STRANGE CONTENT OF BARYONS AT RHIC

B. HIPPOLYTE for the STAR Collaboration
Physics Department, Yale University,
P.O. Box 208124, New Haven CT, 06520, USA.

Via the study of strange particle production within the STAR experiment, we try to address the surprising amount of baryon transport at the Relativistic Heavy Ion Collider (RHIC). We report here preliminary results showing that, at mid-rapidity and for the top energy of RHIC, the number of created baryons exceeds the number transported from the colliding nuclei. However, thanks to the large acceptance of the experimental setup, one could expect to observe the transition between the “soft” regime (low transverse momentum \( p_T \) region corresponding to a bulk of hot and dense matter hadronizing) and the perturbative one (higher \( p_T \) region) where the fragmentation of incoming partons is supposed to dominate hadron production.

1 Introduction

1.1 Strangeness Production at RHIC

In continuation of the long program of heavy ion collision studies new measurements have been performed at RHIC, which successfully switched from the first year (2000) energy of \( \sqrt{s_{NN}} = 130 \text{ GeV} \) to the maximum attainable 200 GeV (second run of 2001). These energies are an order of magnitude higher than those achieved in fixed target experiments at the SPS which makes it more likely that a deconfined partonic phase is created. In order to unambiguously identify such a state of matter, the initial conditions of \( Au+Au \) collisions need to be characterised. As strange quarks are created and not transported from incoming nuclei, strangeness production is expected to be a good estimator of the degree of equilibration of the produced fire-ball. From their subsequent decays, strange particles can be clearly identified with a detector like STAR due to its large phase space coverage complemented by a high efficiency tracking.

1.2 The STAR Experiment

The Solenoidal Tracker At RHIC (STAR) tracking system, situated mainly at mid-rapidity, consists of a large cylindrical Time Projection Chamber (TPC) assisted by an inner silicon detector (SVT) and an outer RICH patch. Charged particle tracks are bent by a longitudinal magnetic field and extrapolated from the detection volume of the TPC toward the SVT and the interaction point. For each track, identification implies topological analyses, specific ionization in the detector gas and/or Cherenkov imaging. Triggering is provided with the simultaneous use of a Central Trigger Barrel and two Zero Degree hadronic Calorimeters located upstream and downstream of the detector along the beam axis. This system was supplemented by two beam-beam counters during the \( p+p \) run. Detailed explanations related to topological analyses

*for the full author list, see [http://www.star.bnl.gov/STAR/smd/collab/sci-apr03.ps](http://www.star.bnl.gov/STAR/smd/collab/sci-apr03.ps)*
in STAR are provided elsewhere. However, one should keep in mind that the strength of such a method resides in the lack of high $p_T$ limitation rather than statistics.

In this paper, the preliminary results shown correspond to both $Au+Au$ and $p+p$ colliding systems. Emphasis will be placed on strange baryon ratios, discussing: (i) Baryon transport using $\bar{B}/B$ ratios; (ii) the behaviour of the $\bar{\Lambda}/\Lambda$ ratio as a function of $p_T$; (iii) mixed strange and multi-strange ratios as a probe of chemical equilibrium.

2 Initial conditions and baryonic number

Important information is encoded in the baryon number transport mechanism, which corresponds to the very early stages of the collision and affects the dynamic evolution of the matter created, more specifically the thermal and chemical equilibration of the system. Net-baryon number has to be conserved from initial interactions to the whole final rapidity interval. At mid-rapidity, the $\bar{B}/B$ ratio yields information on the corresponding net-baryon density, and one can simply compare the valence quark transport from beam rapidities ($\sim 6$ units) to pair production. As a function of the baryon strange quark content and beam energy, a linear trend is clearly seen in Figure 1.

![Figure 1: Anti-baryon/baryon ($\bar{B}/B$) ratios as a function of the strangeness content at RHIC and SPS energies. Left panel corresponds to $A+A$ most central collisions whereas the right one corresponds to $p+p$. These mid-rapidity ratios are corrected for absorption in the detector material and the errors on the data are statistical only. STAR ratios at 130 GeV are corrected for feed-down.](star-figure1.png)

Although the mid-rapidity region is not net-baryon free, the ratios for $Au+Au$ at 200 GeV are even closer to unity than the ones previously reported at 130 GeV and of course than those of the SPS experiments (left panel). This implies that a still sizeable fraction of the baryon number is transported from the incoming nucleus at beam rapidity to the mid-rapidity region. A baryo-chemical potential of $\sim 40$ MeV ($\sim 25$ MeV) for 130 GeV (200 GeV) can be extracted with a widely used statistical formalism. Hadronization is therefore thought to be located close to the region where QCD calculations on the lattice are valid. It is interesting to attribute this behaviour to an energy dependence. Indeed, in comparing $Au+Au$ (even from central to peripheral collisions) and $p+p$ collisions at RHIC, both at 200 GeV, similar $\bar{B}/B$ values are obtained.
3 Soft physics up to moderate transverse momentum

The integrated ratios presented earlier are very convenient since no efficiency corrections are needed. The main assumption is that the detection is charge symmetric and modulo absorption, the efficiency for both charges should be the same. However, the raw spectra are not usually flat as a function of $p_T$ (corrected is exponential-like and 95% of the hadrons produced at RHIC are below 2 $GeV/c$) and the low $p_T$ part dominates the integrated ratio value. Therefore it is legitimate to wonder how these ratios behave as a function of $p_T$, especially because the contribution of baryon transport and pair production should affect strange and strange anti-baryons differently. The example of $\Lambda$ and $\bar{\Lambda}$ is interesting since similar production for both particles were previously reported at 130 GeV. Figure 2 shows STAR preliminary results for the $\bar{\Lambda}/\Lambda$ ratio at 200 GeV. It is $p_T$-independent up to a moderate value of $\sim 4$ GeV/c. Although the $p_T$ range is smaller at 130 GeV due to statistics, similar results are obtained for the $\bar{\Xi}^+/\Xi^-$ ratio.

![STAR PRELIMINARY](image)

Figure 2: STAR measurement of Anti-Lambda/Lambda as a function of transverse momentum at $\sqrt{s_{NN}}=200$ GeV. The ratio is consistent with a flat behavior up to moderate $p_T \approx 4$ GeV/c. Calculations (see references in the text) for pQCD (solid) and soft+quenching at 130 GeV (dashed) are shown for comparison.

Recent investigations have been undertaken to explain baryon dynamics using gluonic baryon junctions. Corresponding calculations but at 130 GeV are superimposed on the figure where it appears the soft+quenching curve is closer to the STAR preliminary data than pQCD inspired calculations. Indeed, no constant decrease is seen for this ratio whereas a turnover may occur around 3 $\sim 4$ GeV/c. Taking into account systematic errors, one needs to extend the measurements at higher $p_T$ in order to draw a pertinent conclusion. Similar baryon ratios (e.g. $\bar{\Xi}^+/\Xi^-$) would certainly be useful for any confirmation of a transition between a “soft” regime and the perturbative one.

4 Highly equilibrated system at hadronization

Strange and multi-strange particle production as a function of entropy is a very important tool for studying chemical equilibration. It has been often shown how difficult it is to reproduce the multi-strange baryon yields with microscopic models including hadronic phases only. Figure 3 shows both strange and multi-strange ratios as a function of beam energy. In the left panel (a), the $\bar{\Xi}^+/h^-$ and $\bar{\Lambda}/h^-$ ratios for the most central data increase from SPS energies to RHIC, whereas the $\Xi^-/h^-$ ratio stays constant and the $\Lambda/h^-$ decreases.
As discussed in section 2, the reduction of the net-baryon density between these two beam energies affect the $\Lambda$ and the $\Xi^-$ differently. Therefore, the behaviour of these ratios with beam energy comes from both the increase of entropy and the decrease in net-baryon density. These effects seem to cancel for the $\Omega = \Omega^- + \Omega^+$, $\Lambda$ and $\bar{\Lambda}$ to $h^-$; however, it is interesting to note that the $\Xi^-/\Lambda$ ratio is a constant from SPS to RHIC (see Figure 3(b)), suggesting that the scale of the multistrange enhancement is the same for both singly and doubly strange baryons.

5 Conclusion

A global picture emerges from the strange baryon production in heavy ion collisions at RHIC. Net-baryon density decreases with increasing collision energies but still differs from zero. It means pair production is now dominant even if baryon transport from beam subsists at mid-rapidity. Strange particle yields are well reproduced by statistical models, which strongly suggests a high degree of chemical and thermal equilibrium at the hadronization stage. The obtained parameters fit well into the region of temperatures and baryo-chemical potentials where lattice QCD calculations predict the phase transition. New measurements with better statistics from STAR will help distinguishing the soft and hard contributions in hadron production. Topological analyses for strange baryons, which benefit from a potentially unlimited $p_T$ coverage, will certainly contribute to this.

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