Inclusive diffraction at ZEUS

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Low-x Workshop
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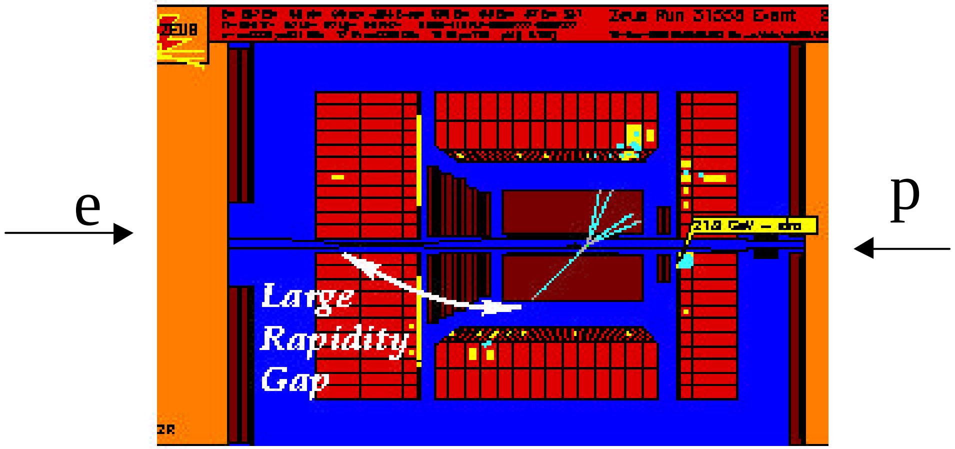
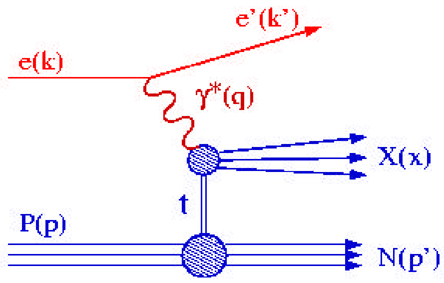
On behalf of ZEUS

- **experimental methods**
- **measurement of t and F distributions**
- **measurements of diffractive cross section**
  - comparison with inclusive ep cross section
- **diffractive cross section at low Q^2**
- **Data interpreted in terms of:**
  - **Regge phenomenology**
  - **color dipole models**

Kinematics of diffractive *ep* scattering



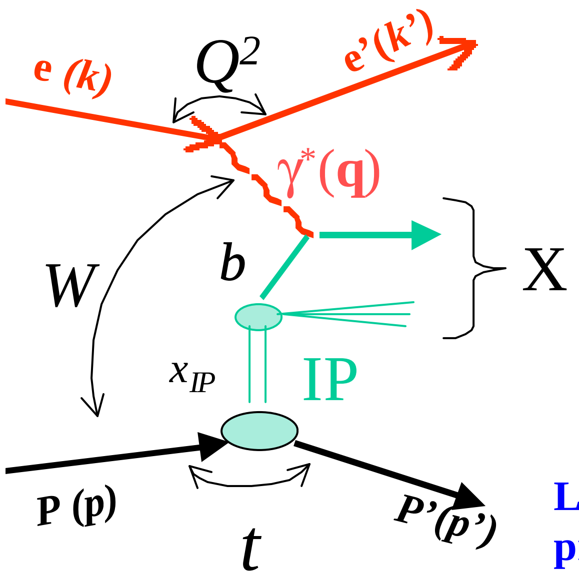


Exchange of color singlet in the t-channel

Pomeron
2-gluons in pQCD

ep ®eXp Single (photon) dissociation

ep ®eXN Double dissociation



Leading proton

$$Q^2 = -q^2 = -(k-k')^2 \qquad x = Q^2/2pq$$

$$W^2 = (p+q)^2 = m_p^2 + Q^2(1/x - 1)$$

$$M_X^2 = (k - k' + p - p')$$

$$x_{IP} = \frac{M_X^2 + Q^2}{W^2 + Q^2} \qquad b = \frac{x}{x_{IP}} = \frac{Q^2}{M_X^2 + Q^2}$$

$t=(p-p')^2$ Φ=azimuthal angle

Diffractive structure function

Cross section can be expressed in terms of diffractive structure function $F_2^{D(4)}$

$$\frac{d^4\sigma_{ep}^{diff}}{d\beta dQ^2 dx_{IP} dt} = \frac{2\pi\alpha^2}{\beta Q^2}\left[1+(1-y)^2\right] F_2^{D(4)}(\beta, Q^2, x_{IP}, t)$$

Integrating over *t*: $\frac{d^3s}{dbdQ^2dx_{IP}}$ or $\frac{d^3s}{dM_X d\ln W^2 dQ^2}$ $\longrightarrow$ $F_2^{D(3)}(b, Q^2, x_{IP})$

- **ep ® eXp** triple-pole **Regge theory** suggests factorization:

$$F_2^{D(4)} = f_{IP/p}(x_{IP}, t)\cdot F_2^{IP}(Q^2,\beta) \qquad f_{IP/p}(x_{IP},t) \approx e^{b_{IP}t}\cdot\frac{1}{x_{IP}^{2a_{IP}(t)-1}}$$

In **resolved Pomeron** models: $f_{IP/p}(x_{IP},t)$ **Pomeron flux factor**

$F_2^{IP}(Q^2,b)$ **Pomeron structure function**
(partonic distributions in the IP,
pQCD evolution in hard diffraction)

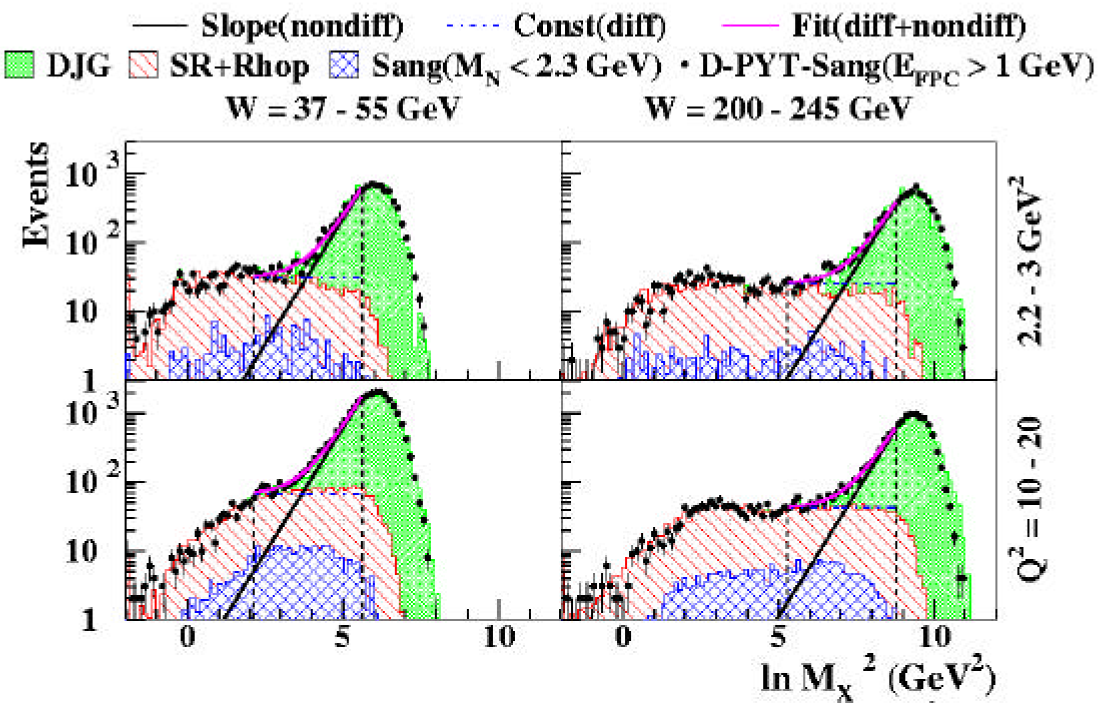
- **ep ® eXN** N not measured, more theoretical and experimental uncertainties

Selection of diffractive events

Leading Proton Spectrometer (LPS)

- insensitive to proton dissociation
- direct measurement of t, x_{L}
- access to high M_X
- low statistics

M_x method



Diffr. $\frac{dN}{d\ln M_X^2} \approx \frac{1}{(M_X^2)^{\alpha_{IP}(0)-1}} \approx const.$

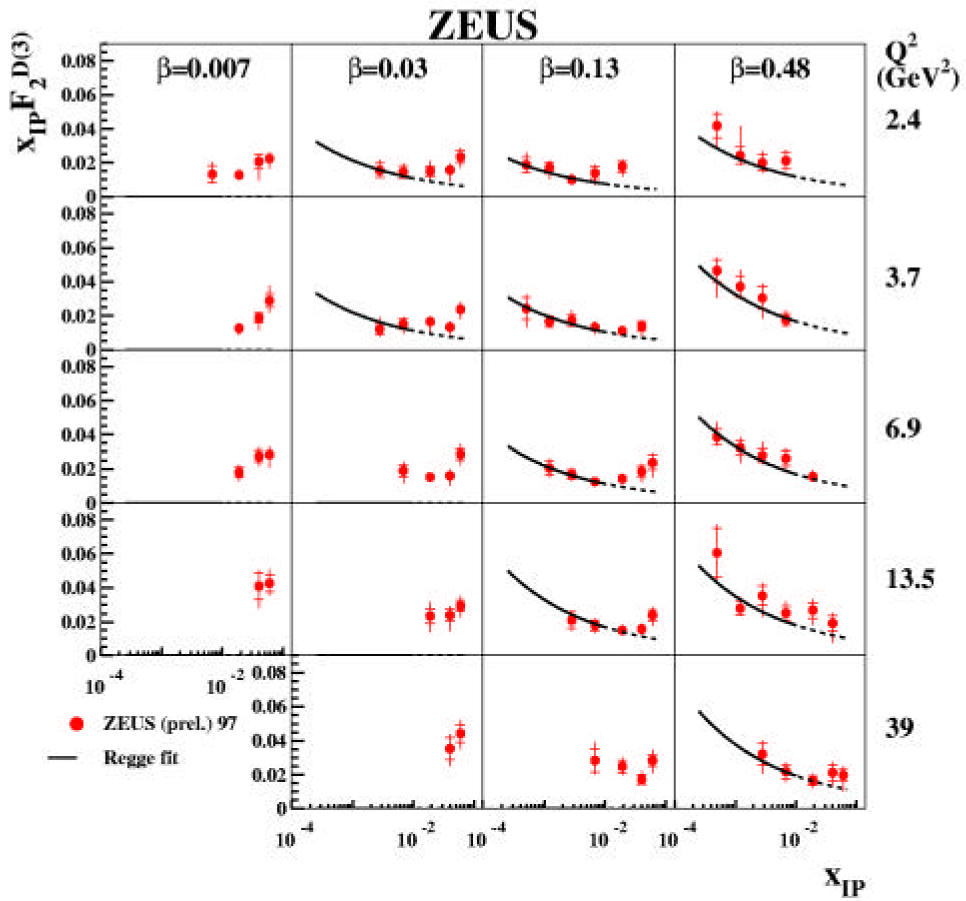
Non-diffr. $\frac{dN}{dh} \approx const$

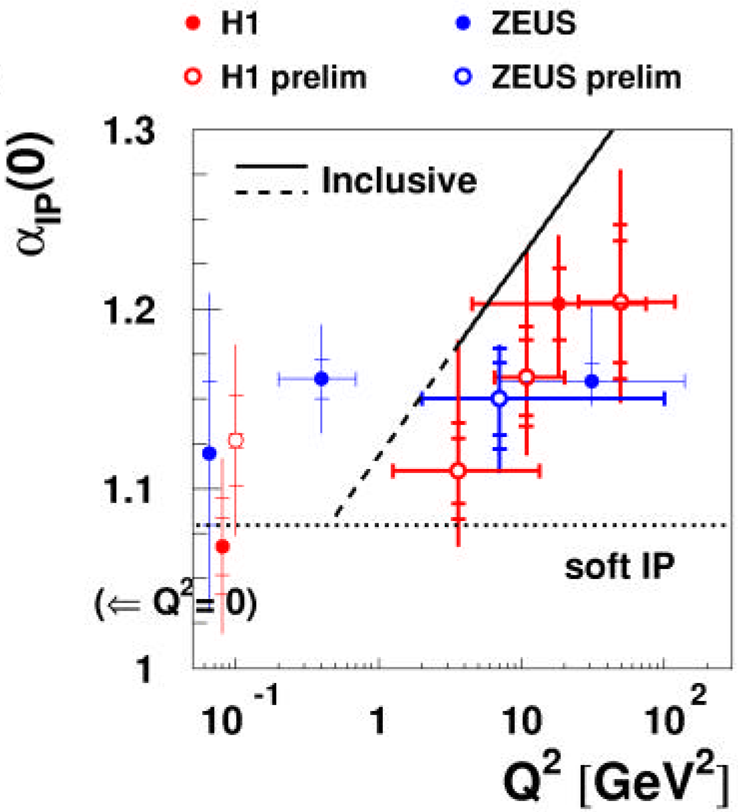
$$\frac{dN}{dlnM_X^2} = D + c \cdot exp(b \cdot lnM_X^2)$$

$$\ln M_X^2 \leq \ln W^2 - h_0$$

- D, c, b from a fit of data
- **contamination from p-dissociation**

Diffractive cross section (LPS)





Fit all data (x_{IP}<0.01) with one form of the flux-factor:

$$x_{IP}F_2^{D(3)}(x_{IP},\beta,Q^2) = \frac{1}{x_{IP}^{2\alpha_{IP}-1}} F_2^{IP}(\beta,Q^2) \qquad a_{IP}(0) = 1.173 \pm 0.018(stat.) \pm 0.017(syst.)^{+0.063}_{-0.035}(mod.)$$

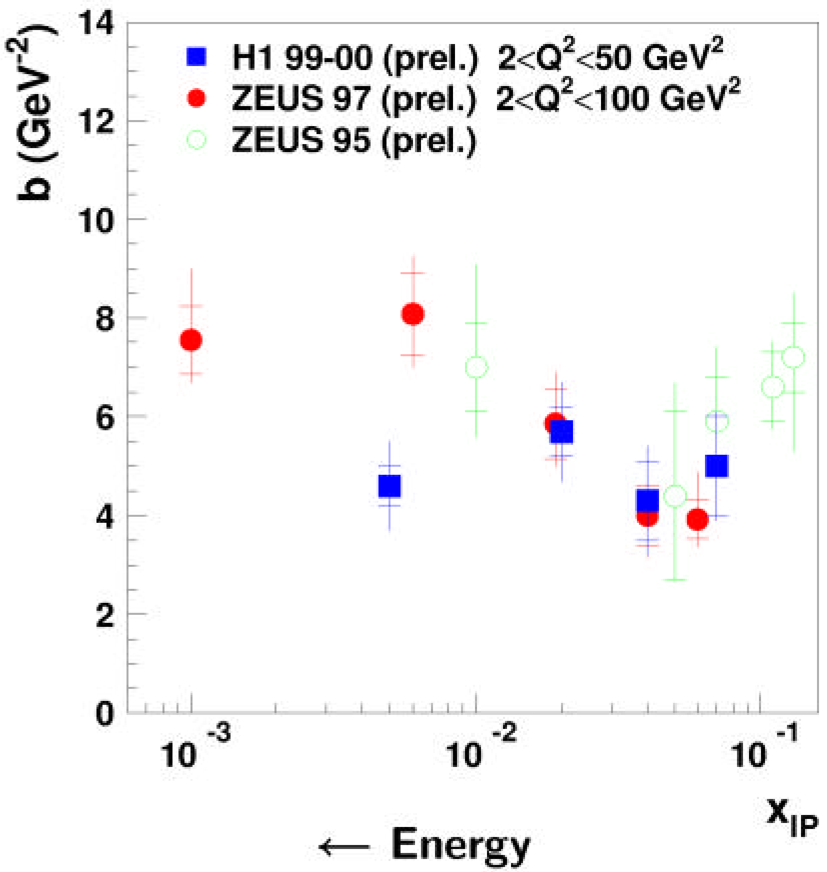
t-distribution (LPS)

Exponential fit to t distribution

$$\frac{d\sigma}{d|t|} \sim e^{-b|t|}$$

Regge phenomenology predicts "shrinkage" of the diffractive peak:

$$b = b_0 + 2a'\ln\frac{W^2}{M_X^2} \approx b_0 + 2a'\ln\frac{1}{x_{IP}}$$



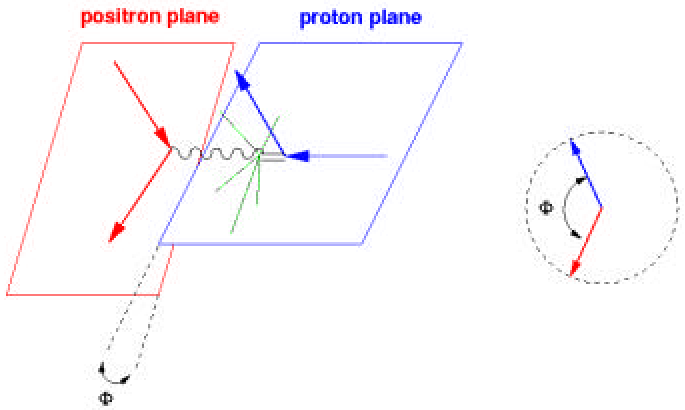
For $x_{IP} < 10^{-2}$, data prevent any firm conclusion

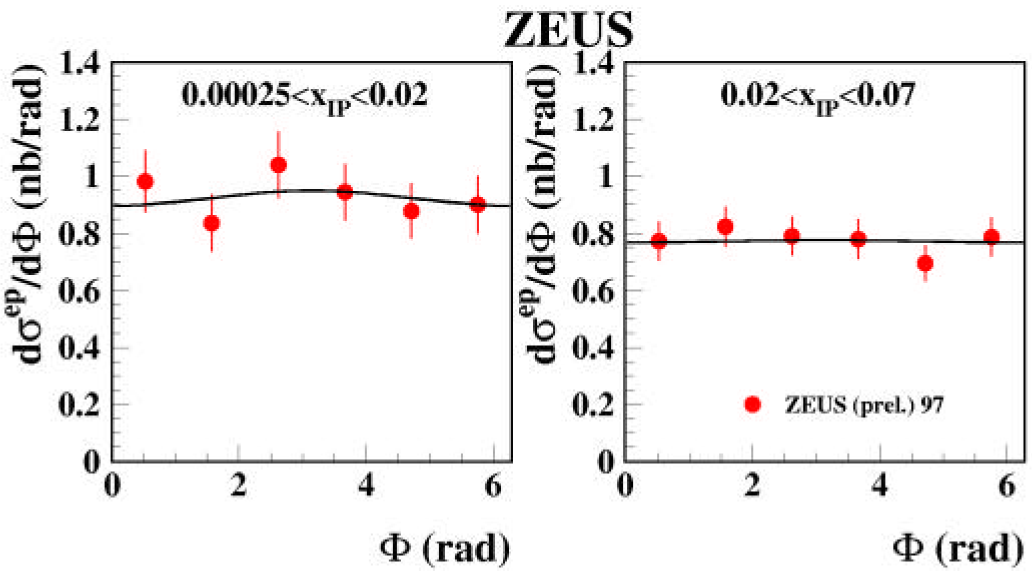
Azimuthal asymmetry (LPS)

For unpolarized positrons: $$\frac{d\sigma^D}{d\Phi} \sim \sigma_T^D + \epsilon\sigma_L^D - 2\sqrt{\epsilon(1+\epsilon)}\,\sigma_{LT}^D\cos\Phi - \epsilon\sigma_{TT}^D\cos 2\Phi$$

Φ – angle between positron and proton scattering planes in γ^*p rest frame

Non-uniform Φ distribution reflects non-zero value of $R^D = \sigma_L^D/\sigma_T^D$





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

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

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

Interference term small at low β

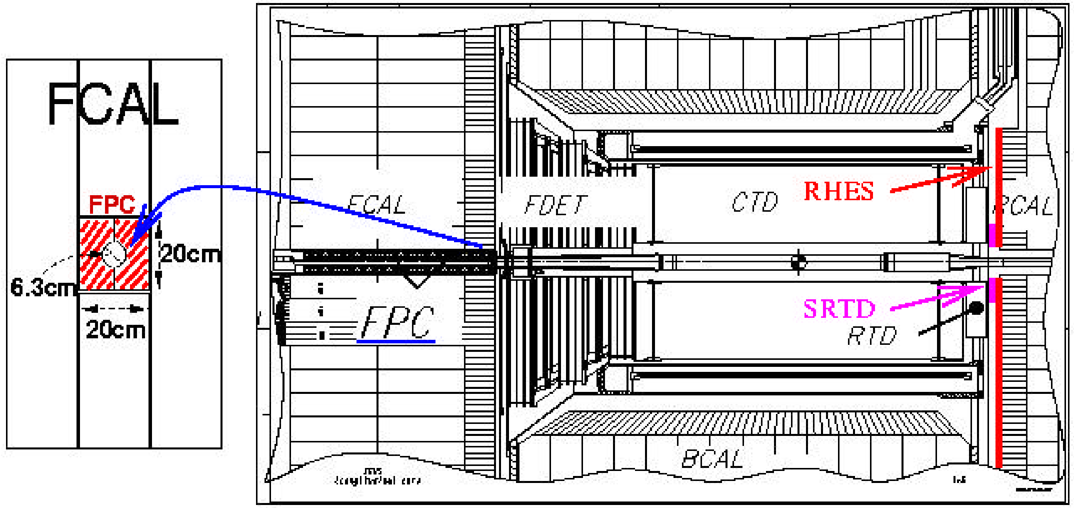
More statistics needed to explore the high β region (large asymmetry expected)

M_X-method using Forward Plug Calorimeter

1998-99 data (4.2 pb^{-1}):

Forward Plug Calorimeter (FPC)
(acceptance for hadronic states from **h~4** to **h~5)**

- kinematic coverage extended to **higher *M_X*** (M_X range increased by a factor 1.7) and **lower *W*.**
- reduced contribution from high-mass proton dissociation

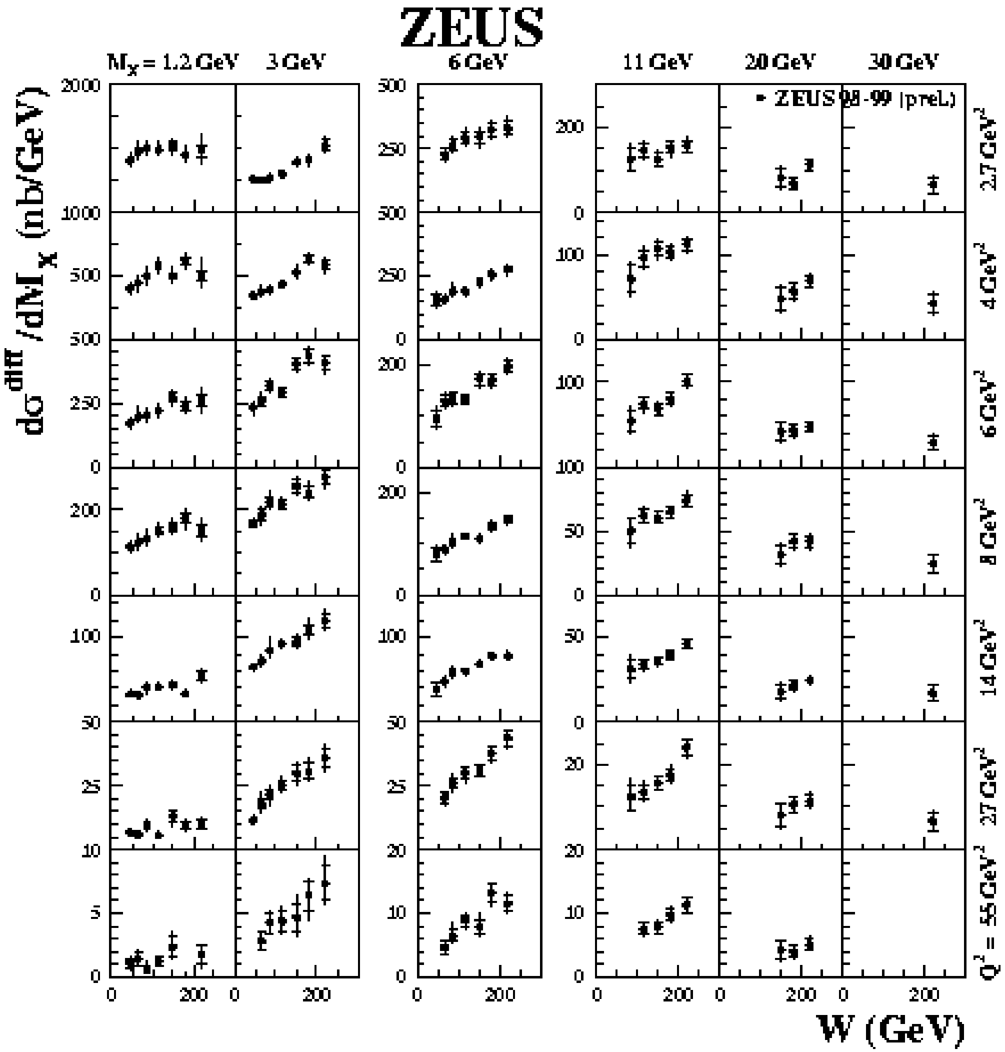


Reduced beam-hole size in the rear direction

- kinematic range extended to **lower *Q^2*, higher *W***

	ZEUS 94	ZEUS 98-99
Q^2 (GeV^2)	**7-140**	**2.2-80**
W (GeV)	**60-200**	**37-245**
M_X (GeV)	**<15**	**<35**
M_N	**<5.5 GeV**	**<2.2 GeV**

Diffractive cross section (M_X-method)



$\gamma^* p \to XN$ cross section

$$\frac{ds^{diff}_{g^* p \to XN}(M_X, W, Q^2)}{dM_X} =$$

$$= \frac{2p}{a} \cdot \frac{Q^2}{(1-y)^2+1} \cdot \frac{ds^{diff}_{ep}}{dM_X \, d\ln W^2 \, dQ^2}$$

p-dissociation events with M_N<2.2 GeV included (events with M_N>2.2 GeV excluded by requiring E_{FPC}>1 GeV)

- M_X< 2 GeV **weak W dependance**
- M_X> 2 GeV **ds/dM_X rises with Q^2**

W dependence (M_X-method)

Under the assumption of IP-exchange in γ^*p interactions:

$$T_{\gamma^* p\rightarrow \gamma^* p} \sim \left(W^2\right)^{\alpha_{IP}(t)} \qquad \alpha_{IP}(t) = \alpha_{IP}(0) + \alpha' \cdot t$$

diffractive cross section:

$$\frac{d\sigma^{diff}}{dM_X^2} \sim (W^2)^{2(\overline{\alpha_{IP}^{diff}(t)}-1)}$$

$\alpha_{IP}^{diff}(0)$

form fit to data

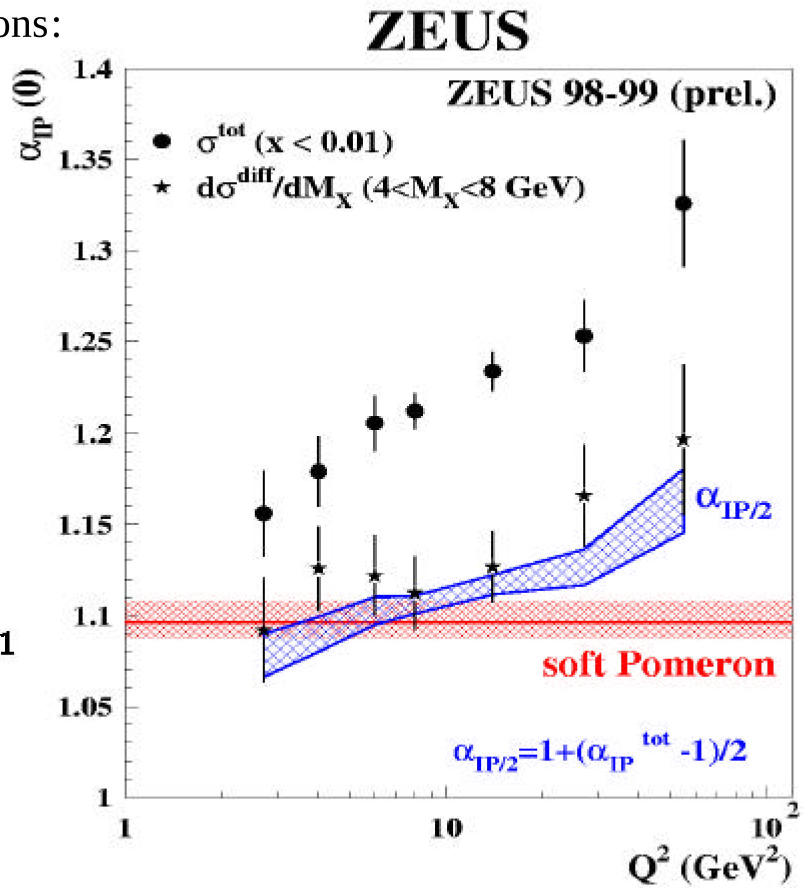
total cross section:

$$\sigma_{tot}^{\gamma^* p} = \frac{4\pi\alpha}{Q^2} \sim$$

$$\sim \frac{1}{W^2} Im T_{\gamma^* p \rightarrow \gamma^* p}(W^2, t=0) \sim (W^2)^{\alpha_{IP}^{tot}(0)-1}$$

Data ($4<M_X<8$ GeV) are consistent with the same W-dependence for the diffractive and the total cross section

$$\alpha_{IP}^{diff} \sim 1 + (\alpha_{IP}^{tot} - 1)/2$$



Regge prediction not fulfilled in DIS regime

Ratio $\sigma^{diff}/\sigma^{tot}$ (M_X-method)

$r_{tot} = s^{diff}/s^{tot}$

$$s^{diff} = \int_{M_a}^{M_b} dM_X \frac{ds^{diff}_{g^* p \to XN, M_N < 2.3GeV}}{dM_X}$$

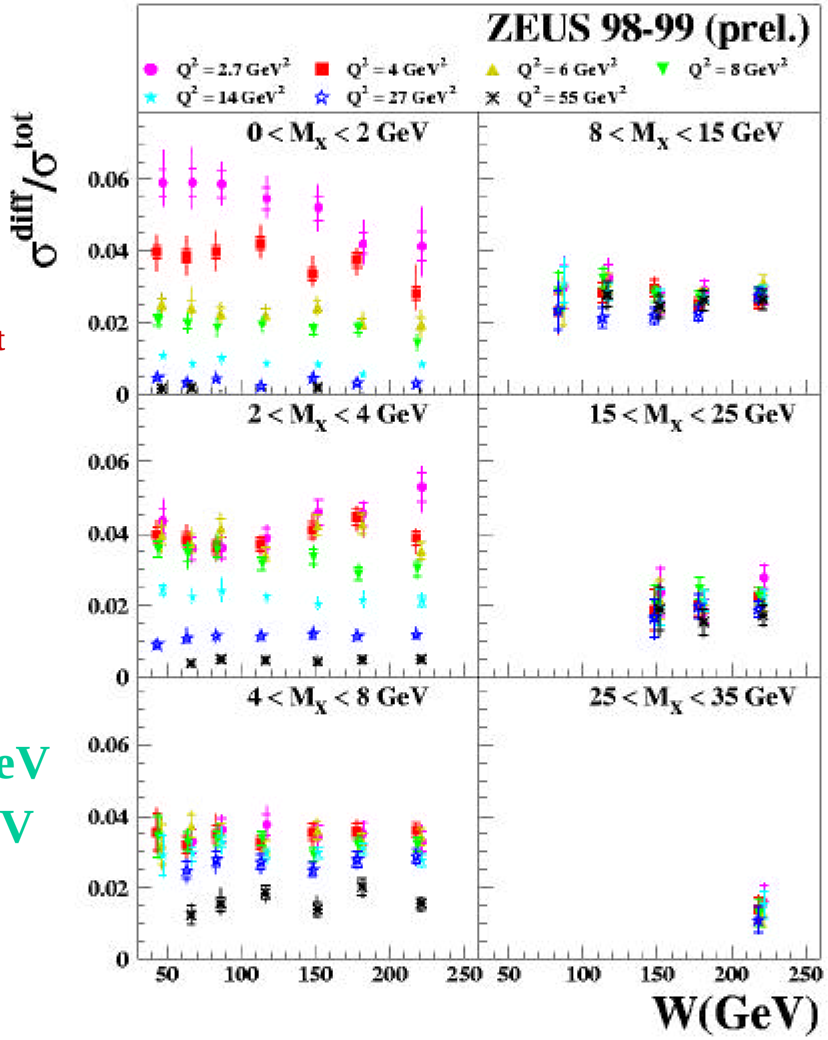
- **low M_X: strong decrease of s^{diff}/s^{tot} with increasing Q^2**
- **high M_X: no Q^2 dependence**

- at W=220 GeV:

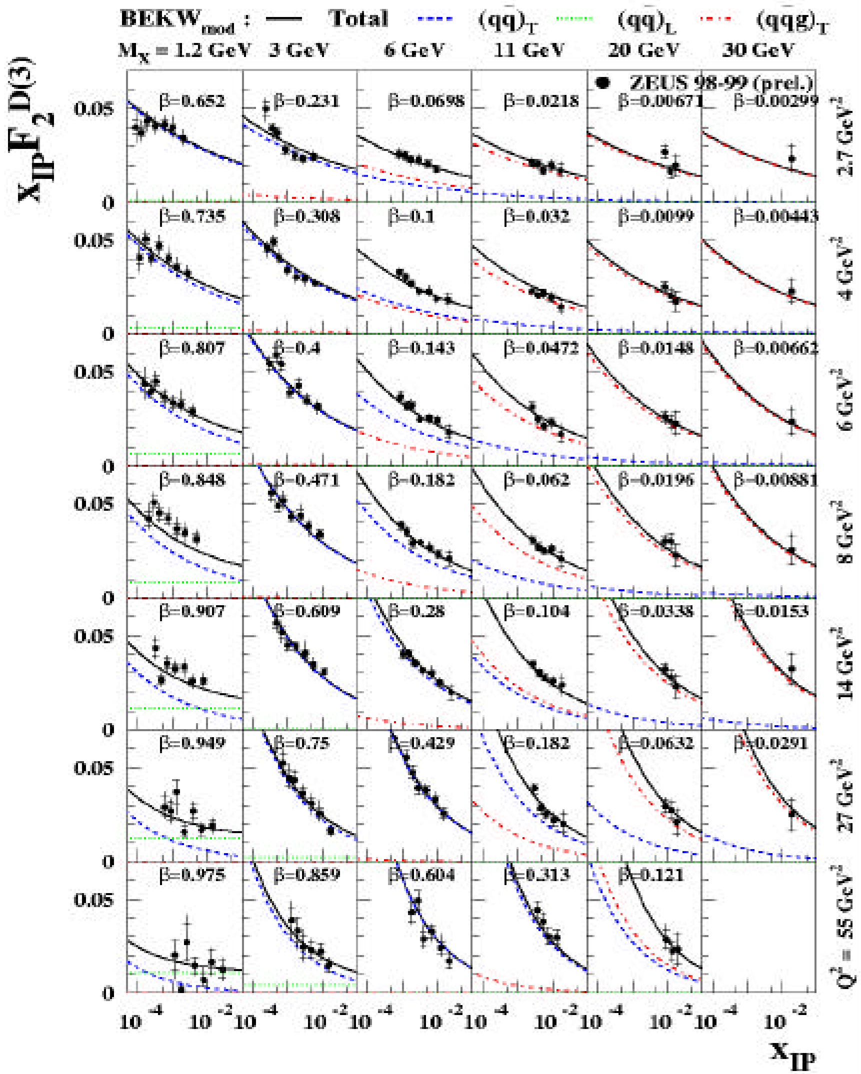
s^{diff}(M_X<35 GeV)/s^{tot} ~ 20 % Q^2= 2.7 GeV
~ 10 % Q^2= 27 GeV

For M_X>2 GeV:

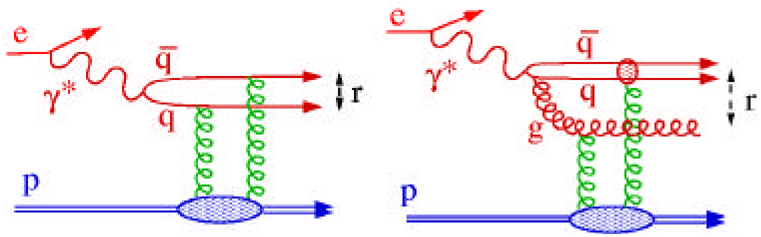
$\sigma^{diff}/\sigma^{tot}$ independent of W !



Comparison with BEKW model



Bartels, Ellis, Kowalski and Wüsthoff,



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

b, Q^2 dependence from photon wave function
x_{IP} dependence fitted to the data (***ZEUS fit ?***)

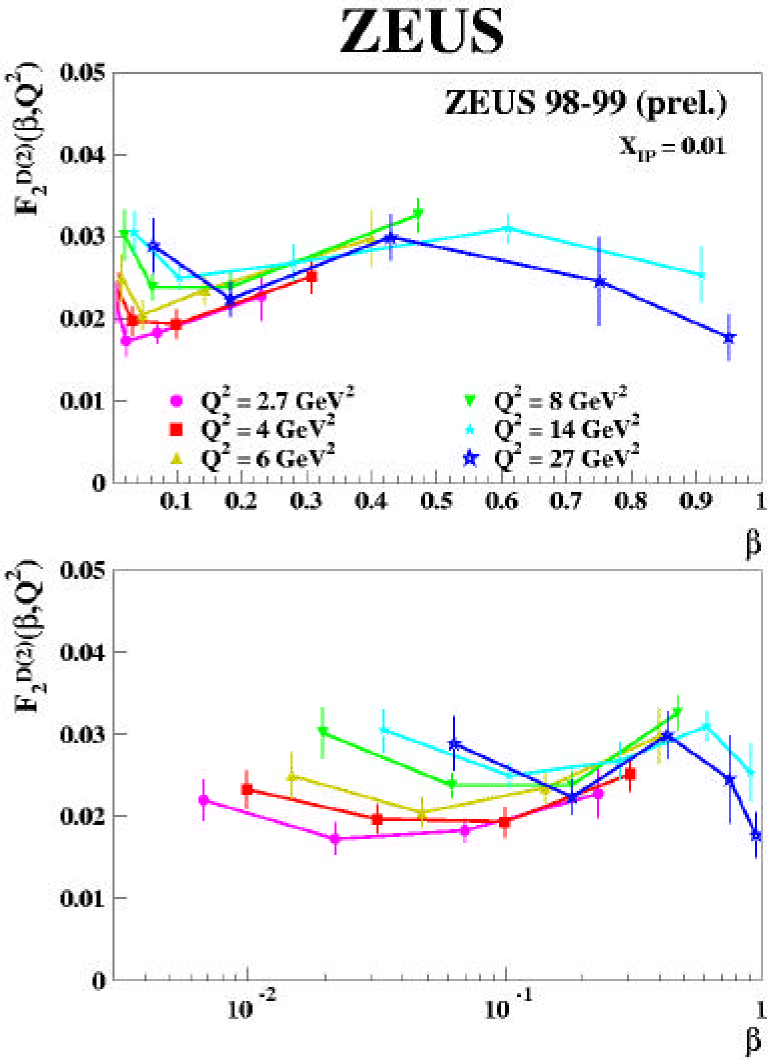
$$F_T^{q\bar{q}} \sim \left(\frac{x_0}{x_{IP}}\right)^{n_T(Q^2)} \beta(1-\beta) \leftarrow$$ **medium b**

$$F_L^{q\bar{q}} \sim \left(\frac{x_0}{x_{IP}}\right)^{n_L(Q^2)} \frac{Q_0^2}{Q^2} \cdot \beta^3(1-\beta)^2 \leftarrow$$ **high b**

$$F_T^{q\bar{q}g} \sim \left(\frac{x_0}{x_{IP}}\right)^{n_g(Q^2)} ln\left(1+\frac{Q^2}{Q_0^2}\right)(1-\beta)^\gamma \leftarrow$$ **small b**
(high Mx,small Q²)

$$n_L \simeq 0 \qquad n_T(Q^2) \simeq n_g(Q^2) \simeq n_1 \ln\left(\frac{Q^2}{Q_0^2}\right)$$

Pomeron structure function (M_X-method)



From the BEKW model:

$$F_2^{D(3)}(Q^2,\beta,x_{IP}) = f_{IP/p}(x_{IP},Q^2)\cdot F_2^{IP}(\beta,Q^2)$$

Parameterization of the flux factor: $$f_{IP/p} = \frac{C}{x_{IP}}\cdot\left(\frac{x_0}{x_{IP}}\right)^{n(Q^2)}$$

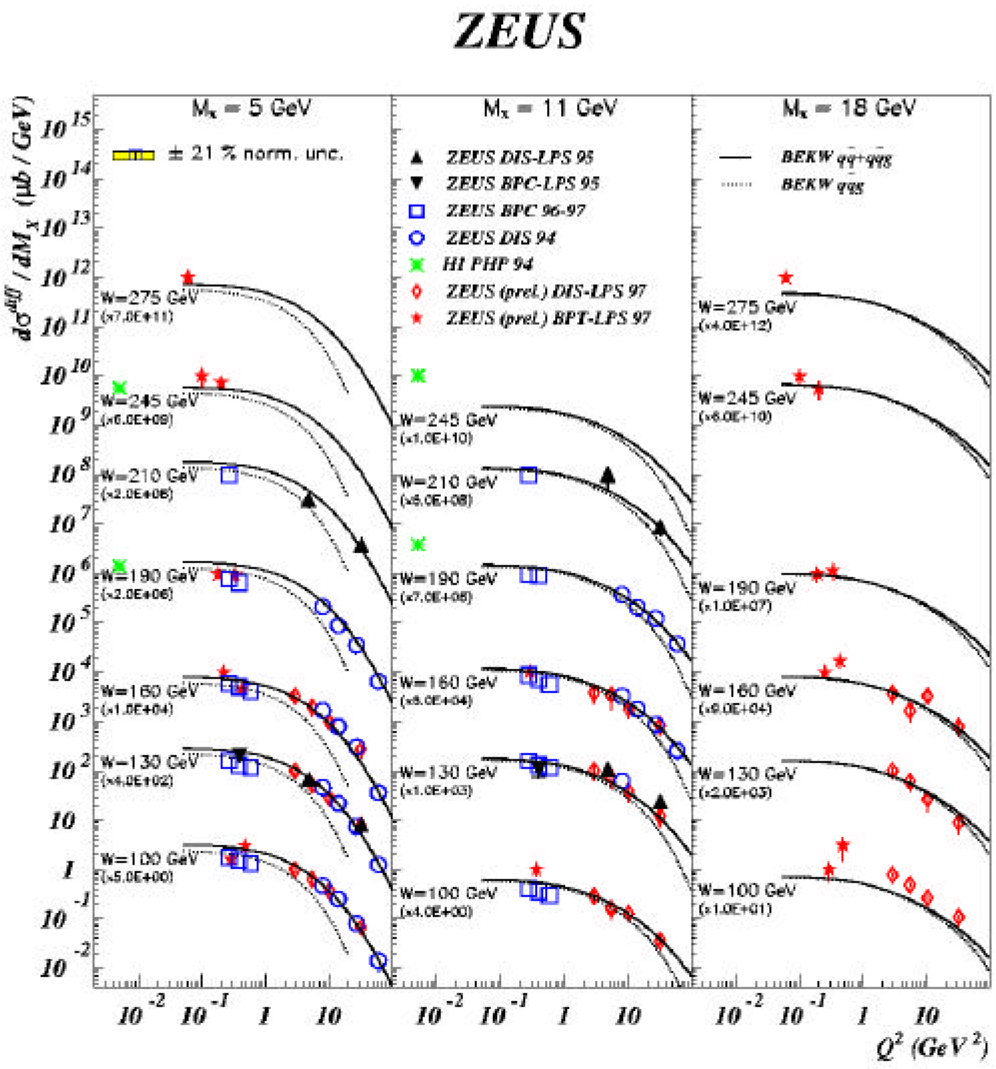
C=1 **x_0=0.01**

$$F_2^{IP}(\beta,Q^2) = x_{IP}F_2^{D(3)}(x_{IP},\beta,Q^2)|_{x_{IP}=x_0}$$

At low β, evidence for a rise of F_2^{IP} as Q^2 increases

indication of pQCD evolution

Diffractive cross section at low Q^2



New low Q^2 points at high M_X, high W

Transition to a constant cross section as $Q^2 \to 0$
(similar to what observed for the total cross section $\sigma^{\gamma^* p}$)

Main features of the data described by BEKW parameterization

g ® qqg fluctuations dominant at low Q^2

Conclusions

Diffractive cross section:

- **recent data from ZEUS with improved precision and extended kinematic range**
- ***W* dependence of diffractive and total cross section similar at high Q^2**
- **Q^2 dependence of the diffractive cross section softens considerably for $Q^2 \rightarrow 0$**
- **data described by the dipole model of BEKW**

Azimuthal asymmetry

- **indication that the interference between L and T photons is small at low β**