THE UNIVERSITY of LIVERPOOL

International Symposium on MultiParticle Dynamics

MEASUREMENT AND QCD ANALYSIS OF INCLUSIVE DIFFRACTION AT HERA

Paul Laycock

Overview:

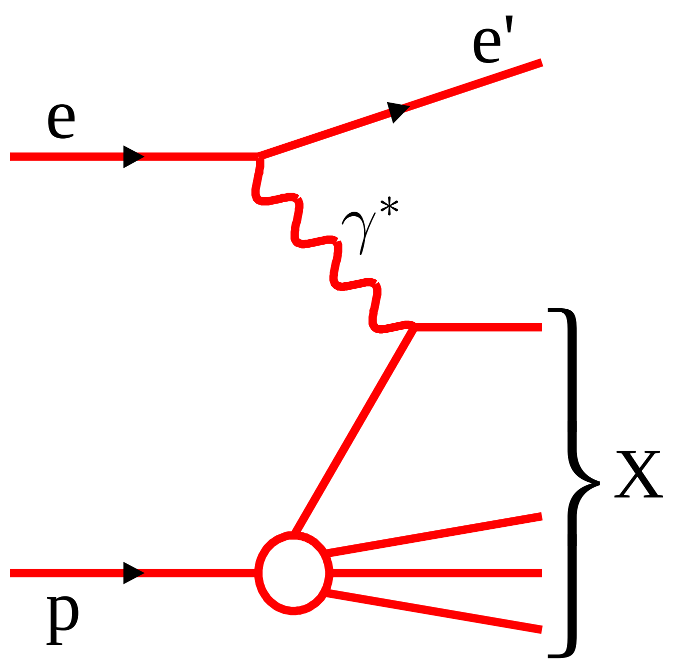
- DIFFRACTION AT HERA
- MEASUREMENT TECHNIQUES
- LATEST MEASUREMENTS
- QCD ANALYSIS
- SUMMARY

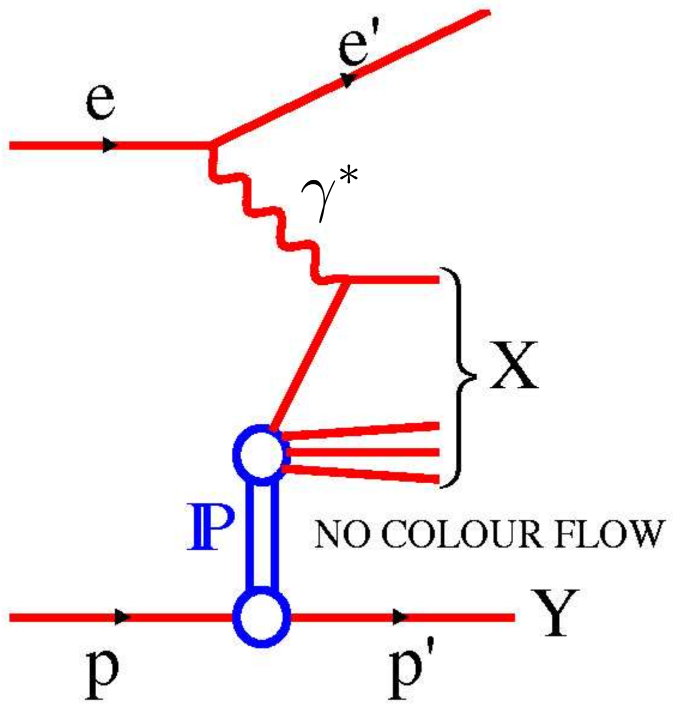
Inclusive Diffractive DIS at HERA

A large fraction of hadronic interactions at high energy are diffractive

Study the QCD Structure of these interactions using :

$$\gamma^* p \longrightarrow X p$$

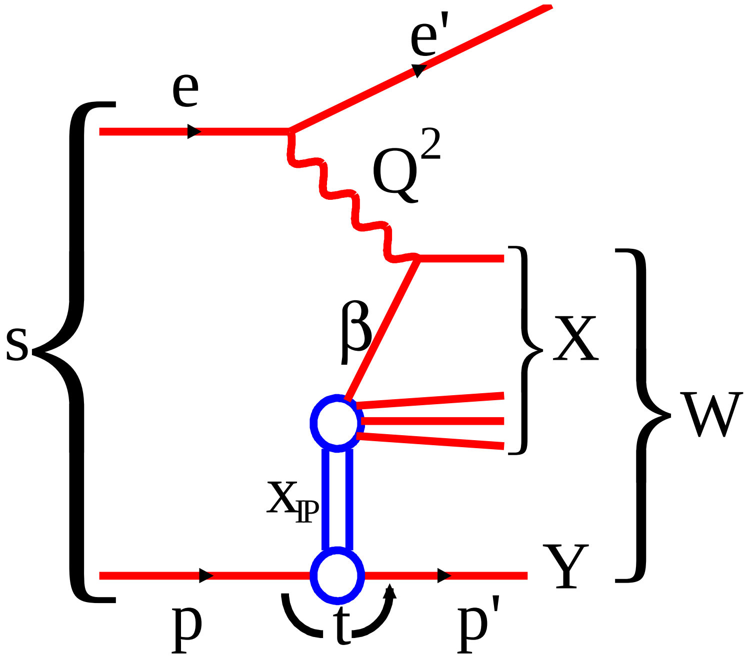




Probe the proton $\longrightarrow F_2^{Proton}$

Probe Diffractive dynamics $\longrightarrow F_2^D$

Inclusive Diffractive DIS $\gamma^* p \longrightarrow Xp$



$$Q^2 = -(e - e')^2 = -q^2$$

$$t = (p - p')^2$$

$$\beta = x_{quark/IP}$$

$$x_{IP} = x_{IP/proton}$$

$$x_{Bjoerken} = \beta \cdot x_{IP}$$

Cross Section :

$$\frac{d\sigma^{ep \longrightarrow eXY}}{d\beta dQ^2 dx_{IP} dt} = \frac{4\pi\alpha^2}{\beta Q^4}\left(1 - y + \frac{y^2}{2}\right)\sigma_r^{D(4)}$$

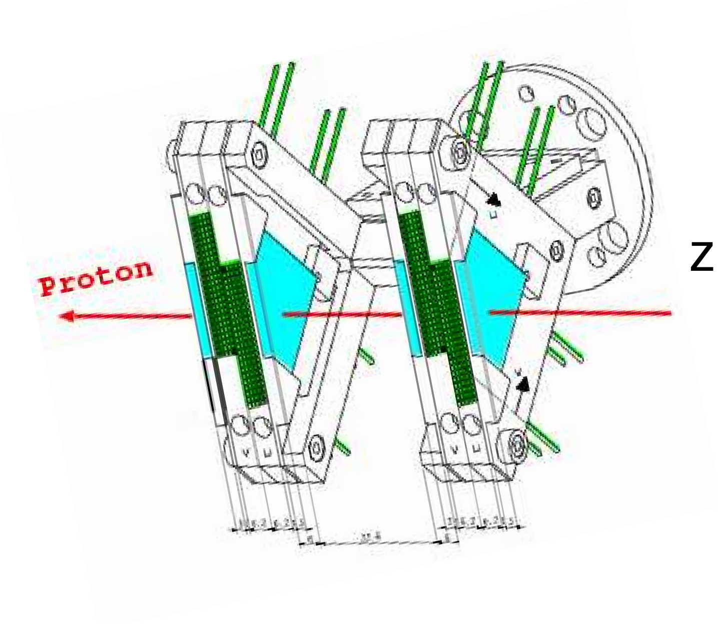
Reduced Cross Section :

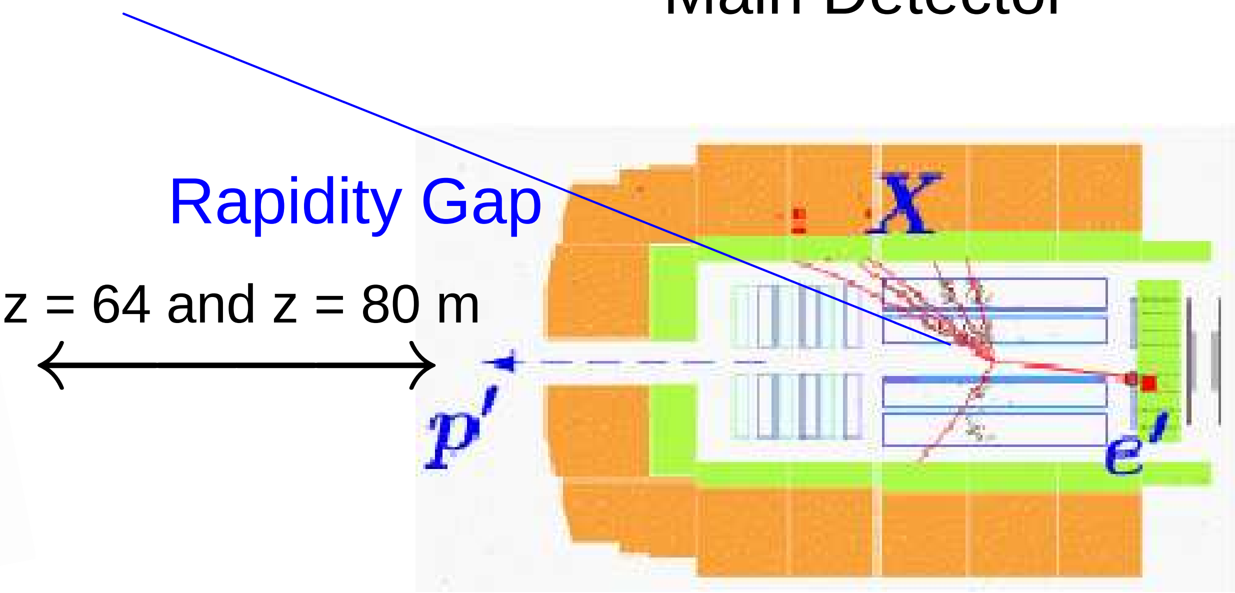
$$\sigma_r^{D(4)} = F_2^{D(4)} - \frac{y^2}{1+(1-y)^2} F_L^{D(4)} \quad (\sigma_r^{D(4)} = F_2^{D(4)} \text{ if } F_L^{D(4)} = 0)$$

Diffraction in HERA $ep \longrightarrow e'Xp'$

FPS Stations

Main Detector





Measure Leading Proton

- Free of p dissociation background
- Measure t and ϕ distributions
- Lower statistics due to acceptance

Require Large Rapidity Gap

- Kinematics measured from X system
- Integrate over t and M_Y
- Higher statistics

New Measurements from HERA

New Measurements from H1 :

Rapidity gap technique

$1.5 < Q^2 < 12 \ \mathrm{GeV}^2$

$6.5 < Q^2 < 120 \ \mathrm{GeV}^2$

FPS technique

$2.5 < Q^2 < 20 \ \mathrm{GeV}^2$

New Measurements from ZEUS :

Rapidity gap technique

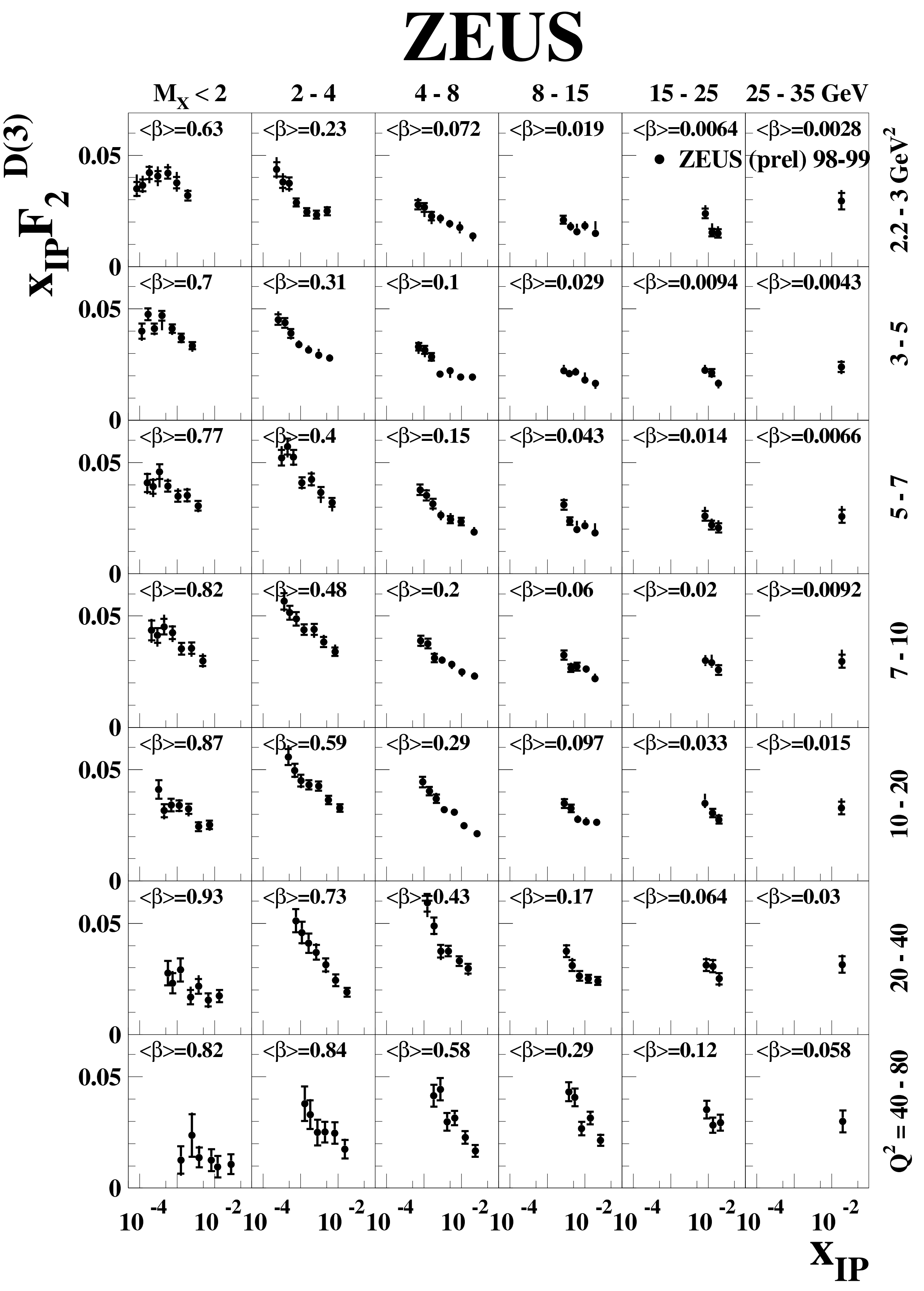
$2.2 < Q^2 < 80 \ \mathrm{GeV}^2$

FPS technique

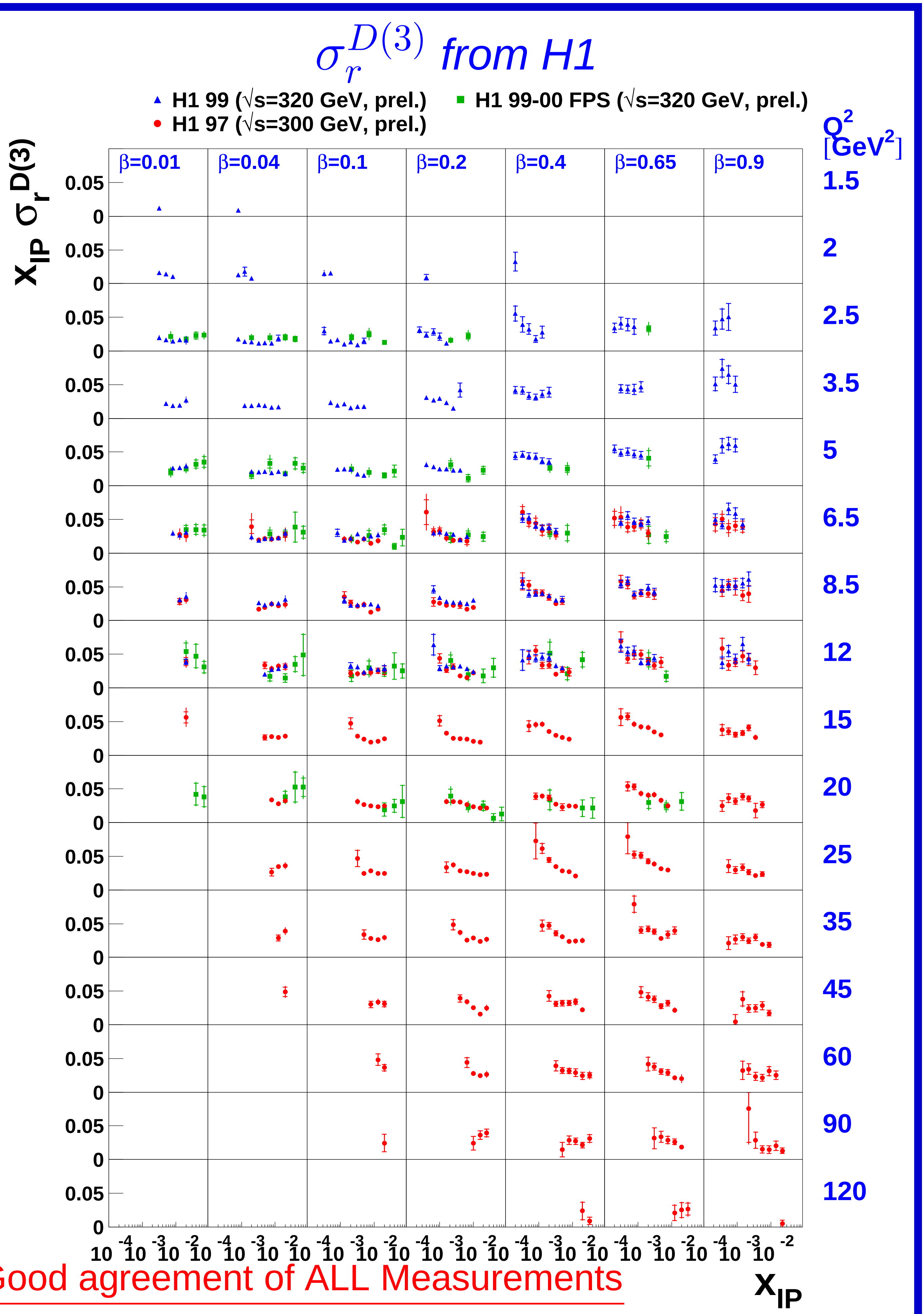
$0.03 < Q^2 < 0.6 \ \mathrm{GeV}^2$

Increase in statistics AND phase space

High precision measurements to test QCD



ZEUS
$M_X < 2$
2 - 4
4 - 8
8 - 15
15 - 25
25 - 35 GeV
<β>=0.63
<β>=0.23
<β>=0.072
<β>=0.019
<β>=0.0064
<β>=0.0028
ZEUS (prel) 98-99
2.2 - 3 GeV^2
<β>=0.7
<β>=0.31
<β>=0.1
<β>=0.029
<β>=0.0094
<β>=0.0043
3 - 5
<β>=0.77
<β>=0.4
<β>=0.15
<β>=0.043
<β>=0.014
<β>=0.0066
5 - 7
<β>=0.82
<β>=0.48
<β>=0.2
<β>=0.06
<β>=0.02
<β>=0.0092
7 - 10
<β>=0.87
<β>=0.59
<β>=0.29
<β>=0.097
<β>=0.033
<β>=0.015
10 - 20
<β>=0.93
<β>=0.73
<β>=0.43
<β>=0.17
<β>=0.064
<β>=0.03
20 - 40
<β>=0.82
<β>=0.84
<β>=0.58
<β>=0.29
<β>=0.12
<β>=0.058
Q^2 = 40 - 80
$x_{IP}F_2^{D(3)}$
0.05
0
10^{-4}
10^{-2}
x_{IP}



Good agreement of ALL Measurements

Factorisation Properties of F_2^D

1. QCD Hard Scattering Factorisation for Diffractive DIS

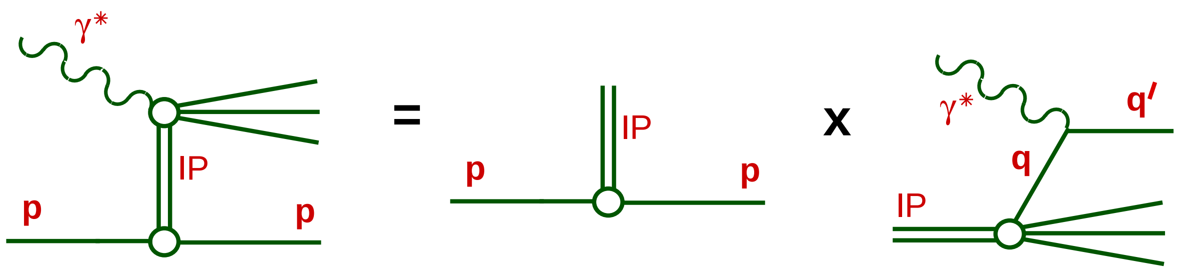
QCD Proof by Collins

$$\sigma(\gamma^* p \to Xp) \;\sim\; p_{q/p}(x_{IP}, t, x, Q^2) \;\otimes\; \hat{\sigma}_{\gamma^* q}(x, Q^2)$$

At fixed x_{IP}, t, Diffractive Parton Densities evolve with x, Q^2 according to DGLAP

2. 'Regge' Factorisation

Additional assumption - Shape of Diffractive pdfs are independent of x_{IP} and t

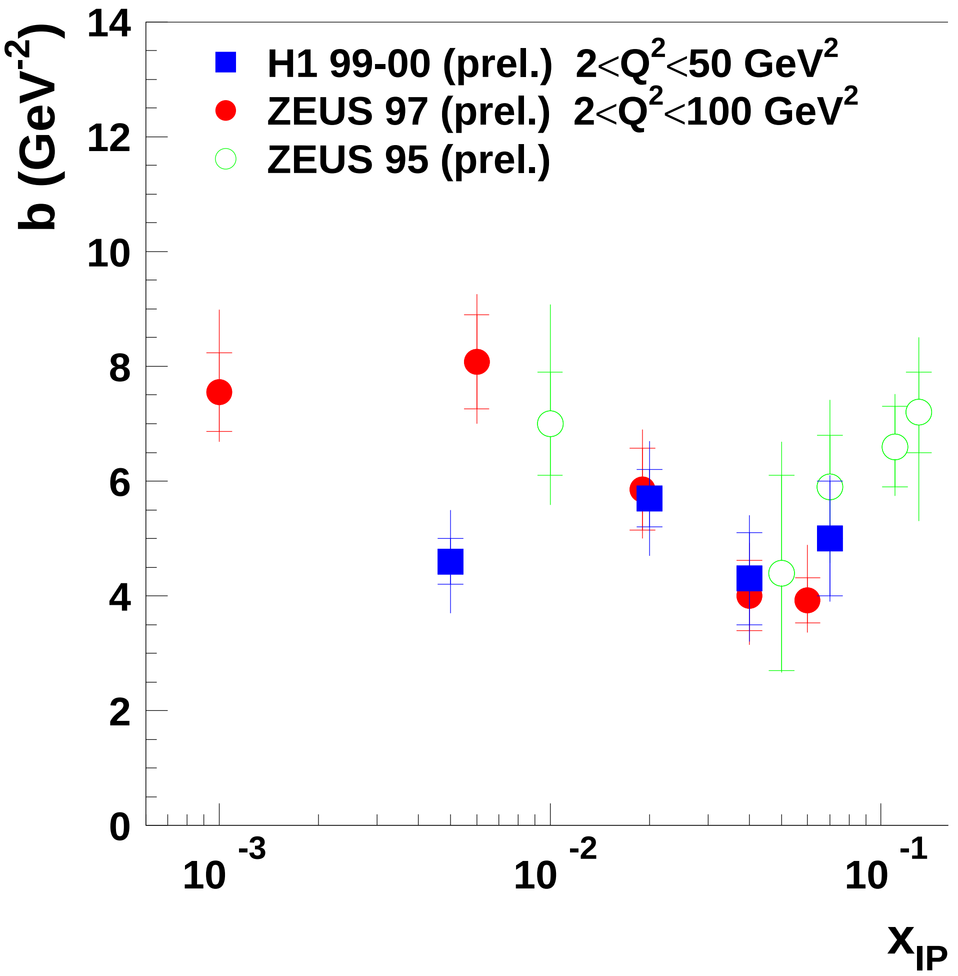


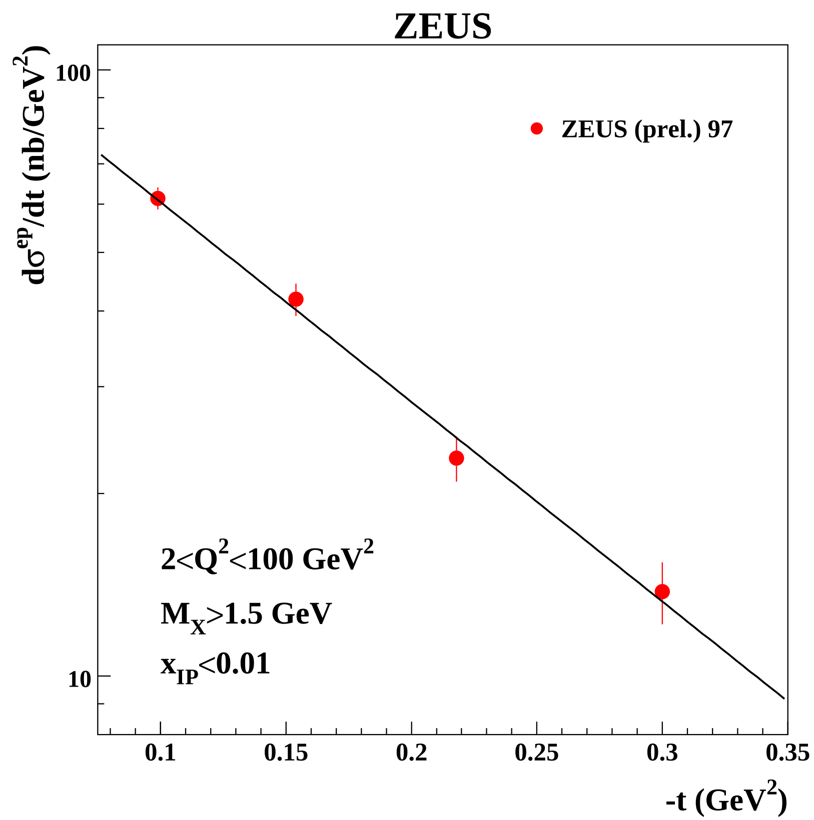
$$\sigma(\gamma^* p \to Xp) \;\sim\; f_{IP/p}(x_{IP}, t) \;\otimes\; p_{q/IP}(\beta, Q^2) \;\otimes\; \hat{\sigma}_{\gamma^* q}(\beta, Q^2)$$

Diffractive flux — Pomeron pdfs — Hard Scatter

Flux parameterised as $$f_{IP/p}(x_{IP}) = \int_{t_{cut}}^{t_{min}} \frac{e^{Bt}}{x_{IP}^{2\alpha(t)-1}}\,\mathrm{d}t$$

t-dependence of the Diffractive Cross section



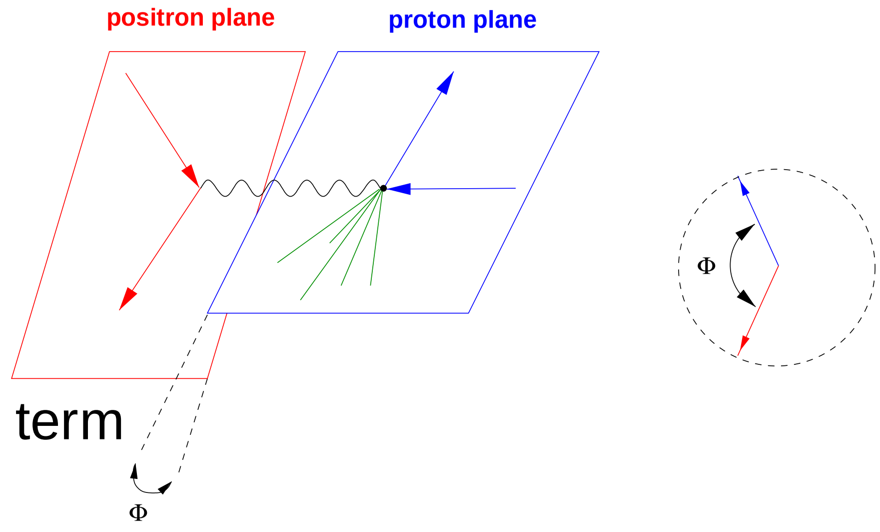


In Regge theory expect shrinkage

$$B = B_0 + 2\alpha' \ln \frac{1}{x_{IP}}$$

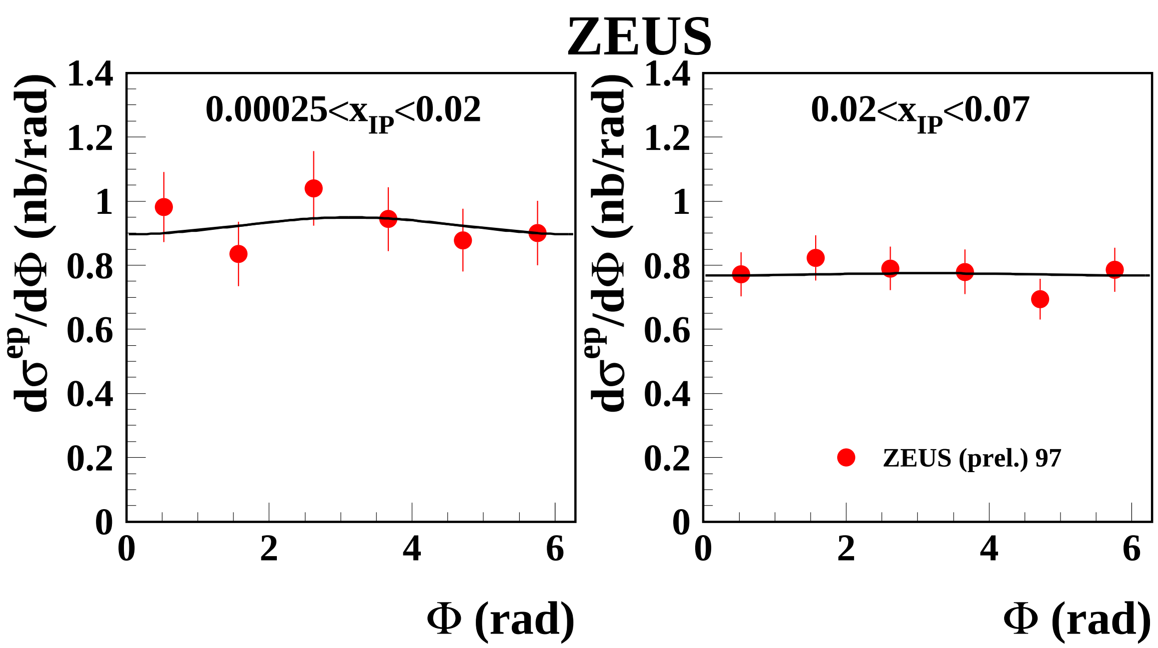
For $x_{IP} < 10^{-2}$ data inconclusive

Φ-*dependence of the Diffractive Cross section*



Φ : Azimuthal angle between positron and proton scattering planes

$\frac{d\sigma^D}{d\Phi}$ sensitive to σ_L^D through interference term



Measurements :

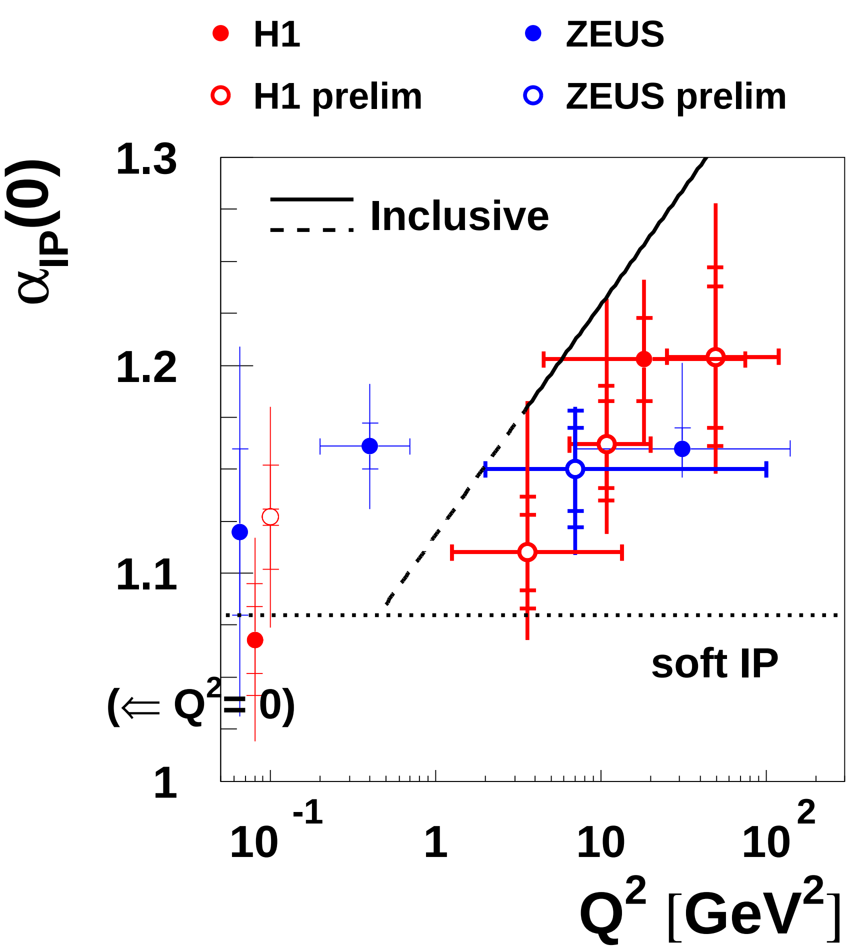
Fit $\frac{d\sigma}{d\Phi} \sim 1 + A_{LT} \cos \Phi$

$A_{LT} = -0.029 \pm 0.066^{+0.026}_{-0.047}$
$(0 \lesssim x_{IP} < 0.02; \beta \approx 0.32)$

$A_{LT} = -0.005 \pm 0.052^{+0.048}_{-0.047}$
$(0.02 < x_{IP} < 0.07; \beta \approx 0.1)$

$\longrightarrow$ Interference term small in measured region

Effective $\alpha_{IP}(0)$



Extraction : $F_2^{D(3)} = A(\beta, Q^2)(\frac{1}{x_{IP}})^{2\alpha(t)-1}$

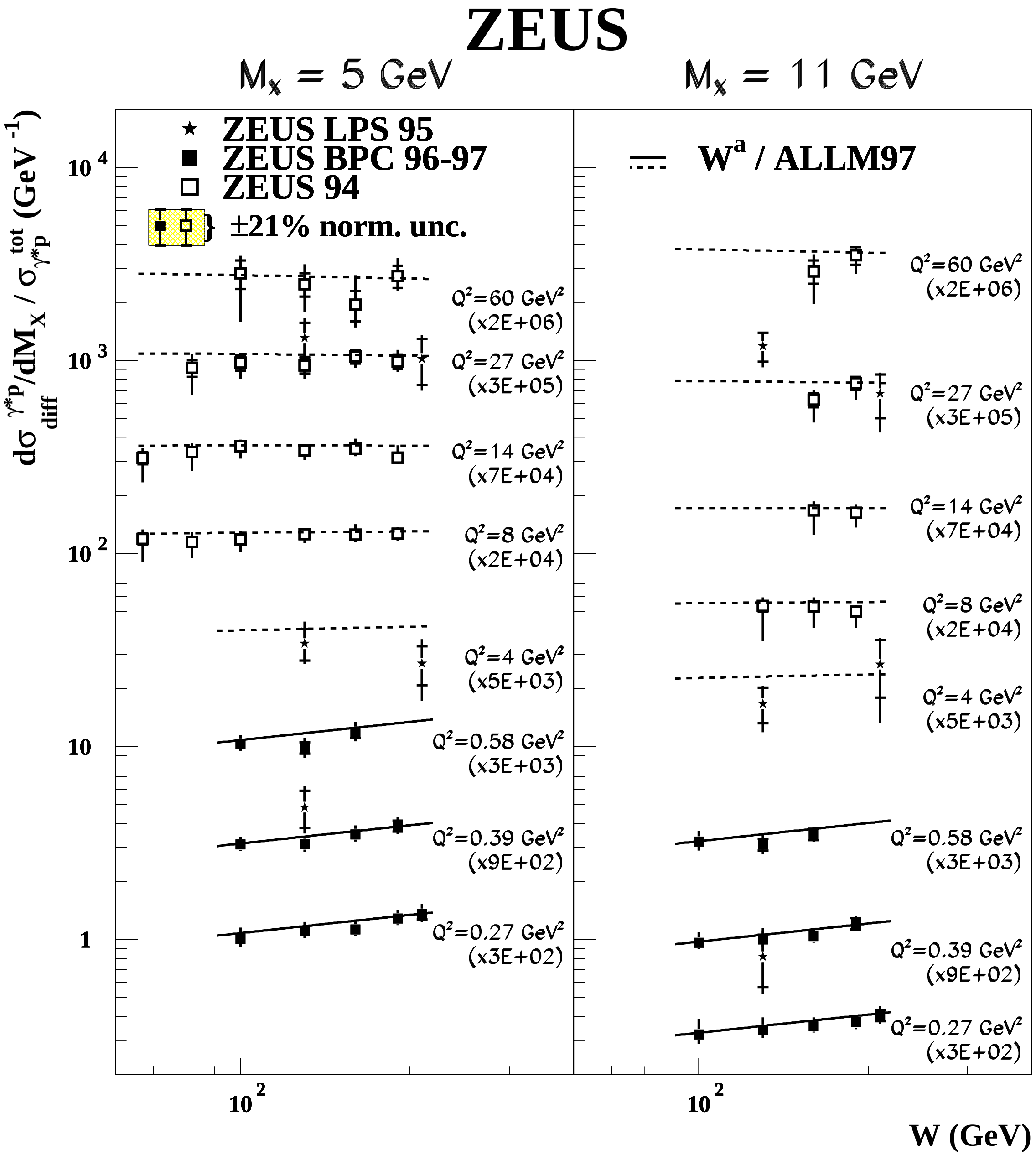
$\alpha_{IP}(0)$ grows with Q^2 ?

$\longrightarrow$ larger than soft pomeron at large Q^2

Growth of effective $\alpha_{IP}(0)$ slower for diffractive than for inclusive ?

Dominant error from ignorance of $F_L^{D(3)}$

Energy dependence of the ratio Diffractive / Inclusive



$$R = \frac{\int (\mathrm{d}\sigma_D^{\gamma p}/\mathrm{d}M_X)}{\sigma_{total}^{\gamma p}}$$

$$\sim \frac{(W^2)^{2(\alpha_{\bar{I}P}-1)}}{(W^2)^{(\alpha_{IP}-1)}} \sim W^{\rho}$$

Transition ($Q^2 \sim 1.0\ \mathrm{GeV}^2$) :

$\rho = 0.24 \pm 0.07(stat.)$

Diffractive rising faster than inclusive

→ Regge behaviour

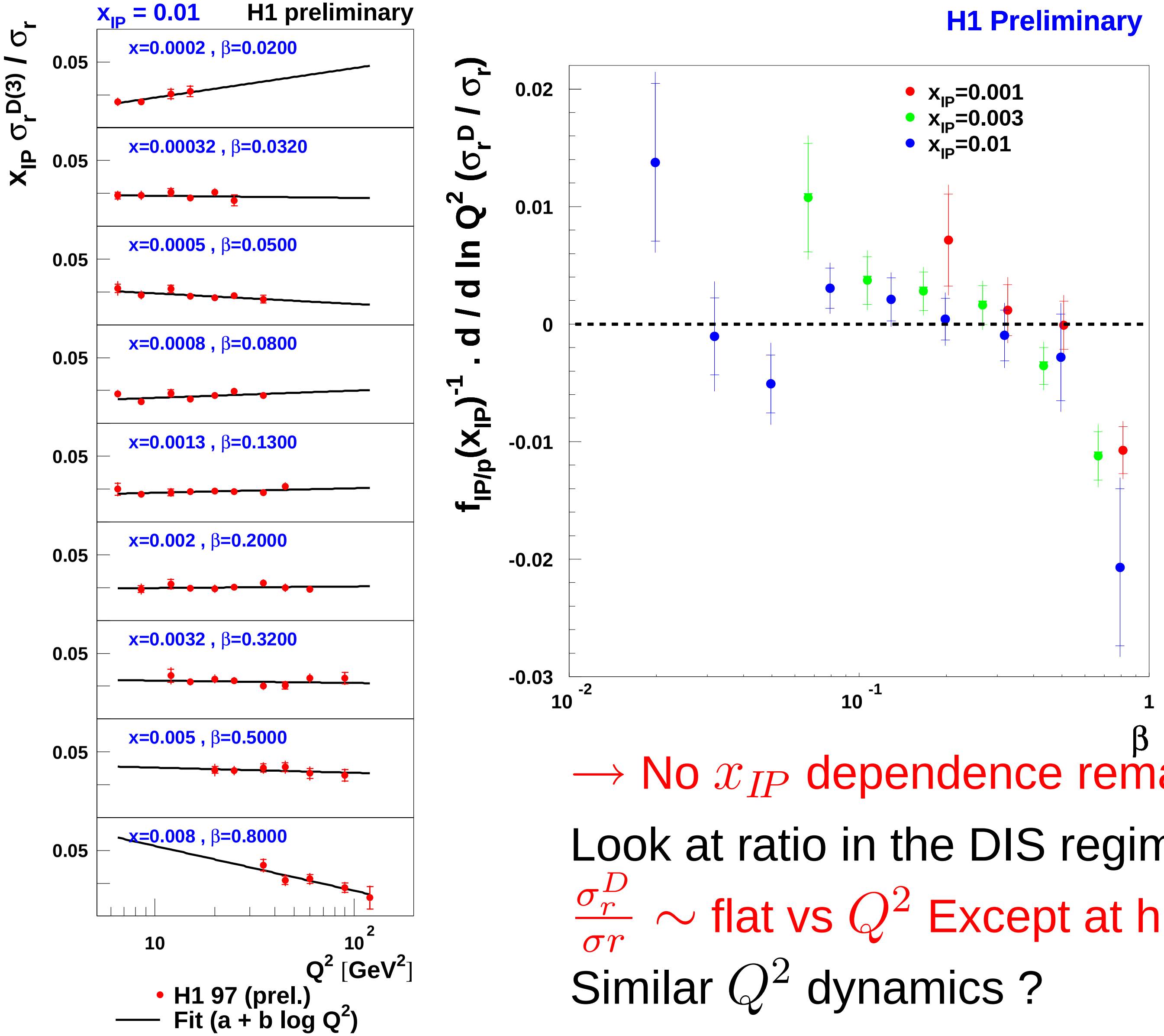
DIS regime ($Q^2 > 4\mathrm{GeV}^2$) :

$\rho = 0.00 \pm 0.03(stat.)$

Same energy dependence

→ Non-Regge behaviour

Logarithmic Q^2 *derivative of ratio* $\frac{\sigma_r^{D(3)}}{\sigma_r}$



Fit $R = A + B \ln Q^2$

Divided by $f_{IP/p}(x_{IP})$

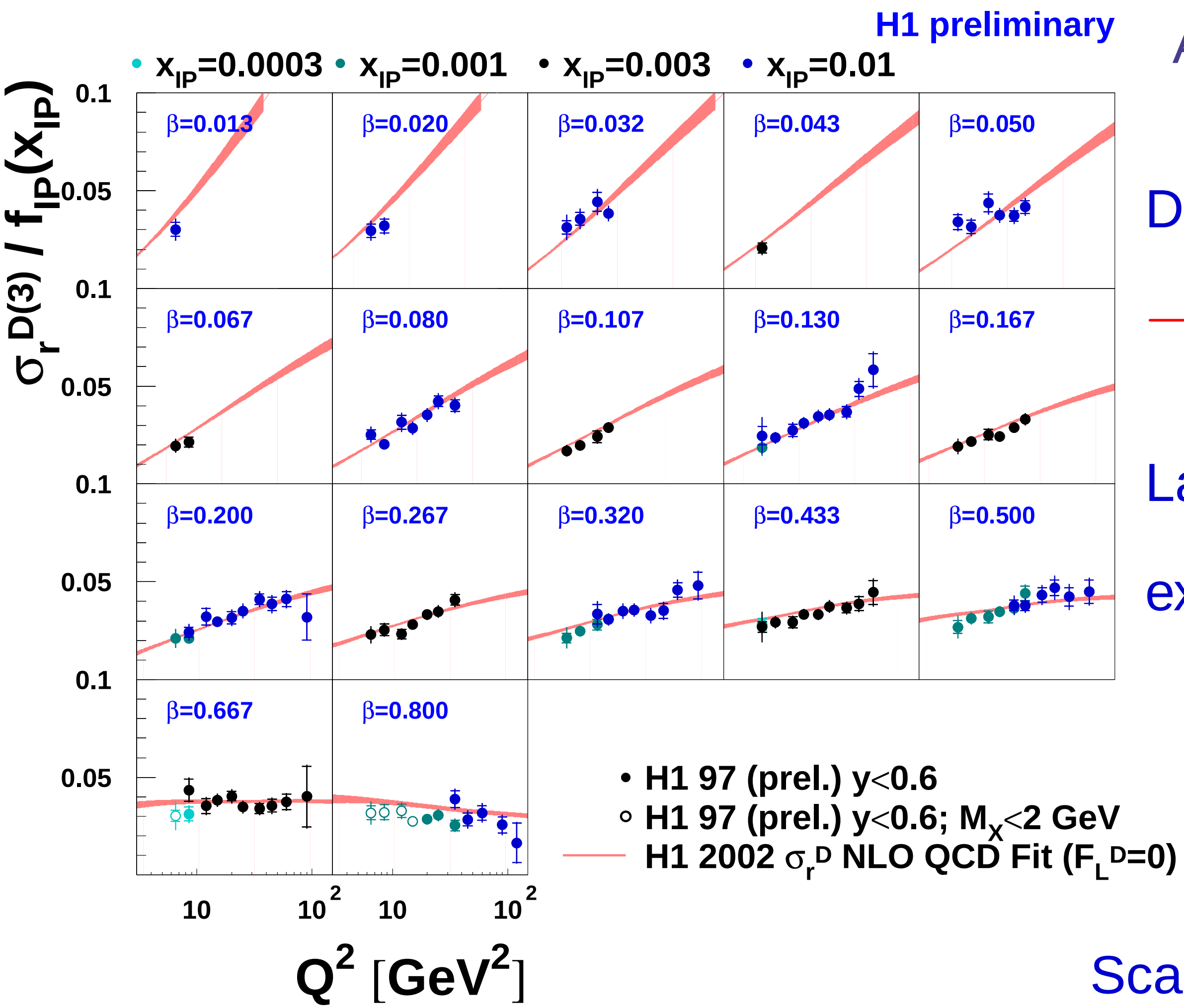
$\rightarrow$ No x_{IP} dependence remains

Look at ratio in the DIS regime

$\frac{\sigma_r^D}{\sigma r} \sim$ flat vs Q^2 Except at highest β

Similar Q^2 dynamics ?

Q^2 Dependence of $\sigma_r^{D(3)}$



At fixed x_{IP} and β

Divide by $f_{IP}(x_{IP})$

$\longrightarrow$ compare different x_{IP} bins

Large +ve Scaling violations

except at highest β

$\longrightarrow$ gluon dominated

Scaling violations similar at

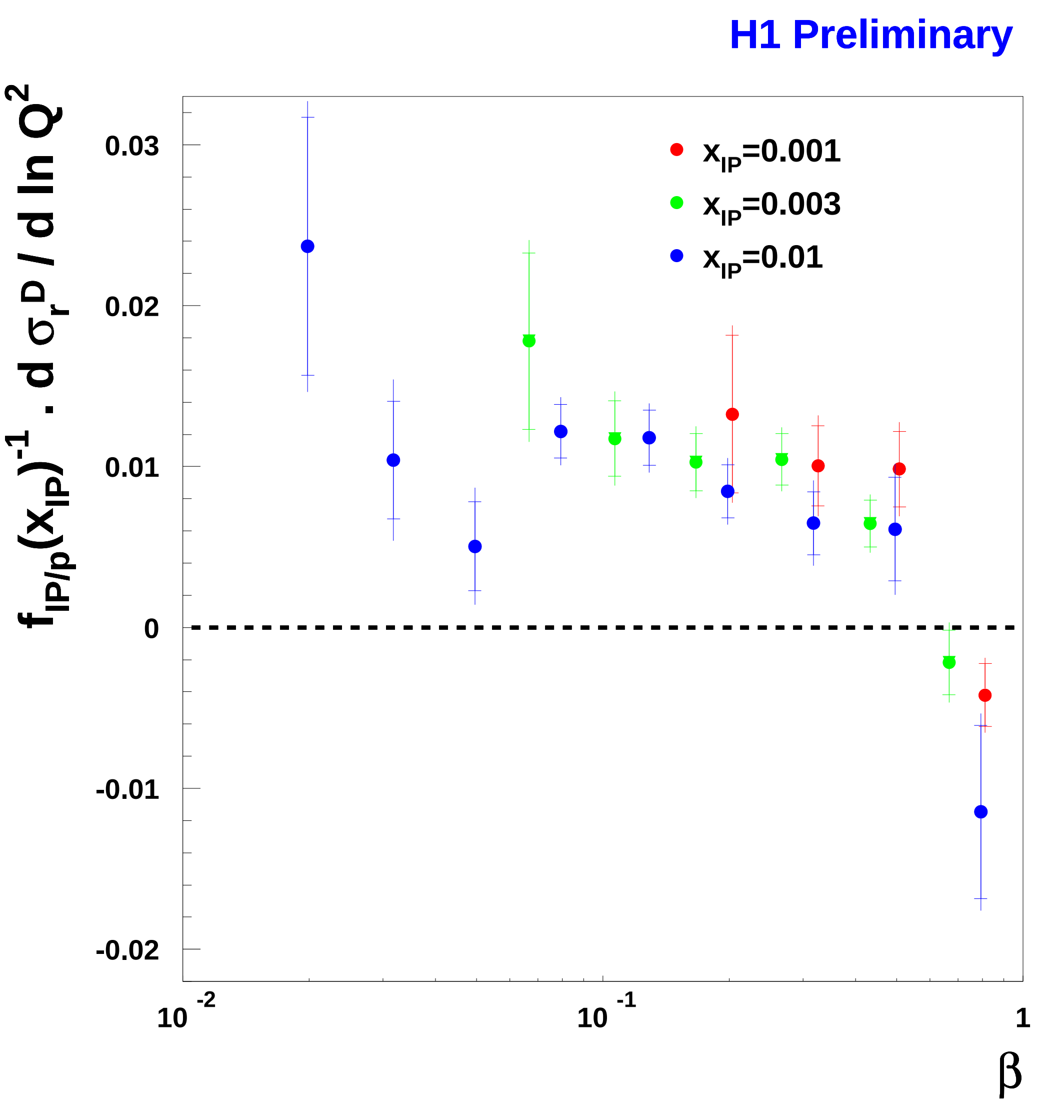
all values of x_{IP}

QCD fit describes the data

Details to follow

$\longrightarrow$ Support for Regge factorisation

Logarithmic Q^2 *derivative of* $\sigma_r^{D(3)}$



Quantify Scaling violations ...

At fixed x_{IP} and β

Fit $\sigma_r^D = A + B \ln Q^2$

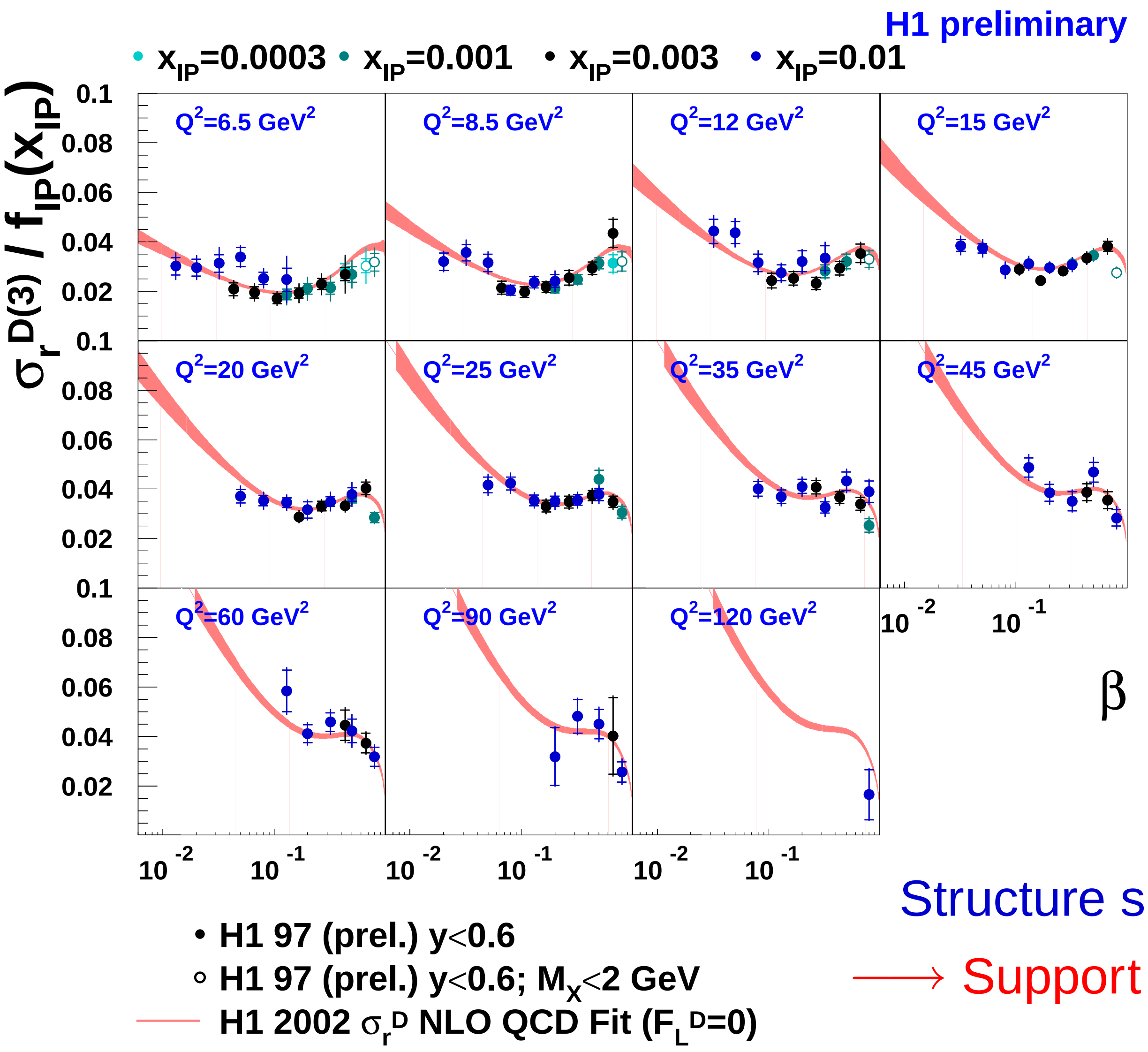
$\longrightarrow B = \frac{d}{d\ln Q^2}(\sigma_r^D)$

Large +ve Scaling violations

Flat at $\beta \simeq 0.6$

$\longrightarrow$ gluon dominated

β Dependence of $\sigma_r^{D(3)}$



At fixed x_{IP} and Q^2

Divide by $f_{IP}(x_{IP})$ to

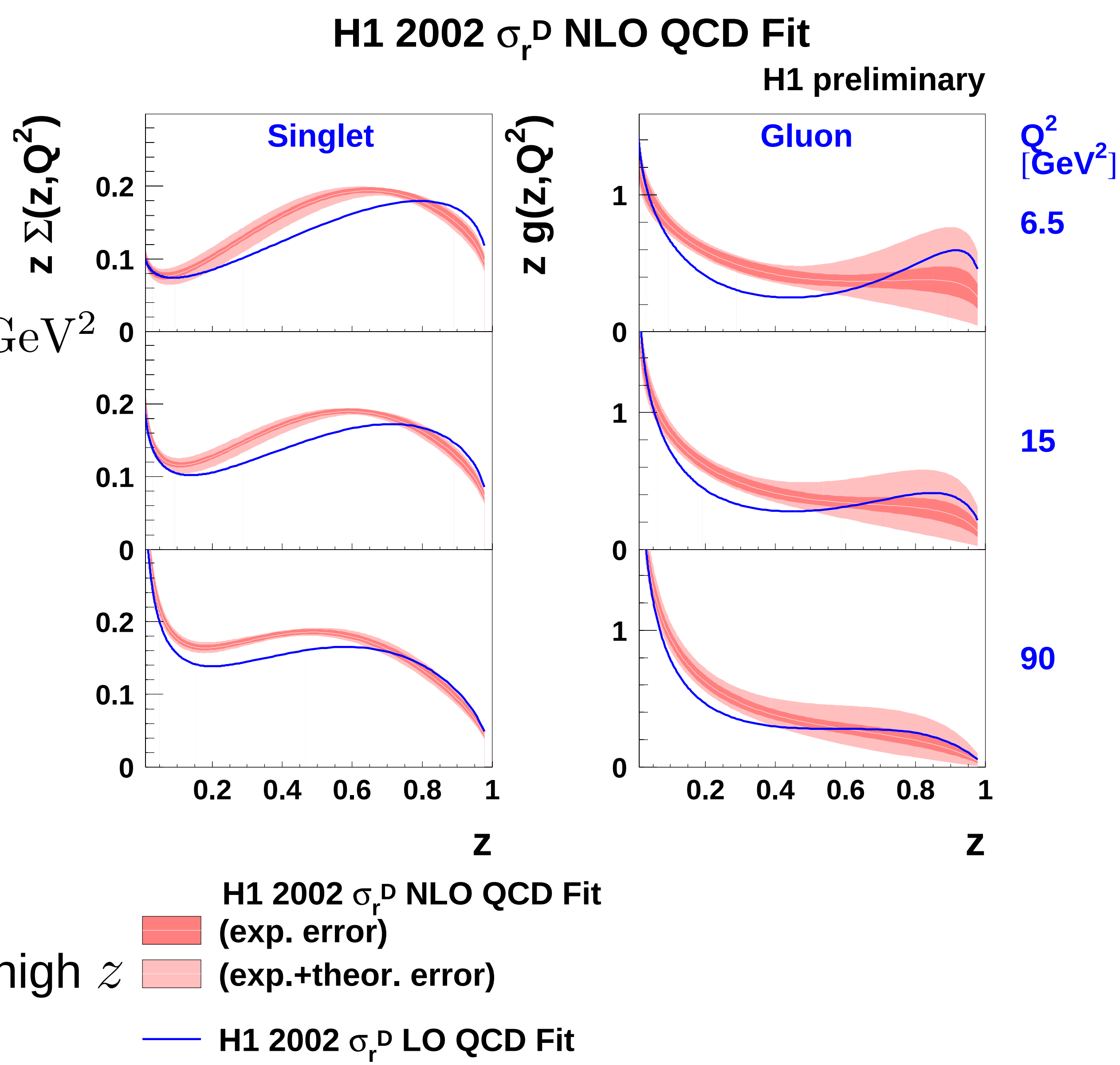
compare different x_{IP} bins

$\longrightarrow$ See full β structure

Structure similar at all values of x_{IP}

$\longrightarrow$ Support for Regge factorisation

New NLO DGLAP Fit ⟶ PDF's



QCD Fit technique :

Singlet Σ and gluon g

components with $Q_0^2 = 3\ \mathrm{GeV}^2$

x_{IP} factorisation

NLO DGLAP evolution

Full propagation of errors

PDF's of diffraction :

Gluon dominated

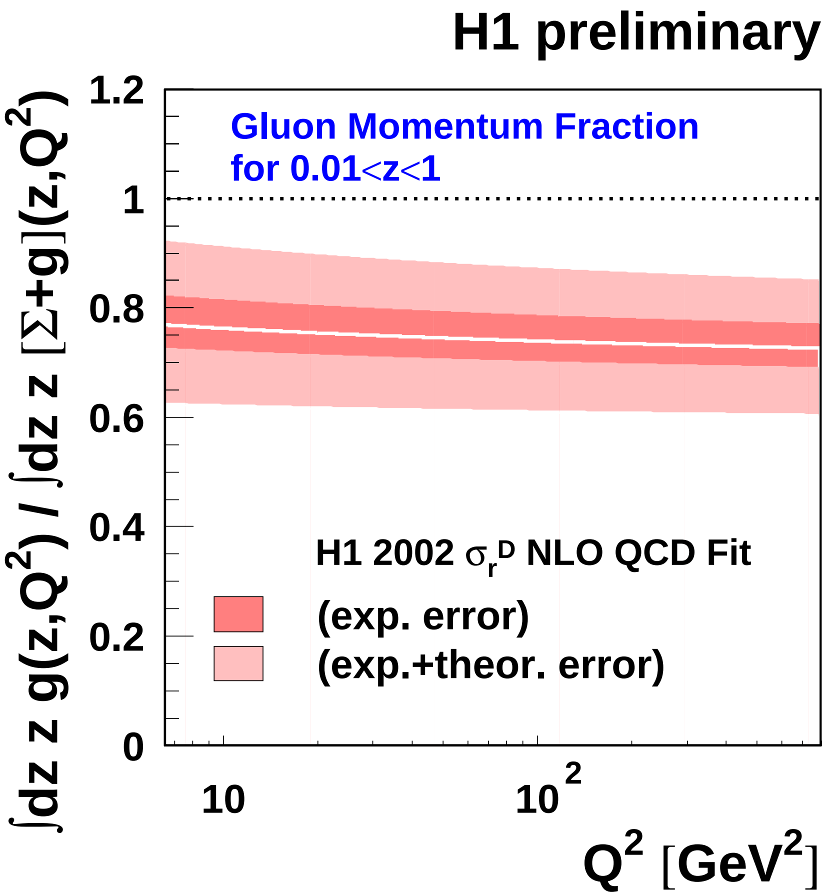
Extend to large z

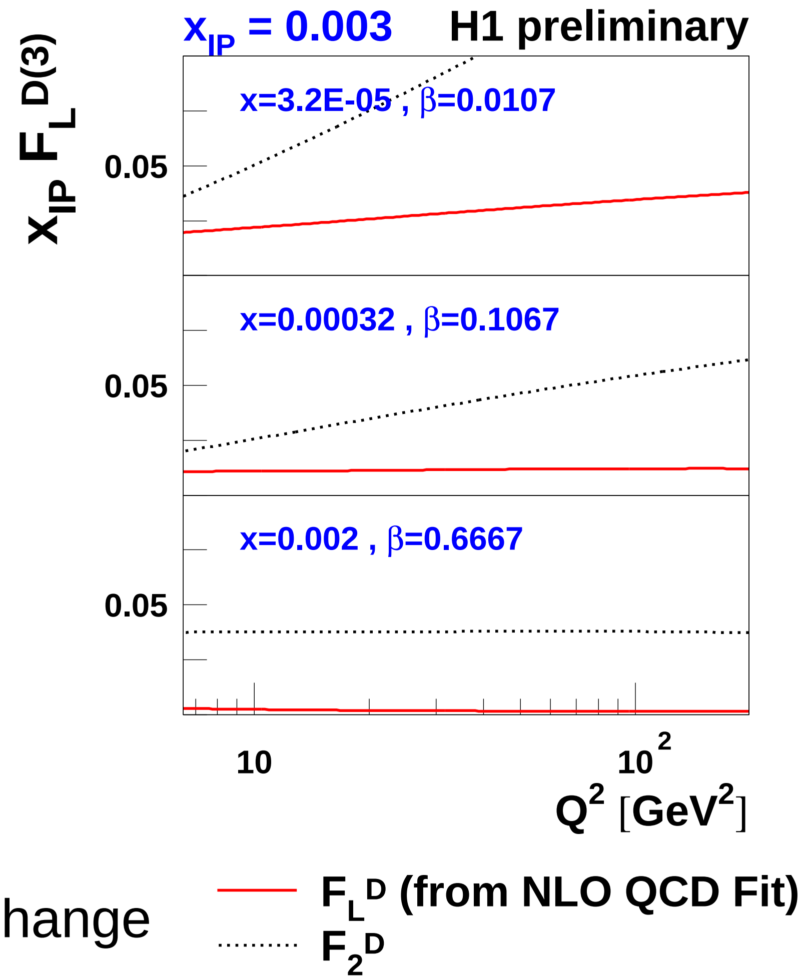
Σ well constrained

Large uncertainty on g at high z

$\longrightarrow$ Consistent with the HERA picture

The gluon momentum fraction and F_L





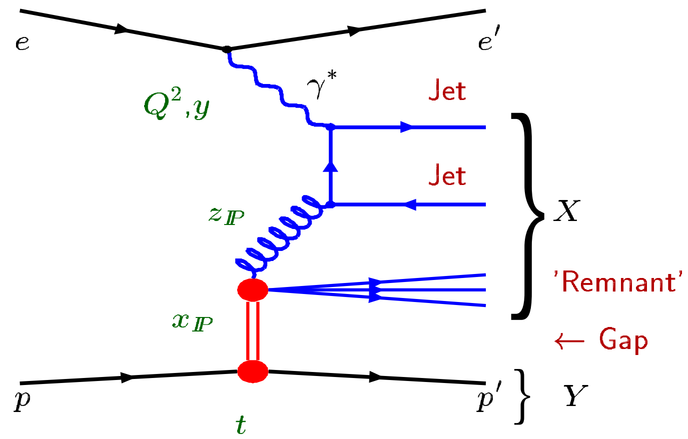
Momentum fraction of diffractive exchange carried by gluons

$\rightarrow 75 \pm 15\%$

F_L^D predicted at leading twist

$\rightarrow$ F_L^D is large at low Q^2 and low β

Factorisation at HERA



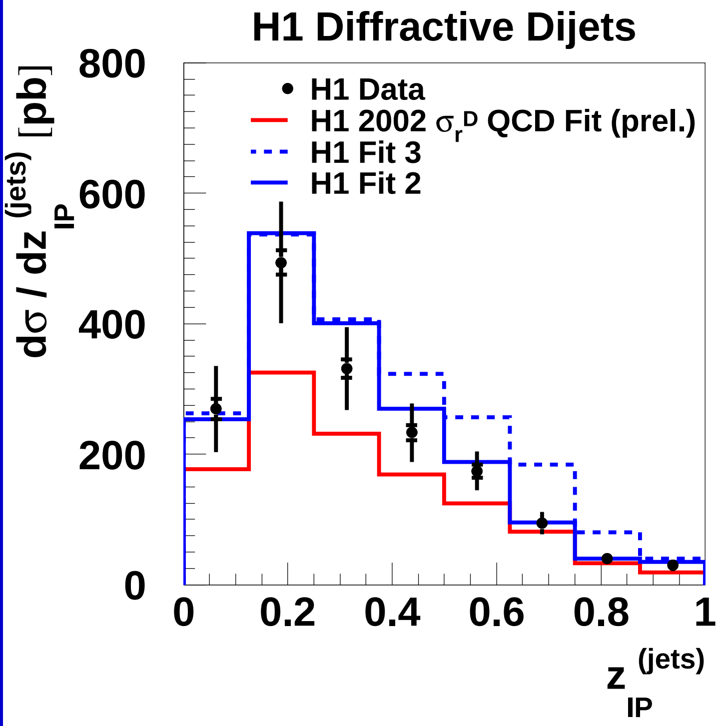
Use PDF's from LO fit to predict diffractive final state

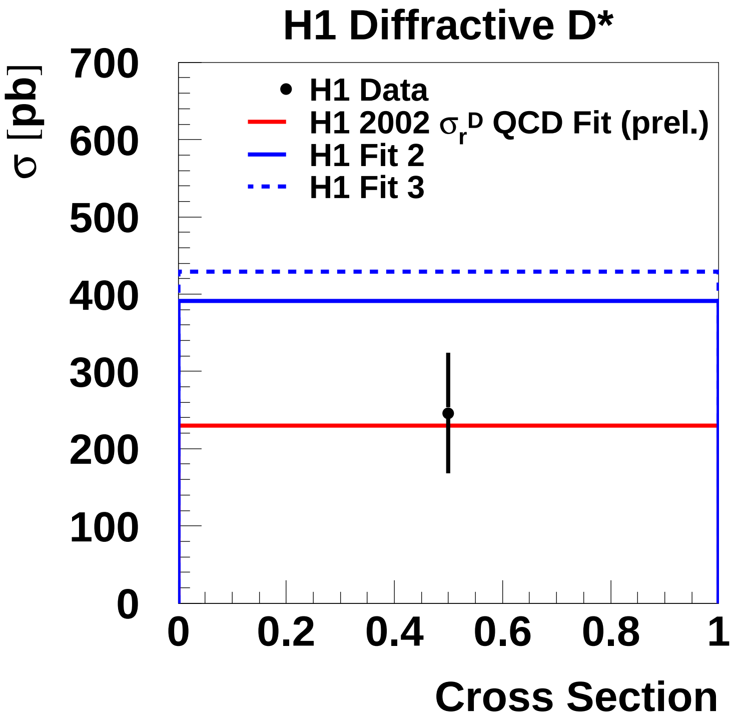
Comparison using RAPGAP

$$\mu^2 = Q^2 + p_T^2 + m^2$$

Differential distributions well described

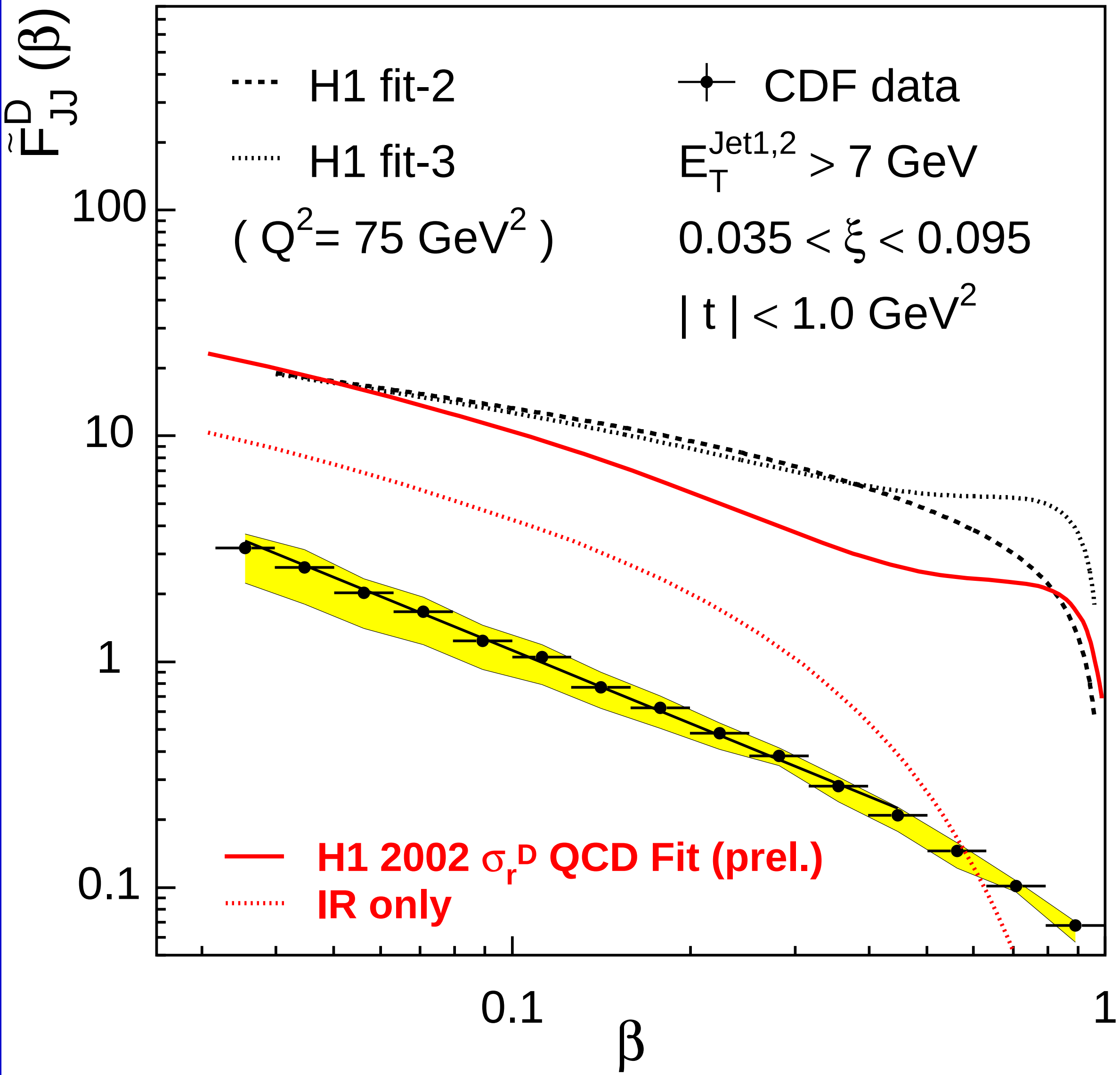
Uncertainty on PDF's not shown





⟶ Consistent with factorisation

Factorisation between HERA and the Tevatron



Use PDF's from HERA to predict diffractive final state

At HERA :

Consistent with factorisation

At the Tevatron :

→ Factorisation broken

Gap survival probability ?

Summary

The Data describing the QCD Structure of Diffractive Interactions has reached high precision. QCD Hard Scattering Factorisation for Diffractive DIS is at the same level of theoretical prescription as for inclusive DIS

$\longrightarrow$ Precision measurements testing precision theory

- **New measurements from H1 and Zeus**
- $\alpha_{IP}(0)$ **larger in DIS than in photoproduction and soft pomeron**
- **Transition region between photoproduction and DIS studied**
- **Suggestion of similar (x, Q^2) dynamics to inclusive DIS at medium** β
- **NLO QCD fit yields PDF's dominated by gluon**
- **Large gluon density persists out to very high** β
- **Factorisation works at HERA**
- **Factorisation breakdown at the Tevatron confirmed**