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Light Nuclei (d, t) Production in Au + Au Collisions at $\sqrt{s_{NN}}$ = 7.7 – 200 GeV

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  - **Data Corrections**
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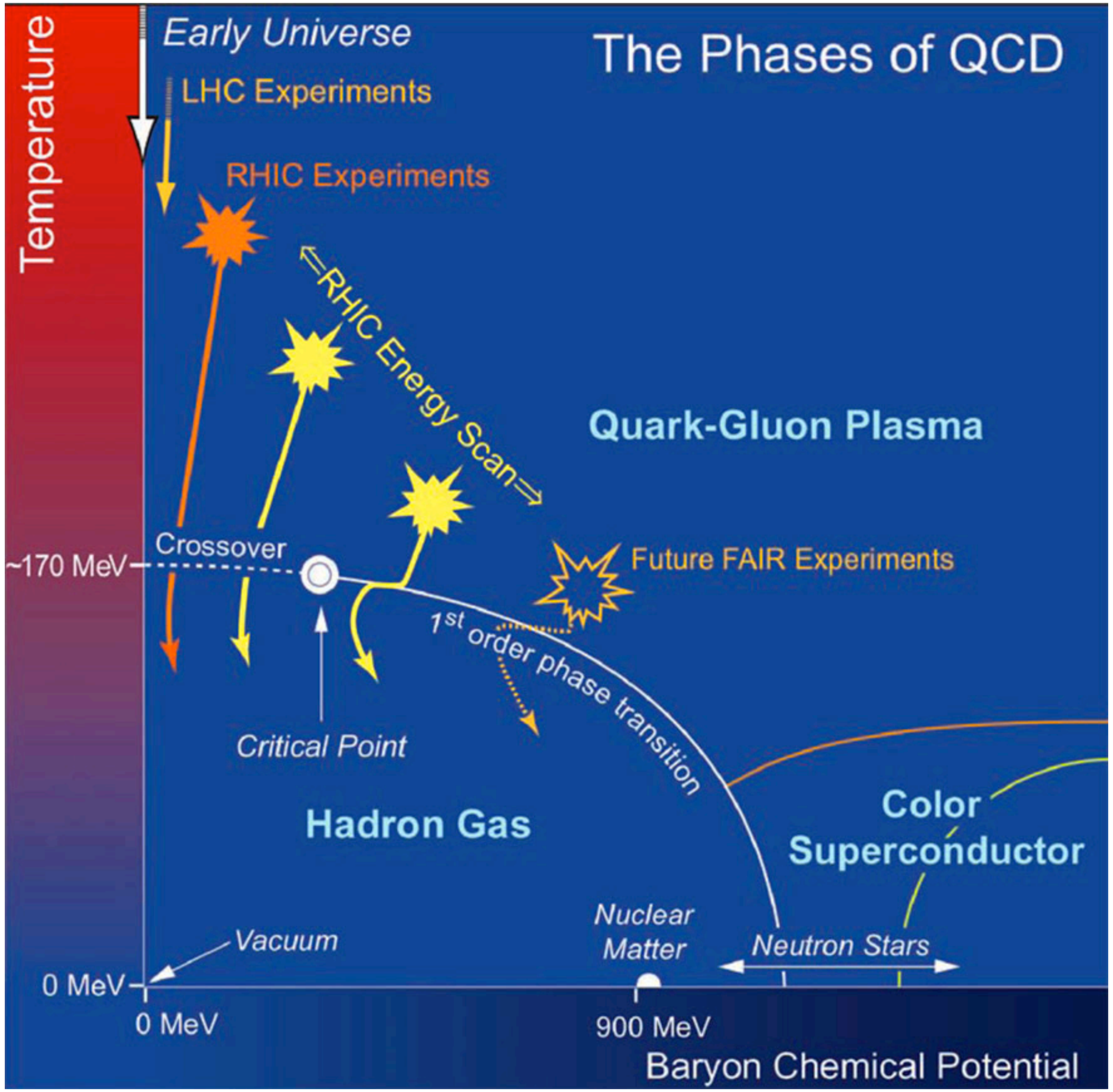
Introduction and Motivation – QCD Phase Diagram

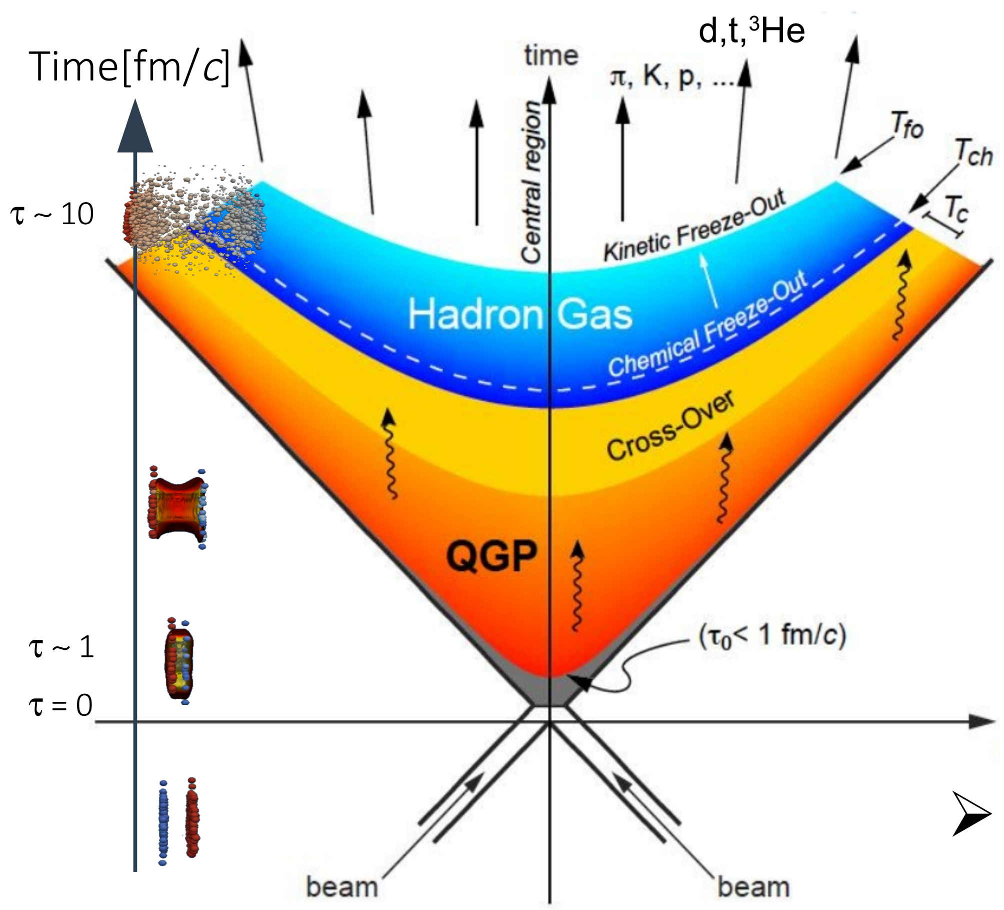


RHIC STAR Beam Energy Scan[1, 2]

$\sqrt{s_{NN}}$ (GeV)	Year	Events (10^6)	μ_B (MeV)
7.7	2010	4	420
11.5	2010	11	315
14.5	2014	27	260
19.6	2011	40	205
27	2011	71	155
39	2010	133	115
54.4	2017	1200	83
62.4	2010	67	72
200	2011	480	20

[1] M.M. Aggarwal et al. (STAR Collaboration), arXiv: 1007.2613
[2] BES-II whitepaper: http://drupal.star.bnl.gov/STAR/starnotes/public/sn0598

Light Nuclei Production – HIC



- **Coalescence picture:** Production of light nuclei with small binding energy, such as triton (8.48 MeV), deuteron (2.2 MeV), formed via final-state coalescence, are sensitive to the local nucleon density [3].

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

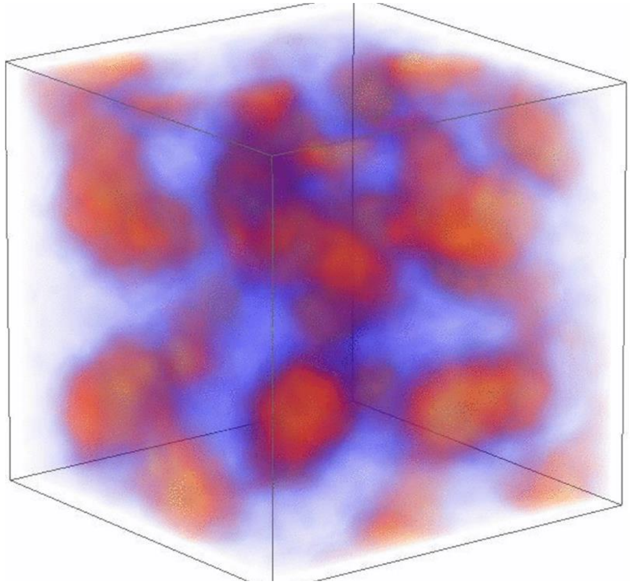
$$B_A = \frac{4\pi}{3} p_0^{3(A-1)} \frac{1}{A!} \frac{M}{m^A} \qquad B_A \propto V_f^{1-A}$$

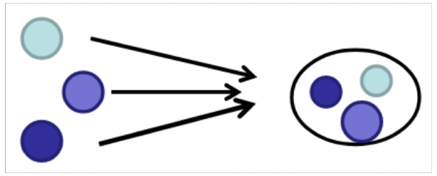
- The coalescence parameter, B_A, reflects the local nucleon density
- In thermal model, $B_A \propto V_f^{1-A}$, V_f is freeze-out volume [4]

[3] László P. Csernai, Joseph I. Kapusta Phys. Reps, 131,223(1986).; [4] A.Z. Mekjian, Phys. Rev. C 17, 1051 (1978).

Light Nuclei Production – Baryon Density Fluctuations

- In the vicinity of the critical point or the first order phase transition, density fluctuations become larger





$$N_d = \frac{3}{2^{1/2}}\left(\frac{2\pi}{m_0 T_{eff}}\right)^{3/2} N_p\langle n\rangle(1 + C_{np})$$

$$N_t = \frac{3^{\frac{3}{2}}}{4}\left(\frac{2\pi}{m_0 T_{eff}}\right)^{3} N_p\langle n\rangle^2(1 + \Delta n + 2C_{np})$$

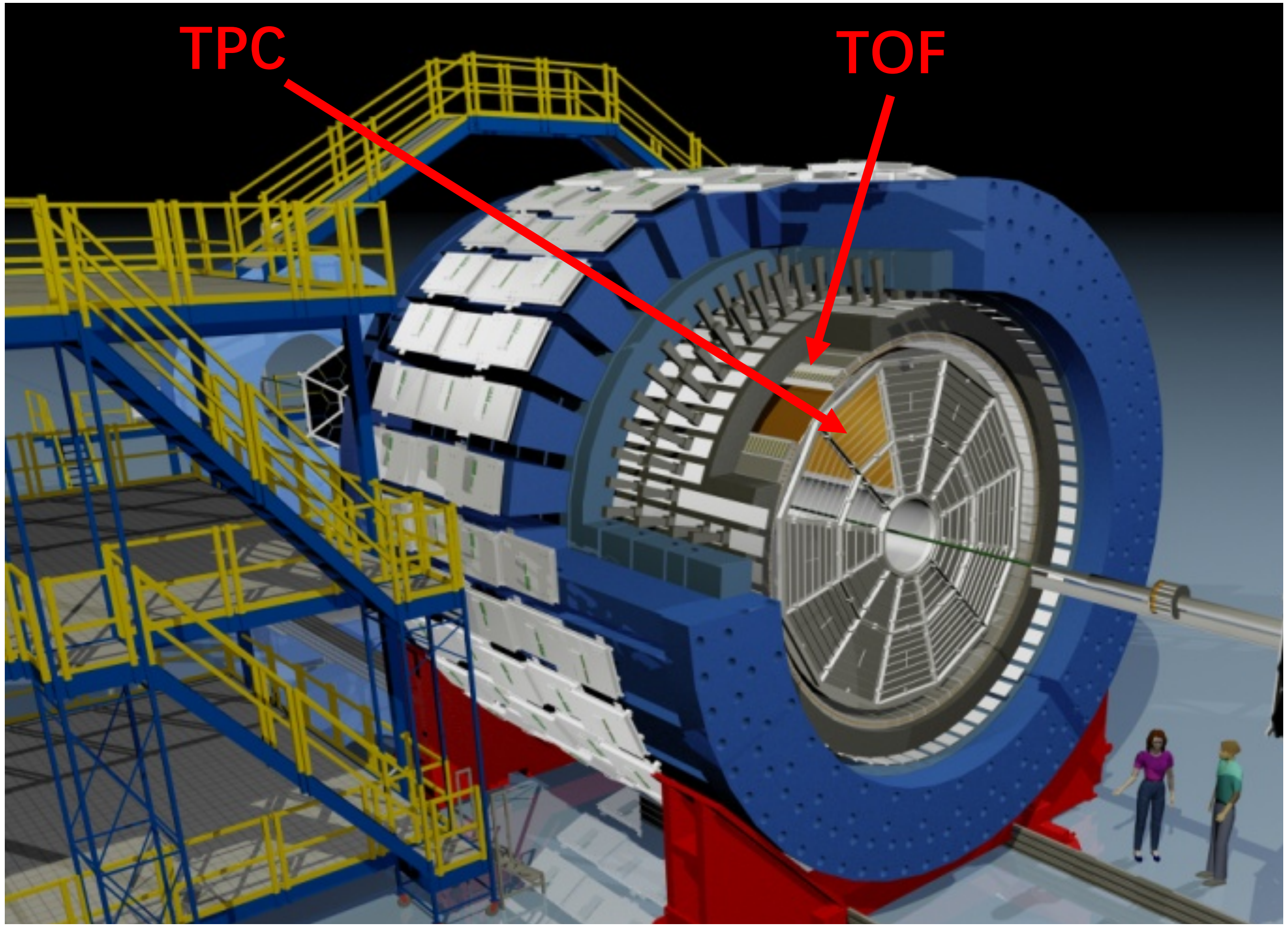
C_{np} characterizes the neutron and proton density correlation.

When $C_{np} = 0$, $\boldsymbol{N_t \cdot N_p/N_d^2 = g(1 + \Delta n)}$ [5].

- Experimentally, one can measure the light nuclei yield ratio to probe the QCD critical point or first order phase transition

[5] *K. J. Sun, L. W. Chen, C. M. Ko, J. Pu, Z. Xu, Phys. Lett. B781, 499 (2018).*

The Solenoidal Tracker At RHIC (STAR)



Time Projection Chamber (TPC)

- ✓ Charged Particle Tracking
- ✓ Momentum reconstruction
- ✓ Particle identification from ionization energy loss (dE/dx)
- ✓ Pseudorapidity coverage $|\eta| < 1.0$

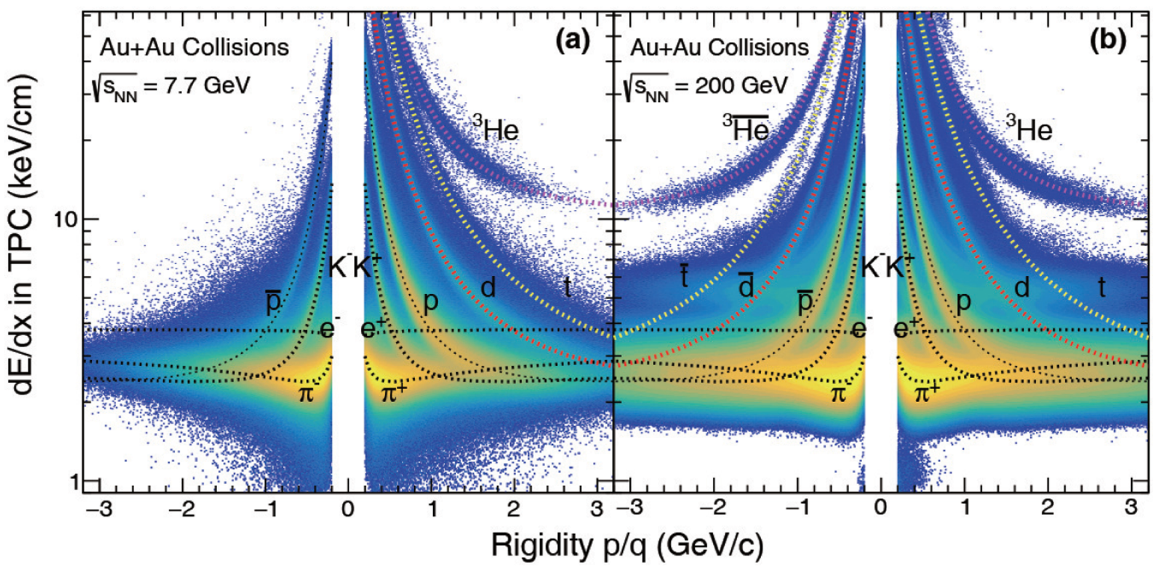
Time-of-Flight (TOF)

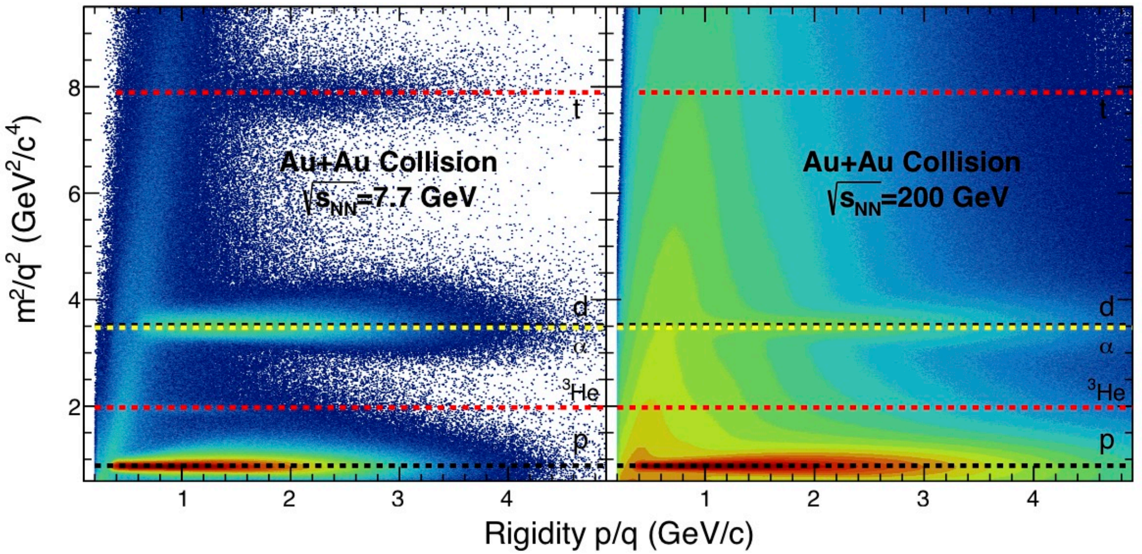
- ✓ Particle identification m^2
- ✓ Pseudorapidity coverage $|\eta| < 0.9$

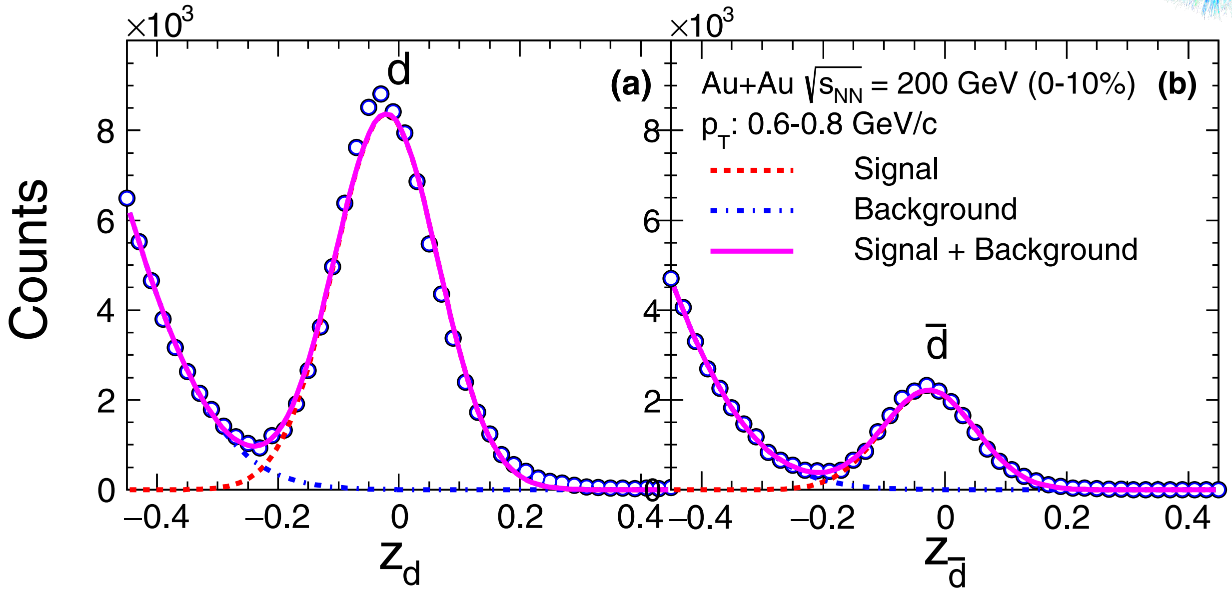
➢ **Excellent Particle Identification**

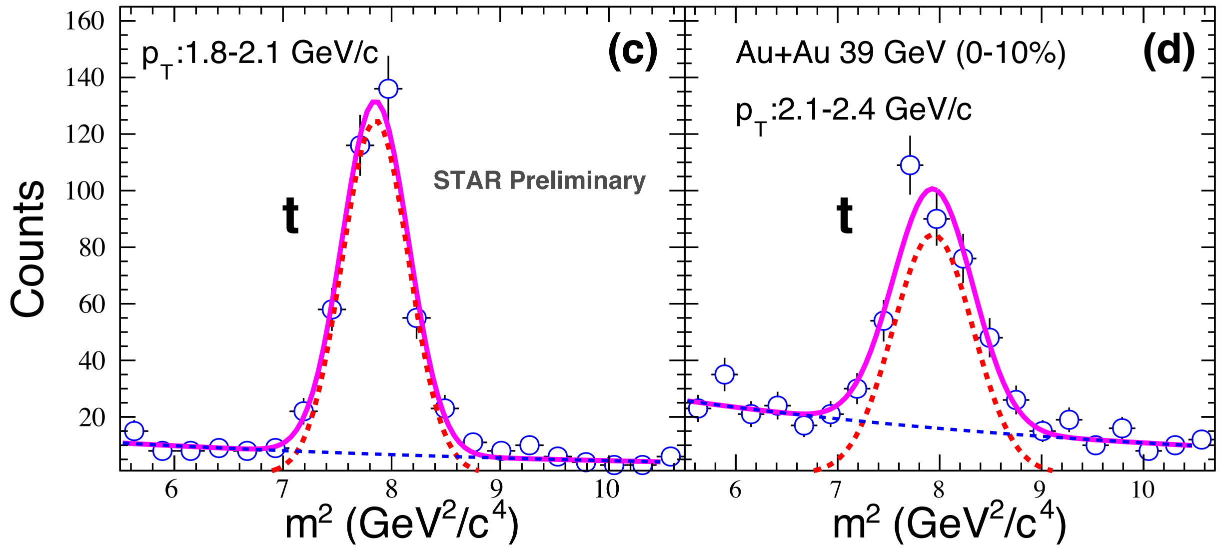
➢ **Large, Uniform Acceptance at Midrapidity**

Particle Identification



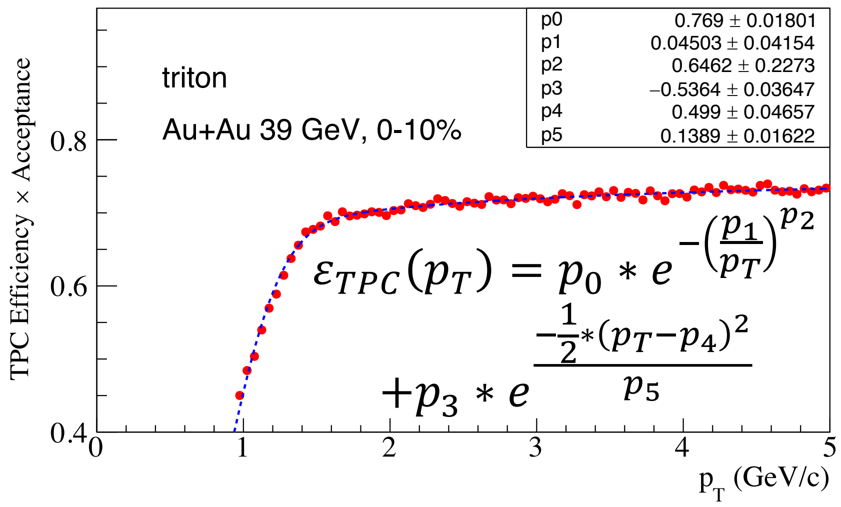


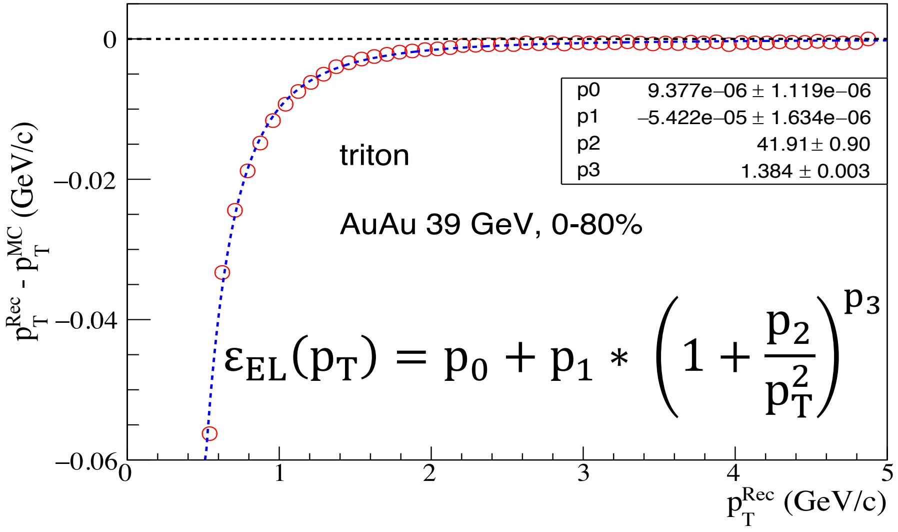


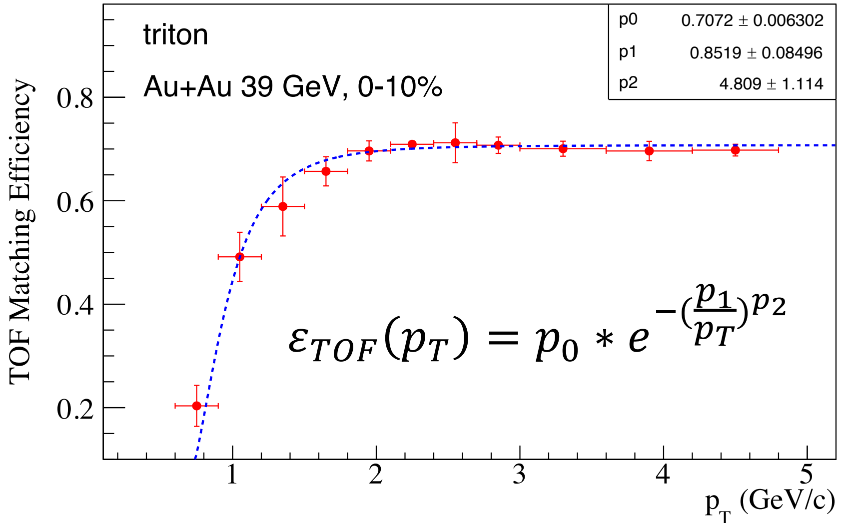


Data Corrections

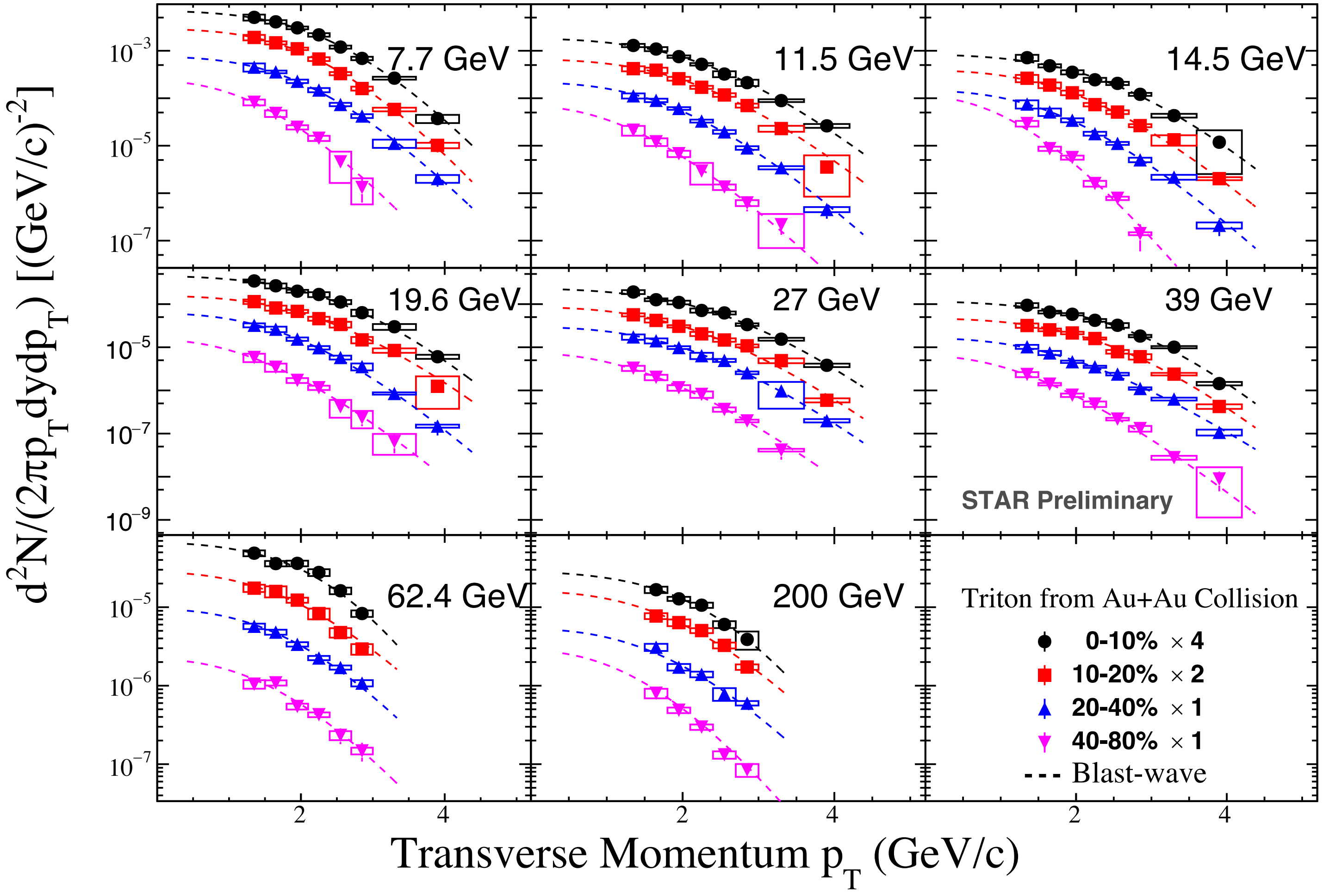
- ✓ TPC tracking efficiency
- ✓ TOF matching efficiency
- ✓ Energy loss corrections
- ✓ Absorption corrections
- ✓ Background subtraction







Transverse Momentum Spectra for Tritons (BES - I)



✭Midrapidity ($|y| \leq 0.5$) transverse momentum distributions of triton

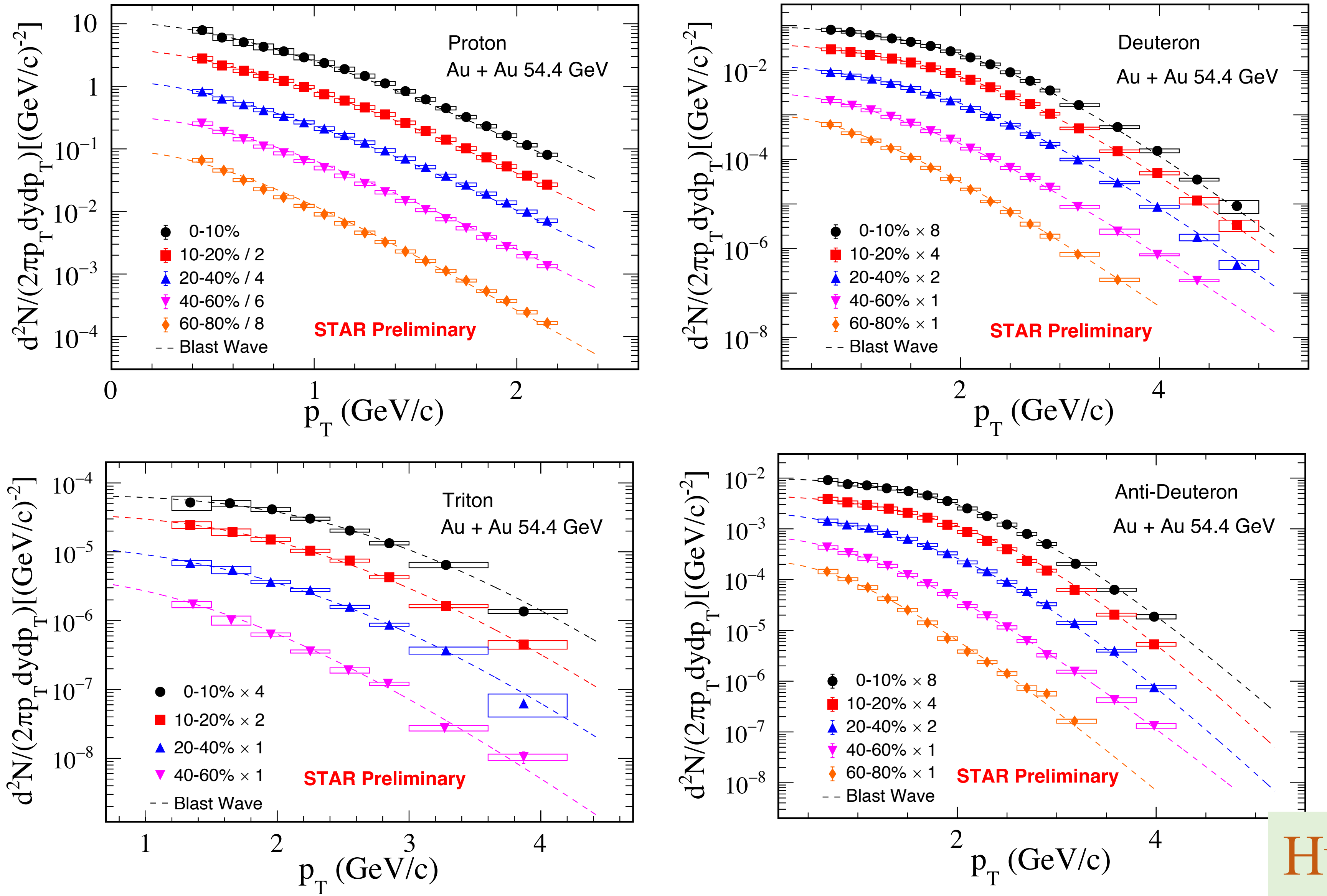
✭Vertical lines and boxes represent statistical and systematic errors respectively

✭Dash lines: blast-wave function fits [6]

$$\frac{d^2N}{p_T dp_T d_y} \propto \int_0^R r dr m_T I_0\left(\frac{p_T sinh\rho}{T}\right) K_1\left(\frac{m_T cosh\rho}{T}\right)$$

[6] *E. Schnedermann, J. Sollfrank, and U. Heinz, PRC 48,2462 (1993).*

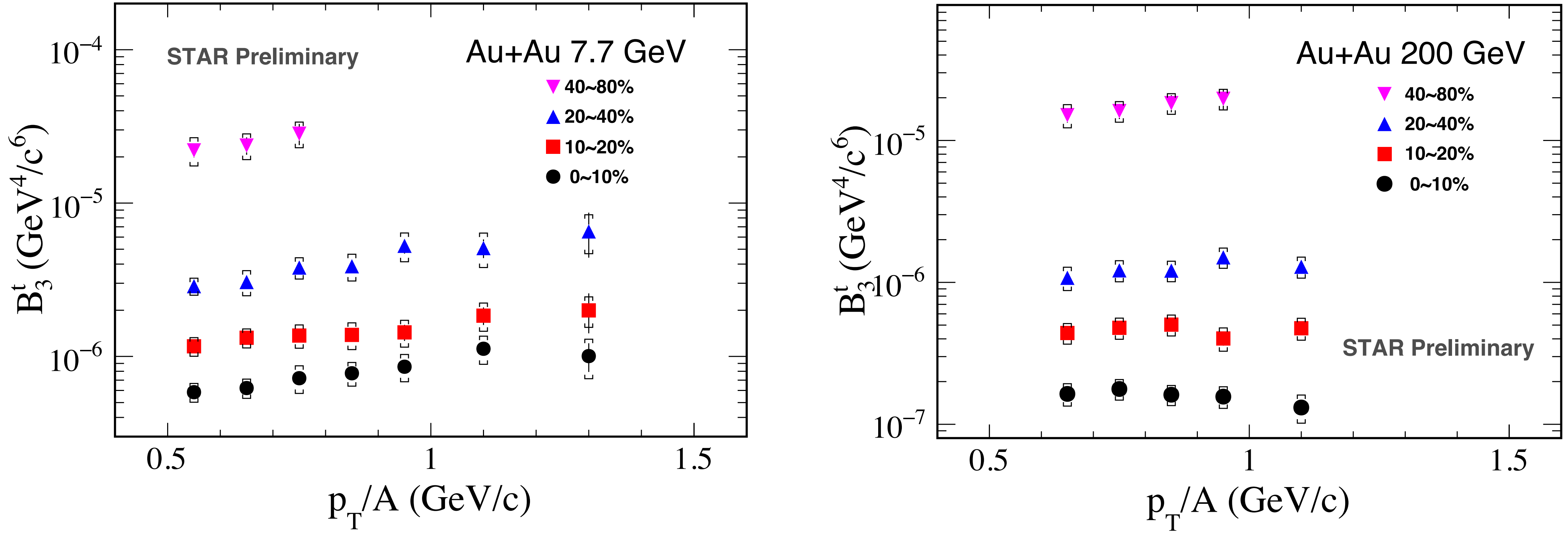
Transverse Momentum Spectra for 54.4 GeV



✯Midrapidity transverse momentum distribution of proton, (anti)deuteron and triton

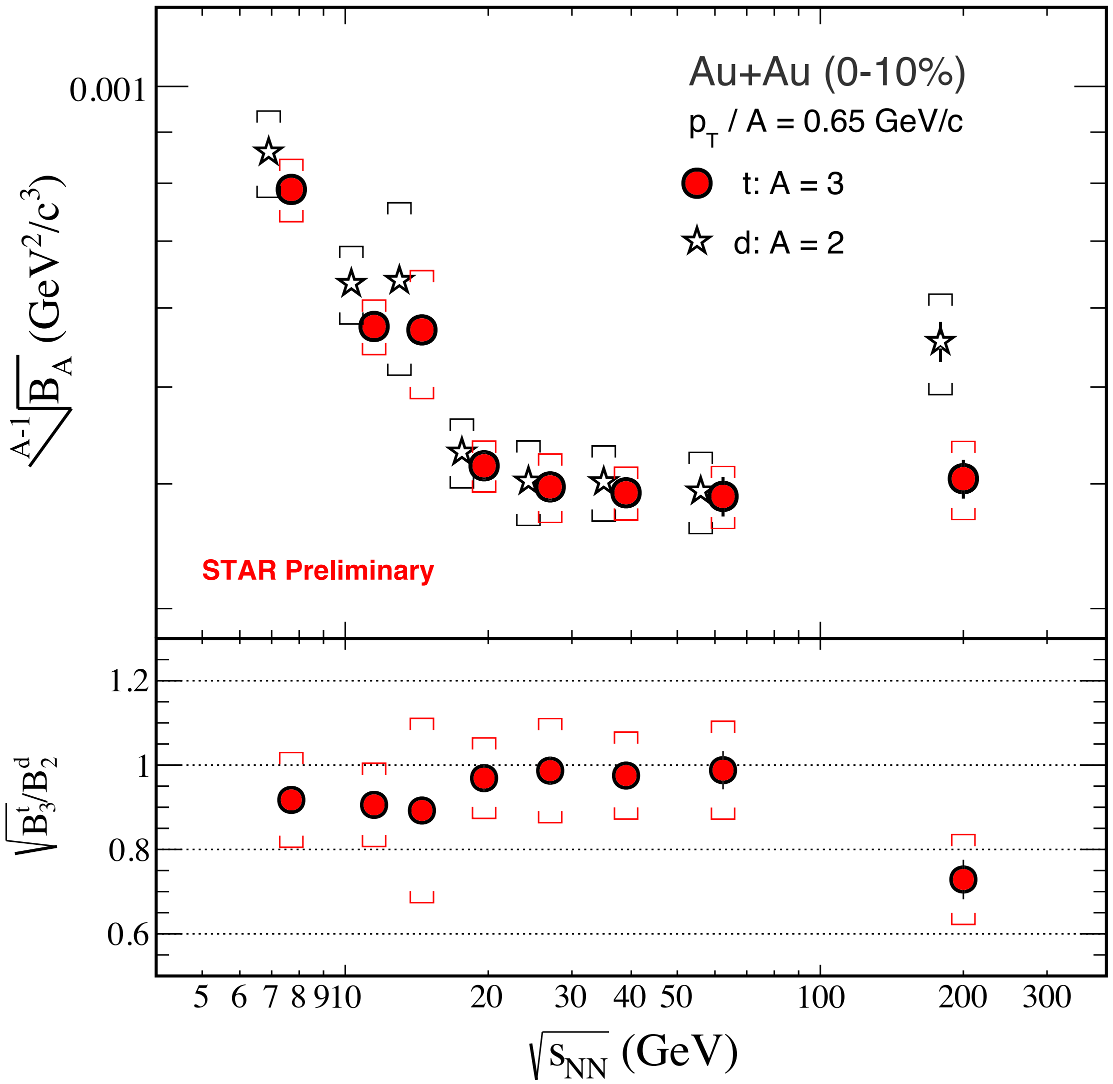
Hui Liu, Poster #389 (CP9)

Coalescence Parameters – B_3^t



☆B_3 decreases from peripheral to central collisions and with increasing collision energy.

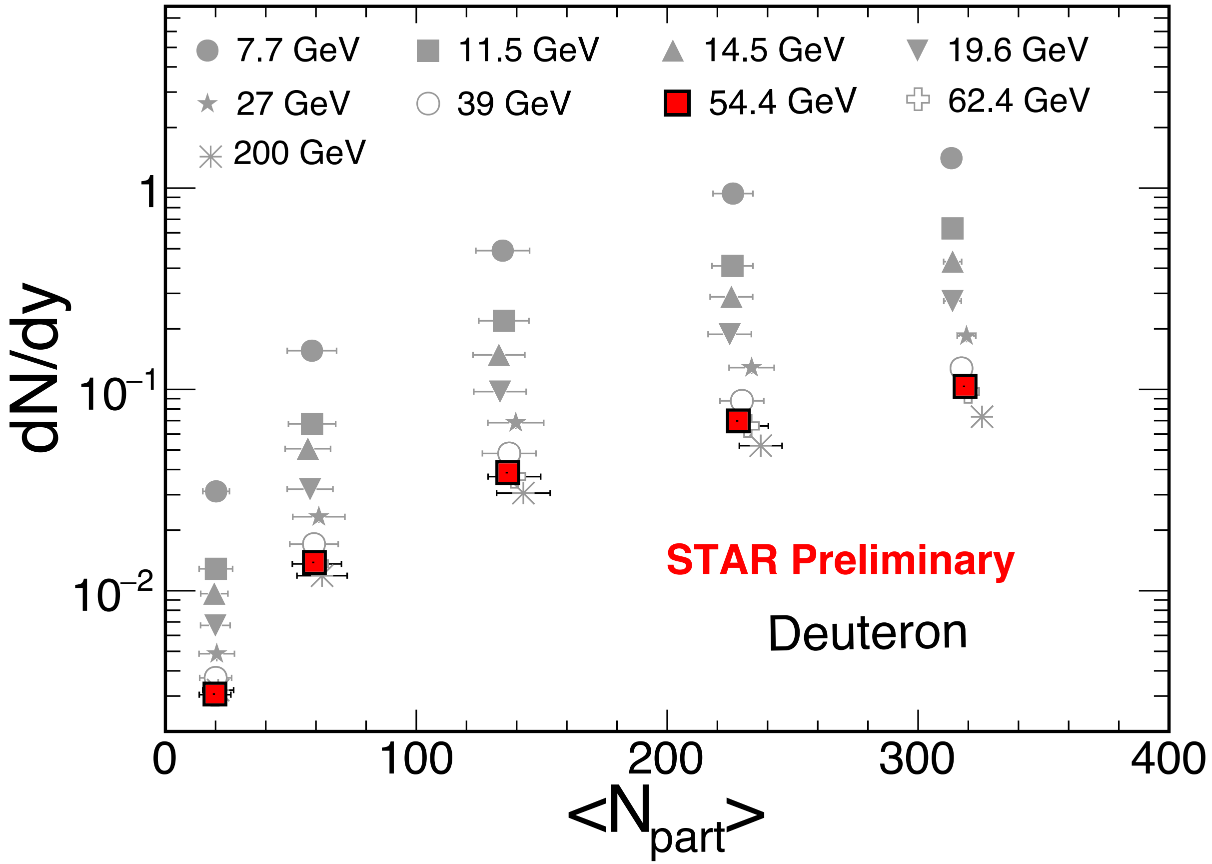
Coalescence Parameters – B_2^d, B_3^t

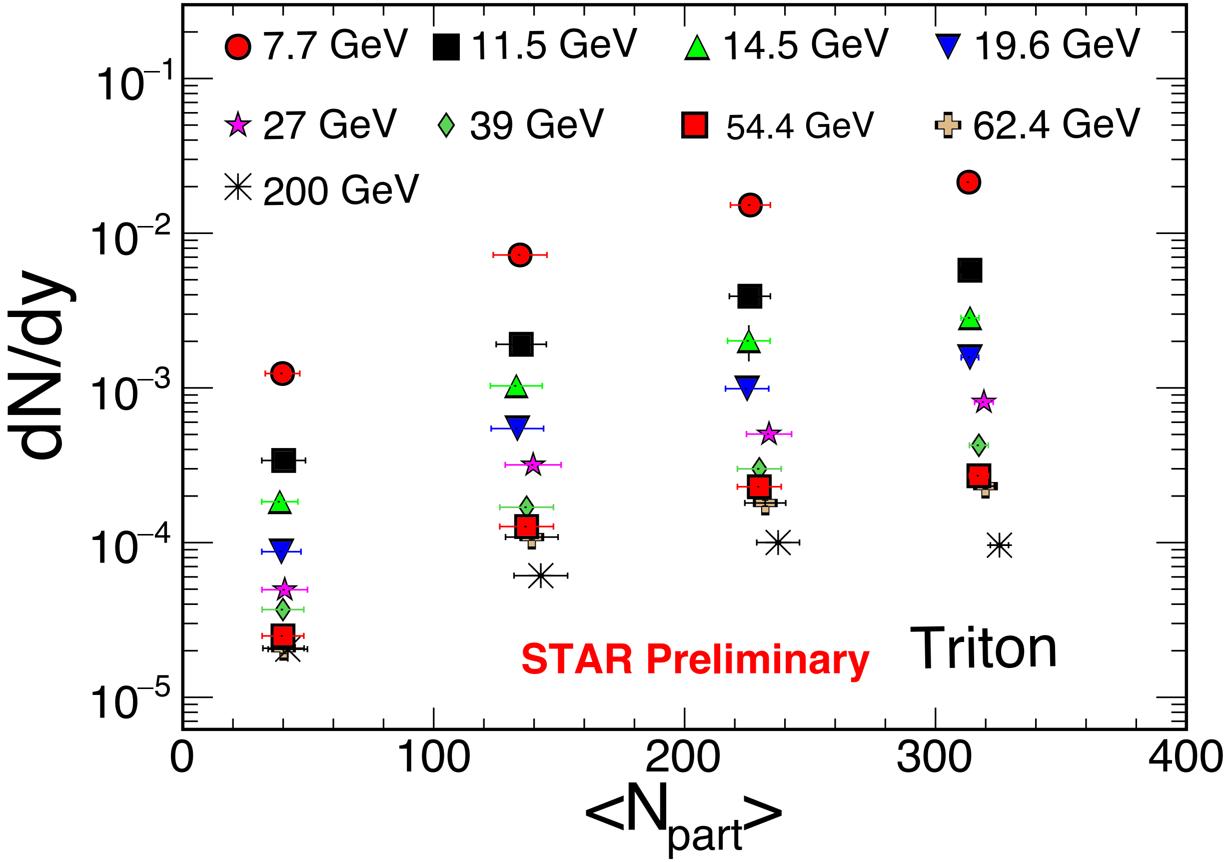


☆At energies below 20 GeV the B_2 and $\sqrt{B_3}$ decreases with increasing collision energy. For $\sqrt{s_{NN}} > 20$ GeV the rate of decrease seems to change and saturate up to 62.4 GeV. The B_2 values at 200 GeV is found to be larger than the BES saturation values [7].

[7] J. Adam et al. [STAR Collaboration], Phys. Rev. C 99, no. 6, 064905 (2019).

dN/dy Integral Yields

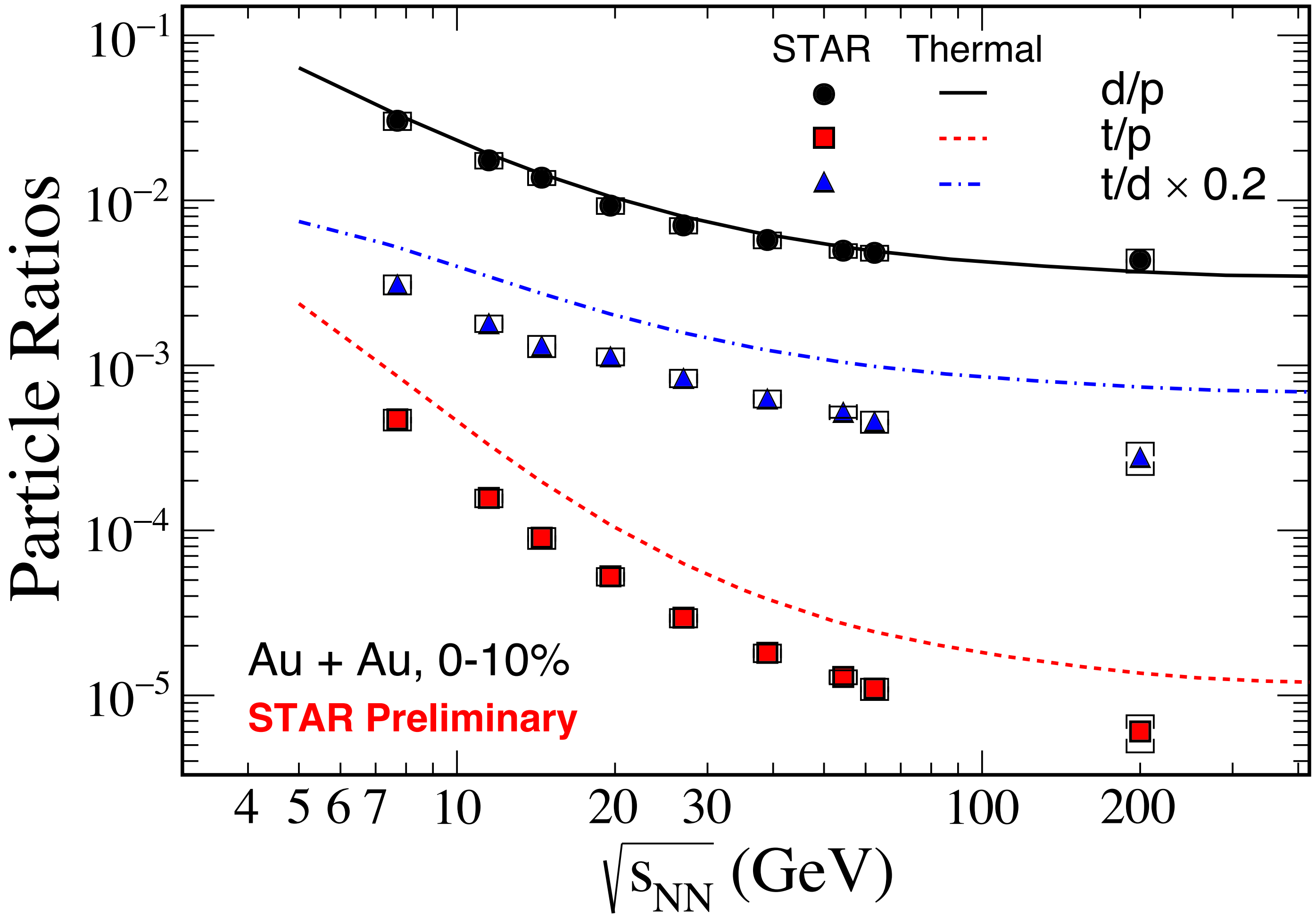




☆dN/dy increases with decreasing energy: baryon stopping.

☆dN/dy increases from peripheral to central collisions.

Particle Ratios



✯Thermal model can describe the d/p ratios [7], but can not describe the t/p, t/d ratios.

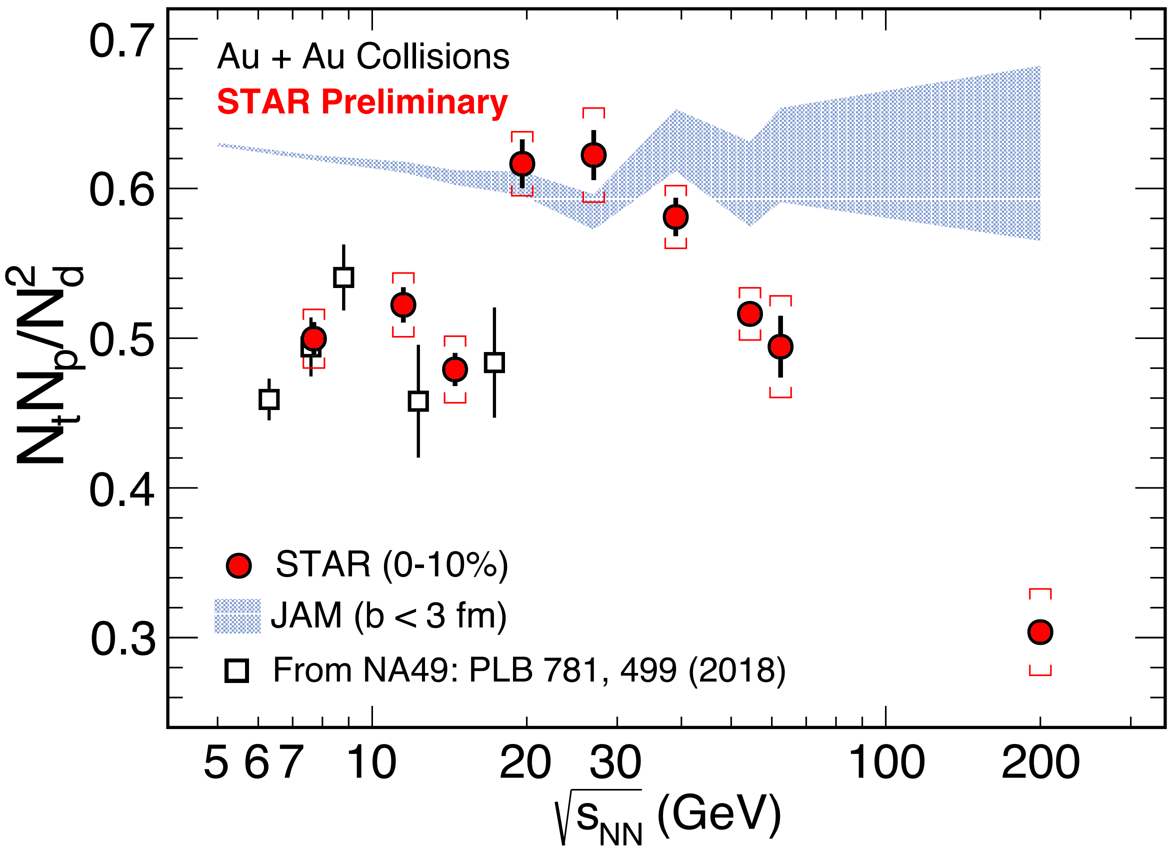
$T_{CF} = T_{CF}^{lim}/(1 + \exp(2.60 - \ln(\sqrt{s_{NN}})/0.45))$

$\mu_B = a/(1 + 0.288\sqrt{s_{NN}})$

With $\sqrt{s_{NN}}$ in GeV and T_{CF}^{lim} = 158.4 MeV and a = 1307.5 MeV [8].

[8] A. Andronic, P. Braun-Munzinger, J. Stachel, H. Stöcker, PLB697 (2011)203.

The Yield Ratio – Neutron Density Fluctuations



$$N_t \cdot N_p / N_d^2 = g(1 + \Delta n),$$

$$with\ g = 0.29$$

The yield ratio is related to neutron density fluctuations.

☆Yield ratio shows a non-monotonic dependence on collision energy in 0-10% Au + Au collisions. A peak is around 20-30 GeV.

[9] *H. Liu et al. arXiv:1909.09304v2 [nucl-th]*

☆JAM model shows a flat energy dependence of yield ratio and disagrees with the data [9].

Summary and Outlook

- We present STAR results of light nuclei ($d, \bar{d}$, and t) from Au + Au collisions at $\sqrt{s_{\mathrm{NN}}}$ = 7.7, 11.5, 14.5, 19.6, 27, 39, 54.4, 62.4, and 200 GeV.
- Coalescence parameters, B_2^d and B_3^t, are extracted for d and t, respectively. B_2^d and $\sqrt{B_3^t}$ are consistent within uncertainties except for 200 GeV.
- The thermal model can describe the d/p ratio but not t/p or t/d ratios.
- The collision-energy dependence of yield ratios shows a non-monotonic behavior at central collisions. A peak is observed around 20-30 GeV.
- Study the QCD phase structure with more statistics in BES-II at RHIC (2019-2021) …

Thank you!

Back Up

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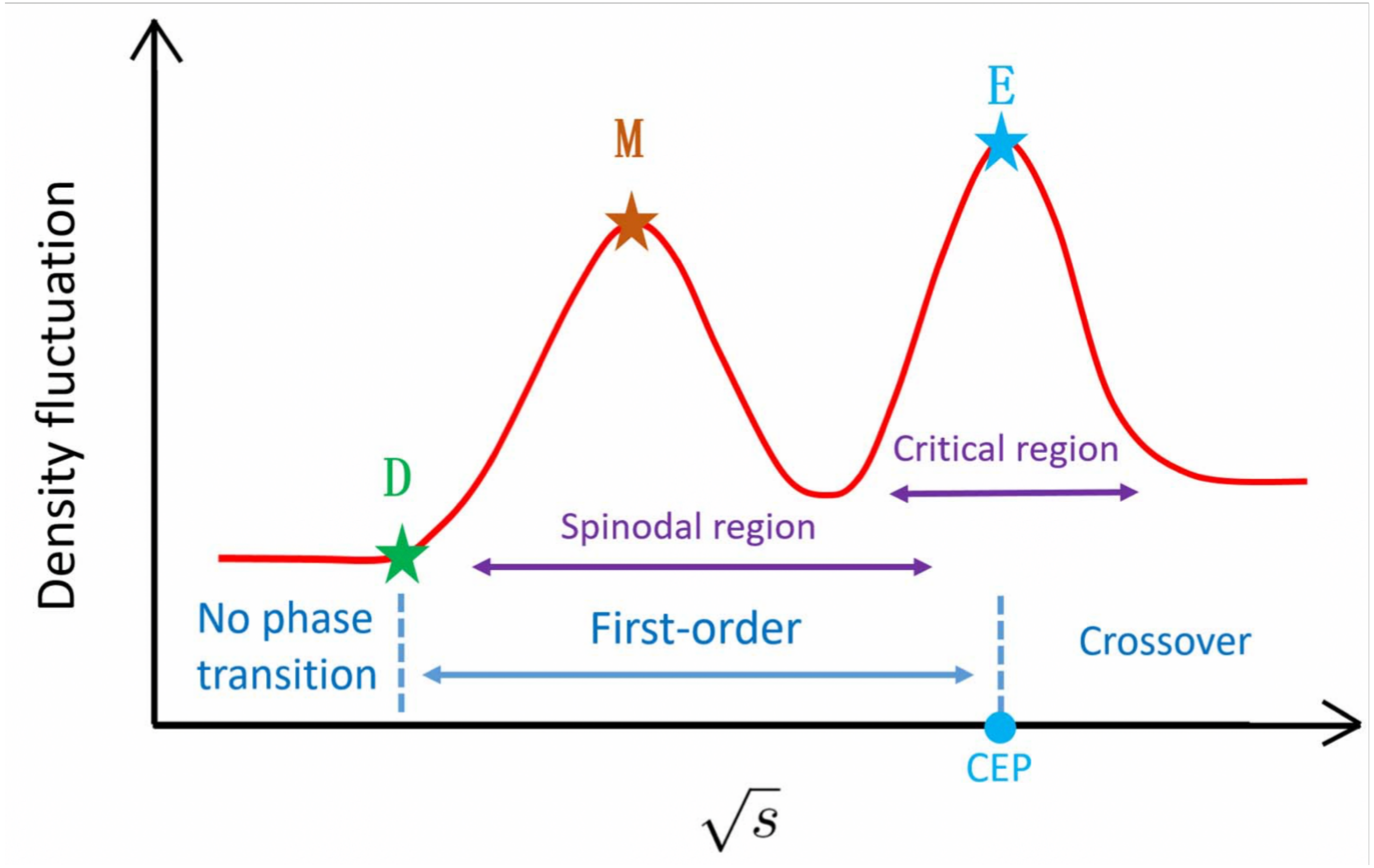

K. J. Sun, L. W. Chen, C. M. Ko, J. Pu, Z. Xu, Phys. Lett. B781, 499 (2018).