

# LEADING PROTON PRODUCTION in DIS at HERA

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# Introduction

- Leading protons (LP) carry large fraction of proton beam-energy ( $x_L$ ) and have small transverse momentum ( $p_T$ )
- LP production mainly soft process, non perturbative-QCD
- Alternative approach needed (example: Reggeon-exchange)
- Possible implication on LHC (simulation of forward protons) and extended cosmic ray showers

## Results discussed in this talk:

Measurement of LP production in DIS ( $Q^2 > 3 \text{ GeV}^2$ ,  $45 < W < 225 \text{ GeV}$ ), for leading proton with  $0.5 < x_L < 1$  (diffractive and not-diffractive regimes) and  $p_T^2 < 0.5 \text{ GeV}^2$ :

- LP longitudinal momentum spectrum
- LP transverse momentum spectrum and slopes
- LP rate vs DIS variables  $x, Q^2$
- LP-tagged structure function
- Comparison to models and other data

# Leading proton production in ep collisions

## LP cross sections vs structure functions:

(QCD-based approach)

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

## Standard fragmentation

- LP from hadronization of p remnant
- Implemented in MC models (Cluster, Lund strings...)

## Virtual particle exchange

$\pi$ , IR, IP

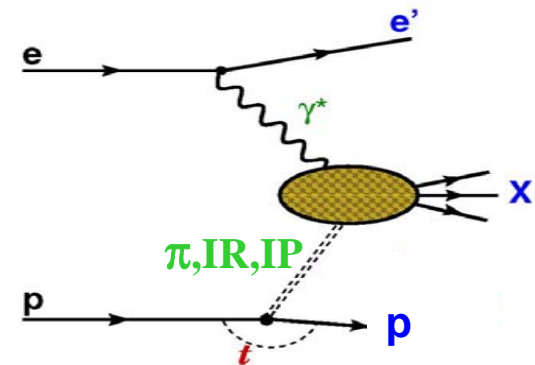
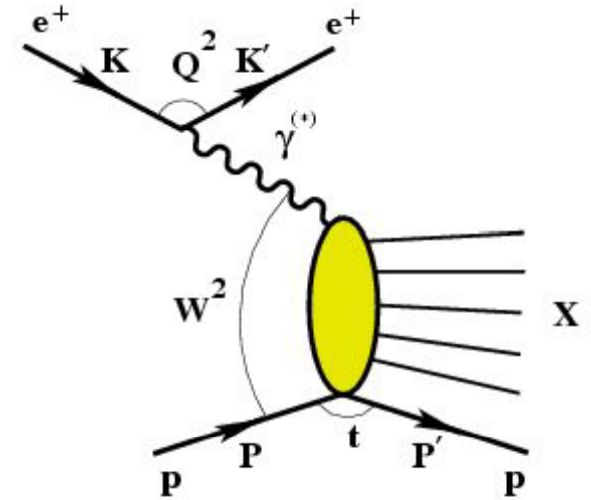
LP also from p fragmentation in double dissociative diffraction

## Kinematics

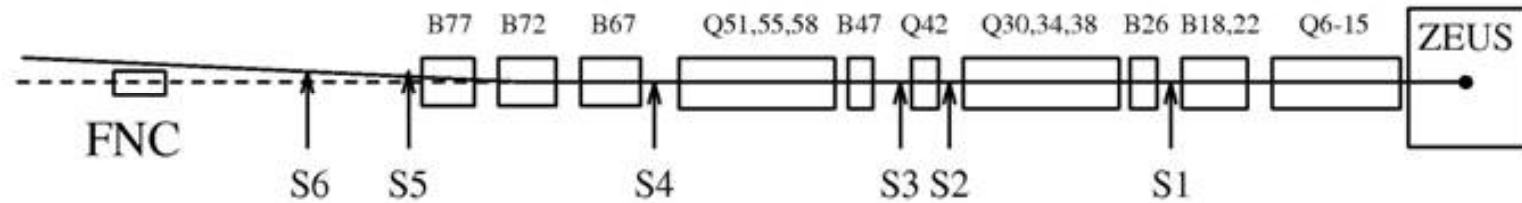
**Lepton vertex variables:**  $x$ ,  $Q^2$ ,  $(W, y)$

**LP variables:**  $p_T^2, x_L = E_{LP}/E_p$

LP and DIS variables assumed to be independent (vertex factorization) <sup>3</sup>

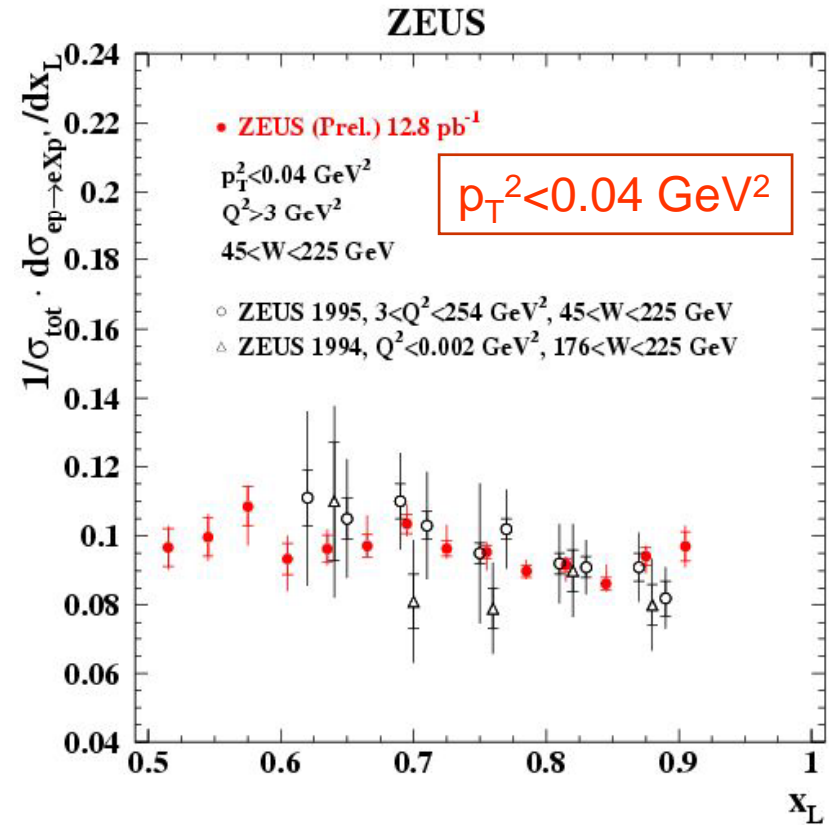
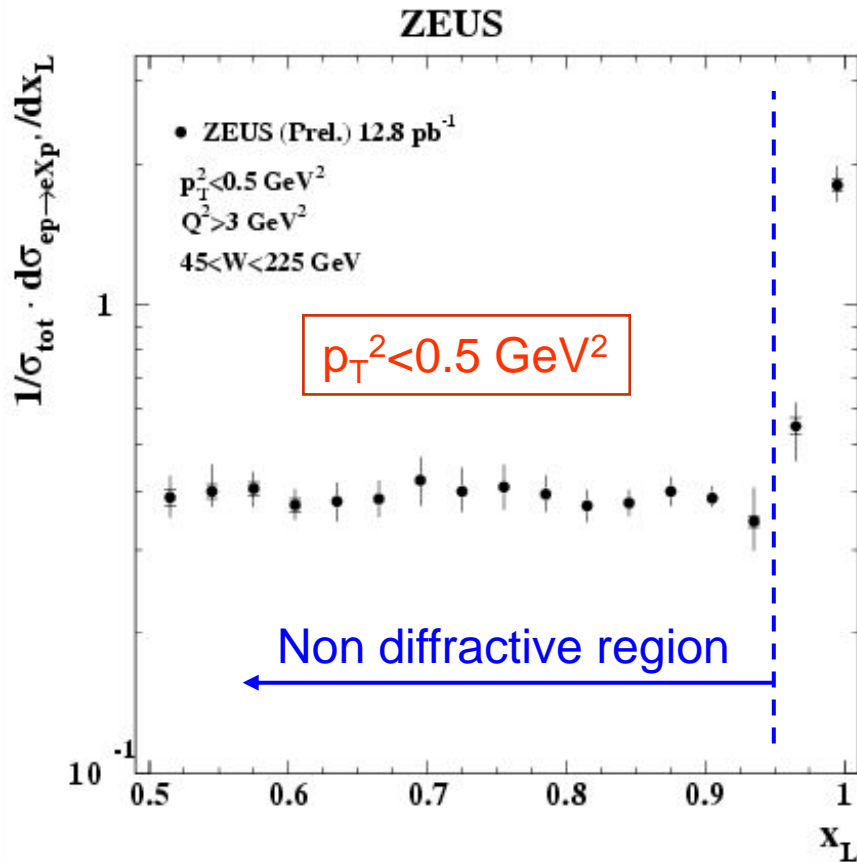


# The ZEUS Leading Proton Spectrometer (LPS)



- 6 stations (s1 → s6) each made by 6 Silicon-detector planes
- Stations positioned at 20 → 90m from I.P.
- Stations inserted at  $10\sigma_{\text{beam}}$  from the proton beam during data taking
- $\sigma_{x_L} < 1\%$   $\sigma_{p_T^2} \sim \text{few MeV}^2$  (better than p-beam spread  $\sim 50\text{-}100$  MeV)
- Full LPS set used in this analysis ( $x_L > 0.5$ , possibility to extend  $x_L > 0.32$ )

# Cross section vs $x_L$

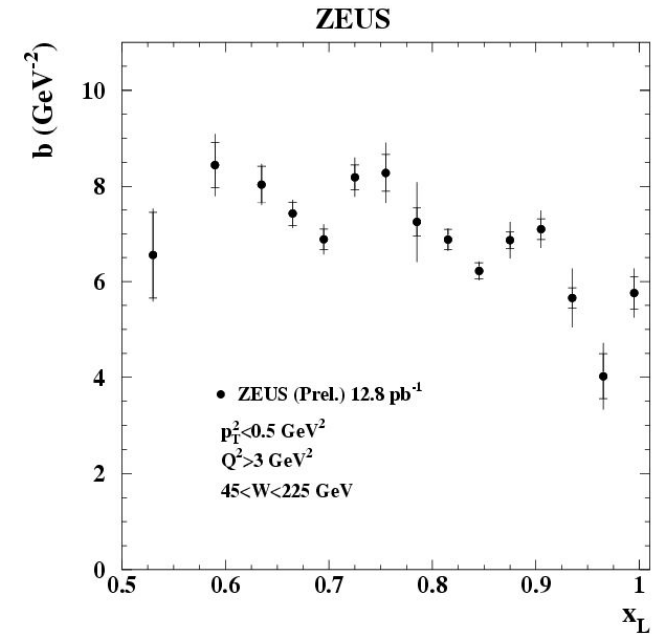
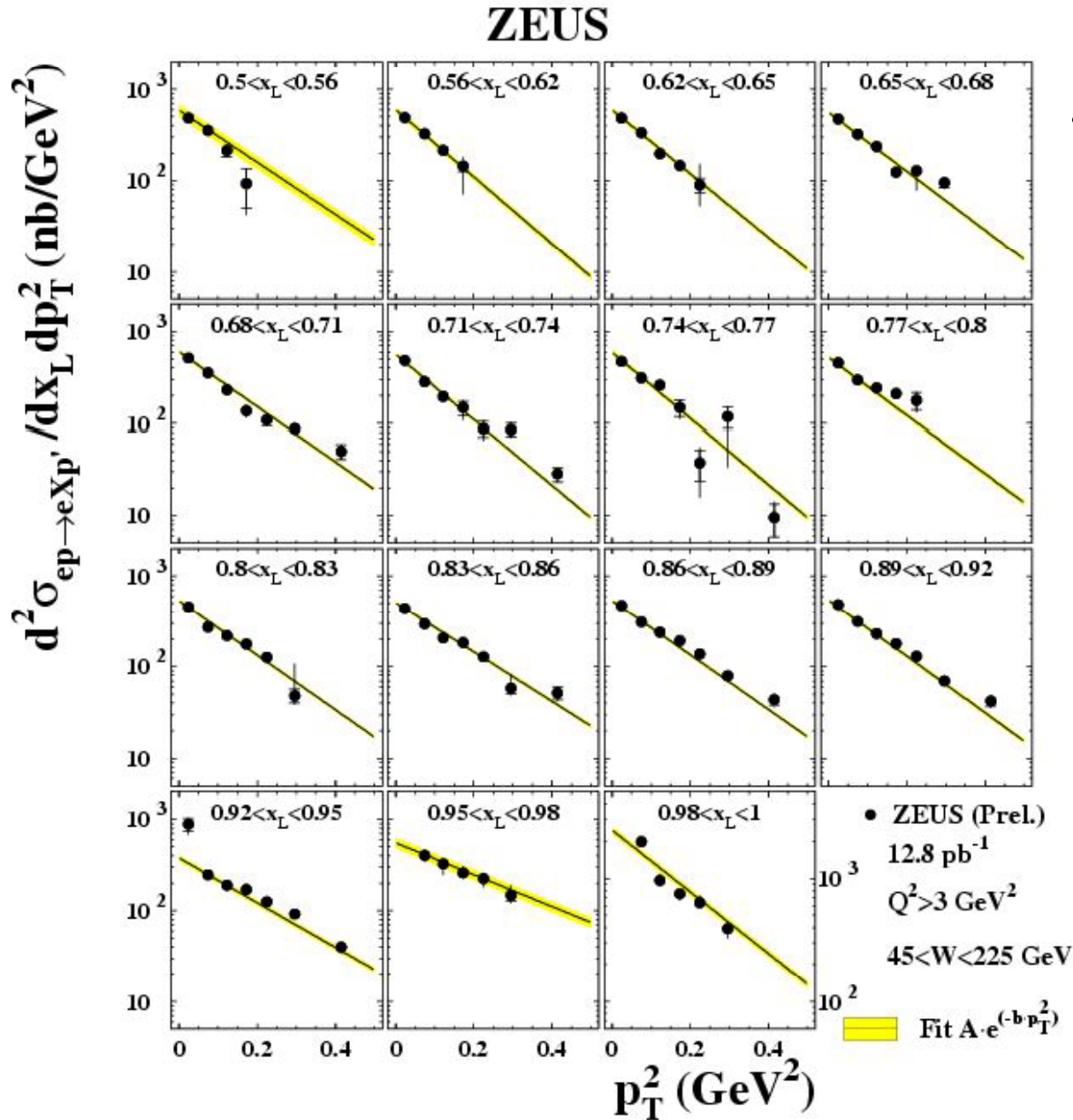


Cross section normalised to inclusive DIS cross section

DIS and photoproduction data are compatible

Flat below diffractive peak

# Cross section vs $p_T^2$ in bins of $x_L$ and slopes



Exponential behaviour

Fit to  $A \cdot \exp(-b \cdot p_T^2)$  shown with stat. error

No strong dependence of  $b$  on  $x_L$

$$\langle b \rangle \approx 6.7 \text{ GeV}^{-2}$$

# Rates to inclusive DIS

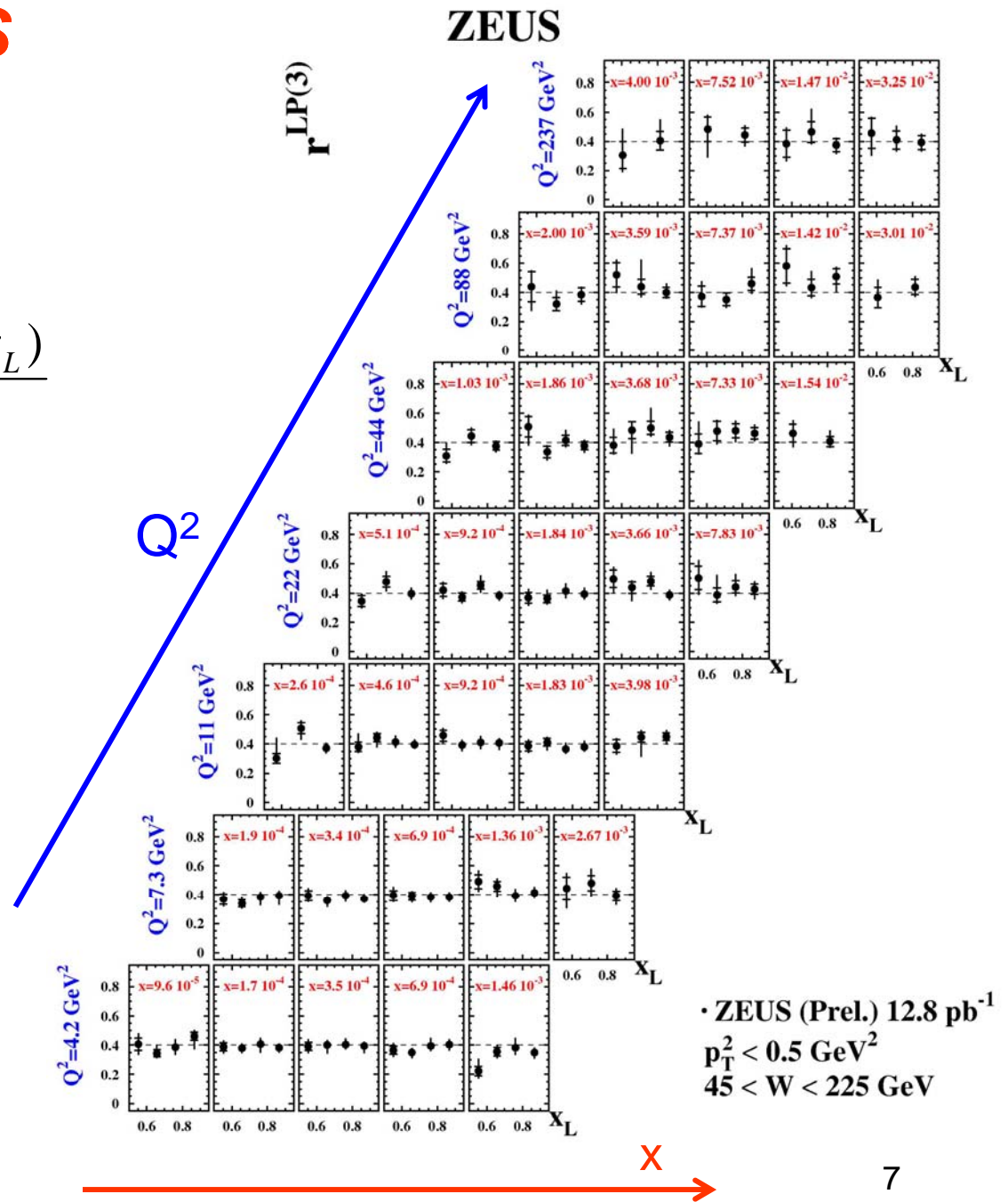
Structure function ratio

$$r^{LP(3)}(x, Q^2, x_L) = \frac{F_2^{LP(3)}(x, Q^2, x_L)}{F_2(x, Q^2)}$$

Information on LP production as a function of DIS variables

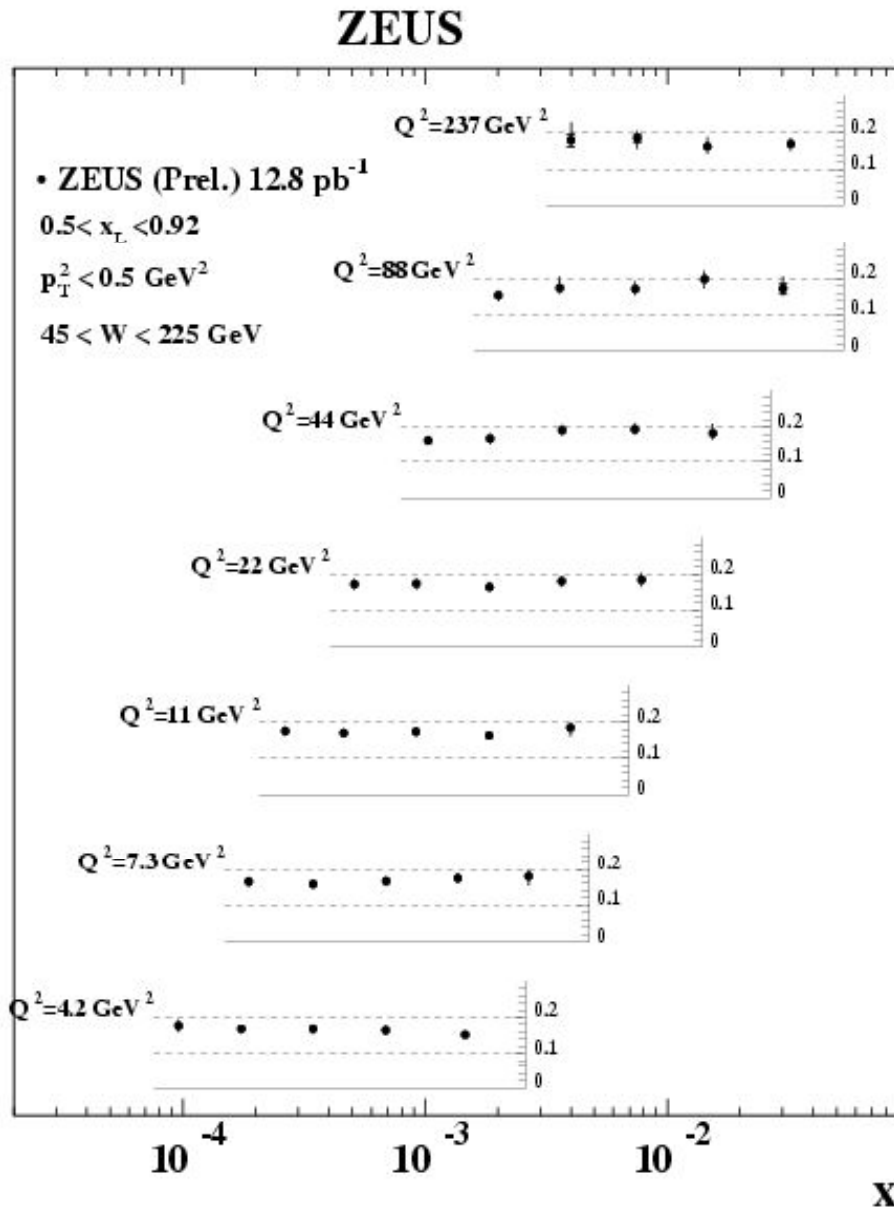
Measurement for  $0.5 < x_L < 0.92$   
(NO diffraction)

$r^{LP(3)}$  almost independent of  $x$  and  $Q^2$  with average value  $\sim 0.4$



# Rates to inclusive DIS - 2

$r^{LP(2)}$



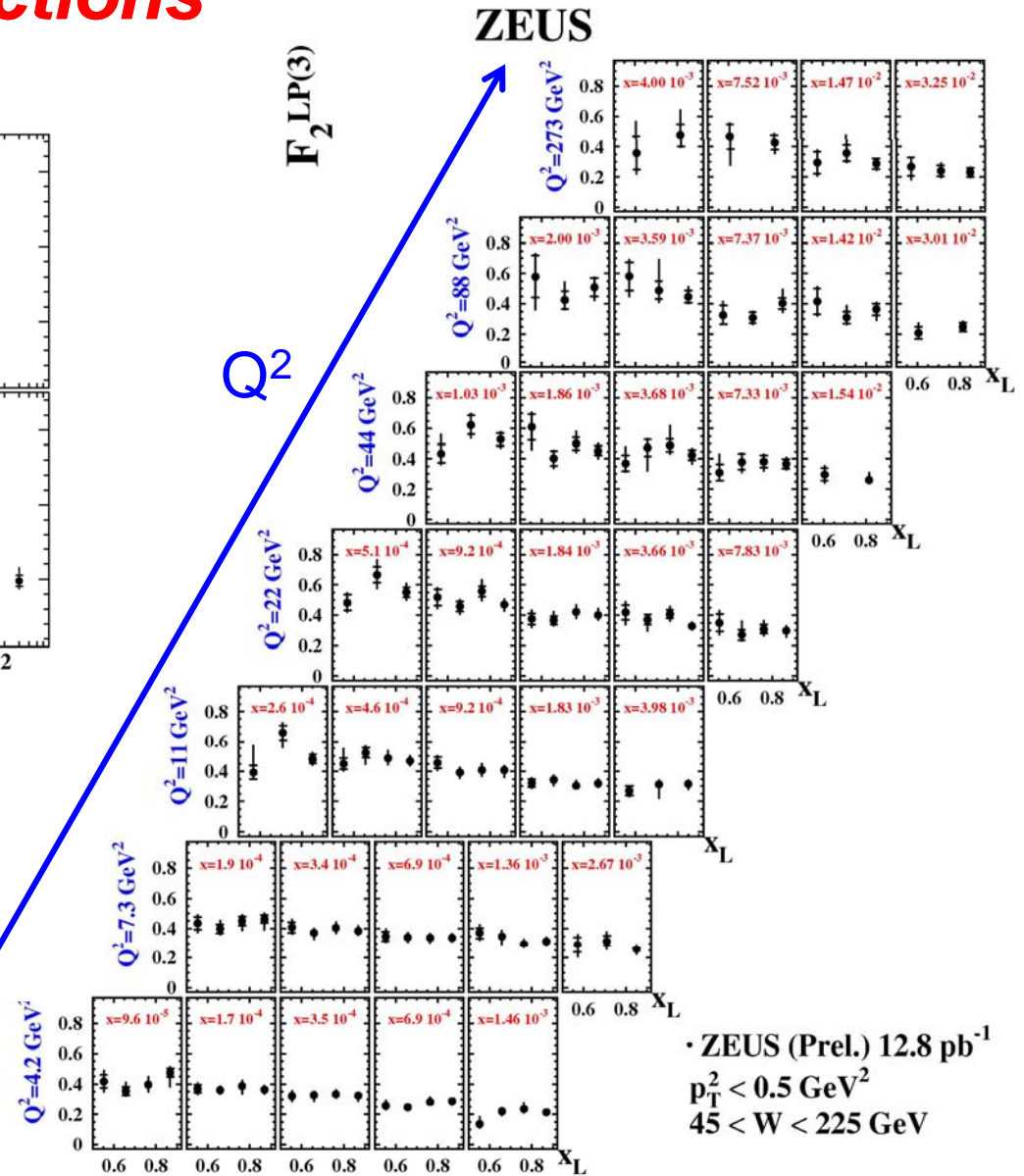
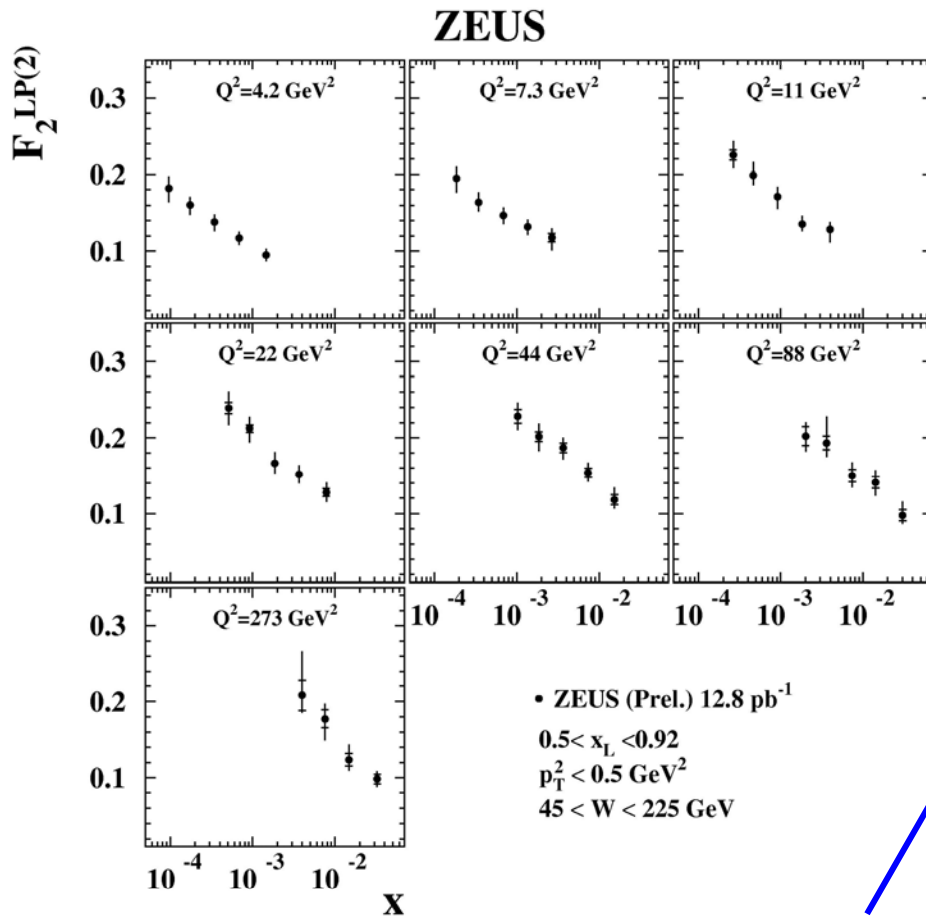
$$r^{LP(2)} = \frac{F_2^{LP(2)}(x, Q^2)}{F_2(x, Q^2)}$$

~17% of DIS events have a LP  
 with 0.5 < x<sub>L</sub> < 0.92, almost  
 independently of x and Q<sup>2</sup>

No clear evidence of vertex  
 factorization violation



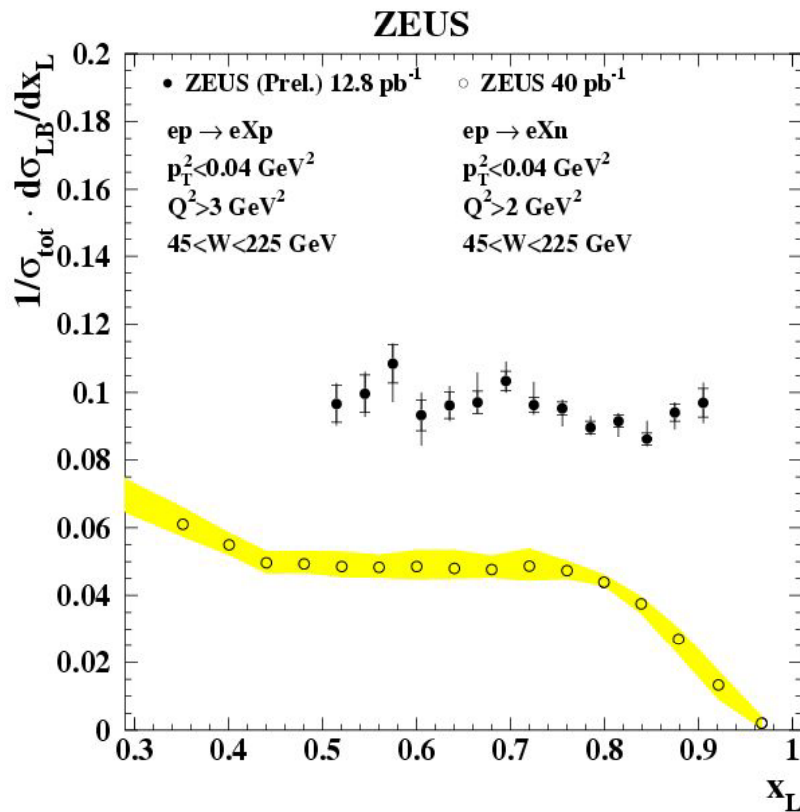
# LP-tagged structure functions



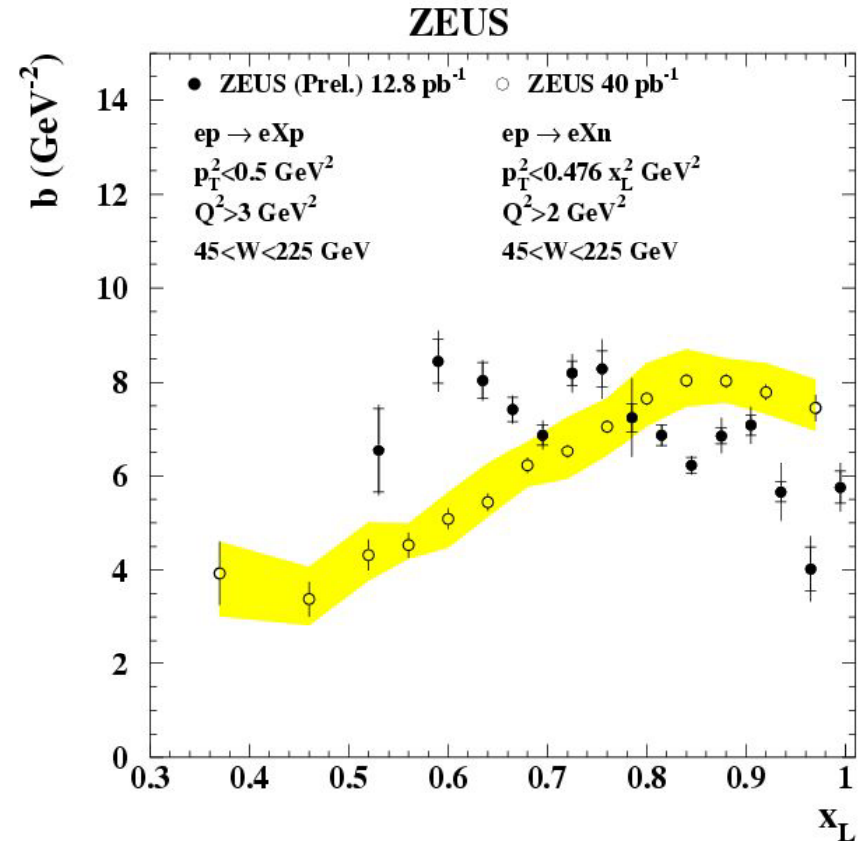
$F_2^{LP} = r^{LP} * F_2$   
 (ZEUS-S parametrization used)  
 $F_2^{LP}$ : same dependence on  $x$  and  $Q^2$  as  $F_2$



# Leading proton vs leading neutron data



Very similar behaviour  $x_L < 0.85$   
 LP cross section almost twice LN

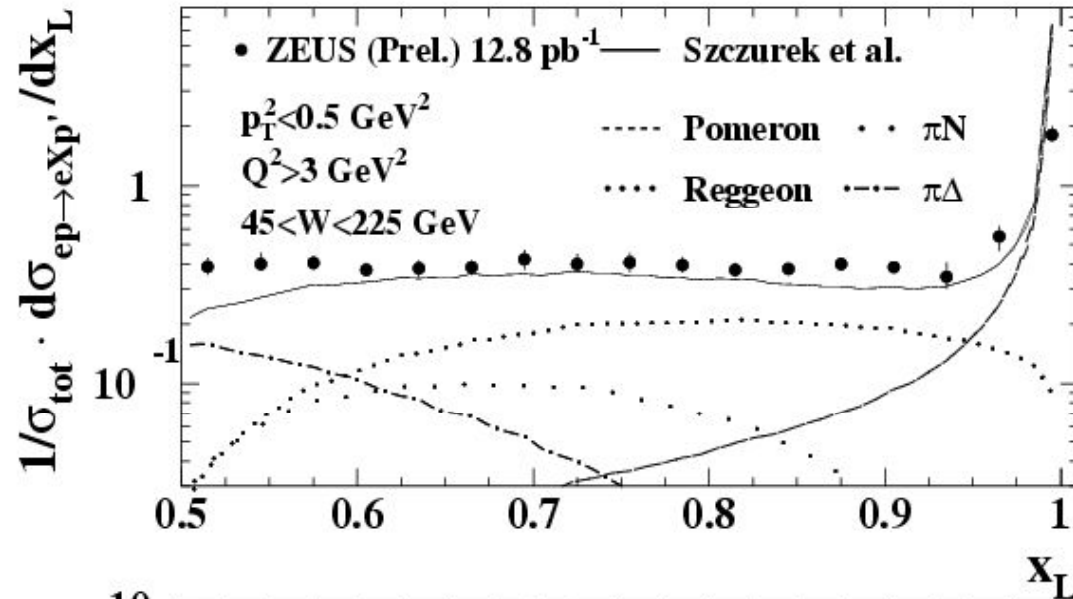


Slopes comparable  $0.7 < x_L < 0.8$   
 where  $\pi$  exchange dominates

In particle exchange model:  
 expected from isovector: LP=1/2LN  
 Other exchanges needed (isoscalars)

# Comparisons to Reggeon exchange model

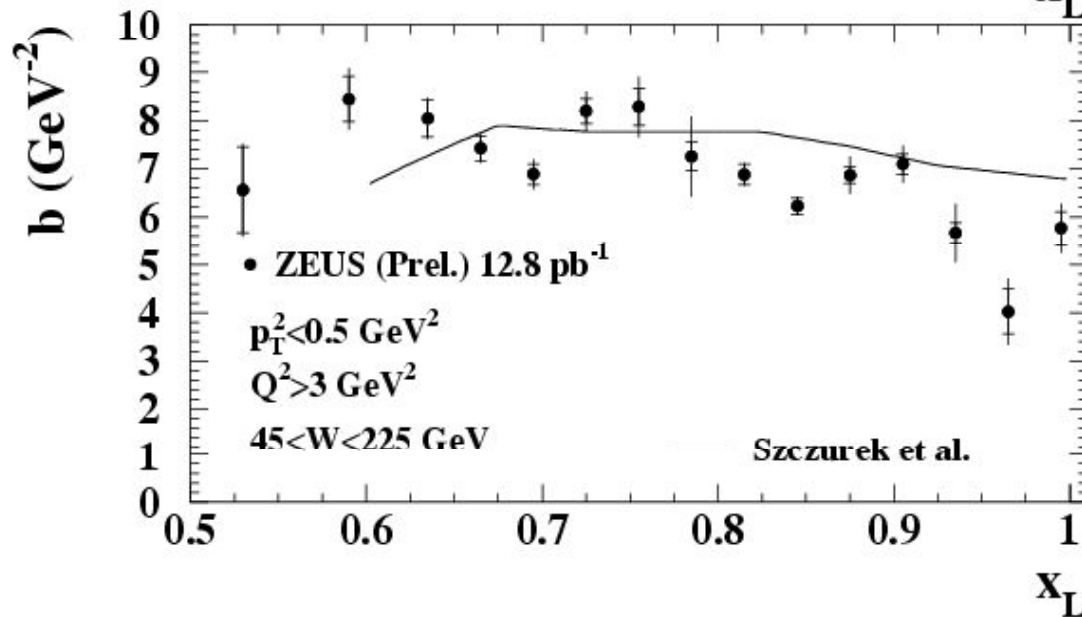
## ZEUS



Very good description in shape

$x_L$  slightly underestimated

b-slope slightly overestimated



# Summary and conclusions

## LP production measured in DIS:

- Cross section vs  $x_L$  flat below the diffractive peak
- LP cross section vs  $p_T^2$  falls exponentially with a mean slope  $\sim 6.7 \text{ GeV}^{-2}$ , approximately independent on  $x_L$
- the rates  $r^{\text{LP}(2)}$  and  $r^{\text{LP}(3)}$  show no dependence on  $x$  and  $Q^2$  and LP structure functions proportional to  $F_2$
- No evidence of vertex factorization violation
- LP and LN: agreement with expectations from particle-exchange models
- A Regge-inspired model reproduces quite well the LP features