Identified particle spectra in Pb-Pb and p-Pb collisions with a modified Tsallis blast-wave model

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1. Background

2. Modified Tsallis blast-wave model

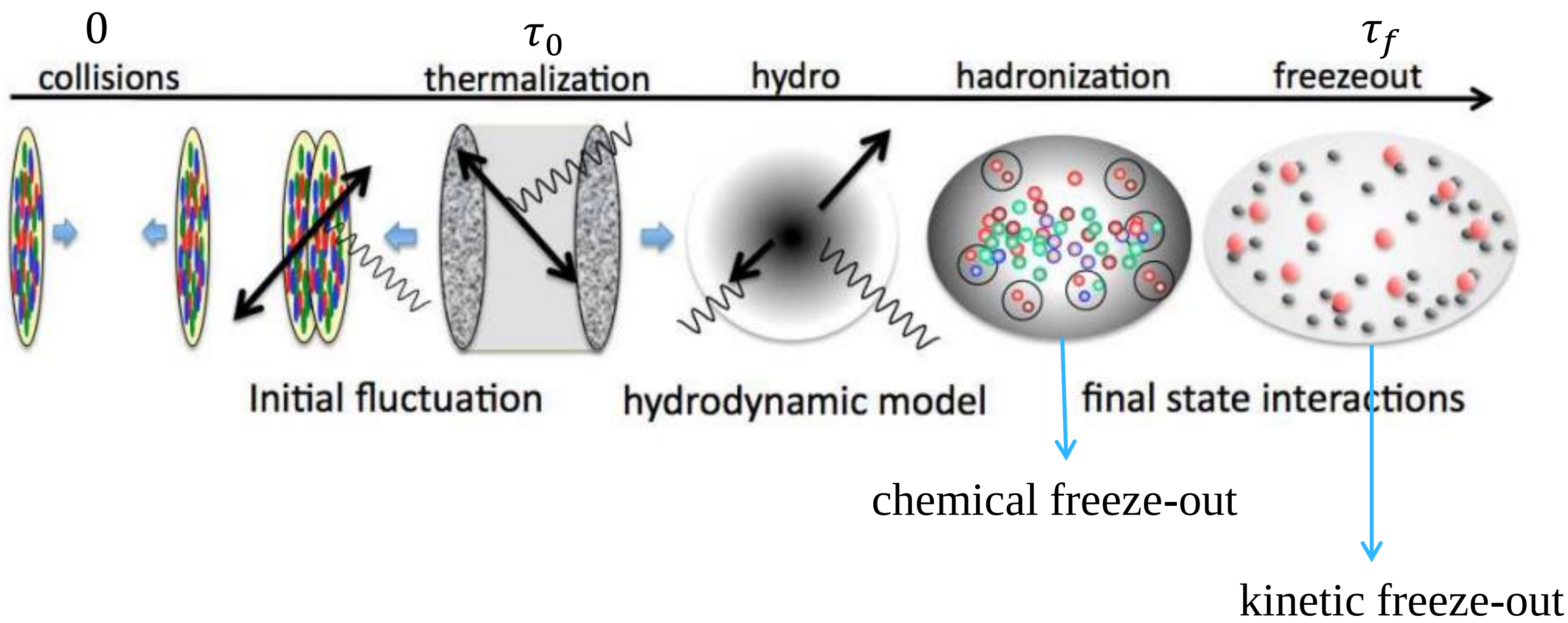
3. Results and conclusions

4. Summary

1. Background

➢Quantum-Chromodynamics (QCD) predicts that at high temperature and energy density there exists a hot and dense strongly interacting matter, quark-gluon plasma(QGP)。 **[E.V. Shuryak, Phys. Rept. 61, 71 (1980)]**

➢ QGP is expected to be produced in ultrarelativistic heavy-ion collisions。



1. Background

➢The transverse momentum (p_T) spectra of identified particles are significant observables in high energy collisions. They are utilized to investigate the dynamics of particle production.

➢In the low p_T region, particles production is governed by soft physics and described by some nonperturbative theory or model, such as the Boltzmann-Gibbs blast-wave model (BGBW).

➢In the high p_T region, it is dominated by hard processes and described by perturbative quantum chromodynamics (pQCD)

1. Background

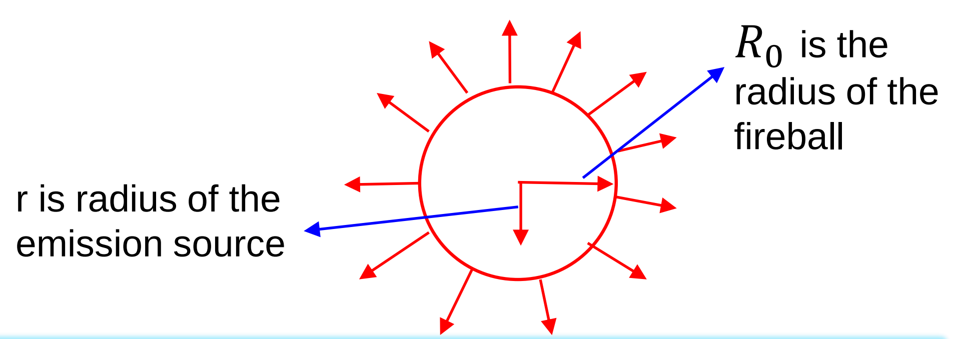
➢The BGBW model has been widely used in the description of the particle spectra in AA and pA collisions at the RHIC and the LHC.

➢BGBW model [Schnedermann E et al, Phys. Rev. C 48 2462 (1993)]

$$\frac{d^2N}{2\pi p_T dp_T dy} \propto m_T \int_0^R r dr\, K_1\left(\frac{m_T \cosh\rho}{T_{\mathrm{kin}}}\right) I_0\left(\frac{p_T \sinh\rho}{T_{\mathrm{kin}}}\right)$$

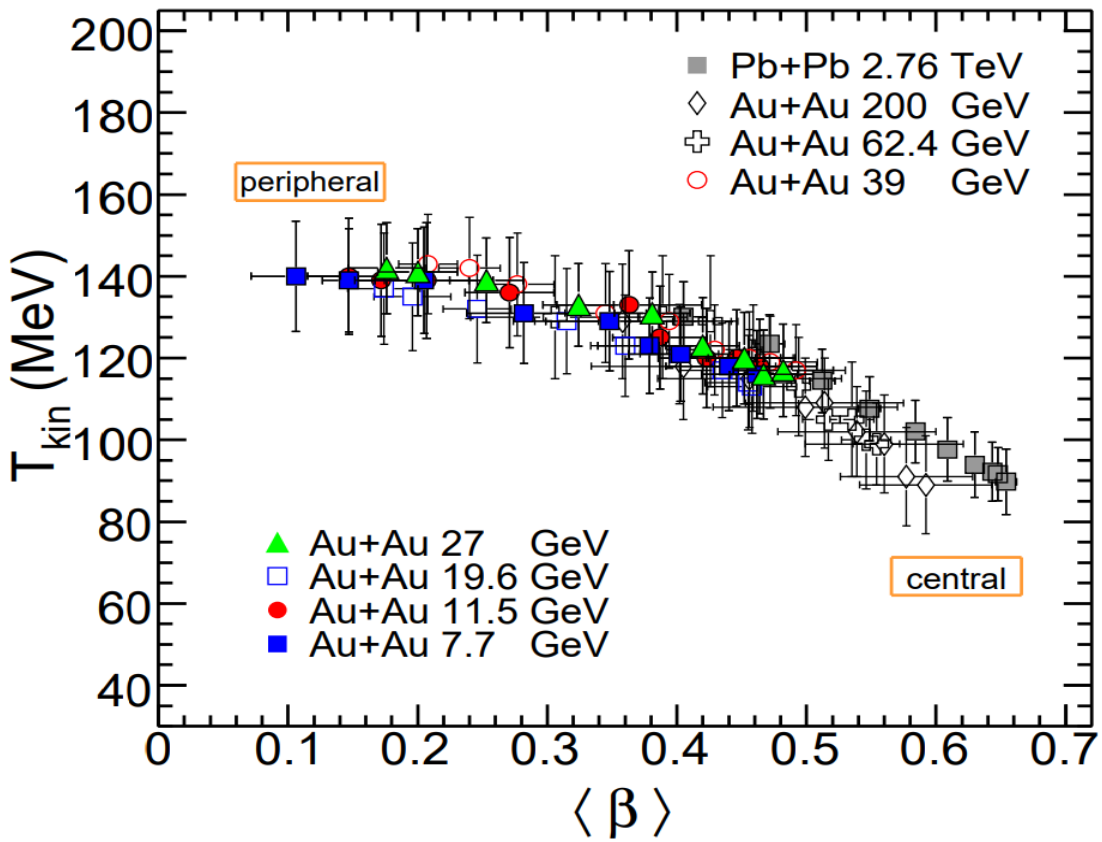
$$\rho = \tanh^{-1}(\beta_r)$$

$$\beta_r = \langle\beta\rangle\left(\frac{r}{R_0}\right)^n \frac{n+2}{2}$$



1. Background

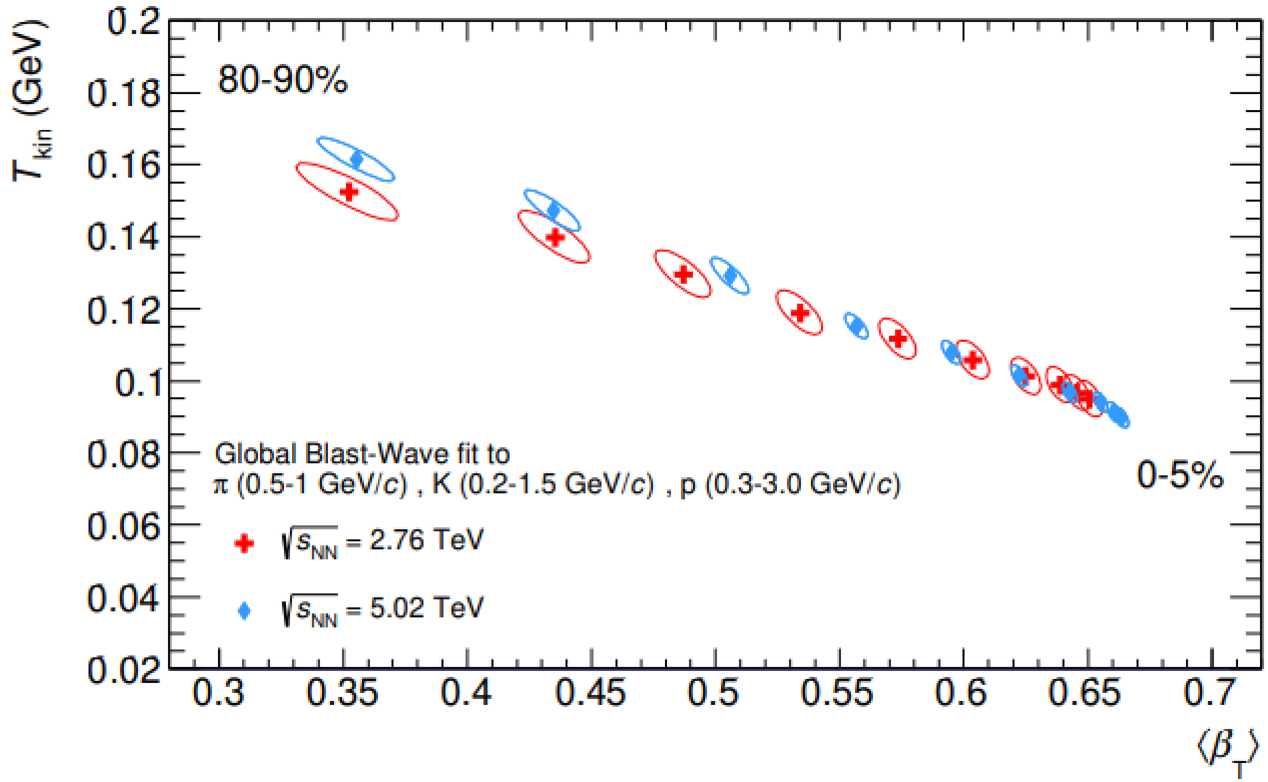
BGBW results of the spectra at RHIC



[L. Adamczyk et al. (STAR Collaboration), Phys. Rev. C 96, 044904 (2017)]

1. Background

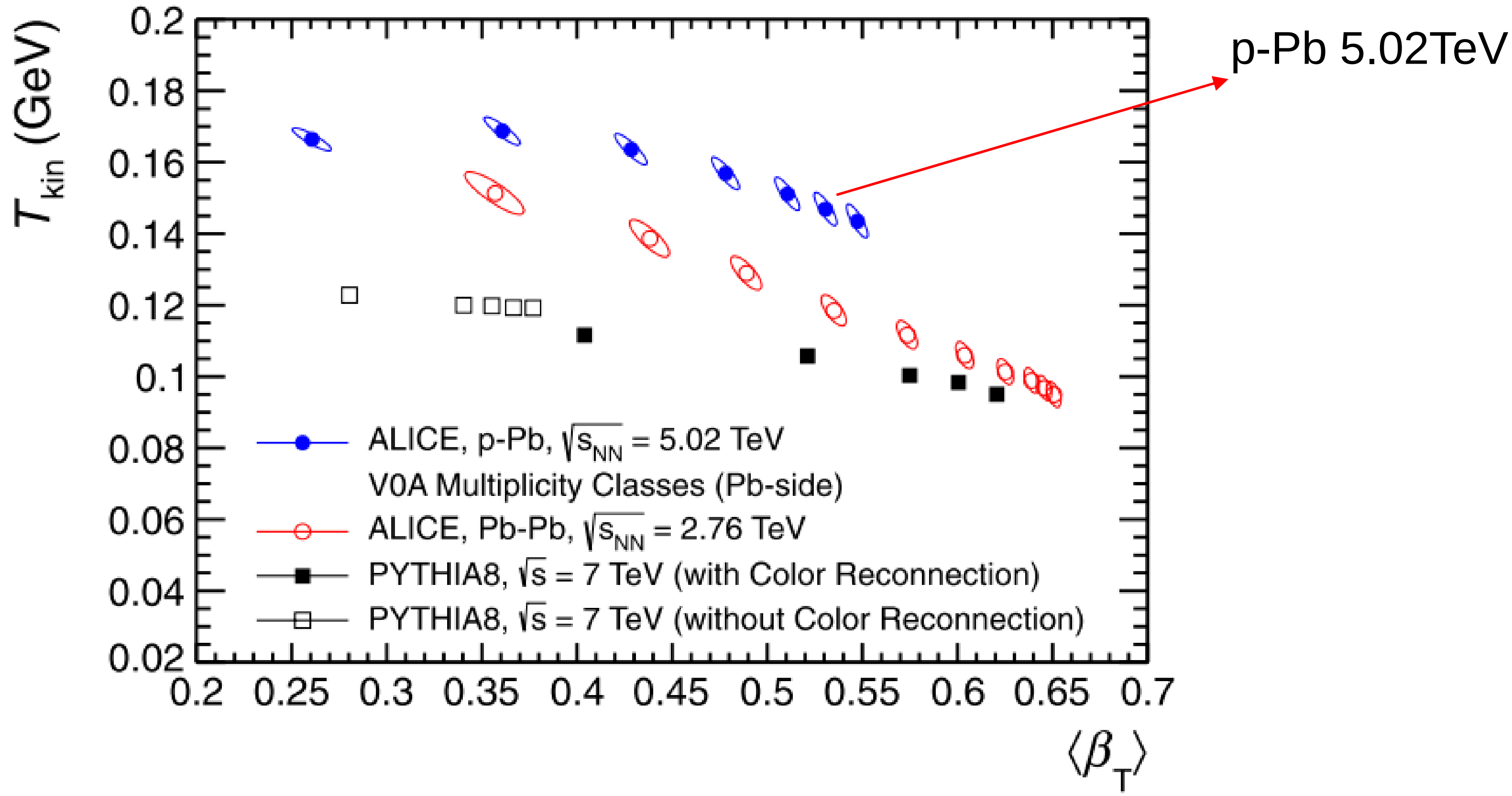
BGBW results in Pb-Pb collisions at 2.76 and 5.02 TeV



[S. Acharya et al. (ALICE Collaboration), Phys. Rev. C 101, 044907 (2020)]

1. Background

BGBW results in p-Pb collisions at 5.02 TeV



[B. Abelev et al. (ALICE Collaboration), Phys. Lett. B 728, 25-38 (2014)]

1. Background

➢In the BGBW model, there is a strong assumption that the system will reach a local thermal equilibrium at some instant of time and then undergoes the hydrodynamic evolution.

➢In fact the initial condition for the hydrodynamic evolution fluctuates event by event.

➢In order to take this fluctuation into account, the authors have changed the sources of particle emission from the Boltzmann distribution to the Tsallis distribution. [Z. Tang et al., Phys. Rev. C 79, 051901(R)]

1. Background

➢TBW model

$$\frac{d^2N}{2\pi p_T dp_T dy} \propto m_T \int_{-Y}^{+Y} \cosh(y_s)\, dy_s \int_{-\pi}^{+\pi} d\phi$$

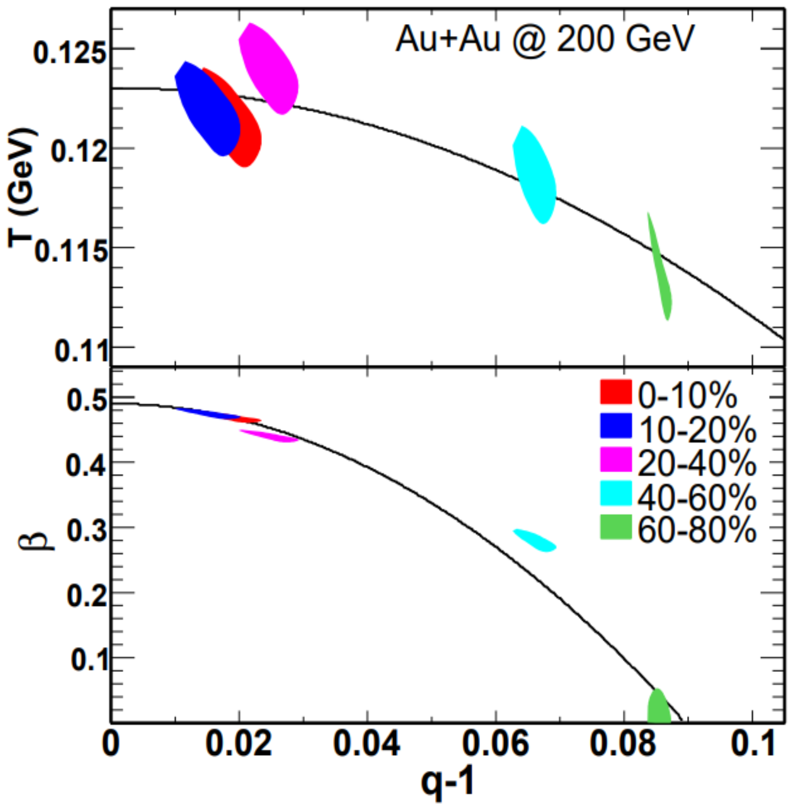
$$\times \int_0^R r dr \left(1 + \frac{q-1}{T}(m_T \cosh(y)\cosh(\rho) - p_T \sinh(\rho)\cos(\varphi))\right)^{\frac{-1}{q-1}}$$

$$\rho = \tanh^{-1}(\beta_r) \qquad \beta_r = \langle\beta\rangle \left(\frac{r}{R_0}\right)^n \frac{n+2}{2}$$

Four free parameters: non-extensive parameter q, kinetic free-out temperature T, average transverse flow velocity $\langle\beta\rangle$, and n determining the velocity profiles.

1. Background

TBW results in Au-Au collisions at 200GeV



[Z. Tang et al., Phys. Rev. C 79, 051901(R) (2009)]

2. Modified Tsallis blast-wave model

$$\frac{d^2N}{2\pi p_T dp_T dy} \propto m_T \int_{-Y}^{+Y} \cosh(y_s)\, dy_s$$
$$\times \int_{-\pi}^{+\pi} d\phi \left(1 + \frac{q-1}{T}\left(m_T \cosh(y)\cosh(\rho_0) - p_T \sinh(\rho_0)\cos(\varphi)\right)\right)^{\frac{-1}{q-1}}$$

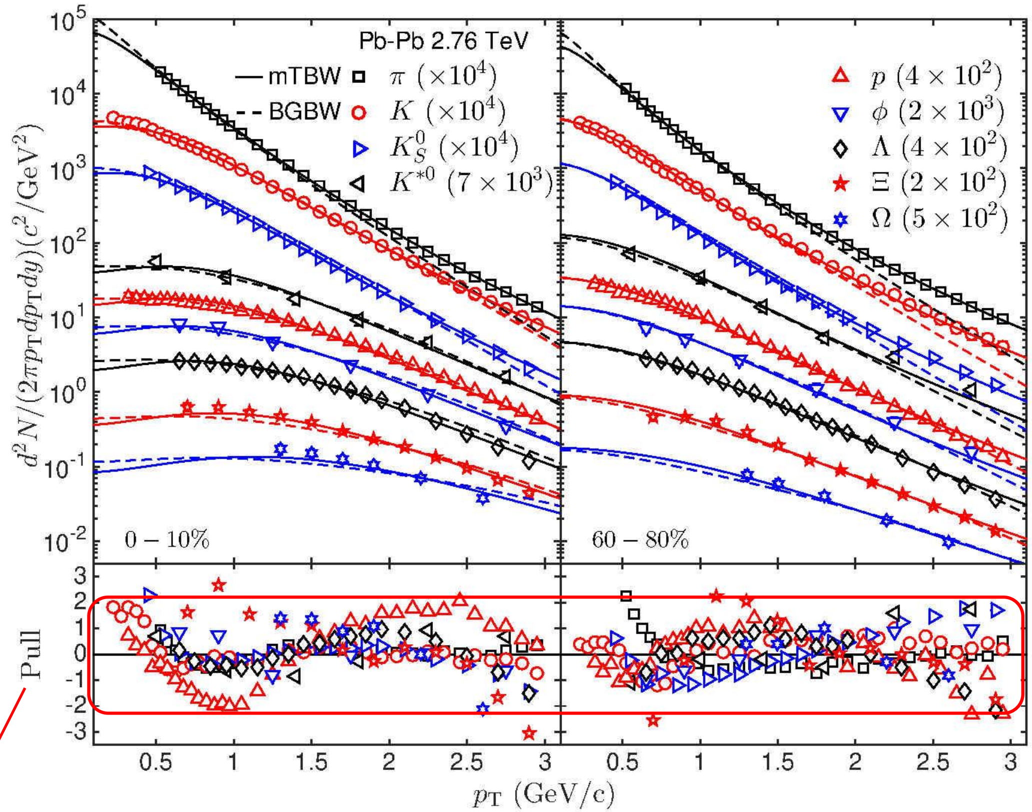
$\rho_0 = \tanh^{-1}\langle\beta\rangle$, dose not depend on the radius of the emitting source, which will reduce the number of free parameters, and thus the number of integrals.

Three free parameters: non-extensive parameter q, kinetic freeze-out temperature T and average transverse flow velocity $\langle\beta\rangle$.

In our investigation, q, T and $\langle\beta\rangle$ are set to be common for all particles.

3. Results and conclusions

Pb-Pb 2.76TeV



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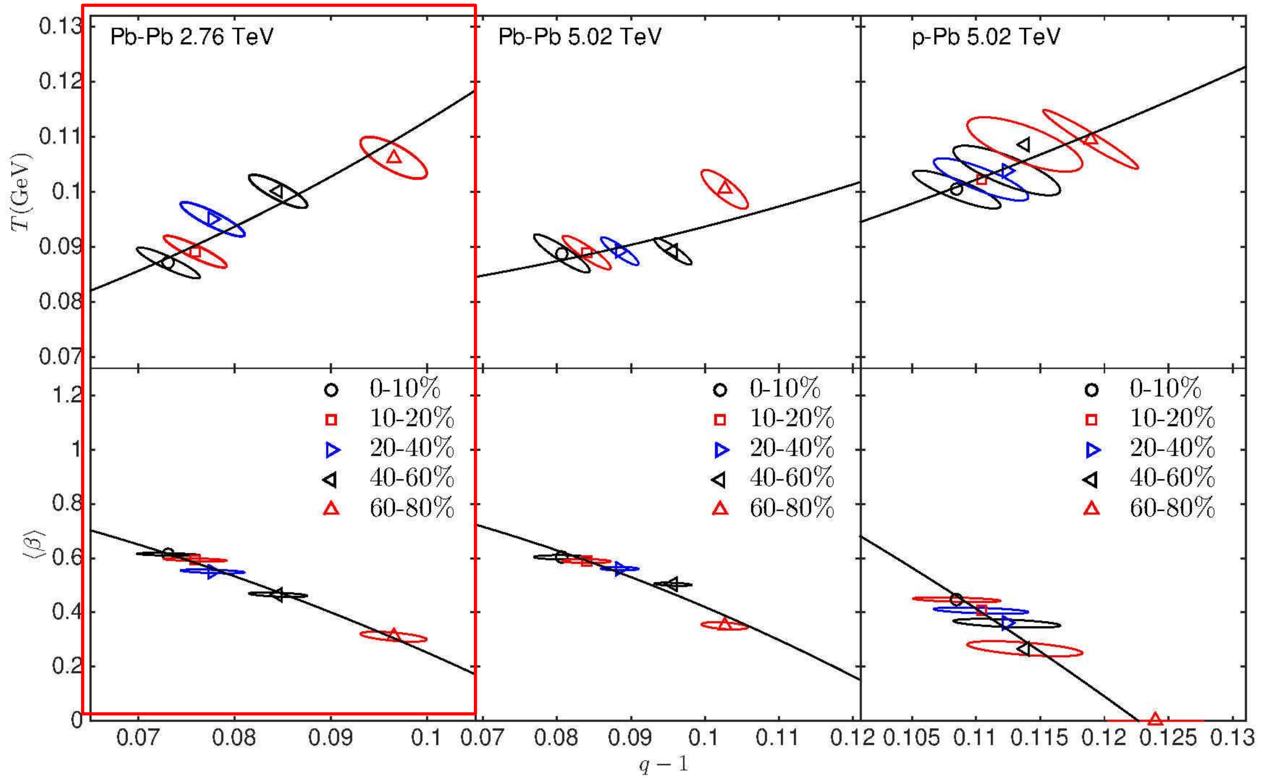
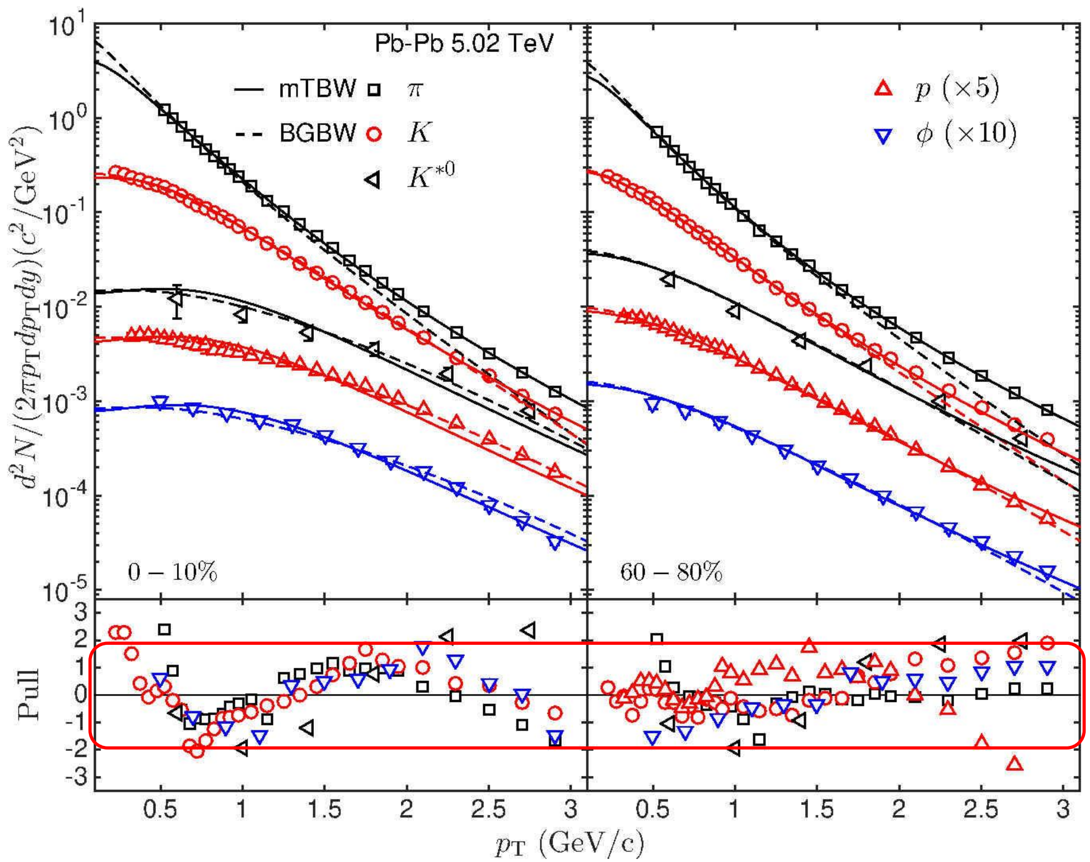
3. Results and conclusions



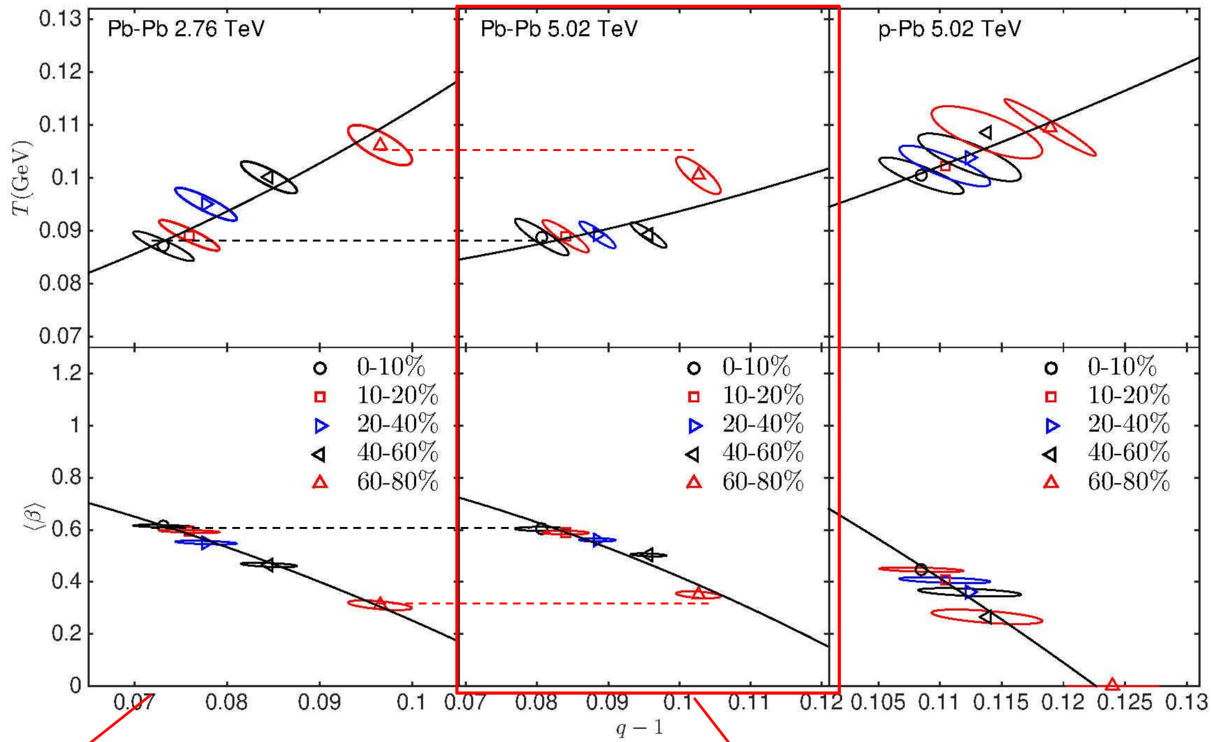
$$\langle\beta\rangle = (1.033 \pm 0.048) - (78.149 \pm 7.689)(q-1)^2$$
$$T = (0.059 \pm 0.013) + (5.350 \pm 2.070)(q-1)^2$$

3．Results and conclusions

Pb-Pb 5.02TeV



3. Results and conclusions

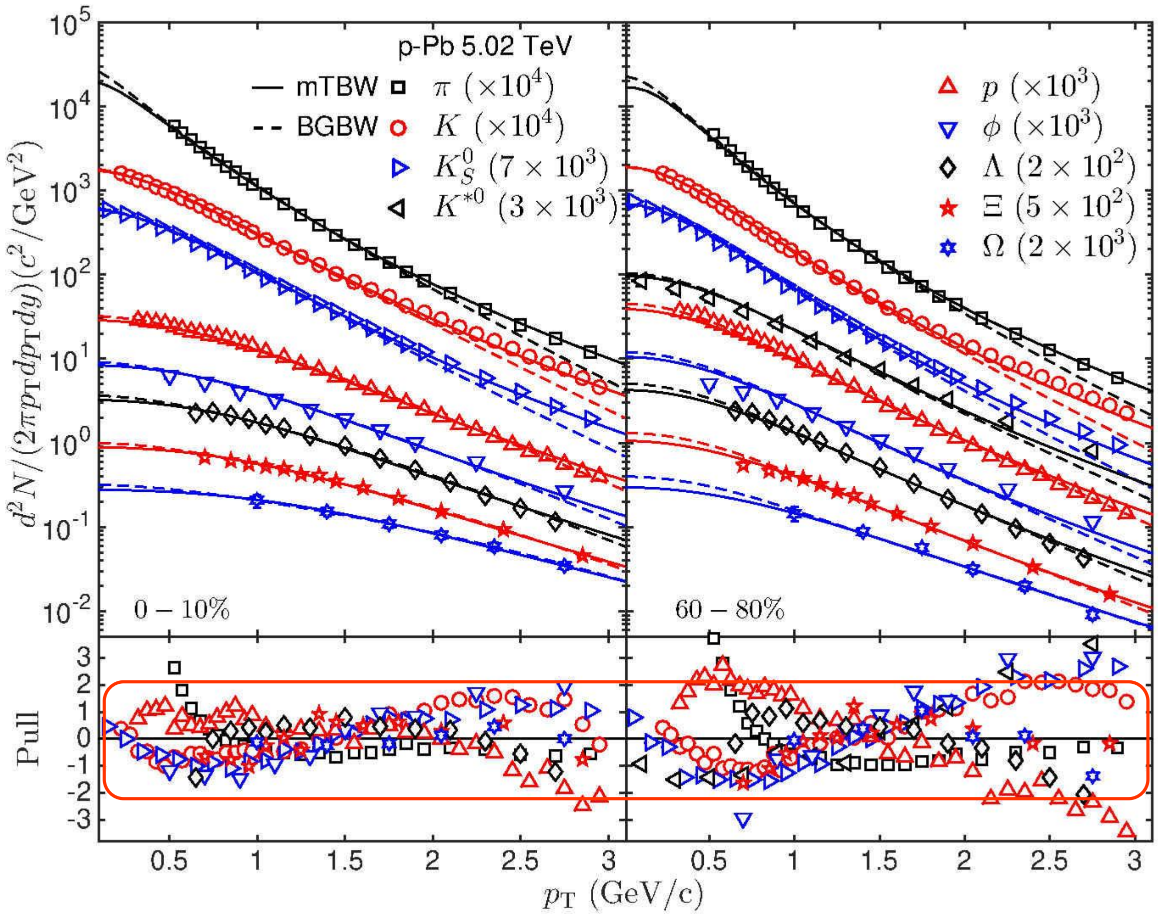


$$\langle\beta\rangle = (1.000 \pm 0.076) - (58.040 \pm 9.856)(q-1)^2$$
$$T = (0.076 \pm 0.009) + (1.744 \pm 1.092)(q-1)^2$$

$$\langle\beta\rangle = (1.033 \pm 0.048) - (78.149 \pm 7.689)(q-1)^2$$
$$T = (0.059 \pm 0.013) + (5.350 \pm 2.070)(q-1)^2$$

3. Results and conclusions

p-Pb 5.02TeV



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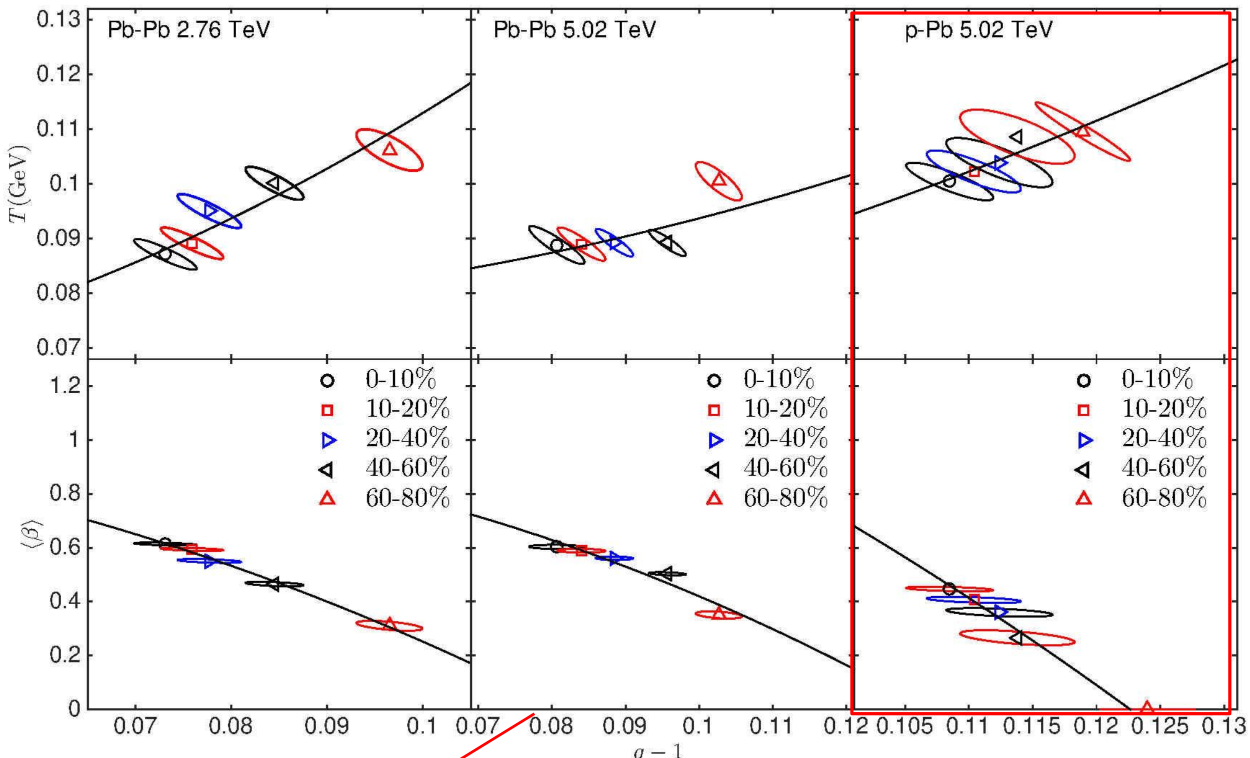


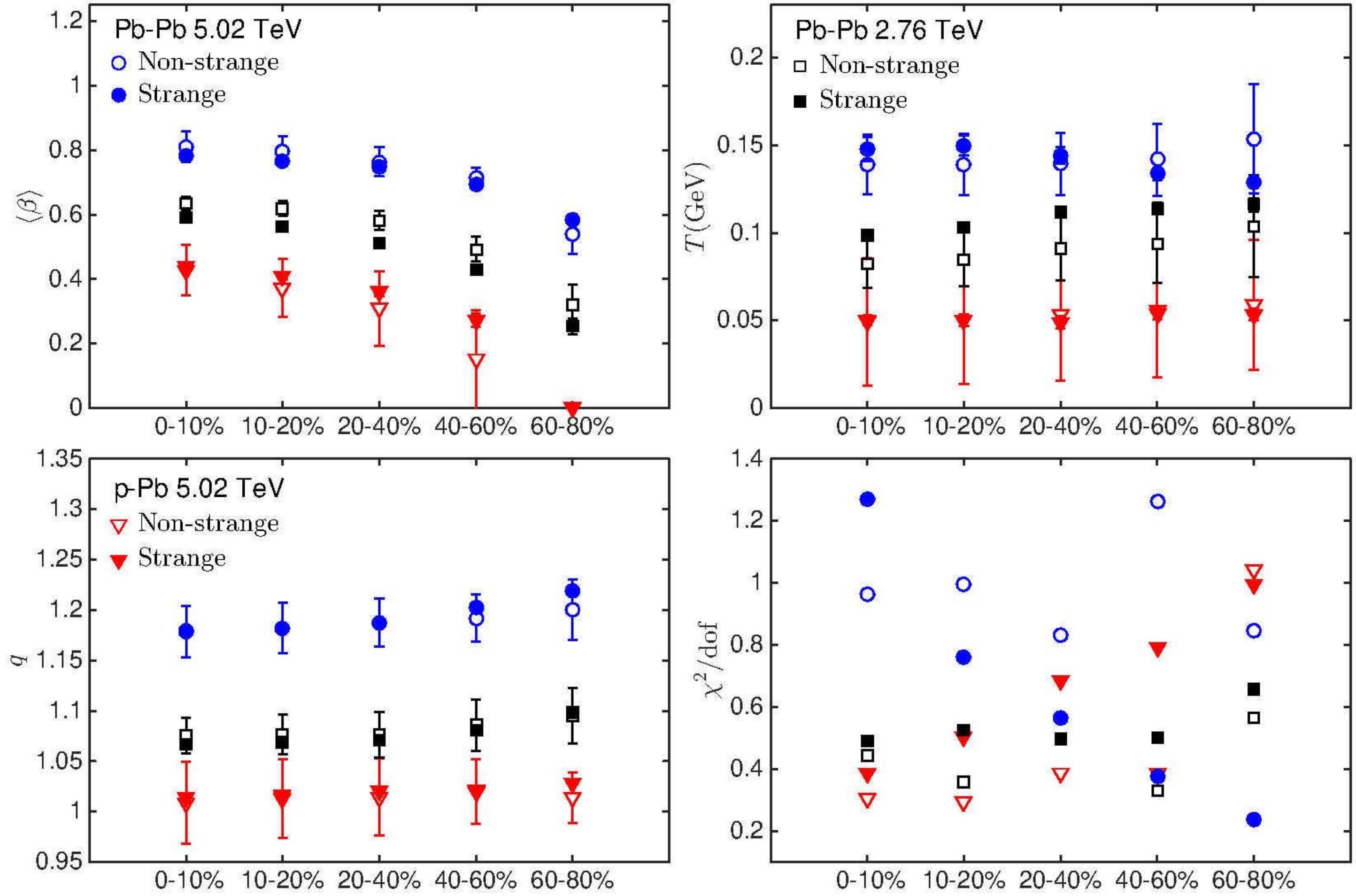
$$\langle\beta\rangle = (2.121 \pm 0.406) - (141.025 \pm 32.688)(q-1)^2$$

$$T = (0.053 \pm 0.012) + (4.054 \pm 0.970)(q-1)^2$$

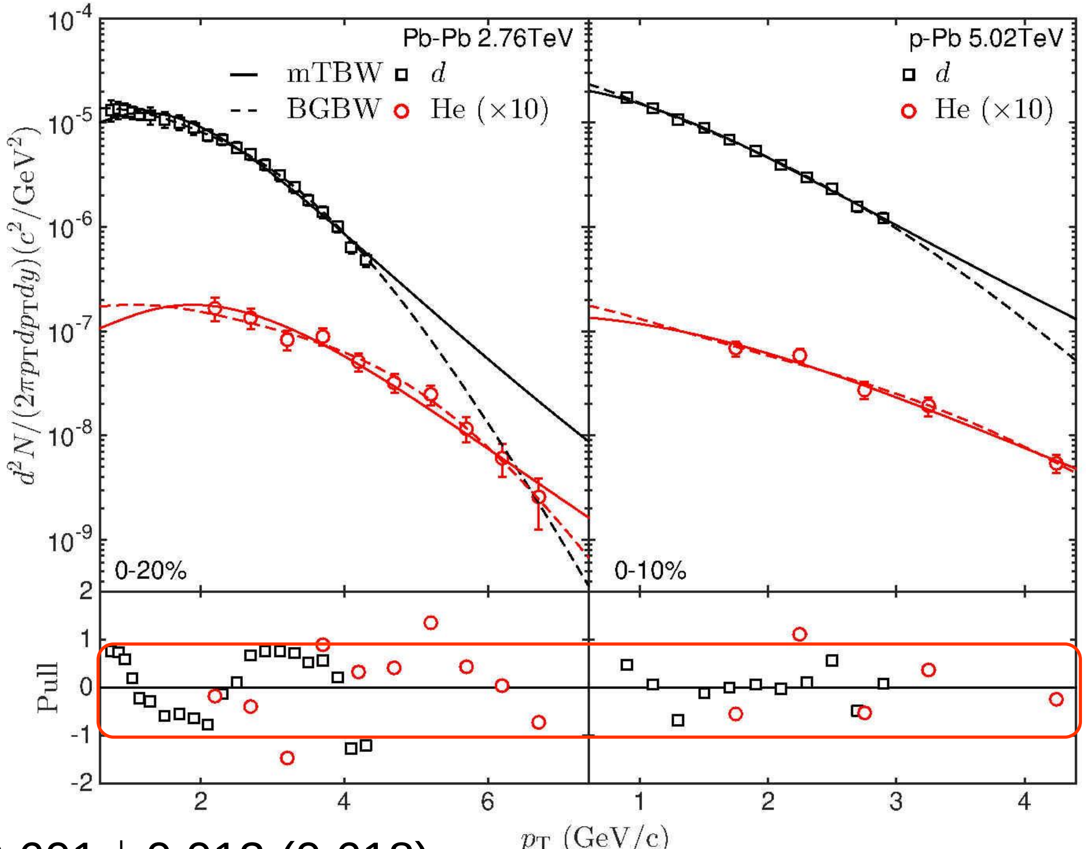
$$\langle\beta\rangle = (1.000 \pm 0.076) - (58.040 \pm 9.856)(q-1)^2$$

$$T = (0.076 \pm 0.009) + (1.744 \pm 1.092)(q-1)^2$$

3．Results and conclusions



3. Results and conclusions



$\langle\beta\rangle$=0.601±0.013 (0.618)
T=0.119±0.041 (0.082)
q=1.057±0.014 (1.078)

$\langle\beta\rangle$=0.348±0.050 (0.438)
T=0.121±0.056 (0.103)
q=1.081±0.017 (1.107)

4. Summary

- $\langle\beta\rangle$ increases with centrality while T and the non-extensive parameter q show the opposite behaviour, indicating a more rapid expansion and less off-equilibrium of the system with increasing centrality.
- In the same colliding system (At the same colliding energy), at higher energy (in the larger system) $\langle\beta\rangle$ prefers to be larger while T to be smaller. A possible explanation is that a larger volume has the kinetic freeze-out later allowing the kinetic temperature to decrease further.
- In central Pb-Pb collisions at 2.76 TeV, strange hadrons tend to freeze out earlier than non-strange hadrons, however in central Pb-Pb and p-Pb collisions at 5.02 TeV, the differences are less than 1σ, it is hard to make a definite conclusion.
- For light nuclei in Pb-Pb (p-Pb) collisions at 2.76 (5.02) TeV, in the scenario of the thermal production, they possibly prefer to freeze out earlier than light hadrons.

Thanks！

$$E\frac{d^3N}{d^3\mathbf{p}} = \int_{\Sigma^\mu} d^3\sigma_\mu p^\mu f(x,p),$$

$$f(x,p) = \frac{2\xi}{(2\pi)^3}\exp\{-p^\mu u_\mu/T_K\},$$

$$u^\mu = \cosh\rho(\cosh\eta, \tanh\rho\cos\phi_b, \tanh\rho\sin\phi_b, \sinh\eta)$$

$$p^\mu = (p^0, \boldsymbol{p}) = (m_T\cosh y, p_T\cos\phi_p, p_T\sin\phi_p, m_T\sinh y)$$

$$\begin{aligned} p^\mu u_\mu &= m_T\cosh\rho\cosh(\eta - y) \\ &\quad -p_T\sinh\rho\cos(\phi_p - \phi_b), \\ p^\mu d^3\sigma_\mu &= \tau m_T\cosh(\eta - y)d\eta r dr d\phi. \end{aligned}$$

$$\frac{d^3N}{p_T dp_T dy d\phi_p} = \frac{2\xi\tau_0}{(2\pi)^3}\int_{\Sigma^\mu} d\eta r dr d\phi m_T\cosh(\eta - y)\exp\left[-\frac{m_T\cosh\rho\cosh(\eta - y) - p_T\sinh\rho\cos(\phi_p - \phi_b)}{T_K}\right].$$

As described in the introduction, in the mTBW model the transverse flow velocity profile does not rely on the radius of the emitting source while in TBW model it does. Thus we would like to compare the results from the mTBW model with those from the TBW model. For central collisions, $\langle\beta\rangle$ and q (T) in Table 1 are (is) larger (smaller) than those (that) from the TBW fit, 0.565±0.006 and 1.030±0.007 (0.097±0.003). For peripheral collisions, $\langle\beta\rangle$, q and T are compatible with the corresponding values from the TBW fit, 0.293±0.012, 1.094±0.003 and 0.107±0.003.