$\bar{p}$ and $\bar{\Lambda}$ Production in Si+Au Collisions at the AGS

Yuedong Wu

Nevis Laboratories,
Columbia University, South Broadway 196, Irvington, NY 10533, USA

for the E802/E859 Collaboration:
ANL–BNL–UCBerkeley–UCRiverside–Columbia–Hiroshima–INS

ABSTRACT

$\bar{p}$ and $\bar{\Lambda}$ production in central Si+Au collisions has been measured by E859 at the BNL-AGS. Preliminary $m_\perp$ spectra are presented for $\bar{p}$'s and $\bar{\Lambda}$'s. The $dn/dy$ distribution for $\bar{p}$'s is also presented. Based on the $\bar{p}$ and $\bar{\Lambda}$ measurements, $\bar{\Lambda}/\bar{p}$ ratios are calculated in the rapidity range of 1.1-1.5.

1. Introduction

Heavy ion collisions at BNL-AGS energies are considered to be in the full stopping regime. In central Si+Au collisions with a beam momentum of 14.6 $A\cdot GeV/c$, the projectile nucleus is stopped by the heavy target nucleus in the center of mass system. It is believed that a region of very high baryon density could be created in such collisions. QCD predicts that in such an extremely hadron-dense condition, ordinary hadronic matter may be transformed into a new phase, the Quark Gluon Plasma (QGP), with an accompanying phase transition [1]. Regardless of whether or not such a phase transition takes place, antibaryon and strangeness enhancement have been expected in AGS heavy ion collisions [2]. On the other hand, because of the large annihilation cross sections of antibaryons [3], $\bar{p}$'s and $\bar{\Lambda}$'s serve very well as sensitive probes of baryon density and formation time. Some early studies [4] also found that in the QGP phase, the ratio of $\bar{s}/\bar{q}$, the number of light antiquarks to the number of strange antiquarks, could be as much as two orders of magnitude higher than that in the hadronic state, so that a large $\bar{\Lambda}$ enhancement could be expected. This makes the combined study of $\bar{p}$ and $\bar{\Lambda}$ production even more interesting. The additional tracking and sophisticated on-line PID second level trigger of E859 made such a study possible.

2. Experiment and Data Set

The E859 apparatus has been described in previous publications ([5], [6]). Briefly, the E859 apparatus was an extension of the E802 spectrometer. By adding additional tracking...
chambers and, more importantly, a new second level on-line PID trigger, E859 had the capability to study the production of rare particles such as $\bar{p}$, $\Lambda$, $\bar{\Lambda}$, and $\phi$. For the data presented here, the second level trigger was set to select only those events in which at least one $\bar{p}$ candidate track passed through the spectrometer. Such an on-line trigger selection substantially enriched the number of $\bar{p}$'s in the event samples. As a result, E859 collected about 10 times more $\bar{p}$'s than that E802 collected. The improved data samples not only produced a better $\bar{p}$ measurement but also made it possible to measure the $m_\perp$ spectrum of the $\Lambda$, a first in any BNL-AGS heavy ion experiment.

The data were collected during the 1991 and 1992 runs at the BNL-AGS, the beam was $^{28}\text{Si}$ at 14.6 A·GeV/c and the targets were Au with thickness of 1% and 2% of an interaction length. The $\bar{p}$ data were taken primarily at the 5°, 14°, and 24° spectrometer settings, but only at the 14° setting were enough data collected for analysis because of the limited acceptance of the larger angle settings and the limited statistics of the 5° setting. In this presentation only central events taken at the 14° spectrometer angle setting (covering the polar angle range from 14° to 28°) were analyzed. Central events were selected with a Target Multiplicity Array (TMA) on-line hardware trigger and off-line software cuts. The qualifying events corresponded to the top 15% of the charged particle multiplicity distribution as measured by the TMA (Fig. 1). The $\bar{p}$ data covered the rapidity range from 0.9 to 1.5, and the $\Lambda$ data covered the rapidity range from 1.15 to 1.75 (Fig. 2).

3. Data Analysis and Preliminary Results

To reduce the systematic error contributed from background subtraction, small $m_\perp$ bins (0.025 GeV/c²) and $y$ bins (0.1 unit) were used in the $\bar{p}$ data analysis. The number of $\bar{p}$'s in each $m_\perp$-$y$ bin was obtained by fitting the $\delta$(TOF) distribution (Fig. 3), which was the difference between the measured time of flight (TOF) of a track and the expected value of TOF assuming that the particle was a $\bar{p}$. The reason for fitting the $\delta$(TOF) distribution instead of fitting the mass distribution was that the $\delta$(TOF) is a constant hardware parameter that does not depend on the particle's momentum so that a single gaussian function can be
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employed to fit $\delta$(TOF) spectrum.

For the $\Lambda$ data a relatively large $m_\perp$ and $y$ bin had to be used because of the limited statistics available (see Fig. 2). The number of $\Lambda$'s in each bin was obtained by fitting the invariant mass spectrum for all $\bar{p}\pi^+$ pairs with a gaussian-shaped peak function plus a background. The resolution of the $\Lambda$ invariant mass did not depend on $m_\perp$ or rapidity. This was confirmed by $\Lambda$ data from the same spectrometer setting but with much better statistics. The peak could therefore be fitted with a single gaussian distribution even if the bin size was large (Fig. 3). To reduce the background under the $\Lambda$ mass peak a reconstructed vertex position cut was applied. Only the $\bar{p}\pi^+$ pairs with reconstructed vertex positions in the range of 5cm to 75cm away from the target were considered. Because of the high $\Lambda$ momentum, the average decay distance is greater than 20cm away from the target. Thus the vertex cut reduces background by more than a factor of three but cut out less than 10% of $\Lambda$'s.

Because of the limited solid angle (25 msr) of the E859/E802 spectrometer, the acceptance in different $m_\perp$-$y$ bins could be very different. The acceptance correction became very important for data analysis especially for $\Lambda$ data. The acceptance, track reconstruction efficiency and trigger performance calculations were done by using a full GEANT-based Monte-Carlo simulation of the E859 apparatus. More than 50,000 $\Lambda$'s and more than 100,000 $\bar{p}$'s inside the spectrometer acceptance were put into GEANT-based Monte-Carlo simulations. The statistical errors on the $\bar{p}$ and $\Lambda$ yields due to acceptance correction were negligible compared with the statistical errors on the data. The resulting $\bar{p}$ and $\Lambda$ yields in each bin were then corrected for experimental acceptance and track reconstruction efficiency. Fig. 4 shows the $m_\perp$ spectra of the $\bar{p}$'s and $\Lambda$'s after the corrections.

The $dn/dy$ and inverse slopes were obtained by fitting with a single exponential function in $m_\perp$ of the form:

$$E \frac{d^3n}{dp^2} = \left( \frac{dn}{dy} \right) \frac{1}{2\pi(m_\pi T + T^2)} e^{-(m_\perp-m_\pi)/T}$$

where $T$ and $dn/dy$ are the two free parameters. The inverse slopes obtained by the method above are listed in table 1. The table shows that the inverse slopes for $\bar{p}$'s are more or less
the same in the $y$ range of 0.9 to 1.5, which is about 180 MeV/c. The inverse slope for $\bar{\Lambda}$'s is about 10 MeV/c higher than that of the $\bar{p}$'s.

As mentioned above, because of the limited statistics for $\bar{\Lambda}$'s, the $m_\perp$ spectrum for only a single $y$ bin could be obtained. It was not possible to get a $\bar{\Lambda}$ $dn/dy$ distribution directly from the integration of measured $m_\perp$ spectra in small $y$ bins. Nevertheless we were very interested in estimating a $\bar{\Lambda}$ $dn/dy$ distribution to compare with the $\bar{p}$ $dn/dy$ distribution in the same $y$ range. An alternative method was therefore applied to obtain the $\bar{\Lambda}$ $dn/dy$. We divided the $\bar{\Lambda}$ data into 4 smaller $y$ bins in the rapidity range of 1.15 to 1.55, then calculated the integrated number of $\bar{\Lambda}$'s in each bin. We assumed that in each such $y$ bin the $\bar{\Lambda}$ $m_\perp$ spectrum had the same inverse slope which was measured with the larger $y$ bin (which was reasonable considering that the inverse slopes for $\bar{p}$ did not change much in the same $y$ range), then the $\bar{\Lambda}$ $dn/dy$ in each of the smaller $y$ bins could be calculated by using the following formula:

$$
\left( \frac{dn}{dy} \right) = \frac{\Delta n}{N \Delta y} \int m_\perp \varepsilon(m_\perp) e^{-m_\perp/T} dm_\perp
$$

where $\Delta n$ is the number of measured $\bar{\Lambda}$'s in a $y$ bin, $N$ is the number of total events and $\varepsilon(m_\perp)$ is the spectrometer acceptance in a given $y$ bin which depends on $m_\perp$ and is calculated by the GEANT-based Monte-Carlo simulation mentioned above. Fig. 5 shows the $dn/dy$ distribution of $\bar{\Lambda}$'s obtained by this method. For comparison, the $\bar{p}$ $dn/dy$ presented above is superposed on the same figure. The figure shows that in the $y$-range 1.15 to 1.55 the $dn/dy$ are more or less flat both for $\bar{p}$ and $\bar{\Lambda}$, which indicates that the large $y$-bin used in $\bar{\Lambda}$ data may not introduce severe systematic errors. On the other hand, the fact that the $\bar{\Lambda}$ measured with two ways has a yield comparable to that of the $\bar{p}$ in the $y$ range 1.15 to 1.55 suggests that a large fraction of the $\bar{p}$'s come from $\bar{\Lambda}$ decay ($\bar{\Lambda} \rightarrow \bar{p} + \pi^+$). In that case, it should be expected that the two particles have similar $dn/dy$ distributions in this rapidity range.
Preliminary Results for the E859

Figure 4: The transverse mass spectra for $\bar{p}$ (left) and $\bar{A}$ (right) in Si+Au central collisions.

Figure 5: The $dn/dy$ distributions for $\bar{p}$ and $\bar{A}$ in Si+Au central collisions. The curve is to guide the eye only, and the error bars are statistical only. The dash line is the $dn/dy$ for $\bar{A}$ measured from $m_\perp$ spectrum by using large $y$ (1.15-1.75) bin.
Table 1: $\bar{p}$, $\Lambda$ inverse slopes in different rapidity bins measured by E859. The errors are statistical only.

<table>
<thead>
<tr>
<th>PID</th>
<th>$\Lambda$</th>
<th>$\bar{p}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$y$ range</td>
<td>1.15–1.75</td>
<td>0.9–1.0</td>
</tr>
<tr>
<td>inverse slope(MeV)</td>
<td>188 ± 26</td>
<td>209 ± 50</td>
</tr>
</tbody>
</table>

Table 2: $\bar{p}$, $\Lambda$ dn/dy and their ratios measured by E859. The rapidity range was from 1.15 to 1.55 for both $\bar{p}$ and $\Lambda$ data. The error on $\bar{p}$ dn/dy is statistical only. The errors on $\Lambda$ dn/dy and the ratios are statistical (first) and systematics

4. Summary and Conclusions

Table 2 summarizes the measured $dn/dy$ for $\bar{p}$'s and for $\Lambda$'s. The $dn/dy$ for $\bar{p}$'s is for all experimentally measured $\bar{p}$ which includes the $\Lambda$ decay products. The $dn/dy$ for $\Lambda$'s is obtained by correcting the data for branching ratio of 64.2% for $\Lambda \rightarrow \bar{p} + \pi^+$ decay. We show two ratios in the table, the yield of $\Lambda$'s to the all experimentally measured $\bar{p}$ yield and, the yield of $\Lambda$'s to the primordial $\bar{p}$ after subtracted the $\bar{p}$ decay products. In E859 apparatus the acceptance for $\bar{p}$'s from $\Lambda$ decay are indistinguishable from primordial $\bar{p}$'s. One major contribution of systematic errors on the $\Lambda$ $dn/dy$ and on the $\Lambda$ to $\bar{p}$ ratios could be the inverse slope measurement of the $\Lambda$ $m_\perp$ spectrum because of the use of a large $y$ bin. To estimate the systematic errors introduced by this, we gave an additional 10% uncertainty to the $\Lambda$ inverse slope. The systematic error due to this uncertainty on estimate the $\Lambda$ yield and the ratio of the yield of $\Lambda$ over the yield of all experimentally measured $\bar{p}$ are about 10%, and the systematic error due to this uncertainty on the ratio of the yield of $\Lambda$ over the yield of primordial $\bar{p}$ is about 17%. The systematic error on the $\bar{p}$ measurement could come from the fitting of the $\bar{p}$ $dn/dy$ spectra. Since about 2/3 of the measured $\bar{p}$'s were from $\Lambda$ decays the single exponential function may not be the best one to be used, because of the limited statistics of the $\Lambda$ data we can not give a quantitative estimate here. Since the $\Lambda$ and $\bar{p}$ data were from the same data sets, most hardware related systematic errors should be canceled in the $dn/dy$ ratio measurements.

5. Acknowledgements

6. References

6. Y. Wang et al., HIPAGS93.