# Non-perturbative Quarkonium Dissociation Rates in the QGP

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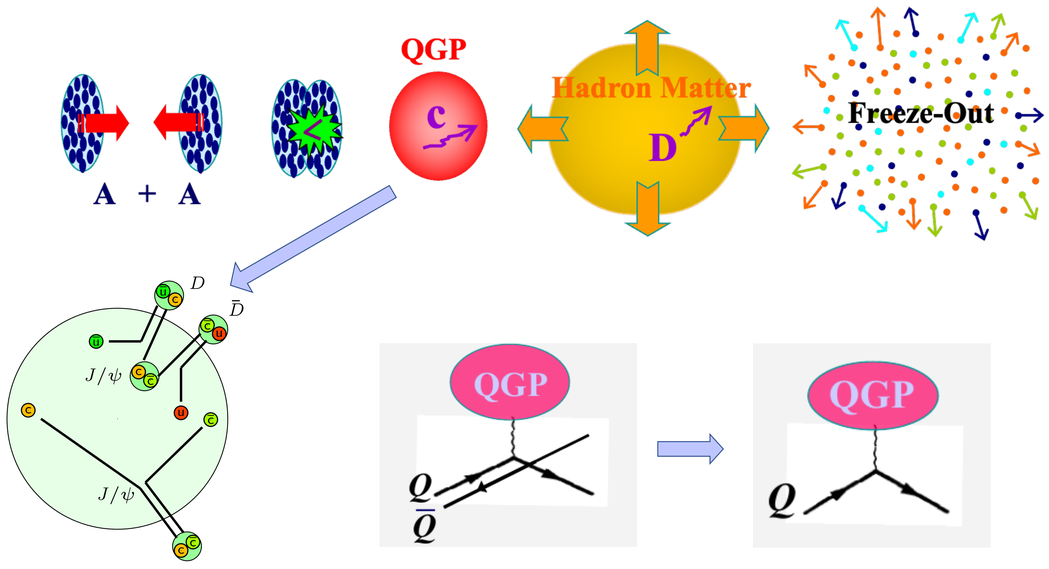
## Motivation

Ultra-Relativistic Heavy-Ion Collisions ⇒ Quark Gluon Plasma (QGP)




Heavy quarkonia: Probe of QGP

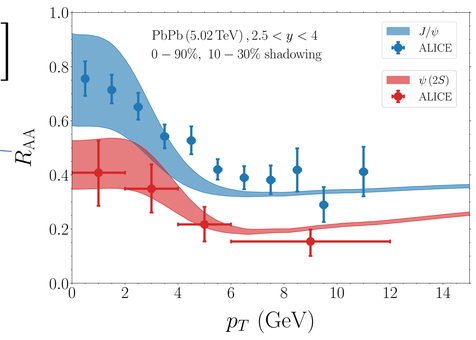
Building block: heavy-light interaction ⇒ Open heavy-flavor transport

[M. He, H. Van Hees, R. Rapp (2022)]

## Transport of Heavy Quarkonia

Rate equation: $\frac{dN_{\mathcal{Q}}}{d\tau} = -\Gamma(T)\left[N_{\mathcal{Q}} - N_{\mathcal{Q}}^{eq}\left(E_B, T, \gamma_Q\right)\right]$

Example: Charmonia production

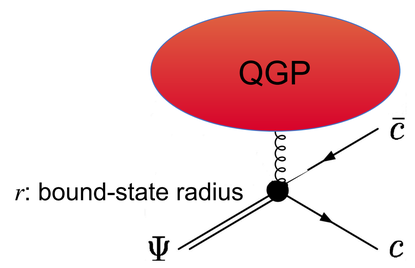



Transport parameters

- $N_{\mathcal{Q}}^{eq}$: equilibrium limit

$$N_{\mathcal{Q}}^{eq} = dV_{\mathrm{FB}}\gamma_{Q_1}\gamma_{Q_2}\int\frac{d^3p}{(2\pi)^3}e^{-\sqrt{m_{\mathcal{Q}}^2+p^2}/T}$$

- $\Gamma$: heavy quarkonium rates
  - Non-perturbative
  - In-medium binding energy
  - Radius of the bound states
  - Interference effect between $Q\bar{Q}$




Example for small $E_B$ (Effective Field Theory)
$\Gamma \sim r^2\kappa$, $\kappa$: heavy-quark (HQ) momentum diffusion coefficient

[L. Grandchamp, R. Rapp (PRL92), X. Zhao, R. Rapp (PRC82), R. Sharma, B. Singh (2302.00508)]

## Quarkonium Reaction Rate $\Gamma_{\mathcal{Q}}^{\mathrm{qf}}$

Momentum dependence of the inelastic parton scattering in quasifree approximation:

$$\Gamma_{\mathcal{Q}}^{\mathrm{qf}}\left(p_{\mathcal{Q}};T\right) = \frac{2}{E_{\mathcal{Q}}}\sum_{p=q,\bar{q},g}\int d^3\bar{p}_i d^3\bar{p}_f d^3\bar{p}_{Q,f}\overline{\left|\mathscr{M}_{p\tilde{Q}\to pQ}\right|^2}(2\pi)^4\delta^{(4)}\left(P_{\mathrm{in}}-P_{\mathrm{out}}\right)d_p f_p\left(E_{p_i}\right)\left[1\pm f_p\left(E_{p_f}\right)\right]\left[1-e^{i\mathbf{q}\cdot\mathbf{r}}\right]$$

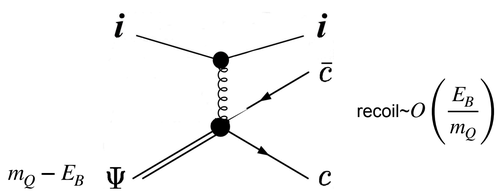
In-medium binding energy

Interference
- 3-body effect
- $r$: radius of the bound states

$\mathscr{M}_{p\tilde{Q}\to pQ}$:
- heavy light scattering amplitude
- Incoming heavy quark mass $\sim m_Q - E_B$
- Neglect recoil of spectator: $E_B \ll m_Q$

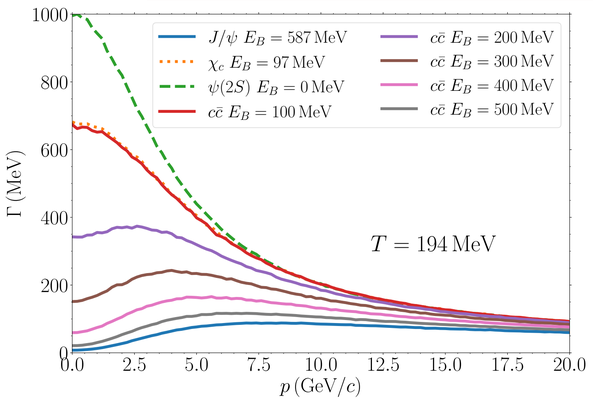
Perturbative: Tree-level amplitude

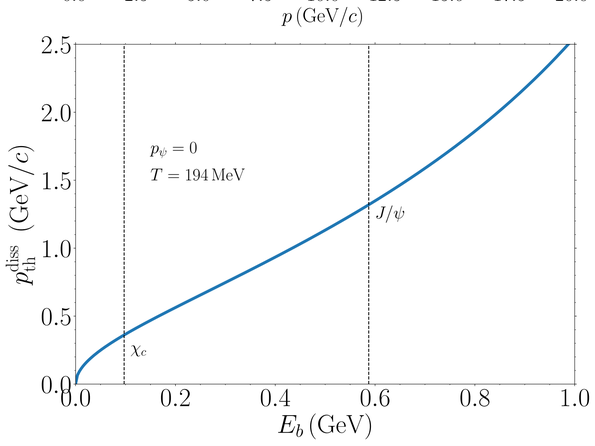
Non-Perturbative: In-medium T-matrix

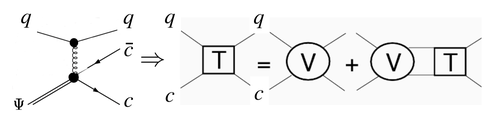



[F. Riek, R. Rapp (PRC82)] [S. Liu and R. Rapp (PRC97)]

## Non-Peturbative Rates (Charmonia)




Heavy light T-matrix

- Large rates at small p and $E_B$
- 1S rate is small at low temperature
- Sensitivity to $E_B$ at small 3-momentum

⇓

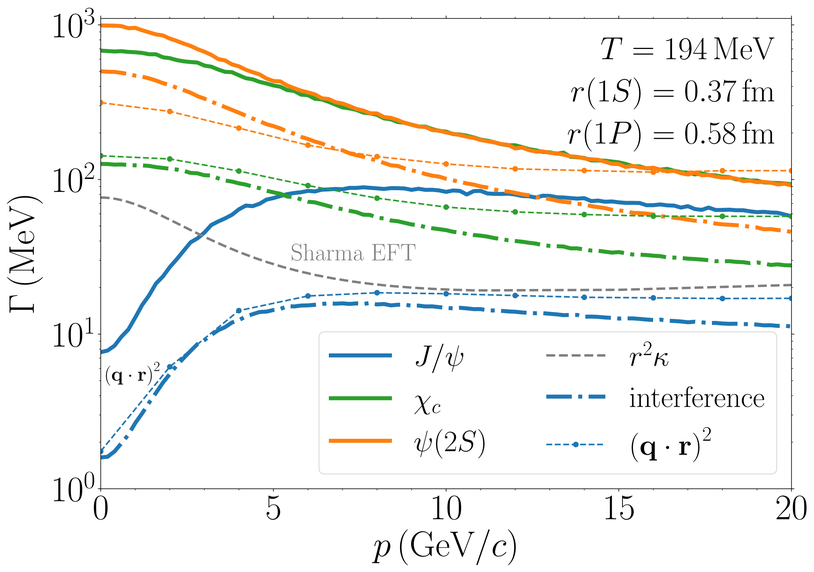
Large light-quark Momentum threshold to dissolve a $c\bar{c}$ with large $E_B$

⇓

Large suppression of non-perturbative interaction strength

## Comparison of Different Approximations

- Dipole expansion: Interference term $1 - e^{i\mathbf{q}\cdot\mathbf{r}} \sim \left(\mathbf{q}\cdot\mathbf{r}\right)^2$
- EFT rates: $\Gamma_{\mathcal{Q}} \sim \kappa r^2$ ⇒ HQ momentum diffusion, size of the bound state




- Dipole expansion: good approximation for large $E_B$, small bound states
- EFT fails at small 3-momentum for large $E_B$

## Conclusions

- Systematic investigation of quarkonium reaction rates
- Multi-scale problem: $M_Q \gg T$, $E_B$, $\Lambda_{\mathrm{QCD}}$, $p_{\mathrm{th}}^{\mathrm{diss}}$, without clear hierarchy ⇒ non-perturbative
- Strong sensitivity of reaction rates to in-medium binding energy + interference (3-body ) effects (especially at small 3-momentum).
- Recover limiting expression $\Gamma \sim r^2\kappa$ for small $E_B$
- Future plan: implement in-medium light and heavy quark spectral functions