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Leading Neutron Production and F_2^{π} at HERA

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D E S Y

for the ZEUS and H1 Collaboration

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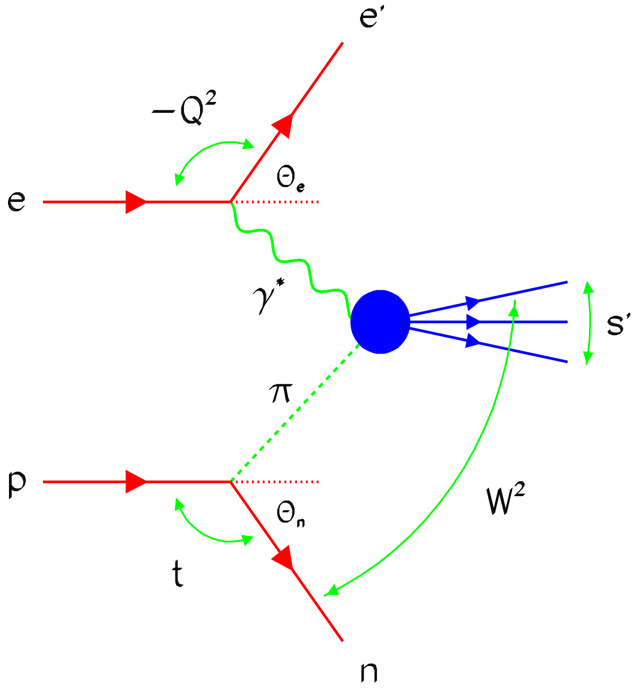
Motivation

Why study leading neutron production at HERA?



Photon vertex
lepton variables:
Q^2, x, W, y

$\Uparrow$

$\Downarrow$

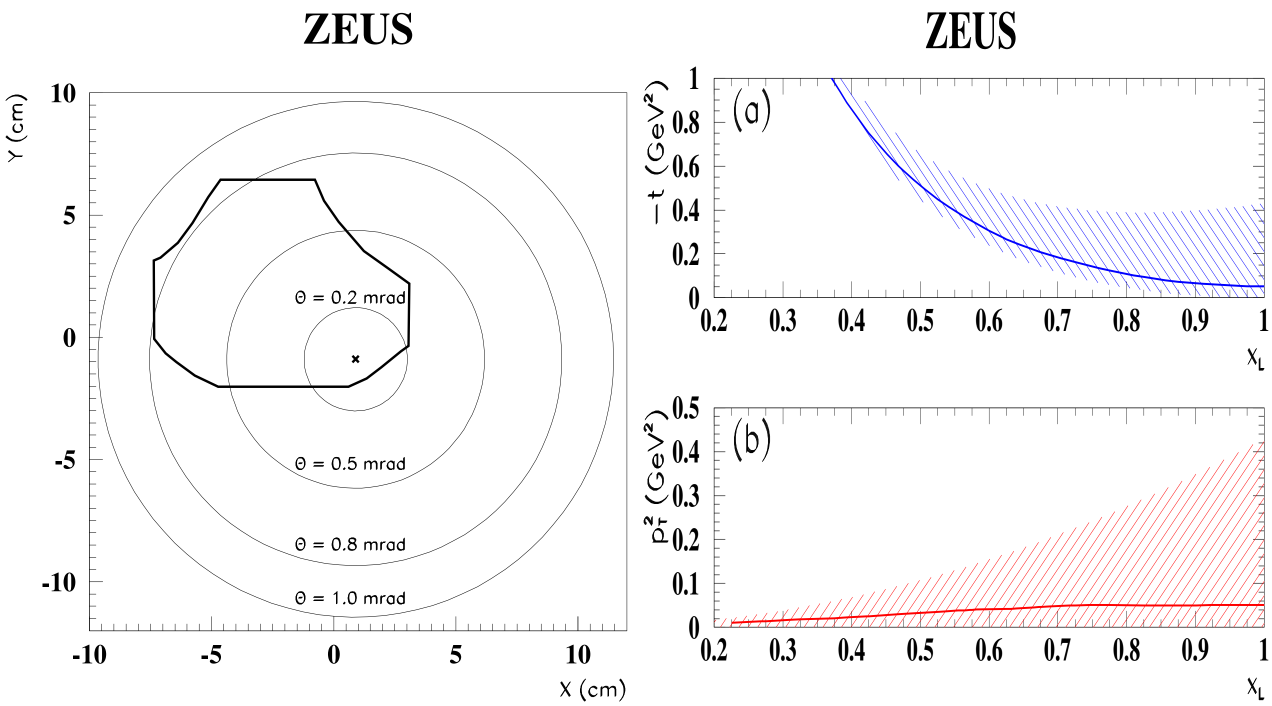
Proton vertex
leading baryon variables:

$$x_L \equiv z = E_{p'}/E_p$$
$$t = (n-p)^2$$
$$= -\frac{p_T^2}{x_L} - \frac{m_B^2(1-x_L)^2}{x_L}$$

- **What are the production mechanism:**
  - exchange processes like One–Pion–Exchange (OPE)
    $\Rightarrow$ measure F_2^π
  - fragmentation of proton remnant
- **Factorization tests:**
  - **Hypothesis 1:** production rate is independent on the particle at the upper vertex
    $\Rightarrow$ look at different processes: γp and pp.
  - **Hypothesis 2:** cross section dependence on neutron variables is independent of the particle production at the photon vertex
    $\Rightarrow$ look at production rates as function Q^2, x, W, y.

Dedicated Forward Detectors

Acceptance of the Forward Neutron Calorimeter as given by HERA beam line:



Analysis Cuts:

$x_L > 0.2$ (ZEUS inclusive) or $x_L \gtrsim 0.5$ (H1 dijets)
$p_T^2 < (0.66 x_L)^2$ GeV^2 from $\theta_n < 0.8$mrad

Three samples in Q^2:

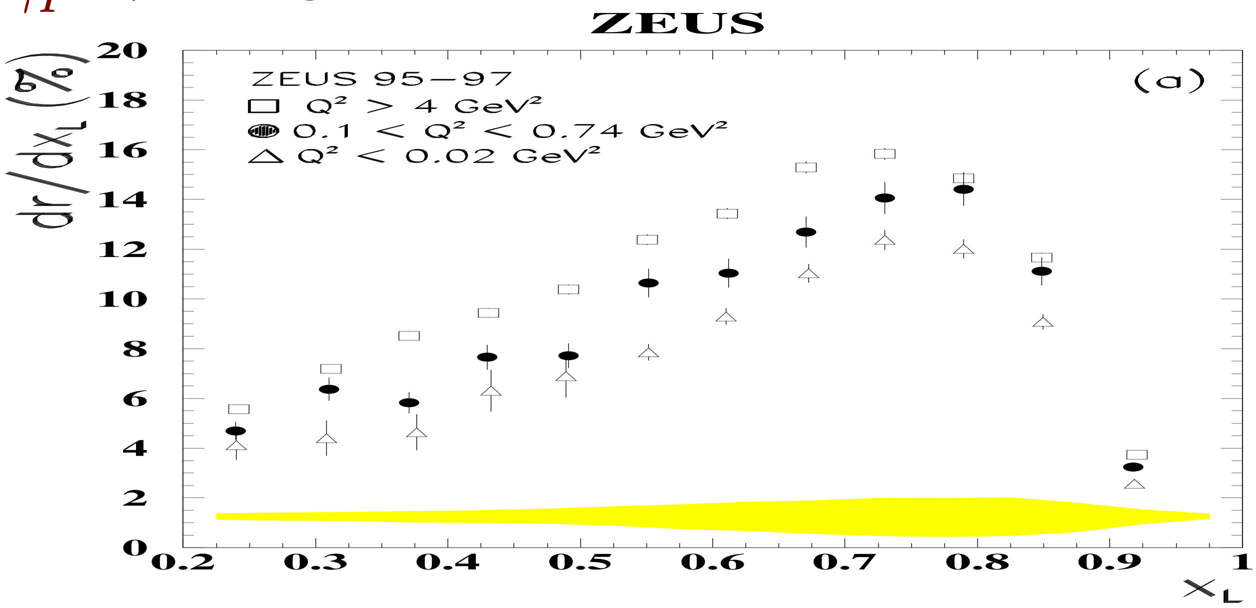
	Q^2 [GeV^2]
DIS	> 4
low Q^2	$0.1 - 0.74$
γp	< 0.02

Measured x_L Spectra

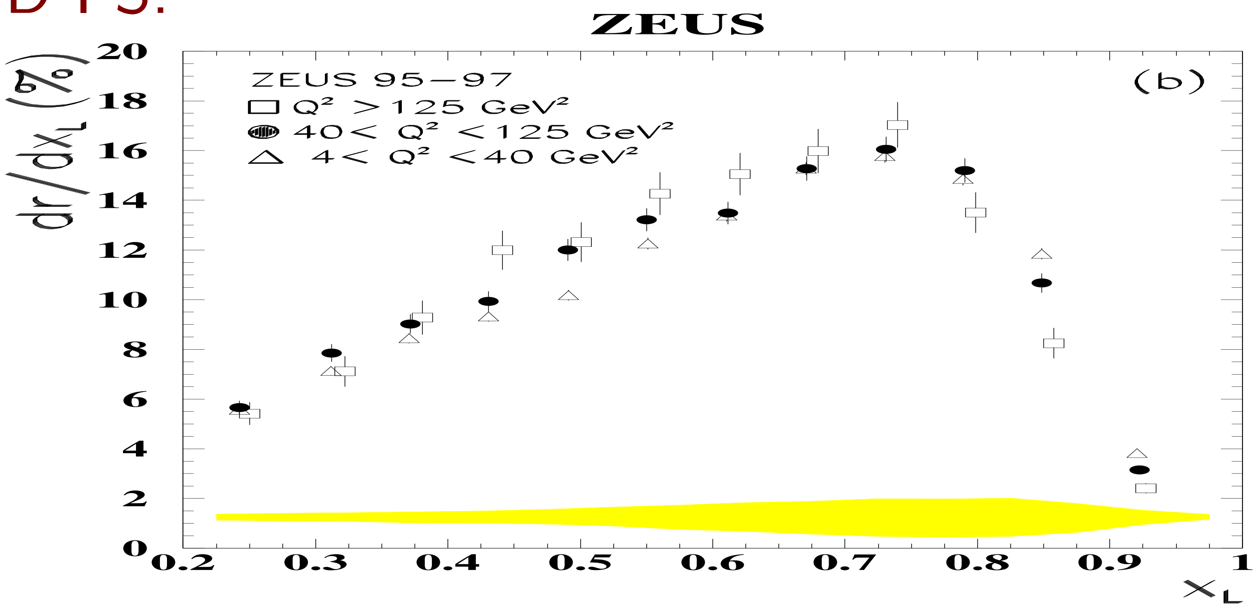
$$r^{LN(3)}(x_L, \Delta p_T^2, x, Q^2) = \frac{N^{LN}(x_L, \Delta p_T^2, x, Q^2)}{N(x, Q^2) \cdot \epsilon^{LN}(x_L, p_T^2)}$$

$$= \frac{F_2^{LN(4)}(x_L, \Delta p_T^2 x, Q^2)}{F_2(x, Q^2)}$$

$\gamma p \Rightarrow$ D I S:



D I S:

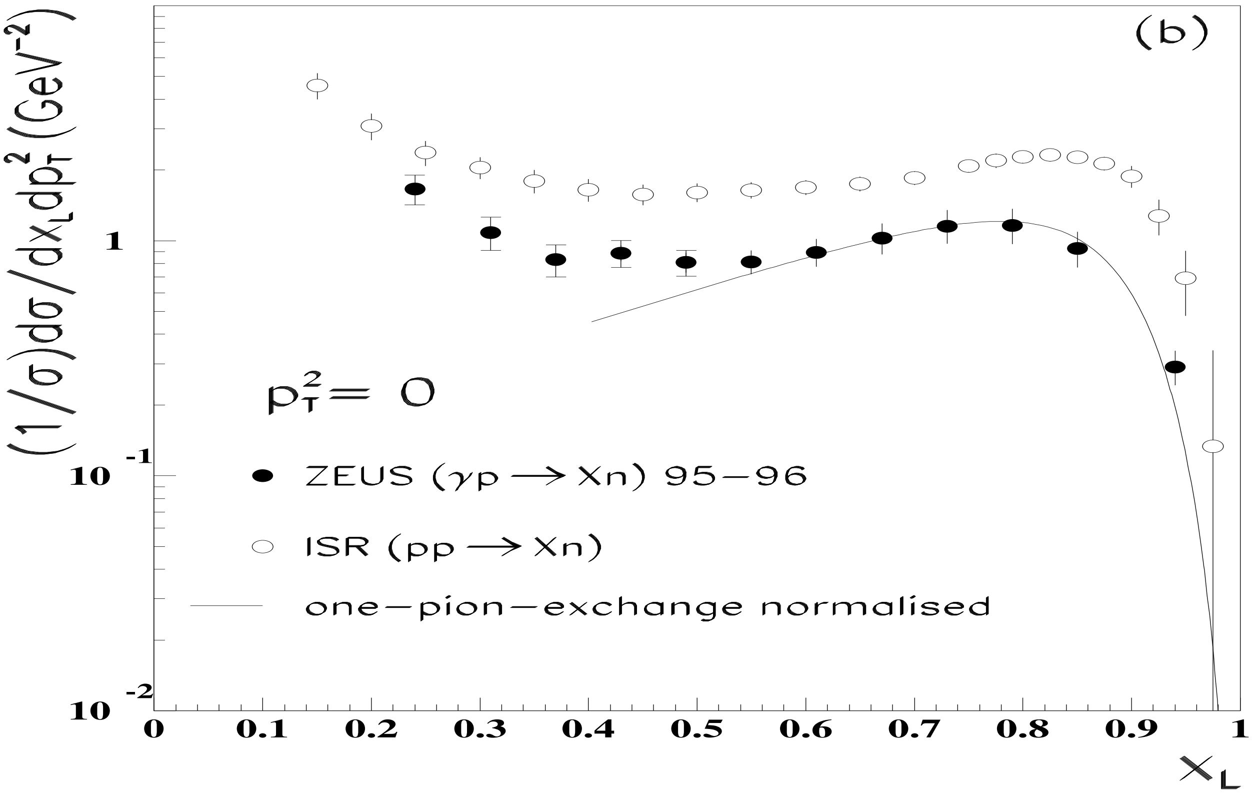


- $\gamma p \Rightarrow$ **DIS: rate increasing**
- **DIS: rate $\approx Q^2$ independent**

Comparison with pp Scattering

Vertex-Factorization:

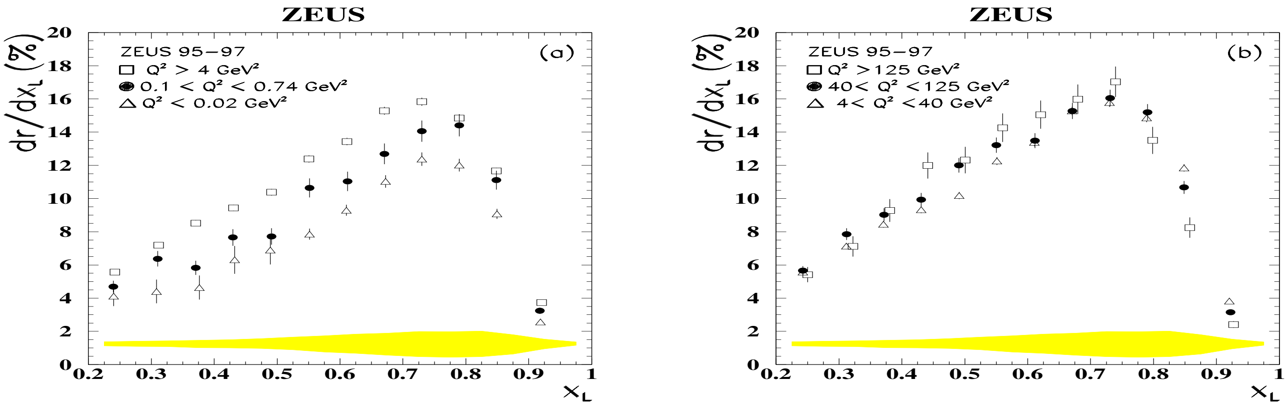
$$\frac{1}{\sigma_{\text{tot}}^{\gamma p}} \frac{d^2\sigma^{\gamma p \to Xn}(x_L, p_T^2)}{dx_L\, dp_T^2} = \frac{1}{\sigma_{\text{tot}}^{pp}} \frac{d^2\sigma^{pp \to Xn}(x_L, p_T^2)}{dx_L\, dp_T^2}$$

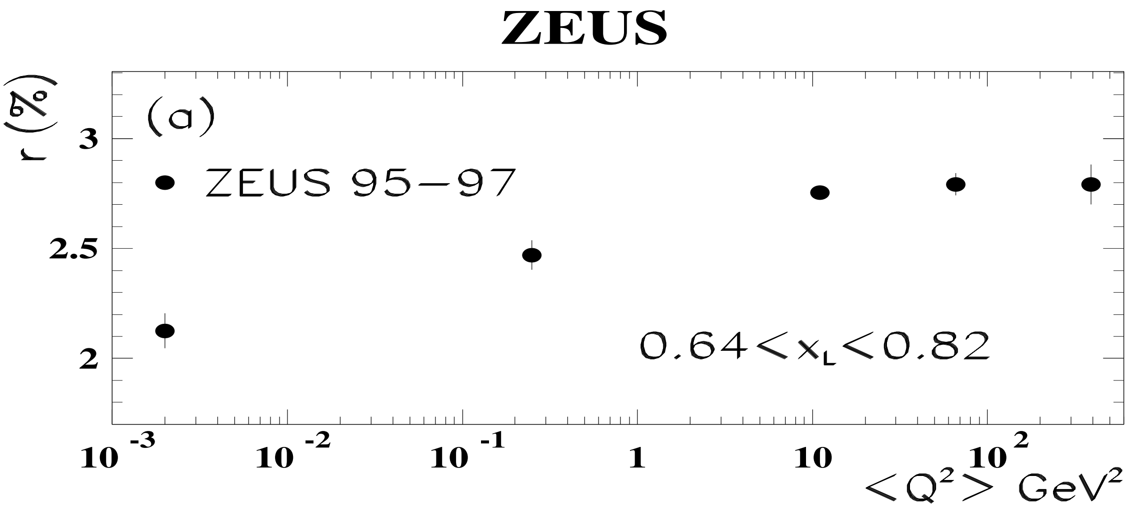


- OPE describes high x_L region
- Shape similar
- Rate in $\gamma p \approx 1/2$ Rate in pp

$\Rightarrow$ Strong Factorization Breaking

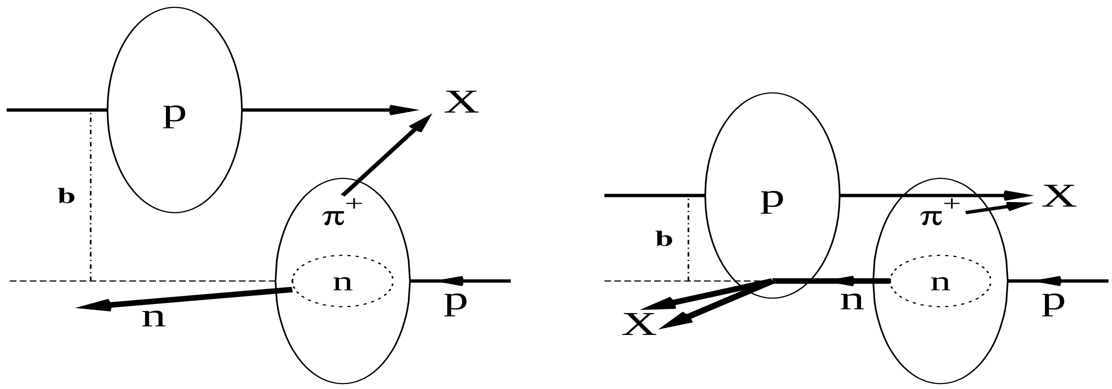
Factorization Test in Q^2





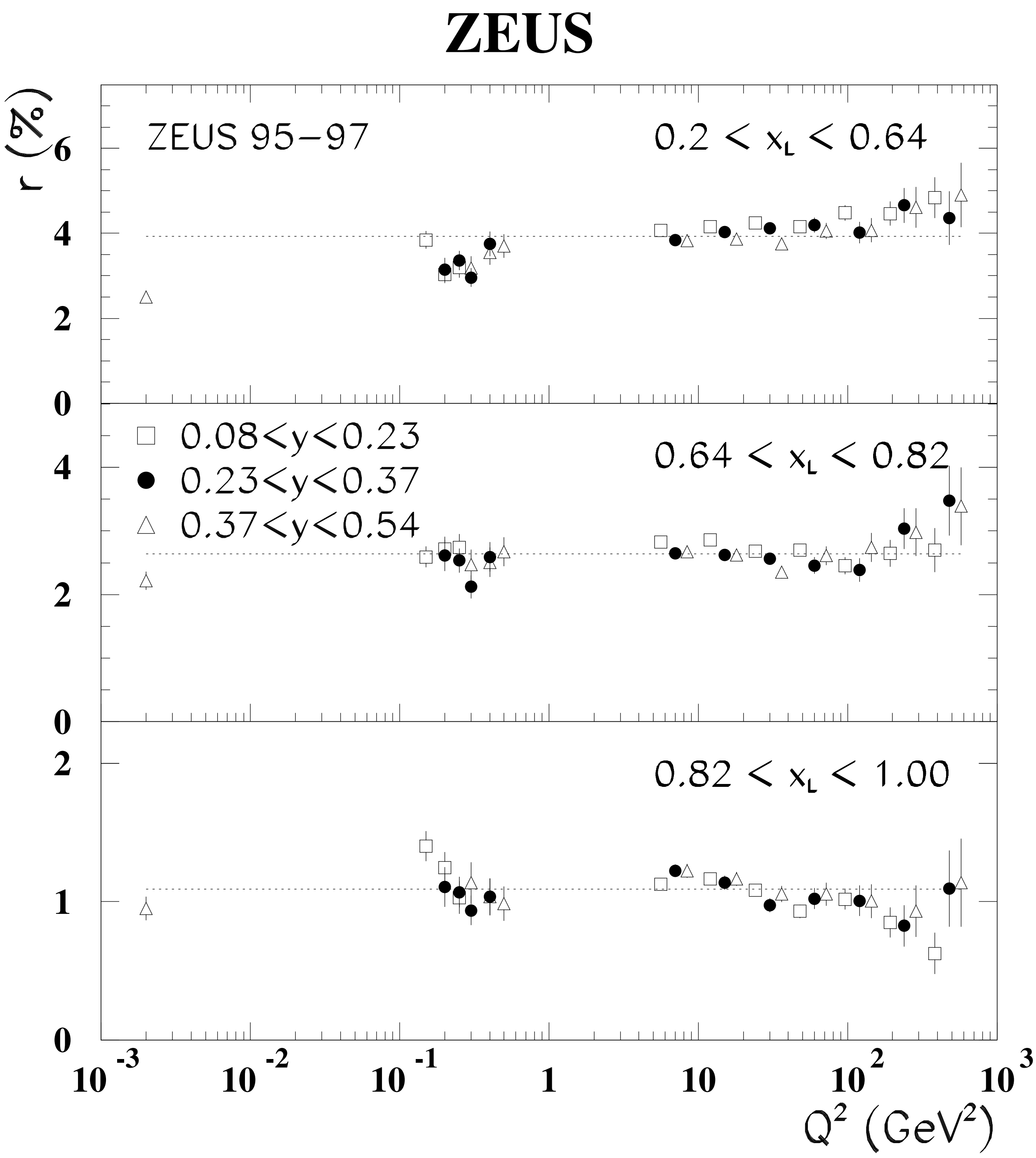
DIS: $\gamma^* \approx$ point-like

γp: $\gamma \approx$ hadron-like, n-rescattering possible



$\Rightarrow$ mild factorization violation ($\approx$ 20%) might be attributable to absorptive effects

Factorization Test in Q^2,y and x_L



- **Flat behavior of r for $0.64 < x_L < 0.82$ in DIS** $\Rightarrow F_2^{LN} \sim F_2$
- **Different behavior in different x_L regions** $\Rightarrow$ **weak factorization violation**

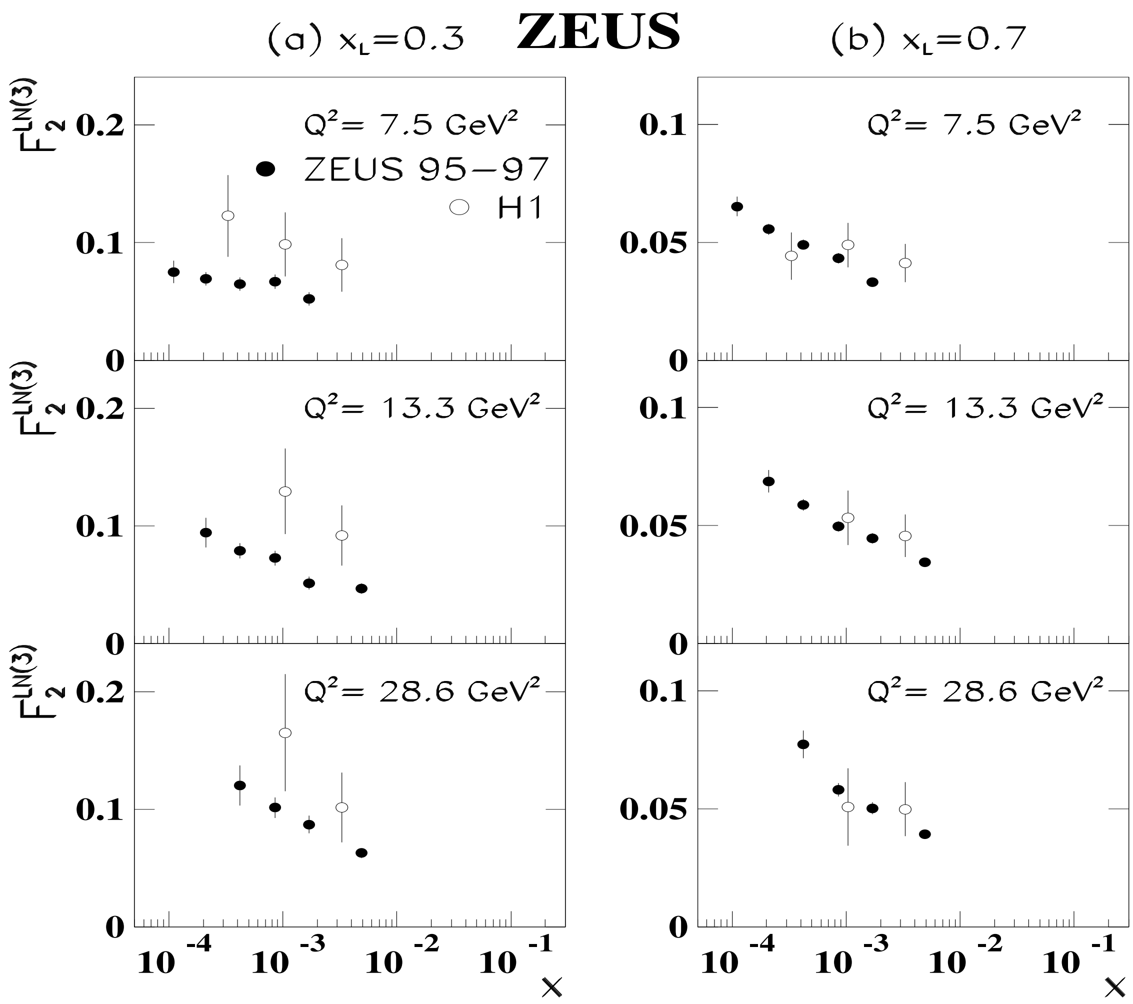
The Structure Function $F_2^{LN(3)}$

Unfold: $F_2^{LN(3)(x_L,x,Q^2)} = \frac{r^{LN(3)}(x_L,x,Q^2)}{\Delta x_L} F_2(x, Q^2)$

Compare to H1 measurement: $p_T < 0.2$ **GeV**

Errors:

- H1: statistical + correlated systematic errors shown
  5.7% normalization uncertainty not shown
- ZEUS: statistical + ZEUS NLO QCD fit uncertainty shown
  ≈7% correlated syst. + normalization uncertainty not shown



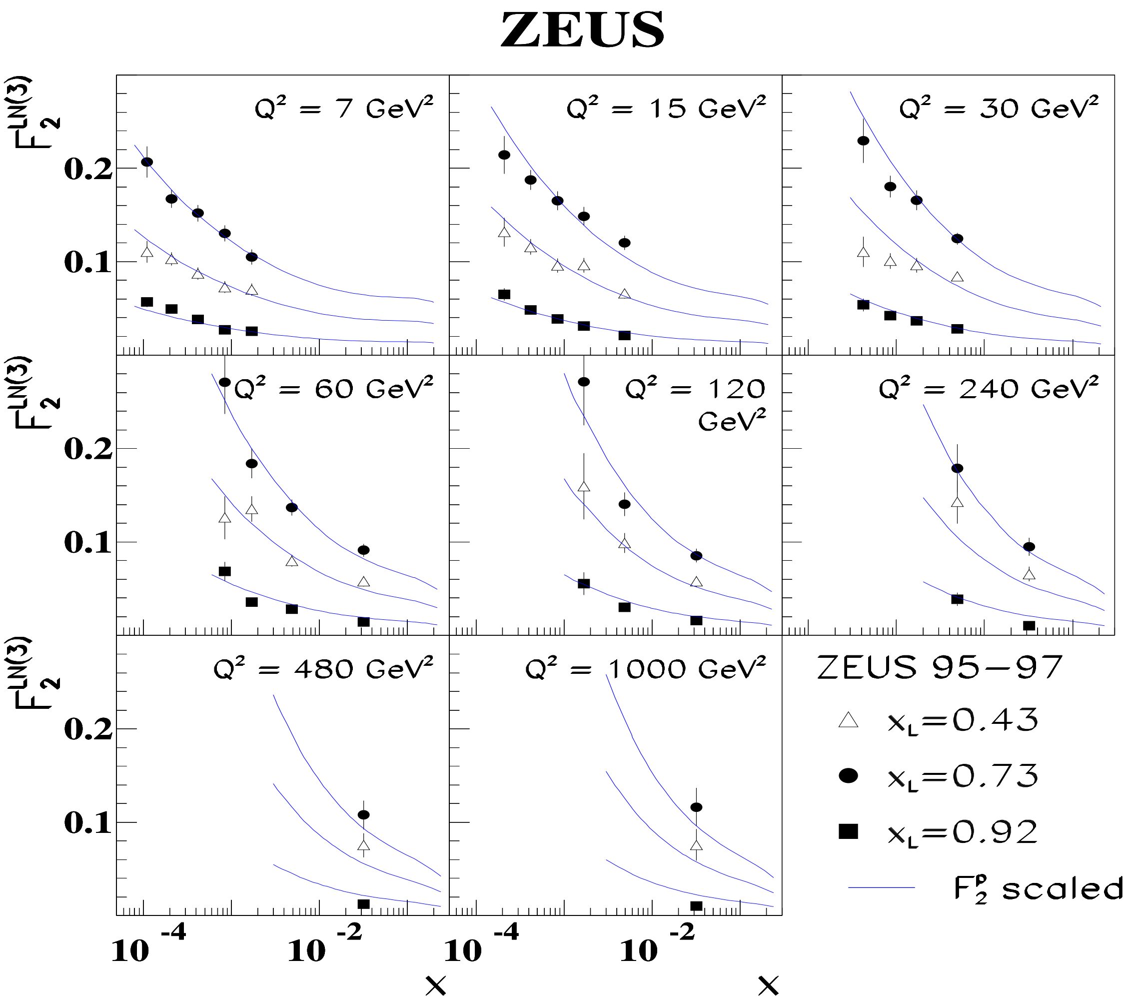
- **Agreement in shape**
- **Agreement in normalization for $x_L = 0.7$**

The Structure Function $F_2^{LN(3)}$

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

$$r^{LN(3)}(x_L,x,Q^2) \approx \text{ flat } \Rightarrow F_2^{LN(3)(x_L,x,Q^2)} \sim F_2(x,Q^2)$$

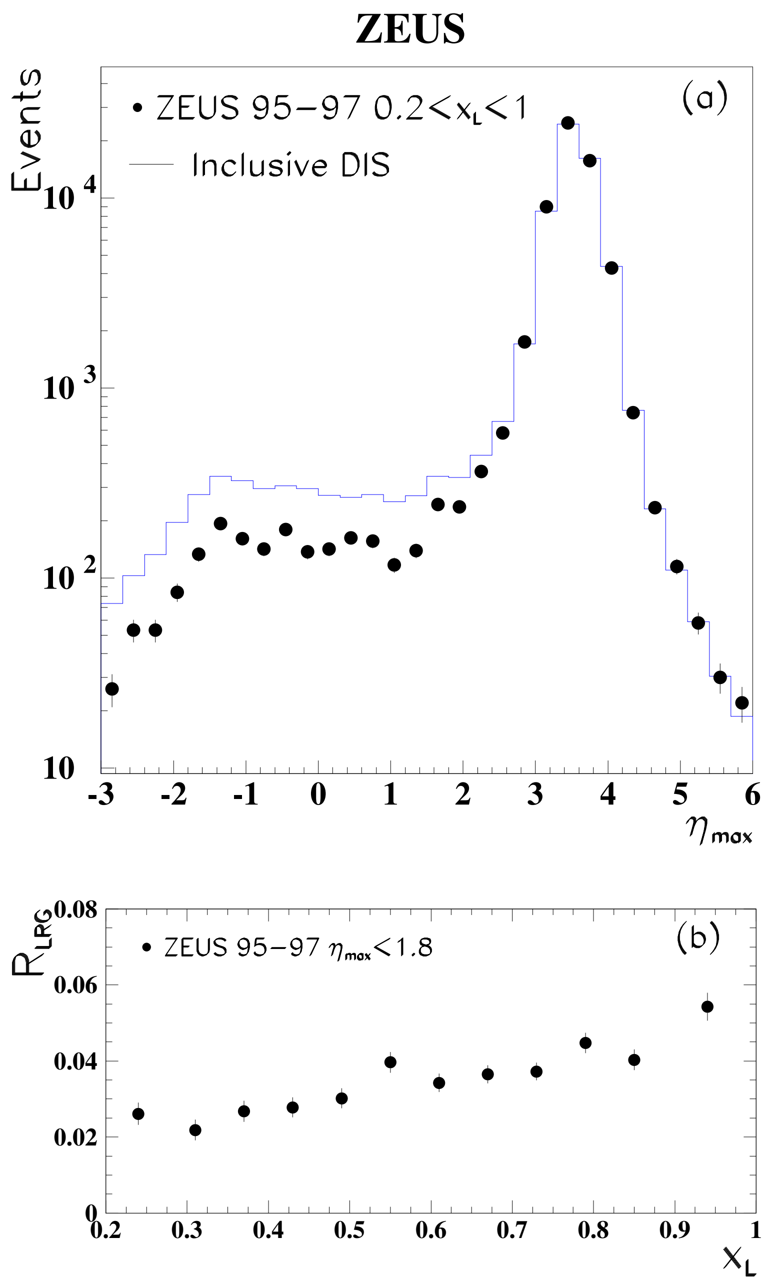
Full p_T^2 range: $p_T^2 < (0.66 x_L)^2$ GeV^2 (from $\theta_n < 0.8$mrad)



- **Acceptance in p_T $\Rightarrow$ normalization of $F_2^{LN(3)}$**
- $F_2(x,Q^2)$ **scaled by** $\langle r^{LN(3)} \rangle / \Delta x_L$ **describes** $F_2^{LN(3)}$

Now unfold F_2^{π} in the high x_L range, where OPE describes the x_L spectra, but first identify the possible background.

LN Production via Diffractive Dissociation



- shape similar for $\eta_{max} < (>)1.8$
- less LRG in LN events

- $\approx$ 4% LRG in DIS with LN (≈ 7% LRG in DIS)

Other contributing exchanges:

- ρ, a_2 exchanges: $\lesssim$ 10% at $x_L = 0.73$
- isovector exchange: $p \to \Delta$, $\Delta^0 \to n\pi^0$, $\Delta^+ \to n\pi^+$
  $\lesssim$ 6% at $x_L = 0.73$

One Pion Exchange major source at $x_L = 0.73$

From $F_2^{LN(4)}$ to F_2^{π}

Separation of $F_2^{LN(4)}$ in π–flux and π–Structure:

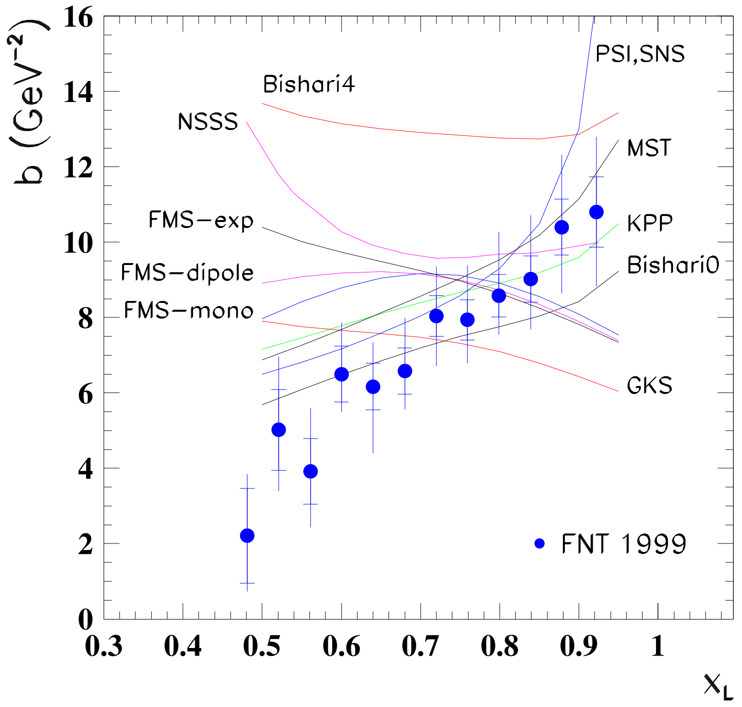
$$F_2^{\mathrm{LN}(4)}(x,Q^2,x_L,t) \quad = \quad f_{\pi/p}(x_L,t)F_2^{\pi}(x/(1-x_L),Q^2,t)$$
$$\cdot(1-\Delta_{\mathrm{abs}}(Q^2,x_L,t))/\Delta x_L$$

$$f_{\pi/p}(x_L,t) = \frac{1}{4\pi}\frac{2g^2_{\pi pp}}{4\pi}\frac{-t}{(t-m_\pi^2)^2}(1-x_L)^{1-2\alpha_\pi(t)}\left[F(x_L,t)\right]^2$$

$g^2_{\pi pp}/(4\pi) = 14.5 = \pi^0 pp$ coupling constant

$\alpha_\pi(t) = \alpha' t$ with $\alpha' = 1$ GeV^{-2}

ZEUS PRELIMINARY 1999



Form-factor $F(x_L,t)$ poorly constrained:

Choose two extreme normalizations for π–flux at $x_L = 0.73$:

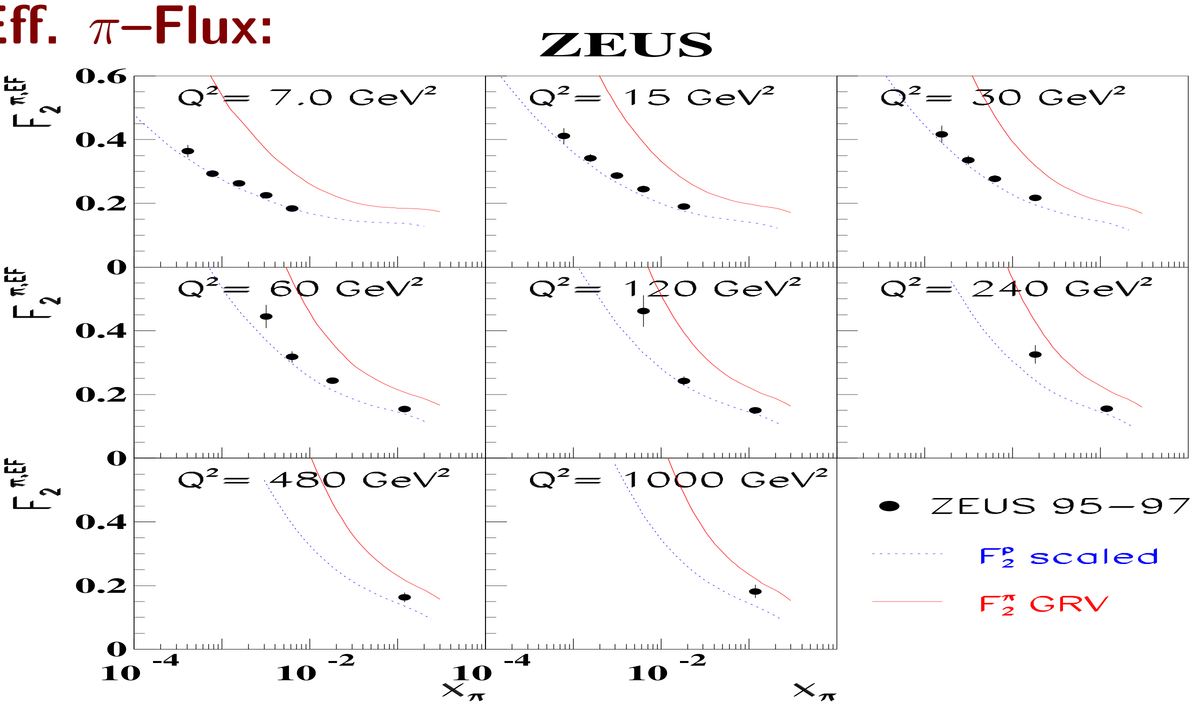
- effective π–flux: Bishari–0 from hadron-hadron-scattering
- Additive Quark Model:

$$\frac{\sigma_{\mathrm{tot}}^{\gamma\pi}(W\sqrt{1-x_L})}{\sigma_{\mathrm{tot}}^{\gamma p}(W)} = \frac{2}{3}(1-x_L)^{\alpha_{I\!P}(0)-1} = 0.60$$

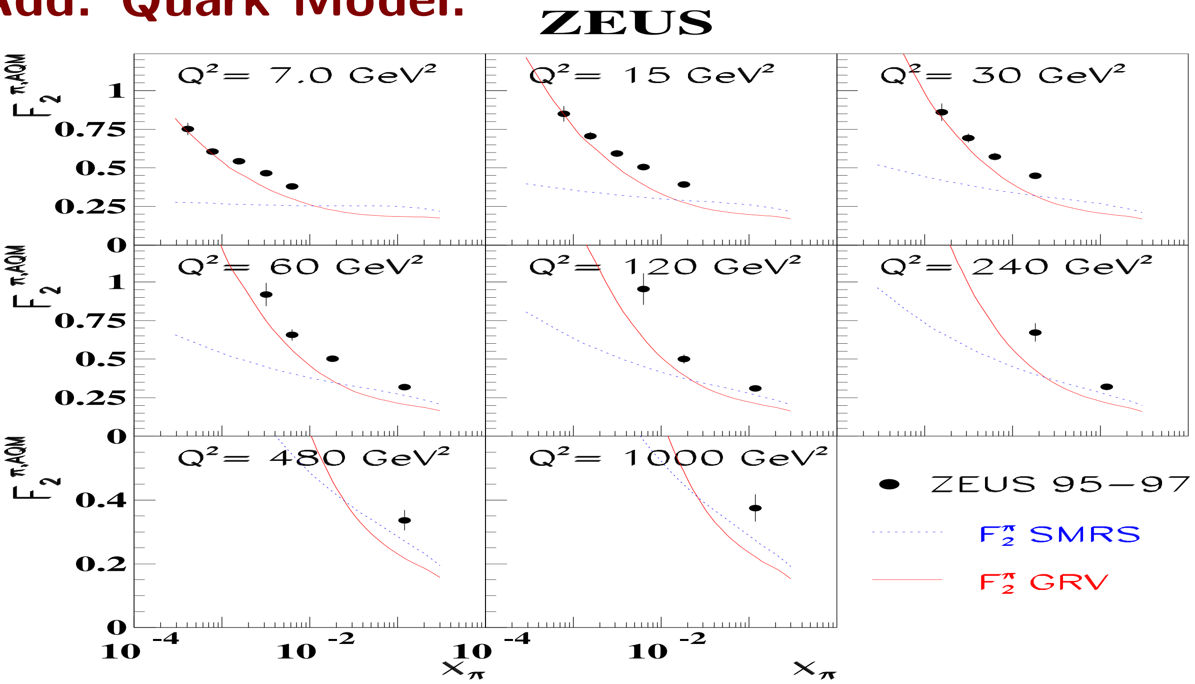
$\Rightarrow$ π–fluxes by a factor ≈ 2 different

F_2^π with Eff. π-Flux or Add. Quark Model

Eff. π–Flux:



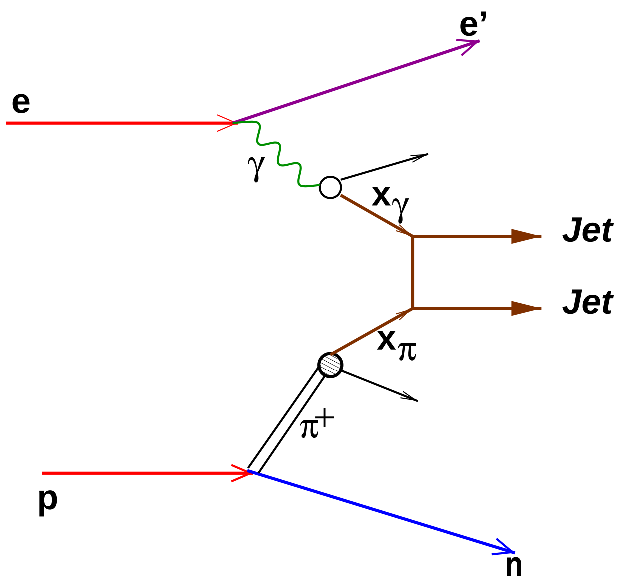
Add. Quark Model:



- $F_2(x, Q^2)$ scaled by 0.361 describes $F_2^{\pi,\text{EF}}$
- F_2^π GRV in agreement with $F_2^{\pi,\text{AQM}}$
- F_2^π SMRS disagrees $F_2^{\pi,\text{AQM}}$ at low x_π

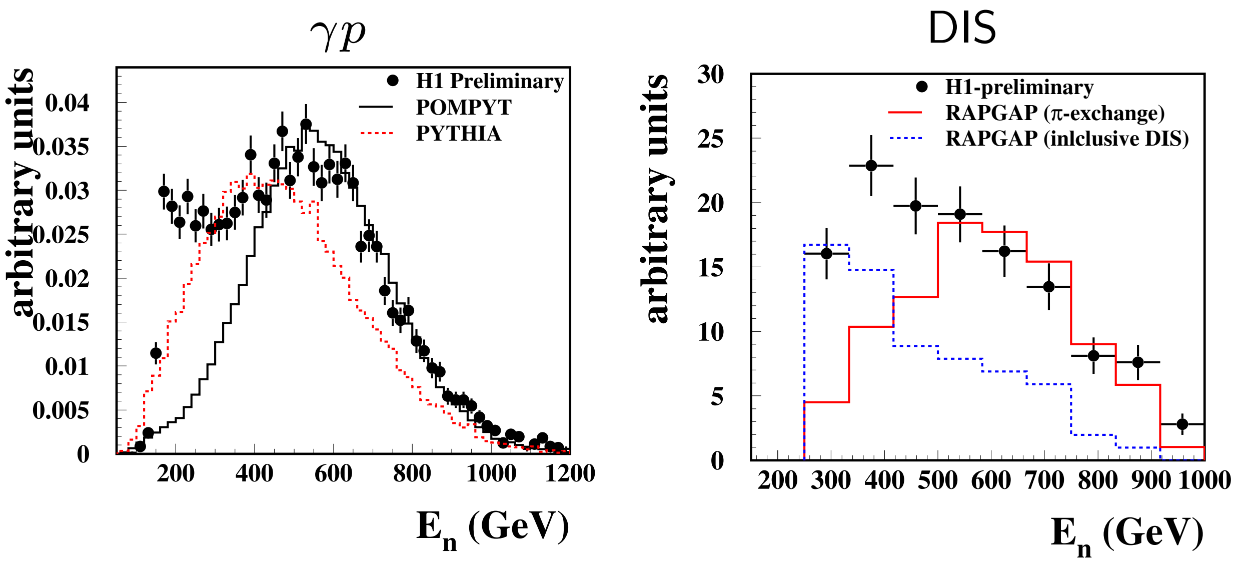
Dijets with a Leading Neutron

Test π exchange picture:



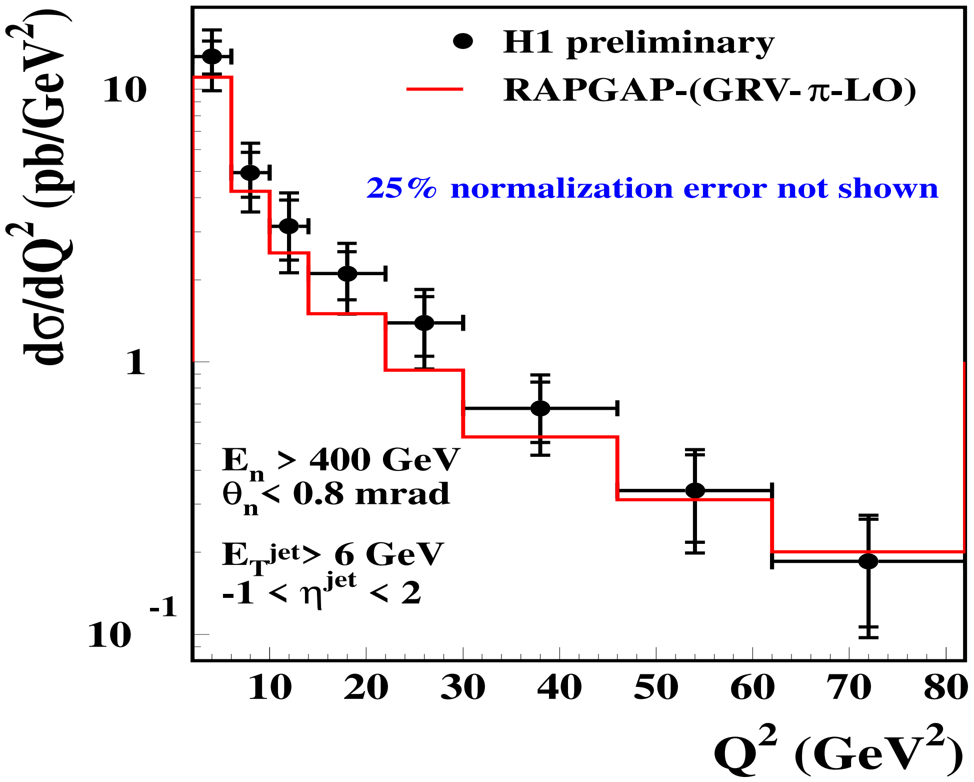
Look at neutron energy spectra, and differential cross sections as function of Q^2, x_π, ...

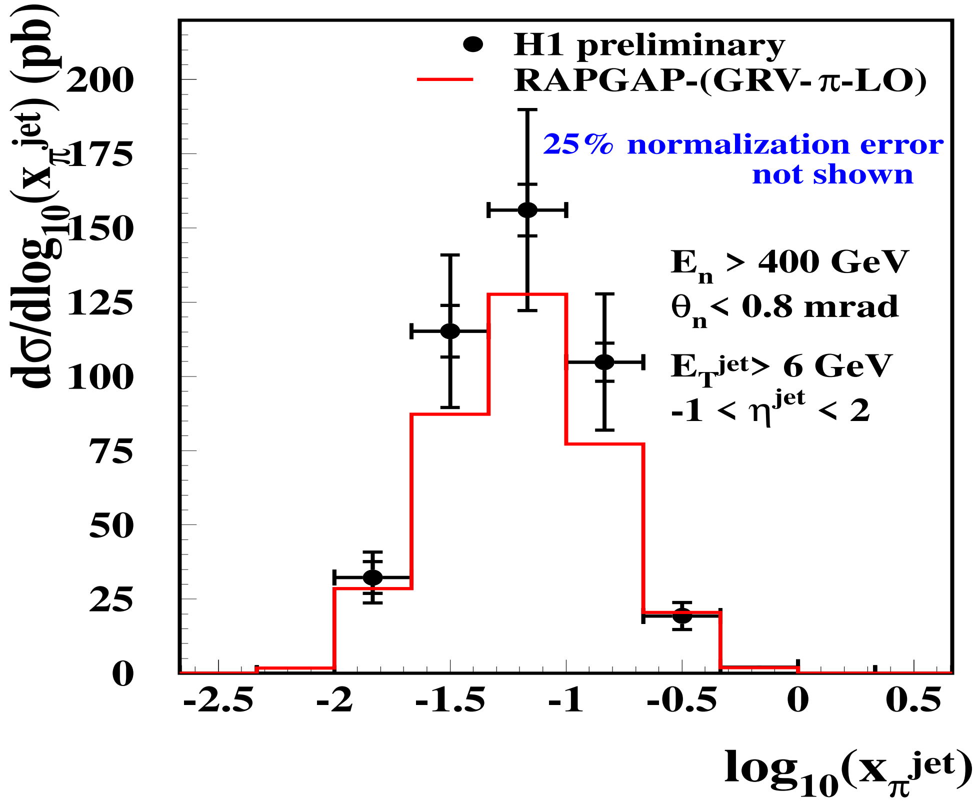
Neutron Energy spectra:



$x_L \gtrsim 0.5$: agreement in shape and rate with One-Pion-Exchange MC models(POMPYT,RAPGAP)

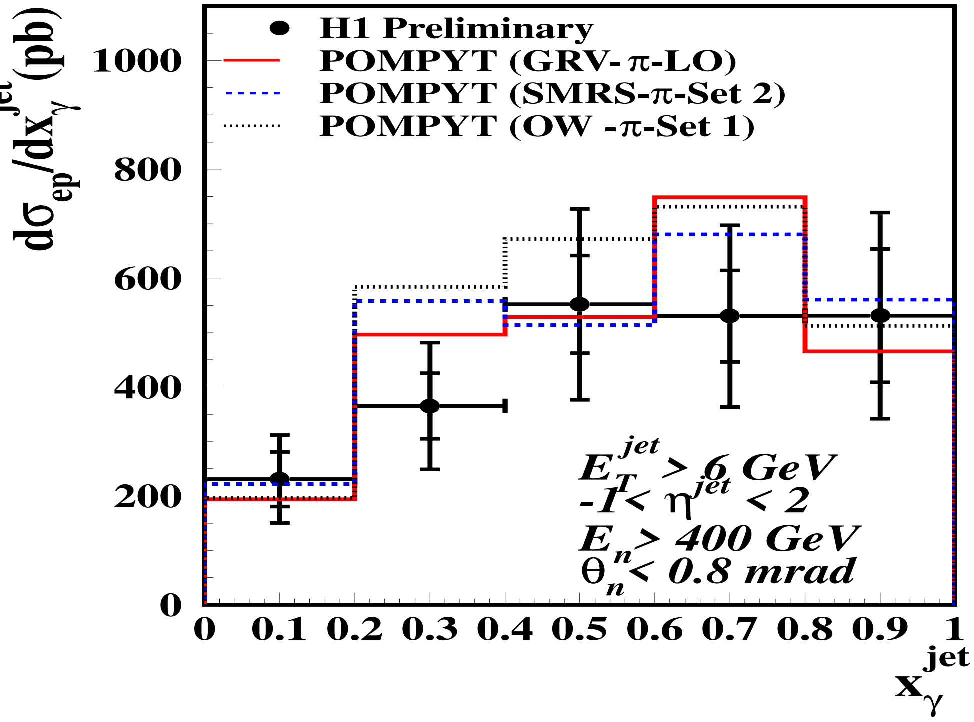
Differential LN Dijets Cross Sections in DIS

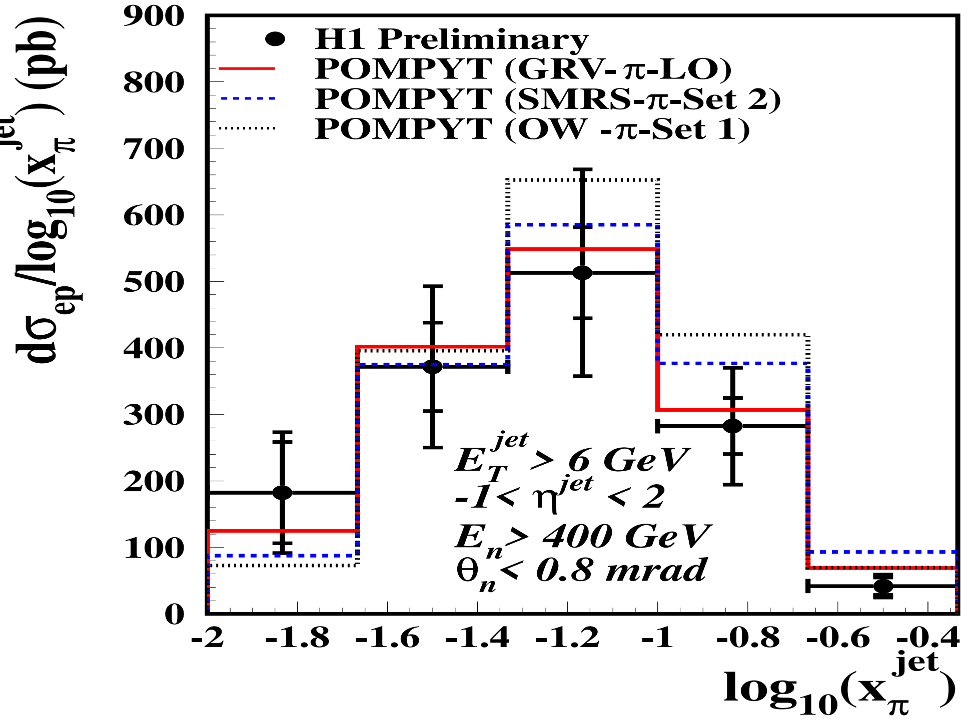




One-Pion-Exchange simulations describe data in shape and normalization

Differential LN Dijets Cross Sections in γp



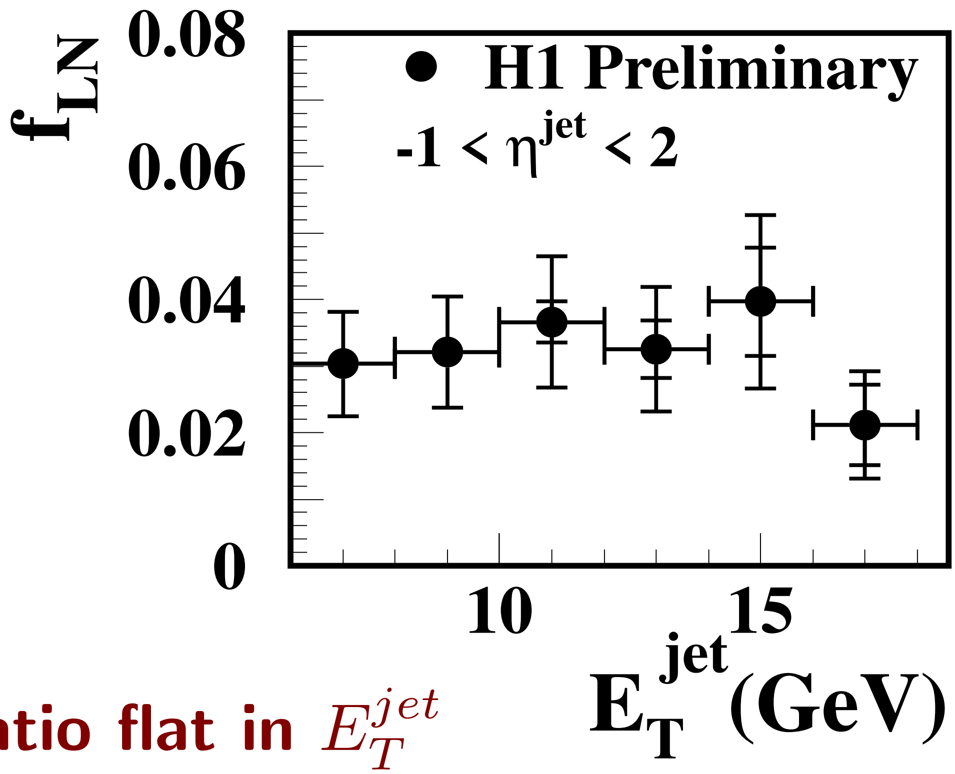


- One-Pion-Exchange simulations with different π structure functions describe data in shape and normalization

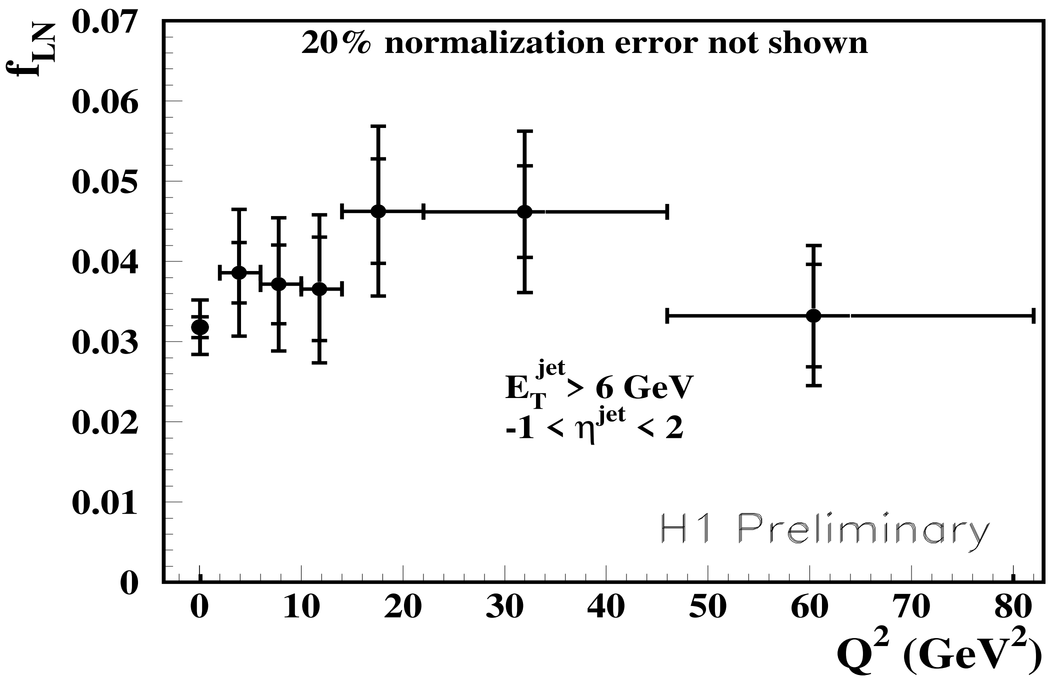
- No preference for any π structure function yet

Factorization Tests with LN Dijets

Look at leading neutron production rate as function of E_T^{jet} and Q^2:



$\Rightarrow$ Ratio flat in E_T^{jet}



$\Rightarrow$ No conclusion about factorization within the experimental uncertainties.

Summary

A lot of new results from the study of leading neutron production at HERA:

- Strong factorization breaking (factor≈2) observed in comparison of γp with pp
- Weak factorization breaking (≈ 20%) observed in production rate dependencies on Q^2 and x_L
- Leading neutron rate flat in x and Q^2 for DIS
- $F_2^{LN(3)}$ measured for $p_T^2 < (0.66 x_L)^2$GeV^2
  $\Rightarrow F_2^{LN(3)} \sim F_2$
- F_2^{π} measured for $p_T^2 < (0.66 x_L)^2$GeV^2 and $0.64 < x_L < 0.82$
  $\Rightarrow$ shape of F_2^{π} and F_2 similar
- Dijet events with a leading neutron in DIS and γp described by One-Pion-Exchange models. Factorization tests performed.

Much more to come from the higher statistics of the data samples '97 and '99 –'00.