# Beam Energy Dependence of Triton Production and Yield Ratio in Au+Au Collisions at RHIC

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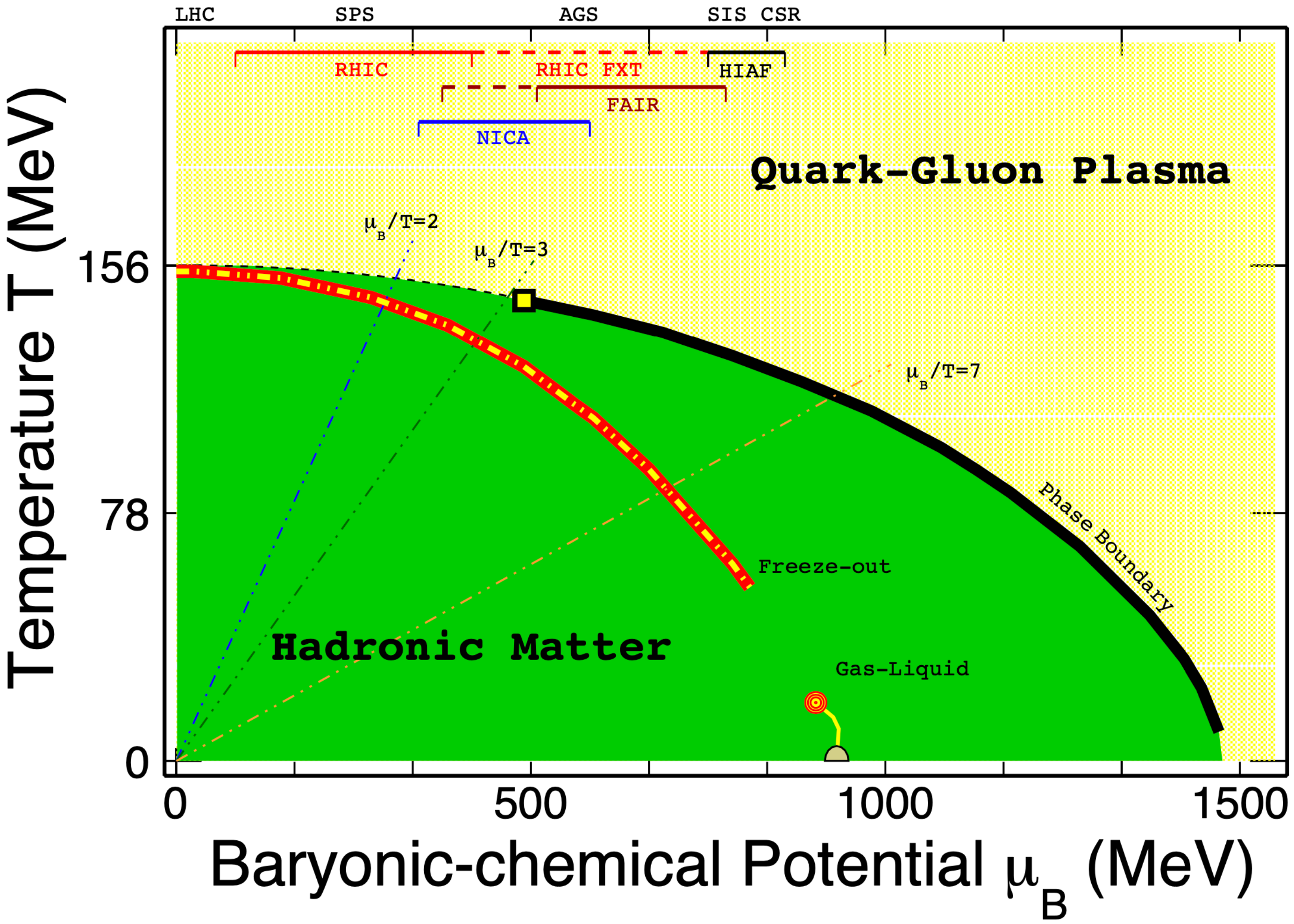
# Outline

- Motivation
- The STAR Experiment
  - Dataset and Particle Identification
- Results and Discussions
  - Particle Yields
  - Particle Yield Ratios
- Summary and Outlook

# Motivation – QCD Phase Diagram and HIC




[1] http://drupal.star.bnl.gov/STAR/starnotes/public/sn0598

1) High temperature:

QGP properties

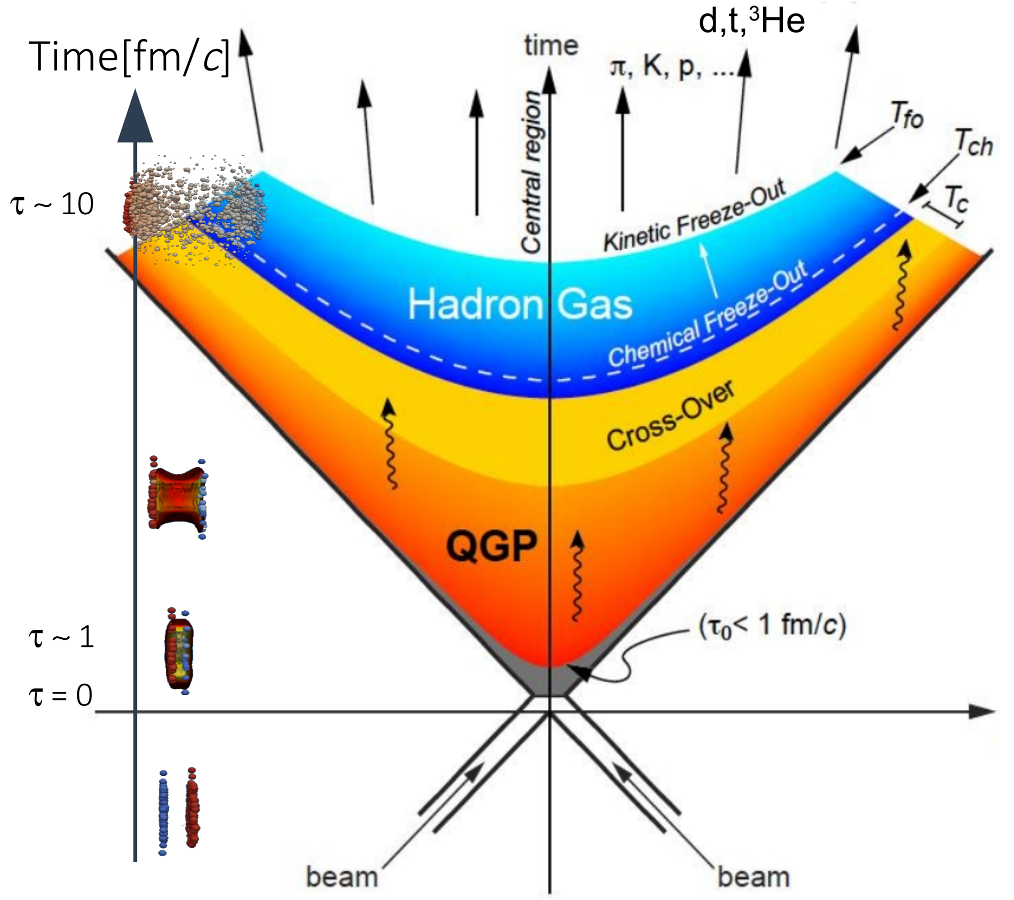
2) High baryon density:

First-order phase boundary and critical point

**Au+Au Collisions at RHIC STAR [1]**

$\sqrt{s_{NN}}$ : 3 - 200 GeV
$\mu_B$ : 750 - 25 MeV

# Production Mechanisms of Light Nuclei in HIC




- Our understanding of the production mechanisms of light nuclei in relativistic heavy-ion collisions are currently incomplete

- Thermal emission

$$N_A \approx g_A V (2\pi m_A T)^{3/2} e^{(A\mu_B - m_A)/T}$$

- Nucleon coalescence

$$N_A = g_c \int d\Gamma \, \rho_s(\{x_i, p_i\}) \times W_A(\{x_i, p_i\})$$

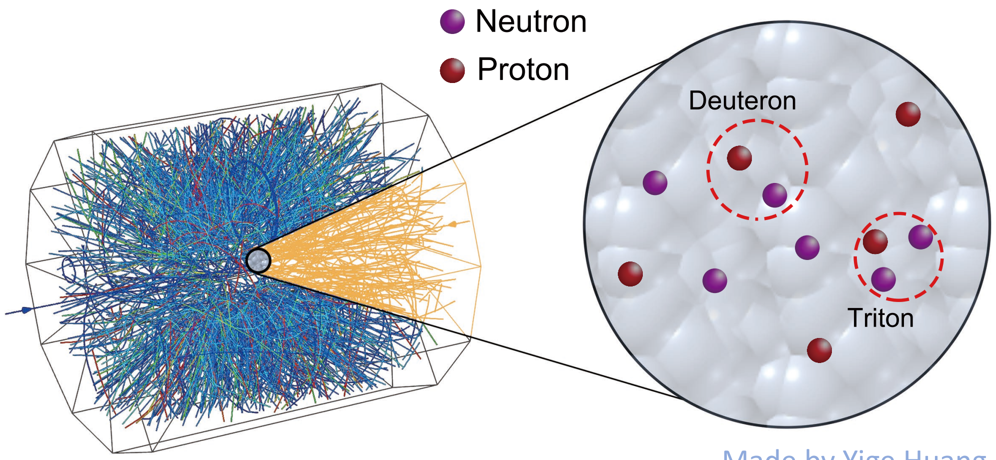
- Hadronic re-scattering

$$\pi NN \leftrightarrow \pi d, NNN \leftrightarrow Nd, NN \leftrightarrow \pi d \dots\dots$$

L. P. Csernai and J. I. Kapusta, Phys. Rept. 131, 223 (1986); R. Scheibl and U. W. Heinz, Phys. Rev. C 59, 1585 (1999); Y. Oh, Z.-W. Lin, and C. M. Ko, Phys. Rev. C 80, 064902 (2009); A. Andronic, P. Braun-Munzinger, K. Redlich, and J. Stachel, Nature 561, 321 (2018); J. Chen, D. Keane, Y.-G. Ma, A. Tang, and Z. Xu, Phys Rept. 760, 1 (2018); D. Oliinychenko, L.-G. Pang, H. Elfner, and V. Koch, Phys. Rev. C 99, 044907 (2019); K.-J. Sun, R. Wang, C. M. Ko, Y.-G. Ma, and C. Shen, (2022), arXiv:2207.12532

# Light Nuclei Production – Neutron Density Fluctuations

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

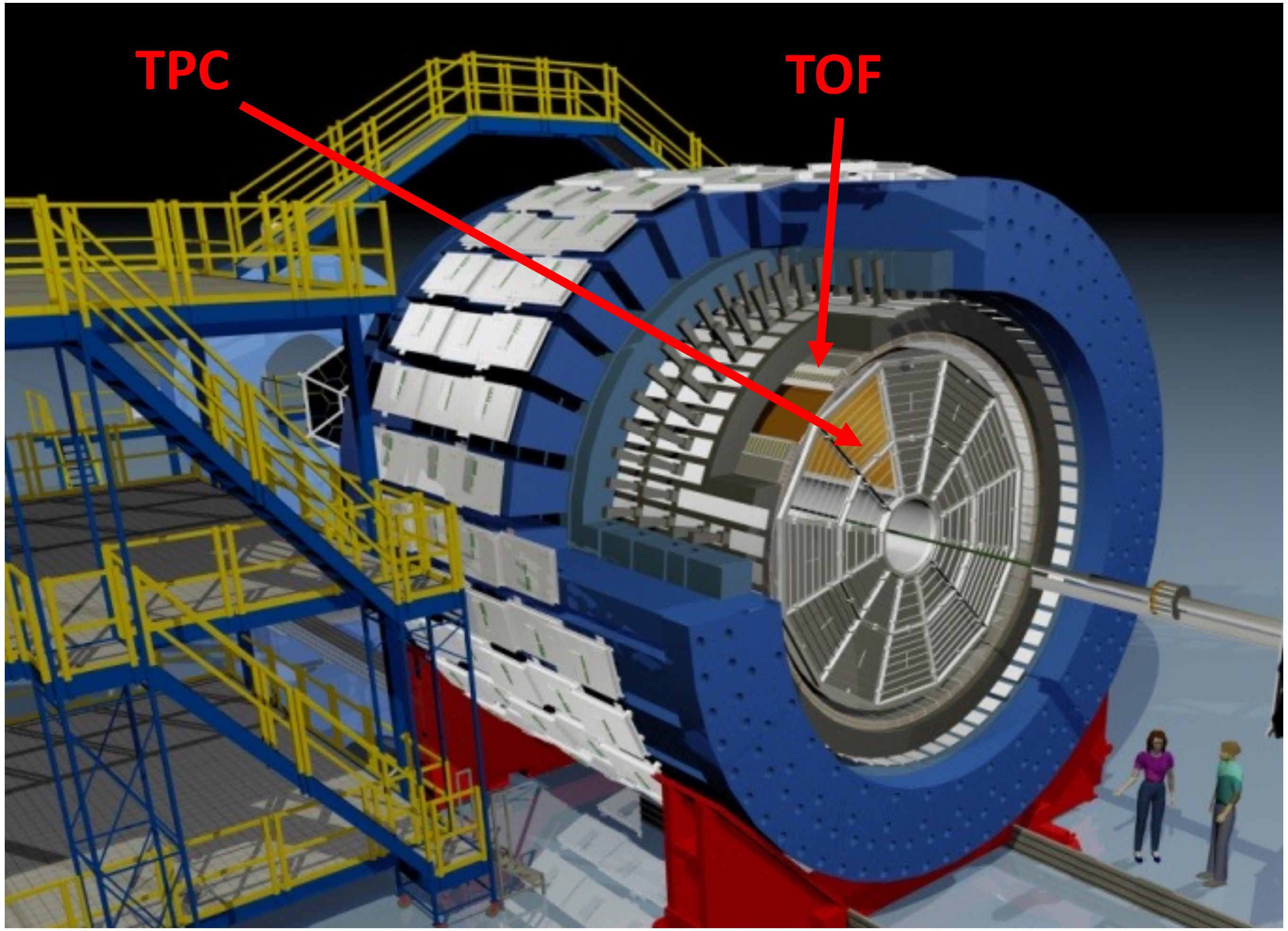



Made by Yige Huang

- In the vicinity of the critical point or the first order phase transition, density fluctuations become larger
- In the nucleon coalescence picture, nuclear compound yield ratio is sensitive to the baryon density fluctuations and can be used to probe 1st order phase transition and/or critical point in heavy-ion collisions

K.-J. Sun, L.-W. Chen, C. M. Ko, J. Pu, and Z. Xu, Phys. Lett. B 781, 499 (2018); E. Shuryak and J. M. Torres-Rincon, Phys. Rev. C 101, 034914 (2020); K.-J. Sun, C. M. Ko, F. Li, J. Xu, and L.-W. Chen, Eur. Phys. J. A 57, 313 (2021); W. Zhao, K.-j. Sun, C. M. Ko, and X. Luo, Phys. Lett. B 820, 136571 (2021); K.-J. Sun, W.-H. Zhou, L.-W. Chen, C. M. Ko, F. Li, R. Wang, and J. Xu, (2022), arXiv:2205.11010

# The Solenoidal Tracker At RHIC (STAR)




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

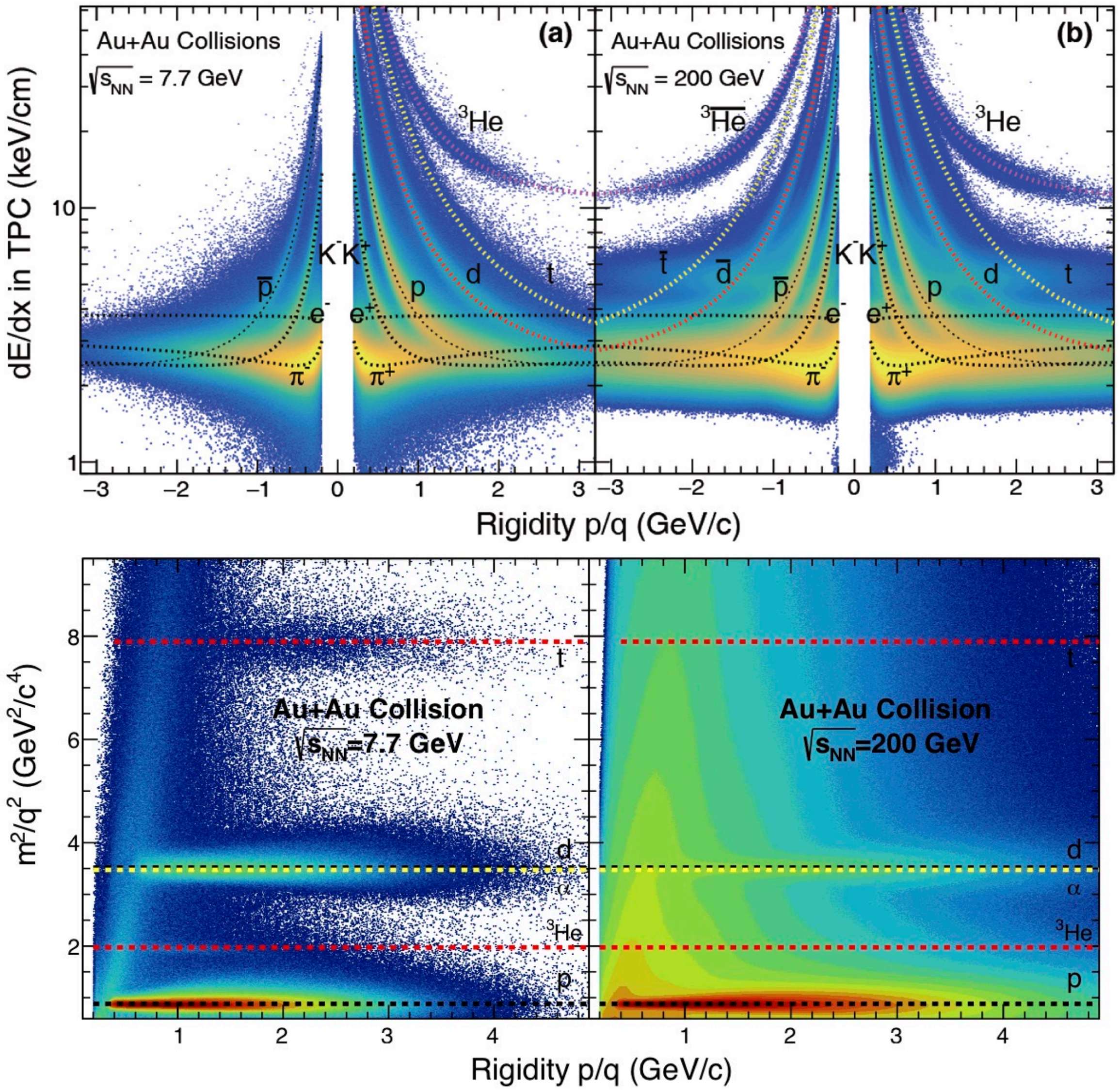
**Time Projection Chamber (TPC)**

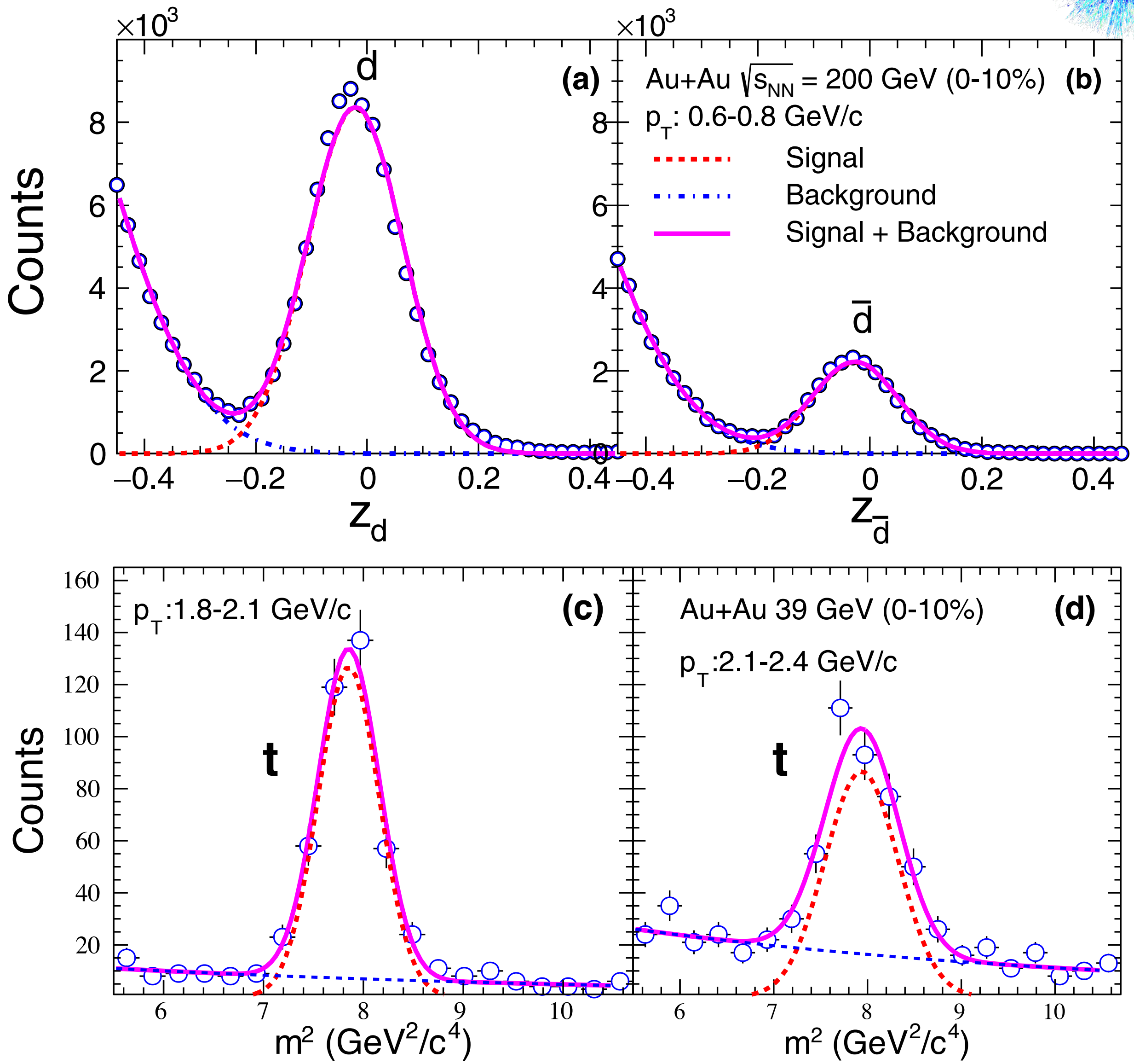
- ✓ Charged particle tracking
- ✓ Momentum reconstruction
- ✓ Particle identification from ionization energy loss ($dE/dx$)
- ✓ Pseudorapidity coverage $|\eta| < 1.0$

**Time-of-Flight (TOF)**

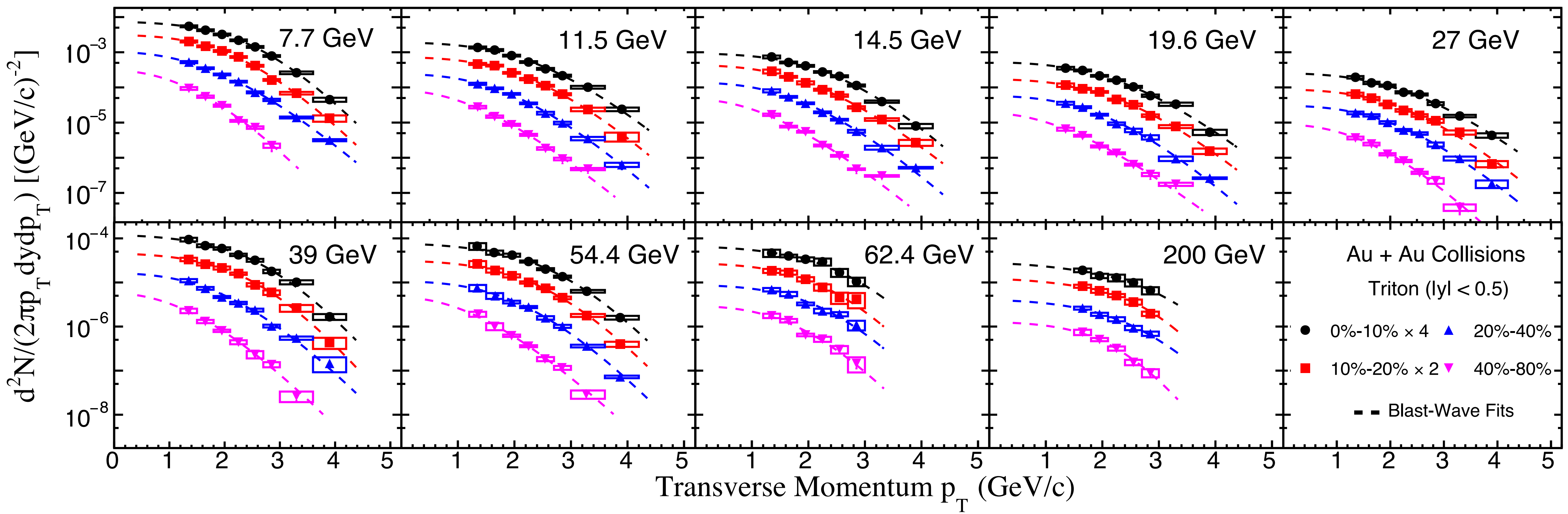
- ✓ Particle identification from $m^2$
- ✓ Pseudorapidity coverage $|\eta| < 0.9$

# Particle Identification & Signal Extraction



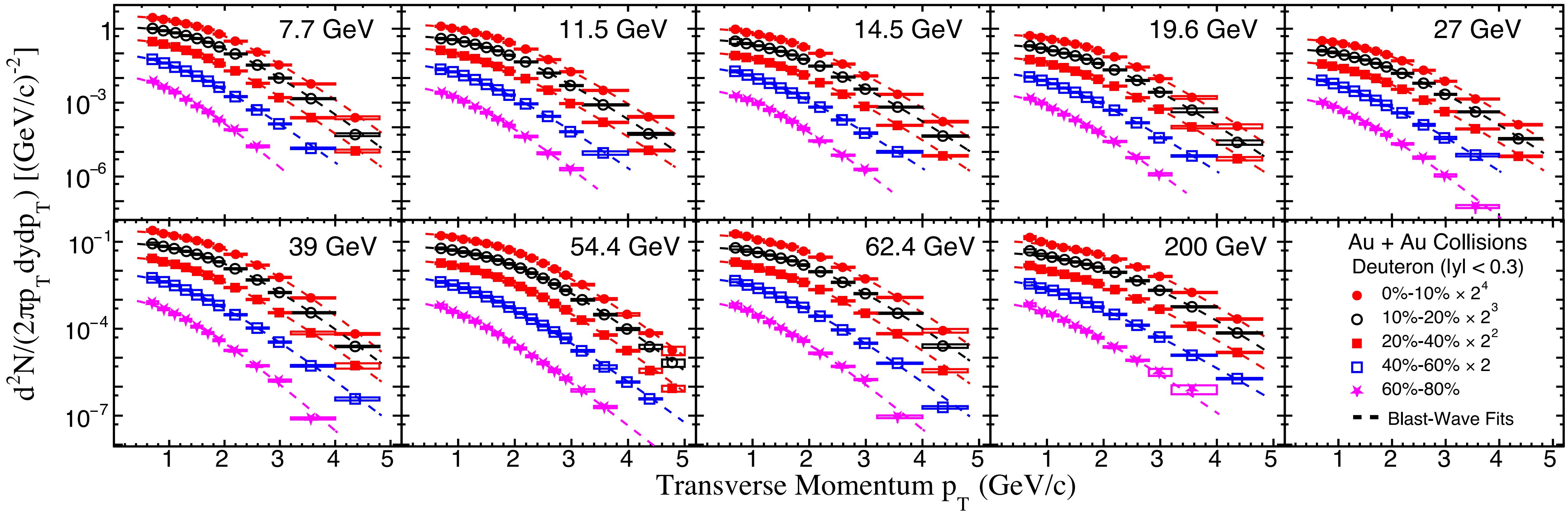
# Transverse Momentum Spectra for Tritons




- ✯Mid-rapidity ($|y| < 0.5$) transverse momentum distributions for tritons
- ✯Dashed lines: Blast-wave function fits

STAR: arXiv:2209.08058
Blast-Wave Fit: E. Schnedermann, J. Sollfrank, and U. Heinz, PRC 48,2462 (1993)

# Transverse Momentum Spectra for Deuterons

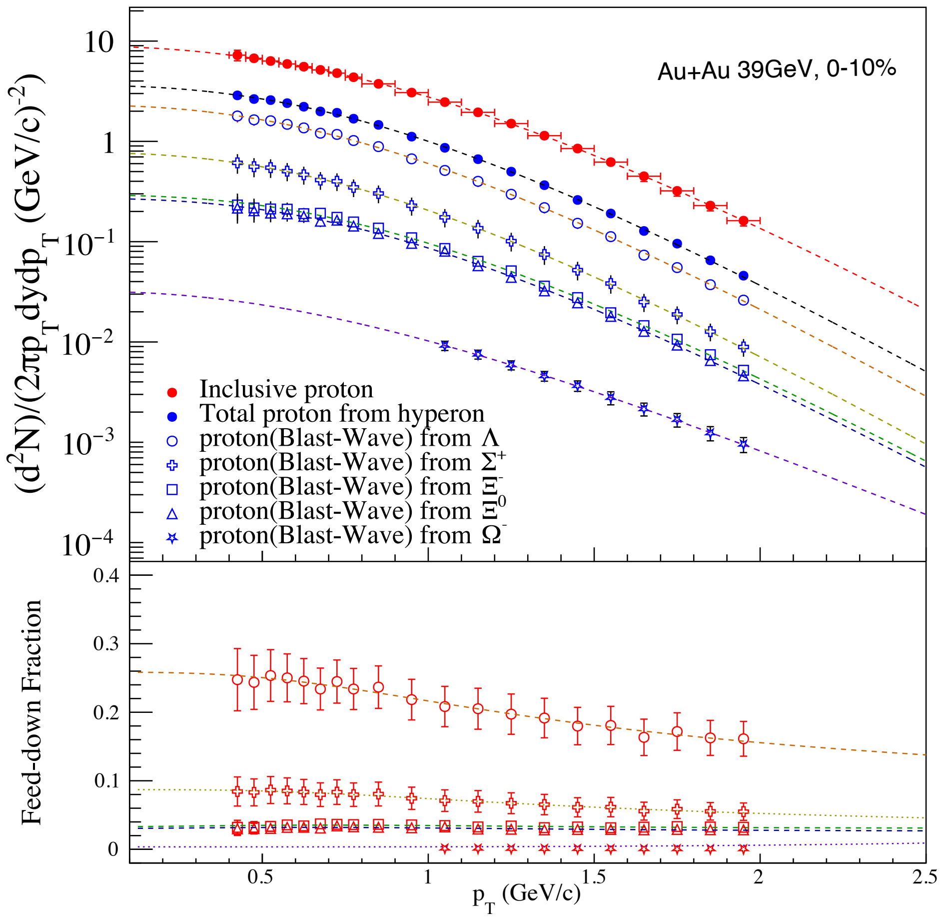


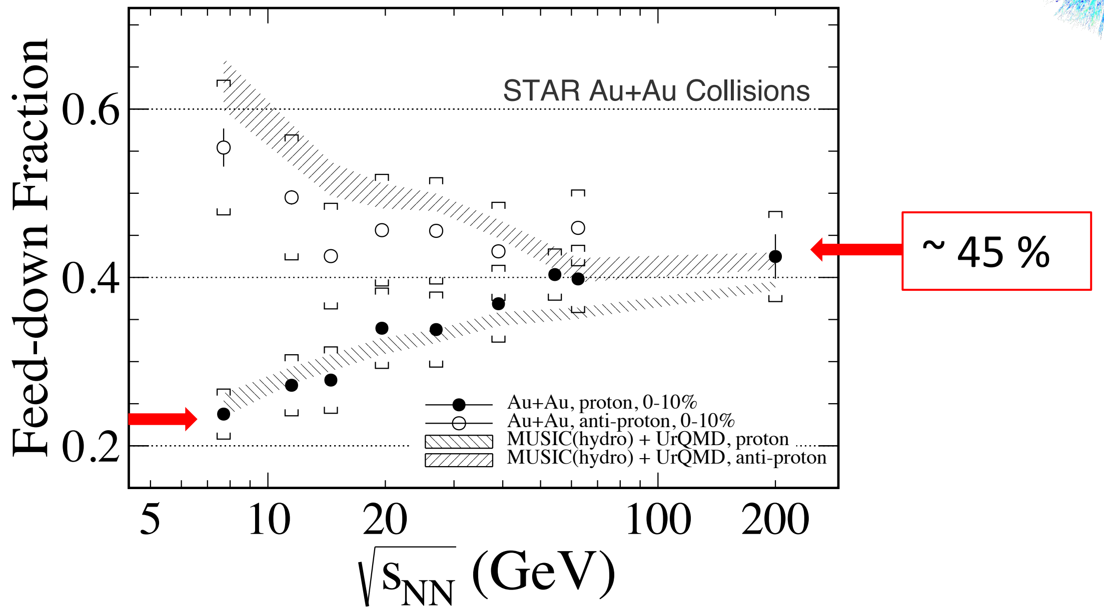

✯Mid-rapidity ($|y| < 0.3$) transverse momentum distributions for deuterons

✯Dashed lines: Blast-wave function fits

STAR: Phys. Rev. C 99, 064905 (2019)

# Proton Weak Decay Feed-down Correction




$\Lambda \longrightarrow p + \pi^-$, branching ratio = 63.9%

$\Sigma^+ \longrightarrow p + \pi^0$, branching ratio = 51.57%

$\Xi^- \longrightarrow \Lambda + \pi^-$, branching ratio = 99.887%

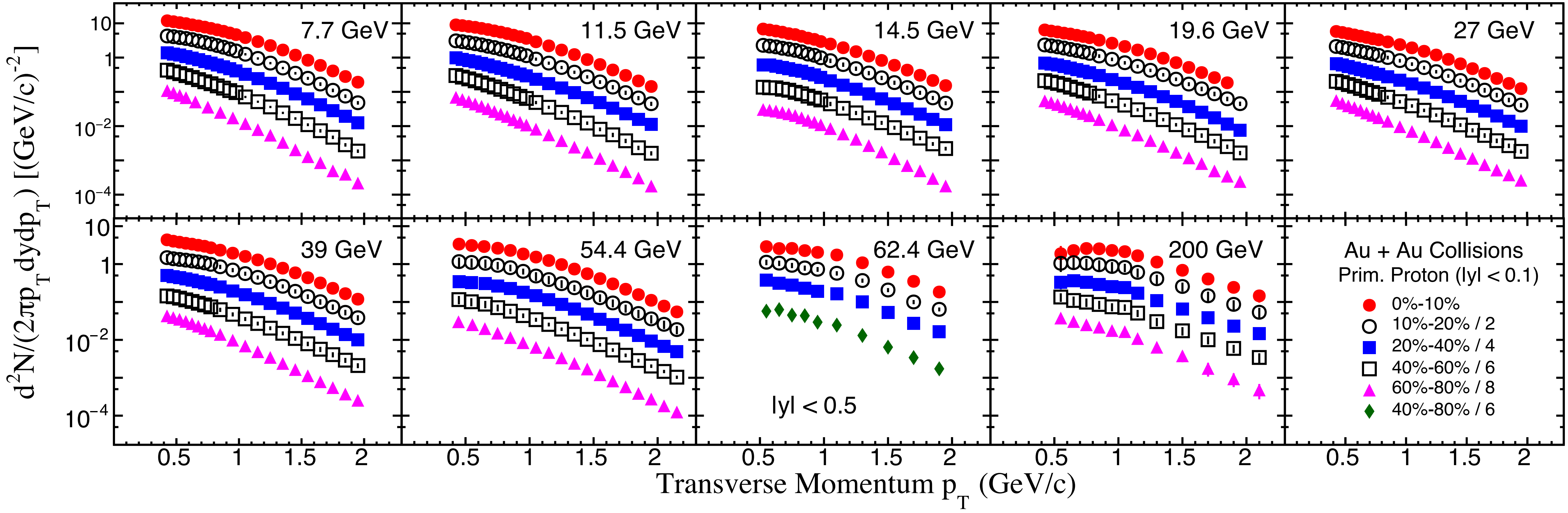
$\Xi^0 \longrightarrow \Lambda + \pi^0$, branching ratio = 99.524%

$\Omega^- \longrightarrow \Lambda + K^-$, branching ratio = 67.8%

- ✰Data driven method: Use STAR published strange particle yields
- ✰From 7.7 – 200 GeV, proton feed-down fraction increases from 25% to 45%

STAR: Phys. Rev. Lett. 97, 152301 (2006); Phys Rev. C 102, 034909 (2020); arXiv:2209.08058

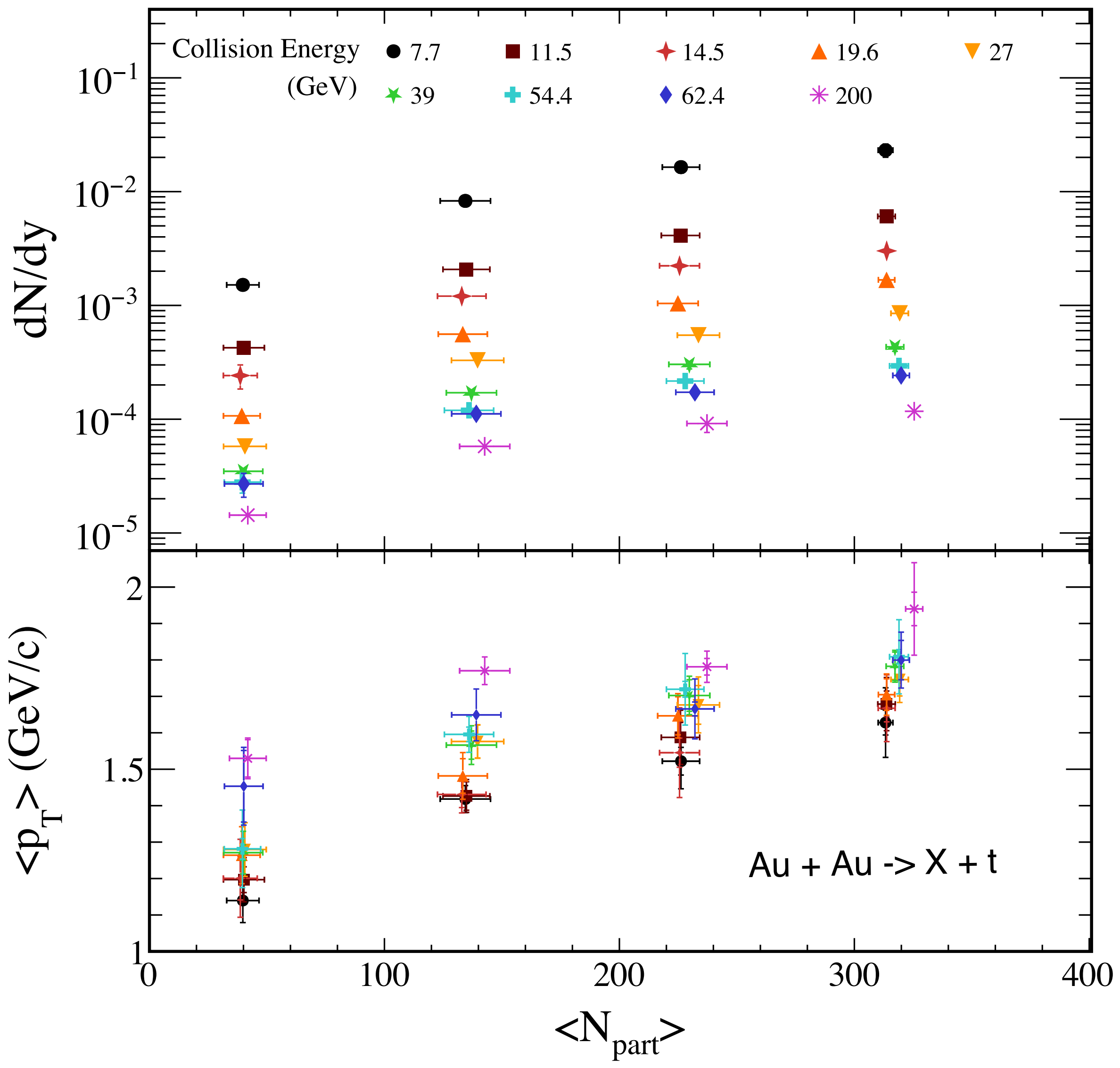
# Transverse Momentum Spectra for Primordial Protons




☆Mid-rapidity transverse momentum spectra for primordial protons

STAR: Phys. Rev. Lett. 97, 152301 (2006); arXiv:2209.08058

# Centrality Dependence of Triton $dN/dy$ & $< p_T >$

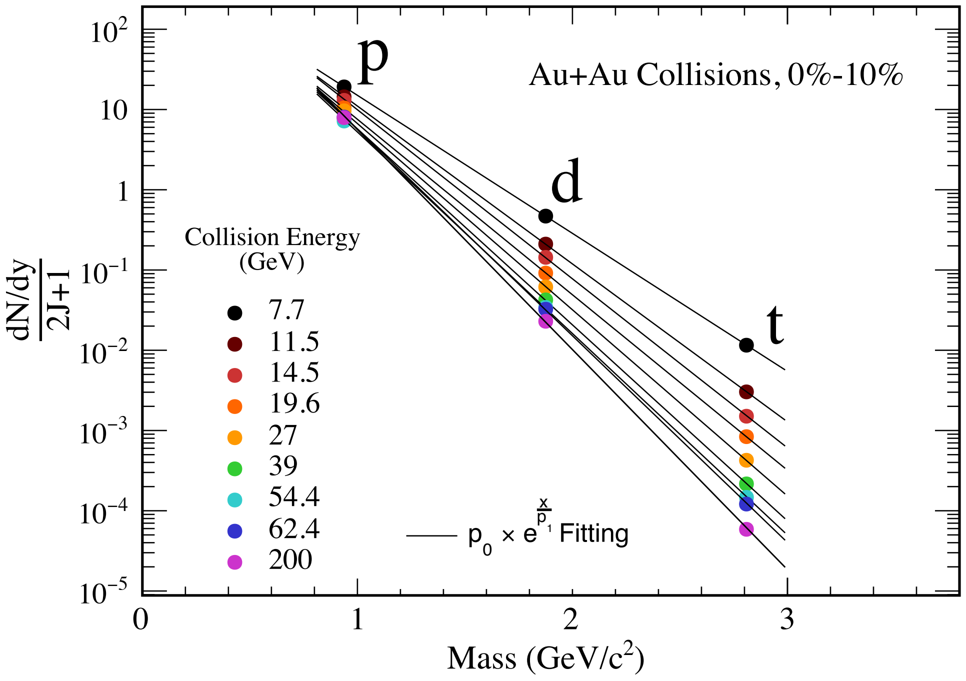


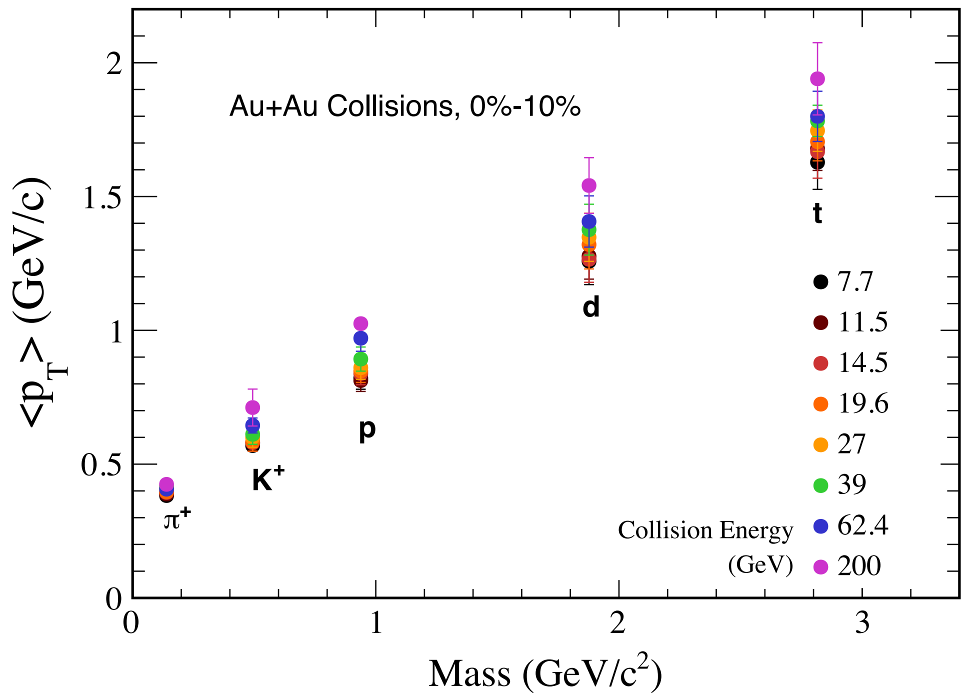

✯ $dN/dy$ for tritons increases with decreasing collision energy: yields driven by baryon density

✯ $< p_T >$ decreases from central to peripheral collisions and with decreasing collision energy

STAR: arXiv:2209.08058

# Mass Dependence of Particle $dN/dy$ & $< p_T >$



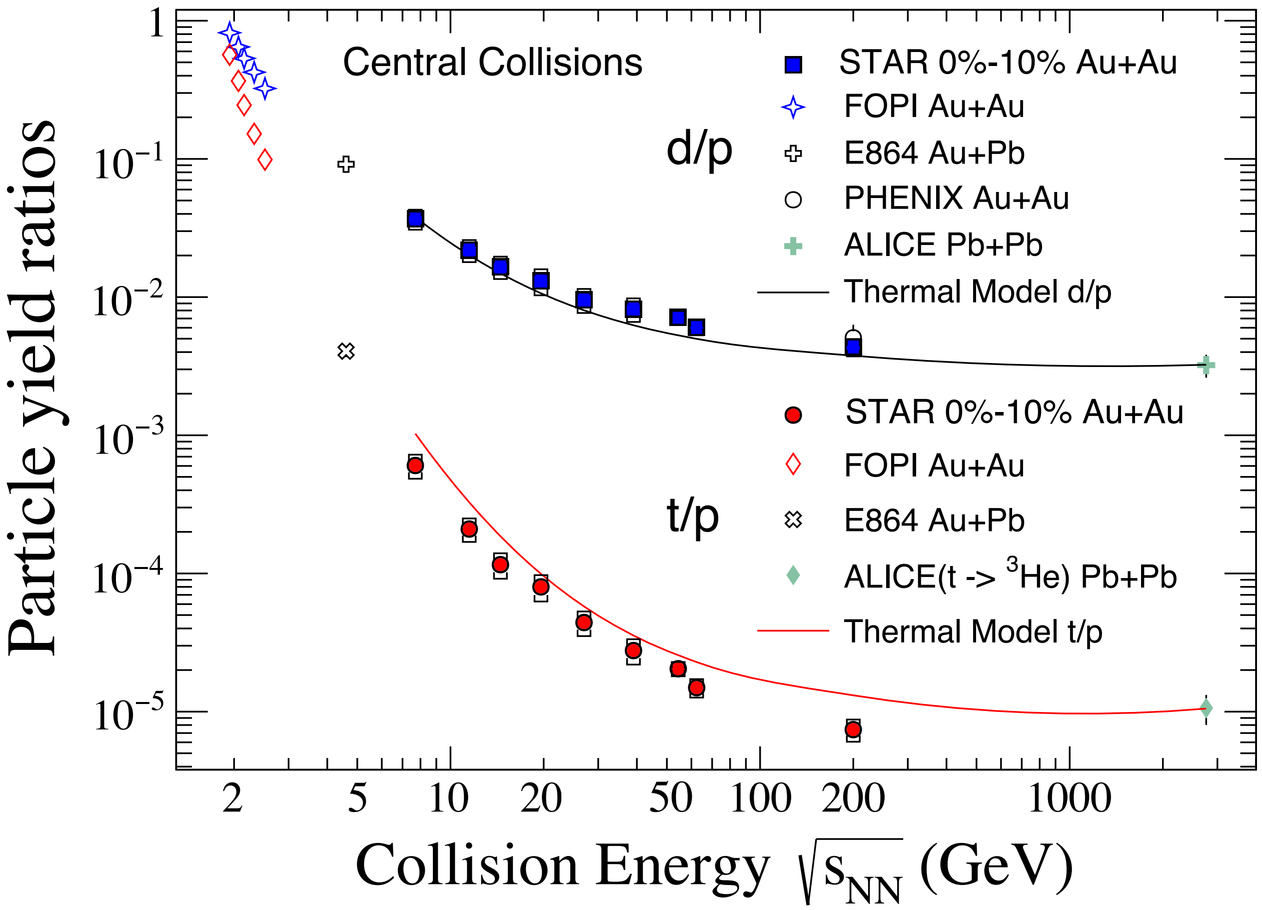




✫Mass dependence of light nuclei yields (divided by the spin degeneracy factor) well described by exponential functions

✫ Average transverse momentum increase with increasing collisions energy and increasing particle mass: influence of radial flow

STAR: Phys. Rev. C 96, 044904 (2017); Phys. Rev. Lett. 97, 152301 (2006); Phys. Lett. B, 655: 104–113, 2007; Phys. Rev. C 101, 024905 (2020); arXiv:2209.08058

# Particle Yield Ratios




☆The triton results follow the trend of the world data, and thermal model overestimates the $N_t/N_p$ ratios

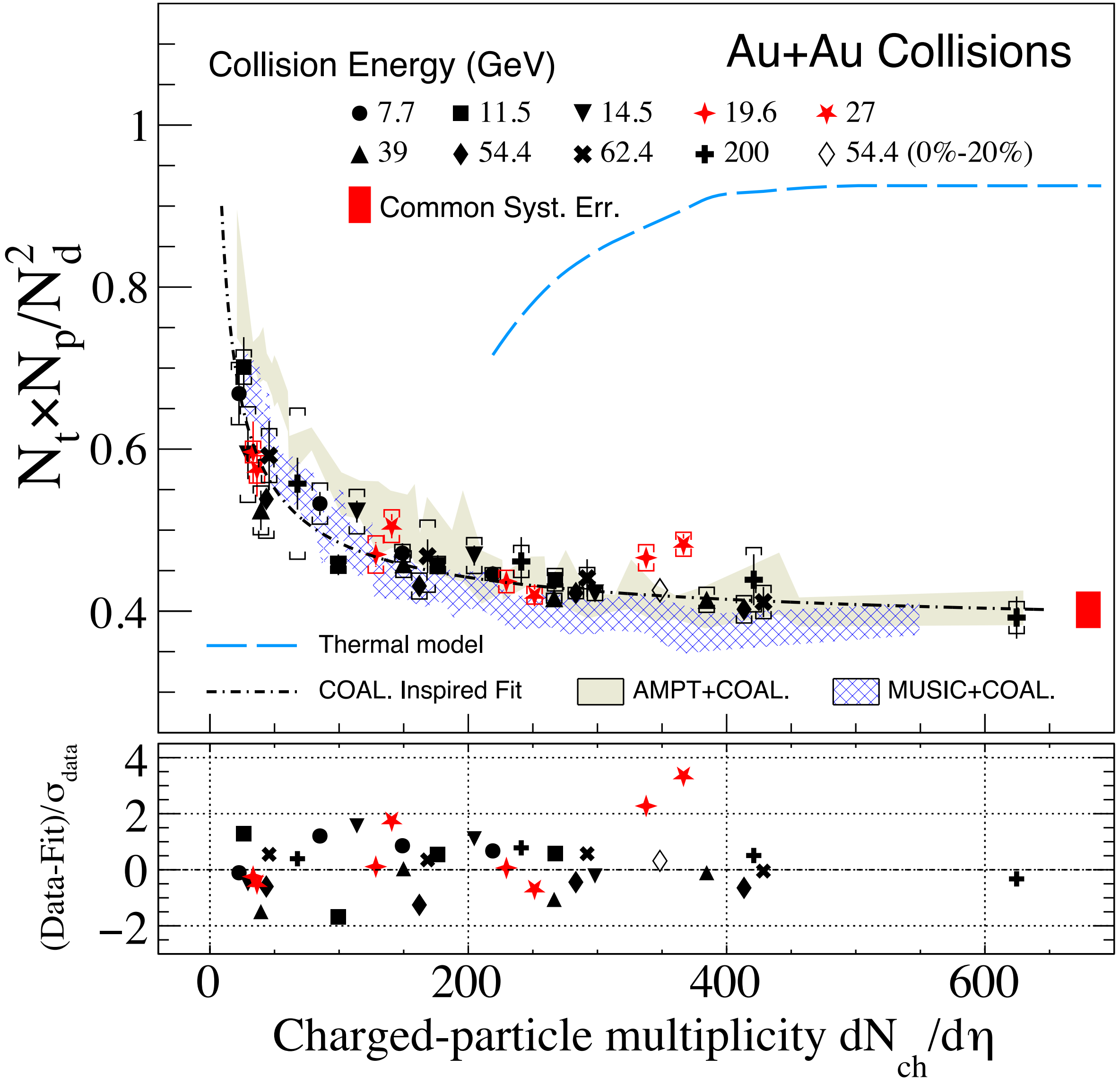
V. Vovchenko, B. Dönigus, B. Kardan, M. Lorenz, and H. Stoecker, Phys. Lett. B , 135746 (2020);

☆The effects of hadronic re-scatterings during hadronic expansion may play an important role in light nuclei production

K.-J. Sun, R. Wang, C. M. Ko, Y.-G. Ma, and C. Shen, (2022), arXiv:2207.12532


STAR: arXiv:2209.08058
W. Reisdorf et al. (FOPI), Nucl. Phys. A 781, 459 (2007);
T. A. Armstrong et al. (E864), Phys. Rev. C 61, 064908 (2000);
S. S. Adler et al. (PHENIX), Phys. Rev. Lett. 94 , 122302 (2005);
S. S. Adler et al. (PHENIX), Phys. Rev. C 69, 034909 (2004);
J. Adam et al. (ALICE), Phys. Rev. C 93, 024917 (2016)

# Multiplicity Dependence of Light Nuclei Yield Ratio



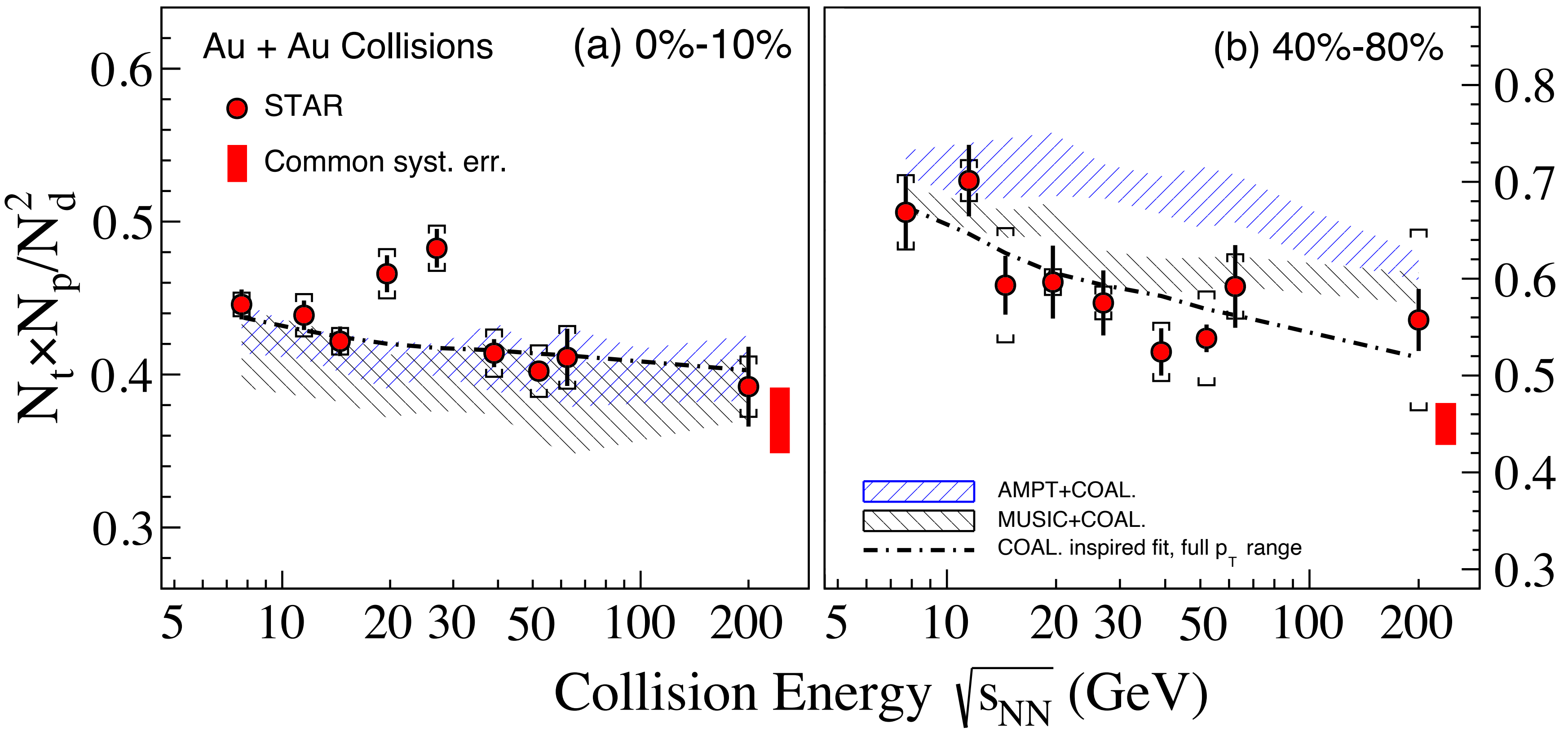

✯The ratio monotonically decreases with increasing $dN_{ch}/d\eta$ and exhibits a scaling behavior: trend driven by interplay between the size of light nuclei and the size of fireball created in HIC

✯The ratio can be described by the coalescence model, but thermal model overestimates the data

✯The ratios at 19.6 and 27 GeV from 0%-10% centrality show enhancements to the coalescence baseline with a combined significance of 4.1 σ

STAR: arXiv:2209.08058

# Collision Energy Dependence of Light Nuclei Yield Ratio

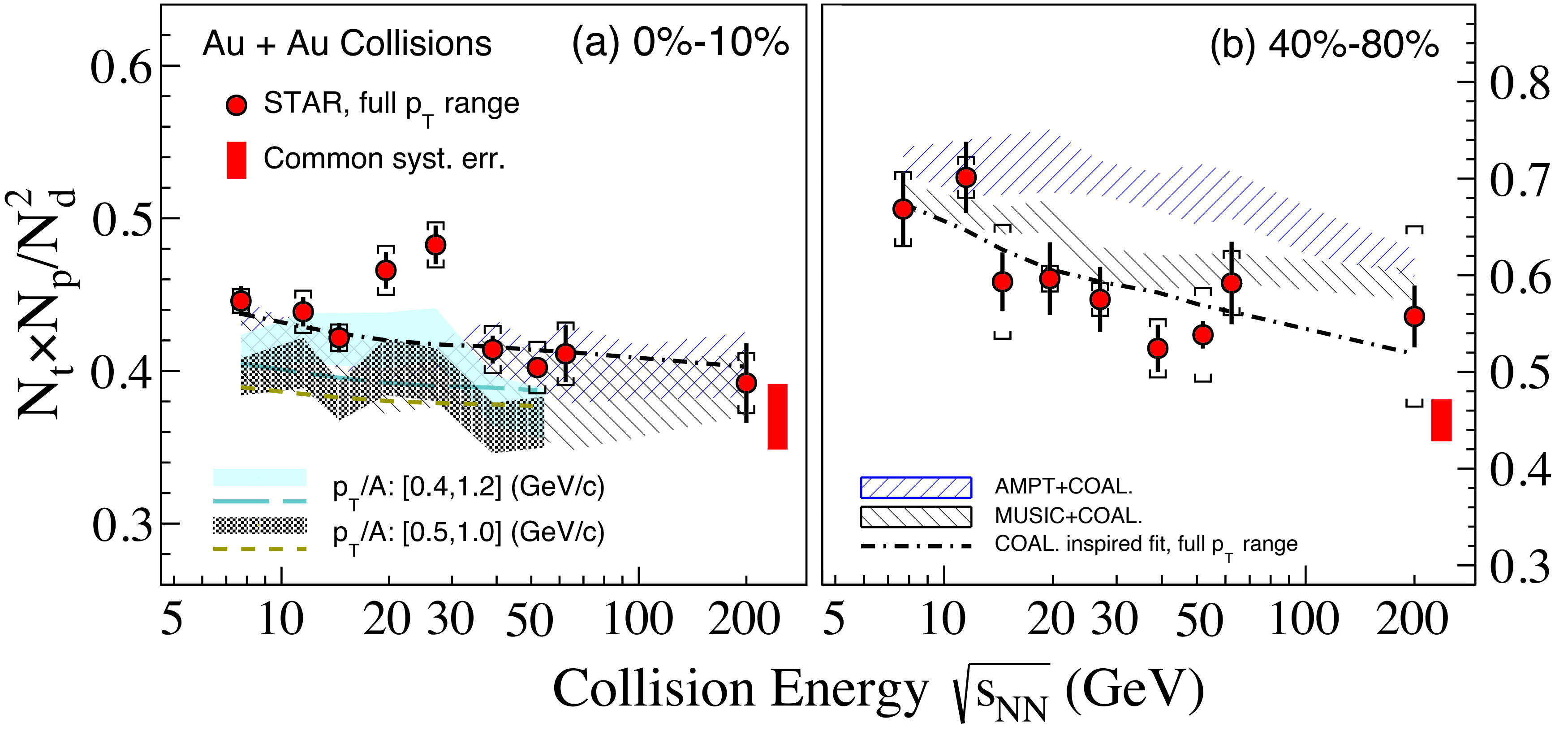



✭Non-monotonic behavior observed in the energy dependence of the yield ratio from 0%-10% central Au+Au collisions around 19.6 and 27 GeV

✭The yield ratio in peripheral (40%-80%) collisions exhibits a monotonic trend and the data can be well described by coalescence models within uncertainties

STAR: arXiv:2209.08058

# Collision Energy Dependence of Light Nuclei Yield Ratio




STAR: arXiv:2209.08058

✮Non-monotonic behavior observed in the energy dependence of the yield ratio from 0%-10% central Au+Au collisions around 19.6 and 27 GeV

✮The yield ratio in peripheral (40%-80%) collisions exhibits a monotonic trend and the data can be well described by coalescence models within uncertainties

✮The significance of the enhancements decreases with decreasing $p_T$ acceptance in the region of interest

# Summary and Outlook

☆We report triton and the primordial proton yields in Au+Au collisions from BES-I

☆The light nuclei yield ratio ($N_t \times N_p / N_d^2$) decreases monotonically with increasing $dN_{ch}/d\eta$ and exhibits a scaling behavior, which can be well described by the coalescence model

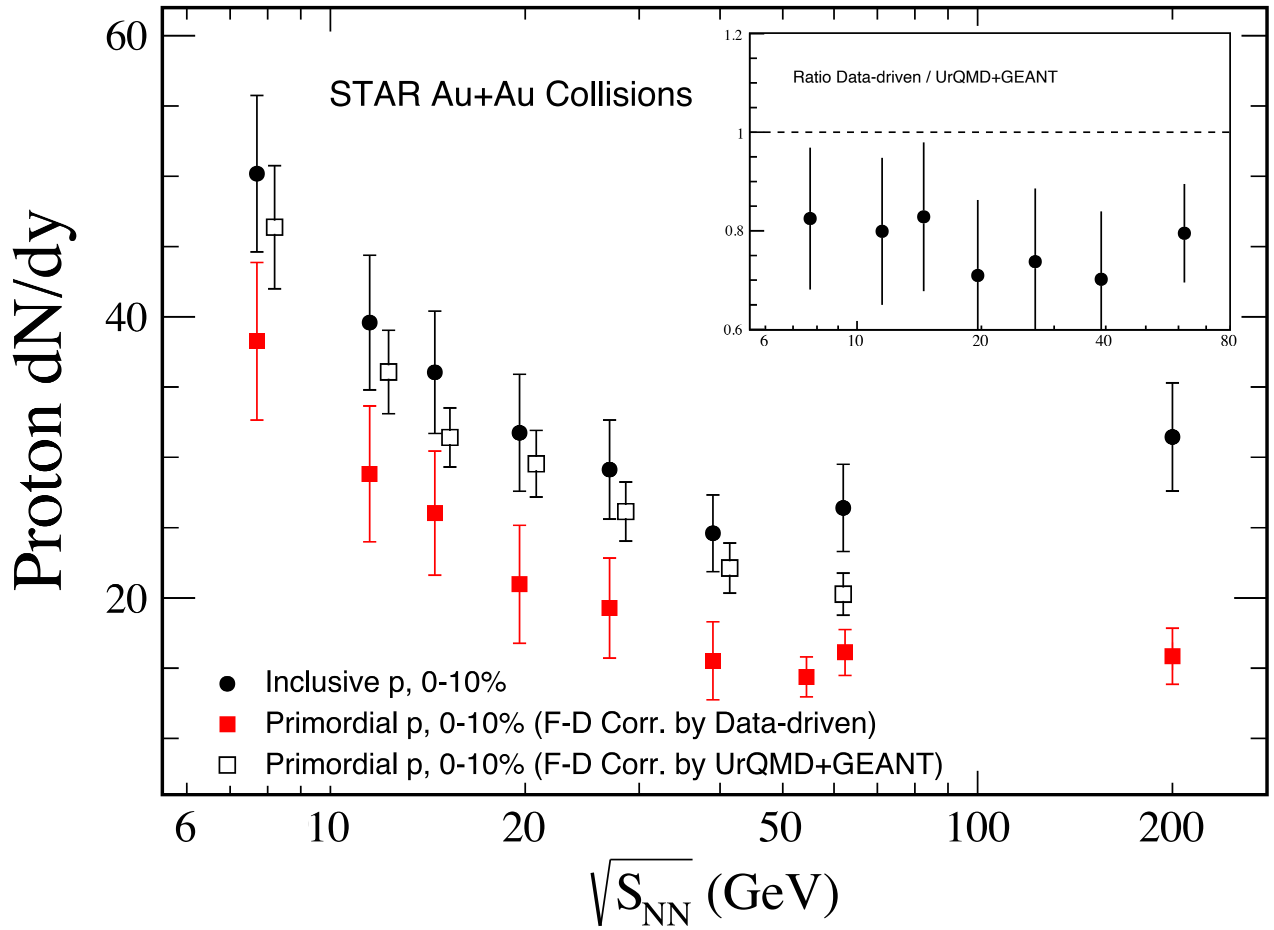
☆Relative to the coalescence baseline, enhancements of the yield ratios are observed in the 0%-10% most central collisions at 19.6 and 27 GeV with a combined significance of 4.1σ. The measured significance of these enhancements decreases with smaller $p_T$ acceptance. The enhancements are not observed in peripheral collisions and in model calculations without critical fluctuations.

## Outlook:

- High statistics data collected during BES-II for $\sqrt{s_{\mathrm{NN}}}$ = 3 - 27 GeV Au+Au collisions

Thank you for your attention!

# Backup




✯The primordial proton yield obtained from the UrQMD+GEANT method [Phys. Rev. Lett. 121, 03230 (2018)] is significantly larger than that from the data driven method