Effects of perturbative and non-perturbative heavy quark transport on B_c production in heavy-ion collisions

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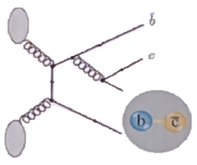
Motivation of studying B_c mesons in heavy-ion collisions



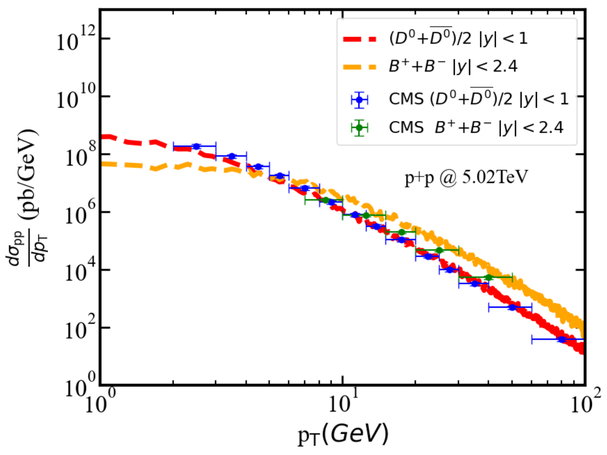
$$gg \longrightarrow B_c + b + \bar{c} \qquad B_c^+ \longrightarrow (J/\psi \longrightarrow \mu^-\mu^+)\mu^+\nu_\mu$$

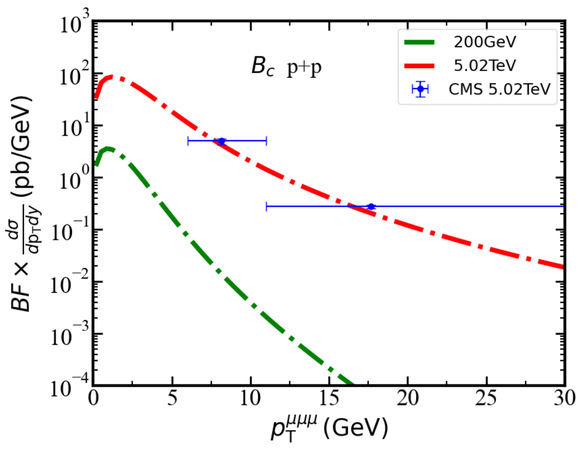
- Recent CMS experiments have measured the bound states of charm and bottom quarks in both pp and AA collisions[1].
- The B_c mesons provide a new opportunity to study the energy loss of open heavy quarks and the formation mechanisms of heavy quark bound states.

B_c production in pp collisions

- Spectra of charm and bottom quarks: FONLL.
- Fragmentation to D^0 and B^+: Pythia.
- Fragmentation to B_c (fit to CMS data):

$$D_{b\to B_c^-}(z) = N\frac{rz(1-z)^2}{[1-(1-r)z]^6}[6-18(1-2r)z+(21-74r+68r^2)z^2 - 2(1-r)(6-19r+18r^2)z^3+3(1-r)^2(1-2r+2r^2)z^4]$$





Dissociation of B_c mesons

- Quasifree scattering dissociation[3] with: $|p_a - p_c| > E_B \ \ (ab \to cd)$.
- Heavy quark elastic scattering rate extracted from the Boltzmann equation:

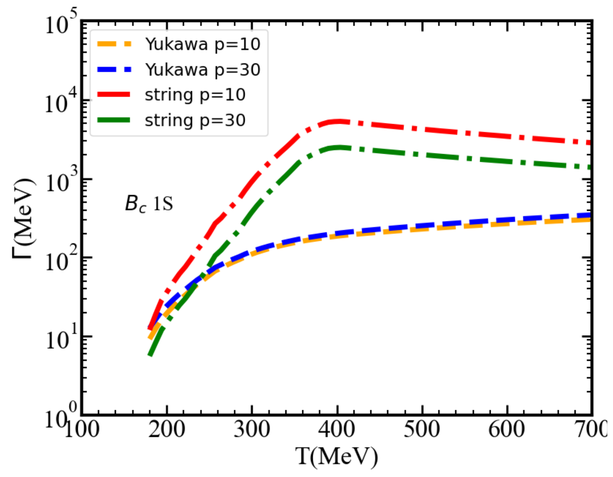
$$\Gamma_a^{el}(E_a,T) = \sum_{b,(cd)}\frac{\gamma_b}{2E_a}\int\prod_{i=b,c,d}\frac{d^3p_i}{E_i(2\pi)^3}f_b(E_b,T)(2\pi)^4\delta^{(4)}(p_a+p_b-p_c-p_d)\,|M_{ab\to cd}|^2$$

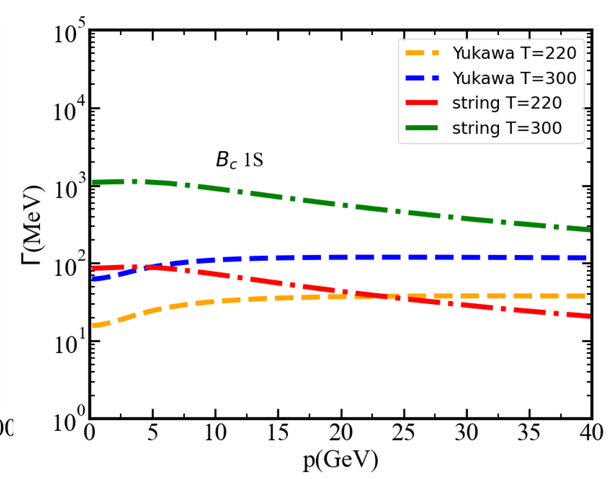
- In the scattering amplitude term $|M|^2$, the Cornell-type potential is used to include both **Yukawa (perturbative) term** and **string (non-perturbative) term**[4].

$$V(r,T) = -\frac{4}{3}\alpha_s\frac{e^{-m_d r}}{r} - \frac{\sigma}{m_s}e^{-m_s r}$$

- The dissociation rate of B_c mesons:

$$\Gamma_{B_c} = \Gamma_c + \Gamma_{\bar{b}} \qquad \gamma m_c v_c + \gamma m_{\bar{b}} v_{\bar{b}} = p_{B_c}$$





- The string interaction leads to much larger dissociation rate of B_c than the Yukawa interaction.

Conclusion and outlook

- The perturbative and non-perturbative interactions yield different medium-modified spectra of open heavy quarks, which further affect the B_c spectrum from recombination and fragmentation.
- Different interactions affect the dissociation of B_c mesons by influencing the scattering rates of heavy flavor quarks with QGP.
- More precise experimental data on B_c in the future can provide a more stringent constraint on heavy quark dynamics in high-energy nuclear collisions, and may also shed light on the inner structure of B_c mesons.

B_c production after medium modification

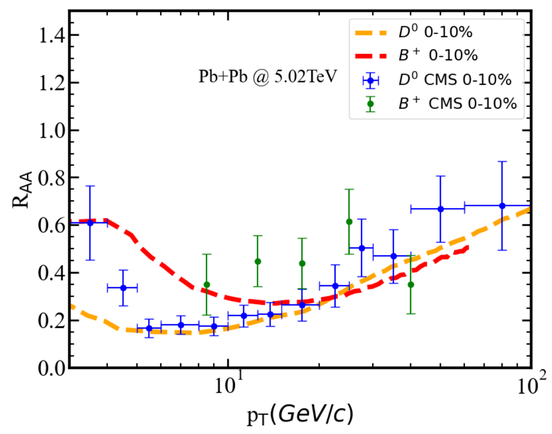
Recombination to B_c mesons

- Medium modified charm and bottom quarks can recombine into B_c according the **coalescence mode**.

$$\frac{d^3N_{B_c}(\vec{p})}{d^3\vec{p}} = C_{rec}g_{B_c}\int d^3\overrightarrow{p_c}\,d^3\overrightarrow{p_{\bar{b}}}\frac{d^3N_c}{d^3\overrightarrow{p_c}}\frac{d^3N_{\bar{b}}}{d^3\overrightarrow{p_{\bar{b}}}}\delta^{(3)}(\vec{p}-\overrightarrow{p_c}-\overrightarrow{p_{\bar{b}}})\omega(\vec{k})$$

$$\omega(\vec{k}) = \frac{(4\pi\sigma^2)^{\frac{3}{2}}}{V_{FB}}\frac{(2\sigma^2k^2)^l}{(2l+1)!!}e^{-\sigma^2k^2} \qquad \sigma^2(1S) = \frac{4}{3}\frac{(m_c+m_{\bar{b}})^2}{m_c^2+m_{\bar{b}}^2}\langle r_{1S}^2\rangle$$

- σ is extracted from the mean-square radii of the B_c mesons [3].
- The fireball volume is scaled from V = 4997 fm^3, calculated using the statistical hadronization model for 0-10% central collisions[2].
- The medium-modified spectra of c and b quarks are extracted from **linear Boltzmann transport (LBT) model** and are constrained by data on open heavy mesons.

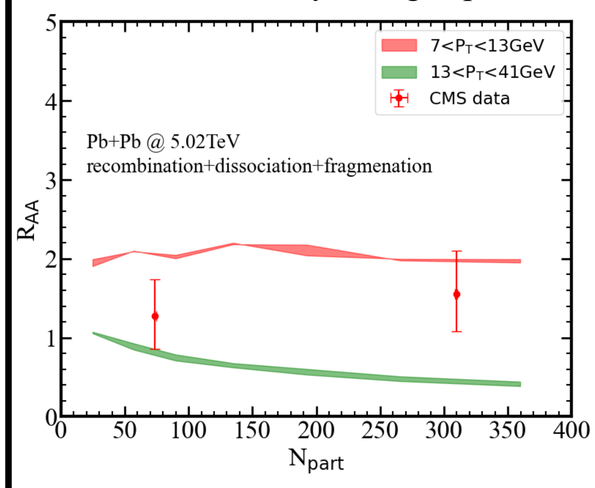


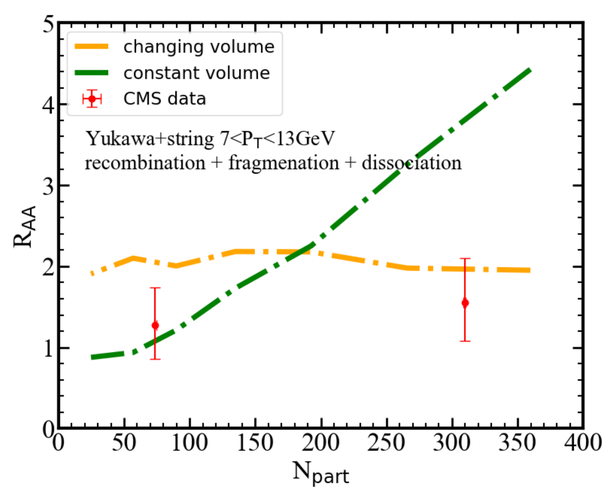
Fragmentation to B_c mesons

- Fragmentation function: $D_{b\to B_c^-}$.

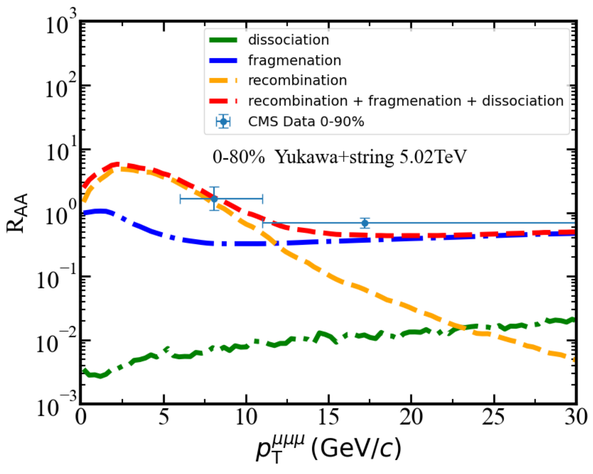
R_{AA} of B_c in Pb+Pb collisions at 5.02 ATeV

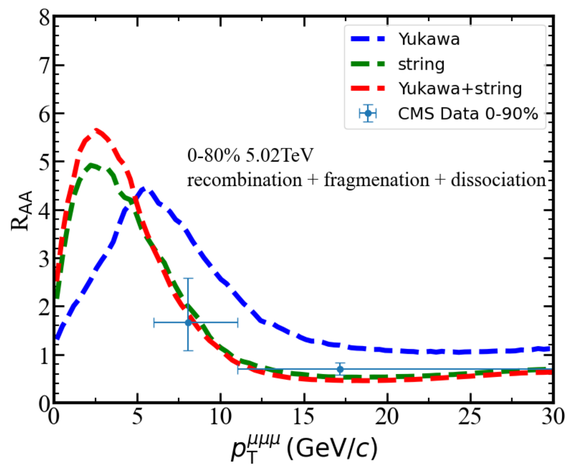
- We obtain Crec by fitting experimental data.





- The recombination of B_c mesons depends on the volume of the QGP.





- Within a LBT model that incorporates both Yukawa and string interactions between heavy quarks and the QGP, we study **dissociation, fragmentation and recombination** of B_c in energetic nuclear collisions.
- Our model provides a satisfactory description of the nuclear modification factor of B_c in Pb+Pb collisions at 5.02 ATeV.

[1] CMS, Armen Tumasyan et al, Phys.Rev.Lett. 128 (2022) 25, 252301.
[2] Zhao, Shouxing, and Min He, *arXiv:2407.05234* (2024).
[3] Wu, Biaogang et al, *Phys.Rev.C* 109 (2024) 1, 014906.
[4] Xing, Wen-Jing, Guang-You Qin, and Shanshan Cao, *Phys. Lett.B* 838 (2023) 137733.