Proton/pion ratios and radial flow in pp and peripheral heavy ion collisions

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Abstract. The production of baryon and mesons in the RHIC heavy-ion experiments has received a lot of attention lately. Although not widely known, the pp data measured concurrently with heavy ion collisions do not find a convincing explanation in terms of simple models. We present the results of an afterburner to Pythia and Hijing event generators, simulating radial flow which seems to qualitatively explain the experimental results when applied to the pp collision data from RHIC at 200 GeV center-of-mass energy.

INTRODUCTION

In heavy ion collisions at RHIC energies some phenomena remain up to now without valid explanation, one of them is the \( p/\pi \) ratios which exhibits a departure from the same ratio, measured in pp collisions at transverse momenta between 2.0 and \( \sim 4.5 \) GeV/c[1]. Although the coalescence model [2] has been widely accepted, it does not provide a satisfactory response to many questions. Beyond the details of the hadronization process which is still a debated question; it is well known that the \( p_t \) spectra of particles of different masses cannot be fit with a unique temperature as would predict a naive thermal model. In the nineties the NA44 collaboration has put in evidence the so called radial flow[3] in heavy ion collisions and it was interpreted as consequence of multiple interaction among the partons after the collisions of ions and before the freeze out of the created system. This interpretation also was confirmed by recent experimental results from RHIC [4].

The flow is understood as reflecting collective aspects of the interacting medium, depending on the collision energy. In central collisions between spherical nuclei, the initial state is symmetric in azimuth implying an isotropic azimuthal distribution of the final state particles. Consequently, any pressure gradient will cause an azimuthally symmetric collective flow of the outgoing particles. This is what we call radial flow.

The relevant observable to study the radial flow is the transverse momenta of the particles. For each particle, the random thermal motion is superimposed onto the collective radial flow velocity, correspondingly, the invariant \( p_t \) distribution depends of the temperature at freeze out, the particle mass, and the velocity profile. The experimental data on radial flow at RHIC indicate two things:

- the temperature lowers with centrality while the flow velocity increases [5].
• even for $pp$ collisions the analysis of the data from STAR yields a flow value of $\approx 0.2 \, c$

This latter result coupled to the fact that in $pp$ collisions the $p/\pi$ ratio could not be reproduced by Pythia has encouraged us to investigate what would be the result of the $p/\pi$ ratio if a flow component would be incorporated.

Consequently, in a first step we have generated flow-free pion and proton spectra using: 1) Pythia [6] with the Popcorn baryon production mechanism (note that from earlier work [7] we know that the differences in the ratio at 200 GeV are not very large when other baryon production mechanisms are used). 2) Hijing 1.36.

In a second step a toy model of the radial flow is incorporated in the $p_t$ spectra and finally our results are compared with the baryon to meson ratio from STAR [8] in $pp$.

**THE RADIAL FLOW AFTER BURNER**

We are assuming that a fireball, thermalized, and expanding was created in a collision from an event generator. The expansion produces an additional momentum to the one created in the collisions. This contribution we call momentum of the flow $p_t,f$ given by $p_t,f = \gamma m \beta$, where $\gamma$ is the Lorentz factor, $\beta$ is the profile velocity and $m$ is the mass of the particle under consideration. In order to add this radial component to the transverse momenta produced by the generators, it is necessary to attribute to the momentum $p_t$ of each particle a randomized position in the transverse plane. Once this is done, the radial flow component is added vectorially.

**RESULTS**

In the left side of Fig. 1 we show the midrapidity ($|\eta| < 1$) transverse momentum spectra obtained with Pythia and Hijing. It is apparent that the two generators do not yield for $pp$ collisions the same result. Hijing predicts a slightly steeper $p_t$ dependence than Pythia. In the right side of the figure 1 we show the effect of the afterburner onto the flow free spectra for the proton case. We have used here a flow velocity of 0.6$c$ to be able to clearly demonstrate the effect. As expected the flow free and afterburner spectra coincide at higher $p_t$.

The ratios $p/\pi$ are shown in Fig. 2. In the left we show the results obtained for a flow velocity $\beta=0.2$ and $0.3$, applied to the HIJING events, compared with the STAR $pp$ data. The right side of the same figure shows the same data fitted with Pythia applying the same flow parameter and an additional one of 0.6$c$. It is obvious that the resulting fit is different, Pythia requiring a much larger flow velocity than Hijing to fit the same spectra.

The model works well also for peripheral heavy ion collisions as shown in Fig. 3 comparing with PHENIX [9] data.
FIGURE 1. Spectra of pions from Pythia and Hijing event generators. The flow effects are shown in the right side, for the protons cases.

FIGURE 2. Proton to pion ratio as function of $p_t$. The left correspond to experimental results on $pp$ collisions from STAR, comparing with our model using Pythia. The right part shows our model using Hijing and comparing it with the experimental results from $pp$ collisions.

SUMMARY

The data of $pp$ collisions at RHIC suggest that even in $pp$ collisions the transverse momentum spectra of different particles are not completely parallel to each other. The analysis suggests that a flow velocity albeit small has to be added. Without entering in the foundation of the existence or not of flow we have constructed a toy model where we apply a given quantity of flow to flow free transverse momentum spectra generated by
FIGURE 3. Ratio proton to pion from Hijing included radial flow with $\beta = 0.2c$ and compared with PHENIX Au + Au peripheral results.

either Pythia with the popcorn baryon production mechanism or Hijing. The obtained results demonstrate that both for $pp$ collisions and peripheral heavy ion collisions we obtain a remarkably good fit to the data using Hijing spectra and the velocities extracted in the experiments. The differences in the quality of the fit observed using Pythia indicate that the initial shape of the spectrum is key to a good reproduction of the data. We conclude that the flow may be one of the key ingredients in the so called Baryon puzzle at RHIC.

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