Energy Dependence of Triton Production and Neutron Density Fluctuations at RHIC

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Outline

- **Introduction and Motivation**

- **The STAR Experiment**
  - **Data Sets and Particle Identification**
  - **Detector Correction and Systematic Error**

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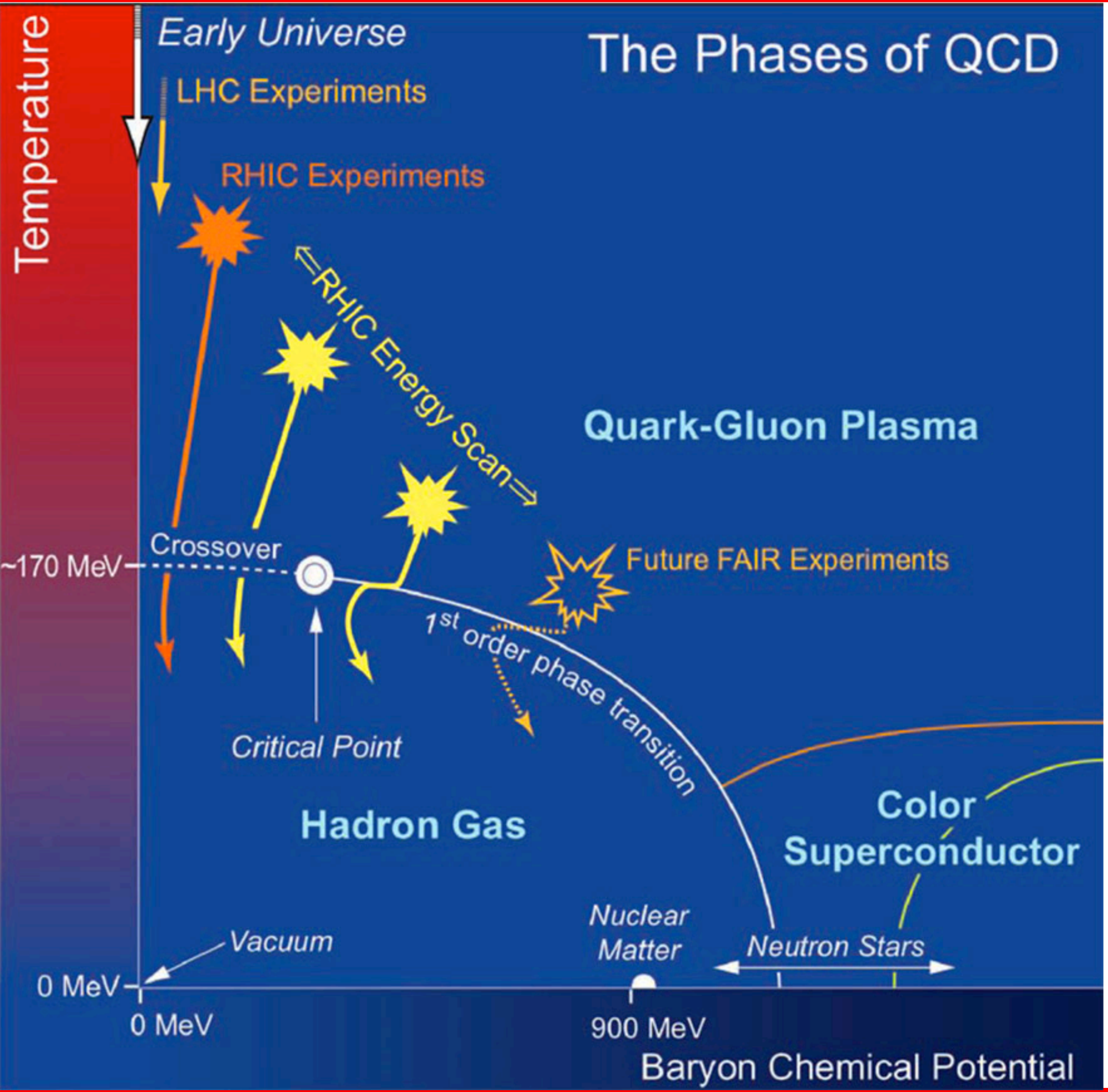
  - **Coalescence Parameters**
  - **Integral Yield dN/dy and $\langle p_T \rangle$**
  - **Particle Ratio**
  - **Neutron Density Fluctuation**

- **Summary**

Introduction and Motivation – QCD Phase Diagram



Theory and Experiment: HIC

1) High temperature:

QGP properties.

2) High baryon density:

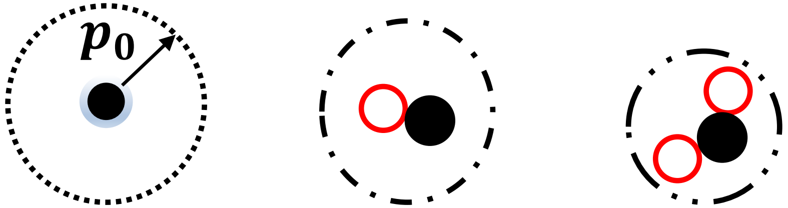
Critical Point and Phase boundary.

3) Search for the type of phase transition and critical point.

Introduction and Motivation – Light Nuclei Formation

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

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



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

$$B_A \propto V_f^{1-A}$$

p_0 = radius of the momentum sphere

- 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.

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

Introduction and Motivation – Neutron density fluctuation

- In the vicinity of the critical point or the first-order phase transition, density fluctuation becomes larger.

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

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

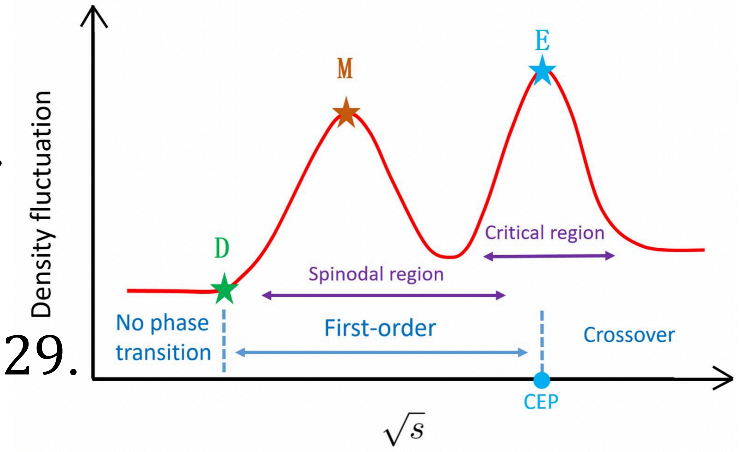
$$N_t \cdot N_p/N_d^2 = g(1+\Delta n) \qquad \Delta n = \langle(\delta n)^2\rangle/\langle n\rangle^2$$

Phase transition

↓

Correlations of nucleons:
Light nuclei (2, 3 …nucleons)

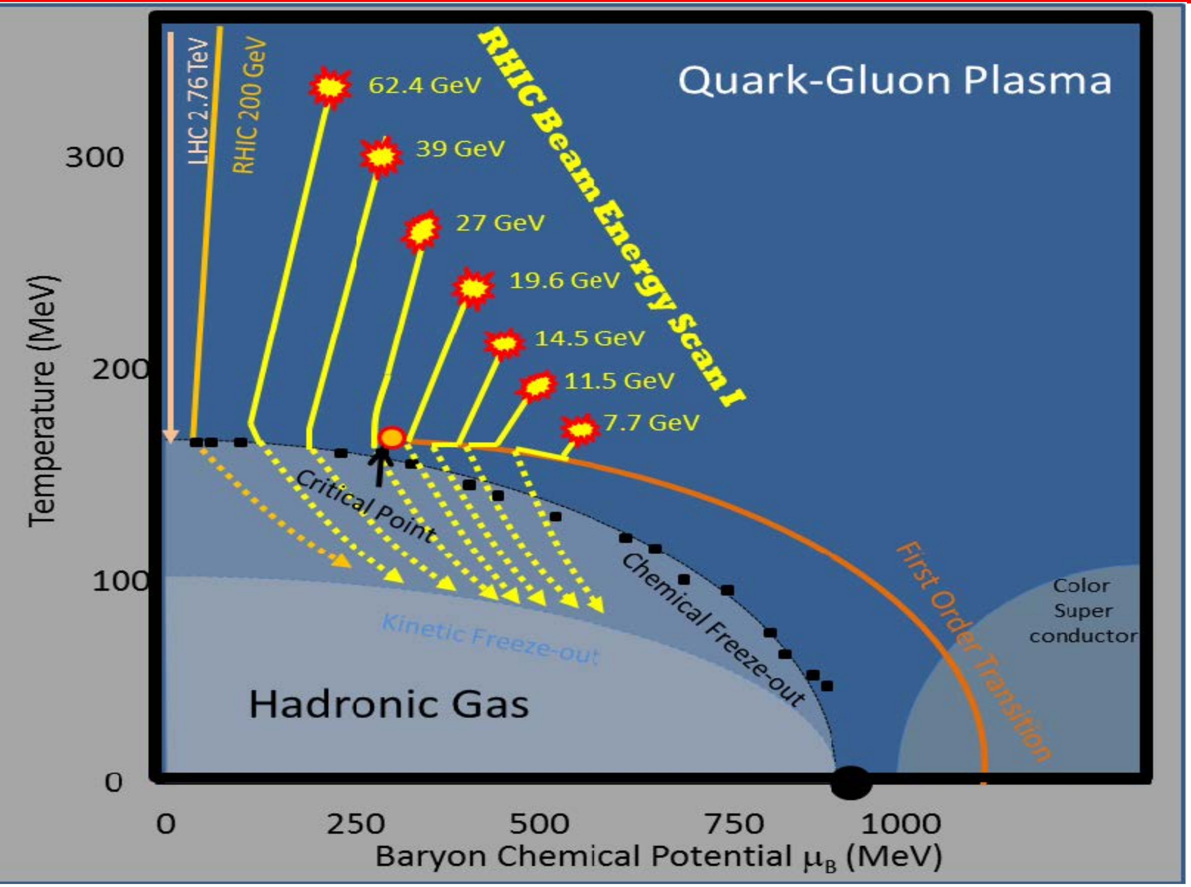
- The neutron density fluctuation can be derived from the yield ratio of light nuclei, hence it provides a tool to search for the QCD critical point.



- Neutron density fluctuation can be expressed as: $\Delta n = \langle(\delta n)^2\rangle/\langle n\rangle^2$
In this case can be approximated as: $N_t \cdot N_p/N_d^2 = g(1+\Delta n)$, with $g = 0.29$.

K. J. Sun, L. W. Chen, C. M. Ko, Z. Xu, Phys. Lett. B774, 103 (2017).
K. J. Sun, L. W. Chen, C. M. Ko, J. Pu, Z. Xu, Phys. Lett. B781, 499 (2018).

RHIC Beam Energy Scan



★ BES-I Au+Au collisions at $\sqrt{s_{NN}}$ = 7.7, 11.5, 14.5, 19.6, 27, 39, 62.4 and 200 GeV.

✓ Search for the Critical Point

✓ Search for the First-order Phase Transition

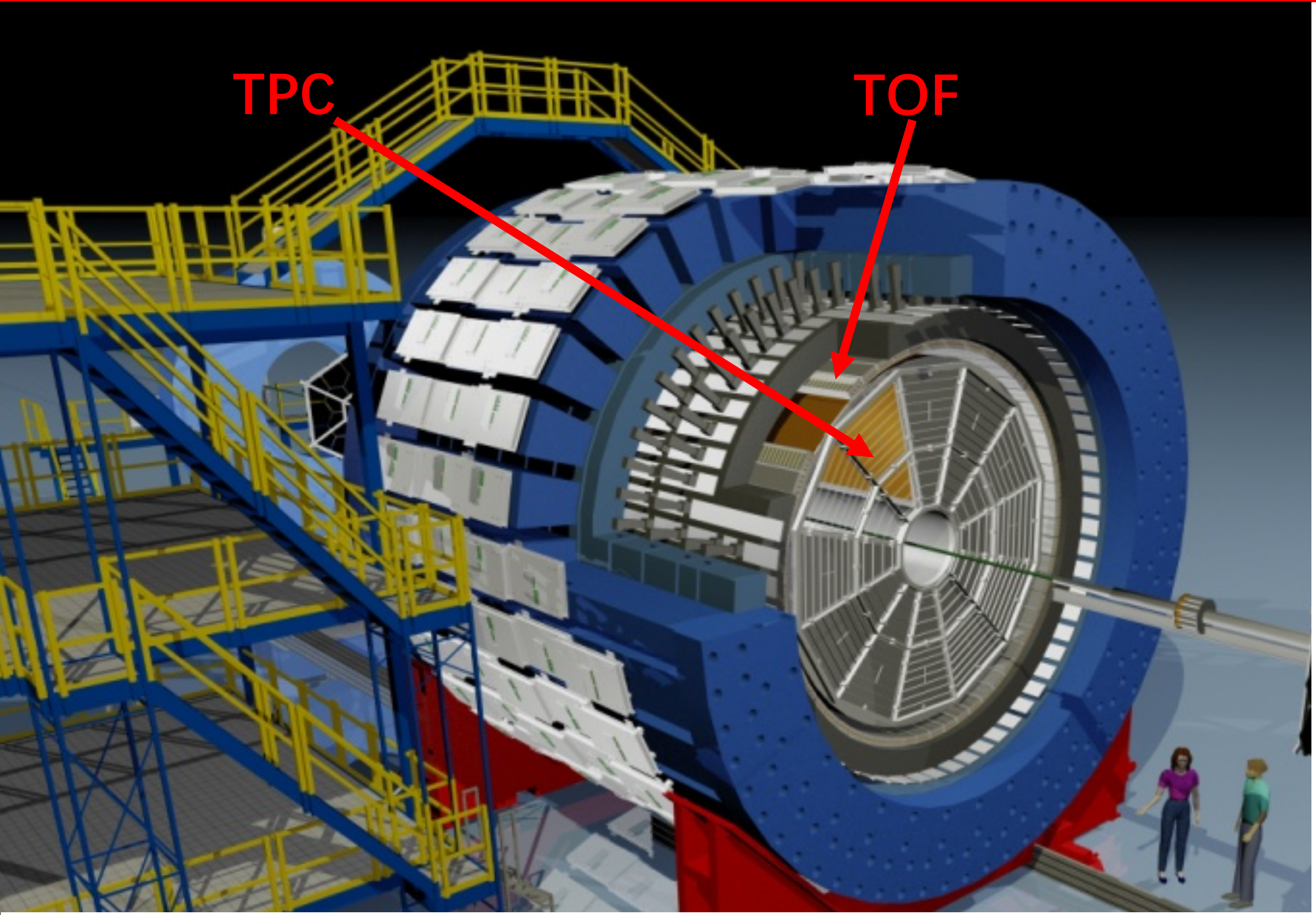
✓ Search for the Threshold of QGP Formation

STAR :arxiv 1007.2613

$\sqrt{s_{NN}}$ (GeV)	7.7	11.5	14.5	19.6	27	39	62.4	200
N_{eve}(M)	4	11	27	40	71	133	67	480
μ_B(MeV)	420	315	260	205	155	115	72	20

J. Cleymans, H. Oeschler, K. Redlich, and S. Wheaton PRC 73,034905 (2006)

The Solenoidal Tracker At RHIC (STAR)



Time Projection Chamber (TPC)

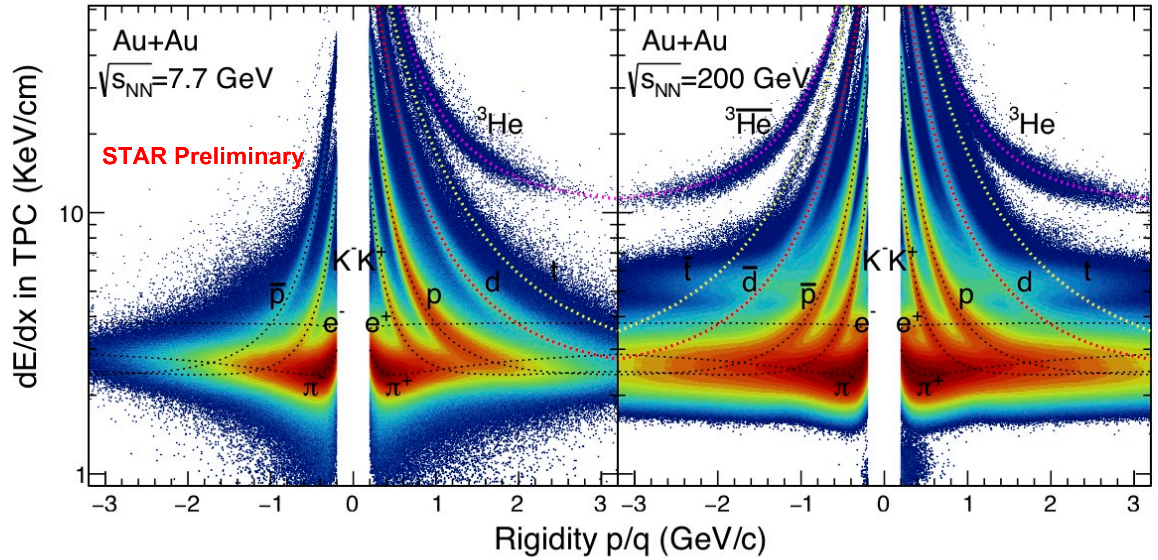
- ✓ Charged Particle Tracking
- ✓ Momentum reconstruction
- ✓ Particle identification from ionization energy loss(dE/dx)
- ✓ Pseudorapidity coverage $|\eta| < 1.0$

Time-of-Flight (TOF)

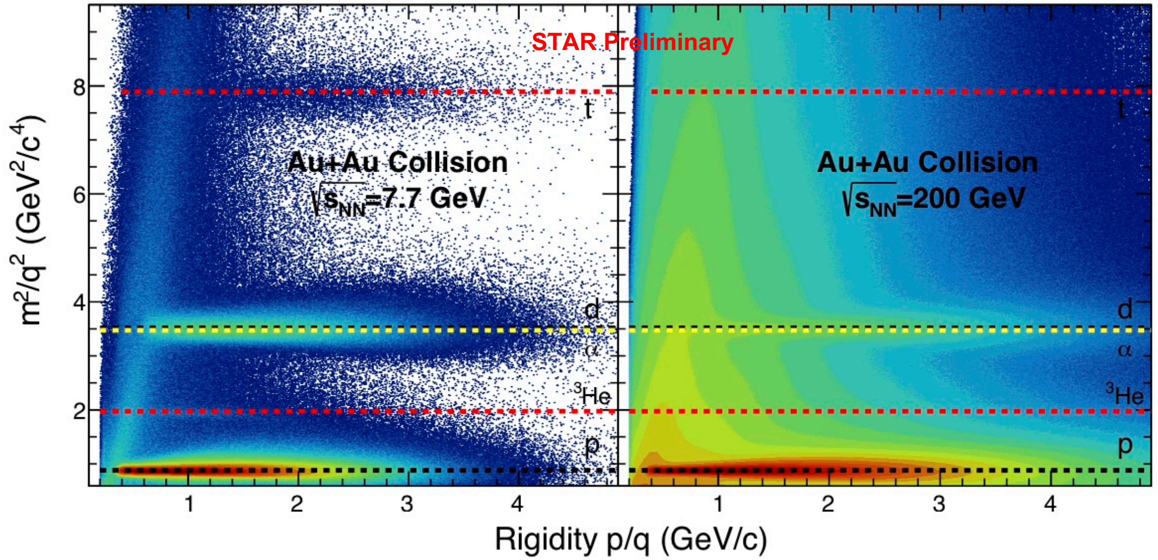
- ✓ Particle identification m^2
- ✓ Pseudorapidity coverage $|\eta| < 0.9$

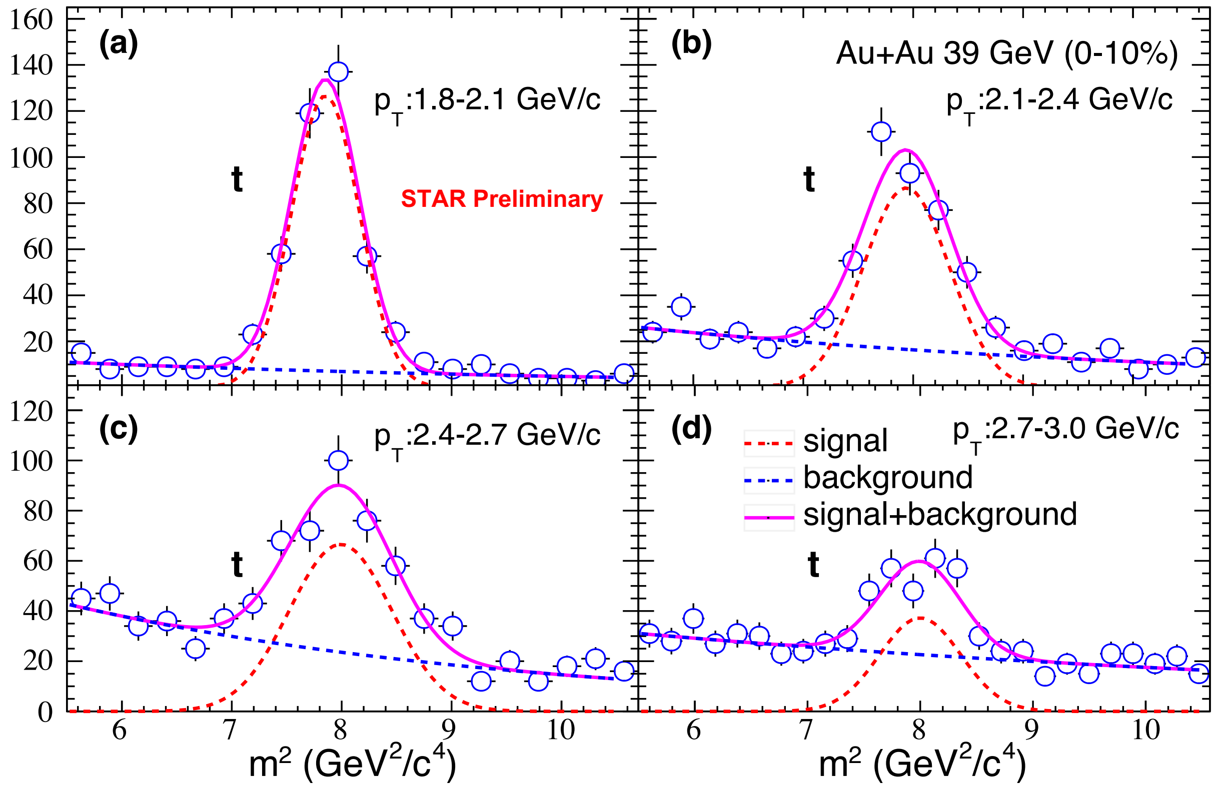
- ➢ **Excellent Particle Identification.**
- ➢ **Large, Uniform Acceptance at Midrapidity.**

Particle Identification



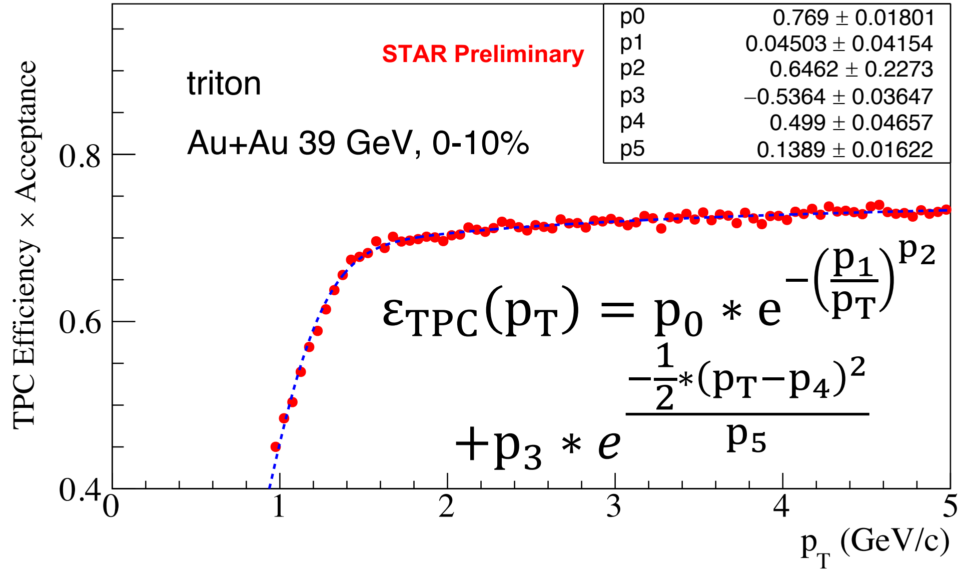
$$z = log\left(\frac{\langle dE/dx\rangle}{\langle dE/\mathrm{d}x\rangle^{BB}}\right) \qquad m^2 = p^2\left(\frac{c^2t^2}{L^2} - 1\right)$$

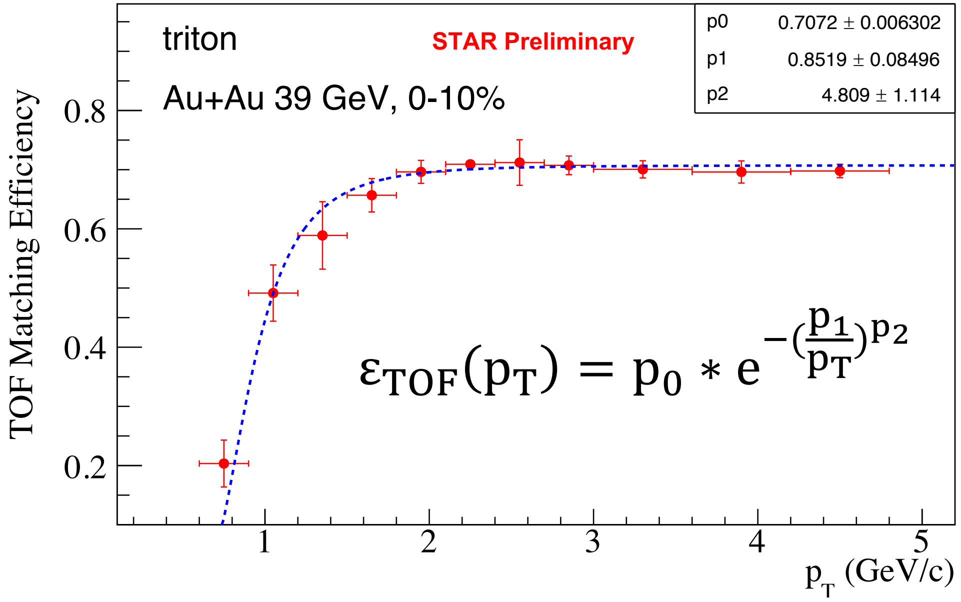




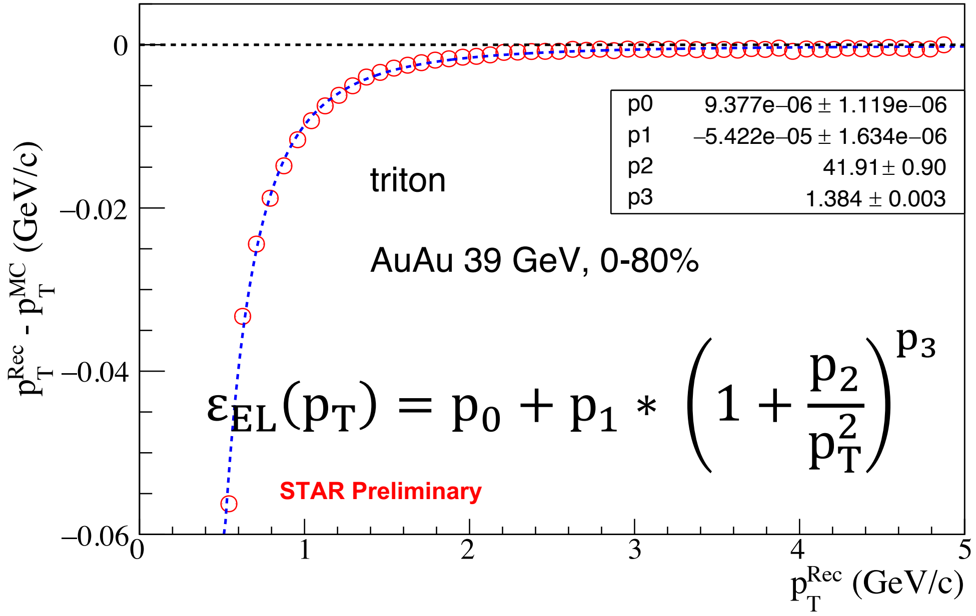
BB : Bethe-Bloch,H. Bichsel, Nucl. Instrum. Meth. A 562, 154 (2006).

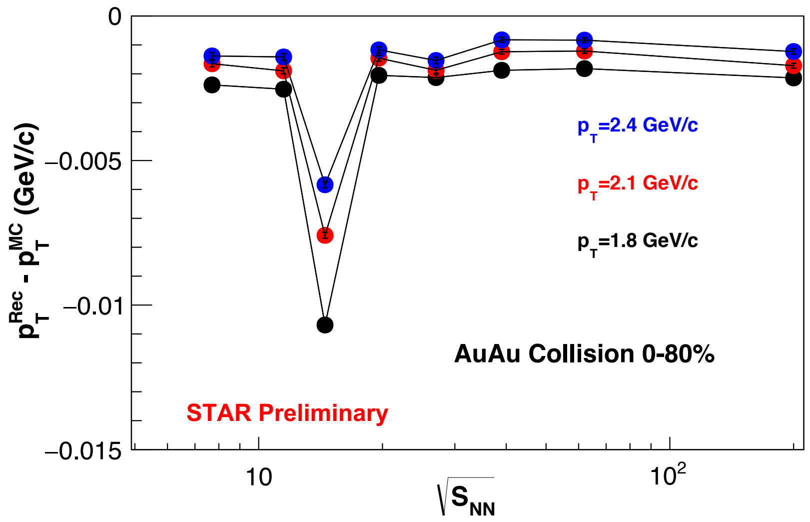
Detector Corrections



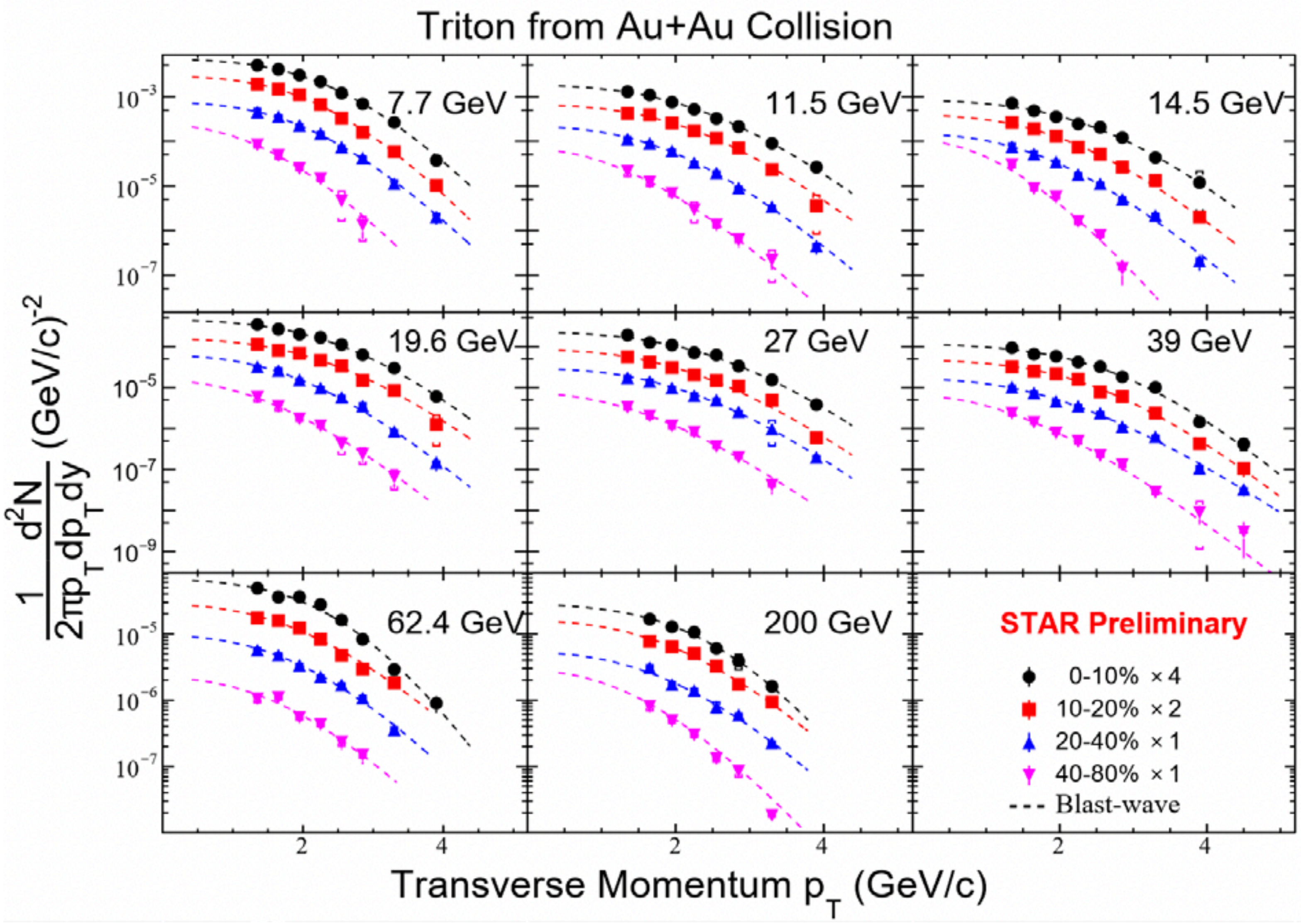


Energy Loss Correction





Transverse Momentum Spectra

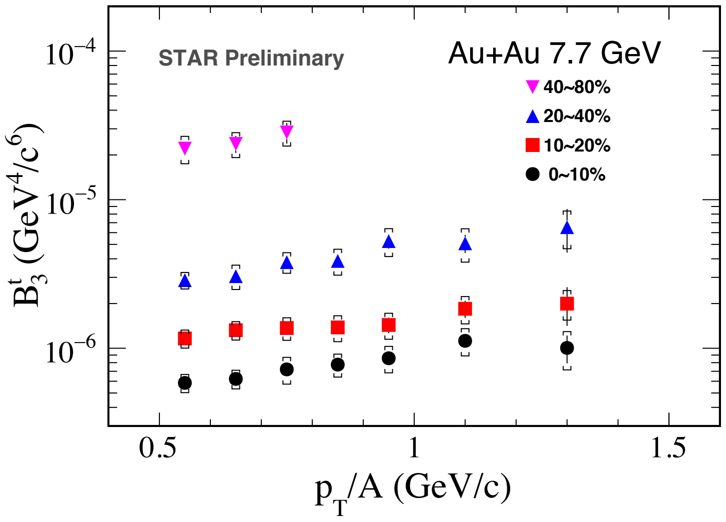


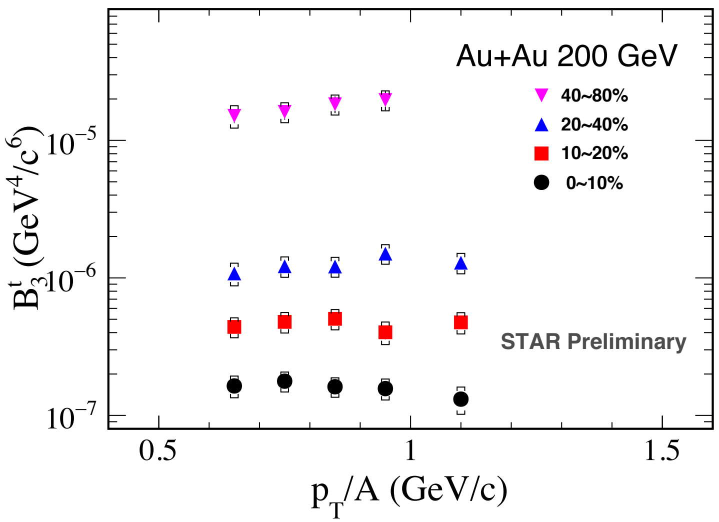
E. Schnedermann, J. Sollfrank, and U. Heinz, PRC 48,2462 (1993)

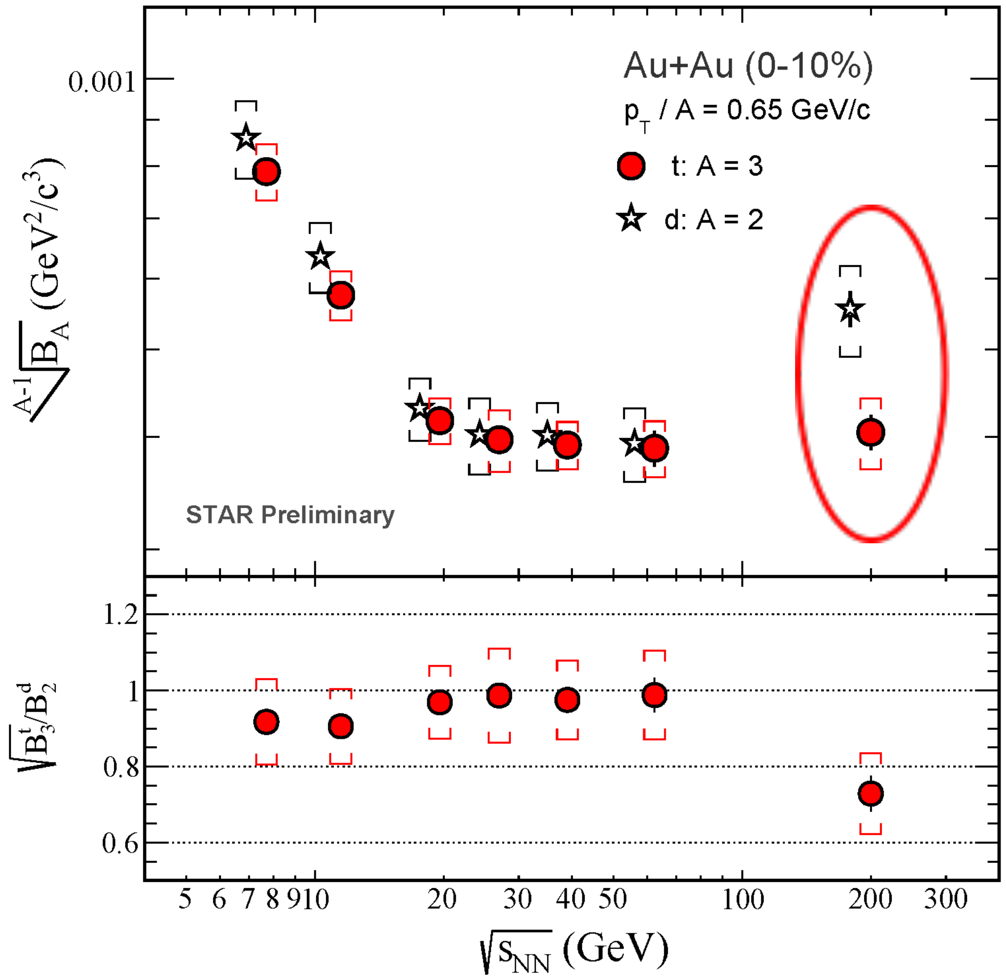
- ✯Mid-rapidity ($|y| \leq 0.5$) transverse momentum distribution of triton from Au+Au Collision.
- ✯Vertical lines and square brackets represent statistical and systematic errors respectively.
- ✯Dash lines: blast-wave function fits.

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

Coalescence Parameters – B_3



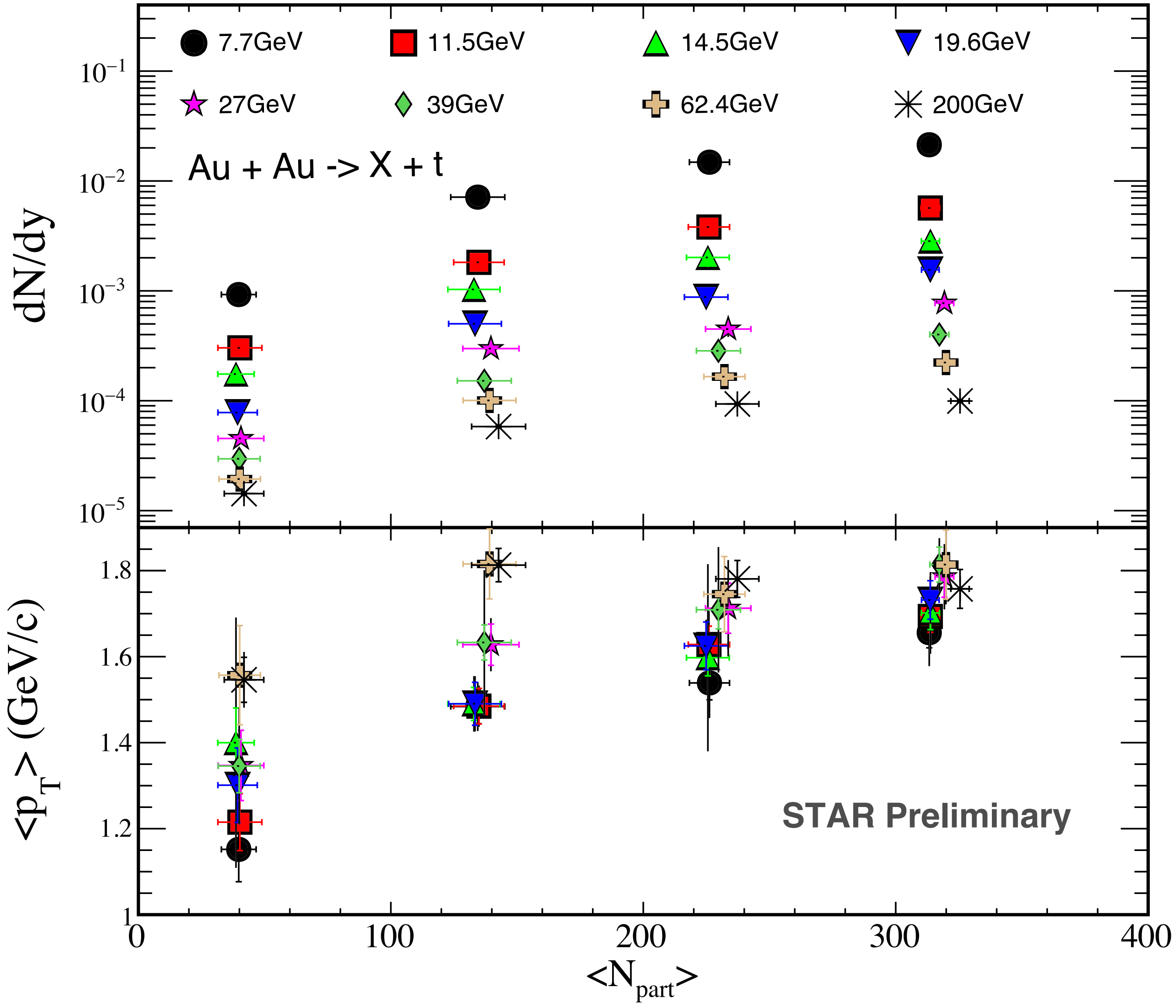




☆B_3 decreases from peripheral to central collisions and with increasing collision energy.

☆B_2 and $\sqrt{B_3}$ are consistent within uncertainties except 200 GeV.

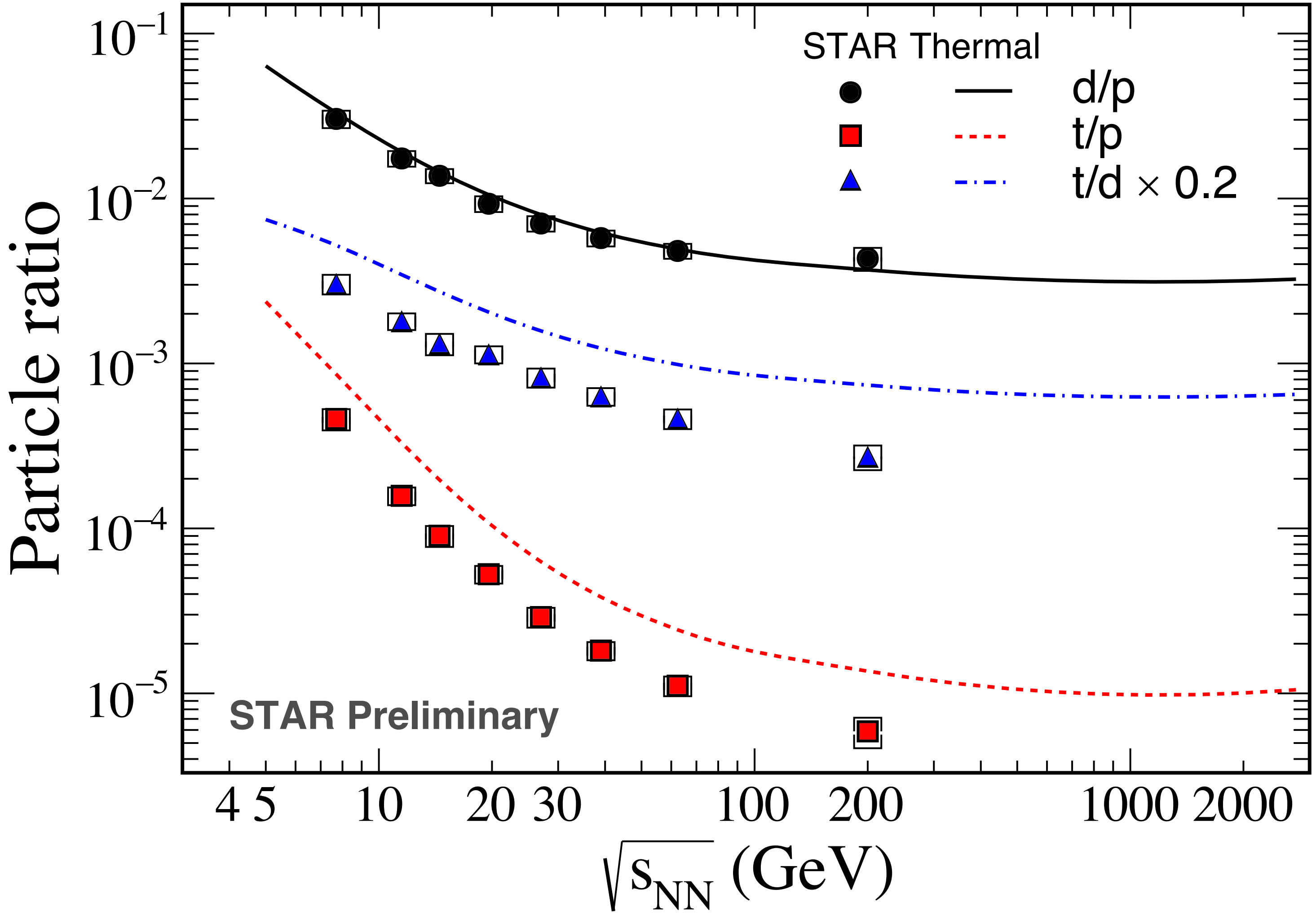
Integral Yield dN/dy and <p_T>



☆dN/dy for t are smaller at higher energies: baryon stopping.

☆ $< p_T >$ decrease from central to peripheral collisions and with decreasing energy.

Particle Ratios



☆Thermal model can describe the d/p ratios, but can not describe the t/p, t/d ratios.

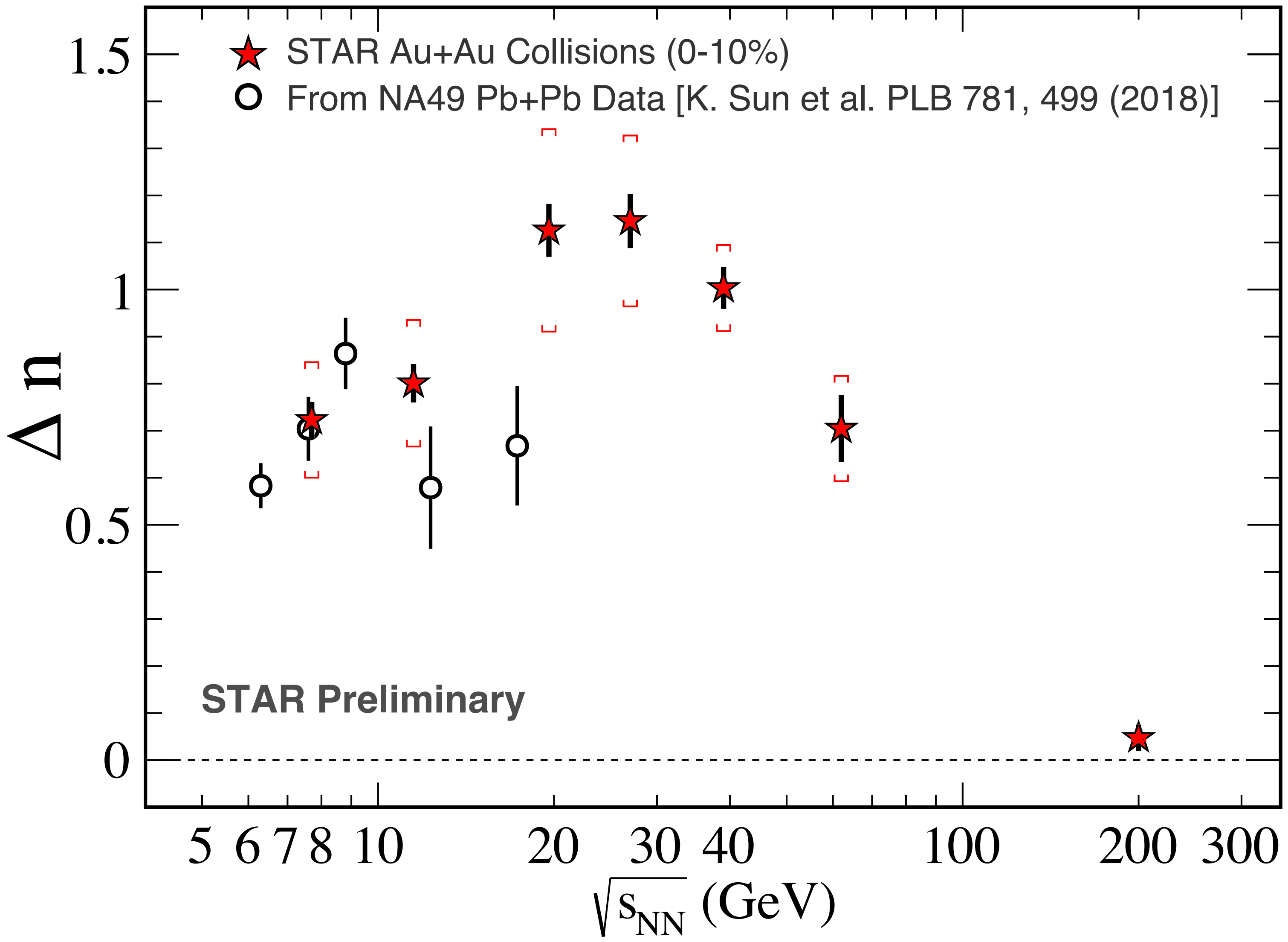
$$T_{CF} = T_{CF}^{lim}/(1 + \exp(2.60 - \ln(\sqrt{s_{NN}})/0.45))$$

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

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

A. Andronic, P. Braun-Munizinger, J. Stachel, H. Stöcker, PLB697 (2011)203

Neutron Density Fluctuation



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

✯Neutron density fluctuation, Δn, shows a non-monotonic behavior on collision energy. Peak around 20 GeV.

Summary

- We present STAR results of t production (dN/dy, $< p_T >$) from Au + Au collisions at $\sqrt{s_{\rm NN}}$= 7.7, 11.5, 14.5, 19.6, 27, 39, 62.4 and 200 GeV.
- Coalescence parameter B_3^t for t are extracted. B_2^d and $\sqrt{B_3^t}$ are consistent within uncertainties except 200 GeV.
- Thermal model can not describe the triton production.
- The neutron density fluctuation, Δn, shows a non-monotonic behavior dependence on collision energy.
- Study the QCD phase structure with more statistics:

  BES-II at RHIC (2019-2021) ……

Thank you!