IGFAE INSTITUTO GALEGO DE FÍSICA DE ALTAS ENERXÍAS 25 1999 2024

FACTORIZATION AND JET FUNCTIONS IN HEAVY ION COLLISIONS

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19/06/2024

WORK IN PROGRESS!

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I. INTRODUCTION

Motivation of this work

In vacuum we know the jet **evolution in virtuality**

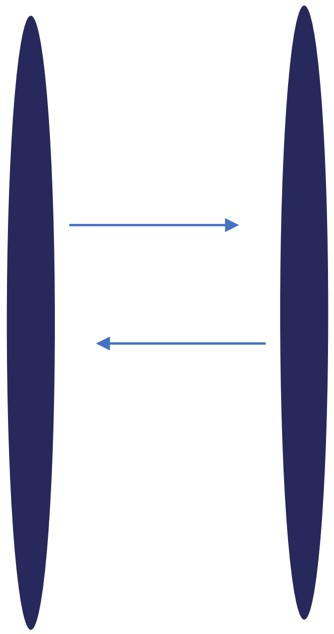
In medium we know the jet **evolution in time**

Consistent way to **combine** virtuality and time evolution of medium jets

Motivation of this work

- ⊕ q^+, collisional energy loss, conventionally believed to be **small**
- ◣ $q_\perp^2/L \sim \hat{q}$, transverse momentum broadening, **jet quenching parameter**
- ⊖ q^-/L, enhanced production of $Q\bar{Q}$ pairs, **a new transport coefficient?**

Modeling the nuclei



We study $\mathbf{A + A \to Jet + \gamma + X}$

Nucleons are consider to be **uncorrelated** (Glauber model)

The jet is created by a **hard collision** among 2 nucleons

The effect of the other nucleons is modeled by a **classical field**

II. FACTORIZATION OF JET CROSS SECTIONS IN HEAVY-ION COLLISIONS

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Factorization of the cross section

$$\frac{d\sigma}{d^2\mathbf{b}dO} = \int\prod_f \left[d\Gamma_{p_f}\right]\delta(O - O(\{p_f\}))\int d^2\mathbf{X}T_{A_1}(\mathbf{X})T_{A_2}(\mathbf{X}-\mathbf{b})\int\frac{d^4x_I d^4p_I}{(2\pi)^4}e^{ip_I\cdot x_I}J_{\mu\nu}(X_T + x_I/2, X_T - x_I/2)$$

$$\times\sum_{X_h}(2\pi)^4\delta(P_{A_1}+P_{A_2}-p_\gamma-p_I-p_{X_h})\frac{1}{2s_{NN}}M_h^{*\mu}(P_{A_1},P_{A_2};p_\gamma,p_{X_h})M_h^{\nu}(P_{A_1},P_{A_2};p_\gamma,p_{X_h})$$

Cross section divided into **jet** and **hard vertex** sectors

Formula still **not factorized**

$$J_{\mu\nu}(X_T + x_I/2, X_T - x_I/2) \propto g_{\mu\nu} - p_I^+\frac{p_{I\mu}\bar{n}_\nu + p_{I\nu}\bar{n}_\mu}{(p_I^+)^2 - \cancel{p_I^2\bar{n}^2}} + p_I^2\frac{\bar{n}_\mu\bar{n}_\nu}{(p_I^+)^2 - \cancel{p_I^2\bar{n}^2}} + \bar{n}^2\cancel{\frac{p_{I\mu}p_{I\nu}}{(p_I^+)^2 - p_I^2\bar{n}^2}} = g_{\perp\mu\nu} + O\left(\frac{m_I^2}{(p_I^+)^2}\right)$$

We must include a **factorization scale** that separates two regimes

- For $m_I \ll p_I^+$ the jet **function factorizes**
- For $m_I \gtrsim p_I^+$ the jet function **cannot be factorized**

The jet function

$$\frac{d\sigma}{d^2\mathbf{b}do\,d^2\mathbf{p}_\gamma d\eta_\gamma} = \int d^2\mathbf{X}\, T_{A_1}(\mathbf{X}) T_{A_2}(\mathbf{X}-\mathbf{b}) \int d\Gamma_{\hat{p}_I} \frac{d}{do} J(\bar{n}\cdot p_I, \vec{n}; \mathbf{X}) \frac{d\sigma_h}{d\Gamma_{\hat{p}_I} d^2\mathbf{p}_\gamma d\eta_\gamma}(P_{A_1}, P_{A_2}; \hat{p}_I, p_\gamma)$$

We will focus on the calculation of the **jet function**

$$\frac{d}{do} J(p_I^+, \vec{n}; \mu^2, \mathbf{X}) \equiv \int_0^{\mu^2} \frac{dm_I^2}{2\pi} \int d^4x_I e^{\frac{i}{2} p_I^+ x_I^- + \frac{i}{2}\frac{m_I^2}{p_I^+} x_I^+} \left(\sum_{m=1}^{\infty} \prod_{j=1}^{m} \int d\Gamma_{p_j} \right) \delta(o - o(\{p_j\}))$$
$$\times \frac{-g_\perp^{\mu\nu}}{2(N_c^2-1)} \langle\langle\langle 0 | \bar{T} A_\mu^a (X + x_I/2) | \{p_j\} \rangle \langle \{p_j\} | T A_\nu^a (X - x_I/2) | 0 \rangle\rangle\rangle$$

The main difference with usual calculations is the **restriction on the virtuality phase space**

Uncertainty in the creation point of the jet $x_I^+ \sim \dfrac{2p_I^+}{m_I^2}$

III. THE JET FUNCTION FOR $Q\bar{Q}$ PRODUCTION AT LO

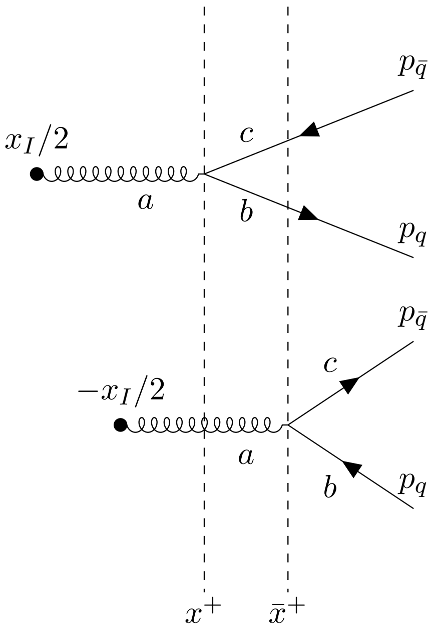
The general formula for the $Q\bar{Q}$ spectrum

$$\frac{dJ}{dz\,dm_I^2}(p_I^+,\vec{n};m_I^2,X)=\frac{1}{2\pi}\int d^2\underline{x}_I\,dx_I^+\,e^{\frac{i}{2}\frac{m_I^2}{p_I^+}x_I^+}\int\frac{d^2\underline{p}_q}{(2\pi)^2}\frac{d^2\underline{p}_{\bar{q}}}{(2\pi)^2}\frac{1}{8\pi z(1-z)p_I^+}$$
$$\times\frac{-1}{2(N_c^2-1)}\langle\langle\langle 0|\,\bar{T}A_{a\mu}(X_T+\tilde{x}_I/2)\,|p_q p_{\bar{q}}\rangle\langle p_q p_{\bar{q}}|\,TA^{a\mu}(X_T-\tilde{x}_I/2)\,|0\rangle\rangle\rangle$$

It can be generalized for any other **3-particle vertex**

Literature results should be recovered in the **limit** $\mu^2\to\infty$

The gluon jet function for $Q\bar{Q}$ in vacuum



[R.K. Ellis, W.J. Stirling and B.R. Webber (2011)]

$$\frac{dJ}{dz dm_I^2}(p_I^+, \vec{n}; m_I^2, X) = \frac{\alpha_s}{2\pi}\frac{1}{m_I^2}P_{Q\leftarrow g}(z, m, m_I^2)\theta(z(1-z)m_I^2 - m^2)$$

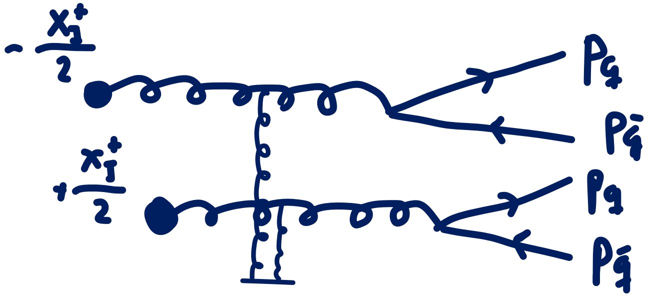
where $P_{Q\leftarrow g}(z, m, m_I^2) \equiv T_F\left[z^2 + (1-z)^2 + \frac{2m^2}{m_I^2}\right]$

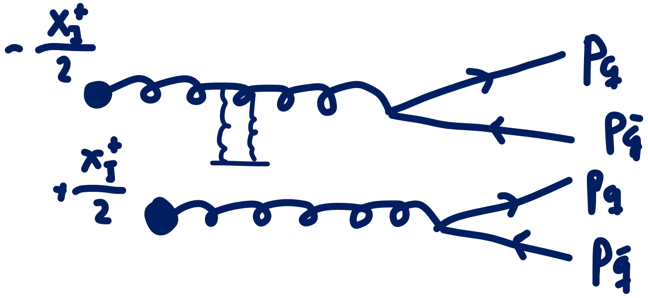
The gluon can only split when it's **virtuality is higher that** $\frac{m^2}{z(1-z)}$

The gluon jet function for $Q\bar{Q}$ in medium

Explore what happens if the gluon **transverses a QCD medium** before splitting

Calculation at **first order in opacity**





We fix $\mu^2 = \frac{m^2}{z(1-z)}$, studying the **phase space forbidden in vacuum**

↓

The virtual diagram cannot contribute, **only real contribution**

The BDMPS-Z formalism

The **background (classical) field** contribution is included as a potential term in the path integral

The only **non-zero correlator** is

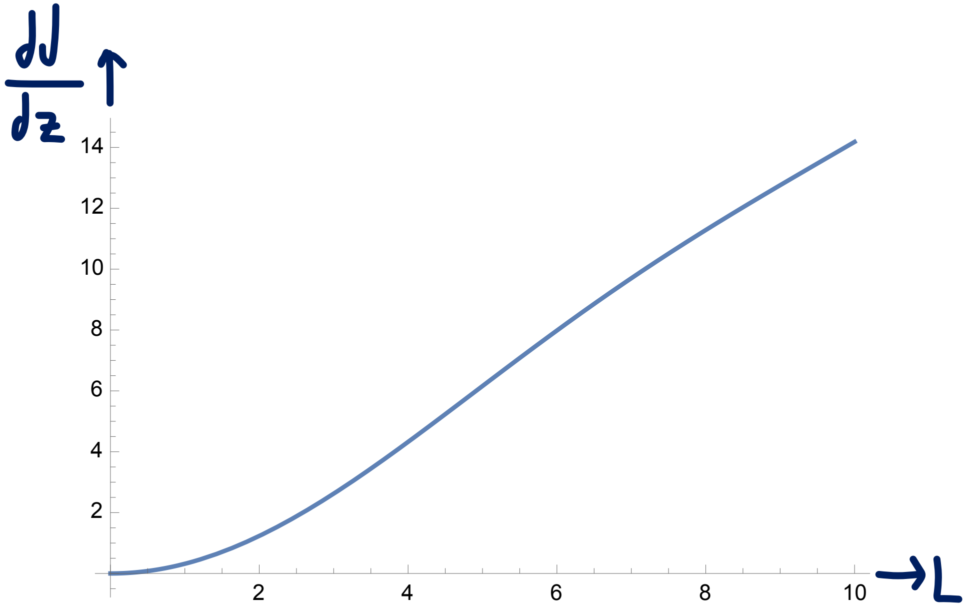
$$\langle A^{a-}(x^+,\underline{x})A^{b-}(y^+,\underline{y})\rangle = \delta(x^+ - y^+)\delta^{ab}2n(t)\sigma(\underline{x} - \underline{y})$$

Medium can transfer whatever virtuality to the jet in a single scattering

Results for medium induced $Q\bar{Q}$ in production

Spectrum of $Q\bar{Q}$ pairs in the vacuum forbidden phase space region

$$\frac{dJ}{dz}\left(\mu^2=\frac{m^2}{z(1-z)}\right)=4\alpha_s(\alpha_s C_A 2n\sigma_T)\int\frac{d^2\underline{p}}{(2\pi)^2}\frac{m^2+[z^2+(1-z)^2]\underline{p}^2}{(\underline{p}^2+m^2)^2}\left\{L\,Si\left(\frac{m^2}{z(1-z)p_I^+}L\right)-\frac{z(1-z)p_I^+}{m^2}\left[1-\cos\left(\frac{m^2}{z(1-z)p_I^+}L\right)\right]\right\}$$



✓ Production of $Q\bar{Q}$ pairs **enhanced by the length** of the medium

✗ **Overestimating the effect** due to non fixed q^-

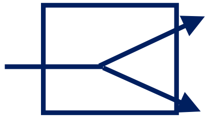
IV. CONCLUSIONS AND OUTLOOK

Conclusions…

- We must introduce a **factorization scale** to separate the jet function from the hard vertex
- The medium **fills with $Q\bar{Q}$** pairs the virtuality phase space that is forbidden in vacuum
- We need to introduce q^- to control the virtuality transfer by the medium

… and outlook

- Develop a model where q^- **depends on the medium parameters**



- Include **splittings inside the medium**

THANKS FOR YOUR ATTENTION!

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