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Beam Energy Scan on Hypertriton Production and Lifetime Measurement at RHIC STAR

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Abstract

We report preliminary results on ${}^3_\Lambda$H production in Au+Au collisions at RHIC at $\sqrt{s_{NN}}$ = 7.7, 11.5, 19.6, 27, 39, and 200 GeV. The beam energy dependence of strangeness population factor $\frac{{}^3_\Lambda H/{}^3He}{\Lambda/p}$ is shown and the result indicates that $\frac{{}^3_\Lambda H/{}^3He}{\Lambda/p}$ has an increasing trend with 1.7σ significance. The hypertriton lifetime combining the above Au+Au collision data set is measured to be $123\pm^{26}_{22}$ (*stat*) ± 10(*sys*) ps.

1. Introduction

The hyperon-nucleon(Y-N) interaction is of great physical interest because it introduces a new quantum number strangeness in ordinary nuclear matter. It is predicted to be the decisive interaction in some high-density matter systems, such as neutron stars [1]. The Relativistic Heavy Ion Collider, RHIC, provides an ideal laboratory to study the Y-N interaction because hyperons and nucleons are abundantly produced in high energy nucleus-nucleus collisions.

The lifetime and decay modes of ${}^3_\Lambda$H , the lightest hypernucleus, which consists of a proton, a neutron and the lightest hyperon Λ, provide valuable insights into the Y-N interaction.

The strangeness population factor S_3, defined as $\frac{{}^3_\Lambda H/{}^3He}{\Lambda/p}$, is a good representation of the local correlation between baryon number and strangeness [2]. It is predicted that S_3 has a different behavior in Quark-Gluon Plasma (QGP) and pure hadron gas [3, 4] thus can be used as a tool to distinguish QGP from a pure hadronic phase.

The RHIC beam energy scan program in 2010-2011 allowed STAR to collect data for Au+Au collisions over a broad range of energies. This provides an opportunity to study the beam energy dependence of S_3. In addition, with increased statistics of present datasets, an improved result of the lifetime measurement of the hypertriton can be obtained. To get an even better statistics, datasets are combined in the lifetime measurement.

2. Analysis Details

In this analysis, the ${}^3_\Lambda$H is reconstructed via the decay channel ${}^3_\Lambda H \rightarrow {}^3He + \pi^-$ and its decay candidates are identified by their ionization energy loss dE/dx using the STAR detector Time

[1]A list of members of the STAR Collaboration and acknowledgements can be found at the end of this issue.

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Projection Chamber (TPC)[6]. The TPC covers full azimuthal angle and has a good charged particle identification ability in the pseudorapidity range from -1.0 to 1.0.

We define dE/dx^{data} and $dE/dx^{Bichsel}$ separately as the dE/dx of the detected particle and its theoretical value. Then we use the quantities $Z = \ln(dE/dx^{data}) - \ln(dE/dx^{Bichsel})$[7] and $n\sigma_\pi = (\ln(dE/dx^{data}) - \ln(dE/dx^{Bichsel}))/\sigma_\pi$ (σ_π is the dE/dx resolution of π)[8] separately for ^{3}He and π^- identification. The cuts: $|Z| < 0.2$ and $|n\sigma_\pi| < 2$ are applied. In addition, strict topology cuts: DCA (distance of closest approach to the collision vertex) < 1 cm and rigidity (momentum/charge) > 1GeV/c, which can avoid contamination from beam-pipe knocked-out ^{3}He and other particles, are also used. With all the cuts applied, ^{3}He + $^3\overline{\text{He}}$ can be identified very well. We apply the same PID method in each energy.

We obtain the $^3_\Lambda$H signal by calculating the invariant mass of its daughters: ^{3}He and π^-. The background invariant mass curve is constructed by rotating one of the daughters (in this analysis π) by 180 degrees in azimuthal angle. This is used to accurately represent the combinatorial background[2]. Further corrections for detector acceptance and inefficiency in particle identification have been made to both $^3_\Lambda$H and ^{3}He yields using the STAR embedding simulation method[9].

3. Results and Discussions

3.1. Hypertriton Production

We successfully reconstruct $^3_\Lambda$H + $^3_{\overline{\Lambda}}\overline{\text{H}}$ signals at different energies. Figure 1 shows the invariant mass distribution of signals from all the beam energies. The background shape is fitted by a double exponential function: $f(x) \propto \exp(-\frac{x}{p_1}) - \exp(-\frac{x}{p_2})$, where p_1 and p_2 are fit parameters. The signal is then fitted by adding a gaussian function to the background, and its yield is derived from bin counting within mass range [2.986, 2.996]GeV/c^2. The peak has a significance of 9.6σ.

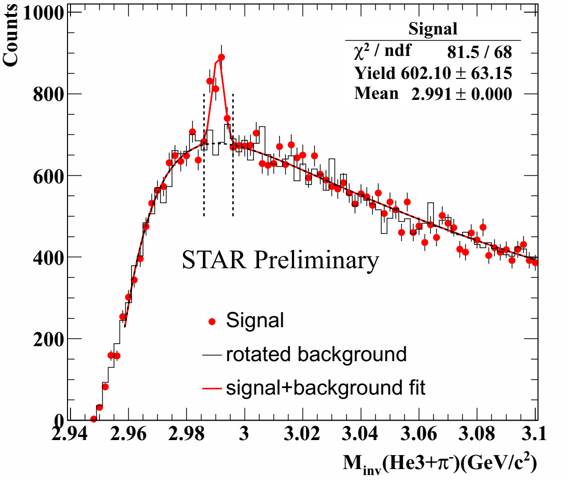

Figure 1: (Color online)$^3_\Lambda$H + $^3_{\overline{\Lambda}}\overline{\text{H}}$ with all datasets combined. Vertical dashed lines represent the mass range we use for bin counting of $^3_\Lambda$H yield.

The V0 ($^3_\Lambda$H vertex) cuts, including the DCA between ^{3}He and π, separate DCA of the $^3_\Lambda$H and π to the collision vertex, and decay length of the $^3_\Lambda$H are separately optimized in each dataset.

3.2. Strangeness Population Factor

The ($^3_\Lambda$H + $^3_{\bar\Lambda}\overline{\mathrm{H}}$)/(^{3}He + $^3\overline{\mathrm{He}}$) ratio is calculated by dividing efficiency corrected ^{3}He + $^3\overline{\mathrm{He}}$ and $^3_\Lambda$H + $^3_{\bar\Lambda}\overline{\mathrm{H}}$ yields within p_T range [2,5]GeV/c. The Λ/p ratio is extracted from [5]. The beam energy dependence of efficiency corrected S_3 is shown in Fig. 2 left panel. Two model calculations from [3, 4] are also included in the plot. From the trend of data points, it is hard to draw a conclusion directly. Therefore, a quantitative calculation is done by applying a zero-order and first-order fit to the data points, as shown in Fig. 2 right panel. From the fit results, we can give a statement that S_3 increases with increasing beam energy with 1.7σ significance.

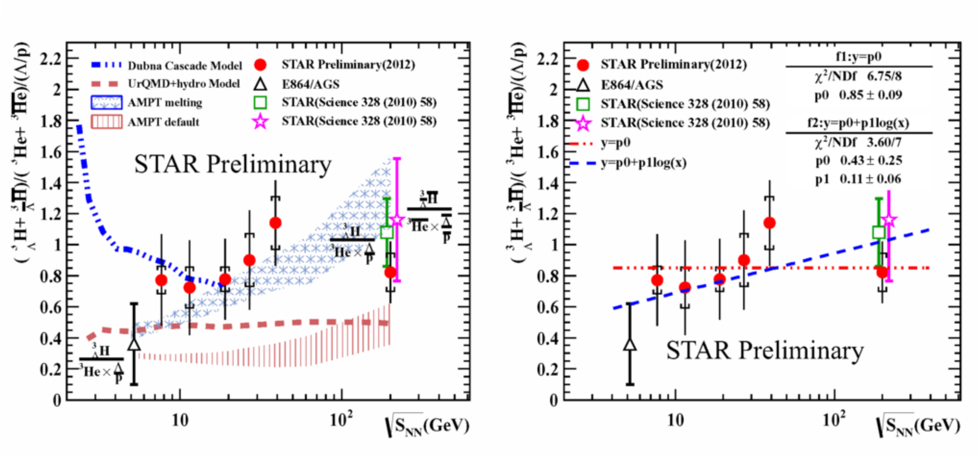

Figure 2: (Color online)(Left) Beam energy dependence of S_3. Lines and shadows: model calculation results. Markers: experimental results. (Right) Quantitative fit of the data points.

3.3. Lifetime Measurement

The hypertriton yield obeys the radioactive decay formula: $N(t) = N(0)e^{-t/\tau} = N(0)e^{-l/(\beta\gamma c\tau)}$ (τ:lifetime, l:$^3_\Lambda$H decay length). We reconstruct $^3_\Lambda$H + $^3_{\bar\Lambda}\overline{\mathrm{H}}$ signals in four $l/(\beta\gamma)$ bins: [2cm,5cm], [5cm,8cm], [8cm,11cm], [11cm,41cm]. The lifetime parameter is then extracted by fitting the decay formula to the 4 data points. Asymmetric statistical errors are calculated by doing χ^2 estimation as shown in the inner panel in the left panel of Fig. 3. The result is $123\pm^{26}_{22}(stat)\pm 10(sys)$ ps. As a comparison, STAR 2010 $^3_\Lambda$H lifetime measurement [2] and the STAR 2010+2012 combined results are also provided. The current measurement is consistent with the STAR 2010 measurement within 1.5σ and is statistically improved.

We consider two kinds of sources for systematic study: 1. choice of V0 topology cuts; 2. choice of bin width and invariant mass range. These effects contribute to the final systematic error. Additional sources of loss, like the interaction between $^3_\Lambda$H and material (air+detector) are also considered, which can be neglected due to its less than 1.5% effect.

As a further cross-check, Λ is reconstructed via the $\Lambda \to p + \pi^-$ decay channel. We use exactly the same method to obtain the Λ lifetime and the result is 260 ± 1 ps which is consistent

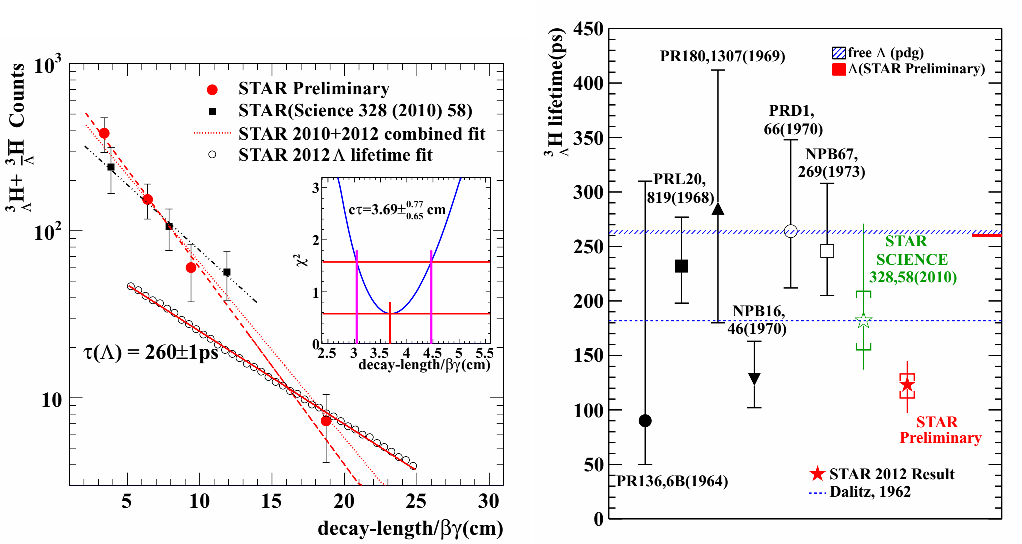

Figure 3: (Color online)(Left) ${}^{3}_{\Lambda}\mathrm{H} + {}^{3}_{\bar{\Lambda}}\overline{\mathrm{H}}$ yield versus $c\tau$. STAR 2012 (solid red circles) and 2010 (solid black squares) measurements are shown. Λ lifetime (open black circles) is shown as a cross-check. (Left inner pad) χ^2 estimation for calculating lifetime statistical errors. (Right) Summary of ${}^{3}_{\Lambda}\mathrm{H}$ lifetime measurements till now.

with the $\tau = 263 \pm 2$ ps compiled by the Particle Data Group [10]. There have been several measurement results of ${}^{3}_{\Lambda}\mathrm{H}$ lifetime till now. We summarize the lifetime values from all the measurements till now in the right panel of Fig. 3.

4. Summary

We present the STAR preliminary analysis on ${}^{3}_{\Lambda}\mathrm{H}$ production in RHIC Au+Au collsions at $\sqrt{s_{NN}} = 7.7, 11.5, 19.6, 27, 39,$ and 200 GeV. The combined ${}^{3}_{\Lambda}\mathrm{H} + {}^{3}_{\bar{\Lambda}}\overline{\mathrm{H}}$ signal is obtained with 9.6σ significance. The beam energy dependence of strangeness population factor $\frac{{}^{3}_{\Lambda}\mathrm{H}/{}^{3}\mathrm{He}}{\Lambda/p}$ is presented and the result indicates that S_3 increases with increasing beam energy with 1.7σ significancy. A statistically improved ${}^{3}_{\Lambda}\mathrm{H}$ lifetime: $123 \pm^{26}_{22}$ $(stat) \pm 10(sys)$ ps, is also presented.

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