Bottomonium suppression at RHIC and LHC

Quark Matter 2018 Venice

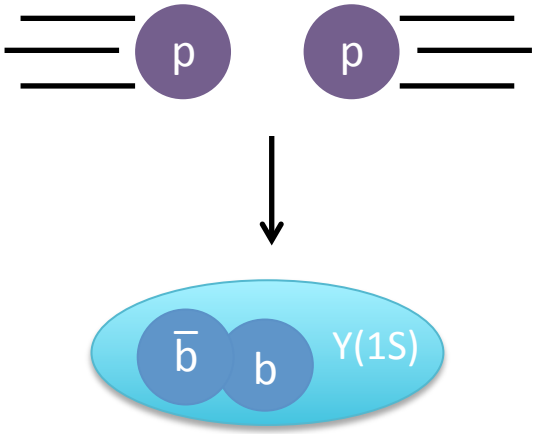
May 15, 2018

Brandon Krouppa

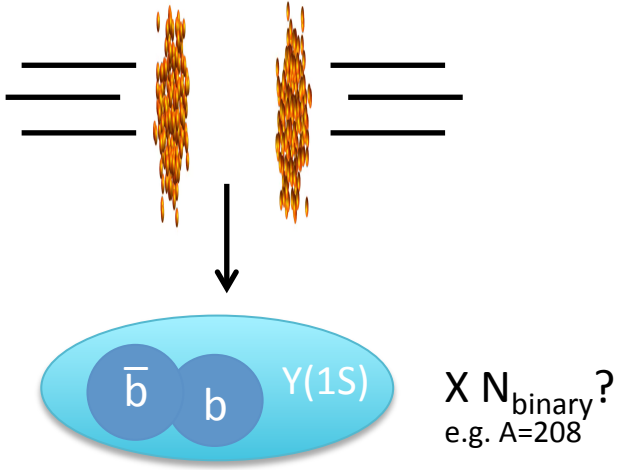
Kent State University
Kent, OH USA

Clear evidence of suppression

High energy
proton-proton collision



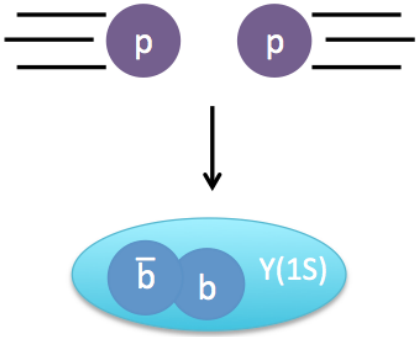
High energy
nucleus-nucleus collision

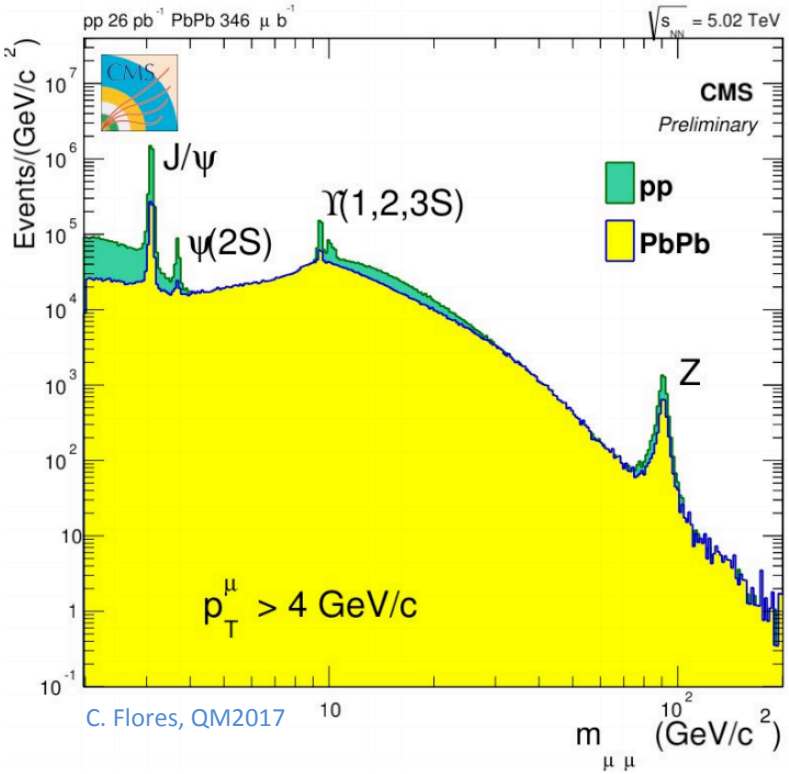


X N_{binary}?
e.g. A=208

Clear evidence of suppression

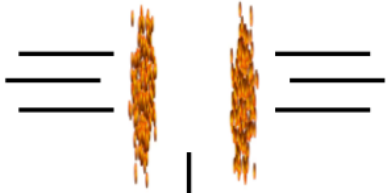
High energy
proton-proton collision





C. Flores, QM2017

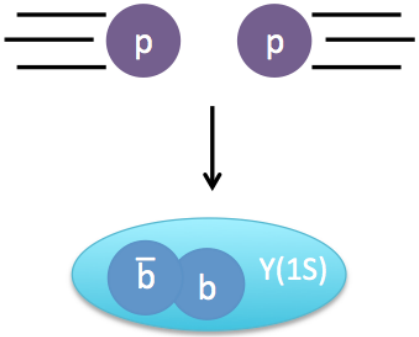
High energy
nucleus-nucleus collision

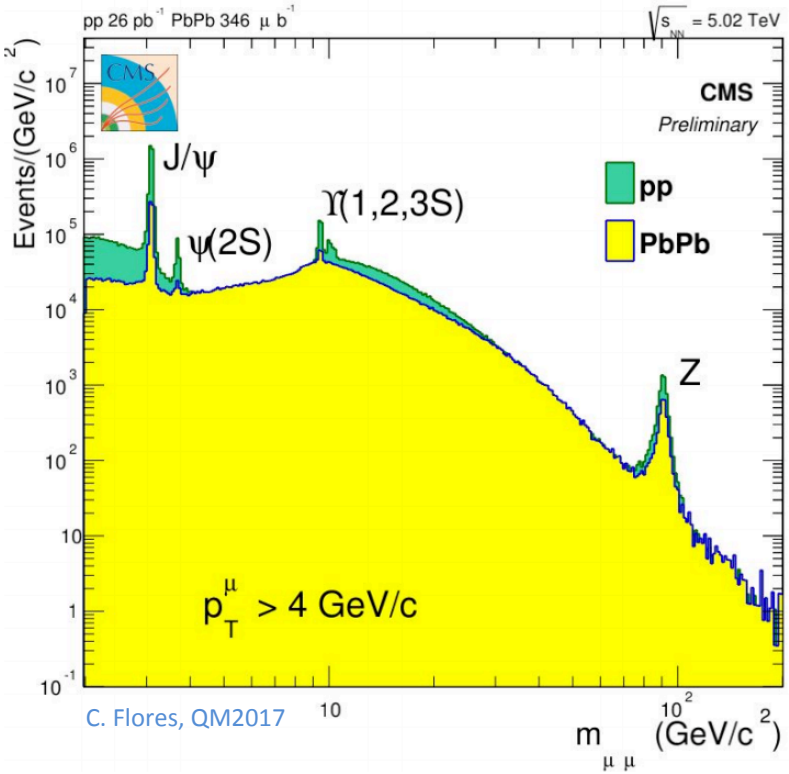


X N_{binary}?
e.g. A=208

Clear evidence of suppression ✓

High energy
proton-proton collision





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High energy
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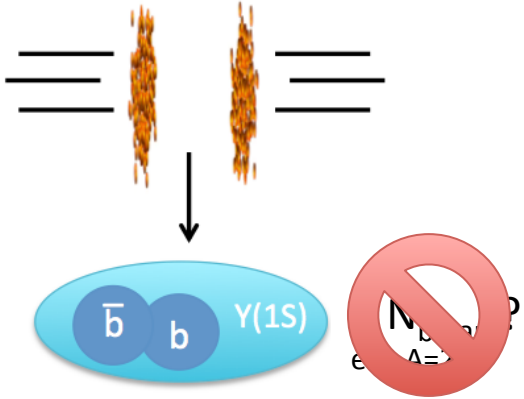


Pieces of the suppression puzzle

Other effects

Effective partonic luminosity modification in nuclei via **nuclear modified PDFs** due to saturation of the parton kinematics phase space, **multiple scattering** of partons in the nucleus before and after the **hard scattering**, the **absorption** or **break-up** of quarkonium states, and the interaction of quarkonium states with other particles produced in the collision (denoted as comovers). [arXiv:1506.03981]

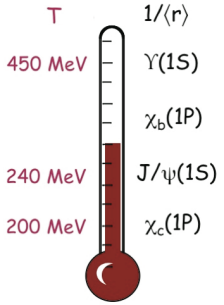
Thermal suppression

The hot QGP provides a violent medium where gluonic dampening causes the heavy quarkonium state to melt. **Quarkonia are sensitive to the full spatiotemporal evolution of the QGP**. Need to compute dynamical processes including non-equilibrium correction.

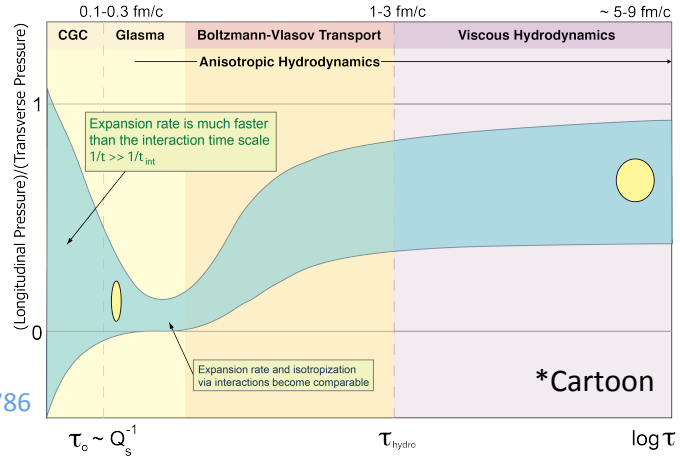
Regeneration

If the population of open- and closed-charm states is high, then it is possible for quarkonia to be regenerated through **recombination of liberated heavy quarks** (swapping dance partners). There can also be local recombination of an individual bound state due to medium interactions (square dancing).

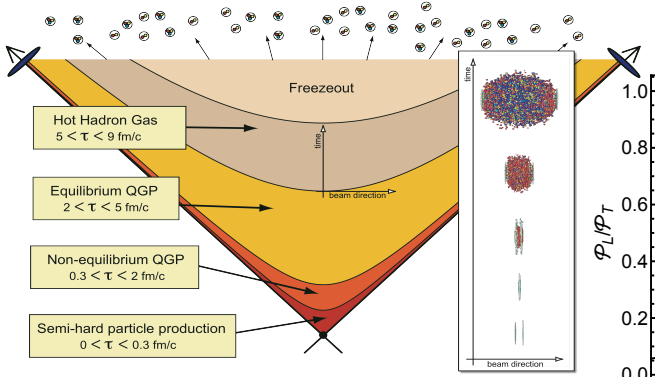
Suppression as a thermometer



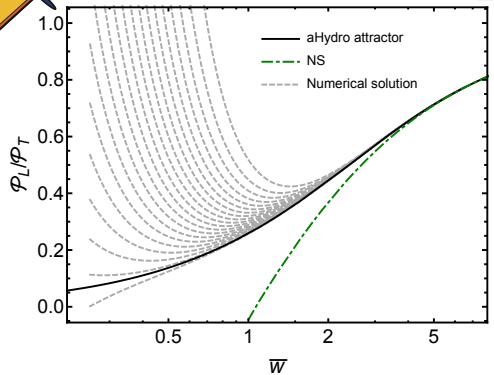
A. Mocsy, P. Petreczky, and MS, 1302.2180



arXiv:1410.5786



arXiv:1709.06644



Solve the 3d Schrödinger EQ with (two) complex-valued potentials

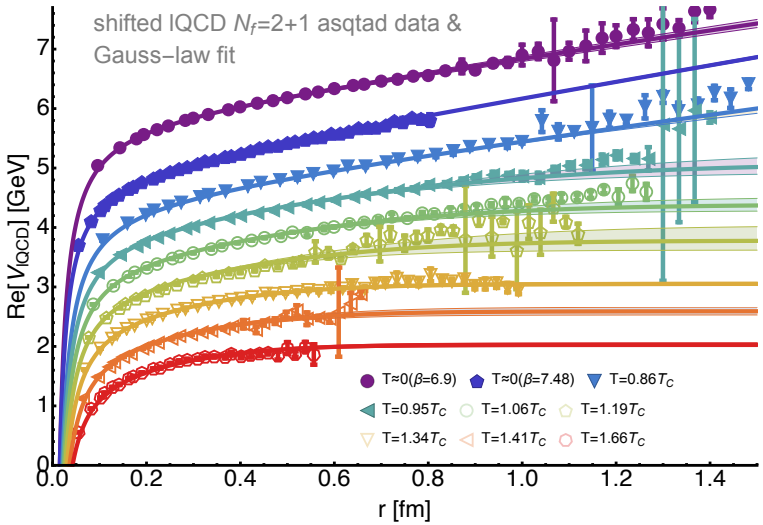
↓

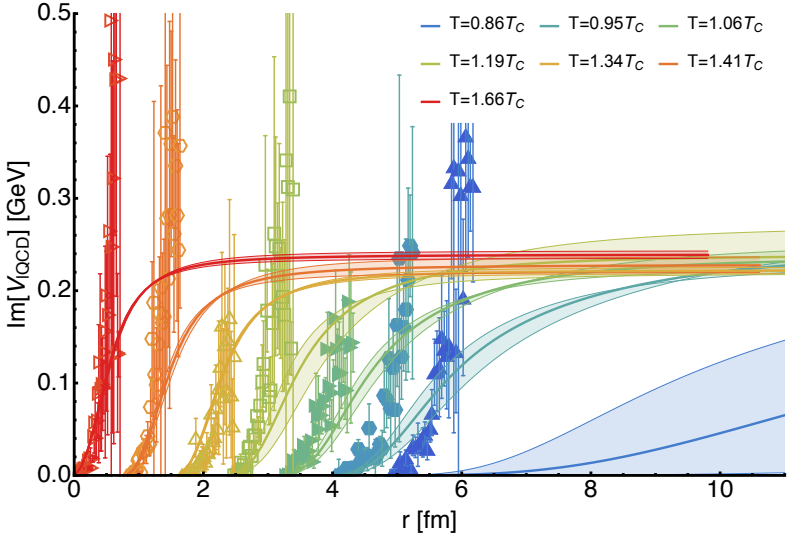
Obtain real and imaginary parts of the binding energies for the $\Upsilon(1S)$, $\Upsilon(2S)$, $\Upsilon(3S)$, $\chi_b(1P)$, $\chi_b(2P)$, and $\chi_b(3P)$ as function of energy density and anisotropy. Yager-Elorriaga and MS, 0901.1998; Margotta, MS, et al, 1101.4651

↓

Fold together with the non-EQ spatiotemporal evolution to obtain the **survival probability**.

Heavy quark potential (Rothkopf)



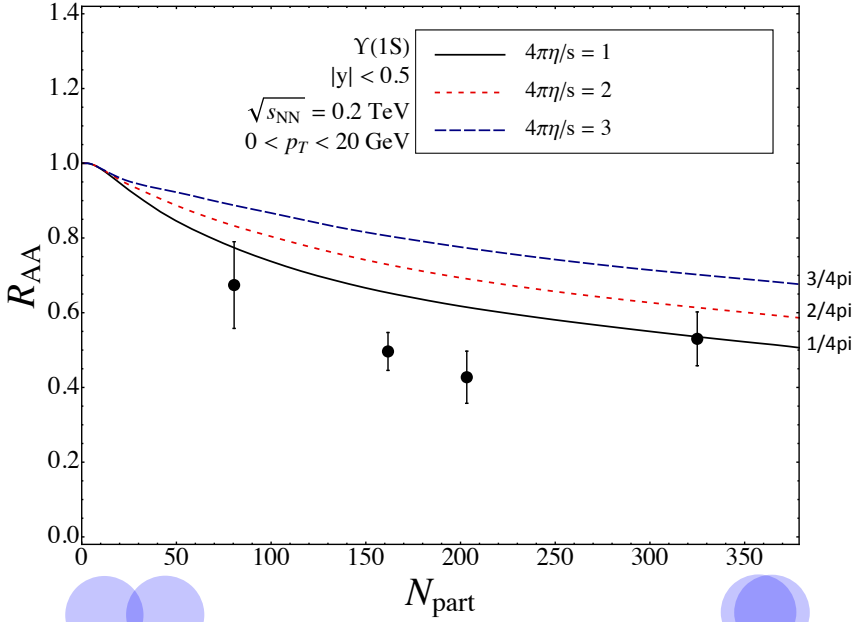


See A. Rothkopf's talk later in this session.
Phys.Rev.D97 (2018) no.1 016017

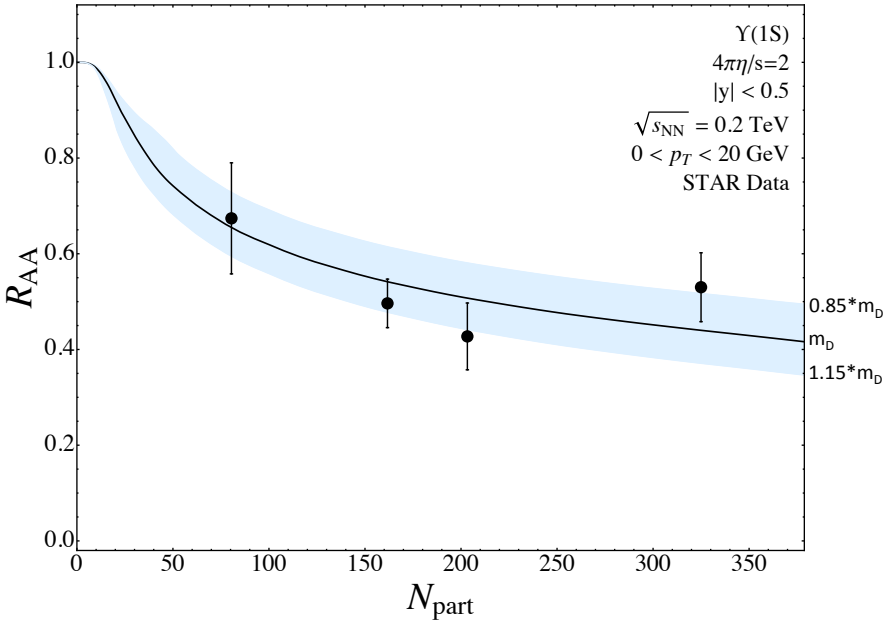
Bottomonium results – 200 GeV Au-Au

- QGP thermometer is continuous!

Strickland-Bazow bottomonia

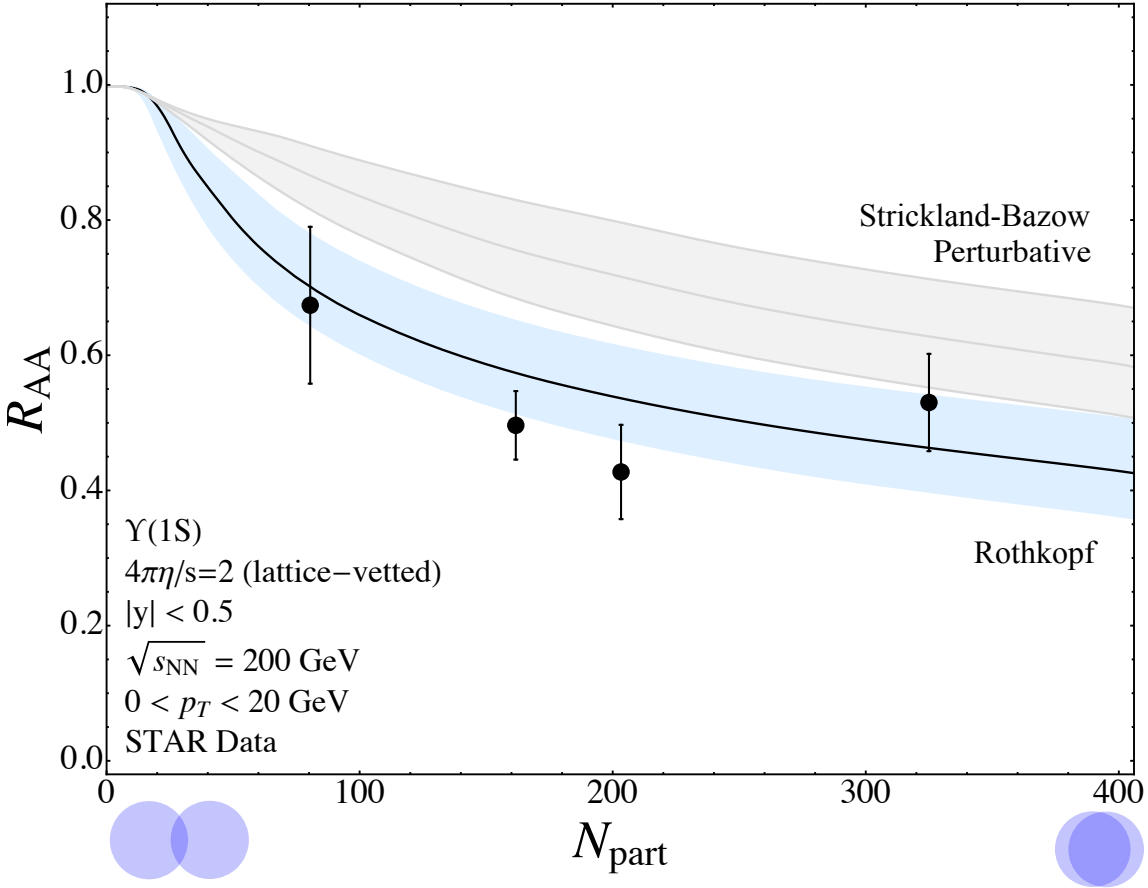


Rothkopf bottomonia



arXiv:1710.02319

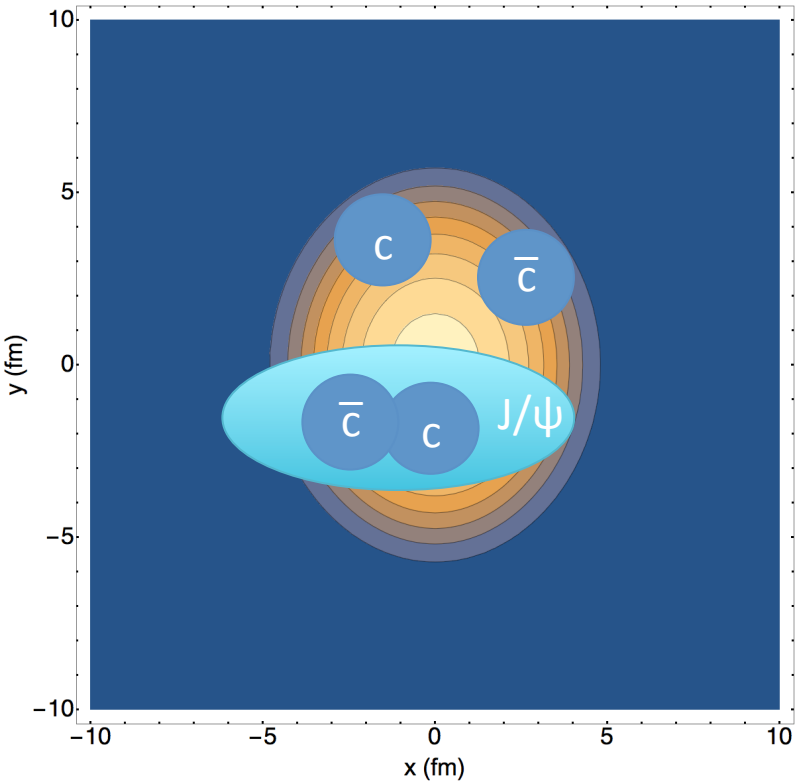
Bottomonium results – 200 GeV Au-Au



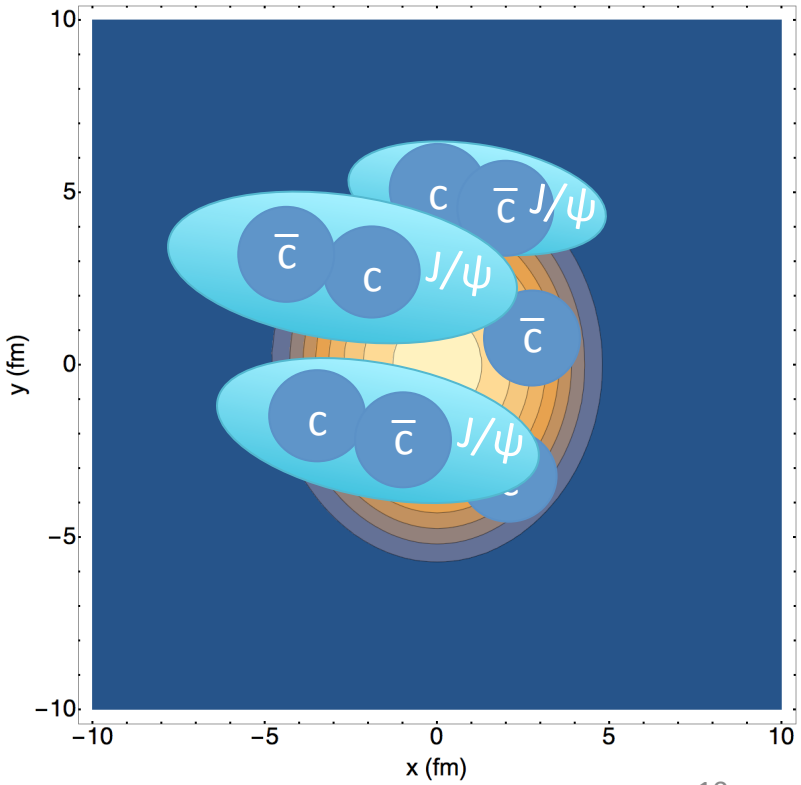
arXiv:1710.02319

Reality check: regeneration (theorizing)

- Larger collision energies and lighter (charm) quark mass



Increase collision energy



Reality check: regen rizing)

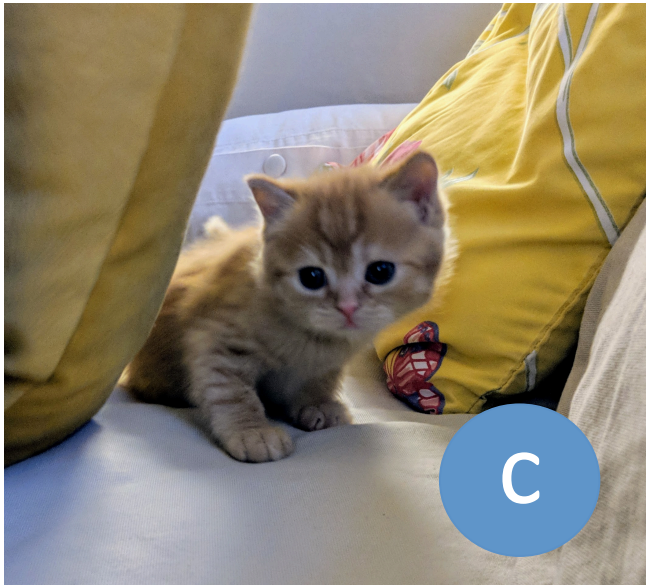
- Larger collision energies and lighte

Wait… I thought this talk was about bottomonia...

Reality check: regeneration (theorizing)

- Larger collision energies and lighter (charm) quark mass

$M_{kitter} < M_{pupper}$



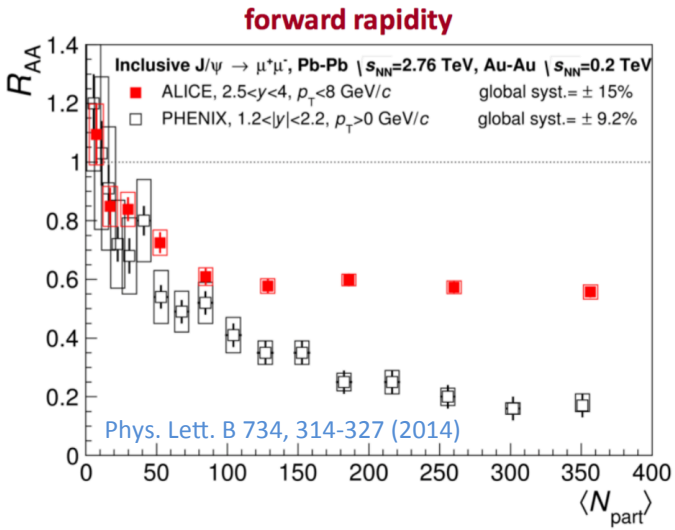
Mike Strickland's new kitten

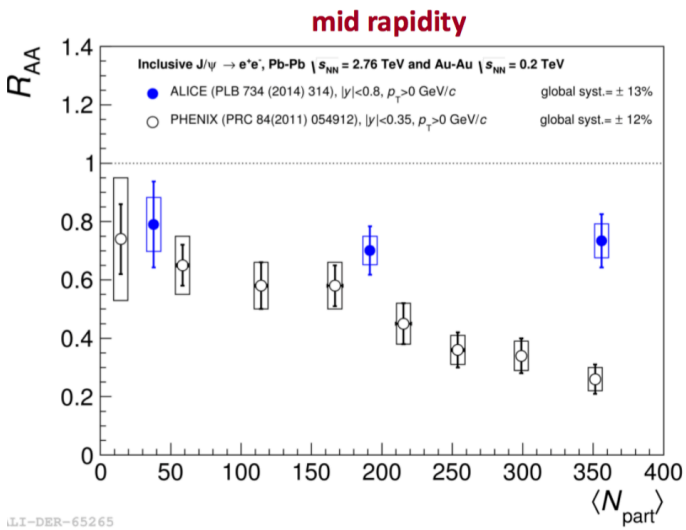
Source: Google

Both have a finite mass → Regeneration possible!

Reality check: regeneration (experimental data)

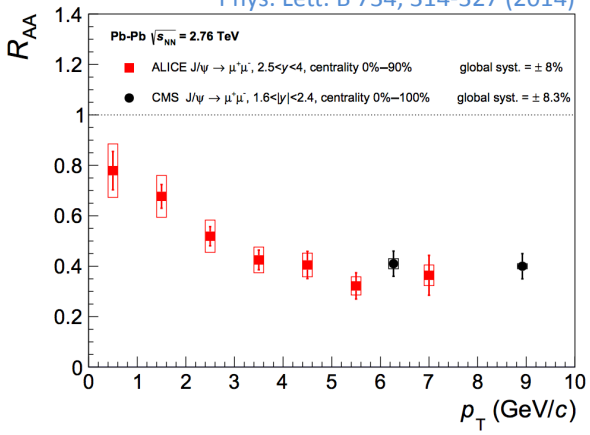
- No significant centrality dependence for ALICE $N_{part} > 70$
- Stronger J/ψ suppression at RHIC at mid and forward rapidity!
- Evidence of regeneration of charmonia states?

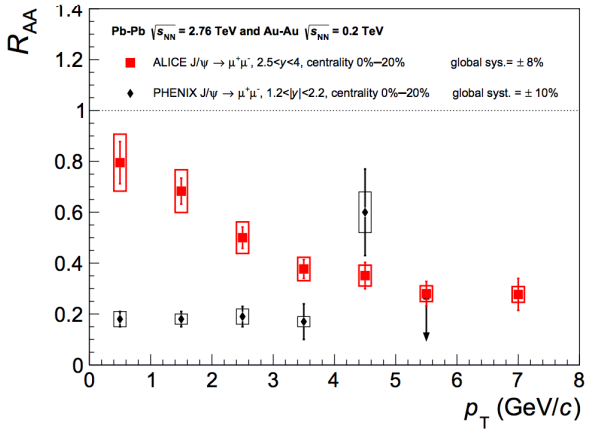




Reality check: regeneration (other models)

Phys. Lett. B 734, 314-327 (2014)

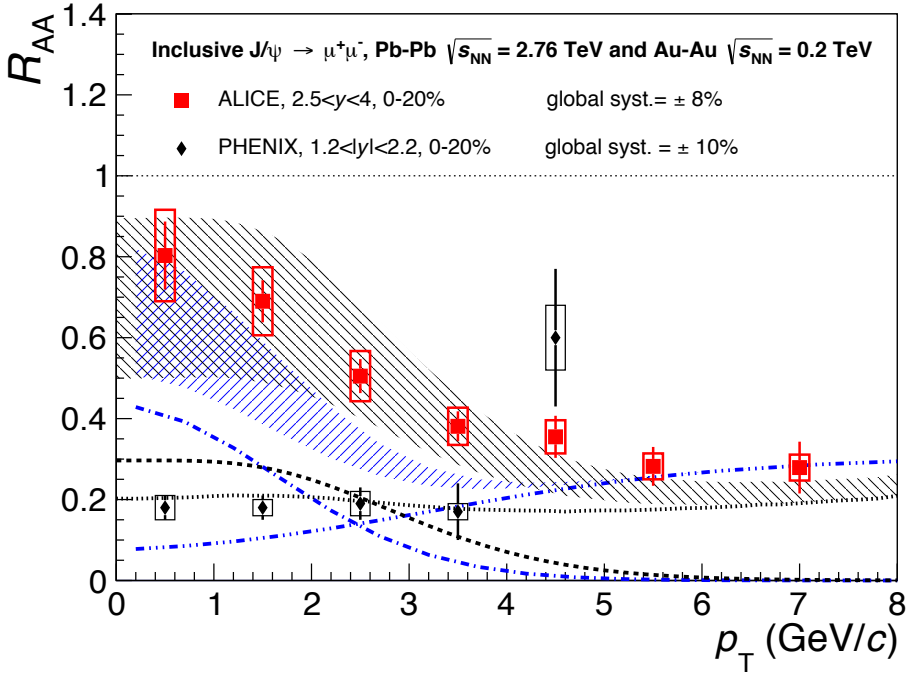




Models

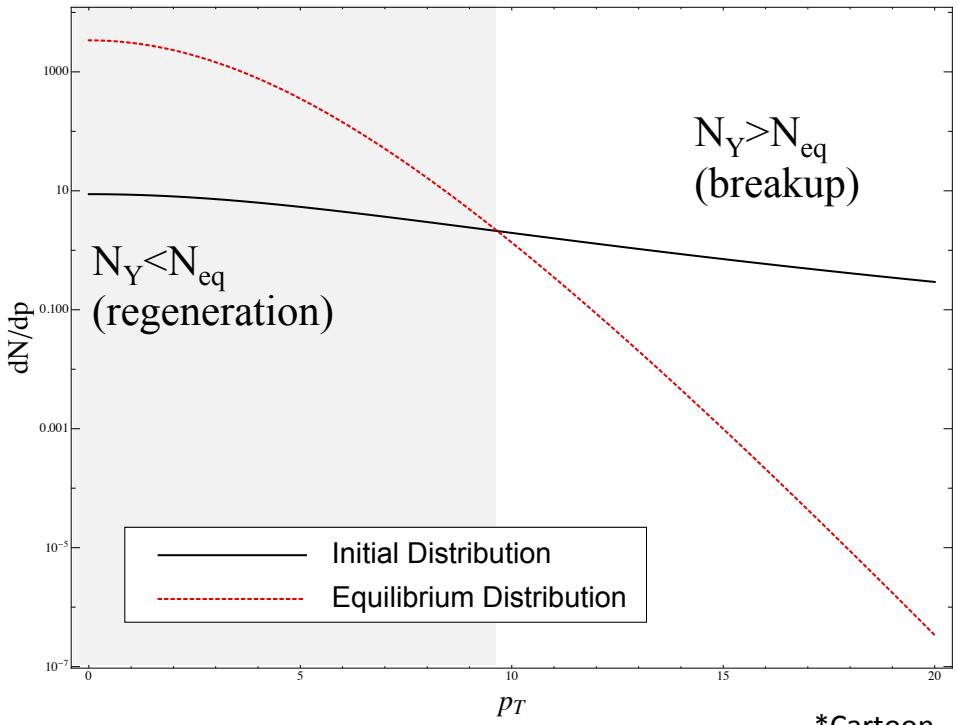
TM1: Zhao-Rapp NPA 859 (2011) 114

TM2 : Zhou et al., PRC 89 (2014) 054911



Reality check: regeneration (for our model)

- Based on the rate equation $\frac{dn(\tau,\mathbf{x})}{d\tau} = -\Gamma(T(\tau,\mathbf{x}))\left[n(\tau,\mathbf{x}) - n_{\rm eq}(T(\tau,\mathbf{x}))\right]$



*Cartoon

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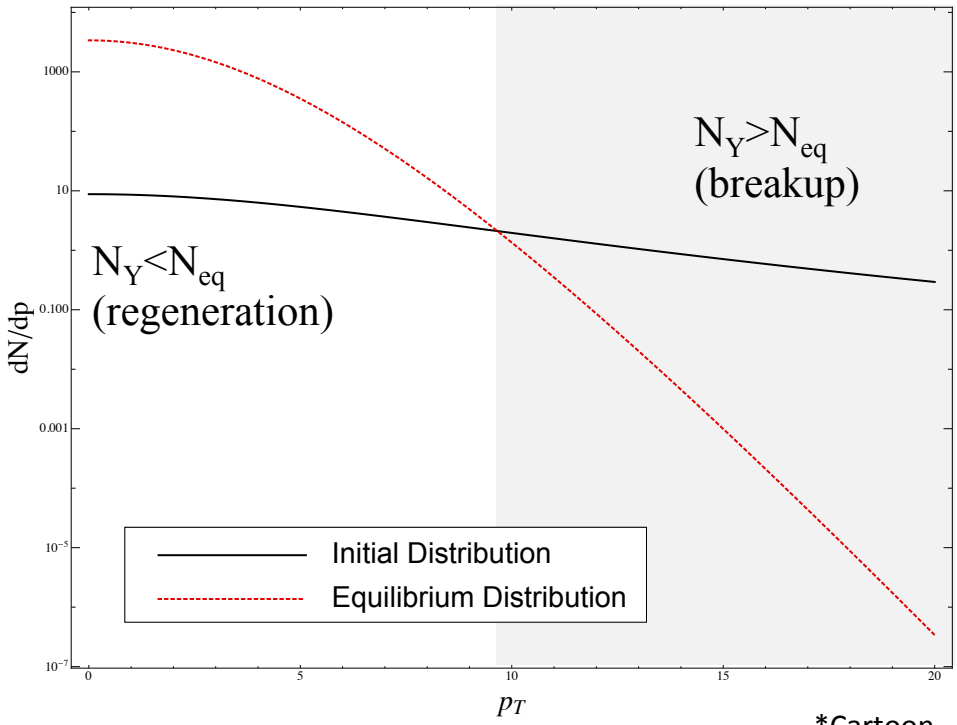

*Cartoon

Reality check: a regeneration component

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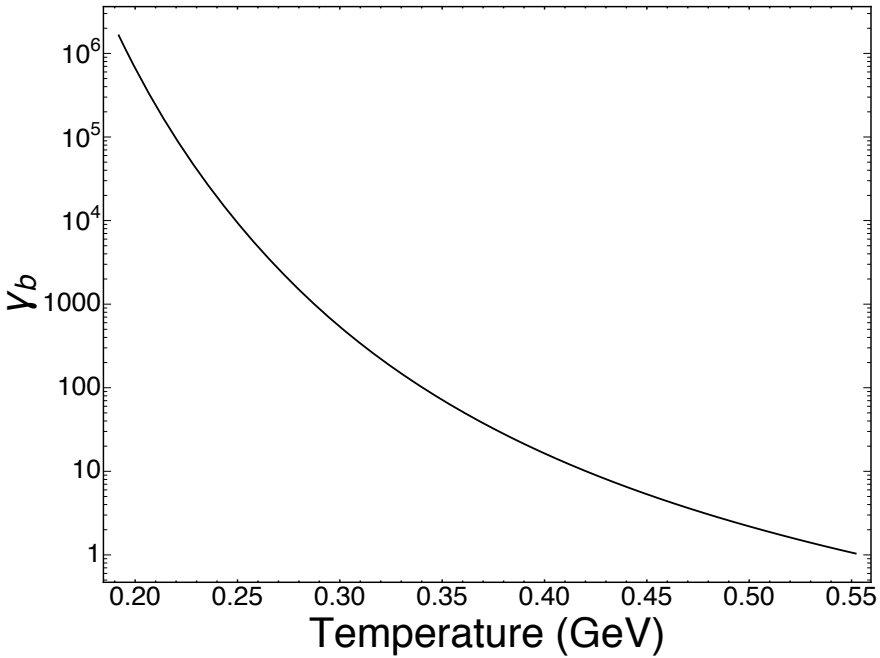


- Factor of γ^2 in $n_{\rm eq}(T(\tau,\mathbf{x}))$

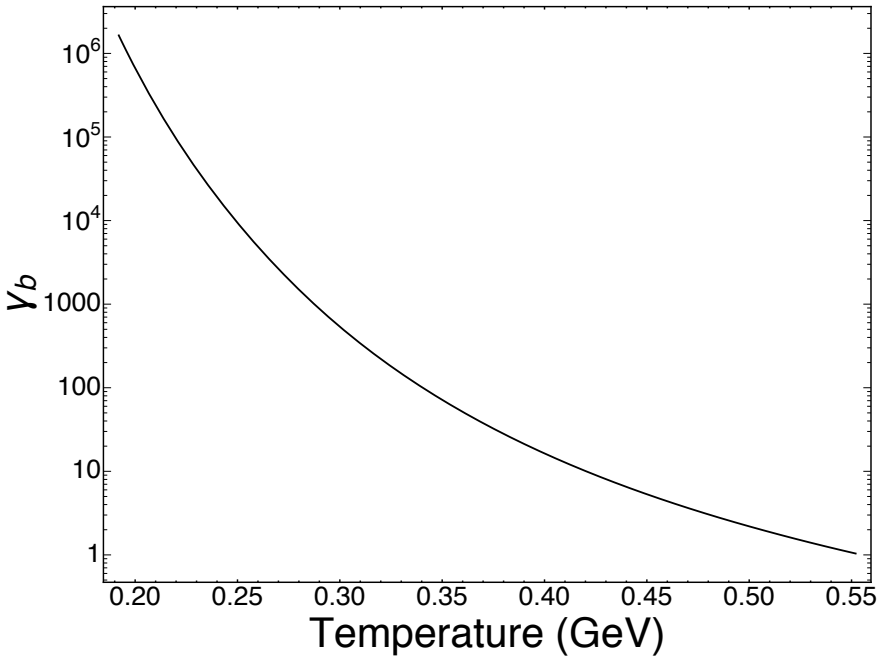
$$n_{\rm eq}(T,\gamma_q) = 3\gamma_q^2(T)\int \frac{d^3q}{(2\pi^3)} f(m;T)$$

arXiv:hep-ph/0305143

- Fugacity factor driving statistical regeneration
- Calculated for bottomonia (left)

Reality check: a regeneration component

- Based on the rate equation $\frac{dn(\tau,\mathbf{x})}{d\tau} = -\Gamma(T(\tau,\mathbf{x}))\left[n(\tau,\mathbf{x}) - n_{\rm eq}(T(\tau,\mathbf{x}))\right]$



- Factor of γ^2 in $n_{\rm eq}(T(\tau,\mathbf{x}))$

arXiv:hep-ph/0305143

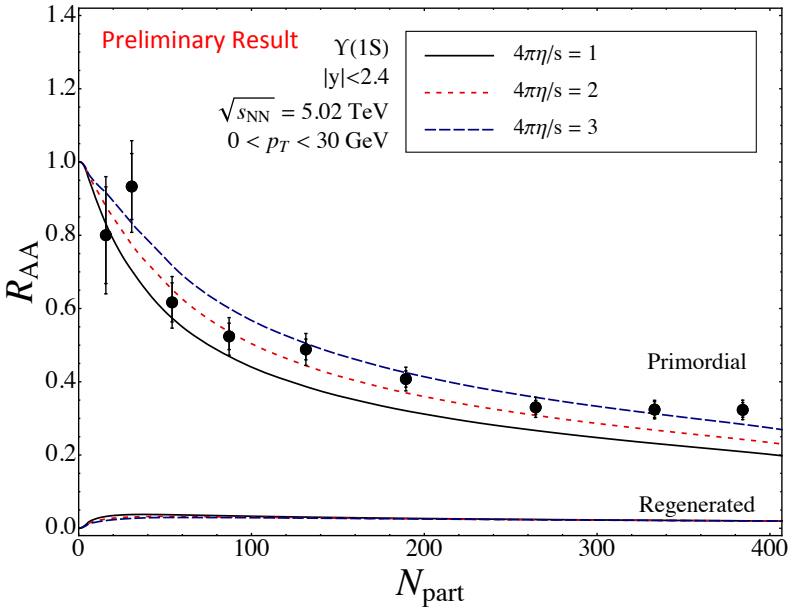
$$N_{q\bar{q}} = \frac{1}{2} N_{\rm op} \frac{I_1(N_{op})}{I_0(N_{op})} + N_{\rm hid}$$

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

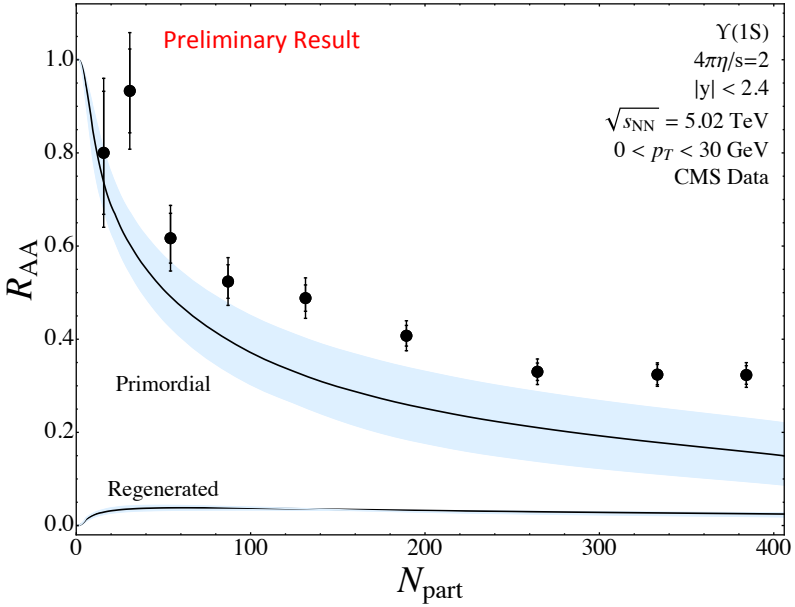
$$N_{\rm hid} = \gamma_q^2 V_{\rm coll} \sum_{\rm states} d_{\rm states} \int \frac{d^3p}{(2\pi)^3} f^{\rm states}(p;T)$$

Bottomonium results – 5.02 TeV Pb-Pb

Strickland-Bazow bottomonia

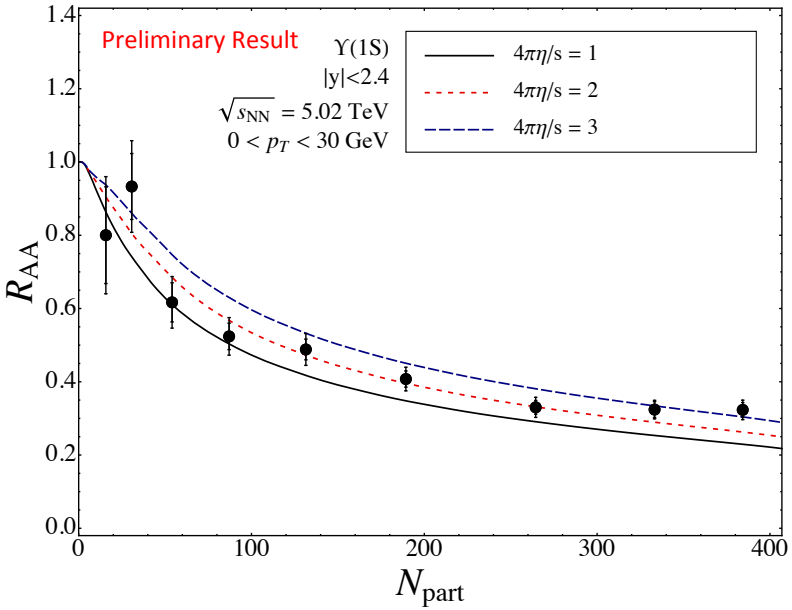


Rothkopf bottomonia

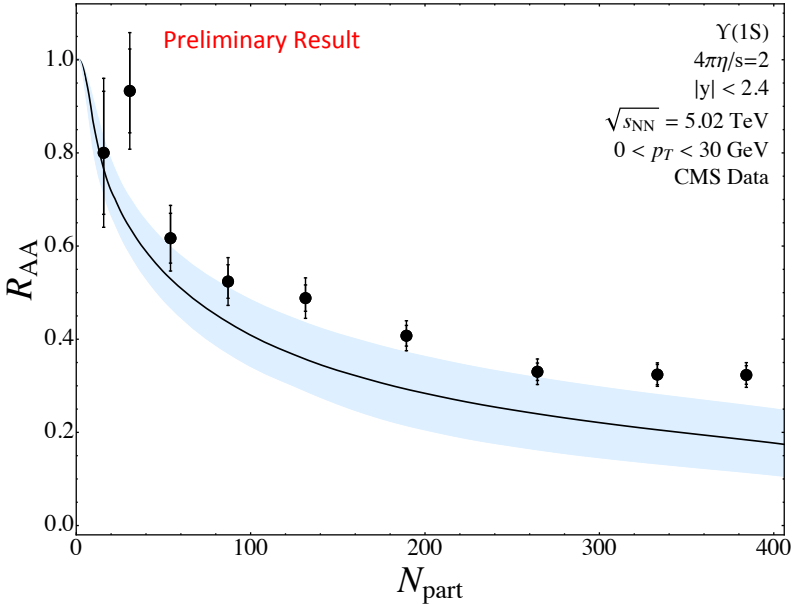


Bottomonium results – 5.02 TeV Pb-Pb

Strickland-Bazow bottomonia

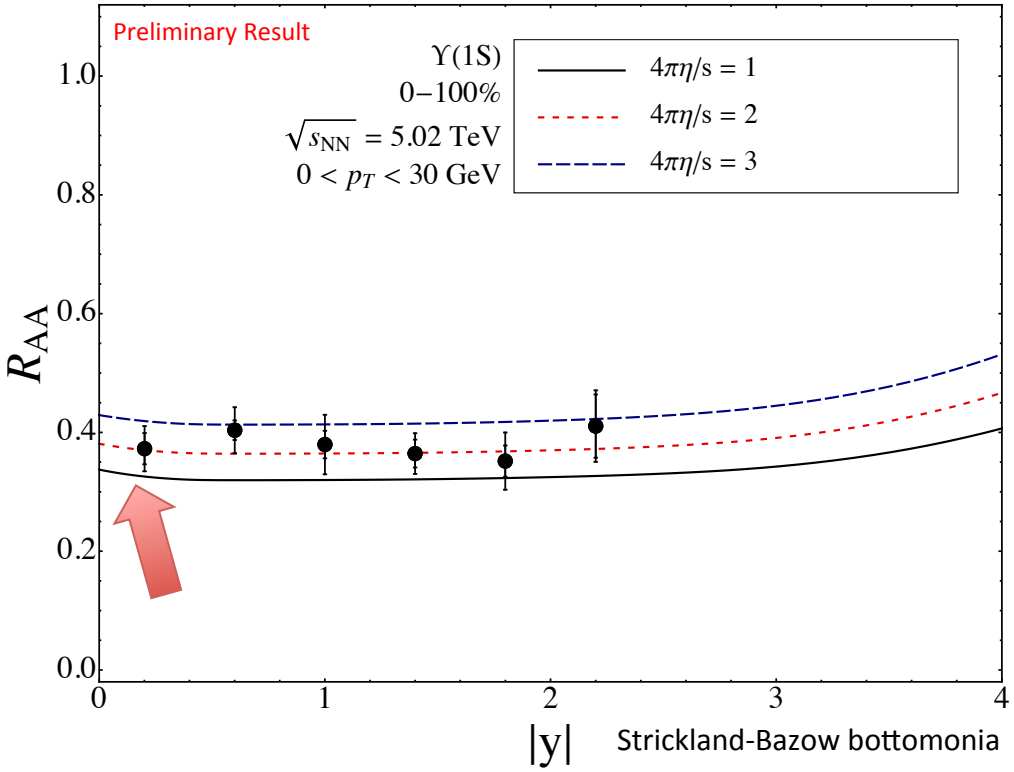


Rothkopf bottomonia



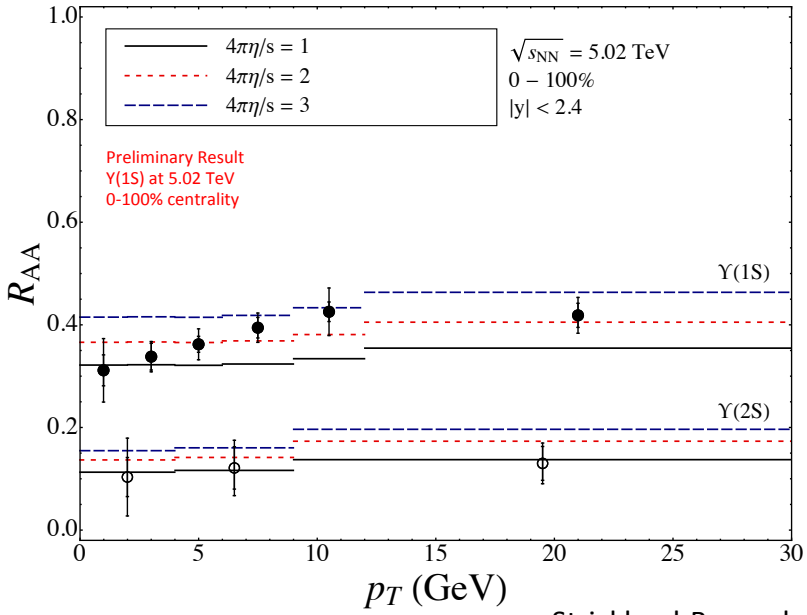
Bottomonium results – 5.02 TeV Pb-Pb

- Small amount of regeneration seen in the mid-rapidity window
- Charmonium expt. data showed regeneration for mid AND forward rapidity
- Indicates less significance for bottomonium regeneration



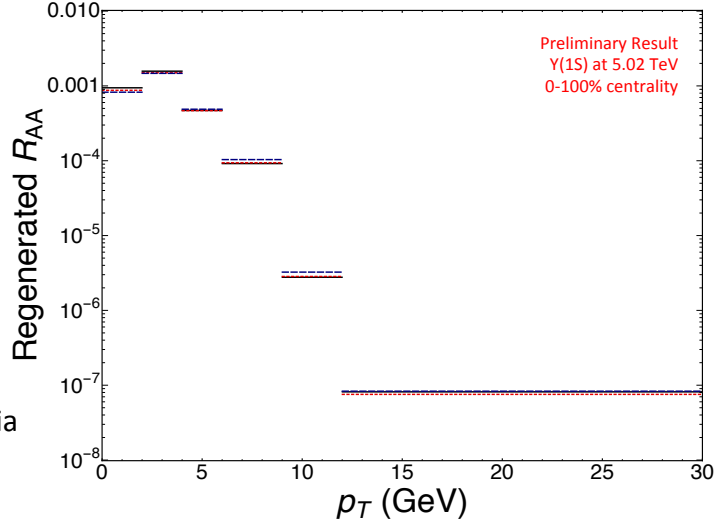
Strickland-Bazow bottomonia

Bottomonium results – 5.02 TeV Pb-Pb



Strickland-Bazow bottomonia

- Regeneration component occurs mostly for low-pt bottomonia
- Regeneration effect is small for relatively massive bottomonia (only mid-rapidity)
- Charmonium state data just finished running



Thank you

Comparison

Between Strickland-Bazow and Rothkopf potentials.

Thermal suppression

Explains the bulk of bottomonium suppression data.

Charmonia

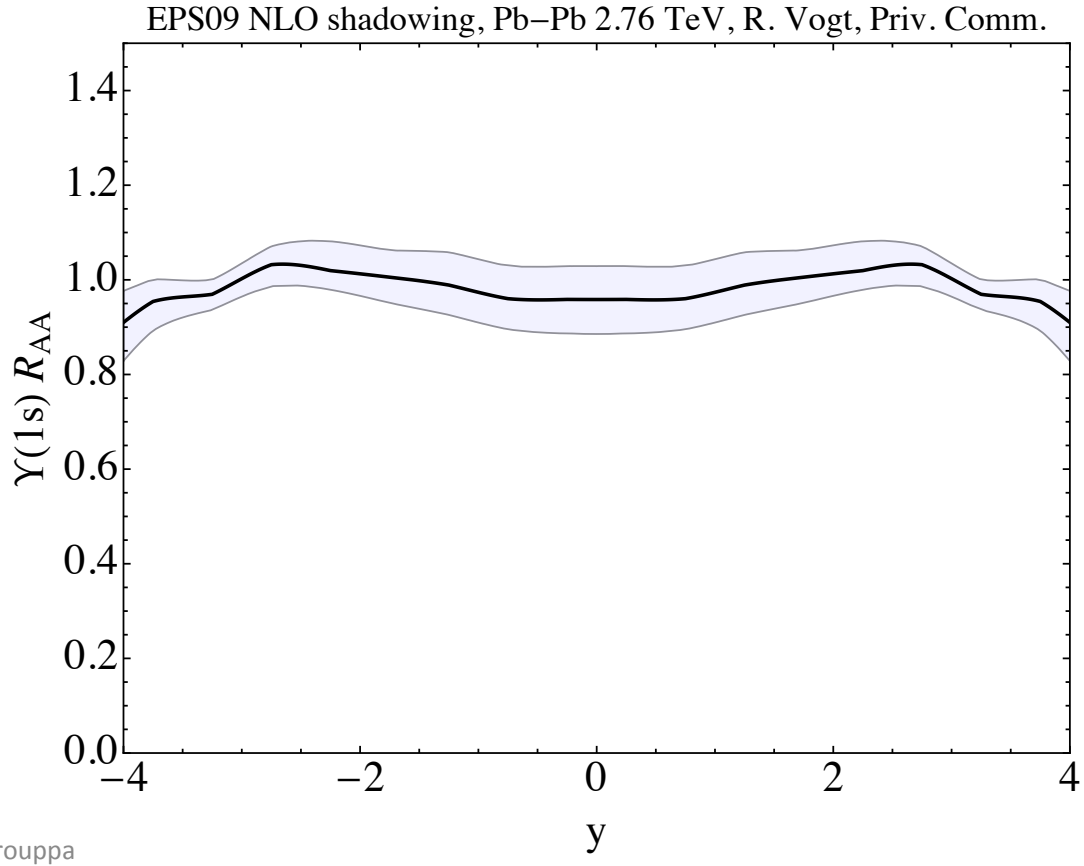
Still reviewing the charmonia calculation; coming soon.

Regeneration

Inclusion of a local regeneration model.

Extra Slides

Extra – CNM effect for bottomonium



- Estimate of CNM using EPS09 NLO shadowing provided by R. Vogt
- Effect seems to be quite small (max ~10%)

Extra - anisotropic hydrodynamics basics

[M. Martinez and MS, 1007.0889]
[W. Florkowski and R. Ryblewski, 1007.0130]

Viscous Hydrodynamics Expansion

$$f(\tau, \mathbf{x}, \mathbf{p}) = \underline{f_{\rm eq}(\mathbf{p}, T(\tau, \mathbf{x}))} + \delta f$$

Non-equilibrium corrections from e.g. shear stress

Isotropic in momentum space

Anisotropic Hydrodynamics (aHydro) Expansion

$$f(\tau, \mathbf{x}, \mathbf{p}) = f_{\rm aniso}(\mathbf{p}, \underbrace{\Lambda(\tau, \mathbf{x})}_{T_\perp}, \underbrace{\xi(\tau, \mathbf{x})}_{\text{anisotropy}}) + \delta \tilde{f}$$

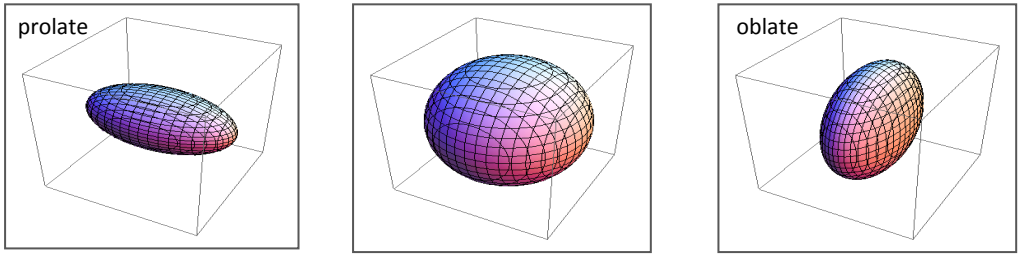
Treat this term perturbatively → "NLO aHydro"

D. Bazow, U. Heinz, and MS, 1311.6720
D. Bazow, U. Heinz, and M. Martinez, 1503.07443

→ "Romatschke-Strickland" form in LRF

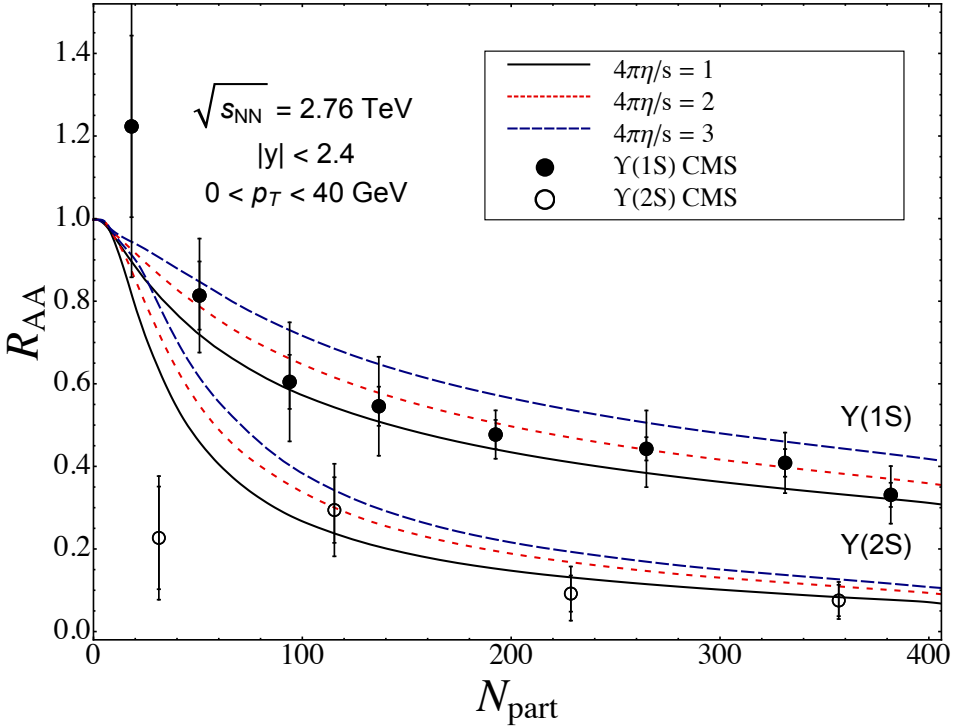
$$f^{LRF}_{\rm aniso} = f_{\rm iso}\left(\frac{\sqrt{\mathbf{p}^2 + \xi(\mathbf{x}, \tau) p_z^2}}{\Lambda(\mathbf{x}, \tau)}\right)$$

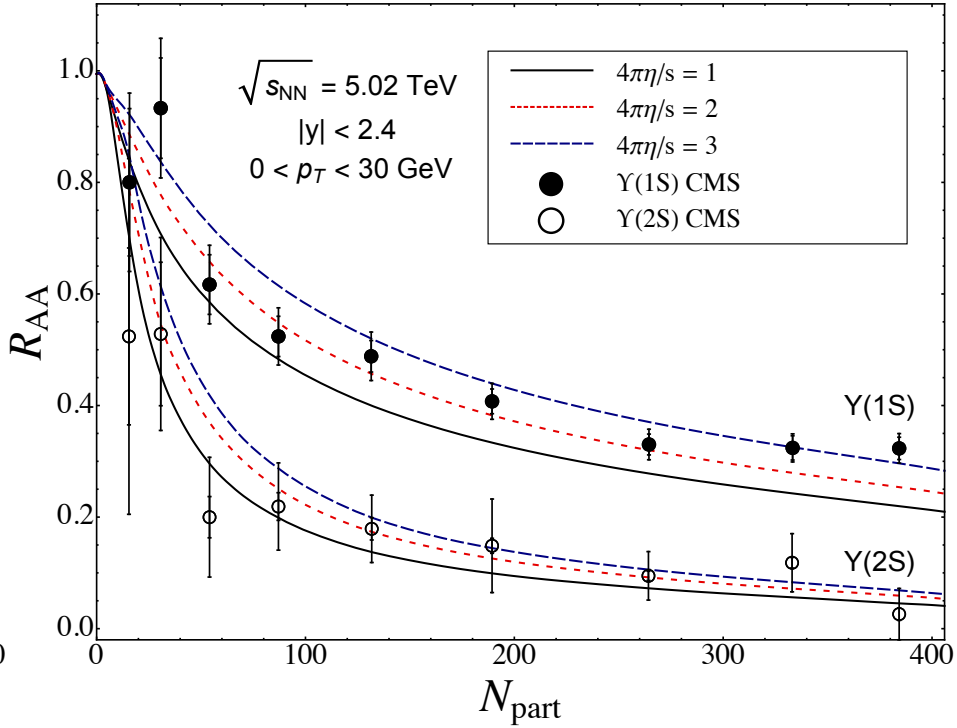
$$\xi = \frac{\langle p_T^2 \rangle}{2 \langle p_L^2 \rangle} - 1$$



$-1 < \xi < 0$ $\quad$ $\xi = 0$ $\quad$ $\xi > 0$

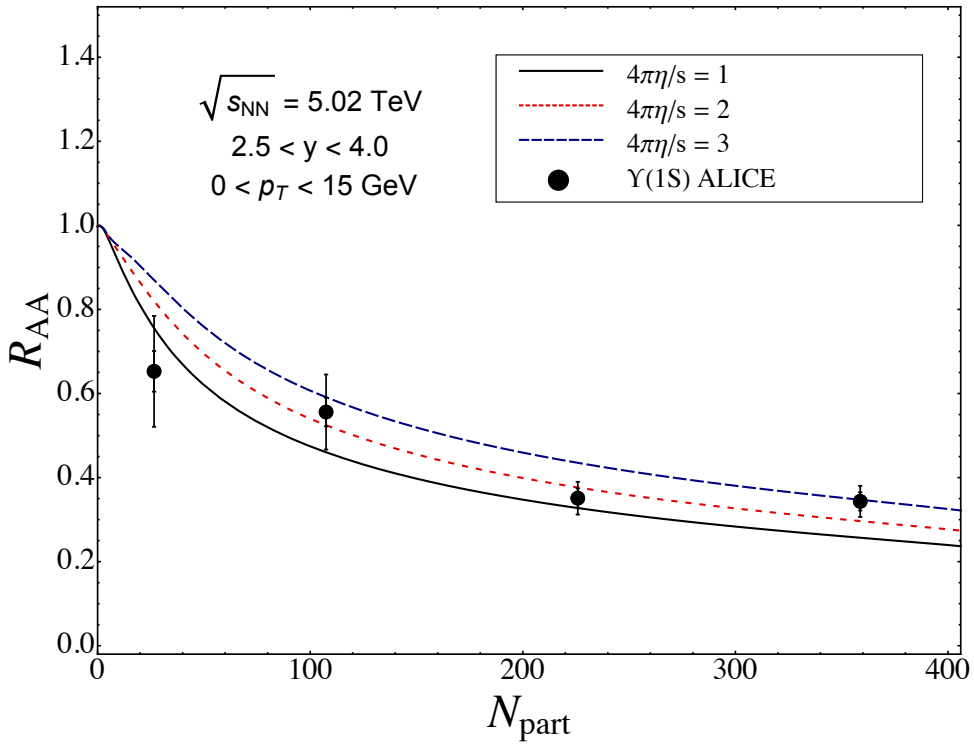
Extra – QM2017 results – CMS N_{part}





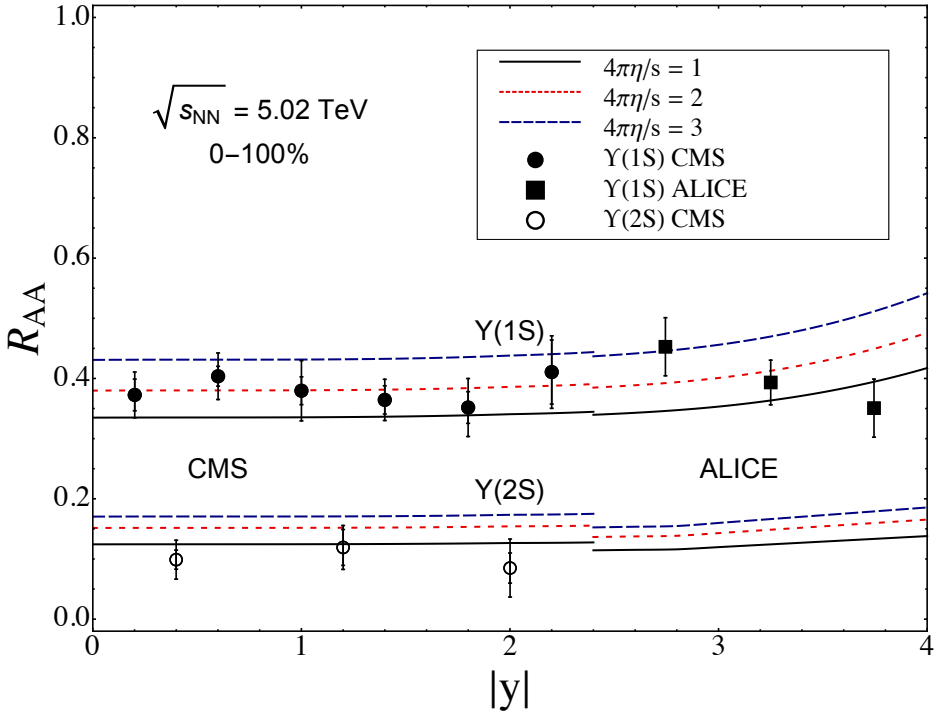
Strickland-Bazow Potential

Extra – QM2017 results – ALICE N_{part}



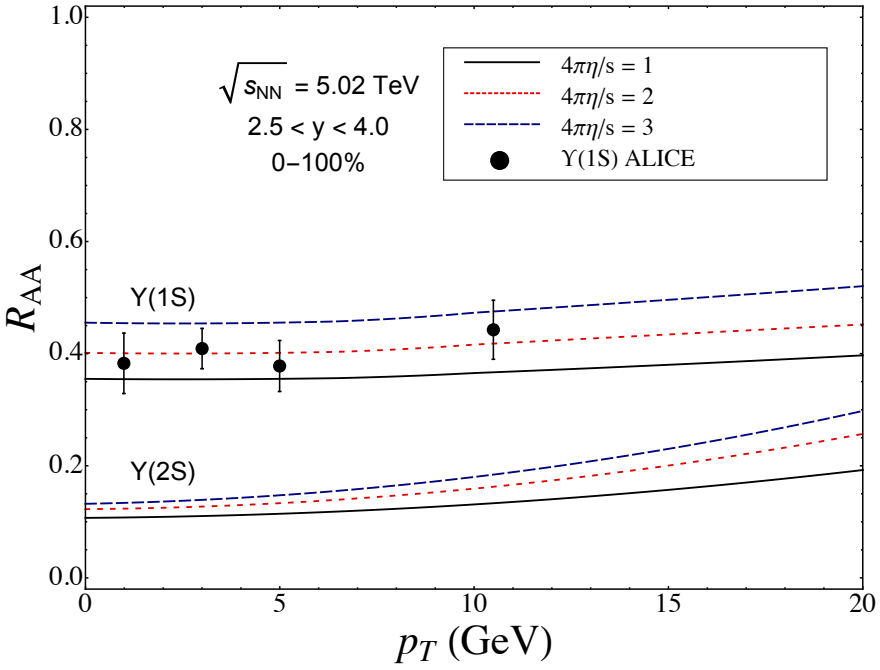
Strickland-Bazow Potential

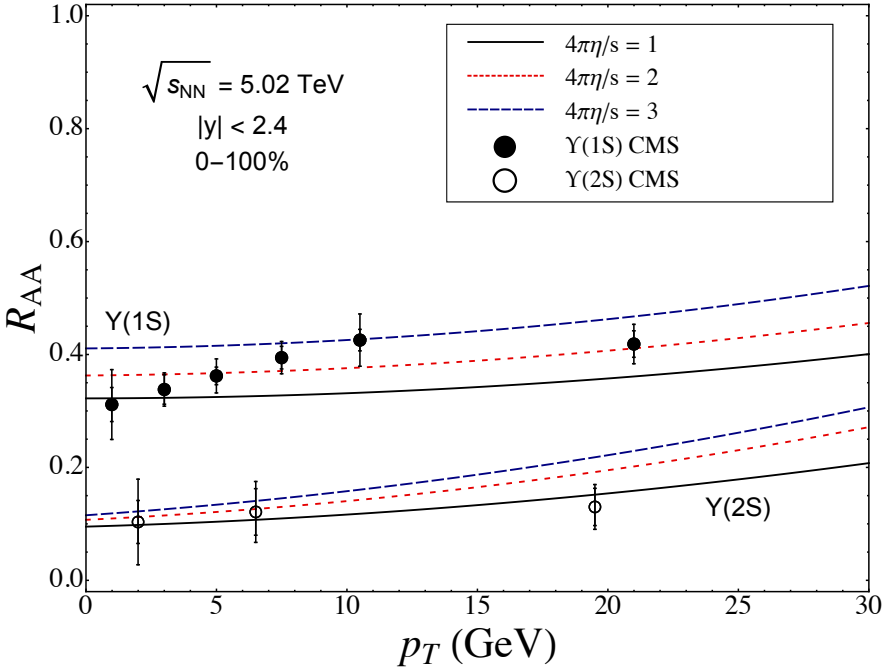
Extra – QM2017 results – Combined |y|



Strickland-Bazow Potential

Extra – QM2017 results – p_T





Strickland-Bazow Potential