ZEUS F_2^D results

XIII International Workshop on Deep Inelastic Scattering
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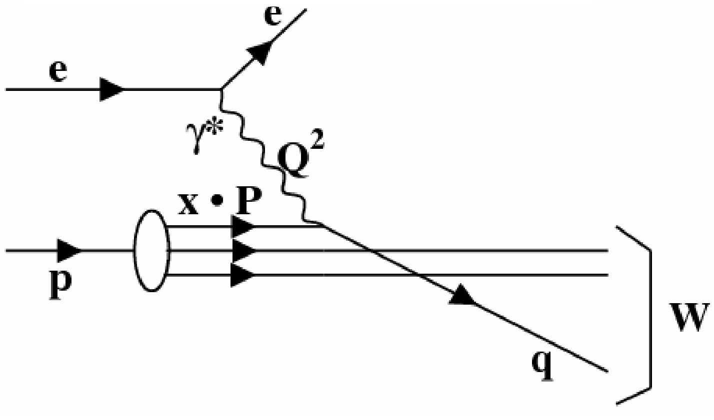
Heuijin Lim (DESY)
on behalf of the ZEUS Collaboration

- Introduction
- Diffractive measurement with **M_X method**
  - ➔ hep-ex/0501060 (Accepted by Nucl, Phys. **B**.)
- Diffractive measurement with **a leading proton**
  - ➔ Eur. Phys. J. **C 38**, 43 (2004) and also hep-ex/0408009
- Summary

Inclusive Diffraction in Deep Inelastic Scattering

Non-peripheral process



Kinematics of ep →eXp

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

$$W = \sqrt{(p+q)^2} \qquad M_X^2 = (k-k'+p-p')^2$$

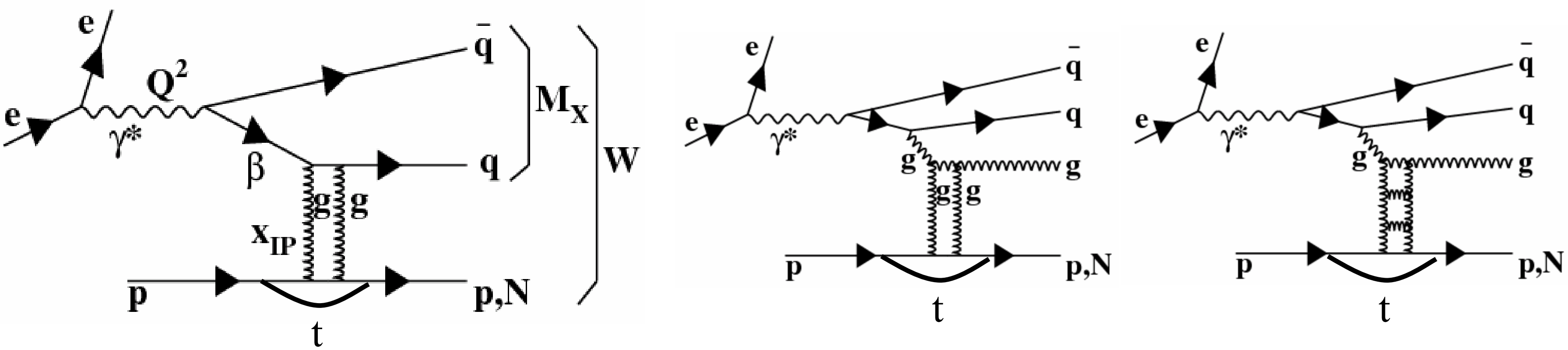
$$x_{IP} \approx \frac{Q^2+M_X^2}{Q^2+W^2} \qquad \beta \approx \frac{Q^2}{M_X^2+Q^2} = \frac{x}{x_{IP}}$$

$$t = (p-p')^2 \qquad x_L = p'_Z/E_p = 1 - x_{IP}$$

Present diffractive measurement in terms of

➔ $d\sigma(M_X,W,Q^2)/dM_X$ and $x_{IP}F_2^{D(3)}(\beta,x_{IP},Q^2)$

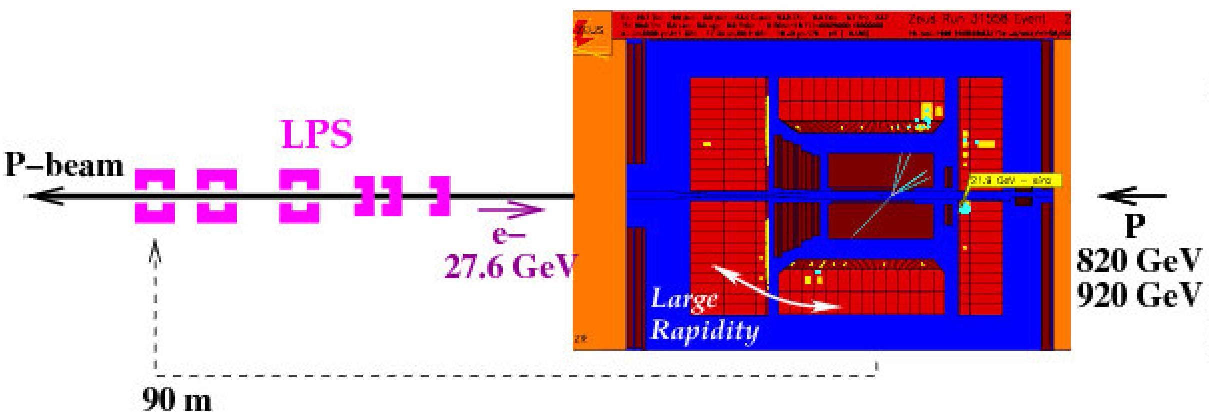
Diffractive process

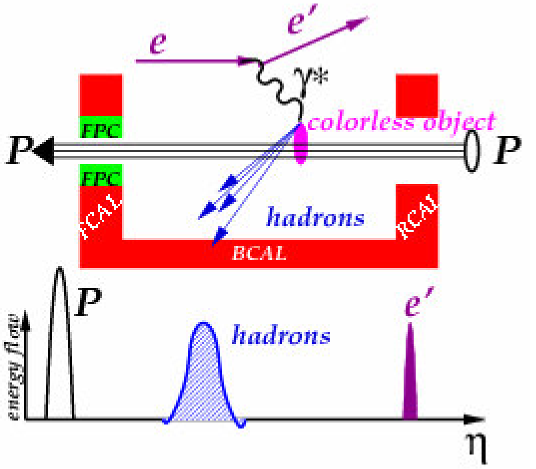


Event Topologies (ep → eXp)

Diffractive scattering

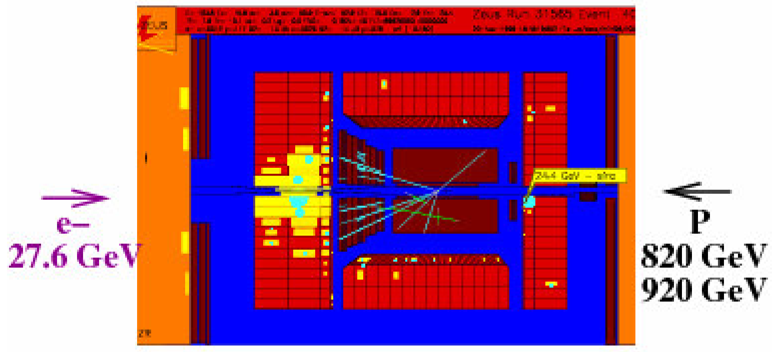
(M_X = 5 GeV, Q^2 = 19 GeV^2, W = 123 GeV)

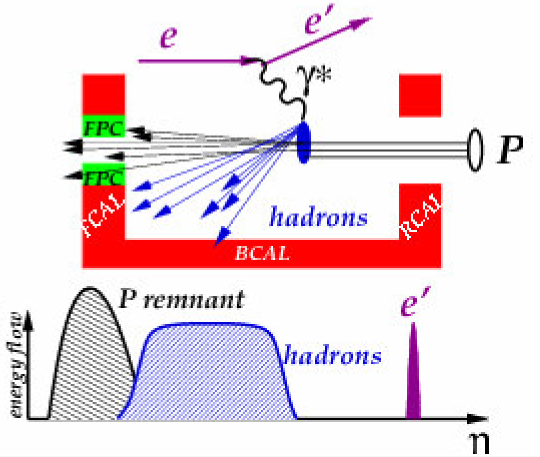




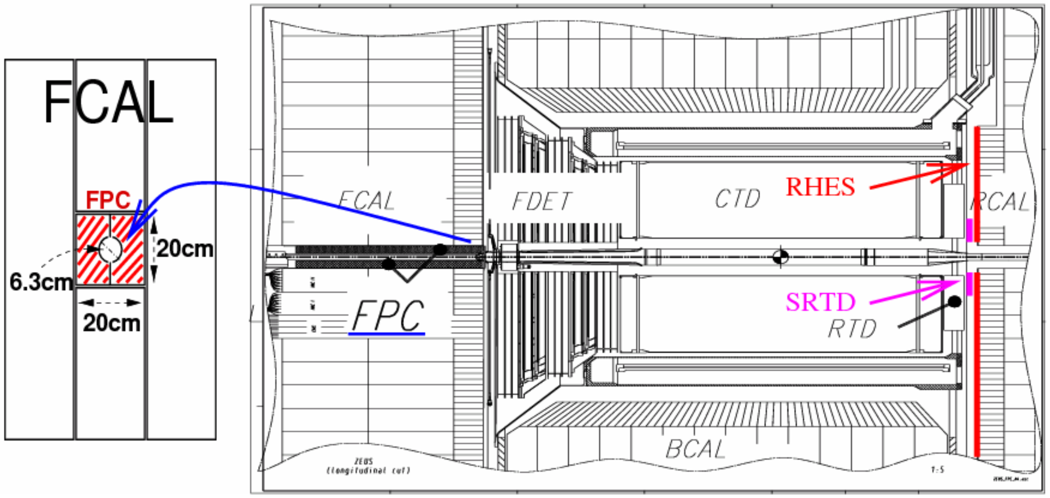
Non-peripheral scattering

(M_X = 45 GeV, Q^2 = 13 GeV^2, W = 93 GeV)





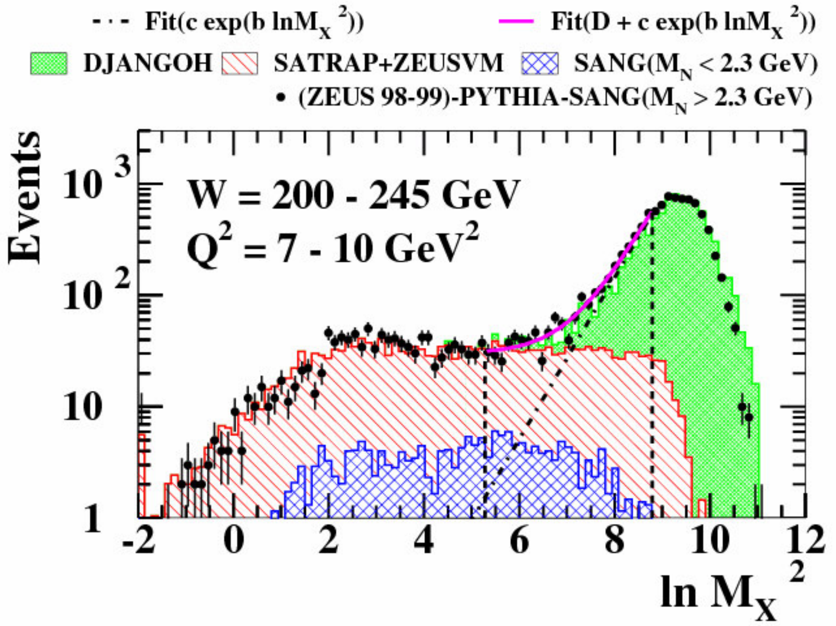
M_X method using Forward Plug Calorimeter



Forward Plug Calorimeter

✓ Increase the accessible M_X range by a factor of 1.7.

✓ If $M_N > 2.3$ GeV deposits $E_{FPC} > 1$GeV,
➔ recognized and rejected



$$\frac{dN}{d\ln M_X^2} = \underbrace{\boldsymbol{D}}_{\text{Diffraction}} + \underbrace{\boldsymbol{c}\cdot\exp(\boldsymbol{b}\cdot\ln M_X^2)}_{\text{Non-diffraction}}$$

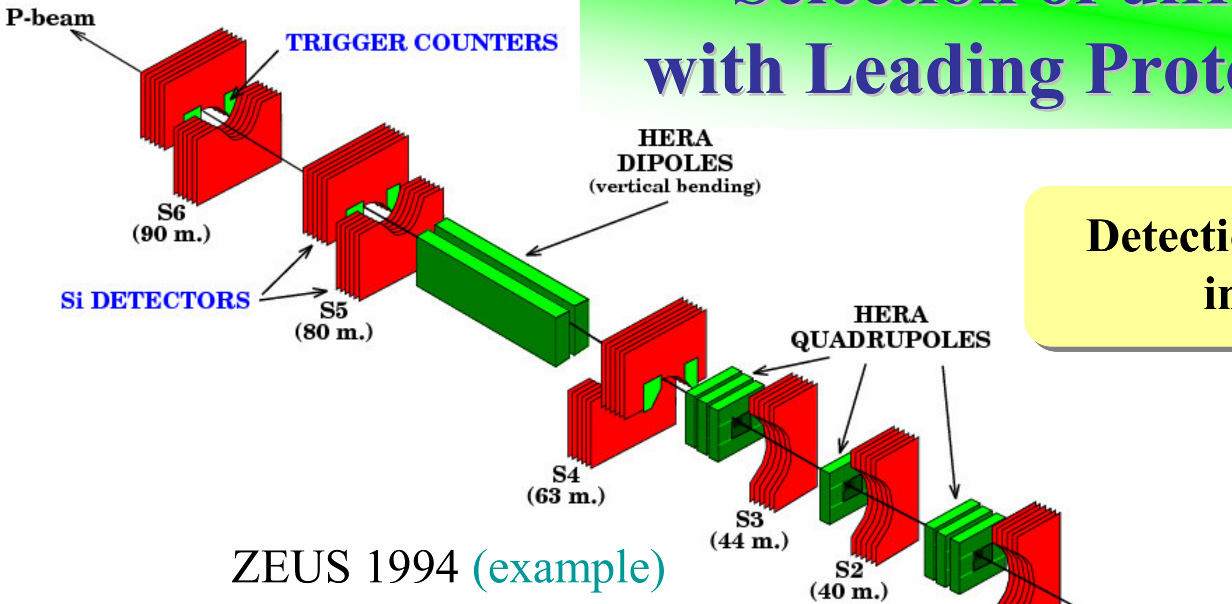
with free parameters, ***D***, ***b*** and ***c*** from fit.

$d\sigma^{diff}_{\gamma^* p\to XN}/dM_X,\ M_N < 2.3\,\mathrm{GeV}$

- $2.2 < Q^2 < 80$ GeV^2
- $37 < W < 245$ GeV
- $0.28 < M_X < 35$ GeV

Using 98-99 data
with 4.2 pb^{-1}

Selection of diffractive events with Leading Proton Spectrometer

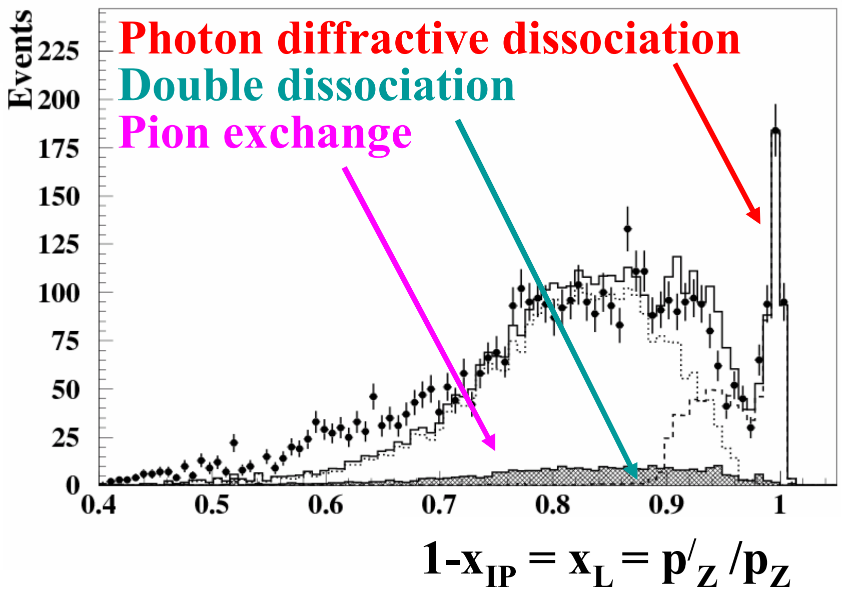


Detection of the scattered proton in LPS with $x_L > 0.9$.

✓ No background from proton dissociation.

✓ Limited statistics due to geometrical acceptance.

ZEUS 1994 (example)



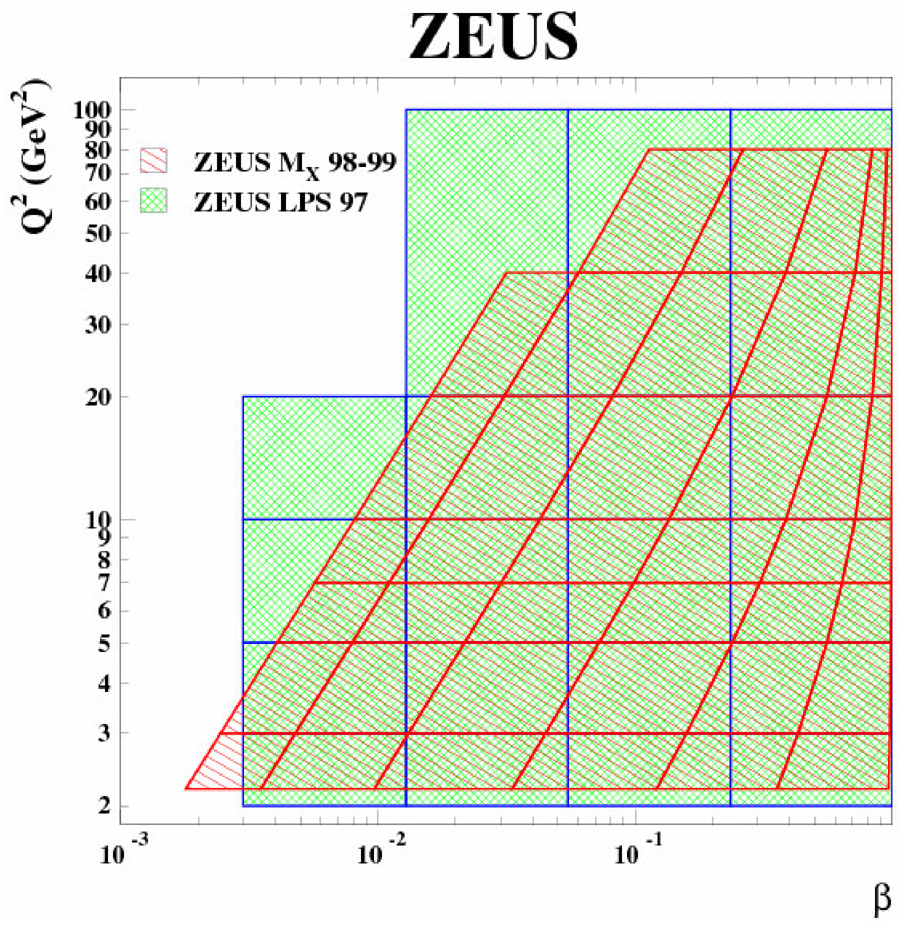
$1\text{-}x_{IP} = x_L = p'_Z / p_Z$

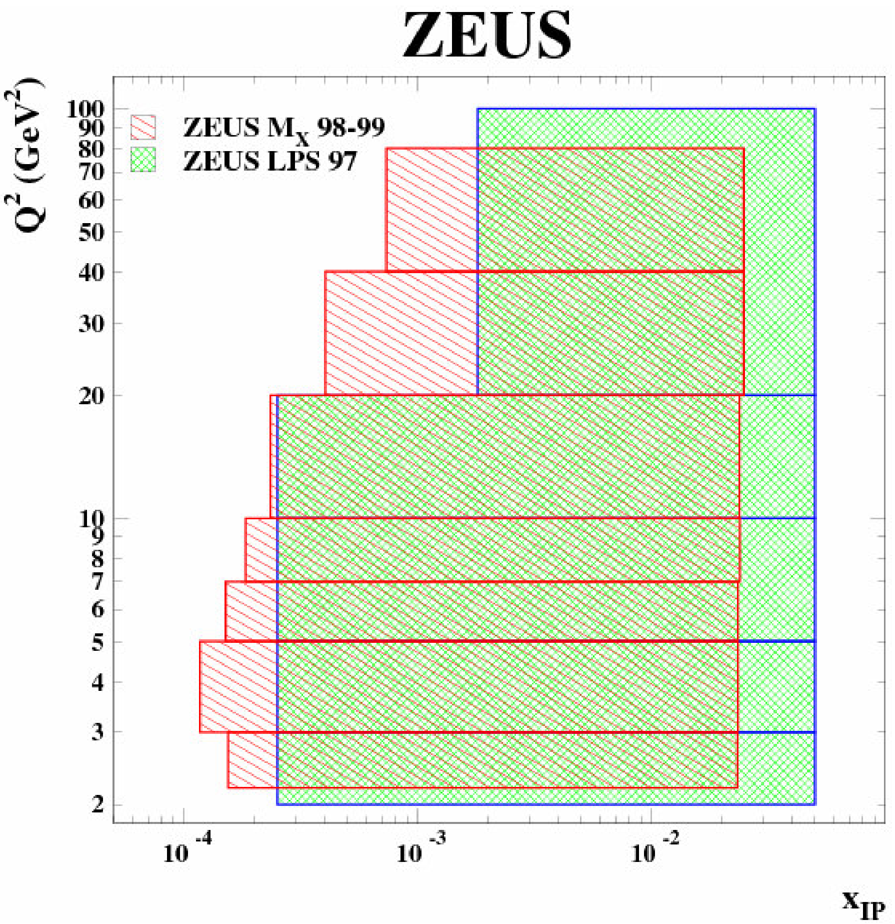
$d\sigma^{diff}_{\gamma^* p \to XN} / dM_X dt$

Using 97 data

- $0.03 < Q^2 < 0.60$ GeV^2 → 3.6 pb^{-1}
  $2 < Q^2 < 100$ GeV^2 → 12.8 pb^{-1}
- $25 < W < 280$ GeV
- $1.5 < M_X < 70$ GeV
- $0 < |t| < 1$ GeV^2

Kinematical ranges





- **M_X method** **:** Lower M_X region (~ higher β region) and lower x_{IP} region.
- **LPS method :** Higher x_{IP} region

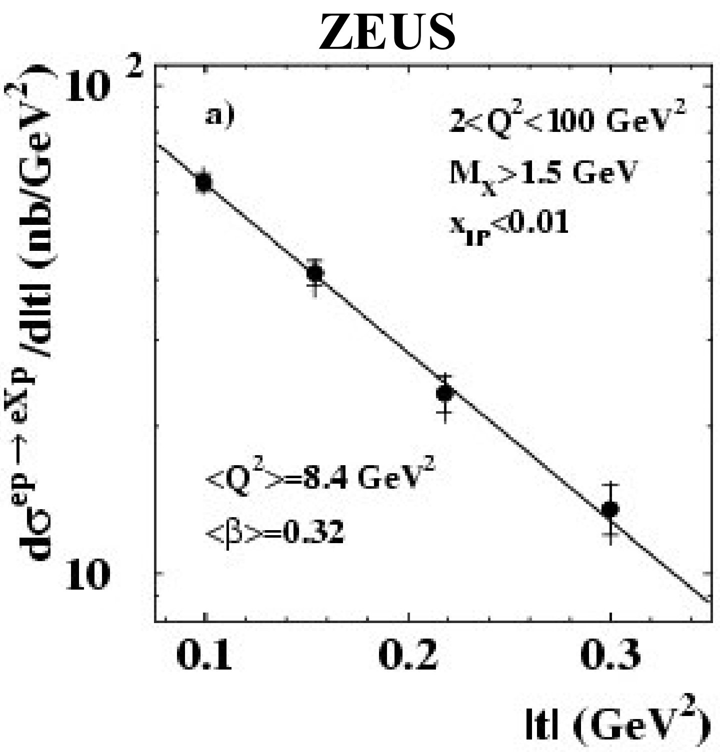
Diffractive Cross Section

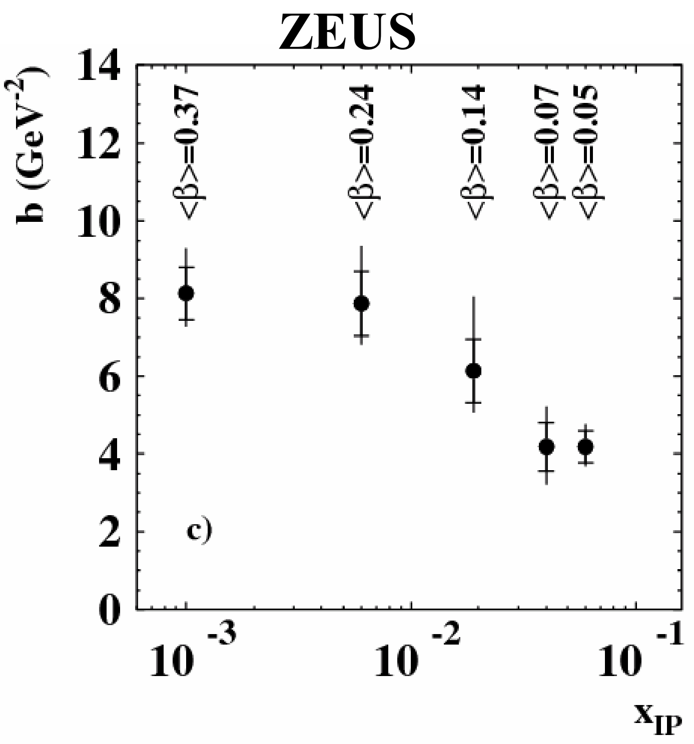
- t dependence
- W dependence
  - → $\alpha_{IP}^{diff}(0)$
- M_X dependence
- $\sigma^{diff}/\sigma^{tot}$

Diffractive Structure Function

- x_{IP} dependence
  - → Q^2 dependence
- Comparison with theory
- β dependence

t dependence of Diffractive Cross Section (LPS)





- Fit t distribution to $d\sigma/d|t| \propto \exp(-b|t|)$

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

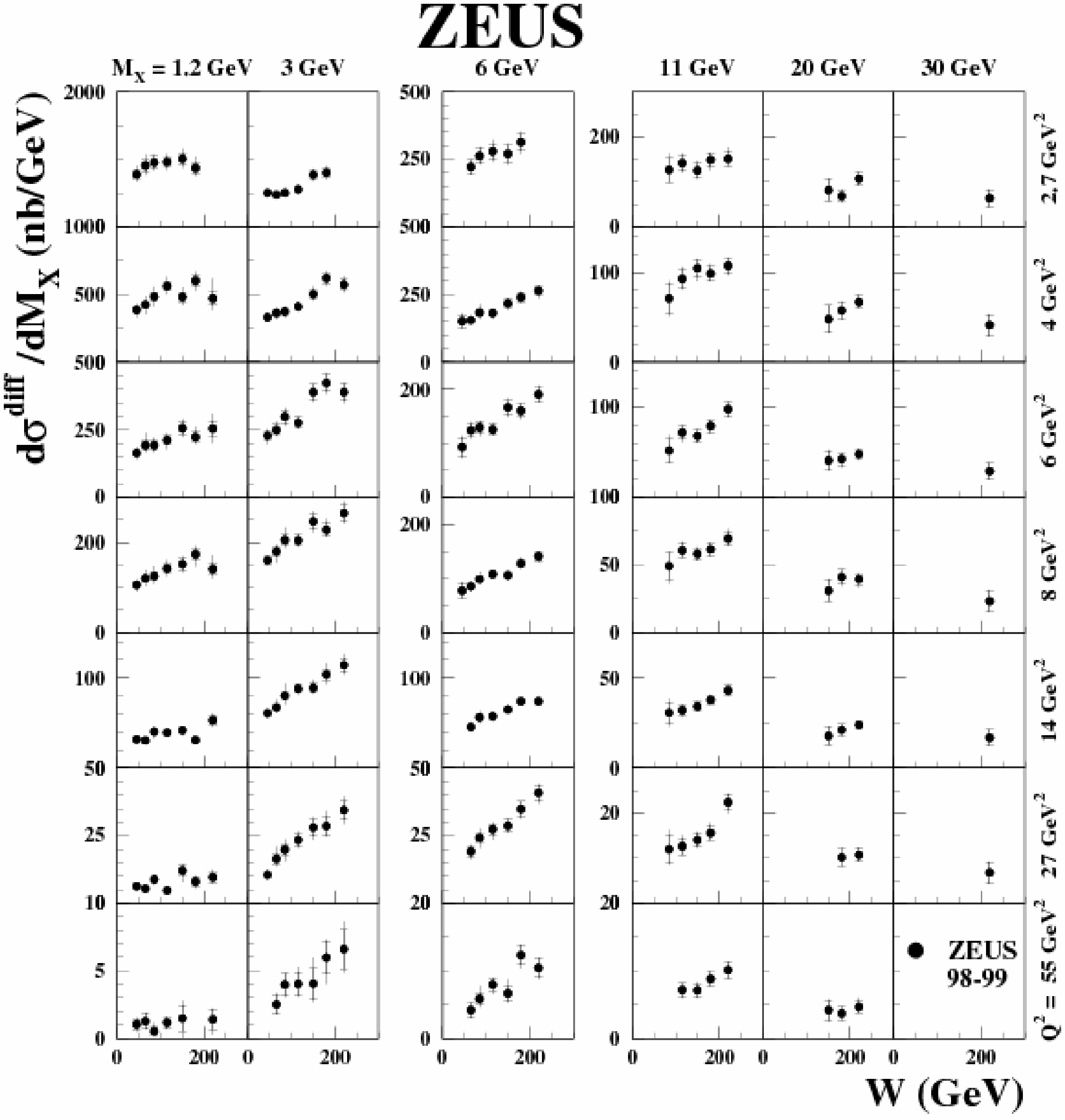
➔ dσ/d|t| shows steep fall-off with t as in elastic hadron-hadron scattering.

- Regge phenomenology predicts "shrinkage" of the diffractive peak:

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

- Additional β dependence expected in models.

Diffractive Cross Section (M_X)

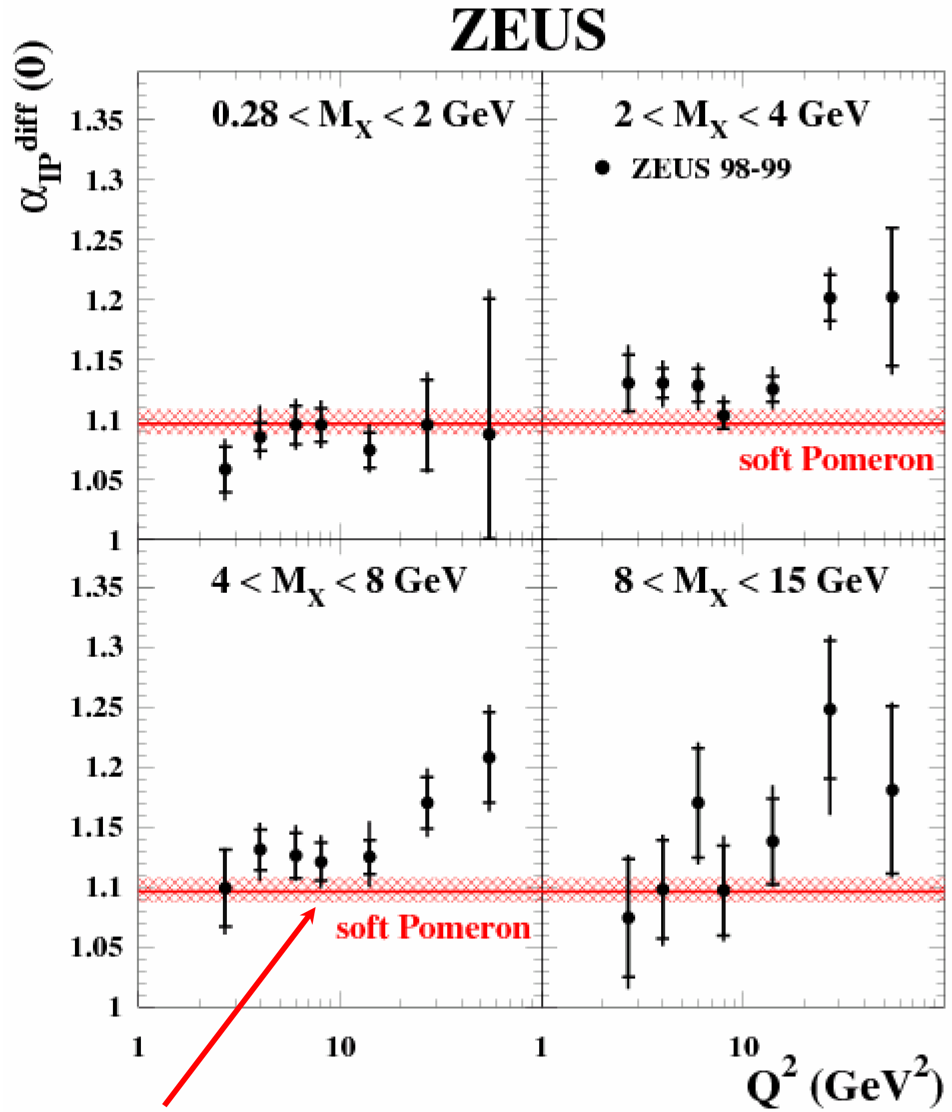


$d\sigma^{diff}_{\gamma^* p \to XN}/dM_X, M_N < 2.3\,\text{GeV}$

- **For $M_X < 2$ GeV,**
  $d\sigma/dM_X$ depends weakly on W.

- **For $M_X > 2$ GeV,**
  $d\sigma/dM_X$ rises rapidly with W.

W dependence of Diffractive Cross Section



$\alpha_{IP}^{soft}(0) = 1.096^{+0.012}_{-0.009}$ from had-had scattering

- **Fit to the diffractive cross section :**

$$\frac{d\sigma^{diff}_{\gamma^* p \to XN}}{d M_X} = h \cdot W^{a^{diff}} \sim (W^2)^{(2\overline{\alpha_{IP}}-2)}$$

(h, a^{diff} free parameters)

Assuming $d\sigma/dt \propto e^{b \cdot t}$ and

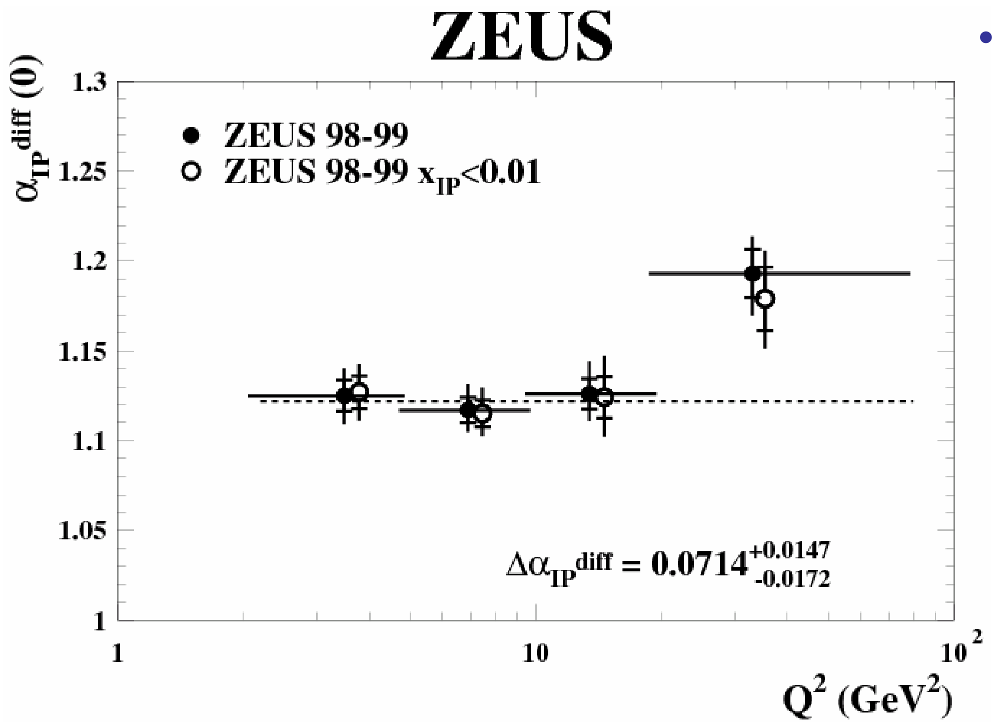
$$\alpha_{IP}(t) = \alpha_{IP}(0) + \alpha'_{IP} \cdot t$$

$$\therefore \alpha_{IP}(0) = \overline{\alpha_{IP}} + \underline{\alpha'_{IP}/b} \approx (a^{diff}/4 + 1) + \underline{0.03}$$

from **LPS**

- **For M$_X$<2 GeV**
  ➔ $\alpha_{IP}^{diff}(0)$ compatible with the soft Pomeron.
- **For larger M$_X$ and Q² > 20 GeV²**
  ➔ $\alpha_{IP}^{diff}(0)$ lies above the results expected from soft Pomeron and increases with Q².

Q^2 dependence of $\alpha_{IP}^{diff}(0)$



- Fit to data with $2 < M_X < 15$ GeV

$$\Delta\alpha_{IP}^{diff} \equiv \alpha_{IP}^{diff}(0; 2.7 < Q^2 < 20\,\text{GeV}^2) - \alpha_{IP}^{diff}(0; 20 < Q^2 < 80\,\text{GeV}^2)$$
$$= 0.0714 \pm 0.0140(\text{stat.})^{+0.0047}_{-0.0100}(\text{syst.})$$

✓ $\alpha_{IP}^{diff}(0)$ is rising with Q^2, with a significance of 4.2 s.d.
✓ Assuming single Pomeron exchange, this observation contradicts Regge factorisation.

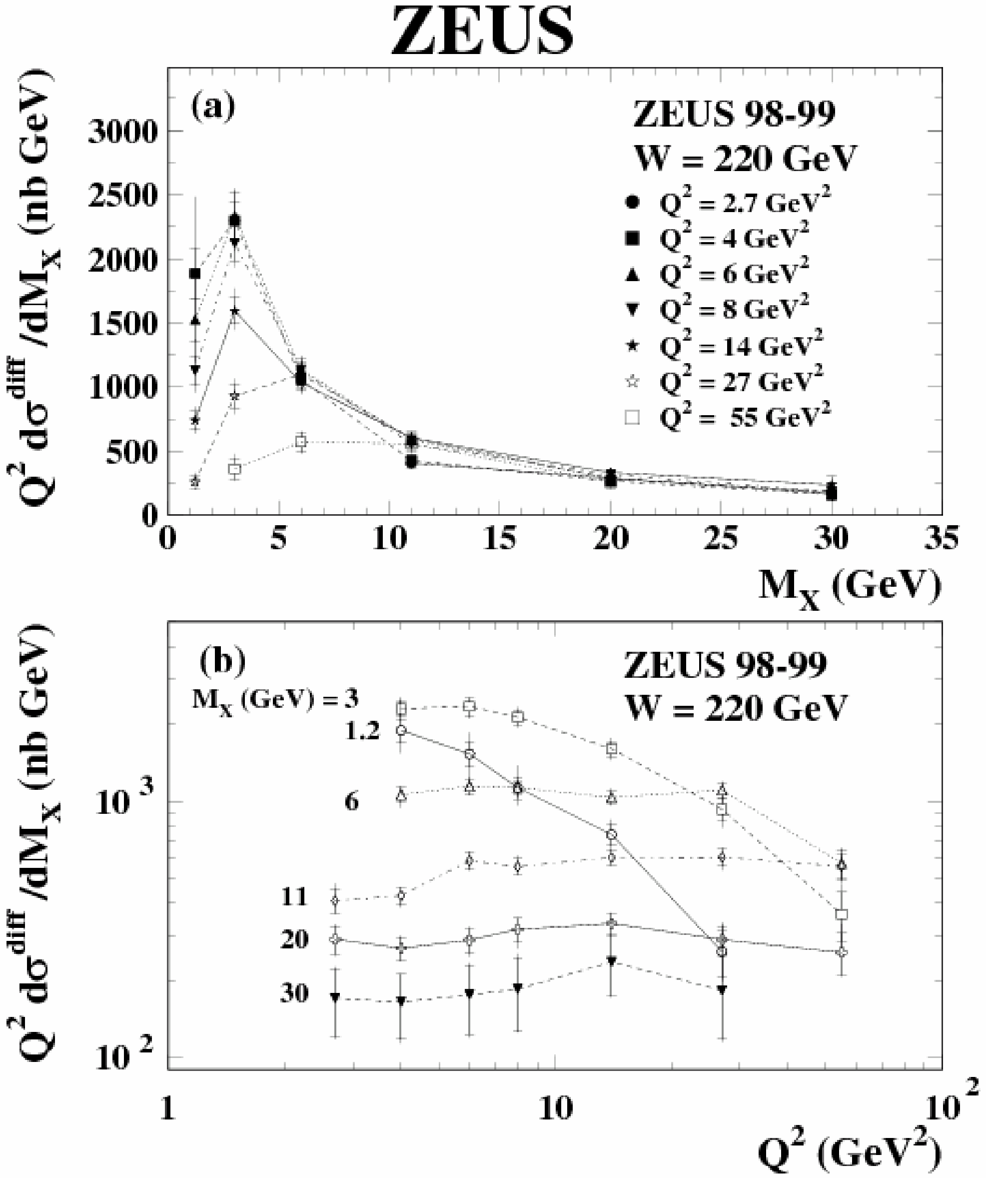
- Fit to data with $2 < M_X < 15$ GeV and $x_{IP} < 0.01$

$$\alpha_{IP}^{diff}(0; 2.7 < Q^2 < 20\,\text{GeV}^2) = 1.1209 \pm 0.0051(\text{stat.})^{+0.0136}_{-0.0122}(\text{syst.})$$

$\Delta\alpha_{IP}^{diff} \equiv 0.0578 \pm 0.0178(\text{stat.})^{+0.0081}_{-0.0118}(\text{syst.})$ ← Affected from the limited x_{IP} range.

➔ Consistent with LPS $\alpha_{IP}^{diff}(0; 0.03 < Q^2 < 39\,\text{GeV}^2) = 1.16 \pm 0.02(\text{stat.}) \pm 0.02(\text{syst.})$

M_X dependence of diffractive cross section

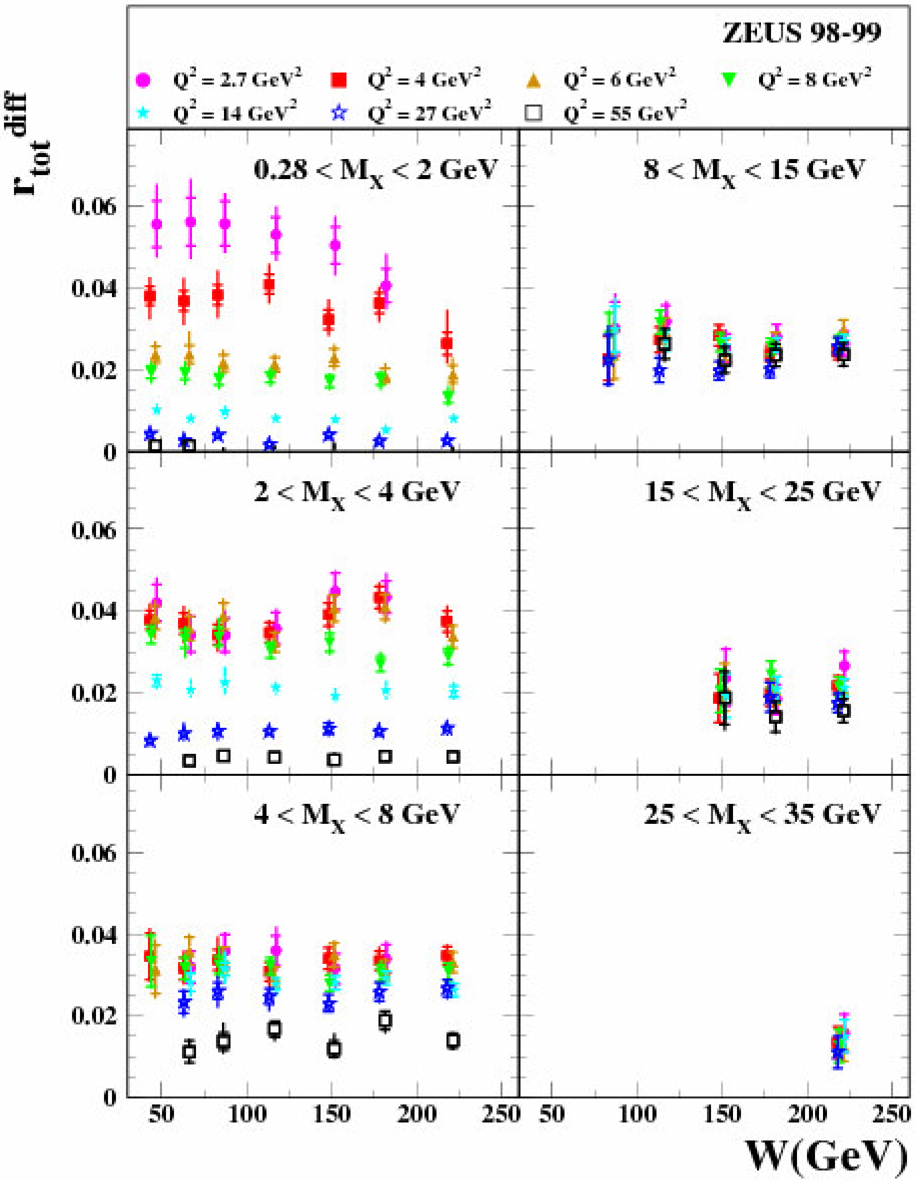


$$Q^2 \cdot \frac{d\sigma^{diff}_{\gamma^* p \to XN}}{dM_X} \quad \text{vs. } M_X \text{ at } W = 220\,\text{GeV}$$

- **For $M_X < 4$ GeV,**
  rapid decrease with Q^2.
  ➔ predominantly higher twist.

- **For $M_X > 10$ GeV,**
  constant or slow rise with Q^2
  ➔ leading twist.

Diffractive contribution of the total cross section



$$r_{tot}^{diff} = \frac{\int_{M_a}^{M_b} dM_X d\sigma^{diff}_{\gamma^* p \to XN, M_N < 2.3\,GeV} / dM_X}{\sigma^{tot}_{\gamma^* p}}$$

- For $M_X < 2$ GeV, falling with W.
- For $M_X > 2$ GeV, constant with W.

- For $M_X < 2$ GeV, decreasing with rising Q^2.
- For $M_X > 8$ GeV, no Q^2 dependence.

➔For larger M_X, σ^{diff} has the similar W and Q^2 dependences as σ^{tot}.

- For the highest W bin (200<W<245 GeV), **σ^{diff} (0.28<M_X<35 GeV, M_N<2.3 GeV) /σ^{tot}**

$$15.8^{+1.2}_{-1.0}\,\% \quad \text{at}\ Q^2 = 4\,GeV^2$$

$$9.6^{+0.7}_{-0.7}\,\% \quad \text{at}\ Q^2 = 27\,GeV^2$$

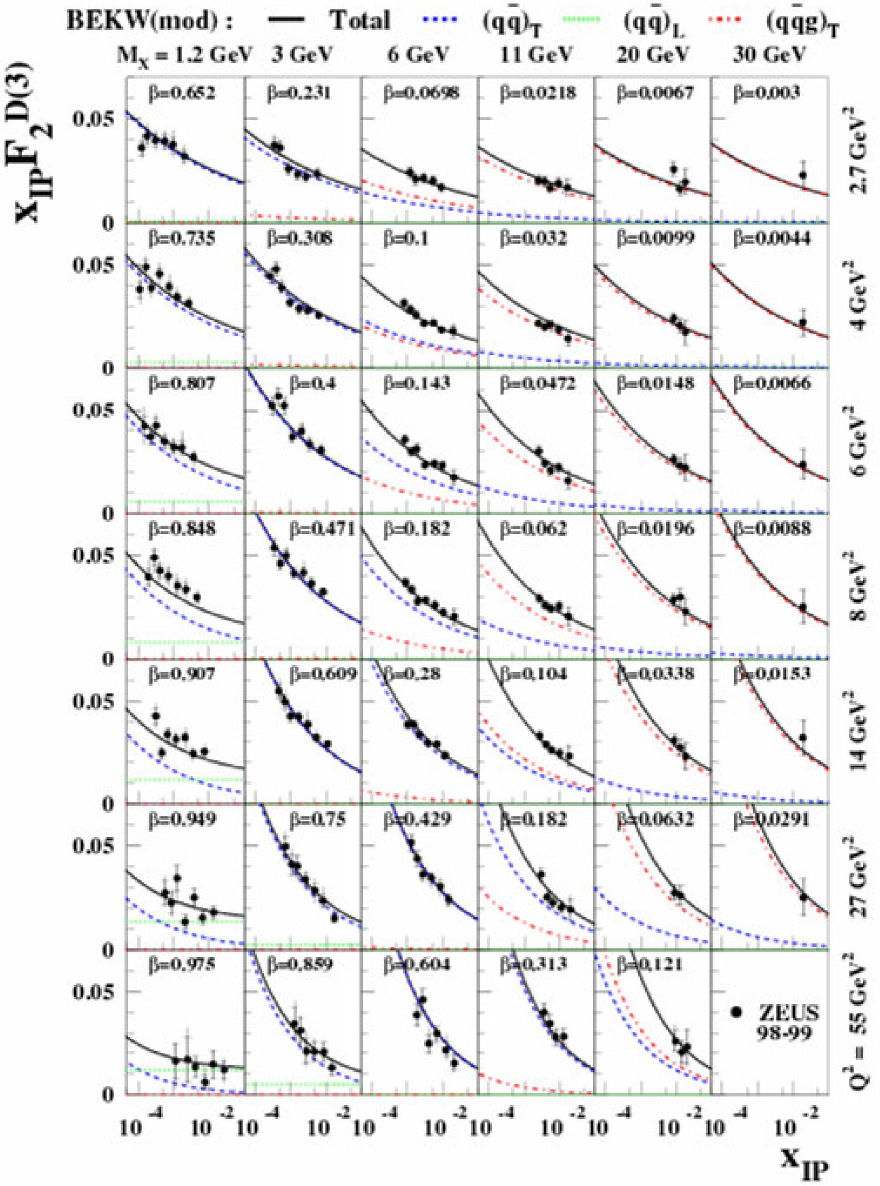
Diffractive Cross Section

- t dependence
- W dependence
  → $\alpha_{IP}^{diff}(0)$
- M_X dependence
- $\sigma^{diff}/\sigma^{tot}$

Diffractive Structure Function

- x_{IP} dependence
  → Q^2 dependence
- Comparison with theory
- β dependence

Diffractive structure function of the proton

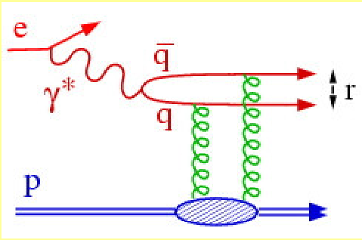


- **For $M_X < 2$ GeV,**
  $x_{IP}F_2^{D(3)}$ is constant with x_{IP}.
- **For $M_X > 2$ GeV,**
  rapid increase as x_{IP} → 0.

- Data are compared with the color dipole model in BEKW parametrisation.

(Bartels, Ellis, Kowalski and Wüsthoff)

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

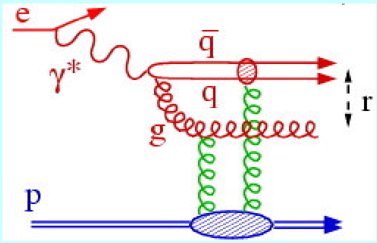


$F_{q\bar{q}}^T \propto \beta(1-\beta)$

dominates at β > 0.15

$F_{q\bar{q}}^L \propto \beta^3(1-2\beta)^2$

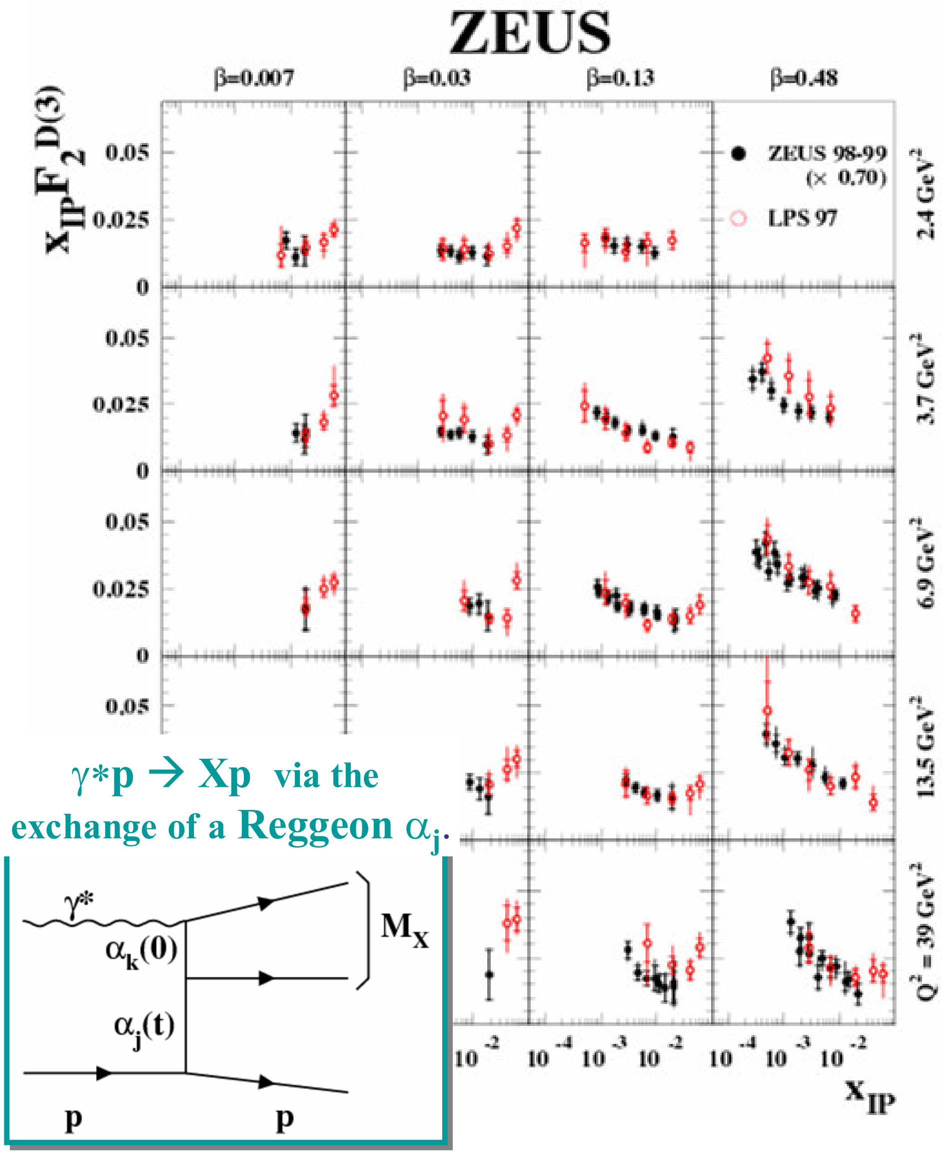
substantial at large β



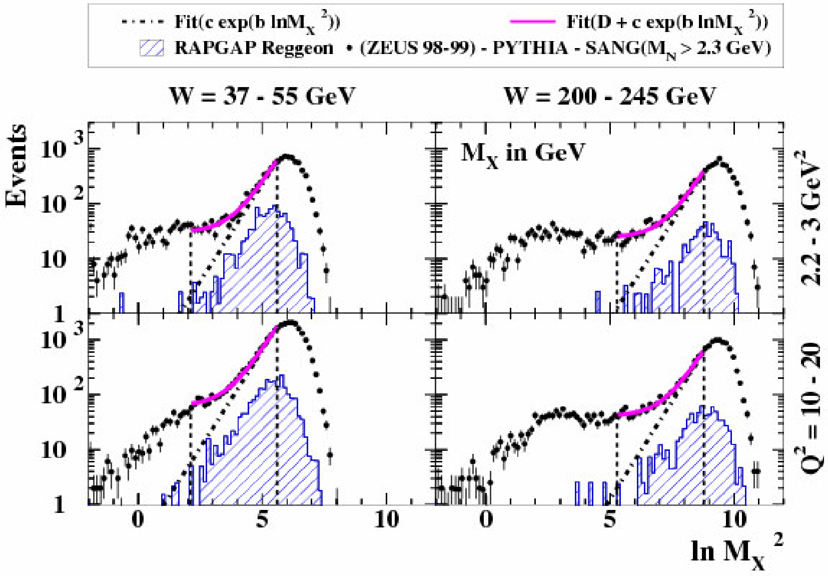
$F_{q\bar{q}g}^T \propto (1-\beta)^\gamma$

dominates at small β

Comparison of LPS and M_X method



$\gamma^*p \rightarrow Xp$ via the exchange of a Reggeon α_j.

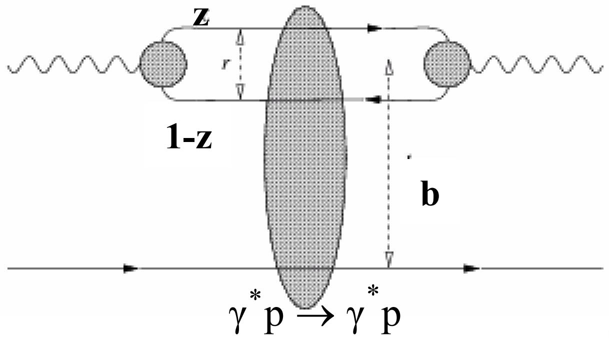


$$\frac{d\sigma^{\mathrm{Reggeon}}_{\gamma^* p\rightarrow XN}}{d\ln M_X^2} \propto \exp\left|(1+\alpha_k(0)-2\bar{\alpha}_j)\cdot \ln M_X^2\right|$$

$$\propto \exp(b_{IR}\cdot \ln M_X^2) \text{ with } b_{IR}=1$$

- M_X method suppresses the Reggeon contributions.
- Good agreement between LPS and M_X method ($\times 0.7$ for $M_N < 2.3$ GeV) except for the region of $x_{IP} > 0.01$ where Reggeon contributions may dominate LPS.

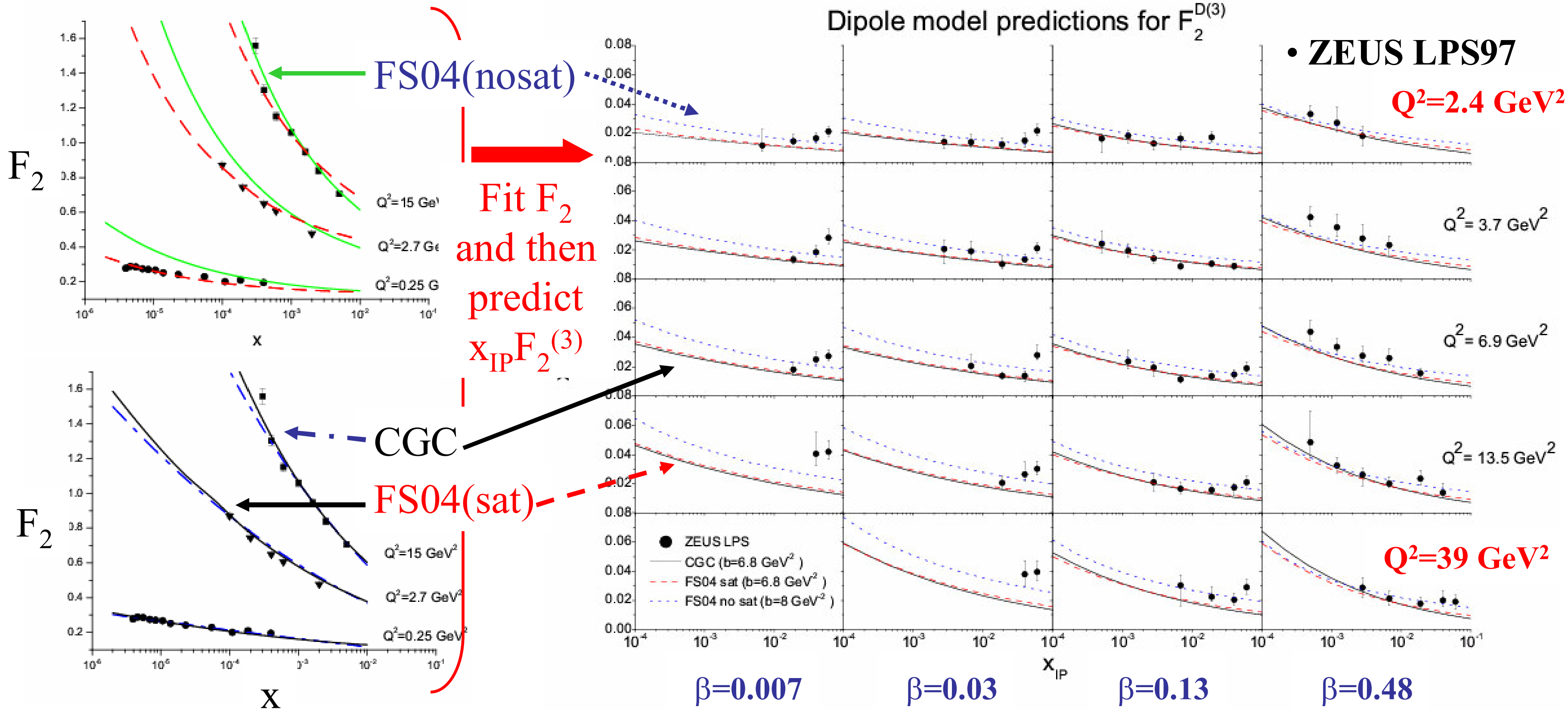
Comparison with Colour Dipole Model - I



J.D. Bjorken, M. Mistry, J. Kogut, D. Soper, N.N. Nikolaev, B.G.Zakharov, M. Genovese, M. Bertini, A.H. Mueller, K. Golec-Biernat, M. Wüsthoff, H. Kowalski, A. Stasto, J. R. Forshaw, G. Kerley, G. Shaw, E. Iancu, K. Itakura, S. Munier ......

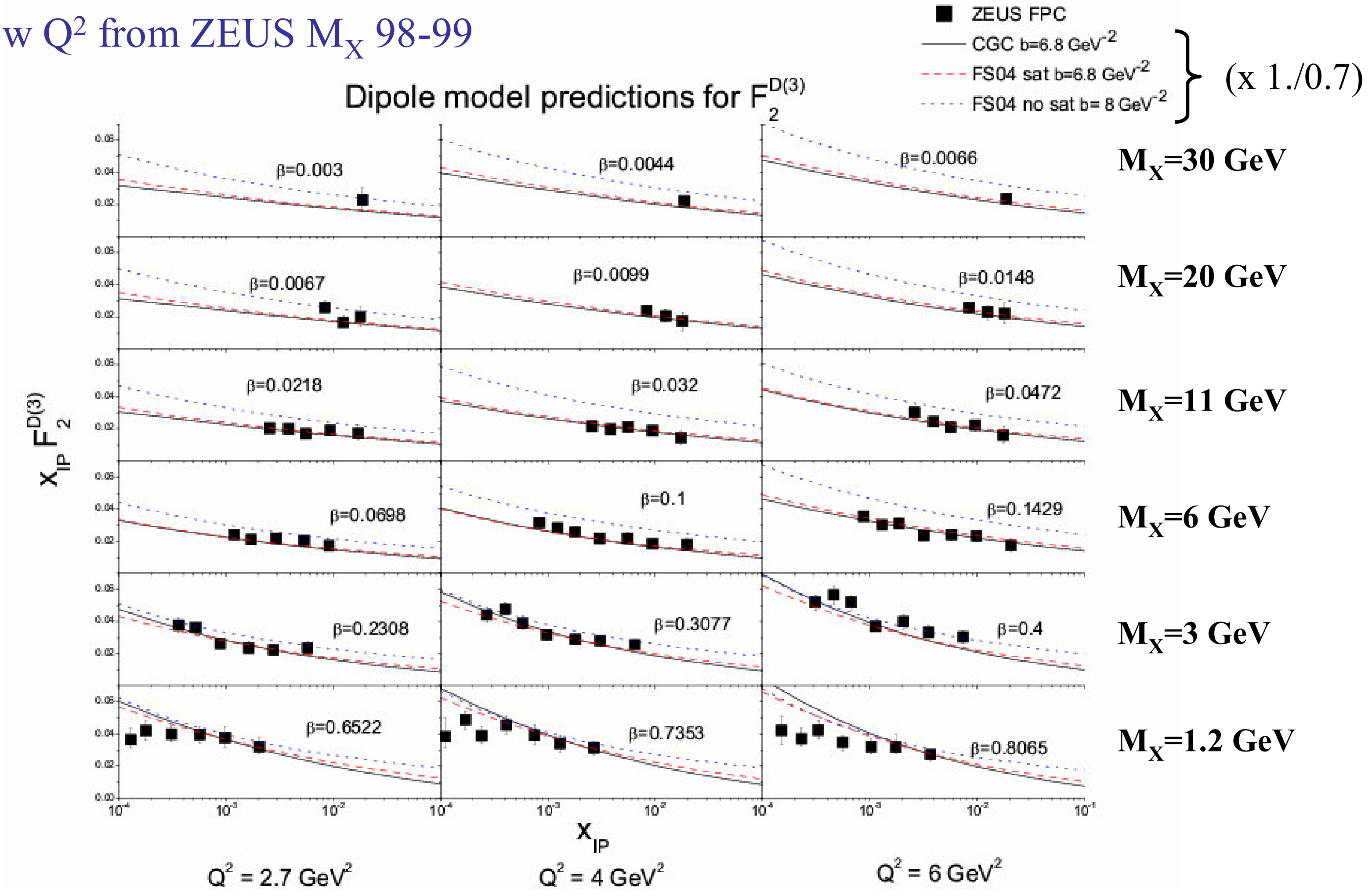
Comparison with **FS04(Forshaw & Shaw) Regge dipole model with/without saturation** and **CGC(Colour Glass Condensate) model** → Refer to hep-ph/0411337.

Thanks to J. Forshaw.



Comparison with Colour Dipole Model - II

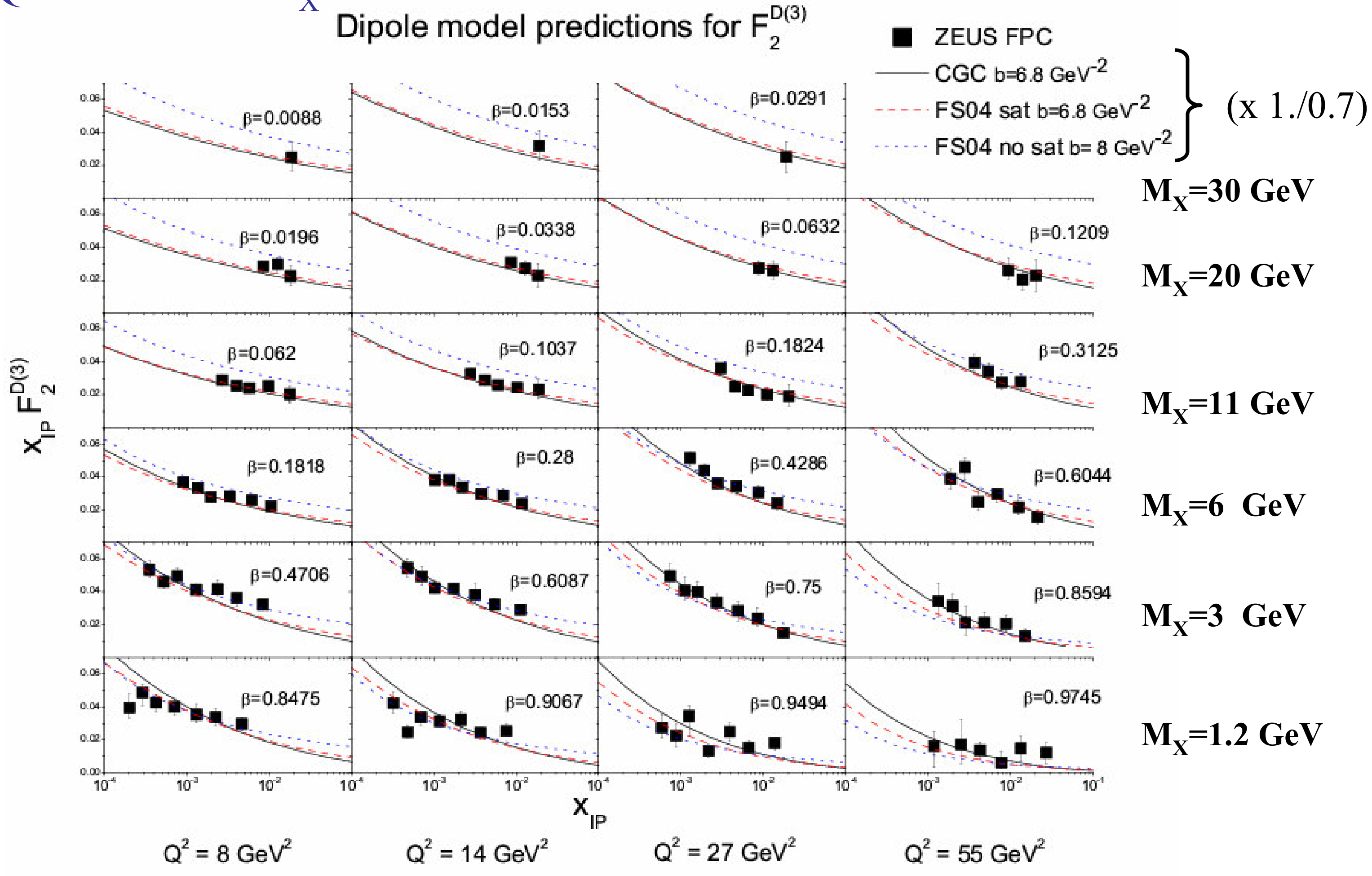
Low Q^2 from ZEUS M_X 98-99



➔ Predictions of model are corrected by 1/0.7 for the M_N<2.3 GeV of ZEUS M_X method.

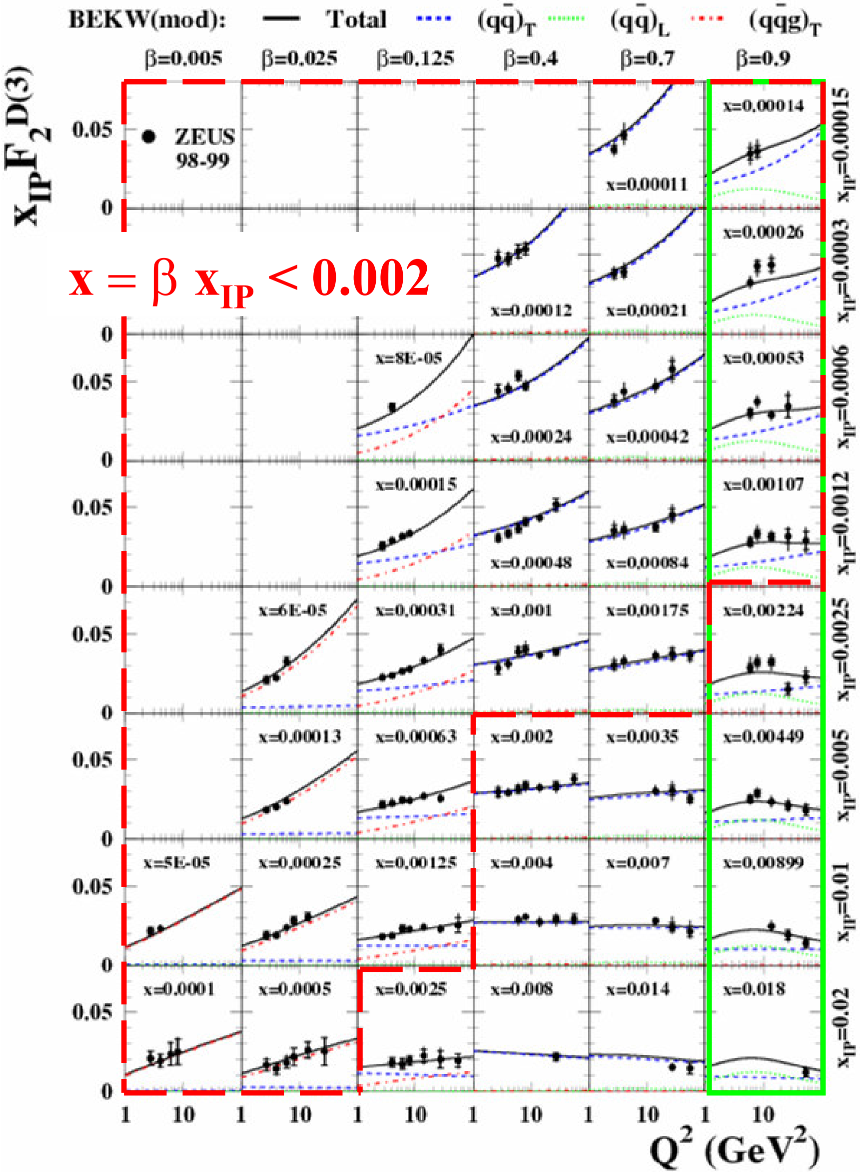
Comparison with Colour Dipole Model - III

High Q^2 from ZEUS M_X 98-99



- CGC and FS04(sat) are able simultaneously to describe F_2 and $x_{IP}F_2D^{(3)}$.
- Forshaw & Shaw have not been able to find a good fit which does not invoke saturation.

Q^2 dependence of $x_{IP}F_2^{D(3)}$



- **For β=0.9**

  (dominated events with $M_X < 2$ GeV),

  ➔ Constant or slowly decreasing with Q^2.

  Expect higher twist effect from $(q\bar{q})_L$.

- For β <= 0.7 and **$x=\beta\ x_{IP} < 0.002$,**

  $x_{IP}F_2^{D(3)}$ increases with increasing Q^2.

  ➔ **Positive scaling violations.**

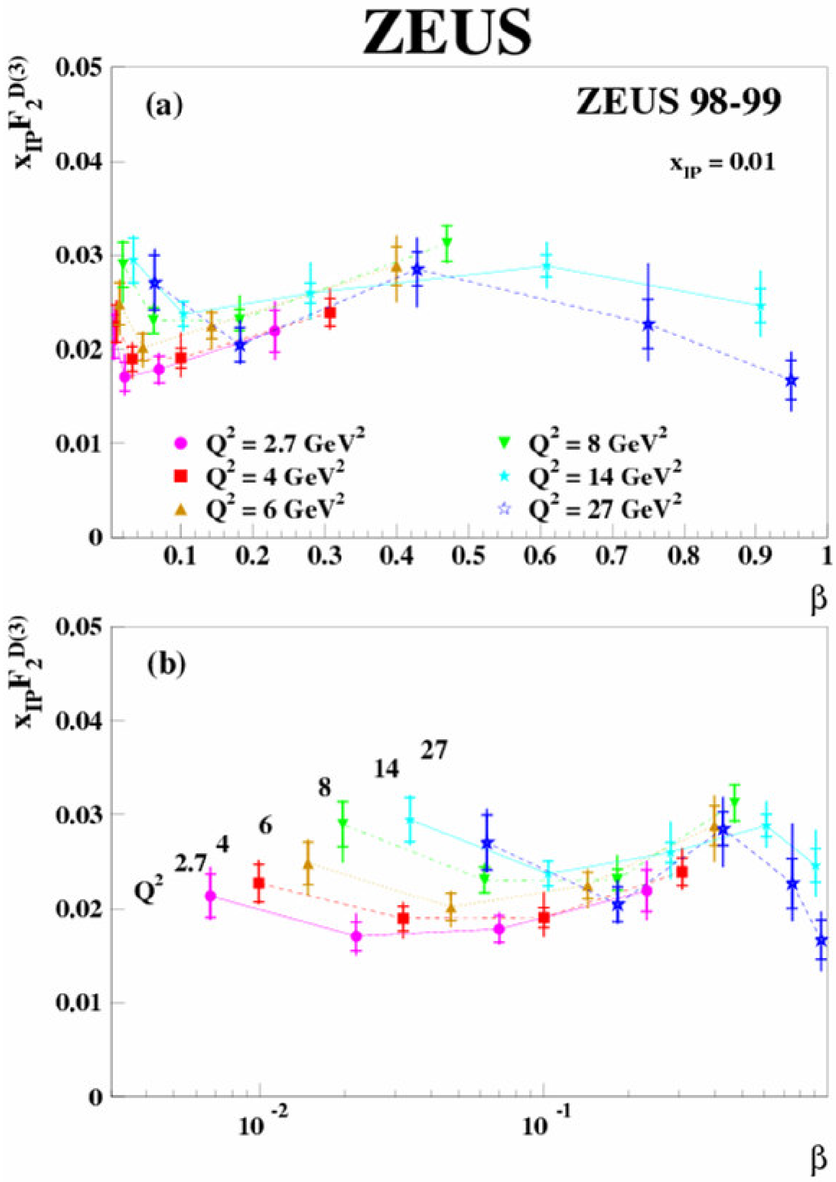
  Suggest perturbative effects such as gluon emission

- For fixed β,

  Q_2 dependence of $x_{IP}F_2^{D(3)}$ changes with x_{IP}.

  ➔ **Inconsistent with the Regge factorisation hypothesis**

β dependence of $x_{IP}F_2^{D(3)}$ at x_{IP}=0.01



- $x_{IP}F_2^{D(3)}$ for $x_{IP}=x_0$=0.01
  ➔ expect this to represent the structure function of Pomeron, up to a normalisation constant.

- **For β > 0.1**
  $x_{IP}F_2^{D(3)}$ has a maximum around β=0.5.
  ➔ The **β(1-β) dependence observed is expected in dipole models** of diffraction by $\gamma^* \to q\bar{q}$ splitting and two gluon exchange.

- **For β < 0.1**
  $x_{IP}F_2^{D(3)}$ rises as β → 0 and the rise accelerates with growing Q^2.
  ➔ Similar to **the logarithmic scaling violation of F_2 at low x** due to QCD evolution.

Summary

- **The measurements of diffraction in DIS with M_X method and with a leading proton show :**

✓ Slope of $d\sigma/d|t|$ is compatible with soft interaction at the proton vertex.

✓ Indication for **Regge factorisation breaking** seen in

  ➔ Q^2 dependence of $\alpha_{IP}^{diff}(0)$

  ➔ Q^2 dependence of $x_{IP}F_2^{D(3)}$ for fixed β and fixed x_{IP}

✓ Diffractive contribution of the total cross section

	$M_X < 2$ GeV	Higher M_X
$\sigma^{diff}/\sigma^{tot}$ ← $\alpha_{IP}^{diff}(0)$	***Decreasing with W*** No Q^2 dependence Soft Pomeron	***Constant with W*** Q^2 dependence Breaking of single Pomeron exchange
$\sigma^{diff}/\sigma^{tot}$ ← $Q^2\ \sigma^{diff}$	***Decreasing with Q^2*** Higher twist behaviour	***Constant with Q^2*** Leading twist behaviour

✓ Diffraction shows evidence for **pQCD evolution with Q^2 as $x_{IP} \rightarrow 0$ or $\beta \rightarrow 0$**.

✓ Data can be described by color dipole model (BEKW, GBW, FS04, CGC ......).

- **Expect new diffractive results with high statistics for an extended kinematic range (especially $Q^2 < 500$ GeV^2) soon.**