ZEUS Leading baryons at low x_L in DIS and photoproduction

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HERA beams: $\mathbf{e^\pm}$ → 27.5 GeV ← $\mathbf{p}$ 820 GeV

e-p center of mass: $\sqrt{s_{ep}}$ = 300 GeV

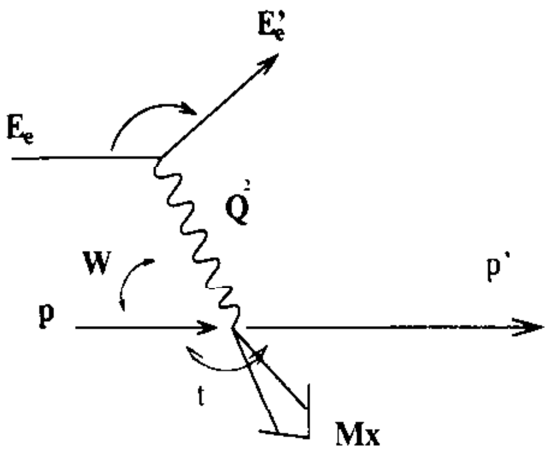
DIS: $\gamma^*(Q^2)$**-p center of mass:** $W_{\gamma p}$ **= 45-225 GeV**

PHP: γ**-p center of mass:** $W_{\gamma p}$ **= 180-225 GeV**

Event selection:

DIS selection	PHP selection
$Q^2 > 4$ GeV^2	
$y < 0.95$	Vertex
Timing	Timing
$E_e > 8$ GeV	$12 < E_e < 18$ GeV
$45 < W_{\gamma^*(Q^2)p} < 225$ GeV	$180 < W_{\gamma p} < 225$ GeV

Leading Baryons at HERA: Kinematics



One more vertex!

Two variables describe the kinematics of the final state leading baryons (LB):

$p_\perp$ Transverse momentum of the LB

p_z Longitudinal momentum of the LB

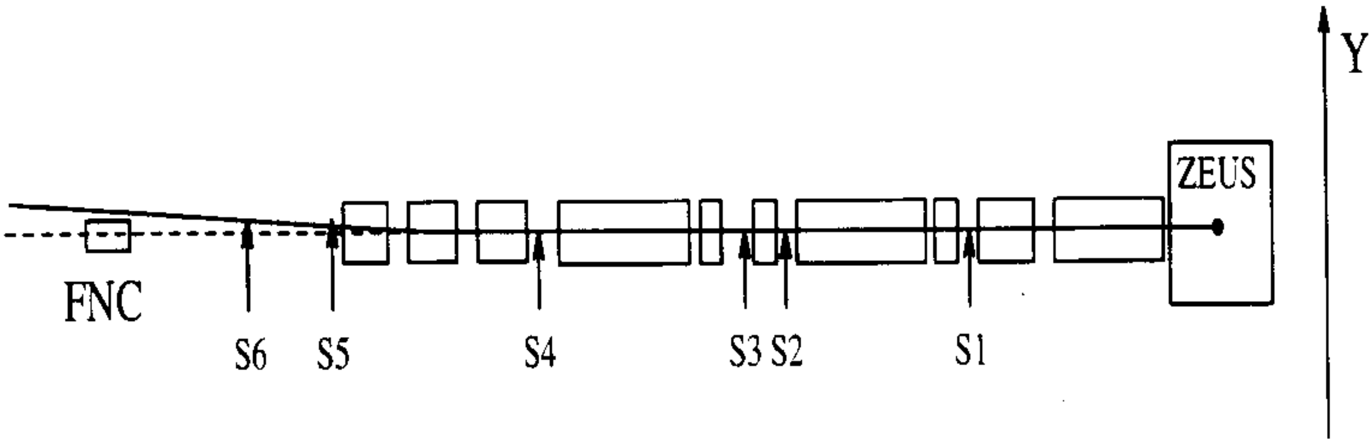
From those variables, the following quantities are defined:

$x_L = \frac{p'_z}{p_z}$ Fraction of beam momentum carried by the LB after the interaction

$t = (p - p')^2 = -\frac{m_p^2 (1 - x_L)^2}{x_L} - \frac{p_\perp^2}{x_L}$ Momentum transfer at the proton vertex

$M_X^2 = W_{\gamma p}^2 (1 - x_L)$ Invariant mass squared

ZEUS forward detectors: Leading Proton Spectrometer (LPS) and Forward Neutron Calorimeter (FNC)

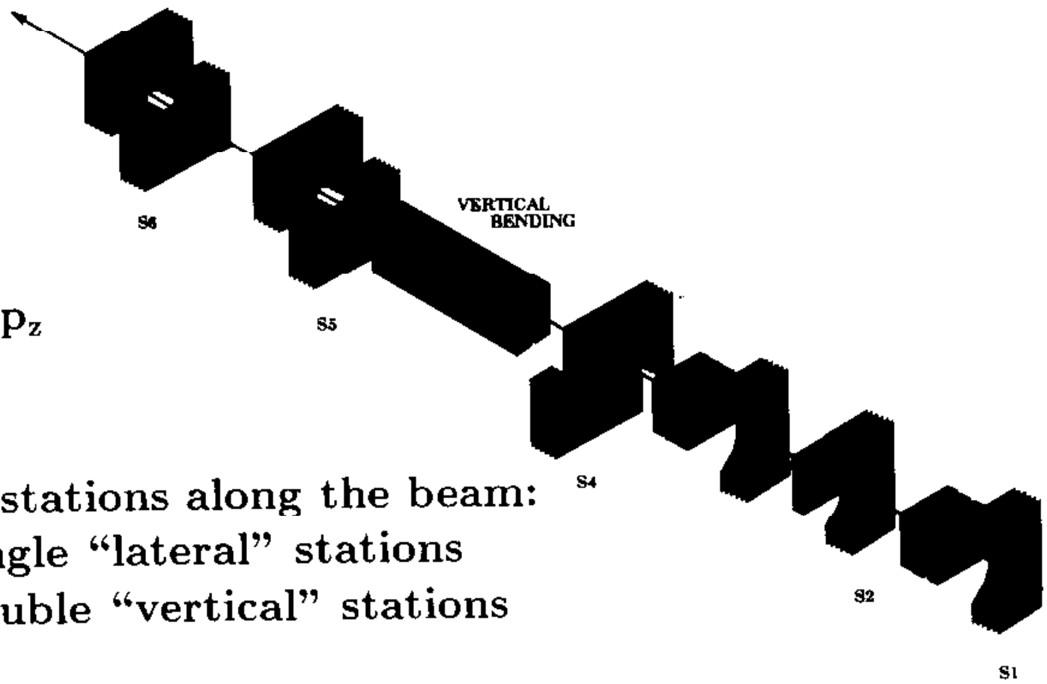


FNC (103m) | LPS S1-S6 (24-90 m)

Neutral/Charged particles	Charged particles
Neutrons	**Protons**
Gammas	**Pions**
Protons	

ZEUS forward detectors: the Leading Proton Spectrometer (LPS)

LPS acceptance: $0.6 < x_L < 1.0$ and $0 < p_\perp^2 < 1$ GeV^2



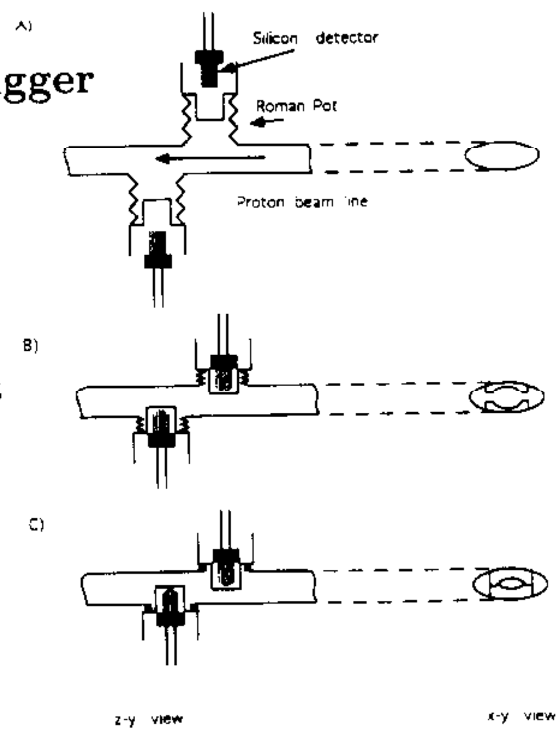
- **Resolution:**
  - $\simeq 0.3$ % on p_z
  - $\simeq 3$ % on $p_\perp$

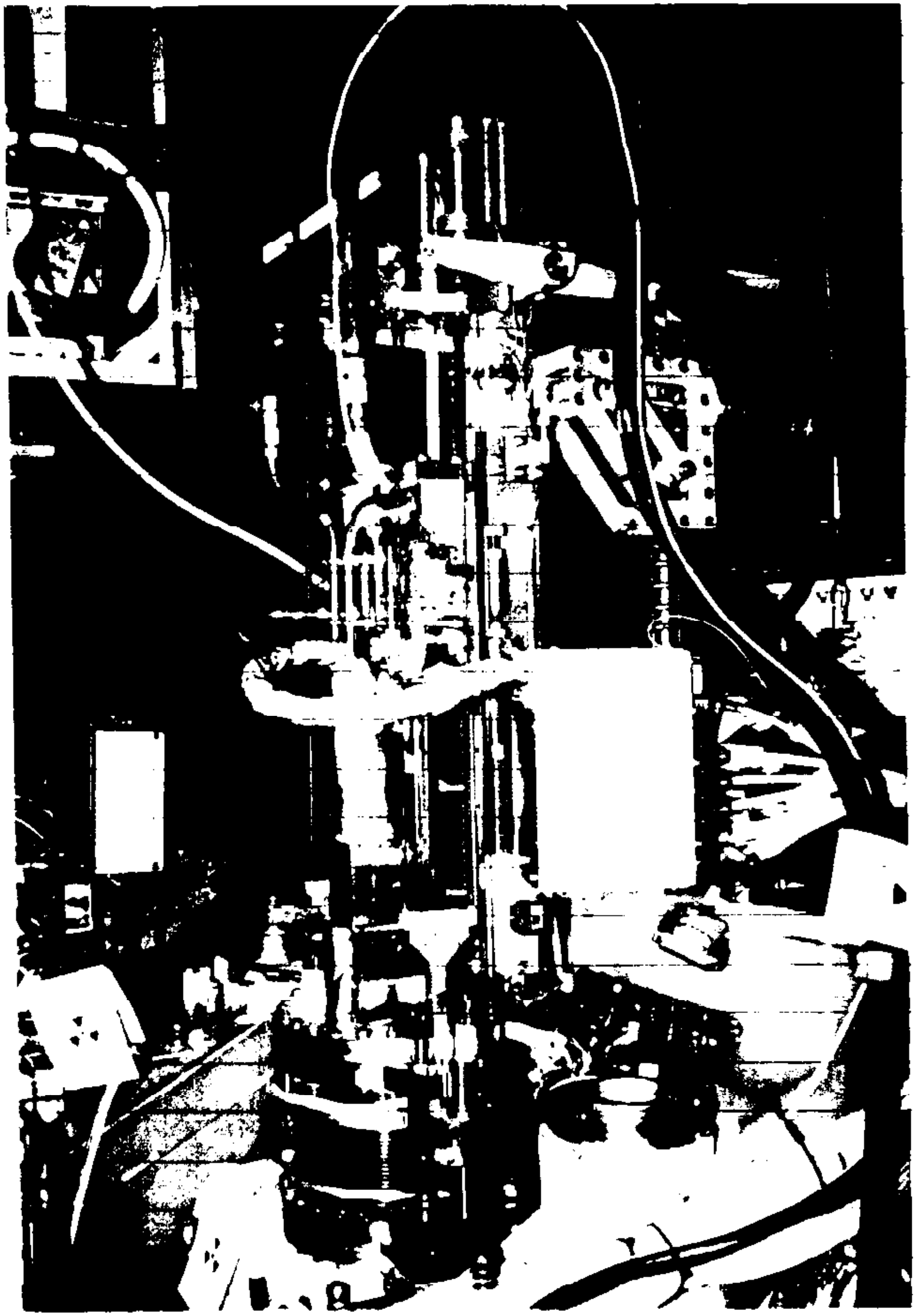
- **Six detector stations along the beam:**
  S1 —— S3 single "lateral" stations
  S4 —— S6 double "vertical" stations

- Collected Luminosity:
  0.9 pb^{-1} in 1994
  2.5 pb^{-1} in 1995. Installed LPS Trigger
  4.0 pb^{-1} in 1996

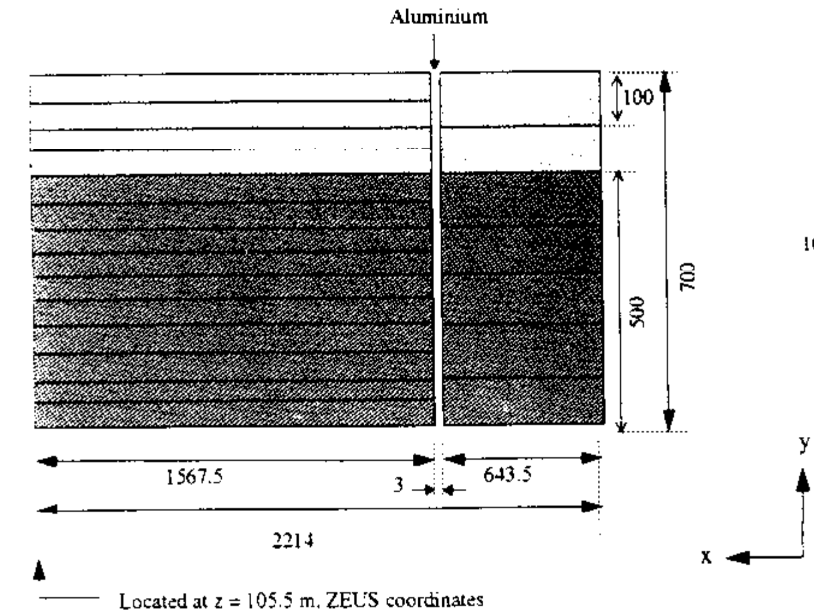
- **Detector operations using Roman pots**

- **Six μstrip silicon detectors per pot**
  - three different strip orientations ($0^\circ, +45^\circ, -45^\circ$)
  pitch: $115\mu m \rightarrow 0^\circ \sqrt{2}\mu m \rightarrow \pm 45^\circ$
  - cut out to follow the 10σ beam profile

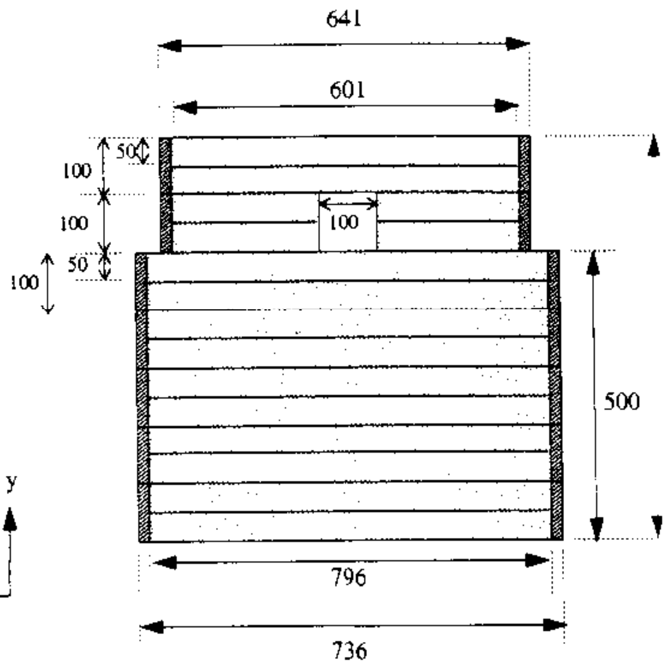




ZEUS forward detectors:
the Forward Neutron Calorimeter (FNC)



SIDE view



FRONT view

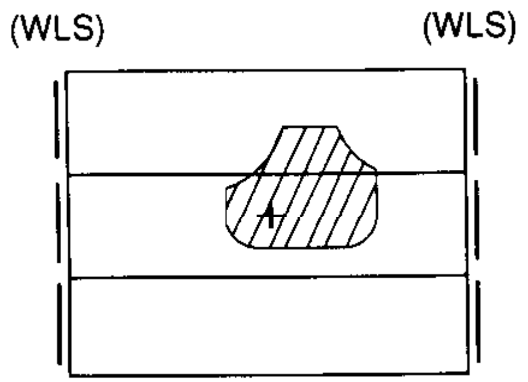
Version FNC III installed in 1995 :

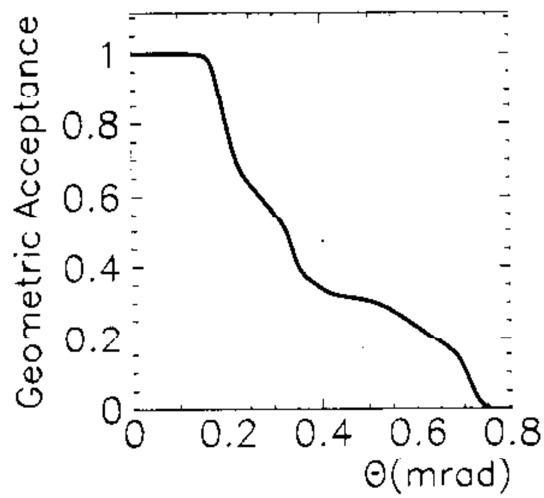
- **Lead-scintillator calorimeter**
- **10 interaction lengths**
- **Vertical position resolution:** **segmented in 5 cm towers** $\rightarrow \mathbf{\Delta y = 10cm/\sqrt{E}}$
- **Horizontal position resolution:** **read-out from both sides** $\rightarrow \mathbf{\Delta x = 20cm/\sqrt{E}}$
- **Energy resolution :** $\sigma(\mathbf{E_n}) \sim \mathbf{0.65\sqrt{E_n}}$
- [redacted]

ZEUS forward detectors: FNC and LPS acceptance

FNC acceptance:

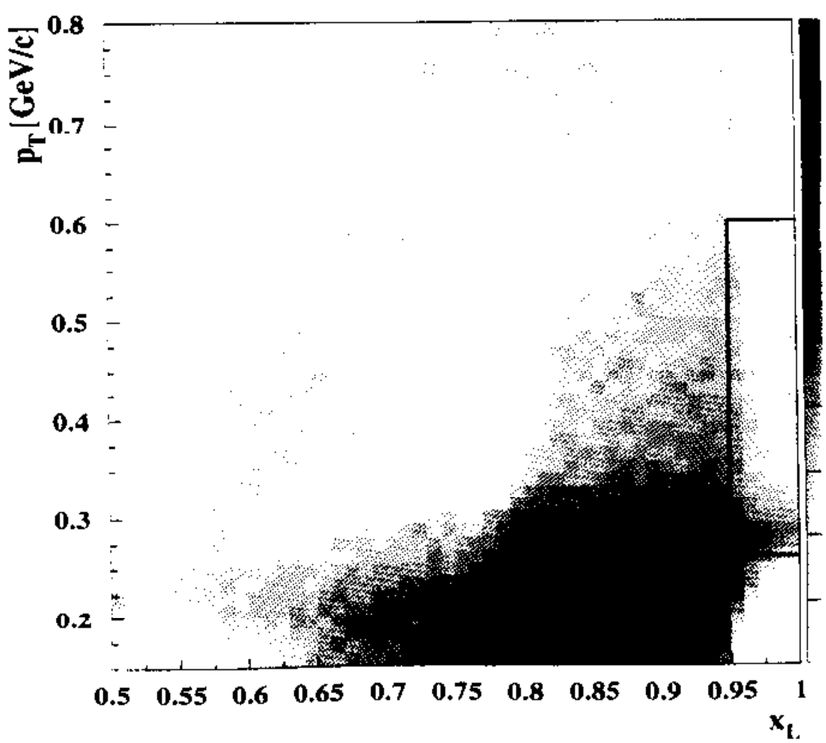
(determined by the beam-pipe apertures)





LPS (1994 configuration) acceptance:

(determined by the beam-pipe apertures and magnet strength)



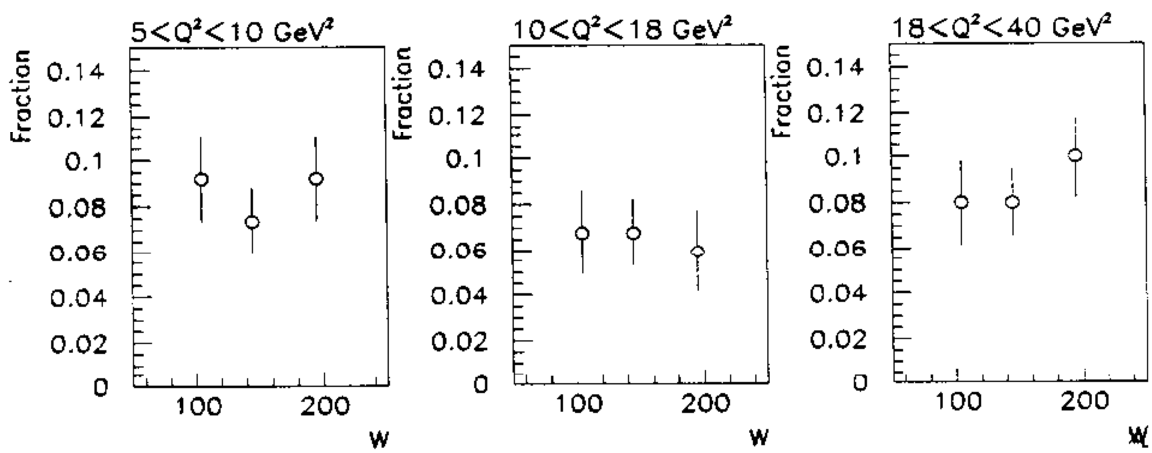
Properties of events with a leading proton

x, Q^2 distributions

DIS events with a leading proton (LP) show the same x, y, Q^2 dependence as the 'other' DIS events

In the interval $t_{lim} < -t < 0.5\,GeV^2$, $0.6 < x_L < 0.92$ they represent 6-10 % of the total DIS cross section

ZEUS 1994 Preliminary



$$\text{Fraction} = \frac{\text{DIS events with a LP with } -t_{lim} < -t < 0.5\ \text{GeV}^2 \text{ and } 0.6 < x_L < 0.92}{\text{All DIS event}}$$

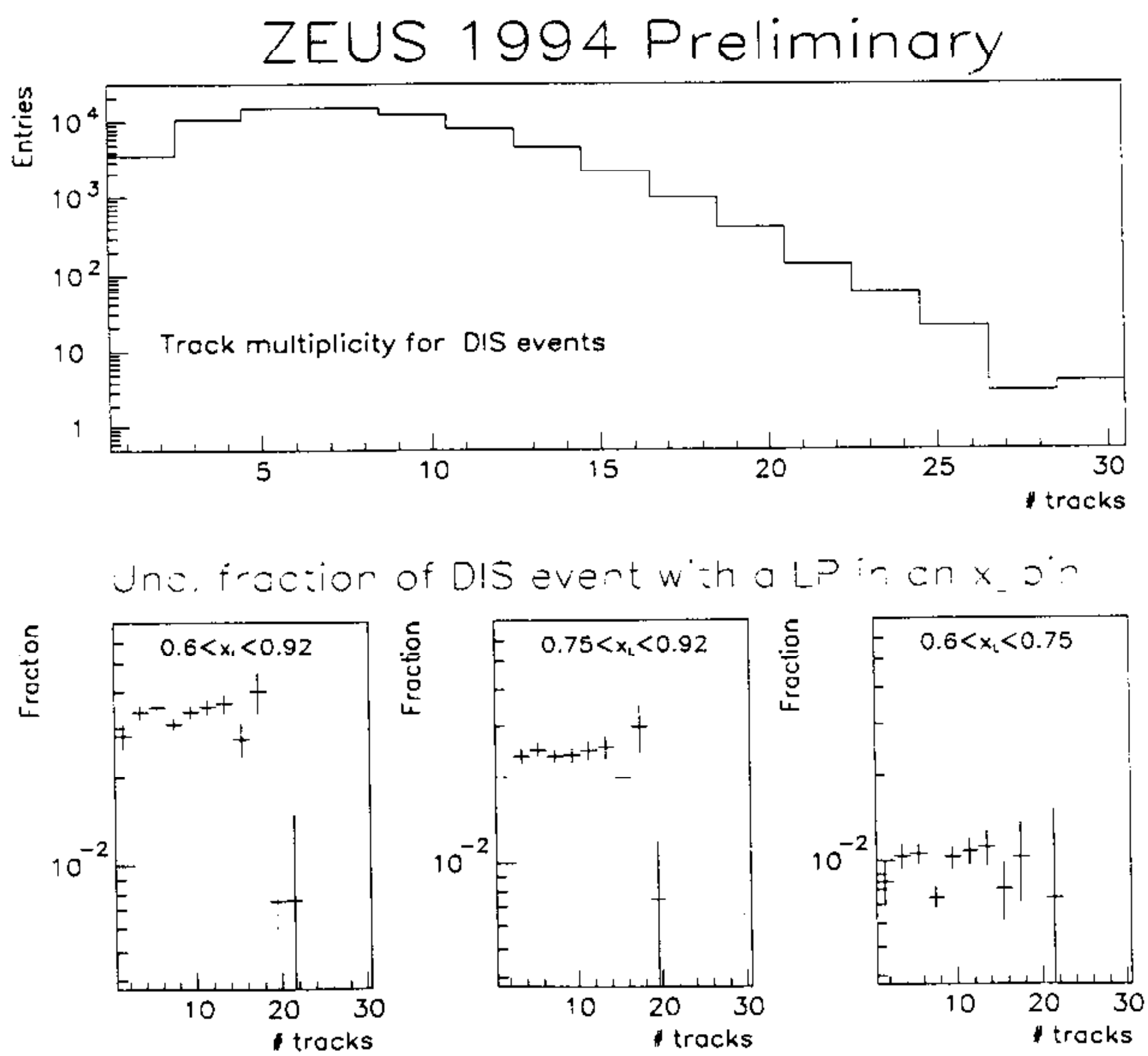
$t_{lim} = \text{MAX}(0.08, +t_{min})$

Statistical error only

Properties of events with a leading proton

Track multiplicity

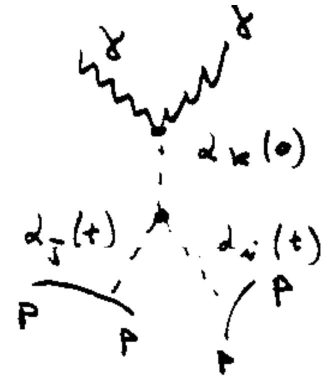
DIS events with a LP with $0.6 < x_L < 0.92$ have the same charged track multiplicity of DIS events



Detour:

In TRIPLE REGGE analysis you can write:

$$\frac{d\sigma}{dx_L\, dW^2} \propto (1-x_L)^{1-\alpha_i(t)-\alpha_j(t)} \left(W^2\right)^{\alpha_k(0)-1}$$



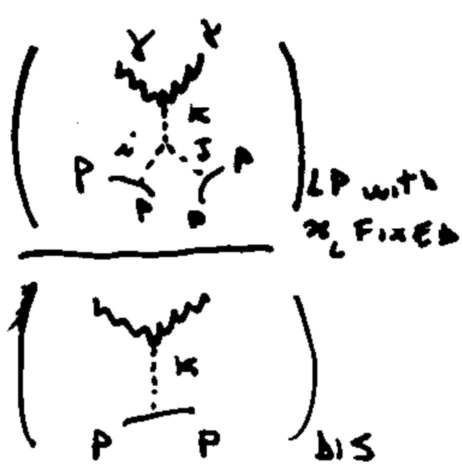
⇒ Fix $(1-x_L)$ using the ZEUS LPS

⇓

W^2 dependence is driven only by $\alpha_k(0)$

⇓

The same as DIS in every x_L bin:

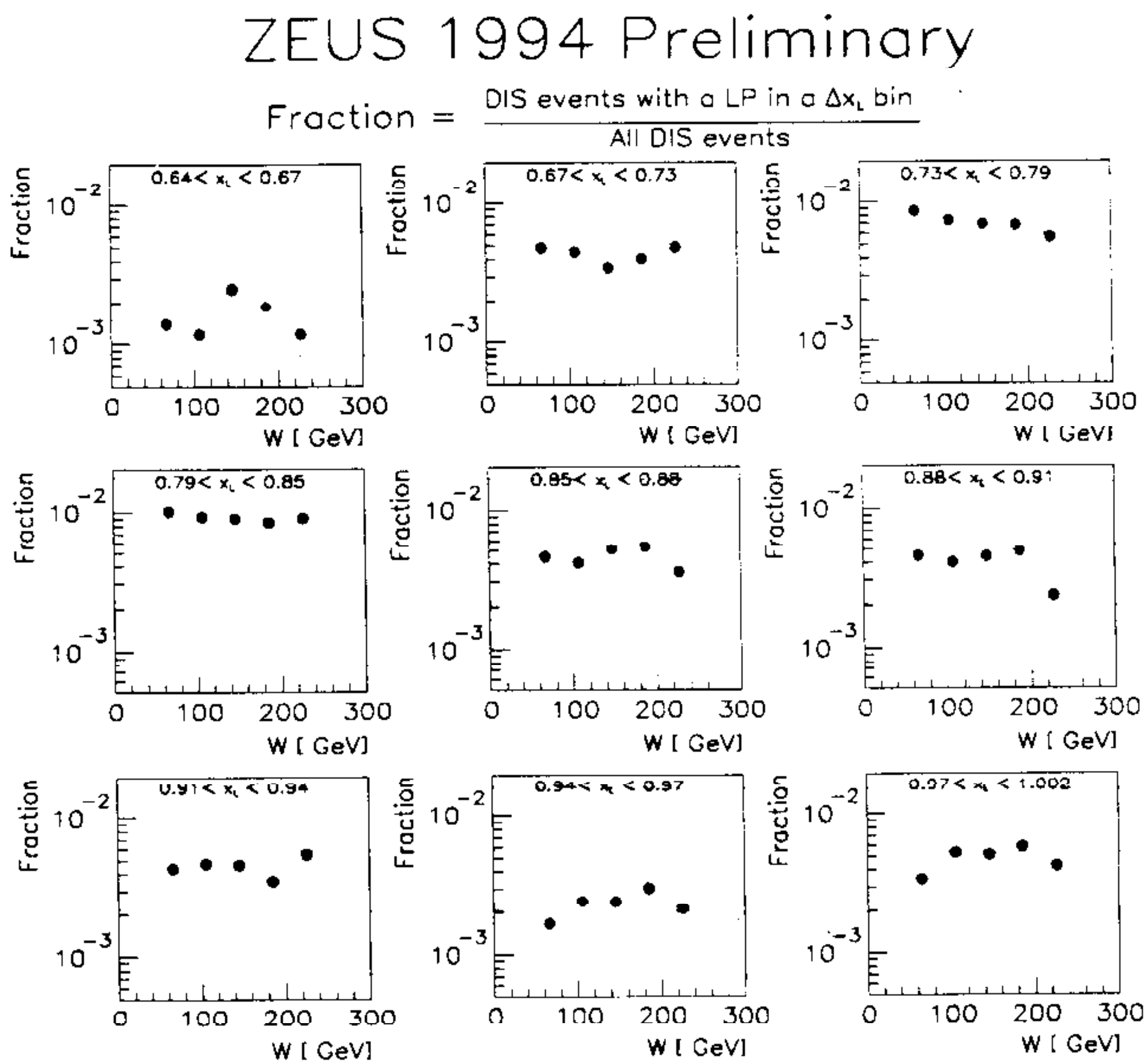


≈ FLAT

Properties of events with a leading proton

Energy dependence

DIS events with a LP show the same energy dependence as the 'other' DIS events, in every x_L interval:

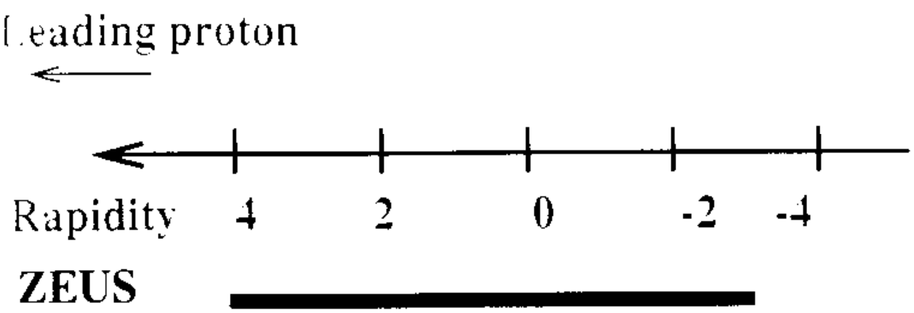


Properties of events with a leading proton

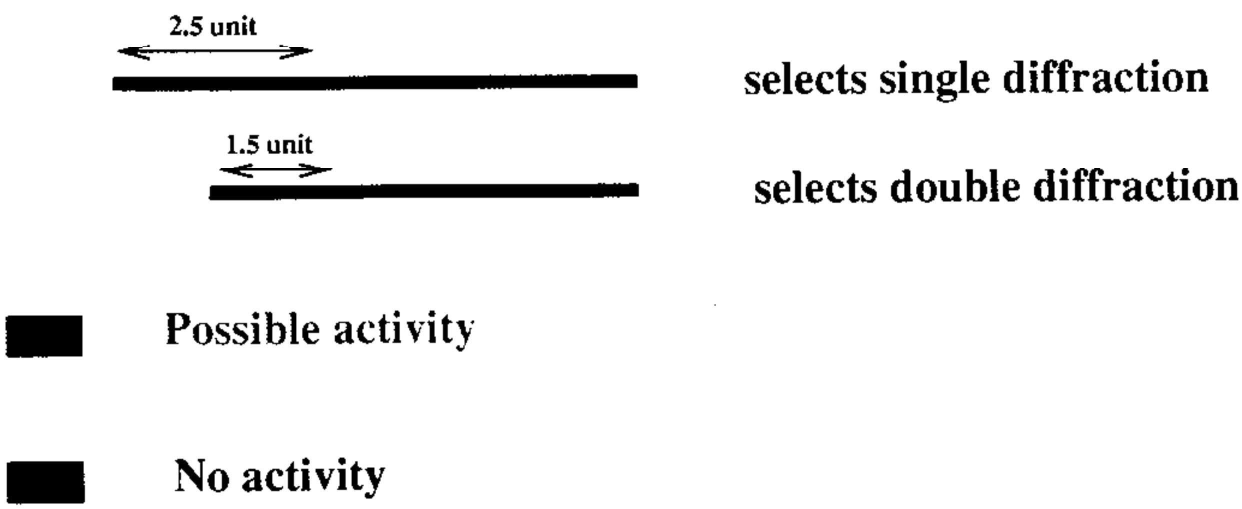
Rapidity gaps in DIS events

If LP are generated in diffractive scattering, $ep \rightarrow Xp$, $ep \rightarrow XYp$, then, according to MC studies, $\sim$ 50% of the time there should be a visible rapidity gap in ZEUS.
A selection criterium, GAPCUT, accepts, according to MC studies, $\sim$ 50% of single diffraction, 40-70 % of double diffraction (considering only the events with a LP in the final state) and less than 2% of non diffractive events.

depending on the generated $\frac{dN}{dM_x} \sim \left(\frac{1}{M_x}\right)^{\alpha}$



Accept the event if:

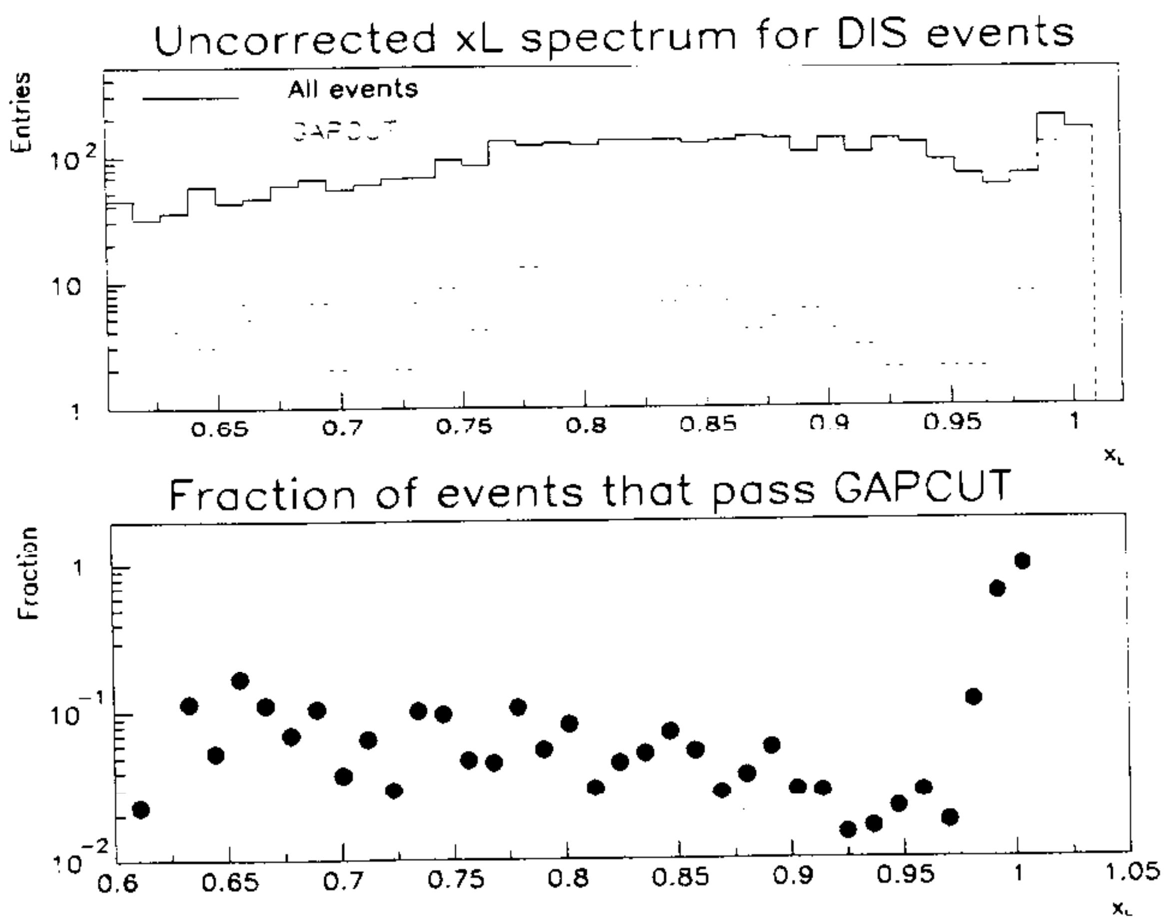


Properties of events with a leading proton

Rapidity gaps in DIS events

At $x_L \sim 1$**, almost all the events show a rapidity gap, while for** $0.6 < x_L < 0.9$ **only a small fraction does.**
The majority of LP with $0.6 < x_L < 0.9$ is generated by a mechanism that is not double diffraction.

ZEUS 1994 Preliminary

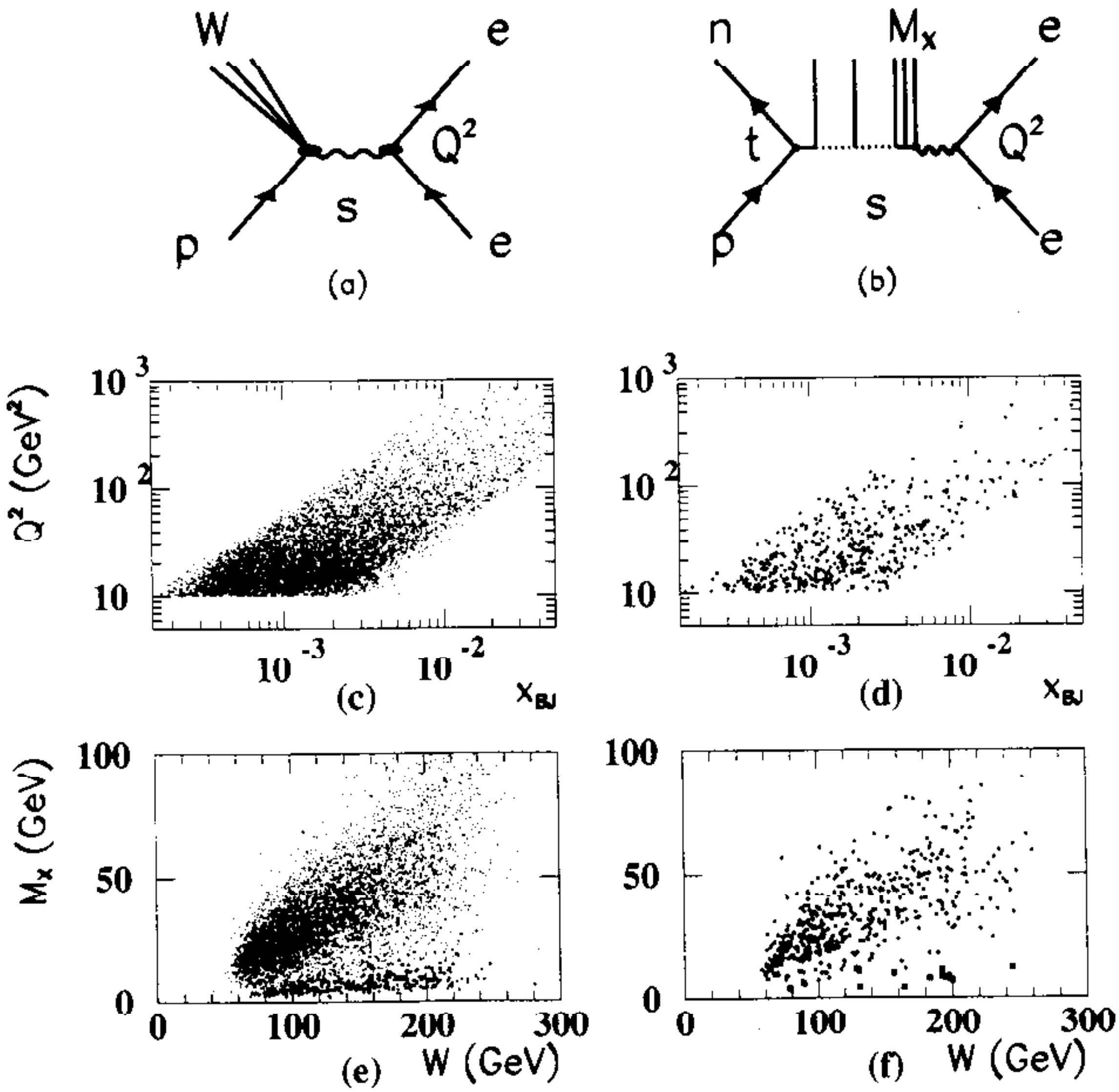


Properties of events with a leading neutron

In addition to standard DIS Event Selection:

$E_n > 400$ GeV

$\text{Rate}_{(E_n>250\ \text{GeV})} < 5$ kHz

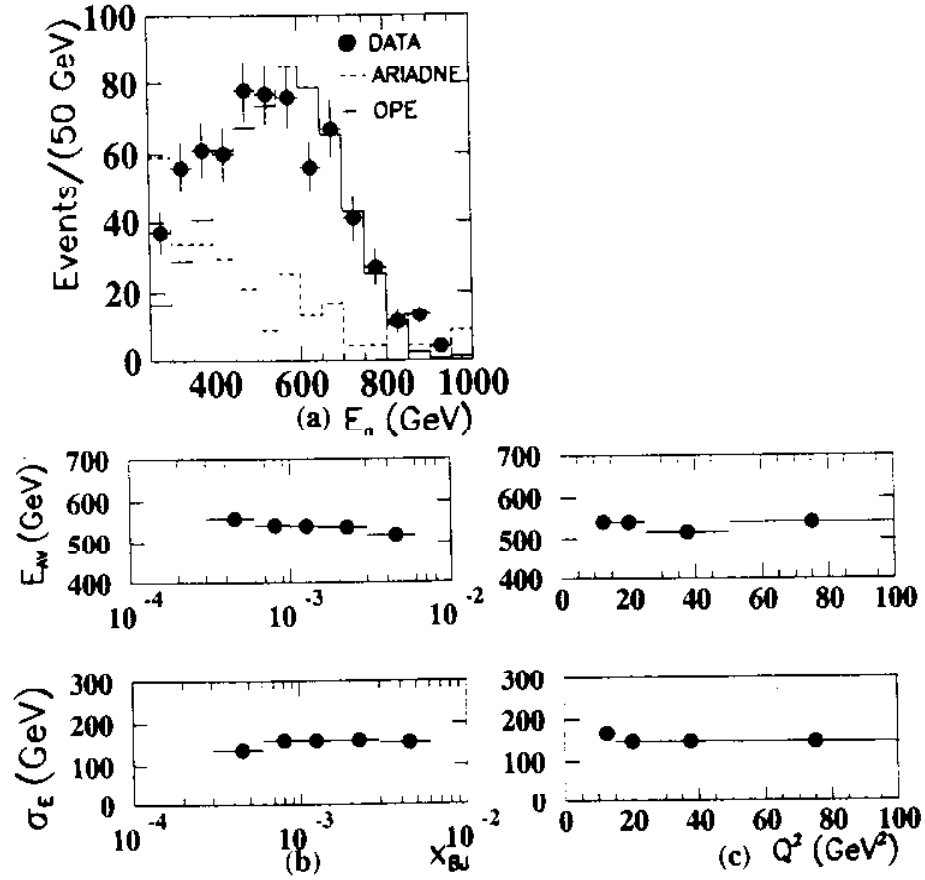


- Background from random beam-gas overlaps is 1.7 %.

Properties of events with a leading neutron

Neutron Energy Spectrum (1994 Data)

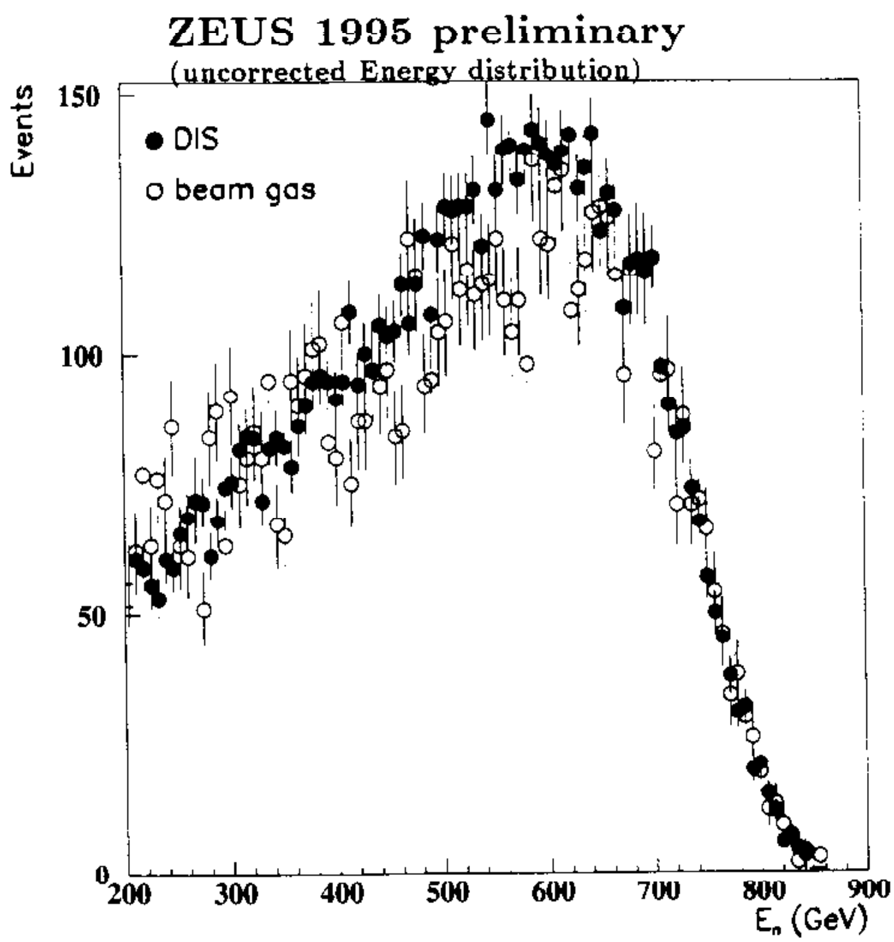
- The Standard Ariadne DIS MC fails to reproduce the shape of the neutron energy spectrum
- A MC based on 'one pion exchange' model fits the data much better
- The average neutron energy is independent from both x and Q^2



Properties of events with a leading neutron

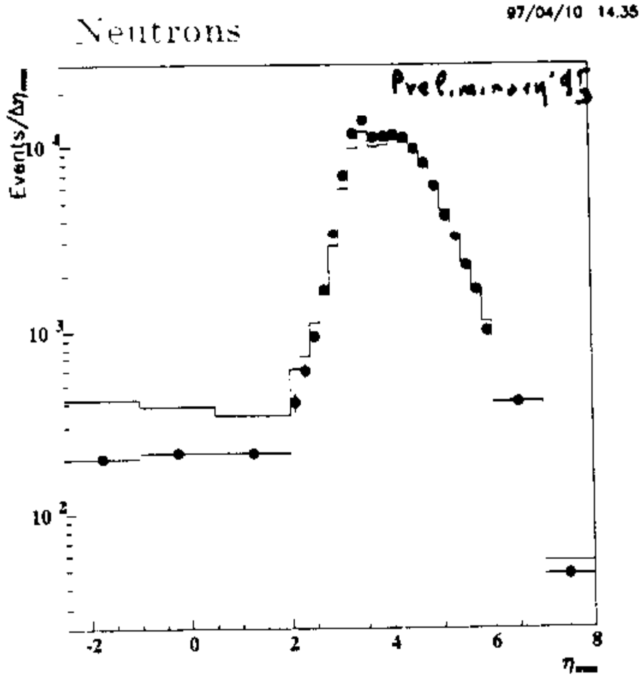
Neutron Energy Spectrum (1995 Data)

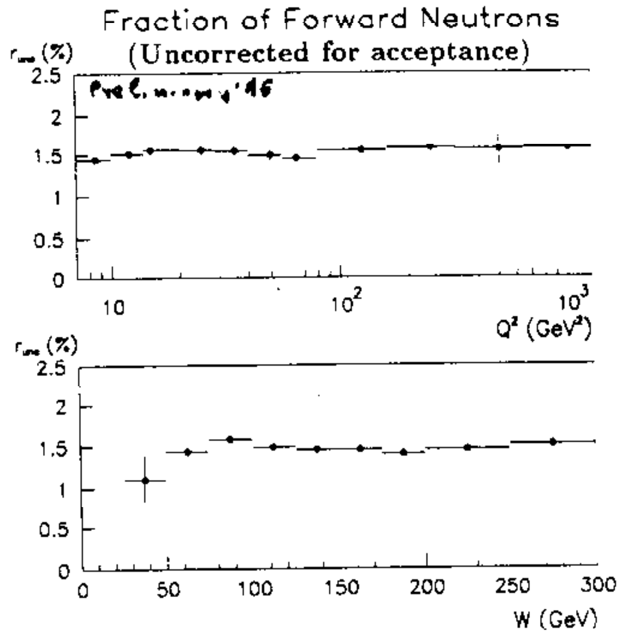
- With much better statistics, 1995 data confirms the 1994 energy spectrum
- DIS and beam-gas events (scattering of the proton beam on [redacted]gas inside the beam-pipe) show the same energy spectrum → proton fragmentation independent of beam



Properties of events with a leading neutron

Comparison with all DIS events (1995 Data)

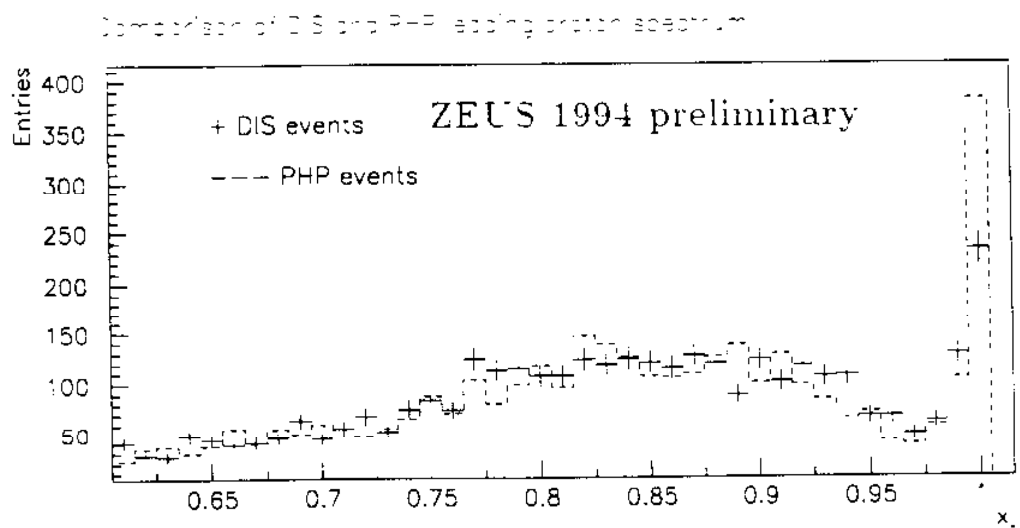




- Production of forward neutron has the same energy and Q^2 dependence of all DIS events. After acceptance correction, $9.1^{+3.6}_{-5.7}$ % of all DIS events have a neutron with $E_n > 400$ GeV and $|t| < 0.5 GeV^2$ (ZEUS 1994 DATA)
- The η_{max} distribution for all DIS events has the same shape as the η_{max} distribution for neutron tagged events at large η_{max}
- For all DIS events, 7% of the events events have $\eta_{max} < 2$ while for the neutron tagged sample this fraction is much lower

Comparison of the x_L spectrum for LP production between DIS and photoproduction

- The shape of the DIS and photoproduction spectra for LP production, apart form the x_L=1 peak, are consistent with each other. The comparison is made using uncorrected spectra
- The ZEUS trigger system does not introduce a bias in the x_L distributions
- The relative normalization of the two plot is arbitrary



Slope parameter 'b' as a function of x_L

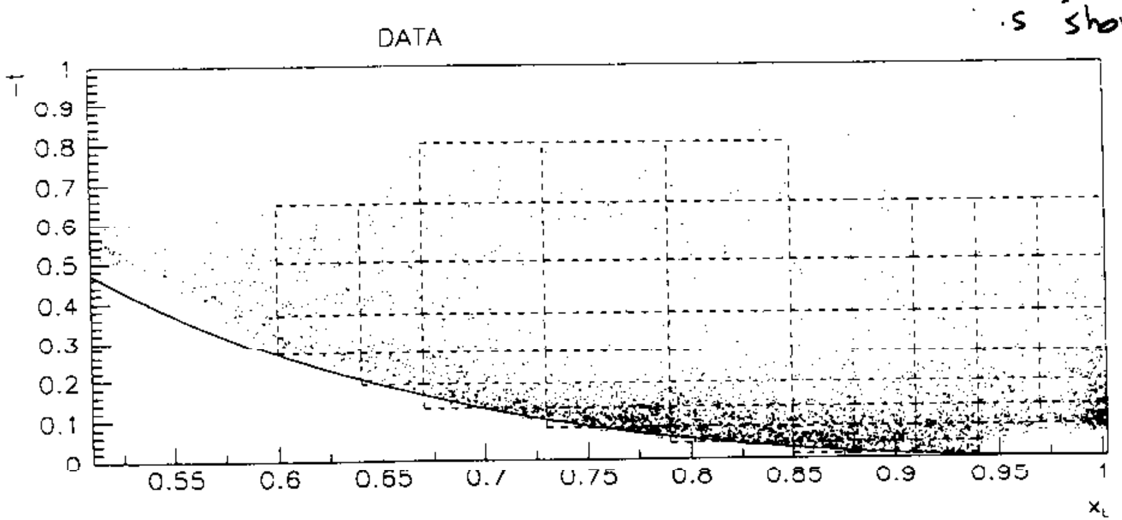
Events in the $x_L - t$ plane

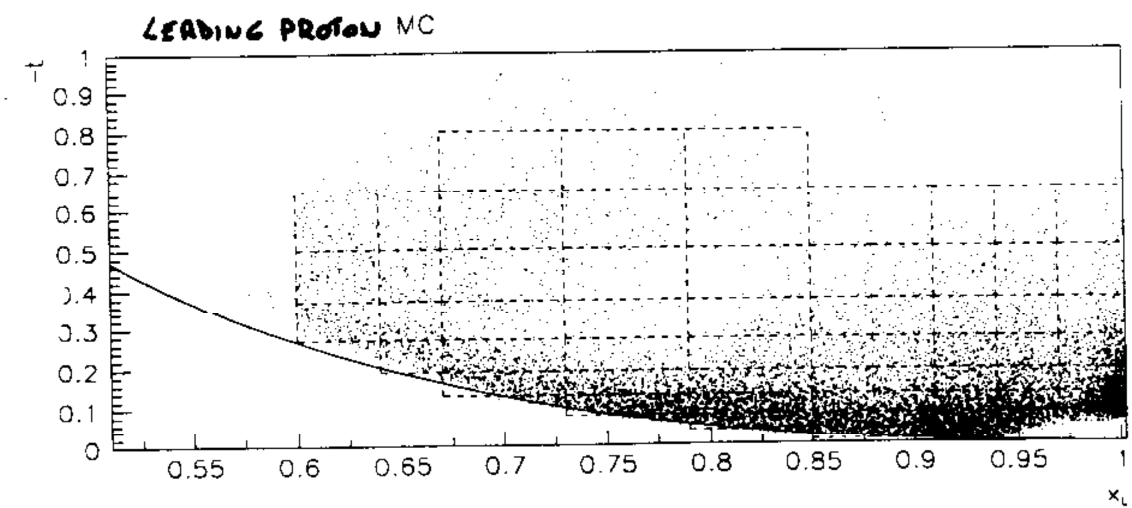
Analysis uses 900 nb^{-1} data → 3500 DIS events

t range: $-t_{min} = \frac{(1-x_L)^2}{x_L} < -t < 0.7\ \mathrm{GeV}^2$

x_L range: $0.6 < x_L < 1.$

Analysis done both in $(x_L - t)$ and $(x_L - p_t^2)$ (here only the $(x_L - t)$ analysis is shown)



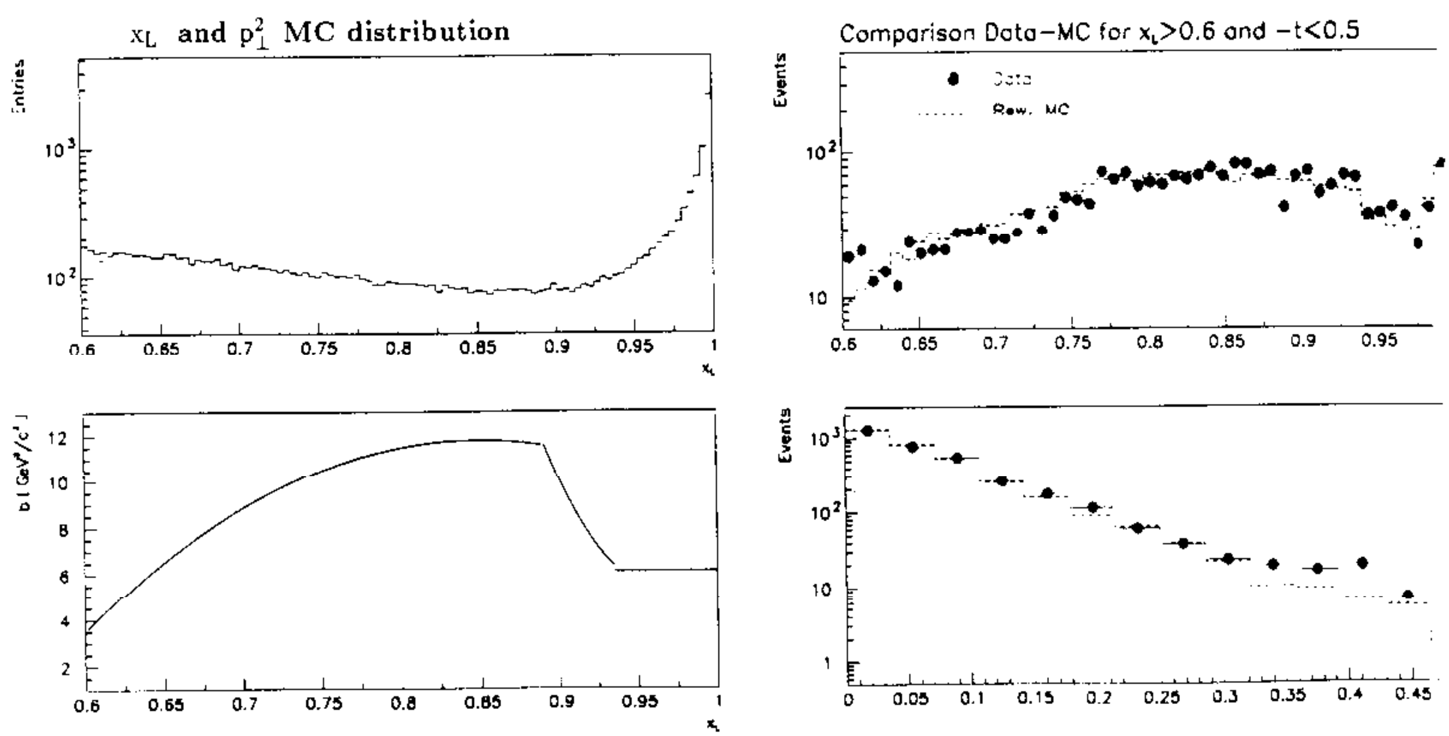


Slope parameter ‘b’ as a function of x_L

Unfolding technique

The analysis is performed using a bin-by-bin unfolding method with a MC that has an ‘x_L’ and ‘$b(x_L)$’ distribution similar to the distributions measured in the data. To obtain the appropriate MC distributions, a value of ‘b’ for different x_L bins is measured and then a reweighting in x_L is performed. The procedure is then repeated.
The chosen MC generated distribution has the form:

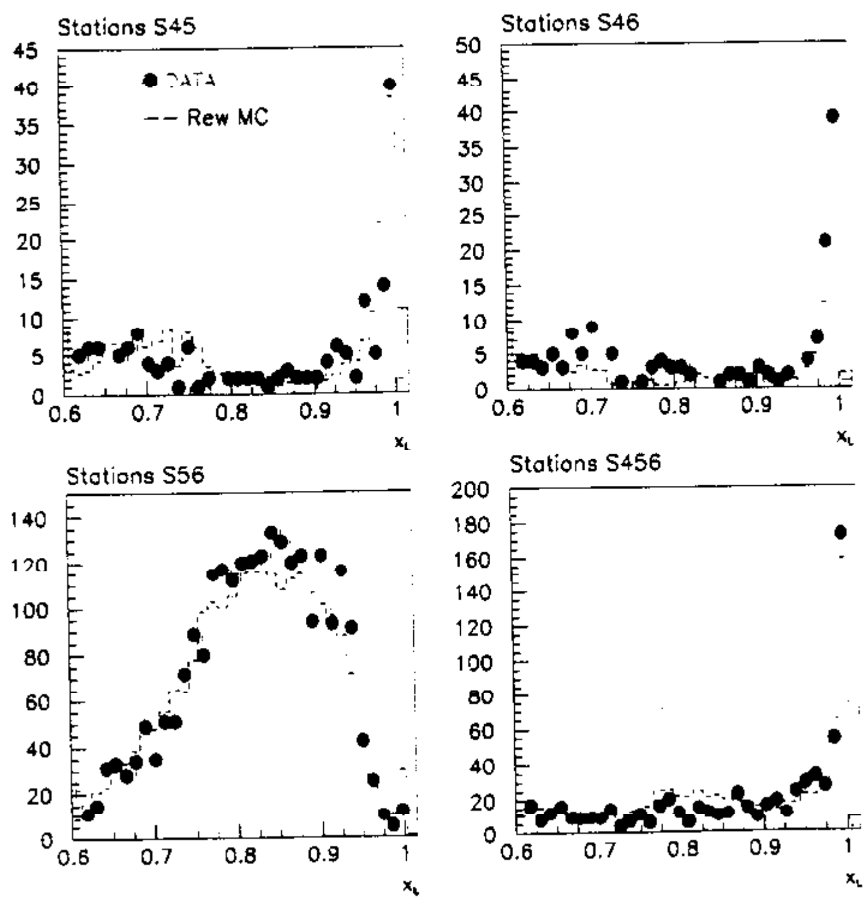
$$\frac{dN}{dp_\perp^2 dx_L} \propto e^{b x_L \cdot p_\perp^2} \times C_1 \times 1 - x_L - \frac{C_2}{1 - x_L}$$



Slope parameter 'b' as a function of x_L

DATA-MC comparisons

A track in the LPS can be reconstructed using either two (S4-S5, S4-S6, S5-S6) or three stations. How the MC models the percentage of tracks going through each possibility is a powerful tool to check the agreement between Data and MC.
For each combination of stations, the normalization and shape of the distributions of the kinematic variables p_x, p_y, p_z has been check.



Slope parameter 'b' as a function of x_L

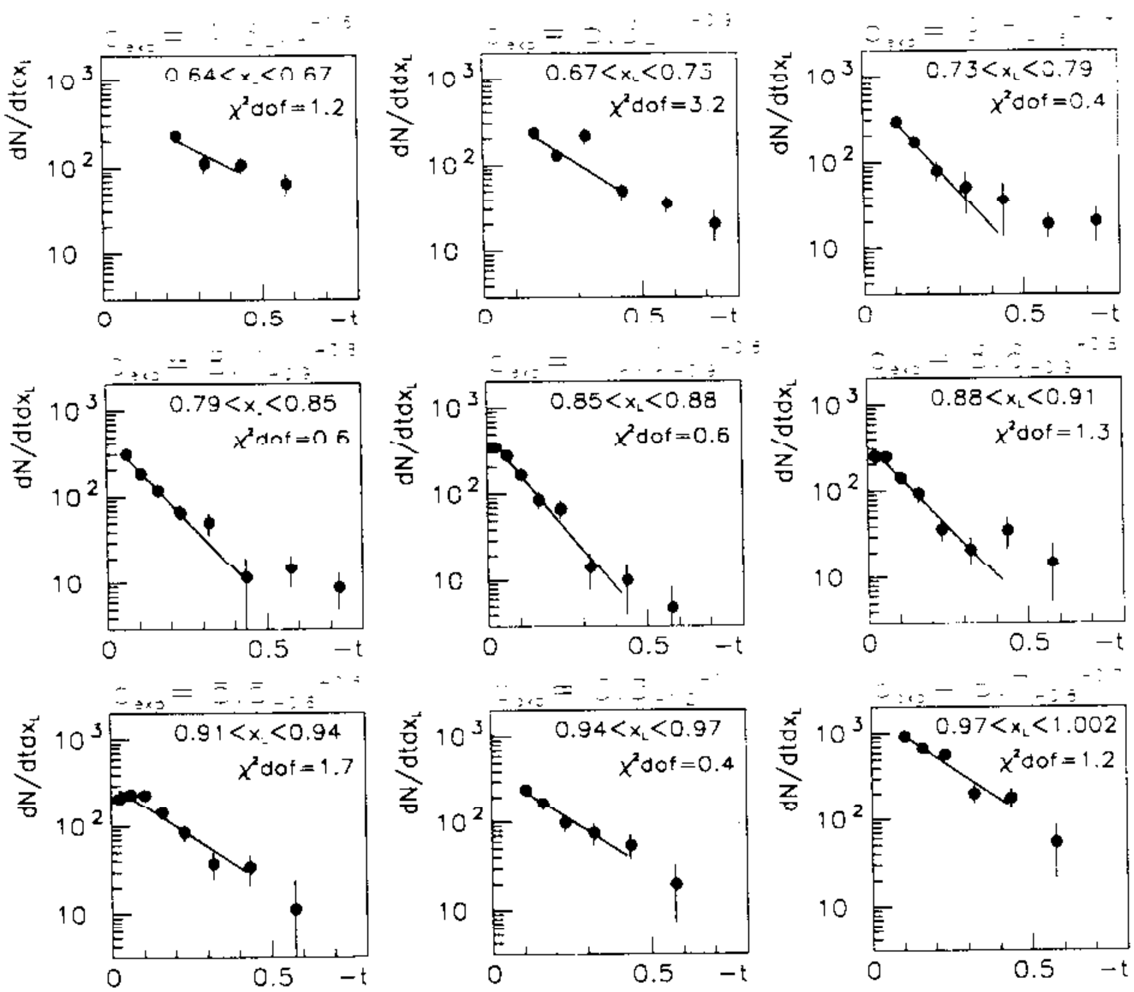
Fit for $t_{min} < -t < 0.5$ GeV^2

The slope parameter of the t distribution has been measured for different x_L bins. The data have been fitted using a single exponential, e^{bt}, in different t ranges:

a) whole t range,

b) $t_{min} < -t < 0.5$ GeV^2 (shown here),

c) $0.08 < -t < 0.5$ GeV^2.

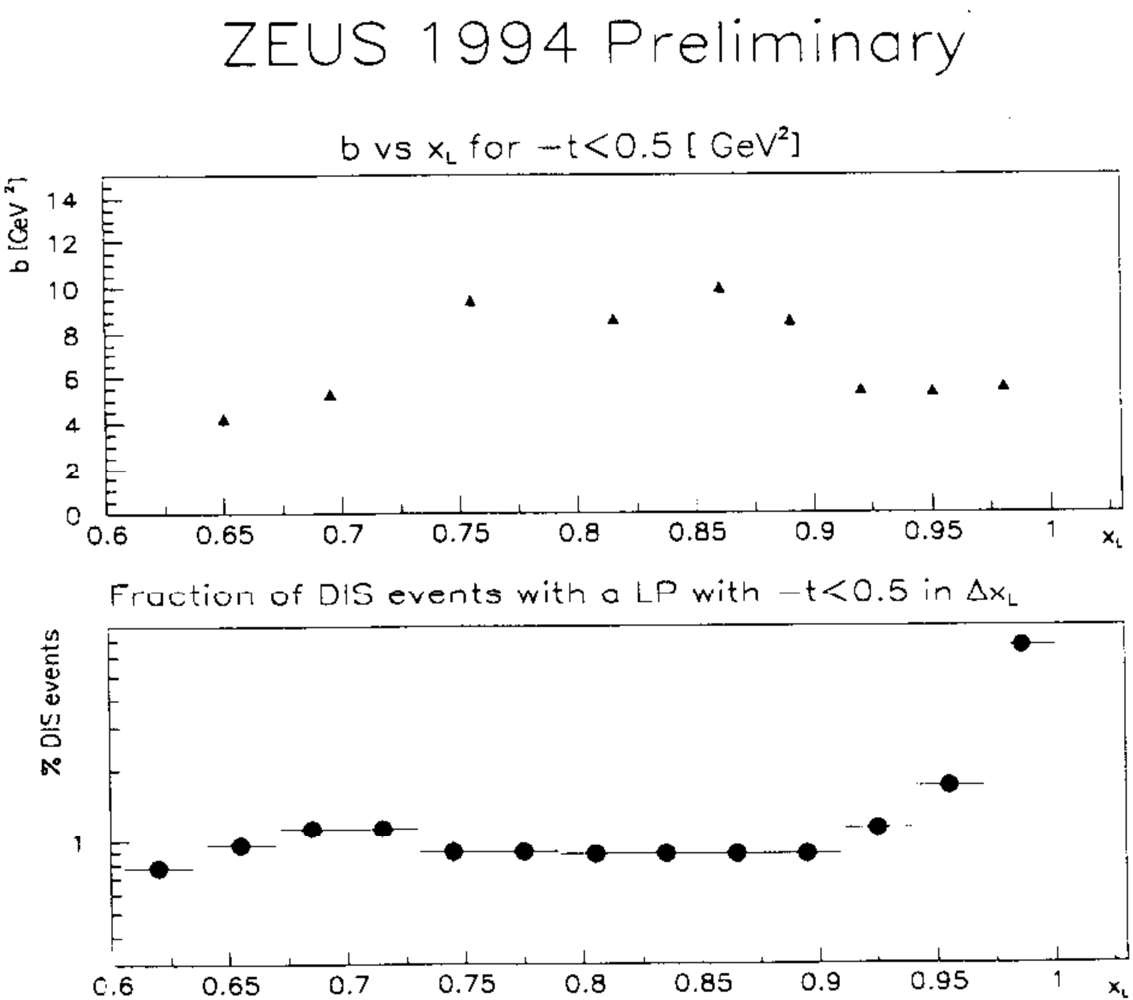


Slope parameter 'b' as a function of x_L

b vs x_L and x_L spectrum

Note that $-t_{min} = \frac{(1-x_L)^2}{x_L} m_p^2$ increases as x_L decreases. For example, at $x_L = 0.65$, $-t_{min} = 0.27$ GeV^2

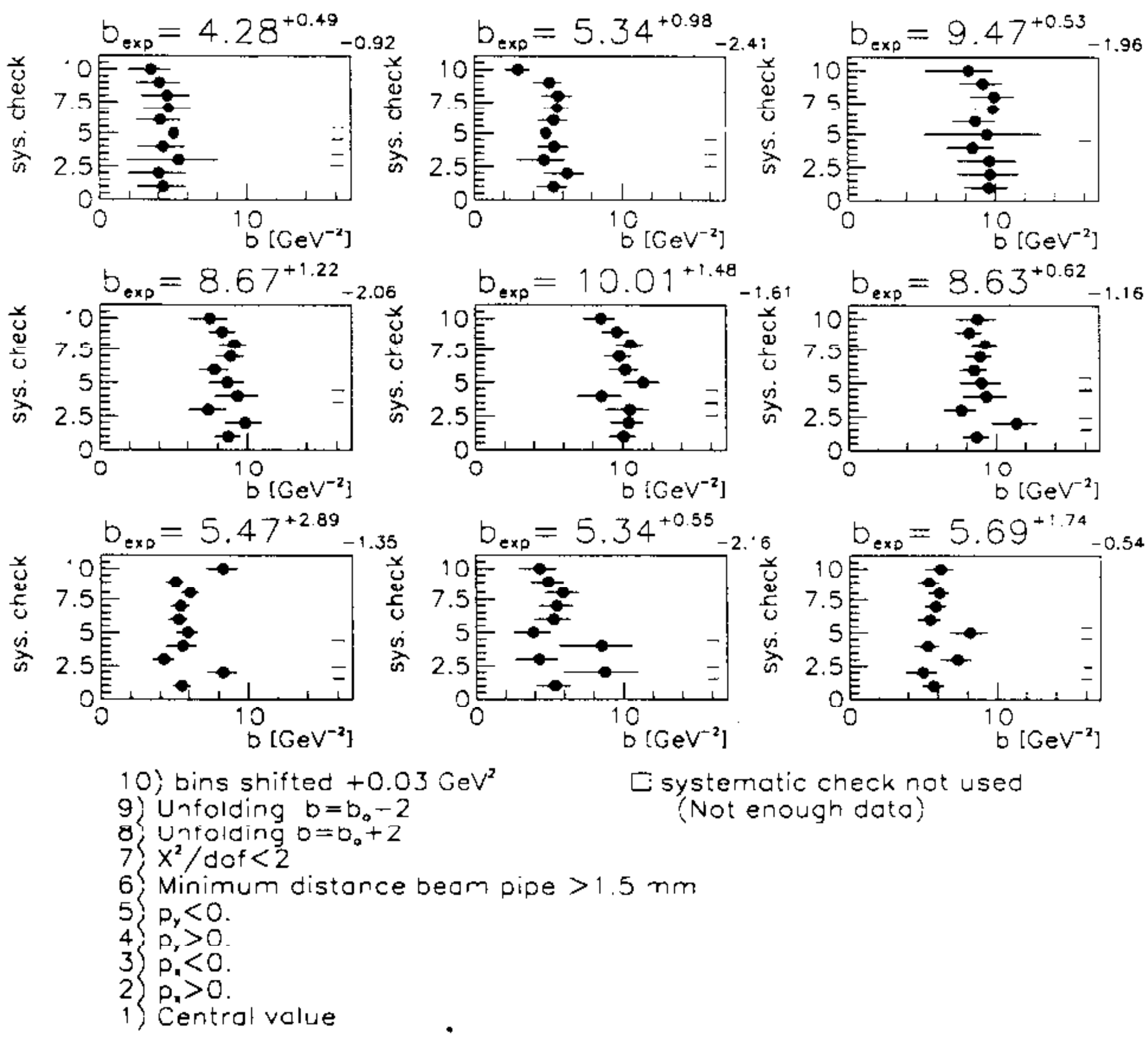
The value of the slope parameter 'b' shows a strong dependence from x_L



Slope parameter 'b' as a function of x_L

Systematic checks for $-t < 0.5 \mathrm{GeV}^2$

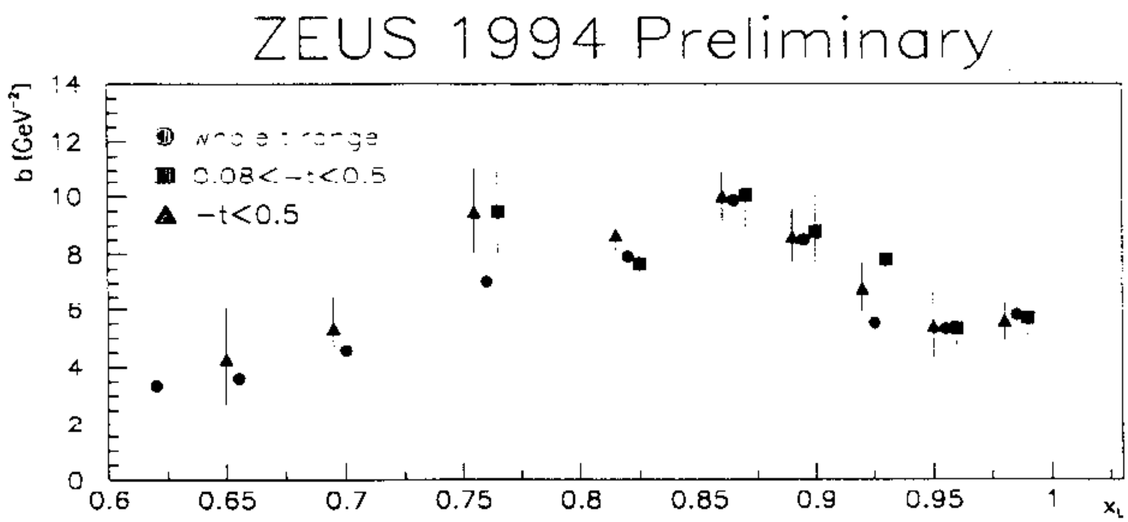
Systematic checks on the proton track quality and position, on the effect of changing the MC 'x_L' and '$b(x_L)$' distributions and on the binning used in the fit have been performed. The effect of different station positioning for each run on the final value of 'b' has been studied and the effect taken into account.

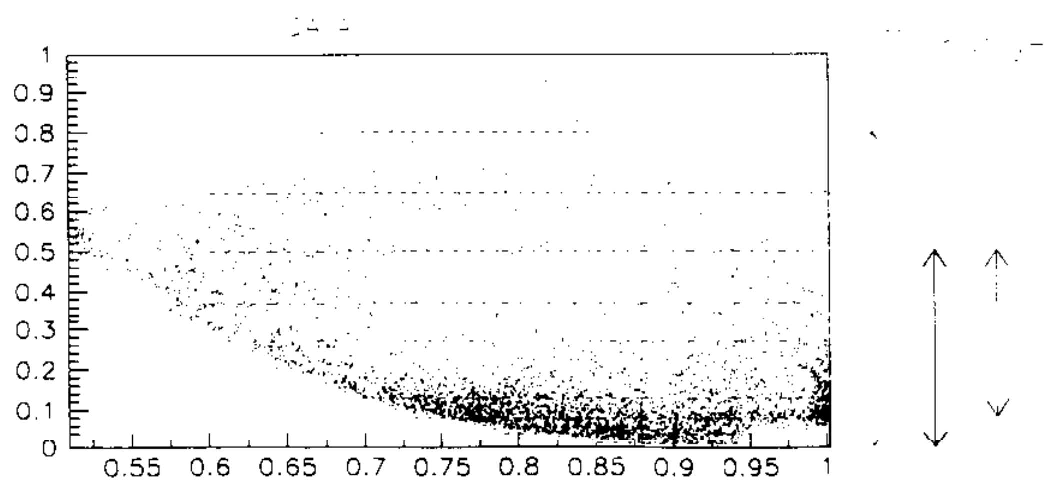


Slope parameter 'b' as a function of x_L

Influence of different t ranges

If the data are a superposition of different effects, then selecting different t ranges might change the result.
No large effects are seen apart from $0.91 < x_L < 0.94$ where excluding the lower t interval increases the values of 'b'.





Comparisons with MC models

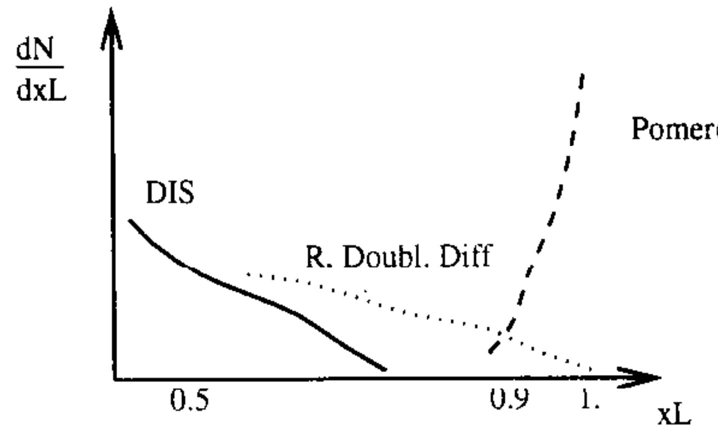
Models used to generate leading protons:

a) **Single diffraction:**
RAPGAP$_{\gamma p}$, EPSOFT$_{\gamma p}$

b) **Double diffraction:**
RAPGAP$_{\gamma p}$, EPSOFT$_{\gamma p}$

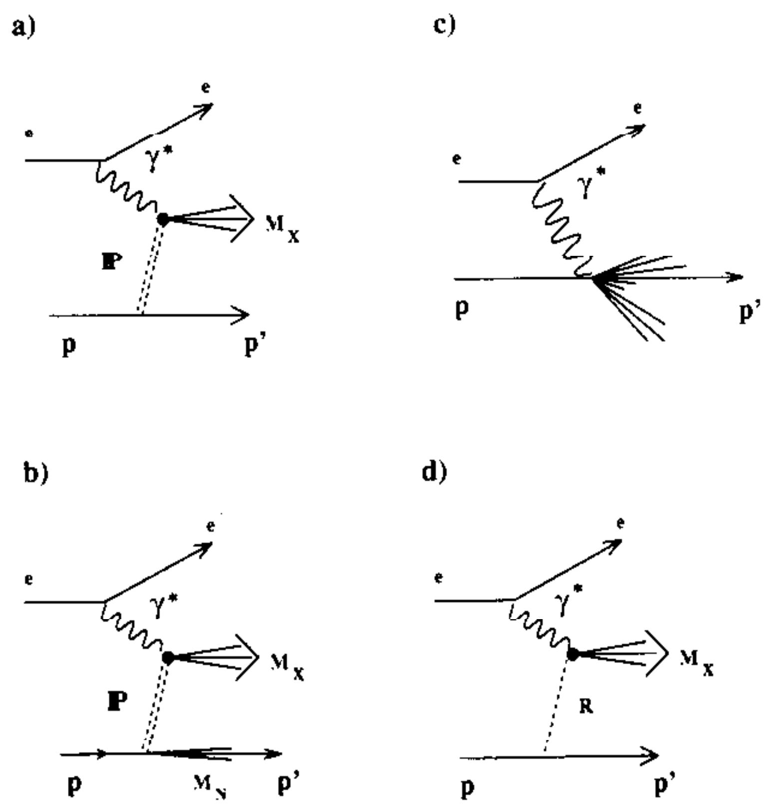
c) **DIS generators:**
ARIADNE, LEPTO6.5

d) **Reggeon exchange:**
RAPGAP π^+-exchange



Each of the above models is important in a given part of the x_L spectrum.

Only LEPTO6.5, using soft color interaction, is proposed as a model for the whole x_L spectrum

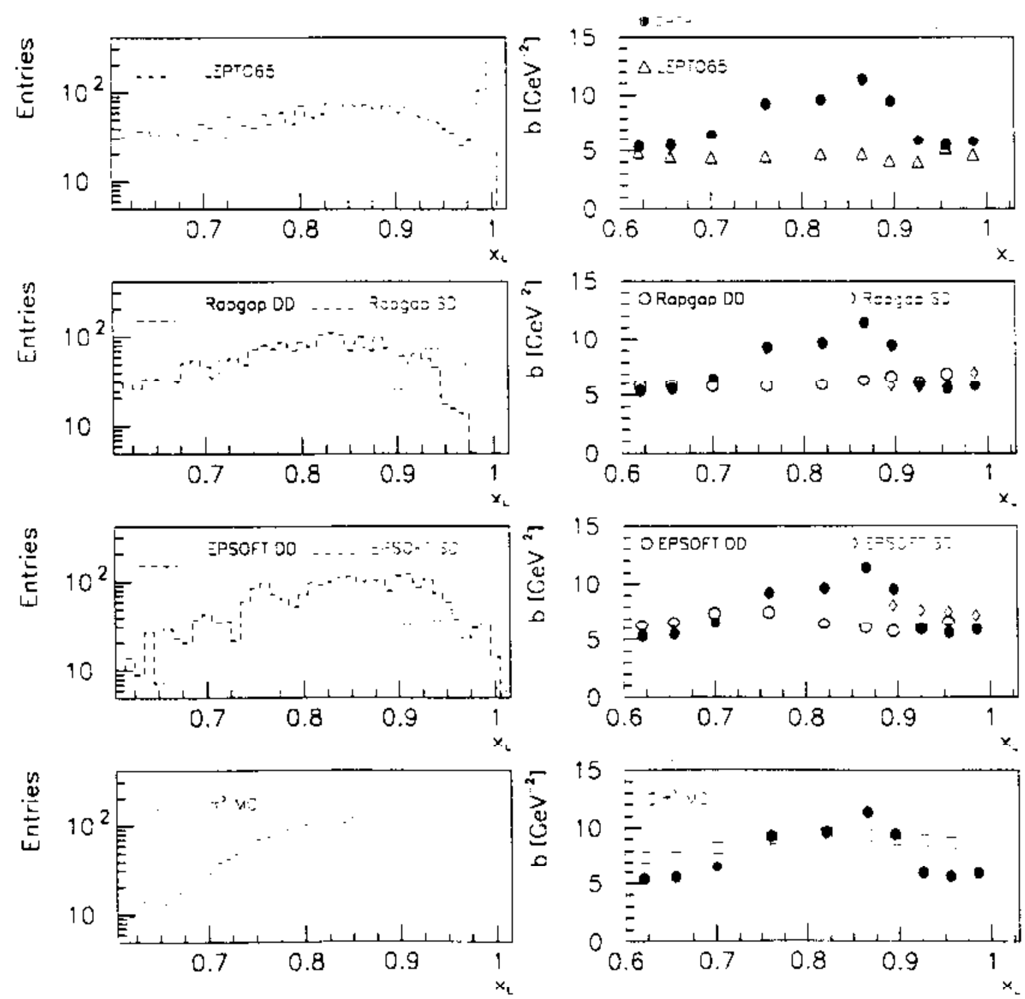


Comparisons with MC models

b values as a function of x_L:

Comparison between DATA and MC (done comparing $b_{p_\perp^2}$ measured over the whole $p_\perp^2$ range) shows that only the π^0-MC reproduces correctly the large values of 'b' at x_L= 0.8-0.9.

The value of 'b' measured for the events that pass GAPCUT in the interval $0.73 < x_L < 0.88$ is consistent with the value measured for all events in the same x_L interval.

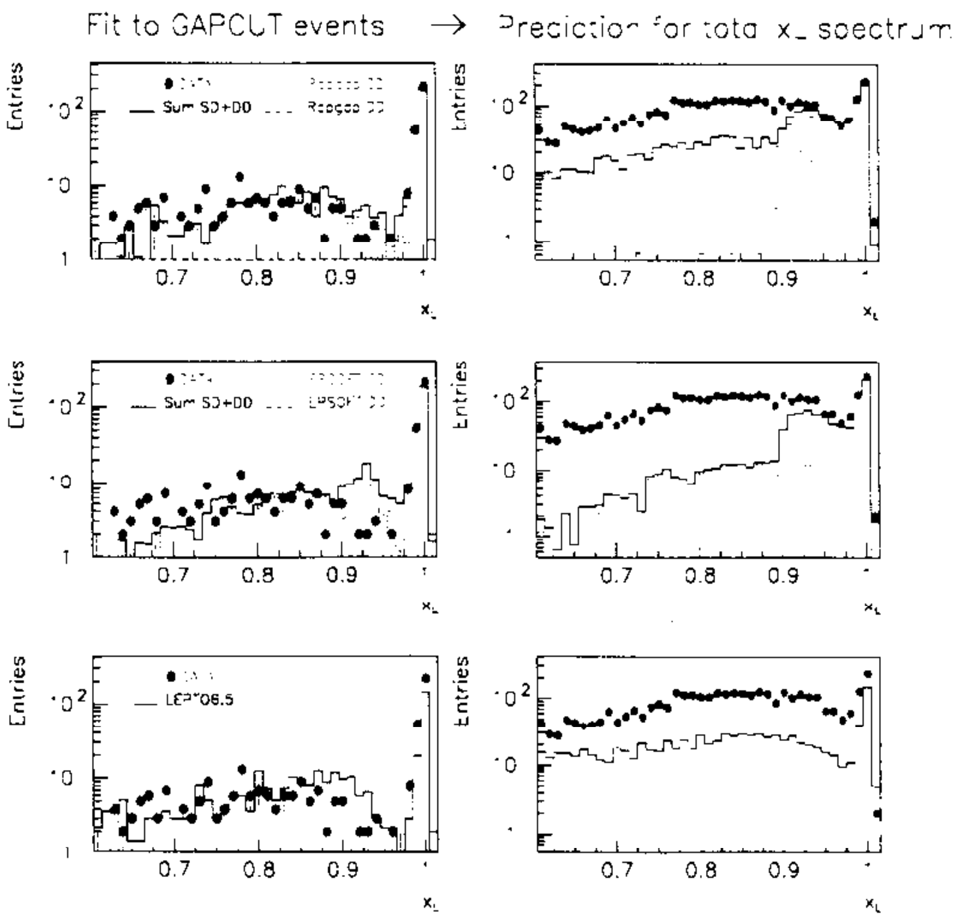


Comparisons with MC models

Rapidity gap events as a function of x_L:

→ **Fitting the data that pass GAPCUT using a combination of SINGLE + DOUBLE diffraction determines the fraction of events generated by "pomeron" exchange. Both fits using** RAPGAP **or** EPSOFT **show that the large majority of events below $x_L \sim$ 0.9 are not due to pomeron exchange. Note that there is a xl>0.9 cut at the generator level for SD events.**

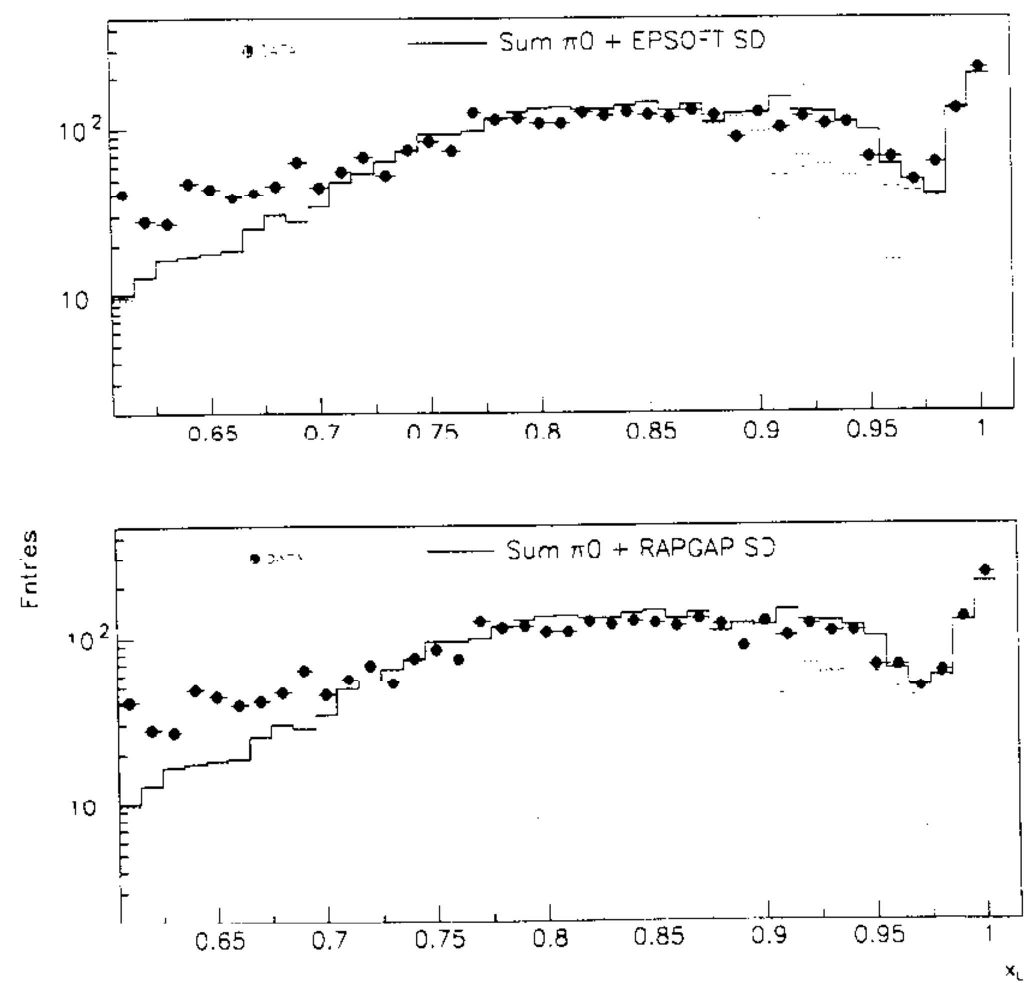
→ LEPTO6.5, **producing gaps via the soft color interaction mechanism, fails to reproduce the data producing too many events that pass GAPCUT**



Comparisons with MC models

π^0-MC fit to the total x_L spectrum:

A good fit to the x_L spectrum for $x_L > 0.7$ is obtained summing the π^0-MC with either RAPGAP or EPSOFT. This sum, however, does not reproduce the GAPCUT x_L spectrum at low x_L since too few events of the π^0-MC pass GAPCUT.



Conclusions

DIS events with a leading baryon show the same dependence on x, y, Q^2, W and track multiplicity as 'normal' DIS.

The majority of events with a leading proton with $0.6 < x_L < 0.9$ do not have a visible large pseudorapidity gap in the interval $0. < \eta < 4.2$ and therefore are not generated in double diffractive processes.

The value of the slope parameter 'b' shows a strong dependence from x_L.

The x_L spectra of leading proton production in DIS and photoproduction show the same general behavior.

Comparison with MC models of the value of $b(x_L)$ and of the x_L spectrum shows that neither SINGLE + DOUBLE diffraction or SINGLE + π^o-MC can explain all the features of the data.

LEPTO6.5 fails to reproduce both the value of $b(x_L)$ and the amount of events with a gap as a function of x_L.