# Leading Baryon Production at HERA

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*On behalf of H1 and ZEUS Collaborations*

*Château Royal de Blois*

*France*

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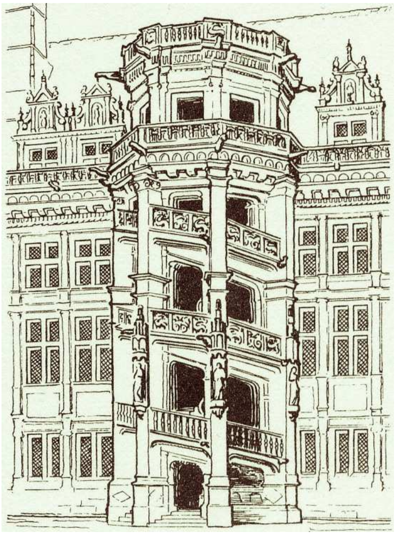


# What can we learn from Leading Baryons?

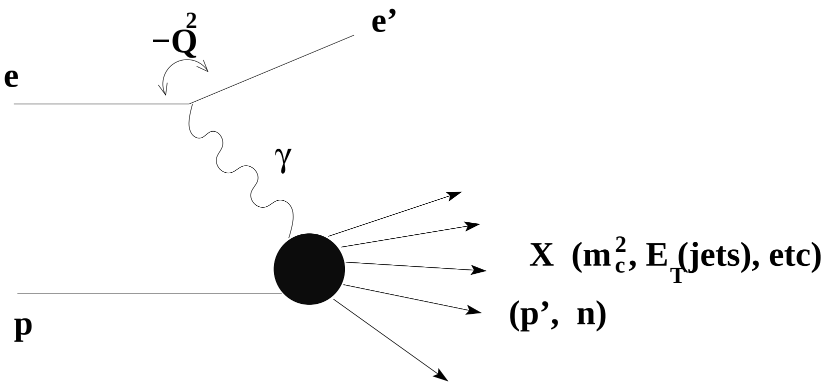
. *In a large fraction of events p,n carry a large fraction of the proton beam energy*

- neutrons: $0.2 < x_L = \frac{E_n}{E_p} < 1$ protons: $0.2 < x_L = \frac{E'_p}{E_p} < 0.97$

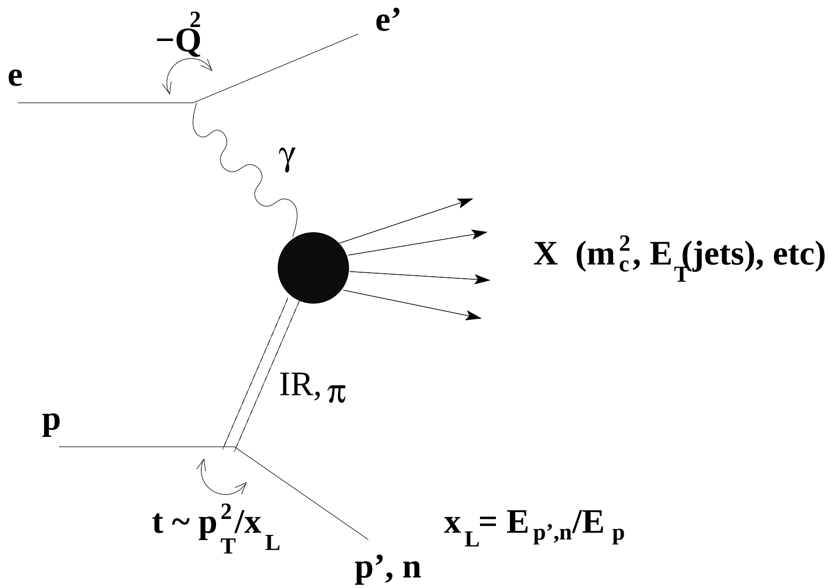
. *Rel. between soft and hard interaction: (two scale physics)*

- hard scale: e.g. $Q^2,\ m^2_{HQ},\ E_T^{jet}$
- soft scale: $p_T$ of the baryon

. *Tests of Particle Exchange Models:*




**standard fragmentation**

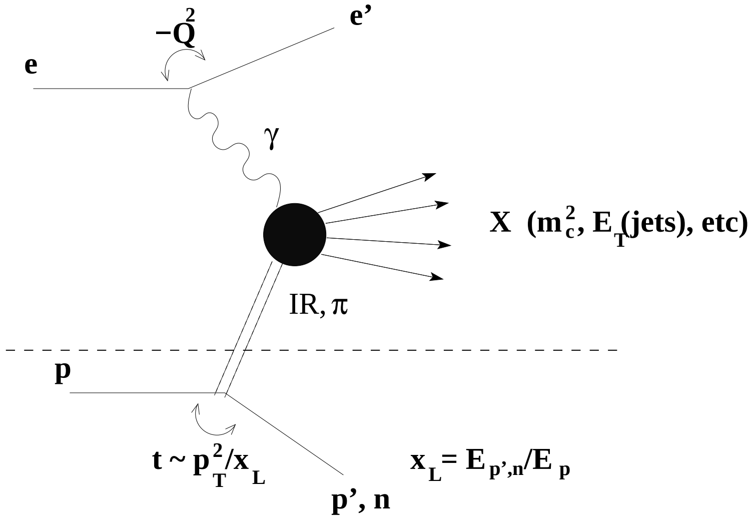



**particle exchange (dominant process)**

# *What can we learn from Leading Baryons?*

. *Probe structure function of the exchanged particle:*

- e.g. leading neutrons: $\sigma_{LN} = f(x_L, t) \times \hat{\sigma}^{\gamma\pi}_{hard}$
- specially important to region unaccessible to Drell-Yan *(gluons and sea)*



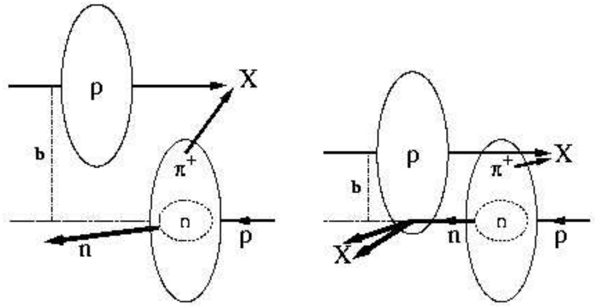

. *Vertex factorization:*

- In the dominant process: leading baryon production is independent of the photon vertex variables
- Many models predict factorization violation (absorption)

*Listing only a few...*

# *Factorization violation models*

**Model 1:** (for leading neutrons) *d'Alesio and Pirner, EPJ A7 (2000) 109*



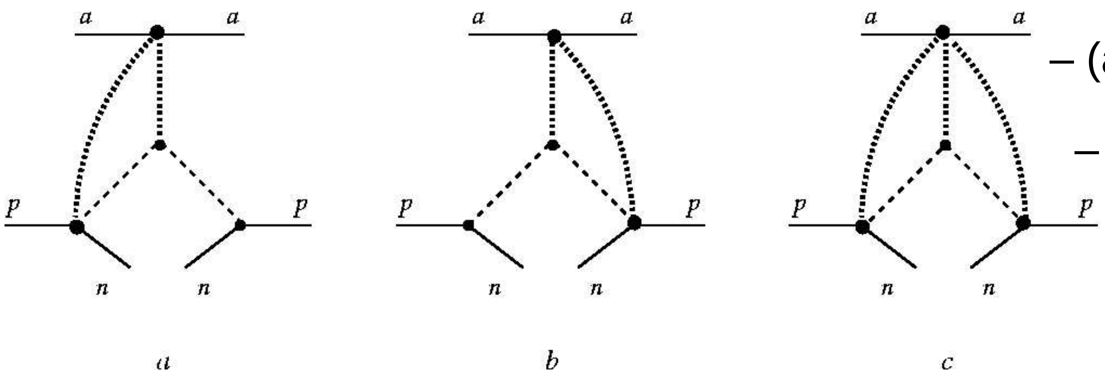

– substitute the proton by a photon for $ep$ collisions

– the larger the photon, fewer neutrons detected (more absorption in PHP than DIS)

– the smaller the $\pi n$ system, fewer neutrons detected

(more absorption in low $x_L$)

**Model 2:** (for leading neutrons) *Nikolaev, Speth and Zakharov, hep-ph/9708290*




– absorption from additional pomeron exchange

– (a)-(c) contribute to the dominant process

– absorption effects different for $ep$ and $pp$

– implies large uncertainties to pion *pdf* parametrizations

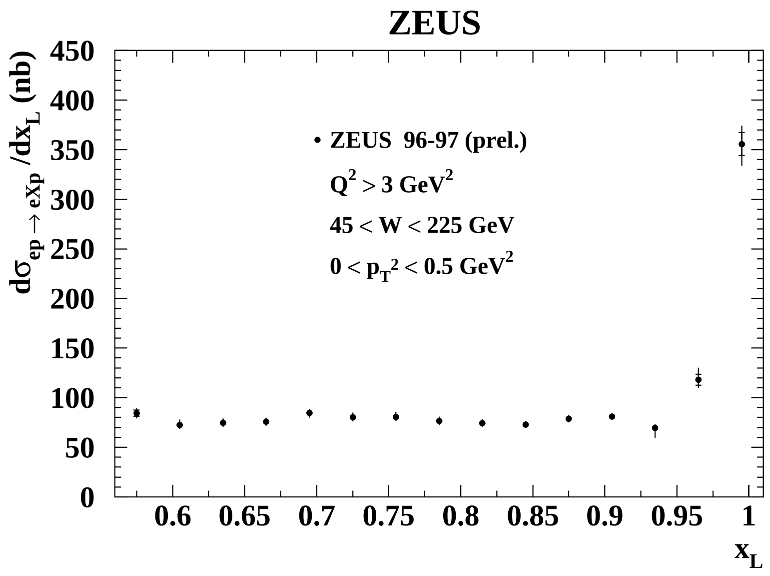
# *Leading Protons*

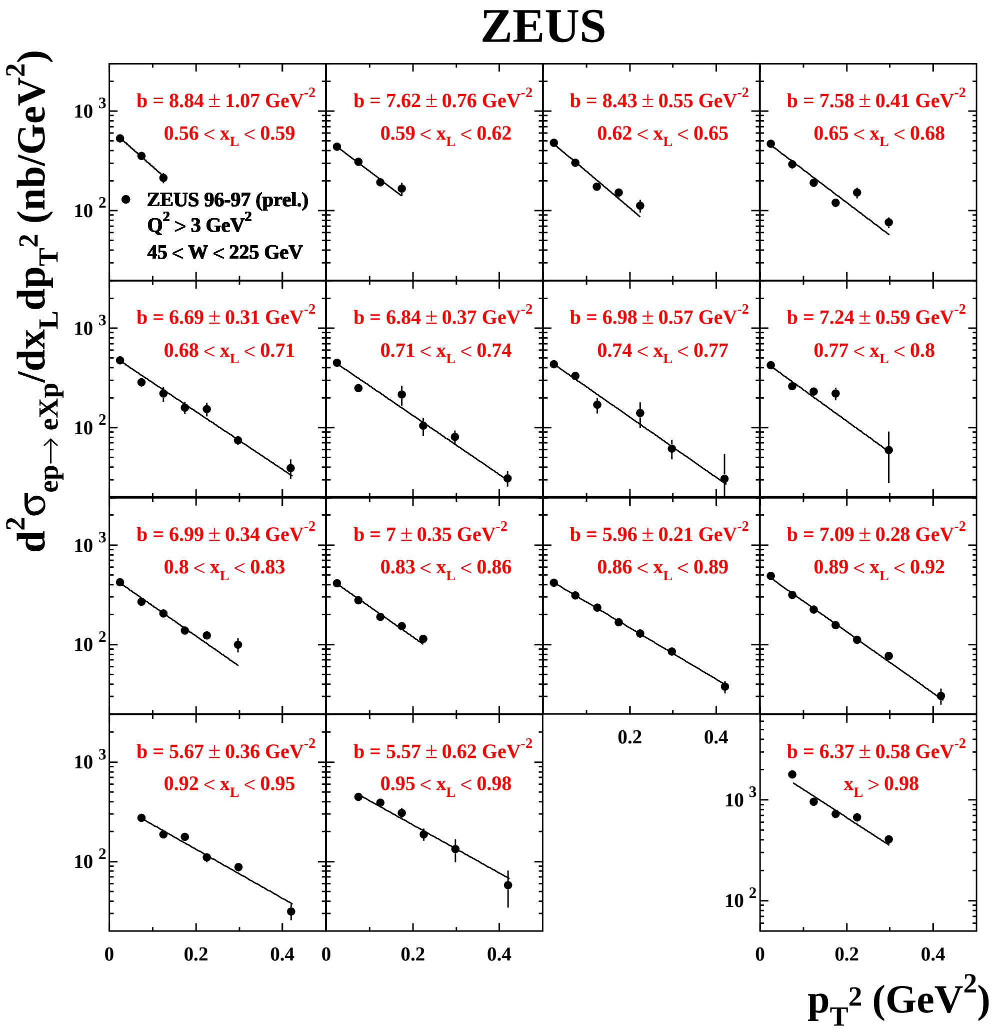
angular distribution →

energy distribution ↓

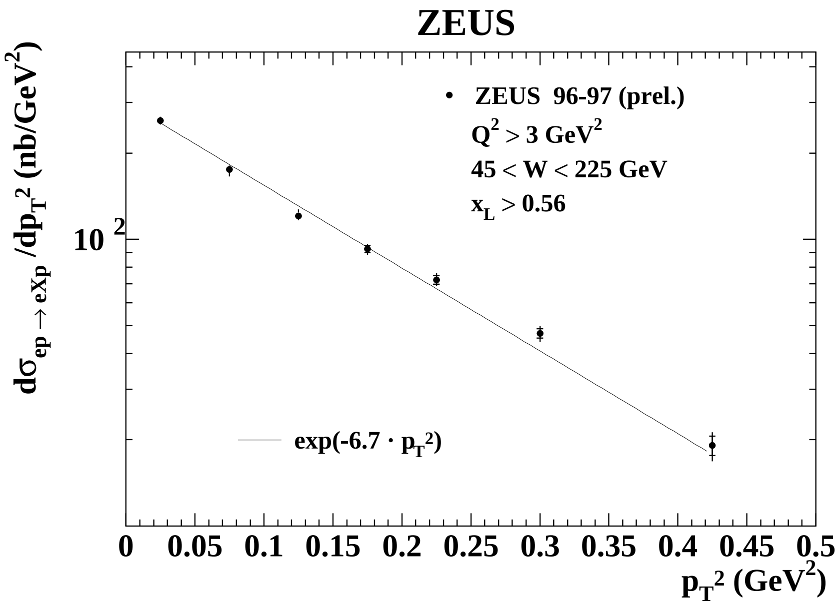
. Very precise data

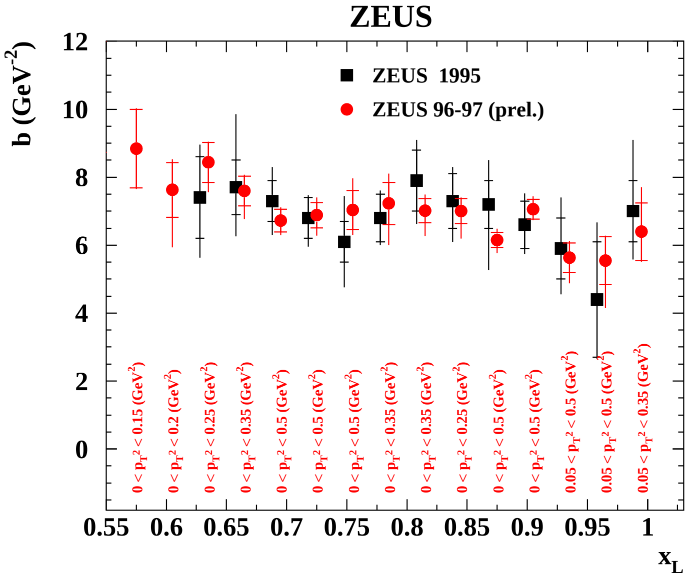
. Flat for $x_L < 0.95$



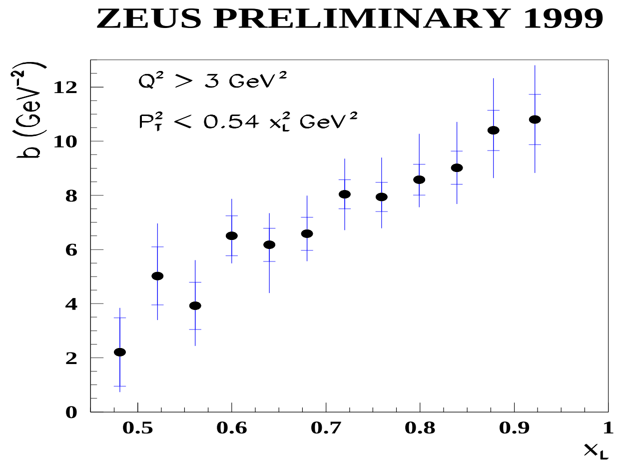
# $b-$slopes



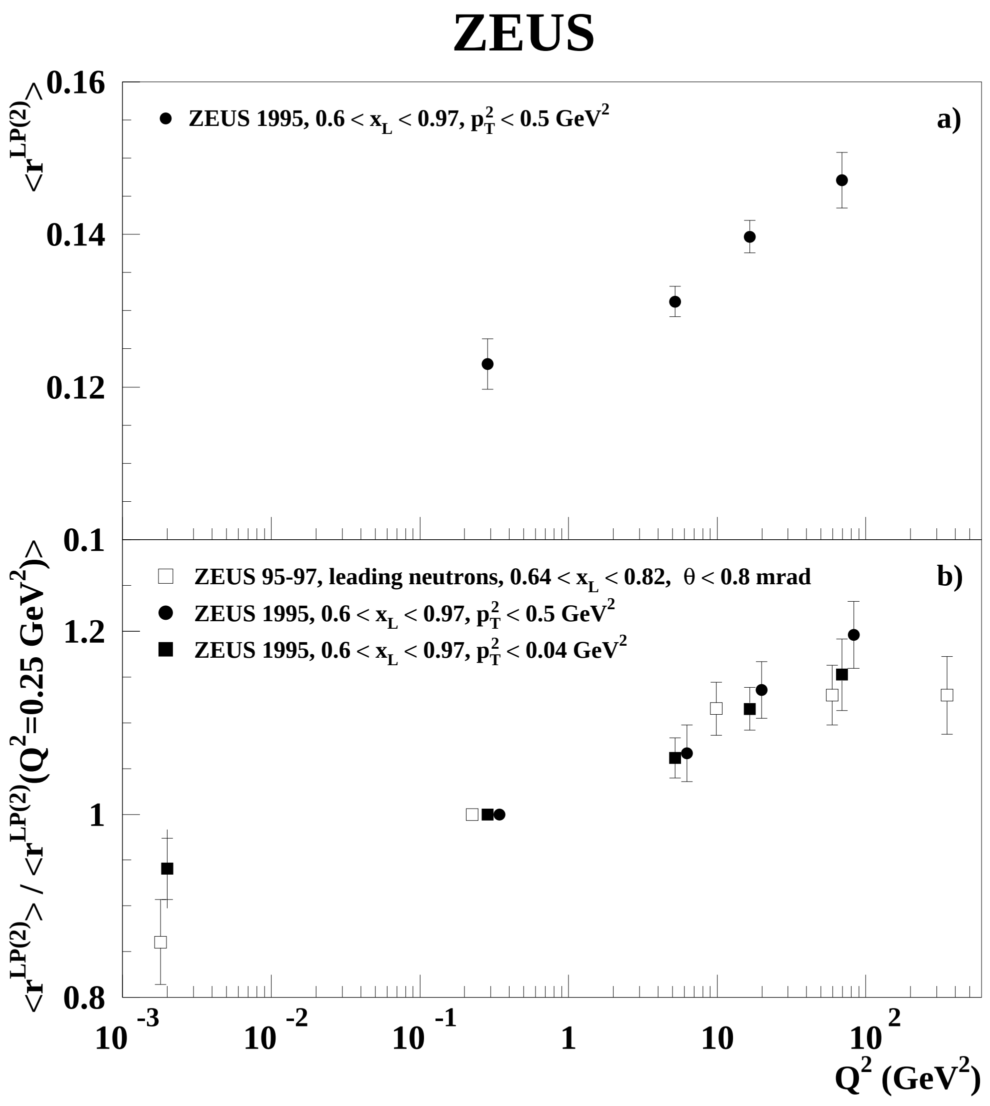

. Protons: slopes flat as a function of $x_L$

compare to Leading Neutrons $\longrightarrow$




. Steep rise for leading neutrons

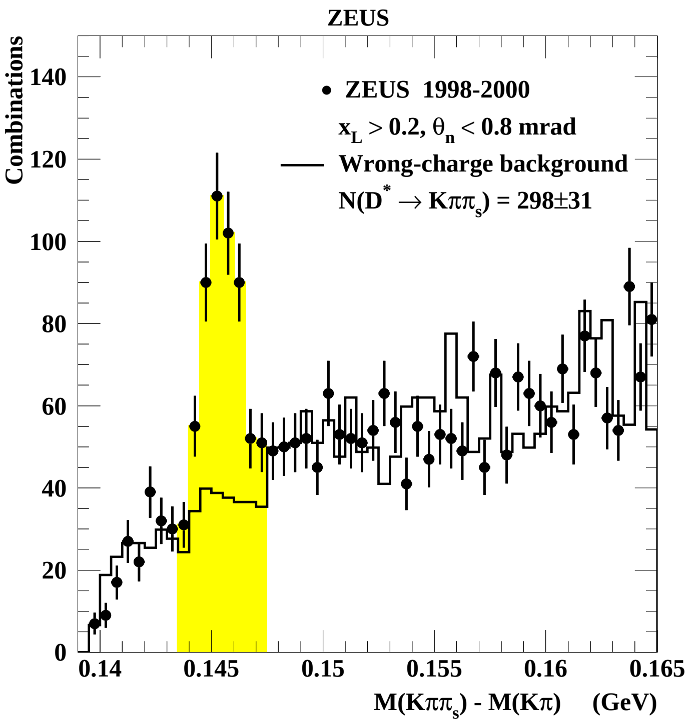
# $Q^2$ *dependence*

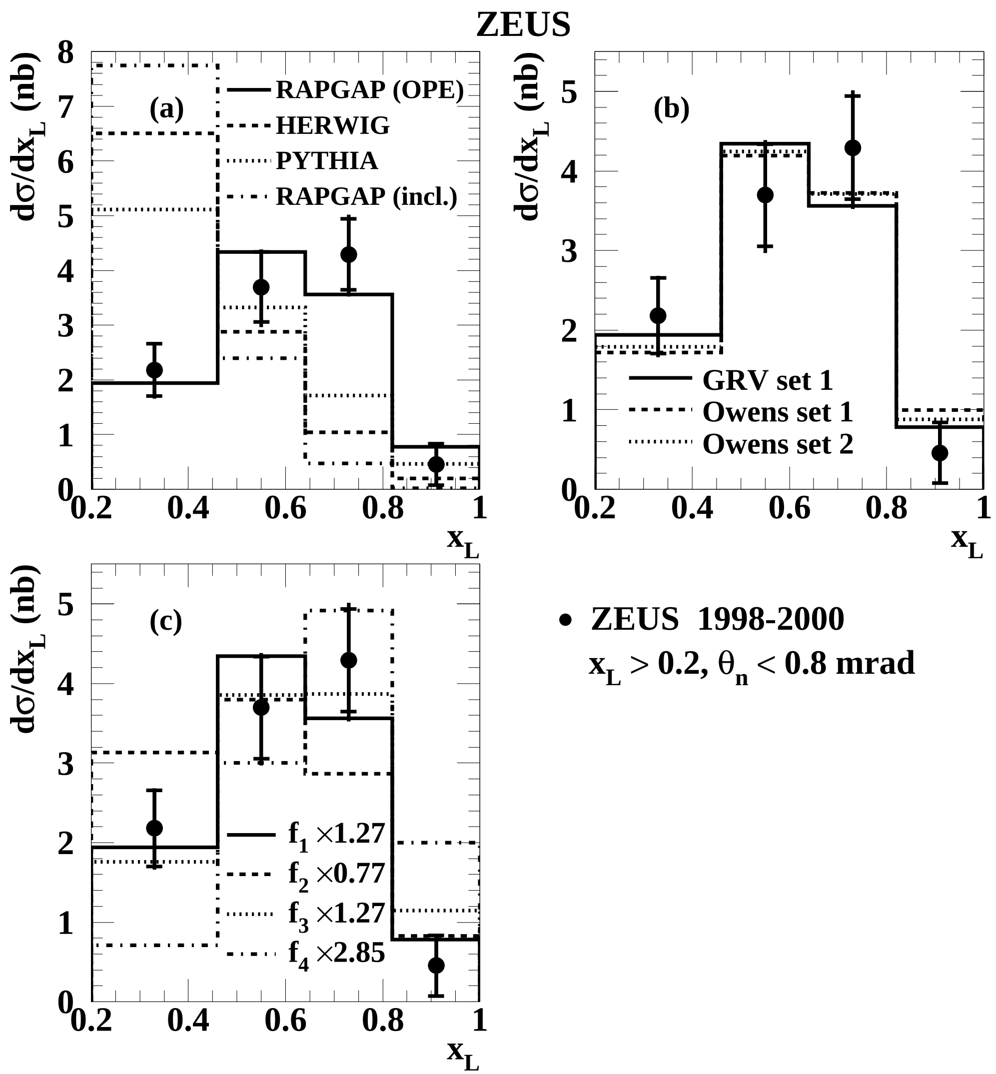



- Production rate decreasing with $Q^2$
- indication of absorption

# *Leading Neutrons: $D*$ photoproduction*

- O.P.E. needed to describe data
- large uncertainty on flux factors ($f_1$ to $f_4$)
- little sensitivity to pion *pdfs*



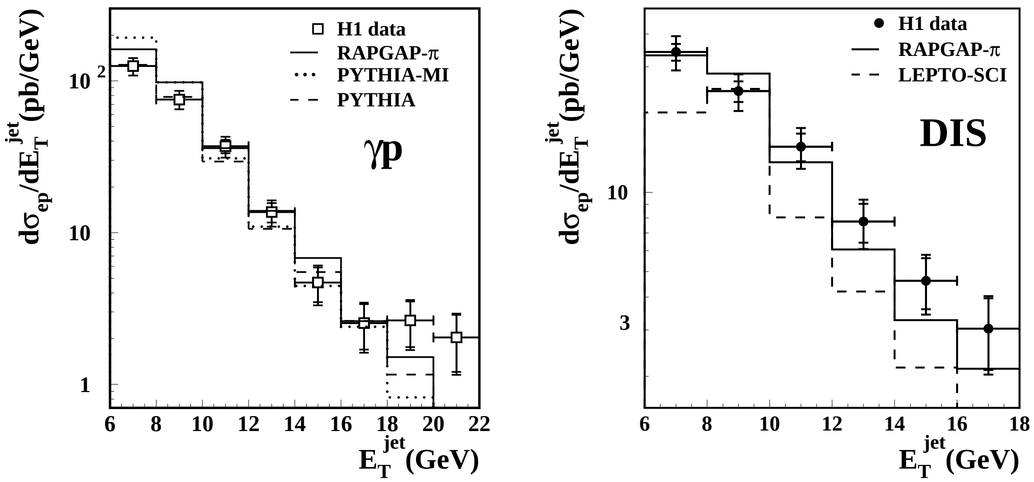



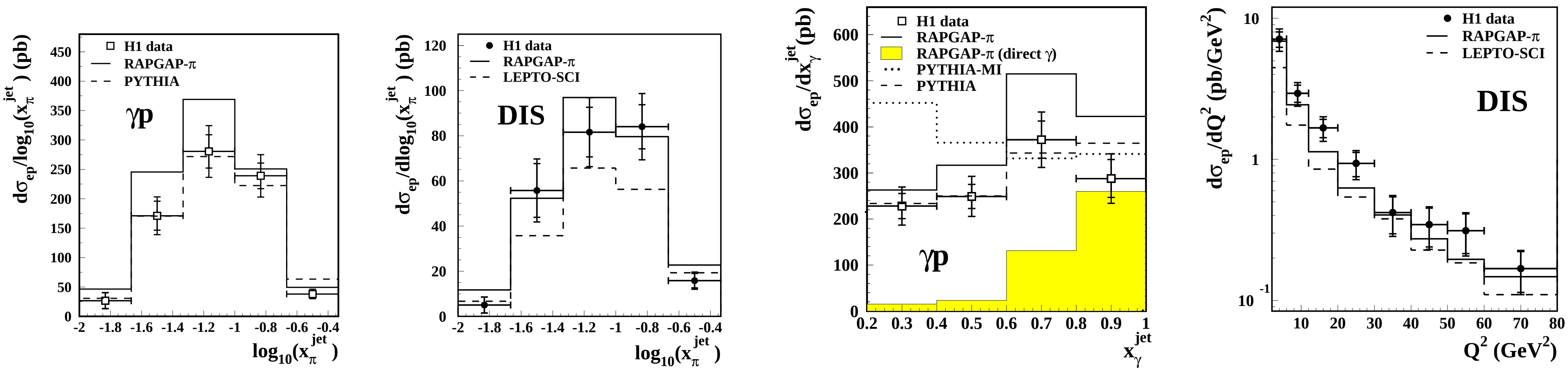
# *Leading Neutrons: dijets*

- O.P.E. needed to describe data

$$x_\pi^{jet} = \frac{\sum_{\text{jets}} E_T^{\text{jet}} e^{\eta^{\text{jet}}}}{2E_p(1-x_L)}$$

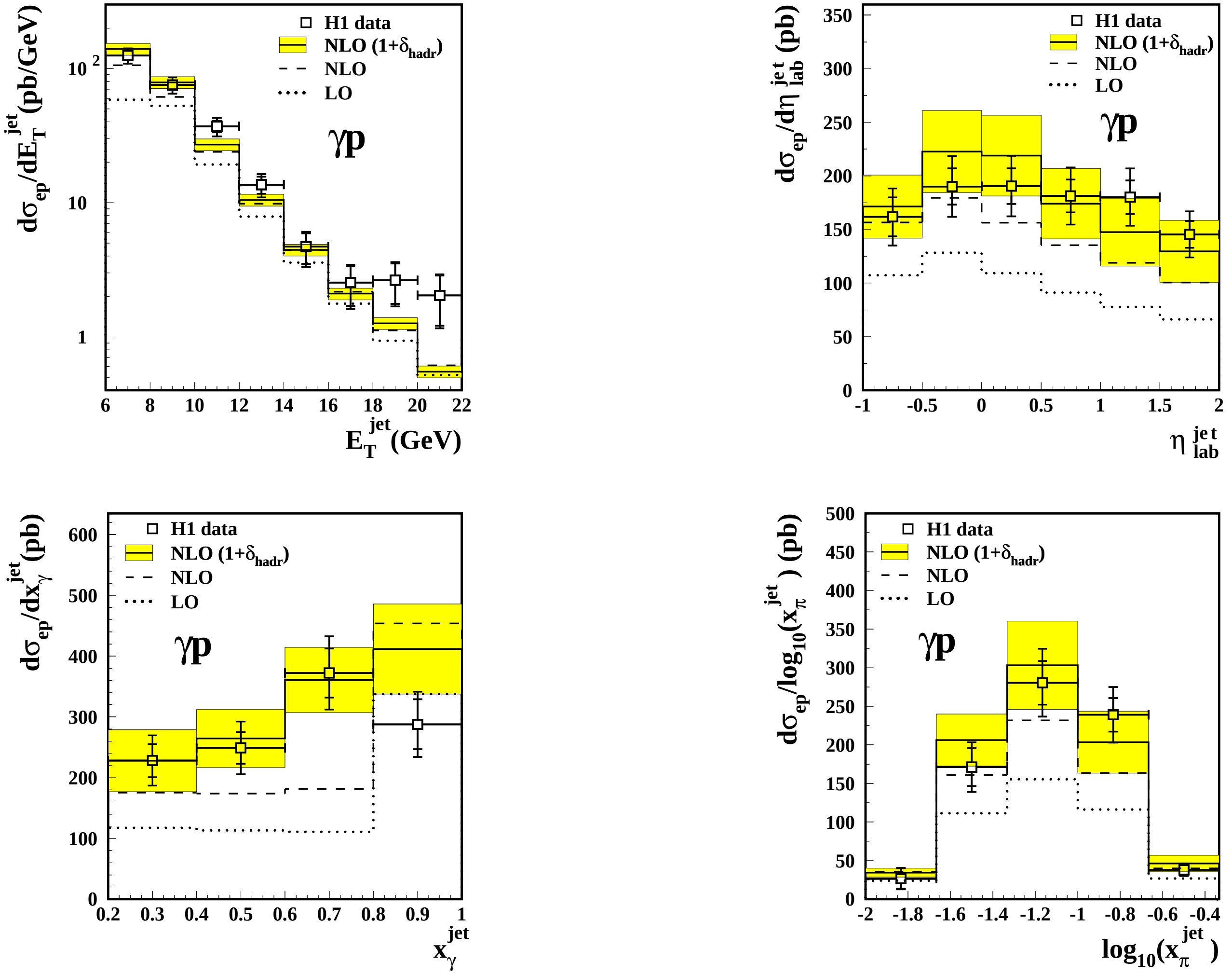
- not possible to discriminate *pdf*s



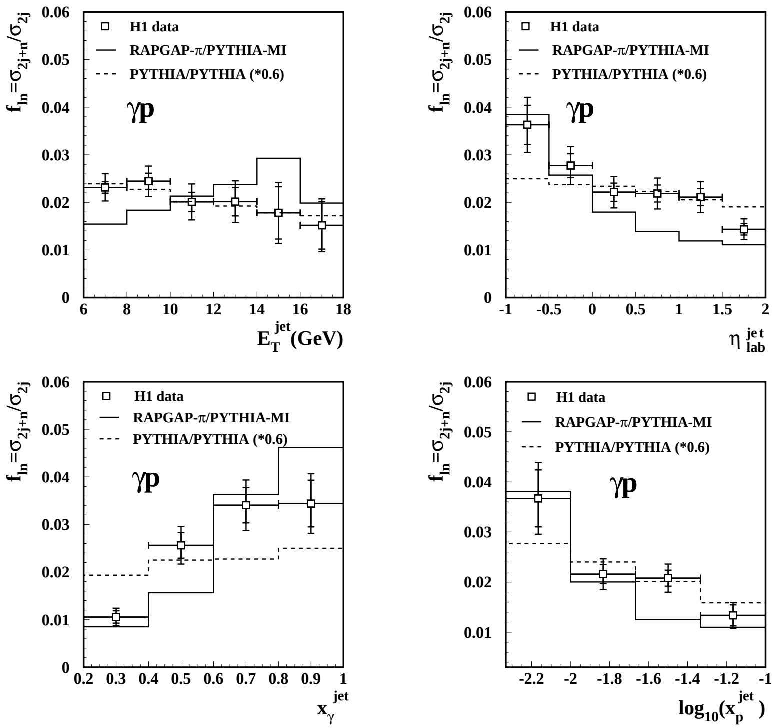
# Leading Neutrons: dijets

- NLO pQCD with O.P.E. *(Klasen,Kramer)* describe data well

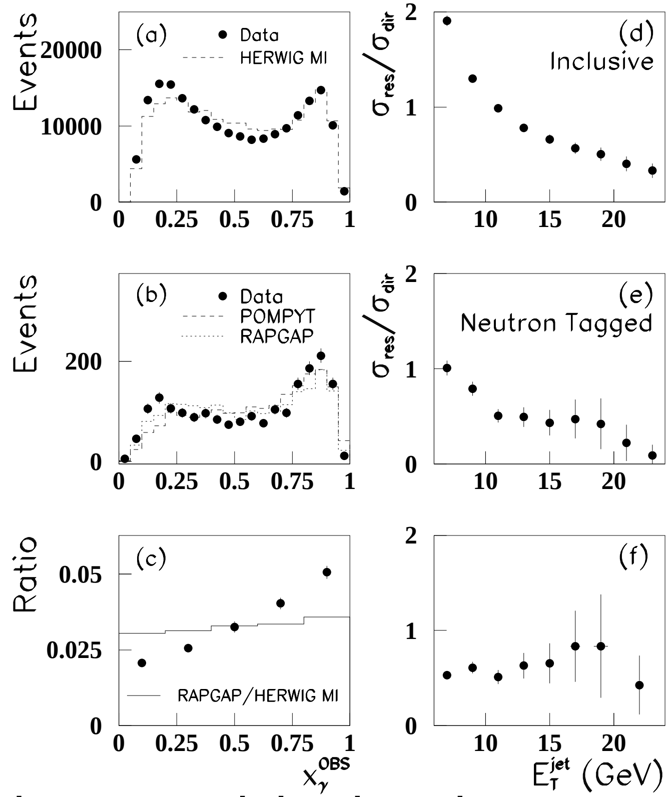


# *Leading Neutrons - ratios dijets+n/inclusive dijets*

## H1 dijets




## ZEUS 1995



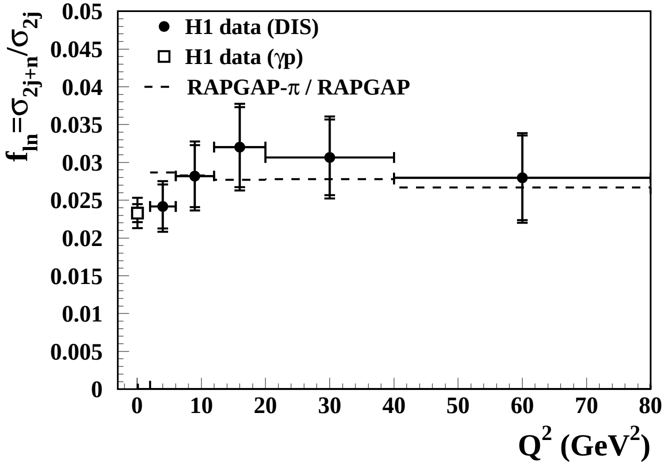

- Neutron production suppressed in resolved-photon enriched region
- Multiple interactions between $\gamma$ and $p$ remnants play a very important role in the inclusive dijets production

absorption ?? → must be disentangled in experiment

prediction from theory ??

# *Leading Neutrons: $Q^2$ dependence*

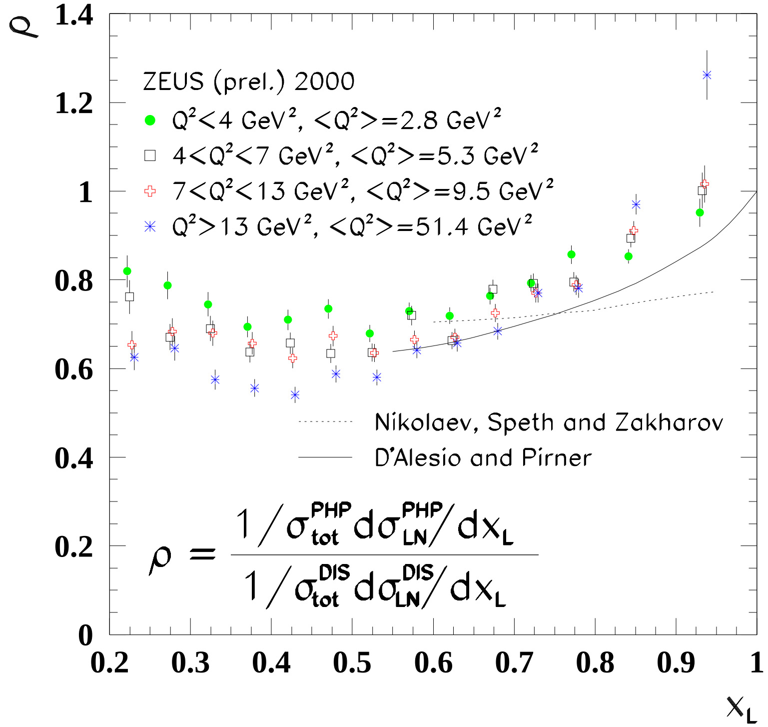
**H1 dijets**




Ratio dijets+n/inclusive dijets

No strong $Q^2$ dependence

**ZEUS**




Vertex factorization: $\rho = 1$

Indication of absorption for lower $x_L$, lower $Q^2$

Qualitative agreement with absorption models

# *Leading Neutrons*

**ZEUS**

charm PhP: $R_{LN}^{D*}(x_L > 0.49) = 6.55 \pm 0.76^{+0.35}_{-0.45}$ %

Inclusive DIS: $R_{LN}^{DIS}(x_L > 0.49) = 5.8 \pm 0.3$ %

Dijet PhP: $R_{LN}^{jj}(x_L > 0.49) = 4.8 \pm 0.4$ %

Inclusive PhP: $R_{LN}^{PhP}(x_L > 0.49) = 4.3 \pm 0.3$ %

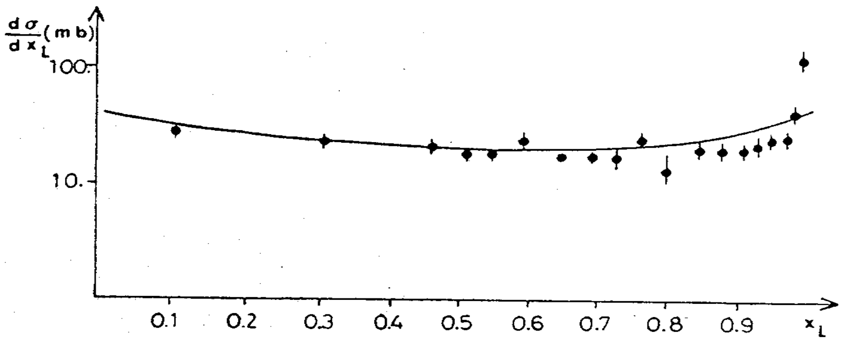
$$\boxed{R_{LN}^{PhP} < R_{LN}^{jj} < R_{LN}^{D*} \approx R_{LN}^{DIS}}$$

Neutrons production suppressed for resolved-photon enriched processes

# 20 years ago...

- 5 -

particle effect. From low energies up to ISR the leading proton spectrum has shown no detectable energy dependence. It is essentially flat in $x_L \equiv E_{proton}/E_{incident}$, apart from the increase in the $x_L \to 1$ limit (diffraction dissociation), and corresponds to a mean value $\langle x_L \rangle \simeq 1/2$, i.e., on the average the leading proton retains half of the incoming energy (see Fig.3)




(Leading proton spectrum at ISR, |9|)

Fig. 3

So far, at the Collider, there are no data on the leading proton (leading anti-proton) spectrum. From cosmic rays there seems to exist an indication of a softening of the spectrum[10]. From our previous discussion on contamination of soft physics by QCD hard physics, with multiple parton interactions and large $P_T$ jets, it is indeed rather natural to expect a softening of the spectrum.

I describe next a very simple geometrical model to evaluate the leading particle spectrum[11]. In a recent paper by Chou, Yang and Yen[12] it was shown, from an analysis of pseudo-rapidity distributions at the SPS pp Collider, that the available energy $E_A$ for particle production in central region is a monotonous decreasing function of the impact parameter b. This result is very suggestive. From our Fig.1 one easily accepts that at $b \to 0$, central collision, the hadrons are mutually stopped and most of their incoming kinetic energy is converted into available energy

from *J. Dias de Deus*

*“Workshop on Elastic and Diffractive Scattering”*

Blois, June 3-6, 1985

“So far, at the Collider, there are no data on the leading proton (leading anti-proton) spectrum...”

# *Summary and outlook*

- 20 years have passed and Leading Baryon production remains a topic of great interest in High-Energy Physics
- HERA has contributed a lot to the understanding of Leading Baryon production, providing a large ammunt of precise data
- Results from Leading Protons:
  - no $x_L$ dependence in cross sections and $b-$slopes
  - rates rising with $Q^2$
- Results from Leading Neutrons:
  - $b-$slopes show steep rise as a function of $x_L$
  - all results compatible with one-pion-exchange Model
  - data still not precise enough to offer improvement to pion *pdf*s
  - absorption effects observed as a function of $x_L,\ Q^2$
- Leading Baryon production suppressed in less 'point-like' processes
  $\rightarrow$ **is it another indication of rescattering?**

## *Summary and outlook*

- Several issues are still to be understood:
  - Leading Neutrons: pion flux factor models must be constrained
  - The role of multiple-interactions / absorption must be understood
- More precise HERA data with leading baryons coming soon
- Input from theorists / phenomenologists is crucial

*END*