Proc. Budapest'02 Workshop on
Quark & Hadron Dynamics (2002) 000–000

Budapest'02 Workshop on
Quark & Hadron Dynamics
Budapest, Hungary
March 3–7, 2002

STAR results on mixed hadron ratios

G. Van Buren[1] for the STAR Collaboration

[1] Brookhaven National Lab,
Upton, New York, 11973-5000, USA

Abstract. The STAR Experiment at RHIC is capable of a wide variety of measurements of the production of various hadrons in nuclear collisions. Measurements of the relative production of particle yields can shed light on the validity of models for hadron production in these collisions which may help characterize the source. 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 some models.

Keywords:
PACS: 25.75.Dw

1. Introduction

Hadron production in a wide variety of colliding systems and energies has been well-described by statistical models [1]. Deviations from some models may be an indication of new physics, perhaps the production of quark gluon plasma (QGP) [2], while agreement with other models may support the prospect of QGP formation or even constrain its properties [3–5]. It is therefore important to evaluate the new data from RHIC in the context of these models.

The STAR Experiment can measure a wide variety of hadron yields at mid-rapidity. While most models for particle production generally ask for global yields (4π 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 (~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 characteristics are approximated by local characteristics.

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.

2. Particle species measured

All of the particle measurements from the STAR Experiment discussed in this paper have been detected solely through techniques involving only the main Time Projection Chamber (TPC). While additional detectors available in data already recorded provide additional identification techniques, the TPC on its own possesses a variety of capabilities for particle identification. Charged pions [6], kaons [7], and (anti)protons [8] are distinguishable at low momenta from observing the degree of ionization the particles produce in the TPC gas. At higher momenta this technique fails, but can be replaced by observing decay vertices within the TPC for the charged kaons [7].

Additionally, decays of other particle species into charged daughters which can be seen in the TPC allow for reconstruction of such species through invariant mass spectra of the daughters. Typically, such spectra suffer from low signal-to-noise because of combinatorical backgrounds. Two different methods exist to solve this problem. The first is background subtraction through event-mixing techniques to determine the background. This method is being used in STAR to attempt to measure strong decays, and provide consistency measurements for weak decays. The second method is background reduction through topological cuts on the decay vertex, which is being used by STAR as the primary technique for measurement of weak decays.

Via invariant mass techniques, STAR has been able to measure yields of the K^0_s [7], (anti)Λ^0 [9], ϕ^0 [10], and $K^{*0}(892)$ [11]. Other species with more complicated decays, such as the π^0, and Ξ^- & Ω^- and their antiparticles, have been observed by STAR in the $\sqrt{s_{NN}}$ = 130 GeV Au+Au collisions. Analyses are in progress to ascertain STAR's efficiencies for reconstructing these particles and determining their yields.

3. Particle production

Besides identified particle measurements, STAR has also measured the negative hadron yield (h^-) at mid-rapidity [12]. Using this as a measure of produced particles in the collision (versus transport from beam constituents), we can characterize the production of certain species as functions of collision energy, or centrality in heavy ion collisions. In particular, overall strangeness production can be characterized by the yields of kaons and lambdas divided by h^-. The data from RHIC shows no clear deviations from constancy for these ratios as a function of centrality, as seen in Fig. 1, and differences from SPS collisions are understood in terms of reduced baryon stopping [9, 13]. If onset of QGP production were to produce threshold effects in

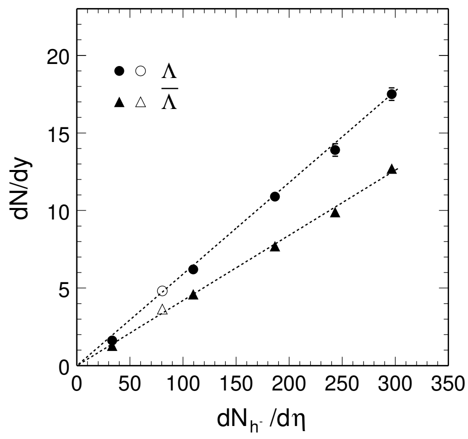

Fig. 1. Λ and $\overline{\Lambda}$ rapidity densities as a function of h^- multiplicity at mid-rapidity. The open symbols are data points from event-mixing techniques while the closed symbols are from techniques solely using topological cuts. Errors shown are statistical only.

these metrics, no such thresholds are obvious in this data. It will be interesting to see if hadrons with multiple strange quarks will follow similar trends, as they should be increasingly sensitive to perturbations in strange quark abundances.

4. Statistical production models

4.1. Thermal equilibrium models

Thermal equilibrium models attempt to characterize the final particle yields in terms of mean thermodynamic parameters which describe an equation of state (EOS) for the colliding system at some hadronic chemical freezeout. In the field of heavy ion physics, the commonly used parameters to describe the EOS are those of baryo-chemical potential ($\mu_{\rm B}$) and temperature (T), along with the requirement that net strangeness is zero. In fact, in the absence of a theory to predict the EOS, thermal equilibrium models must determine these parameters from fits to the data. If the data are consistent with such fits, these models can make no statement about what dynamics the colliding system goes through before the chemical freezeout because a system in equilibrium has no memory of its past. Such a fit is shown in Fig. 2, and is quite good for the RHIC data used. While the agreement with a description of the system in thermal equilibrium is impressive, it is not proof that this description is correct. There also remain further ratios to test, such as those of multistrange baryons (and other rare species which may be observable in the larger datasets

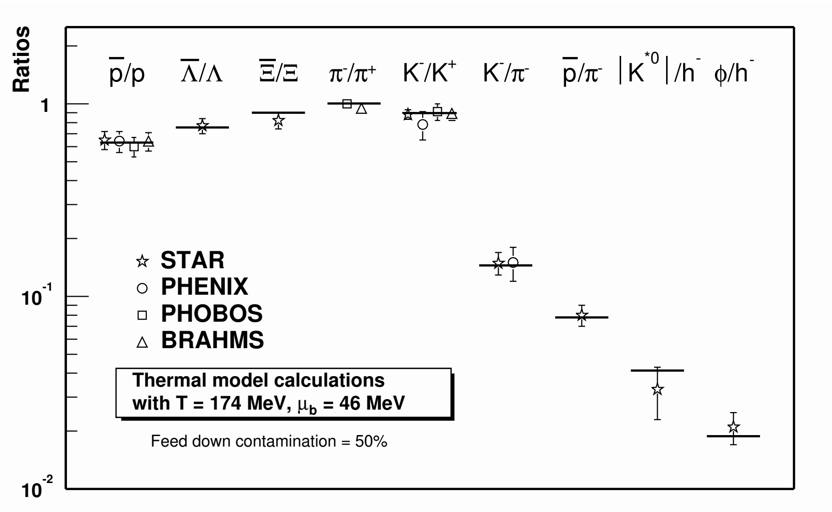

Fig. 2. Comparison between experimental data in Au+Au collisions at $\sqrt{s} = 130$ GeV and thermal equilibrium model calculations of particle ratios from a fit to the data. The parameters of the model from the fit are $T = 174$ Mev, $\mu_B = 46$ MeV. Details can be found in Ref. [14].

collected by STAR at $\sqrt{s_{NN}} = 200$ GeV in 2001) over π^-, which may harbor greater sensitivity in the model fits.

An attempt to provide predictive power to a thermal equilibrium model was made in Ref. [15] by phenomenologically parameterizing $\mu_{\rm B}$ as a function of collision energy for central heavy ion collisions, and constraining T as a function of $\mu_{\rm B}$. The $\sqrt{s_{NN}} = 130$ GeV data and preliminary $\sqrt{s_{NN}} = 200$ GeV data appear to be consistent with these parameterizations at this point [16].

4.2. Quark coalescence model

One can roughly test the basic assumptions of the quark coalescence model with a few simple antiparticle/particle ratios. If one assumes that factors for the yield of hadrons other than the simple product of the constituent quark abundances cancel out, then the ratios shown in Fig. 3 are all equivalent [17]. The data shown do not contradict this assumption, but do not have feeddown corrections.

ALCOR (a quark coalescence model including species-specific yield coefficients) has demonstrated that it too can fit STAR mid-rapidity antiparticle/particle ratios well [17, 18]. However, this is not a stringent test. Because it is also a statistical model, although not an equilibrium model, these simple ratios are driven primarily by the relative difference in the abundance of quarks and antiquarks. Transported

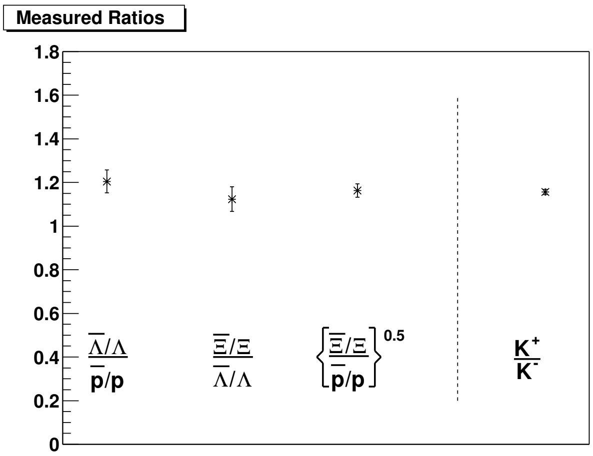

Fig. 3. Simple antiparticle/particle ratios from STAR allow for a rough test of quark coalescence. The data shown include statistical errors only and do not include feeddown corrections.

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/π ratios exemplify some of these dissimilarities, and already have shown good agreement with ALCOR (given some assumptions on $s\bar{s}$ production) [17,18]. Ratios using even more dissimilar species are those of (multi)strange baryons over pions. ALCOR shows strong sensitivity to these ratios, but a comparison to data is not yet applicable without understanding feeddown contributions in the experimental data. Determination of these contributions is in progress in STAR so that a proper comparison can be made.

4.3. Sudden hadronization model

Another statistical model similar to the thermal equilibrium models has been posited which allows for incomplete equilibration of strangeness [4]. One of the predictions of this model is that the production of a QGP in these collisions will result in "(anti)baryon abundances [which] are strongly strangeness dominated" [19]. One of the first-proposed signatures of this was a $\overline{\Lambda}/\overline{p}$ value well above 1.0 [19]. Later revisions of the model including fits to some existing RHIC data have brought this model's value for $\overline{\Lambda}/\overline{p}$ below 1.0, and closer to being in line with the equilibrium models [20, 21]. Again, feeddown contributions to the data are necessary for an accurate comparison with the data. The Phenix Experiment has presented a value for this ratio of 0.95 ± 0.09 (stat.) [22]. This value is higher than the more recent model calculations, but it is unclear that all the necessary feeddown corrections to both the $\overline{\Lambda}$ and $\overline{p}$ have been fully done. Additional uncertainty in the corrections comes from the lack of measurements for $\overline{\Sigma}^{-}$ from any experiment, and no definitive theory for the yield relative to other species. We believe these uncertainties are too large to allow for a meaningful comparison until at least the feeddown contributions from cascade decays can be accounted for.

5. Fireball lifetime

Particle ratios have also been theorized to be useful in determining the lifetime of the fireball [5]. In particular, particles which decay strongly (resonances) are expected to have lifetimes of order similar to that of the fireball. Thus, if an individual resonance decays within the fireball, which means before freezeout, the daughters of the decay have the opportunity to rescatter. If either daughter rescatters, the invariant mass of the parent particle will almost certainly not be reconstructed properly. Thus, the measured yields of such particles will be to some degree less than the actual primordially-produced yield. That degree is determined primarily by the lifetime of the parent particle and the lifetime τ of the fireball. Further assuming some thermal model for particle production can map a ratio such as $K^{*0}(892)/(\text{all } K^{-})$ to a specific temperature T. Two such ratios allow one to fix both τ and T, as shown in Fig. 4, while three ratios allow one to overconstrain the theory and further test its validity. While STAR has in fact measured the ratio $K^{*0}(892)/(\text{all } K^{-})$, we hope to measure either or both of the ratios $\Sigma^{*}(1385)/(\text{all } \Lambda)$ and $\Lambda^{*}(1520)/(\text{all } \Lambda)$ in order to evaluate this theory [23]. These measurements are unlikely in the current set of data from $\sqrt{s_{NN}} = 130$ GeV, but there is optimism that they can be made from the 200 GeV data in hand.

6. Summary

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 STAR Experiment is working to measure as many of these ratios as possible. Current measurements of ratios in Au+Au collisions at $\sqrt{s_{NN}} = 130$ GeV and

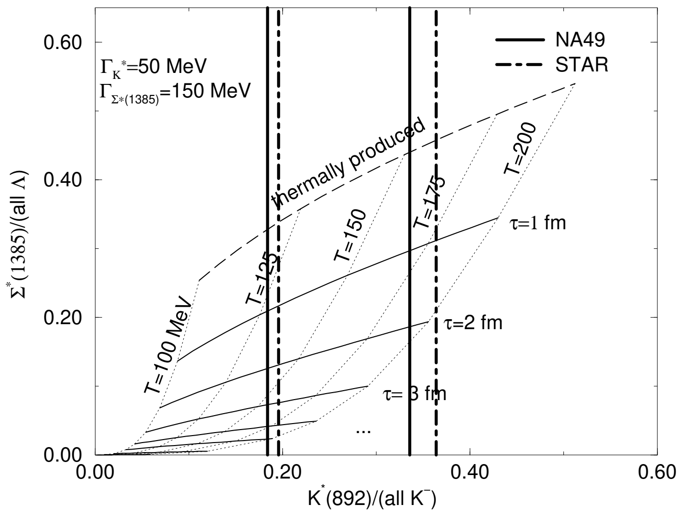

Fig. 4. Dependence of temperature and lifetime of a fireball source on two ratios: $\Sigma^*(1385)/(\text{all }\Lambda)$ and $K^{*0}(892)/(\text{all }K^-)$.

preliminary data from 200 GeV show no obvious deviations from the various statistical models, but are insufficient to resolve model differences. There is optimism that the current set of data from 200 GeV will begin to provide such discrimination.

7. Acknowledgements

I would like to thank P. Lévai and the organizing committee for inviting me to participate in the workshop, as well as for valuable discussions on topics included in this paper. I would also like to thank KFKI RMKI and the US-Hungarian Joint Fund (MAKA) for their support.

References

1. J. Cleymans and K. Redlich, Phys. Rev. Lett. **81** (1988) 5284.
2. J. Rafelski and B. Müller, Phys. Rev. Lett. **48** (1982) 1066.
3. T. S. Biró *et al.*, Phys. Lett. **B347** (1995) 6.
4. J. Rafelski and J. Letessier, Phys. Rev. Lett. **85** (2000) 4695.
5. J. Rafelski, J. Letessier, and G. Torrieri, Phys. Rev. **C64** (2001) 054907.
6. M. Calderon de la Barca Sanchez, PhD Thesis, Yale University (2001), nucl-ex/0111004.
7. C. Adler *et al.*, submitted to Phys. Rev. Lett. (2002).

8. C. Adler *et al.*, Phys. Rev. Lett. **86** (2001) 4778; C. Adler *et al.*, Phys. Rev. Lett. **87** (2001) 262302.
9. C. Adler *et al.*, submitted to Phys. Rev. Lett. (2002), nucl-ex/0203016.
10. C. Adler *et al.*, Phys. Rev. **C65** (2002) 041901(R).
11. C. Adler *et al.*, submitted to Phys. Rev. Lett. (2002).
12. C. Adler *et al.*, Phys. Rev. Lett. **87** (2001) 112303.
13. M. A. C. Lamont *et al.*, *Proc. Strange Quark Matter 2001*, submitted to J. Phys. G (2002).
14. D. Magestro, *Proc. Strange Quark Matter 2001*, submitted to J. Phys. G (2002), hep-ph/0112178.
15. P. Braun-Munzinger *et al.*, Nucl. Phys. **A697** (2002) 902.
16. G. Van Buren *et al.*, *Proc. Strange Quark Matter 2001*, submitted to J. Phys. G (2002), nucl-ex/0201009.
17. J. Zimányi *et al.*, *Proc. XXXth Int. Symp. on Multiparticle Dynamics* ed T. Csörgő *et al.*(Singapore: World Scientific) (2001) 501, hep-ph/0103156.
18. T. S. Biró *et al.*, *Proc. Strange Quark Matter 2001*, submitted to J. Phys. G (2002), hep-ph/0112137.
19. S. Bass *et al.*, Nucl. Phys. **A661** (1999) 205.
20. J. Rafelski and J. Letessier, *Proc. International Workshop on Chiral Fluctuations in Hadronic Matter 2001.*
21. N. Xu and M. Kaneta, Nucl. Phys. **A698** (2002) 306.
22. K. Adcox *et al.*, submitted to Phys. Rev. Lett. (2002), nucl-ex/0204007.
23. C. Markert *et al.*, *Proc. Strange Quark Matter 2001*, submitted to J. Phys. G (2002).