The fragmentation region

INSTITUTE for NUCLEAR THEORY

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Isobel Kolbé, Mawande Lushozi

Institute for Nuclear Theory - ikolbe@uw.edu

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IK, Lushozi 2109.01736 (Submitted to PRC)
IK, Lushozi, McLerran, Yu, Phys.Rev.C 103 (2021) 4, 044908

Elevator Pitch:

Relevant Physics

"Fragmentation region": The region of phase space occupied by particles that have the same rapidity as the target and projectile.

Problem

Bremsstrahlung is hard in this region because it is a perturbative phenomenon affected by the non-perturbative physics of a boosted nucleus

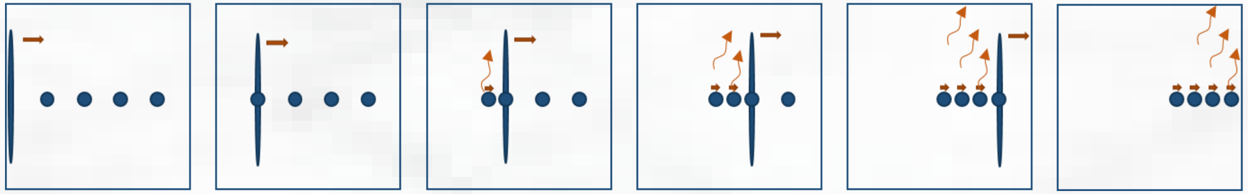
Background

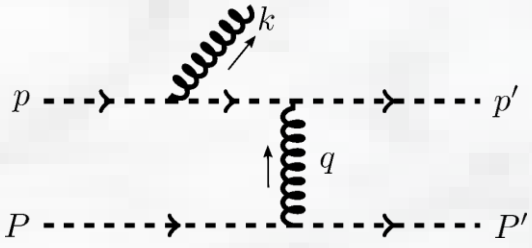
Non-perturbative computation is known: Correct low-k_T behavior.

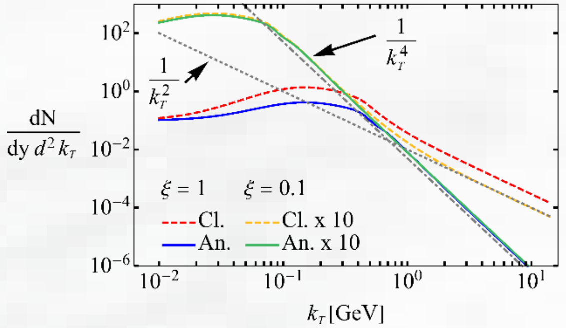
Incorrect high-k_T behavior.

Proposed Solution

Use the pert. result for bremss. for a scalar field with classical color charge to inform a modification of the non-perturbative result in order to get an ansatz with the correct high-k_T behavior.



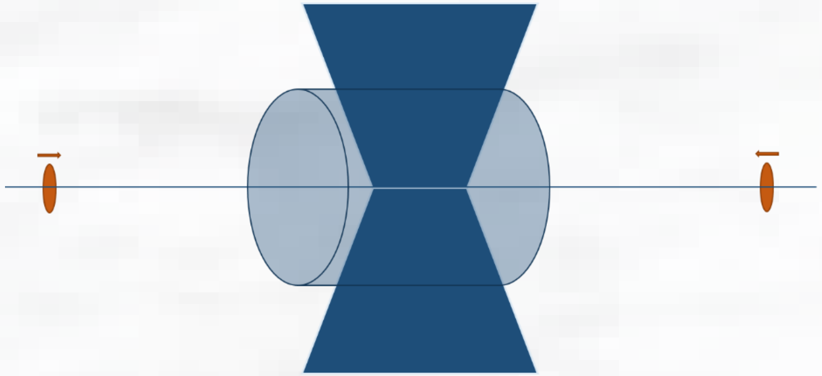




Relevant Physics

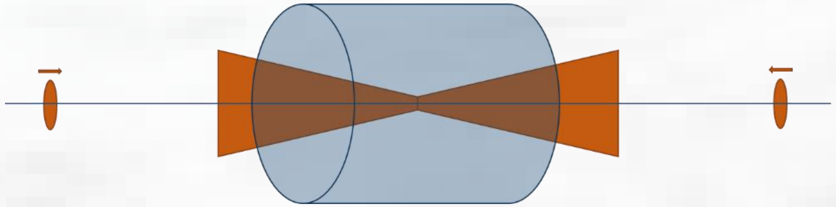
Collider experiment: Study transverse to the beam:

$\mu_B \approx 0$



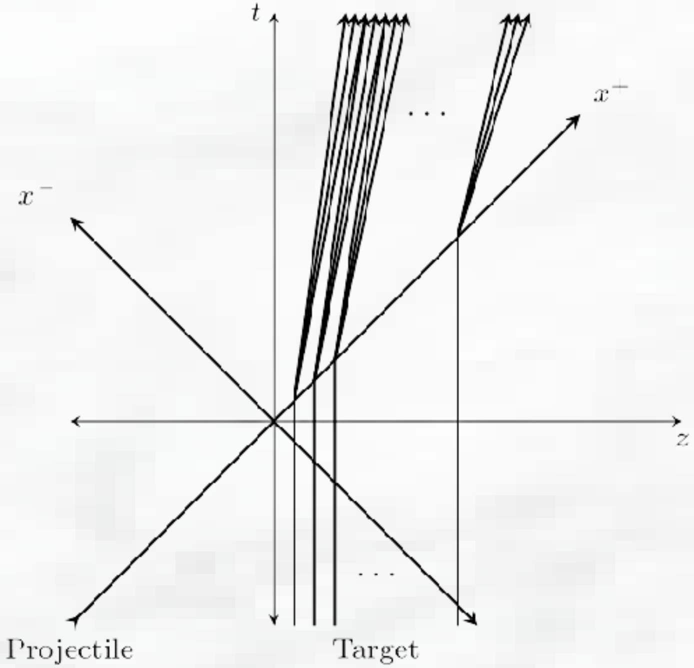
Fragmentation region: At beam rapidity

- Better (easier to measure): Fixed target
- Access high μ_B (see IK, Lushozi, McLerran, Yu for estimates.)



Study the bremsstrahlung resulting from an at-rest nucleus being struck by a highly boosted nucleus (or sheet of colored glass).

The classical calculation (encompassing the physics of the nucleus) was performed by Kajantie *et.al*. We will modify their result.



Classical radiation

(from striking a classical particle with a sheet of colored glass)

Kajantie, McLerran, Paatelainen, PRD **100,** 054011 (2019)
Kajantie, McLerran, Paatelainen, PRD **101,** 054012 (2020)

Kajantie *et.al.* consider the process

$$A + q(p) \rightarrow X + q(p') + g(k)$$

The distribution of gluon radiation (in the classical limit) is then

Fourier transform of two-point correlator – nucleus physics

Spend some time getting comfortable with this formula, then the rest will be clearer

$$\left.\frac{dN}{dy d^2 k_T}\right|_{Cl.} = \frac{g^2 C_F}{16\pi^3} 4 \int \frac{d^2 h}{(2\pi)^2} \tilde{S}(\mathbf{k}-\mathbf{h}) \left[\mathcal{M}^i_{\mathrm{Cl.,bulk}} + \mathcal{M}^i_{\mathrm{Cl.,brems}}\right]^2$$

McLerran-Venugopalan model for the sources in the CGC. Simplest. Gaussian.

$$\mathcal{M}^i_{\mathrm{Cl.,brems}} = \frac{k^i}{k_T^2 + 2(k^-)^2} - \frac{k^i - \xi p'^i}{|\mathbf{k} - \xi\mathbf{p}'|^2 + \xi^2 m^2}$$

$$\mathcal{M}^i_{\mathrm{Cl.,bulk}} = \frac{h^i}{h_T^2 + 2(k^-)^2} - \frac{k^i}{k_T^2 + 2(k^-)^2}$$

We will modify this formula

Use MV, expand resultant Wilson line correlator, integrate delta function:

$$\left.\frac{dN}{dy d^2 k_T}\right|_{\mathrm{Cl.}} \rightarrow \frac{g^2 C_F}{4\pi^3} \left[\frac{k^i}{k_T^2 + 2(k^-)^2} - \frac{k^i - \xi p'^i}{|\mathbf{k} - \xi\mathbf{p}'|^2 + \xi^2 m^2}\right]^2 \propto \frac{1}{k_T^2}$$

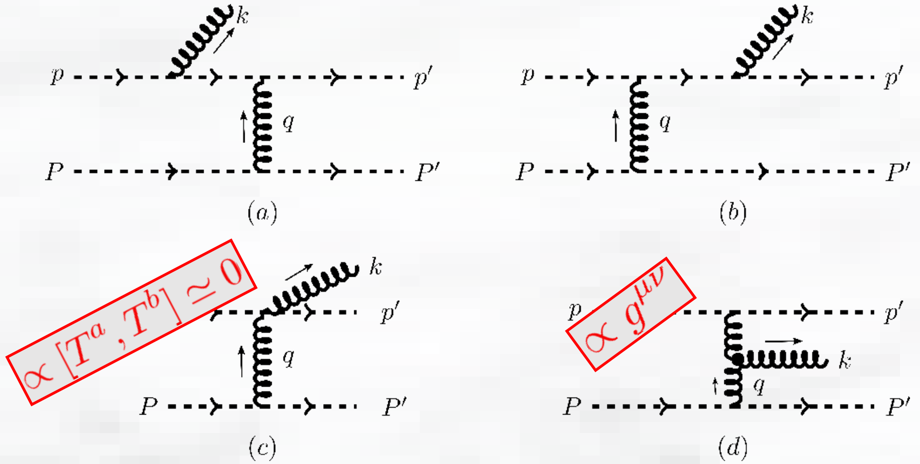
Incorrect: Know from QED and from pQCD bremss. That should go like $\frac{1}{k_T^4}$

Point: To lowest order in the background field, the classical calculation of bremsstrahlung in the fragmentation region does not capture the correct high frequency behavior.

A scalar field with classical color charge

No spin ⇒ No γ matrices
∴ much simpler

Large representation ⇒ generators commute
∴ Color factor factorizes out of all diagrams



Scalar gluon (bremsstrahlung) spectrum:

$$\left.\frac{dN}{dy d^2k_T}\right|_{\text{Sc.}} = \frac{g^2 C_R}{16\pi^3} 4 \frac{1}{1+\xi} \left| \frac{k^i}{k_T^2 + 2(k^-)^2} - (1+\xi) \frac{k^i - \xi p'^i}{|\mathbf{k} - \xi \mathbf{p}'|^2 + \xi^2 m^2} \right|^2$$

Recall classical result to lowest order (in the nucleus field).

$$\left.\frac{dN}{dy d^2k_T}\right|_{\text{Cl.}} \to \frac{g^2 C_F}{4\pi^3} \left[\frac{k^i}{k_T^2 + 2(k^-)^2} - \frac{k^i - \xi p'^i}{|\mathbf{k} - \xi \mathbf{p}'|^2 + \xi^2 m^2} \right]^2$$

Notice: same to terms with only some additional factors of $(1+\xi)$

A very-educated guess:

$$\left.\frac{dN}{dy d^2k_T}\right|_{Cl.} = \frac{g^2 C_F}{16\pi^3} 4 \int \frac{d^2h}{(2\pi)^2} \tilde{S}(\mathbf{k}-\mathbf{h}) \left[\mathcal{M}^i_{\text{Cl.,bulk}} + \mathcal{M}^i_{\text{Cl.,brems}}\right]^2$$

$$\mathcal{M}^i_{\text{Cl.,brems}} = \frac{k^i}{k_T^2 + 2(k^-)^2} - \frac{k^i - \xi p'^i}{|\mathbf{k} - \xi \mathbf{p}'|^2 + \xi^2 m^2}$$

$$\mathcal{M}^i_{\text{Cl.,bulk}} = \frac{h^i}{h_T^2 + 2(k^-)^2} - \frac{k^i}{k_T^2 + 2(k^-)^2}$$

Reshuffle the scalar result and make an inspired **by-hand modification** of the all-orders classical result

$$\widetilde{\mathcal{M}}^i_{\text{An., brems}} = \frac{1}{\sqrt{1+\xi}} \left(\frac{k^i}{k_T^2+2(k^-)^2} - (1+\xi) \frac{k^i - \xi p'^i}{|\mathbf{k}-\xi\mathbf{p}'|^2 + \xi^2 m^2} \right)$$

$$\widetilde{\mathcal{M}}^i_{\text{An., bulk}} = \frac{1}{\sqrt{1+\xi}} \left(\frac{h^i}{h_T^2+2(k^-)^2} - \frac{k^i}{k_T^2+2(k^-)^2} \right)$$

$$\left.\frac{dN}{dy d^2k_T}\right|_{\text{An.}} = \frac{g^2 C_F}{16\pi^3} 4 \int \frac{d^2h}{(2\pi)^2} \tilde{S}(\mathbf{k}-\mathbf{h}) \left[\widetilde{\mathcal{M}}^i_{\text{An., bulk}} + \widetilde{\mathcal{M}}^i_{\text{An., brems}}\right]^2$$

Does this work?