Low x 2010 workshop, June 23-27 2010, Kavala, Greece

Leading Baryons at HERA

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On behalf of the H1 and ZEUS Collaborations

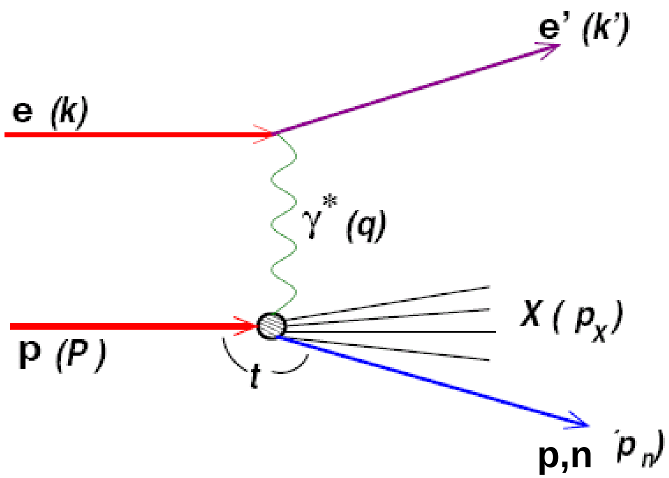
Outline:

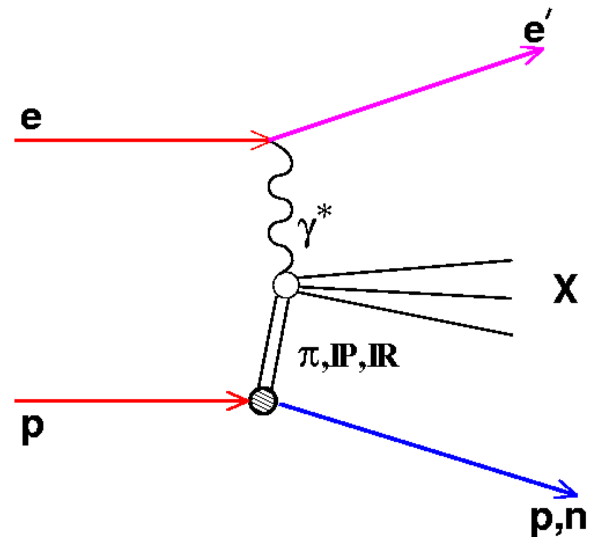
- Introduction
- Leading Protons and Neutrons in DIS
- Leading Neutrons in dijet photoproduction

Introduction

Significant fraction of *ep* scattering events contain a leading proton or leading neutron 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:

Legend:
- **LP: Leading Proton**
- **LN: Leading Neutron**
- **LB: Leading Baryon**
- **γp : photoproduction**



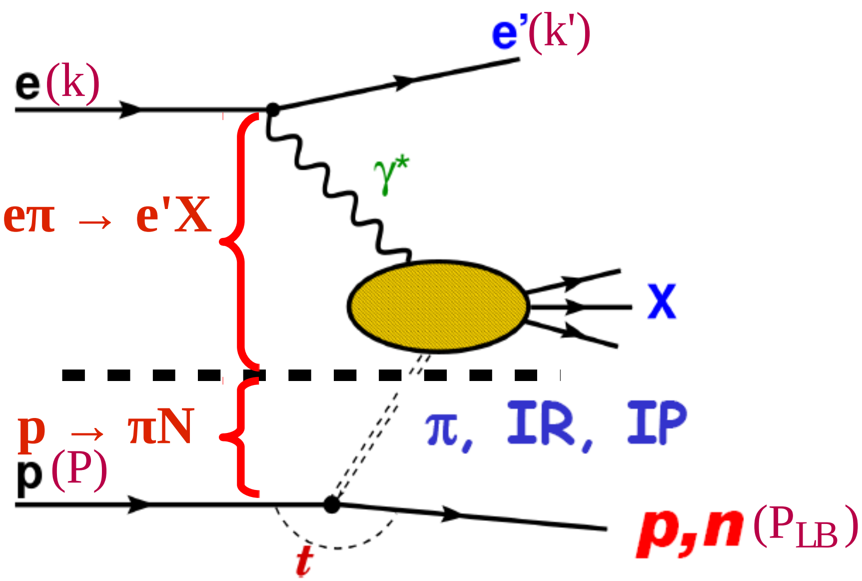


Leading baryon can come from "standard fragmentation"
- implemented in MC models (Lund String)

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)

Kinematics and Factorisation



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

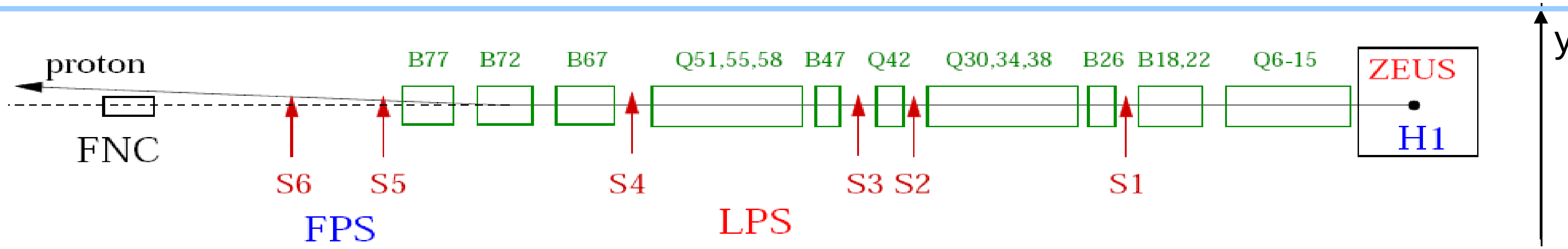
$$\sigma(ep \to e'LBX) = f_{\pi/p}(x_L, t) \times \sigma(e\pi \to e'X)$$

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

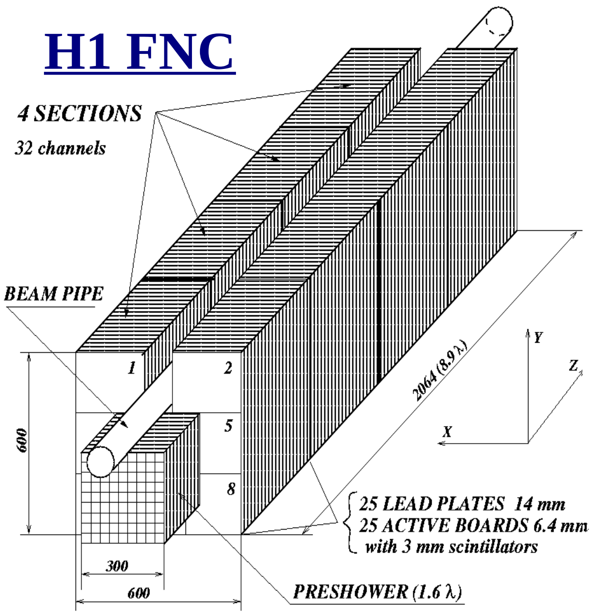
$\sigma(e\pi \to e'X)$ - cross-section of eπ scattering

- LB production independent of photon vertex
- probe structure of exchanged particle
- possible violation of factorisation due to rescattering

Detectors used for measurement of LB



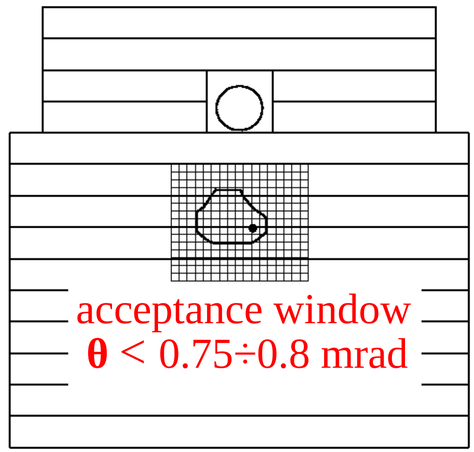
H1 FNC



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

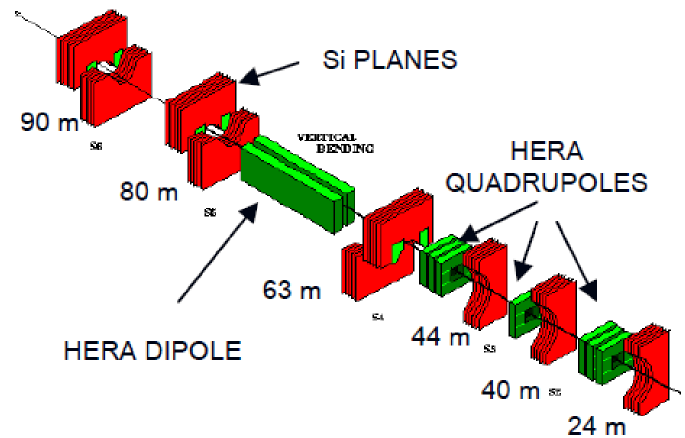
position resolution 2-3 mm

ZEUS FNC+FNT



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

ZEUS LPS



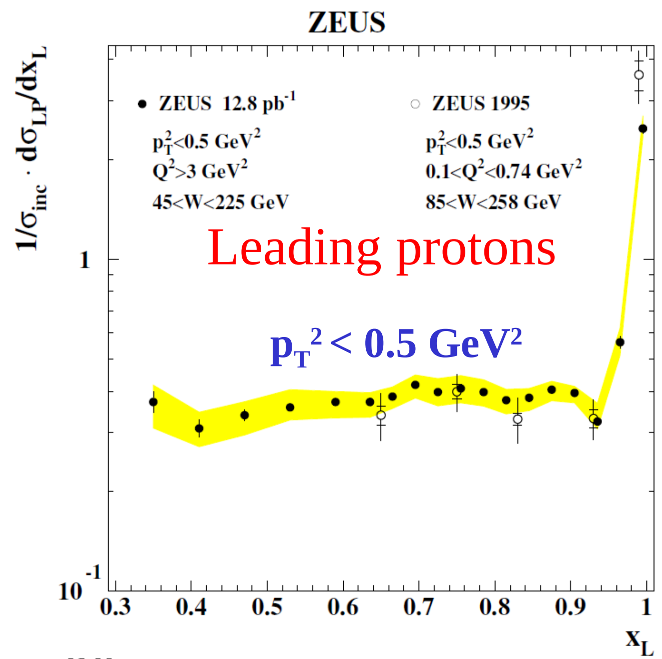
6 stations with **μ**-strip detectors
hit position resolution ~30μm
σ_{XL} <1%, σ_{PT} ~few MeV

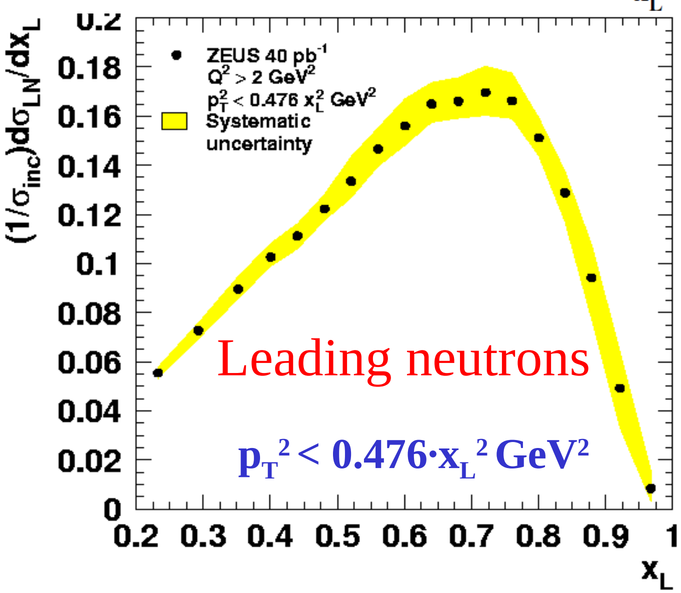
momentum accuracy <1%

Acceptance limited by beam apertures and detector size.

p_T resolution is dominated by p_T spread of proton beam (50-100 MeV).

LB production in DIS: $d\sigma_{LB}/dx_L$ normalised to incl. DIS cross section

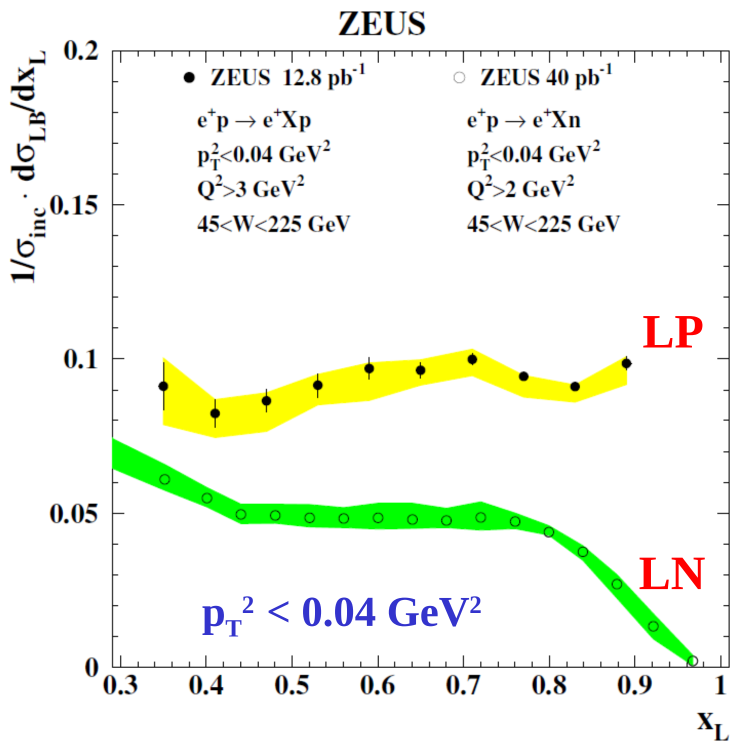




Leading protons: (JHEP 0906:074,2009)
- diffractive peak at $x_L=1$; flat at $x_L<0.95$

Leading neutrons: (Nucl.Phys.B776(2007)1)
- yield goes to zero as x_L approaches 1.0
- drop at $x_L< 0.7$ due to drop in acceptance

restrict to the same p_T^2 range

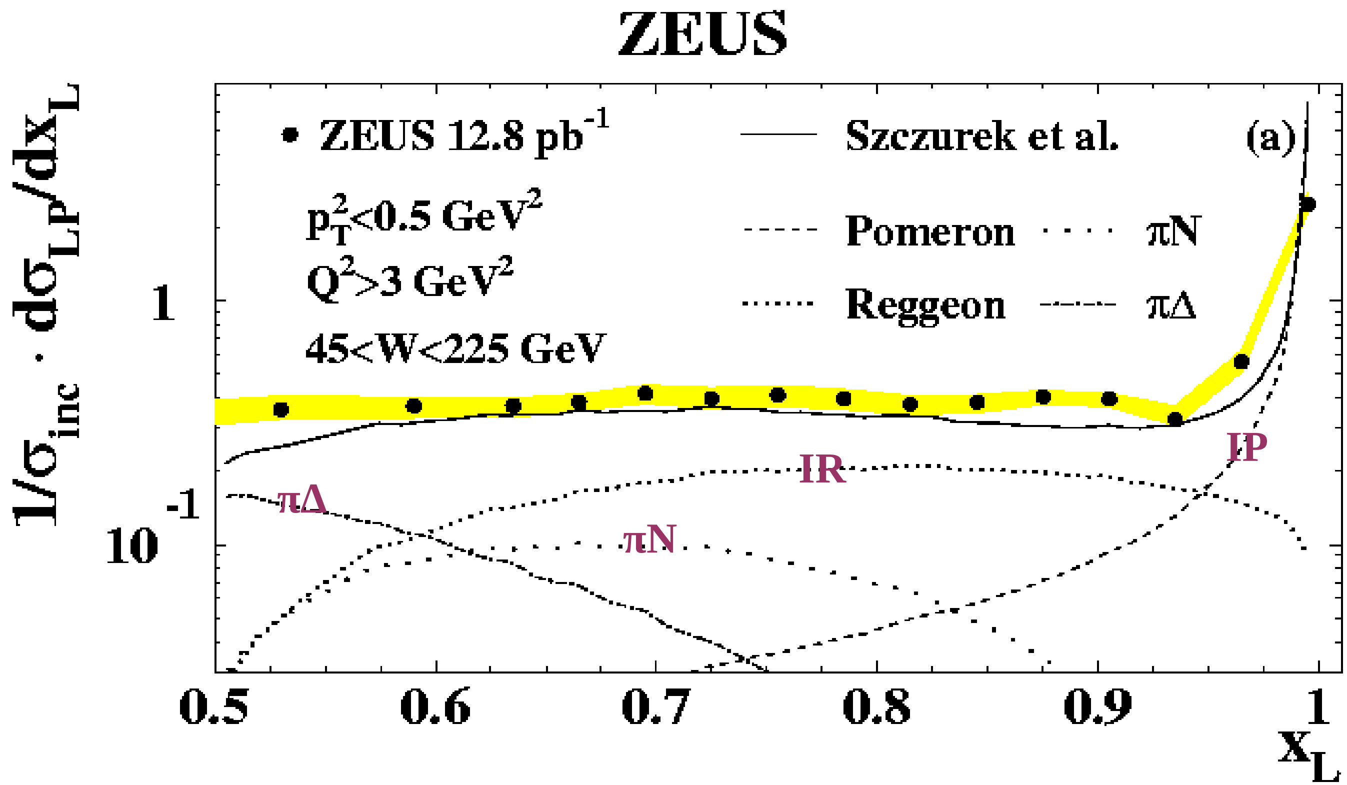


- measurement: LP ~ 2·LN
- for pure isovector particle exchange (e.g. pion) one expects LP = ½·LN

=> more isoscalar exchanges contribute to the LP rates

Comparison with multiple exchanges model

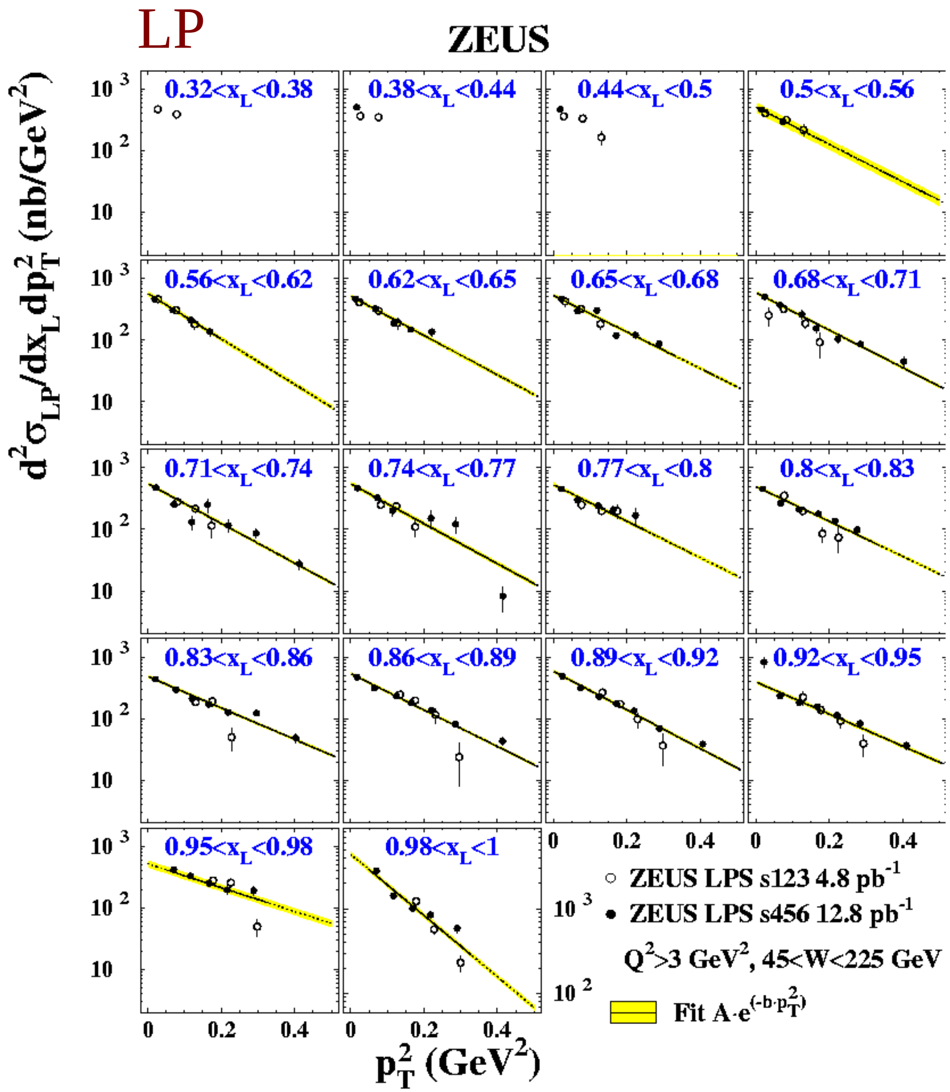
JHEP 0906:074,2009



- **good description of LP yield (and t-slopes) by adding different exchanges**
- **reggeon dominant at medium x_L**

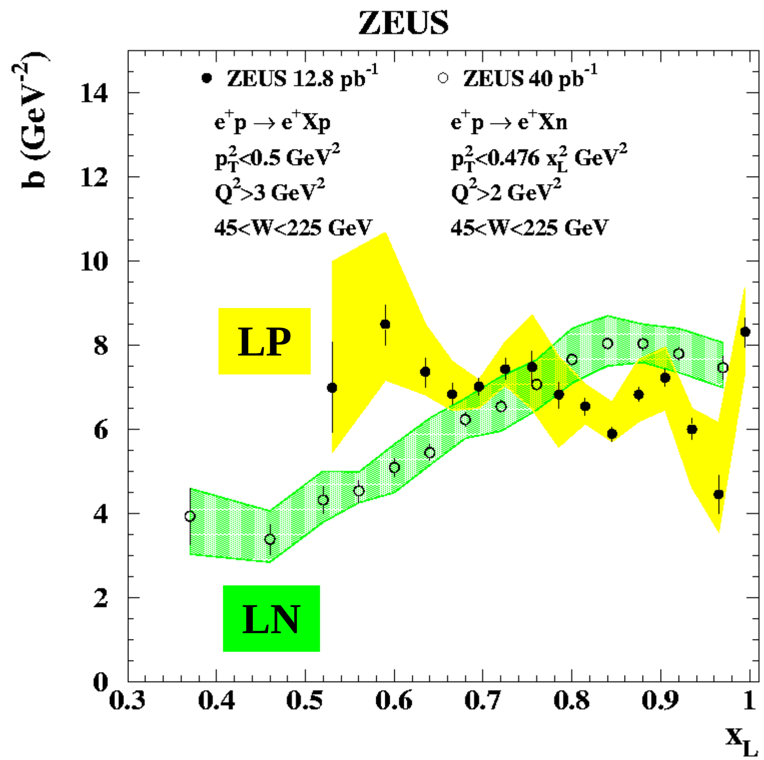
LB production in DIS: p_T^2 distributions in x_L bins

JHEP 0906:074,2009



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

slopes - $b(x_L)$

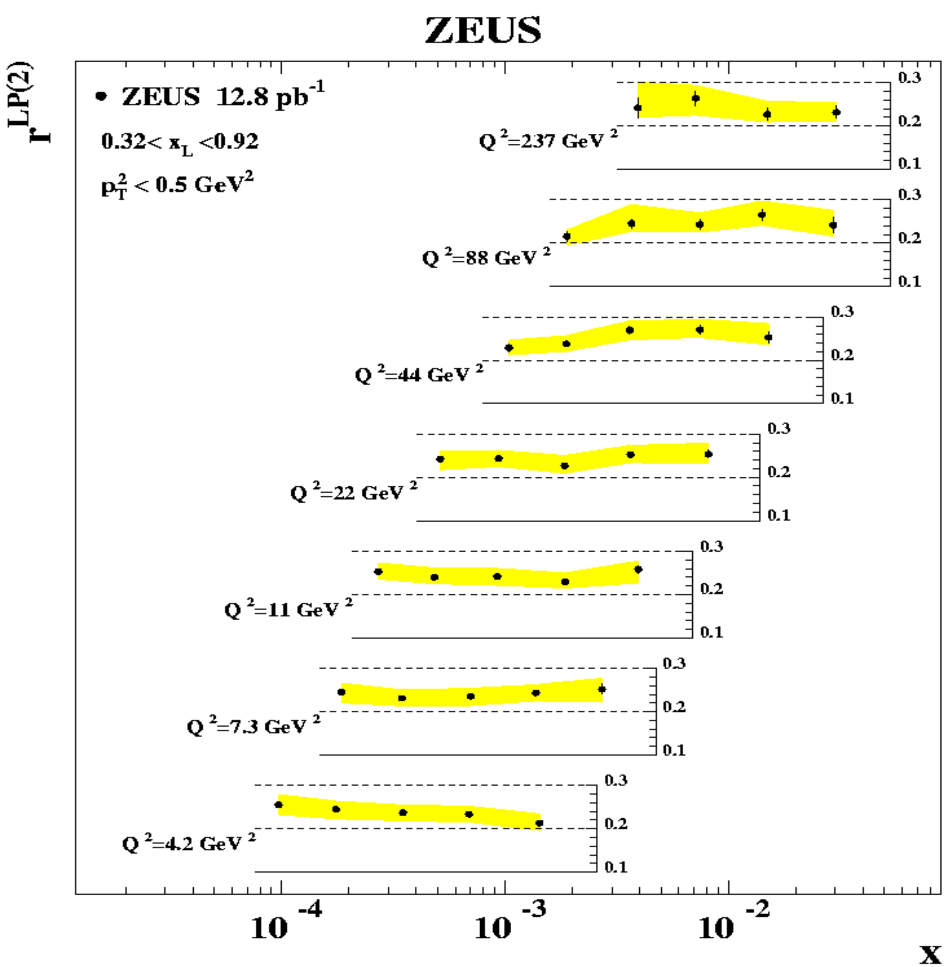


- **different trends for LP and LN**
- **similar slopes for $x_L \approx$ 0.65-0.8**

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

JHEP 0906:074,2009

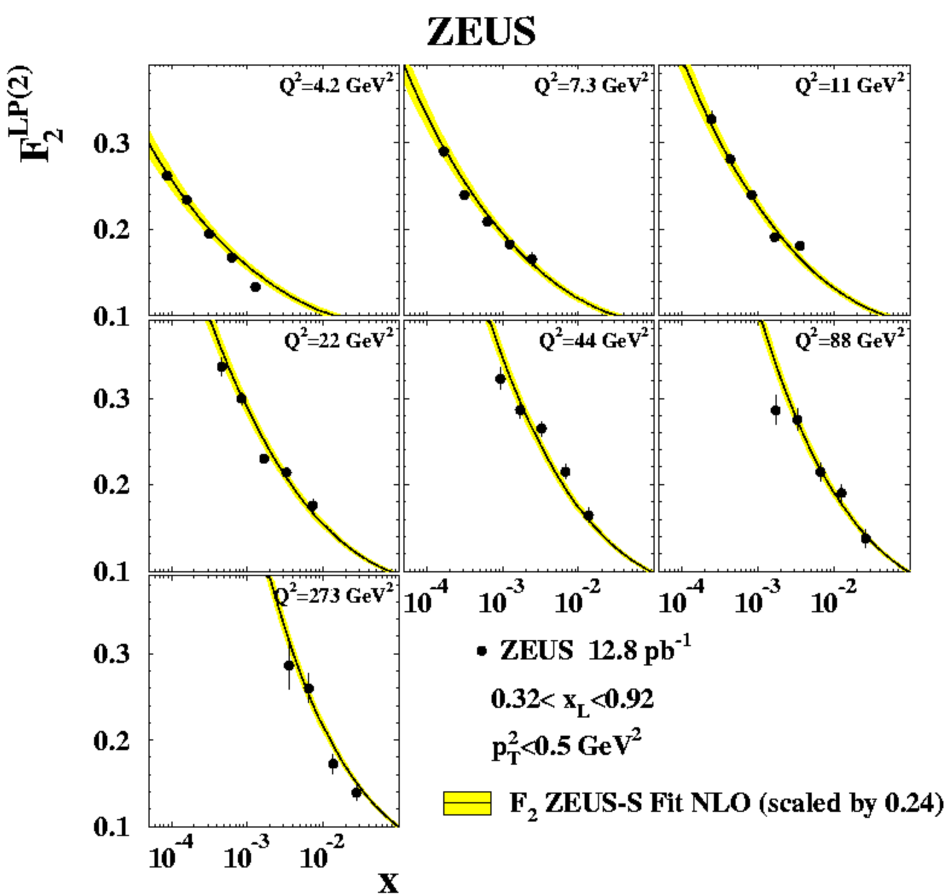
Rates to inclusive DIS



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

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

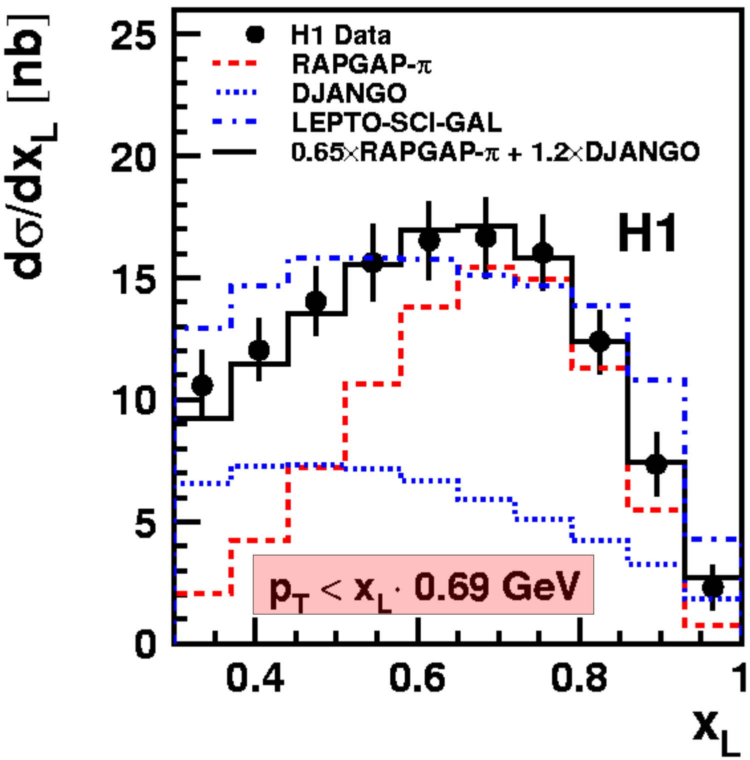
$$\frac{d^2\sigma(ep\rightarrow eXp)}{dx\,dQ^2} = \frac{4\pi\alpha^2}{xQ^4}\left[1-y+\frac{y^2}{2}\right]\cdot F_2^{LP(2)}(x,Q^2)$$

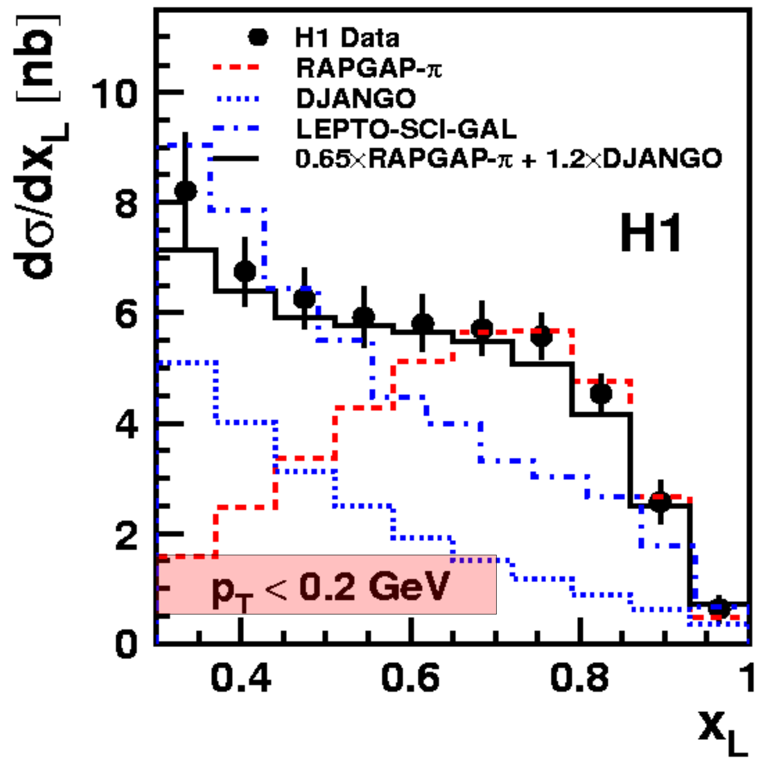


Same trend as inclusive F_2 is observed

Differential cross sections vs x_L

(DESY-09-185)





DJANGO (standard fragmentation) predicts too low cross section, also x_L spectrum shape is too different

RAPGAP π^+-exchange describes data well for $x_L > 0.7$

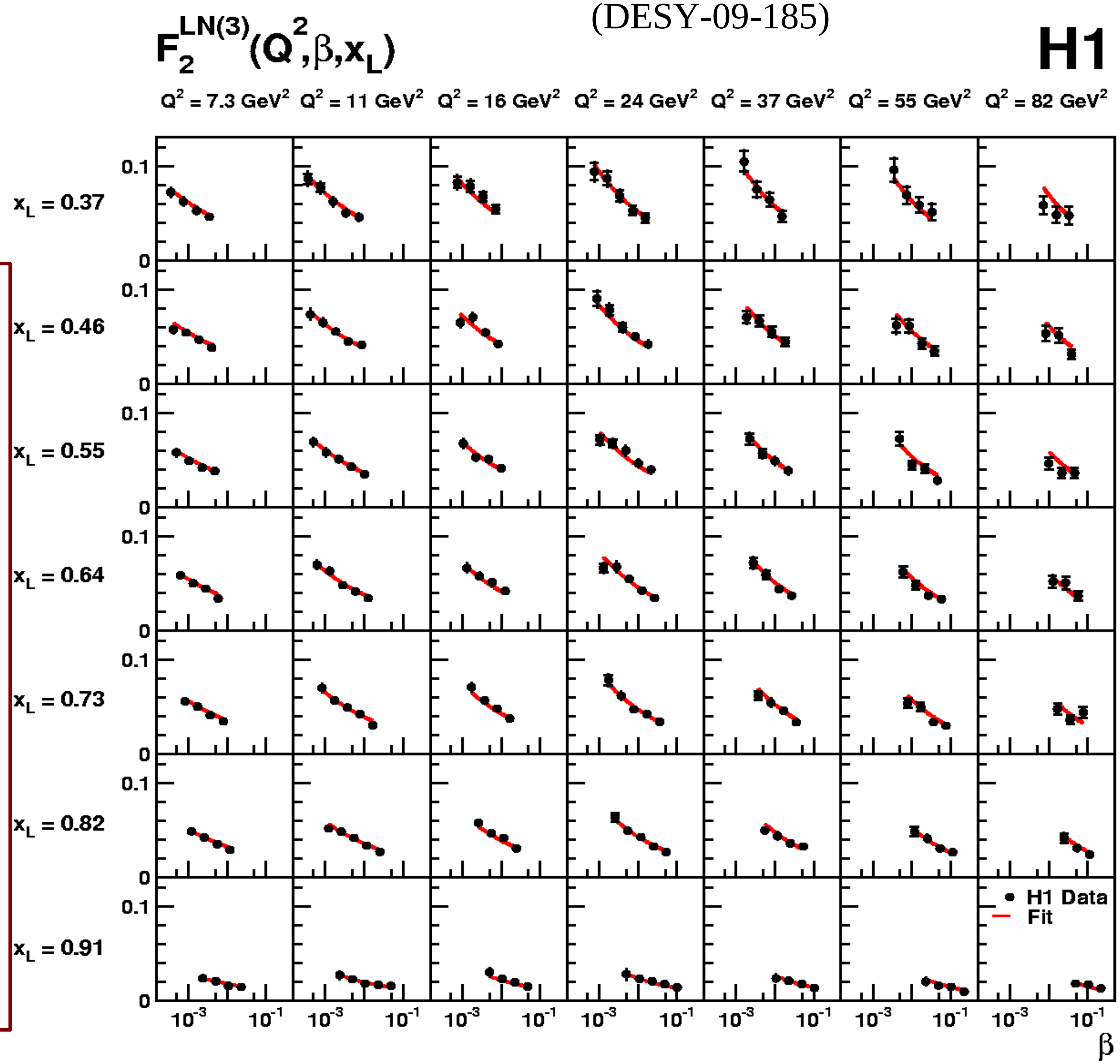
Mixture of the DJANGO and the RAPGAP MC's can be used to describe data in the whole kinematic region

LN production in DIS:

$F_2^{LN}(Q^2,\beta,x_L)$

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

(DESY-09-185)



In particle exchange picture expect proton vertex factorisation:

$F_2^{LN(3)}(Q^2,\beta,x_L) \sim f(x_L)\, F_2^{LN(2)}(Q^2,\beta)$

where $\beta=x/(1-x_L)$ – fraction of exchange momentum carried by struck quark

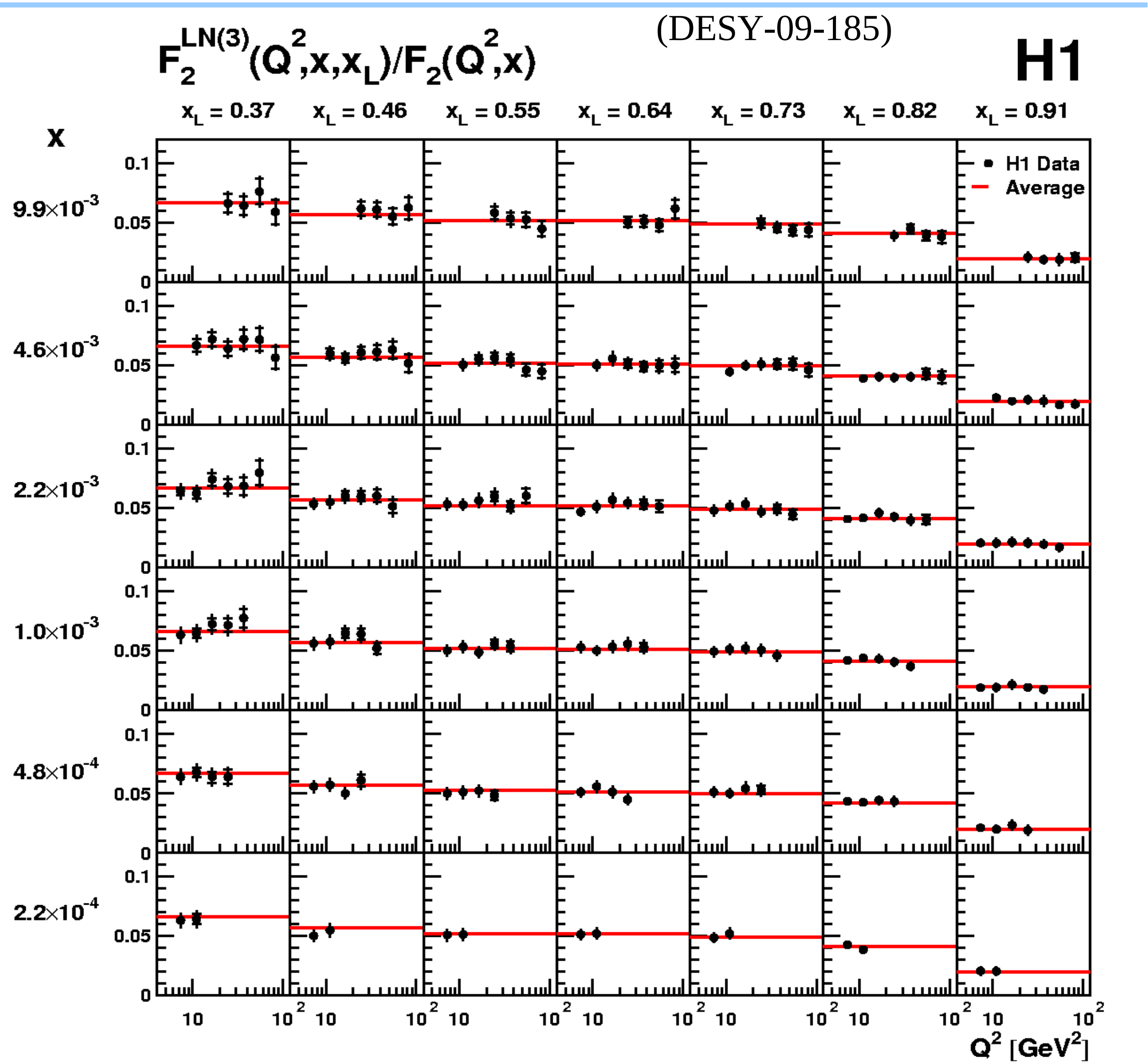
Fit $F_2^{LN(3)}(Q^2,\beta,x_L)$ by power law:

$F_2^{LN(3)}(Q^2,\beta,x_L) \sim \beta^{-\lambda}$

- λ is independent of x_L
  => consistent with vertex factorisation
- λ logarithmically depend on Q^2, similar to inclusive F_2

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 H1PDF2009 parameterisation



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

i.e. LN production rate, kinematics is approx. independent of Q^2 and x

=> consistent with factorisation and limiting fragmentation

Pion Structure Function from F_2^{LN}

Within π^+-exchange model we may try to estimate F_2^{π} from measured F_2^{LN}:

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

where:

$\beta = x/(1-x_L)$ – fraction of pion momentum carried by struck quark (e.g. X_{Bj} for pion)

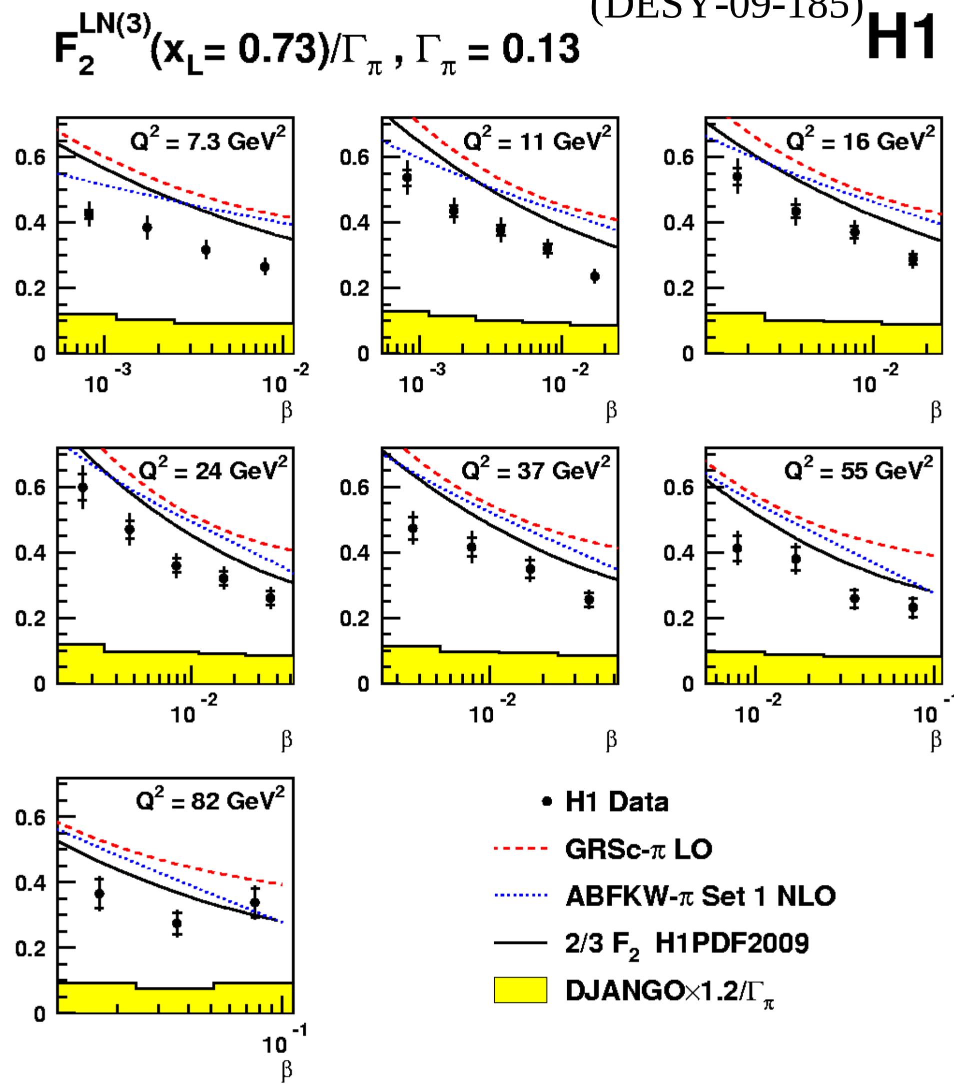
$\Gamma_\pi(x_L)$ is integrated over **t** pion flux

$$\Gamma_\pi = \int f_{\pi/p}(x_L = 0.73, t)\, dt$$

use pion flux parameterisation (Holtmann et al.):

$$f_{\pi^+/p} = \frac{1}{2\pi}\frac{g^2_{p\pi n}}{4\pi}(1-x_L)\frac{-t}{(m^2_\pi - t)^2}\exp\left(-R^2_{\pi n}\frac{m^2_\pi - t}{1-x_L}\right)$$

(DESY-09-185)



Data are sensitive to the parameterisations of the pion structure function (constrained for x > 0.1 from fixed target experiments)

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(DESY-09-185)

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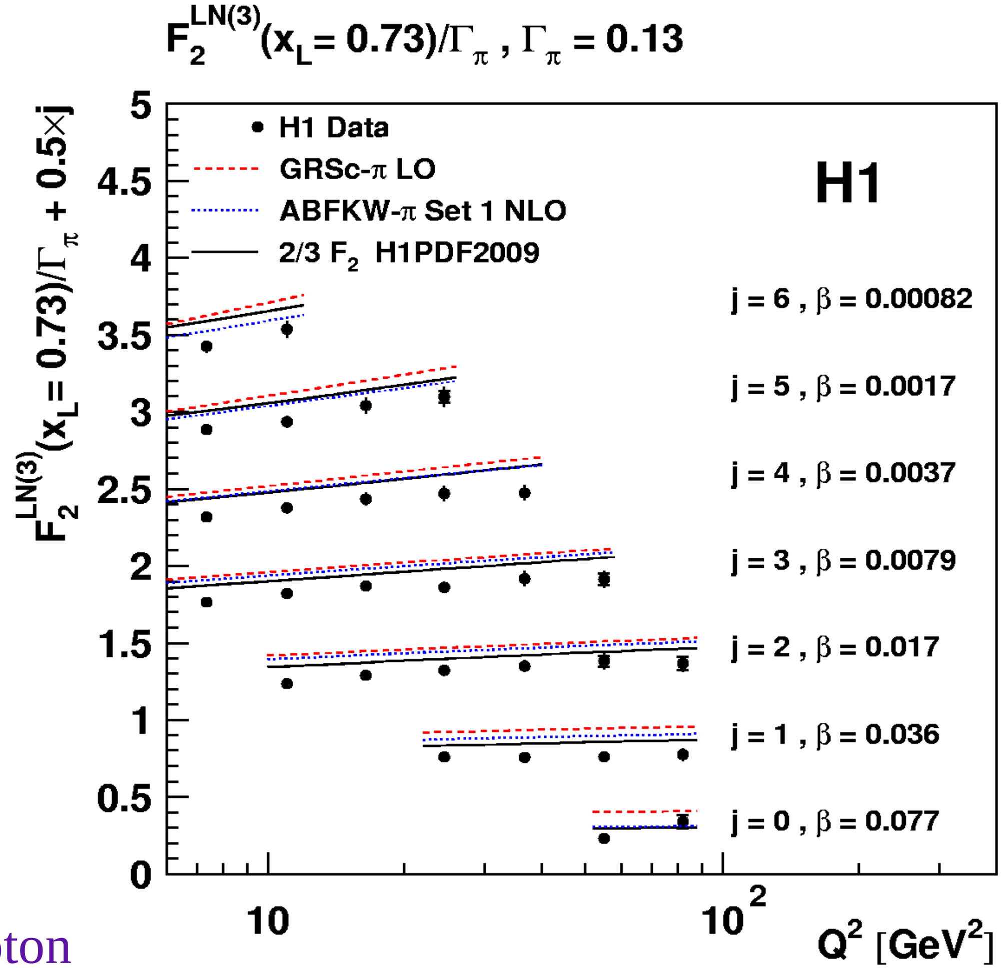
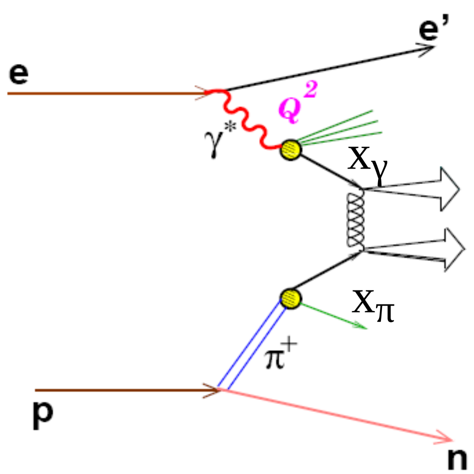


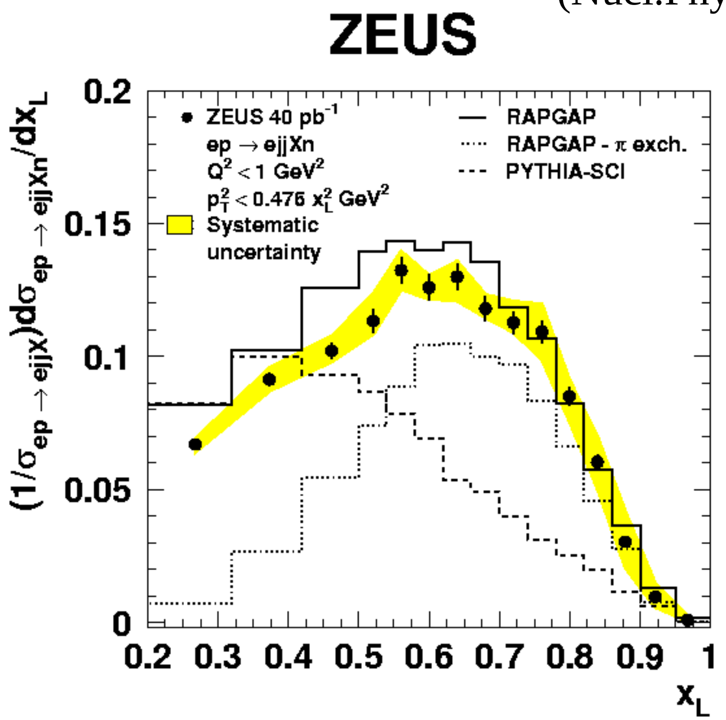
- F_2^π dependence on x and Q^2 similar to proton => universality of hadron structure at low x
- F_2^{LN}/Γ below parameterisations and F_2

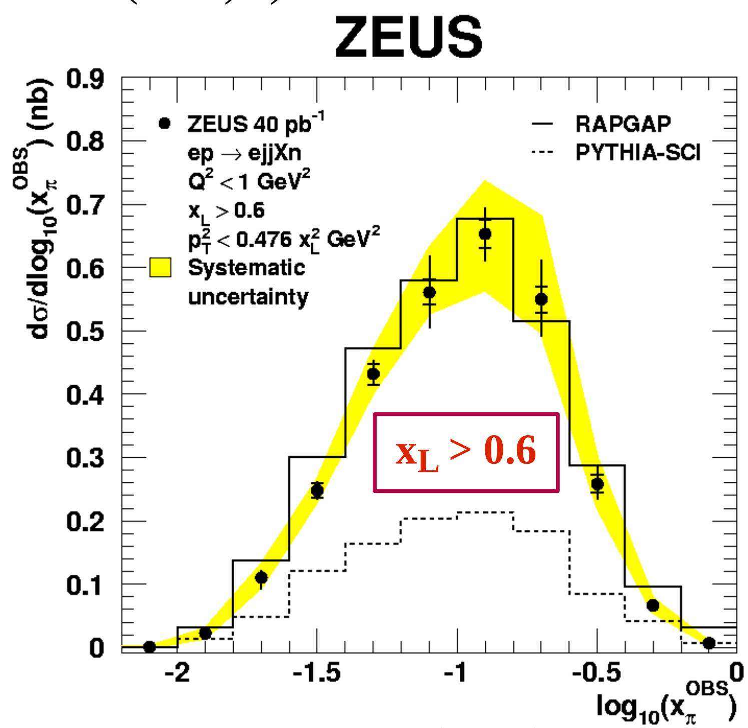
However: large uncertainty of pion flux normalisation: choice of pion flux, absorption...

Dijet photoproduction with Leading Neutron

(Nucl.Phys.B827 (2010) 1)







$Q^2 < 1$ GeV^2, $E_T^{jet1} > 7.5$ GeV, $E_T^{jet2} > 6.5$ GeV

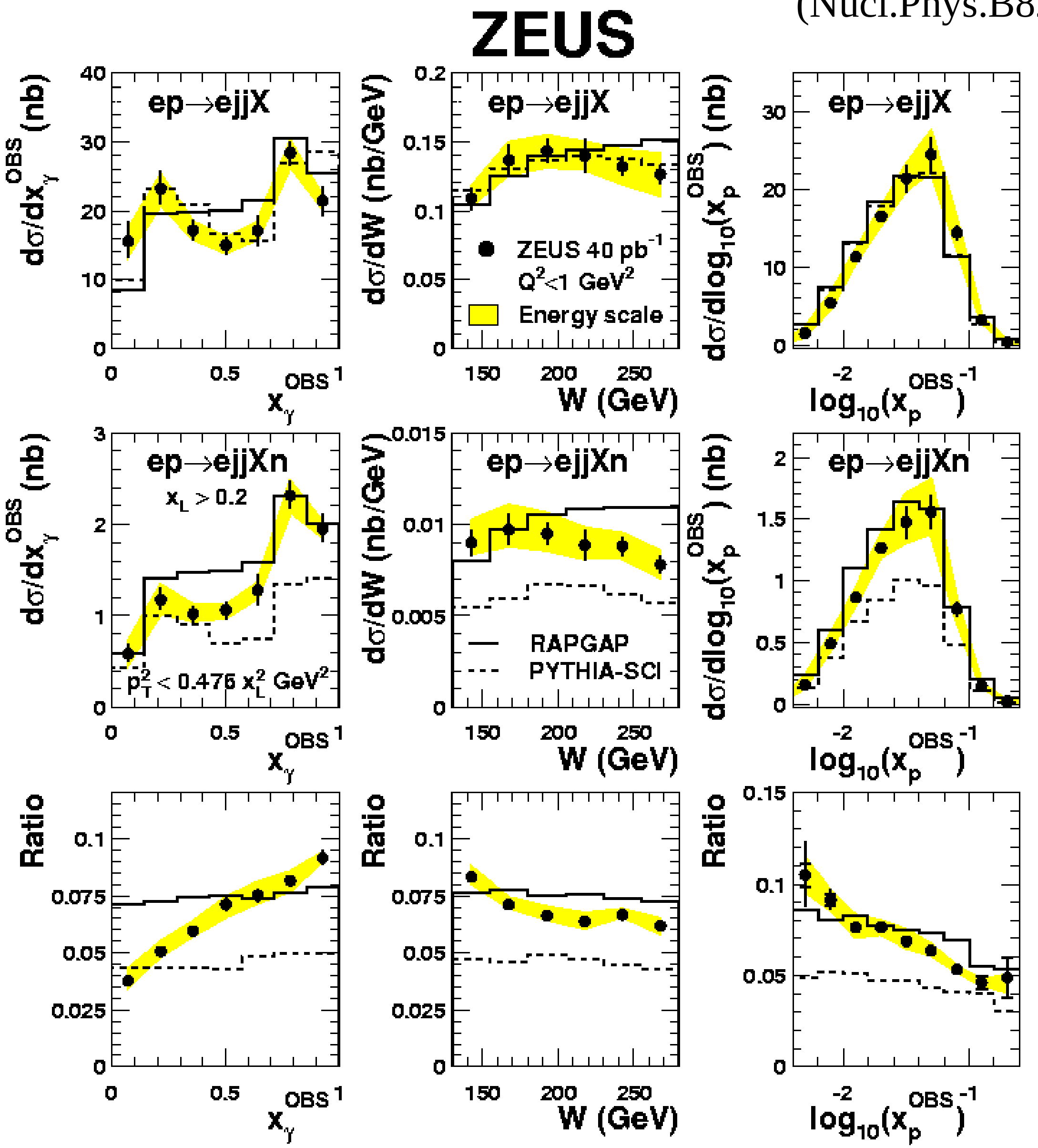
$x_\pi = x_p/(1-x_L)$

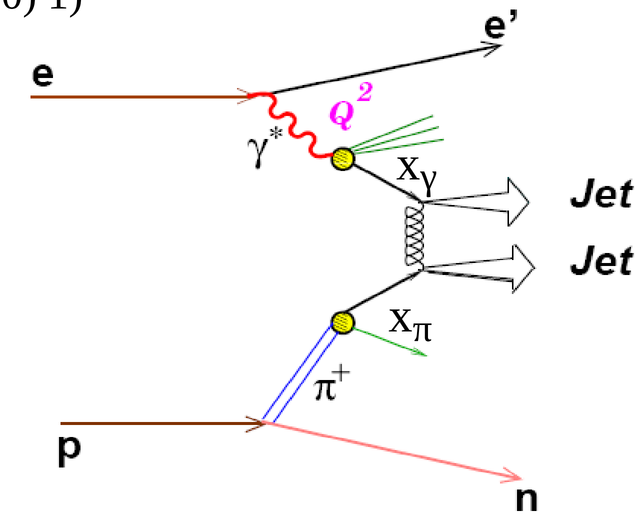
- **In photoproduction ($Q^2 \sim 0$) hard scale provided by jets with high p_T^{jet}**
- **RAPGAP π-exchange and PYTHIA-SCI describe data poor**
- **Pion-exchange is dominating mechanism at high x_L**
- **Full RAPGAP (pion-exchange + inclusive γp) gives good description of data**

LN + dijets in γp:

Differential cross sections

(Nucl.Phys.B827 (2010) 1)





W – total energy of γp system

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

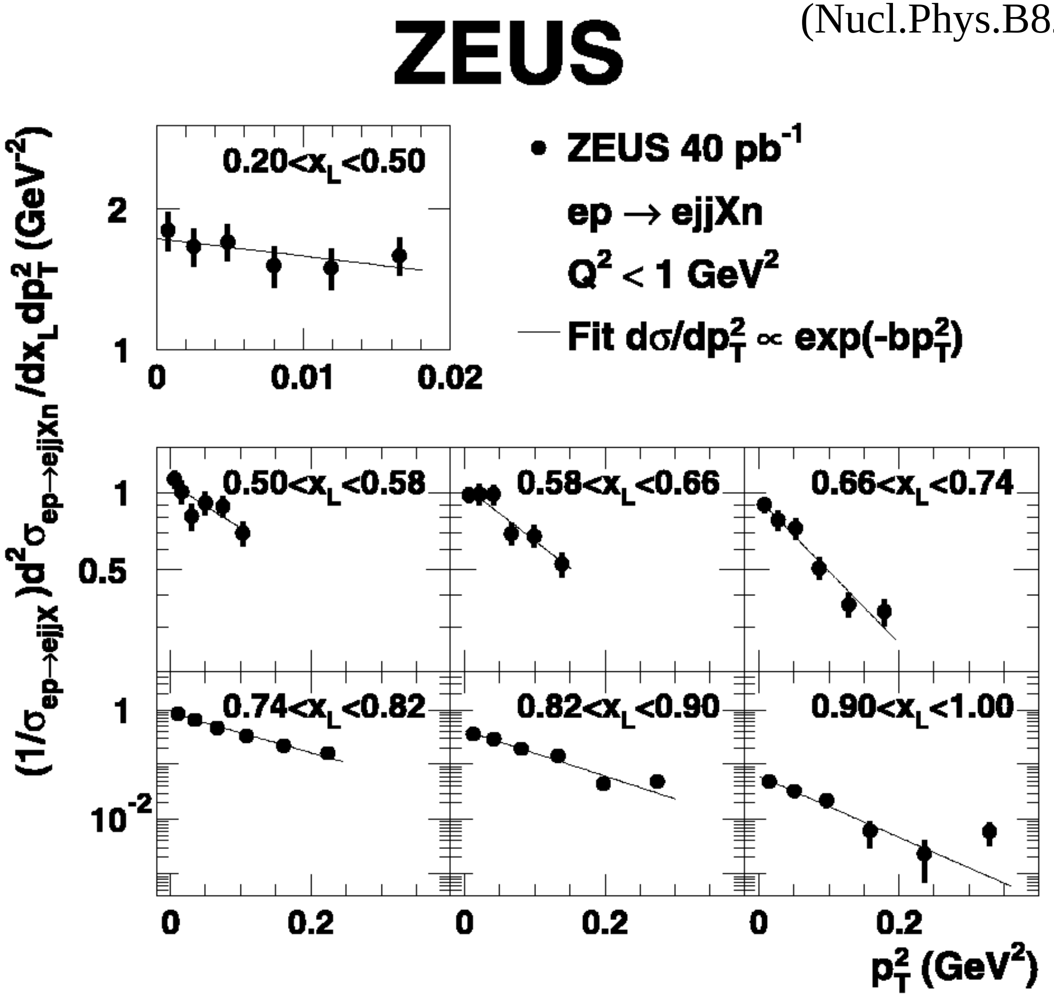
$x_p = \Sigma_{jets} (E+p_z)/(2E_p)$

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

LN + dijets in γp:

p_T^2 distributions in x_L bins; slopes

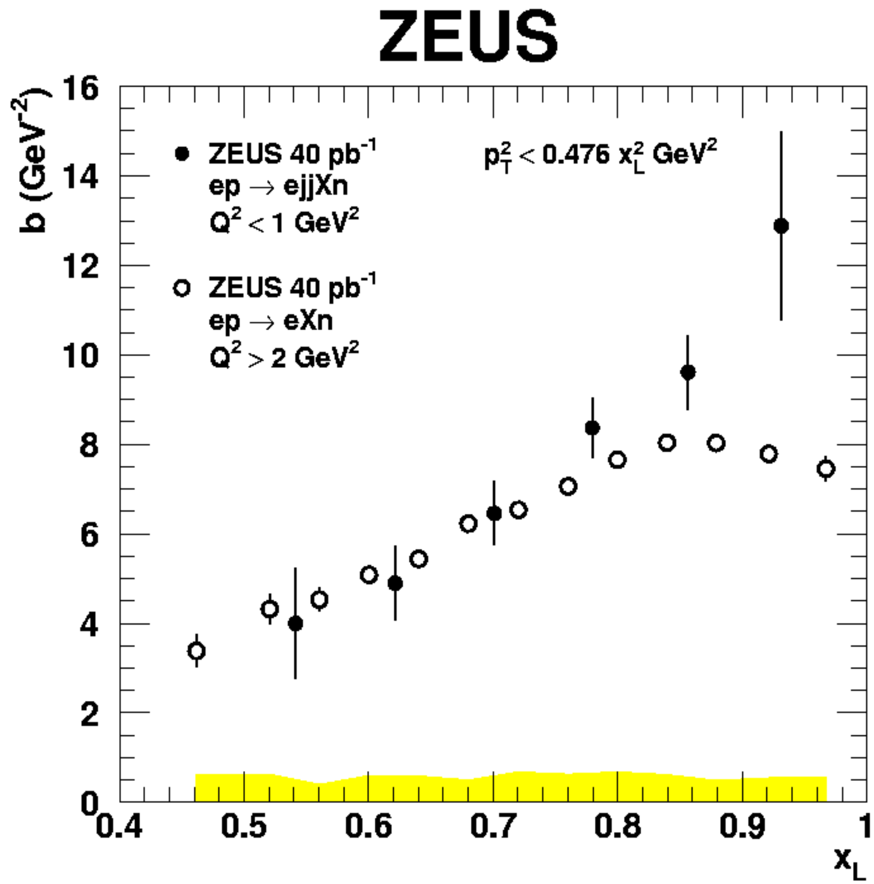
(Nucl.Phys.B827 (2010) 1)



Well described by exponential fall-off in p_T^2

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

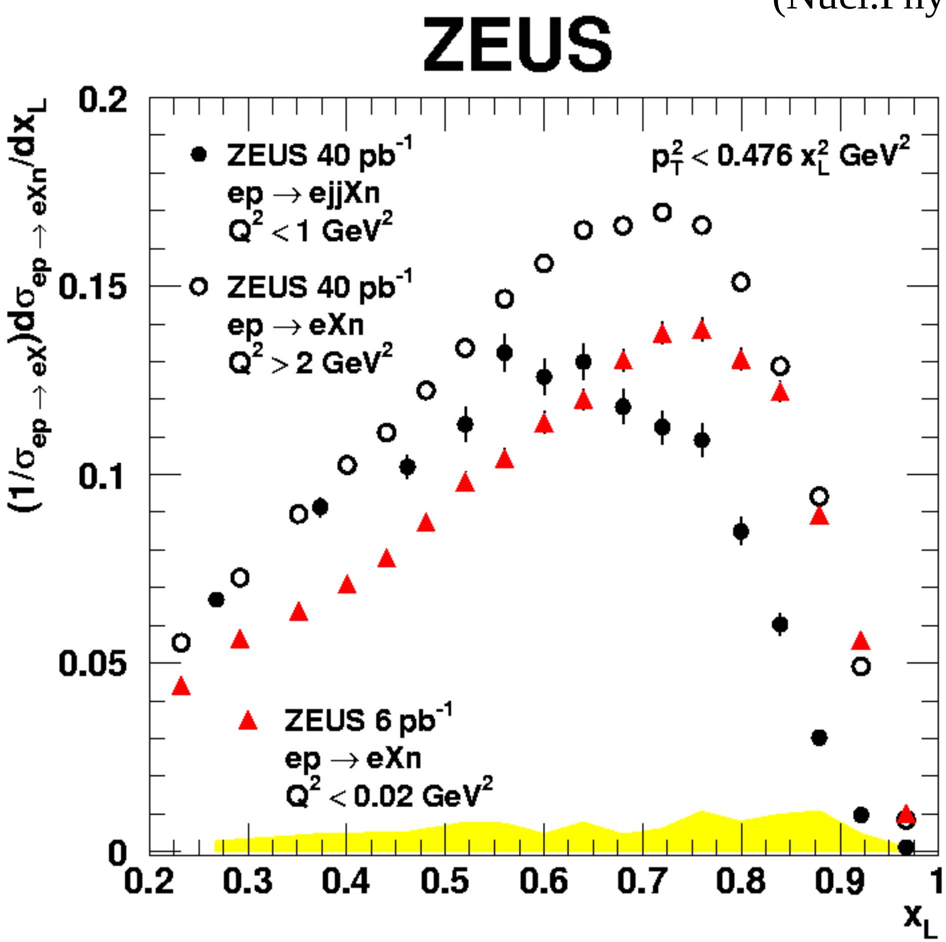
slopes - $b(x_L)$



similar b-values in DIS and γp+dijet,
slightly different at high x_L
=> same production mechanism

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

(Nucl.Phys.B827 (2010) 1)



○ LN in DIS

▲ LN in γp

● LN + dijet in γp

LN production in photoproduction is suppressed vs DIS at low x_L

=> consistent with neutron absorption through rescattering models (more absorption in γp than in DIS due to larger transverse size of real photon)

Suppression is not so prominent in dijet photoproduction (hard scale provided by high E_T^{jet})

Suppression of dijet protoproduction rate at higher x_L is due to phase space limitation: dijets in the final state leave little room for energetic 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^{IP}/F_2 and F_2^{IN}/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**

➔ **Leading baryon data important for an improved theoretical understanding of the proton fragmentation**

Backup slides

Kinematic Range

- **ZEUS: Leading Proton production in DIS (DESY-08-176):**

  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 (DESY-09-185):**

  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 (DESY-09-139):**

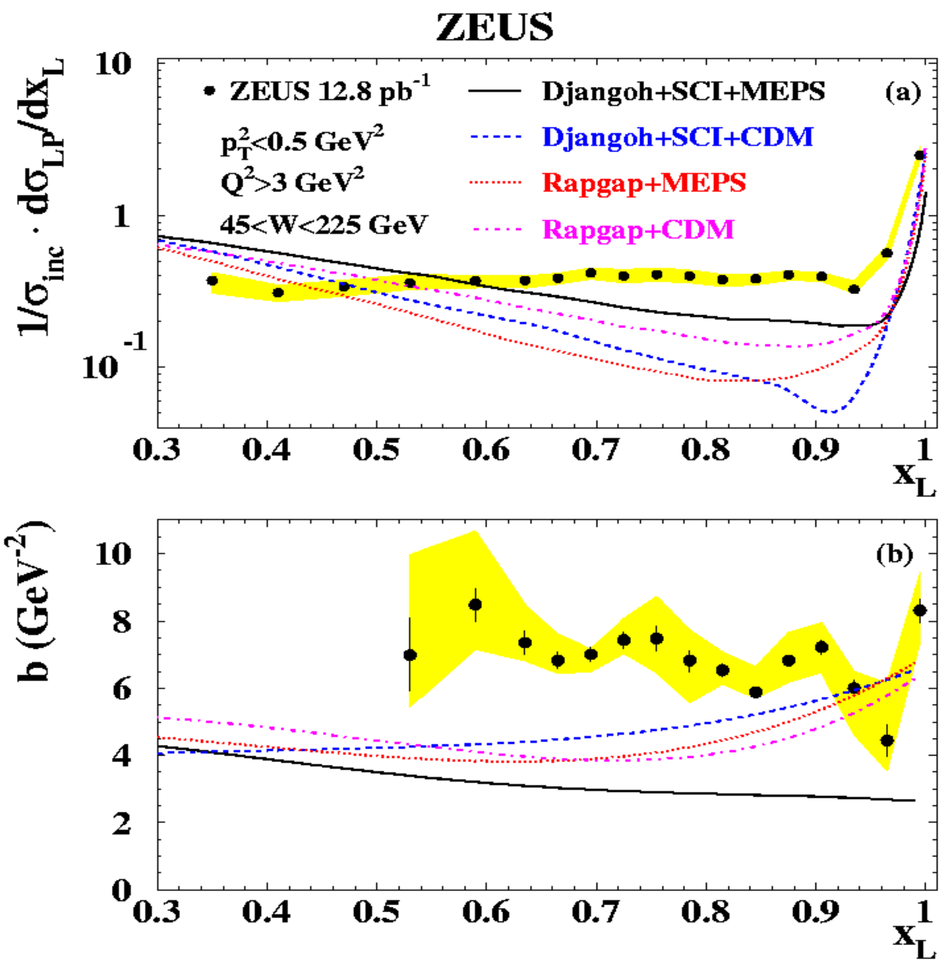
  40 pb^{-1}, $Q^2 < 1$ GeV^2, $p_T^2 < 0.475\, x_L^2$ GeV^2, $x_L > 0.2$, $130 < W < 280$ GeV,

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

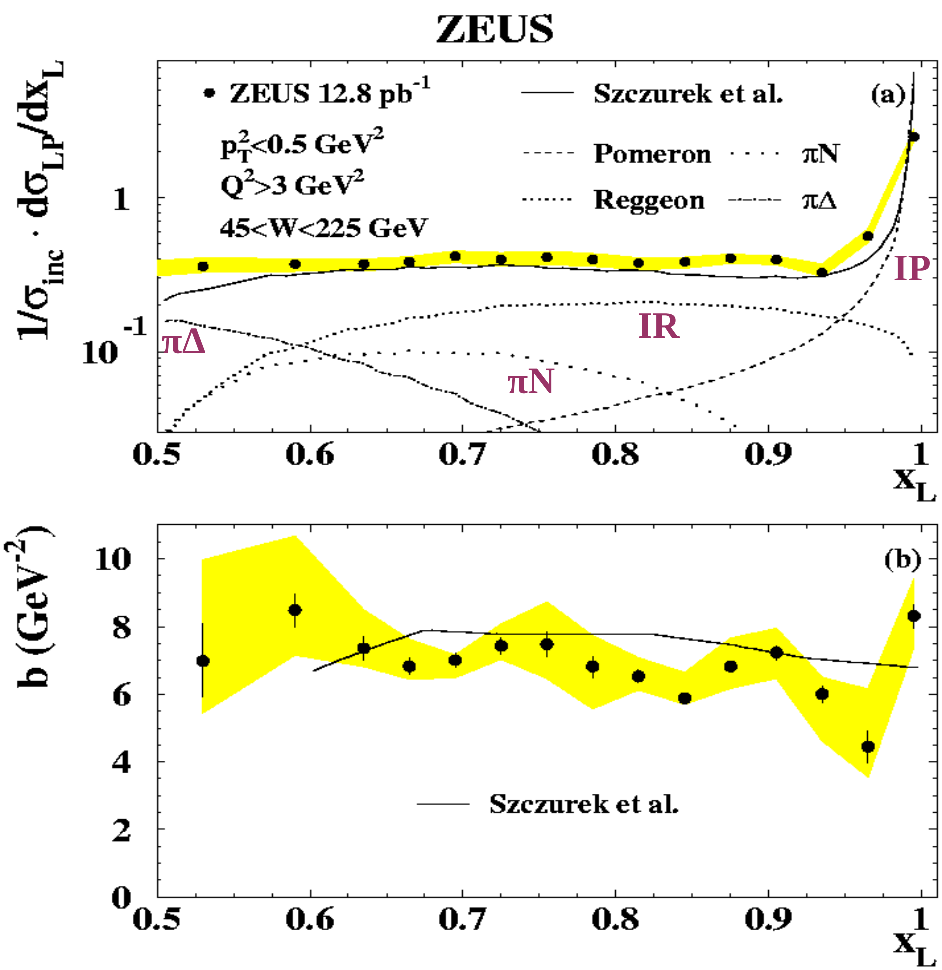
Comparison with models

JHEP 0906:074,2009

Standard fragmentation MC



Model with multiple exchanges



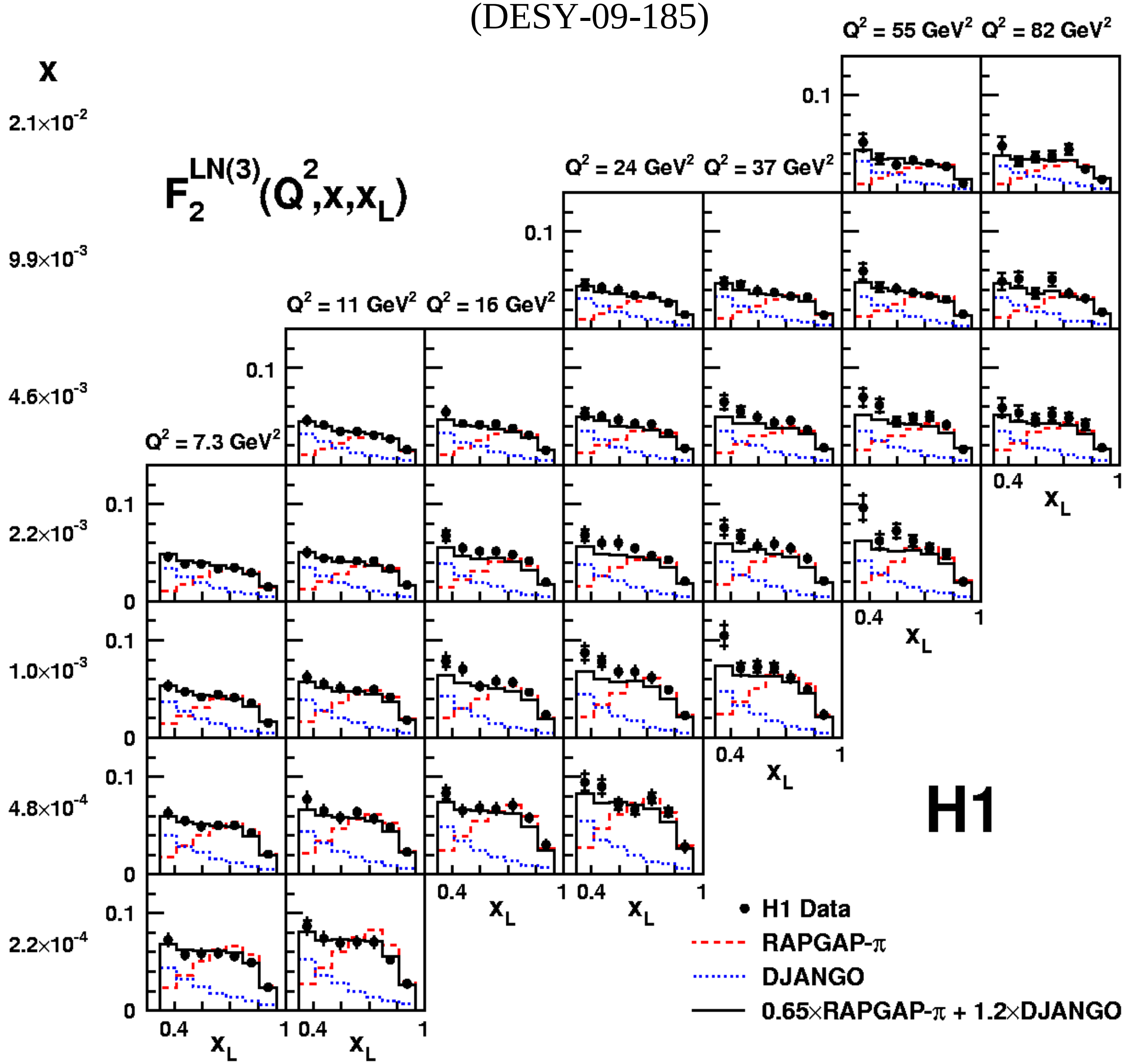
- **good description of diff. peak but all fail at low x_L**
- **slopes are too low at low x_L**

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

Triple differential reduced cross section

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

(DESY-09-185)



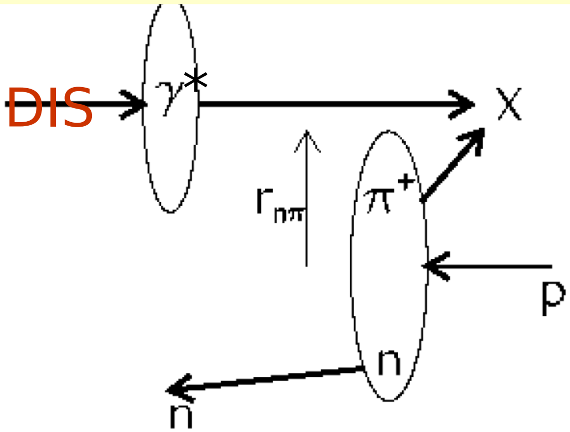
DJANGO (standard fragmentation) predicts too low cross section, also x_L spectrum shape is too different

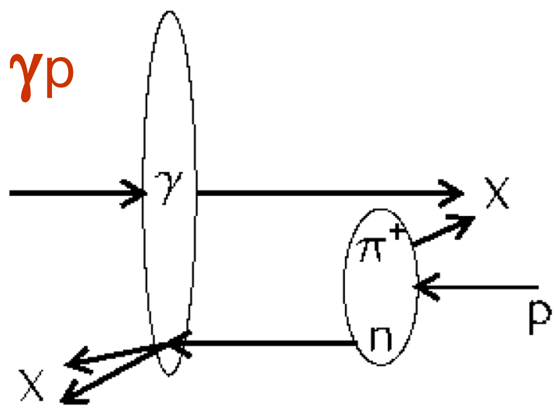
RAPGAP π^+-exchange describes data well for x_L > 0.7

Mixture of the DJANGO and the RAPGAP MC's can be used to describe data in the whole kinematic region

Absorptive corrections

Absorption: important ingredient to interpret the results in terms of particle exchange





Neutron absorption through rescattering:

enhanced when size of π-n system $r\pi_n \sim 1/p_T$ is small w.r.t. the transverse size of **γ**, e.g. at high p_T, low x_L

=> neutron breaks up or

=> is kicked to lower x_L,higher p_T (migration) and/or escapes detector acceptance (absorption loss)

(in other language: multi-Pomeron exchange)

Affects the relative rate of leading neutrons (depends on the scale Q)

more absorption in photoproduction then in DIS,

(real γ transverse size larger than at higher Q²)

→The calculations/models made without absorption may overestimate the measurements

Effects of absorption and migration estimated:

D'Alesio,Pirner; Nikolaev,Speth,Zakharov;
Kaidalov,Khoze,Martn,Ryskin ;
Kopeliovich,Potashnikova,Schmidt,Soffer

LN + dijets in γp:

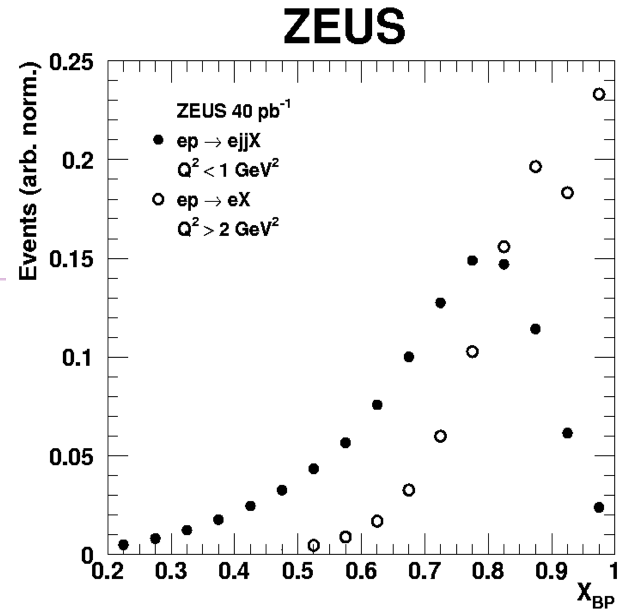
LN in dijet γp vs DIS: kinematic constraints

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

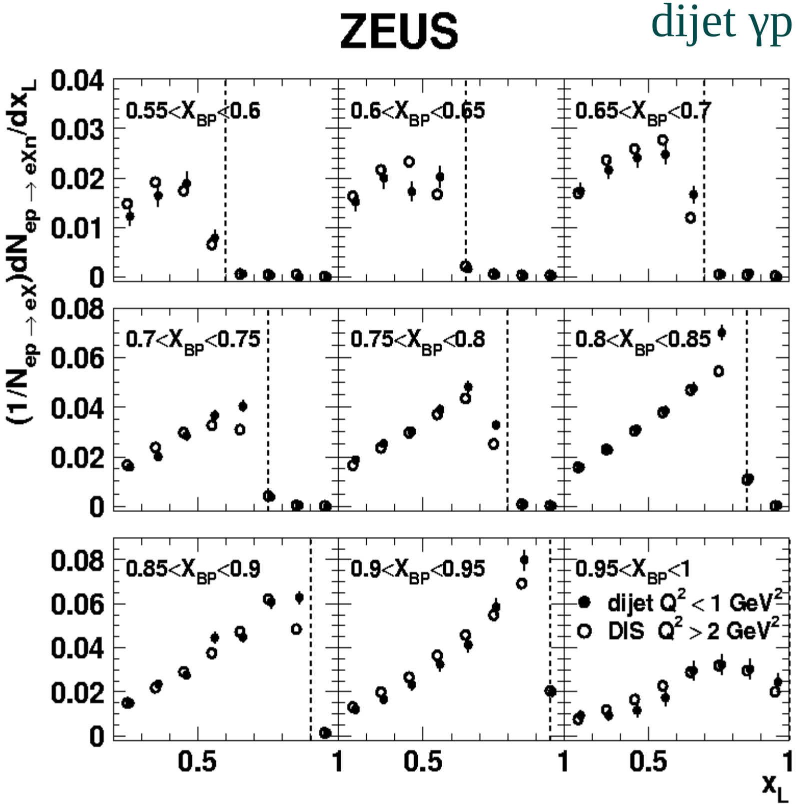
$$x_L < X_{BP} = 1 - (E+P_Z)/(2E_P)$$

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.