O.V. Kancheli, Yad. Fiz.(Rus) {18} (1973) 595

[ale96] ALEPH collaboration, R. Barate et al, CERN / PPE 96-186

[alt82] G. Altarelli, Physics Reports 81 (1982) 1

[dem82] C. De Marzo et al., Phys. Rev. D26, 1019 (1982)

[der86] Derrick et al., Phys. Rev. D34 (1986) 3304

[h1-96a] H1 Collaboration, Aid et al, preprint DESY 96-039 March 1996

[h1-96b] H1 Collaboration, Adlhoff et al., Nucl. Phys. B485 (96) 3

[hla98] M. Hladik, thesis, University of Nantes, 1998

[lan94] A. Donnachie, P.V. Landshoff, Phys. Lett. B332 (1994) 433

[NA35-94] NA35 Collaboration, J. Bächler et al., Phys. Rev. Lett. 72 (1994) 1419

[NA49-98] NA49 Collaboration, H. Appelshäuser et al. , nucl-ex/9810014.

[nmc95] NMC Collaboration, Arneodo et al, Phys. Lett. 364B (1995) 107

[rey81] E. Reya, Physics Reports 69 (1981) 195

[sjo84] T. Sjostrand, Nucl.Phys. B248 (1984) 469

[tan94] C.I. Tan, in Proc. of the Int.Conf. "Elastic and Diffractive Scatering", World Sci.Pub. Co., Singapore, 1994

[UA5-86] UA5 Collaboration, G.J. Alner et al., Z. Phys. C 33 (1986) 1

[wer93] K. Werner, Physics Reports 232 (1993) 87

[wer97] K. Werner, H.J. Drescher, E. Furler, M. Hladik, S. Ostapchenko, in proc. of the "3rd International Conference on Physics and Astrophysics of Quark-Gluon Plasma", Jaipur, India, March 17-21, 1997

[zeus96] ZEUS Collaboration, Derrick et al, preprint DESY 96-076 June 1996