LEADING BARYON PRODUCTION at HERA

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On behalf of H1 and ZEUS Collaborations

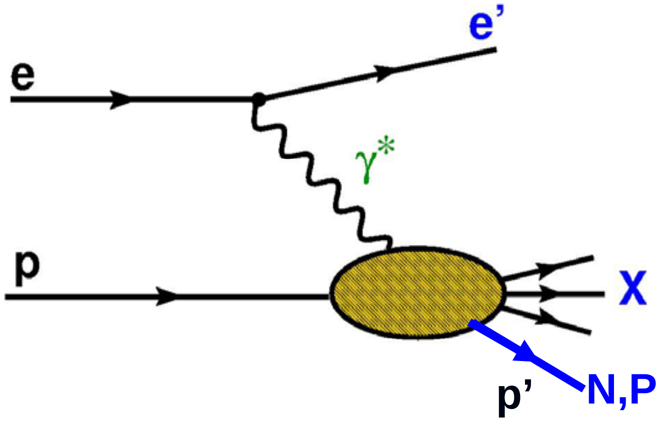
Motivations

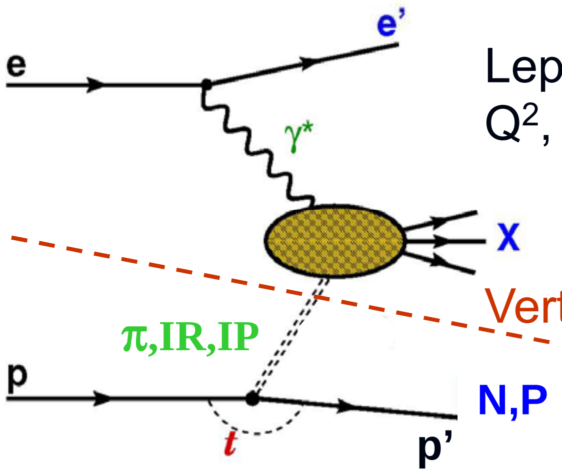
- Large fraction of events with a Leading Baryon (LB) in final state carrying high fraction of the proton beam momentum
- LB produced at small angle in forward direction: difficult detection
- Production mechanism still not clear
- Interest in LB study for next experiments @ LHC
  → absorptive corrections related to gap survival probability (diffractive Higgs, pile-up background...)

Results discussed in this talk:

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

Leading baryon production in ep collisions





Lepton variables
Q^2, W, x, y

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

Standard fragmentation

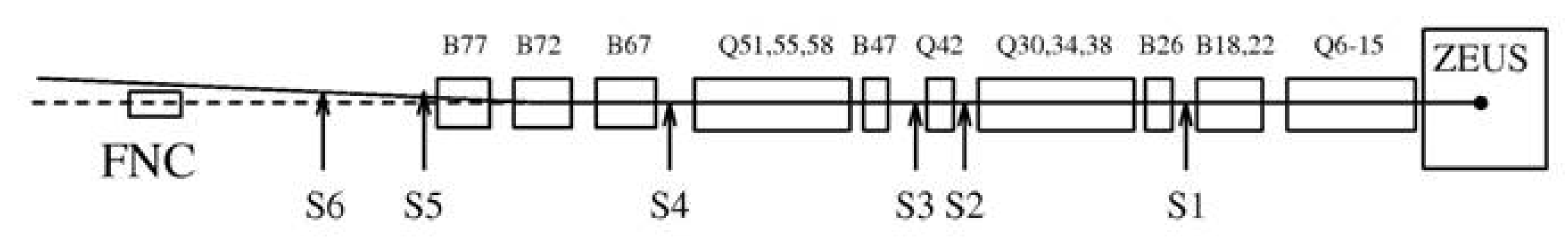
- LB from hadronization of p remnant
- Implemented in MC models (Cluster, Lund strings...)

Virtual particle exchange

- LP: neutral iso-scalar iso-vector (π,IR,IP)
- LN: charged iso-vector(π^+,ρ^+,...)
- LB also from p fragmentation in double dissociative diffraction

LB production affected by absorption and rescattering effects: evidences of vertex factorization violation

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
- $\sigma_{x_L} < 1\%$ $\sigma_{p_T^2}$ ~ few MeV^2 (better than p-beam spread ~ 50 - 100 MeV)

ZEUS Forward Neutron Calorimeter (FNC)

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

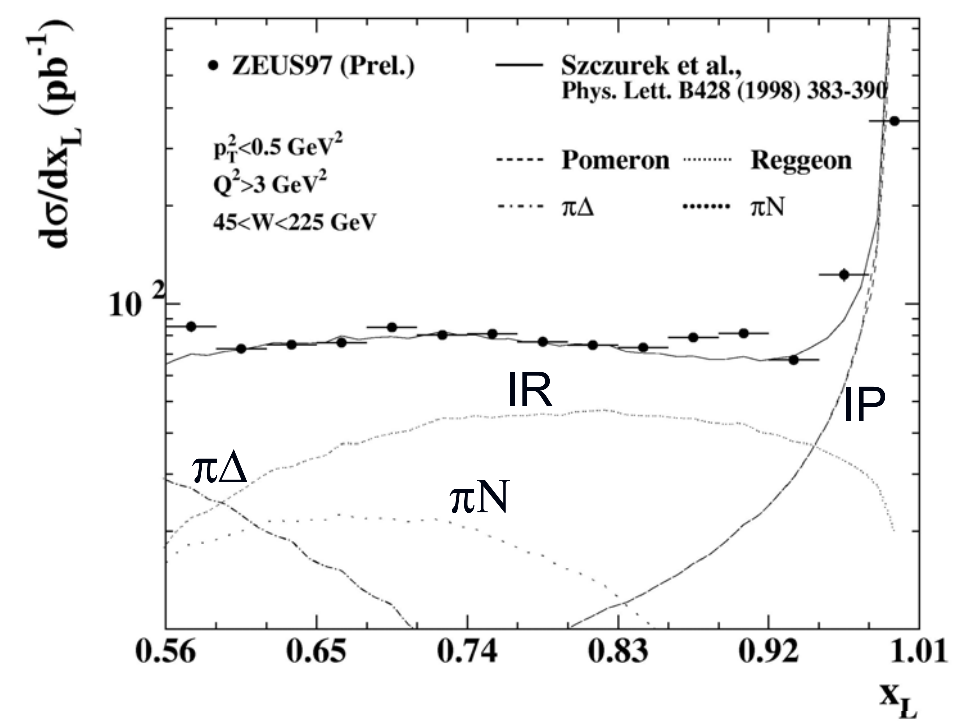
ZEUS Forward Neutron Tracker (FNT)

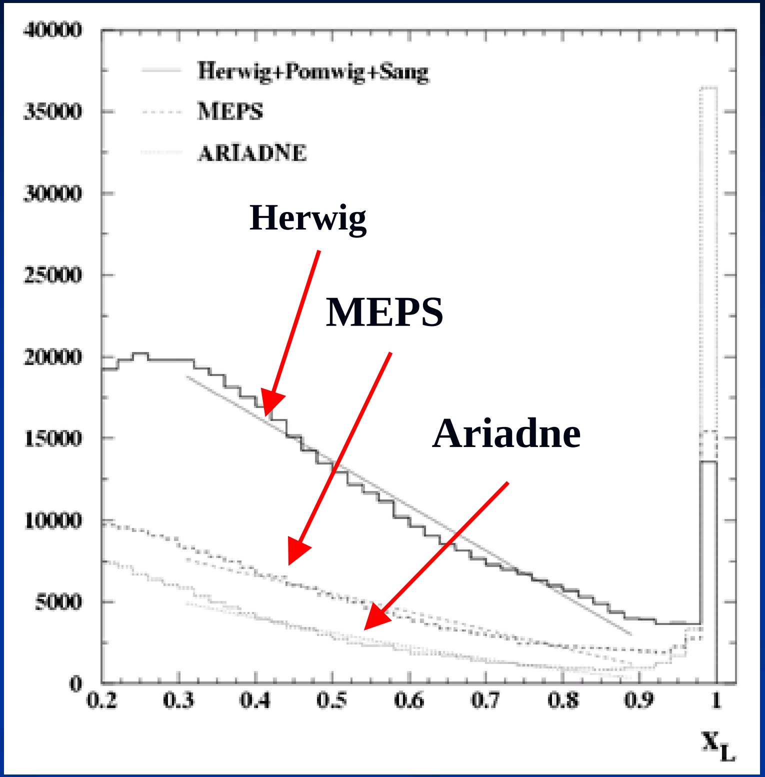
- Scint. hodoscope @ 1λint, $\sigma_{x,y}=0.23$cm, $\sigma_\theta=22\mu$rad

H1 Forward Neutron Calorimeter (FNC)

- Lead-scintillator calorimeter @ 107m from I.P. + veto hodoscopes
- $\sigma(E)/E\approx 20\%$, neutron detection eff. $93\pm5\%$

Leading Proton: cross section vs x_L





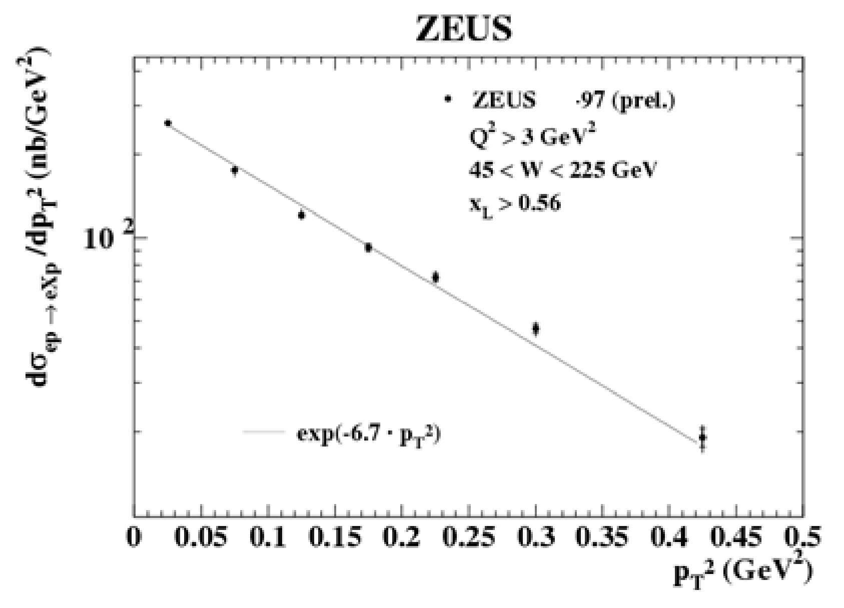
- Flat below diff. peak →$(1-x_L)^\alpha$, α~0
- Good description by reggeon-exchange model

Montecarlo samples (standard fragmentation):

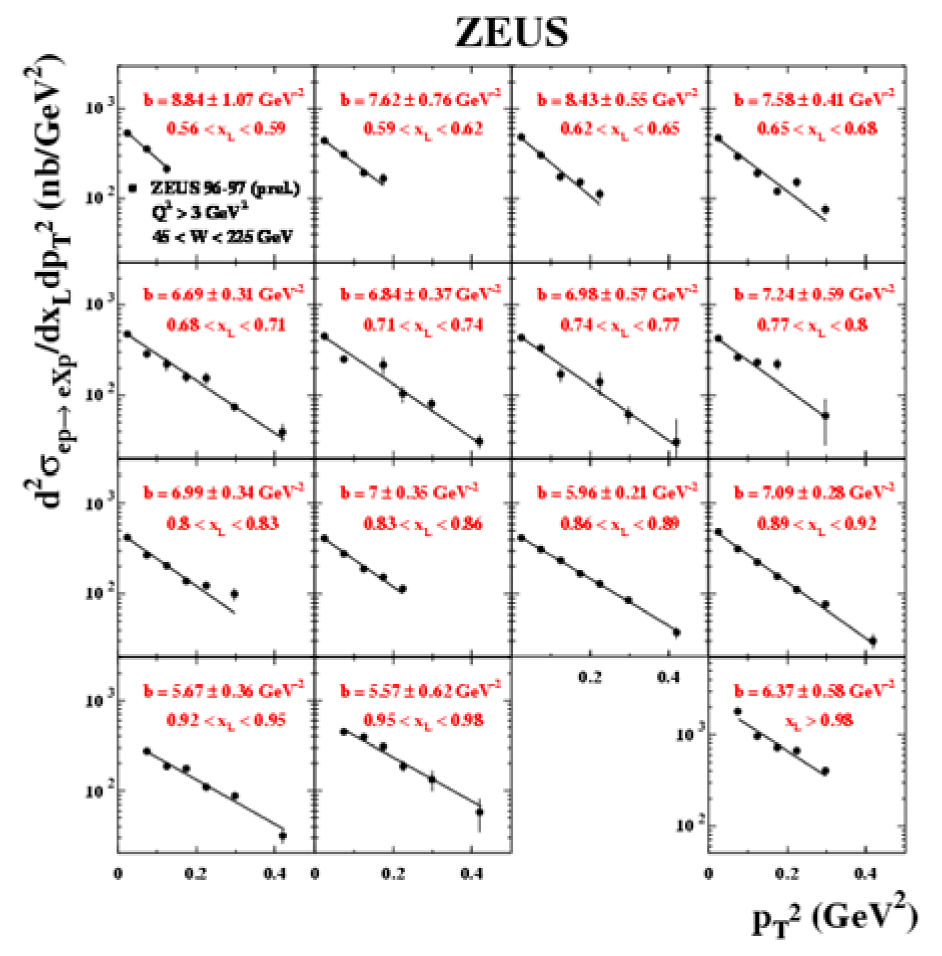
- Herwig (cluster model)
- MEPS (parton shower,SCI)
- Ariadne (CDM)

Bad description of x_L spectrum

LP: cross section vs p_T^2



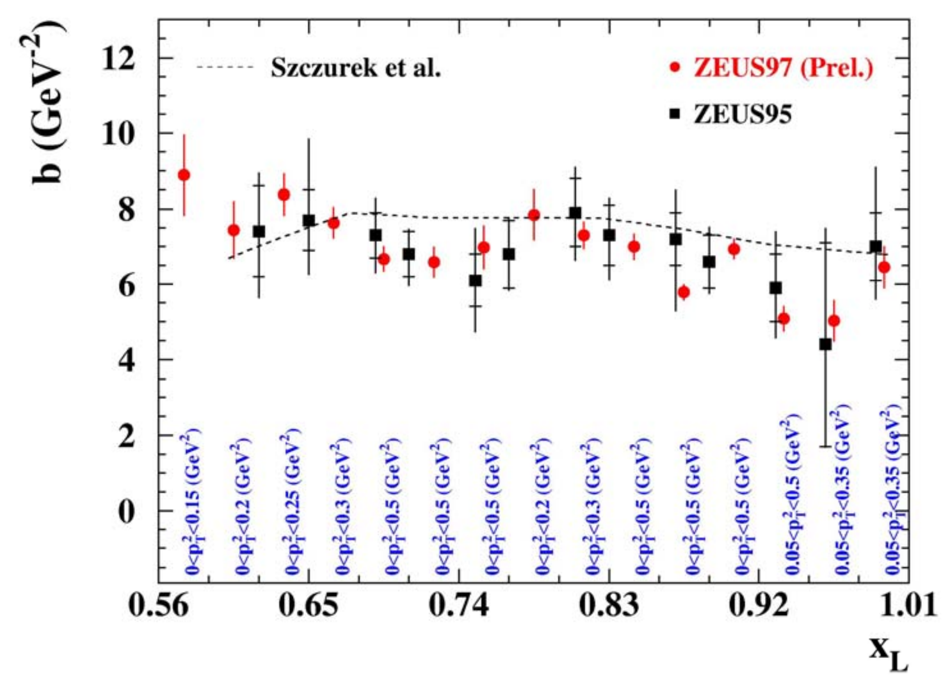
Data distribution ~ exponential

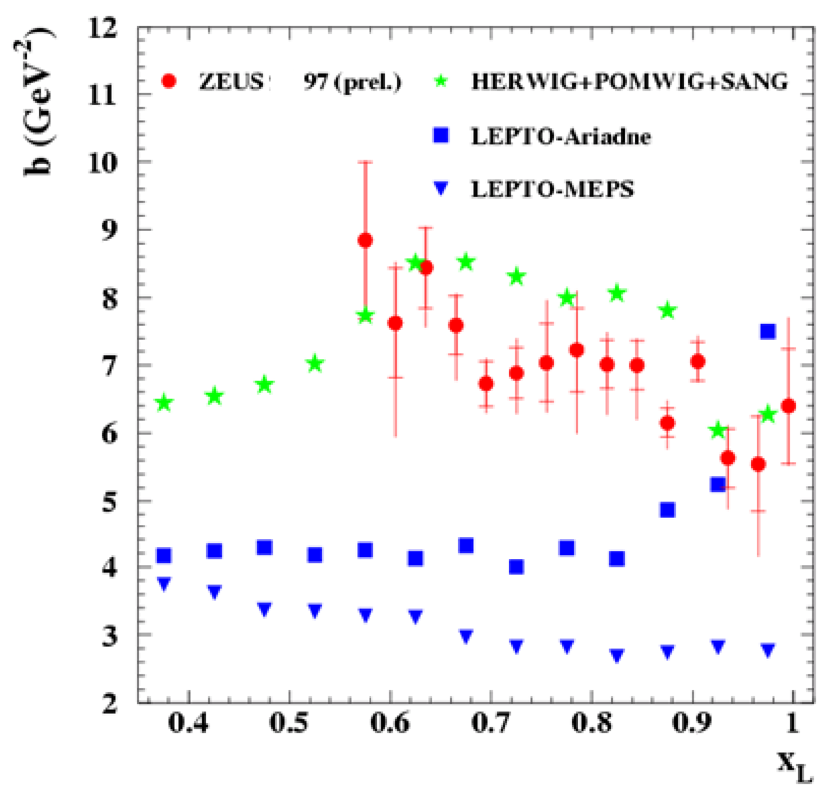


Fit to exponential in each x_L bin:

$$\frac{d^2\sigma}{dx_L dp_T^2} \propto e^{-b(x_L)\cdot p_T^2}$$

LP: b-slopes vs x_L

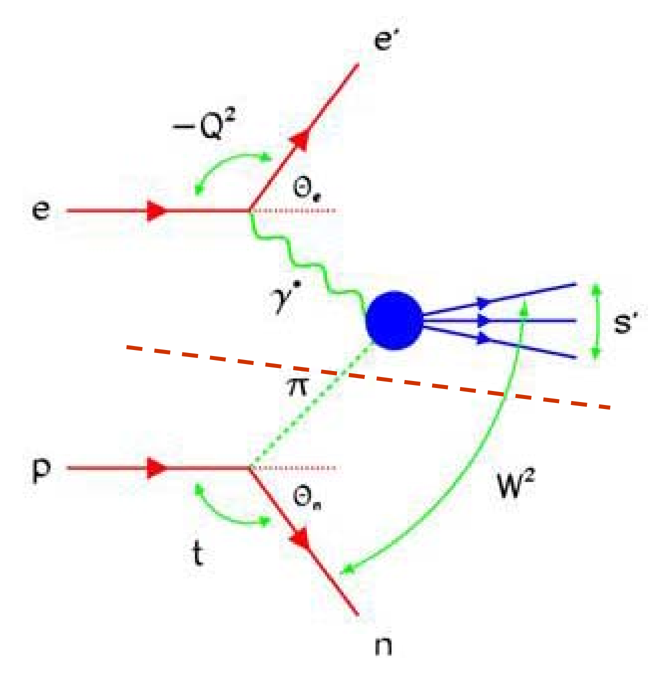




- No strong dependence observed on x_L
- observed fluctuations due to fit range
- Good agreement with prediction from Reggeon-exchange model

- Different slopes in LEPTO
- Better HERWIG
- b-slope not well simulated by fragmentation models

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 $F^2(x_L,t)$ 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

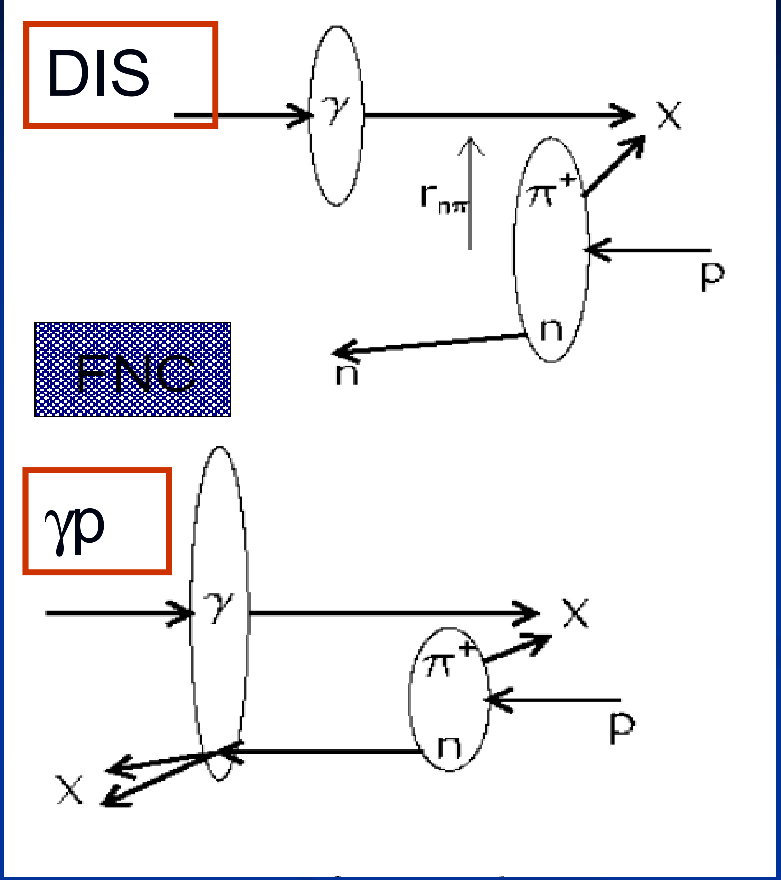
(hep-ph/9708290)

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

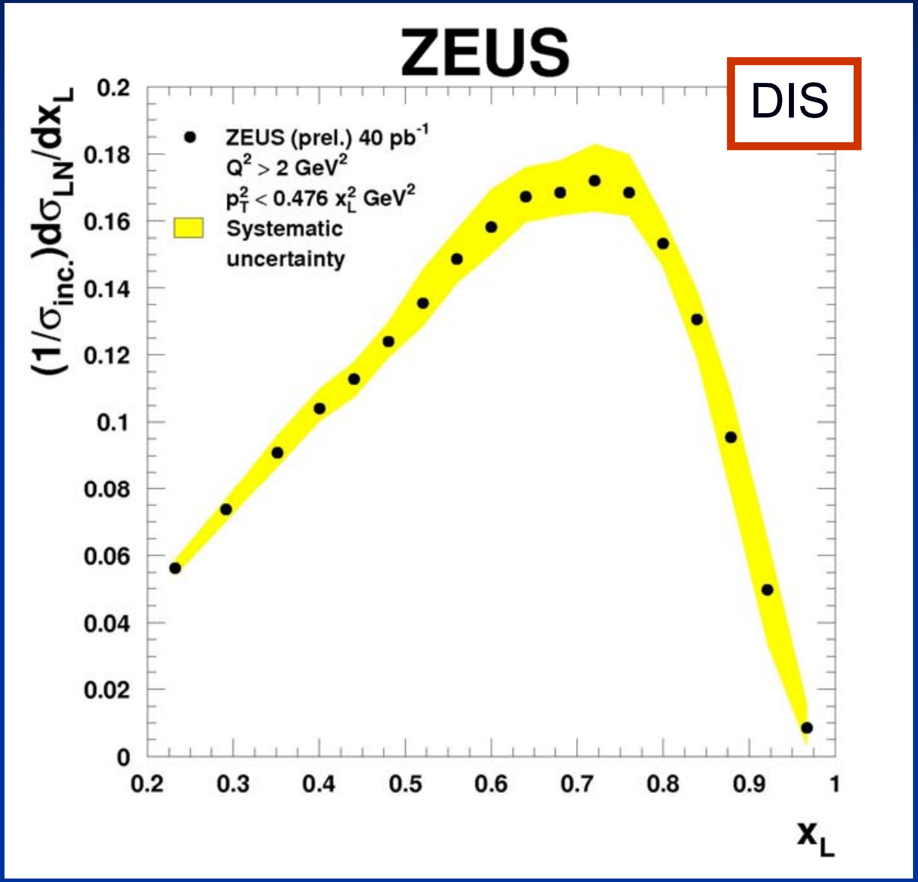
(Kaidalov,) Khoze, Martin, Ryskin (KKMR)

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

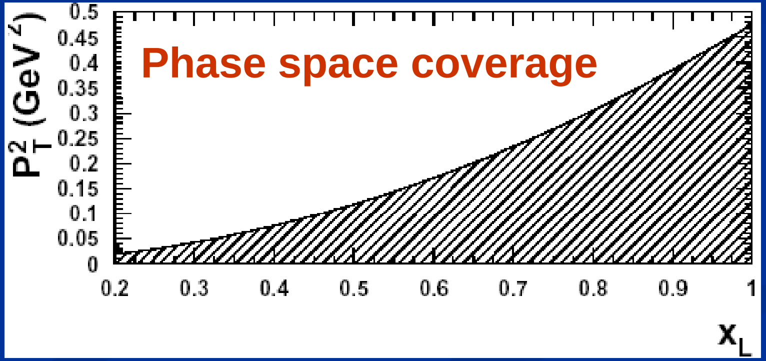
Enhanced absorptive corrections (→ exclusive Higgs @ LHC), calculation of migrations, include also ρ and a_2 exchange (different x_L & p_T dependences)



LN: longitudinal momentum spectrum

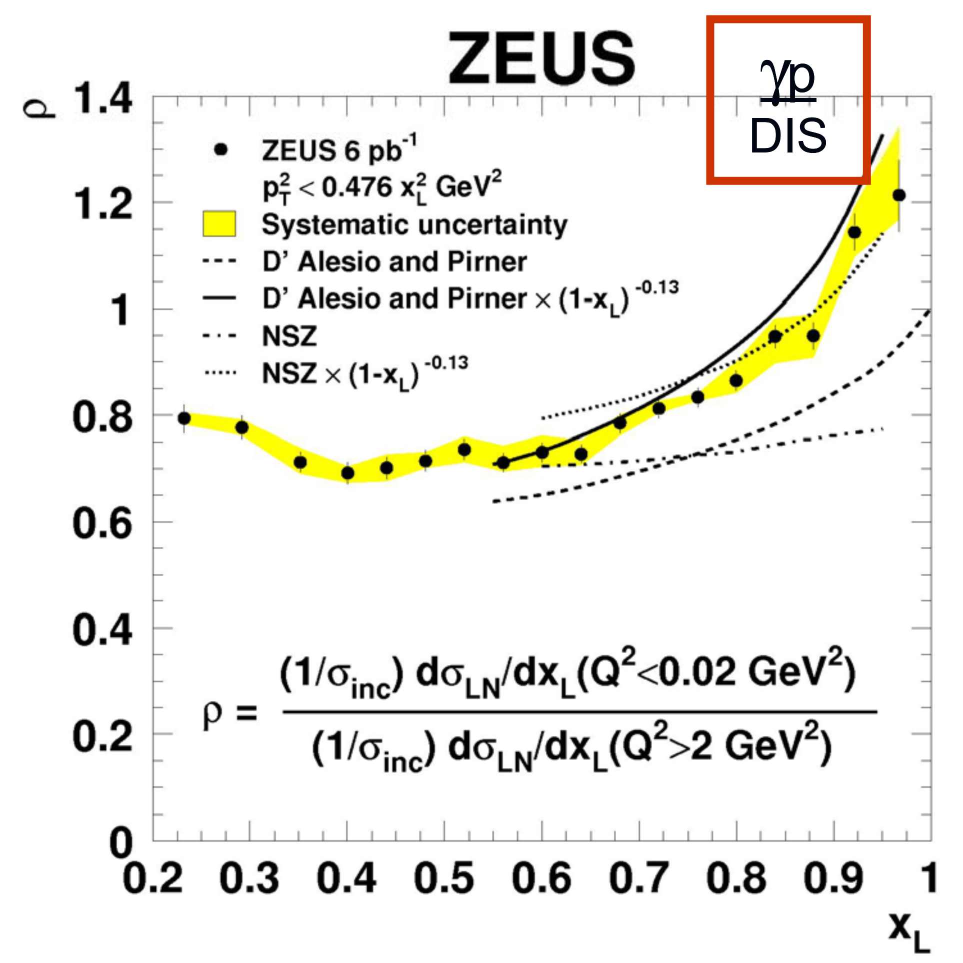


- LN yield increases with x_L due to increase in phase space: $p_T^2 < 0.476\ x_L^2$



- 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

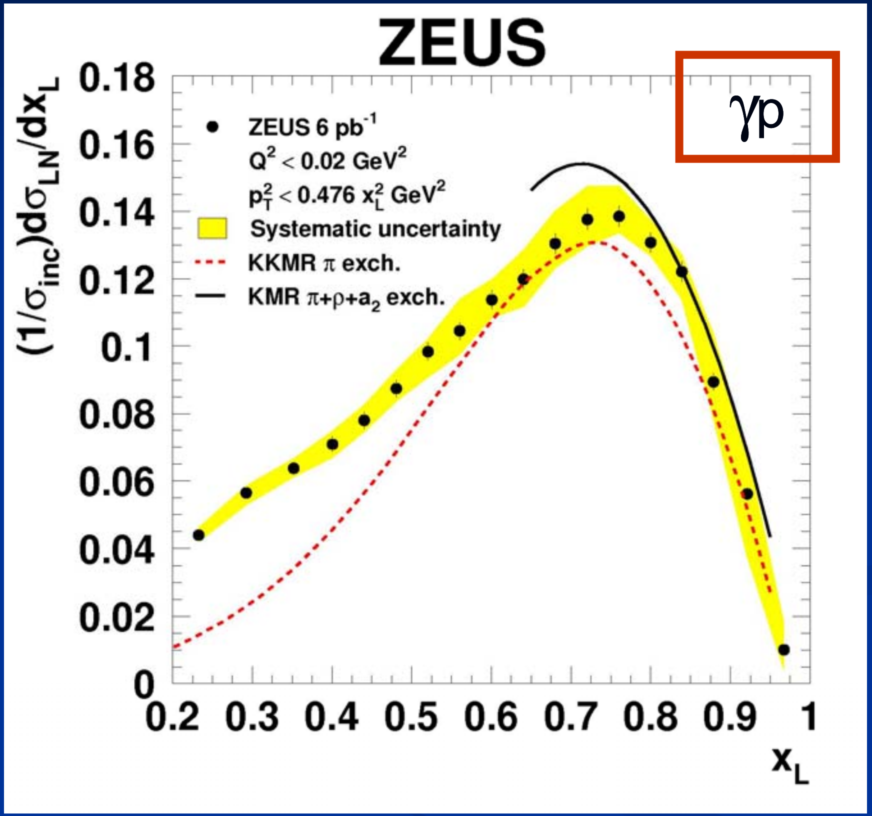
→ factorization violation

LN: KKMR absorption model

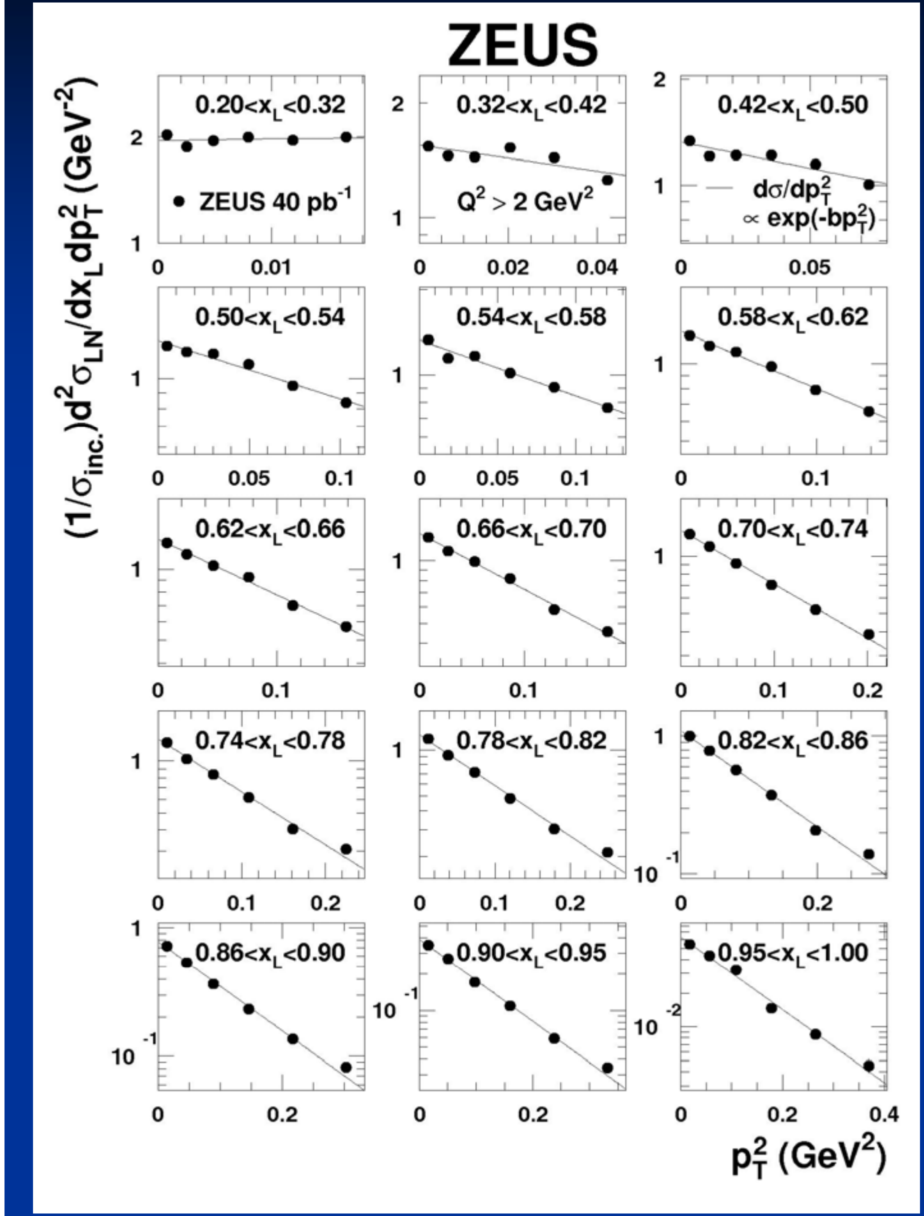
Kaidalov, Khoze, Martin, Ryskin:

including migrations and other iso-vector exchanges

- Pure π exchange (not shown) too high
- Absorption and migrations effects reduces 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

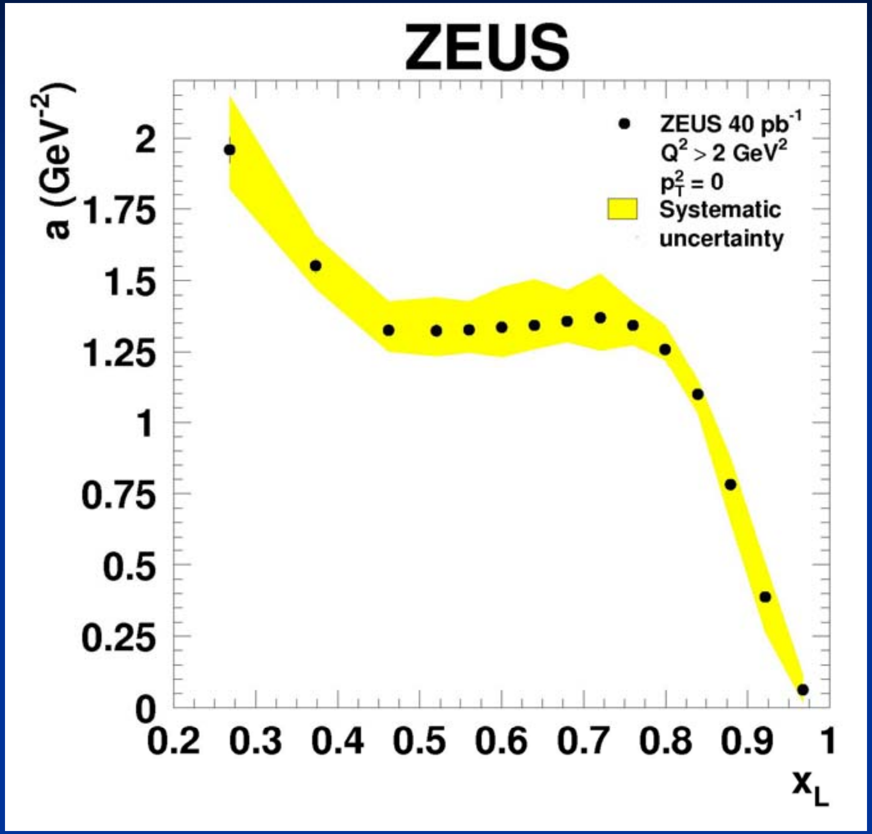


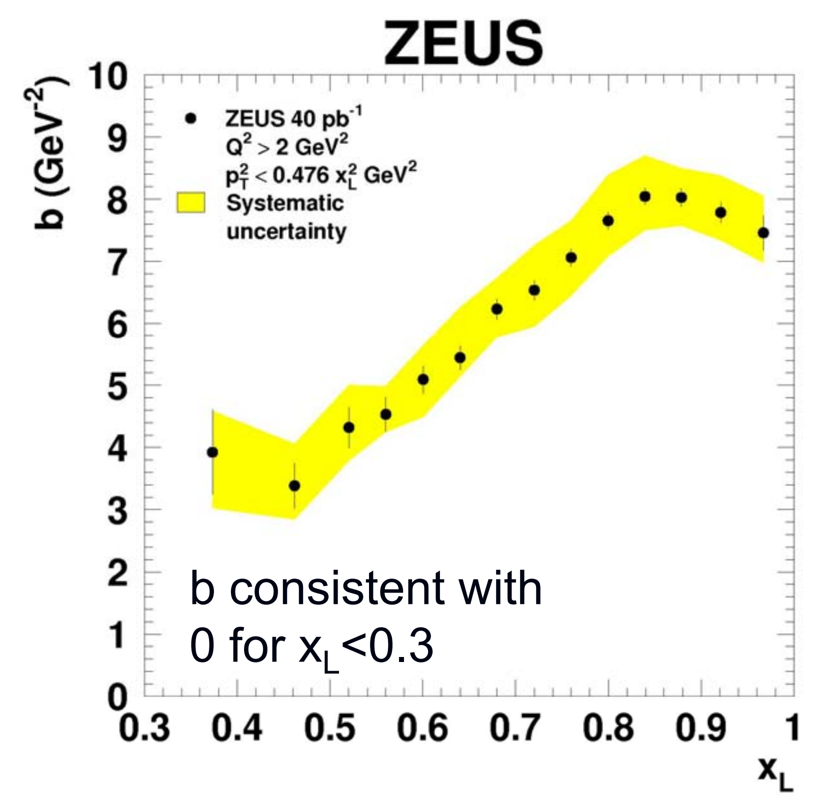
- p_T^2 distributions well described by an exponential

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

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

LN: intercepts and slopes in DIS

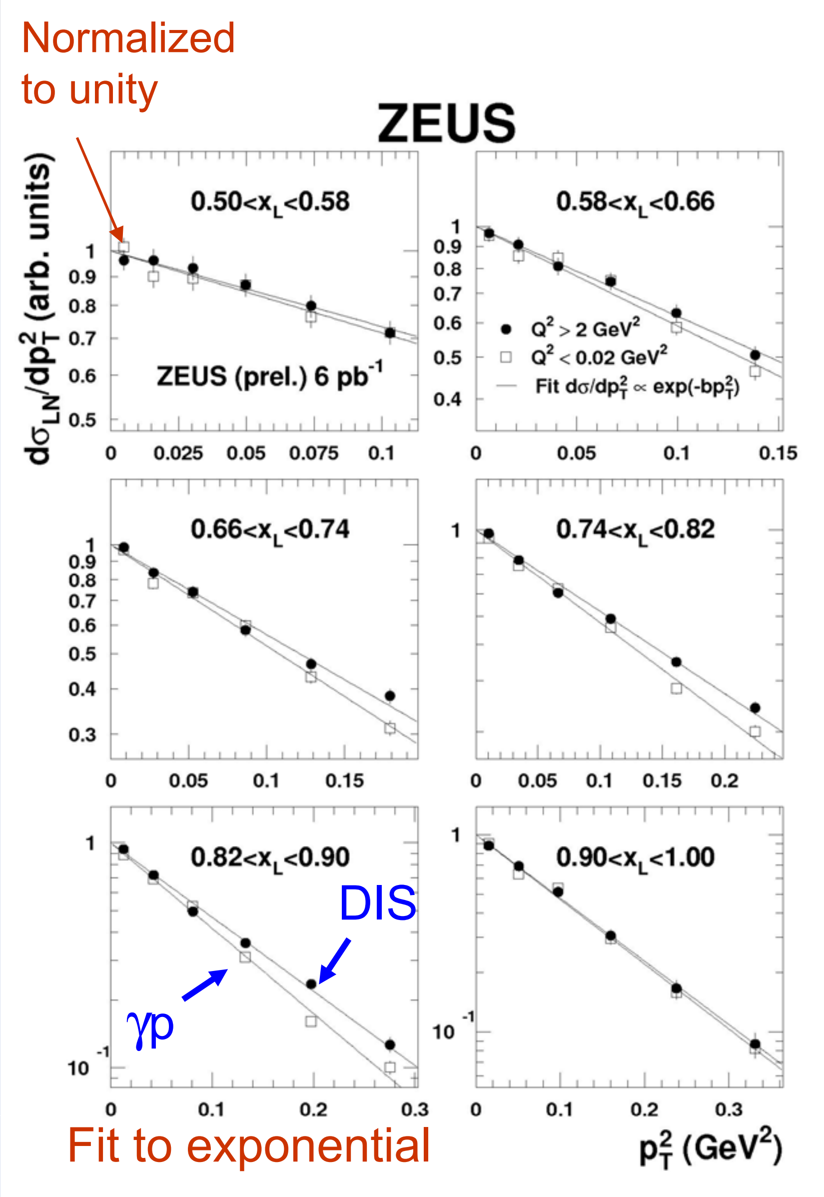




b consistent with 0 for x_L<0.3

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

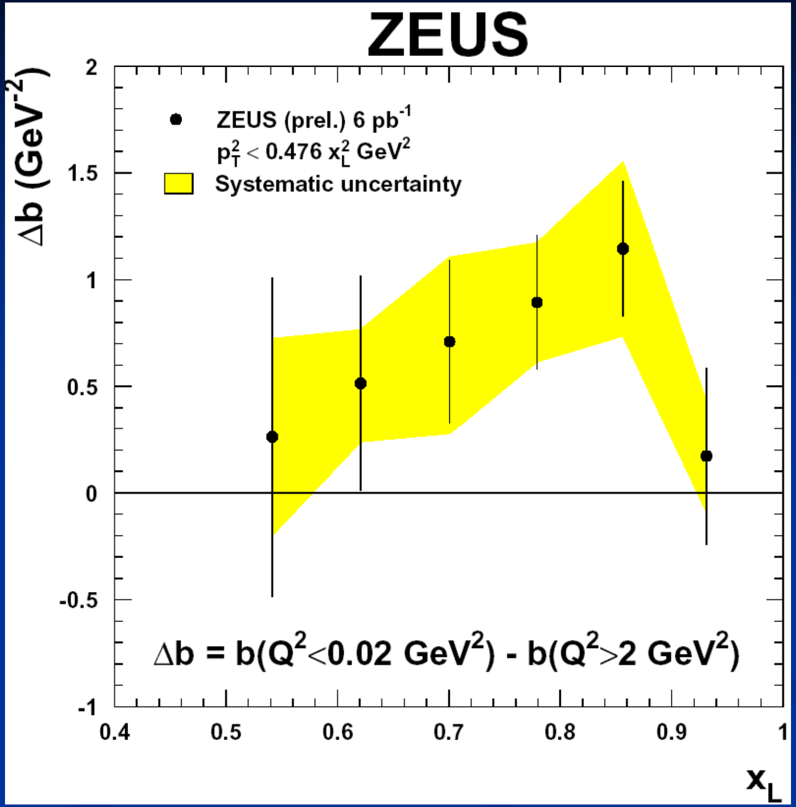
LN b-slopes: DIS & photoproduction comparison


Normalized to unity

Fit to exponential

DIS

γp



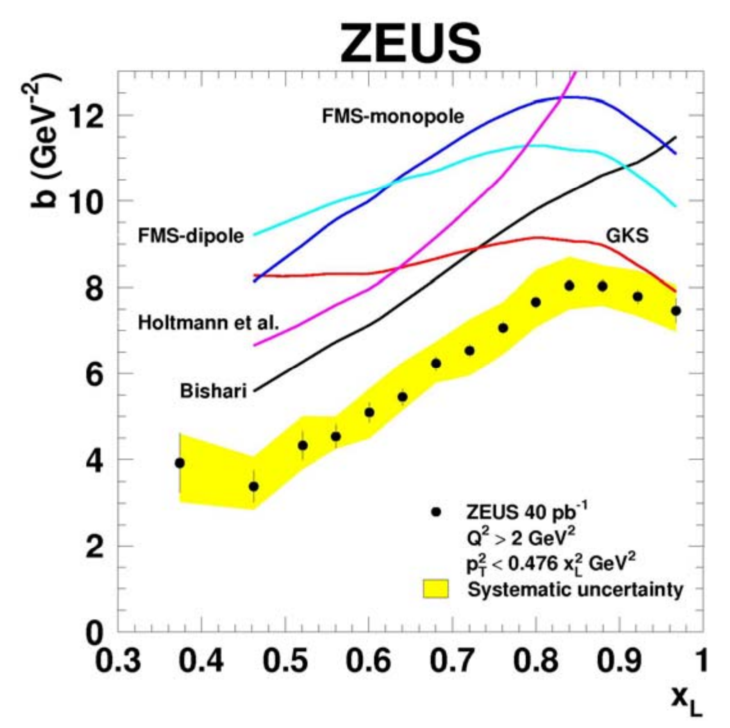
slopes different in photoproduction and DIS in general agreement with expectation from absorption model

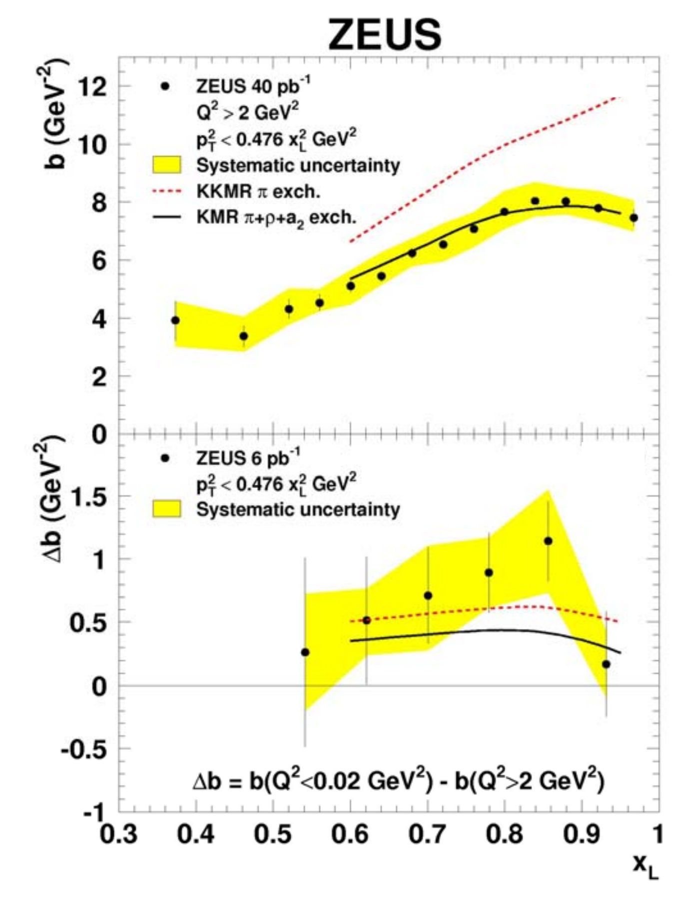
→ more absorption @ small n-π size

→ depletion @ large p_T

→ steeper slope in photoproduction

LN b-slopes: comparison to models





OPE models:

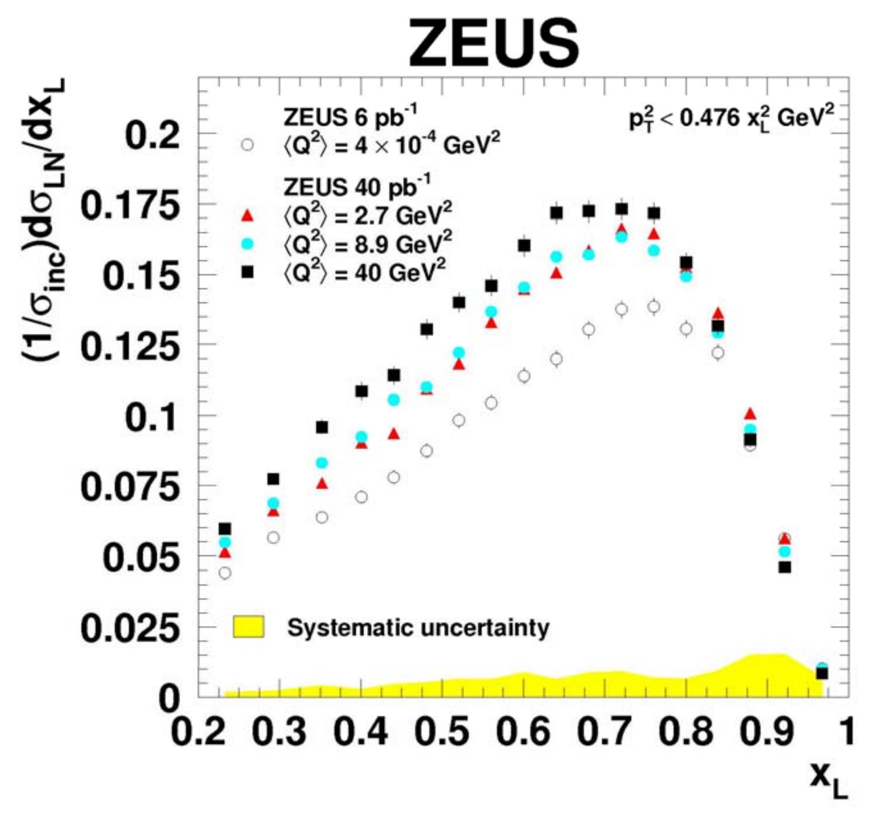
- Dominant at $0.6<x_L<0.9$
- (non-) Reggeized flux, different form factors with different parameters
- none of the models seem to decribe the data well

KKMR model:

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

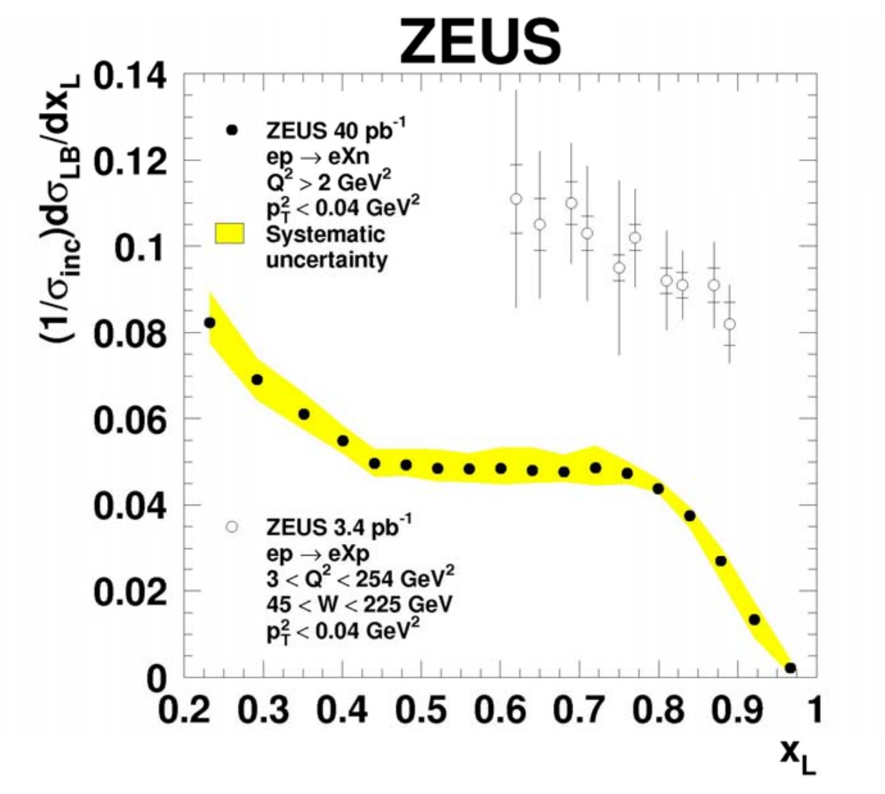
LN spectrum: Q^2 dependence

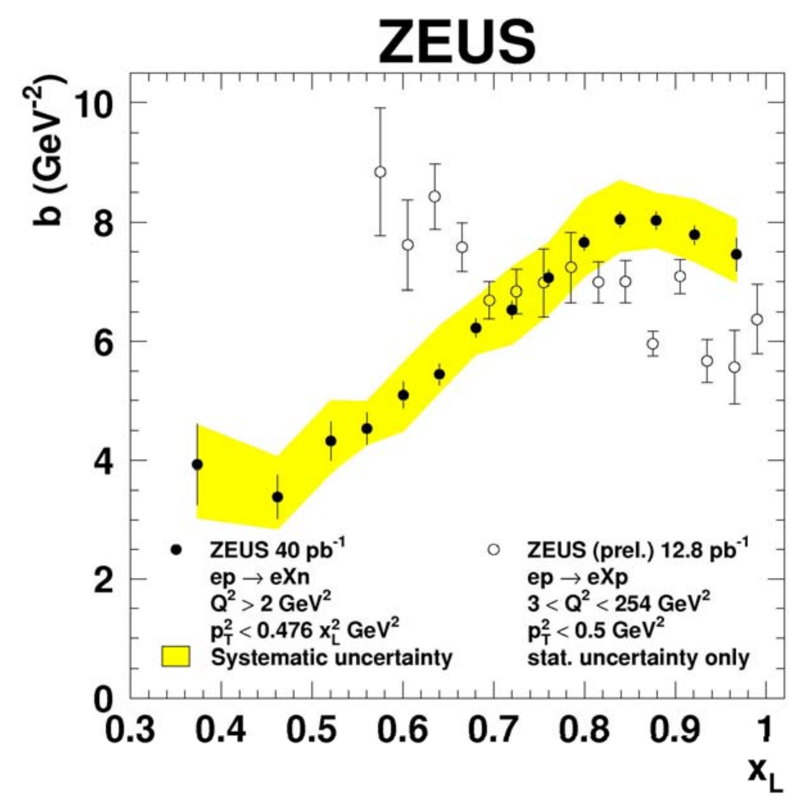
3 Q^2 bins + γp



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

LN: comparison to leading proton





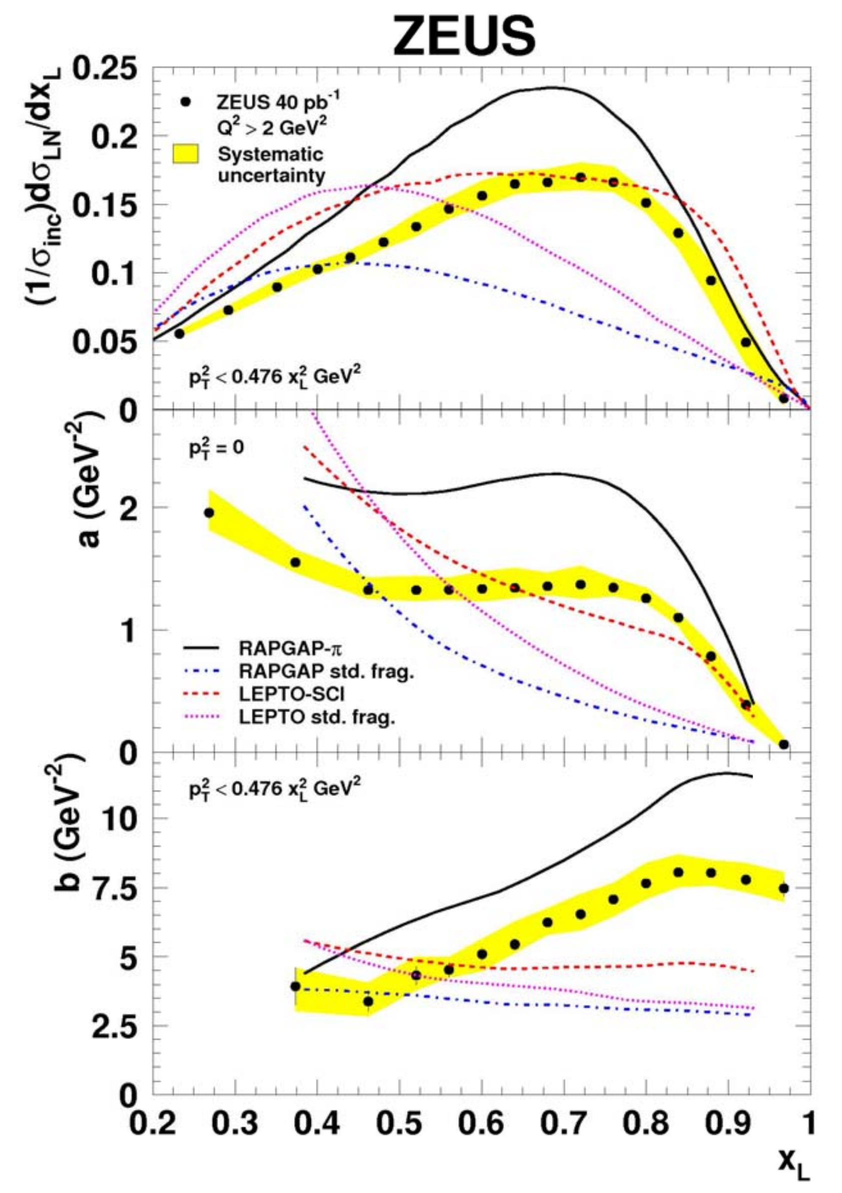
- x_L distribution for cross p_T^2<0.04GeV^2
- For pure isovector exchange isospin Glebsch-Gordan →r^{LP}=1/2 r^{LN}
- r^{LP}>r^{LN} : other exchanges needed

- LN slope increases up to x_L~0.8
- LP slope almost flat
- Similar values in the range 0.7<x_L<0.85 when π exchange dominates

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

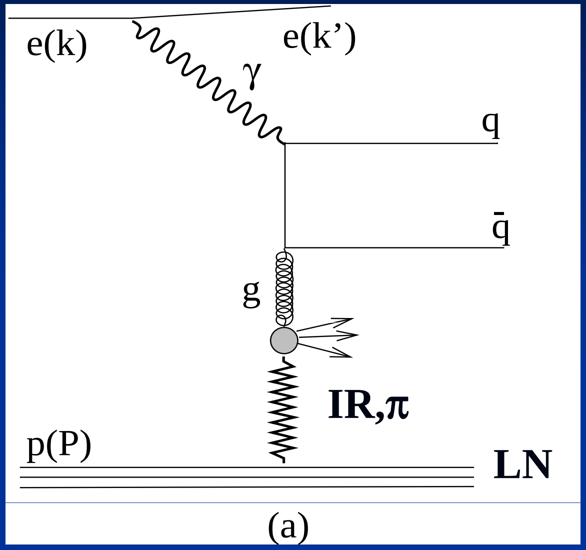
Other models also fail (ARIADNE, CASCADE,PYTHIA,PHOJET)

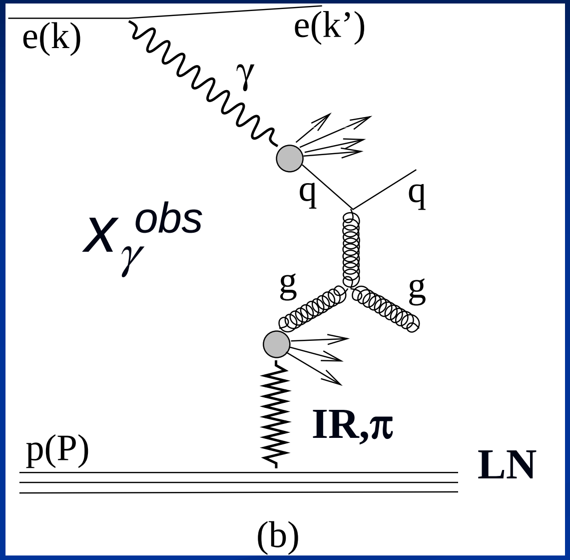


Dijet production with a LN

DIS ↔ direct photoproduction

resolved photoproduction





Re-scattering processes expected for resolved γp: photon acts hadron-like → additional interactions between remnants and scattered partons

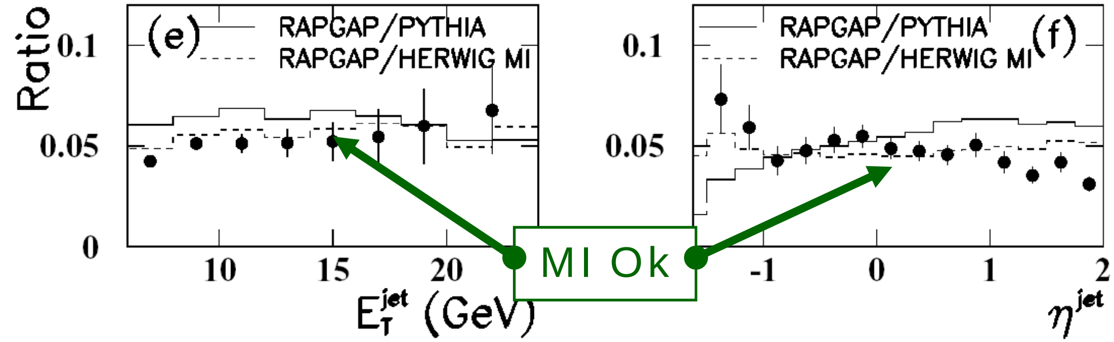
Relevant variable: $$x_\gamma^{obs} = \frac{\sum_{jet1,2} E_T e^{-\eta}}{(E-p_z)_{had}}$$

momentum fraction of the photon entering the hard sub-process.

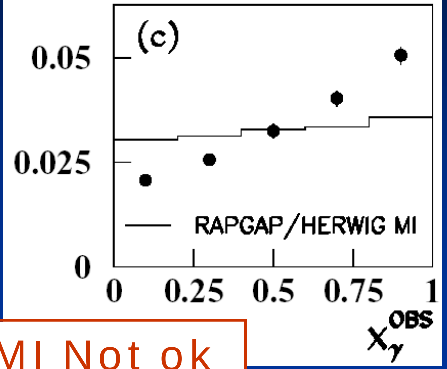
Dijet production with a LN: $\sigma_{jj+n}/\sigma_{jj}$

ZEUS: RAPGAP/HERWIG-MI (··············)

(Nucl.Phys.B596,3(2001))



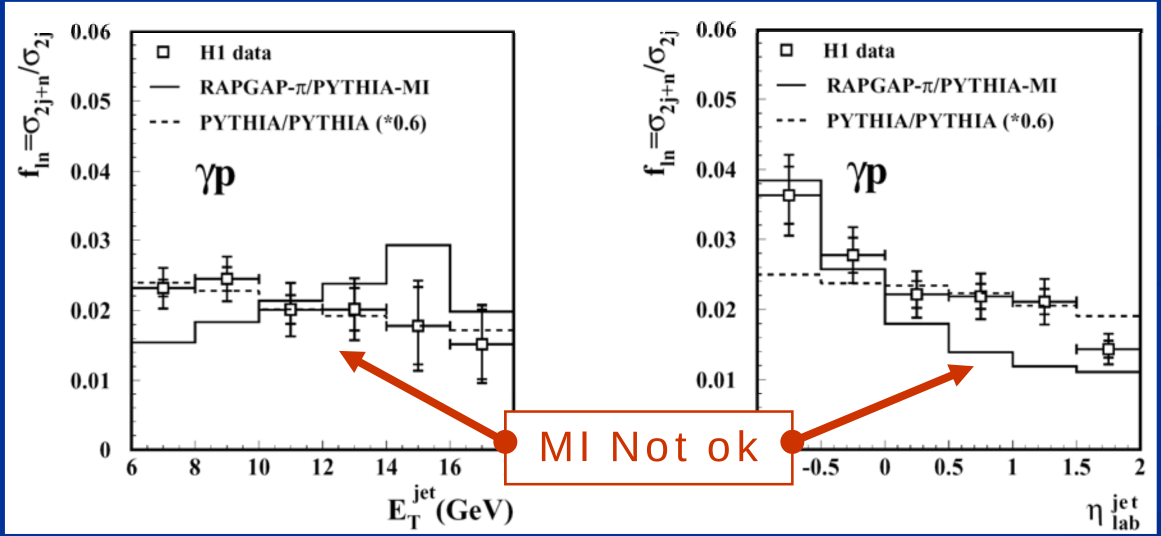
MI Ok



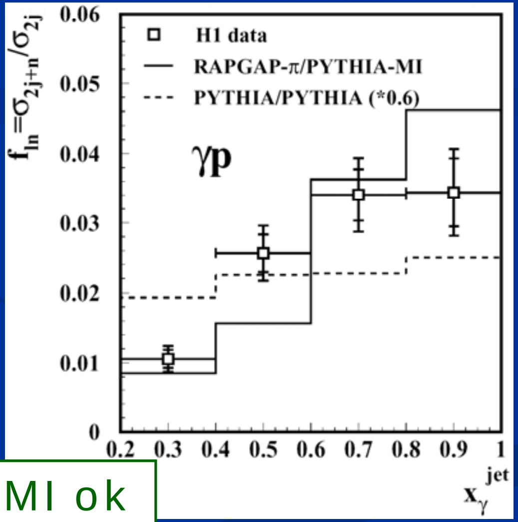
MI Not ok

H1: RAPGAP/PYTHIA-MI (————)

(Eur. Phys. J. C41 (2005) 273-286)



MI Not ok



MI ok

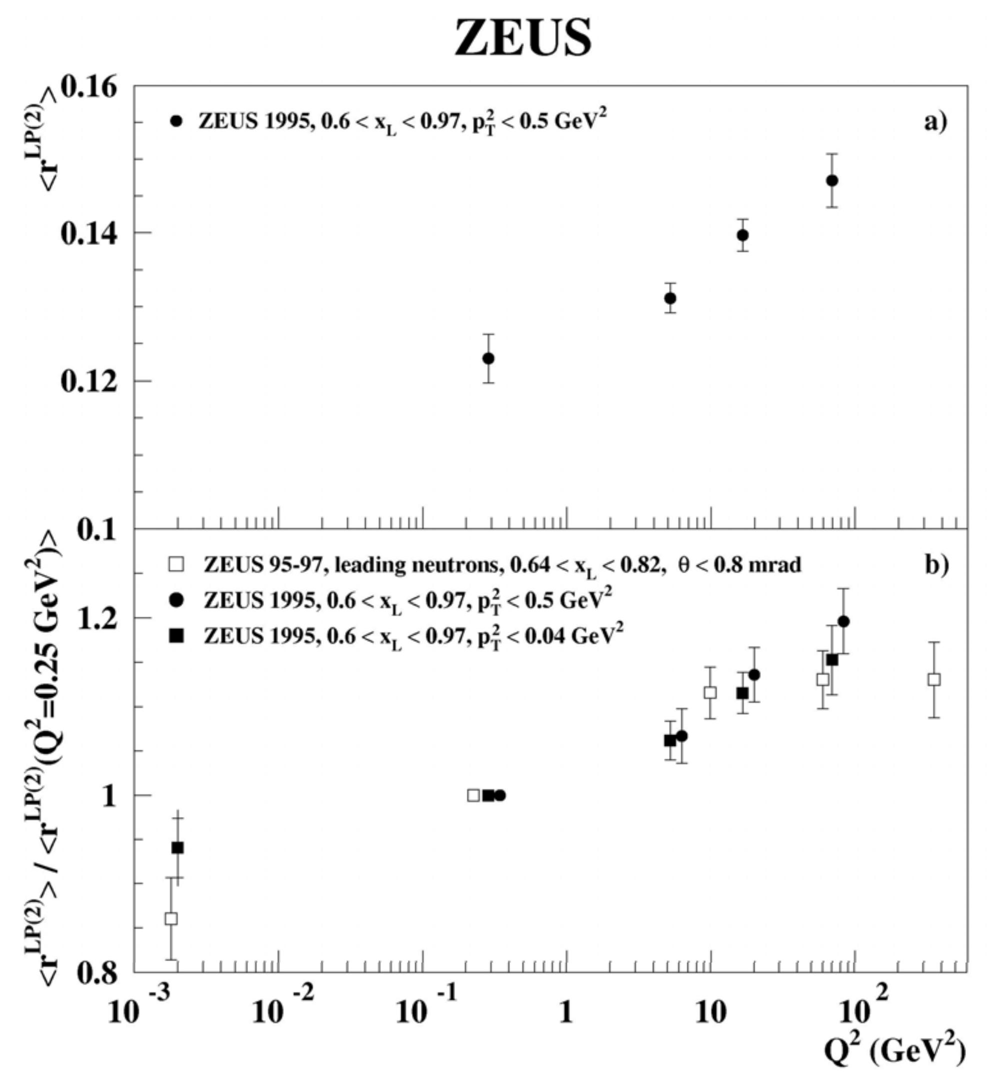
No possibility to decide on factorization breaking due to re-scattering processes in resolved photoproduction (x_γ<1) with hadron-like photon.

Summary

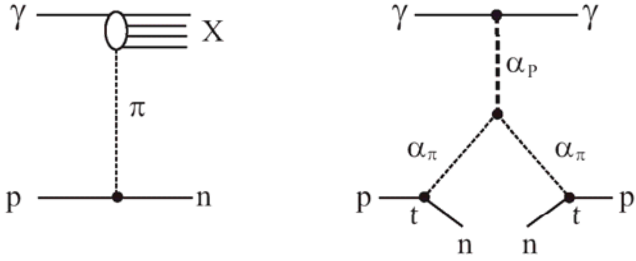
- High precision measurements of leading baryon production available from HERA
- LP spectra measured in DIS and well described by Reggeon-exchange model
- LN production measured in DIS and photoproduction
- LN characterized by rescattering and absorption effects: the data are quite well reproduced by some models
- MC generators in general fail to reproduce the measured quantities → need to tune the generators

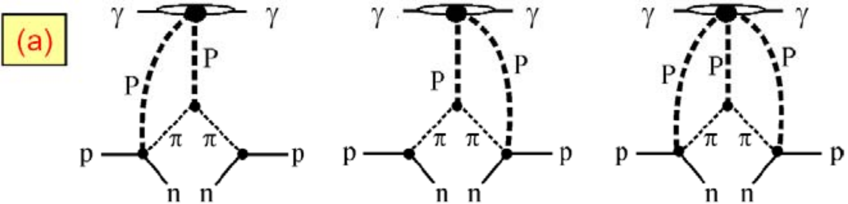
Leading baryon study remains an important topic in HEP with a direct impact on next experiments @ LHC

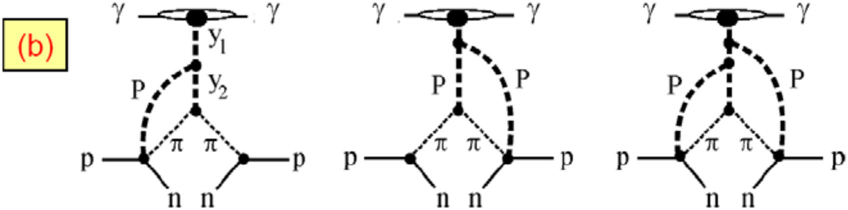
LP absorption effects

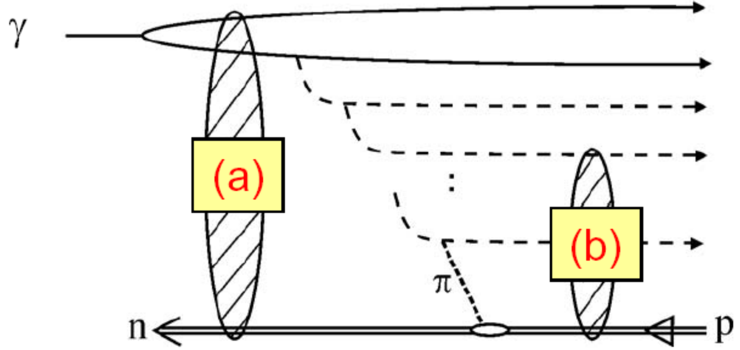


Rescattering model and absorption 1









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

Nikolaev,Speth & Zakharov

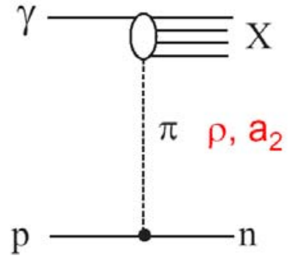
Re-scattering processes via additional pomeron exchanges (Optical Theorem)

(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