Elliptic flow of light nuclei in Au+Au collisions at $\sqrt{s_{NN}}$ = 14.6, 19.6, 27, and 54.4 GeV using the STAR detector

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September 14, 2023

Abstract

Loosely bound light nuclei are produced in abundance in heavy-ion collisions. There are two main possible models to explain their production mechanism - the thermal model and the coalescence model. The thermal model suggests that the light nuclei are produced from a thermal source, where they are in equilibrium with other species present in the fireball. However, due to the small binding energies, the produced nuclei are not likely to survive the high-temperature conditions of the fireball. The coalescence model tries to explain the production of light nuclei by assuming that they are formed at later stages by the coalescence of protons and neutrons near the kinetic freeze-out surface. The final-state coalescence of nucleons will lead to the mass number scaling of the elliptic flow (v_2) of light nuclei. This scaling states that the v_2 of light nuclei scaled by their respective mass numbers will follow very closely the v_2 of nucleons. Therefore, studying the v_2 of light nuclei and comparing it with the v_2 of protons will help us in understanding their production mechanism.

In this talk, we will present the transverse momentum (p_T) and centrality dependence of v_2 of d, t, and ^{3}He in Au+Au collisions at $\sqrt{s_{NN}}$ = 14.6, 19.6,

27, and 54.4 GeV. Mass number scaling of $v_2(p_T)$ of light (anti-)nuclei will be shown and physics implications will be discussed.

1 Introduction

The study of light nuclei and their interaction in high-energy heavy-ion collisions has been a subject of active theoretical and experimental investigations [1]. The production mechanism of light nuclei in heavy-ion collisions is not very well understood. There are two main models that describe this mechanism: the thermal model and the coalescence model. The thermal model suggests that light nuclei are formed near the chemical freezeout (CFO) surface along with other hadrons [2]. However, the low binding energies of light nuclei make it unlikely that they will be able to sustain the high temperature at CFO. The coalescence model, on the other hand, suggests that light nuclei might be formed by the coalescence of nucleons at the later stages of evolution of the system [3]. This will result into the mass number scaling whereby elliptic flow of light nuclei scaled by their respective mass numbers follows closely to elliptic flow of protons [4]. Therefore, by examining the collective flow of light nuclei, valuable insights can be gained into how they are produced in heavy-ion collisions.
In the following sections, we will report the elliptic flow (v_2) of d, t, and ^{3}He in Au+Au collisions at $\sqrt{s_{NN}}$ = 14.6, 19.6, 27, and 54.4 GeV. We will also report the results of the centrality dependence study of v_2 of d in $\sqrt{s_{NN}}$ = 19.6, 27, and 54.4 GeV. Finally, we will show the results from the mass number scaling study of $v_2(p_T)$ of light nuclei.

2 Analysis details

The data presented in these proceedings is from Au+Au collisions collected by the STAR experiment at RHIC in the year 2017 (at $\sqrt{s_{NN}}$ = 54.4 GeV), 2018 (at $\sqrt{s_{NN}}$ = 27 GeV), and 2019 (at $\sqrt{s_{NN}}$ = 19.6 and 14.6 GeV) during the second phase of the Beam Energy Scan (BES-II) program. Light nuclei identification was done using the Time Projection Chamber (TPC) [5] and the Time of Flight (TOF) [6] detectors. TPC serves as the main tracking detector in the STAR experiment and relies on the measurement of specific ionization energy loss (dE/dx) within a large gas volume to identify and track various charged particles. The TOF detector, on the other hand, enables the identification of particles of interest by imposing a constraint on their mass-square (m^2).
Elliptic flow, v_2, is the second order Fourier coefficient of the azimuthal distribution of

the produced nuclei relative to the reaction plane of the Au+Au collision. Since it is not feasible to directly measure the reaction plane angle in an experimental setup, we employ the TPC to construct the second order event plane angle (Ψ_2) as a substitute for the reaction plane angle [7]. In the next section, we will discuss the results of v_2 of d, t, and ^{3}He.

3 Results

3.1 Elliptic flow of light nuclei

Figure 1 shows v_2 as a function of p_T in 0-80% centrality Au+Au collisions at $\sqrt{s_{NN}}$ = 14.6, 19.6, 27, and 54.4 GeV. A monotonous increase with p_T in v_2 of light nuclei is observed across all four center-of-mass energies.

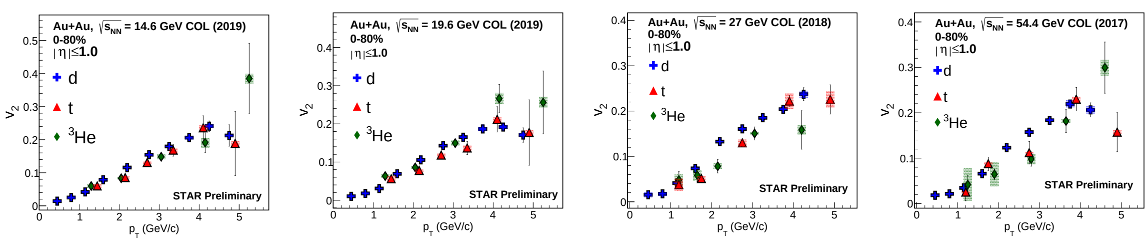

Figure 1: $v_2(p_T)$ of light nuclei (d, t, and ^{3}He) in 0-80% centrality Au+Au collisions at $\sqrt{s_{NN}}$ = 14.6, 19.6, 27, and 54.4 GeV. Vertical lines and shaded bands at each marker represent statistical and systematic uncertainties, respectively.

3.2 Centrality dependence of v_2

Centrality dependence of v_2 of d is shown in Fig. 2. The nuclei v_2 is measured in two centrality ranges 0-30% and 30-80% for Au+Au collisions at $\sqrt{s_{NN}}$ = 19.6, 27, and 54.4 GeV. It is noted that peripheral collisions exhibit higher v_2 values compared to more central collisions. This observation can be attributed to the greater spatial anisotropy in peripheral collisions as opposed to central collisions.

3.3 Mass number scaling

According to the coalescence model, assuming that protons and neutrons behave in the same way, for a light nuclei N with mass number A, we expect $v_{2,N}(p_T) \approx$

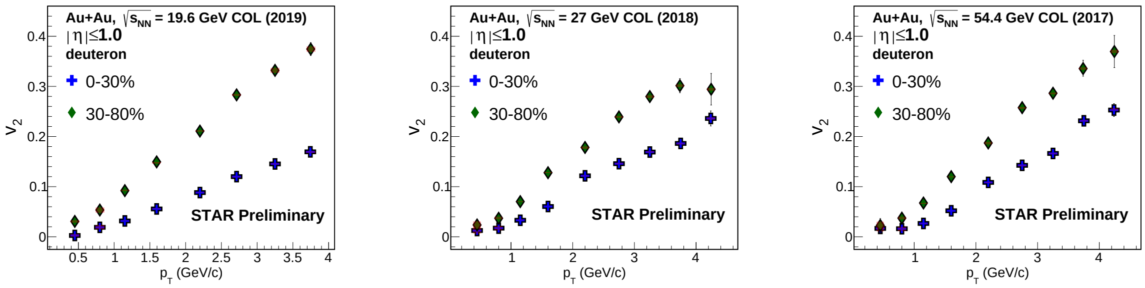

Figure 2: Centrality dependence of v_2 of d as a function of p_T in Au+Au collisions at $\sqrt{s_{NN}}$ = 19.6, 27, and 54.4 GeV. Vertical lines and shaded bands at each marker represent statistical and systematic uncertainties, respectively.

$Av_{2,p}(p_T/A)$, where $v_{2,p}$ is elliptic flow of protons [4, 8, 9]. The phenomenon is referred to as mass number scaling. Figure 3 shows the comparison of v_2/A of light nuclei as a function of p_T/A (where A is the mass number of the nuclei) with v_2/A of proton (where $A = 1$). Proton v_2 has been fitted with a third-order polynomial. The bottom panel in each plot shows the ratio between the v_2/A of light nuclei and the fit to proton v_2. It is observed that v_2 of light nuclei deviates from mass number scaling by 20-30%. However, additional model studies are required to conclude whether the coalescence model is the dominant production mechanism of light nuclei.

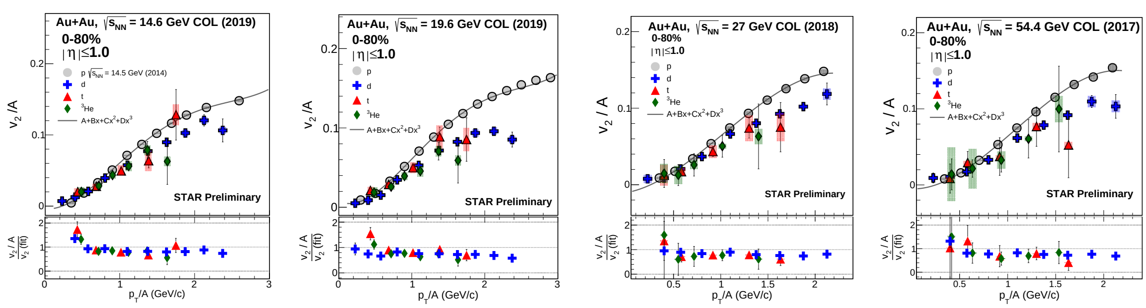

Figure 3: Mass number scaling of v_2/A of light nuclei as a function of p_T/A in minimum bias Au+Au collisions at $\sqrt{s_{NN}}$ = 14.6, 19.6, 27, and 54.4 GeV. Vertical lines and shaded bands at each marker represent statistical and systematic uncertainties, respectively.

4 Conclusion

In summary, we have reported the v_2 of d, t, and ^{3}He in Au+Au collisions at $\sqrt{s_{NN}}$ = 14.6, 19.6, 27, and 54.4 GeV. A monotonic rise of light nuclei v_2 with p_T is observed for all light nuclei species and studied energies. v_2 of d is observed to show a strong centrality dependence being higher for peripheral collisions compared to central collisions. This behaviour can be attributed to the fact that peripheral collisions have higher spatial anisotropy compared to the central ones. In addition, it is also observed that v_2 of light nuclei deviates from mass number scaling by 20-30%.

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