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Physics with Leading Baryons at HERA

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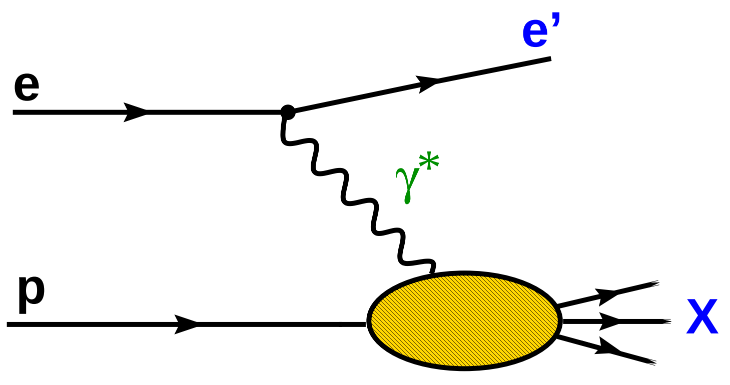
Abstracts: 479, 484, 567, 652, 786, 811

- Introduction
- γp cross-section with a Leading Proton
- Semi-inclusive structure functions
- Di-jet production
- Proton-dissociative photoproduction of ρ mesons at large t
- Conclusions

Introduction

- Possible mechanisms for production of highly energetic proton/neutron in forward direction:
  - Fragmentation of proton remnant
  - Exchange processes (proton emits a virtual particle which undergoes DIS with virtual photon).



$ep \to eX$

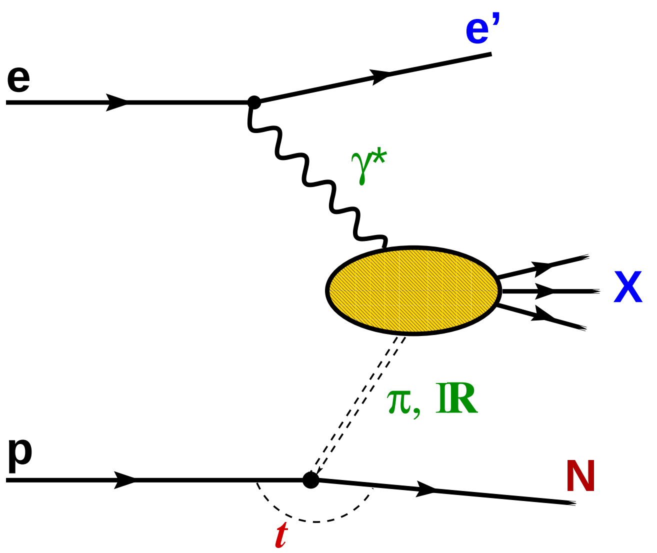
Lepton variables:

$Q^2 = -(e - e')^2$

$x_{bj} = Q^2/(2p \cdot q)$

$y = 1 - E'_e/E_e$

$W^2 = (p + q)^2$



$ep \to eXN$

Leading baryon variables:

$x_L \equiv z = E_{p,n}/E_{beam}$

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

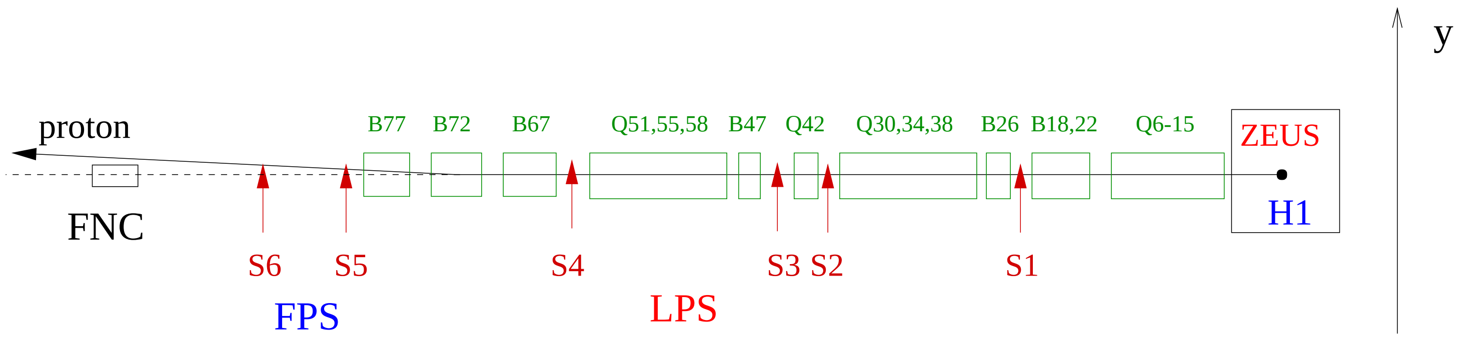
$= \frac{-p_t^2}{x_L} - \frac{m_B^2(1-x_L)^2}{x_L}$

$$\boxed{\sigma(ep \to e'NX) = f_{I\!R/p}(x_L, t) \times \sigma(eI\!R \to e'X)}$$

- Study the mechanism of leading baryon production

- Test factorization hypothesis $\rightarrow$ leading baryon production rate as function of kinematical variables.

Forward detectors at HERA



- **Dedicated detectors installed downstream in proton direction from HERA-interaction point.**

- **Acceptance limited by magnet apertures**
  - **ZEUS-LPS:** $x_L > 0.2,\ p_t < 700\ MeV$
  - **H1-FPS:** $x_L > 0.6,\ p_t < 300\ MeV$
  - **H1 and ZEUS FNC:** $\theta_n \lesssim 0.8\ mrad,\ p_t < 0.66\ x_L$

Semi-Inclusive Cross-section in Photoproduction

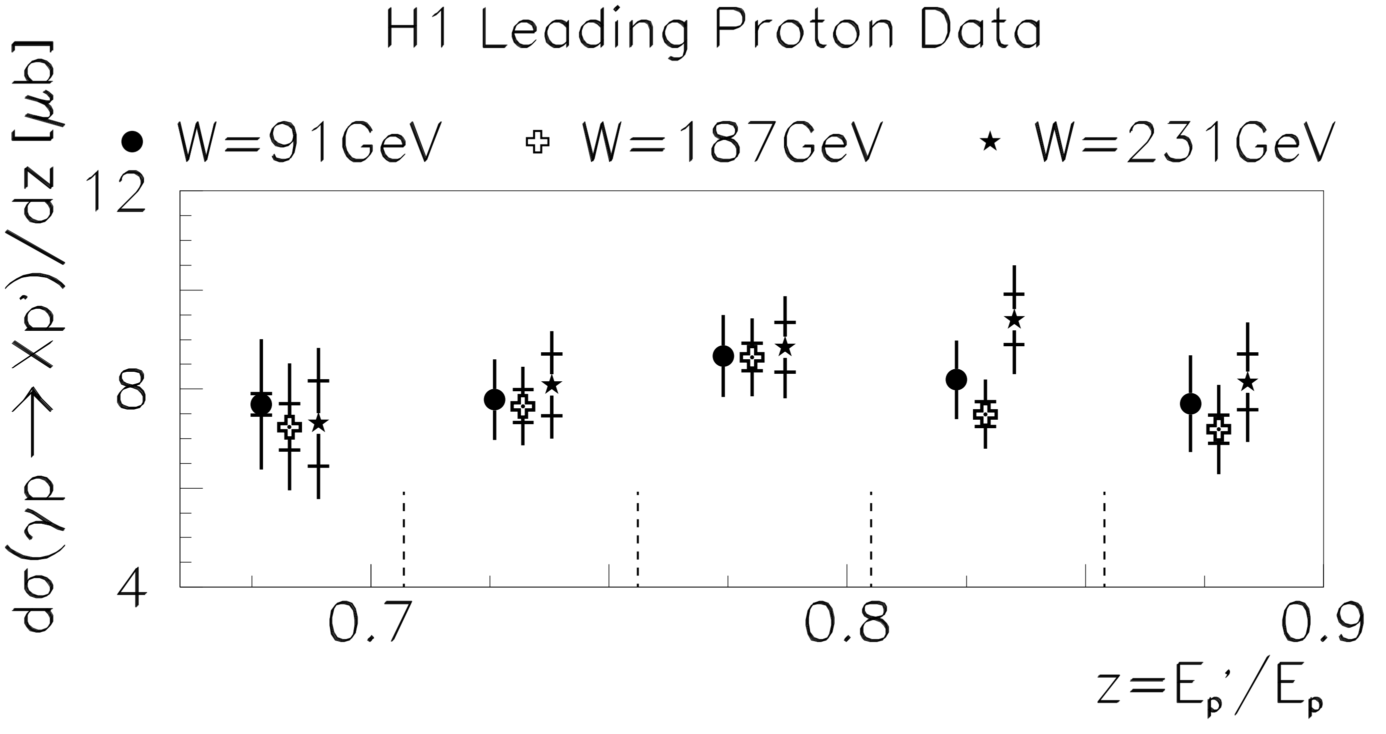
Kinematical range:

$Q^2 < 0.01\ GeV^2$

$W = \sqrt{y \cdot s} = 60 - 250\ GeV$

$x_L (\equiv z) = E'_p / E_p = 0.66 - 0.90$

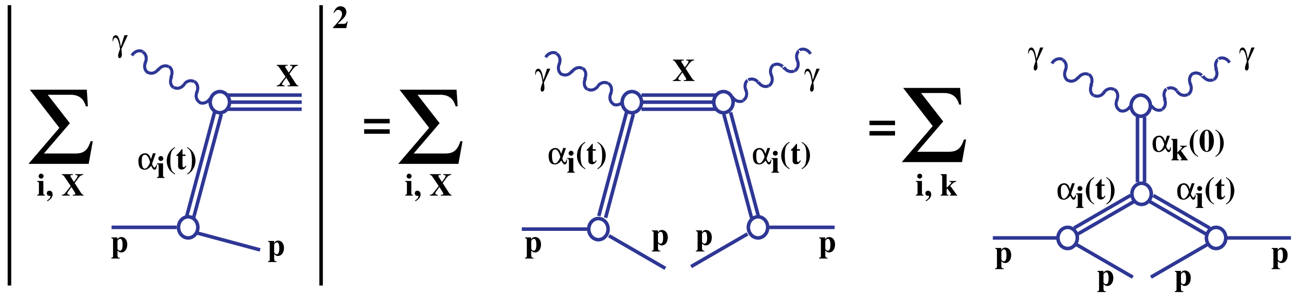
$p_t < 200\ MeV$



- **no z, W and M_X- dependence ($M_X^2 = (1-z)W^2$)**

- $d\sigma/dz = 8.05 \pm 0.06(stat) \pm 0.89(syst)\mu b$
  for $z \in [0.66, 0.90]$ and $p_t < 200\ MeV$
  ($1.17 \pm 0.02(stat) \pm 0.15(syst)\%$ of inclusive γp events)

Triple Regge parameterization $\rightarrow$ study the exchange mechanism via the W and z dependence of semi-inclusive cross-section.



$$\boxed{\frac{d\sigma}{dz} = \frac{A}{b}(e^{bt_{min}} - e^{bt_{max}})(W^2)^{2\alpha_i(0)-1}(M_X^2)^{\alpha_k(0)-2\alpha_i(0)}}$$

assuming:

-α_i effective trajectory for γp exchange,
-α_k effective trajectory for the total $\gamma I\!\!R$ cross section.
-unique t-dependence: e^{bt} with $b = b_0 - 2\alpha_i' ln(1-z)$

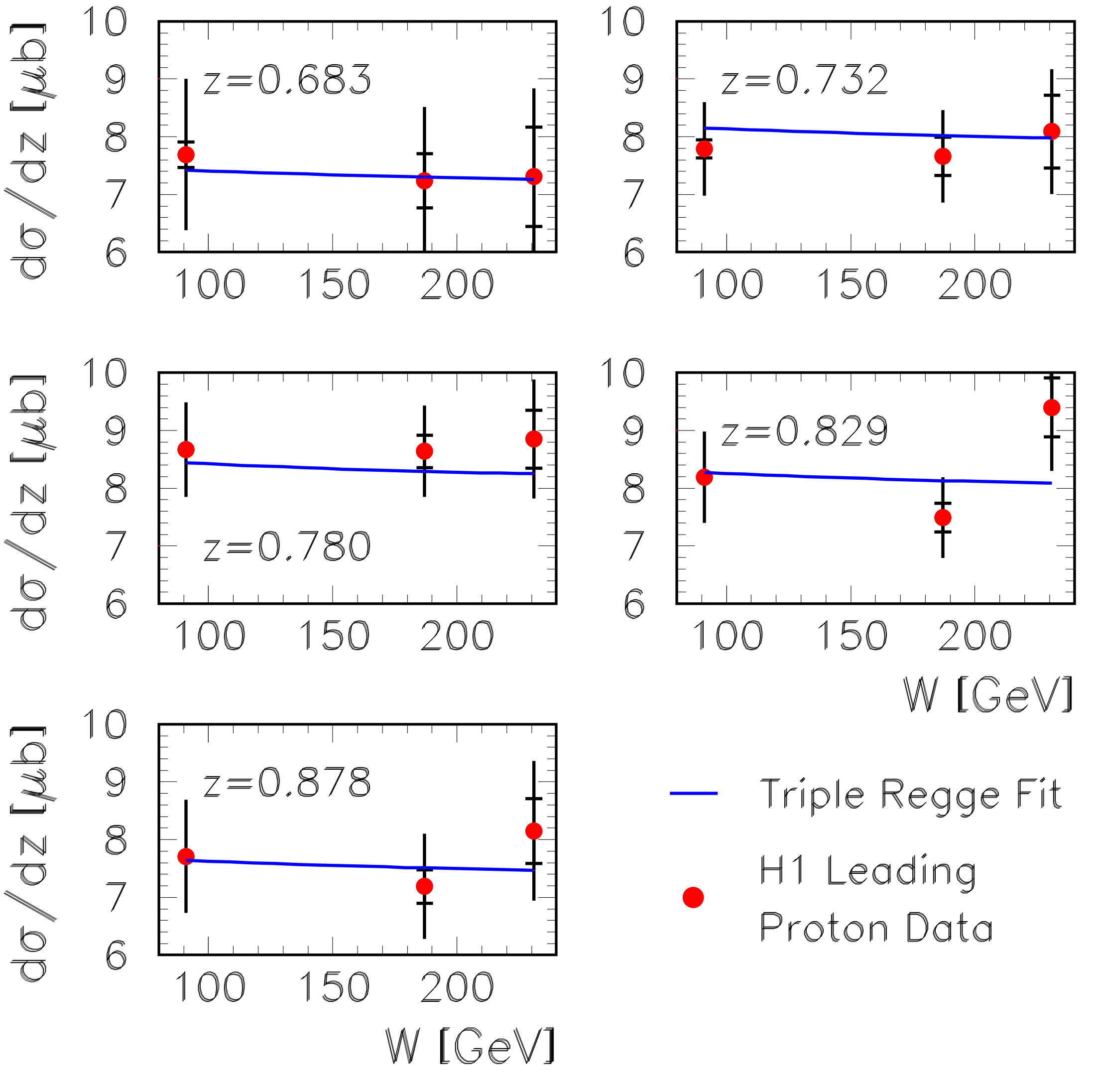
Fit results:

$\alpha_k(0) = 0.99 \pm 0.01(stat) \pm 0.05(syst)$
$\alpha_i(0) = 0.33 \pm 0.04(stat) \pm 0.04(syst)$

$b = 6.2 \pm 0.7(stat) \pm 1.5(syst)GeV^{-2}$ for $z = 0.78$
(compatible with ZEUS direct measurement:
$b = 6.8 \pm 0.8GeV^{-2}$)

Mixture of π and $I\!\!R$ exchanges dominates γp process.
($\alpha_\pi(0) \sim 0$, $\alpha_{I\!\!R}(0) \sim 0.5$).
Total cross section $\gamma(I\!\!R, \pi) \rightarrow X$ mainly by $I\!\!P$ exchange.

Measured cross sections $d\sigma/dz$ with results of triple Regge fits.



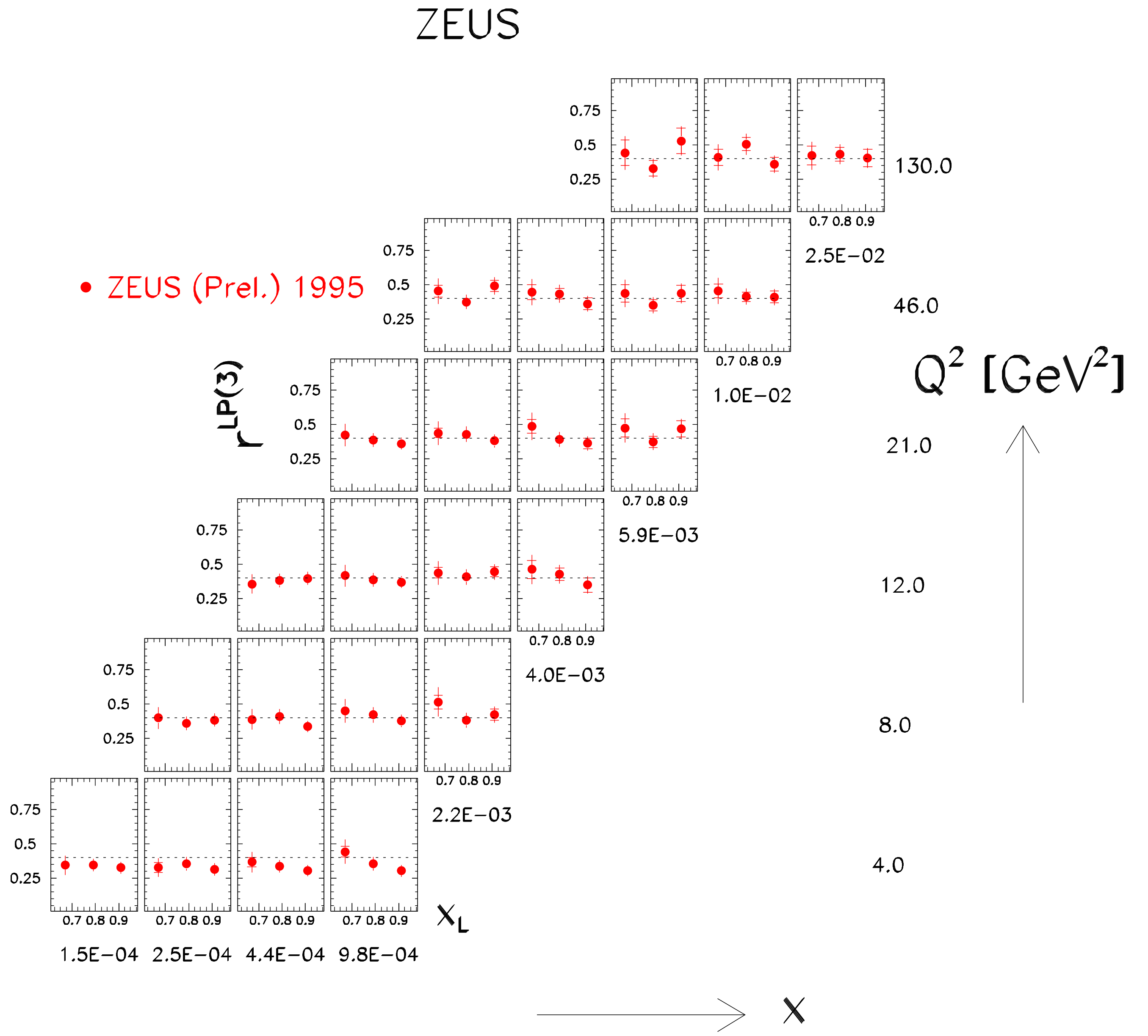
Semi-inclusive structure functions F_2^{LP}

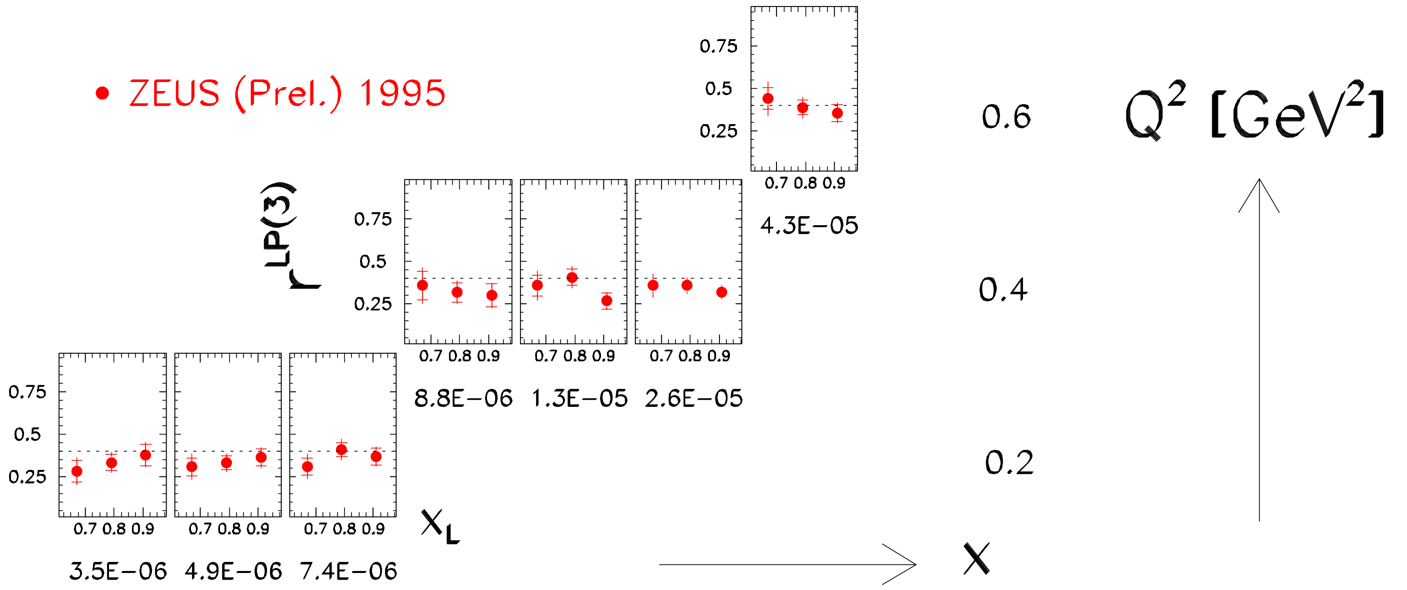
Measurement of semi-inclusive cross-sections relative to the inclusive ep cross-section in the kinematical range:
$0.1 < Q^2 < 254\ GeV^2$,
$0.6 < x_L < 0.97$,
$p_t < 700\ MeV$

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

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

$$F_2^{LP(3)}(x, Q^2; x_L) = \int dp_t^2 F_2^{LP(4)}(x, Q^2, x_L, p_t^2)$$

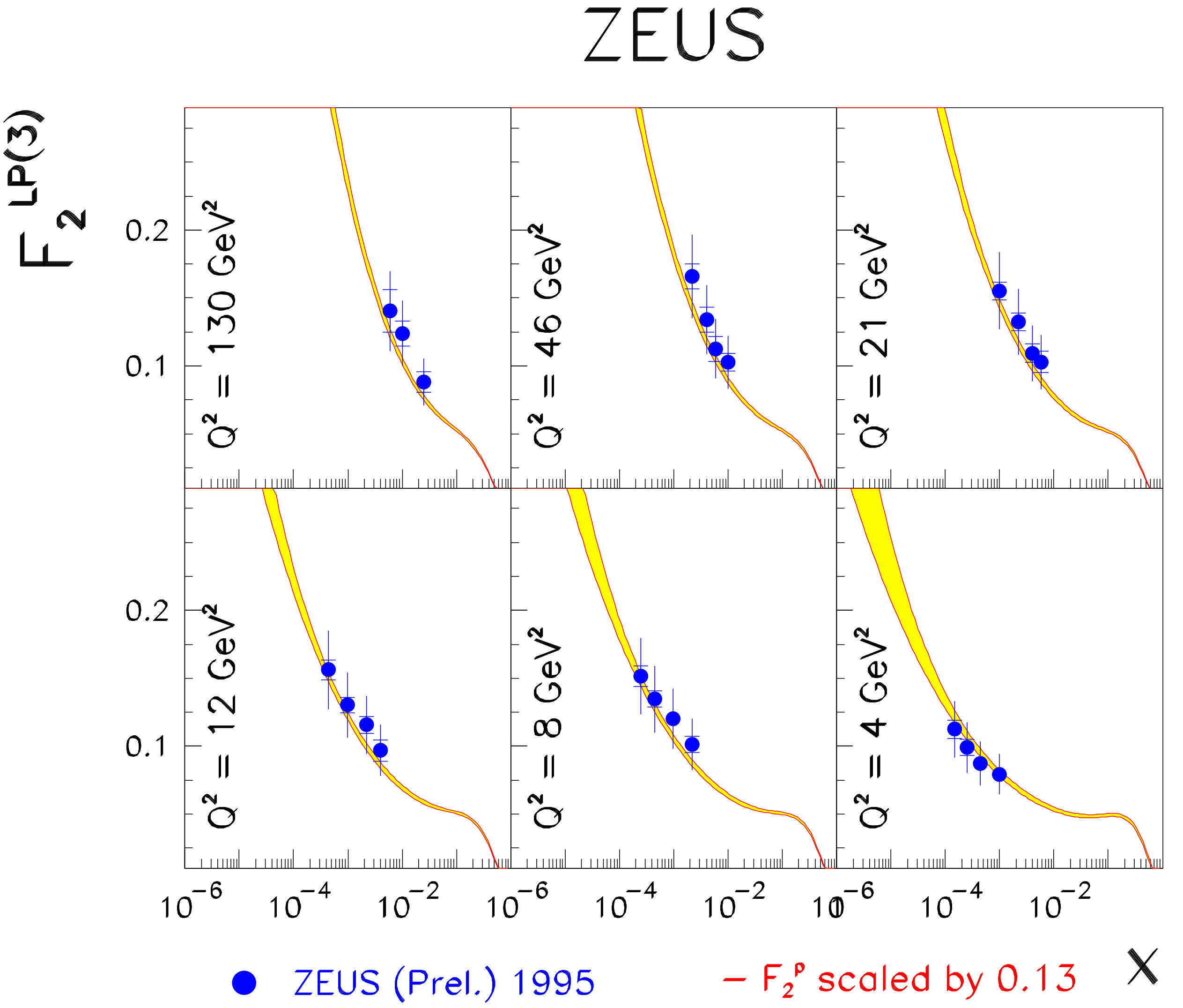




No strong dependence on x, x_L and Q^2,
F_2 and $F_2^{LP(3)}$ have similar (x, Q^2) dependence.

$F_2^{LP(3)}$ from ratios

Ratio $r^{LP(3)}$ multiplied by a parameterization of the measured F_2 (M.Botje QCD fit).



Reasonable agreement between ZEUS and H1 measurements (restricted to the kinematical range $Q^2 \in [2, 50]\ GeV^2$,$x_L \in [0.7, 0.9]$ and $p_t < 0.2\ GeV$).

F_2 follows the data but at higher Q^2 seems to be too low.

Transition photoproduction to DIS

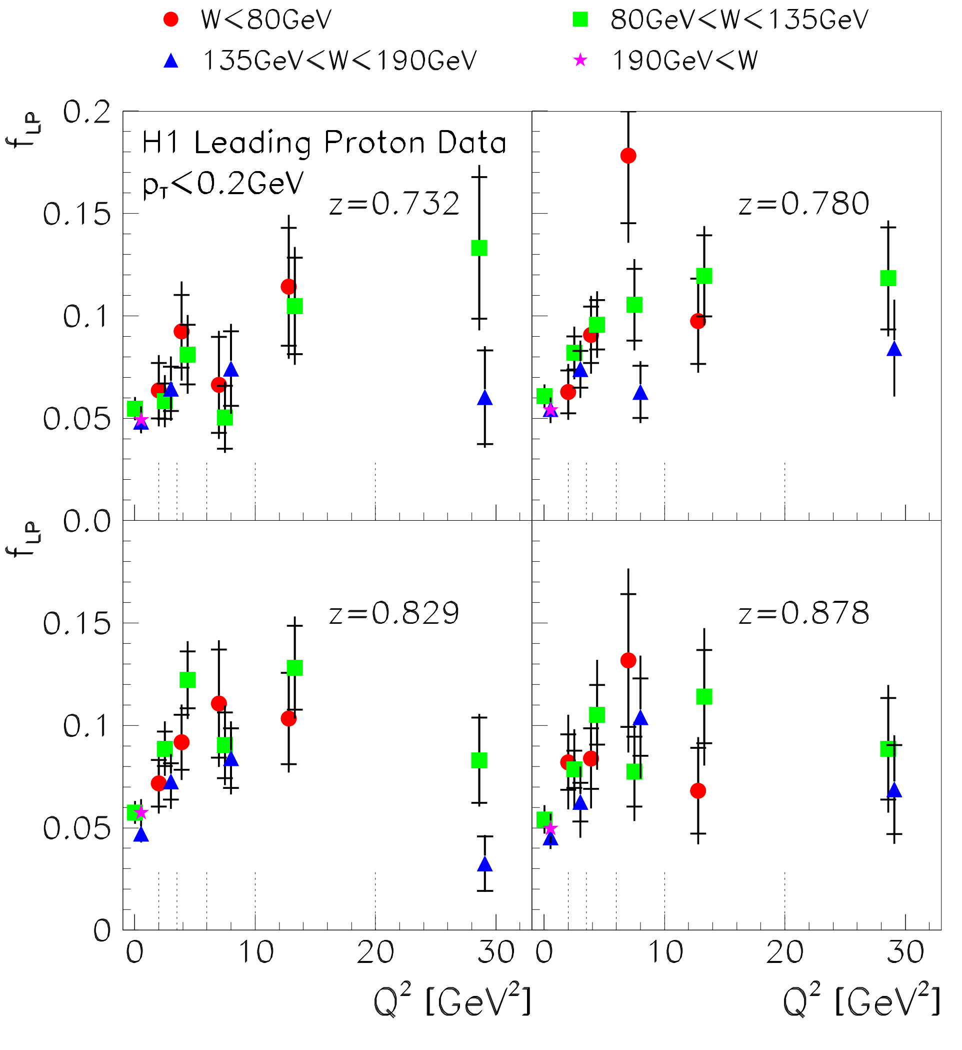
Fraction of events with Leading Protons vs. Q^2 (H1)

- $f_{LP}(Q^2 \sim 0, W, z) = \dfrac{d\sigma_{\gamma p \to X p'}(Q^2 \sim 0, W, z)/dz}{\sigma^{tot}_{\gamma p}(W)}$

  ($\sigma^{tot}_{\gamma p}$ from Donnachie-Landshoff parameterization).

- $f_{LP}(Q^2, W, z) = \dfrac{F_2^{LP(3)}(x, Q^2, z)}{F_2^{H1QCD}(x, Q^2)}$

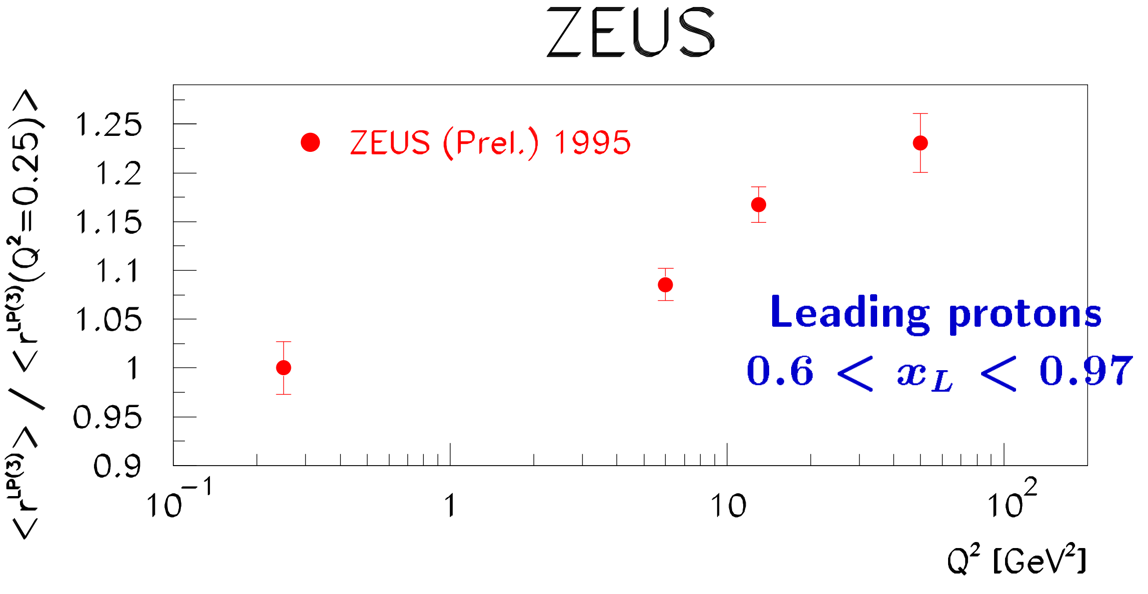
  ($F_2^{LP(3)}$ from *H1 Collab., Eur.Phys.J C6(1999) 587*,
  F_2^{H1QCD} from *H1 Collab., Eur.Phys.J C13(2000) 609*)

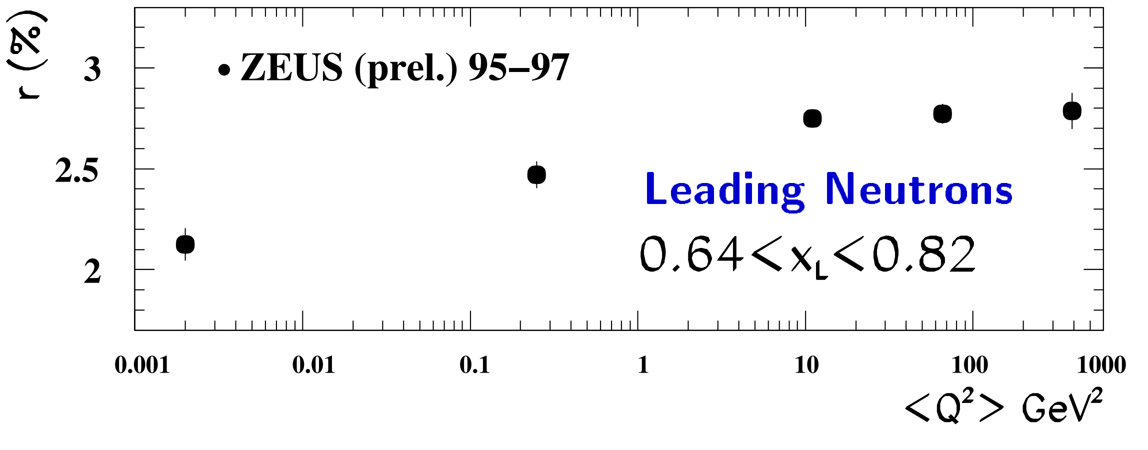


Fraction of LP increases from $\sim 5\%$ in γp to $\sim 10\%$ in the DIS region $\rightarrow$ violation of factorization ?

Fraction of events with Leading Protons and Neutrons vs. Q^2 (ZEUS)

average $r^{LP(3)}$ and $r^{LN(3)}$ over x and x_L

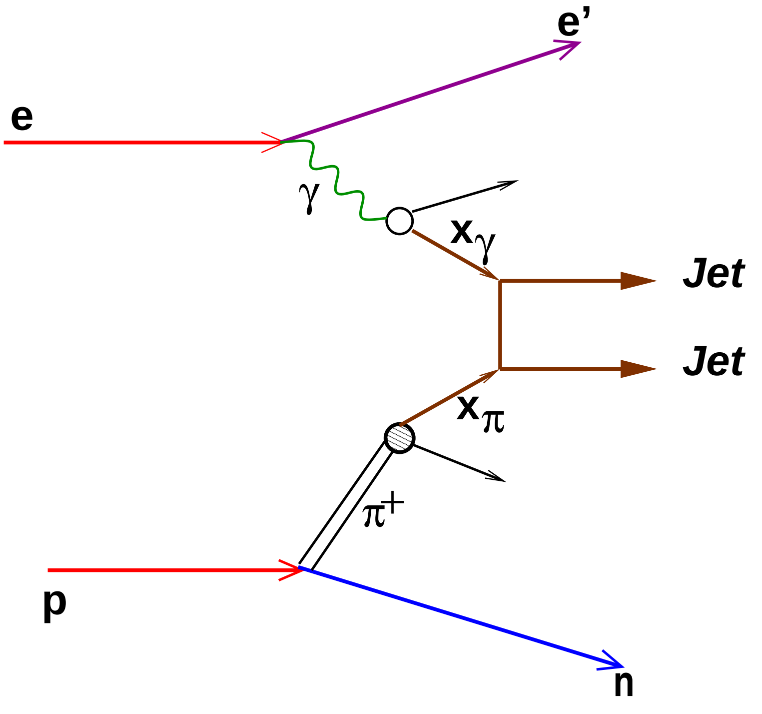




Small violation of factorization: $\sim 30\%$ for $Q^2 \sim 0.1$ to $100\ GeV^2$

- **Absorptive effects (smaller γ size at higher Q^2) ?**
- **Reggeon flux depends on Q^2, factorization breaking ?**

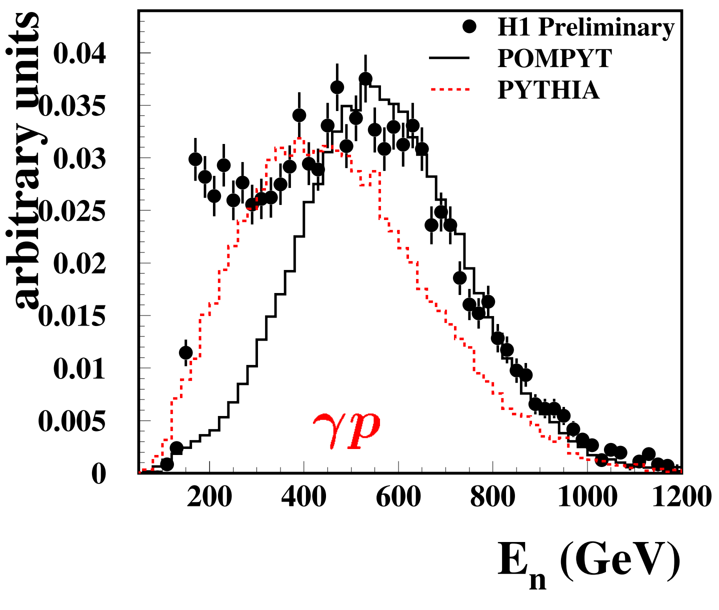
Dijet production with Leading Neutrons

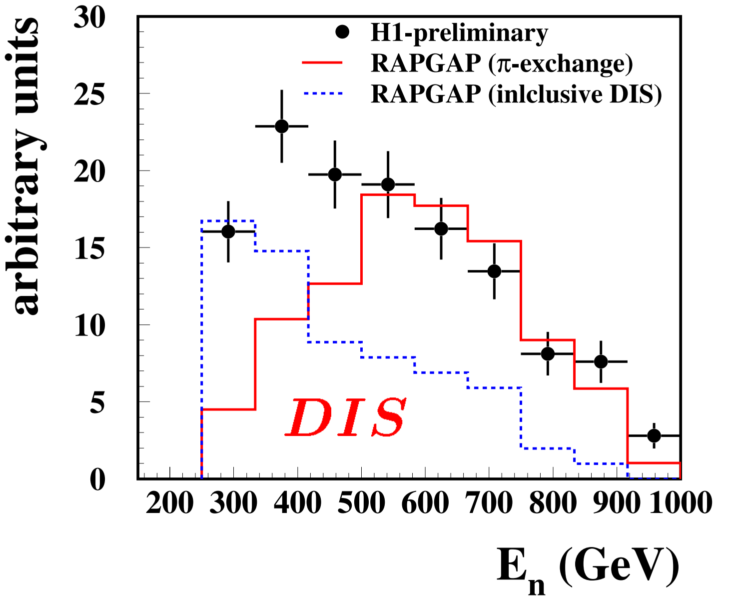


- **ZEUS**
  - $Q^2 < 4\ GeV^2$, $y \in [0.2, 0.8]$ (photoproduction)
  - $E_T^{jet} > 6\ GeV$, $-2 < \eta^{jet} < 2$
  - $E_n > 400\ GeV$, $\theta_n < 0.8 mrad$
- **H1**
  - $Q^2 < 10^{-2}\ GeV^2$, $y \in [0.3, 0.65]$ (photoproduction) or $Q^2 \in [2, 80\ GeV^2]$ (DIS)
  - $E_T^{jet} > 6\ GeV$, $-1 < \eta^{jet} < 2$
  - $E_n > 400\ GeV$, $\theta_n < 0.8 mrad$

Measure: neutron energy spectra, differential jet cross-sections as a function of E_T^{jet}, η^{jet}, x_π^{jet}, x_γ^{jet}.

Neutron energy spectra

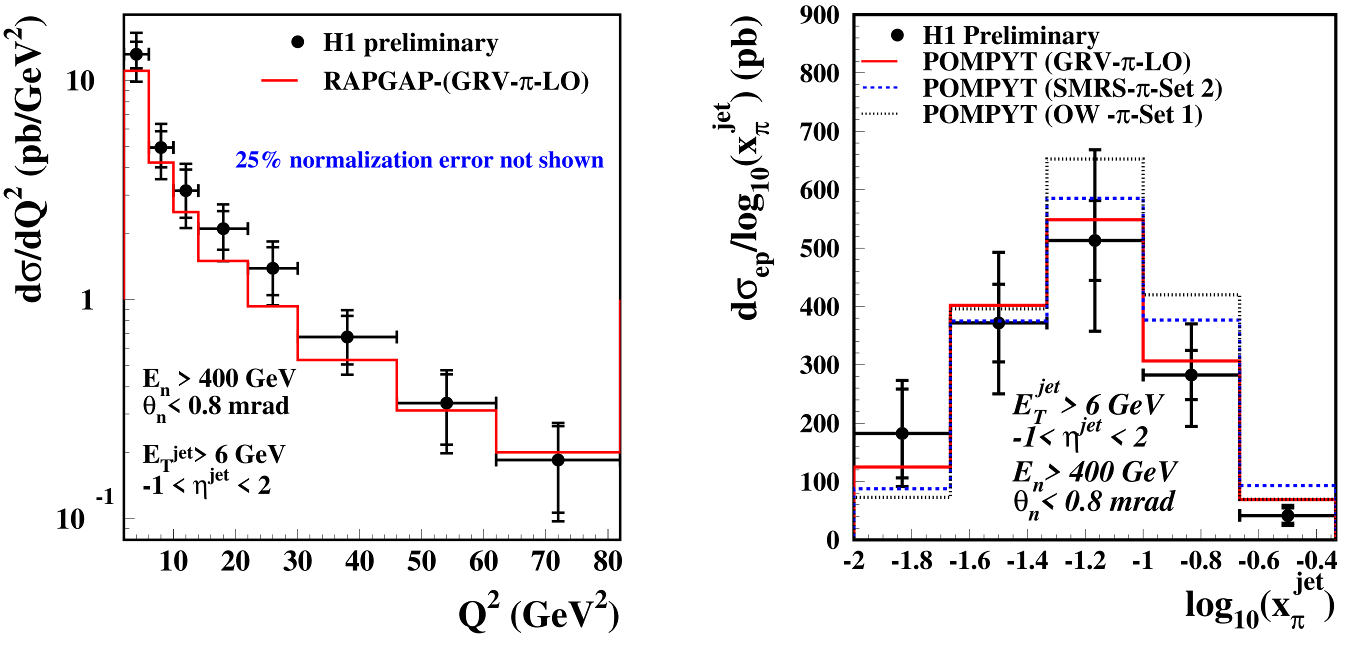




- For $x_L \gtrsim 0.5$ the one-pion-exchange MC models (POMPYT, RAPGAP) describe the shape and normalization of neutron energy spectrum, the inclusive (standard fragmentation) MC's do not.

- Similar conclusions from ZEUS measurements.

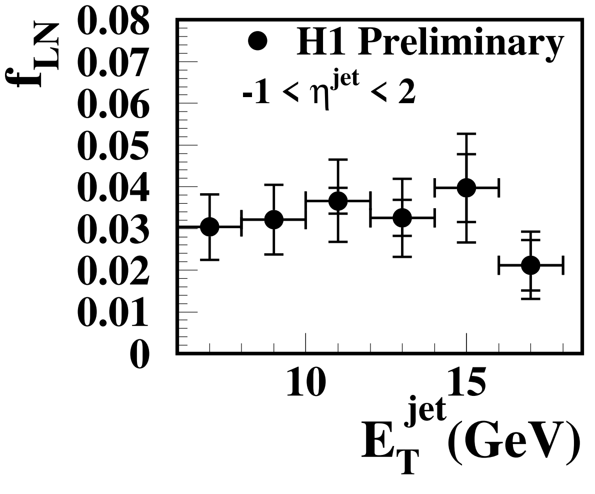
Dijet differential cross-sections

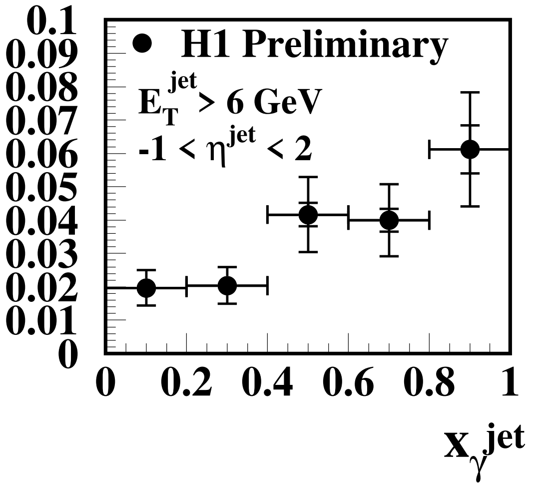


- The one-pion-exchange MC models (POMPYT, RAPGAP) describe the differential jet cross-sections well.

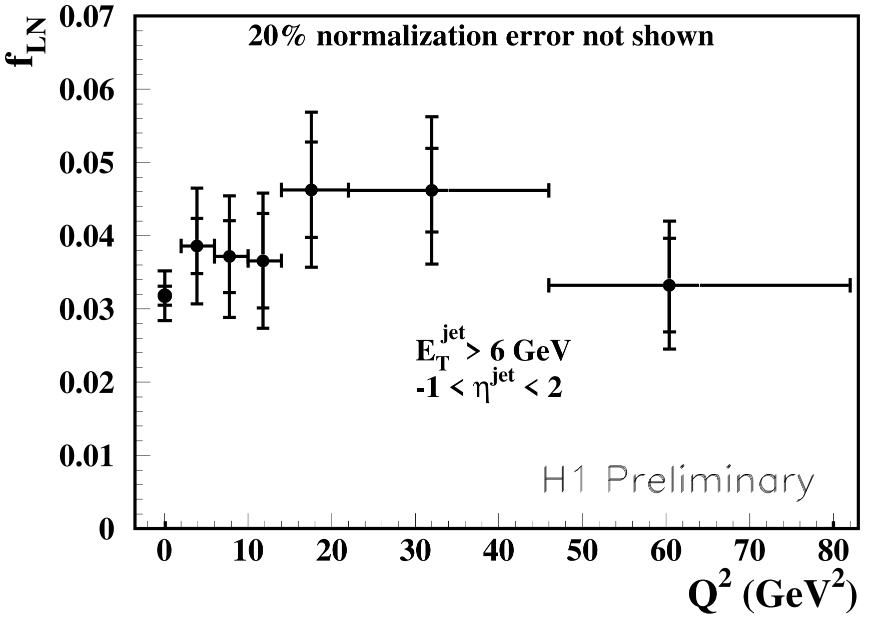
- At the present level of experimental uncertainties in the measurement no preference for any of the π-structure function parameterizations can yet be given.

Factorization tests in Dijet events





E_T^{jet} distribution is similar for inclusive and LN events. Ratio increases with x_γ^{jet} $\rightarrow$ more direct photon contributions in LN events (kinematics ?)



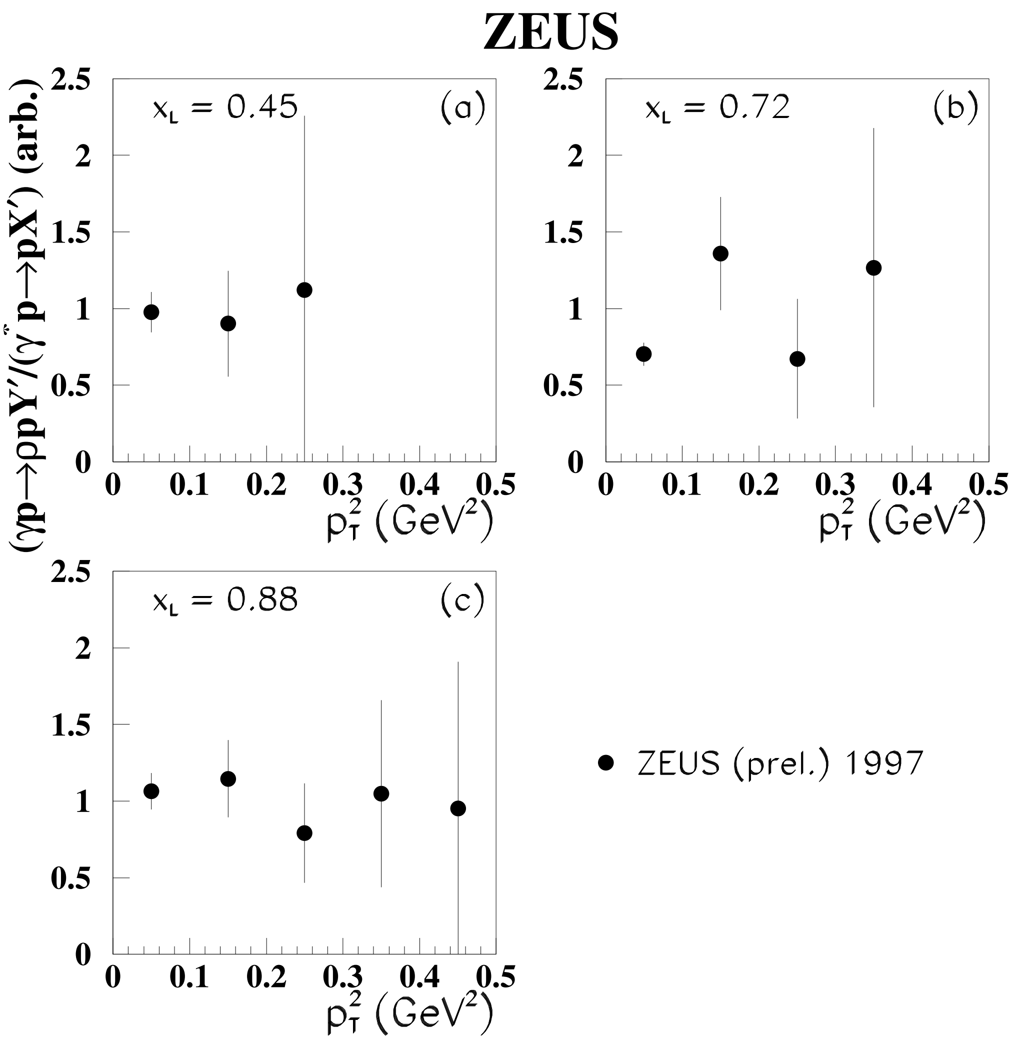
Q^2 dependence of the fraction of dijet events with LN does not show significant deviation from factorization assumption.

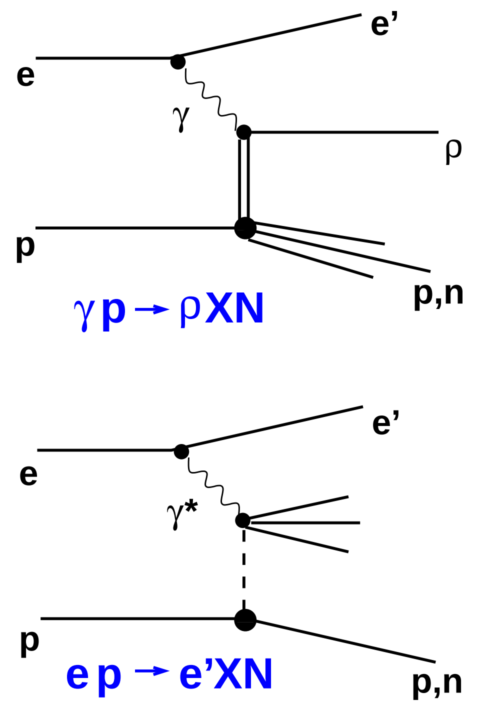
Proton-dissociative photoproduction of ρ mesons at large t

$\gamma p \rightarrow \rho Y$, where system Y dissociates into a proton or neutron, $Y \rightarrow Y'p$ or $Y'n$.

Compare the leading baryon production in high-t ρ-meson events with those in DIS.

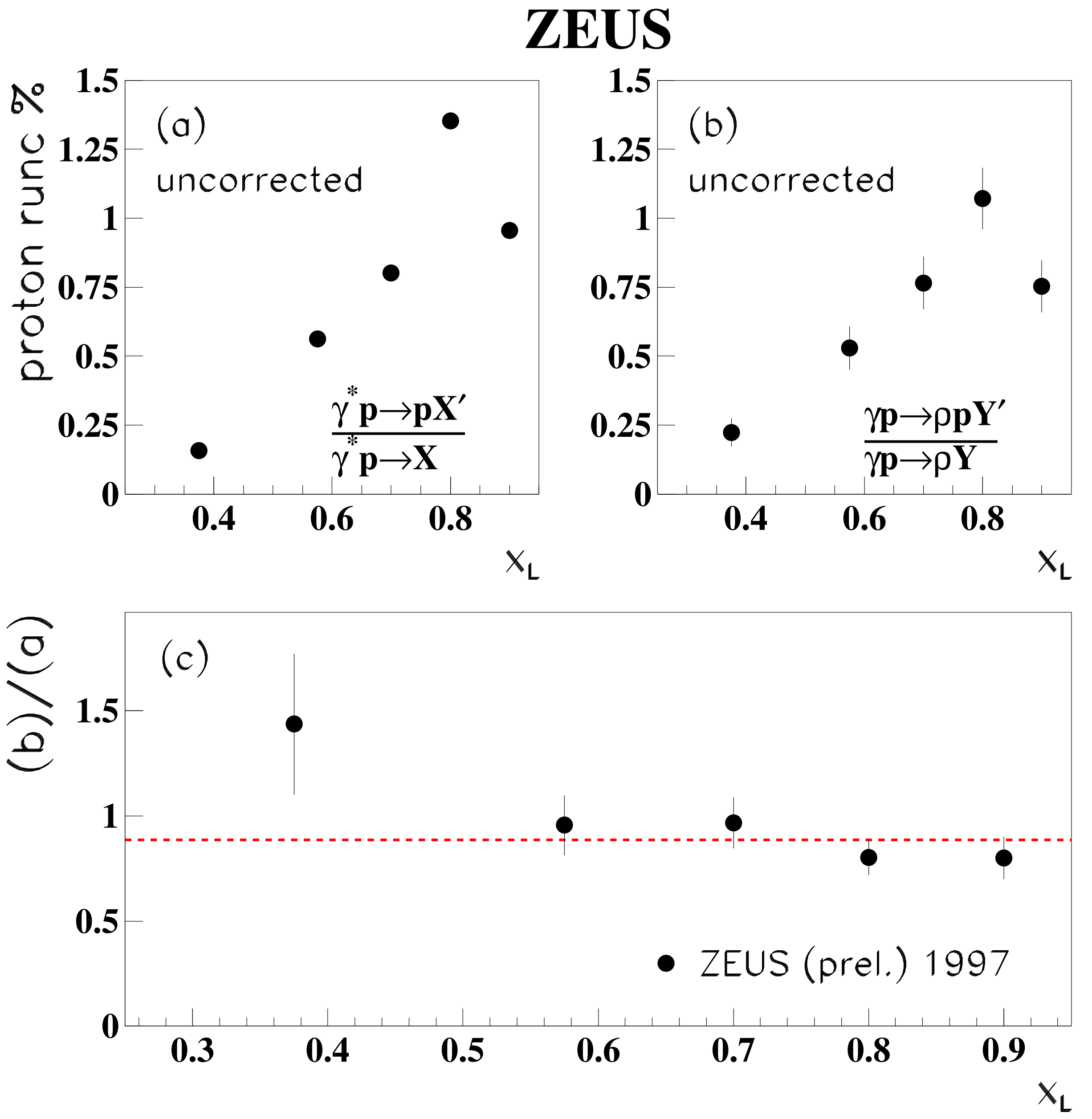
4-momentum transfer for ρ– $|t| > 1.2\ GeV^2$,
Leading proton or neutron– $x_L \gtrsim 0.2$, $p_t < 700\ MeV$





Angular (p_t) distribution of leading protons does not differ significantly between DIS and the photoproduction of diffractive high-t ρ-mesons.

Compare rate of Leading Protons/Neutrons as a function of x_L in high-t ρ-meson events with those in DIS ($Q^2 > 24\ GeV^2$)



Similar distributions and rates of leading protons (and neutrons) in diffractive high-t ρ-mesons and the DIS !

Conclusions

Leading baryon yield is measured over wide kinematical range.

- **Leading proton production in photoproduction is approximately constant as function of W and x_L. In terms of Regge model it can be described by the exchange of effective trajectory having $\alpha_i(0) = 0.33 \pm 0.04(stat) \pm 0.04(syst)$.**

- **F_2^{LB} has the same shape in x_L and has similar x dependence as F_2.**

- **The fraction of Leading Baryons tends to increase with Q^2 (absorptive effects, factorization breaking ?)**

- **Monte Carlo models which include one pion exchange describe the dijet production associated with leading neutron, while the standard fragmentation Monte-Carlo models fail to describe the neutron energy spectrum.**
  Need for a colour singlet component of proton structure.

- **Fraction of dijet events with leading neutron is in general agreement with factorization assumption.**

- **The leading nucleon production is studied in diffractive photoproduced ρ meson events at large momentum transfer ($|t| > 1.2\ GeV^2$).**
  Rates and distributions of leading nucleons are similar to those in DIS.