Hard diffraction

Rikard Enberg
(Uppsala)

ISMD 2010, Antwerp

Overview

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

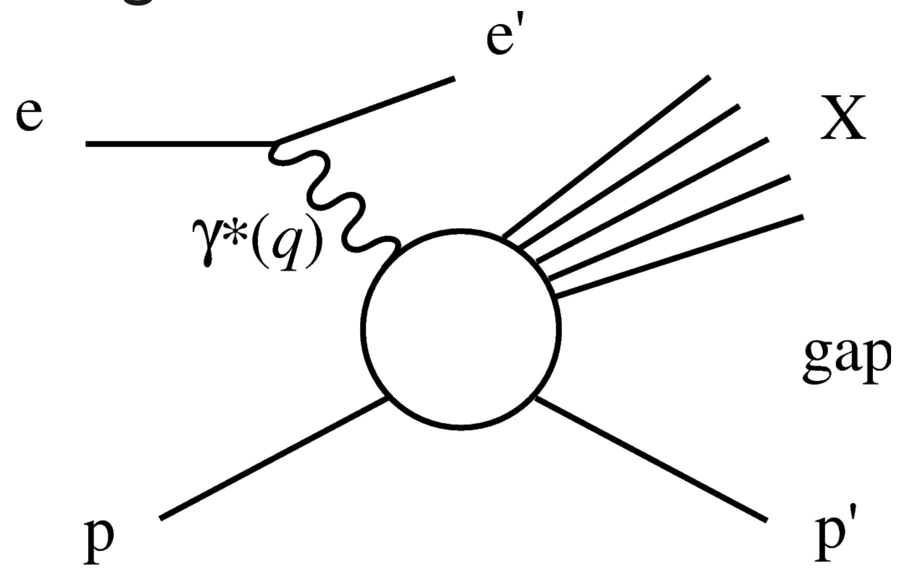
❖ ❖ ❖

- 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



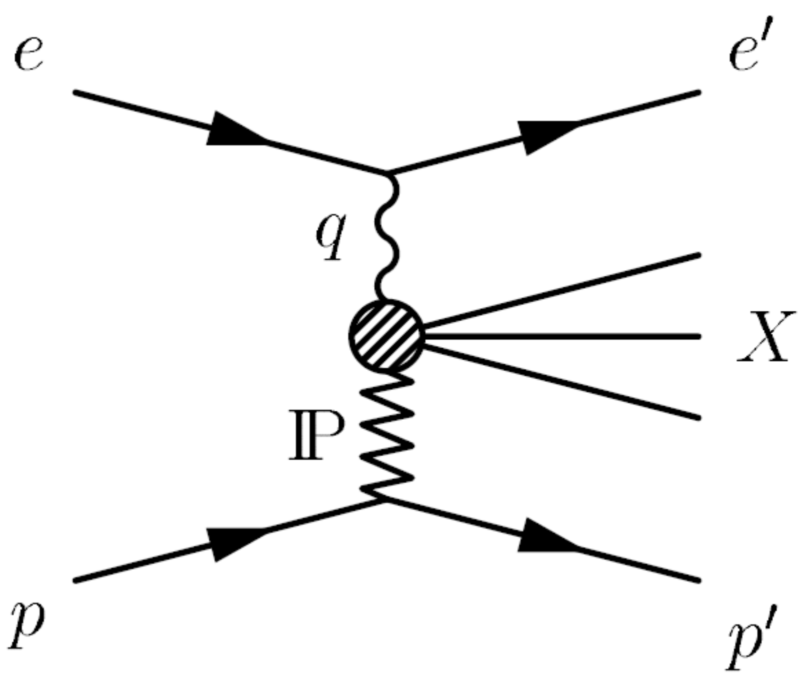
— this leads to a large rapidity gap between the proton and the produced particles (the X-system)

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

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



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

$I\!P$ flux: Taken from Regge theory

$I\!P$ structure: Fitted

The pomeron formalism

The pomeron gives a good description of HERA data

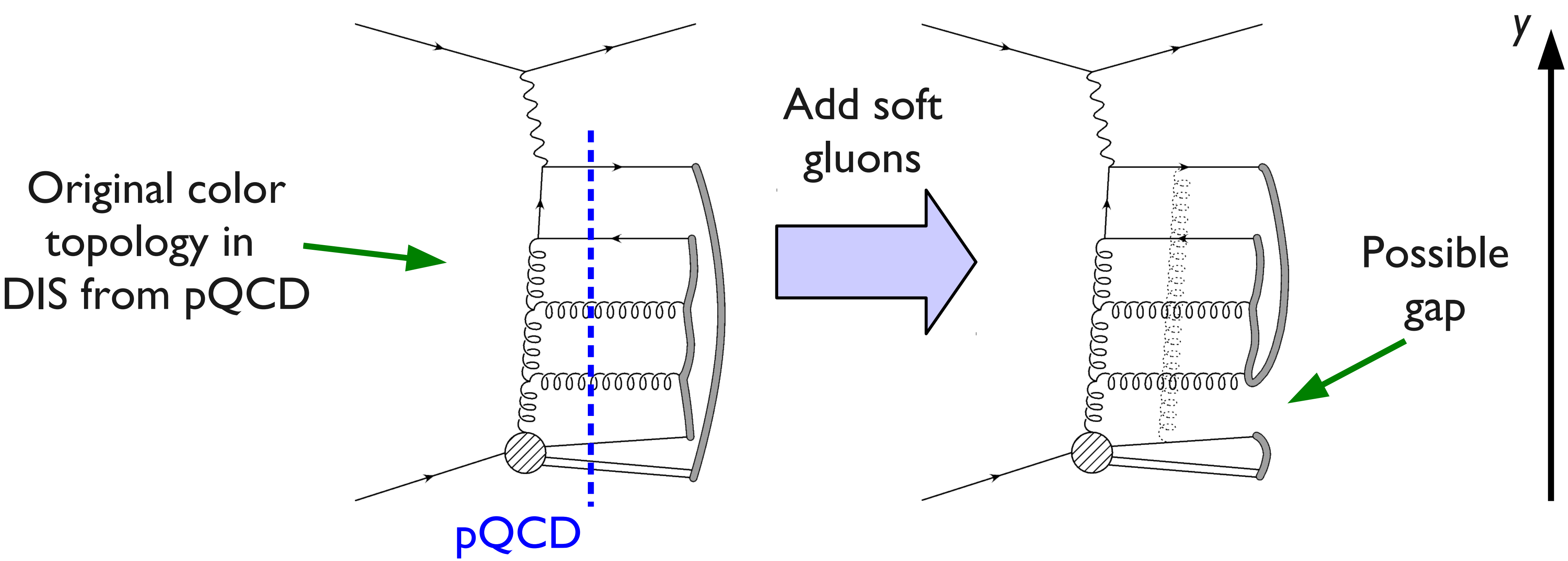
But the fit (pomeron flux and structure) fails completely when applied to Tevatron data!

- 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]

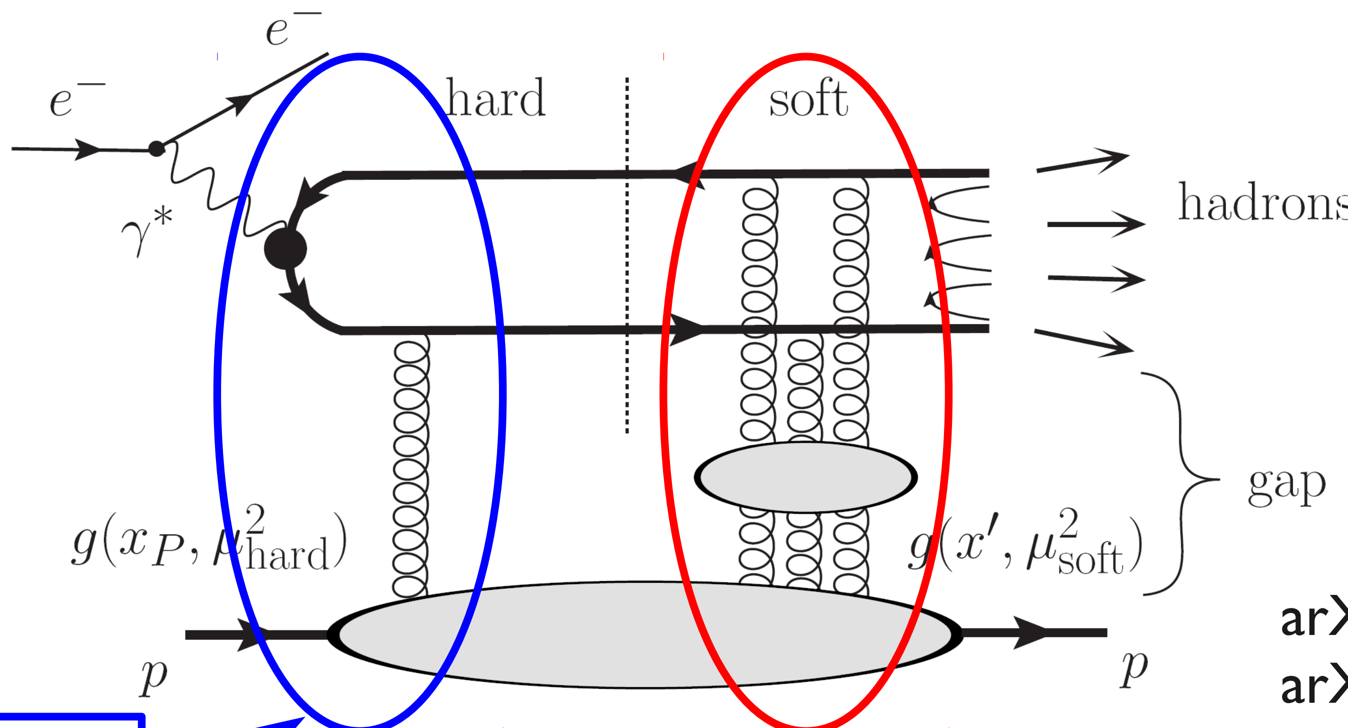
The SCI model reproduces diffractive rates
in both DIS and hadron-hadron!

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



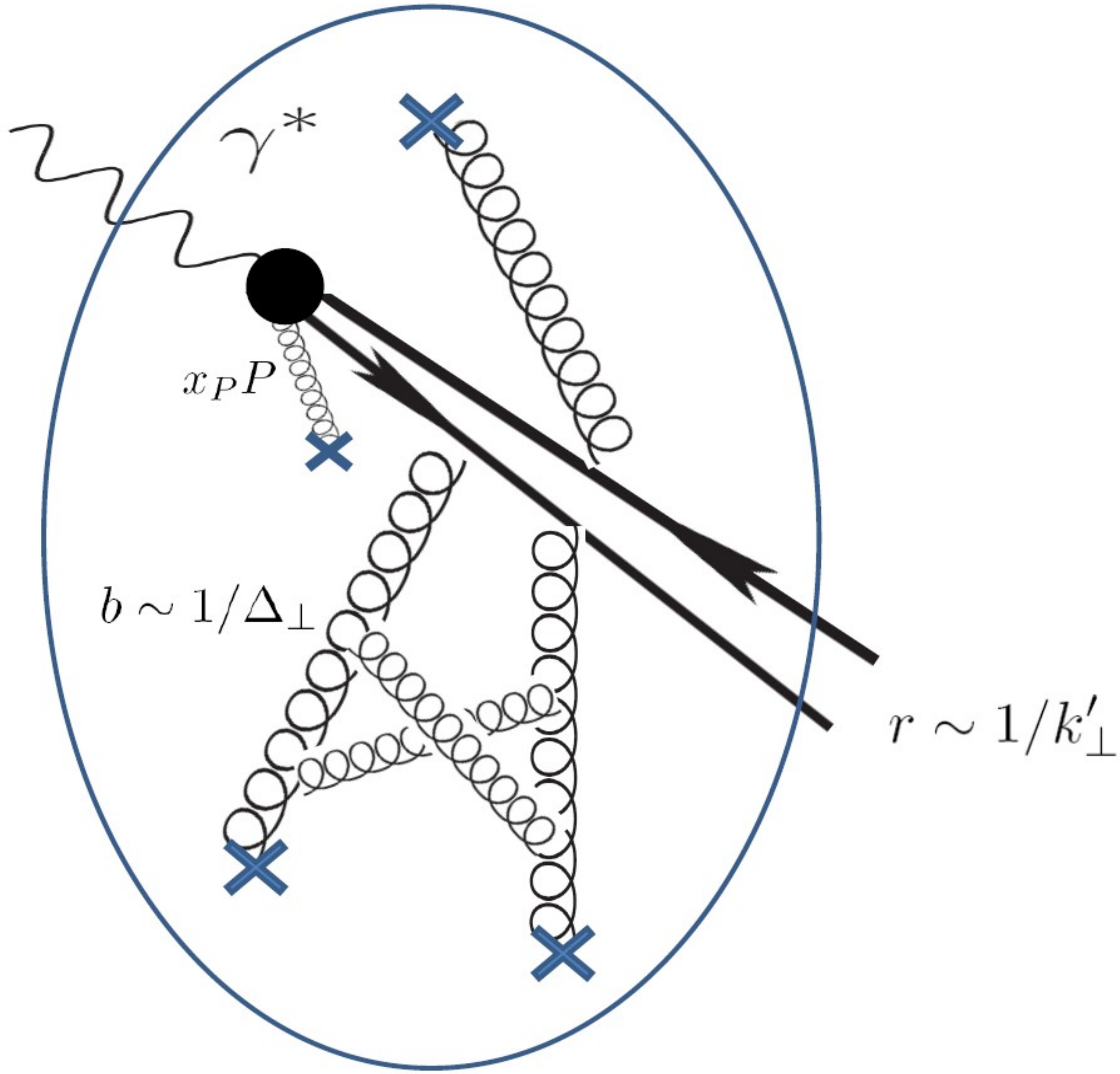
arXiv:1004.2912
arXiv:1005.3399

Hard part: conventional pQCD, *color octet exchange*

Overall exchange is color singlet!

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

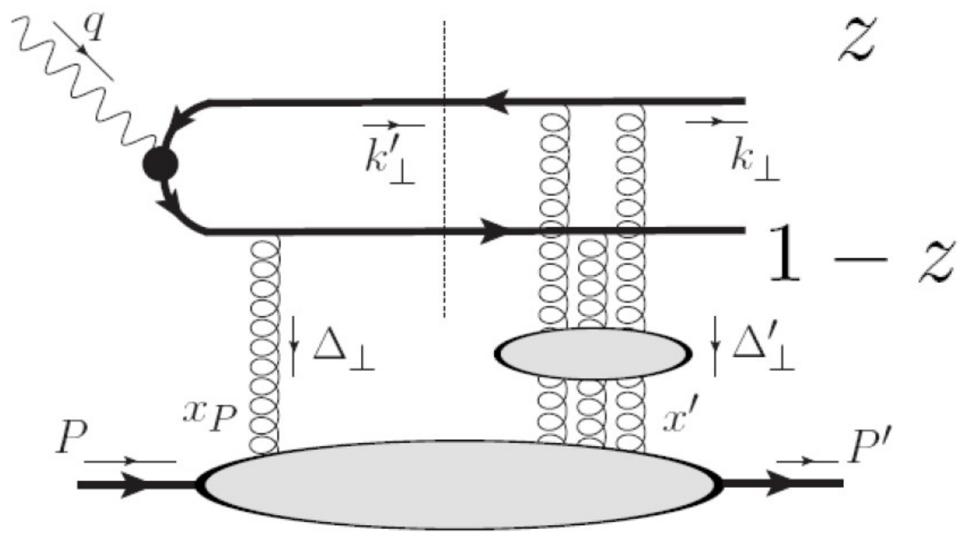
Sketchy sketch



Similar ideas

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

Final state rescattering

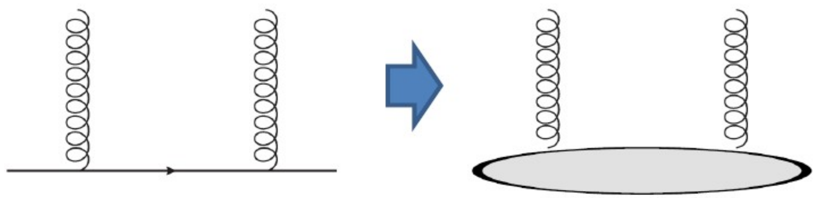


$$x_P \ll 1\,, \quad M_X \ll W \quad |t| \ll Q^2,\, M_X^2 \quad x' \ll x_P$$

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



$C_F \alpha_s / \pi$ $\qquad$ $f_g^{\rm off}(x_P, x', \Delta_\perp^2, \Delta_\perp'^2, \mu_F^2)$

Replace coupling to quark line by PDF

Off-diagonal unintegrated PDF:

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

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

Gaussian ansatz for k_t-dependence:

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

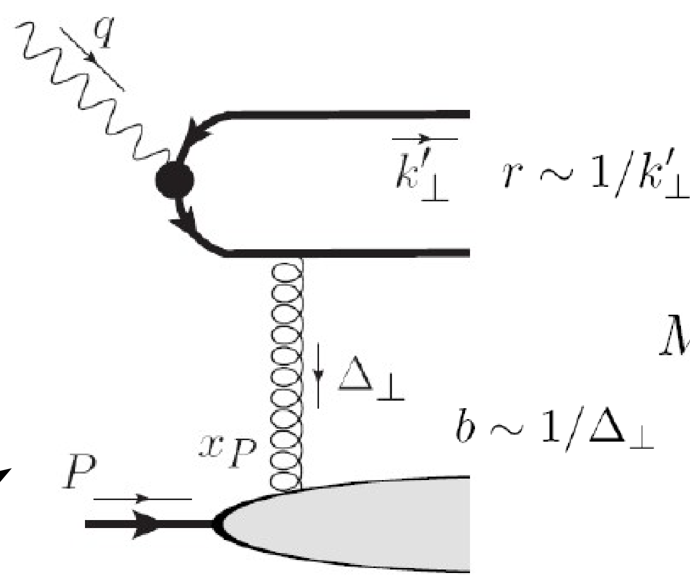
$$f_G(\Delta_\perp^2) = 1/(2\pi\rho_0^2)\, \exp\left(-\Delta_\perp^2/2\rho_0^2\right),$$

Hard-soft factorization

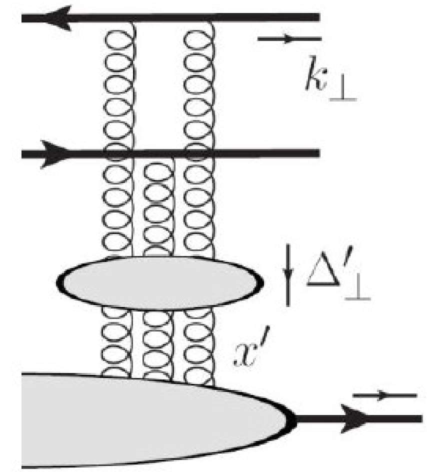
$$M(\delta) \sim \int d^2b e^{-i\boldsymbol{\delta}\mathbf{b}} \hat{M}^{hard}(\mathbf{b}) \cdot \hat{M}^{soft}(\mathbf{b})$$

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

$$M^{hard}_{L,T}(\Delta_\perp, k'_\perp) =$$

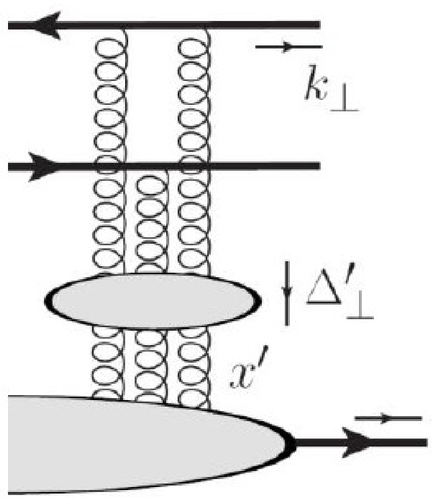


$$M^{soft}(\Delta'_\perp, k_\perp) =$$



DIS amplitude

The soft amplitude



Large-Nc limit: only consider planar diagrams

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

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

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

Fourier transform to (b,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

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

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

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

Final result

qq dipole:

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

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

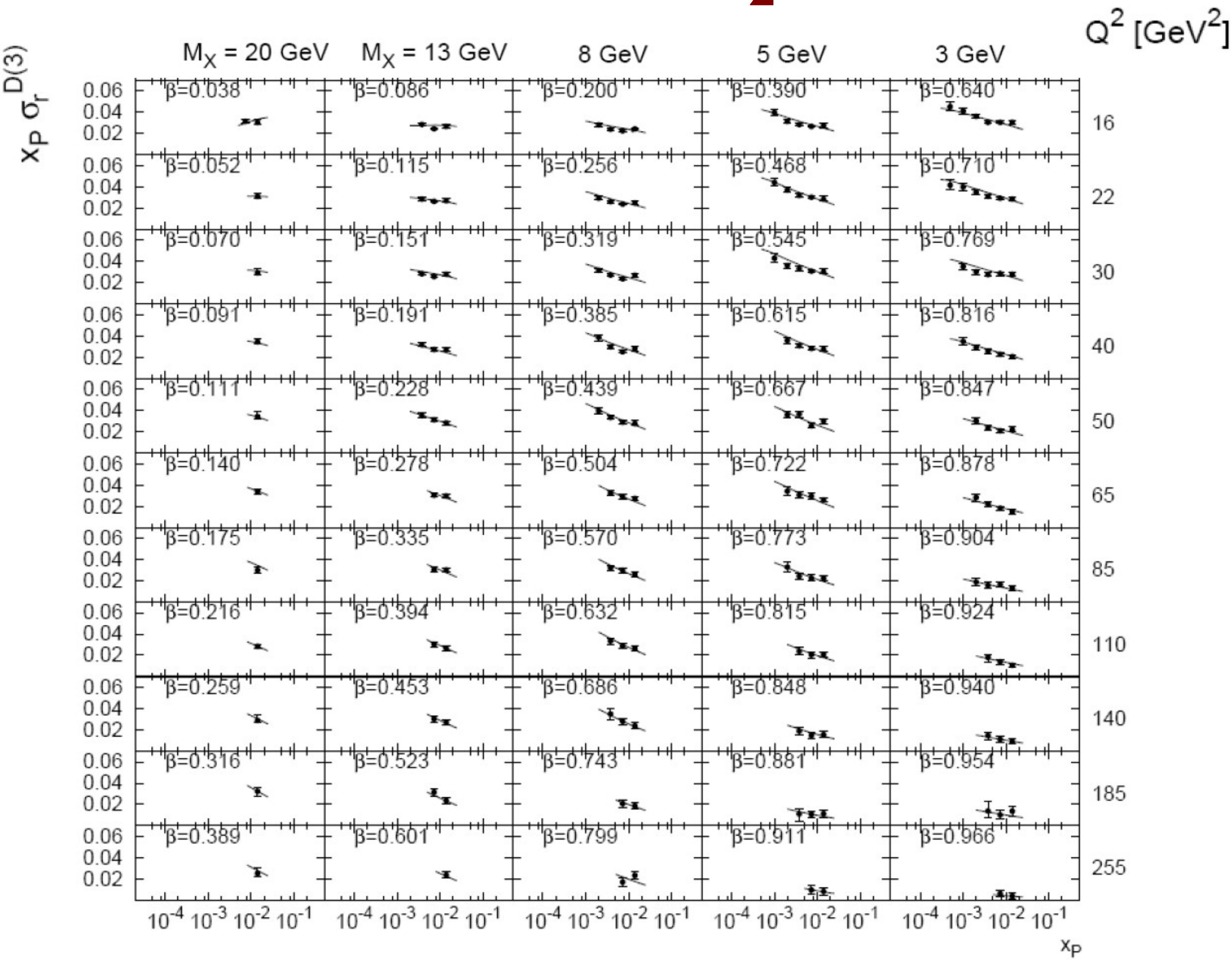
where

$$J_L = i\alpha_s(\mu_F^2) \int d^2\mathbf{r} d^2\mathbf{b}\, e^{-i\boldsymbol{\delta}\mathbf{b}} e^{-i\mathbf{r}\mathbf{k}_\perp} K_0(\varepsilon r) \times \mathcal{V}(\mathbf{b},\mathbf{r}) \Big[1 - e^{\mathcal{A}\mathcal{W}}\Big],$$

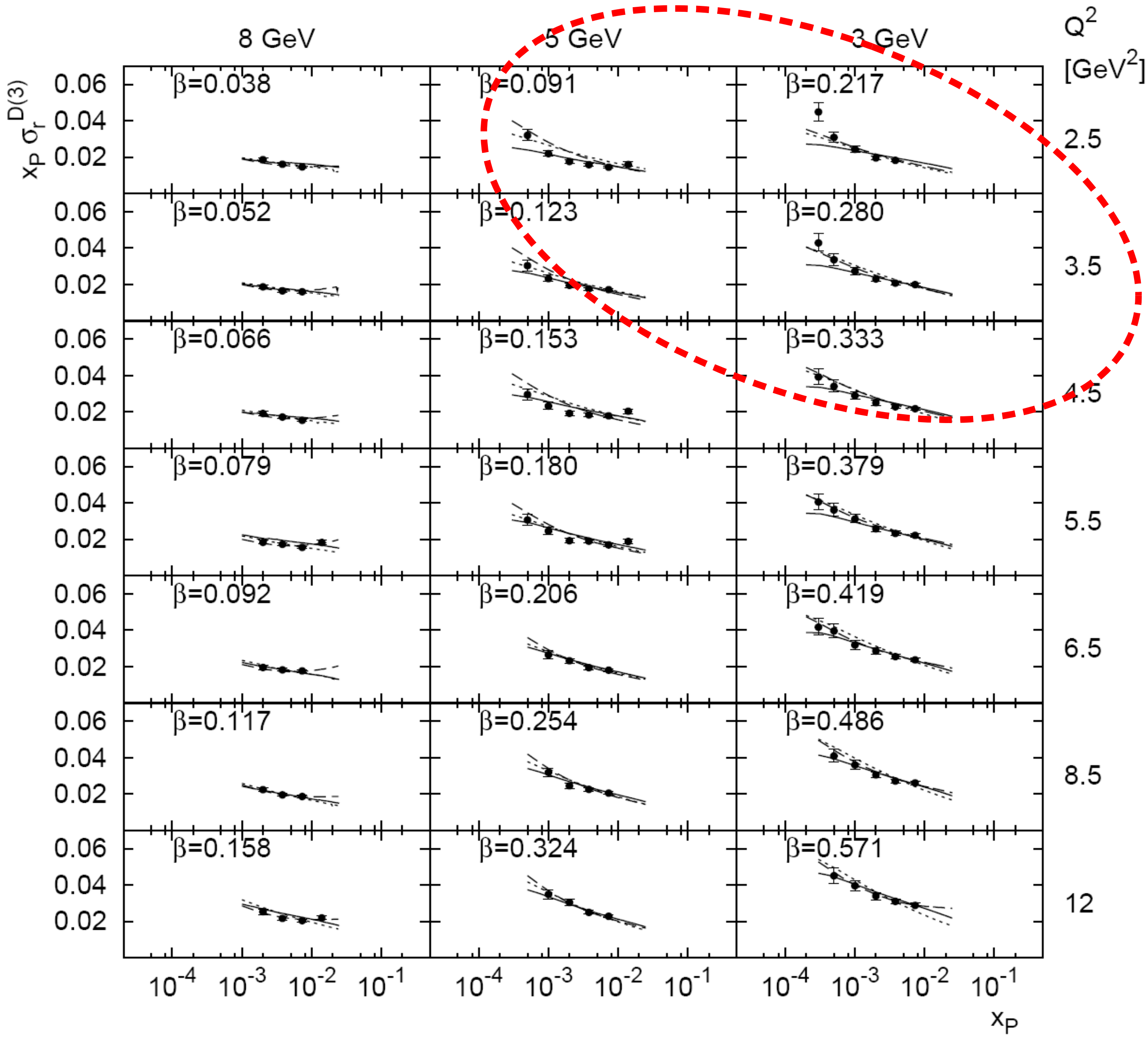
$$J_T = i\alpha_s(\mu_F^2) \int d^2\mathbf{r} d^2\mathbf{b}\, e^{-i\boldsymbol{\delta}\mathbf{b}} e^{-i\mathbf{r}\mathbf{k}_\perp} \varepsilon K_1(\varepsilon r) \times \frac{r_x \pm i r_y}{r} \mathcal{V}(\mathbf{b},\mathbf{r}) \Big[1 - e^{\mathcal{A}\mathcal{W}}\Big].$$

We also include qqg, see papers for details

Comparison with F_2^D — high Q2



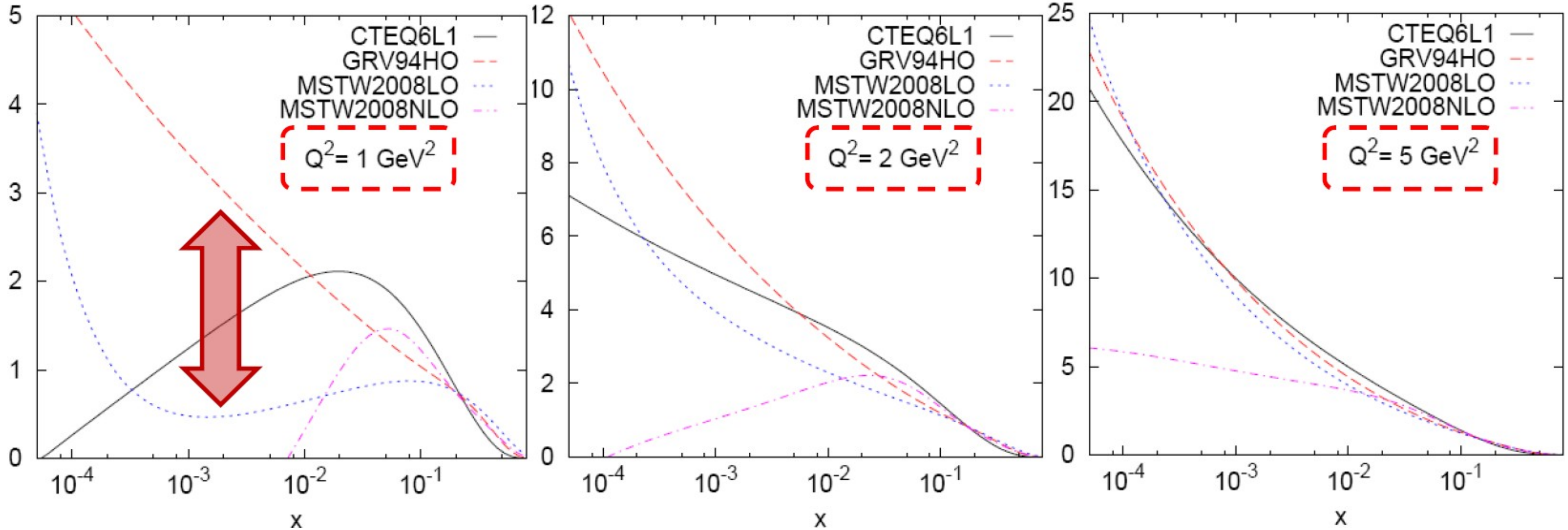
Comparison with F_2^D — lower Q2



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:
  $\alpha_s(\mu^2_{\text{soft}}) = 0.7$
  from Analytic Perturbation Theory

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

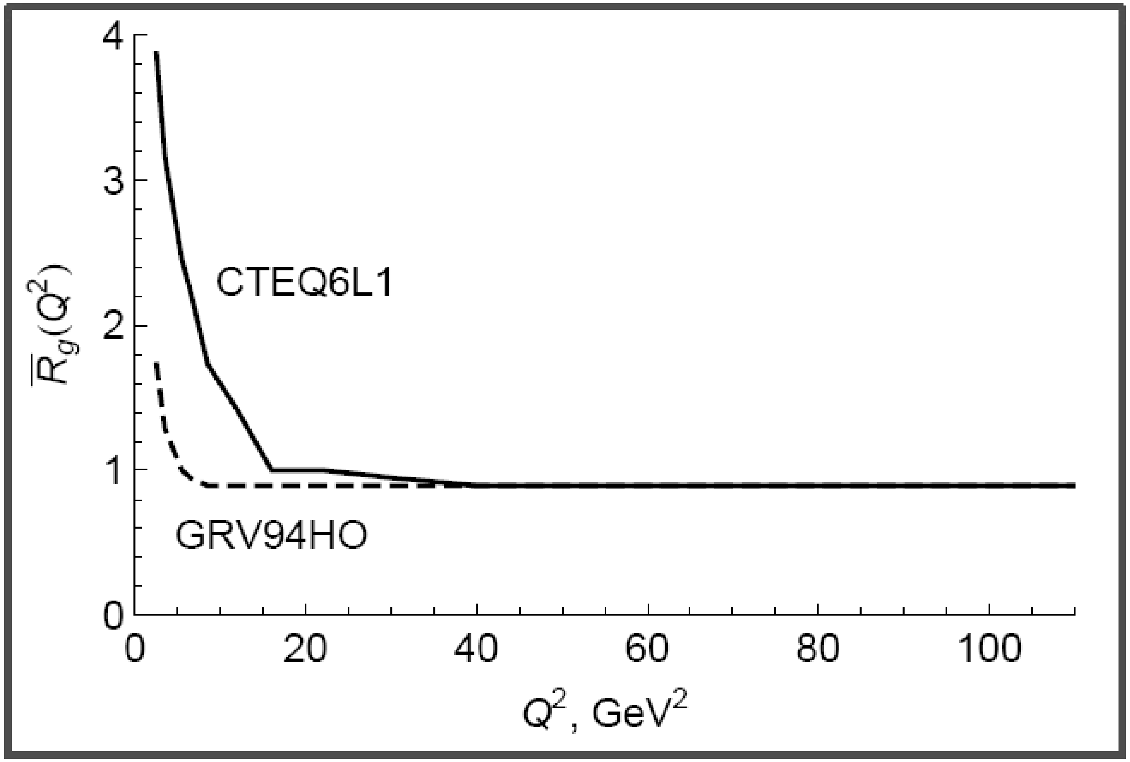
$$\sqrt{x_P}\mathcal{F}_g^{\text{off}} \simeq \sqrt{x_P g(x_P, \mu_F^2)\, x' g(x', \mu^2_{\text{soft}})}\, f_G(\Delta_\perp^2),$$

  Thus we define a "soft gluon PDF":

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

  R_g is remarkably constant ~ 1 almost everywhere

Coupling of soft gluons



Thus we define a "soft gluon PDF":

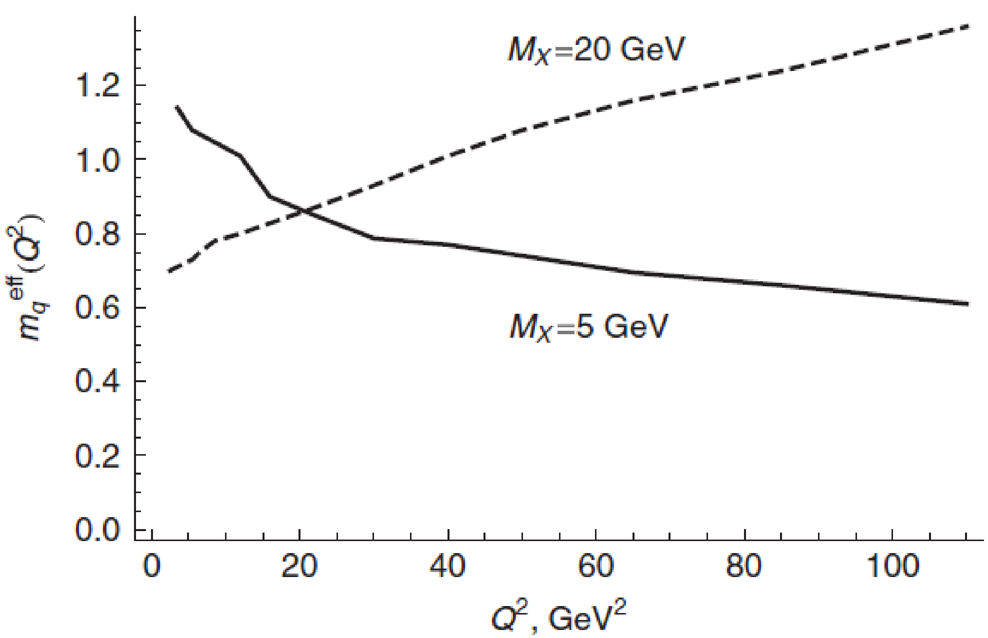
$$\sqrt{x_P}\mathcal{F}_g^{\rm off} \simeq \bar{R}_g(x', \mu_{\rm soft}^2)\sqrt{x_P g(x_P, \mu_F^2)}\, f_G(\Delta_\perp^2)$$

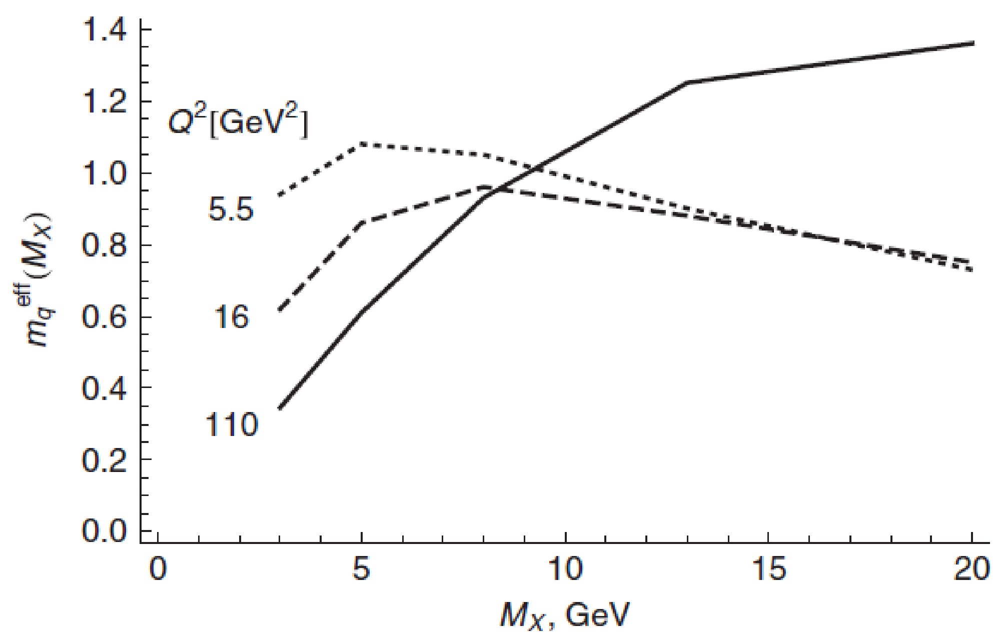
R_g is remarkably constant ~ 1 almost everywhere

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