Diffraction at High and Low Q^2 at HERA

Paul Thompson

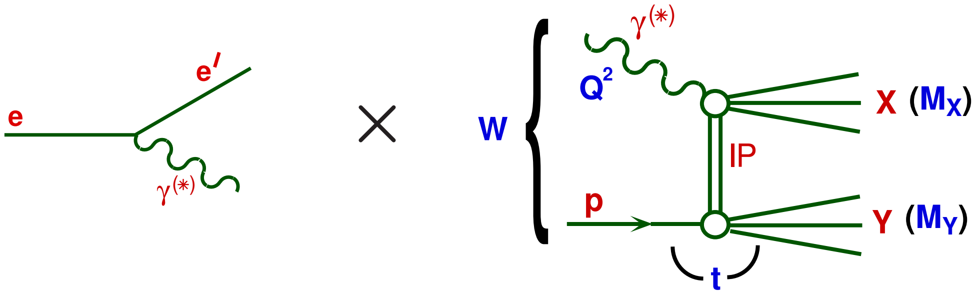
Birmingham University

Representing the H1 and ZEUS Collaborations.

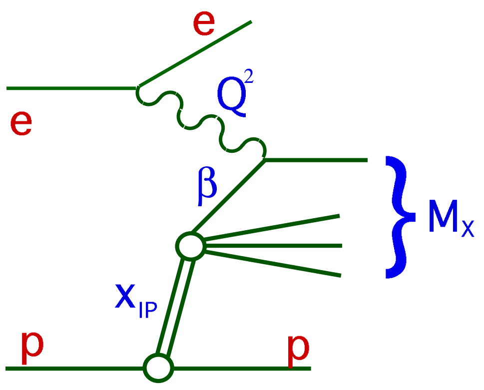
- Kinematics
- Measurement Techniques
- QCD models
- Diffractive Structure Function Measurements
- $\gamma^* p$ centre of mass energy dependence
- β and Q^2 dependences

Diffraction at HERA

At HERA, diffractive $\gamma^{(\star)} p$ interactions can be studied . . .



Diffractive Kinematics



$$x_{I\!P} = \frac{q.(p-p')}{q.p} \simeq \frac{Q^2+M_X^2}{Q^2+W^2}$$

$$\beta = \frac{Q^2}{q.(p-p')} \simeq \frac{Q^2}{Q^2+M_X^2}$$

$$t = (p-Y)^2$$

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

Diffractive Structure Function . . .

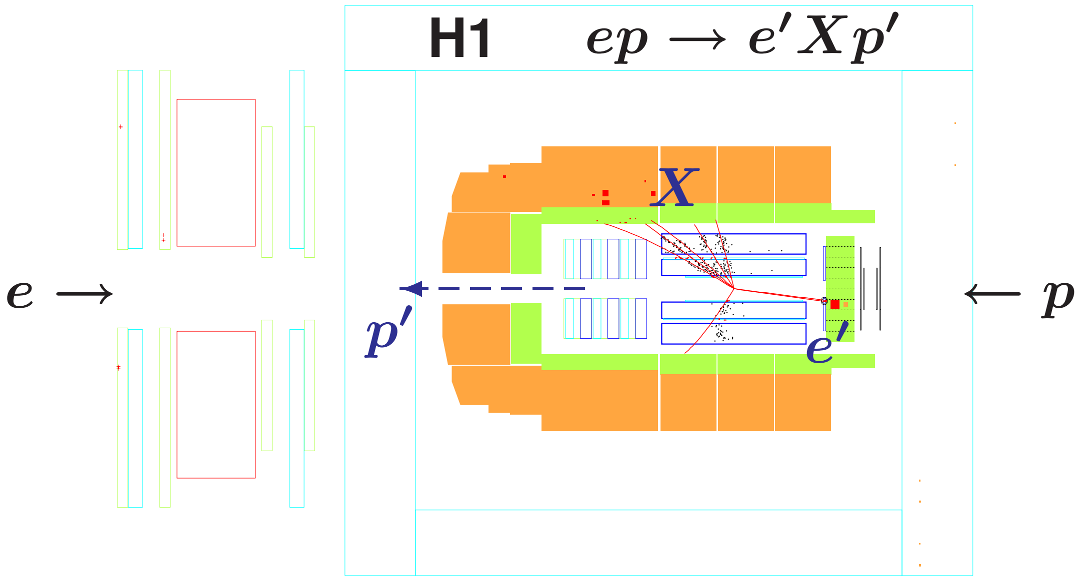
$$F_2^{D(4)}(\beta, Q^2, x_{I\!P}, t) = \frac{\beta\, Q^4}{2\pi\alpha^2(1-y+y^2/2)} \frac{\mathrm{d}\sigma_{ep\to eXY}}{\mathrm{d}\beta\ \mathrm{d}Q^2\ \mathrm{d}x_{I\!P}\ \mathrm{d}t}$$

(Assumes $F_L^{D(4)} = 0$)

Measurement Techniques

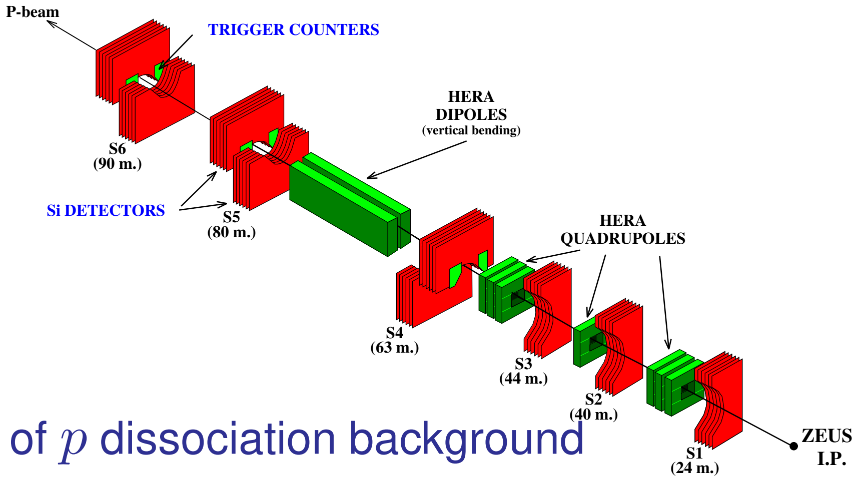
1. Require large rapidity gap

   Reconstruct kinematics from X
   Integrate over t and M_Y



2. Direct measurement of Leading Protons

$$x_L = \frac{p^{LP}}{E_p}\ ,\ t = -\frac{(p_T^{LPS})^2}{x_L}$$



Free of p dissociation background

Measure t distribution

But lower statistics due to acceptance

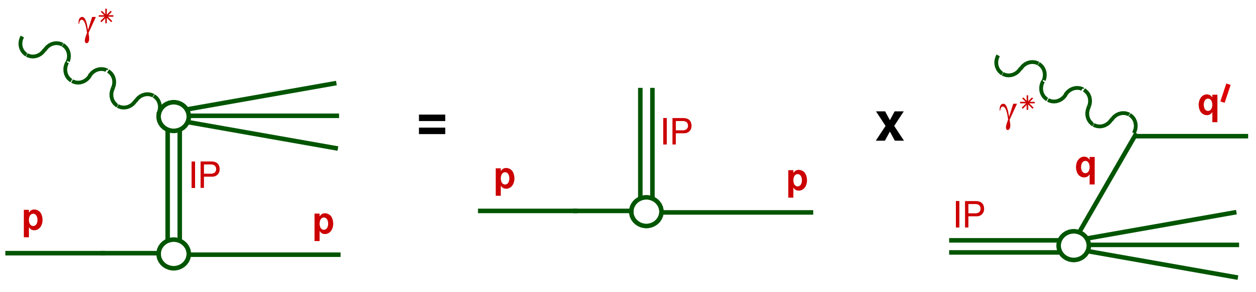
Measure azimuthal asymmetry $\rightarrow$ sensitivity to $R_D = \frac{\sigma_L}{\sigma_T}$

Models of Diffraction

Resolved Pomeron Model

Regge motivated *pomeron* flux

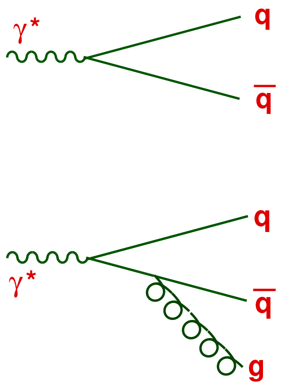
Structure functions evolve according to DGLAP



$$\sigma(\gamma^* p \to Xp) \qquad \sim \qquad f_{\mathrm{IP}/\mathrm{p}}(x_{I\!P}, t) \qquad \otimes \qquad F_2^{\mathrm{IP}}(\beta, Q^2)$$

Dipole Models

$\gamma^* \to q\bar{q}, q\bar{q}g$ well in advance of target in proton rest frame . . .



$\times$

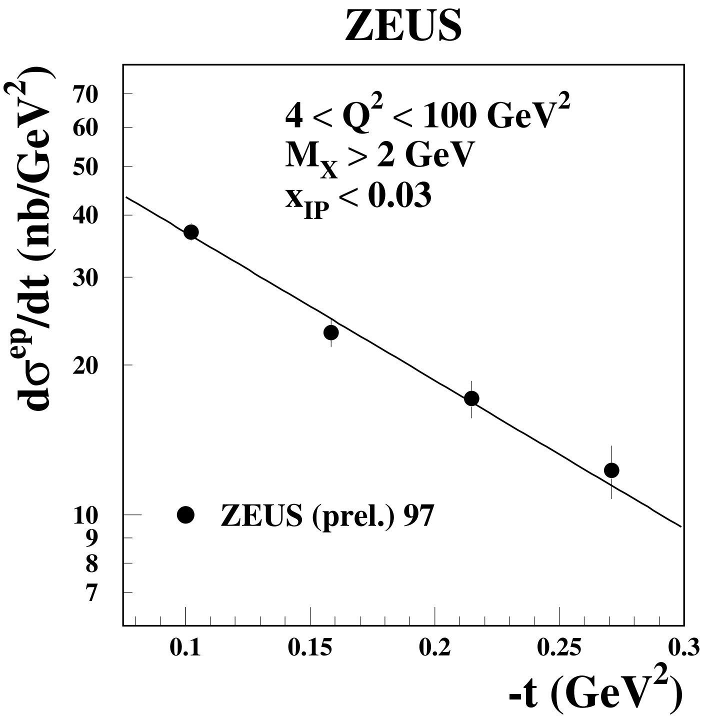
Cross section for colour dipole to scatter elastically from proton

Simple relationships between σ_{tot}, σ_{el} and σ_{dif}

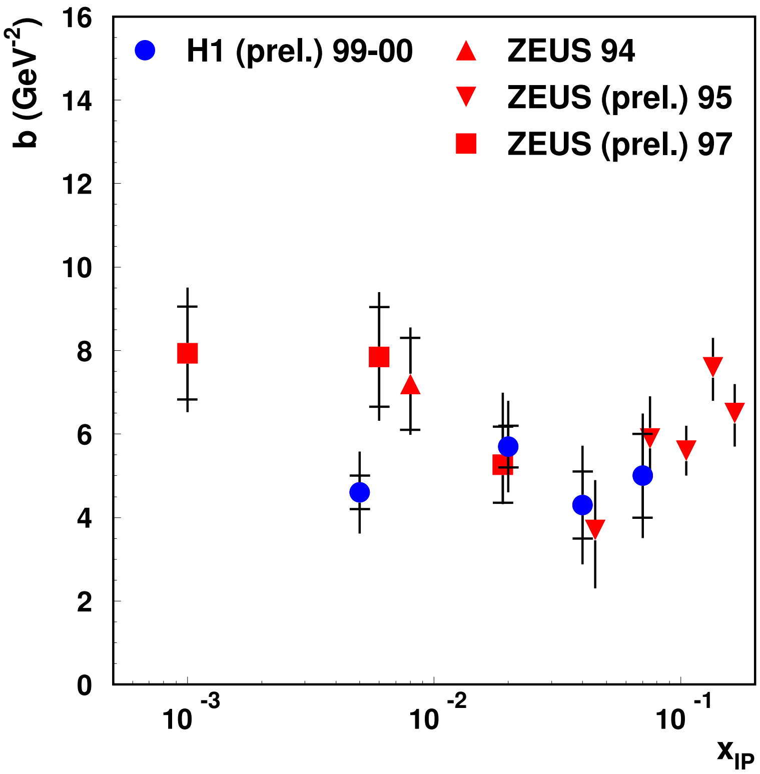
Describe diffraction beyond leading twist (high β?)

e.g. ‘saturation’ model (Golec-Biernat, Wüsthoff)

t Dependence



fit: $\frac{\mathrm{d}\sigma}{\mathrm{d}|t|} \propto e^{(-b|t|)}$ $\quad b = 6.8 \pm 0.6(stat.)^{+1.2}_{-0.7}(syst.)$

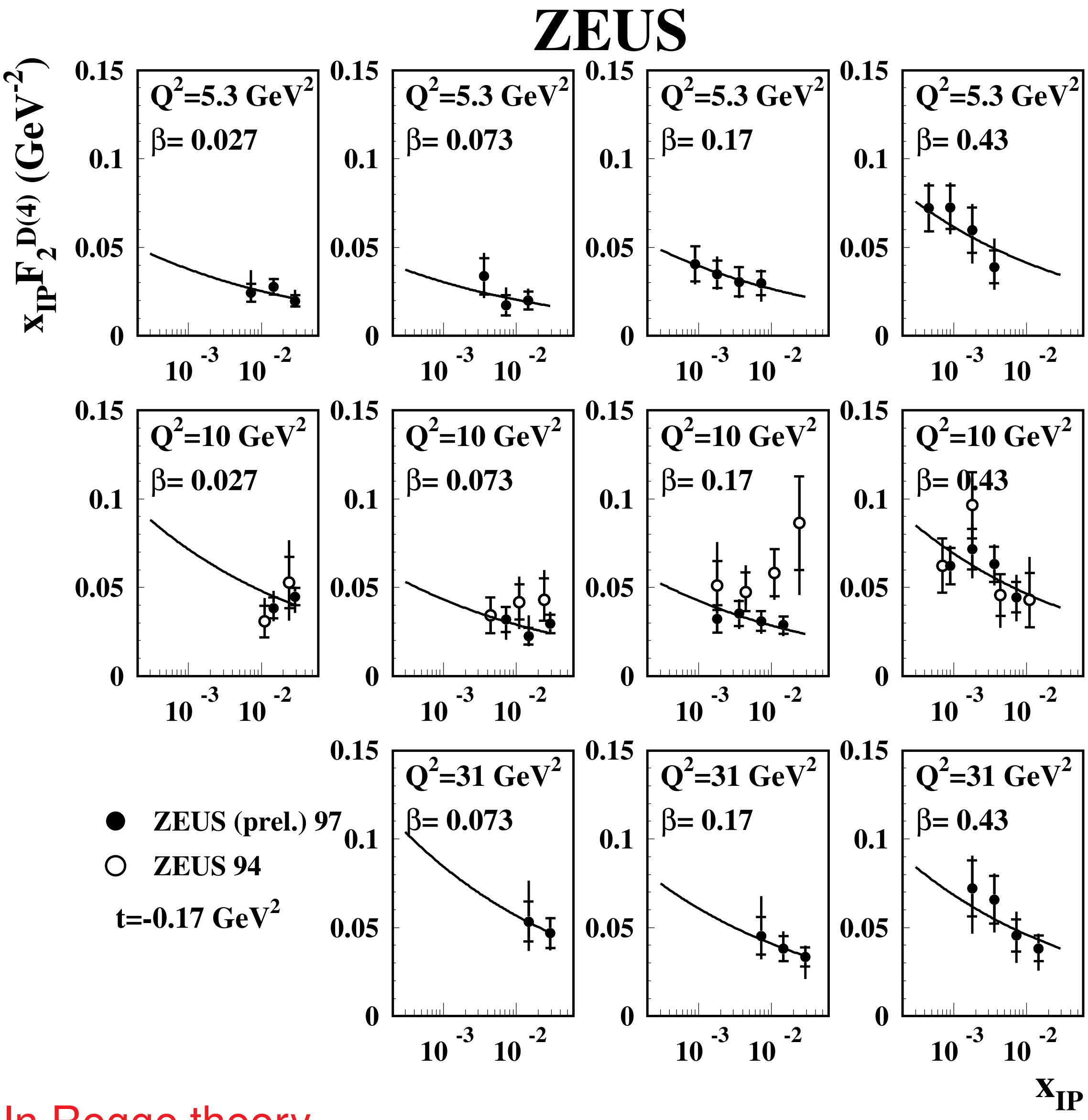


In Regge theory expect shrinkage:

$b = b_0 + 2\alpha' \ln \frac{1}{x_{I\!P}}$

For $x_{I\!P} < 10^{-2}$ data inconclusive

$F_2^{D(4)}$ Measurement



In Regge theory . . .

$$f_{I\!P}(x_{I\!P}, t) \propto \left(\frac{1}{x_{I\!P}}\right)^{2\alpha_{I\!P}(t)-1}$$

$$\alpha_{I\!P}(t) = \alpha_{I\!P}(0) + \alpha' t$$

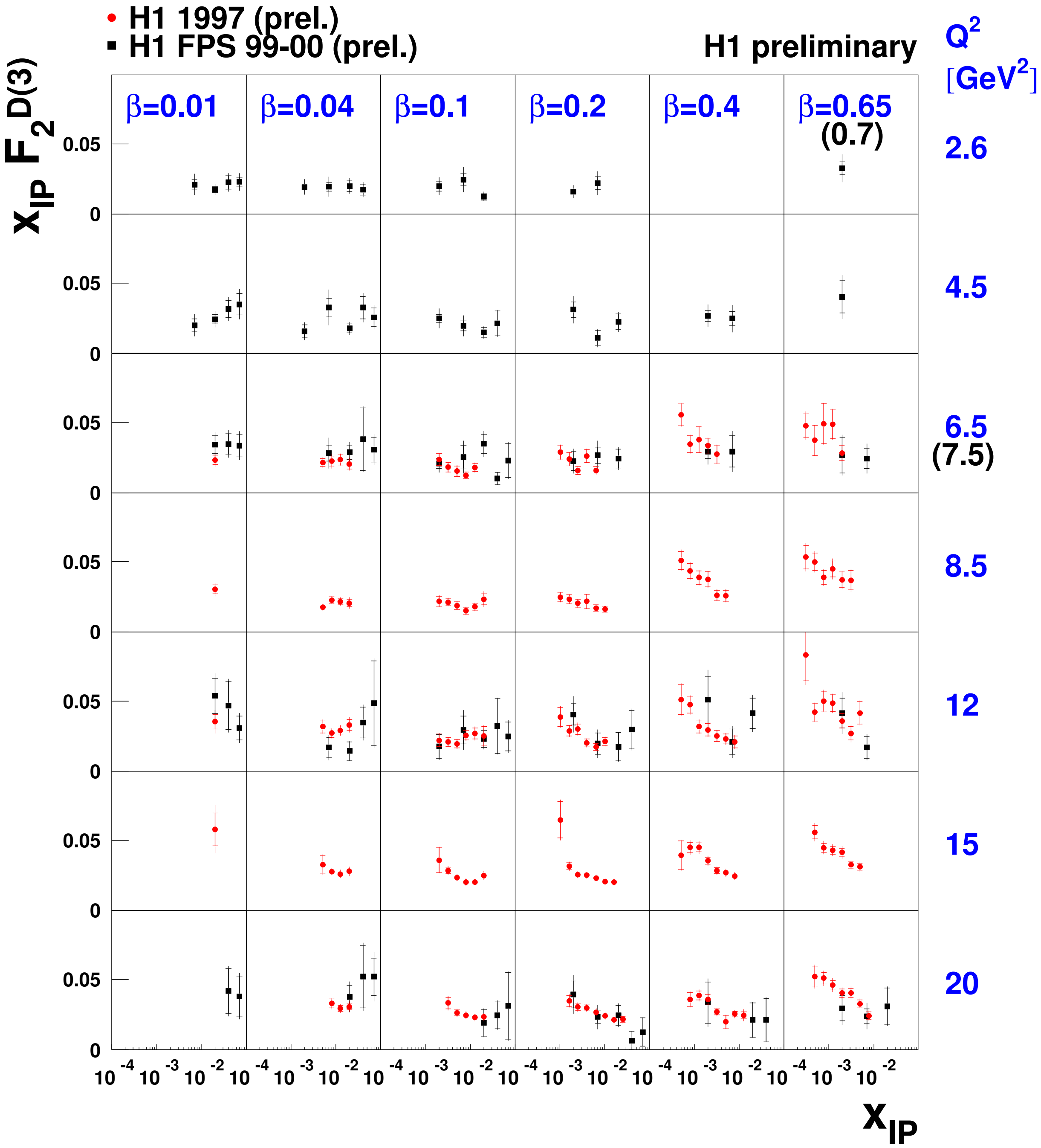
Extract $\alpha_{I\!P}$ by fitting $x_{I\!P}$ dependence at fixed β,Q^2

$$\alpha_{I\!P}(0) = 1.13 \pm 0.03(stat.)^{+0.03}_{-0.01}(syst.)$$

Comparison with Rapidity gap analysis

$F_2^{D(3)} = \int F_2^{D(4)}\,\mathrm{d}t$

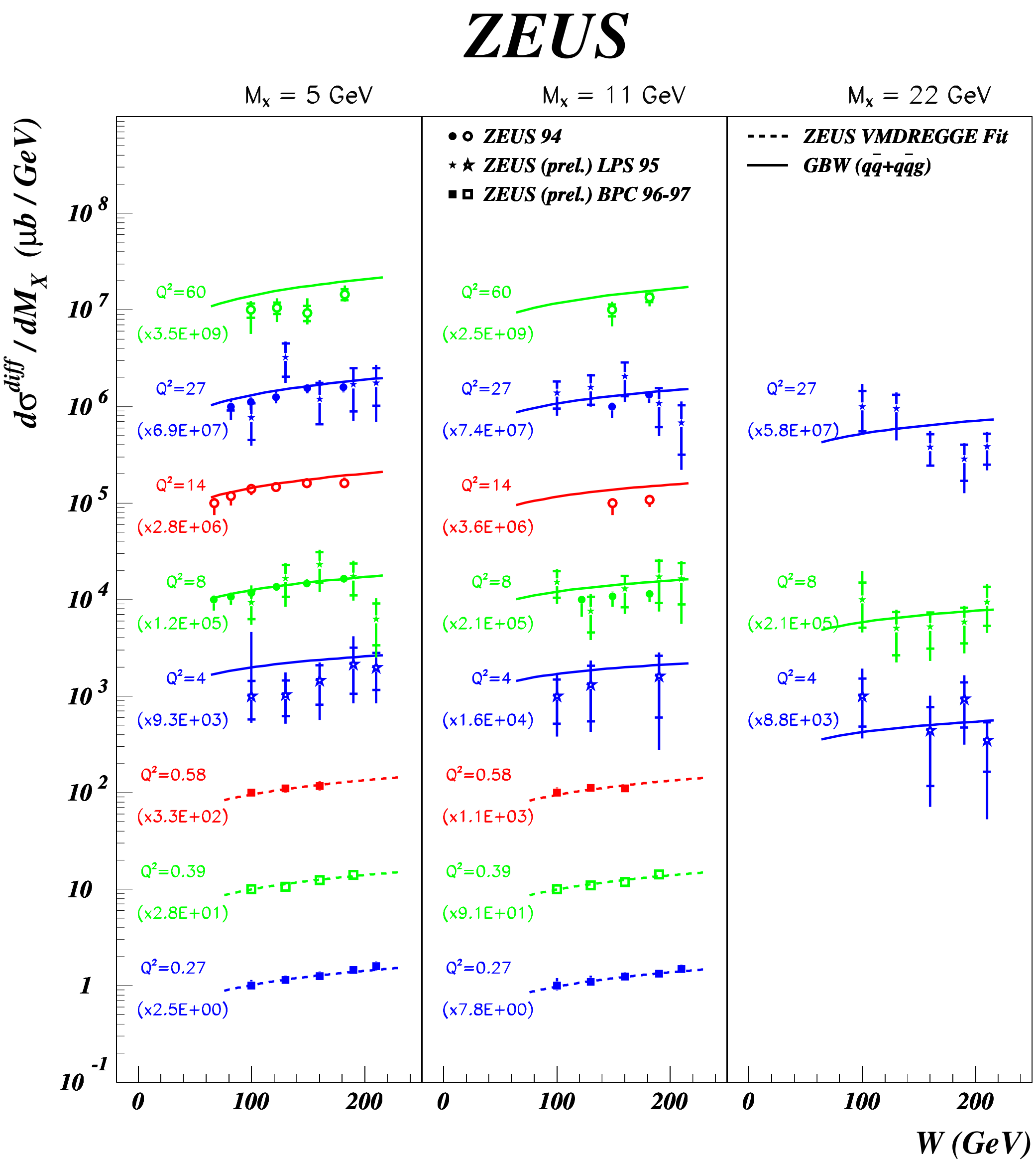
Use measured t-slope to extrapolate to full t range



Extraction of $F_2^{D(3)}$ with measured leading proton compatible with results from rapidity gap analysis

Also $F_2^{D(3)}$ LPS/FPS results from H1 and ZEUS compatible

Energy Dependence of Inclusive Diffraction



$$\frac{d\sigma^{diff}}{dM_X} \propto (W^2)^{2\alpha_{I\!P}-2}$$

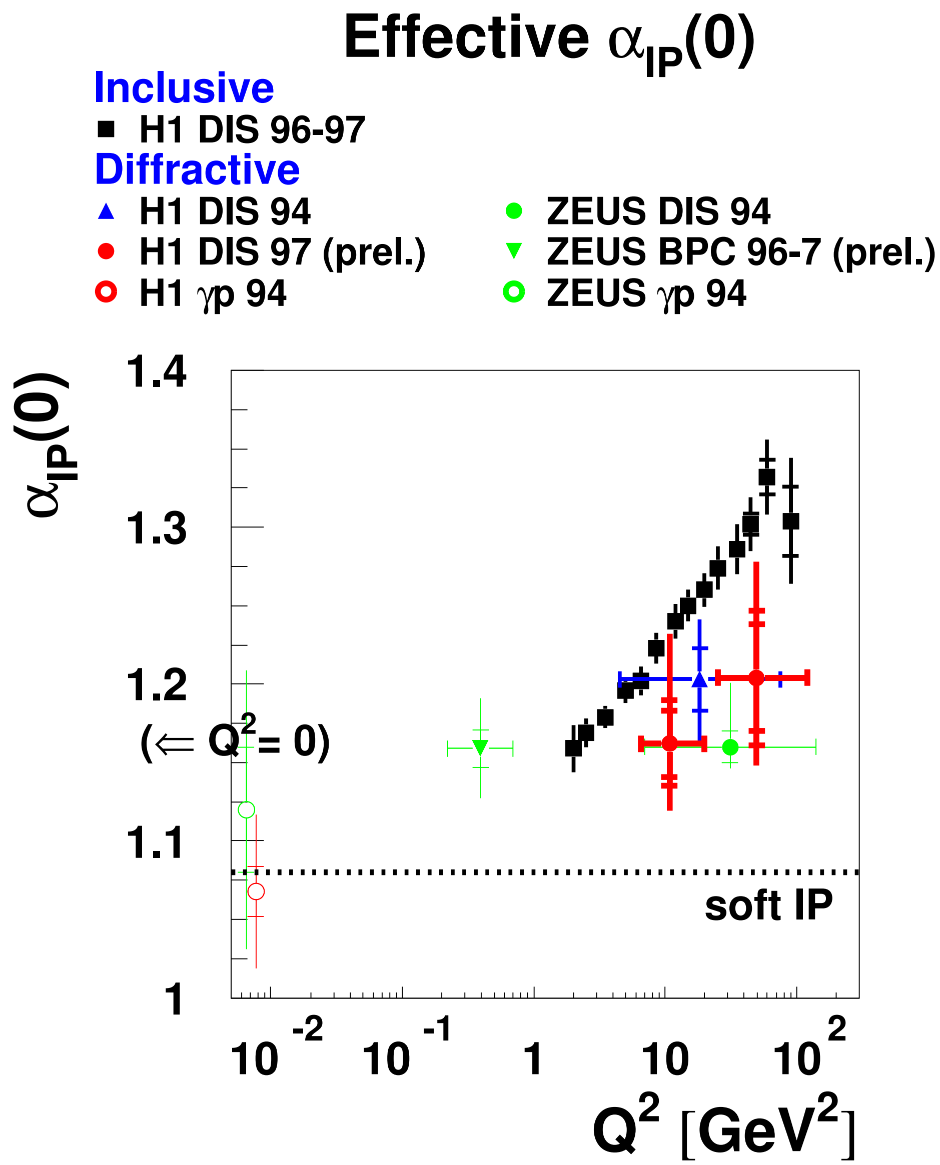
Is there any dependence of $\alpha_{I\!P}(0)$ with Q^2?

How does W dependence compare with inclusive DIS?

Overview of Energy Dependence for F_2 and F_2^D

Compare effective $\alpha_{I\!P}(0)$ from F_2^D and F_2 ...

$x_{I\!P} F_2^D \sim A(\beta, Q^2)\ x^{2-2\langle\alpha_{I\!P}(t)\rangle}$ $\qquad$ $F_2 \sim B(Q^2)\ x^{1-\alpha_{I\!P}(0)}$



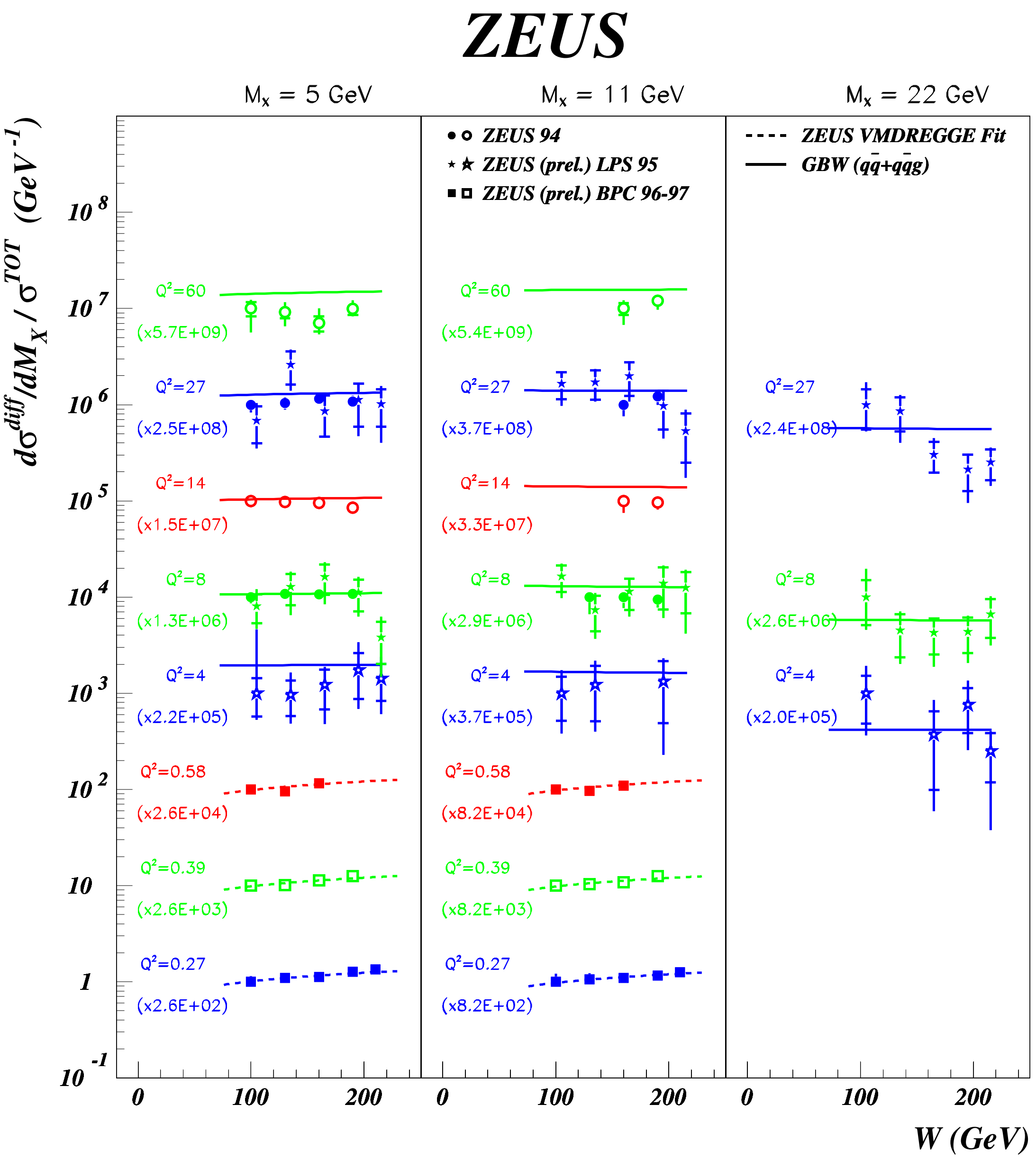
$\alpha_{I\!P}(0)$ grows with Q^2 $\rightarrow$ larger than soft $I\!P$ at large Q^2?

Growth of effective $\alpha_{I\!P}(0)$ slower for diffractive than for inclusive cross section?

Energy dependences of diffractive and inclusive cross sections become similar at large Q^2?

Energy Dependence of Diffractive to Inclusive Ratio

ZEUS data on diffractive / inclusive ratio over wide Q^2 range.



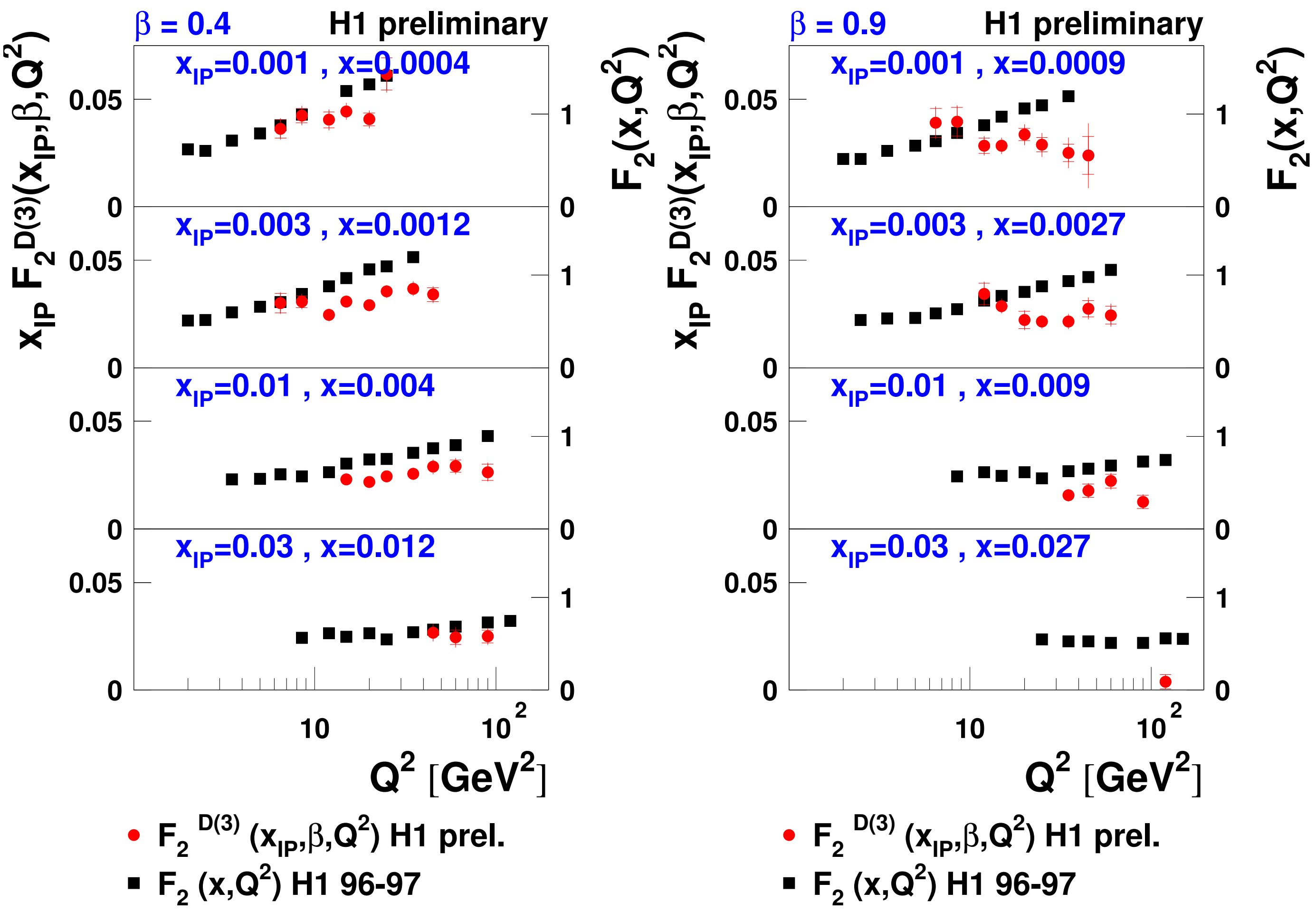
Fits to
$$\frac{\int \mathrm{d}t \;\; \mathrm{d}\sigma^{\mathrm{diff}}_{\gamma^* p\to XY}/\mathrm{d}M_X \;\; \mathrm{d}t}{\sigma^{\mathrm{tot}}_{\gamma^* p\to X}} \propto W^{\rho}$$

$\rho = 0.24 \pm 0.07\,(\mathrm{stat})$ $\quad (0.27 \leq Q^2 \leq 0.58\ \mathrm{GeV}^2$ - Regge-like)

$\rho = 0.00 \pm 0.03\,(\mathrm{stat})$ $\quad (Q^2 \geq 4\ \mathrm{GeV}^2$ - Not Regge-like)

Scaling Violations of F_2 and F_2^D

Compare scaling violations of F_2^D at $x = (x_{I\!P} \cdot \beta)$ with F_2 at x



When compared at the same $\underline{x}$ ...

F_2^D shows similar Q^2 dependence to F_2 at low β.

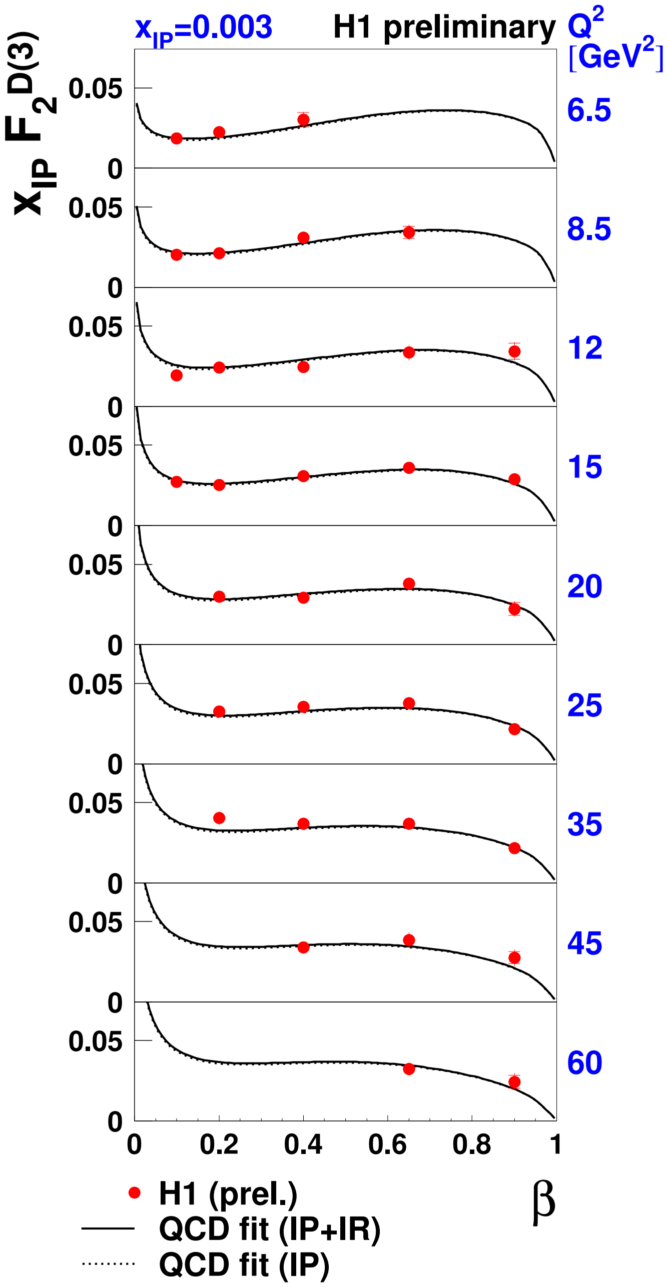
At $\beta = 0.9$, F_2^D falls with Q^2 whereas F_2 continues to rise.

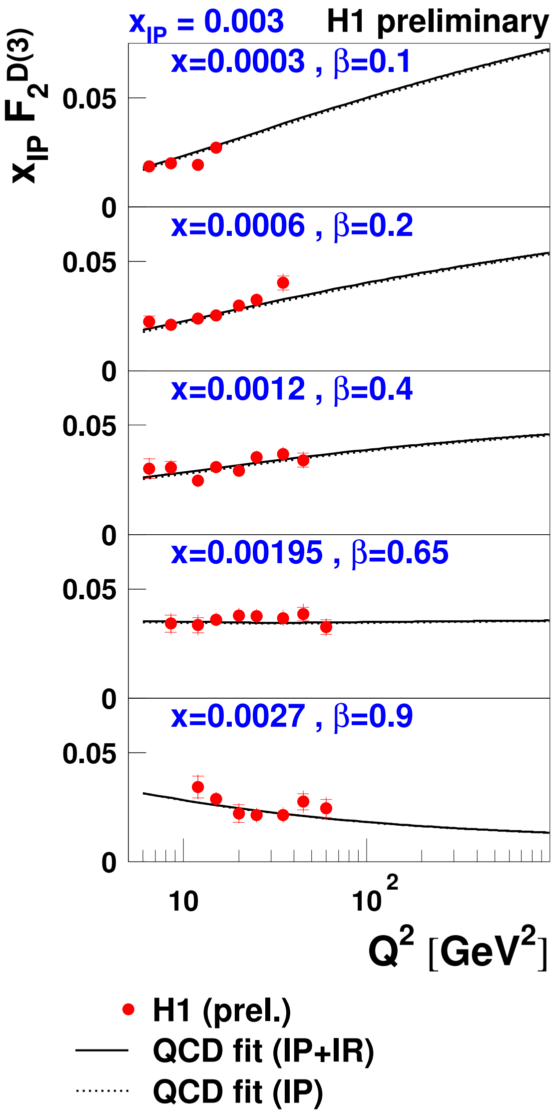
Different dynamics at work in diffractive processes!

e.g. Q^2 suppressed higher twist contributions (e.g. elastic VM production) present at high β

β, Q^2 dependence of $F_2^{D(3)}$

Example results at $x_{I\!P} = 0.003$



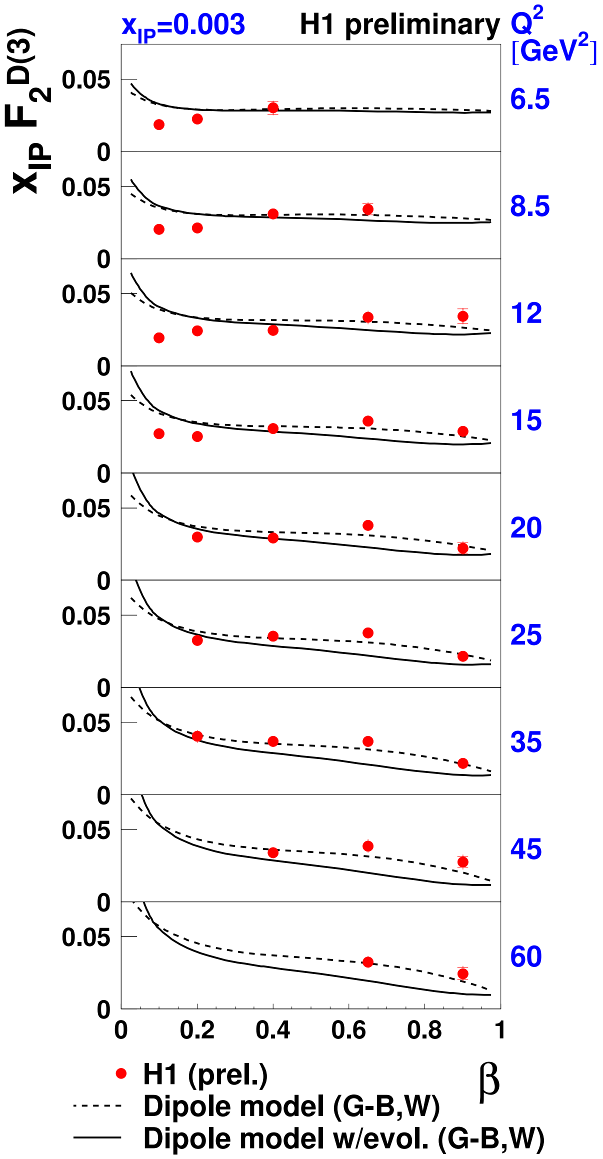


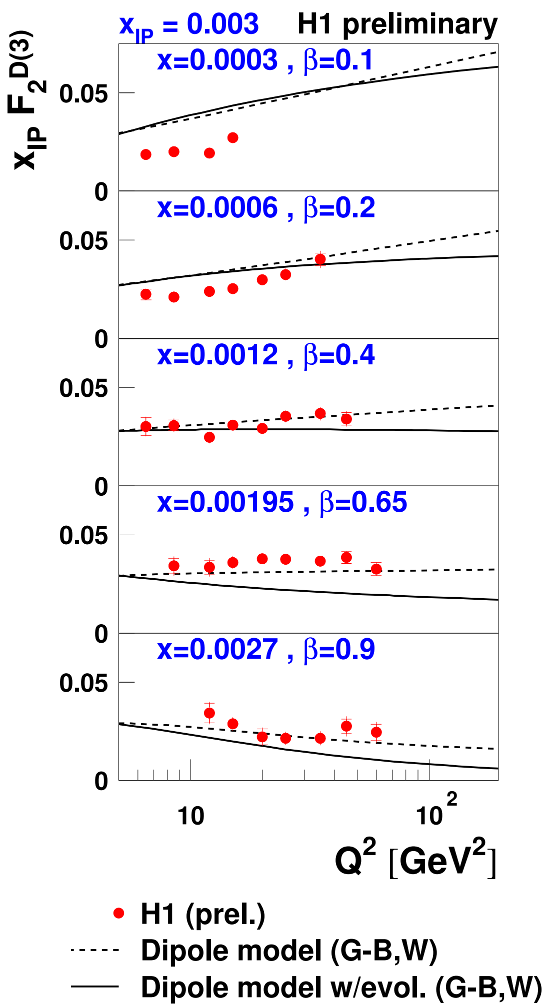
β dependence relatively flat.

Rising scaling violations with $\ln Q^2$ up to large β

Data well described by H1 QCD fit – gluon contribution dominates diffractive pdf's and extends to large fractional momenta

β, Q^2 dependence of $F_2^{D(3)}$





Comparison with ‘saturation model’

General features of data well reproduced . . .

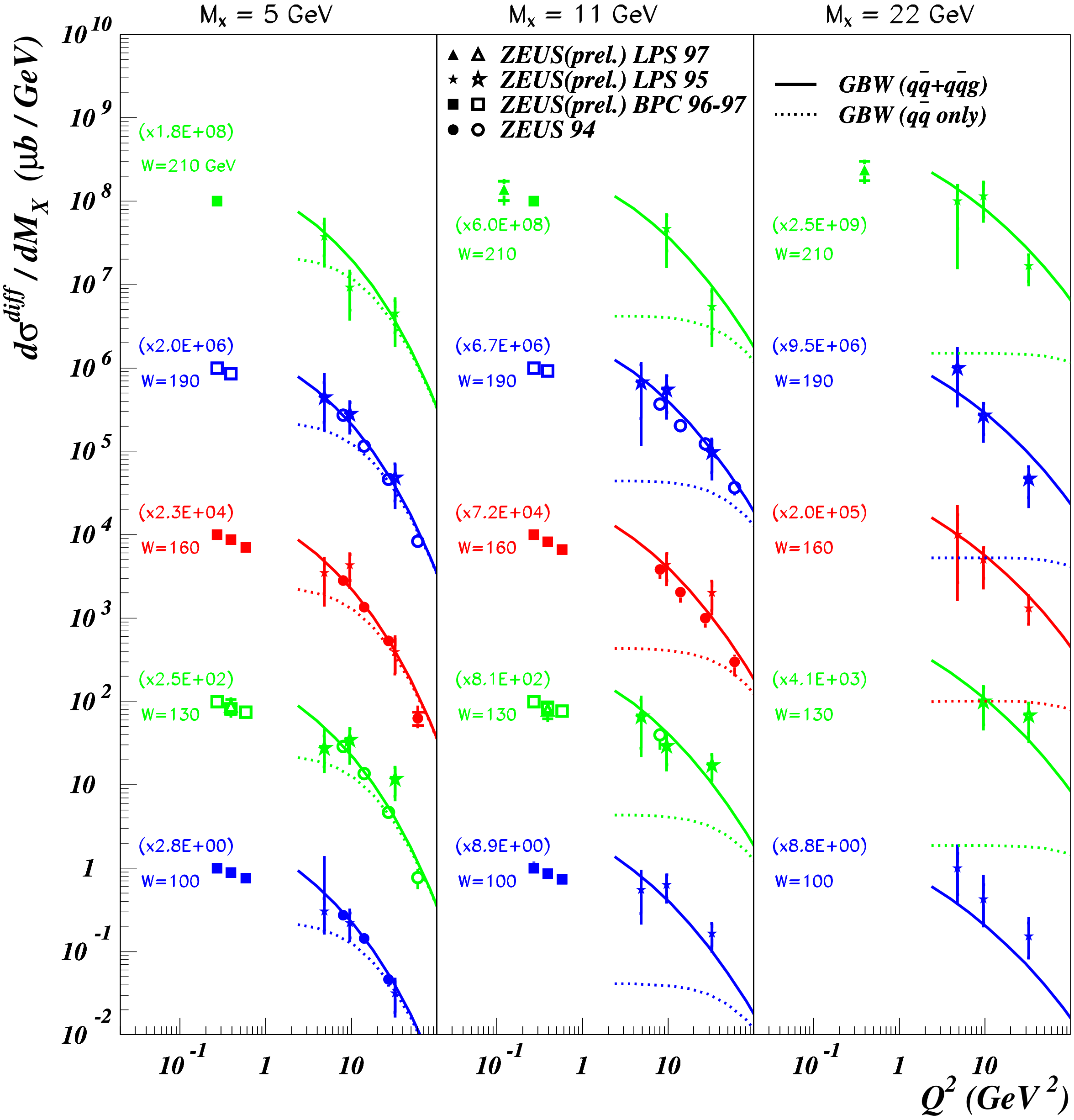
Impressive given that model is basically constrained by F_2!

Higher twist at high β

Inclusion of QCD evolution in model does not help.

Model exceeds data at low β, low Q^2.

Overview of Q^2 Dependence of Inclusive Diffraction



Change in the Q^2 dependence from low Q^2 to DIS

'saturation' model gives good description in region of applicability $Q^2 \geq 4\,\mathrm{GeV}^2$

$q\bar{q}g$ photon fluctuation dominant for large $M_X \equiv$ small β

Summary

- Copious HERA $F_2^{D(3)}$ data - wide kinematic range, improving precision
- Suggestion that $\gamma^* p$ cms energy dependences of diffractive and total cross sections become similar at large Q^2
- (β, Q^2) dependences require diffractive pdf's dominated by gluon density extending to large β
- Dipole models relating F_2^D to F_2 give reasonable overall description of data
- To shed further light on hadronic interactions require even more precise measurements at all scales Q^2, M_X, t