Cold and Hot Medium Effects on Quarkonium production in p-Pb collisions

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Reference: Phys.Lett. B765 (2017) 323-327

Outline

1. Charmonium proposed as a probe for the deconfined matter ------ **Q**uark **G**luon **P**lasma (QGP)

2. **Cold** and **Hot** Medium effects in transport model, including color screening and parton inelastic scatterings on charmonium.

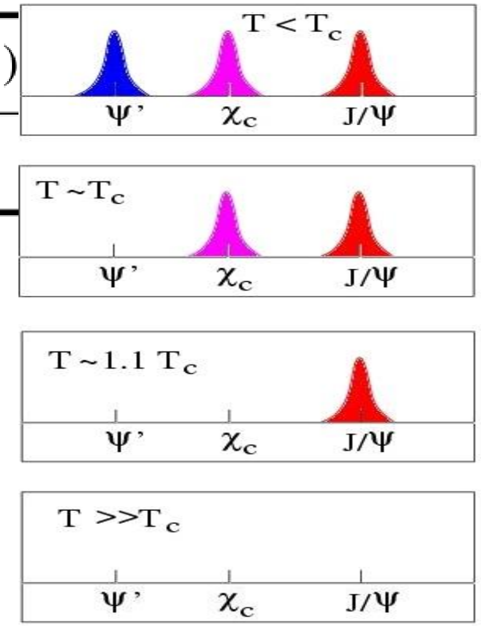
3. Charmonium suppression by cold and Hot medium effects in **p-Pb** collisions **at 5.02 TeV**

4. Summary about charmonium in p-Pb

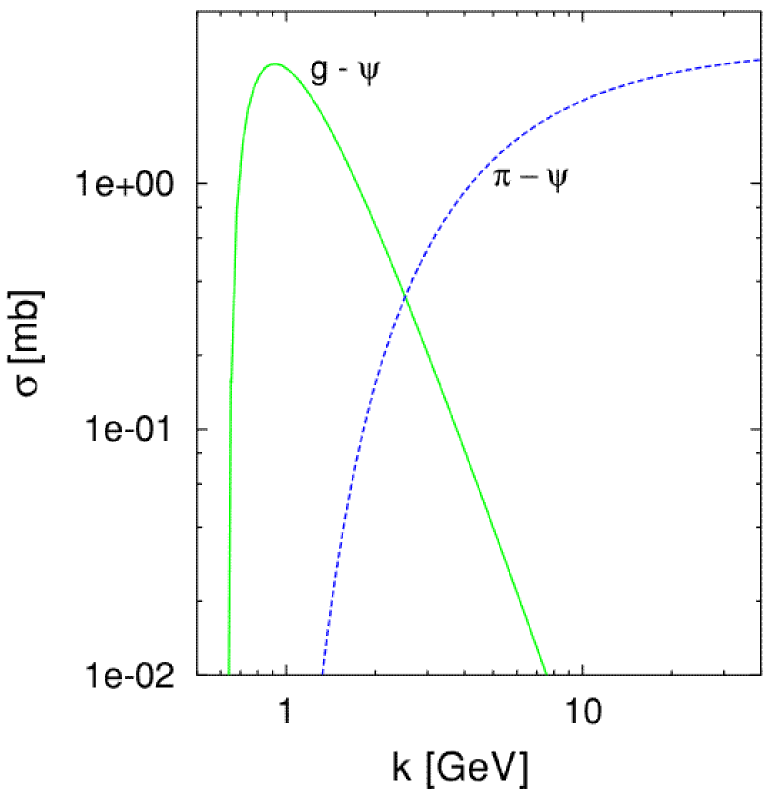
Heavy quarkonium as a probe of QGP

$V = U$

State	$J/\psi(1S)$	$\chi_c(1P)$	$\psi'(2S)$	$\Upsilon(1S)$	$\chi_b(1P)$	$\Upsilon(2S)$
T_d/T_c	2.10	1.16	1.12	>4.0	1.76	1.60



Heavy quarkonium can survive in hadron gas,
its abnormal suppression is an existence of QGP



J/psi as a probe for QGP,
T. Matsui, H. Satz, 86'

Sequential suppression
More Obvious in p-Pb

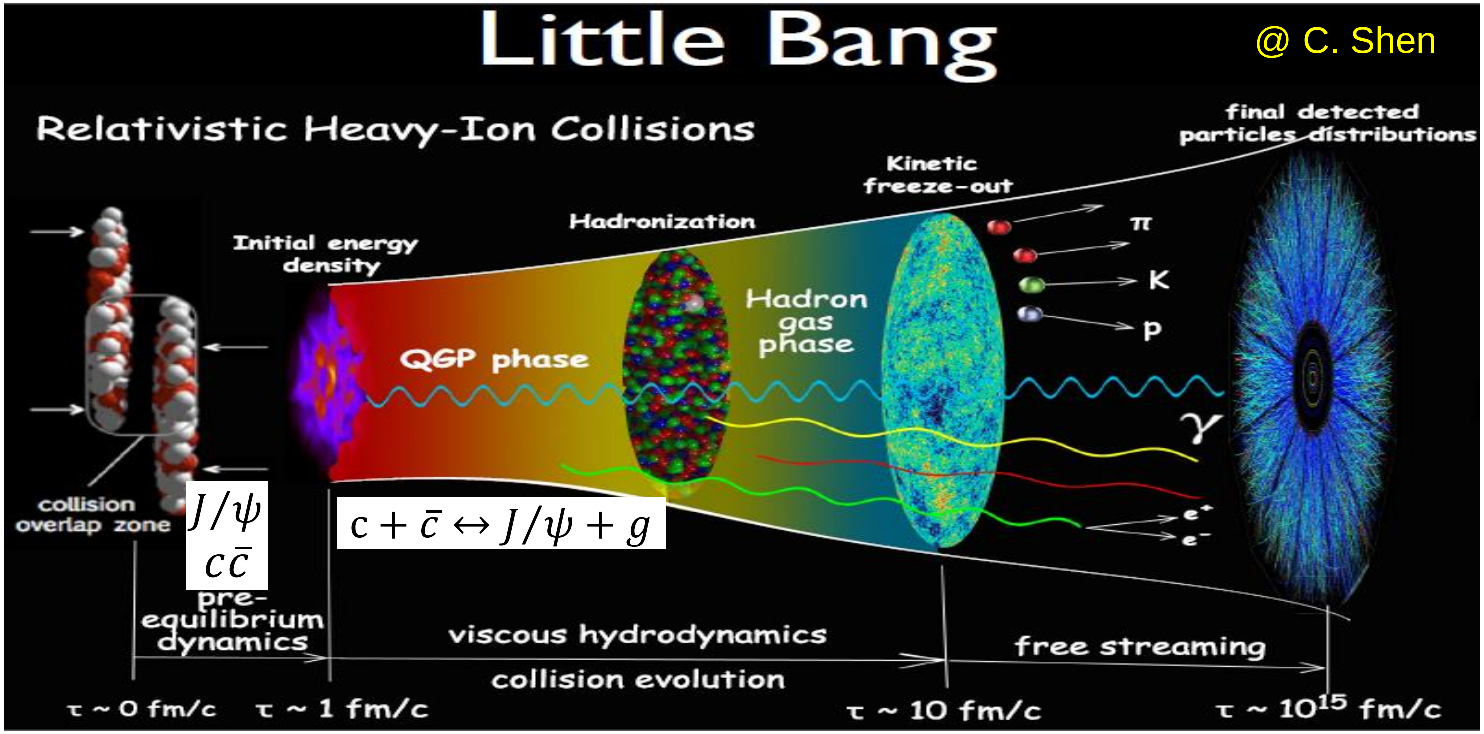
QGP temperature (LHC) ~ 0.3-0.5 GeV,
Charmonium survive in hadron gas

Kharzeev, Satz, 94'

Heavy ion collisions

- In Pb-Pb (or Au-Au) collisions, Quark Gluon Plasma can be produced in the early stage of collisions,
  → strong suppression of J/psi and psi(2S) yields, Well described by Transport models (Tsinghua, TAMU), Coalescence Model…

- In p-Pb, with <u>small system</u> but <u>high colliding energy</u>,
  Hot medium Still exist ?



Heavy quarkonium as a probe of QGP

$V = U$

State	$J/\psi(1S)$	$\chi_c(1P)$	$\psi'(2S)$	$\Upsilon(1S)$	$\chi_b(1P)$	$\Upsilon(2S)$	$\chi_b(2P)$	$\Upsilon(3S)$
T_d/T_c	2.10	1.16	1.12	>4.0	1.76	1.60	1.19	1.17

Transport model

Yunpeng Liu, et al, PLB 11';
Baoyi Chen, PRC 16'

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

$J/\psi + g \to c + \bar{c}$
And Color screening

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

Cold nuclear matter effects included here

Initial distribution from pp collisions

$$\frac{d^2\sigma_{pp}}{dy p_T dp_T} = \frac{(n-1)}{\pi(n-2) < p_T^2 >_{pp}} \left(1 + \frac{p_T^2}{(n-2) < p_T^2 >_{pp}}\right)^{-n} \frac{d\sigma_{pp}}{dy}$$

$$< p_T^2 >_{pA} = < p_T^2 >_{pp} + \Delta$$

$$R_{AA}^{J/\psi} = \frac{N_{AA}^{J/\psi}}{N_{pp}^{J/\psi} N_{coll}}$$

$N_{AA}^{J/\psi}$ → *J/ψ production in AA collisions (with cold and hot matter effects)*

$N_{pp}^{J/\psi}$ → *J/ψ production in pp collisions (without CNM and HM)*

The relation RAA<1 or RAA>1 indicates cold and hot nuclear matter effects.

Heavy quarkonium as a probe of QGP

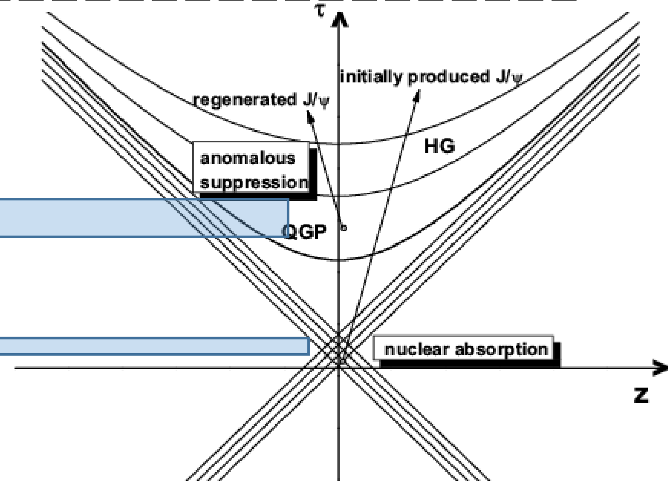
Hydrodynamic equations for QGP evolution:

$$\partial_\mu (T^{\mu\nu}) = 0$$

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

Hot medium effects

Cold nuclear matter effects



- **Cold nuclear matter effects**: *Xianglei Zhu, et al, PLB 05'*

  shadowing effect (parton distribution is affected by other nucleons),

  Cronin effect (parton multi-scatterings with other nucleons, increase charmonium transverse momentum) → change $< p_T^2 >_{pp}$

  1. happens **Before** the formation of QGP
  2. They are **almost the same** for different charmonium states

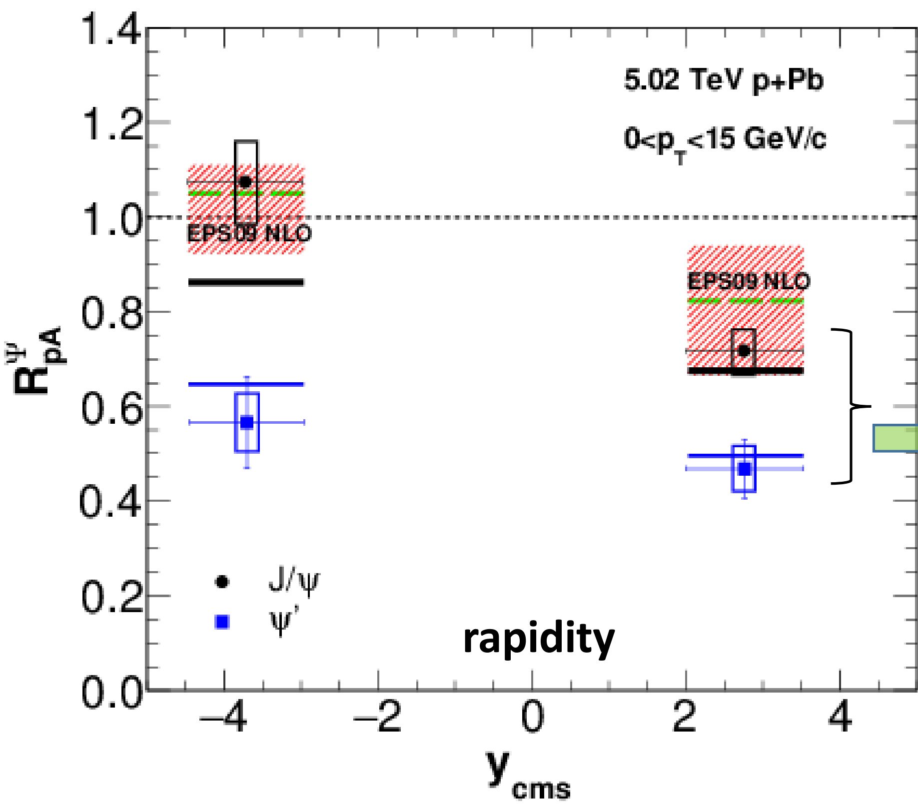
- **Hot nuclear matter effect:**

  color screening (in deconfined matter, QGP)

  particle inelastic scatterings

  Both of them are different for J/ψ and Psi(2S). **Gives different RAA**

charmonium production

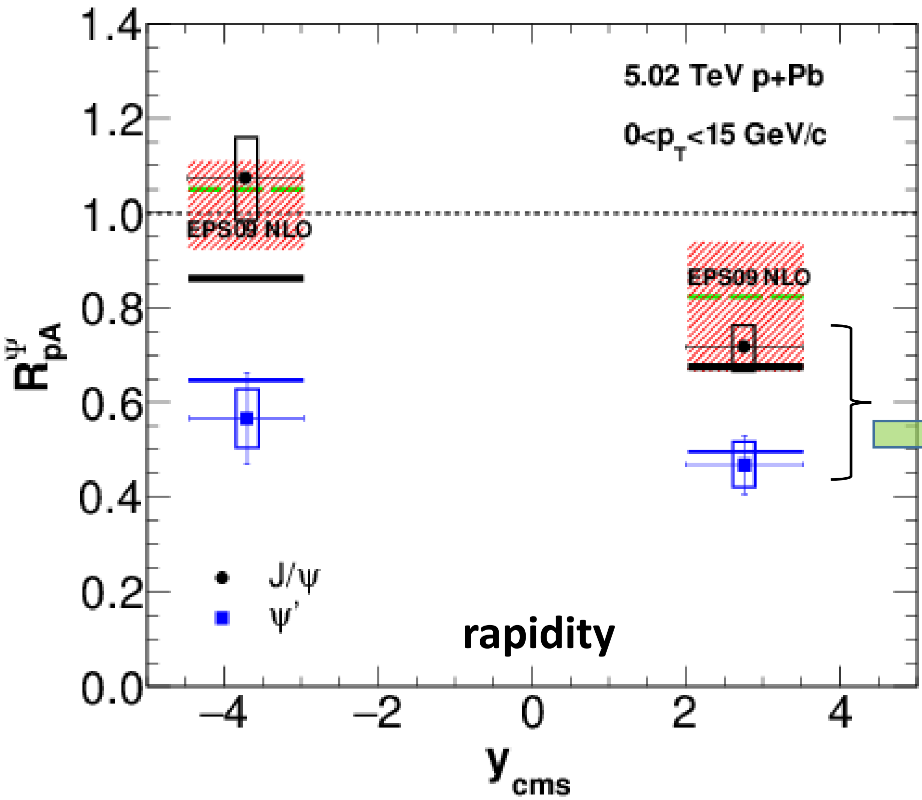


Black and blue lines: transport model with **cold** and **hot** medium effects

- **Shadow region:** *JHEP 1511, 127(2015)*
  only cold nuclear matter effect
  This gives the same suppression for J/ψ and psi'
  can not explain the data.

- **Difference of J/ψ and psi' R_{pA}**
  indicates the final state interaction
  Hadron gas ?   QGP ?

charmonium production



Black and blue lines: transport model with **cold** and **hot** medium effects

1. J/ψ Eigenstate suffer weak suppression in p-Pb, Td(J/psi) ~ 2Tc
2. 1P and 2S suppression is similar: almost the same Td

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- **Difference of J/ψ and psi' R_{pA}**
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Final prompt J/psi : **60% from direct, (30%, 10%) from (1P, 2S) decay**

$$R_{pA}^{\psi'} = R_{pA}^{cold} R_{pA}^{hot}$$

$$R_{pA}^{J/\psi} = 0.6 R_{pA}^{cold} + 0.4 R_{pA}^{\psi'}$$

Estimate at Backward Rapidity (y<0)

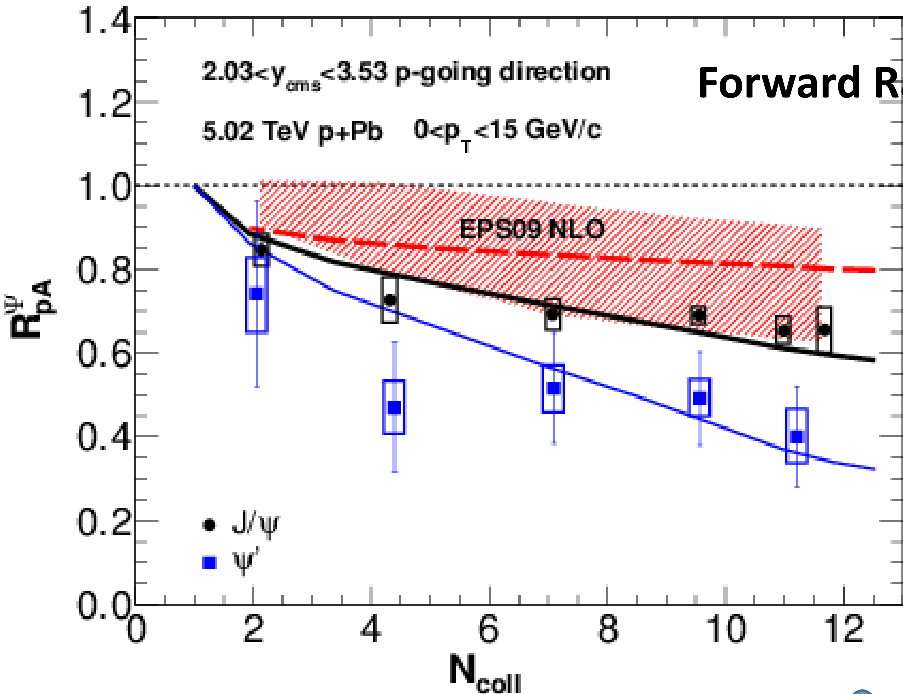
Hot supp.

$$R_{pA}^{\psi'} = R_{pA}^{cold} R_{pA}^{hot} \approx 1.1 \times \mathbf{0.5}$$

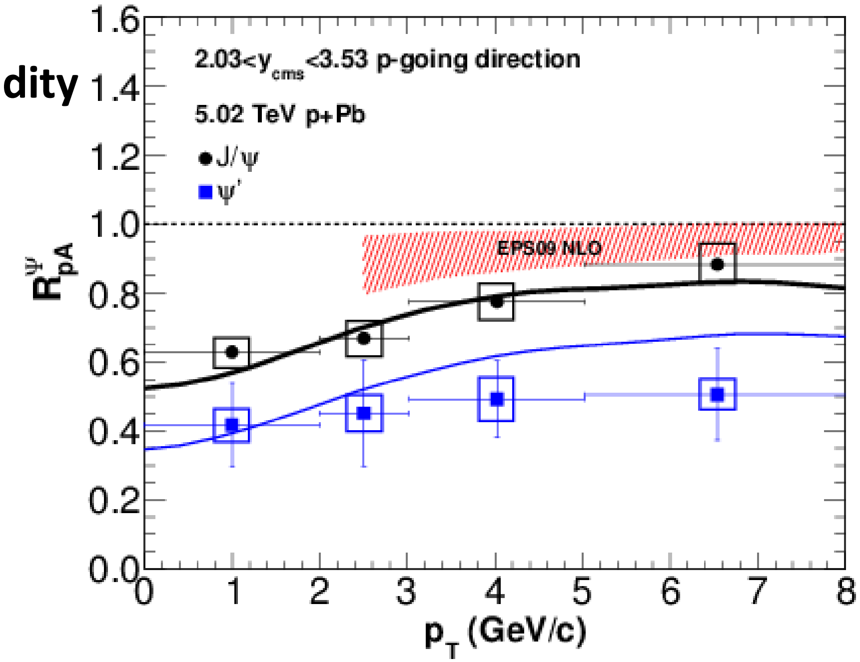
$$R_{pA}^{J/\psi} = 0.6 R_{pA}^{cold} + 0.4 R_{pA}^{\psi'}$$

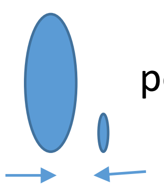
$$= 0.6 \times 1.1 + 0.4 \times R_{pA}^{\psi'} \approx \mathbf{0.88}$$

charmonium production

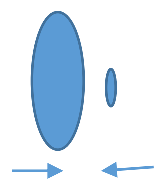


Forward Rapidity





peripheral



central

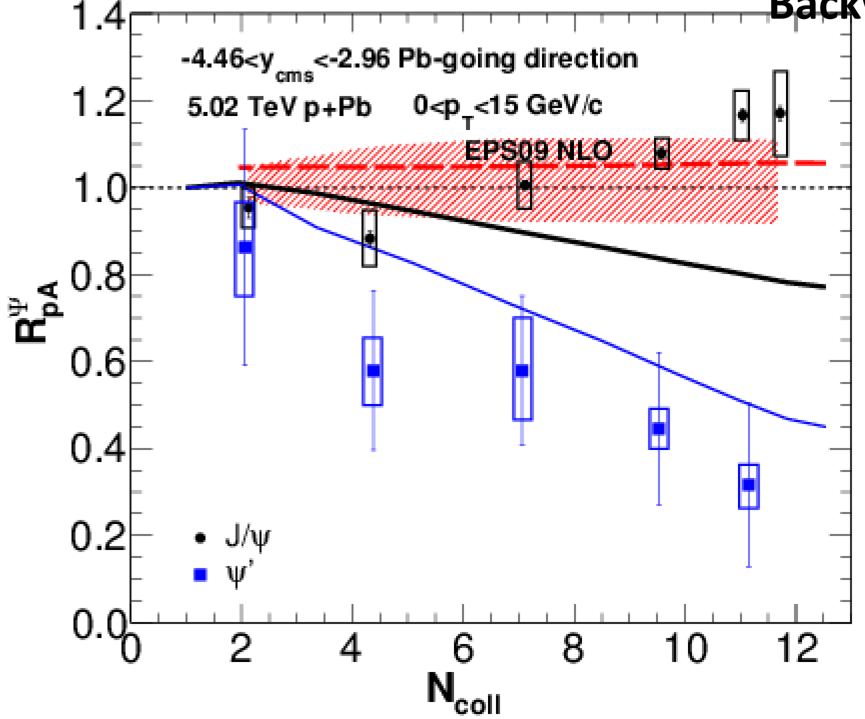
Transverse momentum

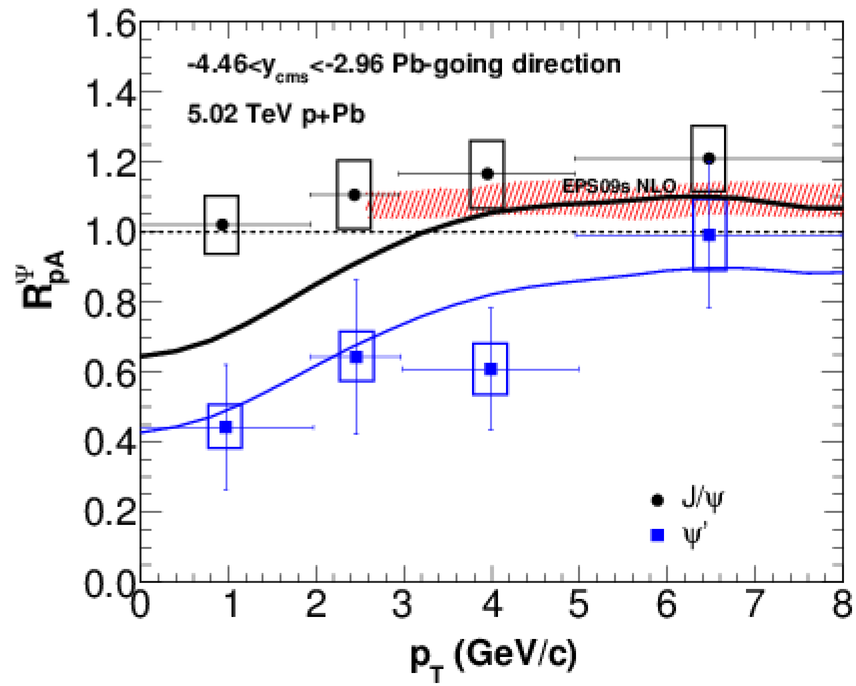
$$T_d^{\psi'} < T_{QGP}^{max}(pA) \approx 1.2T_c < T_d^{J/\psi}$$

1. J/ψ suppression mainly from **Cold nuclear matter effect**, and hot medium effect on psi' (which decays into J/psi)
2. Both cold and hot medium is important for psi', **HNM suppress ~50% of the psi(2S)**
3. Good description of $R_{pA}(p_T)$ for both J/ψ and psi' in Forward rapidity

charmonium production

Backward Rapidity





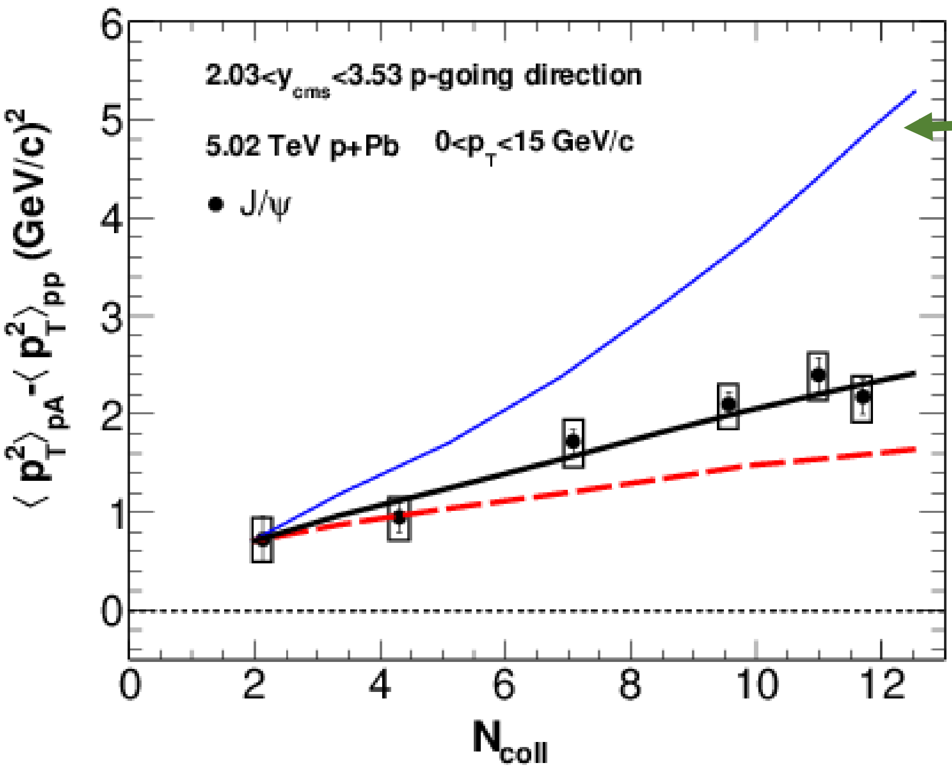
Why? → 1P suppression not strong ?
Transitions between 1S and 2S ?
(arXiv:1612.02089)

Overestimate the J/psi suppression at Ncoll~12 and pT ~ 1GeV/c

Difficulties at backward rapidity:

1. Cold nuclear matter effect seems enough for J/ψ, see dashed line.
2. But stronger suppression of psi(2S) indicates the final state interactions with QGP (or Hadron Gas). This additional suppression will result in stronger suppression of J/psi and psi(2S) at the same time.

charmonium production



J/psi and psi(2S) pT-square

Prediction for psi(2S)

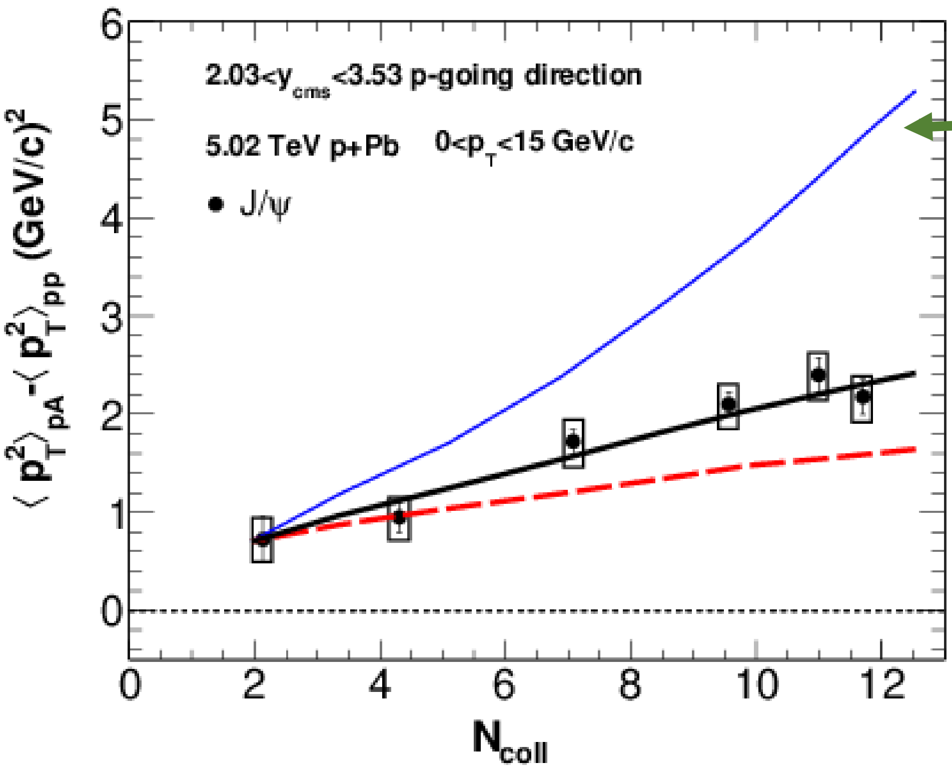
1. Within the picture of J/psi and psi(2S) suppressed by hot medium,

charmonium with Larger pT can escape from the Hot Medium (Leakage effect)

AND

Hot Medium effect is Stronger for psi(2S) than for J/ψ, <u>which makes psi(2S)</u> $< p_T^2 >$ <u>larger than J/psi.</u>

charmonium production



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Discussion

- **Blue line is a qualitative prediction, the exact value depends on:**
  1) the **temperature** and **volume** of **hot medium** in pA collisions,
  2) J/ψ and psi(2S) **formation time** from heavy quark dipole to charmonium eigenstate
  3) **inelastic cross section** between charmonium and hot medium, etc.

But the behavior of <u>**Blue line**</u> <u>> **Black line**</u> stands in this “Cold +Hot” medium scenario.

Summary

- We employ **the Transport model** (widely used in AA collisions, and give good explanation of experimental data from RHIC to LHC),
  including both **cold** and **hot** medium effects on J/ψ and $\psi(2S)$,
  to give the
  J/ψ and $\psi(2S)$ $\quad R_{pA}(y),\ R_{pA}(p_T),\ R_{pA}(N_{coll})$

✓ We find that the hot medium effect is especially important to explain the $\psi(2S)$ stronger suppression compared with J/ψ.

✓ Based on this, we predict a larger $< p_T^2 >$ of $\psi(2S)$ than J/ψ due to stronger hot medium effects on $\psi(2S)$.

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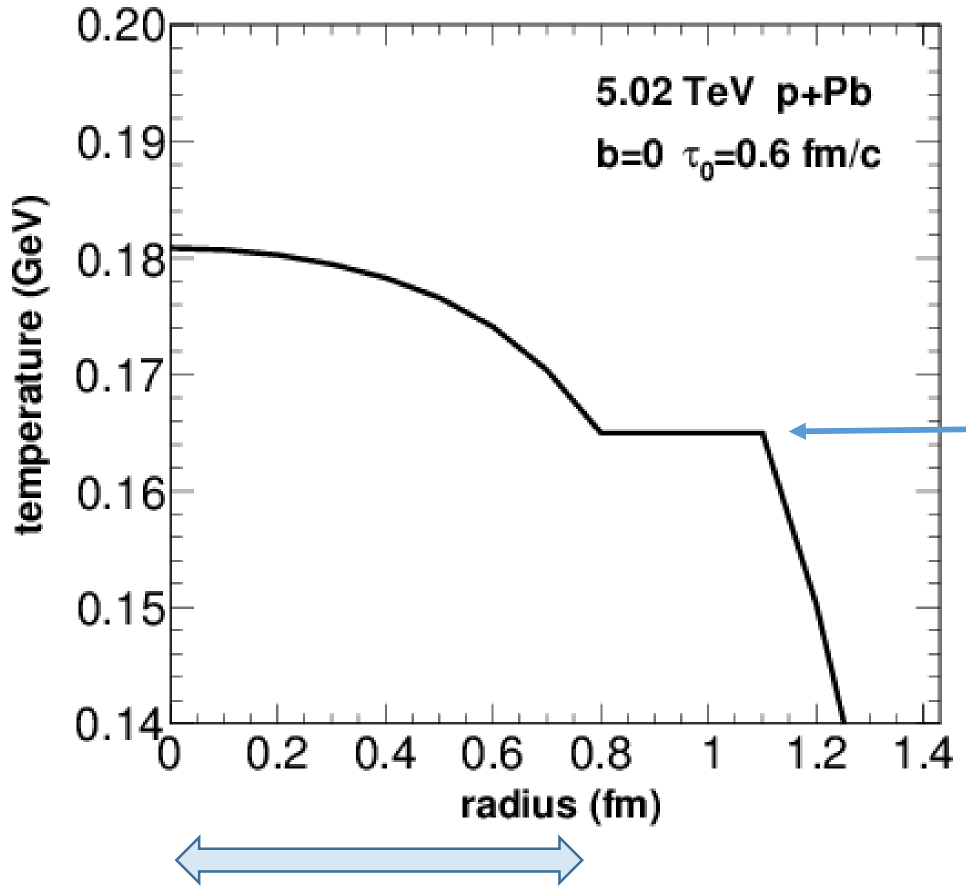
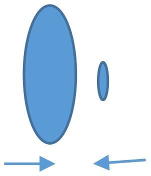
supplement

The initial size of Quark-Gluon-Plasma produced in p-Pb collisions



Critical temperature of QGP, Tc

QGP expansion is described by the (2+1) dimensional ideal hydrodynamics.



The initial size of small QGP is around **proton radius**

Heavy quarkonium as a probe of QGP

J/ψ as a probe of QGP:

J/ψ suffere color screening end inelastic collisions of partons in QGP

$$R_{AA}^{J/\psi} = \frac{N_{AA}^{J/\psi}}{N_{pp}^{J/\psi} N_{coll}}$$

***J/ψ** production in AA collisions (with cold and hot matter effects)*

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Hot medium effects

Cold nuclear matter effects