

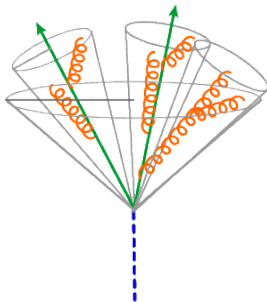
# Color coherence in multiple antenna medium radiation

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## Motivation: jet substructure



- Ideal techniques for heavy ion collisions.
- More direct access to the underlying dynamics:
  - QGP properties.
  - Energy loss.
  - Coherence.

## Color coherence in vacuum

- Is radiation independent?:  $q\bar{q}$  antenna as a laboratory.

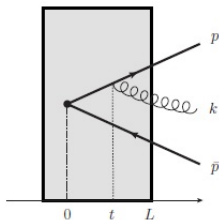
$$\mathcal{M}_{q\bar{q}g} = \text{diagram 1} + \text{diagram 2}$$

$$dN = \frac{d\omega}{\omega} \frac{d\Omega}{2\pi} \frac{\alpha_s C_F}{2\pi} [R_q + R_{\bar{q}} - 2\mathcal{J}]$$

- The spectrum is suppressed at large angles due to the presence of destructive interferences (coherence).
- Angular ordering.

## Color coherence in a medium

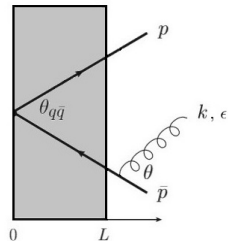
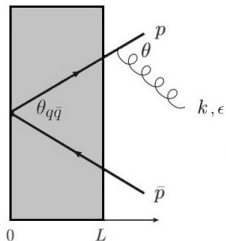
- How does the medium change this picture?



- A parton can change color through interaction with the medium, breaking the correlation between emitted gluons.

## In-medium antenna radiation

- To study the degree of coherence we take a very soft gluon  $\omega \rightarrow 0$  (out-out radiation).



## The decoherence parameter

- The interaction of the  $q\bar{q}$  pair with the medium is described by the survival probability  $\mathcal{S}$ .

$$\mathcal{S} \equiv \frac{1}{N_c^2 - 1} \langle W(\vec{x}_\perp) W^\dagger(\vec{y}_\perp) \rangle$$

$$\mathcal{S} \equiv 1 - \Delta_{med}(t)$$

$$\Delta_{med} \equiv 1 - \exp\left[-\frac{1}{4} \hat{q} L (\vec{x}_\perp - \vec{\bar{x}}_\perp)^2\right]$$

- This factor determines a characteristic time-scale for decoherence of the  $q\bar{q}$  pair.

## The resulting spectrum

$$dN = \frac{d\omega}{\omega} \frac{d\Omega}{2\pi} \frac{\alpha_s C_F}{2\pi} \left[ R_q + R_{\bar{q}} - (1 - \Delta_{med}) 2\mathcal{J} \right]$$

$$\left\{ \begin{array}{l} \Delta_{med} \rightarrow 0 : dN \sim R_q + R_{\bar{q}} - 2\mathcal{J} \\ \quad \boxed{\text{Dilute medium : coherence (angular ordering)}} \\ \Delta_{med} \rightarrow 1 : dN \sim R_q + R_{\bar{q}} \\ \quad \boxed{\text{Opaque medium : decoherence (two independent emitters)}} \end{array} \right.$$

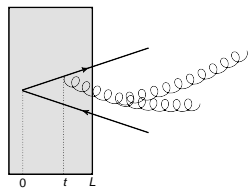
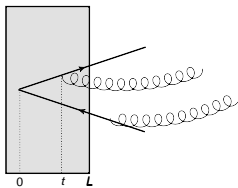
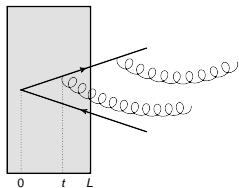
## Main limitations

- We have to deal with more realistic settings:
  - Non-eikonal antenna.
  - Finite formation time.
  - **Multiple emissions.**

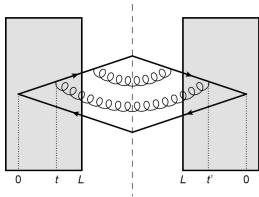


## Multiple emissions

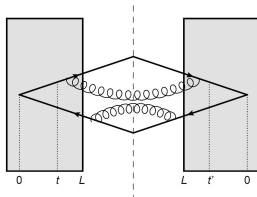
- The antenna provides a simple and intuitive picture.
- Does it hold for more than two emitters?



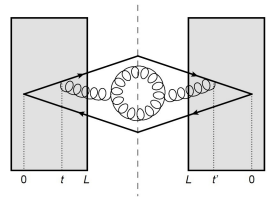
## Direct terms



$$|\mathcal{M}_1|^2 \propto C_F^2$$



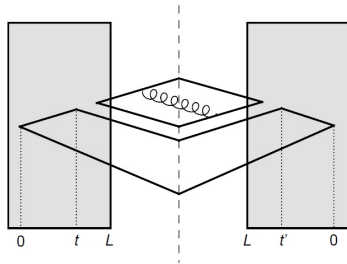
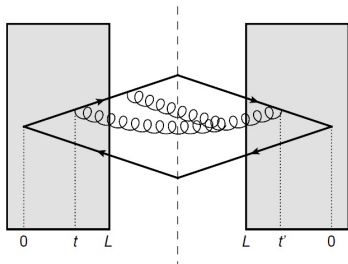
$$|\mathcal{M}_2|^2 \propto C_F^2$$



$$|\mathcal{M}_3|^2 \propto N_c C_F^2$$

- The direct terms are proportional to a color factor.

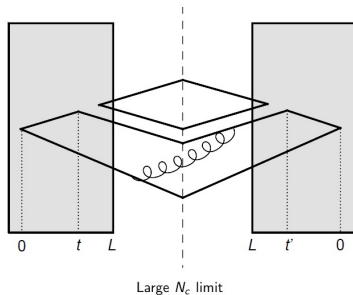
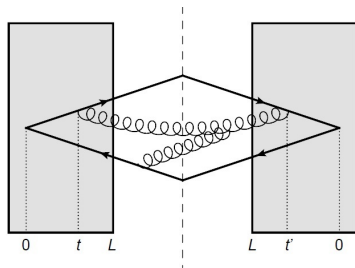
# Interference terms



Large  $N_c$  limit

$$\mathcal{M}_1 \otimes \mathcal{M}_3^* \propto \mathcal{S}(t, L)$$

# Interference terms



$$\mathcal{M}_2 \otimes \mathcal{M}_3^* \propto \mathcal{S}(0, t) \mathcal{S}(t, L)$$

## Multiple emissions results

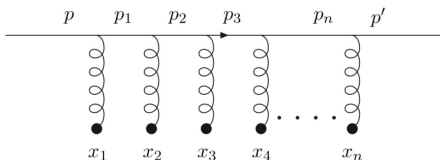
- We have considered the case of three emitters.
- **The interference terms are proportional to the survival probabilities  $\mathcal{S}$  in the  $(0, t)$  and  $(t, L)$  regions: the general result of the antenna is valid for each of the smaller antennas.**
- **If coherence is not preserved after the in-medium splitting, the antenna won't radiate coherently in the following emission.**
- These computations can be generalized to the problem of  $n$  emitters.

## Summary

- Detailed measurements of jet substructure shed light on the intricate nature of the jet interactions with the dense, deconfined QCD matter formed in the collisions.
- Color coherence is essential to understand the jet constituents' energy loss (are they independent or not?).
- In spite of the singlet antenna limitations (eikonal propagation, zero formation time, only one splitting...), it is a very convenient *laboratory*.
- The general result of the singlet antenna is valid for the subsequent antennas in the multiple emissions case.
- These computations go a step forward to obtain a complete description of a QCD cascade.

Thanks for your attention

# Particle propagation in matter

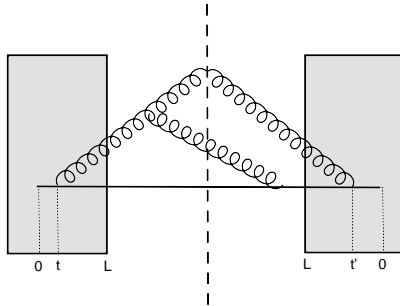


$$W(\vec{x}) = \mathcal{P} \exp \left[ ig \int dx_+ A_-(x_+, \vec{x}) \right]$$

- The effect of the medium is to induce color rotation at each scattering center.
- The quark (a high energy quark) loses a negligible amount of energy and propagates in straight lines (*eikonal* propagation).



# A hard quark propagating through a medium



$$\propto \frac{1}{N_c (N_c^2 - 1)} \left\langle W^{ai}(\vec{0}) W^{ai}(\vec{r}_3) \right\rangle_{(t,t')} \left\langle f^{ijc} f^{\alpha bz} W^{i\alpha}(\vec{r}_3) W^{jb}(\vec{0}) W^{\dagger zc}(\vec{r}'_3) \right\rangle_{(t',L)}$$