Suppression and (re)generation of quarkonium in heavy-ion collisions
at the LHC
EMMI Rapid Reaction Task Force
GSI, Darmstadt, Germany - December 16-20, 2019

Transport model from Tsinghua Group

Baoyi Chen

collaborate with **Pengfei Zhuang**

Transport equation

Transport model

Pengfei Zhuang, Xianglei Zhu,
Yunpeng Liu, Kai Zhou, Baoyi Chen, et al

$$\underbrace{\frac{\partial f_\psi}{\partial t}+\frac{\vec{p}_\psi}{E}\cdot\vec{\nabla}_x f_\psi+\cancel{\vec{F}\cdot\vec{\nabla}_p f_\psi}}_{\text{Phase space density}}=\underbrace{-\alpha_\psi f_\psi+\beta_\psi}_{\text{Hot medium effect}}$$

$\mathrm{J}/\psi + g \rightarrow c + \bar{c}$
$c+\bar{c} \rightarrow \mathrm{J}/\psi + g$

$\partial_\mu\left(\rho_c u^\mu_{QGP}\right)=0$

Dynamical evolution

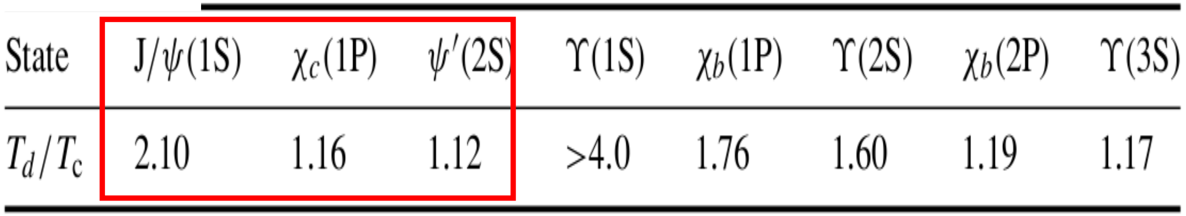
$$\alpha_\psi(\vec{p}_t,\vec{x}_t,\tau,\vec{b})=\frac{1}{2E_t}\int\frac{d^3\vec{k}}{(2\pi)^3 2E_g}\sigma_{g\psi}(\vec{p},\vec{k},T)4F_{g\psi}(\vec{p},\vec{k})f_g(\vec{k},T)$$

$$\beta_\psi(\vec{p}_t,\vec{x}_t,\tau,\vec{b})=\frac{1}{2^4(2\pi)^9E_t}\int\frac{d^3\vec{k}}{E_g}\frac{d^3\vec{q}_c}{E_c}\frac{d^3\vec{q}_{\bar{c}}}{E_{\bar{c}}}W^{\psi g}_{c\bar{c}}(\vec{q}_c,\vec{q}_{\bar{c}})\boxed{f_c(\vec{q}_c,T)\ f_{\bar{c}}(\vec{q}_{\bar{c}},T)}$$
$$\times\ (2\pi)^4\delta^{(4)}(p+k-q_c-q_{\bar{c}})$$

$N^{c\bar{c}\rightarrow J/\psi}\sim(N^{c\bar{c}})^2$

Philosophy: charmonium states can survive and regenerated inside QGP with $T > T_c$

$V = U$



State	J/ψ(1S)	χ_c(1P)	ψ′(2S)	Υ(1S)	χ_b(1P)	Υ(2S)	χ_b(2P)	Υ(3S)
T_d/T_c	2.10	1.16	1.12	>4.0	1.76	1.60	1.19	1.17

$H\Psi = E\Psi$

Transport equation

Transport model

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$$\frac{\partial f_\psi}{\partial t}+\frac{\vec{p}_\psi}{E}\cdot\vec{\nabla}_x f_\psi+\cancel{\vec{F}\cdot\vec{\nabla}_p f_\psi}= -\alpha_\psi f_\psi+\beta_\psi$$

$J/\psi+g\rightarrow c+\bar{c}$
$c+\bar{c}\rightarrow J/\psi+g$

$$\alpha_\psi(\vec{p}_t,\vec{x}_t,\tau,\vec{b})=\frac{1}{2E_t}\int\frac{d^3\vec{k}}{(2\pi)^3 2E_g}\boldsymbol{\sigma_{g\psi}}(\vec{p},\vec{k},T)4F_{g\psi}(\vec{p},\vec{k})\boldsymbol{f_g(\vec{k},T)}$$

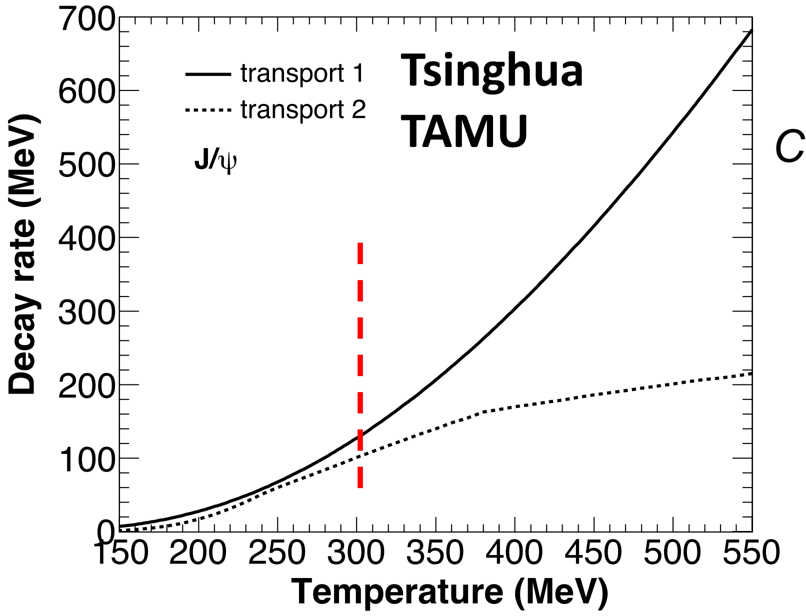
$$\sigma_{g\Psi}(w)=A_0\frac{(w/\epsilon_\Psi-1)^{3/2}}{(w/\epsilon_\Psi)^5}$$

➢ decay rate α_ψ:

① **Color screening effect: included by taking a in-medium binding energy in $\boldsymbol{\sigma_{g\psi}}$**

take a constant (500MeV)

② **Inelastic collisions with partons:** **terms with** $\boldsymbol{\sigma_{g\psi}}(\vec{p},\vec{k},T)\ \boldsymbol{f_g(\vec{k},T)}$



Chin.Phys. C43 (2019), 124101

Temperature dependence
in charmonium dissociation rate:
mainly induced by **gluon bose-distribution**

$\boldsymbol{f_g(\vec{k},T)}$

Transport equation

$$\frac{\partial f_\psi}{\partial t} + \frac{\vec{p}_\psi}{E}\cdot\vec{\nabla}_x f_\psi + \cancel{\vec{F}\cdot\vec{\nabla}_p f_\psi} = -\alpha_\psi f_\psi + \beta_\psi$$

$J/\psi + g \rightarrow c + \bar{c}$
$c + \bar{c} \rightarrow J/\psi + g$

$$\boldsymbol{\partial_\mu\left(\rho_c u^\mu_{QGP}\right) = 0}$$

$$\beta_\psi(\vec{p}_t, \vec{x}_t, \tau, \vec{b}) = \frac{1}{2^4(2\pi)^9 E_t}\int \frac{d^3\vec{k}}{E_g}\frac{d^3\vec{q}_c}{E_c}\frac{d^3\vec{q}_{\bar{c}}}{E_{\bar{c}}} W^{\psi g}_{c\bar{c}}(\vec{q}_c, \vec{q}_{\bar{c}}) \boxed{f_c(\vec{q}_c, T)\ f_{\bar{c}}(\vec{q}_{\bar{c}}, T)}$$
$$\times\ (2\pi)^4\delta^{(4)}(p + k - q_c - q_{\bar{c}})$$

Dynamical evolution

$$N^{c\bar{c}\to J/\psi} \sim (N^{c\bar{c}})^2$$

➢ Regeneration term β_ψ

① **Proportional to charm and anti-charm quark density in (x,p), and cross section**

② **Regeneration can happen inside QGP and also at the hadronization surface**

③ **Regenerated charmonium depends on charm evolution (flow):**

Charm quark kinetic equilibrium (strongly coupled with QGP):

1) momentum distribution : $f_c(\vec{q}_c, T)$ **normalized fermi-distribution**

2) spatial distribution : $\boldsymbol{\partial_\mu\left(\rho_c u^\mu_{QGP}\right) = 0}$ $\boldsymbol{u^\mu_{QGP}}$: hydro fluid velocity

CNM effect & QGP expansion

CNM effect:

① **Shadowing effect:** calculated with **EPS09 NLO model,** added in the charmonium initial distribution $gg(q\bar{q}) \rightarrow J/\psi + g$

$$f_{\Psi}(\mathbf{p}, \mathbf{x}|\mathbf{b}) = (2\pi)^3 \delta(z) \int dz_{\mathrm{A}} dz_{\mathrm{B}} \rho_{\mathrm{A}}(\mathbf{x}_T, z_{\mathrm{A}}) \rho_{\mathrm{B}}(\mathbf{x}_T - \mathbf{b}, z_{\mathrm{B}}) \boxed{\mathcal{R}_{\mathrm{g}}(x_1, \mu_{\mathrm{F}}, \mathbf{x}_{\mathrm{T}}) \mathcal{R}_{\mathrm{g}}(x_2, \mu_{\mathrm{F}}, \mathbf{x}_{\mathrm{T}} - \mathbf{b})} \frac{d\sigma_{\Psi}^{\mathrm{pp}}}{d^3\mathbf{p}}$$

$$\frac{d^2\sigma_{\mathrm{pp}}^{J/\psi}}{dy 2\pi p_T dp_T} = f_{J/\psi}^{\mathrm{Norm}}(p_T|y) \cdot \frac{d\sigma_{\mathrm{pp}}^{J/\psi}}{dy}$$

Phys.Lett. B765 (2017) 323-327

$$f_{J/\psi}^{\mathrm{Norm}}(p_T|y) = \frac{(n-1)}{\pi(n-2)\langle p_T^2\rangle_{pp}}[1 + \frac{p_T^2}{(n-2)\langle p_T^2\rangle_{pp}}]^{-n}$$

Momentum distribution from pp

② **Cronin effect:** partons get extra energy to increase the p_T of initial charmonium before $gg(q\bar{q}) \rightarrow J/\psi + g$

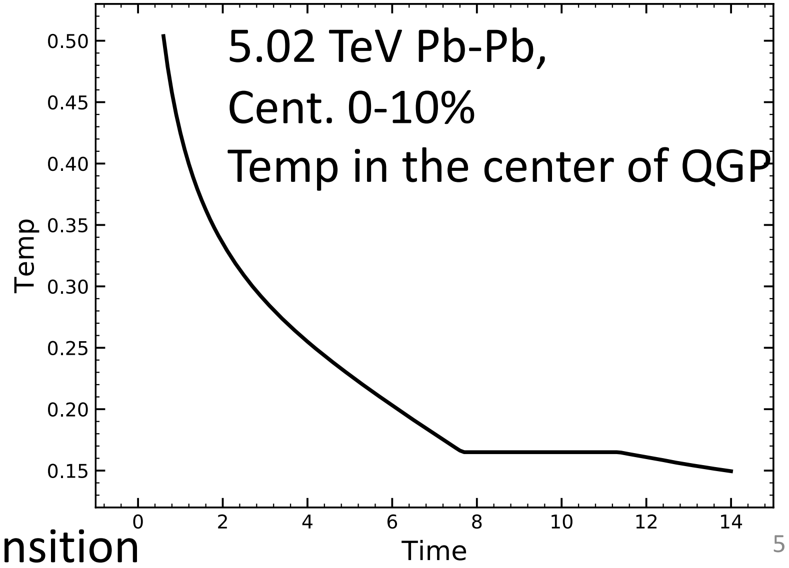
$$\Delta\langle p_T^2\rangle = \langle p_T^2\rangle_{pA} - \langle p_T^2\rangle_{pp}$$

QGP expansion: （2+1）dimension

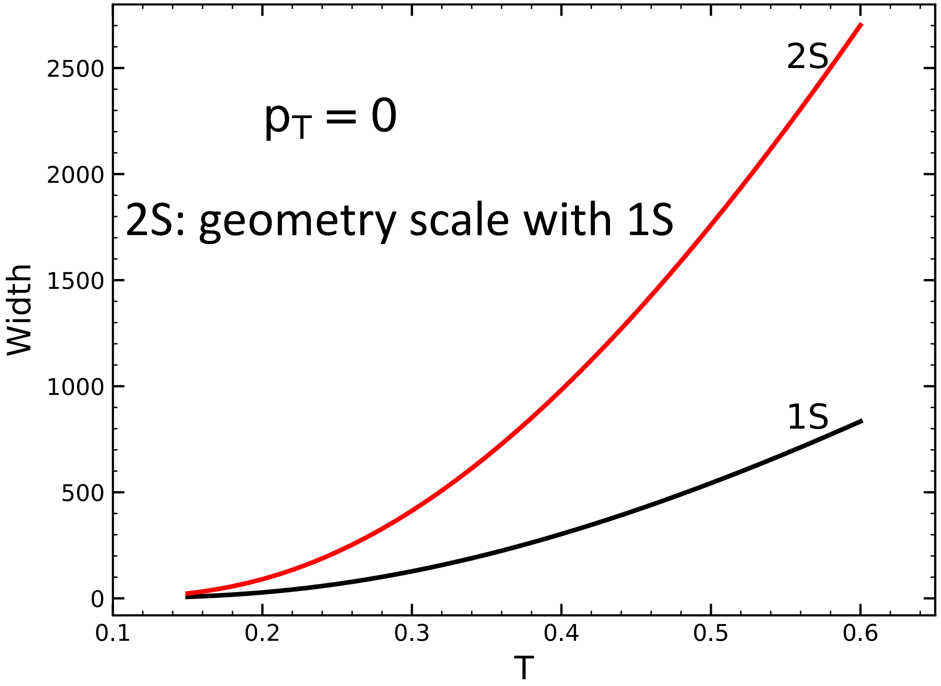
$$\boldsymbol{\partial_\mu T^{\mu\nu} = 0}$$

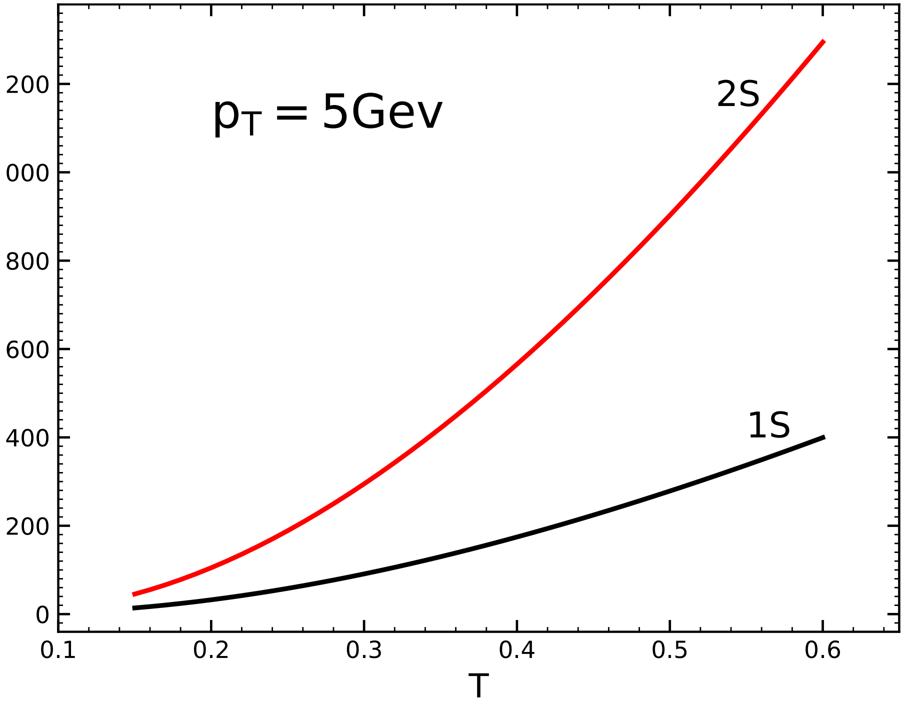
$$T^{\mu\nu} = (e+p)u^\mu u^\nu - g^{\mu\nu}p$$

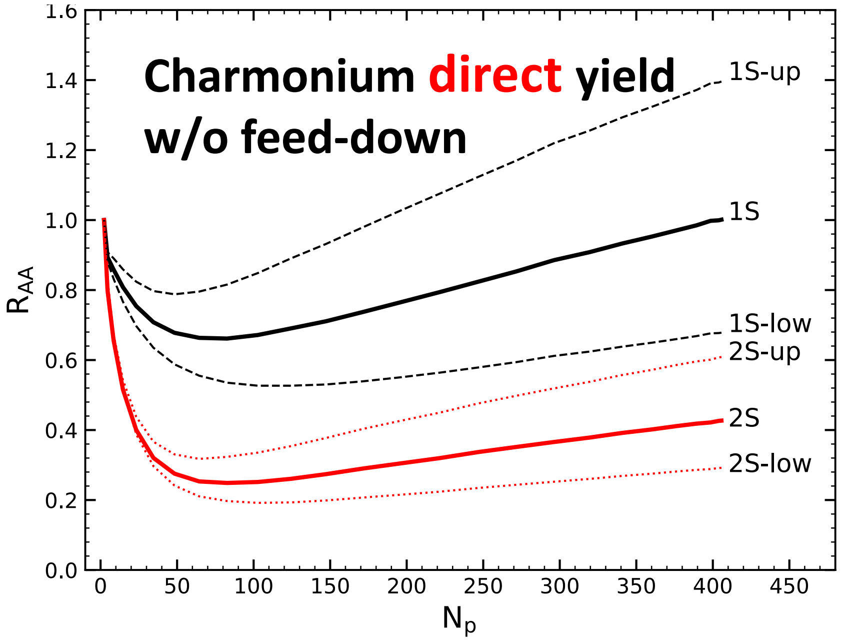
EoS: Ideal gas (QGP) + HRG with first-order transition


5.02 TeV Pb-Pb,
Cent. 0-10%
Temp in the center of QGP

Charmonium yield





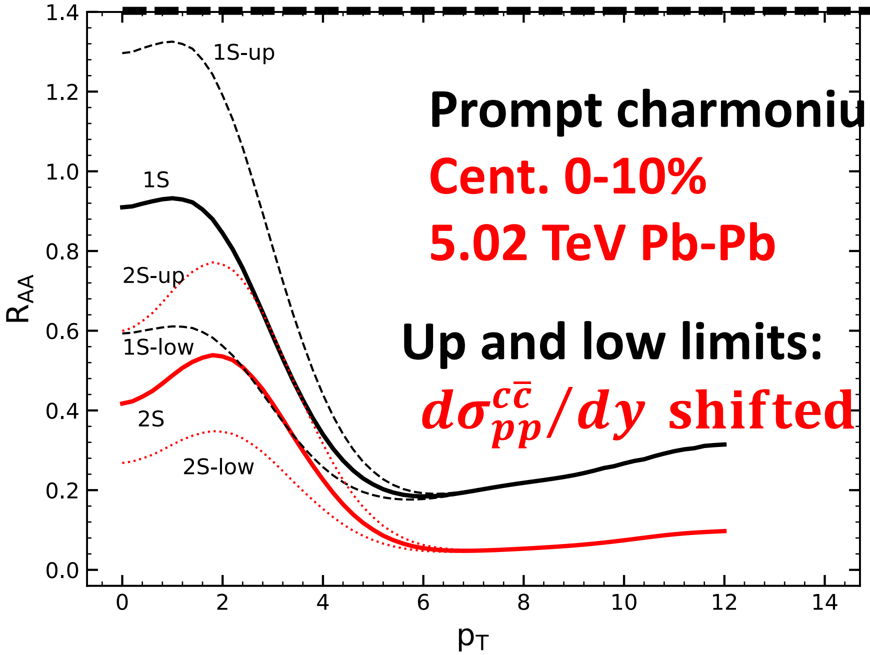


5.02 TeV, Pb-Pb,

Up and low limits:

$d\sigma_{pp}^{c\bar{c}}/dy$ **shifted** $\pm$ **20%**

Charmonium yield



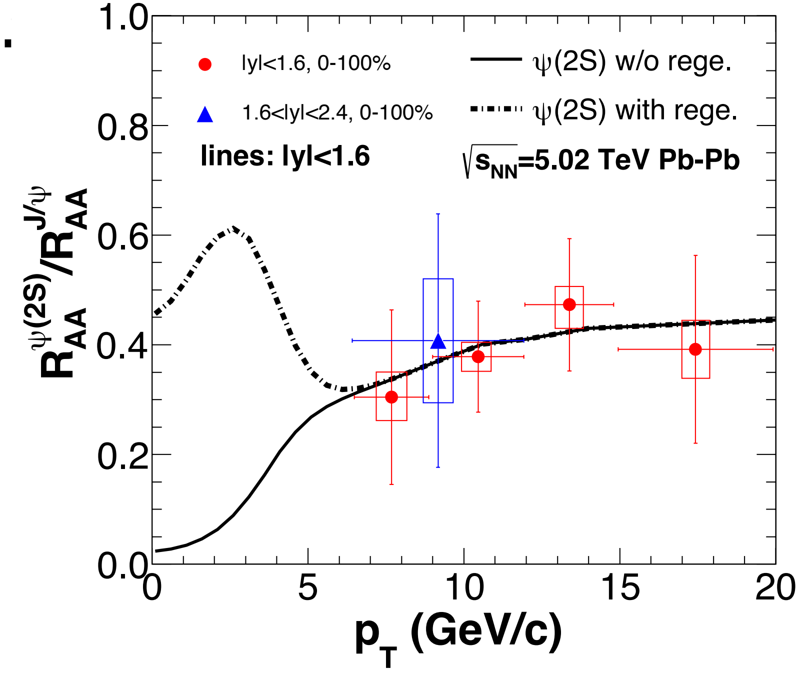
Prompt charmonium

Cent. 0-10%

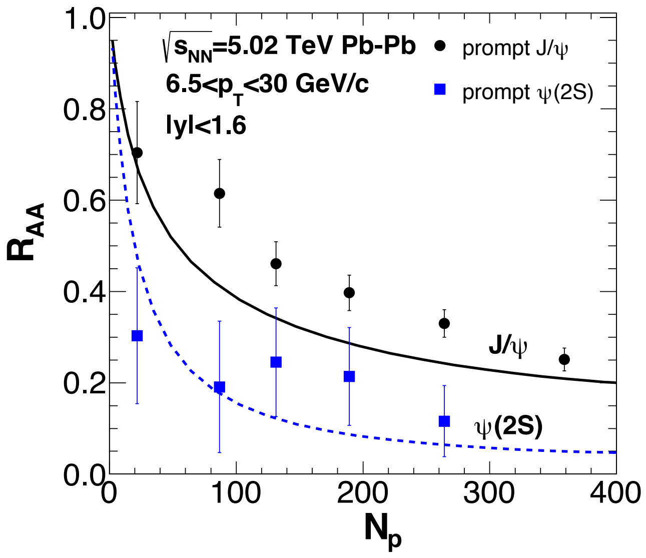
5.02 TeV Pb-Pb

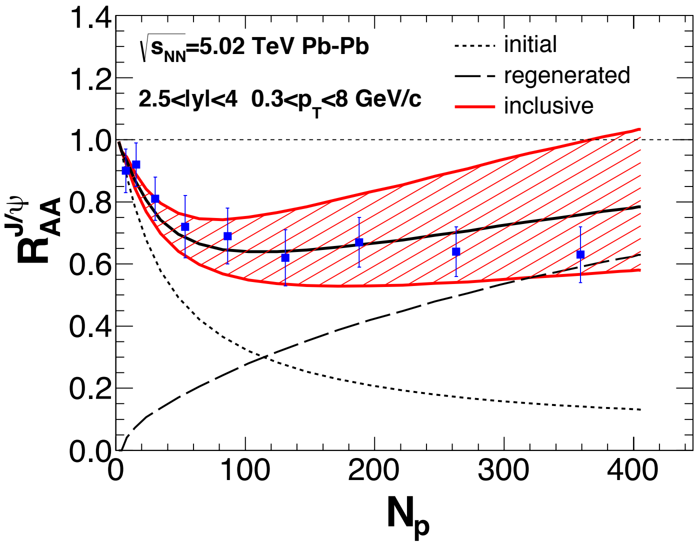
Up and low limits:

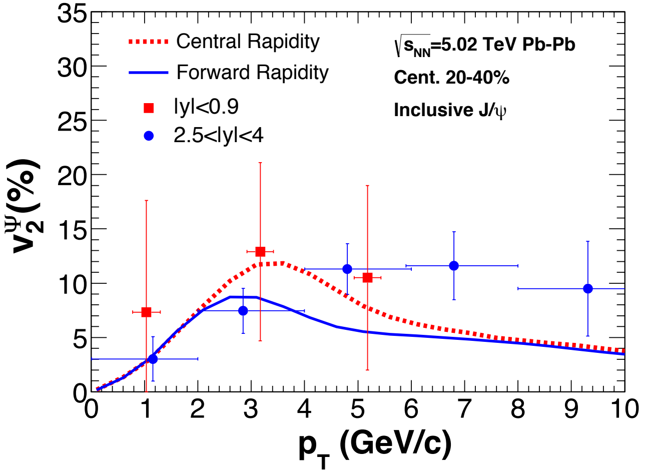
$d\sigma_{pp}^{c\bar{c}}/dy$ **shifted** $\pm$ **20%**



Charmonium 5TeV, Chin.Phys. C43 (2019), 124101





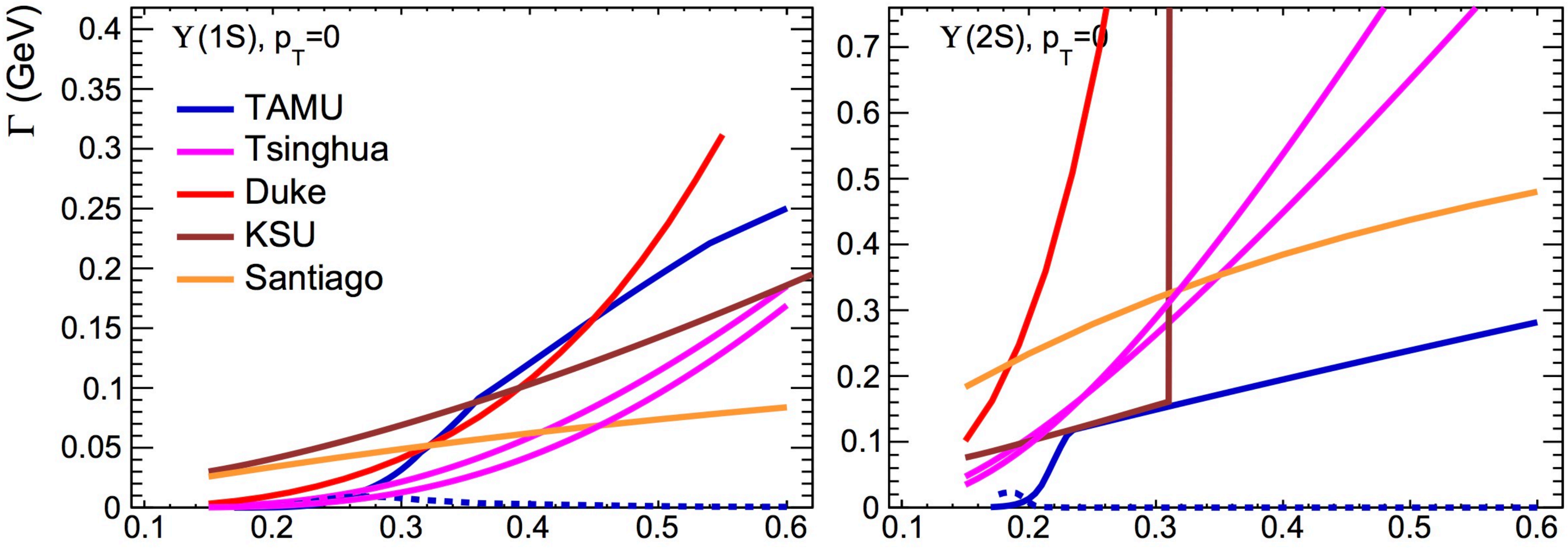


bottomonium

Parameters:

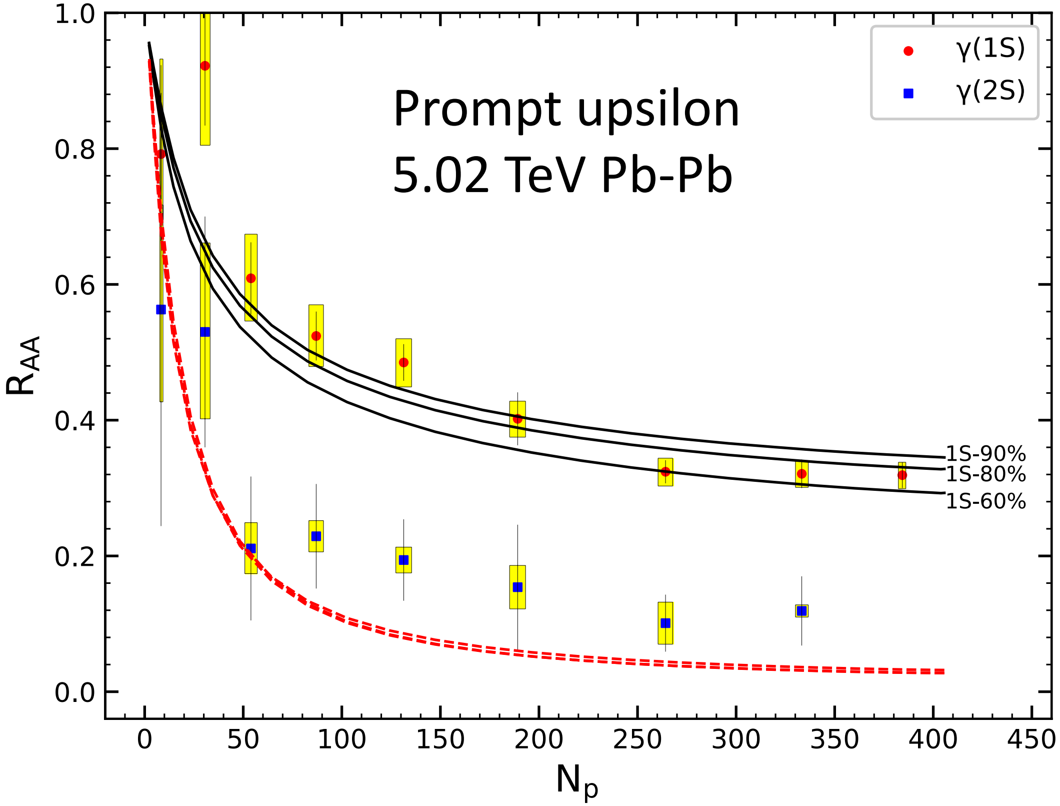
bottomonium binding energy in medium is taken as (60%, 80%) of the vacuum value to consider the different color screening effects from QGP.

Plotted by Andronic Anton

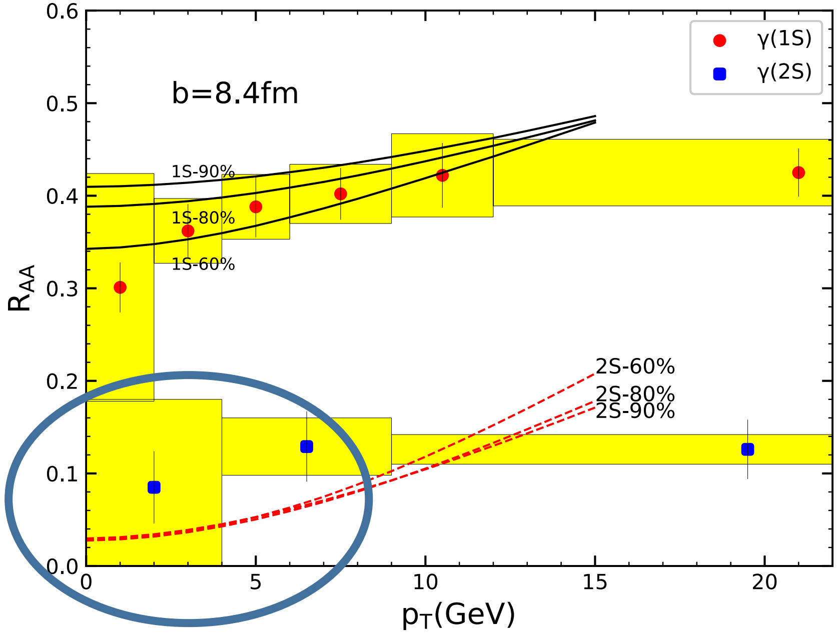


bottomonium

No regeneration included in the below calculations



5.02 TeV Pb-Pb, cent.0-100%, prompt



Both figure absent regeneration

summary

This slide briefly introduce the details of Tsinghua Transport model,

and also show some results about charmonium and bottomonium

at 5 TeV

Thank you for your attention !

End