Bottomia suppression in PbPb collisions at the LHC

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Topics

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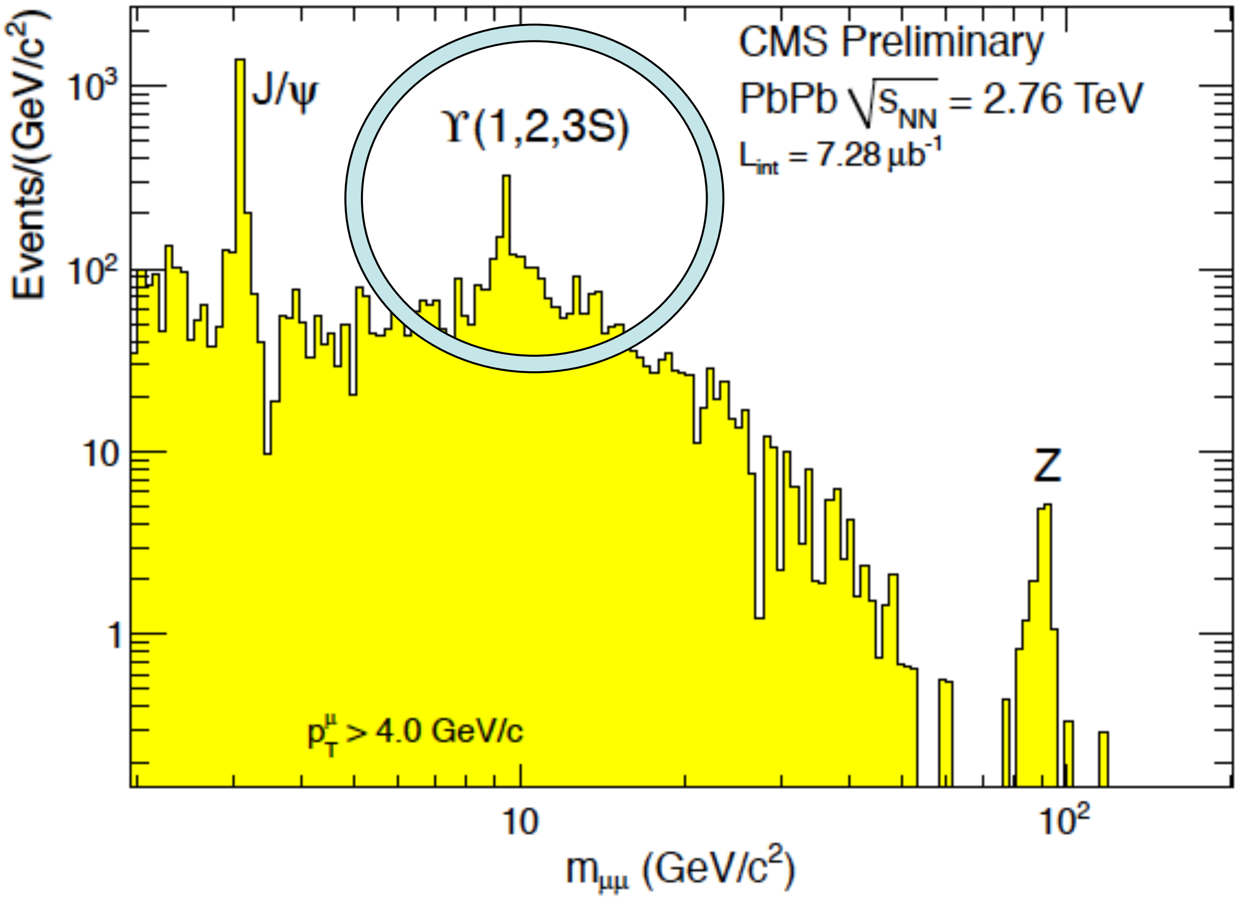
1. Introduction: Upsilon Suppression in PbPb @ LHC



Υ suppression as a sensitive probe for the QGP

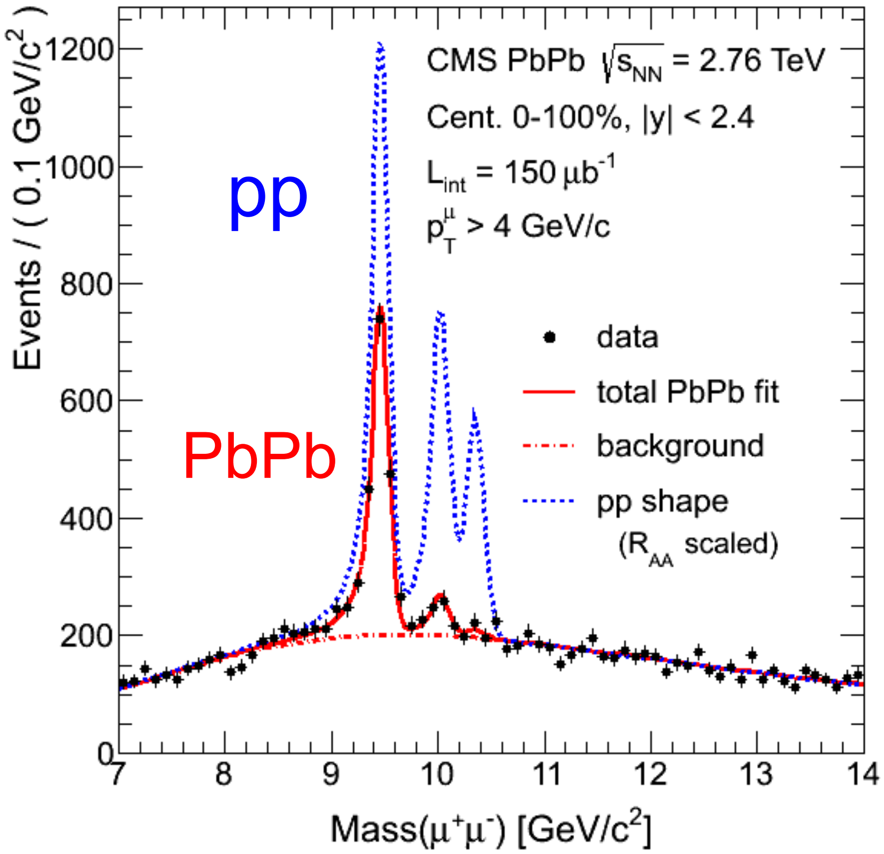
- No significant effect of regeneration
- $m_b \approx 3m_c$ ⇨ cleaner theoretical treatment
- More stable than J/ψ

$E_B(Y_{1S}) \approx 1.10$ GeV
$E_B(J/\psi) \approx 0.64$ GeV

CMS Collab., CMS-PAS-HIN-10-006 (2011)

Υ(nS) states are suppressed in PbPb @ LHC:

CMS



A clear QGP indicator

1. Υ(1S) ground state is suppressed in PbPb:

R_{AA} (Υ(1S)) = 0.56 ± 0.08 ± 0.07 in min. bias

2. Υ(2S, 3S) states are > 4 times stronger suppressed in PbPb than Υ(1S)

R_{AA}(Υ(2S)) = 0.12 ± 0.04 (stat.) ± 0.02 (syst.)

R_{AA}(Υ(3S)) = 0.03 ± 0.04 (stat.) ± 0.01 (syst.)

$$R_{AA} = \frac{N_{PbPb}(Q\bar{Q})}{N_{coll}N_{pp}(Q\bar{Q})}$$

CMS Collab., PRL 109, 222301 (2012)
[Plot from CMS database]

2. The model: Screening, Gludissociation and Collisional broadening of the Υ(nS) states

- Debye screening of all states involved: Static suppression

- The imaginary part of the potential (effect of collisions) contributes to the broadening of the Υ(nS) states: damping

- Gluon-induced dissociation: dynamic suppression, in particular of the Υ(1S) ground state due to the large thermal gluon density

- Reduced feed-down from the excited Υ/χ_b states to Υ(1S) substantially modifies the populations: indirect suppression

F. Vaccaro, F. Nendzig and GW, Europhys.Lett. 102, 42001 (2013); J. Hoelck and GW, unpublished
F. Nendzig and GW, Phys. Rev. C 87, 024911 (2013); J. Phys. G41, 095003 (2014)
F. Brezinski and GW, Phys. Lett.B 70, 534 (2012)

2.1 Screening and damping treated in a nonrelativistic potential model

$$V_{nl}(r,T) = -\frac{\sigma}{m_D(T)}e^{-m_D(T)r} - C_F\alpha_{nl}(T)\left(\frac{e^{-m_D(T)r}}{r} + iT\phi(m_D(T)r)\right)$$

$$\phi(x) = \int_0^\infty \frac{dz\,2z}{(1+z^2)^2}\left(1 - \frac{\sin xz}{xz}\right),\ m_D(T) = T\sqrt{4\pi\alpha_s(2\pi T)\frac{2N_c+N_f}{6}}$$

From the literature

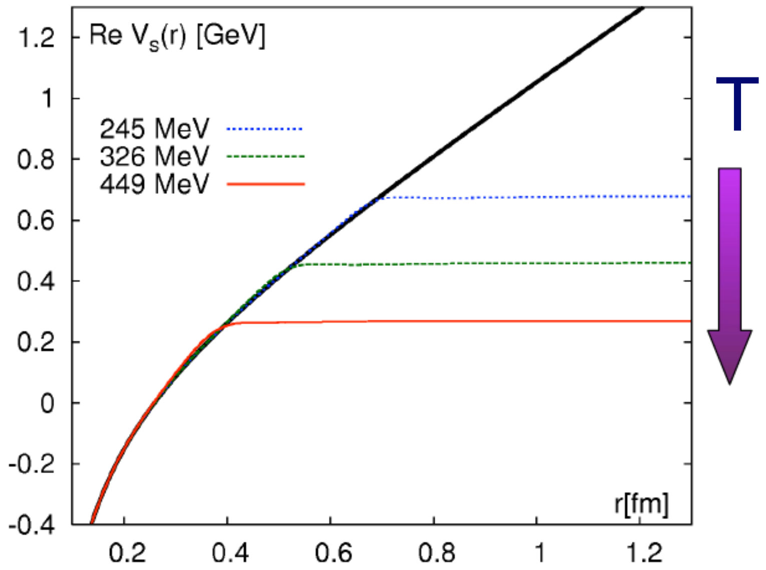
Screened potential: m_D = Debye mass,
$\alpha_{nl}(T)$ the strong coupling constant;
$C_F = (N_c^2 - 1) / (2N_c)$
$\sigma \approx 0.192$ the string tension (Jacobs et al.; Karsch et al.)

Imaginary part: Collisional damping (Laine et al. 2007, Beraudo et al. 2008, Brambilla et al. 2008) for $2\pi T \gg \langle 1/r \rangle$; different form for $2\pi T \ll \langle 1/r \rangle$.

Screened real part of potential, T-dep. imag. part

Constrain $\mathrm{Re}V_s(r)$ by lattice QCD data on the singlet free energy

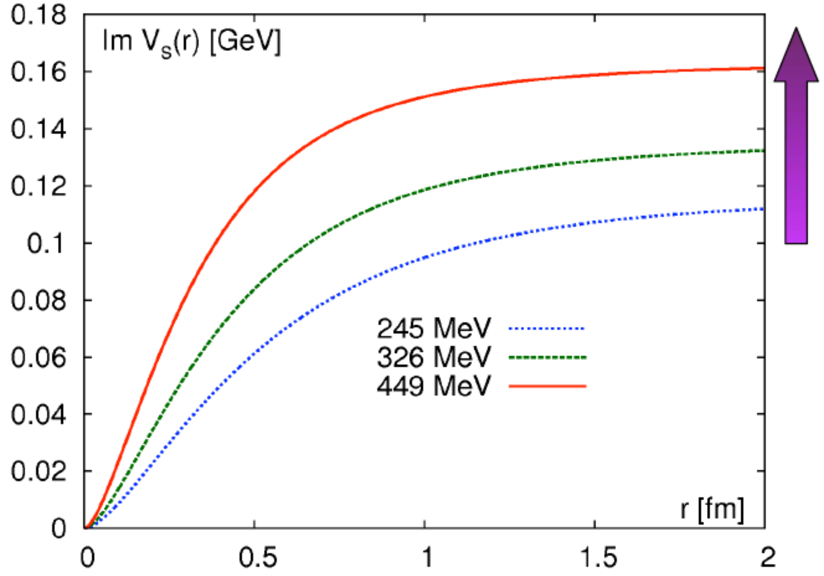
Maximal value



Mócsy, Petreczky, PRL 99 (07) 211602

Take $\mathrm{Im}V_s(r)$ from pQCD calculations

Minimal value



Burnier, Laine, Vepsalainen JHEP 0801 (08) 043
Beraudo, arXiv:0812.1130

Screening

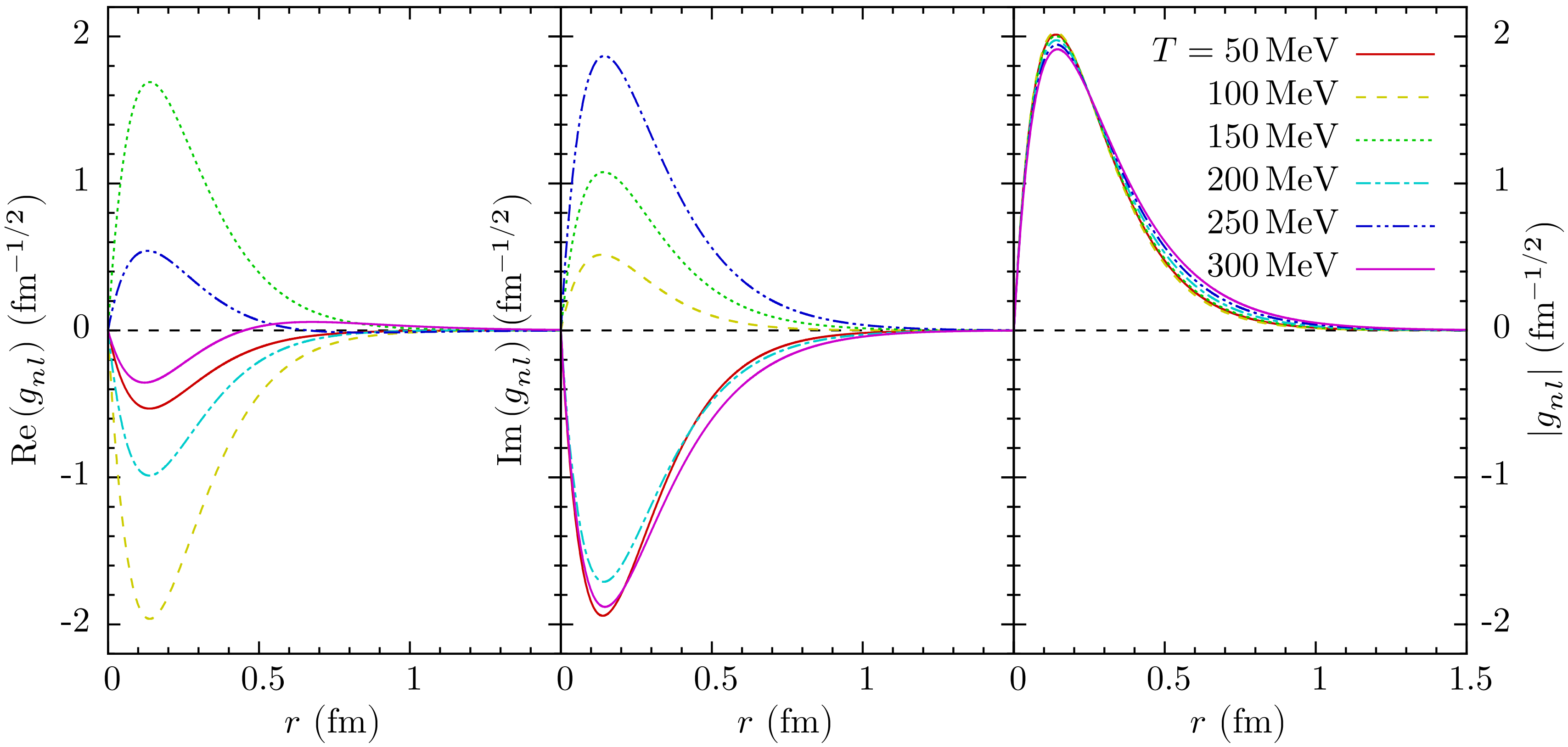
From: A. Mocsy et al.

Damping

Radial wave function of Υ(1S) at temperatures T

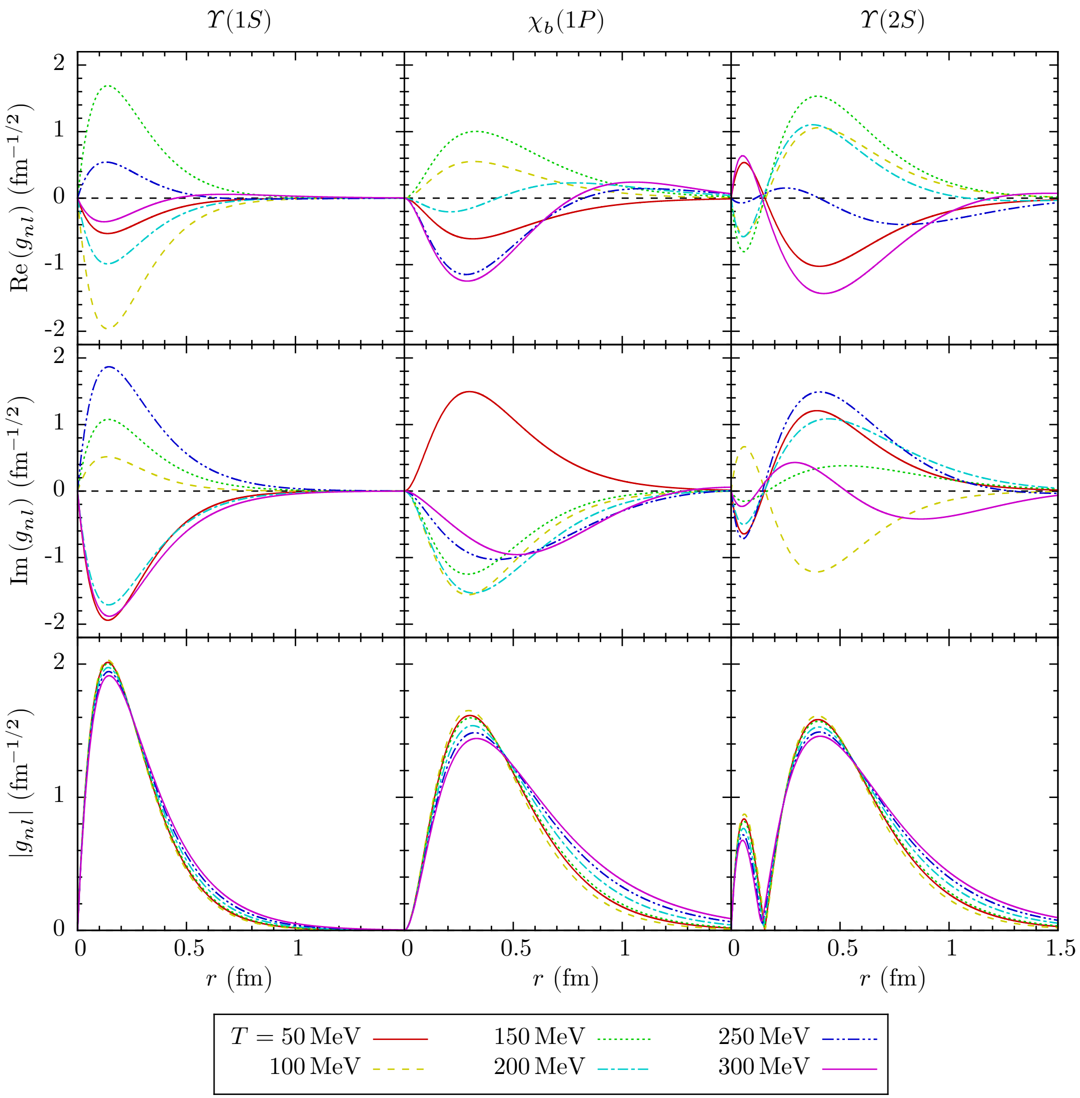
Solutions of the Schoedinger equation with complex potential V(r,T,α_s) for the radial wave functions g_{nl}(r,T),

$$[H(r,T,\alpha_s) - E + i\Gamma/2]g(r) = 0$$



From: J. Hoelck and GW, unpublished

Radial wave functions of $\Upsilon(nS)$, $\chi_b(nP)$ states



Calculate the damping widths $\Gamma_{damp}(T)$ for all six states

$\Upsilon(nS)$, $\chi_b(nP)$, n = 1, 2, 3

2.2 Cross section for gluodissociation

Born amplitude for the interaction of gluon clusters according to Bhanot&Peskin in dipole approximation / Operator product expansion, extended to include the screened coulombic + string eigenfunctions as outlined in Brezinski and Wolschin, PLB 70, 534 (2012)

$$\sigma_{diss}^{nS}(E) = \frac{2\pi^2\alpha_s E}{9} \int_0^\infty dk\, \delta\left(\frac{k^2}{m_b} + \epsilon_n - E\right) |w^{nS}(k)|^2$$

$$w^{nS}(k) = \int_0^\infty dr\, r\, g_{n0}^s(r) g_{k1}^a(r)$$

for the Gluodissociation cross section of the Y(nS) states, and correspondingly for the χ_b(nP) states.

Gludissociation cross section

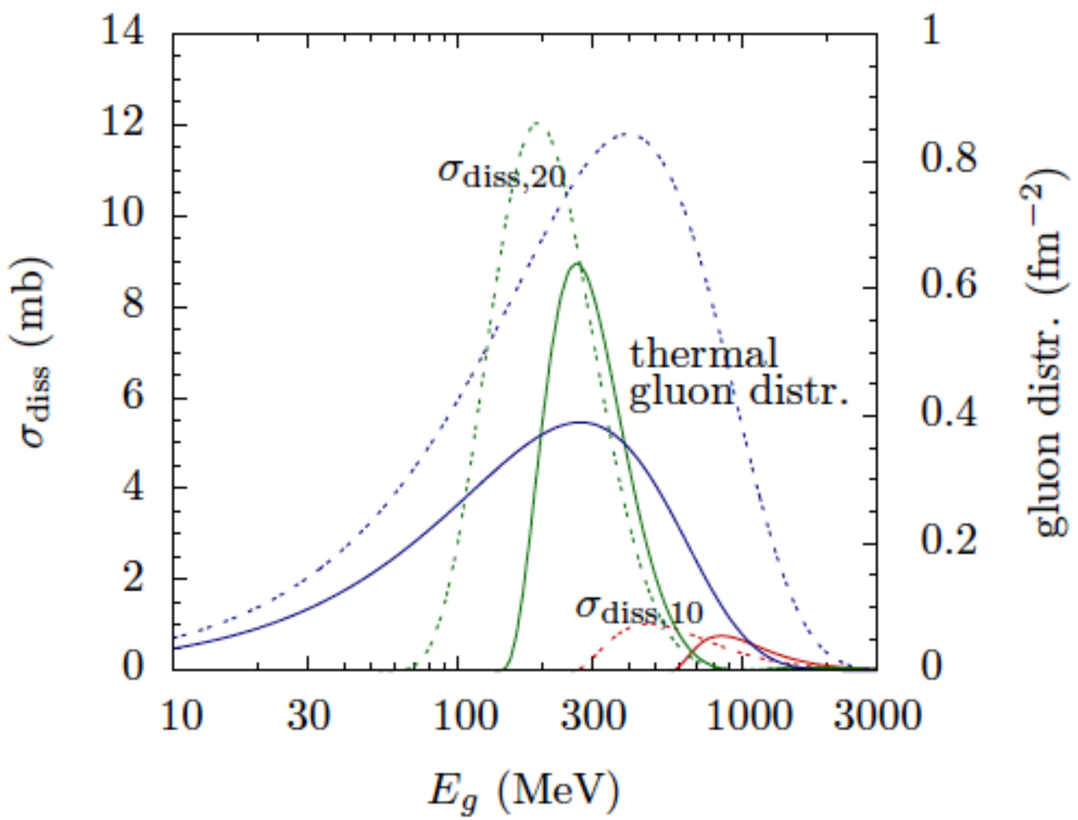


Figure 3. Gludissociation cross section σ_{diss} (left scale) of the $\Upsilon(1S)$ and $\Upsilon(2S)$ and the thermal gluon distribution (right scale) plotted for temperature $T = 170$ (solid curves) and 250 MeV (dotted curves) as functions of the gluon energy E_g.

F. Nendzig and GW, J. Phys. G41, 095003 (2014)

Thermal gluodissociation cross section

Average the gluodissociation cross section over the Bose-Einstein distribution of the thermal gluons in the QGP to obtain the dissociation width at temperature T for each of the six bottomia states involved

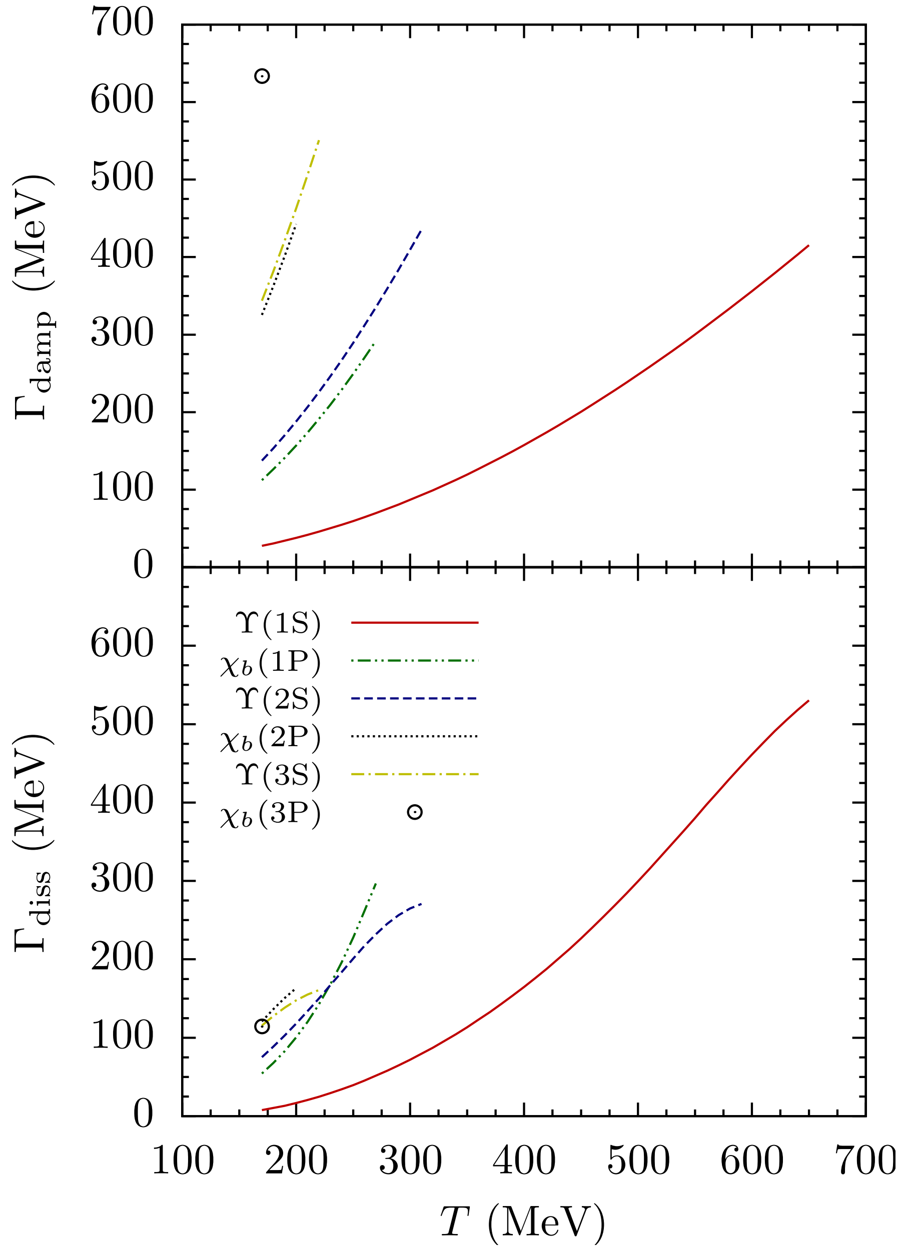
$$\Gamma_{\mathrm{diss},\,nl}(T) \equiv \frac{g_d}{2\pi^2} \int_0^\infty \frac{\mathrm{d}E_g\, E_g^2\, \sigma_{\mathrm{diss},\,nl}\left(E_g\right)}{\mathrm{e}^{E_g/T} - 1}$$

($g_d = 16$)

With rising temperature, the peak of the gluon distribution moves to larger gluon energies E_g, whereas the dissociation cross sections move to smaller E_g, giving rise to a maximum in the gluodissociation width for fixed coupling α_s.
(Larger cross sections at higher temperatures due to running coupling counteract.)

Damping and gluodissociation widths for six bottomia states

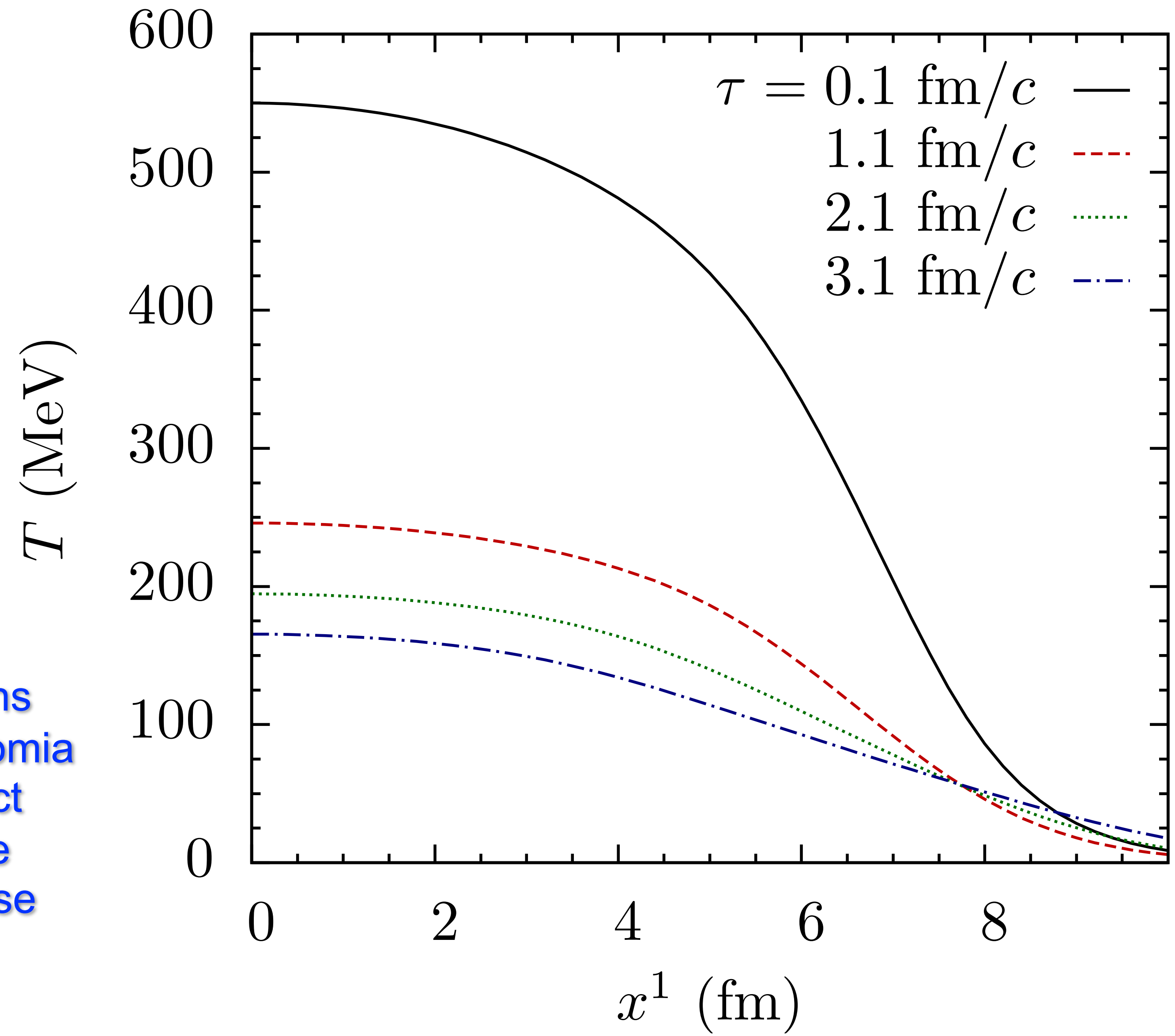
$$\Gamma_{tot}(T) = \Gamma_{damp}(T) + \Gamma_{diss}(T)$$



F. Nendzig and GW, J. Phys. G41, 095003 (2014) ; arXiv:1406.5103

2.3 Hydrodynamic expansion (ideal)

Temperature profile for central collisions at different times τ



Use total decay widths $\Gamma_{tot}(b,x,y)$ of the bottomia states for each impact parameter b and time step t in the transverse (x^1,x^2) plane

Dynamical fireball evolution

Dependence of the local temperature T on impact parameter b, time t, and transverse coordinates x, y evaluated in ideal hydrodynamic calculation with transverse expansion

$$T(b, \tau_{init}, x^1, x^2) = T_0 \left(\frac{N_{mix}(b, x^1, x^2)}{N_{mix}(0,0,0)} \right)^{1/3}$$

$$N_{mix} = \frac{1-f}{2} N_{part} + f N_{coll}, \qquad f = 0.145$$

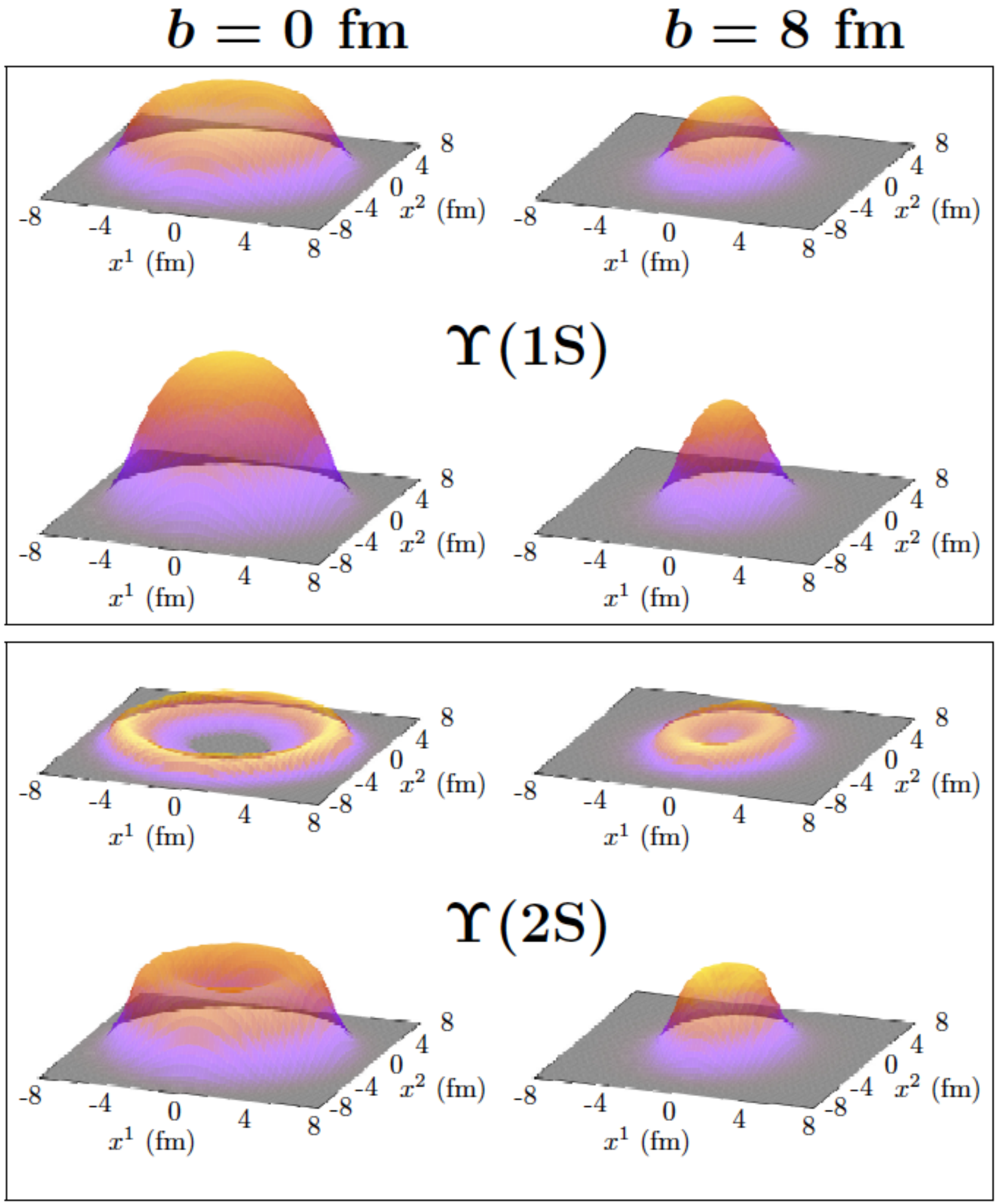
The number of produced $b\bar{b}$-pairs is proportional to the number of binary collision, and the nuclear overlap

$$N_{b\bar{b}}(b,x,y) \propto N_{\rm coll}(b,x,y) \propto T_{AA}(b,x,y)$$

QGP suppression factor (without feed-down and CNM effects):

$$R_{AA}^{QGP} = \frac{\int d^2b \int dx dy \, T_{AA}(b,x,y) \, e^{-\int_{t_F}^{\infty} dt \, \Gamma_{\rm tot}(b,t,x,y)}}{\int d^2b \int dx dy \, T_{AA}(b,x,y)}$$

Integrand in the transverse plane



p_T = 0

p_T = 12 GeV/c

p_T = 0

p_T = 12 GeV/c

J. Phys. G41, 095003 (2014)

2.4 Feed-down cascade including χ_{nP} states

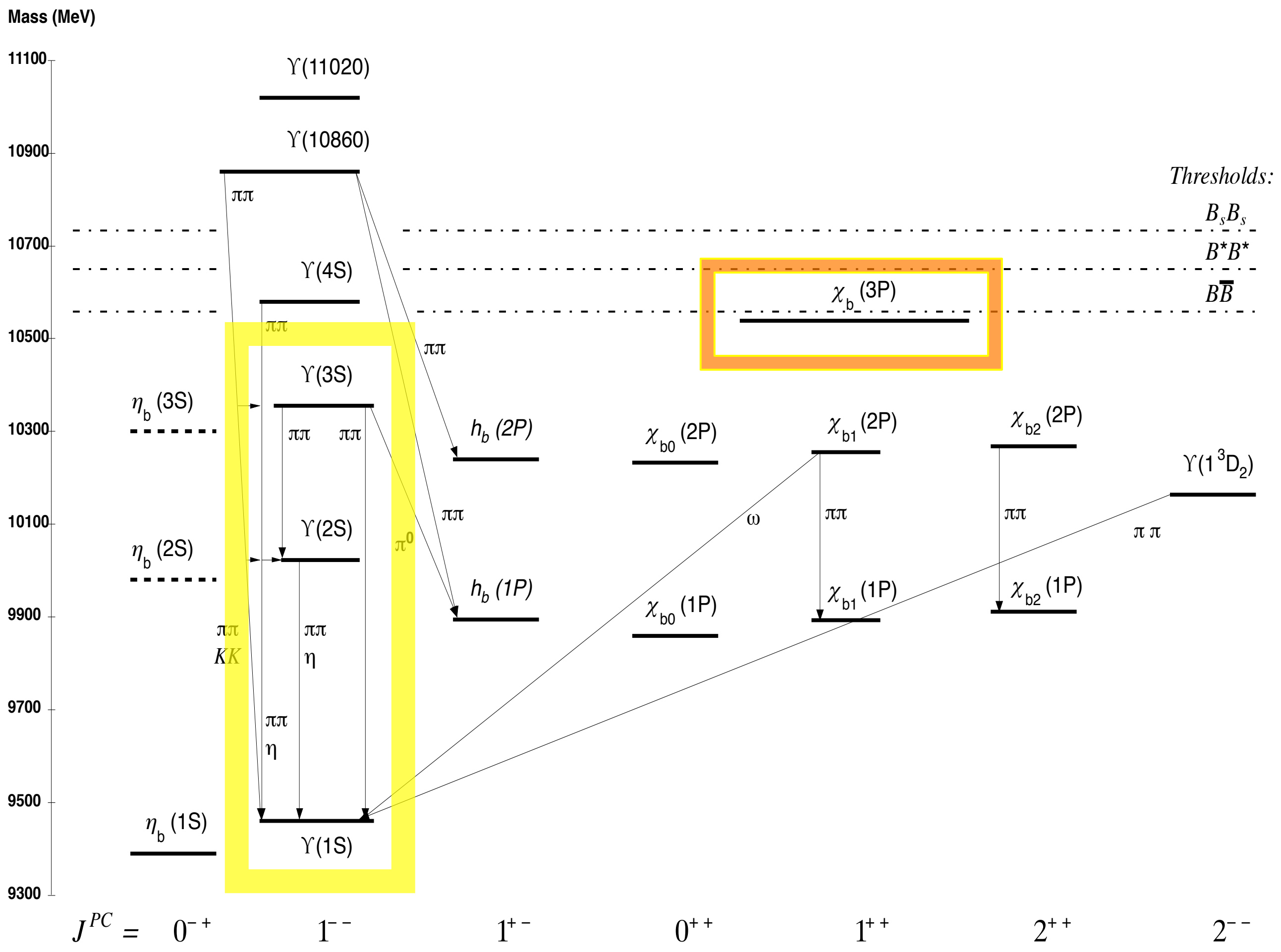
Relative initial populations in pp computed using an inverted cascade from the final populations measured by CMS and CDF(χ_b) [N_{final}(1S):=1]

$N_{initial}$

3S: 0.387

2S: 0.371

1S: 0.458



$N_{initial}$

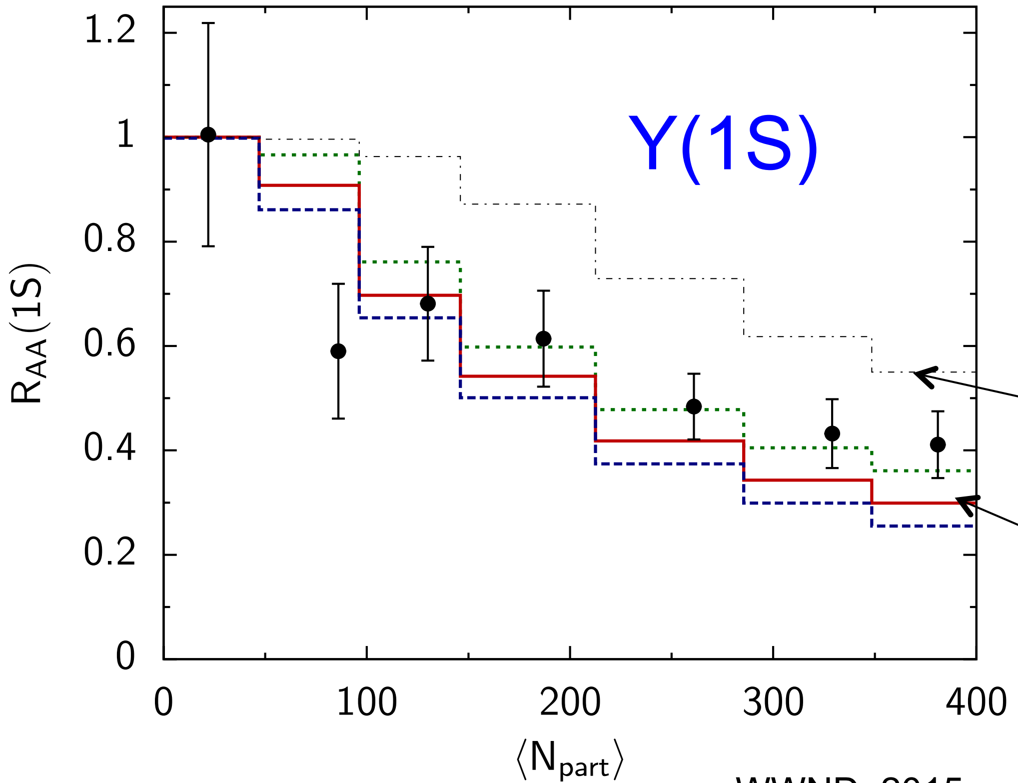
2P: 0.976

1P: 1.29

3. Theoretical vs. exp. (CMS) Suppression factors

- Screening (potential model)
- Gluodissociation (OPE with string tension included)
- Collisional damping (imaginary part of potential)
- Reduced feed-down from excited states

t_F: Υ formation time
t_{QGP}: QGP lifetime
T_{max} @ t_F: 200-800 MeV



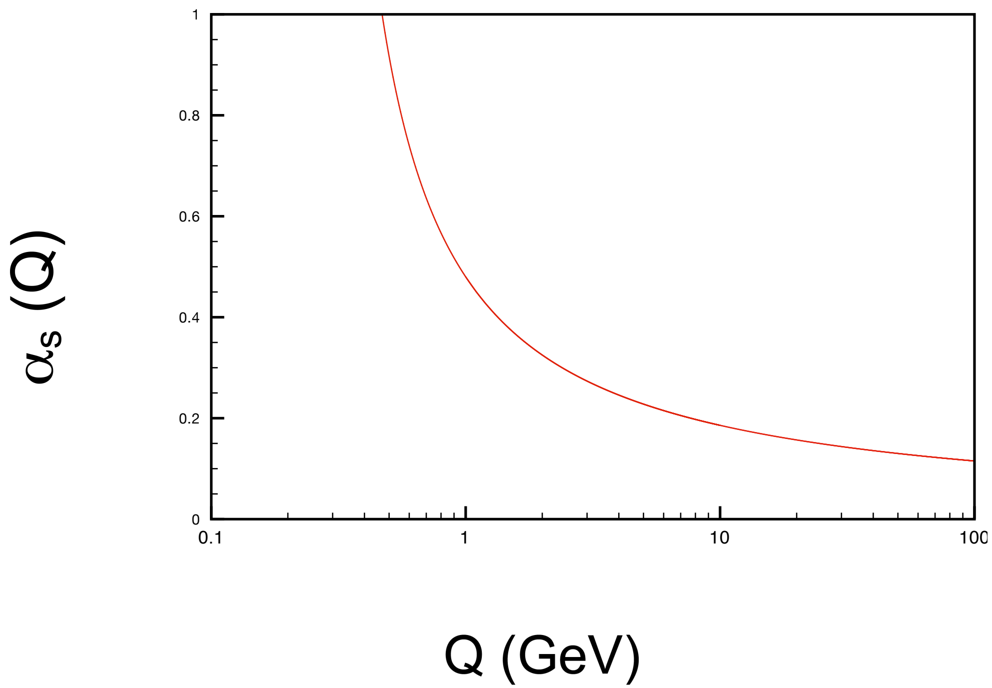
t_F= 0.1 fm/c
t_{QGP}= 4, 6, 8 fm/c

QGP suppression

with modified feed-down cascade

F. Nendzig and GW, Phys. Rev. C 87, 024911 (2013)

Recent model upgrades



2014: Substantial improvements of the model

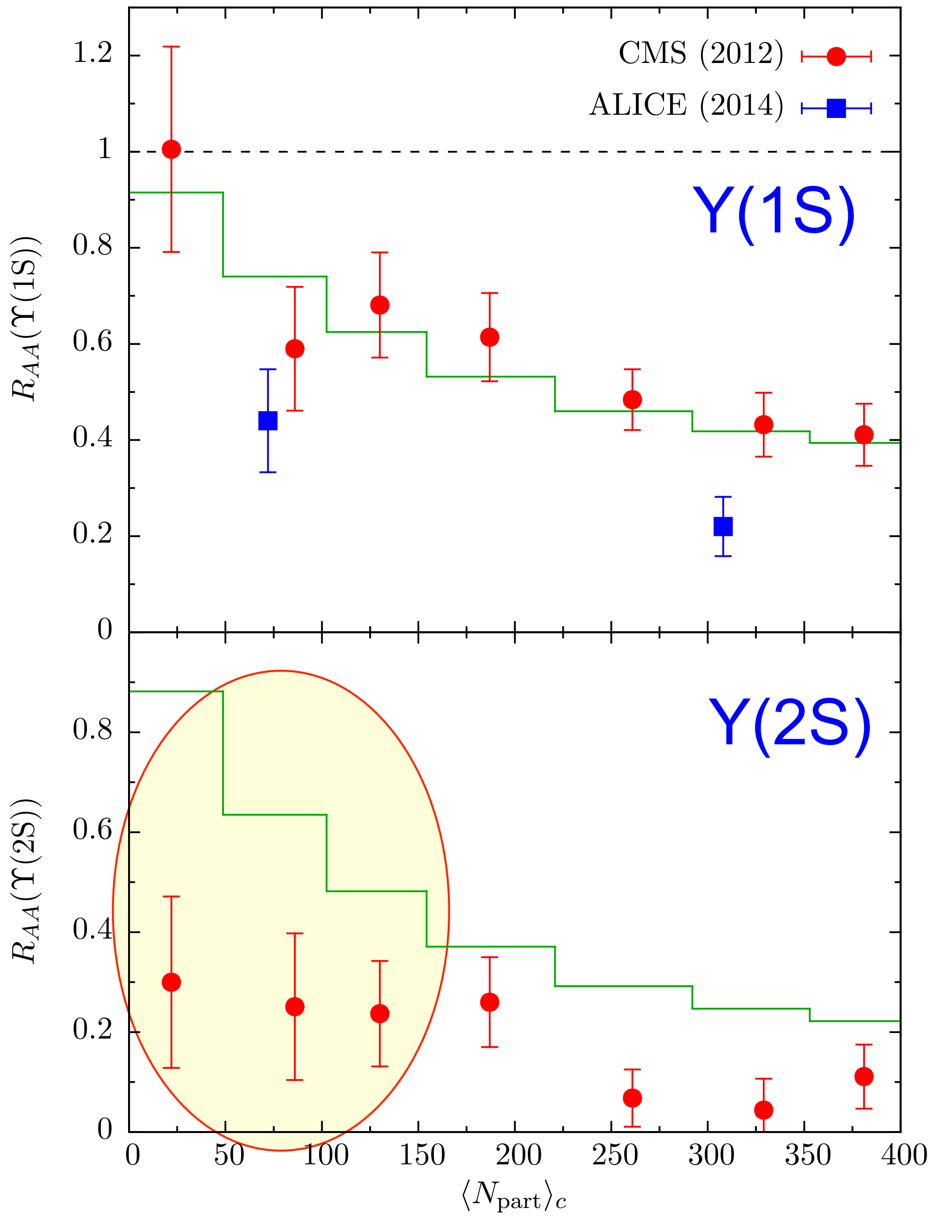
- Consider running of the coupling
- Transverse momentum of the Υ included
- Relativistic Doppler effect
- Improved initial conditions
- T_c = 160 MeV

$$\alpha_s(Q) = \frac{\alpha(\mu)}{1 + \alpha(\mu) b_0 \ln \frac{Q}{\mu}}, \qquad b_0 = \frac{11N_c - 2N_f}{6\pi}$$

F. Nendzig and GW, J. Phys. G41, 095003 (2014)

$\alpha_{nl}(T)$ depends on the solution $g_{nl}(r,T)$ of the Schroedinger eq.: Iterative solution

Theoretical vs. exp. (CMS) Suppression factors



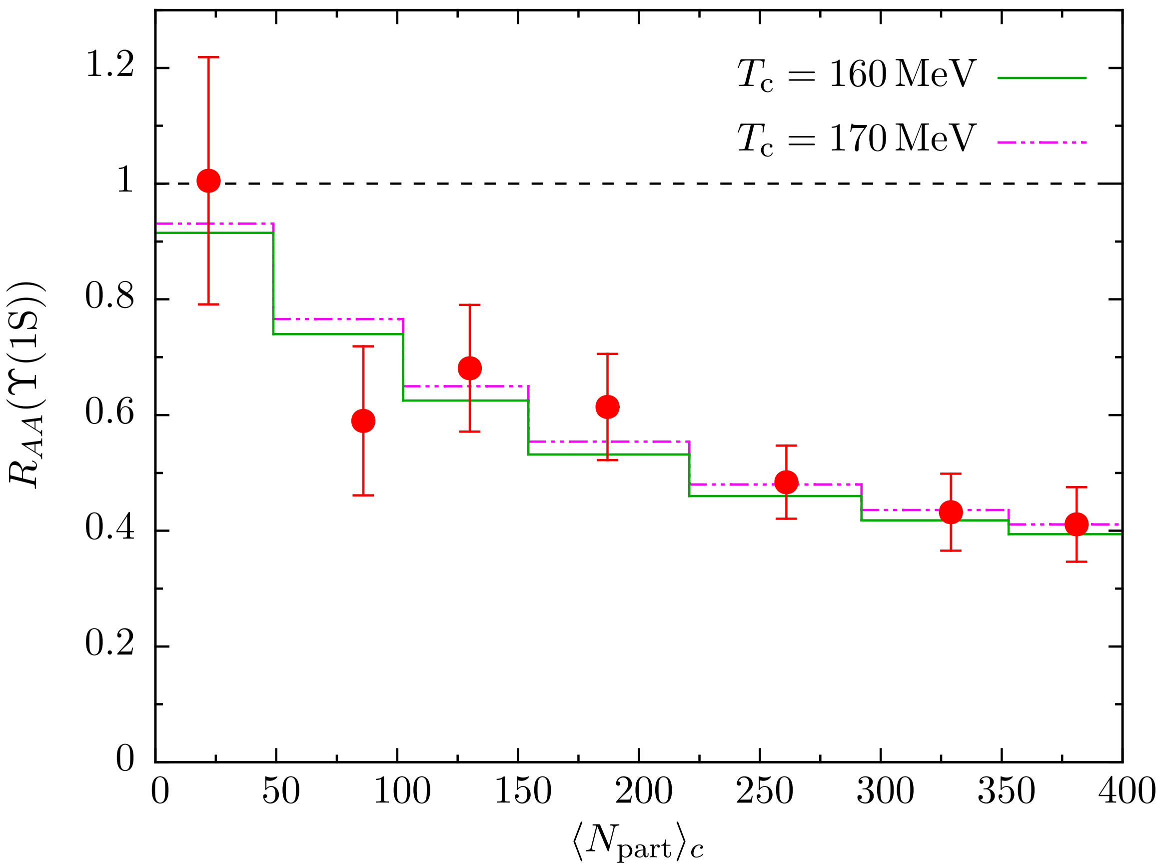
2014: upgraded model

t_F= 0.4 fm/c: Y formation time
T_{max}= 550 MeV: central temp. at b = 0 and t = t_F

Room for additional suppression mechanisms for the excited states: Hadronic dissociation, mostly by pions, is one possibility. Thermal pions are insufficient; direct pions may contribute, and magnetic dissociation.

F. Nendzig and GW, J. Phys. G41, 095003 (2014); J. Hoelck and GW, unpublished

Dependence on T_c at 2.76 TeV

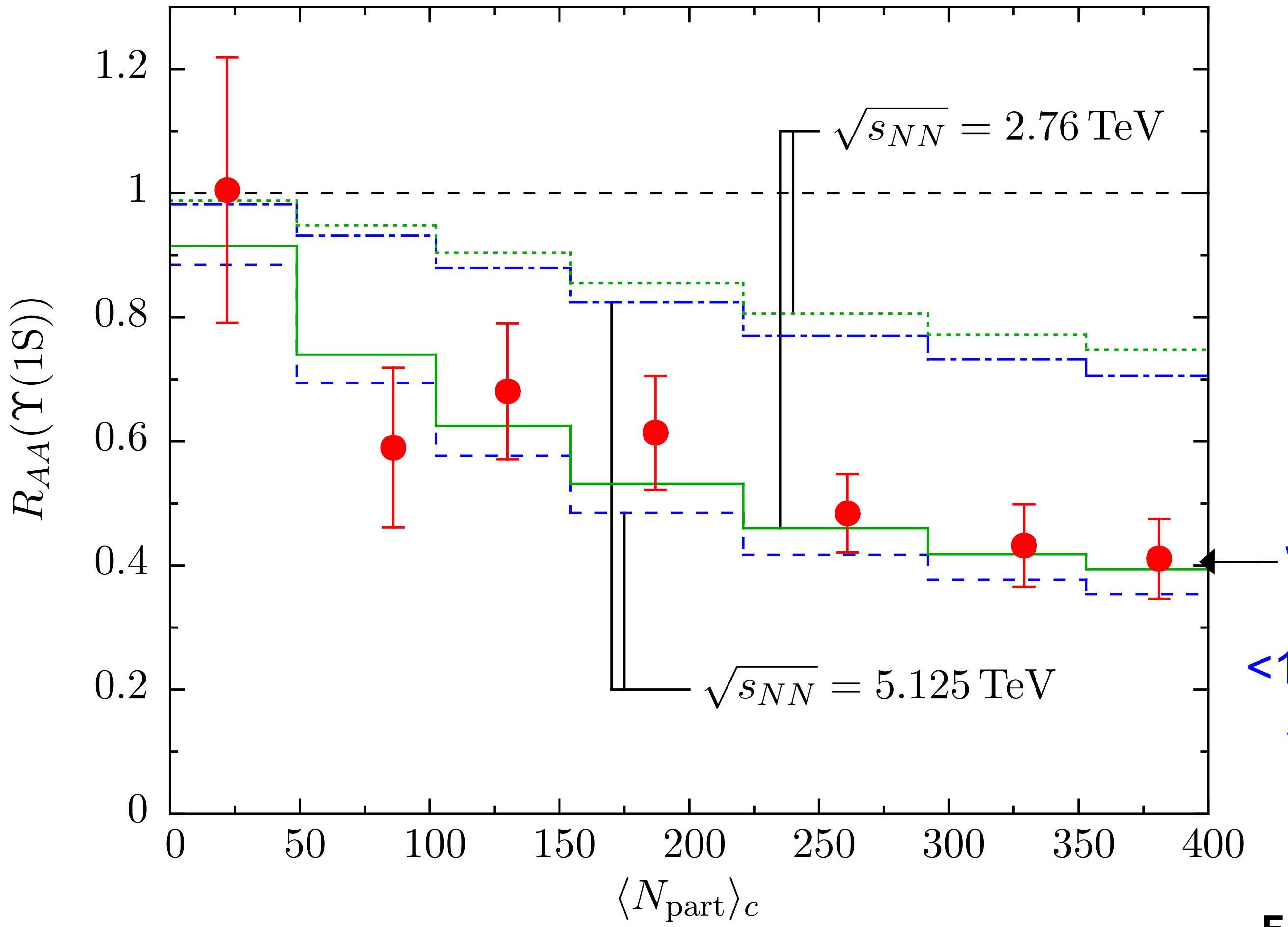


Enhanced suppression for smaller T_c: QGP-induced dissociation processes act longer. But: the effect is small.

< 5% higher suppression for T_c = 160 MeV vs 170 MeV

F. Hoelck and GW, unpublished

4. Prediction for Υ(1S) suppression at 5.125 TeV



t_F: Y formation time
T_{max} @ t_F: 579 MeV

t_F= 0.4 fm/c; use

$$s_0 \propto dN_{ch}/d\eta \propto T_0^3$$

with reduced feed-down

<10% higher suppression at 5.125 TeV vs 2.76 TeV

F. Hoelck and GW, unpublished

5. Conclusion Upsilon suppression

- The suppression of the Υ(1S) ground state in PbPb collisions at LHC energies through gluodissociation, damping, screening, and reduced feed-down has been calculated for min. bias, and as function of centrality, and is found to be in good agreement with the CMS result. Screening is not decisive for the 1S state except for central collisions.

- The enhanced suppression of the Υ(2S, 3S) relative to the 1S state in PbPb as compared to pp collisions at LHC energies (CMS) leaves room for additional suppression mechanisms, in particular for peripheral collisions where discrepancies to the CMS data persist. Hadronic and/or magnetic dissociation of the excited states may be relevant.

Thank you for your attention !