NLO computation of diffractive di-hadron production in the shockwave framework

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QCD Evolution
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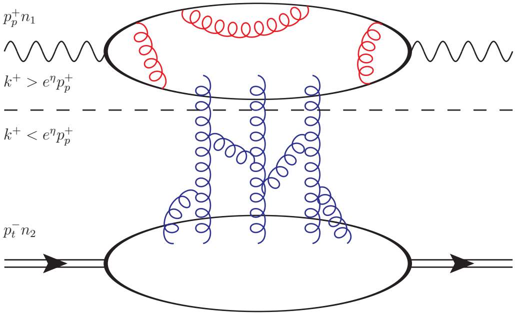
Shockwave formalism

- High-energy limit: $s = (p_p + p_t)^2 \gg Q^2, |p_p|^2, M_t^2, |t|, \ldots$
- n_1^μ, n_2^μ are light-like vectors (+/− directions)
- Working frame: IMF frame where $p_p^+ \sim p_t^- \sim \sqrt{\frac{s}{2}}$



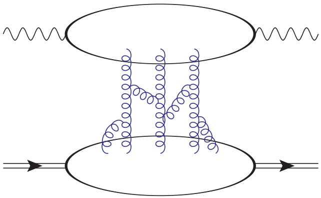
- Separation of gluon field into "fast" (quantum) and "slow " (classical) parts with a cut-off defined by an arbitrary rapidity parameter $\eta < 0$:

$$\mathcal{A}^\mu(k^+, k^-, \vec{k}) = A^\mu(k^+ > e^\eta p_p^+, k^-, \vec{k}) + b^\mu(k^+ < e^\eta p_p^+, k^-, \vec{k})$$

Shockwave formalism

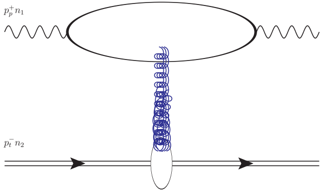
- Boost from target rest frame to the IMF frame with large $\Lambda = \sqrt{\frac{1+\beta}{1-\beta}} \sim \frac{\sqrt{s}}{M_t}$:

$$\begin{cases} b^+(x^+, x^-, \vec{x}) & = \Lambda^{-1} b_0^+(\Lambda z^+, \Lambda^{-1} z^-, \vec{z}) \\ b^-(x^+, x^-, \vec{x}) & = \Lambda b_0^-(\Lambda z^+, \Lambda^{-1} z^-, \vec{z}) \\ b^i(x^+, x^-, \vec{x}) & = b_0^i(\Lambda z^+, \Lambda^{-1} z^-, \vec{z}) \end{cases}$$



$b_0^\mu(x)$

boost $\longrightarrow$



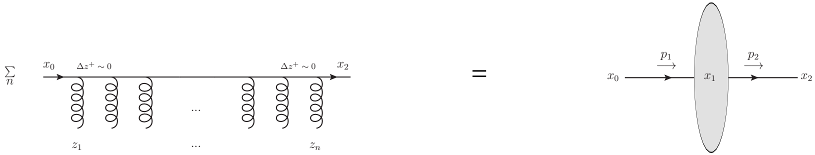
$$b^\mu(x^+, x^-, \vec{x}) = \delta(x^+)\mathbf{B}(\vec{x}) n_2^\mu + \mathcal{O}\left(\Lambda^{-1}\right)$$

Shockwave approximation

- Gauge choice: $A \cdot n_2 = 0$

  $A \cdot b = 0 \implies$ Simple effective Lagrangian

Quark line through the shockwave and Wilson line



- Interactions with the simple shockwave field:
  - Independence on x^- $\implies$ conservation of p^+ (eikonal approximation)
  - $\delta(x^+)$ $\implies$ interactions at a single transverse coordinate.
- Resummation of the multiple interactions into a Wilson line :

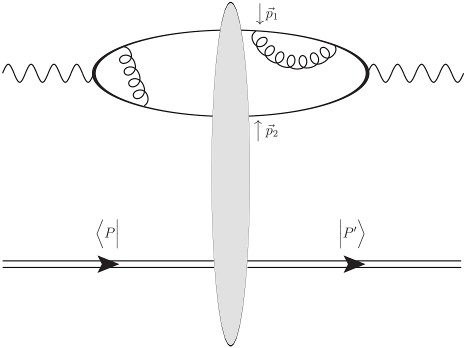
$$U(\vec{z}\,) = \mathcal{P} \exp\left[ig \int_{-\infty}^{+\infty} dz^+ b^- \left(z^+, \vec{z}\right)\right]$$

$$U(\vec{p}\,) = \int d^d\vec{z}\; e^{-i\vec{p}\cdot\vec{z}}\, U(\vec{z}\,)$$

- Quark line through the shockwave:

$$G(x_2, x_0)|_{x_2^+>0>x_0^+} = \int d^D x_1\, \delta(x_1^+) G_0(x_{21}) U(\vec{x}_1) \gamma^+ G_0(x_{10})$$

Scattering amplitude in the shockwave approximation



$$\mathcal{M}^\eta = \int d^d\vec{p}_1 d^d\vec{p}_{2\perp} \Phi^\eta(\vec{p}_1, \vec{p}_2\perp) \left\langle P' \left| \left[\mathrm{Tr}\left(U_1^\eta U_2^{\eta\dagger}\right) - N_c \right] (\vec{p}_1, \vec{p}_2) \right| P \right\rangle$$

Dipole operator:

$$\mathcal{U}_{ij}^\eta = 1 - \frac{1}{N_c} \mathrm{Tr}\left[U^\eta(\vec{z}_i) U^{\eta\dagger}(\vec{z}_j) \right]$$

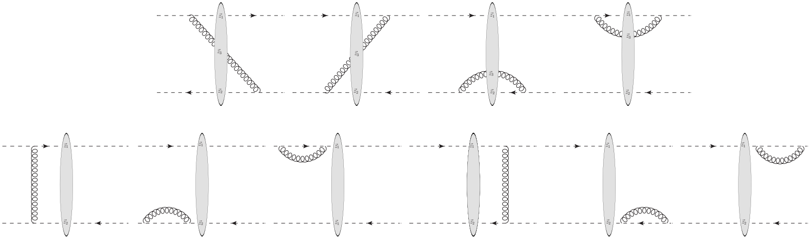
Balitsky-JIMWLK equations

- Balitsky-JIMWLK evolution equations [Balitsky, Jalilian-Marian, Iancu, McLerran, Weigert, Leonidov, Kovner] equations:

$$\frac{\partial \mathcal{U}_{12}^{\eta}}{\partial \eta} = \frac{\alpha_s N_c}{2\pi^2} \int d^2\vec{z}_3 \left(\frac{\vec{z}_{12}^{\,2}}{\vec{z}_{23}^{\,2}\vec{z}_{31}^{\,2}} \right) \Big[\underbrace{\mathcal{U}_{13}^{\eta} + \mathcal{U}_{32}^{\eta} - \mathcal{U}_{12}^{\eta}}_{\text{BFKL}} - \mathcal{U}_{13}^{\eta}\mathcal{U}_{32}^{\eta} \Big]$$

$$\frac{\partial \mathcal{U}_{13}^{\eta}\mathcal{U}_{32}^{\eta}}{\partial \eta} = \cdots \qquad \longleftarrow \quad \text{Balitsky hierarchy}$$

$$\vdots$$



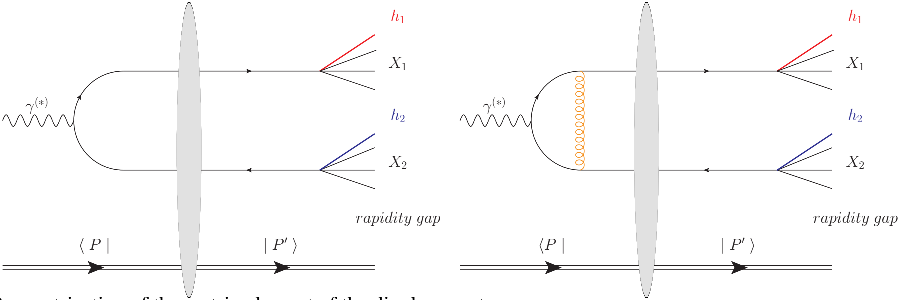
Diffractive di-hadron production

- Study the diffractive di-hadron production at NLO :

$$\gamma^{(*)}(p_\gamma) + P(p_0) \rightarrow h_1(p_{h1}) + h_2(p_{h2}) + X + P(p_0') \qquad (X = X_1 + X_2)$$

  Rapidity gap between $(h_1 h_2 X)$ and $P'(p_0')$.

- General kinematics (t, Q^2) and arbitrary photon polarization: process could be either photo-production or electro-production



Parametrization of the matrix element of the dipole operator:

$$\left\langle P'(p_0') \middle| \mathrm{Tr}\left[U\left(\frac{\vec{z}}{2}\right) U^\dagger\left(-\frac{\vec{z}}{2}\right)\right] - N_c \middle| P(p_0) \right\rangle \equiv 2\pi\,\delta\left(p_{00'}^-\right) F(\vec{z})$$

$$\int d^d z_\perp e^{-i(\vec{z}\cdot\vec{p})} F(\vec{z}) \equiv \mathbf{F}(\vec{p})\,.$$

Hybrid factorisation

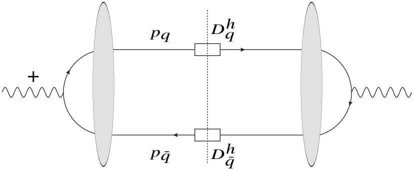
Hybrid factorization:

- Collinear factorization: Hard scale with $\Lambda^2_{QCD} \ll \vec{p}^{\,2}_{h_1} \sim \vec{p}^{\,2}_{h_2}$.
  Constraint $\vec{p}^{\,2} \gg \vec{p}^{\,2}_{h_{1,2}}$ with $\vec{p}$, the relative transverse momentum of the two hadrons.
  $\Longrightarrow$ Use of single hadron fragmentation function (FF) only to describe hadronization.
- The shockwave factorisation :
  Partonic process at LO and NLO has been calculated in [Boussarie, Grabovsky, Szymanowski, Wallon (2016)].
- Saturation region : $\vec{p}^{\,2}_{h_1} \sim \vec{p}^{\,2}_{h_2} < Q_s^2$

LO cross-section

- Sudakov decomposition for the momenta: $p_i^\mu = x_i p_\gamma^+ n_1^\mu + \frac{\vec{p}^{\,2}}{2x_i p_\gamma^+} n_2^\mu + p_\perp^\mu$.

$$p_\gamma = \overset{+\quad\;\; -\quad\;\; \perp}{\left(p_\gamma^+, -\frac{Q^2}{2p_\gamma^+}, \vec{0}\right)}$$



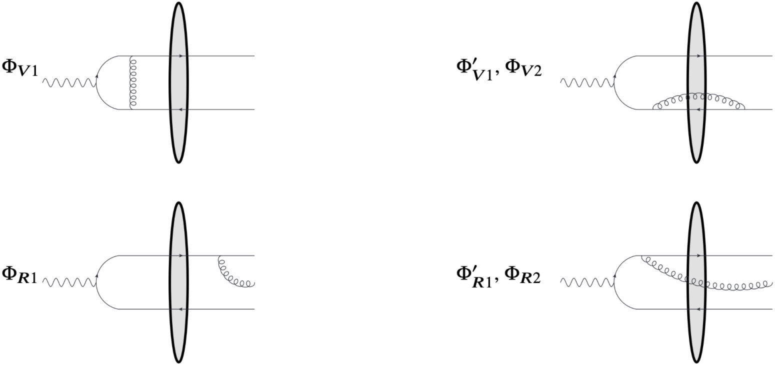
- Collinearity $(p_q^+, \vec{p}_q) = (x_q/x_{h_1})(p_{h_1}^+, \vec{p}_{h_1})$ and $(p_{\bar{q}}^+, \vec{p}_{\bar{q}})(x_{\bar{q}}/x_{h_2})(p_{h_2}^+, \vec{p}_{h_2})$:

$$\frac{d\sigma_{0JI}^{h_1 h_2}}{dx_{h_1} dx_{h_2} d^d\vec{p}_{h_1} d^d\vec{p}_{h2}} = \sum_q \int_{x_{h_1}}^1 \frac{dx_q}{x_q} \int_{x_{h_2}}^1 \frac{dx_{\bar{q}}}{x_{\bar{q}}} \left(\frac{x_q}{x_{h1}}\right)^d \left(\frac{x_{\bar{q}}}{x_{h2}}\right)^d$$

$$D_q^{h_1}\left(\frac{x_{h_1}}{x_q}\right) D_{\bar{q}}^{h_2}\left(\frac{x_{h_2}}{x_{\bar{q}}}\right) \frac{d\hat{\sigma}_{JI}}{dx_q dx_{\bar{q}} d^d\vec{p}_q d^d\vec{p}_{\bar{q}}} + (h_1 \leftrightarrow h_2)$$

J, I labels the photon polarization for respectively the complex conjugated amplitude and the amplitude.

NLO impact factor before fragmentation

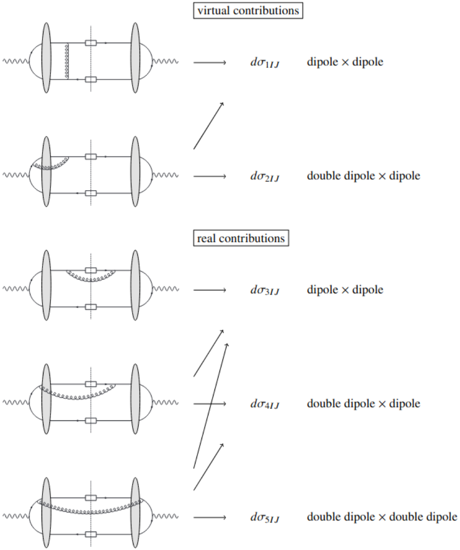


Rapidity divergences ($x_g \to 0$, $\vec{p}_g$ arbitrary)

- Present in Φ_{V2}
- Of the form $\ln \alpha$, α longitudinal cut-off $p_g^+ = x_g p_\gamma^+ > \alpha p_\gamma^+$
- Subtraction term : $\Phi_0 \otimes \mathcal{K}_{B-JIMWLK} \implies \tilde{\Phi}_{V2} = \Phi_{V2} - \Phi_0 \otimes \mathcal{K}_{B-JIMWLK}$ is finite

NLO cross-section in a nutshell and divergences

Operator structure classification :



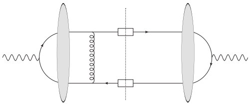
NLO cross-section in a nutshell and divergences

IR divergences to deal with:

- Collinear divergences $\vec{p}_g \propto \vec{p}_q$ or $\vec{p}_g \propto \vec{p}_{\bar{q}}$
- Soft divergences where $x_g \to 0$ and $p_{g\perp} = x_g u_\perp \sim x_g \to 0$ where $u_\perp$ of order p_T.

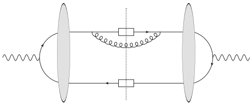
Regularization with dimensional regularization $D = 2 + d = 4 + 2\epsilon$ and longitudinal cut-off $|x_g| > \alpha$.

- We prove the cancellation of divergences between the divergent part of $d\sigma_{3JI}$, counterterms from FF renormalization, and $d\sigma_{1JI}$.
- The finite terms are extracted.



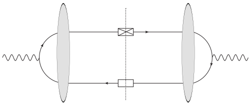
$\downarrow$

$d\sigma_{1IJ}$



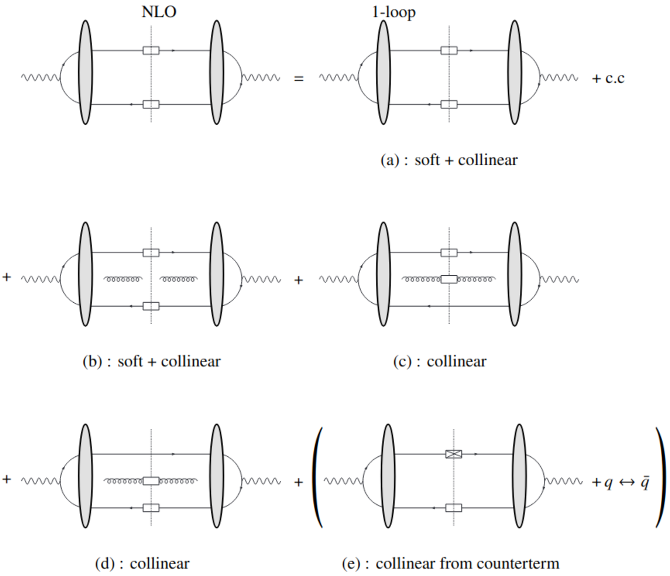
$\downarrow$

$d\sigma_{3IJ}$



counterterm

NLO cross-section in a nutshell and divergences



Counterterm from the renormalization of FF: diagram (e)

bare dressed

$$D_q^{h_1}\left(\frac{x_{h_1}}{x_q}\right) = D_q^{h_1}\left(\frac{x_{h_1}}{x_q},\mu_F\right) - \frac{\alpha_s}{2\pi}\left(\frac{1}{\hat{\epsilon}} + \ln\frac{\mu_F^2}{\mu^2}\right)\int_{\frac{x_{h_1}}{x_q}}^{1}\frac{d\beta_1}{\beta_1}$$
$$\times\left[P_{qq}(\beta_1)D_q^{h_1}\left(\frac{x_{h_1}}{x_q\beta_1},\mu_F\right) + P_{gq}(\beta_1)\,D_g^{h_1}\left(\frac{x_{h_1}}{\beta_1 x_q},\mu_F\right)\right]$$

with the usual DGLAP splitting functions

$$P_{qq}(z) = C_F\left[\frac{1+z^2}{(1-z)_+} + \frac{3}{2}\delta(1-z)\right]$$
$$P_{gq}(z) = C_F\frac{1+(1-z)^2}{z}$$

+ prescription: $\int_a^1 d\beta\frac{F(\beta)}{(1-\beta)_+} = \int_a^1 d\beta\frac{F(\beta)-F(1)}{1-\beta} - \int_0^a d\beta\frac{F(1)}{1-\beta}$

$\frac{1}{\hat{\epsilon}} = \frac{\Gamma(1-\epsilon)}{(4\pi)^\epsilon\epsilon} \sim \frac{1}{\epsilon} + \gamma_E - \ln(4\pi)$

Counterterm cross-section for LL

$$\frac{d\sigma_{LL}^{h_1 h_2}}{dx_{h_1} d_{h_2} d^d p_{h_1\perp} d^d p_{h_2\perp}}\Big|_{\text{ct}} = \frac{4\alpha_{\text{em}} Q^2}{(2\pi)^{4(d-1)} N_c} \sum_q \int_{x_{h_1}}^1 dx_q \int_{x_{h_2}}^1 dx_{\bar{q}} x_q x_{\bar{q}} \left(\frac{x_q}{x_{h_1}}\right)^d \left(\frac{x_{\bar{q}}}{x_{h_2}}\right)^d \delta(1 - x_q - x_{\bar{q}})$$

$$\times \mathcal{F}_{LL}\left(-\frac{\alpha_s}{2\pi}\right)\left(\frac{1}{\hat{\epsilon}} + \ln\frac{\mu_F^2}{\mu^2}\right) Q_q^2 \left\{ \int_{\frac{x_{h_1}}{x_q}}^1 \frac{d\beta_1}{\beta_1} \left[C_F \frac{1+\beta_1^2}{(1-\beta_1)_+} D_q^{h_1}\left(\frac{x_{h_1}}{\beta_1 x_q}, \mu_F\right) D_{\bar{q}}^{h_2}\left(\frac{x_{h_2}}{x_{\bar{q}}}, \mu_F\right) \right.\right.$$

$$+ P_{gq}(\beta_1) D_g^{h_1}\left(\frac{x_{h_1}}{\beta_1 x_q}, \mu_F\right) D_{\bar{q}}^{h_2}\left(\frac{x_{h_2}}{x_{\bar{q}}}, \mu_F\right)\Bigg] + \int_{\frac{x_{h_2}}{x_{\bar{q}}}}^1 \frac{d\beta_2}{\beta_2} \left[P_{gq}(\beta_2) D_q^{h_1}\left(\frac{x_{h_1}}{x_q}, \mu_F\right) D_g^{h_2}\left(\frac{x_{h_2}}{\beta_2 x_{\bar{q}}}, \mu_F\right) \right.$$

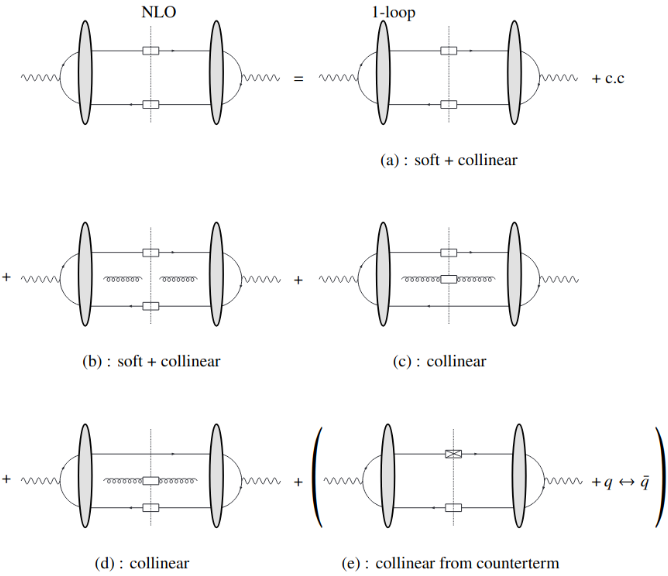
$$\left.\left. + C_F \frac{1+\beta_2^2}{(1-\beta_2)_+} D_q^{h_1}\left(\frac{x_{h_1}}{x_q}, \mu_F\right) D_{\bar{q}}^{h_2}\left(\frac{x_{h_2}}{\beta_2 x_{\bar{q}}}, \mu_F\right)\right] + 3C_F D_q^{h_1}\left(\frac{x_{h_1}}{x_q}, \mu_F\right) D_{\bar{q}}^{h_2}\left(\frac{x_{h_2}}{x_{\bar{q}}}, \mu_F\right)\right\}$$

$$+ (h_1 \leftrightarrow h_2)$$

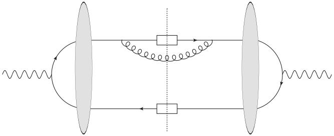
$\mathcal{F}_{LL}$ contains the non-perturbative part: matrix elements of the dipole operators on the target states

$$\mathcal{F}_{LL} = \left| \int d^d \vec{p}_2 \frac{\mathbf{F}\left(\frac{x_q}{2x_{h_1}} \vec{p}_{h_1} + \frac{x_{\bar{q}}}{2x_{h_2}} \vec{p}_{h_2\perp} - \vec{p}_2\right)}{\left(\frac{x_{\bar{q}}}{x_{h_2}} \vec{p}_{h_2} - \vec{p}_2\right)^2 + x_q x_{\bar{q}} Q^2} \right|^2$$

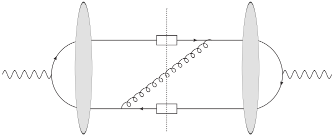
Diagrams (b), (c), (d)



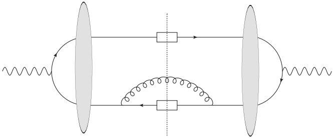
Divergent diagrams in diagram (b), (c), (d)



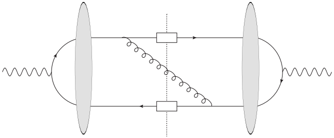
(1) : soft + collinear (qg)



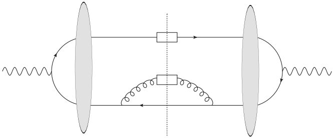
(2) : soft



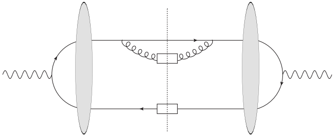
(3) : soft + collinear $(\bar{q}g)$



(4) : soft



(5) : collinear $(\bar{q}g)$



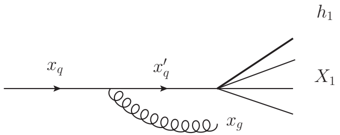
(6) : collinear (qg)

Important points for the calculation of collinear divergences

- Change variables to have longitudinal momentum fraction expressed wrt to the parent parton rather than the photon.
  This is to be able to compare to the counterterm.

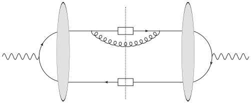
  Example: To extract the collinear divergences from qg splitting, do:

$$x'_q = \beta_1 x_q,$$
$$x_g = (1-\beta_1) x_q.$$



- To disentangle the transverse momentum of the spectator parton and be able to integrate over it without touching the non-perturbative part
  ⇒ Fourier transform of the matrix element of the dipole operator.

Specific case : diagram (1)



$$
\left.\frac{d\sigma_{3LL}^{q\bar{q}\to h_1 h_1}}{dx_{h_1}\, d_{h_2}\, d^d p_{h_1}\, d^d p_{h_2}}\right|_{\text{coll qg}}
= \frac{4\alpha_{\text{em}} Q^2}{(2\pi)^{4(d-1)} N_c} \sum_q \int_{x_{h_1}}^1 \frac{dx'_q}{x'_q} \int_\alpha^1 \frac{dx_g}{x_g} \int_{x_{h_2}}^1 \frac{dx_{\bar{q}'}}{x_{\bar{q}'}}\, \delta(1 - x'_q - x'_{\bar{q}} - x_g)
$$

$$
\times \left(\frac{x'_q}{x_{h_1}}\right)^d \left(\frac{x'_{\bar{q}}}{x_{h_2}}\right)^d Q_q^2 D_q^{h_1}\left(\frac{x_{h_1}}{x'_q}, \mu_F\right) D_{\bar{q}}^{h_2}\left(\frac{x_{h_2}}{x'_{\bar{q}}}, \mu_F\right) \frac{\alpha_s}{\mu^{2\epsilon}} C_F \frac{d^d p_{g\perp}}{(2\pi)^d}
$$

$$
\times \int d^d \vec{p}_2\, \mathbf{F}\left(\frac{x'_q}{2x_{h_1}}\vec{p}_{h_1\perp} + \frac{x'_{\bar{q}}}{2x_{h_2}}\vec{p}_{h_2} - \vec{p}_{2\perp} + \frac{\vec{p}_g}{2}\right)
$$

$$
\times \int d^d \vec{p}_{2'}\, \mathbf{F}^*\left(\frac{x'_q}{2x_{h_1}}\vec{p}_{h_1} + \frac{x'_{\bar{q}}}{2x_{h_2}}\vec{p}_{h_2} - p_{2'\perp} + \frac{\vec{p}_g}{2}\right)
$$

$$
\times \frac{(dx_g^2 + 4x'_q(x'_q + x_g))x_{\bar{q}}^2(1 - x'_{\bar{q}})^2}{\left(x'_{\bar{q}}(1 - x'_{\bar{q}})Q^2 + \left(\frac{x'_{\bar{q}}}{x_{h_2}}\vec{p}_{h_2} - \vec{p}_2\right)^2\right)\left(x'_{\bar{q}}(1 - x'_{\bar{q}})Q^2 + \left(\frac{x'_{\bar{q}}}{x_{h_2}}\vec{p}_{h_2} - \vec{p}_{2'}\right)^2\right)\left(x'_q\vec{p}_g - x_g\frac{x'_q}{x_{h_1}}\vec{p}_{h_1}\right)^2}
$$

$$
+ (h_1 \leftrightarrow h_2)
$$

Results for diagram (1)

$$\frac{d\sigma_{3LL}^{q\bar{q}\to h_1 h_2}}{dx_{h_1} dx_{h_2} dp_{h_1\perp}^d p_{h_2\perp}}\Big|_{\text{coll. qg div}} = \frac{4\alpha_{\text{em}} Q^2}{(2\pi)^{4(d-1)} N_c} \sum_q \int_{x_{h_1}}^1 dx_q \int_{x_{h_2}}^1 dx_{\bar{q}}\; x_q x_{\bar{q}} \left(\frac{x_q}{x_{h_1}}\right)^d \left(\frac{x_{\bar{q}}}{x_{h_2}}\right)^d \delta(1-x_q-x_{\bar{q}})$$

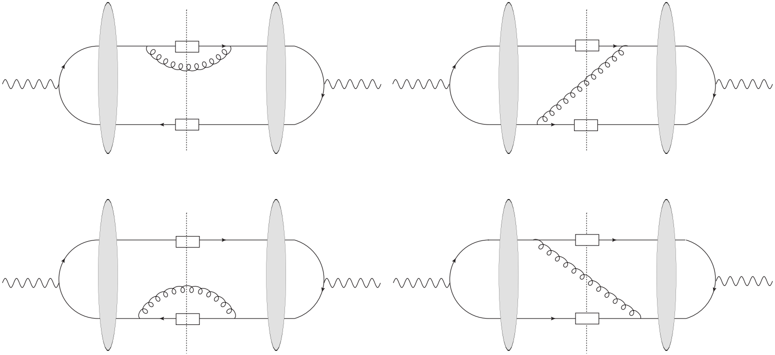
$$\times \int d^d\vec{p}_2 \int d^d\vec{z}_1 \frac{e^{-i\vec{z}_1\cdot\left(\frac{x_q}{2x_{h_1}}\vec{p}_{h_1}+\frac{x_{\bar{q}}}{2x_{h_2}}\vec{p}_{h_2}-\vec{p}_2\right)} F(\vec{z}_1)}{x_q x_{\bar{q}} Q^2 + \left(\frac{x_{\bar{q}}}{x_{h_2}}\vec{p}_{h_2}-\vec{p}_2\right)^2} \int d^d\vec{p}_{2'} \int d^d\vec{z}_2 \frac{e^{i\vec{z}_2\cdot\left(\frac{x_q}{2x_{h_1}}\vec{p}_{h_1\perp}+\frac{x_{\bar{q}}}{2x_{h_2}}\vec{p}_{h_2}-\vec{p}_{2'}\right)} F^*(\vec{z}_2)}{x_q x_{\bar{q}} Q^2 + \left(\frac{x_{\bar{q}}}{x_{h_2}}\vec{p}_{h_2}-\vec{p}_{2'}\right)^2}$$

$$\times \frac{\alpha_s}{2\pi}\frac{1}{\hat{\epsilon}} Q_q^2 \left[\int_{\frac{x_{h_1}}{x_q}}^1 \frac{d\beta_1}{\beta_1} C_F \frac{1+\beta_1^2}{(1-\beta_1)_+} D_q^{h_1}\left(\frac{x_{h_1}}{\beta_1 x_q},\mu_F\right) D_{\bar{q}}^{h_2}\left(\frac{x_{h_2}}{x_{\bar{q}}},\mu_F\right) - 2C_F \ln\left(1-\frac{x_{h_1}}{x_q}\right) D_q^{h_1}\left(\frac{x_{h_1}}{x_q},\mu_F\right) D_{\bar{q}}^{h_2}\left(\frac{x_{h_2}}{x_{\bar{q}}},\mu_F\right)\right.$$

$$\left. + \int_{\frac{x_{h_1}}{x_q}}^{1-\frac{\alpha}{x_q}} d\beta_1 C_F \frac{2}{1-\beta_1}\left(\frac{c_0^2}{\left(\frac{z_{1\perp}-z_{2\perp}}{2}\right)^2\mu^2}\right)^{\epsilon} D_q^{h_1}\left(\frac{x_{h_1}}{x_q},\mu_F\right) D_{\bar{q}}^{h_2}\left(\frac{x_{h_2}}{x_{\bar{q}}},\mu_F\right)\right] + (h_1 \leftrightarrow h_2)\,.$$

- Cancellation with counterterm,
- Second term comes from the introduction of the + prescription and will be removed with a term in the soft contribution,
- Third term is to be removed: double-counting with soft contribution.

Soft limit



Rescaling $\vec{p}_g = x_g \vec{u}$ to isolate the divergences in the form $\int_\alpha^1 \frac{dx_g}{x_g^{3-d}}$ and putting $x_g \to 0$ in the rest of the integrand.

Soft divergence

$$\left.\frac{d\sigma_{3LL}^{q\bar{q}\to h_1 h_2}}{dx_{h_1} d_{h_2} d^d p_{h_1\perp} dp_{h_2\perp}}\right|_{\text{soft div}} = \frac{4\alpha_{\text{em}} Q^2}{(2\pi)^{4(d-1)} N_c} \sum_q \int_{x_{h_1}}^1 dx_q \int_{x_{h_2}}^1 dx_{\bar{q}}\; x_q x_{\bar{q}} \left(\frac{x_q}{x_{h_1}}\right)^d \left(\frac{x_{\bar{q}}}{x_{h_2}}\right)^d$$

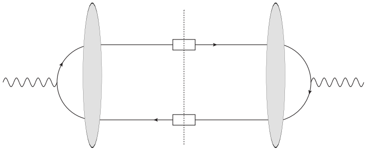
$$\times\, \delta(1 - x_q - x_{\bar{q}}) Q_q^2 D_q^{h_1}\left(\frac{x_{h_1}}{x_q}, \mu_F\right) D_{\bar{q}}^{h_2}\left(\frac{x_{h_2}}{x_{\bar{q}}}, \mu_F\right) \mathcal{F}_{LL}$$

$$\times\, \frac{\alpha_s C_F}{2\pi} \frac{1}{\hat{\epsilon}} \left[-4 \ln\alpha + 2\ln x_q + 2\ln\left(1 - \frac{x_{h_1}}{x_q}\right) - 4\epsilon \ln^2\alpha \right.$$

$$\left. -4\epsilon \ln\alpha \ln\left(\frac{\left(\frac{\vec{p}_{h_1}}{x_{h_1}} - \frac{\vec{p}_{h_2}}{x_{h_2}}\right)^2}{\mu^2}\right) + 2\ln x_{\bar{q}} + 2\ln\left(1 - \frac{x_{h_2}}{x_{\bar{q}}}\right)\right] + (h_1 \leftrightarrow h_2)$$

Cancellation with the residual divergence from the collinear term.

Virtual corrections



1-loop

Cancellation between virtual corrections and soft and with counterterm.

$$\frac{d\sigma_{1LL}^{q\bar{q}\to h_1 h_2}}{dx_{h_1} d_{h_2} d^d p_{h_1\perp} d^d p_{h_2\perp}}\Bigg|_{\text{div}} = \frac{4\alpha_{\text{em}} Q^2}{(2\pi)^{4(d-1)} N_c} \sum_q \int_{x_{h_1}}^1 dx_q \int_{x_{h_2}}^1 dx_{\bar{q}}\ x_q x_{\bar{q}} \left(\frac{x_q}{x_{h_1}}\right)^d \left(\frac{x_{\bar{q}}}{x_{h_2}}\right)^d$$

$$\times\, \delta(1 - x_q - x_{\bar{q}}) Q_q^2 D_q^{h_1}\left(\frac{x_{h_1}}{x_q}, \mu_F\right) D_{\bar{q}}^{h_2}\left(\frac{x_{h_2}}{x_{\bar{q}}}, \mu_F\right) \mathcal{F}_{LL}$$

$$\times\, \frac{\alpha_s}{2\pi} C_F \frac{1}{\hat{\epsilon}} \left[-4\epsilon \ln(\alpha) \ln\left(\frac{\mu^2}{\left(\frac{\vec{p}_{h_2}}{x_{h_2}} - \frac{\vec{p}_{h_1}}{x_{h_1}}\right)^2}\right) + 4\ln(\alpha) \right.$$

$$\left. +4\epsilon \ln^2(\alpha) - 2\ln(x_q x_{\bar{q}}) + 3 \right] + (h_1 \leftrightarrow h_2)$$

Conclusions

Summary

- Computation of the NLO cross-section of the diffractive production of a pair of hadrons with large p_T
- Saturation window: $\vec{p}^{\,2} < Q_s^2$
- Full cancellation of divergences has been observed between real corrections, virtual ones, and counterterm from FF renormalization.
- General kinematics (Q^2, t) and arbitrary photon polarization: process could be either photo-production or electro-production
- The results are applicable to ultra-peripheral collisions at the LHC.

Outlook

- Diffractive production of a single hadron with large p_T

  [Fucilla, Grabovsky, Li, Szymanowski, Wallon (to appear)]

- Phenomenological analysis

Thank you for your attention!