Jet Formation and Interference in Quark Gluon Plasma

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Jets
Single Gluon Emission
Two Gluon Emission
Interference
Interference
Interference
Coherent Branching

\[ \begin{array}{c|c|c}
2 & \cong & 2 \\
\hline
\hline
2 & \cong & 2 \\
\hline
+ & \hline
\end{array} \]
In-Medium Interferences
In-Medium Interferences
In-medium antenna problem

Mehtar-Tani, Salgado Tywoniuk 10,11,12
JCS, Iancu 11
Blaizot, Dominguez, Mehtar-Tani, Iancu, 12
Armesto, Ma, Martinez, Mehtar-Tani, Salgado 13
Dynamical Antenna

➢ How does the formation of antenna affect interferences?
Dynamical Antenna

➤ How does the formation of antenna affect interferences?
➤ And the interactions prior to the formation?
Dynamical Antenna

➤ How does the formation of antenna affect interferences?
➤ And the interactions prior to the formation?

Two gluon emission rate!
Diagrams, Diagrams, Diagrams
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Diagrams, Diagrams, Diagrams
Diagrams, Diagrams, Diagrams
Diagrams, Diagrams, Diagrams
Diagrams, Diagrams, Diagrams

+ 10 real diagram

+ 15 virtual contributions
Diagrams, Diagrams, Diagrams

+ 10 real diagram

+ 15 virtual contributions

... a mess....
Diagrams, Diagrams, Diagrams

+ 10 real diagram

+ 15 virtual contributions

... a mess....

Fickinger, Ovanesyan, Vitev 13
Arnold and Iqbal 15
Limits

➤ Strong energy ordering: \( E_q \gg \omega_H \gg \omega_S \) \( \iff \) \( z = \frac{\omega_S}{\omega_H} \ll 1 \)

➤ Small emission angles: \( \theta_H \ll 1, \theta_S \ll 1, \text{ but } r = \frac{\theta_H}{\theta_S} \) arbitrary

➤ Hard gluon from vacuum shower; soft gluon medium induced

\[ K_H^\perp \gg K_S^\perp \sim q_{\text{medium}} \]
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Two different order of limits

➤ \( z \to 0, \) \( r \) fixed

➤ \( r \to 0, \) \( z \to 0 \)
limits

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Two different order of limits

- \( z \to 0, \ r \text{ fixed} \)
- \( r \to 0, \ z \to 0 \)

\( \tau_H \ll \tau_s \)
Early Antenna

\[ 2 \]

\[ = P_{\text{vac}} (K_{H}^{\perp}) \times \text{Antenna} (\theta_{H}) \]

+ \( 2 \times \text{Prefactor} \sin(t_{s}/T_{\text{long}}) \sin(t_{s}/T_{\text{short}}) \)

Out-of-cone term that vanishes for isotropic kicks
Early Antenna

\[ 2 = P_{\text{vac}} (K_{H^\perp}) \times \text{Antenna} (\theta_H) \]

\[ + 2 \times \text{Prefactor} \sin\left(\frac{t_s}{T_{\text{long}}}\right) \sin\left(\frac{t_s}{T_{\text{short}}}\right) \]

Out-of-cone term that vanishes for isotropic kicks
Early Antenna

\[ P_{\text{vac}} (K_{H\perp}) \times \text{Antenna} (\theta_H) \]

\[ + 2 \times \text{Prefactor} \sin\left(\frac{t_s}{\tau_{\text{long}}}\right) \sin\left(\frac{t_s}{\tau_{\text{short}}}\right) \]

Out-of-cone term that vanishes for isotropic kicks

\[ \tau_{\text{short}} \sim z \tau_{\text{long}} \]
Antenna Spectrum

Unresolved antenna

$\mu_D$

Resolved antenna

$\mu_D$
Antenna Spectrum

- Unresolved antenna

- N=1 opacity spectrum off a single quark

- Medium blind to the hard gluon

- Resolved antenna
Antenna Spectrum

Unresolved antenna

N=1 opacity spectrum off a single quark

Medium blind to the hard gluon

Resolved antenna

Gunion-Bertsch of quark
+ Gunion-Bertsch of gluon
+ Broading of vac antenna
- Vac antenna

Medium interacts with the hard gluon
Late Time Antenna

\[ \frac{2}{N=1 \text{ opacity spectrum}} \]

off a single quark

\[ + \left( \text{Gunion-Bertsch off gluon} \right) \left( 1 - \cos\left(\frac{t_s}{T_H}\right) \right) \]
Late Time Antenna

\[ 2 \]

= \( N=1 \) opacity spectrum off a single quark

+ \(( \text{Gunion-Bertsch off gluon} ) \left( 1 - \cos\left( \frac{t_s}{T_H} \right) \right)\)

- An q-g antenna is formed after a time \( T_H \)
- Once the antenna is formed, it is totally resolved
Late Time Antenna

\[ \text{2} = \text{N=1 opacity spectrum off a single quark} \]

\[ + \left( \text{Gunion-Bertsch off gluon} \right) \left( 1 - \cos \left( \frac{t_s}{T_H} \right) \right) \]

- An q-g antenna is formed after a time \( T_H \)
- Once the antenna is formed, it is totally resolved

Note: In this limit \( \frac{T_{\text{resolv}}}{T_H} \to 0 \)
Organizing principle for jets in medium:

Simple space-time picture for in-medium interferences

(completes JCS, Mehtar-Tani, Tywoniuk, Salgado 12)

➤ Consider jets as a succession of antennas
  ➤ Each antenna appears after formation time
  ➤ Narrow antennas \((r_\perp < \mu_D)\) are invisible to the medium
    ➤ They Lose energy as a colored parton with overall charge
  ➤ Wide antennas \((r_\perp > \mu_D)\) are resolved
    ➤ Independent E-loss of each parton
Conclusions

Organizing principle for jets in medium:

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(in a dense medium replace \(\mu_D\) with \(\hat{q} L\))

(JCS, Mehtar-Tani, Tywoniuk, Salgado 12)