

Hard diffraction

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Overview

- What is hard diffraction:
 - Diffractive DIS, hadron-hadron
- Old models:
 - pomeron model, Soft Color Interactions

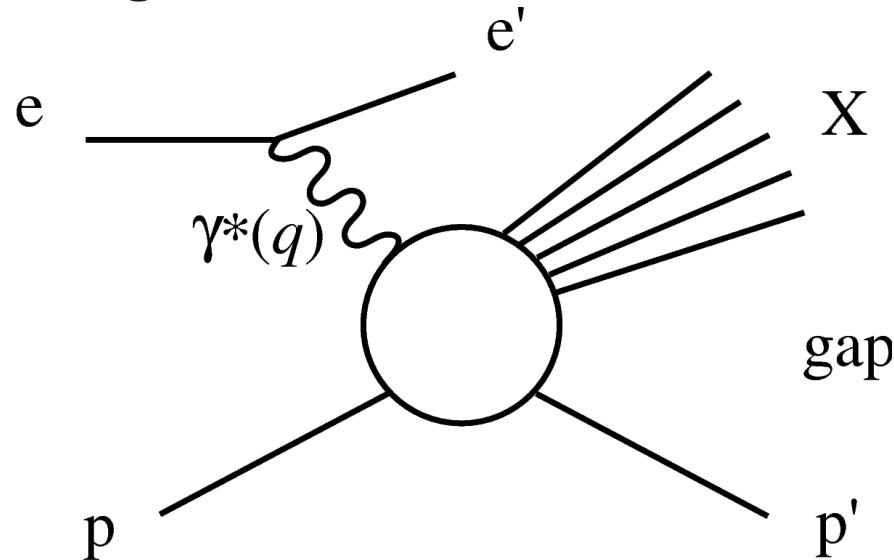


- Our approach:
 - Diffraction from rescattering of final state partons

Based on R. Pasechnik, RE, G. Ingelman, [arXiv:1004.2912](#) and [arXiv:1005.3399](#)

What is hard diffraction?

In 10–20% of DIS events, the proton escapes intact, keeping a large fraction of its initial momentum



— this leads to a **large rapidity gap** between the proton and the produced particles (the X-system)

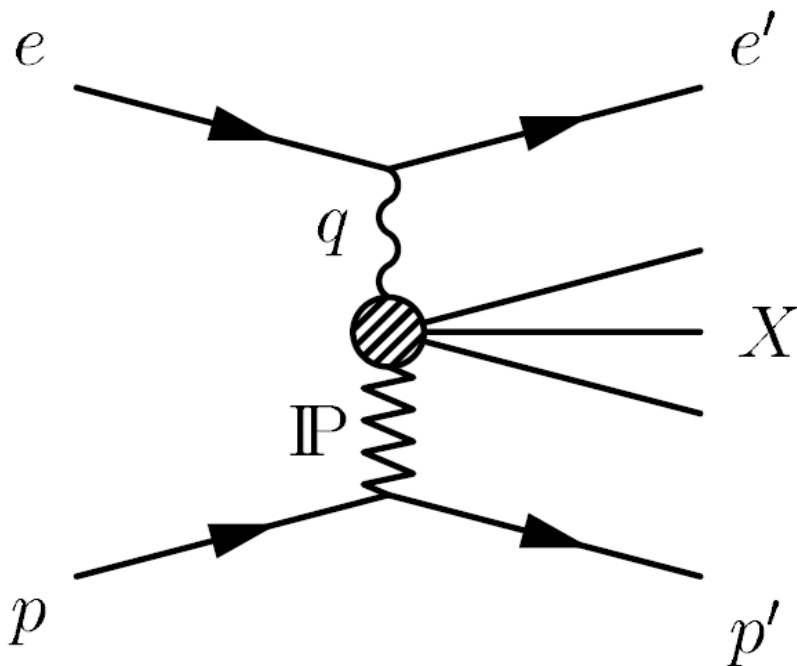
The net t -channel exchange must be **color singlet**

— a ***pomeron?***

The pomeron formalism

Assuming DIS on a hadronic “pomeron” radiated from the proton, the *diffractive structure function* is Regge factorized

$$\frac{d\sigma}{dx dQ^2 dx_{\mathbb{P}} dt} = \frac{4\pi\alpha^2}{\beta Q^4} \left(1 - y + \frac{y^2}{2}\right) F_2^{D(4)}$$



$$F_2^{D(4)}(x, Q^2, x_{\mathbb{P}}, t) = \underbrace{f(x_{\mathbb{P}}, t)}_{\mathbb{P} \text{ flux}} \underbrace{F_2^{\mathbb{P}}(\beta, Q^2)}_{\mathbb{P} \text{ structure}}$$

Taken from
Regge theory

Fitted

The pomeron formalism

The pomeron gives a good description of HERA data

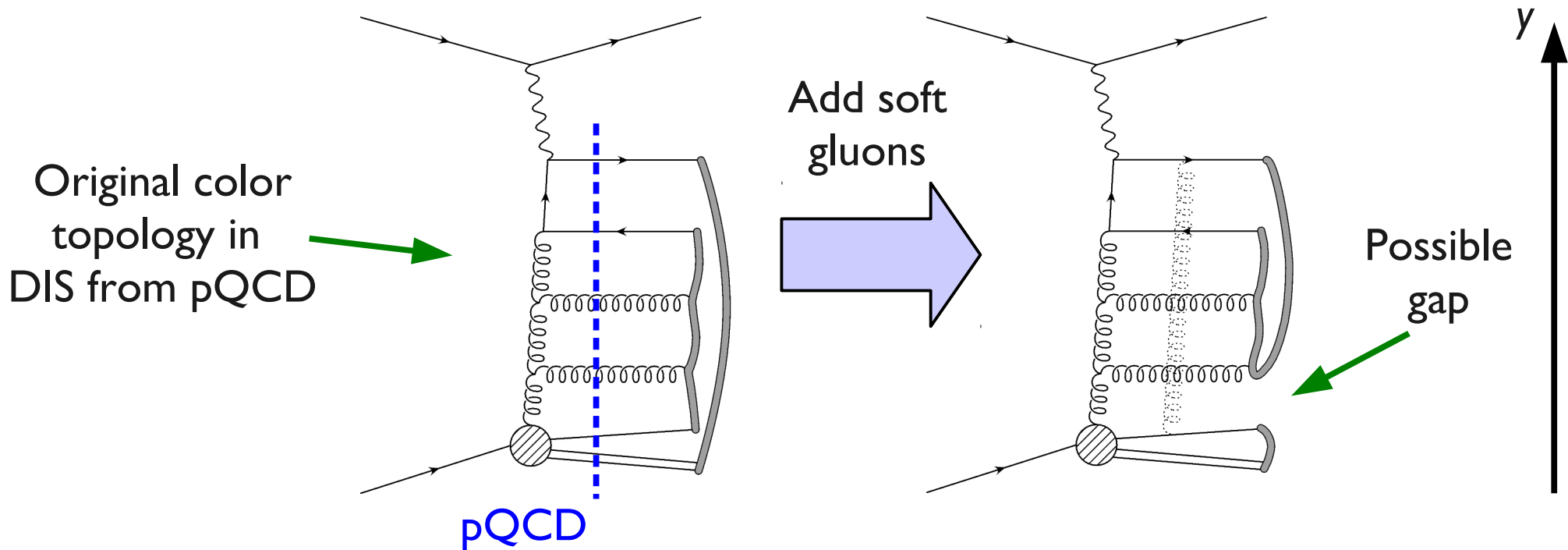
But the fit (pomeron flux and structure) **fails completely** when applied to Tevatron data!

- QCD factorization doesn't hold for diffractive pp!
- Regge factorization questionable

Also: this model doesn't tell us what's going on in diffraction from “real” QCD

Soft Color Interaction model (SCI)

- Phenomenological MC model by Edin, Ingelman, Rathsman
- Soft color exchanges in final state “after” hard process
- Changes color topology



Soft Color Interaction model (SCI)

SCI model has been compared to data with good agreement:

- diffractive DIS
[Edin, Ingelman, Rathsman, hep-ph/9508386, hep-ph/9602227, hep-ph/9605281, hep-ph/9912539]
- hard diffraction in hadron–hadron coll. at the Tevatron
[RE, Ingelman, Tîmneanu; hep-ph/0106246, hep-ph/0210408]

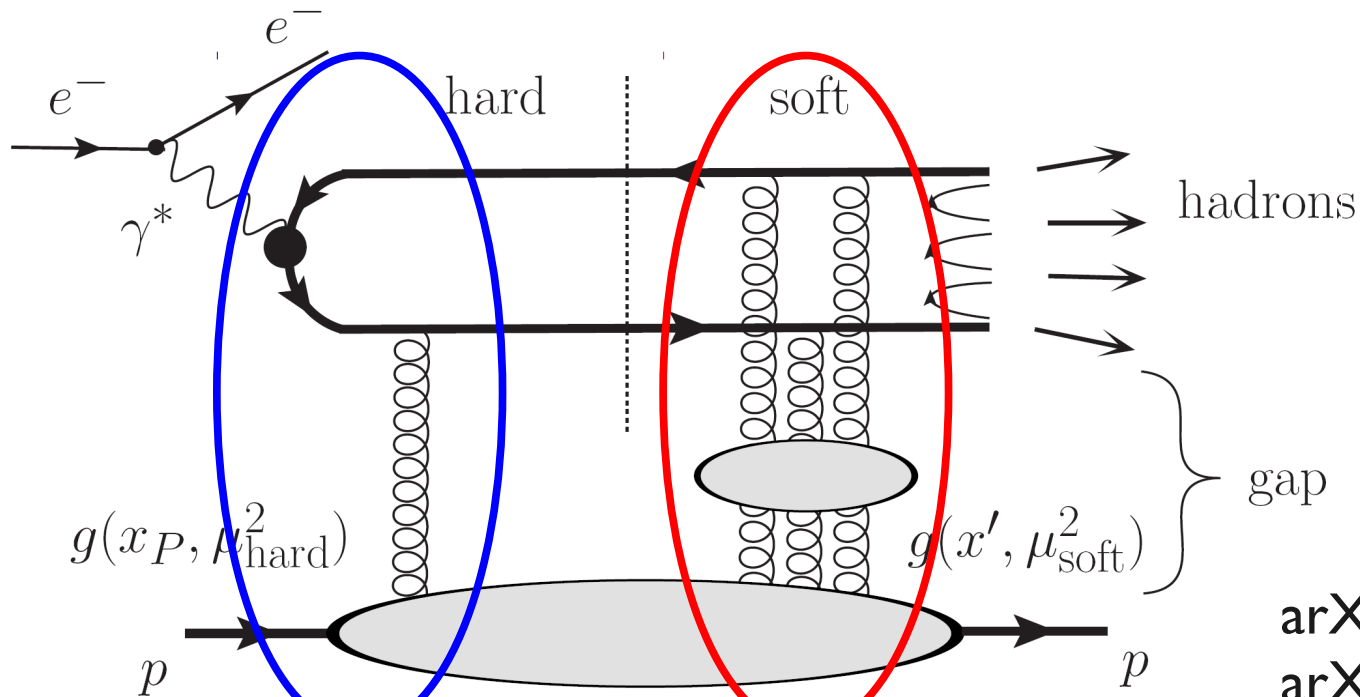
The SCI model reproduces diffractive rates
in both DIS and hadron-hadron!

But it is not theoretically well-founded.

Soft rescattering in QCD

- The SCI model is just a simple phenomenological ansatz, and we would like to go further and understand from QCD why it seems to work.
- Study soft gluon exchanges in the final state
- Some first steps were taken in Brodsky, RE, Hoyer, Ingelman, hep-ph/0409119
- **Here: explicit model constructed with resummation of soft gluon exchanges**

Diffractive DIS from rescattering



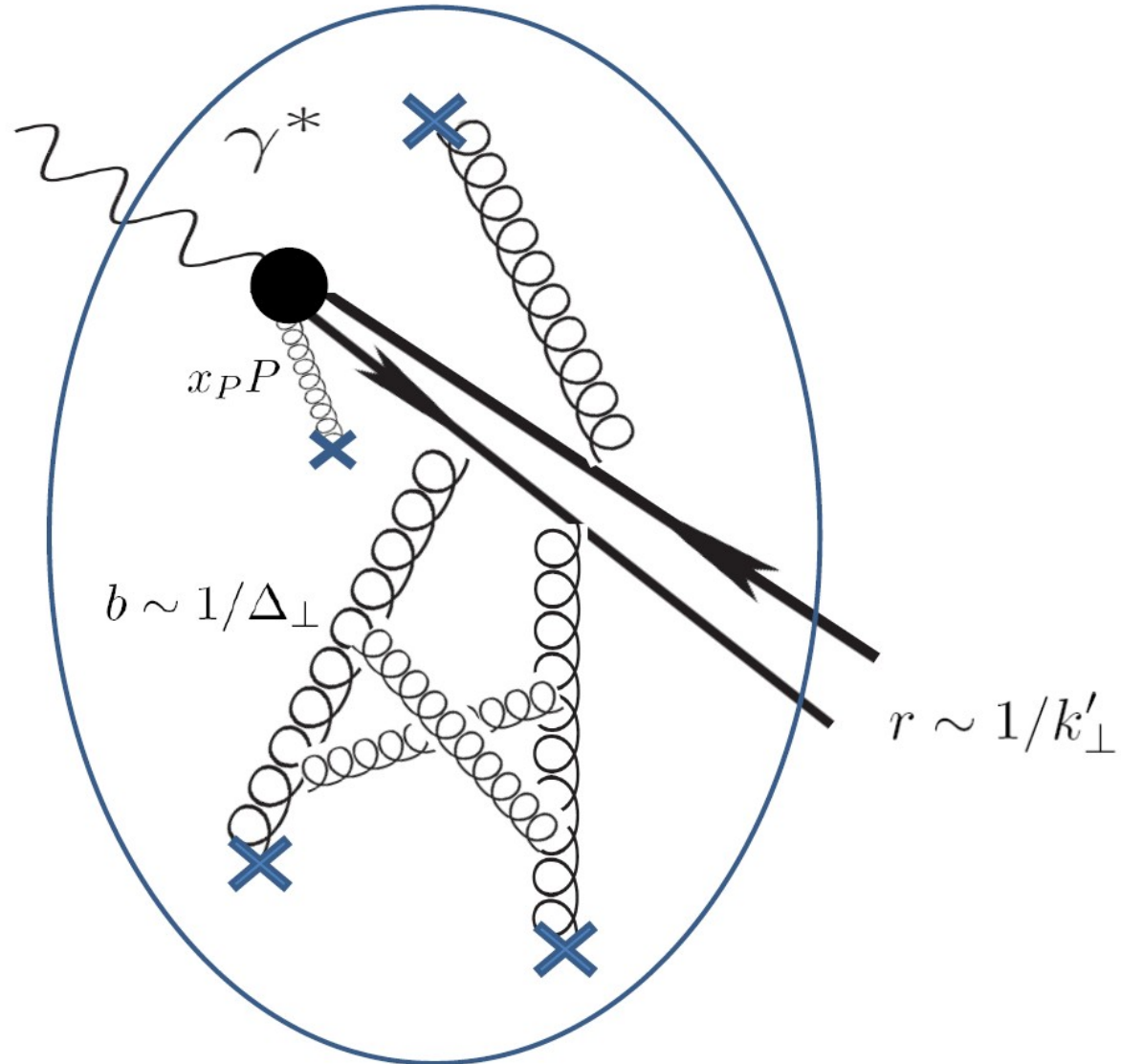
arXiv:1004.2912
arXiv:1005.3399

Hard part:
conventional
pQCD,
color octet
exchange

**Overall
exchange is
color singlet!**

Soft part: resum soft
multigluon exchange
(non-perturbative),
color screening

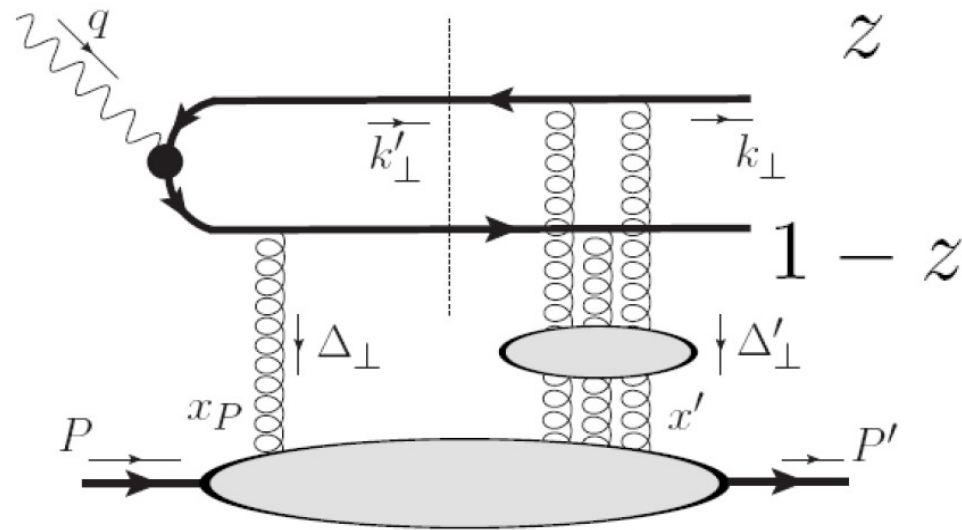
Sketchy sketch



Similar ideas

- Hautmann and Soper: soft rescattering of dipole
- Brodsky, RE, Hoyer, Ingelman
- Hebecker et al.
- Peschanski et al.

Final state rescattering

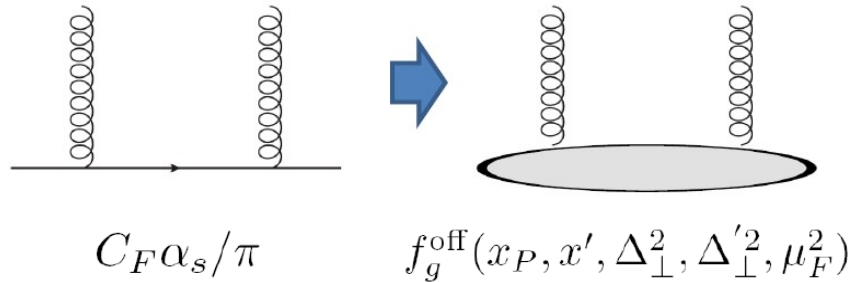


$$x_P \ll 1, \quad M_X \ll W \quad |t| \ll Q^2, \quad M_X^2 \quad x' \ll x_P$$

The first, hard gluon carries x_p , the soft gluons x'

- we factorize into a hard part and a soft part
- We use k_t -factorization at the proton

kt-factorization



Replace coupling
to quark line by PDF

Off-diagonal
unintegrated PDF:

$$\mathcal{F}_g^{\text{off}} \simeq \sqrt{\mathcal{F}_g(x_P, \Delta_{\perp}^2, \mu_F^2) \mathcal{F}_g(x', \Delta'_{\perp}{}^2, \mu_{\text{soft}}^2)},$$

$$\frac{f_g(x, \Delta_{\perp}^2)}{\Delta_{\perp}^2} \equiv \mathcal{F}(x, \Delta_{\perp}^2) \rightarrow \text{const}, \quad \Delta_{\perp}^2 \rightarrow 0$$

Gaussian ansatz
for k_t -dependence:

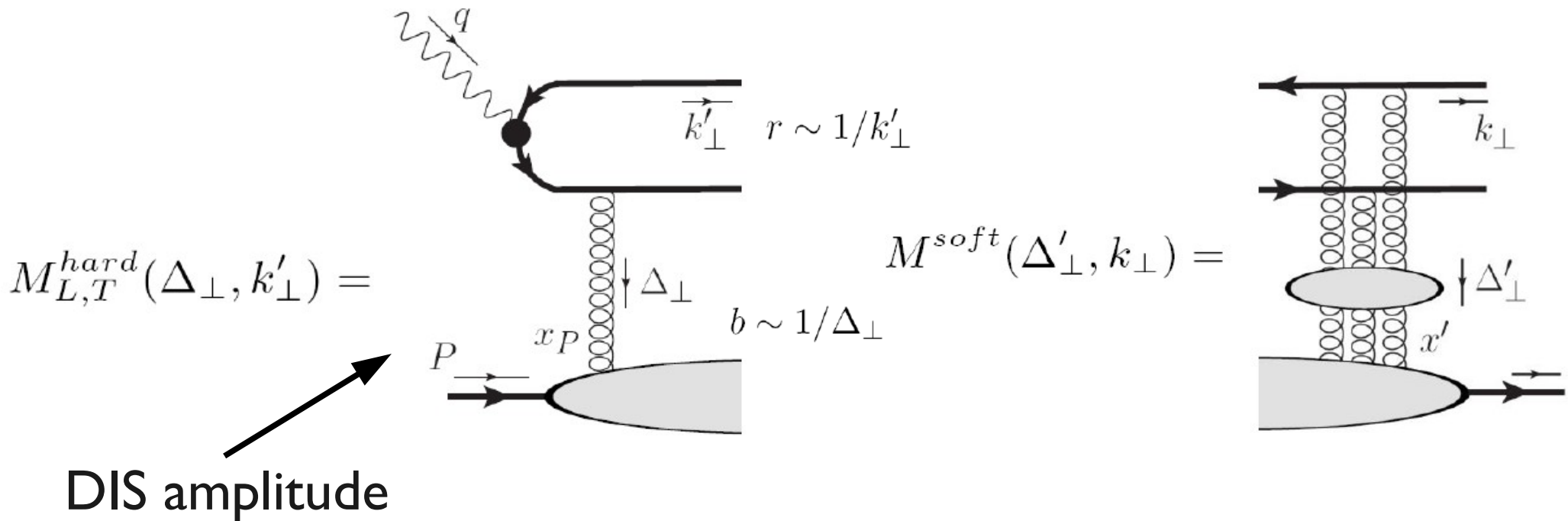
$$\sqrt{x_P} \mathcal{F}_g^{\text{off}} \simeq \sqrt{x_P g(x_P, \mu_F^2) x' g(x', \mu_{\text{soft}}^2) f_G(\Delta_{\perp}^2)},$$

$$f_G(\Delta_{\perp}^2) = 1/(2\pi\rho_0^2) \exp(-\Delta_{\perp}^2/2\rho_0^2),$$

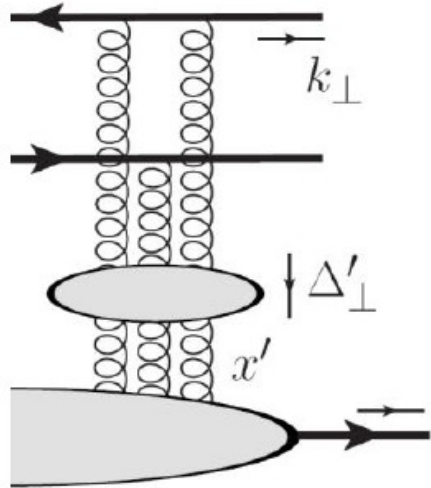
Hard-soft factorization

$$M(\delta) \sim \int d^2b e^{-i\delta\mathbf{b}} \hat{M}^{hard}(\mathbf{b}) \cdot \hat{M}^{soft}(\mathbf{b})$$

$$\delta \equiv \sqrt{-t} = |\Delta_{\perp} + \Delta'_{\perp}|$$



The soft amplitude



Large- N_c limit: only consider planar diagrams

$$e^{-i\mathbf{r}\mathbf{k}'_{\perp}} M_1^{soft} = \mathcal{A} e^{-i\mathbf{r}\mathbf{k}_{\perp}} \frac{1}{\Delta'_{\perp 2}} \left[e^{-i\mathbf{r}\Delta'_{\perp}} - 1 \right],$$

$$e^{-i\mathbf{r}\mathbf{k}'_{\perp}} M_2^{soft} = \frac{\mathcal{A}^2}{2!} e^{-i\mathbf{r}\mathbf{k}_{\perp}} \times$$

$$\int \frac{d^2\Delta'_{2\perp}}{(2\pi)^2} \frac{1}{\Delta'_{1\perp} \Delta'_{2\perp}} \left[e^{-i\mathbf{r}\Delta'_{\perp}} - e^{-i\mathbf{r}\Delta'_{2\perp}} - e^{-i\mathbf{r}\Delta'_{1\perp}} + 1 \right]$$

Fourier transform to (\mathbf{b}, \mathbf{r}) :

$$e^{-i\mathbf{r}\mathbf{k}'_{\perp}} \hat{M}_1^{soft} = e^{-i\mathbf{r}\mathbf{k}_{\perp}} \mathcal{A} \cdot \mathcal{W}(\mathbf{b}, \mathbf{r}),$$

$$e^{-i\mathbf{r}\mathbf{k}'_{\perp}} \hat{M}_2^{soft} = e^{-i\mathbf{r}\mathbf{k}_{\perp}} \frac{\mathcal{A}^2 \cdot \mathcal{W}(\mathbf{b}, \mathbf{r})^2}{2!}$$

where

$$\mathcal{A} = ig_s^2 C_F / 2 \quad \mathcal{W}(\mathbf{b}, \mathbf{r}) = \frac{1}{2\pi} \ln \frac{|\mathbf{b} - \mathbf{r}|}{|\mathbf{b}|}$$

The series exponentiates: [inspired by Brodsky et al., PRD 65, 114025 (2002)]

$$e^{-i\mathbf{r}\mathbf{k}'_{\perp}} \hat{M}^{soft}(\mathbf{b}, \mathbf{r}) = -e^{-i\mathbf{r}\mathbf{k}_{\perp}} \left(1 - e^{\mathcal{A} \mathcal{W}(\mathbf{b}, \mathbf{r})} \right)$$

Final result

qq dipole: $x_P F_L^{D(4)} = \mathcal{S} Q^4 M_X^2 \int_{z_{min}}^{\frac{1}{2}} dz (1-2z) z^2 (1-z)^2 |J_L|^2$

$$x_P F_T^{D(4)} = 2\mathcal{S} Q^4 \int_{z_{min}}^{\frac{1}{2}} dz (1-2z) \left\{ (1-z)^2 + z^2 \right\} |J_T|^2,$$

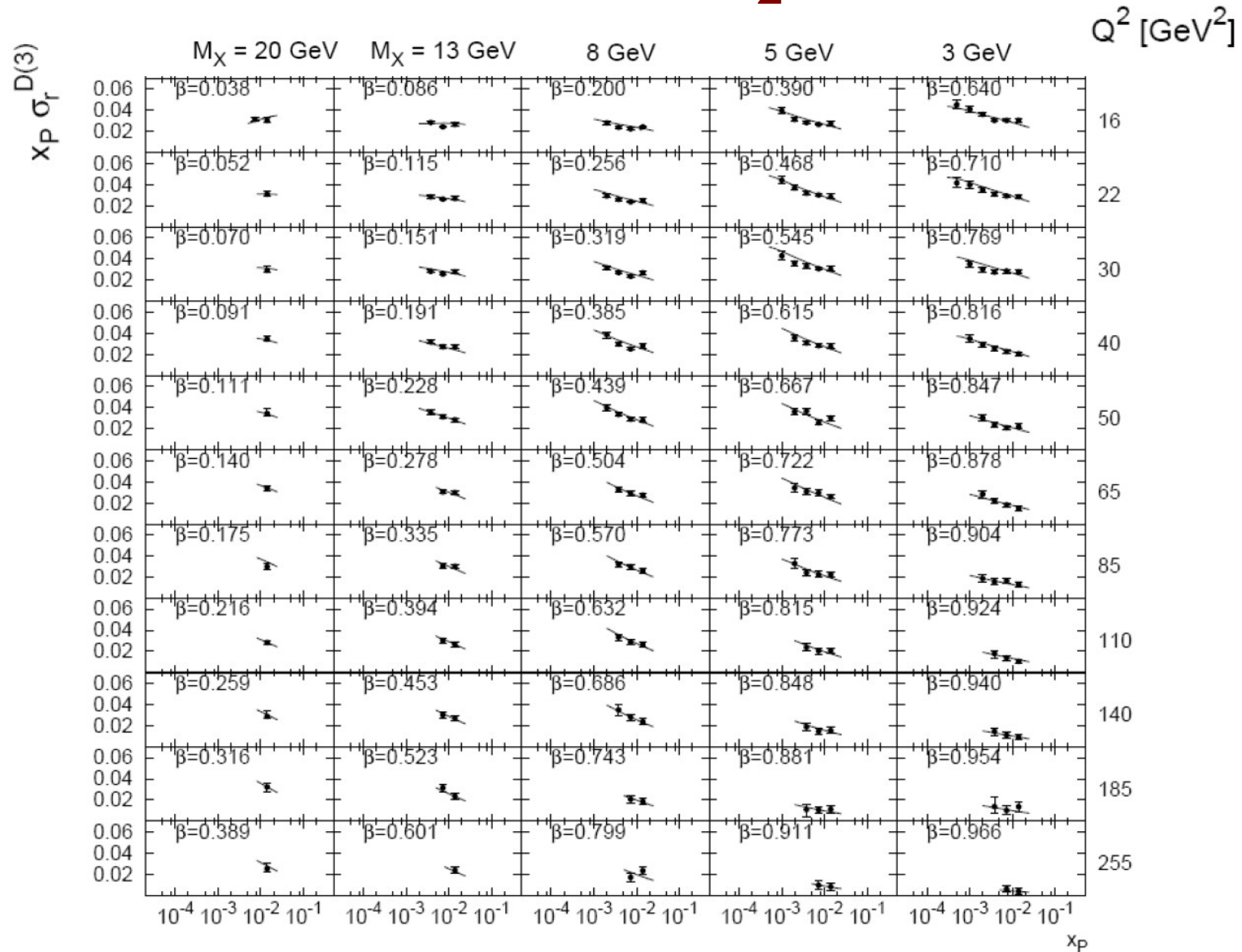
where $J_L = i\alpha_s(\mu_F^2) \int d^2\mathbf{r} d^2\mathbf{b} e^{-i\delta\mathbf{b}} e^{-i\mathbf{r}\mathbf{k}_\perp} K_0(\varepsilon r)$

$$\times \mathcal{V}(\mathbf{b}, \mathbf{r}) \left[1 - e^{\mathcal{A}\mathcal{W}} \right],$$

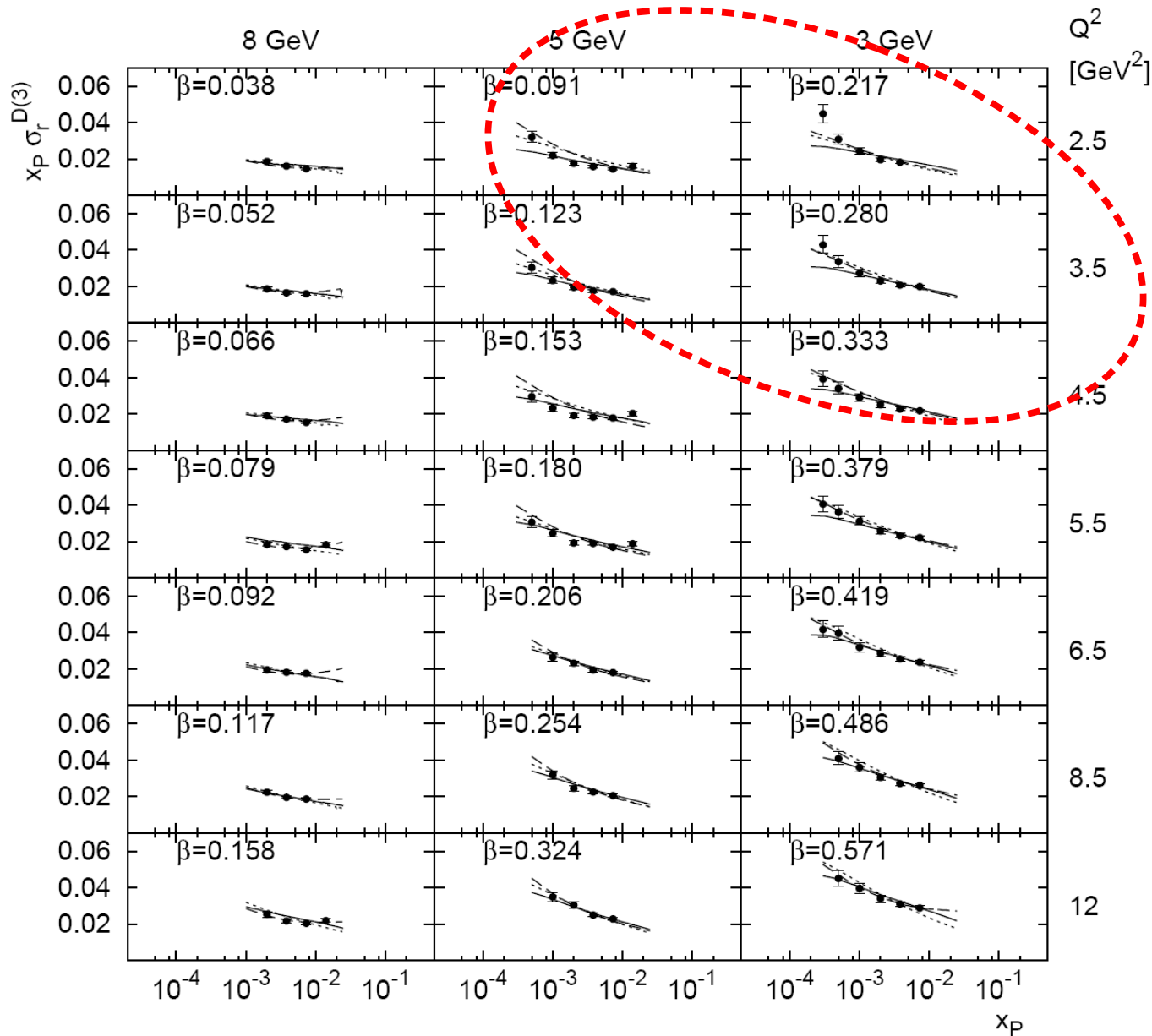
$$J_T = i\alpha_s(\mu_F^2) \int d^2\mathbf{r} d^2\mathbf{b} e^{-i\delta\mathbf{b}} e^{-i\mathbf{r}\mathbf{k}_\perp} \varepsilon K_1(\varepsilon r)$$
$$\times \frac{r_x \pm ir_y}{r} \mathcal{V}(\mathbf{b}, \mathbf{r}) \left[1 - e^{\mathcal{A}\mathcal{W}} \right].$$

We also include qgg, see papers for details

Comparison with F_2^D — high Q^2



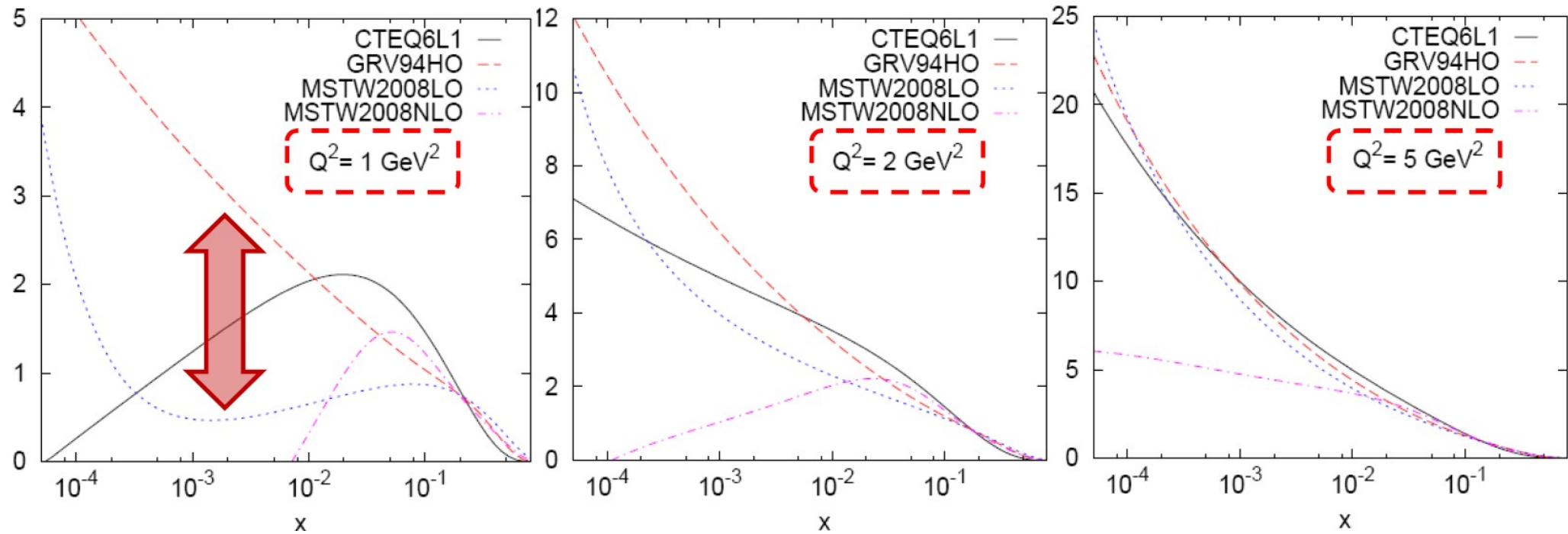
Comparison with F_2^D — lower Q^2



Here the curves are for different parametrizations of $g(x, Q^2)$

Uncertainty from PDFs at low Q^2

PDF uncertainties



There are large differences in parametrizations
for small x and Q^2

Coupling of soft gluons

- Soft gluon coupling to quarks in dipole:

$$\alpha_s(\mu_{\text{soft}}^2) = 0.7$$

from Analytic Perturbation Theory

- Soft gluon coupling to proton remnant through the off-diagonal gluon distribution:

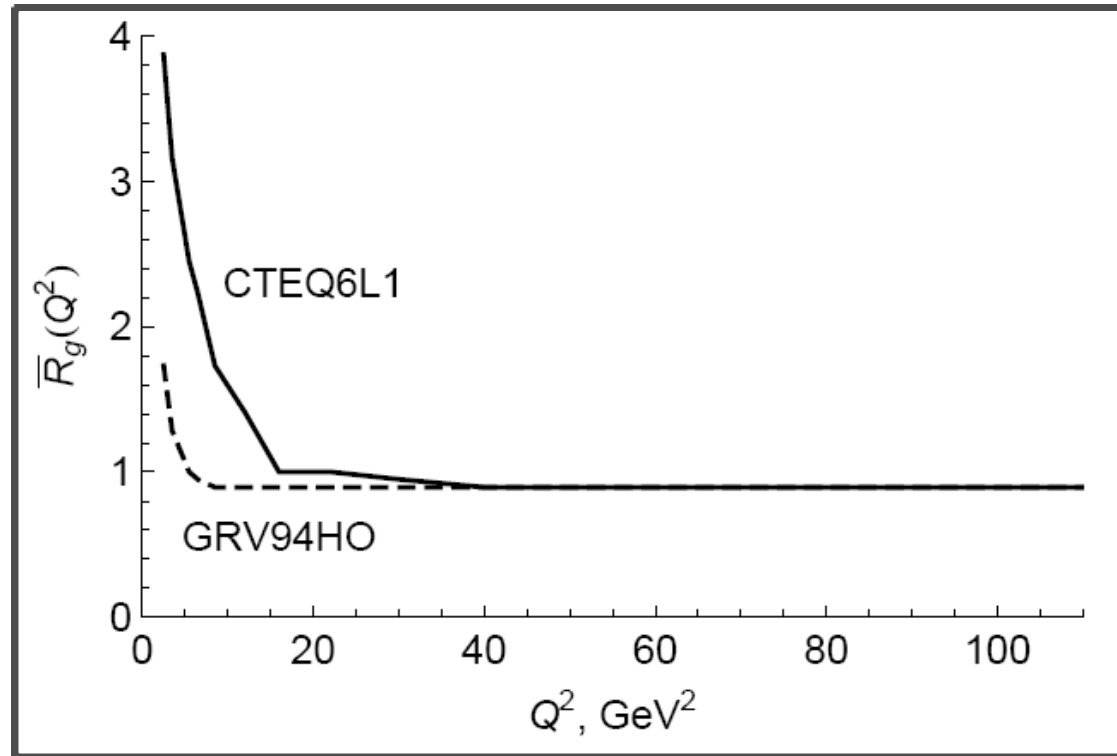
$$\sqrt{x_P} \mathcal{F}_g^{\text{off}} \simeq \sqrt{x_P g(x_P, \mu_F^2) x' g(x', \mu_{\text{soft}}^2) f_G(\Delta_{\perp}^2)},$$

Thus we define a “soft gluon PDF”:

$$\sqrt{x_P} \mathcal{F}_g^{\text{off}} \simeq \bar{R}_g(x', \mu_{\text{soft}}^2) \sqrt{x_P g(x_P, \mu_F^2) f_G(\Delta_{\perp}^2)}$$

\bar{R}_g is remarkably constant ~ 1 almost everywhere

Coupling of soft gluons



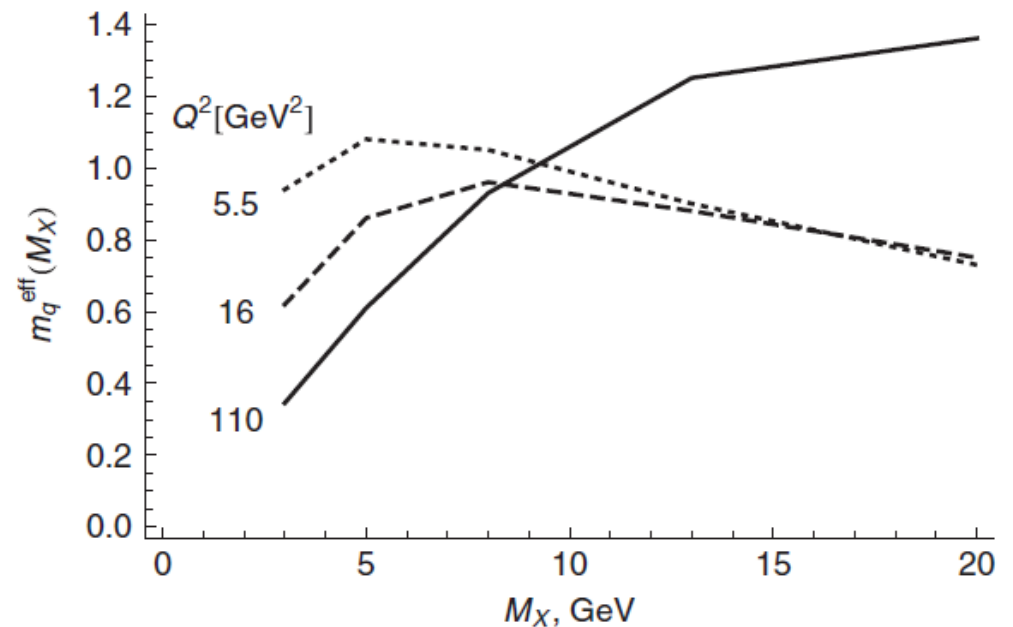
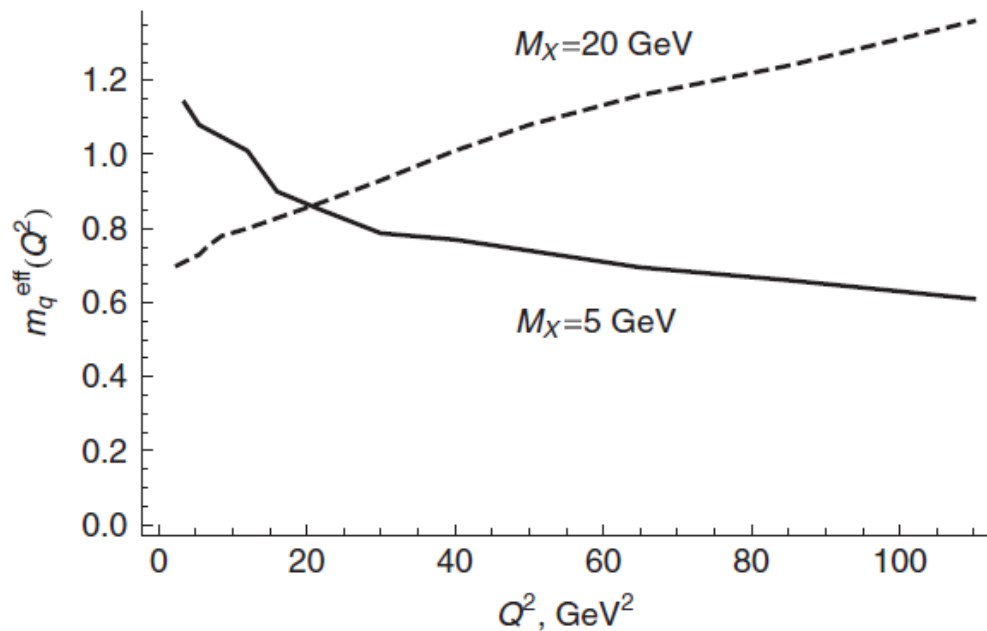
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\bar{R}_g is remarkably constant ~ 1 almost everywhere

Physical parameters

- IR regulator: gluon mass = Λ_{QCD} (only in “NLO” correction)
- Effective “constituent” quark mass in dipole m^{eff}



Hadron-hadron

- We would like to test this model for different processes (diffractive and non-diffractive)
- In particular in hadron-hadron collisions—not completely straightforward
- We are making a Monte Carlo implementation
- Contributes to underlying event!
(cf. Rick Field's talk, Hannes Jung's talk)

In particular, this is color reconnection where the “probability” depends on the dynamics!

Summary

- Hard diffraction is important to understand QCD dynamics
- Rapidity gaps related to underlying event
- New model for soft rescattering → diffraction
- Could be important in hadron-hadron collisions