FACTORIZATION AND JET FUNCTIONS IN HEAVY ION COLLISIONS

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Motivation

- In vacuum we know how jets **evolve in virtuality**
- In medium we know how jets **evolve in light-cone time**
- We aim to **consistently combine virtuality and time evolution** for in-medium jets

Relevant transport coefficients

- q^+, **collisional energy loss**, conventionally small
- $\frac{q_\perp^2}{L} \sim \hat{q}$, **jet quenching parameter** [R. Baier, Y.L. Dokshitzer, A.H. Mueller, S. Peigne and D. Schiff, Nucl. Phys. B 484 (1997) 265.]
- q^-/L, can enhance the production of $Q\bar{Q}$ pairs, **new transport coefficient?**

Factorization of the jet cross section

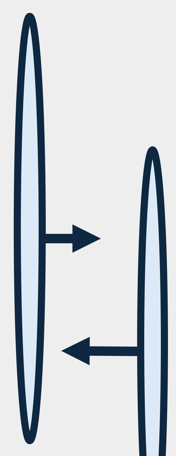
$$\frac{d\sigma}{d^2\mathbf{b}dO} = \int \prod_f \left[d\Gamma_{p_f}\right] \delta(O - O(\{p_f\})) \int d^2\mathbf{X} T_{A_1}(\mathbf{X}) T_{A_2}(\mathbf{X} - \mathbf{b}) \int \frac{d^4x_I d^4p_I}{(2\pi)^4} e^{ip_I \cdot x_I} J_{\mu\nu}(X_T + x_I/2, X_T - x_I/2)$$
$$\times \sum_{X_h} (2\pi)^4 \delta(P_{A_1} + P_{A_2} - p_\gamma - p_I - p_{X_h}) \frac{1}{2s_{NN}} M_h^{*\mu}(P_{A_1}, P_{A_2}; p_\gamma, p_{X_h}) M_h^{\nu}(P_{A_1}, P_{A_2}; p_\gamma, p_{X_h})$$

Divided in **jet** and **hard vertex** sectors but still not factorized

We must include a **factorization scale** in the initial jet virtuality m_I

- For $m_I \ll p_I^+$, **the cross section factorizes**
- For $m_I \sim p_I^+$, **the cross section cannot be factorized**

[CL, Bin Wu, and Carlos Salgado, work in progress]



- Nuclei modelled as **uncorrelated nucleons**
- Collision between **only one pair** of nucleons

[N. Armesto, F. Cougoulic and B. Wu, 2407.19243.]

The factorized formula reads

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

The hard cross section can be calculated from the nPDFs and tree level amplitudes

The jet function in light-cone gauge is written as

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

Focusing on the production of $Q\bar{Q}$ pairs

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

! In our formalism, the jet cross section **depends on the initial virtuality** of the jet

$Q\bar{Q}$ production in vacuum

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

Known results, correctly reproduced by our model [R.K. Ellis, W.J. Stirling and B.R. Cambridge University Press (2011).]

The gluon can only split if **its virtuality squared is higher than** $\frac{m^2}{z(1-z)}$

$Q\bar{Q}$ production in medium

We fix the factorization scale $\mu^2 = \frac{m^2}{z(1-z)}$ to study **how the medium fills the region of the phase space that was forbidden in vacuum**

We only consider diagrams **at first order in opacity** and only the case where **the gluon splits after exiting the medium**

We model the effect of the medium over the jet using **classical fields**, and considering that the **only non-vanishing correlator** of the fields is [Casalderrey-Solana and C.A. Salgado, Acta Phys. Polon. B 38 (2007) 3731.]

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

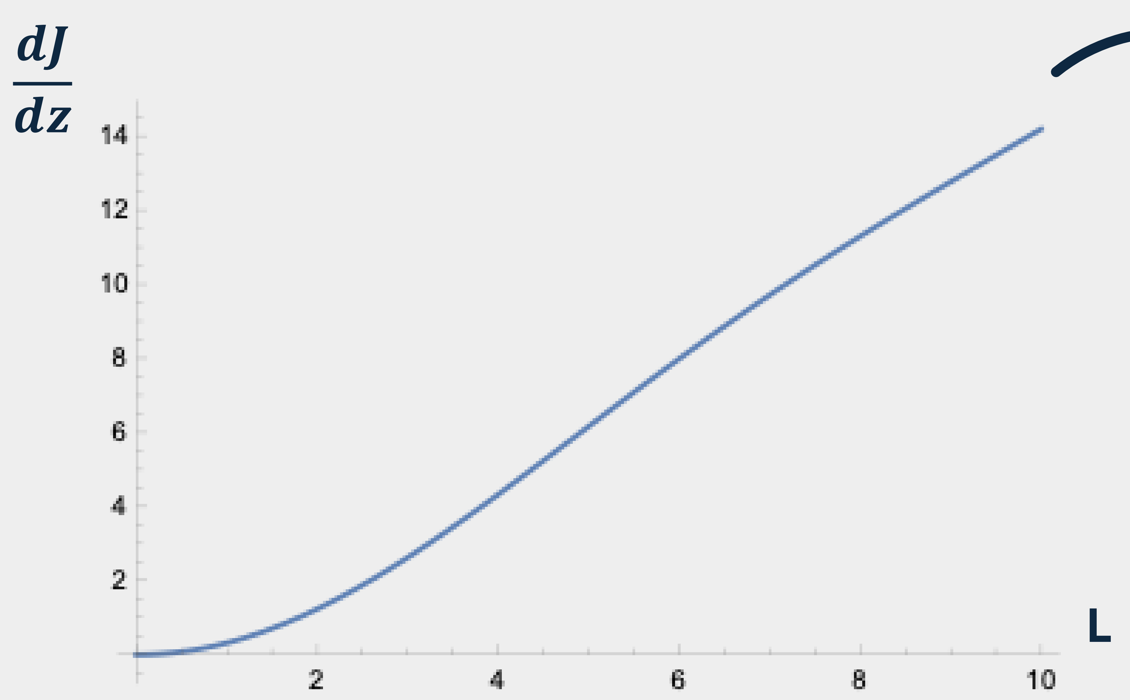
The x^+coordinate of the collision with the medium is **completely localized** due to the delta in the correlator, so its conjugated variable, the q^- transferred by the medium is **completely delocalized**

The **jet can then extract as much virtuality as desired** from the medium in a single scattering

We are **overestimating the number of $Q\bar{Q}$ pairs** produced

A POTENTIAL PROBLEM !!!

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



Outlook

- We must develop a model where the virtuality transferred by the medium is controlled by the medium parameters
- We must include the diagrams where **the splitting happens inside the medium** and perform **resummation in opacity** if possible

Conclusion

The medium **fills the region of the phase space that was forbidden in vacuum** by transferring virtuality to the jet

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