Quarkonia: the search for a coherent framework

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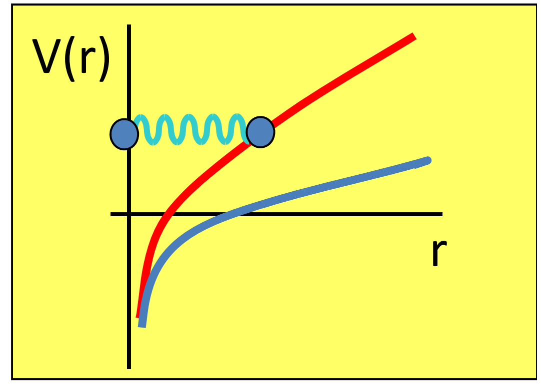
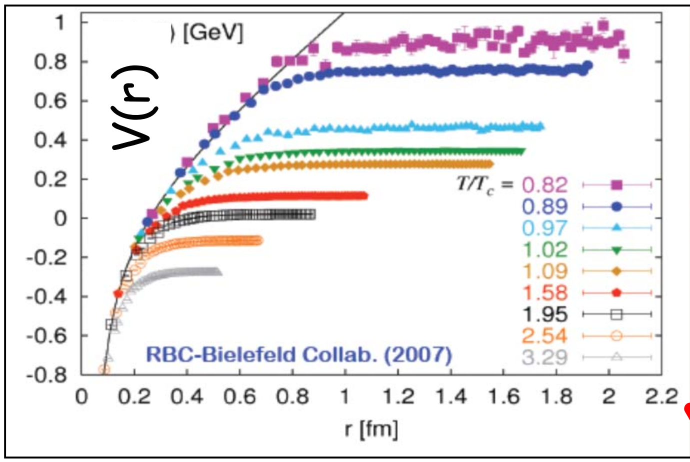
Quarkonium production: the typical introduction….

Potential between q-anti-q pair grows linearly at large distances

$$V(r) = -\frac{4}{3}\frac{\alpha_s}{r} + kr$$



Screening of long range confining potential at high enough temperature or density.

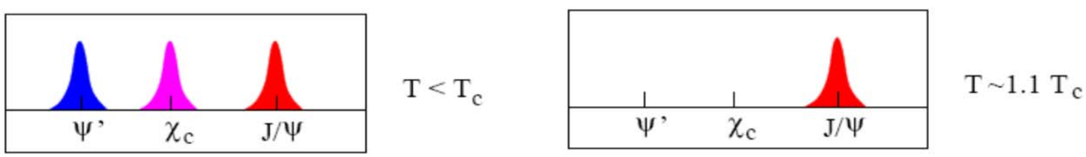


What happens when the range of the binding force becomes smaller than the radius of the state?

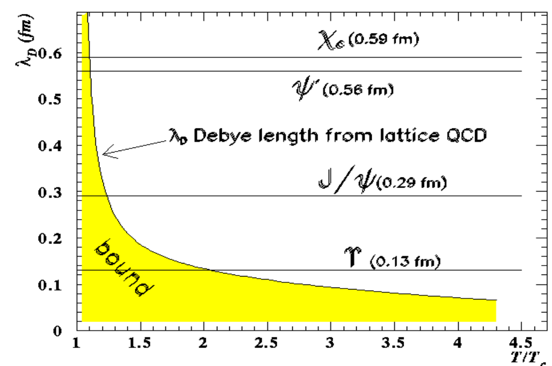
different states "melting" at different temperatures due to different binding energies.

Matsui and Satz:

J/ψ destruction in a QGP by Debye screening



J/Ψ suppression = QGP signature



But the story is not so simple…. Open questions

- Can the melting temperature(s) be uniquely determined ?
- Are there any other effects, not related to colour screening, that may induce a suppression of quarkonium states ?
- Are there effects that can induce an enhancement of quarkonium?
- Is it possible to define a "reference"(i.e. unsuppressed) process in order to properly define quarkonium suppression ?
- Do we understand charmonium production in elementary p+p collisions?
- Do experimental observations fit in a coherent picture ?

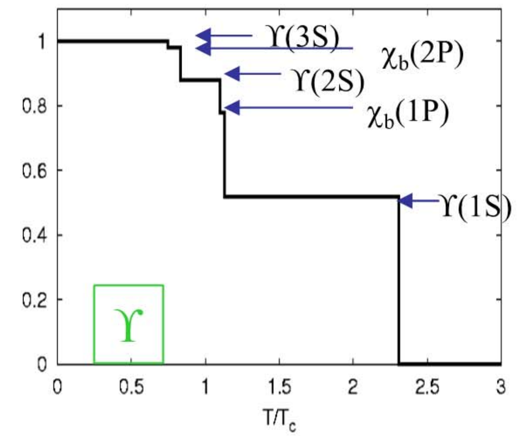
Charmonia/bottomonia topics

Three main topics

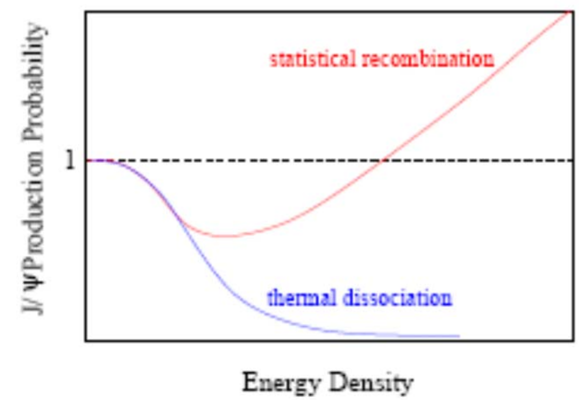
Sequential suppression

Charmonium → J/χ , ψ_c, $\psi(2S)$

Bottomonium Υ →(1S), $\Upsilon(2S)$, $\Upsilon(3S)$, χ_b

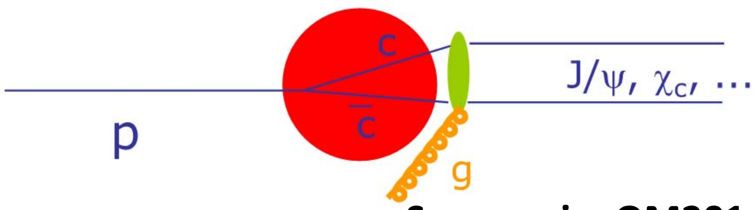


Two competing mechanisms



Cold nuclear matter effects

High density, collectivity

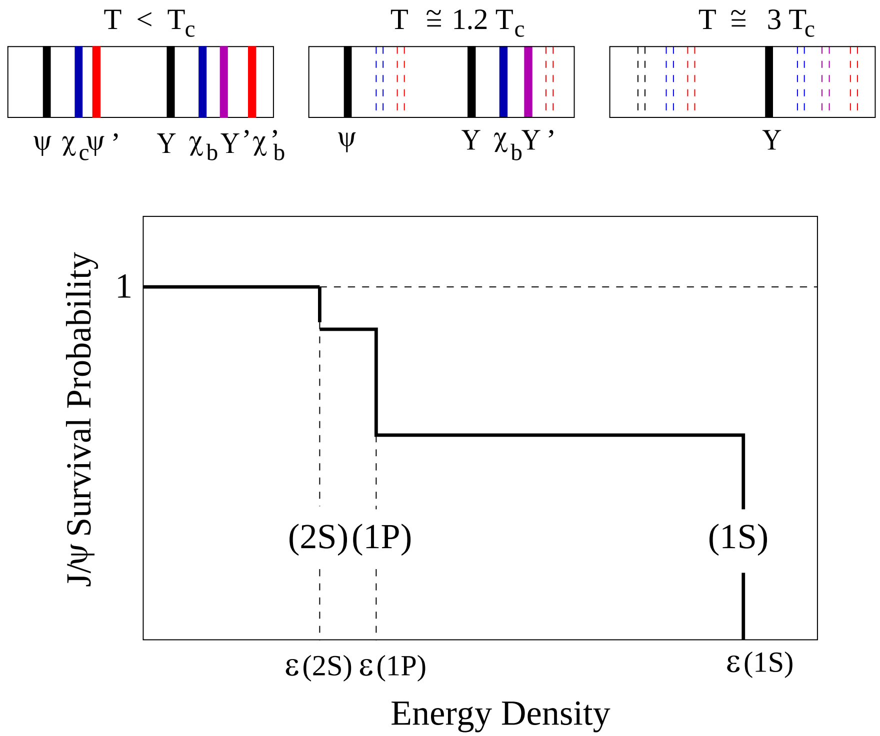


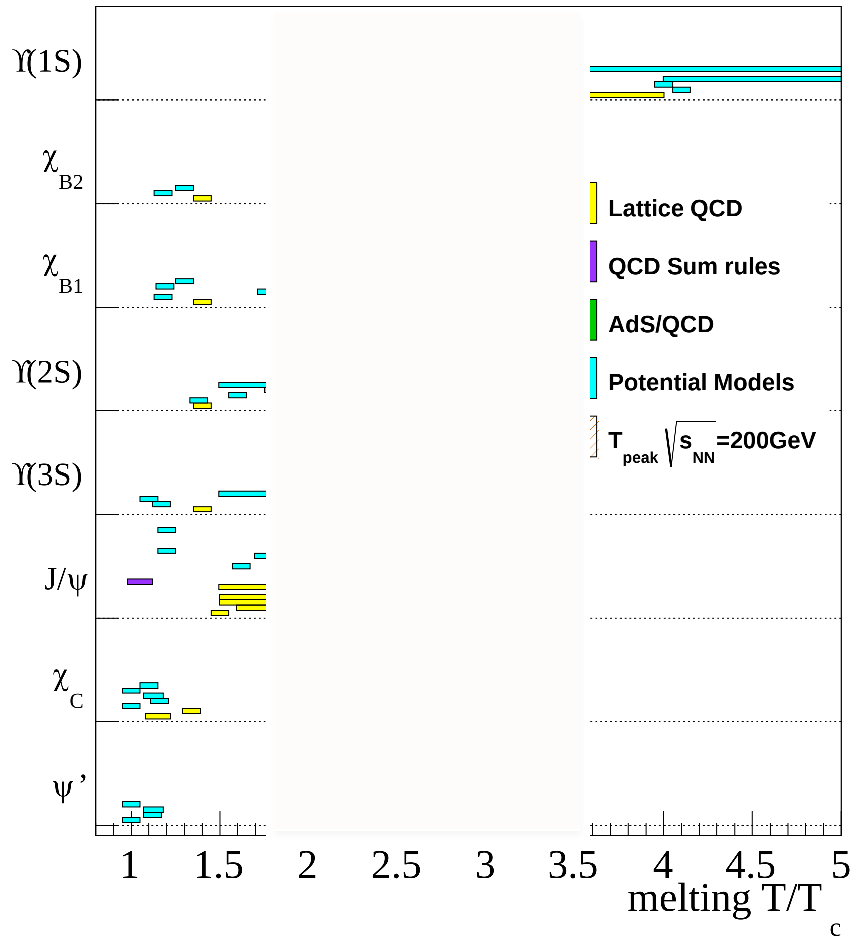
Scomparin, QM2014

Quarkonium and the QGP - "sequential suppression"

H.Satz, arXiv:1310.1209

LQCD results (still debated) ...⟶





quarkonium as thermometer ?

PHENIX, arXiv:1404.2246 (da Silva, QM2014)

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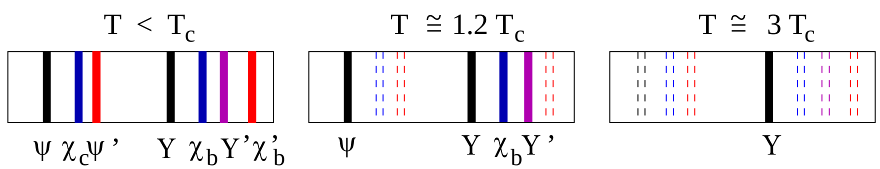
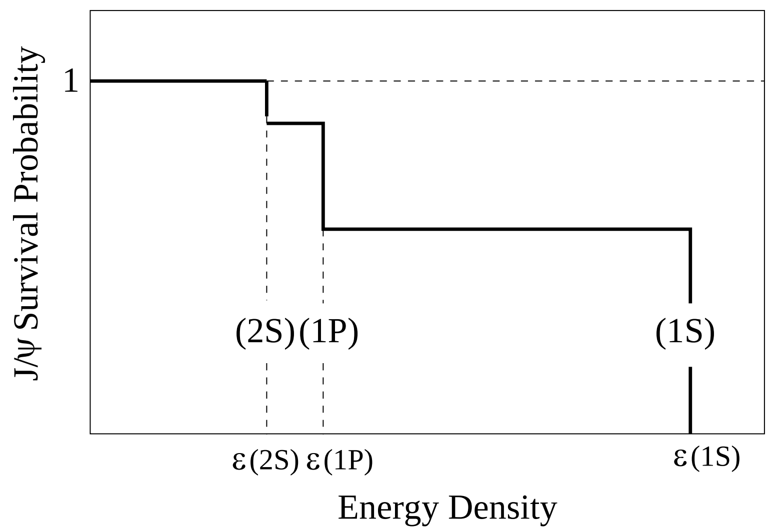
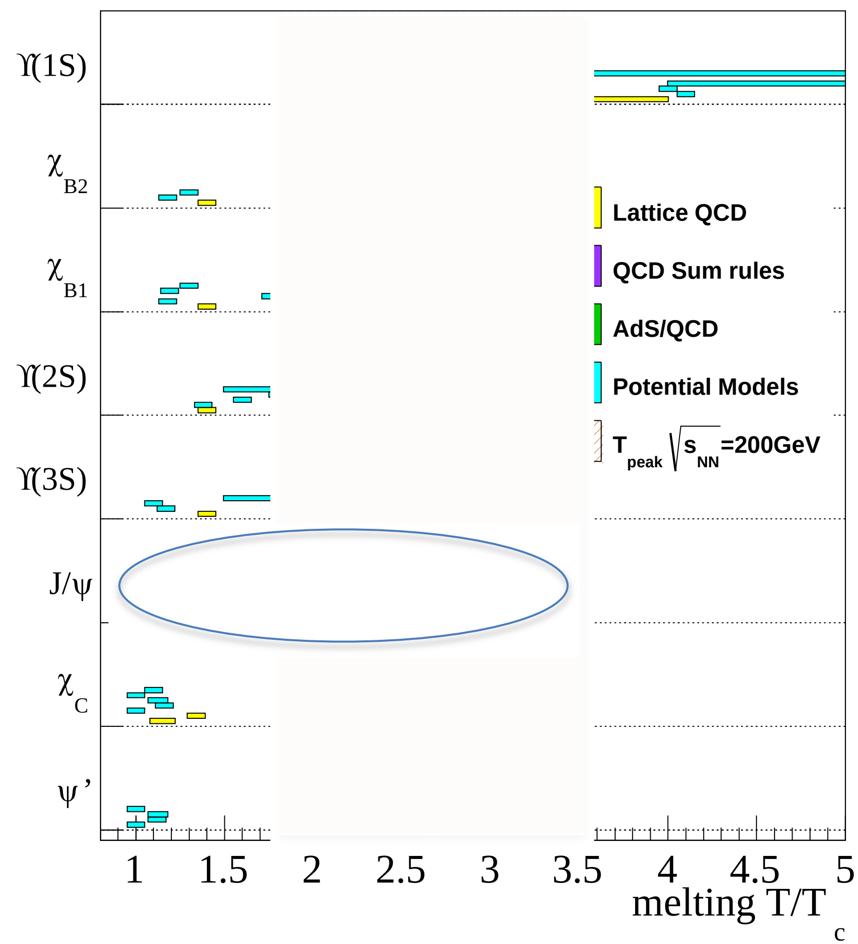
H.Satz, arXiv:1310.1209

LQCD results (still debated) ...−→







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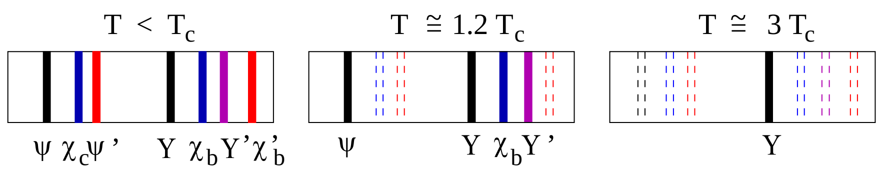
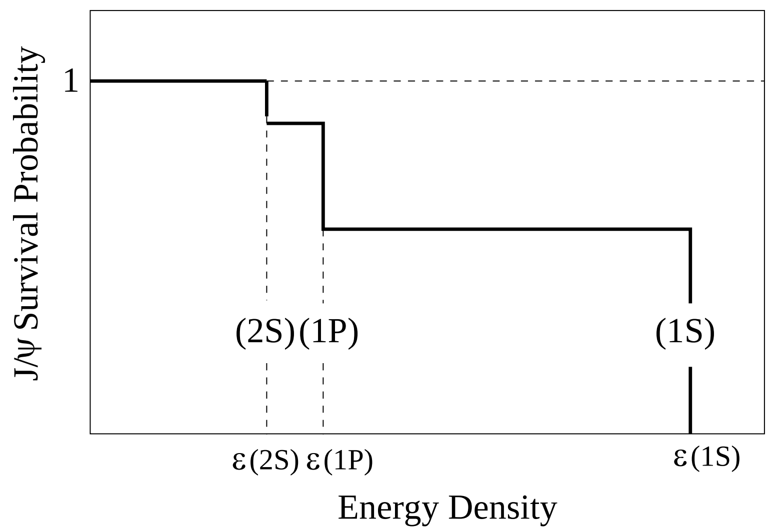




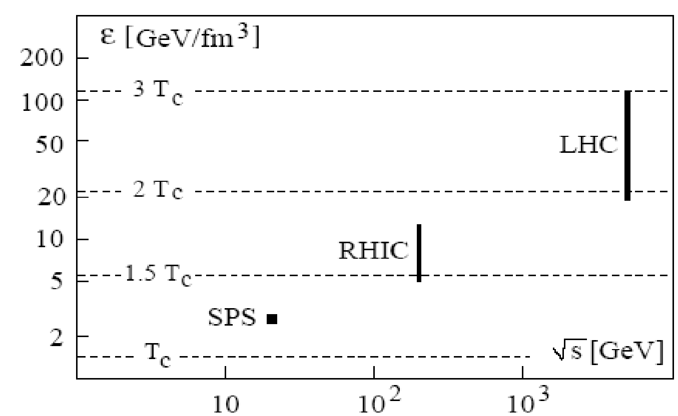
- By determine heavy quark potential V(r,T) in finite T QCD and solving Schrodinger eq:

Dissociation temperatures T_{diss}/T_c

state	$J/\psi(1S)$	$\chi_c(1P)$	$\psi'(2S)$
$V(r,T) = U(r,T)$	2.1	1.2	1.1
$V(r,T) = F(r,T)$	1.2	1.0	1.0

Energy densities:

0.5-1.5 GeV/fm^3 = 1.0 T_c
10 GeV/fm^3= 1.5 T_c
30 GeV/fm^3= 2.0 T_c



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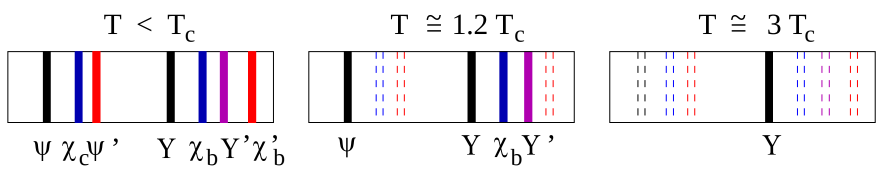

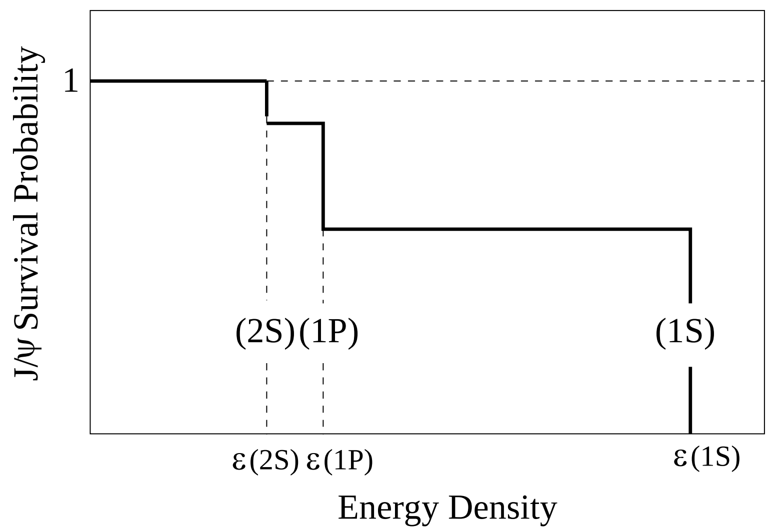

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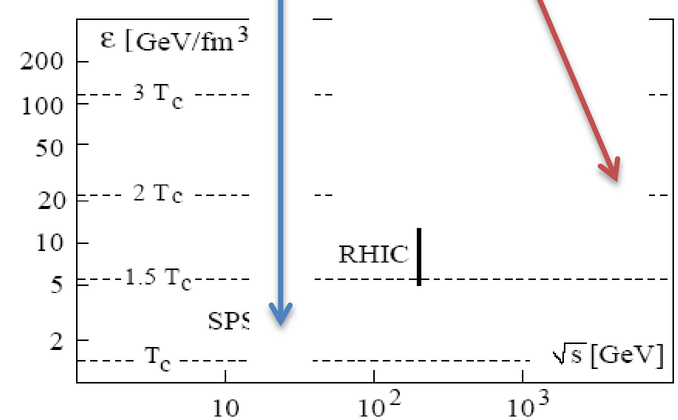
$V(r,T) = F(r,T)$	1.2		

Energy densities:

0.5-1.5 GeV/fm³ = 1.(

10 GeV/fm³= 1.5 T_c

30 GeV/fm³= 2.0 T_c



Quarkonium and the QGP - “sequential suppression”

...a low p_T-phenomenon

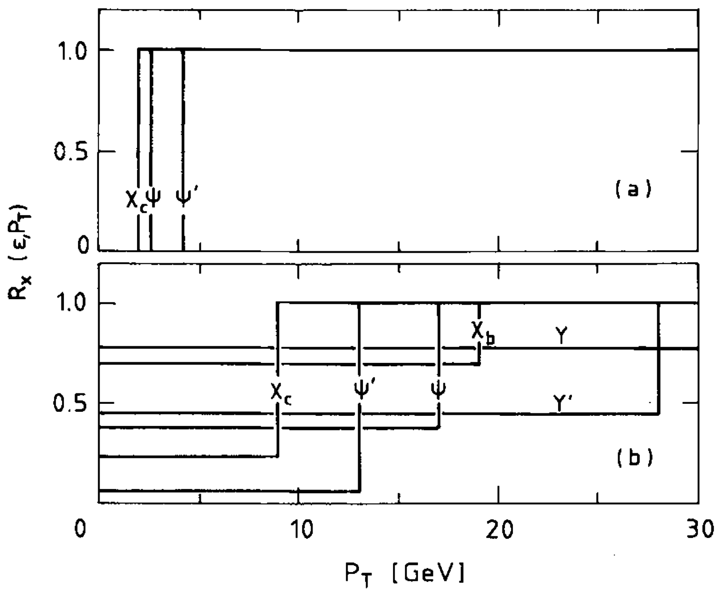


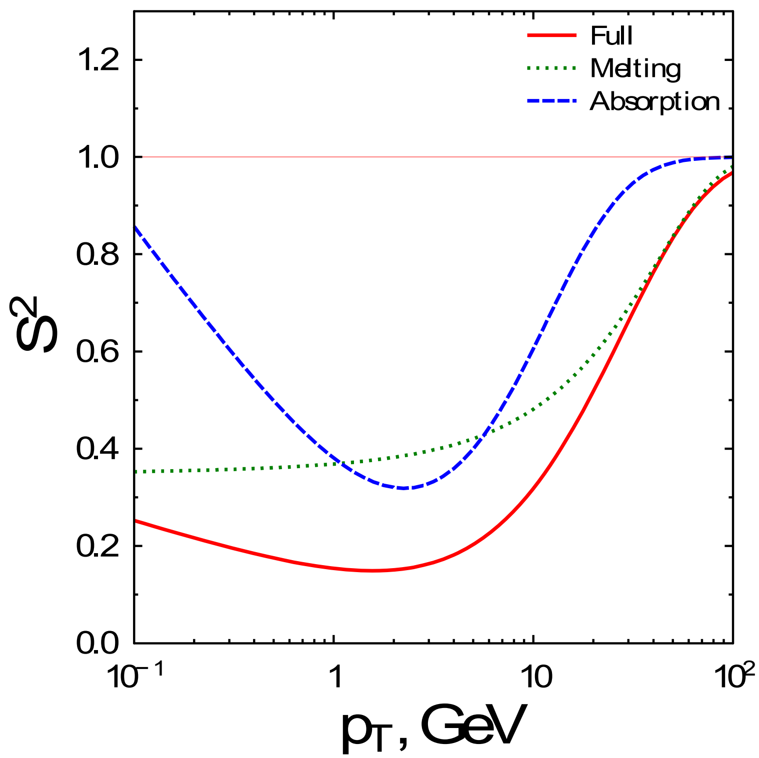
Fig. 3a, b. The transverse momentum dependence of suppression by colour screening **a** and by absorption **b**, for $\varepsilon = 3$ GeV/fm^3

Karsch, Satz, ZPC 51 (1991) 209

Digal, Petreczky, Satz, PRD 64 (2001) 094015

Karsch, Kharzeev, Satz, PLB 637 (2006) 75

new results for J/ψ: (Kopeliovich)



close to full suppression at low p_T

At large pT the medium becomes fully transparent, because the initial dipole size is “frozen”, and the projection to the J/Ψ wave function remains the same as in pp

Satz, Kharzeev, Kopeliovich…

Theoretical models

Statistical hadronization model

Braun-Munzinger, Stachel, PLB 490 (2000) 196; NPA 789 (2006) 334, PLB 652 (2007) 259

all charm quarks are produced in primary hard collisions ($t_{c\bar{c}} \sim 1/2m_c \simeq 0.1$ fm/c)
thermalized in QGP (thermal, but not chemical equilibrium)
charmed hadrons are formed at chemical freeze-out together with all hadrons ("generation") . ..
no J/ψ survival in QGP (full screening)

if supported by data, J/ψ looses status as "thermometer" of QGP

Transport models

Ralf Rapp et al

implement screening picture with space-time evolution of the fireball (hydro-like)

continuous destruction and "(re)generation" ("recombination")

Thews et al., PRC 63 (2001) 054905 ...
"TAMU", PLB 664 (2008) 253, NPA 859 (2011) 114, EPJA 48
"Tsinghua", PLB 607 (2005) 107, PLB 678 (2009) 72, arXiv:14

$$\frac{dN_{J/\psi}}{d\tau} = \lambda_F N_c N_{\bar{c}} [V(\tau)]^{-1} - \lambda_D N_{J/\psi} \rho_g$$

Similar gain and loss diferential eqs.

Comover model

Capella et al., PLB 393 (1997) 431; PLB 430 (1998) 23; PRC 59 (1999) 395;
PRL 85 (2000) 2080; EPJC 42 (2005) 419; EPJC 61 (2009) 865; PLB 731 (2014) 57

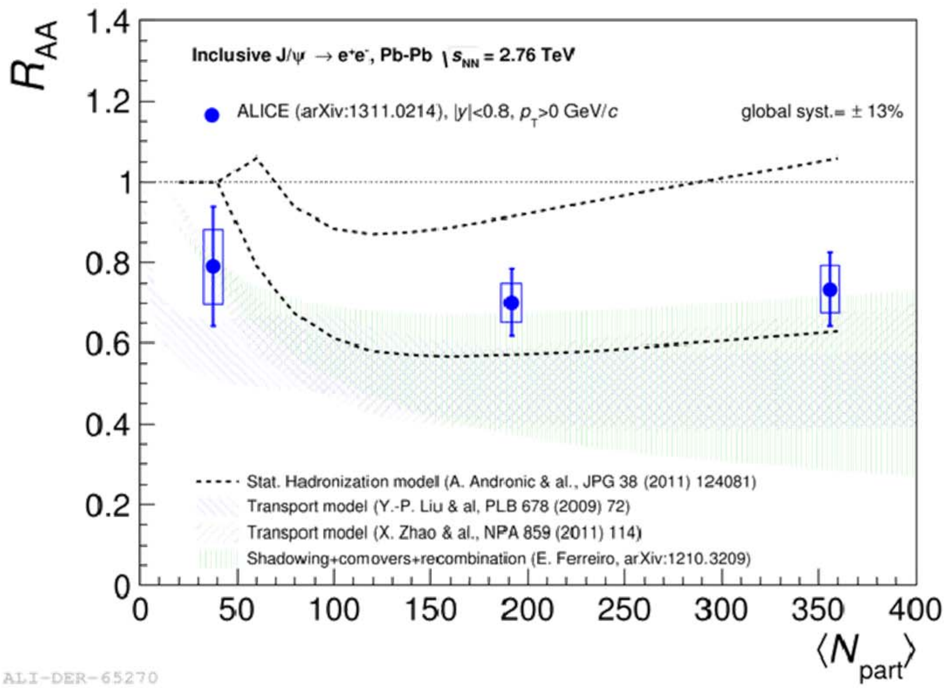
Similar to transport model
Hadronic and partonic comovers contribute
to suppression and recombination
No thermalization

$$\tau \frac{dN^{J/\psi}}{d\tau}(b,s,y) = -\sigma \{ N_{J/\psi} N^{co} - N_D N_{\bar{D}} \}$$

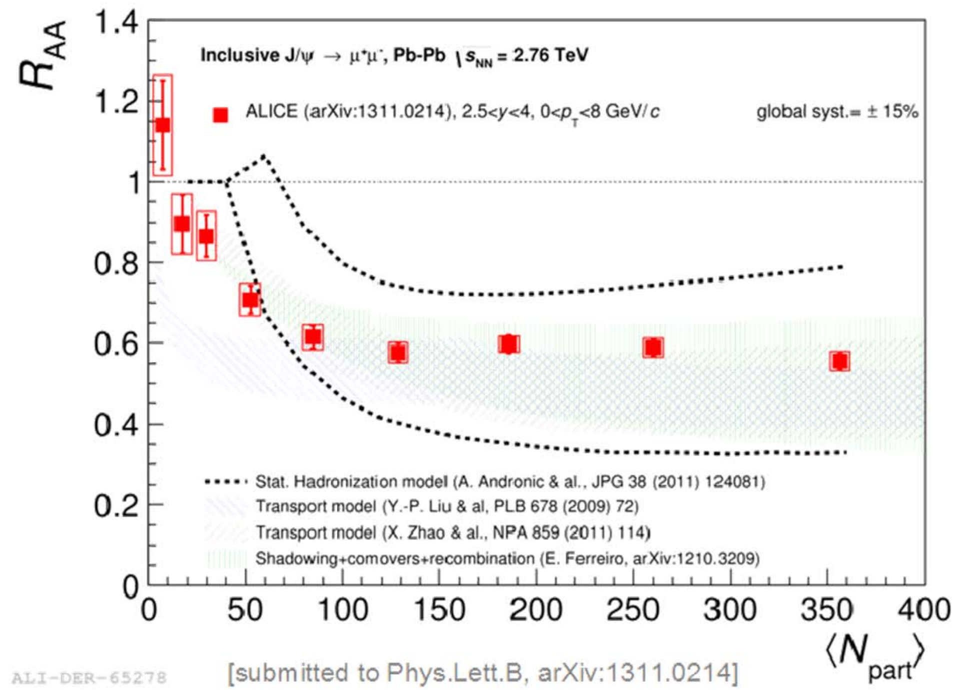
Inclusive J/ψ R_{PbPb} versus Event Centrality @ LHC

Comparison to theory calculations

mid-rapidity |y|<0.8



forward rapidity 2.5<y<4



[submitted to Phys.Lett.B, arXiv:1311.0214]

Statistical hadronization, transport and comover models with
recombination component can describe the trend in data

Recombination: proportional to $\frac{\left(\mathrm{d}\sigma_{pp}^{c\bar{c}}/\mathrm{d}y\right)^2}{\sigma_{pp}\,\mathrm{d}\sigma_{pp}^{J/\psi}/\mathrm{d}y}$

Statistical hadronization model

Braun-Munzinger, Stachel, PLB 490 (2000) 196; NPA 789 (2006) 334, PLB 652 (2007) 259

$\mathrm{d}\sigma_{pp}^{c\bar{c}}/\mathrm{d}y$ = 0.25-0.35 mb wo shadowing

all charm quarks are produced in primary hard collisions ($t_{c\bar{c}} \sim 1/2m_c \simeq$ 0.1 fm/c)

thermalized in QGP (thermal, but not chemical equilibrium)

charmed hadrons are formed at chemical freeze-out together with all hadrons ("generation") . ..

no J/ψ survival in QGP (full screening)

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Similar gain and loss diferential eqs.

Comover model

Capella et al., PLB 393 (1997) 431; PLB 4

PRL 85 (2000) 2080; EPJC 42 (2005) 419;

$\mathrm{d}\sigma_{pp}^{c\bar{c}}/\mathrm{d}y$ = 0.5-0.7 mb w shadowing

Similar to transport model

Hadronic and partonic comovers contribute to suppression and recombination

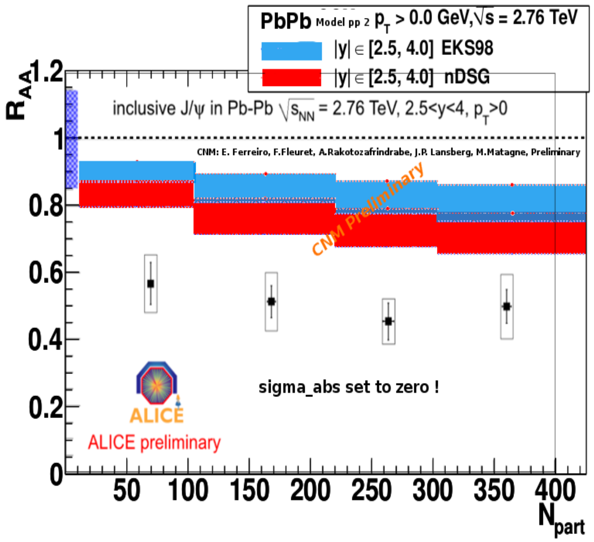
No thermalization

$$\tau \frac{dN^{J/\psi}}{d\tau}(b,s,y) = -\sigma \left\{ N_{J/\psi} N^{co} - N_D N_{\bar{D}} \right\}$$

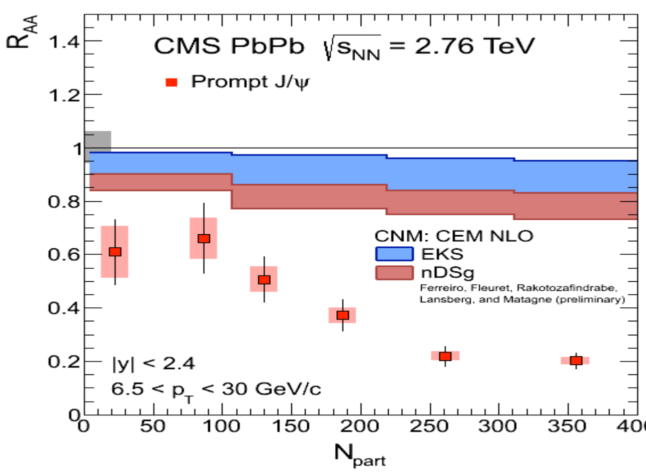
Initial shadowing effects are important: J/ψ production in PbPb @ LHC

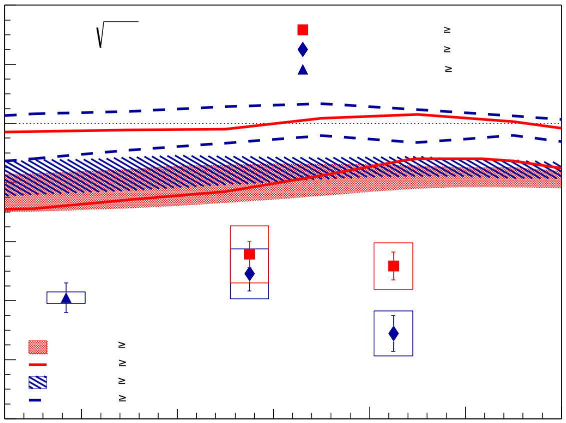
- Nuclear shadowing is an initial-state effect on the partons distributions
- Gluon distribution functions are modified by the nuclear environment
- PDFs in nuclei different from the superposition of PDFs of their nucleons

Shadowing effects increases with energy (1/x) and decrease with Q^2 (m_T)



Rakotozandrabe, Ferreiro, Fleuret, Lansberg , Matagne Nucl. Phys. A855, 327 (2011)



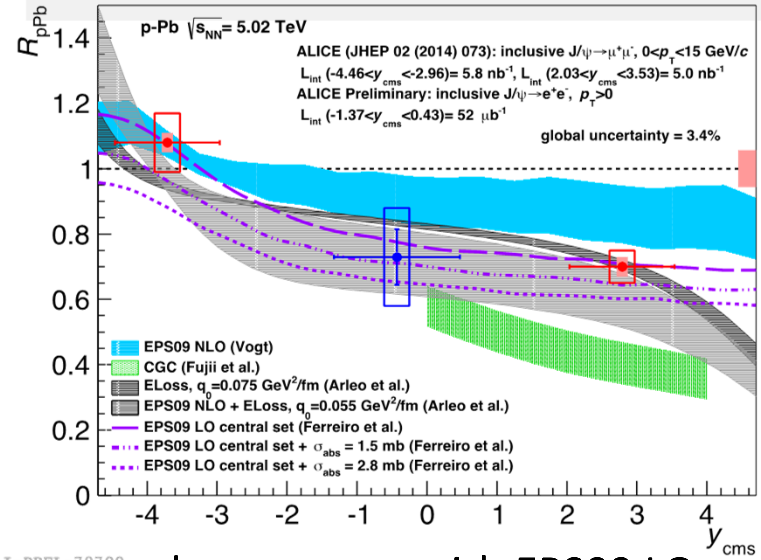


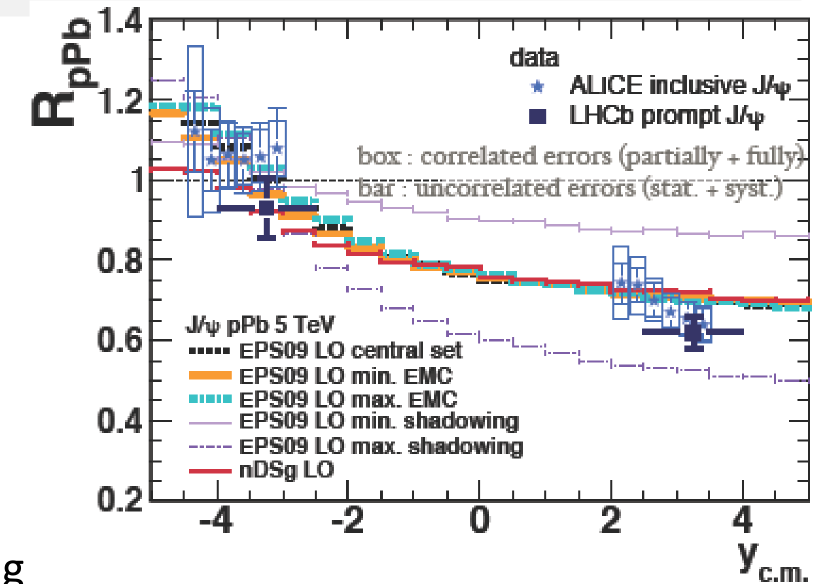
Production mechanism affects CNM effects intimately:

- Shadowing depends on momentum fraction x of the target (and projectile in AA) which is influenced by how the state was produced: 2 → 1 or 2 → 2 process
- Production can also affect other CNM effects,

since singlet and octet states can be absorbed differently

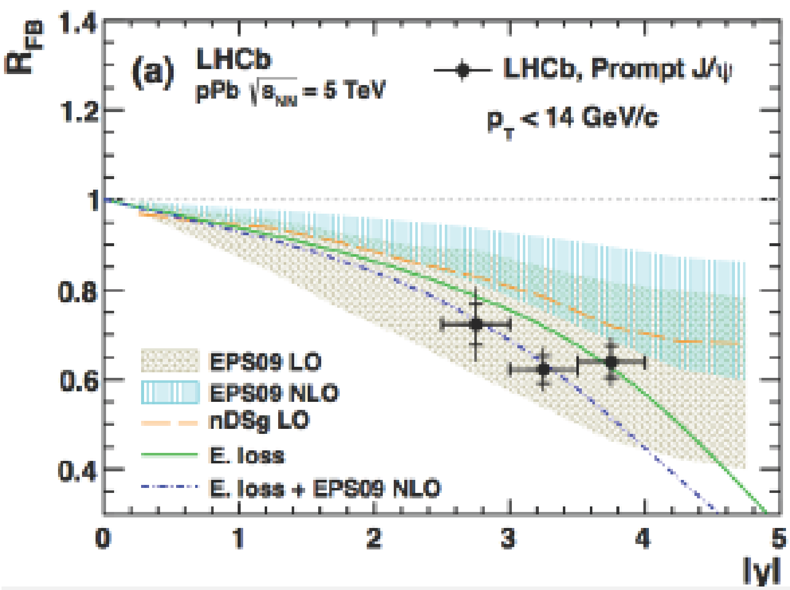
Cross check: J/ψ production in pPb @ LHC

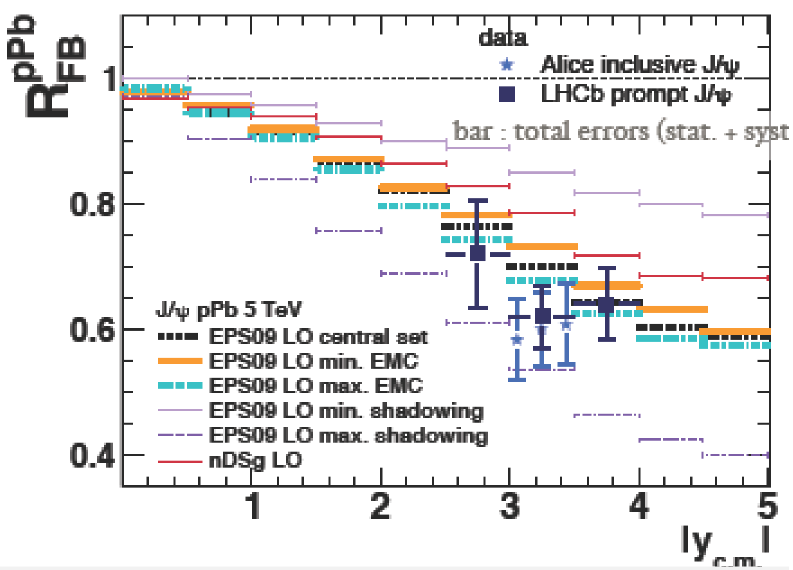




good agreement with EPS09 LO and nDSg shadowing
also consistent w energy loss models w/wo EPS09NLO shadowing
EPS09 NLO and CGC calculation disfavored

E.G.F, F. Fleuret, J.P. Lansberg, A.Rakotozafindrabe arXiv:1305.4569





What have we learnt from J/ψ production in pPb and PbPb @ LHC?

J/ψ production seems at least qualitatively understood

Initial cold nuclear matter effects can be described with shadowing and/or energy loss

Production in HI collisions is described by a combination of

- suppression (either color screening, or in-medium dissociation)
- recombination (either in-medium or at phase boundary)

High density medium,
Not necessairly thermalized

Challenge will be to discriminate between these possible scenarios

What is the state of the art for ψ(2)?

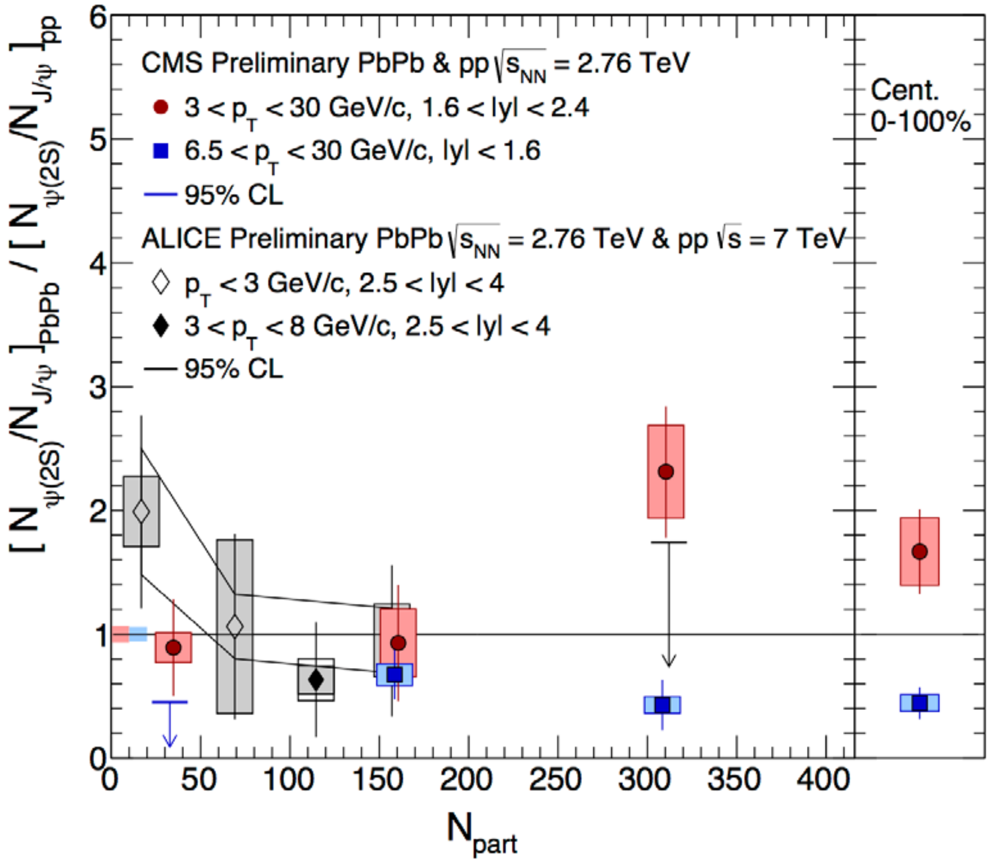
Note that initial cold nuclear matter effects (shadowing and/or energy loss) are considered to be the same for than for the J/ψ

Nevertheless, in-medium effects depending on density (comovers) would be able to distinguish between them

Ratio $[\psi(2S)/J/\psi]_{PbPb}/[\psi(2S)/J/\psi]_{pp}$ @ LHC

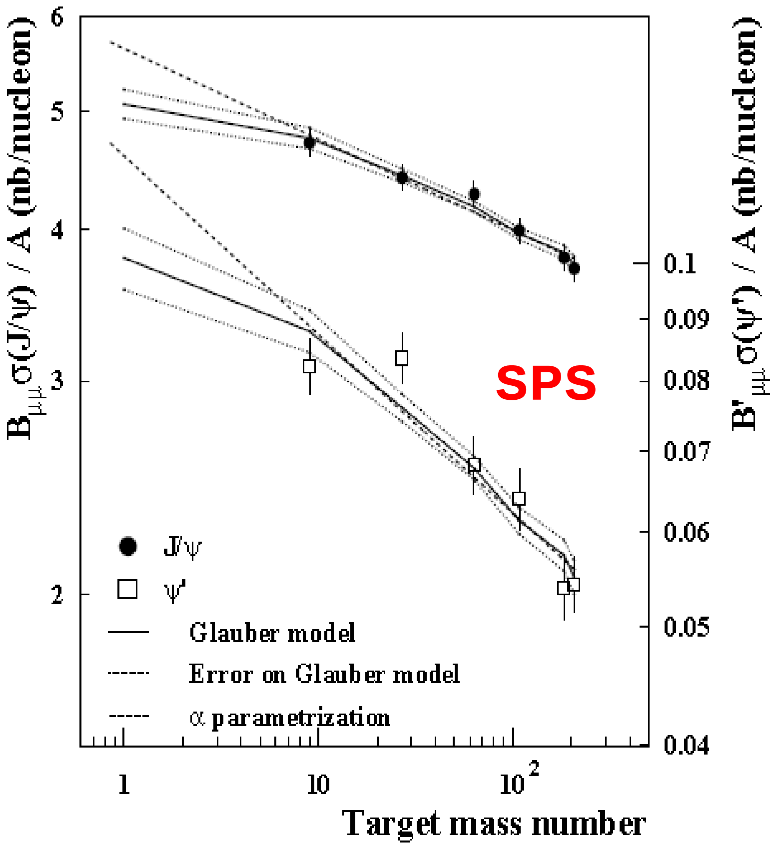
Surprisingly large $(\psi'/\psi)_{PbPb}$ / $(\psi'/\psi)_{pp}$ ratio confirmed

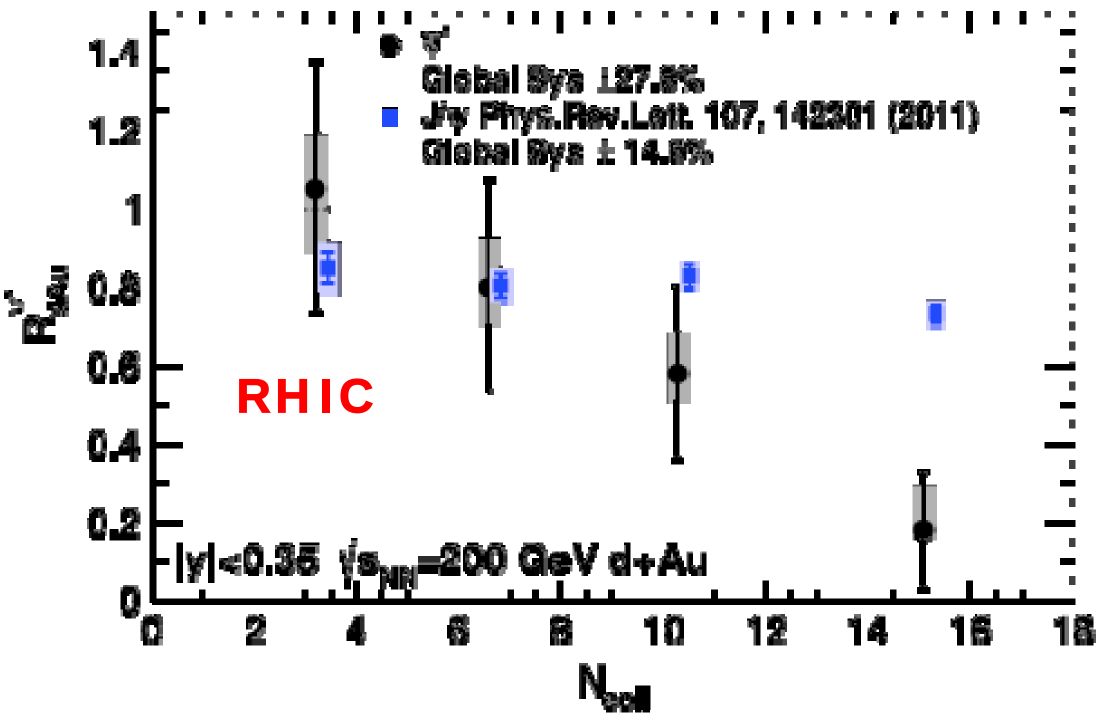
- ψ' very suppressed at high p_T (more than ψ)
- Much less at lower p_T



But... is it really so surprising?

ψ(2S) and J/ψ in pA @ SPS and RHIC

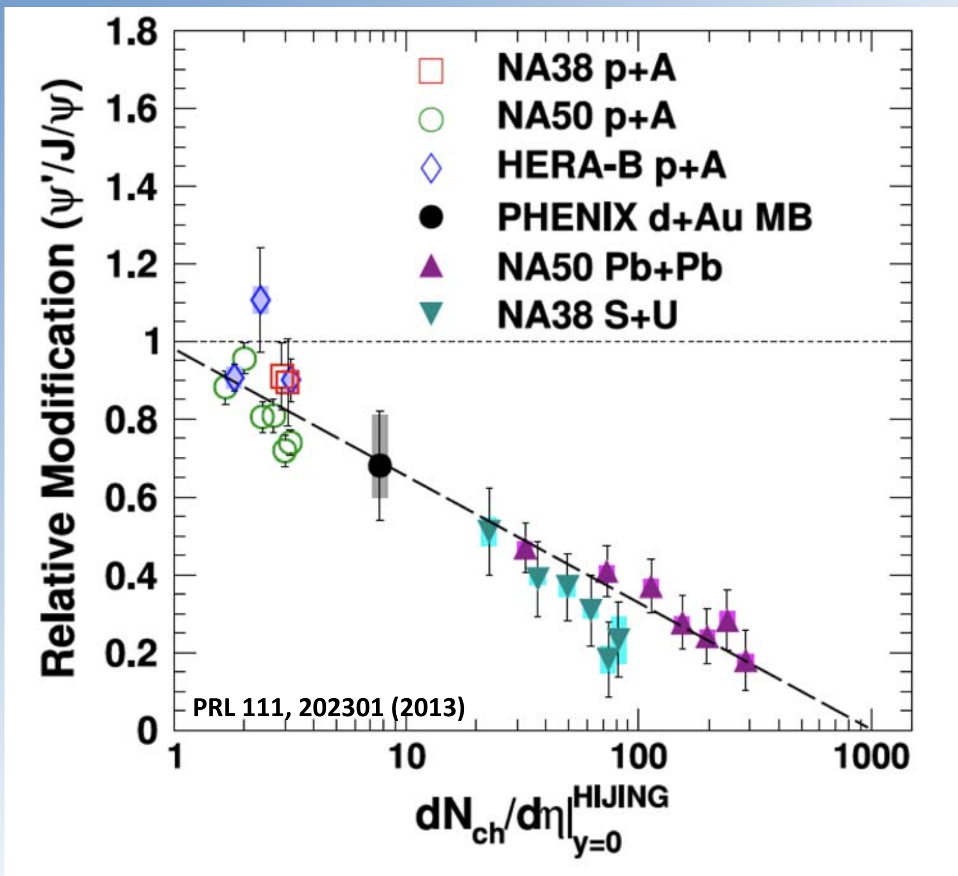




In pA collisions at all energies:

$R_{pA}^{J/\psi} > R_{pA}^{\psi'}$

Relative Modification of $\psi(2s)/\psi(1s)$ – particle density



Relative modification in *all* systems follows common trend with increasing produced particle density.

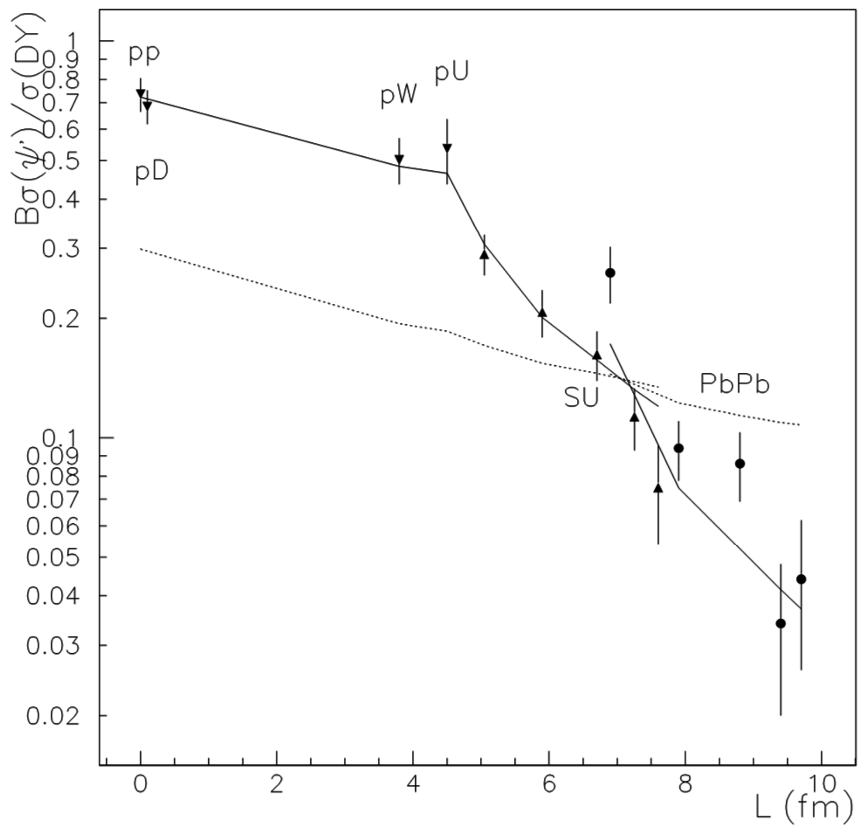
Co-mover (or medium?) density seems to be the relevant quantity.

Matt Durham - Quark Matter 2014 16

M. Durham QM2014

ψ(2S) and J/ψ @ SPS: comover scenario

In a comover scenario, expected stronger suppression for 2S that 1S in pA, Increasing with centrality



$\sigma_{co\text{-}J/\psi} = 0.65$ mb, $\sigma_{co\text{-}\psi(2S)} = 6$ mb

Capella et al, Phys.Lett. B430 (1998) 23

Some words about comover scenario

$$\tau \frac{d\rho^{J/\psi}(b,s,y)}{d\tau} = -\sigma_{co}\ \rho^{J/\psi}(b,s,y)\ \rho^{medium}(b,s,y)$$

- Our equations have to be integrated between initial time τ_0 and freeze-out time τ_f.

- The solution depends only on the ratio τ_f/τ_0.

- We use the inverse proportionality between proper time and densities, $\tau_f/\tau_0 = \rho(b,s,y)/\rho_{pp}(y)$

$\rho_{pp}(y)=$ density per unit rapidity for mb pp collisions

$\rho(b,s,y) =$ density produced in the primary collisions

- Our densities can be either hadrons or partons:

σ_{co}: **effective cross-section averaged over the interaction time**

- **Survival probability $S_{co}(b,s)$ of the J/ψ due to comovers interaction:**

$$S^{co}(b,s) \equiv \frac{N^{J/\psi(final)}(b,s,y)}{N^{J/\psi(initial)}(b,s,y)} = \exp\left[-\sigma_{co}\ \rho^{co}(b,s,y)\ell n\left(\frac{\rho^{co}(b,s,y)}{\rho_{pp}(0)}\right)\right]$$

Some words about comover scenario

σ_{co} is the effective comover cross-section averaged from time τ_0 to freeze-out

A large contribution to the integral comes from the few first fm/c after the collision, where the system is in a pre-hadronic stage.

Actually, Brodsky and Mueller introduced the comover interaction as a coalescence phenomenon at the partonic level.

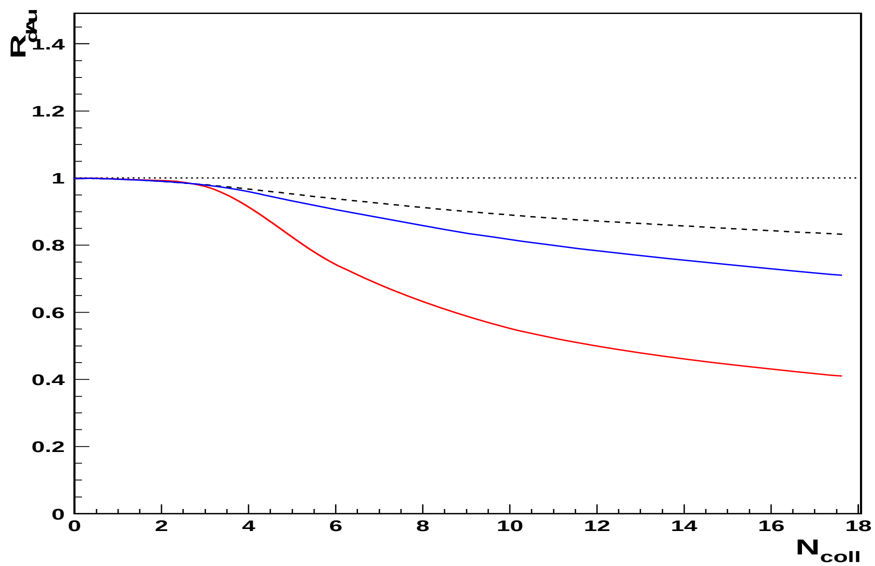
For times close to τ_0, one is dealing with a dense interacting parton system and thus the precise relation between σ_{co} and the J/ψ (ψ') hadron cross-section is not established

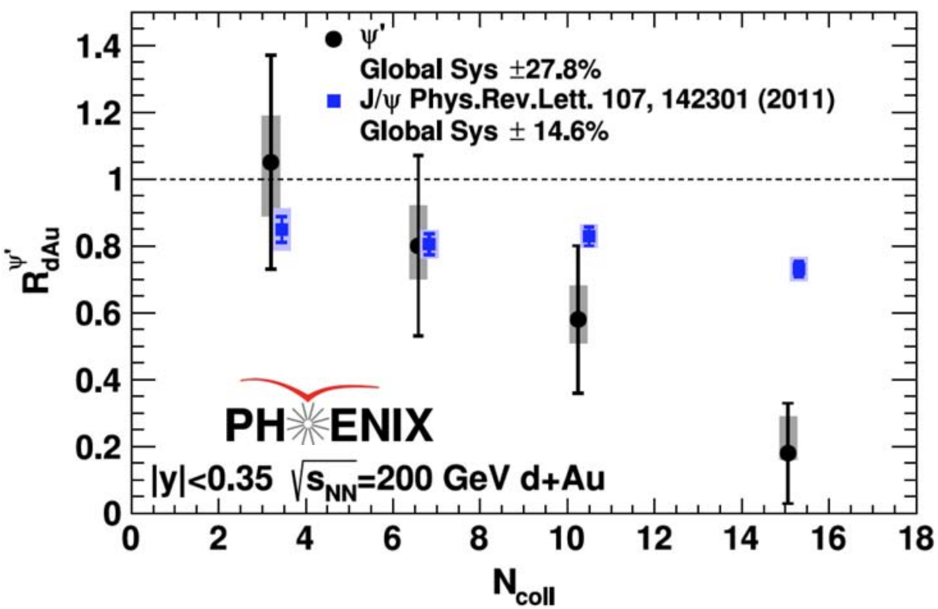
Geometrical considerations, together with different theoretical calculations (multipole expansion in QCD , non-perturbative effects…) $\sigma_{co-\psi(2S)} / \sigma_{co-J/\psi} \approx 10$

ψ(2S) and J/ψ in dAu @ RHIC: comover scenario

$$\tau \frac{\mathrm{d}N_{J/\psi}}{\mathrm{d}\tau}\,(b,s,y) \;=\; -\sigma_{co} N^{co}(b,s,y) N_{J/\psi}(b,s,y)$$

$$S^{\mathrm{co}}(b,s) \;= \exp\left[-\sigma_{\mathrm{co}} N^{\mathrm{co}}(b,s,y) \ln\left(N^{\mathrm{co}}(b,s,y)/N_{pp}(0)\right)\right]$$





ψ(2S) and J/ψ in dAu @ RHIC: comover scenario

$$\tau \frac{dN_{J/\psi}}{d\tau}(b,s,y) = -\sigma_{co} N^{co}(b,s,y) N_{J/\psi}(b,s,y)$$

$$S^{co}(b,s) = \exp\left[-\sigma_{co} N^{co}(b,s,y) \ln\left(N^{co}(b,s,y)/N_{pp}(0)\right)\right]$$

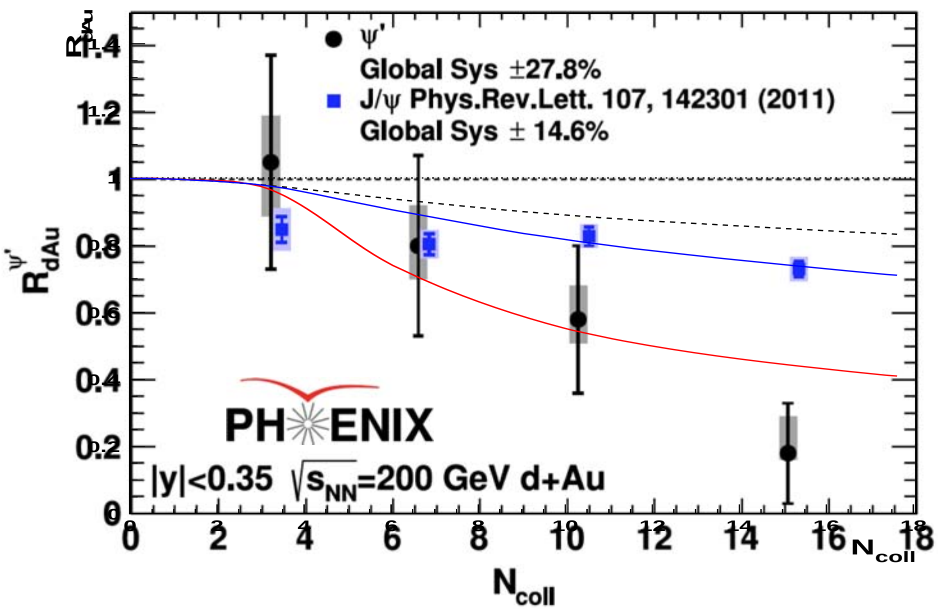
- Identical shadowing for ψ(2S) and J/ψ

- J/ψ suppression due to the combined effect of shadowing and comover dissociation

- ψ (2S) suppression due to the combined effect of shadowing and stronger comover dissociation

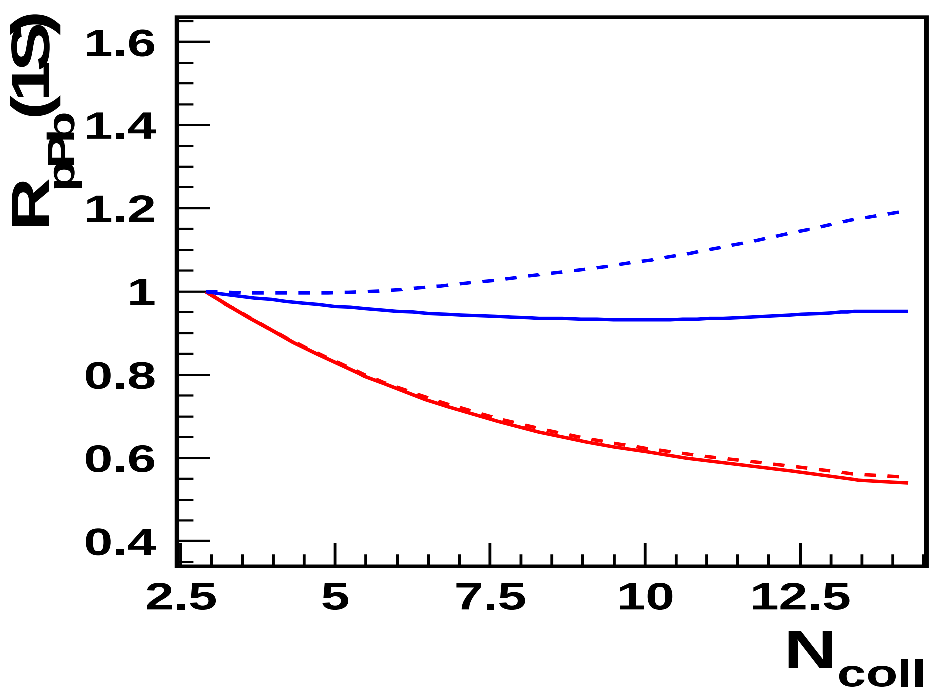
$$\sigma_{co\text{-}\psi(2S)} > \sigma_{co\text{-}J/\psi}$$

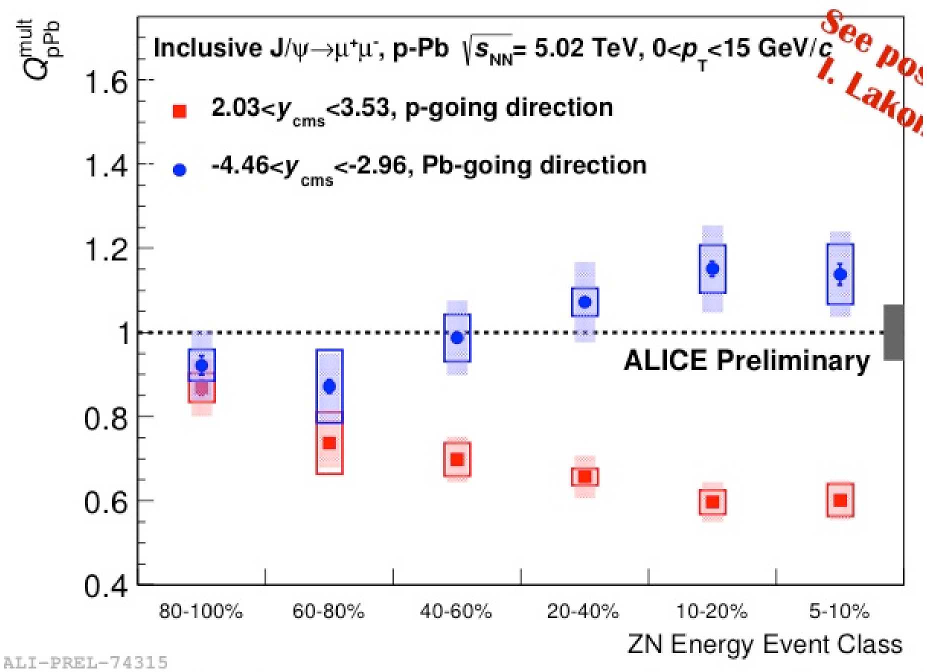
- No recombination in any case



$\sigma_{co\text{-}\psi(2S)}$ = 6 mb, $\sigma_{co\text{-}J/\psi}$ = 0.65 mb
(identical to the ones used at SPS & LHC)
PLB430 (1998), PRL 85 (2000) 2080, PLB731 (2014) 57

J/ψ in pPb @ LHC: comover scenario





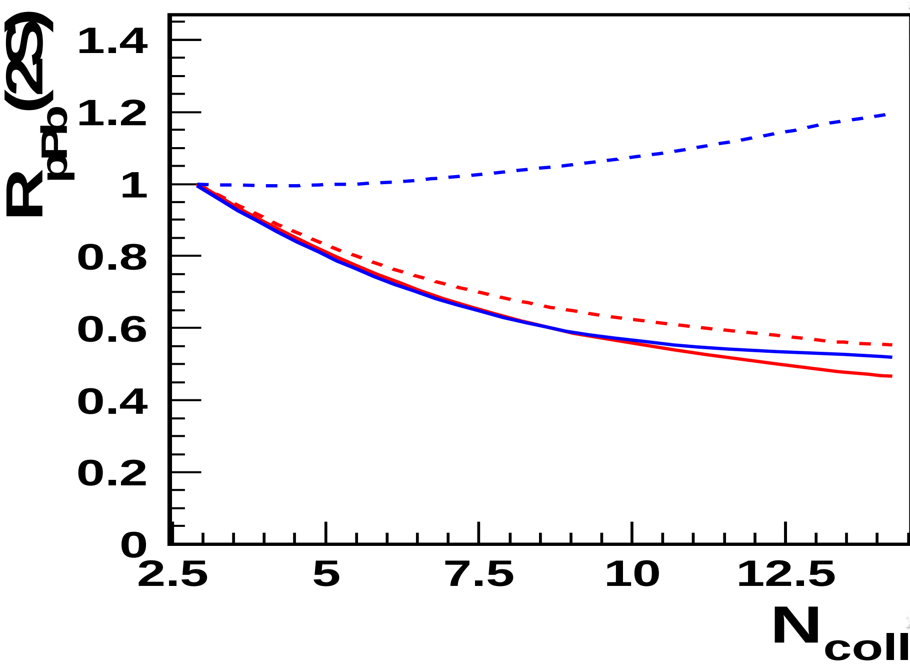
- Strong shadowing suppression in the forward rapidity region
- Slight antishadowing in the backward rapidity region
- Comoving medium suppression very small in the forward region due to small medium density

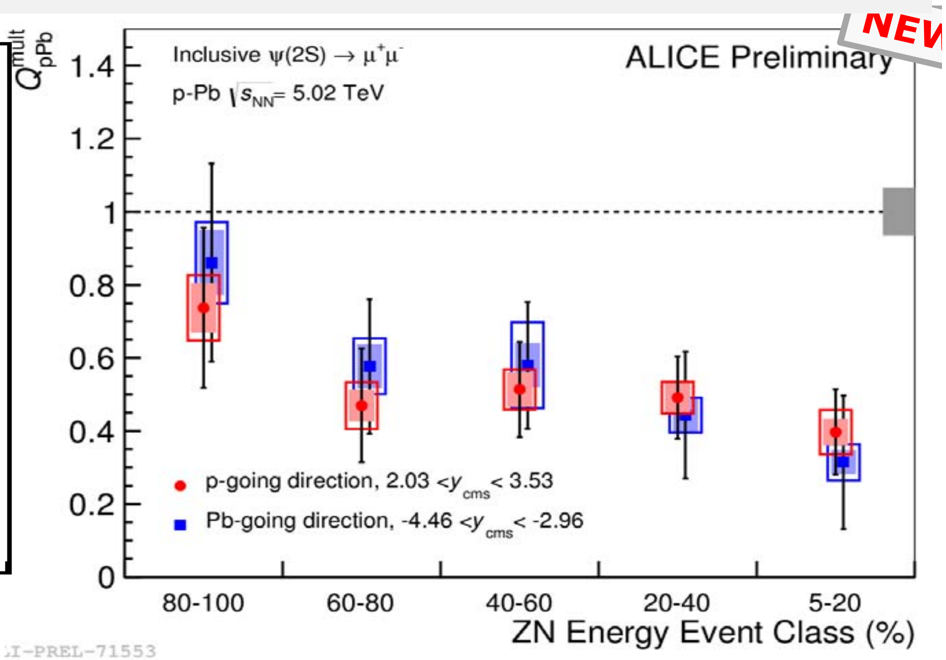
⇒ **Total effect mostly due to shadowing in the forward region**

- Comover suppression not negligible in the backward region due to larger medium density

=> **Combined effect of antishadowing and comover suppression in the backward region**

ψ(2S) in pPb @ LHC: comover scenario





- Strong shadowing suppression in the forward rapidity region
- Slight antishadowing in the backward rapidity region
- Comoving medium suppression very small in the forward region due to small medium density

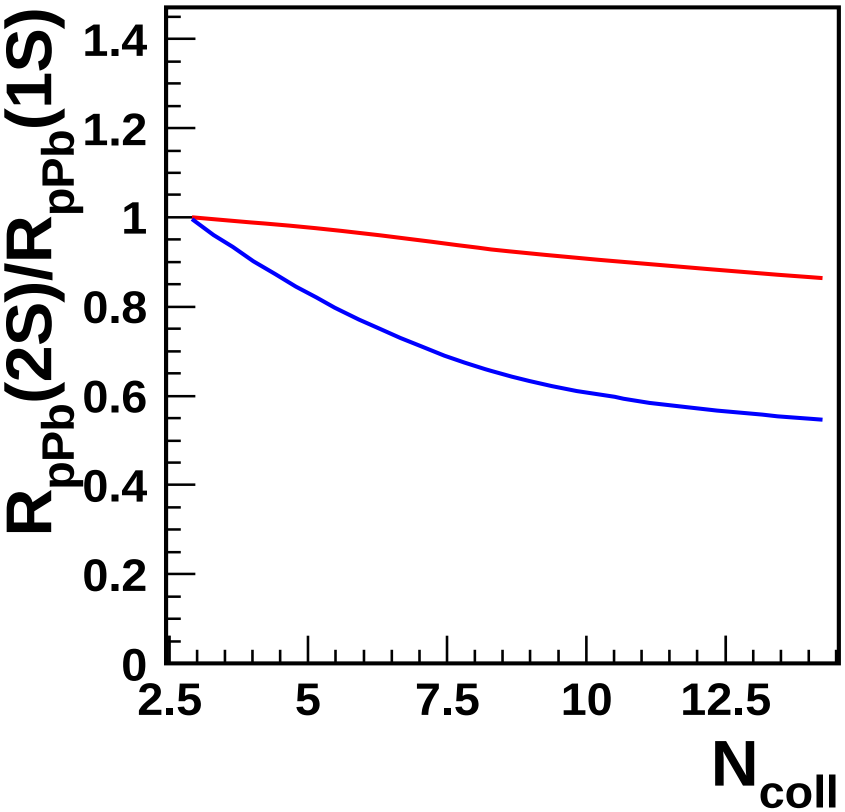
⇒ **Total effect mostly due to shadowing in the forward region**

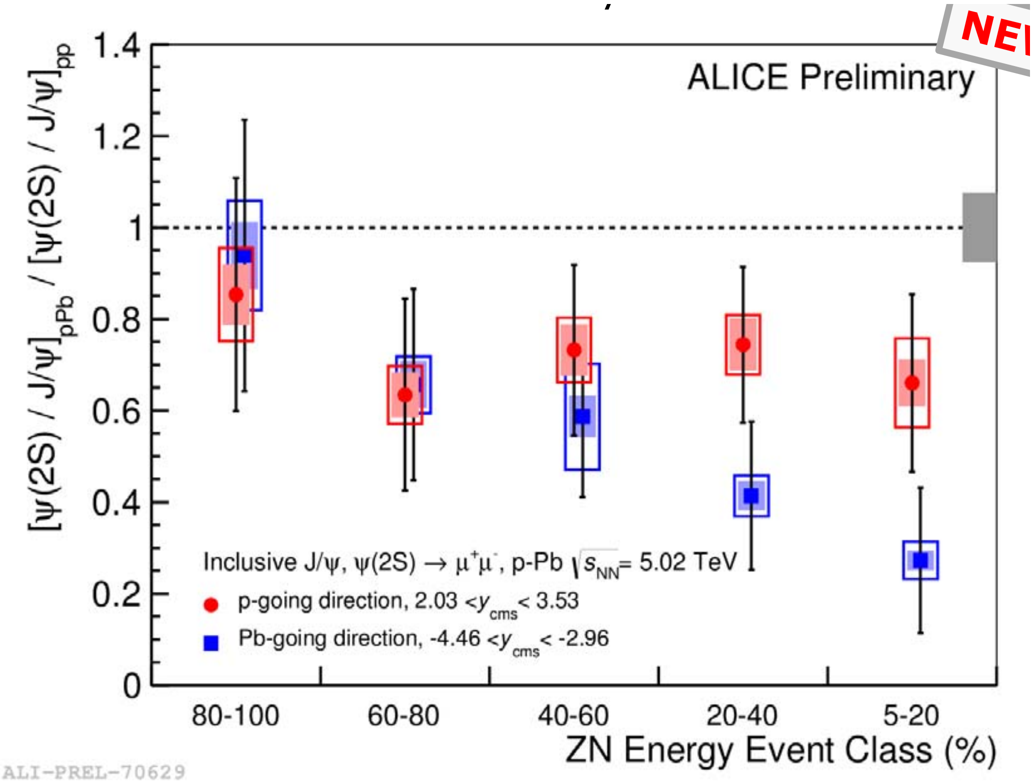
- Comoving medium suppression relevant in the backward region due to larger medium density

⇒ **Combined effect of antishadowing and comover suppression in the backward region**

Identical shadowing on J/ψ and ψ(2S), stronger comover suppression on ψ(2S) due to larger σ_{co}

[ψ(2S)/J/ψ]$_{pPb}$/[ψ(2S)/J/ψ]$_{pp}$ @ LHC: comover scenario



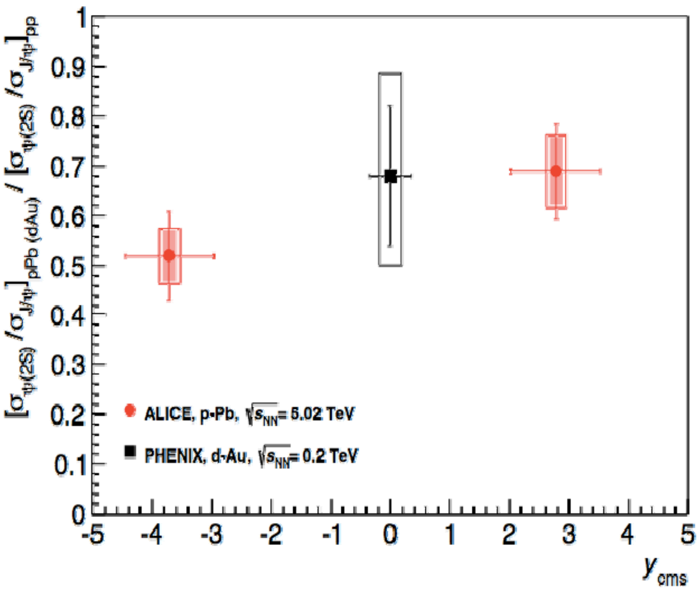


Identical shadowing effects for ψ(2S) and J/ψ

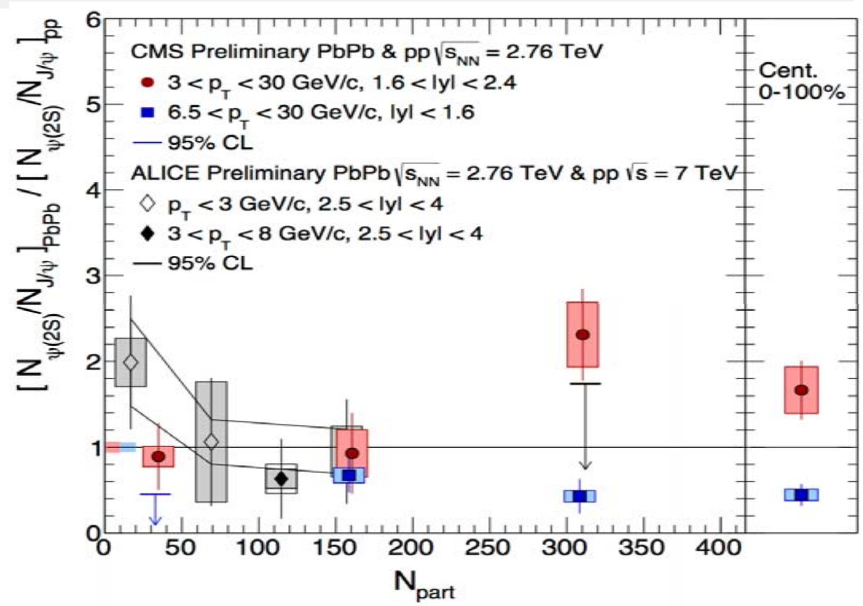
[ψ(2S) / J/ψ] < 1 due to comover interactions, that affects strongerly the ψ(2S)

This effect is more important in the backward region, since the density of comovers is higher there

$[\psi(2S)/J/\psi]_{pPb}/[\psi(2S)/J/\psi]_{pp}$ vs. $[\psi(2S)/J/\psi]_{PbPb}/[\psi(2S)/J/\psi]_{pp}$



2S more supressed than 1S in pPb



2S less supressed than 1S in PbPb or ....
Suppression + recombination at low pT?

4 Conclusions **Peter Braun-Munzinger, Krzysztof Redlich EPJC16 (2000) 519**

We have considered the possibility of the secondary charmonium production in ultrarelativistic heavy ion collisions at LHC energy. Admitting thermalization of a partonic medium crated in a collision and the subsequent first order phase transition to a hadronic matter we have shown that the secondary charmonium production appears almost entirely during the mixed phase. The yield of secondarily produced ψ mesons is very sensitive to the hadronic absorption cross section. Within the context of the short distance QCD approach this leads to negligible values for J/ψ regeneration. The ψ' production, however, can be large and may even exceed the initial yield from primary hard scattering. Thus it is conceivable that at LHC energy the ψ' charmonium state can be seen in the final state whereas J/ψ production can be entirely suppressed. The appearance of the ψ' in the final state could be thus considered as an indication for the charmonium production from the secondary hadronic rescattering.

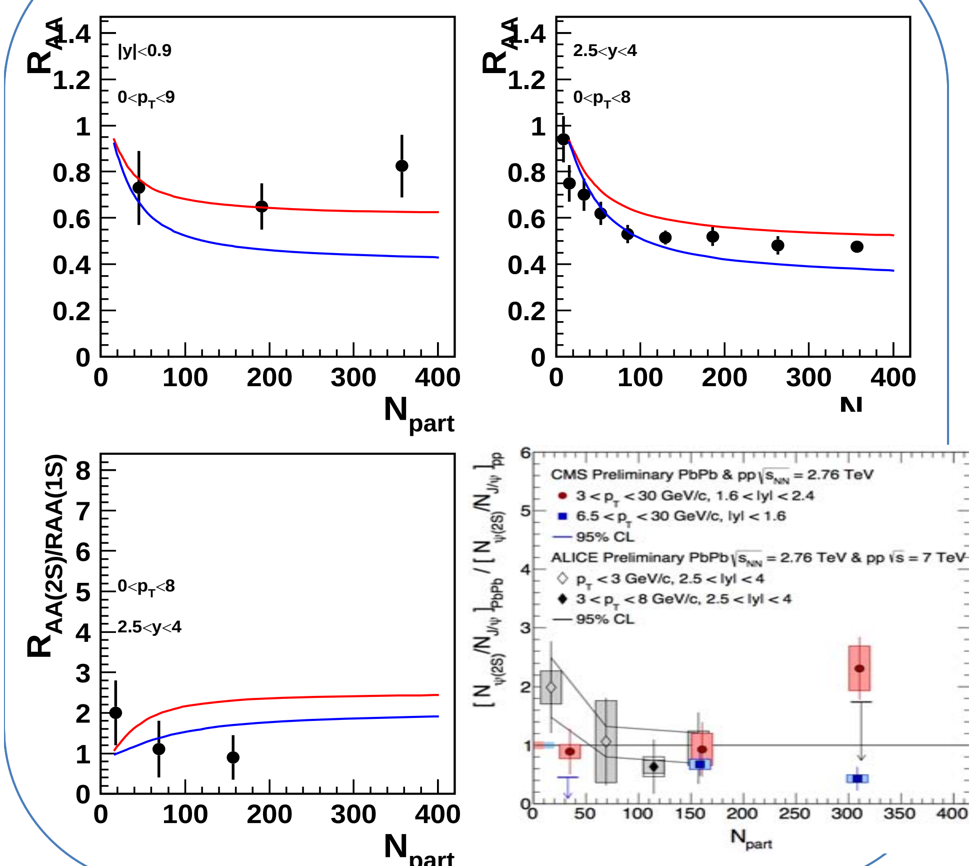
Comover dissociation + recombination in PbPb at LHC?

[ψ(2S)/J/ψ]$_{PbPb}$ / [ψ(2S)/J/ψ]$_{pp}$ @ LHC: Comover results

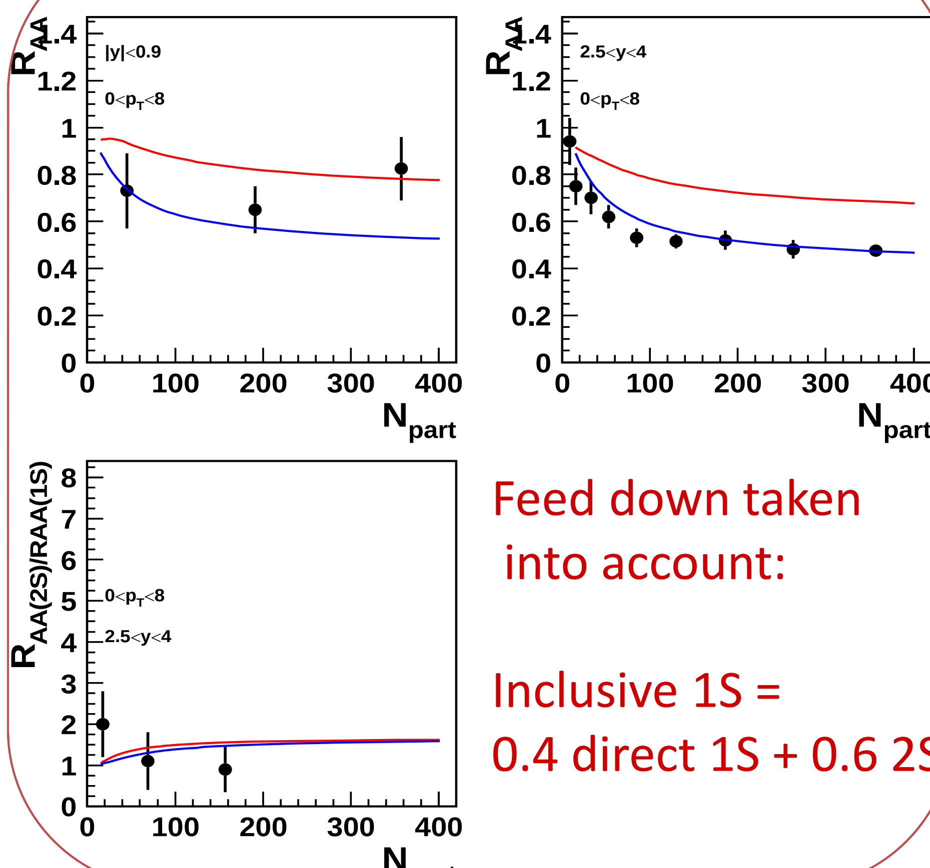
$$\tau \frac{\mathrm{d}N_{J/\psi}}{\mathrm{d}\tau}\,(b,s,y) \;=\; -\sigma_{co}\left[N^{co}(b,s,y)N_{J/\psi}(b,s,y) \;-\; N_c(b,s,y)N_{\bar{c}}(b,s,y)\right]$$

$$S^{co}(b,s,y) \;=\; \exp\left\{-\sigma_{co}\left[N^{co}(b,s,y) - \frac{N_c(b,s,y)N_{\bar{c}}(b,s,y)}{N_{J/\psi}(b,s,y)}\right]\ln\left[\frac{N^{co}(b,s,y)}{N_{pp}(0)}\right]\right\}$$

Exact numerical solution



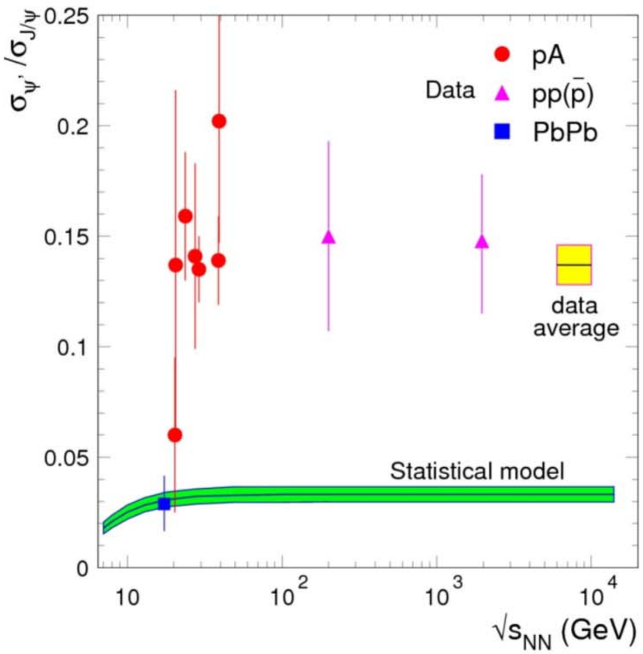
Exact numerical solution

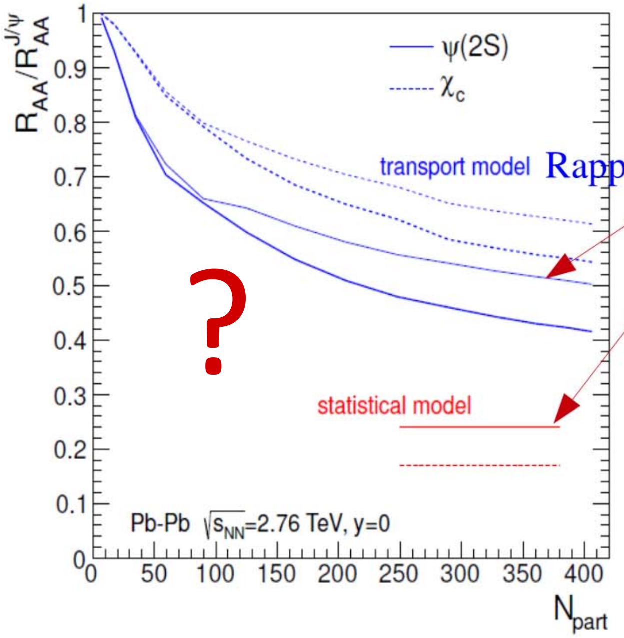


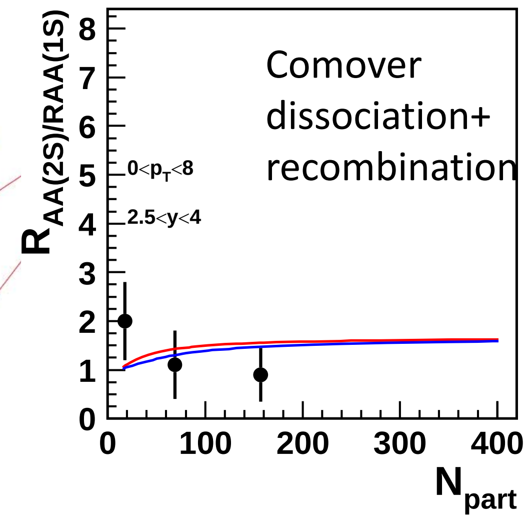
Feed down taken into account:

Inclusive 1S = 0.4 direct 1S + 0.6 2S

formation of charmonia from deconfined quarks: psi' is crucial cornerstone

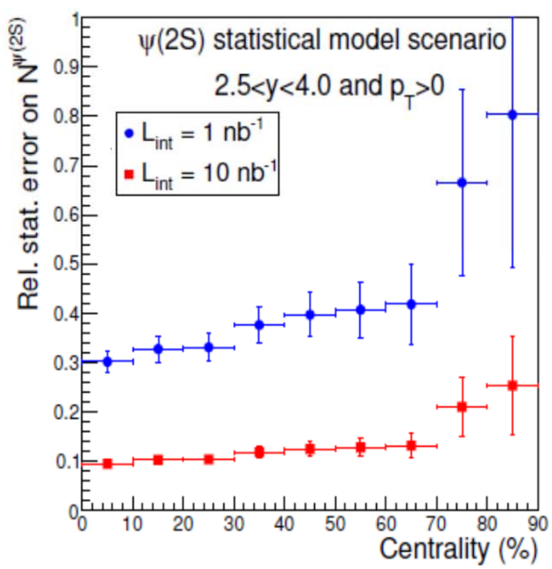




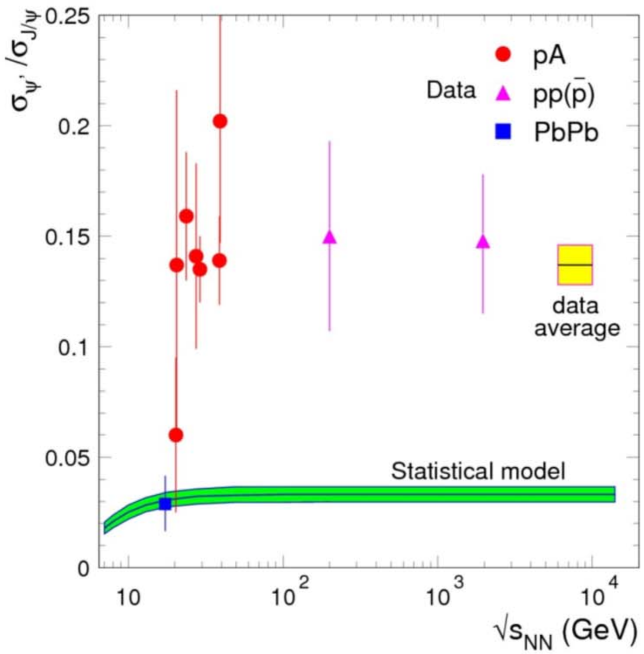


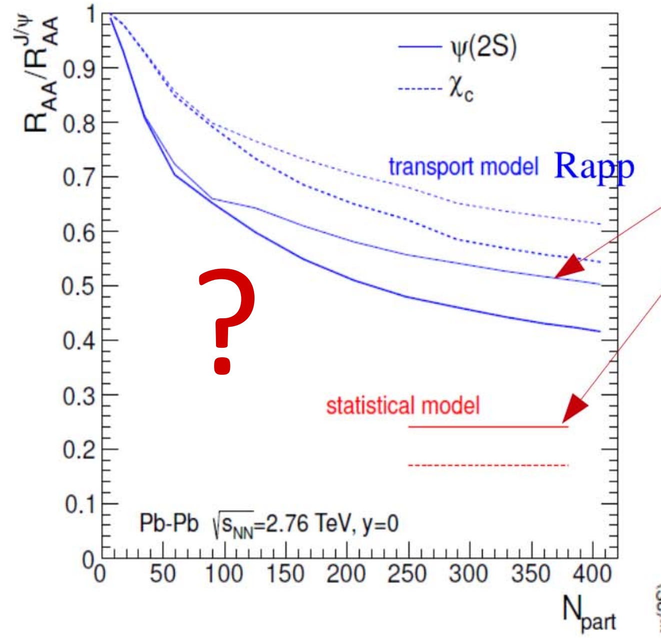
for statistical hadronization need to see suppression by Boltzmann factor

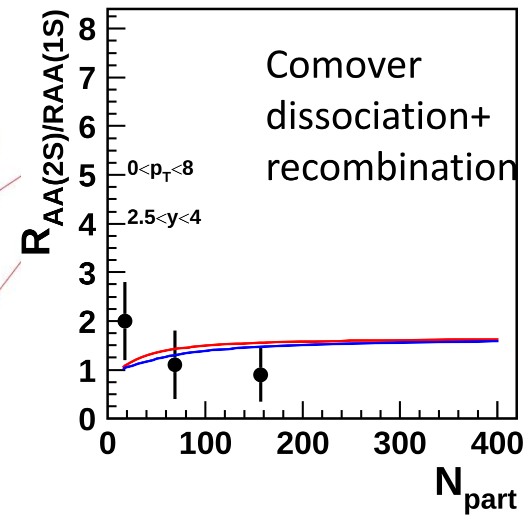
expected ALICE performance muon arm



formation of charmonia from deconfined quarks: psi' is crucial cornerstone







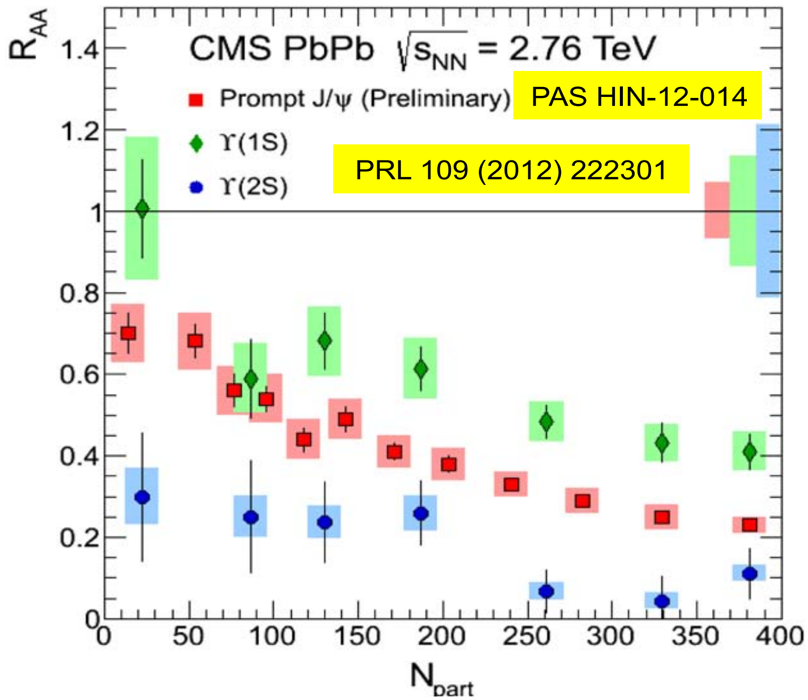
$$\frac{\left(\mathrm{d}\sigma_{pp}^{c\bar{c}}/\mathrm{d}y\right)^2}{\sigma_{pp}\,\mathrm{d}\sigma_{pp}^{J/\psi}/\mathrm{d}y}$$

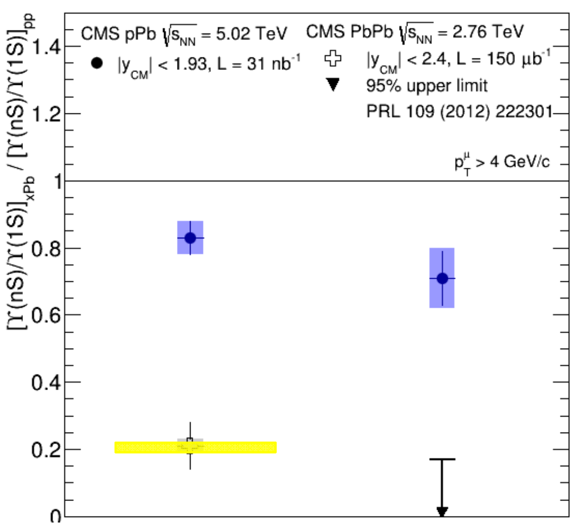
Peter Braun-Munzinger, Krzysztof Redlich EPJC16 (2000) 519

4 Conclusions

We have considered the possibility of the secondary charmonium production ... vy ion collisions at LHC energy. Admitting thermalization of a partonic medium crated in a collision and the subsequent first order phase transition to a hadronic matter we have shown that the secondary charmonium production appears almost entirely during the mixed phase. The yield of secondarily produced ψ mesons is very sensitive to the hadronic absorption cross section. Within the context of the short distance QCD approach this leads to negligible values for J/ψ regeneration. The ψ' production, however, can be large and may even exceed the initial yield from primary hard scattering. Thus it is conceivable that at LHC energy the ψ' charmonium state can be seen in the final state whereas J/ψ production can be entirely suppressed. The appearance of the ψ' in the final state could be thus considered as an indication for the charmonium production from the secondary hadronic rescattering.

ϒ(1S), ϒ(2S), ϒ(3S) in PbPb



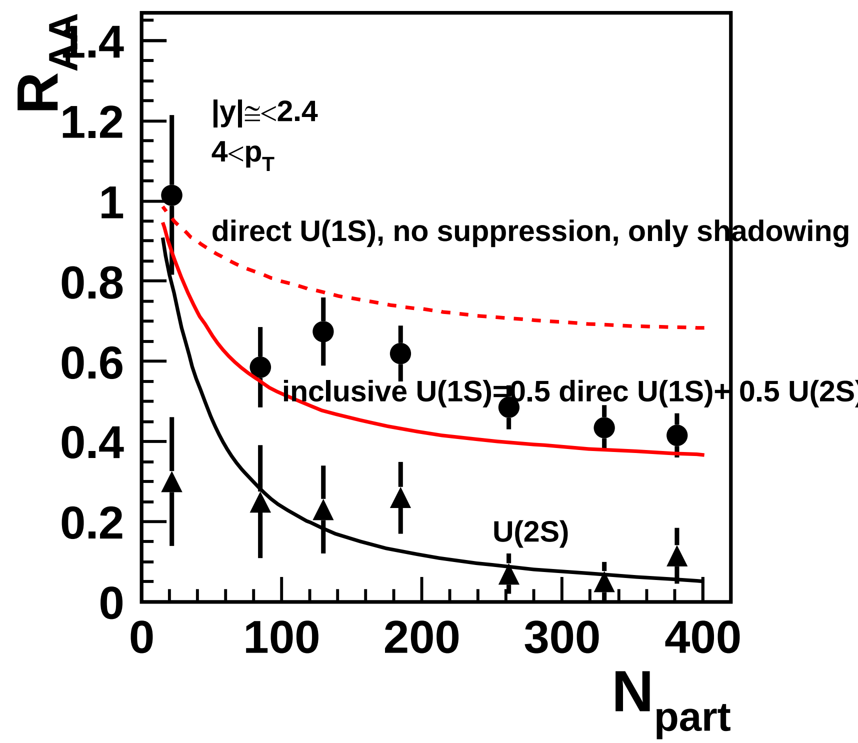


Sequential suppression of the three states in order of their binding energy

Clear suppression of ϒ(2S)

ϒ(1S) suppression consistent with excited state suppresion (≈ 50% feed down)

Comover dissociation



What have we learnt from quarkonia production @ LHC?

J/ψ production seems at least qualitatively understood

Initial cold nuclear matter effects can be described with shadowing and/or energy loss

Production in HI collisions is described by a combination of

- suppression (either color screening, or in-medium dissociation)
- recombination (either in-medium or at phase boundary)

High density medium,
Not necessarily thermalized

Challenge will be to discriminate between these possible scenarios

What is the state of the art for ψ(2)?

Crucial to distinguish among the models

Note that cold nuclear matter effects (shadowing and/or energy loss) are considered to be the same for than for the J/ψ

Nevertheless, in-medium effects depending on density (comovers) would be able to distinguish between them

ϒ(2S) and (3S) are strongly suppressed at LHC.
ϒ(1S) suppression is the same at RHIC and LHC, consistent with higher mass excited states suppression
No recombination, but some shadowing effects

Two sources of J/Ψ suppression in a hot medium:

B. Kopeliovich
QM2014

(i) Debye screening, i.e. weakening of the binding potential, which can lead to disappearance of the bound level (melting)

(ii) Color-exchange interactions of the c-cbar dipole with the medium, leading to a break-up of the colorless dipole (absorption).

Path integral technique

B.G.Zakharov & B.K. PRD44(1991)3466

$$\left[i\frac{d}{dz} - \frac{m_c^2 - \Delta_{r_?}}{E\ /2} - V_{\bar{q}q}(z, r_?) \right] G_{\bar{q}q}(z_1, r_{?1}; z, r_?) = 0$$

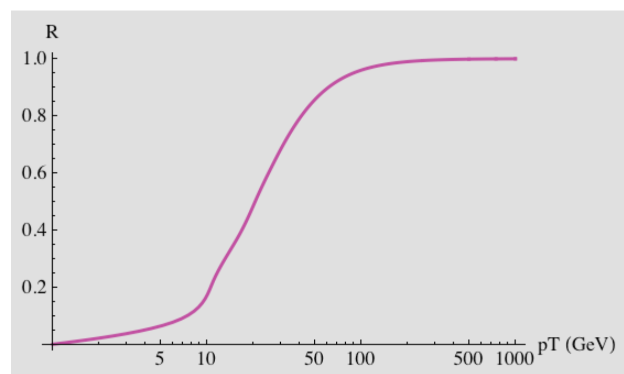
$$\mathrm{Im}V_{\bar{q}q}(z, r_?) = -\frac{v}{4}\hat{q}(z)\, r_?^2$$ Absoption q ≈3.6 T^3

Melting $\mathrm{Re}V_{\bar{q}q}(z, r)$

The melting scenario assumes that lacking a bound level the quarks fly away, resulting in disappearance of J/Ψ. However, the quark distribution amplitude still can be projected to the charmonium wave function.

Even in the extreme case of lacking any potential between c and c-bar (T -> ∞), still the J/Ψ can survive.

At large pT the medium becomes fully transparent, because the initial dipole size is “frozen”, and the projection to the J/Ψ wave function remains the same as in pp



CIM: Comover suppression and recombination

Capella, Bravina, Ferreiro, Kaidalov ,Tywoniuk, Zabrodin **Eur. Phys. J. C58 (2008) 437**

We modify the rate equation to include effects of **recombination** of c-cbar pairs in the comovers scenario

$$\tau \frac{dN^{J/\psi}}{d\tau}(b,s,y) = -\sigma\{N_{J/\psi}N^{co} - N_D N_{\bar{D}}\}$$

$$\tau \frac{\mathrm{d}N_{J/\psi}}{\mathrm{d}\tau}(b,s,y) = -\sigma_{co}\left[N^{co}(b,s,y)N_{J/\psi}(b,s,y) - N_c(b,s,y)N_{\bar{c}}(b,s,y)\right]$$

$$S^{co}(b,s,y) = \exp\left\{-\sigma_{co}\left[N^{co}(b,s,y) - \frac{N_c(b,s,y)N_{\bar{c}}(b,s,y)}{N_{J/\psi}(b,s,y)}\right]\ln\left[\frac{N^{co}(b,s,y)}{N_{pp}(0)}\right]\right\}$$

$$S^{co}(b,s,y) = \exp\left\{-\sigma_{co}\left[N^{co}(b,s,y) - C(y)n(b,s)S^{sh}_{HQ}(b,s)\right]\ln\left[\frac{N^{co}(b,s,y)}{N_{pp}(0)}\right]\right\}$$

$$C(y) = \frac{\left(\mathrm{d}N^{c\bar{c}}_{pp}/\mathrm{d}y\right)^2}{\mathrm{d}N^{J/\psi}_{pp}/\mathrm{d}y} = \frac{\left(\mathrm{d}\sigma^{c\bar{c}}_{pp}/\mathrm{d}y\right)^2}{\sigma_{pp}\,\mathrm{d}\sigma^{J/\psi}_{pp}/\mathrm{d}y}$$

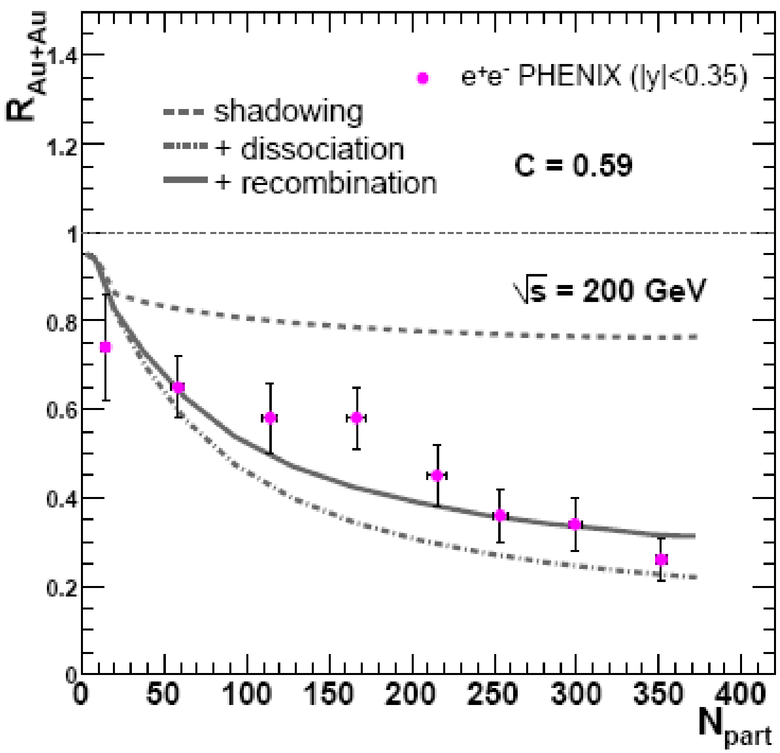
pp cross sections from experiments and PYTHIA

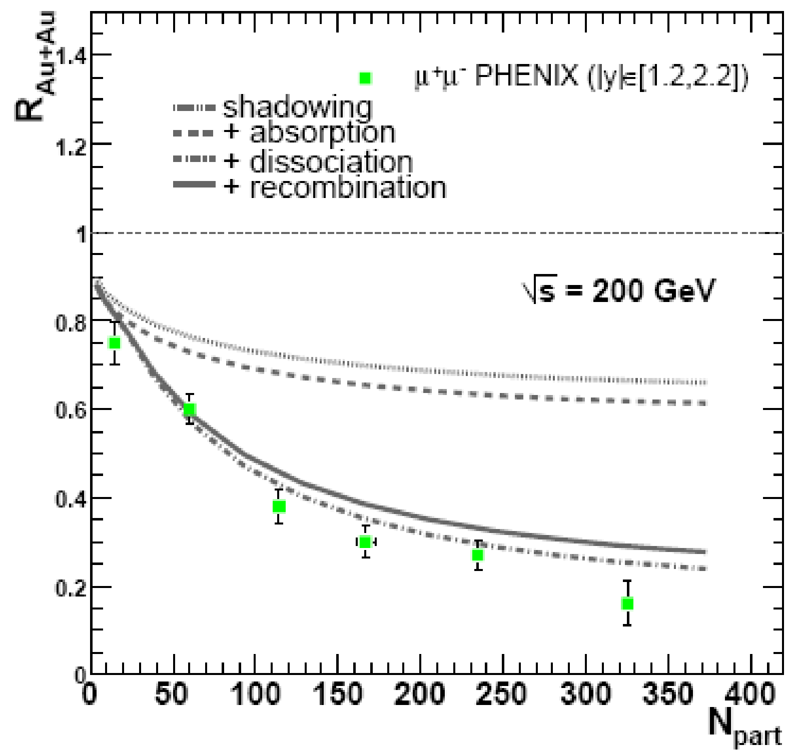
No free parameters

CIM: Comover suppression and recombination

Comparation to Au+Au @ RHIC data

Capella, Bravina, Ferreiro, Kaidalov, Tywoniuk, Zabrodin **Eur. Phys. J. C58 (2008) 437**





C=0.59 $\frac{d\sigma_{pp}^{c\bar{c}}}{dy}$ $123 \pm 12 \pm 45\ \mu\text{b}$

C=0.32 $\frac{d\sigma_{pp}^{c\bar{c}}}{dy}$ $70.9 \pm 14\ \mu\text{b}$

CIM describes properly the rapidity dependence of the suppression @ RHIC

Regeneration less relevant at forward rapidities

ψ(2S) and J/ψ in dAu @ RHIC: comover scenario

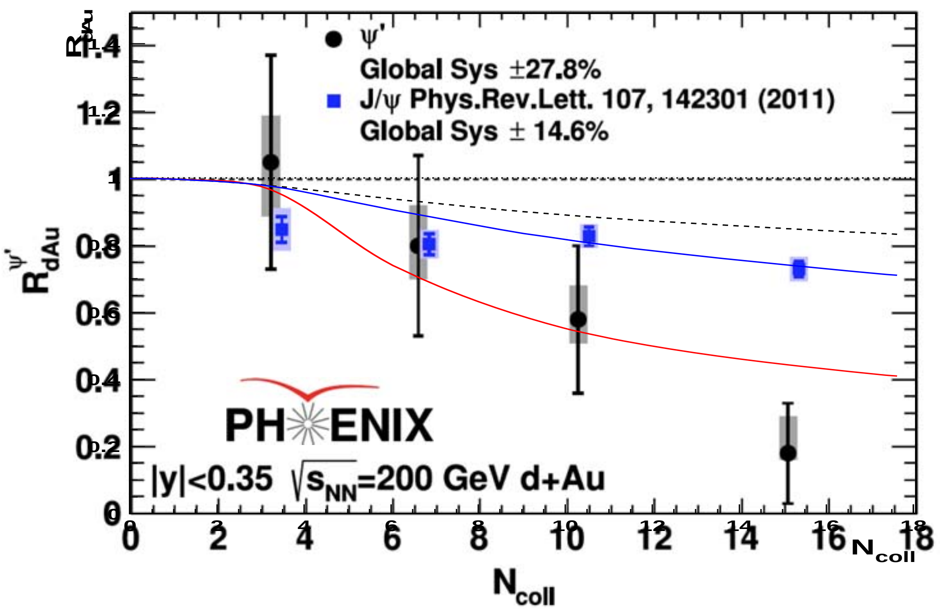
$$\tau \frac{\mathrm{d}N_{J/\psi}}{\mathrm{d}\tau}(b,s,y) = -\sigma_{co} N^{co}(b,s,y) N_{J/\psi}(b,s,y)$$

$$S^{\rm co}(b,s) = \exp\left[-\sigma_{\rm co} N^{\rm co}(b,s,y) \ln\left(N^{\rm co}(b,s,y)/N_{pp}(0)\right)\right]$$

- Identical shadowing for ψ(2S) and J/ψ
- J/ψ comover suppression σ_{co}= 0.65 mb (identical to the one used at SPS & LHC)

  PRL 85 (2000) 2080, PLB731 (2014) 57
- ψ(2S) comover suppression σ_{co}= 6 mb (identical to the one used at SPS & LHC)

  PLB430 (1998
- No recombination in any case



$[\psi(2S)/J/\psi]_{pPb}/[\psi(2S)/J/\psi]_{pp}$ vs. $[\psi(2S)/J/\psi]_{PbPb}/[\psi(2S)/J/\psi]_{pp}$