Leading Baryon production at HERA with the ZEUS forward detectors

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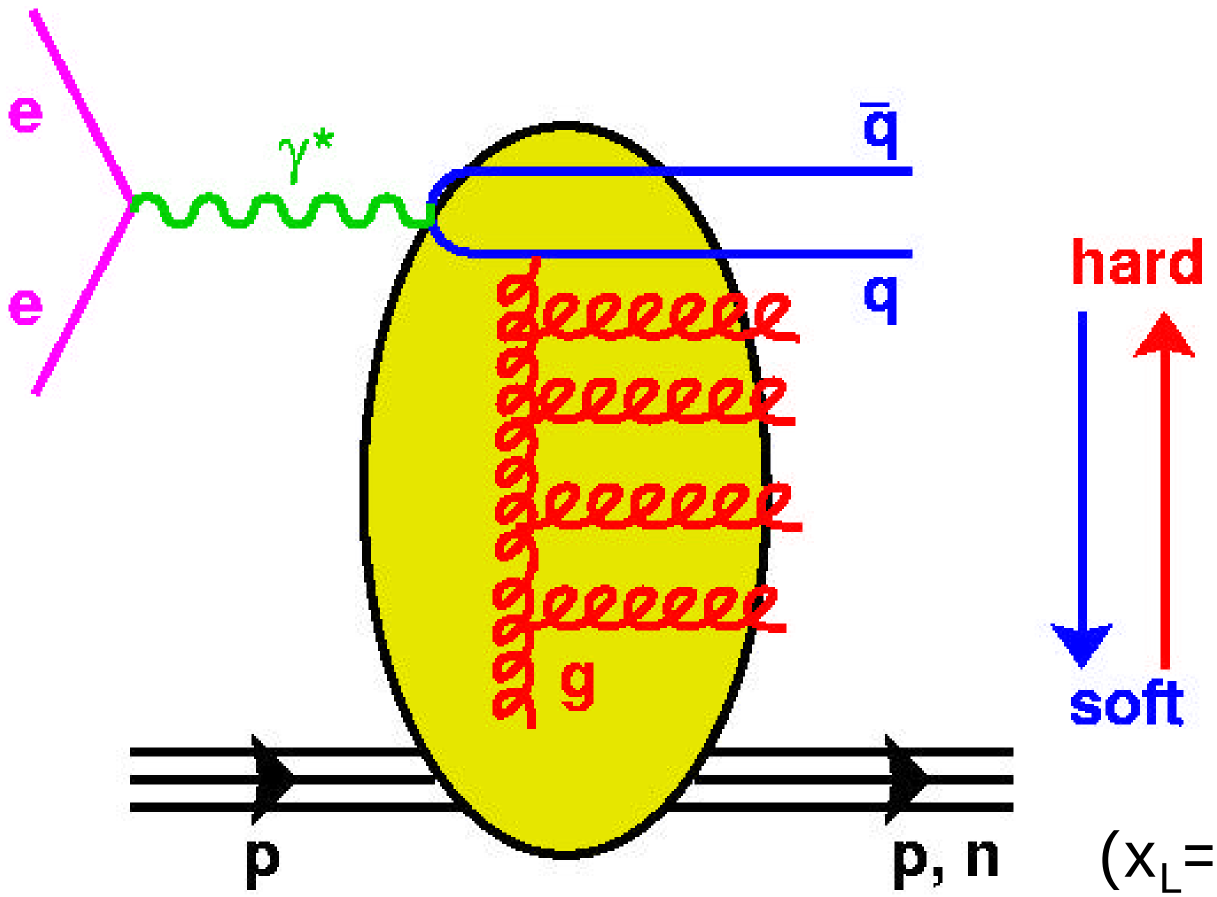
ZEUS

Introduction

Study of leading baryon production at small t in hadronic interactions ⇒ soft process

At HERA, at small x:



Scales of the reaction:

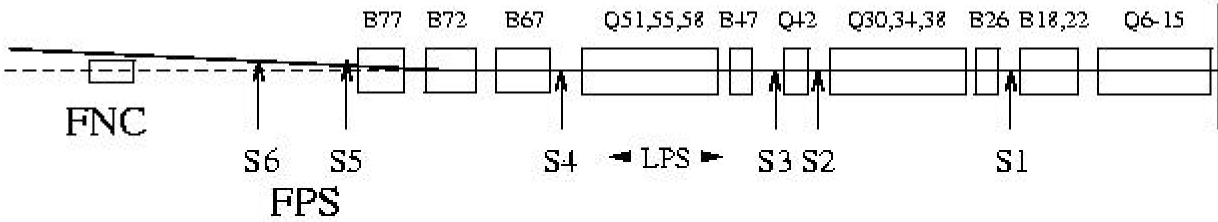
$Q^2 = 0.1 – 1000\ \mathrm{GeV}^2$

$p_t^2 < 0.5\ \mathrm{GeV}^2$

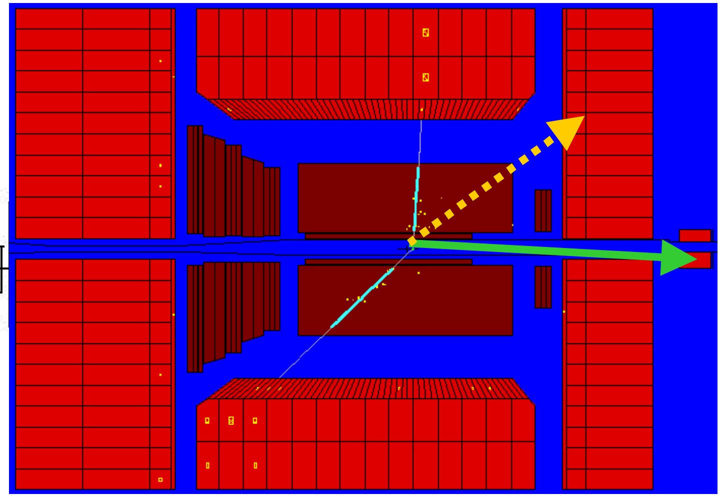
$(x_L = E_{p,n}/E_{beam},\ p_t^2)$

ZEUS forward detectors

Leading Proton Spectrometer (LPS):
6 stations at z=24-90 m (last three used)
Acceptance limited by magnet apertures
to $x_L > 0.6$ and $p_t^2 < 0.5$ GeV^2



DIS sample:
positron in CAL
($Q^2 > 3$ GeV^2)

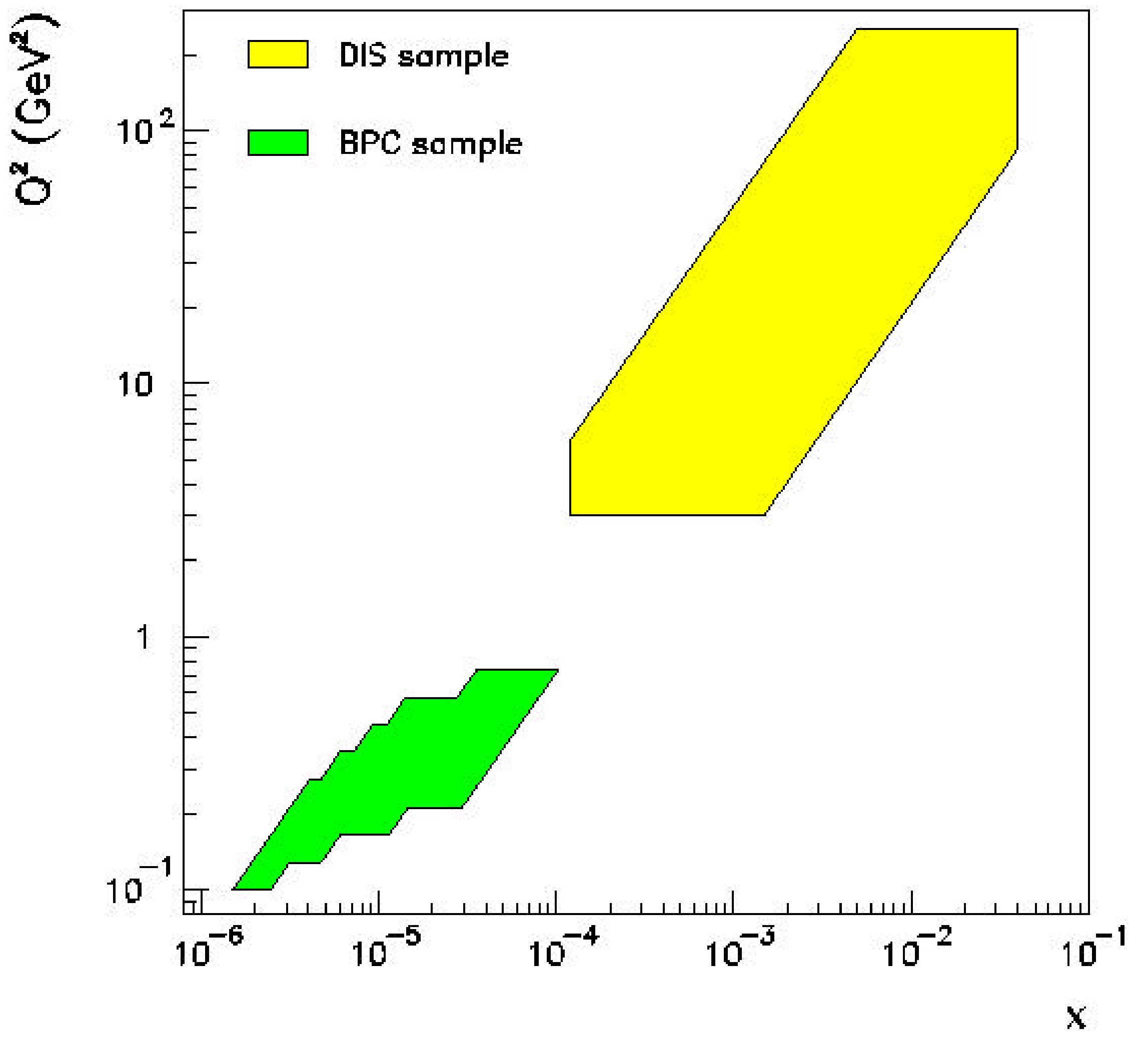


Forward Neutron Calorimeter:
z=106-107 m, on zero-degree line
Acceptance limited by magnet
apertures to $\theta_n < 0.8$ mrad

BPC sample:
positron in BPC
($Q^2 \sim 0.1$-0.6 GeV^2)

BPC = Beam Pipe Calorimeter

Kinematic plane (positron)



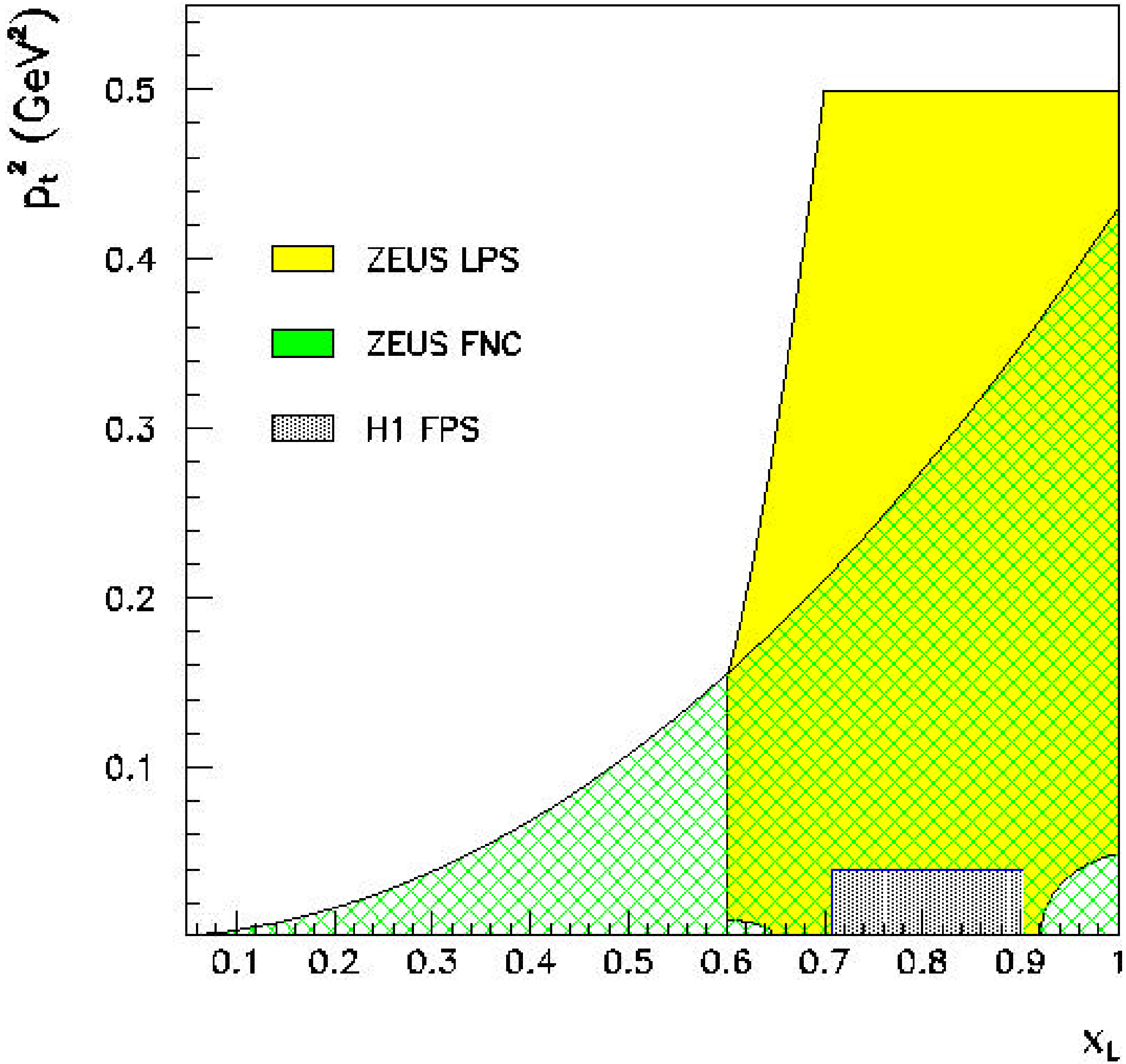
DIS sample:

- $3 < Q^2 < 254$ GeV^2
- $45 < W < 225$ GeV
- 1.2E-4 < x < 2.E-2

BPC sample:

- $0.1 < Q^2 < 0.74$ GeV^2
- $85 < W < 258$ GeV

Kinematic plane (baryon)



Protons

ZEUS LPS:

- $0.6 < x_L < 1$
- $P_t^2 < 0.5$ GeV^2

H1 FPS:

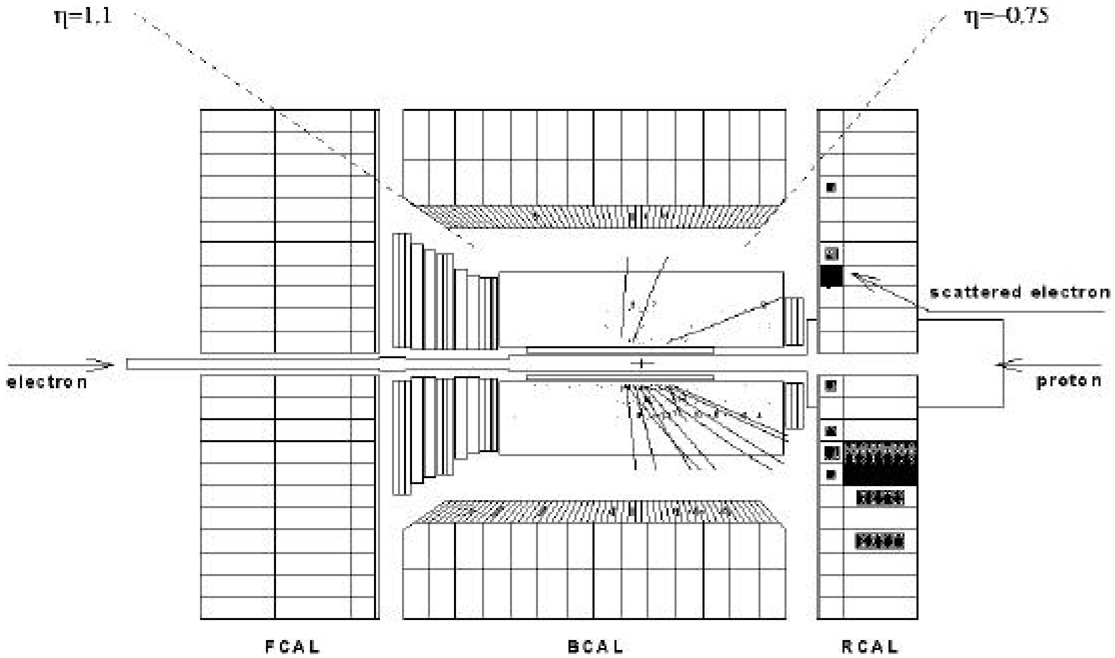
- $0.7 < x_L < 0.9$
- $p_t^2 < 0.04$ GeV^2

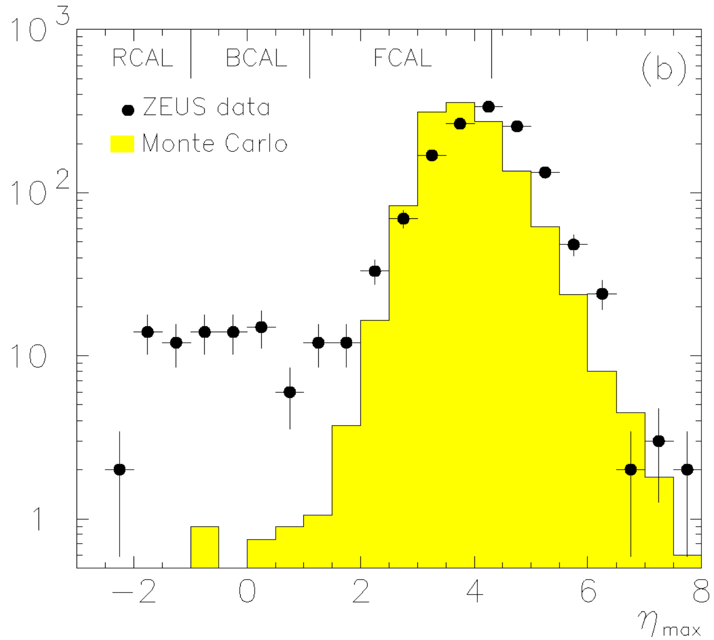
Neutrons

ZEUS FNC:

- $\theta_n < 0.8$ mrad
- $p_t^2 < (0.66\ x_L)^2$

η_{MAX} selection of diffraction

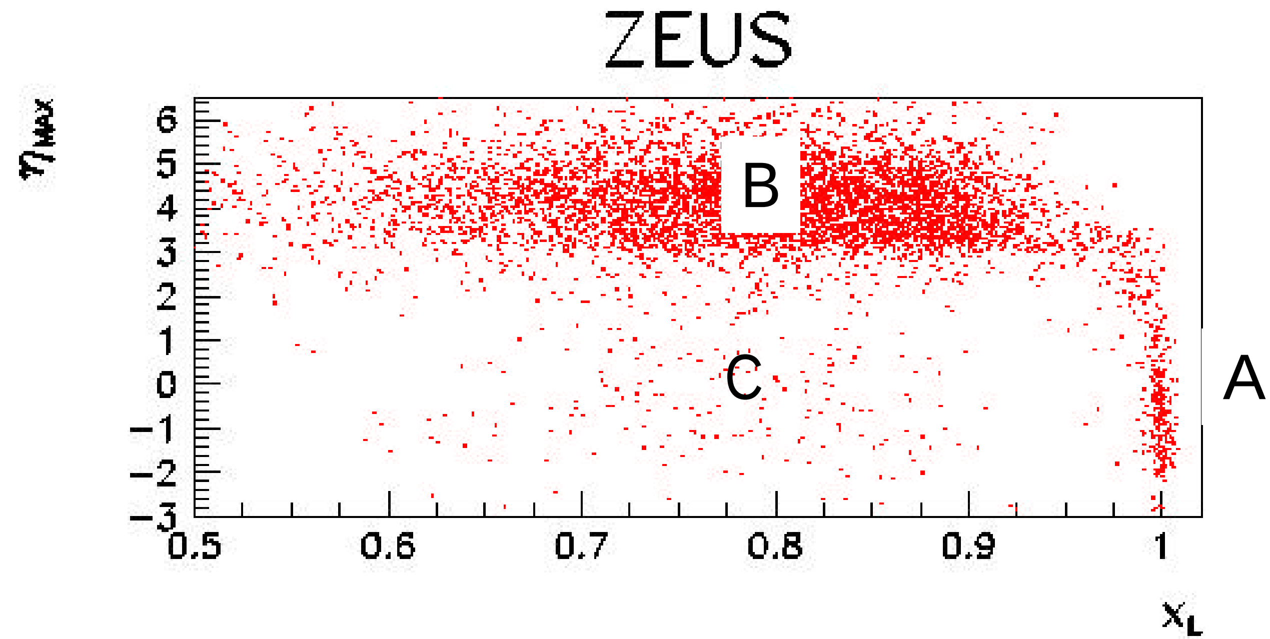




Rapidity gap selection of diffractive events: $\eta_{MAX} < 1.8$

η_{MAX} = pseudorapidity of the most forward energy deposit

Rapidity gap events with a LP

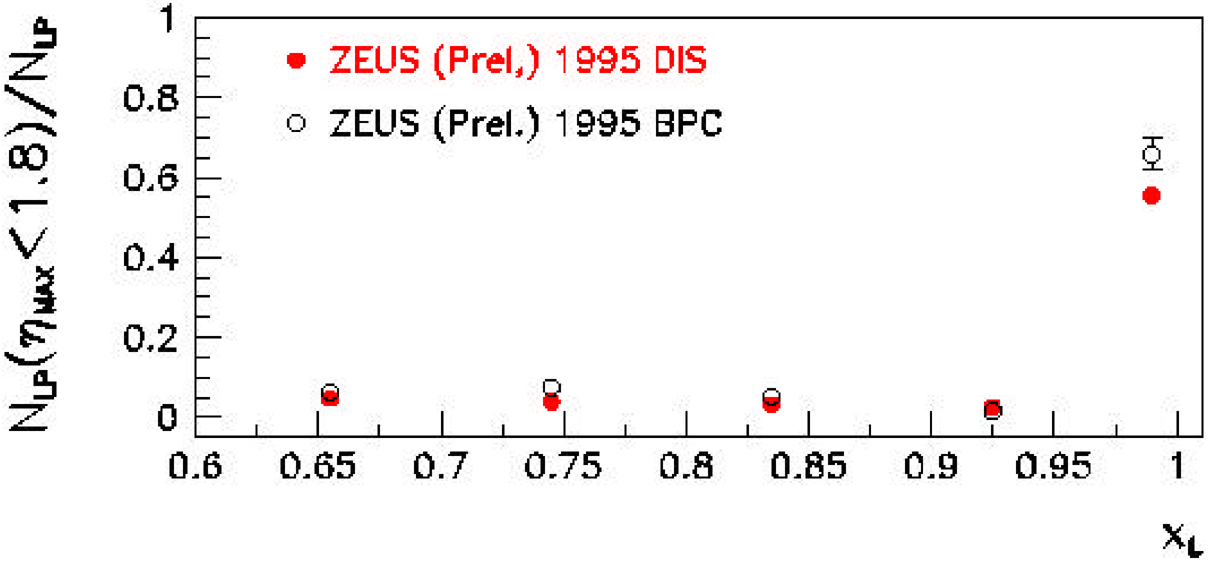


A: a rapidity gap is observed in ZEUS, diffractive events;

B: high η_{MAX}, lower x_L , higher mass

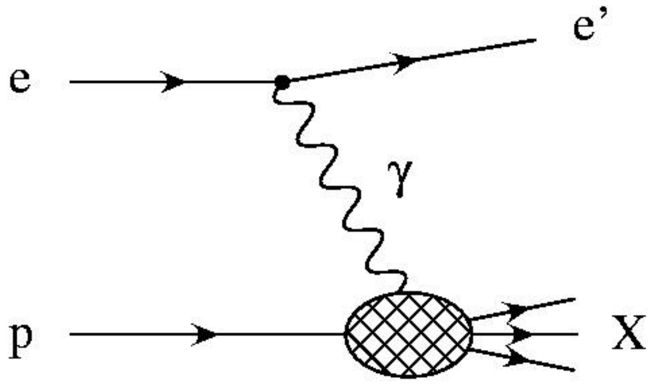
$$M_X \propto \sqrt{1 - x - x_L}$$

C: proton diffractive dissociation.



⇒ diffractive dissociation accounts for a small fraction of the low x_L protons

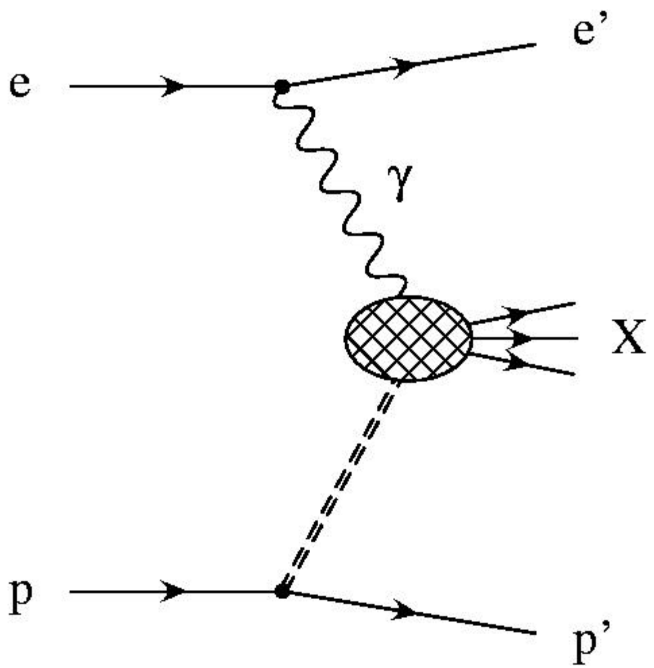
Inclusive/semi-inclusive reactions



Inclusive reaction $ep \rightarrow eX$

$$\frac{d^2\sigma}{dx\,dQ^2} = \frac{4\pi\alpha^2}{x\,Q^4}\left(1 - y + \frac{y^2}{2}\right)F_2\left(x,Q^2\right)$$

Semi-inclusive case



$$\frac{d^4\sigma}{dx\,dQ^2 dx_L\,dp_t^2} = \frac{4\pi\alpha^2}{x\,Q^4}\left(1 - y + \frac{y^2}{2}\right)F_2^{LP(4)}\left(x,Q^2;x_L,p_t^2\right)$$

in the framework of fracture functions

$$M_2^{p/p}\left(x,Q^2;x_L,p_t^2\right) = F_2^{LP(4)}\left(x,Q^2;x_L,p_t^2\right) = \sum_i e_i^2\,x\,M_i^{p/p}\left(x,Q^2;x_L,p_t^2\right)$$

$M_2^{p/p}$ = structure function of p conditioned to target containing p w/ x_L and p_t^2

Experimental observable $r^{LP(2)}$

Fraction of events with a leading proton:

$$r^{LP(2)}\left(x,Q^2\right)=\frac{N^{LP}\left(x,Q^2,\Delta x_L,\Delta p_t^2\right)}{N\left(x,Q^2\right)}\frac{1}{\varepsilon_{LPS}\left(x_L,p_t^2\right)}$$

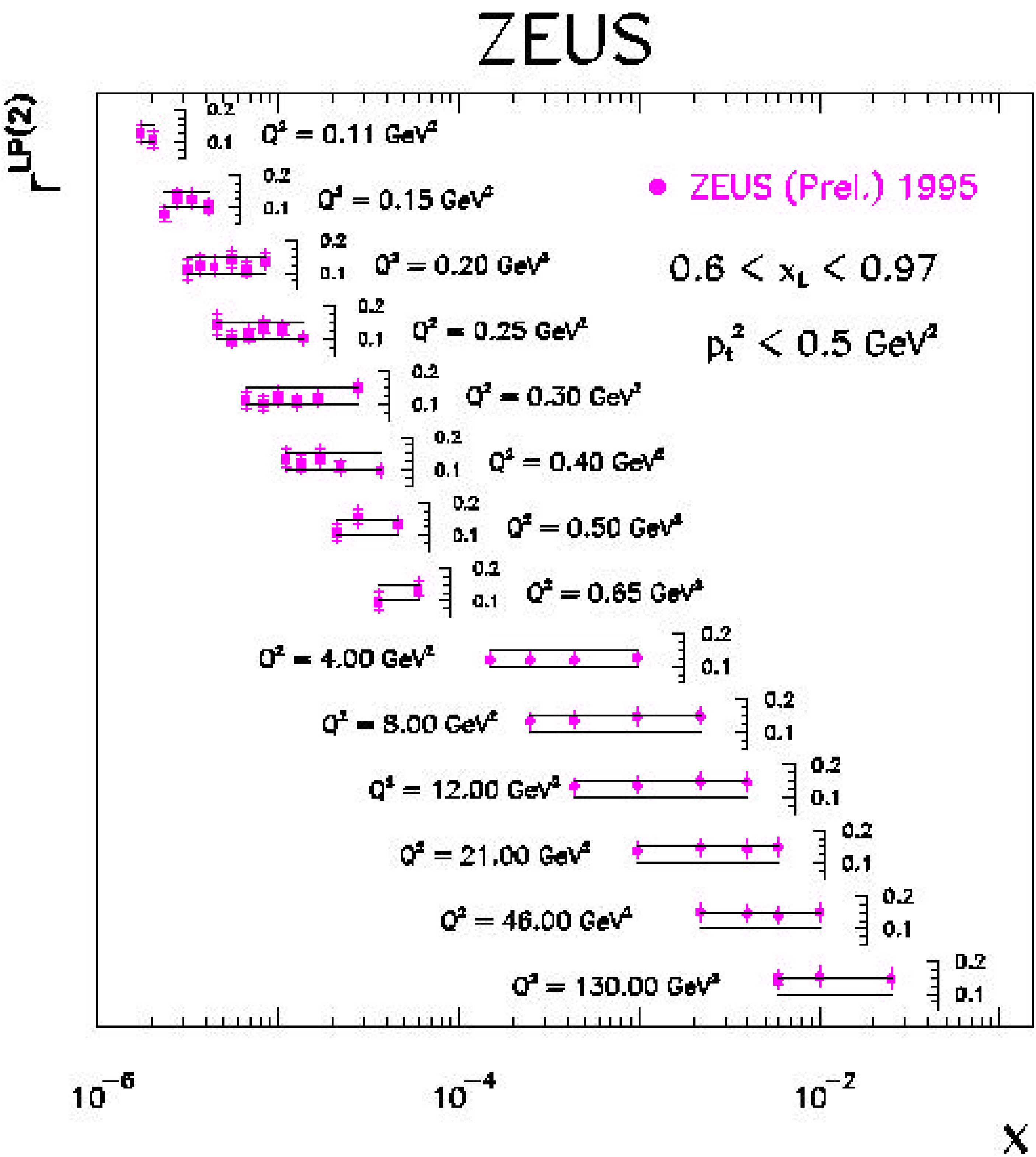
with ($0.6 < x_L < 0.97$ and $p_t^2 < 0.5$ GeV^2)

$$r^{LP(2)}\left(x,Q^2\right)=\frac{\overline{F}_2^{LP(2)}\left(x,Q^2\right)}{F_2\left(x,Q^2\right)}$$

where

$$\overline{F}_2^{LP(2)}\left(x,Q^2\right)=\int_{\Delta p_t^2}dp_t^2\int_{\Delta x_L}dx_L\,F_2^{LP(4)}\left(x,Q^2,x_L,p_t^2\right)$$

$r^{LP(2)}$ for LPs



No strong Q^2 or x dependence.

F_2 and $\overline{F}_2^{LP(2)}$ have similar (x,Q^2) dependence.

Experimental observable $r^{LP(3)}$

Fraction of events with a leading proton:

$$r^{LP(3)}\left(x, Q^2; x_L\right) = \frac{N^{LP}\left(x, Q^2; x_L, \Delta p_t^2\right)}{N\left(x, Q^2\right)} \frac{1}{\varepsilon_{LPS}\left(x_L, p_t^2\right)}$$

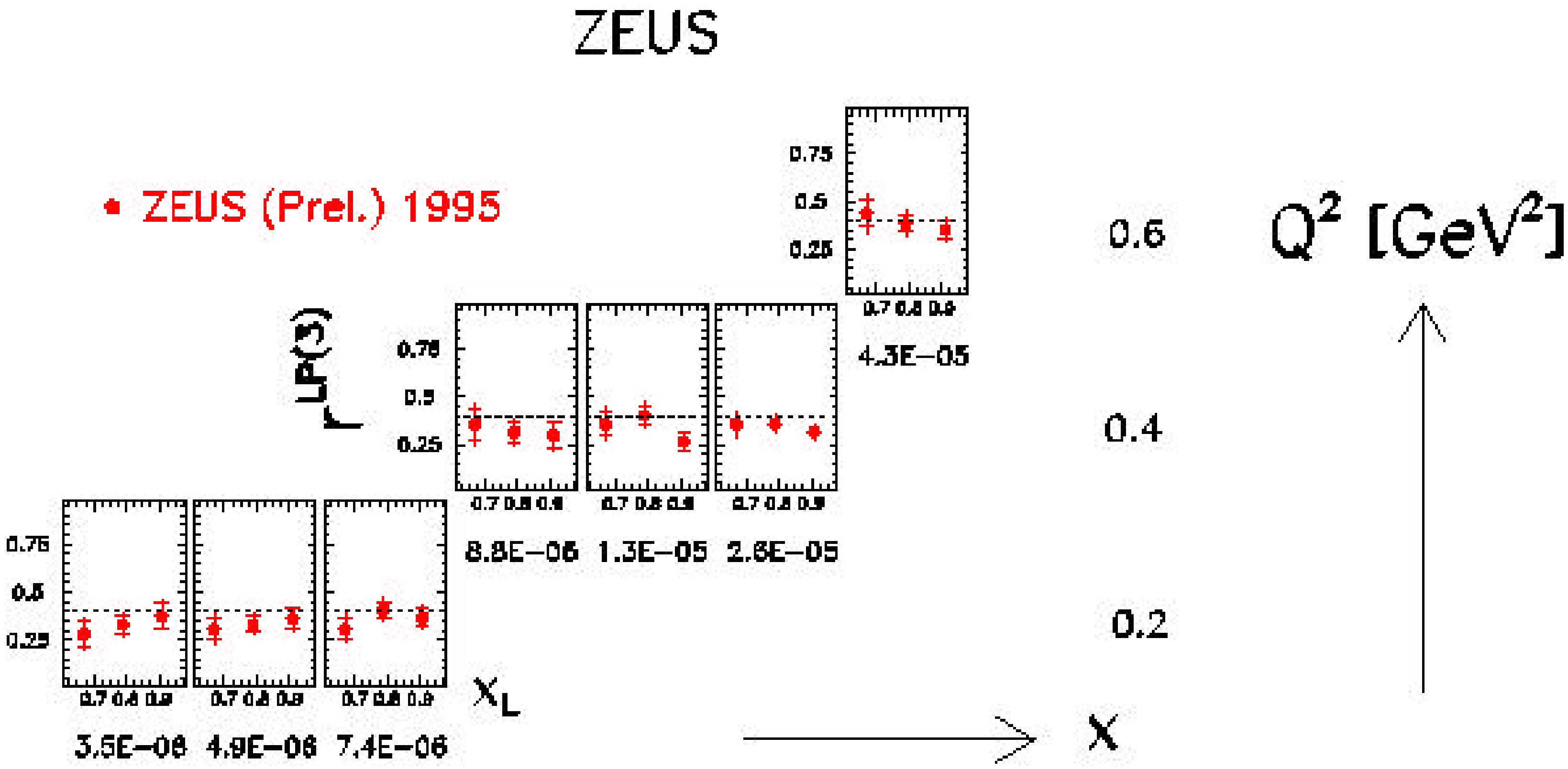
with ($0.6 < x_L < 0.97$ and $p_t^2 < 0.5$ GeV^2)

$$r^{LP(3)}\left(x, Q^2; x_L\right) = \frac{\overline{F}_2^{LP(3)}\left(x, Q^2; x_L\right)}{F_2\left(x, Q^2\right)}$$

where

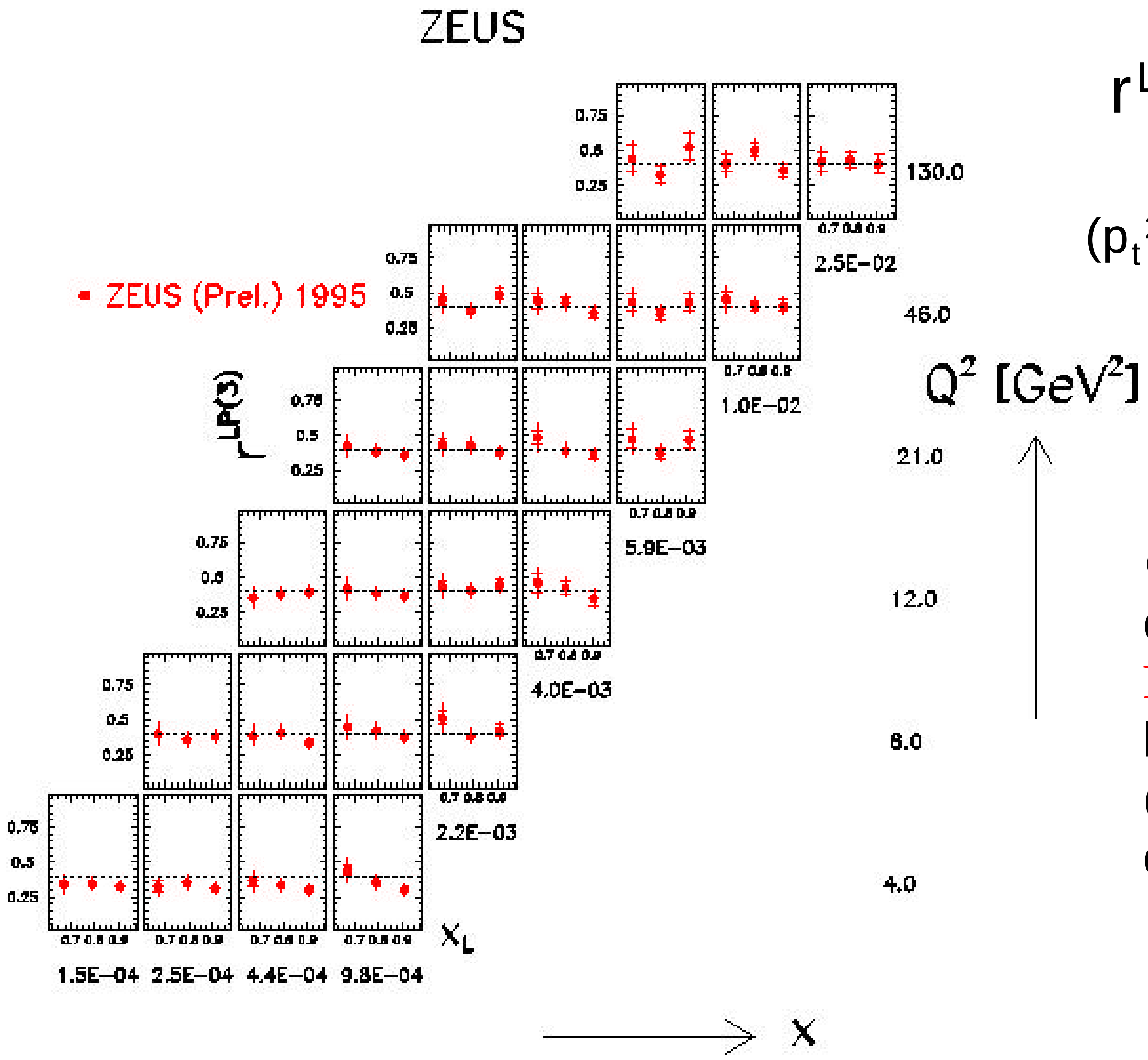
$$\overline{F}_2^{LP(3)}\left(x, Q^2; x_L\right) = \int_{\Delta p_t^2} dp_t^2 \; F_2^{LP(4)}\left(x, Q^2, x_L, p_t^2\right)$$

$r^{LP(3)}$ BPC sample ($p_t^2 < 0.5$ GeV^2)



No strong Q^2, x or x_L dependence.

F_2 and $\overline{F}_2^{LP(3)}$ have similar (x,Q^2) dependence.

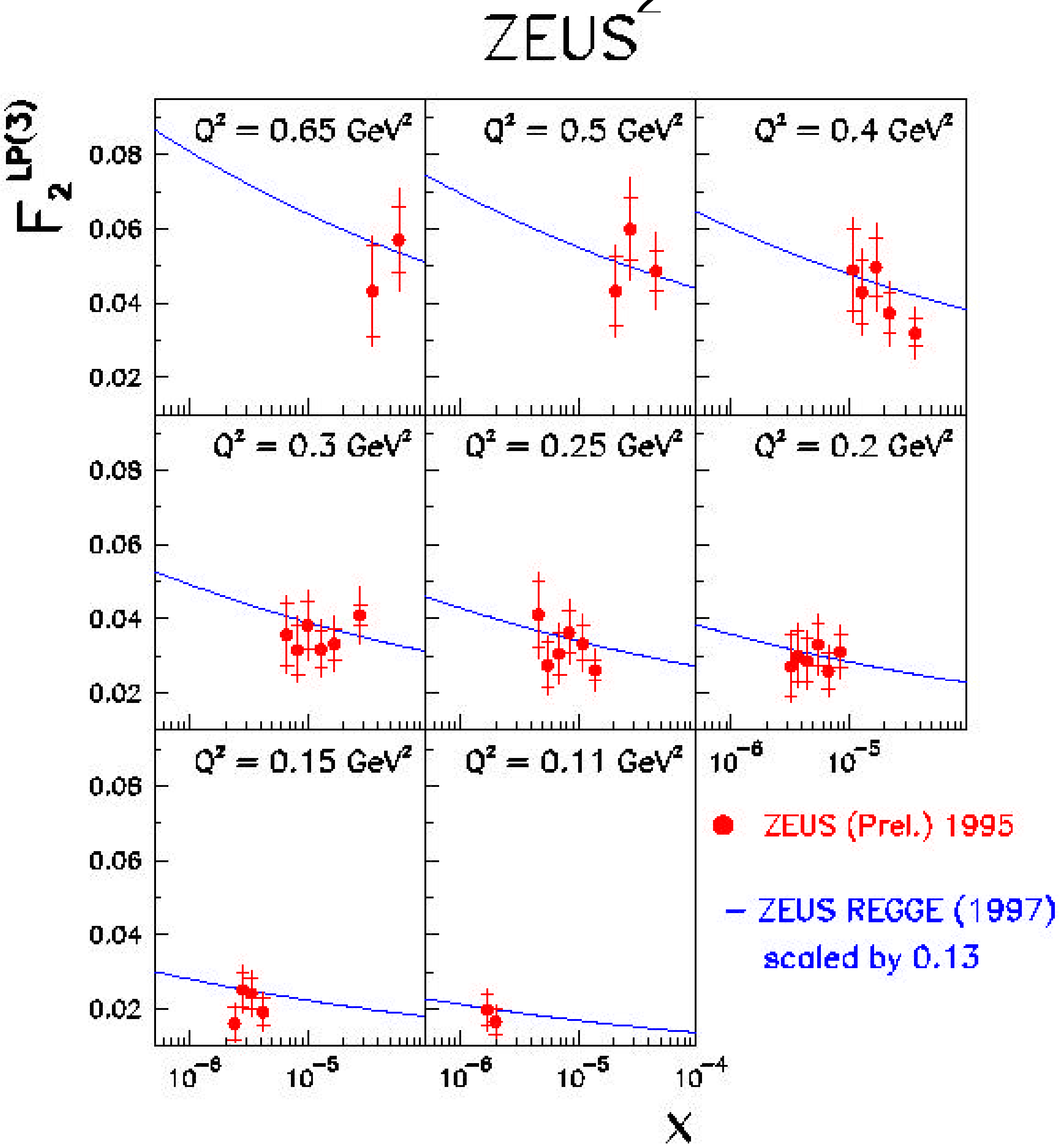


$r^{LP(3)}$ DIS sample

($p_t^2 < 0.5$ GeV^2)

No strong Q^2, x or x_L dependence. F_2 and $\overline{F}_2^{LP(3)}$ have similar (x,Q^2) dependence.

$F_2^{LP(3)}$ BPC sample

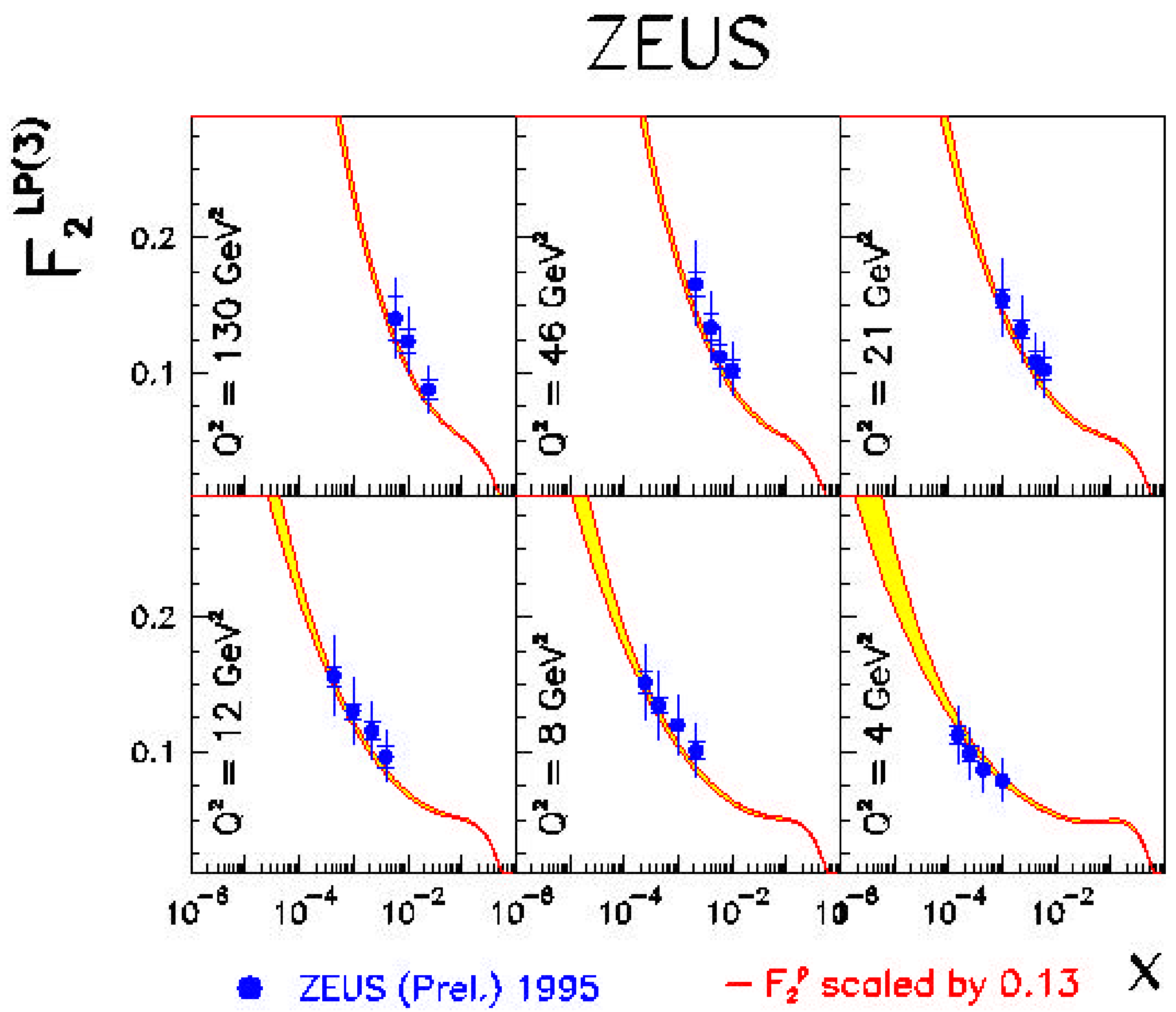


Ratio multiplied by a parameterization of the measured F_2

ZEUS Regge = Fit to published ZEUS low Q^2 F_2 data

Parameterization scaled down to 0.13 describes the trend of the data

$F_2^{LP(3)}$ DIS sample

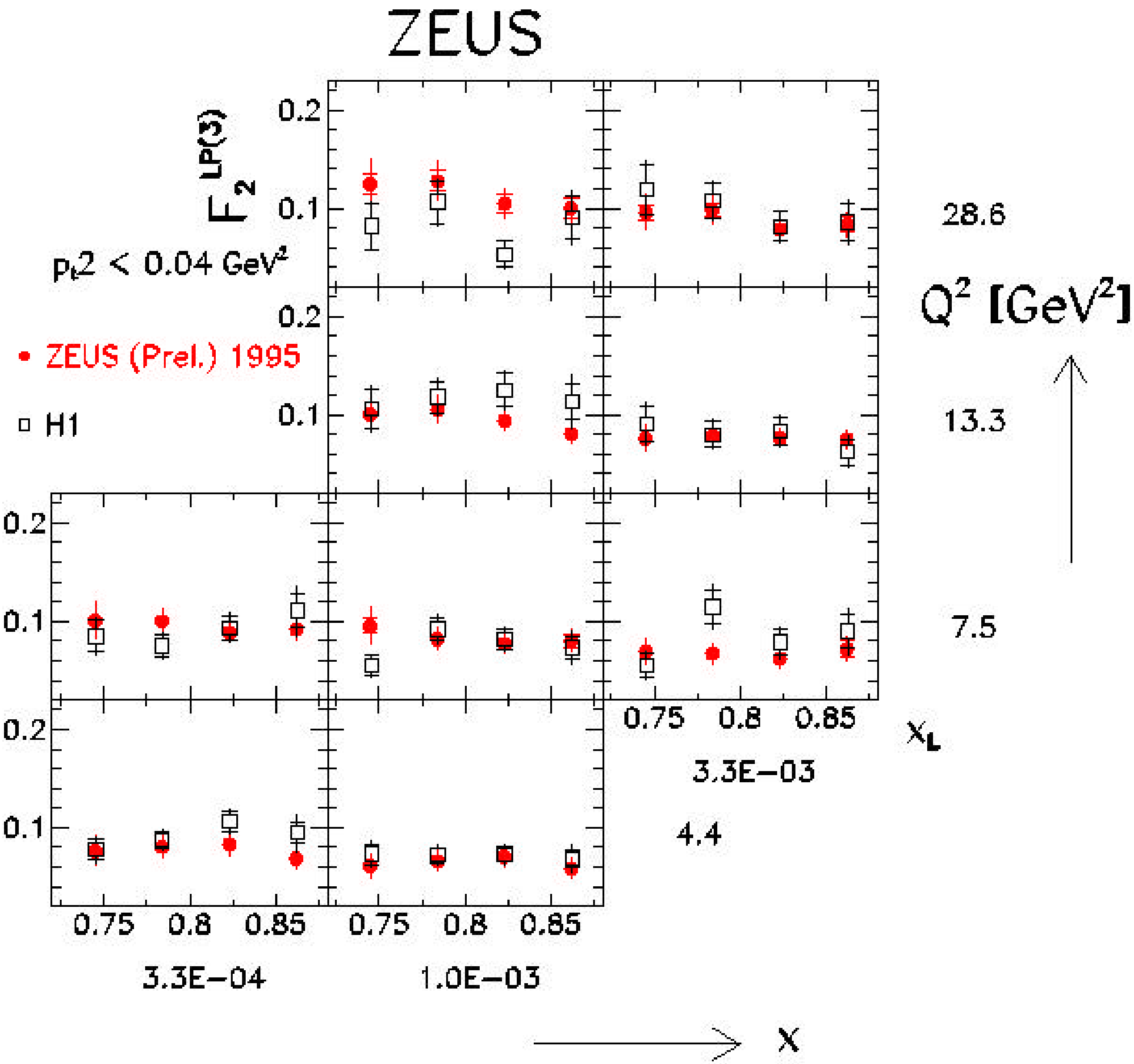


Ratio multiplied by a parametrization of the measured F_2 (M.Botje QCD fit)

F_2 scaled by 0.13

follows the data but higher Q^2 seems to prefer higher values.

$F_2^{LP(3)}$ ZEUS-H1 comparison



Restricting the kinematic range to H1 FPS:

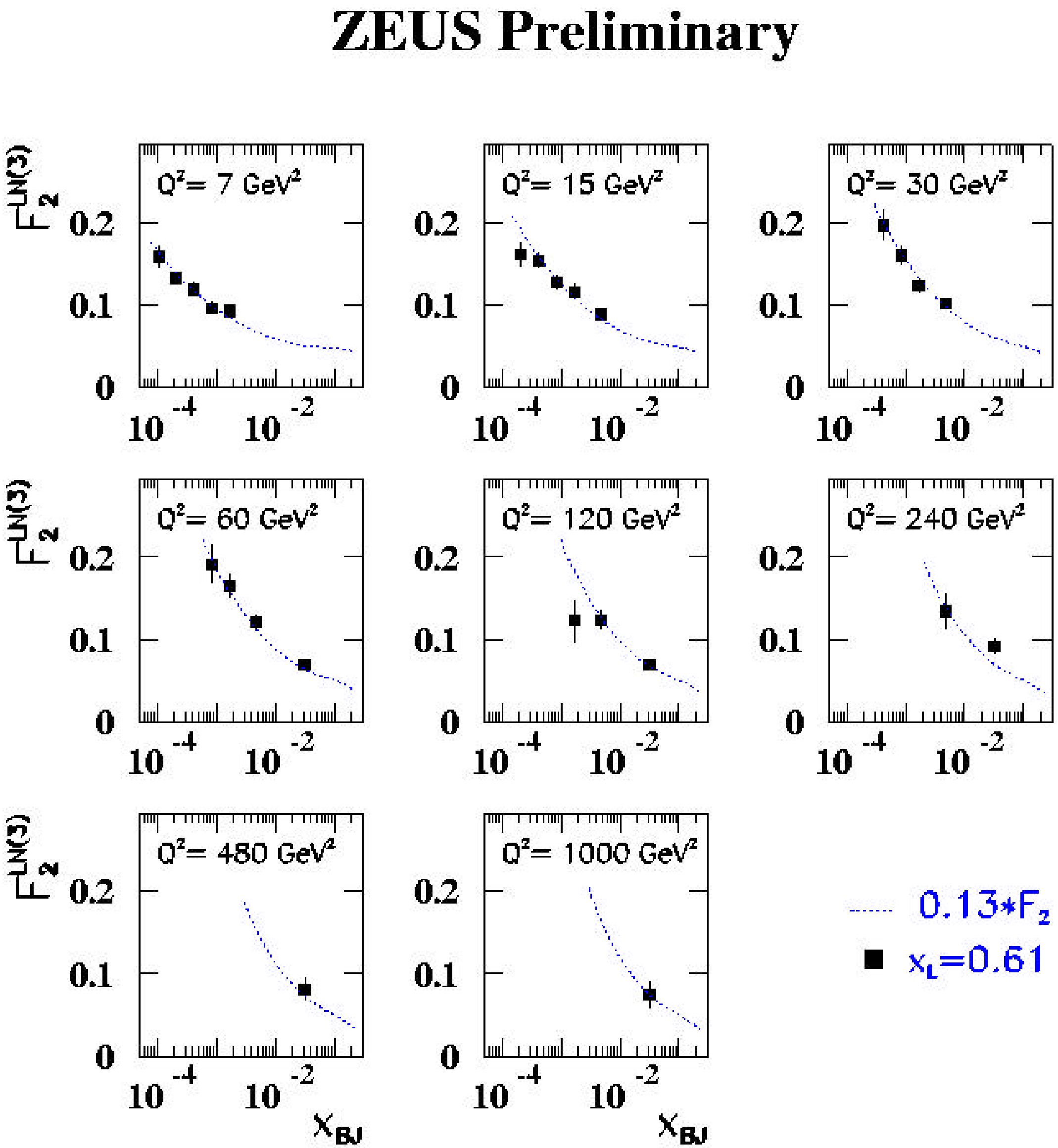
- $p_t < 200$ MeV
- $0.7 < x_L < 0.9$

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

⇓

reasonable agreement between the measurements

$F_2^{LN(3)}$ DIS sample



Ratio (p_t < 0.4 GeV) multiplied by a parametrization of the measured F_2

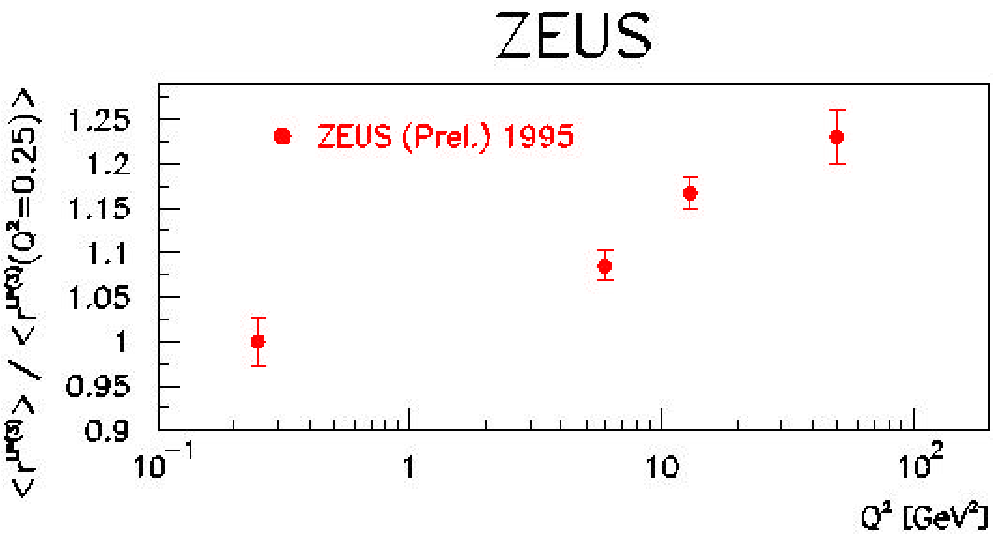
(M.Botje QCD fit)

Parametrization scaled down to 0.13 describes the trend of the data

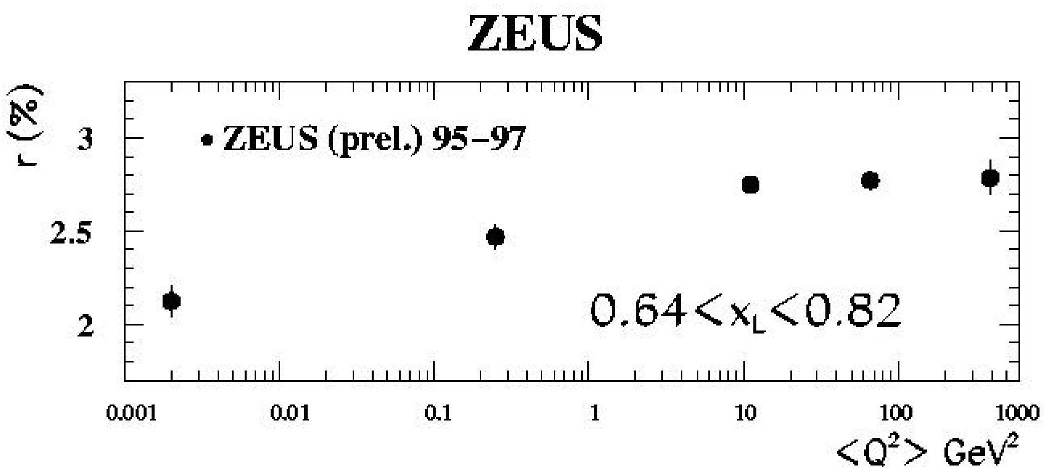
(accidental similarity with protons, different acceptance and production rates!)

Q^2 dependence of r – protons and neutrons

Averaging $r^{LP(3)}$ over x and x_L reveals a small violation of factorization: 15% for Q^2 ~ 0.1 to 100 GeV^2



LP



LN

- different evolution of F_2 and $M_2^{p/p}$ (or $M_2^{p/n}$)?
- absorptive effects in the γ^*p system (smaller γ size at higher Q^2)?

Conclusions

• r^{LP} is approx. independent of Q^2, x (and x_L) over a wide region ($0.1 < Q^2 < 254$ GeV^2 and $10^{-6} < x < 2 \cdot 10^{-2}$) suggesting factorization of proton and electron vertices;

• F_2 and F_2^{LP} ($\sim M_2^{p/p}$) have similar Q^2,x dependence and F_2^{LP} is independent of x_L

• However there is a weak dependence of r^{LP} on Q^2: 15% for Q^2 varying from 0.1 to 100 GeV^2 $\Rightarrow$ small factorization breaking ($\Rightarrow$ absorptive effects ? $\Rightarrow$ Different evolution of F_2 and F_2^{LP} ?)

• Similar effect seen in the neutrons.

Reserve transparencies

σ_{LN}/σ

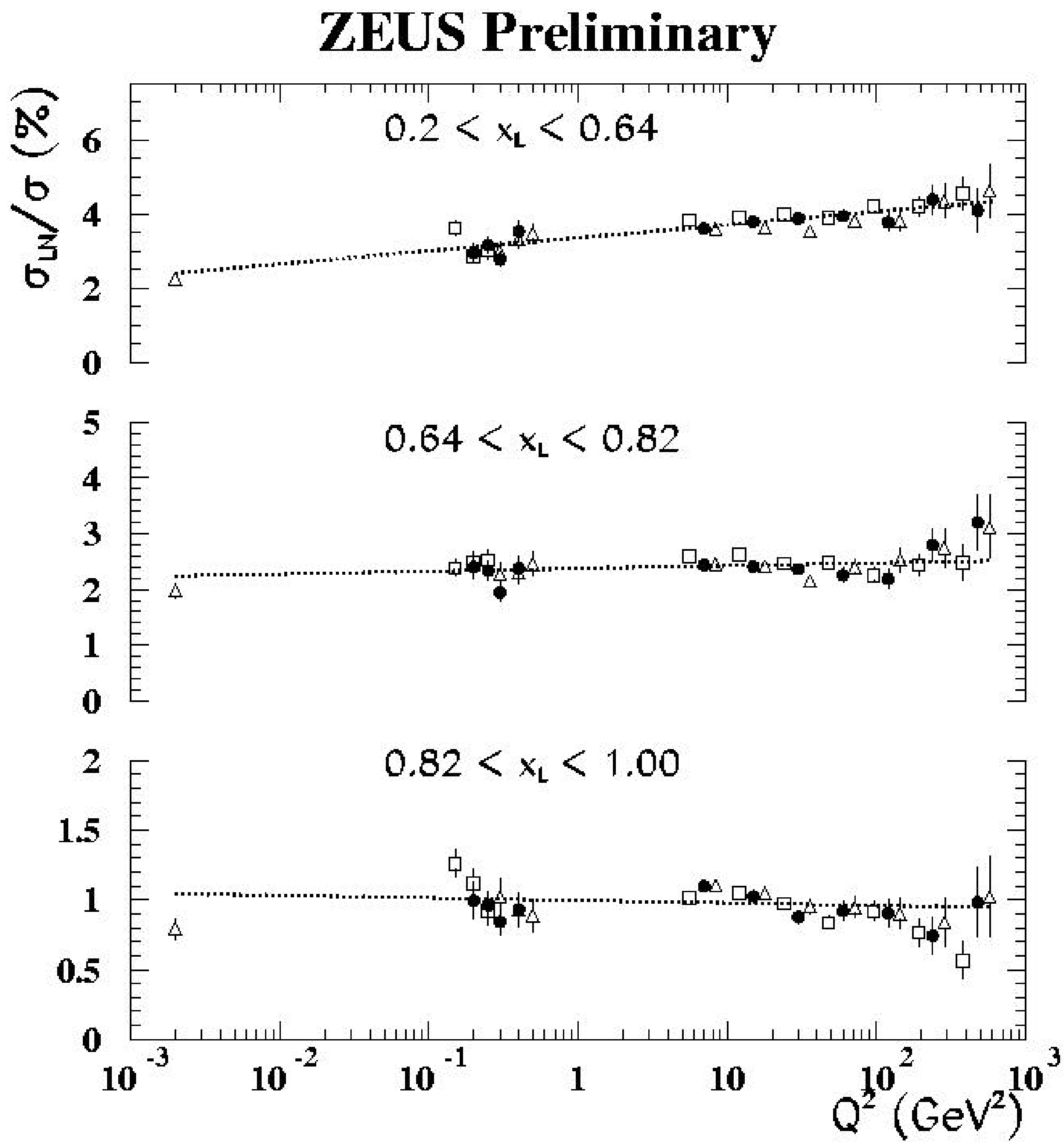
σ_{LN}/σ versus x_L and Q^2 for different y ranges

independent of y

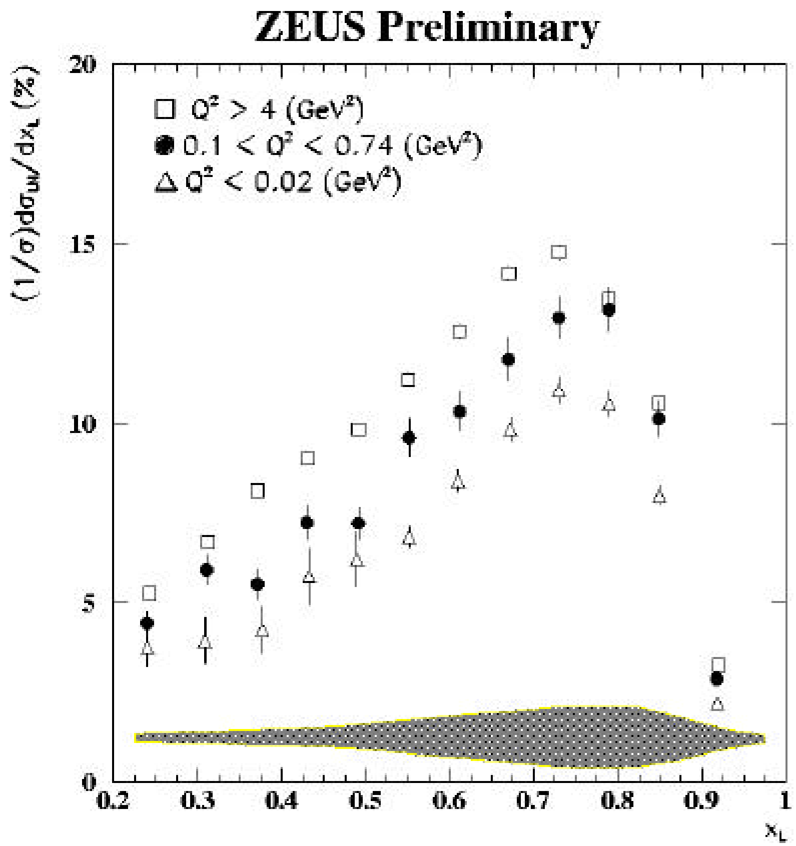
- □ $0.08 < y < 0.23$
- ● $0.23 < y < 0.37$
- △ $0.37 < y < 0.54$

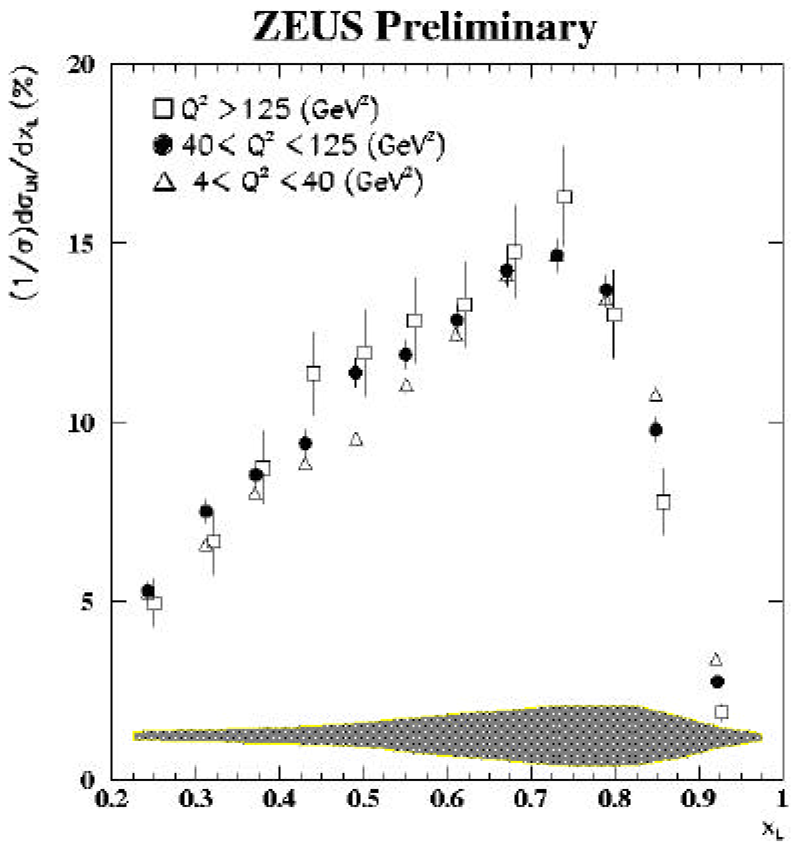
slow rise at low x_L, ~ constant for $x_L > 0.64$

line = linear fit to $\log Q^2$ including all y bins



Leading neutron spectra vs Q^2





Data integrated up to $p_t = 0.66\ x_L$

Shape is similar, but fraction of neutrons increasing with Q^2