

Leading Baryon Production at HERA



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On behalf of the H1 and ZEUS Collaborations

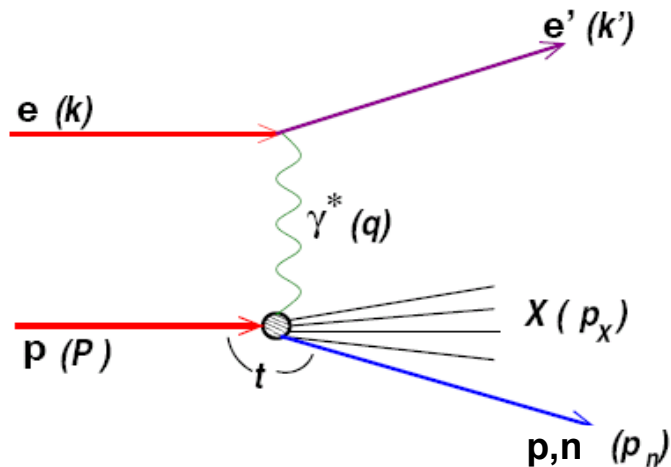


Outline:

- ♦ **Leading proton production in DIS.**
(ZEUS Collaboration)
- ♦ **Leading neutron production in DIS.**
(H1 Collaboration)
- ♦ **Leading neutron in dijet photoproduction.**
(ZEUS Collaboration)

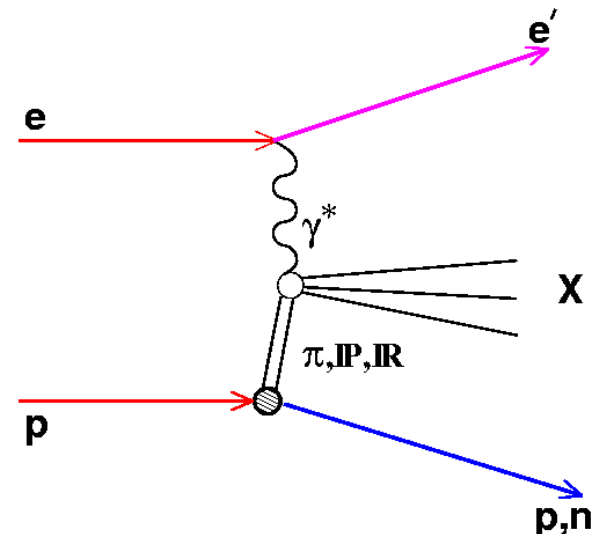
Introduction

- Significant fraction of ep scattering events contain a leading proton or leading neutron (LB) in the final state carrying a substantial portion of the energy of the incoming proton: $e+p \rightarrow e+LB+X$
- Different production models are available



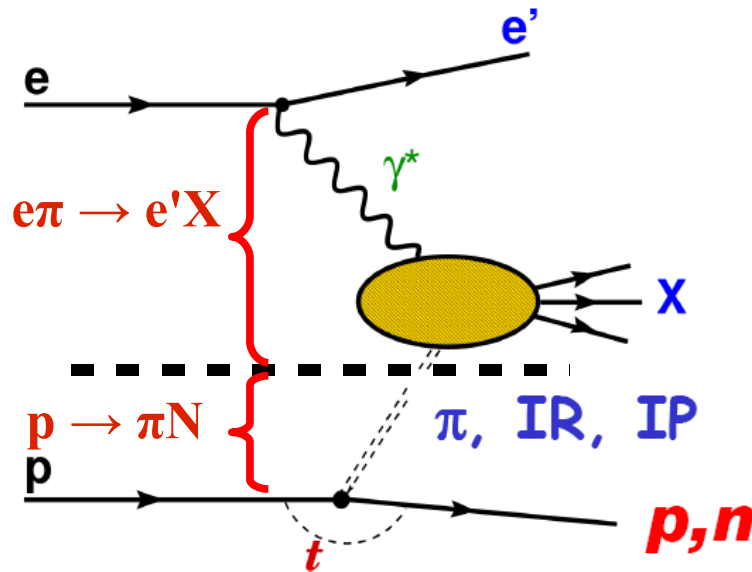
Leading baryon can come from “standard fragmentation”

- implemented in MC models (Lund String)



Leading baryon can be produced via **exchange** of virtual particle:

- leading protons: IP, IR, π_0 (isoscalar + isovector)
- leading neutrons: π^+, ρ^+, a_2 (isovector)



Lepton variables:

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

$$x = Q^2 / (2Pq)$$

$$y = s / (xQ^2)$$

Leading baryon variables:

$$x_L = E_{LB} / E_p$$

$$t = (P - P_{LB})^2 \quad (\text{or } p_T^2)$$

In the exchange model the cross sections factorise, e.g. for one pion exchange (OPE)

$$\sigma(ep \rightarrow e'NX) = f_{\pi/p}(x_L, t) \times \sigma(e\pi \rightarrow e'X)$$

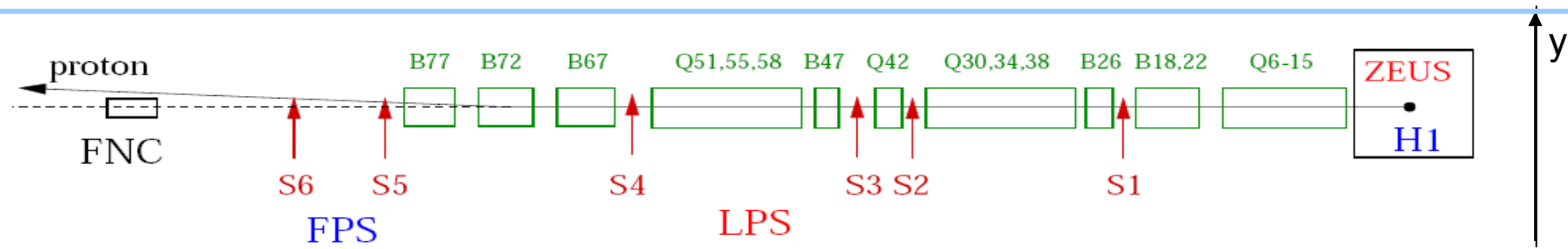
$f_{\pi/p}(x_L, t)$ - pion flux:

probability to emit pion from the proton with given x_L, t

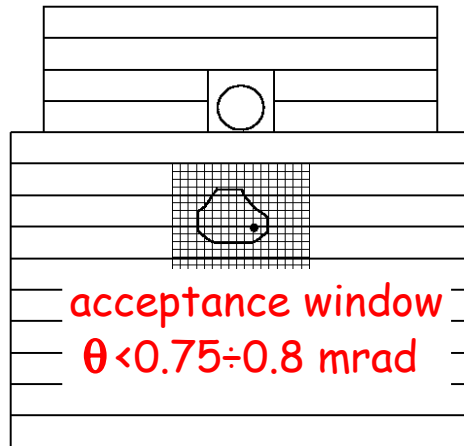
$\sigma(e\pi \rightarrow e'X)$ - cross-section of $e\pi$ scattering

- LB production independent of photon vertex
- probe structure of exchanged particle
- models predict factorisation violation – rescattering

Detectors used for measurement of LB



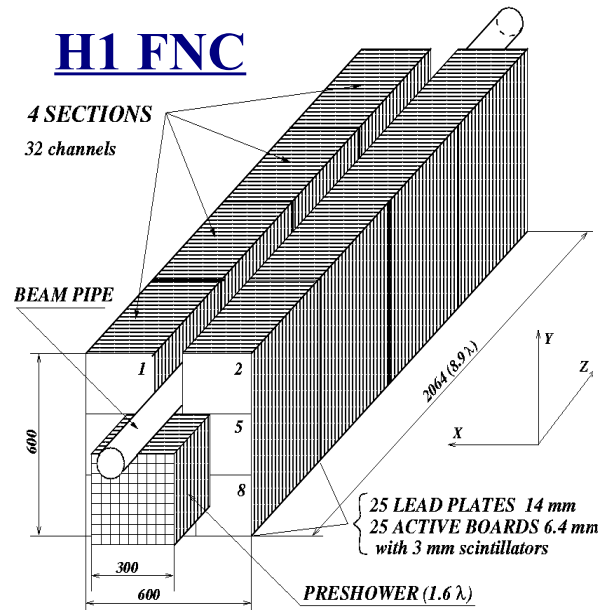
ZEUS FNC+FNT



14 towers, 17x15 grid
 of the FNT hodoscopes,
 $\sigma_E/E \approx 0.7/\sqrt{E}$

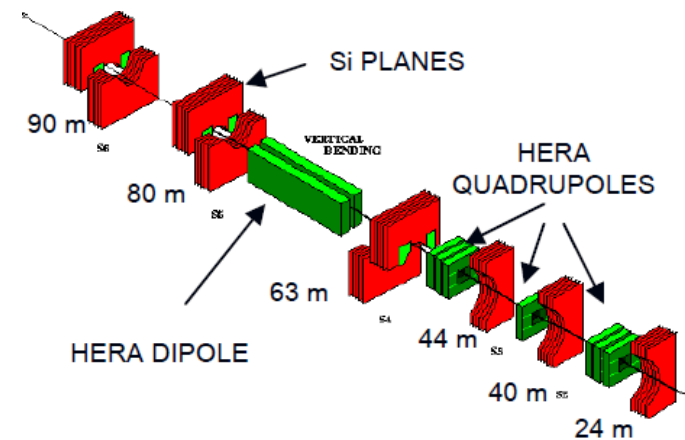
position resolution 2-3mm

H1 FNC



$\sigma_E/E \approx 0.63/\sqrt{E} \oplus 2\%$

ZEUS LPS



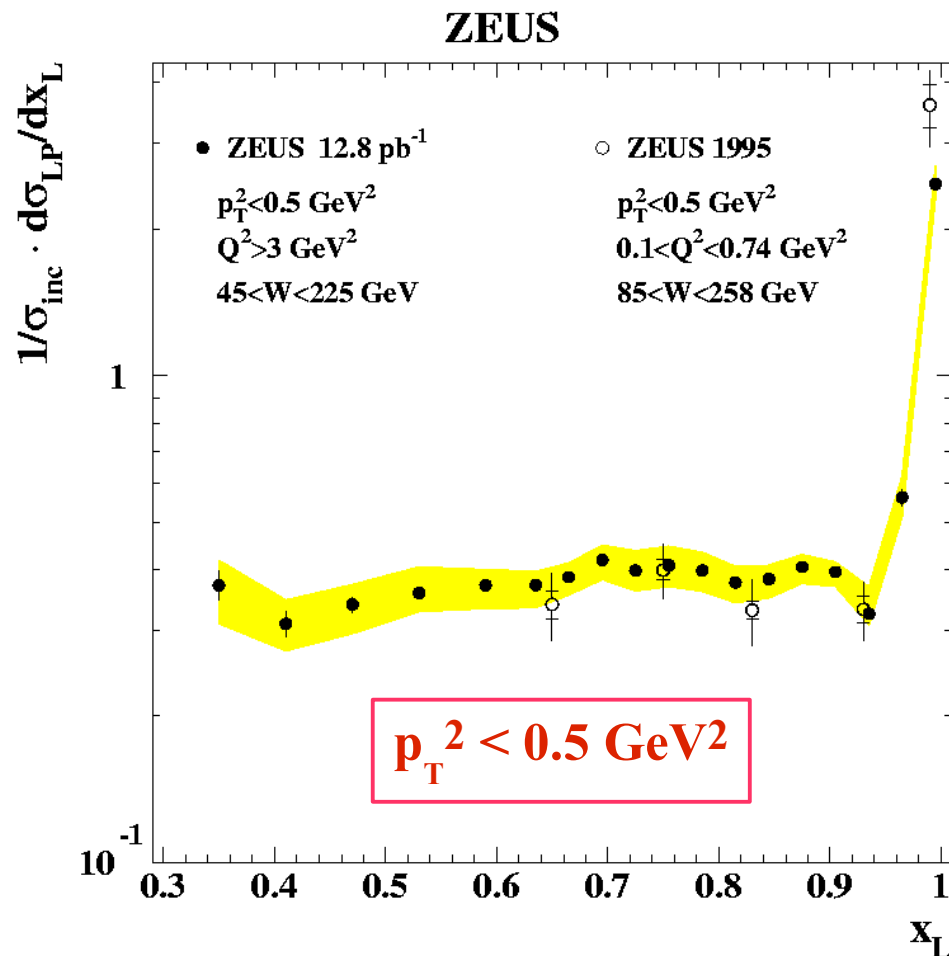
6 stations with μ -strip detectors
 hit position resolution $\sim 30 \mu\text{m}$
 $\sigma_{XL} < 1\%$, $\sigma_{PT} \sim \text{few MeV}$

momentum accuracy $< 1\%$

Acceptance limited by beam apertures and detector size.
 p_T resolution is dominated by p_T spread of proton beam (50-100 MeV).

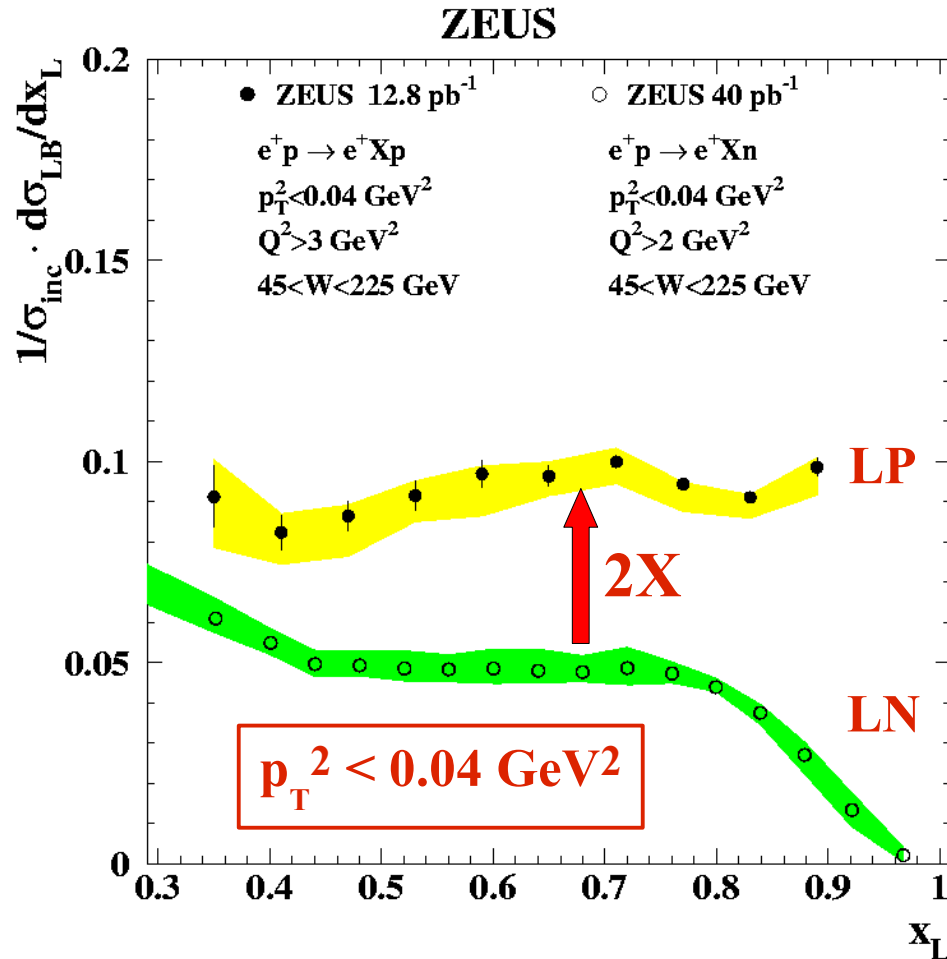
Leading Proton production in DIS

(DESY- 08 - 176, to be published in JHEP)

$d\sigma_{LP}/dx_L$ normalised to the inclusive DIS cross section

12.8 pb⁻¹
 $Q^2 > 3 \text{ GeV}^2$
 $p_T^2 < 0.5 \text{ GeV}^2$
 $45 < W < 225 \text{ GeV}$
 $x_L > 0.32$

- clear diffractive peak at $x_L \rightarrow 1$
- proton yield flat below $x_L \approx 0.95$
- consistent with earlier low Q^2 data



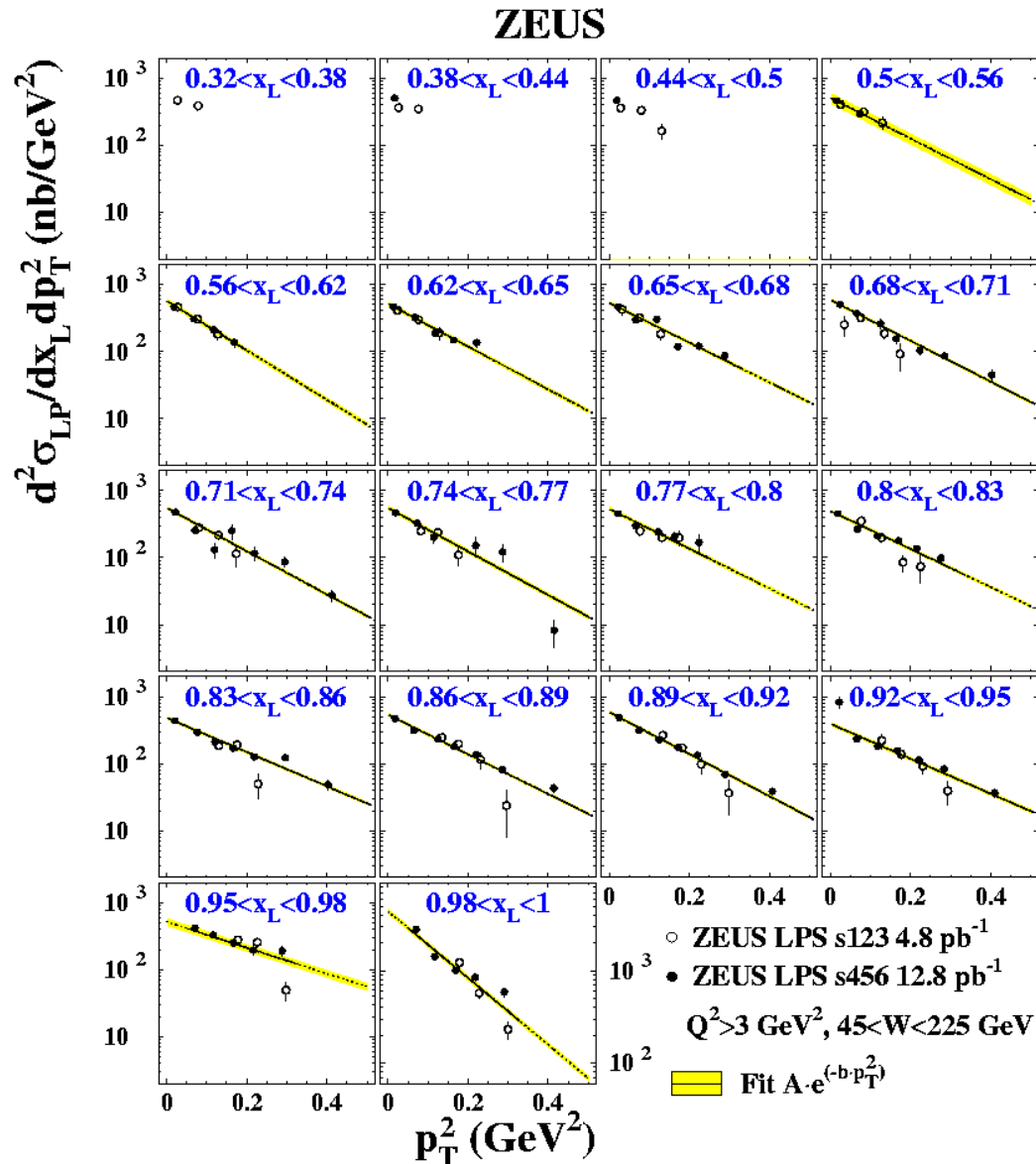
- **Restricted to a common p_T^2 range where the detector acceptances overlap**
- **For pure isovector (e.g. pion) particle exchange one expects:**

$$\text{LP} = \frac{1}{2} \text{LN}$$

- **Data suggest:**

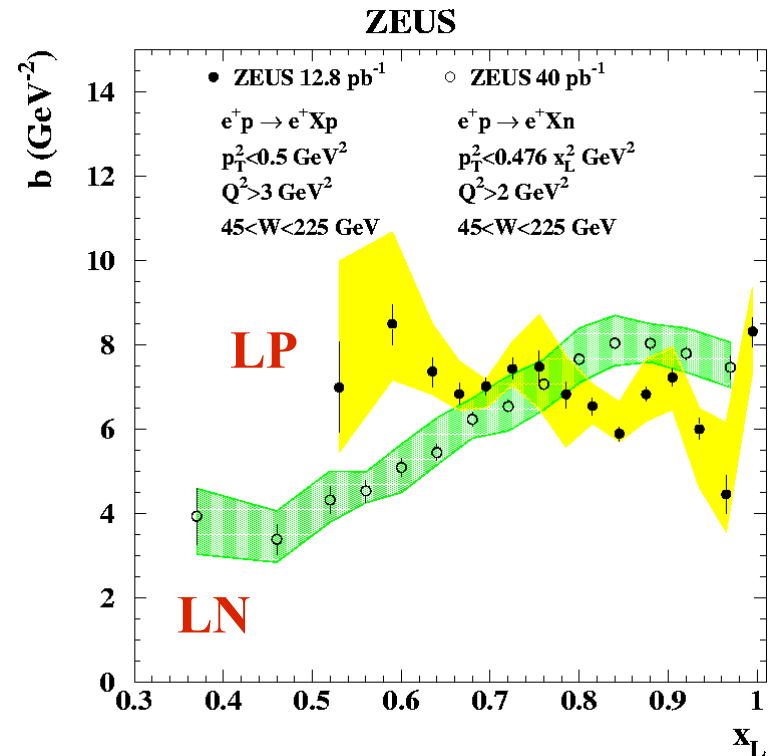
$$\text{LP} = 2 \text{LN}$$

Additional IR contributions are needed to account for the observed LP rates



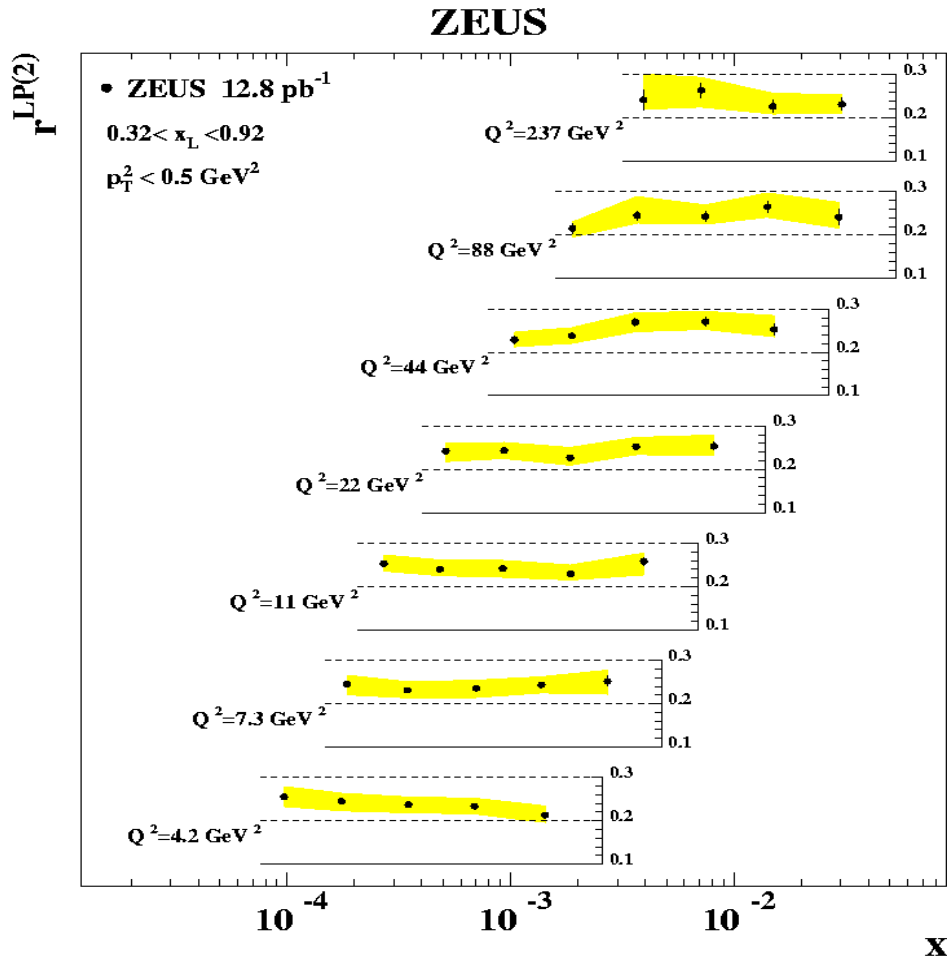
Fit by
$$\frac{1}{\sigma_{inc}} \frac{d\sigma_{LP}}{dp_T^2 dx_L} = a(x_L) \cdot e^{-b(x_L) p_T^2}$$

slopes - $b(x_L)$



- clear different trends for LP and LN
- similar slopes for $x_L \approx 0.65-0.8$

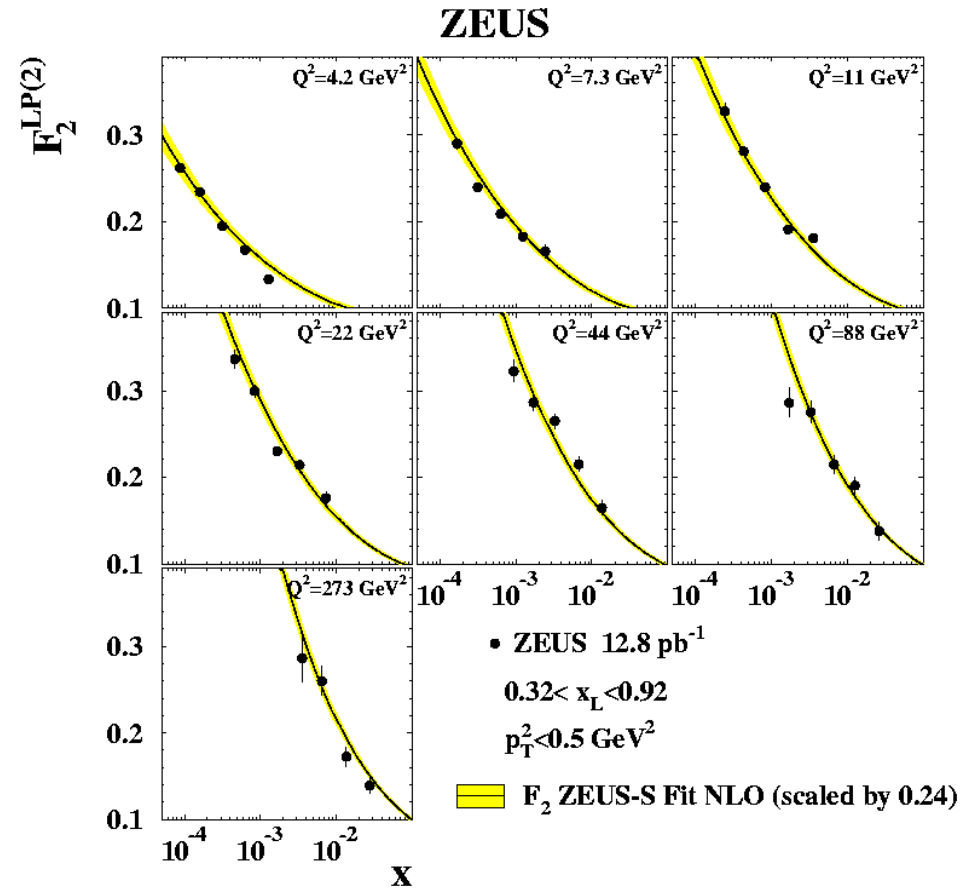
Rates to inclusive DIS



$r^{LP(2)}$ is approximately constant vs x and Q^2
with average value ~ 0.24

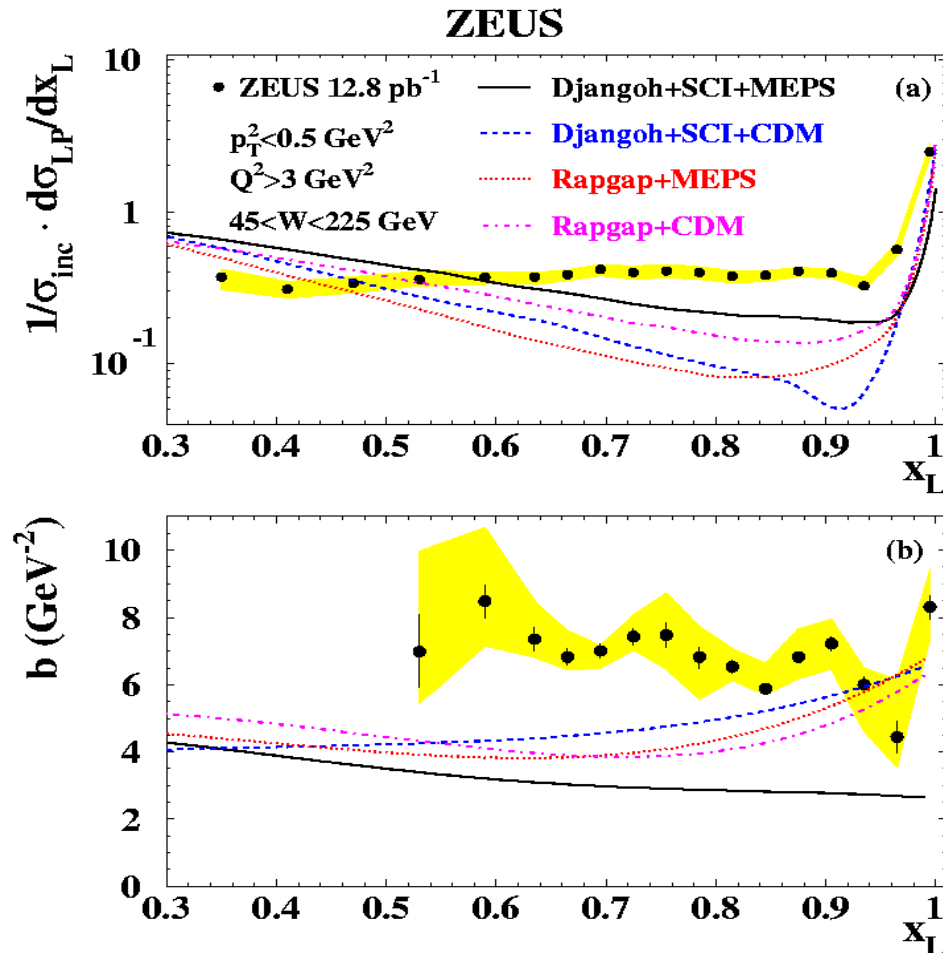
Structure function $F_2^{LP(2)}$

$$\frac{d^2 \sigma(ep \rightarrow eXp)}{dx dQ^2} = \frac{4\pi\alpha^2}{xQ^4} \left[1 - y + \frac{y^2}{2} \right] \cdot F_2^{LP(2)}(x, Q^2)$$



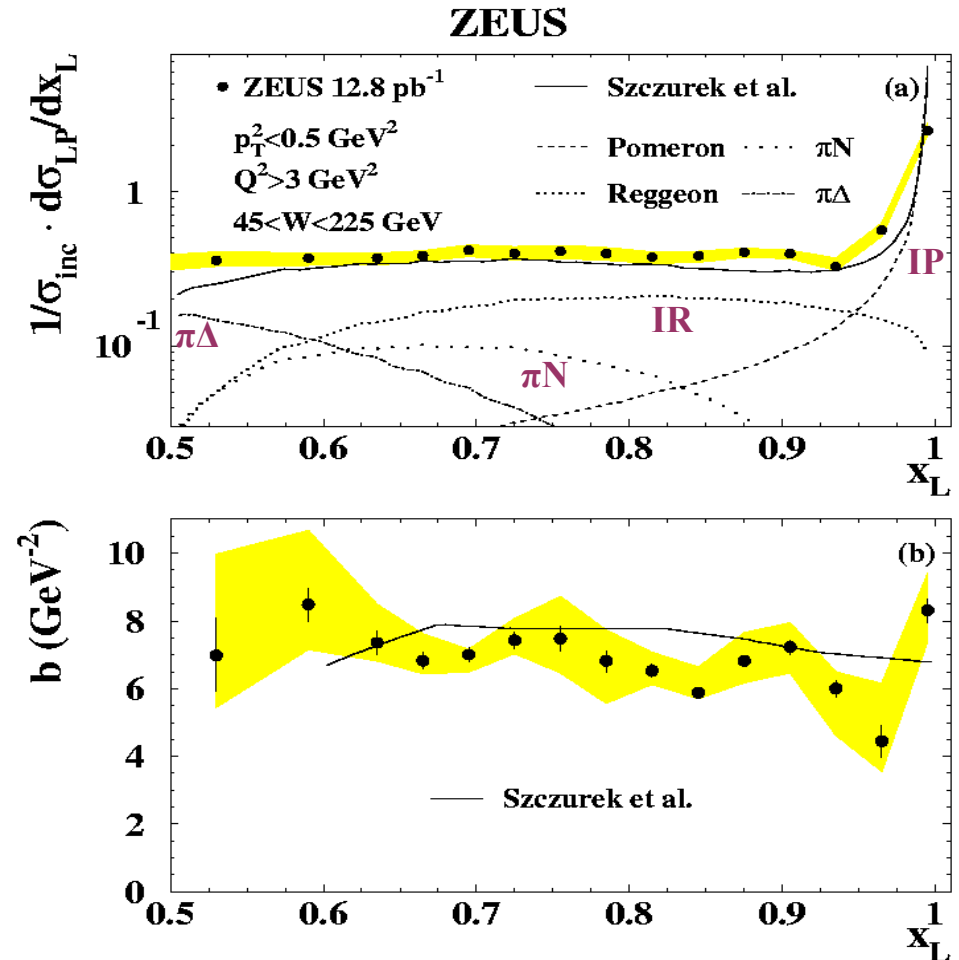
same trend as inclusive F_2 is observed

Standard fragmentation MC



- good description of diff. peak but all fail at low x_L
- slopes are too low at low x_L

Model with multiple exchanges

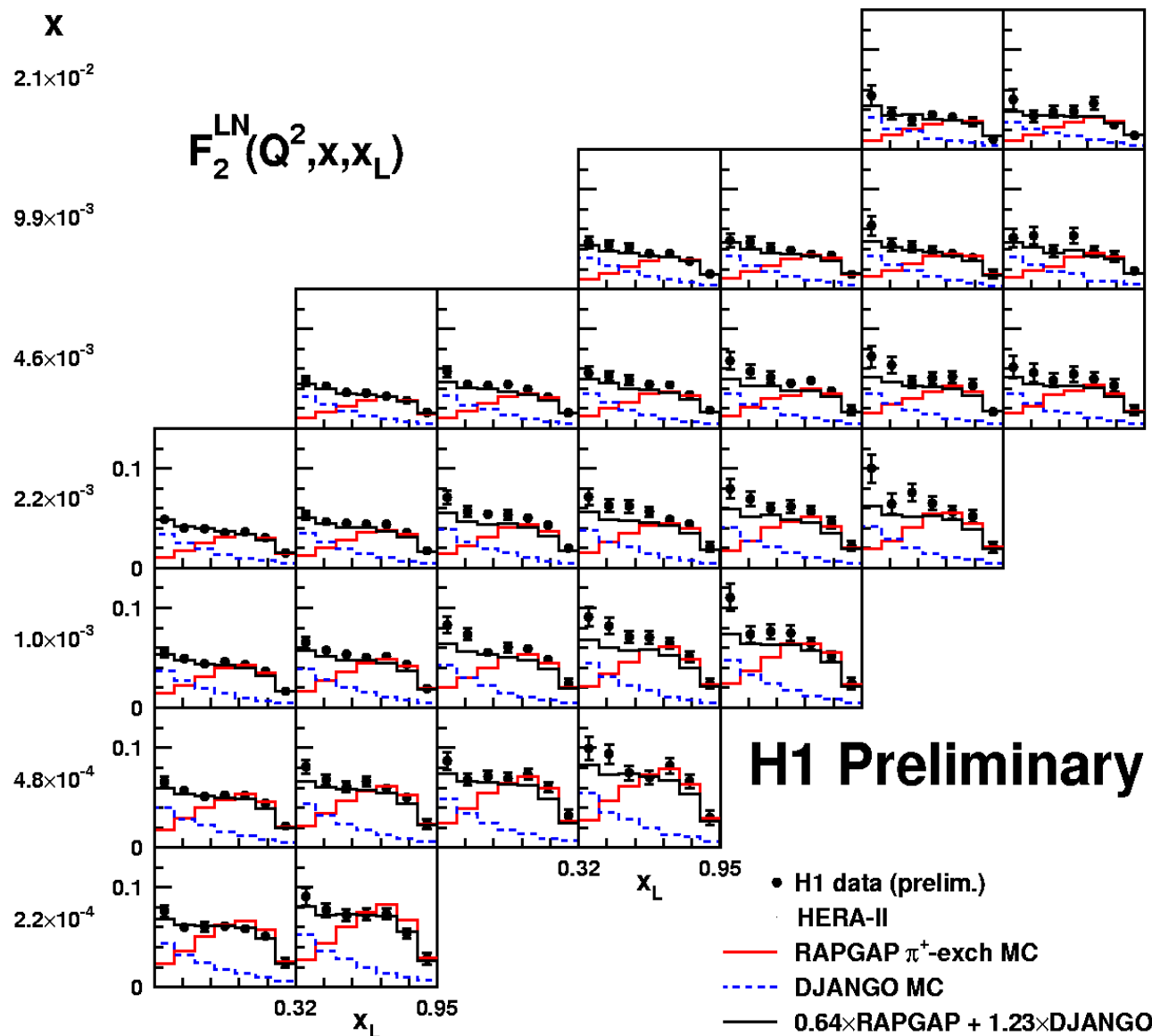


- good description of LP yield and slope by adding different exchanges
- reggeon dominant at medium x_L

Leading Neutron production in DIS

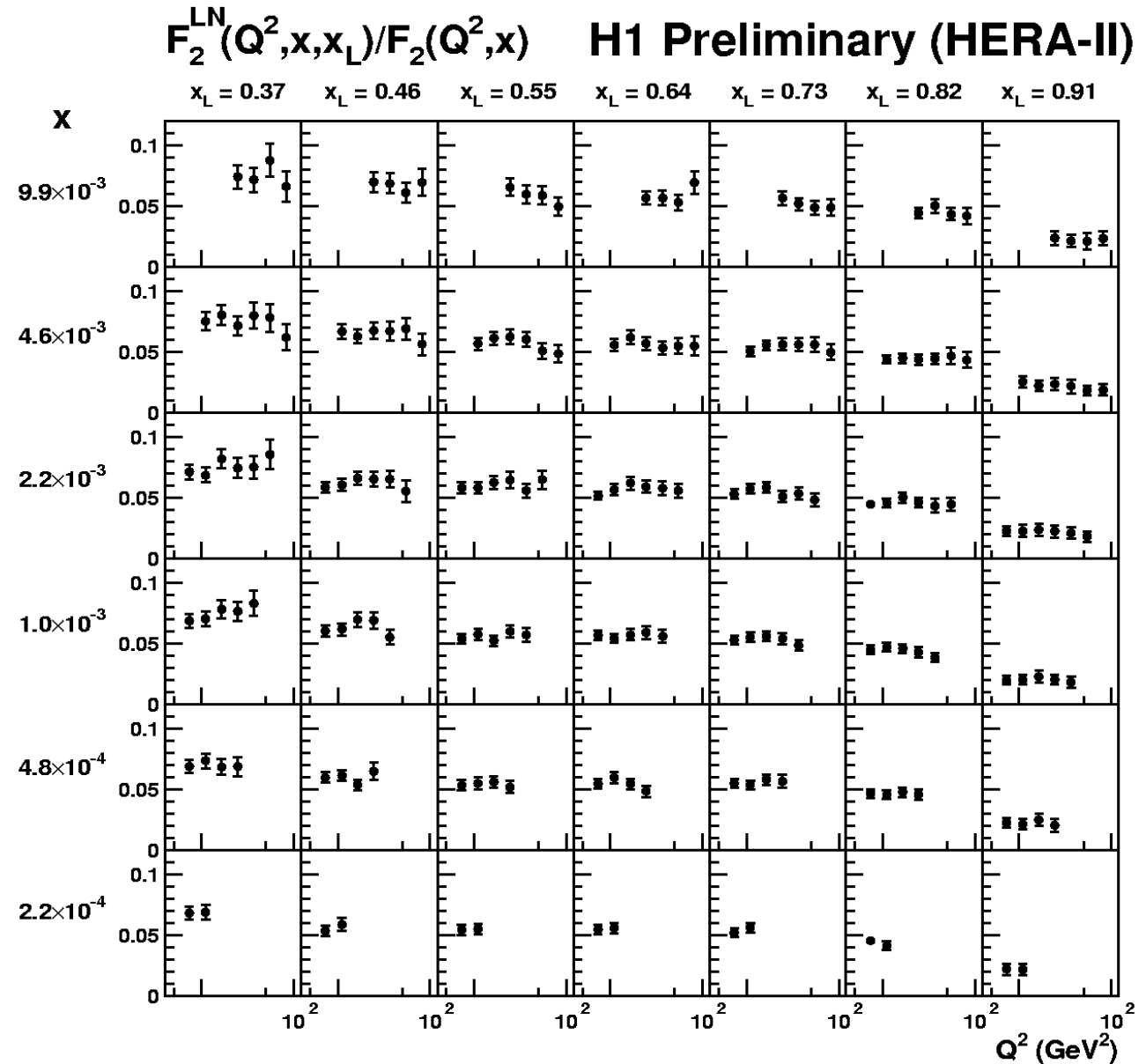
122 pb⁻¹
6 < Q² < 100 GeV²
p_T² < 0.04 GeV²
0.32 < x_L < 0.95

- $$Q^2 = 7.3 \text{ GeV}^2 \quad Q^2 = 11 \text{ GeV}^2 \quad Q^2 = 16 \text{ GeV}^2 \quad Q^2 = 24 \text{ GeV}^2 \quad Q^2 = 37 \text{ GeV}^2 \quad Q^2 = 55 \text{ GeV}^2 \quad Q^2 = 82 \text{ GeV}^2$$



$F_2(Q^2, x)$ from the H1
parameterisation
(Eur.Phys.J.C21 (2001) 33)

$F_2^{\text{LN}}(Q^2, x, x_L)/F_2(Q^2, x)$
is mostly flat in Q^2 and x
 $\Rightarrow$ similar to the Leading
Proton measurement



In the π -exchange picture leading neutron production cross section can be expressed as the product of the pion flux and the pion structure function F_2^π from the measured F_2^{LN} :

$$\sigma_{ep \rightarrow enX}(\beta, Q^2, x_L, t) = f_{\pi^+/p}(x_L, t) \times \sigma_{e\pi \rightarrow eX}(\beta, Q^2), \quad \text{where } \beta = x/(1-x_L)$$

Assuming that pion exchange is dominating at $x_L \approx 0.7$ and $p_T < 0.2$ GeV we can estimate F_2^π from the $F_2^{\text{LN}(3)}$ measurement according to:

$$F_2^{\text{LN}(3)}(\beta, Q^2, x_L) = \Gamma_\pi(x_L) \times F_2^\pi(\beta, Q^2)$$

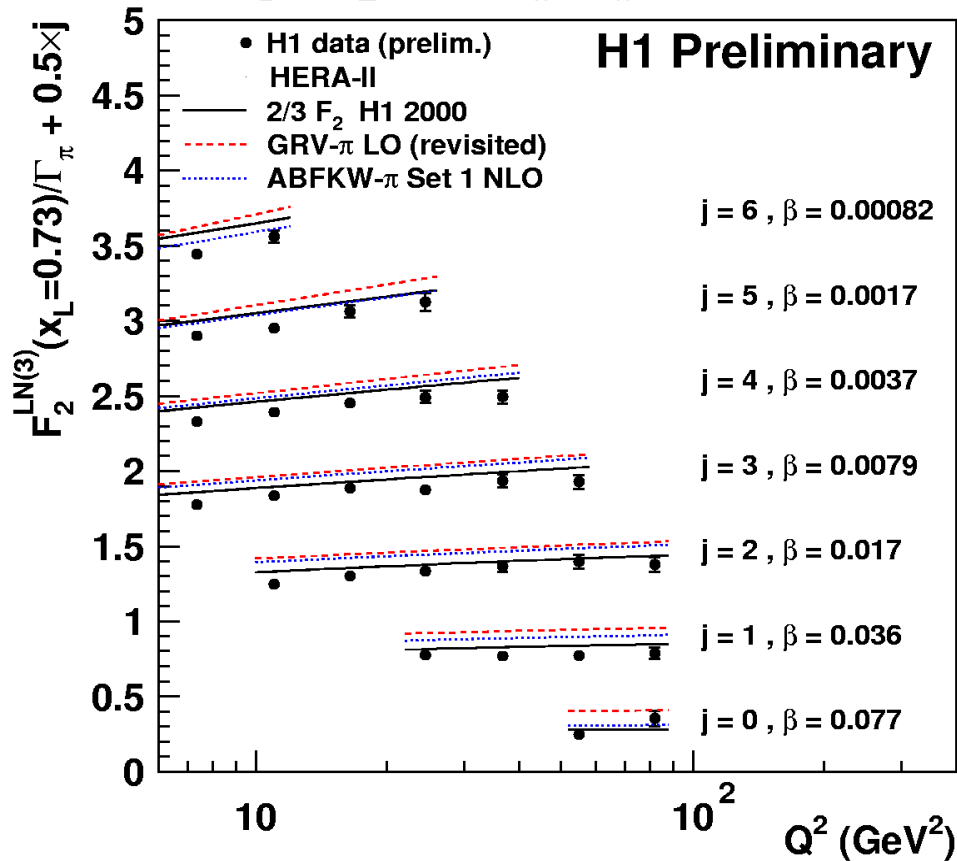
where Γ_π is integrated over t pion flux

$$\text{Using pion flux } f_{\pi^+/p} = \frac{1}{2\pi} \frac{g_{p\pi n}^2}{4\pi} (1-x_L) \frac{-t}{(m_\pi^2 - t)^2} \exp\left(-R_{\pi n}^2 \frac{m_\pi^2 - t}{1-x_L}\right) \Rightarrow \text{at } x_L = 0.73 \quad \Gamma_\pi = 0.131$$

(other pion flux form-factors give other values of $\Gamma_\pi \Rightarrow$ global normalisation factor on F_2^π)

No background subtraction or absorption correction applied

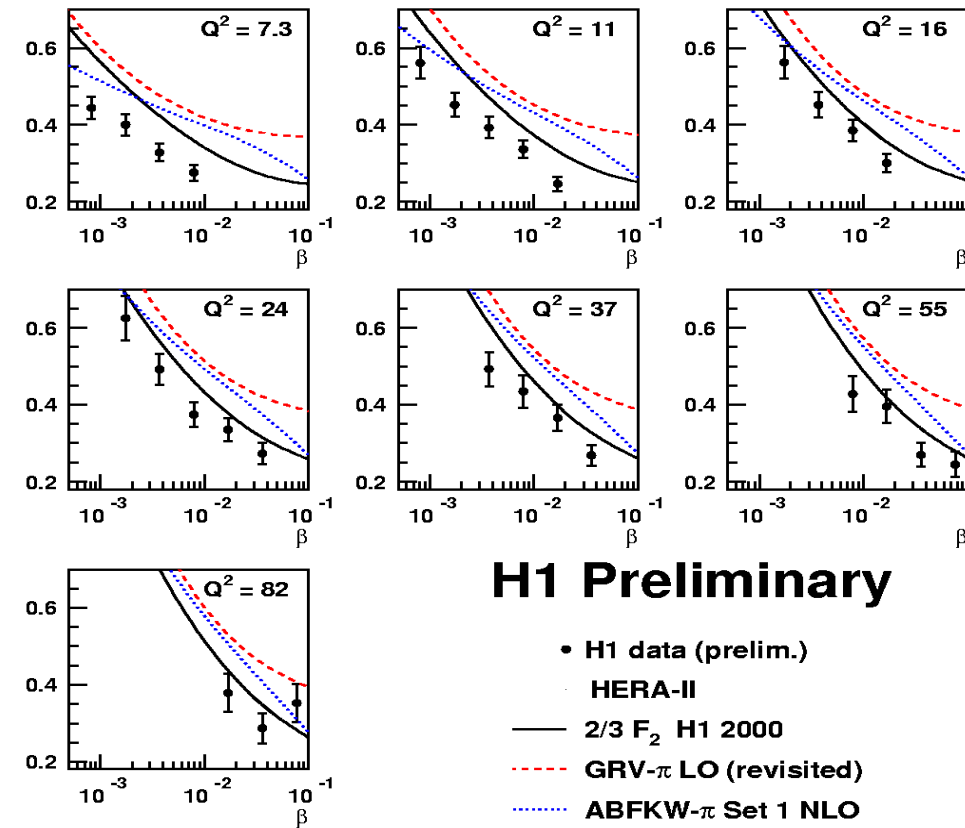
$$F_2^{\text{LN}(3)}(x_L = 0.73)/\Gamma_\pi, \Gamma_\pi = 0.131$$



Data compared to parameterisations:

- 2/3 of proton F_2
- GRV- π LO (revisited)
- ABFKW- π Set 1 NLO

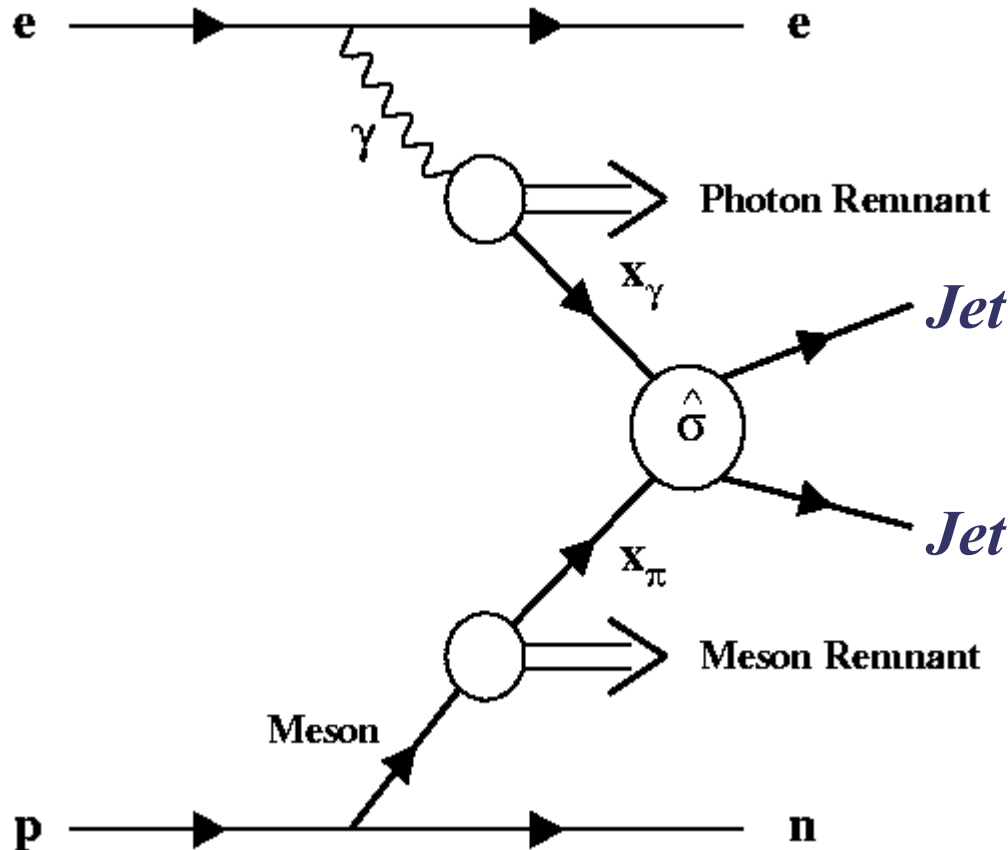
$$F_2^{\text{LN}(3)}(x_L = 0.73)/\Gamma_\pi, \Gamma_\pi = 0.131$$



The F_2^π exhibits a rise with Q^2 (i.e. scaling violation) and steep rise with decreasing β . Similar to pion and proton structure functions parameterisations.

Leading Neutron with Dijet in photoproduction

40 pb^{-1} , $Q^2 < 1 \text{ GeV}^2$, $p_T^2 < 0.475 x_L^2 \text{ GeV}^2$,
 $x_L > 0.2$, $E_T^{\text{jet1}} > 7.5 \text{ GeV}$, $E_T^{\text{jet2}} > 6.5 \text{ GeV}$,
 $-1.5 < \eta^{\text{jet1,2}} < 2.5$

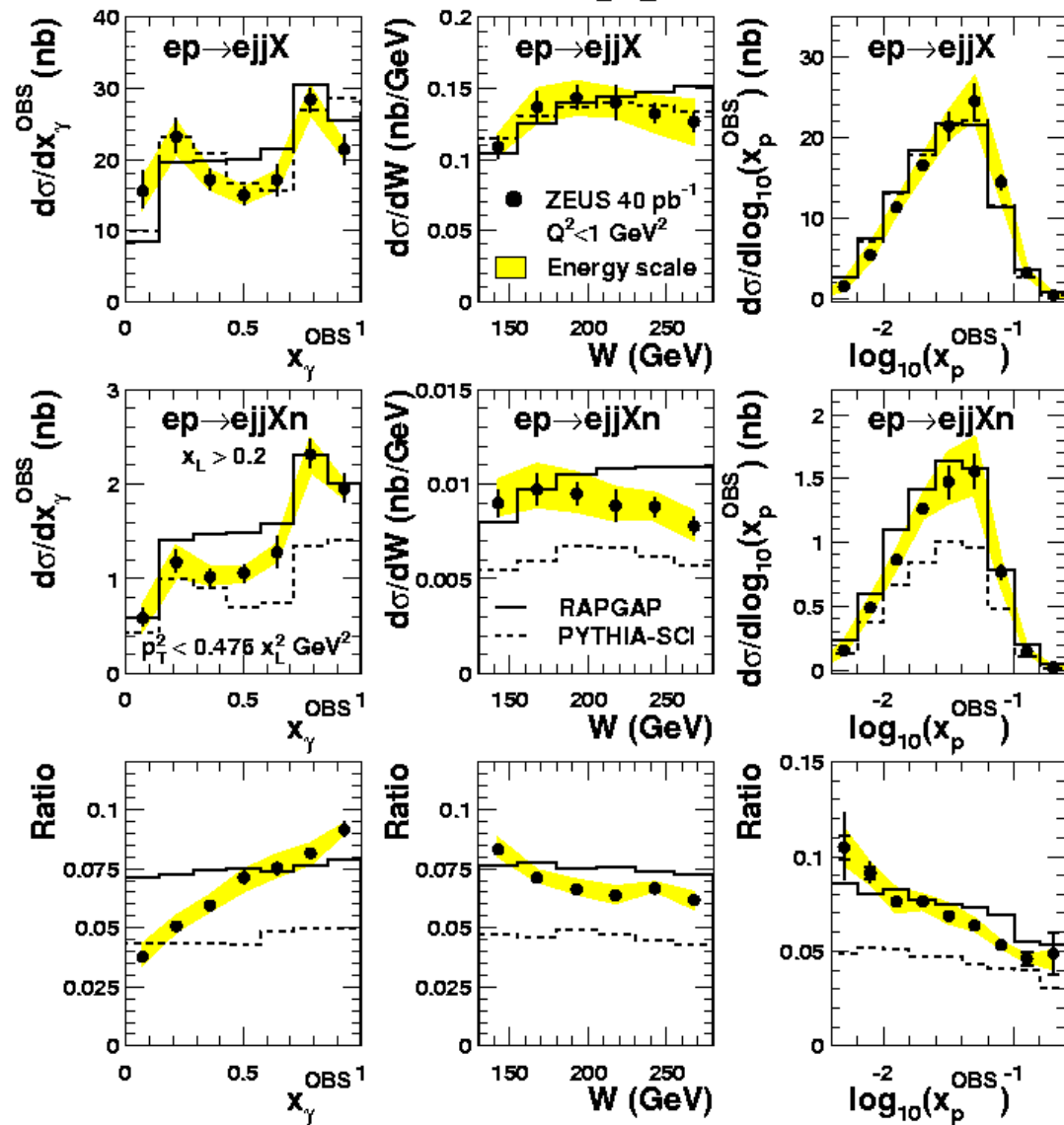


Absorption effects increase from high $Q^2 \Rightarrow \gamma p$

i.e. hard $\Rightarrow$ soft scale

A hard scale in γp can be introduced by requiring high E_T jets

ZEUS



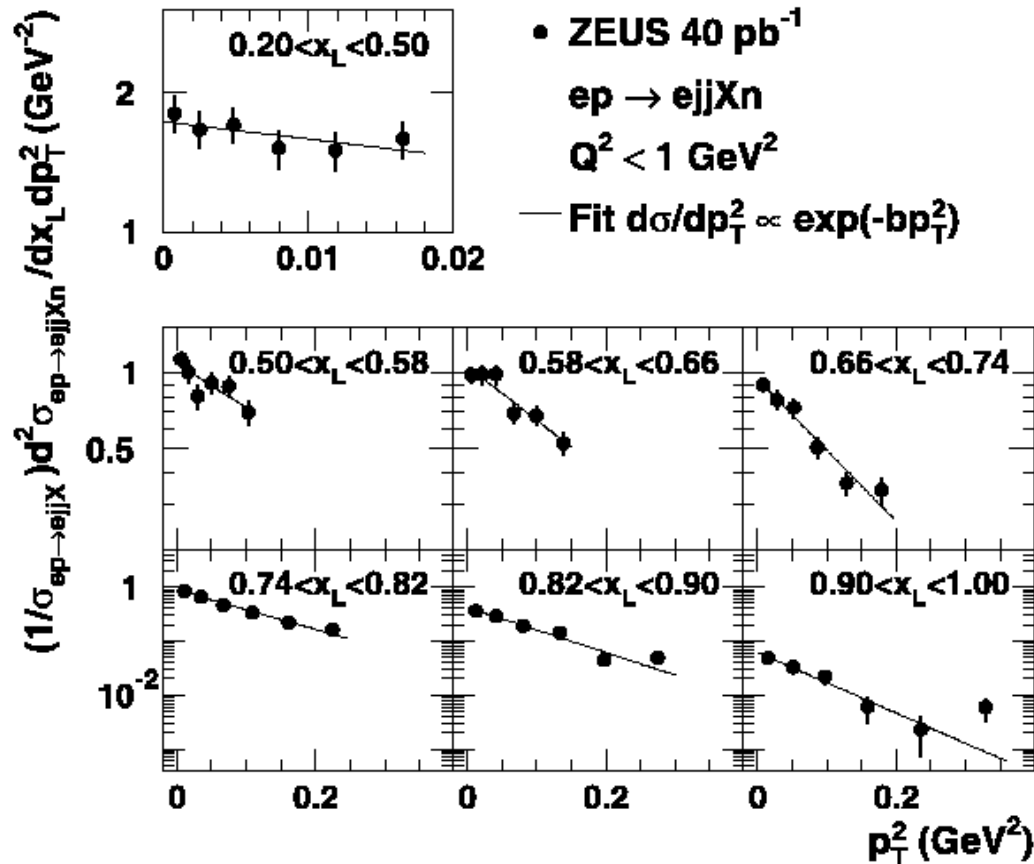
W – total energy of
photon-proton system

$$x_\gamma = \sum_{\text{jets}} (E - p_z) / (2yE_e)$$

$$x_p = \sum_{\text{jets}} (E + p_z) / (2E_p)$$

- strong dependence of ratio on x_γ (also on W , x_p).
- seems that resolved photon is suppressed in neutron events

ZEUS

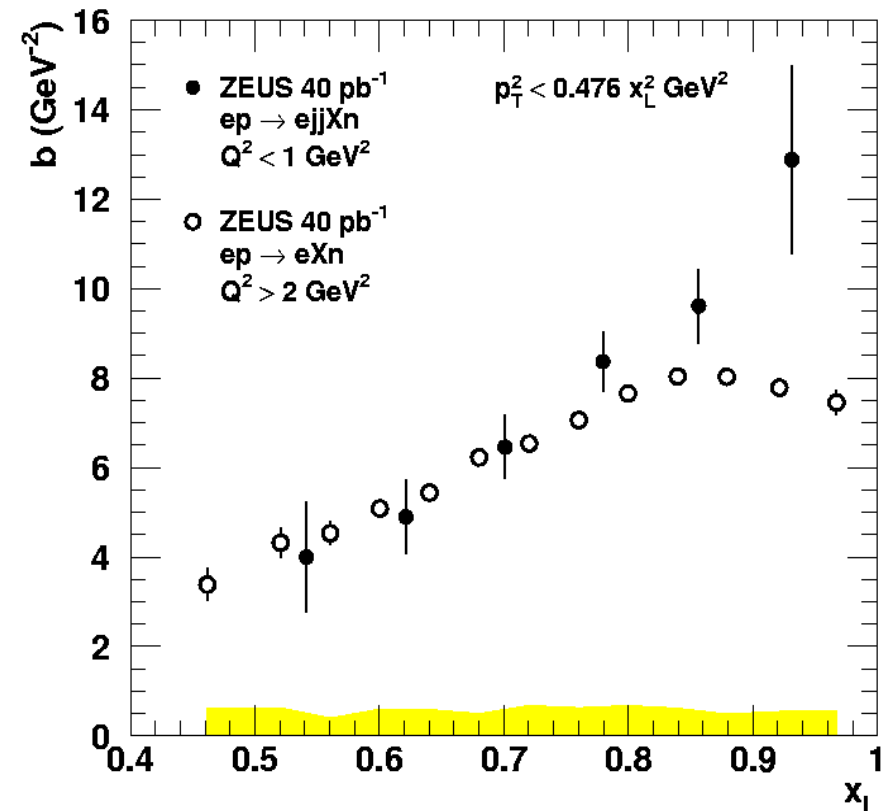


Well described by exponential fall-off in p_T^2

$$\frac{1}{\sigma_{inc}} \frac{d\sigma_{LN}}{dp_T^2 dx_L} = a(x_L) \cdot e^{-b(x_L) p_T^2}$$

slopes - $b(x_L)$

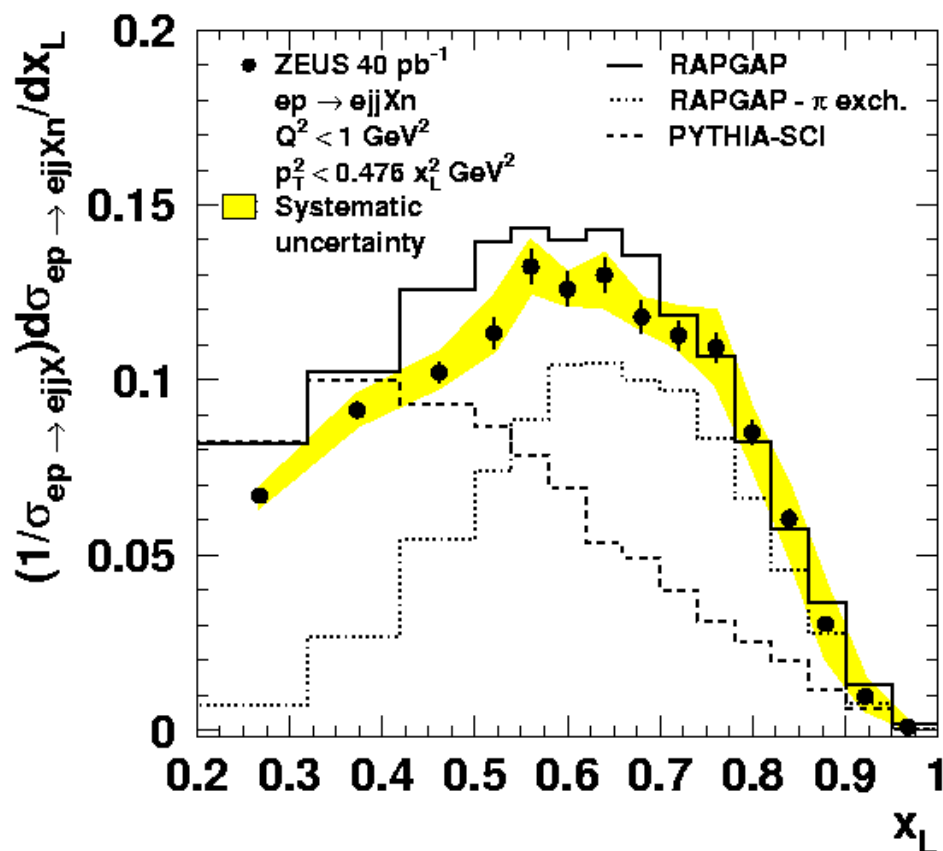
ZEUS



similar slopes in DIS and γp +dijet

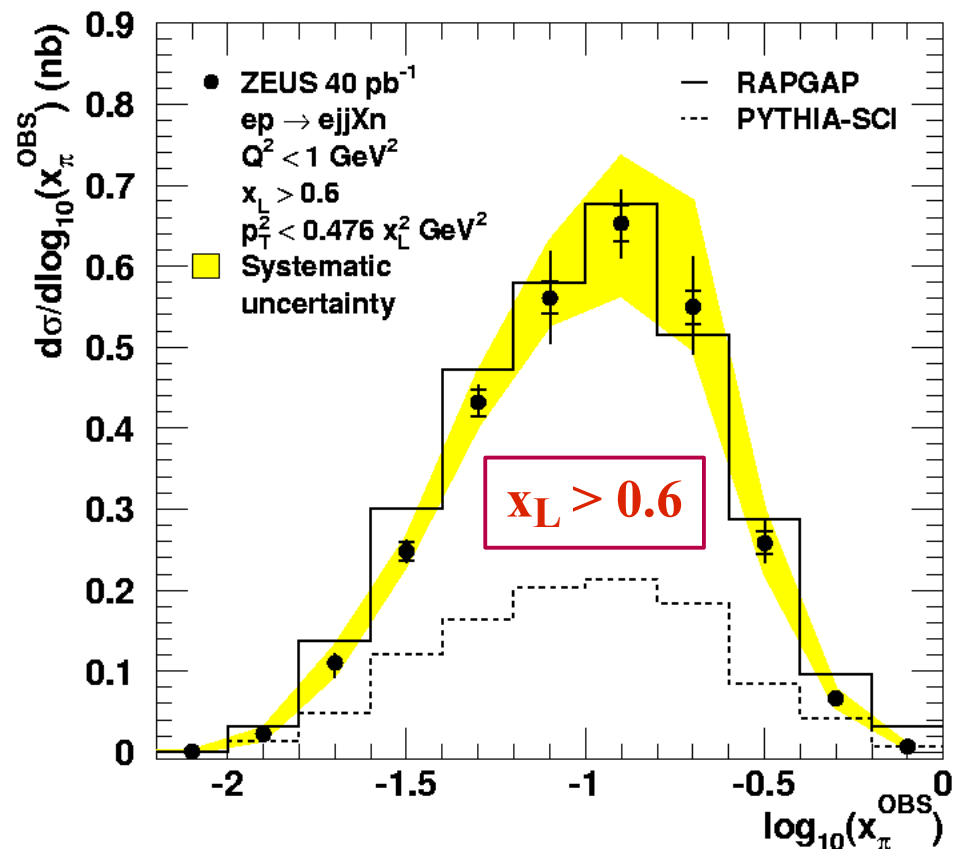
=> Same production mechanism

ZEUS



- **RAPGAP π -exchange only and PYTHIA-SCI describe data poor**
- **Pion exchange is dominating mechanism at high x_L**
- **Full RAPGAP gives good description of data**

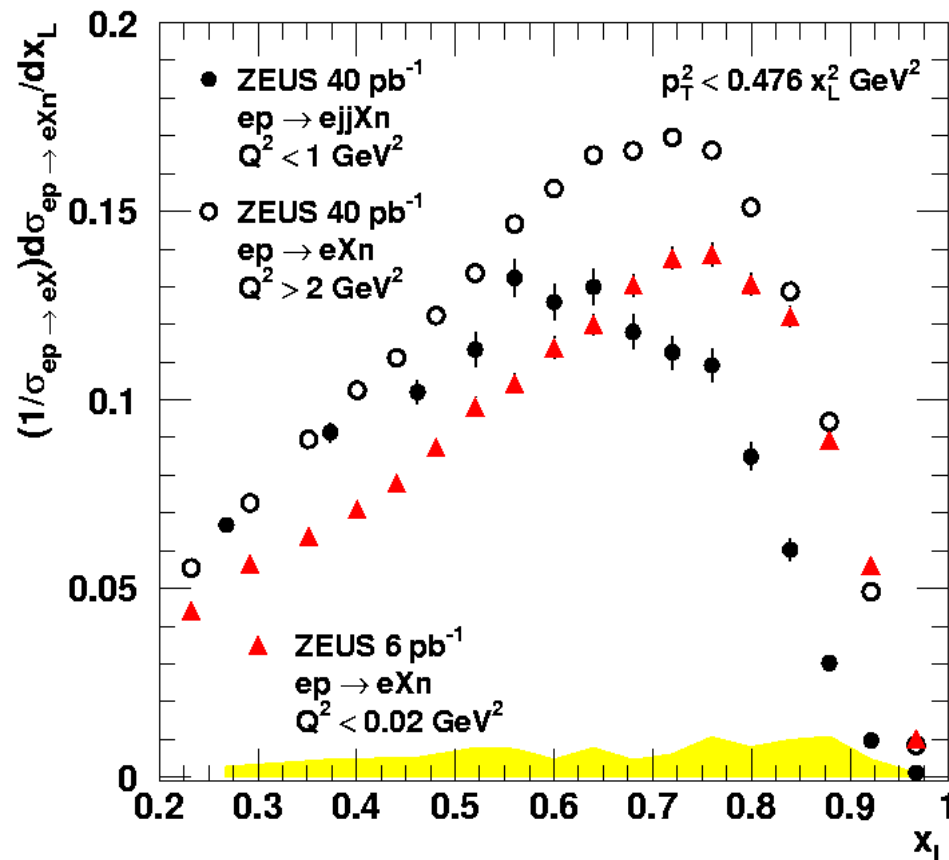
ZEUS



$$x_\pi = x_p / (1 - x_L)$$

**P.D.F. parameters from $x_\pi > 0.1$
 $\Rightarrow$ OK also at lower x_π**

ZEUS



- LN in DIS
- LN + JJ in γp
- ▲ LN in γp

- ◆ Protoproduction with jets is suppressed vs DIS at low x_L
 $\Rightarrow$ consistent with rescattering models
- ◆ Effect not prominent in photoproduction with high E_T jets
- ◆ Phase space limitation: dijets in the final state leave little room for energetic high x_L neutrons

Leading Baryons are good testing ground to study soft vs hard physics

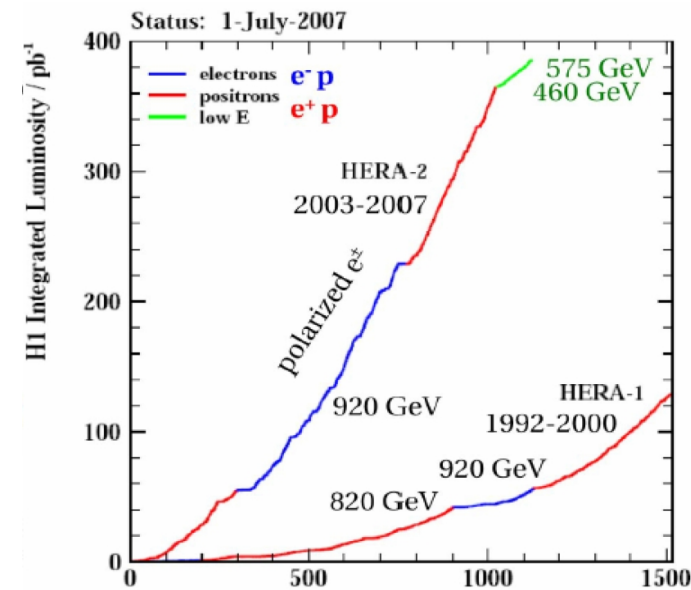
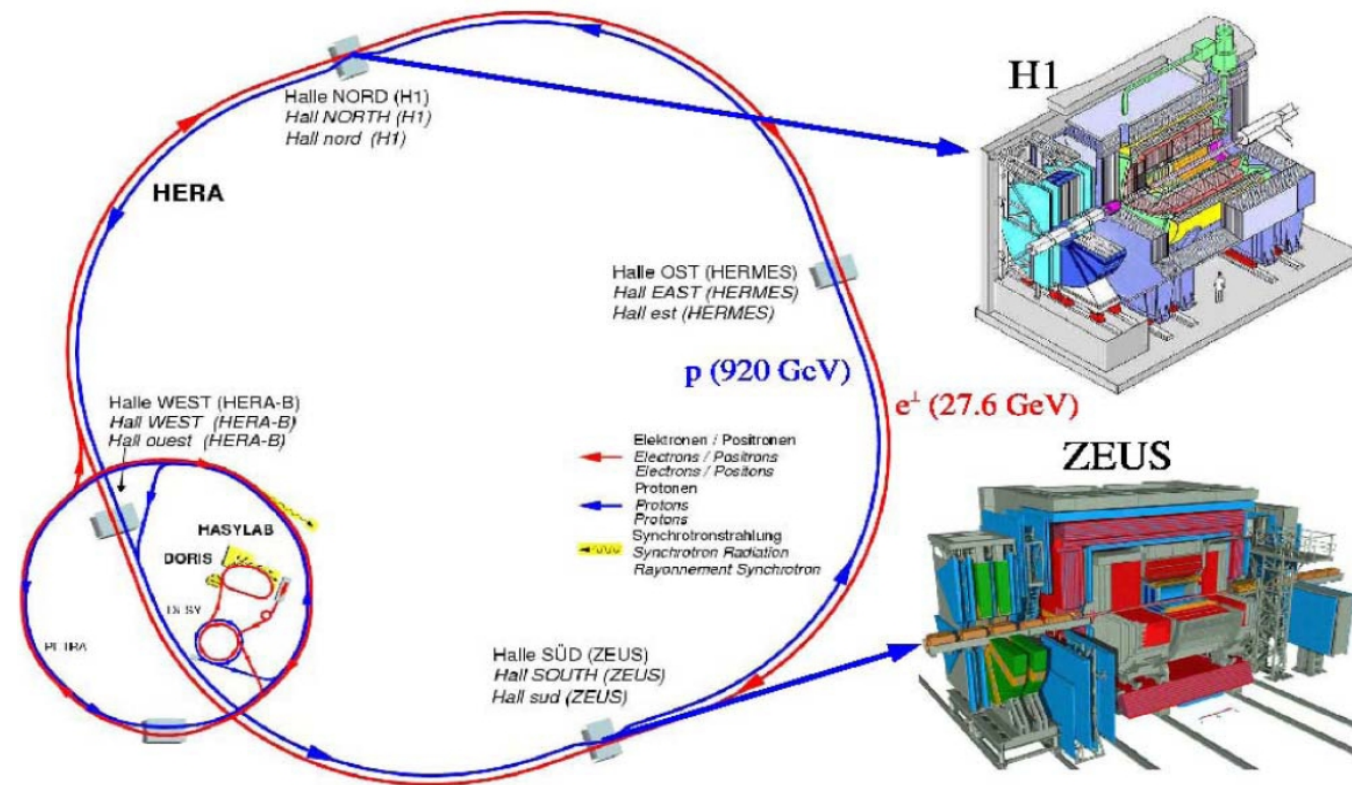
- Precise measurements of LB x_L and p_T^2 presented in DIS, γp with dijets.
- Fragmentation MC-models without meson exchange do not describe the data.
- Models with virtual meson exchange describe data better.
- F_2^{LP}/F_2 and F_2^{LN}/F_2 ratios are independent of x and Q^2
- For LN production, pion structure F_2^π estimated and compared with parameterisations of pion structure function
- Reintroducing hard scale in γp with high E_T jets: absorption effect not prominent

Backup slides

HERA

The world's only electron/positron-proton collider at DESY, Hamburg.

$E_e = 27.6 \text{ GeV}$, $E_p = 920 \text{ GeV}$ (also 820, 460 and 575 GeV). $\sqrt{s}$ up to 320 GeV.



HERA-1: 1992 - 2000
HERA-2: 2003 - 2007

Two colliding experiments: H1 and ZEUS

Total lumi: 0.5 fb^{-1} per experiment

- **ZEUS: Leading Proton production in DIS:**

12.8 pb^{-1} , $Q^2 > 3 \text{ GeV}^2$, $p_T^2 < 0.5 \text{ GeV}^2$, $x_L > 0.32$, $45 < W < 225 \text{ GeV}$

- **H1: Leading Neutron production in DIS:**

122 pb^{-1} , $6 \text{ GeV}^2 < Q^2 < 100 \text{ GeV}^2$, $p_T^2 < 0.04 \text{ GeV}^2$, $0.32 < x_L < 0.95$

- **ZEUS: Leading Neutron + Dijets in photoproduction:**

40 pb^{-1} , $Q^2 < 1 \text{ GeV}^2$, $p_T^2 < 0.475 x_L^2 \text{ GeV}^2$, $x_L > 0.2$, $130 < W < 280 \text{ GeV}$,

$E_T^{\text{jet1}} > 7.5 \text{ GeV}$, $E_T^{\text{jet2}} > 6.5 \text{ GeV}$, $-1.5 < \eta^{\text{jet1,2}} < 2.5$

DIS and γp have very different inclusive cross sections σ_{inc}

=> for sensible comparisons look at $\sigma_{\text{LB}}/\sigma_{\text{inc}}$

Additional benefit: systematic uncertainties of central detector cancel

=> Most measured by ZEUS LB cross sections are relative to inclusive ones

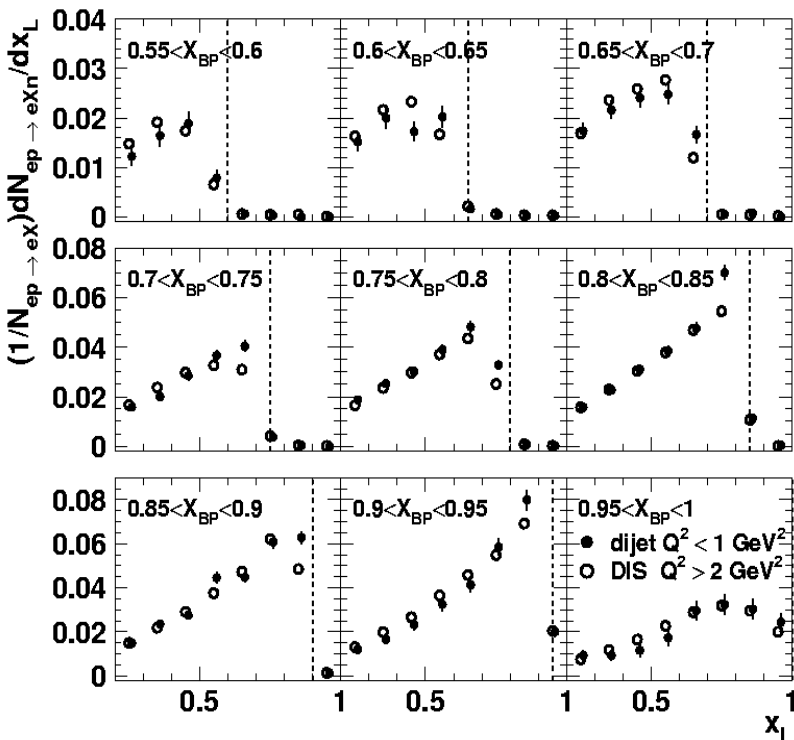
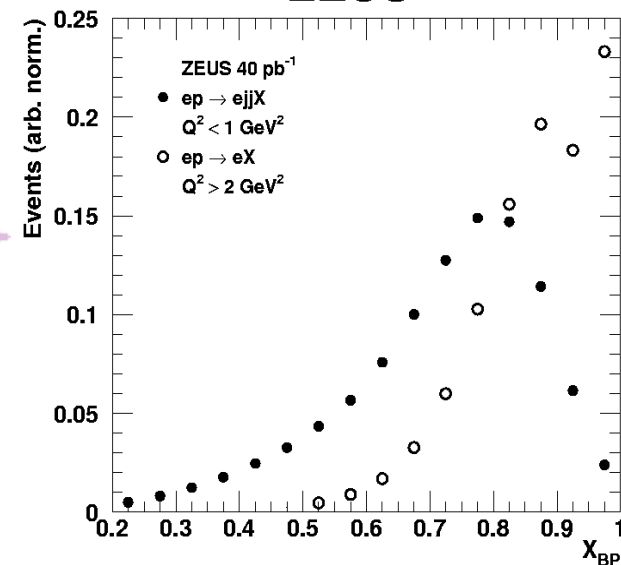
Consider X_{BP} = fraction of p-energy available for LN production

$$x_L < X_{BP} = 1 - (E + P_Z)/(2E_p)$$

X_{BP} dist. is different in DIS and dijet γp :
much less energy available in
dijet γp for LN production

ZEUS

ZEUS



Reweight DIS LN x_L dist. to match the X_{BP} dist. in dijet γp

- ♦ suppression at high x_L dist. mostly gone
- ♦ large suppression at low x_L seen in γp without jets not there

For fixed X_{BP} , same LN rate and x_L spectrum

Differences in the x_L spectra
due to kinematic suppression.