Production of Light Nuclei in Au+Au Collisions with the STAR BES-II Program

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Abstract

The studies of the production of light nuclei, such as deuteron, triton, and helium nuclei in heavy-ion collisions, are essential for understanding the dynamics of nuclear matter under extreme conditions. In addition, the yields of light nuclei and their ratios serve as an effective method for distinguishing between the thermal and coalescence models. The significantly larger datasets from the STAR Beam Energy Scan phase-II, combined with enhanced detector capabilities, allow for more precise and comprehensive measurements compared to phase-I.

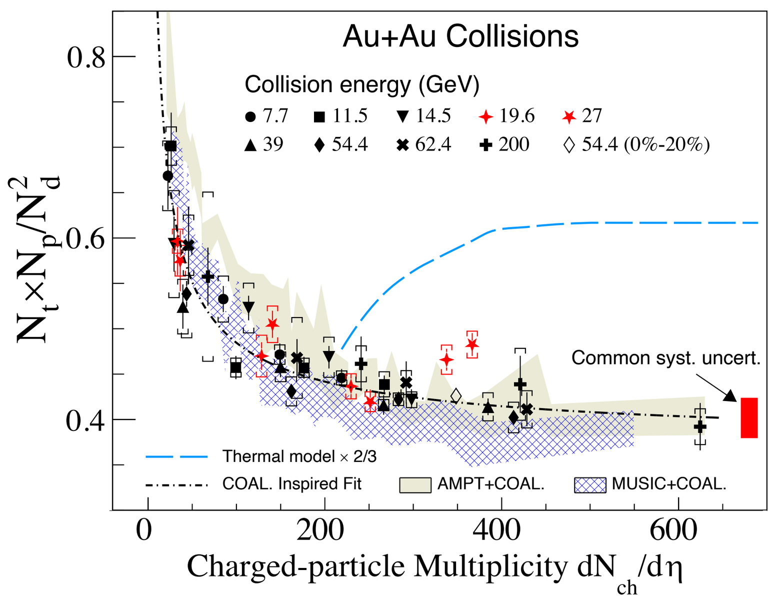
In this poster, we will present measurements of light nuclei production, including $\mathrm{p}, \bar{\mathrm{p}}, \mathrm{d}, \bar{\mathrm{d}}, {}^3\mathrm{He}$ in Au+Au collisions at BES-II energies of $\sqrt{s_{\mathrm{NN}}}$ = 7.7–27 GeV. The results will cover the centrality dependence of transverse momentum (p_{T}) spectra and dN/dy. We will also report the coalescence parameters (B_{A}) and the particle ratios. The physics implications of these results will be discussed.

Introduction

- QCD phase transition expectations
  - Low baryon density: crossover.
  - High baryon density: 1st-order phase boundary.
  - Intermediate baryon density: critical point (between crossover and 1st-order phase transition line).
- Light nuclei, such as deuteron and ${}^3\mathrm{He}$, are loosely bound objects with small binding energies. These are formed via coalescence of nucleons [1, 2].

$$E_{\mathrm{A}}\frac{d^3N_{\mathrm{A}}}{d^3p_{\mathrm{A}}} = B_{\mathrm{A}}\left(E_{\mathrm{p}}\frac{d^3N_{\mathrm{p}}}{d^3p_{\mathrm{p}}}\right)^{Z}\left(E_{\mathrm{n}}\frac{d^3N_{\mathrm{n}}}{d^3p_{\mathrm{n}}}\right)^{A-Z} \approx B_{\mathrm{A}}\left(E_{\mathrm{p}}\frac{d^3N_{\mathrm{p}}}{d^3p_{\mathrm{p}}}\right)^{A}.$$

where A and Z are the mass and charge number of the nucleus. B_{A} is the coalescence parameter.



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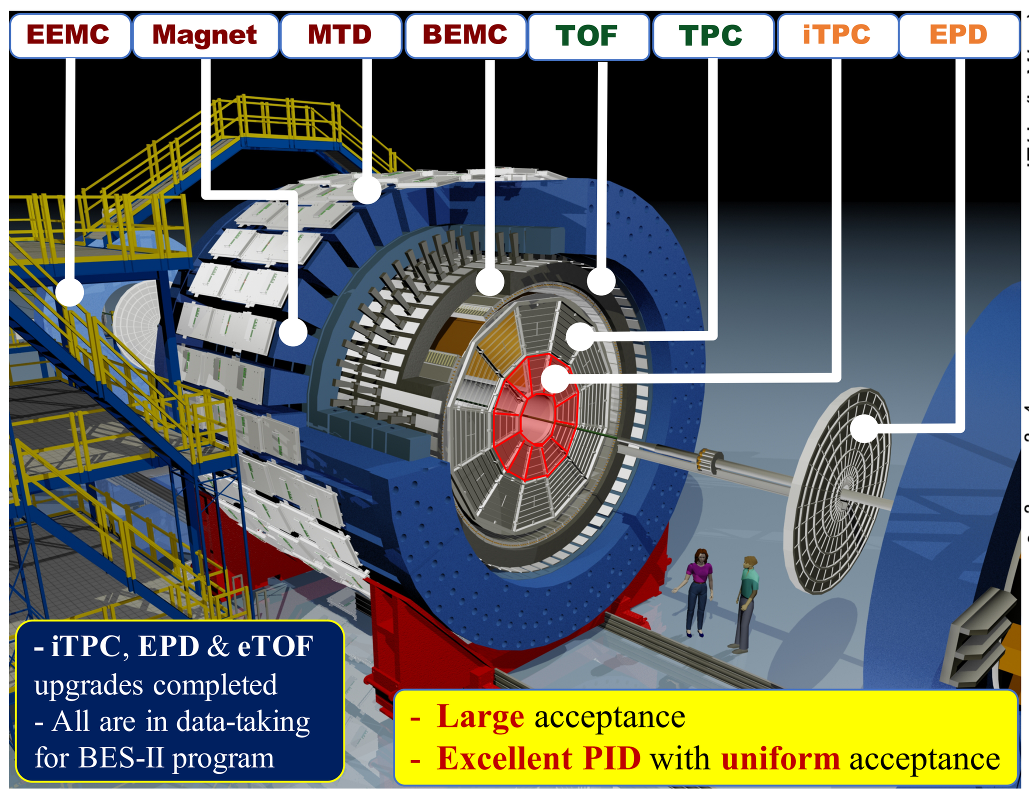
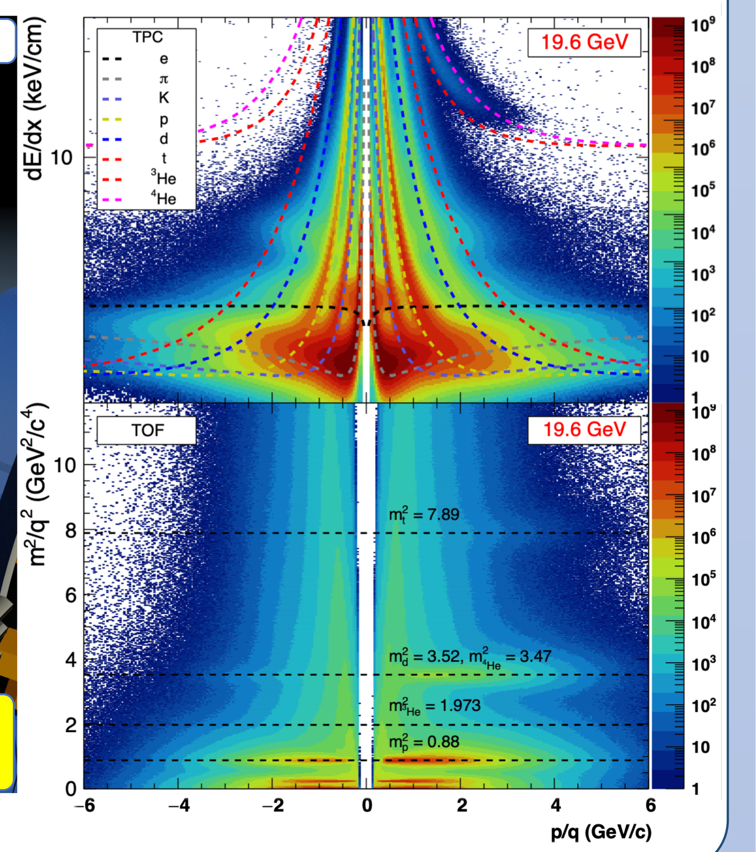
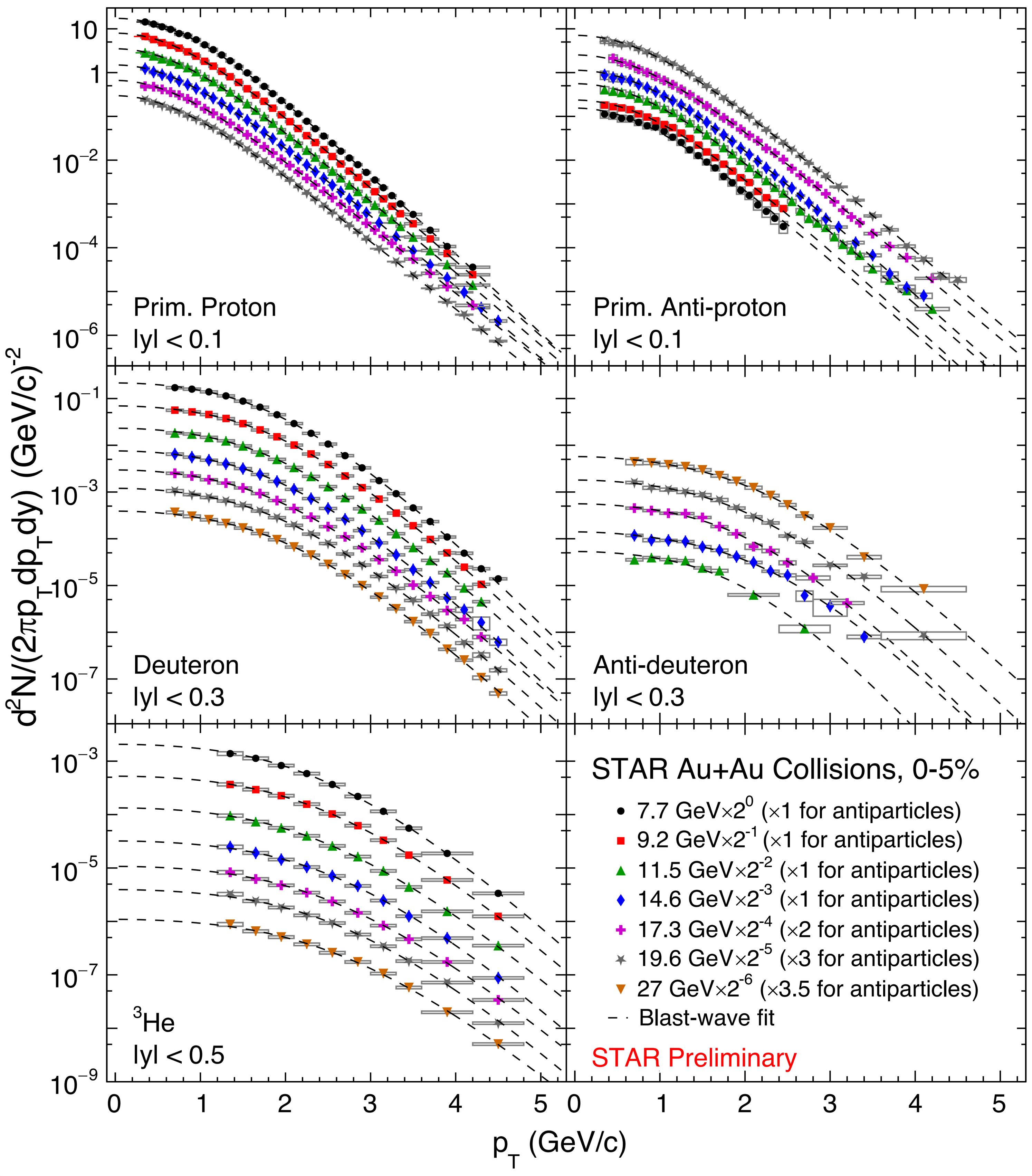
- Due to the increasing correlation length and a formation of an instability in the spinodal domain, both the critical fluctuations and first-order phase transition may induce large baryon density fluctuations [3, 4].

STAR Detector and Particle Identification

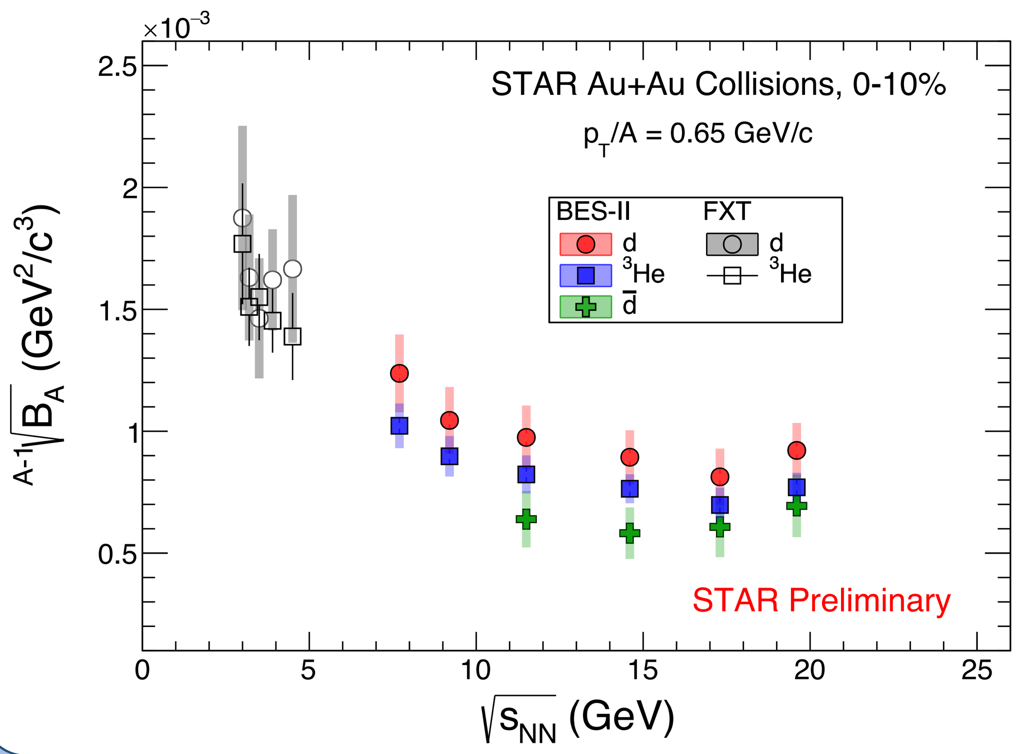




Transverse Momentum Spectra

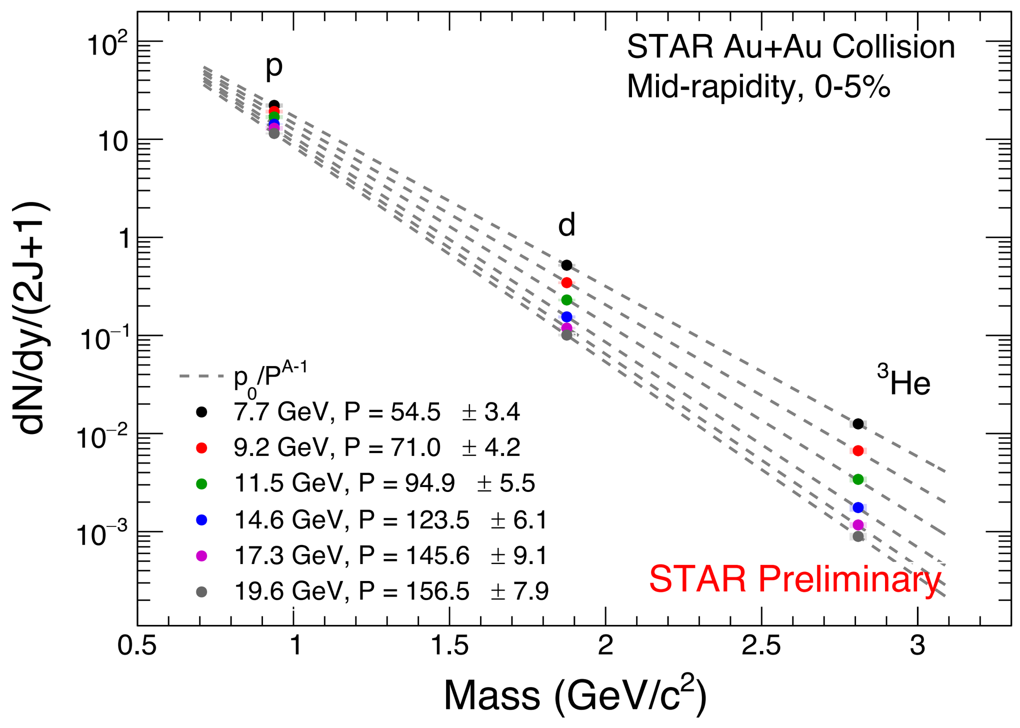


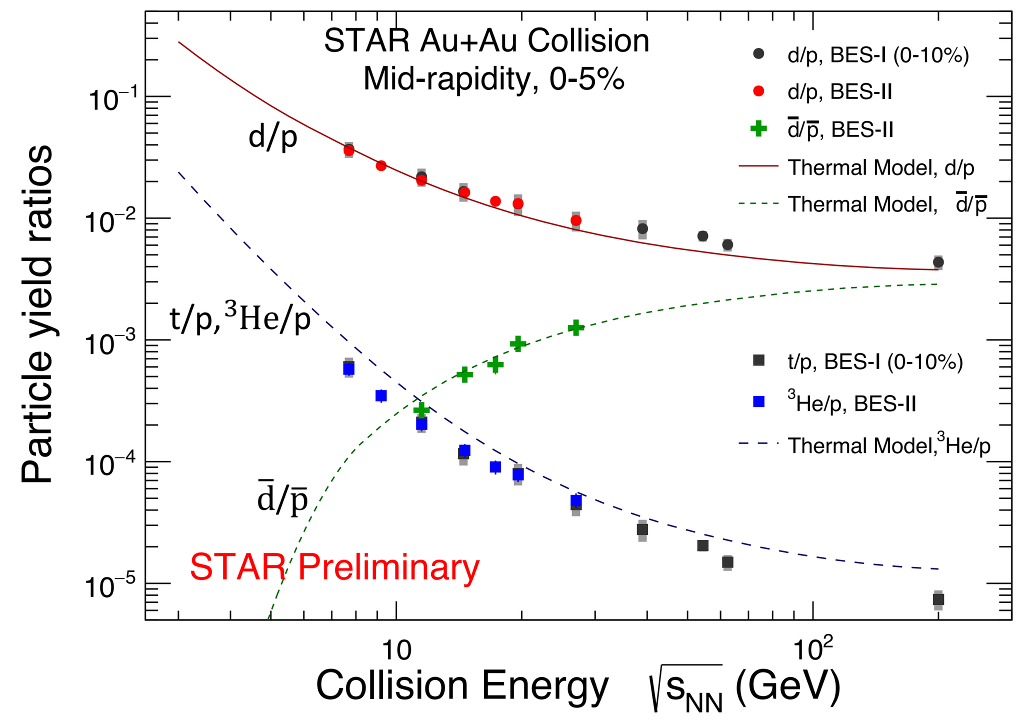
Coalescence Parameters



- The neutron in $B_2(\mathrm{d})$ and $B_3({}^3\mathrm{He})$ is replaced by proton, corrected using the n/p fraction from the thermal model. Neutron in $B_2(\bar{\mathrm{d}})$ is replaced by anti-proton.
- $^{A-1}\sqrt{B_A}$ decrease with increasing energy due to the larger effective volume [2, 3].
- The coalescence parameters for deuterons, anti-deuterons, and ${}^3\mathrm{He}$ are consistent within 2σ.

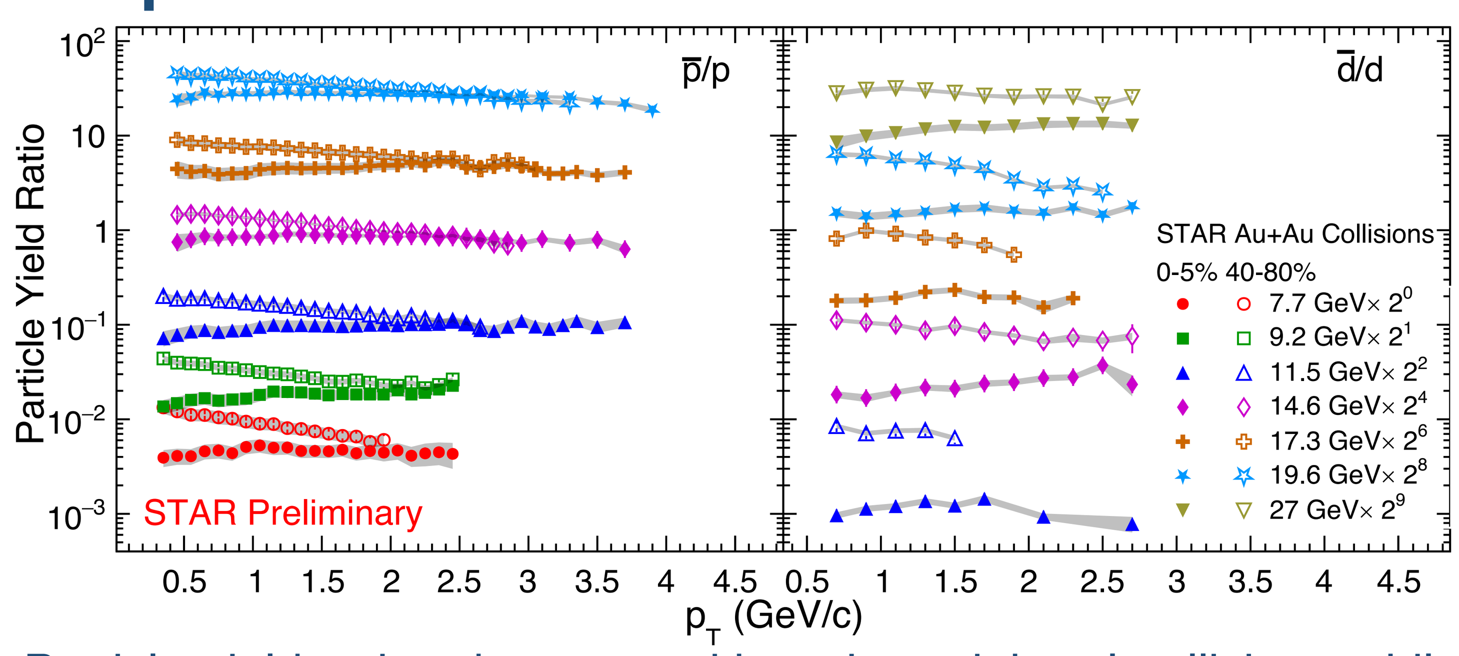
Particle Yields and Ratios





- The dN/dy/(2J+1) follows p_0/P^{A-1}, with p_0 and P as fit parameters and A the mass number. The penalty factor P increases with increasing beam energy, which can be attributed to the decrease in baryon density, leading to a reduced probability of forming high-mass clusters.
- The d/p and $\bar{\mathrm{d}}/\bar{\mathrm{p}}$ ratio can be well described by the thermal model [5], while the t/p and ${}^3\mathrm{He}$/p ratios are overestimated by a factor of two approximately.

Anti-particle to Particle Ratio



- Particle yield ratios decrease with p_{T} in peripheral collisions while being more flat in central collisions for both $\bar{\mathrm{p}}$/p and $\bar{\mathrm{d}}$/d.
- The p_{T} dependence shows no obvious difference across different energies.

Summary

- We report light nuclei productions (proton, deuteron, Helium-3, and anti-proton, anti-deuteron) in Au+Au collisions at $\sqrt{s_{\mathrm{NN}}}$ = 7.7–27 GeV from RHIC STAR BES-II.
- The $\mathrm{N_d/N_p}$ and $\mathrm{N_{\bar{d}}/N_{\bar{p}}}$ can be described by the thermal model, but $\mathrm{N_{{}^3He}/N_p}$ are overestimated.
- Due to the larger effective volume, coalescence parameter is found to decrease with increase collisions.

References

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