Leading Baryon Production at HERA

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Topics

Properties of Leading Baryons

- Kinematical Variables
- Detectors and Data Samples
- Energy Spectra and Angular Distributions
- Absorptive Effects
- Relative Production Rates
- Semi-Inclusive Structure Functions
- Factorization
- Scaling Violations

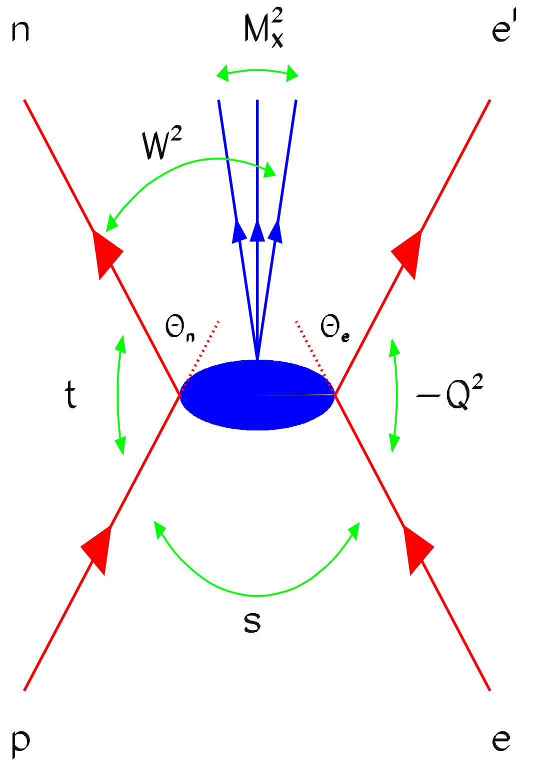
Implications for Proton and Pion Structure

- Pion Exchange
- Methods of Analysis
  - Unnormalized Tagged Beam Approach
  - Effective Flux Method
- $\gamma\pi$ Total Cross Section
- Structure Function of the Pion
- Discussion

Summary

Kinematical Variables

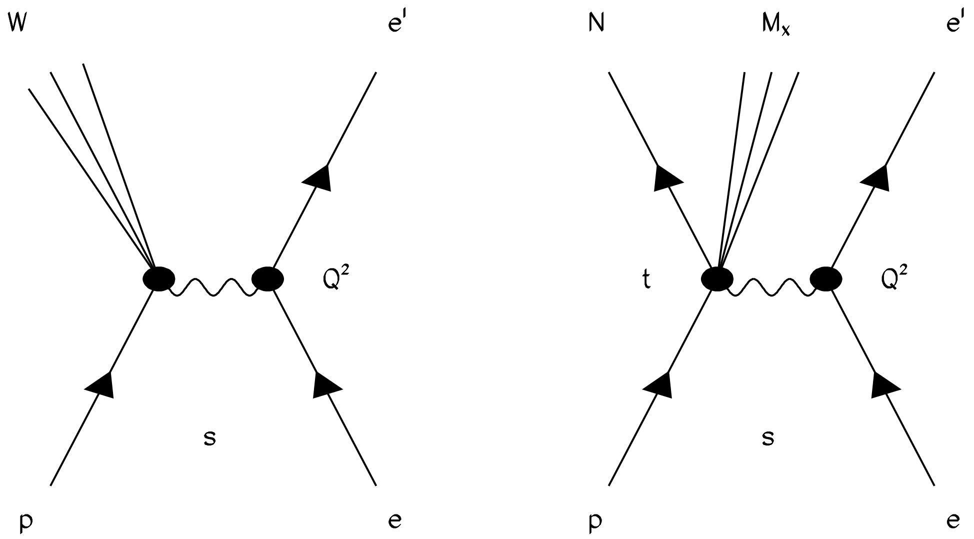
- Inclusive & Semi-Inclusive Reactions $ep \to e'(N)X$



- Lepton variables: variables:
  $Q^2 = -(e - e')^2 = -q^2$
  $x_{BJ} = Q^2/(2p \cdot q)$
  $y = p \cdot q / p \cdot e$
  $W^2 = M_N^2 + Q^2(1 - x_{BJ})/x_{BJ}$
- Leading baryons variables:
  $x_L = n \cdot e / p \cdot e \simeq n_+/p_+ \simeq E_N/E_p$
  $p_T = E_N \theta_N$
  $t = (p - n)^2 = -p_T^2/x_L - M_N^2(1 - x_L)^2/x_L$

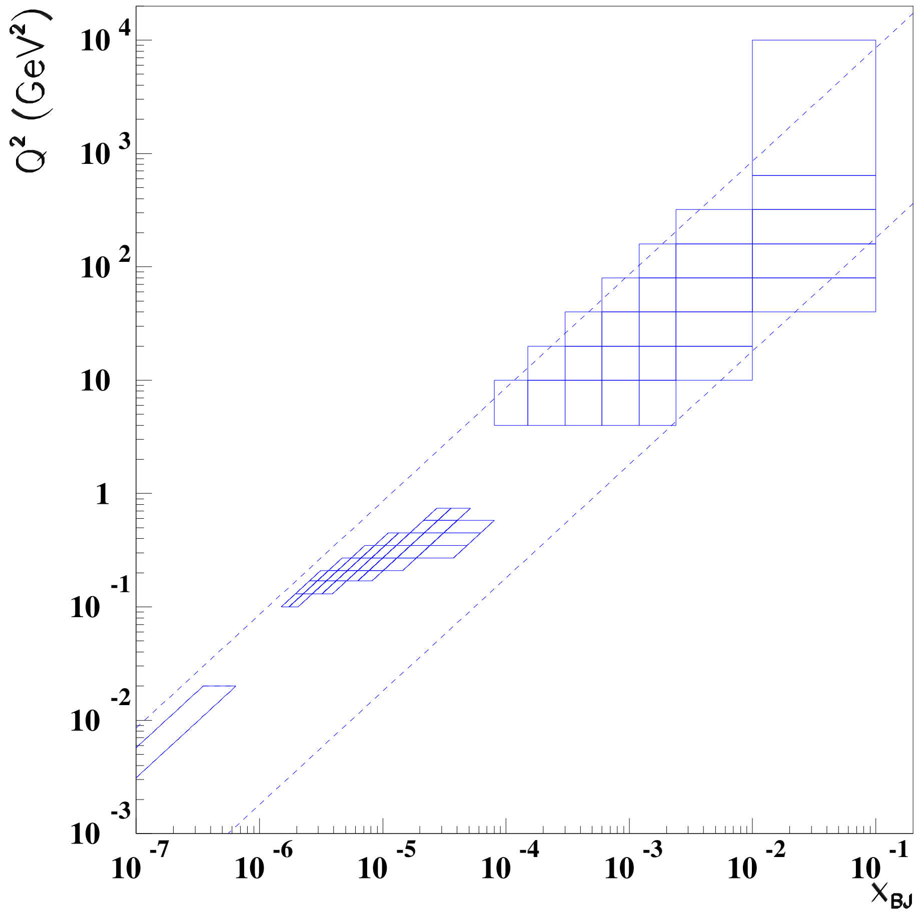
Kinematical Variables

- Lepton described by standard DIS kinematical variables:
  Q^2, W^2, x_{BJ}, y



- Leading baryons described by:
  $x_L = E_N/E_p$, energy fraction
  θ_N, scattering angle
  $p_T = E_N\theta_N$, transverse momentum
  $t = -p_T^2/x_L - M_N^2(1-x_L)^2/x_L$, momentum transfer^2
- Analogous variables:
  $x_L \sim (1-y)$
  $t \sim -Q^2$

Kinematic Plane



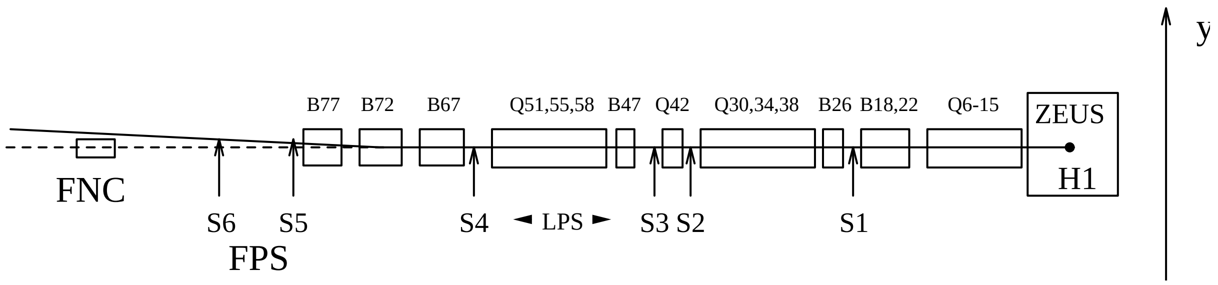
Photoproduction $Q^2 < 0.02$ GeV^2

Transition $0.1 < Q^2 < 0.74$ GeV^2

DIS $4 < Q^2 < 10^4$ Gev^2

Forward Beam Line at HERA

- Downstream in proton direction from HERA IR:



- Vertical bend from z= 65-80 m:
  Analyzing magnets for proton spectrometers
  Sweeping magnets for neutron calorimeters

- 3 stations of ZEUS LPS S4-S6 z=65-96 m
  2 stations of H1 FPS at z=80,91 m
  $\Rightarrow x_L \gtrsim 0.6$

- ZEUS and H1 FNC on zero-degree line at z=106-107 m
  Magnets apertures limit acceptance to $\theta < 0.8$ mrad
  $\Rightarrow p_T < 0.66 x_L$ GeV

Forward Dectectors

- H1 FPS: 1995
  scintillating fiber tracker
  $\sigma_{x_L} \approx 1\%$, $\sigma_{p_T} < 70$ MeV

- ZEUS LPS: 1995
  silicon microstrip tracker
  σ_{x_L} few %, $\sigma_{p_T} \approx 5$ MeV

- H1 FNC: 1996
  lead-scintillating fiber matrix
  $\sigma_E/E \approx 20\%$, $\sigma_{xy} \lesssim 0.5$ cm

- ZEUS FNC: 1995-1997
  lead-scintillator sandwich, WLS readout
  $\sigma_E/E \approx$ 2-5%, $\sigma_{xy} \approx 1.4$ cm

- ZEUS FNT: 1999
  scintillator hodoscope, strip width 1.2 cm
  1 λ deep in FNC, $\sigma_{xy} \approx 0.3$ cm

Semi-Inclusive Structure Function F_2^{LB}

- Direct Measurement

$$\frac{\mathrm{d}^4\sigma(ep \to e'NX)}{\mathrm{d}x_{BJ}\mathrm{d}Q^2\mathrm{d}x_L\mathrm{d}p_T^2} = \frac{4\pi\alpha^2}{x_{BJ}Q^4}\left(1 - y + \frac{y^2}{2}\right) F_2^{LB(4)}(x_{BJ}, Q^2, x_L, p_T^2)$$

- Ratio Measurement

$$\begin{aligned} r &\equiv \frac{1}{Acc(x_L, p_T^2)} \frac{N(x_{BJ}, Q^2, x_L, p_T^2)}{N(x_{BJ}, Q^2)} \\ &= \frac{\frac{\mathrm{d}^4\sigma(ep\to e'NX)}{\mathrm{d}x_{BJ}\mathrm{d}Q^2\mathrm{d}x_L\mathrm{d}p_T^2}\Delta x_L \Delta p_T^2}{\frac{\mathrm{d}^2\sigma(ep\to e'X)}{\mathrm{d}x_{BJ}\mathrm{d}Q^2}} \\ &= \frac{F_2^{LB(4)}(x_{BJ}, Q^2, x_L, p_T^2)\Delta x_L \Delta p_T^2}{F_2^p(x_{BJ}, Q^2)} \\ &= \frac{\frac{\mathrm{d}^4\sigma(\gamma^* p\to NX)}{\mathrm{d}x_{BJ}\mathrm{d}Q^2\mathrm{d}x_L\mathrm{d}p_T^2}\Delta x_L \Delta p_T^2}{\frac{\mathrm{d}^2\sigma(\gamma^* p\to X)}{\mathrm{d}x_{BJ}\mathrm{d}Q^2}} \end{aligned}$$

N: number of events in a bin
Acc: acceptance of forward detector
$\Delta x_L \Delta p_T^2$: bin size

Corrections are small and depend on
difference between tagged and inclusive

Ratio Measurement

Systematics errors greatly reduced:

- Luminosity measurement
- Trigger efficiency
- Central calorimeter acceptance
- Monte Carlo modeling of final state
- Radiative corrections
- Uncertainty in F_L/F_2

Ratios determine F_2^{LB}:

$$F_2^{LB(4)}(x_{BJ}, Q^2, x_L, p_T^2) = \frac{r}{\Delta x_L \Delta p_T^2} F_2^p(x_{BJ}, Q^2)$$

r is a *measured* function of x_{BJ}, Q^2, x_L, p_T^2
F_2^p is a *measurement* or *parameterization* the proton's F_2

Factorization

- Limiting Fragmentation

$$F_2^{LB} = f(x_L, p_T^2) F(x_{BJ}, Q^2)$$

Complete separation of baryon and lepton variables

- Particle Exchange Factorization

$$F_2^{LB} = f(x_L, p_T^2) F\left(x_{BJ}/(1 - x_L), Q^2\right)$$

Partial separation of baryon and lepton variables

- Power Laws
For power law energy dependences of cross sections

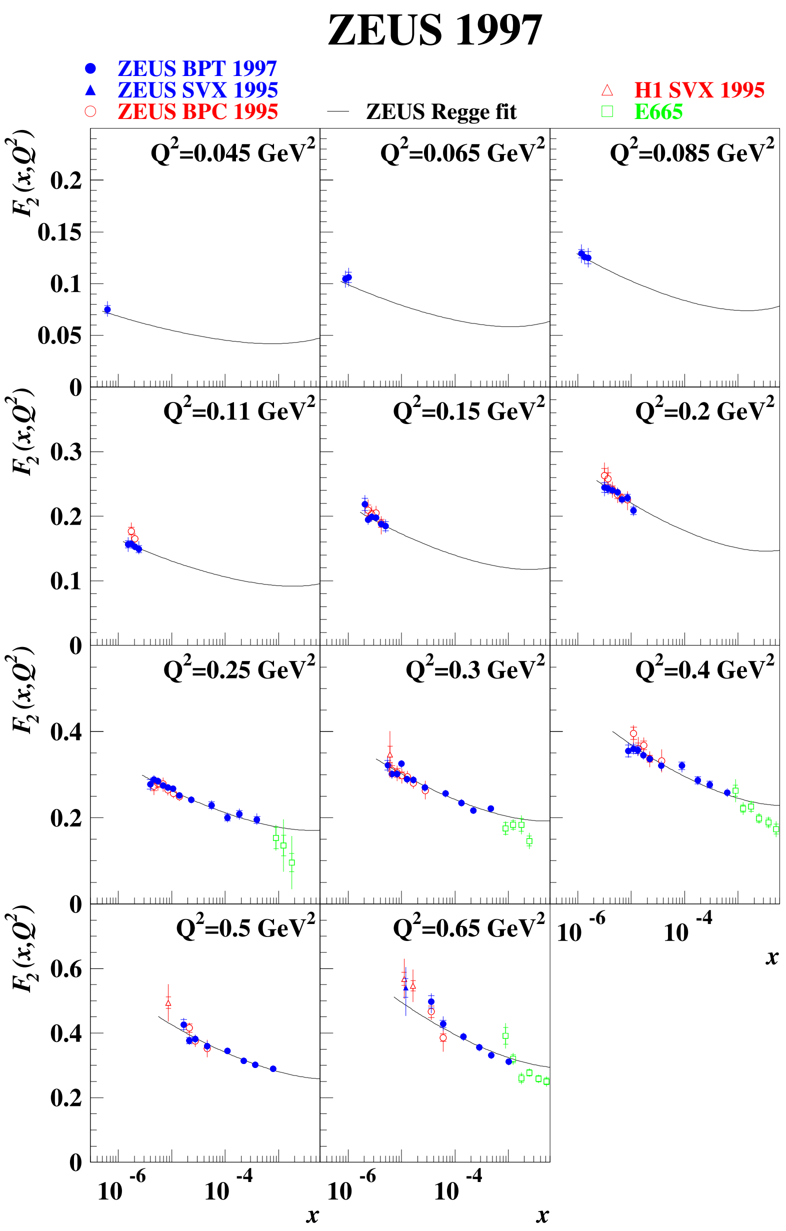
$$F \sim (1/x_{BJ})^{\lambda}$$

Particle Exchange $\Rightarrow$ Limiting Fragmentation

- Limiting Fragmentation & Particle Exchanges $\Rightarrow$ power law
- Study ratio

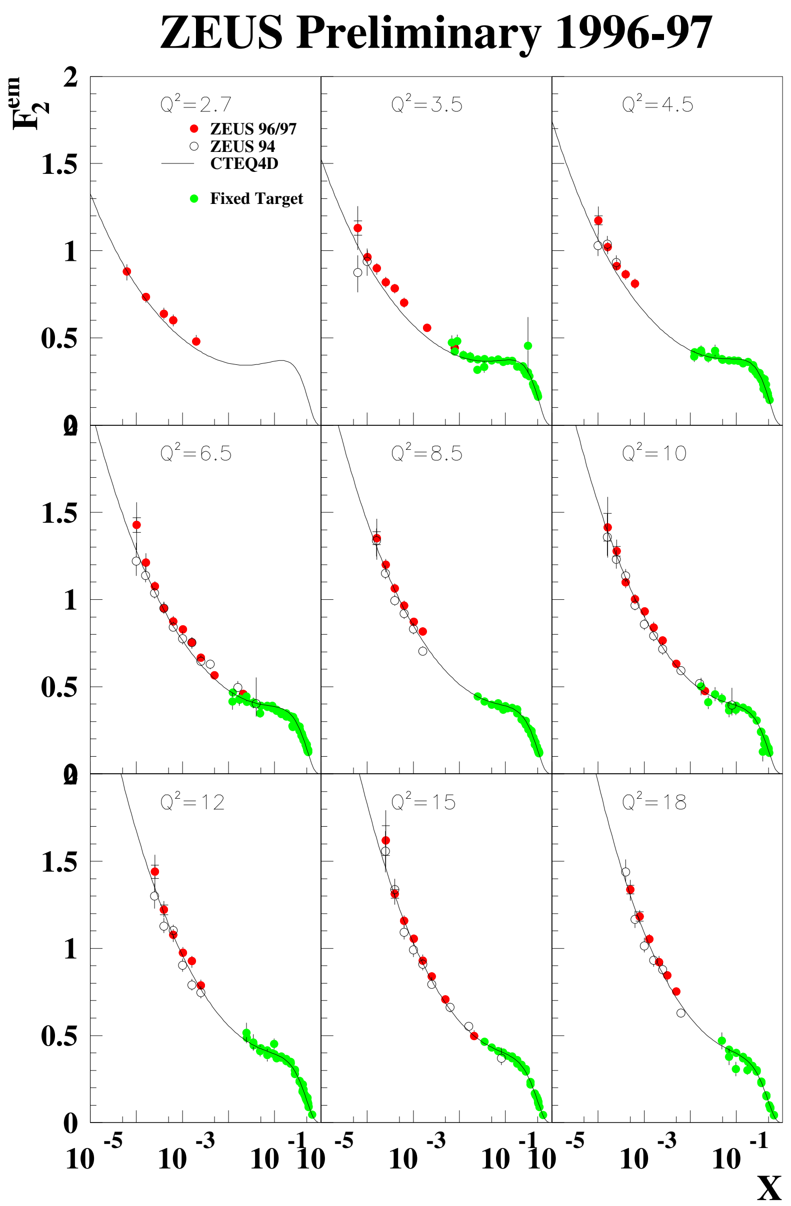
$$\begin{aligned} \mathrm{r} &= \text{(Leading Baryons)/(All DIS)} \\ &\propto F_2^{LB}/F_2^{p} \end{aligned}$$

Measurement of F_2 at Low Q^2 and High W



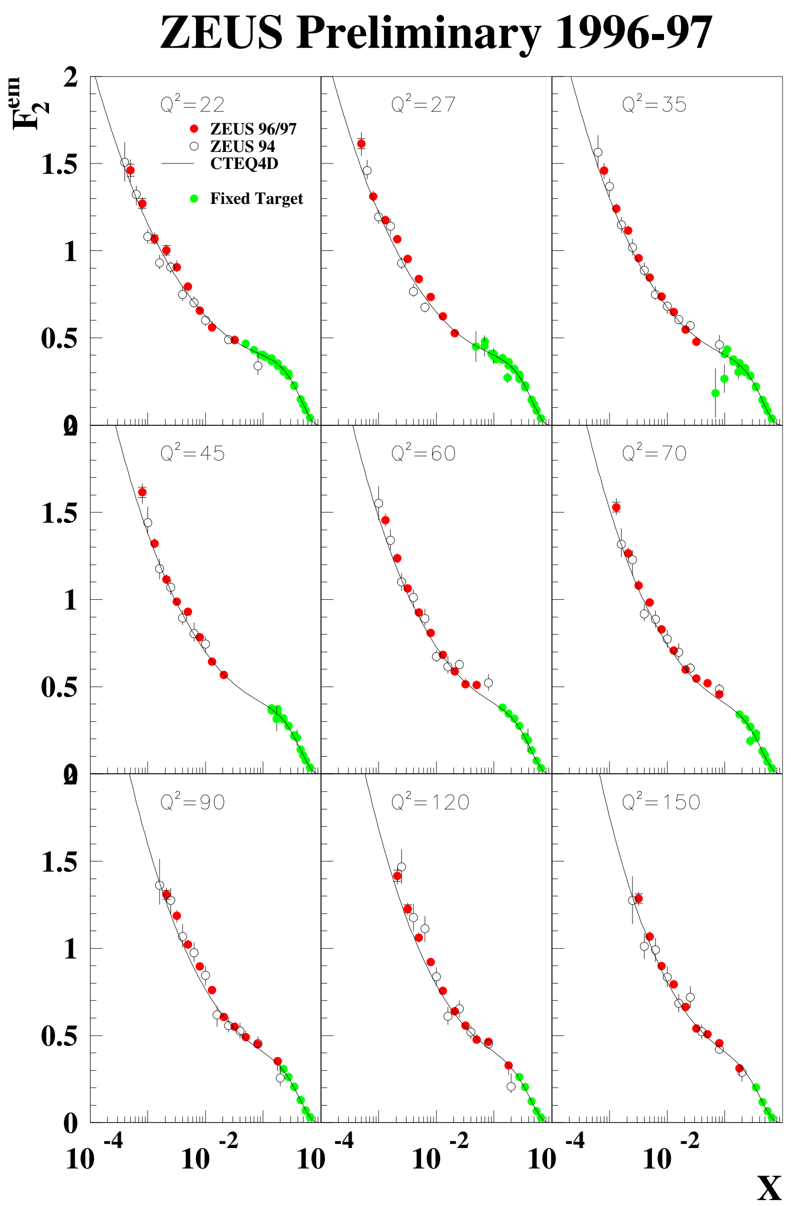
$$F_2(x, Q^2) = \left(\frac{Q^2}{4\pi^2\alpha}\right) \cdot \left(\frac{M_0^2}{M_0^2 + Q^2}\right) \cdot \left(A_{\mathbb{R}} \cdot \left(\frac{Q^2}{x}\right)^{\alpha_{\mathbb{R}}-1} + A_{\mathbb{P}} \cdot \left(\frac{Q^2}{x}\right)^{\alpha_{\mathbb{P}}-1}\right)$$

Measurement of F_2 at Medium and High Q^2



At small x, $F_2 \propto (1/x)^{\lambda_{eff}}$

Measurement of F_2 at Medium and High Q^2



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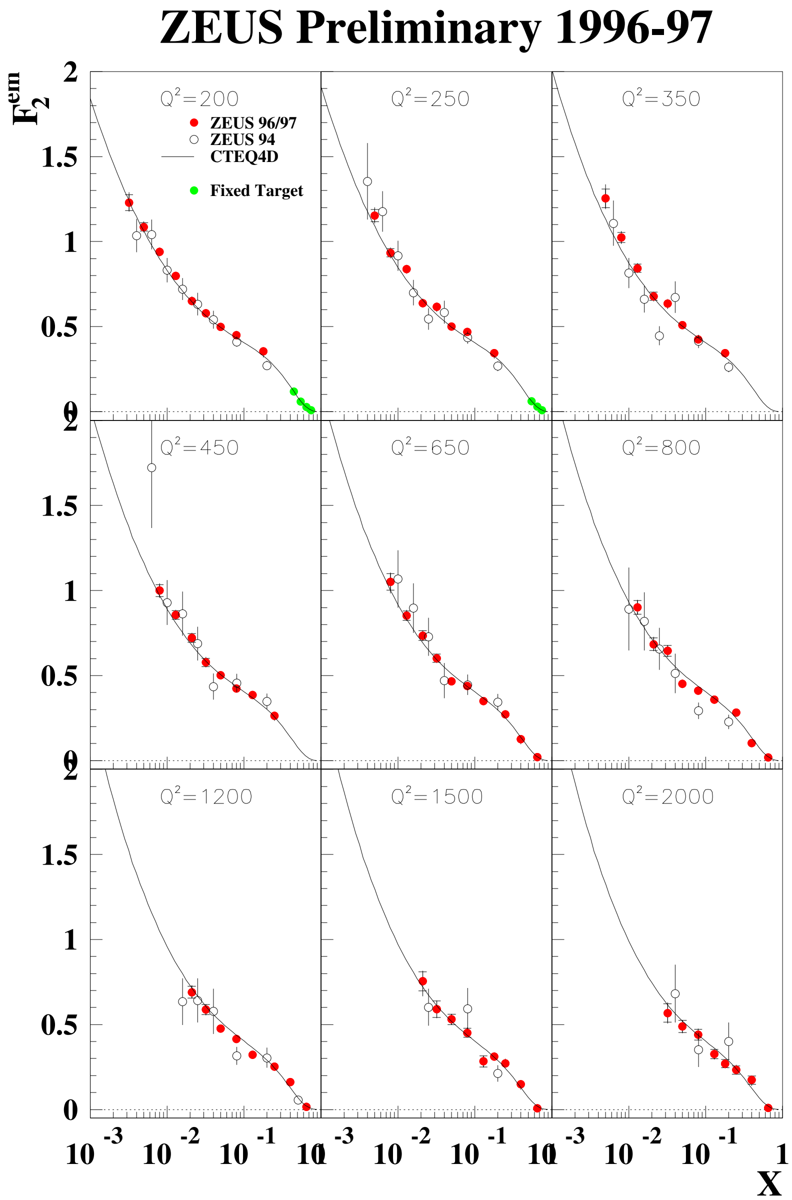

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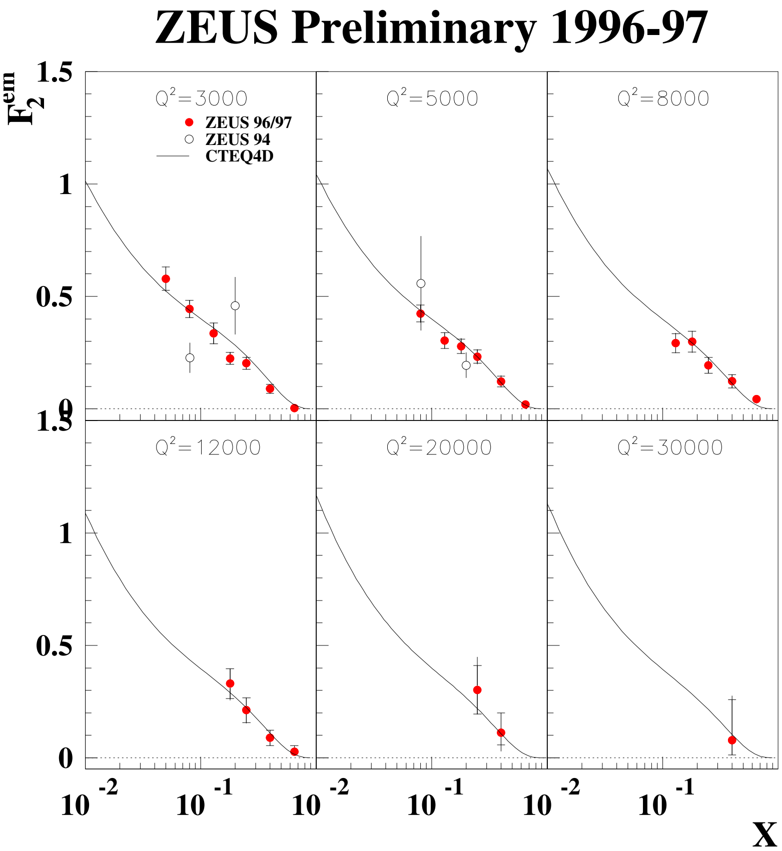
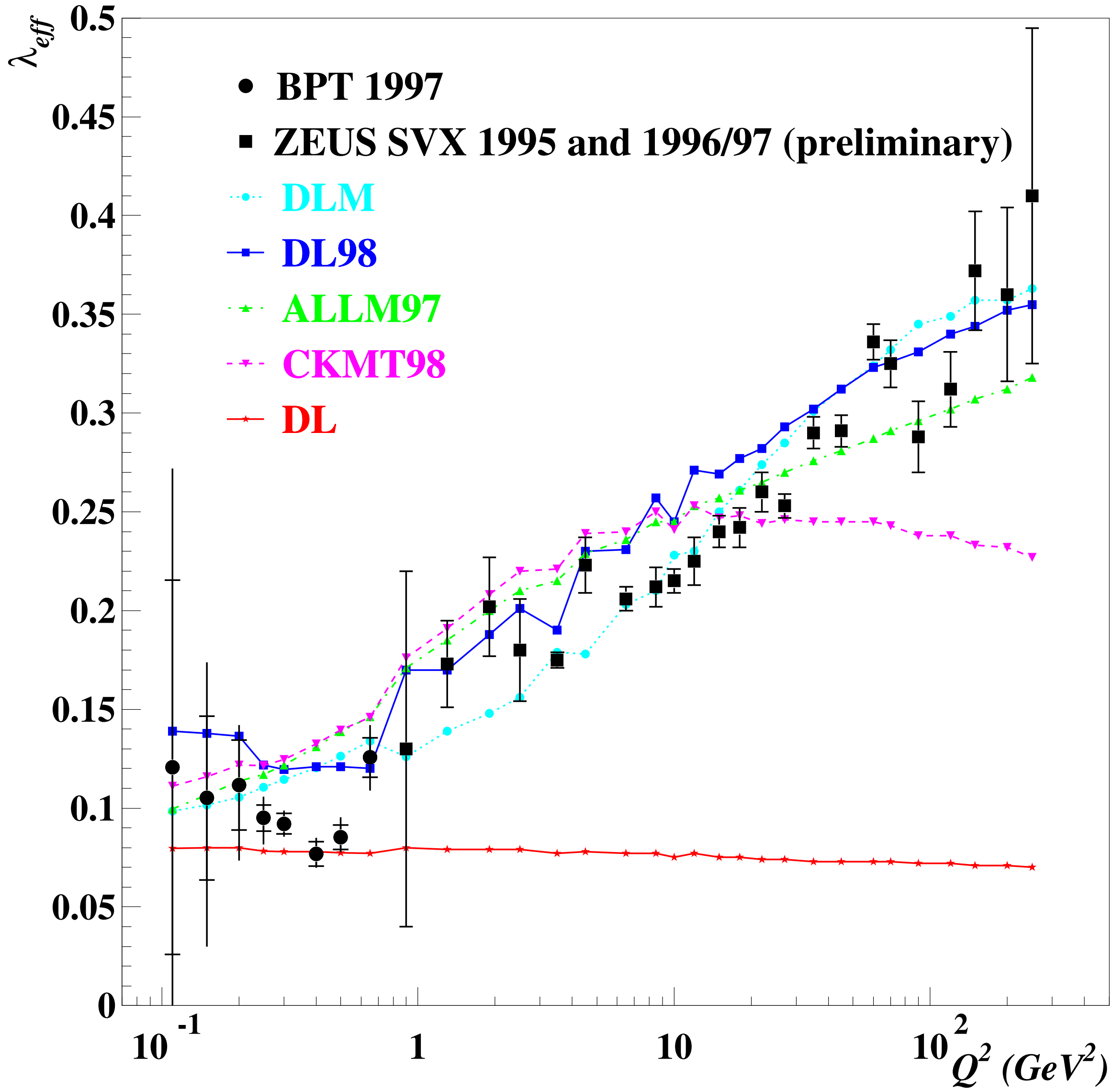


At small x, $F_2 \propto (1/x)^{\lambda_{eff}}$

Power Law Behavior of F_2



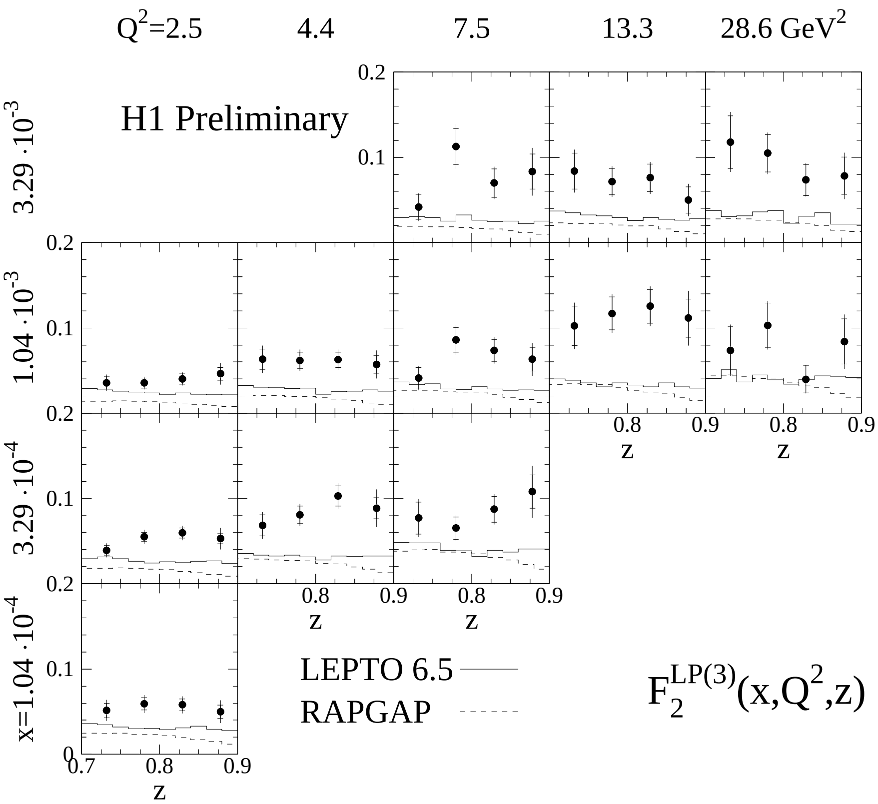
$$F_2 \simeq A(Q^2)\left(\frac{1}{x}\right)^{\lambda_{eff}(Q^2)}$$

$$\lambda_{eff} \equiv \frac{d \ln F_2}{d \ln x}$$

Semi-Inclusive Structure Function $F_2^{LP(3)}$

$$F_2^{LB(3)}(x_{BJ},Q^2,x_L) \quad = \quad \int \mathrm{d}p_T^2 F_2^{LB(4)}(x_{BJ},Q^2,x_L,p_T^2)$$

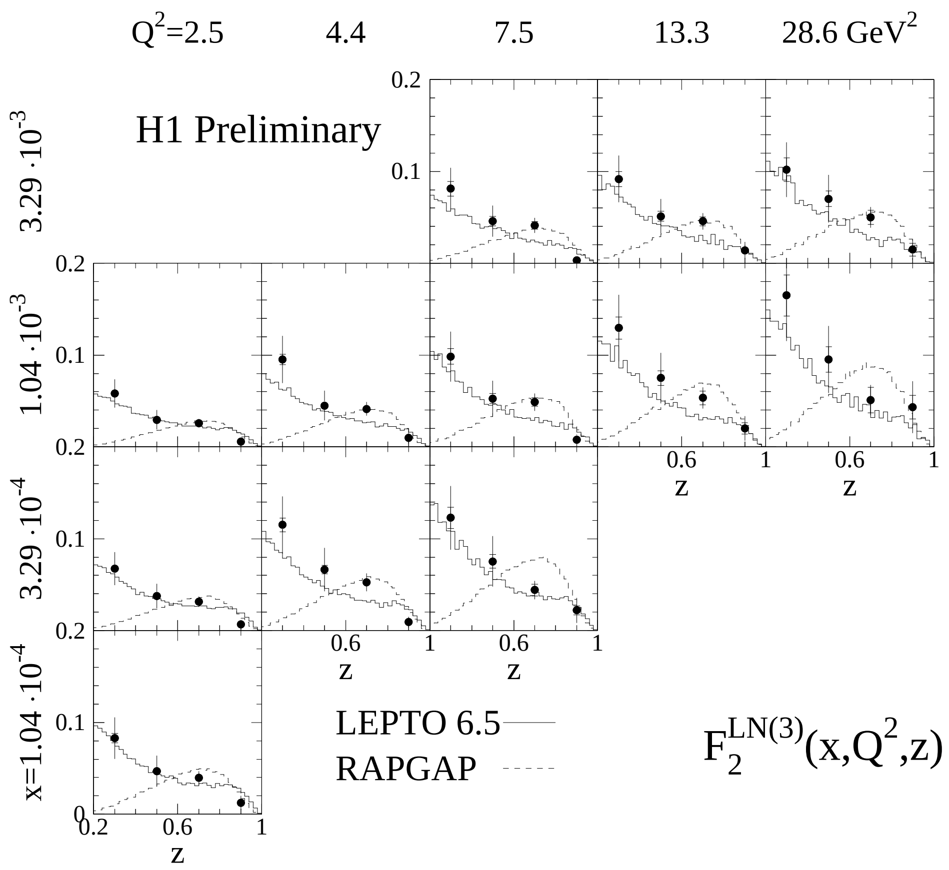
- Integrate over p_T
- Extract $F_2^{LP(3)}$ in bins of x_{BJ}, Q^2 and x_L for $p_T \leq 0.2$ GeV:



- $z \equiv x_L$, $0.7 < x_L < 0.9$, $p_T < 0.2$ GeV
- $F_2^{LP(3)}$ flat in x_L, rising with Q^2 (scale breaking?)
- Shape is constant $\Rightarrow$
  Limiting Fragmentation for protons

Semi-Inclusive Structure Function $F_2^{LN(3)}$

- Extract $F_2^{LN(3)}$ in bins of x_{BJ}, Q^2 and x_L for $p_T \leq 0.2$ GeV:



- $z \equiv x_L$, $0.2 < x_L < 1$, $p_T < 0.2$ GeV
- $F_2^{LN(3)}$ same shape in x_L at all (x_{BJ}, Q^2), rise with Q^2 (scale breaking?)
- Shape is constant $\Rightarrow$ Limiting Fragmentation for neutrons

H1's Regge Model for Baryon Production

- Write $F_2^{LB(3)}$ as sum over exchanged particles flux $\times$ structure functions:

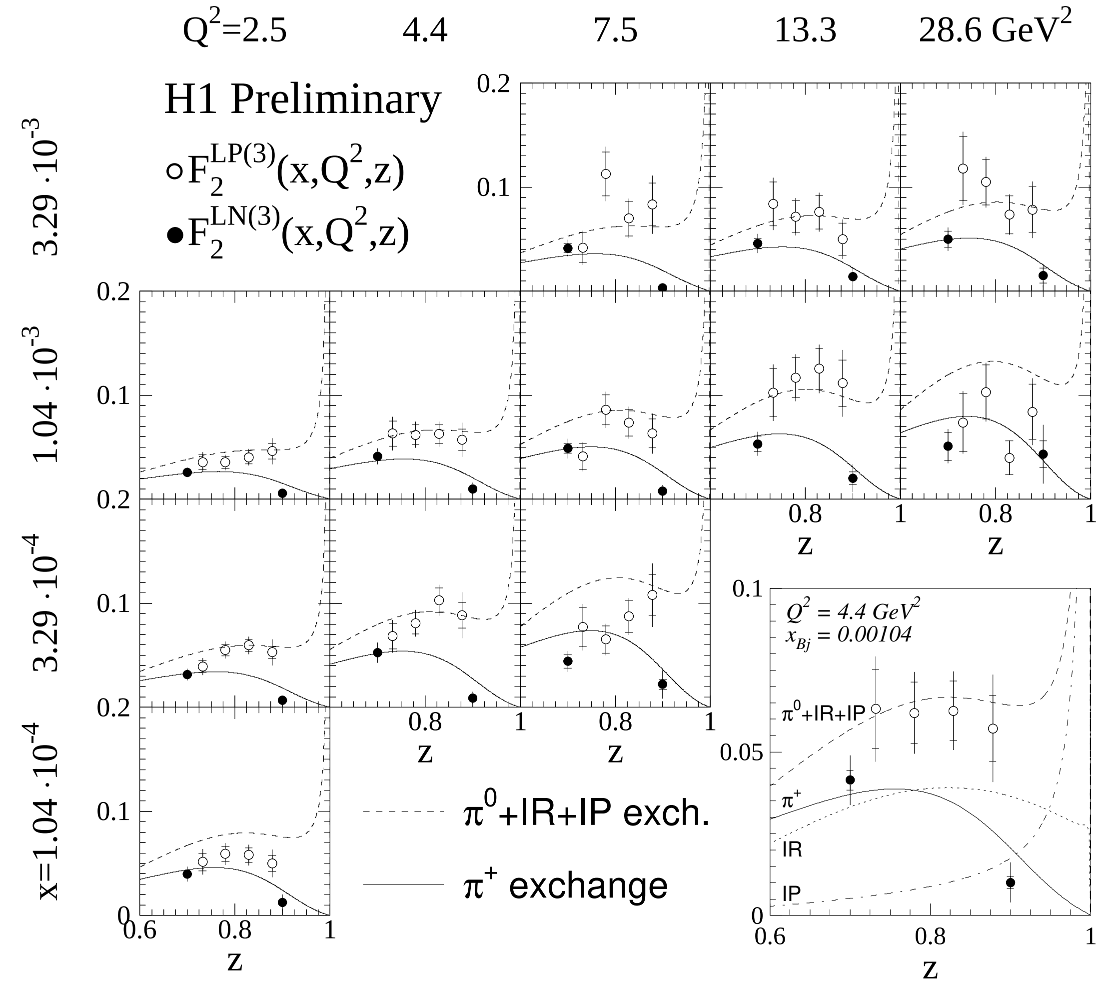
$$F_2^{LB(3)}(x_{BJ}, Q^2, x_L) = \sum_i f_{i/p}(x_L) F_2^i(\beta, Q^2)$$

$$\beta = \frac{x_{BJ}}{1 - x_L}, \qquad i = I\!P, \pi, I\!R \in \{\rho, \omega, a_2, f_2\}$$

- For neutrons exchanged particle has $I = 1$.
  Candidates: π^+, ρ^+, a_2^+
  ρ^+, a_2^+ estimated contribution $< 10\%$ of π^+
- For protons exchanged particle can have $I = 0$ or 1.
  Candidates: $I\!P$, π^0, ρ^0, ω, a_2^0, f_2
  Only $I\!P$, π^0, f_2 expected to contribute significantly
- Couplings, flux factors from hadron-hadron data
- Use F_2^π from GRV parameterization, assume $F_2^f = F_2^\pi$ and $F_2^{I\!P} = \frac{(0.026)}{(0.12)} F_2^\pi$

H1's Regge Model for Baryon Production

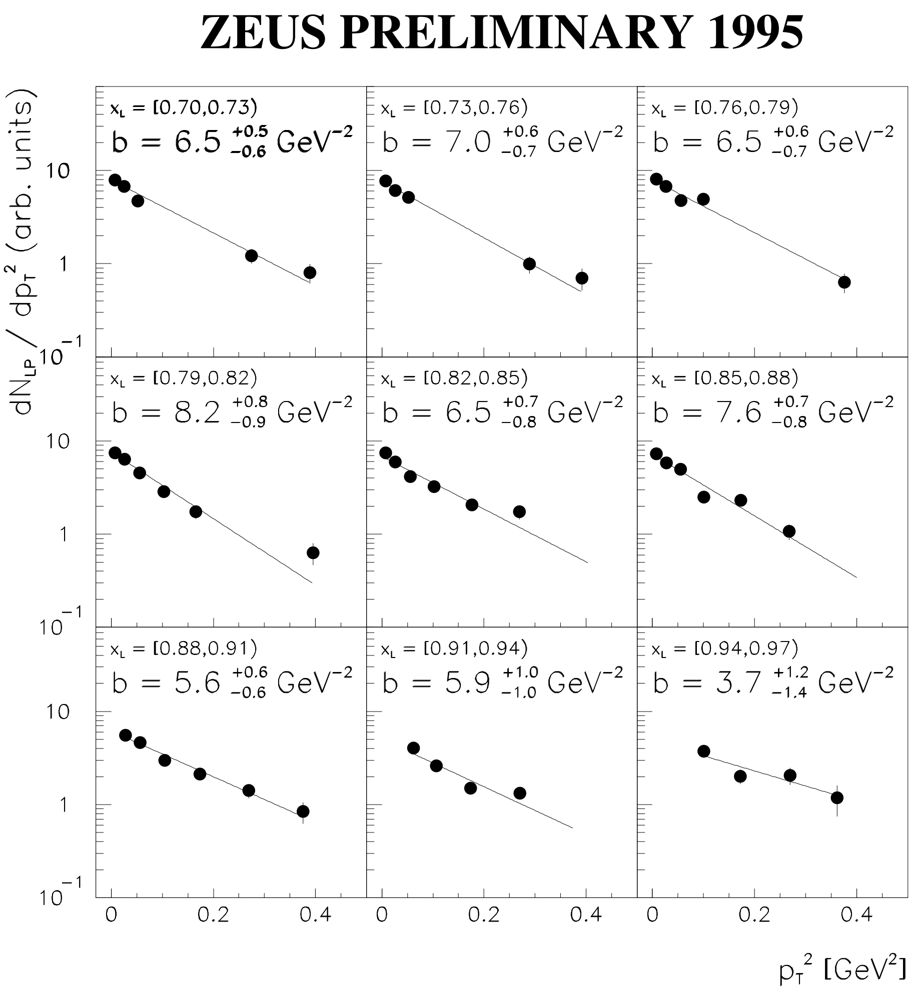
- H1 $F_2^{LB(3)}$, $p_T \leq 0.2$ GeV data with predictions of model:



- Good description of the proton data for $x_L > 0.7$, with f_2 exchange contribution approximately twice π^0 exchange

Angular Distribution of Protons

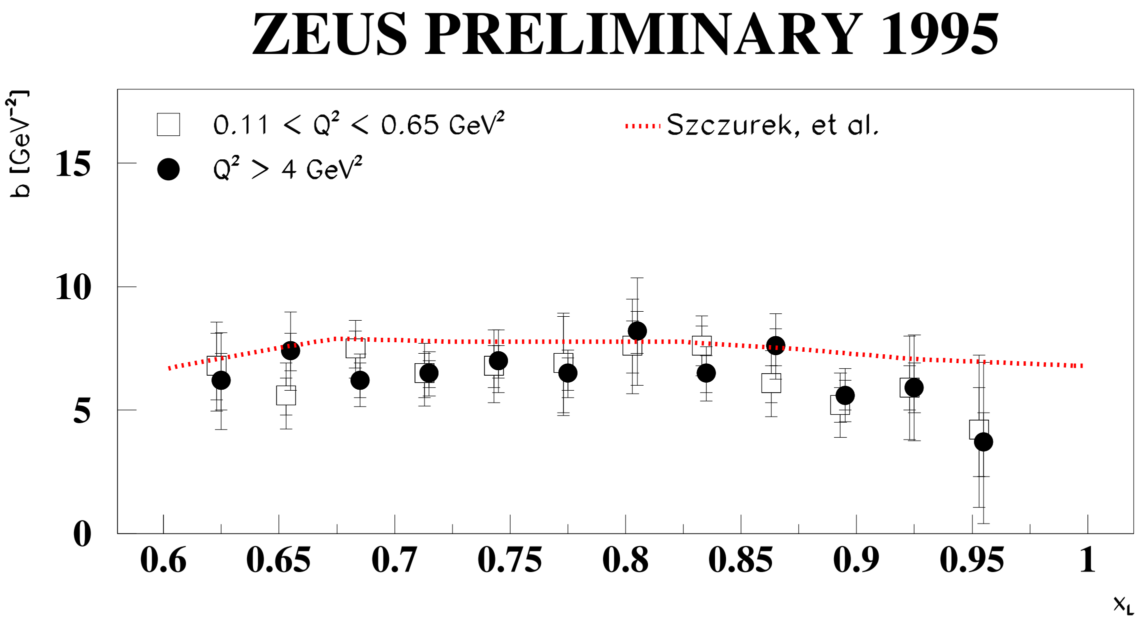
- Proton p_T^2 distributions measured in ZEUS LPS:



- Parameterize $\frac{\mathrm{d}N}{\mathrm{d}p_T^2} \propto e^{-bp_T^2}$, measure slopes b vs. x_L:

Angular Distribution of Protons

- Study of b vs. x_L for $\frac{dN}{dp_T^2} \propto e^{-bp_T^2}$ for protons :

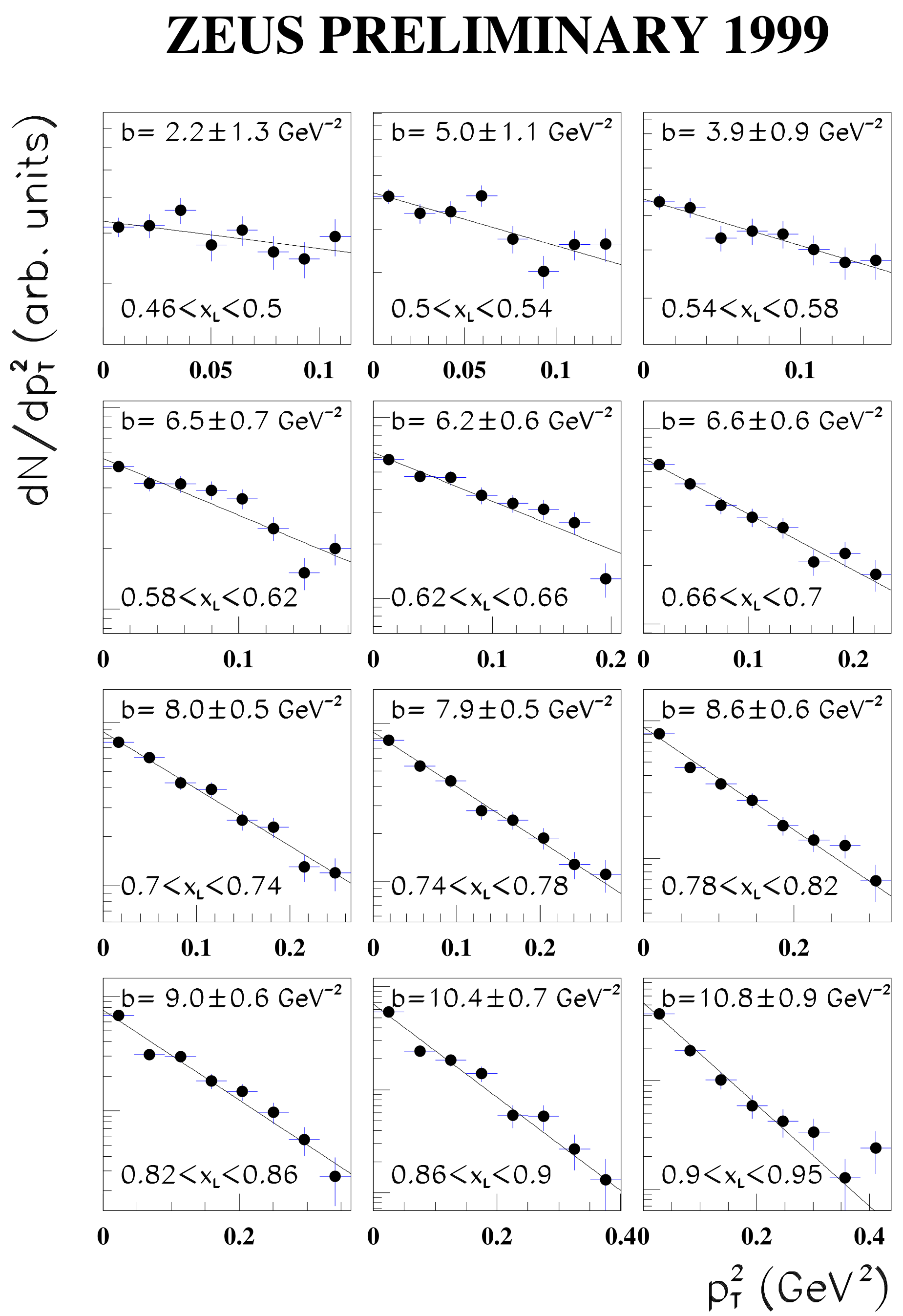


Angular distribution independent of x_L
Angular distribution same for low and high Q^2 $\Rightarrow$
Limiting Fragmentation

- Model predicts slightly higher b, but $b \sim$ independent of x_L

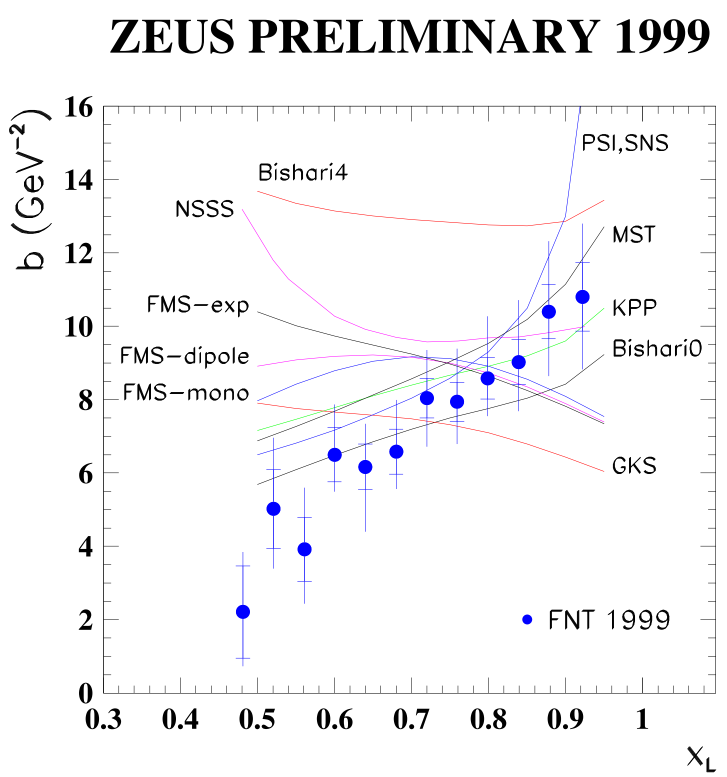
Angular Distribution of Neutrons in DIS

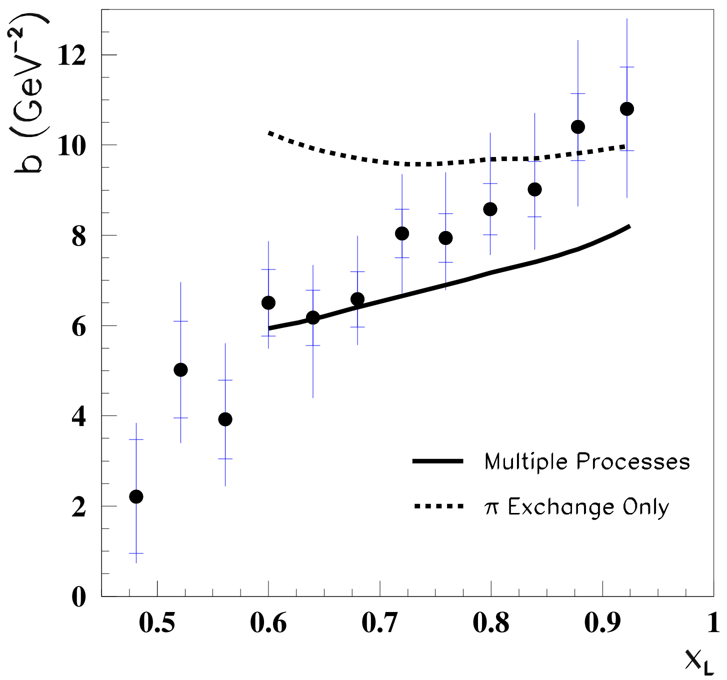
Neutron p_T^2 distributions measured in ZEUS FNT:



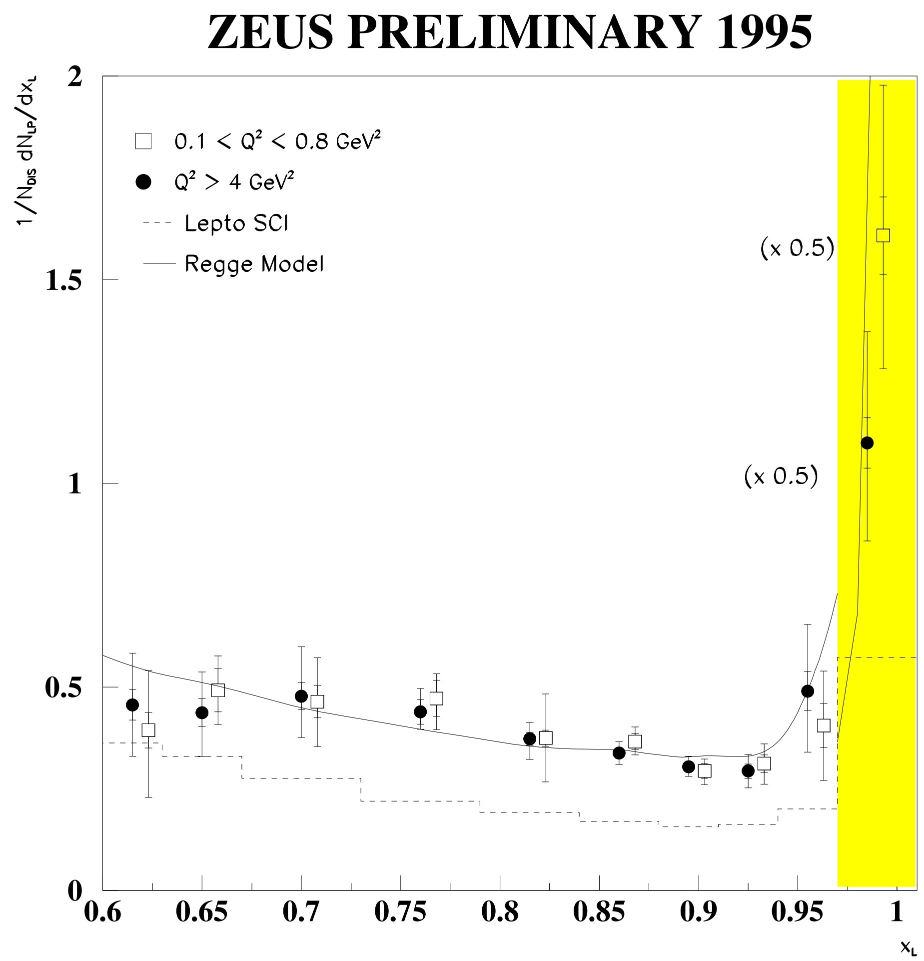
Parameterize $\frac{\mathrm{d}N}{\mathrm{d}p_T^2} \propto e^{-bp_T^2}$, measure slopes b vs. x_L

Angular Distribution of Neutrons in DIS



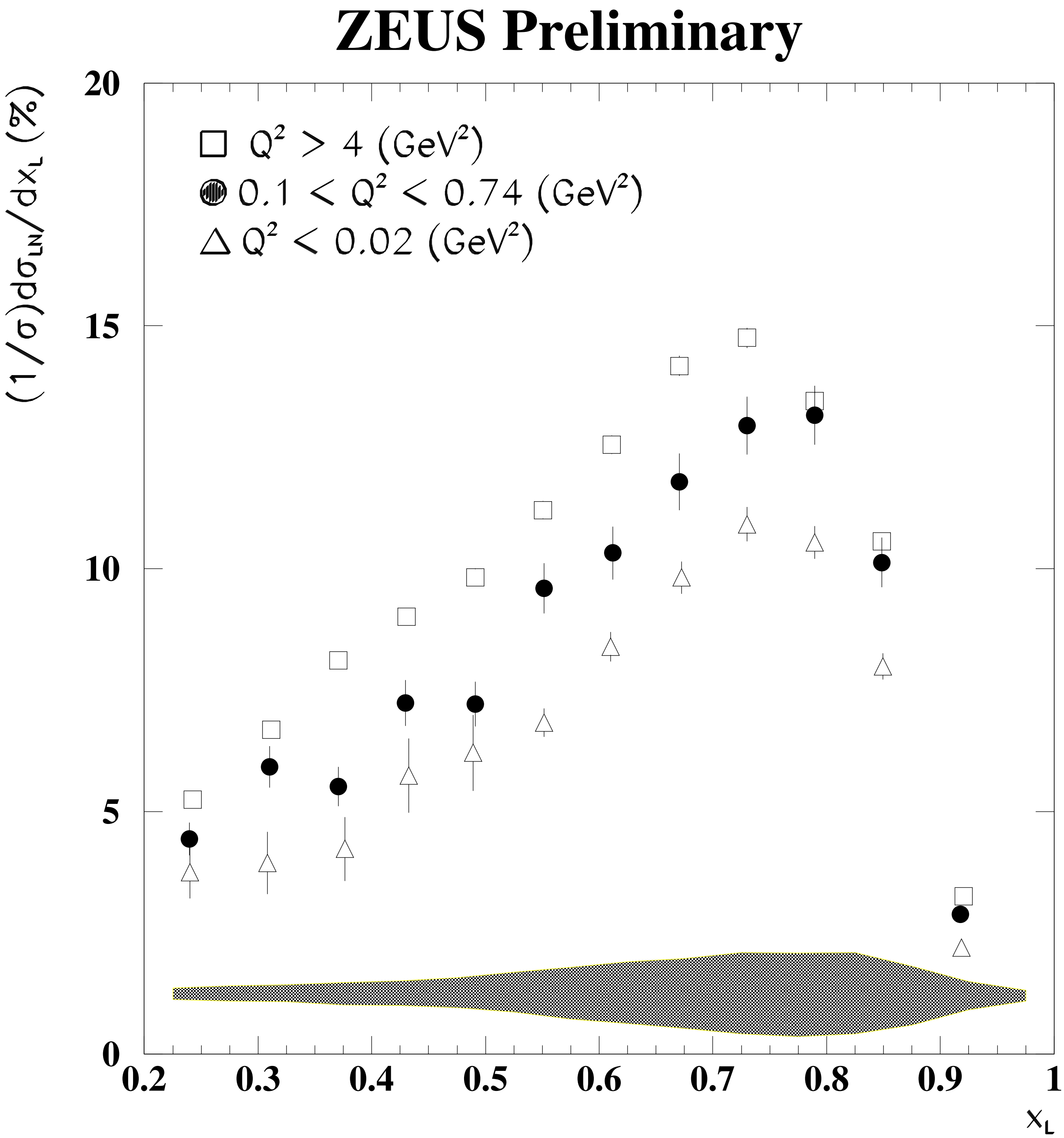


Proton Energy Spectrum



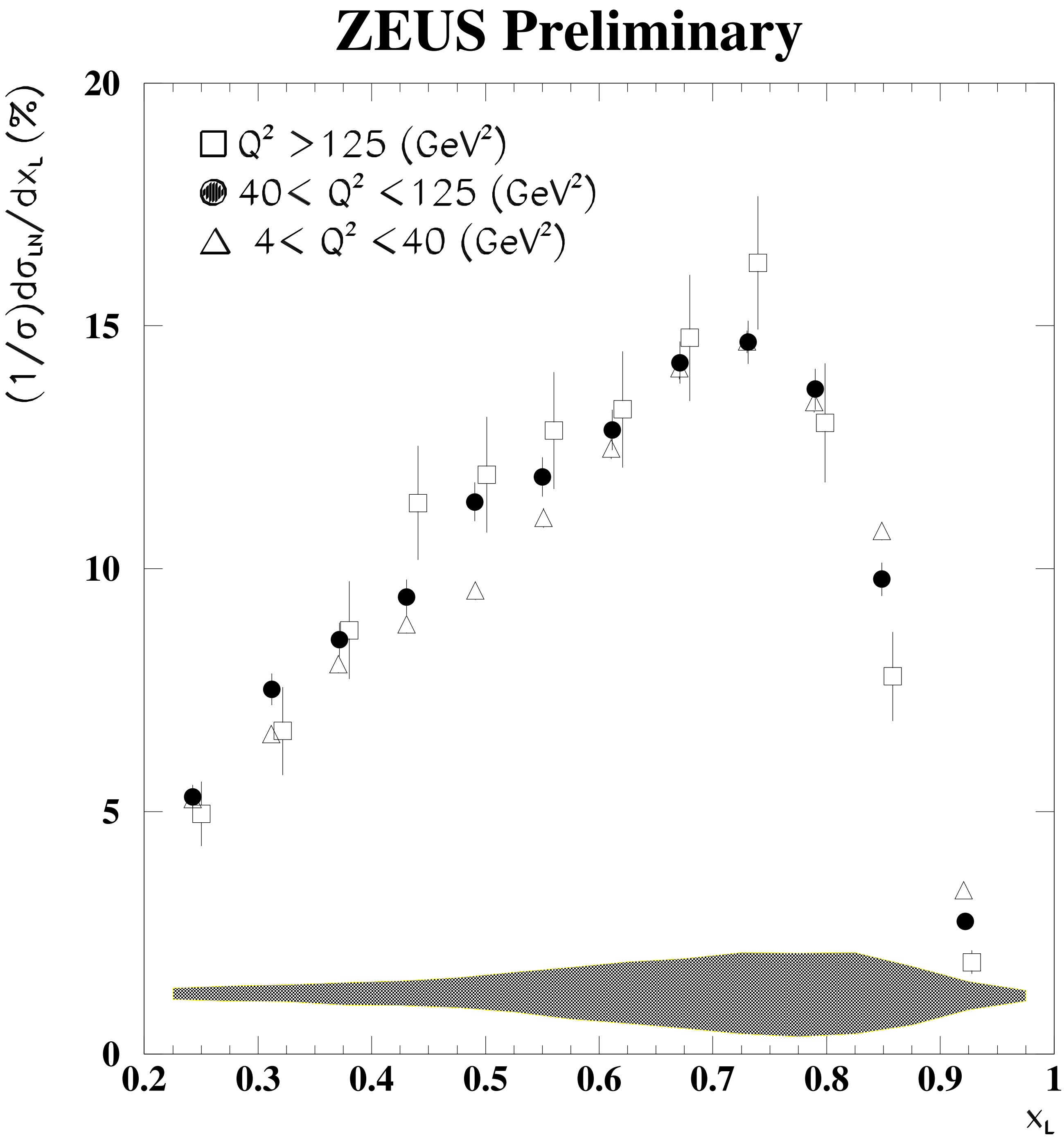
- Szczurek, Nikolaev, Speth Regge Model
- Different exchanges sum to produce flat proton spectrum for $p_T^2 \leq 0.5$ GeV^2 and $0.6 < x_L < 0.9$ as also seen with ZEUS LPS :
- (Note here highest x_L point plotted scaled down by 0.5)
- Limiting Fragmentation: shape and rate (13%) unchanged from low to high Q^2.

Neutron Energy Spectrum



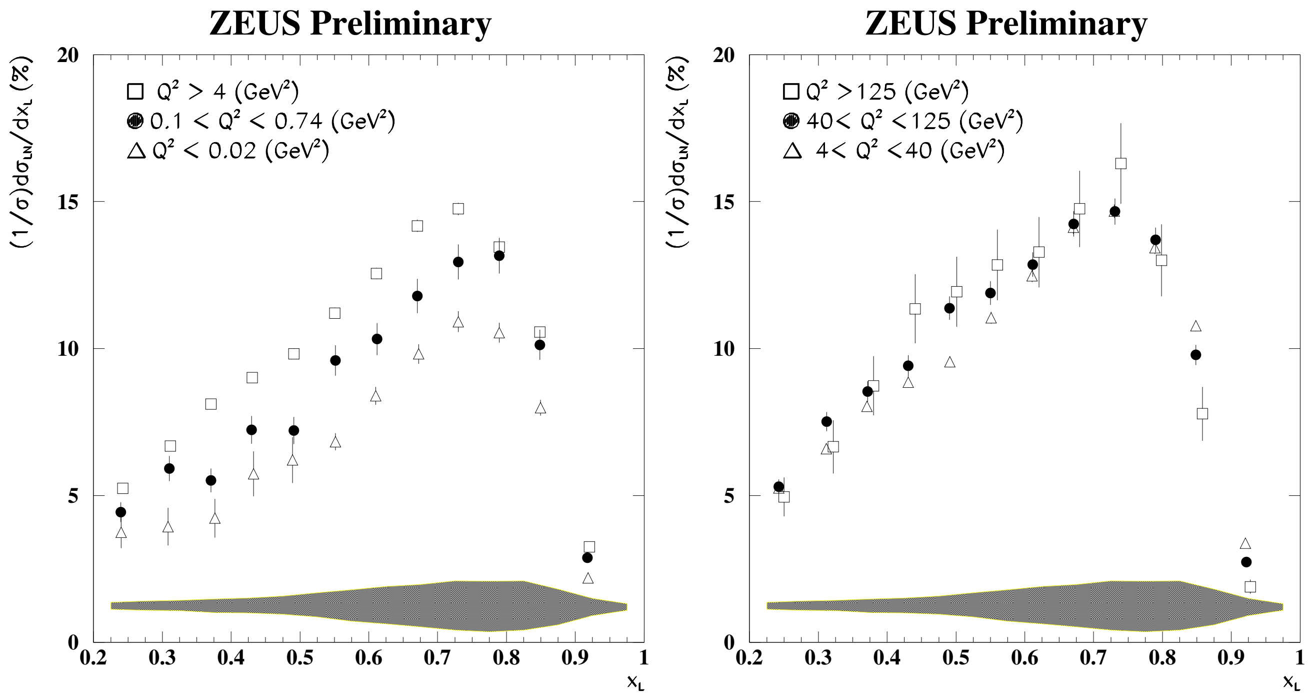
$$\theta_n < 0.8 \ \ \mathrm{mrad} \quad \rightarrow \quad p_T < 0.66 x_L \ \ \mathrm{GeV}$$

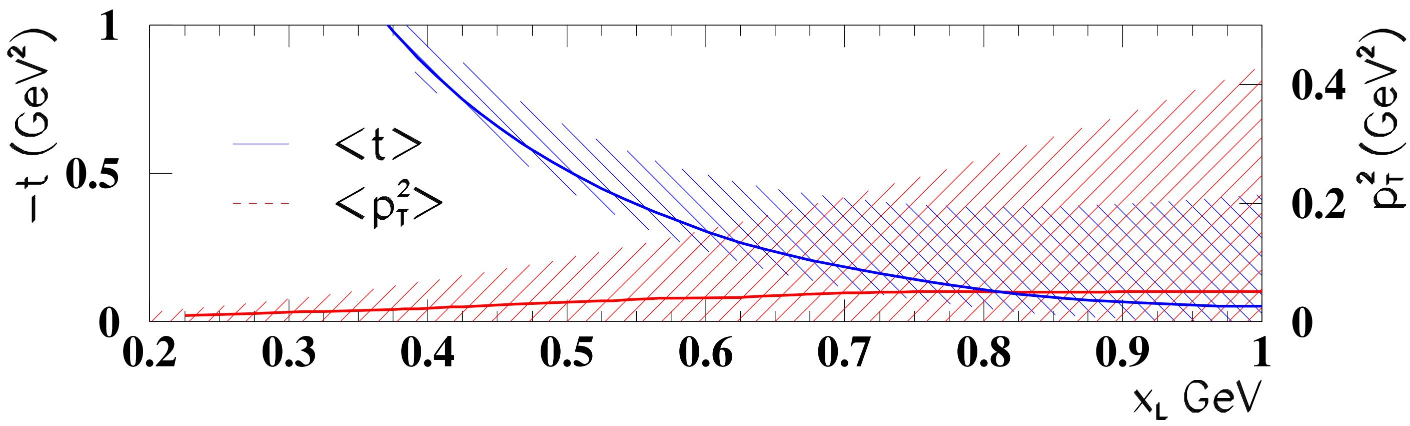
Neutron Energy Spectrum



$\theta_n < 0.8$ mrad $\rightarrow$ $p_T < 0.66 x_L$ GeV

Neutron Energy Spectrum



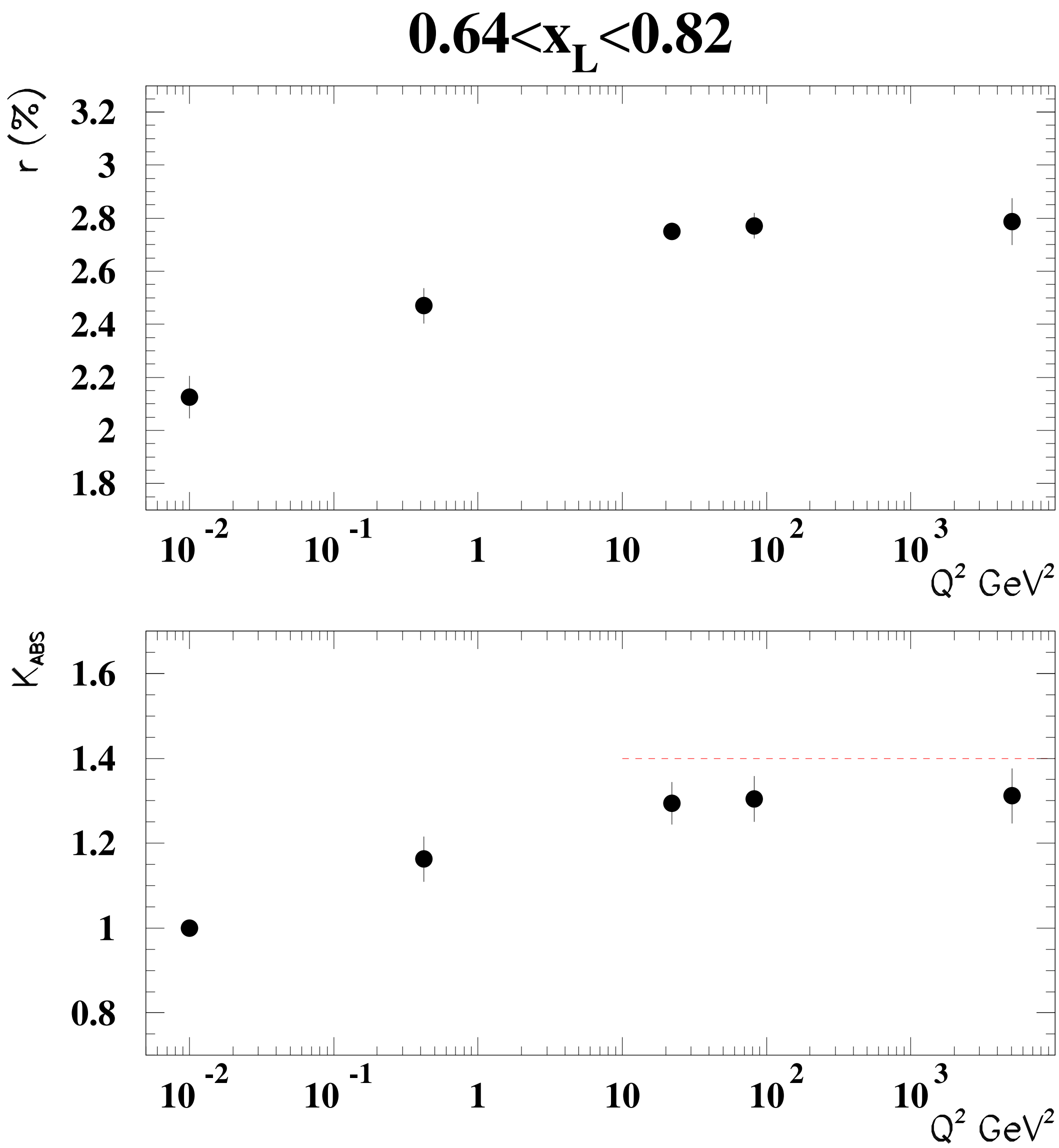


$$\theta_n < 0.8 \ \ \mathrm{mrad} \quad \rightarrow \quad p_T < 0.66 x_L \ \ \mathrm{GeV}$$

p_T range increases as x_L increases

- Shape of spectrum approximately independent of Q^2
- Rise in relative yield from photoproduction to DIS

Absorption



$$K_{abs}(x_L, Q^2) \equiv \frac{\sigma\left(Q^2=0\right)}{\sigma\left(Q^2\right)} \frac{\sigma_{LN}\left(x_L, Q^2\right)}{\sigma_{LN}\left(x_L, Q^2=0\right)}$$

As Q^2 increases, photon size decreases

$\Rightarrow$ absorption decreases, neutron yield increases

Comparison to Hadron-Proton Scattering

$x_L > 0.4$ and $|t| < 1$ GeV^2

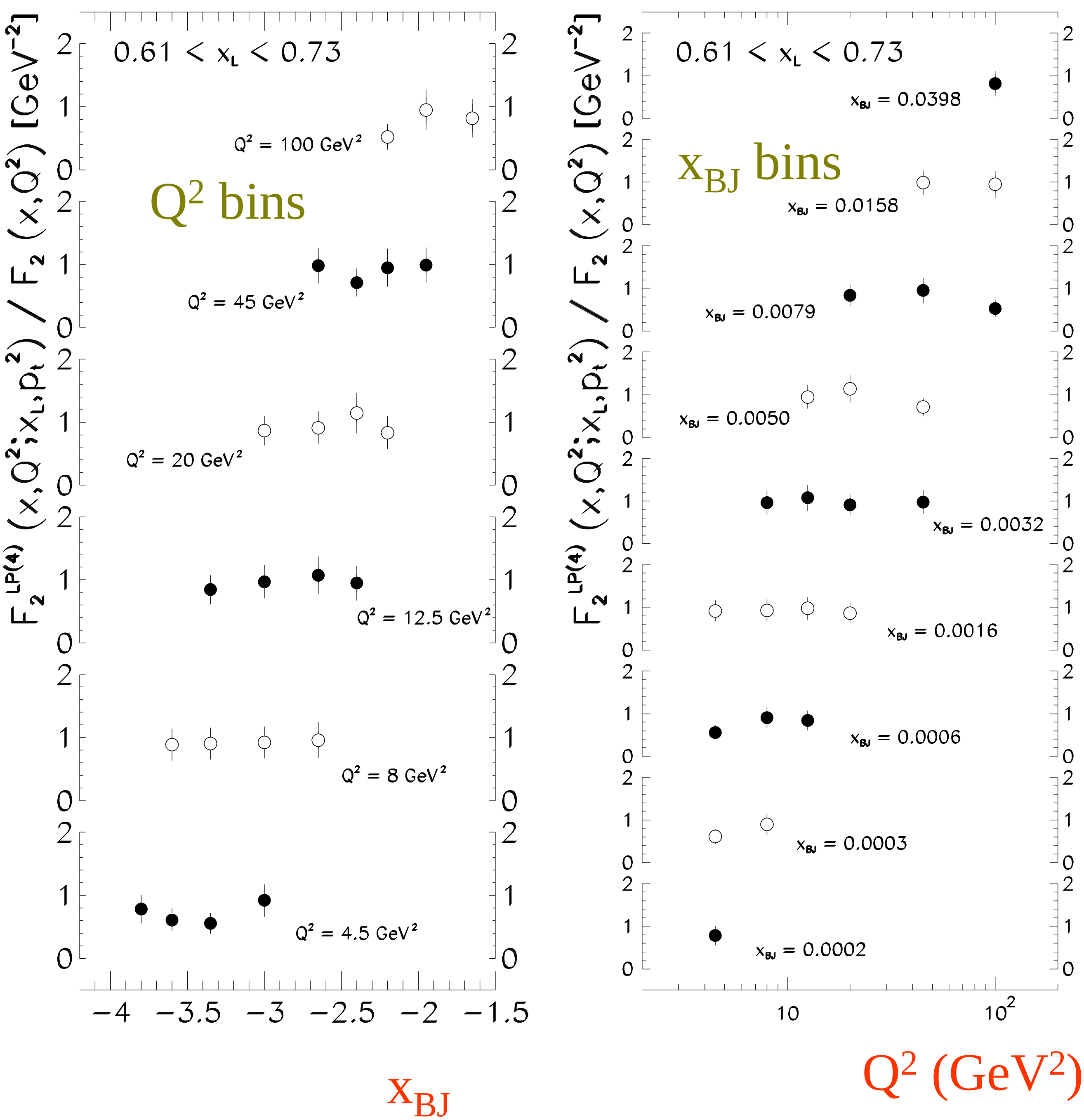
	beam momentum (GeV)	σ (mb)	Experiment
$pn \to Xp$	100	5.70 ± 0.27	hanlon
	195	5.15 ± 0.25	eisenberg
	205	5.5 ± 0.3	hartner
	400	5.52 ± 0.26	hanlon
$\pi^+ n \to Xp$	100	3.61 ± 0.18	hanlon
$\pi^- n \to Xp$	205	2.8 ± 0.2	abramowicz
	360	3.1 ± 0.2	abramowicz

For $x_L > 0.4$ and $\theta < 0.8$ mrad
Relative yield of neutrons in hadroproduction $\approx$ 10%

Compare Relative yield of neutrons in photoproduction $\approx$ 5%

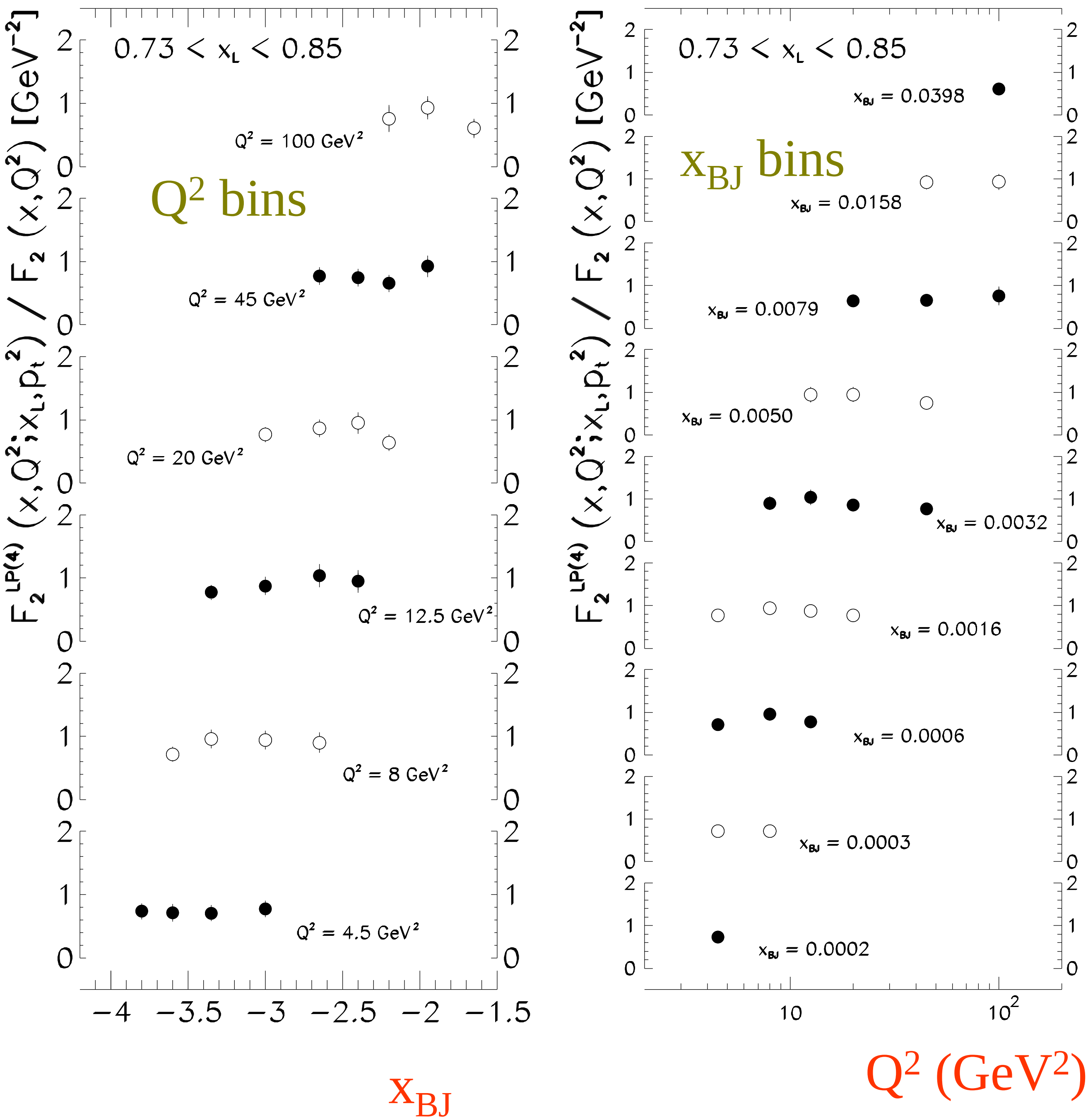
F_2^{LP} / F_2^{DIS} vs x_{BJ}, Q^2
$0.61 < x_L < 0.73$

ZEUS PRELIMINARY 1995



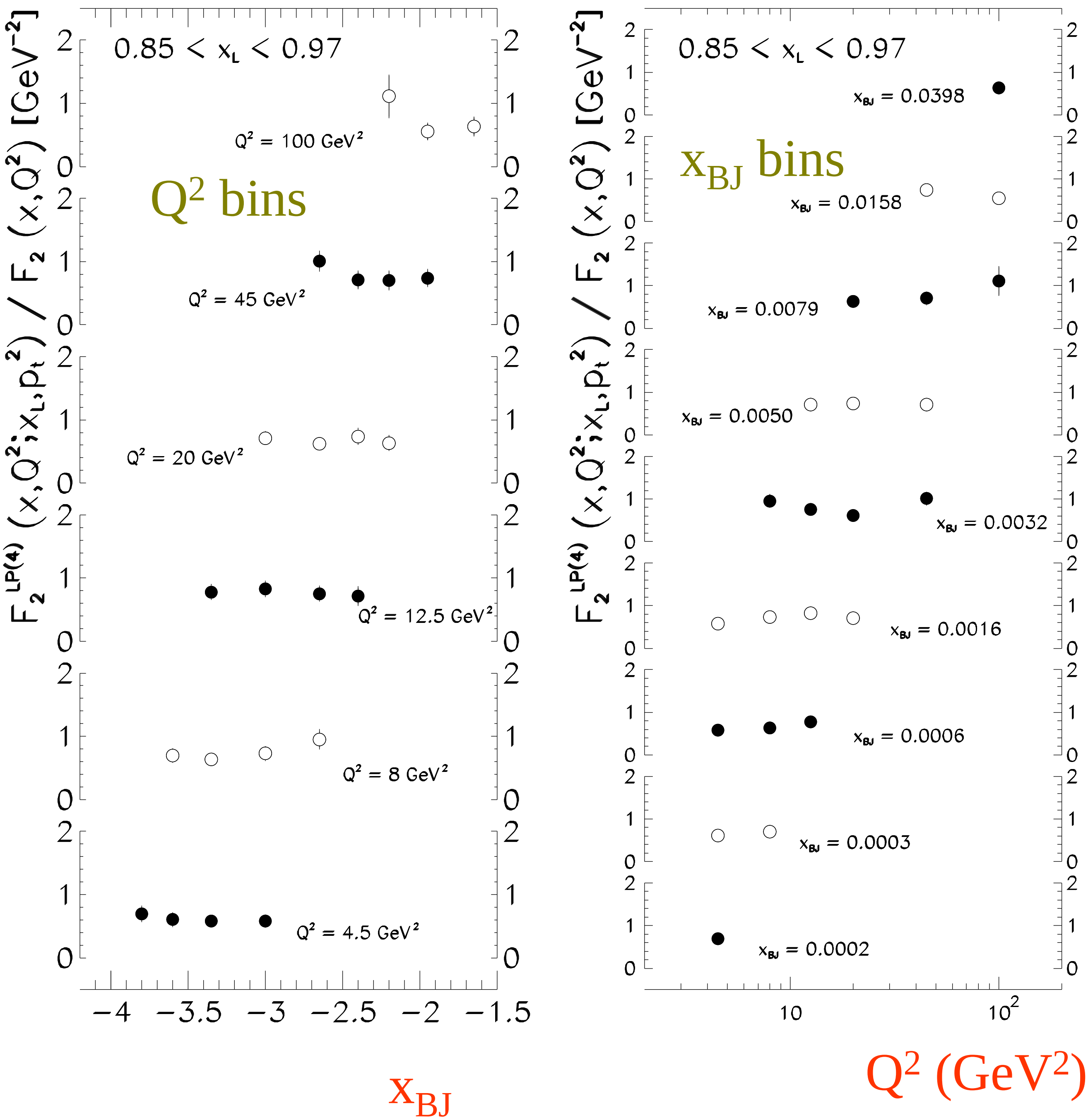
F_2^{LP}/ F_2^{DIS} vs x_{BJ}, Q^2
$0.73 < x_L < 0.85$

ZEUS PRELIMINARY 1995

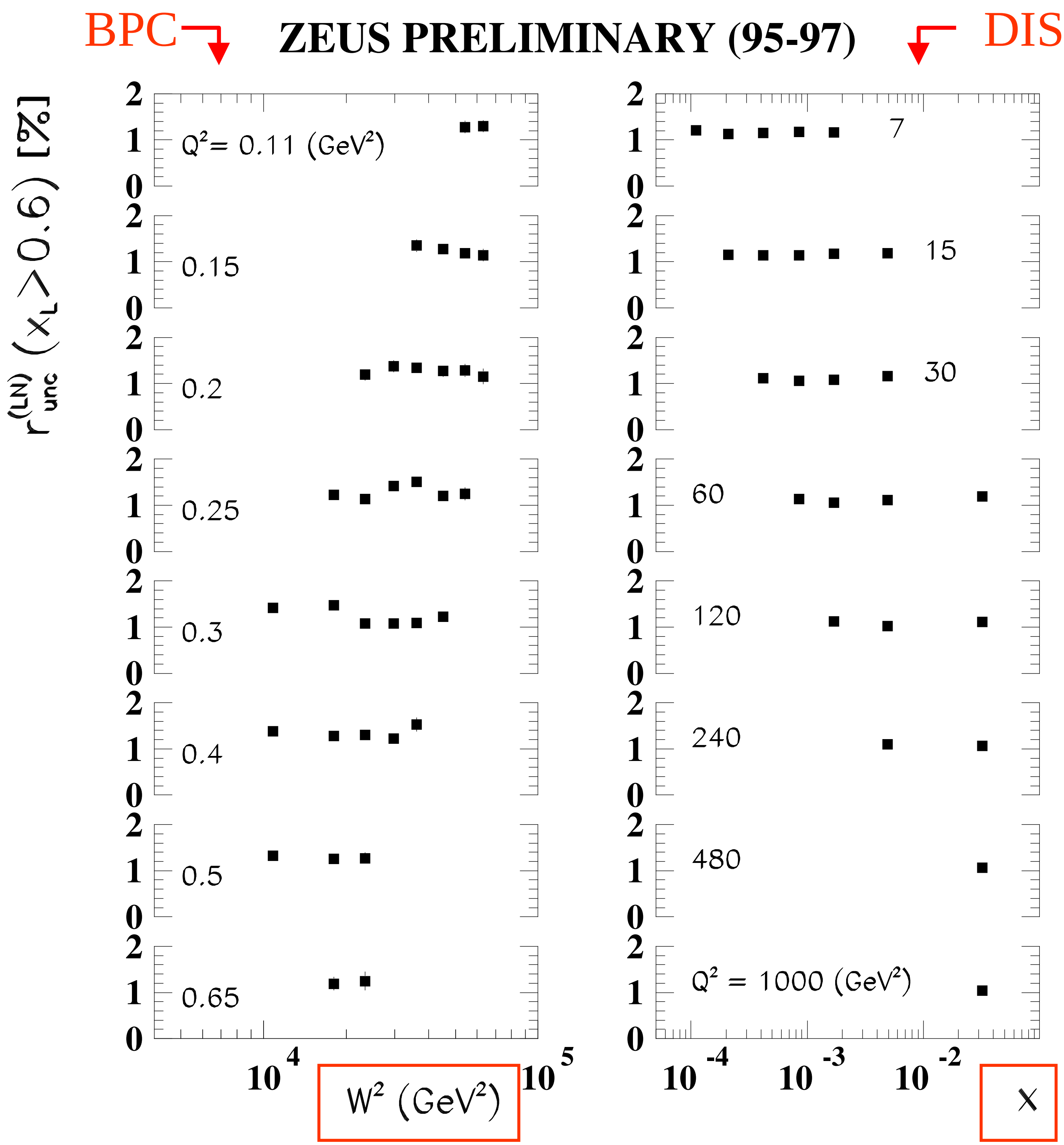


F_2^{LP} / F_2^{DIS} vs x_{BJ}, Q^2
$0.85 < x_L < 0.97$

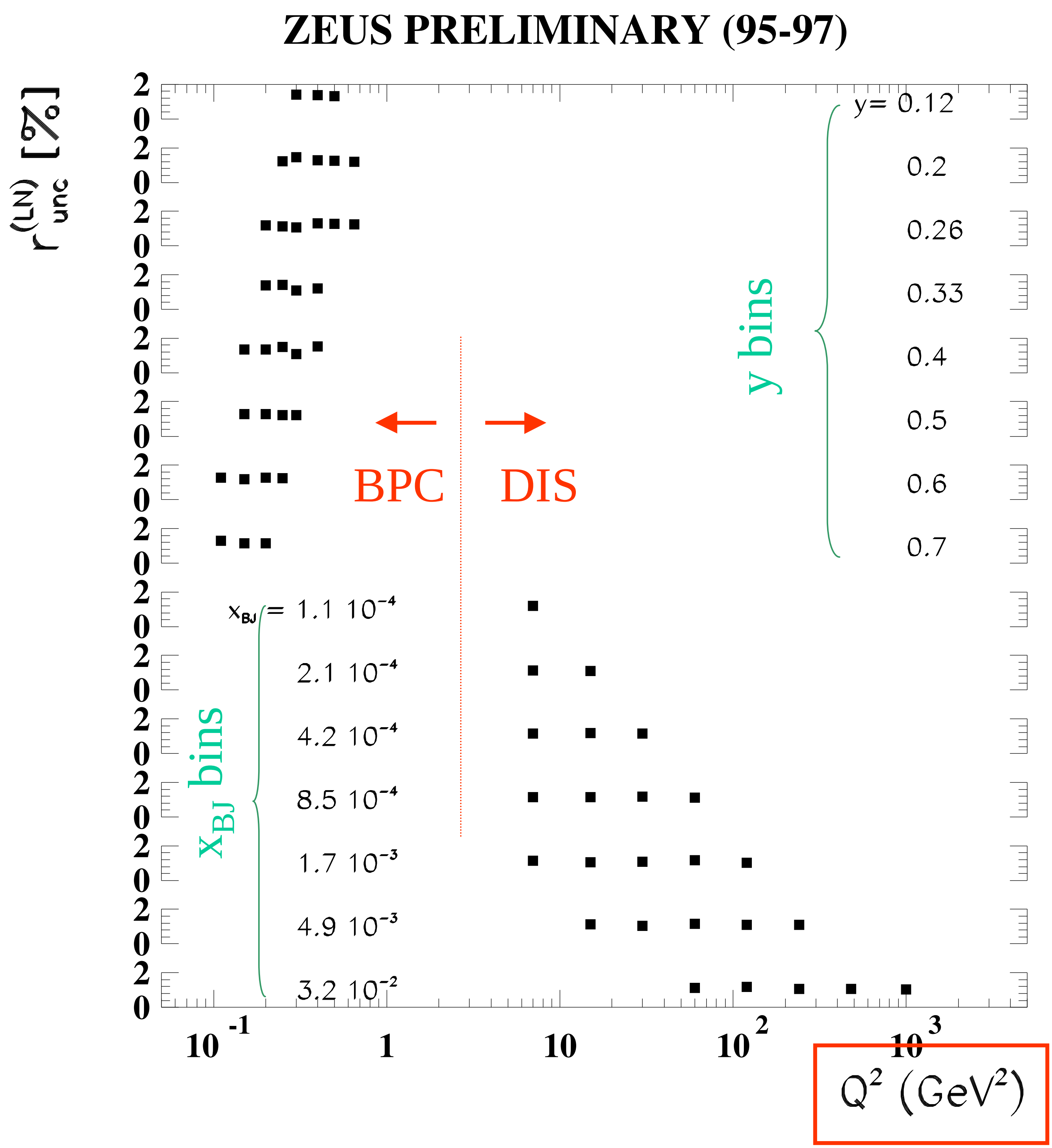
ZEUS PRELIMINARY 1995



r_{unc}^{LN} (Q^2 bins, x_L>0.6)

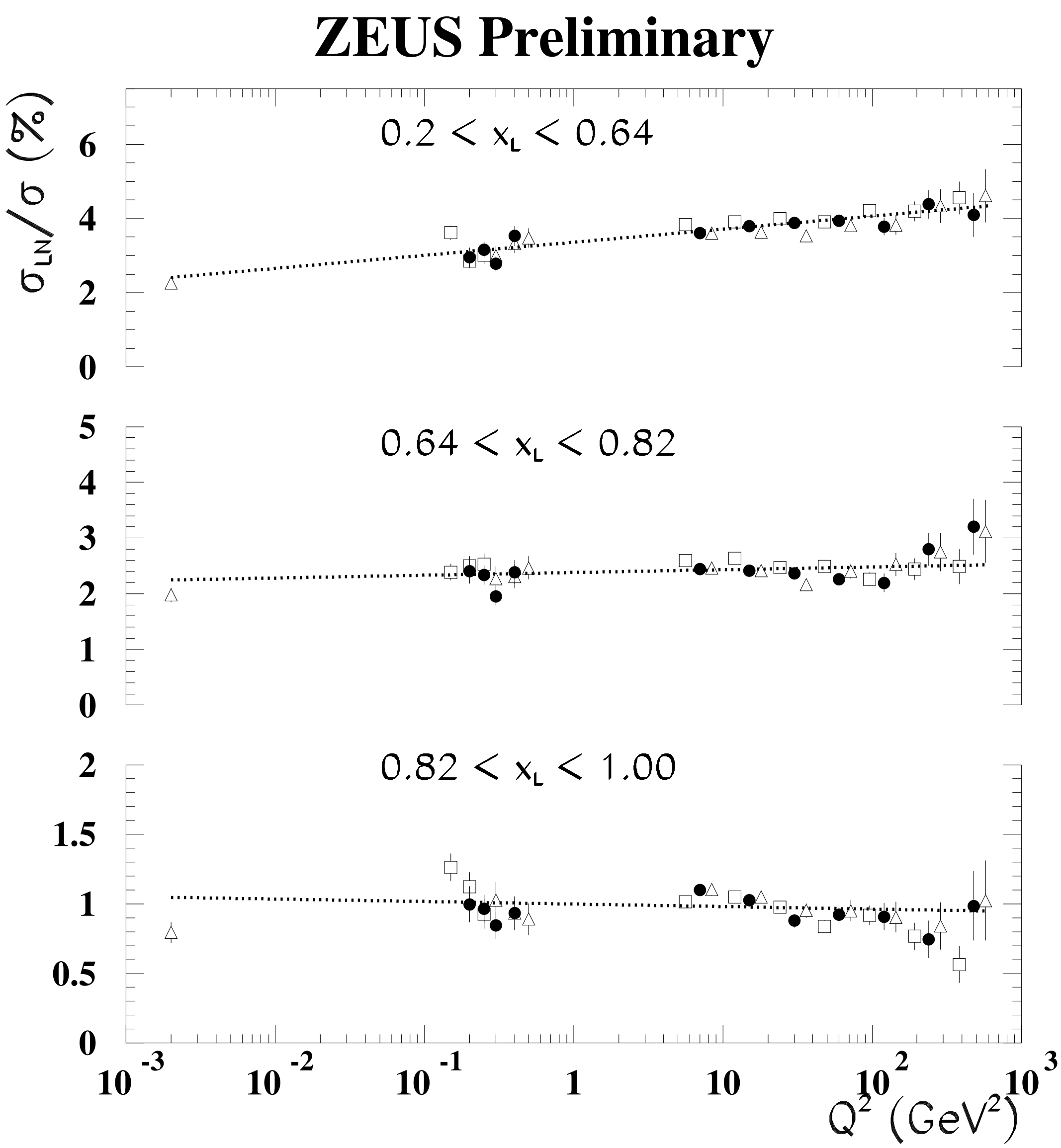


r_{unc}^{LN} versus Q^2 (xL>0.6)



Ratio of Leading Neutrons

From $Q^2 = 2 \cdot 10^{-3}$ to 10^3 GeV^2



□ $0.08 < y < 0.23$

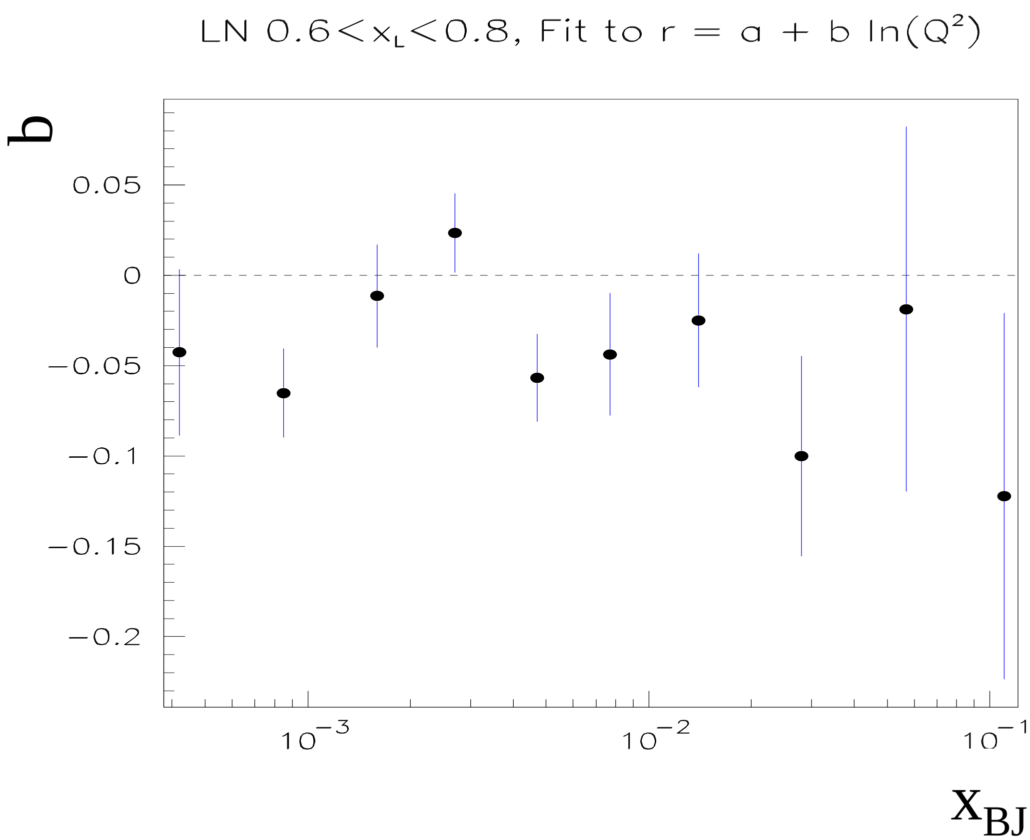
● $0.23 < y < 0.37$

△ $0.37 < y < 0.54$

Kinematic requirement $x_L < (1 - x_{BJ})$

How flat is “flat” ?
DIS, $x_L > 0.6$

Leading neutrons r_{unc}^{LN}



Leading protons F_2 ratio

Dependence on x_{BJ}: Fit to $x_{BJ}^{-(\delta\lambda)Q2}$ yields
$\delta\lambda=0.014\pm0.012$

Dependence on Q^2: Fit to $a+b\ln Q^2$ yields
$b = 0.04 \pm 0.03$

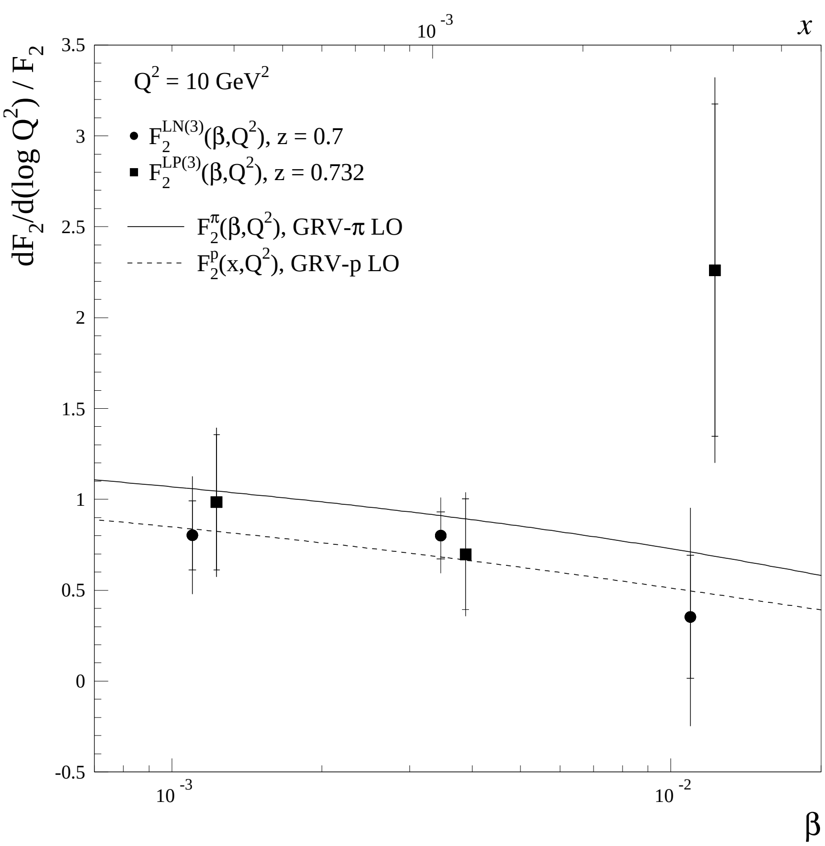
Scaling Violations

- $r^{LB} \approx$ constant $\Rightarrow$ scaling violations same for both inclusive F_2^p, semi-inclusive F_2^{LB} and F_2^{π} (assuming OPE)

$$\frac{\mathrm{d}r^{LB}}{\mathrm{d}\ln Q^2} = 0 \Rightarrow \frac{\mathrm{d}\ln F^{LB}}{\mathrm{d}\ln Q^2} = \frac{\mathrm{d}\ln F^{p}}{\mathrm{d}\ln Q^2}$$

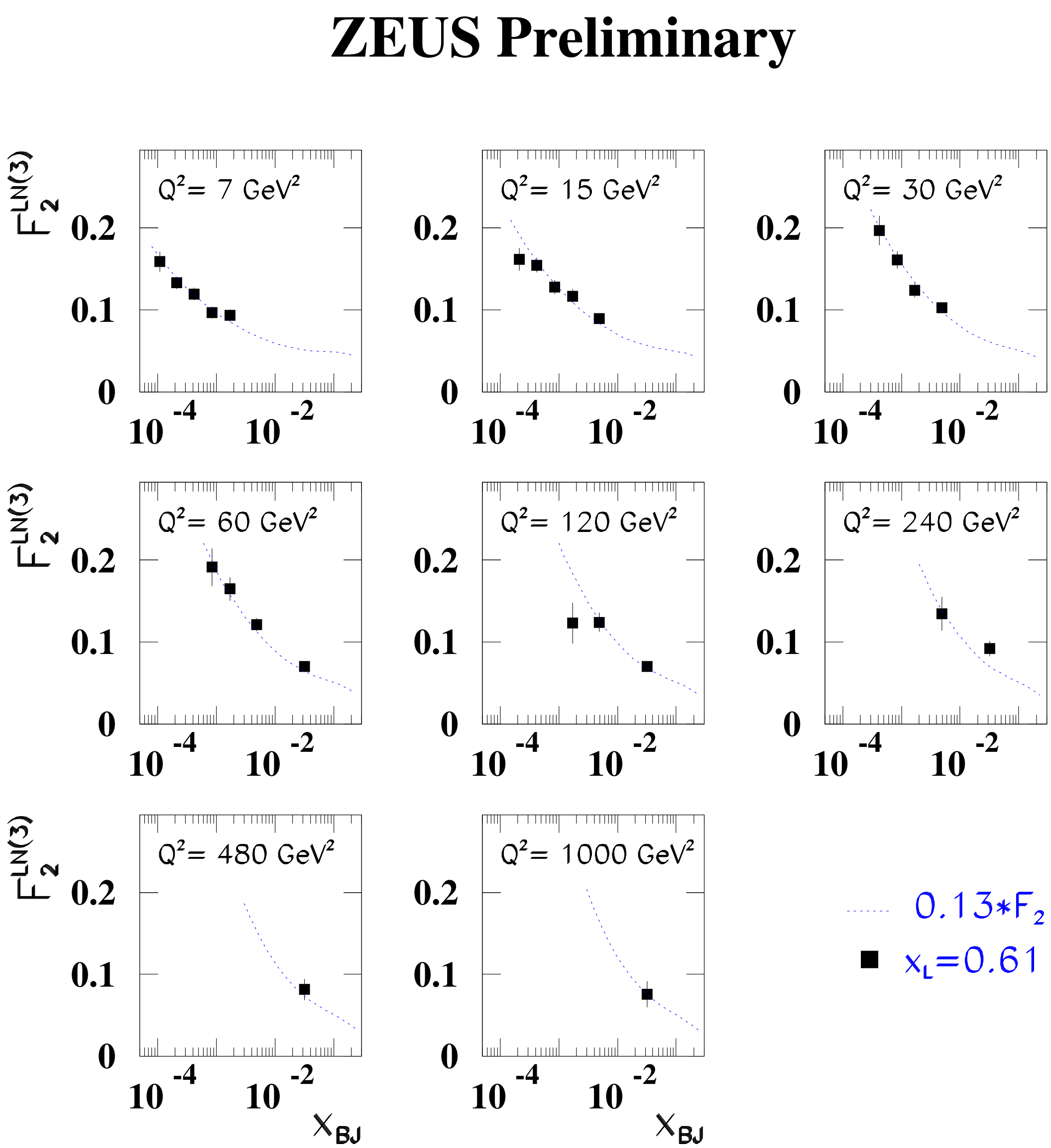
- Explicitly seen in H1 fit of the scaling violations:

H1 Preliminary



$$\beta = \frac{x_{BJ}}{1 - x_L}$$

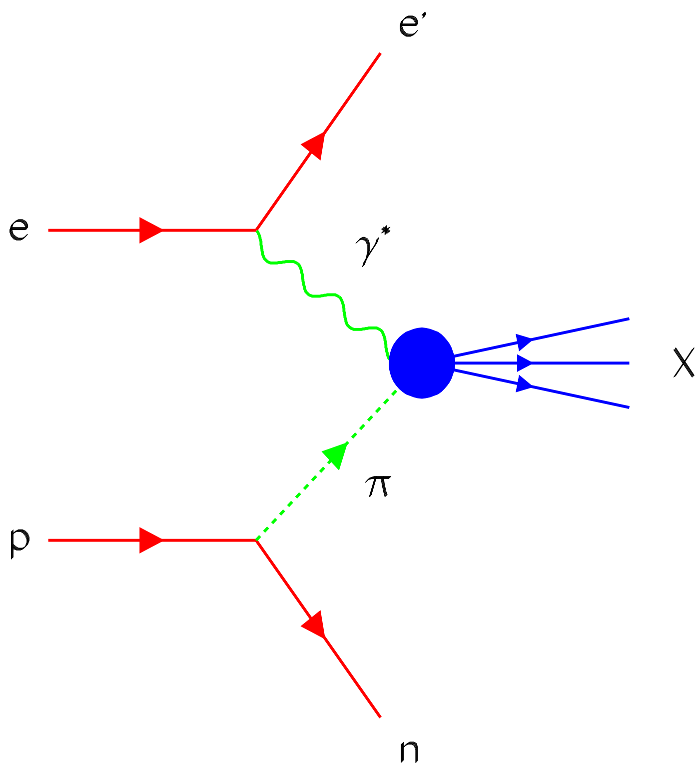
Determination of F_2^{LN} from Ratios



$$F_2^{LN(3)}(x_{BJ}, Q^2, x_L) = \frac{r}{\Delta x_L} F_2(x_{BJ}, Q^2)$$

MEASURMENT $\rightarrow \dfrac{r}{\Delta x_L}$, ZEUS NLO fit $\rightarrow F_2(x_{BJ}, Q^2)$

Pion Exchange



$$\frac{d\sigma_{LN}}{dx_L dt}(x_L, t, Q^2, W^2) = f_{\pi/p}(x_L, t)\sigma_{\gamma^*\pi}((1-x_L)W^2, Q^2)$$

$$f_{\pi/p}(x_L, t) = \frac{1}{4\pi}\frac{g^2}{4\pi}\frac{-t}{(t-m_\pi^2)^2}(1-x_L)^{1-2\alpha_\pi(t)}\,(F(x_L, t))^2$$

$f_{\pi/p}$: the splitting function for $p \to n\pi$
$\alpha_\pi(t)$: the Regge trajectory of the pion
$g^2/4\pi$: the $p\pi n$ coupling constant
$F(x_L, t)$: Pion-nucleon form factor

Experimental Difficulty

Pion exchange dominates the splitting $p \to n$

Experimentalist wants to extract information on pion

But:

- ρ and a_2 exchange contribute (10-20% ?)
- Δ production contributes $p \to \Delta \to n\pi$ (5-15% ?)
- There are rescattering effects (absorptive corrections) (20-30% ? in photoproduction, smaller in DIS)
- There are off-mass-shell effects (5-10% ?)
- There are uncertainties in the pion flux because of form factor and trajectory uncertainties (100% ?)
- The $p\pi n$ coupling constant is uncertain (5% ?)

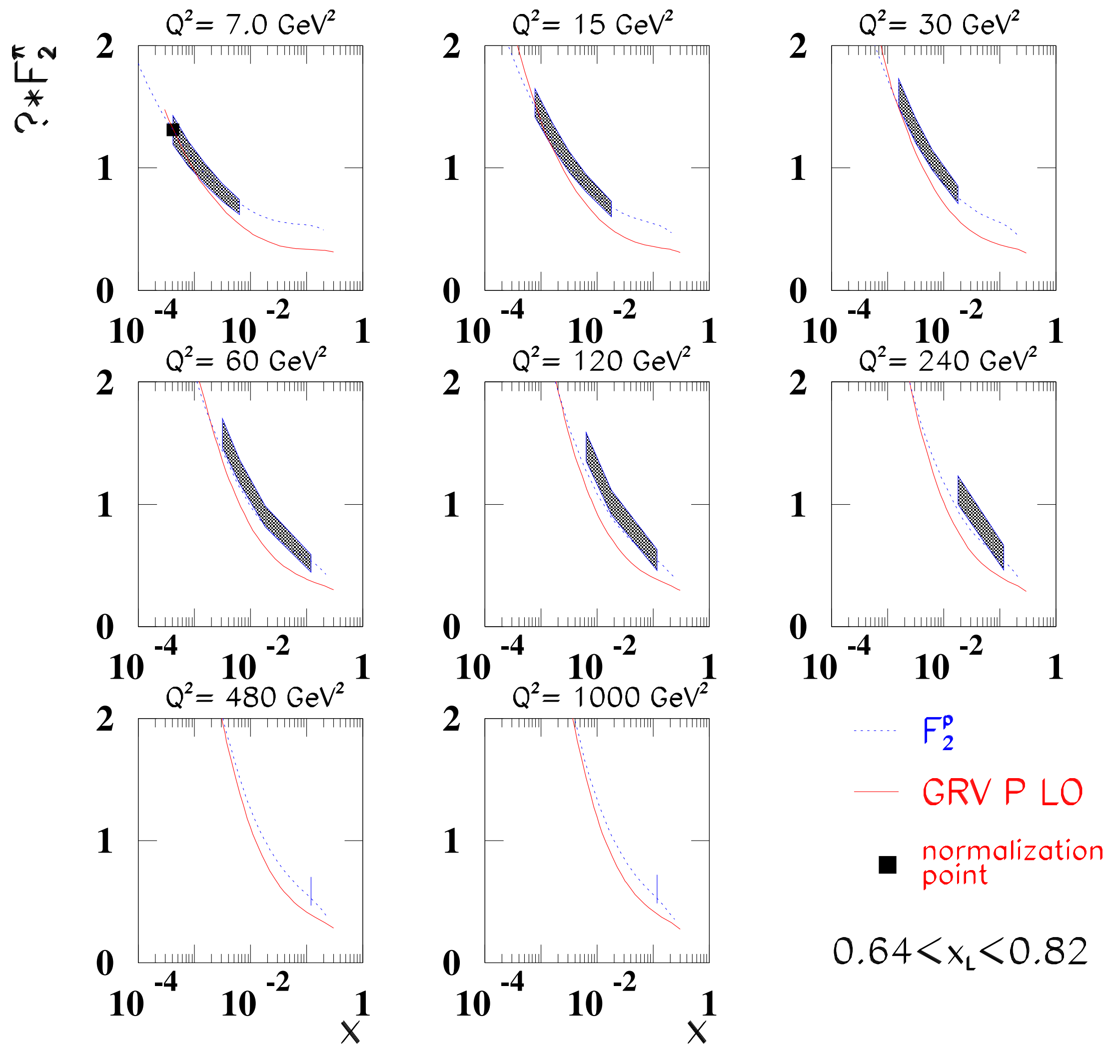
Challenge — to find a way to sidestep theoretical problems:

- Unnormalized tagged beam approach
- Effective flux method

Unnormalized Tagged Beam

- Backgrounds not expected to distort x_{BJ} and Q^2 dependence
- The neutron determines the energy of the pion
- For fixed x_L bin only overall normalization unknown

$\Rightarrow$ measure dependence of F_2^π on x_{BJ} and Q^2



$$F_2^\pi(x,Q^2) \propto F_2^{LN}\left(x/(1-x_L),Q^2\right) \propto F_2^p\left(x/(1-x_L),Q^2\right)$$

Effective Flux Method

Don't need understand each background *separately*

Need only net effect of *all* backgrounds

Nature provides a *calibration* process:
$pn \to Xp$ (or $p \to n$)

Deconvolve ($\oslash$) measured leading neutron spectrum and measured πp total cross section

$$f_{eff}(x_L, t) \equiv \frac{d\sigma^{pn\to Xp}}{dx_L dt} \oslash \sigma^{\pi p \to X}$$

f_{eff} determined *solely by experiment*

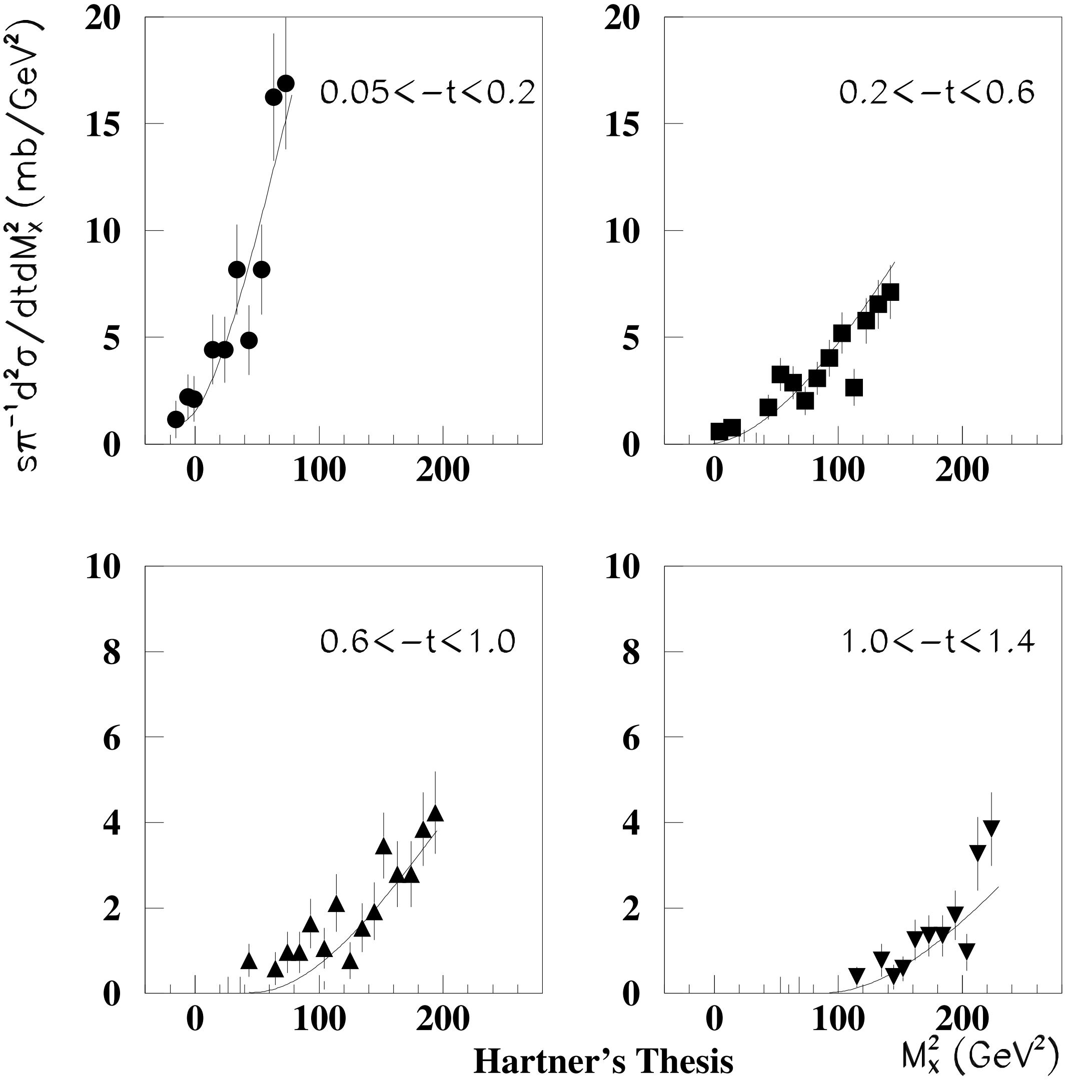
By construction f_{eff} accounts for *all backgrounds*
to pion exchange in $pn \to Xp$

Experiments at Fermilab and CERN show:

$$\begin{aligned} f_{eff}(x_L, t) &= \frac{1}{4\pi}\frac{g^2}{4\pi}\frac{-t}{(t-m_\pi^2)^2}(1-x_L)^{1-2t} \\ g^2/4\pi &= 29 \end{aligned}$$

Universal behavior of hadronic cross sections $\Rightarrow$
f_{eff} effective for $\pi p \to Xn$ and $\gamma p \to Xn$

200 GeV pn→pX



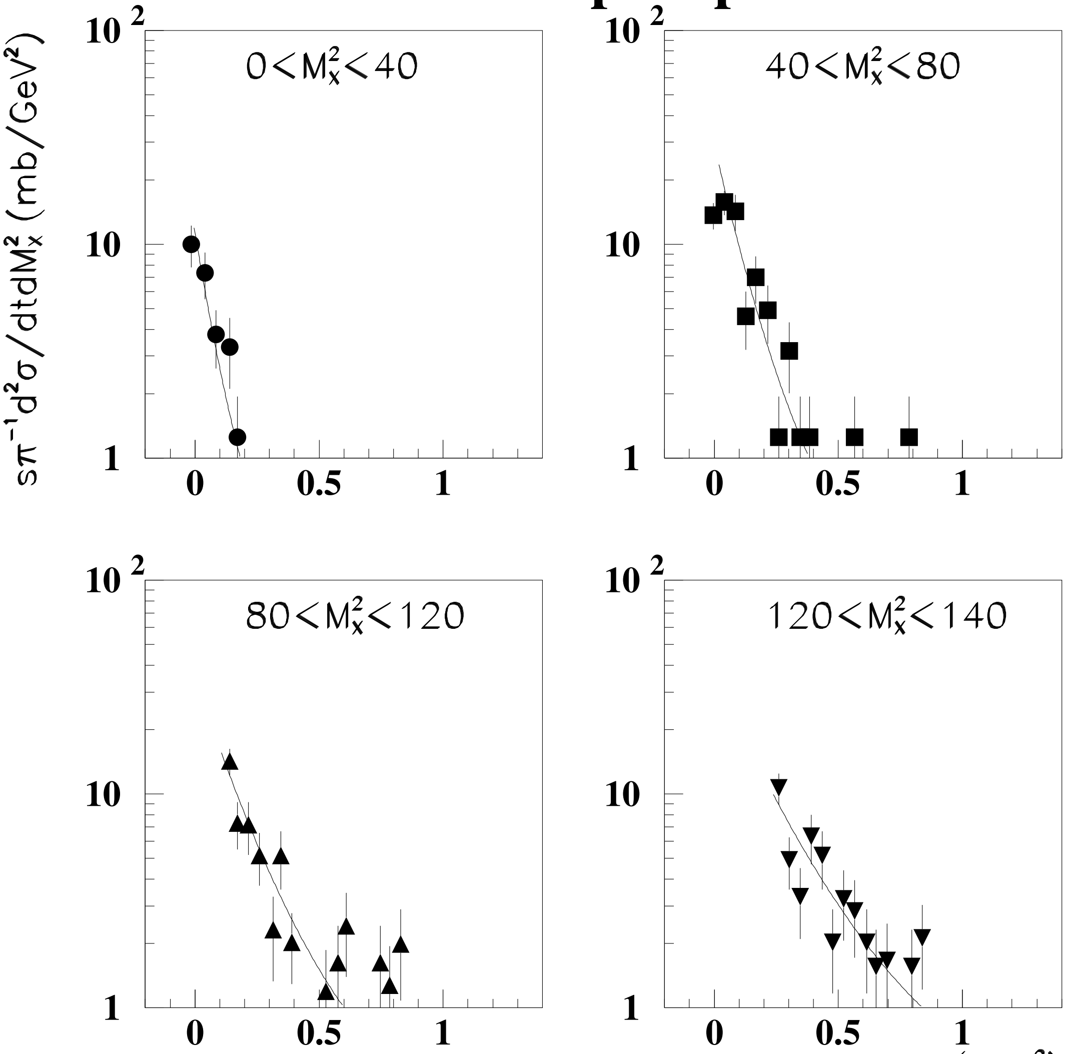
Hartner's Thesis

$$\frac{d\sigma_{pn\to Xp}}{dx_L dt}(x_L, t, s) = f_{eff}(x_L, t)\sigma_{\pi p}((1 - x_L)s)$$

$$f_{eff}(x_L, t) = \frac{1}{4\pi}\frac{g^2}{4\pi}\frac{-t}{(t - m_\pi^2)^2}(1 - x_L)^{1-2t}$$

$$g^2/4\pi = 29$$

200 GeV pn→pX



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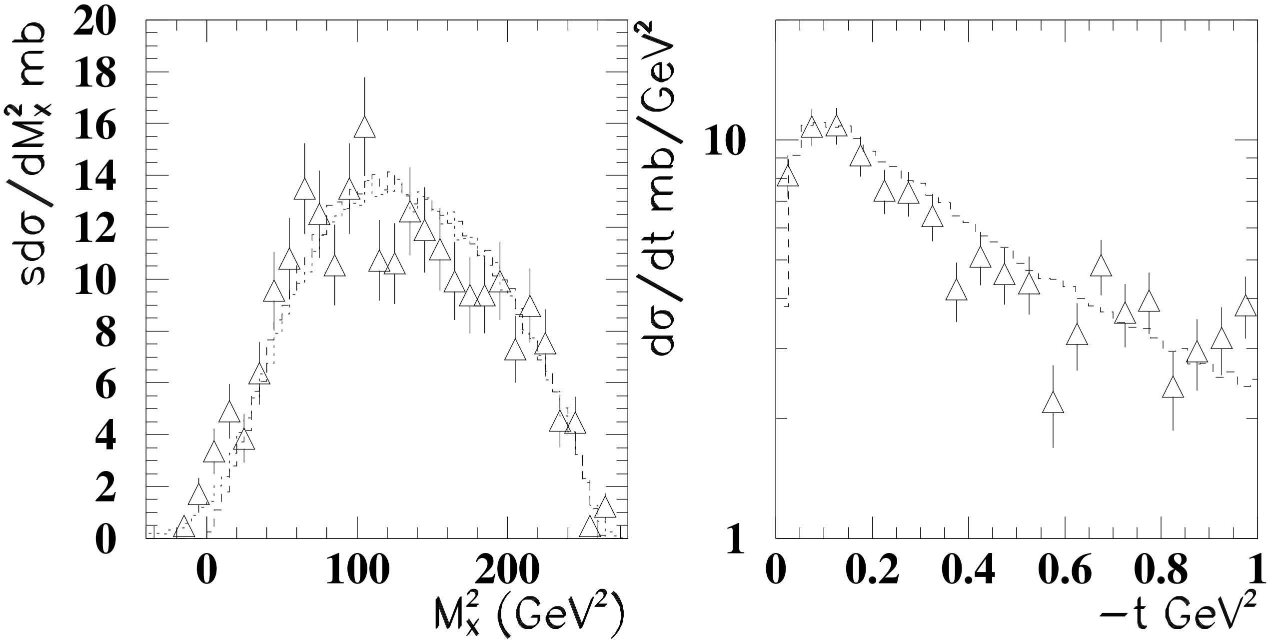
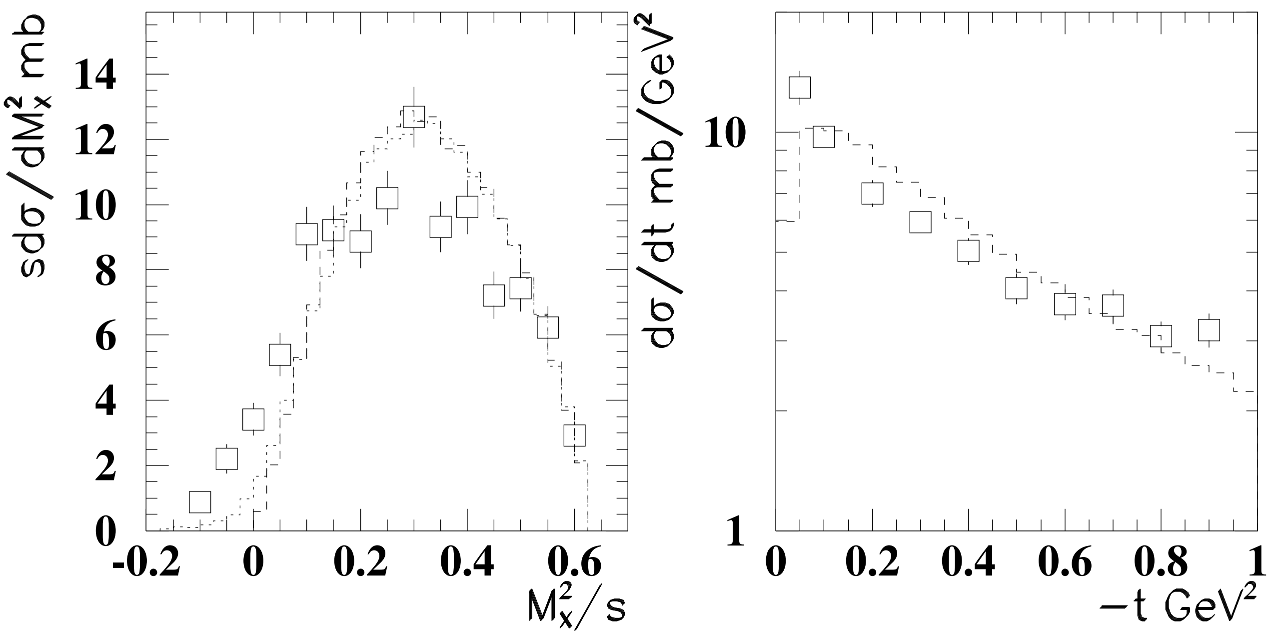


400 GeV pn→pX



Histograms normalized to the data

$\sigma_{\gamma\pi}$ in Photoproduction

Hadron-hadron total cross sections:

$$\sigma_{\gamma p}(W^2) = A_{\gamma p, I\!P}(W^2)^{\alpha_{I\!P}-1} + A_{\gamma p, I\!R}(W^2)^{\alpha_{I\!R}-1}$$

$$\sigma_{\gamma \pi}(W^2) = A_{\gamma \pi, I\!P}(W^2)^{\alpha_{I\!P}-1} + A_{\gamma \pi, I\!R}(W^2)^{\alpha_{I\!R}-1}$$

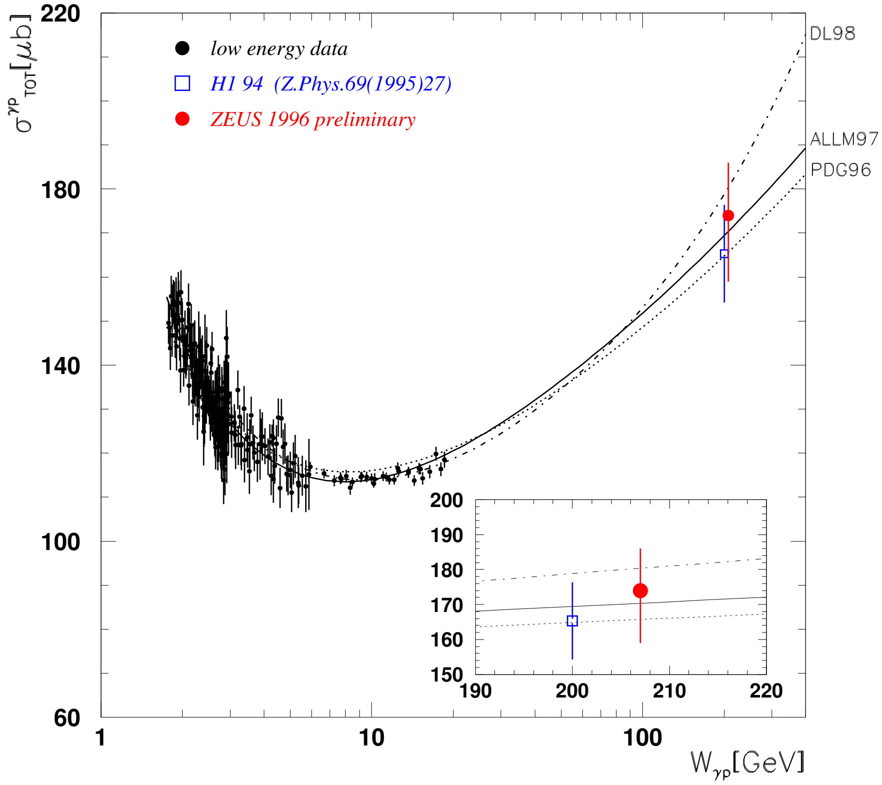
$\alpha_{I\!P} \simeq 1.1$, $\alpha_{I\!R} \simeq 0.5 \Rightarrow$ $I\!R$ term negligible at high W

Effective flux method $\Rightarrow$

$$\begin{aligned} \frac{1}{\sigma_{\gamma p}} \frac{d\sigma_{LN}}{dx_L dt} &= \frac{1}{\sigma_{\gamma p}} f_{eff} \otimes \sigma_{\gamma\pi} \\ &= \frac{A_{\gamma\pi, I\!P}}{A_{\gamma p, I\!P}} (1-x_L)^{\alpha_{I\!P}-1} f_{eff} \end{aligned}$$

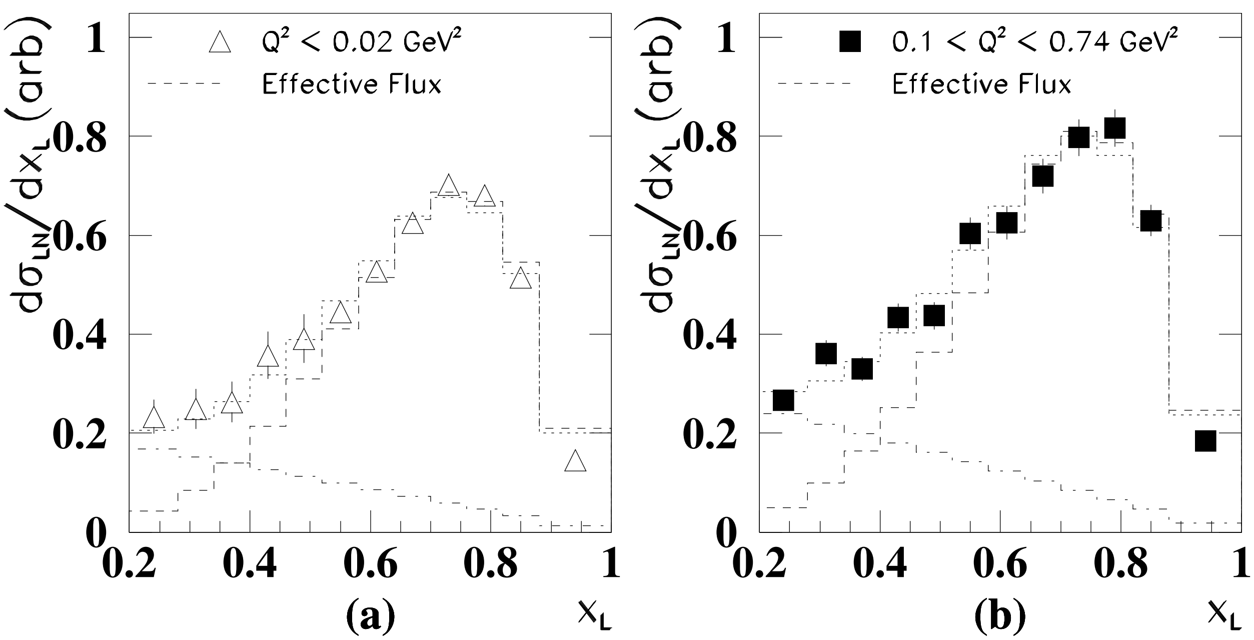
- f_{eff}: *effective* splitting function $p \to n\pi$
- f_{eff} fixed by *experiment* $pn \to Xp$
- Only normalization $A_{\gamma\pi, I\!P}/A_{\gamma p, I\!P}$ unknown

$\sigma^{\gamma p}_{TOT}$ preliminary results



$$\sigma^{\gamma p}_{TOT}(W_{\gamma p} = 207\text{GeV}) = 172 \pm 1^{+13}_{-15}\ \mu b$$

$\sigma_{\gamma\pi}$ in Photoproduction



Compare f_{eff} to neutron spectrum in photoproduction

$$f_{eff} \rightarrow (1 - x_L)^{\alpha_{\mathbb{P}} - 1} f_{eff}, \ \alpha_{\mathbb{P}} = 1.1$$

1. Normalize flux to data $0.58 < x_L < 0.88$
2. Flux + linear term $(1 - x_L)$
   fit to data $0.2 < x_L < 0.88$

[2] $\Rightarrow \approx$ 10% background under peak

$\sigma_{\gamma\pi}$ in Photoproduction

$$\frac{A_{\gamma\pi,I\!P}}{A_{\gamma p,I\!P}} = \frac{r}{\int\int dt dx_L (1-x_L)^{\alpha_{I\!P}-1} f_{eff}} = 0.31 \pm 0.01$$

For $p_T < 0.66 x_L$ GeV and $0.64 < x_L < 0.82$:
$r =$ 2.1% and $\int\int =$ 0.068

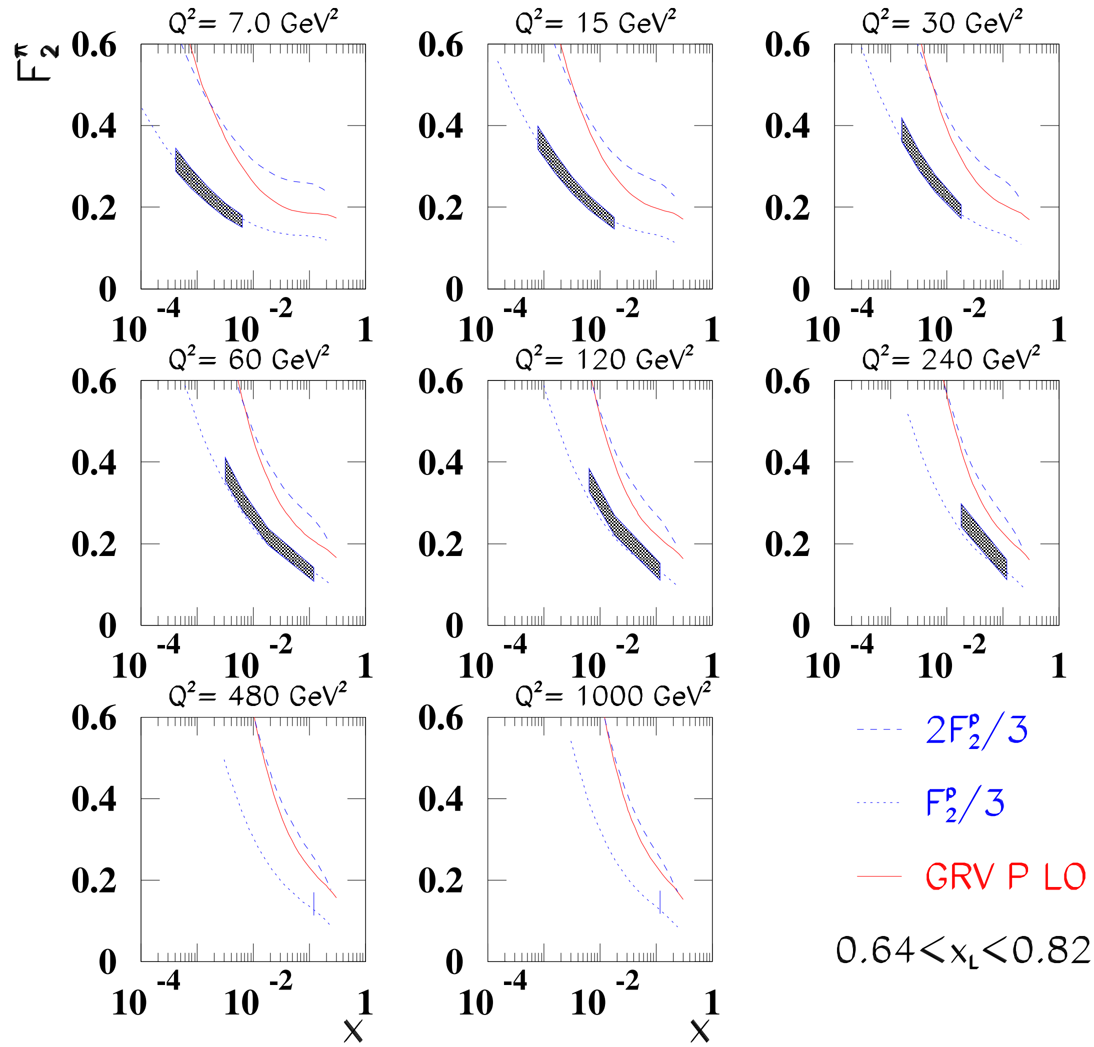
$\sigma(\gamma\pi) \approx \sigma(\gamma p)/3$ at large W

Energy dependence like γp total cross section

Systematic uncertainties:

- 10% FNC normalization uncertainty
- No uncertainty assigned to flux integral, $\alpha_{I\!P} = 1.1$
- No correction for linear term underlying effective flux

Effective Flux Method



$$f_{eff}^{DIS} = K_{abs} f_{eff}, \;\; K_{abs} = 1.3$$

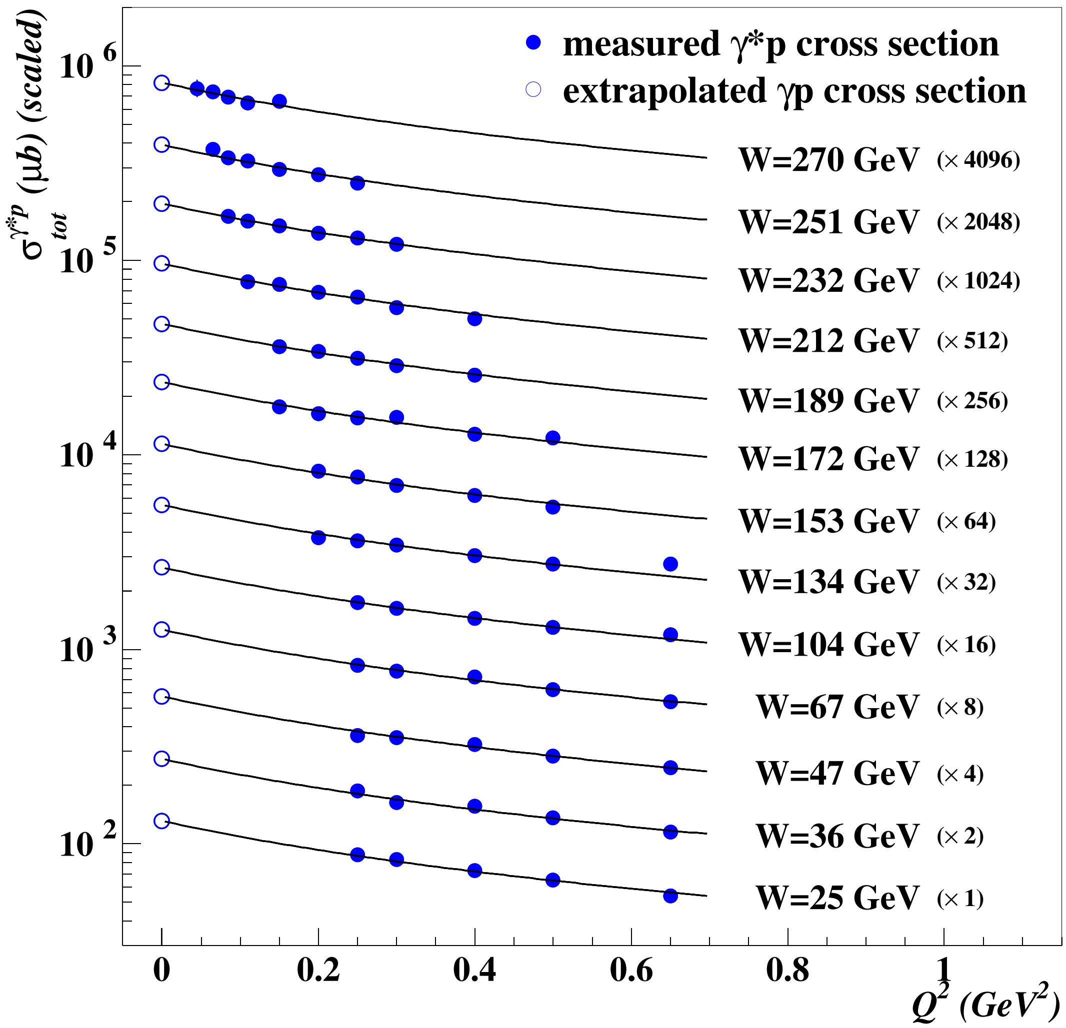
$$F_2^\pi\left(x, Q^2\right) = \frac{1}{\int\int dx_L dt f_{eff}^{DIS}(x_L, t)} r F_2^p(x/(1 - x_L), Q^2)$$

$$\text{ZEUS NLO QCD Fit} \;\; \Rightarrow F_2^p$$

$$F_2^\pi\left(x, Q^2\right) \approx \frac{1}{3} F_2^p(x, Q^2)$$

F_2 at Very Low Q^2

ZEUS 1997 (Preliminary)



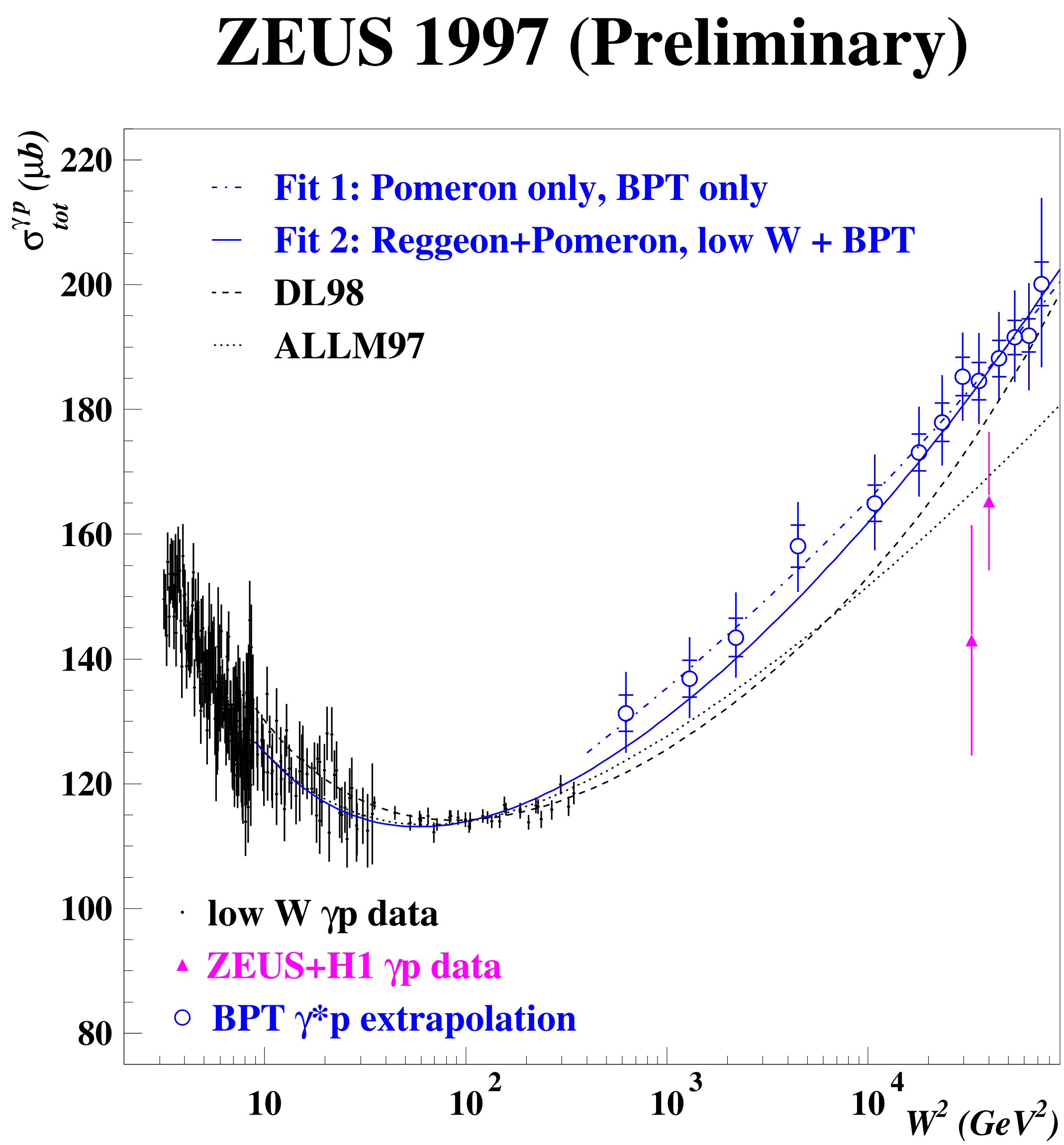
$$F_2(x,Q^2) = \left(\frac{Q^2}{4\pi^2\alpha}\right)\cdot\left(\frac{M_0^2}{M_0^2+Q^2}\right)\cdot\left(A_{\mathbb{R}}\cdot\left(\frac{Q^2}{x}\right)^{\alpha_{\mathbb{R}}-1} + A_{\mathbb{P}}\cdot\left(\frac{Q^2}{x}\right)^{\alpha_{\mathbb{P}}-1}\right)$$

$$= \left(\frac{Q^2}{4\pi^2\alpha}\right)\cdot\sigma^{\gamma^*p}(W^2,Q^2), \quad W^2 = Q^2/x$$

Extrapolation to $Q^2 = 0$

Consistency requires effective flux *increases* in DIS:

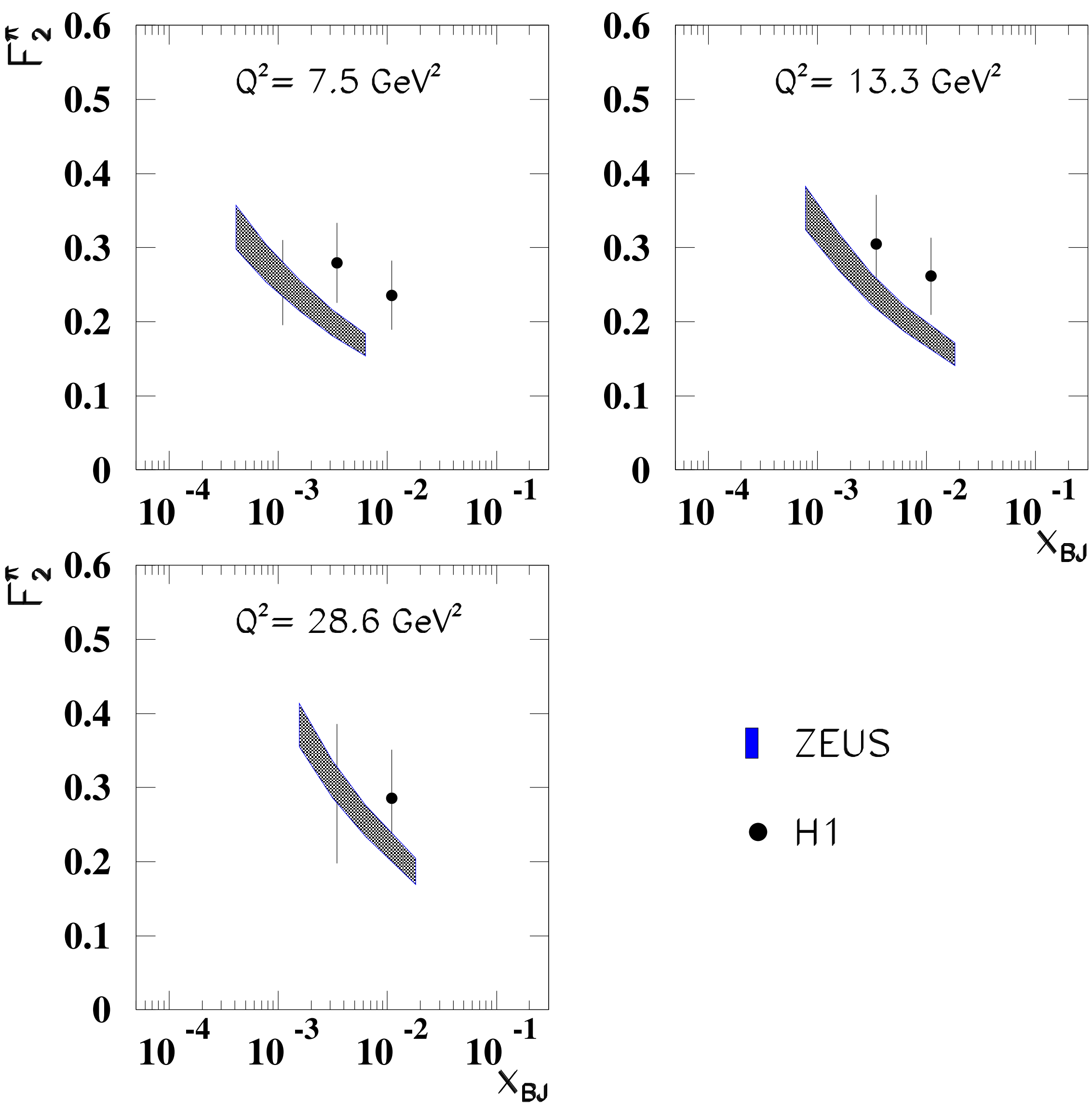
$$f_{eff}^{DIS} = K_{abs} f_{eff} > f_{eff}$$



Extrapolation from $0.1 < Q^2 < 0.74$ GeV^2 *higher* than $Q^2 = 0$

Relative neutron yield in $0.1 < Q^2 < 0.74$ *higher* than $Q^2 = 0$

Comparison to H1



- H1 data lowered by absorptive factor 0.75
- H1 flux 0.131

Discussion

Pion is like a proton at small x

Proton is like a pion at small x

Are all hadrons alike at small x?

Theoretical ideas:

- Dynamically Generated Sea
- Valence Quark Constituent Models

$$F_2^h(x, Q^2) = \int_x^1 dz f_h(z) F_2^q(x/z, Q^2)$$

- Generalized Vector Meson Dominance
- Photon Dipole Models
- Double Asymptotic Scaling of the QCD Evolution Equations

$\Longrightarrow$ Universality in hadron structure at small x

Discussion

Measurement of F_2 counts quarks

$$N \simeq \frac{1}{< e_q^2 >} \int \frac{F_2(x)}{x} dx$$

$F_2^\pi \simeq F_2^p/3 \Rightarrow$

- Number of partons in pion is 1/3 the proton
- parton $number$ density in pion approximately same as proton

Summary

- Leading baryons measured over wide kinematic range:
  $Q^2 = 2 \cdot 10^{-3}$ GeV^2 to $Q^2 = 10^4$ GeV^2
  $x_L > 0.2$, $p_T < 0.7$ GeV
- $F_2^{LP(4)}(x_{BJ}, Q^2, x_L, p_T^2) \approx A \exp(-6p_T^2) \cdot F_2^p(x_{BJ}, Q^2)$
- $F_2^{LN(3)}(x_{BJ}, Q^2, x_L) \approx A(Q^2) \cdot f(x_L) \cdot F_2^p(x_{BJ}, Q^2)$
  $A(Q^2 > 4$ GeV$^2) \approx$ constant
- Approximate Limiting Fragmentation
- Particle Exchange Factorization
- Observe factorization breaking
- Evidence for absorption (rescattering) for leading neutrons:
  relative yield rises from photoproduction to DIS
  saturates in DIS
  shape of energy distribution insensitive to Q^2
- Standard Monte Carlo models in poor agreement with data
- Diffractively dissociating protons are a minor component of neutron production
- Neutron production with photoproduced dijets
  consistent with pion exchange
  rate lies between inclusive photoproduction and DIS rates

Summary

- For $x_L \gtrsim 0.6$ effective flux in agreement with neutron data — both angular distribution and energy spectrum
- Electroproduction data comparable to hadroproduction data with relative rate reduced by about 50%
- $\sigma_{\gamma\pi}$ determined at high W
- F_2^π determined at low x
- $F_2^\pi \propto F_2^p$ (Unnormalized tagged beam)
  $F_2^\pi = F_2^p/3$ (Effective flux)
- Conjectures:
  1. Properties of leading baryon *intrinsic* to incident proton
  2. All hadrons are alike at low x
     $F_2^h \propto$ universal function
  3. Normalization of F_2^h at low x
     $\propto$ number of inter-valence connections
  4. The number density of partons in hadrons is approximately constant: $n_\pi \approx n_p$
  5. Valence quark counting rules break down for $\gamma\pi$ total cross section — $\sigma^{\gamma\pi} \neq 2\sigma^{\gamma p}/3$