Thermo-Coalescence model for deuteron production in heavy ion collisions at LHC

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(Dated:)

I. INTRODUCTION

Relativistic heavy-ion collisions offer a unique opportunity to study the formation dynamics of light nuclei. Light nuclei being loosely bound via residual strong interactions, as compared to underlying collision energies and temperature of the produced medium, are particularly interesting for investigation. The low binding energy (∼8 MeV per nucleon) of these nuclei makes their survival in the hot medium (with a typical freeze-out temperature T_{CFO} ∼160 MeV) very unlikely, thus questioning their production through thermal models. The other picture, of the coalescence model, however, provides promising predictions, supported by the observed quark number scaling of elliptic flow, suggesting that deuterons form via recombination of protons and neutrons close in phase-space.

In this work, we propose a combined "thermo-coalescence model" to describe light nuclei production in ultra-relativistic heavy-ion collisions. We assume nucleons are thermally produced, with frozen momentum distributions at kinetic freeze-out, suitably described by a boosted thermal model - specifically the hydro inspired blast-wave model. The parameters from the blast-wave fits of protons are then used to describe light nuclei distribution via the coalescence approach inspired by Ref. [1].

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II. BLAST WAVE FIT OF LIGHT HADRONS AND TWO NUCLEON COALESCENCE

Blast-wave model is a hydro-inspired phenomenological model widely used in heavy-ion collisions to describe the inclusive transverse momentum distributions of the various hadron species emitted at the freeze-out. In this work, a boost-invariant blast-wave model is employed, details of which can be found here [2]. Considering irrotational and boost-invariant flow, the thermal single-particle transverse momentum spectrum of proton has been fitted with the blast wave model to obtain the freeze-out parameters i.e., the kinetic freeze-out temperature T, the maximum transverse velocity β_0, and the exponent of transverse profile n.

Once we have fixed these quantities at kinetic freeze-out, we apply them to two-nucleon coalescence to study the light nuclei production following the methodology prescribed in [1]. The transverse momentum spectrum of deuteron formed by nucleon recombination is expressed as:

$$\frac{dN_{\rm Deu}}{d^2P_T dy}\Big|_{y=0} = C_D \int_0^R r_\perp dr_\perp\, M_T\, I_0\left[\frac{P_T \sinh\rho(r_\perp)}{T}\right] \int_0^1 dx\ |\phi_D(x)|^2\, k_D(x,P_T)\,, \tag{1}$$

where,

$$k_D(x,P_T) = K_1\left[\frac{\cosh\rho(r_\perp)}{T}\left(\sqrt{m_P^2 + x^2P_T^2} + \sqrt{m_P^2 + (1-x)^2P_T^2}\right)\right] \tag{2}$$

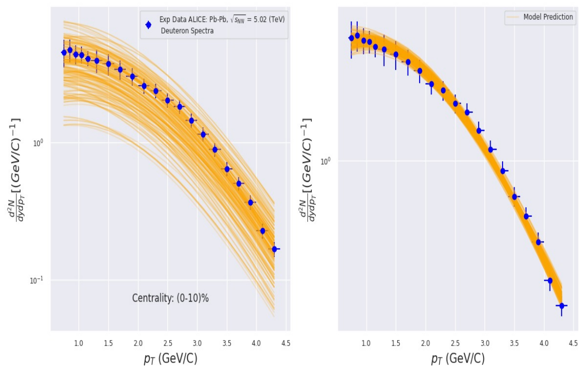

FIG. 1: Bayesian fit for deuterons transverse momentum(p_T) spectra from most central Pb-Pb collisions at $\sqrt{s_{NN}}$= 5.02 TeV. The parameters obtained from proton fit have been used to describe the deuteron spectra in addition to two more parameters, C_D and α. The multiple curves(left) represent the different iterations of the model parameter values to predict the best values that describe the data(right).

Here p_T and $M_T = \sqrt{p_T^2 + M^2}$ are the transverse momentum and transverse mass of the light nuclei, respectively. For the functional form of $\phi_D(x)$, which is the deuteron wave function, governing the likelihood of coalescence of nucleons into nuclei, we choose the normalized function

$$\phi_D(x) = \frac{\sqrt{\Gamma(4\alpha+2)}}{\Gamma(2\alpha+1)}\left[x(1-x)\right]^{\alpha}, \qquad (3)$$

In Eqs. (1) C_D should be fixed by matching the yield of deuteron.

III. RESULTS AND DISCUSSIONS

We test the validity of our model by analyzing the deuteron production in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV at LHC. We have fitted the transverse momentum distribution of the protons using a boost-invariant blast-wave model. The parameters that are kept free in the fit are the kinetic freeze-out temperature (T_{kin}), transverse flow velocity (β_T), flow profile (n), radius (R), and proper time (τ_F). We have used Bayesian inference method for fitting the p_T spectra of proton. Unlike conventional methods, like least squares, which only give you the most likely parameter values with some uncertainty, Bayesian fitting incorporates prior knowledge and is generally more robust. The method involves generating a set of parameters and training the model with the parameters. Then we use the trained model to fit the experimental data and get the best value of parameters. The Bayesian inference method is particularly good at handling the correlation between the model parameters and is very useful for model with large number of parameters. This approach provides more detailed information, including how certain or uncertain we are about the parameter values.

The obtained fit parameters have been used as input to fit the deuteron spectra using eq(1). The free parameters in the deuteron fit are C_D and α. The fit for deuteron p_T spectra, using Bayesian inference method is shown in Figure.1. The model has managed to reproduce the experimental measurements, and the obtained fit parameters from the blast-wave fit of protons have described the deuteron spectra well, justifying the assumption that thermally produced and equilibrated nucleons undergo coalescence to form light nuclei. Detailed results, including the proton fits using Blast-wave and the correlations between parameters as estimated by the Bayesian method will be presented at the symposium.

References

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