Quarkonium suppression. A model for shadowing and medium effects

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Based on ...

- Escobedo and Ferreiro, Simple model to include initial-state and hot-medium effects in the computation of quarkonium nuclear modification factor, Phys. Rev. D 105 (2022) 1, 1.

Outline

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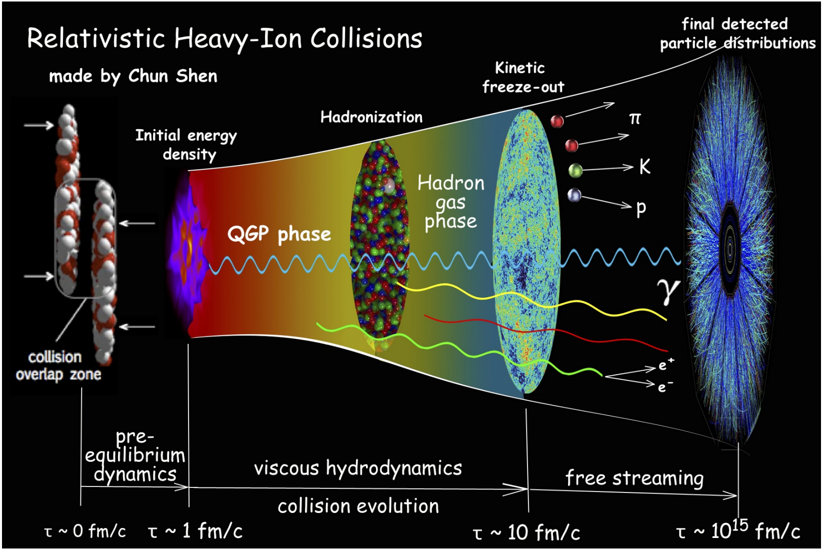
- Quarkonium is a good probe of the QGP. Not only it is formed in the initial instants of the collision but also it was predicted by Matsui and Satz that quarkonium melts in the QGP. Therefore, by measuring quarkonium suppression we can infer the properties of the medium.
- Moreover, a heavy ion is not equivalent to an uncorrelated ensemble of protons. This can also modify the probability of quarkonium formation. Initial state effects.

A heavy ion collision



R_{AA}, the nuclear modification factor

In the Glauber model, the nucleus is seen as a collection of uncorrelated protons moving eikonally on the longitudinal direction.

$$R_{AA} = \frac{N_{HQ}^{AA}}{N_{col} N_{HQ}}$$

where

- N_{HQ}^{AA} is how much quarkonium is produced in a heavy ion collision.
- N_{col} is the number of nucleon-nucleon collisions in that heavy ion collision.
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R_{AA} is not one if

- There are medium effects.
- There are initial effects, i.e. if a heavy ion collision is not equivalent to N_{col} proton-proton collisions.

Hot medium effects

Phenomena that modify quarkonium population in a QGP

- Screening of chromoelectric fields at large distances. Inhibits quarkonium formation if quarkonium's size is larger than screening length.
- Medium induced decay width.
- Recombination. A heavy quark-antiquark pair can meet inside of the medium and form a new bound state. Important for charmonium but sub-leading effect for bottomonium.

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Survival probability

If we ignore recombination, we can encode medium effects in a survival probability S.

- Given S as a function of the initial temperature. Can we compute R_{AA}?

Motivation

To develop a framework to easily compute R_{AA} in the cases in which the survival probability is given by a simple analytical formula.
Questions we wish to answer:

- What is the initial temperature as a function of $x_\perp$?
- How does the quarkonium production probability depends on $x_\perp$?
- Compute R_{AA} for a given S.

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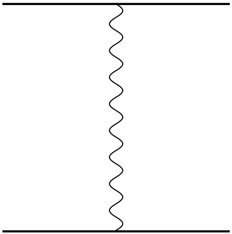
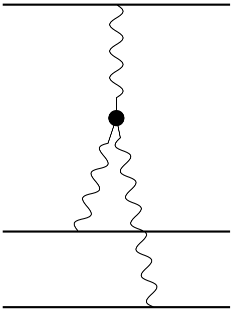
- Corrections beyond the Glauber model can be implemented by including some non-trivial interaction between Pomerons.
- In our case, we use a model that includes a triple Pomeron vertex.

Pomeron exchanges





Some definitions

The thickness function is the density of nucleons in the transverse plane

$$T_A(x, y) = \int_{-\infty}^{\infty} \rho(x, y, z)$$

In the Glauber model, the density of collisions at a given point is proportional to

$$n_{col}(x_\perp, b) = T_A\left(x_\perp + \frac{b}{2}\right) T_B\left(x_\perp - \frac{b}{2}\right)$$

where b is the impact parameter. Note the unconventional choice, we use a reference system in which $x_\perp = 0$ corresponds to the center of the overlapping region, not to the center of one of the nuclei.

Some definitions II

A participant is a nucleon that collides at least once. The density of participants at a given point in the transverse plane is

$$n_{part}(x_\perp, b) = T_A\left(x_\perp + \frac{b}{2}\right)\left(1 - \left(1 - \frac{T_B\left(x_\perp - \frac{b}{2}\right)\sigma}{B}\right)^B\right) + T_B\left(x_\perp - \frac{b}{2}\right)\left(1 - \left(1 - \frac{T_A\left(x_\perp + \frac{b}{2}\right)\sigma}{A}\right)^A\right)$$

R_{AA} is often given as a function of the total number of participants N_{part}. More participants implies more central collisions.

Initial-effect model

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In this model, the probability to create a particle at a given point in the transverse plane is proportional to

$$S^{sh}(\mathbf{s}, \mathbf{b}) = \frac{T_A\left(\mathbf{s} + \frac{\mathbf{b}}{2}\right)}{1 + A\ F(y, p_T) T_A\left(\mathbf{s} + \frac{\mathbf{b}}{2}\right)}\ \frac{T_B\left(\mathbf{s} - \frac{\mathbf{b}}{2}\right)}{1 + B\ F(-y, p_T) T_B\left(\mathbf{s} - \frac{\mathbf{b}}{2}\right)}$$

Note that it depends on both rapidity and transverse momentum.

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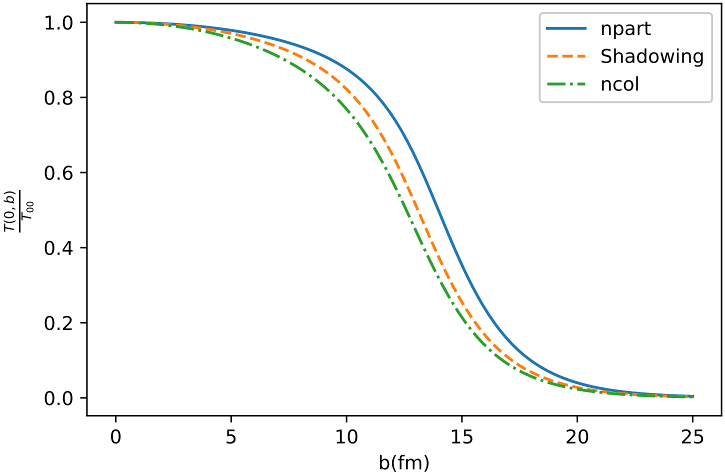
- As a comparison, we can also compute the temperature that we obtain changing S_π^{sh} to n_{part} or n_{col}.

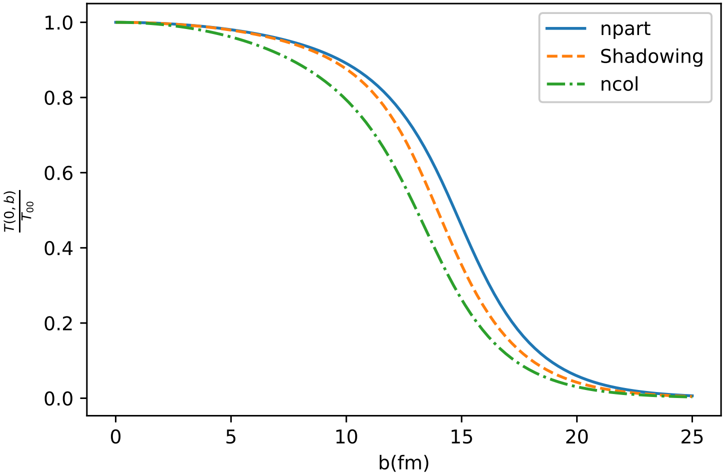
Temperature in the center of the overlapping region

RHIC, $\sqrt{s} = 200\ GeV$



Temperature in the center of the overlapping region

LHC, $\sqrt{s} = 5.02\ TeV$



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$$\langle T_{HQ}(b)\rangle = T_{00}\frac{\int d^2 s S^{sh}_{HQ}(\mathbf{s},\mathbf{b})\left(\frac{S^{sh}_{\pi}(\mathbf{s},\mathbf{b})}{S^{sh}_{\pi}(\mathbf{0},\mathbf{0})}\right)^{1/4}}{\int d^2 s S^{sh}_{HQ}(\mathbf{s},\mathbf{b})}$$

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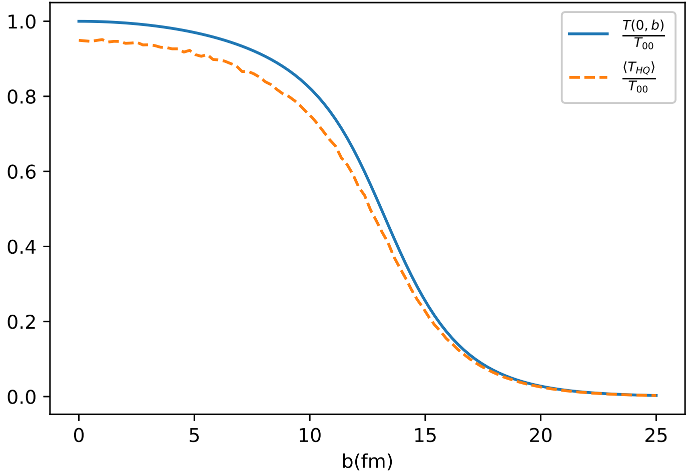
- We might ask if the temperature seen by a quarkonium state is close to the temperature at the center of the plateau.

$\langle T_{HQ} \rangle$ versus $T_0(0, b)$

RHIC, $\sqrt{s} = 200\ GeV$



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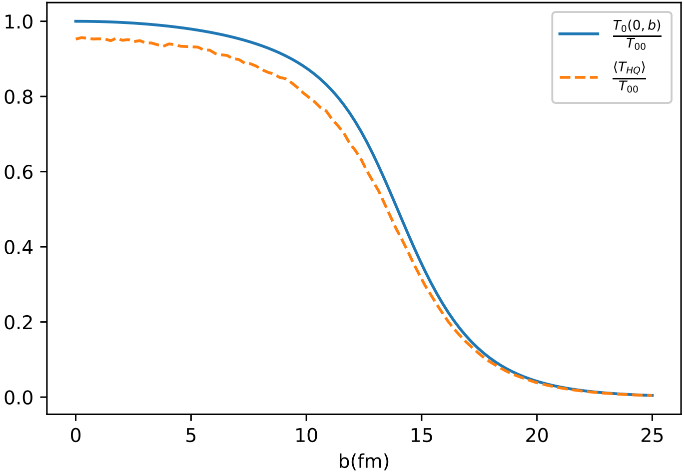

Outline

Computation of R_{AA}

$$R_{AB}(b) = \frac{N^{AB}_{HQ}(b)}{N^{pp}_{HQ} T_{AB}(b)}$$

where

$$N^{AB}_{HQ}(b) = N^{pp}_{HQ} \int d^2 s S^{sh}_{HQ}(\mathbf{s}, \mathbf{b}) S_{med}(\mathbf{s}, \mathbf{b})$$

and

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- If $S_{med} = 1$ there are no medium effects. R^{CNM}_{AA}.
- If $S^{sh}_{HQ} = T_{AB}$ we ignore the triple Pomeron vertex. Original Glauber model. R^{T}_{AA}.

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$$S_{med}(\mathbf{s},\mathbf{b}) = \begin{cases} \mathrm{e}^{-\frac{3aT_0(\mathbf{s},\mathbf{b})^3 t_0}{b^2}\left(\mathrm{e}^{-\frac{b}{T_0(\mathbf{s},\mathbf{b})}}\left(1+\frac{b}{T_0(\mathbf{s},\mathbf{b})}\right)-\mathrm{e}^{-\frac{b}{T_f}}\left(1+\frac{b}{T_f}\right)\right)} & T_0(\mathbf{s},\mathbf{b}) > T_f \\ 1 & T_0(\mathbf{s},\mathbf{b}) \leq T_f \end{cases}$$

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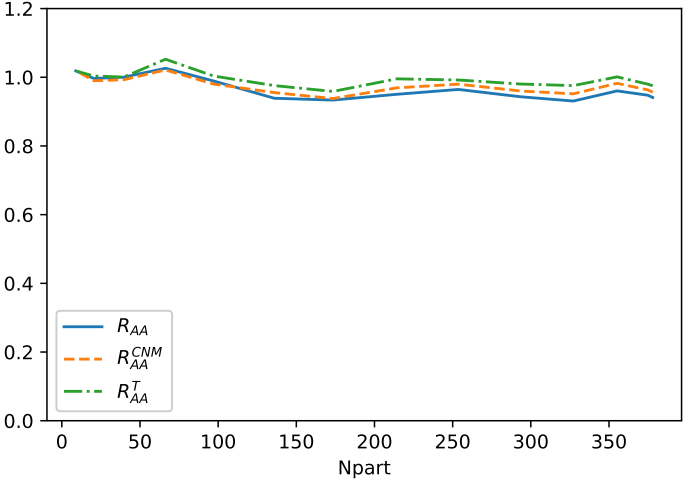
- The model exploits the fact that the open quantum systems description simplifies to a rate equation when $E \gg \Gamma$.

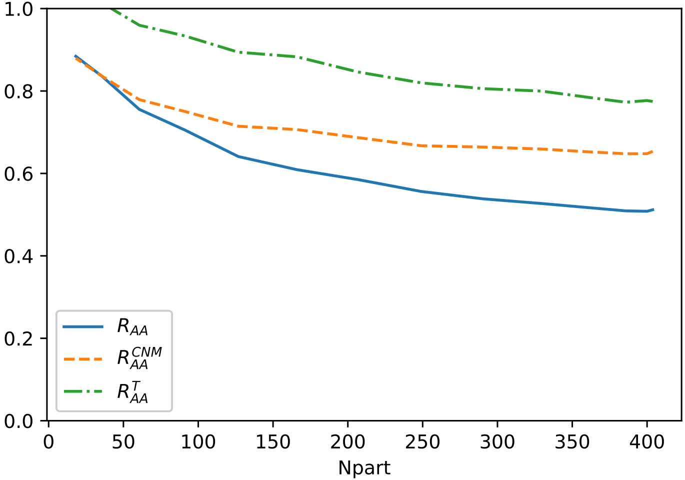
R_{AA}

$\Upsilon(1S)$



R_{AA}

$\Upsilon(1S)$,LHC



Gap model, $\Upsilon(2S)$

Again, we can compute the decay width numerically and fit it with a (different) analytical function.

$$S_{med}(\mathbf{s},\mathbf{b}) = \begin{cases} \mathrm{e}^{-1.5aT_0t_0\left(\left(\frac{T_0}{T_f}\right)^2-1\right)-3bT_0^2t_0\left(\frac{T_0}{T_f}-1\right)} & T_0(\mathbf{s},\mathbf{b}) > T_f \\ 1 & T_0(\mathbf{s},\mathbf{b}) \leq T_f \end{cases}$$

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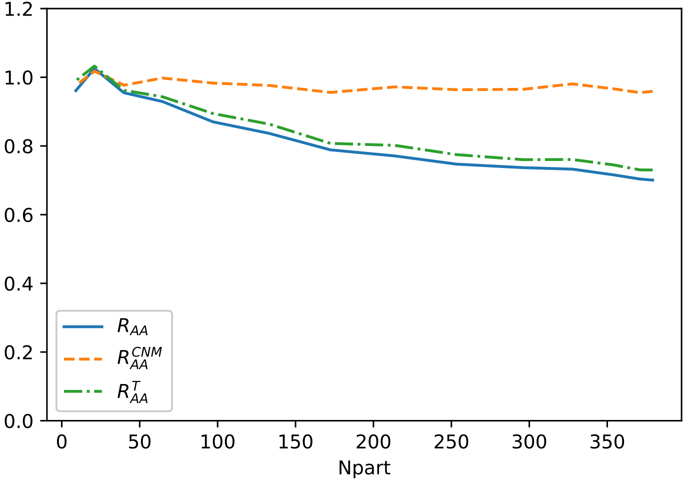

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- In conclusion, we see a very mild direct modification of $\Upsilon(1S)$ both by shadowing and medium effects.

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- Very mild effects for $\Upsilon(1S)$ at sPhenix.