Measurements of the Diffractive Structure Function $F_2^{D(3)}(\beta, Q^2, x_{I\!P})$ at HERA

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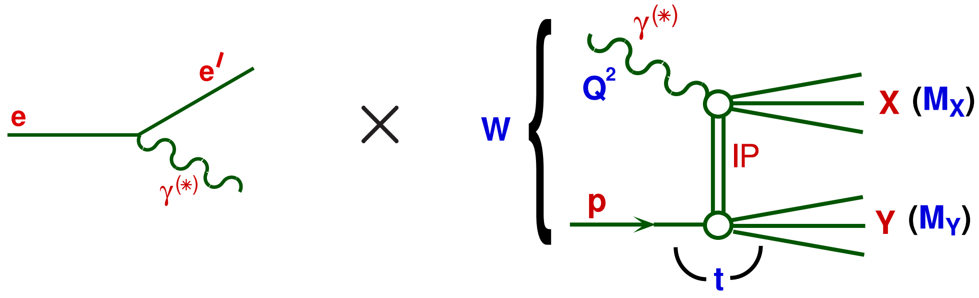
Representing the H1 and ZEUS Collaborations.

- Inclusive Diffraction at HERA.
- $\gamma^* p$ centre of mass energy dependence
- QCD structure of Diffraction
- Comparison with Colour Dipole Models

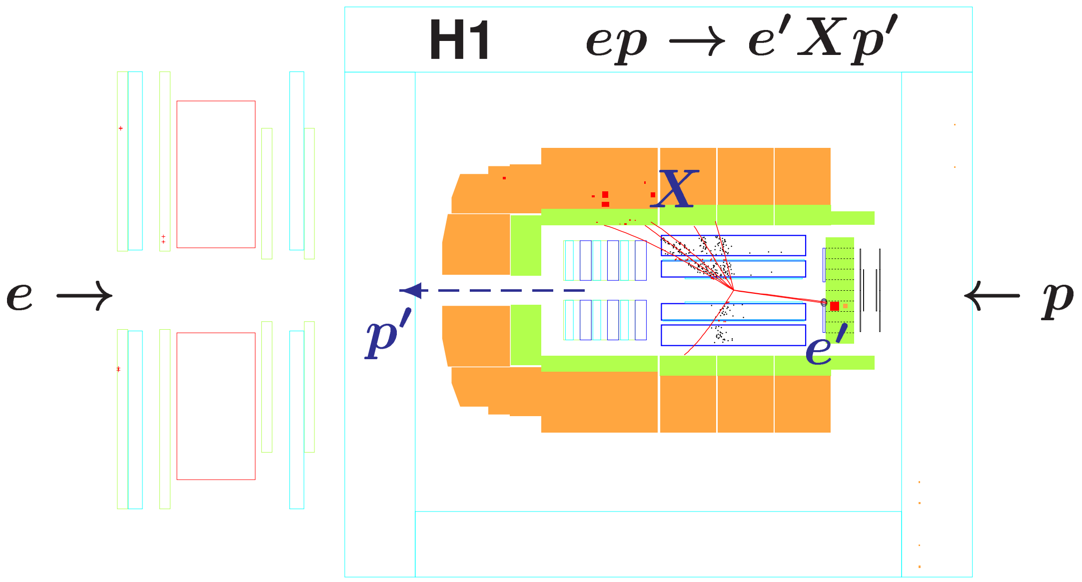
Diffraction at HERA

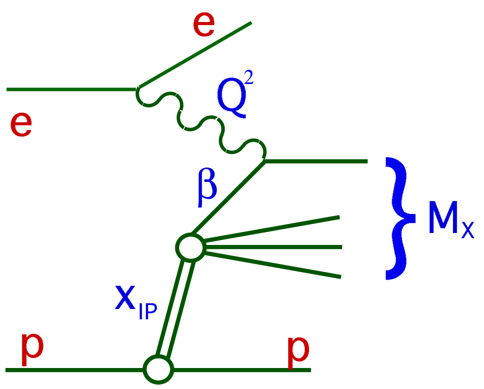
At HERA, diffractive $\gamma^{(\star)}p$ interactions can be studied ...



All five kinematic variables can be measured ...

... This talk concerned with large Q^2, low $|t|$, $Y = p$





$$x_{I\!P} = \frac{q.(p-p')}{q.p} = x_{(I\!P/\mathrm{p})}$$

$$\beta = \frac{Q^2}{q.(p-p')} = x_{(q/I\!P)}$$

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

Diffraction of Virtual Photons, $\gamma^\star p \to Xp$

Two complementary measurement techniques ...

1. Direct measurement of Leading Protons

   See talk of Florian Göbel

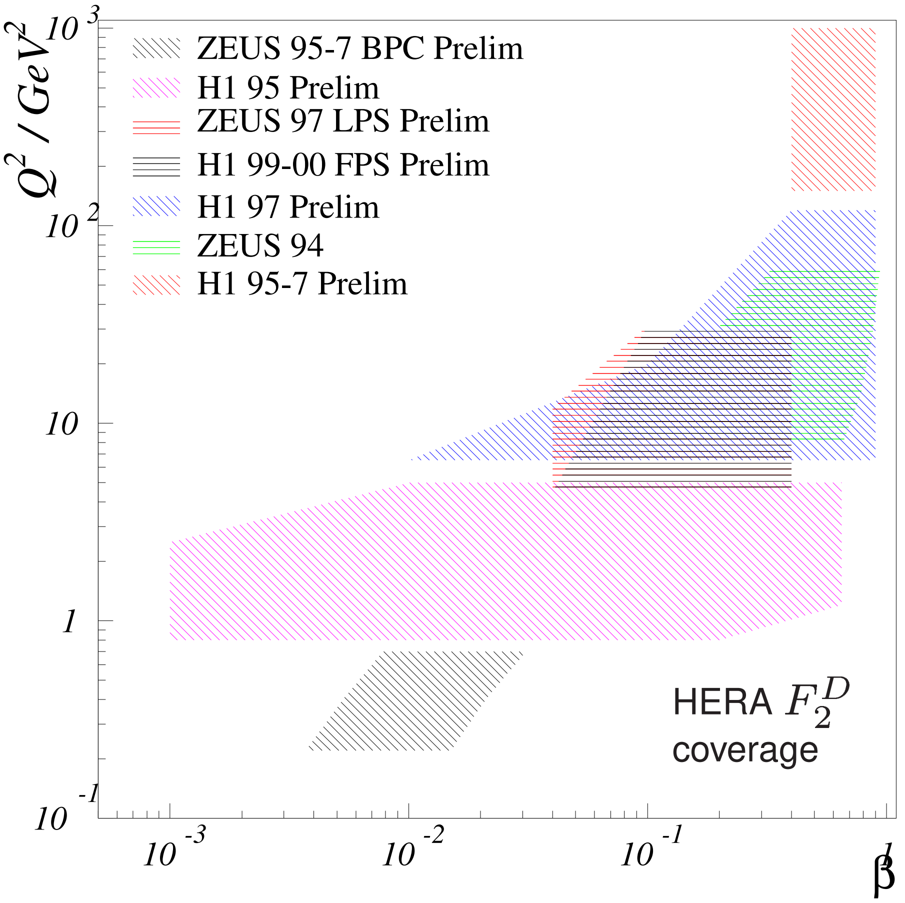
2. Require large rapidity gap separating p from X

   Reconstruct kinematics from X

Data presented as a Diffractive Structure Function ...

$$F_2^{D(3)}(\beta, Q^2, x_{I\!P}) = \frac{\beta\ Q^4}{4\pi\alpha^2\ (1-y+y^2/2)} \frac{\mathrm{d}\sigma_{ep\to eXY}}{\mathrm{d}\beta\ \mathrm{d}Q^2\ \mathrm{d}x_{I\!P}}$$

(Assumes $F_L^{D(3)} = 0$)

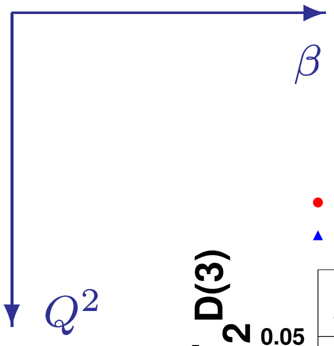


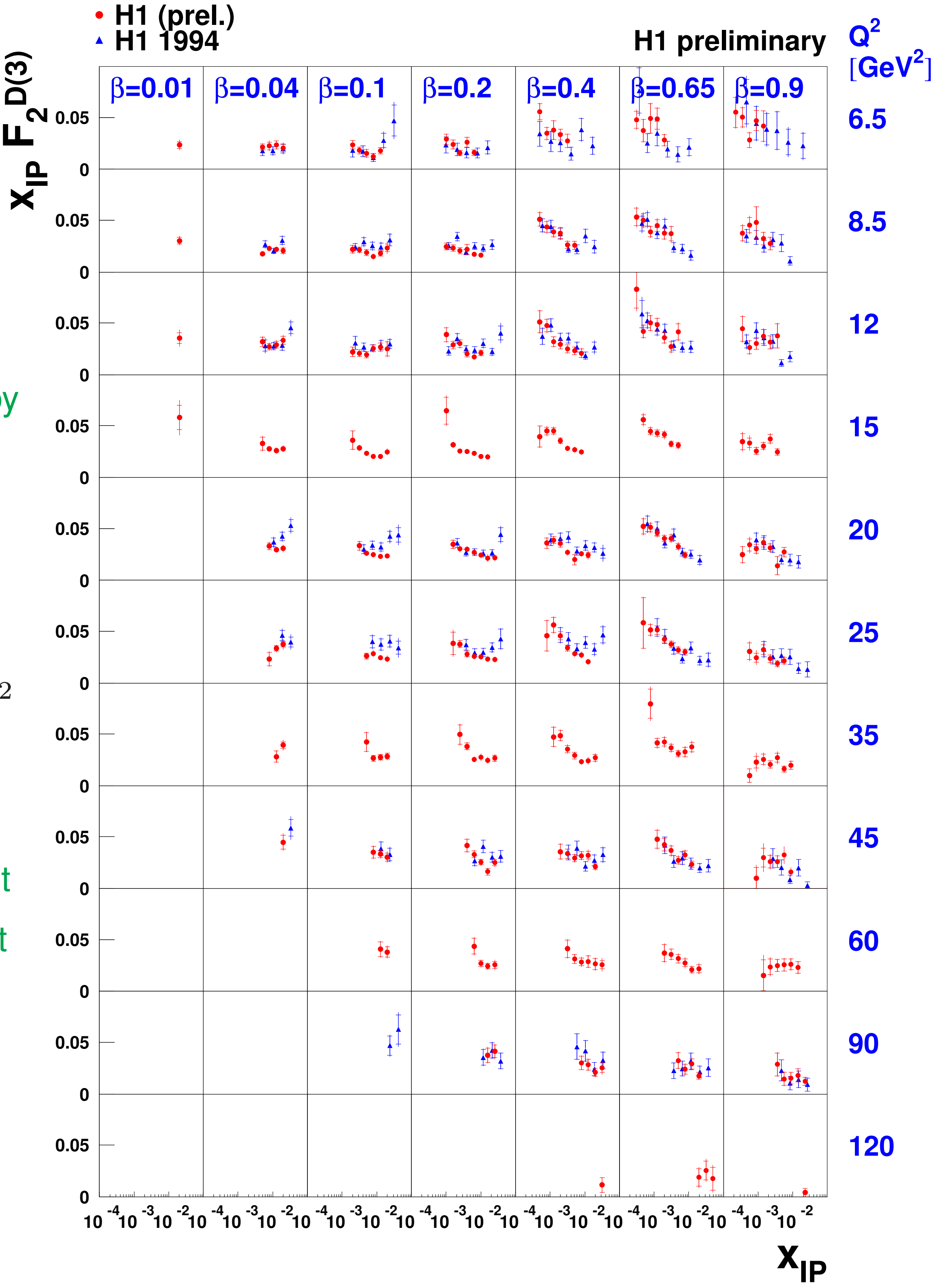
New H1 data for this conference:
$6.5 \leq Q^2 \leq 120\ \mathrm{GeV}^2$,
$0.04 \leq \beta \leq 0.9$
$x_{I\!P} < 0.05$

Selected by demanding large rapidity gap

Integrated over
$M_Y < 1.6\ \mathrm{GeV}$,
$|t| < 1\ \mathrm{GeV}^2$

Comparison between H1 1994 and 1997 F_2^D Data





Improved high Q^2 statistics by factor ~ 5

Increased number of $x_{I\!P}$ and Q^2 points.

Agreement throughout most of kinematic range

Factorisation Properties of $F_2^{D(3)}$

QCD Hard Scattering Factorisation for Diffractive DIS:-

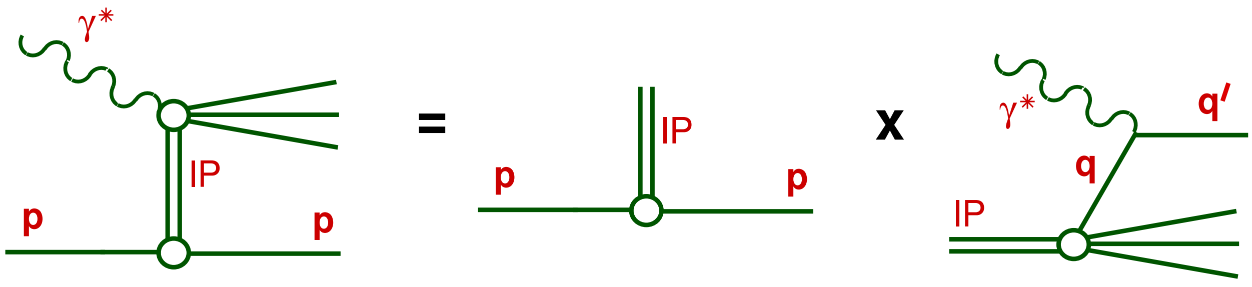
(Trentadue, Veneziano, Berera, Soper, Collins ...)
Diffractive parton densities $f(x_{I\!P}, t, x, Q^2)$ express proton parton probability distributions with intact final state proton at particular $x_{I\!P}, t$ ...

$$\sigma(\gamma^* p \rightarrow Xp) \sim \sum_i f_{i/p}(x_{I\!P}, t, x, Q^2) \otimes \hat{\sigma}_{\gamma^* i}(x, Q^2)$$

At fixed $x_{I\!P}, t$, $f(x_{I\!P}, t, x, Q^2)$ evolve with x, Q^2 according to DGLAP equations.

'Regge' Factorisation:-

Soft hadron phenomenology suggests a universal *pomeron* ($\mathrm{I\!P}$) exchange can be introduced, with flux dependent only on $x_{I\!P}, t$ (Donnachie, Landshoff, Ingelman, Schlein ...)



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

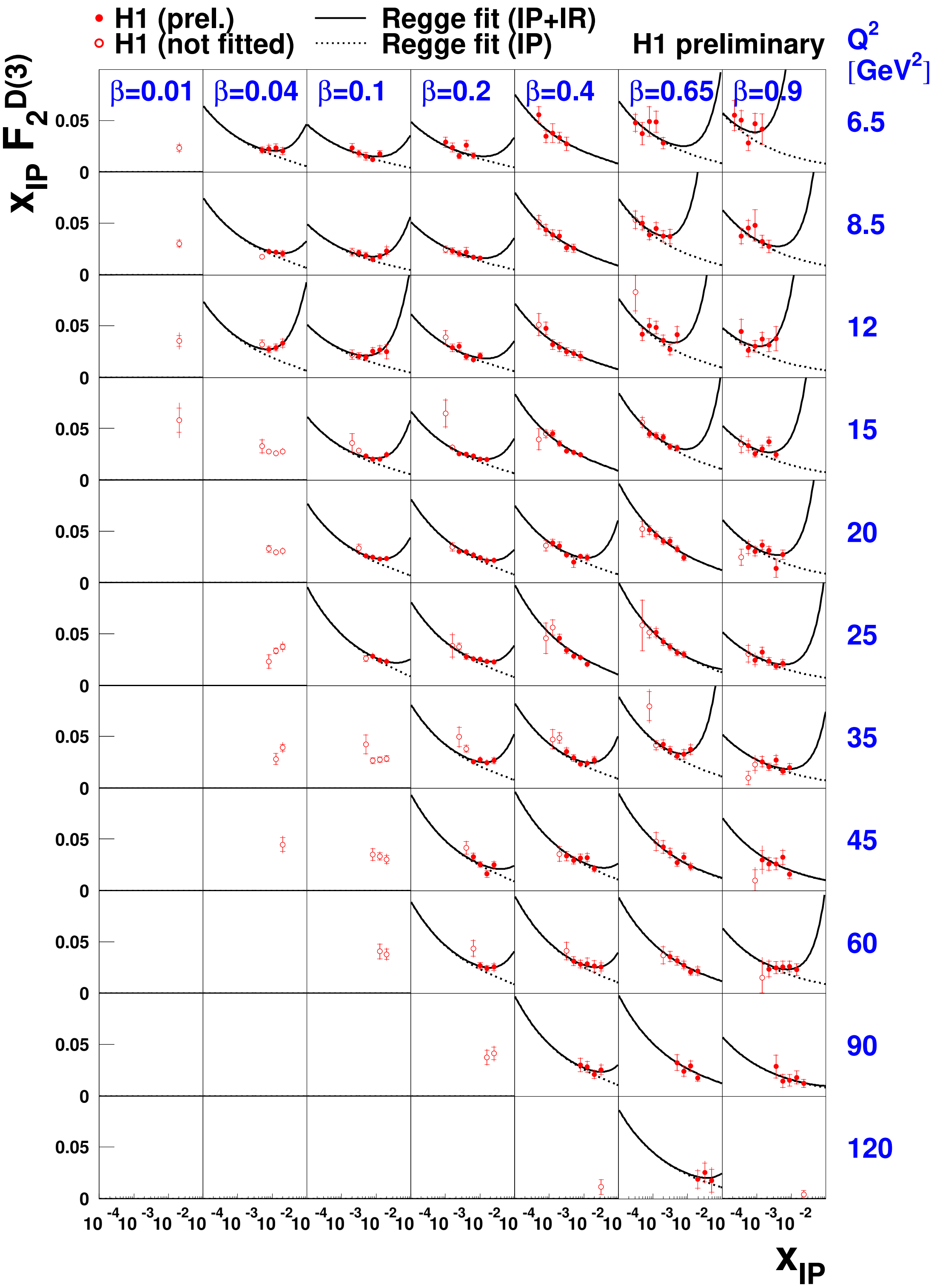
$$\sim f_{\mathrm{I\!P}/\mathrm{p}}(x_{I\!P}, t) \otimes \sum_i f_{i/\mathrm{I\!P}}(\beta, Q^2) \otimes \hat{\sigma}_{\gamma^* i}(\beta, Q^2)$$

‘Regge’ Fits to H1 1997 F_2^D Data

Test ‘Regge’ fac’n by fitting $x_{\mathbb{P}}$ dependence at fixed β, Q^2.

Data well described by exchange of two universal trajectories $\mathbb{P}$ and $\mathbb{R}$ ($\chi^2/\mathrm{ndf} = 0.95$).

No evidence for variation of $\alpha_{\mathbb{P}}(0)$ with β, Q^2.



Variation of Energy Dependence with Q^2

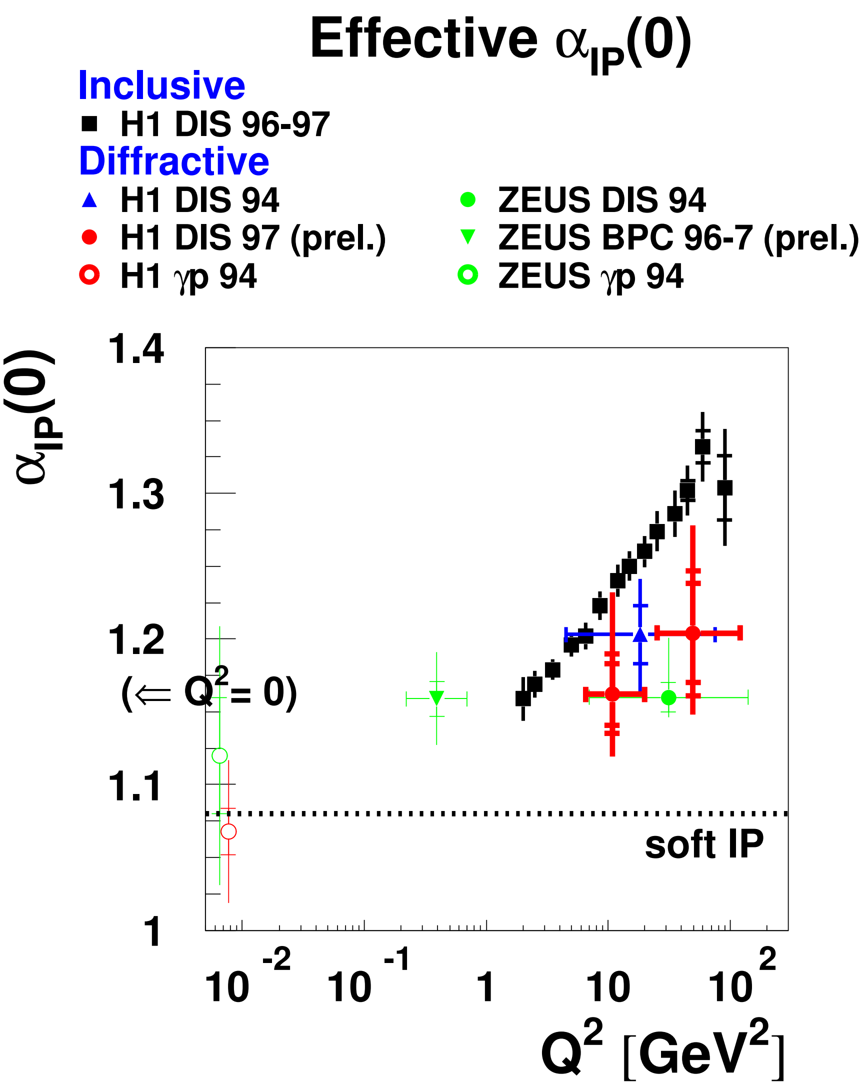
$\alpha_{I\!P}(0) = 1.173 \pm 0.018\,(\text{stat.}) \pm 0.017\,(\text{syst.})\,{}^{+0.063}_{-0.035}\,(\text{model})$

Error dominated by model dependence $0 < F_L^{D(3)} < F_2^{D(3)}$

Compatible results if data divided into two Q^2 ranges

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

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



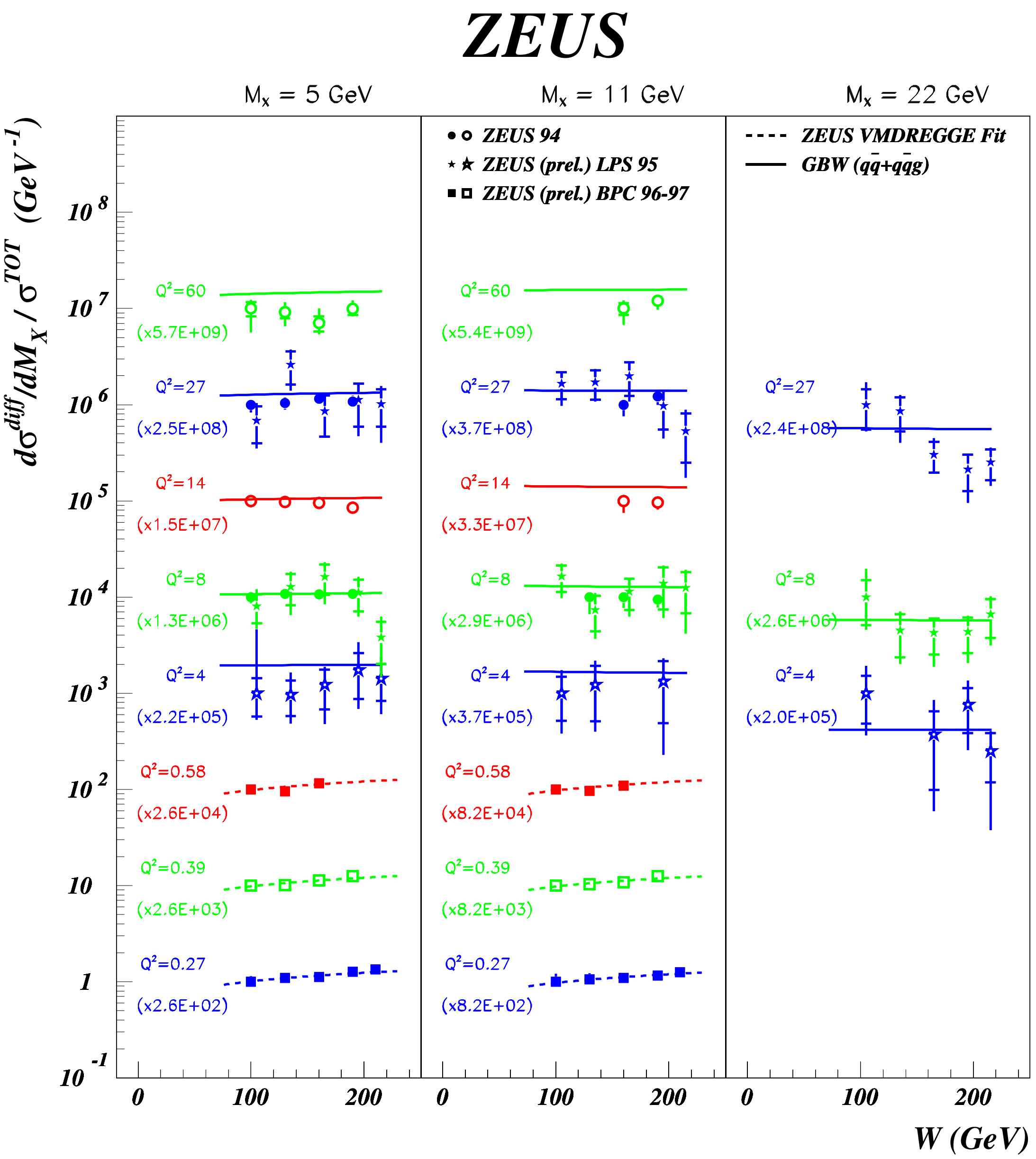
$\alpha_{I\!P}(0)$ grows with Q^2 $\rightarrow$ larger than soft $I\!P$ at large Q^2

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.



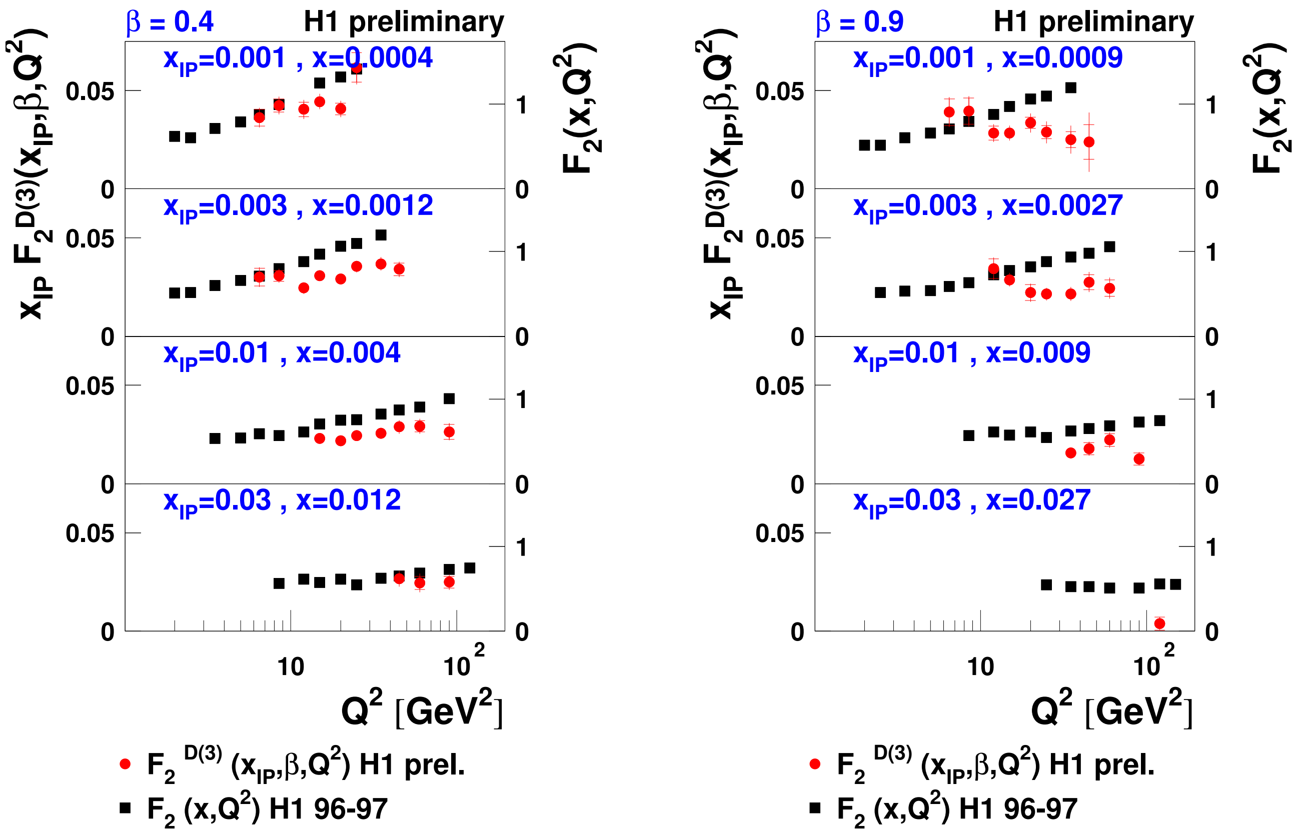
Fits to $$\frac{\int \mathrm{d}t \;\; \mathrm{d}\sigma^{\mathrm{diff}}_{\gamma^* p \to XY} / \mathrm{d}M_X \;\; \mathrm{d}t}{\sigma^{\mathrm{tot}}_{\gamma^* p \to X}} \propto W^{\rho}$$

$\rho = 0.24 \pm 0.07\,(\mathrm{stat})$ $\quad(0.27 \leq Q^2 \leq 0.58\ \mathrm{GeV}^2$ - 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 $F_2^{D(3)}$

(β, Q^2) dependences of $F_2^{D(3)}$ at fixed $x_{I\!P}$ sensitive to diffractive parton densities.

Precision H1 measurements at 4 fixed $x_{I\!P}$ values.

Parameterise (u, d, s) singlet, gluon densities at $Q_0^2 = 2\,\mathrm{GeV}^2$.

Fit β, Q^2 dependence using DGLAP equations.

Require $y < 0.45$ (F_L^D small)

Require $\beta \leq 0.9,\ M_X > 2\,\mathrm{GeV}$ (higher twists small)

Regge motivated parameterisation of $x_{I\!P}$ dependence.

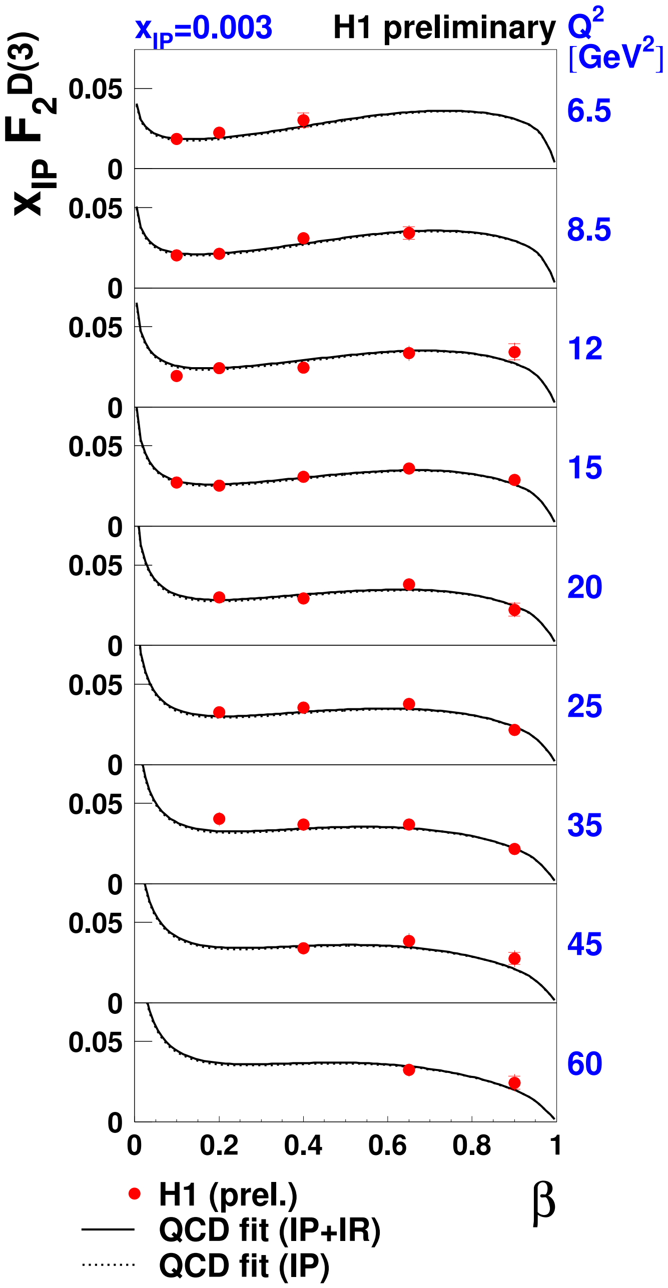
Small meson contribution at large $x_{I\!P}$, small β

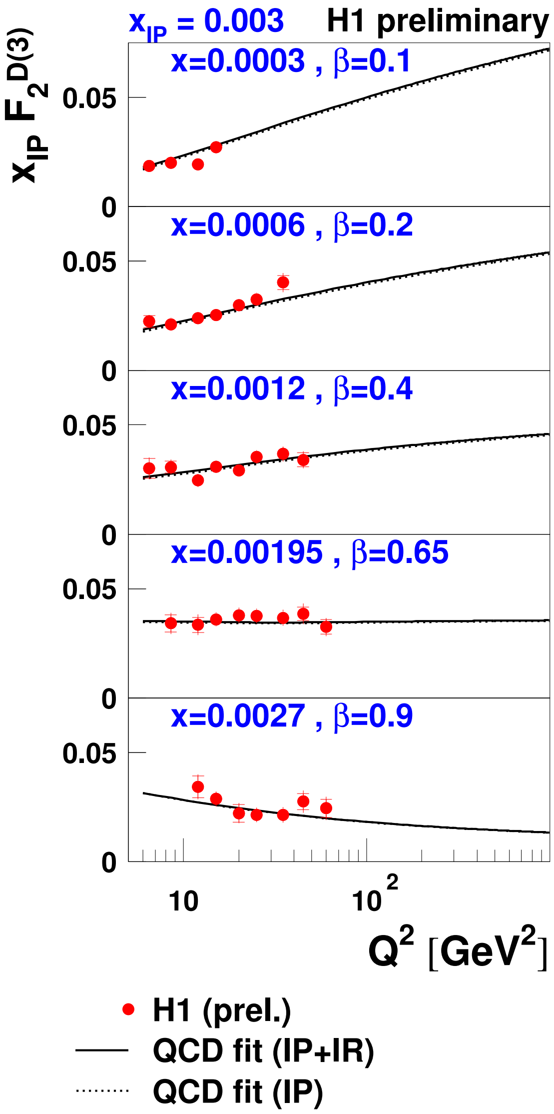
Fit incorporating QCD collinear factorisation and Regge factorisation describes data well.

Extracted parton densities dominated by large gluon distribution extending to high fractional momentum.

β, Q^2 dependence of $F_2^{D(3)}$

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



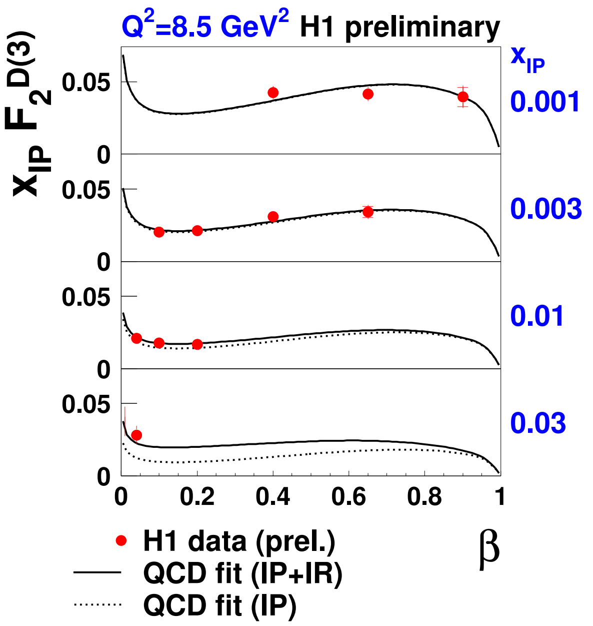


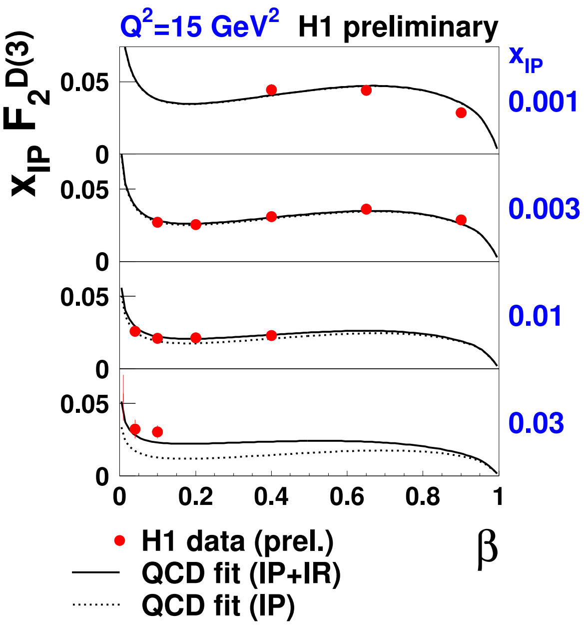
β dependence relatively flat.

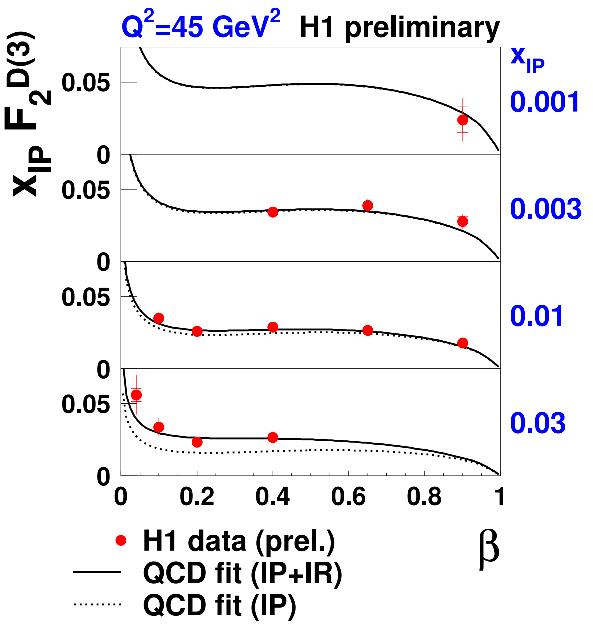
Rising scaling violations with $\ln Q^2$ up to large β

Require large gluon contribution in diffractive pdf's, extending to large fractional momenta.

Variation of diffractive pdf's with $x_{I\!P}$?







Variations with $x_{I\!P}$ well described by Regge $\mathbb{P}$, $\mathbb{R}$ flux factors.

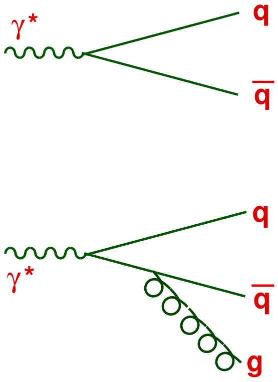
No evidence for breakdown of Regge factorisation hypothesis.

Sub-leading exchange ($\mathbb{R}$) contribution negligible except at high $x_{I\!P}$, low β

Colour Dipole Models

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

Partonic fluctuations scatter elastically from proton.



$\times$

Cross section for colour dipole to scatter elasticelly from proton

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

Describe diffraction beyond leading twist (high β?)

Joint description of F_2 and F_2^D ...

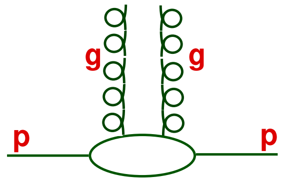
Different approaches to the dipole cross section ...

- Non-perturbative interaction with proton colour field

e.g. 'semi-classical' model
(Buchmüller, Gehrmann, Hebecker)

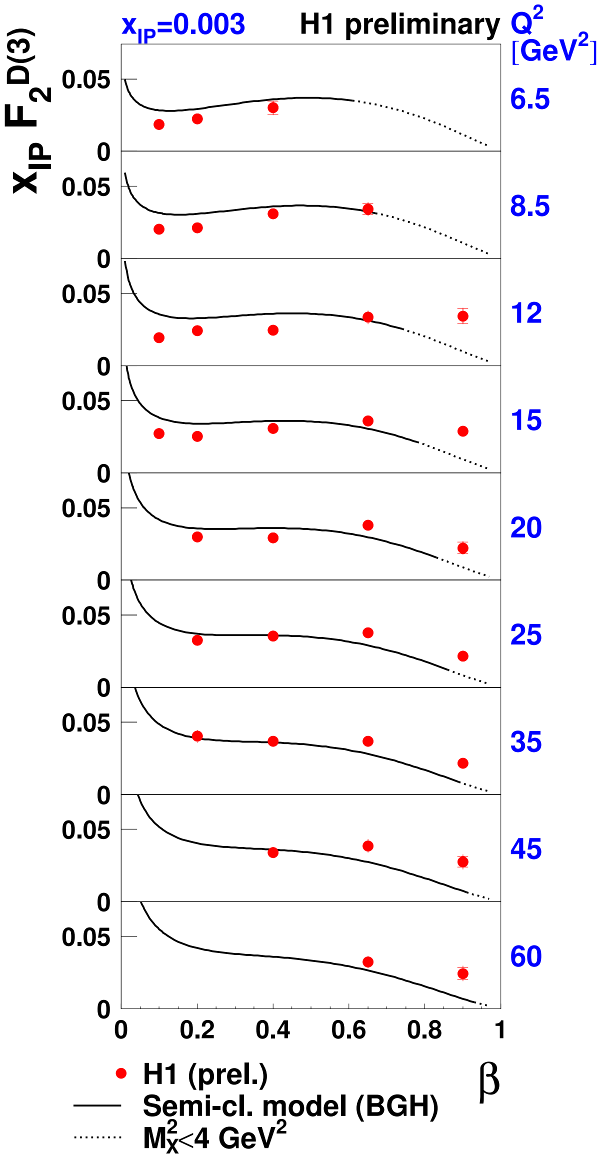
- Partonic - two gluon exchange

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

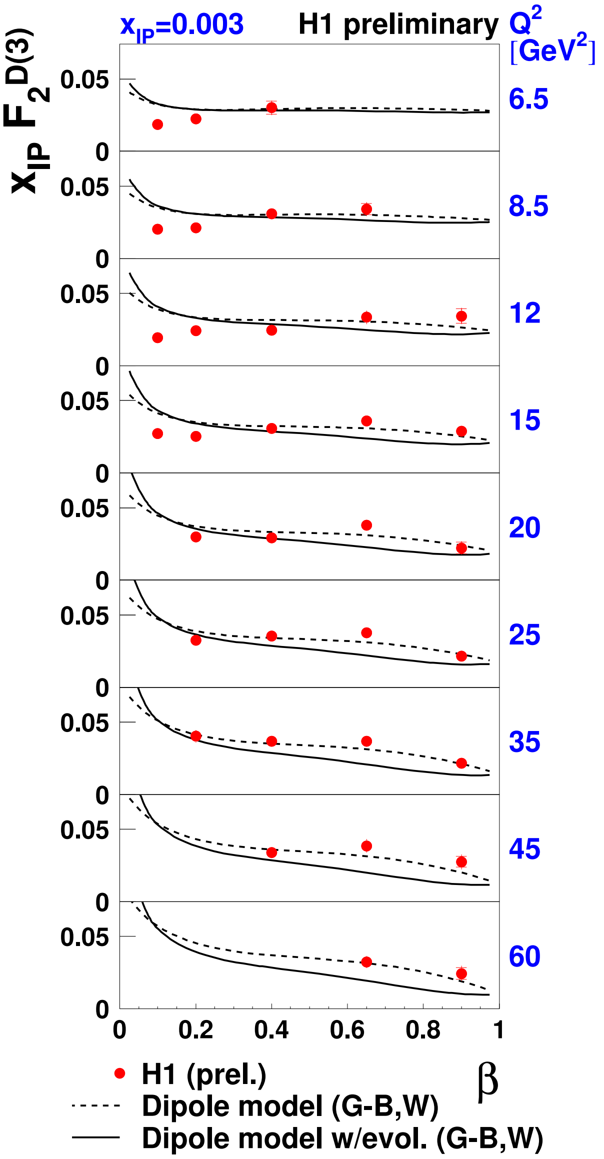


Colour Dipole Models

Non-perturbative



Partonic



General features of data well reproduced . . .

Impressive given that models basically constrained by F_2 data!

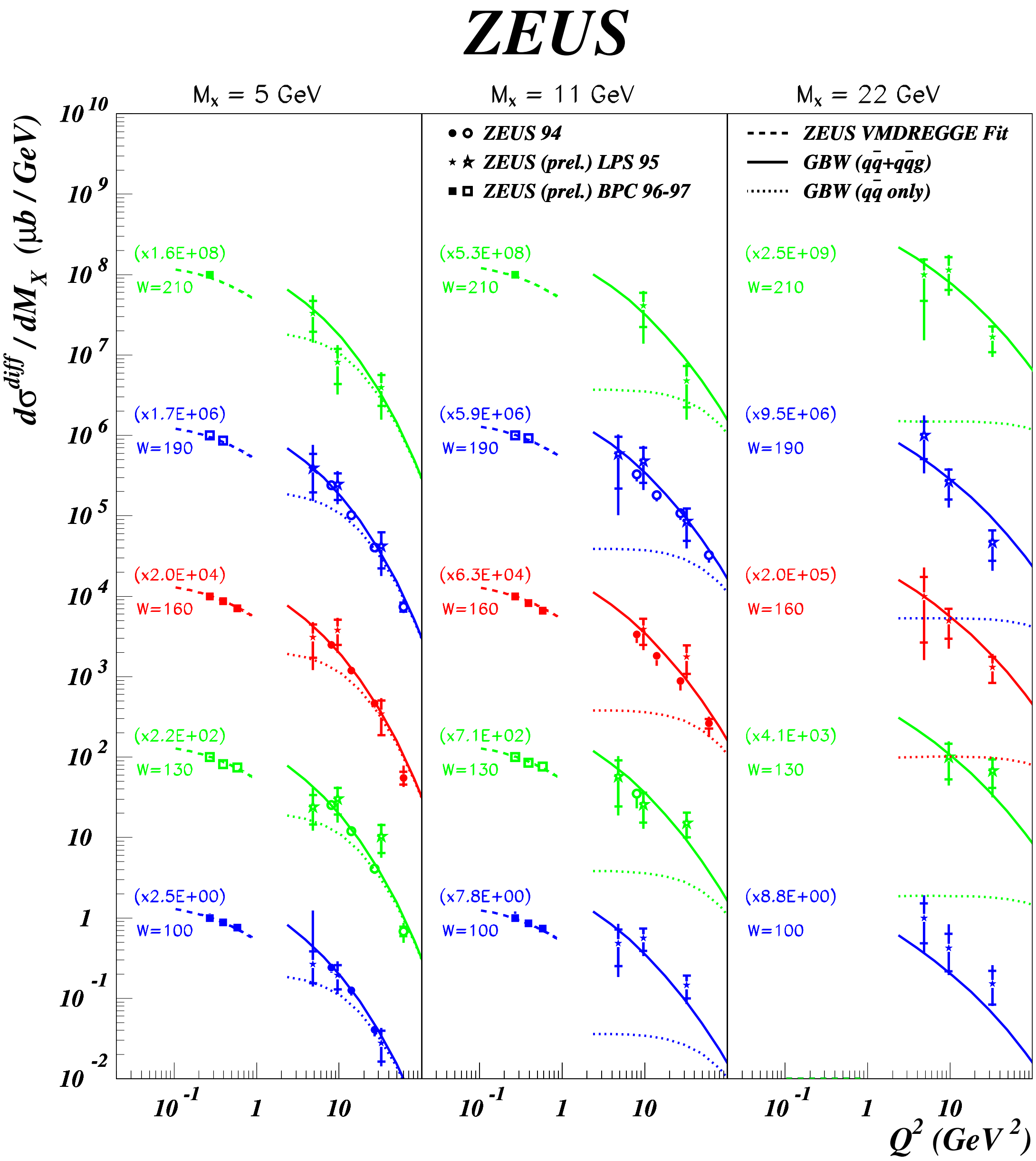
Partonic model - higher twist at high β $\rightarrow$ better description

Inclusion of QCD evolution in partonic model does not help.

Both models exceed data at low β, low Q^2.

Partonic Colour Dipole Model

Comparison with ZEUS data . . .



Good description for $Q^2 \geq 4\ \mathrm{GeV}^2$

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

Model not yet able to describe $Q^2 \leq 1\ \mathrm{GeV}^2$

Summary

- Copious HERA $F_2^{D(3)}$ data - wide kinematic range, improving precision

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- Effective $\alpha_{\mathbb{P}}(0)$ larger than soft $\mathbb{P}$ at large Q^2
- No evidence for deviations from 'Regge' factorisation within large Q^2 data
- $\gamma^* p$ cms energy dependences of diffractive and total cross sections become similar at large Q^2

- (x, Q^2) dependence of F_2 and F_2^D similar except at largest $\beta \equiv$ smallest M_X
- (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 - fine detail not yet correct