Rapidity Gaps and Tests of Models of Diffractive DIS

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Ellis, Ross, Phys.Lett. B384 (1996) 293
ERW, hep-ph/9812385

Outline

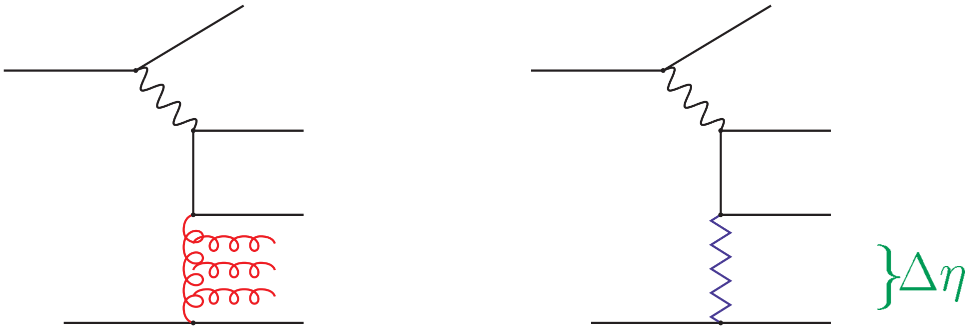
- Introduction
- Kinematics
- Consequences of Strong Pseudo-Rapidity Cuts
- Tests of Pomeron Models
- Comparison with Experiment
- Summary and Conclusions

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**

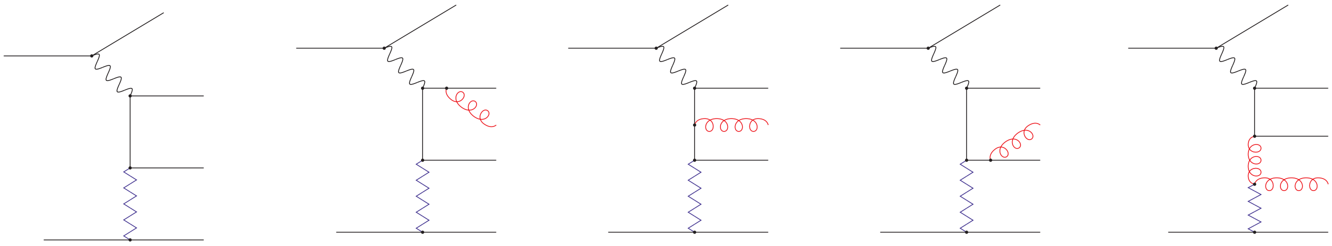
$\longrightarrow$ pomeron



Pseudo–rapidity:

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

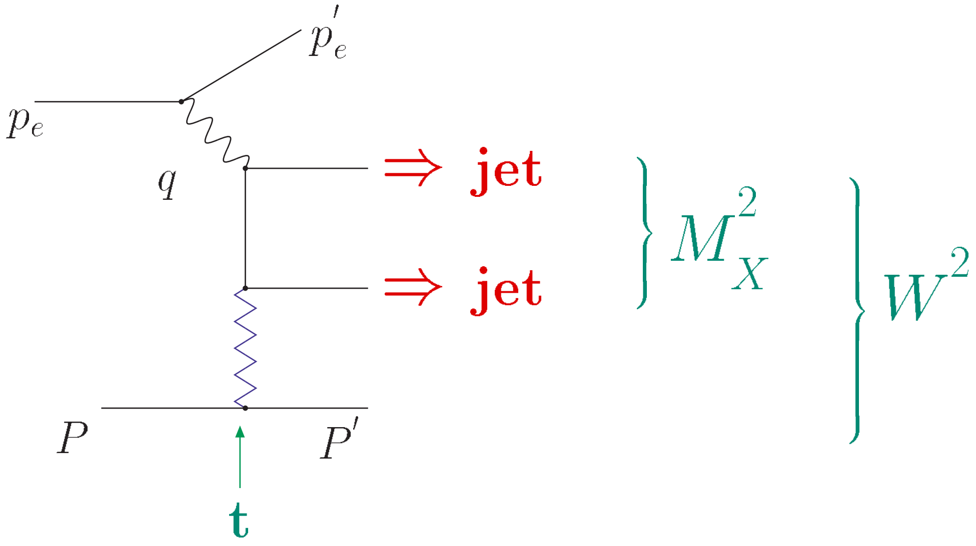
Diffractive DIS $\equiv$ photon probing structure of $\mathbb{P}$



Kinematics I

$$e + P \rightarrow e^{'} + P^{'} + X$$

Diffractive dijet production: $\gamma^* \rightarrow q\bar{q}$



$Q^2 = -q^2$ photon virtuality

$x_{\mathrm{Bj}} = \frac{Q^2}{2P\cdot q}$ Bjorken variable $y = \frac{Q^2}{x_{\mathrm{Bj}}\, s}$

$x_{I\!P} = \frac{(P-P')\cdot q}{P\cdot q} \approx \frac{Q^2+M_X^2}{Q^2+W^2}$ proton momentum in $I\!P$

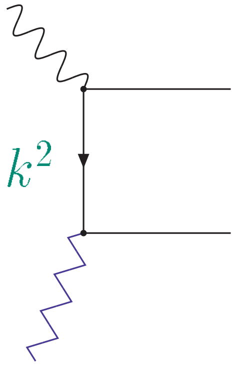
$t = (P - P^{'})^2$ momentum transfer at P vertex

$\beta \approx \frac{Q^2}{Q^2+M_X^2}$ $I\!P$ momentum in struck quark

$x = \beta x_{I\!P}$

Kinematics II

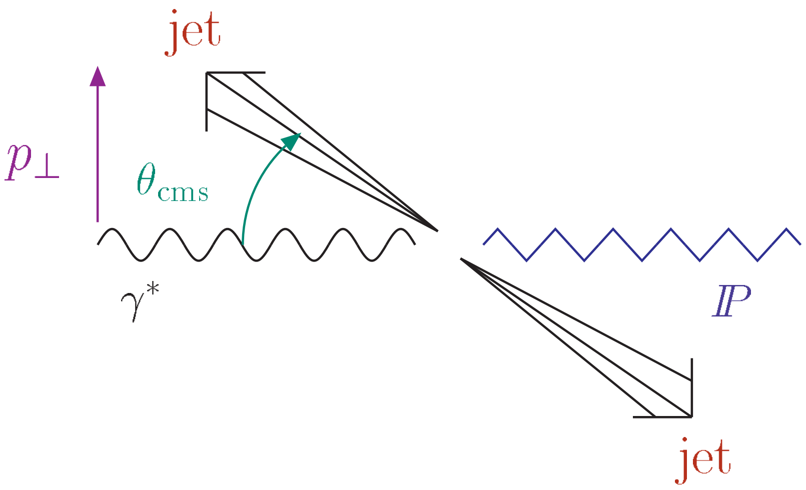
- **Exchanged quark virtuality** **($\gamma^* - I\!\!P$ cms):**



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

$\theta_{\rm cms}$ = **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 ∼ *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 $F_2^{I\!P}$:

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

LRG Events: Experiment and Theory

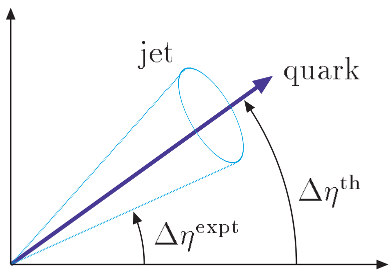
Early analyses used very strong rapidity cuts

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

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

- These cuts are made at *hadron* level

- Corresponding pseudo-rapidity at *parton* level:



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

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

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

e.g.

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

Consequences of large rapidity gap cuts

Ellis, Ross 1996

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

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

boost: LAB → CMS

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

$\phi_{\rm lab}$ **= 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:** $-k^2 = \frac{Q^2}{2\beta}(1-\cos\theta_{\rm cms})$

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

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

Pseudo-rapidity cut data

Q^2 GeV^2	β	$x_{I\!P}$	$-k^2_{\mathrm{min}}$ GeV^2
8.5	0.065	0.00365	2.3
		0.00649	6.7
12	0.065	0.00649	6.9
		0.01154	19
		0.02052	44
		0.03648	82
	0.175	0.00429	2.5
		0.00762	6.4
		0.01355	14
		0.02410	26
	0.375	0.00356	1.1
		0.00632	2.7
		0.01125	5.5
	0.65	0.00649	1.2
25	0.065	0.01154	21
		0.02052	55
		0.03648	120
		0.06488	200
	0.175	0.00429	2.7
		0.00762	7.4
		0.01355	18
25	0.175	0.02410	38
		0.04285	62
	0.375	0.00356	1.3
		0.00632	3.3
		0.01125	7.5
		0.02000	14
	0.65	0.00649	1.5
		0.01154	3.1
50	0.175	0.00762	8.2
		0.01355	22
		0.02410	51
		0.04285	95
		0.07620	140
	0.375	0.00356	1.4
		0.00632	3.8
		0.01125	9.4
		0.02000	20
		0.03556	35
	0.65	0.00649	1.9
		0.01154	4.2
		0.02052	7.9

Struck quark virtuality constraints for large pseudo-rapidity cut data

“Pomeron structure function”

Diffractive structure function:

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

- for η_{max} , Q^2, $x_{I\!P}$ such that $p_\perp^2 > 1\ \mathrm{GeV}^2$:
  - very sensitive to lower limit of $p_\perp^2$
  - $p^2_{\perp\,\mathrm{min}}$ very sensitive to Q^2, β, $x_{I\!P}$ through boost parameters

Therefore:

- $F_{2_{\mathrm{LRG}}}^{D(3)}$ does not factorize into $f_{I\!P/P}\, F_2^{I\!P}(Q^2,\beta)$:
  - even though full structure function $F_2^{D(3)} = \int_0^{M_X^2/4}$ might
  - $x_{I\!P}$ dependence feeds in through $p^2_{\perp\,\mathrm{min}}$

Tests of Pomeron Exchange Models

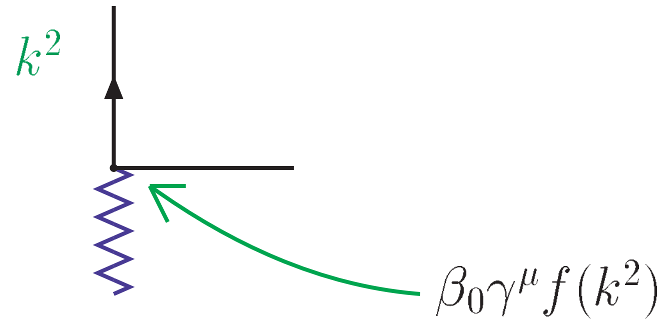
1. **Pseudo-rapidity gap data for which $k^2_{\rm min} > 1\,{\rm GeV}^2$**
   - see large–k^2 behaviour
   - $k^2_{\rm min}$ very sensitive to β and $x_{I\!P}$
   - need pseudo-rapidity cut data with:
     - wider range of Q^2, β, $x_{I\!P}$
     - better statistics

2. **Two data samples with different rapidity cuts:**
   - model-independent confirmation of phase space reductions
   - test of k^2-dependence of models

- **We compared five models with large rapidity gap diffractive structure function data:**
  - Donnachie–Landshoff
  - Ellis–Ross
  - Single Gluon
  - Scalar Pomeron
  - Two-Gluon

Donnachie-Landshoff Form Factor Model

- **Extend model of proton-proton scattering**



D–L form factor:

$$f(k^2) = \frac{\Lambda^2}{\Lambda^2 - k^2} \qquad \Lambda^2 \approx 1\,\mathrm{GeV}^2$$

- **approximate point-like coupling**
- $f(k^2)$ **preserves scaling of** $F_2^{D(3)}$

Also:

- **very sensitive to virtuality,** k^2

Ellis-Ross Form Factor Model

E–R form factor:

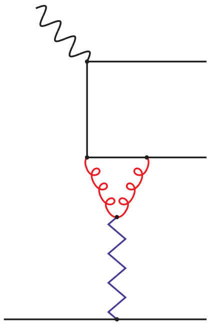
$$f(k^2) = \sqrt{\frac{\Lambda^2}{\Lambda^2 - k^2}}$$

Motivation:

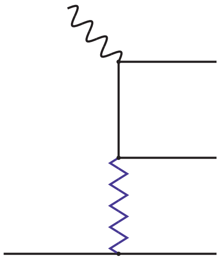
- more contribution from large k^2
- less sensitive to pseudo-rapidity cuts
- logarithmic scaling violation

Also:

Compare



and



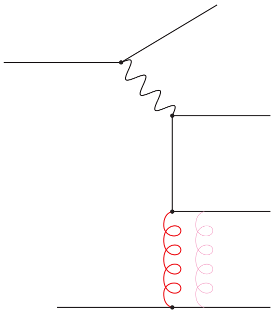
$\longrightarrow$ extra $1/k^2$ in cross section

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

Single gluon exchange

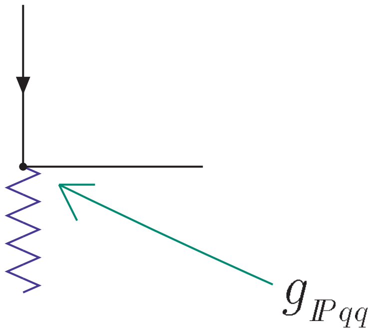
Buchmüller, Hebecker 1995

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



Scalar pomeron exchange

Vermaseren *et al* 1998

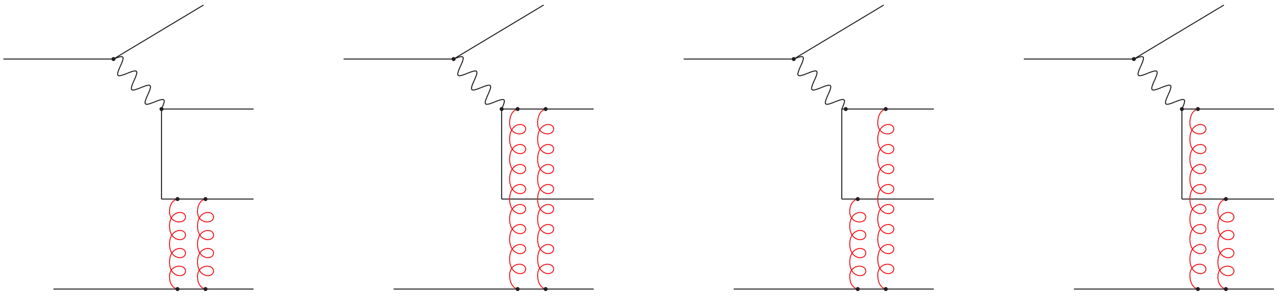


- $g_{I\!Pqq}$ point-like quark–pomeron coupling
- no form factor

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**

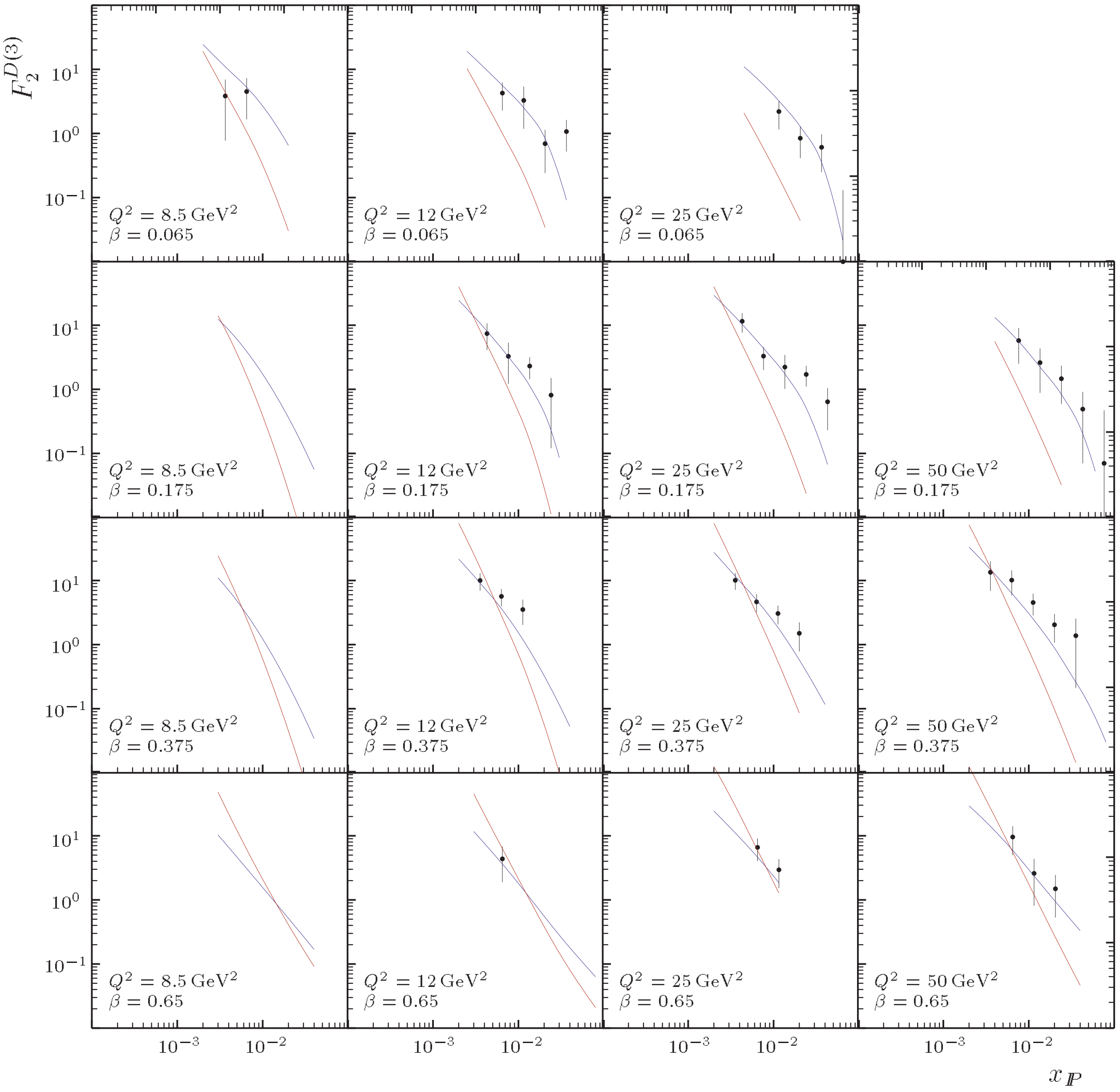
- **Diffractive structure function (at large $p^2_{\perp\,\mathrm{min}}$)**

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

– not seen in data

E-R and D-L models

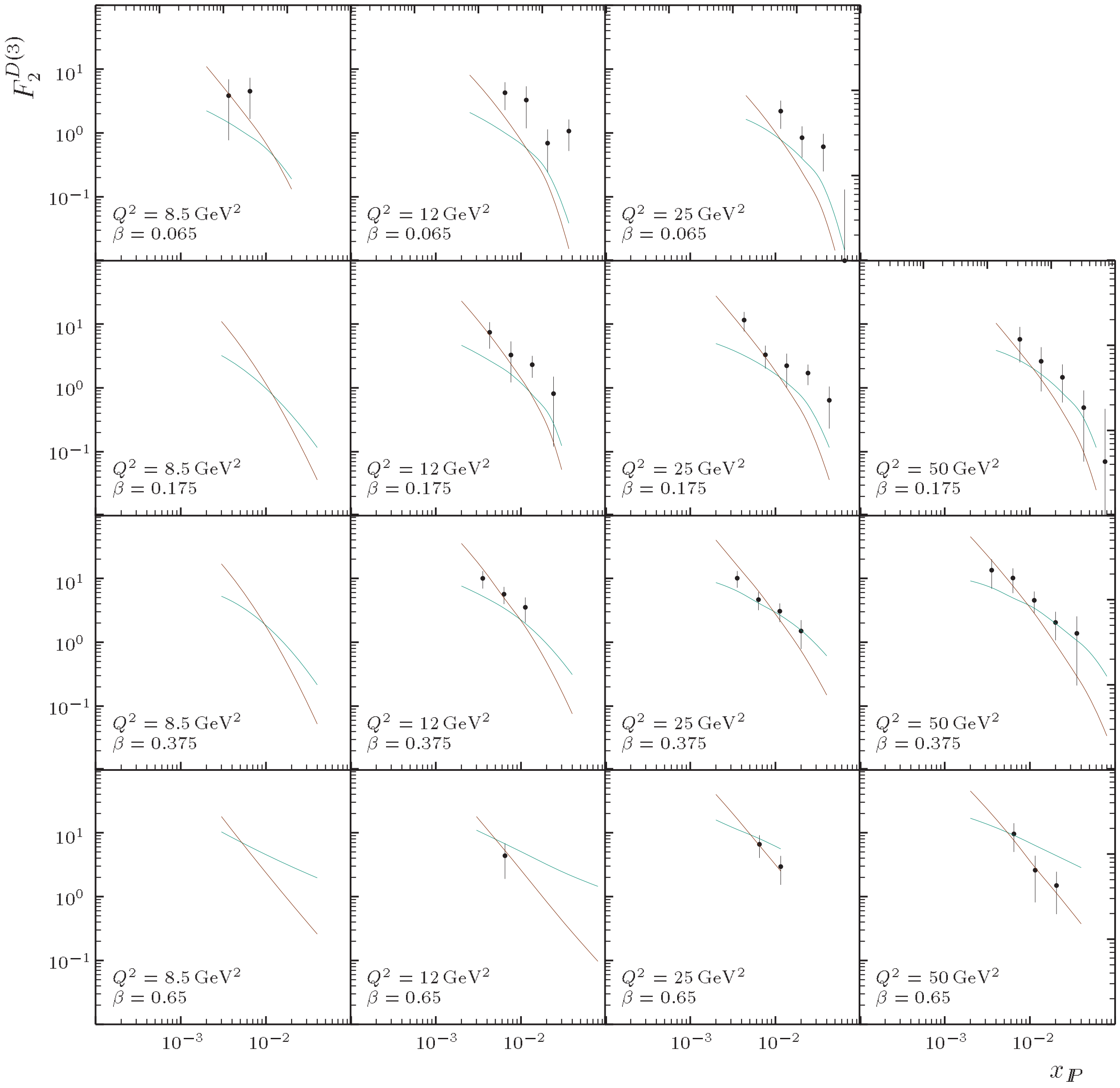
- **Diffractive structure function**



Diffractive structure function $F_2^{D(3)}$ for E-R and D-L form factor models. Pseudo-rapidity cut: $\eta_{\max} = 1.8$. Pomeron intercept $\alpha_{I\!P}(0) = 1.08$. Points correspond to data for which $-k^2_{\min} > 1\,\mathrm{GeV}^2$. Blue line is the Ellis-Ross (E-R) model, red line is Donnachie-Landshoff (D-L) model.

Single Gluon and Scalar Pomeron models

- **Diffractive structure function**

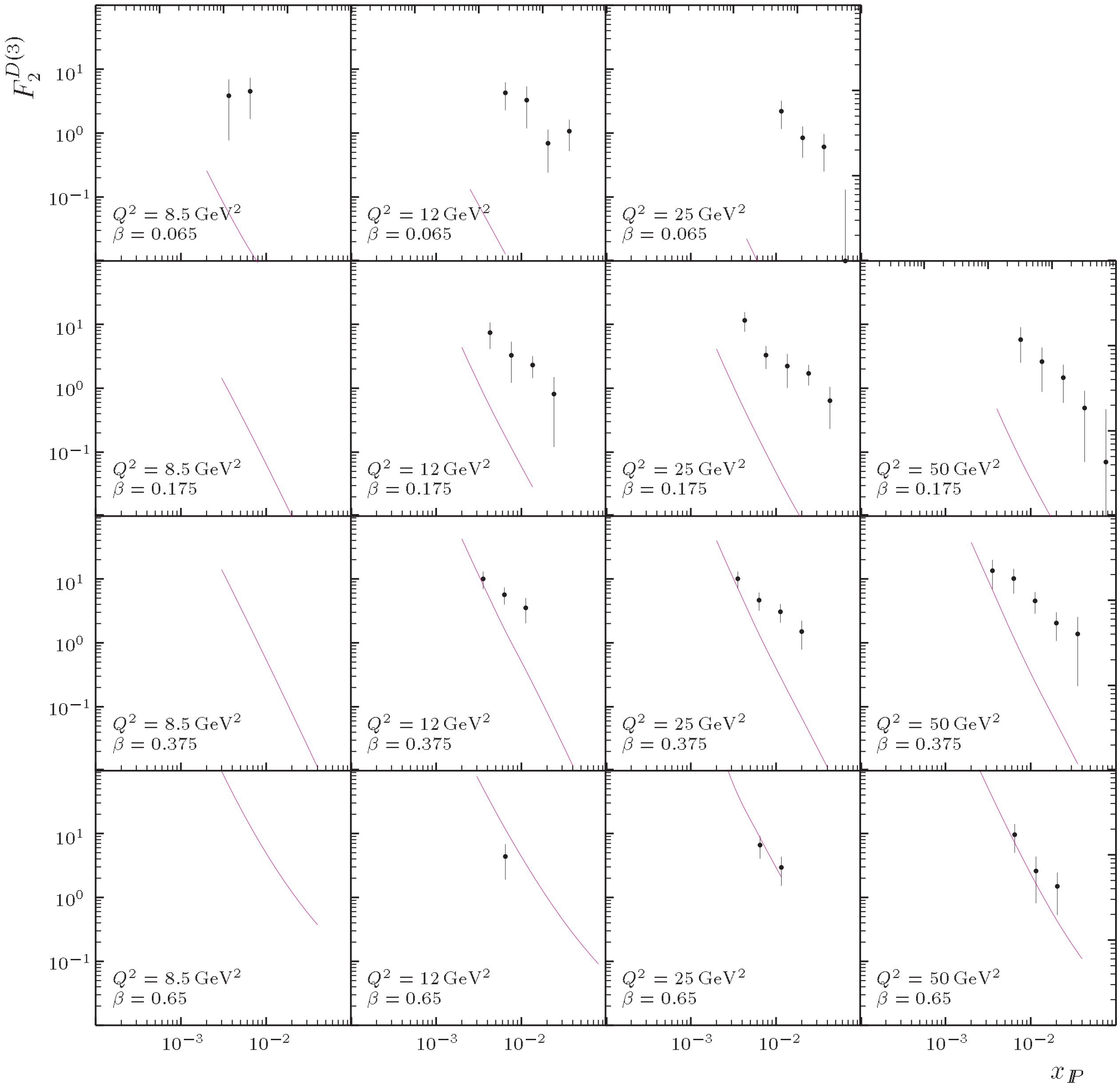


Diffractive structure function $F_2^{D(3)}$ for single gluon exchange and scalar pomeron models.

Green line is the single gluon exchange model, brown line is the scalar pomeron model.

Two-Gluon Model

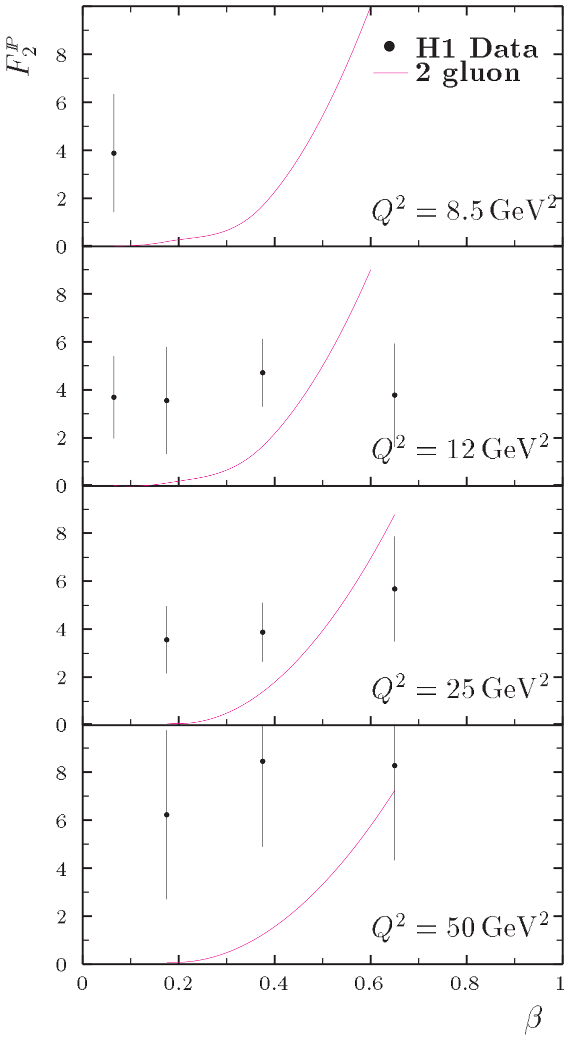
- **Diffractive structure function**



Diffractive structure function $F_2^{D(3)}$ for two-gluon model.

Two-Gluon Model

- **Pomeron "structure function"**



Pomeron structure function $F_2^{I\!P}$ for two-gluon exchange model.

Summary of fits of models with data

	χ^2/dof	
	$\alpha_{I\!P}(0) = 1.08$	$\alpha_{I\!P}(0) = 1.2$
E-R:	$37/41$	$54/41$
D-L:	$102/41$	$97/41$
Single gluon:	$64/41$	$57/41$
Scalar Pomeron:	$48/41$	