A Color Mutation Hadronic Soft Interaction Model – Eikonal Formalism and Branching Evolution

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Abstract

ECOMB is established as a hadronic multiparticle production generator by soft interaction. It incorporates the eikonal formalism, parton model, color mutation, branching, resonance production and decay. A partonic cluster, being color-neutral initially, splits into smaller color-neutral clusters successively due to the color mutation of the quarks. The process stops at hadronic resonance, $q\bar{q}$ pair, formation. The model contains self-similar dynamics and exhibits scaling behavior in the factorial moments.

1 Introduction

The study of multiparticle production in low-p_T processes has been pursued for over twenty years. Since they involve soft interactions, they cannot be treated in perturbative QCD. In the absence of any reliable theoretical approach to the problem, many models have been proposed, most of which are represented in the review volumes published ten years ago[1]. Nearly all of those models have since been shown to be inadequate in light of the data on fluctuations and intermittency[2]. In this paper we propose a model[3] that incorporates some aspects of non-perturbative QCD and is capable of generating the features of the intermittency data.

Our approach embraces many time-honored properties of hadronic collisions. Since hadrons are extended objects, the eikonal formalism is at the foundation of our model. Thus it is not difficult for our model to possess the virtues of geometrical scaling, approximate KNO scaling and unitarity. In order to build into the model features of chromodynamics, quarks and gluons are introduced into the eikonal formalism. The parton model is the gateway into the microscopic domain of color interactions. Plus the initialization of partons in 2 dimensional color space and in 1 dimensional rapidity space, this formalism provides a proper description of the initial condition of the partonic evolution during the interaction. The rest of the model is the description of the partonic evolution and the hadronization in the end of the evolution.

We shall call this model ECOMB[3], which stands for eikonal color mutation branching. Since the partons play a fundamental role in this model, it is significantly close to QCD. There are a few parameters in the model. They are adjusted to fit a large body of experimental data on low-p_T processes for $\sqrt{s} \lesssim 100$ GeV. They include σ_{el}, σ_{inel}, $\langle n \rangle$, C_q, dn/dy, P_n, and F_q for all s in the range $10 < \sqrt{s} < 100$ GeV, and all rapidity intervals. They actually cover all average and fluctuation features of the hadronic interaction.

2 Initialization in pp Soft Collision

To focus on processes in which hard subprocesses are unimportant, we confine our attention to the energy range $10 < \sqrt{s} < 100$ GeV, which covers the CERN ISR energies. From parton model point of view, this soft process with a relative smaller momentum transfer undergoes a relative longer time evolution of partons than hard subprocess. High energy hadronic collision takes number of partons which are involved in the collision into an excited state. This forms the initial condition for the successive partonic evolution. To set the initial condition, we need to generate the number of involved partons and the initial distributions of those partons over the phase space and color quantum number space.

2.1 Geometrical Effect on pp Soft Collision

Total number of partons involved in the interaction is essentially related to the collision geometry and interaction energy. Two of the well known experimental results, geometrical scaling and approximate Koba-Neilsen-Olesen (KNO) scaling, provide immediate constrains on the collision geometry. The eikonal formalism of hadronic collisions gives us an ideal geometrical framework to fit all the constrains.

In terms of the eikonal function $\Omega(b)$, the geometrical scaling, i.e., σ_{el}/σ_{tot} is roughly constant, can be guaranteed, if Ω depends only on the scaled impact parameter $R = b/b_0(s)$. The eikonal function is determined based on early experiments[4] as

$$\Omega(R) = -\ell n \left(1 - 0.71 e^{-1.17R^2}\right) \quad . \tag{1}$$

One of the basic assumption is that the distribution of total number of parton is a convolution of distributions corresponding to the individual impact parameter with a kernel. This kernel $g(R) = 1 - exp\{-2\Omega(R)\}$, called reduced inelasticity function, describes the probability of having an inelastic collision at R. Furthermore, this inelasticity function can be expanded into a series of multi-order re-scattering. Eventually, the distribution of parton number can be written in,

$$P_\nu = \int dR^2 \sum_{\mu=1}^{\infty} \pi_\mu(R) B_\nu^\mu \quad , \tag{2}$$

where the function π_μ gives the probability of the μ-th order re-scattering, and the more fundamental distribution B_ν^μ, corresponding to the μ-th order re-scattering at R, is found to be a Furry distribution. Thus the P_ν generates sufficient fluctuation in parton number and eventually generates the KNO scaling in the hadronic final states, see Fig. 1. Moreover, only two parameters are needed to yield the proper energy dependence.

2.2 Initial distribution in phase space

The initial state is that there are ν partons distributed in some fashion in a linear array in rapidity space. The usual parton distribution in momentum fraction (at the lowest accessible Q^2) implies roughly a flat η distribution with rapid damping toward zero at large η. It is modeled as a summation of $\rho^{(1)}(\eta)$ and $\rho^{(2)}(\eta)$, in which, $\rho^{(1)}(\eta)$ and $\rho^{(2)}(\eta)$ indicate the forward and backward semi-spheres respectively. Each of them has a relative narrow central plateau and decline edges down to zero on the both sides. Those two cluster are located in forward and backward area respectively, and only small portion of partons overlap in a limited central region $(-\eta_0, \eta_0)$ after collision follows from the known fact that the correlation between produced particles is short-ranged, because the soft interaction range is short in the conventional wisdom.

2.3 Initial Distribution in Color Space

In the color space spanned by I_3 and Y, a quark is represented by a vector, which has the coordinates of one of the triplets: $(1/2, 1/3), (-1/2, 1/3)$, and $(0, -2/3)$. An antiquark is represented by a vector directed opposite to one of the above. As a distribution of partons in the η space is generated, say, $\rho^{(2)}(\eta)$ between $-\eta_{\max} \leq \eta \leq \eta_0$, we assign to each parton a color vector consistent with the requirement that the quarks and antiquarks come in pairs, but their orderings in the η and the color spaces are totally random. The partons in $\rho^{(1)}(\eta)$ are distributed similarly, but completely independently, between $-\eta_0 \leq \eta \leq \eta_{\max}$. Due to the merge in the central region $(-\eta_0, \eta_0)$, ν partons are no longer divided into two separate color neutral groups. A parton system being "neutral" means that the vector sum over all members within the system equals to zero.

3 Color mutation evolution

We now consider the evolution of a configuration due to QCD dynamics. A nonperturbative treatment of ν simultaneously interacting color charges is, of course, too difficult to contemplate here. We reduce the problem by considering pairwise near-neighbor interaction via the exchange of a gluon in any of the s-, t-, or u-channel, whichever is applicable.

For every global configuration α of the ν partons, with $\nu - 1$ links between them, there is an associated energy E_α. E_α equals to the summation of squared color charges which are felt by the links through their ends. The summation is over all the $\nu - 1$ links. While the charge associated to, say i-th, link is define as $\sum_{j=1}^{i} \vec{c}_j$, where $\vec{c}_j$ is the color vector for j-th parton.

Whenever a local pair of partons interact, i.e. the color switched between them, the outcome may or may not affect the global configuration. Our statistical approach to the determination of the global configuration α, consistent with favoring the lowest energy state, requires that the probability for configuration α to occur is proportional to $e^{-\beta E_\alpha}$, where β is a free parameter.

In the meanwhile the system undergoing color mutation due to the exchanging of gluon, there is a momentum transferring between the partons and therefore their positions in rapidity space fluctuate. Whether the link length contracts or expands depends on the attractiveness or repulsiveness of the net color forces that act on the two ends of the link. To determine the nature of that force is beyond the scope of this treatment. We shall model the change in link length by a stochastic approach. We randomly determine the amount of the change in the length of the link depending on two free parameters. The change can be either positive or negative.

A fission of the color-singlet cluster occurs, when it contains two color-singlet subclusters, since no confining force exists between them. Thereafter, the color mutation process is applied to the two subsystems separately and independently. This is repeated again and again until all subclusters consist of only $q\bar{q}$ pairs. We always keep the center of the cluster invariant to conserve momentum. When a hadron is formed from a $q\bar{q}$ pair, the hadron momentum rapidity y will be identified with a value of η taken randomly between the η values of the quark and antiquark. A rough identification of y with η is justified for free particles at high energy.

When branching process terminates, the $q\bar{q}$ pairs are identified as hadrons, which may be pions, kaons, or resonances. Those resonances must be allowed to decay before the total number and distribution of particles are counted for the final state of the event. The probabilities of producing various resonances and stable (in strong interaction) particles have been studied experimentally in pp collisions in [5]. We give each hadron a transverse momentum according to a "standard" exponential distribution of transverse momentum squared with an average transverse momentum as 400MeV. If the $q\bar{q}$ pair forms a resonance, then we assume an isotropic decay distribution in the rest frame of the resonance.

4 Results

There are six parameters introduced in the model. They are to be varied to fit the data on inclusive distributions and on fluctuations of the exclusive distributions. The data[6] in the energy range of $22 < \sqrt{s} < 63$ GeV are used to determinate the parameters. In Fig. 2 we show the pseudorapidity distributions to compare with ECOMB as an example.

The parameters that influence the evolution process of mutation and branching are determined by trying to reproduce the intermittency data. i.e. the factorial moments F_q for $q = 1, 2, ...$ and their variants [2]. we show the intermittency results calculated with ECOMB and the data from [8] in Fig. 3. It should be noted that to achieve the fits attained is highly nontrivial. If any part of the dynamical process in generating the hadrons is altered, one would not be able to obtain the rising factorial moments, no matter how many parameters are used.

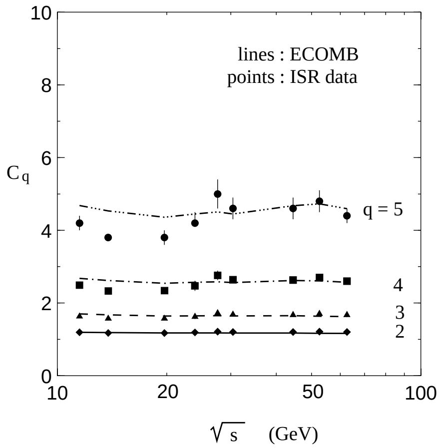

Fig. 1

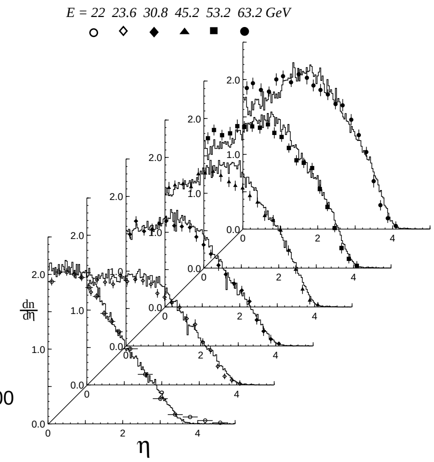

Fig. 2

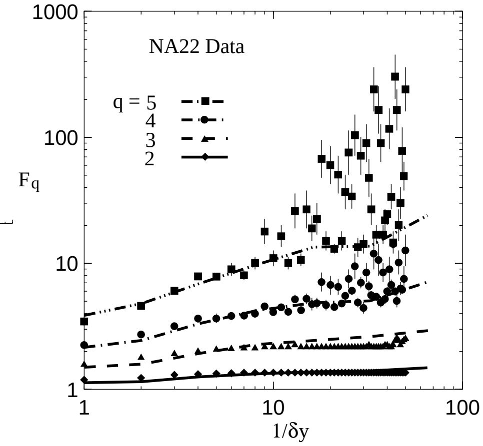

Fig. 3

Figure 1: Standard moments of the multiplicity distribution. The data are from Ref. [7]; Figure 2: Rapidity distributions of produced charged particles at several central mass energies. Symbols are the data from Ref. [6], while the histograms are the result of ECOMB; Figure 3: Intermittency data of normalized factorial moments for $q = 2 - 5$. The data are from Ref. [8]. The lines are determined from ECOMB.

5 Conclusion

It is rather satisfying that we have been able to reproduce the intermittency data in Fig. 3. Scaling behavior of that type implies self-similarity in the dynamics of particle production.

We have amalgamated many concepts that form various elements of the conventional wisdom about soft interaction. They include: (a) hadrons having sizes, (b) eikonalism, (c) parton model, (d) interaction of quarks via gluons, (e) statistical properties of a many-body system, (f) spatial contraction and expansion of a color system, and (g) resonance production. They are interlaced by intricate connections described in this paper.

Acknowledgments

A fruitful collaboration with R.C. Hwa is gratefully acknowledged.

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