LEADING BARYON PRODUCTION at HERA

Lorenzo Rinaldi
On behalf of H1 and ZEUS Collaborations

Motivations

- Large fraction of events with a Leading Baryon (LB)
- LB produced at small angle in forward direction: difficult detection
- Production mechanism still not clear: soft scale, alternative approach needed
- Interest in LB study for next experiments @ LHC
  → absorptive corrections related to gap survival probability (diffractive Higgs, pile-up background...)

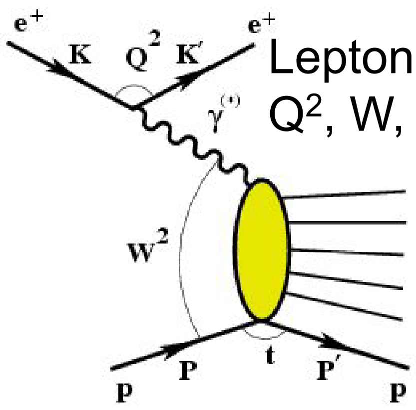
Results discussed in this talk:

- Leading Proton (LP) spectra in DIS → NEW
- Leading Neutron (LN) spectra in DIS and γp
- Dijet γp with a LN → NEW
- Latest developments in theory
- Comparison with models

Leading baryon production in ep collisions

LB cross sections vs structure functions:
(QCD-based approach)

$$\frac{d^4\sigma(x,Q^2,x_L,p_T^2)}{dx\,dQ^2\,dx_L\,dp_T^2}=\frac{4\pi\alpha^2}{xQ^4}\left(1-y+\frac{y^2}{2}\right)F_2^{LB(4)}(x,Q^2,x_L,p_T^2)$$

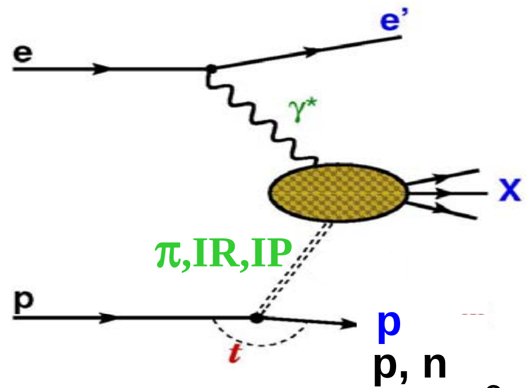


Lepton variables
Q^2, W, x, y

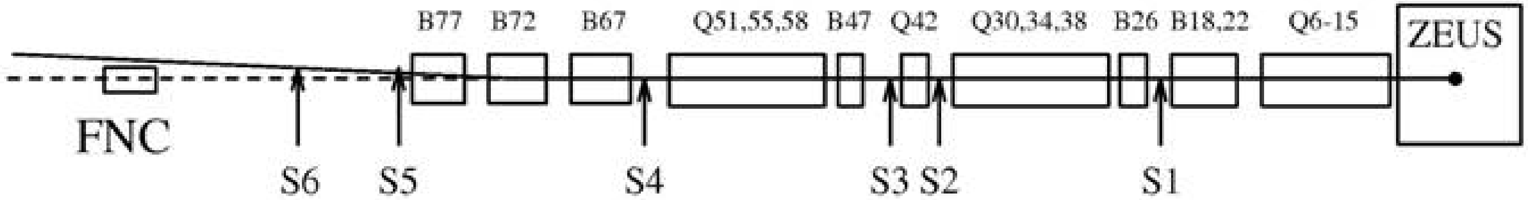
Standard fragmentation
- LB from hadronization of p remnant
- Implemented in MC models
(Cluster, Lund strings...)

LB variables:
p_T^2, $x_L=E_{LB}/E_p$
$t=(p-p')^2$

Virtual particle exchange
π, IR, IP, ρ,..
LB also from p fragmentation in double dissociative diffraction



Leading baryon detectors



ZEUS Leading Proton Spectrometer (LPS)

- 6 stations each made by 6 Silicon-detector planes
- Stations inserted at $10\sigma_{beam}$ from the proton beam during data taking
- $\sigma_{x_L} < 1\%$ $\sigma_{p_T^2} \sim$ few MeV^2 (better than p-beam spread ~ 50 - 100 MeV)

H1 Forward proton spectrometer (FPS)

- 2 stations each made by 4 scintillating fibres hodoscopes planes
- θ_x= 5μrad θ_y=100μrad, Energy resolution 8 GeV
- Acceptance $500<E_{p'}<780$ GeV

ZEUS Forward Neutron Calorimeter (FNC)

- 10λ lead-scintillator sandwich
- $\sigma/E = 0.65/\sqrt{E}$, Energy scale=2%
- Acceptance $\theta_n<0.8$ mrad, azimuthal coverage 30%

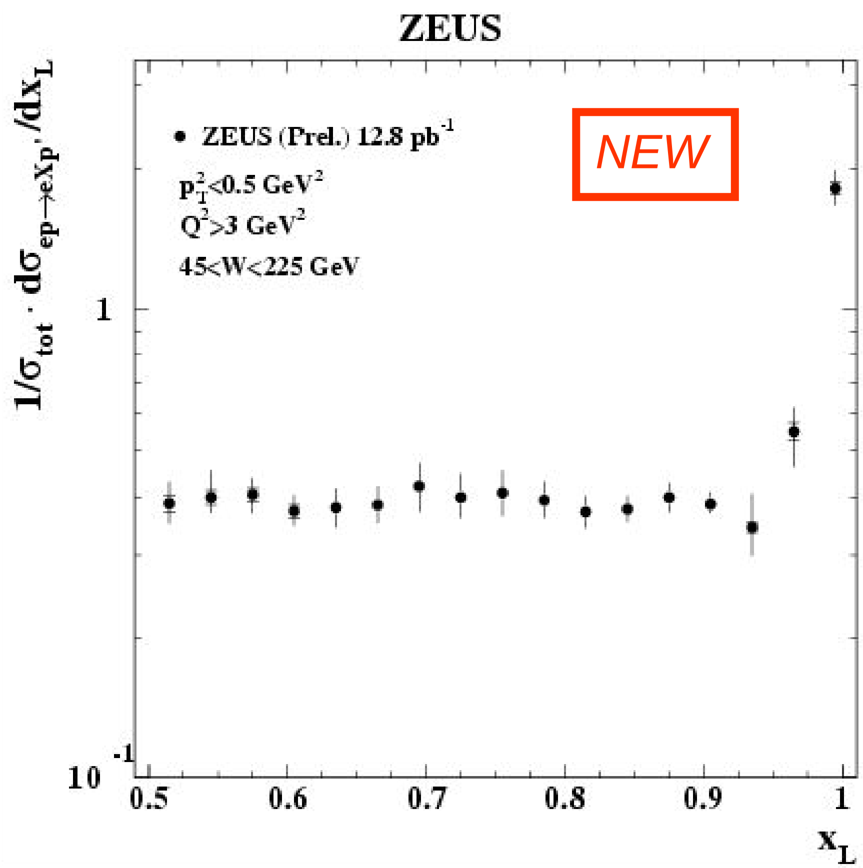
ZEUS Forward Neutron Tracker (FNT)

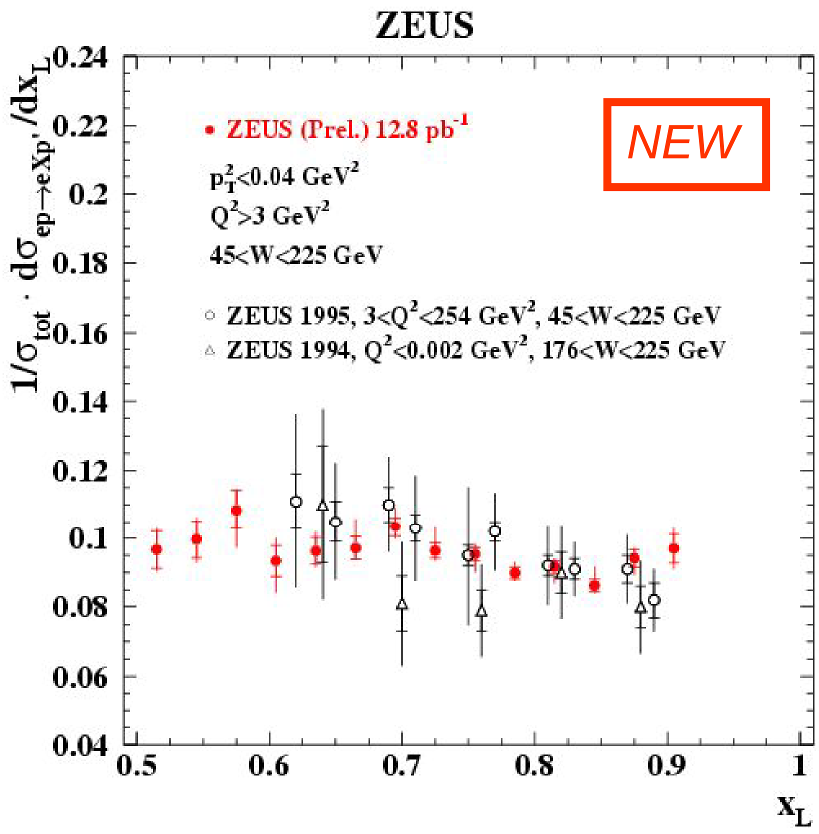
- Scint. hodoscope @ 1λint, $\sigma_{x,y}$=0.23cm, σ_θ=22μrad

H1 Forward Neutron Calorimeter (FNC)

- Lead-scintillator calorimeter @ 107m from I.P. + veto hodoscopes
- $\sigma(E)/E \approx 20\%$, neutron detection eff. 93±5%

Leading Proton: cross section vs x_L



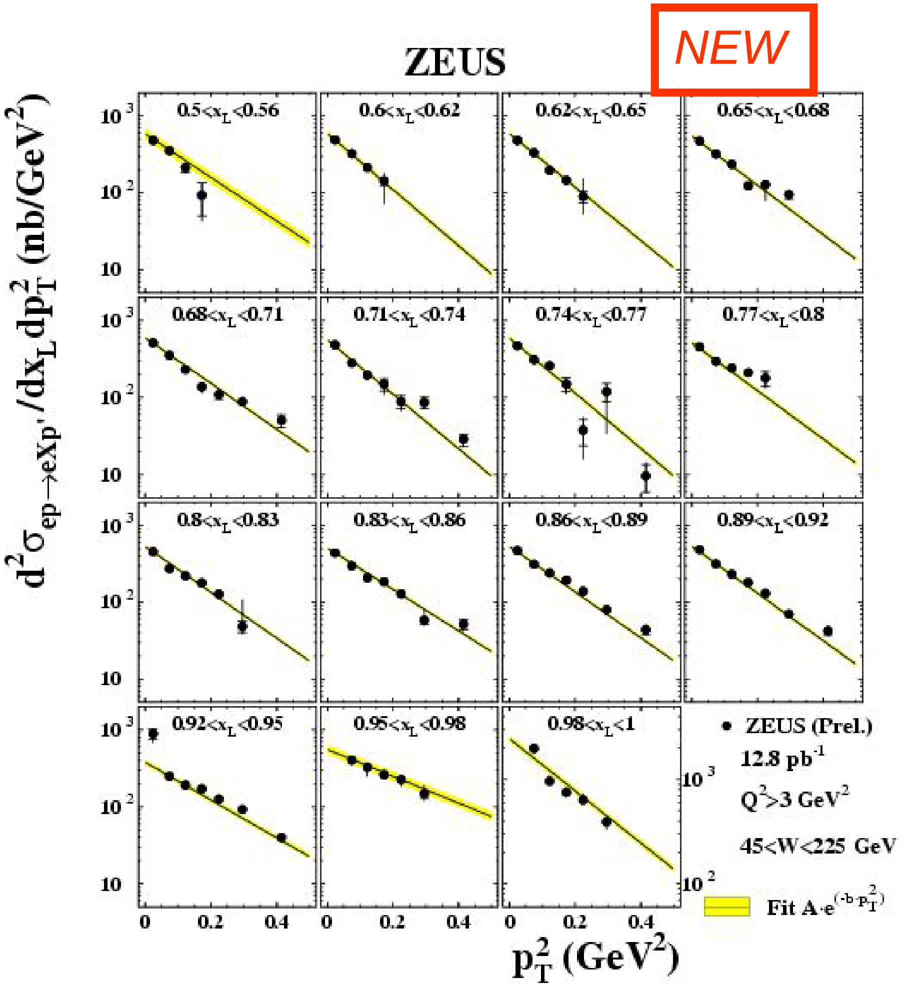


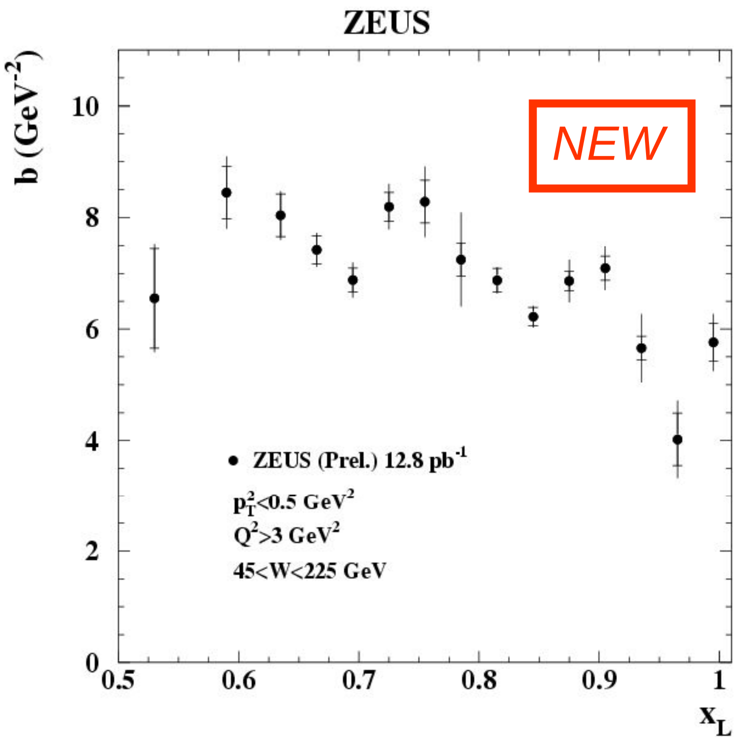
Flat below diffractive peak

Cross section at low p_T^2
Agreement with photoproduction

NEW LP results: LPS stations full set used

LP: cross section vs p_T^2 and b-slopes





Exponential behaviour
Fit to A*exp(-b*p_T^2) shown with
stat. error

No strong dependence of b on x_L

LP: ratio to inclusive DIS

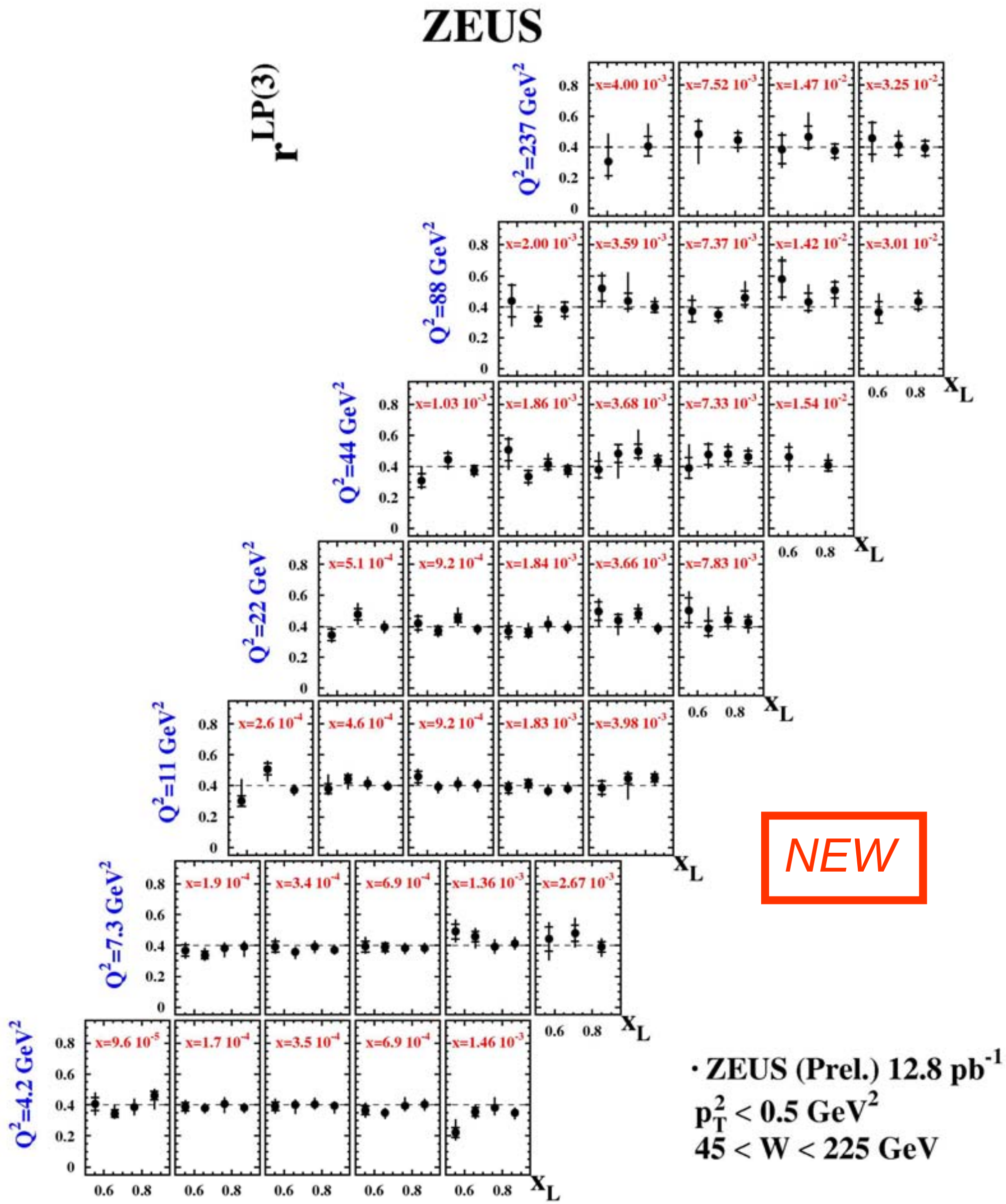
Structure function ratio

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

$$r^{LP(2)}=\frac{F_2^{LP(2)}(x,Q^2)}{F_2(x,Q^2)}$$

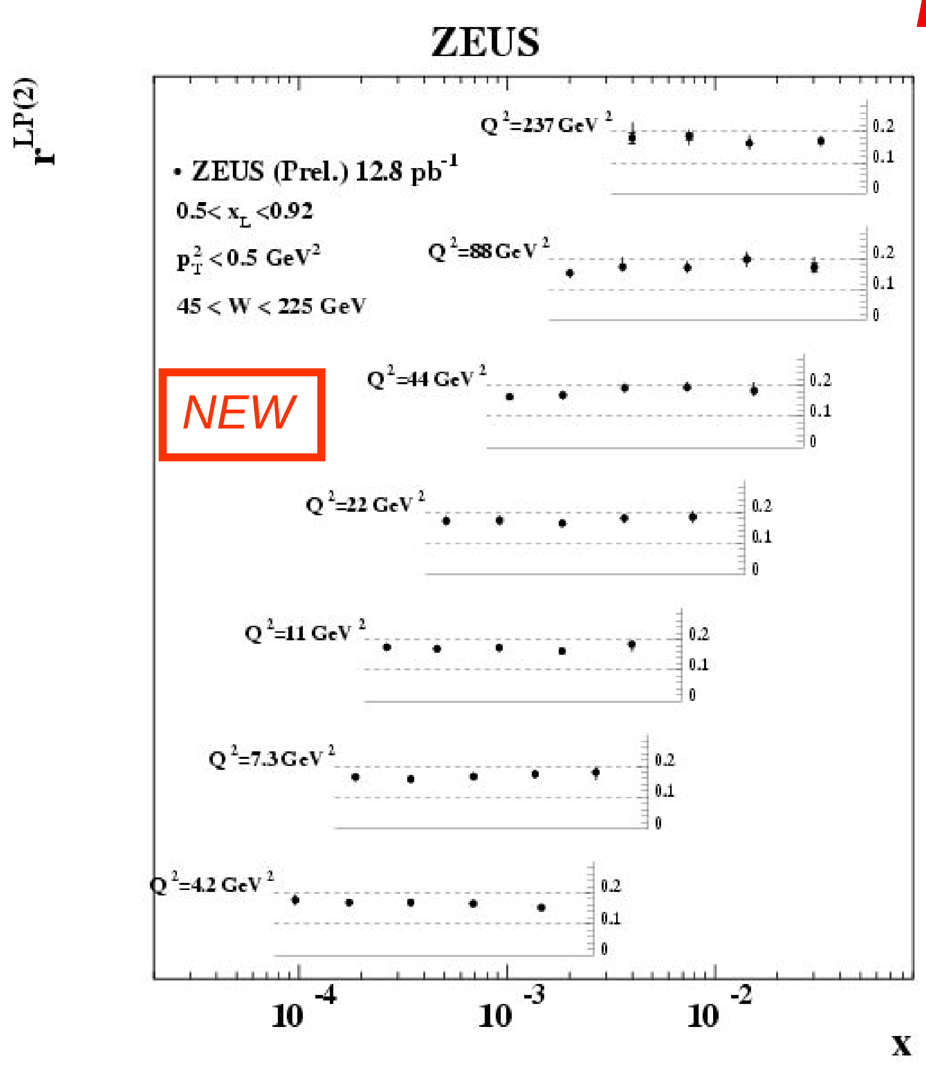
Information on LP production
as a function of DIS variables

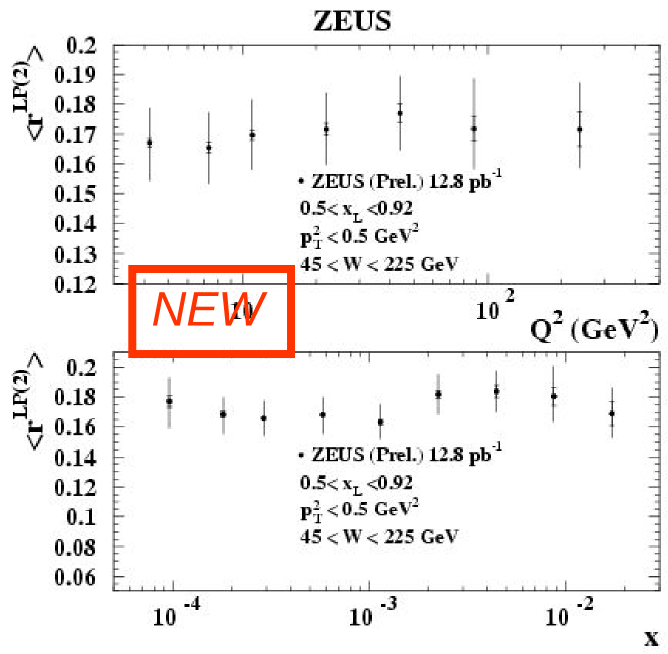
Test of vertex factorization



NEW

Ratios to inclusive DIS - 2



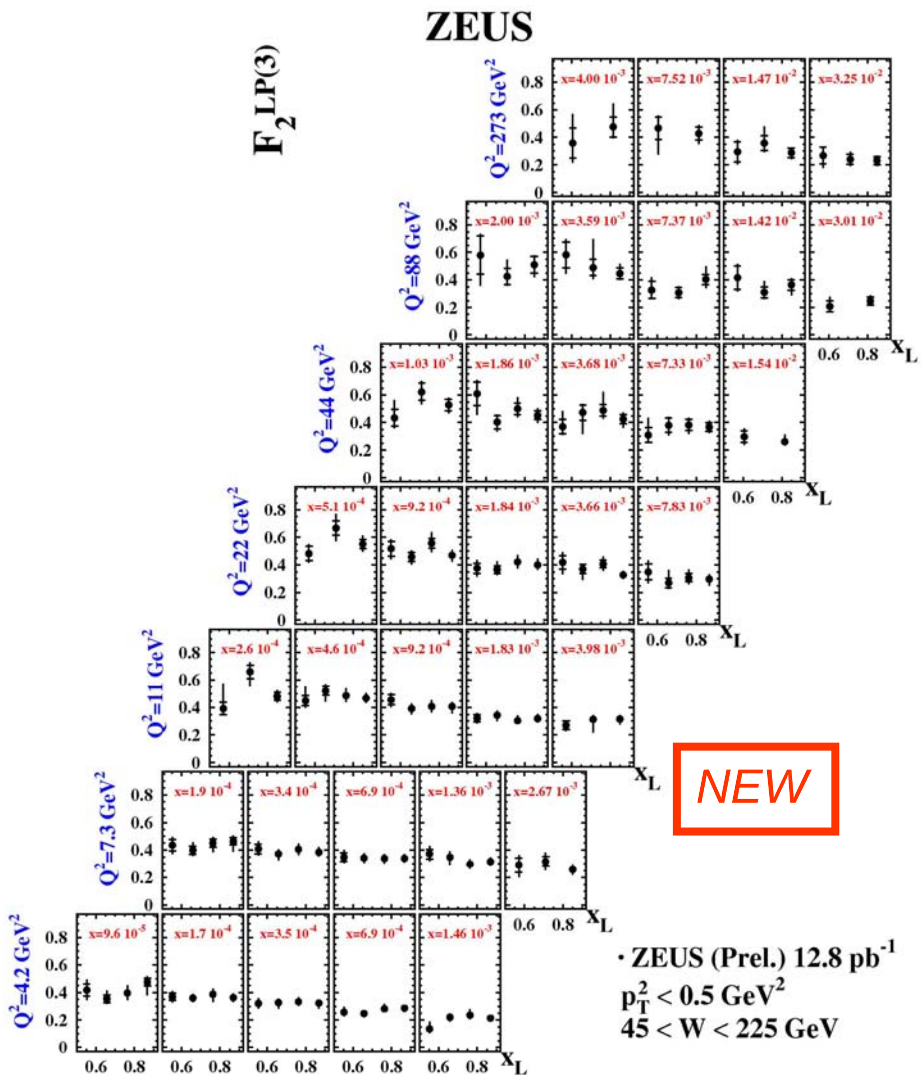


No strong dependence on x and Q^2 when integrating over $0.5<x_L<0.92$

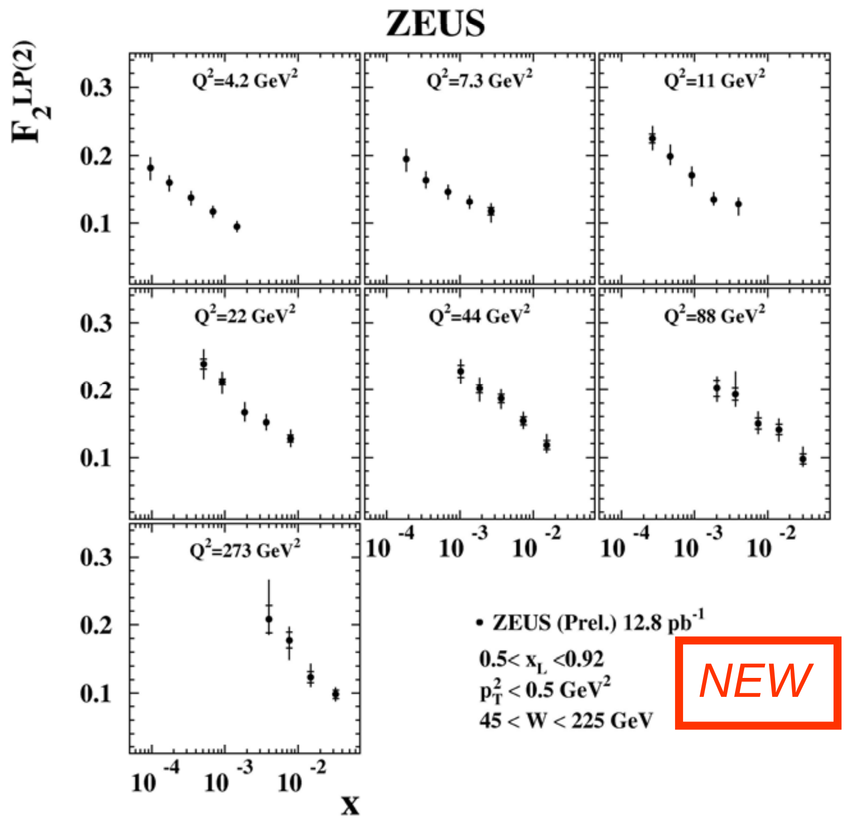
17-18% of DIS events have a LP with $0.5<x_L<0.92$, almost independently of x and Q^2

No clear evidence of vertex factorization violation

LP structure functions



NEW



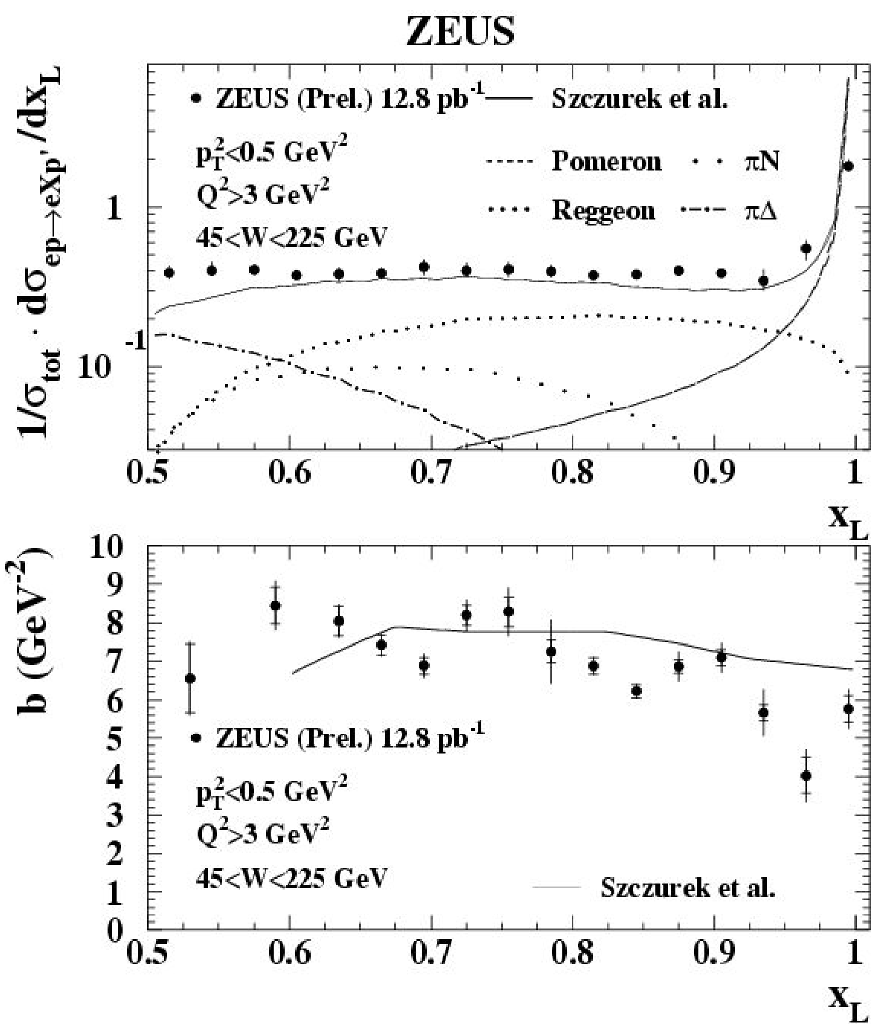
NEW

$F_2^{LP} = r^{LP} * F_2$ (ZEUS-S parametrization used)

F_2^{LP}: same dependence on x and Q^2 as F_2

Comparisons to Reggeon exchange model

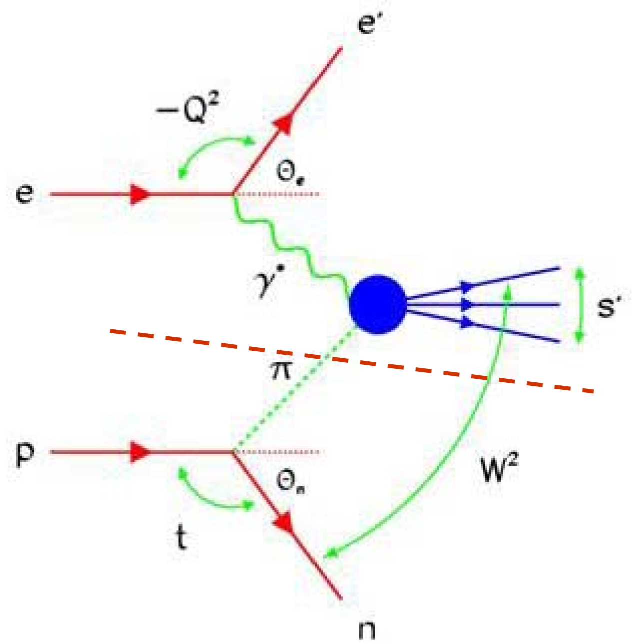
Predictions good in shape but:
x_L slighty underestimated
b-slope slightly overestimated



Szczurek et al.,
Phys Lett B428, 383 (1998)
Pomeron
Reggeon
πΔ
πN

Leading Neutron: One-Pion-Exchange model

O.P.E. partially explains the LN production



$$\frac{d\sigma_{ep\to eXn}(W^2,Q^2,x_L,t)}{dx_L dt} = f_{\pi/p}(x_L,t)\cdot\sigma_{\gamma^*\pi}((1-x_L)W^2,Q^2)$$

$$f_{\pi/p}(x_L,t) \propto \frac{-t}{(t-m_\pi^2)^2}(1-x_L)^{\alpha(t)}F^2(x_L,t)$$

$\alpha(t)$ and form factor $F^2(x_L,t)$ model dependent

Longitudinal momentum spectrum and p_T^2 slopes discriminate between different parametrizations of fluxes

Rescattering model and absorption

D'Alesio and Pirner

(EPJ A7(2000) 109)

Neutron rescatters on γ hadronic component.

Absorption enhanced when

- π-n system size larger → low x_L
- γ size larger → photoproduction

Nikolaev,Speth and Zakharov

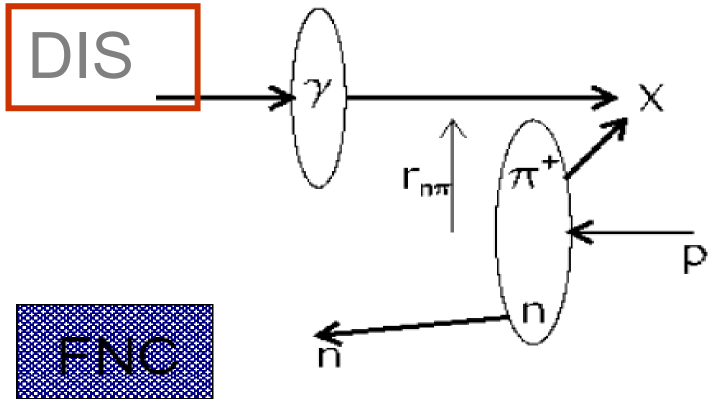
(hep-ph/9708290)

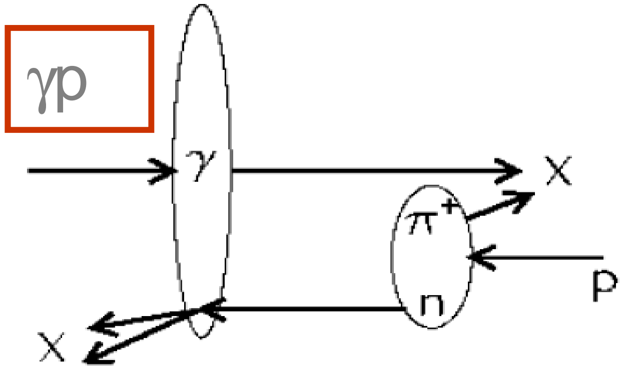
Re-scattering processes via additional Pomeron exchanges (Optical Theorem)

Kaidalov, Khoze, Martin, Ryskin (KKMR)

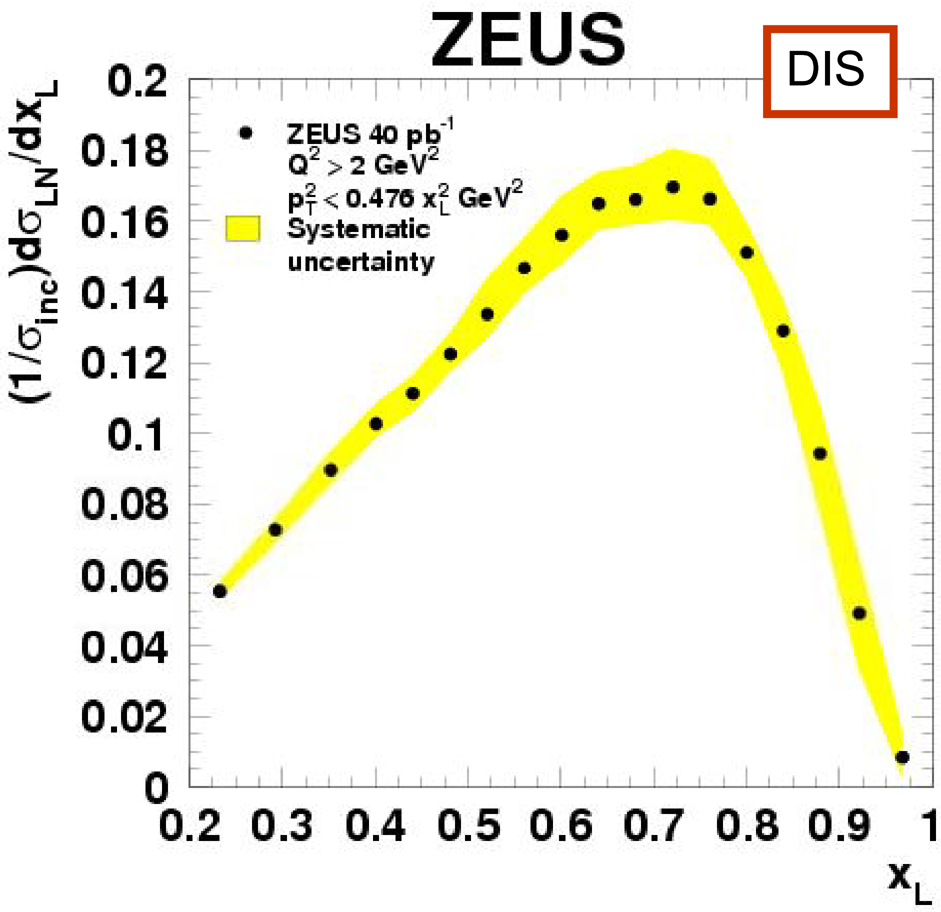
(hep-ph/0602215, hep-ph/0606213)

Enhanced absorptive corrections (→ exclusive Higgs @ LHC), calculation of migrations, include also ρ and a_2 exchange (different x_L & p_T dependences)

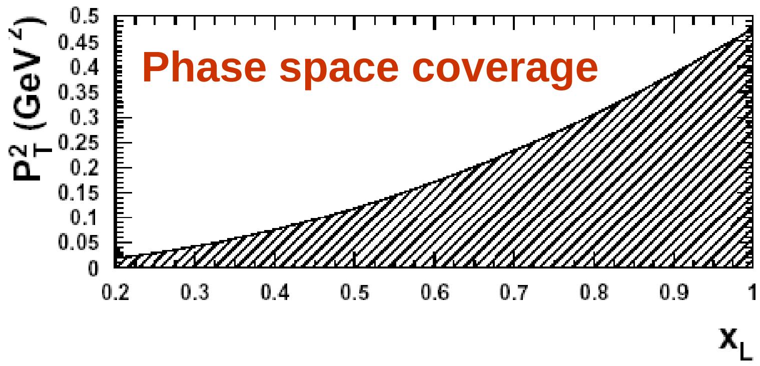




LN: longitudinal momentum spectrum

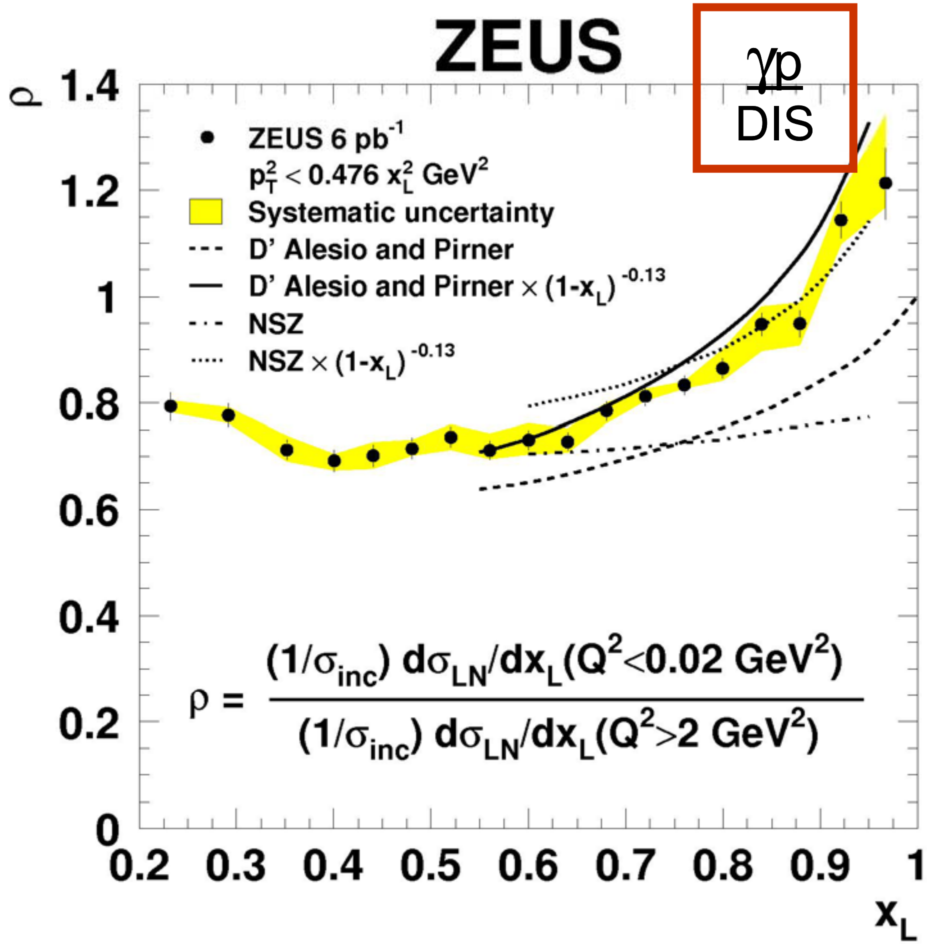


- LN yield increases with x_L due to increase in phase space: $p_T^2 < 0.476\ x_L^2$



- LN yield decreases for $x_L \rightarrow 1$ due to kinematic limit

LN: ratio γp/DIS



Data compared to OPE with absorption.

• Qualitatively similar to D'Alesio and Pirner (loss through absorption)

• Nikolaev,Speth and Zakharov model also shown: similar trend but weaker x_L dependence

W dependence:

$\sigma \sim W^{\alpha}$, $\alpha(\sigma_{\gamma p}) \neq \alpha(\sigma_{\gamma^* p})$

$W_{\pi}^2 = (1-x_L) W_p^2 \rightarrow (1-x_L)^{-0.13}$

absorption rate rescaled

Models in agreement with data

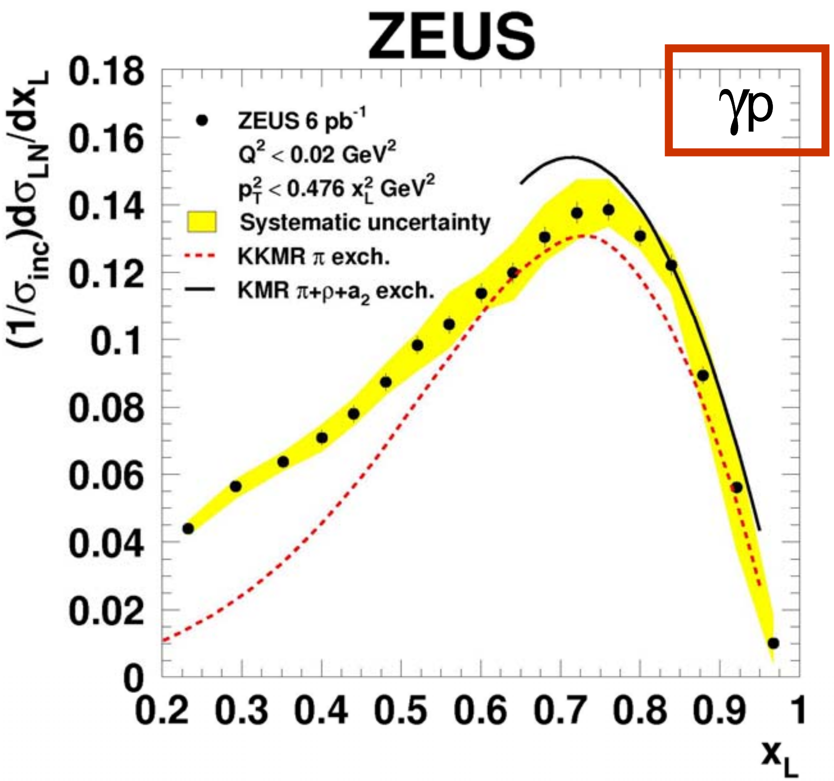
• LN yield in PHP < yield in DIS

→ factorization violation

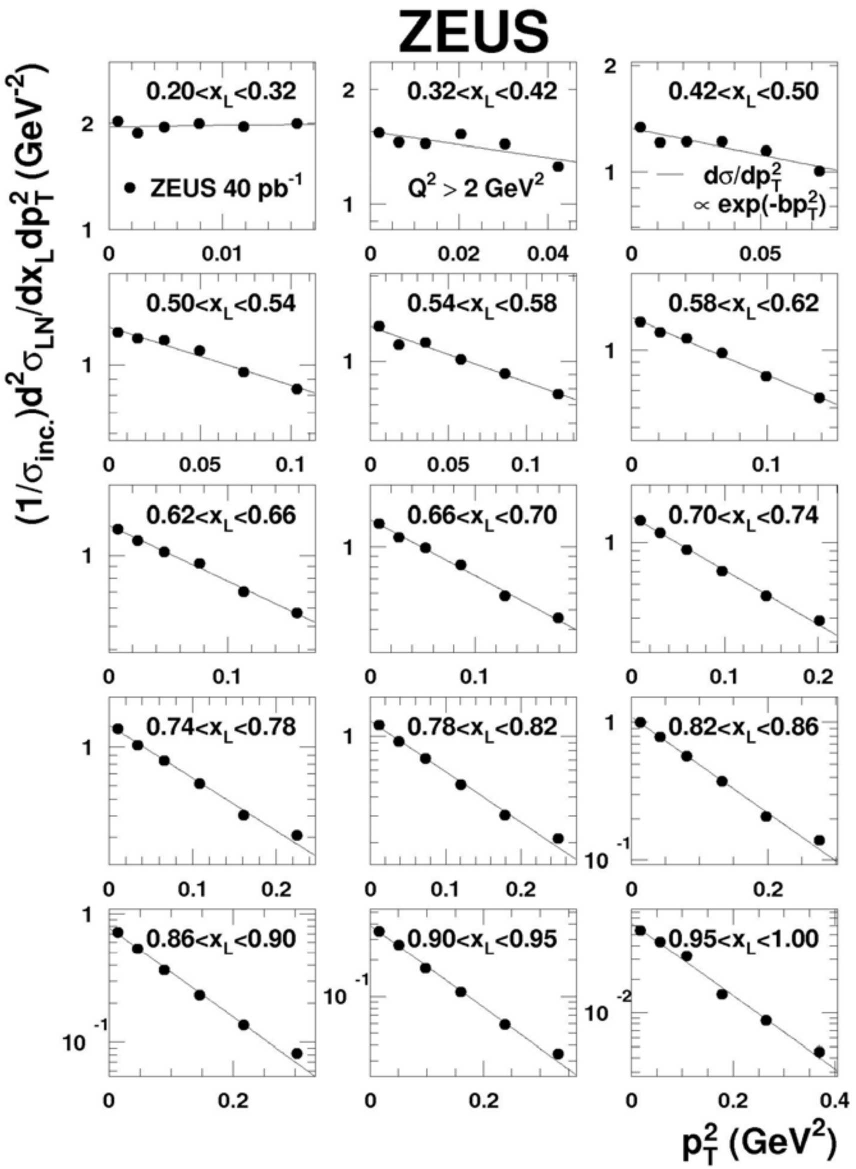
LN: KKMR absorption model

Kaidalov, Khoze, Martin, Ryskin:

- Pure π exchange (not shown) too high
- Absorption and migration effects reduce the LN yield and fit the data better
- Additional ρ and a_2 exchanges enhance the LN yield



LN: DIS cross section vs p_T^2 in x_L bins

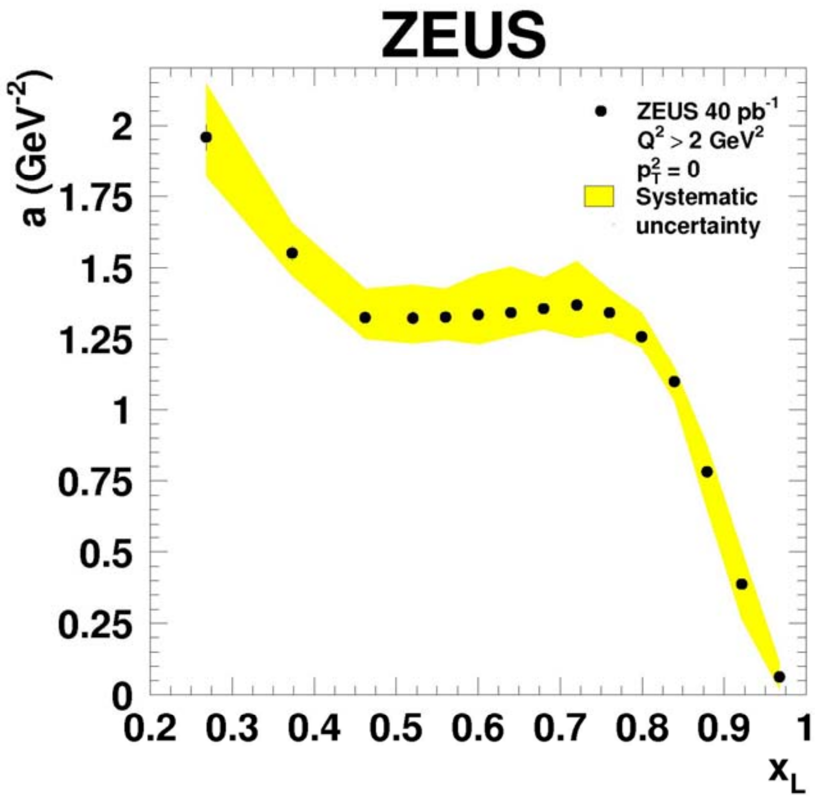


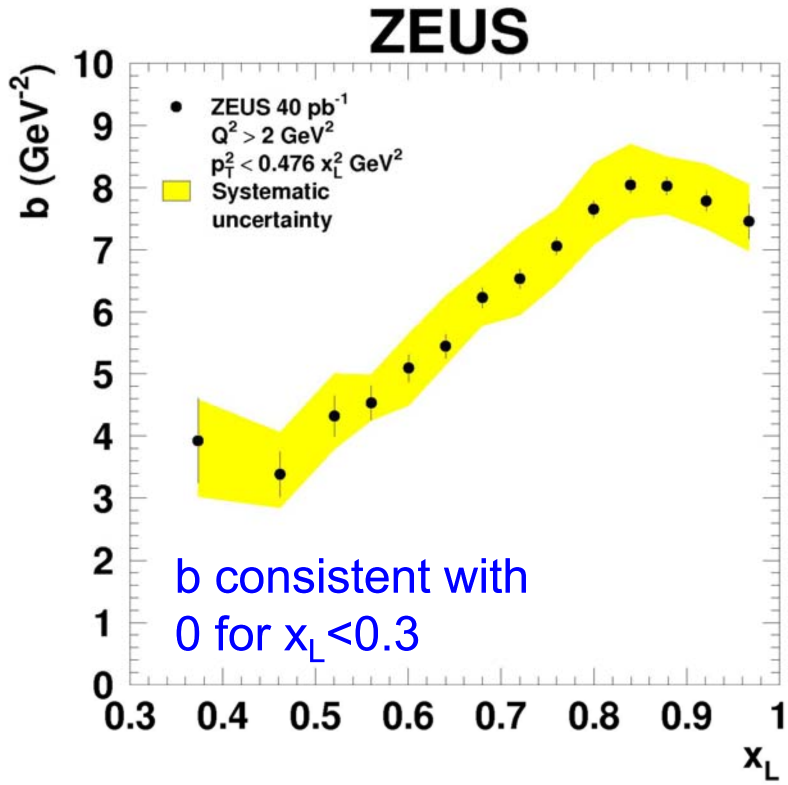
- p_T^2 distributions well described by an exponential

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

- Intercept $a(x_L)$ and slopes $b(x_L)$ fully characterize the x_L-p_T^2 spectra

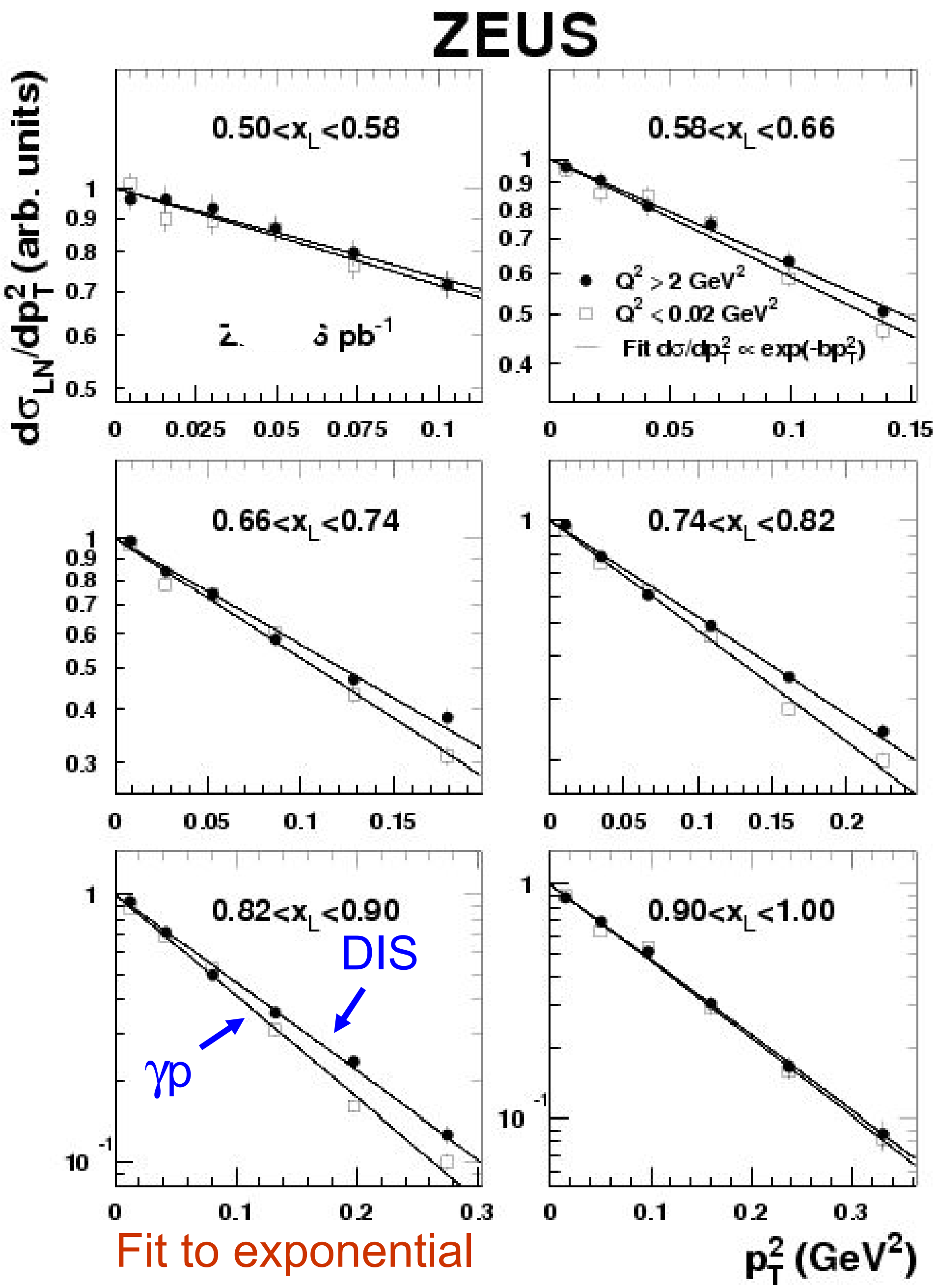
LN: intercepts and slopes in DIS



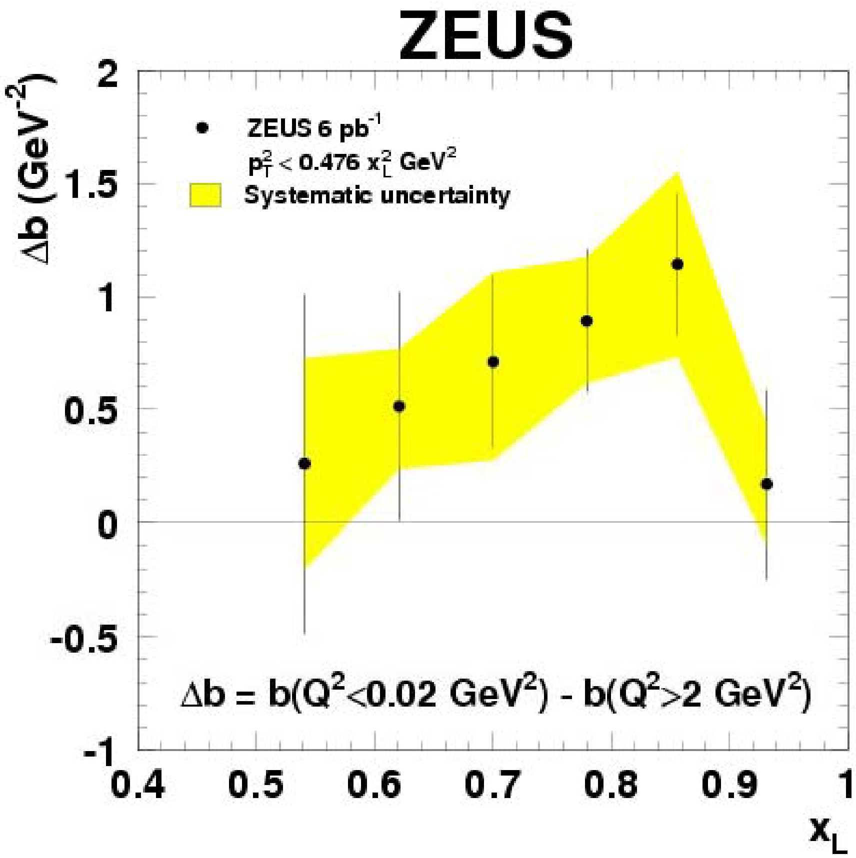


$$\frac{1}{\sigma_{inc}} \frac{d^2\sigma_{LN}}{dx_L dp_T^2} = a(x_L) \cdot e^{-b(x_L) p_T^2}$$

LN b-slopes: DIS & photoproduction comparison

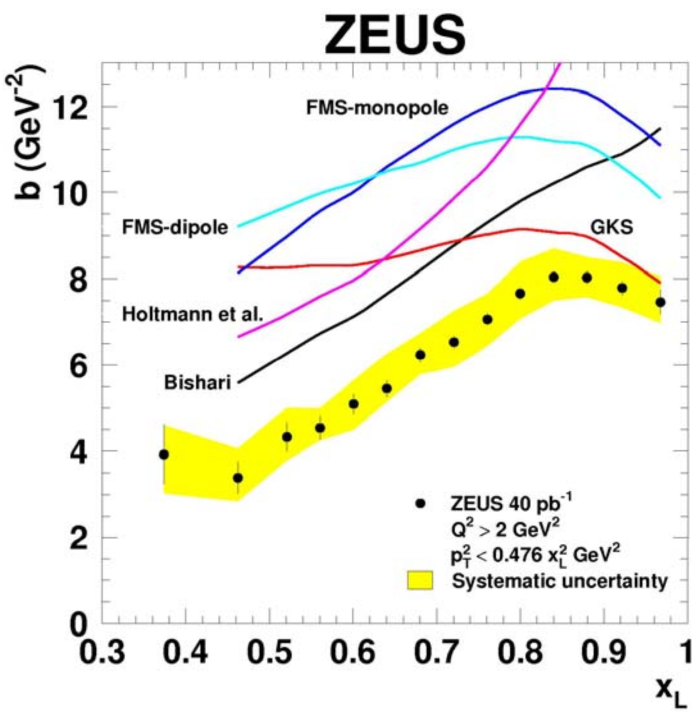


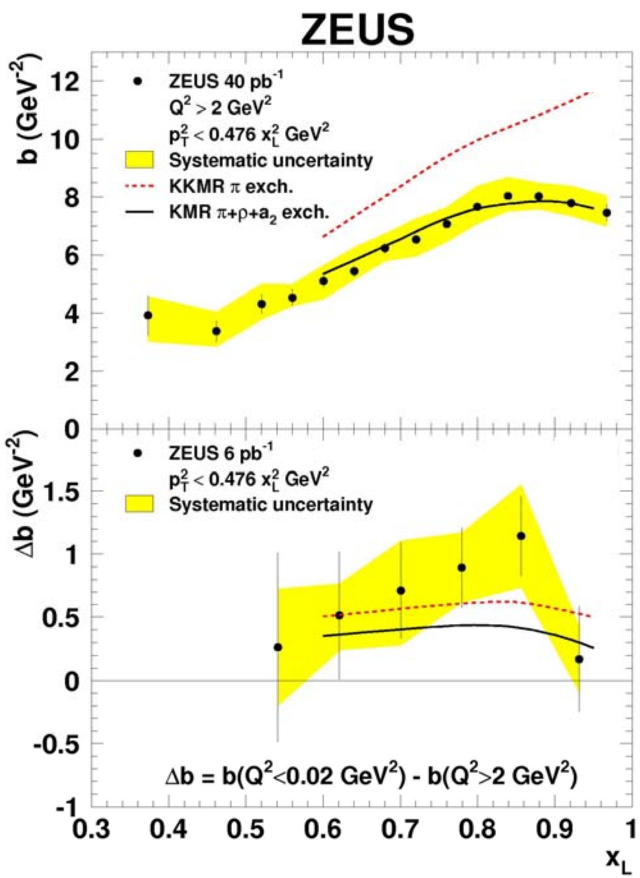
Fit to exponential



slopes different in γp and DIS
in general agreement with
expectation from absorption models

LN b-slopes: comparison to models





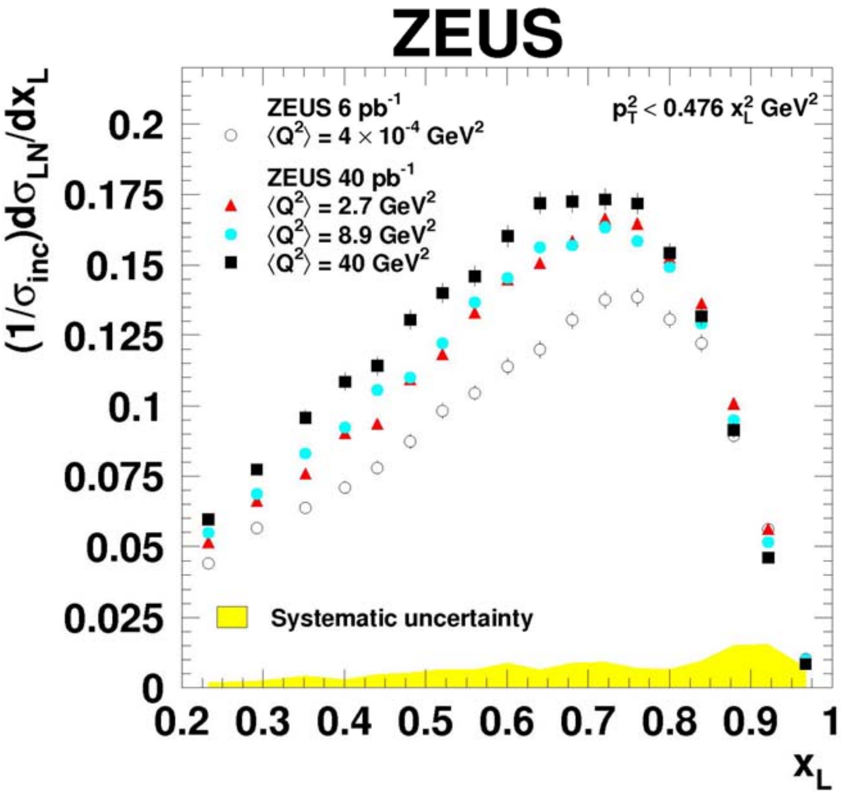
OPE models:

- Dominant at $0.6<x_L<0.9$
- (non-) Reggeized flux, different form factors with different parameters
- none of the models seem to decribe the data well

KKMR model:

good description of the data considering absorption effects and ρ, a_2 exchange contributions

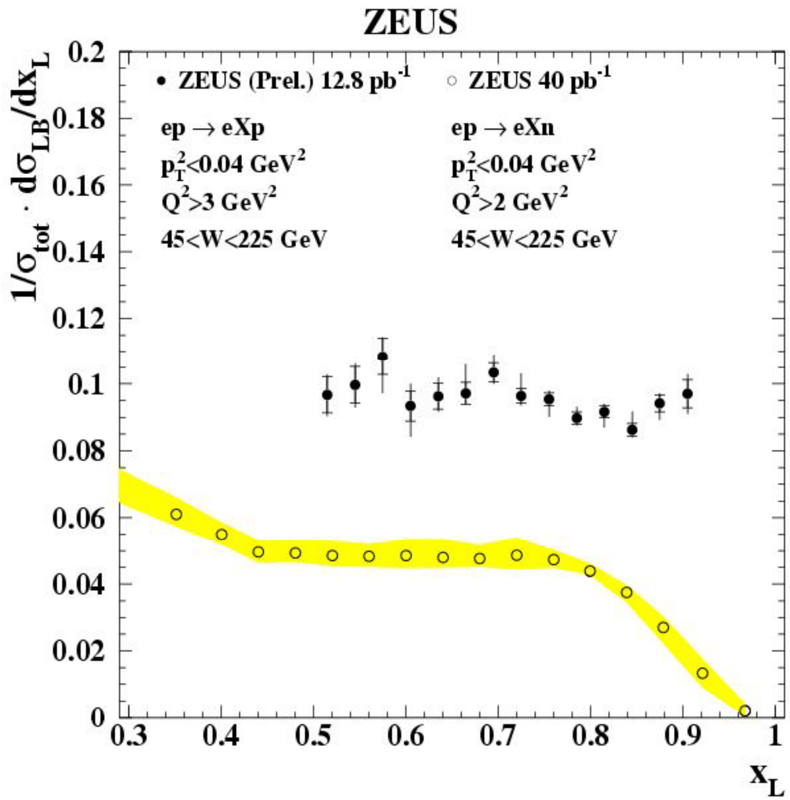
LN spectrum: Q^2 dependence

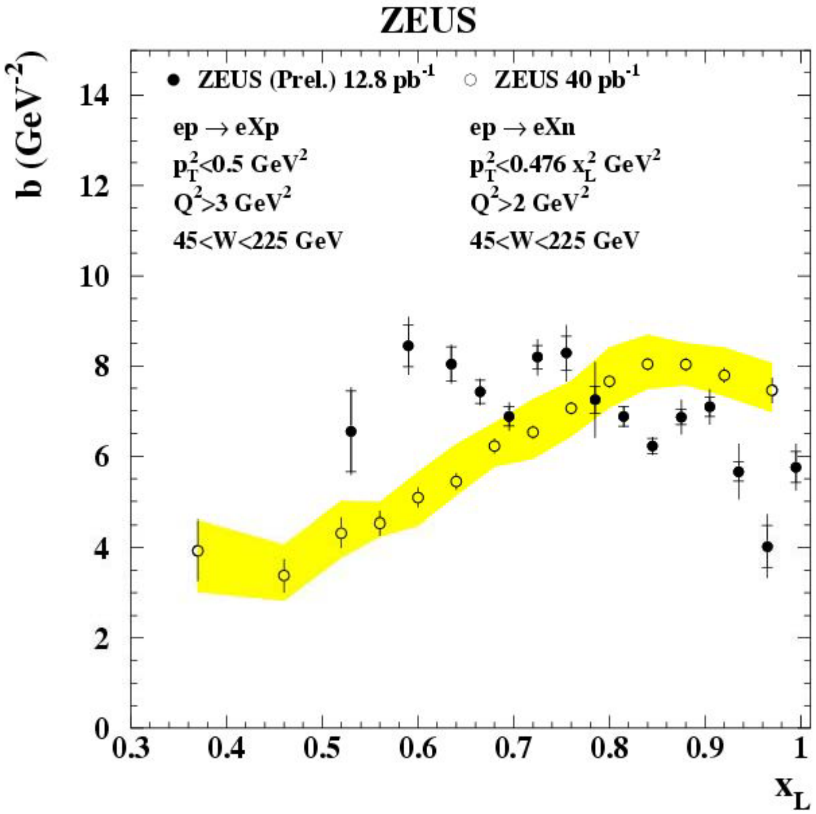


3 Q^2 bins + γp

- LN yield increases monotonically with Q^2
- consistent with absorption (larger Q^2 → smaller γ)

Comparisons LP - LN data





Very similar behaviour x_L<0.85
LP cross section almost twice LN

Slopes comparable 0.7<x_L<0.8
where π exchange dominates

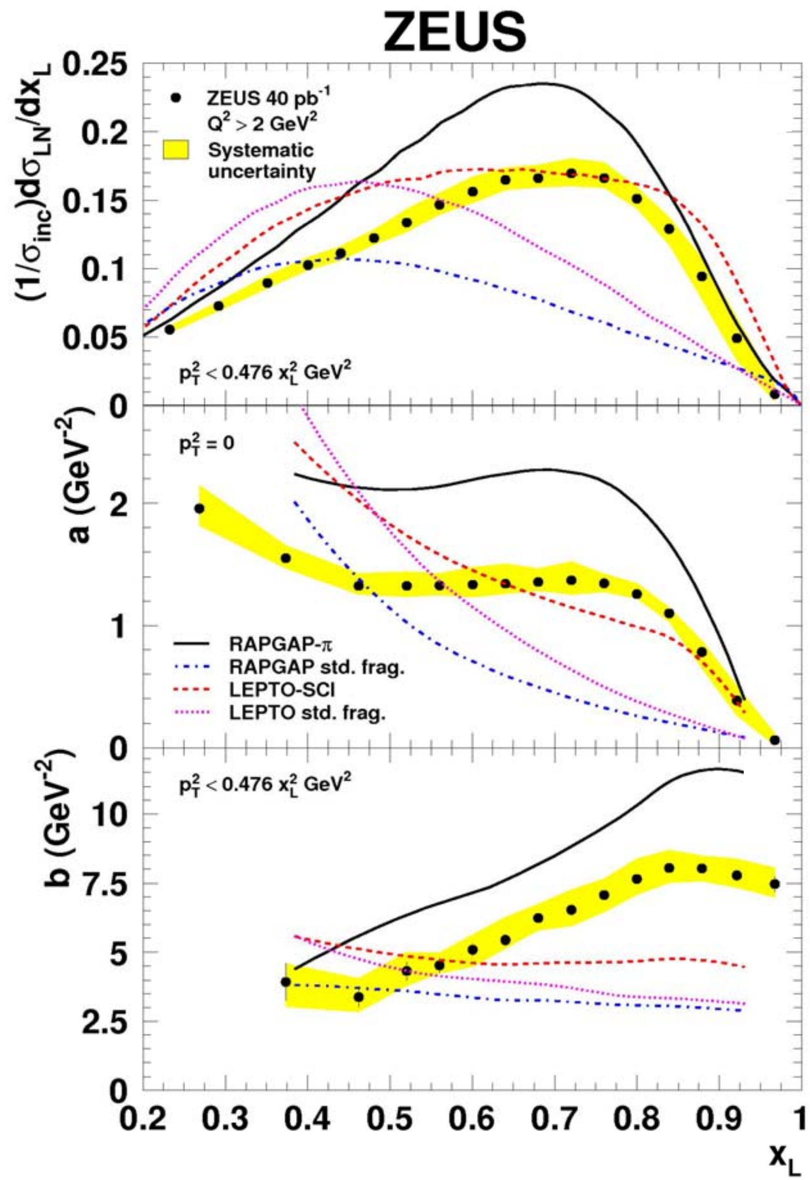
In particle exchange model:
expected from isospin-1: LP=1/2LN
Other exchanges needed (isoscalars)

LN production compared to MC predictions

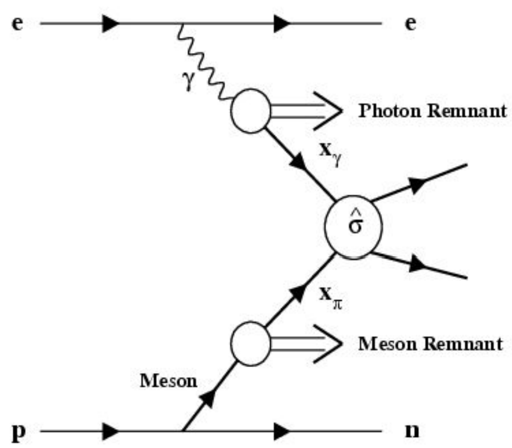
- Compare LN DIS distribution to MC models:
  - RAPGAP standard fragmentation
  - RAPGAP OPE
  - LEPTO standard fragmentation
  - LEPTO soft color interaction
- Both standard fragmentation fail
  - Too few n, too few x_L
  - b-slopes too low

- RAPGAP-OPE: close to data in shape but not in magnitude
- LEPTO-SCI: reasonable description of x_L spectrum and intercepts, bad slopes

Other models also fail (ARIADNE, CASCADE,PYTHIA,PHOJET)



Dijet γp with a LN

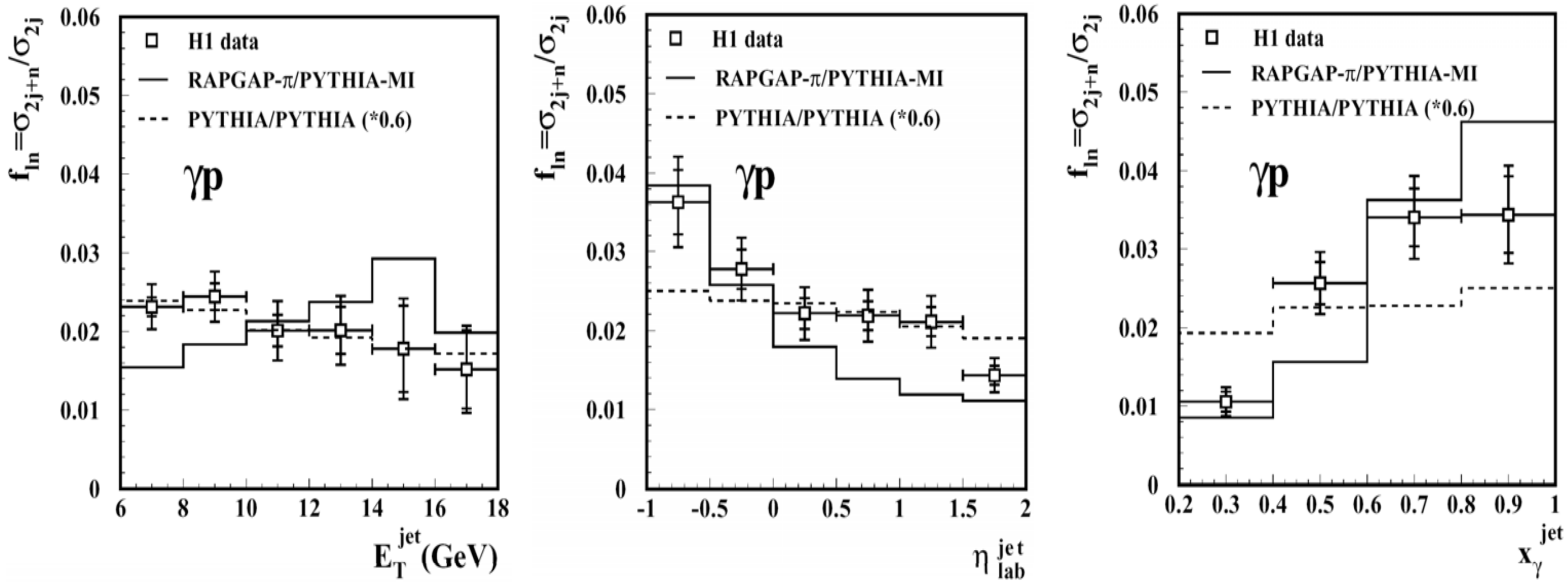


Presence of jets hard-scale

Naively, rescattering effects expected in resolved photoproduction:

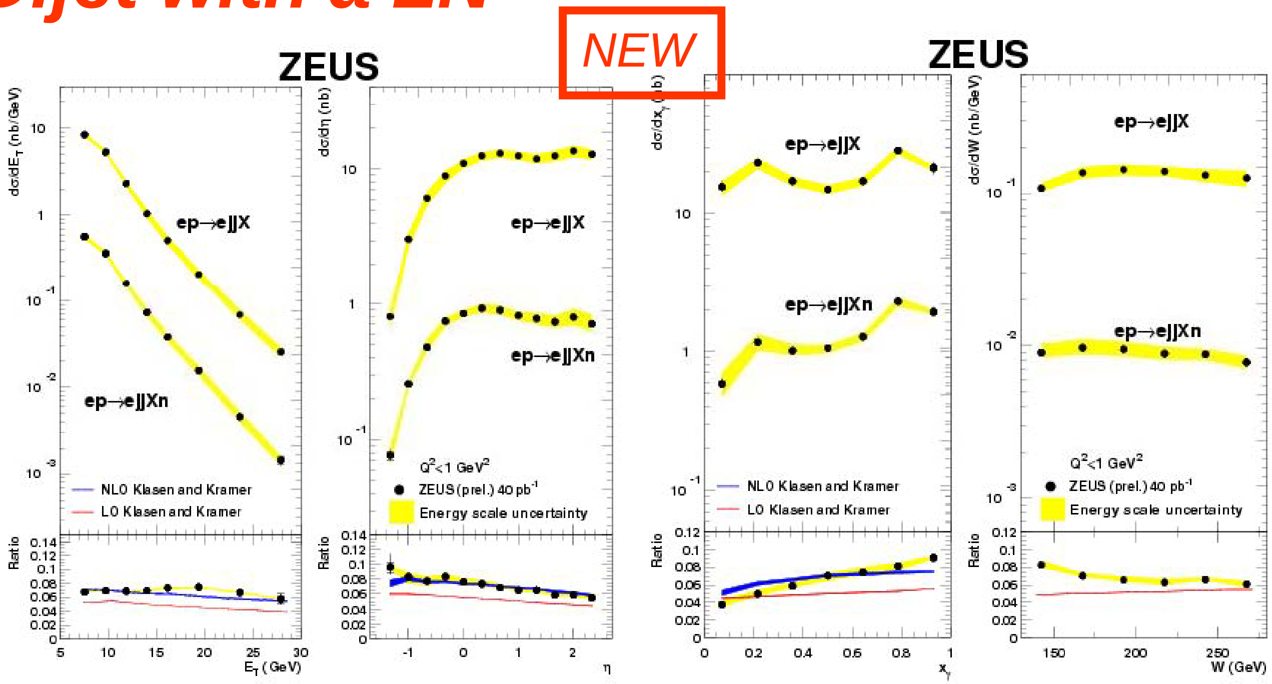
$$x_\gamma^{obs} = \frac{\sum_{jet1,2} E_T e^{-\eta}}{(E-p_z)_{had}}$$

→ low x_γ, photon acts like a hadron



H1 data: ratios (jj+LN)/jj reasonably well described by photoproduction MC

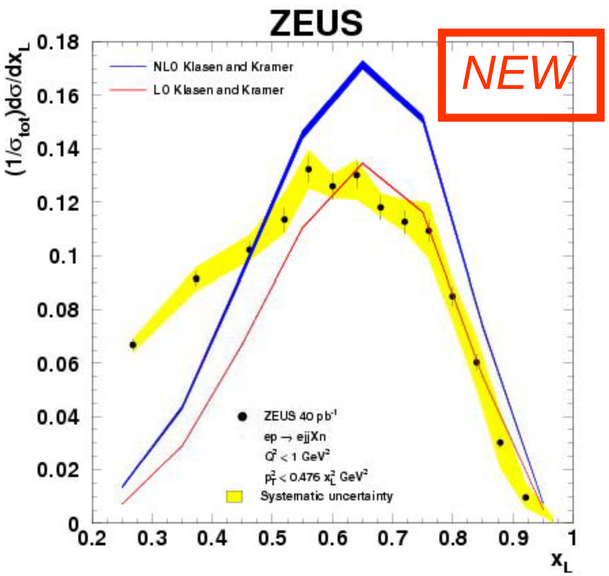
Dijet with a LN



Ratios (LN+jj)/jj

Model by Klasen and Kramer based on OPE

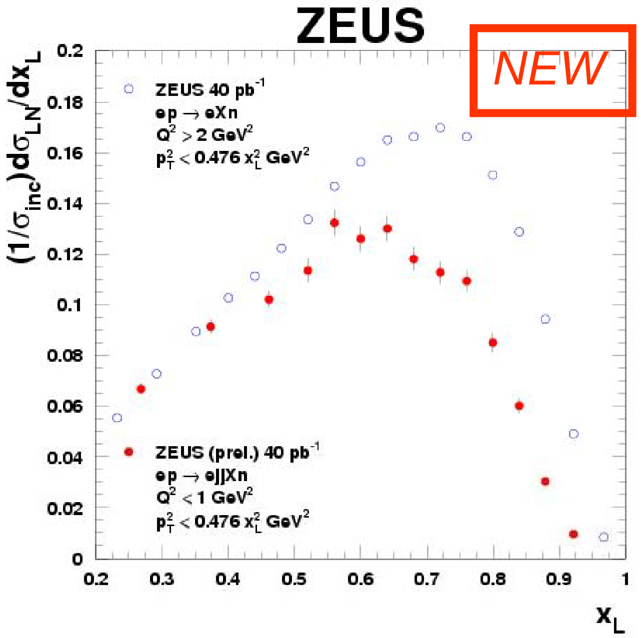
Ratios well described by NLO predictions



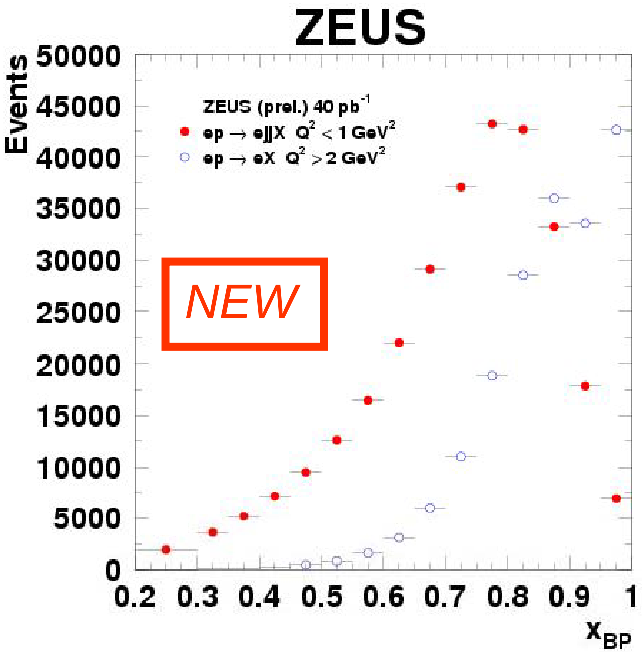
x_L spectrum:

Reasonable shape, NLO too high

Dijet production with a LN



ep→ejjnX vs ep→enX
Suppression observed in dijet+LN:
Kinematic or absorption/rescattering?

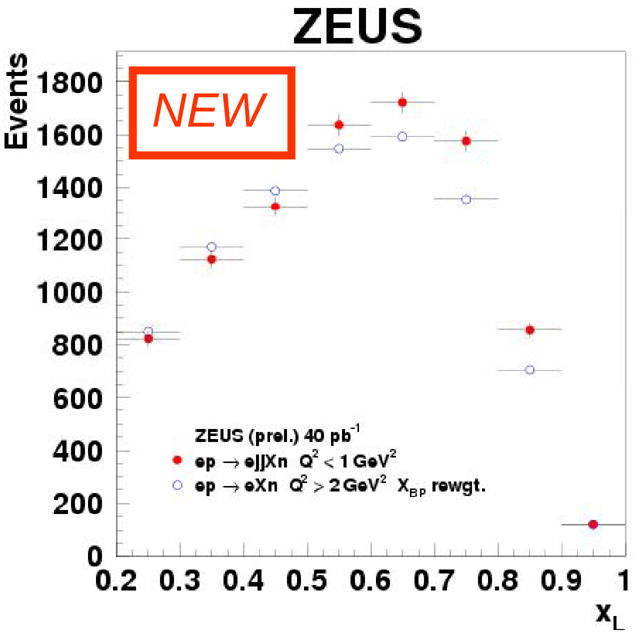


Look at $x_{BP}=1-(E+p_Z)/2E_p$

→Fraction of proton beam energy available for particle production in the forward beampipe

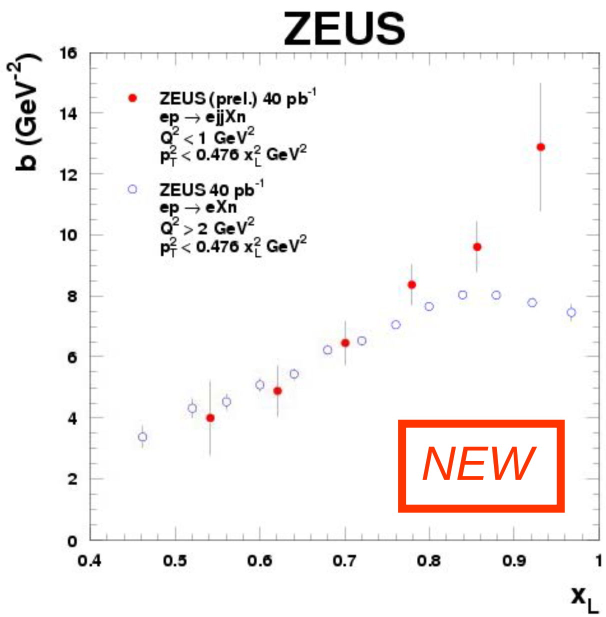
Kinematic constraint: $x_L<x_{BP}$
The lower x_{BP} values in dijet-γp constrain the neutrons to lower x_L than DIS

Dijet with a LN



After reweighting x_{BP}, the x_L distributions of the two processes ep→ejjnX and ep→enX agree:
Mainly kinematic effect, no clear evidences of absorption

b-slopes
No significant difference within errors



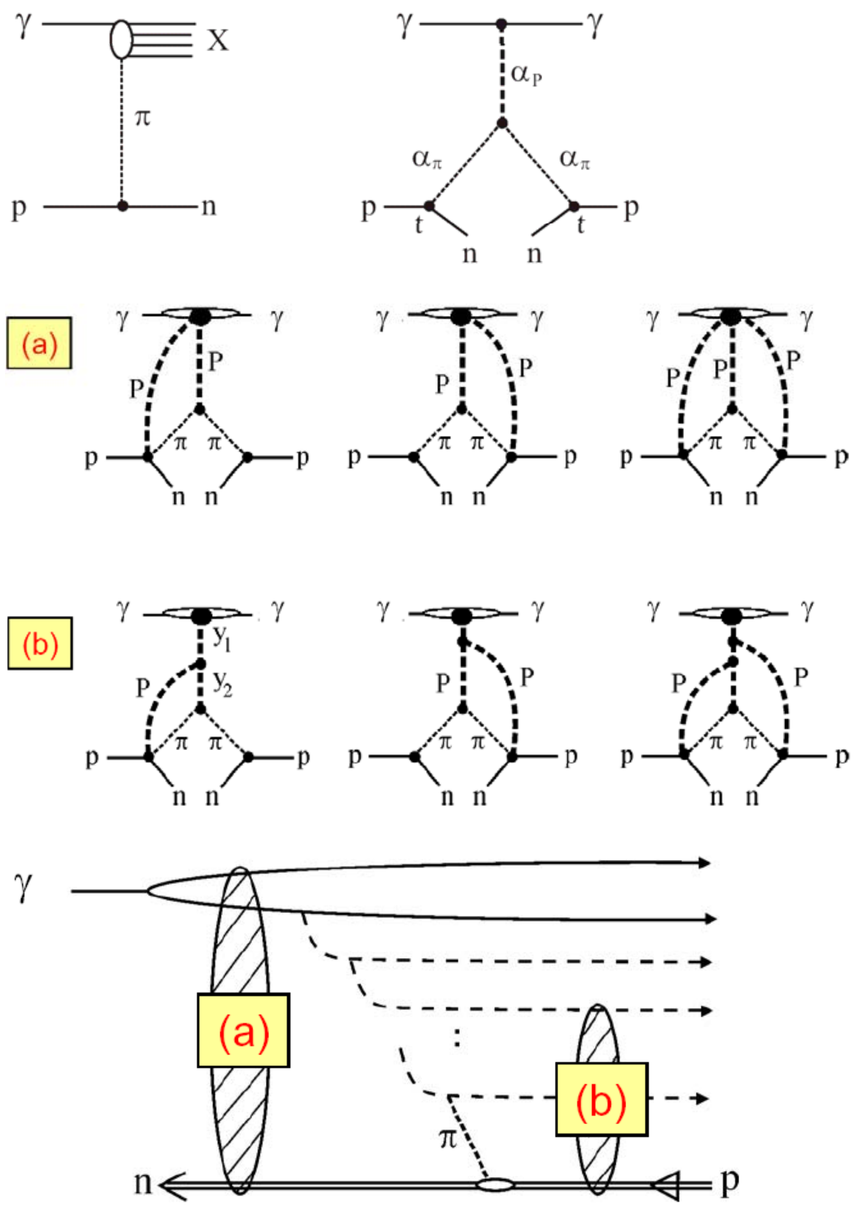
Summary

- LP spectra in DIS; well described by Reggeon-exchange model
- LP production as a function of DIS variables: no dependence observed
- LN production measured in DIS and γp
- LN characterized by rescattering and absorption effects: well reproduced by some models
- MC generators in general fail to reproduce the measured quantities → need to tune the generators
- Dijet-γp with LN: suppression most probably due to kinematic effects.

HERA provided high precision measurements of leading baryon production.

Now it's time to work together with theory people and apply our knowledge to the next future physics

Rescattering model and absorption 1



Model 1: One pion exchange in the framework of triple-Regge formalism

Nikolaev,Speth & Zakharov

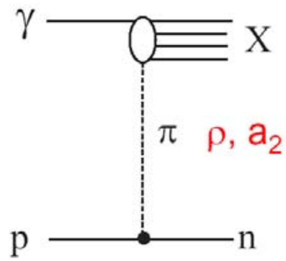
Re-scattering processes via additional pomeron exchanges (Optical Theorem)

(hep-ph/9708290)

(Kaidalov,) Khoze, Martin, Ryskin (KKMR)

Enhanced absorptive corrections (→ exclusive Higgs @ LHC), calculation of migrations, include also ρ and a_2 exchange (different x_L & p_T dependences)

(hep-ph/0602215, hep-ph/0606213)



Rescattering model and absorption 2

Model 2: calculations from D'Alesio and Pirner in the framework of target fragmentation (EPJ A7(2000) 109)

- more absorption when photon size larger (small Q^2) → less neutrons detected in photoproduction
- more absorption when mean π-n system size ($\langle r_{n\pi} \rangle$) smaller at low x_L → less neutrons detected at low x_L
- more absorption → fewer neutrons detected with higher p_T^2 → larger b-slope expected in photoproduction