Physics With Leading Neutrons at HERA

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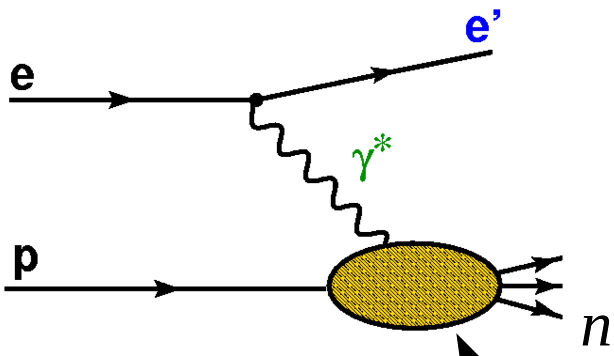
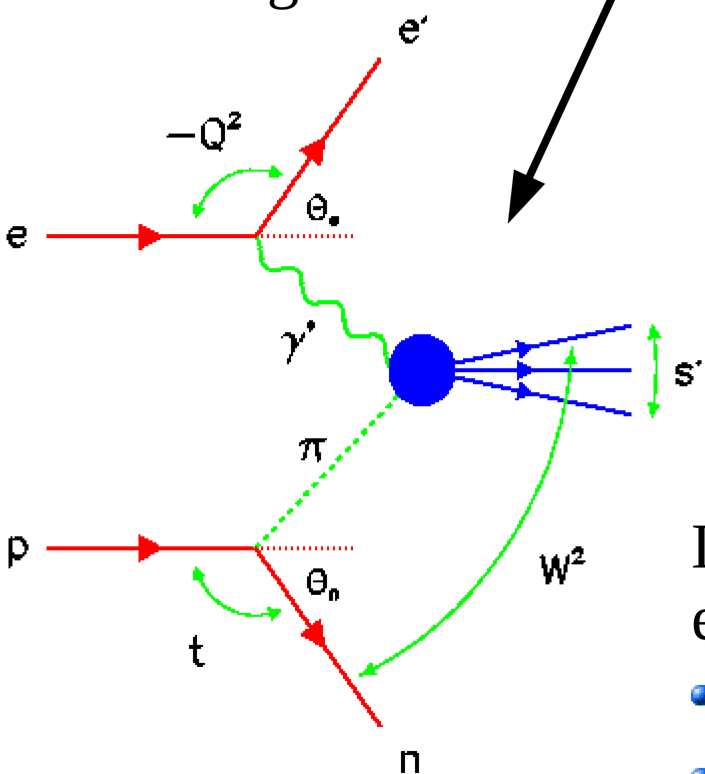
On behalf of the H1 and ZEUS collaborations

- Motivation: One pion exchange
  Absorption (rescattering)
- Leading neutrons (LN) in DIS and photoproduction (γp) with dijets:
  rates and kinematic dependences comparison with
  - standard fragmentation models
  - pion exchange models
  - NLO QCD calculations
- p_T spectra of leading neutrons in inclusive DIS & photoproduction:
  - comparison to pion exchange models
  - effects of absorption
- Summary

Motivation: One Pion Exchange



LN can result from 'standard' fragmentation



One Pion Exchange: (O.P.E.):

- Proton fluctuates into virtual π-n system
- Virtual π interacts with $\gamma^{(*)}$
- Real n can be detected
- Cross section factorizes:

$$\sigma_{ep\rightarrow eXn}(W^2, Q^2, x_L, t) = f_{\pi/p}(x_L, t)\,\sigma_{e\pi}((1-x_L)W^2, Q^2)$$

- Lepton vertex variables ~ independent of baryon vertex variables

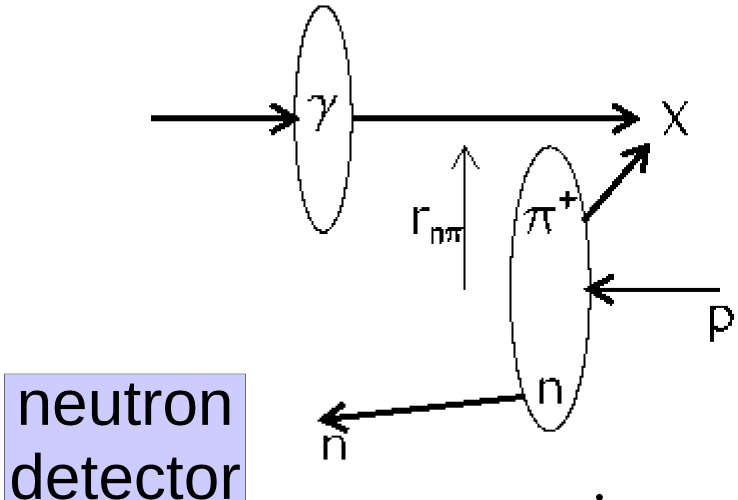
Lepton variables e.g. DIS:

- $Q^2 = \gamma^*$ 4-mom.^{2}
- $W = \gamma^*$-p c.m. E

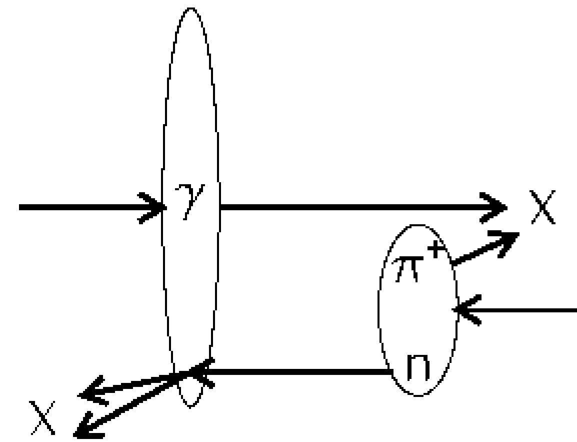
LN observables (baryon variables):

- $x_L = E_n/E_p$
- p_T or $t = -p_T^2/x_L - m_N^2(1-x_L)^2/x_L$
- Models predict x_L, p_T^2 distributions

Motivation: Rescattering model



no rescattering,
n detected



rescattering, *n* lost
(lower x_L, higher p_T)

- γ size ~ 1/Q   (Q = γ virtuality):

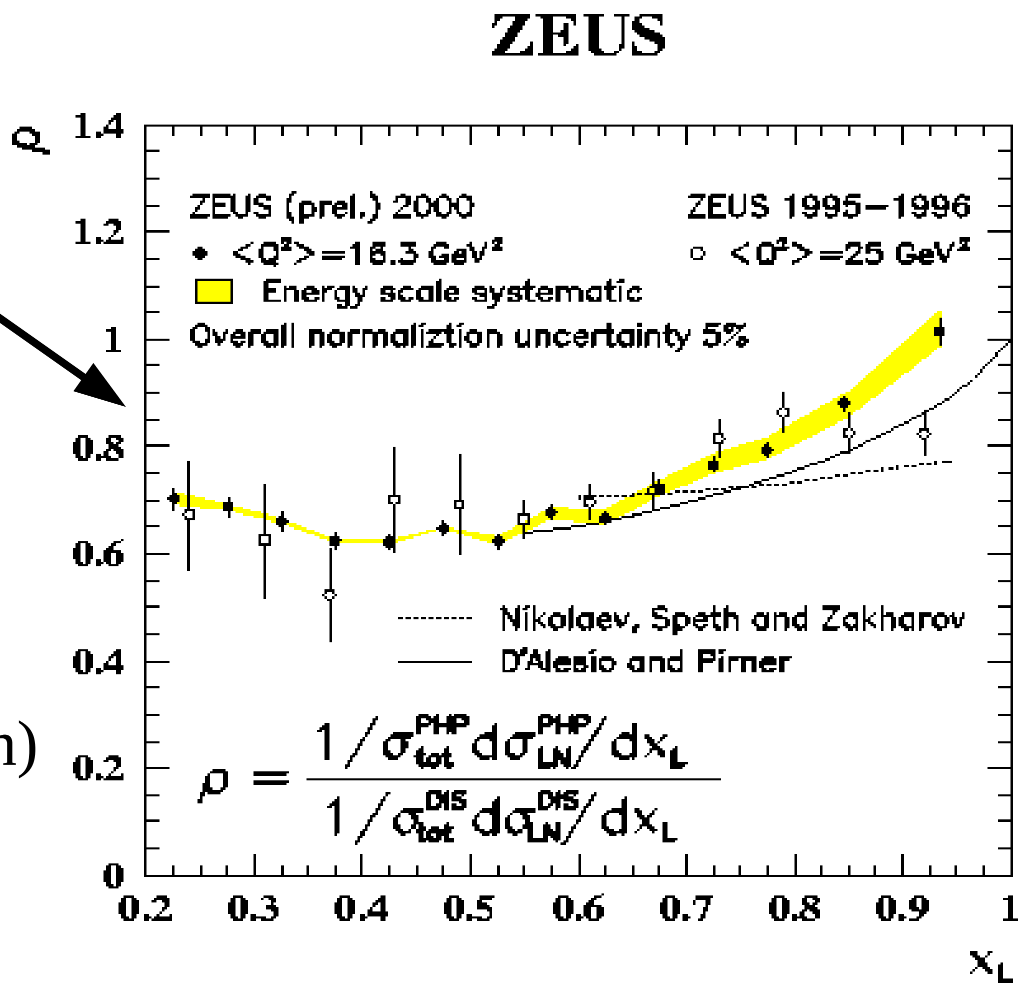
  $\Rightarrow$ more rescattering at lower Q^2; compare DIS (Q^2>0) and γp (Q^2~0)
- In π exchange models, $\langle r_{n\pi} \rangle$ smaller at lower x_L:

  $\Rightarrow$ more rescattering @ lower x_L
- smaller $\langle r_{n\pi} \rangle$ ~ higher $p_{T:}$

  $\Rightarrow$ fewer high p_T *n* in photoproduction, steeper p_T distributions

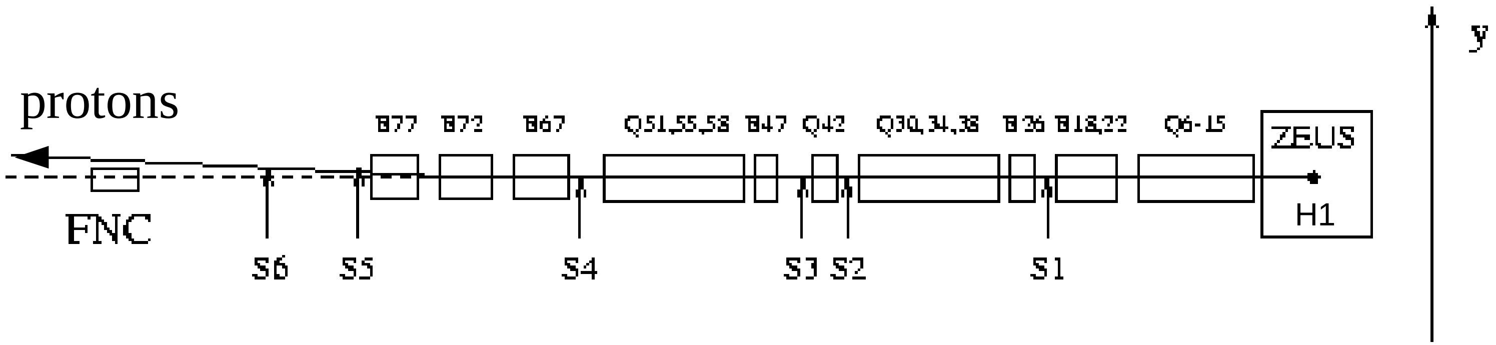
Motivation: Rescattering

- Ratio of x_L distributions: γp/DIS each normalized by inclusive (no LN requirement) cross section
- Observed fewer low x_L neutrons in γp than in DIS ✓
- Same trend in rescattering (absorption) model of D'Alesio & Pirner



<u>Here will compare p_T^2 distributions in DIS and γp for the first time</u>

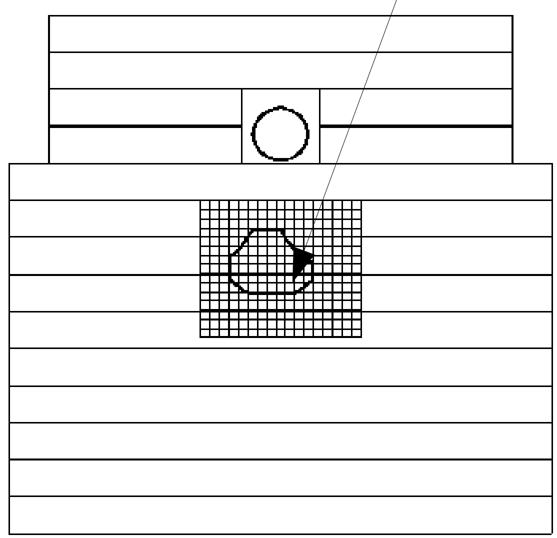
LN detectors:
Forward Neutron Calorimeter (FNC)



- ~100 m from I.P. in proton direction
- Protons bent upward; FNC acceptance at 0°

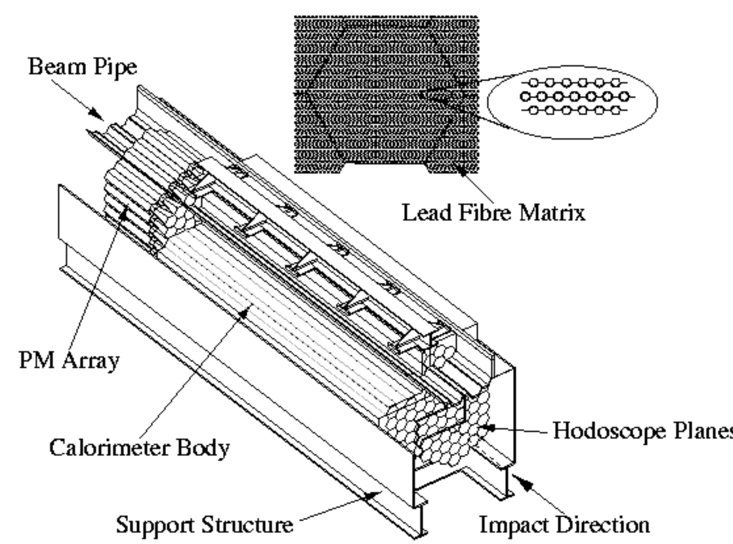
ZEUS FNC:

- Pb-scintillator sandwich
- $\sigma_E/E \approx 70\%/\sqrt{E}$
- Position detector hodoscope 1 λ_I deep
- $\sigma_{x,y} = 2.3$ mm
- p_T resolution dominated by proton beam spread



H1 FNC:

- Pb-scintillator spaghetti
- $\sigma_E/E \approx 20\%$ for $E_n > 300$ GeV



LN with dijets: Data sample & kinematics

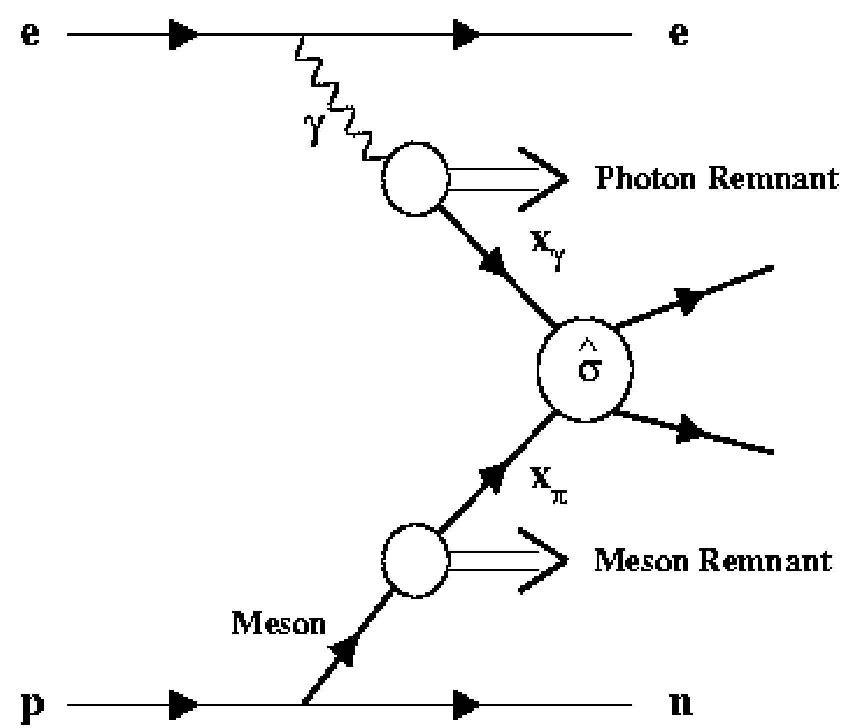
- Hadronic final state w/ 2 high E_T jets:

  $e + p \rightarrow e' + n + jet_1 + jet_2 + X$

  $E_T^1 > 7$ GeV, $E_T^2 > 6$ GeV
- Samples in γp ($Q^2 < 0.01$ GeV^2) and DIS ($2 < Q^2 < 80$ GeV^2) regimes
- Jets characterized by E_T, η (pseudorapidity)
- Also: x_γ, fractional momentum of the parton from photon which enters the hard interaction

  $x_\gamma \sim 1$: direct γp, photon pointlike

  $x_\gamma < 1$: resolved γp, photon has structure, size



LN with dijets: Monte Carlo models

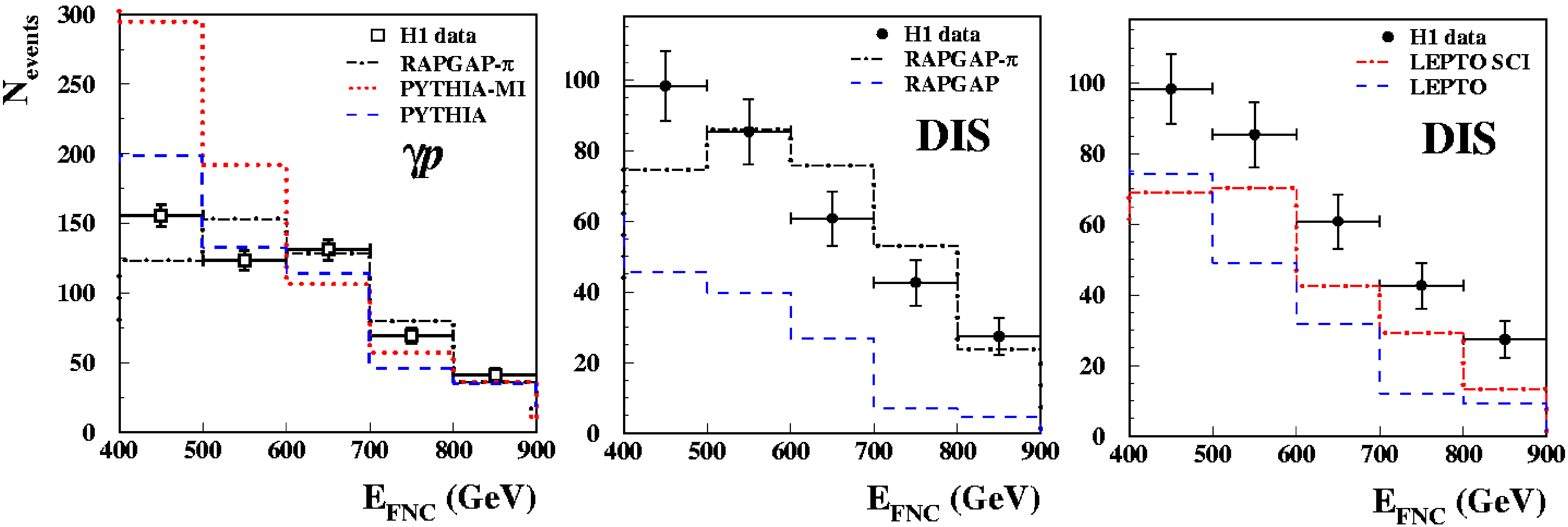
	Photoproduction	DIS
π-exchange	RAPGAP-π, POMPYT	RAPGAP-π
Inclusive (no π-exchange)	PYTHIA-MI, PYTHIA	RAPGAP, LEPTO, LEPTO-SCI
NLO calculations (π-exch.)	M.Klasen & G.Kramer	

- RAPGAP, LEPTO 'standard' DIS MC; PYTHIA 'standard' γp MC
- RAPGAP-π = RAPGAP + π-exchange
- POMPYT = PYTHIA + π-exchange, similar results as RAPGAP-π
- PYTHIA -MI = PYTHIA + multi-parton interactions;

  necessary to describe inclusive dijet γp
- LEPTO-SCI = LEPTO + soft color interactions;

  LN production enhanced via non-perturbative color rearrangements
- Hadronization corrections applied to NLO calculation, determined from MC
- Here models passed through detector simulation, compared to uncorrected data

LN with dijets: x_L spectra

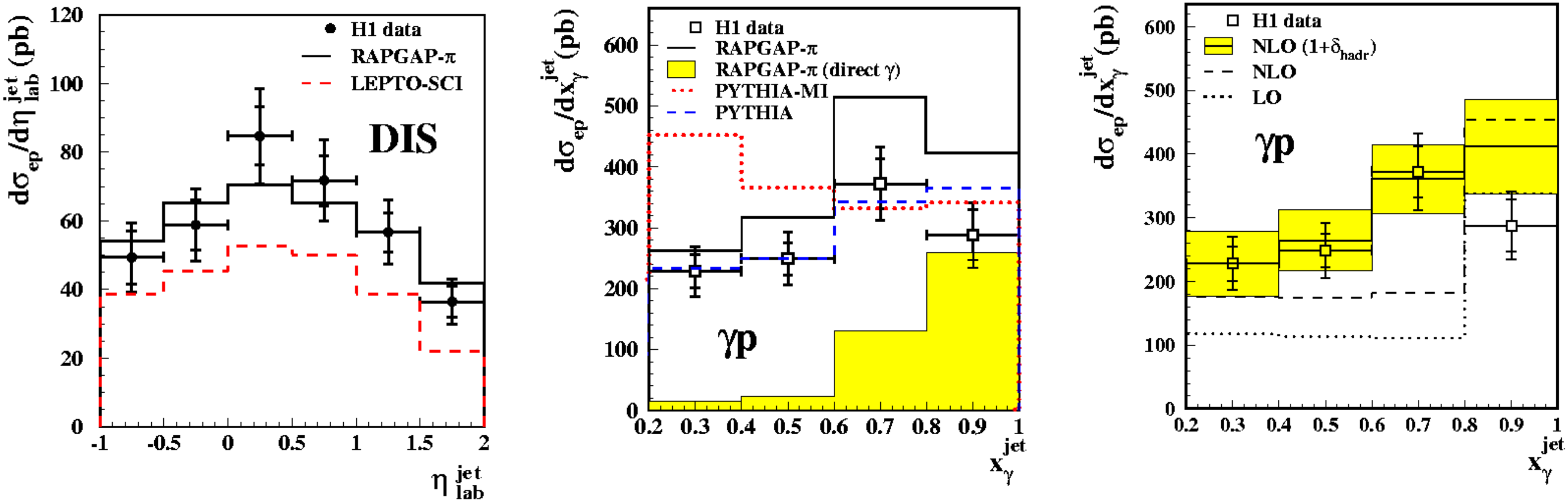


$x_L = E_{FNC} / E_{p\text{-beam}}$

- Well described by π-exchange MC models
- 'Standard' DIS models predict too low neutron rate
- 'Standard' *γp* model PYTHIA w/ multiple interactions predicts too high rate

  w/o multiple interactions PYTHIA give reasonable description of x_L

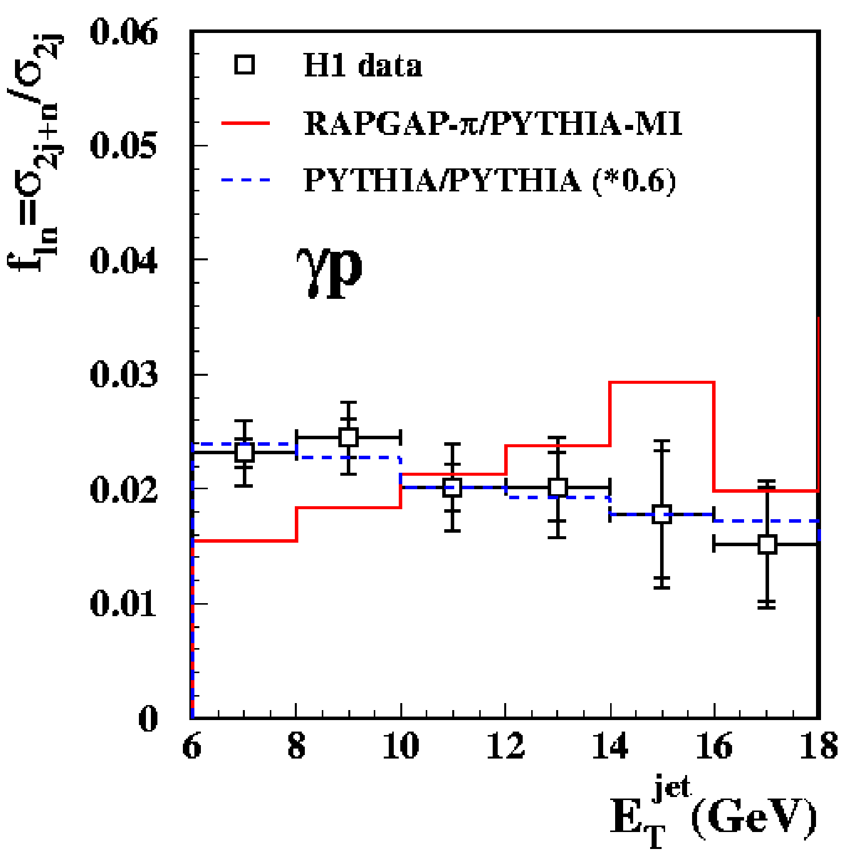
LN with dijets: kinematic dependencies

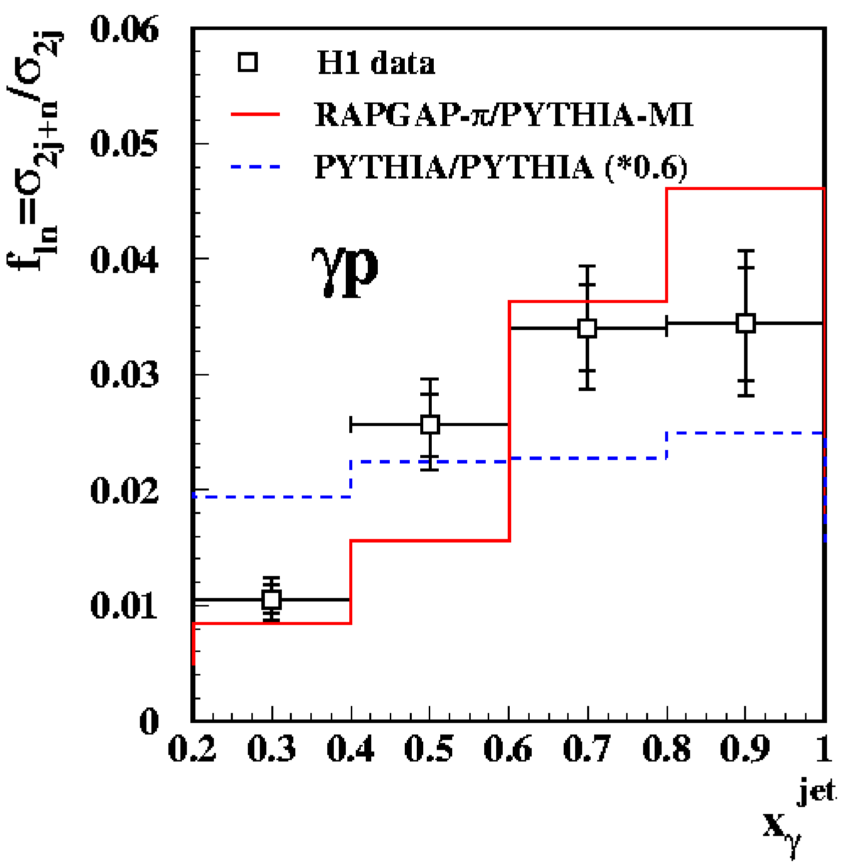


- Well described by π-exchange MC models
- PYTHIA describes LN data, but not inclusive *γp*
- LEPTO-SCI too low; PYTHIA-MI too high at low x_γ: too much resolved
- NLO QCD calculation, corrected for hadronization describes the data

LN with dijets: LN ratios

Fraction of inclusive dijet γp with LN: test of factorization

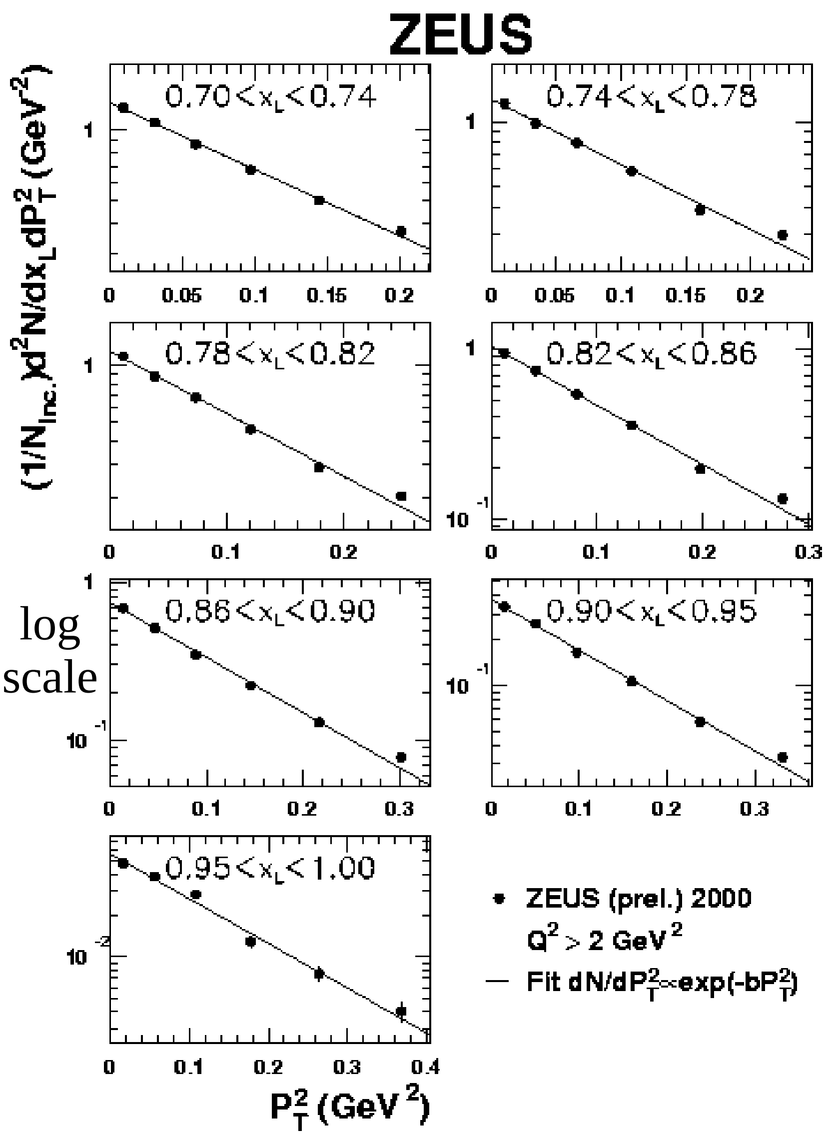




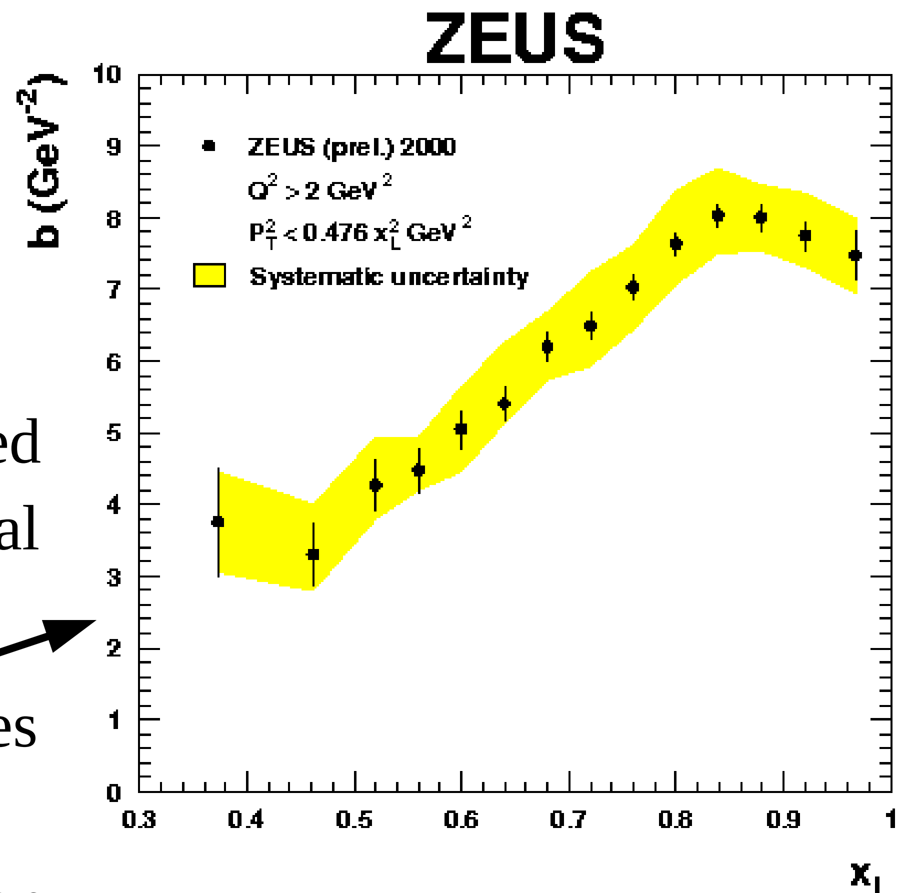
- f_{LN} almost independent of E_T: factorization
- f_{LN} strong dependence on x_γ; not phase space (PYTHIA): factorization breaking
- Fewer LN at low x_γ, resolved photon region
- Resolved photon 'larger': absorption effect? A calculation would be nice...

LN in DIS: $p_T^{\,2}$ distributions

- LN in inclusive DIS regime: $Q^2 > 2$ GeV^2
- Limited neutron scattering angle $\Rightarrow p_T^{\,2} < 0.476 x_L^{\,2}$ GeV^2

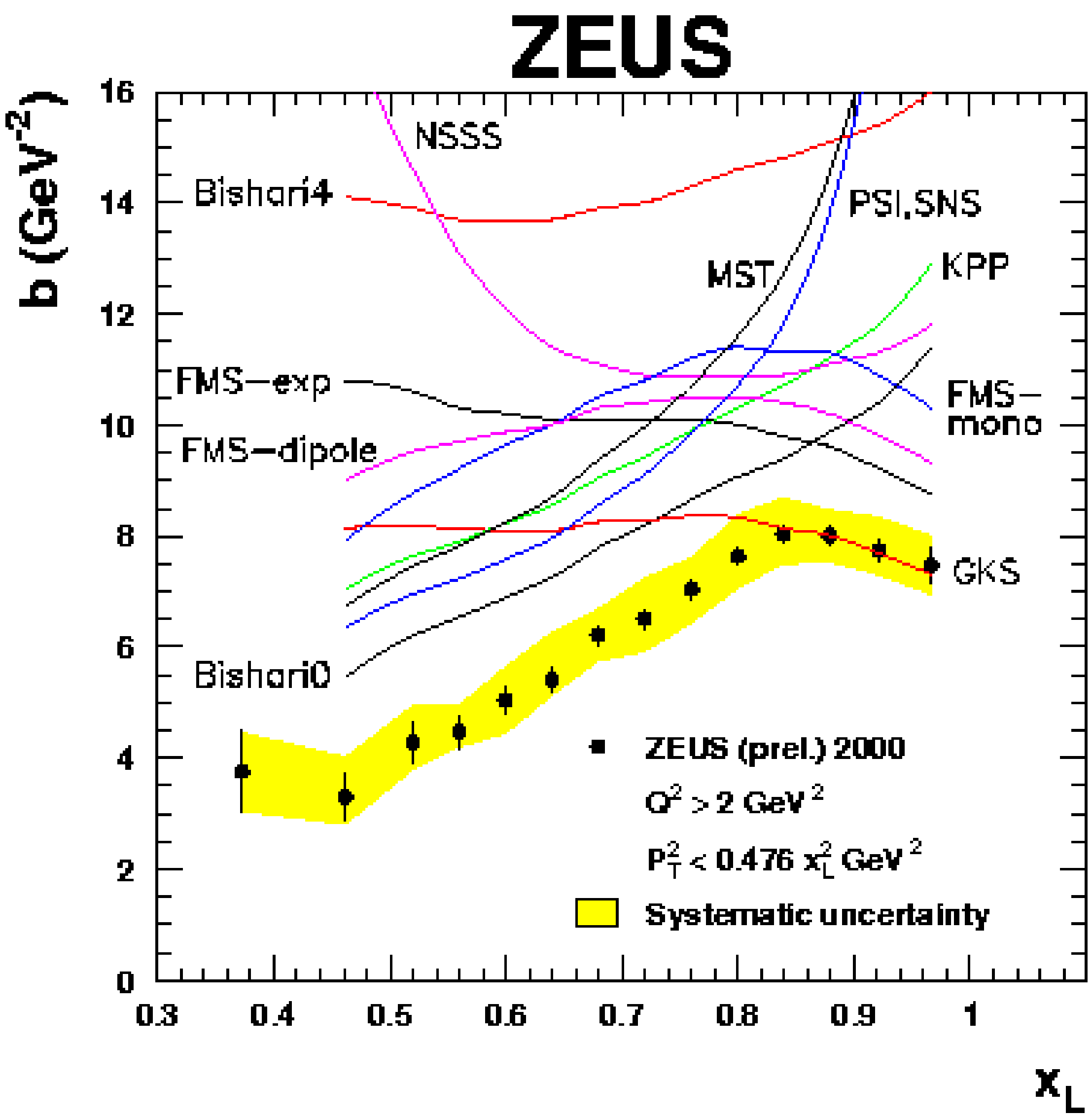


- Data here corrected for acceptance, resolution
- Well described by exponential $\exp(-bp_T^{\,2})$
- b characterizes steepness of $p_T^{\,2}$ distribution



b consistent with zero for $x_L < 0.3$

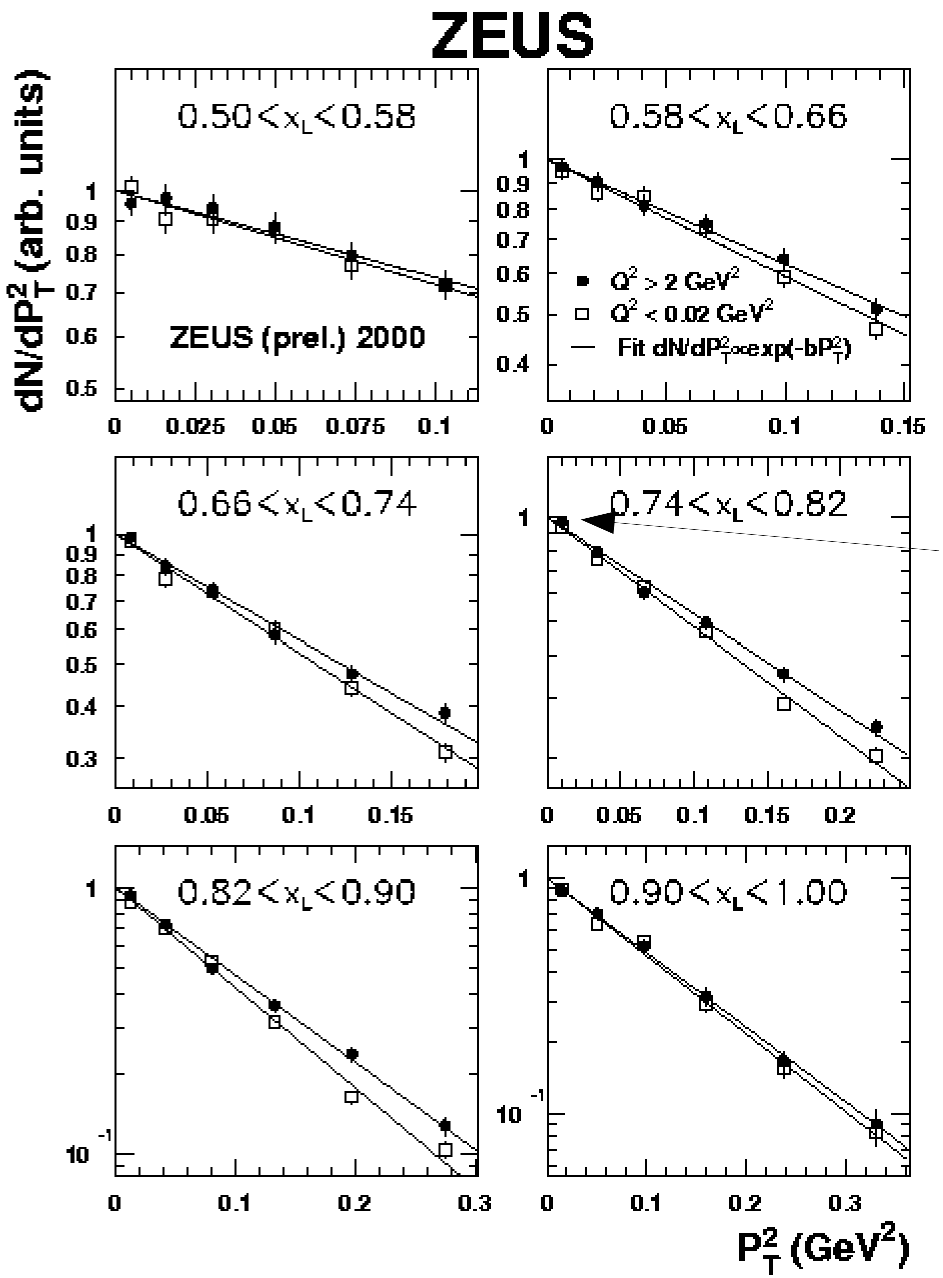
LN in DIS: p_T^2 distributions



References in HEP2005 paper #343

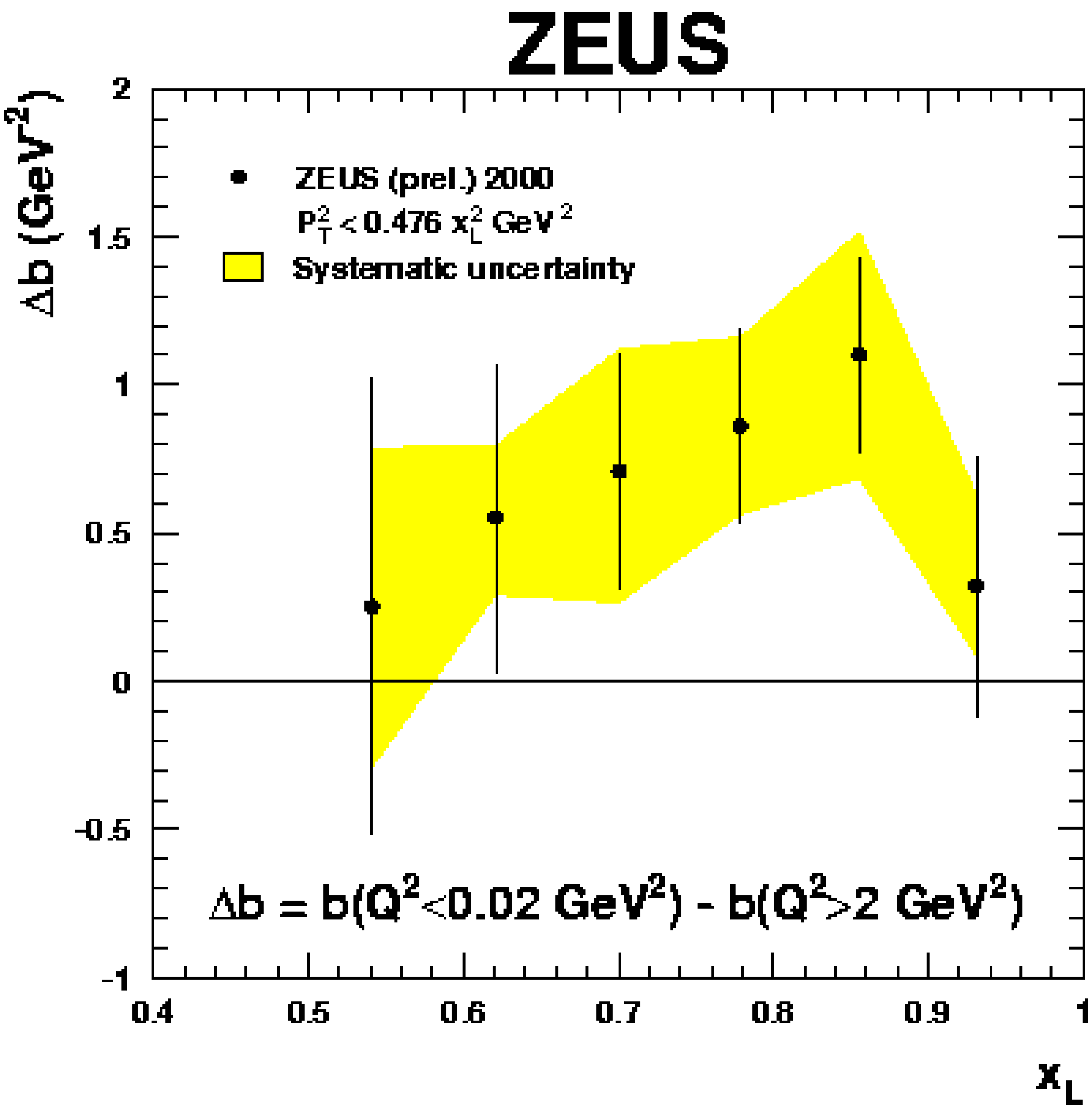
- Numerous models for π-exchange in the literature
- Essentially different form factors at *p*-*n*-π vertex
- Parameterized from low energy *pp*, π*p* data
- Not exponential, but can MC models and fit like data
- None describe data over whole x_L range
- π-exchange expected to dominate for $0.6<x_L<0.9$; Bishari0 closest (also simplest model)
- Varying contributions other than π-exchange across x_L?

LN in γp & DIS: $p_T^{\,2}$ distributions



- Compare LN in DIS and γp (Q^2<0.02 GeV ^{2}) regimes
- Normalize @ $p_T^{\,2}$=0 GeV ^{2} to compare slopes
- In γp relatively fewer LN at high $p_T^{\,2}$
- Qualitatively consistent with expectation from absorption model

LN in γp & DIS: p_T^2 distributions



- Some systematic uncertainties on b(γp), b(DIS) cancel in Δb = b(γp)-b(DIS)
- Slopes in γp larger than in DIS for $0.6 < x_L < 0.9$
- Qualitatively consistent with expectation from absorption
- Quantitative comparison would be nice
  $\Rightarrow$ need a calculation...

Summary

- 'Standard' fragmentation does not describe LN production:
  generally predict too low LN rate
- π-exchange models give reasonable description of LN in γp & DIS:
  LN rate, x_L spectra, kinematic dependencies
- π-exchange models in literature do not describe p_T spectra very well:
  contributions from other processes?
- Effects consistent with absorption have been observed:
  LN in inclusive γp, resolved γp of dijets
- New calculations of absorption would be nice:
  x_γ, LN p_T dependencies
- An invitation to our calculational colleagues!