Gluon Radiation off Heavy Flavor Jets

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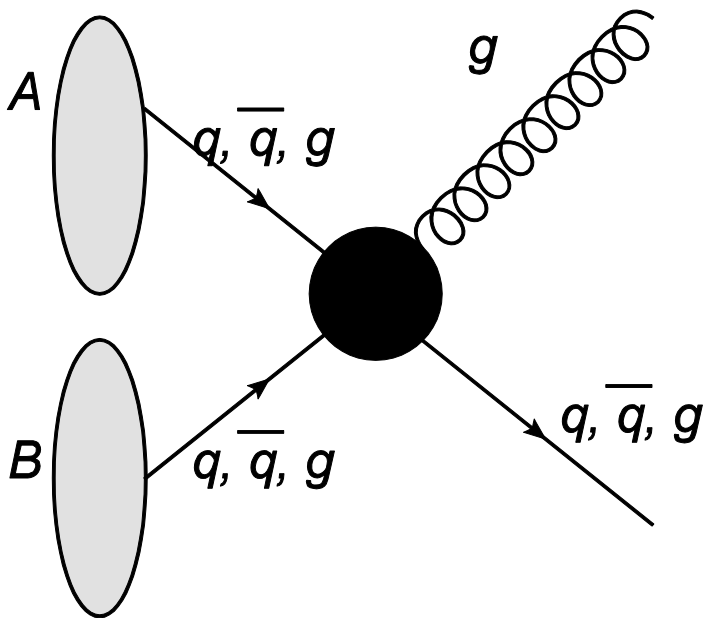
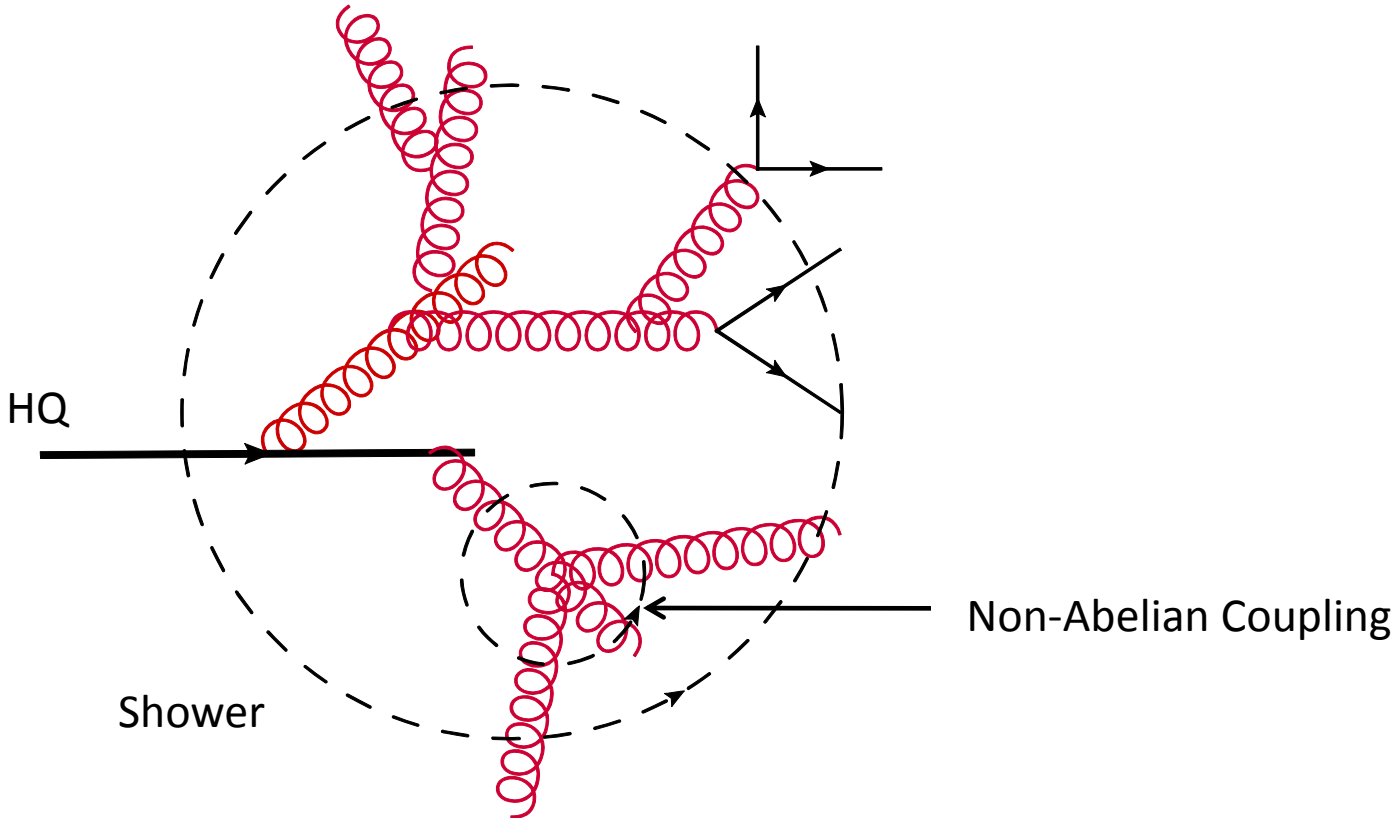
Stages of development of jet



- High energy quarks/gluons produced early in the collision.

- Quark-Gluon medium formed



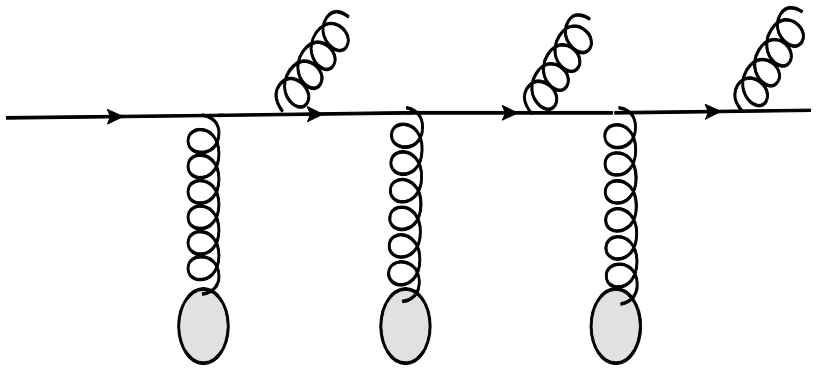
- Hadronization

•Jet interacts with medium through collisional and radiative processes.

• Radiative energy loss of a jet in dense QCD matter needs multiple scattering scenario.

Different energy loss models

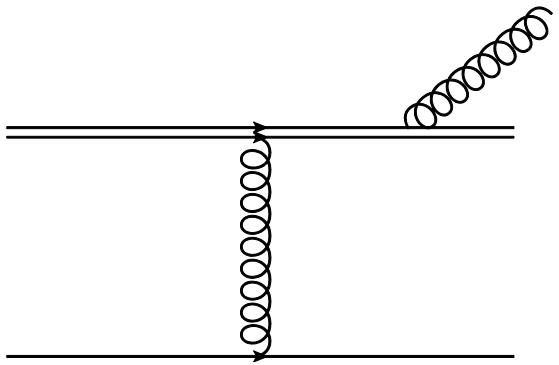
BDMPS-Z ASW GLV



Static scattering centres

• There is a continuous endeavor to remove different approximations used in the energy loss models.

• We aim to remove them at the level of single gluon emission scenario, at least.



• What are these *different approximations* used in the energy loss models ?

• Soft-eikonal 1+eikonal 2-collinear approximation

Gluons make very small angles with emitting particles: $\omega >> k_\perp$

No recoil of jet due to radiation:

$E >> k_\perp$

No recoil of jet due to scattering:

$E >> q_\perp$

Energy of jet (E) >> Energy of emitted gluon (ω)

Table: Summary of approximations used in different studies and removal of them

	Approxns. used	Approxns. removed
1. Jet Models: **BDMPS-Z, ASW, GLV**	***Soft-eikonal1+eikonal2-collinear***	
2. **Raktim Abir et al., PRD 85, 054012(2012)**	***Soft-eikonal1+eikonal2***	***collinear***
3. **Present work***	***Soft-eikonal2***	***collinear, eikonal1***

* T. Bhattacharyya , S. Mazumder and Raktim Abir, arXiv: 1307.6931

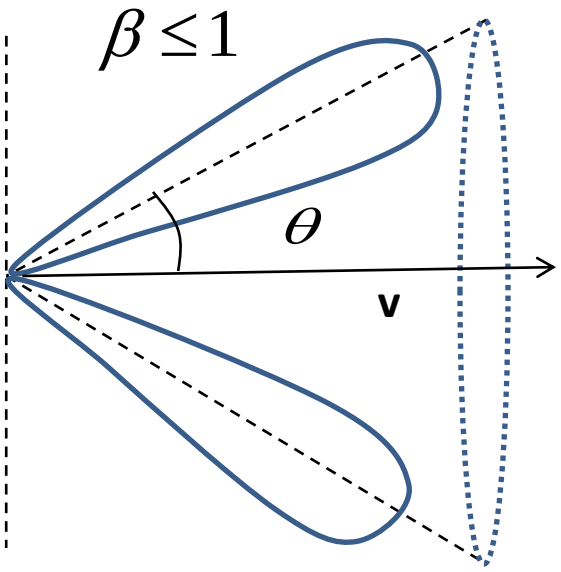
Classical Mechanics of ***non-relativistic*** heavy particles

No bending and no radiation at $\theta = 0$ ➡ **Dead-cone**

J. D. Jackson, Classical Electrodynamics

Classical Mechanics of ***relativistic*** heavy particles

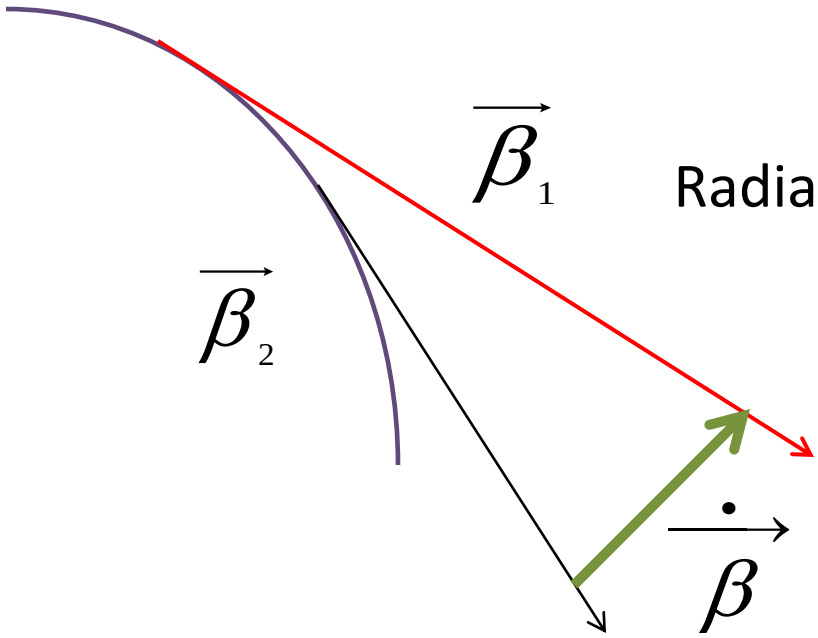
- Eikonality: Linear motion: velocity || acceleration



No radiation at $\theta = 0$ ➡ **Dead Cone**

J. D. Jackson, Classical Electrodynamics

- Non-eikonality: bending: velocity $\perp$ acceleration



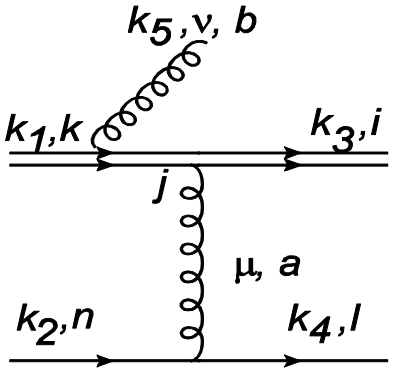
Radiation at $\theta = 0$ ⇒ No dead-cone

Quantum field theory of relativistic heavy particle

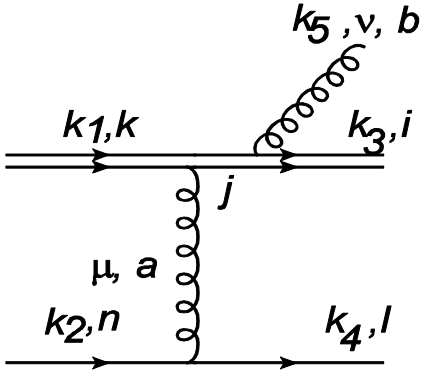
• Eikonal (straight) path: No radiation along the direction of propagation of heavy quarks

• Non-eikonal (bent) path: Does radiation around the direction of propagation of heavy quark exist if the jet recoils due to scattering?

How does the heavy quark radiation spectrum look like when it bends inside medium ?



(1)



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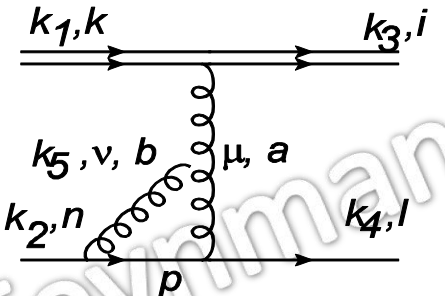

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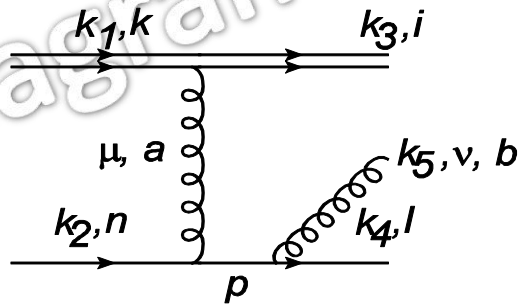

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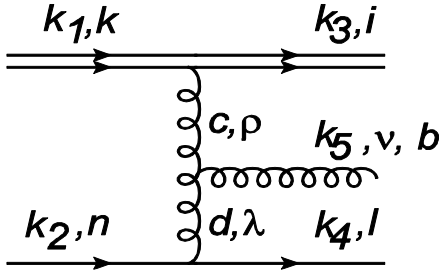


$$\left|M_{Qq\to Qqg}\right|^2 = \frac{128}{27} g^6 \frac{s^2}{t^2} \frac{1}{k_\perp{}^2} J^2 \left[f_1 \left(1+\Delta_M{}^2 \cot^2 \frac{\theta_g}{2} \right) - f_2 \cot^2 \frac{\theta_g}{2} + \frac{f_3}{J^2} \tan^2 \frac{\theta_g}{2} \right]$$

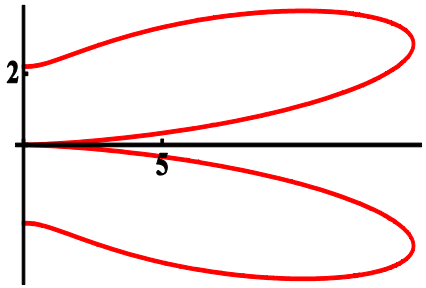
$$= \frac{16}{3} g^2 \left|M_{Qq\to Qq}\right|^2 \frac{F}{k_\perp{}^2}$$

Non-eikonal gluon emission spectrum

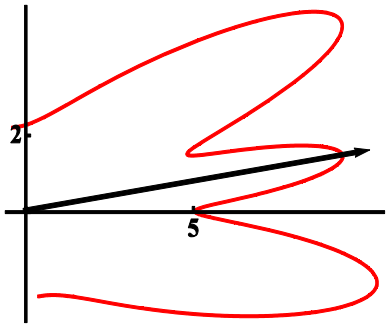
$$J^2 = \frac{\left(1-\Delta_M{}^2\right)^2}{\left(1+\Delta_M{}^2 \cot^2 \frac{\theta_g}{2}\right)^2}; \quad f_i = f_i\left(\Delta_M, z, \varsigma, \theta_g\right); \quad \Delta_M = \frac{m}{\sqrt{s}},$$

$$z^2 = \frac{t}{s}, \; \varsigma = \frac{q_\perp}{\sqrt{s}}; \quad \left|M_{Qq\to Qq}\right|^2 = \frac{8}{9} g^4 \frac{s^2}{t^2} \left(1-\Delta_M{}^2\right)^2$$

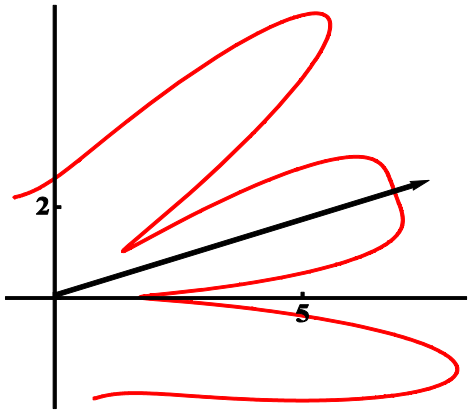
Polar plots of gluon emission spectrum for different non-eikonality



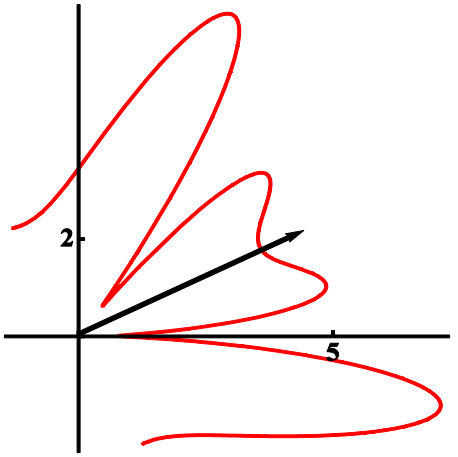
$$\varsigma\left(=\frac{q_\perp}{\sqrt{s}}\right)=0.00$$



$$\varsigma=0.15$$

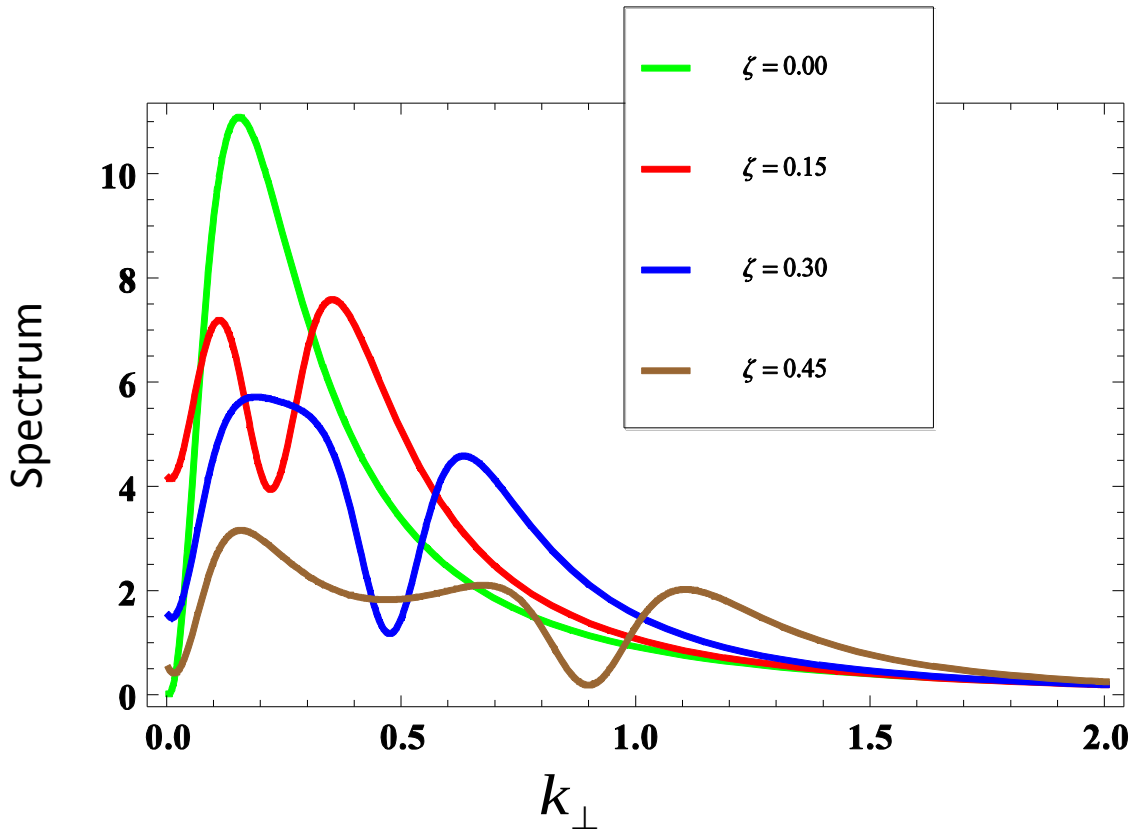


$$\varsigma=0.30$$



$$\varsigma=0.45$$

Effect of non-eikonality on emission spectrum



Different kinematic limits of the non-eikonal gluon spectrum

- Eikonal limit: $\varsigma \to 0$

$$\left|M_{Qq\to Qqg}\right|^2 \to 12\, g^2 \left|M_{Qq\to Qq}\right|^2 \left\{\frac{1}{k_\perp{}^2}\left(1+\Delta_M{}^2 e^{2\eta_g}\right)^{-2}\right\}$$

Abir et al., PRD

where $\eta_g = -\ln\left(\tan\frac{\theta_g}{2}\right)$

- Massless limit: $\Delta_M \to 0$, $O\left(\frac{t}{s}\right)$

$$\left|M_{qq'\to qq'g}\right|^2 = 12\,g^2\left|M_{qq'\to qq'}\right|^2 \frac{1}{k_\perp{}^2}\left(1+\frac{16t}{9s}+\frac{t}{9s}\cosh 2\eta_g\right)$$

Which exactly reproduces the mid-rapidity $\left(\eta_g = 0\right)$ result of
Raktim Abir PRD 87, 034036(2012)

- Small emission angle limit $\theta_g \to 0,\ m << \sqrt{s}$

$$\left|M_{Qq\to Qqg}\right|^2 = 12\,g^2\left|M_{Qq\to Qq}\right|^2 \frac{1}{k_\perp{}^2}\left(1+\frac{\theta_0{}^2}{\theta^2}\right)^{-2}$$

Dokshitzer and Kharzeev, PLB 519, 199 (2001)
JPG 17, 1481 (1991)

Possible scopes and applications

- Consideration of non-eikonality is needed for studying transverse momentum broadening

→ Effect on the equilibrium distribution of HQ as well as on viscosity

PRD 89,014002

- Multiple scattering and multi-gluon emission

- Similar calculation for $Qg \to Qgg$ → total energy loss

- Removal of eikonal trajectory 2 (equivalently, 'soft') approximation