Glauber胶子的因子化与超级领头对数重求和

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Collinear factorization for inclusive observables

For inclusive observables, sensitive only to a single high-energy scale *Q*, we have

$$\sigma = \sum_{a,b} \int_0^1 dx_1 dx_2\, \hat{\sigma}_{ab}(Q, x_1, x_2, \mu_f)\, f_a(x_1, \mu_f)\, f_b(x_2, \mu_f) + \mathcal{O}(\Lambda_{\rm QCD}/Q)$$

partonic cross sections: perturbation theory

parton distribution functions (PDFs): nonperturbative

power corrections nonperturbative

The right way to look at this formula is effective theory

$$\sigma = \sum_{a,b} \int_0^1 dx_1 dx_2\, C_{ab}(Q, x_1, x_2, \mu) \langle P(p_1)|O_a(x_1)|P(p_1)\rangle \, \langle P(p_2)|O_b(x_2)|P(p_2)\rangle + \mathcal{O}(\Lambda_{\rm QCD}/Q)$$

Wilson coefficient:
matching at $\mu \approx Q$
perturbation theory

RG-evolution

low-energy matrix elements
nonperturbative

power suppressed operators

The matching coefficient C_{ab} is independent of external states and insensitive to physics below the matching scale μ.

Can use quark and gluon states to perform the matching.

- **Trivial matrix elements**

$$\langle q_{a'}(x'p)|O_a(x)|q_{a'}(x'\,p)\rangle = \delta_{aa'}\,\delta(x'-x)$$

- **Wilson coefficients are partonic cross section**

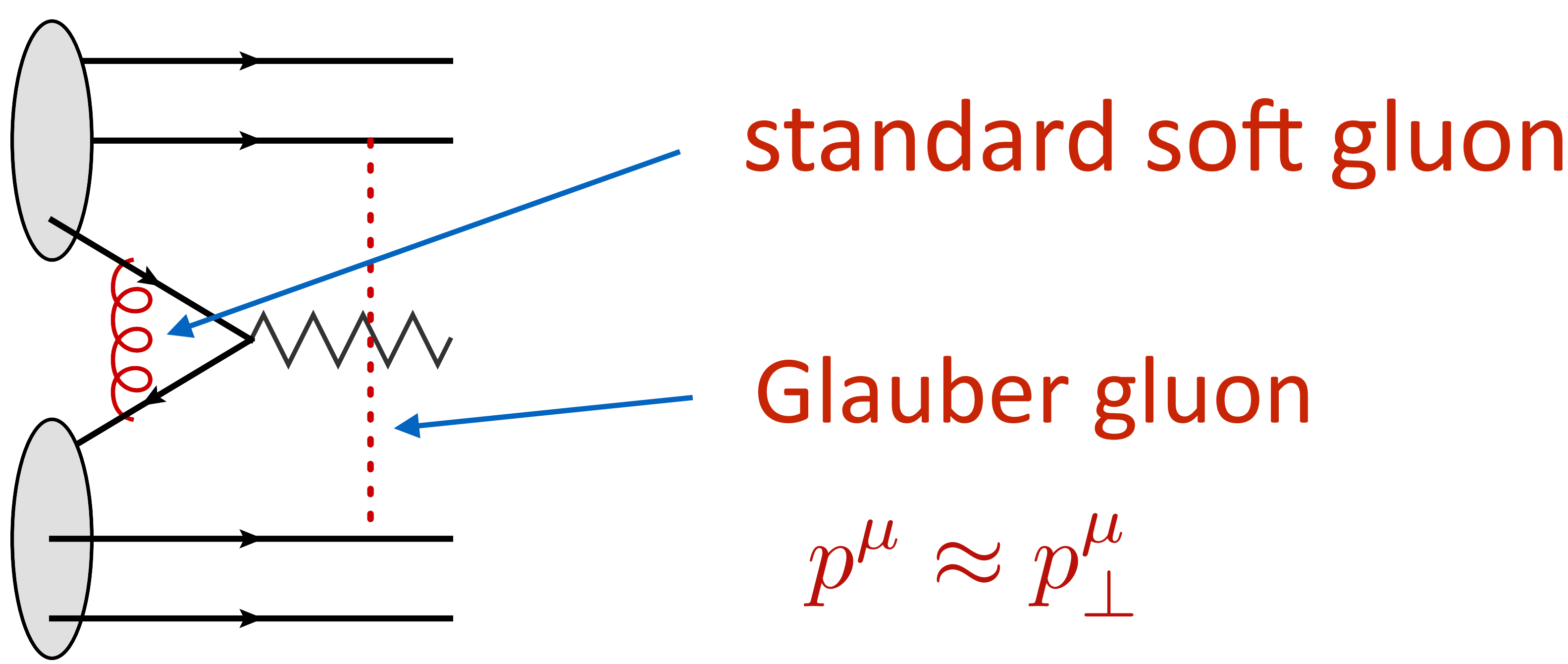
$$C_{ab}(Q,x_1,x_2) = \hat{\sigma}_{ab}(Q,x_1,x_2)$$

- **Bare Wilson coefficients have divergencies. Renormalization induces dependence on μ.**

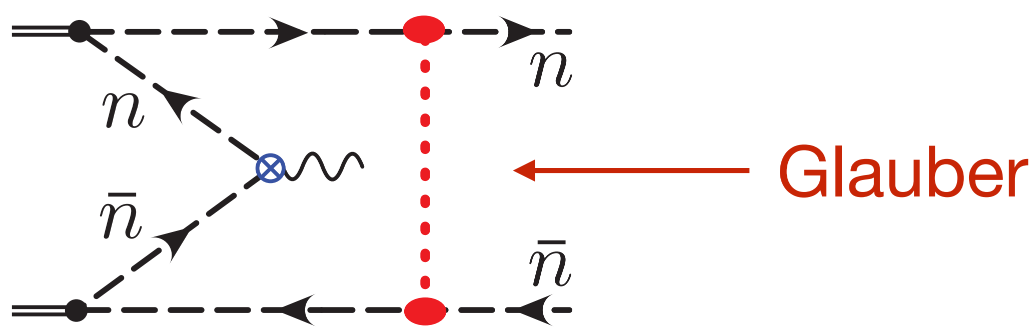
Quite nontrivial that the low-energy matrix element factorizes into a product

$$\langle P(p_1)|O_a(x_1)|P(p_1)\rangle \, \langle P(p_2)|O_b(x_2)|P(p_2)\rangle$$

One should be worried about long-distance interactions mediated by soft gluons



All proton collisions include forward component (proton remnants)



Absence of factorization-violation due to Glauber gluons is important element of factorization proof for Drell-Yan process. Bodwin '85; Collins, Soper, Sterman '85 '88 …

e.g. TMD factorization is violated in di-jet/di-hadron production

Collins, Qiu `07; Collins `07, Vogelsang, Yuan `07; Rogers, Mulders `10, …

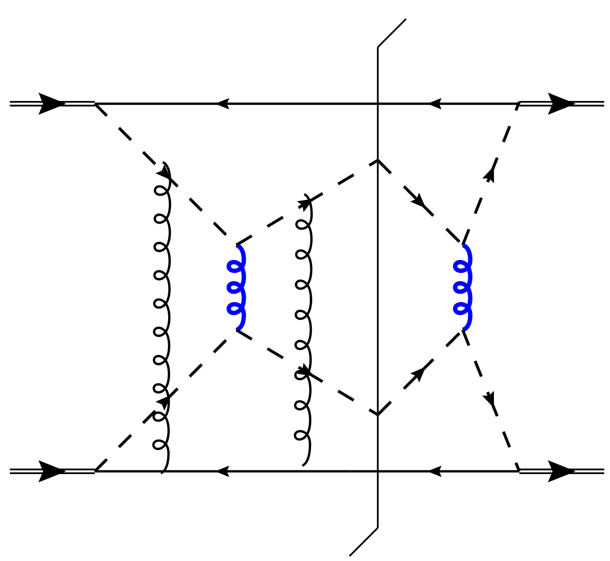
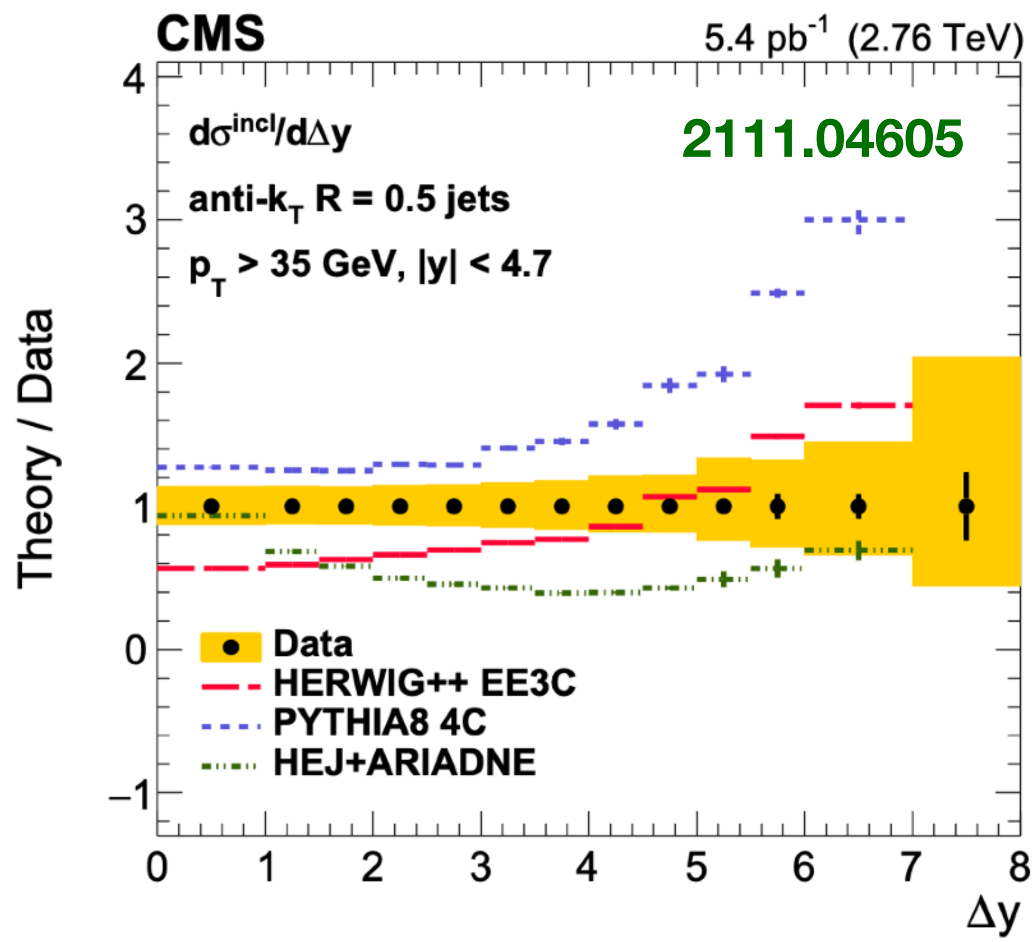


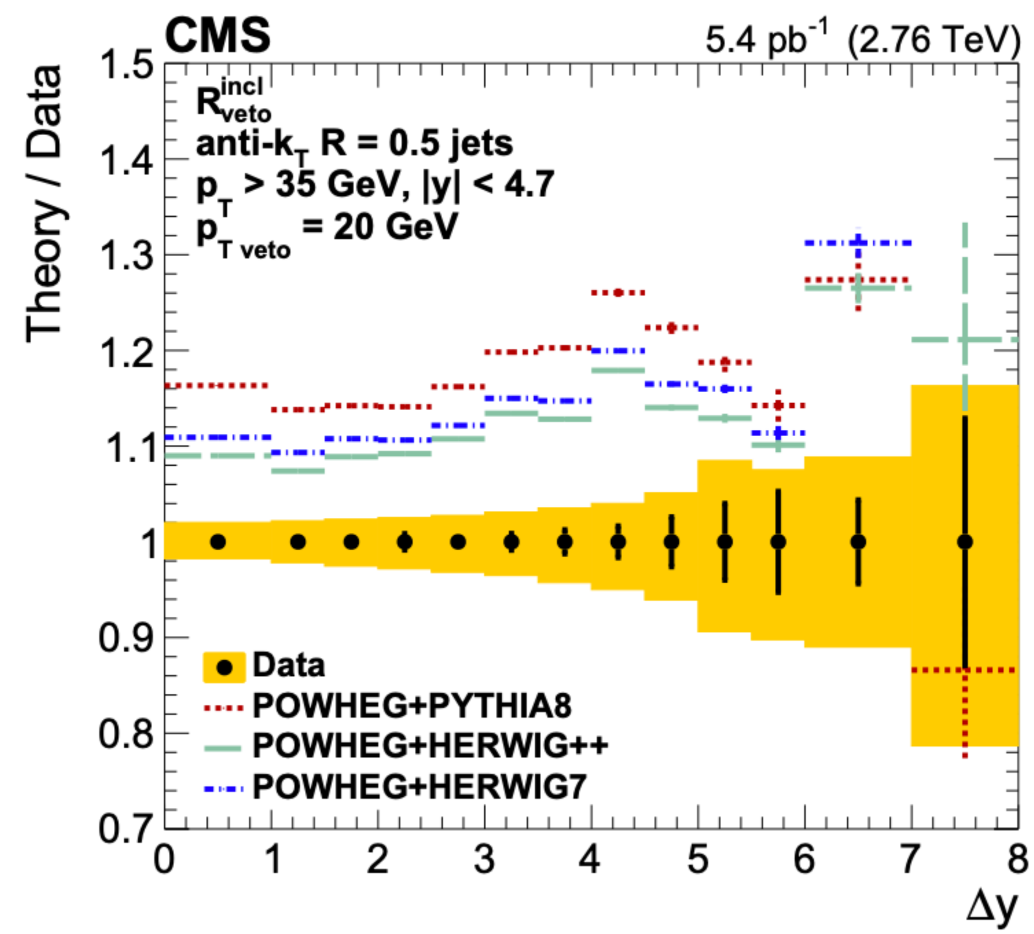
FIG. 8 (color online). The exchange of two extra gluons, as in this graph, will tend to give nonfactorization in unpolarized cross sections.

We remark that, because the TMD factorization breaking effects are due to the Glauber region where all components of gluon momentum are small, the interactions responsible for breaking TMD factorization are associated with large distance scales.

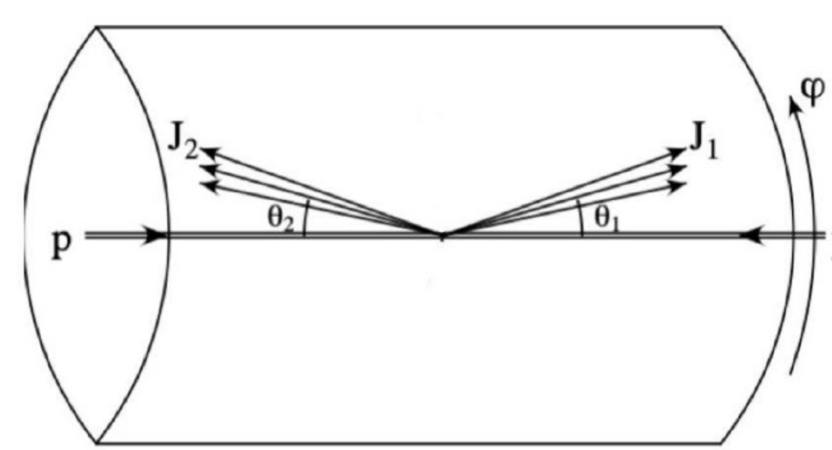
Rogers, Mulders `10

Dijet events with large rapidity gap at the LHC

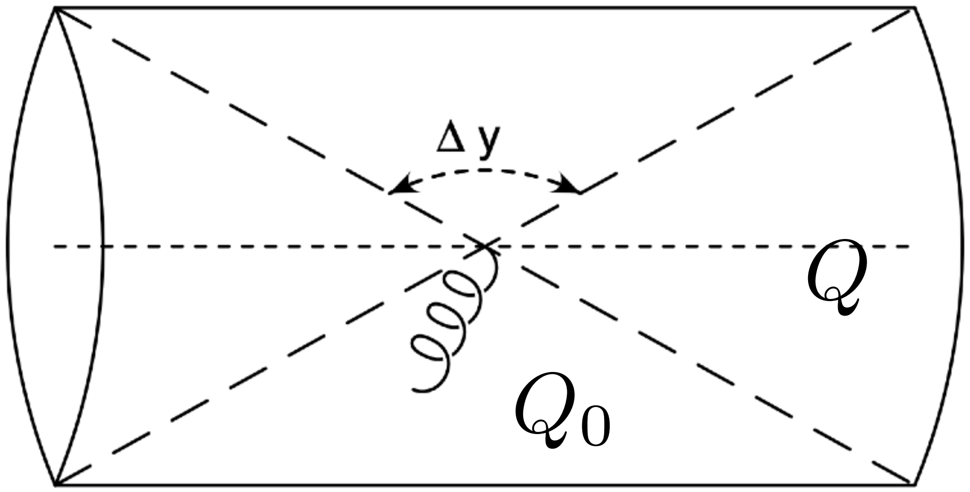




None of the DGLAP-based Monte Carlo generators using LO or NLO calculations can provide a complete description of all measured cross sections and their ratios



Central jet veto at the LHC

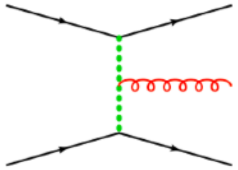


leading logs:

$$e^+e^-, ep: \quad \alpha_s^n \ln^n\left(\frac{Q}{Q_0}\right)$$

$$pp: \qquad \cdots \qquad + \alpha_s^3 (i\pi)^2 \ln^3\left(\frac{Q}{Q_0}\right) \times \alpha_s^n \ln^{2n}\left(\frac{Q}{Q_0}\right)$$

- **Such events was originally suggested on the basis of color flow considerations in QCD Bjorken ’93**
- **Global Logs resummation is first done by Oderda & Sterman ’98**
- **Forshaw, Kyrieleis, Seymour ’06 have analyzed the effect of Glauber phases in non-global observables directly in QCD**
  - **Collinear logarithms starting at 4 loops: Super-leading logs**



- **Even 15 years after this effect was discovered, leading order resummation is unknown, process dependence is unknown,**
  - **At forth order there are 1,746,272 diagrams !!!**
- **We apply renormalization-group approach and obtain the all-order results of leading SLLs Becher, Neubert, DYS ’21 PRL**

All-order results of leading Super-Leading Logs

(Becher, Neubert, DYS '21 PRL + '22 in progress)

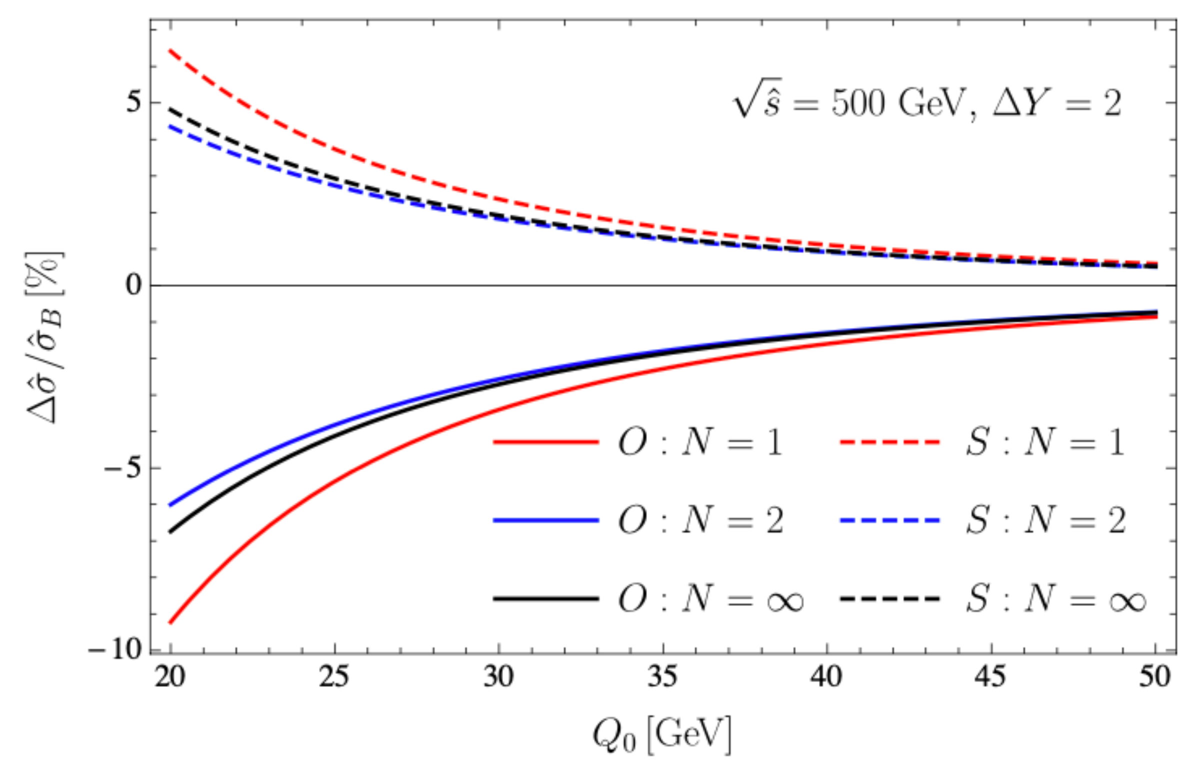
All-order structure: Kampe de Feriet function (a two-variable generalization of the generalized hypergeometric series, the general sextic equation can be solved in terms of it)

$$\Sigma(v,w) = \sum_{m=0}^{\infty}\sum_{r=0}^{\infty} \frac{(1)_{m+r}(1)_m\left(\frac{1}{2}\right)_r}{(2)_{m+r}\left(\frac{5}{2}\right)_{m+r}} \frac{(-w)^m(-vw)^r}{m!\,r!}$$

$$= {}^{1+1}F_{2+0}\left(\begin{matrix} 1 : 1, \frac{1}{2} ; \\ 2, \frac{5}{2} : \quad ; \end{matrix}, -w, -vw\right)$$

$$w = \frac{N_c\alpha_s(\bar\mu)}{\pi}\ln^2\left(\frac{\mu_h}{\mu_s}\right)$$

Numerical results



Red: Four loop **Blue: Five loop** **Black: all order**

Sudakov suppression of the superleading logarithms is weaker than the one present for global observables

Global logs ⟶ $e^{-\omega}$

Superleading logs $\xrightarrow{\omega \to \infty}$ $\frac{1}{\omega}$

Summary and outlook

- **Factorization is at the heart of any quantitative prediction using pQCD**
- **We investigate naive factorization violation effects using the gap fraction of QCD jets at hadron colliders**

$$\sigma_{2\to M}(Q_0) = \int dx_1 \int dx_2 \sum_{m=2+M}^{\infty} \langle \boldsymbol{\mathcal{H}}_m(\{\underline{n}\}, x_1, x_2, s, \mu) \otimes \boldsymbol{\mathcal{W}}_m(\{\underline{n}\}, Q_0, x_1, x_2, \mu) \rangle$$

- **The results are obtained by solving renormalization group equations order-by-order**

$${}^{1+1}F_{2+0}\left(\begin{matrix} 1 : 1, \frac{1}{2} ; \\ 2, \frac{5}{2} : \quad ; \end{matrix}, -w, -vw \right)$$

- **Subleading superleading logs?**
- **Low energy theory from Glauber gluons ?**
- **Non-perturbative corrections?**

Thank you