Color reconnection and flow-like patterns in pp collisions.

I.A. Maldonado-Cervantes[1], E. Cuautle[1], Guy Paic.[1], A. Ortiz Velasquez[2] and Peter Christiansen.[2]

[1]Instituto de Ciencias Nucleares, Universidad Nacional Autónoma de México. Apartado Postal 70-543, México Distrito Federal 04510, México

[2]Lund, University, Department of Physics, Division of Particle Physics, Box 118, SE-221 00, Lund, Sweden.

E-mail: ivonne@nucleares.unam.mx

Abstract. Data collected at the LHC are confronted with the possible existence of flow in pp collisions. Here we present a study inside the framework of PYTHIA 8, showing that it contains implicit flow-like effects coming from multiple hard subcollisions and color string formation between initial and final partons from independent hard scatterings: color reconnection. We present studies with strange hadron observables in pp collisions at 7 TeV. Studies have been done both for minimum bias and multiplicity intervals in events with and without color reconnection to isolate the flow-like effect.

1. Introduction

The existence of something that is called flow has been taken as a proof of collective behavior of partons and hadrons. In central heavy ion collisions the transverse pressure gradient causes a transverse hydrodynamic expansion. This effect is transmitted to hadrons via a boost by the local velocity field. The transverse flow shifts the emitted particles to higher transverse momentum p_{T}, affecting the baryon to meson ratio as a function of p_{T} which exhibits an enhancement of the ratio and its position is pushed to higher momenta when one goes from peripheral to central Pb-Pb collisions [1]. In pp collisions at $\sqrt{7}$ TeV, the behavior of different ratios of particles could be related with flow. The ratios $(p^+ + p^-)/(\pi^+ + \pi^-)$ and $(\Lambda^0 + \bar{\Lambda}^0)/(2 \times K_s^0)$ exhibits a small enhancement, and it looks like there is no or little energy dependence [2] which is qualitatively well reproduced by PYTHIA version 8.17 [3] tune 4C [4], even though in general PYTHIA underestimates the production of strange particles [5].
The aim of this work is to show that the enhancement in the baryon to meson ratio is attributed to color reconnection, a mechanism present in PYTHIA 8.

2. Color reconnection

Color reconnection (CR) is a microscopic mechanism in which final partons are connected by color string, in such a way that the total string length becomes as short as possible [6]. One string connecting two partons follows the movement of the partonic end points. The effect of this movement is a common boost of the string fragments. With CR two partons from independent hard scattering at mid-rapidity can color reconnect and make a large transverse boost (Fig. 1).

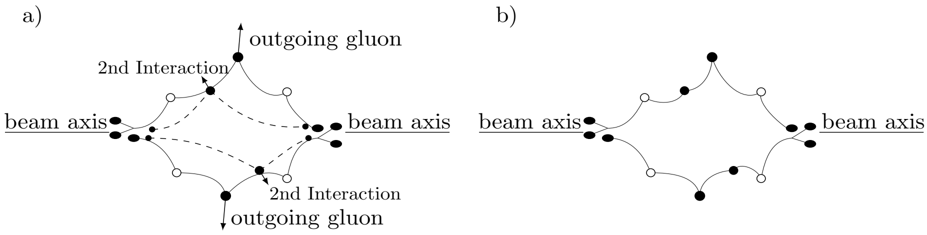

Figure 1. The figure illustrates the color reconnection mechanism in the string fragmentation model. The outgoing partons which are color connected to the projectile and target remnants (continuous lines) are reconnect with the partons in the second hard scattering (in dashed lines). (a) Color reconnected string (b).

3. Studies to isolate the flow-like effect.

The parameter which controls CR is the reconnection range (RR) which enters in the probability to merge a hard scale $\hat{p}_T$ system with one of a harder scale, tune 4C uses the value $RR = 1.5$ which gives a good description of mean transverse momentum as a function of multiplicity.

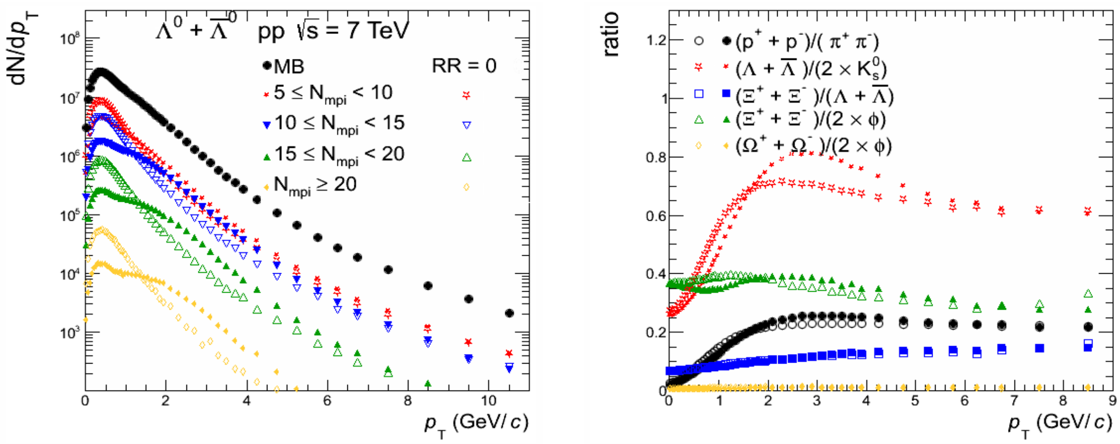

Figure 2. Spectra (left) and baryon to meson ratios (right) with RR = 1.5 (solid points) and without CR, RR = 0 (open points). We observe that CR typically produces a bump around $2.5 - 3$ GeV/c.

Comparison with and without CR. To study the effect we simulate MB events with PYTHIA 8, tune 4C, with (RR = 1.5) and without (RR = 0) CR. Left side of Fig. 2 shows the evolution of the p_{T} spectra of Λ for ranges of the number of Multiple Parton Interactions (MPI), from this it is observed a harder spectra when CR are included. Also shown in the right side of Fig. 2 different baryon to meson ratios as well as heavy to light meson ratios as a function of p_{T}, all of them shown a bump around $2.5-3$ GeV/c which diminishes when CR is turned off. The position of the maximum is shifted to larger p_{T} values when CR is included, however after $p_{\mathrm{T}} > 7$ Gev/c, the particles ratio are unaffected by CR. A qualitatively similar evolution of the spectral shapes and particles ratios with collision centralities has been observed in heavy ion collisions [7].
MPI and Particle ratios. In reference [8] We shown that the baryon to meson ratios are enhanced in events with increased MPI activity. In events with more than 20 MPI's the peak is also pushed

up to higher p_{T}, a characteristic effect of flow. On the contrary, in events with less than 5 MPI's the ratio behaves like in simulations without CR.

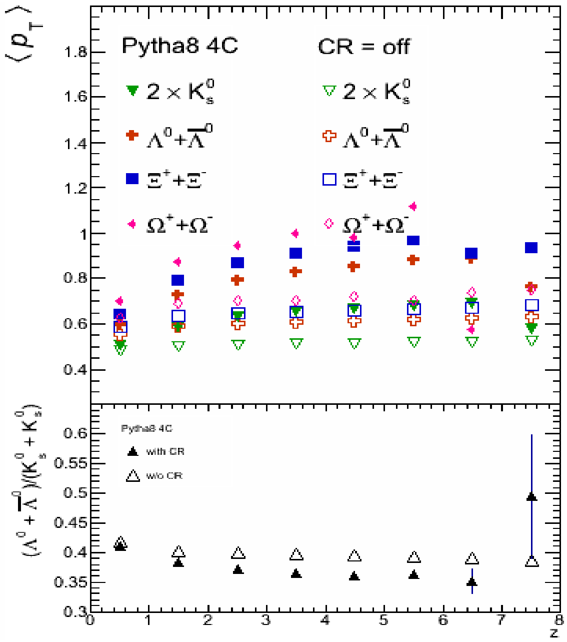

Figure 3. The behavior of the $\langle p_{\mathrm{T}} \rangle$ as a function of multiplicity($z = dN/d\eta/\langle dN/d\eta \rangle$) for strange hadrons.

$\langle p_{\mathrm{T}} \rangle$ as a function of multiplicity. At LHC energies the CMS collaboration has published p_{T} spectra for pions, kaons and protons as a function of the track multiplicity. They found that $\langle p_{\mathrm{T}} \rangle$ increases with multiplicity, this can only be described by PYTHIA when CR is included.

In Fig. 3 we observe an increase of $\langle p_{\mathrm{T}} \rangle$ with multiplicity when CR is turned on, while it is essentially flat when color reconnection is turned off. The stronger increase of $\langle p_{\mathrm{T}} \rangle$ for heavy hadrons mimics a flow-like effect due to the string boost.

Energy dependence. If the center of mass energy is increased in the simulations the MPI activity increases and the peak is shift further out in p_{T} and the magnitude increases. So the effect of CR becomes more prominent at higher energies.

4. Summary

The CR scheme used in the PYTHIA 8 event generator exhibits a qualitatively new feature that has potentially important consequence on our understanding of the details of the pp collisions. The "flow" mechanism present in PYTHIA 8 does not require thermalization or a medium to be formed. This could lead us to make predictions that are different from hydrodynamics for small systems as pp and p-Pb.

Acknowledgments

Support for this work has been received by CONACyT under grant numbers 101597 and PAPIIT-UNAM under grant number IN108414.

References

[1] Ortiz Velasquez A (for the ALICE Collaboration) 2013 *Nucl. Phys.* **A904-905** 763c
[2] Aamodt K *et al* (ALICE Collaboration) 2011 *Eur. Phys. J C* **71** 1594
[3] Sjöstrand T, Mrenna S and Skands P 2008 *Computer Phys. Commun.* **178** 852
[4] Corke R and Sjöstrand T 2011 *JHEP* **1103** 32
[5] Abelev B *et al* (ALICE Collaboration) 2012 *Eur. Phys. J C***72** 2183
[6] Sjöstrand T, Mrenna S and Skands P 2006 *JHEP* **0605** 026
[7] Aamodt K *et al* (ALICE Collaboration) 2013 K^0_s and Λ production in Pb-Pb collisions at $\sqrt{S_{NN}} = 2.76$ TeV *e-print* arXiv:1307.5530v1
[8] Ortiz Velasquez A, Christiansen P, Cuautle Flores E, Maldonado Cervantes I A and Paić G (2013) *Phys. Rev. Lett.* **111** 042001