NLO impact factor for inclusive photon+dijet production in e+A DIS at small x

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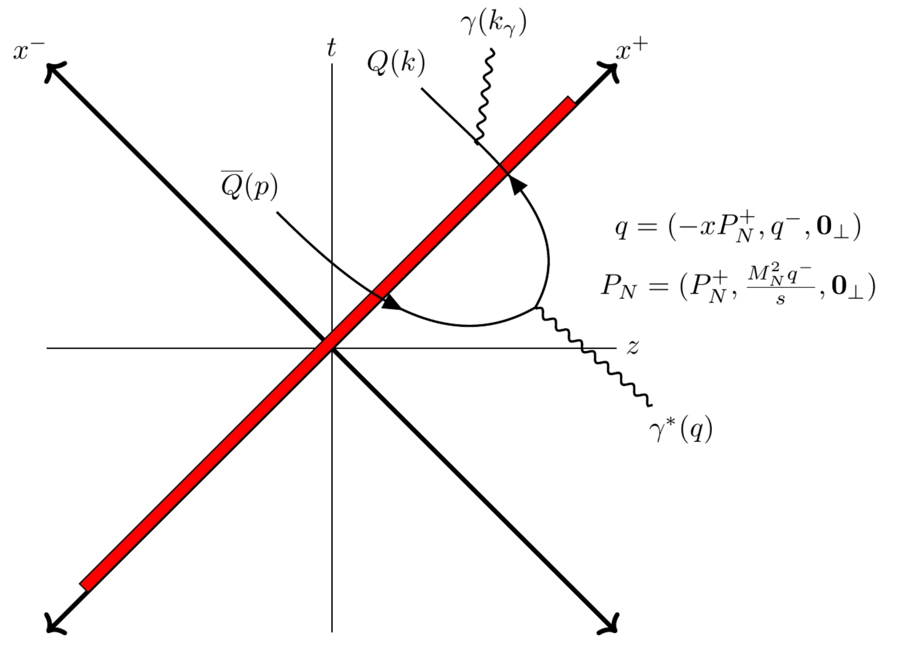
Introduction



The right moving nucleus with large P_N^+ has its x^- extent Lorentz contracted

We present a first computation[1,2,3] of the NLO impact factor for inclusive photon+dijet production in deeply inelastic electron-nucleus (e+A) scattering in the saturation regime of QCD.

This process can act as a clean probe of the strongly correlated gluonic matter at the high energies and luminosities provided by a future **Electron Ion Collider** (EIC). Our results calculated in the **Color Glass Condensate (CGC) EFT** framework can also be used to compute the cross-sections for such processes as inclusive dijet, photon+jet and fully inclusive DIS.

QCD at small x: CGC EFT

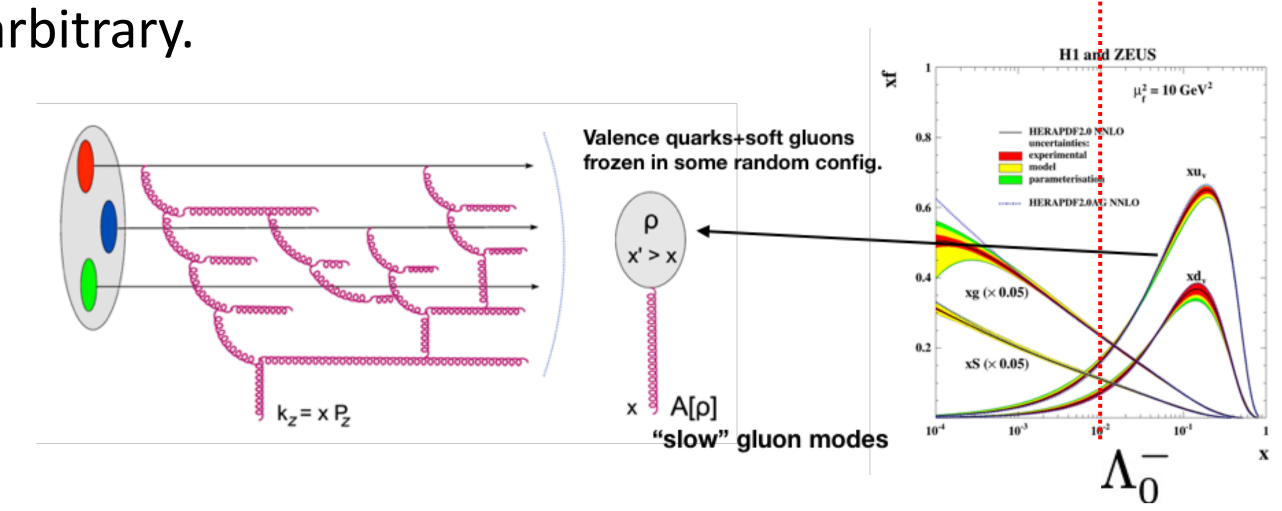
Color Glass Condensate (CGC): classical effective field theory (EFT) in the non-linear regime of QCD, describing gluon fields (small x partons) coupled to static color sources (large x partons).

$$D_\nu F^{\nu\mu,a}(x) = \delta^{\mu +}\rho^a(x^-, \boldsymbol{x}_\perp)$$

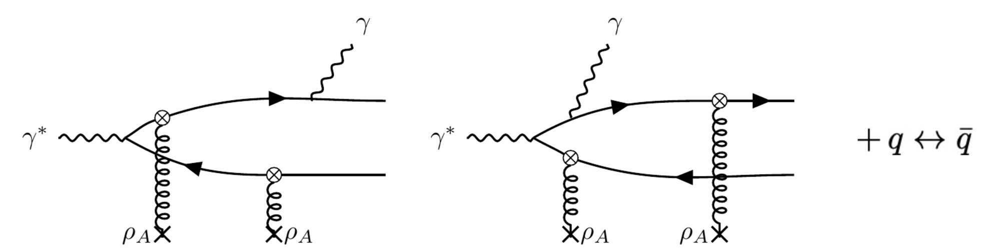
Gauge invariant, stochastic weight functional $\mathcal{W}_x[\rho]$ gives probability of finding a configuration ρ . $\mathcal{W}_x[\rho]$ is built by integrating out soft gluon fluctuations in layers of x.
Initial condition at low energy (x ~ 0.01) -> McLerran-Venugopalan (MV) model.

Small x evolution from LO to NLO: the Wilsonian RG ideology

At leading order (LO) in the CGC power counting, the scale separating soft and hard partons in a hadron/nucleus is arbitrary.



Allowed LO processes

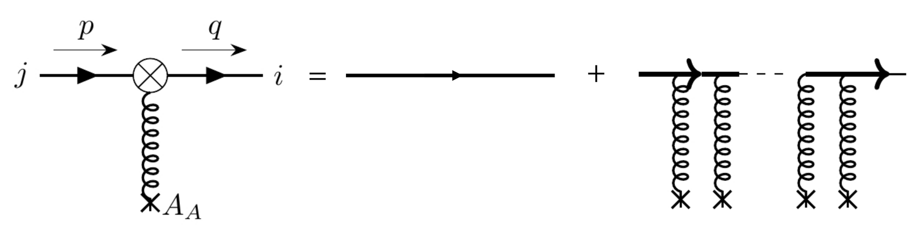


$$\langle \mathrm{d}\sigma_{\mathrm{LO}}\rangle = \int [\mathcal{D}\rho_A]\, W_{\Lambda_0^-}[\rho_A]\, \mathrm{d}\hat{\sigma}_{\mathrm{LO}}[\rho_A]$$

How do we compute this in the CGC EFT?

Use "shockwave" (anti) quark propagator in the background classical field of the nucleus.

$$S(q,p) = S_0(q)\, \mathcal{T}_q(q,p)\, S_0(p)$$

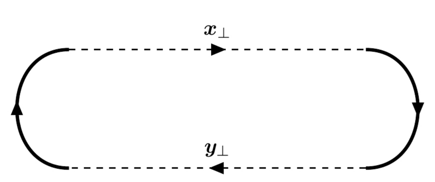


$$\mathcal{T}_q(q,p) = (2\pi)\delta(q^- - p^-)\gamma^- \mathrm{sign}(p^-) \int \mathrm{d}^2\boldsymbol{z}_\perp\, e^{-i(\boldsymbol{q}_\perp - \boldsymbol{p}_\perp).\boldsymbol{z}_\perp}\, \tilde{U}^{\mathrm{sign}(p^-)}(\boldsymbol{z}_\perp)$$

$$\frac{\mathrm{d}^3\sigma^{\mathrm{LO}}}{\mathrm{d}x\mathrm{d}Q^2\mathrm{d}^6K_\perp \mathrm{d}^3\eta_K} = \frac{\alpha_{em}^2 q_f^4 y^2 N_c}{512\pi^5 Q^2}\, \frac{1}{(2\pi)^4}\, \frac{1}{2}\, L^{\mu\nu} X_{\mu\nu}^{\mathrm{LO}}$$

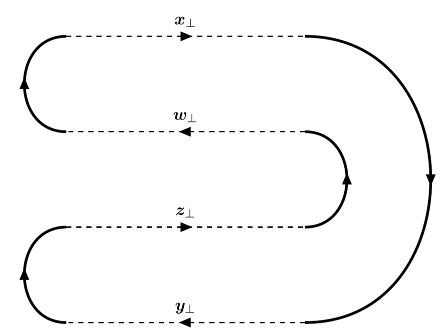
$$X_{\mu\nu}^{\mathrm{LO}} \propto \Xi(\boldsymbol{x}_\perp, \boldsymbol{y}_\perp; \boldsymbol{y}'_\perp, \boldsymbol{x}'_\perp)$$

$$\Xi(\boldsymbol{x}_\perp, \boldsymbol{y}_\perp; \boldsymbol{y}'_\perp, \boldsymbol{x}'_\perp) = 1 - D_{xy} - D_{y'x'} + Q_{y'x';xy}$$



$$D_{xy} = \frac{1}{N_c}\left\langle \mathrm{Tr}\left(\tilde{U}(\boldsymbol{x}_\perp)\tilde{U}^\dagger(\boldsymbol{y}_\perp)\right)\right\rangle$$

$$Q_{xy;zw} = \frac{1}{N_c}\left\langle \mathrm{Tr}\left(\tilde{U}(\boldsymbol{x}_\perp)\tilde{U}^\dagger(\boldsymbol{y}_\perp)\tilde{U}(\boldsymbol{z}_\perp)\tilde{U}^\dagger(\boldsymbol{w}_\perp)\right)\right\rangle$$

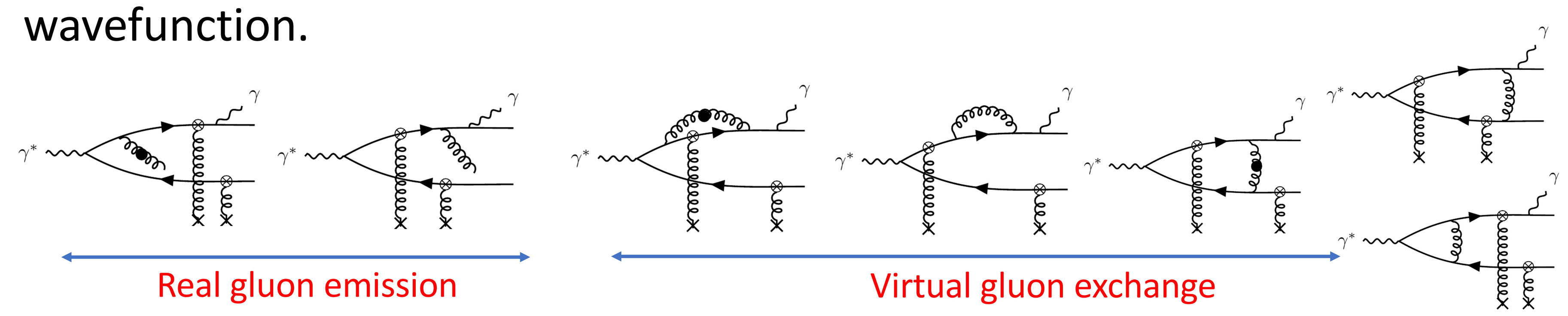


Gauge invariant dipole and quadrupole Wilson line correlators: universal building blocks of high energy QCD.

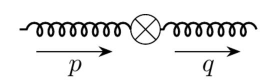
We recover usual nuclear PDF in the collinear limit of LO result.

What happens at NLO?

At next-to-leading order (NLO) in the CGC power counting, we have to account for quantum fluctuations in both the dipole as well as the nuclear wavefunction.

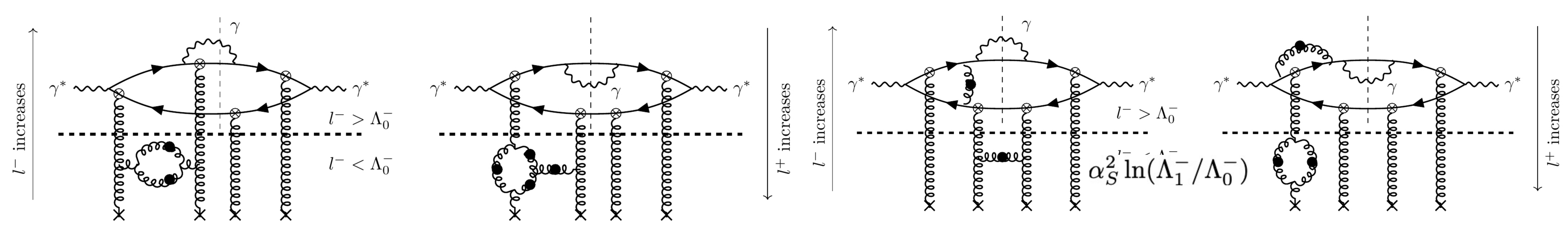


+ permutations of γ-emission vertex + q $\leftrightarrow$ $\bar{q}$

Computation steps: Use "dressed" gluon propagator  in $A^- = 0$ gauge

$$\mathcal{T}_g^{\mu\nu}(q,p) = -2\pi\delta(q^- - p^-) \times (2p^-) g^{\mu\nu}\, \mathrm{sign}(p^-) \int \mathrm{d}^2\boldsymbol{z}_\perp\, e^{-i(\boldsymbol{q}_\perp - \boldsymbol{p}_\perp).\boldsymbol{z}_\perp}\, U^{\mathrm{sign}(p^-)}(\boldsymbol{z}_\perp)$$

- ❖ Regulate UV divergences using dim. regularization in d=2-ε dimensions.
- ❖ Regulate spurious $l^- = 0$ gluon pole by imposing cutoff at initial scale of longitudinal momentum, Λ_0^-.
- ❖ Use jet definitions to restrict phase space integration for real gluon amplitude squared. Collinear divergences cancel between real and virtual graphs giving an IR safe cross-section.



This is what we have computed

$$\langle \mathrm{d}\sigma\rangle_{\mathrm{NLO+NLL}x} \simeq \int [\mathcal{D}\rho_A] \left(W^{NLLx}[\rho_A]\left\{\mathrm{d}\hat{\sigma}_{\mathrm{LO}}[\rho_A] + \boxed{\mathrm{d}\hat{\sigma}_{\mathrm{NLO}}^{\mathrm{finite}}[\rho_A]}\right\} + \boxed{O(\alpha_S^3 \ln(\Lambda_1^-/\Lambda_0^-))}\right)$$

$$\boxed{W_{\Lambda_1^-}^{NLLx}[\rho_A] = \left\{1 + \ln(\Lambda_1^-/\Lambda_0^-)(\mathcal{H}_{\mathrm{LO}} + \mathcal{H}_{\mathrm{NLO}})\right\} W_{\Lambda_0^-}[\rho_A]}$$

Accuracy of result

Use extant results on NLO JIMWLK Hamiltonian[4]

Summary

First computation of NLO impact factor for inclusive photon+dijet production at NLO+NLLx accuracy. Independent cross-check on previous results in literature on fully inclusive DIS at NLO. Techniques of computation can be extended to higher loops for both e+A and p+A collisions. Numerical implementation will provide predictions for future EIC measurements.

References

1. K. Roy and R. Venugopalan, JHEP 05, 013 (2018), arXiv: 1802.09550 [hep-ph].
2. K. Roy and R. Venugopalan, PoS DIS2018 (2018) 053.
3. K. Roy and R. Venugopalan, in preparation.
4. A. Kovner, M. Lublinsky, Y. Mulian, arXiv: 1310.0378, 1405.0418; M. Lublinsky and Y. Mulian, arXiv: 1610.03453; S. Caron-Huot, arXiv: 1309.6521; A. V. Grabovsky, arXiv: 1307.5414, I. Balitsky and G. Chirilli, arXiv: 0710.4330.