Light nuclei production in heavy-ion collisions at RHIC

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Abstract

Light nuclei (anti-nuclei) can be produced in heavy-ion collisions by the recombination of produced nucleons (anti-nucleons) or stopped nucleons. This formation process is called final-state coalescence. The production of light nuclei is dependent on the baryon density and the correlation (freeze-out) volume. Therefore, by studying the yield and azimuthal anisotropy of light nuclei (anti-nuclei) and comparing them with that of proton (anti-proton) we can gain insight in the particle production mechanism via coalescence and physical properties of the expanding system at the thermal freeze-out. In this poster, we present the invariant yields of d and $\bar{d}$ for Au+Au collisions at $\sqrt{s_{NN}}$ = 7.7, 11.5, 19.6, 27 and 39 GeV from the STAR experiment at RHIC. Light nuclei are identified using the Time Projection Chamber (TPC) and Time-of-Flight (TOF) detectors of the STAR experiment. The TOF detector enhances the identification of the light nuclei and extends their p_T reach beyond 1 GeV/c. The p_T spectra of nuclei have been compared with $p(\bar{p})$ to obtain the nuclei to nucleon ratio and B_2 parameter to understand the light nuclei production mechanism in heavy-ion collisions.

1. Introduction

- Light nuclei are expected to form at a later stage of the evolution due to their low binding energy (~2.22 MeV for d, $\bar{d}$ and ~8 MeV for t, ^3He).
- Mass number scaling of nuclei v_2 suggests coalescence of light nuclei to be the underlying mechanism of nuclei formation in Heavy-ion collisions (HIC). This coalescence mechanism can be studied in detail by studying the nuclei spectra and comparing them with proton (anti-proton) spectra.
- The light nuclei (anti-nuclei) invariant yield is related to invariant yield of nucleon (anti-nucleon) as,

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

  where B_A is called the coalescence parameter.

- Coalescence parameter B_2 (for d, $\bar{d}$) and B_3 (for t, ^3He) are related to the baryon density and correlation (freeze-out) volume of the system. Therefore, studying light nuclei we can gain insight in the physical characteristics of the system during the freeze-out.
- Measurement of B_2 in BES ($\sqrt{s_{NN}}$ = 7.7, 11.5, 19.6, 27, 39 and 62.4 GeV) would provide insight in the particle production mechanism via coalescence.
- $\bar{d}/\bar{p}$ ratio was found to follow a universal trend as a function of energy (Fig.2).
- Measurement of $\bar{d}/\bar{p}$ in the BES ($\sqrt{s_{NN}}$ = 7.7, 11.5, 19.6, 27, 39 and 62.4 GeV) would test this universality.

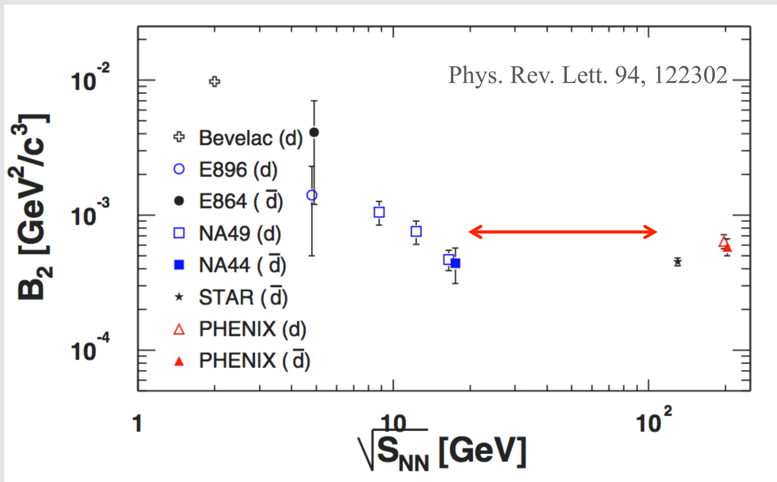

Fig.1 : B_2 parameter as measured by different experiments.

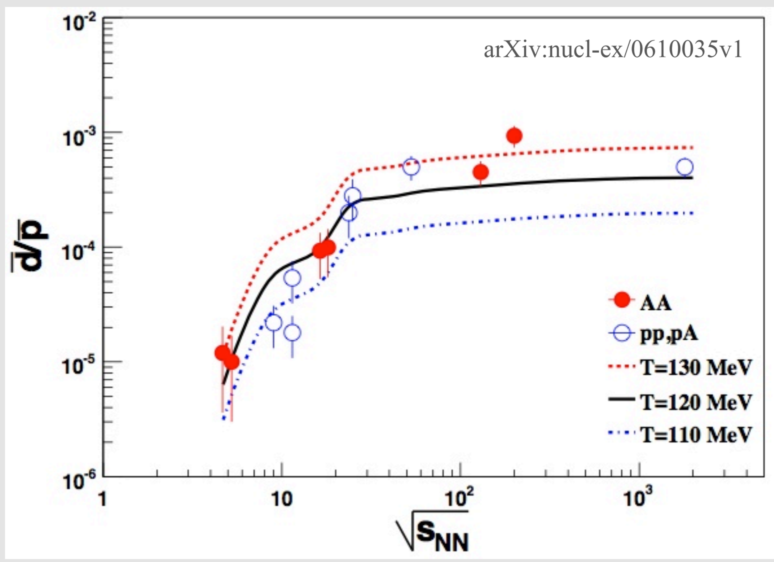

Fig.2 : $\bar{d}/\bar{p}$ as a function of $\sqrt{s_{NN}}$.

2. STAR Experiment & Analysis

- The STAR experiment consists of several detectors, among which TPC and TOF are primarily used for particle identification (Fig. 3).
- The Time Projection Chamber (TPC) is the main tracking device for charged particles at STAR. It covers pseudo-rapidity window of -1.0 <η< 1.0 in full azimuth.
- The average energy loss (<dE/dx>) per unit length of a charged particle as a function of rigidity (momentum / charge) as measured by TPC is shown in Fig. 4. The solid lines corresponds to the theoretical values.
- Identification of nuclei: we define a quantity Z as,

$$Z = \ln\left(\frac{(dE/dx)_{measure}}{(dE/dx)_{predict}}\right)$$

  and then we fit this Z distribution to calculate light nuclei yield for p_T < 1.0 GeV/c.

- The Time of Flight (TOF) detector measures the time taken by charged particle to travel from its point of origin to the detector, and hence calculates its velocity (β). Therefore, using β from TOF and momentum (p) from TPC, we can obtain the mass of a charged track using the relativistic mass formula: $m^2 = p^2(1/\beta^2 - 1)$. A qualitative plot is shown in Fig. 5.
- Identification of nuclei using TOF: Light nuclei yields were measured from the m^2 distribution in fine p_T bins. Using the TOF we can measure yield of light nuclei up to p_T ~4.0 GeV/*c*.

Event Cuts:
$|Vertex_z|$ < 50 cm for 7.7,11.5 19.6, 27 GeV,
$|Vertex_z|$ < 40 cm for 39, 62.4 GeV,
$|V_r|$ < 1.0 cm for all energy.

Track cuts:
$N_{HitsFits}$ > 25,
$N_{HitsdEdx}$ > 10,
DCA < 1 cm
$|\eta|$ < 1.0
$|y|$ < 0.3

$\sqrt{s_{NN}}$ (GeV)	Events (x10^6)
62.4	61
39	119
27	49
19.6	24
11.5	11
7.7	3

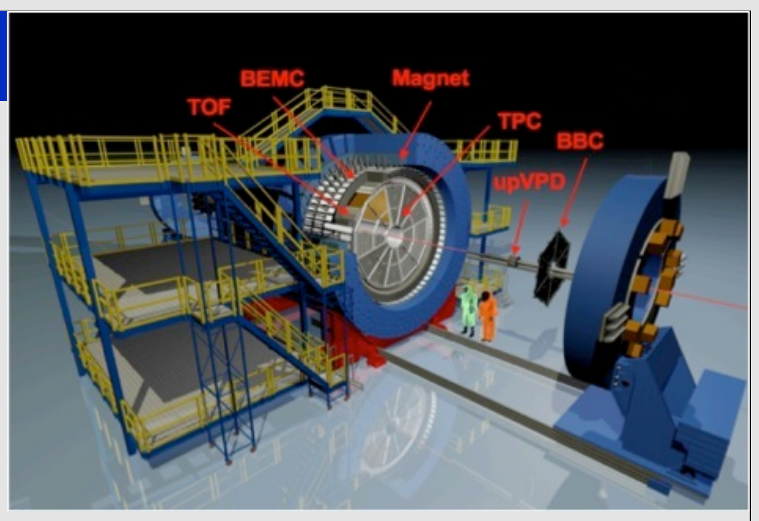

Fig.3 : 3D view of the STAR Experiment.

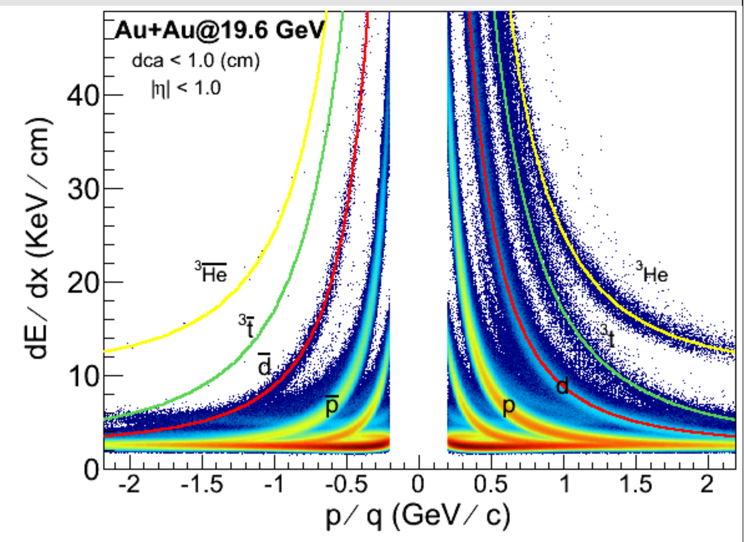

Fig.4 : Mean specific energy loss <dE/dx> as a function of rigidity.

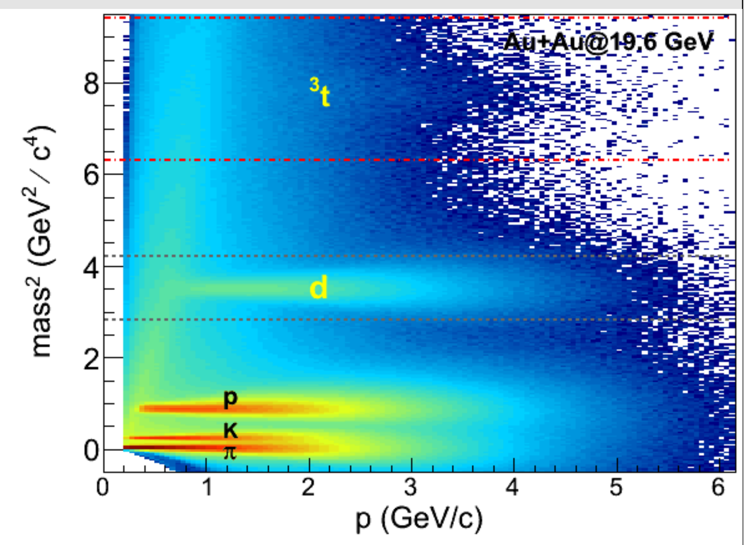

Fig.5 : (Mass)^2 as a function of momentum of charged particles.

3. Invariant yields vs. p_T

- p_T spectra are corrected for tracking efficiency and TOF matching efficiency.
- p_T spectra are also corrected for the absorption in detector materials and beam-pipe-fragment contamination effects.

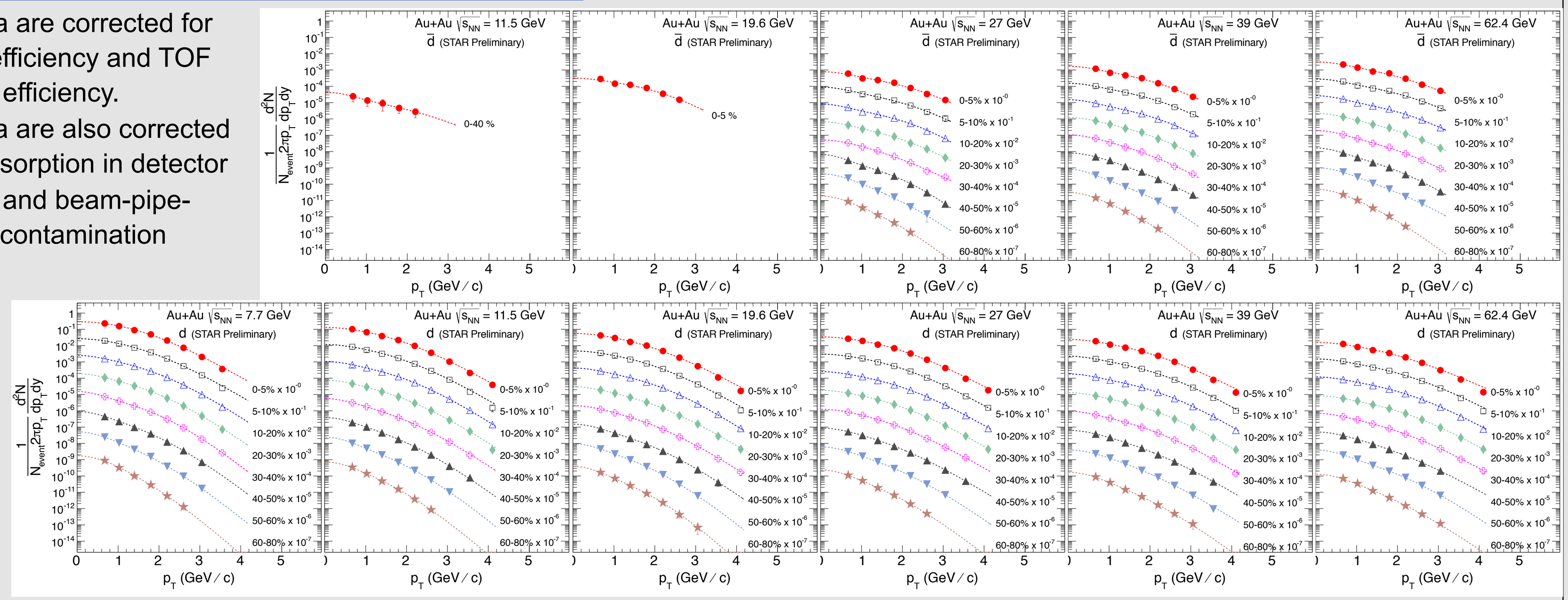

Fig.6 : p_T spectra of $\bar{d}$ (upper panel) and d (lower panel). The curves correspond to Blast-wave fit to data.

4. Results-I

- ✓ $\langle p_T\rangle$ of $\bar{d}$ and d are similar for beam energies studied.
- ✓ $\langle p_T\rangle$ of both $\bar{d}$ and d increase monotonically with increasing centrality.
- ✓ N_{part} scaled $\bar{d}$ and d yields show weak centrality dependence.
- ✓ both B_2 and $\bar{B}_2$ decrease with increasing centrality for all beam energies indicating the correlation volume (V_f) increases with increasing centrality.
- ✓ Both B_2 and $\bar{B}_2$ show weak energy dependence.

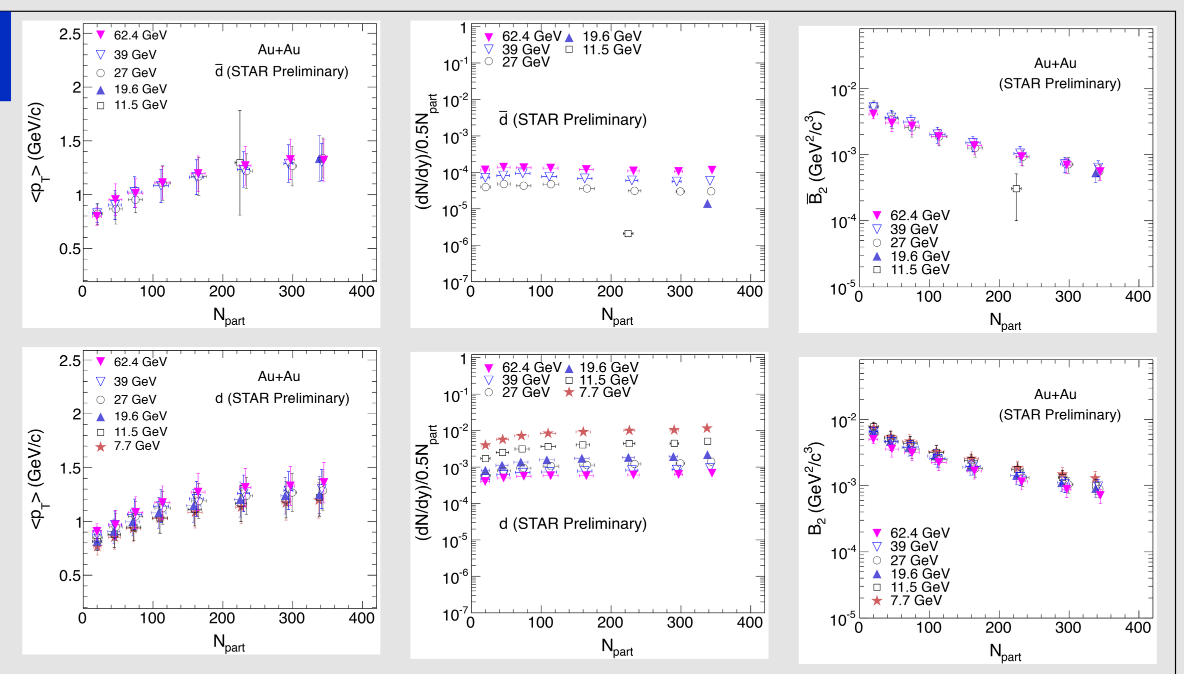

Fig.7 : Centrality dependence of $\langle p_T\rangle$, N_{part}-scaled integrated yield and B_2 of $\bar{d}$ (upper panel) and d (lower panel).

5. Results-II Energy dependence of B_2 and $d/\bar{p}$

- ✓ The measurements of B_2 of $\bar{d}$ and d performed in this analysis are shown by open and filled star symbol respectively, in Fig. 8.
- ✓ B_2 measurements in this work are consistent with other previous measurements in similar energies.
- ✓ B_2 is almost constant with respect to energy This indicates that the source volume does not change appreciably with center-of-mass energy (with the caveat that B_2 varies as a function of centrality).
- ✓ $\bar{d}/\bar{p}$ ratio measured in this analysis consistent with the previous measurement in the similar energy range.
- ✓ $\bar{d}/\bar{p}$ ratio increases monotonically with beam energies and reaches a plateau above ISR beam energy regardless of the beam species.

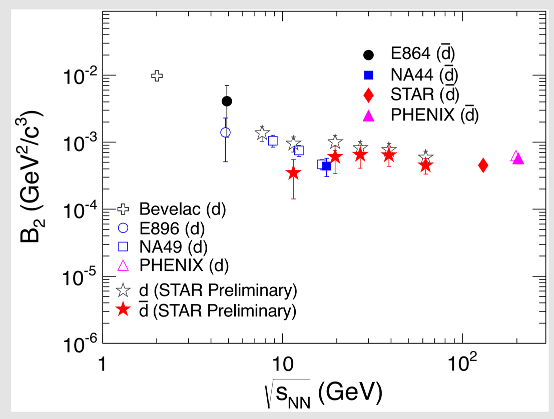

Fig.8 : B_2 measured in $\sqrt{s_{NN}}$ = 7.7, 11.5, 19.6, 27, 39 and 62.4 GeV (open and solid star).

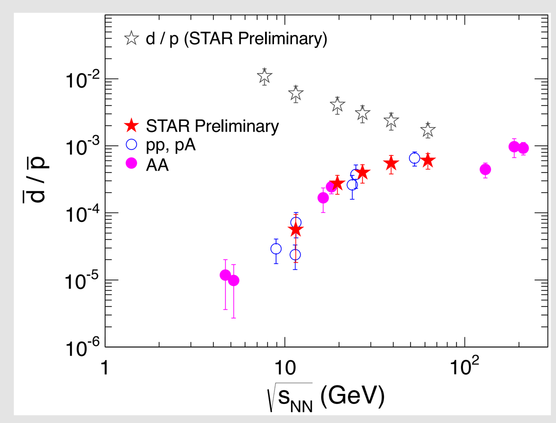

Fig.9 : $\bar{d}/\bar{p}$ measured in $\sqrt{s_{NN}}$ = 7.7, 11.5, 19.6, 27, 39 and 62.4 GeV (open and solid star).

6. Summary

- Light nuclei p_T spectra are presented for Au+Au collisions at $\sqrt{s_{NN}}$ = 7.7, 11.5, 19.6, 27, 39 and 62.4 GeV.
- $\langle p_T\rangle$ of $\bar{d}$ and d are almost same and show weak energy dependence.
- N_{part} scaled $\bar{d}$ and d yields shows no significant centrality dependence.
- B_2 of $\bar{d}$ and d shows strong centrality dependence but no significant beam energy dependence.
- $\bar{d}/\bar{p}$ ratio increases monotonically with beam energies and reaches a plateau above ISR beam energy regardless of the beam species.

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