Results on Inclusive Diffraction From The ZEUS Experiment

Presented by B.Loehr on behalf of ZEUS

Data from the running period 1999-2000.

The last period with the ZEUS Forward Plug Calorimeter (FPC) and the Leading Proton Spectrometer (LPS) installed.

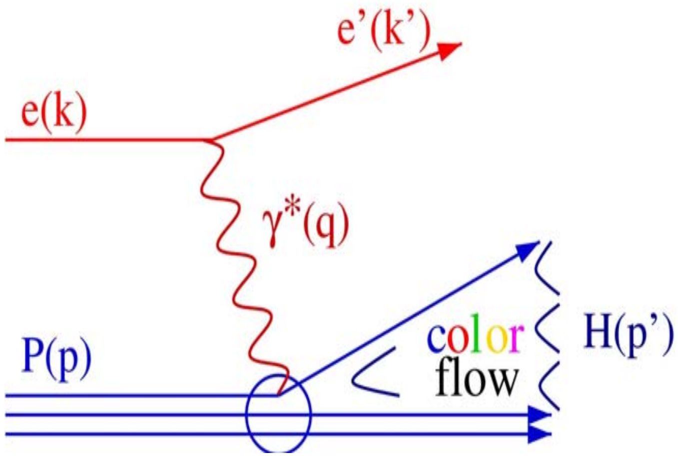
Three methods to extract inclusive diffractive events:

- Leading proton spectrometer
- The M_X – method
- Large rapidity gap method

We attempt to get a consistent picture from these three methods using data from the same running period.

Kinematics of DIS and Diffraction

Inclusive DIS events :



$s = (k+p)^2$ — center of mass energy squared

$Q^2 = -q^2 = -(k-k')^2$ — virtuality, size of the probe

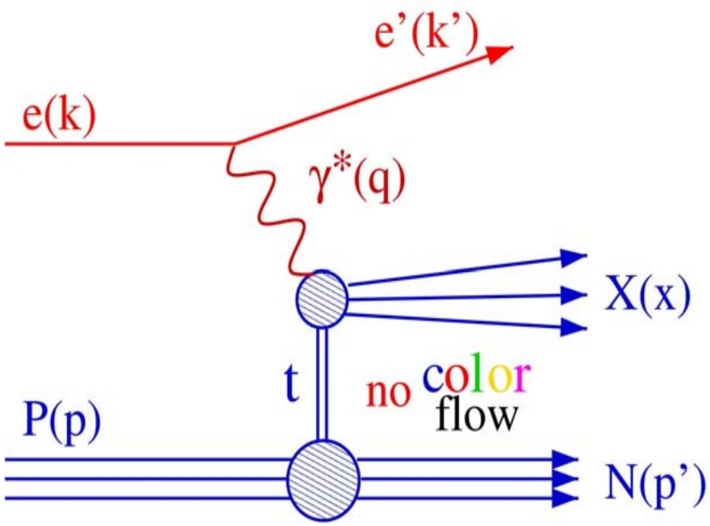
$W^2 = M_H^2 = (p+q)^2$ — γ^* - proton cms energy squared

$x = \frac{Q^2}{2p \cdot q}$ — x: fraction of the proton carried by the struck parton

$y = \frac{p \cdot q}{p \cdot k}$ — y: inelasticity, fraction of the electron momentum carried by the virtual photon

$Q^2 = x \cdot y \cdot s$

Diffractive DIS events :



For diffractive events in addition 2 variables

M_x — mass of the diffractive system x

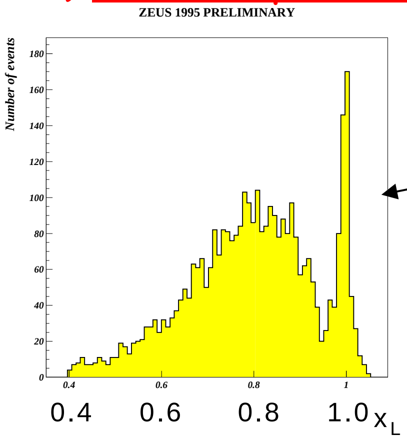
$t = (p-p')^2$ — four-momentum transfer squared at the proton vertex

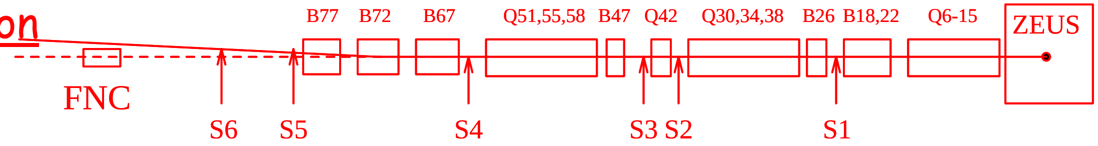
$x_{IP} = \frac{(p-p') \cdot q}{p \cdot q} = \frac{M_X^2 + Q^2}{W^2 + Q^2}$ — momentum fraction of the proton carried by the Pomeron

$\beta = \frac{Q^2}{2(p-p') \cdot q} = \frac{x}{x_{IP}} = \frac{Q^2}{M_X^2 + Q^2}$ — fraction of the Pomeron momentum which enters the hard scattering

Extraction of diffractive events (I)

1.) Forward proton detection





$x_L \approx 1$ -> diffractively scattered proton ; $x_L \approx 1 - x_{IP}$

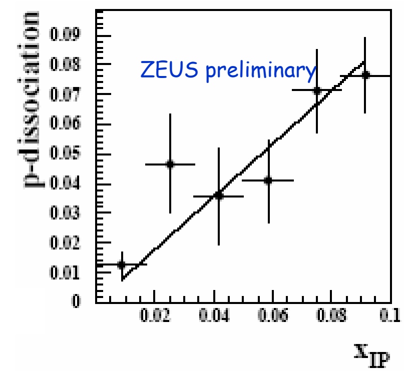
$$t = -\frac{p_T^2}{x_L} - \frac{(1-x_L)^2}{x_L} M_p^2$$

the only method to measure the t-distribution

LPS has small acceptance

Forward proton tagged events are practically free of proton dissociation background.

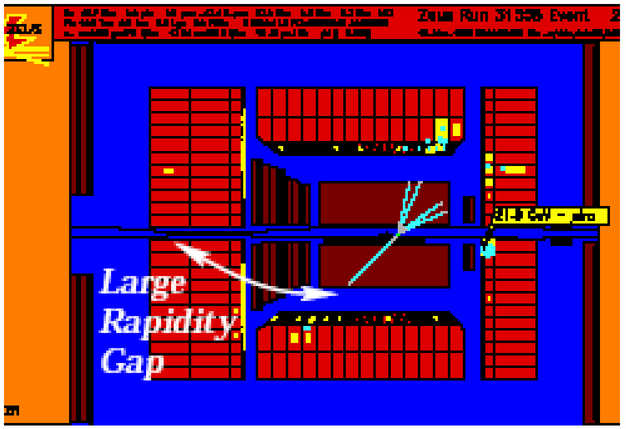
They contain, however, contributions from Reggeon exchange at high x_{IP} or low x_L.



2.) The large (pseudo)rapidity (η_{max}) method

$$\eta_{max} = -\ln \tan(\Theta_{min}/2)$$

No tracks or energy deposits in calorimeter for rapidities greater than η_{max} or at angles less than Θ_{min}.



Events tagged by a large rapidity are dominated by diffraction but they contain contributions from proton dissociation and from Reggeon exchange.

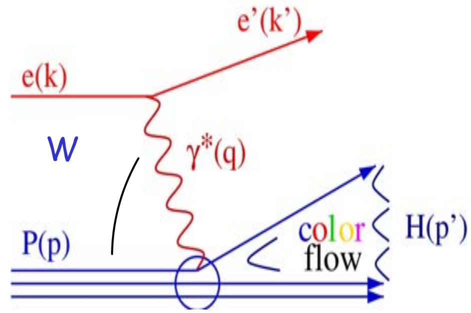
Extraction of diffractive events (II)

3.) The M_x-method

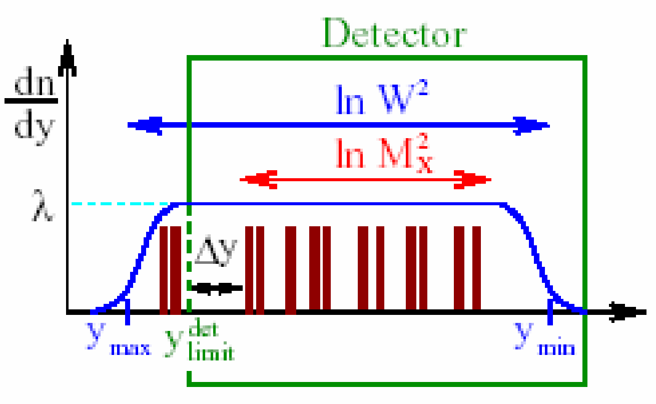
(i) Nondiffractive events :

Rapidity $y = \frac{1}{2} \ln \frac{E+p_z}{E-p_z}$

Property of a produced particle



Uncorrelated particle emission between incoming p-direction and scattered quark.



$$W^2 = c_0 e^{y_{max} - y_{min}}$$

$$M_X^2 = c_0 e^{y_{limit} - y_{min}}$$

$$\frac{dN_{part}}{dy} = \lambda = \text{const.}$$

Poisson distr. for Δy in nondiffractive events

$$P(0) = e^{-\lambda \Delta y} \Rightarrow \frac{dN_{nondiff}}{d \ln M_X^2} = c \cdot e^{b \cdot \ln M_X^2}$$

(ii) Diffractive events :

$$\frac{dN_{diff}}{dM_X^2} \propto \frac{1}{(M_X^2)^n}$$

At high energies and not too low M_X

$n \approx 1$

$$\Rightarrow \frac{dN_{diff}}{d \ln M_X^2} \approx \text{const.}$$

Extraction of diffractive events (III)

(iii) Nondiffractive + diffractive contributions

$$\frac{dN}{d\ln M_X^2} = D + c \cdot e^{b \cdot \ln M_X^2}$$

D is the diffractive contribution

Two approaches :

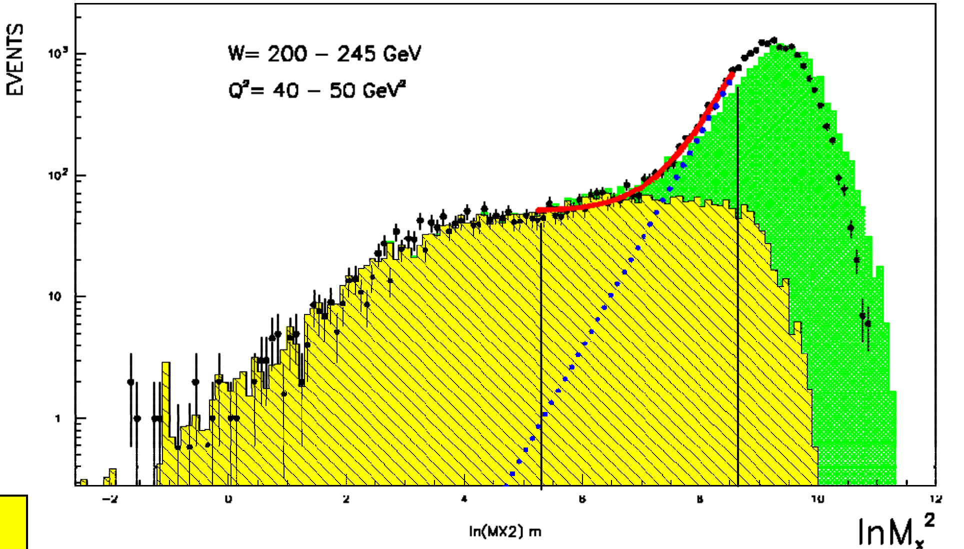
1.) take D=const. for a limited range in $\ln M^2_X$

2.) take D from a BEKW-model (*see later*) parametrization which describes our measured data. This is an iterative procedure.

Fit slope b, c and D

for $\ln M_X^2 \leq \ln W^2 - \eta_0$

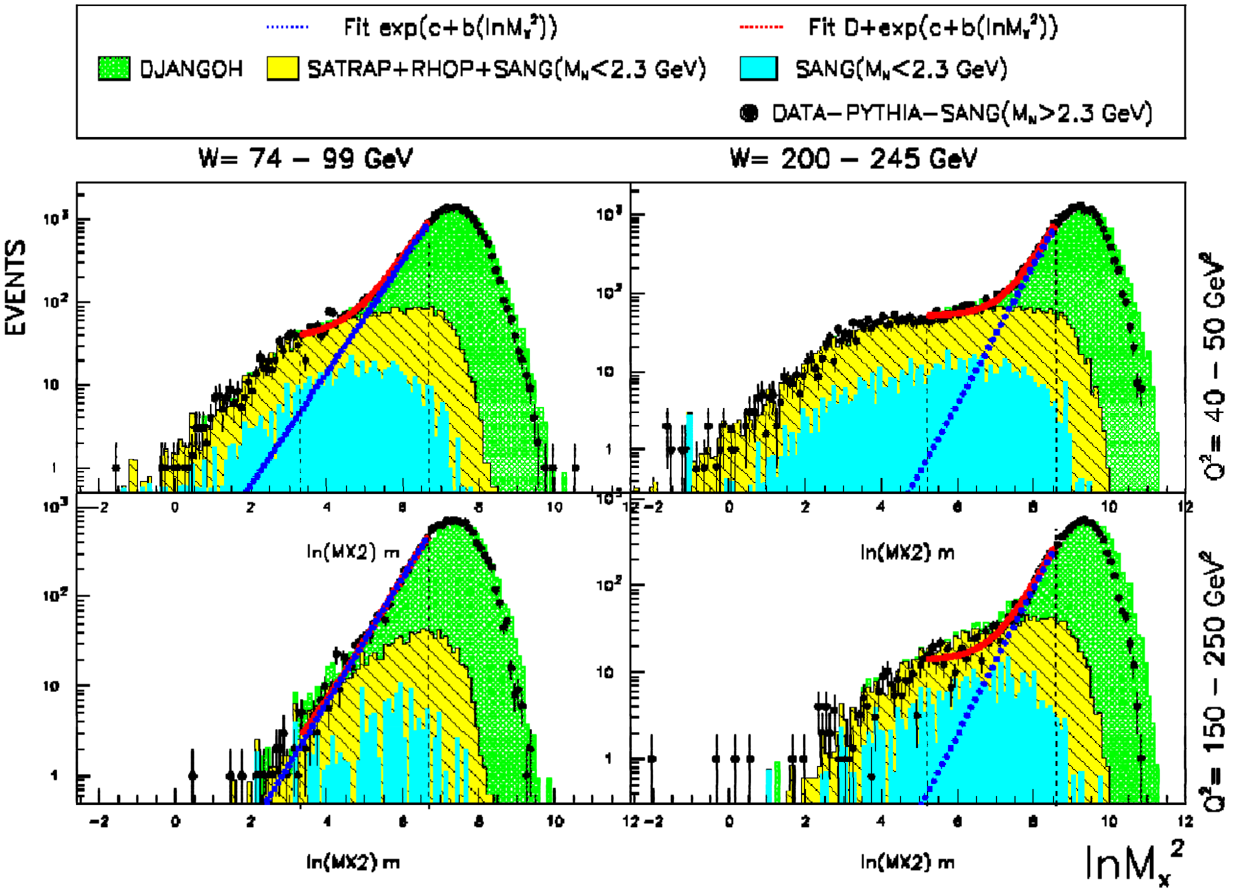
Determine diffractive events by subtracting nondiffractive events from measured data bin by bin as calculated from fitted values b and c.



Both approaches give the same results

The ZEUS M_X-Analysis (I)

Example of $\ln M_X$-distributions for four kinematical bins :



fit to data in the fit region

fitted slope of of nondiffractive events

Diffractive data selected by the M_X-method contain proton dissociative events but no contributions from Regge exchange

MC-simulation :

nondiffractive : DJANGOH

diffractive : SATRAP

proton diss.: SANG

SANG adjusted to fit data which are dominated by proton dissociation

Proton dissociation can be reliably calculated for M_N > 2.3 GeV and has been subtracted from data

The ZEUS M_X-results contain contributions from proton dissociation for masses M_N < 2.3 GeV.

ZEUS M_X - data from 1998 - 2000 (II)

Mx 98-99, Mx 99-00 (prel.)

Mx 98-99 :

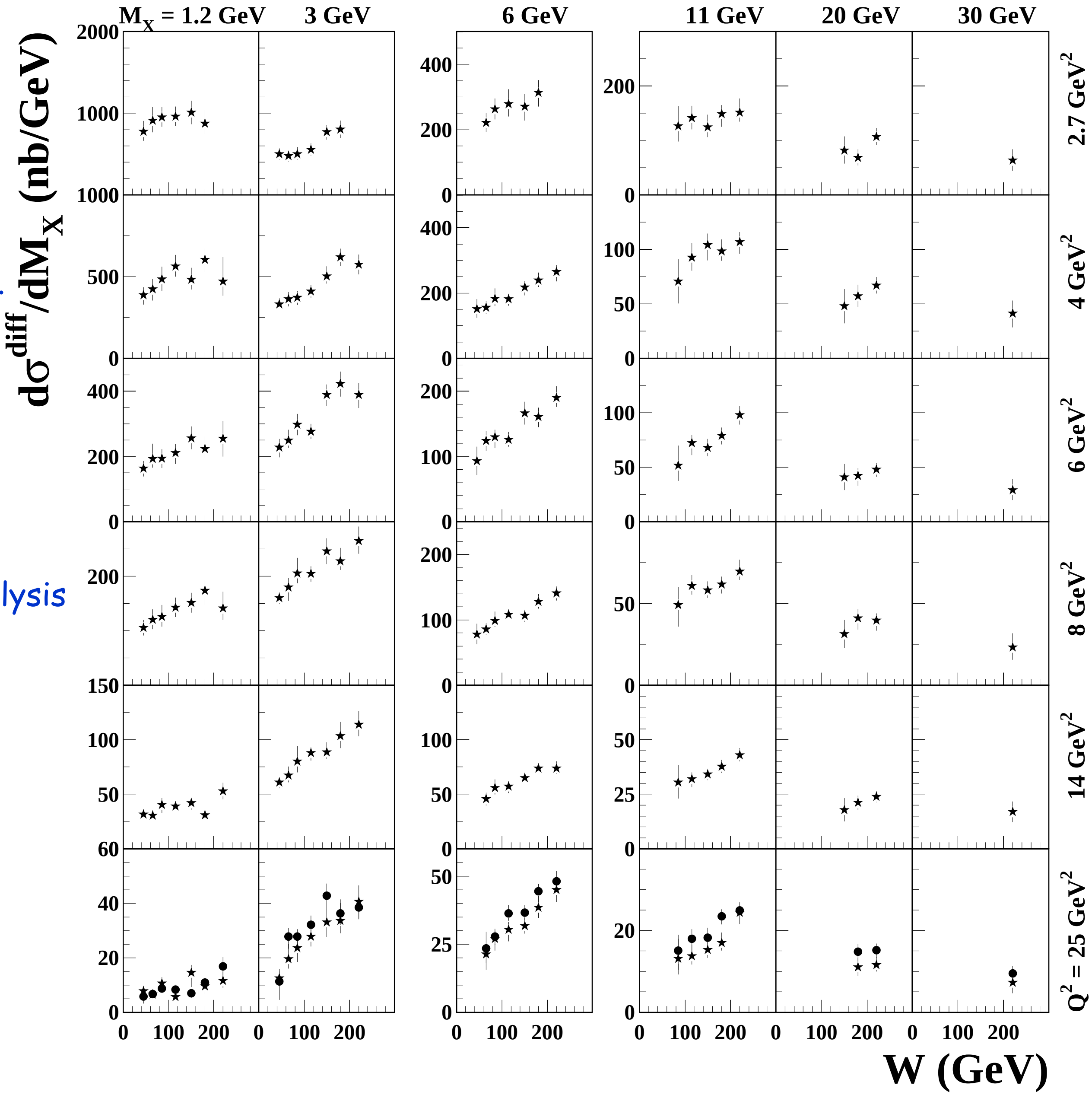
Published data from 1998-1999 period

(ZEUS Coll., S.Chekanov et al. Nucl. Phys B 713, 3 (2005))

Prel. Mx 99-00:

Preliminary results from 1999-2000 period.
Extension of Mx 98-99 analysis to higher Q².

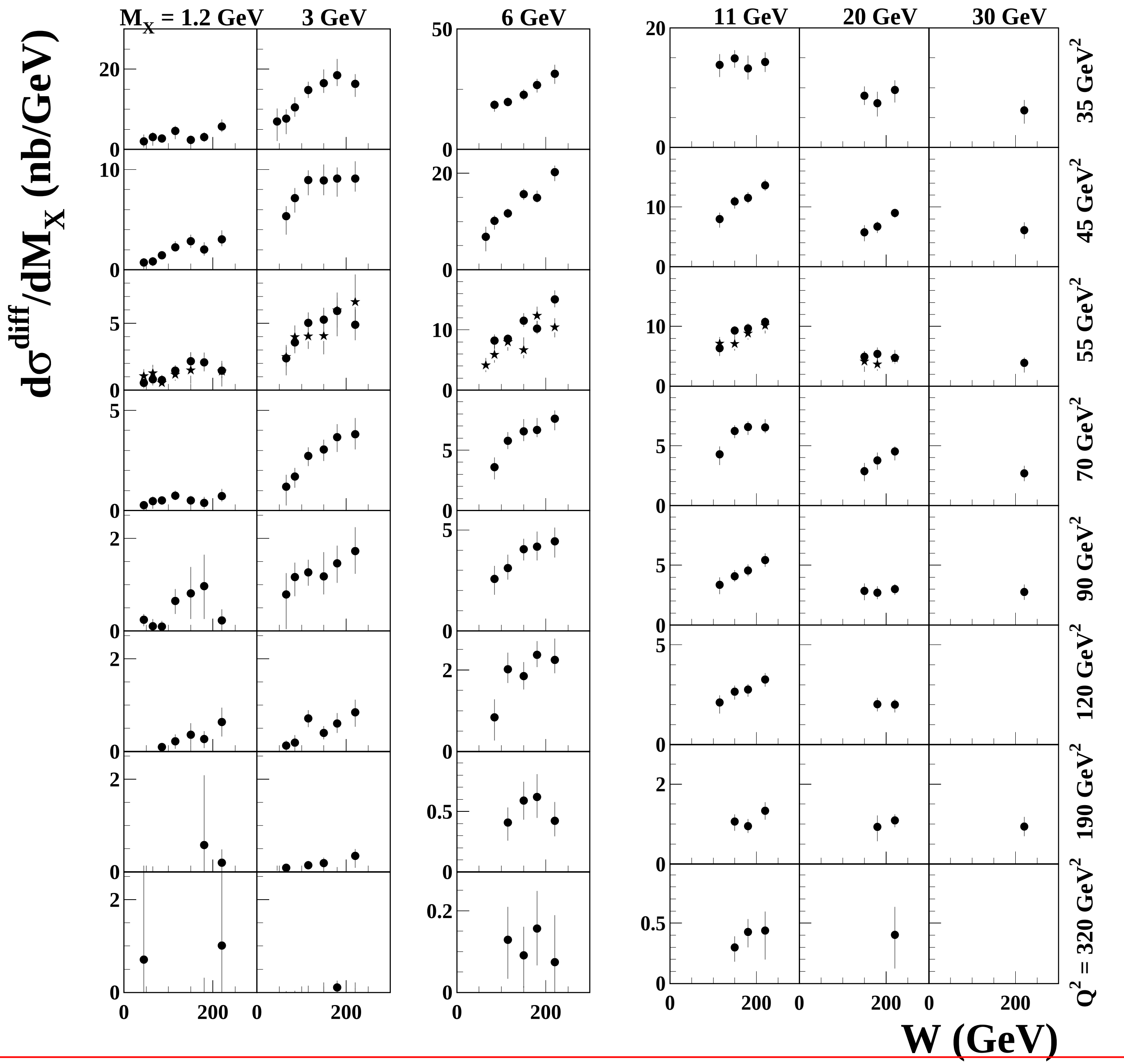
Mx 98-99 and Mx 99-00 analyses have common bin at Q² = 25 GeV²



ZEUS Mx 98-99, ZEUS Mx 00 (prel.)

Mx 98-99:

Prel.
Mx 99-00:



Mx 98-99 and Mx 99-00 analyses have common bin at Q^2 = 55 GeV²

Within syst. errors good agreement between Mx 98-99 and Mx 99-00 results

Fit W-dependence of inclusive DIS and inclusive diffractive DIS cross sections

Inclusive DIS:

For small x, F_2 rises rapidly as x-> 0

$$F_2 = c \cdot x^{-\lambda} \qquad W \propto \frac{1}{x}$$

$$\lambda = \alpha_{IP}(0) - 1$$

Inclusive diffractive DIS:

$$\frac{d\sigma_{\gamma^* p \to XN}}{dM_X} = h \cdot \left(\frac{W}{W_0} \right)^{a^{diff}}$$

$$\overline{\alpha}_{IP} = 1 + \frac{a^{diff}}{4}$$ averaged over t

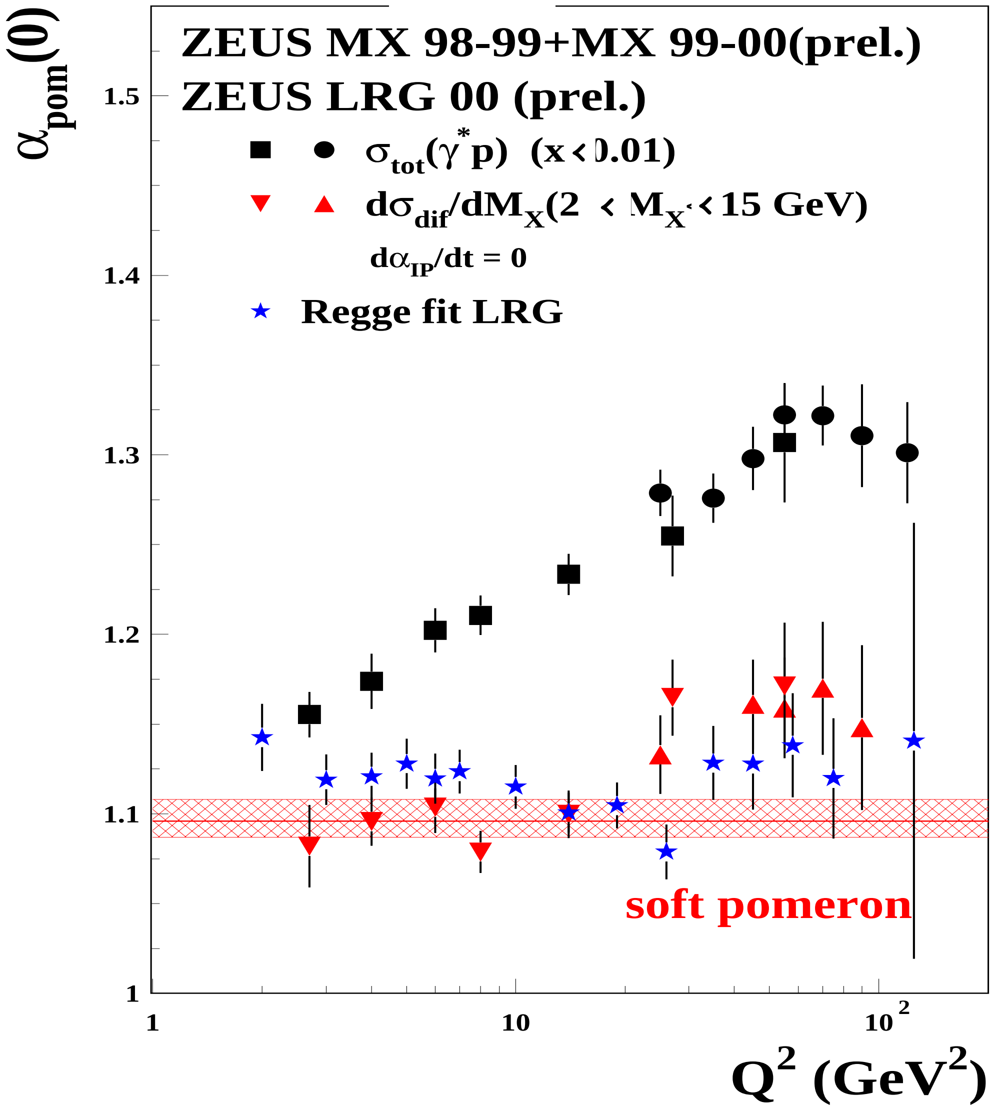
$$\alpha_{IP}(t) = \alpha_{IP}(0) + \alpha'_{IP} \cdot t$$

$$\frac{d\sigma}{dt} = f(t) \cdot e^{2(\alpha_{IP}(t)-1) \cdot \ln\left(\frac{W}{W_0}\right)^2}$$

$$\frac{d\sigma}{dt} \propto e^{A \cdot t}$$ for small t.

take $A = 7.9 \pm 0.5(stat.)\,^{+0.9}_{-0.5}(syst.)\,GeV^2$

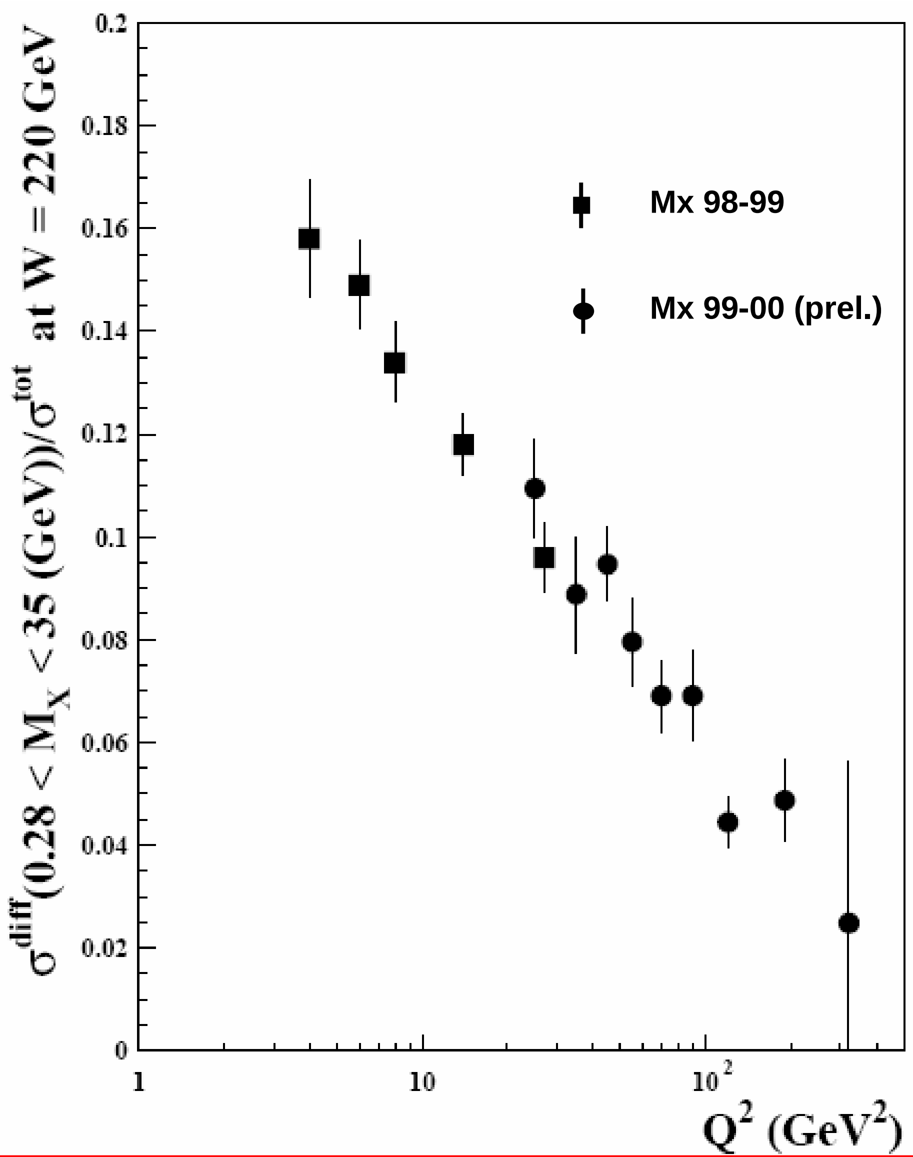
as measured by ZEUS LPS



Inclusive DIS and inclusive diffractive DIS are not described by the same 'Pomeron'.

Ratio of total diffractive cross-section to total DIS cross-section

Ratio plotted at W=220 GeV because only there the full M_X range is covered by measurments



$r = \sigma^{diff}(0.28 < M_X < 35\ GeV)/\sigma^{tot}$

Within the errors of the measurements r is independent of W.

At W=220 GeV, r can be fitted by

$$r = 0.22 - 0.034 \cdot \ln(1+Q^2)$$

This logarithmic dependence of the ratio of total diffractive cross-section to the total DIS cross section indicates that diffraction is a leading twist process for not too low Q^2.

$$\frac{d^4\sigma}{dQ^2 dt dx_{IP} d\beta} = \frac{2\pi\alpha_{em}}{\beta Q^2}[1-(1-y)^2]\cdot F_2^{D(4)}(Q^2,t,x_{IP},\beta)$$

ZEUS neglects the contribution from longitudinal structure function

H1 defines :

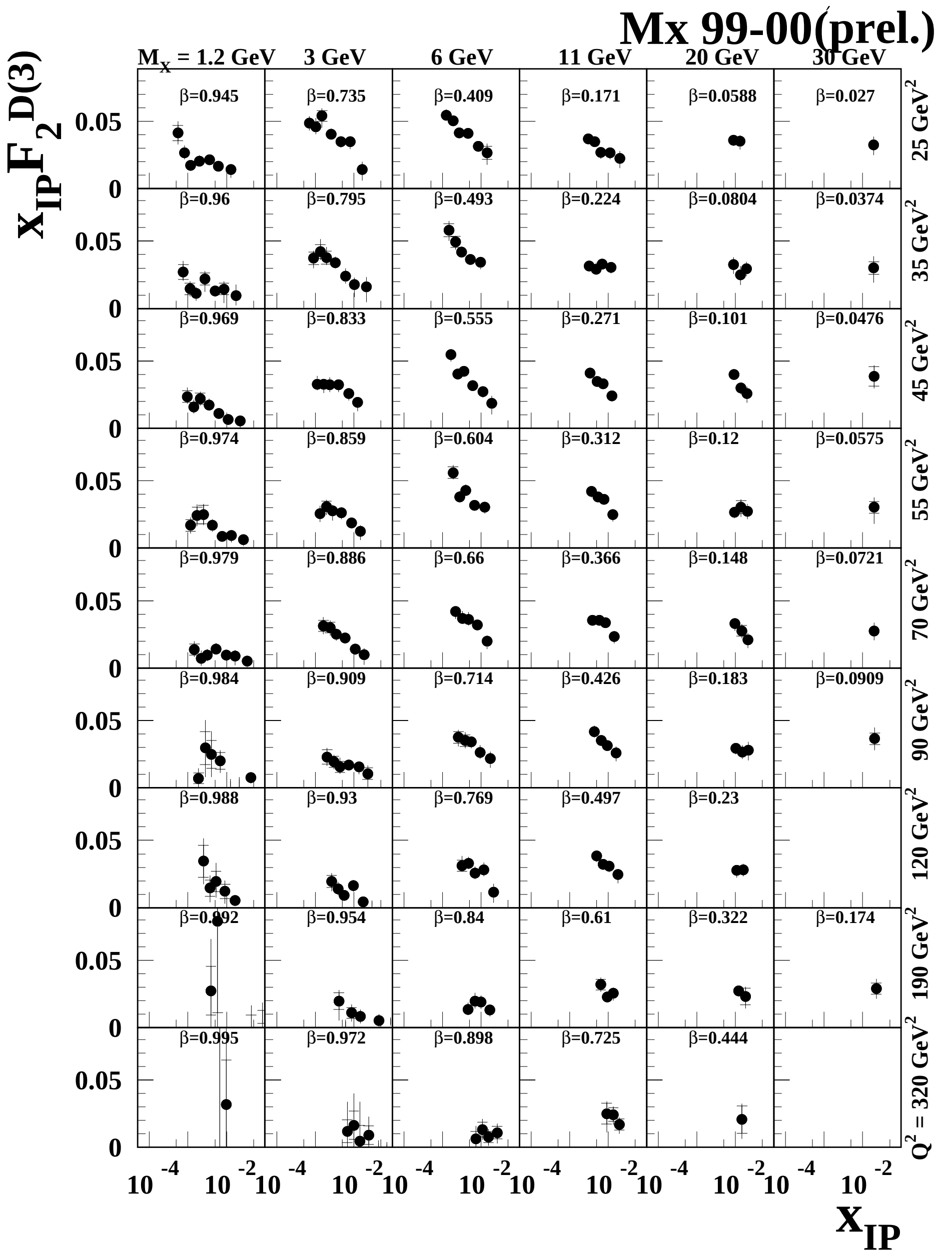
$$\sigma_r^D = F_2^D - \underbrace{\frac{y^2}{1+(1-y)^2}F_L^D}_{\text{sizable only at high } y}$$

If t is not measured :
(LRG and M_X-method)

$$\frac{d^3\sigma^{diff}_{\gamma^* p\to XN}}{dQ^2 d\beta dx_{IP}} = \frac{2\pi\alpha^2}{\beta Q^4}\left[1+(1-y)^2\right]\cdot F_2^{D(3)}\left(\beta, x_{IP}, Q^2\right)$$

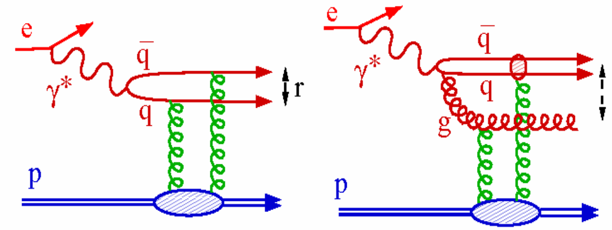
$$\frac{1}{2M_X}\frac{d\sigma^{diff}_{\gamma^* p\to XN}\left(M_X, W, Q^2\right)}{dM_X} = \frac{4\pi^2\alpha}{Q^2\left(Q^2+M_X^2\right)} x_{IP} F_2^{D(3)}\left(\beta, x_{IP}, Q^2\right)$$

If $F_2^{D(3)}\left(\beta, x_{IP}, Q^2\right)$ is interpreted in terms of quark densities, it specifies the probability to find in a proton which undergoes a diffractive interaction a quark carrying a fraction $x = \beta x_{IP}$ of the proton momentum.



ZEUS Mx 99-00 (prel.)

ZEUS modified BEKW Fit



Fit with BEKW model

(Bartels, Ellis, Kowalski and Wüsthoff, 1998)

- $x_{I\!P} F_2^{D(3)} = c_T \cdot F^T_{q\bar{q}} + c_L \cdot F^L_{q\bar{q}} + c_g \cdot F^T_{q\bar{q}g}$

$$F^T_{q\bar{q}} = \left(\frac{x_0}{x_{I\!P}}\right)^{n_T(Q^2)} \cdot \beta(1-\beta)\,,$$

$$F^L_{q\bar{q}} = \left(\frac{x_0}{x_{I\!P}}\right)^{n_L(Q^2)} \cdot \frac{Q_0^2}{Q^2+Q_0^2} \cdot \left[\ln\left(\frac{7}{4} + \frac{Q^2}{4\beta Q_0^2}\right)\right]^2 \cdot \beta^3(1-2\beta)^2\,,$$

$$F^T_{q\bar{q}g} = \left(\frac{x_0}{x_{I\!P}}\right)^{n_g(Q^2)} \cdot \ln\left(1+\frac{Q^2}{Q_0^2}\right) \cdot (1-\beta)^{\gamma}$$

assume $n_T(Q^2) = c_4 + c_7 \ln\left(1+\frac{Q^2}{Q_0^2}\right)$, $n_L(Q^2) = c_5 + c_8 \ln\left(1+\frac{Q^2}{Q_0^2}\right)$,

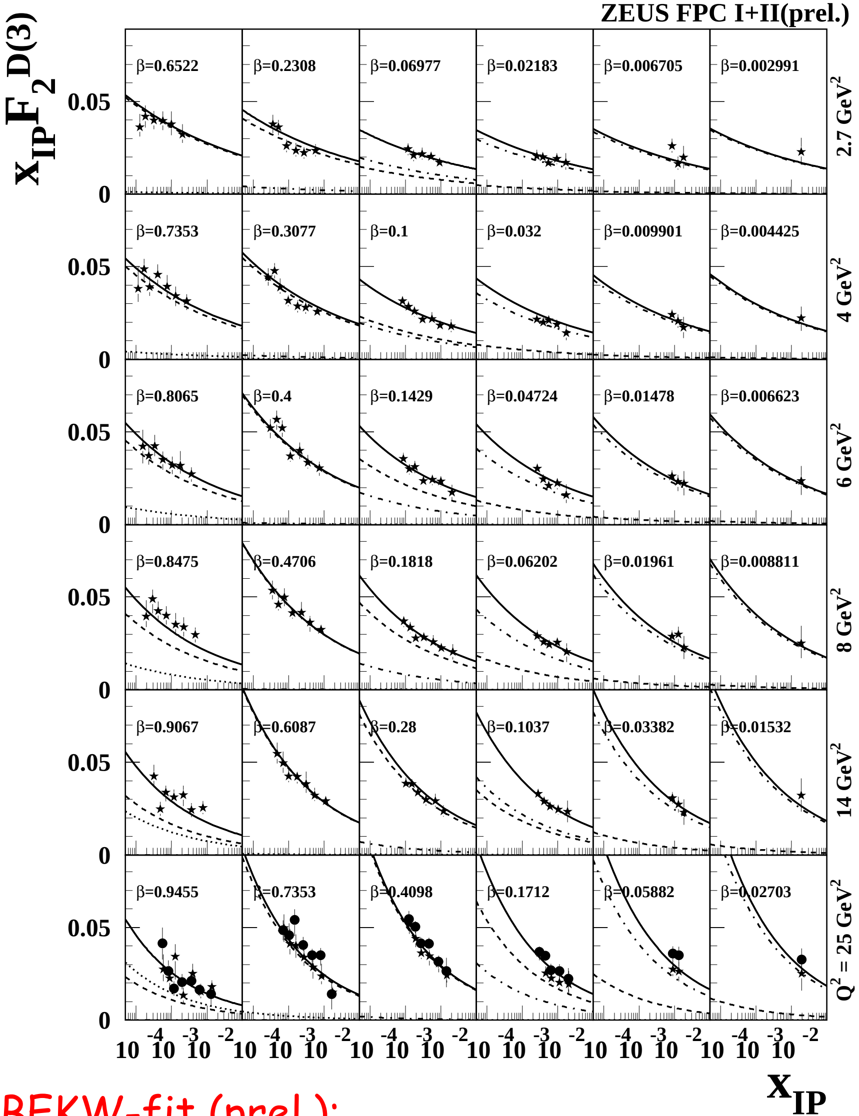
$$n_g(Q^2) = c_6 + c_9 \ln\left(1+\frac{Q^2}{Q_0^2}\right)$$

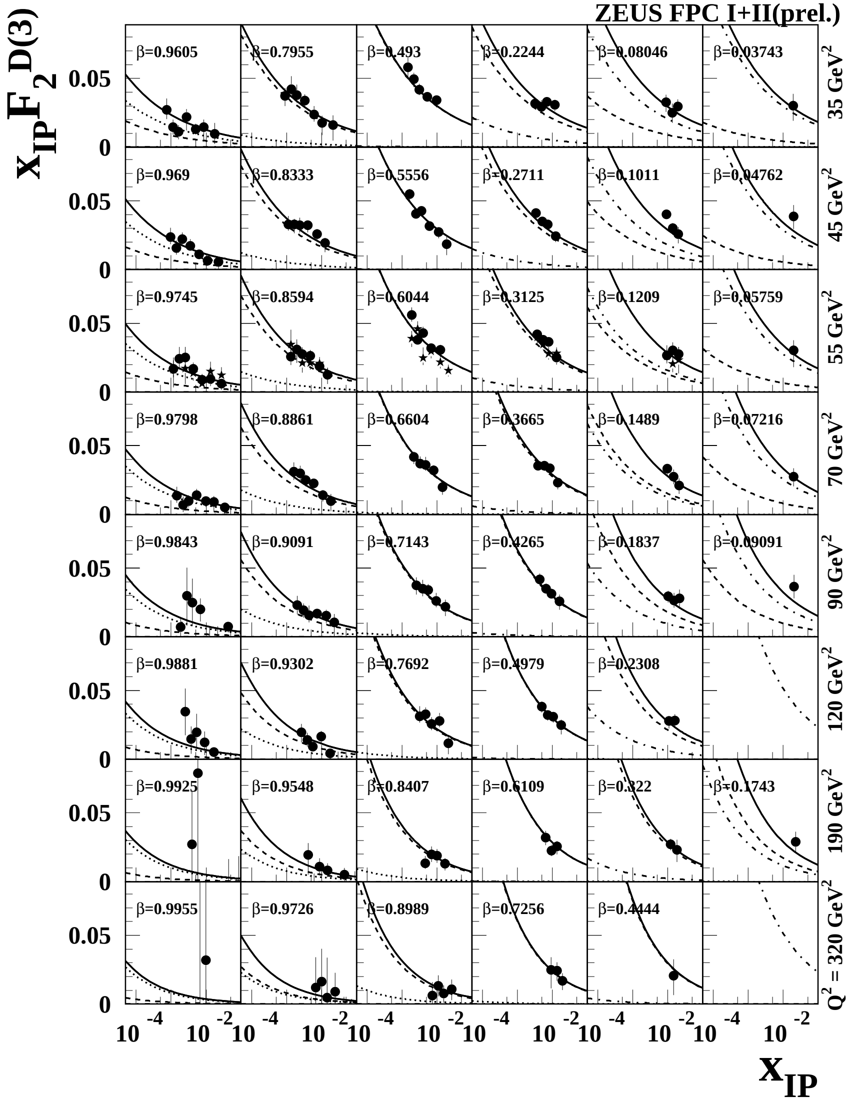
The ZEUS data support taking $n_T(Q^2) = n_g(Q^2) = n_1 \cdot \ln(1+Q^2/Q^2_0)$ and $n_L = 0$

Taking $x_0 = 0.01$ and $Q^2_0 = 0.4$ GeV² results in the modified BEKW model (BEKW(mod)) with the 5 free papameters :

c_T , c_L , c_g , $n_1^{T,g}$, γ

$x_{IP}F_2D(3)$ Results from the Mx 98-99 and Mx 99-00 Analyses with BEKW(mod) Fit (I)





BEKW-fit (prel.):

> 400 points, 5 parameters
χ^2/n_D = 0.71 , total errors

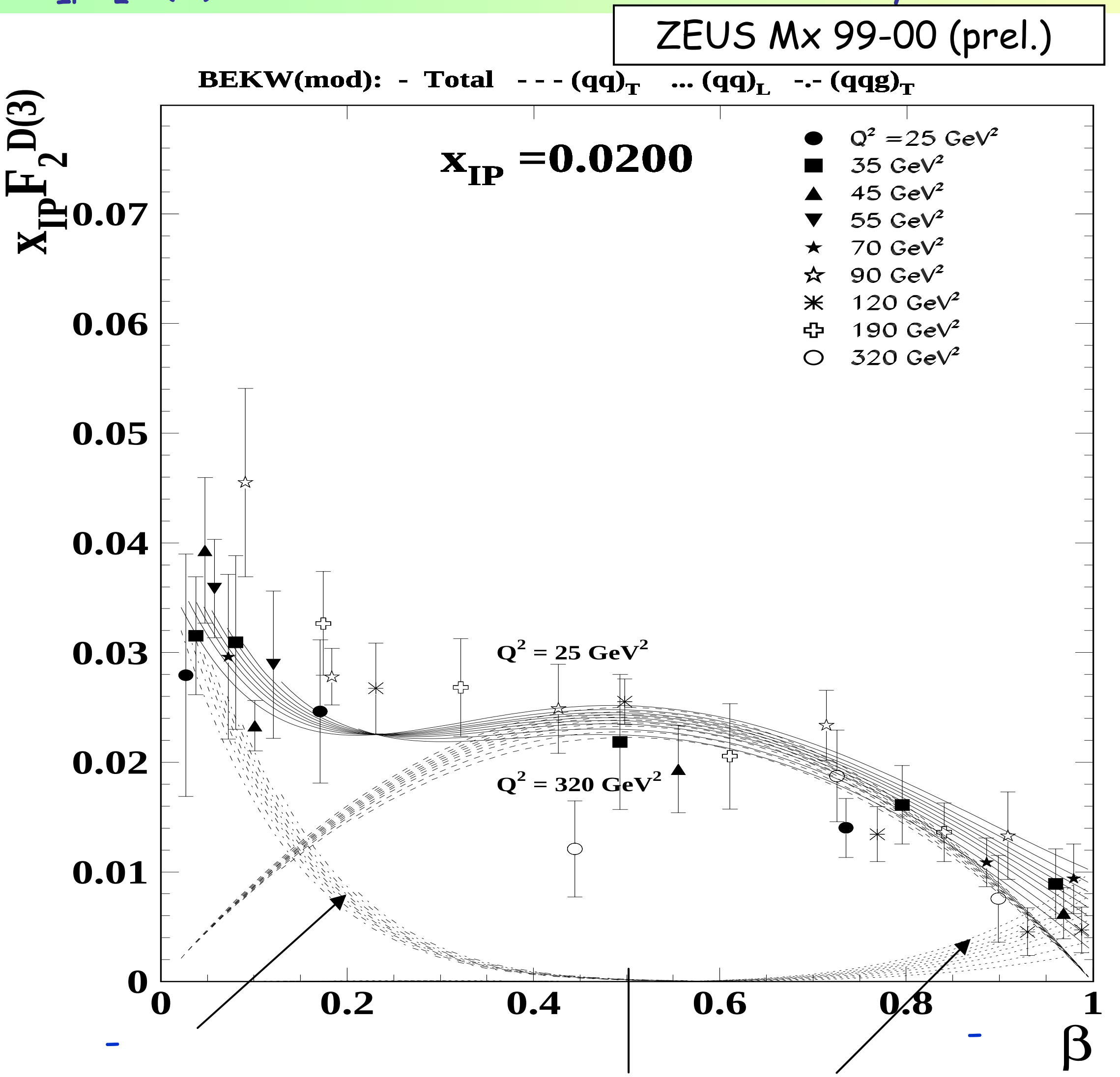
sum of all contributions

longitudinal qq contribution

transverse qq contribution

transverse qqg contribution

$x_{IP}F_2D(3)$ Results from the Mx 99-00 Analysis with BEKW(mod) Fit (II)



Fixed x_{IP} = 0.02

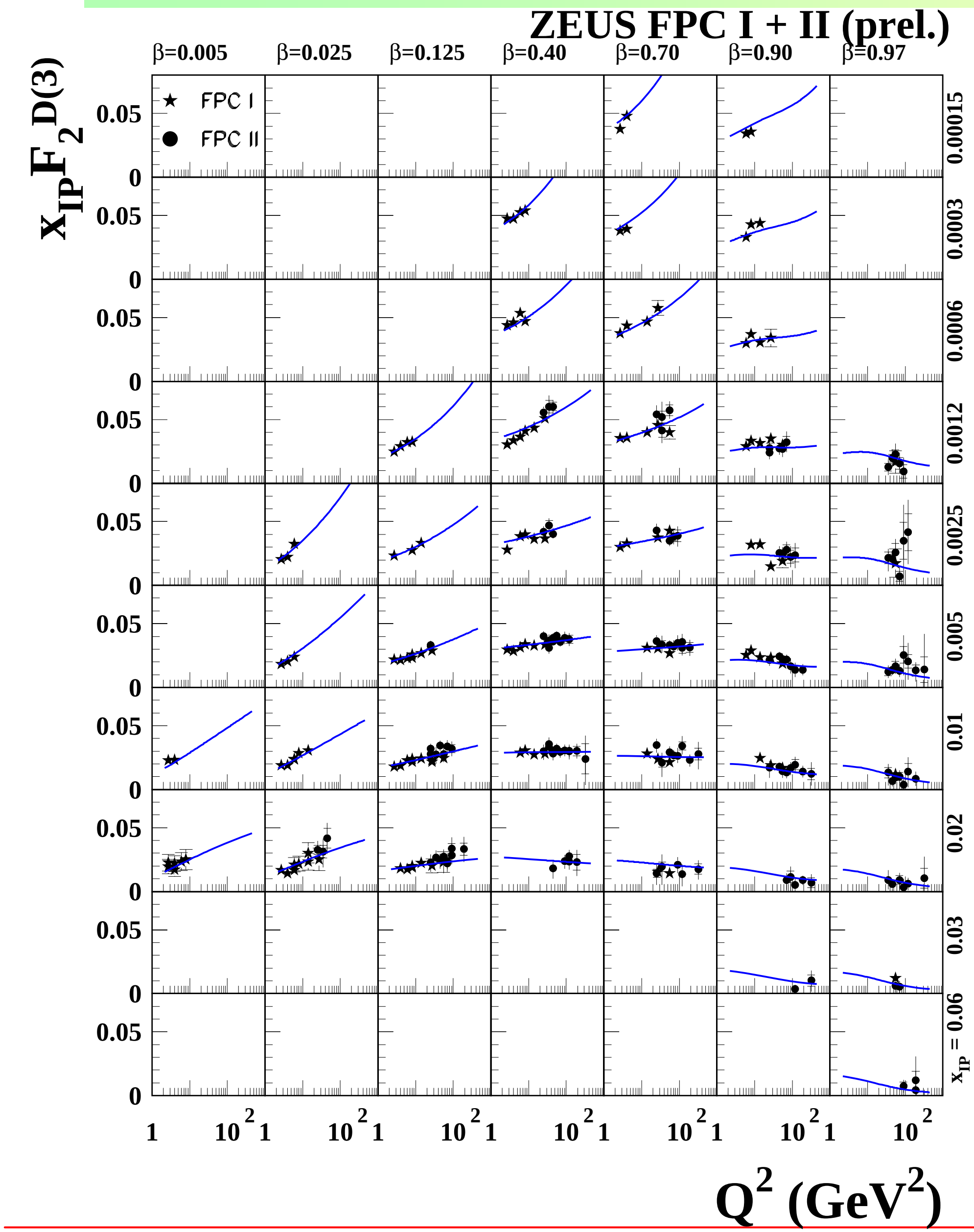
25 < Q^2 < 320 GeV^2 in one plot

The 3 contributions from BEKW(mod) fit for the above Q^2 values plotted

qqg-contributions

longitudinal qq-contributions

The BEKW model has an effective QCD-type Q^2-evolution incorporated.

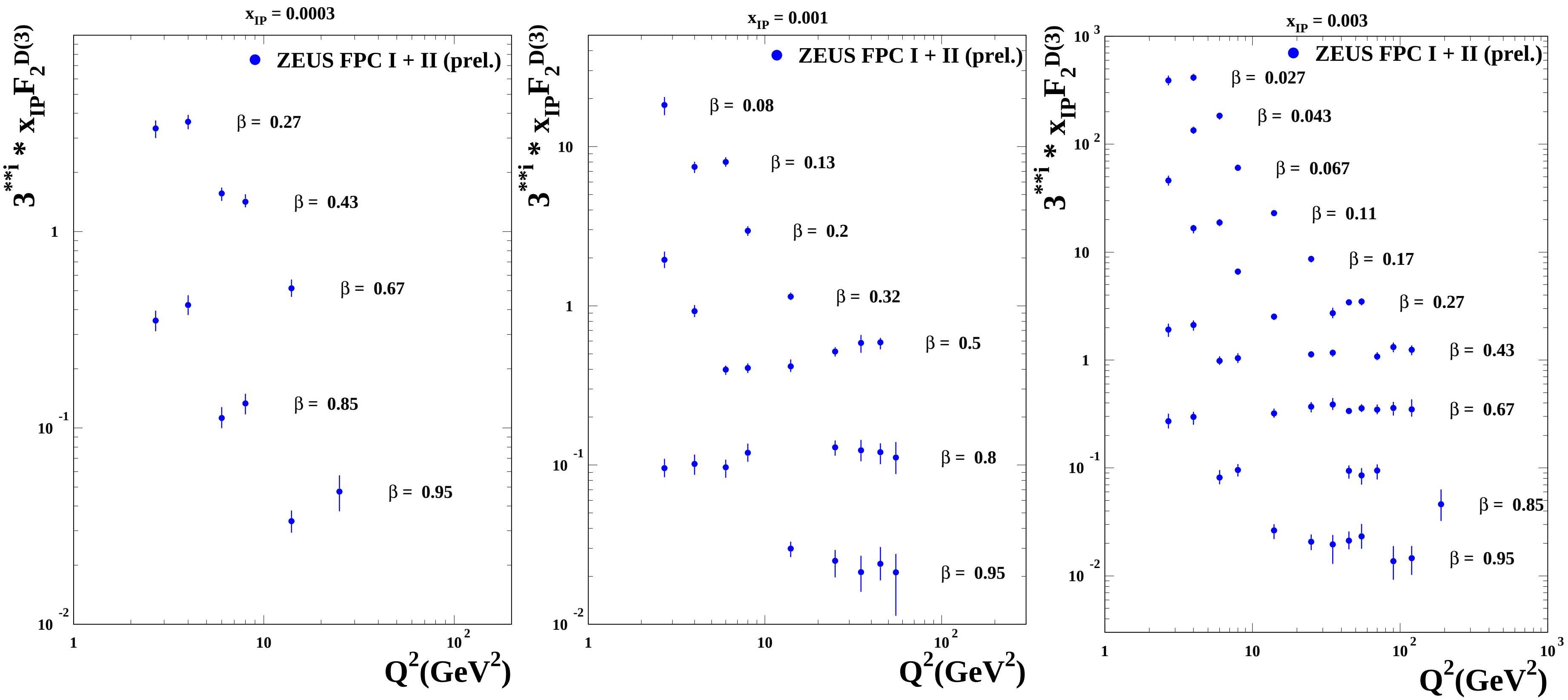


Result of the BEKW(mod) fit

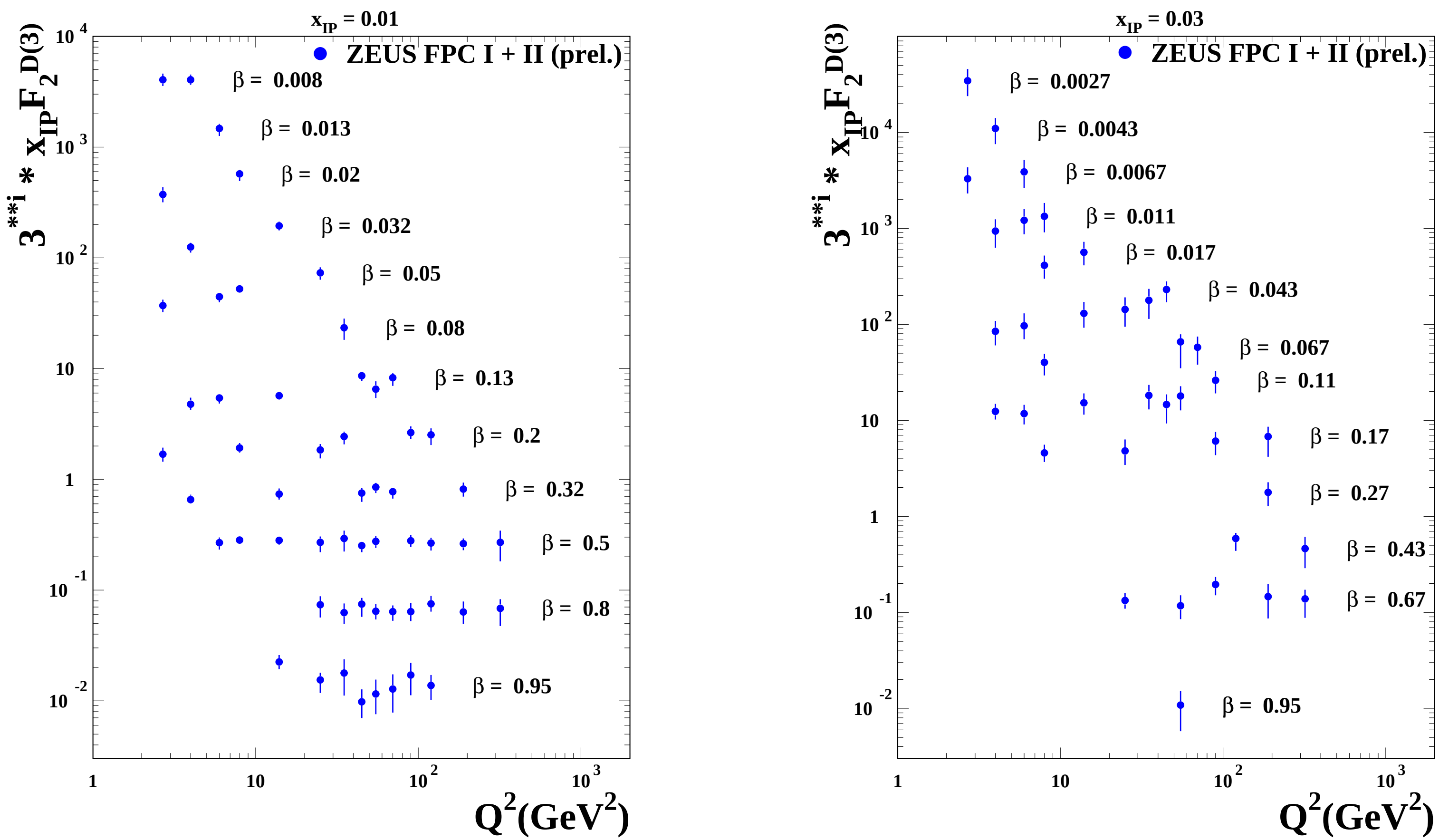
$x_{IP}F_2D(3)$ shows considerable scaling violations:

from positive scaling violations over near constancy to negative scaling violations.

$x_{IP}F_2D(3)$ Results from the Mx 98-99 and Mx 99-00 Analyses : Q^2-dependence (I)



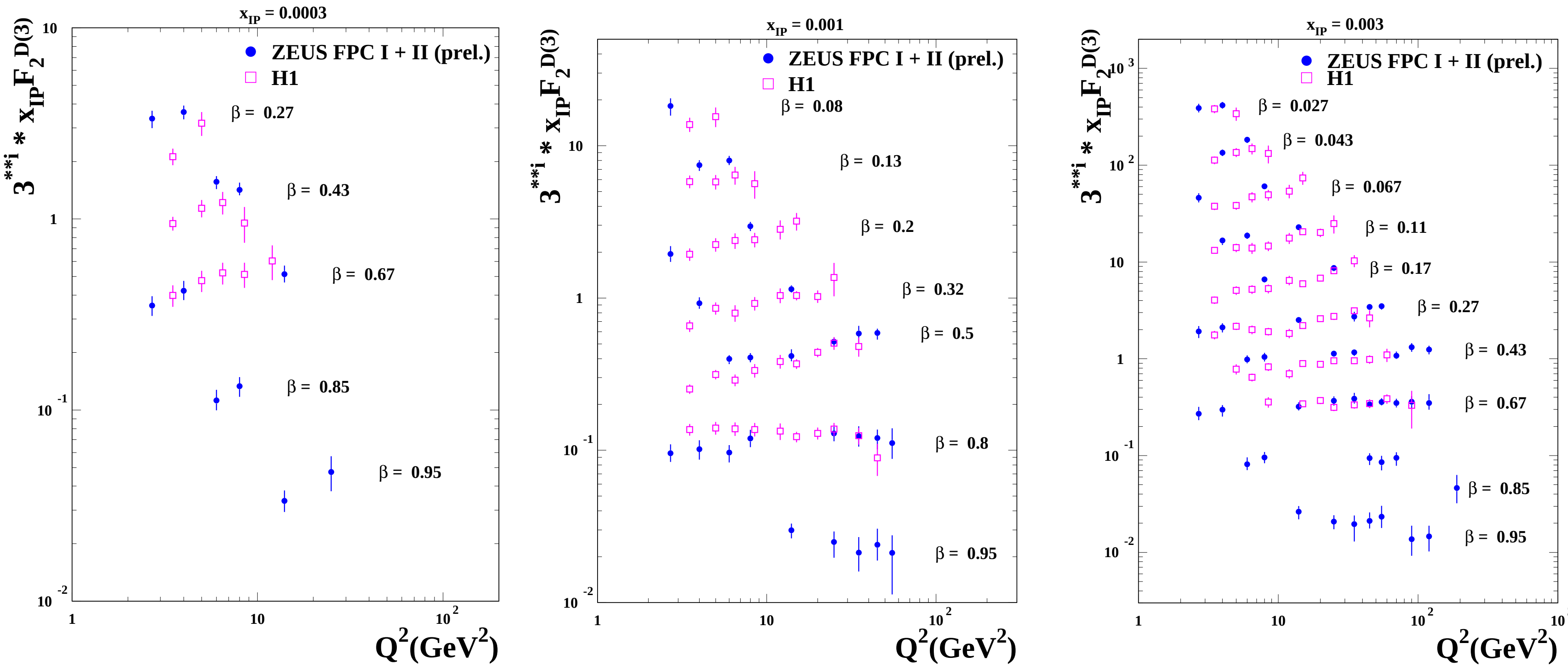
$x_{IP}F_2D(3)$ Results from the Mx 98-99 and Mx 99-00 Analyses : Q^2-dependence (II)



Q^2 dependence of $x_{IP}F_2D(3)$

The region $x_{IP} \cdot \beta = x < 6 \cdot 10^{-4}$ is dominated by positive scaling violations.
For $0.002 < x < 0.02$ constancy is observed

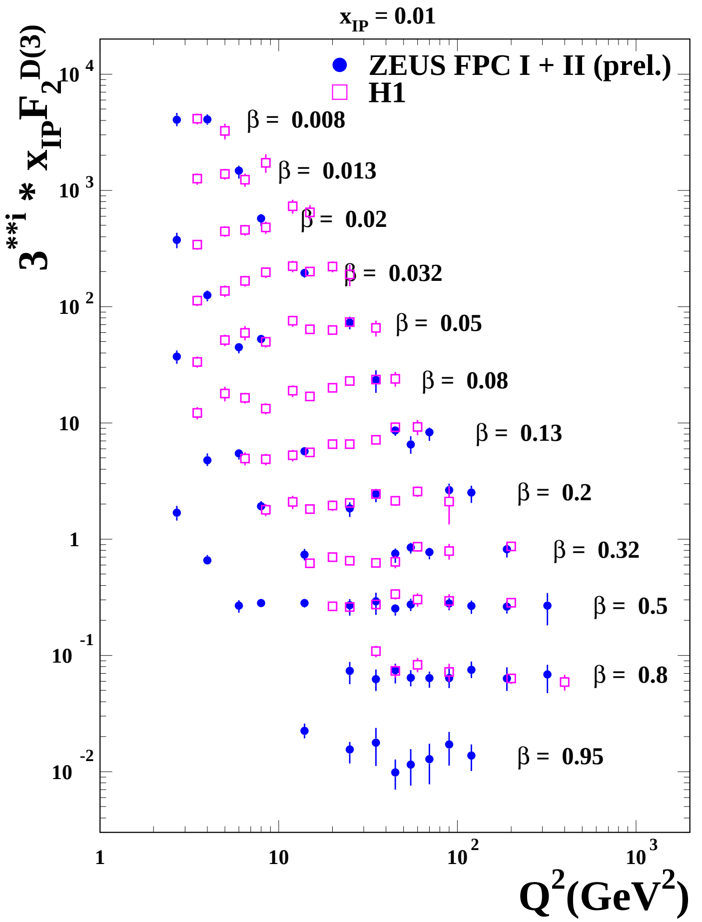
$x_{IP}F_2D(3)$ Results from the Mx 98-99 and Mx 99-00 Analyses Comparison with H1 Results (I)

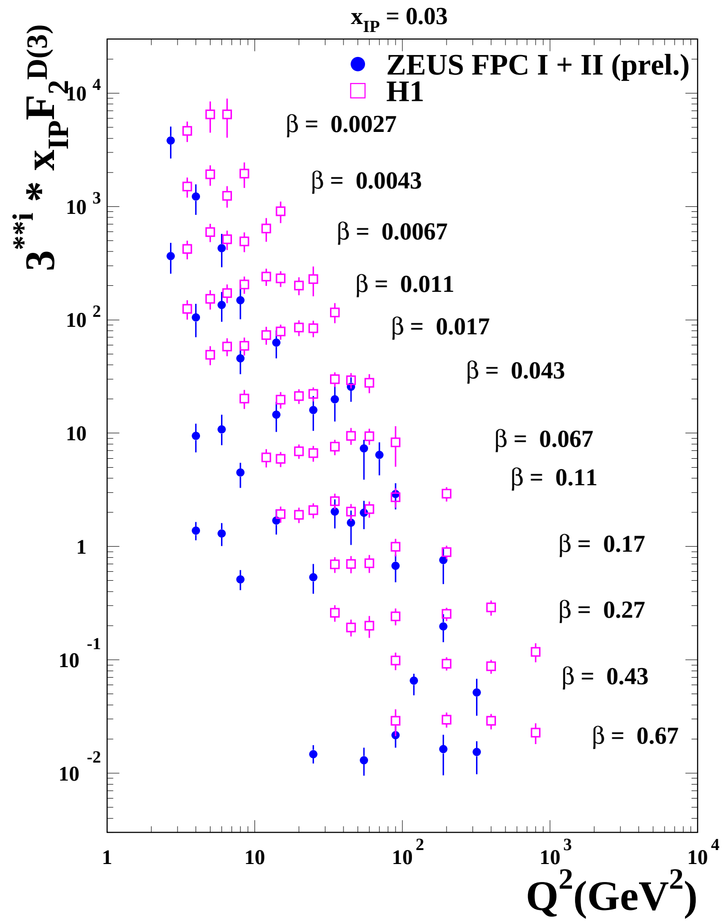


Note: ZEUS results contain contributions from p-dissociation with masses $M_{p\text{-}diss}$< 2.3 GeV , H1 results contain contributions with masses $M_{p\text{-}diss}$< 1.6 GeV.

ZEUS results do not contain contributions from Reggeon-exchanges, H1 results may contain such contributions for higher x_{IP}.

$x_{IP}F_2D(3)$ Results from the Mx 98-99 and Mx 99-00 Analysis
Comparison with H1 Results (II)





Comparison to H1 data

Fair agreement,
except maybe for a few (x_{IP},β) bins

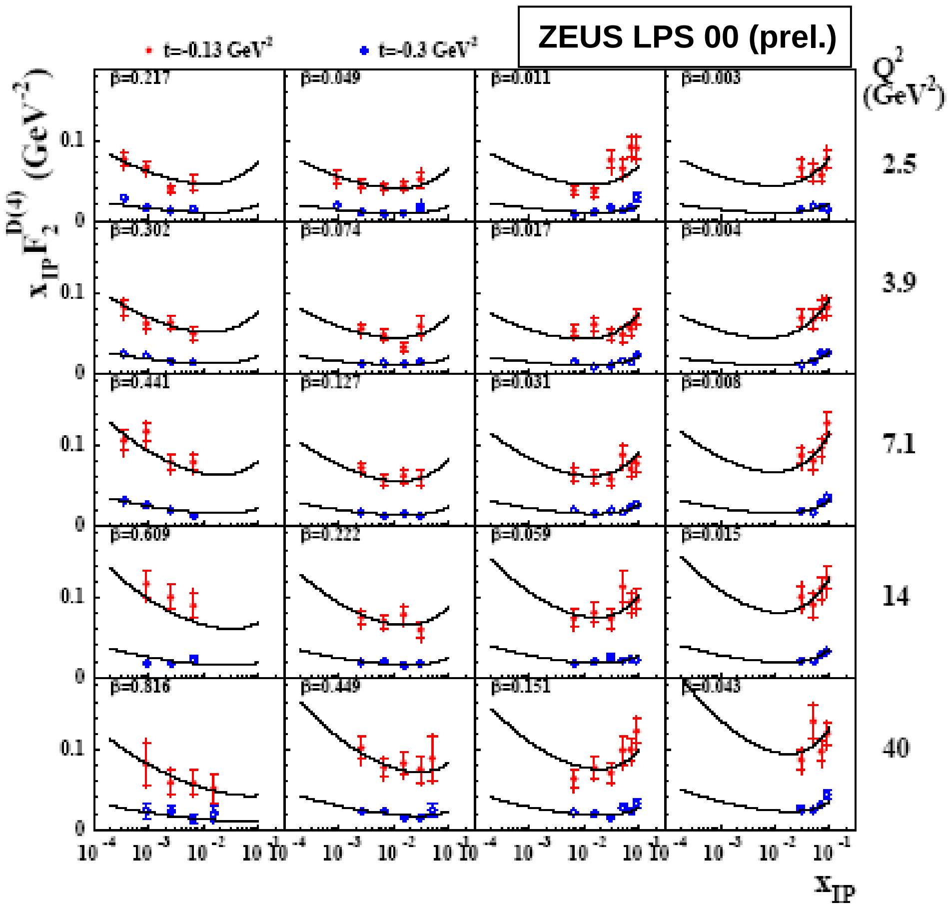
Note: ZEUS points are shifted to H1 bins using BFKL parametrization. Only those ZEUS point are shown for which the shift was <30%.

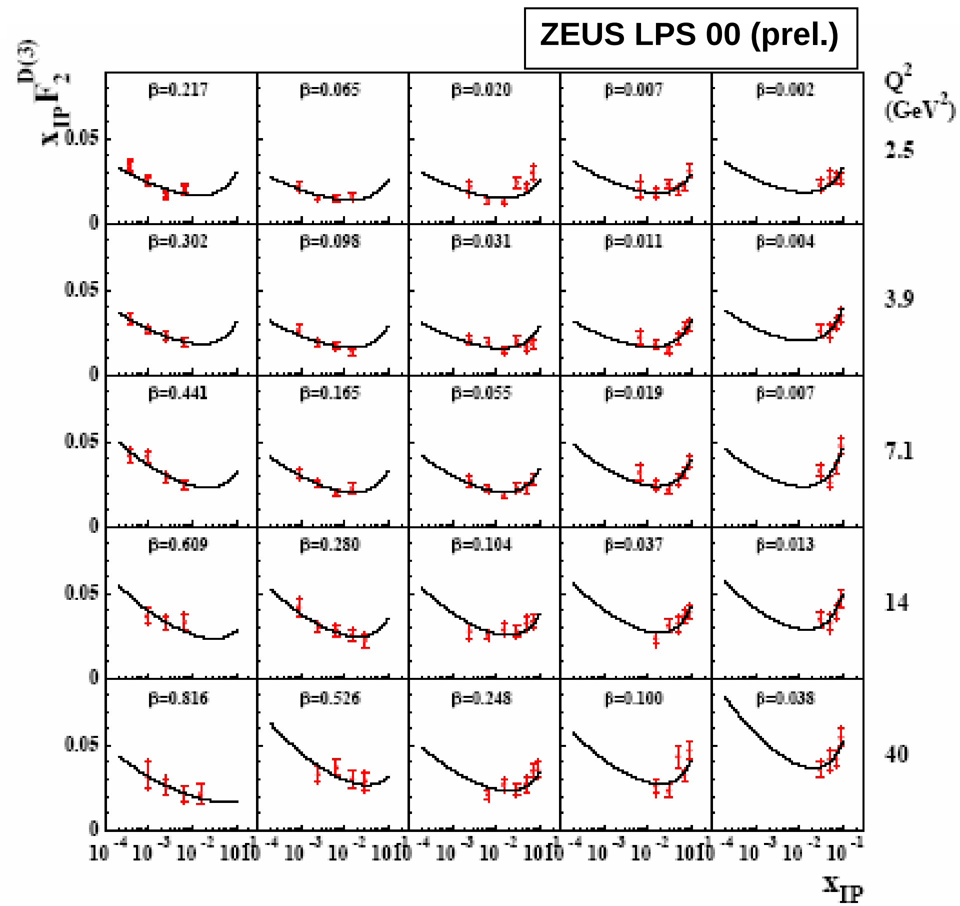
ZEUS Results from the LPS I

Diffractive structure functions from ZEUS LPS mesurements

Regge fit : $F_2^{D(4)} = f_{IP}(x_{IP},t) \cdot F_2^{IP}(\beta,Q^2) + n_{IR} \cdot f_{IR}(x_{IP},t) \cdot F_2^{IR}(\beta,Q^2)$

● t = 0.13 GeV² ● t = 0.3 GeV²



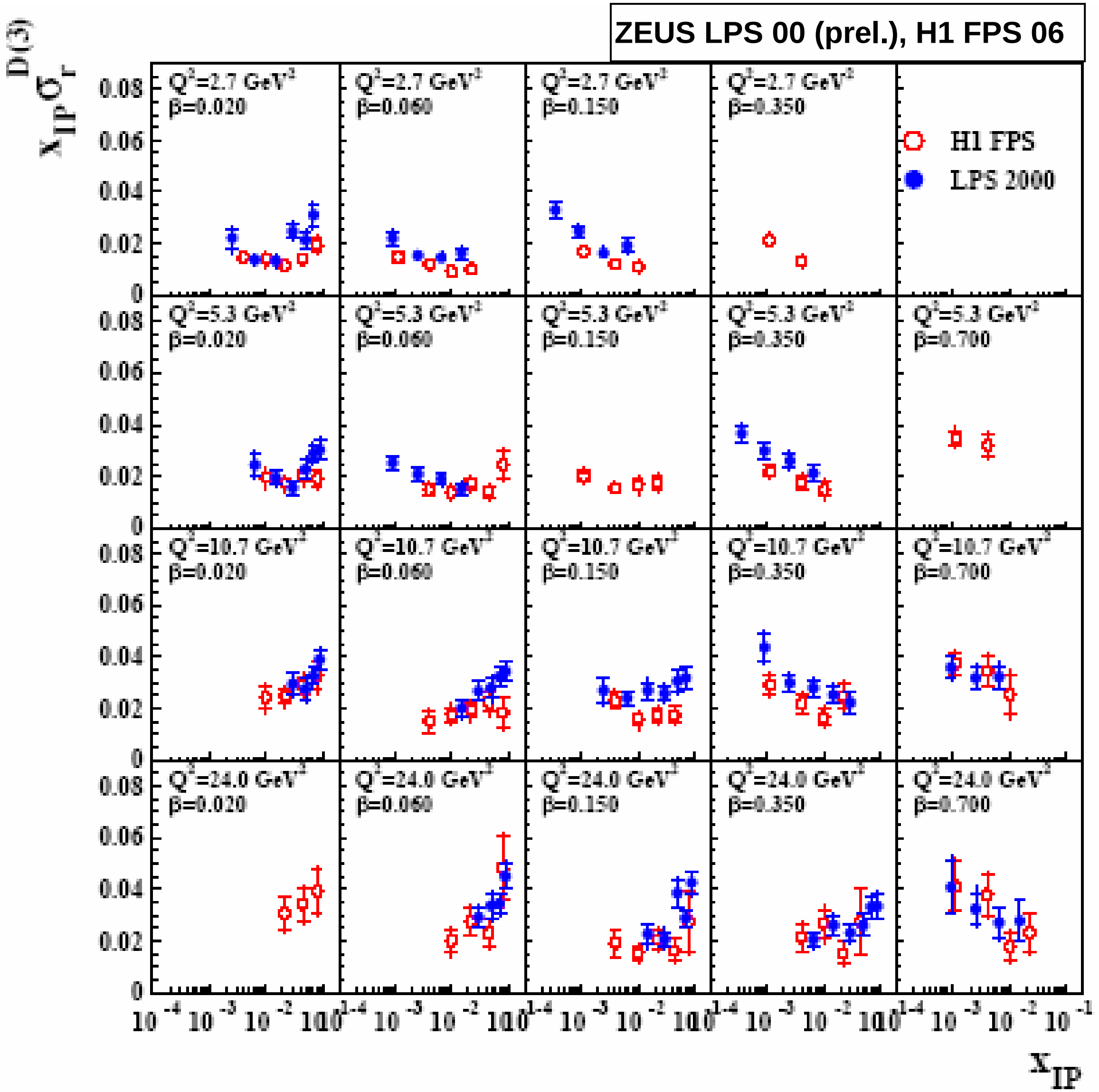


Fit parameters: $\alpha_{IP}(0) = 1.10 \pm 0.02(\text{stat.})^{+0.01}_{-0.02}(\text{syst.}) + 0.02(\text{model})$ $\alpha'_{IP} = -0.03 \pm 0.07(\text{stat.})^{+0.04}_{-0.08}\ \text{GeV}^{-2}$

$B_{IP} = 7.2 \pm 0.7(\text{stat.})^{+1.4}_{-0.7}(\text{syst.})\ \text{GeV}^{-2}$ $\alpha_{IR}(0) = 0.75 \pm 0.07(\text{stat.})^{0.02}_{-0.04}(\text{syst.}) \pm 0.05(\text{model})$

ZEUS Results from the LPS (II)

Comparison of LPS results with recent H1 FPS results



$R^D = \sigma_L^{\gamma^* p \to pX} / \sigma_T^{\gamma^* p \to pX}$

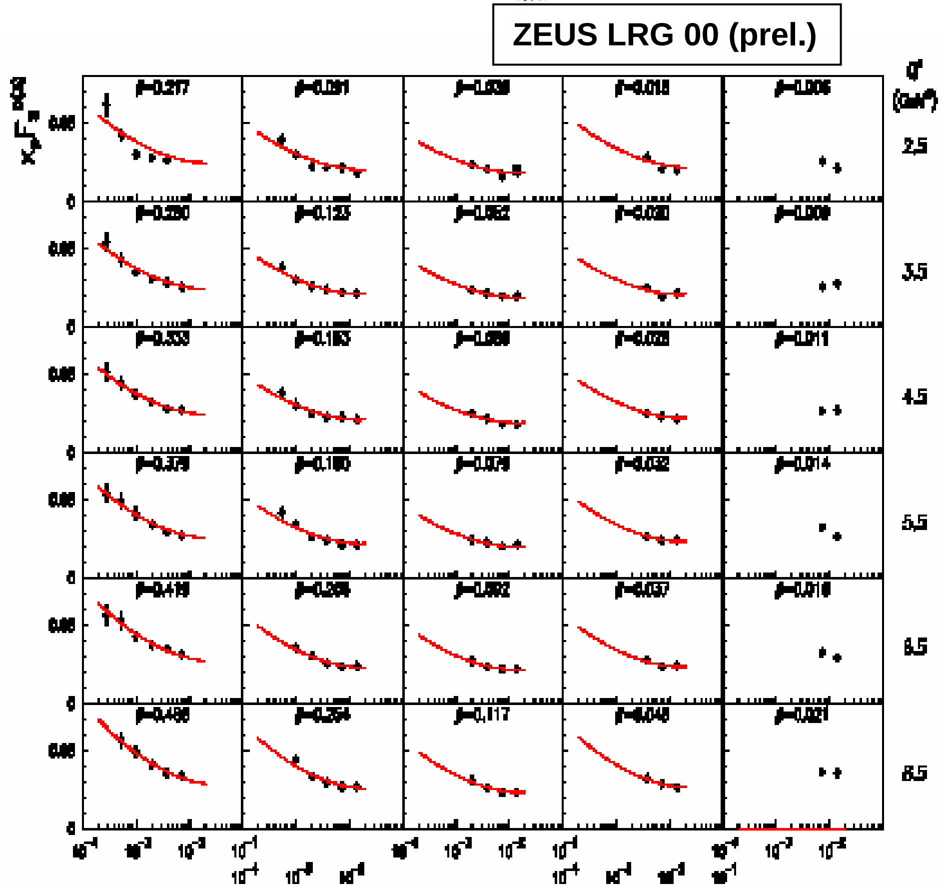
$R^D = 0$ -> $x_{IP} F_2^{D(3)} = x_{IP} \sigma_r^{D(3)}$

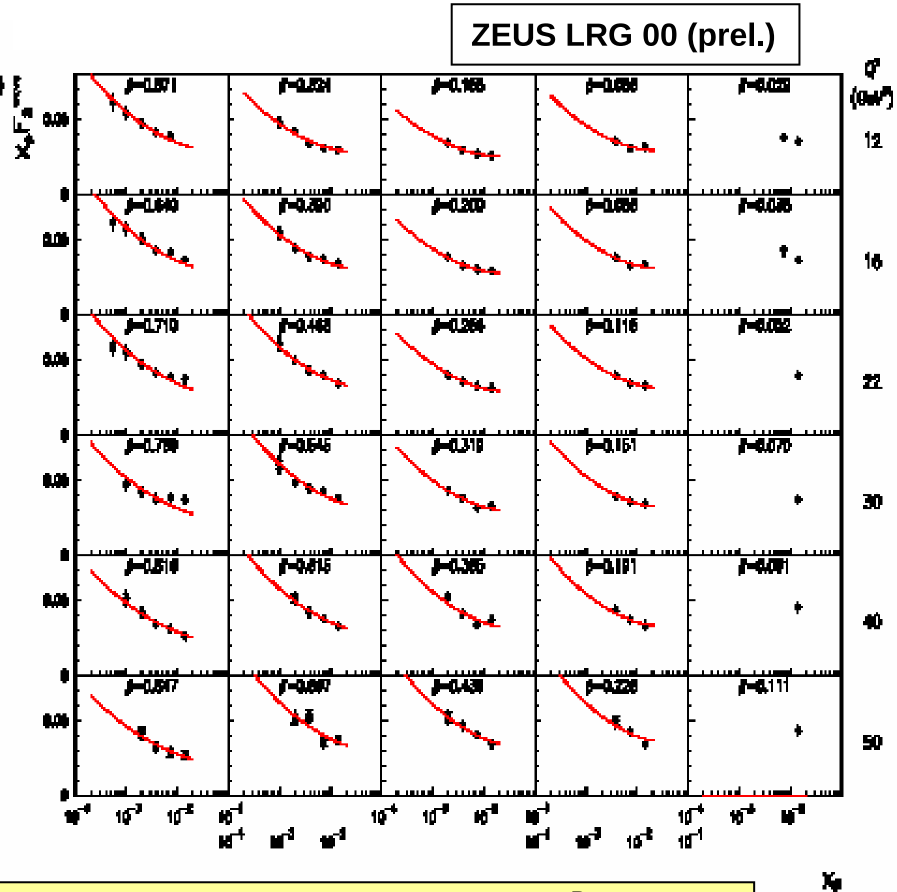
Not shown are the normalization Uncertainties of +12/-10 % for the ZEUS LPS data and +/-10% for the H1 FPS data.

The agreement is good

ZEUS Results from the LRG Method (I)

Events selected by : $\eta_{max} < 3.0$ and energy in the Forward Plug Calorimeter (FPC) < 1 GeV





$$F_2^{D(3)} = f_{IP}(x_{IP}) \cdot F_2^{IP}(\beta, Q^2) + n_{IR} \cdot f_{IR}(x_{IP}) \cdot F_2^{IR}(\beta, Q_2) \quad \text{with} \quad f_{IP,IR}(x_{IP}) = \int \frac{e^{B_{IP,IR} t}}{x_{IP,IR}^{2\alpha_{IP,IR}(t)-1}} dt$$

Results of a Regge-fit

Fit results :

$\alpha_{IP}(0) = 1.117 +/- 0.005 \, ^{+0.024}_{-0.007}$

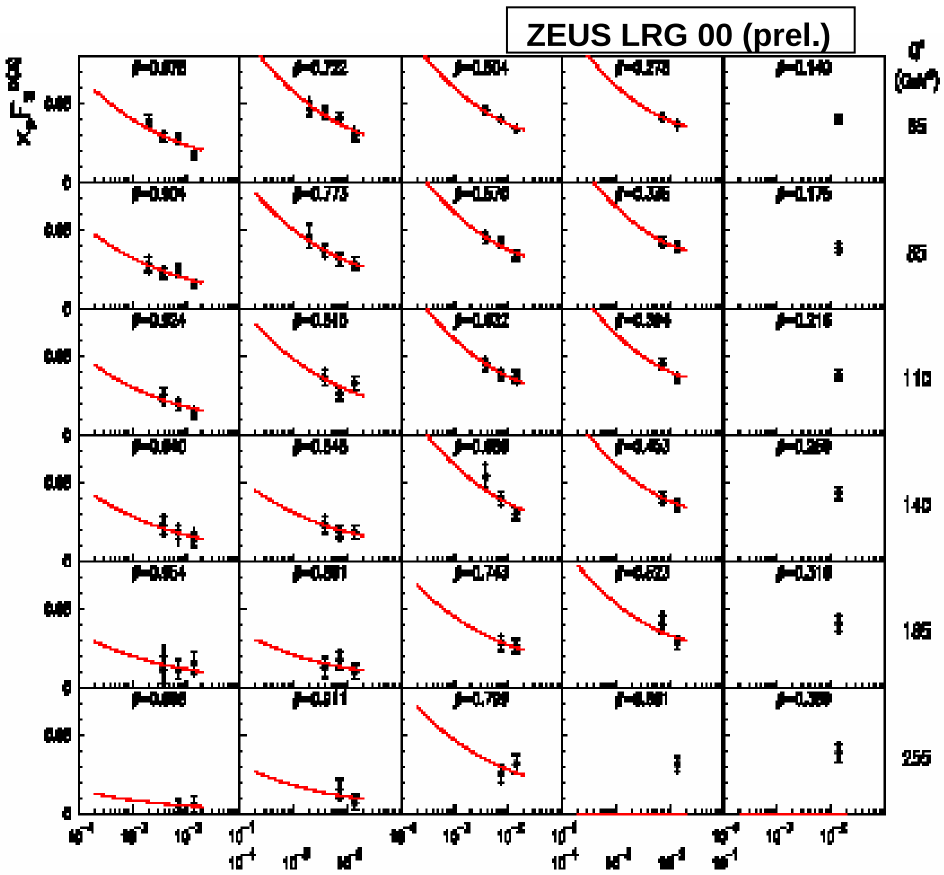
Input parameters to the Regge -fit:

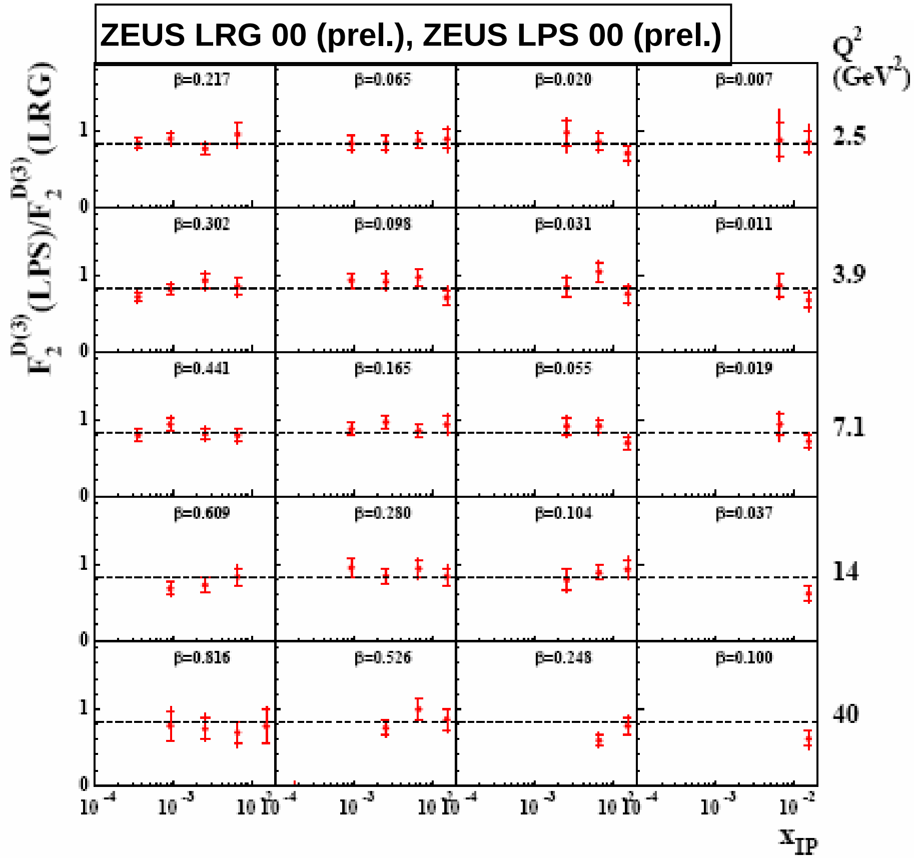
$\alpha_{IR}(0) = 0.75$, $B_{IR} = 2.0$ GeV^{-2}

$\alpha'_{IP} = 0.0$ GeV^{-2} , $B_{IP} = 7.2$ GeV^{-2}

ZEUS Results from the LRG Method (II)

Comparison of ZEUS LRG data with LPS data



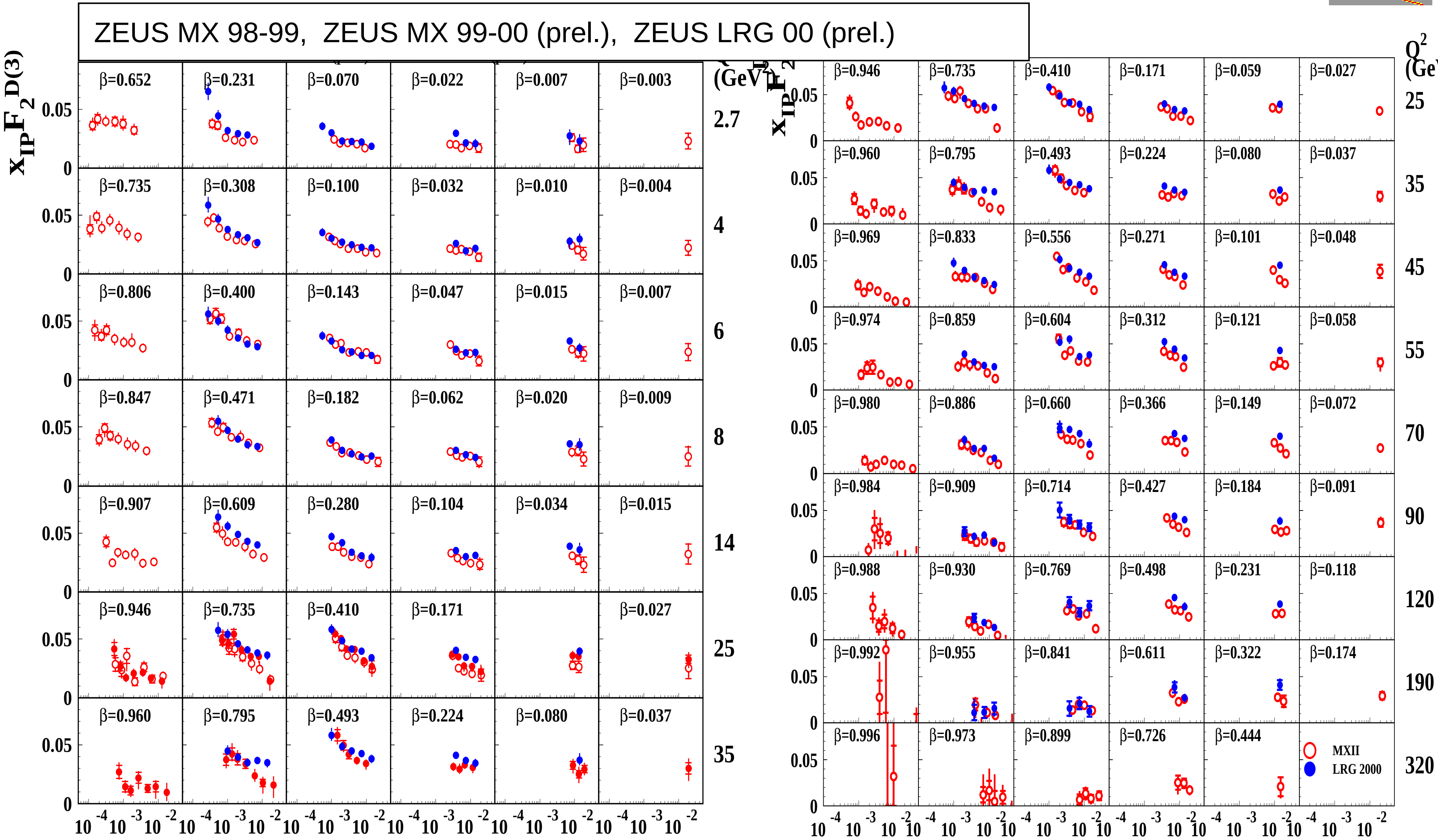


The ratio LPS/LRG = 0.82 +/- 0.01(stat.) +/- 0.03(syst)
it is independent of Q^2 and β

The Regge-fit gives a good description of the ZEUS LRG data with χ^2/ndf = 159/185

Not shown is the normalization uncertainty of the LPS measurement of about 10%.

ZEUS : Comparison of Results from the M_X-, and LRG- Method (I)

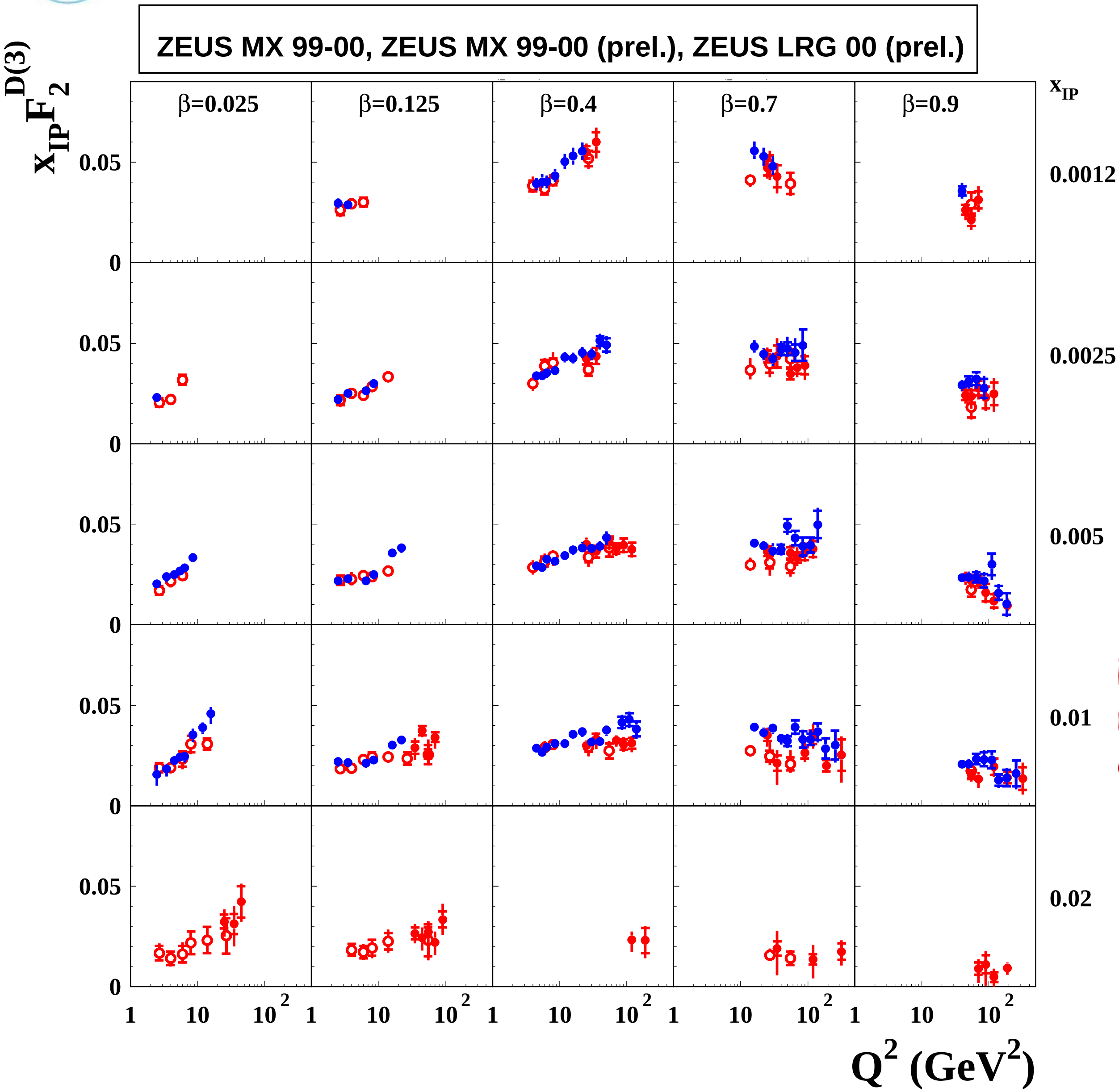


x_{IP}

In general good agreement
for $x_{IP} < 0.01$

For $x_{IP} > 0.01$ one can expect some differences from Reggeon contributions to the LRGdata.

ZEUS : Comparison of Results from the M_X-, and LRG- Method (II)



Comparison of
ZEUS LRG with ZEUS M_X results:

$x_{IP}F_2^{D(3)}$
as a function of Q^2

- ZEUS Mx 90-99
- ZEUS Mx 99-00 (prel.)
- ZEUS LRG 00 (prel.)

Reasonable agreement, maybe there is a normalization difference.

Work is continuing to understand remaining differences

Summary

- ZEUS presented preliminary results on inclusive diffraction from 3 different methods for the extraction of inclusive diffractive events.
- Results from all 3 methods are derived from data taken during the same time.
- The results span a wide range of the kinematic region up to high Q^2.
- There is good to reasonable agreement for the results from all 3 methods.
- There is good to reasonable agreement for the Q^2-dependence of the structure function between the M_X-method, the LRG-method and the H1 data.
- There is also good agreement compared to results from H1 for the FPS method.
- Work continues to understand some remaining minor differences, in particular with respect to the relative normalisations.
- We try to get a consistent picture out of the results from these three methods.