Heavy quarks and charmonium at RHIC and LHC within a partonic transport model

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H-QM Helmholtz Research School Quark Matter Studies

Abstract

The production and evolution of heavy flavor particles are studied in central and non-central heavy-ion collisions at RHIC and LHC using the partonic transport model *B*oltzmann *A*pproach *o*f *M*ulti–*P*arton *S*catterings (BAMPS) [1, 2, 3, 4, 5].

The model: BAMPS

BAMPS [6, 7] simulates the full space-time evolution of the QGP by solving the Boltzmann equation,

$$\left(\frac{\partial}{\partial t}+\frac{\mathbf{p}_i}{E_i}\frac{\partial}{\partial \mathbf{r}}\right) f_i(\mathbf{r},\mathbf{p}_i,t)=\mathcal{C}_i^{2\to 2}+\mathcal{C}_i^{2\leftrightarrow 3}+\dots\ ,$$

for on-shell partons and pQCD interactions. Currently, gluons (g), heavy quarks (Q), and J/ψ are implemented with the following interactions: $gg\to gg$, $gg\to ggg$, $ggg\to gg$, $gg\to Q\bar{Q}$, $Q\bar{Q}\to gg$, $gQ\to gQ$, $g\bar{Q}\to g\bar{Q}$, $J/\psi g\to c\bar{c}$ and $c\bar{c}\to J/\psi g$ [6, 7, 1, 4].

Heavy quark production

As full space-time simulations with BAMPS reveal, secondary heavy quark production in the QGP at RHIC is very small compared to the initial yield [1]. On the contrary, at LHC charm production in the QGP takes a sizeable fraction of the initial yield and is even of the same order for some scenarios. Bottom production in the QGP, however, is very small both at RHIC and LHC and can be neglected.

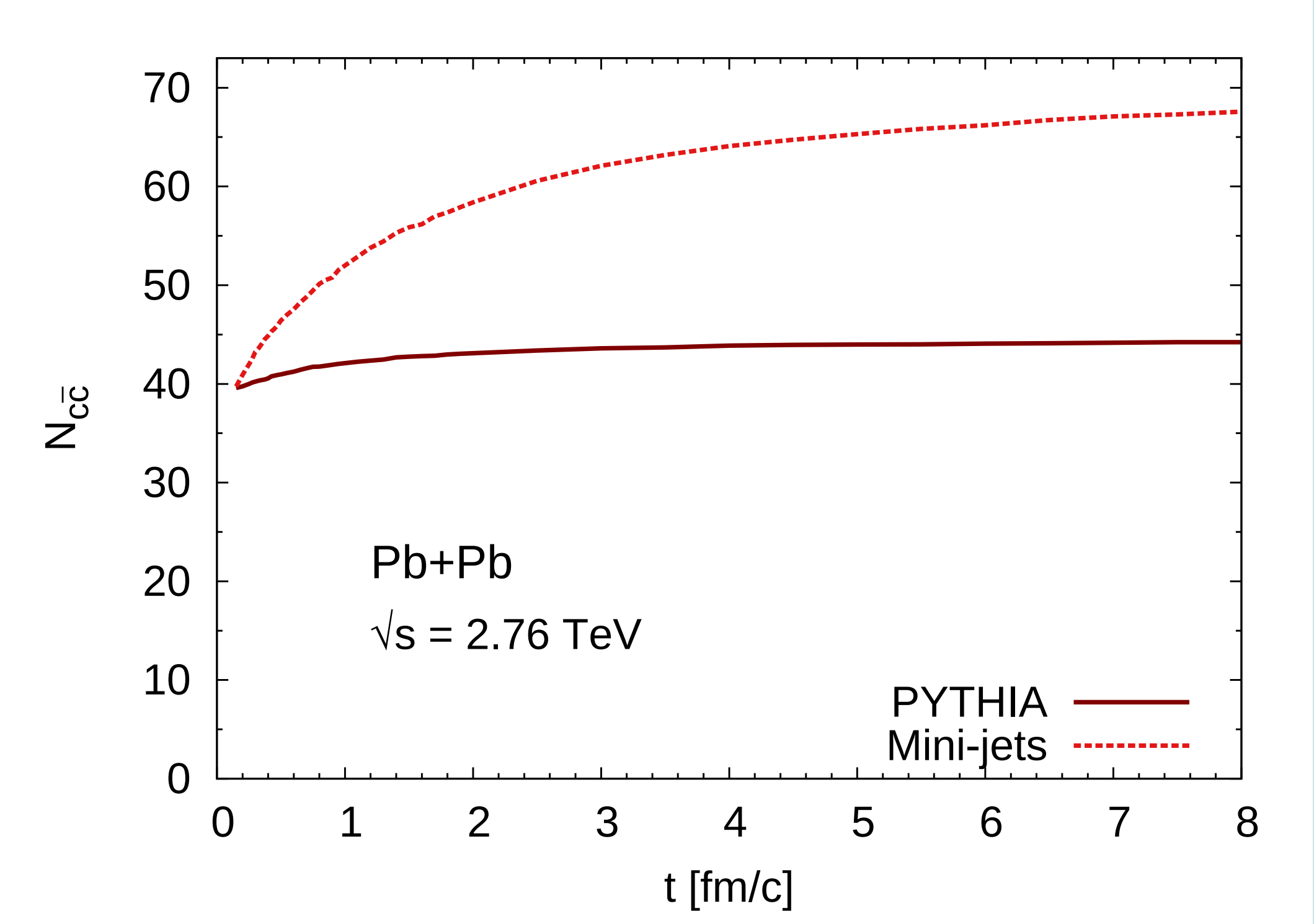

Figure 1: Number of charm quark pairs produced in a central Pb+Pb collision at LHC with $\sqrt{s_{NN}}=2.76\,\mathrm{TeV}$ as a function of time simulated with BAMPS. The initial parton distributions are obtained with PYTHIA and the mini-jet model.

J/ψ suppression

To estimate the initial J/ψ distribution we parametrize the p+p production cross section and take cold nuclear matter effects such as shadowing, nuclear absorption and the Cronin effect into account [5]. The space-time evolution of J/ψ is carried out with BAMPS, which also allows dissociation and regeneration of J/ψ.

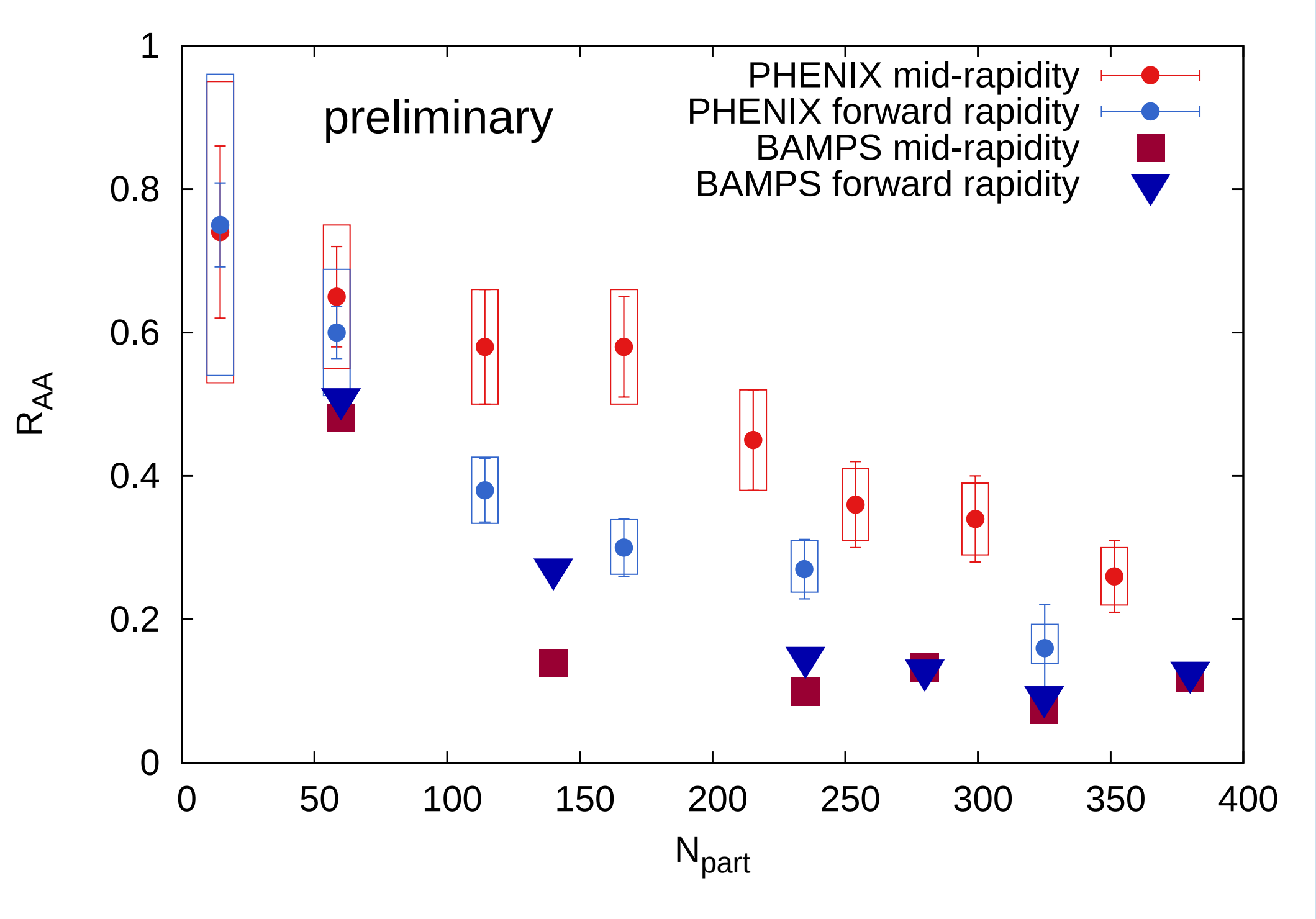

Figure 2: R_{AA} of J/ψ at mid-rapidity $|y|<0.35$ for Au+Au collisions at RHIC as a function of the number of participants, together with experimental data [8].

Preliminary results of the nuclear modification factor R_{AA} of J/ψ obtained with BAMPS for forward and mid-rapidity are slightly smaller than the measured data, but resemble the overall shape. Reasons for this could be an overestimation of suppression due to cold nuclear matter effects or the small regeneration cross section.

Elliptic flow and nuclear modification factor of heavy quarks

Commonly used observables for investigating the coupling of heavy quarks with the medium are the elliptic flow and the nuclear modification factor of heavy quarks:

$$v_2=\left\langle \frac{p_x^2-p_y^2}{p_T^2}\right\rangle \qquad R_{AA}=\frac{\mathrm{d}^2N_{AA}/\mathrm{d}p_T\mathrm{d}y}{N_{\mathrm{bin}}\,\mathrm{d}^2N_{pp}/\mathrm{d}p_T\mathrm{d}y}$$

Elastic scatterings of heavy quarks with the gluonic medium using a constant coupling $\alpha_s=0.3$ and the Debye mass for screening the t channel cannot reproduce the experimentally measured elliptic flow [2]. However, this discrepancy can be lowered – even on the elastic scattering level – by taking the running of the coupling into account and by improving the Debye screening of the t channel:

$$\frac{1}{t}\to\frac{1}{t-\kappa\, m_D^2}$$

The prefactor κ is mostly set to 1 in the literature without a sophisticated reason. However, one can fix this factor analytically to $\kappa\approx 0.2$ by comparing the energy loss per unit length $\mathrm{d}E/\mathrm{d}x$ of the LO cross section including κ to the energy loss obtained within the hard thermal loop approach [9, 10, 4].

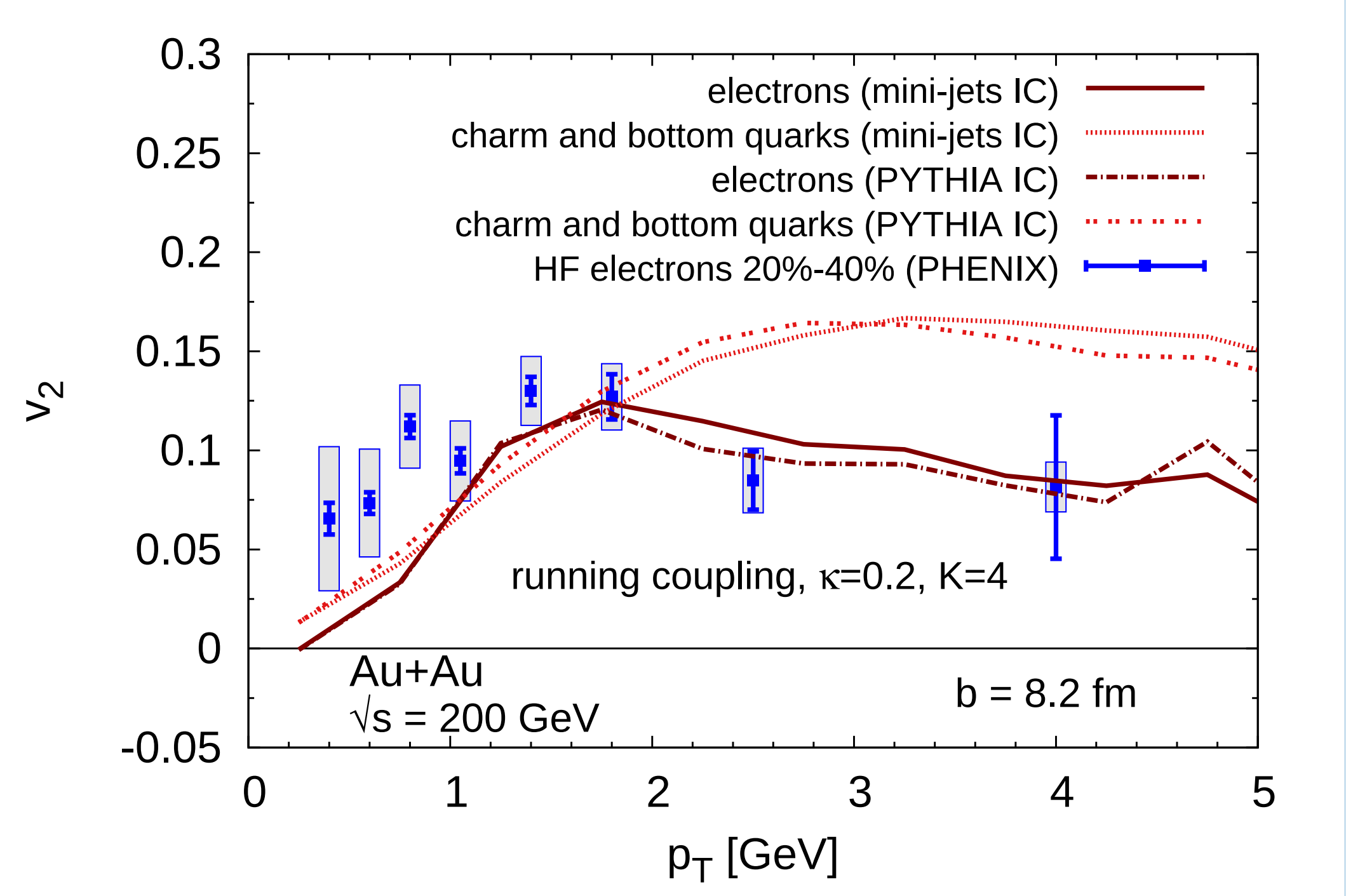

Figure 3: Elliptic flow v_2 of heavy quarks and heavy flavor electrons with pseudo-rapidity $|\eta|<0.35$ for Au+Au collisions at RHIC with an impact parameter of $b=8.2\,\mathrm{fm}$. The curves are obtained with PYTHIA and mini-jet initial conditions (IC) for the gluons. The cross section of $gQ\to gQ$ is multiplied with the factor $K=4$. For comparison, data of heavy flavor electrons for the centrality class of 20 %–40 % [11] is shown.

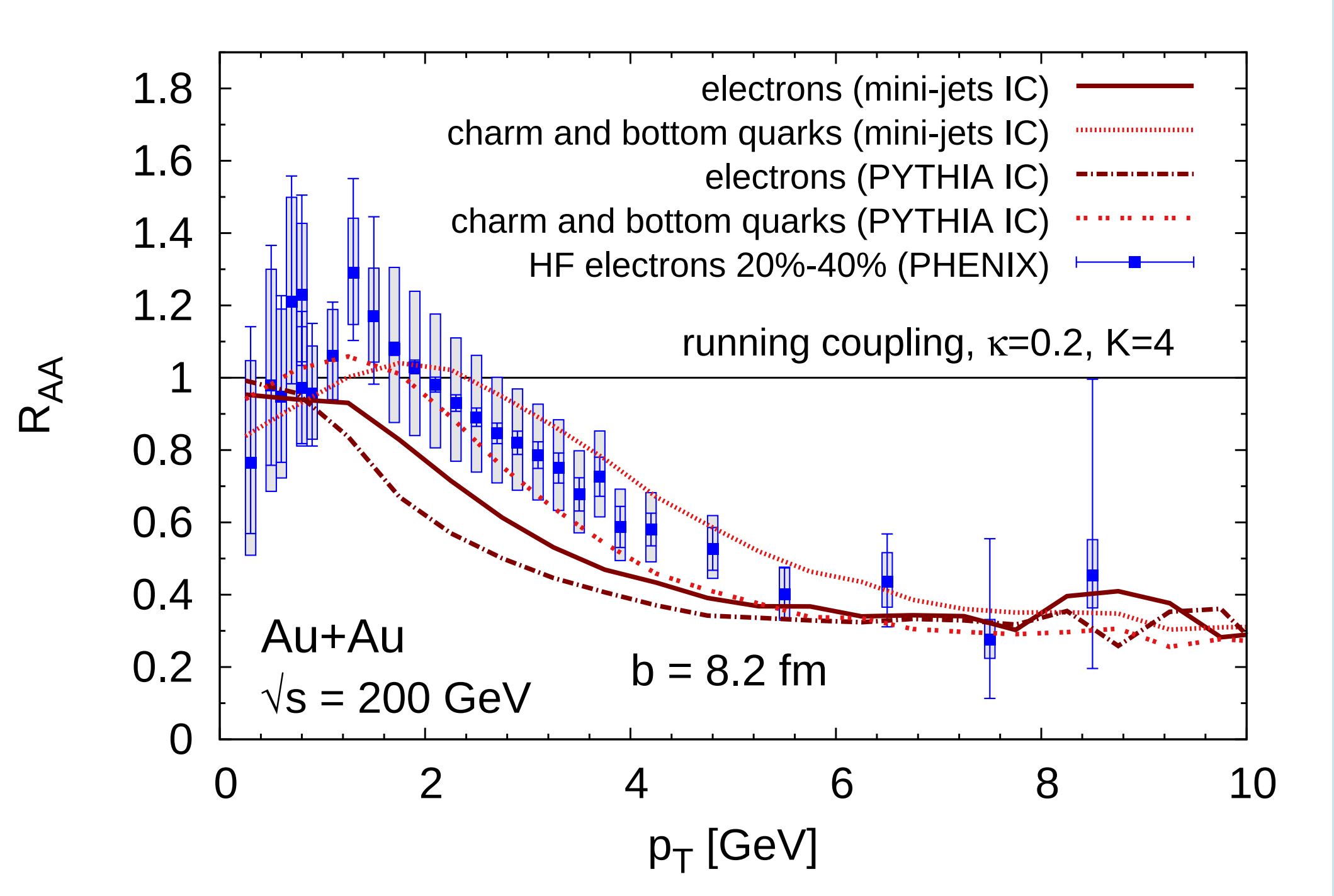

Figure 4: Nuclear modification factor R_{AA} of heavy quarks and heavy flavor electrons at RHIC for the same configurations as in Fig. 3.

To be compatible with the measured v_2 and R_{AA} the elastic cross section of heavy quarks scattering off gluons must be multiplied with $K=4$. This factor is assumed to stand for radiative corrections, which will be checked in a forthcoming study. With $K=4$ a good agreement with the data is found for large p_T both for v_2 and R_{AA}. For small p_T Peterson fragmentation is not suitable and coalescence might play an important role, which modifies the v_2 and R_{AA} due to the contribution of light quarks.

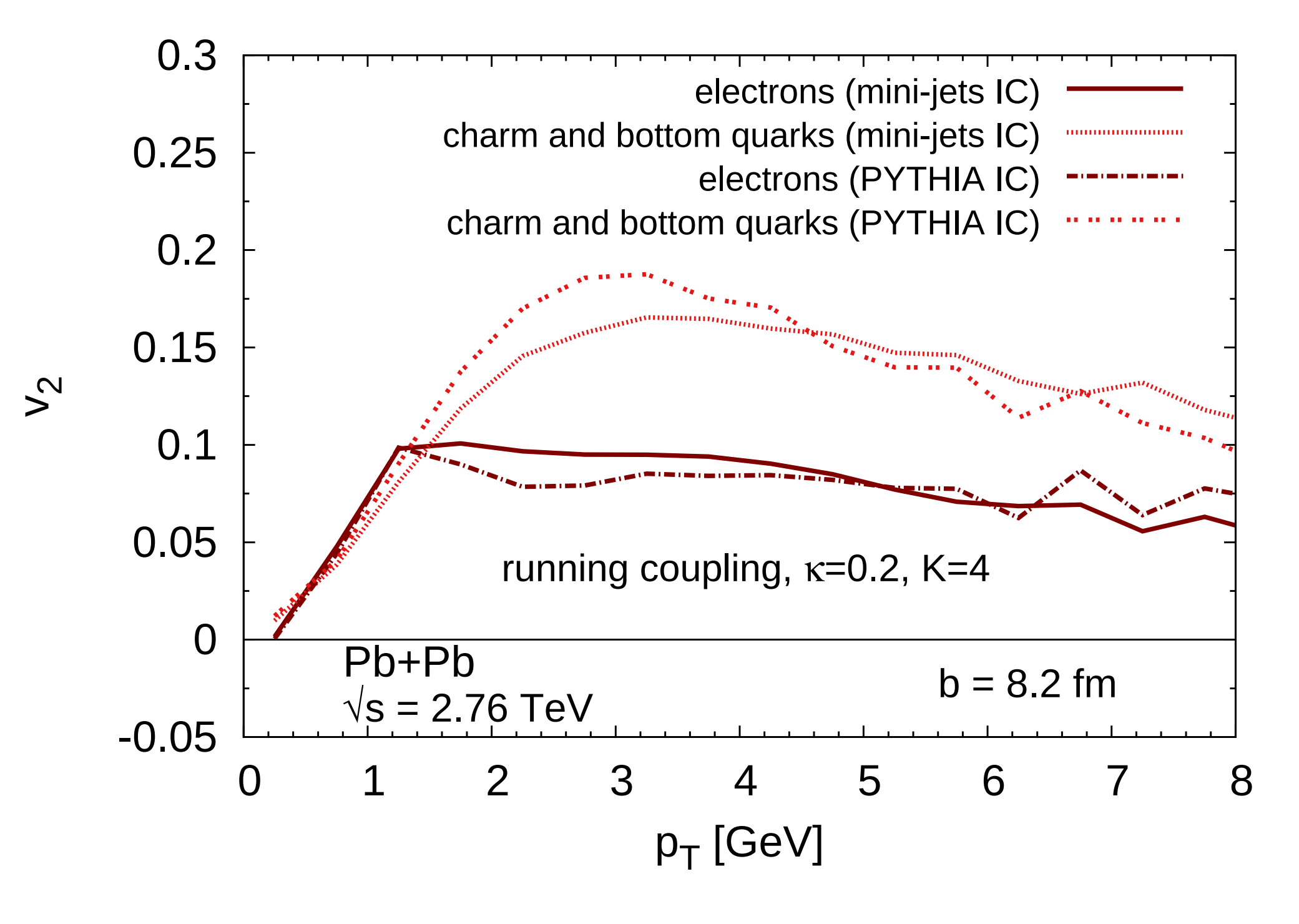

Figure 5: As in Fig. 3, but for Pb+Pb collision at LHC with $\sqrt{s_{NN}}=2.76\,\mathrm{TeV}$.

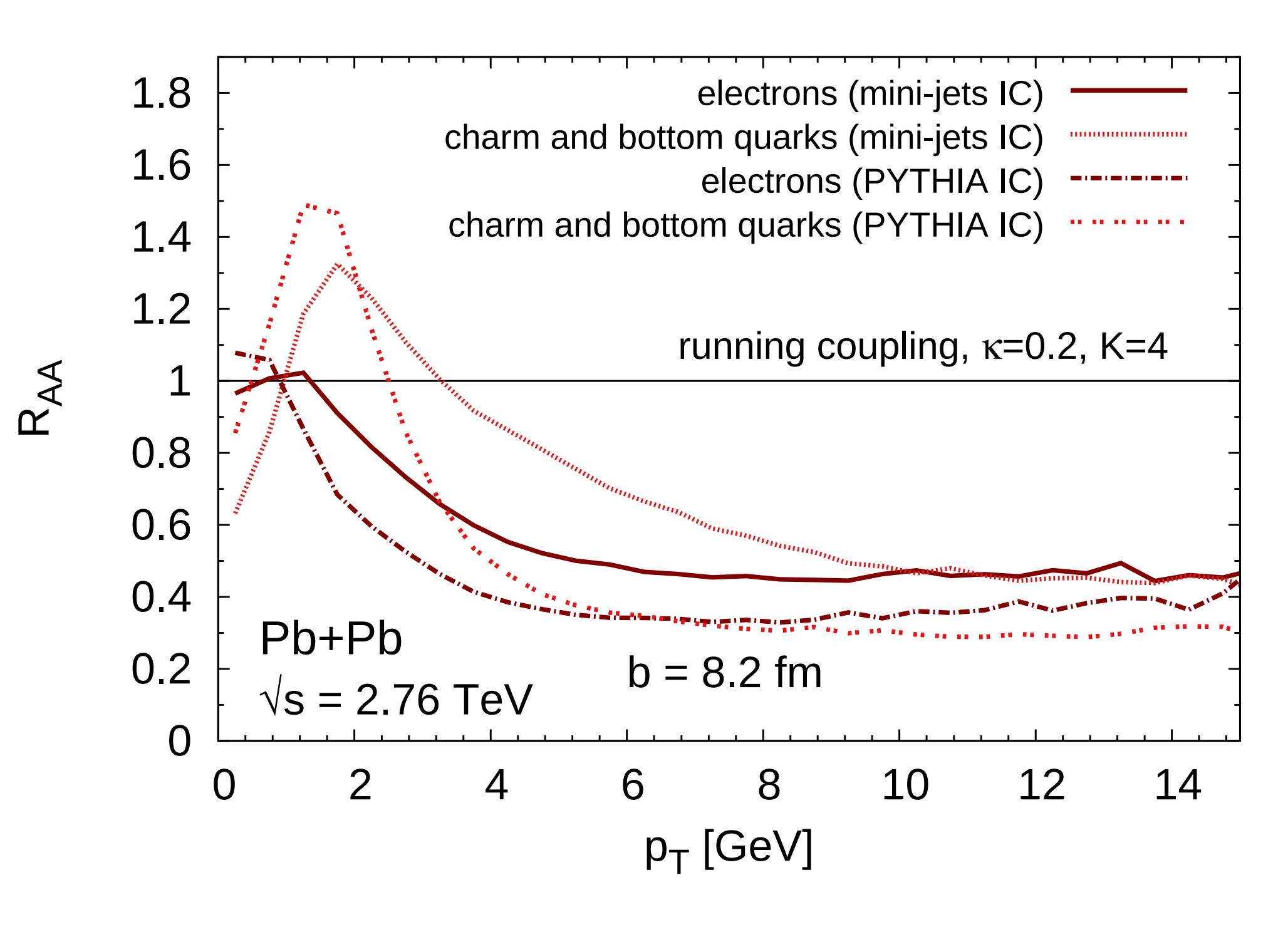

Figure 6: As in Fig. 4, but for Pb+Pb collision at LHC with $\sqrt{s_{NN}}=2.76\,\mathrm{TeV}$.

At LHC the elliptic flow and suppression of electrons from charm quarks are slightly larger than at RHIC. However, the contribution from bottom quarks becomes important also at smaller p_T. As a consequence, the v_2 and R_{AA} at LHC are very similar to the RHIC results.

Conclusions

The production and space-time evolution of charm and bottom quarks is studied with the pQCD based transport model BAMPS. At LHC charm production in the QGP can be comparable to the initial yield. In a preliminary study we find that J/ψ is slightly more suppressed as experimental data suggests. Elastic energy loss of heavy quarks in the QGP is quite sizeable if one improves the calculation of the cross section by taking the running coupling and a more precise Debye screening into account. However, in order to explain the experimentally measured elliptic flow and nuclear modification factor next-to-leading order contributions must be taken into account, which we plan to do in the future.

References

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