Yields and elliptic flow of $d(\bar{d})$ and $^3He(^3He)$ in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV

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Abstract. We present the transverse momentum spectra at mid-rapidity for $d$, $\bar{d}$ ($1 < p_T < 4$ GeV/c) and $^3He$, $\bar{^3He}$ ($2 < p_T < 6$ GeV/c) measured by the STAR experiment at RHIC and extract the coalescence parameters $B_2$ and $B_3$ (respectively). We also present the $v_2$ measurement for $d(\bar{d})$ and $^3He(\bar{^3He})$. We find that the $d(\bar{d})$ and $p(\bar{p})$ $v_2$ follows the atomic mass number $A$ scaling within errors and a negative $v_2$ has been observed for $\bar{d}$ at low $p_T$.

1. Introduction

In relativistic heavy ion collisions, light nuclei and their particles can be formed from created nucleons and anti-nucleons or stopped nucleons [1]. Since the binding energy is small, this formation process can only happen at the late stage of the evolution when interactions between nucleons and other particles are weak. This process is called final-state coalescence [2] [3]. Therefore, the production of light nuclei provides a tool to measure freeze-out properties, such as particle density [4], correlation volume and collective motion. Invariant nucleus yield can be related [2] to the primordial yields of nucleons by Equation (1):

$$E_A \frac{d^3N_A}{d^3p_A} = B_A(E_p \frac{d^3N_p}{d^3p_p})^Z (E_n \frac{d^3N_n}{d^3p_n})^{A-Z} \approx B_A(E_p \frac{d^3N_p}{d^3p_p})^A$$

where $B_A$ is the coalescence parameter. $E \frac{d^3N}{d^3p}$ is the invariant yield of nucleons or nuclei. $A$ and $Z$ are the atomic mass number and atomic number, respectively. $p_A$ and $p_p$ are the momenta of nucleus and proton where $p_A = A \cdot p_p$. $B_A$ is related to the freeze-out correlation volume [2]: $B_A \propto V^{1-A}$.

2. Experiment and analysis

The data presented here are obtained from the Time Projection Chamber (TPC) and the Time-Of-Flight (TOF) detectors in the STAR experiment [5] at RHIC in the year

‡ Supported by National Natural Science Foundation of China (10475074 10620120286)
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Figure 1. (a) TPC $dE/dx$ as a function of rigidity. Lines are expected values for $d(d)$ and $^3He(^3He)$ predicted by the Bichsel function. (b) $Z$ distribution of $^3He$ (solid line) and $^3He$ (dashed line). (c) $n\sigma_d$ distribution of $d$ at $0.7 < p_T < 1.0$ GeV/$c$ with a Gaussian fit including an exponential background. (d) $m^2(m^2 = (p/\beta/\gamma)^2)$ distribution for $d$ from TOF after TPC $dE/dx$ selections at $2.5 < p_T < 3.0$ GeV/$c$, with a Gaussian fit including a linear background.

2004. A data sample of 25 million (16 million for TOF) central triggered events and 24 million (15 million for TOF) minimum-bias triggered events is used for this analysis. Figure 1 presents the particle identification techniques and methods. Figure 1 (a) shows the ionization energy loss ($dE/dx$) of charged tracks as a function of rigidity ($\text{rigidity} = |\text{momentum/charge}|$) measured by the TPC at $-1 < \eta < 1$. Figure 1 (b) shows $Z$ ($Z = \log(dEdx|_{\text{measure}}/dEdx|_{\text{predict}})$) distribution for $^3He$ and $^3He$ signals. After tight track quality selections, the $^3He(^3He)$ signals are essentially background free. We use counting method to derive the yields. Figure 1 (c) shows $n\sigma_d$ (extracted from $dE/dx$) distribution for $d$ at $0.7 < p_T < 1.0$ GeV/$c$. The signal was fit with a Gaussian function and an exponential background. Figure 1 (d) shows $m^2$ distribution for $d$ at $2.5 < p_T < 3.0$ GeV/$c$ measured by TOF after the $dE/dx$ selections. The signal was fit with a Gaussian function and a linear background. The acceptance and tracking efficiencies were studied by Mont Carlo GEANT simulations [6]. The results presented are corrected for these effects. Elliptic flow parameter $v_2$ was calculated by the event plane method.

3. Results

Figure 2 shows the $p_T$ spectra and the extracted coalescence parameters $B_2$ and $B_3$ for $d(d)$ and $^3He(^3He)$. Here the proton and anti-proton spectra are taken from Ref. 7. The $p(\bar{p})$ spectra have been corrected for feed-down from $\Lambda(\bar{\Lambda})$ and $\Sigma^\pm$ weak decays [7]. $B_2$ for $d(d)$ is consistent with $\sqrt{B_3}$ for $^3He(^3He)$, which indicates that the correlation volumes for $d(d)$ and $^3He(^3He)$ are similar. Both $B_2$ and $B_3$ show strong centrality
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Figure 2. Upper panel: $p_T$ spectra of $d(d)$ (left panel) and $^3He(^3He)$ (right panel) for different centralities. Solid symbols and open symbols represent the positive charged particles and negative charged particles respectively. Lower panel: Coalescence parameters $B_2$ and $\sqrt{B_3}$ as a function of $p_T/A$ for positive charged particles (left panel) and negative charged particles (right panel). Errors are statistical only.

dependence. In more central collisions, a smaller coalescence parameter indicates that the correlation volume at thermal freeze-out is larger and the probability of formation of light nuclei is less. Figure 3 (a) shows $v_2$ as a function of $p_T$ for $d+d$, $^3He+^3He$ and $\bar{d}$ in minimum-bias collisions. The results with both $v_2$ and $p_T$ scaled by $A$ are shown in Figure 3 (b). For comparison, the baryon $v_2$ [8] is also shown as the solid line. $d+d$ and baryon $v_2$ seems to follow the $A$ scaling within errors, indicating that the $d+d$ are formed through the coalescence of $p(p)$ and $n(n)$ just before the thermal freeze-out. The scaled $^3He+^3He$ $v_2$ appears to deviate from the the baryon $v_2$. Further conclusions are limited by poor statistics, so clearly more data are needed. The $\bar{d}$ $v_2/A$ as a function of centrality fraction is shown in Figure 3 (c). The two panels represent results for two different regions of $p_T$. $\bar{d}$ has a negative $v_2$ in central and mid-central collisions in the transverse momentum range of $0.2 < p_T < 0.7$ GeV/c. This negative $v_2$ is consistent with a large radial flow, as the blast-wave predictions show. At the same $p_T/A$ where the $\bar{d}$ is negative, the $\bar{p}$ $v_2$ is consistent both with zero and with the $d$ $v_2$, due to large uncertainties. Though the blast-wave model predicts the generic feature of negative $v_2$, quantitative agreement between data and model throughout the entire centrality and $p_T$ range is lackings.

4. Summary

Taking advantage of the combining STAR TPC and TOF detectors capabilities, we have measured the $d(d)$ and $^3He(^3He)$ transverse momentum spectra and elliptic flow.
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Figure 3. (a) The elliptic flow parameter $v_2$ from minimum bias collisions as a function of $p_T$ for $^3He + ^3He$ (triangles), $d + \bar{d}$ (filled circles) and $\bar{d}$ (open circles); solid line represents the baryon $v_2$. (b) $d + \bar{d}$ and $^3He + ^3He$ $v_2$ as a function of $p_T$, both $v_2$ and $p_T$ have been scaled by A. Errors are statistical only. (c) Low $p_T$ $\bar{d}v_2/A$ (filled squared) as a function of centrality fraction $(0 - 10\%, 10 - 20\%, 20 - 40\%, 40 - 80\%$, respectively). Errors are statistical only. $\bar{p} v_2$ is also shown as open triangles. Blast-wave predictions are show as solids lines ($\bar{d}$) and dashed lines ($\bar{p}$).

The value of the coalescence parameters $B_2$ and $\sqrt{B_3}$, extracted from the spectral measurements, are found to be consistent. Systematic studies of $B_2$ and $B_3$ have shown decreasing trends as function of collision centrality, consistent with an increasing source size from peripheral to central collisions. Comparative analysis of the elliptic flow measurements show that $d(\bar{d})$ and $p(\bar{p}) v_2$ scales with atomic mass number A, which is expected natural consequence of final-state coalescence. The negative $\bar{d}$ $v_2$ values observed at low $p_T$ are consistent with a large radial flow in the soft sector.

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