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Leading Baryon Production at HERA

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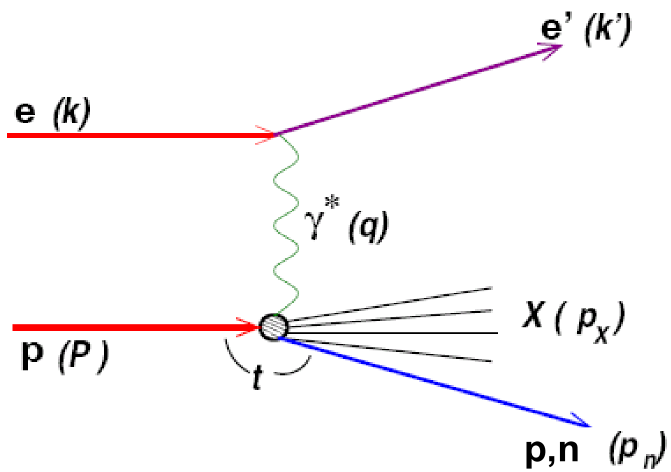
On behalf of the H1 and ZEUS Collaborations

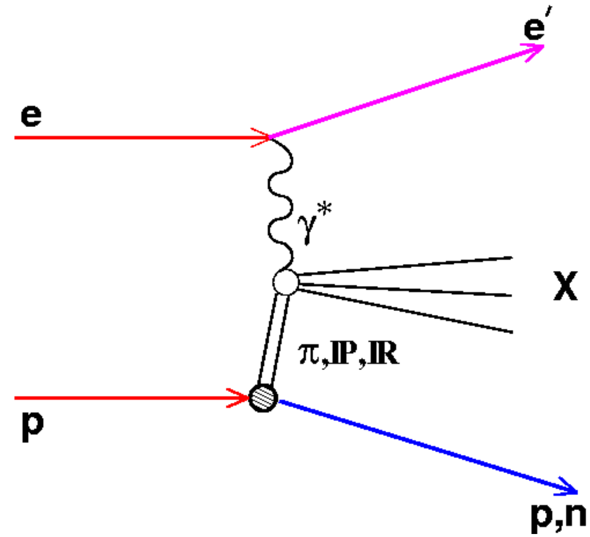
Outline:

- **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 → e+LB+X**
- **Different production models are available**

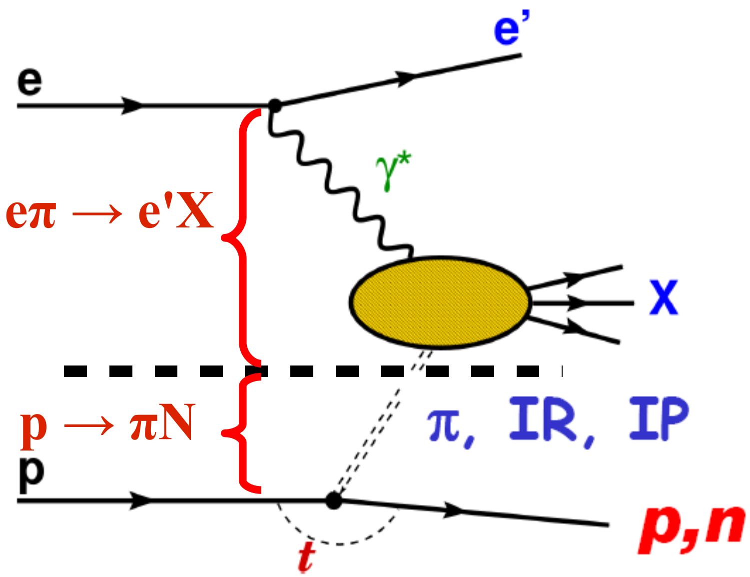




Leading baryon can come from "standard fragmentation"
- **implemented in MC models (Lund String)**

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:

$x_L = E_{LB}/E_p$
$t = (P-P_{LB})^2$ (or p_T^2)

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

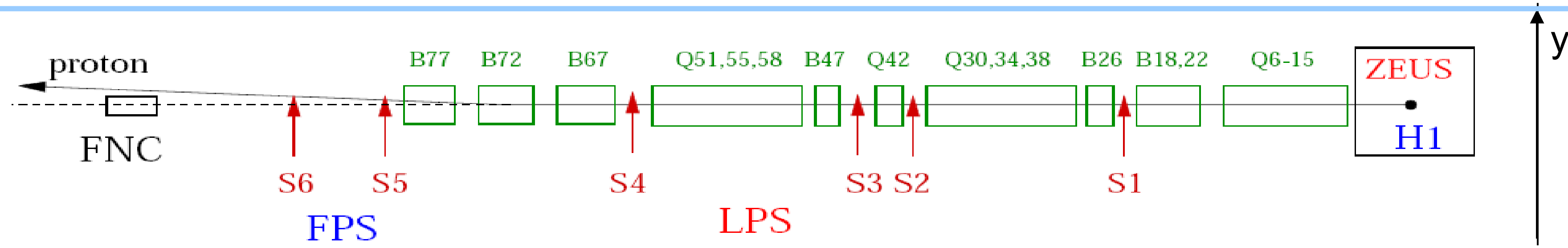
$$\sigma(ep \to e'NX) = f_{\pi/p}(x_L, t) \times \sigma(e\pi \to e'X)$$

$f_{\pi/p}(x_L,t)$ - pion flux:
probability to emit pion from the proton with given x_L, t

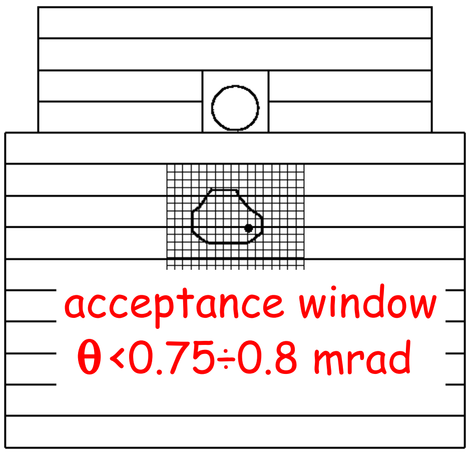
$\sigma(e\pi \to e'X)$ - cross-section of eπ scattering

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

Detectors used for measurement of LB

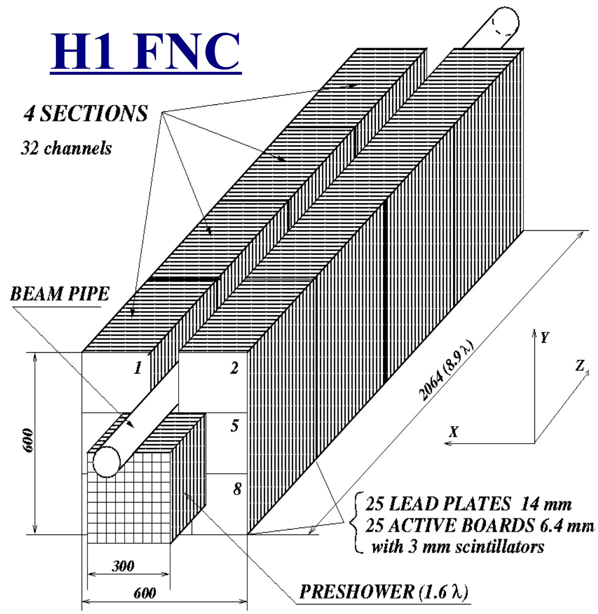


ZEUS FNC+FNT



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

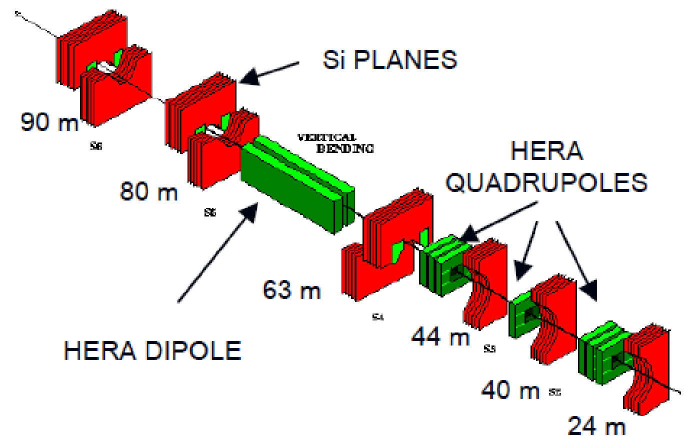
H1 FNC



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

position resolution 2-3mm

ZEUS LPS



6 stations with μ-strip detectors
hit position resolution ~30μm
σ_{XL}<1%, σ_{PT}~few MeV

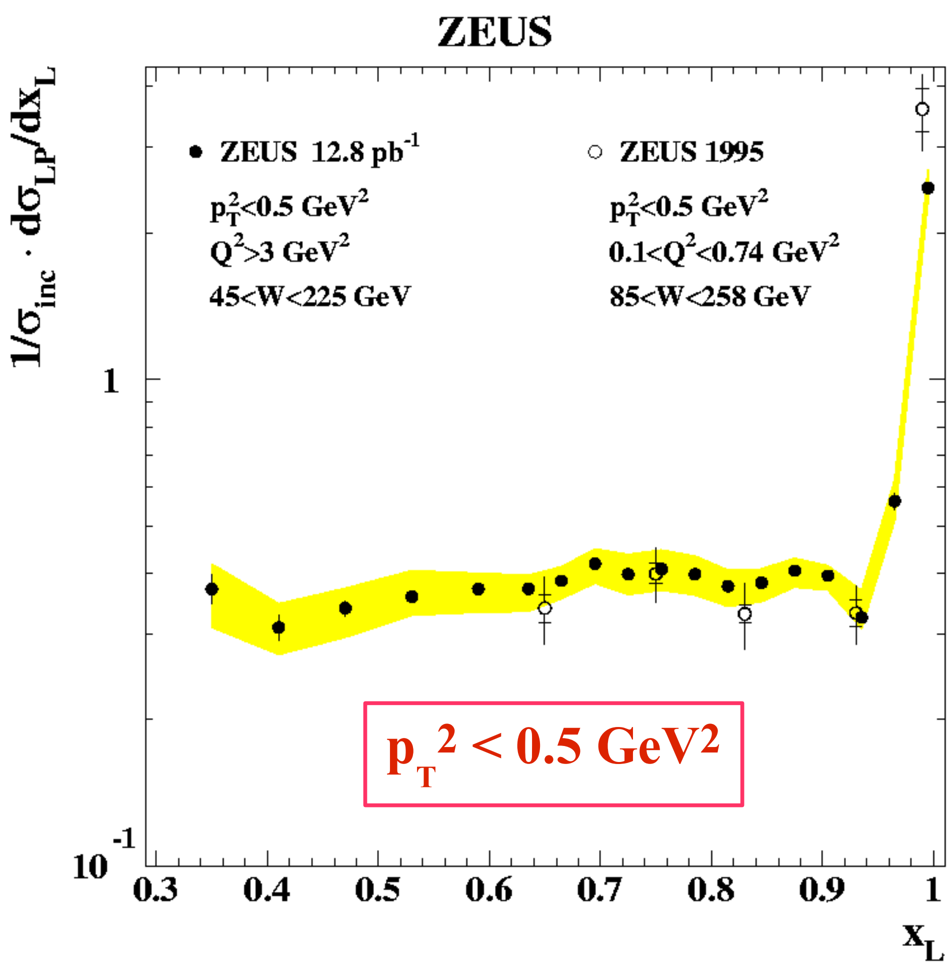
momentum accuracy <1%

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)

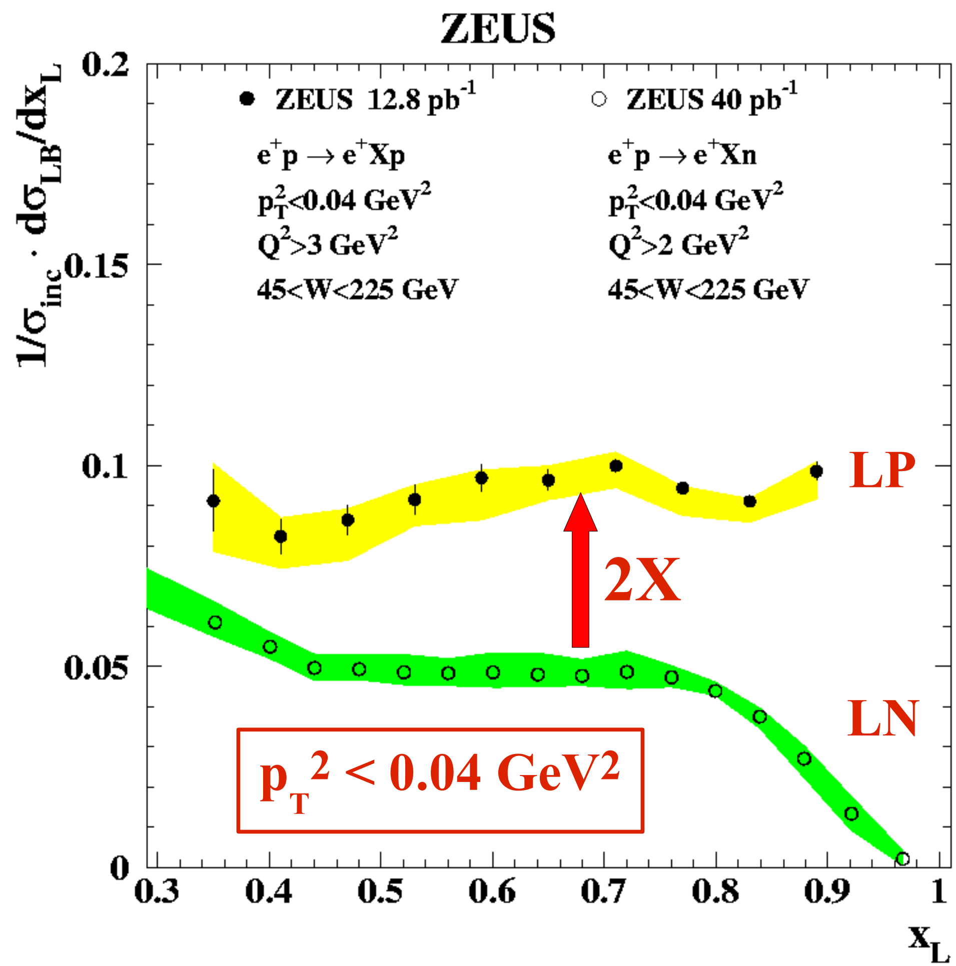
$d\sigma_{LP}/dx_L$ normalised to the inclusive DIS cross section



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

Comparison LP, LN yields



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

LP = ½ LN

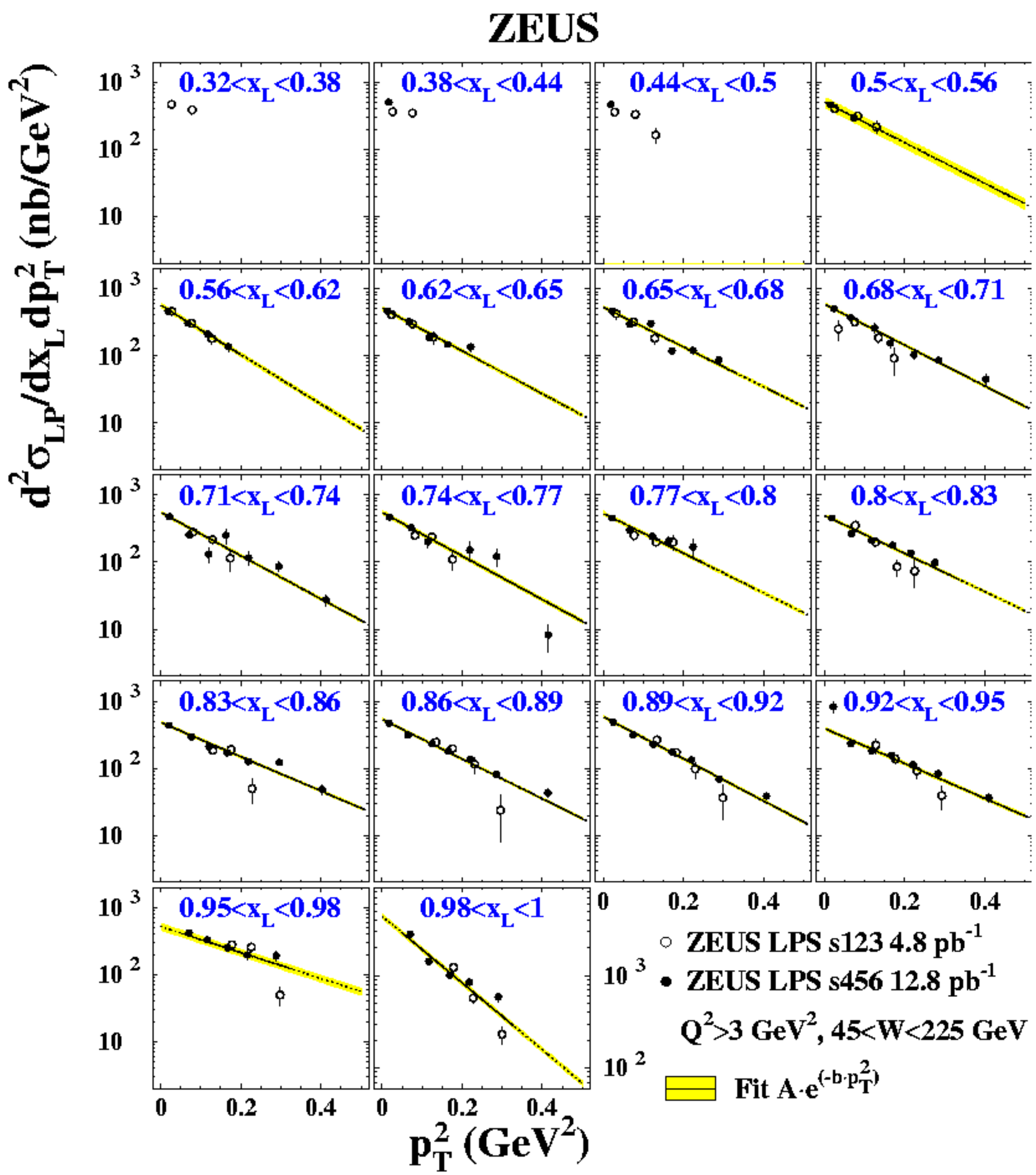
- **Data suggest:**

LP = 2 LN

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

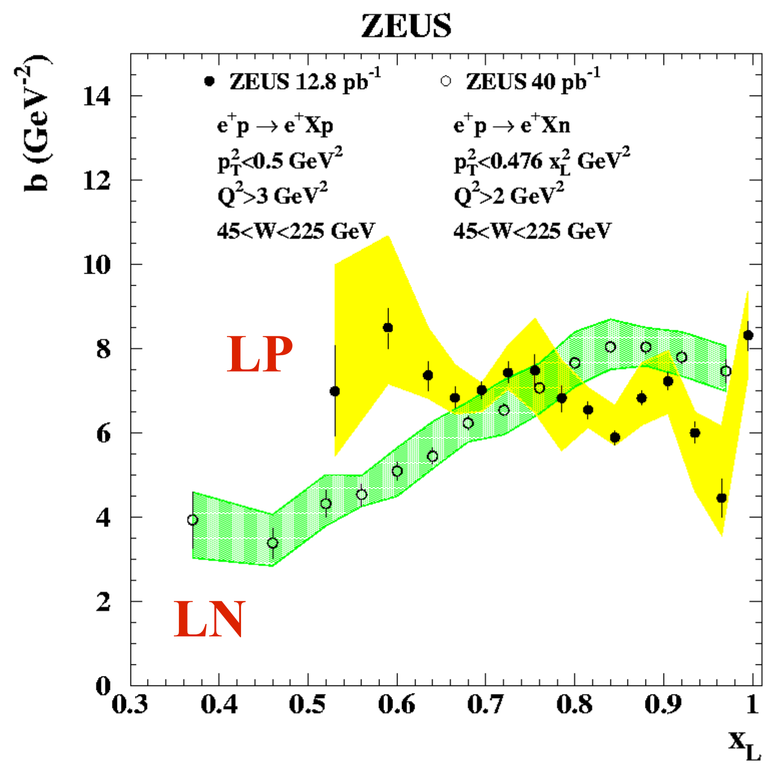
LP production in DIS:

P_T^2 distributions in x_L bins



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

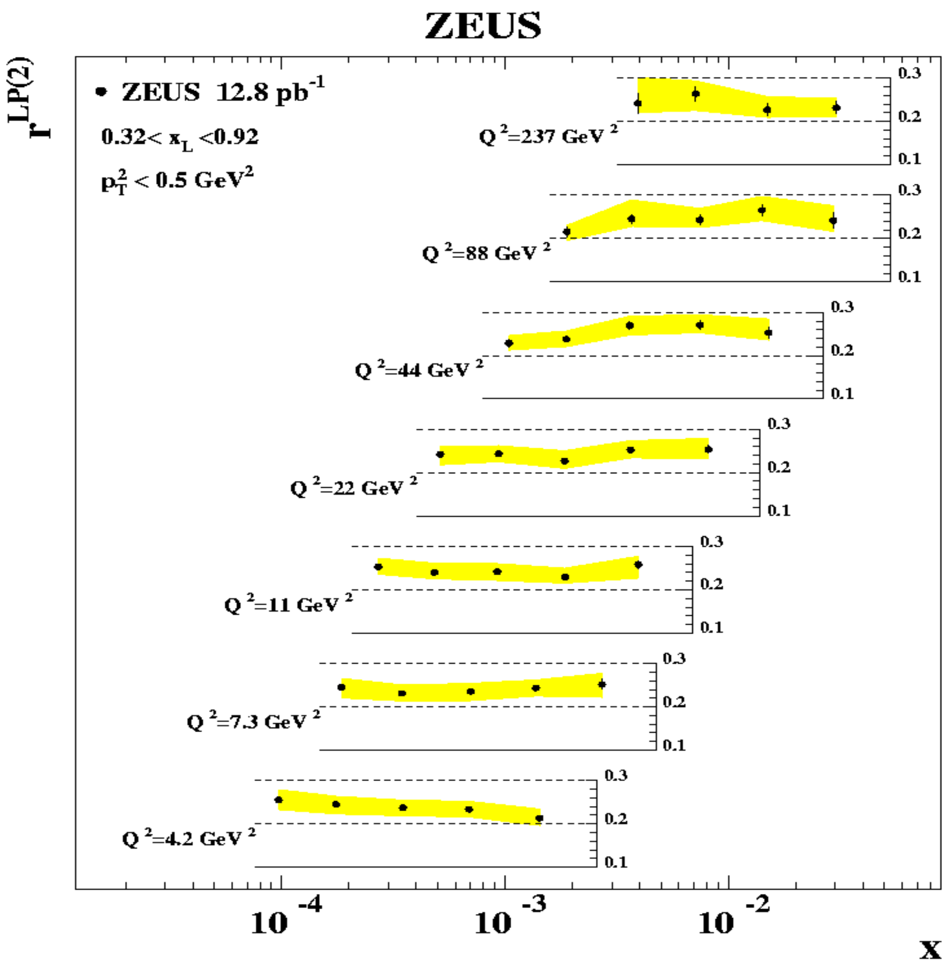
slopes - $b(x_L)$



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

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

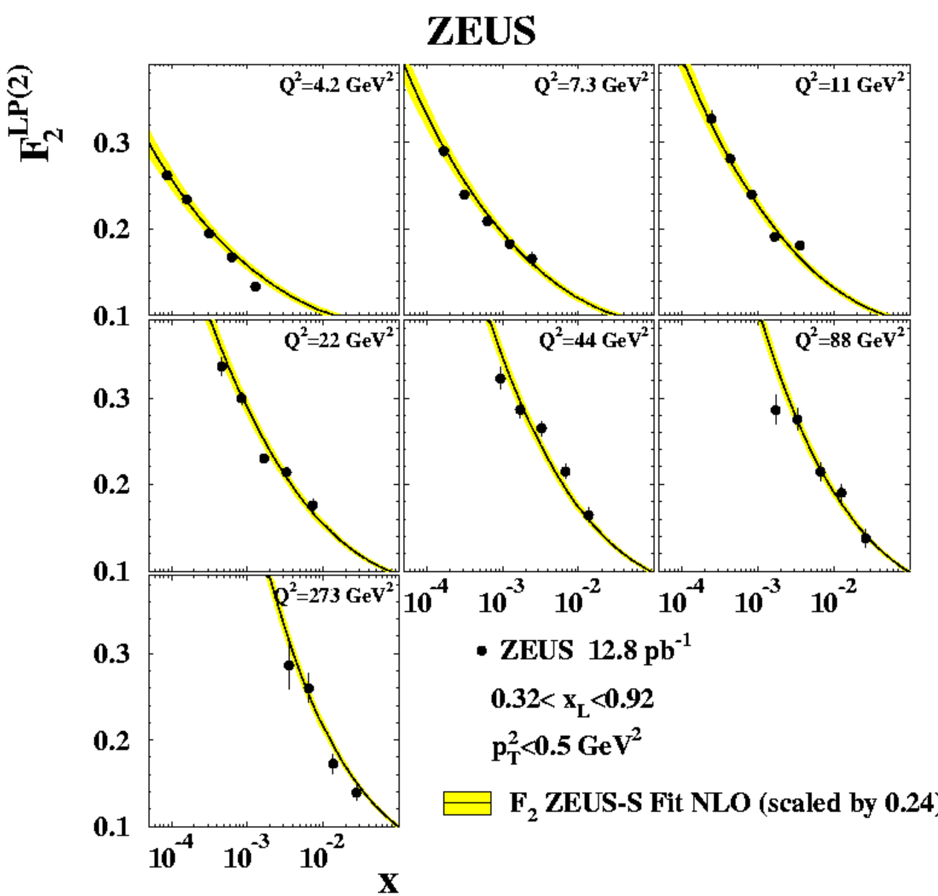
Rates to inclusive DIS



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

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

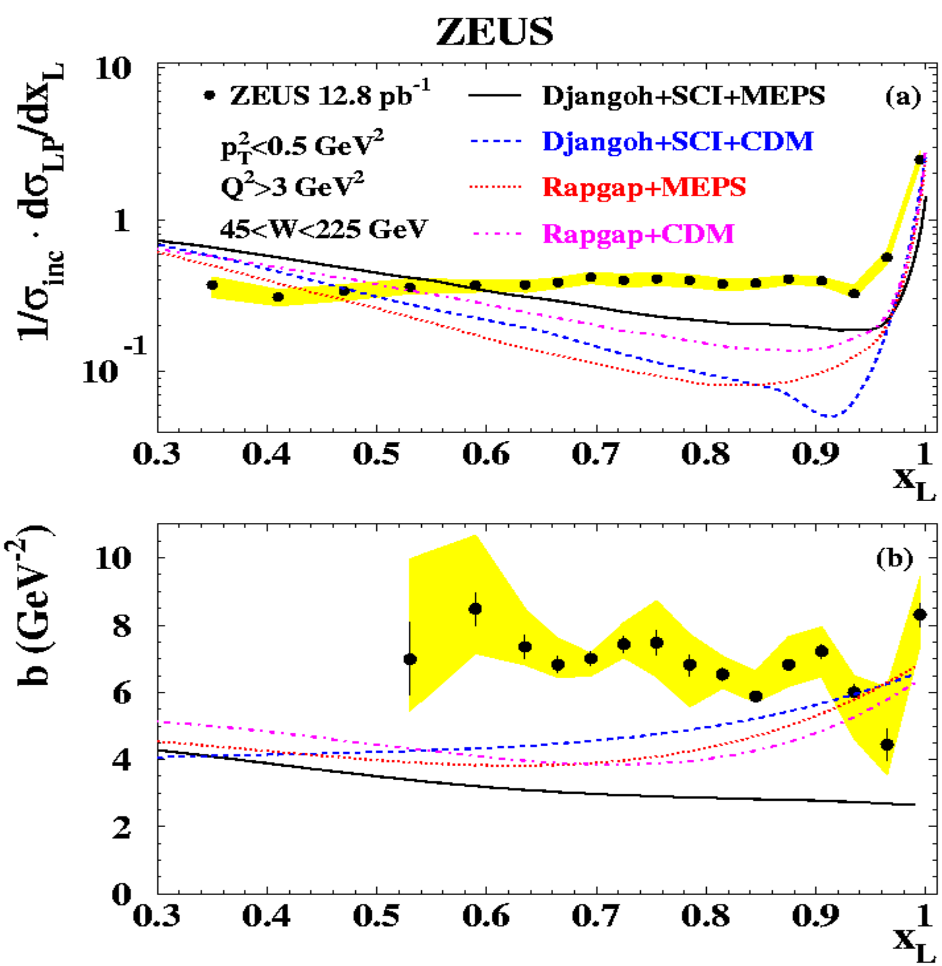
$$\frac{d^2\sigma(ep\rightarrow eXp)}{dx\,dQ^2} = \frac{4\pi\alpha^2}{xQ^4}\left[1-y+\frac{y^2}{2}\right]\cdot F_2^{LP(2)}(x,Q^2)$$



same trend as inclusive F_2 is observed

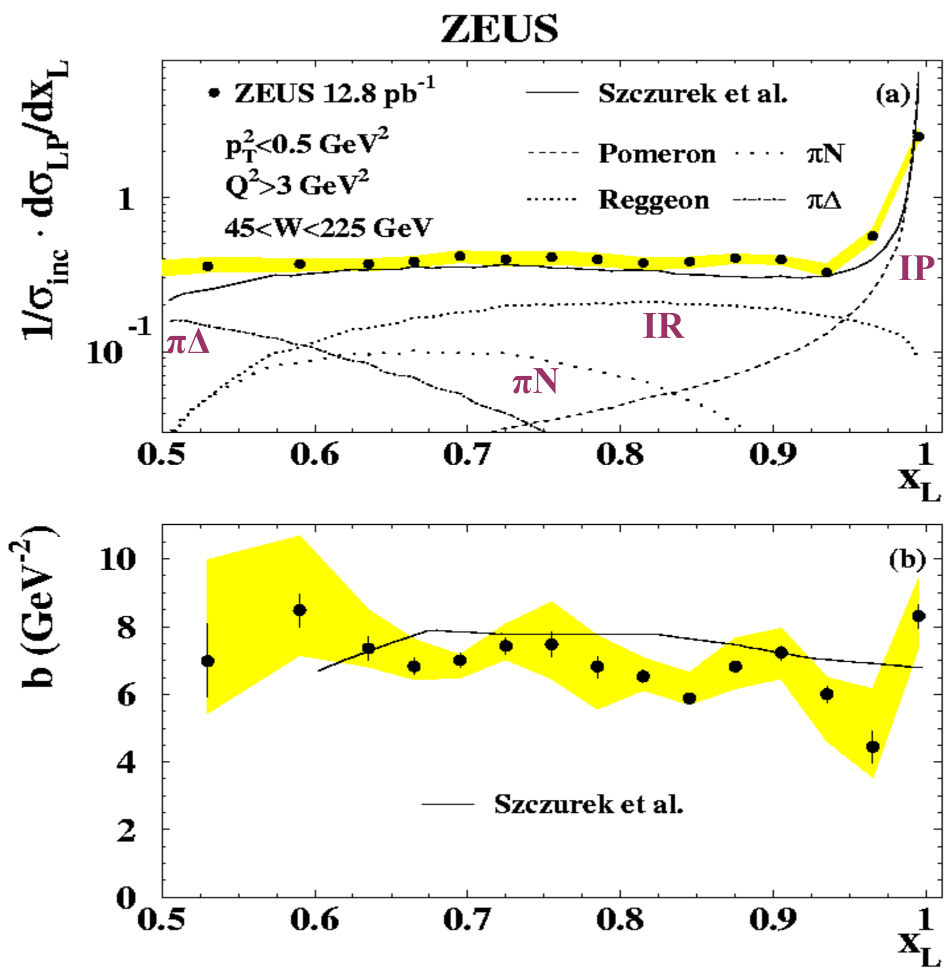
LP production in DIS: Comparison to models

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

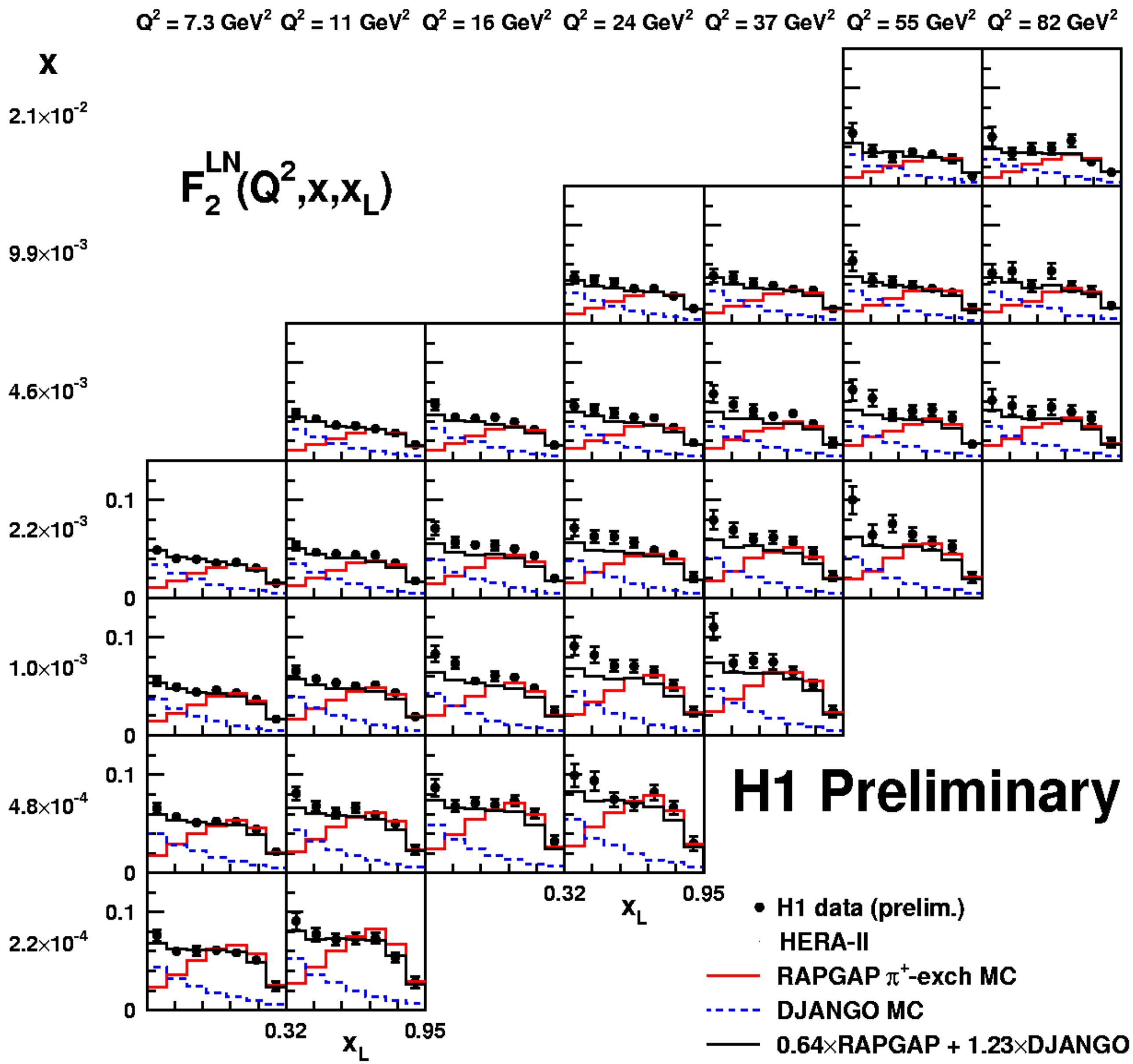
LN production in DIS:

Triple differential reduced cross section

$$\frac{d^3\sigma(ep\to enX)}{dQ^2\,dx\,dx_L} = \frac{4\pi\alpha^2}{xQ^4}\left[1-y+\frac{y^2}{2}\right]\cdot F_2^{LN}(Q^2,x,x_L)$$

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

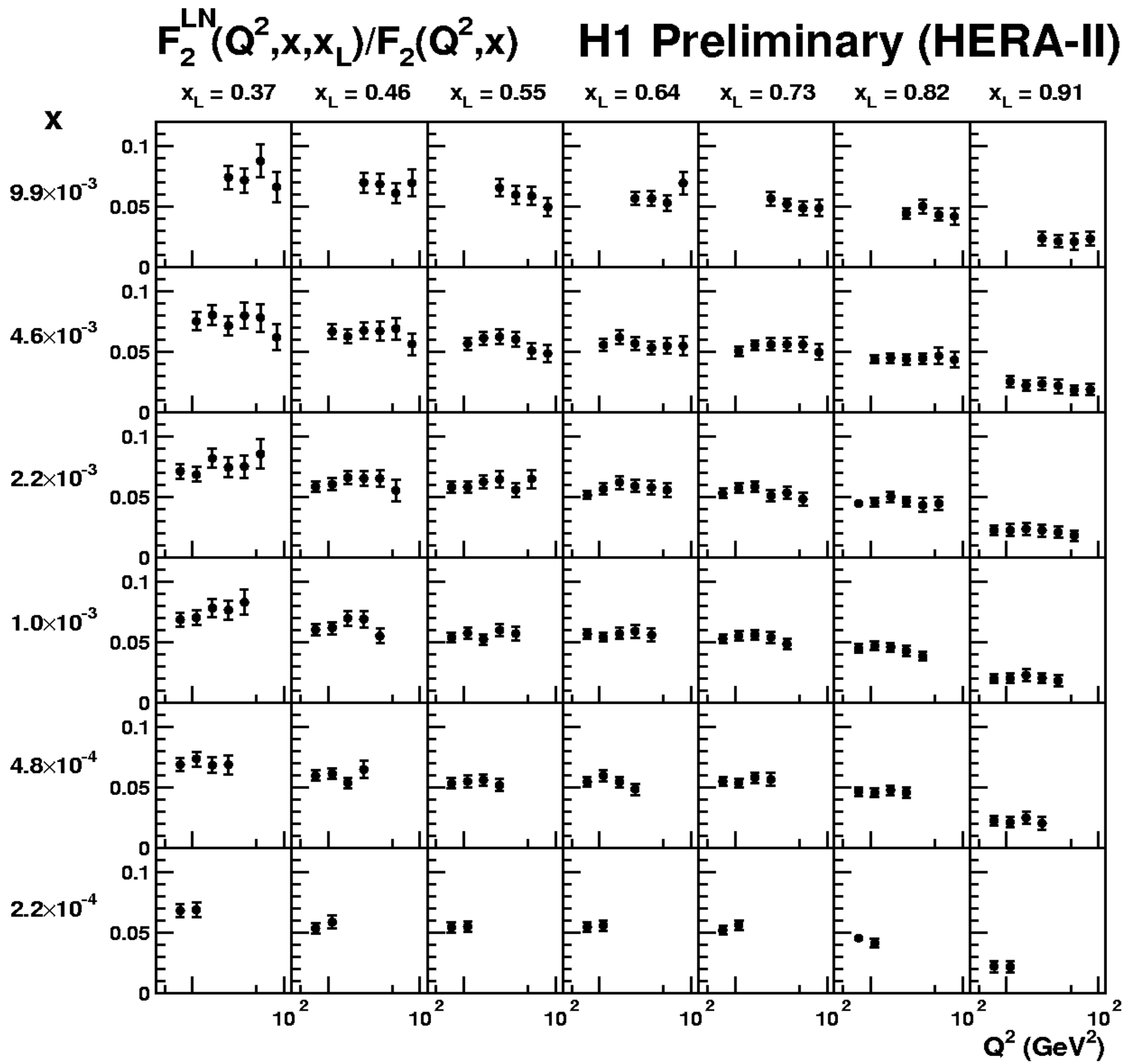
- DJANGO (standard fragmentation) predicts too low cross section, also x_L spectrum shape is too different
- RAPGAP π^+-exchange describes data well for $x_L > 0.7$
- Mixture of the DJANGO and the RAPGAP MC's can be used to describe data in the whole kinematic region



LN production in DIS:

$F_2^{LN}(Q^2,x,x_L)$ to $F_2(Q^2,x)$ ratio

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



$F_2^{LN}(Q^2,x,x_L)/F_2(Q^2,x)$ is mostly flat in Q^2 and x

=> similar to the Leading Proton measurement

Estimate for Pion Structure Function from F_2^{LN}

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} :

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

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 $F_2^{LN(3)}$ measurement according to:

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

where Γ_π is integrated over t pion flux

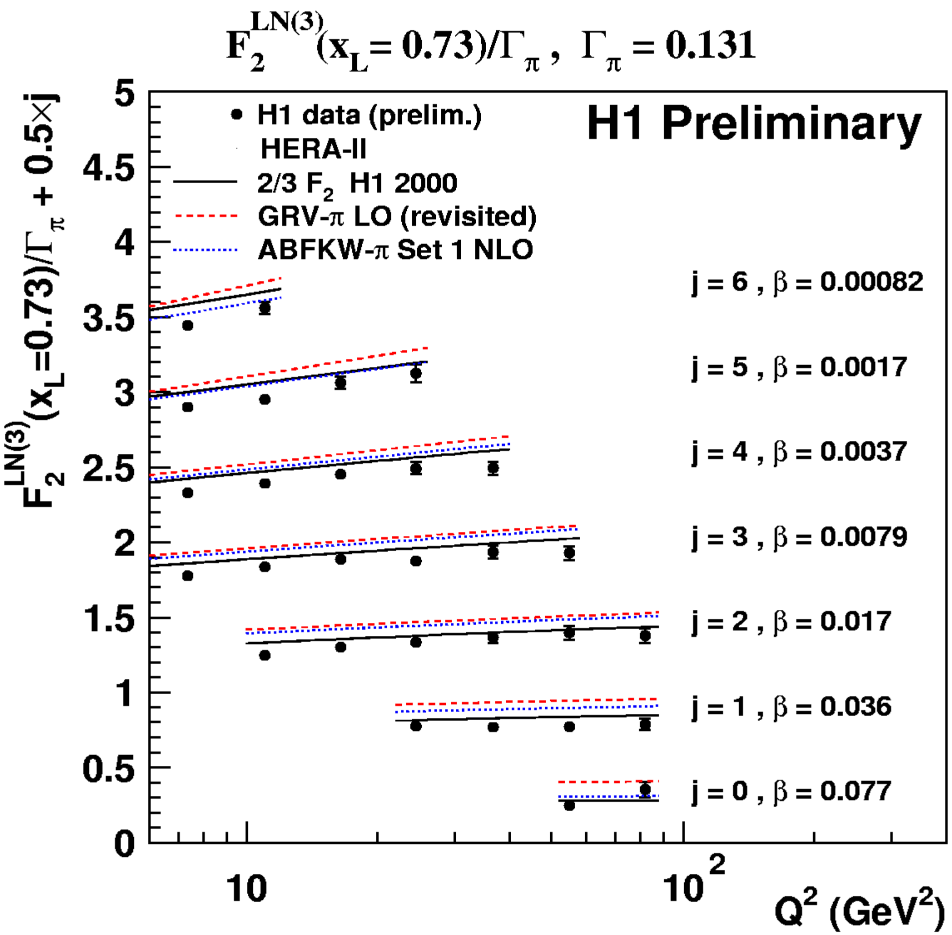
Using pion flux $f_{\pi^+/p} = \frac{1}{2\pi}\frac{g^2_{p\pi n}}{4\pi}(1-x_L)\frac{-t}{(m_\pi^2-t)^2}\exp\left(-R^2_{\pi n}\frac{m_\pi^2-t}{1-x_L}\right)$ => at $x_L = 0.73$ $\Gamma_\pi = 0.131$

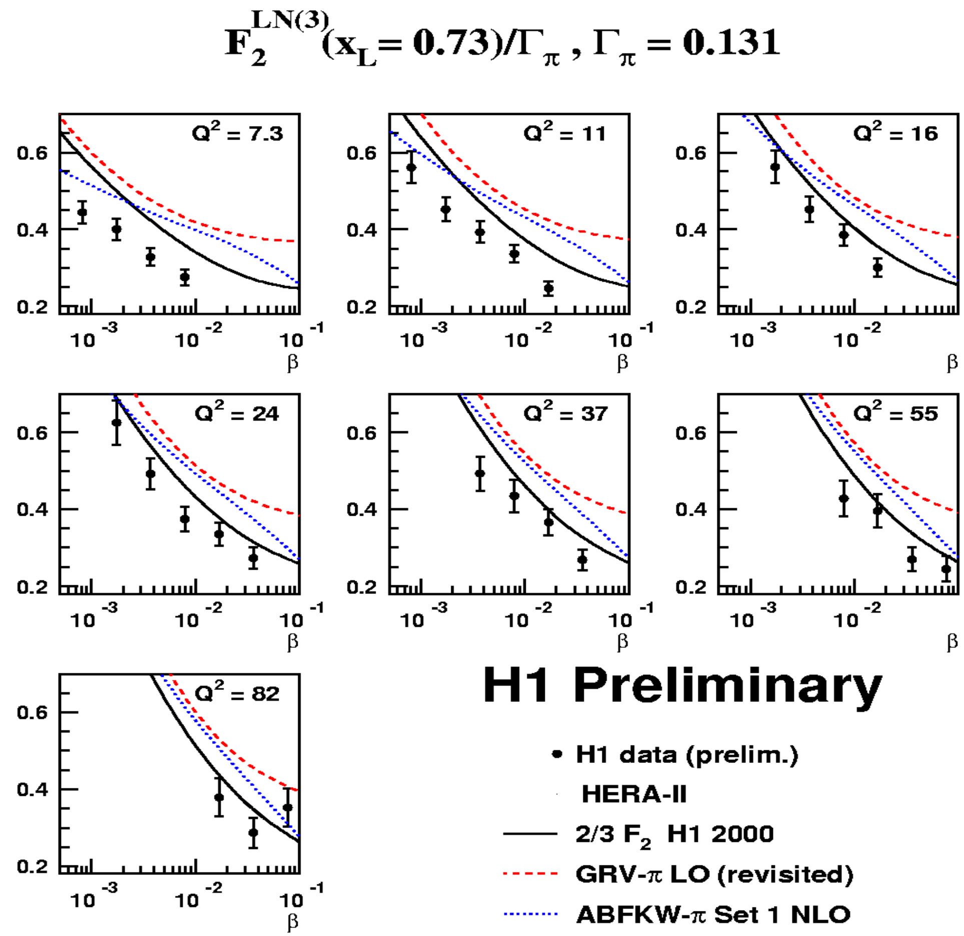
(other pion flux form-factors give other values of Γ_π => global normalisation factor on $\mathbf{F_2^{\pi}}$)

No background subtraction or absorption correction applied

LN production in DIS:

Pion Structure Function from F_2^{LN}





Data compared to parameterisations:

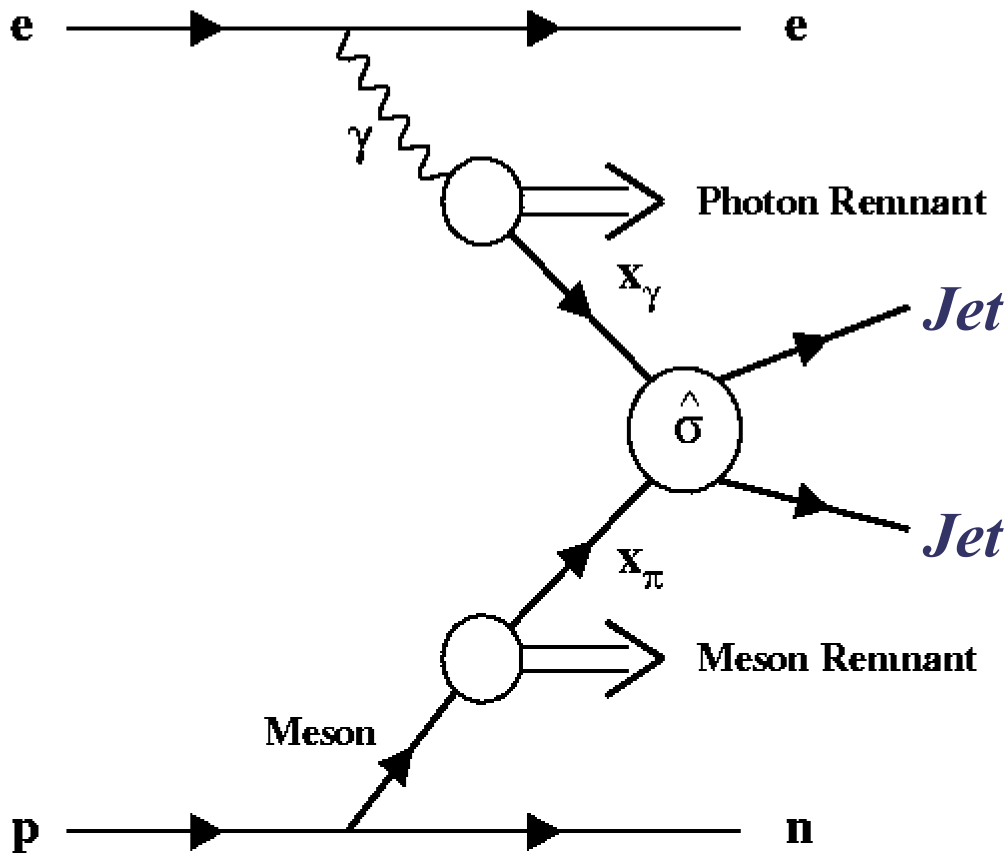
- 2/3 of proton F_2
- GRV-π LO (revisited)
- ABFKW-π Set 1 NLO

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

Dijet photoproduction with LN

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

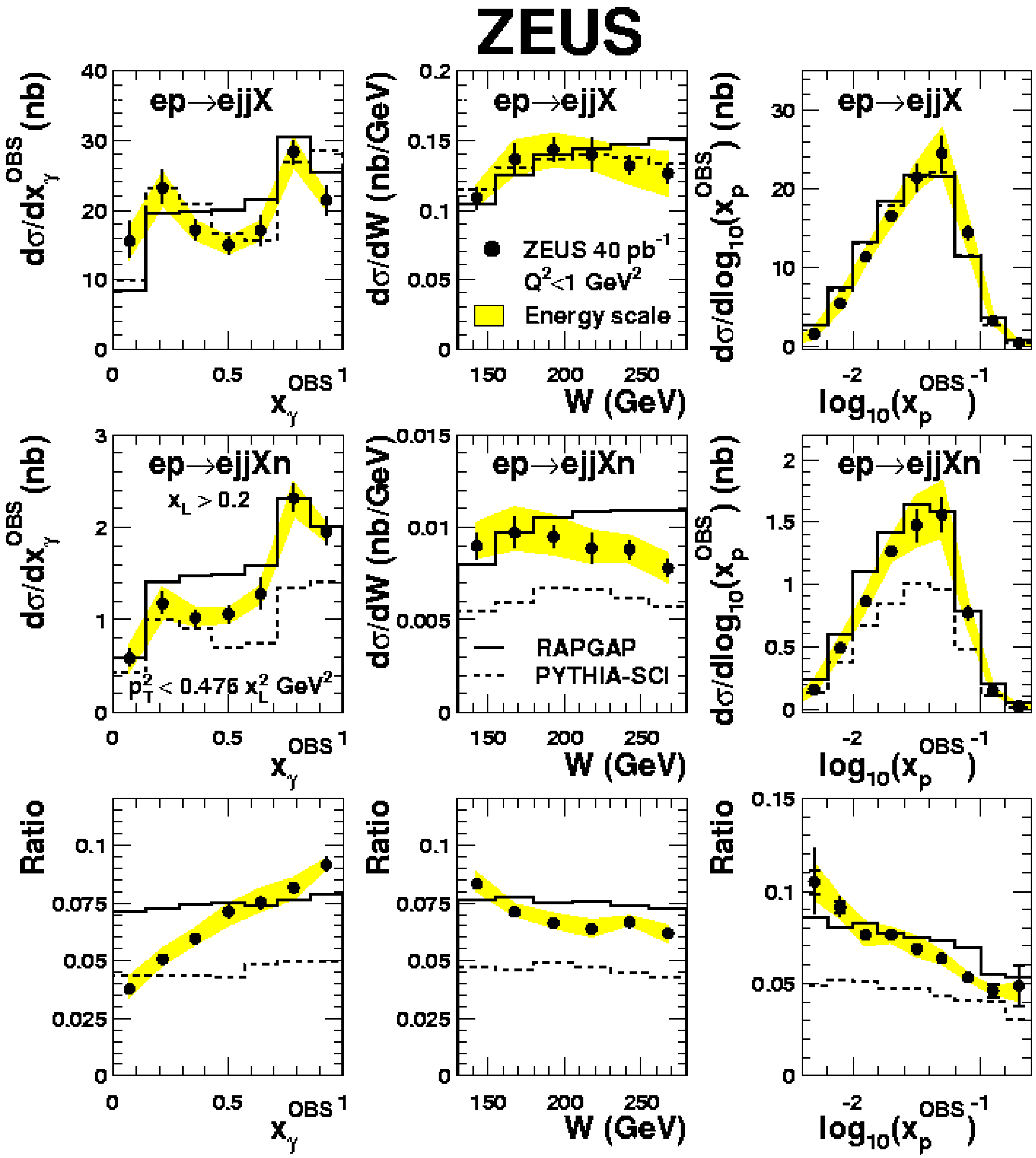


Absorption effects increase from high Q^2 => γp

i.e. hard => soft scale

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

Differential cross sections



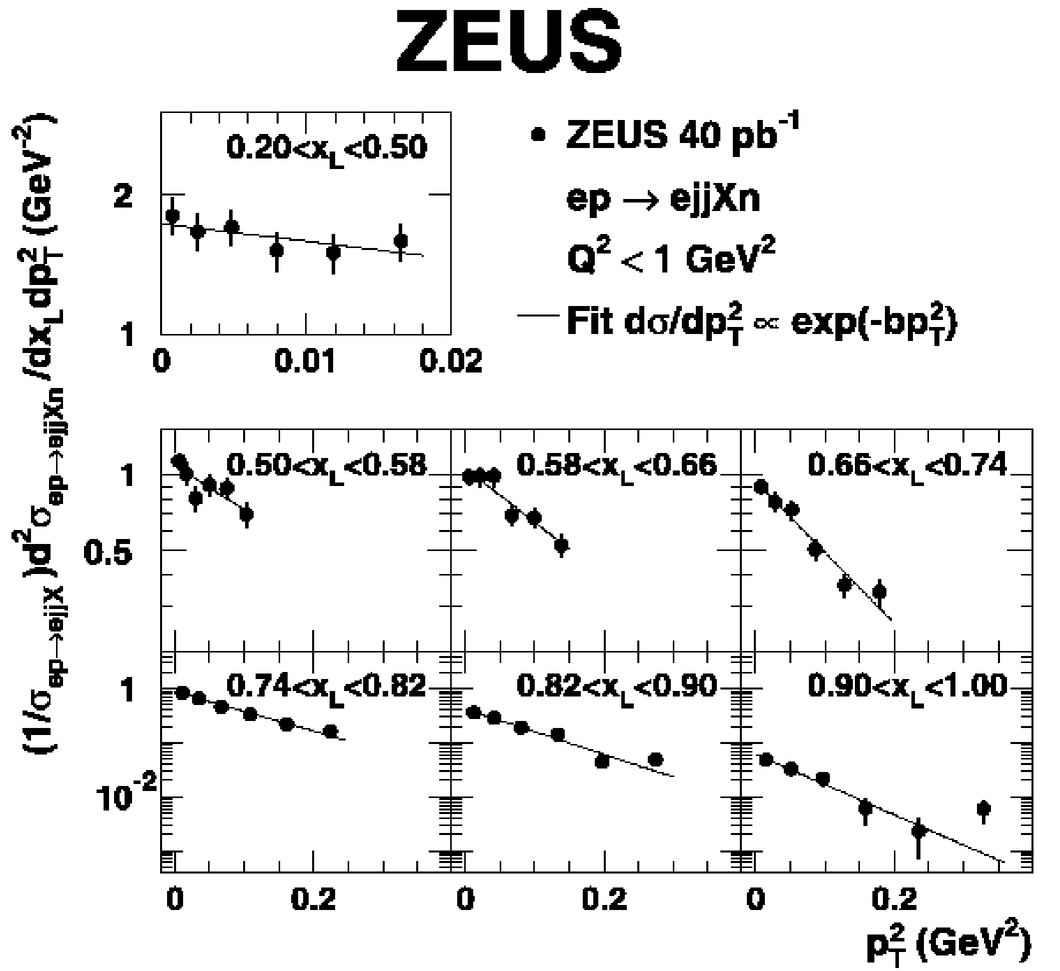
W – total energy of photon-proton system

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

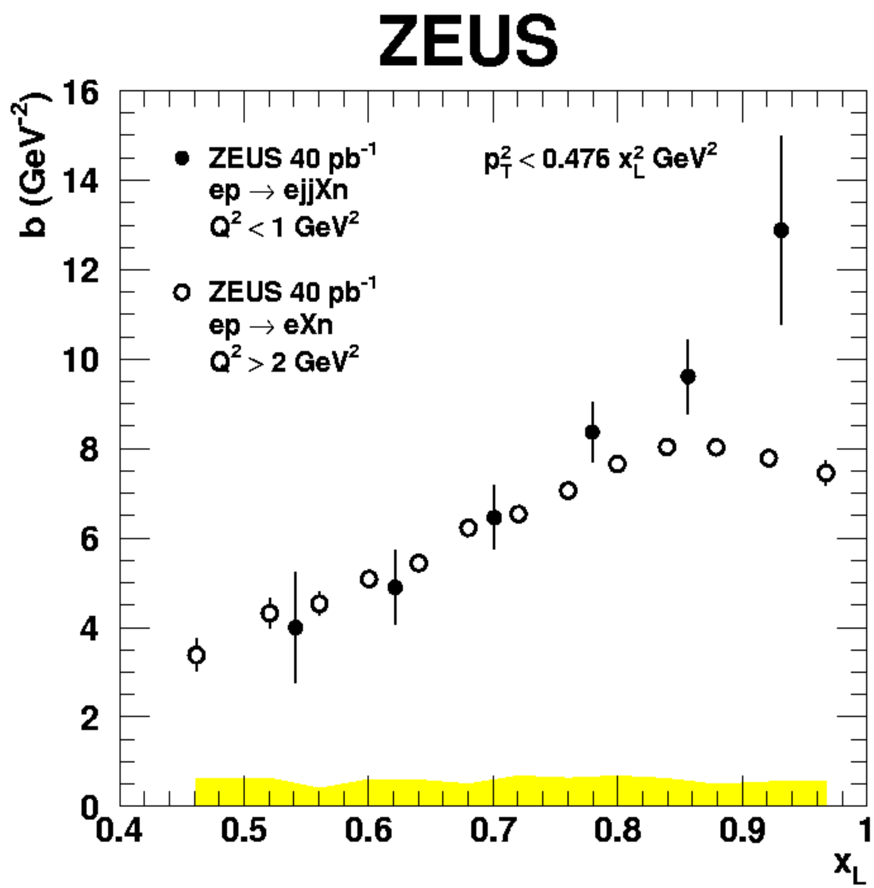
$x_p = \Sigma_{jets}(E+p_z)/(2E_p)$

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

p_T^2 distributions in x_L bins; slopes



slopes - $b(x_L)$



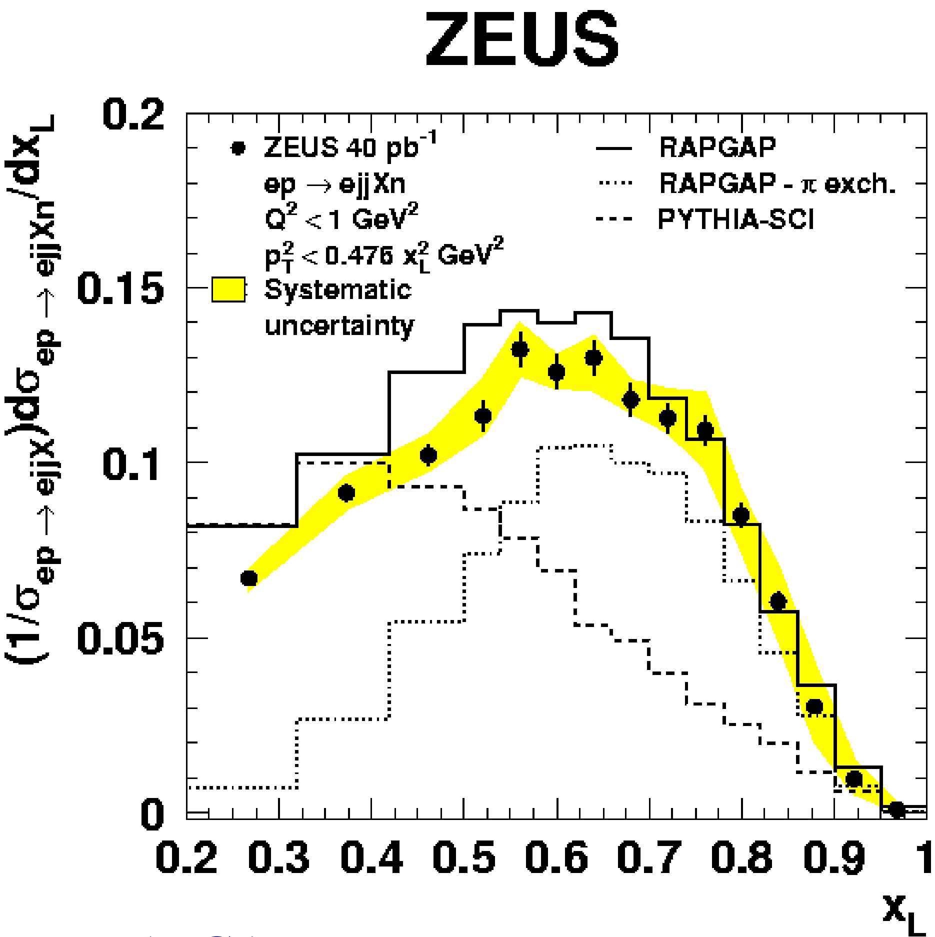
Well described by exponential fall-off in p_T^2

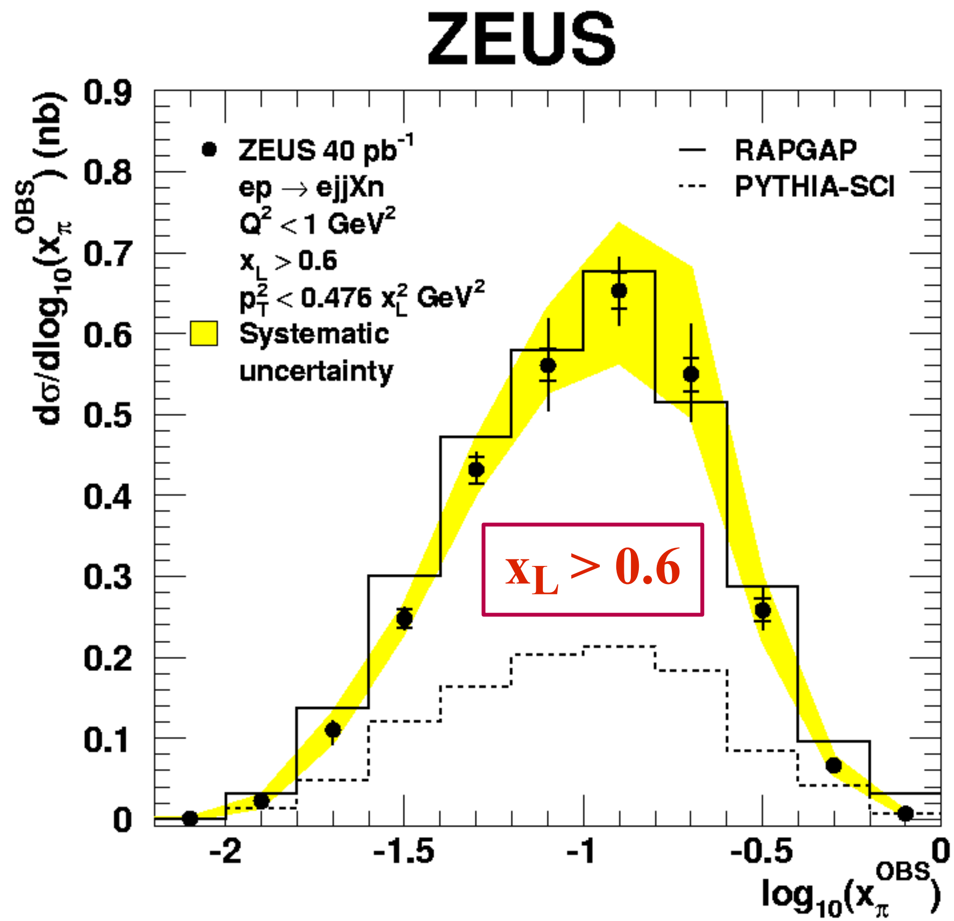
$$\frac{1}{\sigma_{inc}} \frac{d\sigma_{\text{LN}}}{dp_T^2\, dx_L} = a(x_L) \cdot e^{-b(x_L)\, p_T^2}$$

similar slopes in DIS and γp+dijet

=> Same production mechanism

Comparison with Models



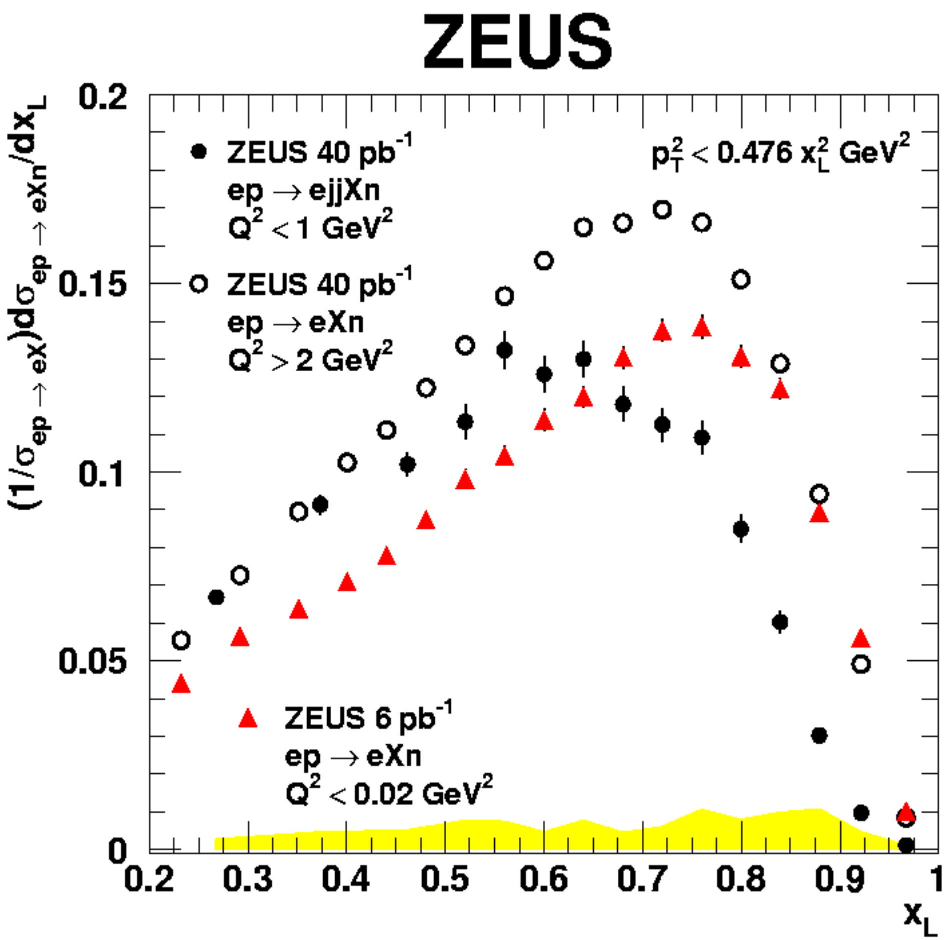


- **RAPGAP π-exchange only and PYTHIA-SCI describe data poor**
- **Pion exchange is dominating mechanism at high x_L**
- **Full RAPGAP gives good description of data**

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

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

"LN + dijet in γp" vs "LN in DIS" vs "LN in γp"



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

- **Protoproduction with jets is suppressed vs DIS at low x_L => 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**

Summary

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

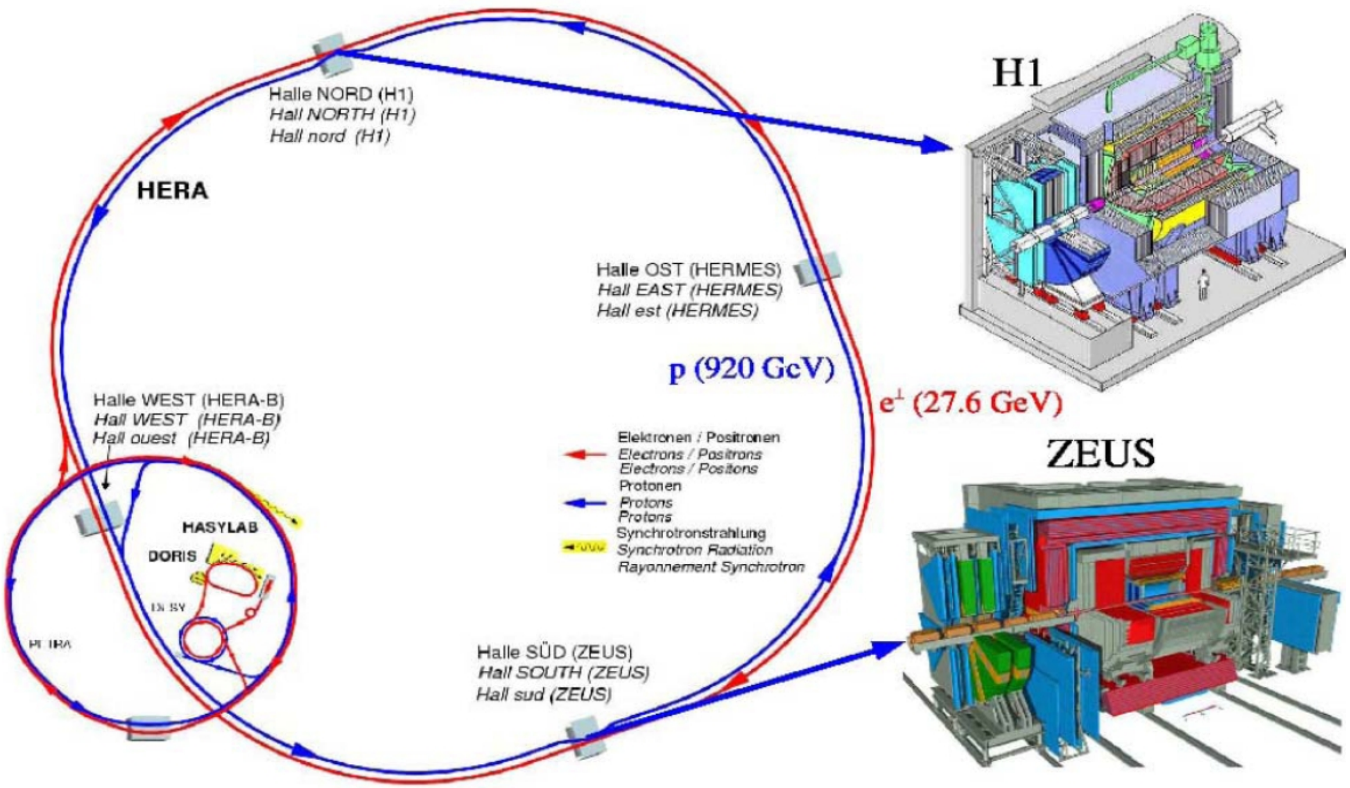
- **Precise measurements of LB x_L and p_T^2 presented in DIS, γp with dijets.**
- **Fragmentation MC-models without meson exchange do not describe the data.**
- **Models with virtual meson exchange describe data better.**
- **F_2^{LP}/F_2 and F_2^{LN}/F_2 ratios are independent of x and Q^2**
- **For 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**

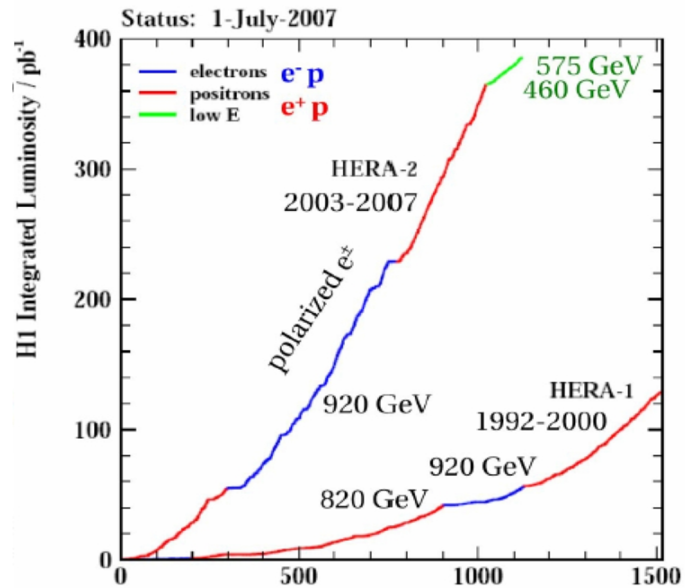
Backup slides

HERA

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

E_e = 27.6 GeV, E_p = 920 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

DATA Sets

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

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

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

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

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

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

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

DIS and γp have very different inclusive cross sections σ_{inc}
=> for sensible comparisons look at σ_{LB}/σ_{inc}
Additional benefit: systematic uncertainties of central detector cancel

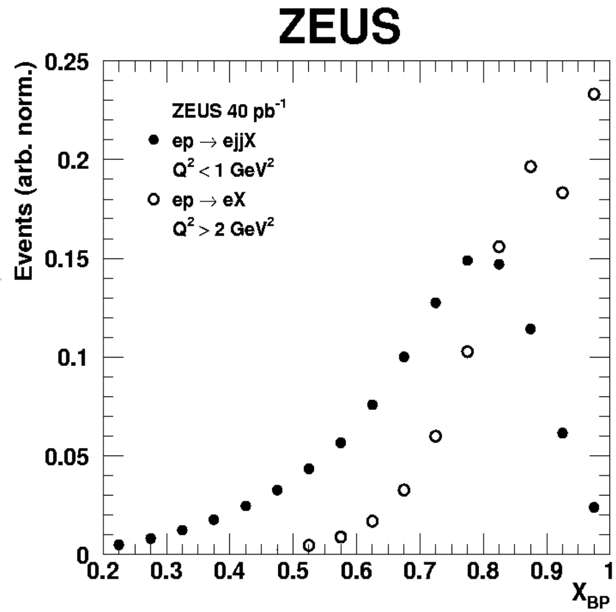
=> Most measured by ZEUS LB cross sections are relative to inclusive ones

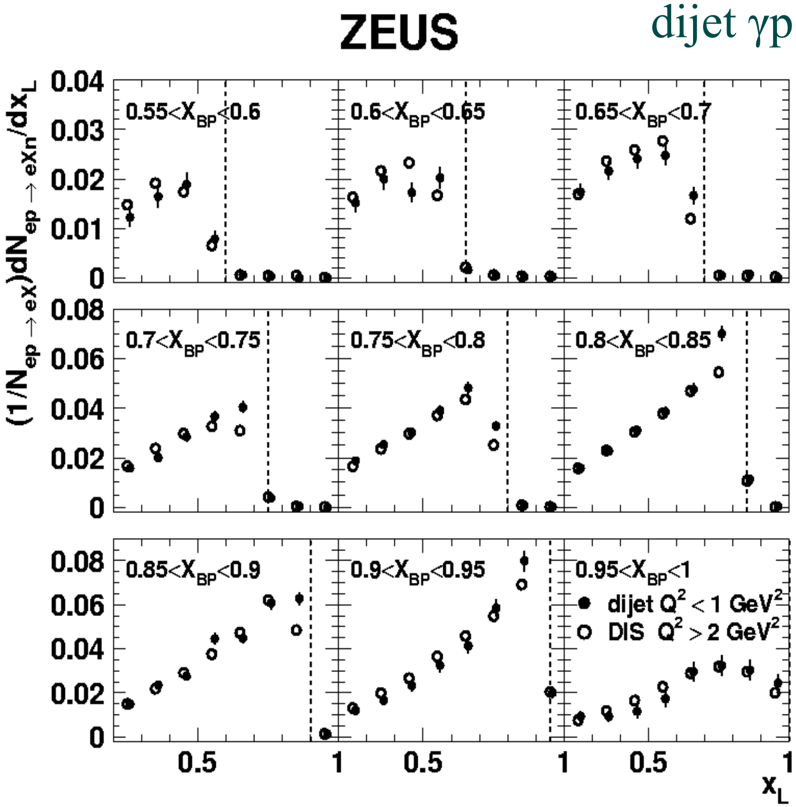
LN in dijet γp vs DIS: kinematic constraints

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





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.