# Open heavy flavor and $J/\psi$ at RHIC and LHC within a 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 *Boltzmann Approach to Multi–Parton Scatterings* (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), light quarks (q), heavy quarks (Q), and $J/\psi$ are implemented with the following interactions for heavy flavor: $gg \leftrightarrow Q\bar{Q}$, $q\bar{q} \leftrightarrow Q\bar{Q}$, $gQ \to gQ$, $qQ \to qQ$, and $J/\psi g \leftrightarrow c\bar{c}$ [1, 3].

## $J/\psi$ suppression and flow

With taking cold nuclear matter effects such as shadowing, nuclear absorption and the Cronin effect into account [4] the space-time evolution of $J/\psi$ is carried out with BAMPS, which also allows dissociation and regeneration of $J/\psi$.

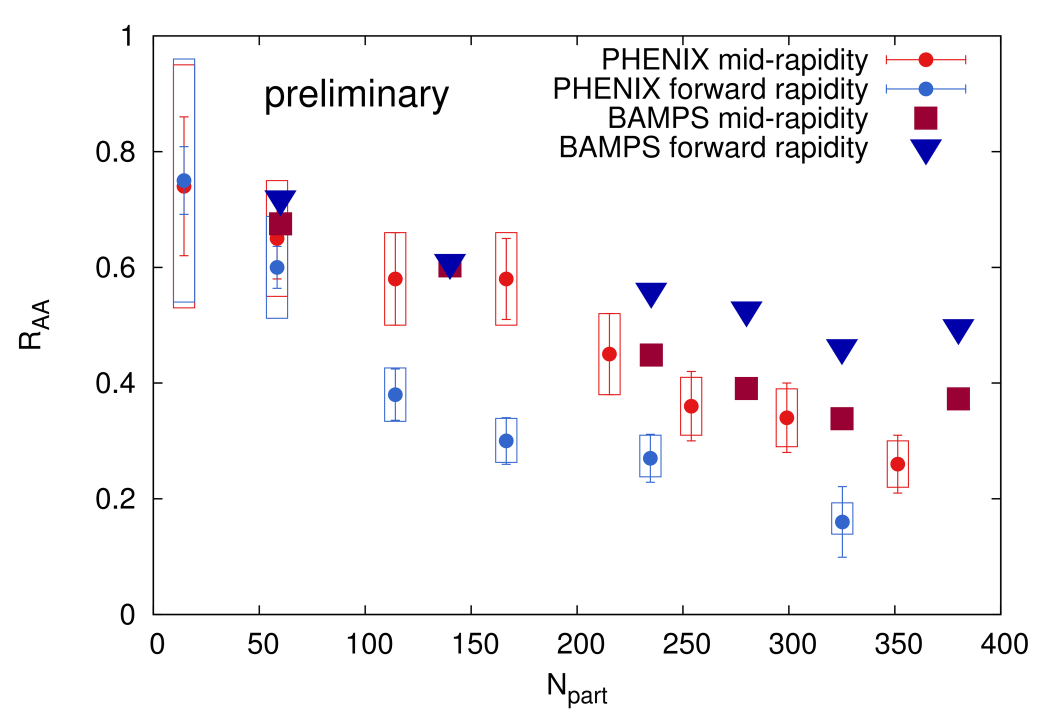


**Figure 1:** $R_{AA}$ of $J/\psi$ at mid-rapidity $|y| < 0.35$ and forward rapidity $1.2 < y < 2.2$ for Au+Au collisions at RHIC as a function of the number of participants, together with experimental data [8].

Preliminary results of the nuclear modification factor $R_{AA}$ of $J/\psi$ obtained with BAMPS agree well with the data at mid-rapidity, but are slightly too large at forward rapidity. The elliptic flow of all $J/\psi$ is very small and consistent with the experimental data.

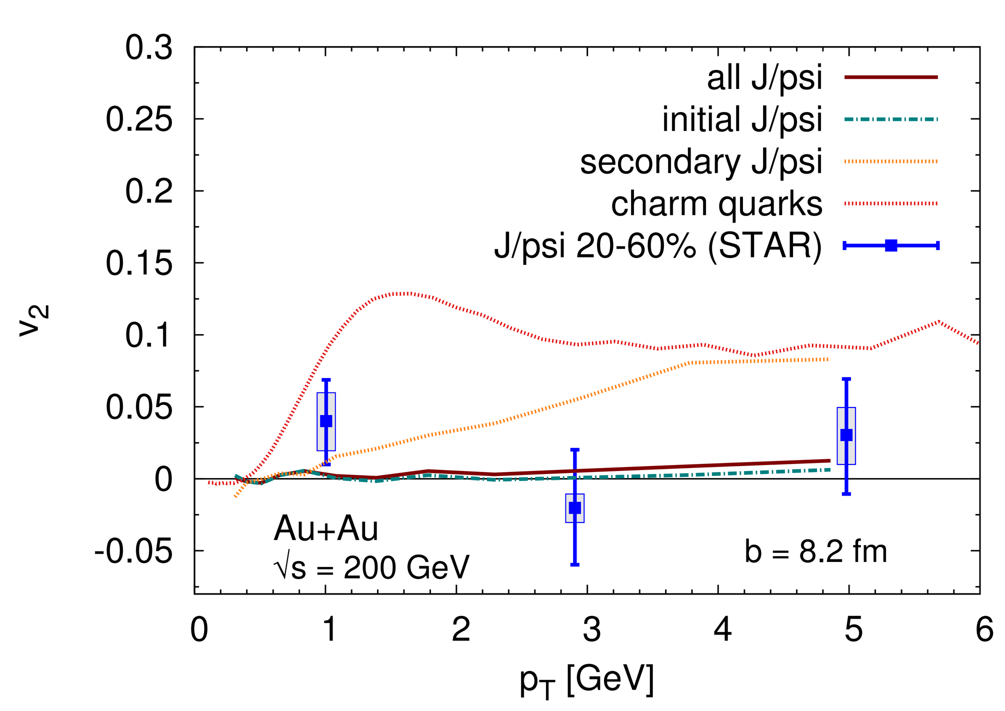


**Figure 2:** Elliptic flow of $J/\psi$ at RHIC with data [9]. For comparison the charm quark $v_2$ is also shown.

## Elliptic flow and nuclear modification factor of open heavy flavor

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:

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

We employ the running coupling and an improved screening procedure, that reproduces the energy loss from hard thermal loop calculations, which effectively enhances the heavy quark cross section with the medium:

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

The prefactor $\kappa$ 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 $\kappa$ to the energy loss obtained within the hard thermal loop approach [3].

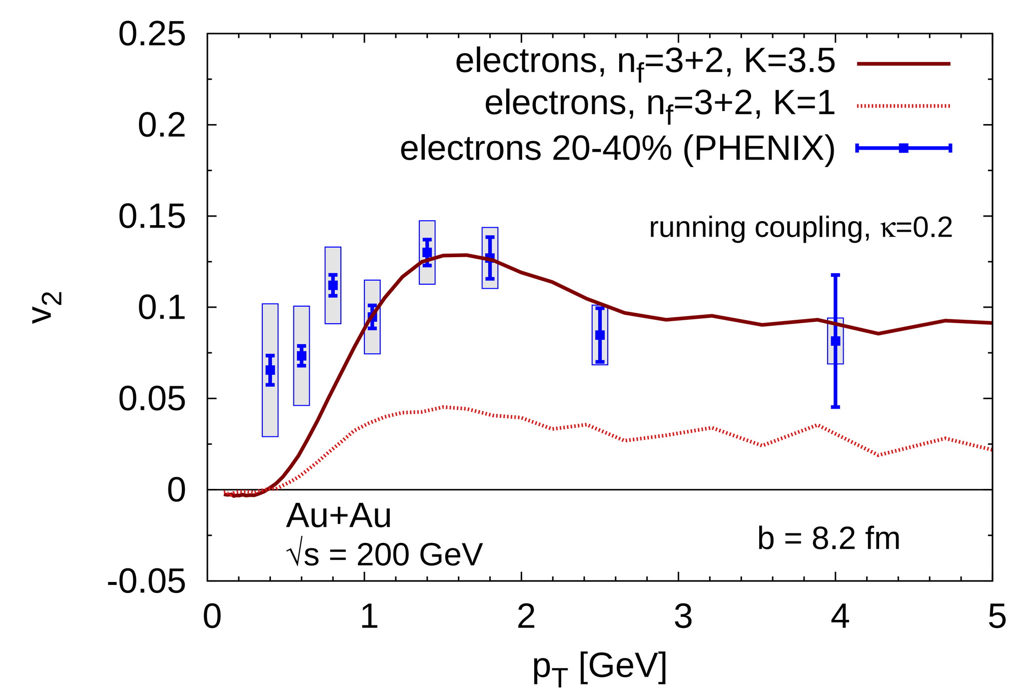


**Figure 3:** Elliptic flow $v_2$ of heavy flavor electrons for Au+Au collisions at RHIC. The heavy quark cross section with light partons is multiplied with the factor $K = 3.5$. For comparison, data of heavy flavor electrons [10] is shown.

Quantitative comparisons [2, 3, 5] show that elastic processes are responsible for a large fraction of the energy loss of heavy quarks. However, they are not able to reproduce the data of the nuclear modification factor or elliptic flow of any heavy flavor particle species. This is not surprising since we expect that radiative $2 \to 3$ processes also play an important role and that both processes together should account for the measured suppression and flow. Currently, we mimic the radiative influence by effectively increasing the elastic cross section by a factor $K = 3.5$ which fits the heavy flavor elliptic flow and $R_{AA}$ data from RHIC [5].

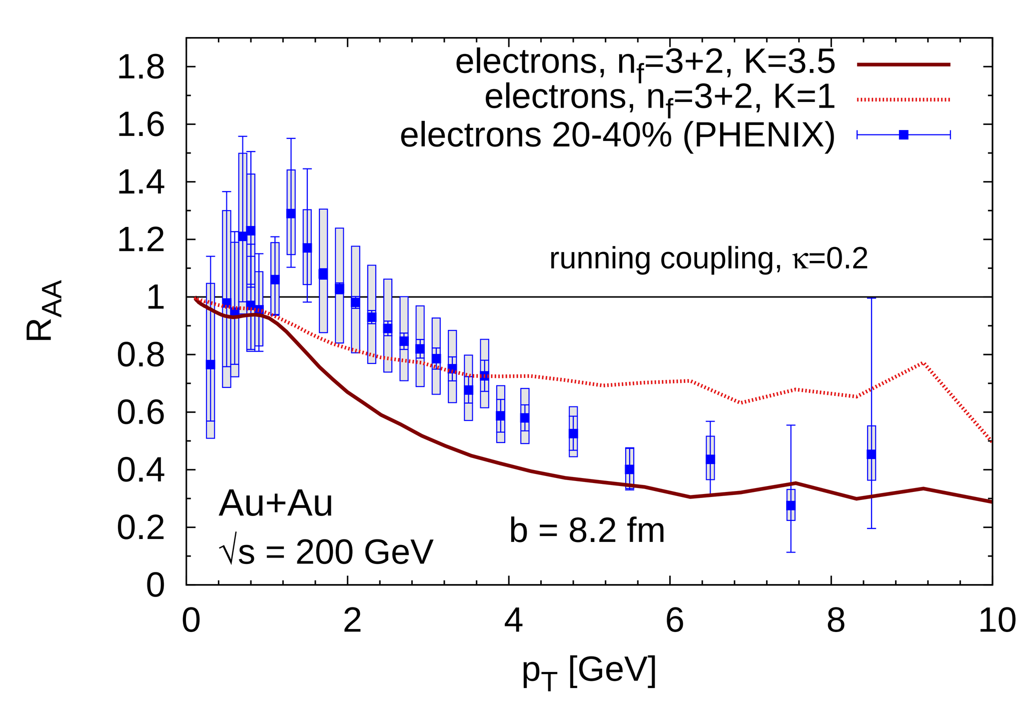


**Figure 4:** Nuclear modification factor $R_{AA}$ of heavy flavor electrons at RHIC for the same configurations as in Fig. 3.

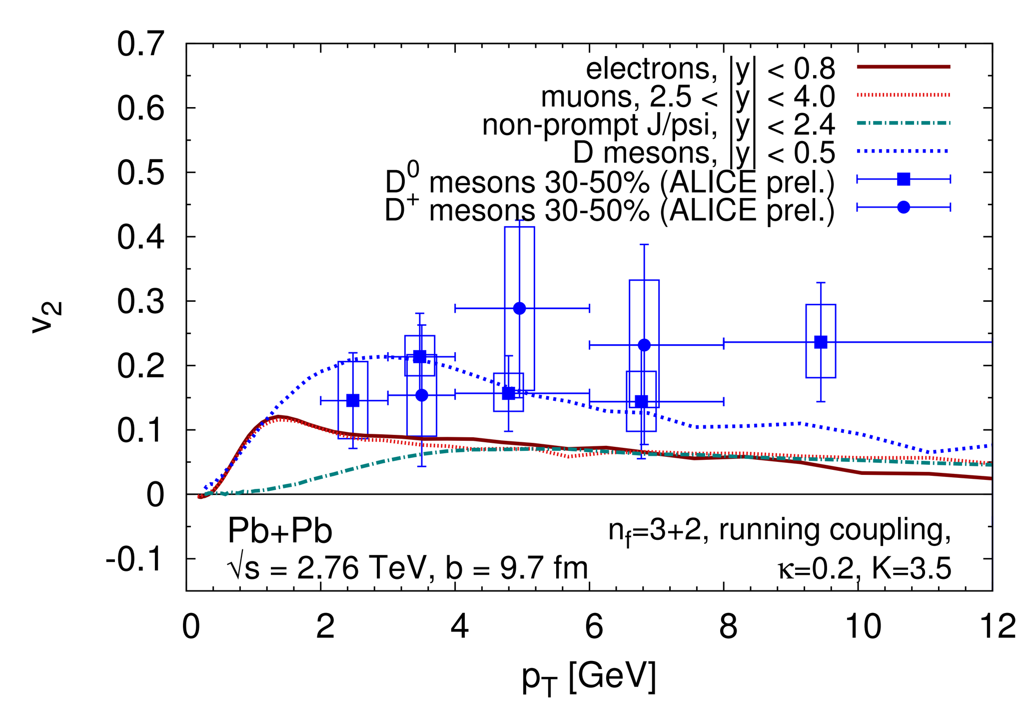


**Figure 5:** Elliptic flow $v_2$ of $D$ mesons, non-prompt $J/\psi$, muons, and electrons as a function of transverse momentum for Pb+Pb collisions at LHC together with data [11].

With the same parameter we find a good agreement with the $D$ meson elliptic flow data at LHC. However, the $R_{AA}$ of $D$ mesons, non-prompt $J/\psi$, and muons are underestimated.

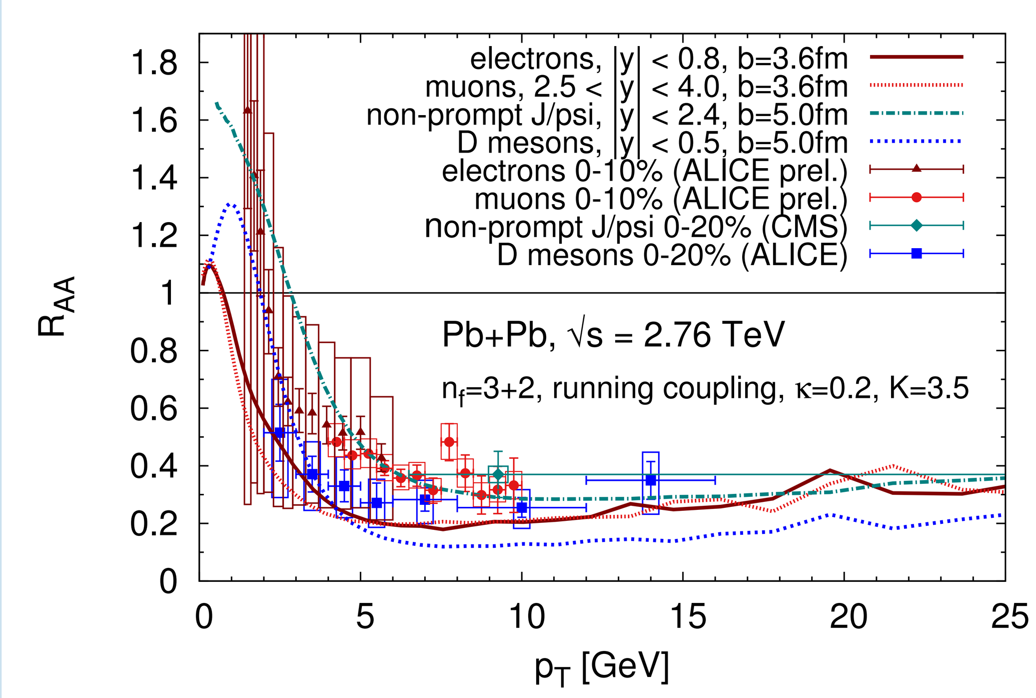


**Figure 6:** Nuclear modification factor $R_{AA}$ of $D$ mesons, non-prompt $J/\psi$, muons, and electrons as a function of transverse momentum for Pb+Pb collisions at LHC together with data [12, 13, 14].

First BAMPS results with radiative contributions look very promising. The RHIC electron $R_{AA}$ can be described without a $K$ factor.

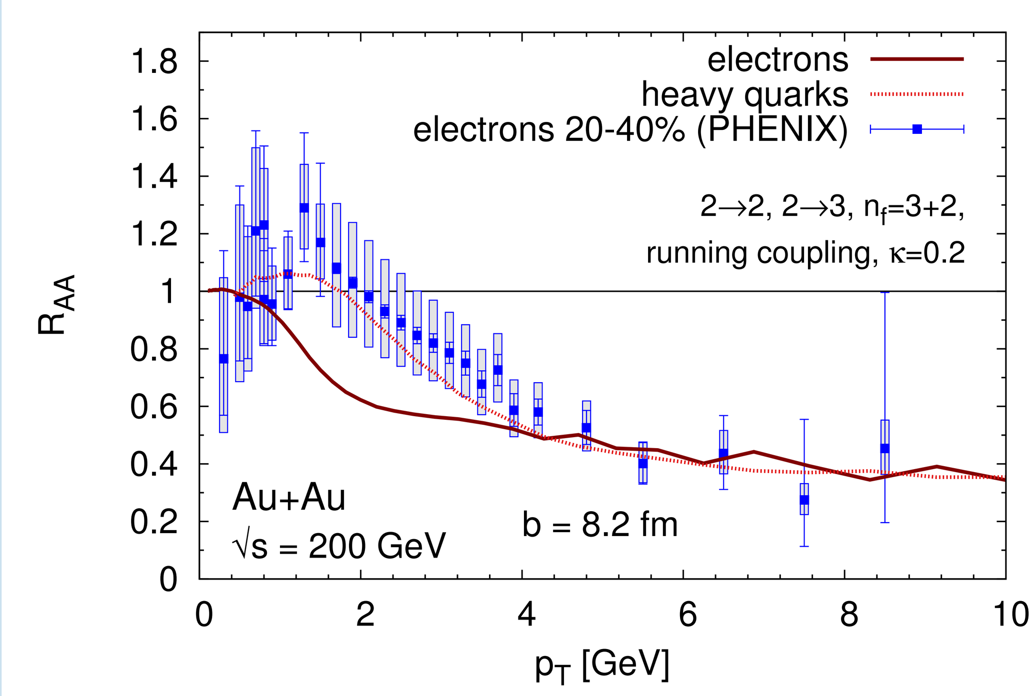


**Figure 7:** Preliminary results on the nuclear modification factor $R_{AA}$ of electrons at RHIC (cf. Fig. 4) with also radiative processes for heavy quarks and without any $K$ factor.

## Conclusions

The production and space-time evolution of charm and bottom quarks are studied with the pQCD based transport model BAMPS. In a preliminary study we find that $J/\psi$ observables at RHIC are rather well described by BAMPS. 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 radiative contributions must be taken into account, which is work in progress.

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