Elliptic flow of multi-strange baryons $\Xi$ and $\Omega$ in Au+Au collisions at $\sqrt{s_{NN}}=200$ GeV

Javier Castillo for the STAR Collaboration †
Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA
E-mail: JECastillo@lbl.gov

Abstract. The first measurement of the elliptic transverse flow for multi-strange baryons $\Xi$ and $\Omega$ in high energy heavy ion collisions is presented, which may indicate the presence of partonic collectivity. A hydrodynamically inspired model fit to the transverse momentum spectra and elliptic flow of $\Xi^-$ and $\Xi^+$ indicates that these particles might be emitted from the system at a high temperature ($\sim 150$ MeV) with significant radial transverse flow and that the emitting system is spatially asymmetric.

1. Introduction

In heavy ion collisions we aim to investigate nuclear matter under extreme conditions of pressure and temperature which is expected to lead to the creation of deconfined partonic matter, the Quark Gluon Plasma (QGP). Lattice QCD calculations predict the transition from this partonic system to a hadronic state at $T_c \approx 150 - 180$ MeV [1]. In this thermalized state that is the QGP, collective effects among constituents such as transverse flow will develop. Due to the initial spacial asymmetry of the system in non central collisions a strong and self quenching elliptic component of the transverse flow should also be present. Since transverse flow is cumulative and should not be affected by the hadronization process, the final observed transverse flow will have a contribution from the partonic stage. Multi-strange baryons have been suggested to be sensitive to the early stage of the collision [2] due to their predicted low hadronic cross sections [3]. Elliptic flow, due to its self quenching nature, has also proven to be a good tool for understanding the properties of the early stage of the collisions. Thus multi-strange baryon elliptic flow could be a valuable probe of the initial partonic system.

2. Multi-strange baryons reconstruction and analysis

In this paper we present the first measurement of the azimuthal anisotropy (characterized by the elliptic flow parameter $v_2$) of multi-strange baryons $\Xi$ and $\Omega$. Using the STAR detector at RHIC, multi-strange baryons are reconstructed via the

† For the full author list and acknowledgments, see Appendix “Collaborations” of this volume.
topology of their decay $\Xi \to \Lambda + \pi$ and $\Omega \to \Lambda + K$ followed by $\Lambda \to p + \pi$. Simple cuts on geometry, kinematics and particle identification via specific ionization are applied to reduce the combinatorial background. Figure 1 shows the invariant mass distribution for (a) $\Xi^- + \Xi^+$ and (b) $\Omega^- + \Omega^+$ in minimum-bias collisions (0-80% of the total hadronic cross-section) where a clear peak can be seen over the remaining combinatorial background. The background can be determined by sampling two regions on either side of the peak. It can also be reproduced by rotating the $\Lambda$ candidates by $180^\circ$ and then reconstructing $\Xi$ and $\Omega$ candidates (solid lines in Fig. 1 (a) and (b)). Both methods give equivalent results. We calculate $v_2$ from the distribution of the particle raw yields as a function of the azimuthal angle with respect to the reaction plane. The $\Xi$ and $\Omega$ candidates are thus divided in $\phi - \Psi_{RP}$ bins, and the raw yields for each bin are extracted from the invariant mass distributions as described above. The reaction plane is estimated by the event plane which is calculated from the azimuthal distribution of primary tracks. To avoid autocorrelation, tracks associated with a $\Xi$ or $\Omega$ candidate are excluded from the event plane calculation. Figure 1 shows the $\phi - \Psi_{RP}$ raw yield distributions of (c) $\Xi^- + \Xi^+$ and (d) $\Omega^- + \Omega^+$ from the minimum bias data set in the $1.5 < p_T < 3.5$ GeV/c range. These distributions exhibit a clear $\cos(2(\phi - \Psi_{RP}))$ oscillation indicating that both $\Xi$ and $\Omega$ particles have non zero elliptic flow. Furthermore, we note that the oscillations for $\Xi$ and $\Omega$ are of the same magnitude as will be discussed later. The observed $v_2$ is corrected to account for the finite resolution of the event plane [4]. We calculate this event plane resolution by the random subevents method. Finally, the corrected transverse momentum spectra are obtained as described in [2].

3. Results and discussions

Figure 2 shows the first measurement of $v_2$ for multi-strange baryons $\Xi^- + \Xi^+$ and $\Omega^- + \Omega^+$ as a function of $p_T$ for the minimum bias data set. We first observe that the
\( \Xi \) and \( \Omega \) \( v_2 \) at \( \sqrt{s_{NN}} = 200 \text{ GeV} \)

\[ v_2(p_\perp) \quad \text{for} \quad \Xi^- + \Xi^+ \quad \text{and} \quad \Omega^- + \Omega^+ \quad \text{from minimum bias collisions}. \] The results for \( \Xi^- + \Xi^+ \) and \( \Omega^- + \Omega^+ \) are also shown. See text for a description of the curves.

**Figure 2.** \( v_2(p_\perp) \) for \( \Xi^- + \Xi^+ \) and \( \Omega^- + \Omega^+ \) from minimum bias collisions. The results for \( \Xi^- + \Xi^+ \) and \( \Omega^- + \Omega^+ \) are also shown. See text for a description of the curves.

Secondly, the \( v_2(p_\perp) \) for \( \Omega \) in the measured \( p_\perp \) range is clearly non-zero and is consistent with the one measured for \( \Xi \), indicating that even the triply-strange baryon \( \Omega \) shows significant elliptic flow. Also shown in Fig. 2 are the \( v_2 \) for \( \Lambda^0 + \bar{\Lambda} \) and \( \Xi^- + \Xi^+ \). The colored band represent typical hydrodynamic model calculations \[9\] from \( \pi \) to \( \Omega \) mass and the results of a hydro-inspired model fit (discussed later) are shown as solid lines. We observe that the \( p_\perp \) dependence of the elliptic flow parameter for \( \Xi \) is similar to that of the \( \Lambda \). This supports the previously established baryon to meson dependence of the elliptic flow parameter \[5\]. This particle type dependence of the \( v_2(p_\perp) \) in the intermediate \( p_\perp \) region is naturally accounted for by the quark coalescence or recombination models \[6, 7, 8\] with the underlying assumption of partonic collectivity. In such hadronization models, hadrons are formed by quark coalescence from a partonic system. The particle \( v_2(p_\perp) \) is then predicted to show number of constituent quarks scaling. Figure 3 shows the scaled \( v_2/n \) versus \( p_\perp/n \) where \( n \) is the number of constituent quarks of the particle for \( \Lambda^0 + \bar{\Lambda} \), \( \Xi^- + \Xi^+ \), and \( \Xi^- + \Xi^+ \), where \( n \) is the number of constituent quarks for each particle.

**Figure 3.** \( v_2/n \) as a function of \( p_\perp/n \) for \( \Lambda^0 + \bar{\Lambda} \), \( \Xi^- + \Xi^+ \), and \( \Xi^- + \Xi^+ \), where \( n \) is the number of constituent quarks for each particle.

\( v_2 \) for \( \Xi \) increases with \( p_\perp \) reaching a saturation value of \( \sim 0.18 \) at \( p_\perp \sim 3.0 \text{ GeV/c} \). Secondly, the \( v_2(p_\perp) \) for \( \Omega \) in the measured \( p_\perp \) range is clearly non-zero and is consistent with the one measured for \( \Xi \), indicating that even the triply-strange baryon \( \Omega \) shows significant elliptic flow. Also shown in Fig. 2 are the \( v_2 \) for \( \Lambda^0 + \bar{\Lambda} \) and \( \Xi^- + \Xi^+ \). The colored band represent typical hydrodynamic model calculations \[9\] from \( \pi \) to \( \Omega \) mass and the results of a hydro-inspired model fit (discussed later) are shown as solid lines. We observe that the \( p_\perp \) dependence of the elliptic flow parameter for \( \Xi \) is similar to that of the \( \Lambda \). This supports the previously established baryon to meson dependence of the elliptic flow parameter \[5\]. This particle type dependence of the \( v_2(p_\perp) \) in the intermediate \( p_\perp \) region is naturally accounted for by the quark coalescence or recombination models \[6, 7, 8\] with the underlying assumption of partonic collectivity. In such hadronization models, hadrons are formed by quark coalescence from a partonic system. The particle \( v_2(p_\perp) \) is then predicted to show number of constituent quarks scaling. Figure 3 shows the scaled \( v_2/n \) versus \( p_\perp/n \) where \( n \) is the number of constituent quarks of the particle for \( \Lambda^0 + \bar{\Lambda} \), \( \Xi^- + \Xi^+ \), and \( \Xi^- + \Xi^+ \). The coalescence approach seems to hold for multi-strange baryons. This could be another indication of the presence of partonic collectivity at the early stage of the collision. Furthermore, the partonic flow of the \( s \) quark seems to be of similar magnitude than that of the \( u \) and \( d \) quarks.

A simultaneous fit of the \( p_\perp \) spectra and the \( v_2(p_\perp) \) of \( \Xi^- + \Xi^+ \) for the minimum bias data set can be performed using an extension \[10\] of a hydro-inspired model \[11\]. In this model, all considered particles are emitted from a thermal expanding source with a transverse rapidity \( \rho = \tanh^{-1}(\beta) \), where \( \beta \) is the transverse velocity, at the thermal freeze-out temperature \( T_{fo} \). Furthermore, the transverse flow rapidity is assumed to be asymmetric with respect to the reaction plane, and can be described as \( \rho = \rho_0 + \rho_\alpha \cos(2\phi) \). Finally, a spatial asymmetry of the source at freeze-out can be
\( \Xi \) and \( \Omega \) \( v_2 \) at \( \sqrt{s_{NN}} = 200 \) GeV

![Figure 4](image)

**Figure 4.** The minimum bias (a) \( p_\perp \) and (b) \( v_2(p_\perp) \) of \( \Xi^-+\Xi^+ \). The lines are the results from the hydro inspired model fits to the \( \Xi^- \) and \( \Xi^+ \) \( m_\perp \) spectra and \( \Xi^-+\Xi^+ v_2(p_\perp) \). The solid line corresponds to the best fit (\( \varepsilon = 0.17 \pm 0.04 \)) while the dashed line corresponds to the fit with fixed eccentricity \( \varepsilon = 0.0 \).

introduced and described by the eccentricity \( \varepsilon = \frac{R_y^2-R_x^2}{R_y^2+R_x^2} \) where \( R_x \) and \( R_y \) are the source radii in the in-plane and out-of-plane directions respectively. Using the implementation described in [10] to fit our data in the range \( 0.7 < p_\perp < 2.5 \) GeV, we obtain \( T_{fo} = 142 \pm 17 \) MeV, \( \rho_0 = 0.80 \pm 0.05 \) (\( \langle \beta_\perp \rangle = 0.47 \pm 0.03 \)), \( \rho_0 = 0.047 \pm 0.017 \) and \( \varepsilon = 0.17 \pm 0.05 \). As previously observed [2], the \( \Xi \) data is, within this framework, best described with high \( T_{fo} \) and low \( \langle \beta_\perp \rangle \). We also note that the \( v_2(p_\perp) \) for \( \Xi \) seems to favor an out-of-plane extended source at freeze-out. Indeed, the solid line in figure [4] shows the \( v_2(p_\perp) \) of \( \Xi \) which results from the previous fit, i.e. \( \varepsilon = 0.17 \), together with the result of a fit which requires the source to be azimuthally symmetric, i.e. \( \varepsilon = 0.0 \) (dashed line). Clearly the data is best described by an asymmetric source. We note that at \( \sqrt{s_{NN}} = 130 \) GeV, the STAR \( v_2 \) of \( \pi, K \) and \( p \) also required the emitting source to be spatially asymmetric and found \( \varepsilon = 0.04 \pm 0.01 \) for the minimum bias data set (0–85%) [12]. Also at \( \sqrt{s_{NN}} = 200 \) GeV, the source eccentricity at the freeze-out of the \( \pi \) as calculated from azimuthally sensitive \( \pi \) HBT ranges from \( \varepsilon \sim 0.01 \) for the most central collisions to \( \varepsilon \sim 0.13 \) for the most peripheral bin [13]. Finally, a fit to the PHENIX \( \pi, K \) and \( p \) spectra and \( v_2 \) [14, 15] results in \( \varepsilon = 0.121 \pm 0.004 \) [16].

4. Conclusion

In summary, we have reported the first measurement of multi-strange baryons \( \Xi \) and \( \Omega \) elliptic flow in high energy nucleus nucleus collisions which may indicate the presence of partonic collectivity. Both \( \Xi \) and \( \Omega \) show a significant elliptic flow which is of the same magnitude as for other particles e.g. \( \Lambda \). The coalescence approach seems to also describe the multi-strange baryons \( v_2 \) at intermediate \( p_\perp \). A hydro-inspired thermal model consistently describes both \( \Xi \) \( m_\perp \) spectra and \( v_2(p_\perp) \) and requires a high temperature and an asymmetric source at thermal freeze-out.
References

[1] F. Karsch, Nucl. Phys. A698, 199 (2002).
[2] J. Adams et al., (STAR Collaboration), Accepted by Phys. Rev. Lett.; nucl-ex/0307024
[3] H. van Hecke, H. Sorge and N. Xu, Phys. Rev. Lett. 81, 5764 (1998).
[4] A. M. Poskanzer and S. A. Voloshin, Phys. Rev. C58, 1671 (1998).
[5] J. Adams et al., (STAR Collaboration), Phys. Rev. Lett. 92, 052302 (2004).
[6] D. Molnar and S. A. Voloshin, Phys. Rev. Lett. 91, 092301 (2003).
[7] V. Greco, C. M. Ko and P. Levai, Phys. Rev. C68, 034904 (2003).
[8] R. J. Fries, B. Muller, C. Nonaka, S. A. Bass, Phys. Rev. C68, 044902 (2003).
[9] P. Huovinen, P.F. Kolb, U. Heinz, P.V. Ruuskanen, and S. Voloshin, Phys. Lett. B503, 58(2001).
[10] F. Retiere and M. A. Lisa, arXiv:nucl-th/0312024
[11] E. Schnedermann, J. Sollfrank, and U. Heinz, Phys. Rev. C48, 2462 (1993).
[12] C. Adler et al., (STAR Collaboration), Phys. Rev. Lett. 87, 182301 (2001).
[13] J. Adams et al., (STAR Collaboration), submitted to Phys. Rev. Lett.; nucl-ex/0312009
[14] S. S. Adler et al., (PHENIX Collaboration), Submitted to Phys. Rev. C; nucl-ex/0307022
[15] S. S. Adler et al., (PHENIX Collaboration), Phys. Rev. Lett. 91, 182301 (2003).
[16] F. Retiere, these proceedings.