# Leading particle spectra as a tool to tune the color reconnection models

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**Abstract**

Kinematic variables like average transverse momenta and multiplicity distributions in $pp$ interactions at the LHC energies have been successfully described by phenomenological models which include color reconnection as part of the hadronisation processes. In the present work the transverse momentum distribution of the leading particles produced in $pp$ interaction, are investigated using the PYTHIA 8 event generator with different color reconnection modes. The effect of the different modes is reported in function of the multiplicity of the events.

## 1 Introduction

A considerable amount of work has been dedicated by several groups, in the implementation of interactions among partons in the initial and final state, following the general idea of QCD. The color fields are modeled by strings interacting in the final state before hadronisation. Among them the color reconnection (CR) hadronisation mechanism has allowed to fit simultaneously the multiplicity and the $p_t$ distributions in $pp$ collisions. The attractive of the models implying multiparton interactions and color reconnection is that they consider plausible QCD mechanisms. In recent publications [1–4] the effects of the CR in producing flow-like effects in $pp$ collisions has been investigated. The similarity with the predictions of hydrodynamics is striking and it would be very interesting to decide which approach is favored by nature. It was pointed out in Ref. [5] that it will be an important task for future experimental and phenomenological studies to find ways of disentangling color reconnection effects from hydrodynamics ones.

A key element in comparing color reconnection with hydrodynamics results might be to study the results for the two approaches in function of the transverse momentum range. Namely, the boost effect of the radial flow on transverse momentum diminishes at larger $p_t$ values, getting rather small above $p_t$ larges that 3 $GeV/c$. In the color reconnection modes, on the other hand, it is the probability to reconnect strings that gets smaller at higher transverse momenta.

Following the general idea exposed in [6,7] a Multiple Parton Interaction ($MPI$) system with a scale $p_t$ of the hard interaction ( normally happens in $2 \to 2$ QCD processes) can be merged with one of a harder scale with a probability that is $(R_{rec}P_{T0})^2/((R_{rec}P_{T0})^2 + P_T^2)$, where $R_{rec}$ is the

color reconnection range and $P_{T0}$ is the phase space cut of processes. The latter being the same energy-dependent dampening parameter as used for $MPI's$. Thus it is easy to merge a low-$p_t$ system with any other, but difficult to merge two high-$p_t$ ones with each other. However, for relatively hard transverse momenta of $\approx 10\ GeV/c$ the probability is still sizable so that we decided to investigate the behavior of the spectra at transverse momenta higher than the range where hydrodynamics and CR coincide in the qualitative description.
Our special interest is to see the effect of color reconnection at relatively high $p_t$ values where we expect little influence of hydrodynamics. To see this effect we have chosen to study the leading particles in each event. By leading we mean the highest detected charged particle in the acceptance, for each event. We have studied the two cases of color reconnection: mode 0 - the original PYTHIA recipe, where the gluons of a lower-$p_t$ $MPI$ system are merged with the ones in a higher-$p_t$ $MPI$; mode 1 - new scheme, where the gluons of a lower-$p_t$ $MPI$ system are merged with the ones in a higher-$p_t$. In both cases of color reconnection the QCD color rules are incorporated, and determine the probability that a reconnection is allowed.

## 2 Results and discussion

We have generated 100 million events for each CR mode, and for the no CR case for $pp$ collisions at 7 $TeV$. Only the charged particles were taken into account excluding the weak decays, in a pseudorapidity interval of $|\eta| < 0.8$. All the PYTHIA parameters were set to the default values.

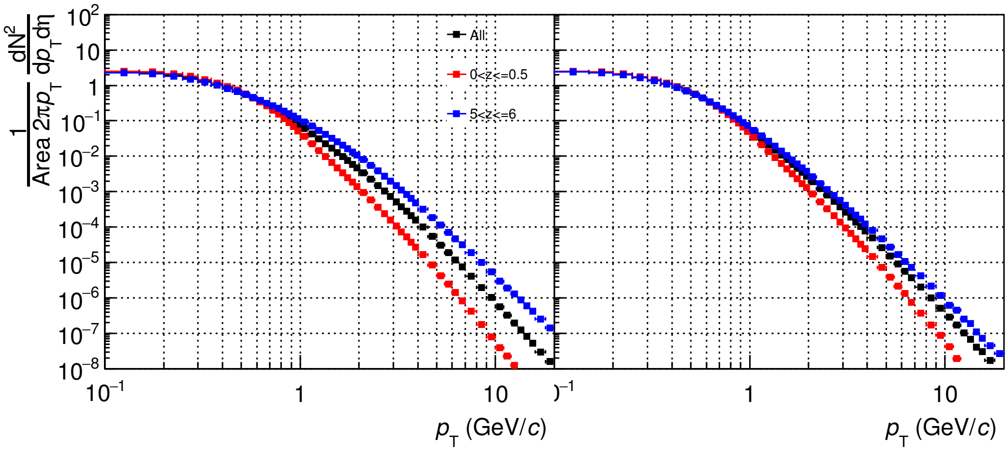


Figure 1: (Color online). Transverse momentum spectra for different multiplicities with CR mode 1 (left), and without CR (right)

In figure 1 we show the generated transverse momentum spectra obtained with CR mode 1 (left)

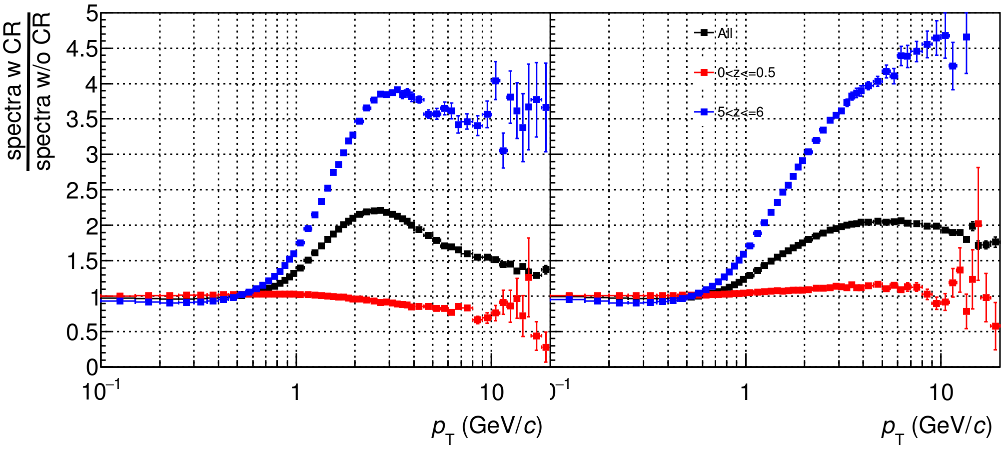


Figure 2: (Color online). Left panel: the ratio of the inclusive spectra with CR mode 1 to the spectra without CR. On the right one: the ratio for the case of the CR mode 0, as described in the text.

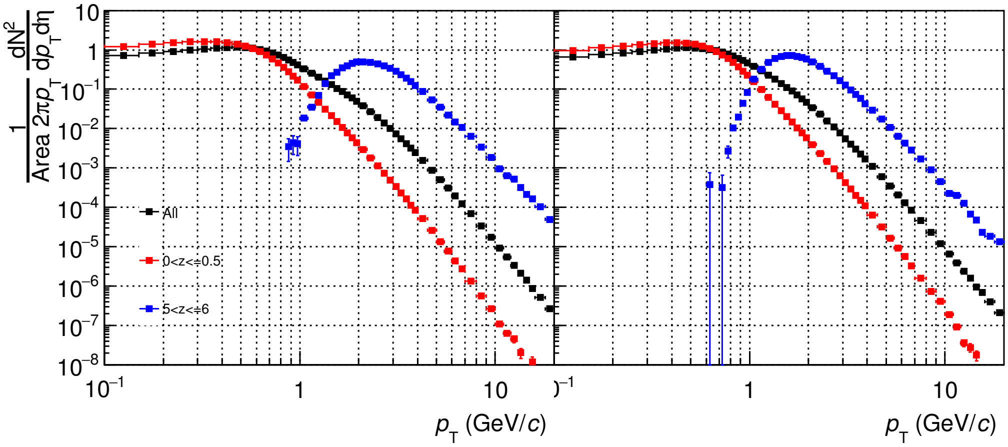


Figure 3: (Color online). Transverse momentum spectra of leading pions for three multiplicity ranges with (left) and without (right) CR mode 1.

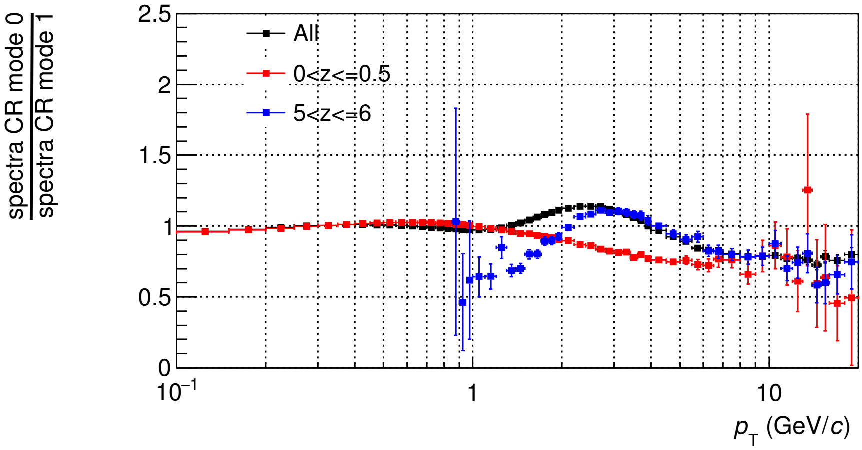


Figure 4: (Color online). Ratio of the leading particle $p_t$ spectra for the case of CR mode 0 to the same spectra generated with mode 1.

and without CR (right) for the case of minimum bias events, and for two multiplicity ranges, defined in terms of the parameter $z = N_{ch}/ < N_{ch} >$: $0.0 < z < 0.5$ and $5 < z < 6$, which means low and high multiplicity events. Those distributions clearly show the $p_t$ dependence with the multiplicity. We observe harder spectra when CR is included with respect to those without CR ones.

In Fig2, the ratio of the inclusive spectra with and without CR are shown for the same $z$ bins as in the Fig.1. The left panel corresponds to the case CR mode 0, while the right side is for CR mode 1. From figure 2, we see that the spectra ratios show a very important dependence with the multiplicity, predominantly at high momenta, but significant differences are also observed for the CR modes used, especially, at high momenta. It is important to note that the effect of CR gets much more important at higher multiplicities which indicates that the lowest multiplicity range has a behavior very similar to no CR and could therefore be used for reference in the analysis of CR effects in experimental data.

In Fig. 3, we show the spectra for the leading pions, simulated in the same multiplicity ranges as in Figs. 1 and 2 for the CR mode 1(left) and without CR (right). It is visible that the peak of the high multiplicity distribution is shifted towards higher multiplicities by almost 1 $GeV/c$! Essentially the same behavior is observed for protons and other identified particles.

In the Fig. 4, we show the ratio of the leading particle spectra for the cases of CR mode 0 to the same spectra generated with CR mode 1. One observes that the high multiplicity events present the largest differences between the two modes.

In conclusion, we see that the color reconnection mechanisms have a very marked incidence on transverse momentum spectra at high $p_t$. We have also demonstrated that the lowest multiplicity bins yields results very similar to the case with no color reconnection so that it may be used in experimental analysis to extract the ratios at high multiplicities instead of the no CR option used in this work. The ratio of the lowest multiplicity bin corresponding to events with less than half the mean multiplicity to the highest multiplicities renders possible an experimental check of the importance of color reconnection and a method to tune it. It is shown that different CR modes do produce slight differences among them, most significantly at highest $p_t$ values, indicating possible studies on pQCD of this effects. A comparison with other hydrodynamics based generators like EPOS will allow an interesting comparison which could be composed to experimental data.

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