Bottomonium thermal limit in the KSU approach

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Suppression and (re)generation of quarkonium in heavy-ion collisions at the LHC

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U.S. DEPARTMENT OF ENERGY

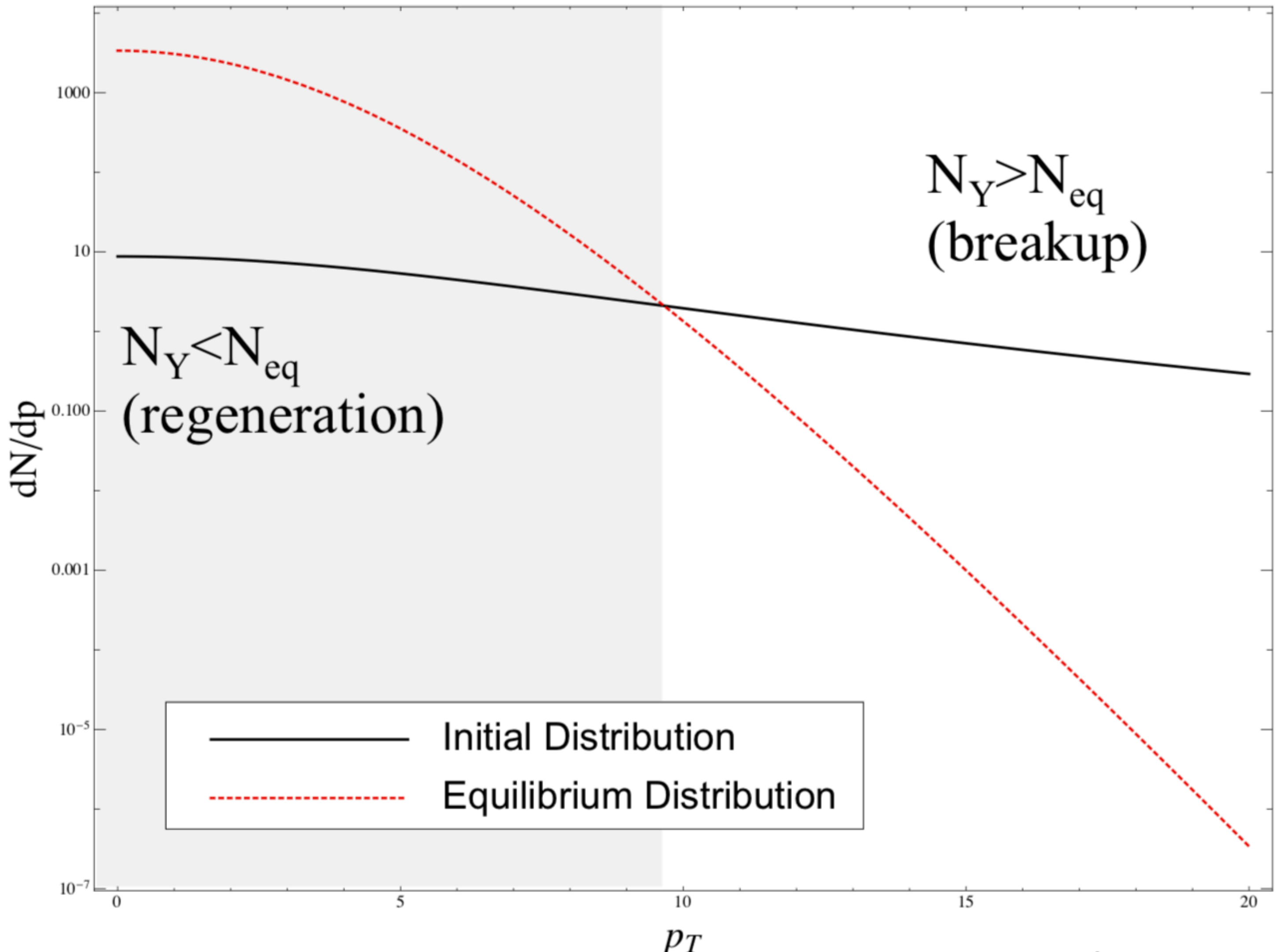
Including regeneration

- In my former student Brandon's dissertation he included regeneration by generalizing the TAMU prescription X. Du, R. Rapp, and M. He, (2017), arXiv:1706.08670 [hep-ph].

$$\frac{dn(\tau,\mathbf{x})}{d\tau} = -\Gamma(\tau,\mathbf{x})\Big[n(\tau,\mathbf{x}) - n_{\rm eq}(T(\tau,\mathbf{x}))\Big],$$

$$f_{\rm eq} = \frac{3}{(2\pi)^3}\gamma^2 {\rm Exp}\left[-\cosh(y)\sqrt{p_T^2+m^2}/T(\xi,\Lambda)\right],$$

- Once σ_{qqbar} is scaled to heavy-ion collisions with N_{coll}, we divide by the total inelastic cross section to determine the number of q qbar pairs one expects in a heavy-ion collision.



1000
10
0.100
0.001
10^{-5}
10^{-7}
dN/dp
0
5
10
15
20
p_T
$N_Y > N_{eq}$
(breakup)
$N_Y < N_{eq}$
(regeneration)
Initial Distribution
Equilibrium Distribution

*Cartoon

Fugacity computation

- Within f_{eq} is a fugacity factor γ_q which dictates the amount of local regeneration in the plasma
- The first task is to derive γ_q as a function of the local effective temperature, T

Braun-Munzinger, Stachel, arXiv: 0007059 [nucl-th]

$$N_{q\bar{q}} = \frac{1}{2} N_{\rm op} \frac{I_1(N_{op})}{I_0(N_{op})} + N_{\rm hid},$$

$$N_{\rm op} = \gamma_q V_{\rm coll} d_b \int \frac{d^3p}{(2\pi)^3} f^q(p;T),$$

$$N_{\rm hid} = \gamma_q^2 V_{\rm coll} \sum_{\rm states} d_{\rm states} \int \frac{d^3p}{(2\pi)^3} f^{\rm states}(p;T),$$

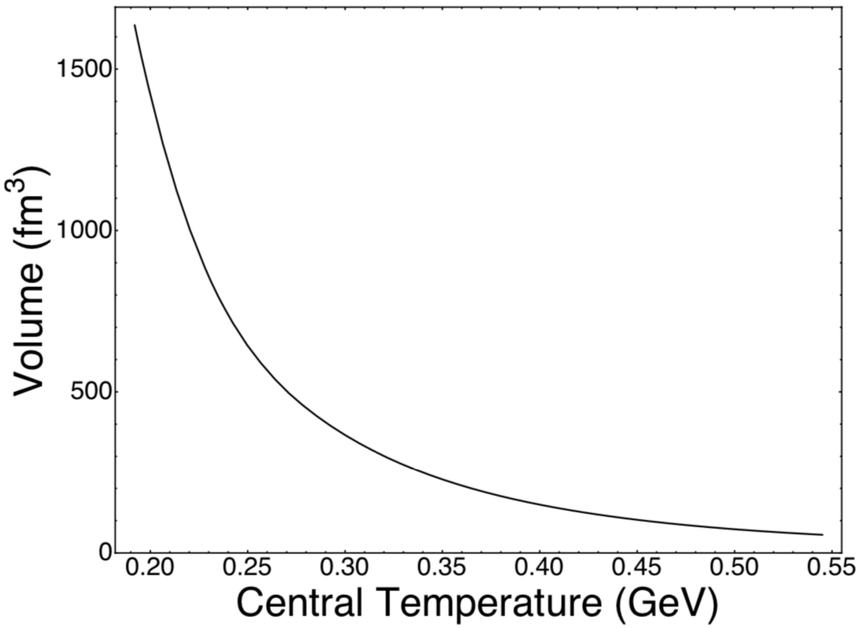
Full Cross Section $\sigma_{b\bar{b}}$	0.2 TeV	2.76 TeV	5.02 TeV
pp $\to b\bar{b} + X$ [μb] ($\lvert y \rvert < 0.5$)	0.92	-	-
pp $\to b\bar{b} + X$ [μb] ($\lvert y \rvert < 2.4$)	-	82.56	156.96
pp $\to b\bar{b} + X$ [μb] ($2.5 < y < 4.0$)	-	12.90	24.60

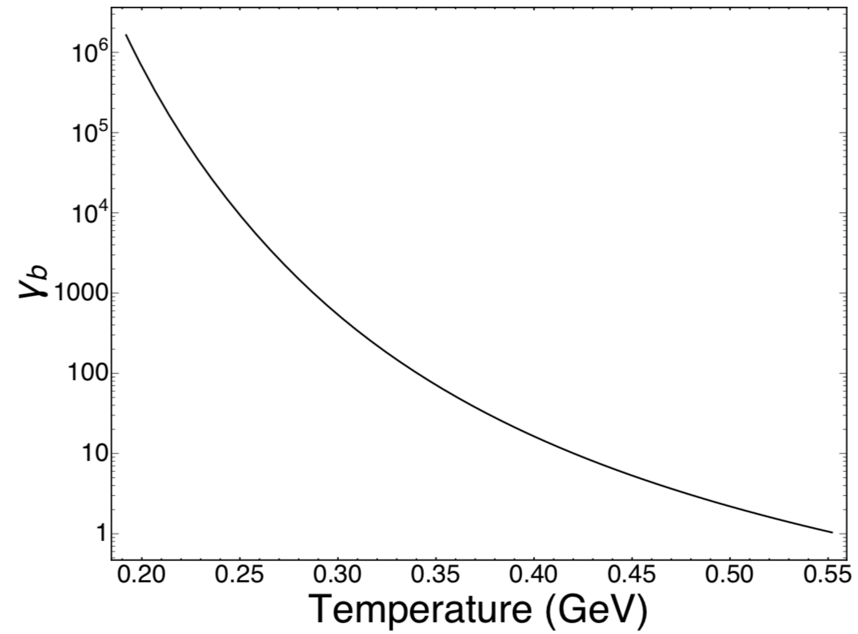
TABLE I. $b\bar{b}$ production cross sections for various experimental windows in rapidity.

Fugacity computation example

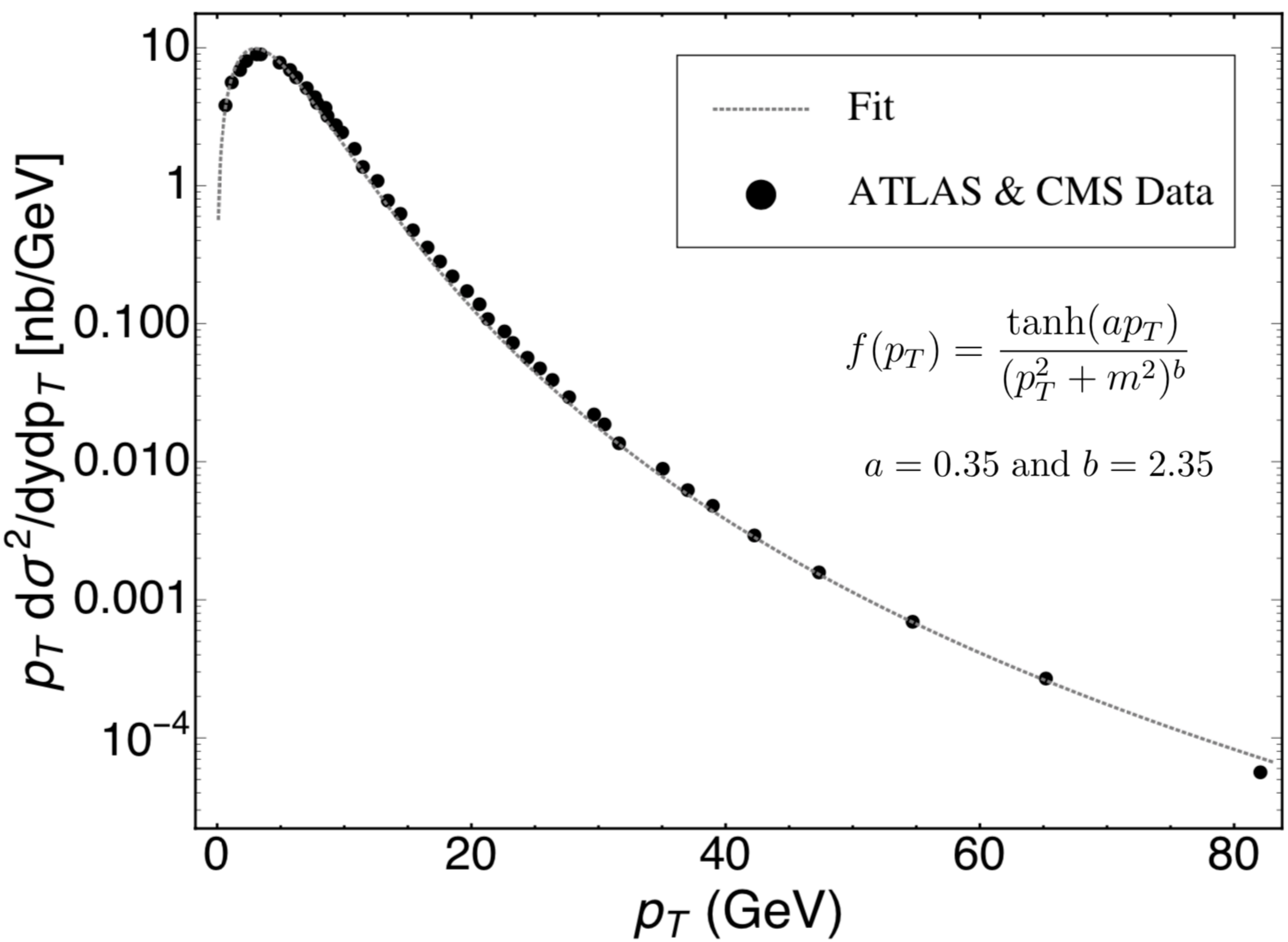
$$N_{q\bar{q}} = \frac{1}{2} N_{\rm op} \frac{I_1(N_{op})}{I_0(N_{op})} + N_{\rm hid},$$

$$N_{\rm op} = \gamma_q V_{\rm coll} d_b \int \frac{d^3p}{(2\pi)^3} f^q(p;T), \qquad N_{\rm hid} = \gamma_q^2 V_{\rm coll} \sum_{\rm states} d_{\rm states} \int \frac{d^3p}{(2\pi)^3} f^{\rm states}(p;T),$$





Initial conditions 1

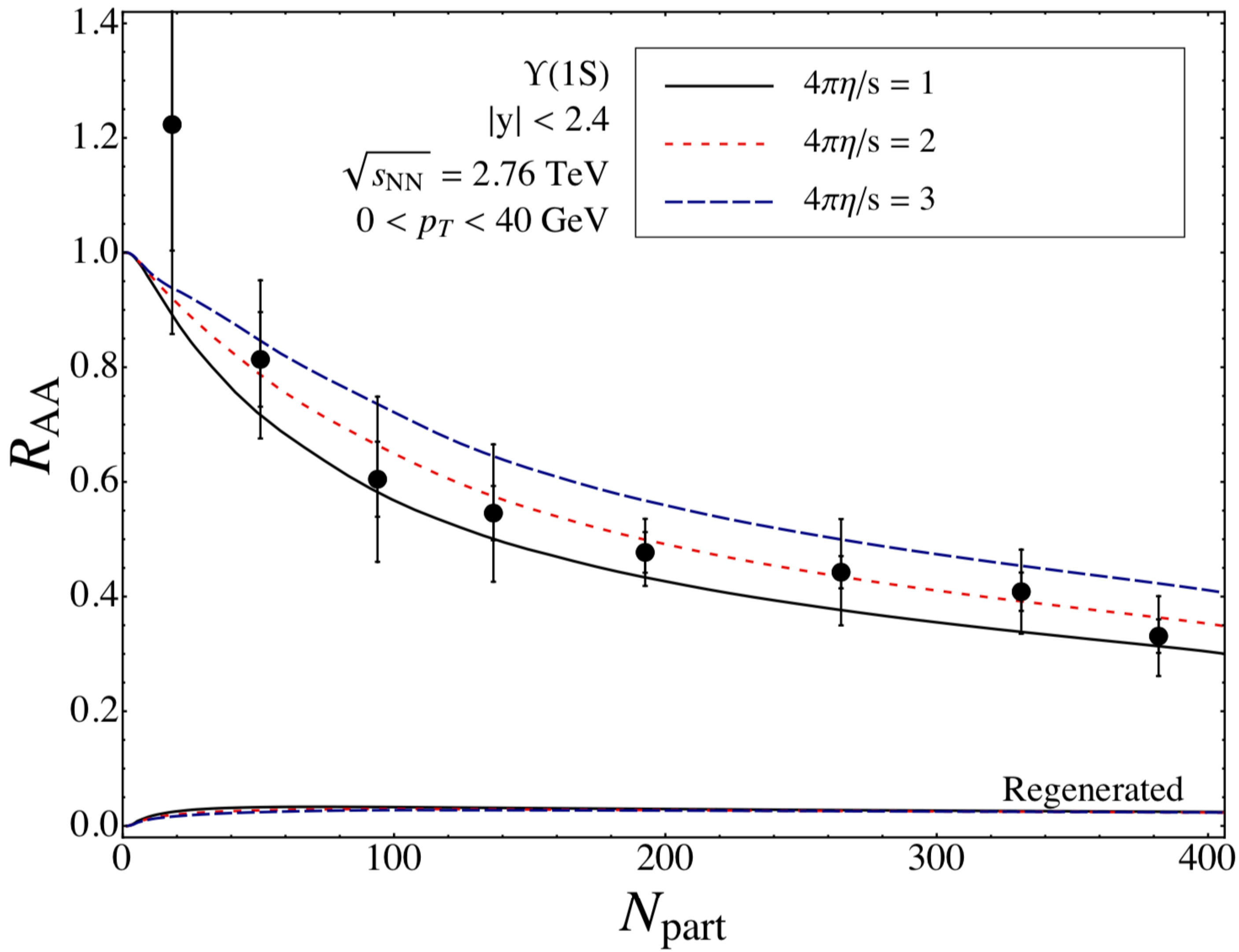


Initial conditions 2

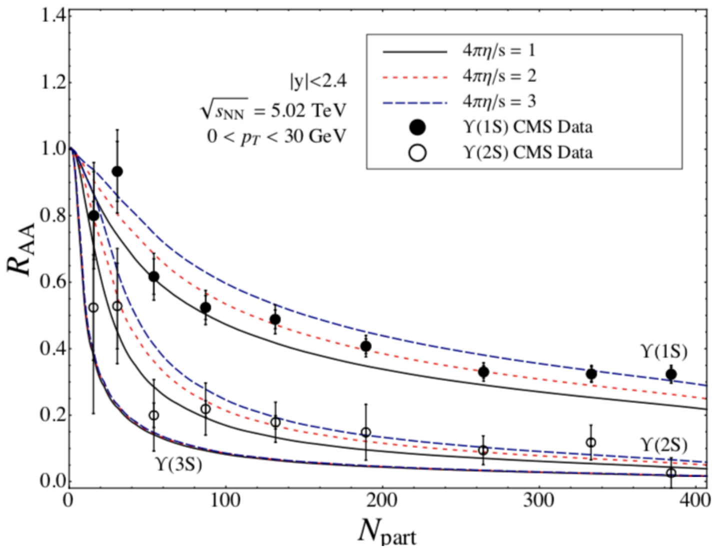
Full Cross Section	0.2 TeV	2.76 TeV	5.02 TeV
pp $\to \Upsilon(1S)$ ($\|y\| < 0.5$) [nb]	2.35	-	-
pp $\to \Upsilon(1S)$ ($\|y\| < 2.4$) [nb]	-	145.44	276.48
pp $\to \Upsilon(1S)$ ($2.5 < y < 4.0$) [nb]	-	22.65	43.20
pp $\to \Upsilon(2S)$ ($\|y\| < 0.5$) [nb]	0.77	-	-
pp $\to \Upsilon(2S)$ ($\|y\| < 2.4$) [nb]	-	48.00	91.20
pp $\to \Upsilon(2S)$ ($2.5 < y < 4.0$) [nb]	-	7.50	14.25
pp $\to \Upsilon(3S)$ ($\|y\| < 0.5$) [nb]	0.13	-	-
pp $\to \Upsilon(3S)$ ($\|y\| < 2.4$) [nb]	-	0.01	0.02
pp $\to \Upsilon(3S)$ ($2.5 < y < 4.0$) [nb]	-	0.002	0.003
pp $\to \chi_b(1P)$ ($\|y\| < 0.5$) [nb]	0.40	-	-
pp $\to \chi_b(1P)$ ($\|y\| < 2.4$) [nb]	-	24.72	47.00
pp $\to \chi_b(1P)$ ($2.5 < y < 4.0$) [nb]	-	3.85	7.34
pp $\to \chi_b(2P)$ ($\|y\| < 0.5$) [nb]	0.12	-	-
pp $\to \chi_b(2P)$ ($\|y\| < 2.4$) [nb]	-	7.27	13.82
pp $\to \chi_b(2P)$ ($2.5 < y < 4.0$) [nb]	-	1.13	2.16
pp $\to \chi_b(3P)$ ($\|y\| < 0.5$) [nb]	0.02	-	-
pp $\to \chi_b(3P)$ ($\|y\| < 2.4$) [nb]	-	1.09	2.07
pp $\to \chi_b(3P)$ ($2.5 < y < 4.0$) [nb]	-	0.16	0.32

TABLE II. Bottomonium state cross sections for $\Upsilon(nS)$ and $\chi_b(mP)$ states in various experimental windows in rapidity.

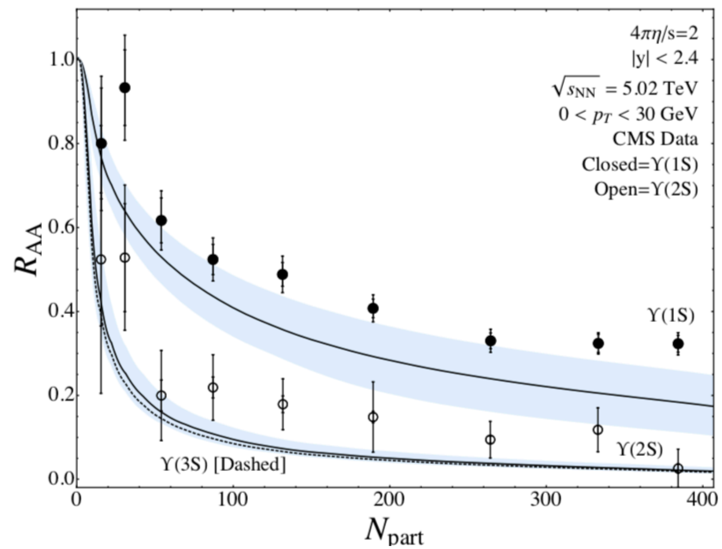
Including regeneration



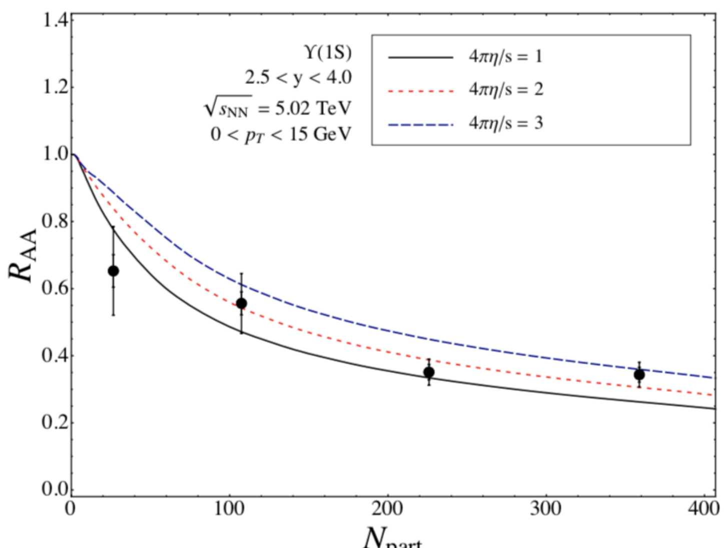
Results 1



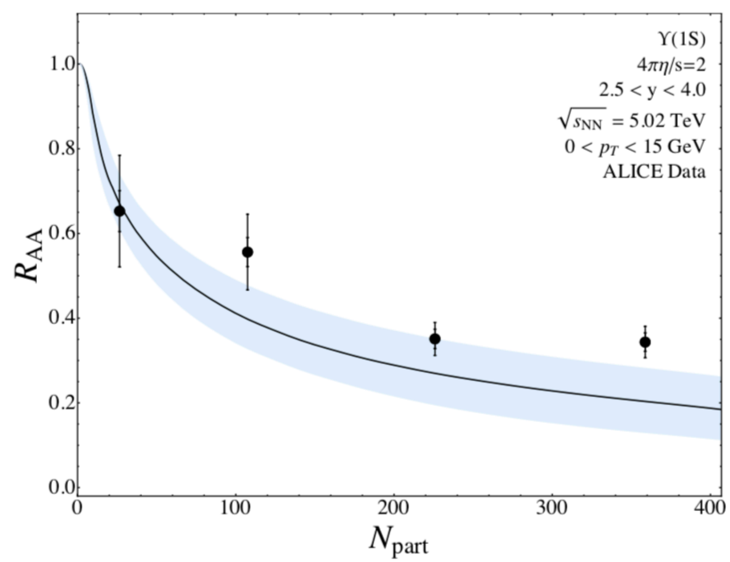
$4\pi\eta/s = 1$
$4\pi\eta/s = 2$
$4\pi\eta/s = 3$
Υ(1S) CMS Data
Υ(2S) CMS Data
|y|<2.4
$\sqrt{s_{NN}}$ = 5.02 TeV
$0 < p_T < 30$ GeV
Υ(1S)
Υ(2S)
Υ(3S)
R_{AA}
N_{part}



$4\pi\eta/s$=2
|y| < 2.4
$\sqrt{s_{NN}}$ = 5.02 TeV
$0 < p_T < 30$ GeV
CMS Data
Closed=Υ(1S)
Open=Υ(2S)
Υ(1S)
Υ(2S)
Υ(3S) [Dashed]
R_{AA}
N_{part}

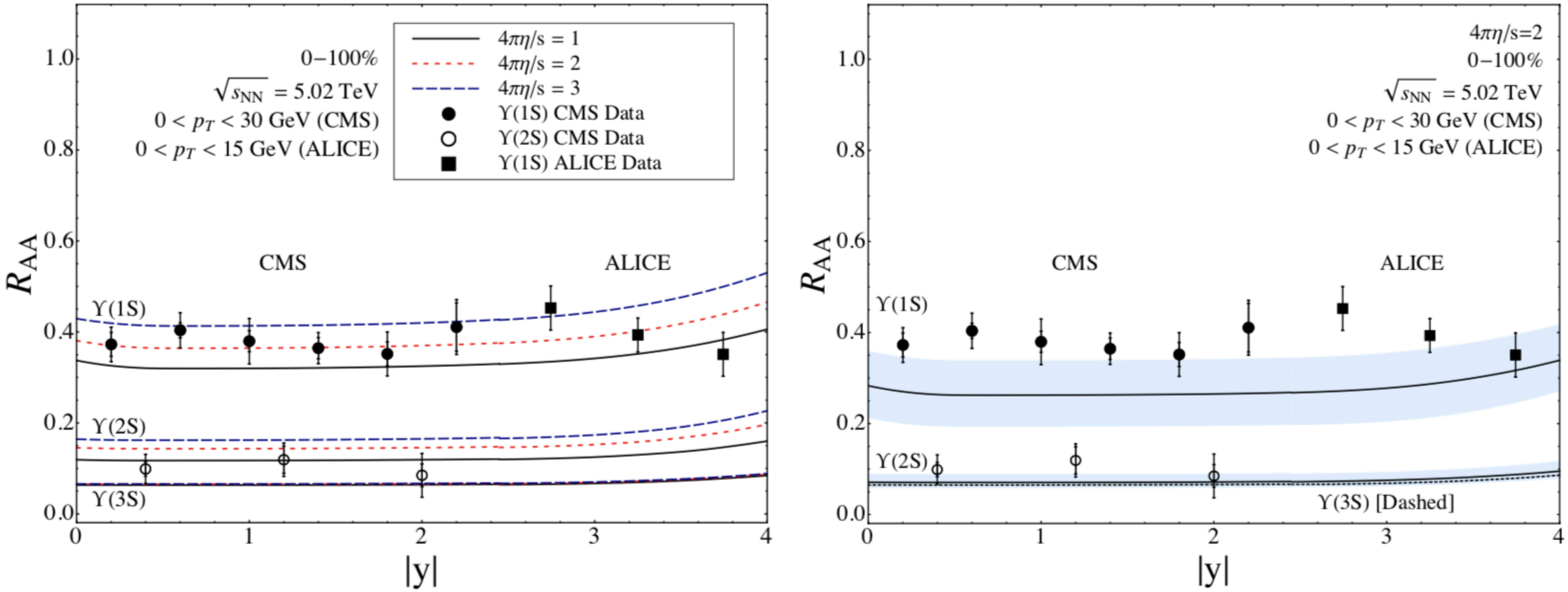


Υ(1S)
2.5 < y < 4.0
$\sqrt{s_{NN}}$ = 5.02 TeV
$0 < p_T < 15$ GeV
$4\pi\eta/s = 1$
$4\pi\eta/s = 2$
$4\pi\eta/s = 3$
R_{AA}
N_{part}



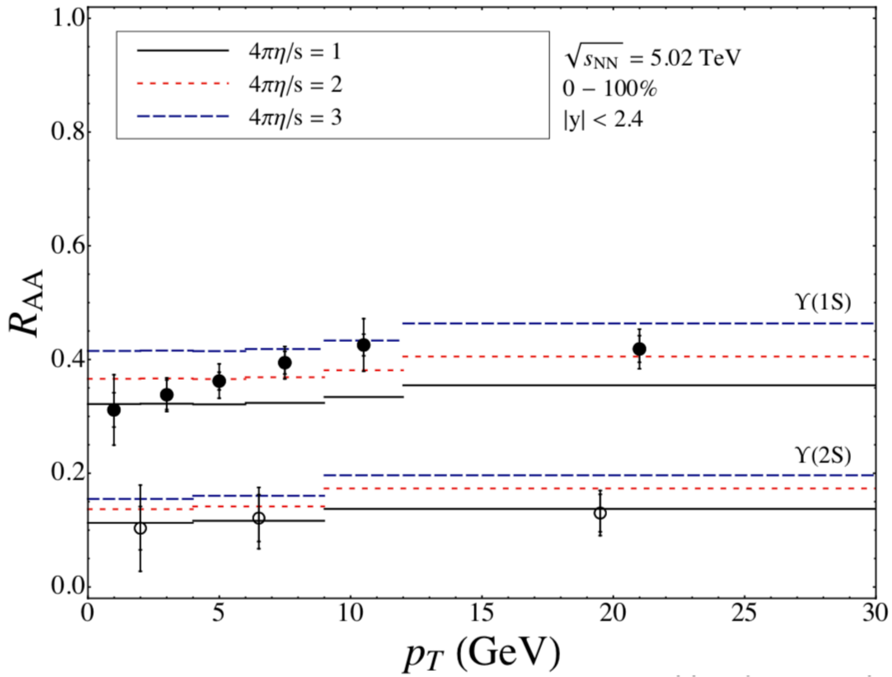
Υ(1S)
$4\pi\eta/s$=2
2.5 < y < 4.0
$\sqrt{s_{NN}}$ = 5.02 TeV
$0 < p_T < 15$ GeV
ALICE Data
R_{AA}
N_{part}

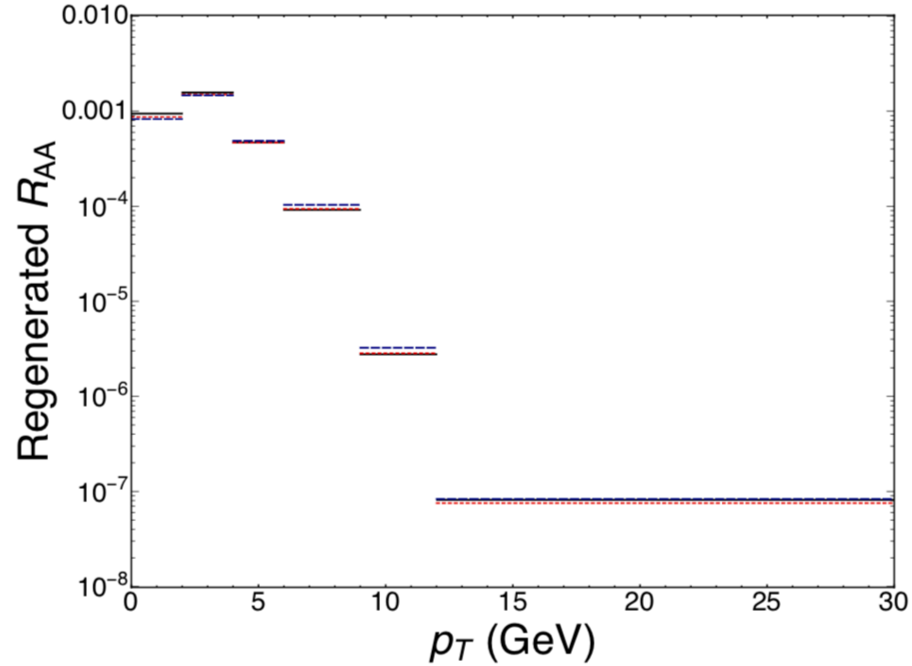
Results 2



0–100%
$\sqrt{s_{NN}}$ = 5.02 TeV
0 < p_T < 30 GeV (CMS)
0 < p_T < 15 GeV (ALICE)
4πη/s = 1
4πη/s = 2
4πη/s = 3
Υ(1S) CMS Data
Υ(2S) CMS Data
Υ(1S) ALICE Data
CMS
ALICE
Υ(1S)
Υ(2S)
Υ(3S)
R_{AA}
|y|
4πη/s=2
Υ(3S) [Dashed]

Results 2 Continued





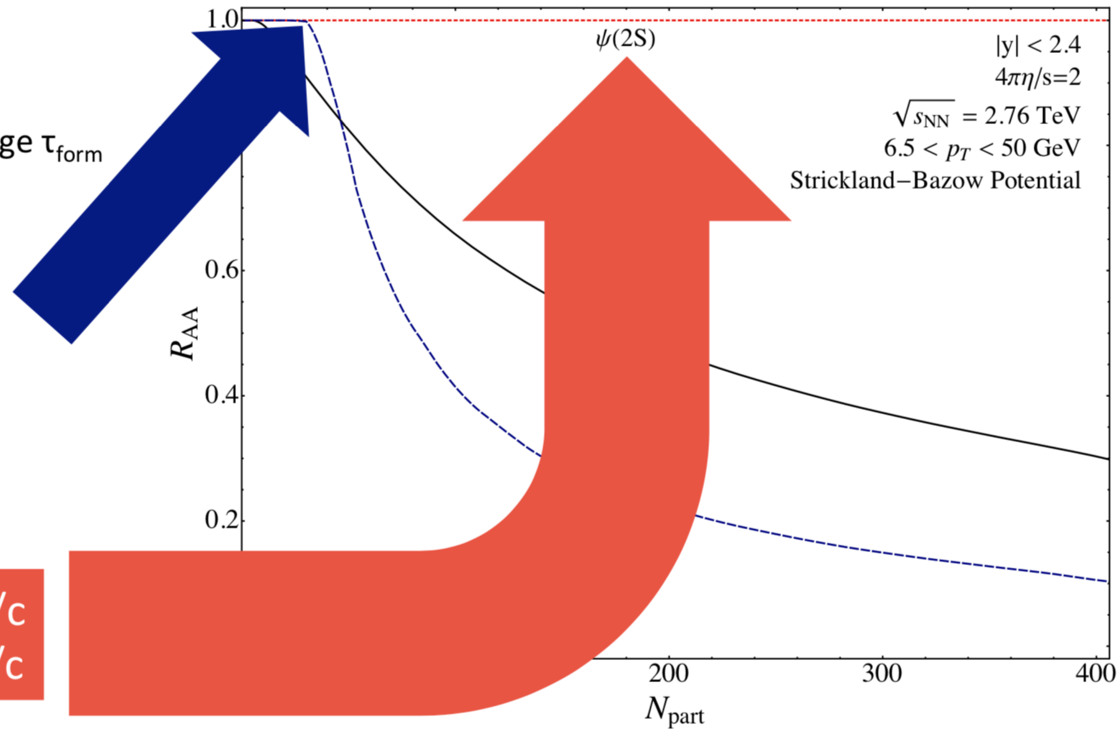
Conclusions

- Bottomonium regeneration is small

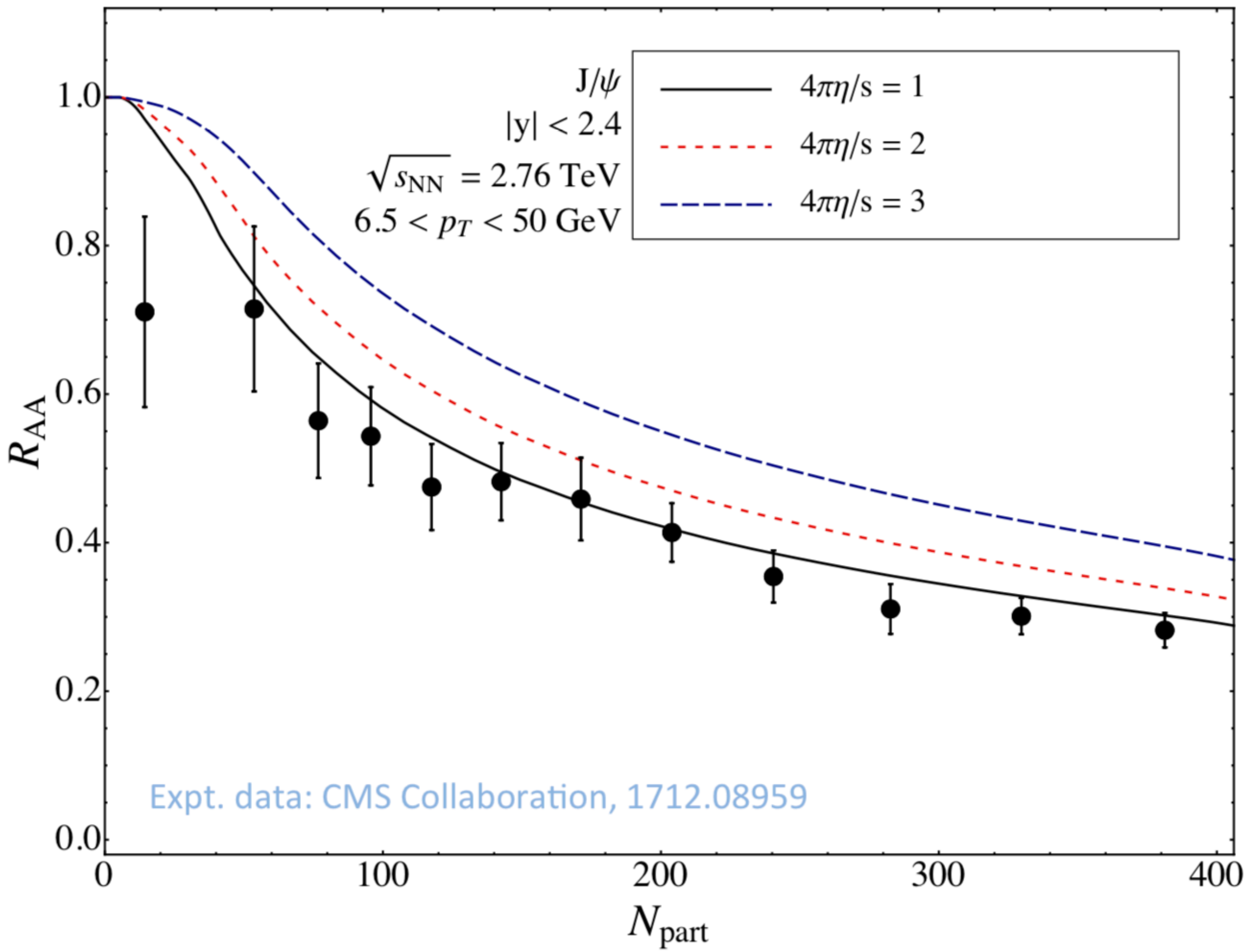
Charmonium results – 2.76 TeV Pb-Pb

- Raw suppression yields for three charmonoium states
- Shielding of suppression due to large τ_{form}

$\tau_{form}=(E_T/M)*\tau^0_{form}$
$p_{T,min}$=6.5 GeV/c
τ^0_{form}=0.8 fm/c
QGP present after 1.7 fm/c



τ^0_{form}=3.9 fm/c
QGP not present after 7.9 fm/c


J/ψ
|y| < 2.4
√sNN = 2.76 TeV
6.5 < pT < 50 GeV
4πη/s = 1
4πη/s = 2
4πη/s = 3
Expt. data: CMS Collaboration, 1712.08959
RAA
Npart
0.0
0.2
0.4
0.6
0.8
1.0
0
100
200
300
400