

High energy resummation in direct photon production

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Outline

The two-scale problem

High energy resummation

Prompt-photon production

The off-shell impact factor

Conclusions and outlook

A single-scale problem

- ▶ Collinear factorization

$$\sigma(x, Q^2) = C(x, Q^2/\mu^2, \alpha_s(\mu^2)) \otimes F(x, \mu^2)$$

$$x \equiv \frac{Q^2}{S}$$

- ▶ Resummation of collinear logs $\left(\alpha_s \log \frac{Q^2}{\mu^2}\right)^n$ by a renormalization group approach
 \implies DGLAP PDFs evolution

Accurate predictions in the region

$$\Lambda^2 \ll Q^2 \sim S$$

A two-scale problem

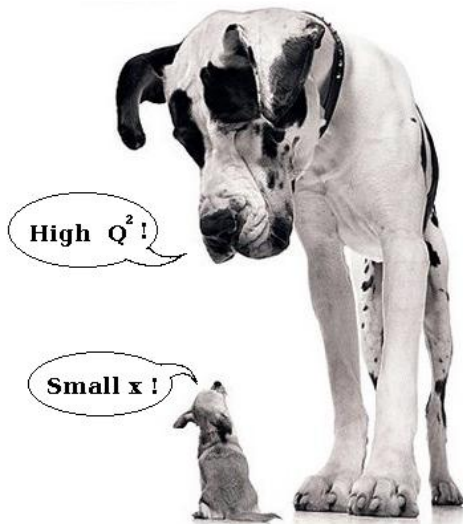
In the TeV energy range
(@LHC) hadronic collisions
enter a two scale regime:

$$\Lambda^2 \ll Q^2 \ll S$$

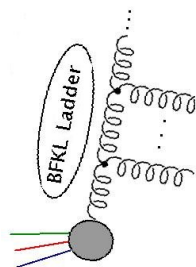
where QCD perturbation
theory is affected by large

$$(\alpha_s \log x)^n$$

RESUMMATION!!



Ladders, Logs and k_t -factorization



The **small- x contributions** to the cross section stem from **strong ordered** gluon emissions in the t -channel (BFKL ladders).

k_t -factorization theorem^a

$$\sigma(x, Q^2) = \int_0^{Q^2} \frac{d\mathbf{k}^2}{\mathbf{k}^2} \int_x^1 \frac{dz}{z} \hat{\sigma}(\mathbf{k}^2/Q^2, x/z) \mathcal{F}(\mathbf{k}^2, z)$$

provides a simple **recipe to resum the LL x** enhancement of the coefficient function in terms of the partonic cross section $\hat{\sigma}$ with **off-shell incoming gluons**.

^aS. Catani, M. Ciafaloni, F. Hautmann (1991)

Conjugate variables

We introduce the adimensional variables

$$\xi = \frac{k^2}{Q^2}, \quad x = \frac{Q^2}{S}$$

and the impact factor in Mellin space

$$h(N, M) = M \int_0^1 dx x^{N-1} \int_0^\infty d\xi \xi^{M-1} \hat{\sigma}(\xi, x)$$

x vs N
 ξ vs M

High energy in N space:

$$\log^k x \rightarrow \frac{1}{N^{k-1}}$$

High energy resummation HOWTO

The high energy resummation at LLx can be performed by using the following

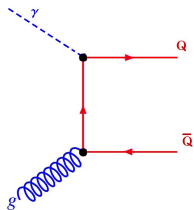
Recipe



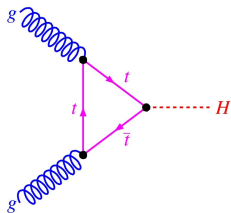
1. compute the cross section at leading order with **off-shell** incoming gluons:
 - ▶ Sudakov parametrization: $k^\mu = z_i p_i^\mu + \mathbf{k}^\mu \rightarrow k^2 = -\mathbf{k}^2$
 - ▶ Polarization sum (eikonal) $\sum_\lambda \epsilon_\mu^\lambda(k) \epsilon_\nu^\lambda(k) = \frac{k_\mu k_\nu}{k^2}$
2. perform the **Mellin** integrations to obtain $h(N, M)$
3. identify M as the sum of the leading singularities of the small- x resummed anomalous dimension:

$$\sigma(N, \dots) = h(N, M = \gamma_s \left(\frac{\alpha_s}{N} \right)) (1 + \mathcal{O}(\alpha_s))$$

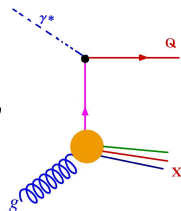
Applications



1. **Heavy flavour** photo- lepto- and hadro- production
S. Catani, M. Ciafaloni, F. Hautmann (1991)

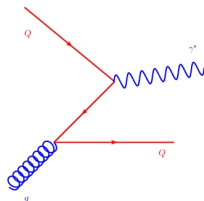


2. **DIS**
S. Catani, F. Hautmann (1994),
G. Altarelli *et Al.* (2008)



3. **Higgs production**
S. Marzani *et Al.* (2009)

4. **Drell-Yan**
S. Marzani, R. D. Ball (2009)



Prompt photon production

► Motivations

- PP is the most important **reducible background** for the $H \rightarrow \gamma\gamma$ signal.
- an useful tool to probe the **gluon density**.
- very low values of x ! ($p_{\perp}^{\gamma} \gtrsim 20 \text{ Gev} \rightarrow x \gtrsim 10^{-5}$)

► Known results

- **NLO cross section** ($\mathcal{O}(\alpha\alpha_s^2)$)
P. Aurenche *et Al.* (1988)
R. K. Ellis, D. A. Ross (1990)
L. E. Gordon, W. Vogelsang (1993)
- **NLL Sudakov resummation**
S. Catani *et Al.* (1999)

Direct-photon production

$$H_1(P_1) + H_2(P_2) \rightarrow \gamma(q) + X$$

Collinear Factorization

$$\sigma^\gamma(N) = \sum_{a,b} F_{a/H_1}(N) F_{b/H_2}(N) \left(\overset{\text{direct}}{C_{ab}^\gamma(N)} + \sum_c \overset{\text{fragmentation}}{D_{c/\gamma}(N)} C_{ab}^c(N) \right)$$

Direct component at LO

$$q(\bar{q})g \rightarrow \gamma q(\bar{q})$$

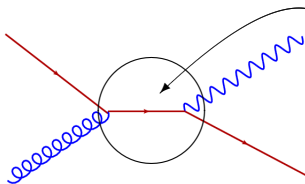
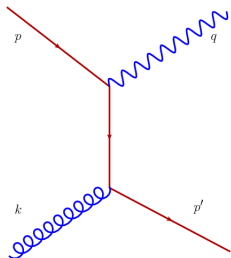
$$q\bar{q} \rightarrow \gamma g$$

$$\sigma^\gamma(N) = \int_0^1 dx x^{N-1} \mathbf{q}^3 \frac{d\sigma(x)}{d\mathbf{q}}$$

\mathbf{q} = transverse momentum of γ

Scaling variable $\rightarrow x = \frac{4\mathbf{q}^2}{S}$

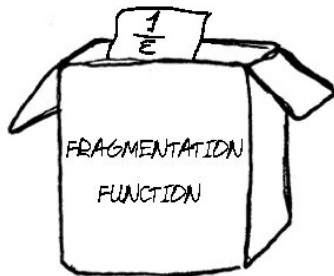
Off-shell amplitude and collinear divergence



With an off-shell incoming gluon γ and q can be collinear!

\Rightarrow Divergence!

- ▶ Phase space integrations in $4+2\epsilon$ dimensions
- ▶ The final state collinear divergence must be absorbed in the **fragmentation function** definition.



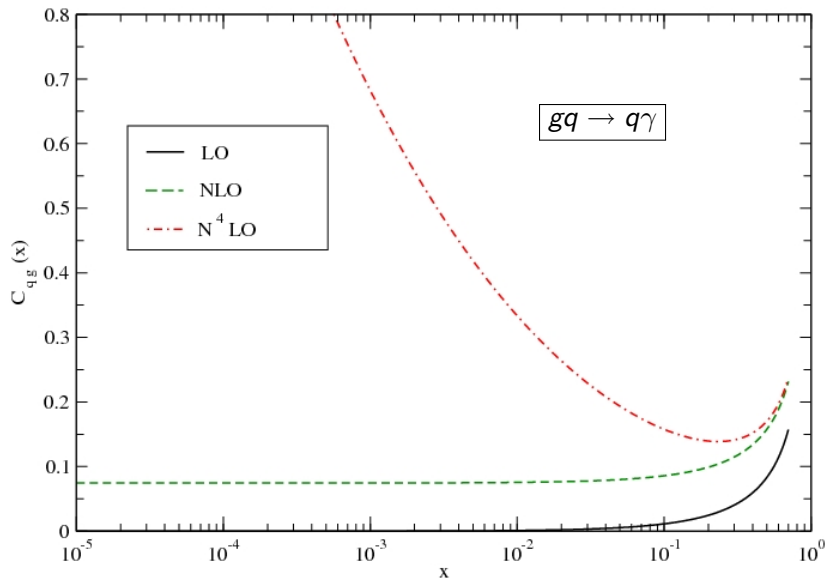
Impact factor

$$h(N=0, M) = \frac{\alpha\alpha_s\pi}{C_A} \left\{ \frac{(7-7M+2M^2)}{(M-1)(M-2)(2M-3)} (\pi \cot(M\pi) + 2H_{M-2} + \frac{2}{M-1}) + \frac{1}{2-M} \right\}$$

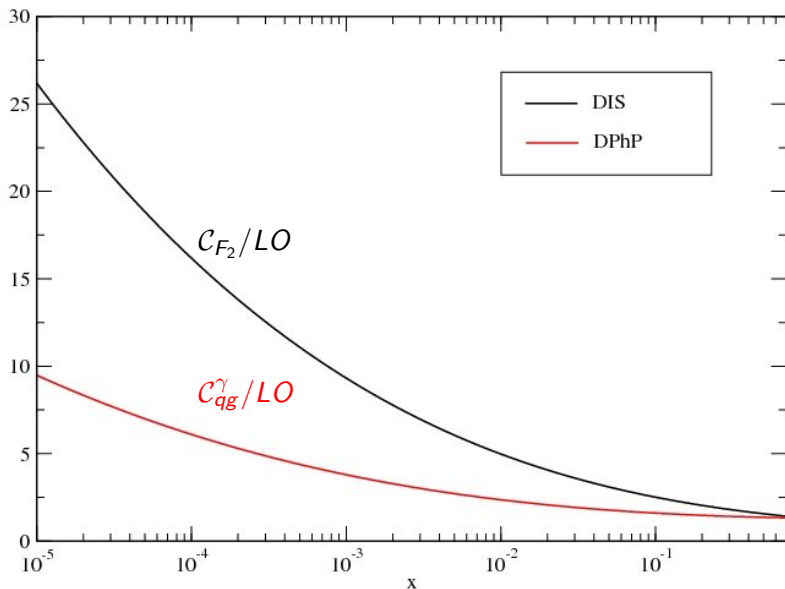
where **poles in $N=0$** are produced by the identification:

$$M = \gamma_s \left(\frac{\alpha_s}{N} \right) = \frac{\alpha_s C_A}{\pi N} + \mathcal{O} \left(\frac{\alpha_s}{N} \right)^4$$

Coefficient function



Direct photon and DIS



Conclusions and outlook

- ▶ Direct photon production at high energy: impact factor and coefficient function.
- ▶ Fragmentation component?
- ▶ Resummed **coefficient functions** + resummed **evolution**
- ▶ Phenomenology!

