Multiparticle production: an old-fashioned view

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Abstract We consider the dynamics of high energy multiparticle production and discuss how the space-time picture of inelastic interaction may reveal itself in identical particles Bose-Einstein correlations.

1 Introduction

The high energy interaction is usually described as the interaction of coloured particles (quarks and gluons) mediated by gluon exchange. On the other hand due to confinement we can observe the colourless meson or baryons only. That is the same final amplitude of a few(colourless) particles production should be described in terms of colourless objects (degrees of freedom). Recall that in initial state we deal with the proton or mesons or photon which has no colour. In terms of QCD these incoming particles may be treated as some colour dipole (or higher multipole) formed by constituent quarks (and gluons). The interaction (say, after the gluon exchange) changes the colours of initial constituents. The new state can be viewed as a few new dipoles (multipoles), Each of them is again colourless but the mass of this new dipole is now large. The simplest example is the quark-antiquark pair produced by the heavy photon in $e^+e^-$ annihilation. Originally this pair was produced at very small distances but the momenta of the quark and the antiquark are large and directed in opposite sides. So the separation between the quarks (and the dipole moment) increases. Correspondingly increases the strenght of colour electric field between these quarks. When the strenght of colour field becomes sufficiently large the new quark-antiquark pair is produced from the vacuum fluctuations. Since this pair is produced from the vacuum it is colourless. This new pair breaks the colour string and as a result we obtain two new dipoles\footnote{For simplicity we talk here about the dipoles only.}, each of a smaller mass. The situation is repeated in each
new dipole, so that finally we observe a system of few dipoles with the mass of the order of the ordinary hadron mass which should be identified with the secondary hadrons.

Recall that this picture is based on the famous Swinger model - QED in 1+1 dimensions.

Starting with the energy $\sqrt{s}$ this way we get the final multiplicity $N \propto \ln s$ and not $N \propto \sqrt{s}$. In other words it is enough to break the string $\ln s$ times to provide the low ($\sim 1$ GeV) mass of each dipole and a finite (say, $\sim 3 - 10$ GeV) energy of the pair of the nearest dipoles.

Such a picture for the first time was implemented in the LUND-string model [1]. It is the key-stone of the hadronization routing used in many general purpose Monte Carlo generators.

We have to emphasize that all the process of multiparticle production was described above in terms of the colourless objects – incoming dipoles, new colourless pairs produced from the vacuum fluctuations and the secondary dipoles. That is it can be reworded in terms of the colourless (hadron) degrees of freedom. Indeed, many years ago V.N. Gribov discussed the possibility to treat the Pomeron as the high energy vacuum fluctuation which contains the $\ln s$ Feynman partons including the "wee" partons with low rapidities in the wave function of a fast hadron. [2]. Then the multiparticle production from one or few 'cut' Pomerons might be calculated with the help of the AGK cutting rules [3].

Note that the picture predicts the plato in rapidity distribution of secondaries. Moreover, since QCD is the logarithmical theory we have to expect a slow growth of the mean transverse momenta with the energy increasing due to a larger available phase space. This is the origing of the fact that asymptotically the slope of the BFKL Pomeron trajectory $\alpha'_{BFKL} \to 0$ [4].

The detailed experimental study of multiparticle production became possible only after start of the first hadron collider at CERN. UA1 experiment [5] has made somewhat unexpected discovery: the radius of a radiation source in $pp$ collisions at centre-off-mass energy from 0.2 to 0.9 TeV depends on particles multiplicity but not on beam energy. This feature quite naturally might be described in the frame of multiperipheral model [6, 7].
2 The size measured by Bose-Einstein correlations

The size of the secondary hadrons source measured via the Bose-Einstein correlation (BEC) of identical pions radiated by the same colour string (or by the one cutted Pomeron) does not increases with energy. It is determined by the internal structure of the string or by the mean transverse momenta, $p_T$, of the particles which form the Pomeron. On the other hand the total cross section and the interaction radius measured by the $t$-slope of elastic amplitude increase with energy. This large interaction radius is generated by more complicated diagrams with the multi-Pomeron exchange or with a few strings. That is in BEC we have to see at least two different radii - one corresponding to the correlation of two pions emitted from the same string/Pomeron and another one caused by the observation of two pions radiated from two different strings/Pomerons. The second radius should be larger.

In the recent paper it was proposed to fit the data on BEC by the formulae which contains two different scales in order to extract both the radius corresponding to an individual string or Pomeron and the radius caused by the separation between the different strings/Pomerons. Note that the relative contribution of these two component may depend on different factors. In particular, on the multiplicity in a given event and/or on the mean transverse momentum of the pions in the pair. Indeed, in the case with a larger number of cut Pomerons (or strings) we expect a larger multiplicity. That is in a low multiplicity events we observe mainly the pairs radiated from the same (one) Pomeron while at a high multiplicities we deal mainly with the two pions emitted from the different strings/Pomerons.

On the other hand, since the inclusive cross section falls down steeply with the pion $p_T$ selecting the pairs with a larger $k_T = (p_{T1} + p_{T2})/2$ already at $k_T \sim 1$ GeV we actually will get the pairs where both pions are produced from the same minijet with jet $E_T \sim$ few GeV. In such a case the BEC will gives the radius of the parent minijet.

It is amusing to mention that all features of the radiated Pomeron presented above might be recognized in Fig.3 of the CMS publication. Later

\footnote{In the case of the multiperipheral model for the Pomeron the size is driven by the $p_T$ of the hadrons in the multiperipheral ladder.}
similar results have been published by the ATLAS \cite{10}. Recall that in these papers the analysis was done using the fit with only one radius which, depending on the multiplicity of a particular event and \( k_T \) of the pair, should be considered as some “average” between the small radius of an individual source and the source-source separation. Nevertheless:

- At small small multiplicity, one might see ONLY small ”radiator”, \( \sim 1\, fm \).
- The size of this object depends on BEC pairs transverse momentum : the higher this momentum the better the resolution of BEC-femtoscope.
- The size of this object is independent on beam energy.
- The correlation strength (\( \lambda \)) at the smallest multiplicity has a maximal value (\( \lambda \approx 1 \)), giving no chance for other radiation sources.
- At high multiplicity, the size of radiation zone is mainly determined by the pions radiated from different Pomerons, i.e. it depends on Pomerons spatial distribution over the radiation region. To be more precise, observed radius of the radiation zone is a ”weighted” mean of the separations between the Pomerons ( at multiplicity \( \sim 100 \) there are \( \sim 10–15 \) Pomerons) and much larger values of the radius observed via BEC (with only one scale) in a large multiplicity events corresponds to the large distances between Pomerons. Under such conditions the strength of correlations decreases with multiplicity ( ”sharing” between different ”processes”).

In terms of the quark-gluon degrees of freedom we may say that experiment favor the scenario where the hadronization of the quark-gluon system/matter/liquid passes via the formation of a number of relatively small size colourless bubbles/drops which finally produces the hadrons.

3 Conclusion

The experiments indicates that secondaries are produced by some small size sources distributed over a much larger (of order of the whole radiation size ) domain. These sources may be considered as the individual Pomerons or as the minijets or the colour strings between the jets which emit the ‘spray’
of hadrons. Note that the value of small radius measured in a low multiplicity events (where we observe the one cut Pomeron or the low $p_T$ colour tube/string between the incoming constituents) is (up to experimental accuracy) the same as that for the relatively large $k_T$ pairs (where we study the minijet fragmentation). That is in both cases we deal with the hadronization of the same colour string.

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