Inclusive Diffraction at HERA from the ZEUS Experiment

Jarosław Łukasik, DESY / AGH-UST Cracow
on behalf of the ZEUS collaboration

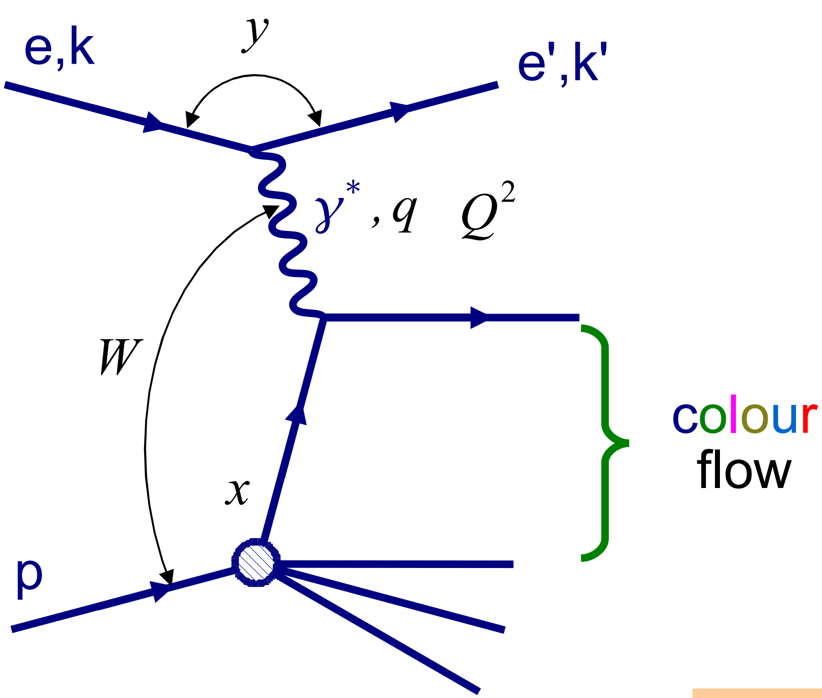
3rd HERA and the LHC workshop

Outline

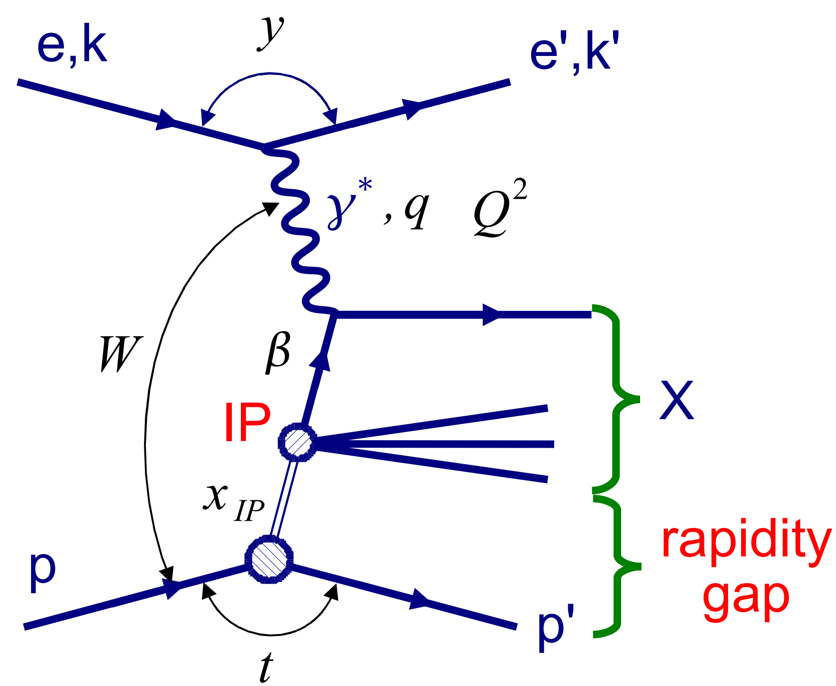
- Introduction – description of NC diffractive DIS, event topologies, structure functions
- Methods of diffractive sample selection: LPS, LRG, M_X
- Preliminary results, comparisons
- Summary

NC Deep Inelastic *ep* Scattering

Standard



Diffractive



Q^2, x, y

$x \equiv \frac{Q^2}{2p \cdot q}$

$x = \beta x_{IP}$

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

M_X – diffractive mass

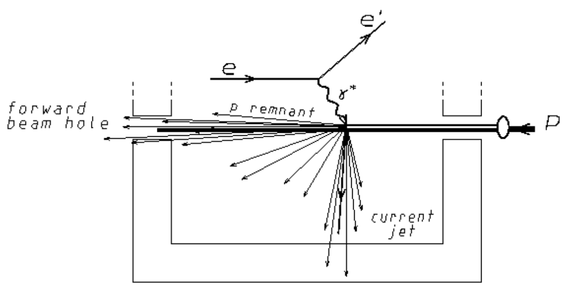
$x_{IP} = \frac{(p-p')\cdot q}{p \cdot q}$ – fraction of the proton momentum carried by the *IP*

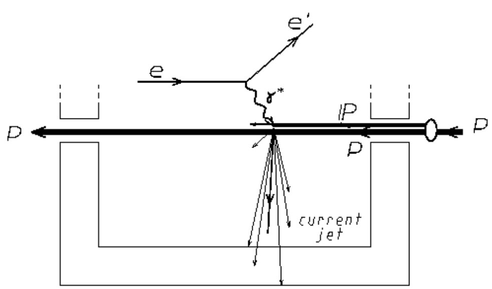
$\beta = \frac{Q^2}{2(p-p')\cdot q}$ – fraction of the *IP* momentum carried by the struck quark

Event topologies

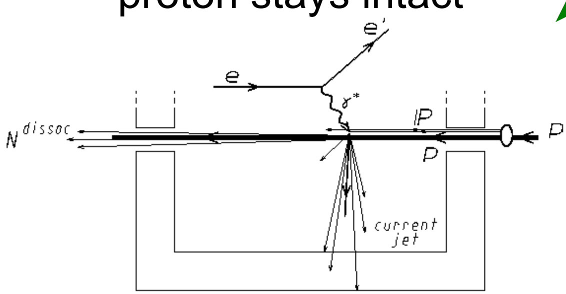
non-diffractive DIS

diffractive DIS

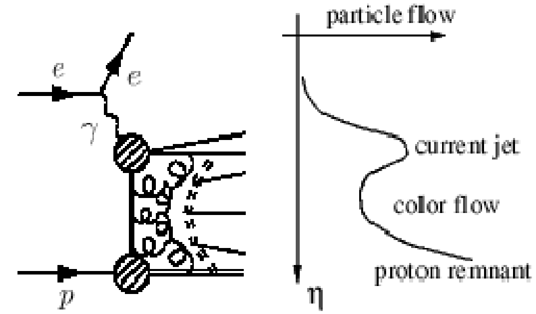


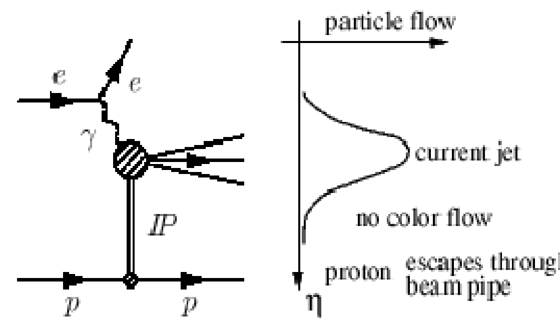


proton stays intact



proton dissociation





Diffractive structure functions

$$\frac{d^4\sigma^D_{\gamma* p}}{dQ^2\, d\beta\, dx_{IP}\, dt} = \frac{2\pi\alpha^2_{em}}{\beta Q^4}\left(1+\left(1-y\right)^2\right) F_2^{D(4)}\left(Q^2, \beta, x_{IP}, t\right)$$

Regge factorization:

$$F_2^{D(4)}\left(\beta, Q^{2,} x_{IP}, t\right) = f_{IP}(x_{IP}, t)\, F_2^{IP}\left(\beta, Q^2\right)$$

IP flux

IP structure function

When *t* is not measured:

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

H1 definition:

$$\sigma_r^D = F_2^D - \frac{y^2}{1+(1-y)^2} F_L^D$$

(contribution from F_L^D is neglected in ZEUS measurements)

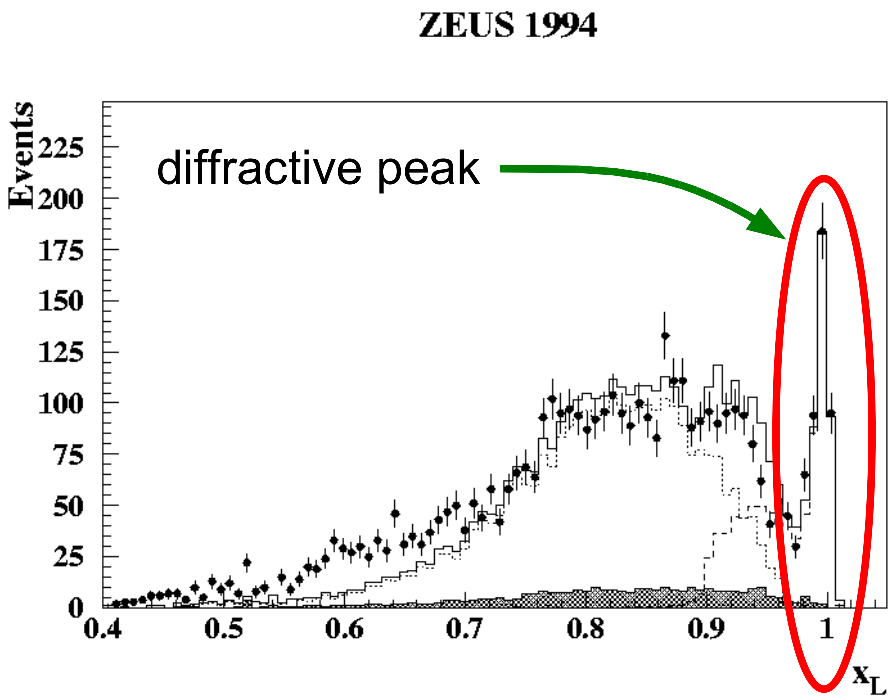
Differential cross section vs. M_X:

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

Scattered proton tagging

- In most of the diffractive events outgoing proton stays intact and provides a clean experimental signature
- Since p_T of the outgoing proton is expected to be small (<1 GeV typically), it escapes through the forward beam hole
- A fraction of these events can be detected by the Leading Proton Spectrometer (LPS)
- LPS measures the momentum of the scattered proton using track deflection induced by the magnets located along the p beam line
- **Drawback**: limited acceptance of the LPS (few %), dependent on x_L and p_T of outgoing proton

$x_L = \frac{p_z'}{p_z}$ spectrum:

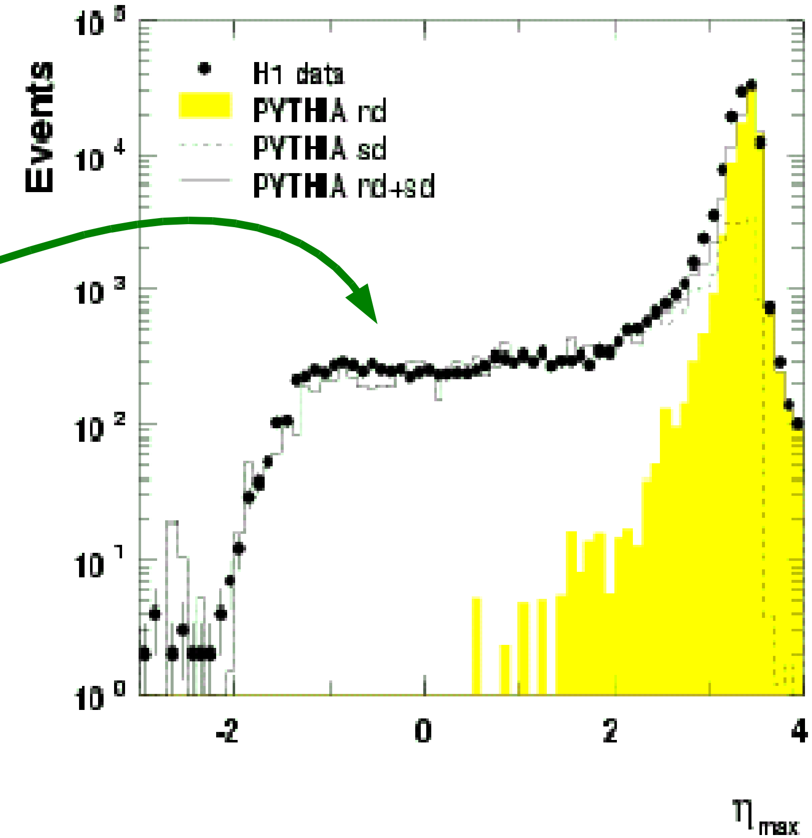


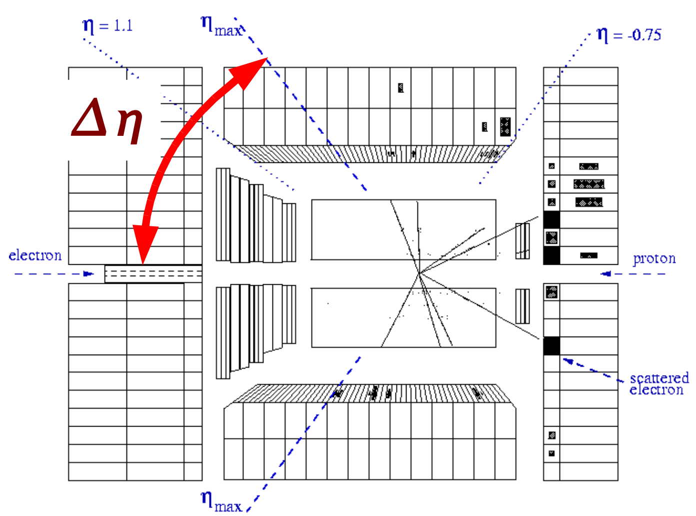
x_L>0.97 – a clean sample of diffractive events

Selection methods – LRG

- Presence of a large rapidity gap between the system *X* and outgoing proton (or proton remnant system *N*)
- Pseudorapidity of the most forward going particle: η_{max} distribution
- Plateau like structure, due to diffractive events mainly, extends to low η_{max} values – diffractive tail
- **Drawback:** background from proton dissociation, inclusive low multiplicity DIS events

η_{max} spectrum:





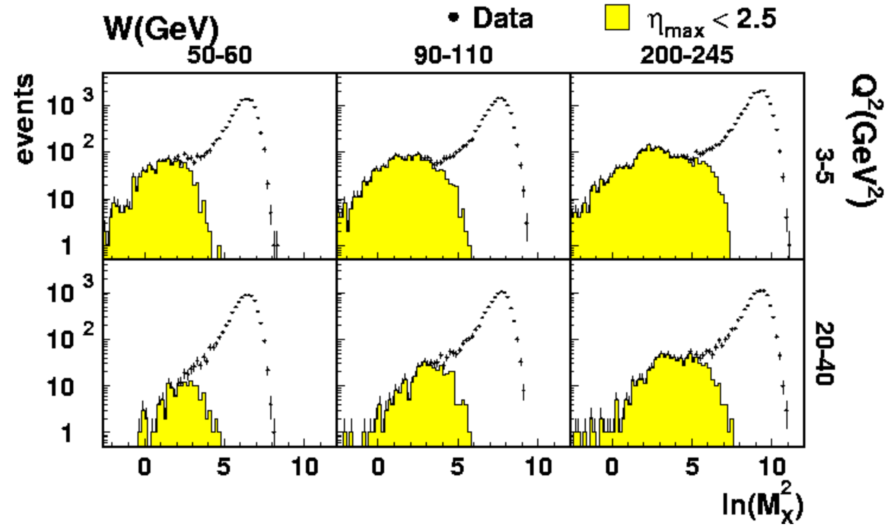
$\eta_{max} < 3$ – a small non-diffractive background

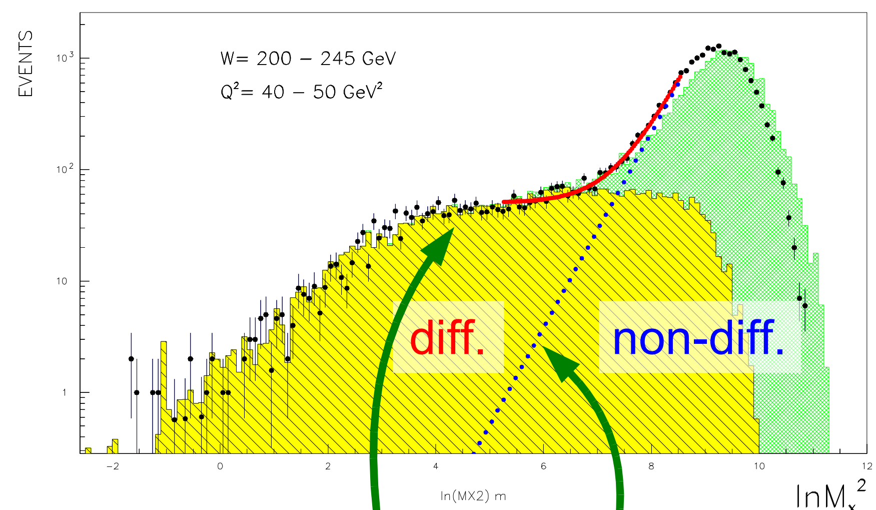
Selection methods – M_X

- properties of $\ln(M_X^2)$ distribution:
    - flat for diffractive events
    - for non-diffractive events – exponential fall-off towards low masses
    - position of the non-diffractive peak changes with W

- identifies the diffractive contribution as the excess of events over the exponential fall-off of the non-diffractive part

Drawback:
- sensitivity to the proton dissociation background





$$\frac{dN}{d\ln(M_X^2)} = D + c\exp(b\ln(M_X^2))$$

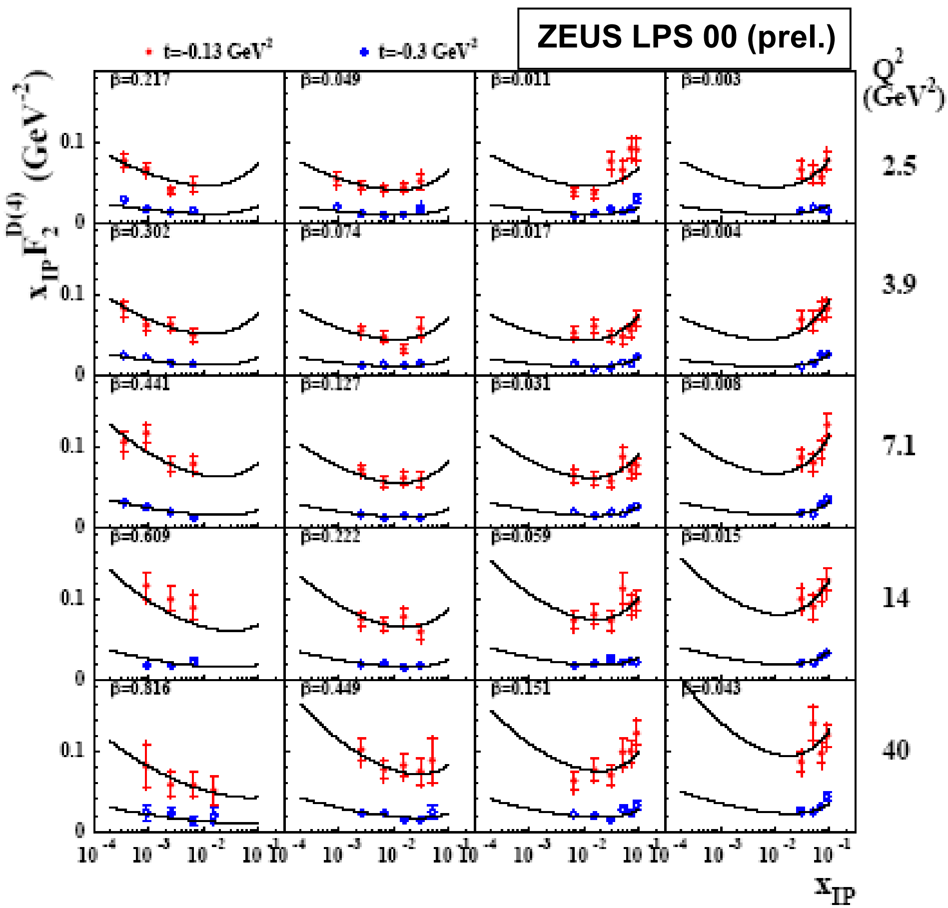
Details of the analyses

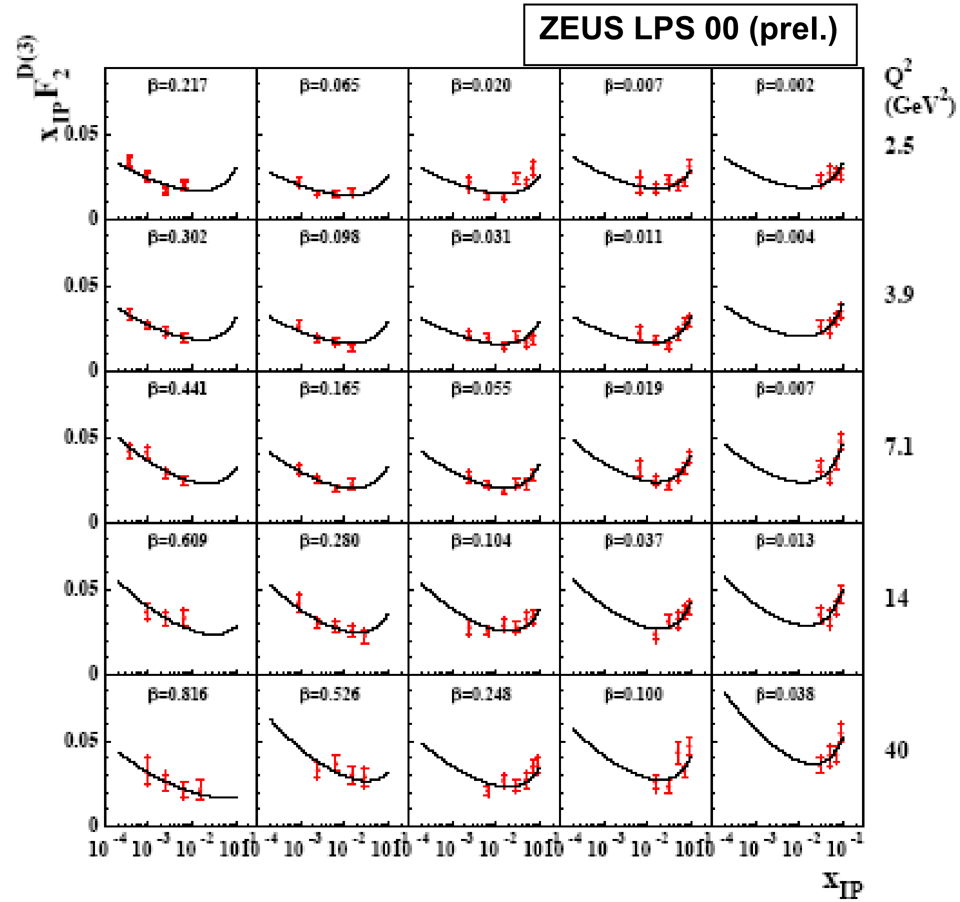
- DATA
  - 2000e+, Lumi = 32.6 pb^{-1} (LPS), Lumi = 45.4 pb^{-1} (LRG)
  - 99-00, Lumi = 52.4 pb^{-1} (M_X)
  - Three analysis methods applied for the same data taking period
- Kinematic coverage
  - LPS: $2 < Q^2 < 120$ GeV^2, $40 < W < 240$ GeV, $2 < M_X < 40$ GeV
  - LRG: $2 < Q^2 < 305$ GeV^2, $40 < W < 240$ GeV, $2 < M_X < 25$ GeV
  - M_X: $25 < Q^2 < 320$ GeV^2, $45 < W < 220$ GeV, $1.2 < M_X < 30$ GeV
- Event selection
  - Scattered electron in the calorimeter
  - LPS: detection of scattered proton
  - LRG: energy in the Forward Plug Calorimeter (FPC) < 1 GeV, $\eta_{max} < 3$
- Backgrounds
  - LPS data
    - corrected for beam halo events (after E-P_z < 1860 GeV cut: 3%)
    - corrected for proton dissociation events (9% at $x_{IP} = 0.1$, negligible in the $x_{IP} < 0.01$ region)
    - photoproduction background – negligible
  - LRG data
    - corrected for non-diffractive DIS events (up to 10%)
    - proton dissociative events (estimated with the help of LPS: ~18%) not rejected
  - M_X data
    - corrected for non-diffractive DIS events
    - background from proton dissociation for $M_N > 2.3$ GeV estimated with SANG MC – results were corrected; no Reggeon contribution
    - The M_X results contain contributions from proton dissociation for masses $M_N < 2.3$ GeV

ZEUS LPS results (1)

Diffractive structure functions:

● t = 0.13 GeV² ● t = 0.3 GeV²





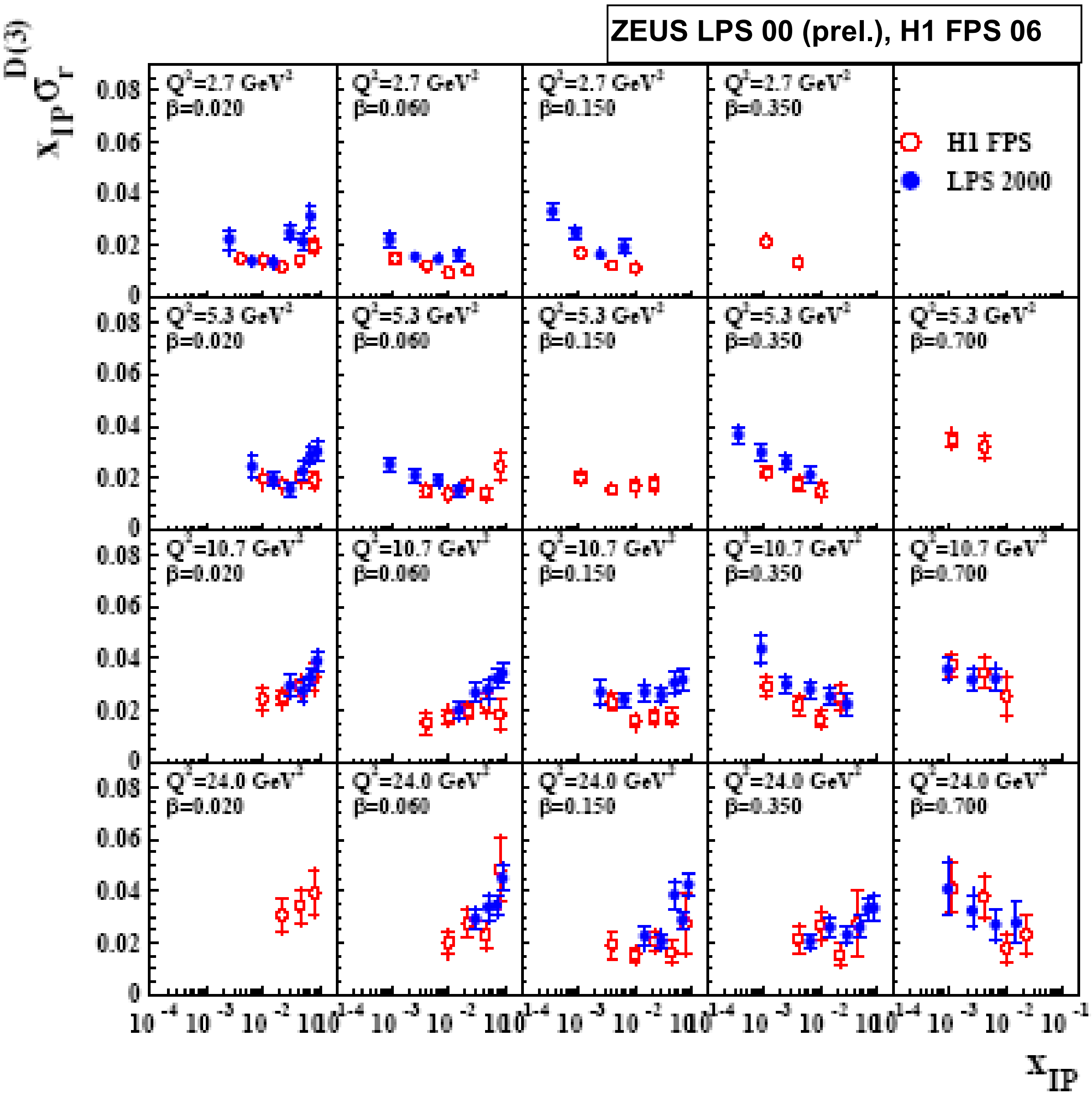
—— Regge fit: $F_2^{D(4)} = f_{IP}(x_{IP},t)\cdot F_2^{IP}(\beta,Q^2) + n_{IR}\cdot f_{IR}(x_{IP},t)\cdot F_2^{IR}(\beta,Q^2)$

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 LPS results (2)

Comparison of recent LPS and H1 FPS results:



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

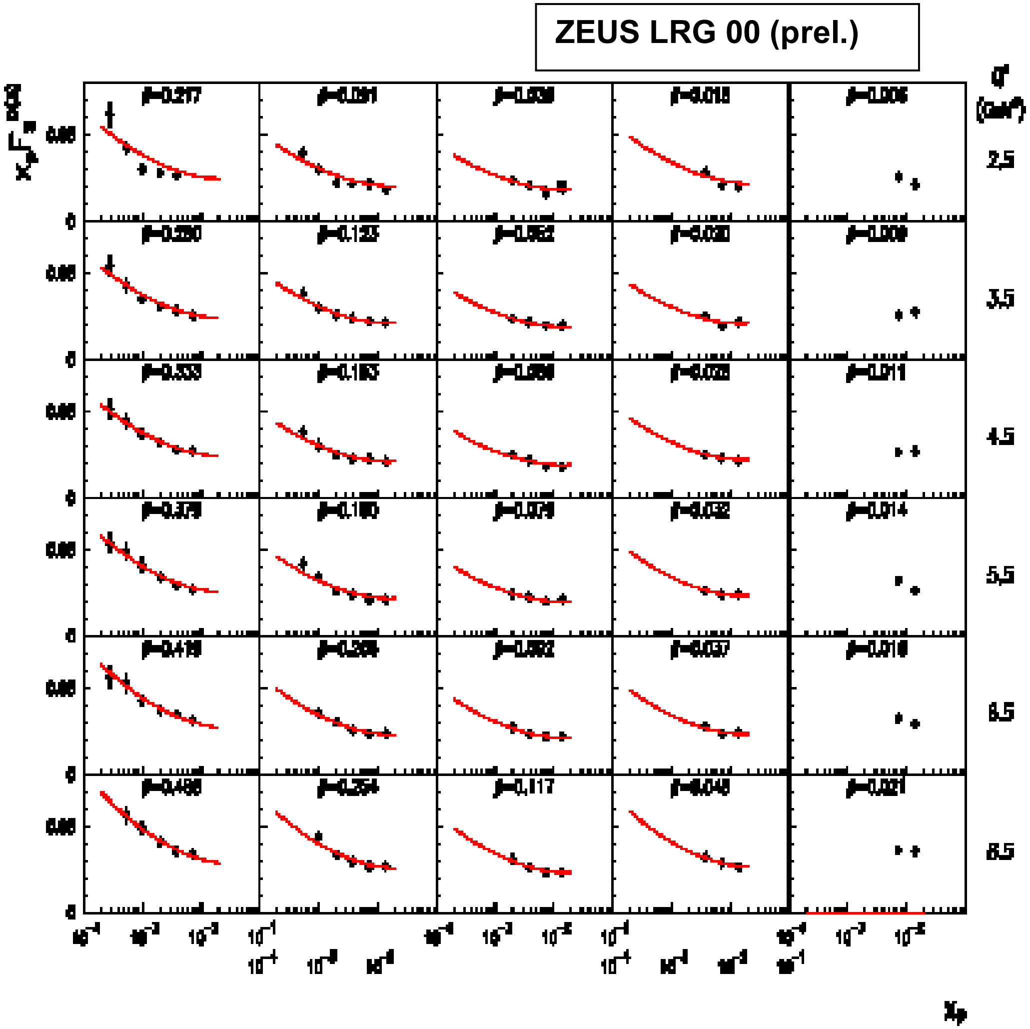
$$R^D = 0 \longrightarrow x_{IP} F_2^{D(3)} = x_{IP} \sigma_r^{D(3)}$$

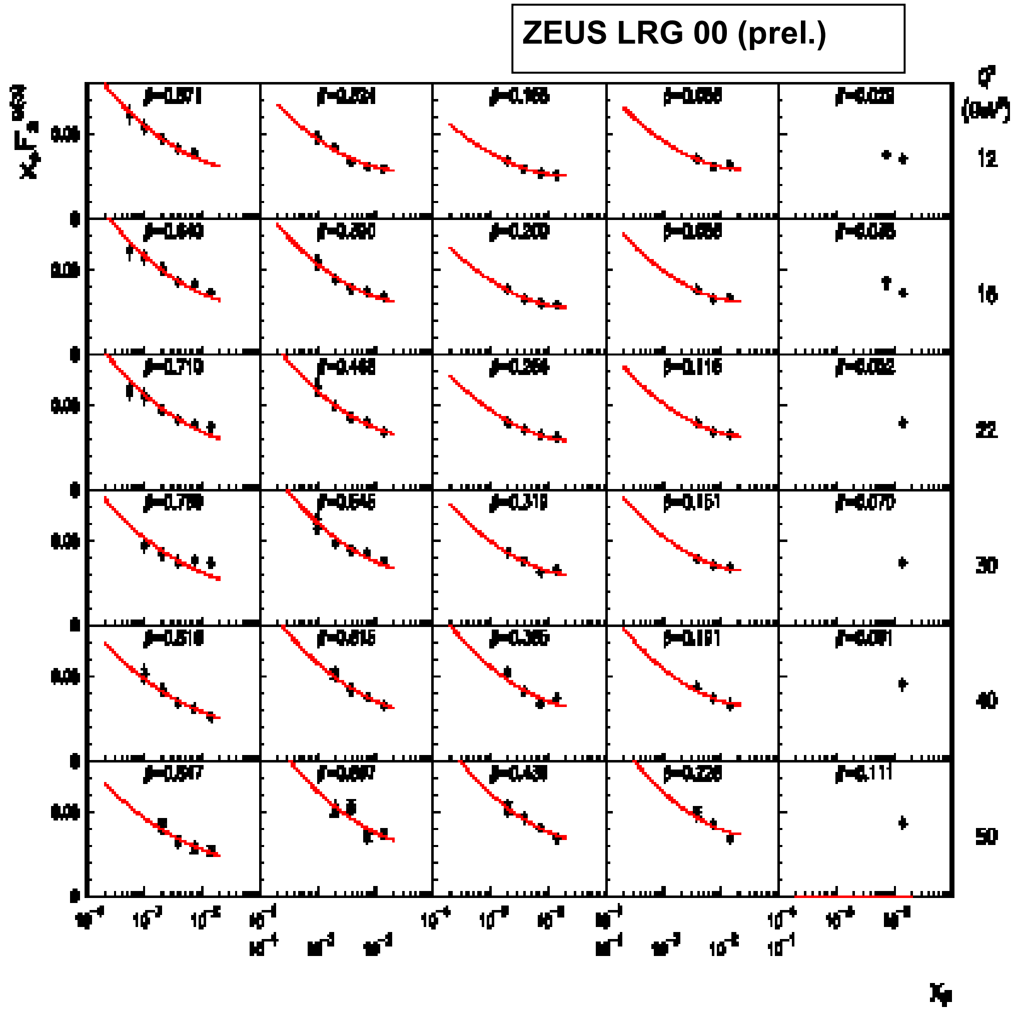
Normalization uncertainties are not shown:

- +12% / -10% for ZEUS LPS
- +/-10% for the H1 FPS data

The agreement is fair

ZEUS LRG results (1)





Input parameters to the Regge-fit:

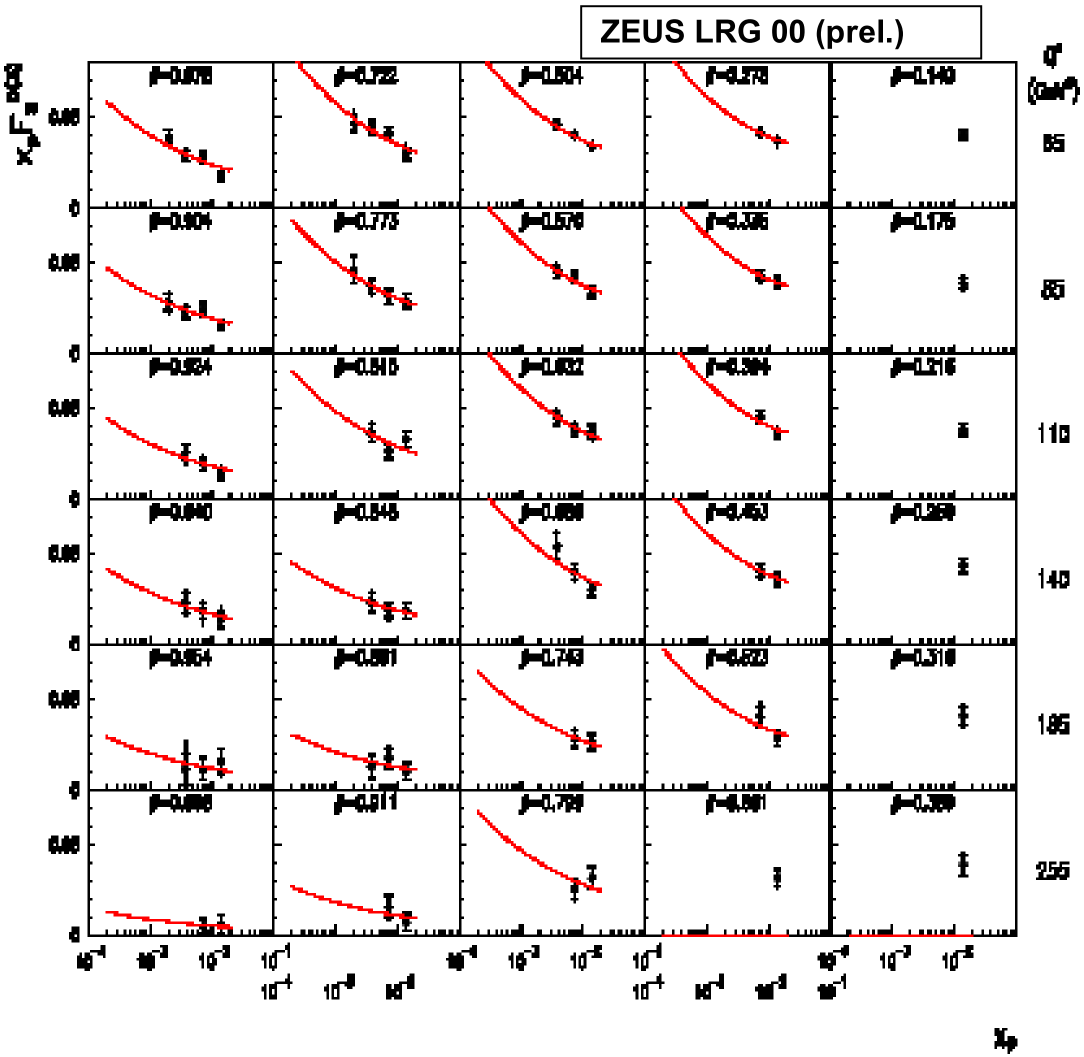
$\alpha_{IR}(0) = 0.75$, $B_{IR} = 2.0$ GeV^{-2}

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

Regge fit

Fit results: $\alpha_{IP}(0) = 1.117 \pm 0.005^{+0.024}_{-0.007}$

ZEUS LRG results (2)

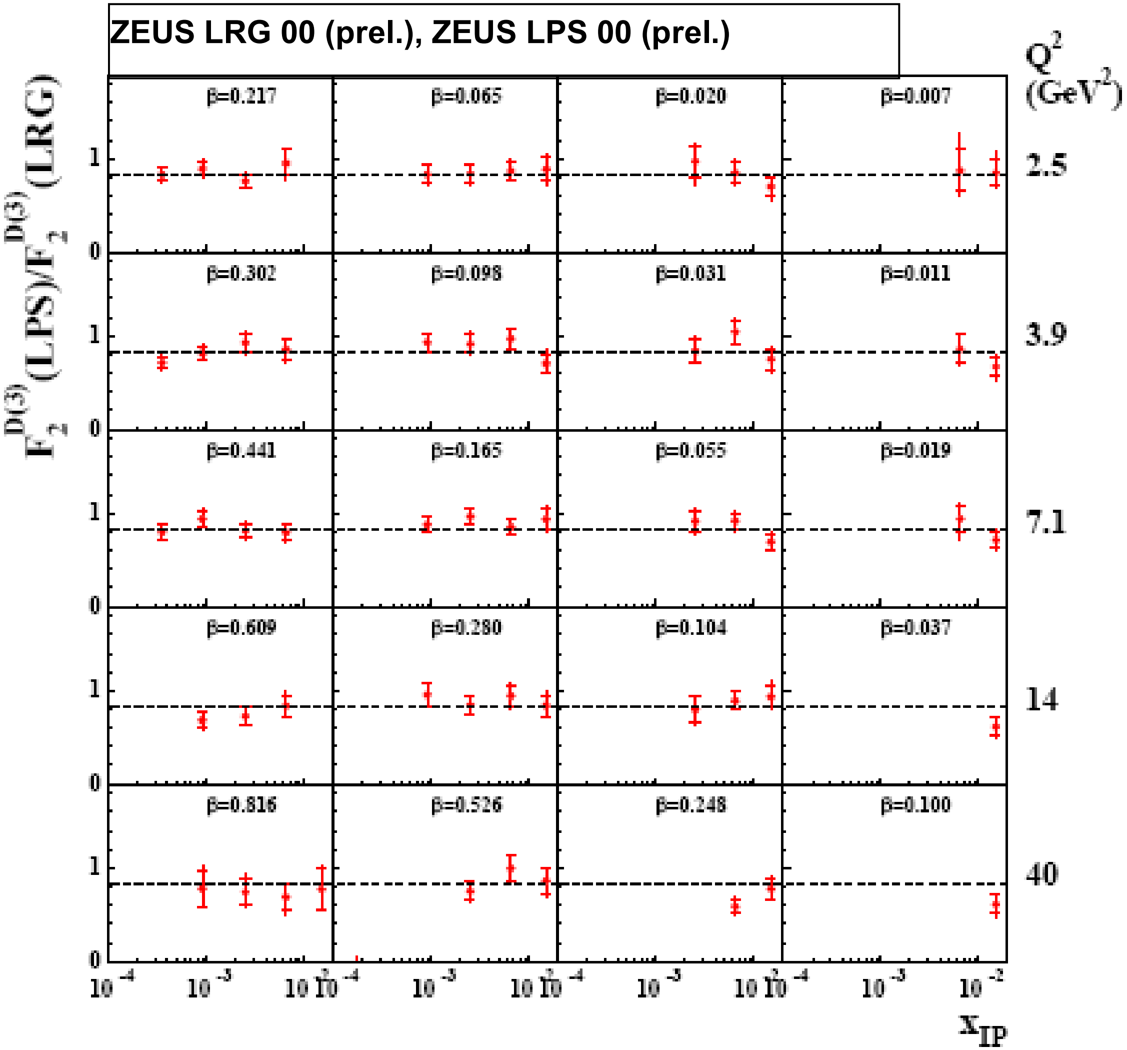


The Regge-fit gives a good description of the ZEUS LRG data

χ^2/ndf = 159/185 (=0.86)

ZEUS LRG results (3)

Comparison of the ZEUS LRG with LPS data:

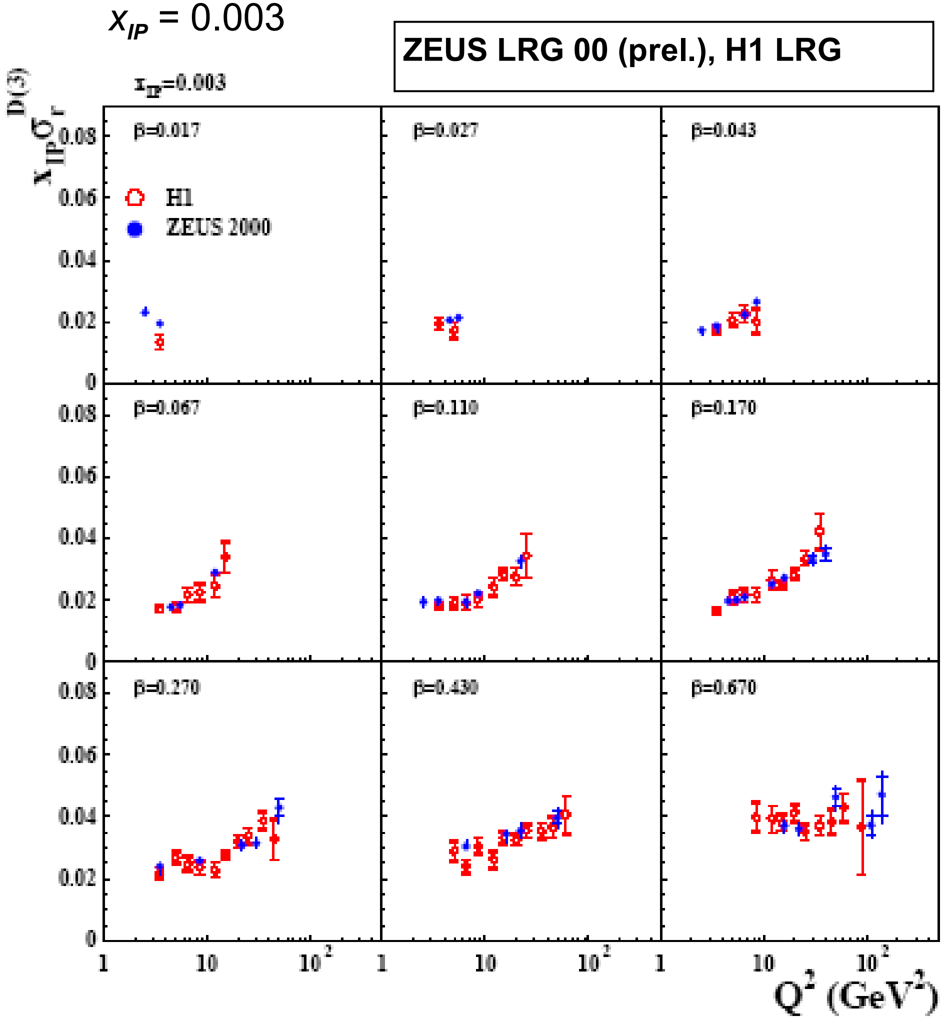


LPS/LRG = 0.82 ±0.01(stat.) ±0.03(syst.)
independent of Q^2 and β

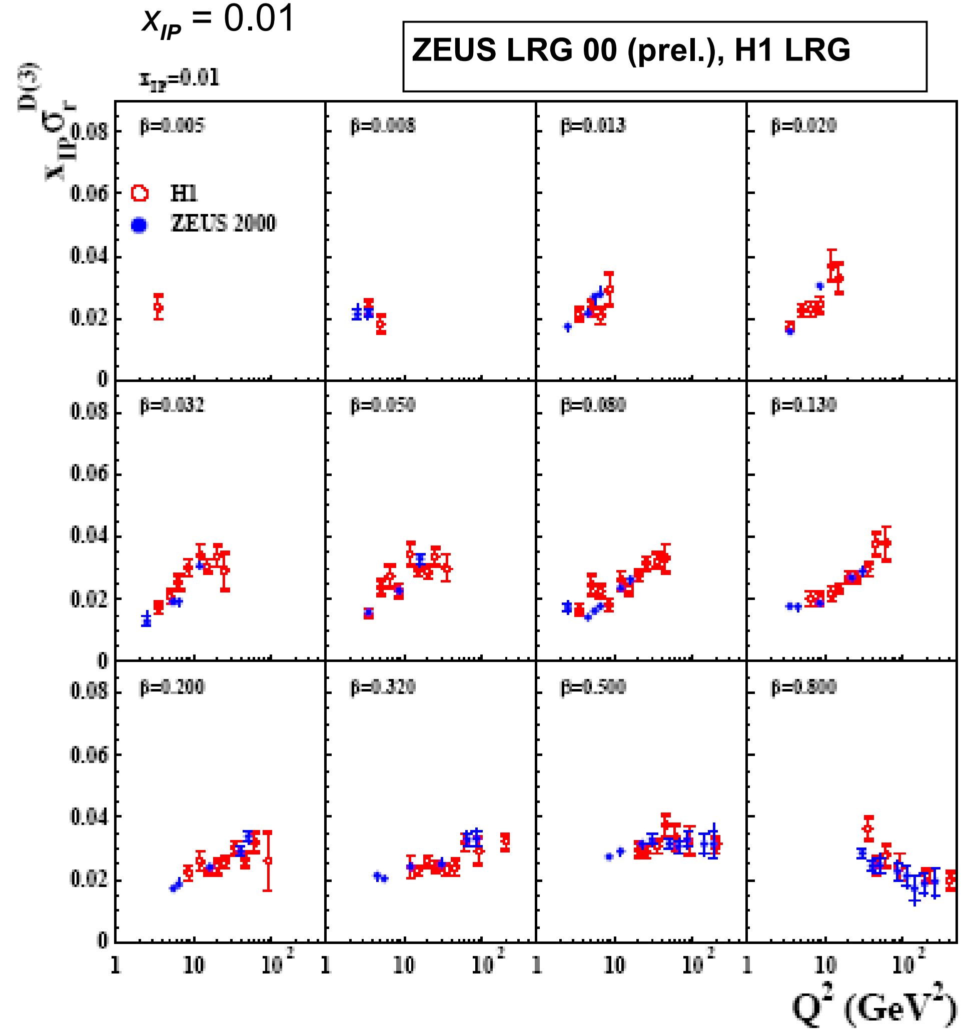
~10% normalization uncertainty of the LPS measurement is not shown

LRG results – ZEUS vs. H1

x_{IP} = 0.003



x_{IP} = 0.01



- Fraction of proton dissociation events for ZEUS and H1 detectors is different
- The ZEUS LRG data are normalized to the H1 LRG data

Good agreement is observed

ZEUS M_X results (1)

M_X 98-99:

1998-1999 published data

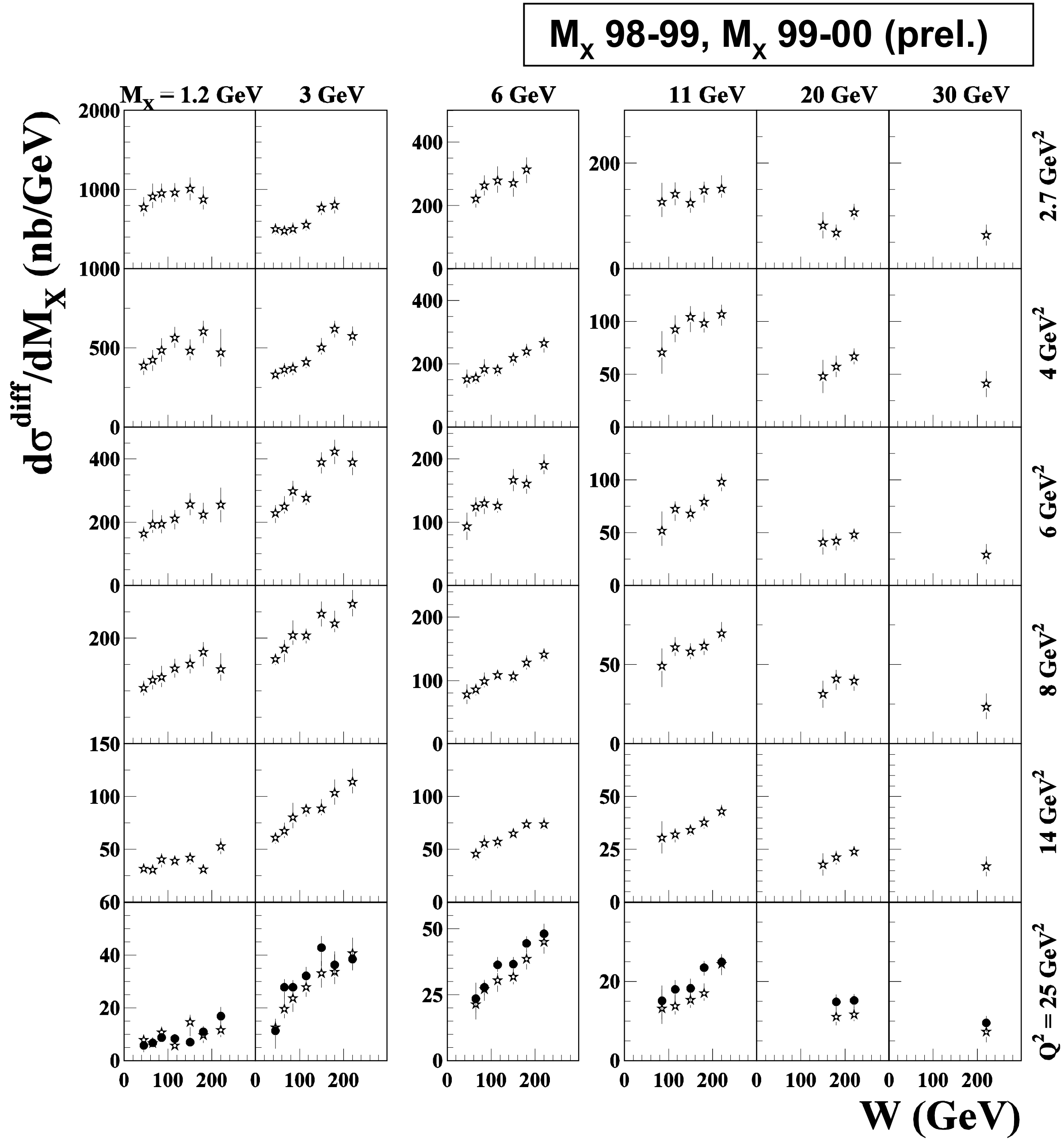
(ZEUS Coll., S. Chekanov et al., Nucl. Phys. B 713, 3 (2005))

Prel. M_X 99-00:

1999-2000 preliminary results

Extension of M_X 98-99 analysis to higher Q^2

M_X 98-99 and M_X 99-00 analyses have common bin at Q^2=25 GeV^2

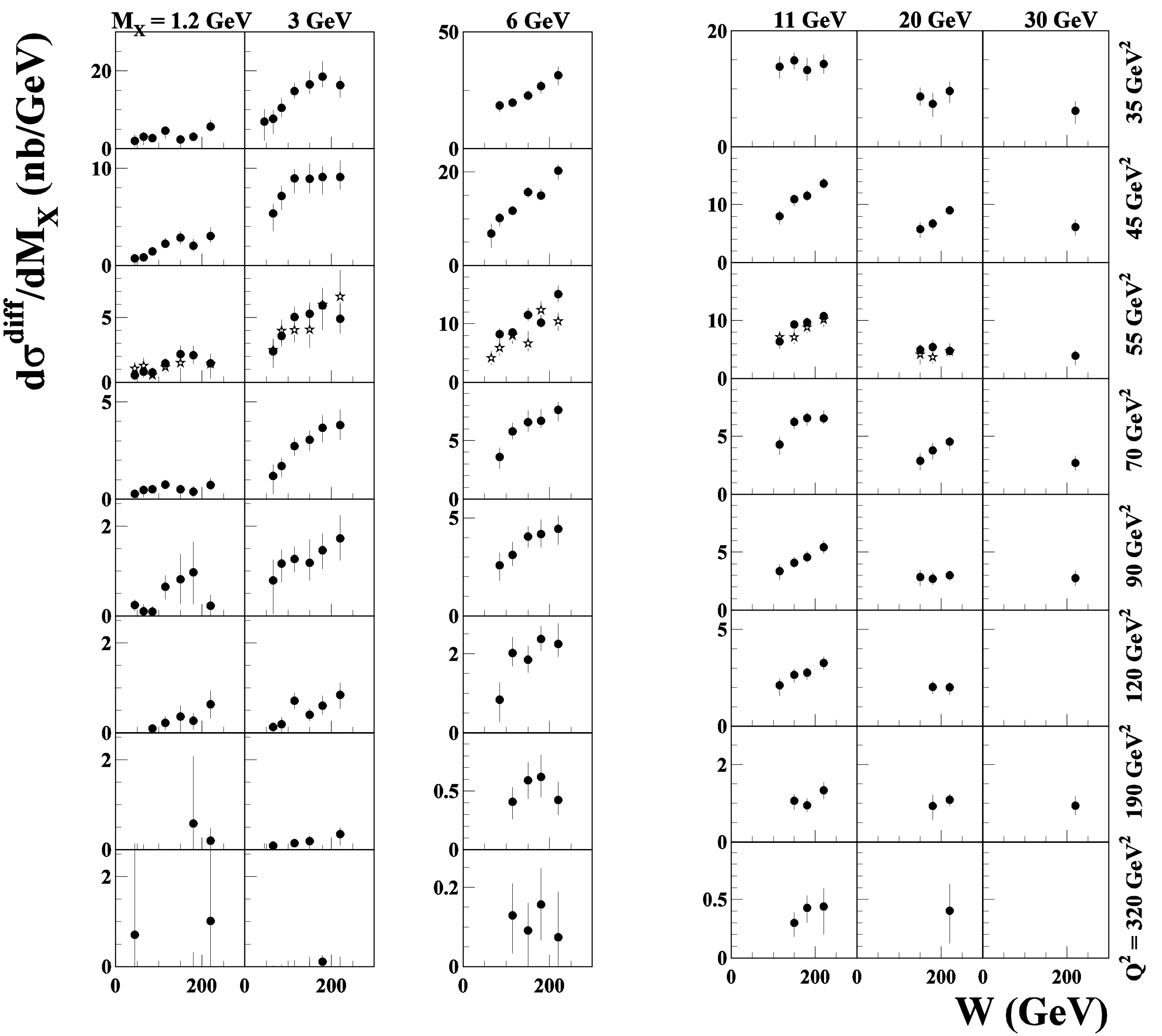


ZEUS M_X results (2)

M_X 98-99: ★

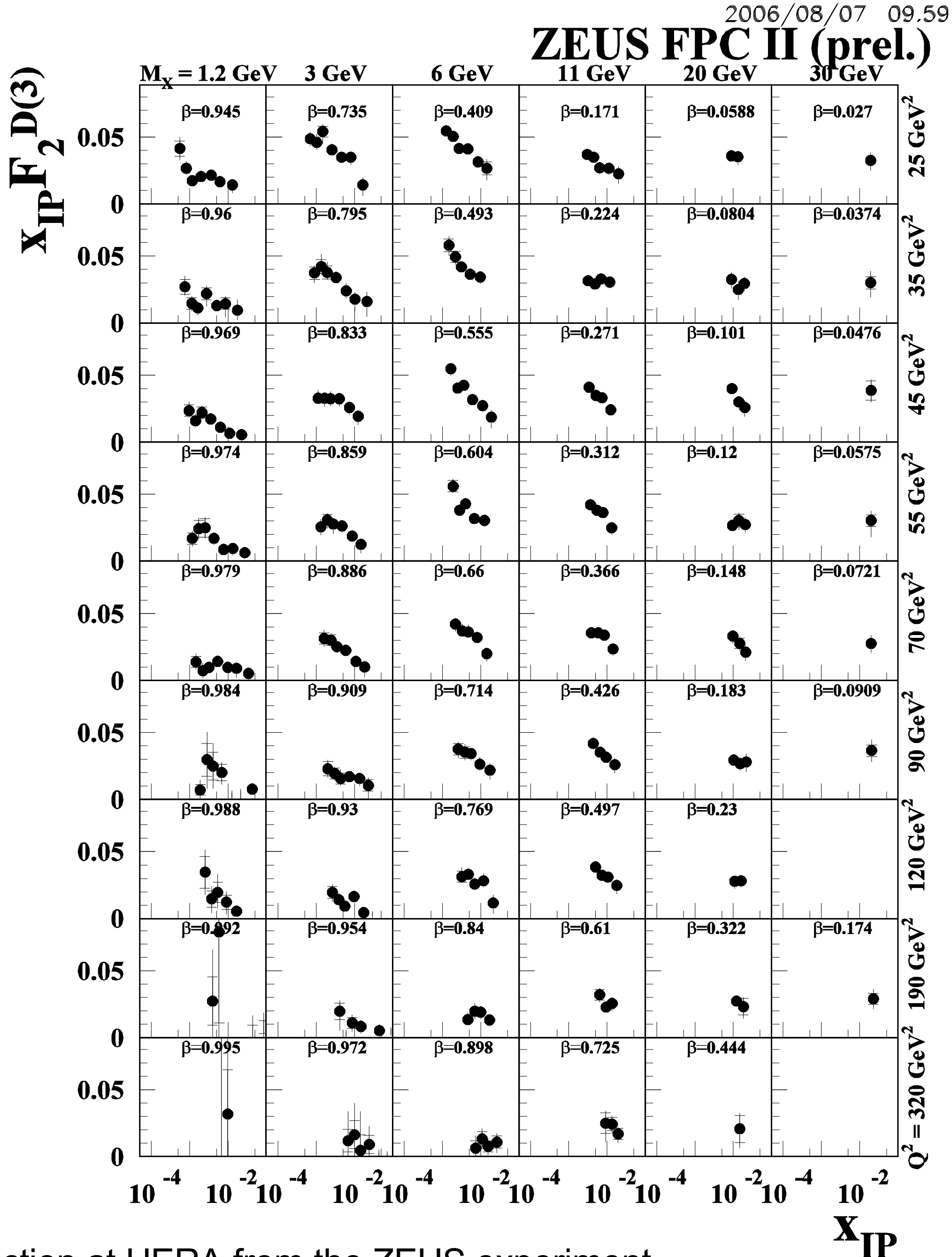
Prel. M_X 99-00: ●

M_X 98-99 and M_X 99-00 analyses have common bin at Q^2=55 GeV^2

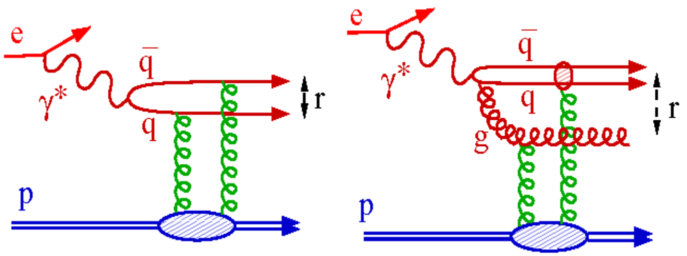


ZEUS M_X: $x_{IP}F_2^{D(3)}$ results

Prel. M_X 99-00



ZEUS modified BEKW fit



Fit with BEKW model

(Bartels, Ellis, Kowalski and Wüsthoff, 1998)

- $x_{IP} F_2^{D(3)} = c_T \cdot F_{q\bar{q}}^T + c_L \cdot F_{q\bar{q}}^L + c_g \cdot F_{q\bar{q}g}^T$

$$F_{q\bar{q}}^T = (\frac{x_0}{x_{IP}})^{n_T(Q^2)} \cdot \beta(1-\beta) \,,$$

$$F_{q\bar{q}}^L = (\frac{x_0}{x_{IP}})^{n_L(Q^2)} \cdot \frac{Q_0^2}{Q^2+Q_0^2} \cdot [\ln(\frac{7}{4} + \frac{Q^2}{4\beta Q_0^2})]^2 \cdot \beta^3(1-2\beta)^2 \,,$$

$$F_{q\bar{q}g}^T = (\frac{x_0}{x_{IP}})^{n_g(Q^2)} \cdot \ln(1+\frac{Q^2}{Q_0^2}) \cdot (1-\beta)^{\gamma}$$

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

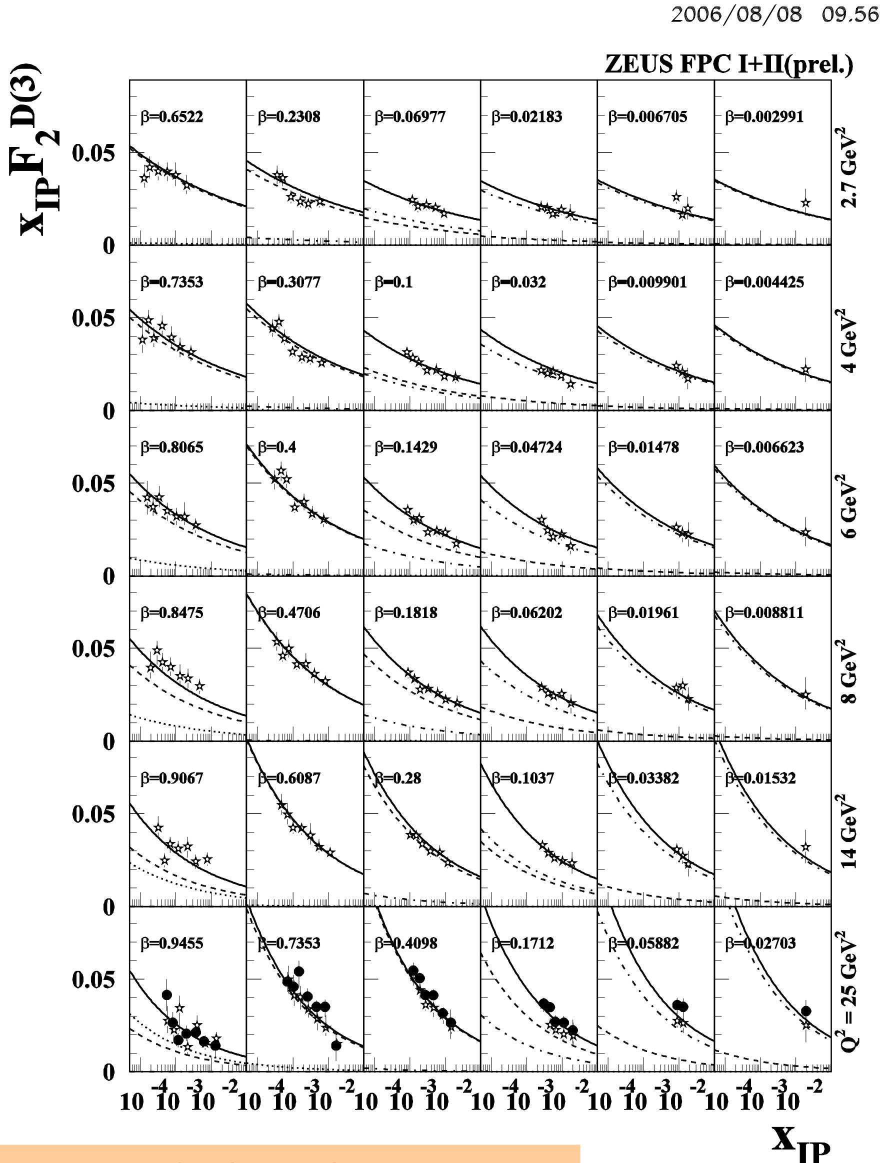
$$n_g(Q^2) = c_6 + c_9 \ln(1+\frac{Q^2}{Q_0^2})$$

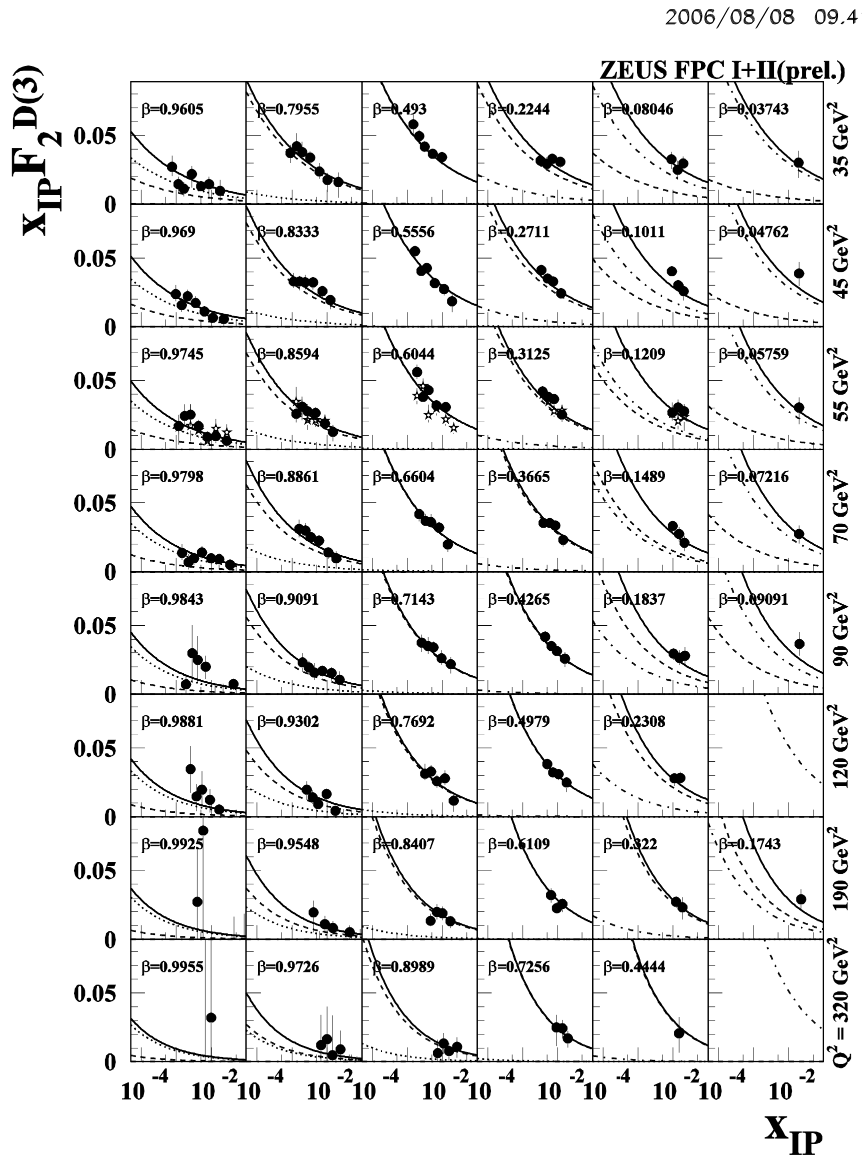
The ZEUS data favour $n_T(Q^2) = n_g(Q^2) = n_1 \ln(1+Q^2/Q_0^2)$ and $n_L = 0$

Taking $x_0 = 0.01$ and $Q_0^2 = 0.4$ GeV^2 results in the modified **BEKW model**

$c_T, c_L, c_g, n_1^{T,g}, \gamma$

ZEUS M_X: $x_{IP}F_2^{D(3)}$ results with BEKW(mod) fit (1)

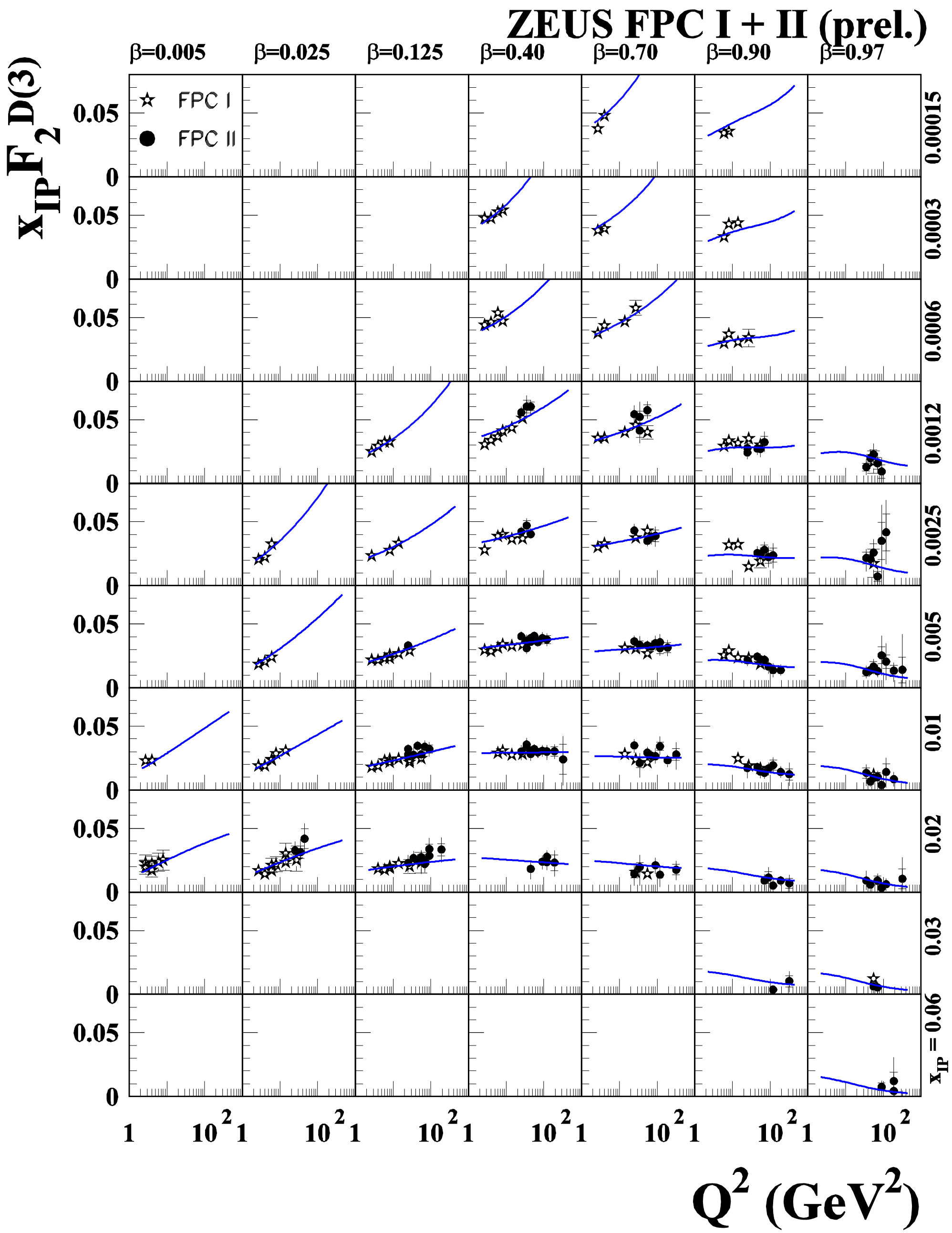




BEKW-fit (prel.):
- >400 point, 5 parameters
- χ^2/n_D=0.71, total errors

———	sum of all contributions	— — —	transverse $q\bar{q}$ contribution
········	longitudinal $q\bar{q}$ contribution	· — · —	transverse $q\bar{q}g$ contribution

ZEUS M_X: $x_{IP}F_2^{D(3)}$ results with BEKW(mod) fit (2)

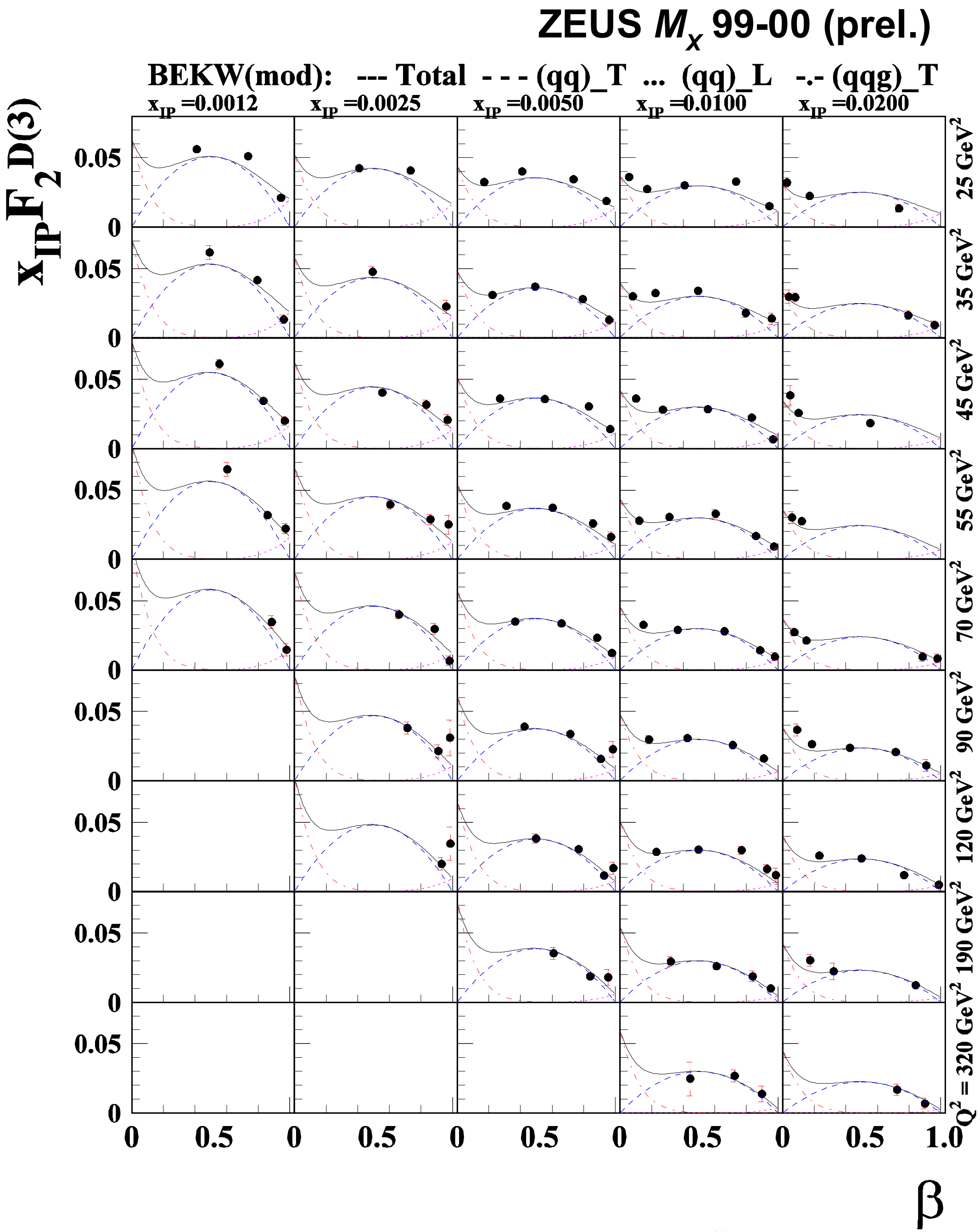


result of the BEKW(mod) fit

$x_{IP}F_2^{D(3)}$ shows scaling violations:

from positive scaling violations over near constancy to negative scaling violations

ZEUS M_X: $x_{IP}F_2^{D(3)}$ results with BEKW(mod) fit (3)

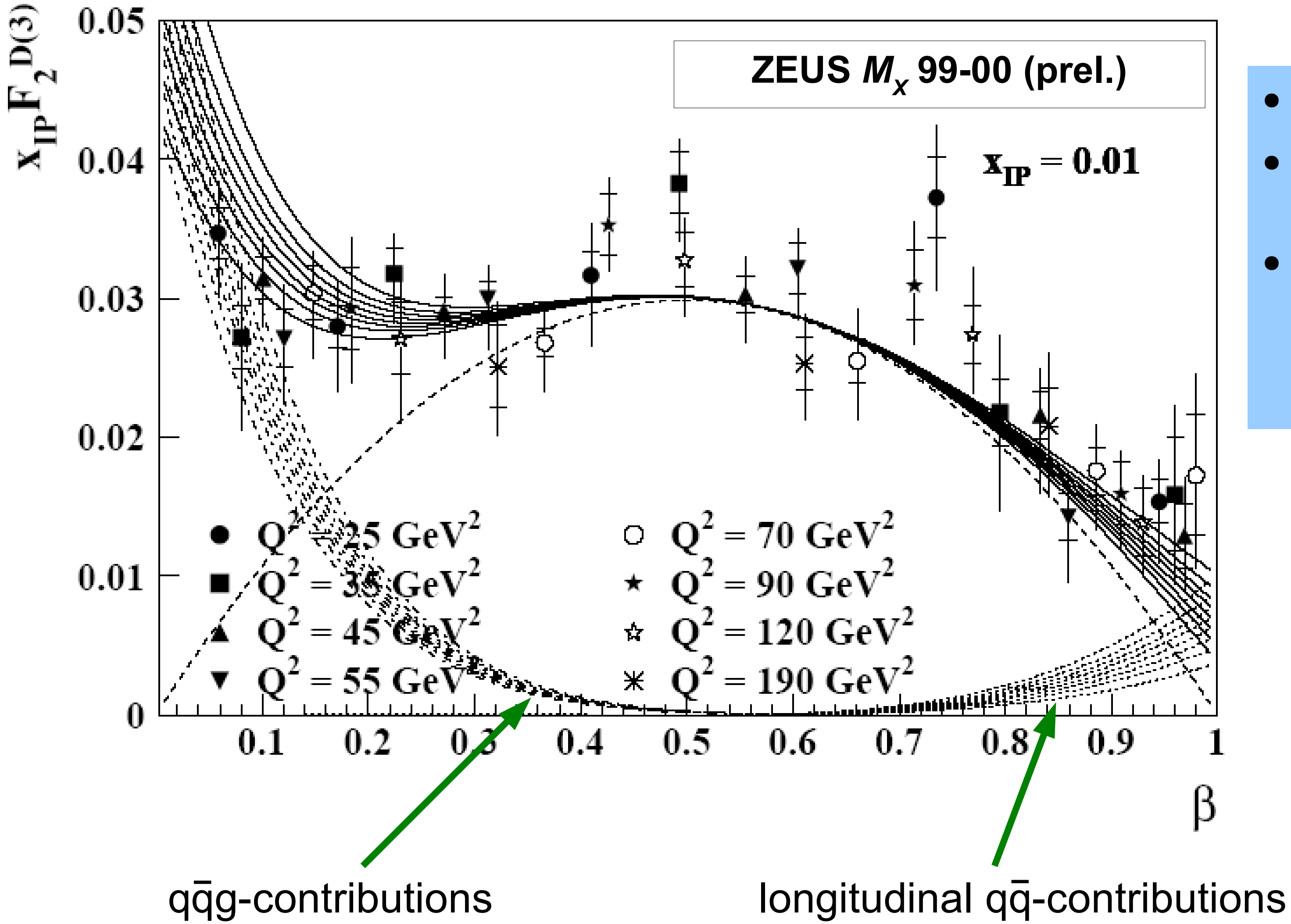


— result of the BEKW(mod) fit

$x_{IP}F_2^{D(3)}$ exhibits:

- a broad maximum around β=0.5 which is due to the transverse q$\bar{q}$-contribution
- a steep rise towards small β which is generated by the q$\bar{q}$g-contribution
- a longitudinal q$\bar{q}$-contribution which is sizeable only at very high β and causes the structure function not to vanish at β=1

ZEUS M_X: $x_{IP}F_2^{D(3)}$ results with BEKW(mod) fit (4)

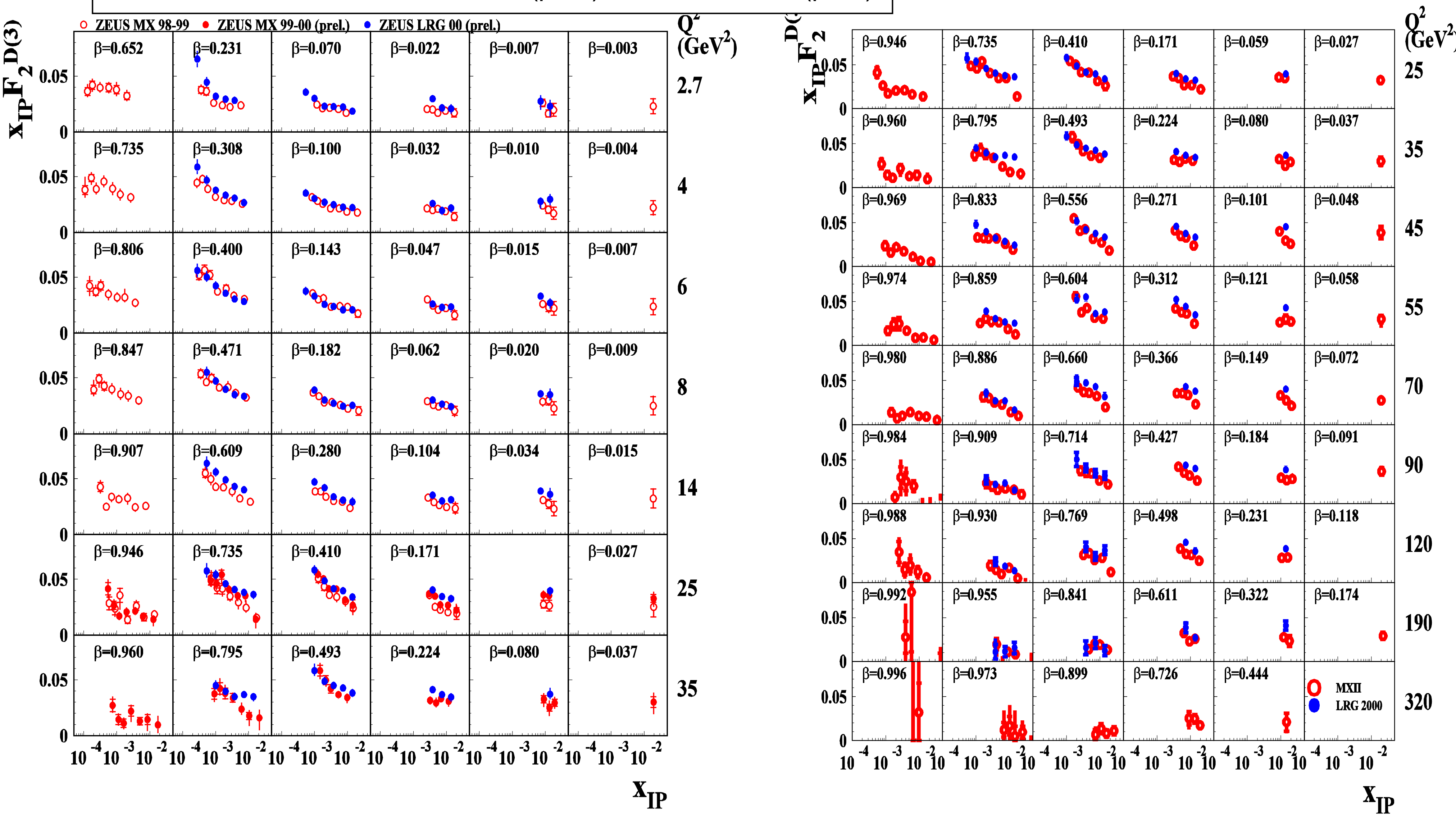


- fixed $x_{IP} = 0.01$
- $25<Q^2<190$ GeV^2 on one plot
- the 3 contributions from BEKW(mod) fit for the above Q^2 values plotted

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

ZEUS: comparison of M_X and LRG results (1)

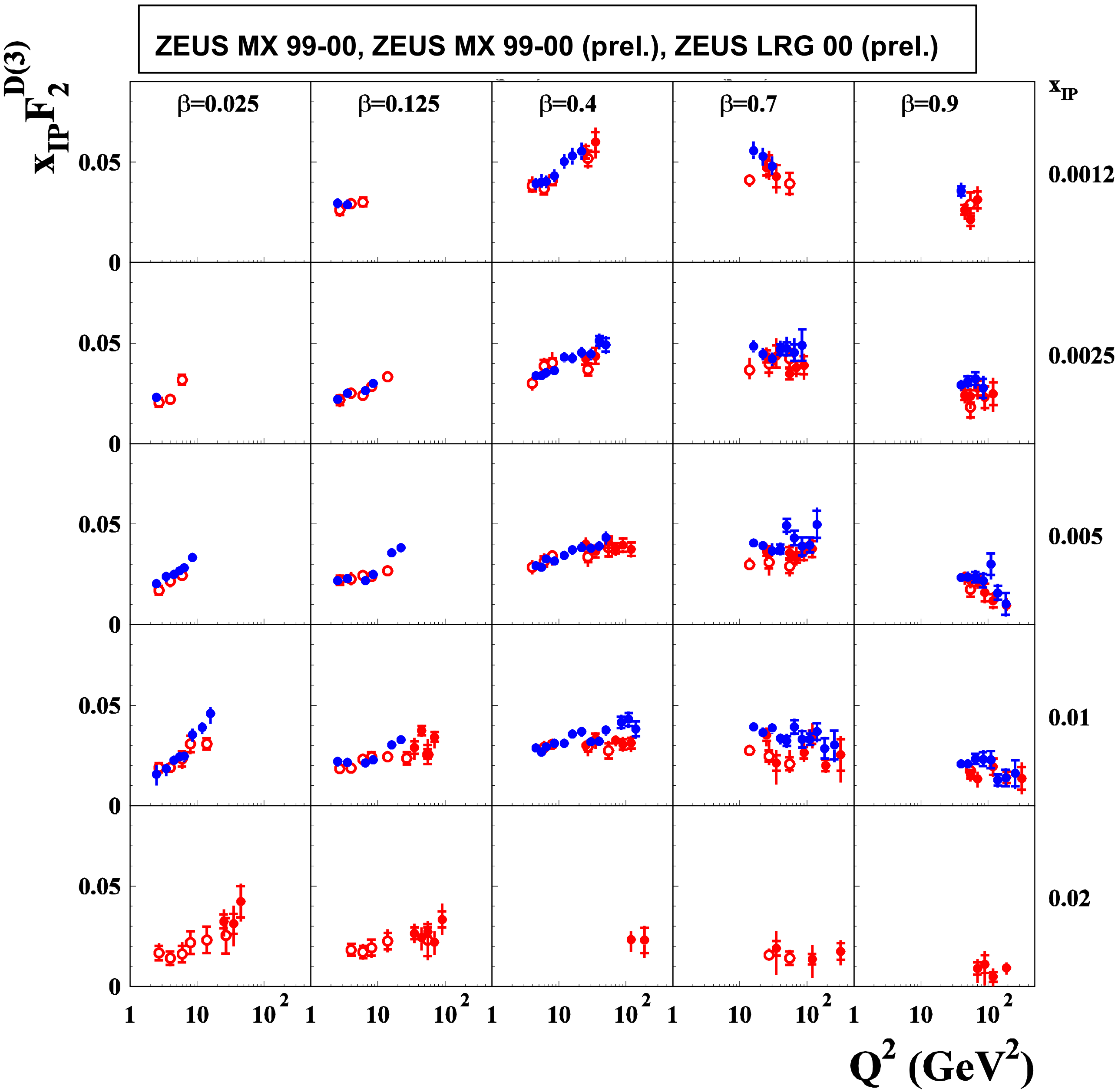
ZEUS MX 98-99, ZEUS MX 99-00 (prel.), ZEUS LRG 00 (prel.)



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

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

ZEUS: comparison of M_X and LRG results (2)



$x_{IP}F_2^{D(3)}$ vs. Q^2

- ○ ZEUS M_X 98-99
- ● ZEUS M_X 99-00 (prel.)
- ● ZEUS LRG 00 (prel.)

- reasonable agreement
- work on understanding remaining differences is continuing

Summary

- ZEUS presented preliminary results on inclusive diffraction obtained with three different methods
- Results for all three methods are derived from data taken during the same time
- The results span a wide kinematic range, up to high Q^2
- There is a good to reasonable agreement for the results from all three methods
- There is also a good agreement compared to H1 results for the LRG and FPS methods
- Work on understanding some remaining minor differences, in particular with respect to the relative normalisation, continues
- We try to get a consistent picture