Production of light nuclei in heavy-ion collisions via a coalescence mechanism

Yoshini Bailung[1],* Sudhir Pandurang Rode[2], Neha Shah[3], and Ankhi Roy[1]
[1] *Department of Physics, Indian Institute of Technology Indore, Simrol, Madhya Pradesh, INDIA*
[2] *Veksler and Baldin Laboratory of High Energy Physics, Joint Institute for Nuclear Research, Dubna, 141980, Moscow region, Russian Federation and*
[3] *Department of Physics, Indian Institute of Technology Patna, Bihta, Bihar, INDIA*

1. Introduction

Experiments carried out at accelerator facilities such as CERN and BNL aim to study the characteristic properties of the baryon-free hot and dense QCD matter produced in these Ultra-relativistic heavy-ion collisions [1]. Amongst many probes to study these properties, an important measurement involves the formation of low-energy nucleon clusters or bound states. A deuteron, which is a bound state of a proton and a neutron are produced and measured at these experiments. These measurements are important to understand the novel low-energy QCD interactions. Moreover, nuclei measurements can also shed light on the baryon asymmetry and search for dark matter.

Although the experimental measurements are abundant, a coherent understanding of their production mechanism is still unknown. The binding energies of these light nuclei states are $\sim \mathcal{O}$(MeV), as opposed to the temperatures at kinetic freezeout ($\sim \mathcal{O}$(100 MeV)). Popular models that deal with light-nuclei production are the thermal and coalescence models. A thermal model assumes the light nuclei production occurs in between chemical and kinetic freezeout, whereas the coalescence model assumes the nuclei production at the kinetic freezeout.

In this contribution, we discuss the production of various light nuclei species such as deuterons, helium-3s and tritons via a coalescence afterburner. The afterburner is preceded by an event generator of choice which allow us to probe different scenarious of the heavy-ion collision experiments. Using the AMPT event generator, we report the results for Au+Au and Pb+Pb collisions at various RHIC and LHC energies. At lower energies, we implement UrQMD + coalescence for Pb+Pb collisions at SPS energies and test the model on different light nuclei measurements. Finally, modern transport models such as SMASH, are also coupled to a coalescence model and the results are compared to experimental measurements at different RHIC energies.

*Electronic address: yoshini.bailung.1@gmail.com

2. The Coalescence Model

The coalescence mechanism of nucleons to form a light nuclei happens after the kinetic freeze-out. The coalescence parameter "B_A" is described as

$$E_A \frac{d^3N}{dp_A^3} = B_A \left(E_p \frac{d^3N_p}{dp_p^3} \right)^Z \left(E_n \frac{d^3N_n}{dp_n^3} \right)^{A-Z} \tag{1}$$

where $E\frac{d^3N}{dp^3}$ is the invariant yield, A and Z are the atomic mass number and atomic number of the nucleons. The coalescence conditions for a nuclei formation are defined by their phase space distribution, where conditions based on their relative distance (Δr) and relative momenta needs to be satisfied (Δp). Modern coalescence models involve a probabilistic approach to the coalescence conditions where the phase space probablities are defined by the wigner density which is obtained from the light nuclei wave-function.

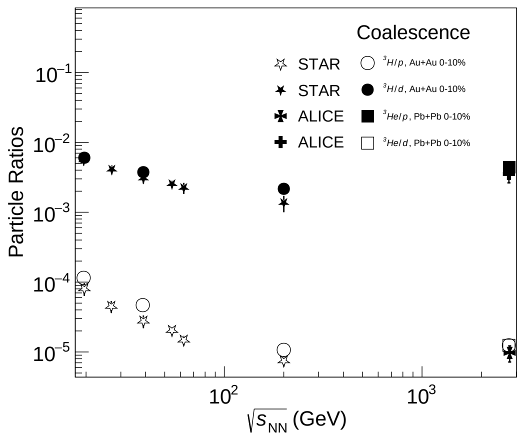

FIG. 1: Particle ratios from AMPT+Coalescence model as a function of $\sqrt{s_{\rm NN}}$ (GeV) for central Au+Au ad Pb+Pb collisions. Results are compared to experimental measurements.

3. Results and discussion

Fig. 1 shows the various ratios for deuterons, tritons, helium 3 and protons as function of center of mass energies. These results are obtained with the AMPT event generator and a simple coalescence afterburner. Figure 2 (Top) shows the coalescence parameter B_A as a function of deuteron $p_{\rm T}$ for Au+Au and Pb+Pb collisions at $\sqrt{s}_{\rm NN} = 39$ GeV and $\sqrt{s}_{\rm NN} = 2.76$ TeV respectively. Overall, AMPT + Coalescence model shows a good agreement with the experimental results [2]. In Figure 2 (Below), we show the B_2 predictions for a hybrid UrQMD + coalescence model for Pb+Pb collisions at SPS energies. These results show that a simple coalescence model is able to provide a comprehensive description of light nuclei production across various collision energies.

Moreover, we check the implementation of modern coalescence models, using deuteron Wigner functions. We couple this model with the new transport model, "SMASH" to provide a complete description of light nuclei production across various centralities and collision energies.

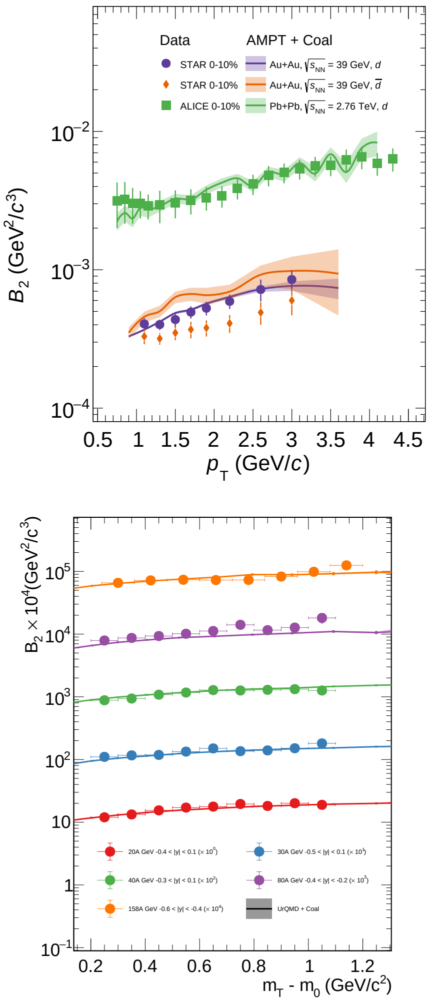

FIG. 2: (Top)The B_2 parameter vs $p_{\rm T}$ of deuterons and anti-deuterons for central Au+Au collisions at $\sqrt{s}_{\rm NN} = 39$ GeV and Pb+Pb collisions at $\sqrt{s}_{\rm NN} = 2.76$ TeV using AMPT + Coalescence model. (Bottom) The B_2 parameter vs $m_0 - m_{\rm T}$ of deuterons for central Pb+Pb collisions at 20, 30, 40, 80, and 158 AGeV using UrQMD + Coalescence model.

References

[1] J. Adam *et al.* [ALICE], Phys. Rev. C **93** (2016) no.2, 024917

[2] Y. Bailung, N. Shah and A. Roy, Nucl. Phys. A **1037** (2023), 122701