Quarkonium formation process in relativistic heavy ion collisions

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Time-dependent Schrodinger equation + Hydro

$\tau_{c\bar{c}} < 0.1\ fm$ $\tau_{\psi} < \tau_0(\sim 0.6\ fm)$

Pre-equilibrium — QGP evolution (hydro) — time

$V_{c\bar{c}}(r) = Cornell$ — **pp data** — $V_{c\bar{c}}(r,T) = Lattice\ (F, U)$

$\tau = 0$ (Pb-Pb) — τ_0 $c\bar{c}$ dipole

Time-dependent Schrodinger equation

$$i\hbar\frac{\partial}{\partial t}\psi(r,t) = [-\frac{\hbar^2}{2m_\mu}\nabla^2 + V(r,t)]\psi(r,t)$$

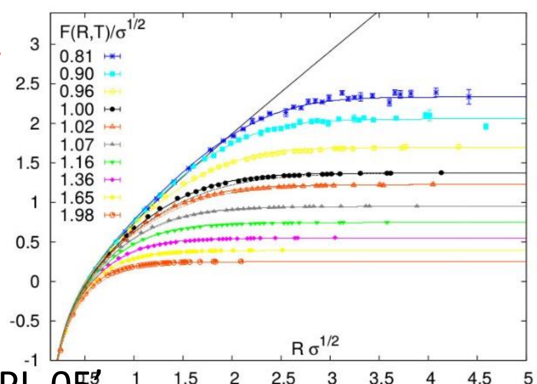
J. Cugnon, P.B. Gossiaux, ZPC, 93'
R. Katz, P. B. Gossiaux, 16'
B.Z. Kopeliovich, et al, PRC, 15'
Taesoo Song, et al, PRC, 15'

- mS eigenstate components in one dipole:

$$c_{mS}(t) = \langle R_{mS}(r)|\frac{\psi(r,t)}{r}\rangle = \int R_{mS}(r)\psi(r,t)\cdot rdr$$

- Heavy quark potential :

Real part: (Lattice)



S.Digal, et al, EPJ, 05'

$V = F$

$V = U = F + T(-\partial F/\partial T)$

imaginary part(HTL):

$$\mathbf{Im}V(r) = -\frac{g^2 C_F T}{4\pi}\widetilde{f}(\hat{r})$$

$$\widetilde{f}(\hat{r}) = 2\int_0^{\infty} dz \frac{z}{(z^2+1)^2}[1 - \frac{\sin(z\hat{r})}{z\hat{r}}]$$

M. Laine, et al, JHEP, 07'
M. Strickland, PRC, 15'

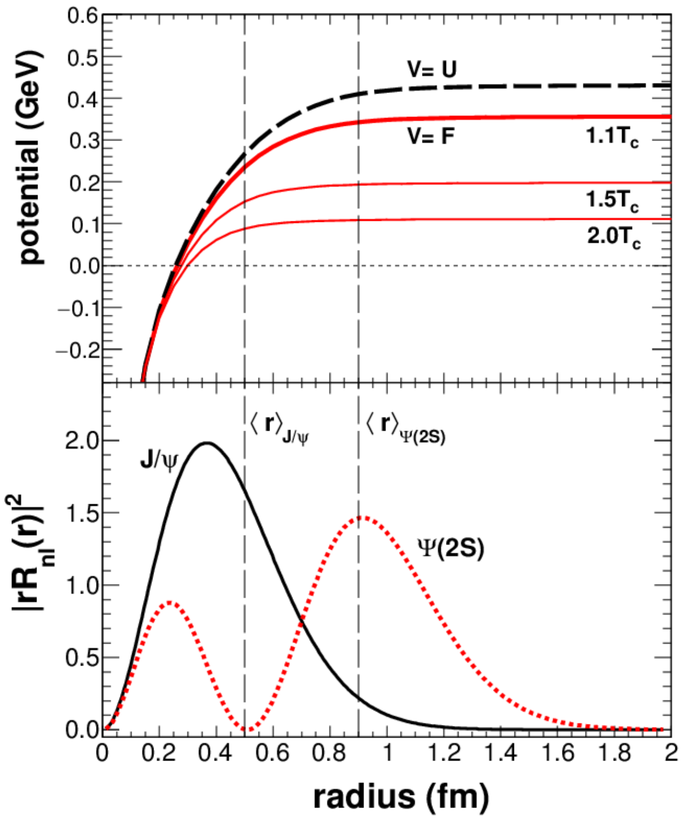
Initialization of $c\bar{c}$ wavefunction

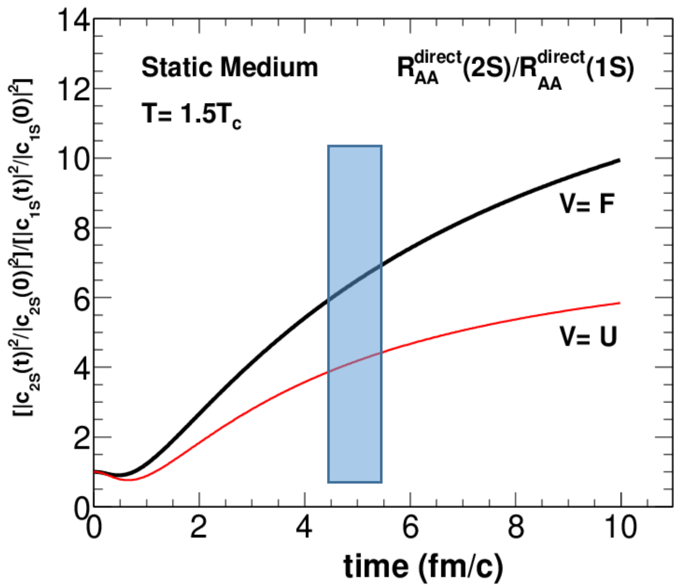
- Gaussian wave: $\phi_0(r) = Ae^{\frac{-r^2}{2\sigma_0^2}}$

$$\int dr \cdot r^2 |\phi_0\ (r)|^2 = 1$$

$$A = \frac{2}{\pi^{1/4}\sigma_0^{3/2}}$$

Fixed by pp data:
Direct 2S/1S





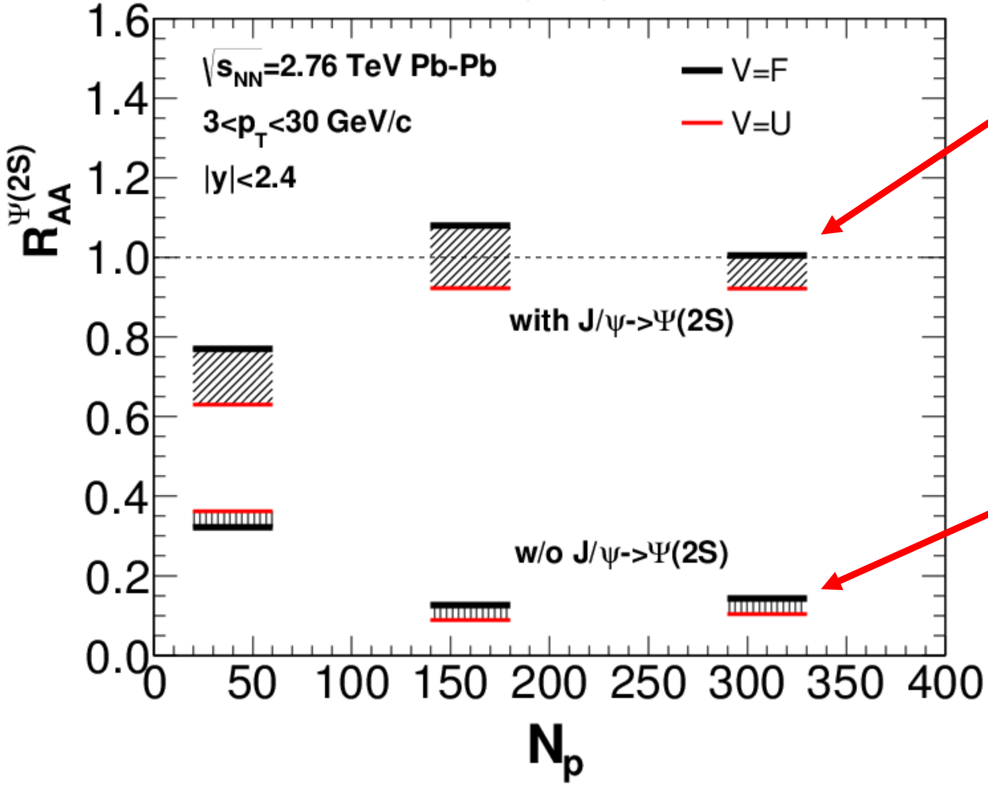
Direct
$R_{AA}(2S)/R_{AA}(1S)$

- Strong color screenin at ~ 2Tc, $c\bar{c}$ dipole wavefunction expands outside
- Most of ccbar dipoles can move out of QGP in time ~5 fm/c

Enhancement of charmonium 2S

Nuclear modification factor of 2S

$R_{AA}(2S)$



1) Initialize the wavefunction of $c\bar{c}$ dipole with **Gaussian function** (both 1S and 2S component)

2S implemented by ***1S->2S***

2) Initialize the wavefunction of $c\bar{c}$ dipole with **2S eigenstate**

Small $R_{AA}(2S)$, consistent with ***Sequential suppression model***

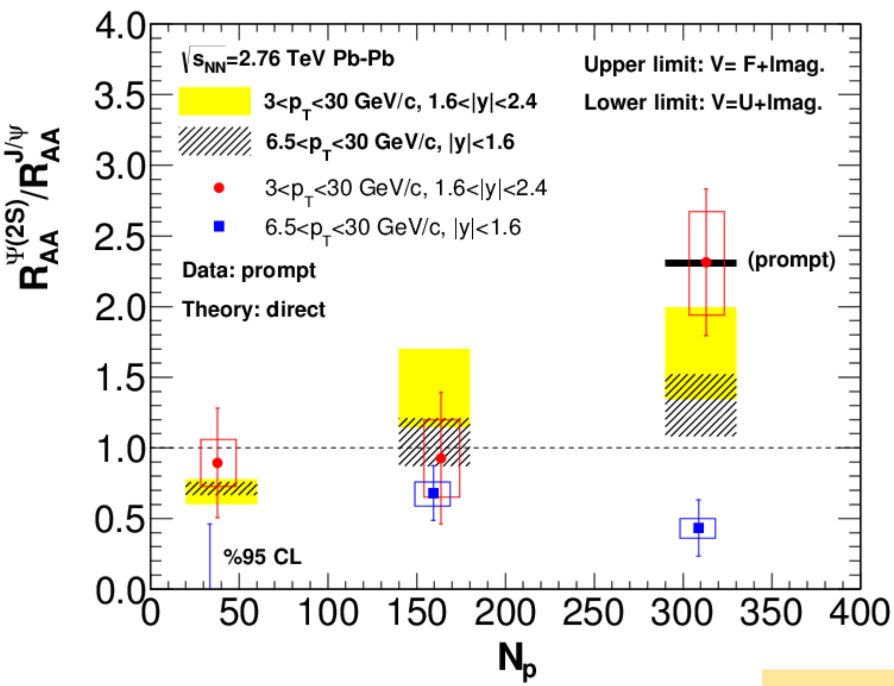
Background: hydro
Potential: only real part

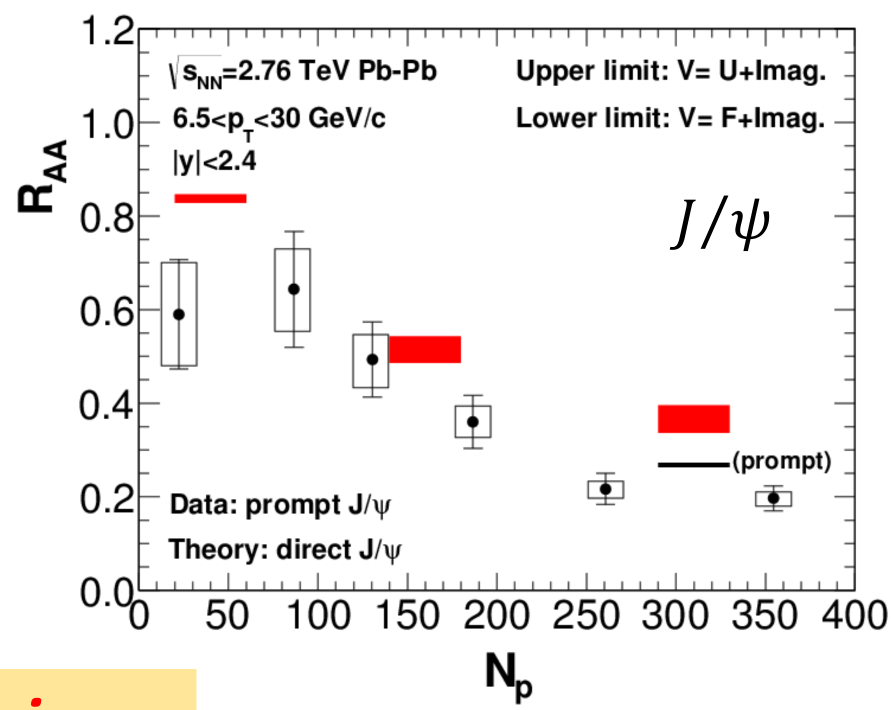
R_{AA} in heavy ion collisions

- Nuclear Modification factor R_{AA}:

EPS09s NLO

$$R_{AA}^{mS} = \frac{\int d\vec{x}_0 d\vec{p}_0 \, |c_{mS}(t,\vec{x}_0,\vec{p}_0)|^2 \frac{dN_{c\bar{c}}}{d\vec{x}_0 d\vec{p}_0} \mathcal{S}(\vec{x}_0,\vec{p}_0)}{\int d\vec{x}_0 d\vec{p}_0 \, |c_{mS}(t_0,\vec{x}_0,\vec{p}_0)|^2 \frac{dN_{c\bar{c}}}{d\vec{x}_0 d\vec{p}_0}}$$

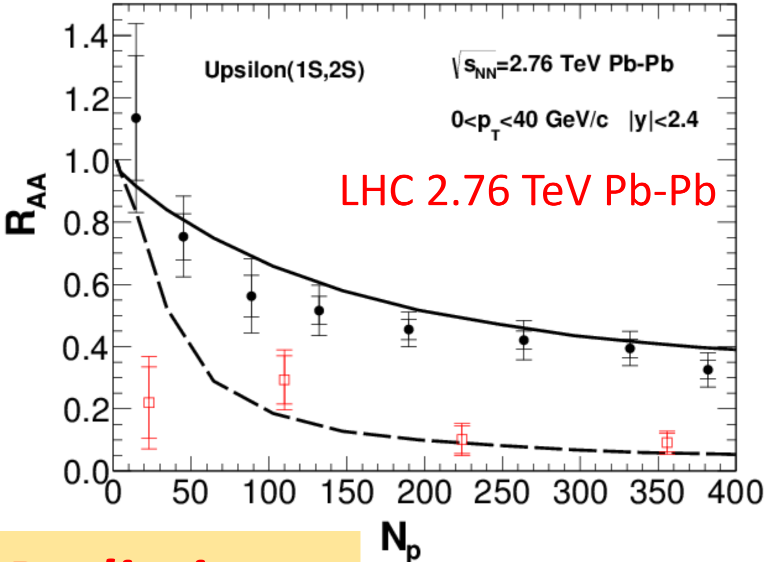




Preliminary

- Now, we do not include pT-dependence in our heavy quark potential.

Prompt upsilon (1S, 2S) at RHIC and LHC



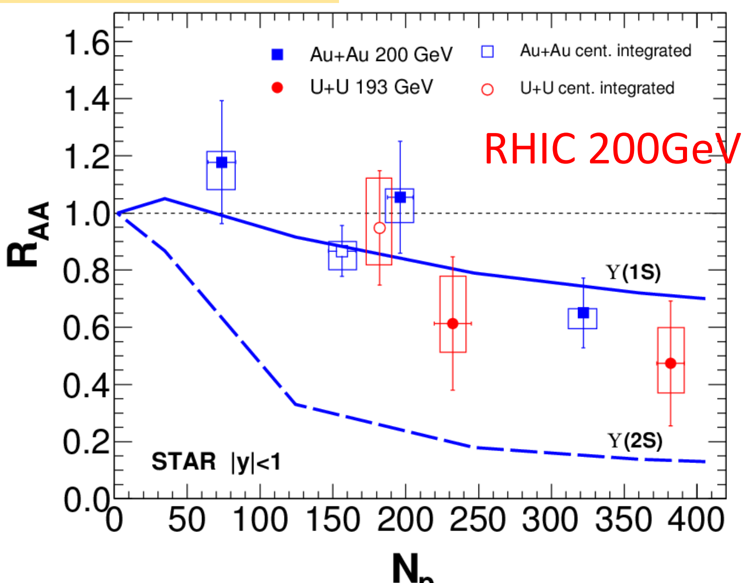
- Mean radius: $< r >_{\Upsilon(1S)} \sim 0.28$ fm, $< r >_{\Upsilon(2S)} \sim 0.56$ fm,

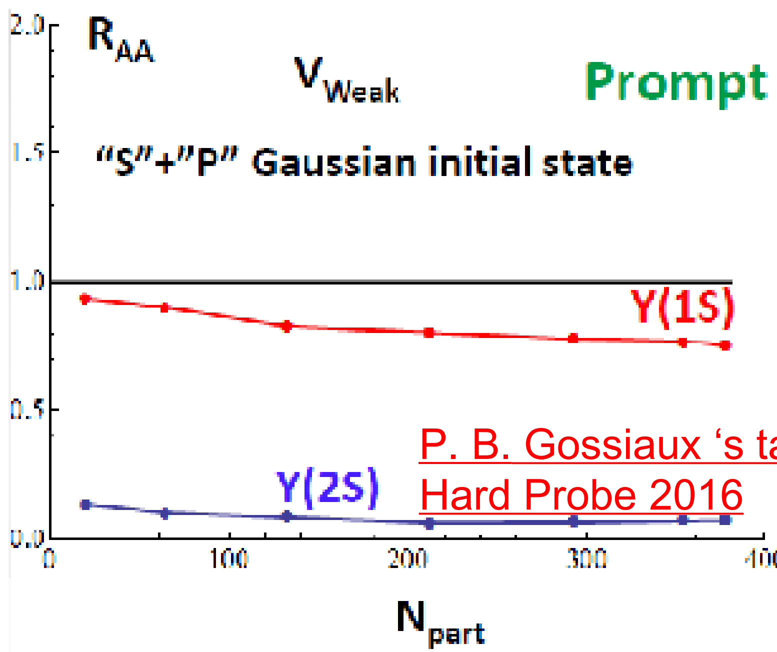
1S strongly bind even at LHC energy; 2S suffer strong suppression due to color screening effect.

→ no double ratio enhancement

Preliminary

Theory: prompt





P. B. Gossiaux 's talk in Hard Probe 2016

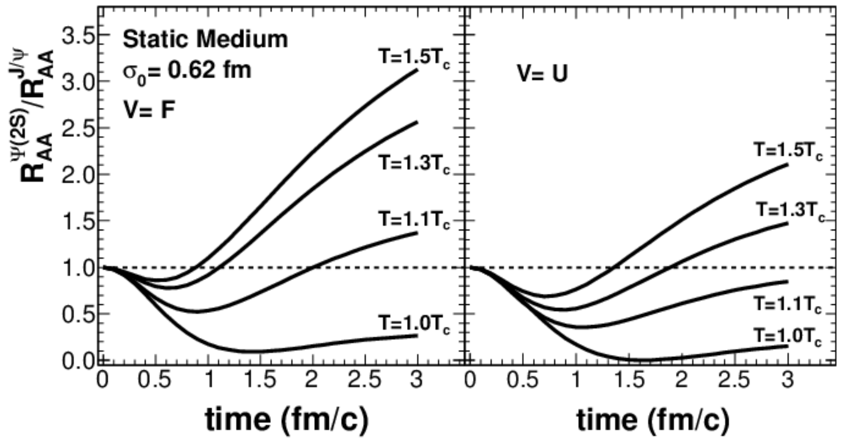
Summary

1) To be clear, at LHC,
regeneration from uncorrelated c and $\bar{c}$ (off-diagonal contribution) **still dominates the total charmonium yields** and **the yield in low pT bin.**

2) Both **formation process** and **sequential regeneration** should contribute to the double ratio $R_{AA}(2S)/R_{AA}(1S)$ **in middle and high pT bins.**

3) **Internal evolutions** between 1S and 2S **is especially important for** $\frac{R_{AA}(2S)}{R_{AA}(1S)}$

Double ratio
enhanced and suppressed
in different T



Thank organizers and committee very much for this flash talk.