Impact factor for the exclusive diffractive production of 2 forward jets with NLO accuracy

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RB, A.V.Grabovsky, L.Szymanowski, S.Wallon
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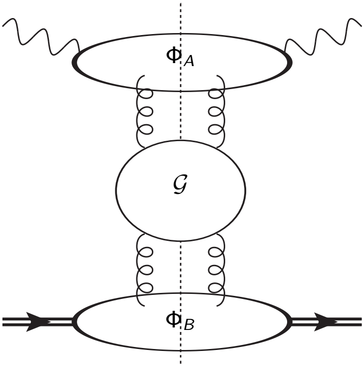
Probing QCD in the Regge limit and towards saturation

What kind of observable?

- Perturbation theory should apply : a hard scale Q^2 is required
- One needs semihard kinematics : $s \gg p_T^2 \gg \Lambda_{QCD}^2$ where all the typical transverse scales p_T are of the same order
- Saturation is reached when $Q^2 \sim Q_s^2 \propto \left(\frac{A}{x}\right)^{\frac{1}{3}}$: the smaller $x \sim \frac{Q^2}{s}$ is and the heavier the target ion, the easier saturation is reached.
- Typical processes : DIS, Mueller-Navelet double jets, ultraperipheral events at the LHC...

Precision tests of BFKL dynamics

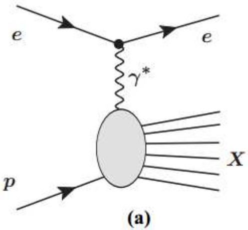
- The BFKL kernel is known at NLL accuracy, resumming $\alpha_s(\alpha_s \log s)^n$ corrections (Lipatov, Fadin ; Camici, Ciafaloni)
- Very few impact factors are known at NLO accuracy
  - $\gamma^* \to \gamma^*$ (Bartels, Colferai, Gieseke, Kyrielis, Qiao; Balitsky, Chirilli)
  - Forward jet production (Bartels, Colferai, Vacca ; Caporale, Ivanov, Murdaca, Papa, Perri ; Chachamis, Hentschinski, Madrigal, Sabio Vera)
  - Inclusive production of a pair of hadrons separated by a large interval of rapidity (Ivanov, Papa)
  - $\gamma_L^* \to \rho_L$ in the forward limit (Ivanov, Kostsky, Papa)



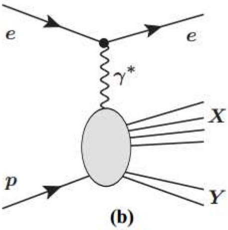
Diffractive DIS

Rapidity gap events at HERA

Experiments at HERA : about 10% of scattering events reveal a rapidity gap



DIS events



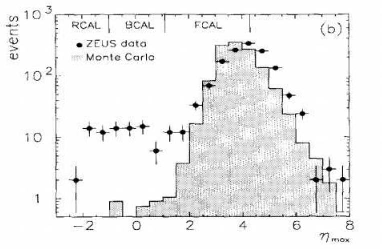
DDIS events

DIS : Deep Inelastic Scattering, DDIS : Diffractive DIS

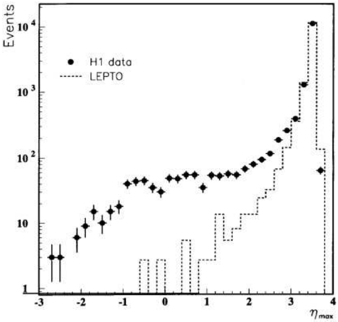
Diffractive DIS

Rapidity gap events at HERA

Experiments at HERA : about 10% of events reveal a rapidity gap



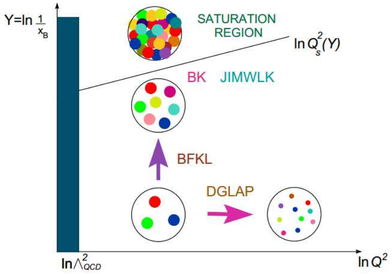
ZEUS, 1993



H1,1994

Diffractive DIS

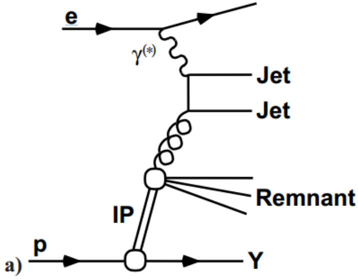
Theoretical approaches for DDIS using pQCD



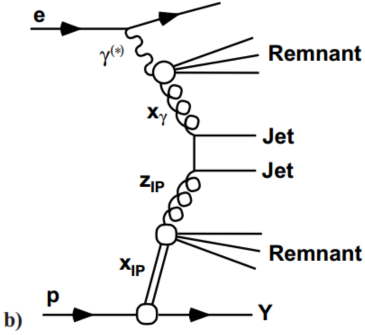
- Collinear factorization approach
  - Relies on a QCD factorization theorem, using a hard scale such as the virtuality Q^2 of the incoming photon
  - One needs to introduce a diffractive distribution function for partons *within a pomeron*
- k_T factorization approach for two exchanged gluons
  - low-x QCD approach : $s \gg Q^2 \gg \Lambda_{QCD}$
  - The pomeron is described as a two-gluon color-singlet state

Theoretical approaches for DDIS using pQCD

Collinear factorization approach



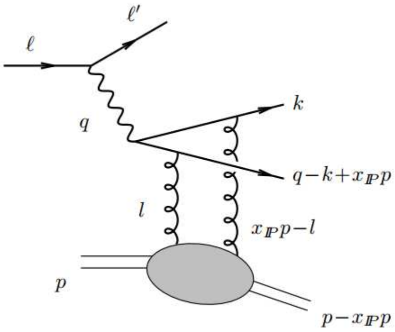
Direct



Resolved

Theoretical approaches for DDIS using pQCD

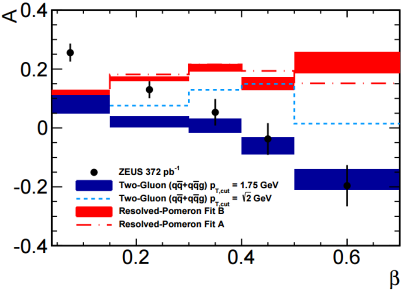
k_T-factorization approach : two gluon exchange



Bartels, Ivanov, Jung, Lotter, Wüsthoff
Braun and Ivanov developed a similar model in collinear factorization

Theoretical approaches for DDIS using pQCD

Confrontation of the two approaches with HERA data



ZEUS collaboration, 2015

NLO computations in the shockwave framework

The shockwave approach

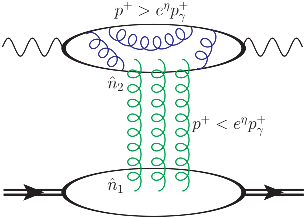
One decomposes the gluon field $\mathcal{A}$ into an internal field and an external field :

$$\mathcal{A}^\mu = A^\mu + b^\mu$$

The internal one contains the gluons with $p_g^+ > e^\eta p_\gamma^+$ and the external one contains the gluons with $p_g^+ < e^\eta p_\gamma^+$. One writes :

$$b_\eta^\mu(z) = \delta(z^+) B_\eta(\vec{z}) n_2^\mu$$

Intuitively, large boost Λ along the $+$ direction :



$$b^+(x^+, x^-, \vec{x}) \to \frac{1}{\Lambda} b^+\left(\Lambda x^+, \frac{1}{\Lambda} x^-, \vec{x}\right)$$

$$b^-(x^+, x^-, \vec{x}) \to \Lambda b^-\left(\Lambda x^+, \frac{1}{\Lambda} x^-, \vec{x}\right)$$

$$b^i(x^+, x^-, \vec{x}) \to b^i\left(\Lambda x^+, \frac{1}{\Lambda} x^-, \vec{x}\right)$$

Lightcone variables $x^+ \equiv \frac{x^0 + x^3}{\sqrt{2}}, \quad x^- \equiv \frac{x^0 - x^3}{\sqrt{2}}$

Propagator through a shockwave

$$G\left(z_2,\, z_0\right) = -\int d^4 z_1 \theta\left(z_2^+\right)\delta\left(z_1^+\right)\theta\left(-z_0^+\right) G\left(z_2 - z_1\right)\gamma^+ G\left(z_1 - z_0\right) U_1$$

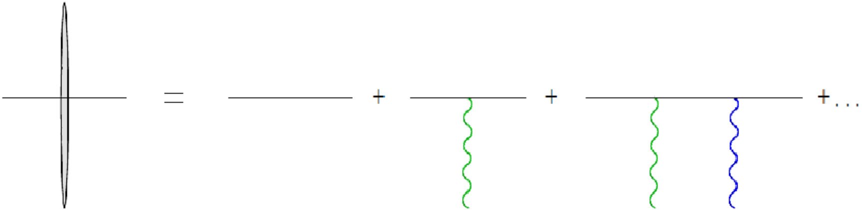
$$G\left(q,\, p\right) = \left(2\pi\right)\theta\left(p^+\right)\int d^D q_1 \delta\left(q + q_1 - p\right) G\left(q\right)\gamma^+ \tilde{U}_{\vec{q}_1} G\left(p\right)$$

Wilson lines :

$$U_i = U_{\vec{z}_i} = U\left(\vec{z}_i, \eta\right) = P\exp\left[ig\int_{-\infty}^{+\infty} b_\eta^-\left(z_i^+, \vec{z}_i\right) dz_i^+\right]$$

$$U_i = 1 + ig\int_{-\infty}^{+\infty} b_\eta^-(z_i^+, \vec{z}_i)dz_i^+ + (ig)^2\int_{-\infty}^{+\infty} b_\eta^-(z_i^+, \vec{z}_i) b_\eta^-(z_j^+, \vec{z}_j)\theta(z_{ji}^+)dz_i^+ dz_j^+$$

...



Evolution equation for a color dipole

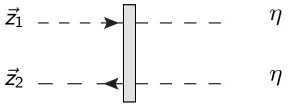
Dipole operator

$$\mathbf{U}_{12}^{\eta} = \frac{1}{N_c}\mathrm{Tr}\left(U_1^{\eta} U_2^{\eta\dagger}\right) - 1$$

involving Wilson lines

$$U_1^{\eta} = \ldots\left[1 + igb_{\eta}(z^+ + \Delta z^+, \vec{z}_1)\Delta z^+\right]\left[1 + igb_{\eta}(z^+, \vec{z}_1)\Delta z^+\right]\ldots$$

$$U_2^{\eta} = \ldots\left[1 + igb_{\eta}(z^+ + \Delta z^+, \vec{z}_2)\Delta z^+\right]\left[1 + igb_{\eta}(z^+, \vec{z}_2)\Delta z^+\right]\ldots$$



Evolution equation for a color dipole

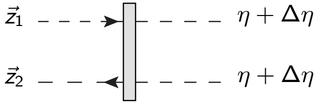
Dipole operator

$$\mathbf{U}_{12}^{\eta+\Delta\eta} = \frac{1}{N_c}\mathrm{Tr}\left(U_1^{\eta+\Delta\eta} U_2^{(\eta+\Delta\eta)\dagger}\right) - 1$$

involving Wilson lines

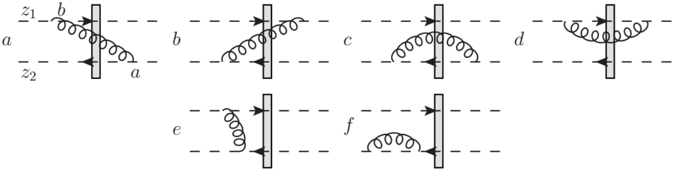
$$U_1^{\eta+\Delta\eta} = \ldots\left[1 + igb_{\eta+\Delta\eta}(z^+ + \Delta z^+, \vec{z}_1)\Delta z^+\right]\left[1 + igb_{\eta+\Delta\eta}(z^+, \vec{z}_1)\Delta z^+\right]\ldots$$

$$U_2^{\eta+\Delta\eta} = \ldots\left[1 + igb_{\eta+\Delta\eta}(z^+ + \Delta z^+, \vec{z}_2)\Delta z^+\right]\left[1 + igb_{\eta+\Delta\eta}(z^+, \vec{z}_2)\Delta z^+\right]\ldots$$



Balitsky's hierarchy of equations

$$\mathbf{U}_{12}^{\eta+\Delta\eta} - \mathbf{U}_{12}^{\eta}$$



B-JIMWLK equation

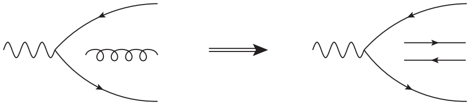
[Balitsky, Jalilian-Marian, Iancu, McLerran, Weigert, Leonidov, Kovner]

$$\frac{\partial \mathbf{U}_{12}}{\partial \eta} = \frac{\alpha_s N_c}{2\pi^2} \int d\vec{z}_3 \frac{\vec{z}_{12}^{\,2}}{\vec{z}_{13}^{\,2}\vec{z}_{23}^{\,2}} \left[\mathbf{U}_{13} + \mathbf{U}_{32} - \mathbf{U}_{12} - \mathbf{U}_{13}\mathbf{U}_{32}\right]$$

$$\frac{\partial \mathbf{U}_{13}\mathbf{U}_{32}}{\partial \eta} = \ldots$$

The BK equation

Mean field approximation, or 't Hooft limit $N_c \to \infty$ in Balitsky's equation



[Mueller]

$\Rightarrow$ BK equation [Balitsky, 1995] [Kovchegov, 1999]

$$\frac{\partial \mathbf{U}_{12}}{\partial \eta} = \frac{\alpha_s N_c}{2\pi^2} \int d\vec{z}_3 \frac{\vec{z}_{12}^{\,2}}{\vec{z}_{13}^{\,2}\vec{z}_{23}^{\,2}} \left[\mathbf{U}_{13} + \mathbf{U}_{32} - \mathbf{U}_{12} - \mathbf{U}_{13}\mathbf{U}_{32}\right]$$

Evolves a dipole into a double dipole

Non-linear term : saturation

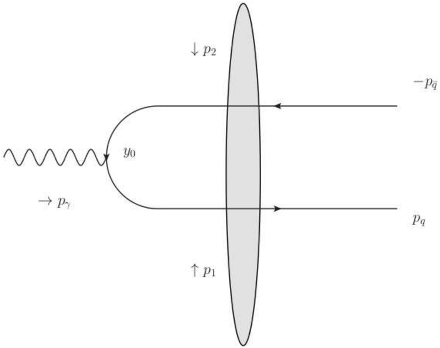
Assumptions

- Regge limit : $s \gg Q^2 \gg \Lambda_{QCD}$
- No approximation for the outgoing gluon, contrary to e.g. :
  - Collinear approximation [Wüsthoff, 1995]
  - Soft approximation [Bartels, Jung, Wüsthoff, 1999]
- Lightcone coordinates $\left(p^+, p^-, \vec{p}\right)$ and lightcone gauge $n_2 \cdot \mathcal{A} = 0$
- Transverse dimensional regularization $d = 2 + 2\varepsilon$, longitudinal cutoff

$$p_g^+ < \alpha p_\gamma^+$$

- Shockwave (Wilson lines) approach [Balitsky, 1995]

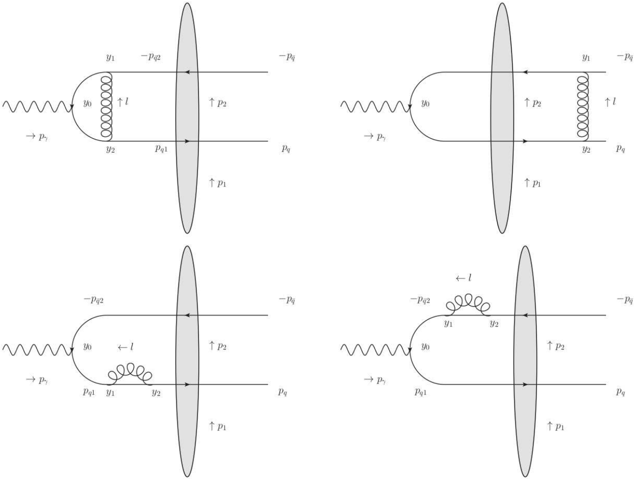
Leading Order



$$\mathcal{A}_0 = \varepsilon_\alpha N_c \int d^d \vec{p}_1 d^d \vec{p}_2 \Phi_0^\alpha (\vec{p}_1, \vec{p}_2) \delta (\vec{p}_{q1} + \vec{p}_{\bar{q}2}) \tilde{\mathbf{U}}_{12}$$

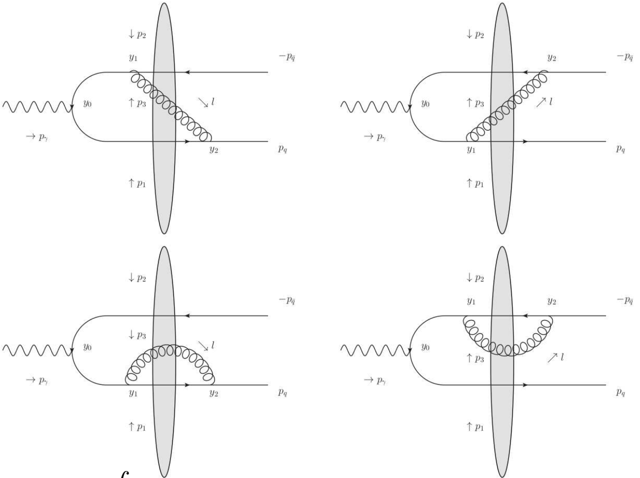
$p_{ij} \equiv p_i - p_j$

First kind of virtual corrections



$$\mathcal{A}_{V1} \quad \propto \quad \varepsilon_\alpha N_c \int d^d \vec{p}_1 d^d \vec{p}_2 \Phi^{\alpha}_{V1}\left(\vec{p}_1,\, \vec{p}_2\right) \delta\left(\vec{p}_{q1} + \vec{p}_{\bar{q}2}\right) \left(\frac{N_c^2-1}{N_c}\right) \tilde{\mathbf{U}}_{12}$$

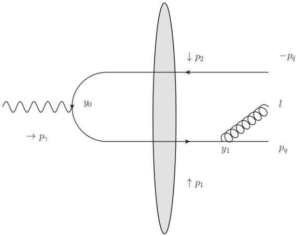
Second kind of virtual corrections

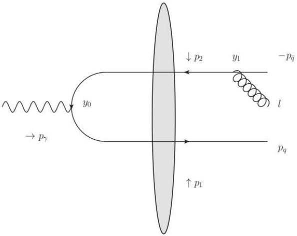


$$\mathcal{A}_{V2} \quad \propto \quad \varepsilon_\alpha N_c \int d^d\vec{p}_1 d^d\vec{p}_2 d^d\vec{p}_3 \Phi^{\alpha}_{V2}\left(\vec{p}_1,\, \vec{p}_2,\, \vec{p}_3\right) \delta\left(\vec{p}_{q1} + \vec{p}_{\bar{q}2} - \vec{p}_3\right)$$

$$\left[\delta\left(\vec{p}_3\right)\left(\frac{N_c^2 - 1}{N_c}\right) \tilde{\mathbf{U}}_{12} + N_c \left(\tilde{\mathbf{U}}_{13}\tilde{\mathbf{U}}_{32} + \tilde{\mathbf{U}}_{13} + \tilde{\mathbf{U}}_{32} - \tilde{\mathbf{U}}_{12}\right)\right]$$

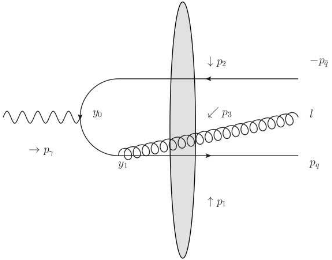
First kind of real corrections

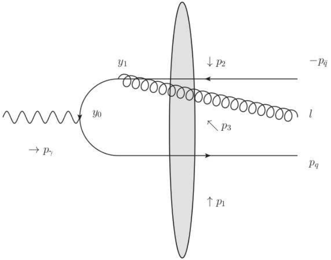




$$\mathcal{A}_{R1} \quad = \quad \varepsilon_\alpha N_c \int d^d\vec{p}_1 d^d\vec{p}_2\, \Phi^{\alpha}_{R1}\left(\vec{p}_1,\ \vec{p}_2\right) \delta\left(\vec{p}_{q1} + \vec{p}_{\bar{q}2} + \vec{p}_g\right) \left(\frac{N_c^2 - 1}{N_c}\right) \tilde{\mathbf{U}}_{12}$$

Second kind of real corrections



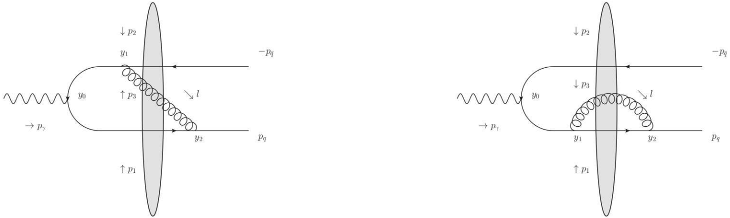


$$
\begin{aligned}
\mathcal{A}_{R2} &= \varepsilon_\alpha N_c \int d^d\vec{p}_1 d^d\vec{p}_2 d^d\vec{p}_3 \Phi^\alpha_{R2}\left(\vec{p}_1,\ \vec{p}_2,\ \vec{p}_3\right)\delta\left(\vec{p}_{q1}+\vec{p}_{\bar{q}2}+\vec{p}_{g3}\right) \\
&\left[\left(\frac{N_c^2-1}{N_c}\right)\tilde{\mathbf{U}}_{12}\delta\left(\vec{p}_3\right)+N_c\left(\tilde{\mathbf{U}}_{13}\tilde{\mathbf{U}}_{32}+\tilde{\mathbf{U}}_{13}+\tilde{\mathbf{U}}_{32}-\tilde{\mathbf{U}}_{12}\right)\right]
\end{aligned}
$$

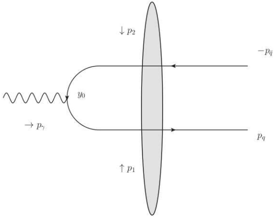
Divergences

- Rapidity divergence $p_g^+ \to 0$ — $\Phi_{V2}\Phi_0^* + \Phi_0\Phi_{V2}^*$
- UV divergence $\vec{p}_g^{\,2} \to +\infty$ — $\Phi_{V1}\Phi_0^* + \Phi_0\Phi_{V1}^*$
- Soft divergence $p_g \to 0$ — $\Phi_{V1}\Phi_0^* + \Phi_0\Phi_{V1}^*, \Phi_{R1}\Phi_{R1}^*$
- Collinear divergence $p_g \propto p_q$ or $p_{\bar{q}}$ — $\Phi_{R1}\Phi_{R1}^*$
- Soft and collinear divergence $p_g = \frac{p_g^+}{p_q^+} p_q$ or $\frac{p_g^+}{p_{\bar{q}}^+} p_{\bar{q}}$, $p_g^+ \to 0$ — $\Phi_{R1}\Phi_{R1}^*$

Rapidity divergence



Double dipole virtual correction Φ_{V2}



B-JIMWLK evolution of the LO term : $\Phi_0 \otimes \mathcal{K}_{BK}$

Rapidity divergence

B-JIMWLK equation

$$\frac{\partial \tilde{\mathbf{U}}_{12}^{\alpha}}{\partial \log \alpha} = 2\alpha_s N_c \mu^{2-d} \int \frac{d^d \vec{k}_1 d^d \vec{k}_2 d^d \vec{k}_3}{(2\pi)^{2d}} \delta(\vec{k}_1 + \vec{k}_2 + \vec{k}_3 - \vec{p}_1 - \vec{p}_2)\left(\tilde{\mathbf{U}}_{13}\tilde{\mathbf{U}}_{32} + \tilde{\mathbf{U}}_{13} + \tilde{\mathbf{U}}_{32} - \tilde{\mathbf{U}}_{12}\right)$$
$$\times \left[2\frac{(\vec{k}_1 - \vec{p}_1)\cdot(\vec{k}_2 - \vec{p}_2)}{(\vec{k}_1 - \vec{p}_1)^2(\vec{k}_2 - \vec{p}_2)^2} + \frac{\pi^{\frac{d}{2}}\Gamma(1-\frac{d}{2})\Gamma^2(\frac{d}{2})}{\Gamma(d-1)} \left(\frac{\delta(\vec{k}_2 - \vec{p}_2)}{\left[(\vec{k}_1 - \vec{p}_1)^2\right]^{1-\frac{d}{2}}} + \frac{\delta(\vec{k}_1 - \vec{p}_1)}{\left[(\vec{k}_2 - \vec{p}_2)^2\right]^{1-\frac{d}{2}}} \right) \right]$$

η rapidity divide, which separates the upper and the lower impact factors

$$\tilde{\mathbf{U}}_{12}^{\alpha}\Phi_0 \to \Phi_0 \tilde{\mathbf{U}}_{12}^{\eta} + \log\left(\frac{e^{\eta}}{\alpha}\right) \mathcal{K}_{BK} \Phi_0 \left(\tilde{\mathbf{U}}_{13}\tilde{\mathbf{U}}_{32} + \tilde{\mathbf{U}}_{13} + \tilde{\mathbf{U}}_{32} - \tilde{\mathbf{U}}_{12}\right)$$

Rapidity divergence

Virtual contribution

$$(\Phi^{\mu}_{V2})_{div} \propto \Phi^{\mu}_{0} \left\{ 4 \ln\left(\frac{x\bar{x}}{\alpha^2}\right) \left[\frac{1}{\varepsilon} + \ln\left(\frac{\vec{p}_3^{\,2}}{\mu^2}\right)\right] - \frac{6}{\varepsilon} \right\}$$

BK contribution

$$(\Phi^{\mu}_{BK})_{div} \propto \Phi^{\mu}_{0} \left\{ 4 \ln\left(\frac{\alpha^2}{e^{2\eta}}\right) \left[\frac{1}{\varepsilon} + \ln\left(\frac{\vec{p}_3^{\,2}}{\mu^2}\right)\right] \right\}$$

Sum : the α dependence cancels

$$(\Phi'^{\mu}_{V2})_{div} \propto \Phi^{\mu}_{0} \left\{ 4 \ln\left(\frac{x\bar{x}}{e^{2\eta}}\right) \left[\frac{1}{\varepsilon} + \ln\left(\frac{\vec{p}_3^{\,2}}{\mu^2}\right)\right] - \frac{6}{\varepsilon} \right\}$$

Rapidity divergence

Cancellation of the remaining $1/\epsilon$ divergence

Convolution

$$(\Phi'^{\mu}_{V2} \otimes \mathbf{UU}) = \int d^d\vec{p}_1 d^d\vec{p}_2 d^d\vec{p}_3 \left\{ 4\ln\left(\frac{x\bar{x}}{e^{2\eta}}\right)\left[\frac{1}{\varepsilon} + \ln\left(\frac{\vec{p}_3^{\,2}}{\mu^2}\right)\right] - \frac{6}{\varepsilon} \right\}$$
$$\times \quad \delta(\vec{p}_{q1} + \vec{p}_{\bar{q}2} - \vec{p}_3)\left[\tilde{\mathbf{U}}_{13} + \tilde{\mathbf{U}}_{32} - \tilde{\mathbf{U}}_{12} - \tilde{\mathbf{U}}_{13}\tilde{\mathbf{U}}_{32}\right]\Phi^{\mu}_0(\vec{p}_1, \vec{p}_2)$$

Rq :

- $\Phi_0(\vec{p}_1, \vec{p}_2)$ only depends on one of the t-channel momenta.
- The double-dipole operators cancels when $\vec{z}_3 = \vec{z}_1$ or $\vec{z}_3 = \vec{z}_2$.

This permits one to show that the convolution cancels the remaining $\frac{1}{\varepsilon}$ divergence.

Then $\tilde{\mathbf{U}}^{\alpha}_{12}\Phi_0 + \Phi_{V2}$ is finite

Divergences

- Rapidity divergence
- UV divergence $\vec{p}_g^{\,2} \to +\infty$ — $\Phi_{V1}\Phi_0^* + \Phi_0\Phi_{V1}^*$
- Soft divergence $p_g \to 0$ — $\Phi_{V1}\Phi_0^* + \Phi_0\Phi_{V1}^*$, $\Phi_{R1}\Phi_{R1}^*$
- Collinear divergence $p_g \propto p_q$ or $p_{\bar{q}}$ — $\Phi_{R1}\Phi_{R1}^*$
- Soft and collinear divergence $p_g = \frac{p_g^+}{p_q^+} p_q$ or $\frac{p_g^+}{p_{\bar{q}}^+} p_{\bar{q}}$, $p_g^+ \to 0$ — $\Phi_{R1}\Phi_{R1}^*$

Contructing a finite cross section

Exclusive diffractive production of a forward dijet

From partons to jets

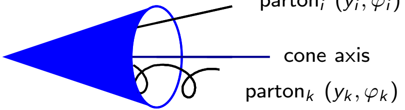
Soft and collinear divergence

Jet cone algorithm

We define a cone width for each pair of particles with momenta p_i and p_k, rapidity difference ΔY_{ik} and relative azimuthal angle $\Delta\varphi_{ik}$

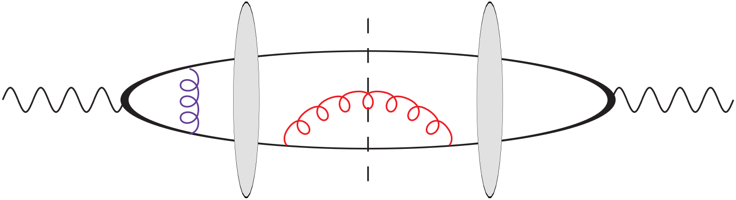
$$(\Delta Y_{ik})^2 + (\Delta\varphi_{ik})^2 = R_{ik}^2$$

If $R_{ik}^2 < R^2$, then the two particles together define a single jet of momentum $p_i + p_k$.



Applying this in the small R^2 limit cancels our soft and collinear divergence.

Remaining divergence



- UV divergence $\vec{p}_g^{\,2} \to +\infty$

$$\Phi_{V1}\Phi_0^* + \Phi_0\Phi_{V1}^*$$

- Soft divergence $p_g \to 0$

$$\Phi_{V1}\Phi_0^* + \Phi_0\Phi_{V1}^*, \Phi_{R1}\Phi_{R1}^*$$

- Collinear divergence $p_g \propto p_q$ or $p_{\bar{q}}$

$$\Phi_{R1}\Phi_{R1}^*$$

Remaining divergence

Soft real emission

$$(\Phi_{R1}\Phi_{R1}^*)_{soft} \propto (\Phi_0\Phi_0^*)\int_{\text{outside the cones}} \left|\frac{p_q^\mu}{(p_q.p_g)} - \frac{p_{\bar{q}}^\mu}{(p_{\bar{q}}.p_g)}\right|^2 \frac{dp_g^+}{p_g^+}\frac{d^d p_g}{(2\pi)^d}$$

Collinear real emission

$$(\Phi_{R1}\Phi_{R1}^*)_{col} \propto (\Phi_0\Phi_0^*)\,(\mathcal{N}_q + \mathcal{N}_{\bar{q}})$$

Where $\mathcal{N}$ is the number of jets in the quark or the antiquark

$$\mathcal{N}_k = \frac{(4\pi)^{\frac{d}{2}}}{\Gamma(2-\frac{d}{2})}\int_{\alpha p_\gamma^+}^{p_{jet}^+} \frac{dp_g^+ dp_k^+}{2p_g^+ 2p_k^+}\int_{\text{in cone k}} \frac{d^d\vec{p}_g d^d\vec{p}_k}{(2\pi)^d\,\mu^{d-2}} \frac{\mathrm{Tr}\left(\hat{p}_k\gamma^\mu\hat{p}_{jet}\gamma^\nu\right) d_{\mu\nu}(p_g)}{2p_{jet}^+\left(p_k^- + p_g^- - p_{jet}^-\right)^2}$$

Those two contributions cancel exactly the virtual divergences (both UV and soft)

Cancellation of divergences

Total divergence

$$(d\sigma_1)_{div} = \alpha_s \frac{\Gamma(1-\varepsilon)}{(4\pi)^{1+\varepsilon}} \left(\frac{N_c^2-1}{2N_c}\right) (S_V + S_V^* + S_R + \mathcal{N}_{jet1} + \mathcal{N}_{jet2}) d\sigma_0$$

Virtual contribution

$$\begin{aligned} S_V &= \left[2\ln\left(\frac{x_j x_{\bar{j}}}{\alpha^2}\right) - 3\right]\left[\ln\left(\frac{x_j x_{\bar{j}} \mu^2}{(x_j \vec{p}_{\bar{j}} - x_{\bar{j}} \vec{p}_j)^2}\right) - \frac{1}{\epsilon}\right] \\ &+ 2i\pi \ln\left(\frac{x_j x_{\bar{j}}}{\alpha^2}\right) + \ln^2\left(\frac{x_j x_{\bar{j}}}{\alpha^2}\right) - \frac{\pi^2}{3} + 6 \end{aligned}$$

Real contribution

$$\begin{aligned} S_R + \mathcal{N}_{jet1} + \mathcal{N}_{jet2} &= 2\left[\ln\left(\frac{(x_{\bar{j}}\vec{p}_j - x_j \vec{p}_{\bar{j}})^4}{x_{\bar{j}}^2 x_j^2 R^4 \vec{p}_{\bar{j}}^{\,2} \vec{p}_j^{\,2}}\right) \ln\left(\frac{4E^2}{x_{\bar{j}} x_j (p_\gamma^+)^2}\right)\right. \\ &+ 2\ln\left(\frac{x_{\bar{j}} x_j}{\alpha^2}\right)\left(\frac{1}{\epsilon} - \ln\left(\frac{x_{\bar{j}} x_j \mu^2}{(x_{\bar{j}}\vec{p}_j - x_j \vec{p}_{\bar{j}})^2}\right)\right) - \ln^2\left(\frac{x_{\bar{j}} x_j}{\alpha^2}\right) \\ &+ \left.\frac{3}{2}\ln\left(\frac{16\mu^4}{R^4 \vec{p}_j^{\,2} \vec{p}_{\bar{j}}^{\,2}}\right) - \ln\left(\frac{x_j}{x_{\bar{j}}}\right) \ln\left(\frac{x_j \vec{p}_{\bar{j}}^{\,2}}{x_{\bar{j}} \vec{p}_j^{\,2}}\right) - \frac{3}{\epsilon} - \frac{2\pi^2}{3} + 7\right] \end{aligned}$$

Cancellation of divergences

Total divergence

$$div = S_V + S_V^* + S_R + \mathcal{N}_{jet1} + \mathcal{N}_{jet2}$$

$$= 4\left[\frac{1}{2}\ln\left(\frac{(x_{\bar{j}}\vec{p}_j - x_j\vec{p}_{\bar{j}})^4}{x_{\bar{j}}^2 x_j^2 R^4 \vec{p}_{\bar{j}}^{\,2}\vec{p}_j^{\,2}}\right)\left(\ln\left(\frac{4E^2}{x_{\bar{j}}x_j(p_\gamma^+)^2}\right)+\frac{3}{2}\right)\right.$$

$$\left. + \ln(8) - \frac{1}{2}\ln\left(\frac{x_j}{x_{\bar{j}}}\right)\ln\left(\frac{x_j\vec{p}_{\bar{j}}^{\,2}}{x_{\bar{j}}\vec{p}_j^{\,2}}\right) + \frac{13-\pi^2}{2}\right]$$

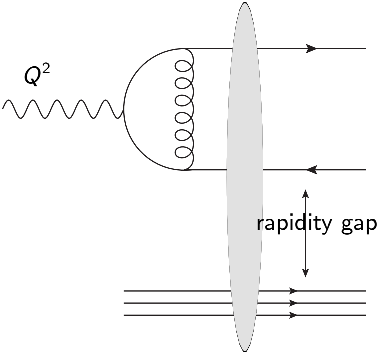
Our cross section is thus finite

Conclusions

- We computed the amplitude for the production of an open $q\bar{q}$ pair in DDIS
- Using this result, we constructed a finite expression for the cross section for the exclusive production of dijets
- The remaining part can be expressed as a finite integral, so it can be used straightforwardly for phenomenology
- Any model can be used for the matrix elements of the Wilson line operators (GBW, AAMQS if the target is a proton or an ion)
- The target can also be perturbative, involving any impact factor...

General amplitude

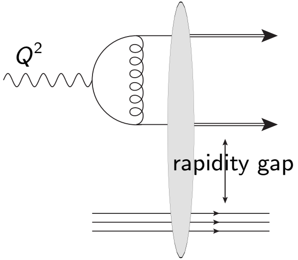
- Most general kinematics
- The hard scale can be Q^2, t, M_X^2 or m^2 in the (future) massive extension of our computation.
- The target can be either a proton or an ion, or another impact factor.
- One can study ultraperipheral collision by tagging the particle which emitted the photon, in the limit $Q^2 \to 0$.



The general amplitude

Phenomenological applications : exclusive dijet production at NLO accuracy

- HERA data for exclusive dijet production in diffractive DIS can be fitted with our results
- We can also give predictions for the same process in a future electron-ion or electron-proton collider (EIC, LHeC...)
- For $Q^2 = 0$ we can give predictions for ultraperipheral collisions at the LHC



Amplitude for diffractive dijet production

Phenomenological applications : exclusive trijet production at LO accuracy

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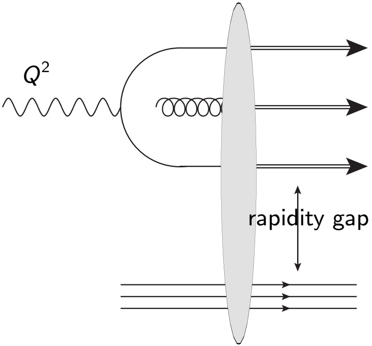
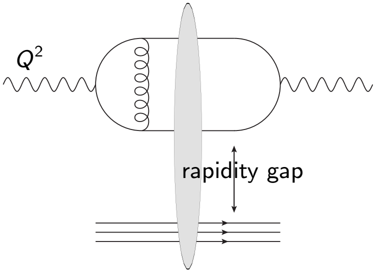


Amplitude for diffractive trijet production

[Ayala,Hentschinski,Jalilian-Marian,Tejeda-Yeomans]

NLO DIS

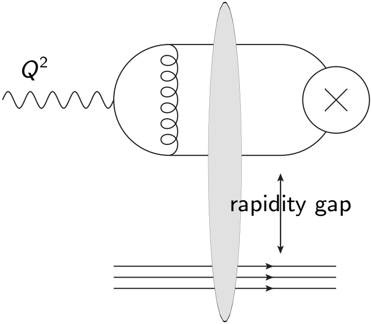
- One can adapt our general amplitude to obtain the NLO expression for (non diffractive) DIS
- Such a result would have to be compared with Balitsky and Chirilli's result, and with an ingoing study by Beuf.



NLO DIS cross section

Diffractive production of a ρ meson

- By forcing the quark and antiquark to be collinear and using the right Fierz projection, one can study ρ production
- Generalization of previous results of Ivanov, Kotsky, Papa to the non-forward case
- This would give a better understanding of the formal transition between BFKL and BK

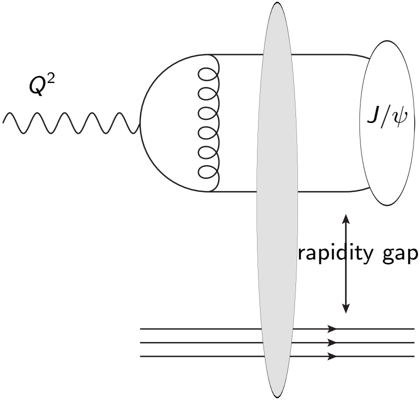


Amplitude for diffractive ρ production

$$\Phi_{BK} \otimes \mathcal{K}_{BK} \otimes \Phi'_{BK} = (\Phi_{BFKL} \otimes \mathcal{O})(\mathcal{O}^{-1} \otimes \mathcal{K}_{BFKL}\mathcal{O})(\mathcal{O}^{-1} \otimes \Phi'_{BFKL})$$

With an added mass

- Open charm production (straightforward)
- Heavy quarkonium production (in the Color Evaporation formalism)



Amplitude for diffractive production of a charmonium

Conclusion

- We provided the full computation of the impact factor for the exclusive diffractive production of a forward dijet with NLO accuracy in the shockwave approach
- It leads to an enormous number of possible phenomenological applications to test QCD in its Regge limit and towards saturation in past, present and future *ep*, *eA*, *pp* and *pA* colliders
- Several theoretical extensions could be obtained with slight modifications to our result