Examining the model dependence of extracting the kinetic freeze-out temperature and transverse flow velocity in small collision system

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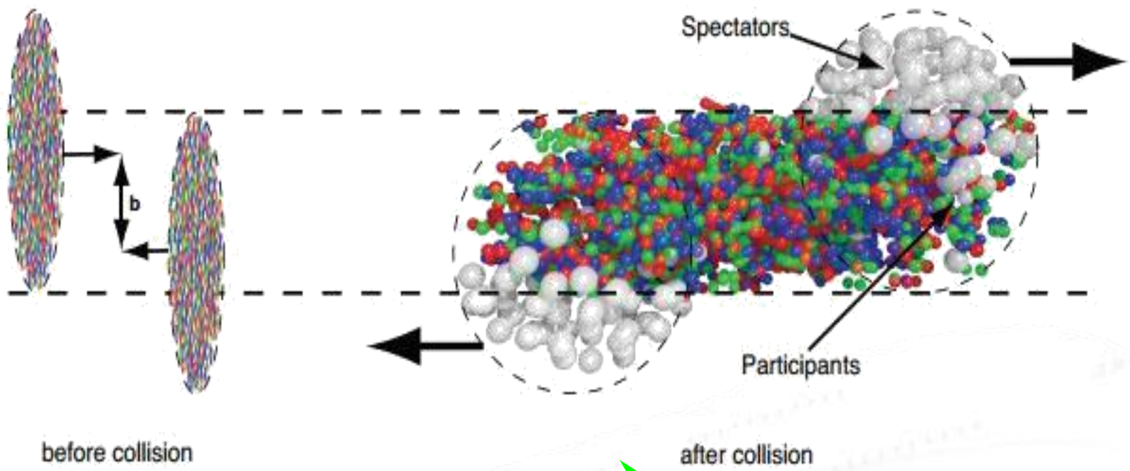
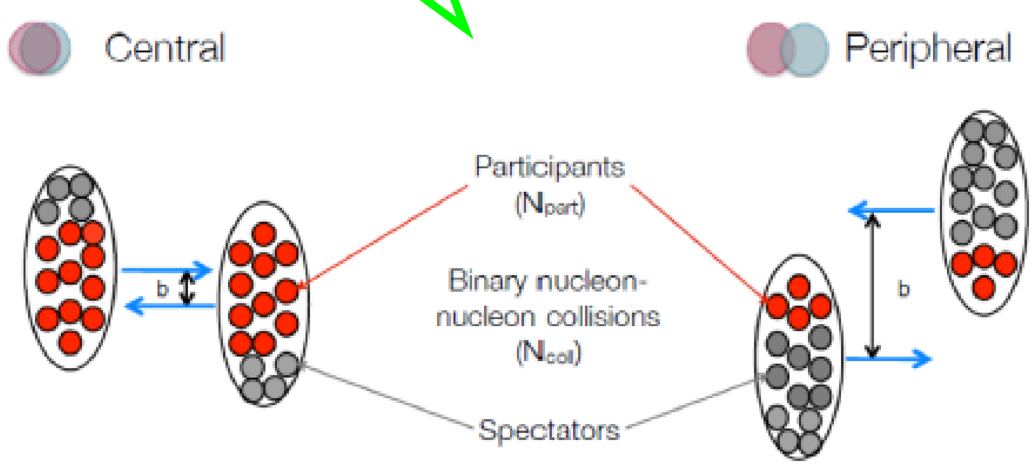
Content

1 Research background



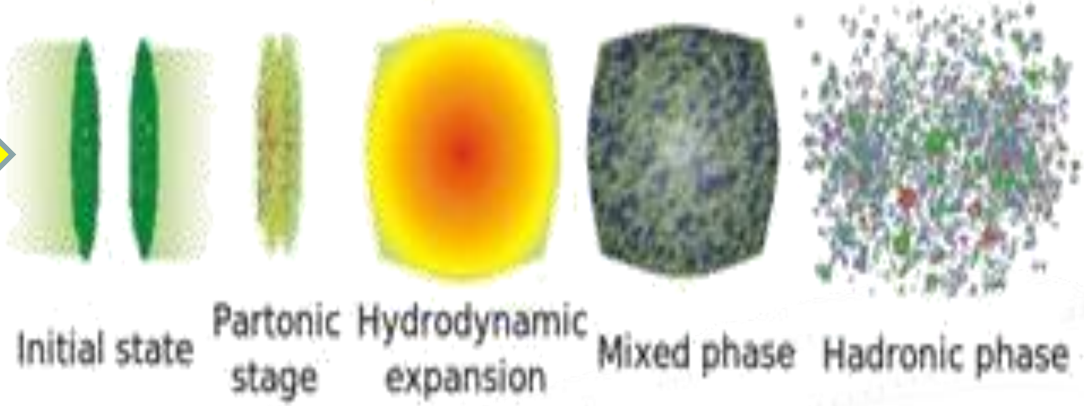
Collision Centrality

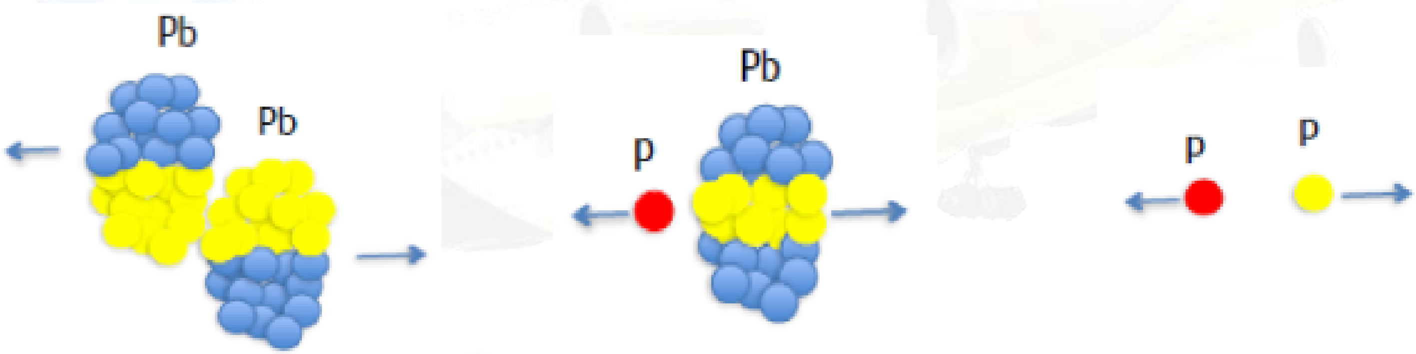
Participant-Spectator Model



1 Research background

The process of specific evolution





1 Research background

- The interacting system at the kinetic freeze-out (the last stage of collisions) stays at a thermodynamic equilibrium state or local equilibrium state, when the particle emission process is influenced not only by the thermal motion but also the flow effect.
- By analyzing the transverse momentum spectra of final-state particles, one can obtain the kinetic freeze-out temperature of interacting systems (emission sources) and the transverse flow velocity of produced particles.

1 Research background

Temperature
flow velocity

} **very important concept in high energy nucleus-nucleus collisions**

1. **The chemical freeze-out temperature**
2. **The kinetic freeze-out temperature**
3. **Effective temperature**
4. **transverse flow velocity, longitudinal flow velocity**

1 Research background

1

The chemical freeze-out temperature **describes** the excitation degree of the interacting system

at the stage of chemical equilibrium

2

The kinetic freeze-out temperature **describes** the excitation degree of the interacting system

at the stage of kinetic and thermal equilibrium

3

The effective temperature can be **extracted** from the transverse momentum spectra

by using some distribution laws

4

flow effect

describes the kinetic expansion characteristics

of the interacting system

2 Research Methods

Four methods for extracting

- **Kinetic freeze-out temperature**
- **Transverse flow velocity**

Four Methods

1. the Blast-Wave model with Boltzmann-Gibbs statistics — **(i) the BGBW model**
2. the Blast-Wave model with Tsallis statistics — **(ii) the TBW model**
3. $T = T_0 + am_0$, $\langle p_T \rangle = b_1 + \beta_T \overline{m}$ — **(iii) the alternative method based on Boltzmann statistics**
4. $T = T_0 + am_0$, $\langle p_T \rangle = b_1 + \beta_T \overline{m}$ — **(iv) the alternative method based on Tsallis statistics**

2 Research Methods

(i) The BGBW model results in the p_T distribution to be

$$f_1(p_T) = C_1 p_T m_T \int_0^R r dr \times I_0\left[\frac{p_T \sinh(\rho)}{T_0}\right] K_1\left[\frac{m_T \cosh(\rho)}{T_0}\right]$$

E. Schnedermann, J. Sollfrank, and U. Heinz, Phys. Rev. C 48, 2462 (1993)

E. Schnedermann and U. Heinz, Phys. Rev. C 47, 1738 (1993).

transverse mass → $m_T = \sqrt{p_T^2 + m_0^2}$

boost angle → $\rho = \tanh^{-1}[\beta(r)]$

self-similar flow profile → $\beta(r) = \beta_S (r/R)^{n_0}$

the flow velocity on the surface of the thermal source (→ β_S)

$\beta_T = (2/R^2) \int_0^R r\beta(r) dr = 2\beta_S/(n_0+2)$

$n_0 = 2$

2 Research Methods

(ii) The TBW model results in the p_T distribution to be

Z. B. Tang, Y. C. Xu, L. J. Ruan, G. van Buren, F. Q. Wang, and Z. B. Xu, Phys. Rev. C 79, 051901(R) (2009).

$$f_2(p_T) = C_2 p_T m_T \int_{-\pi}^{\pi} d\phi \int_0^R r dr \Big\{ 1 + \frac{q-1}{T_0} [m_T \cosh(\rho) - p_T \sinh(\rho) \cos(\phi)] \Big\}^{-q/(q-1)}$$

$n_0 = 1$ ⟶ $\beta_T = 2\beta_S/(n_0+2) = (2/3)\beta_S$

$-1/(q-1)$ ⟶ $-q/(q-1)$

H. Zheng and L. L. Zhu, Adv. High Energy Phys. 2016, 9632126 (2016).

2 Research Methods

(iii) The Alternative method based on Boltzmann statistics

$$T = T_0 + am_0$$

$$\langle p_T \rangle = b_1 + \beta_T \overline{m}$$

$$\langle p \rangle = b_2 + \beta \overline{m}$$

H.-L. Lao, H.-R. Wei, F.-H. Liu, and R. A. Lacey, Eur. Phys. J. A 52, 203 (2016).

the form of Boltzmann distribution

J. Cans and D. Worku, Eur. Phys. J. A 48, 160 (2012).

$$f_3(p_T) = \frac{1}{N}\frac{dN}{dp_T} = C_3 p_T m_T \exp\left(-\frac{m_T}{T}\right)$$

2 Research Methods

(iv) The Alternative method based on Tsallis statistics

$$T = T_0 + am_0$$

$$\langle p_T \rangle = b_1 + \beta_T \overline{m}$$

$$\langle p \rangle = b_2 + \beta \overline{m}$$

H.-L. Lao, H.-R. Wei, F.-H. Liu, and R. A. Lacey, Eur. Phys. J. A 52, 203 (2016).

H. Zheng and L. L. Zhu, Adv. High Energy Phys. 2016, 9632126 (2016).

the form of Tsallis distribution

$$f_4(p_T) = \frac{1}{N}\frac{dN}{dp_T} = C_4 p_T m_T \left(1 + \frac{q-1}{T} m_T\right)^{-q/(q-1)}$$

2 Research Methods

For the spectra in a wide p_T range, we have to consider the contribution of hard scattering process

The contribution of hard process is parameterized to an inverse power-law

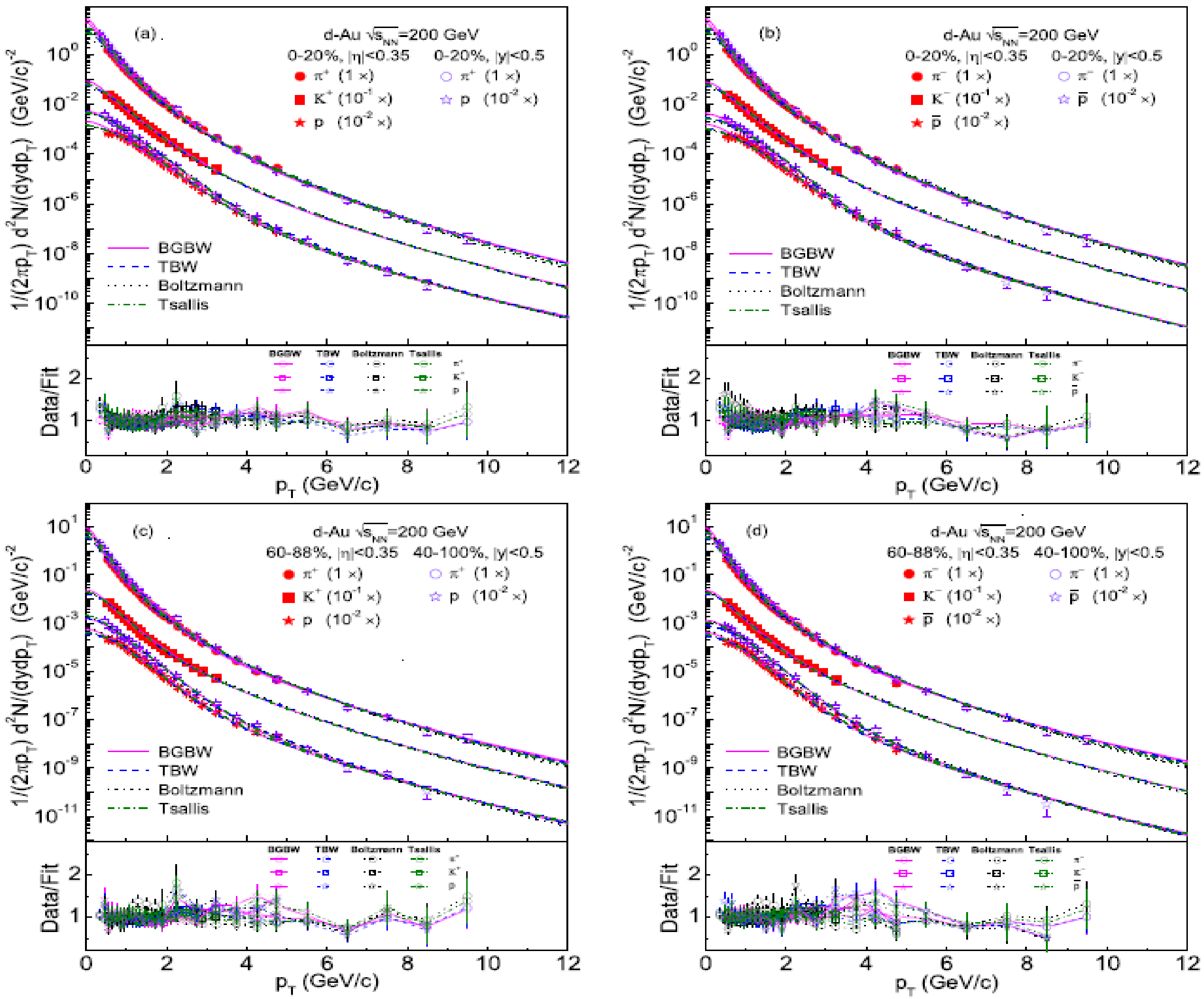
$$f_H(p_T) = A p_T \left(1 + \frac{p_T}{p_0}\right)^{-n}$$

G. Arnison et al. (UA1 Collaboration), Phys. Lett. B 118, 167 (1982).

We can use a superposition of both contributions of soft and hard processes

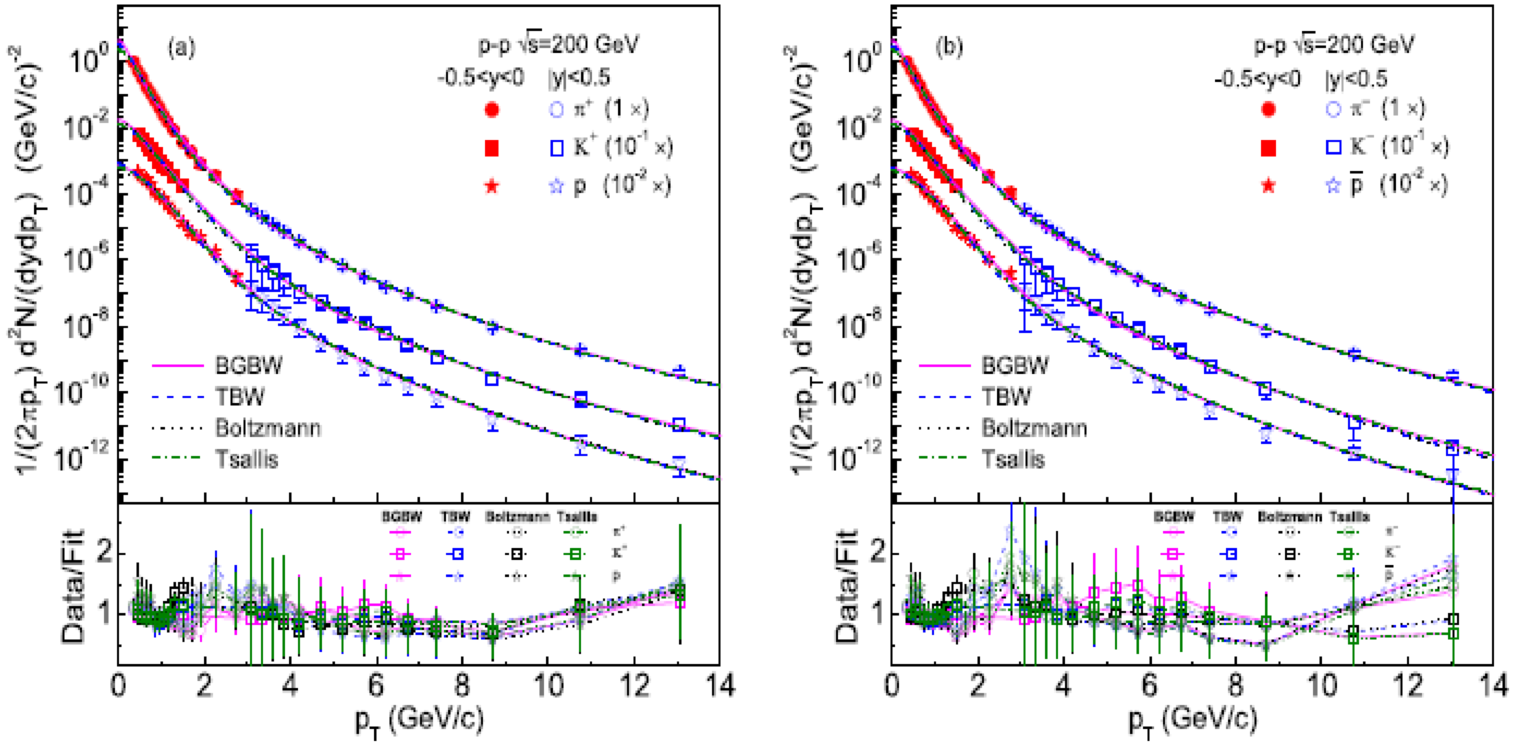
$$f_0(p_T) = k f_S(p_T) + (1-k) f_H(p_T)$$

3 Results



The symbols are taken from literature, the curves are our fitting results

3 Results



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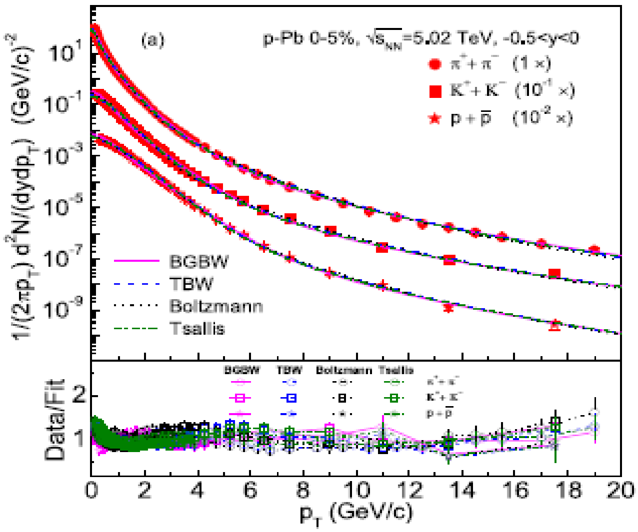

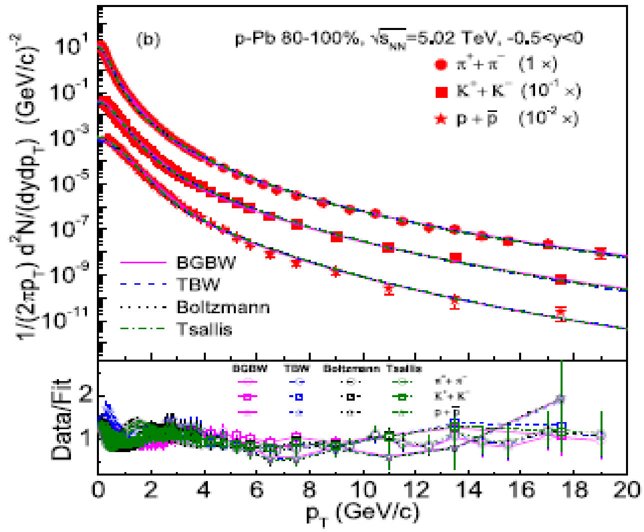

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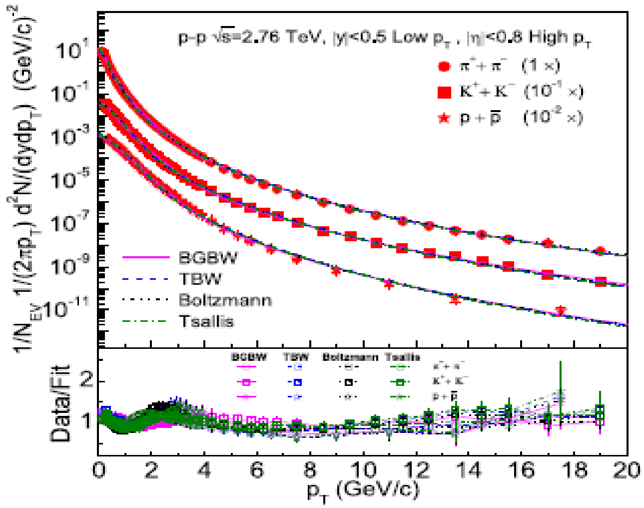
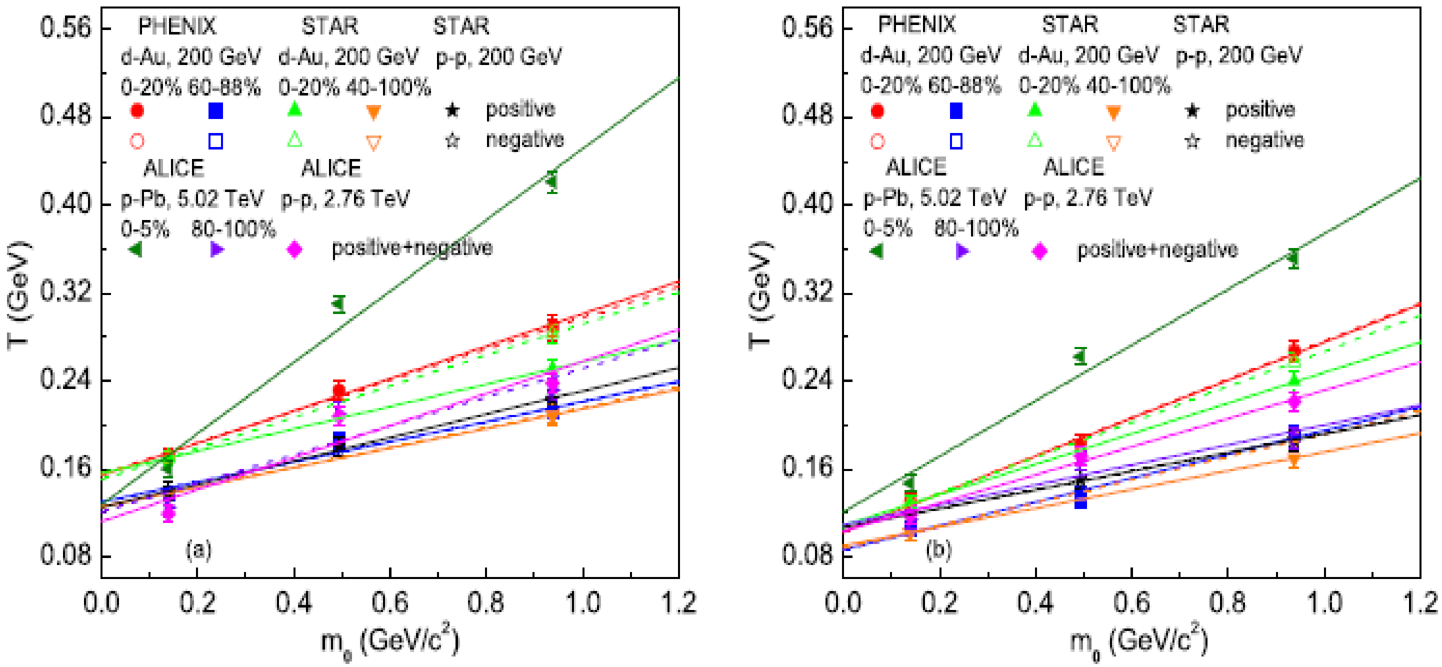


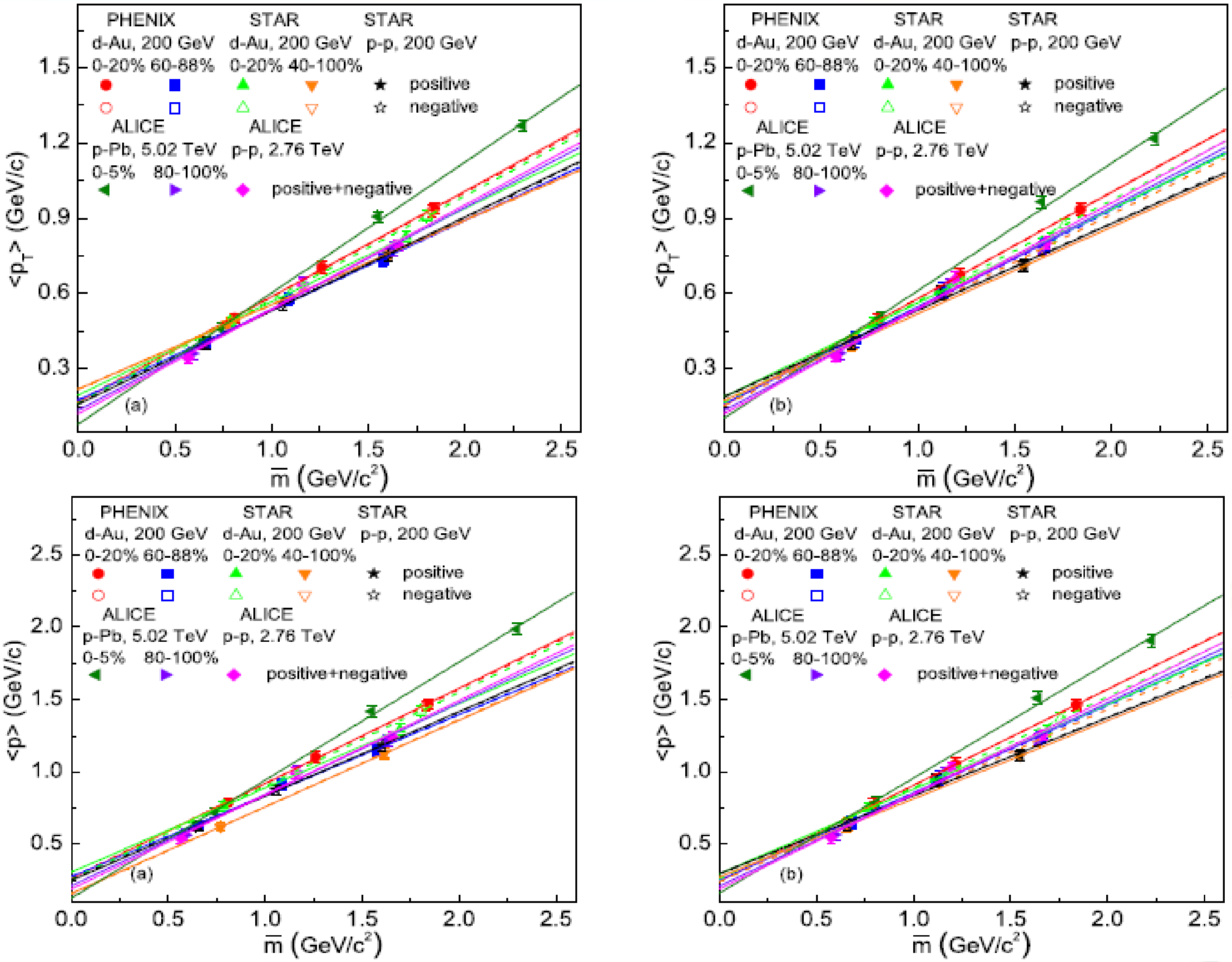
3 Results



$$T = T_0 + am_0$$

H.-L. Lao, F.-H. Liu, B.-C. Li, M.-Y. Duan, arXiv:1708.07749 [nucl-th] (2017).

3 Results



$$\langle p_T \rangle = b_1 + \beta_T \overline{m}$$

$$\langle p \rangle = b_2 + \beta \overline{m}$$

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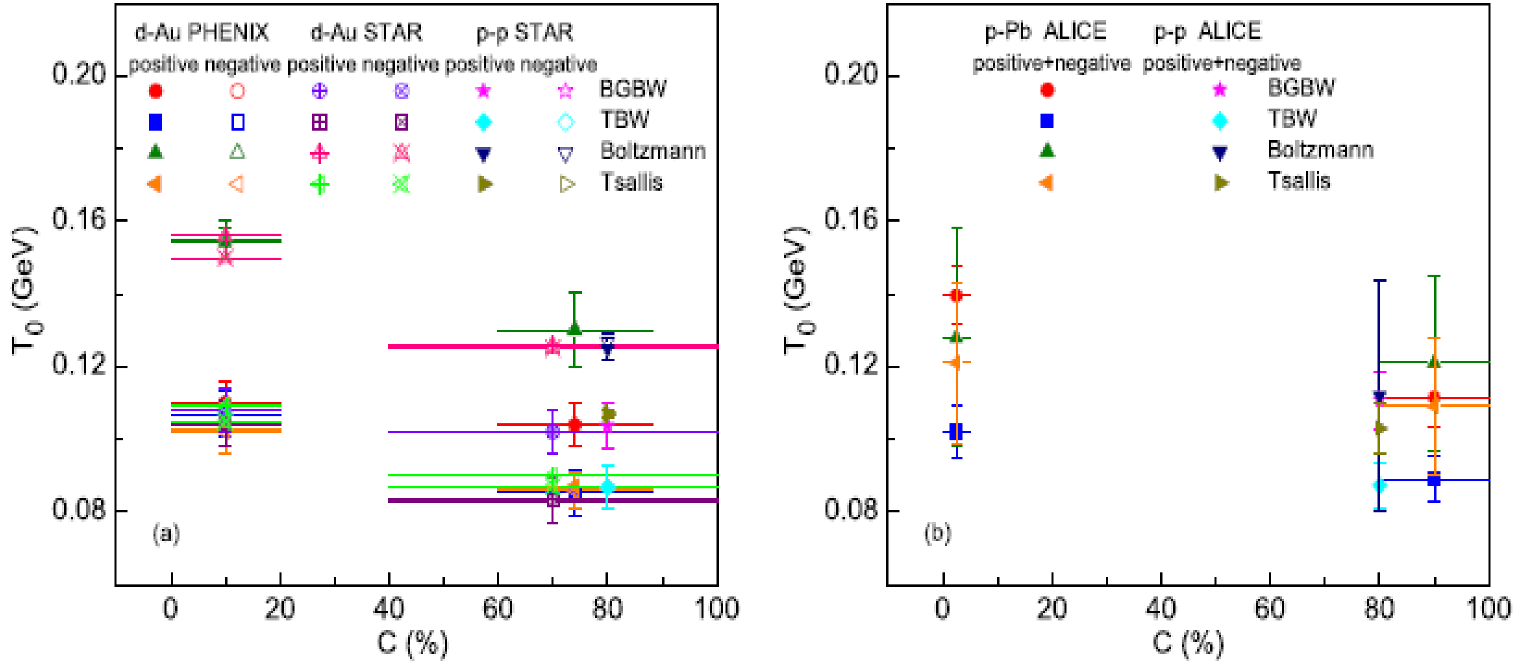
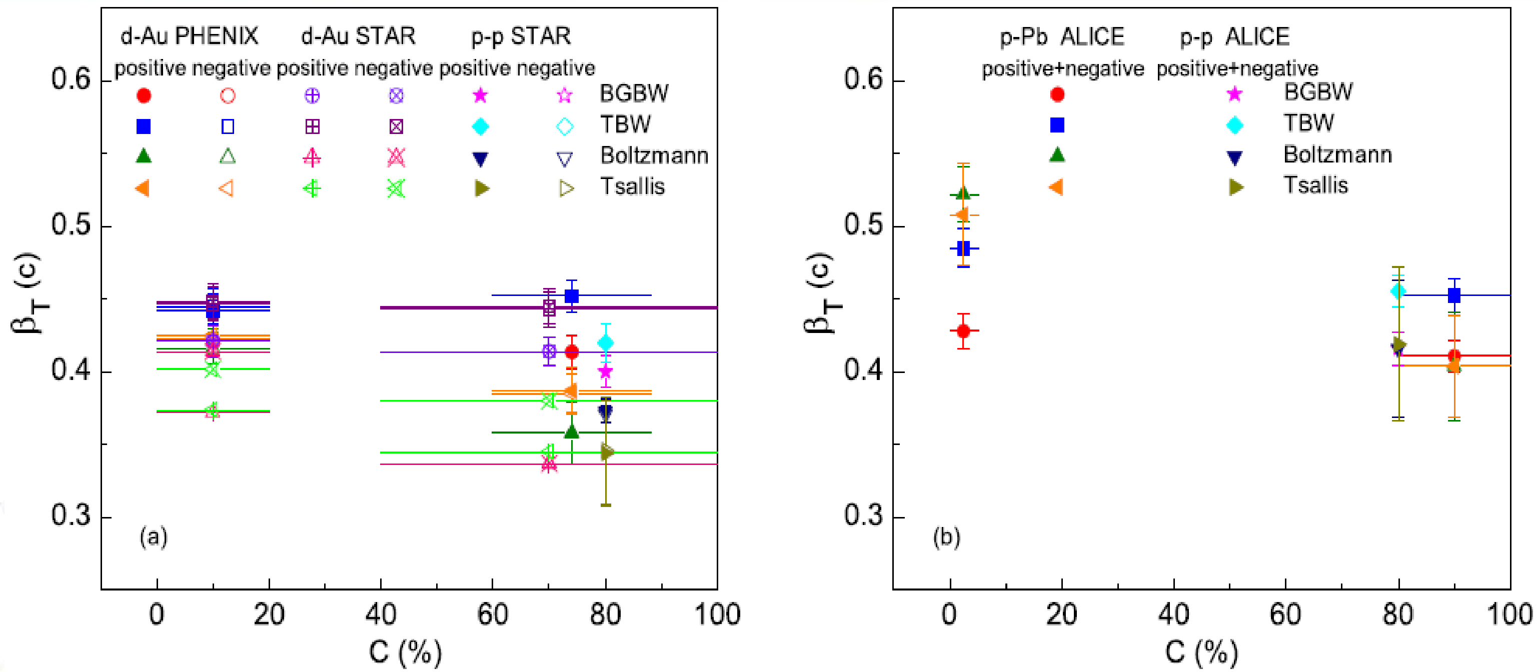


T_0 **Central** > **Peripheral**

LHC ≥ **RHIC**

pp **is similar to** **Peripheral collisions**

3 Results



β_T **Peripheral** → **Central** show a slightly increase or nearly invariant

RHIC → **LHC**

pp is similar to Peripheral collisions

4 Conclusions

1. **The p_T spectra of $\pi^\pm$, $K^\pm$, p and $\bar{p}$ produced in pp and d-Au collisions at the RHIC, as well as pp and p-Pb collisions at the LHC, have been analyzed by four methods.**

2. **The four methods present similar results, and in some cases these results are in agreement with each other within errors.**

3. **T_0 in central d-Au and p-Pb collisions is relatively larger than that in peripheral d-Au and p-Pb collisions, and β_T in central d-Au and p-Pb collisions is slightly larger than or equal to that in peripheral d-Au and p-Pb collisions.**

4

Central d-Au and p-Pb collisions are similar to central Au-Au and Pb-Pb collisions, and peripheral d-Au and p-Pb collisions are similar to peripheral Au-Au and Pb-Pb collisions.

5

Comparing with central nucleus-nucleus collisions, pp collisions are closer to peripheral nucleus-nucleus collisions due to similar numbers of participant nucleons.

6

In central collisions, the excitation degree at the kinetic freeze-out is mainly determined by the maximum nucleus and collision energy, but not the numbers of participant nucleons and binary collisions.

Thank you for your attention!

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