Upsilon 1S and 2S suppression in p−Pb and Pb−Pb collisions at LHC: Centrality and Transverse Momentum Dependence

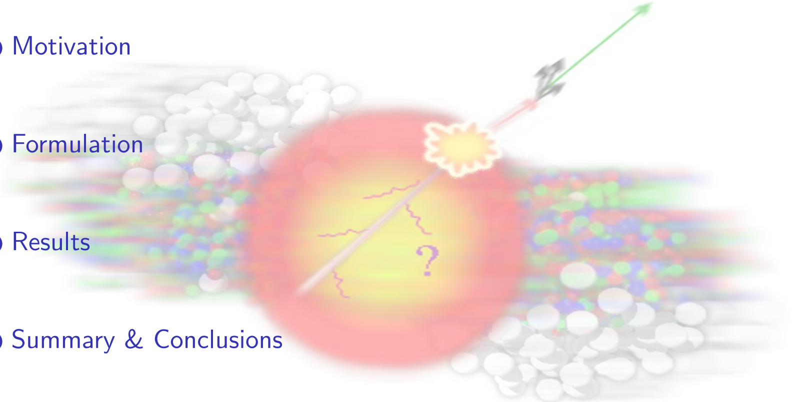
Captain R. Singh, S. Ganesh and **M. Mishra**

Department of Physics

Birla Institute of Technology and Science - Pilani

XXIII DAE-BRNS HIGH ENERGY PHYSICS SYMPOSIUM

December 10-14, 2018, IIT Madras, Chennai, Tamil Nadu, India.



Motivation

- The quarkonia suppression is a key signature to study the formation of QGP in A−A collisions.
- Bottomonium suppression is thought to be cleaner probe: Very less production of secondary $b\bar{b}$ pairs are the cause of negligible regeneration of bottomona in QGP.
- However, a precise estimate of bottomonium suppression needs to incorporate recombination due to correlated $b - \bar{b}$ pairs.
- Old predictions and observations; no QGP in p−A collisions, thought to be an important probe to explain CNM effects. But recent p−Pb collisions data at LHC show "collectivity", a probable QGP.
- Present work, is based on the our research work:
  Captain R. Singh et al., arXiv:1802.09918v2..

Bottomonium Transport in QGP Medium

- We model suppression and recombination processes using the rate equations;

$$\frac{dN_{\Upsilon(nl)}}{d\tau} = \Gamma_{F,nl} N_b \; N_{\bar{b}} \; [V(\tau)]^{-1} - \Gamma_{D,nl} N_{\Upsilon(nl)}$$

- This transport equation is solvable analytically under the assumption of $N_\Upsilon(nl) < N_{b\bar{b}}$ at τ_0:

$$N_{\Upsilon(nl)} \;=\; \epsilon(\tau_{QGP}) \left[N_{\Upsilon(nl)}(\tau_0) + N_{b\bar{b}}^2 \int_{\tau_0}^{\tau_{QGP}} \Gamma_{F,nl}(\tau) [V(\tau)\epsilon(\tau)]^{-1} d\tau \right]$$

Captain R. Singh et al., Phy. Rev. C 92, 034916 (2015).

Collisional Damping

- The singlet potential we are using for quarkonia is given by:

$$V(r,m_D) = \frac{\sigma}{m_D}(1 - e^{-m_D\,r}) - \alpha_{eff}\left(m_D + \frac{e^{-m_D\,r}}{r}\right)$$
$$-i\alpha_{eff}\,T\int_0^\infty \frac{2\,z\,dz}{(1+z^2)^2}\left(1 - \frac{\sin(m_D\,r\,z)}{m_D\,r\,z}\right)$$

- Here, $m_D = T\sqrt{4\pi\alpha_s^T\left(\frac{N_c}{3} + \frac{N_f}{6}\right)}$; $\alpha_{eff} = \frac{4\alpha}{3} = (4/3)\times 0.22$; $N_f = 3$; $\alpha_s^T = 0.47$; $\sigma = 0.192\ GeV^2$.

- The collisional damping dissociation time constant is $\Gamma_{damp} = \int [\psi^\dagger\,[Im(V)]\,\psi]dr.$

Gluonic Dissociation

- Gluonic dissociation cross section is given as;

$$\sigma_{diss,nl}(E_g) = \frac{\pi^2 \alpha_s^u E_g}{N_c^2} \sqrt{\frac{m}{E_g + E_{nl}}} \left(\frac{l|J_{nl}^{q,l-1}|^2 + (l+1)|J_{nl}^{q,l+1}|^2}{2l+1} \right),$$

where, $\alpha_s^u = 0.59$; and $J_{nl}^{ql'} = \int_0^\infty dr r g_{nl}^*(r) h_{ql'}(r)$.

- Using the gluonic dissociation cross section, the dissociation time constant $\Gamma_{gdiss,nl}$ can be written as:

$$\Gamma_{gdiss,nl} = \frac{g_d}{2\pi^2} \int_0^\infty \frac{dp_g \, p_g^2 \sigma_{diss,nl}(E_g)}{e^{E_g/T} - 1} \; ; \; g_d = 16$$

- The total decay rate employing gluonic dissociation and collisional damping is $\Gamma_D = \Gamma_{damp} + \Gamma_{gdiss}$.

G. Wolschin et al., Phys. Rev. C 87, 024911 (2013).

Regeneration due to Gluonic De-excitation

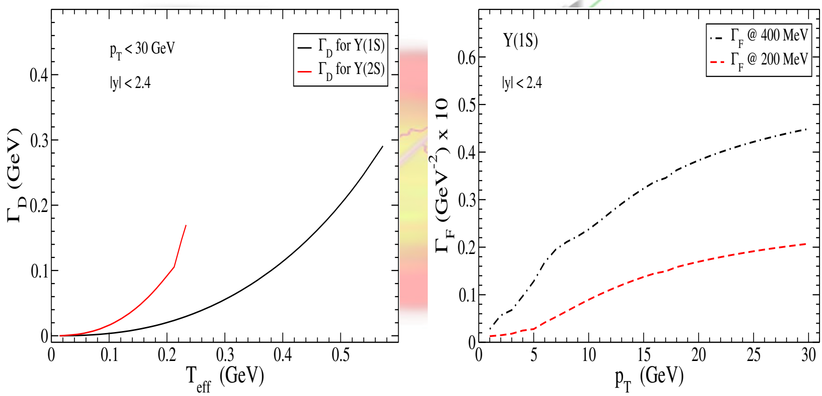
- *Regeneration:* $\Rightarrow$ Formation of Υ due to correlated $q\bar{q}$ pair transition from color octet to color singlet state.
- Recombination factor, $\Gamma_{F,nl}$;

$$\Gamma_{F,nl} = \frac{\int_{p_{b,min}}^{p_{b,max}} \int_{p_{\bar{b},min}}^{p_{\bar{b},max}} dp_b \, dp_{\bar{b}} \, p_b^2 \, p_{\bar{b}}^2 \, f_b \, f_{\bar{b}} \, \sigma_{f,nl} \, v_{rel}}{\int_{p_{b,min}}^{p_{b,max}} \int_{p_{\bar{b},min}}^{p_{\bar{b},max}} dp_b \, dp_{\bar{b}} \, p_b^2 \, p_{\bar{b}}^2 \, f_b \, f_{\bar{b}}}$$

- The recombination cross section $\sigma_{f,nl}$:

$$\sigma_{f,nl} = \frac{48}{36} \sigma_{diss,nl} \frac{(s - M_{nl}^2)^2}{s(s - 4\, m_b^2)},$$

Dissociation Factor Γ_D Vs T_{eff} and Regeneration Factor Γ_F Vs p_T



Suppression due to Colour Screening

- The colour screening model used in the present work is based on pressure profile in the transverse plane and cooling law for pressure based on QPM EOS for QGP.
  The cooling law for pressure is given by:
- $p(\tau, r) = A + \frac{B}{\tau^q} + \frac{C}{\tau} + \frac{D}{\tau^{c_s^2}}$;

  where $A = -c_1$, $B = c_2 c_s^2$, $C = \frac{4\eta q}{3(c_s^2 - 1)}$ and $D = c_3$.
- $c_1 = -c_2 \tau'^{-q} - \frac{4\eta}{3 c_s^2 \tau'}$; $c_2 = \frac{\epsilon_0 - \frac{4\eta}{3c_s^2}\left(\frac{1}{\tau_0} - \frac{1}{\tau'}\right)}{\tau_0^{-q} - \tau'^{-q}}$;
- $c_3 = (p_0 + c_1)\,\tau_0^{c_s^2} - c_2 c_s^2 \tau_0^{-1} - \frac{4\eta}{3}\left(\frac{q}{c_s^2 - 1}\right)\tau_0^{\left(c_s^2 - 1\right)}$

Suppression due to Colour Screening

- Using above cooling laws, we determine the screening radius (r).
- Survival of quarkonia due around screening radius (r) is obtained in the form of survival probability;

$$S_c(p_T, N_{part}) = \frac{2(\alpha+1)}{\pi R_T^2} \int_0^{R_T} dr\, r\, \phi_{max}(r) \left\{1 - \frac{r^2}{R_T^2}\right\}^{\alpha},$$

where $\alpha = 0.5$, R_T and ϕ_{max} (which is a function of p_t and r_s).

P. K. Srivastava, M. Mishra and C. P. Singh, Phys. Rev. C 87, 034903 (2013).

CNM Effect

- We use the EPS09 parametrization to obtain the shadowing $S^i(A, x, \mu)$ for nucleus with mass A, momentum fraction x and scale μ.

$$S^i_\rho(A, x, \mu, \vec{r}) = 1 + N_\rho(S^i(A, x, \mu) - 1)\frac{\int dz \rho_A(\vec{r}, z)}{\int dz \rho_A(0, z)}$$

where N_ρ is determined by the following normalization condition:

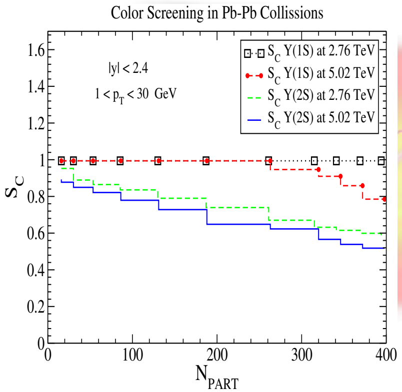
$$\frac{1}{A}\int d^2 r dz \rho_A(s) S^i_\rho(A, x, \mu, \vec{r}) = S^i(A, x, \mu)$$

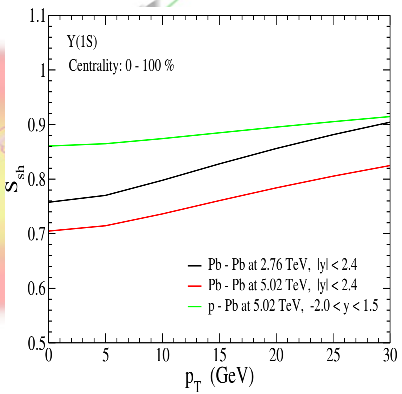
- The suppression factor due to CNM effect is thus determined by,

$$S_{sh} = R_{AB}(N_{part}; b) = \frac{dN_{AB}/dy}{T_{AB}(b) d\sigma_{pp}/dy}$$

R. Vogt, Phys. Report. p.p. 197, 310 (1999).

Color Screening Survival Probability S_c Vs N_{PART} and Shadowing Factor S_{sh} Vs p_T





Net Survival Probability, S_P

- The net production of Υs includes hot and cold nuclear matter effects.
- The initially suppressed Υs due to shadowing effect is given as;

$$N^{i}_{\Upsilon(nl)}(\tau_0, p_T, b) = N_{\Upsilon(nl)}(\tau_0, b)\; S_{sh}(p_T, b)$$

- Now solution of transport Eq. can be written as:

$$N^{f}_{\Upsilon(nl)} = \epsilon(\tau_{QGP})\left[N^{i}_{\Upsilon(nl)}(\tau_0) + N^2_{b\bar{b}} \int_{\tau_0}^{\tau_{QGP}} \Gamma_{F,nl}(\tau)[V(\tau,b)\epsilon(\tau)]^{-1} d\tau\right]$$

- The survival probability due to shadowing, gluonic dissociation along with collisional damping and recombination, is defined as

$$S^{\Upsilon}_{gd}(p_T, b) = \frac{N^{f}_{\Upsilon(nl)}(p_T, b)}{N_{\Upsilon(nl)}(\tau_0, b)}$$

The net yield obtained after color screening of survival probability (S_c);

$$S_P(p_T, b) = S^{\Upsilon}_{gd}(p_T, b)\; S^{\Upsilon}_{c}(p_T, b).$$

Feed-down from higher resonances

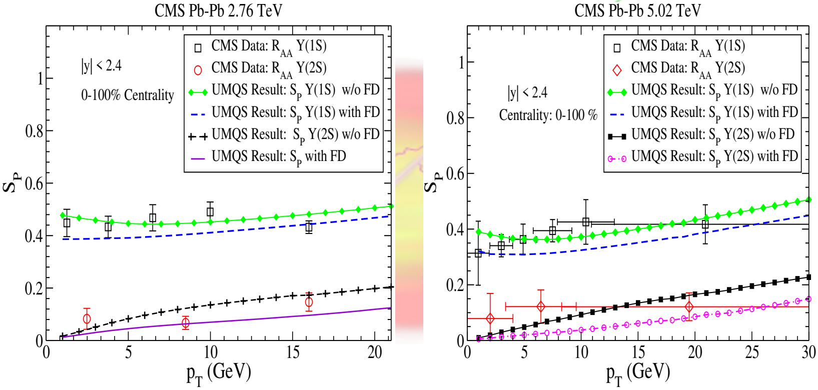
- Feed-down of $\chi_b(2P)$ and $\Upsilon(3S)$ into $\Upsilon(2S)$, effectively suppress its production. Feed-down fractions for $\Upsilon(2S)$, we have considered that $\sim 65\%$ of $\Upsilon(2S)$ come up by direct production whereas $\sim 30\%$ is from the decay of $\chi_b(2P)$ and $\sim 5\%$ is from the decay of $\Upsilon(3S)$.

- Similarly, feed-down for $\Upsilon(1S)$ is obtained by considering that $\sim 68\%$ of $\Upsilon(1S)$ come up by direct production whereas $\sim 17\%$ is from the decay of $\chi_b(1P)$ and $\sim 9\%$ is from the decay of $\Upsilon(2S)$. The feed-down of $\chi_b(2P)$ and $\Upsilon(3S)$ into $\Upsilon(1S)$ is taken as $\sim 5\%$ and $\sim 1\%$, respectively.

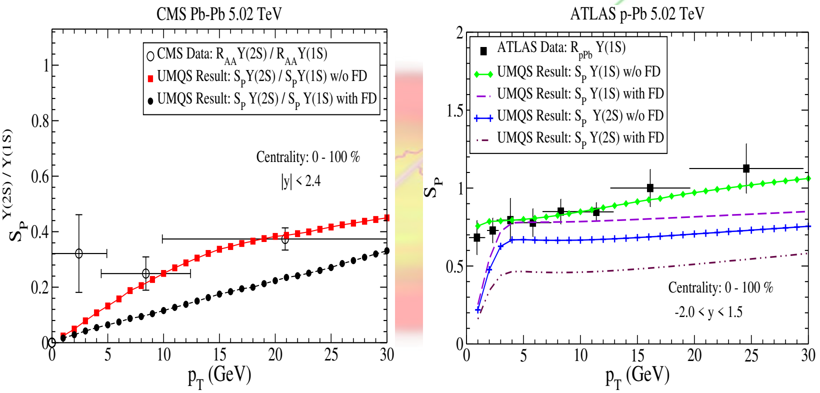
- The $\Upsilon(1S)$ yield of a mixed system after incorporating feed-down correction is expressed as;

$$S_P^f = \frac{0.68\ N_{\Upsilon(1S)}\ S_P^{\Upsilon(1S)} + 0.17\ N_{\chi_b(1P)} S_P^{\chi_b(1P)} + 0.086\ N_{\Upsilon(2S)}\ S_P^{\Upsilon(2S)} + 0.051\ N_{\chi_b(2P)} S_P^{\chi_b(2P)} + 0.01\ N_{\Upsilon(3S)}\ S_P^{\Upsilon(3S)}}{0.65\ N_{\Upsilon(1S)} + 0.15\ N_{\chi_b(1P)} + 0.20\ N_{\Upsilon(2S)} + 0.051\ N_{\chi_b(2P)} + 0.01\ N_{\Upsilon(3S)}}$$

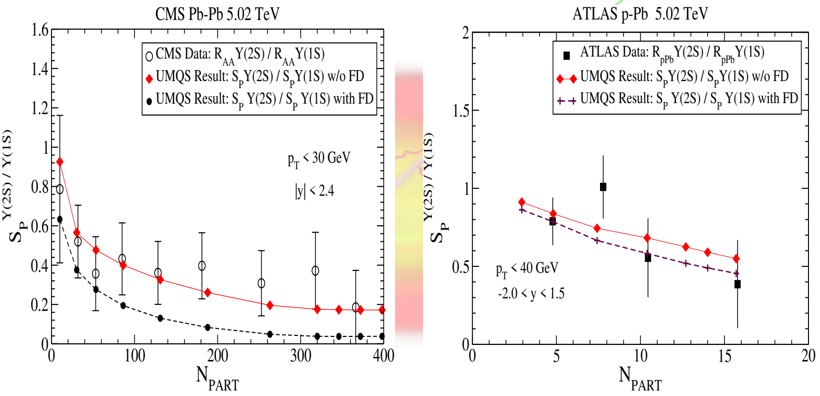
R_{AA} against Transverse momentum p_T



R_{AA} against Transverse momentum p_T



R_{AA} against Centrality



Summary & Conclusions

- Outcomes of our model show that the bottomonium suppression is the combined effect of hot and cold nuclear matters.
- The color screening effect is almost insignificant to suppress the $\Upsilon(1S)$ production while it significantly suppressed $\Upsilon(2S)$ production in Pb−Pb and p−Pb collisions at all the LHC energies.
- The gluonic dissociation along with the collisional damping mechanisms play an important role in $\Upsilon(1S)$ and $\Upsilon(2S)$ in Pb−Pb and p−Pb collisions. Our model suggests a effective regeneration of $\Upsilon(1S)$ in Pb−Pb at $\sqrt{s_{NN}} = 2.76$ & 5.02 TeV.
- QGP formation in p−Pb collision clearly explained by $\Upsilon(1S)$ suppression are around unity with large uncertainty and no direct experimental results are available for $\Upsilon(2S)$ suppression. However, an indirect experimental information of $\Upsilon(2S)$ suppression is available in the form of double ratio. Our model predicted the $\Upsilon(2S)$ suppression in p−Pb collisions.

Acknowledgment

Captain R. Singh and M. Mishra aknowledge Department of Science and Technology (DST), New Delhi for financial support and Department of Physics, BITS-Pilani for providing the research facilities.


Thank you