Medium-enhanced $c\bar{c}$-radiation

Maximilian Attems,1,* Jasmine Brewer,1,† Gian Michele Innocenti,2,‡ Aleksas Mazeliauskas,1,§ Sohyun Park,1,¶ Wilke van der Schee,1,** and Urs Achim Wiedemann1,††

1 Theoretical Physics Department, CERN, CH-1211 Genève 23, Switzerland
2 Experimental Physics Department, CERN, CH-1211 Genève 23, Switzerland

We show that the very same Baier-Dokshitzer-Mueller-Peigné-Schiff – Zakharov (BDMPS-Z) parton energy loss formalism that predicts a medium-induced depletion of high-$p_T$ single inclusive charm spectra results in a medium-enhanced $c\bar{c}$-pair production within high-$p_T$ jets.
Heavy quark production and energy loss in high-energy collisions

- Heavy quarks $m_{c,b} \gg \Lambda_{QCD}$
  $\Rightarrow$ short-distance perturbative production.
- Scattering with Quark Gluon Plasma
  $\Rightarrow$ long-distance gluon radiation $c \to cg$
- Observed modification of $p_T$ spectra
  $\Rightarrow$ heavy flavour quenching

New effect: interaction with the medium modifies $g \to c\bar{c}$ splitting rate!
Colinear splitting $g \rightarrow c\bar{c}$ in parton shower

- Factorization in the colinear limit

$$\sigma_{gg \rightarrow c\bar{c}X} = \sigma_{gg \rightarrow gg} \cdot \frac{\alpha_s}{2\pi} \frac{1}{Q^2} \cdot P_{g \rightarrow c\bar{c}}$$

  - hard gluons
  - splitting function

- Formation time $t_{\text{form}} \sim \frac{E_g}{Q^2}$

  => boosted pairs are produced late

- Interaction with the medium changes the number of charmed hadrons.

Modification of $\frac{1}{Q^2} P_{g \rightarrow c\bar{c}}$ calculable in the perturbative BDMPS-Z framework.

See arXiv:2203.11241, talk by Sohyun Park, Wed, 08:40
\( g \rightarrow c\bar{c} \) splitting function: \( P_{g \rightarrow c\bar{c}} \)

- In vacuum, e.g., Pythia shower,
  \[
  \left( \frac{1}{Q^2} P_{g \rightarrow c\bar{c}} \right)^{\text{vac}} = \frac{1}{Q^4 z (1 - z)} (m_c^2 + \kappa^2 [z^2 + (1-z)^2])
  \]
  where \( \kappa = \frac{1}{2} (k_c - k_{\bar{c}}) \)

- In medium \( P_{g \rightarrow c\bar{c}} \) is modified
  \[
  \left( \frac{1}{Q^2} P_{g \rightarrow c\bar{c}} \right)^{\text{tot}} = 2 \Re e \frac{1}{4 E_g z (1 - z)} \int_{t_{\text{init}}}^{t_{\infty}} dt \int_{t}^{t_{\infty}} d\bar{t} e^{i \frac{m_c^2}{2 E_g z (1 - z)} (t - \bar{t})} \int dr_{\text{out}} K [r_{\text{in}}, t; r_{\text{out}}, \bar{t}]
  \]
  \[
  \times e^{-\frac{1}{2} \int_{t}^{t_{\infty}} d\xi n(\xi) \sigma_3 (r_{\text{out}}, z)} e^{-i \kappa \cdot r_{\text{out}}} \left[ m_c^2 + \frac{\partial}{\partial r_{\text{in}}} \cdot \frac{\partial}{\partial r_{\text{out}}} [z^2 + (1 - z)^2] \right] \]

- In multiple soft scattering approximation
  \[
  n(\xi) \sigma_3 (r_{\text{out}}, z) = \frac{1}{2} \hat{q} (C_F - N_c z (1 - z)) r_{\text{out}}^2, \quad C_F = \frac{4}{3}
  \]

Various model estimates \( 1 \text{ GeV}^2 \lesssim C_F \hat{q} L \lesssim 8 \text{ GeV}^2 \)
Broadening and enhancement of $c\bar{c}$ pairs

We observe enhancement of the splitting function over wide phase-space.

\[
\frac{\left(\frac{1}{Q^2} P_{g\to c\bar{c}}\right)^{\text{tot}}}{\left(\frac{1}{Q^2} P_{g\to c\bar{c}}\right)^{\text{vac}}} = 1 + \text{weight}
\]

\[
E_g = 20 \left(\frac{L}{4\text{ fm}}\right) \text{ [GeV]}
\]

\[
\hat{q}L = 4 \text{ GeV}^2
\]

Idea: reweight vacuum shower (Pythia) with medium modified splitting functions.
Medium-induced charm meson production inside jets

- Consider the fraction of jets with $D^0, \bar{D}^0$ pairs ⇒ contains $g \rightarrow c\bar{c}$ splitting.
- Reweight each $g \rightarrow c\bar{c}$ splitting ⇒ explore range of $\hat{q}$ values for for PbPb.
- Compare with the unmodified $pp$ fraction.

10-40% enhancement of $D^0\bar{D}^0$ tagged jets ⇒ novel test of BDMPS-Z picture.

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Backup
Statistics estimates of $D^0\bar{D}^0$ tagged jets

Expected PbPb luminosity $\mathcal{L} = 10\,\text{nb}^{-1} \Rightarrow$ equivalent $\mathcal{L}_{pp} = 0.1\,\text{fb}^{-1}$

At $p_T \sim 80\,\text{GeV}$ expect to measure $\mathcal{O}(1000)\, D^0\bar{D}^0$ jets via $K^-\pi^+$ channel.
Effect of enhanced gluon radiation to $c\bar{c}$ splitting

Gluon no-splitting probability given by Sudakov factor:

$$S_{g\to\text{All}}^{\text{tot}} = \exp\left[-\frac{\alpha_s}{2\pi} \int \frac{dQ^2}{Q^2} dz \left( P_{g\to c\bar{c}}^{\text{vac}} + P_{g\to c\bar{c}}^{\text{med}} + P_{g\to X}^{\text{vac}} + P_{g\to X}^{\text{med}} \right) \right] = S_{g\to c\bar{c}}^{\text{tot}} S_{g\to X}^{\text{tot}},$$

Probability (to split into $c\bar{c}$) & (not to split in anything else):

$$\left(1 - S_{g\to c\bar{c}}^{\text{tot}} \right) S_{g\to X}^{\text{tot}} = \int \frac{dQ^2}{Q^2} dz \left( P_{g\to c\bar{c}}^{\text{vac}} + P_{g\to c\bar{c}}^{\text{med}} \right) \exp\left[-\frac{\alpha_s}{2\pi} \int \frac{dQ^2}{Q^2} dz P_{g\to X}^{\text{med}} \right].$$

However relative probability (not to split in anything else) is suppressed by $\alpha_s$

$$\exp\left[-\frac{\alpha_s}{2\pi} \int \frac{dQ^2}{Q^2} dz P_{g\to X}^{\text{med}} \right] \sim e^{-\frac{\alpha_s}{2\pi} \# \left( \hat{q}_L^2 - \hat{q}_L^2 \right)} = 1 - O(\alpha_s).$$

While medium enhancement probability (to split into $c\bar{c}$) is not suppressed.