Collective expansion in pp collisions using the Tsallis statistics

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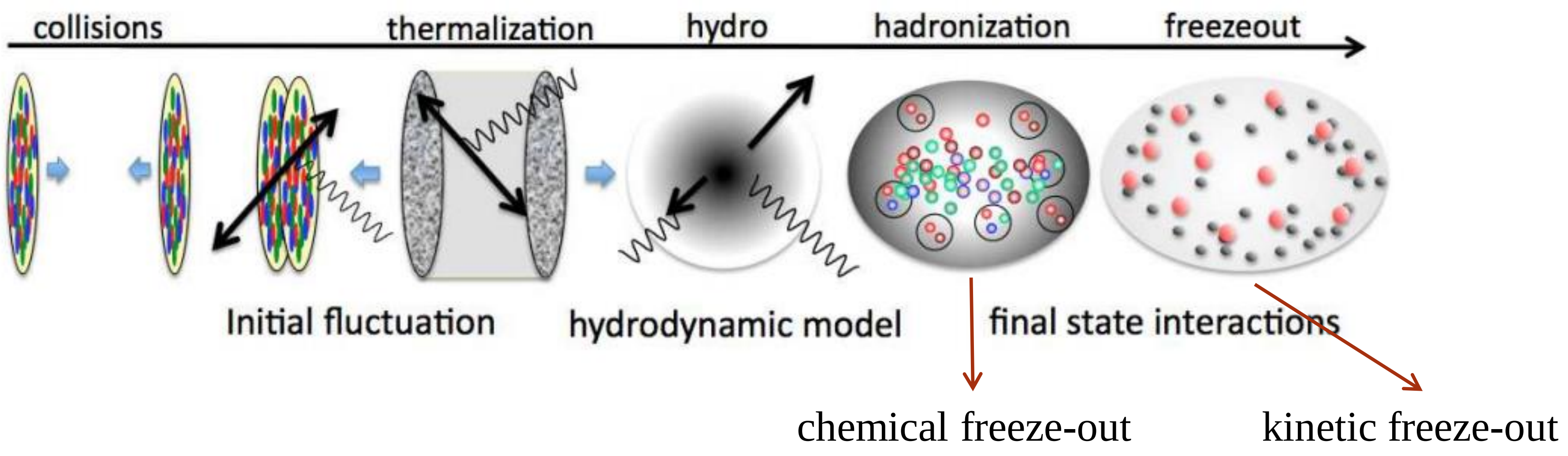
This work will appear in arXiv soon.

Contents

Background and motivation

- Quantum-Chromodynamics (QCD) predicts that at high temperature and energy density there exists a hot and dense strongly interacting matter denoted as quark-gluon plasma(QGP).
  [E.V. Shuryak, Phys. Rept. 61, 71 (1980)]
- QGP is expected to be produced in ultrarelativistic heavy-ion collisions.



Background and motivation

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

$$\frac{d^2N}{2\pi p_T dp_T dy} \propto m_T \int_0^{R_0} r dr\, K_1\left(\frac{m_T \cosh\rho}{T}\right) I_0\left(\frac{p_T \sinh\rho}{T}\right) \qquad \beta_r = \beta_s\left(\frac{r}{R_0}\right)^n \qquad \rho = \tanh^{-1}(\beta_r)$$

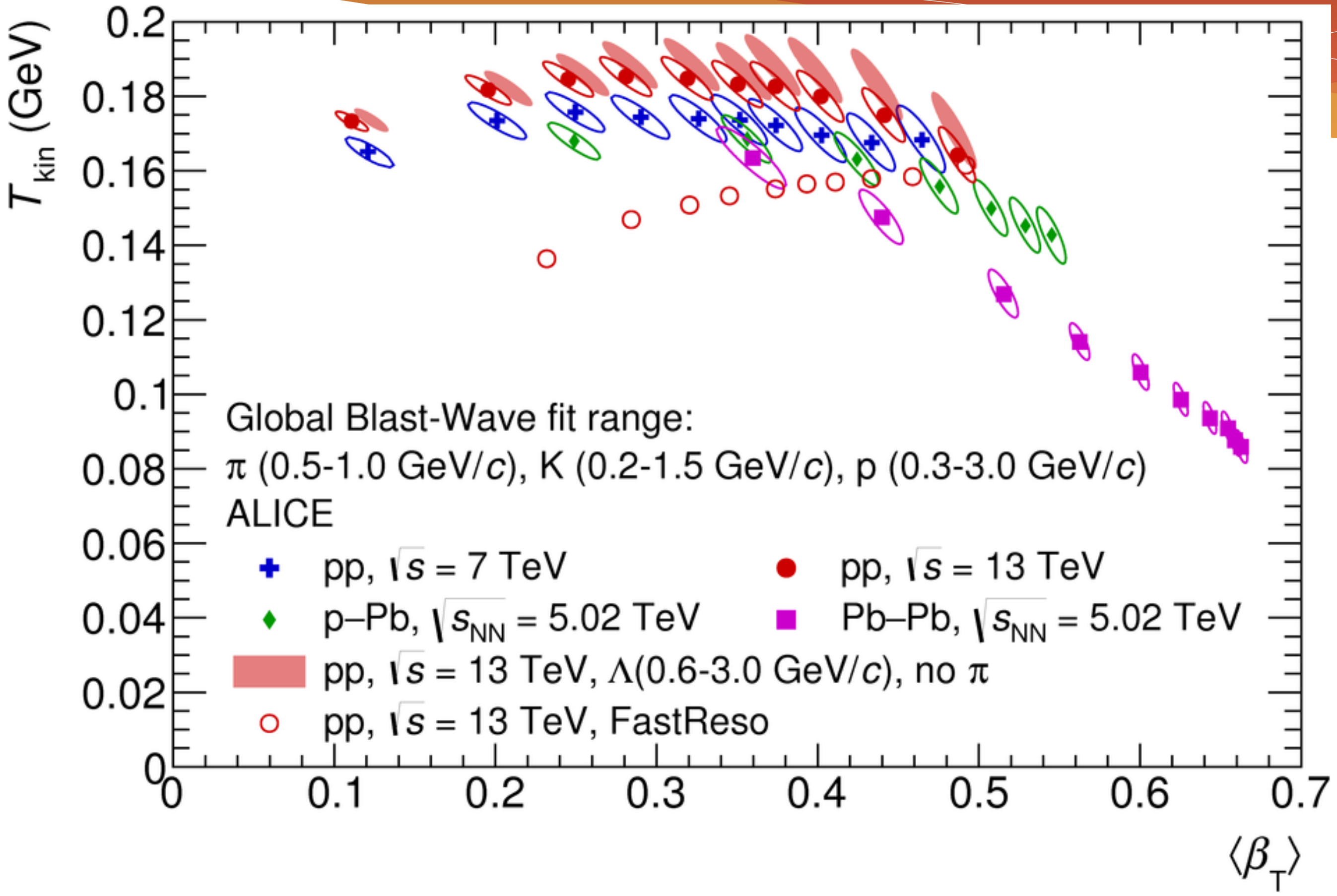
E. Schnedermann *et al.* , Phys. Rev. C **48,** 2462 (1993)

Background and motivation

- In pp collisions at 7 and 13 TeV, the p_T spectra of identified particles get harder with the increase of the charged-particle multiplicity, with the effect being more obvious for particles with larger mass.
- This trend is highly similar to that observed in the evolution of the spectra in p-Pb and Pb-Pb collisions.
- Moreover, double-ridge structures have also been observed in high-multiplicity pp collisions. [G. Aad *et al*. Phys. Rev. Lett. 116, 172301 (2016)]
- These collective phenomena are reminiscent to observations attributed to the creation of QGP in Pb-Pb collisions.

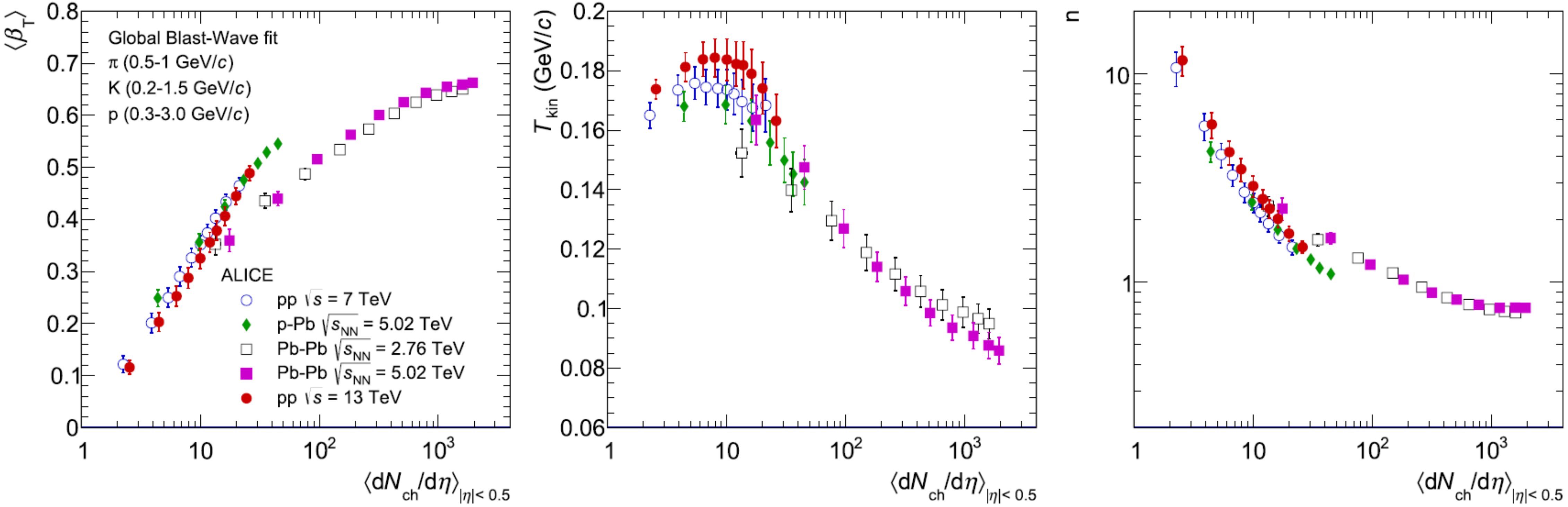
Background and motivation

pp, $\sqrt{s}$ =7 and 13 TeV
Global Blast-wave fit
Different multiplicity



S. Acharya *et al.* (ALICE Collaboration), Eur. Phys. J. C (2020) 80:693

Background and motivation

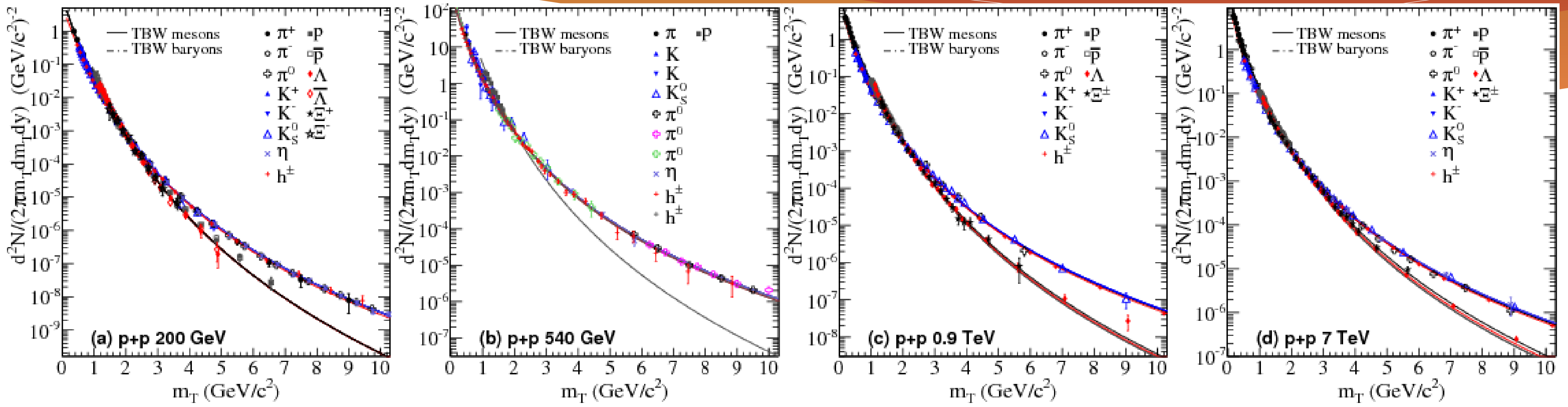


S. Acharya *et al.* (ALICE Collaboration), Eur. Phys. J. C (2020) 80:693

Background and motivation

- 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.
- However, in fact the initial condition for the hydrodynamic evolution fluctuates from event to event.
- In order to take this fluctuation into account, the authors have changed the sources of particle emission in the BGBW model from the Boltzmann distribution to the Tsallis distribution (TBW). Zebo Tang *et al.* , Phys. Rev. C **79**, 051901 (2009)

Background and motivation



$\sqrt{s}$	$\langle\beta\rangle$	T (MeV)	$q_M - 1$	$q_B - 1$	χ^2/ndf
7 TeV	0.320 ± 0.005	70.3 ± 0.8	0.1314 ± 0.0003	0.1035 ± 0.0008	490/431
900 GeV	0.264 ± 0.005	74.6 ± 0.5	0.1127 ± 0.0003	0.0827 ± 0.0008	545/501
540 GeV	$0.000^{+0.105}_{-0.000}$	81.8 ± 0.6	0.1158 ± 0.0007	0.0841 ± 0.0036	205/168
200 GeV	$0.000^{+0.124}_{-0.000}$	92.3 ± 2.7	0.0946 ± 0.0006	0.0743 ± 0.0015	268/268

K. Jiang *et al.*, Phys. Rev. C **91**, 024910 (2015)

Background and motivation

- ALICE and CMS Collaboration have published the identified particle transverse momentum spectra in pp collisions at $\sqrt{s_{NN}} = 0.9, 2.76, 5.02, 7, 13$ TeV.
- The ALICE collaboration has also presented the identified particle spectra in pp collisions at 7 and 13 TeV with different charged-particle multiplicities.

Motivations:

- Investigate the dependence of the radial flow $\langle\beta\rangle$, Tsallis temperature T and the degree of off-equilibrium q on the collision energy in pp collisions.
- Predict the identified particle spectra in pp collisions at 8 and 14 TeV.
- Investigate the dependence of the parameters $\langle\beta\rangle$, T and q on the multiplicity.
- Shed some light on the possible underlying mechanism for particle productions.

Method

Tsallis blast-wave model

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

$$\times \int_0^{R_0} r dr\, [1 + \frac{q-1}{T}(m_T \cosh(y_s)\cosh(\rho) - p_T \sinh(\rho)\cos(\phi))]^{\frac{-1}{q-1}}$$

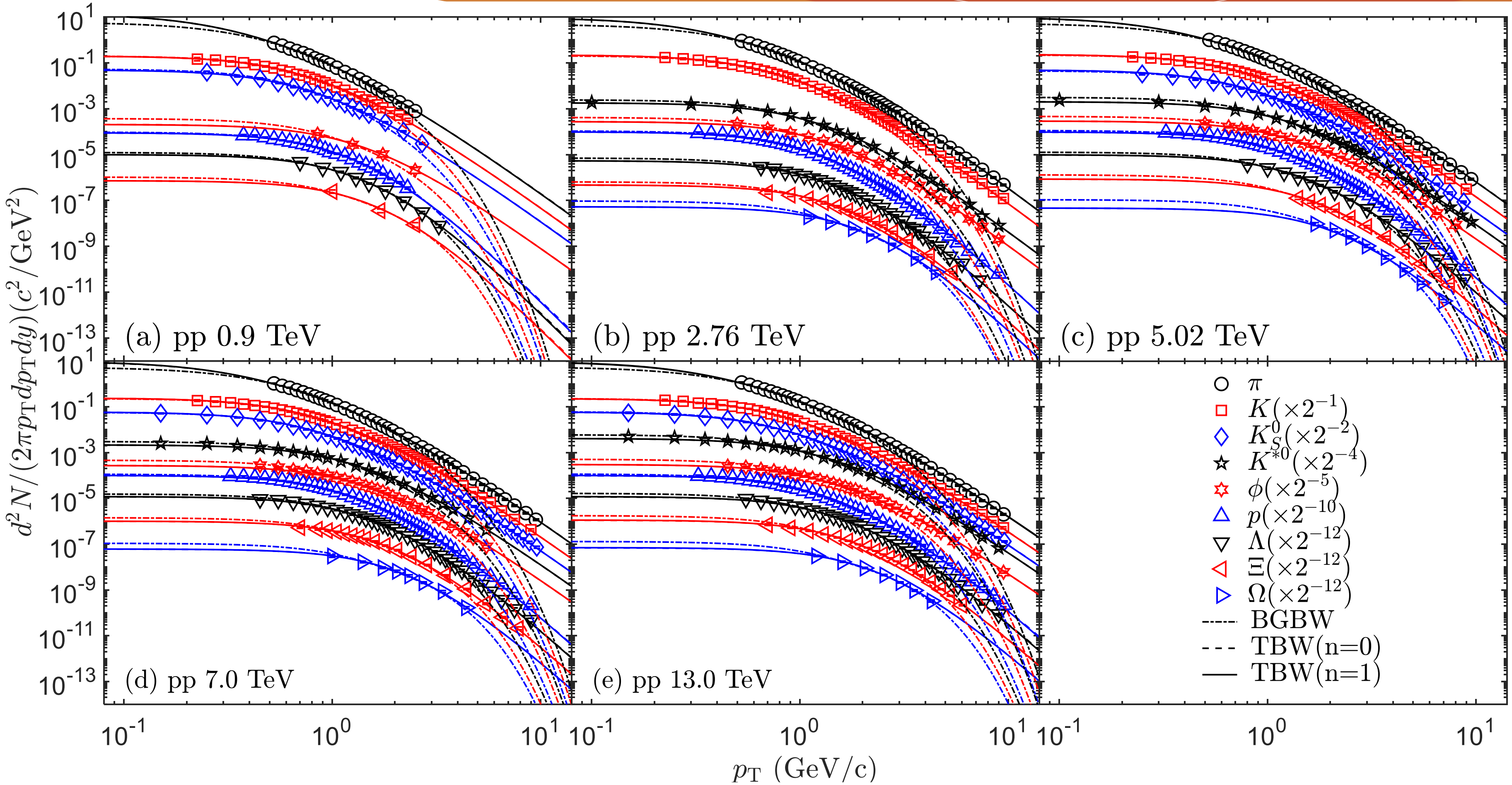
$$\rho_0 = \tanh^{-1}\langle\beta\rangle \qquad \langle\beta\rangle = \frac{2}{n+2}\beta_s \qquad \beta_r = \beta_s\left(\frac{r}{R_0}\right)^n$$

- In our research, we consider two kinds of velocity profiles for TBW model:

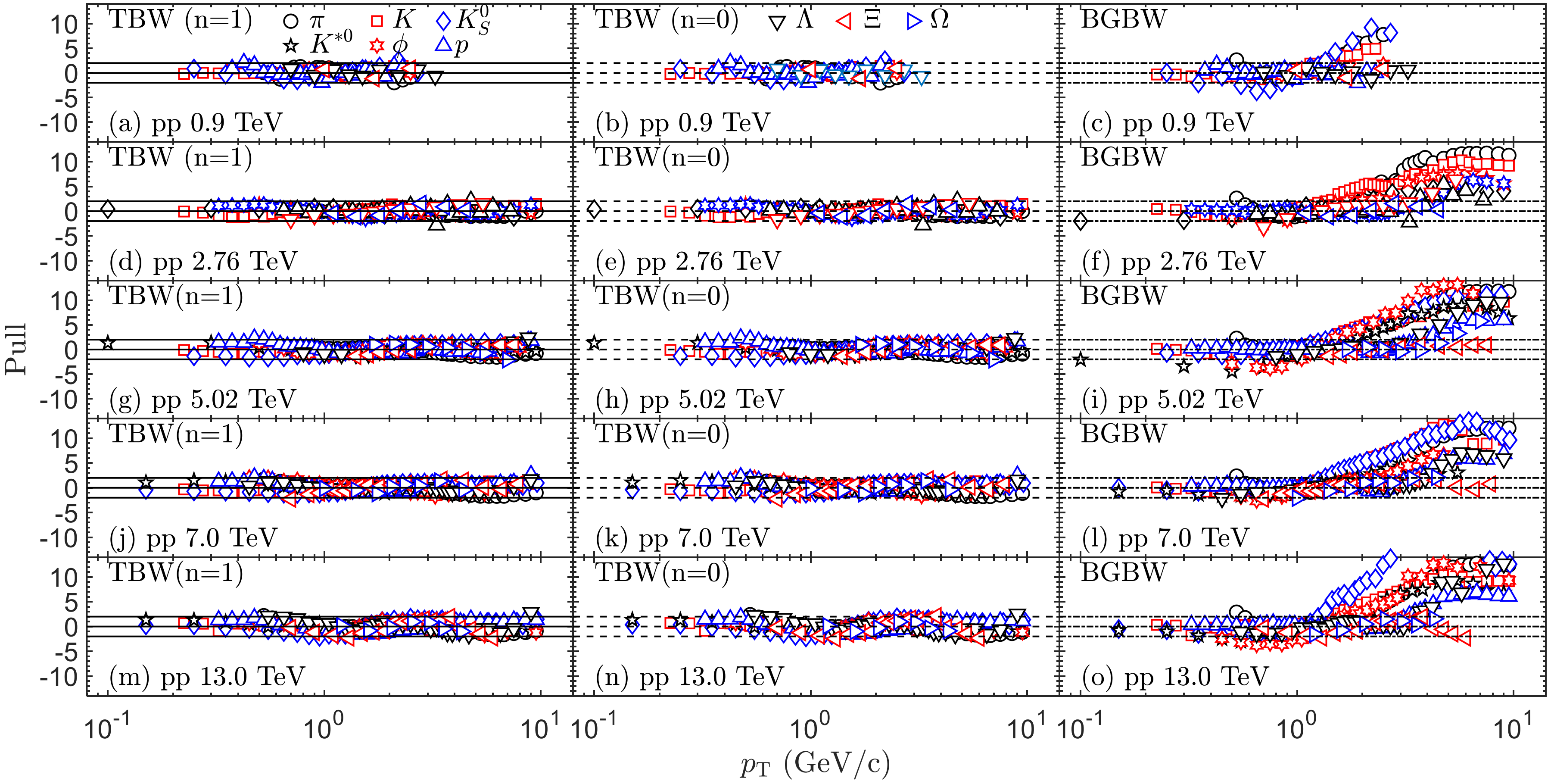
  Linear profile, n=1; Constant profile, n=0.
- Free parameters: non-extensive parameter q, temperature T and average velocity $\langle\beta\rangle$.
- $\langle\beta\rangle$ and T are common for all particles. While q_M (q_B) are the same for all of the mesons (baryons).

Results and discussions

pp 0.9, 2.76, 5.02, 7.0, 13.0 TeV
Transverse momentum spectra

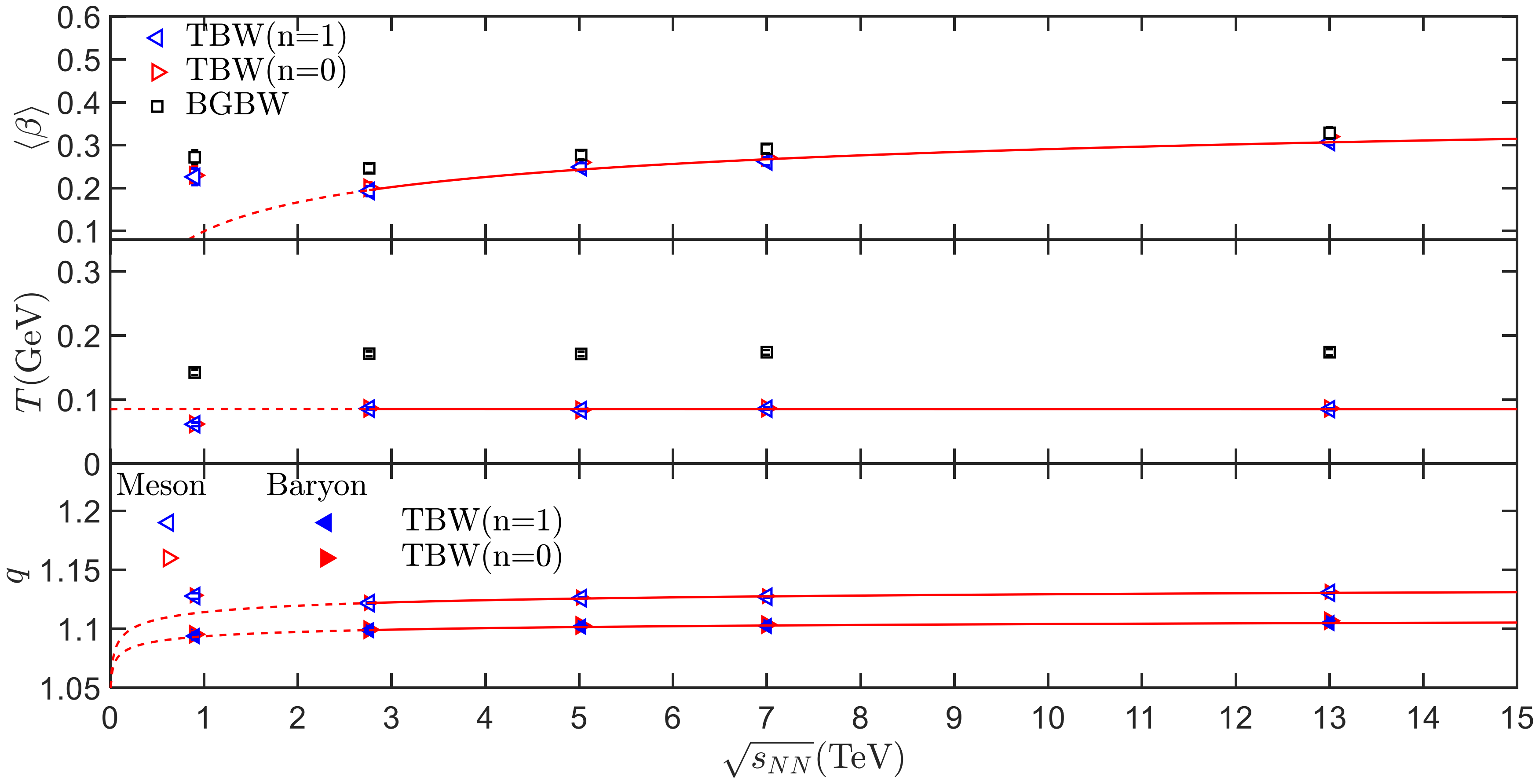


Results and discussions



$$\text{Pull} = \frac{\text{data}-\text{fit}}{|\Delta\text{data}|}$$

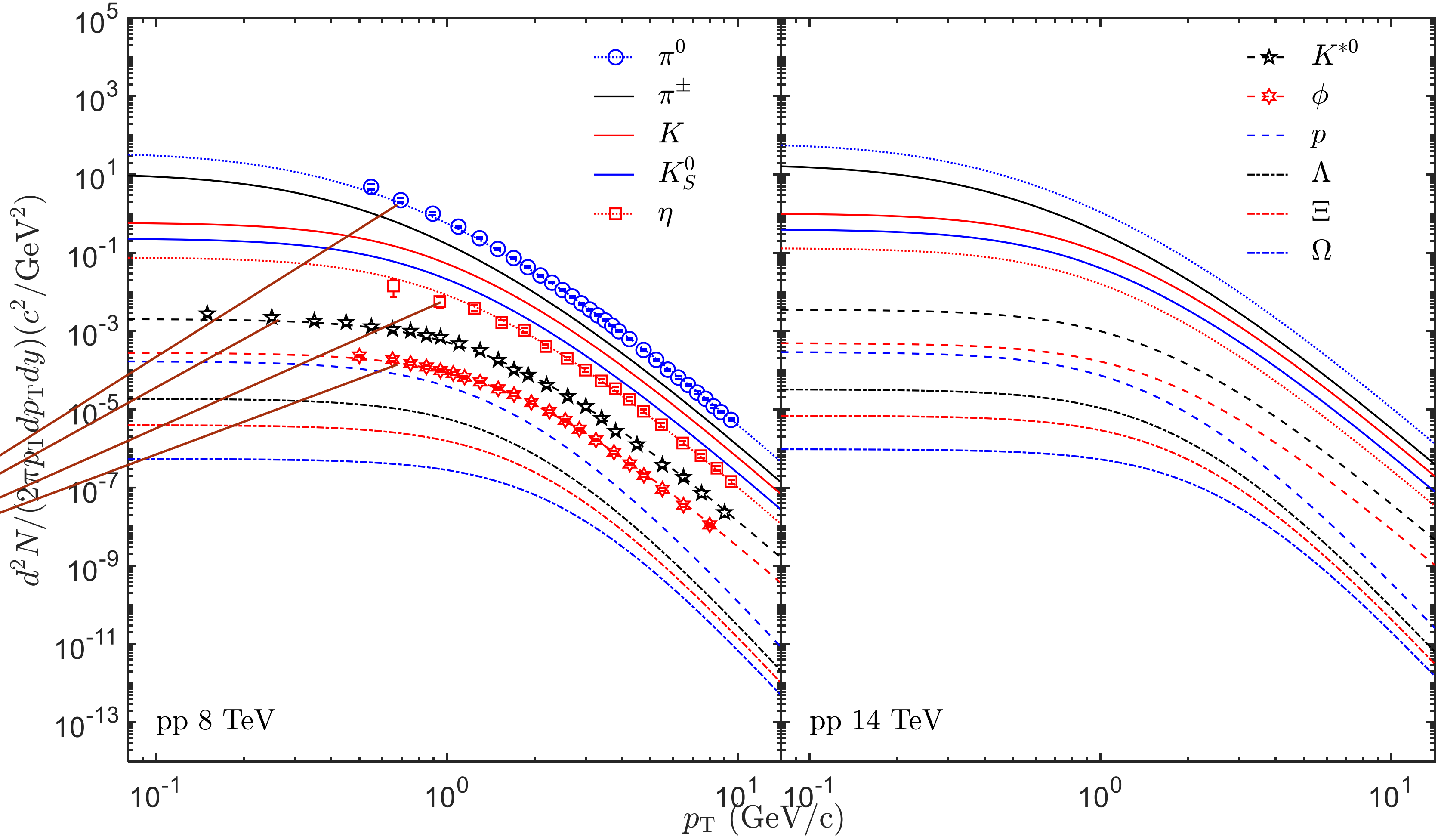
Results and discussions



Results and discussions

Predicted spectra in pp collisions at 8 and 14 TeV.

Confirm the prediction



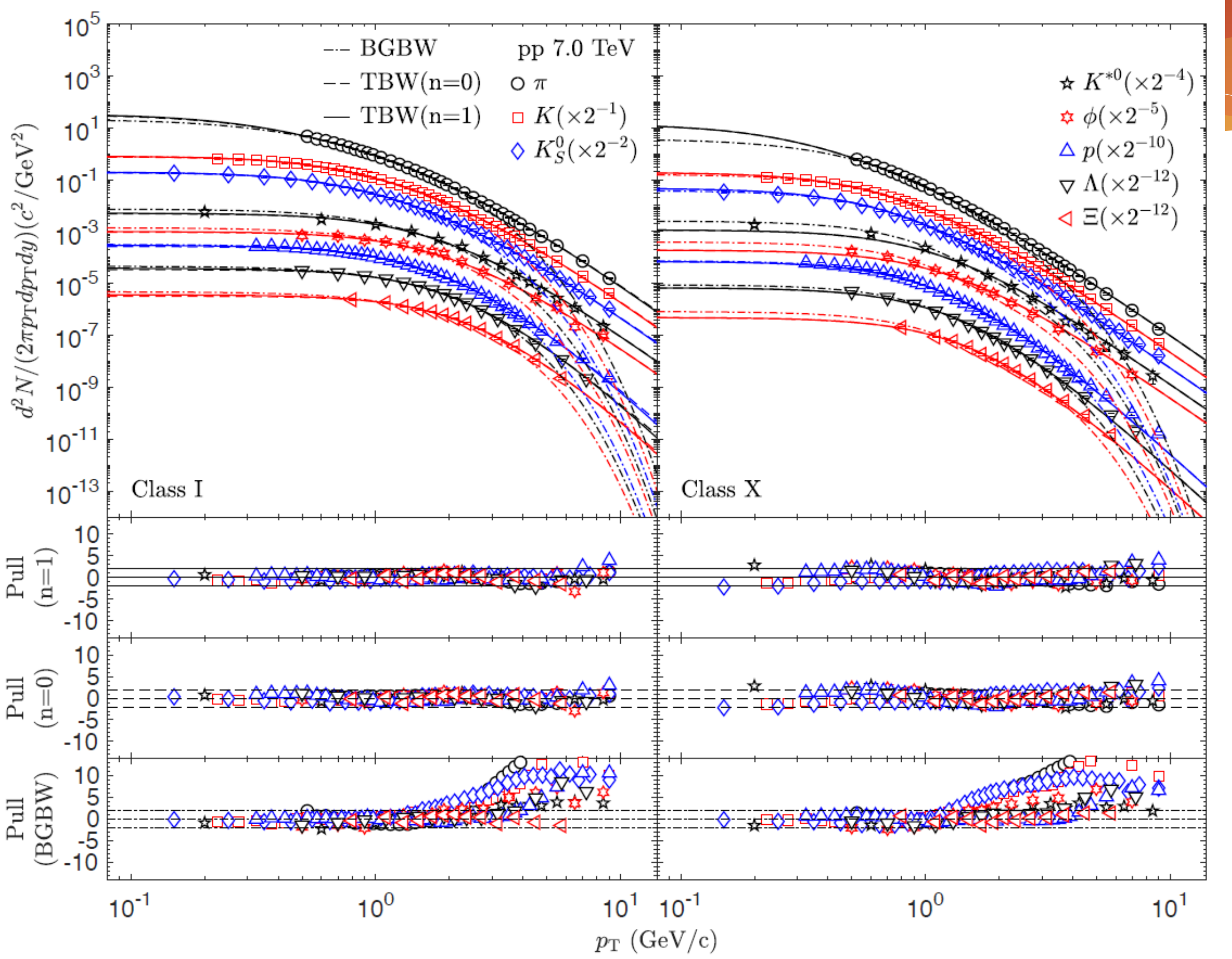
Predicted value: At 8 TeV, $\langle\beta\rangle$ = 0.2762, T = 85.4 MeV, q_M = 1.1282, q_B = 1.1033

At 14 TeV, $\langle\beta\rangle$ = 0.3108, T = 85.4 MeV, q_M = 1.1308, q_B = 1.1051

Results and discussions

pp 7.0 TeV Class I, X

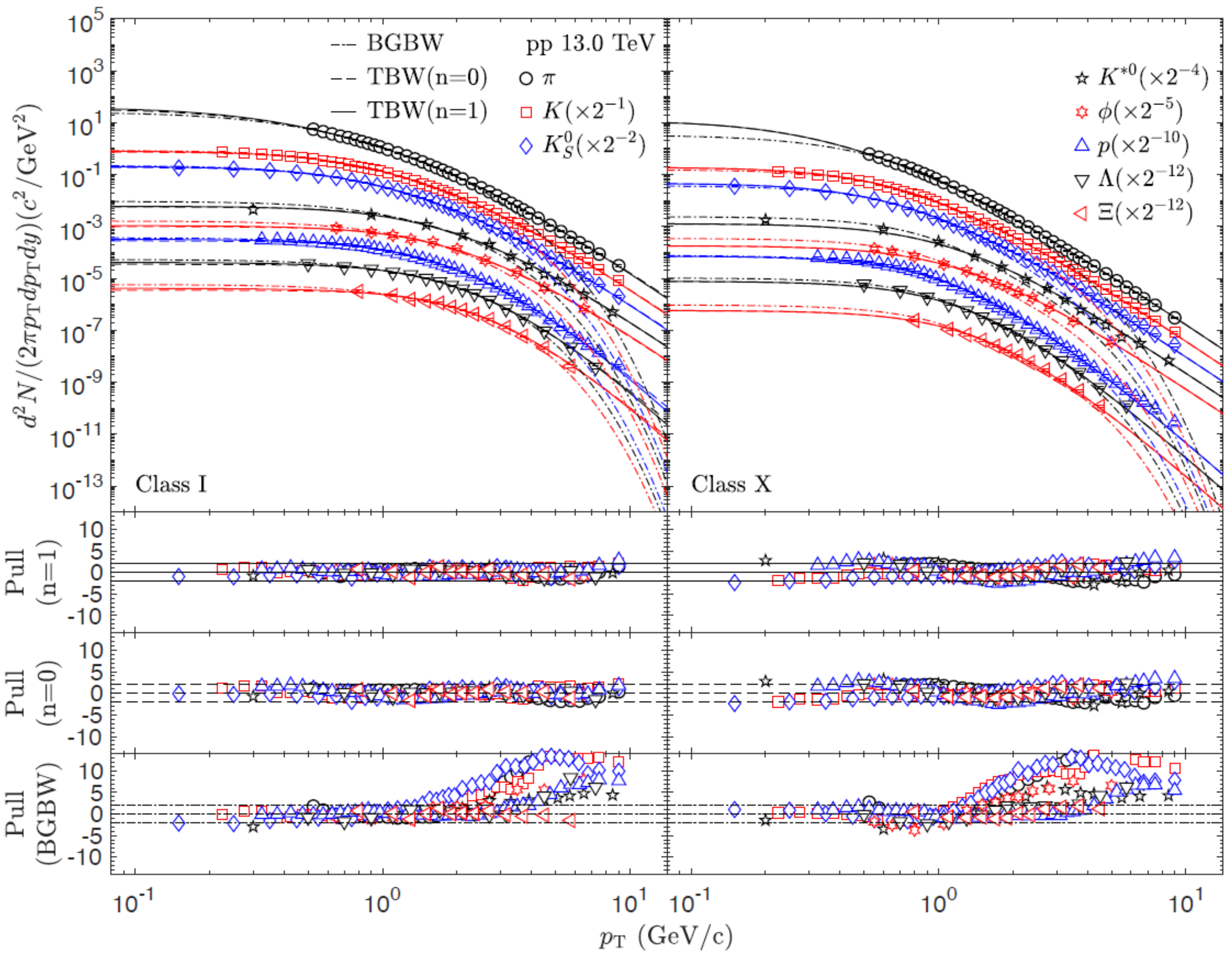
	$\langle dN_{ch}/d\eta \rangle$
Class I	21.3 ± 0.6
Class X	2.26 ± 0.12



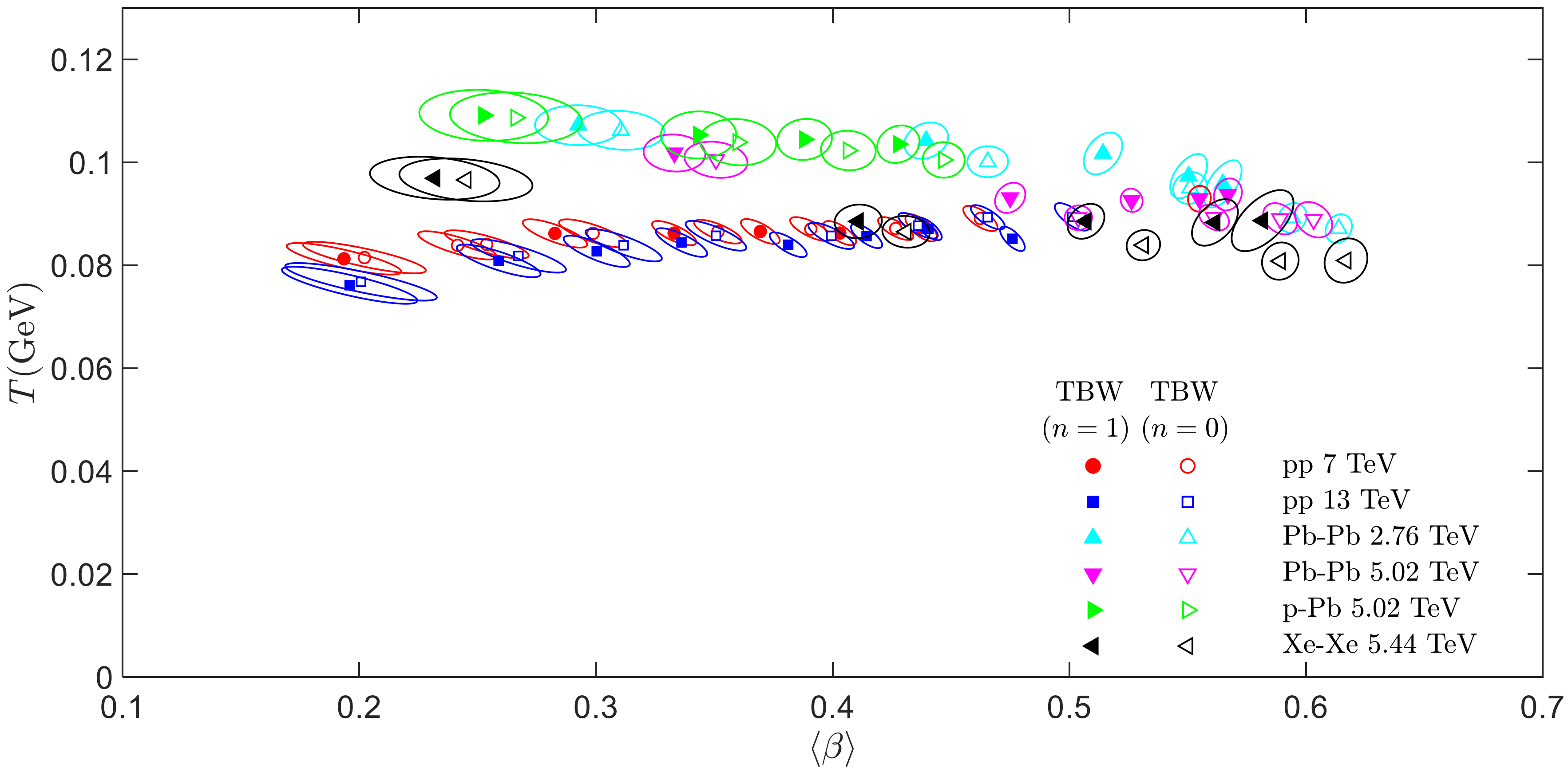
Results and discussions

pp 13.0 TeV Class I, X

	$\langle dN_{ch}/d\eta \rangle$
Class I	26.02 ± 0.35
Class X	2.55 ± 0.04

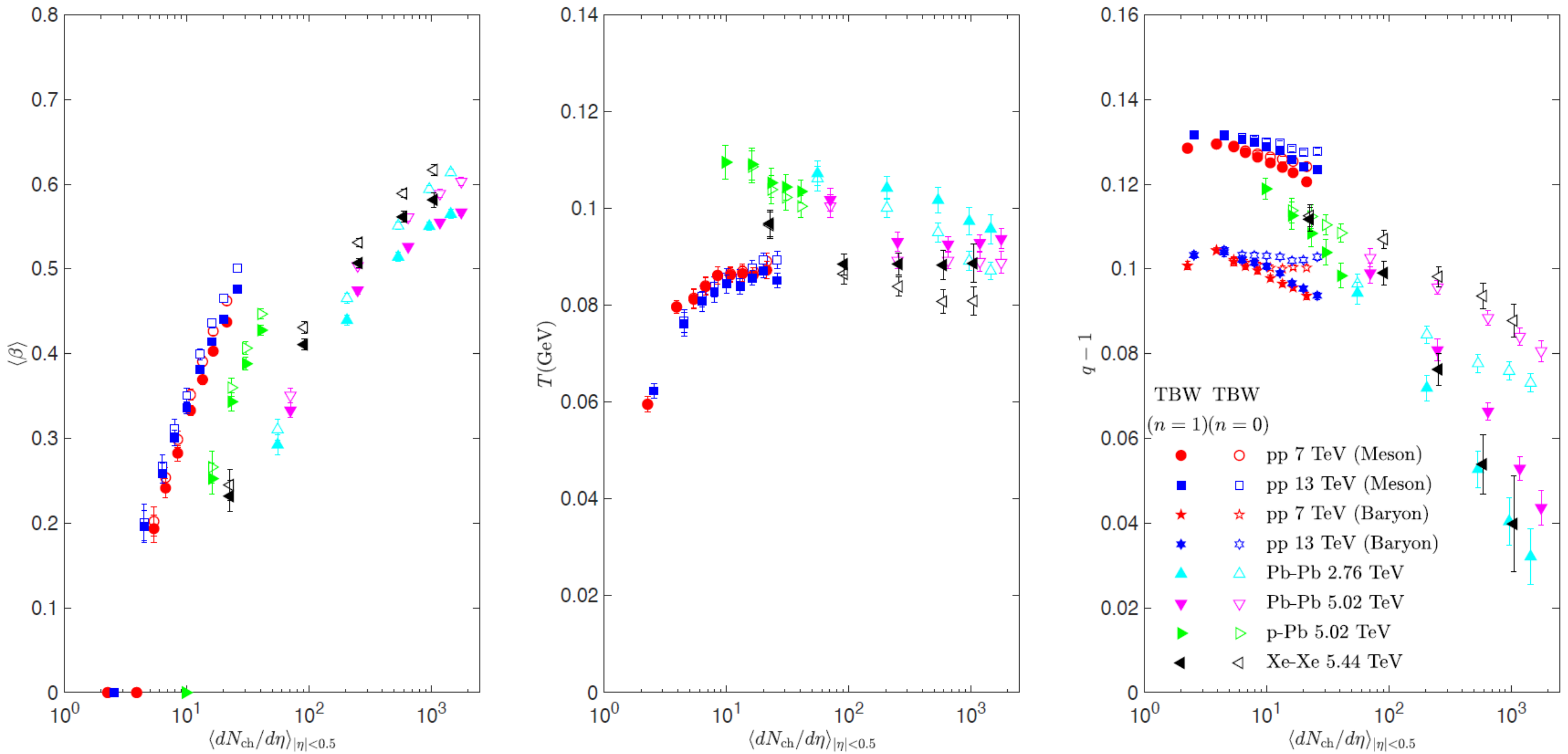


Results and discussions



Guorong Che *et al.* J. Phys. G: Nucl. Part. Phys. 48 095103(2021)

Results and discussions



Summary

- The $\langle\beta\rangle$ and the q increases with $\sqrt{s}$, while the T first increases with energy up to 2.76 TeV and then saturates around 85 MeV.
- In pp collisions both at 7 and 13 TeV, with the increase of multiplicities, T grows with $\langle\beta\rangle$ until it saturates at around 89 MeV.
- At both energies, $\langle\beta\rangle$ increases with the multiplicity while the q shows the opposite behavior, which is similar to that observed in Pb-Pb, Xe-Xe and p-Pb collisions at the LHC energy regime. However, T increases with the multiplicity, which is opposite to the trend observed in Pb-Pb, Xe-Xe and p-Pb collisions.
- At similar charged-particle multiplicities, $\langle\beta\rangle$ in pp collisions is larger than those in Pb-Pb, Xe-Xe, which indicates that the size of the colliding system might have significant effects on the final state particle dynamics.

Thanks!

Back up

$$\lambda_f \propto \frac{1}{\pi d^2 n_f},$$

$$n_f = \frac{N}{V_f} = \frac{N}{4/3\pi R_f^3};$$

$$R_f = R_0 + \int_{\tau_0}^{\tau_f} \beta_s dt.$$

$$\int_{\tau_0}^{\tau_f} \beta_s dt = \beta' \cdot (\tau_f - \tau_0) \propto \langle\beta\rangle \cdot (\tau_f - \tau_0).$$

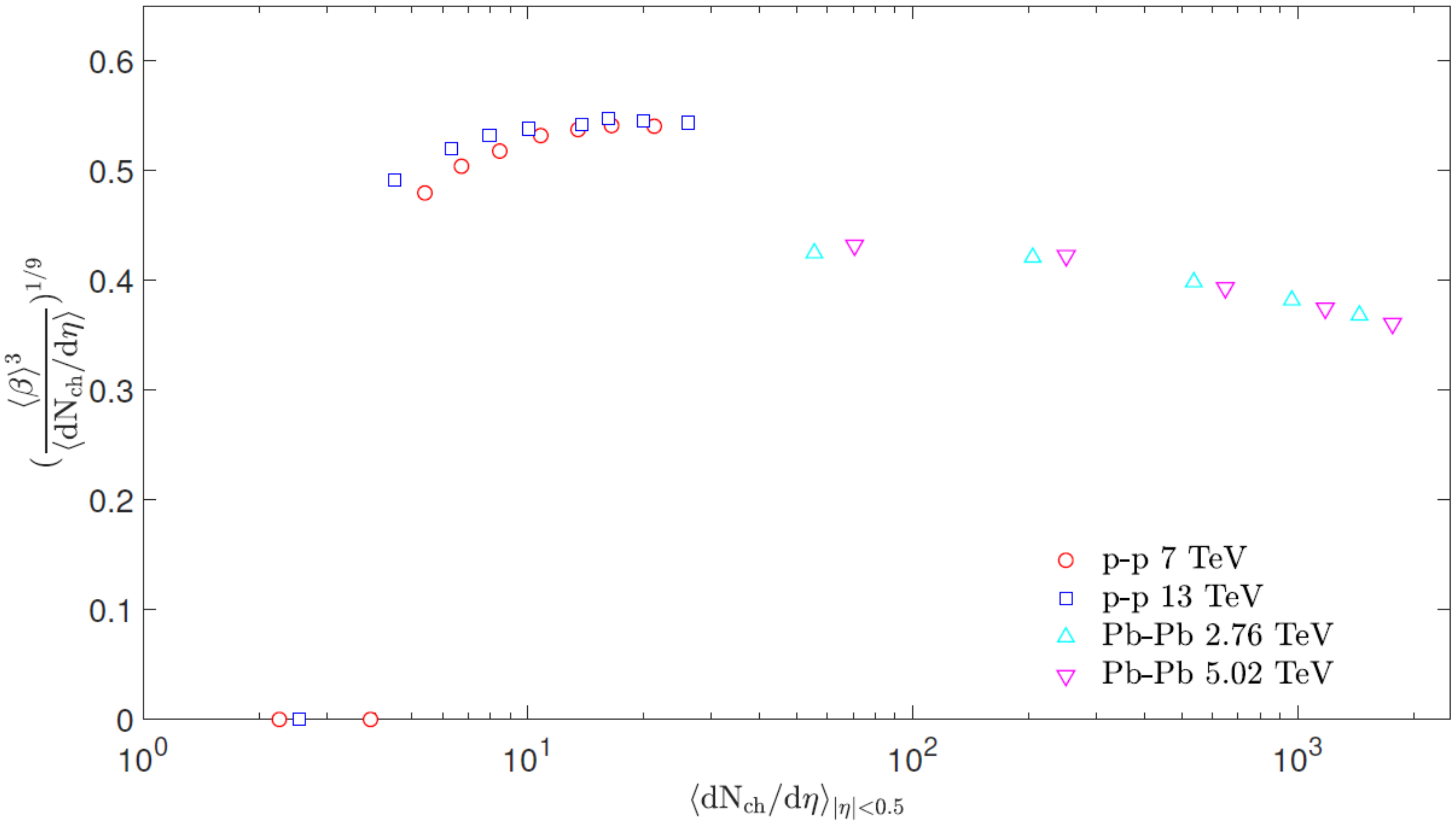
For $R_f \gg R_0$ and $\tau_f \gg \tau_0$, we get $R_f = \langle\beta\rangle\tau_f$,

$$\lambda_f \propto \langle\beta\rangle^3 \tau_f^3 N^{-1}.$$

$$T_f = T_0 \left(\frac{\tau_0}{\tau_f}\right)^{1/3}$$

$$T_f \propto T_0 \left(\frac{\langle\beta\rangle^3}{N\lambda_f}\right)^{1/9}$$

Back up


0.6
0.5
0.4
0.3
0.2
0.1
0
$(\frac{\langle\beta\rangle^3}{\langle dN_{ch}/d\eta\rangle})^{1/9}$
10^0
10^1
10^2
10^3
$\langle dN_{ch}/d\eta\rangle_{|\eta|<0.5}$
p-p 7 TeV
p-p 13 TeV
Pb-Pb 2.76 TeV
Pb-Pb 5.02 TeV