Thermal production of charms and charmonia in quark-gluon plasma

Zhengyu Chen
Tsinghua University, China

Kai Zhou, Carsten. Greiner (Frankfurt University)

Pengfei Zhuang (Tsinghua University)

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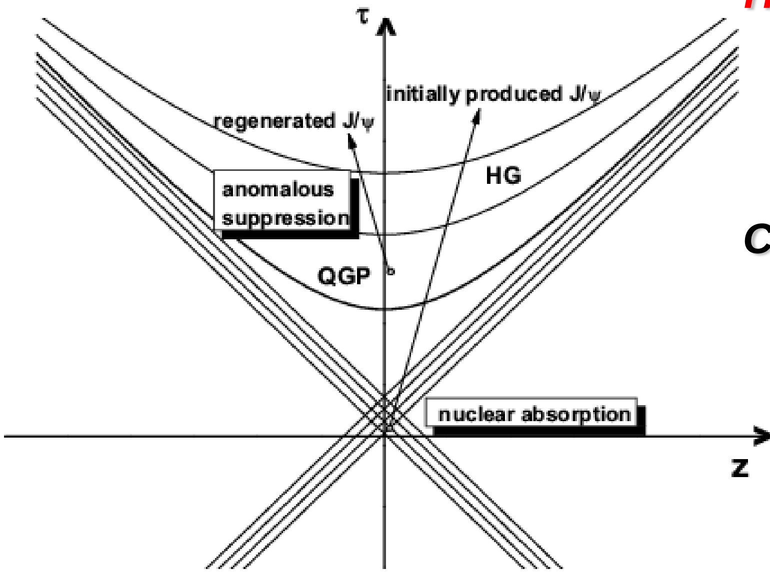
Introduction

Matsui and Satz(1986): ***J/Psi suppression as a probe of QGP in HIC***



Hot Nuclear Matter effects:

1) ***suppression in QGP and HG*** *(Masui, Satz et al.)*

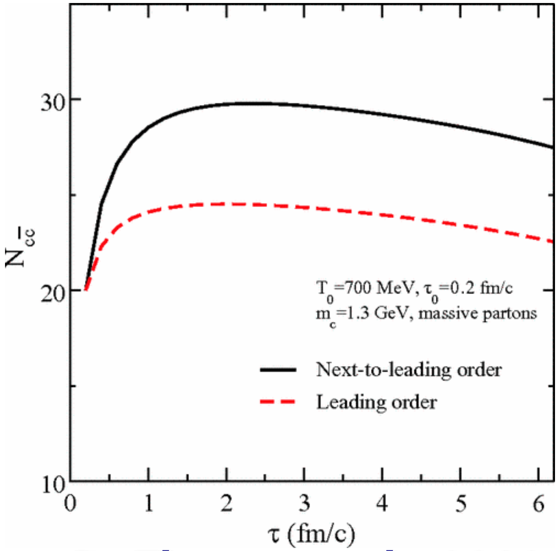
2) ***regeneration in QGP and HG*** *(PBM, Thews, R.Rapp et al.)*

Cold Nuclear Matter effects:

1) ***nuclear absorption*** *(J.Huefner, A.Capella et al.)*

2) ***Cronin effect*** *(J.W.Cronin, J.Huefner et al.)*

3) ***shadowing effect*** *(A.H.Mueller, M.Gyulassy, R.Vogt, E.Ferreiro et al.)*



B. Zhang, et al. 2008

All the heavy quarks are initially produced!

$$\partial_\mu N^\mu = 0$$

How about the thermal charm production and its contribution to charmonia ?

Thermal production of charms

- ***charm production processes***

  Leading Order:

  $$q+\bar{q} \to c+\bar{c} \quad g+g \to c+\bar{c}$$

  Next-to-leading Order:

  $$q+\bar{q} \to c+\bar{c}+g \qquad g+g \to c+\bar{c}+g$$

- ***rate equation***

  $$\partial_\mu N^\mu = R_{gain} - R_{loss}$$

  $$R_{gain} = \frac{dN_{reaction}}{d^4x} = \frac{1}{\upsilon}\int \frac{d^3p_1}{(2\pi)^3 2E_1}\frac{d^3p_2}{(2\pi)^3 2E_2} 4F_{12}\sigma_{12} f_1 f_2$$

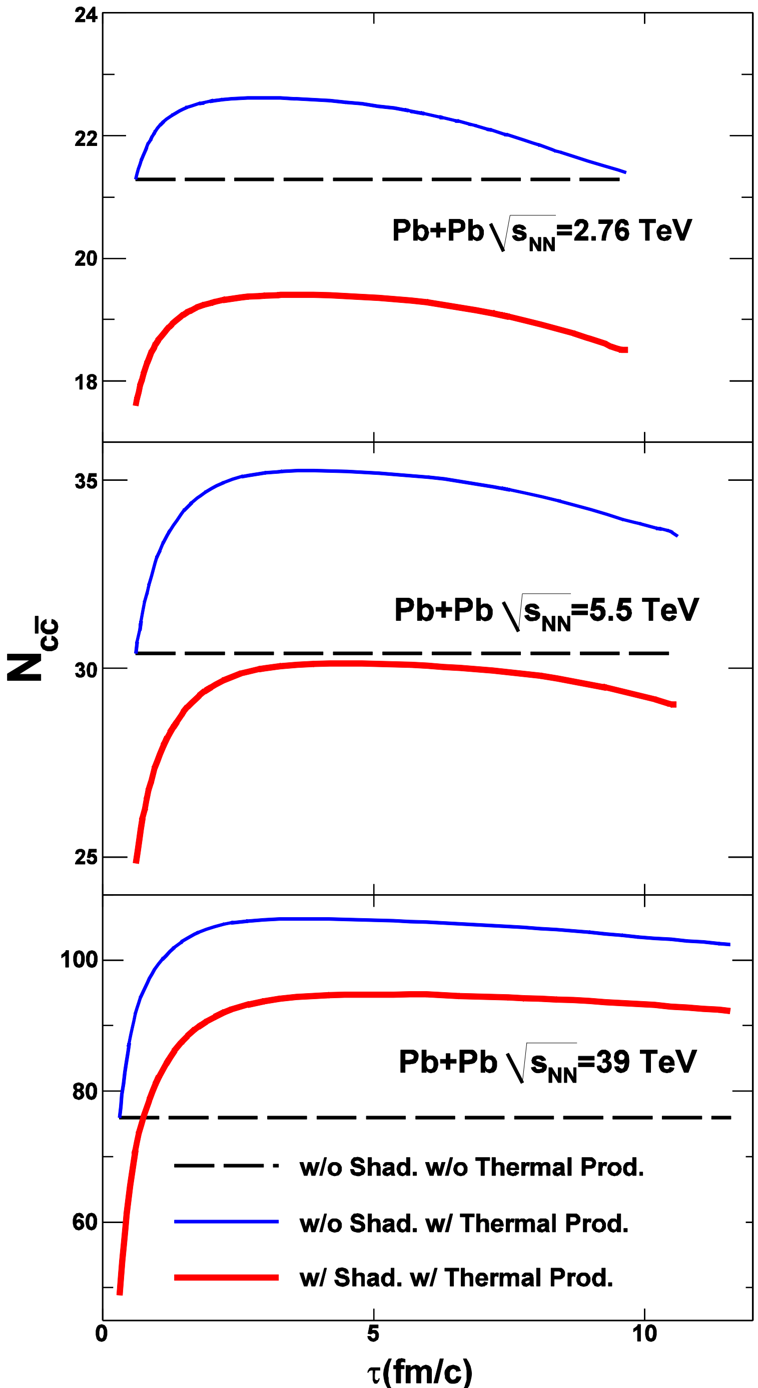
  σ_{12} ***is the charm pair production cross section(P. Nason et al. 1988)***

  R_{loss} ***can be obtained by using detailed balance***

- ***local temperature and fluid velocity from hydrodynamics***

  $$\partial_\mu T^{\mu\nu} = 0 \qquad \partial_\mu j^\mu = 0$$

  $$T^{\mu\nu} = (\varepsilon + p)u^\mu u^\nu - g^{\mu\nu} p \qquad j^\mu = nu^\mu$$



charm number evolution

@ 2.76TeV, the thermal production is cancelled by shadowing.

@ 5.5 TeV , thermal charm production comparable with shadowing.

@ 39 TeV , thermal charm production overcomes shadowing.

Thermal production of charmonia

- ***transport approach***

L. Yan et al. (2006), Y. Liu et al. (2009), K. Zhou et al. (2014)

- ***quarkonium transport equations***

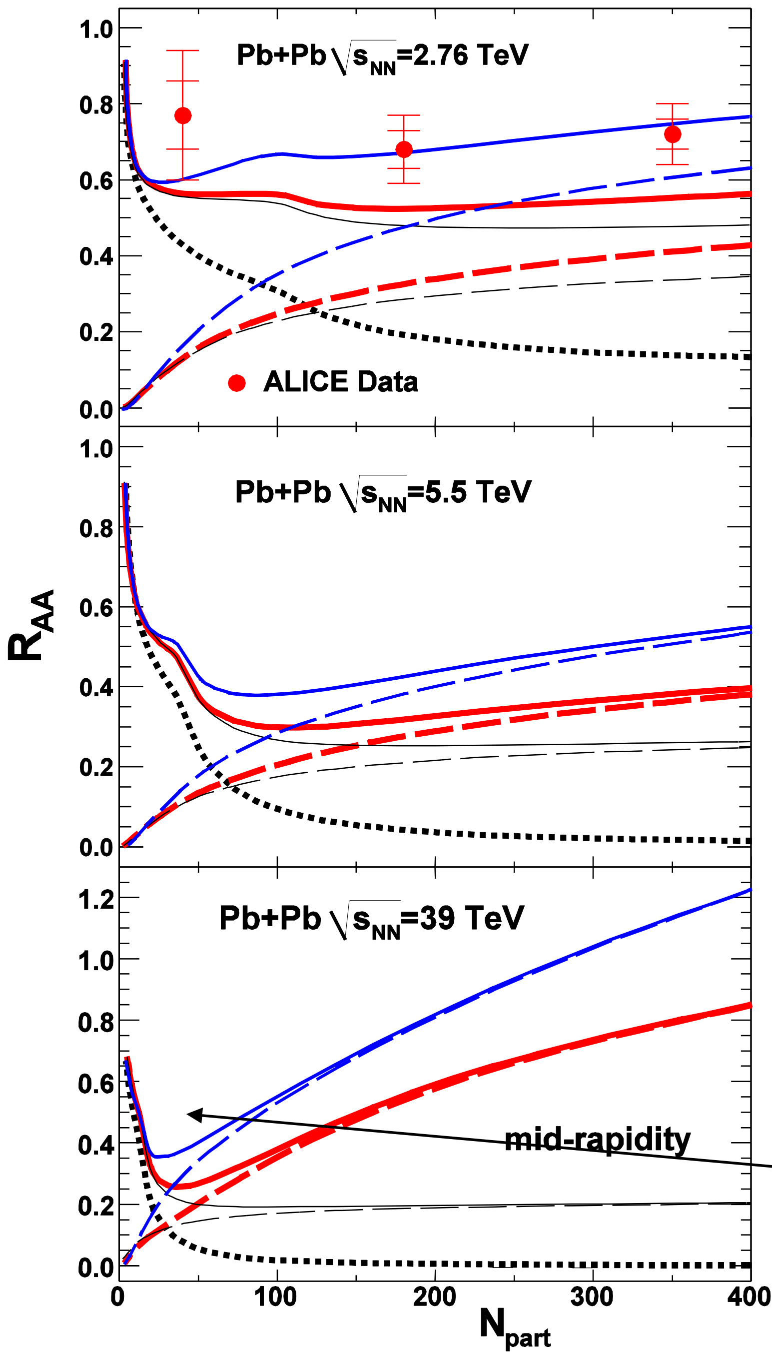
$$\partial_\tau f_\Psi + \mathbf{V}_\Psi \cdot \nabla f_\Psi = -\alpha_\Psi f_\Psi + \beta_\Psi$$

$$(\Psi = J/\psi,\ \chi_c,\ \psi')$$

$$\alpha_\Psi(\mathbf{p}_t, \mathbf{x}_t, \tau|\mathbf{b}) = \frac{1}{2E_\Psi}\int \frac{d^3\mathbf{p}_g}{(2\pi)^3 2E_g} W_{g\Psi}^{c\bar{c}}(s) f_g(\mathbf{p}_g, \mathbf{x}_t, \tau)\Theta\left(T(\mathbf{x}_t, \tau|\mathbf{b}) - T_c\right),$$

$$\beta_\Psi(\mathbf{p}_t, \mathbf{x}_t, \tau|\mathbf{b}) = \frac{1}{2E_\Psi}\int \frac{d^3\mathbf{p}_g}{(2\pi)^3 2E_g}\frac{d^3\mathbf{p}_c}{(2\pi)^3 2E_c}\frac{d^3\mathbf{p}_{\bar{c}}}{(2\pi)^3 2E_{\bar{c}}} W_{c\bar{c}}^{g\Psi}(s) f_c(\mathbf{p}_c, \mathbf{x}_t, \tau|\mathbf{b}) f_{\bar{c}}(\mathbf{p}_{\bar{c}}, \mathbf{x}_t, \tau|\mathbf{b}) \times (2\pi)^4 \delta^{(4)}(p + p_g - p_c - p_{\bar{c}})\Theta\left(T(\mathbf{x}_t, \tau|\mathbf{b}) - T_c\right),$$

Including thermal charm production



Numerical results

@2.76TeV

Thermal production increase R_{AA}, 0.48-- →0.55(with shadowing);
Thermal production increase R_{AA}, 0.48-- →0.77(without shadowing).

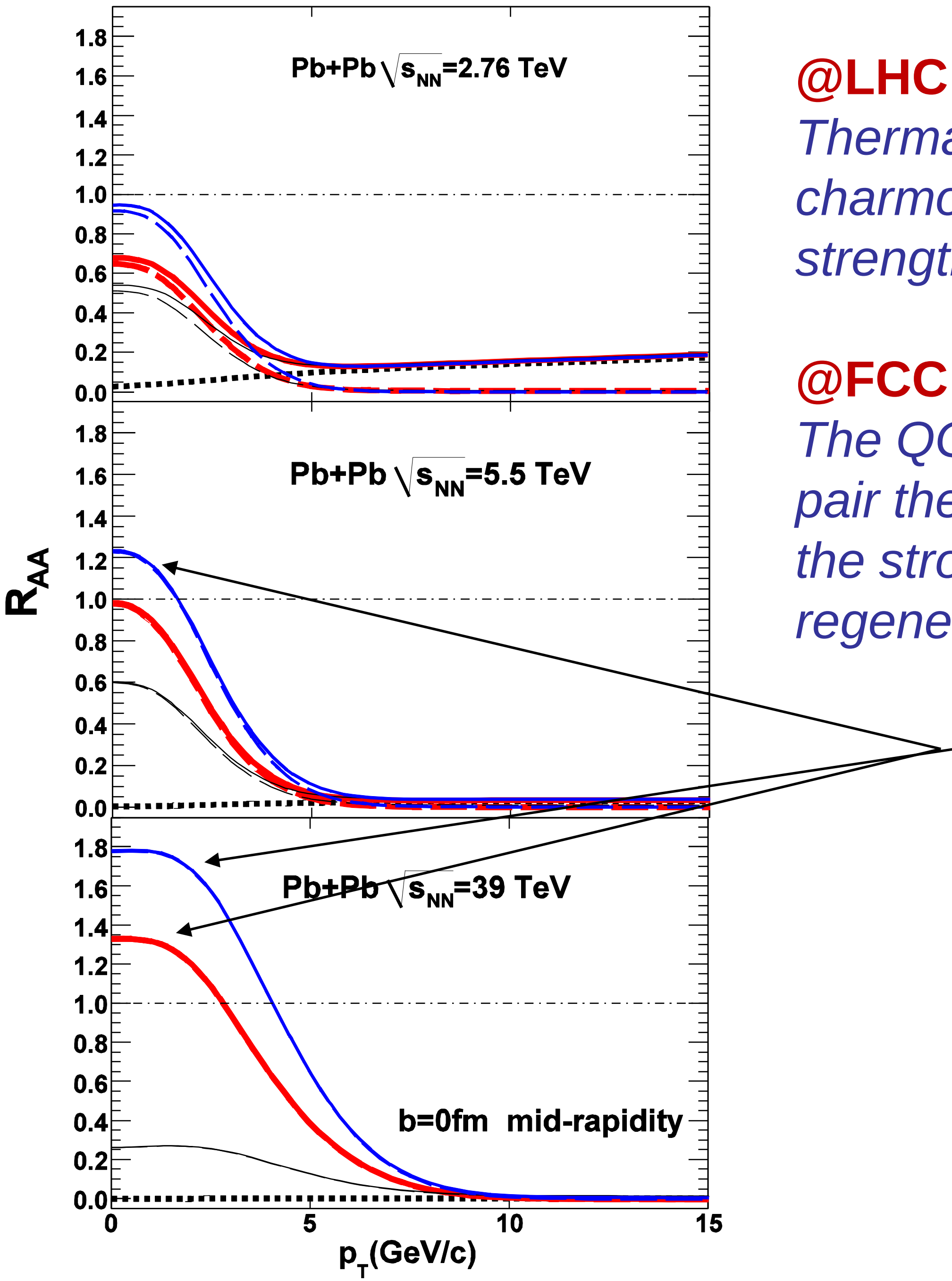
@5.5TeV

With thermal production, R_{AA} appears a flat structure; Without thermal production, R_{AA}, shows a slightly increasing trend.

@39TeV

Thermal production increase R_{AA}, 0.2-- →0.85(with shadowing);
Thermal production increase R_{AA}, 0.2-- →1.25(without shadowing).

valley structure



@LHC

Thermal charm production enhances the charmonium regeneration further, which strengthens the decreasing trend.

@FCC

The QGP becomes a rich source for charm pair thermal production, and this overcome the stronger suppression through regeneration.

exceed unit

Summary

- ***At FCC , the thermal charm production dramatically enhances the charm quark pairs yield.***

- ***At FCC , RAA presents a clearly valley structure due to the competition between the strong suppression and strong regeneration with centrality.***

- ***At FCC , differential RAA as a function of pT can even exceed 1 with thermal charm production in central collisions.***

Thank You!