Leading Neutron Energy & p_T Distributions from ZEUS

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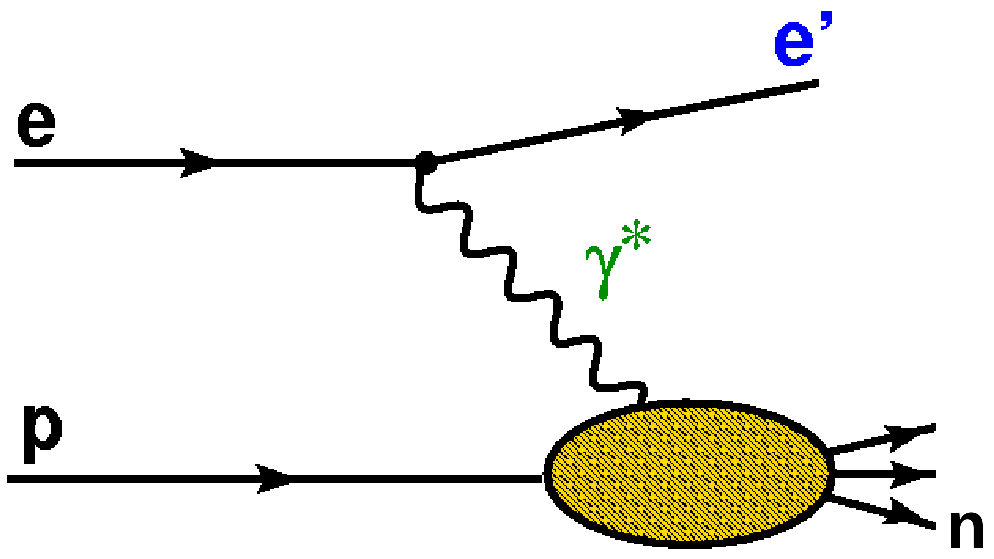
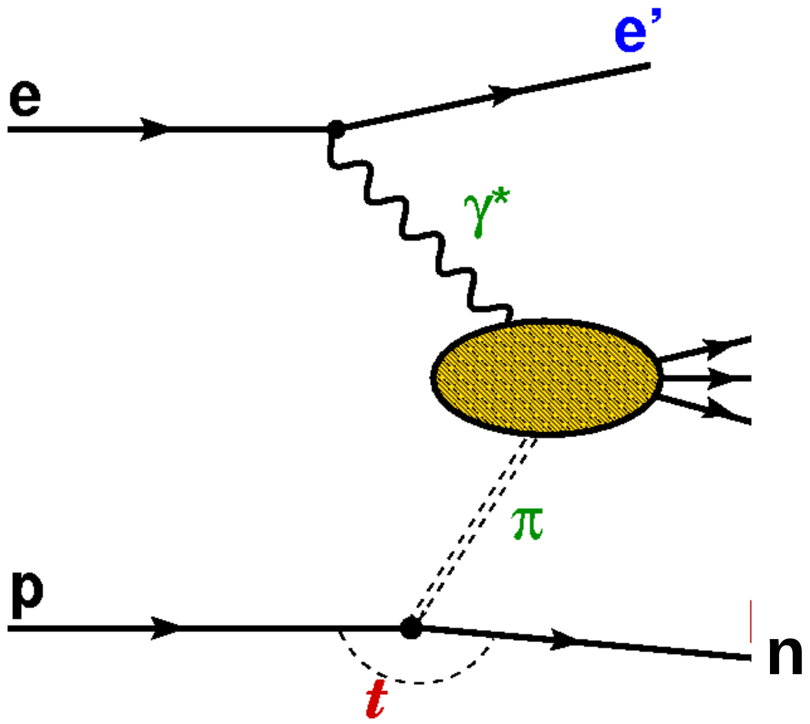
Outline:

- Motivations: LN production, One Pion Exchange (OPE), absorption
- Data sets: DIS, photoproduction (γp), LN measurement
- LN in DIS: energy, p_T distributions & Q^2 dependences
- Comparison: LN in photoproduction & DIS
- Comparison: LN & leading protons
- Comparison: LN in MC models, w/ & w/o OPE
- Comparison: OPE models, absorption (rescattering) models

Motivations: LN production, OPE



$x_L = E_n/E_p$



- LN can come from 'standard' fragmentation (baryon # has to go somewhere)
- Can compare to 'standard' MC gens.: x_L, p_T^2 distributions

- LN can be produced via isovector exchange: One Pion Exchange (OPE)
- Parameterizations from low energy hadronic scattering data. Can compare: x_L, p_T^2 distributions

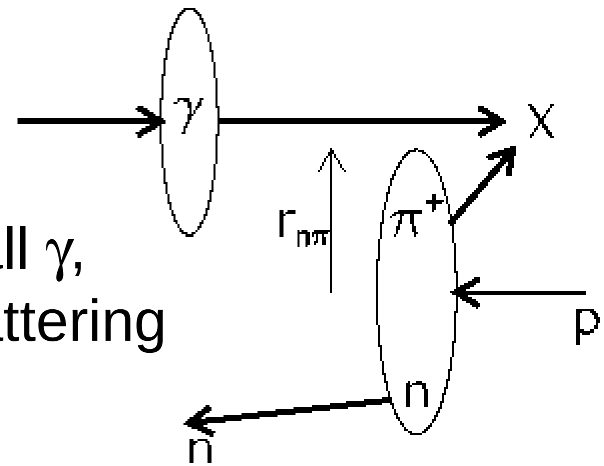
Motivations: Absorption

In DIS γ^* is small; in photoproduction γ large, rescattering (absorption) of *n* may occur:

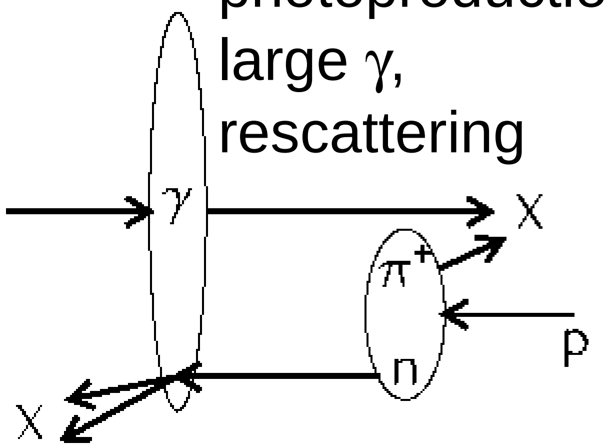
- Compare photoproduction & DIS:
  - x_L , p_T^2 distributions
  - effects of absorption?
- Compare to absorption (loss) calculations of D' Alesio & Pirner: Eur. Phys. J. **A7** (2000) 109
- Recently: (Kaidalov,) Khoze, Martin, Ryskin 'Leading neutron spectra' hep-ph/0602215 'Information from LN@HERA hep-ph/0606213
- They calculate the effects of *absorption* (rescattering), and subsequent *migration* of LN in (x_L, p_T^2) space, and more exchanged particles π+(ρ,a_2).

absorption gap ⇔ survival

DIS small γ,
no rescattering



photoproduction
large γ,
rescattering



n kicked to lower x_L, higher p_T; may escape detection (migration)

Data Sets

<u>Inclusive data (i.e. no LN tag):</u>

- DIS: $Q^2 > 2$ 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

<u>LN measurement:</u> Forward Neutron Calorimeter (FNC) & Tracker (FNT)

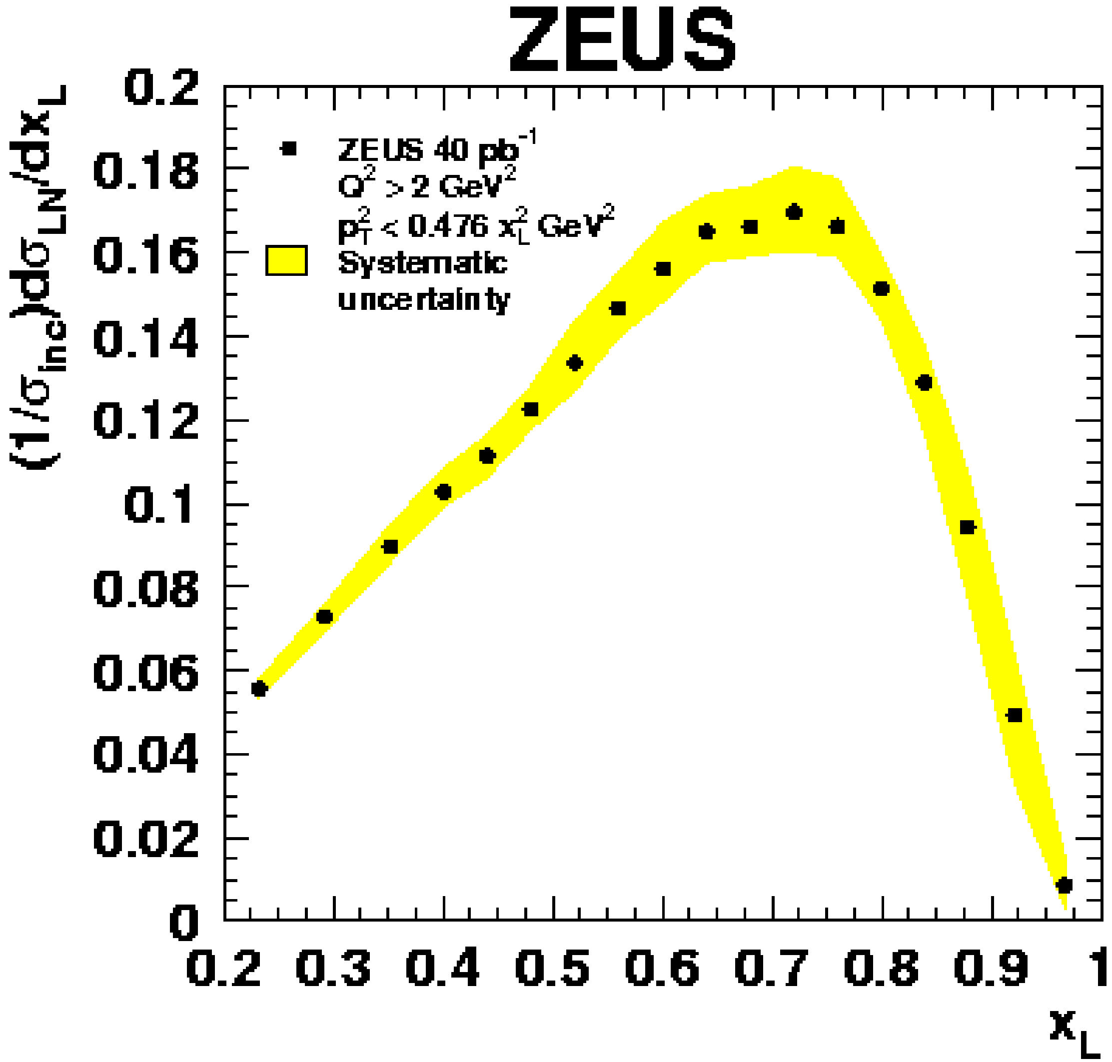
- 10.2 λ_I Pb-scint. calorimeter 105m from I.P.
- Scintillator hodoscope 1 λ_I into calorimeter for position detection
- Energy resolution $\sigma_E/E \approx 0.7/\sqrt{E}$
- p_T resolution dominated by proton beam p_T spread ~50-100 MeV
- Magnet apertures limit $\Theta_n < 0.75$ mrad $\Rightarrow p_T^{\ 2} < 0.476\ x_L^{\ 2}$ GeV^2

<u>LN yields:</u>

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

LN in DIS: x_L distribution

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



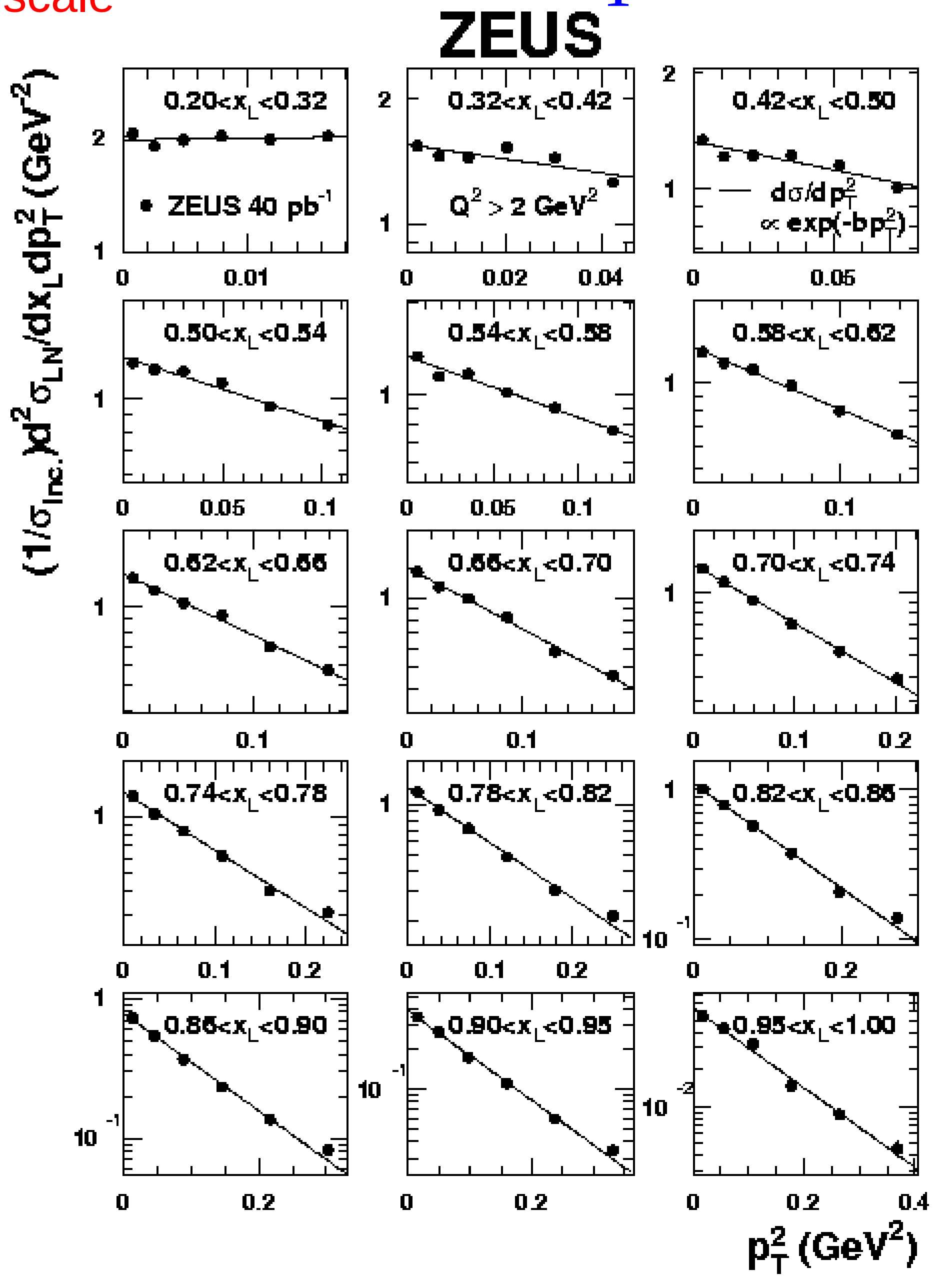
Systematic uncertainties from:

- Proton beam 0° point
- FNC energy scale
- Dead material before FNC

$p_T^{\,2}$ distributions DIS

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

log scale



note varying $p_T^{\,2}$ ranges $\propto x_L^{\,2}$

- $p_T^{\,2}$ distributions well described by an exponential:

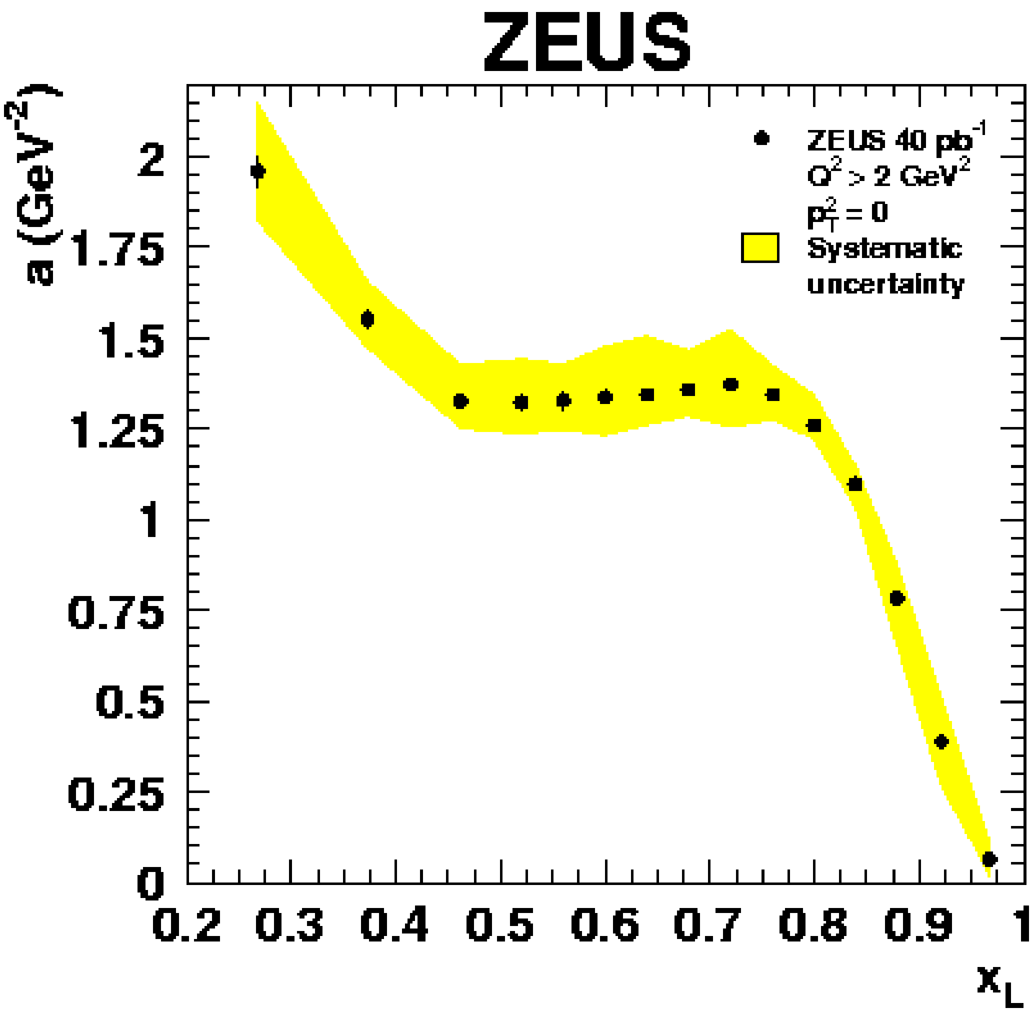
$$\frac{1}{\sigma_{inc}}\frac{d^2\sigma_{LN}}{dx_L dp_T^2} = a(x_L)e^{-b(x_L)p_T^2}$$

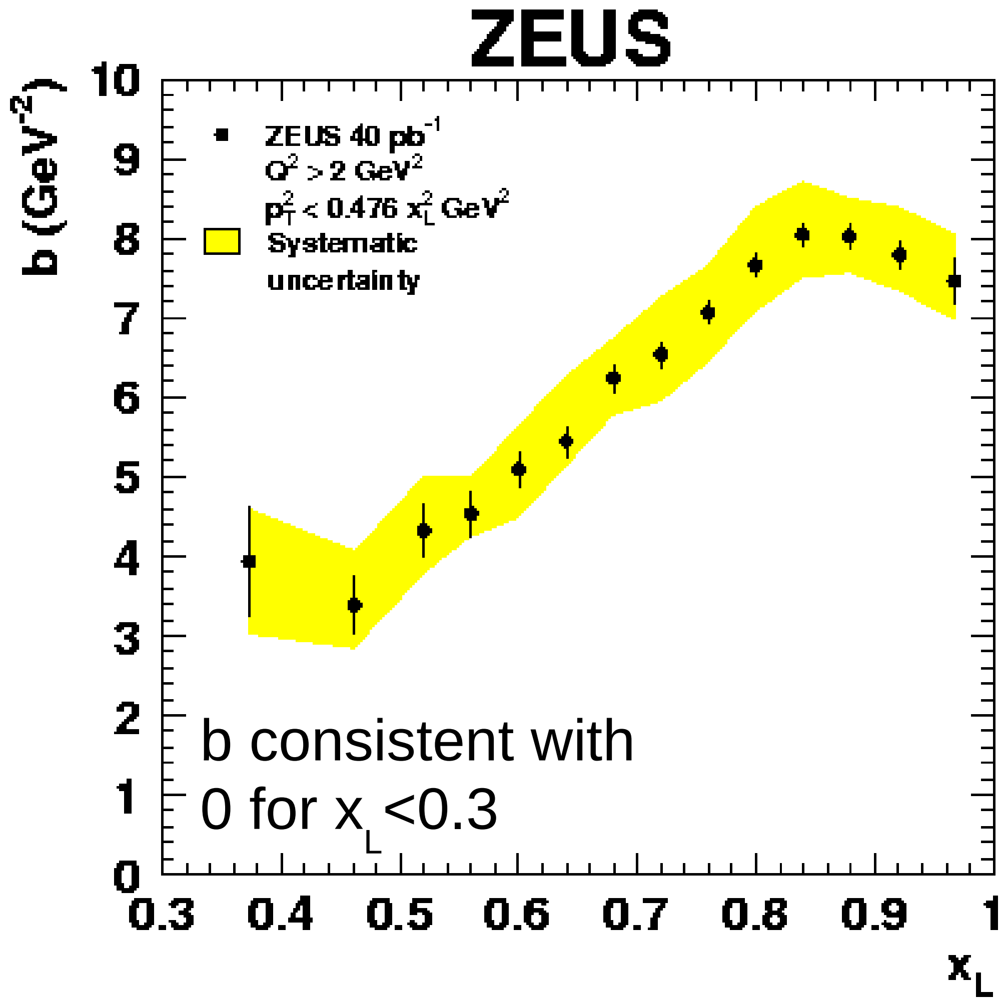
- Together intercepts $a(x_L)$ and slopes $b(x_L)$ fully characterize $(x_L, p_T^{\,2})$ distribution

- Well described by exponential in $p_T^{\,2}$

p_T^2 distributions: slopes & intercepts

- DIS intercepts $a(x_L)$:
- DIS slopes $b(x_L)$:



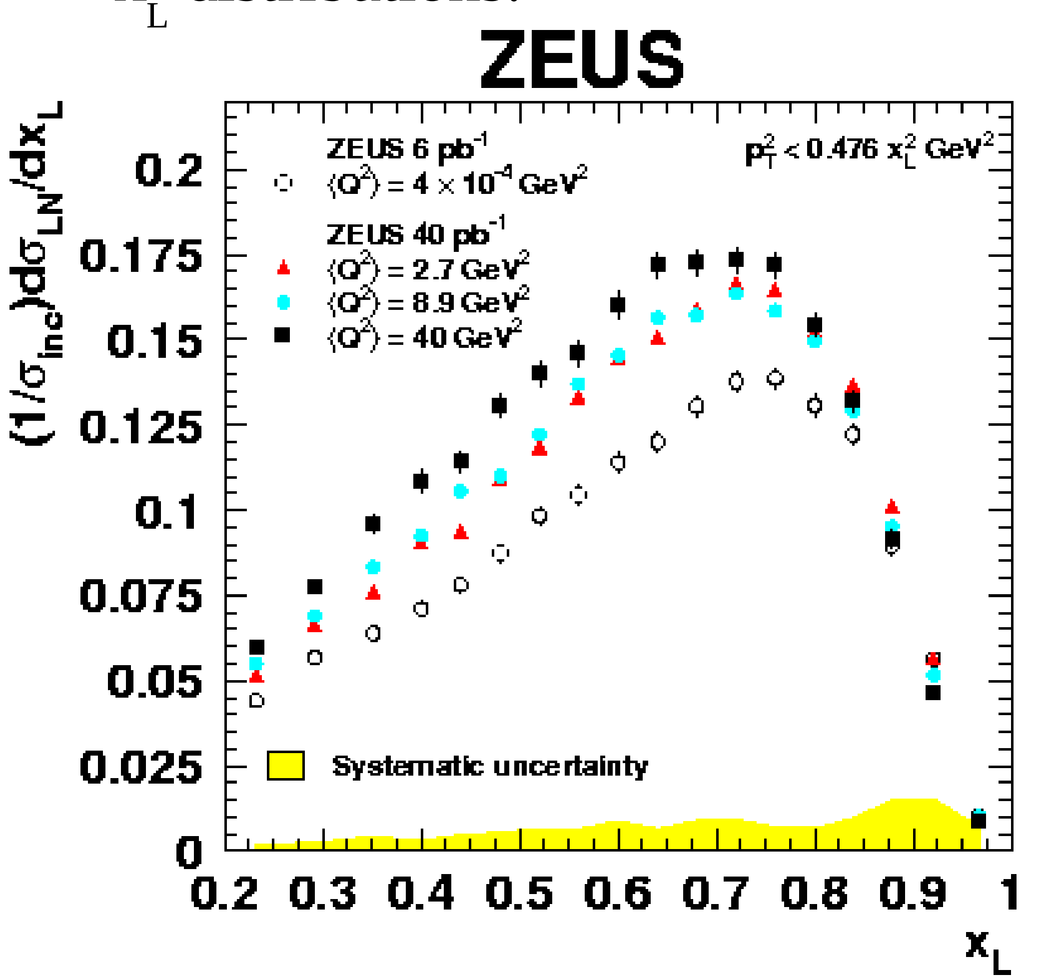


$$\frac{1}{\sigma_{inc}}\frac{d^2\sigma_{LN}}{dx_L dp_T^2} = a(x_L)e^{-b(x_L)p_T^2}$$

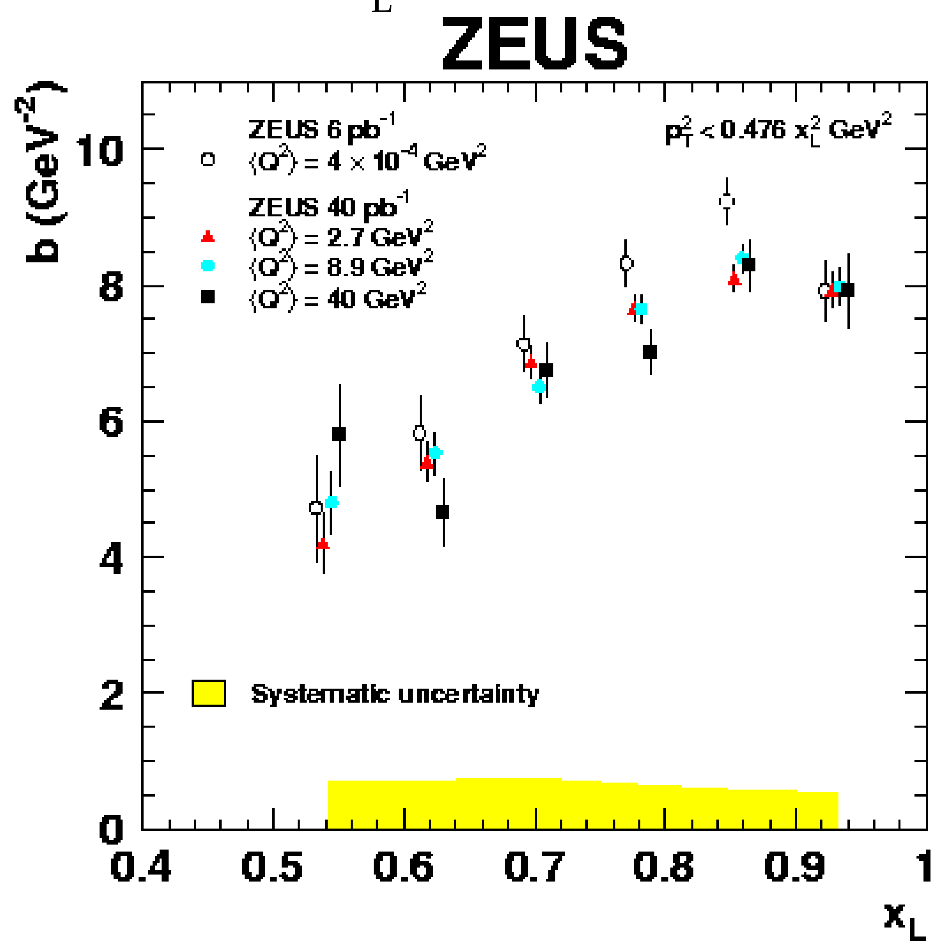
Q^2 dependence of LN production

3 Q^2 bins DIS + γp:

- x_L distributions:



- slopes $b(x_L)$:



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

  larger $Q^2 \Rightarrow$ smaller γ

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

Further comparison: γp & DIS

To minimize systematic uncertainties in comparison:

- Use only DIS from period when γp+LN trigger active (~20% of DIS sample)
- Many LN systematic uncertainties cancel taking ratios:
- Ratio of x_L distributions: γp/DIS
- Ratio of p_T^2 distributions: γp/DIS

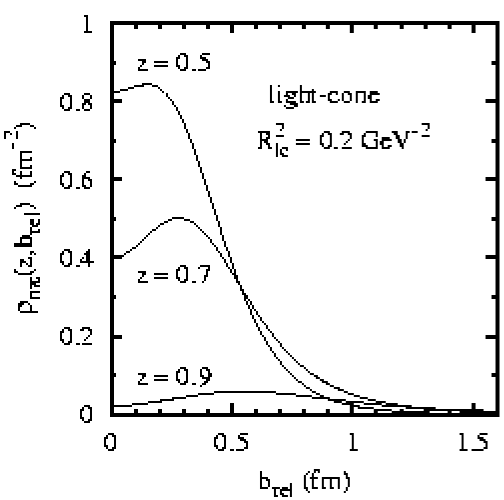
$\Rightarrow$ $\Delta b = b(\gamma p) - b(DIS)$

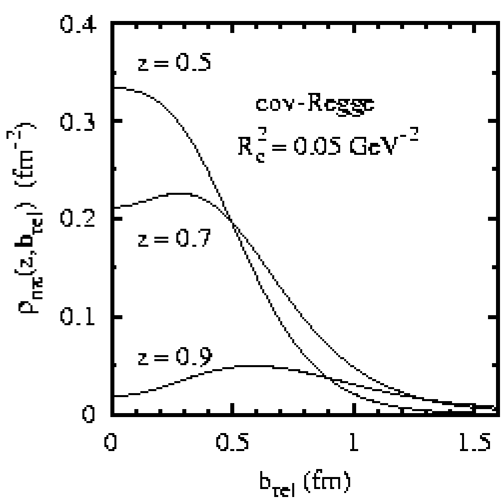
Comparison γp/DIS: x_L distributions

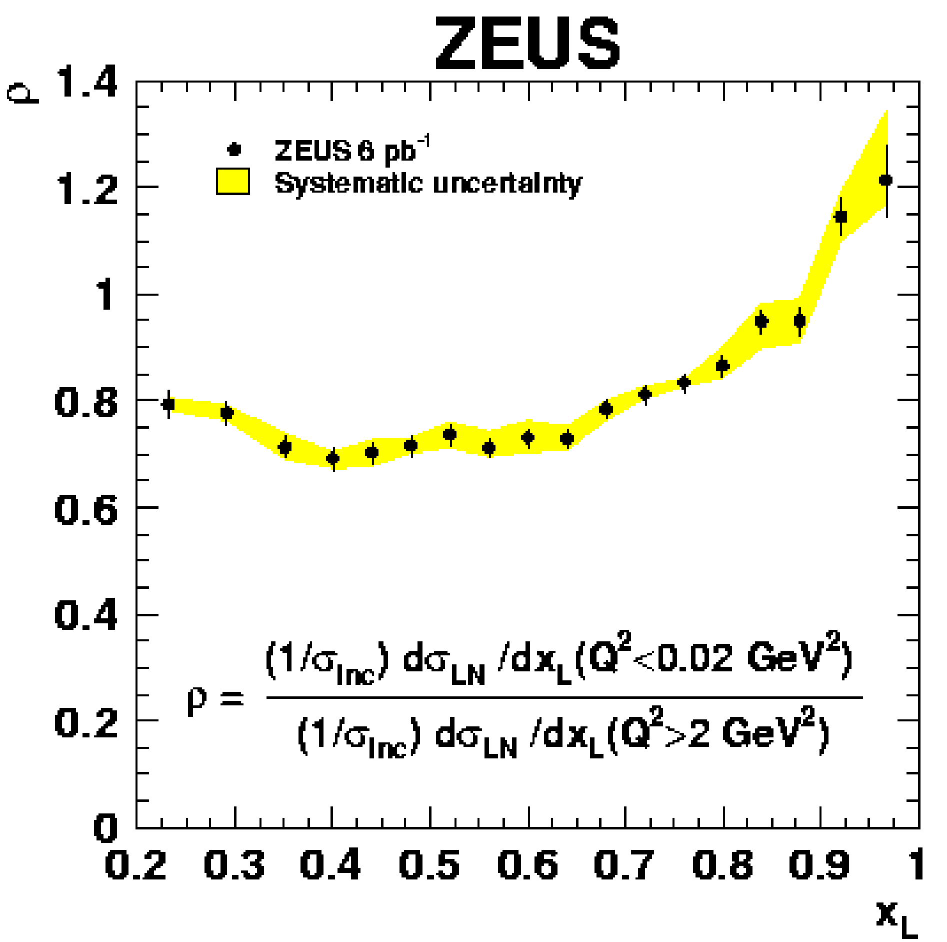
- Ratio ~70% mid-x_L, rising to 1 as $x_L \rightarrow 0.9$

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

- mean $r_{n\pi}$ decreases at lower x_L:



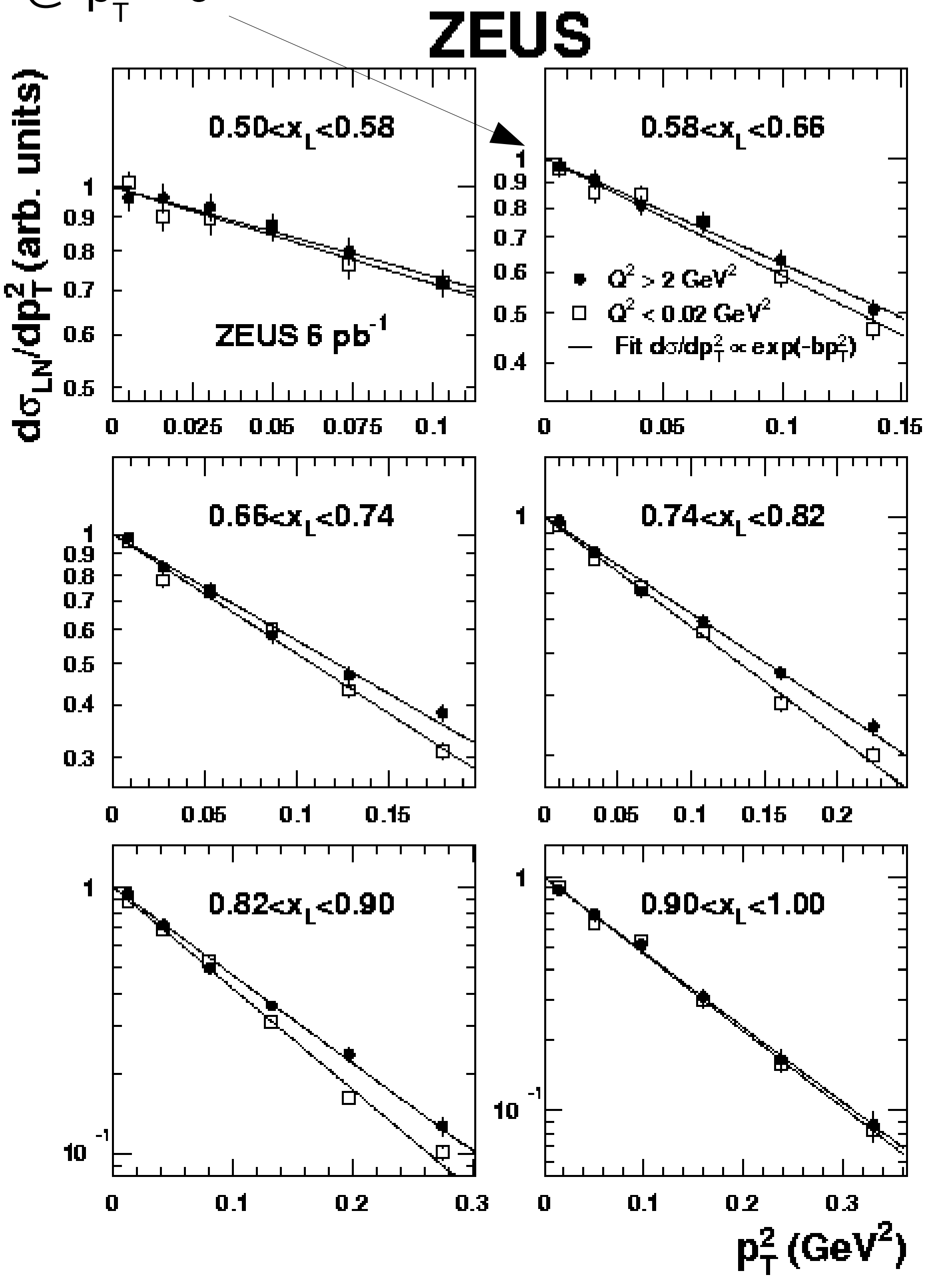


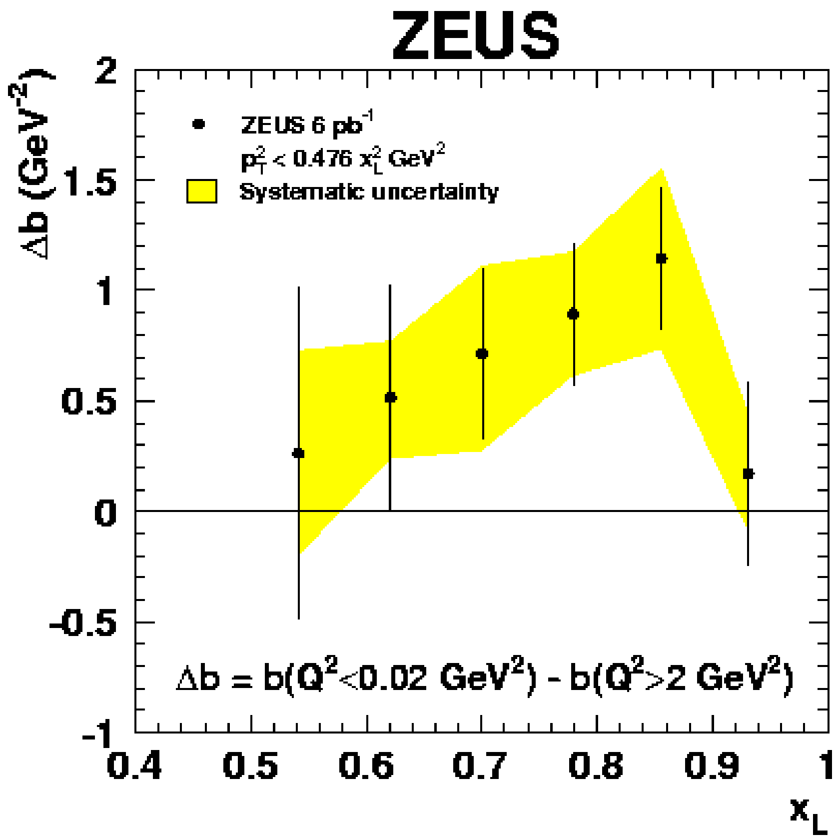


- smaller $r_{n\pi}$ ⇒ more absorption at lower x_L

Comparison γp/DIS: p_T^2 distributions

normalized
@ p_T^2 =0

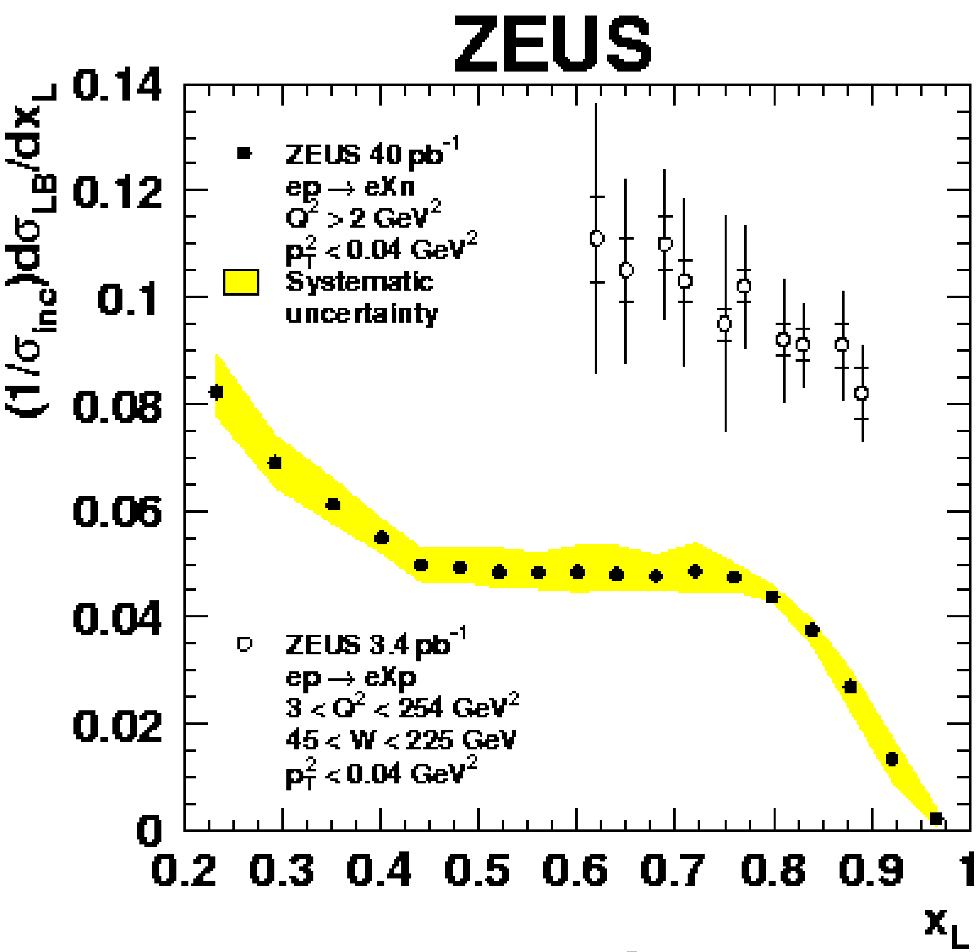




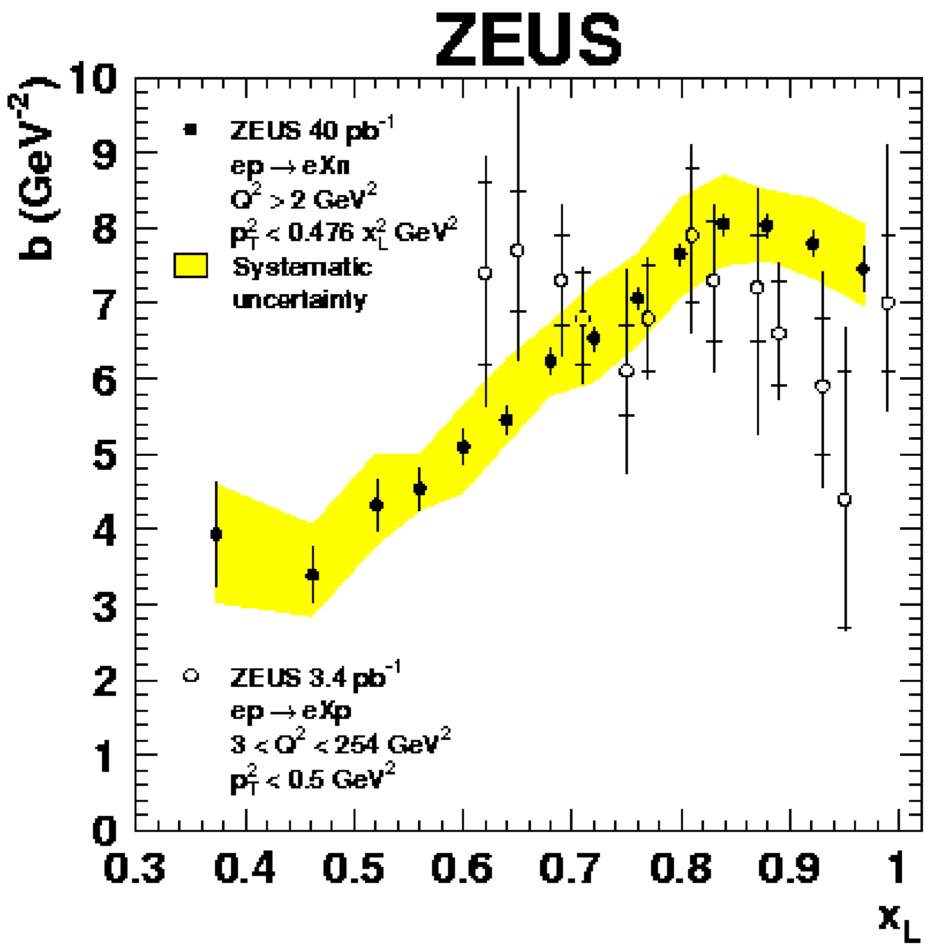
- Small but clear difference:
  b(γp) > b(DIS) for $0.6<x_L<0.9$
- Qualitatively consistent w/ absorption:
  more abs. @ small $r_{n\pi}$ ~ large p_T
  fewer LN @ high p_T ⇒ larger slope

Comparison: LN & leading protons

- DIS x_L distribution p_T^2<0.04 GeV^2:



- DIS b-slopes:



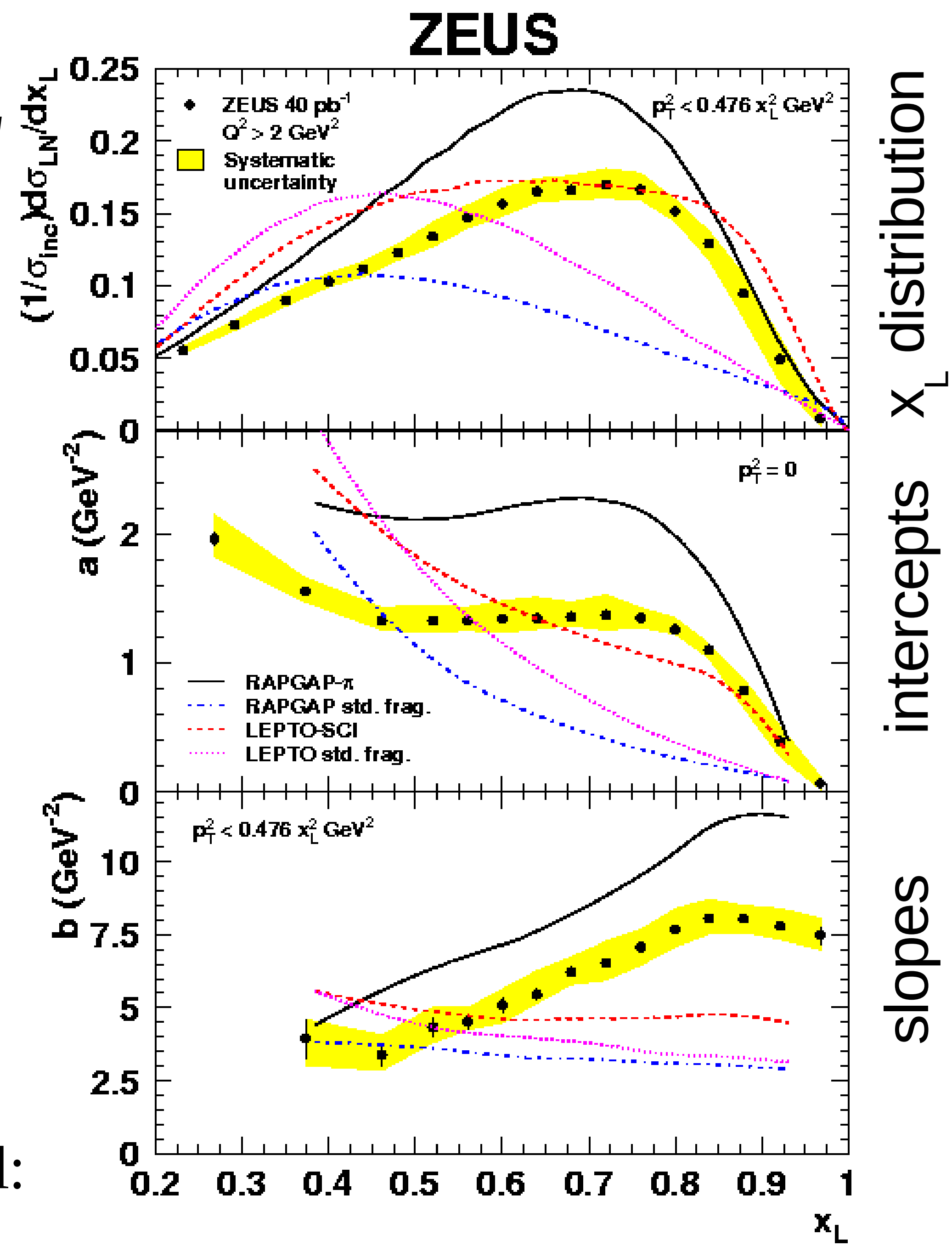
- For pure isovector exchange isospin Clebsch-Gordan $\Rightarrow r_{LP} = \frac{1}{2} r_{LN}$
- $r_{LP} > r_{LN} \Rightarrow$ other exchanges needed
- Different exchanges conspire to give ~flat $b(x_L)$ for LP

Comparison: MC models

- Compare to two MC models:
  - RAPGAP w/ 'standard fragmentation'
  - RAPGAP w/ OPE
  - LEPTO w/ 'standard fragmentation'
  - LEPTO w/ soft color interactions
- ~default settings for all models
- Here compare to DIS LN distributions:

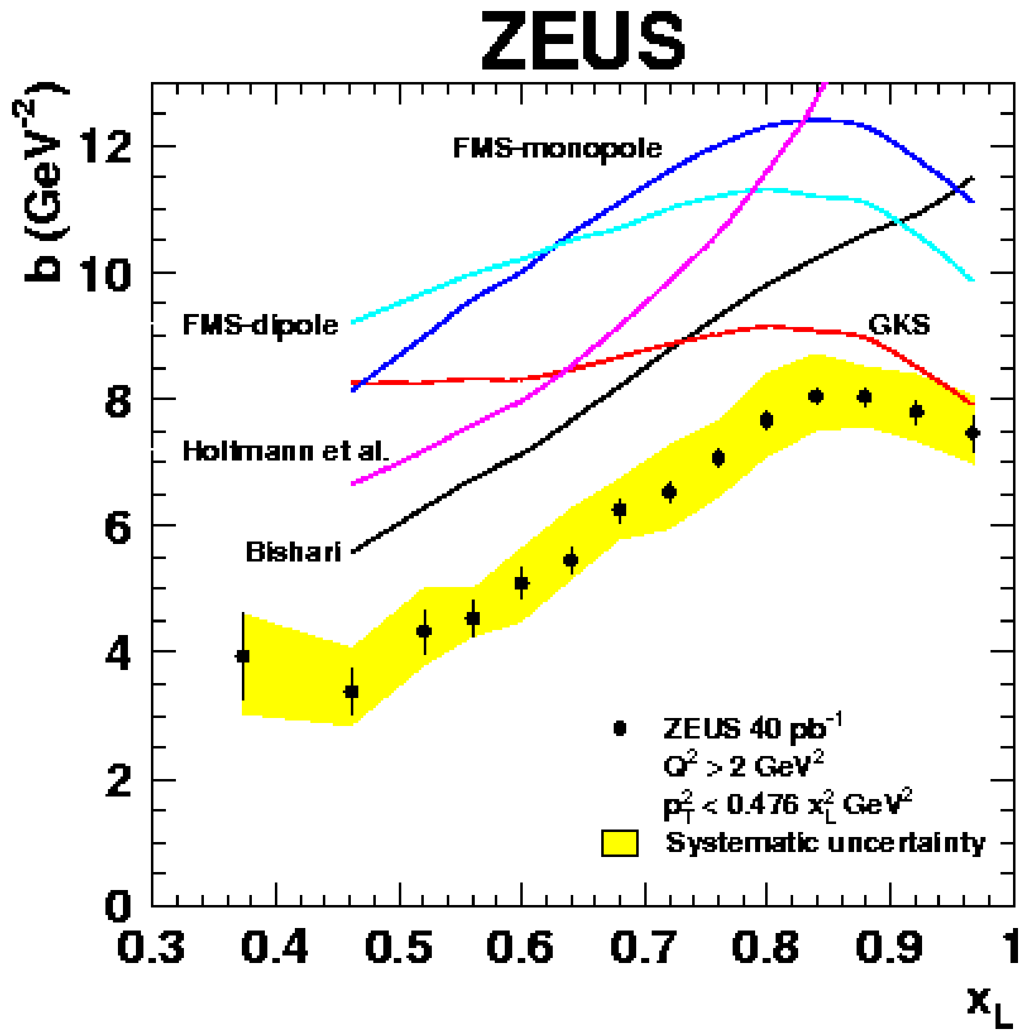
Both std. frag. too few *n*, too low x_L

- LEPTO-SCI ~OK in shape, magnitude, but slopes to small, flat
- RAPGAP-OPE closest to data
- Other DIS, γp std. frag. models also fail: ARIADNE, CASCADSE, PYTHIA, PHOJET)



Comparison: OPE models

- 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

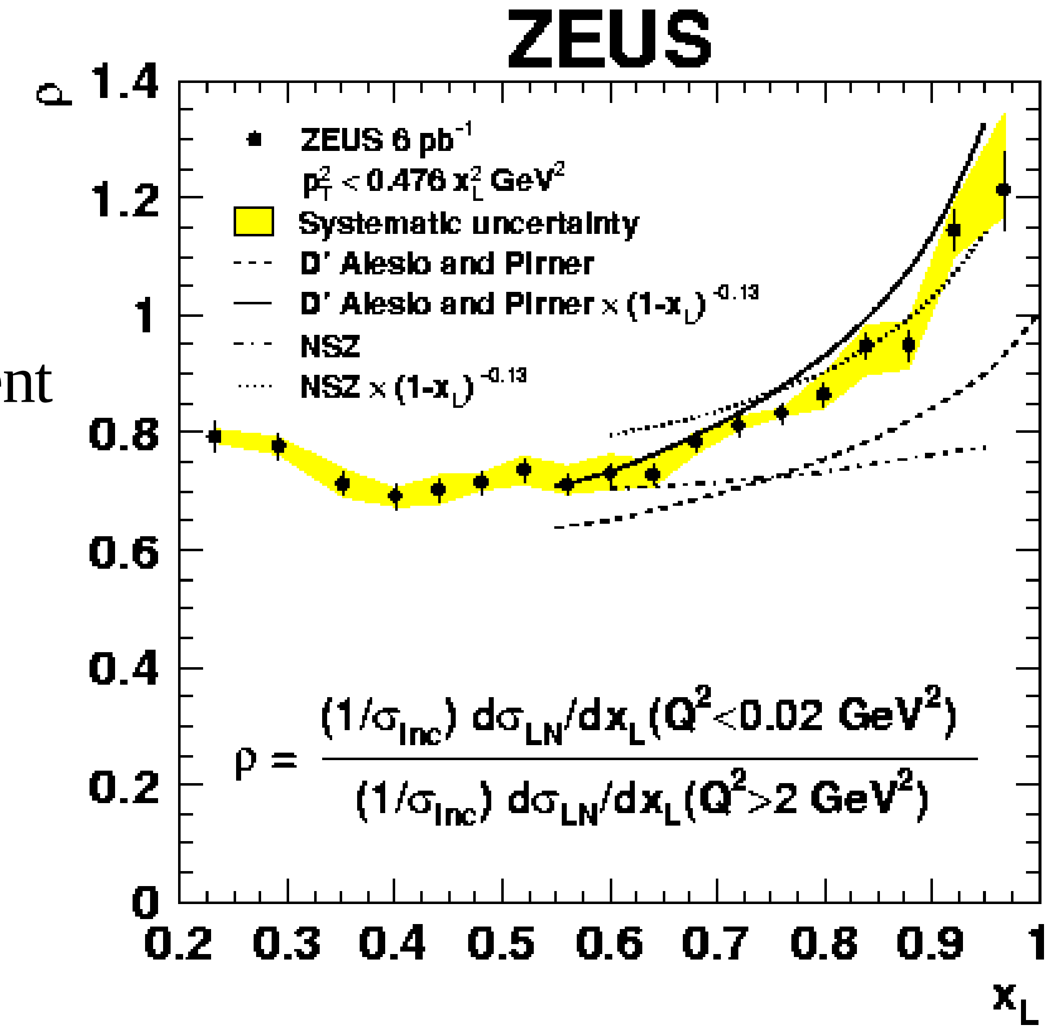


Compare γp/DIS: OPE w/ absorption

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

<u>W dependence:</u>

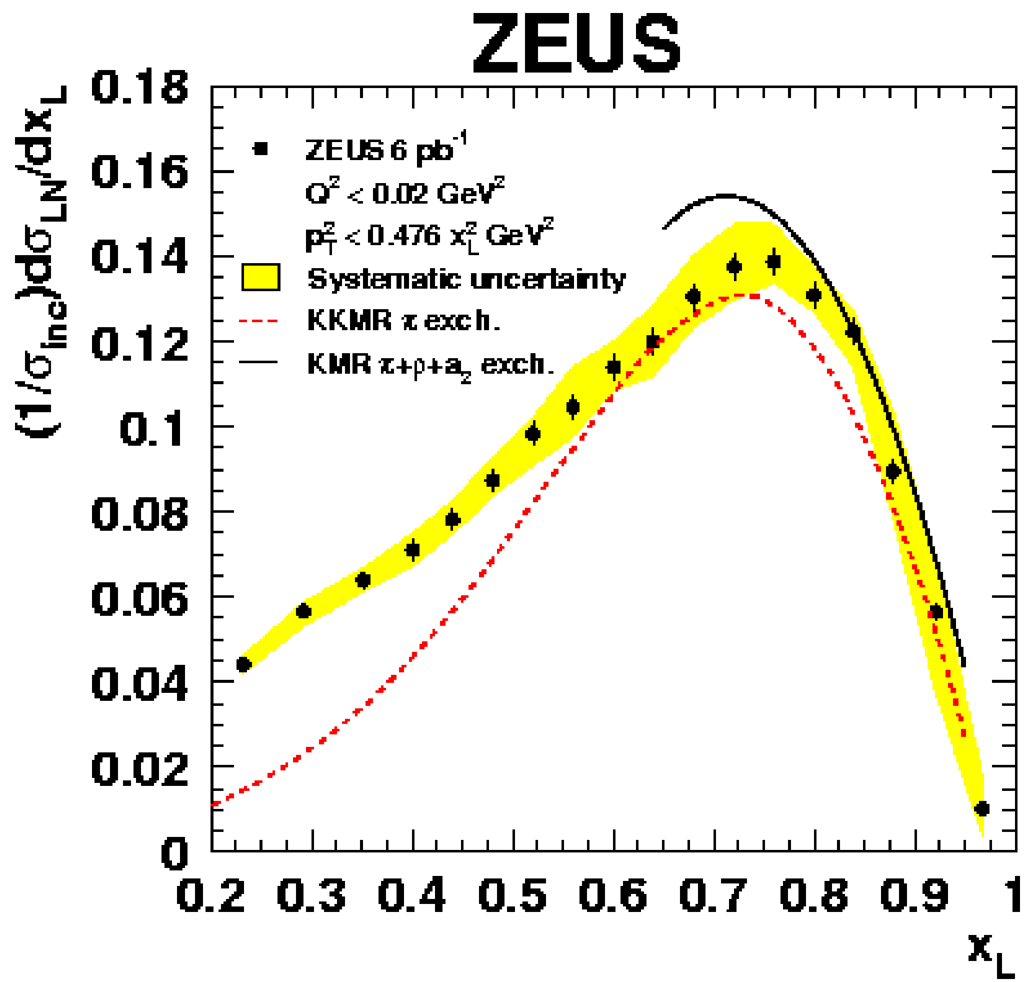
- Know for $\gamma^{(*)}p$: $\sigma_{\gamma p}$, $\sigma_{DIS\text{-}p}$ have different α's: $\sigma \propto W^{\alpha}$ (W = $\gamma^{(*)}p$ c.m. energy)
- Assume same α's for $\sigma_{\gamma\pi}$, $\sigma_{DIS\text{-}\pi}$
- Also: $W^2_{\pi} = (1-x_L)W^2_p$
- ⇒ scale absorption ratio by $(1-x_L)^{-0.1}$
- Nice agreement with data



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

Comparison: OPE w/ absorption, migration, other exchanges

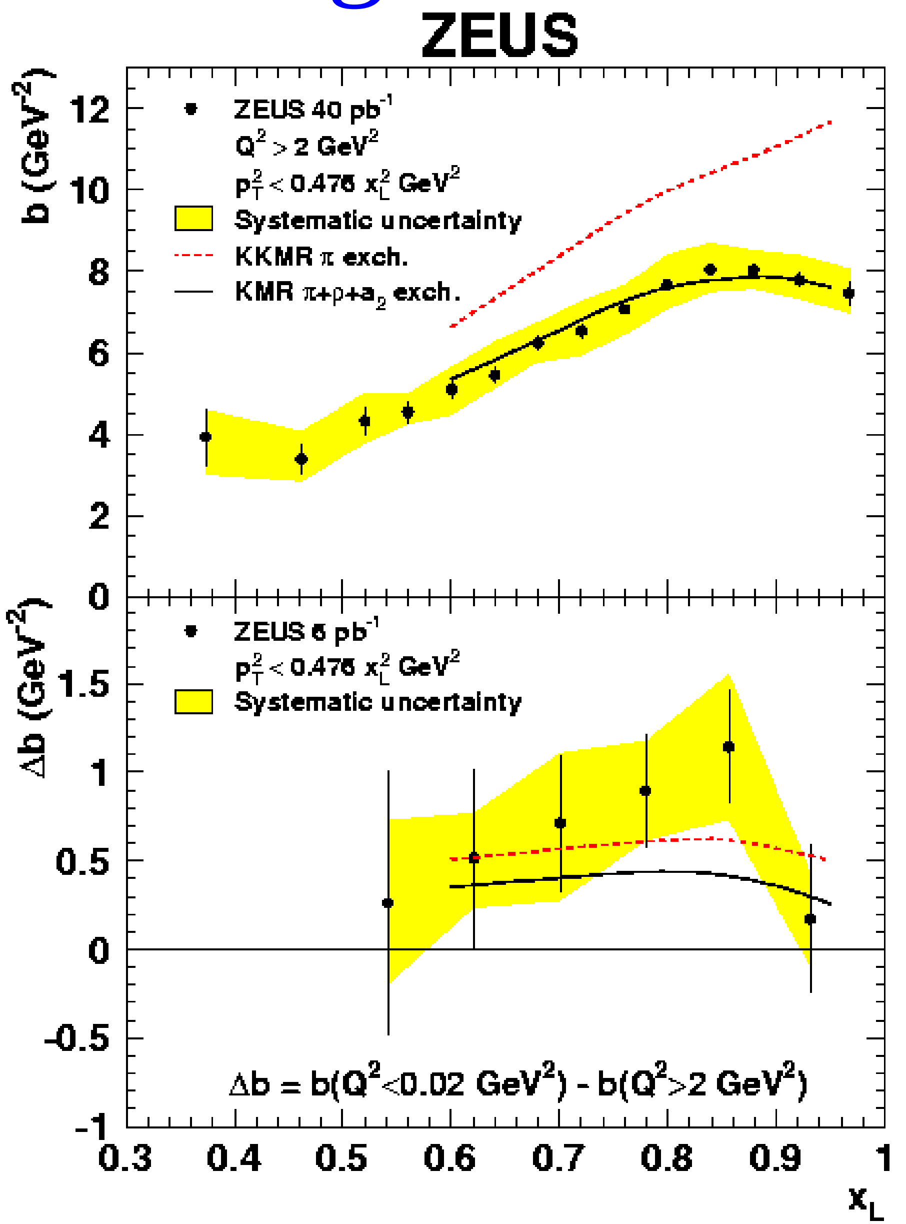
- Recent work of Kaidalov, Khoze, Martin & Ryskin:
  - start with pure OPE
  - some *n* rescatter on γ
  - rescattered *n* migrate in (x_L, p_T)
- Overall ~50% loss from pure OPE
- Reasonable agreement with LN in γp:
- More recent work of Khoze, Martin & Ryskin:
  - add (ρ, a_2) exchanges (motive next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



Comparison: OPE w/ absorption, migration, other exchanges

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

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



Summary

- Best measured LN x_L, p_T distributions in DIS, γp
- Comparison DIS↔γp: evidence for absorption of *n* in large γ
- MC models with 'standard' fragmentation do not describe the data;

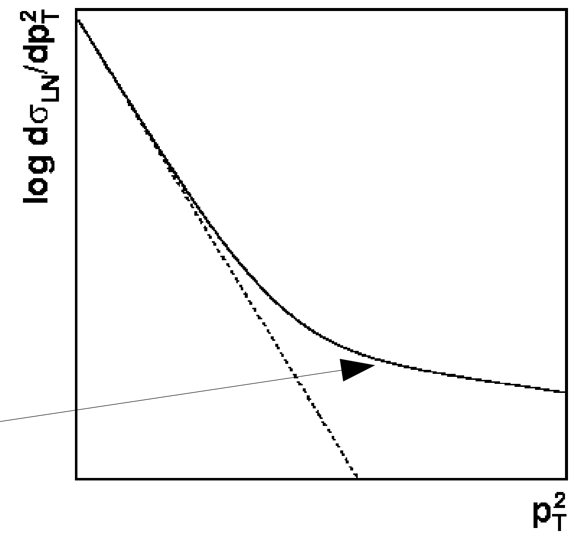
  LEPTO-SCI better; RAPGAP OPE best MC
- Pure OPE does not fully describe data: slopes wrong
- More refined calculations w/ OPE+absorption+migration:

  reasonable xL shape, magnitude; slopes still off
- Addition of (ρ,a_2) exchanges:

  ⇒ very promising agreement with data

EXTRAS

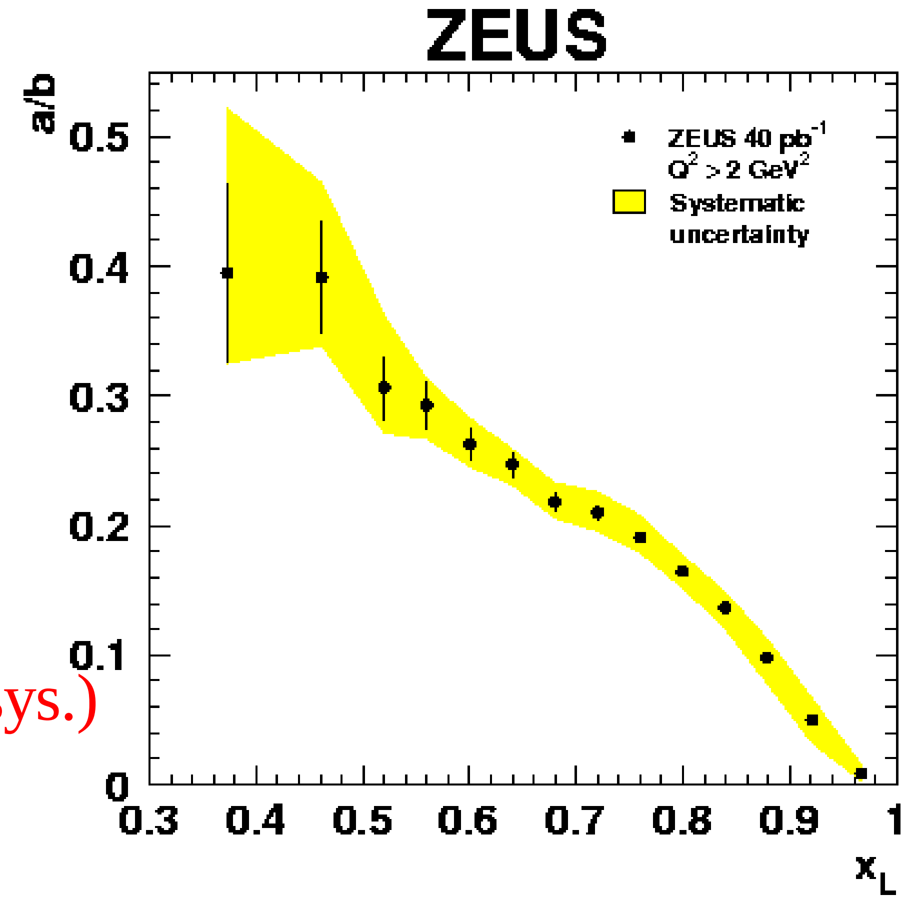
“Total LN rate”



- Could consider integrating exponentials over $p_T^{\ 2} \rightarrow \infty$
- Caveats:

  - Ignores possible flatter $p_T^{\ 2}$ component

  - And extrapolates well outside acceptance



- Anyway result is:

  dN/dx_L = a/b = intercept/slope:

- Integrating over x_L (where b>0) gives:

$r_{LN}(x_L>0.32) = 0.159 \pm 0.008(\text{stat.})^{+0.019}_{-0.006}(\text{sys.})$