Unified description of p_T dependent Υ (1S) Suppression in hot QCD matter

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Abstract

Bottomonium are produced in the heavy ion collisions and their production is modified compared with elementary collisions. This modification in the production of bottomonia happens due to the presence of hot and dense QCD matter, named as quark-gluon plasma (QGP) formed in ultra relativistic heavy ion collisions. We present here a comprehensive model based on color screening, collisional damping due to exchange of soft gluons between the $b\bar{b}$ pair and gluonic dissociation caused by absorption of gluon which led $b\bar{b}$ pair transition from color singlet to color octet state. We have also taken cold nuclear matter effect, mainly shadowing effect, in our consideration as it modifies the quarkonia production in heavy ion collisions. We employ the above model to analyze the data on Upsilon suppression measured in terms of nuclear modification factor, R_{AA} versus transverse momentum, p_T and centrality obtained from Pb+Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV LHC energy. We find that our model describes the LHC data reasonably well.

Unified Model of Quarkonia Suppression (UMQS)

- We model Υ suppression and regeneretion processes using the rate equation [1]:

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

- The analytical solution:

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

here, $N_{\Upsilon}^{i}(\tau_0, b) = N_{\Upsilon}(\tau_0, b) S_{sh}$

- The survival probability of Υ due gluonic dissociation, collisional damping, shadowing and recombination:

$$S_g(p_T, b) = N_{\Upsilon}^{f}(p_T, b)/N_{\Upsilon}(\tau_0, b)$$

- **Net Suppression:** The survival probability of Υ after incorporating most possible medium effect:

$$S_P(p_T, b) = S_c(p_T, b) * S_g(p_T, b)$$

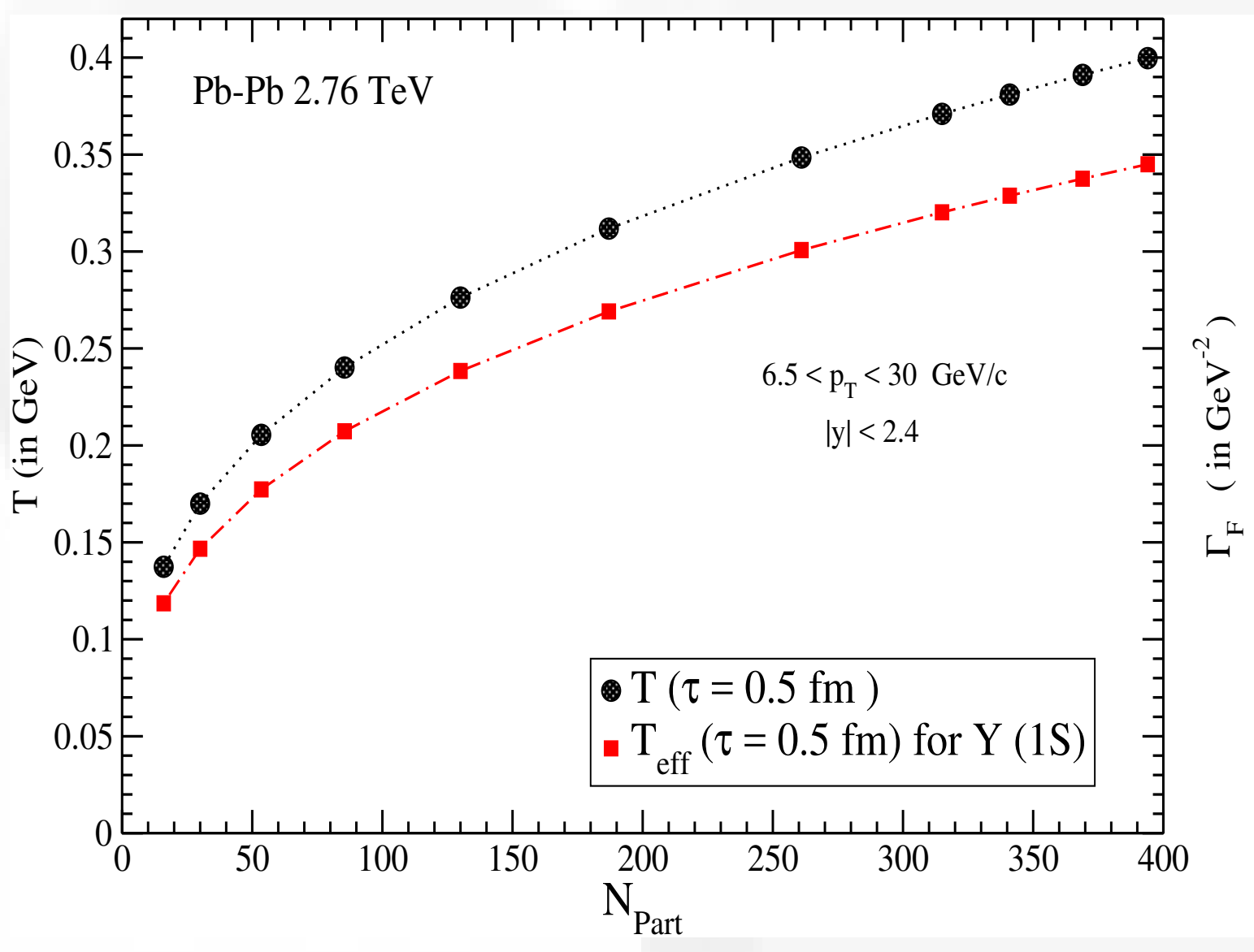
Effective Temperature, $\mathrm{T_{eff}}$

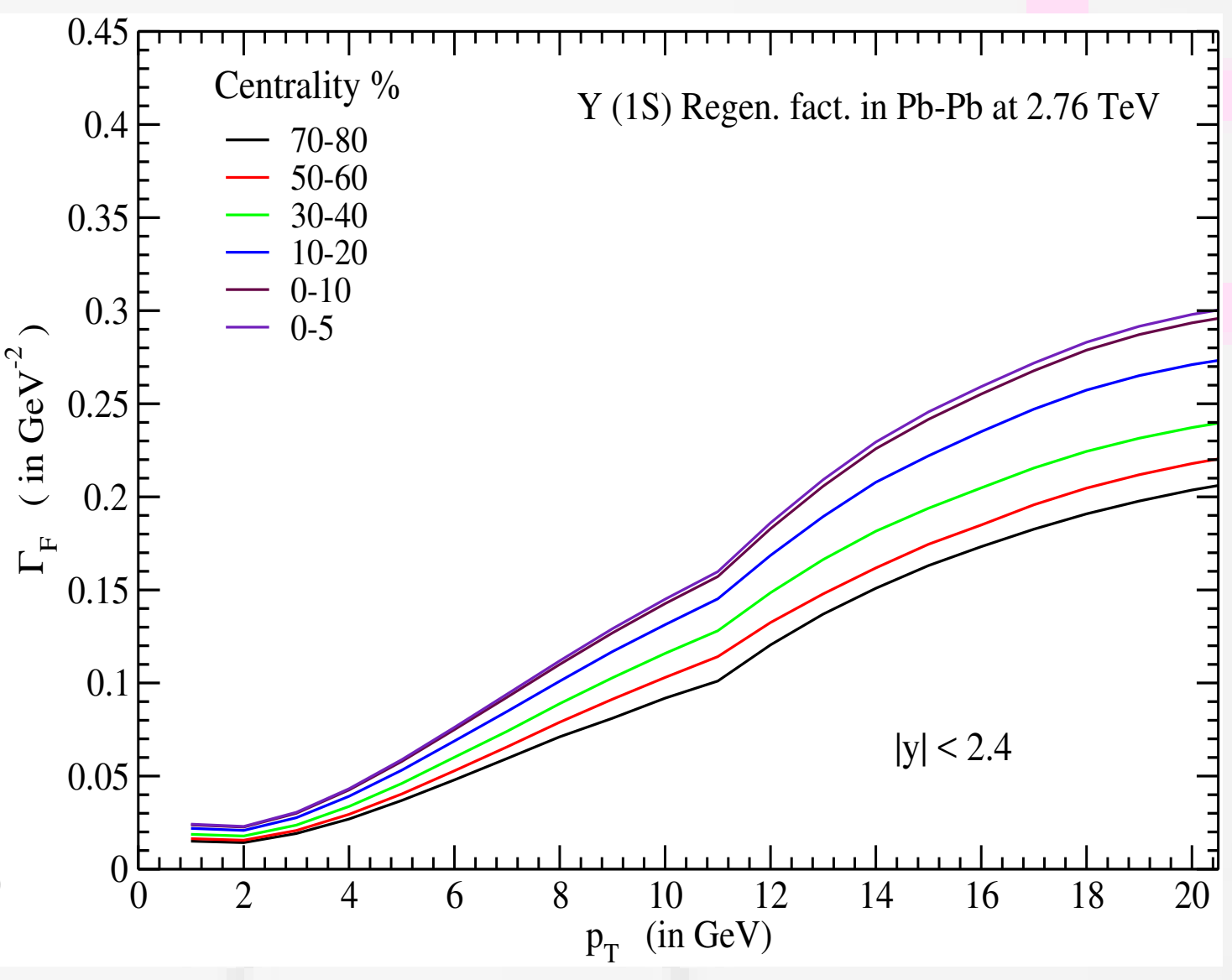
- Because of heavy mass scale and formation time, quarkonia does not share the same temperature with medium .
- Proposed effective temperature [8]

$$\langle T\rangle_{\theta} = \frac{T(b,\tau)\sqrt{1-v_{rel}^{2}}}{2v_{rel}}\, ln\left[\frac{1+v_{rel}}{1-v_{rel}}\right]$$

- here, $T(b, \tau)$ is from the cooling law:

$$T(b,\tau) = T_0\left[\frac{N_{\beta}}{N_{\beta_0}}\ \frac{\tau_0}{\tau}\right]^{1/3}$$





Introduction

High-energy collisions between heavy nuclei provided multiple indications of deconfined phase of matter (QGP) that exists at phenomenally high temperatures and pressures. Experiments at the LHC [6, 7] consolidate many evidence for this exotic medium existence and allow its properties to be characterized. The quarkonia suppression is one of the key signatures in identifying the existence of QGP in high energy heavy-ion collisions. In QGP medium quarkonium states formed in the early pre-thermal stages of the collision can be suppressed because of color screening, gluonic dissociation and collisional damping and CNM effects. The regeneretion of quarkonia is also possible due to presence $q\bar{q}$ pair, this regeneretion mechanism is just the inverse of the breakup reaction happens in the later stage of QGP. In it, Bottomonium suppression is one of the cleaner because it is thought that very less number of secondary bottom quarks and anti quarks are produced in heavy ion collisions and due to this regeneretion of Υ would be negligible in dense QCD matter. But regeneretion of Υ could be possible due to the de-excitation of gluonic dissociation mechanism, which is the transition from color octet $b\bar{b}$ state to color singlet state. In our Unified model of Quarkonia Suppression we incorporated most the possible suppression mechanisms along with regeneretion due to correlated $b\bar{b}$ pair. Using available production cross sections for $b\bar{b}$ and Υ, we have calculated the number of $b\bar{b}$ pairs and Υ produced in heavy ion collisions at LHC at $\sqrt{S_{NN}} = 2.76$ TeV. To explain the Υ suppression in HICs our model (UMQS) incorporates the recombination mechanism. So because of the recombination, the over all suppression of bottomonium will be reduced. To include suppression and recombination mechanism in account we developed a framework of coupled rate equation.

Bottomonium Suppression Mechanisms

- ***Color Screening*** $\Rightarrow$ The color 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:

$$p(\tau, r) = A + \tfrac{B}{\tau^{q}} + \tfrac{C}{\tau} + \tfrac{D}{\tau^{c_s^2}};$$ where A, B, C and D are constants [2, 3].

Calculated $p(\tau, r)$ at initial time $\tau = \tau_i$ and screening time $\tau = \tau_s$ and by combining the pressure profiles, we get the screening radius, r_s.
The Color screening survival probability, S_c:

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

- ***Collisional damping*** $\Rightarrow$ Soft gluons mediate between $q\bar{q}$ pairs cause dissociation.
The potential used in this work is given as [4]:

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

Using above potential we calculated collisional damping:

$$\Gamma_{damp} = \int[\psi^{\dagger}\,[Im(V)]\,\psi]dr$$

- ***Gluonic Dissociation*** $\Rightarrow$ The gluonic dissociation cross section [4] as;

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

Gluonic dissociation factor,$\Gamma_{gdiss,nl}$;

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

The gluonic dissociation along with collisional damping: $\Gamma_D = \Gamma_{damp} + \Gamma_{gdiss}$.

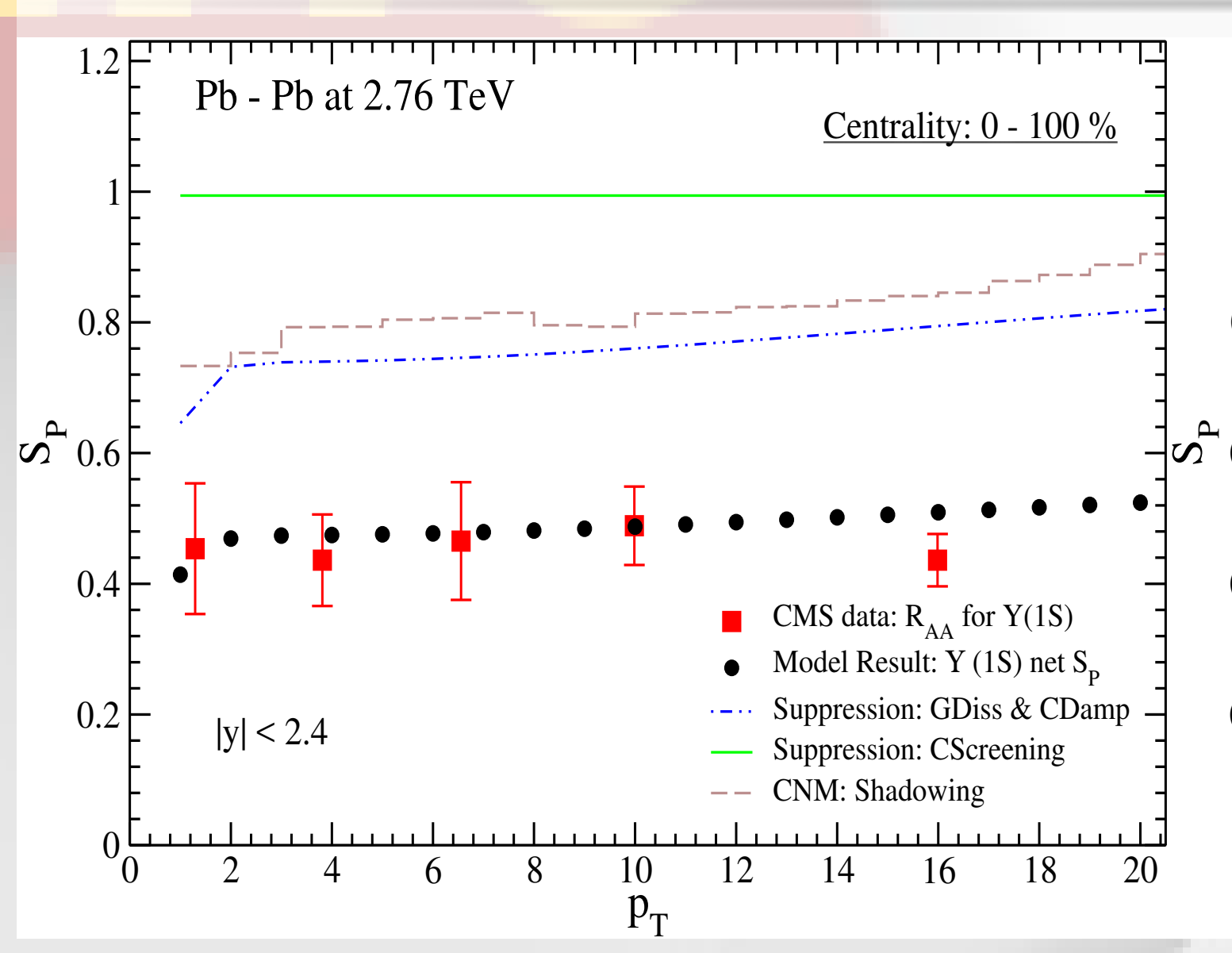
The suppression factor;

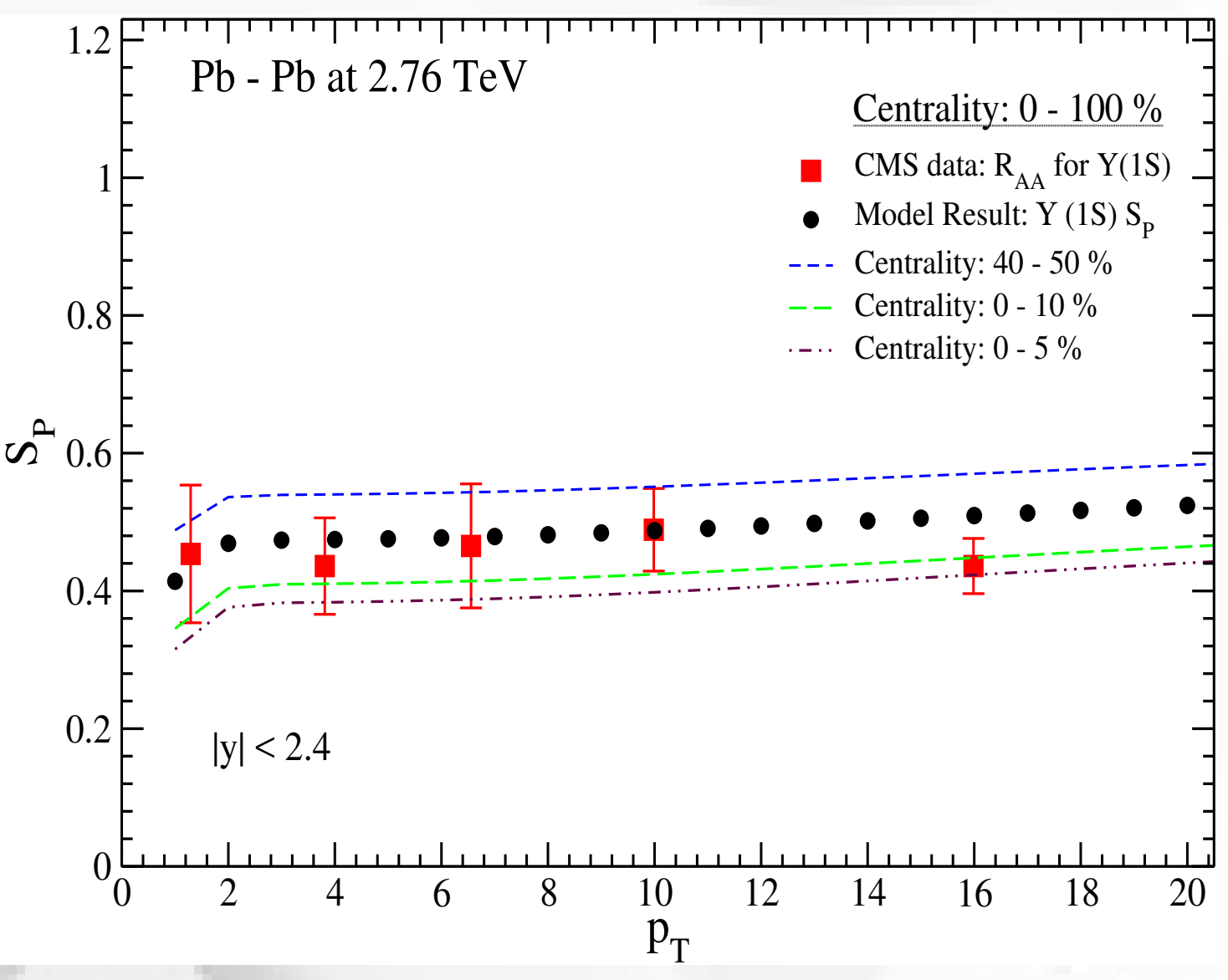
$$\epsilon(\tau) = exp\left[-\int_{\tau_0}^{\tau}\Gamma_D\, dt\right]$$

CNM Effect

- *Shadowing* $\Rightarrow$ Initial-state nuclear effects on the parton densities.
- We use the EPS09 parameterization [5], to obtain the shadowing $S^{i}(A, x, \mu)$ for nucleus with mass A, momentum fraction x and scale μ.
- The CNM shadowing suppression factor is the determined by; $S_{sh} = \frac{d\sigma_{AB}/dy}{T_{AB}(b)d\sigma_{pp}/dy}$

Results: S_P Vs p_T





Recombination Mechanism

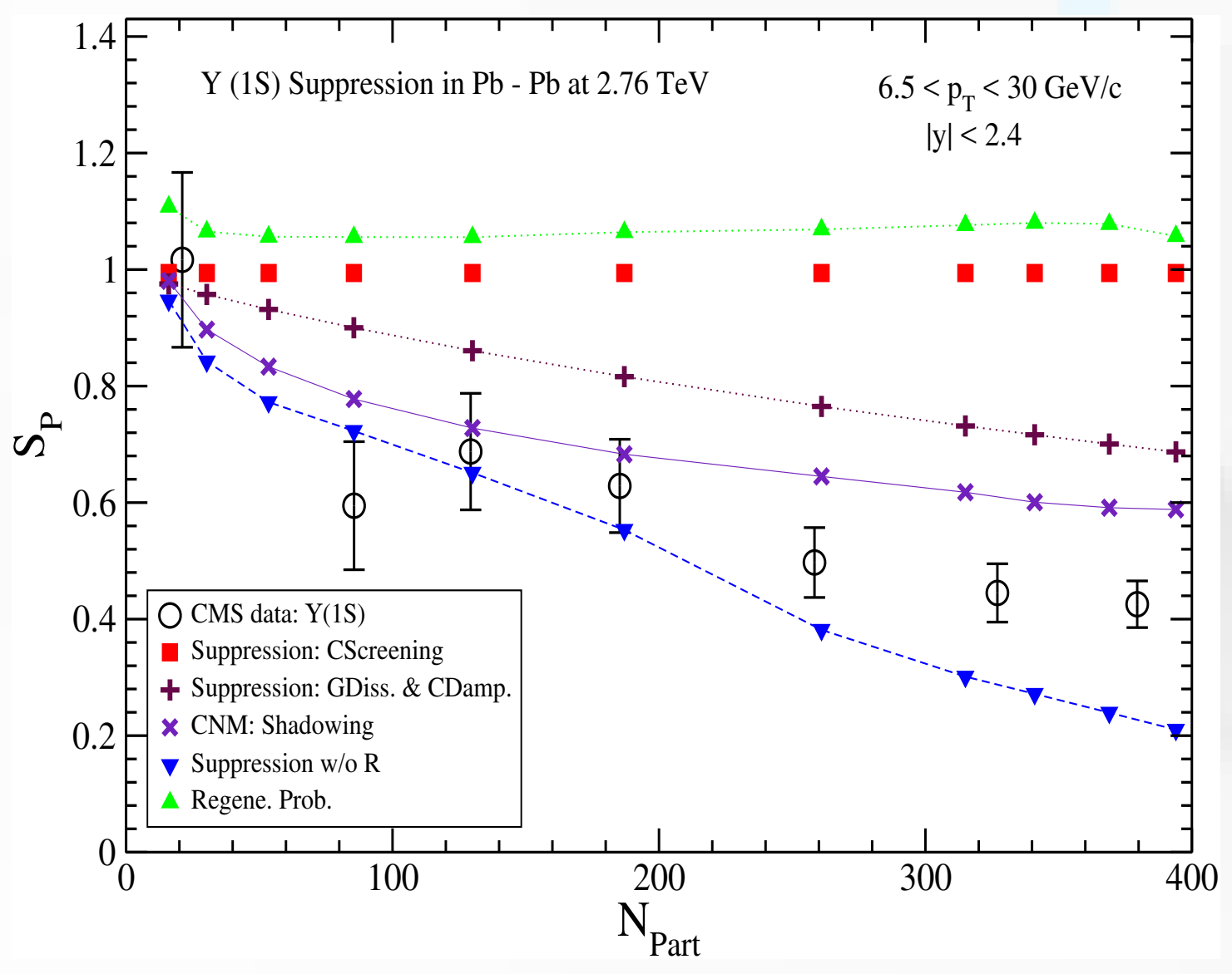
- *Regeneration:* $\Rightarrow$ Formation of Υ due to correlated $q\bar{q}$ pair transition from color octet to color singlet state.
- Recombination factor, $\Gamma_{F,nl}$;

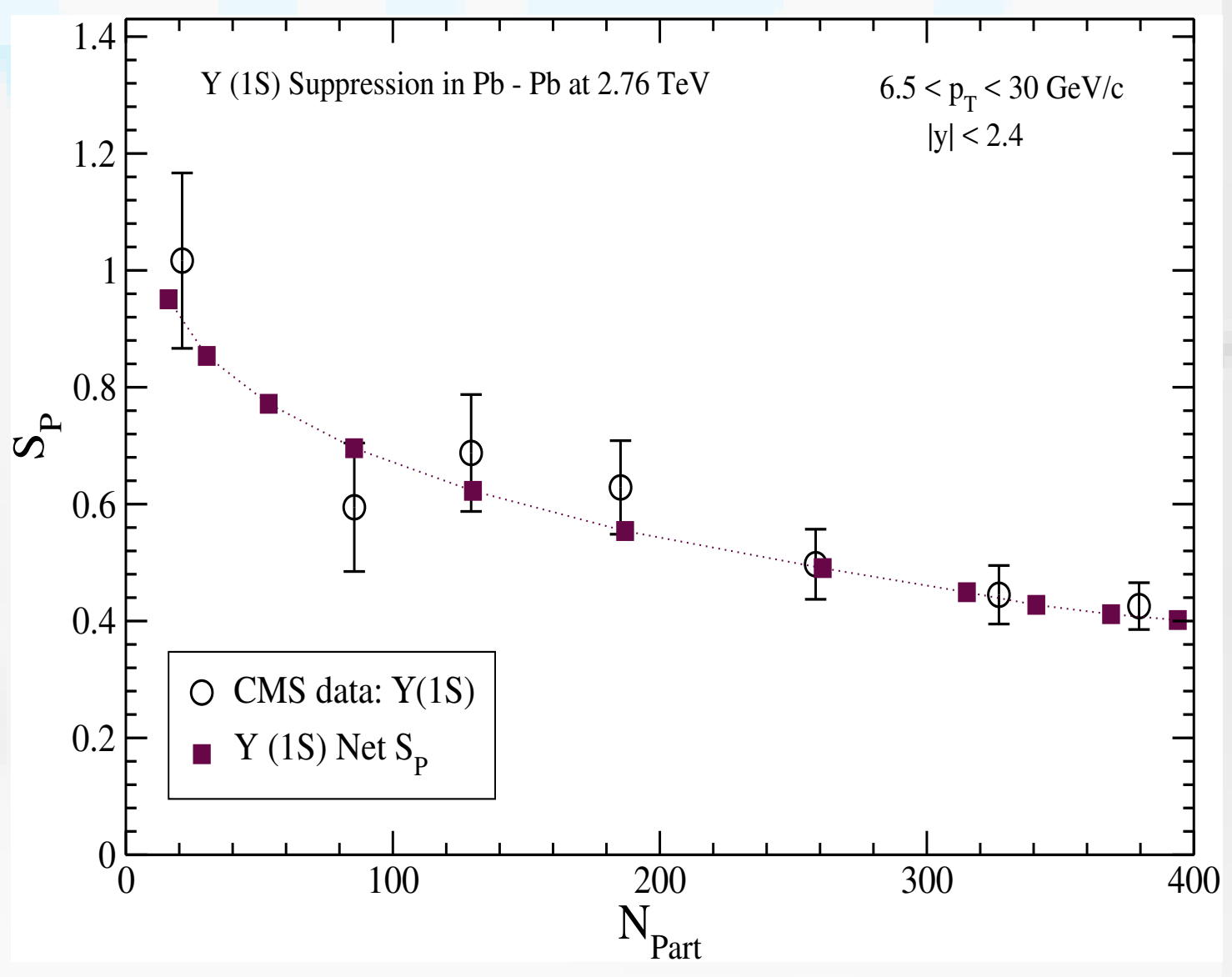
$$\Gamma_{F,nl} = \frac{\int_{p_{b,min}}^{p_{b,max}}\int_{p_{\bar{b},min}}^{p_{\bar{b},max}} dp_b\, dp_{\bar{b}}\, p_b^2\, p_{\bar{b}}^2\, f_b\, f_{\bar{b}}\, \sigma_{f,nl}\, v_{rel}}{\int_{p_{b,min}}^{p_{b,max}}\int_{p_{\bar{b},min}}^{p_{\bar{b},max}} dp_b\, dp_{\bar{b}}\, p_b^2\, p_{\bar{b}}^2\, f_b\,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

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

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

Results: S_P Vs Centrality





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