Rapidity Gaps and Tests of Diffractive DIS Models

J. Williams (Oxford)
Manchester, March '99

J. Ellis, G.G. Ross, JCW, hep-ph/9812385

Intro

I. Phase space issues from rapgap cuts

- LRG constraints
- Where to look. . . or not to look
- Regge-factorization breaking

II. Models of $I\!P$ exchange

- Discussion of models
- Comparison with $F_2^{D(3)}$ data

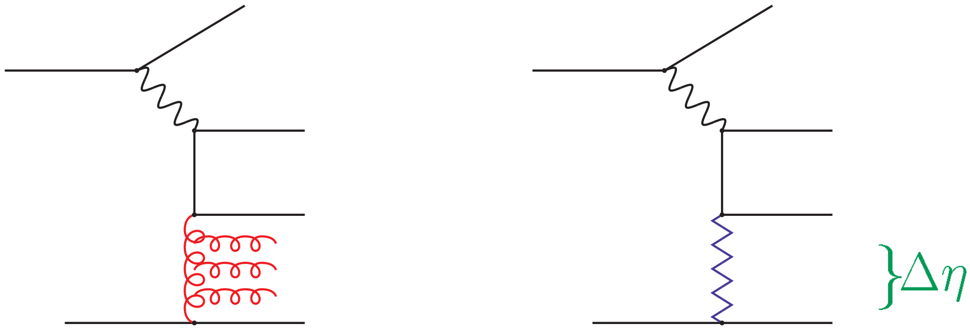
Summary/Future Prospects

Large Rapidity Gap Diffractive DIS

$\sim$ 10 % events at HERA have large rapidity gap

- excess of gap events over QCD expectation
- rapidity gap indicates colourless exchange

$\longrightarrow$ pomeron



Pseudo–rapidity:

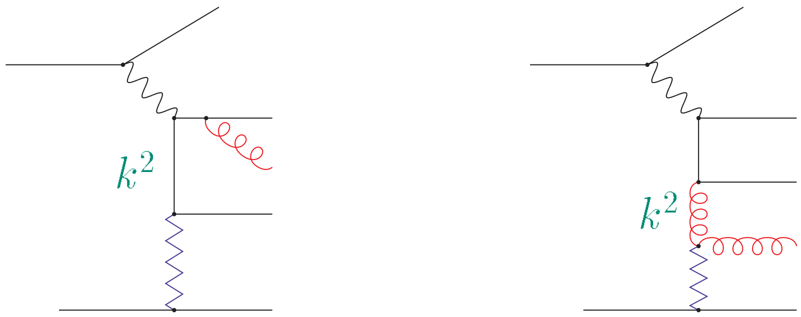
$$\eta = -\ln \tan \left(\frac{\theta_{lab}}{2} \right)$$

Diffractive DIS $\equiv$ photon probing structure of $I\!\!P$

Comments

1. **For some Q^2 , β , $x_{I\!P}$ and $\eta_{\max}$, $k^2_{\min}$ very large.**

2. **We have extended the original calculation to include events like:**

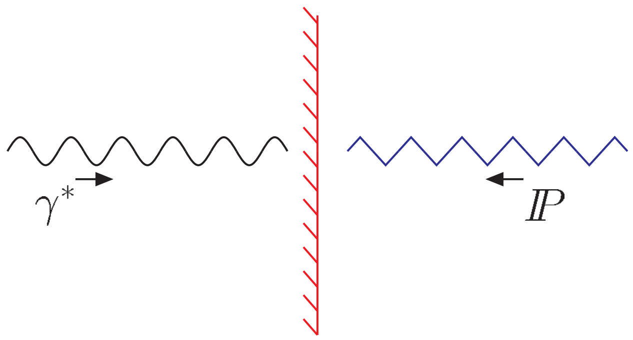


constraint :

$$-\mathbf{k}^2_{\min}\,(\text{multijet}) \gtrsim -\frac{\mathbf{1}}{\mathbf{3}}\,\mathbf{k}^2_{\min}\,(\text{dijet})$$

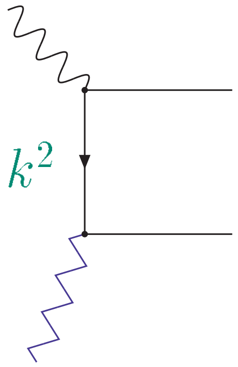
3. **If we have $\eta_{\max}$, Q^2 , β , $x_{I\!P}$ such that $\theta^{\text{cms}}_{\min} > 90°$:**

$\longrightarrow$ **see *no* events:**



Kinematics II

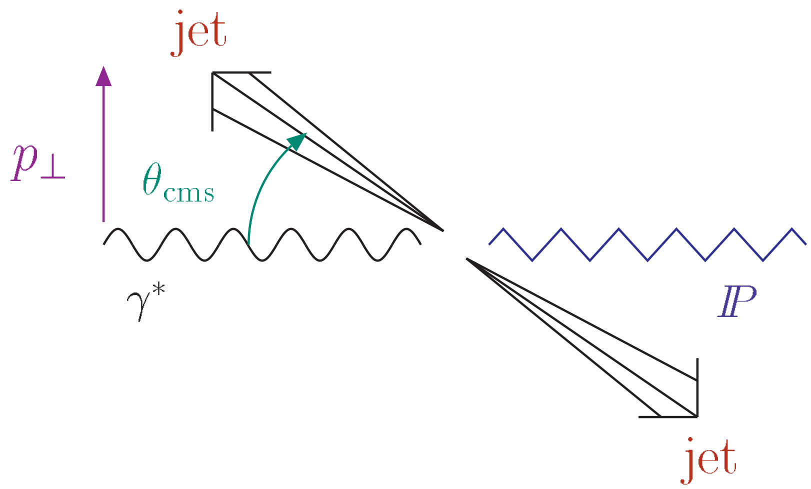
- **Exchanged quark virtuality** ($\gamma^* - I\!P$ cms):



$$-k^2 = \frac{Q^2}{2\beta}\,(1 - \cos\theta_{\rm cms})$$

$\theta_{\rm cms}$ = **angle between jets and proton direction**

- **Jet transverse momentum** ($\gamma^* - I\!P$ cms):



$$p_\perp^2 = \frac{M_X^2}{4}\sin^2\theta_{\rm cms}$$

Pomeron Structure

- **Ingelman–Schlein (1985):**
  - **pomeron $\sim$ *hadronic***

Diffractive Structure Function $F_2^{D(3)}$:

$$\frac{\mathrm{d}^3\sigma^{\mathrm{diff}}}{\mathrm{d}Q^2\,\mathrm{d}\beta\,dx_{I\!P}} = \frac{2\pi\alpha_{\mathrm{em}}^2}{\beta Q^4}\left\{[1+(1-y)^2]F_2^{D(3)}(Q^2,\beta,x_{I\!P}) - y^2 F_L\right\}$$

Pomeron Structure Function $F_2^{I\!P}$:

$$F_2^{D(3)}(Q^2,\beta,x_{I\!P}) = f_{I\!P/P}(x_{I\!P})\,F_2^{I\!P}(Q^2,\beta)$$

Rapidity Gaps: Experiment and Theory

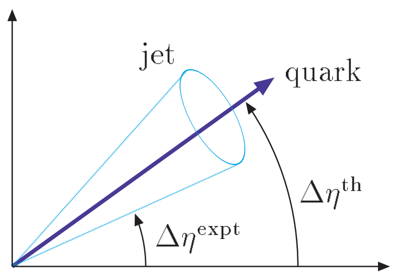
Early analyses used very strong rapidity cuts

H1: $\eta_{\rm max} = 1.8 \quad \Rightarrow \theta_{\rm min} \approx 18^\circ$

ZEUS: $\eta_{\rm max} = 1.5 \quad \Rightarrow \theta_{\rm min} \approx 25^\circ$

- These cuts are made at *hadron* level

- Corresponding pseudo-rapidity at *parton* level:



Assume: Hadronization radius of jets $\sim \frac{1}{2} - 1$ unit of pseudo-rapidity

Therefore: for experimental cuts, $\eta^{\rm exp}_{\rm max}$, estimate:

$$\eta^{\rm th}_{\rm max} \approx \eta^{\rm exp}_{\rm max} - 0.5$$

e.g.

$$\eta^{\rm exp}_{\rm max} = 1.8 \quad \Rightarrow \quad \theta^{\rm th}_{\rm min} \approx 30^\circ$$

Consequences of large rapidity gap cuts

Ellis, Ross 1996

- **H1, ZEUS: Rapidity gap cuts $\rightarrow$ diffraction**
- **Ellis–Ross: Cuts *may* restrict phase space:**

in LAB coords: $\eta = -\ln\tan\frac{\theta_{\mathrm{lab}}}{2}$

boost: LAB $\rightarrow$ CMS

$$1-\cos\theta_{\mathrm{cms}} = \frac{(1-\beta_1)(1-\beta_2^2)}{1-\beta_1\cos\theta_{\mathrm{lab}} - \sqrt{1-\beta_1^2}\,\beta_2\sin\theta_{\mathrm{lab}}\cos\phi_{\mathrm{lab}}}\,(1-\cos\theta_{\mathrm{lab}})$$

ϕ_{lab} **= azimuthal angle**

$\beta_1(Q^2,\beta,x_{I\!P}),\ \beta_2(Q^2,\beta,x_{I\!P})$ **= boost parameters**

in $\gamma^* - I\!P$ **CMS:** $-k^2 = \frac{Q^2}{2\beta}(1-\cos\theta_{\mathrm{cms}})$

$$\boxed{\eta_{\max} \Rightarrow \theta^{\mathrm{lab}}_{\min} \Rightarrow \theta^{\mathrm{cms}}_{\min} \Rightarrow -k^2_{\min}}$$

- **The *magnitude* of $k^2_{\min}$ depends strongly on Q^2, β, $x_{I\!P}$.**

Pomeron "structure function"

Diffractive structure function:

$$F_2^{D(3)} = \int_0^{M_X^2/4} \mathrm{d}p_\perp^2 \, \frac{\mathrm{d}^4\sigma}{\mathrm{d}Q^2 \, \mathrm{d}\beta \, \mathrm{d}x_{I\!P} \, \mathrm{d}p_\perp^2}$$

- **for $\eta_{\max}$, Q^2, $x_{I\!P}$ such that $p_\perp^2 > 1$ GeV^2, *extract***

$$F_{2\,\mathrm{LRG}}^{D(3)} = \int_{p_{\perp\,\min}^2}^{M_X^2/4} \mathrm{d}p_\perp^2 \, \frac{\mathrm{d}^4\sigma}{\mathrm{d}Q^2 \, \mathrm{d}\beta \, \mathrm{d}x_{I\!P} \, \mathrm{d}p_\perp^2}$$

- $p_{\perp\min}^2$ **is a function of $x_{I\!P}$!**

Therefore:

- $F_{2\,\mathrm{LRG}}^{D(3)}$ **extracted from experiment not expected to factorize into $f(x_{I\!P})\, F_2^{I\!P}(Q^2, \beta)$:**
  - **Even though full structure function $F_2^{D(3)}$ might**
  - **Can't extract well-defined pomeron "structure function", $F_2^{I\!P}$.**

II. Looking at Large Rapidity Cut Data

1. **Look at diffractive DIS data as a function of** $\eta_{\max}$ **:**

   – **once get to** $k^2_{\min} >$ a few GeV **, expect to see reduction of extracted diffractive structure function**

   – **model-independent confirmation of phase space reductions**

   – **test of** $k^2\,(p^2_\perp)$ **dependence of models**

2. **Look at large** $k^2_{\min}$ **data:**

   – $k^2_{\min}$ **very sensitive to** β **and** $x_{I\!P}$

   – **see large–**k^2 **behaviour**

- **We looked at 4 classes of dDIS models:**

  – **Vector-like pomeron with form factor**

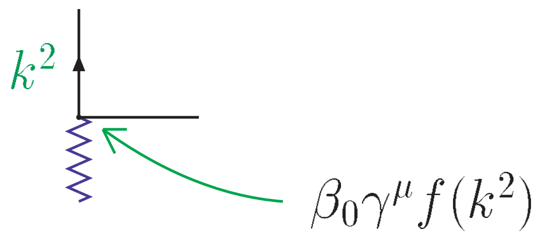
  – **Single Gluon/Soft colour exchange**

  – **Scalar Pomeron**

  – **Two-Gluon**

Comparison of $I\!\!P$-exchange (dijet) models with large rapgap $F_2^{D(3)}$ data

1. Form factor models



Donnachie–Landshoff:

D-L, Phys.Lett. B185 (1997) 403
B191 (1987) 309

$$f(k^2) \sim \frac{1}{k^2}$$

- Extension of $P - P$ scattering model
- $f(k^2)$ preserves $F_2^{D(3)}$ scaling
- strong suppression with large k^2

Ellis–Ross:

E-R, Phys.Lett. B384 (1996) 293

$$f(k^2) \sim \frac{1}{k}$$

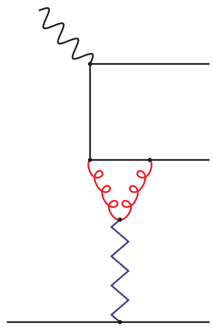
- logarithmic scaling violations in $F_2^{D(3)}$
- contribution from whole k^2 range

E–R motivation

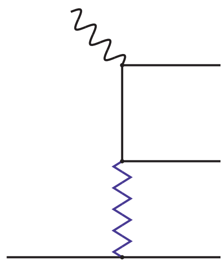
1.

- **data not sensitive to rapgap cuts**

2. Compare:



and



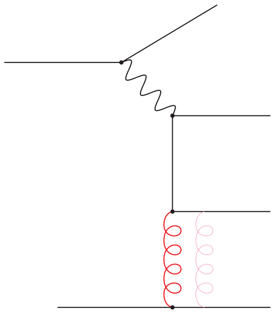
$\longrightarrow$ **extra $1/k^2$ in cross section**

$\longrightarrow$ **identify with form factor $f^2(k^2)$**

2. Single gluon exchange

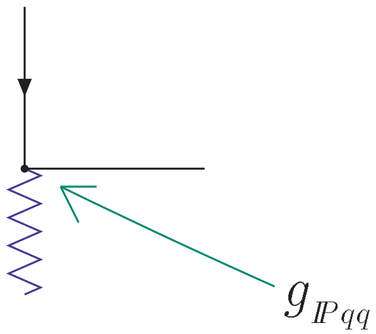
Buchmüller, Hebecker 1995

- colour singlet part of single gluon exchange
- one hard gluon determines dynamics
- additional soft gluons dress colour



3. Scalar pomeron exchange

Vermaseren *et al* 1998

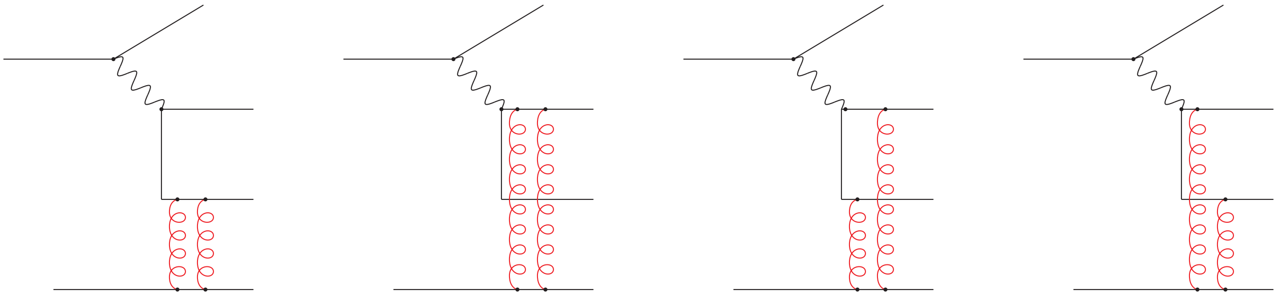


- $g_{I\!Pqq}$ point-like quark–pomeron coupling
- no form factor

4. Two-gluon model

Landshoff, Nachtmann 1987
Diehl 1995, 1998

- **two non-interacting gluons**



- **first two diagrams ∼ "particle exchange"**
- **need all four diagrams for gauge invariance**

- **Diffractive structure function (at large $p^2_{\perp\,\min}$)**

$$F_2^{D(3)} \sim \beta^3\,(1-\beta)$$

– not seen in data

Summary/Future Prospects

Large Pseudo-Rapidity Cuts:

- For some (calculable) range of parameters Q^2, β, and $x_{I\!P}$:

  • ***Significant reduction in phase space available for diffractive DIS***

  • Quantifying this result leads to a ***test of models of diffractive DIS***

- Source of $x_{I\!P}$ factorization-breaking

- We examined 4 classes of pomeron exchange models:

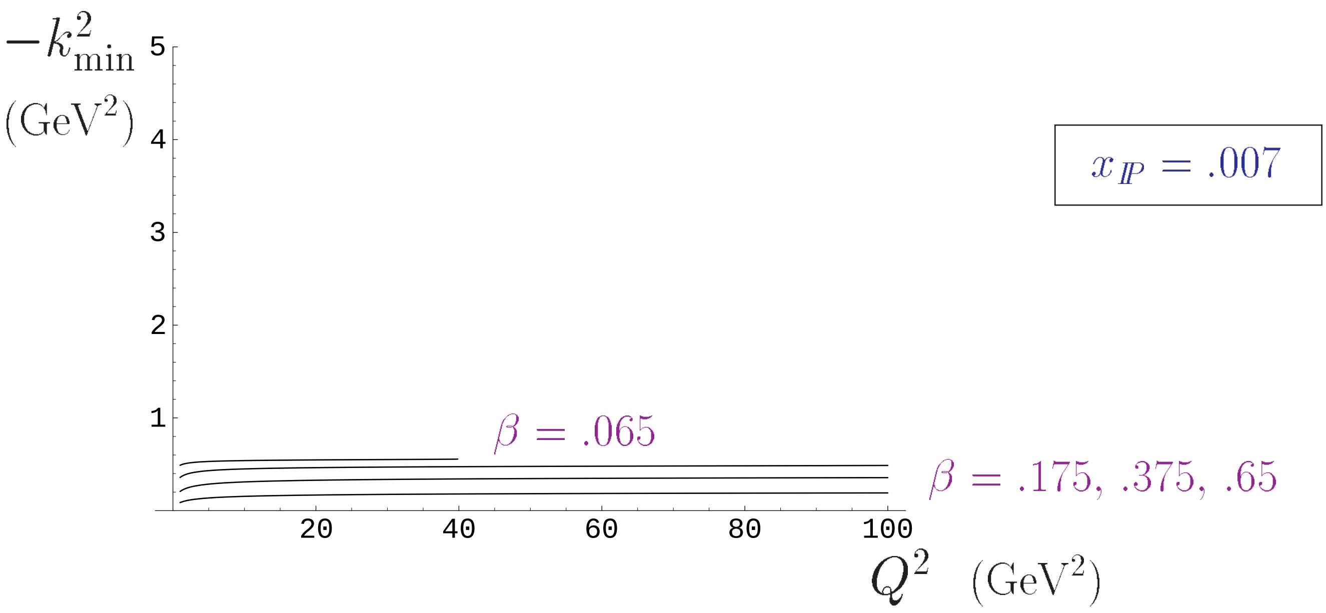
  – E–R form factor model fits well

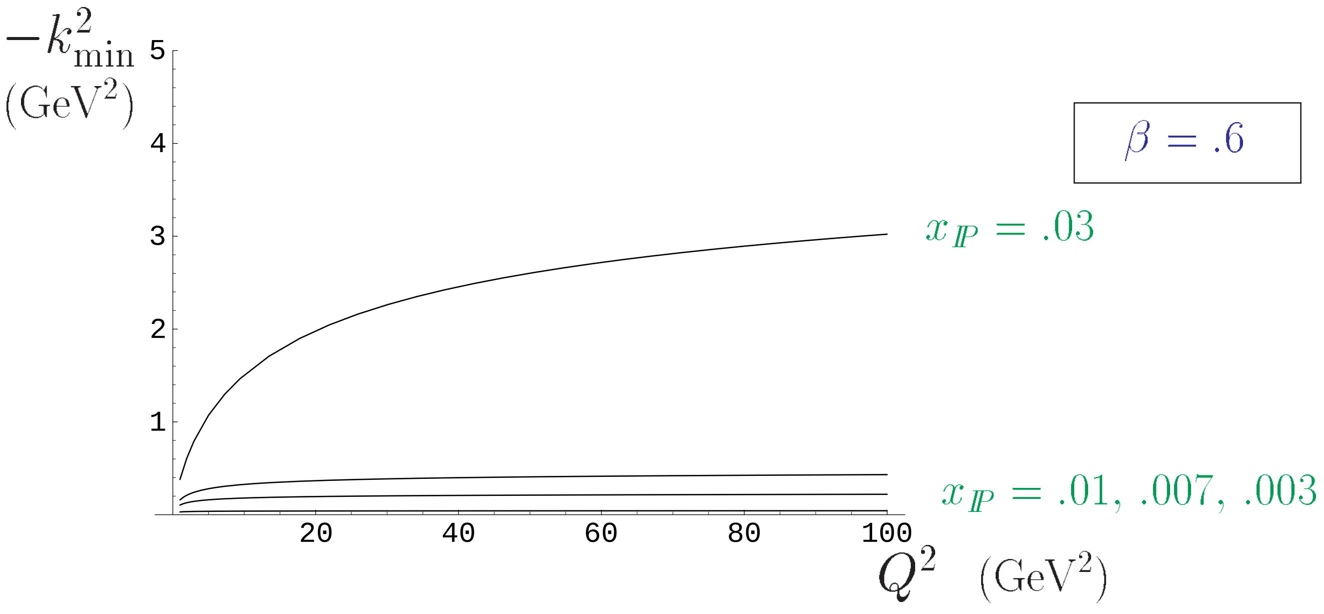
  – Two-gluon model does not describe β-dependence

- Need more data with strong $\eta_{\max}$ to test ideas here

- Monte Carlo studies of LRG production under way

Dependence of $-k^2_{\min}$ on Q^2, β, and $x_{I\!P}$





$$\eta_{\max} = 3.2 \quad (\text{expt})$$