Leading baryons at ZEUS

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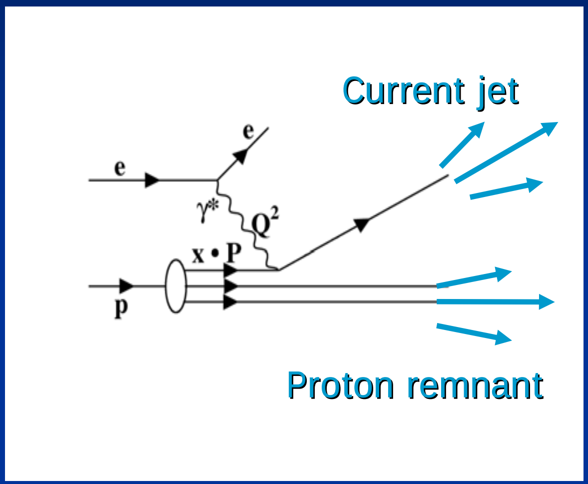
ZEUS Collaboration

Outline

- Introduction
- Recent results from HERAI data
  - Leading protons (12.8 pb^{-1})
  - Leading neutrons (40 pb^{-1})
- Comparison to models
- Dijets and leading neutrons in γp (40 pb^{-1})

Semi-inclusive reaction



DIS (Q^2 > 1-2 GeV^2)

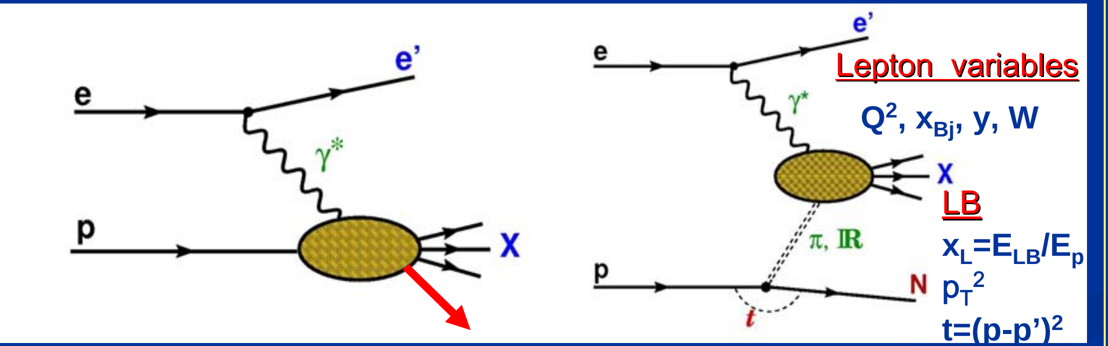
$$ep \rightarrow e + LB + X$$

Scale for secondary particle production decreases from Q2 (current region) to a soft hadronic scale (proton fragmentation region)

Photoproduction - γp

Hadronic component of the photon.
Can re-introduce hard scale (e.g. requiring high-pT jets)

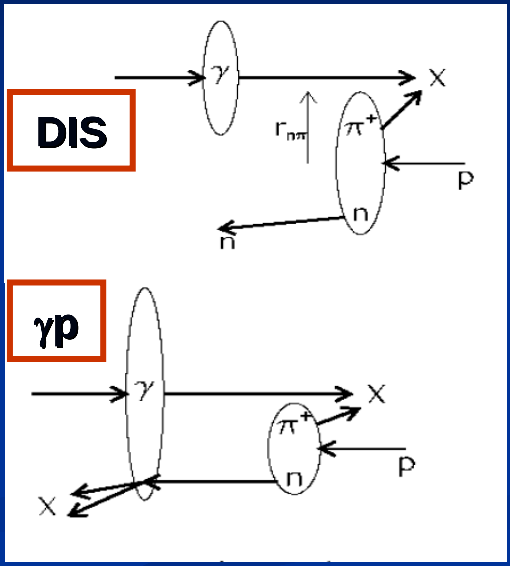
Production Models



MC fragmentation models
- Cluster model (Herwig)
- MEPS, parton shower + SCI
- CDM (Ariadne)

Dynamical particle-exchange models
- leading protons: π_0, IR, IP (isoscalar + isovector)
- leading neutrons: π^+, ρ^+, … (isovector)

Rescattering and absorption



D'Alesio and Pirner - "geometrical" picture (EPJ A7 (2000) 109)

e.g. LN production via p-exchange - Neutron absorption through rescattering

❑ Absorption: neutron rescatters on γ hadronic component
(enhanced when p-n system size $r_{pn} \sim 1/p_T$ is small w.r.to the γ transverse size).

Pion-flux: $\langle r_{\pi n} \rangle$ increases with x_L → more absorption at low x_L

- n kicked to lower x_L & higer p_T → migration
- n may escape detection → absorption loss

❑ More absorption in photoproduction than DIS (γ transverse "size" larger)

Additional Corrections

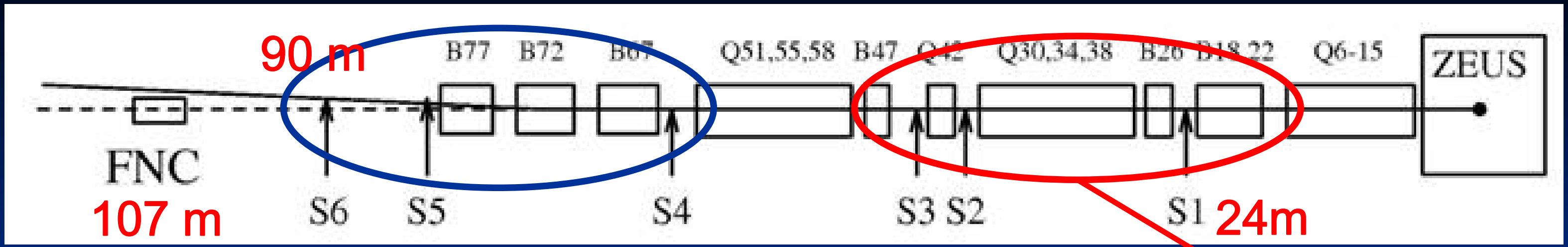
Nikolaev, Speth, Zakharov (NSZ), Kaidalov, Khoze, Martin, Ryskin (KKMR)
(hep-ph/9708290, 0602215, 0606213)

❑ Corrections due to re-scattering processes via additional IP exchanges (→ Uncertainties in π structure function extraction)

❑ Enhanced absorptive corrections, calculation of migrations, inclusion of additional exchanges (ρ and a2) (→ different x_L & p_T dependences)

- Measure x_L and p_T^2 dist.
- Study Q^2 dependence
- Compare γp and DIS
- Look for effects due to absorption

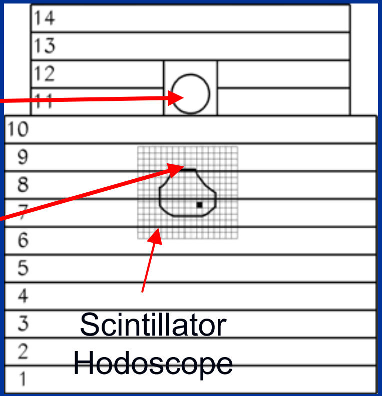
Main experimental tools

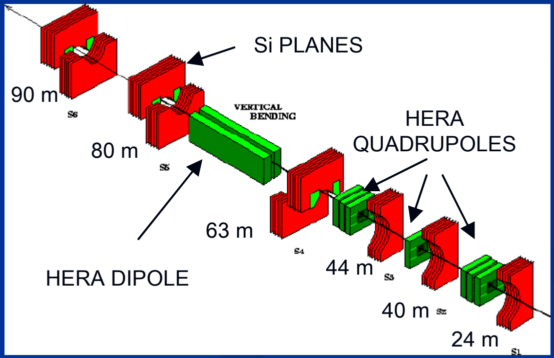


Lower x_L accessible

Forward Neutron Calorimeter + Tracker

Leading Proton Spectrometer





S1-S2-S3 and S4-S5-S6

Independent spectrometers

Accepted p_T varies with x_L.
For x_L>0.6, p_T^2 <0.5 GeV², <A> ~ 15%

- **FNC:** 10λ lead-scintillator sandwich
- $\sigma/E = 0.65/\sqrt{E}$, Energy scale 2%
- Acceptance θ_n<0.8 mrad, azimuthal coverage 30%. For x_L>0.6, <A>~25%.
- **FNT**: Scint. hodoscope @ $1\lambda_{int}$, $\sigma_{x,y}$=0.23 cm, σ_θ=22 μrad

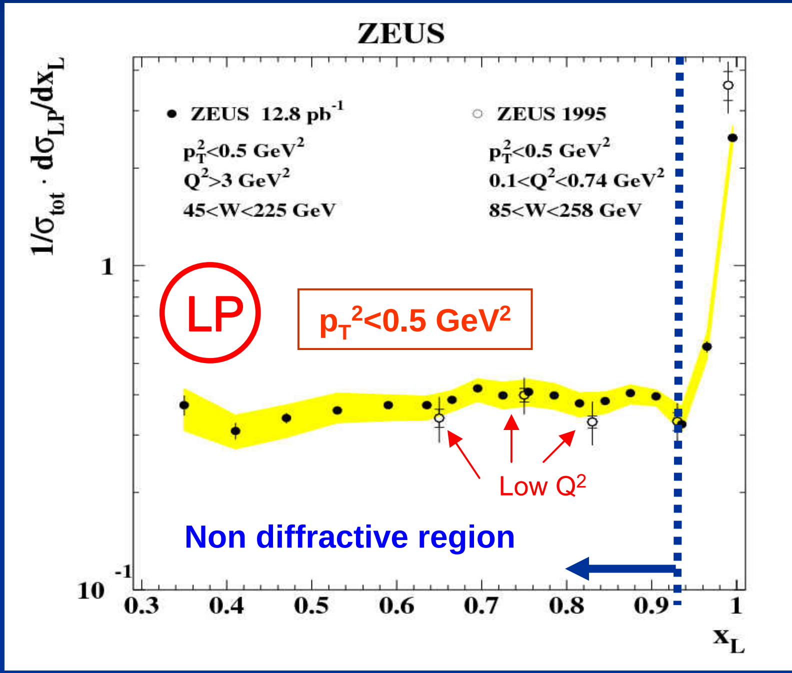
LPS: 6 stations (6 Silicon-detector planes each, hit resolution ~ 30 μm)

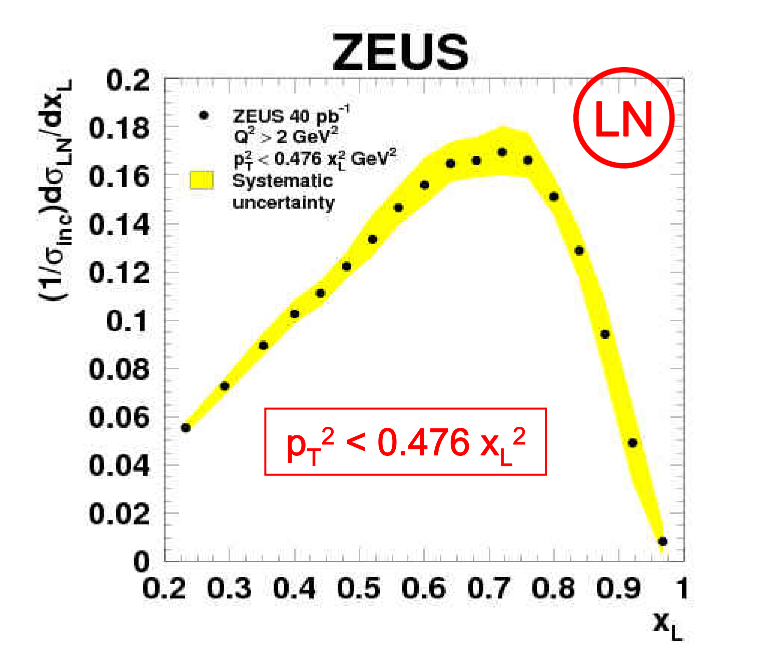
- Stations inserted at $10\sigma_{beam}$ from the proton beam during data taking
- σ_{x_L} < 1%, $\sigma_{p_T^2}$ ~ few MeV²

p_T^2 resolution better than p-beam spread (~ 50 - 100 MeV)

x_L and p_T^2 spectra

x_L yields: normalized to inclusive DIS





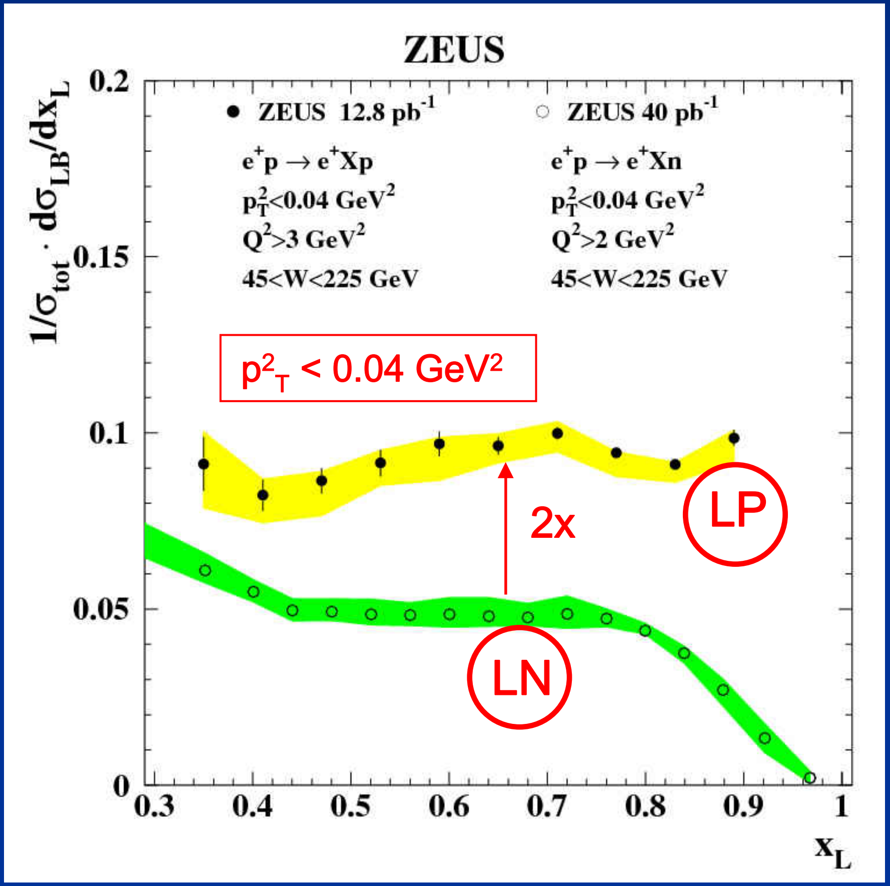
Yield flat below diffractive peak

DIS and earlier low Q^2 data are compatible

LN: Yield → 0 at kinematic limit, x_L →1

Drop at x_L < 0.7 due to drop in acceptance

x_L – comparison LP, LN



Same p_T^2 range: $p_T^2 < 0.04$ GeV^2

Pure isovector exchange (like pion)

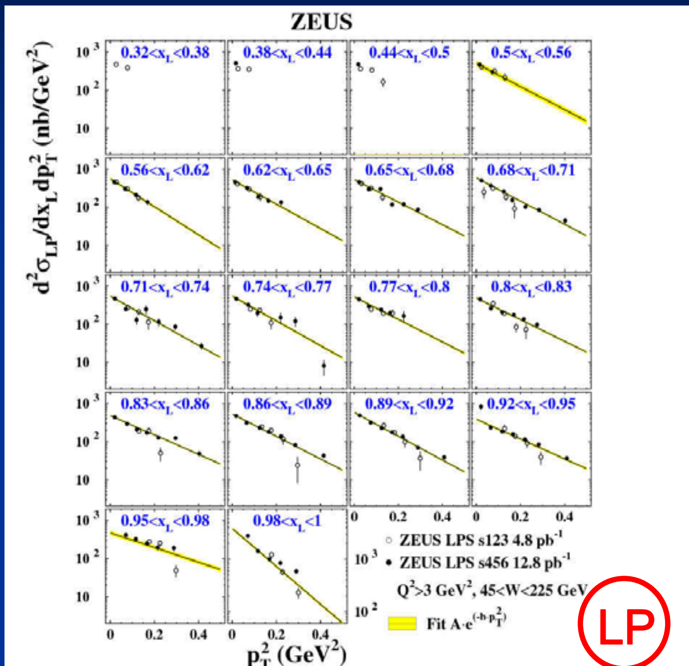
LN = 2 LP

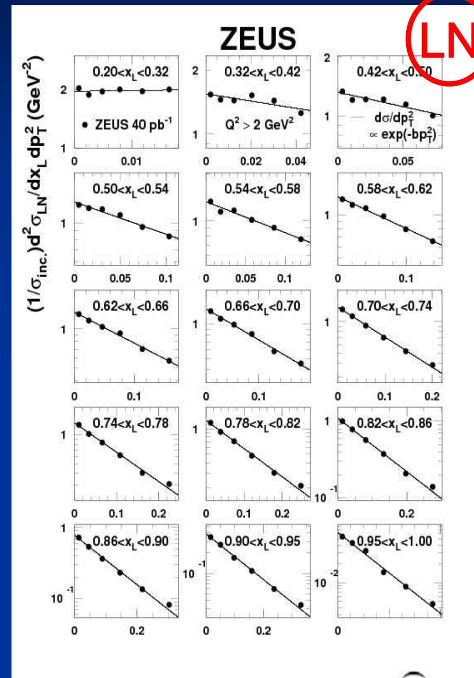
Data show :

LP ~ 2 LN

➔ Other isoscalar IR contributions needed to account for the LP rates

P_T^2 distributions in x_L bins





LN:

p_T^2 range varies with x_L bin

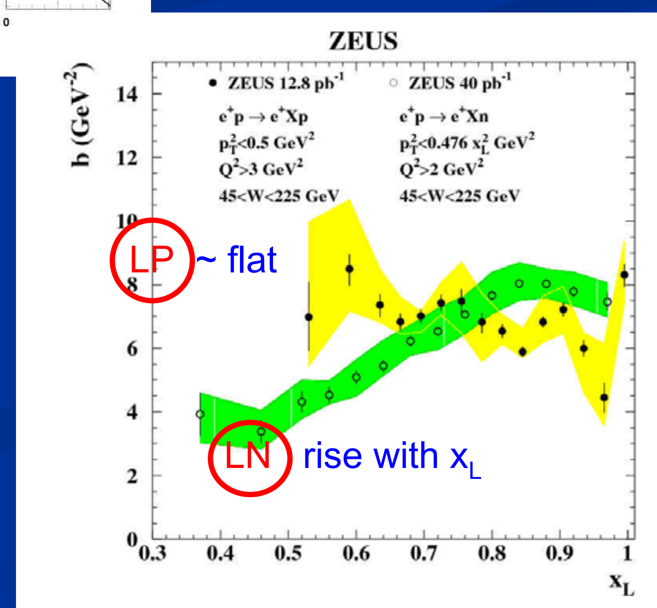
Exponential behaviour

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

SLOPES

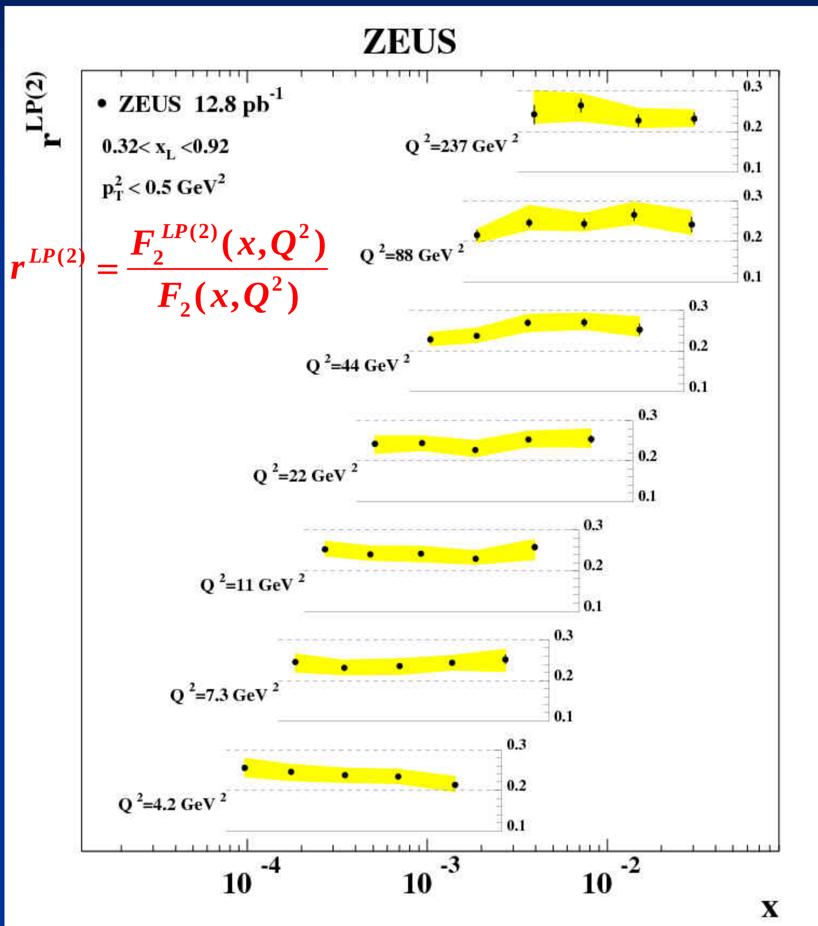
Different trend.

Similar around $x_L \sim 0.7$



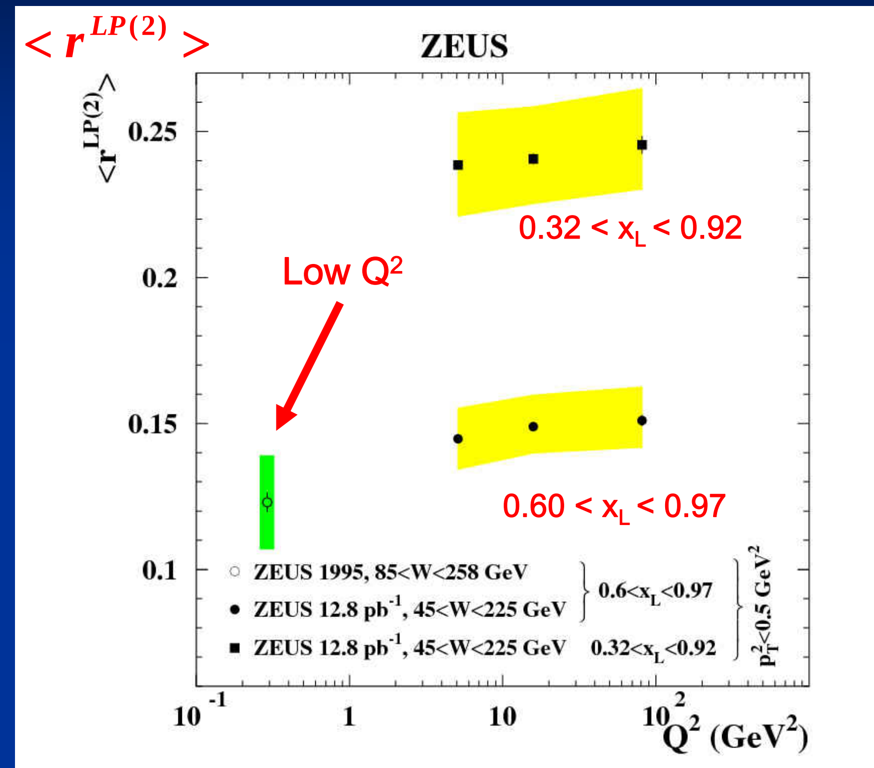
Q^2 dependence

LP rates to inclusive DIS



~24% of DIS events have a LP with $0.32<x_L<0.92$, almost independently of x and Q^2

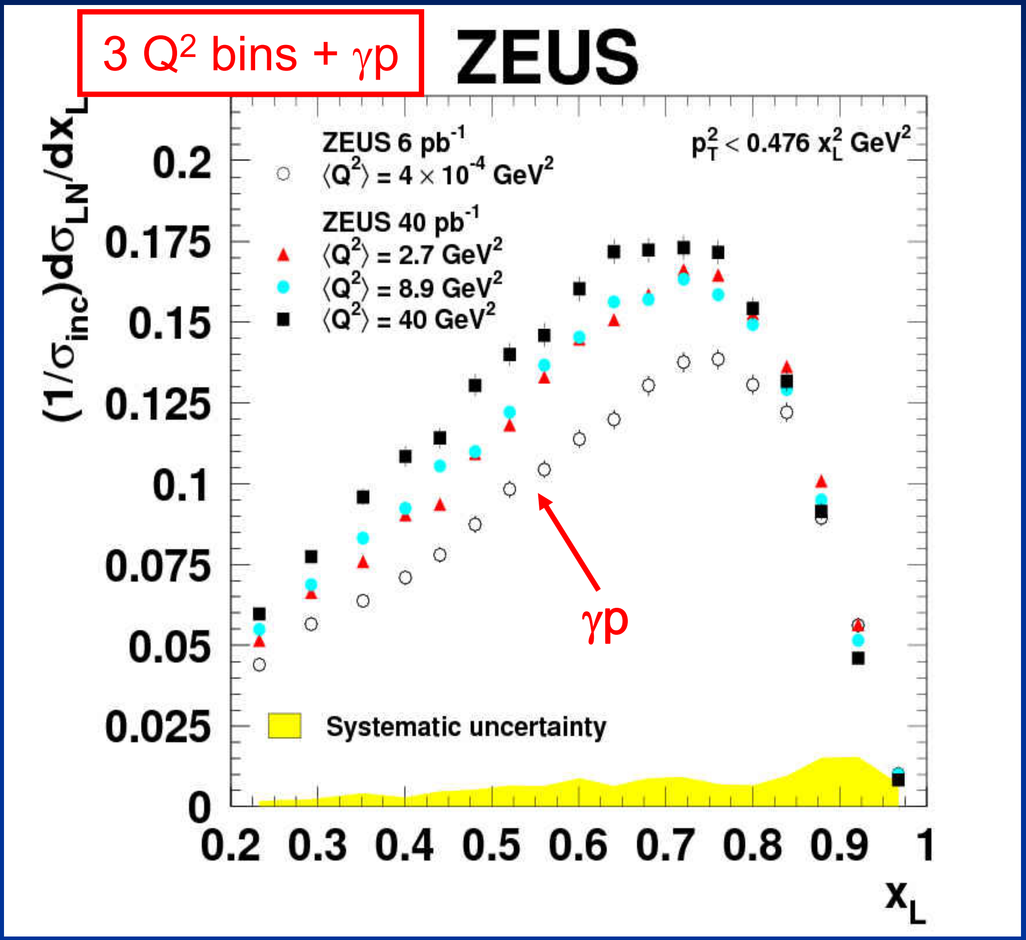
Average LP yield vs Q^2



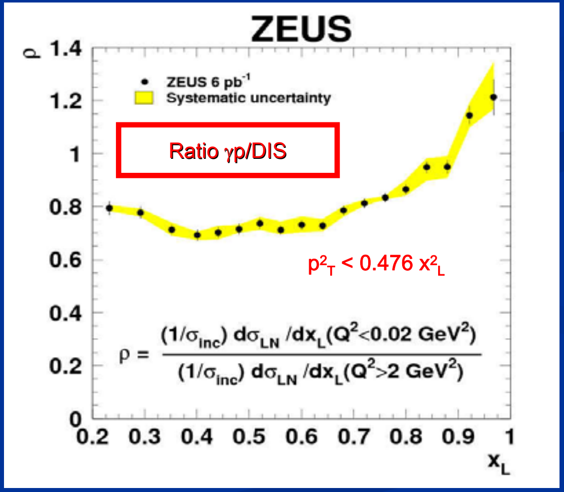
Slight decrease with decreasing Q^2 (larger γ^* transverse size) not excluded

Consistent with absorptive effects

LN: Q^2 dependence of x_L yields



- ➢ Yield decreases with decrease of Q^2: large effect from DIS to γp
- ➢ Smaller Q^2 dependence at intermediate values
- ➢ Violation of vertex factorization



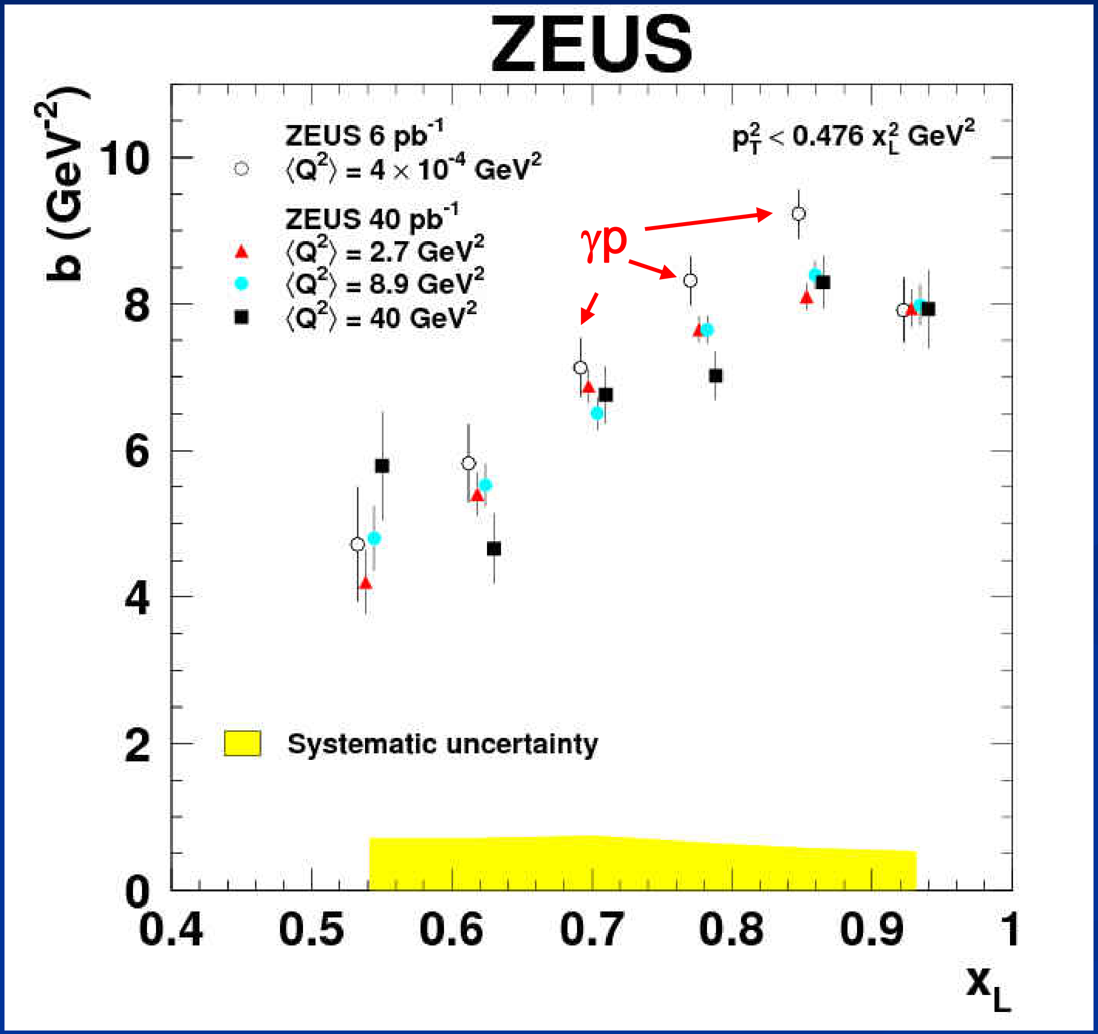
Ratio γp / DIS

- ❑ intermediate x_L ~ 70%
- ❑ $x_L \rightarrow 1$ rises above 1

<u>Consistent with absorption</u>

- π-n separation decreases at low x_L
- smaller separation → more absorption at low x_L

LN: Q^2 dependence of p^2_T slopes



- DIS – slopes:

~ no Q^2 dependence

- γp – slopes:

higher in $0.6 < x_L < 0.9$

<u>Consistent with absorption</u>

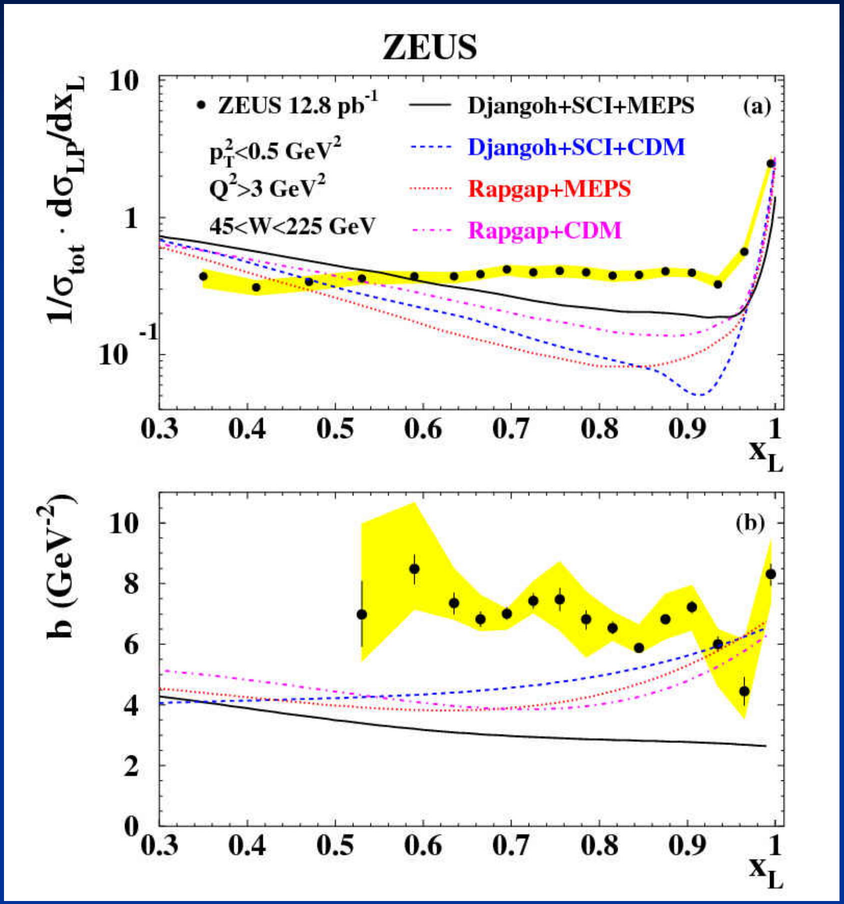
Large p_T → small $r_{\pi n}$ → more abs.

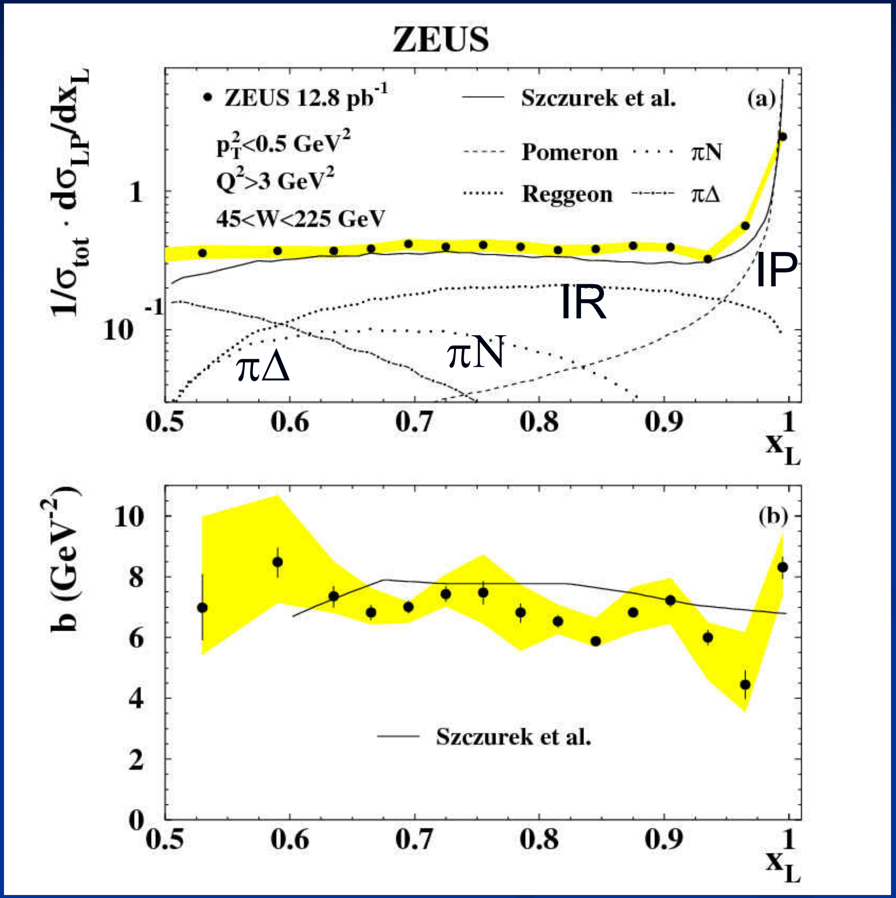
→ Fewer LN at high P_T

→ Steeper slope

Comparison to models

Leading Protons - DIS





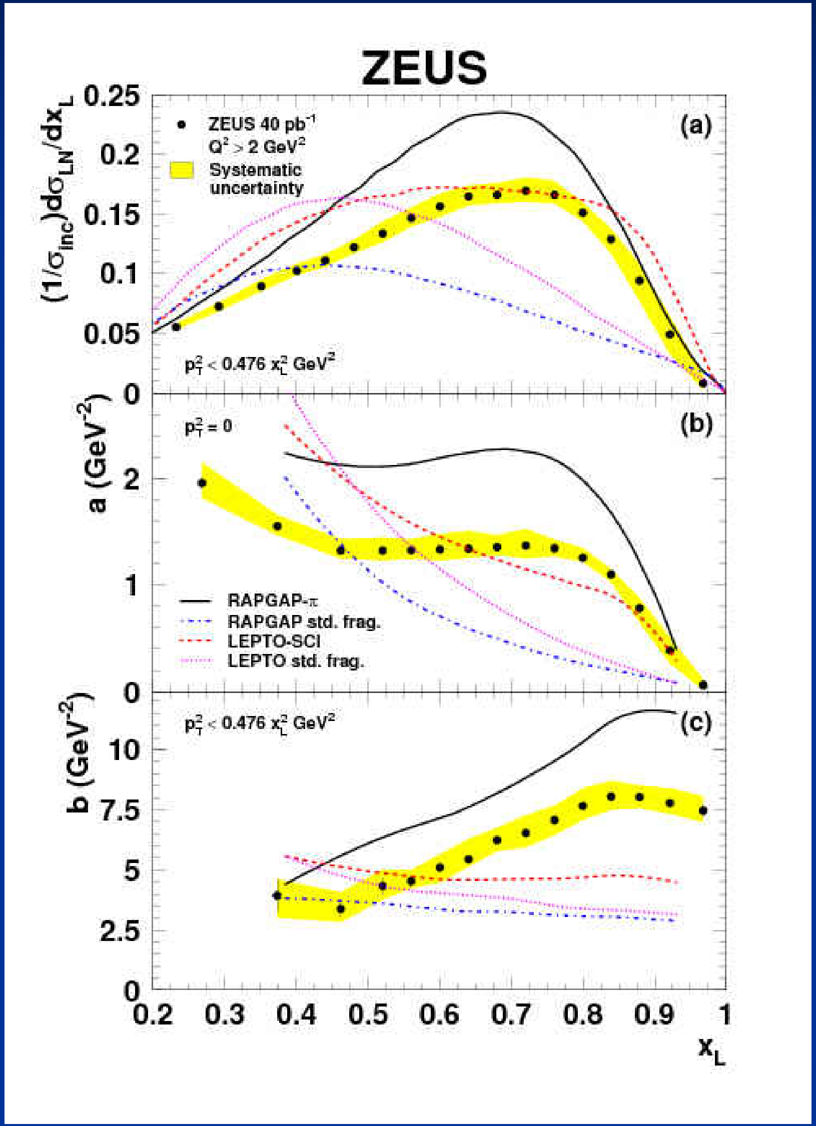
Standard fragmentation MC models fail to describe the data out of the diffractive peak

DJANGOH+SCI+MEPS ~ ok b(x_L) shape

Reasonable description by π, IR, IP exchange models

Isoscalar IR dominates at intermediate x_L

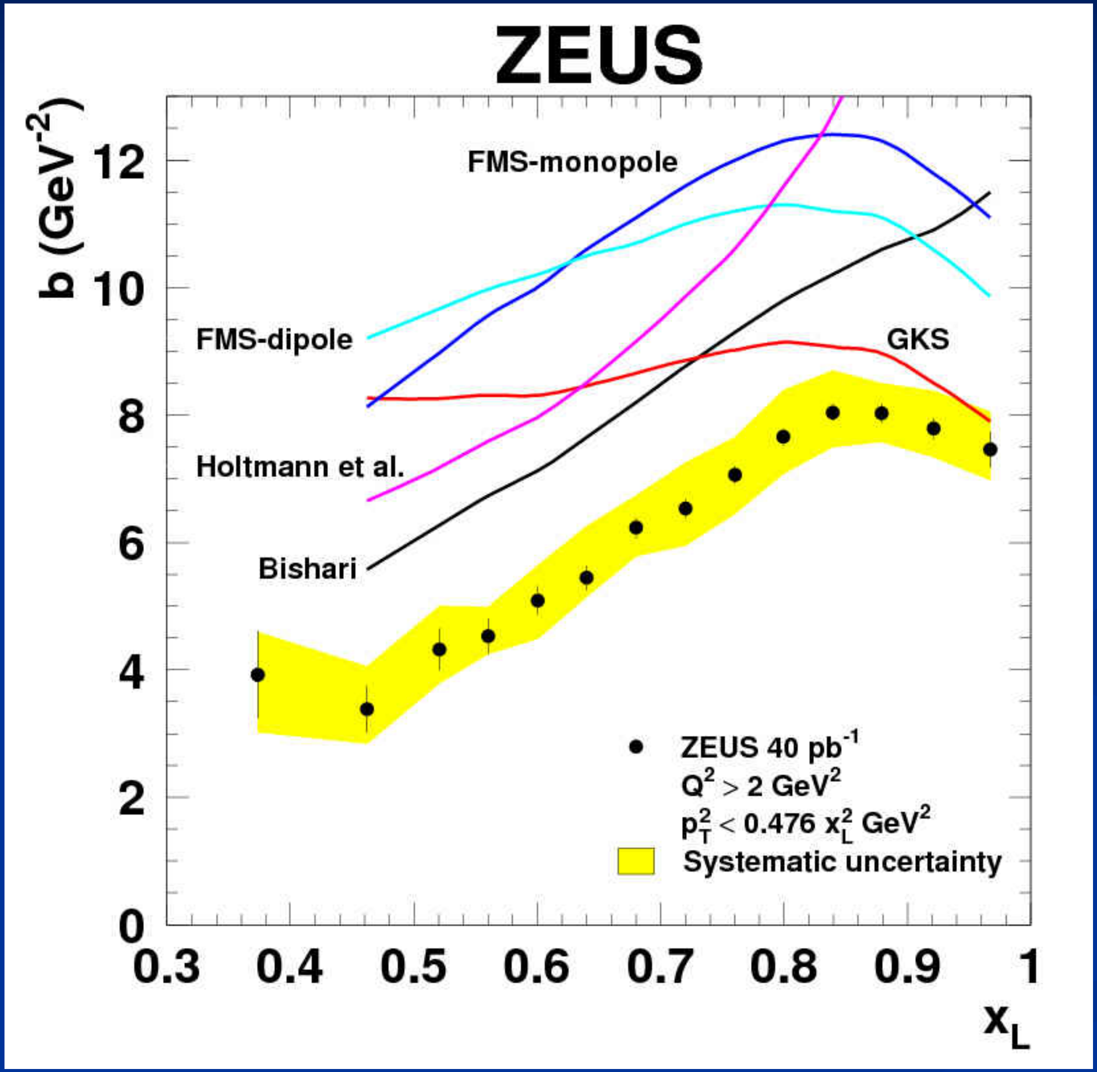
Leading Neutrons – DIS MC models



MC models generally fail to reproduce all the features of the data

- ❑ Standard Fragmentation models: understimate the neutron yield and the x_L dstribution predicts too many at low x_L
- ❑ RAPGAP: St. Fragm. + π-xchng → shapes ~ OK
- ❑ LEPTO+SCI: x_L shapes ~ ok, yield ~ ok, not slopes

LN: DIS - OPE Models



$$\frac{d\sigma_{ep\to enX}}{dx_L dp_T^2} = f_\pi(x_L, p_T^2)\times\sigma_{e\pi}(s_{e\pi})$$

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

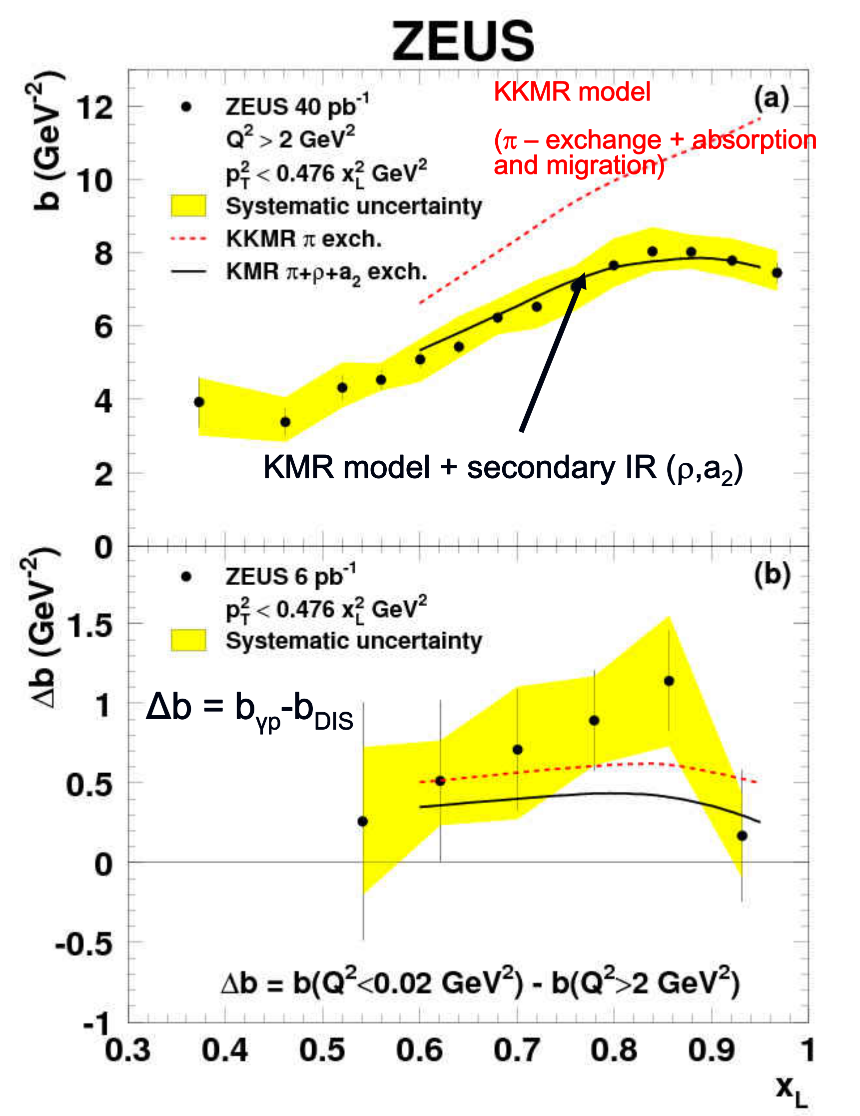
p_T^2 dependence from flux factor

Models shown differ by π-flux parametrization

Reasonable agreement in shape, not in rate

p_T^2 slope (not shown) too high: π-xchng alone not enough

LN: DIS – absorption, rescattering + additional IR



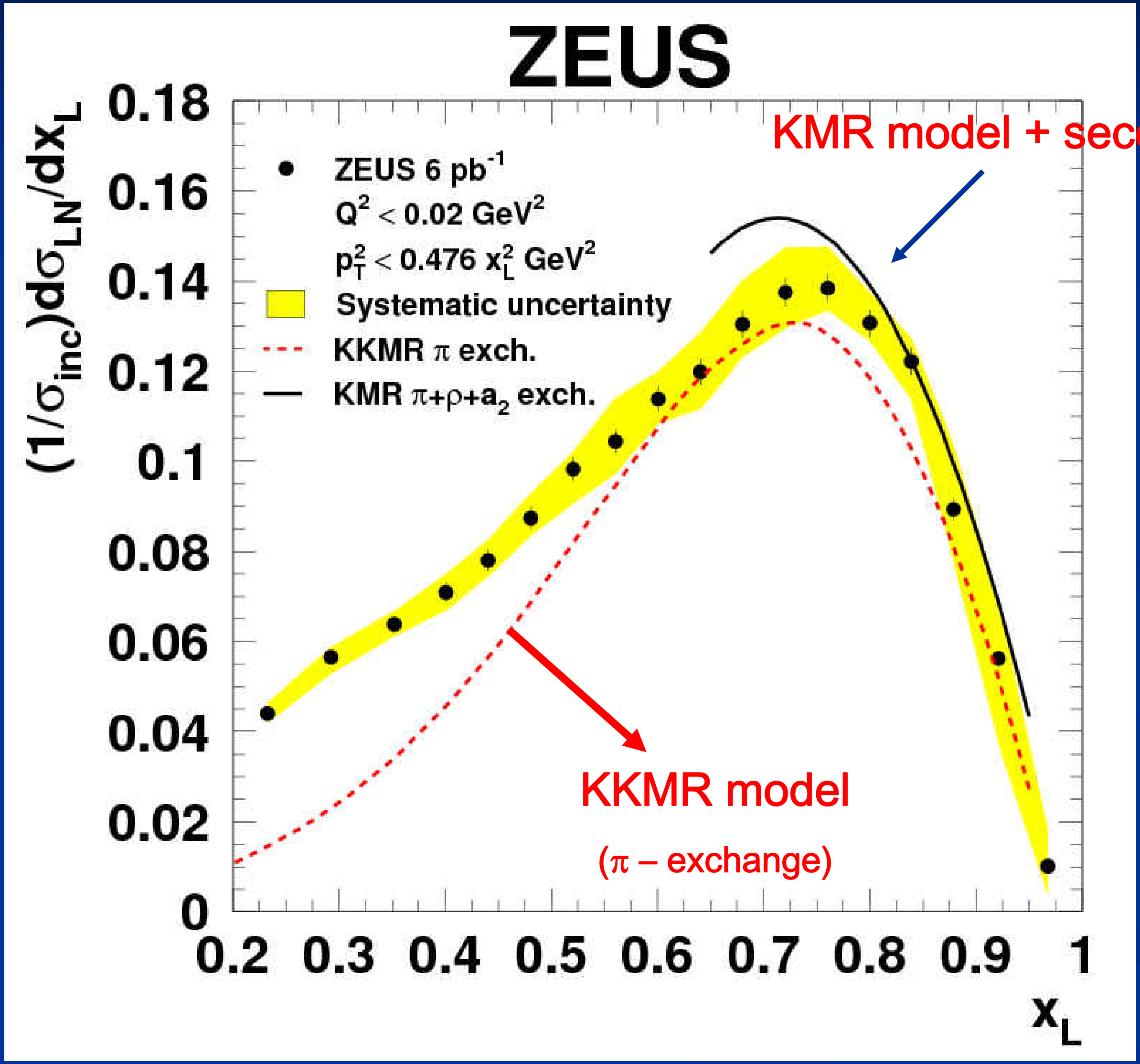
DIS - Slopes

(K)KMR model

Absorption & migration included in the predictions: not sufficient to describe the slopes

Good description of data when additional IR included

LN: Photoproduction - x_L

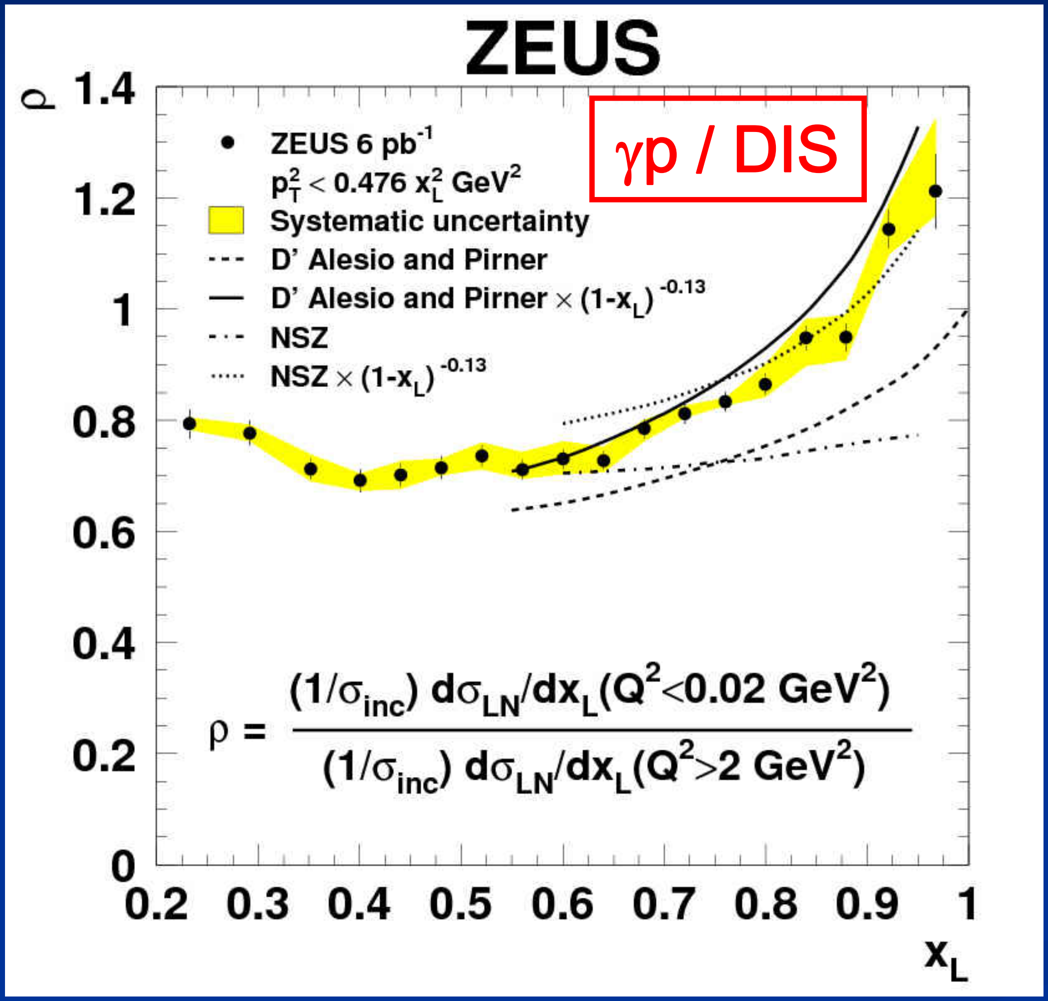


Pure π-xch. + **inclusion migrations** in x_L and p^2_T after rescattering

Reasonable description of shape and normaliz.

Add (r,a2)-xch: again reasonable agreement in γp

LN: comparison of x_L yields: γp/DIS



Models: OPE + absorption

$$\sigma_{\gamma\pi} \propto s_{\gamma\pi}^{\ \lambda} = [(1-x_L)\times W_{\gamma p}^{\ 2}]^{\lambda}$$

ZEUS

$$\frac{\sigma_{\gamma\pi}}{\sigma_{\gamma^*\pi}} = (1-x_L)^{\Delta\lambda} = (1-x_L)^{-0.13}$$

(different cms energy dependence)

Good agreement with the data

LN + dijets in photoproduction

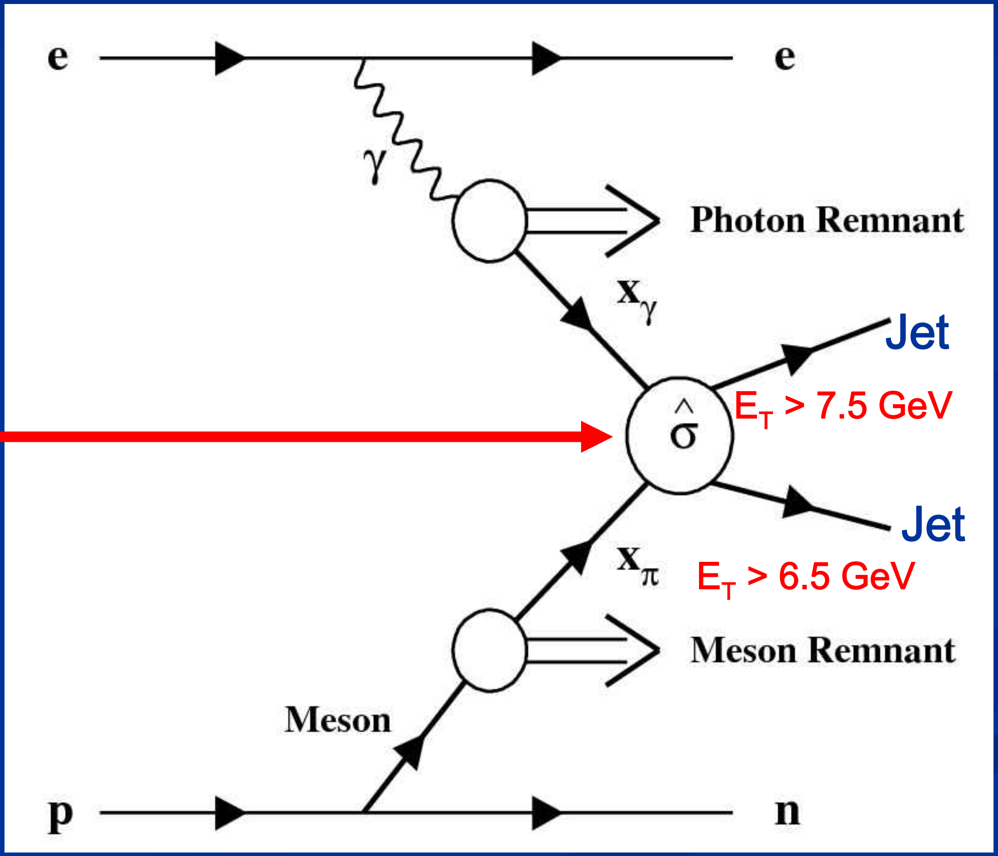
Leading n in γp + dijets

Absorption effects seen going from hard → soft scale

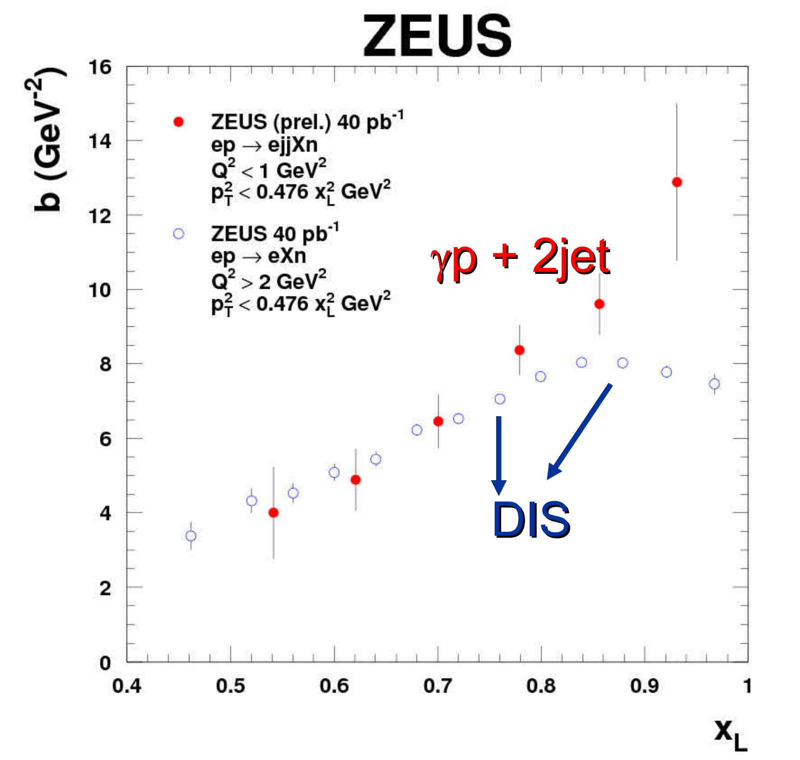
High Q^2 → Low Q^2 → γp

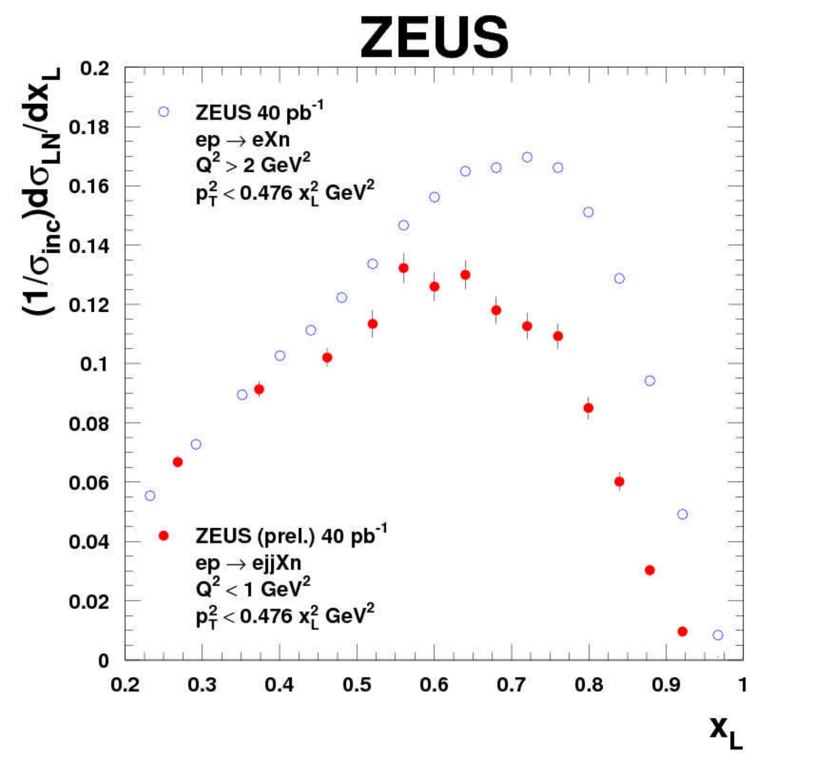
Reintroduce a hard scale in γp

Still absorption?



LN+jj (γp) vs LN (DIS)





b-slopes similar in magnitude and shape in DIS and γp+dijet

→ Same production mechanism

- γp without jets: suppression at low x_L
- γp with jets: suppression at high x_L

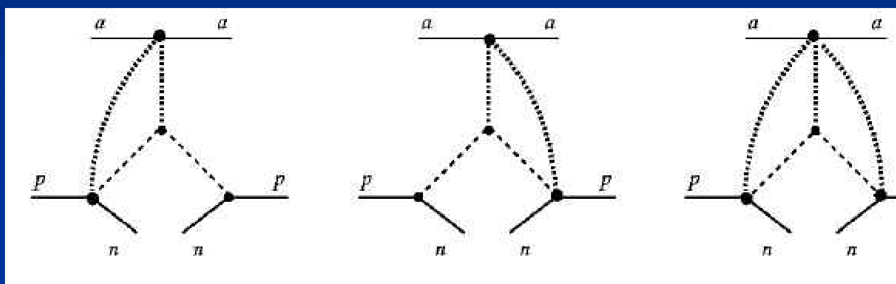
Not yet firm conclusions on absorption

Summary

- Recent ZEUS data on LB production in DIS, γp, γp+dijets as a tool to study hard ←→ soft physics
- Observation of factorization breaking effects going from hard to soft scales, mostly in LN
- Standard fragmentation MC-models fail to describe the data: improvement with particle-exchange implemented
- LP: needs isoscalar IR contributions to explain the data
- LN: pure p exchange not sufficient (slopes not described)
- Recent calculations with π exchange and absorption + migration corrections improve the agreement in shape and magnitude of the x_L spectra
- Additional exchanges (ρ, a_2) improve further
- γp + hard jets: more work needed

Extras

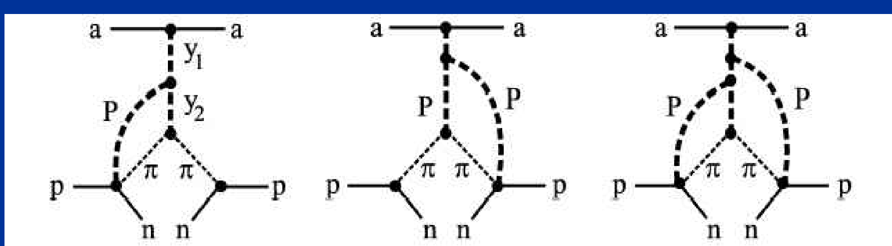
Additional corrections



Nikolaev, Speth and Zakharov (NSZ)
(hep-ph/9708290)

Corrections due to re-scattering processes via additional IP exchanges

(→ Uncertainties in π structure function extraction)

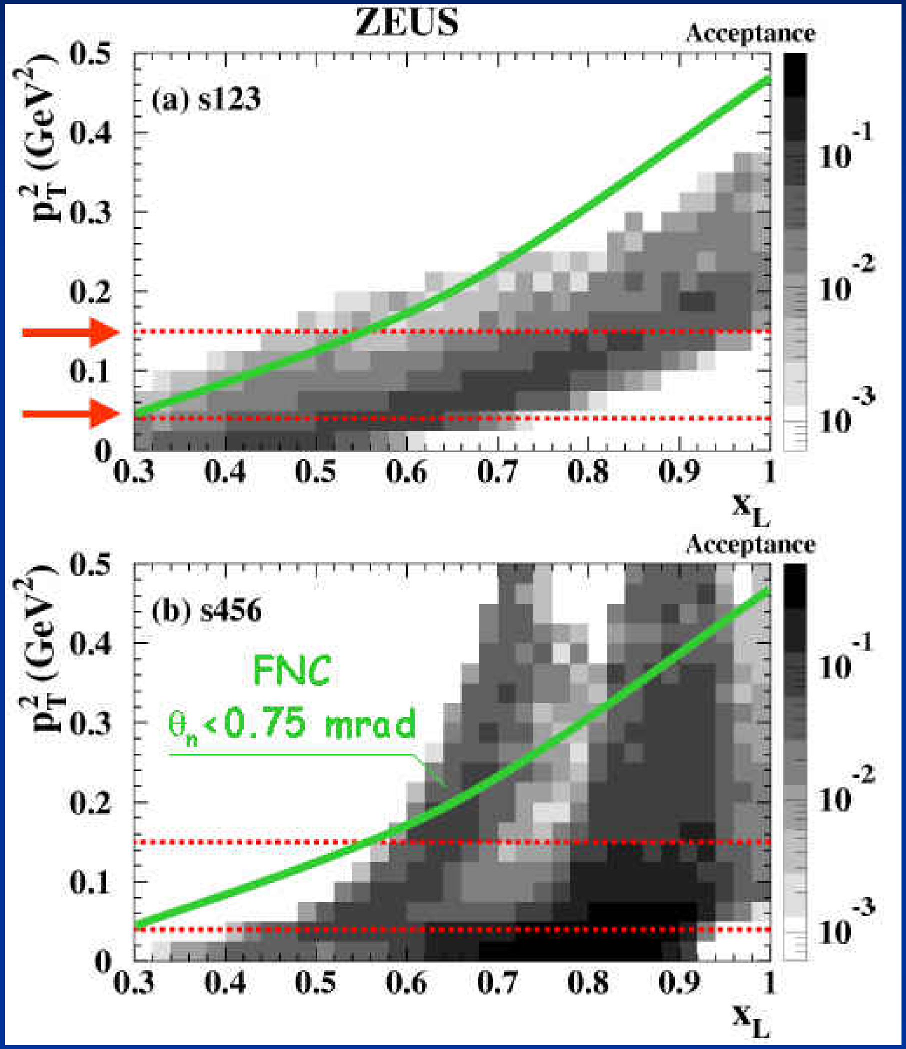


(Kaidalov,) Khoze, Martin, Ryskin (KKMR)
(hep-ph/0602215, hep-ph/0606213)

Enhanced absorptive corrections, calculation of migrations, inclusion of exchange of ρ and a_2

(→ different x_L & p_T dependences)

Acceptance



LPS

Acceptance limited by beam elements and detector size

S1-S2-S3 and S4-S5-S6 are **independent** spectrometers: **very small overlap**

Accepted p_T range varies with x_L

$x_L > 0.6 \rightarrow p^2_T < 0.5$ GeV^2

<Acceptance> ~ 15%

FCN

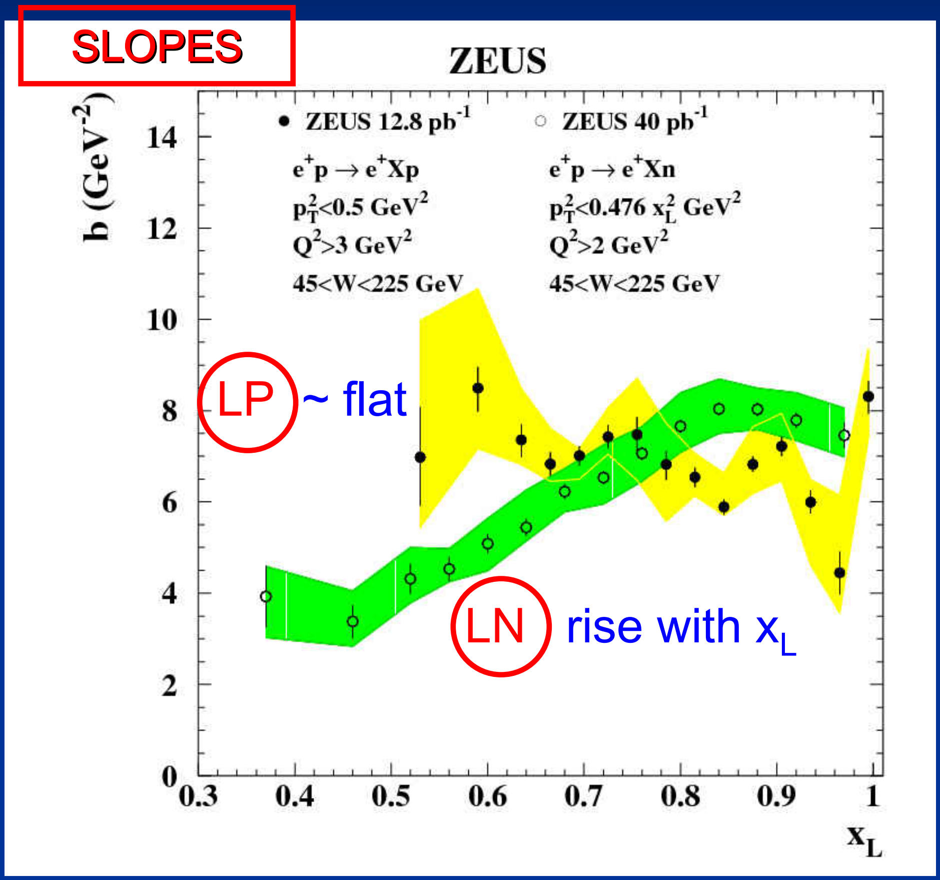
Restricted to $\Theta_n < 0.75$ mrad

p_T range increases with x_L

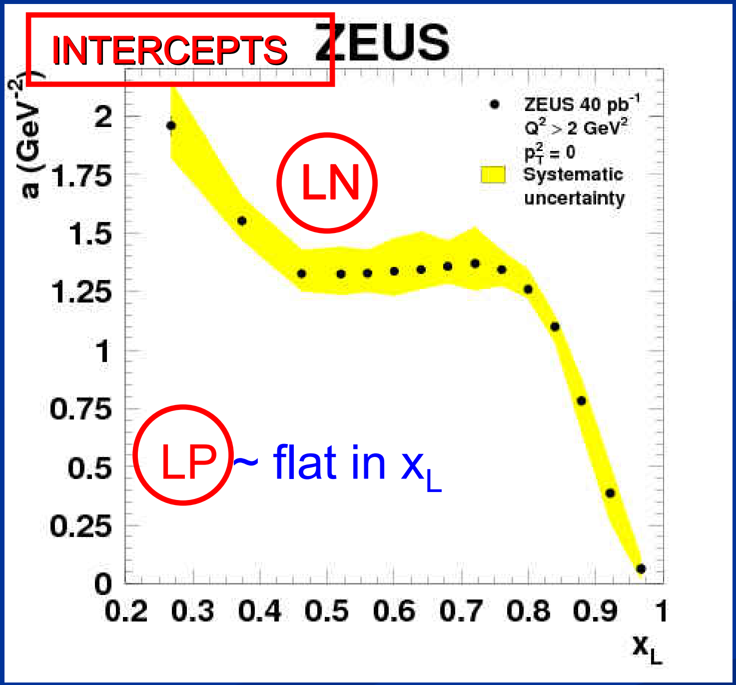
For $x_L > 0.6$, $\Theta_n < 0.75$ mrad

<Acceptance> ~ 25%

Slopes and intercepts



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



Different trend. Similar around $x_L \sim 0.7$

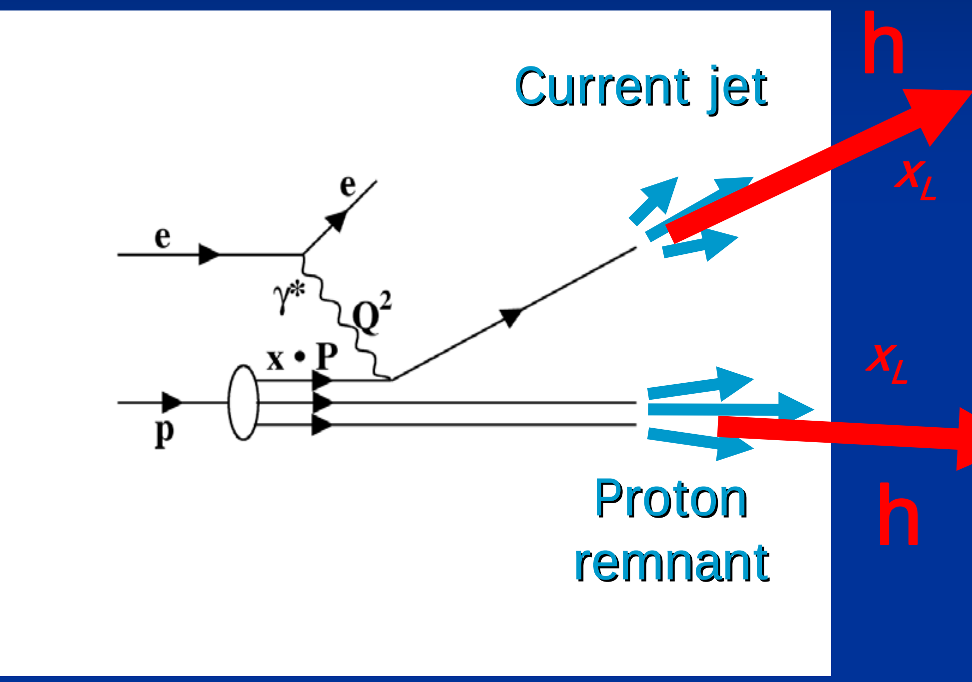
LN falls with x_L

Flat for $0.4 < x_L < 0.8$

Fracture Functions approach

L.Trentadue, G.Veneziano

Phys. Lett. B323, 201 (1994)



Production in the current region

$$\sigma_{current} \sim \sum_q c_q f_{q/p}(x) D_{h/q}(x_L)$$

Fragmentation function

Production in the target region: F.F.

$$\sigma_{target} \sim \sum_q c_q (1-x) M_{q,h/p}[x,(1-x)x_L]$$

Fracture function

$$\sigma = \sigma_{current} + \sigma_{target}$$

- F.F. are non-perturbative universal functions (absorb collinear singularities at LO in α_S)

- Q^2 dependence governed by evolution equations

Dynamical models allow to link them to concepts like structure-functions of exchanged objects (e.g. IR trajectories)