STAR Strangeness Results from $\sqrt{s_{NN}} = 130$ GeV Au+Au Collisions (and first results from 200 GeV)

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Abstract. The STAR Experiment at RHIC is capable of a wide variety of measurements of the production of strange hadrons in nuclear collisions. Measurements of the relative production of strange baryons, antibaryons, and kaons can shed light on the baryon densities achieved in these collisions and on the validity of models for production yields. We will present here preliminary results on these measurements at RHIC energies of $\sqrt{s_{NN}} = 130$ GeV and 200 GeV and discuss comparisons to models.

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1. Introduction

Hadron production in a wide variety of colliding systems and energies has been well-described by statistical models [1]. Deviations from these models may be an indication of new physics, perhaps the production of quark gluon plasma [2]. It is therefore important to test for such deviations in new data from RHIC.

The STAR experiment can measure a wide variety of hadron yields at mid-rapidity. While statistical models for particle production generally ask for global yields ($4\pi$ measurements), this may not be necessary at RHIC. Particle yields at high rapidities are expected to have significant content from the initial colliding nuclei, leading to truly different sources with different statistical descriptions at mid-rapidity and at high rapidity. Because beam rapidity is large ($\sim 5$-6) in the center-of-mass frame at RHIC energies, contamination from the high-rapidity hadron sources should be small at mid-rapidity. This should allow a rather clean measurement of the source there, provided that global equilibrium is approximated by local equilibrium.

In order to allow the use of data from different RHIC experiments in model fits and comparisons, taken at varying definitions of a central-collision selection, it is helpful to take particle ratios instead of absolute yields. This has the side benefit of also reducing some common-mode errors in particle yield measurements.

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2. Models & $\sqrt{s_{NN}} = 130$ GeV Data

2.1. Thermal Statistical Models

For a thermal model to make predictions about particle ratios, it must have a description of the equation of state (EOS) of the system at chemical freezeout. In the field of heavy ion physics, the commonly used parameters to describe the EOS are those of baryo-chemical potential ($\mu_B$) and temperature ($T$), along with the requirement that net strangeness is zero. The authors of Ref. [3] chose two phenomenological parameterizations to provide these quantities for central heavy ion collisions:

$$\mu_B(\sqrt{s_{NN}}) \simeq \frac{1.27 \text{ GeV}}{1 + \sqrt{s_{NN}}/(4.3 \text{ GeV})}$$

(1)

$$\langle E \rangle / \langle N \rangle \simeq 1 \text{ GeV}$$

(2)

Constrained by the strangeness neutrality, $\langle E \rangle / \langle N \rangle$ depends only upon $\mu_B$ and $T$, so $T$ is determined by the above equations for any collision energy $\sqrt{s_{NN}}$. Via a canonical partition function (necessary, at least at low energies, to ensure exact strangeness conservation [4]), they arrive at ratios of particles as a function of $\sqrt{s_{NN}}$. Their predictions for the energy dependence of these ratios hold rather well at AGS and SPS energies [5], and lead to an expected slight drop in ratios of strange to non-strange particles going from SPS to RHIC energies (see Ref. [3] for an explanation). The drop is most notable for the ratio of $\Lambda$ to $\pi$ yields. Although preliminary $\Lambda$ yields have been presented by STAR at this conference [6], the proper comparison requires full understanding of feeddown contributions to the $\Lambda$ yields and is still in progress.

Though not as large, the $\Xi^-/\pi^+$ ratio is still expected to drop by more than 30% in this model. The $\Xi$ does not have significant feeddown corrections, so the comparison is easier. STAR has also presented preliminary $\Xi^-$ and $\Xi^+$ yields at this conference [7], and using a STAR preliminary $\pi^-$ yield [8] (which we know approximates the $\pi^+$ yield well [9]), we can evaluate the prediction.

The result is a measured ratio nearly twice as large as that predicted! One must, of course, consider the significance of the difference. The statistical error on the ratio is $\sim 7\%$, with a systematic error expected to be $\sim 20\%$, so the data point is close to two standard deviations away from the prediction.

Conversely, one might ask how sensitive the statistical models are to these ratios. In Ref. [10], the authors apply a grand canonical model to many particle ratios from 130 GeV RHIC data. They find that the model fits the measured data well (with chemical potential not too different from the parameterization of (1)), and go on to show the expected range of several strange/non-strange particle ratios given their fit parameters, as well as the sensitivity of these ratios to their temperature parameter $T$. This sensitivity is demonstrated by the theoretical curves shown in figure [10]. The STAR preliminary values for some of these ratios are also shown. It is worthwhile to note that the two measured ratios shown are both too high by approximately the same amount from the model calculations simply because the $K/\pi$ ratios are in the fit, leaving only
the over-abundance of $\Xi^-$ and $\Xi^+$ to offset the ratios (the relative abundance between $\Xi^-$ and $\Xi^+$ being rather well-constrained by the chemical potential). It is clear that these models cannot accommodate the preliminary yields of the $\Xi^-$ and $\Xi^+$.

2.2. Quark Coalescence Model

ALCOR (a quark coalescence model) has demonstrated that it can fit STAR mid-rapidity antiparticle/particle ratios involving strangeness well [11]. Because it is also a statistical model, although not an equilibrium model, these ratios are driven primarily by the relative difference in the abundance of quarks and antiquarks. Transferred numbers of valence quarks (or baryon number) to mid-rapidity are smaller than those from pair production processes at RHIC collision energies, so this relative difference becomes smaller, driving the ratios towards one and diminishing statistical sensitivity to small differences. It is therefore not surprising that all statistical models fit antiparticle/particle ratios rather well at these (and higher) energies.

More powerful in distinguishing between models are ratios between highly dissimilar particle species. Differences may include quark flavor content, mass, spin, and general abundance, for example (although these are not completely independent quantities). The $K/\pi$ ratios exemplify some of these dissimilarities, and already have shown good agreement with ALCOR (given some assumptions on $s\pi$ production) [11]. Even more highly dissimilar are the $\Xi/\pi$ ratios. ALCOR over-predicts the ratio by more than 10%, although taking into account the $\sim 20\%$ systematic error of the measured ratio brings the data into agreement with the model for the $\Xi$ yields [12].

3. First Results from $\sqrt{s_{NN}} = 200$ GeV Data

3.1. Quality of New Data

Figure 2 shows the preliminary invariant mass peaks for $\Lambda$ and $\bar{\Lambda}$ in 50,000 minimum bias $\sqrt{s_{NN}} = 200$ GeV events taken from the 2001 run. It is simple to extract a...
preliminary $\bar{\Lambda}/\Lambda$ ratio from this data because most of the inefficiencies cancel out, resulting in a value only slightly higher than the ratio from 130 GeV [6]. However, it is important to note that this number is not corrected for absorption of antiprotons in the detector apparatus. The correction for this data is now quite significant as there is more material in the detector due to the addition of the Silicon Vertex Tracker and associated components, raising the ratio further.

3.2. Comparison with Model Prediction

Using the parameterization given in (1), $\mu_B$ at 200 GeV should be $\sim 26.7$ MeV. The authors of Ref. [13] use a ”strangeness-canonical” scheme (a grand canonical model modified to include exact strangeness conservation) and the parameterization of (2) to arrive at predictions for antiparticle/particle ratios as a function of $\mu_B$. One can read off the value from their calculations for a small range of temperatures that $\bar{\Lambda}/\Lambda$ should be slightly above or close to 0.8. It appears that the preliminary STAR data from 200 GeV will be in this range after correcting for absorption. This says little about the statistical model because of its loss of sensitivity to antiparticle/particle ratios at these energies, but it indicates that the parameterization of (1) is at least close. If this parameterization is correct, it implies that we must go to very high collision energies to legitimately approximate a net-baryon-free region at mid-rapidity.

4. Conclusions

All statistical models do rather well at fitting antiparticle/particle ratios at RHIC. This comes in part from the approach of these ratios to a value of one. Not only do the models begin to lose sensitivity to these ratios as this happens, the experimental measures of these ratios also lose their resolving power due to inherent measurement errors. Ratios between highly dissimilar particles become more and more important for distinguishing between models, the $\Xi/\pi$ ratios being a good example.

It is clear that the preliminary measurements of the $\Xi$ yields from STAR in central Au+Au collisions at $\sqrt{s_{NN}} = 130$ GeV are not in agreement with thermodynamic statistical models. If the multiple strange quarks in the $\Xi$ are the source of this enhancement, it would be very interesting to see the results of the $\Omega$ yields, even if the measurement errors are very large. Nonetheless, the quark coalescence model appears
to provide a better match for the values of $\Xi/\pi$, without sacrificing other particle ratios. Because the prediction of this model is in clear disagreement with the thermal models, it will be very important to finalize these results.

Finally, the parameterization given by (1) and (2) appear to hold at both RHIC energies run so far, indicating that these energies are still not producing a net-baryon-free region at mid-rapidity in Au+Au collisions.

References

[1] Cleymans J and Redlich K 1988 *Phys. Rev. Lett.* **81** 5284
[2] Rafelski J and Müller B 1982 *Phys. Rev. Lett.* **48** 1066
[3] Braun-Munzinger P *et al* 2002 *Nucl. Phys. A* **697** 902
[4] Keränen A and Becattini F 2001 *Preprint* [nucl-th/0112021](http://arxiv.org/abs/nucl-th/0112021)
[5] Redlich K 2002 *these proceedings*; Kadija K (NA49 Collaboration) 2002 *these proceedings* (Kadija K (NA49 Collaboration) 2002 *Preprint* [hep-ex/0201025](http://arxiv.org/abs/hep-ex/0201025))
[6] Lamont M A C (STAR Collaboration) 2002 *these proceedings*
[7] Castillo J (STAR Collaboration) 2002 *these proceedings*
[8] Calderon de la Barca Sanchez M 2001 PhD Thesis Yale University (Calderon de la Barca Sanchez M 2001 *Preprint* [nucl-ex/0111004](http://arxiv.org/abs/nucl-ex/0111004))
[9] Back B B *et al* 2001 *Phys. Rev. Lett.* **87** 102301
[10] Braun-Munzinger P *et al* 2001 *Phys. Lett. B* **518** 41; Magestro D 2002 *these proceedings* (Majestro D 2001 *Preprint* [hep-ph/0112178](http://arxiv.org/abs/hep-ph/0112178))
[11] Zimányi J *et al* 2001 *Proc. XXXth Int. Symp. on Multiparticle Dynamics* ed T Csörgö *et al* (Singapore: World Scientific) p 501 (Zimányi J *et al* 2001 *Preprint* [hep-ph/0103153](http://arxiv.org/abs/hep-ph/0103153))
[12] Biro T *et al* 2002 *these proceedings* (Biro T *et al* 2001 *Preprint* [hep-ph/0112137](http://arxiv.org/abs/hep-ph/0112137))
[13] Becattini F *et al* 2001 *Phys. Rev. C* **64** 024901