NLO Corrections to Di-Jet Production in DIS Using the Color Glass Condensate

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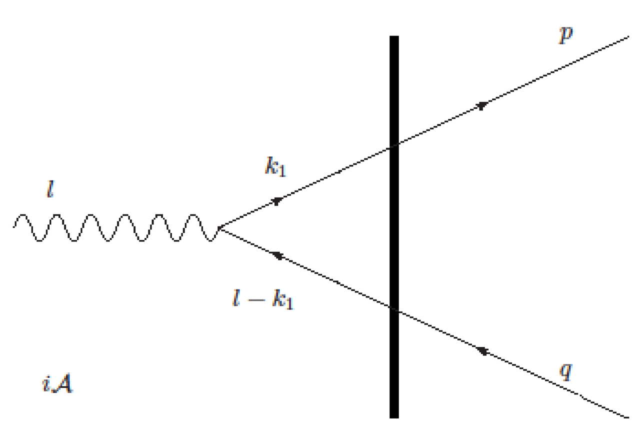
Abstract

Di-Jet angular correlations serve as a sensitive probe of saturation physics in the Color Glass Condensate (CGC), an effective theory of QCD in which a heavy target nucleus can be modeled as a classical background field. The leading order cross section for di-jet production in Deep Inelastic Scattering (DIS) is well known but experiments at the Electron Ion Collider will be sensitive to corrections. Here we present our preliminary results for the calculation of Next to Leading Order (NLO) corrections to di-jet production in DIS at small Bjorken x, where the target nucleus is treated as a CGC. The Wilson line correlators are averaged according to the gaussian (MV) model, and we use the spinor helicity formalism for efficient calculation of the spin structure.

Introduction

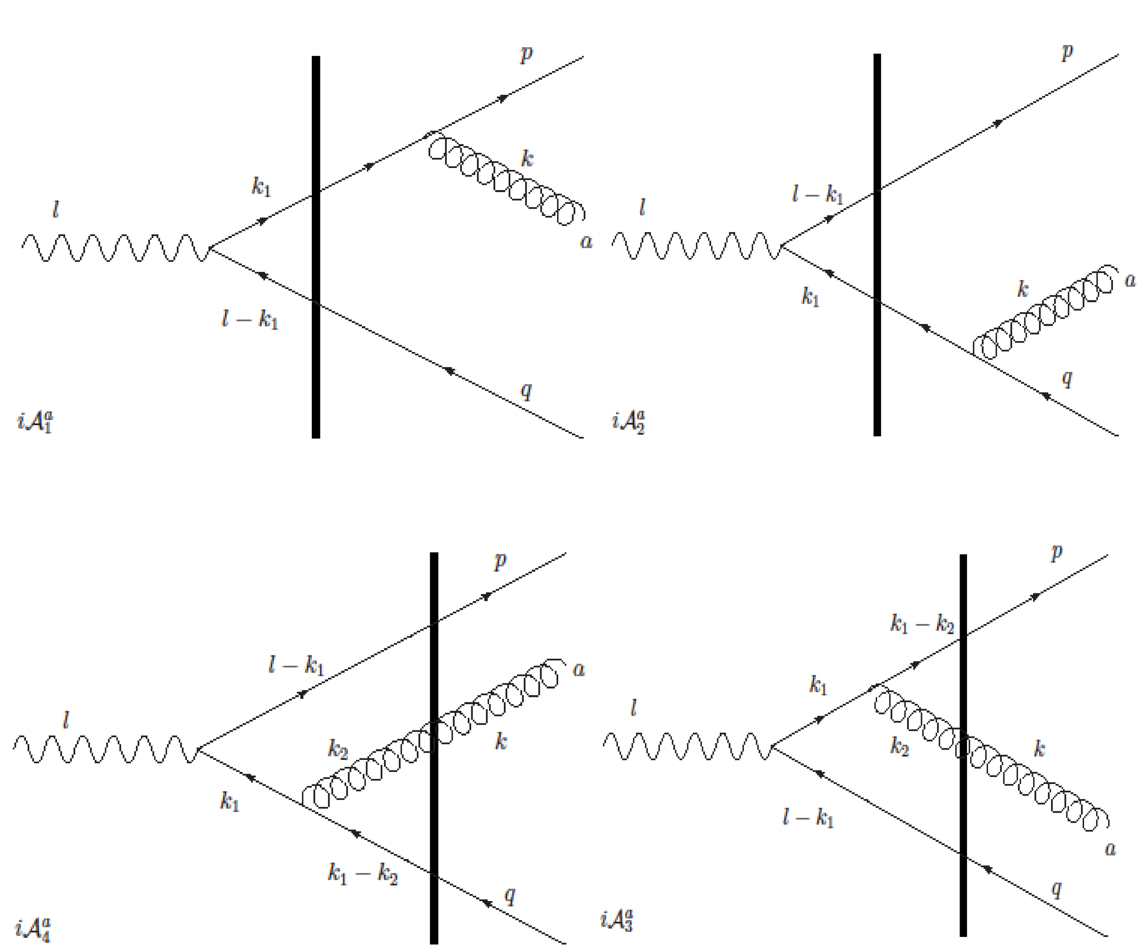
In the Color Glass Condensate effective theory of QCD a target nucleus may be treated as a classical background field. Incident particles can then interact with this background field via *multiple scattering*. The leading order cross section for di-jet production in DIS is well known [1] but experiments at the Electron-Ion Collider will be sensitive to corrections.

Leading Order Diagram



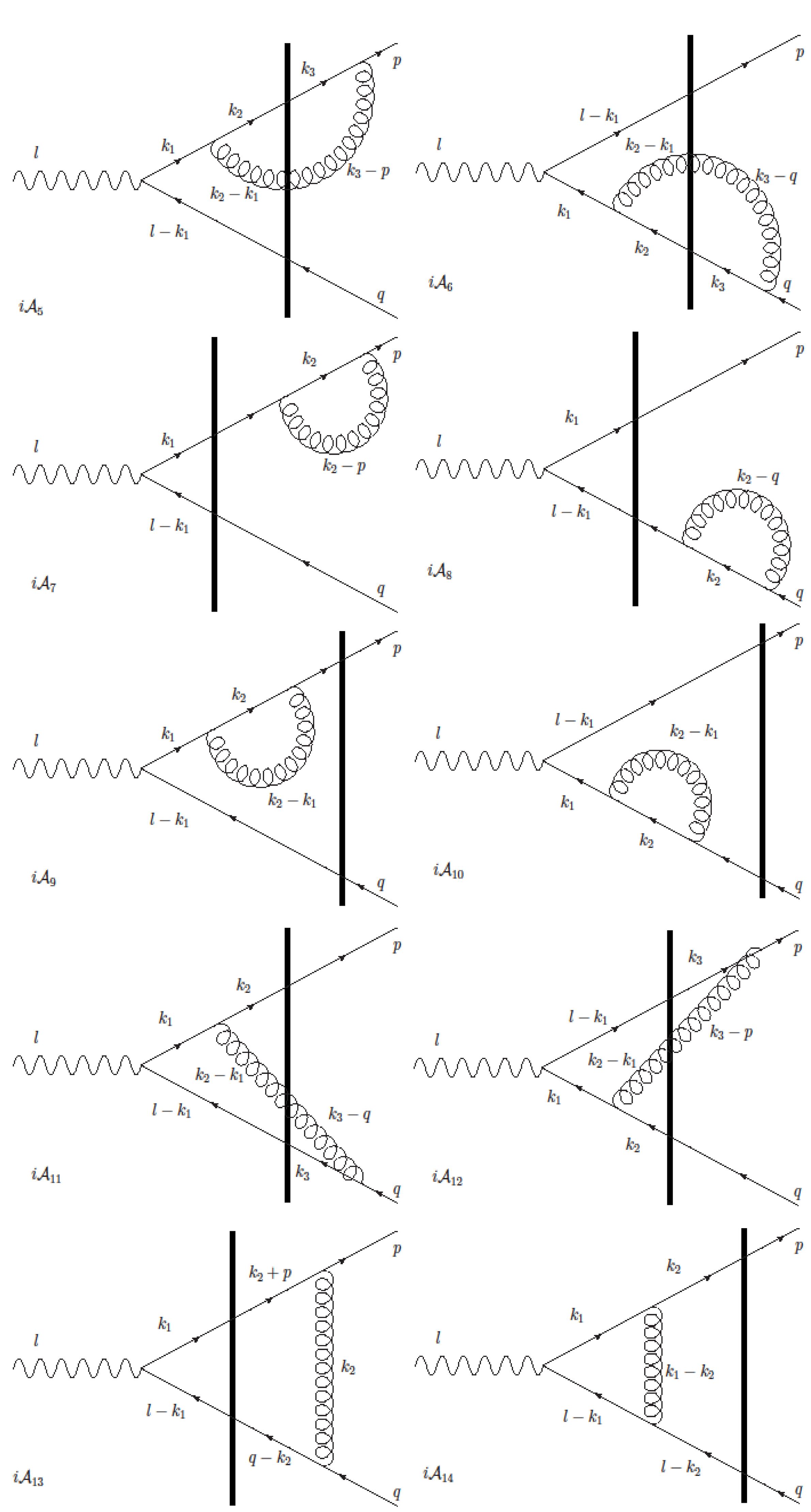
The leading order amplitude involves the exchanged virtual photon splitting into a quark anti-quark pair, which then interact with the target. The solid vertical line indicates this interaction. The NLO corrections receive both real and virtual contributions.

Real Corrections



These amplitudes were studied in [2]. In the differential cross section we will need to integrate over the outgoing gluon's phase space.

Virtual Corrections



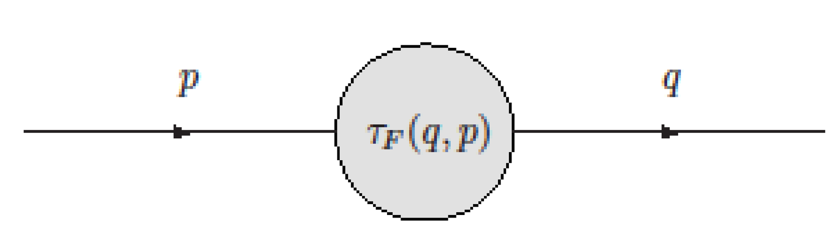
Calculations

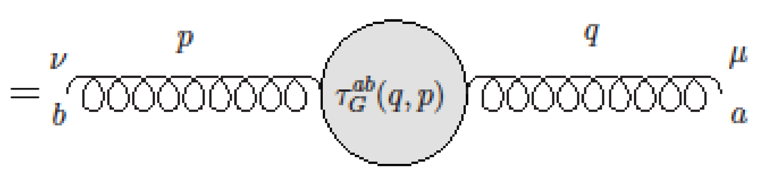
We define free propagators $S^0(p)$ and $G^0(p)^{ab}_{\mu\nu}$ for quarks and gluons, respectively. We also define modified propagators $S(q,p)$ and $G(q,p)^{ab}_{\mu\nu}$ which include the multiple scattering contribution [2].

$$S_0(p) = \frac{i\not{p}}{p^2+i\epsilon}, \quad G_0(p)^{ab}_{\mu\nu} = \frac{i\delta^{ab}d_{\mu\nu}(p)}{p^2+i\epsilon}$$

$$S(q,p) = S_0(q)\tau_F(q,p)S_0(p)$$

$$G(q,p)^{ab}_{\mu\nu} = G^0_{\mu\sigma}(q)\tau^{ab}_G(q,p)G^{0\,\sigma}_{\nu}(p)$$

$S(q,p) =$ 

$G(q,p)^{ab}_{\mu\nu} =$ 

The multiple scattering contributions τ are written in terms of fundamental Wilson lines (for quarks) and adjoint Wilson lines (for gluons). For example, the quark multiple scattering contribution takes the following form [2].

$$\tau_F(q,p) = 2\pi\delta(q^+-p^+)\not{n}\int \mathrm{d}^2\mathbf{x}\left[\theta(q^+)V(\mathbf{x}) - \theta(-q^+)V^\dagger(\mathbf{x})\right]e^{-i(\mathbf{q}-\mathbf{p})\cdot\mathbf{x}}$$

$$V(\mathbf{x}) = \mathcal{P}\exp\left(ig\int \mathrm{d}x^+ A^-(x^+,\mathbf{x})\right)$$

With these modified propagators, we can then write down the NLO amplitudes. Here we show a small sample.

$$i\mathcal{A}_5 = \int \frac{\mathrm{d}^4k_1}{(2\pi)^4}\frac{\mathrm{d}^4k_2}{(2\pi)^2}\frac{\mathrm{d}^4k_3}{(2\pi)^4}\bar{u}(p)(ig\gamma^\mu t^a)S(k_3,k_2)(ig\gamma^\nu t^b)S^0(k_1)$$
$$(ie\not{\epsilon}(l))S(k_1-l,-q)S^0(-q)^{-1}v(q)G^{ba}_{\nu\mu}(k_2-k_1,k_3-p)$$

$$i\mathcal{A}_6 = \int \frac{\mathrm{d}^4k_1}{(2\pi)^4}\frac{\mathrm{d}^4k_2}{(2\pi)^4}\frac{\mathrm{d}^4k_3}{(2\pi)^4}\bar{u}(p)S^0(p)^{-1}S(p,l-k_1)ie\not{\epsilon}(l)S^0(-k_1)$$
$$ig\gamma^\mu t^a S(-k_2,-k_3)ig\gamma^\nu t^b v(q)G^{ab}_{\mu\nu}(k_2-k_1,k_3-q)$$

$$i\mathcal{A}_{11} = \int \frac{\mathrm{d}^4k_1}{(2\pi)^4}\frac{\mathrm{d}^4k_2}{(2\pi)^4}\frac{\mathrm{d}^4k_3}{(2\pi)^4}\bar{u}(p)S^0(p)^{-1}S(p,k_2)ig\gamma^\mu t^a S^0(k_1)$$
$$ie\not{\epsilon}(l)S(k_1-l,-k_3)ig\gamma^\nu t^b v(q)G^{ab}_{\mu\nu}(k_2-k_1,k_3-q)$$

$$i\mathcal{A}_{12} = \int \frac{\mathrm{d}^4k_1}{(2\pi)^4}\frac{\mathrm{d}^4k_2}{(2\pi)^4}\frac{\mathrm{d}^4k_3}{(2\pi)^4}\bar{u}(p)ig\gamma^\mu t^a S(k_3,l-k_1)ie\not{\epsilon}(l)S^0(-k_1)$$
$$ig\gamma^\nu t^b S(-k_2,-q)S^0(-q)^{-1}v(q)G^{ba}_{\nu\mu}(k_2-k_1,k_3-p)$$

These amplitudes can then be simplified by inserting the definition of our modified propagators and performing the integrals over the remaining internal momenta.

We collect all the spin structure of the amplitudes into a Dirac "Numerator" N_i and evaluate these for all helicity combinations using the spinor helicity formalism.

$$N_5 = \bar{u}(p)\gamma^\mu\not{k}_3\not{n}\not{k}_2\gamma^\nu\not{k}_1\not{\epsilon}(l)(\not{k}_1-\not{l})\not{n}v(q)d_{\nu\sigma}(k_2-k_1)d^\sigma_\mu(k_3-p)$$

$$N_6 = \bar{u}(p)\not{n}(\not{l}-\not{k}_1)\not{\epsilon}(l)\not{k}_1\gamma^\mu\not{k}_2\not{n}\not{k}_3\gamma^\nu v(q)d_{\mu\sigma}(k_2-k_1)d^\sigma_\nu(k_3-q)$$

$$N_{11} = \bar{u}(p)\not{n}\not{k}_2\gamma^\mu\not{k}_1\not{\epsilon}(l)(\not{k}_1-\not{l})\not{n}\not{k}_3\gamma^\nu v(q)d_{\mu\sigma}(k_2-k_1)d^\sigma_\nu(k_3-q)$$

$$N_{12} = \bar{u}(p)\gamma^\mu\not{k}_3\not{n}(\not{l}-\not{k}_1)\not{\epsilon}(l)\not{k}_1\gamma^\nu\not{k}_2\not{n}v(q)d_{\nu\sigma}(k_2-k_1)d^\sigma_\mu(k_3-p)$$

As an example, here we show the evaluated numerators N_5 and N_{11} for the case of a longitudinally polarized photon and a right-handed quark (the anti-quark is always polarized opposite to the quark).

$$N_5^{L;+} = \frac{2^5(l^+)^2Q(z_1z_2)^{3/2}}{(z_1-z_3)^2}\Bigg\{z_1^2\left[\left(\mathbf{k}_3-\frac{z_3}{z_1}\mathbf{p}\right)\cdot\boldsymbol{\epsilon}\right]\left[\left(\mathbf{k}_2-\frac{z_3}{z_1}\mathbf{k}_1\right)\cdot\boldsymbol{\epsilon}^*\right]$$
$$+z_3^2\left[\left(\mathbf{k}_3-\frac{z_3}{z_1}\mathbf{p}\right)\cdot\boldsymbol{\epsilon}^*\right]\left[\left(\mathbf{k}_2-\frac{z_3}{z_1}\mathbf{k}_1\right)\cdot\boldsymbol{\epsilon}\right]\Bigg\}.$$

$$N_{11}^{L;+} = \frac{-2^5(l^+)^2Qz_3\sqrt{z_1z_2}}{(z_2-z_3)^2}\Bigg\{z_3(1-z_3)\left[\left(\mathbf{k}_3-\frac{z_3}{z_2}\mathbf{q}\right)\cdot\boldsymbol{\epsilon}\right]\left[\left(z_1\mathbf{k}_1-(1-z_3)\mathbf{k}_2\right)\cdot\boldsymbol{\epsilon}^*\right]$$
$$+z_1z_2\left[\left(\mathbf{k}_3-\frac{z_3}{z_2}\mathbf{q}\right)\cdot\boldsymbol{\epsilon}^*\right]\left[\left(z_1\mathbf{k}_1-(1-z_3)\mathbf{k}_2\right)\cdot\boldsymbol{\epsilon}\right]\Bigg\}.$$

With all the numerators computed in this way, one can then perform the transverse momentum integrals.

Ongoing Work

This is an ongoing project. Our goal is to calculate all of these NLO corrections to the di-jet production differential cross section. In the result, we will use the gaussian (MV) model to average over the color sources in the target [3]. In this model, the color averaged trace of two Wilson lines takes the form:

$$\frac{1}{N_c}\left\langle \mathrm{Tr}\,V(\mathbf{x}_1)V^\dagger(\mathbf{x}_2)\right\rangle = e^{-Q_s^2(\mathbf{x}_1-\mathbf{x}_2)^2\log\frac{1}{\Lambda|\mathbf{x}_1-\mathbf{x}_2|}}$$

Here Λ is an infrared regulator. We will establish factorization (or lack thereof) in these corrections.

Future Outlook

These NLO corrections can also be accessed via other methods. For example, calculations using light-front perturbation theory are also well suited to the problem. We look forward to comparing results with other groups using different methods.

With the upcoming Electron-Ion Collider, the increased sensitivity means that these corrections will soon be experimentally testable.

There are also avenues for future calculations, since our methods involving the spinor helicity formalism allow us to also access polarized cross sections.

Acknowledgements

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References

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