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Study of the pion and proton production in pp collisions at 14 TeV

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Abstract:
The hadronization into baryons is still a theoretically ill defined process.
The event generator Pythia 6.3 includes several mechanisms for the production of baryons in its code. We have simulated events at the nominal pp collision energy of LHC 14 TeV including in the simulations three mechanisms, Simple Popcorn, Advanced popcorn, and Baryon Junction. The results are discussed in view of their sensitivity to experimentally accessible observables namely multiplicity distribution and ratios of $\bar{p}$/p and p/π.

1 Introduction

In heavy ion collisions at RHIC two phenomena remain up to now without a valid explanation: one is the p/π ratios which exhibits a departure from the same ratio, measured in pp collisions at transverse momenta between 2.0 and the maximum reach of identification at RHIC ~4.5 GeV/c[1], the second deals with the ratio $\bar{p}/p$ which has been measured to be virtually independent of the p_t of the particles [2], and is smaller than expected if classical mechanisms of baryon stopping only are invoked. Hence it is legitimate to say that, as of today, all the details of hadronization into baryons are not well understood neither in nucleon nor in nucleus nucleus collisions.

Therefore it is of the highest interest to use the possibilities of the ALICE tracking and PID detectors in the central rapidity to study in details the proton production and compare with the existing models. We have mapped the results we might expect in pp collisions at 14 TeV using as a guideline the different baryon production mechanisms incorporated in the latest version of Pythia [3].

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2 Pion and proton production

Production of mesons and baryons depends on the fragmentation processes. While the meson production is represented as a simple piece of the string between two $q - \bar{q}$ endpoints the extension to the case of baryons is not straightforward. Actually there are different scenarios like diquark, Simple Popcorn, Advanced Popcorn and Baryon Junction mechanism that we will shortly review. A general description of these models can be found in the Pythia Manual [3] and references there in.

2.1 Diquark picture

In most string models particle production in a pp collision occurs mainly in the form of two diquark-quark strings. There is strong experimental evidence that with a large probability the diquark acts as a single entity and fragments directly into a leading baryon. Since the diquark is fast in average, taking a large fraction of the incoming proton momentum, the produced baryon will be in the proton fragmentation region. The corresponding baryon spectrum at rapidity $y \sim 0$ decreases, quite fast with energy - roughly as s^{-1} [4].

In Pythia, the probability to produce various diquarks pairs is parametrized with: the probability to pick a $\bar{q}q$ diquark rather than a q, a suppression factor associated with diquarks containing a strange quark, the suppression of spin 1 relative to spin 0. One important constraint is the requirement of a symmetric state of three quarks. When a diquark and quark are joined to form a baryon, the combination is therefore weighted with the probability that they form a symmetric three quark state.

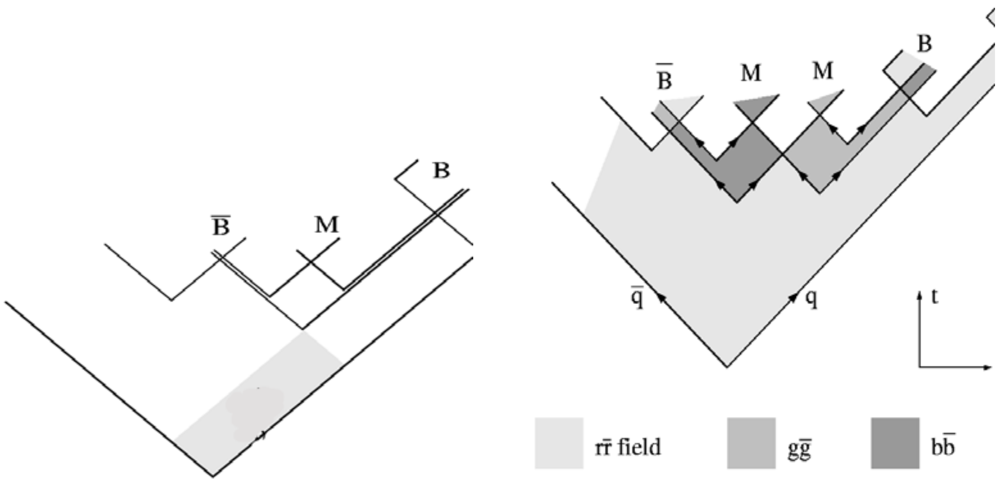


Figure 1: The system configurations of Simple (left) and Advanced (right) Popcorn. The left show the $BM\bar{B}$ system. The right show an example of two pairs of quarks produced to form a $\bar{B}MMB$ system.

2.2 Simple Popcorn

In this picture diquarks as such are never produced, but rather baryons appear from the successive production of several $q_i\bar{q}_i$ pairs. It assumes that the original q is red r and the $\bar{q}$ is $\bar{r}$. The produced pairs $(q_1\bar{q}_1)$, are such that $\bar{q}_1$ is pulled towards q and vice versa, and two separate colour-singlet systems $q\bar{q}_1$ and $q_1\bar{q}$ are formed. Usually the pairs are such that there is net colour charge acting on either q_1 or $\bar{q}_1$. The sequence of production is the same for the other pair $q_2\bar{q}_2$, where q_2 now is pulled towards qq_1 and $\bar{q}_2$ towards $q\bar{q}_1$ with not net colour field between q_2 and $\bar{q}_2$. When all these happens, the baryon B will be made up out of q_1, q_2 and some q_4 produced between q and q_1, and $\bar{B}$ of $\bar{q}_1$, $\bar{q}_2$ and some $\bar{q}_5$. Hence, the B and $\bar{B}$ will be neighbours in rank and will share two quarks pairs. With two production vertex $q_2\bar{q}_2$ and $q_3\bar{q}_3$, a central meson $\bar{q}_2q_3$ may be formed. The configuration is then $BM\bar{B}$ (see Fig 1 (left)).
The relative probability for a $BM\bar{B}$ systems given by the uncertainty relation suppression of having a q_1 and q_2 sufficiently far apart so that a meson may be formed inbetween. The suppression of the $BM\bar{B}$ system is estimated by $\mid \Delta_F \mid^2 \approx exp(-2\mu_\perp M_\perp/\kappa)$, where $\mu_\perp$ and $M_\perp$ are the transverse masses of q_1 and the meson, respectively. The model depends on some parameters, like quark and diquarks masses. The default parameter values are based on a combination of experimental observation and internal model predictions. A complete description of the model is given by Anderson [5].

2.3 Advanced Popcorn

A new version of the popcorn is given in [6]. This new version takes better account of the detailed kinematics of the process. For instance, it has implemented two parameters which govern both the diquarks and the intermediate meson production. Additionally configurations like $BMM\bar{B}$ are considered in a natural way (see Fig. 1 (right)).

3 String Fragmentation

In the string picture, the various points where the string breaks by the production of $q\bar{q}$ pairs are causally disconnected. One may therefore make the convenient choice of starting an iteration process at the ends of string and proceeding towards the middle. The string fragmentation is rather complicated for a generic multiparton state, however, we only describe briefly the main ideas in order to get the baryon junction model incorporated in the production of hadrons.

3.1 Junction

When a quark or several quarks are kicked out of an incoming proton, different kinds of string topology can be produced. The main is Y shape string, with a quark at each end and a *junction* where the strings meet. As quarks are pulled out, the junction will also move, so as to minimize the total string energy. In the rest frame the opening

angle between any pairs of quarks is 120^0, so that the forces acting on the junction cancel.
Each of the three strings fragment as ordinary strings, in back to back $q\bar{q}$ pairs of jets. And iterative procedure can be used by which the q is combined with a newly produced q_1, to form a meson and leave behind a jet q_1. Eventually, when the energy is not anymore sufficient to produce pairs, the three remaining quarks $q_i q_j q_k$ form a single baryon, which thus has a reasonably small momentum in the rest frame of the junction. In this sense, the junction is the carrier of the net baryon number of the system. This process results in a usual slower decrease of the baryon contributions at $y \sim 0$ and the energy ($\sim s^{1/4}$) [4]. The algorithm to implement this in a Monte Carlo is not easy. An approximation consists in taking two of the strings, preferably the ones with the lowest energy, and fragment them until their remaining energy is below some cut off value. The two remaining flavours are combined into one effective diquark which is assigned all the remaining energy and momentum. The resulting string piece, between this diquarks and the third diquark, can now be considered as described for simple $q\bar{q}$ string.

3.2 Underlying events and baryon junction

Pythia 6.3 has incorporated a new mechanism for baryon production. Baryon junction [7, 4] together with underlying events (UE) gives interesting results. The major characteristics are as follow: We have multiple interaction [8] between two or more partons instead of one as before. The basic scheme is based on $2 \rightarrow 2$ QCD matrix elements convoluted with standard parton densities, and a sequence of $p_\perp$ ordered interactions are generated. The sequence is stopped at some lower cut off scale $p_{\perp min}$. An impact parameter dependence of the probability to form a junction is also introduced, considering a hadronic matter distribution for the hadron-hadron interactions. The hadronic matter distribution is parameterized in different ways: Gaussian, double Gaussian or $\exp(-\mathrm{b}^{\mathrm{d}})$, where b is the impact parameter. These distributions affect directly the multiplicity distributions. The flavour content of the beam remnant has been taken into account, and as a consequence, the parton distribution function suffer some modifications. All of these elements were considered to simulate events in Pythia 6.3.

4 Proton production in pp collisions at 14 TeV

We present simulations with the above mentioned mechanisms in order to investigate their influences in some experimental observables. The simulation at this time do not take into account the feed down of weaks decays on protons and pions. The collision energies were 200 GeV to compare to experimental results and 14 TeV to LHC. For each case 10^6 events were generated.

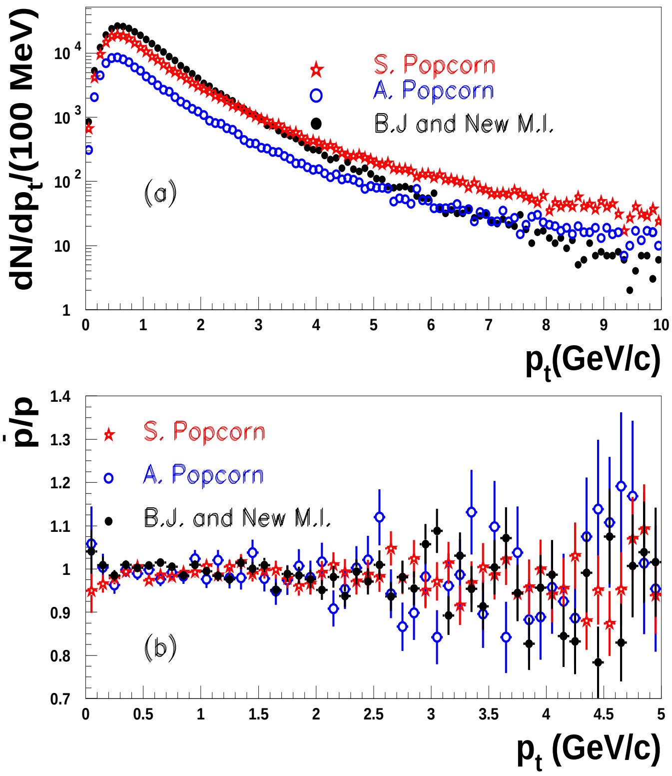


Figure 2: P_t spectrum (a) and ratio for anti proton to proton (b) for three different models. Advanced Popcorn, Simple Popcorn and Baryon Junction.

4.1 $\bar{p}/p$ ratio

Fig. 2 shows the p_t and the ratio antiproton to proton from Popcorn Advanced compared to Simple Popcorn and Baryon Junction with new Multiple Interaction models. Qualitatively we observe from Fig. 2a that Simple Popcorn produces more protons compared to the Advanced popcorn, in all the p_t range. This behaviour comes from the model, because Advanced Popcorn has higher probability to produce $\bar{B}MMB$ systems, consequently there are more mesons and less baryons compared to Simple Popcorn. The spectrum at low p_t from Baryon Junction is higher than for the other at low p_t. This behaviour is because the mechanism itself favour the production of low momentum protons. Although the Baryon Junction does produce distinct p_t spectra with a specific behavior at high p_t, the $\bar{p}/p$ is the same for three models, see Fig. 2b. Recent experimental data of $\bar{p}/p$ at 200 GeV [2] show a completely different behaviour compared to Baryon Junction at two energies, as we can see in Fig. 3.

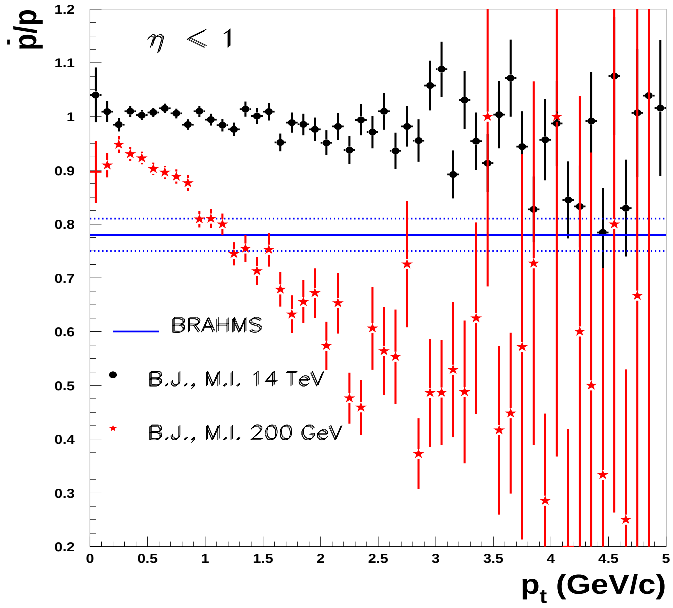


Figure 3: Antiproton to proton ratio versus p_t for one production mechanism: Baryon Junction. The solid line is the central value and dotted are errors bar from BRAHMS at 200 GeV

4.2 p/π ratio

The production rates of baryons and mesons are best exemplified with the ratios of proton versus pions. Fig. 4 shows the ratios obtained with the three models. Indeed in this ratio there is important differences observed both in the whole pseudorapidity and in the central rapidity. Since the multiplicity distributions are different depending on the mechanism see Fig. 5, we have also extracted the predictions for different multiplicity bins. The results are shown in Fig. 6a and Fig. 6b for the multiple interaction plus baryon junction and for the Simple Popcorn mechanism. From the simulations it is impossible to determine a clear trend with multiplicity although significant differences are observed.

The case of the proton to kaon production ratio in function of p_t is qualitatively similar to the case of the p/π ratio.

5 Conclusion

The particle identification of ALICE in pp collisions will allow interesting insight on the mechanism of baryon production. We have demonstrated here that the p/π ratio in the existing Pythia mechanisms allow for a large spread. Although the $\bar{p}/p$ ratios are very stable and do not depend on the mechanism (at 14 TeV) it is useful to remind that Pythia does not reproduce the existing data measured in pp collisions at RHIC [2] as is showed in Fig. 3. We see that, while Pythia at 200 GeV clearly indicate a slope stemming from the increasing contribution of valence quarks with p_t, the experimental data are flat and are much below the predictions. The Pythia

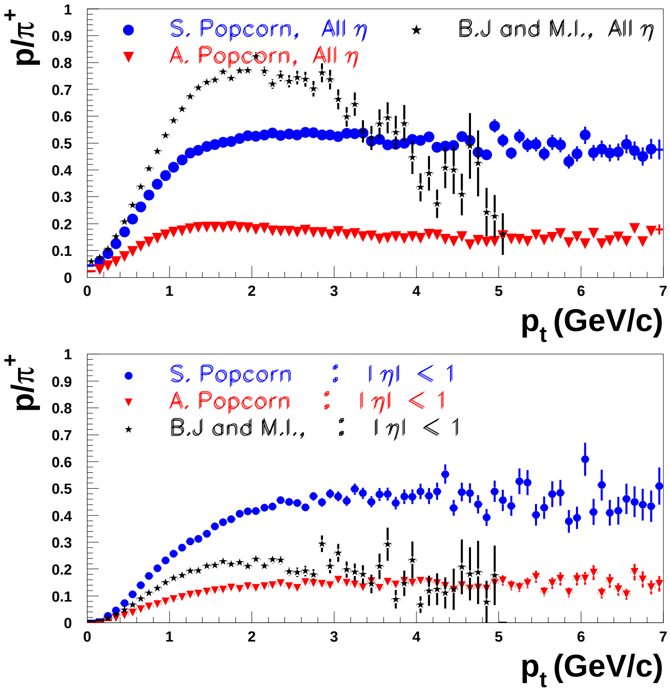


Figure 4: Proton to pion ratio as function of p_t, comparing the Advanced, Simple Popcorn and Baryon Junction mechanism of production.

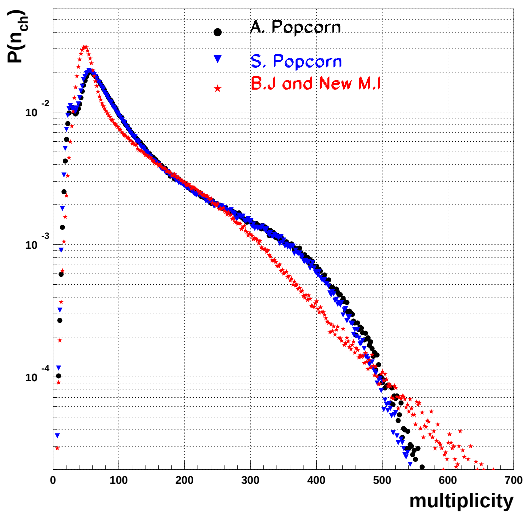
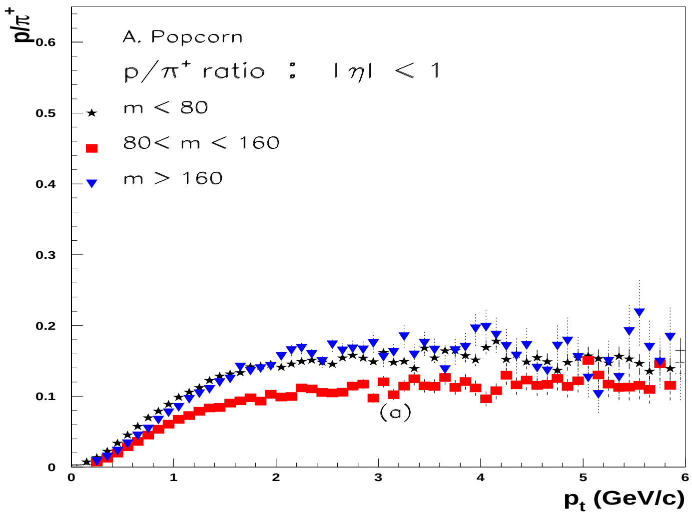


Figure 5: Charge multiplicity distributions for three different baryon production mechanisms



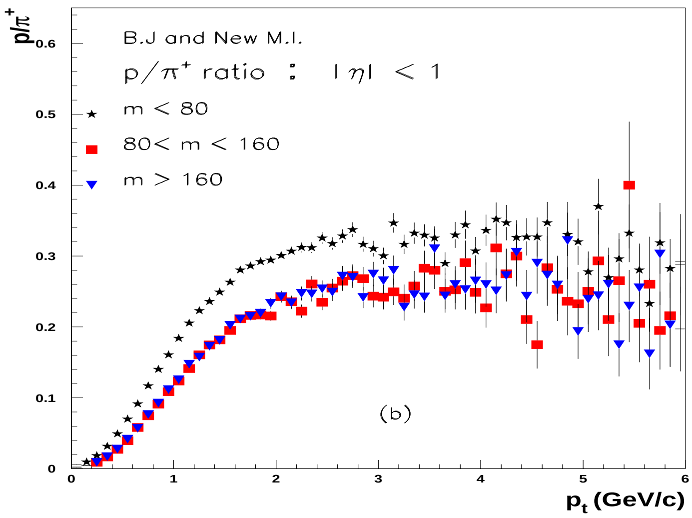


Figure 6: Proton to pion ratio versus multiplicity, m, for popcorn (a) and baryon junction (b) production mechanism

predictions for other models give essentially the same result. Therefore it is not excluded that the $\bar{p}/p$ ratio at LHC be also in contradiction to the presently available mechanisms.

6 Acknowledgments

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