Sequential Regeneration of Charmonia in Heavy-Ion Collisions

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1. Introduction

- Large Enhancement for $\psi'$
- Large Suppression for $\psi'$

![Graphs and plots showing results for $R_{dAu}$ and $R_{pPb}$, with annotations for CMS PbPb & pp $\sqrt{s_{NN}} = 2.76$ TeV and ALICE, p-Pb $\sqrt{s_{NN}} = 5.02$ TeV, inclusive J/$\psi$, $\psi(2S) \rightarrow \mu^+\mu^-$.]

- Large Enhancement for $\psi'$
- Large Suppression for $\psi'$
2. Quarkonium Transport in Heavy-Ion Collisions

- **Rate Equation**
  \[
  \frac{dN_\psi}{dT} = - \Gamma_\psi \left( N_\psi - N_{\psi}^{eq} \right)
  \]

- **Transport coefficients**
  - Chemical relaxation rate \( \Gamma_\psi \)
  - Equilibrium limit \( N_{\psi}^{eq} \)

- **Inelastic Reactions**
  - **Hadronic dissociation:**
    - \( J/\psi + \pi \rightarrow D + \bar{D}^* \), \( \bar{D} + D^* \)
    - \( J/\psi + \rho \rightarrow D + \bar{D} \)
    - \( J/\psi + \rho \rightarrow D^* + \bar{D}^* \)
  - **QGP dissociation:**
    - \( J/\psi + q(g) \rightarrow c + \bar{c} + q(g) \)

- **Evolve rate equation over expanding fireball evolution in heavy-ion collisions**
3.1 Fireball in pA/dA collisions

QGP formation time:
- AuAu RHIC $\sim 0.6$ fm
- dAu RHIC $\sim 0.9$ fm
- pPb LHC $\sim 0.9$ fm
3.2 Hadronic Dissociation Rates for Charmonia

- SU(4) meson-exchange model \[\text{[Lin+Ko, PRC 62 (2000)]}\]

\[ J/\psi + \rho \rightarrow D + \bar{D} \]
\[ J/\psi + \rho \rightarrow D^* + \bar{D}^* \]
\[ J/\psi + \pi \rightarrow D + \bar{D}^* , \bar{D} + D^* \]

- Contributions from 52 mesons (no baryon yet)

\[ \Gamma_{\text{diss}}^{X+J/\psi}(T) = \int \frac{d^3 k}{(2\pi)^3} f_X(E_X(k); T) \sigma_{\text{in}}^{X+J/\psi}(s, s_{\text{thr}}) v_{\text{rel}} \]

- Rate scaled by geometric size from J/ψ to ψ'
3.2 Dissociation Rates for Charmonia

- Small hadronic rate for J/ψ
- Sizeble hadronic rate for ψ'

Du+Rapp, NPA 943 (2015)
3.3 Charmonia in dAu at RHIC

- For $J/\psi$, hadronic rate negligible
- For $\psi'$, both QGP and hadronic rates relevant
3.3 Charmonia in pPb at LHC

ψ' much more suppressed than J/ψ due to hot medium
4.1 Charmonia in PbPb collision: Sequential regeneration

RAA time evolution

- Blastwave description for $J/\psi$ and $\psi'$:

$$ dN_{\text{reg}}^{\text{reg}} \over dp_t dp_t = N_0(b) m_t \int_0^k r dr K_1 \left( \frac{m c h \rho(r)}{T} \right) I_0 \left( \frac{p_t s h \rho(r)}{T} \right) $$

- $J/\psi \sim 200\text{MeV}$
- $\psi' \sim 160\text{MeV}$

- $\psi'$ regenerated later than $J/\psi$

- Flow pushes $\psi'$ to higher $p_T$
4.2 Sequential regeneration of charmonia and the $\psi'$ puzzle

- Trend of sequential regeneration calculation consistent with data
5. Conclusion

- Revisited hadronic dissociation rates of charmonia, including more complete set of reactions

- Larger hadronic dissociation rate for $\psi'$ generates larger suppression of $\psi'$ than $J/\psi$ in dA/$pA$ collisions

- Sequential regeneration mechanism with large hadronic rate can qualitatively explain the enhanced $\psi'$ over $J/\psi$ double ratio in PbPb

Thanks!