Measurements on Proton and Light Nuclei Production in Au+Au Collisions by RHIC-STAR in the High Baryon Density Region

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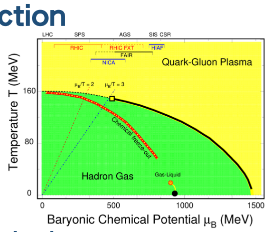
Abstract

Light nuclei, such as deuteron and triton, are loosely bound objects, and their yields are expected to be sensitive to baryon density fluctuations. They may be used to probe the signature of a first-order phase transition and/or critical point in the QCD phase-diagram. In this poster, we present the collision centrality and rapidity dependence of proton and light nuclei production in Au+Au collisions at $\sqrt{s_{NN}}$ = 3.0, 3.2, 3.5, 3.9 and 4.5 GeV recorded by the STAR experiment in fixed-target mode. The transverse momentum (p_T) spectra, coalescence parameters (B_A), particle ratios, kinetic freeze-out temperature (T_{kin}), and collective velocity (β_T) are shown and compared with results from collider energies.

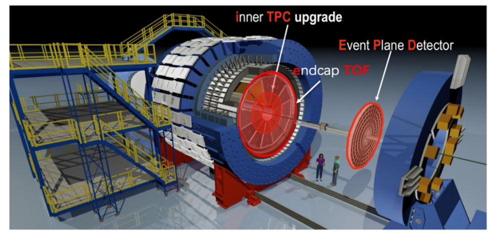
Introduction

- **QCD Phase Transition**
  - **High Temperature: QGP properties**
  - **High Baryon Density: Critical Point and 1st order phase boundary[1]**



- **Light Nuclei Production Mechanism**
  - **Thermal[2] and Coalescence[3] Approach**

The Solenoidal Tracker At RHIC (STAR)

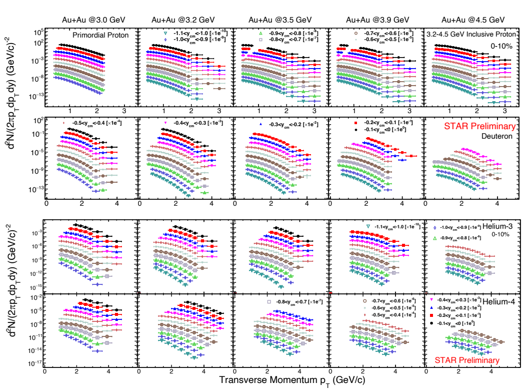


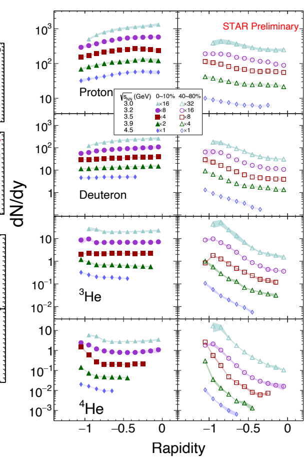
- **BES-II detector upgrade**

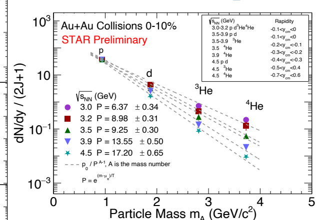
In Au+Au collisions at $\sqrt{s_{NN}}$ = 3.0, 3.2, 3.5, 3.9 and 4.5 GeV

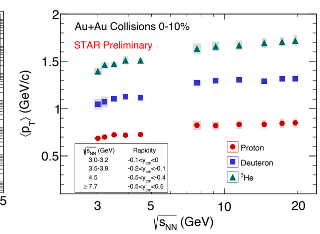
- iTPC
  cover full area, $-2.4 < \eta < 0$
  better dE/dx, $p_T > 60$ MeV/c.
- eTOF
  at the east end of STAR,
  $-2.15 < \eta < -1.55$

Light Nuclei p_T spectra, dN/dy & $< p_T >$



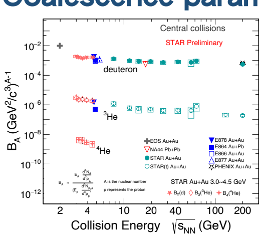


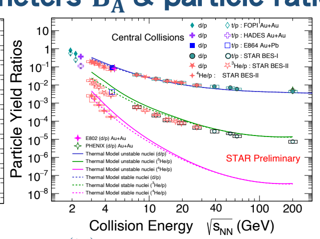




- Light nuclei with larger mass numbers show higher dN/dy from target to mid-rapidity and central to peripheral collisions, suggesting fragment contributions to their production.
- dN/dy/(2J+1) was fit with $\frac{p_0}{P^{A-1}}$, where P is the penalty factor and determined by Boltzmann factor $e^{\frac{m-\mu_B}{T}}$. P value increases with increasing beam energy, indicating suppression formation of high-mass objects at higher energies.
- Proton, deuteron and ^{3}He $<p_T>$ increases below $\sqrt{s_{NN}}$ = 4.5 GeV, but stays flatter between $\sqrt{s_{NN}}$ = 7.7 and $\sqrt{s_{NN}}$ = 19.6 GeV. This behavior will be studied in $\sqrt{s_{NN}}$ = 4.5-7.7 GeV in the future.

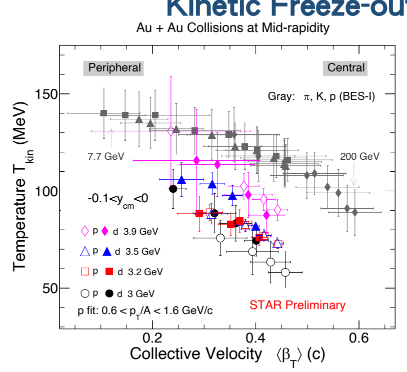
Coalescence parameters B_A & particle ratio





- $E_A \frac{d^3N_A}{d^3p_A} = B_A \left(E_p \frac{d^3N_p}{d^3p_p}\right)^Z \left(E_n \frac{d^3N_n}{d^3p_n}\right)^{A-Z} \approx B_A \left(E_p \frac{d^3N_p}{d^3p_p}\right)^A$, $B_A \propto \left(\frac{1}{V_{eff}}\right)^{(A-1)}$
- As the energy increases, B_A becomes smaller, reflecting that the effective volume of the system[4] becomes larger.
- Thermal model[5] overestimates d/p and ^{3}He/p ratios, regardless of whether feed-down from unstable nuclei is included or not. For ^{4}He/p, considering only stable nuclei, thermal model is consistent with the experiment data.

Kinetic Freeze-out Dynamics



- The differing trends in T_{kin} and $<\beta_T>$ for protons and deuterons ($\sqrt{s_{NN}}$ = 3.0-3.9 GeV) imply they share distinct kinetic freeze-out surfaces.
- For $\sqrt{s_{NN}}$ = 3.0-3.9 GeV, proton T_{kin} increases with energy while $<\beta_T>$ stays approximately constant. This trend is different for $\sqrt{s_{NN}} \geq 7.7$ GeV, may implying a different medium equation of state (EoS).

Summary

- We presented light nuclei production (p_T spectra, dN/dy, $<p_T>$, particle ratio, and B_A) and kinetic freeze-out parameters (T_{kin}, $<\beta_T>$) in Au+Au collisions at $\sqrt{s_{NN}}$ = 3.0-4.5 GeV by STAR experiment, studying their rapidity and energy dependence.
- The thermal model overestimates light nuclei ratio d/p and ^{3}He/p, but consistent with ^{4}He/p only considering stable nuclei.
- The extracted kinetic freeze-out parameters (T_{kin}, $<\beta_T>$) may imply that the equation of state describing the hot, dense nuclear matter at low collision energies ($\sqrt{s_{NN}}$ = 3.0-3.9 GeV) differs from that observed at higher energies.

References

[1] X. F. Luo et al., PHYSICS 50, 98-107 (2021)

[2] A. Andronic et al., Nature 561, 321-330 (2018)

[3] K. J. Sun et al., Phys. Lett. B 792, 132-137 (2019)

[4] V. Gaebel et al., arXiv: 2006.12951 (2020)

[5] V. Vovchenko et al., Phys. Rev. C 93, 064906 (2016)

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