Multi-strange baryon correlations in $p+p$ and $d+Au$ collisions at $\sqrt{s_{NN}} = 200$ GeV

Betty Bezverkhny for the STAR Collaboration

Physics Department, Yale University, P.O.Box 208120, New Haven, CT 06520, USA
E-mail: betty.bezverkhny@yale.edu

Abstract. Multi-strange baryon correlations with charged hadrons have been measured in the $p+p$ and $d+Au$ reference systems at $\sqrt{s_{NN}} = 200$ GeV for future comparison with correlations in $Au+Au$ collisions. Weak correlation peaks are observed on both the same side as the high $p_T$ ($p_T > 2$ GeV$/$c) $\Xi$ (the trigger particle), and on the away side ($\pi$ radians away in azimuth) in the $p+p$ data. A quantitative analysis requires better statistics than is presently available. Distinct peaks are also seen in PYTHIA simulations of $p+p$ collisions, but spectra comparison between PYTHIA and data shows that PYTHIA does not reproduce the data. A clear correlation is also present in $d+Au$ data, establishing a reference foundation for a future $Au+Au$ study.

1. Introduction

The STAR (Solenoidal Tracker At RHIC) Collaboration has made much progress in understanding the medium produced at RHIC. In the past four years STAR has shown the matter created in RHIC’s most central $Au+Au$ collisions to be about a hundred times denser than normal cold nuclear matter [1]. STAR has also shown collective behaviour of this ultra-dense medium [2]. However, there remains much to understand about the properties of the medium itself. What are the differences in particle-antiparticle production mechanisms in this extremely dense environment? Given this environment, are particles that contain strangeness produced differently than the non-strange particles? What fraction of multi-strange baryons made in top-energy $Au+Au$ collisions is produced in jets? Is that the predominant mechanism in $p+p$ and $d+Au$ collisions? What is the extent of the $p_T$ range of the particles produced predominantly in jets? How does it compare to a $Au+Au$ system, where there may be a QGP?

Multi-strange baryon correlations may help understand strange particle production modes in central $Au+Au$ collisions by measuring jet-produced strangeness. Like other high $p_T$ charged particles, high $p_T$ multi-strange baryons are likely to be a result of fragmentation after initial state hard scattering and thus probe the early times of the collision volume. Hard parton scattering will often result in back-to-back jets, which produce particles highly correlated in the same jet cone or the others on the opposite
side. Since a complete jet reconstruction in central \( Au+Au \) collisions is impossible due to the high multiplicity environment, we use statistical reconstruction of strange-particle jets by measuring azimuthal correlations of high \( p_T \) \( \Xi \) baryons with high \( p_T \) charged tracks on an event-by-event basis. This method has proved effective for the back-to-back jet suppression measurement in the \( Au+Au \) collisions [1], and is currently being used to study \( \Lambda+\bar{\Lambda} \) and \( K_0^S \) correlations in \( Au+Au \) [3]. Both \( p+p \) and \( d+Au \) data are suitable as a reference for a \( Au+Au \) study [1], as in neither collision system QGP formation is likely. This article presents the foundation of such a reference study.

2. Analysis method

For the study presented in this article 14M minimum bias \( p+p \) events (Year 2002 data) and 20M minimum bias \( d+Au \) events (Year 2003 data) are used.

The main component of the STAR detector used for this analysis is its large Time Projection Chamber (TPC) [4], which has a \( 2\pi \) azimuthal coverage and pseudorapidity \( (\eta) \) range \( < |1.5| \). Complementing the STAR TPC, the Central Trigger Barrel (CTB) was also used in this study [5]. The tracks are reconstructed in the TPC, while the high rate capability of the CTB is used to ensure the correlated particles come from the same event.

One challenge in a correlation analysis is to find enough events where a correlation is topologically feasible. In \( p+p \) collisions, the physics of the reaction and the efficiency of the detector allow for topological reconstruction [6] of only approximately three \( \Xi^- \) or \( \Xi^+ \) per \( 10^3 \) events. Only a fraction of these trigger \( \Xi \) particles have \( p_T \) greater than the minimum cut-off used in this study: 2 GeV/c per particle. The low mean multiplicity of a \( p+p \) event (5.5 tracks) makes it difficult to find suitable correlation partners, therefore the associated particle cut-off is set low at 1.5 GeV/c.

To make a correlation between a \( \Xi \) baryon and a high \( p_T \) track in a given event one first applies loose selections to find potential \( \Xi^- \) and \( \Xi^+ \) particles in each event. Secondly, one looks for single tracks that would pass a given \( p_T \) cut-off. The background decreases as the \( p_T \) cut-off is raised. After a list of eligible tracks and \( \Xi \) candidates is made, each \( \Xi \) is used as a trigger particle for correlations. Each potentially correlated high \( p_T \) track is checked to ensure it is not a decay product of the \( \Xi \). The azimuthal angle \( (\Delta\phi) \) between the \( \Xi \) and a high \( p_T \) track is calculated and plotted. After analyzing the entire event sample, the correlation function is normalized by the number of trigger particles and fit with two Gaussians constrained to wrap around \( 2\pi \). The means are fixed at \( \Delta\phi = 0 \) and \( \Delta\phi = \pi \), and the signal is assumed to sit on a flat background. A more sophisticated background subtraction is planned for the future.
3. Current results

3.1. p+p Year 2002 data set and PYTHIA simulation

The 2002 data set is the only sufficiently large p+p minimum bias data set taken so far by STAR. The relatively clean environment of a p+p collision allows us to examine these data and determine whether there are sufficient statistics to establish a reference with which to compare central Au+Au collisions.

One of the ways to understand the data at hand is to perform a simulation. This was done using the PYTHIA 6.22 event generator [7]. \(3.2 \times 10^7\) PYTHIA events were produced of which \(4.2 \times 10^5\) events had at least one \(\Xi^-\) and \(1.9 \times 10^3\) had at least one \(\Xi^-\) within \(y < |0.75|\) and with \(p_T > 2\,\text{GeV/c}\). Performing the identical analysis described above for the data, one finds that with 1921 \(\Xi\) trigger particles there are 705 \(\Xi\)-charged hadron correlations, with 1.4 correlations per correlated particle (Table 1). In other words, if a \(\Xi^-\) was correlated, more than a third of the time it correlated with more than one track in the same event. The resultant correlation is shown in Fig. 1, where a clear same-side and a distinct away-side peak are seen. The same-side peak obtained in this simulation contains 12% more correlations than the away-side peak, and is 33% higher.

Although correlations are observed in both the p+p data and that of simulated particles from PYTHIA, a comparison of the two spectra shows that the simulation does not reproduce the data. While the PYTHIA integrated yield is higher (\(dN/dy = 0.00318\) for PYTHIA, \(dN/dy = 0.00181 \pm 0.00008\) the p+p data [9]), it grossly underpredicts the yields in the region of interest (\(p_T > 2\,\text{GeV/c}\)), at the same time overstating the yields below \(p_T = 0.8\,\text{GeV/c}\) (Fig. 2). This might be altered by adjusting various PYTHIA parameters, such as tuning the hard processes parameters and allowing for
After performing a simulation, we proceed to examine characteristics of events containing a Ξ to learn about the environment for production of high \( p_T \) Ξ baryons in elementary processes. One characteristic is the number of valid primary tracks found in an event (event multiplicity). A valid primary track in this study is a track reconstructed with more than 15 (out of possible 46) fit points, and which comes within 3 cm of the primary collision vertex. Preliminary studies indicate that indeed, the multiplicity of an event with a reconstructed Ξ particle differs significantly from that of an average minimum bias sample event. As can be seen in Fig. 3, the mean multiplicity of an event with a Ξ produced and reconstructed is almost twice as high as the mean multiplicity of 5.5 primary tracks per event. This enhanced multiplicity suggests a higher mean \( p_T \) for these events, and thus the multi-strange particles we see in \( p+p \) collisions are likely to be created in more violent collisions and thus in jet events [8]. Further investigation is under way.
### Table 1. PYTHIA, \( p+p \), and \( d+Au \) values extracted: signal (a), background (b), number of trigger particles (c), correlations obtained (d), number \( \Xi \) correlated (e), correlations per correlated \( \Xi \) (f), same-side peak yield (g), and the away-side yield (h).

|       | a       | b       | c     | d    | e     | f    | g     | h     |
|-------|---------|---------|-------|------|-------|------|-------|-------|
| PYTHIA| -       | -       | 1921  | 705  | 516   | 1.4  | 394   | 311   |
| \( p+p \) data | 772 ± 31 | 168     | 972   | 295  | 232   | 1.3  | -     | -     |
| \( d+Au \) data | 3576 ± 66 | 711     | 4395  | 4309 | 2521  | 1.7  | 2032  | 2277  |

#### 3.2. \( p+p \) analysis results

Loose geometrical and \( \Lambda \) mass cuts were applied to find both the \( \Xi^- \) and its antiparticle in the minimum bias \( p+p \) data set. The looseness of the cuts for the selected \( p_T \) range allows for a 10% increase in reconstruction efficiency compared to cuts applied to the entire \( \Xi p_T \) range. The drawback of loosening the selections is the slight increase in background (B) under the signal (S) peak, as seen in Fig. 4. The S/B for the resultant peak is found to be 4.6.

A tight cut around the \( \Xi \) mass peak between 1.312 GeV/c\(^2\) and 1.330 GeV/c\(^2\) selects the \( \Xi \) candidates for correlation. Fitting the signal with a Gaussian and a constant background yields \( S = 772 ± 31 \) and \( B = 168 \). Since the number of counts in the selected mass region varies slightly from fit values, the actual number of trigger particles was 972. Only 232 of these were correlated resulting in 295 correlations, or 1.3 correlations per \( \Xi \) candidate, i.e., as in PYTHIA, in about a third of the events where a correlation was possible, more than one track with \( p_T > 1.5 \) GeV/c was found (Table 1).

The correlation function may be seen in Fig. 5. Although both the same- and the away-side peaks are visible, the statistics to extract any quantitative information are lacking. There are correlations in \( p+p \), and the higher the trigger momentum, the larger fraction of the available \( \Xi \) baryons is correlated, as may be inferred from Fig. 6.

#### 3.3. \( d+Au \) analysis results

Another \( Au+Au \) reference to consider is the \( d+Au \) data set taken by STAR in 2003. Since the collisions are no longer nucleon-on-nucleon, but rather nucleus-on-nucleus, nuclear effects such as the Cronin effect \([10]\), initial state shadowing \([11]\), and re-scattering are present. The \( d+Au \) collision environment is not as clean as in \( p+p \) collisions; however, the statistics are much more abundant.

Utilizing these statistics, and applying a tighter set of cuts than the one used in the \( p+p \) data set, a mass peak with over \( 4 \times 10^3 \) correlation candidates is obtained, as shown Fig. 7. As before, there is a 2 GeV/c transverse momentum cut applied and a Gaussian plus a constant are fit to yield the values in Table 1. As demonstrated in Fig. 8, only 32% of correlated events had one primary track with sufficiently high \( p_T \), the others had two or more tracks available for correlation. This is not surprising, since the mean multiplicity of a \( d+Au \) event is several times higher than that of a \( p+p \) collision. Further study of the multiplicity dependence of selected \( \Xi \) events is planned.
Finally, we come to the correlation function in $d+Au$. As seen in Fig. 9, the $d+Au$ data set has sufficient statistics to fit two emerging peaks. Contrary to what we saw in $p+p$ PYTHIA simulations, and in line with the $p+p$ data, the same-side peak is equal or smaller than the away-side peak, which could be explained by depletion of the available high $p_T$ tracks on the same side by the $\Xi$ decay itself, which uses up at least 3.3 GeV of the available jet-cone energy. The peaks in the $d+Au$ correlation function have widths: $\sigma_{same} = 1.29 \pm 0.26$ radians and $\sigma_{away} = 1.02 \pm 0.23$ radians, comparable to those in $p+p$ data.

4. Conclusions

4.1. What has been learned so far

Despite the lack of available statistics in the current $p+p$ data set, there is still information to be extracted. We have demonstrated a correlation between the
Multi-strange correlations

multiplicity of a collision and production of a \( \Xi \) (Fig. 5). We also know that the higher the trigger \( \Xi p_T \), the more likely one is to find correlation partners for the trigger particle (Fig. 6), and once an associated particle is found, it is probable that there is more than one such particle available. All of this combined indicates that in \( p+p \) collisions high \( p_T \) \( \Xi \) baryons are likely to be produced in jets.

The \( d+Au \) data set looks very promising as a reference. A careful analysis of the background and setting the \( p_T \) cut-off higher and at multiple levels for both the trigger and the associated particles is necessary for establishing a reliable base line. So far the height of the same-side peak (Fig. 9) is consistent with that of \( \Lambda \) particles in a \( Au+Au \) analysis [3], however, its size and width in relation to the away side peak differs both from the PYTHIA predictions (Fig. 10) and the peak measured in charged-hadron analysis [11]. As is the case with high-\( p_T \) \( \Xi \) and \( \Xi^+ \) particles in the \( p+p \) data set, high-\( p_T \) \( \Xi \) and \( \Xi^+ \) particles found in \( d+Au \) are likely to be produced in jets.

4.2. Outlook

To obtain a tool for further understanding of the multi-strange production mechanism, PYTHIA simulations need to be tuned. Furthermore, in the \( d+Au \) data set there needs to be a soft-physics subtraction to understand better the background. To gain in statistics for the continued study, the symmetrical Gaussian peaks can be folded [11]. There are also high \( p_T \)-triggered \( d+Au \) and \( p+p \) data sets, yet to be analyzed. Comparing triggered results to those in minimum bias collisions should lead to a better understanding of the relationship between jets and multi-strange particles.

Along with the statistics-rich \( \sqrt{s_{NN}} = 200 \) GeV \( Au+Au \) data set taken by STAR in 2004 and soon to be processed, there is also a new \( \sqrt{s_{NN}} = 62 \) GeV \( Au+Au \) data set obtained by STAR during the same run year. Looking for multi-strange correlations there will help establish the framework for analysis in \( \sqrt{s_{NN}} = 200 \) GeV \( Au+Au \) data.

One hopes this study, in conjunction with other identified particle studies, builds a foundation for a better understanding of production mechanisms for all strange particles.

References

[1] Adler C et al (STAR Collaboration) 2003 Phys. Rev. Lett. 90 082302
[2] Adler C et al (STAR Collaboration) 2003 Phys. Rev. Lett. 90 032301
[3] Guo Y 2004 Hot Quarks 2004 Proceedings
[4] Ackermann K H et al (STAR Collaboration) 1999 Nucl. Phys. A661 681c
[5] Bieser F S et al 2003 Nucl. Inst. and Methods A 499 766-777
[6] Adams J et al (STAR Collaboration) 2004 Phys. Rev. Lett. 92 182301
[7] Sjöstrand T, Lönnblad L and Mrenna S 2001 Preprint hep-ph/0108264
[8] Gans J 2004 Inclusive Charged Hadron Transverse Momentum Spectra at \( \sqrt{s_{NN}} = 200 \) GeV for \( pp \) and \( dAu \) Collisions at RHIC Ph.D. thesis, Yale University
[9] Witt R 2004 J. Phys. G: Nucl. Part. Phys 30 S205-S210
[10] Guylassey M, Vitev I, Wang X N and Zhang B W 2003 Preprint nucl-th/0302077
[11] Tang A 2004 J. Phys. G: Nucl. Part. Phys 30 S1235
Multi-strange baryon correlations in $p+p$ and $d+Au$ collisions at $\sqrt{s_{NN}} = 200$ GeV

Betty Bezverkhny for the STAR Collaboration

Physics Department, Yale University, P.O.Box 208120, New Haven, CT 06520, USA

E-mail: betty.bezverkhny@yale.edu

Abstract. Multi-strange baryon correlations with charged hadrons have been measured in the $p+p$ and $d+Au$ reference systems at $\sqrt{s_{NN}} = 200$ GeV for future comparison with correlations in $Au+Au$ collisions. Weak correlation peaks are observed on both the same side as the high $p_T$ ($p_T > 2$ GeV/c) $\Xi$ (the trigger particle), and on the away side ($\pi$ radians away in azimuth) in the $p+p$ data. A quantitative analysis requires better statistics than is presently available. Distinct peaks are also seen in PYTHIA simulations of $p+p$ collisions, but spectra comparison between PYTHIA and data shows that PYTHIA does not reproduce the data. A clear correlation is also present in $d+Au$ data, establishing a reference foundation for a future $Au+Au$ study.

1. Introduction

The STAR (Solenoidal Tracker At RHIC) Collaboration has made much progress in understanding the medium produced at RHIC. In the past four years STAR has shown the matter created in RHIC’s most central $Au+Au$ collisions to be about a hundred times denser than normal cold nuclear matter [1]. STAR has also shown collective behaviour of this ultra-dense medium [2]. However, there remains much to understand about the properties of the medium itself. What are the differences in particle-antiparticle production mechanisms in this extremely dense environment? Given this environment, are particles that contain strangeness produced differently than the non-strange particles? What fraction of multi-strange baryons made in top-energy $Au+Au$ collisions is produced in jets? Is that the predominant mechanism in $p+p$ and $d+Au$ collisions? What is the extent of the $p_T$ range of the particles produced predominantly in jets? How does it compare to a $Au+Au$ system, where there may be a QGP?

Multi-strange baryon correlations may help understand strange particle production modes in central $Au+Au$ collisions by measuring jet-produced strangeness. Like other high $p_T$ charged particles, high $p_T$ multi-strange baryons are likely to be a result of fragmentation after initial state hard scattering and thus probe the early times of the collision volume. Hard parton scattering will often result in back-to-back jets, which produce particles highly correlated in the same jet cone or the others on the opposite
side. Since a complete jet reconstruction in central Au+Au collisions is impossible due to the high multiplicity environment, we use statistical reconstruction of strange-particle jets by measuring azimuthal correlations of high \( pt \) \( \Xi \) baryons with high \( pt \) charged tracks on an event-by-event basis. This method has proved effective for the back-to-back jet suppression measurement in the \( Au+Au \) collisions [1], and is currently being used to study \( \Lambda+\bar{\Lambda} \) and \( K^0_S \) correlations in \( Au+Au \) [3]. Both \( p+p \) and \( d+Au \) data are suitable as a reference for a \( Au+Au \) study [1], as in neither collision system QGP formation is likely. This article presents the foundation of such a reference study.

2. Analysis method

For the study presented in this article 14M minimum bias \( p+p \) events (Year 2002 data) and 20M minimum bias \( d+Au \) events (Year 2003 data) are used.

The main component of the STAR detector used for this analysis is its large Time Projection Chamber (TPC) [4], which has a \( 2\pi \) azimuthal coverage and pseudorapidity \( (\eta) \) range \(< \lvert 1.5 \rvert \). Complementing the STAR TPC, the Central Trigger Barrel (CTB) was also used in this study [5]. The tracks are reconstructed in the TPC, while the high rate capability of the CTB is used to ensure the correlated particles come from the same event.

One challenge in a correlation analysis is to find enough events where a correlation is topologically feasible. In \( p+p \) collisions, the physics of the reaction and the efficiency of the detector allow for topological reconstruction [6] of only approximately three \( \Xi^{-} \) or \( \Xi^{+} \) per \( 10^3 \) events. Only a fraction of these trigger \( \Xi \) particles have \( pt \) greater than the minimum cut-off used in this study: 2 GeV/c per particle. The low mean multiplicity of an \( p+p \) event (5.5 tracks) makes it difficult to find suitable correlation partners, therefore the associated particle cut-off is set low at 1.5 GeV/c.

To make a correlation between a \( \Xi \) baryon and a high \( pt \) track in a given event one first applies loose selections to find potential \( \Xi^{-} \) and \( \Xi^{+} \) particles in each event. Secondly, one looks for single tracks that would pass a given \( pt \) cut-off. The background decreases as the \( pt \) cut-off is raised. After a list of eligible tracks and \( \Xi \) candidates is made, each \( \Xi \) is used as a trigger particle for correlations. Each potentially correlated high \( pt \) track is checked to ensure it is not a decay product of the \( \Xi \). The azimuthal angle \( (\Delta\phi) \) between the \( \Xi \) and a high \( pt \) track is calculated and plotted. After analyzing the entire event sample, the correlation function is normalized by the number of trigger particles and fit with two Gaussians constrained to wrap around \( 2\pi \). The means are fixed at \( \Delta\phi = 0 \) and \( \Delta\phi = \pi \), and the signal is assumed to sit on a flat background. A more sophisticated background subtraction is planned for the future.
3. Current results

3.1. p+p Year 2002 data set and PYTHIA simulation

The 2002 data set is the only sufficiently large p+p minimum bias data set taken so far by STAR. The relatively clean environment of a p+p collision allows us to examine these data and determine whether there are sufficient statistics to establish a reference with which to compare central Au+Au collisions.

One of the ways to understand the data at hand is to perform a simulation. This was done using the PYTHIA 6.22 event generator [7]. \(3.2 \times 10^7\) PYTHIA events were produced of which \(4.2 \times 10^5\) events had at least one \(\Xi^-\) and \(1.9 \times 10^3\) had at least one \(\Xi^-\) within \(y < |0.75|\) and with \(p_T > 2\) GeV/c. Performing the identical analysis described above for the data, one finds that with 1921 \(\Xi\) trigger particles there are 705 \(\Xi\)-charged hadron correlations, with 1.4 correlations per correlated particle (Table 1). In other words, if a \(\Xi^-\) was correlated, more than a third of the time it correlated with more than one track in the same event. The resultant correlation is shown in Fig. 1, where a clear same-side and a distinct away-side peak are seen. The same-side peak obtained in this simulation contains 12\% more correlations than the away-side peak, and is 33\% higher.

Although correlations are observed in both the p+p data and that of simulated particles from PYTHIA, a comparison of the two spectra shows that the simulation does not reproduce the data. While the PYTHIA integrated yield is higher (dN/dy = 0.00318 for PYTHIA, dN/dy = 0.00181 ± 0.00008 the p+p data [9]), it grossly underpredicts the yields in the region of interest (\(p_T > 2\) GeV/c), at the same time overstating the yields below \(p_T = 0.8\) GeV/c (Fig. 2). This might be altered by adjusting various PYTHIA parameters, such as tuning the hard processes parameters and allowing for
Multi-strange correlations

After performing a simulation, we proceed to examine characteristics of events containing a Ξ to learn about the environment for production of high \( p_T \) Ξ baryons in elementary processes. One characteristic is the number of valid primary tracks found in an event (event multiplicity). A valid primary track in this study is a track reconstructed with more than 15 (out of possible 46) fit points, and which comes within 3 cm of the primary collision vertex. Preliminary studies indicate that indeed, the multiplicity of an event with a reconstructed Ξ particle differs significantly from that of an average minimum bias sample event. As can be seen in Fig. 3, the mean multiplicity of an event with a Ξ produced and reconstructed is almost twice as high as the mean multiplicity of 5.5 primary tracks per event. This enhanced multiplicity suggests a higher mean \( p_T \) for these events, and thus the multi-strange particles we see in \( p+p \) collisions are likely to be created in more violent collisions and thus in jet events [8]. Further investigation is under way.

Figure 3. Reference event charged particle multiplicity as a function of \( p_T \) of the Ξ in \( \sqrt{s} = 200 \) GeV \( p+p \) collisions.

Figure 4. Ξ⁻ and Ξ⁺ mass peak in \( \sqrt{s} = 200 \) GeV \( p+p \) data set for particles with \( p_T > 2 \) GeV/c.

Figure 5. \( \sqrt{s} = 200 \) GeV \( p+p \) data uncorrected Ξ - charged primary track azimuthal correlation.

Figure 6. \( p_T \) distributions of correlated and uncorrelated uncorrected Ξ particles in \( \sqrt{s} = 200 \) GeV \( p+p \) data set.
Table 1. PYTHIA, p+p, and d+Au values extracted: signal (a), background (b), number of trigger particles (c), correlations obtained (d), number Ξ correlated (e), correlations per correlated Ξ (f), same-side peak yield (g), and the away-side yield (h).

|        | a  | b   | c   | d   | e   | f    | g    | h    |
|--------|----|-----|-----|-----|-----|------|------|------|
| PYTHIA | -  | -   | 1921| 705 | 516 | 1.4  | 394  | 311  |
| p+p    | 772±31| 168 | 972 | 295 | 232 | 1.3  | -    | -    |
| d+Au   | 3576±66| 711 | 4395| 4309| 2521| 1.7  | 2032 | 2277 |

3.2. p+p analysis results

Loose geometrical and Λ mass cuts were applied to find both the Ξ⁻ and its antiparticle in the minimum bias p+p data set. The looseness of the cuts for the selected $p_T$ range allows for a 10% increase in reconstruction efficiency compared to cuts applied to the entire Ξ $p_T$ range. The drawback of loosening the selections is the slight increase in background (B) under the signal (S) peak, as seen in Fig. 4. The S/B for the resultant peak is found to be 4.6.

A tight cut around the Ξ mass peak between 1.312 GeV/$c^2$ and 1.330 GeV/$c^2$ selects the Ξ candidates for correlation. Fitting the signal with a Gaussian and a constant background yields $S = 772\pm31$ and $B = 168$. Since the number of counts in the selected mass region varies slightly from fit values, the actual number of trigger particles was 972. Only 232 of these were correlated resulting in 295 correlations, or 1.3 correlations per Ξ candidate, i.e., as in PYTHIA, in about a third of the events where a correlation was possible, more than one track with $p_T > 1.5$ GeV/$c$ was found (Table 1).

The correlation function may be seen in Fig. 5. Although both the same- and the away-side peaks are visible, the statistics to extract any quantitative information are lacking. There are correlations in p+p, and the higher the trigger momentum, the larger fraction of the available Ξ baryons is correlated, as may be inferred from Fig. 6.

3.3. d+Au analysis results

Another Au+Au reference to consider is the d+Au data set taken by STAR in 2003. Since the collisions are no longer nucleon-on-nucleon, but rather nucleus-on-nucleus, nuclear effects such as the Cronin effect [10], initial state shadowing [11], and rescattering are present. The d+Au collision environment is not as clean as in p+p collisions; however, the statistics are much more abundant.

Utilizing these statistics, and applying a tighter set of cuts than the one used in the p+p data set, a mass peak with over $4 \times 10^3$ correlation candidates is obtained, as shown Fig. 7. As before, there is a 2 GeV/$c$ transverse momentum cut applied and a Gaussian plus a constant are fit to yield the values in Table 1. As demonstrated in Fig. 8 only 32% of correlated events had one primary track with sufficiently high $p_T$, the others had two or more tracks available for correlation. This is not surprising, since the mean multiplicity of a d+Au event is several times higher than that of a p+p collision. Further study of the multiplicity dependence of selected Ξ events is planned.
Multi-strange correlations

Figure 7. \( \Xi^- \) and \( \Xi^+ \) mass peak in \( \sqrt{s_{NN}} = 200 \text{ GeV} \) \( d+Au \) minimum bias data set for particles with \( p_T > 2 \text{ GeV/c} \).

Figure 8. Number of uncorrected charged tracks correlated per \( \Xi \) in an eligible \( \sqrt{s_{NN}} = 200 \text{ GeV} \) \( d+Au \) minimum bias event.

Figure 9. \( \Xi \) - uncorrected charged primary track azimuthal correlation in \( d+Au \) \( \sqrt{s_{NN}} = 200 \text{ GeV} \) minimum bias data.

Finally, we come to the correlation function in \( d+Au \). As seen in Fig. 9, the \( d+Au \) data set has sufficient statistics to fit two emerging peaks. Contrary to what we saw in \( p+p \) PYTHIA simulations, and in line with the \( p+p \) data, the same-side peak is equal or smaller than the away-side peak, which could be explained by depletion of the available high \( p_T \) tracks on the same side by the \( \Xi \) decay itself, which uses up at least 3.3 GeV of the available jet-cone energy. The peaks in the \( d+Au \) correlation function have widths: \( \sigma_{\text{same}} = 1.29 \pm 0.26 \text{ radians} \) and \( \sigma_{\text{away}} = 1.02 \pm 0.23 \text{ radians} \), comparable to those in \( p+p \) data.

4. Conclusions

4.1. What has been learned so far

Despite the lack of available statistics in the current \( p+p \) data set, there is still information to be extracted. We have demonstrated a correlation between the
multiplicity of a collision and production of a $\Xi$ (Fig. 5). We also know that the higher the trigger $\Xi p_{T}$, the more likely one is to find correlation partners for the trigger particle (Fig. 5), and once an associated particle is found, it is probable that there is more than one such particle available. All of this combined indicates that in $p+p$ collisions high $p_{T} \Xi$ baryons are likely to be produced in jets.

The $d+Au$ data set looks very promising as a reference. A careful analysis of the background and setting the $p_{T}$ cut-off higher and at multiple levels for both the trigger and the associated particles is necessary for establishing a reliable base line. So far the height of the same-side peak (Fig. 4) is consistent with that of $\Lambda$ particles in a $Au+Au$ analysis [3], however, its size and width in relation to the away side peak differs both from the PYTHIA predictions (Fig. 4) and the peak measured in charged-hadron analysis [1]. As is the case with high-$p_{T} \Xi$ and $\Xi^{+}$ particles in the $p+p$ data set, high-$p_{T} \Xi$ and $\Xi^{+}$ particles found in $d+Au$ are likely to be produced in jets.

4.2. Outlook

To obtain a tool for further understanding of the multi-strange production mechanism, PYTHIA simulations need to be tuned. Furthermore, in the $d+Au$ data set there needs to be a soft-physics subtraction to understand better the background. To gain in statistics for the continued study, the symmetrical Gaussian peaks can be folded [11]. There are also high $p_{T}$-triggered $d+Au$ and $p+p$ data sets, yet to be analyzed. Comparing triggered results to those in minimum bias collisions should lead to a better understanding of the relationship between jets and multi-strange particles.

Along with the statistics-rich $\sqrt{s_{NN}} = 200$ GeV $Au+Au$ data set taken by STAR in 2004 and soon to be processed, there is also a new $\sqrt{s_{NN}} = 62$ GeV $Au+Au$ data set obtained by STAR during the same run year. Looking for multi-strange correlations there will help establish the framework for analysis in $\sqrt{s_{NN}} = 200$ GeV $Au+Au$ data.

One hopes this study, in conjunction with other identified particle studies, builds a foundation for a better understanding of production mechanisms for all strange particles.

References

[1] Adler C et al (STAR Collaboration) 2003 Phys. Rev. Lett. 90 082302
[2] Adler C et al (STAR Collaboration) 2003 Phys. Rev. Lett. 90 032301
[3] Guo Y 2004 Hot Quarks 2004 Proceedings
[4] Ackermann K H et al (STAR Collaboration) 1999 Nucl. Phys. A661 681c
[5] Bieser F S et al 2003 Nucl. Inst. and Methods A 499 766-777
[6] Adams J et al (STAR Collaboration) 2004 Phys. Rev. Lett. 92 182301
[7] Sjöstrand T, Lonnblad L and Mrenna S 2001 Preprint hep-ph/0108264
[8] Gans J 2004 Inclusive Charged Hadron Transverse Momentum Spectra at $\sqrt{s_{NN}} = 200$ GeV for $pp$ and $dAu$ Collisions at RHIC Ph.D. thesis, Yale University
[9] Witt R 2004 J. Phys. G: Nucl. Part. Phys 30 S205-S210
[10] Guylassy M, Vitev I, Wang X N and Zhang B W 2003 Preprint nucl-th/0302077
[11] Tang A 2004 J. Phys. G: Nucl. Part. Phys 30 S1235
Matched High $p_T$ Tracks

$\sqrt{s_{NN}} = 200$ GeV

STAR Preliminary