Mean transverse mass of hadrons in proton-proton reactions

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(Dated: October 28, 2014)

Abstract

An energy dependence of the mean transverse mass $\langle m_T \rangle$ at mid-rapidity in proton-proton ($p+p$) reactions is studied within the ultra-relativistic quantum molecular dynamics (UrQMD). The UrQMD model predicts a nonmonotonous dependence of $\langle m_T \rangle$ on collision energy for several hadron species: for π^+, p, K^+, and Λ the mean transverse mass has a maximum at the center of mass energy region $5 \leq \sqrt{s} \leq 8$ GeV. These results are a consequence of an interplay of two contributions: 1) excitations and decays of the baryonic resonances N^* and Δ; 2) excitations and decays of the baryonic strings. The UrQMD results do not show any nonmonotonous dependence of $\langle m_T \rangle$ on $\sqrt{s}$ for π^-, K^-, and antiprotons. Whether a nonmonotonous dependence of $\langle m_T \rangle$ at mid-rapidity on the collision energy for π^+, p, K^+, and Λ is relevant for real $p+p$ interactions will be soon checked experimentally by the NA61/SHINE Collaboration.

PACS numbers: 25.75.Gz, 25.75.Ag

Keywords:

In recent paper,

V.Yu. Vovchenko, D.V. Anchishkin, and M.I. Gorenstein,

Phys. Rev. C **90**, 024916 (2014),

we analyzed the NA61/SHINE data,

N. Abgrall *et al.* [NA61 Collaboration], Eur. Phys. J. C **74**, 2794 (2014),

on π^- spectra in $p+p$ reactions within the ultra-relativistic quantum molecular dynamics (UrQMD). The version UrQMD-3.3p2,

H. Petersen, M. Bleicher, S.A. Bass, and H. Stöcker, arXiv:0805.0567 [hep-ph], was used.

Recently a new version, UrQMD-3.4 (code is available at http://urqmd.org/) was released. It will be used in the present study.

Both the data and the UrQMD simulations demonstrate a monotonous increase of $\langle m_T \rangle$ with collision energy for π^- at mid-rapidity. This is shown in Fig. 1:

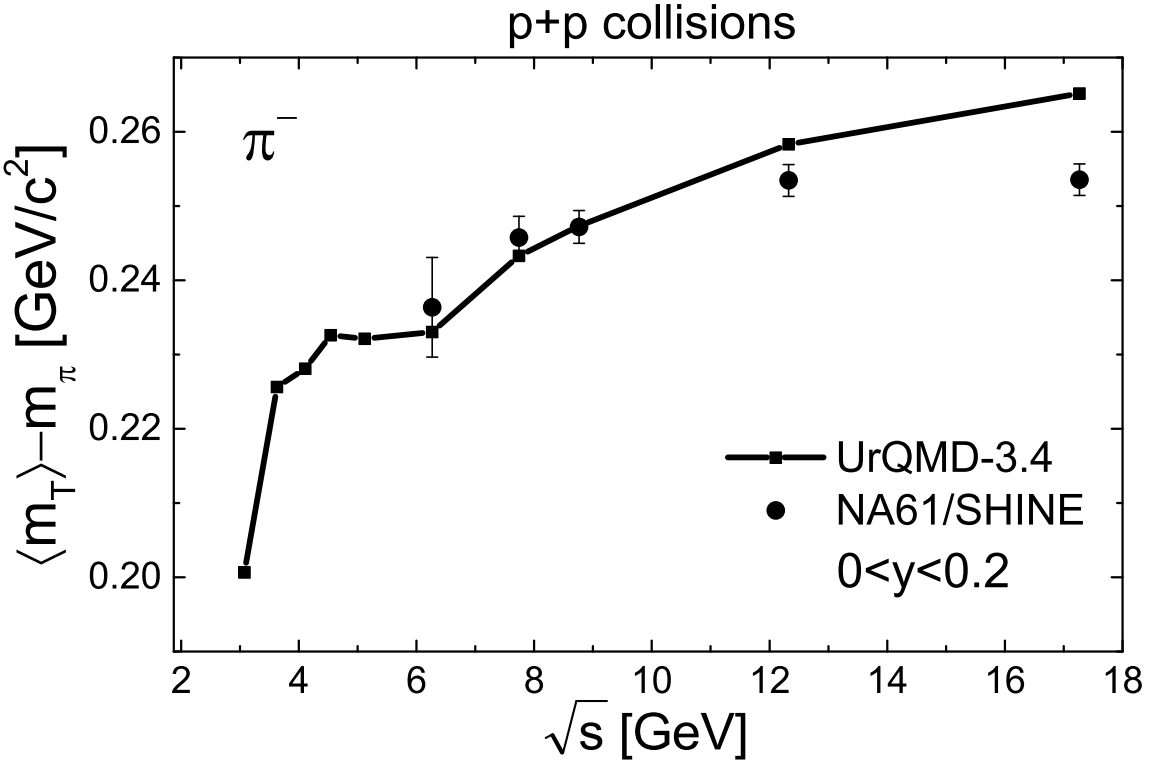

Figure 1:

Unexpectedly, the mean transverse mass of positively charged pions evaluated at mid-rapidity has a maximum at $\sqrt{s} \cong 4.5$ GeV and decreases notably with the collision energy inside the region of $\sqrt{s} = 5 - 8$ GeV. This is shown in Fig. 2:

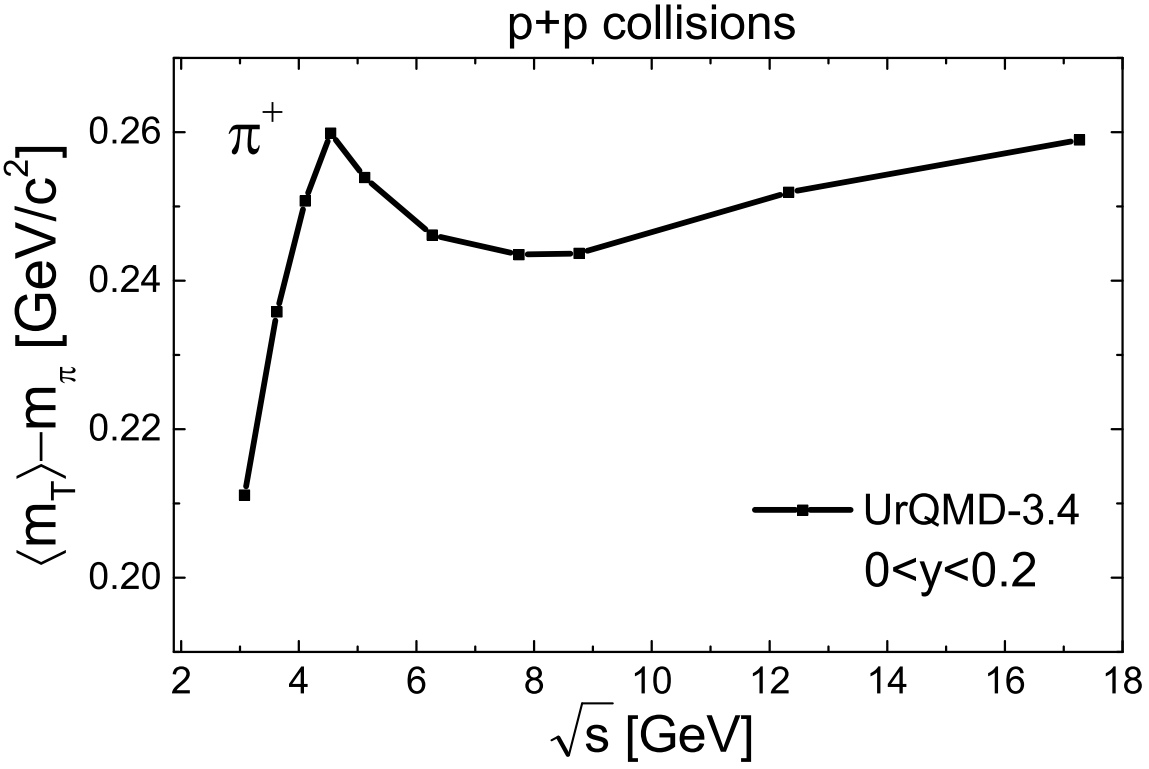

Figure 2:

A dependence of $\langle m_T \rangle$ on $\sqrt{s}$ for π^+ appears to be qualitatively different in the UrQMD and Hadron-String-Dynamics (HSD) transport models:

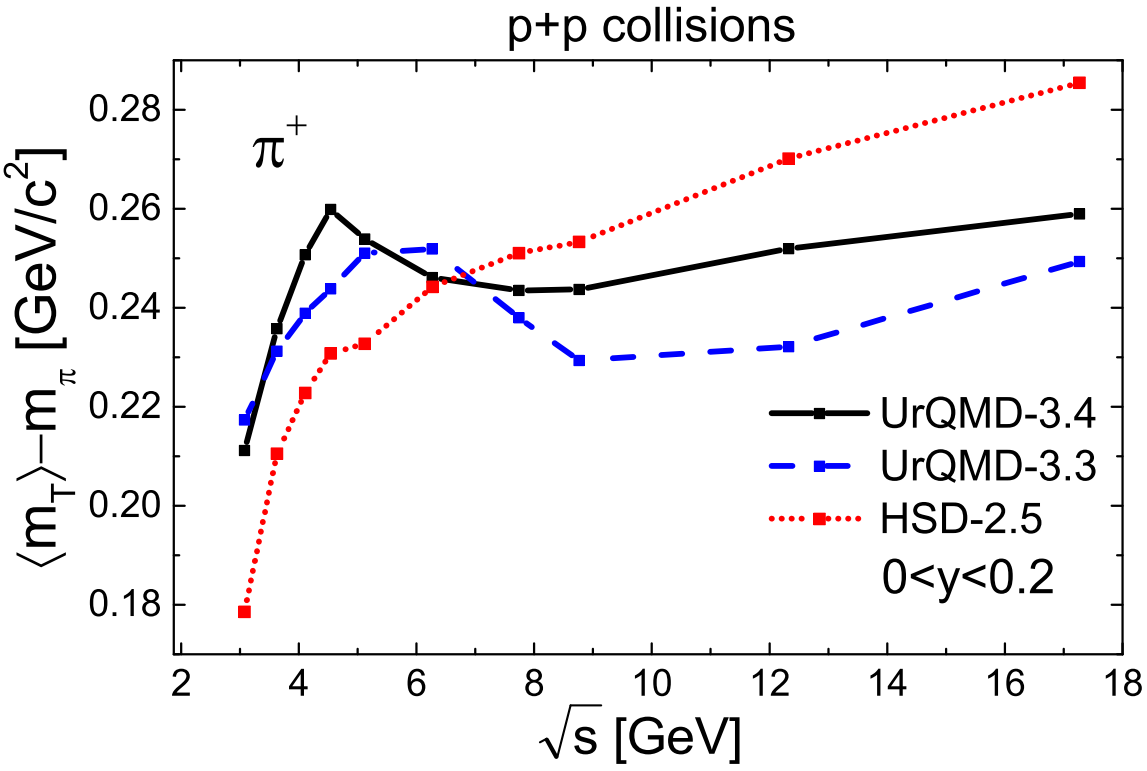

Figure 3:

Even more dramatic behavior is found for protons:

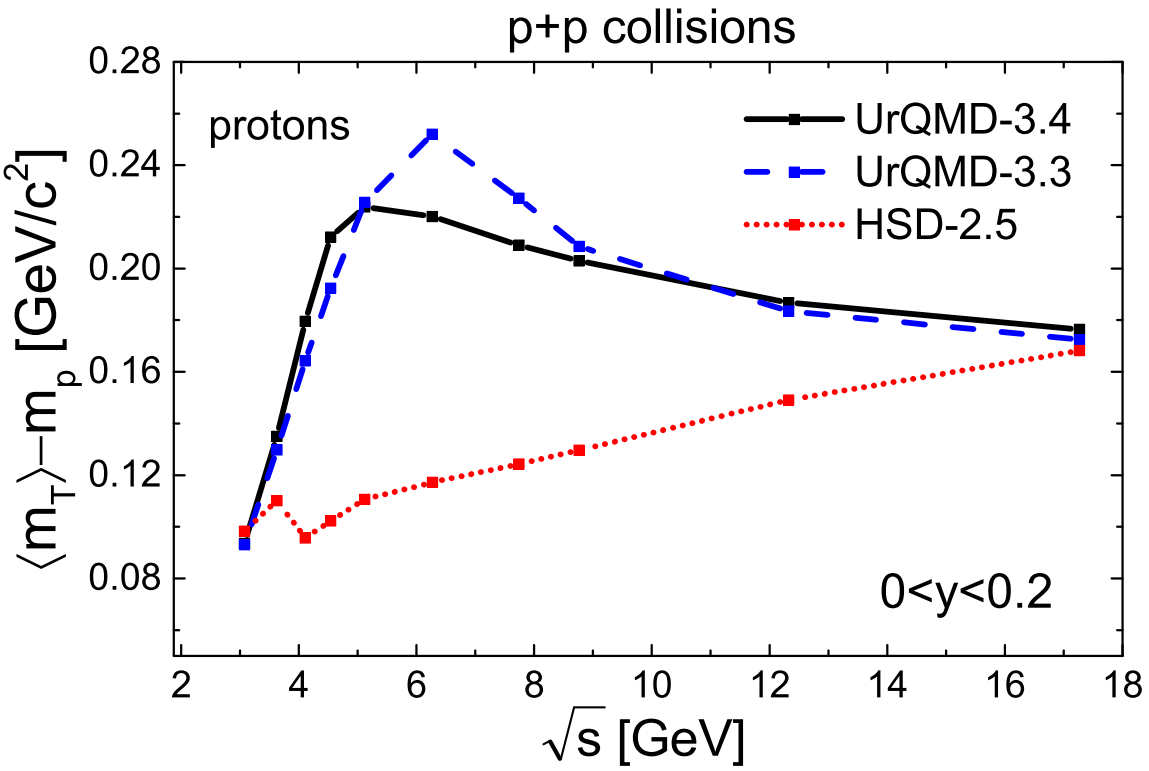

Figure 4:

A physical origin of the non-monotonous dependence of $\langle m_T \rangle$ on $\sqrt{s}$ in UrQMD for π^+ and protons in $p+p$ reactions is connected to a presence of two different sources of secondary hadrons. Main inelastic reactions at small energies are the following:

$$\begin{aligned} & p+p \to p+\Delta^+ \ , \qquad p+p \to n+\Delta^{++} \ , \\ & p+p \to \Delta^+ + \Delta^+ \ , \qquad p+p \to \Delta^0 + \Delta^{++} \ , \\ & p+p \to p+N^+ \ , \qquad p+p \to N^+ + \Delta^+ \ , \qquad p+p \to N^0 + \Delta^{++} \ . \end{aligned} \tag{1}$$

The reactions listed in (1) give the dominant contribution to the $p+p$ inelastic cross section at small collision energies. However, at $\sqrt{s} \geq 4$ GeV the excitations of baryonic strings,

$$p \ + \ p \ \to \ \text{String} \ + \ \text{String} \ , \tag{2}$$

open the new channels of hadron production. At collision energies $\sqrt{s} > 6$ GeV the string production dominates in the UrQMD description of inelastic $p+p$ cross section.

1) The excitations of baryonic resonances listed in (1) and their decays to final hadrons (*rescattering events*).

2) The excitation of strings according to (2) and their decays to final hadrons (*string events*).

The mean transverse mass of a final hadron can be presented as

$$\langle m_T \rangle \;=\; f_B \, \langle m_T \rangle_B \;+\; f_S \, \langle m_T \rangle_S \;, \tag{3}$$

where f_B and f_S are the fractions of multiplicities, and $\langle m_T \rangle_B$ and $\langle m_T \rangle_S$ are the transverse masses for a given hadron species from excited baryons (1) and from strings (2), respectively,

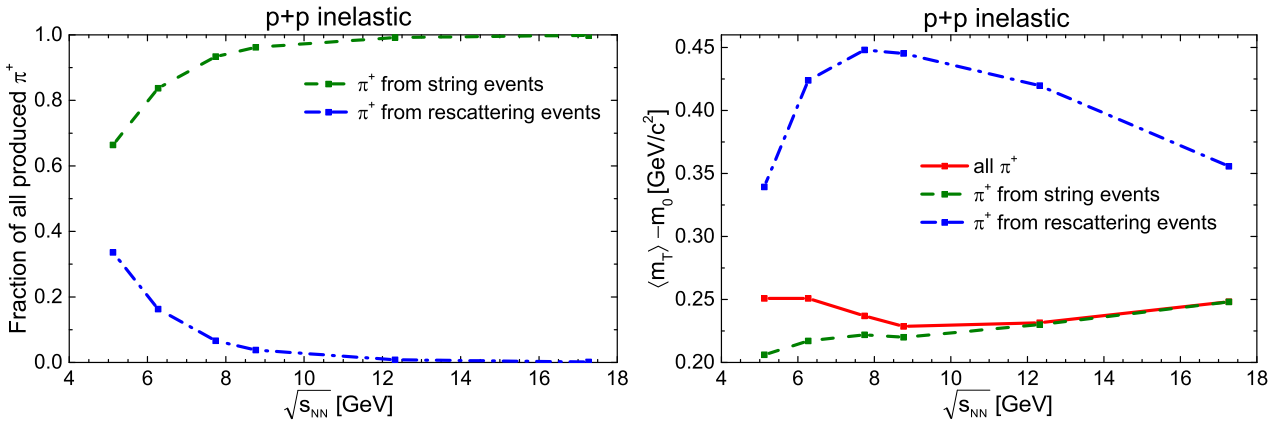

Figure 5:

A non-monotonous energy dependence for the mid-rapidity values of $\langle m_T \rangle$ for π^+ and protons in $p+p$ reactions found in UrQMD is a consequence of an interplay of the contributions from the baryonic resonances and strings. Note that **UrQMD** includes the baryonic resonances N^* and Δ with artificially large masses **which are not listed in the Particle Data Tables**. The number of baryon species N^* and Δ in the **HSD** model is smaller than that in UrQMD. In fact, even **not all baryonic resonances from the Particle Data Tables are included**.

K^- and $\overline{p}$ can not appear from decays of the baryonic resonances N^* and Δ. Thus, UrQMD does not show any non-monotonous dependence of $\langle m_T \rangle$ on $\sqrt{s}$ for K^- and $\overline{p}$.

Protons and π^+ are obviously produced from decays of baryonic resonances N^* and Δ. Heavy N^* have also the following decay channel: $N^* \to \Lambda + K^+$. Therefore, Eq. (3) can be also applied to a description of $\langle m_T \rangle$ for Λ and K^+ in $p+p$ reactions. These UrQMD results are shown in Fig. 6:

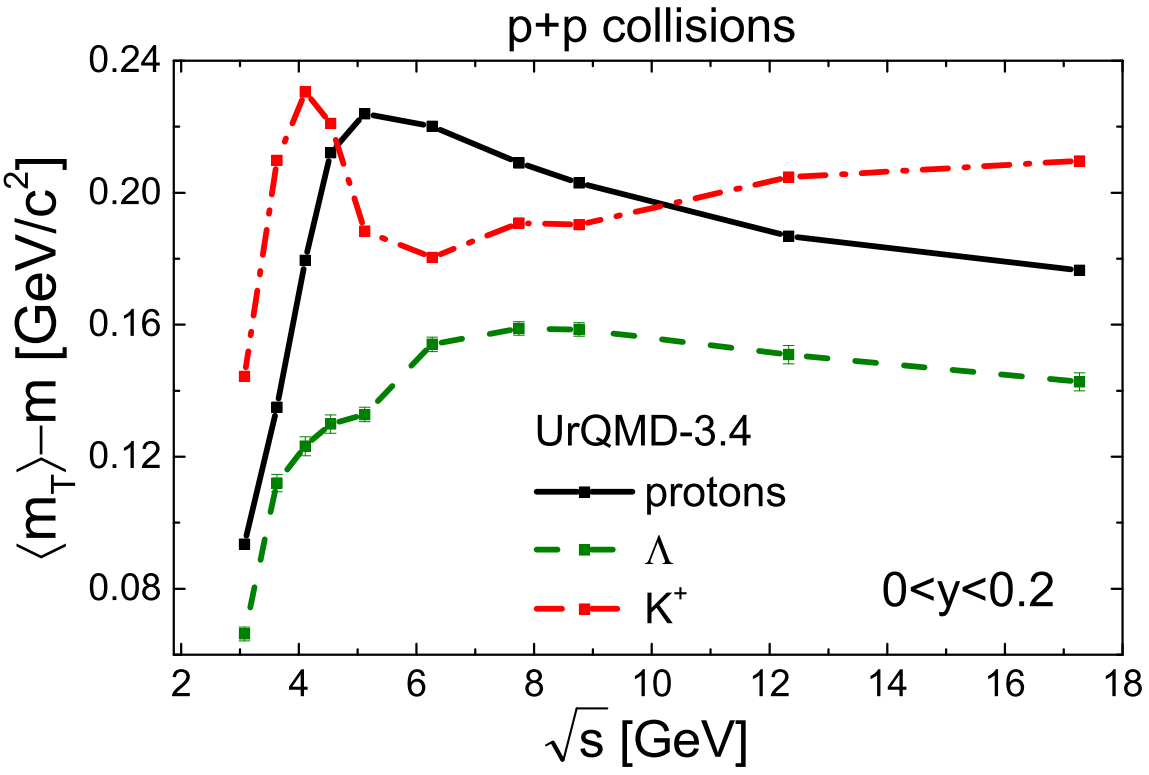

Figure 6: