Inclusive Diffraction and Leading Baryons at HERA

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local!

for the H1 and ZEUS Collaborations

- Inclusive Diffraction in DIS
- Leading Baryons
- Conclusions

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QCD AND HIGH ENERGY HADRONIC INTERACTIONS
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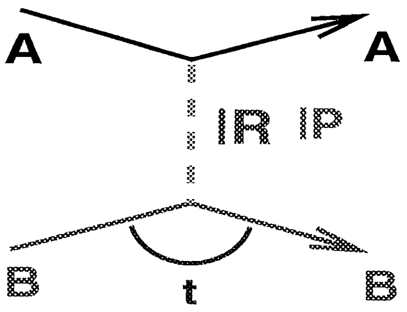
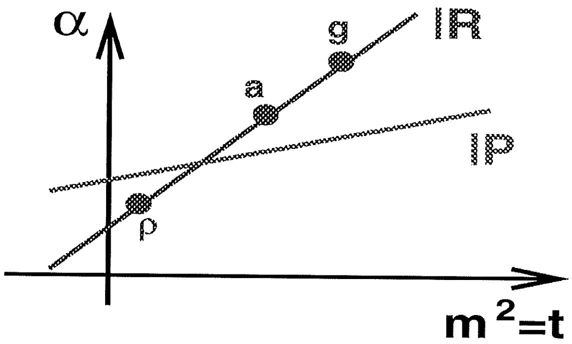
Hadron-Hadron Scattering and Regge Phenomenology

Hadron-Hadron data described by Regge Model



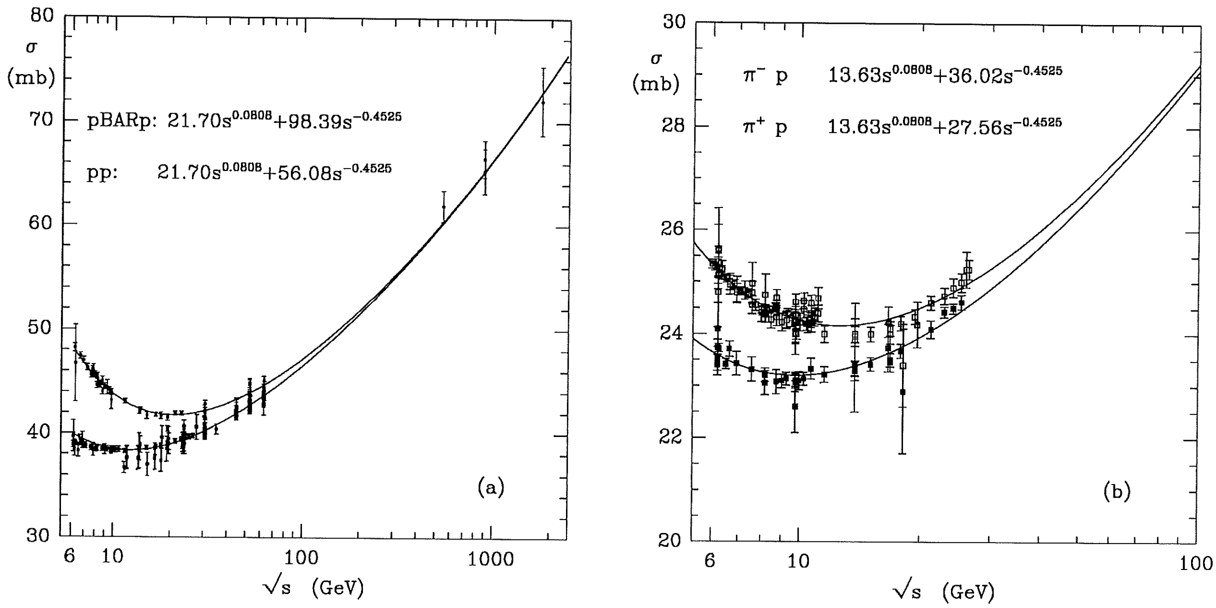


Regge Trajectories : $\alpha(t) = \alpha(0) + \alpha' \cdot t$

- $I\!P$-trajectory has the quantum numbers of the vacuum

$$\sigma_{tot} = X s^{\alpha_{I\!P}(0)-1} + Y s^{\alpha_{I\!R}(0)-1}$$

- $I\!R$-exchange dominates at low energy ($\alpha_{I\!R}(0) < 1$)
- $I\!P$-exchange dominates at high energy ($\alpha_{I\!P}(0) \gtrsim 1$)



⇒ $I\!P$-dominated processes referred as Diffraction

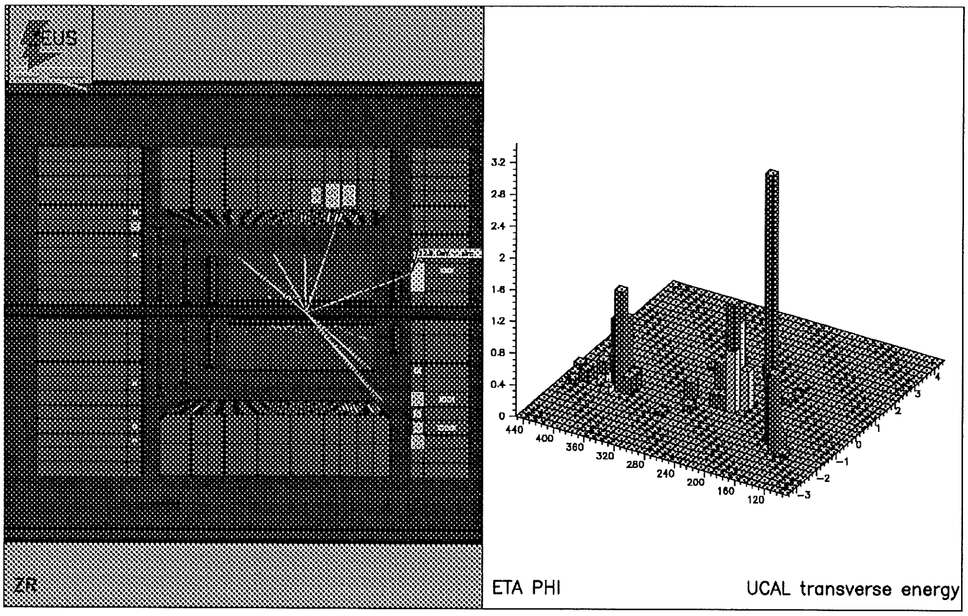
$$\alpha_{I\!P}(t) = \alpha_{I\!P}(0) + \alpha'_{I\!P} t = 1.085 + 0.25t$$

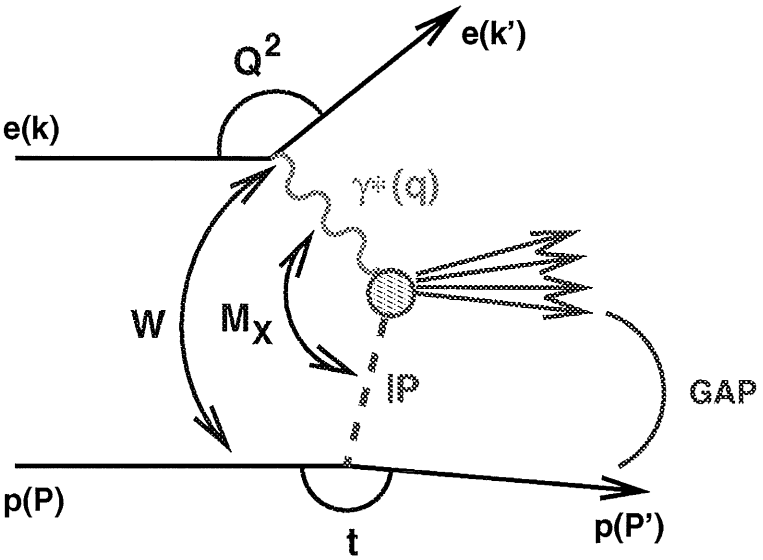
⇒ No description of the $I\!P$ in terms of QCD

Inclusive Diffraction at HERA

Observation of events without activity in the forward region ($8-10\%$ of the DIS cross section)

$\Rightarrow$ Exchange of colour singlet (Diffraction $\rightarrow$ $I\!P$-exchange)





$$Q^2 = -q^2$$

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

$$x_{I\!P} = \frac{M_x^2 + Q^2 - t}{W^2 + Q^2 - M_p^2}$$

$$\beta = \frac{Q^2}{M_x^2 + Q^2 - t}$$

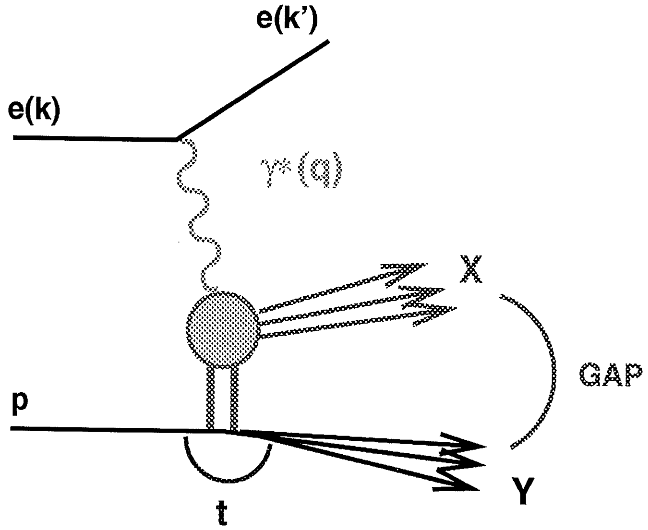
$x_{I\!P}$ $\Rightarrow$ fraction of proton momentum carried by $I\!P$

β $\Rightarrow$ fraction of $I\!P$ momentum carried by struck quark

$\Rightarrow$ The large γ-virtualities at HERA allow to study the $I\!P$-structure and formulate it in terms of QCD (quarks and gluons)

Inclusive Measurement of Diffractive DIS

(H1 Collab., Z. Phys. C76 (1997) 613)



$4.5 < Q^2 < 75$ GeV^2
$2 \cdot 10^{-4} < x_{I\!P} < 0.04$
$0.04 < \beta < 0.9$

- Selection of Diffraction based on LRG (Y-system constrained to $M_Y \lesssim 1.6$ GeV, $|t| \lesssim 1$ GeV^2)

$$\frac{d^3\sigma_{ep\to eYX}}{d\beta dQ^2 dx_{I\!P}} = \frac{2\pi\alpha^2}{\beta Q^4}[1+(1-y)^2]F_2^{D(3)}(\beta, Q^2, x_{I\!P})$$

$$F_2^{D(3)}(\beta, Q^2; x_{I\!P}) = f_{I\!P/p}(x_{I\!P})F_2^{D(2)}(\beta, Q^2)$$

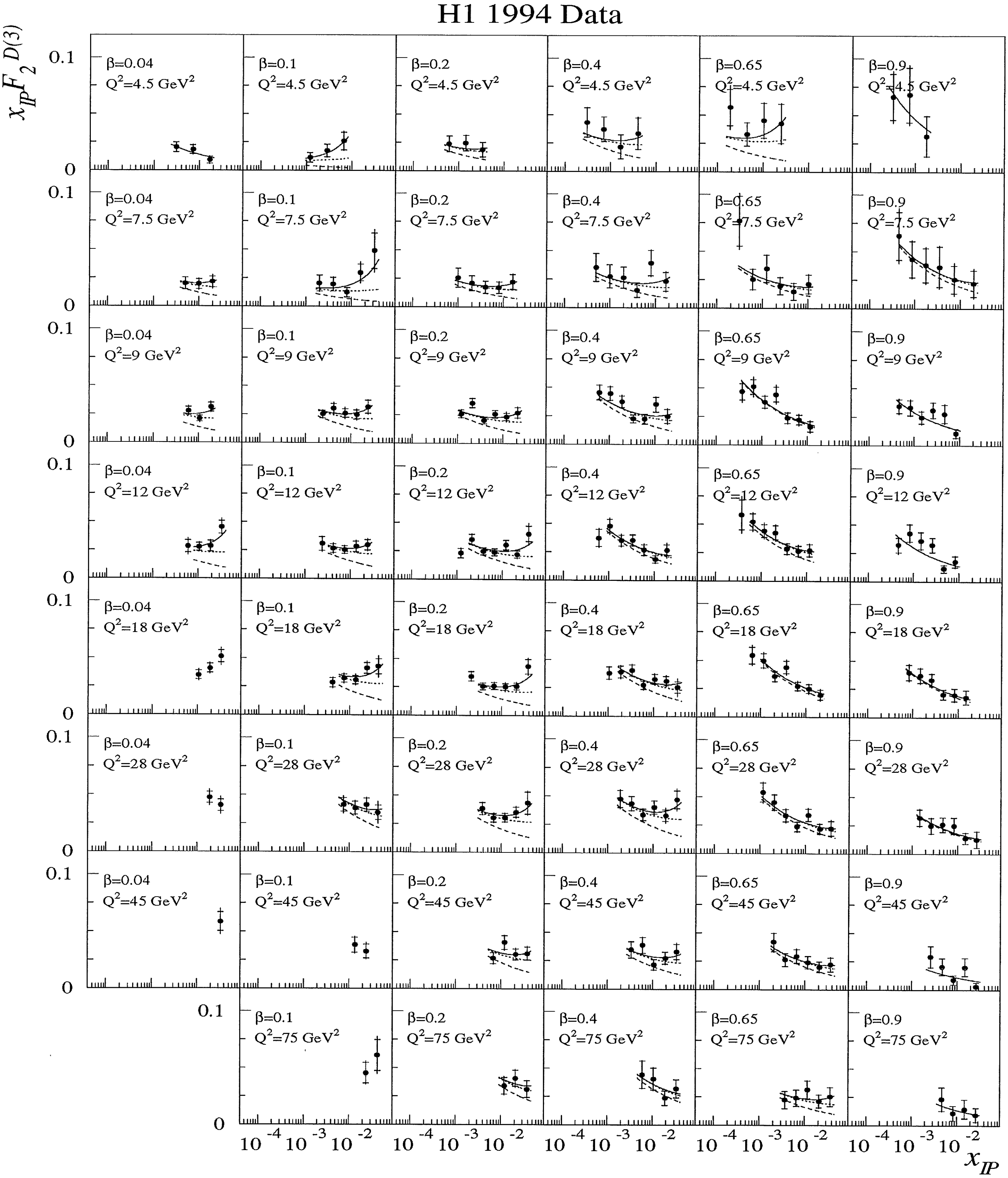
⇒ $x_{I\!P}F_2^{D(3)}$ is either falling or approximately constant as $x_{I\!P}$ increases (at fixed β, Q^2); **consistent with a dominant diffractive contribution from $I\!P$-exchange**

⇒ $x_{I\!P}$-dependence is found to vary with β and Q^2 (breaking of Regge factorization with only $I\!P$ exchange)

⇒ Additional sub-leading Reggeon exchange:

$$F_2^{D(3)} = f_{I\!P/p}(x_{I\!P})F_2^{I\!P}(\beta, Q^2) + f_{I\!R/p}(x_{I\!P})F_2^{I\!R}(\beta, Q^2)$$

Measurement of $F_2^{D(3)}(\beta, Q^2, x_{I\!P})$



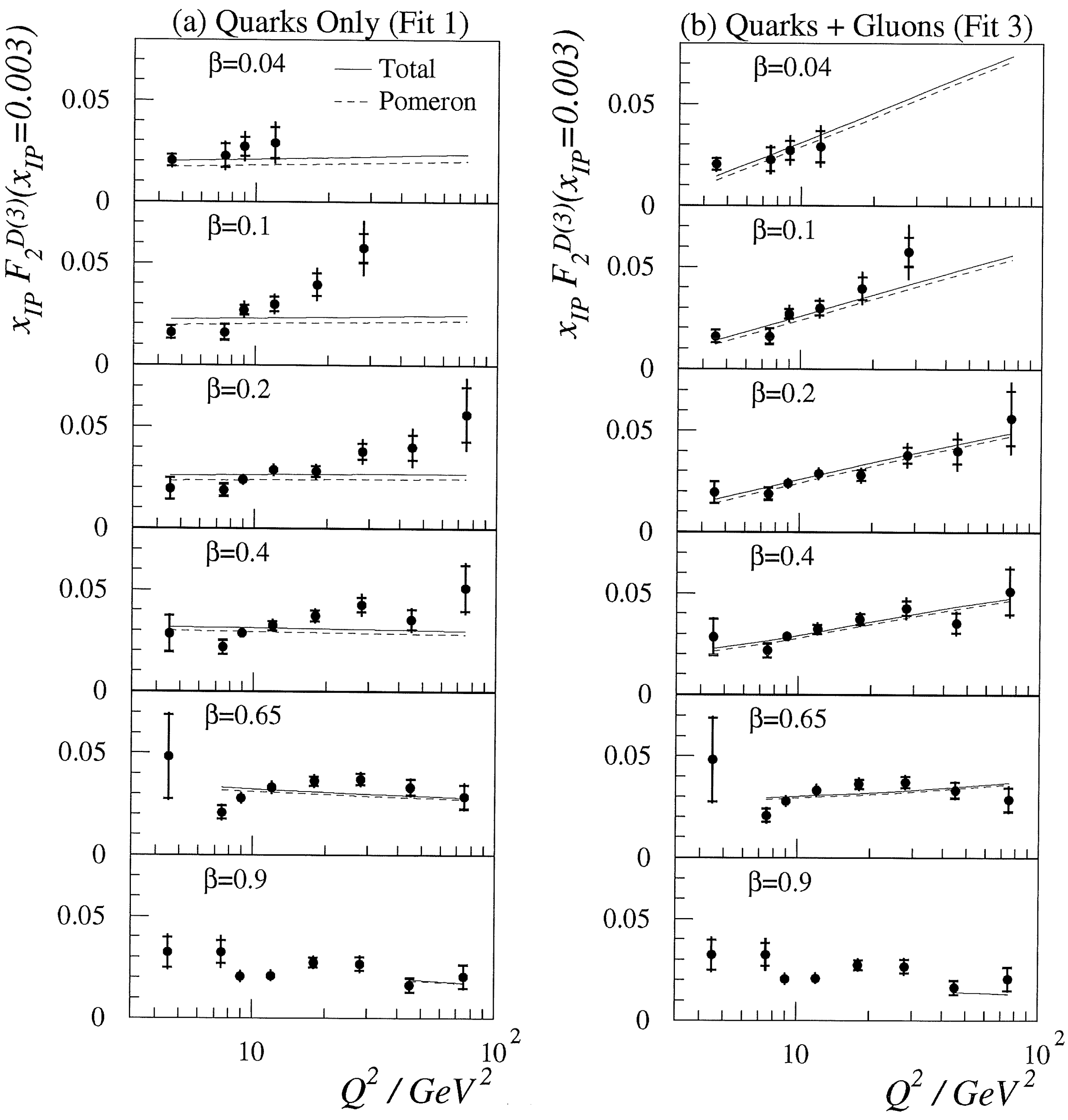
$$\alpha_{I\!P}(0) = 1.203 \pm 0.020(\text{stat}) \pm 0.013(\text{syst})^{+0.030}_{-0.035}(\text{model})$$

$$\alpha_{I\!R}(0) = 0.50 \pm 0.11(\text{stat}) \pm 0.11(\text{syst})^{+0.09}_{-0.10}(\text{model})$$

Scaling Violations of $F_2^{D(3)}$

$F_2^{D(3)}(\beta, Q^2, x_{I\!P} = 0.003)$ **close to** $F_2^{I\!P}(\beta, Q^2)$

H1 1994



⇒ Rising scaling violations up to large β suggesting a large gluon component in the $I\!P$

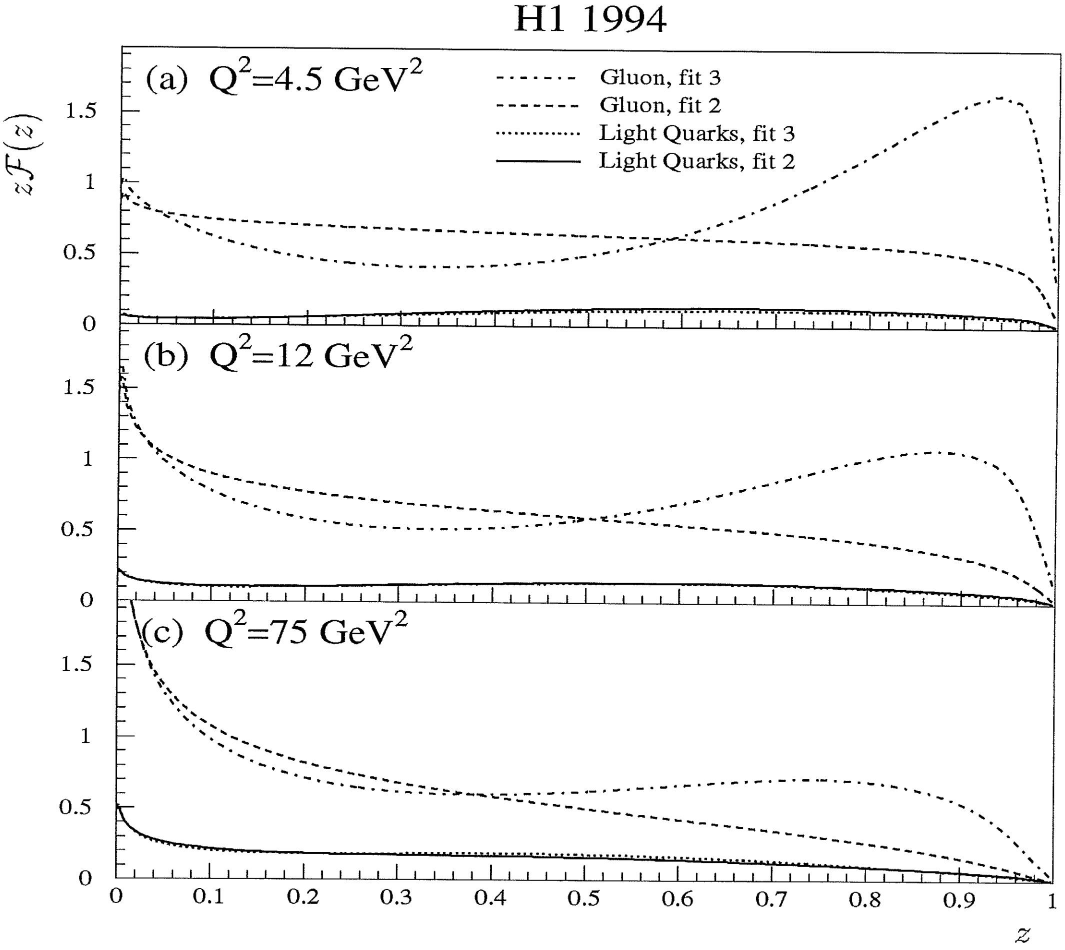
NLO DGLAP Fits to $F_2^{D(3)}$

Parameterization of quark and gluon densities in $I\!P$ at the starting scale $Q_0^2 = 3$ GeV^2

$$zF_i(z, Q^2 = Q_0^2) = [\Sigma_{j=1}^{n} C_j^i P_j(2z-1)]^2 \cdot e^{\frac{a}{z-1}}$$

$P_j \equiv$ Chebychev polynomials

- (For $I\!R$ the π-structure functions assumed)
- Evolution to $Q^2 > Q_0^2$ using NLO DGLAP equations



$I\!P$ dominated by gluons

$\sim 90\%$ gluon at $Q^2 = 4.5$ GeV^2

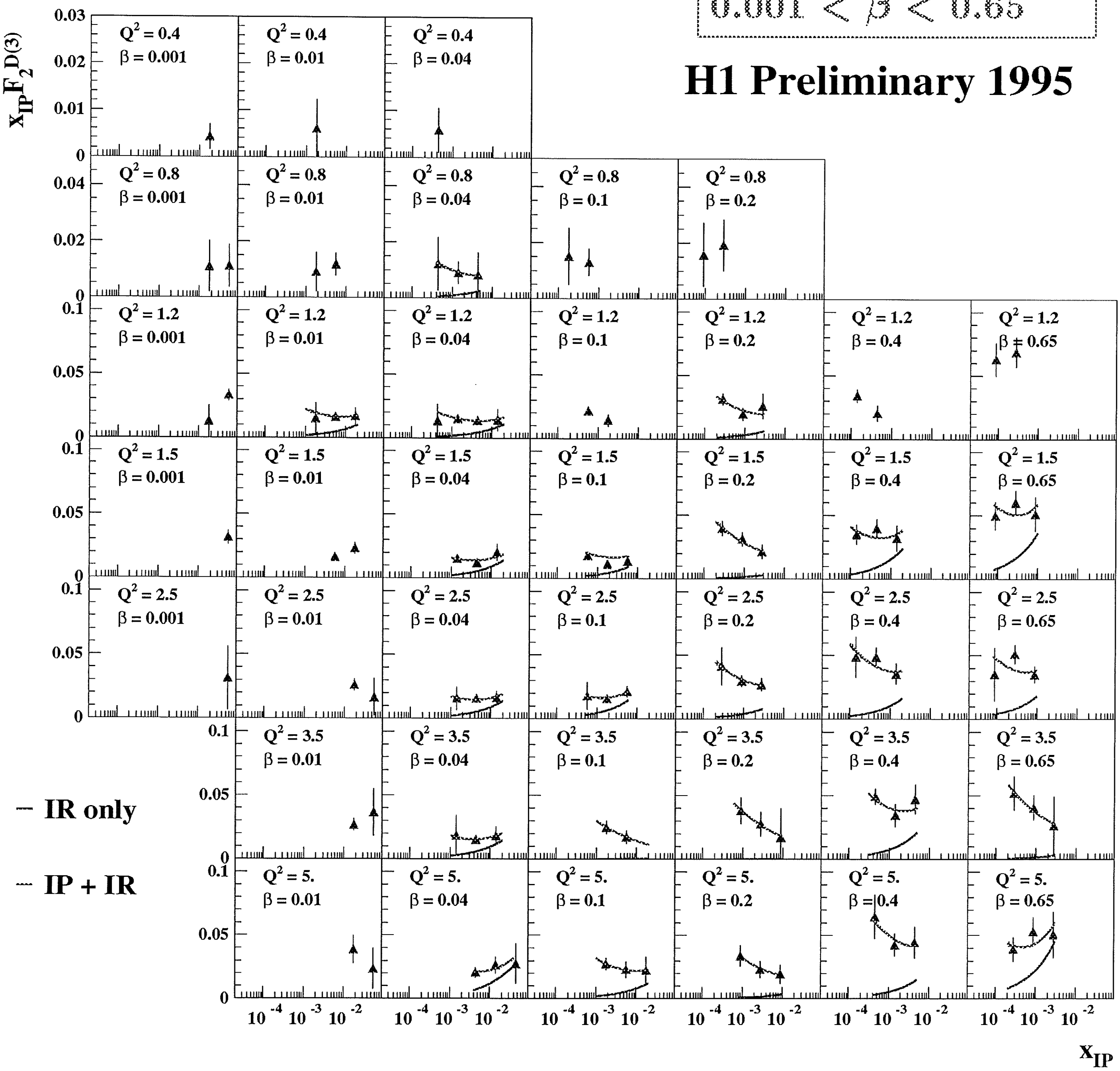
Measurement of $F_2^{D(3)}$ at low and high-Q^2

(H1 Collab., ICHEP98, Vancouver)

- H1 extends the previous measurement of $F_2^{D(3)}$ to lower and higher Q^2-regions

$0.4 < Q^2 < 5$ GeV^2
$x_{I\!P} < 0.05$
$0.001 < \beta < 0.65$

H1 Preliminary 1995

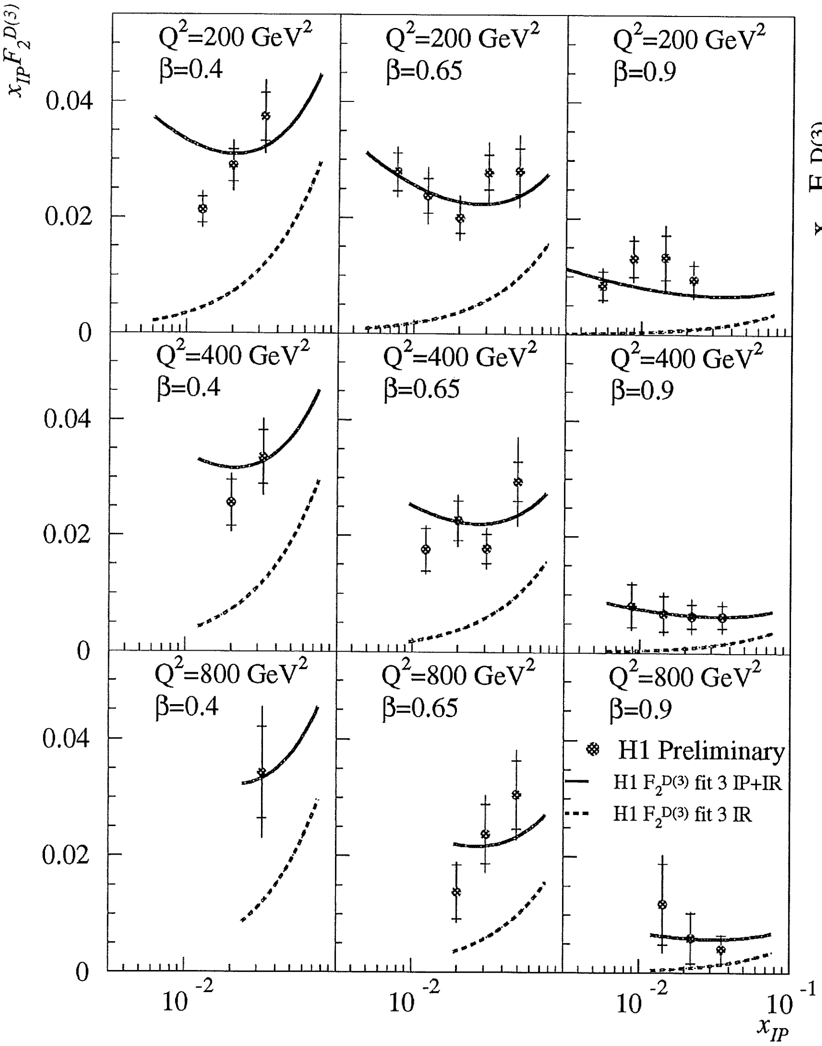


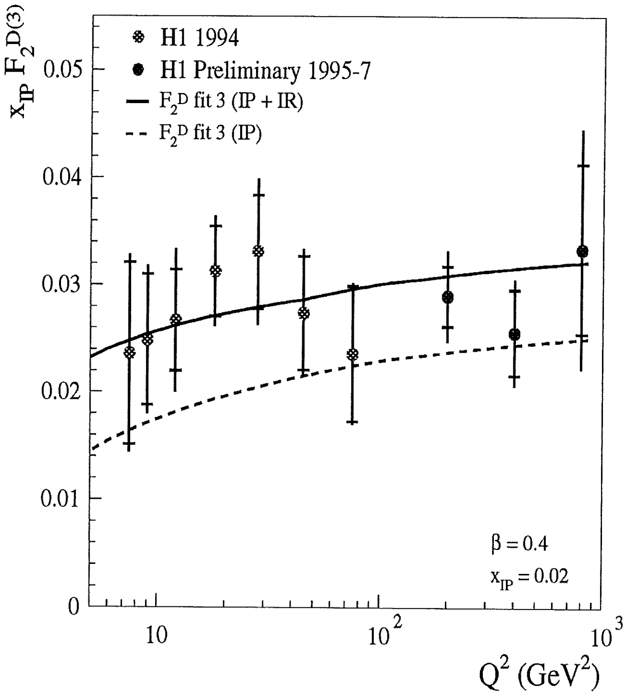
$\Rightarrow$ The data is consistent with the exchange of gluon-dominated $I\!P$ and additional sub-leading $I\!R$

Measurement of $F_2^{D(3)}$ at low and high-Q^2

- **H1 shows that diffractive interactions are still present at very high-Q^2**

$200 < Q^2 < 800$ GeV^2, $x_{I\!P} < 0.05$, $0.4 < \beta < 0.9$



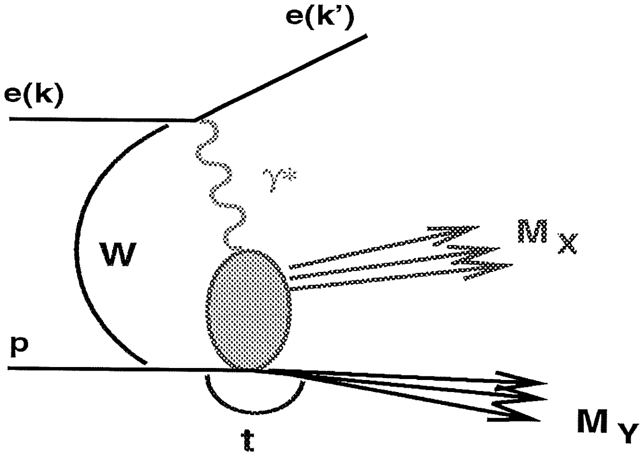


⇒ The Regge parameterization (obtained at low-Q^2 and evolved using NLO-DGLAP evolution equations) provides a reasonable description of the high-Q^2 measurements

⇒ The data is consistent with the exchange of gluon-dominated $I\!P$ and additional $I\!R$ in the whole Q^2 range studied ($0.4 < Q^2 < 800$ GeV^2)

Measurement of the Diffractive Cross Section in DIS

(ZEUS Collab., Eur. Phys. J. C6 (1999) 43-66)



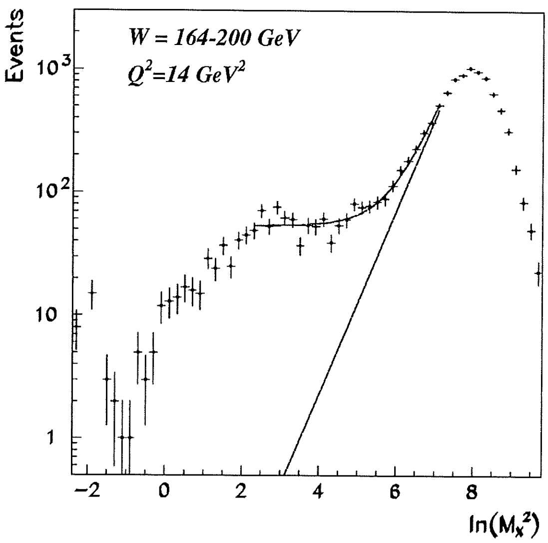
$7 < Q^2 < 140$ GeV^2

$60 < W < 200$ GeV

$M_X < 15$ GeV

$M_Y < 5.5$ GeV

- Selection of Diffraction based on the different M_x-distribution for (non)diffractive processes



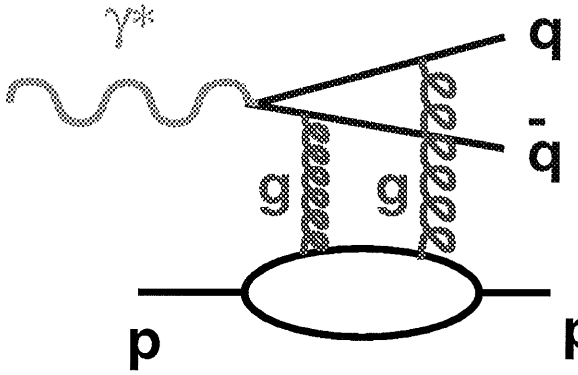
Non-diffractive DIS exponential suppressed

$$\frac{dN}{dln(M_x^2)} = D + C \cdot e^{b \cdot ln(M_x^2)}$$

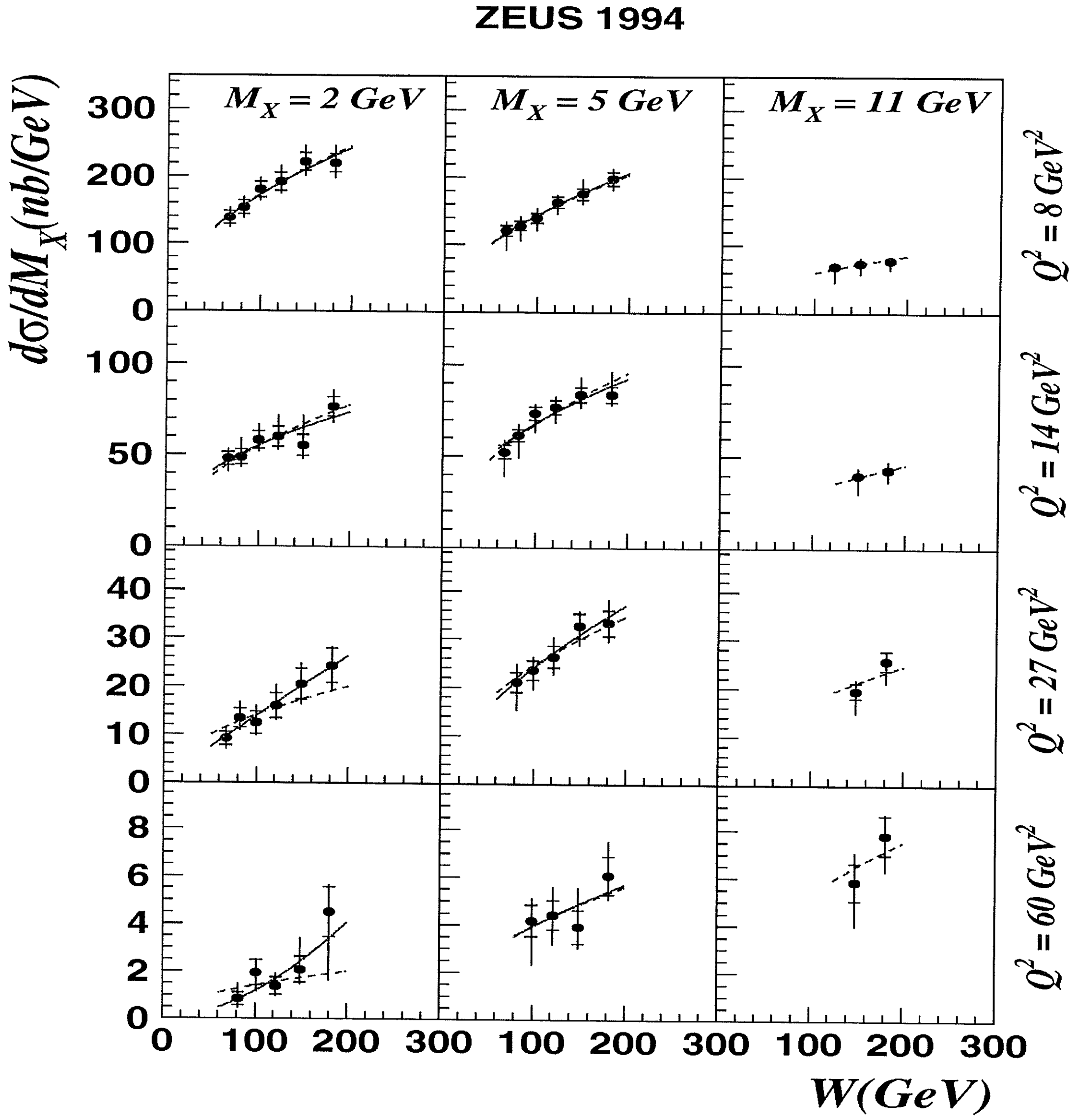
D ≡ Diffractive contribution

⇒ Reggeon contribution suppressed

- pQCD-motivated models as theoretical framework



Measurement of $\frac{d\sigma_{\gamma^* p \to XY}}{dM_X}(M_x, Q^2, W)$



A rapid rise with W is observed

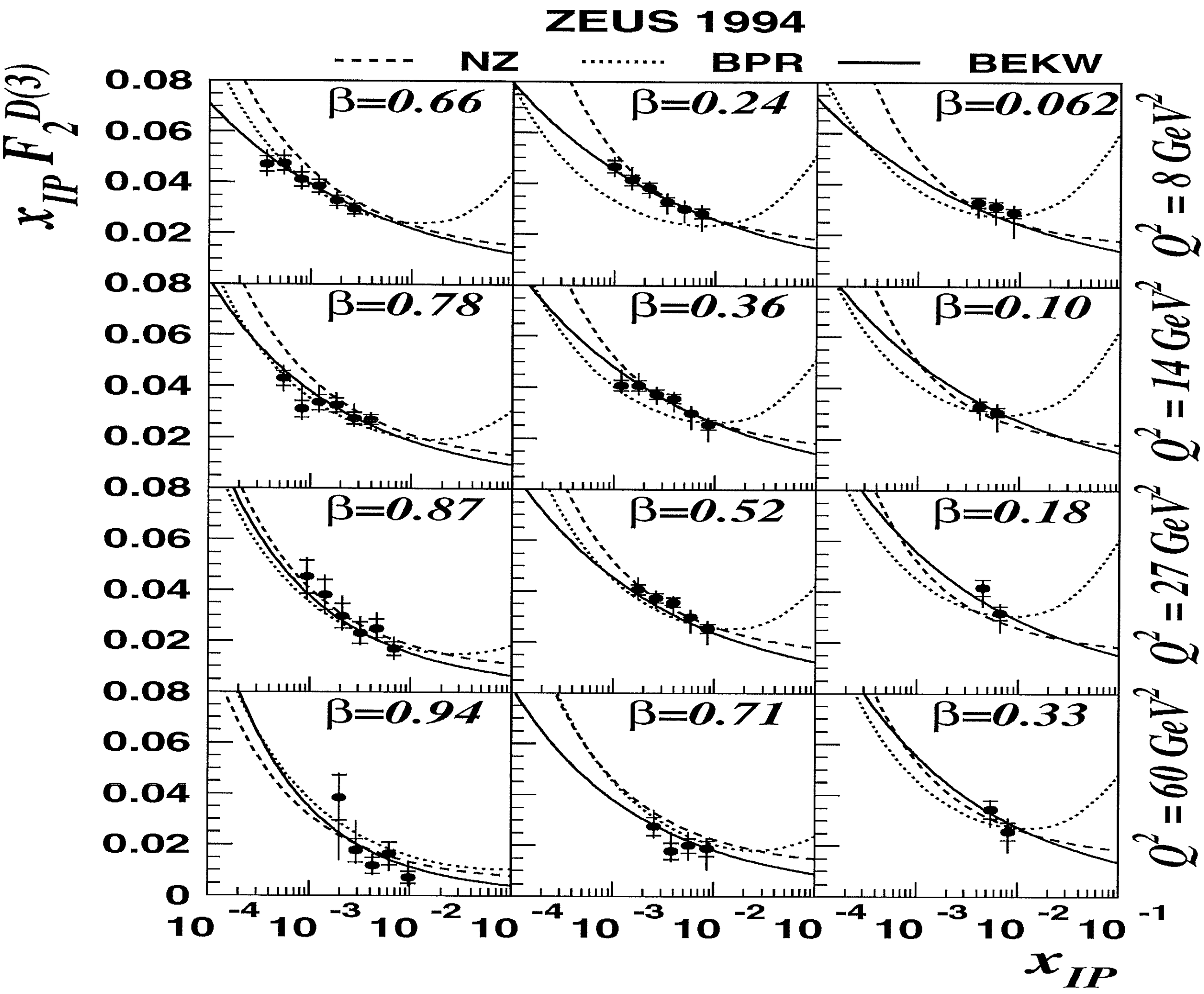
$$\frac{d\sigma_{\gamma^* p \to XY}}{dM_X} = h \cdot W^{4\overline{\alpha}_{I\!P} - 4} \qquad (\overline{\alpha}_{I\!P} \equiv \text{t-average } \alpha_{I\!P})$$

$$\overline{\alpha}_{I\!P} = 1.127 \pm 0.009(\text{stat})^{+0.039}_{-0.012}(\text{syst})$$

$$\alpha^{ZEUS}_{I\!P}(0) = 1.16 \pm 0.01(\text{stat}) \pm 0.02(\text{syst})$$

Measurement of $F_2^{D(3)}(\beta, Q^2, x_{I\!P})$

$$\frac{1}{2M_X}\frac{d\sigma_{\gamma^* p\to XY}}{dM_X} = \frac{4\pi^2\alpha}{Q^2(Q^2+M_X^2)}x_{I\!P}F_2^{D(3)}(\beta, Q^2, x_{I\!P})$$



⇒ $x_{I\!P}F_2^{D(3)}$ decreases with increasing $x_{I\!P}$

⇒ Consistent with: $F_2^{D(3)} \propto f_{I\!P}(x_{I\!P})F_2^{D(2)}(\beta, Q^2)$

$$f_{I\!P}(x_{I\!P}) \propto (1/x_{I\!P})^n, \quad (n \simeq 2\overline{\alpha}_{I\!P} - 1)$$

$$n = 0.253 \pm 0.017(\text{stat})^{+0.077}_{-0.023}(\text{syst})$$

⇒ Consistent with pQCD-motivated models

Conclusions

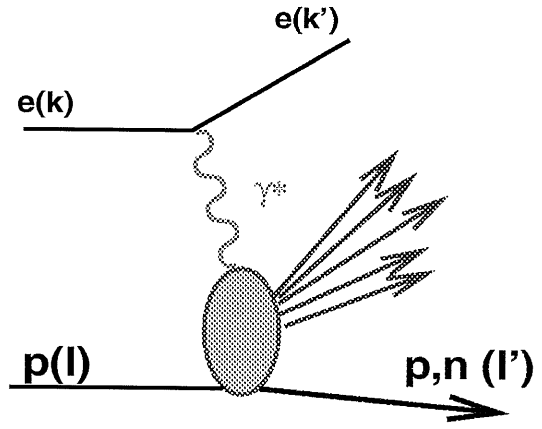
- Consistent Picture of Diffraction in DIS (from the $F_2^{D(3)}$ measurements) with a large gluon content of the $I\!P$
  (Detailed studies have been performed on the hadronic final state confirming the validity of this picture)

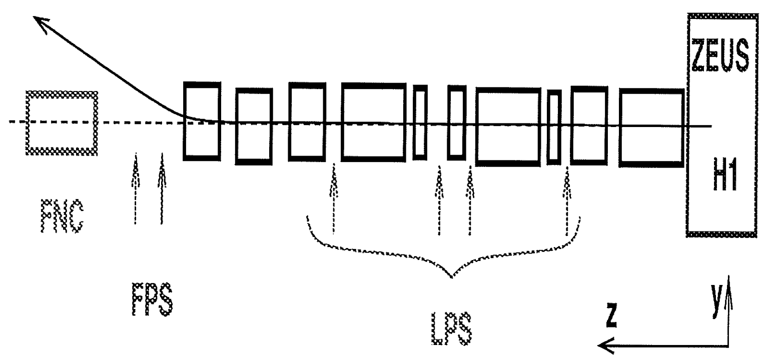
- pQCD-motivated models are also able to describe the $F_2^{D(3)}$ measurements

Leading Baryon Production at HERA

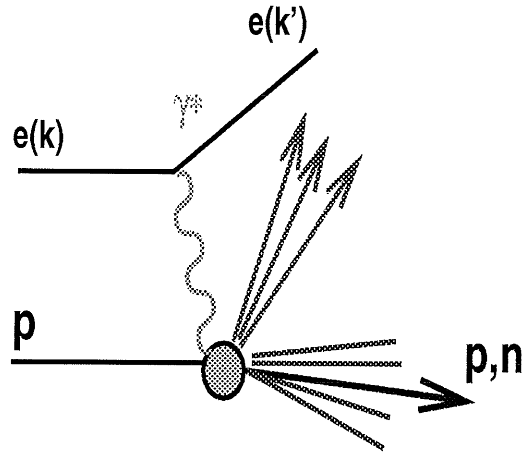
- Studies of the proton-fragmentation region are possible by measuring the production of leading baryons in DIS

- ZEUS (LPS,FNC) and H1 (FPS,FNC) detect leading protons and neutrons





- Two different approaches to describe leading baryon production:

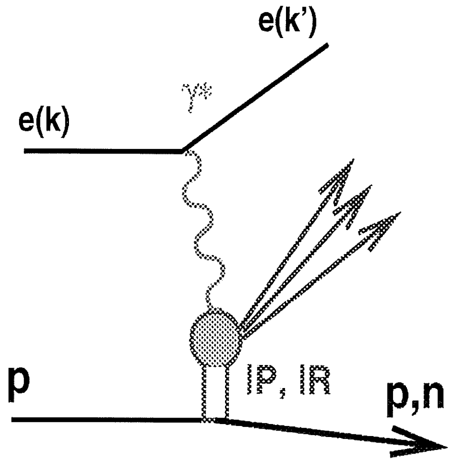


Leading Baryons from p-fragmentation

$$\sigma_{ep\rightarrow e'NX} = N(z,t)\cdot\Gamma(x,Q^2)$$

$$z \equiv x_L = l'/l$$

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



Regge Model

$$\sigma_{ep\rightarrow e'NX} = N(z,t)\cdot\Gamma(\beta,Q^2)$$

$$\beta = x/(1-z)$$

$I\!P$-exchange only for $x_L \gtrsim 0.95$

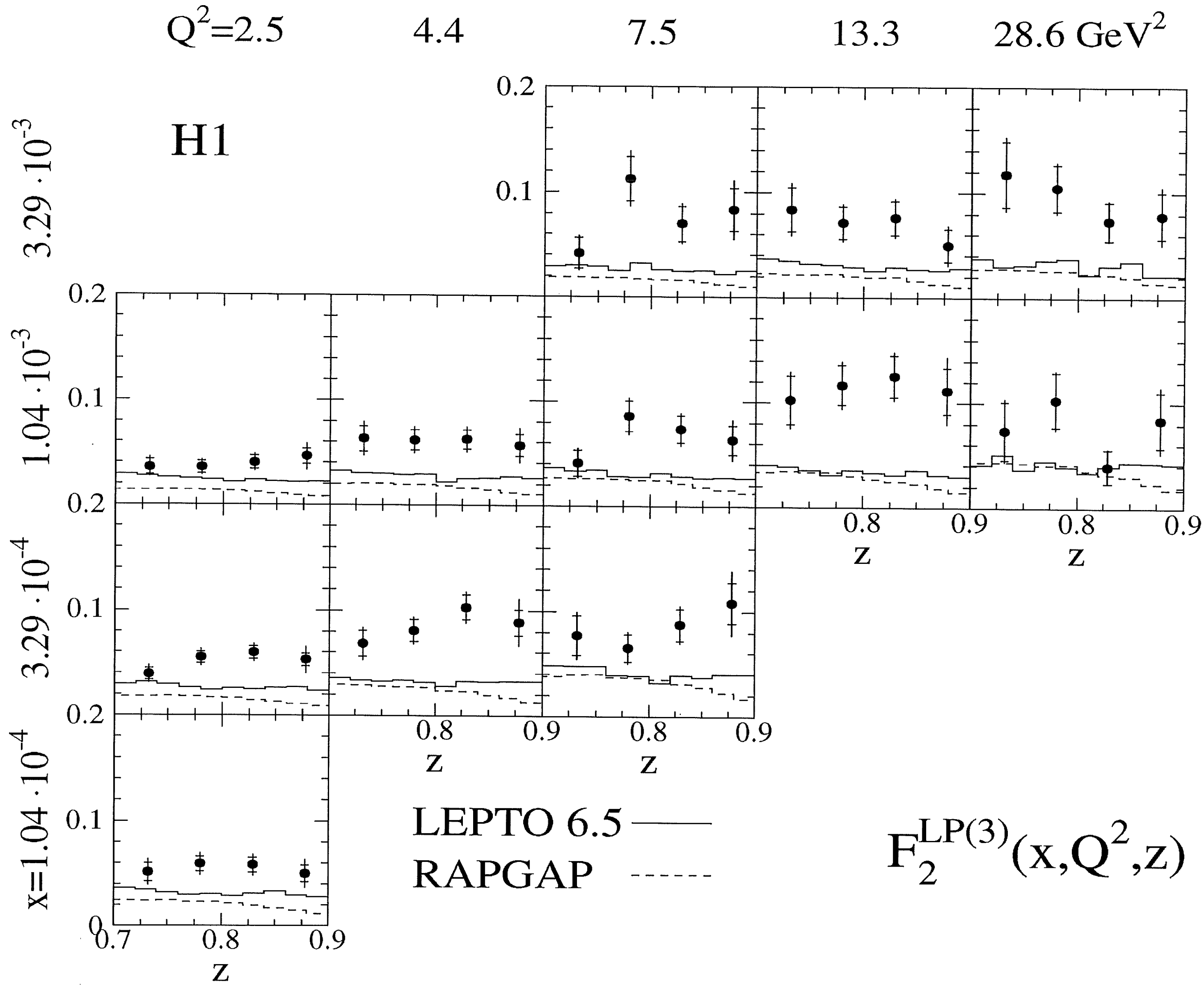
Semi-Inclusive Structure Function F_2^{LP}

(H1 Collab., Eur. Phys. J. C6 (1999) 587)

$$\frac{d^3\sigma(ep \to ePX)}{dx dQ^2 dz} = \frac{4\pi\alpha^2}{xQ^4}(1 - y + \frac{y2}{2}) F_2^{LP(3)}(x, Q^2, z)$$

PROTONS

$2 < Q^2 < 50$ GeV^2, $6 \cdot 10^{-5} < x < 6 \cdot 10^{-3}$



⇒ F_2^{LP} flat in x_L, rising with Q^2 (Scaling Violation)

⇒ LEPTO+SCI does not describe the data

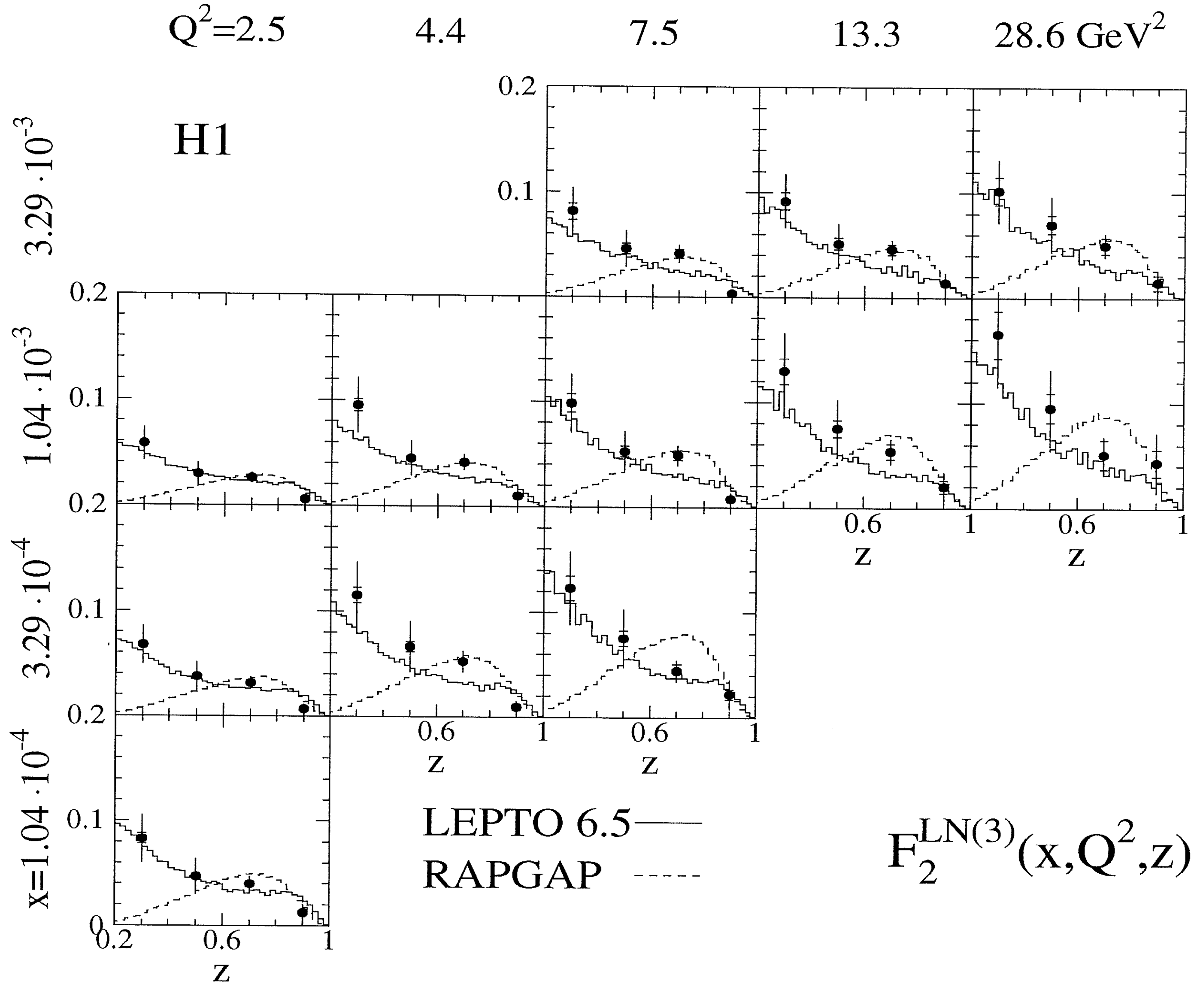
⇒ RAPGAP(O.P.E) does not describe the data (needs more than π-exchange)

Semi-Inclusive Structure Function F_2^{LN}

$$\frac{d^3\sigma(ep \to eNX)}{dxdQ^2dz} = \frac{4\pi\alpha^2}{xQ^4}(1 - y + \frac{y2}{2})F_2^{LN(3)}(x, Q^2, z)$$

NEUTRONS

$2 < Q^2 < 50$ GeV^2, $\quad 6 \cdot 10^{-5} < x < 6 \cdot 10^{-3}$



$\Rightarrow F_2^{LN}$ same shapes in x_L at all (x, Q^2)

$\Rightarrow$LEPTO+SCI describes F_2^{LN}

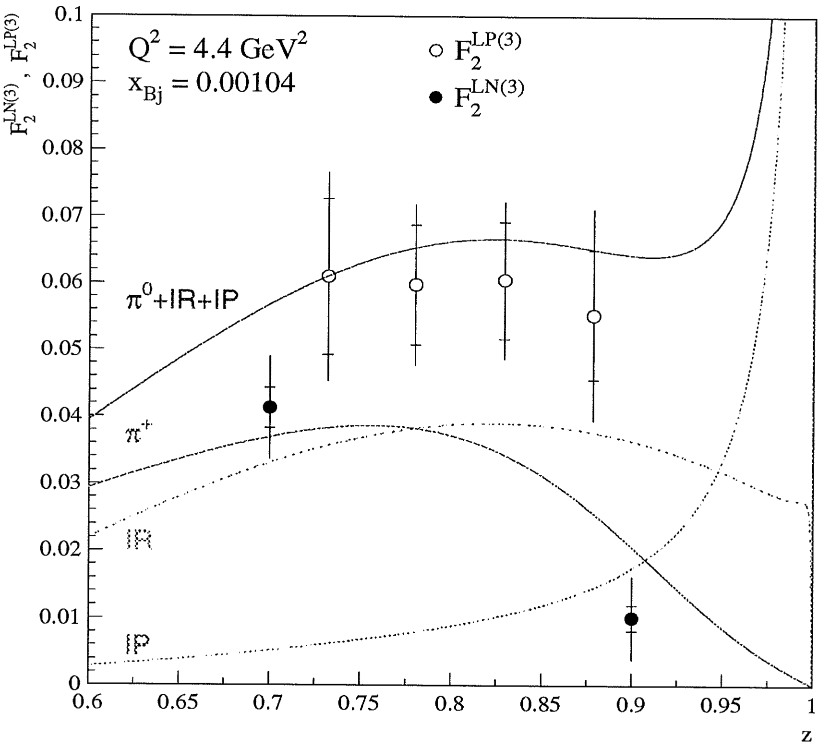
$\Rightarrow$RAPGAP(O.P.E) only describes F_2^{LN} for $x_L > 0.7$

Regge Model for Baryon Production

$$F_2^{LB(3)}(\beta, Q^2, z) = \Sigma_i f_{i/p}(z) F_2^i(\beta, Q^2)$$

- Neutrons $\rightarrow \pi^+$ (ρ^+, $a_2^+ < 10\%$ of π^+)
- Protons $\rightarrow I\!P$, π^o, f_2 (ω, a_2^o, $\rho^o \rightarrow$ small contrib.)
- π, $I\!P$, $I\!R$ flux-factors from hadron-hadron data
- F_2^i unknown at low-β (in data $F_2^{D(3)}$ from $\beta > 0.04$)

$$F_2^\pi \text{ from GRV}, \quad F_2^{I\!R} = F_2^\pi, \quad F_2^{I\!P} = \frac{0.026}{0.12} F_2^{I\!R}$$



$\Rightarrow$ Good description of the data for $z \gtrsim 0.7$

$\Rightarrow$ Neutrons: π^+ contribution describes the data

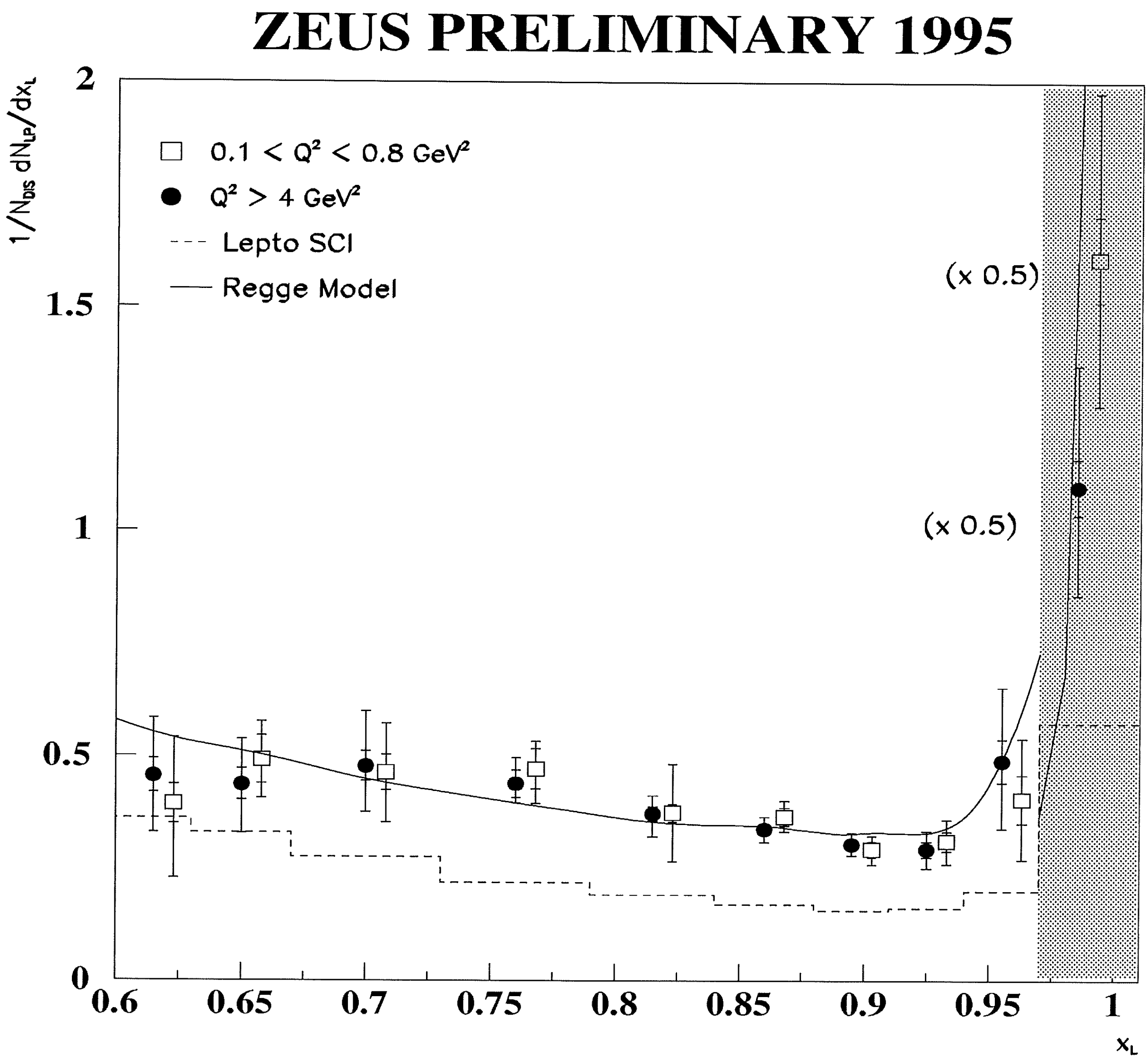
$\Rightarrow$ Protons: Contribution from f_2 and π^o

Measurement of the x_L-distribution for Leading Protons

(ZEUS Collab., ICHEP98, Vancouver)

- Measurements performed in two regions of Q^2

  ($0.1 < Q^2 < 0.8$ GeV^2 and $Q^2 > 4$ GeV^2)



⇒ Q^2-independent (Projectile/Target factorization)

⇒ Flat Proton-spectrum for $0.6 < x_L < 0.9$

⇒ LEPTO+SCI describes the shape (for $0.6 < x_L < 0.9$)

⇒ Regge-model (Szczurek et al.) describes the data

Conclusions

- Large fraction of DIS events with Leading Baryons in the final state
- Regge-Factorization and Limiting Fragmentation hypotheses consistent with the measurements
- Regge Models describe the production of Leading Baryons for $x_L \gtrsim 0.7$