Leading Baryon production at HERA

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HERA-LHC W.S., 27.05.08, CERN

Outline LB proton (LP) and neutron (LN) production:

- Motivations: LB production, virtual particle exchange, absorption

DATA:

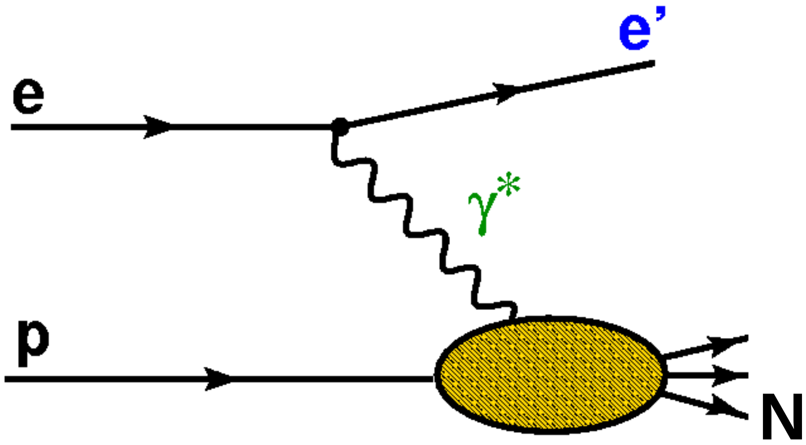
- Data sets: DIS, photoproduction (γp), dijets in γp; LB measurement
- LB in DIS & γp: energy, p_T distributions
- LB production Q^2 dependences
- Comparison: LN in DIS & γp+jj (high E_T dijets)

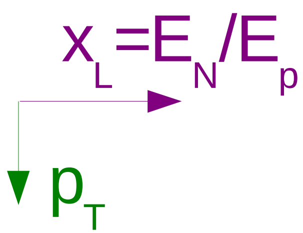
MODELS:

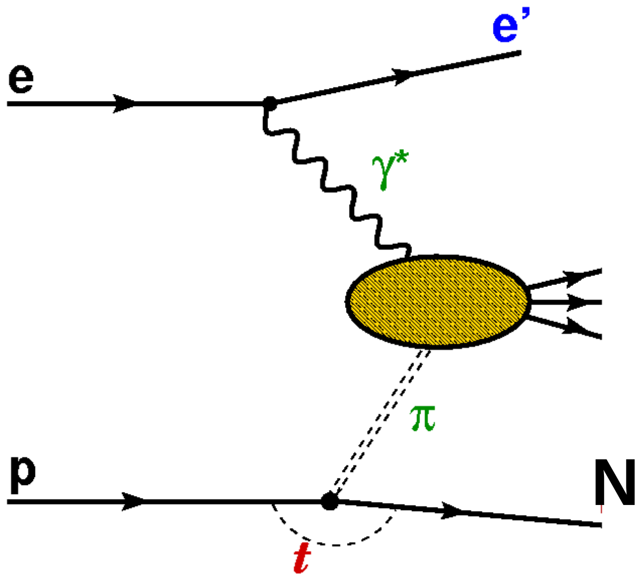
- Comparison: LB in MC models, w/ & w/o virtual particle exchange
- Comparison: LN π-xch. models, absorption (rescattering) models

Apology: older well-known H1 LB results not shown here

Motivations: LN production, virtual exchange







e.g.
π–xch.

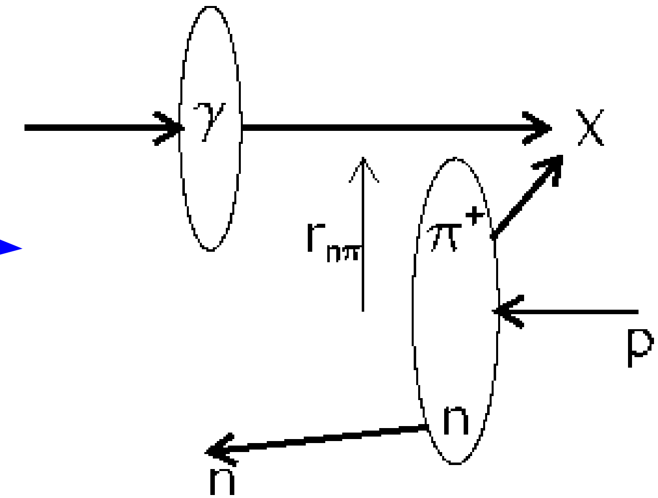
- LB can come from 'standard' fragmentation (baryon # has to go somewhere)
- Can compare to 'standard' MC gens.: x_L, p_T^2 distributions
- LB can be produced via exchange of virtual particles: isovector (*p*&*n*) and isoscalar (*p* only).
- Parameterizations from low energy hadronic data. Compare: x_L, p_T^2 dist.
- Cross section factorizes:

$$\sigma_{ep\to eNX}(W^2,Q^2,x_L,p_T) = f_{\pi/p}(x_L,p_T)\ \sigma_{e\pi\to eX}(W^2/(1-x_L),Q^2)$$

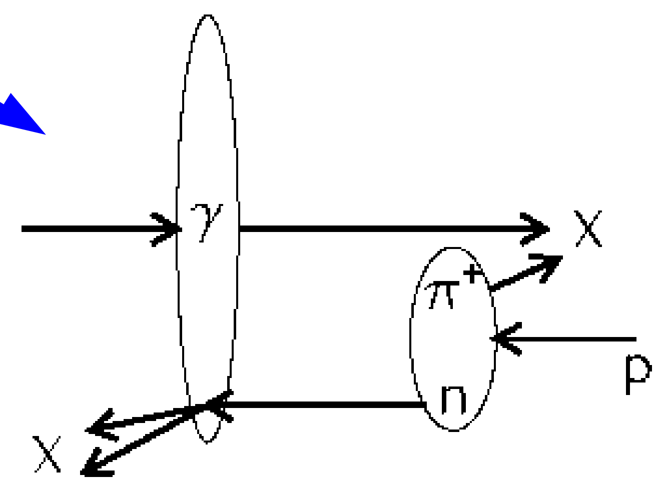
Motivations: Absorption (Rescattering)

For e.g. LN production via π-exchange:

- In DIS γ^* is small; small chance both *n*,π scatter on γ^*: *n* reaches detector



- In photoproduction γ large; if *n*-π separation smaller rescattering of *n* may occur: *n* kicked to lower xL & higher pT (migration) and may escape detection (absorption loss)



- In another language: multi-Pomeron exchange
- Compare photoproduction & DIS:
  - x_L , p_T^2 distributions
  - effects of absorption?
- Compare to absorption (loss) calculations of: D' Alesio & Pirner; (Kaidalov,) Khoze, Martin, Ryskin

Data sets, LB measurement

LB are selected from inclusive data sets (i.e. no LB tag):

- DIS: $Q^2 > 2$-3 GeV^2, $\langle Q^2 \rangle \approx 13$ GeV^2; 3 subsets $\langle Q^2 \rangle \approx 2.7, 8.9, 40$ GeV^2
- γp: $Q^2 < 0.02$ GeV^2, e^+ tagged $\Rightarrow 150 < W_{\gamma p} < 270$ GeV
- Dijets in γp: $Q^2 < 1$ GeV^2, $130 < W_{\gamma p} < 280$ GeV, $E_T^{1(2)} > 7.5(6.5)$ GeV

LB measurement

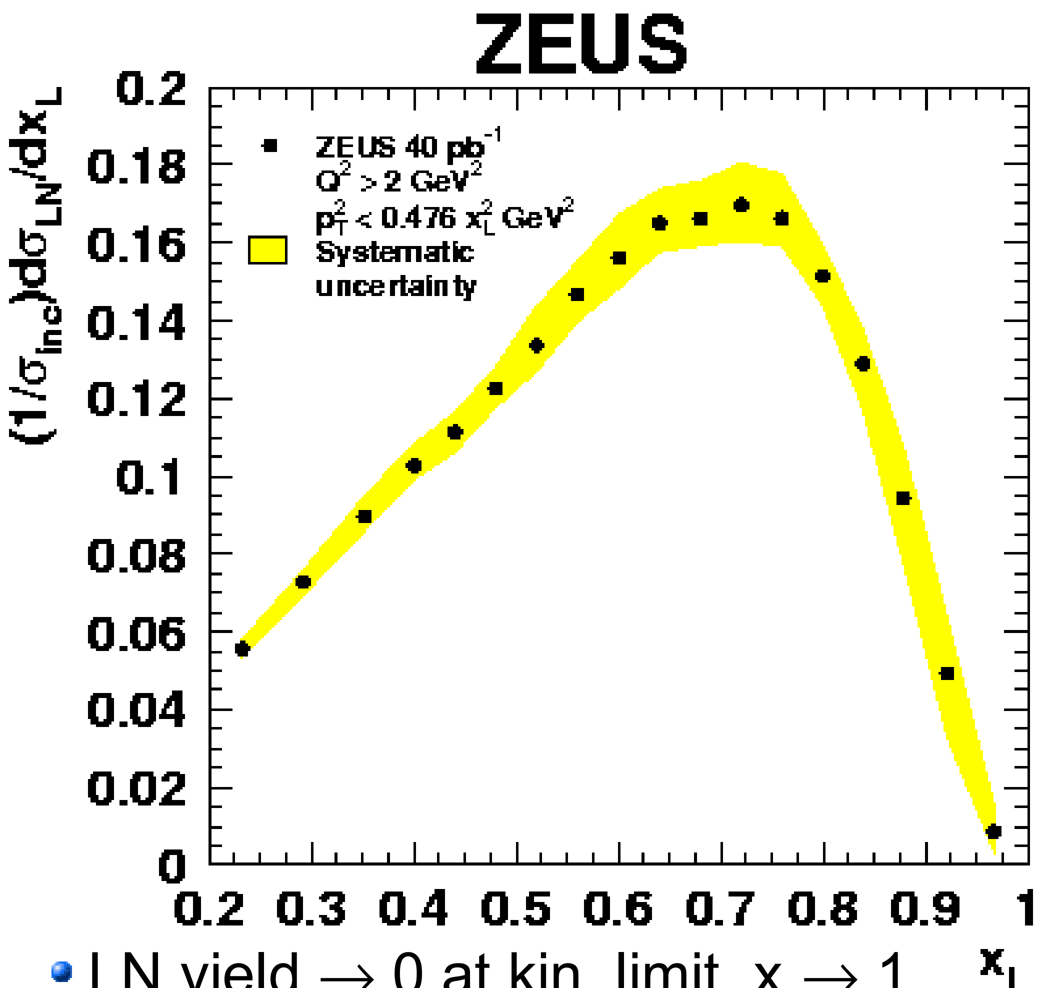
- LN: calorimeter 105m from I.P., scintillator hodoscope posn. det.
  - Energy resolution: $\sigma_E/E \approx 0.7/\sqrt{E}$; apertures limit $\theta_n \Rightarrow p_T^{\,2} < 0.476\, x_L^{\,2}$ GeV^2
- LP: Si-strip detectors along HERA *p*-beam line
  - Energy resolution: $\sigma_E/E \approx <1\%$; apertures limit $p_T^{\,2} < 0.5$ GeV^2
- Both: p_T resolution dominated beam p_T spread; $\sigma_{PT} \sim 50$-$100\, x_L$ MeV

LB yields:

- DIS, γp have very different inclusive cross sections σ_{inc}
- For sensible comparisons look at LN yields: $r_{LB} \equiv \sigma_{LB}/\sigma_{inc}$
- Additional benefit: systematic uncertainties of central ZEUS cancel; only have LB systematic uncertainties

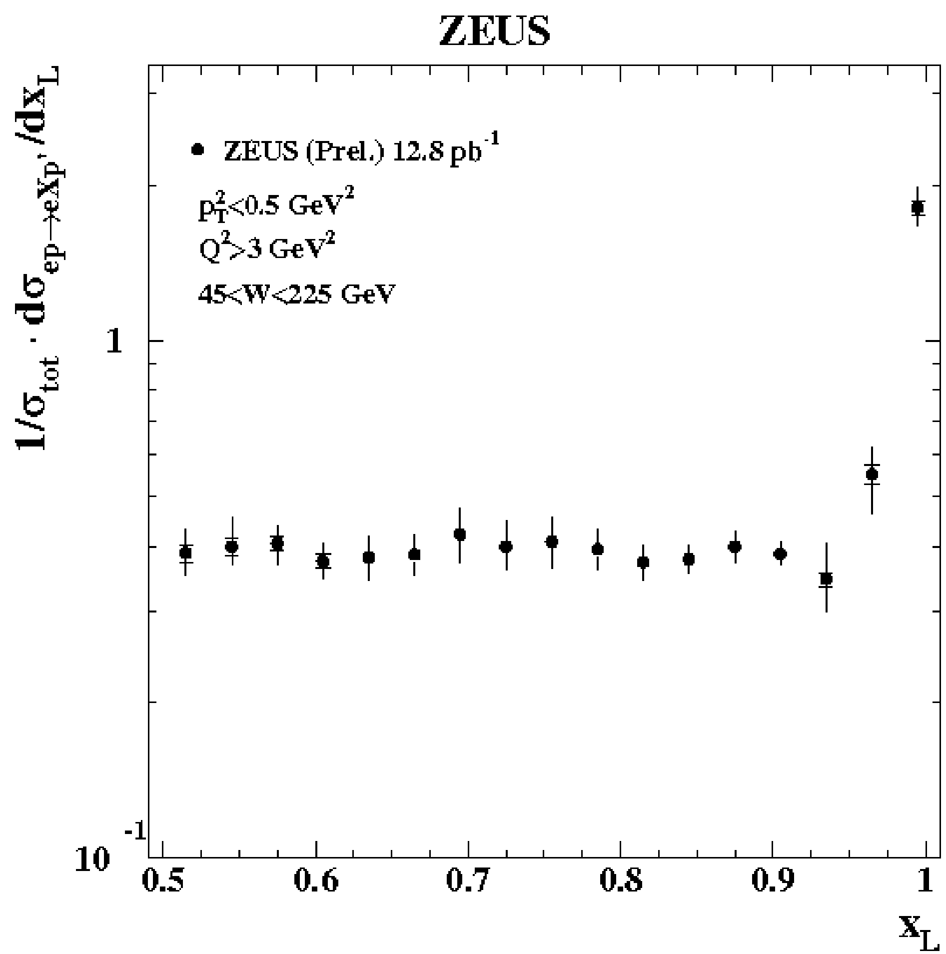
DIS x_L distributions: max. p_T ranges

- LN: $p_T^2 < 0.476\, x_L^2$ GeV^2



- LN yield $\rightarrow$ 0 at kin. limit $x_L \rightarrow 1$
- Below $x_L \approx 0.7$ yield drops due to decreasing p_T^2 range

- LP: $p_T^2 < 0.5$ GeV^2

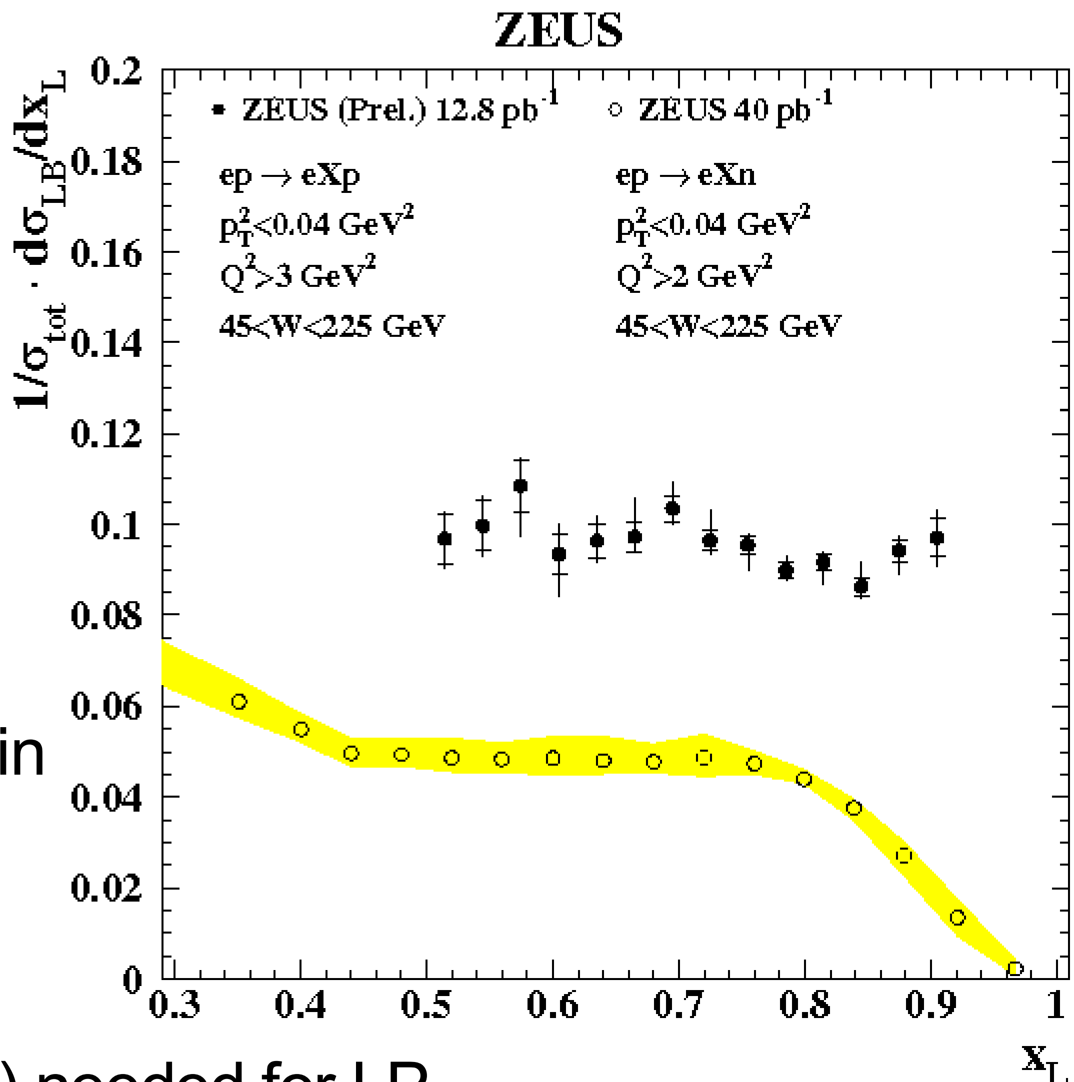


- LP yield diffractive peak $x_L \rightarrow 1$
- Below $x_L \approx 0.95$ yield flat

DIS x_L distributions: same p_T range

- LP/LN: $p_T^2 < 0.04$ GeV^2

Both detectors acceptances overlap at low p_T for $0.5 < x_L < 0.9$:



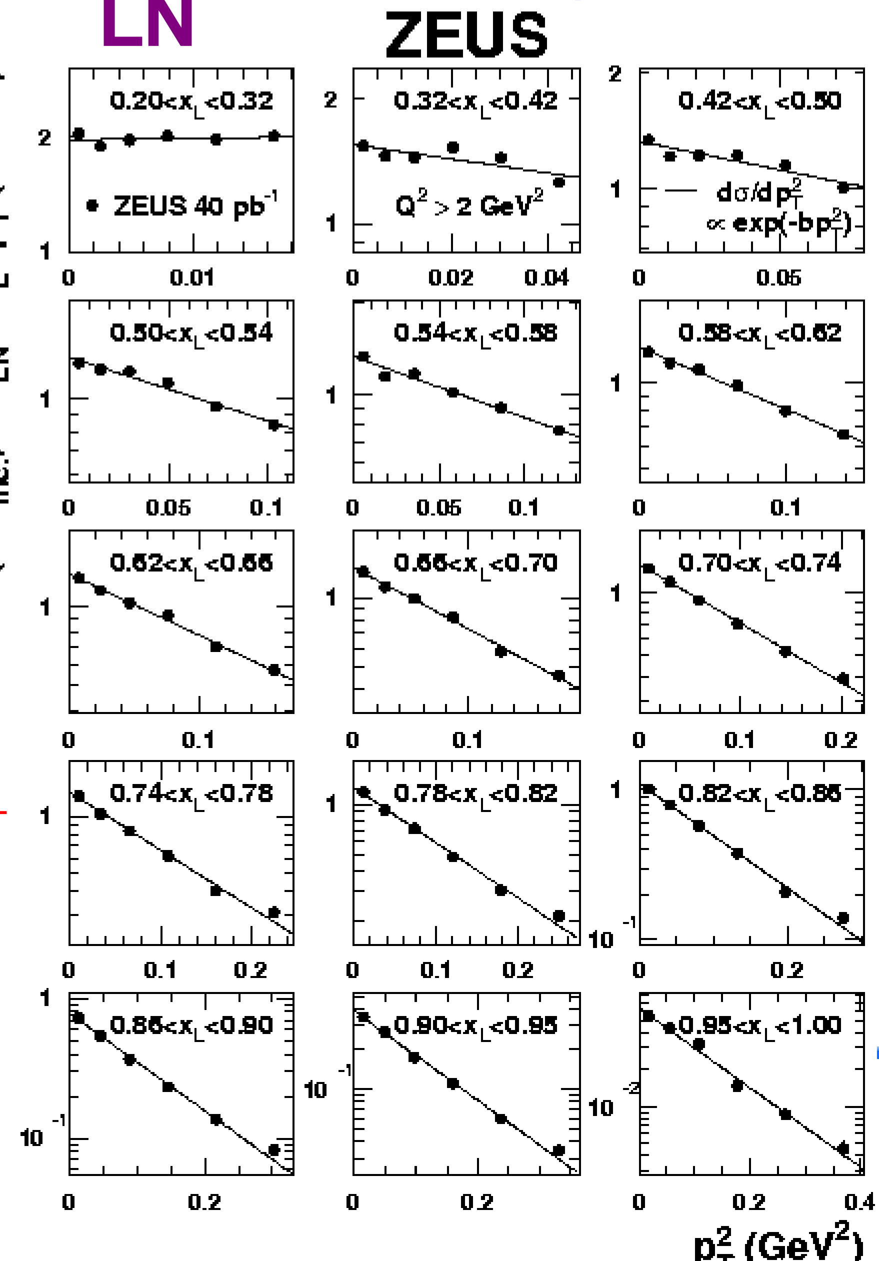
- For pure isovector exchange isospin Clebsch-Gordan $\Rightarrow r_{LP} = \frac{1}{2} r_{LN}$
- Data: $r_{LP} \approx 2\, r_{LN}$
- $\Rightarrow$ additional exchanges (isoscalar) needed for LP

$p_T^{\,2}$ distributions DIS

$$\frac{1}{\sigma_{inc}}\frac{d^2\sigma_{LN}}{dx_L dp_T^2}$$

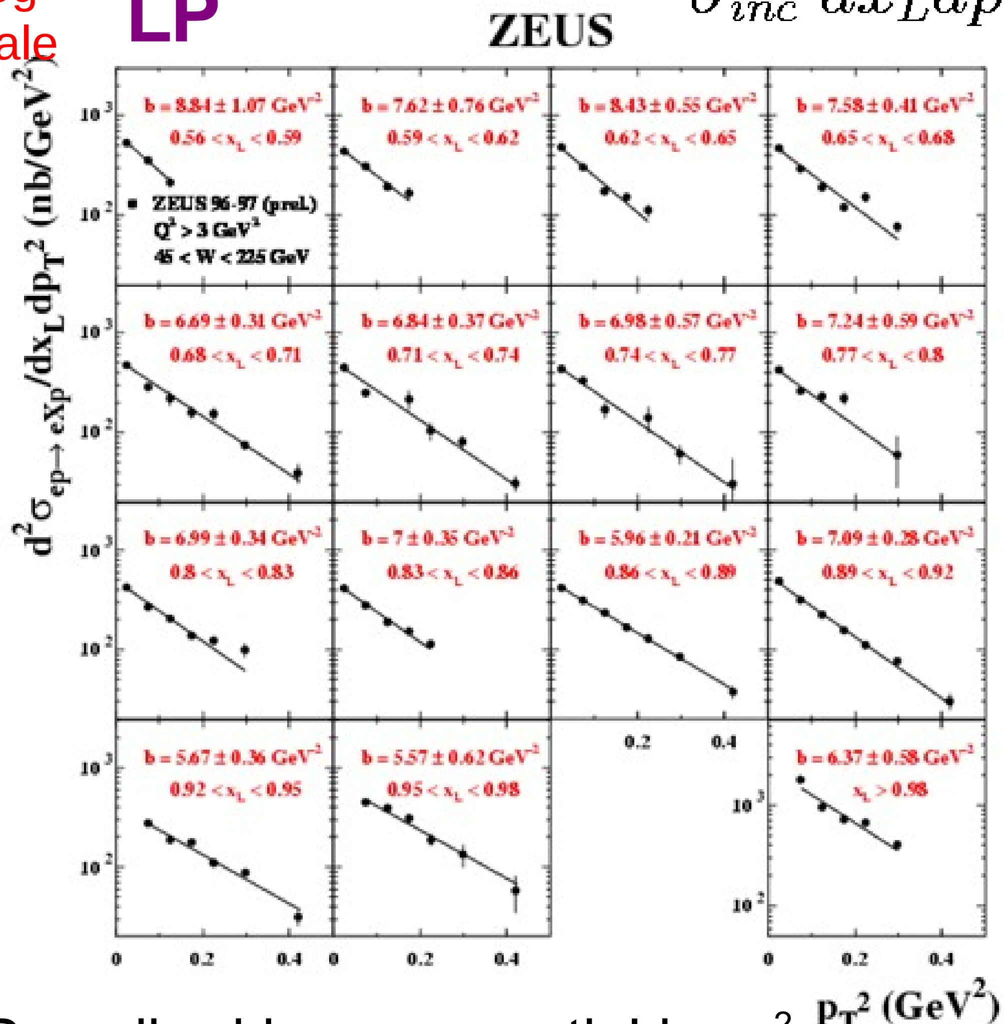
LN

note varying LN $p_T^{\,2}$ ranges



log scale

LP



- Described by exponential in $p_T^{\,2}$:

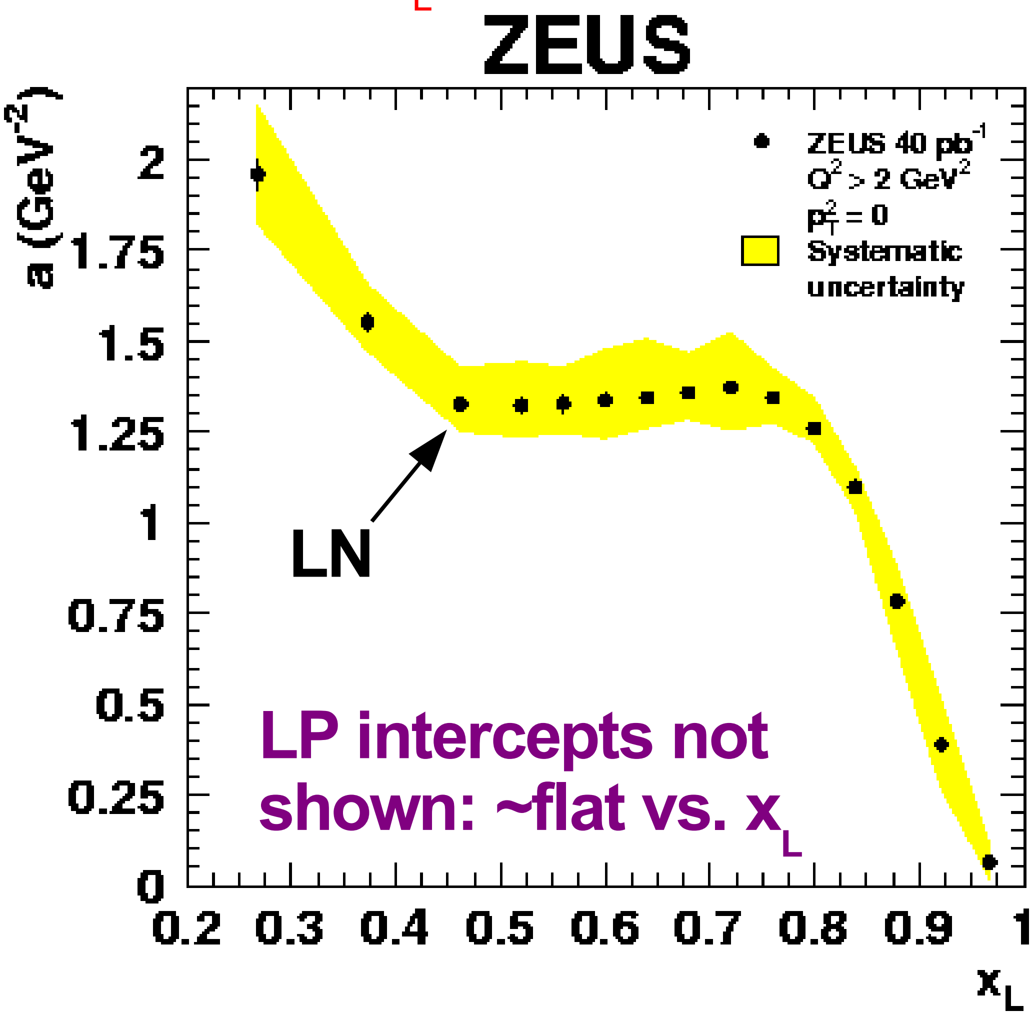
$$\frac{1}{\sigma_{inc}}\frac{d^2\sigma_{LN}}{dx_L dp_T^2} = a(x_L)e^{-b(x_L)p_T^2}$$

- Intercepts $a(x_L)$ and slopes $b(x_L)$ fully characterize $(x_L, p_T^{\,2})$ dist.

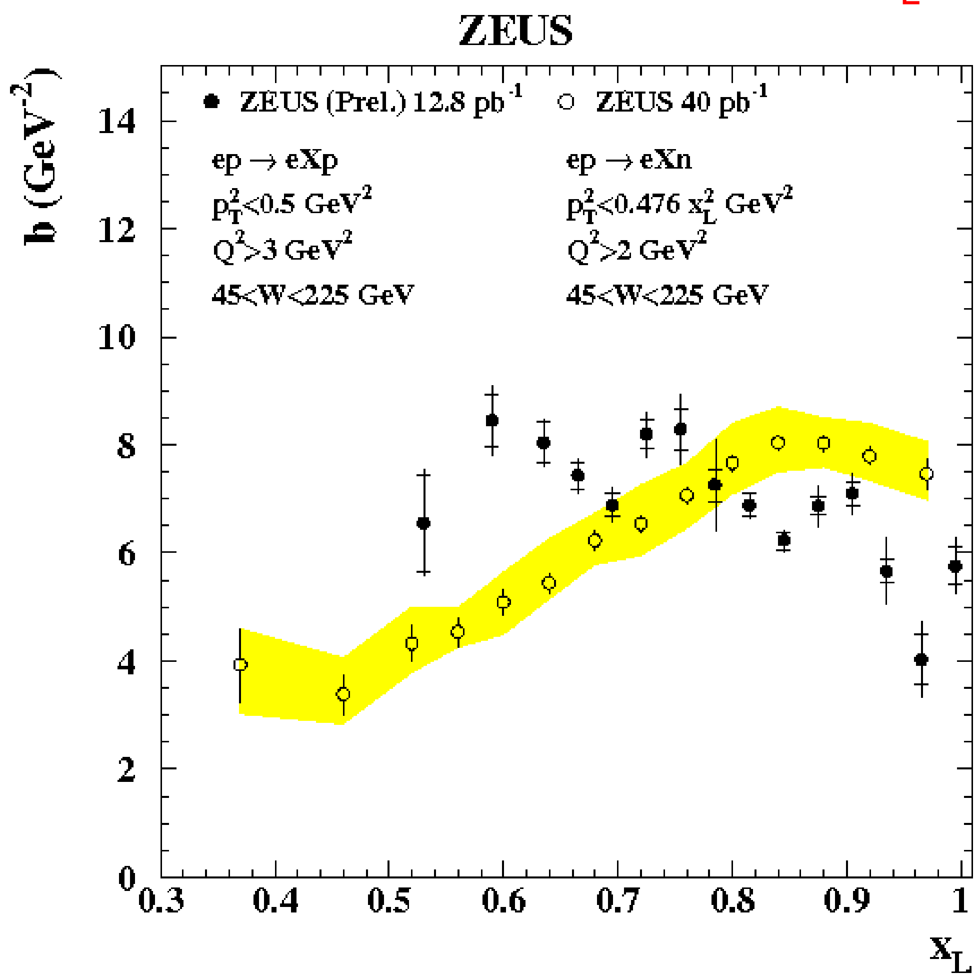
DIS p_T^2 distributions: slopes & intercepts

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

- intercepts $a(x_L)$:



- slopes $b(x_L)$:

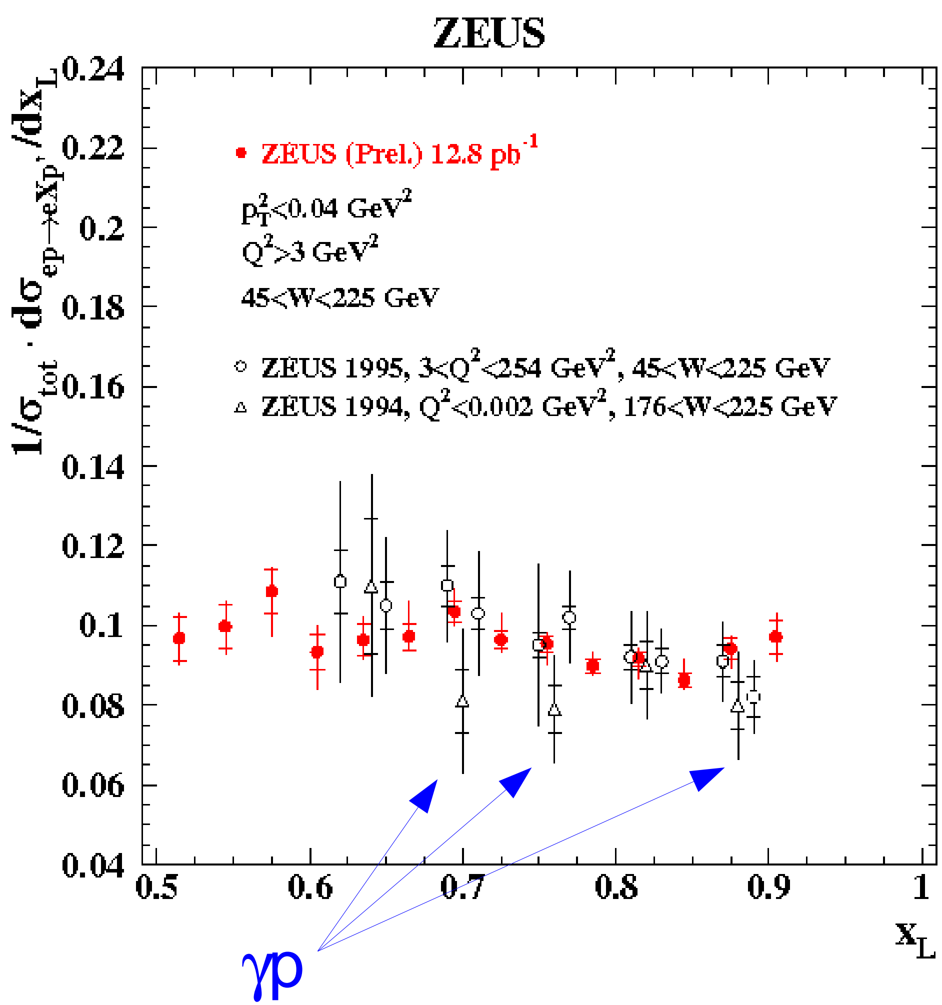


- LN intercepts fall with x_L, bump/plateau/shoulder $0.4<x_L<0.8$
- LN slopes sharp rise w/ x_L
- LP slopes ~flat w/ x_L

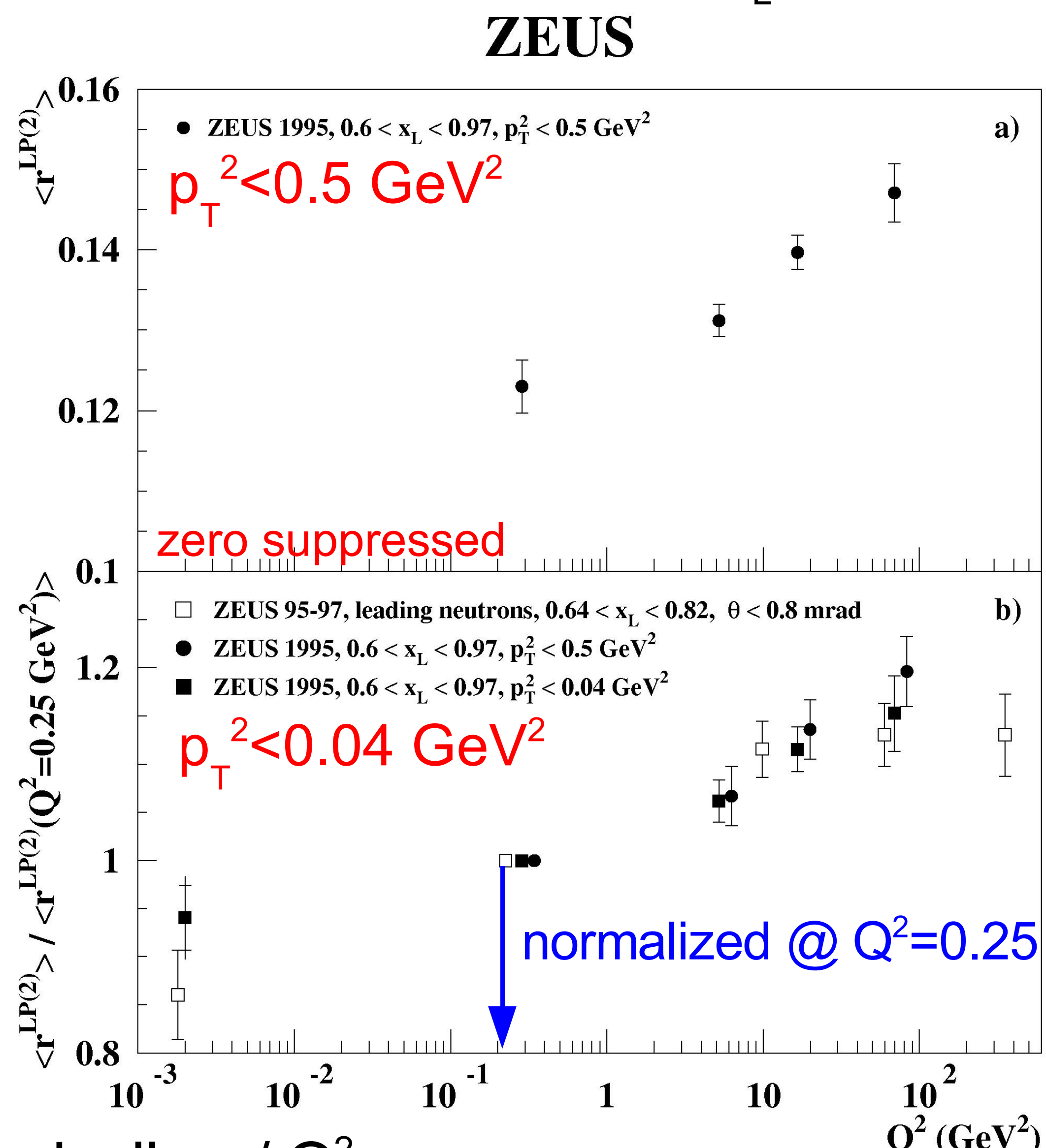
Q^2 dependence of LP production

<u>DIS + γp:</u>

- x_L distributions:



- Total yield $0.6<x_L<0.9$:

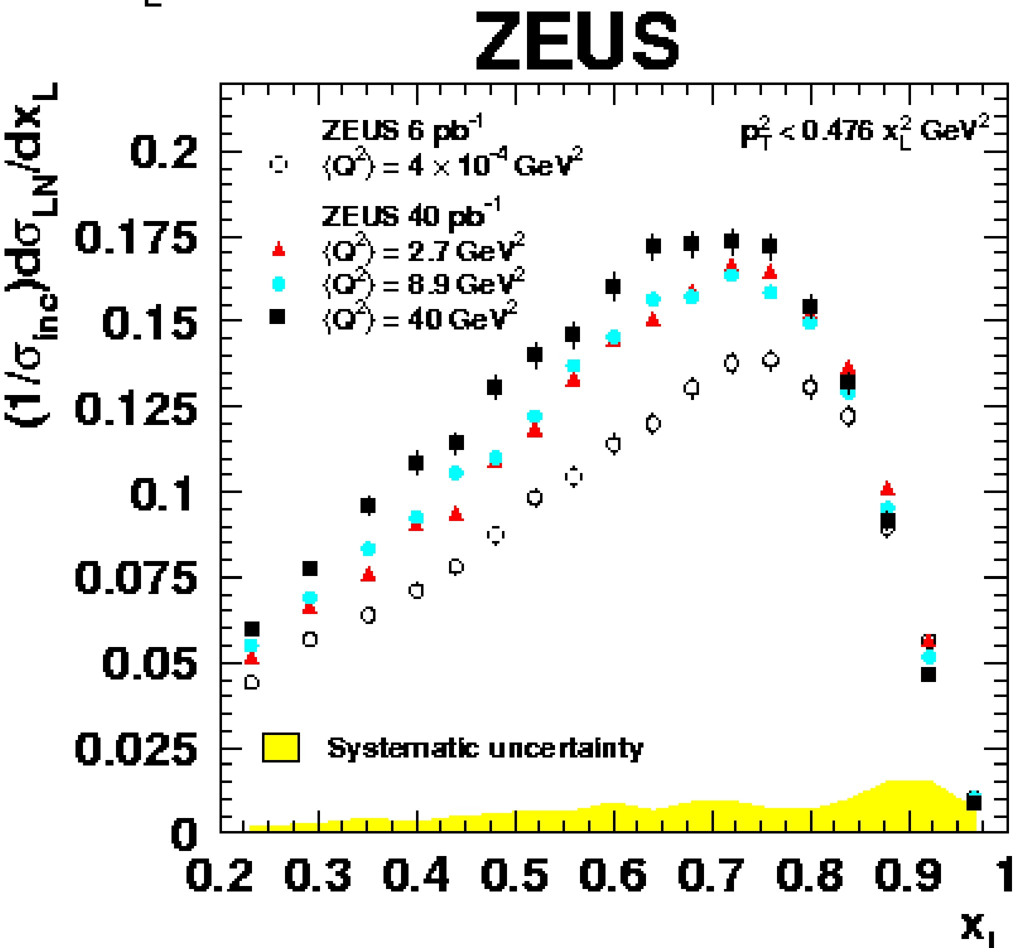


- LP yield increases monotonically w/ Q^2
- Consistent w/ absorption: larger $Q^2 \Rightarrow$ smaller γ, less absorp.

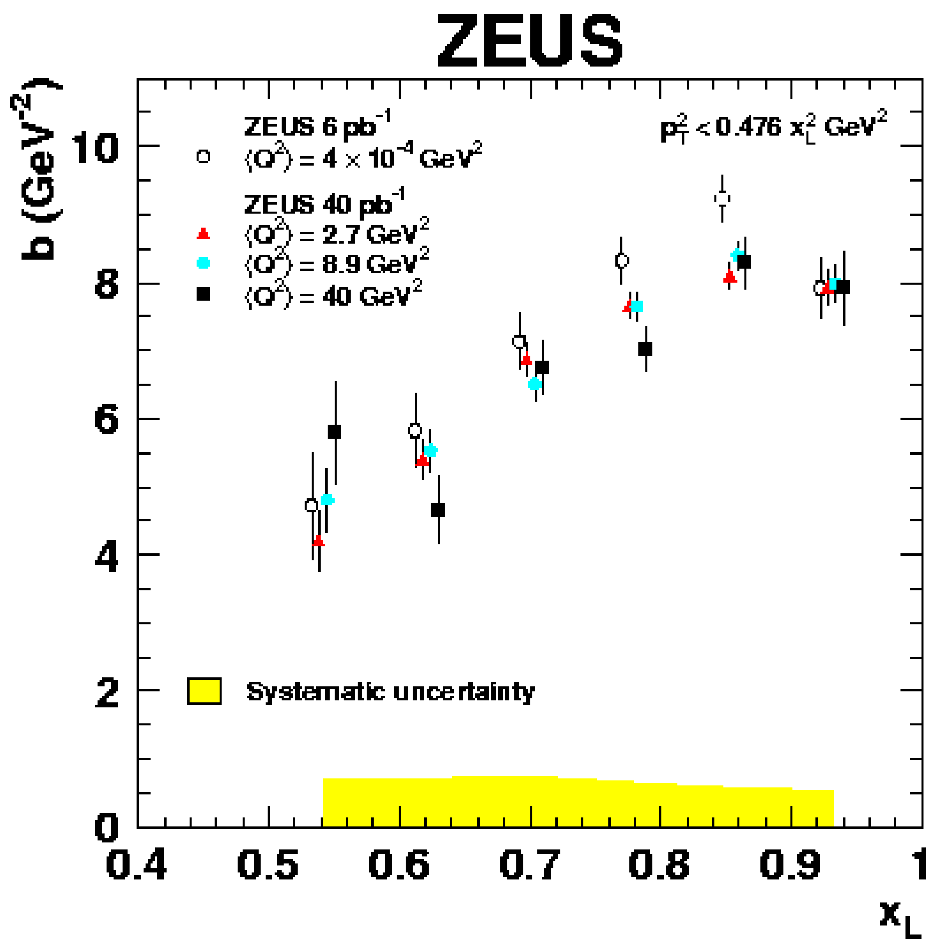
Q^2 dependence of LN production

<u>3 Q^2 bins DIS + γp:</u>

- x_L distributions:



- slopes $b(x_L)$:



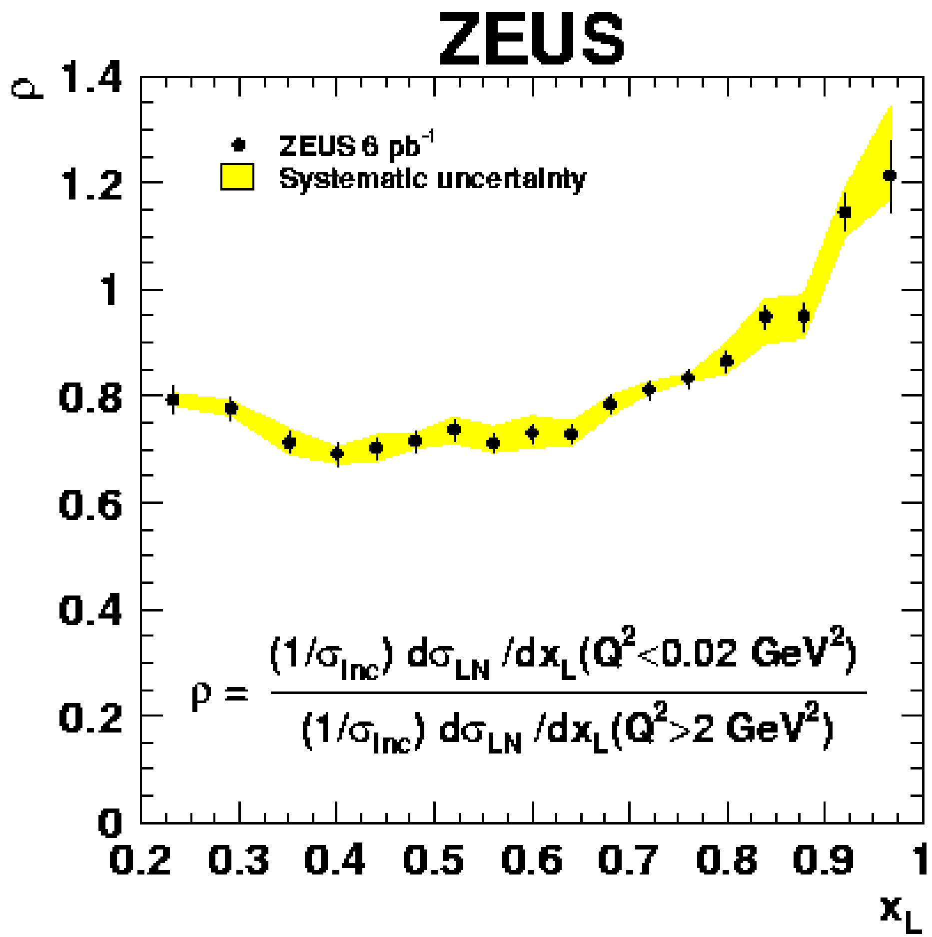
- LN yield increases monotonically w/ Q^2
- Consistent w/ absorption:

  larger $Q^2 \Rightarrow$ smaller γ, less absorp.

- slopes for 3 Q^2 bins ~same
- slope for γp significantly larger

Compare γp/DIS: LN x_L distributions

- Combine all DIS Q^2>2 GeV^2, compare to γp x_L dist.: ratio

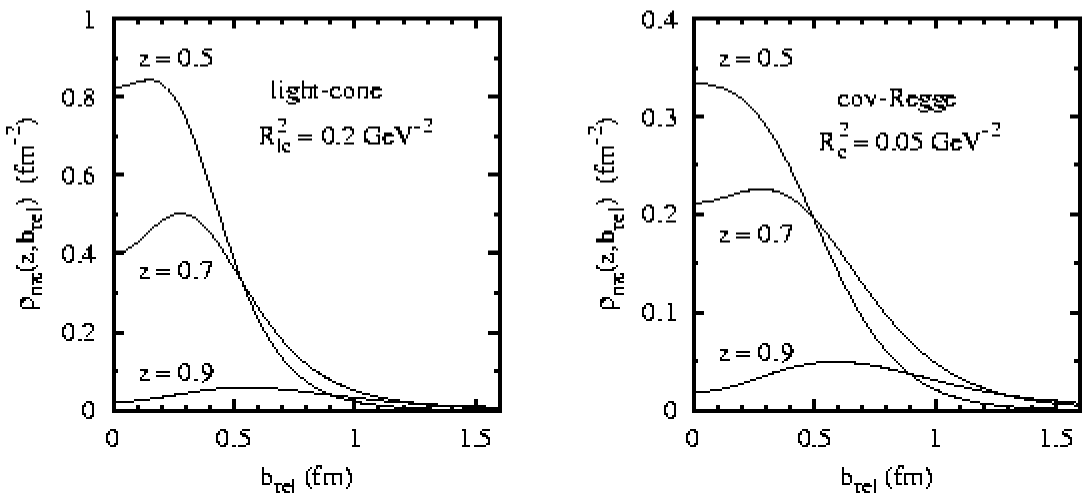


Ratio ~70% mid-x_L,

rising above 1 as $x_L \rightarrow 0.9$

<u>Qualitatively consistent w/ absorption:</u>

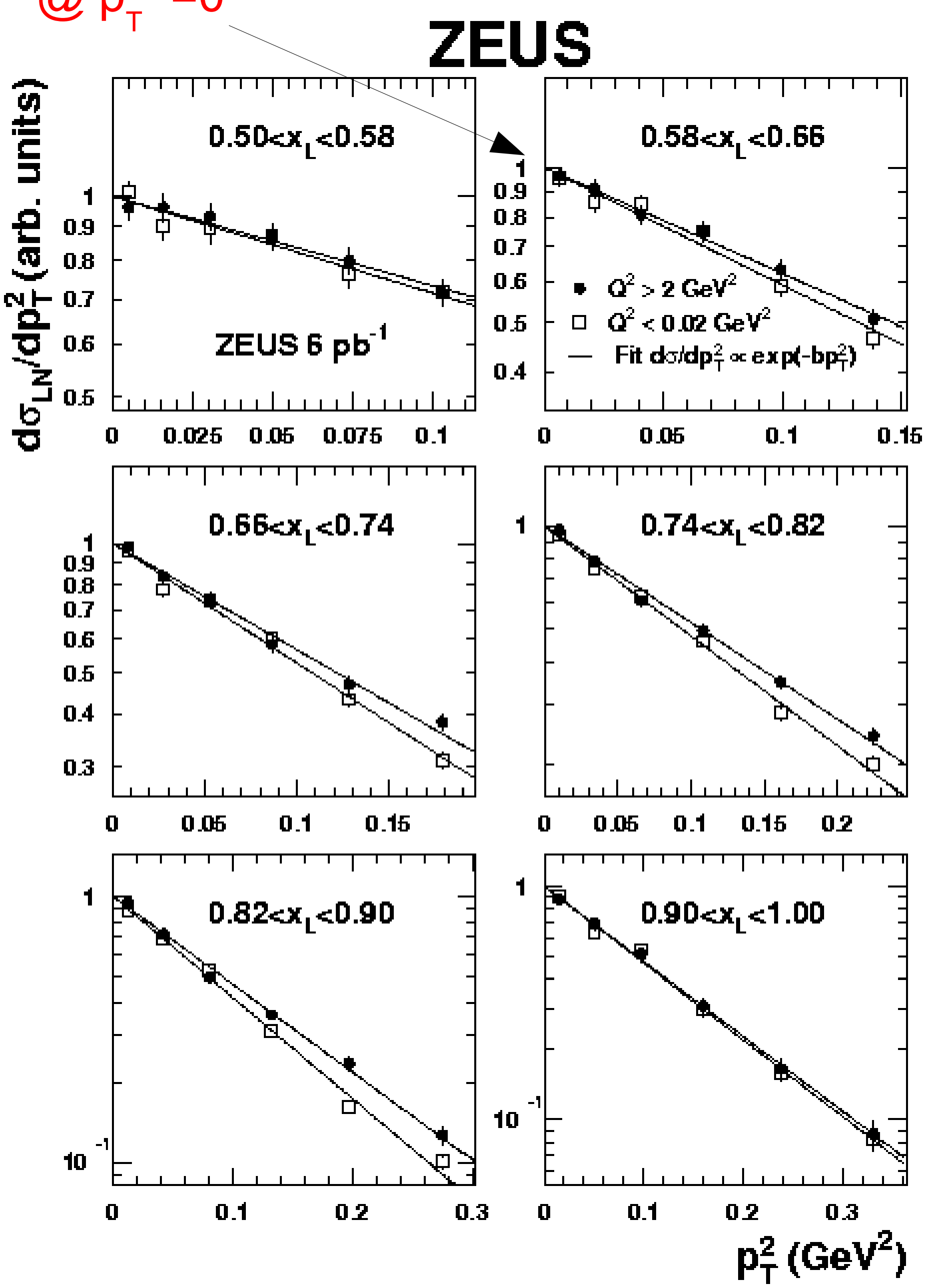
- Exchange model: mean *n*-π separation $r_{n\pi}$ decreases at lower x_L:

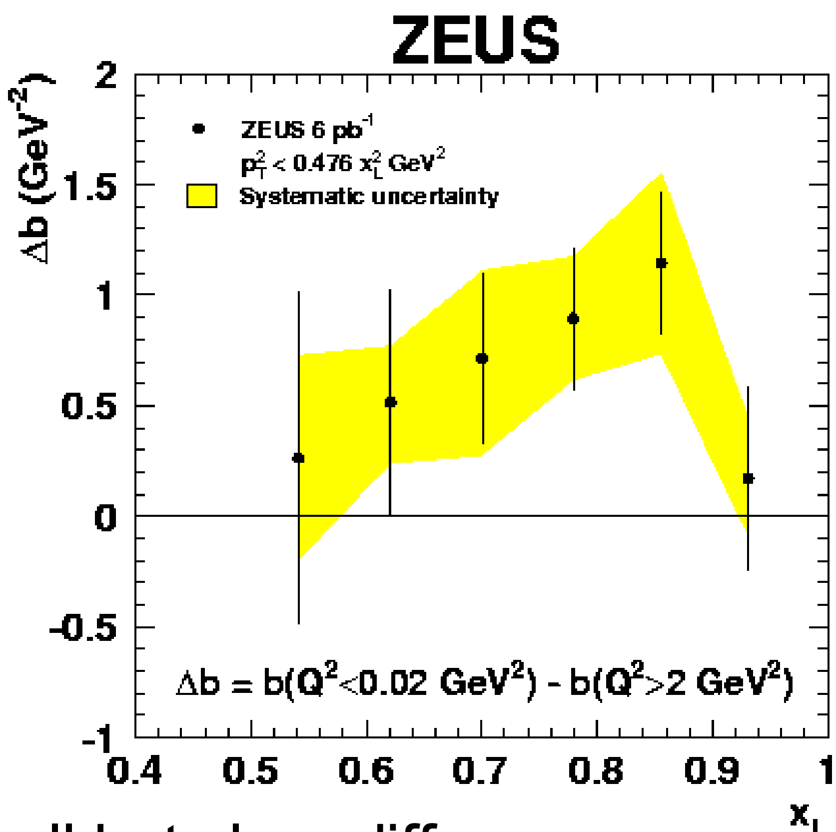


- smaller $r_{n\pi} \Rightarrow$ more absorption at lower as x_L as in data

Compare γp/DIS: LN p_T^2 distributions

normalized @ $p_T^2=0$

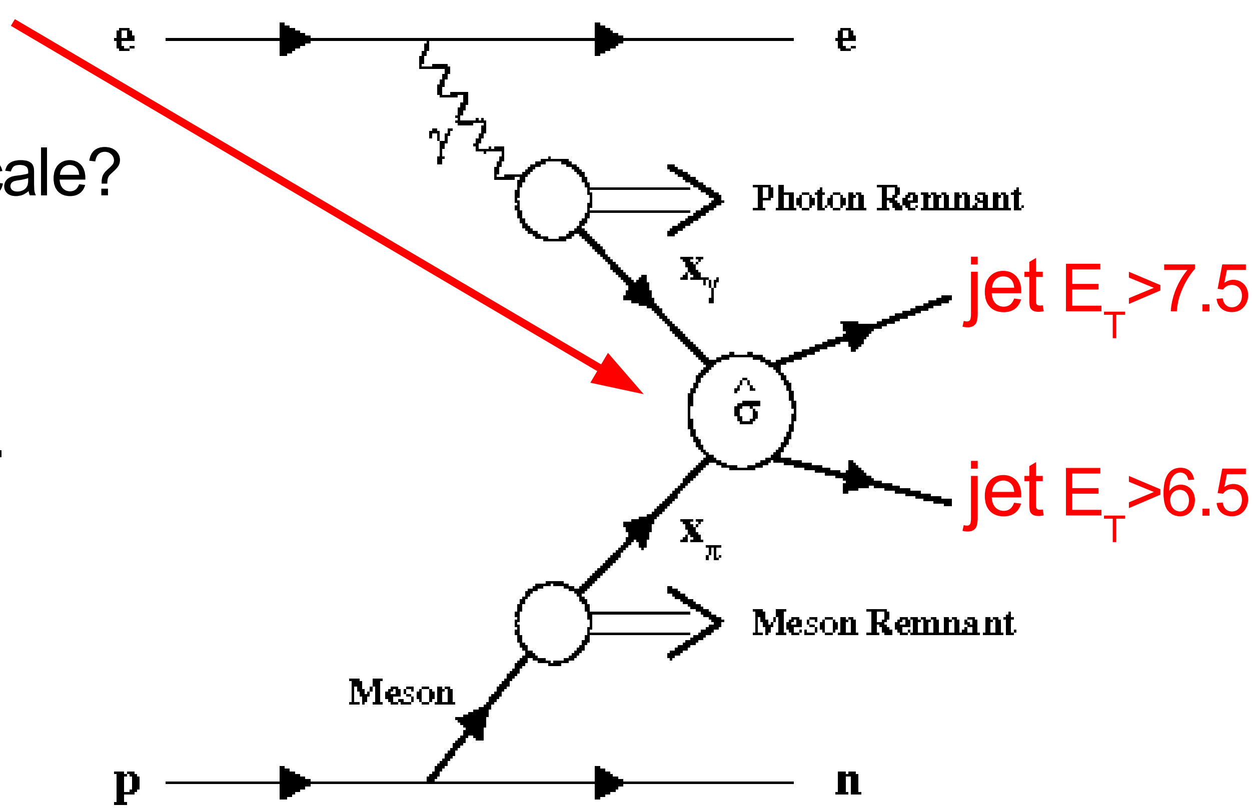




- Small but clear difference:
  $b(\gamma p) > b(\mathrm{DIS})$ for $0.6<x_L<0.9$
- Qualitatively consistent w/ absorption:
  more abs. @ small $r_{n\pi}$ ~ large p_T
  fewer LN @ high p_T $\Rightarrow$ larger slope

Compare LN in γp+jj & DIS

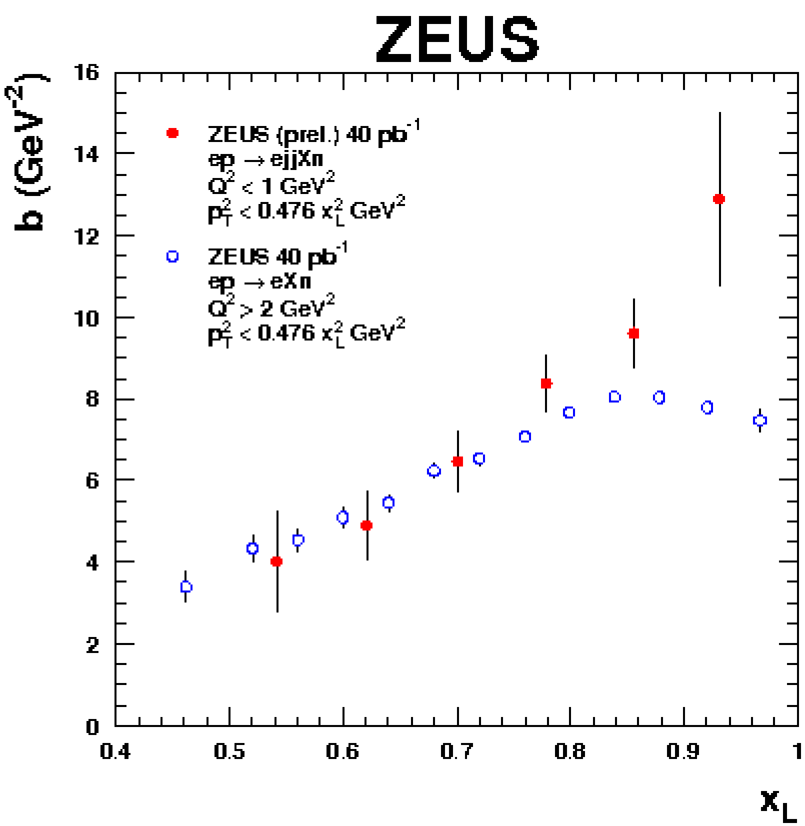
- We have seen effects qualitatively consistent with absorption going hi-$Q^2 \rightarrow$lo-$Q^2 \rightarrow \gamma$p
- Going from hard$\rightarrow$soft scale increasing absorption
- Suppose in γp we reintroduce a hard scale by requiring high E_T dijets:
- Still signs of absorption?
- Or eliminated by high E_T scale?



- Recent LN in γp+jj results...

Compare LN in γp+jj & DIS : $p_T^{\,2}$ & x_L dist.

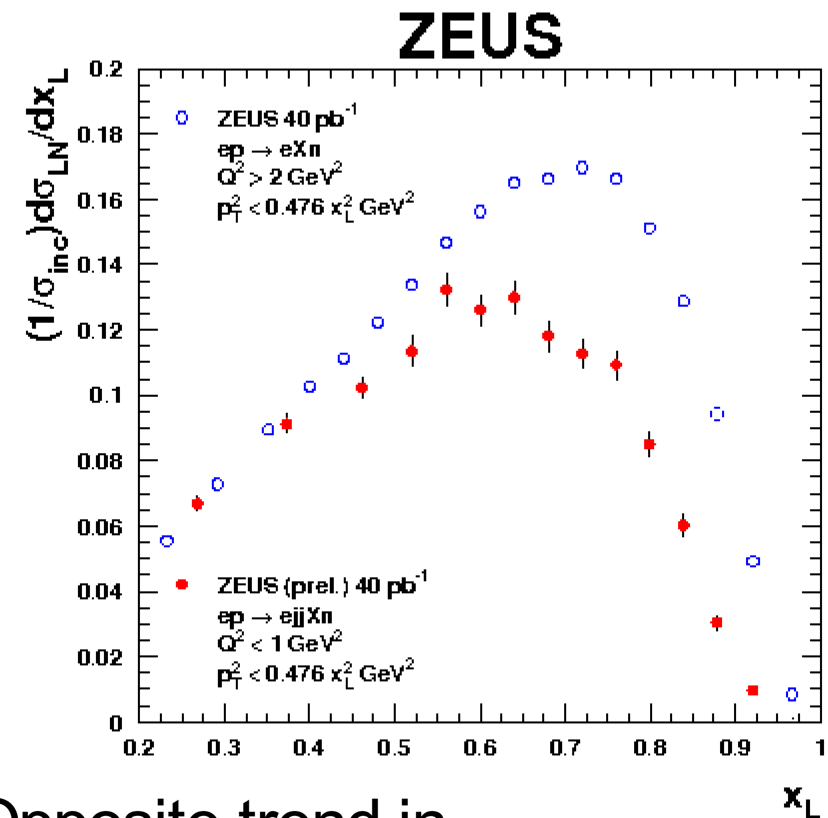
- The $p_T^{\,2}$ dist. in γp+jj again exponentials w/ slope *b*:



- Still ~same as DIS:

  ⇒ same production mechanism
- Statistics limit further conclusions

- But the x_L dist. strikingly different!

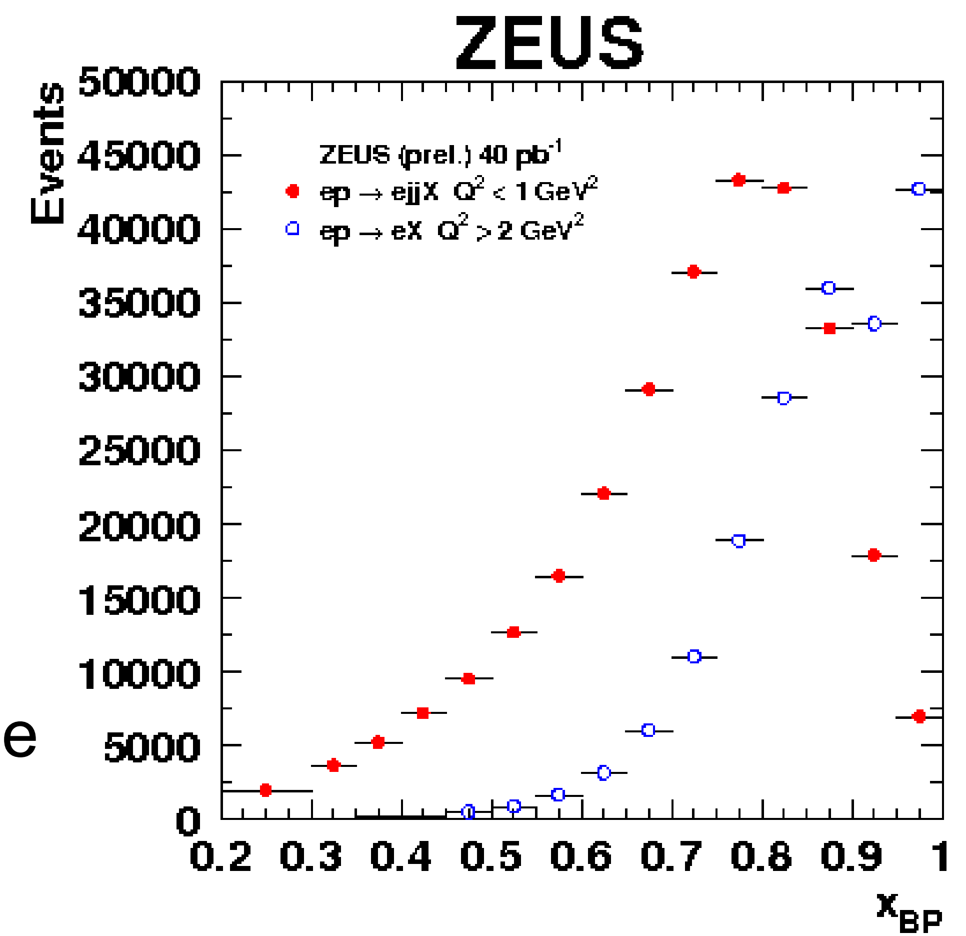


- Opposite trend in

  hi-Q^2→lo-Q^2→γp w/o jet requir.
- There supression @ *low* x_L
- Here supression @ *high* x_L
- Kinematic suppression?

LN in γp+jj & DIS : kinematic constraints

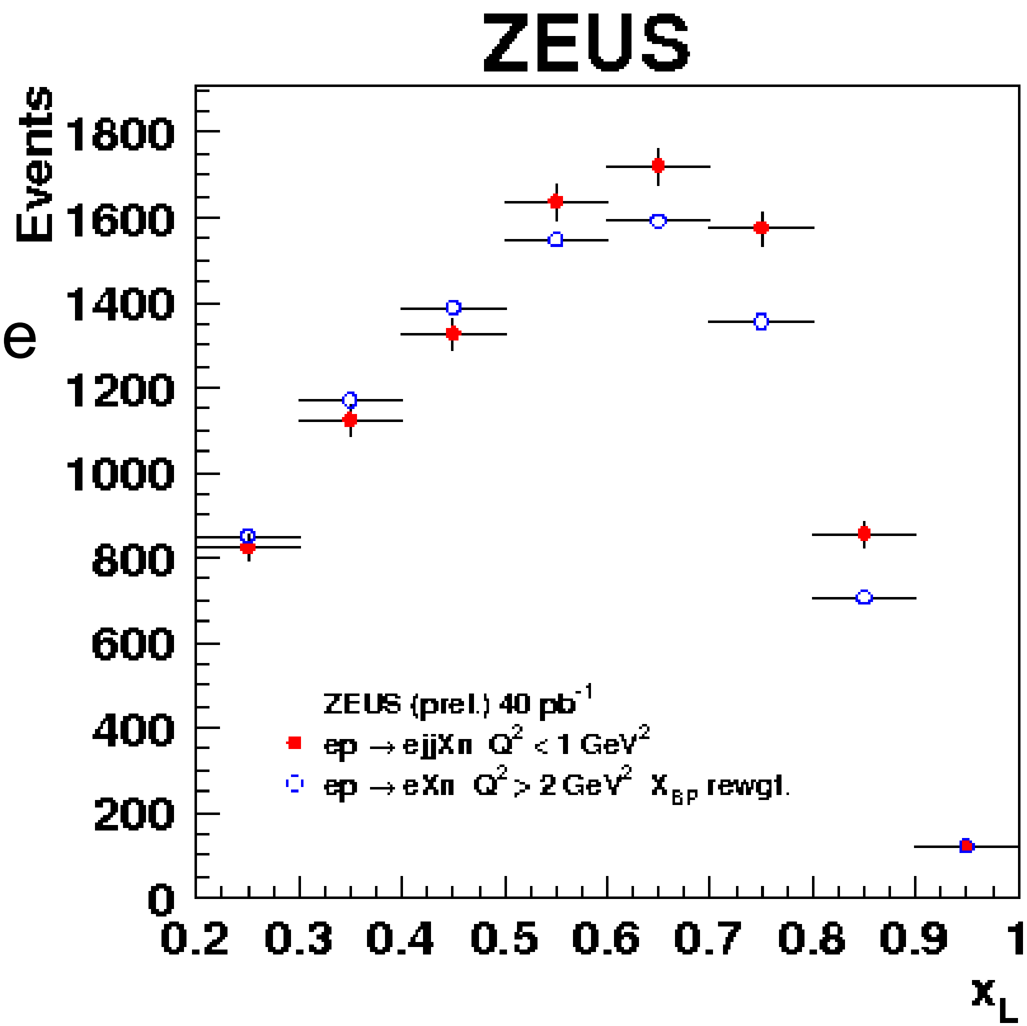
- The requirement of high-E_T dijets exacts a price on the phase space available for LB production
- We can quantify this with energy measurement in the central detector:
  X_{BP} = fraction *p*-energy available for LB down beam-pipe (BP)
  (note: $X_{BP} = 1\text{-}X_{Pom}$ in diffraction)



- Very different for DIS & γp+jj:
  - DIS typically >80% *p*-energy available
  - in γp+jj much less available
- Can test this quantitatively:
  - take LN in DIS
  - reweight to match X_{BP} in γp+jj
  - compare rewgtd. DIS x_L to γp+jj x_L distribution

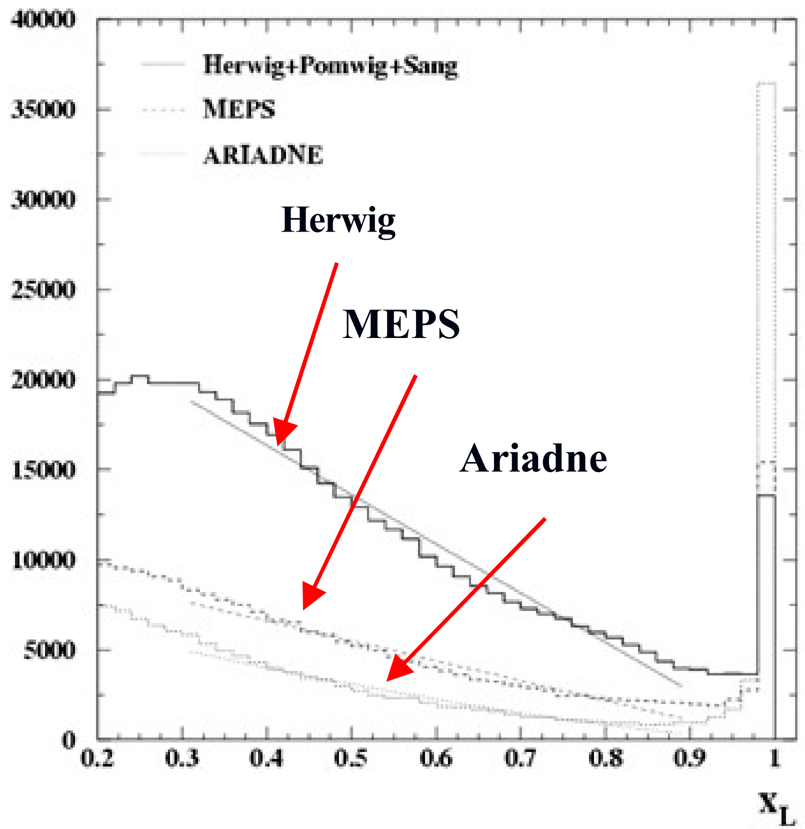
LN in γp+jj & DIS : X_{BP} rewgtd. x_L dist.

- Reweighting the DIS LN x_L to match the X_{BP} in γp+jj we get:
- Suppression @ high x_L mostly gone
- Large suppression @ low x_L seen in γp w/o jet requirment not there
- Conclusion (tentative): introducing a hard scale via high jet E_T reduces/removes absorption effects
- More careful MC studies of kinematic effects ongoing...



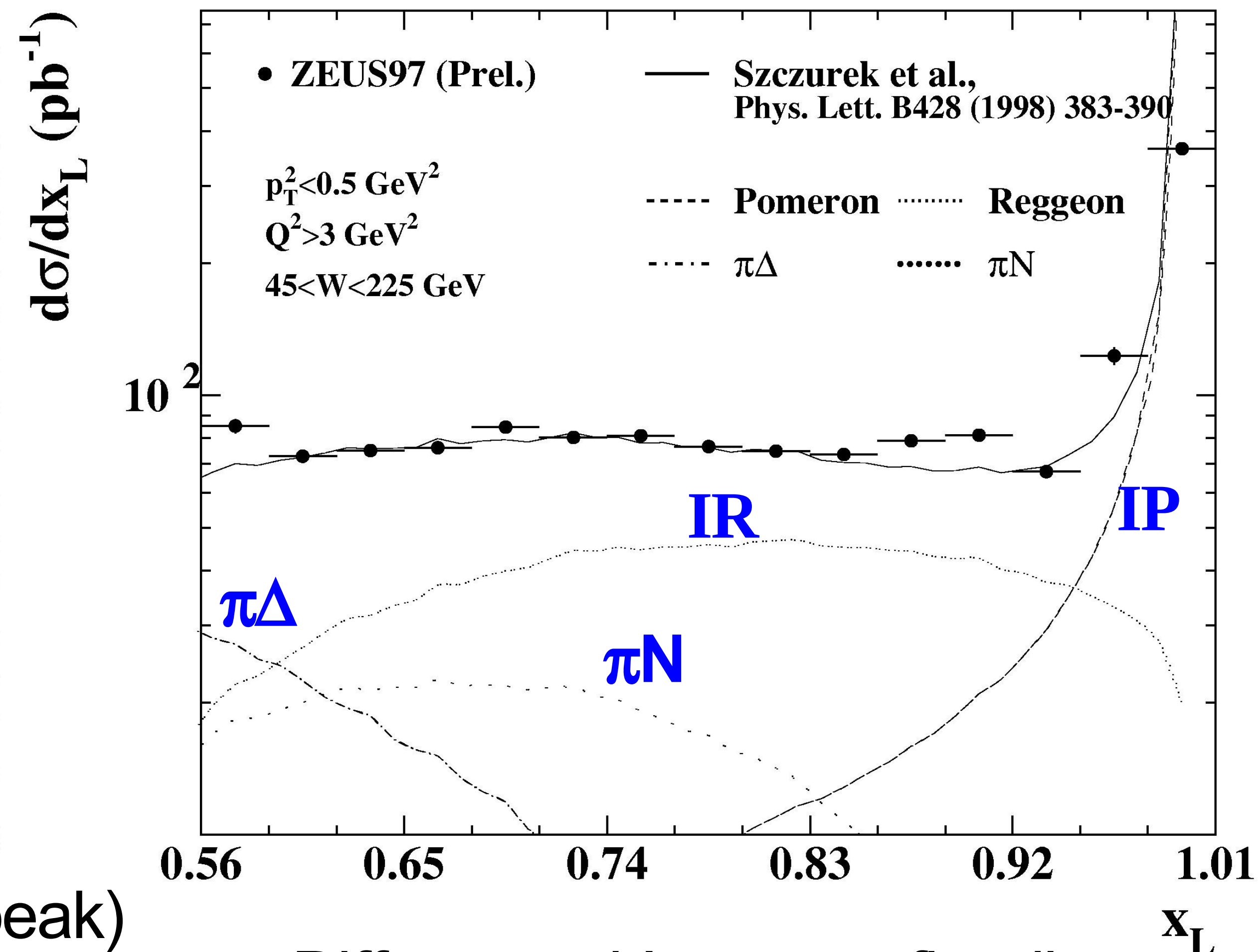
Model comparisons: DIS LP x_L

- 'Std. fragmentation' MCs:



- All fall with x_L (except diff. peak)
- Not flat like data, fail

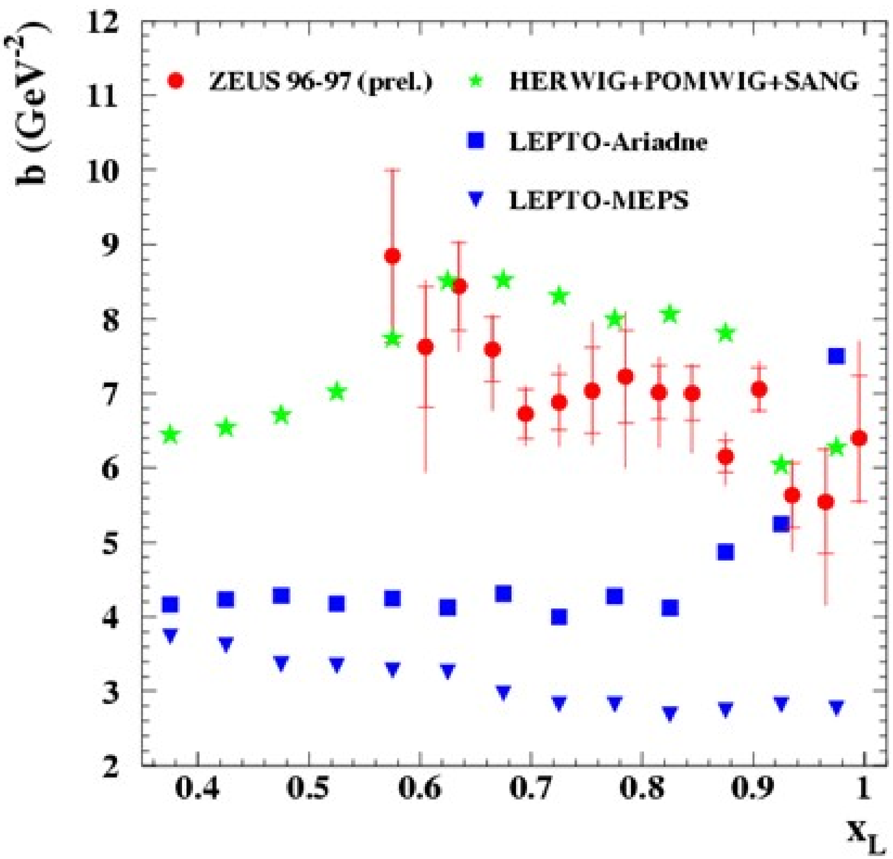
- Model w/ multiple exchanges:



- Different xch's sum to flat dist.
- Good agrrement w/ data

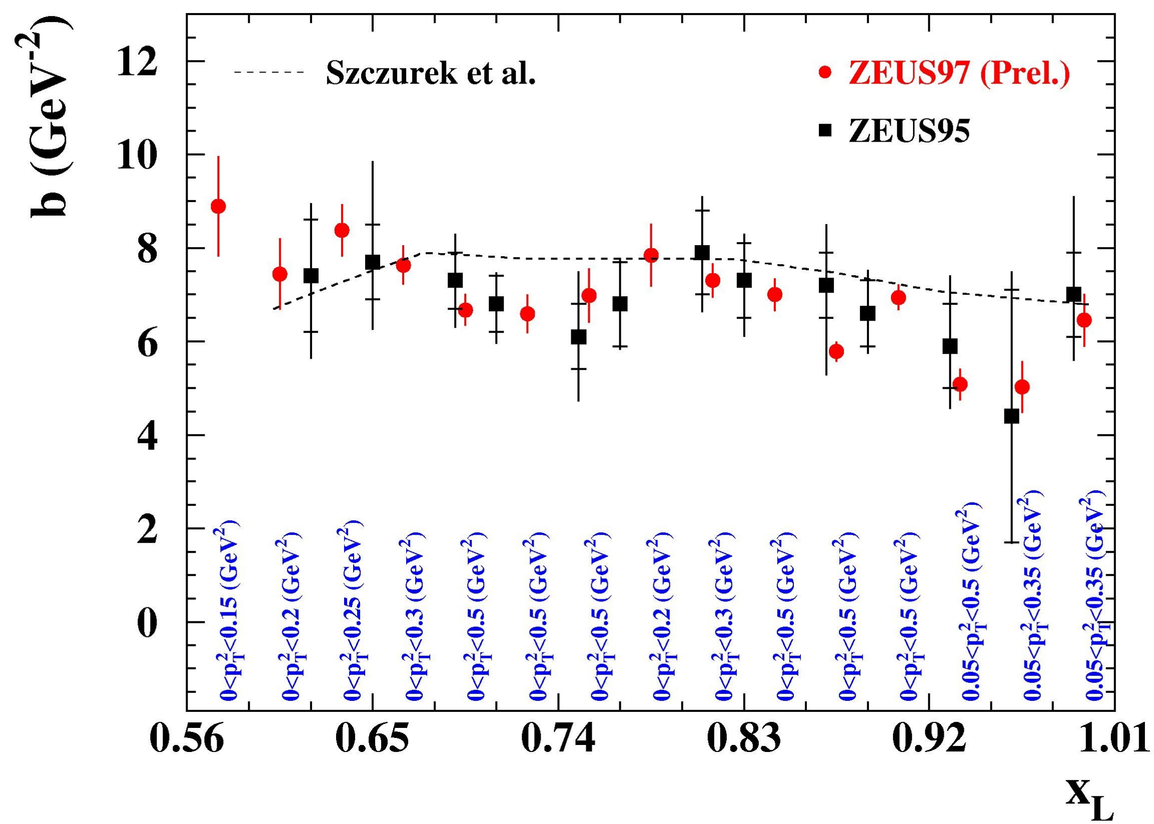
Model comparisons: DIS LP slopes

- 'Std. fragmentation' MCs:



- Ariadne, MEPS slopes too small
- Herwig ~ data

- Model w/ multiple exchanges:



- Different xch's conspire to flat dist.
- Good agreement w/ data

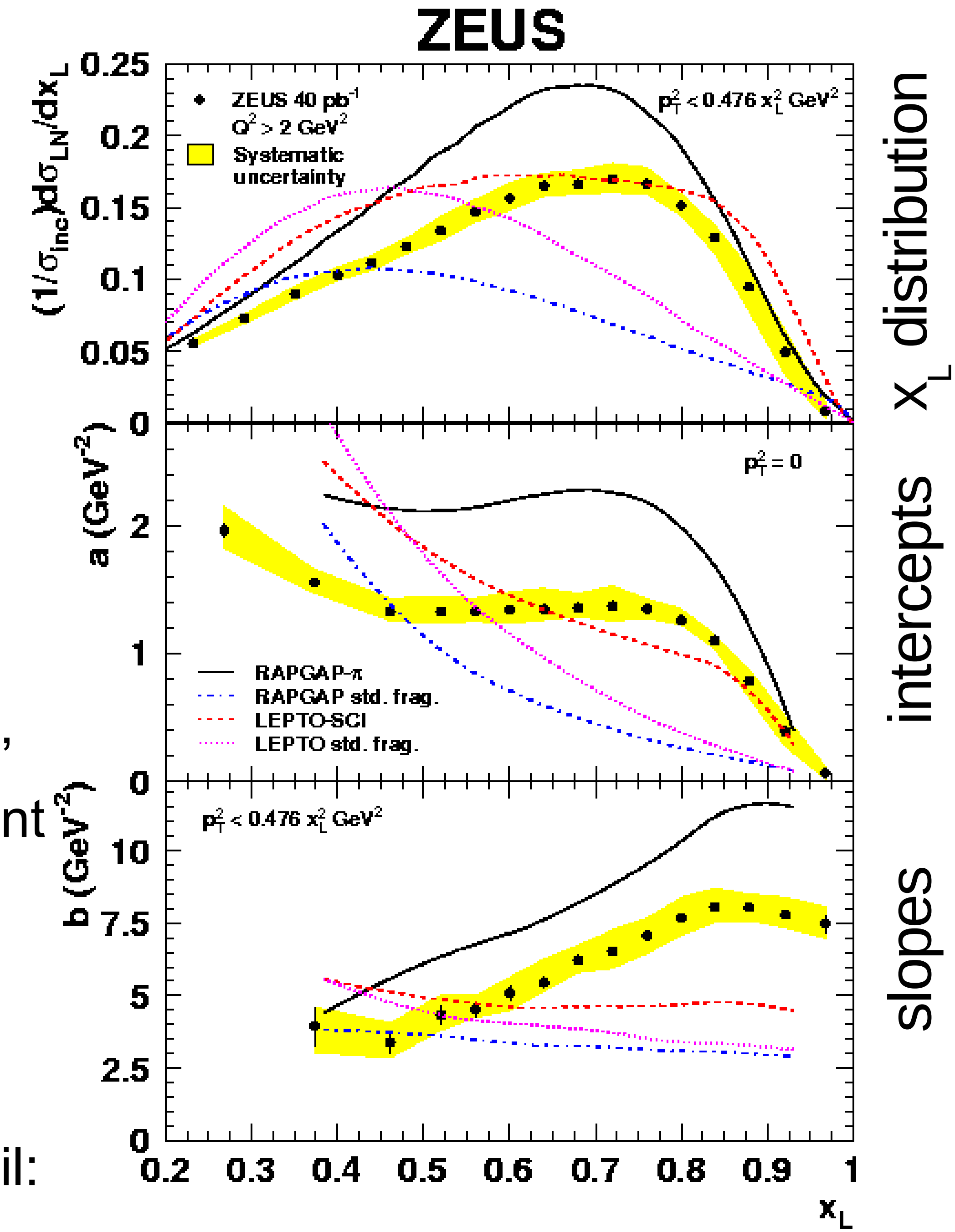
Model comparisons: DIS LN

- Compare to 2 MC models, 2 options:
  - RAPGAP w/ 'std. fragmentation'
  - RAPGAP w/ π-exchange
  - LEPTO w/ 'std. fragmentation'
  - LEPTO w/ soft color interactions
- ~default settings for all models
- Both std. frag. too few *n*, too low x_L
- LEPTO-SCI ~OK in shape, magnitude,

  but slopes too small, ~not x_L dependent
- **RAPGAP w/ π-xch. closest to data**

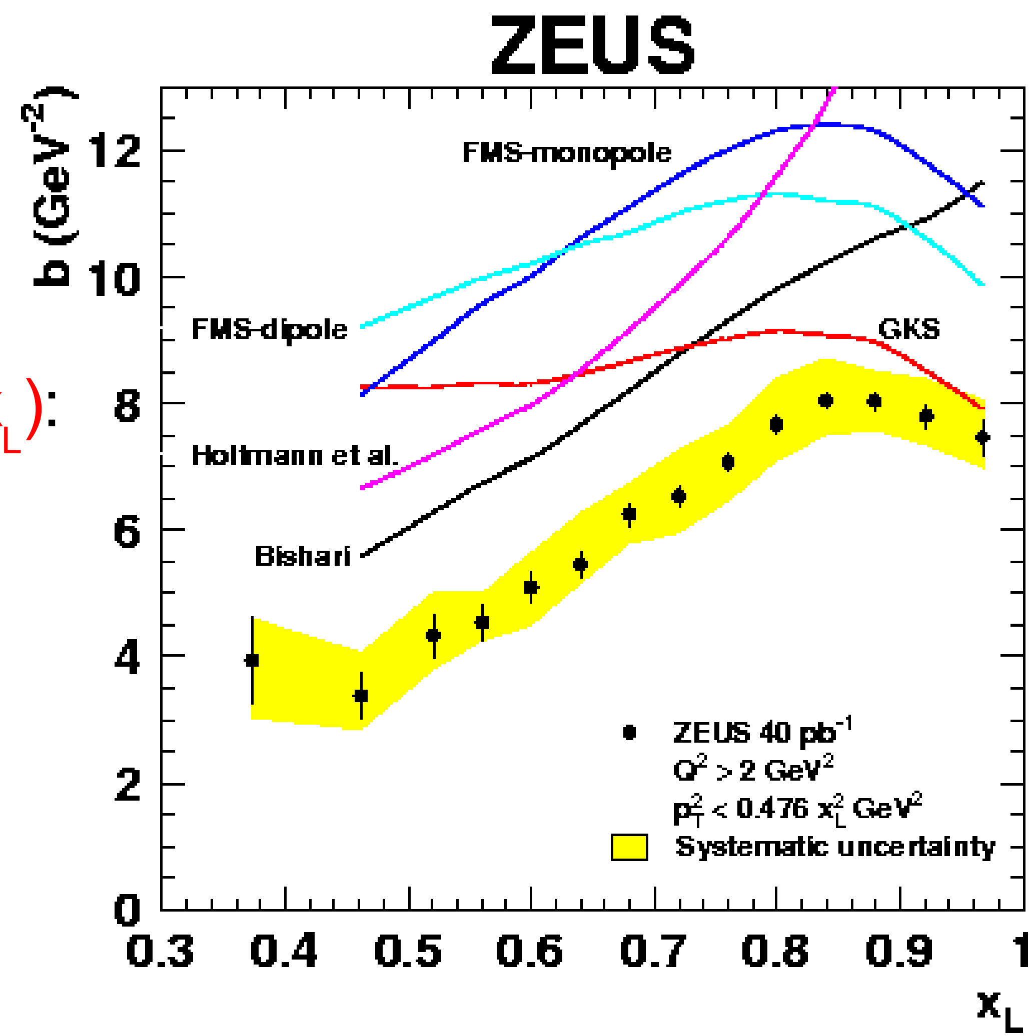
  (but slopes too high)
- Other DIS, γp std. frag. models also fail:

  ARIADNE, CASCADE, PYTHIA, PHOJET



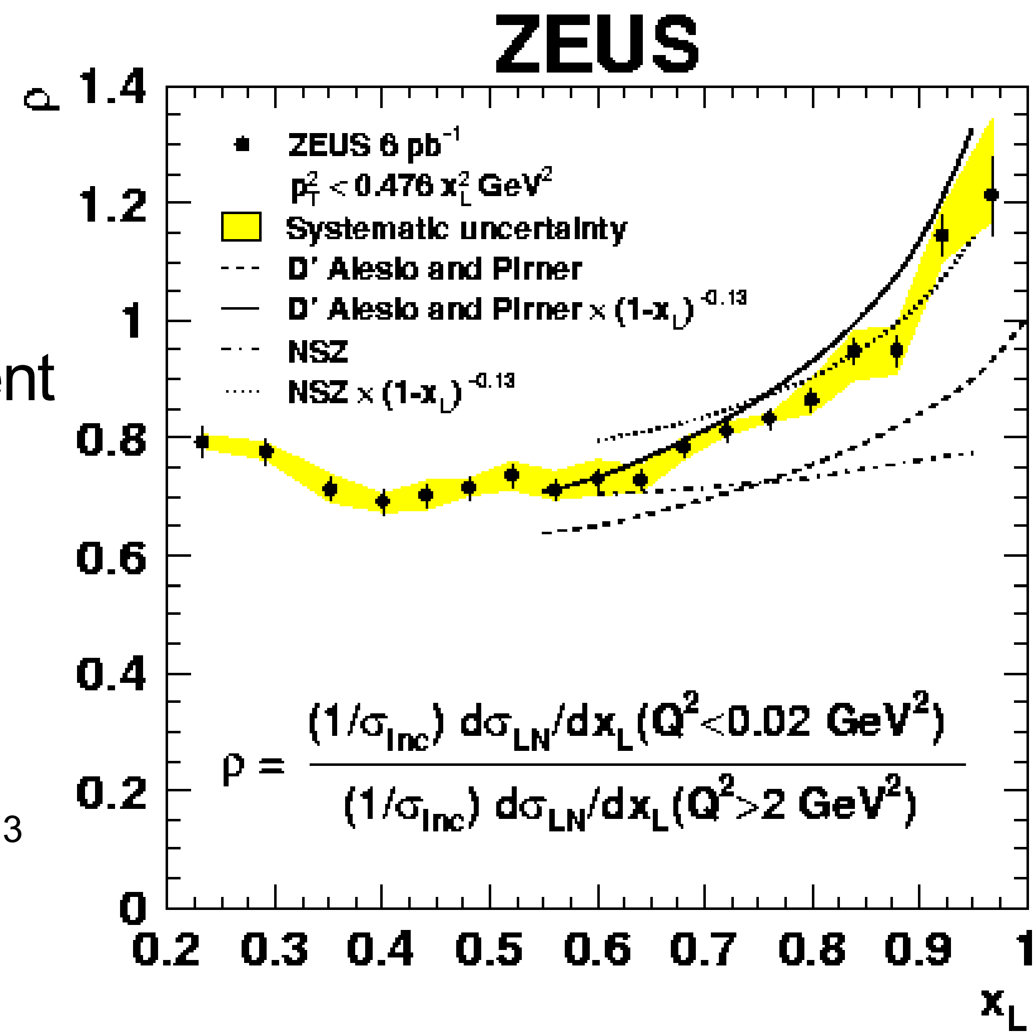
Compare π-xch. models: DIS LN slopes

- Numerous parameterizations of pion flux $f_{\pi/p}(x_L,p_T)$ in literature
- Here compare to measured DIS $b(x_L)$:
- Best agreeing models shown here; others wildly off
- All give too large $b(x_L)$
- More refinement needed: absorption, migration



Compare πp/DIS: π-xch. w/ absorption

- Ratio x_L dist. γp/DIS:
- Qualitatively similar to D' Alesio & Pirner (loss through absorption)



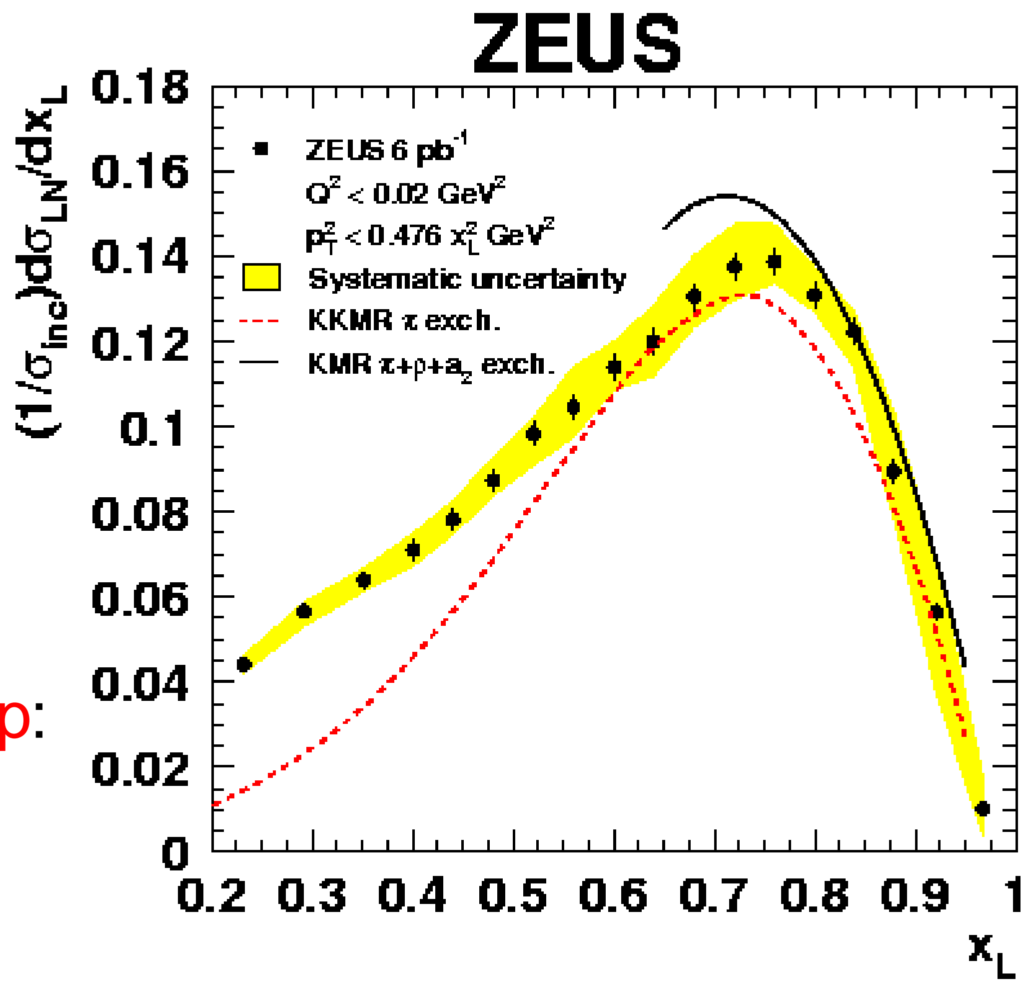
<u>W dependence:</u>

- Know for $\gamma^{(*)}$p: $\sigma_{\gamma p}$, $\sigma_{DIS\text{-}p}$ have different α's: $\sigma \propto W^{\alpha}$ (W = $\gamma^{(*)}$p c.m. energy)
- Assume same α's for $\sigma_{\gamma\pi}$, $\sigma_{DIS\text{-}\pi}$
- Also: $W^2_{\gamma\pi} = (1-x_L)W^2_{\gamma p}$
- $\Rightarrow$ scale absorption ratio by $(1-x_L)^{-0.13}$
- Nice agreement with data

- Also shown: model of Nikolaev, Speth and Zakharov
- Similar, but weaker x_L dependence

Compare: π-xch. w/ absorption, migration, other exchanges

- Work of Kaidalov, Khoze, Martin & Ryskin:
  - start with pure π-xch.
  - some *n* rescatter on γ
  - rescattered *n* migrate in (x_L,p_T)
- Overall ~50% loss from pure OPE
- Reasonable agreement with LN in γp:
- Subsequent work of Khoze, Martin & Ryskin:
  - add (ρ,a_2) exchanges (motive next slide)
- Again reasonable agreement with LN in γp

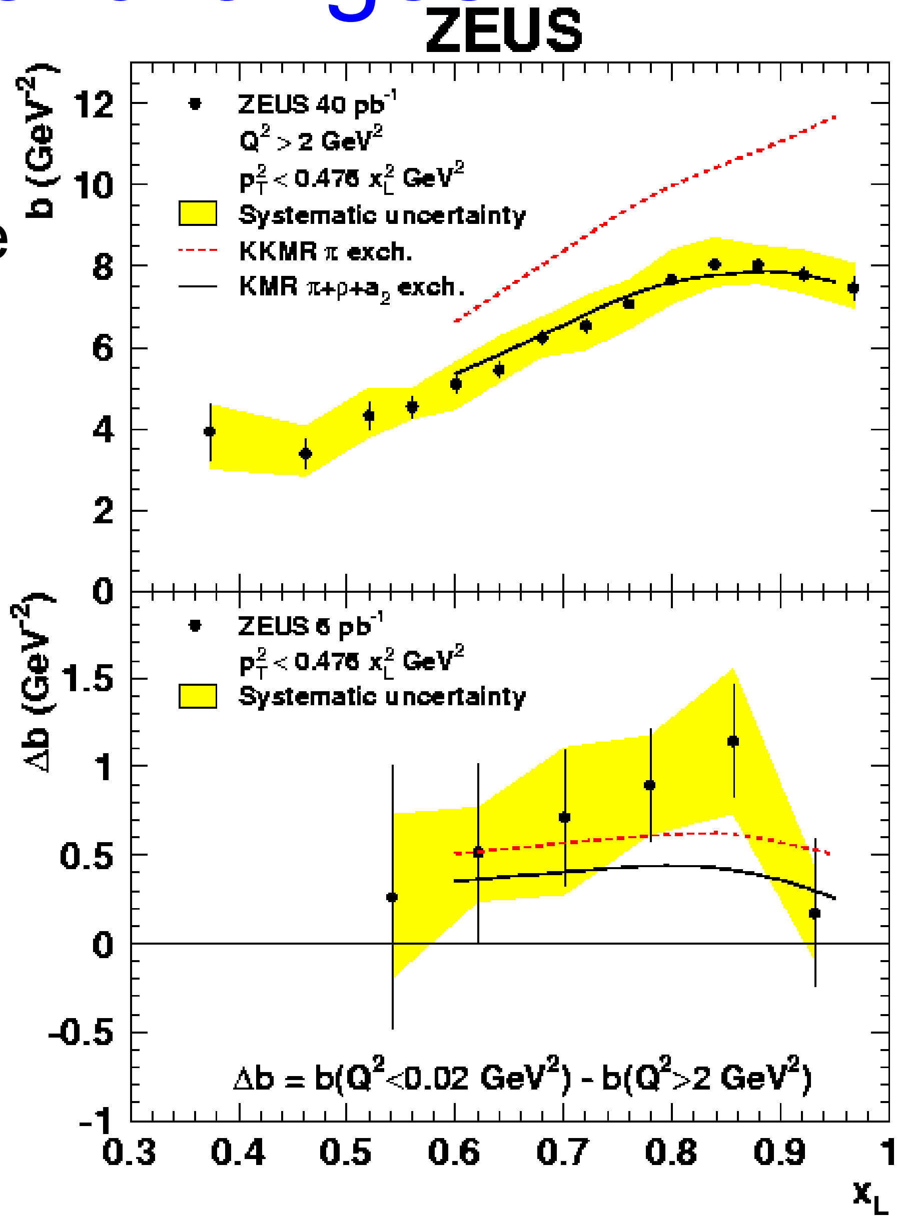


Compare: π-xch. w/ absorption, migration, other exchanges

- Absorption+migration with pion exchange alone does not describe slopes; too high in magnitude, no turnover @ high x_L

  Δb ~ OK

- Addition of (ρ,a_2) exchanges gives good description of both slopes magnitude and x_L dependence,Δb still OK



Summary

DATA:

- Best measured LB x_L, p_T distributions in DIS, γp, γp+jj
- Evolution hi-$Q^2 \rightarrow$lo-$Q^2 \rightarrow \gamma$p: evidence for absorption of LB in large γ
- Reintroduce hard scale in γp w/ high ET jets: absorption reduced

MODELS:

- MC models with 'standard' fragmentation do not describe the data
- Models with virtual particle exchange much better
- Pure π-xch. does not fully describe LN data: slopes wrong
- More refined calculations w/ π-xch.+absorption+migration:

  reasonable x_L shape, magnitude; slopes still off
- Addition of (ρ,a_2) exchanges: $\Rightarrow$ very promising agreement with data