Leading baryon production and inclusive diffraction at HERA with the ZEUS experiment

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Highlights:

- ✓ Leading proton production models;
- ✓ Vertex factorization and violation: absorption/re-scattering models;
- ✓ Pion structure function.

- ✓ New results on inclusive diffraction from very low to high Q^2;
- ✓ Model comparisons.

List of new results discussed

Leading baryons

- ✓ ICHEP02 paper 833, LP w/ LPS, PHP-BPC-DIS, “Leading proton production in e^+p collisions at HERA”, to be submitted to Nucl. Phys. B;
- ✓ ZEUS Coll., LN PHP-BPC-DIS, DESY-02-39 (hep-ex/0205076), accepted by Nucl. Phys. B;
- ✓ ICHEP02 paper 824, LN PHP + DIS ,“Properties of events containing leading neutrons in DIS and PHP at HERA”.

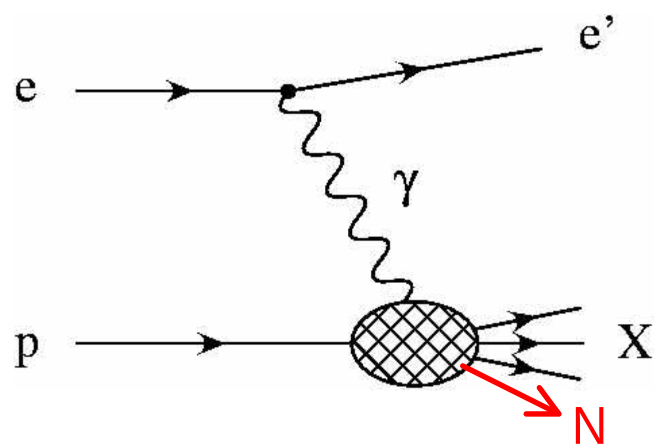
diffraction

- ✓ ICHEP02 paper 821, M_X method DIS, (Q^2 2-80 GeV^2), “Deep inelastic diffractive scattering with the ZEUS Forward Plug Calorimeter”;
- ✓ ICHEP02 paper 822, LPS BPC, (Q^2 0.03-0.6 GeV^2), “The diffractive cross section at small Q^2 at HERA”;
- ✓ ICHEP02 paper 823, LPS DIS, “get the title”;

Introduction

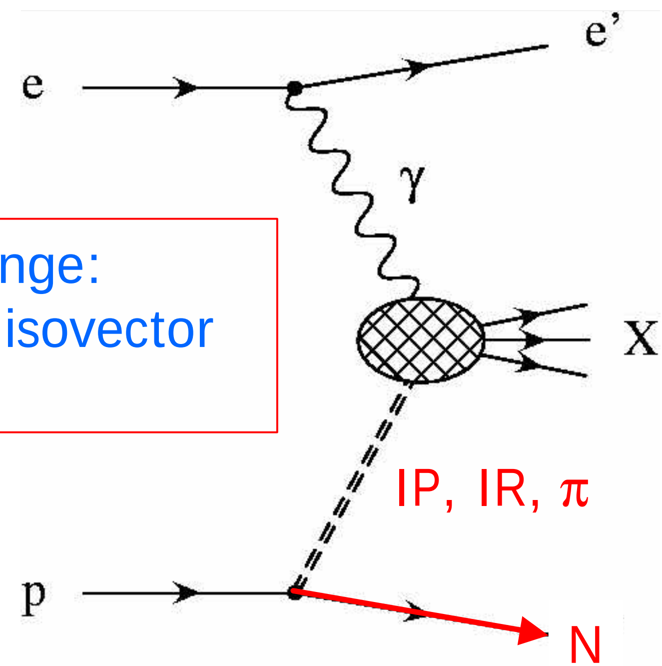
Leading baryon production at small t in hadronic interactions ⇒ soft process.
Conserving baryon number:

In standard fragmentation:
final state N from p remnant



In particle exchange models:
baryon from exchange of virtual
Pomeron, Reggeon (e.g. ρ,ω,f_2), π.

Exchange:
p: isoscalar, isovector
n: isovector.

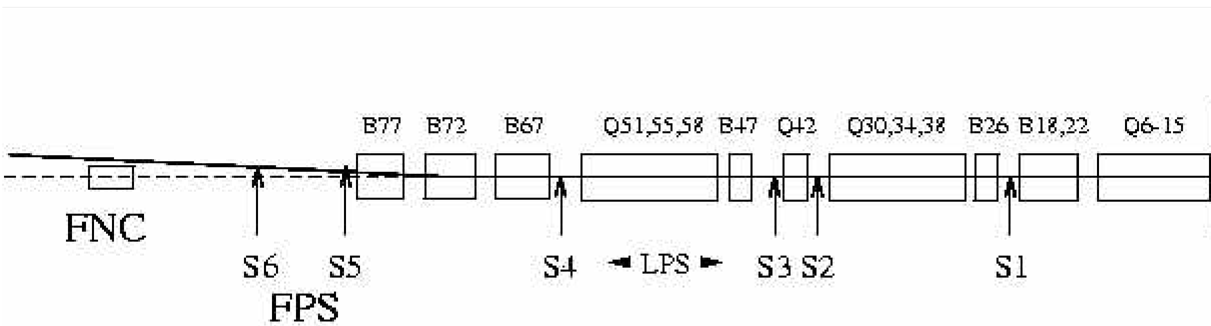


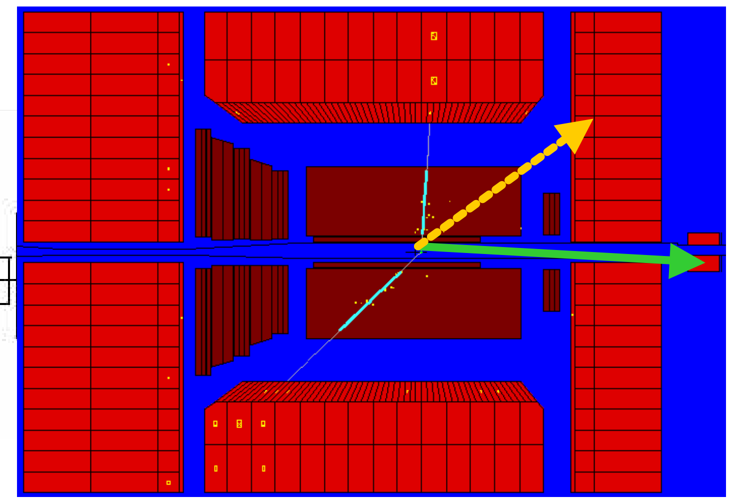
$(x_L = E_{p,n}/E_{beam},\ p_t^2)$

ZEUS forward detectors

DIS sample: positron in CAL ($Q^2 > 3$ GeV^2)

Leading Proton Spectrometer (LPS):
6 stations at z=24-90 m (last three used)
Acceptance limited by magnet apertures to $x_L > 0.6$ and $p_t^2 < 0.5$ GeV^2





Forward Neutron Calorimeter (FNC):
z=106-107 m, on zero-degree line
Acceptance limited by magnet apertures to $\theta_n < 0.8$ mrad

PHP sample: positron in LUMI ($Q^2 < 0.02$ GeV^2)

BPC sample: positron in BPC ($Q^2 \sim 0.1$-0.6 GeV^2)

BPC = Beam Pipe Calorimeter

Pion structure function, F_2^{π}

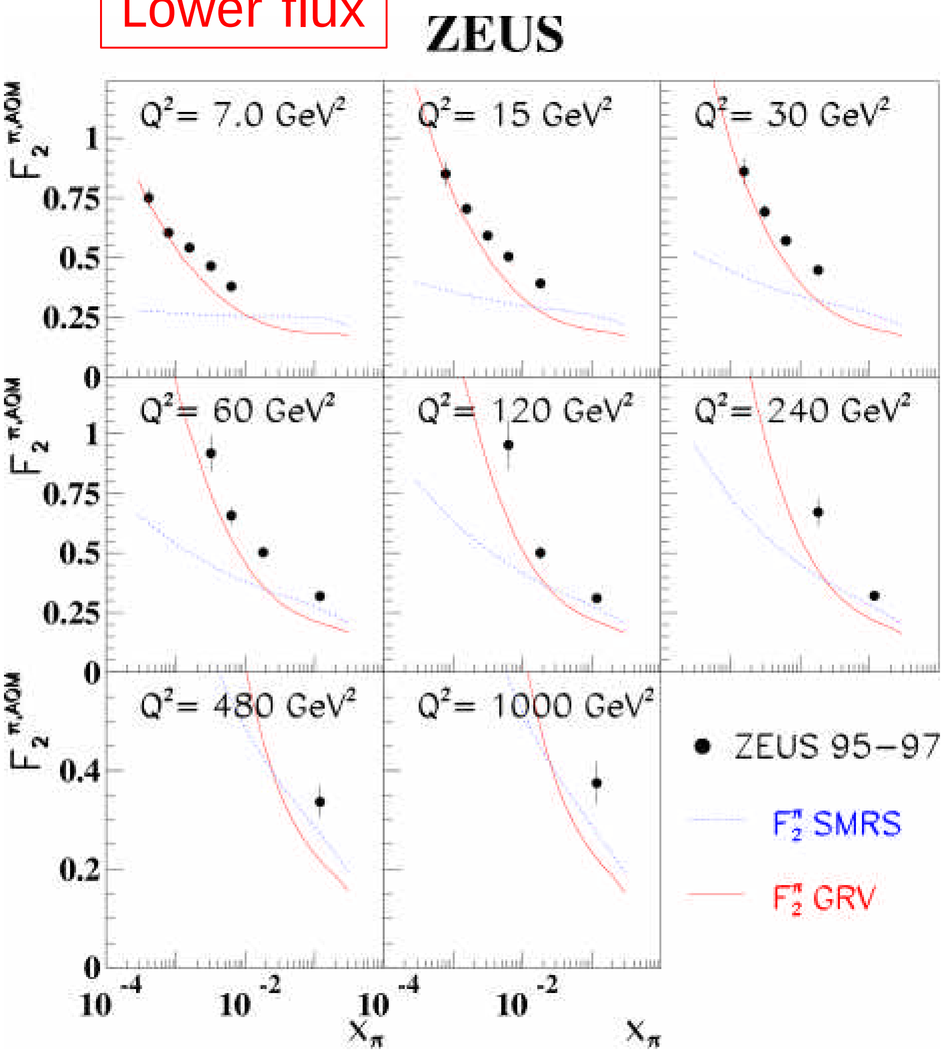
- WHERE: in the region where factorization is ~ valid: high Q^2 and high x_L and OPE describes the spectra.
- HOW: as the cross section, the structure function factorizes:

$$F_2^{LN}(x_{Bj}, Q^2; x_L, t) = f_{\pi/p}(x_L,t) \times F_2^{\pi}(x_{Bj} / (1 - x_L), Q^2)$$

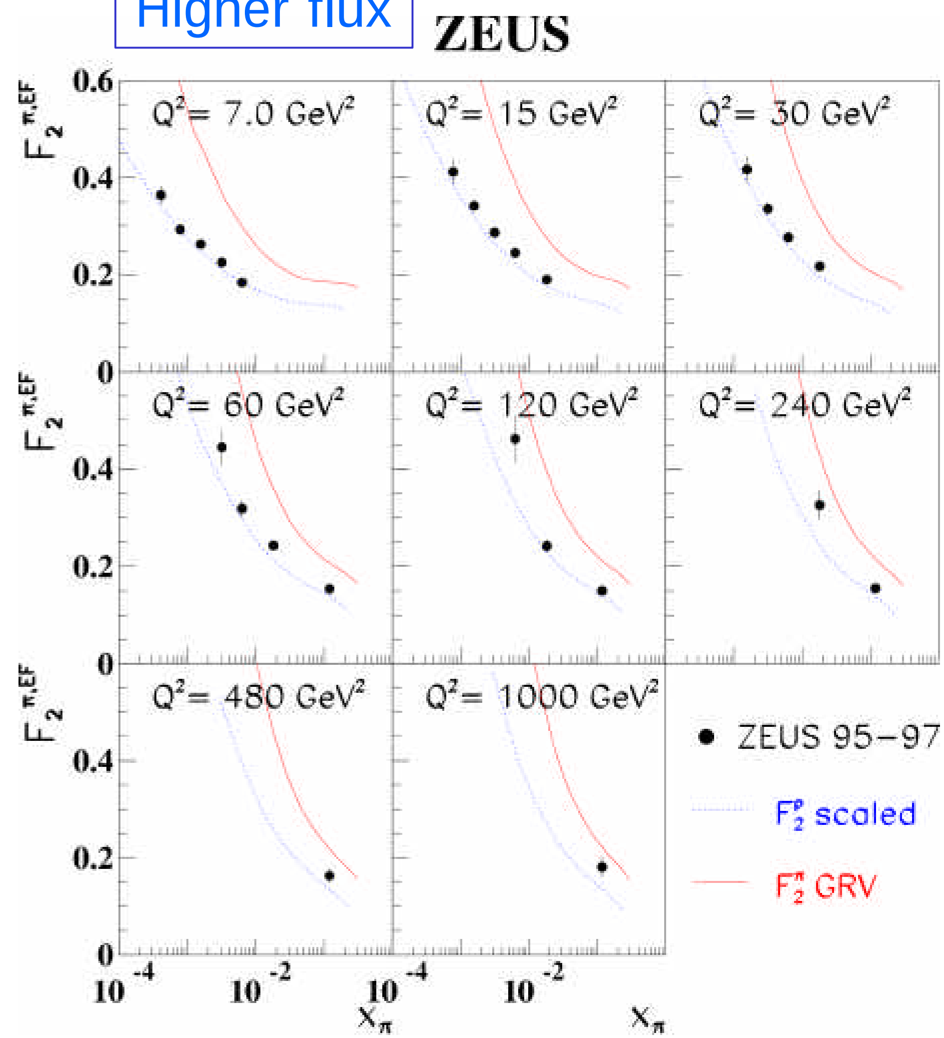
  - Use measured F_2^{LN}, $f_{\pi/p}$ from literature, then extract F_2^{π}
  - Use the x_L region where the background is smallest ($x_L = 0.73$)
- In the literature, at $x_L = 0.73$, flux value varies by a factor ~ 2
- Use extremes of flux
- Compare to parametrization of F_2^{π} extracted from pp data (low Q^2, high x_{Bj} fixed target data)

Pion structure function , F_2^{π}

Lower flux



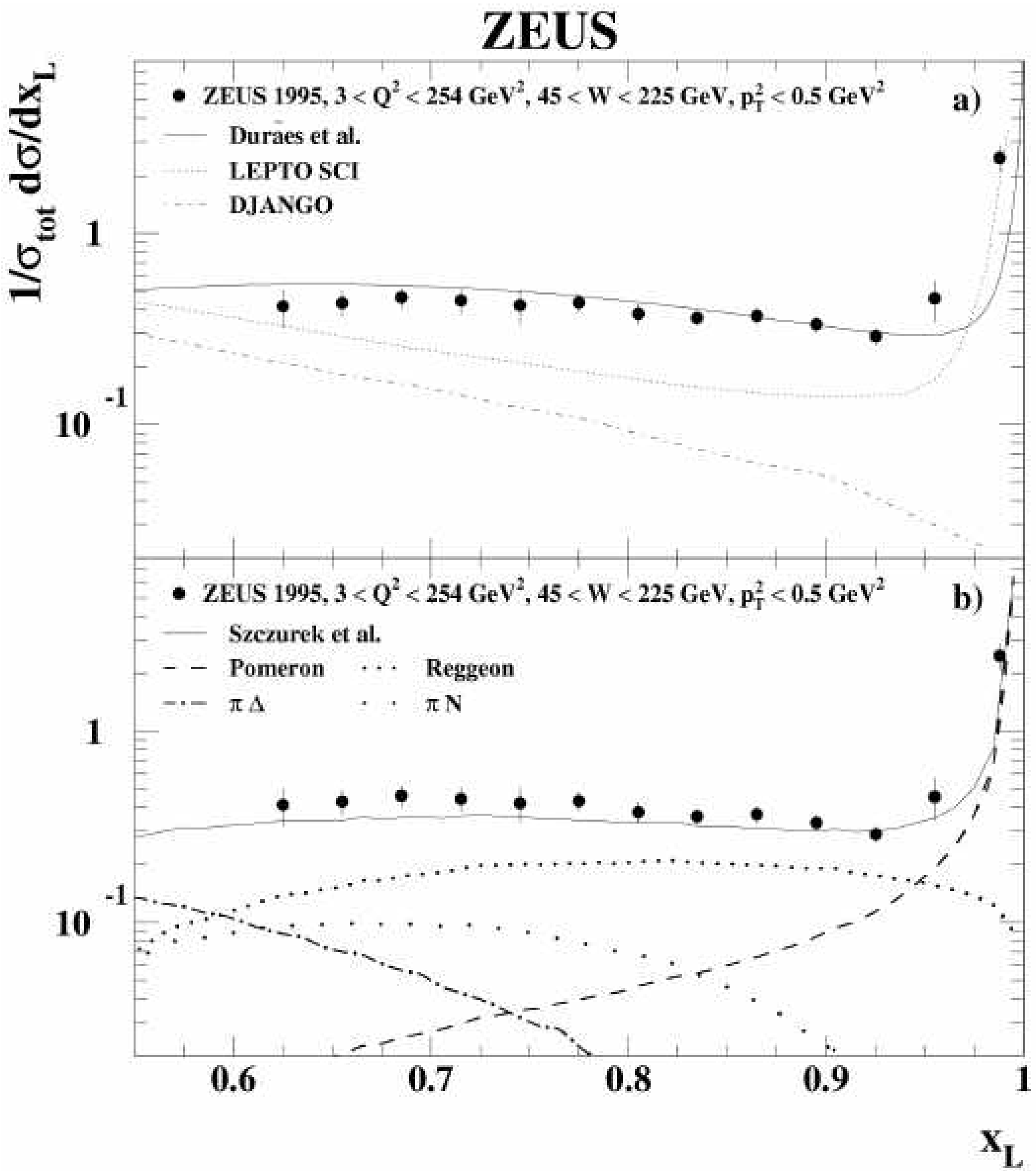
Higher flux



Can discriminate between parametrizations at high Q^2, low x

F_2^{π} approx. $\propto F_2^{p}$

Energy spectra



Shape and data normalization is compared to:

✓ standard fragmentation models → do not describe data;

✓ QCD inspired model, the Gluon-Iteracting model of Durães et al. gives a better description;

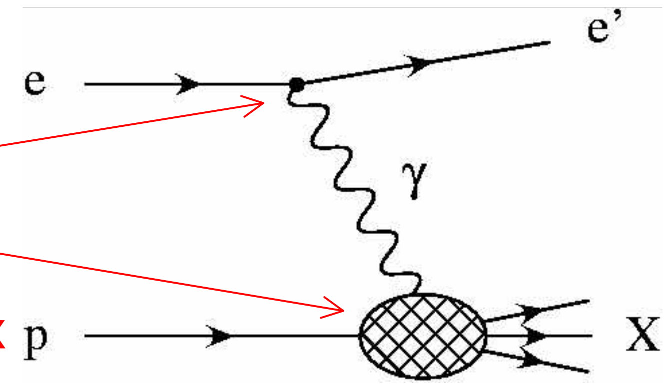
✓ exchange models, need multiple processes (Pomeron, Reggeon, π° and π–Δ) to describe the data.

Vertex factorization

Under the factorization hypothesis,

$\sigma(ep \rightarrow eNX) \propto G_{p,p'} \times G_{e,e'}$

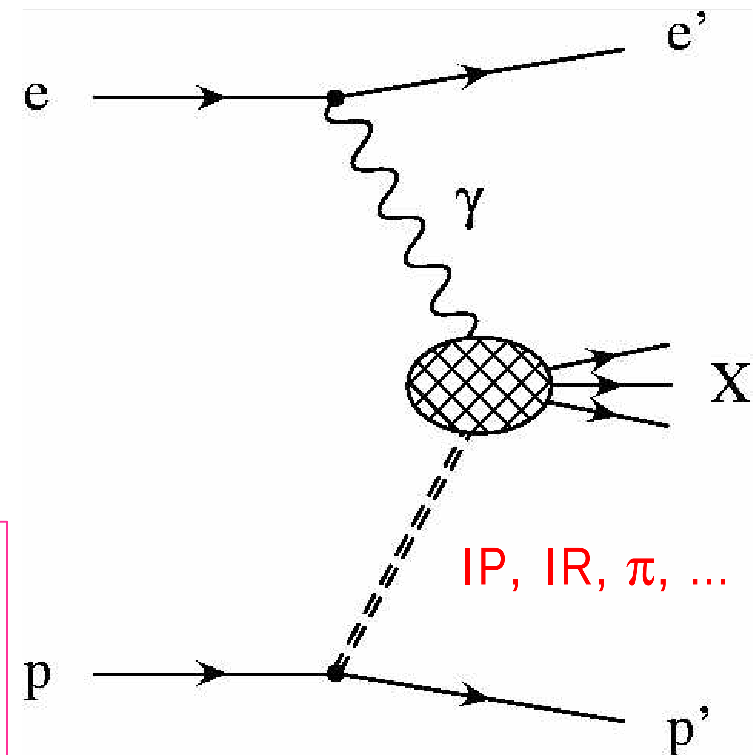
i.e lepton vertex ~ independent of baryon vertex



Direct implication of exchange models → the *ep* cross section factorizes, e.g. for π exchange,

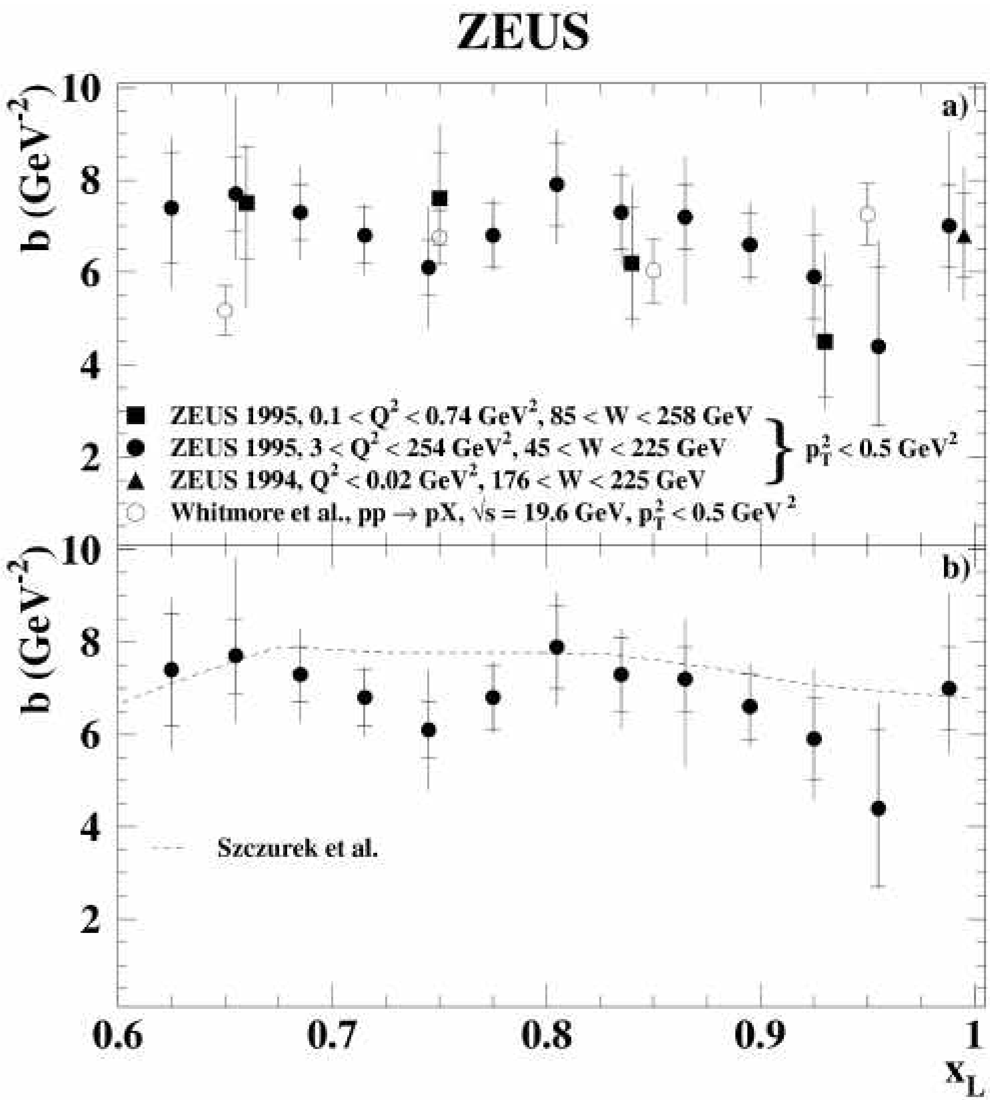
$\sigma(ep \rightarrow eNX) = f_{IP/p}(x_L,t) \times \sigma(eIR \rightarrow eX)$

IR flux in p



⇒ Cross section dependence on baryon variables (x_L and p_t^2) independent of those at the lepton vertex

dN/dp_t^2 for protons, b slopes



p_t^2 distributions measured up to 0.5 GeV^2 and fit to A exp ($-b\, p_t^2$).

b related to int. radius ($b = R^2/4$).

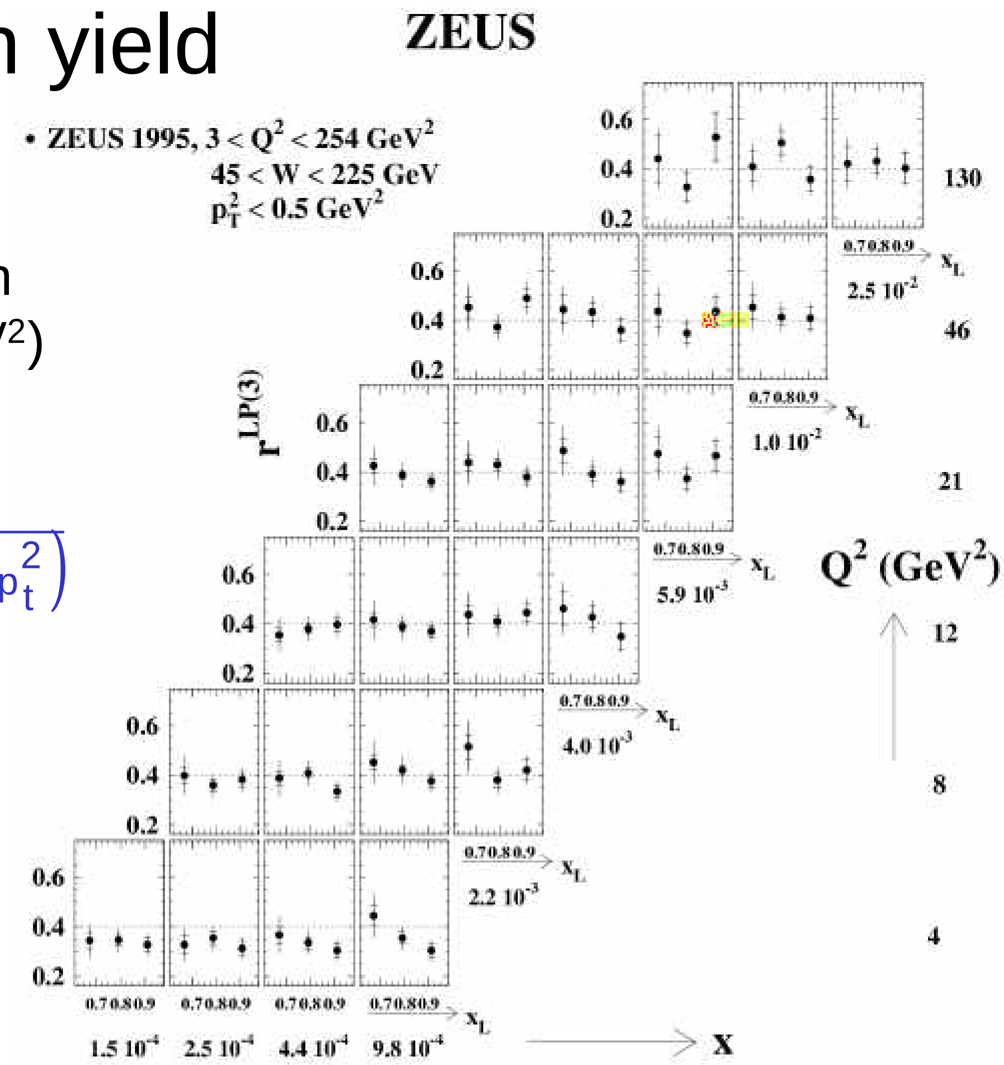
No dependence on x_L or Q^2 is apparent.

Data compatible w/ pp data at $\sqrt{s}$ = 19.6 GeV.

→ Vertex factorization.

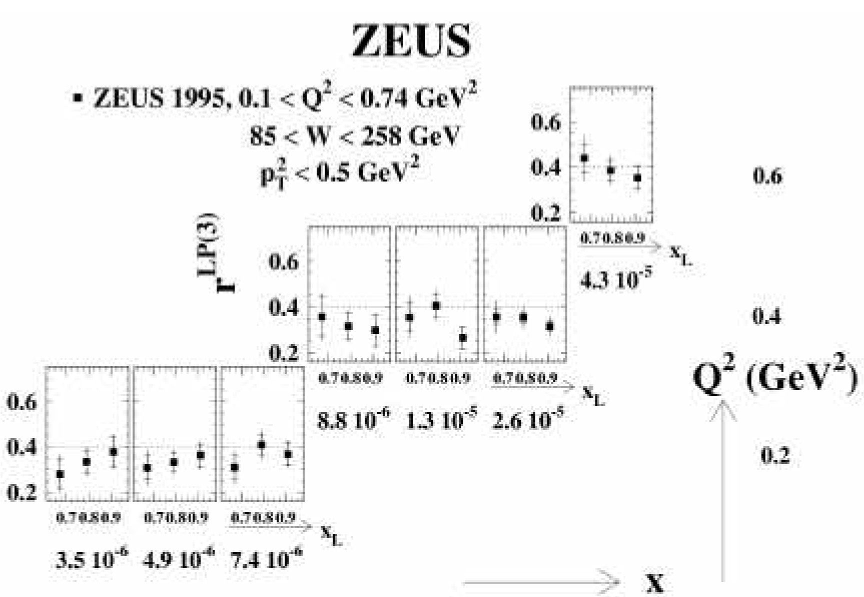
Data are well described by a Regge inspired model.

Proton yield



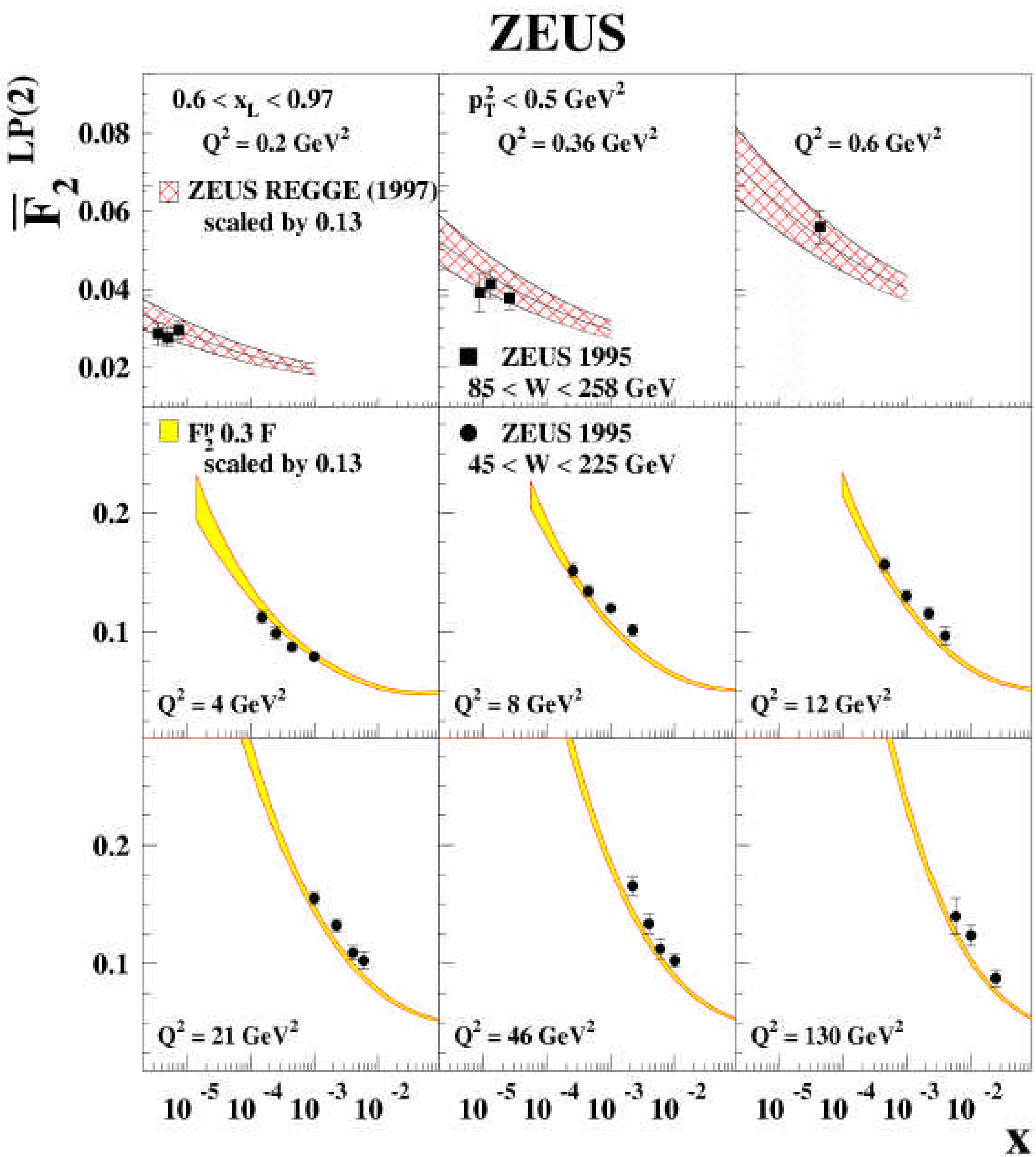
Fraction of events with a leading proton
(with $0.6 < x_L < 0.97$ and $p_t^2 < 0.5$ GeV^2)

$$r^{LP(3)}\left(x, Q^2; x_L\right) = \frac{?^{LP}\left(x, Q^2; x_L, ?p_t^2\right)}{?\left(x, Q^2\right)} \frac{1}{e_{LPS}\left(x_L, p_t^2\right)}$$



⇒ approximately no x_L or Q^2 dependence

$\overline{F}_2^{LP(2)}$



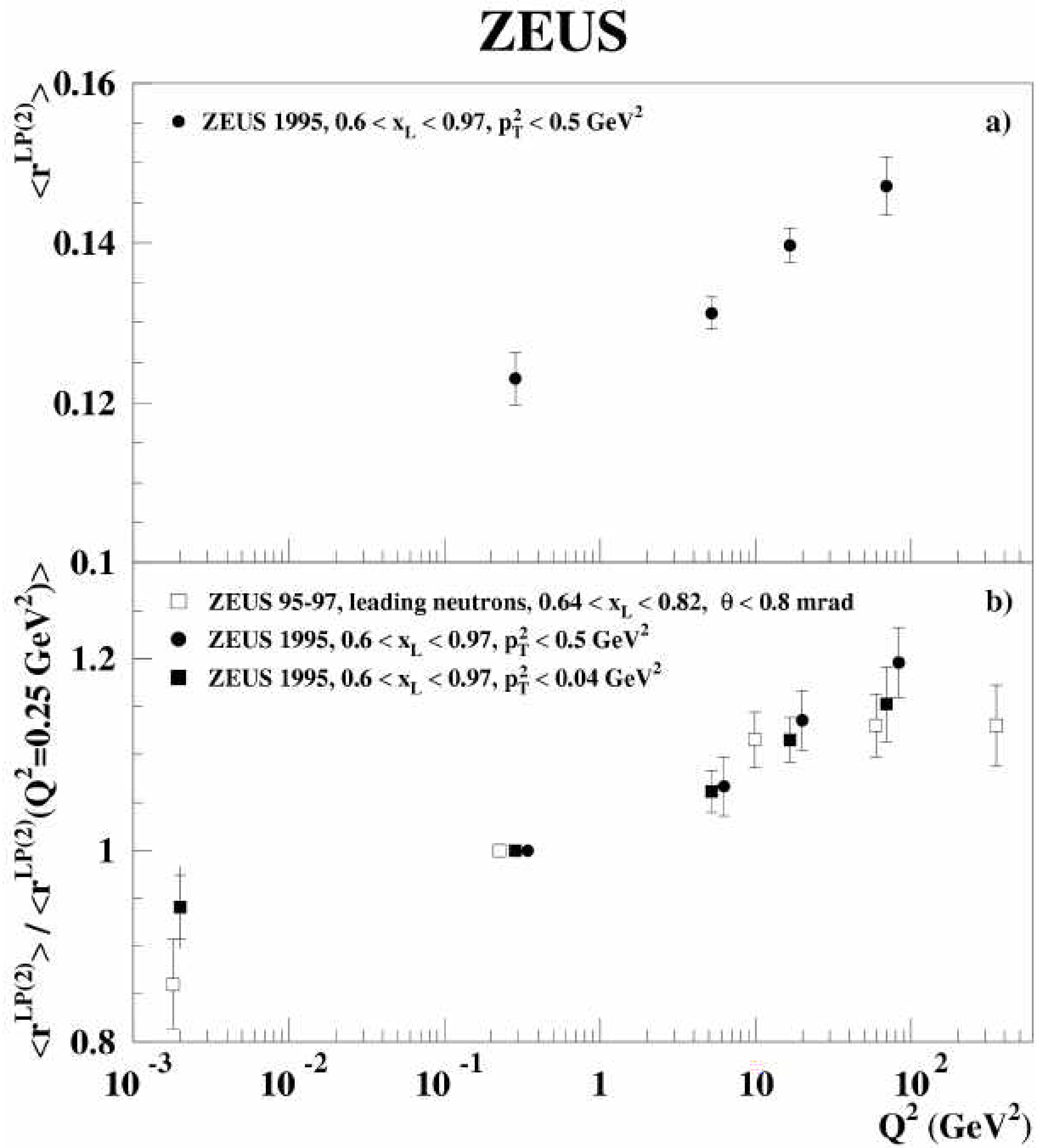
Ratio multiplied by:

- ✓ fit to published ZEUS low Q^2 F_2 data (ZEUS Regge);
- ✓ F_2 parameterization (M.Botje QCD fit)

$$F_2^{LP(2)} = F(x_{Bj},Q^2) \langle r^{LP(2)} \rangle$$

⇒ F_2 , scaled down, well describes F_2^{LP} (small variations w/ Q^2)

⇒ Result similar to neutrons



Factorization violation

Averaging $r^{LP(3)}$ over x and x_L reveals a small violation of factorization: 15-20% for Q^2 ~ 0.02 to 100 GeV^2 (somewhat higher for n)

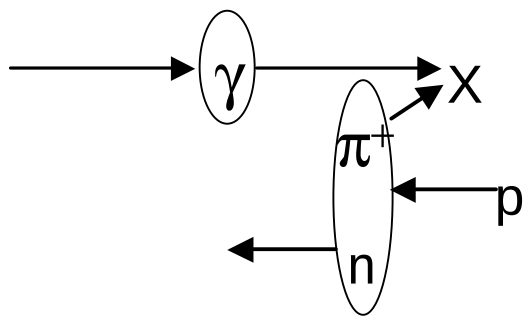
- different evolution of F_2 and $F_2^{LP(2)}$?

- absorptive effects in the $\gamma^* p$ system (smaller γ size at higher Q^2)?

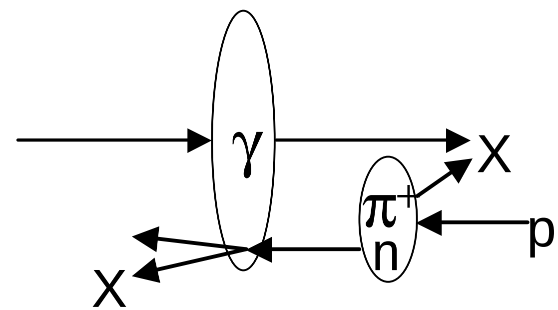
Factorization Violation

Within exchange picture, factorization can be violated, e.g. via rescattering models (D'Alesio & Pirner)

e.g. n production via π^+ exchange:



no rescattering,
n detected



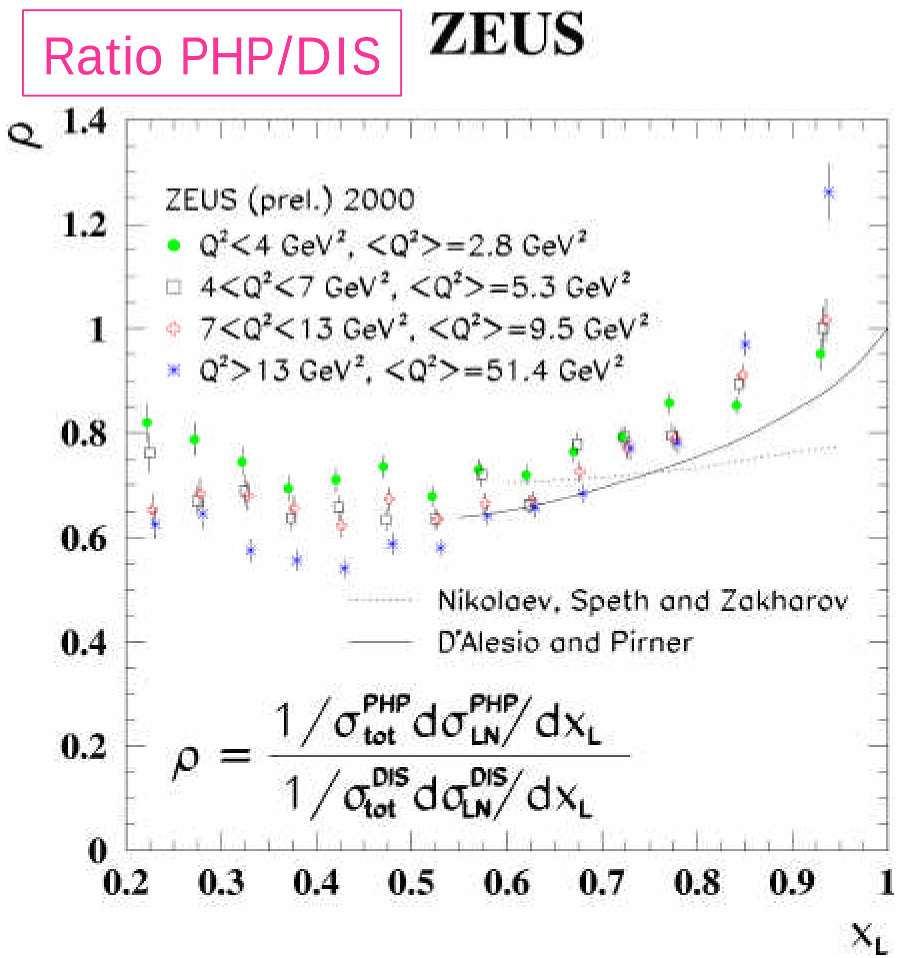
rescattering, n lost
(lower x_L, higher p_t)

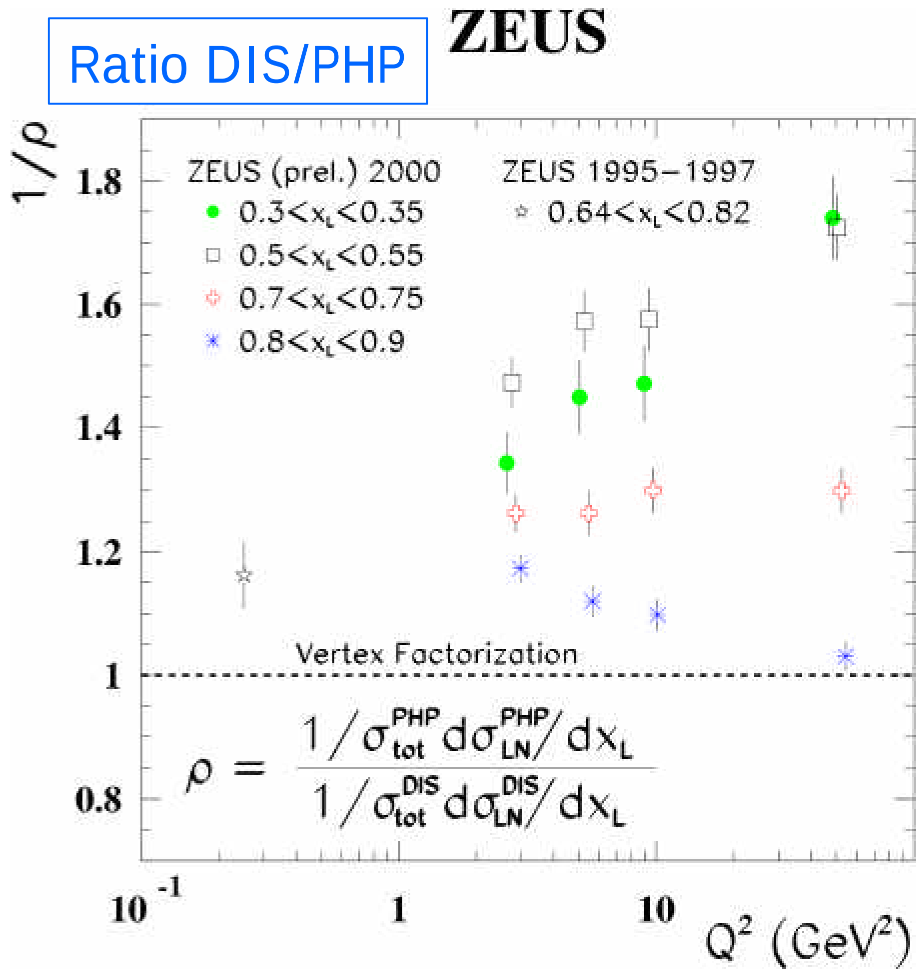
DIS: γ^* ~ point like

PHP: γ ~ hadron like, (size ~ 1/Q), ⇒ rescattering more probable

In OPE $\langle r_{n\pi} \rangle$ smaller at lower x_L ⇒ more rescattering at lower x_L

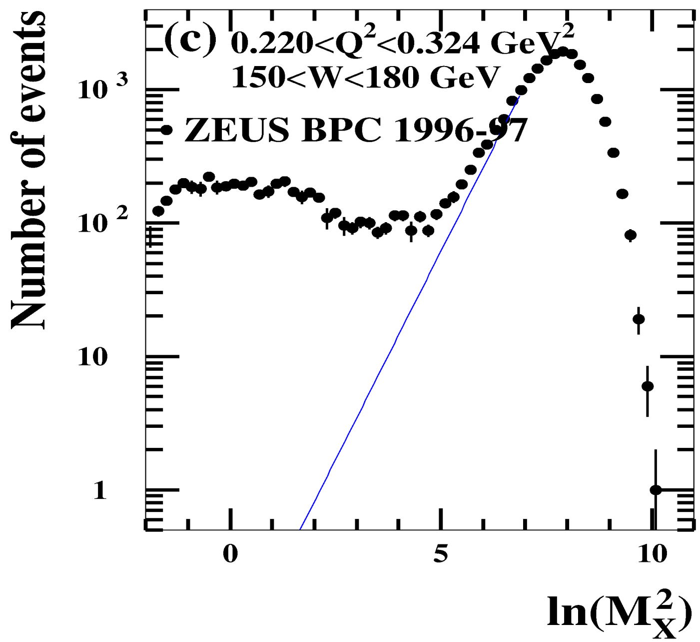
Neutron x_L spectra vs Q^2





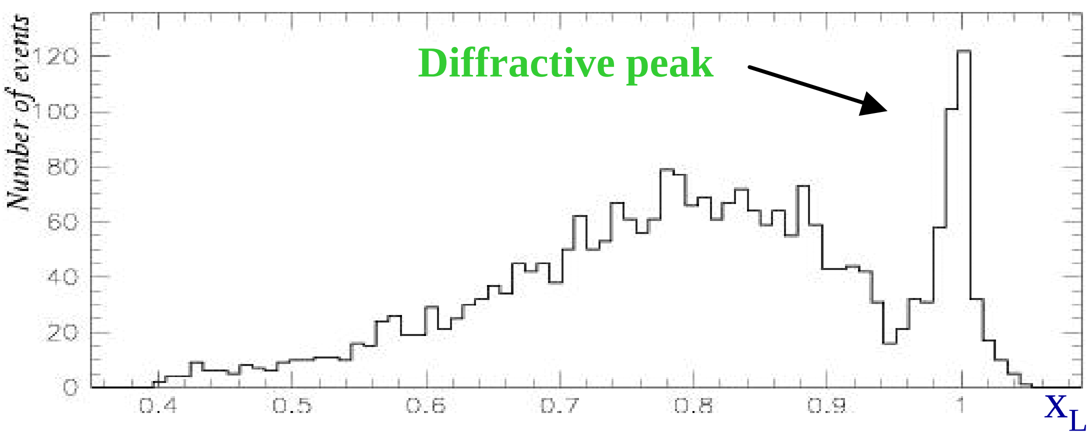
- fewer neutrons at lower x_L and lower Q^2
- rescattering model (valid for Q^2 ~ 10–100 GeV^2) gives a qualitative description
- ratio is also a function of x_L

Selection of Diffractive events



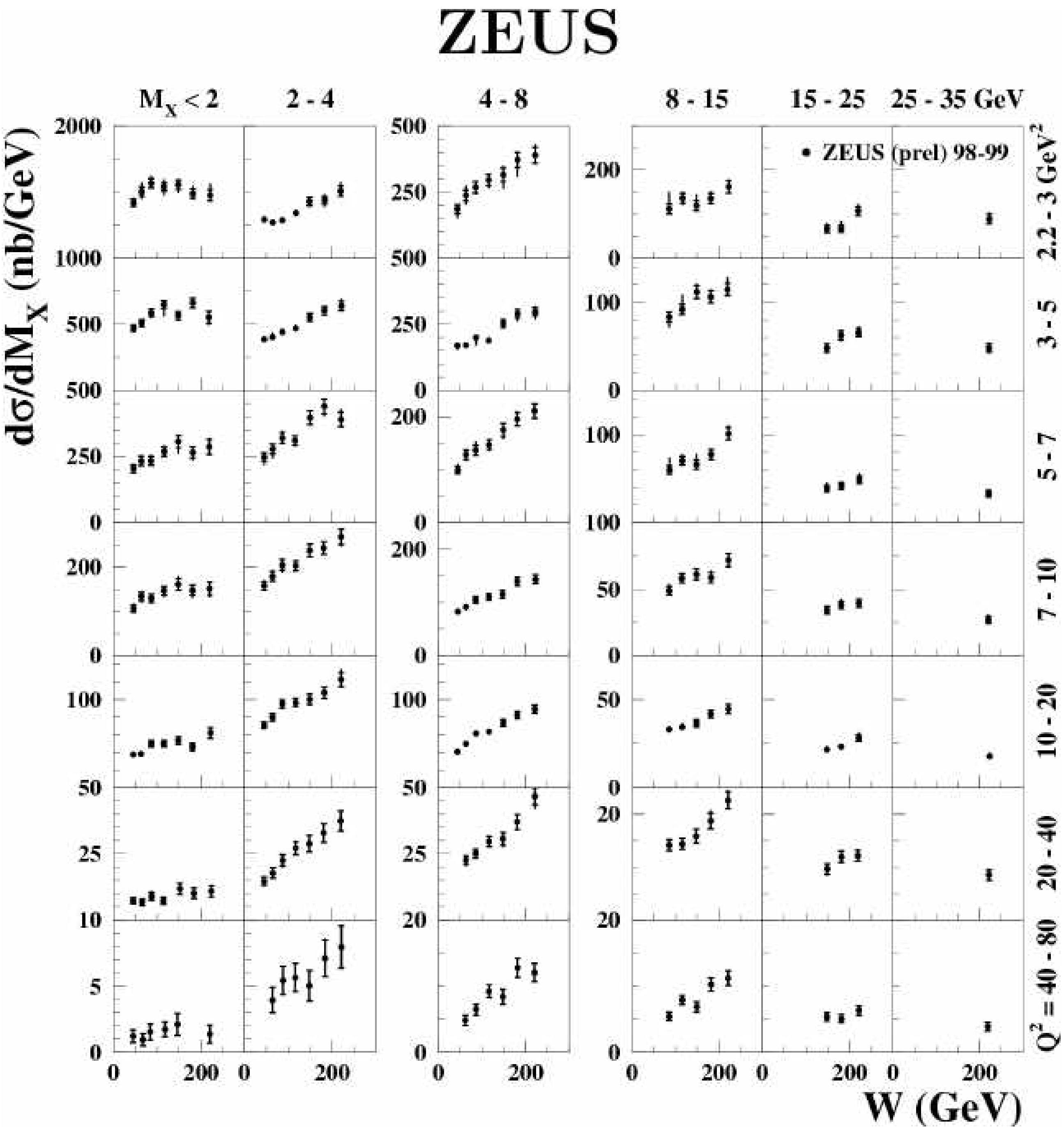
M_X method:

- Good statistics
- t measurement not possible
- Large systematics from p-diss



LPS method:

- Measurement of t distribution
- Free of p-diss background
- Lower acceptance



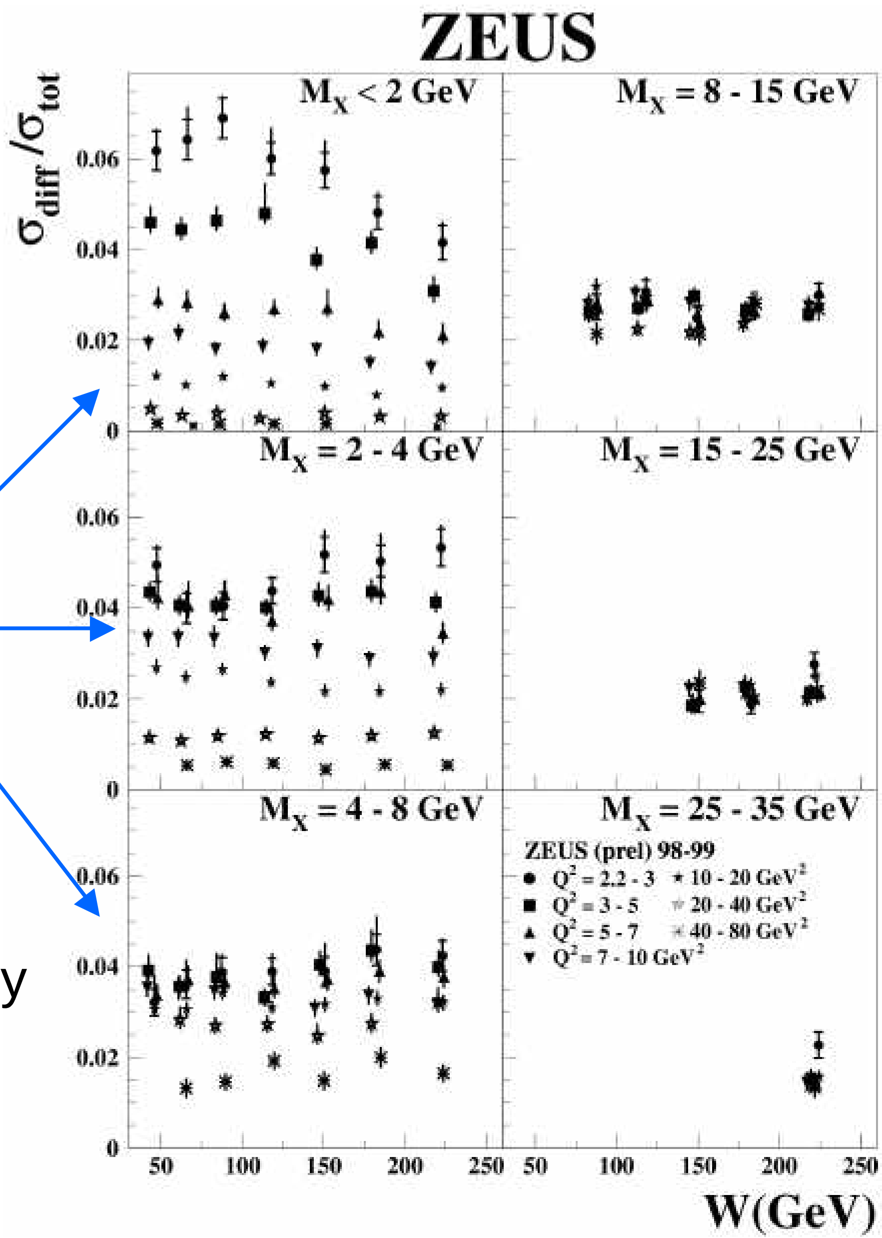
Diffractive cross section (DIS)

- New measurement w/ Forward Plug Calorimeter (FPC);
- x4 more data points;
- Large increase in kinematics range;
- Reduce substantially N_{diss} (M_N < 2.3 GeV).

→ Strong rise w/ W at high M_X

$\sigma^{diff}/\sigma^{tot}$

$$r_{tot}^{diff} = \frac{\int_{M_a}^{M_b} dM_X \, d\sigma^{diff}/dM_X}{\sigma^{tot}_{\gamma^* p}}$$



r_{tot}^{diff} falling w/ W and Q^2

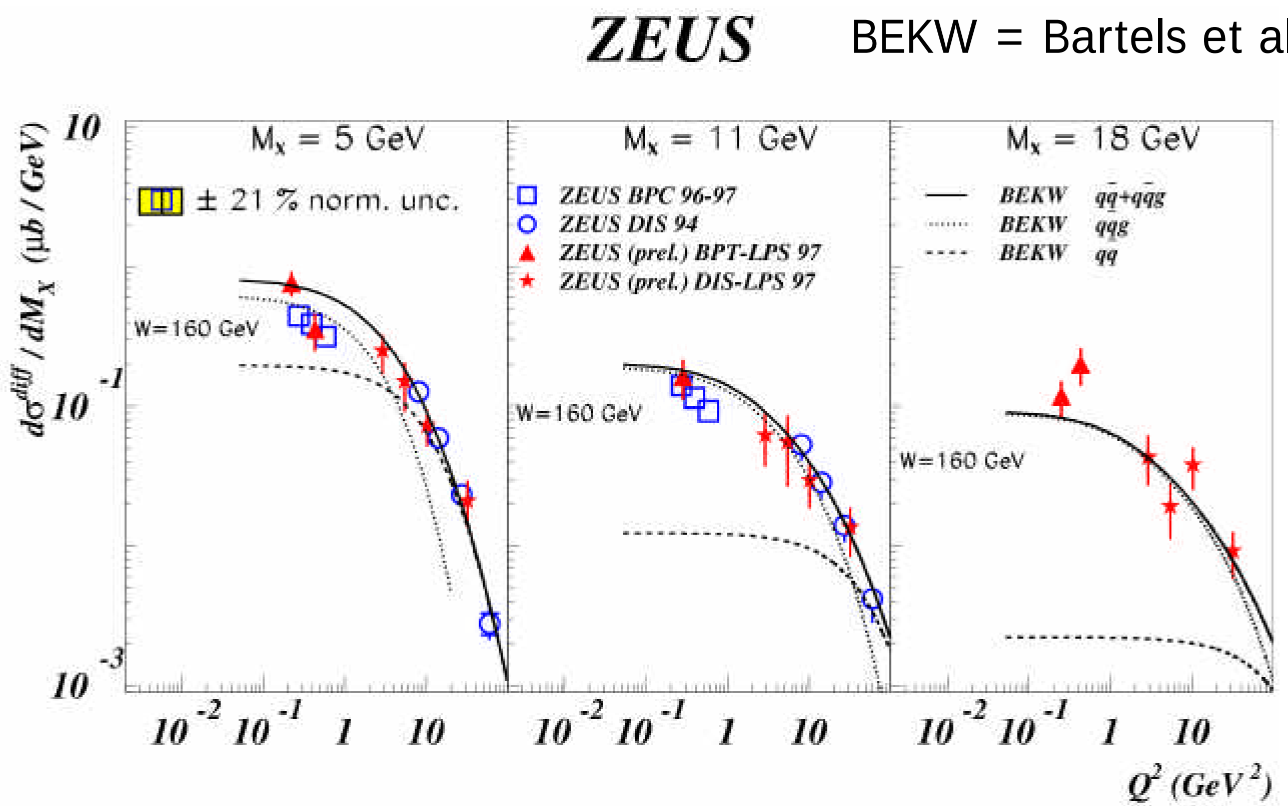
σ_{tot} and σ_{diff} approx. same W and Q^2 dependence

$M_X < 4$ GeV might be dominated by light quarks (except J/Ψ, 10-15%)

$M_X > 4$ GeV contribution from open charm might be substantial

Diffractive cross section (BPC)

BEKW = Bartels et al., Eur. Phys. J C7, 443 (1999)



New data in the BPC (transition ?) region

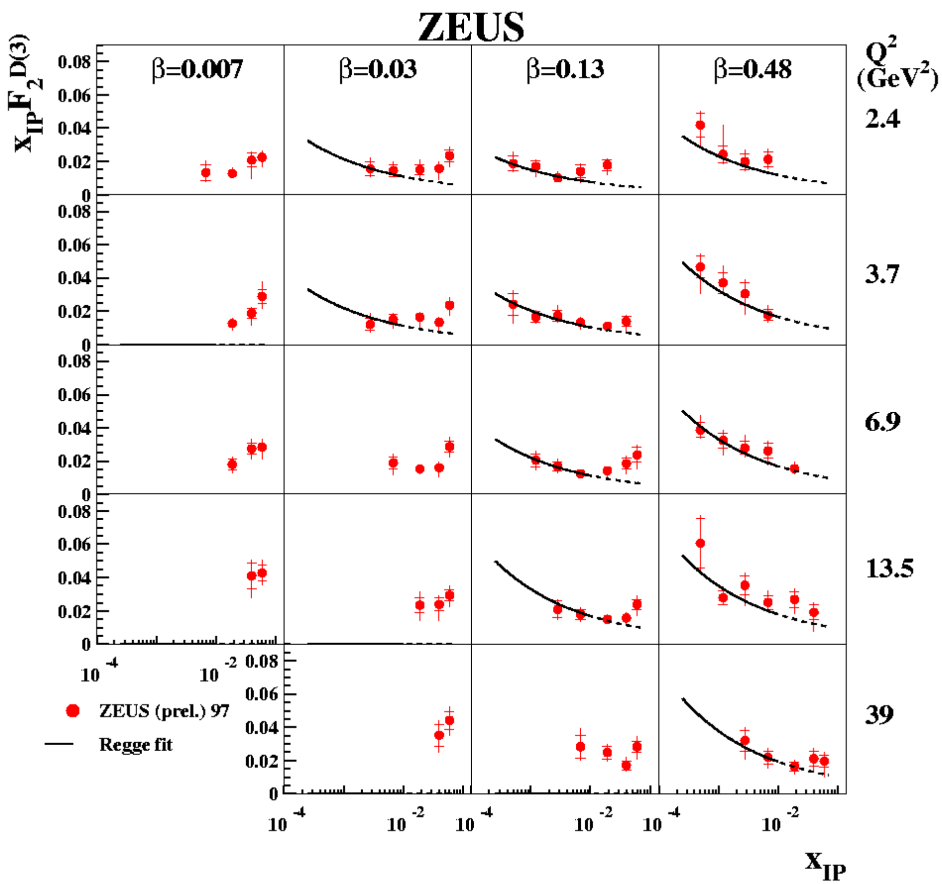
Main features of the data well described by BEKW parametrization

$q\bar{q}g$? fluctuations dominant

– for large M_X

– for low Q^2

Extraction of α_{IP}



Common x_{IP} dependence in all bins consistent with the assumption of Regge factorization

from Regge factorization:

$$F_2^{D(3)} = f_{IP/p}(x_{IP}) \times F_2^{IP}(\beta, Q^2)$$

with $f_{IP}(x_{IP}) \propto \left(\frac{1}{x_{IP}}\right)^{2\alpha_{IP}(t)-1}$

$$\alpha_{IP}(t) = \alpha_{IP}(0) + \alpha_{IP}'(t)$$

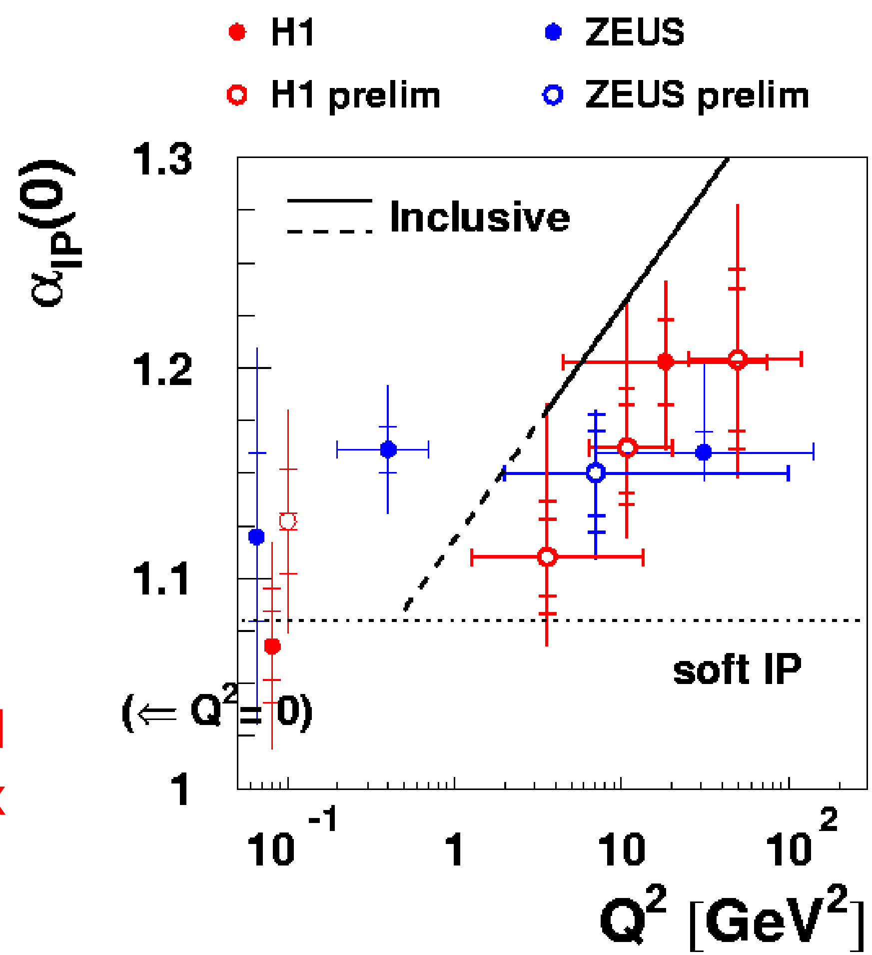
by fitting x_{IP} dep. at fixed ß,Q^2: $\alpha_{IP}(0) = 1.14 \pm 0.02(stat.) \pm 0.02(stat.)^{+0.04}_{-0.02}(model)$

Is the Pomeron universal ?

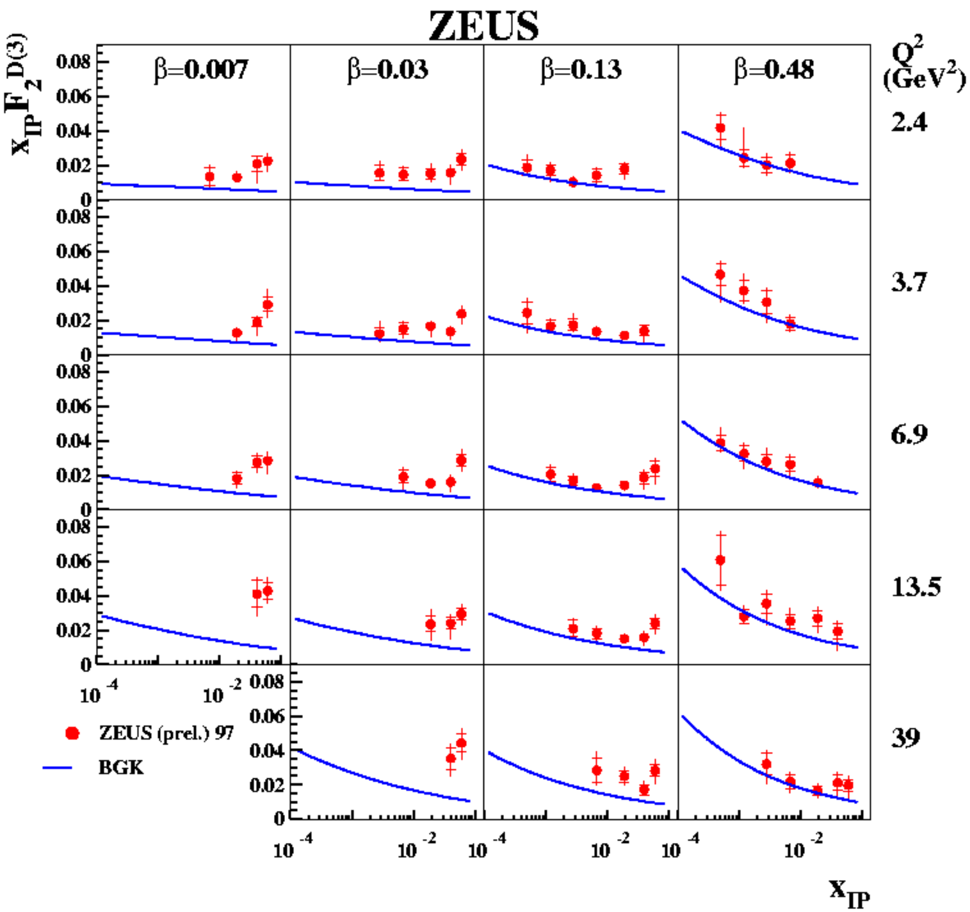
$a_{IP}(0)$ measured in diffraction at different Q^2

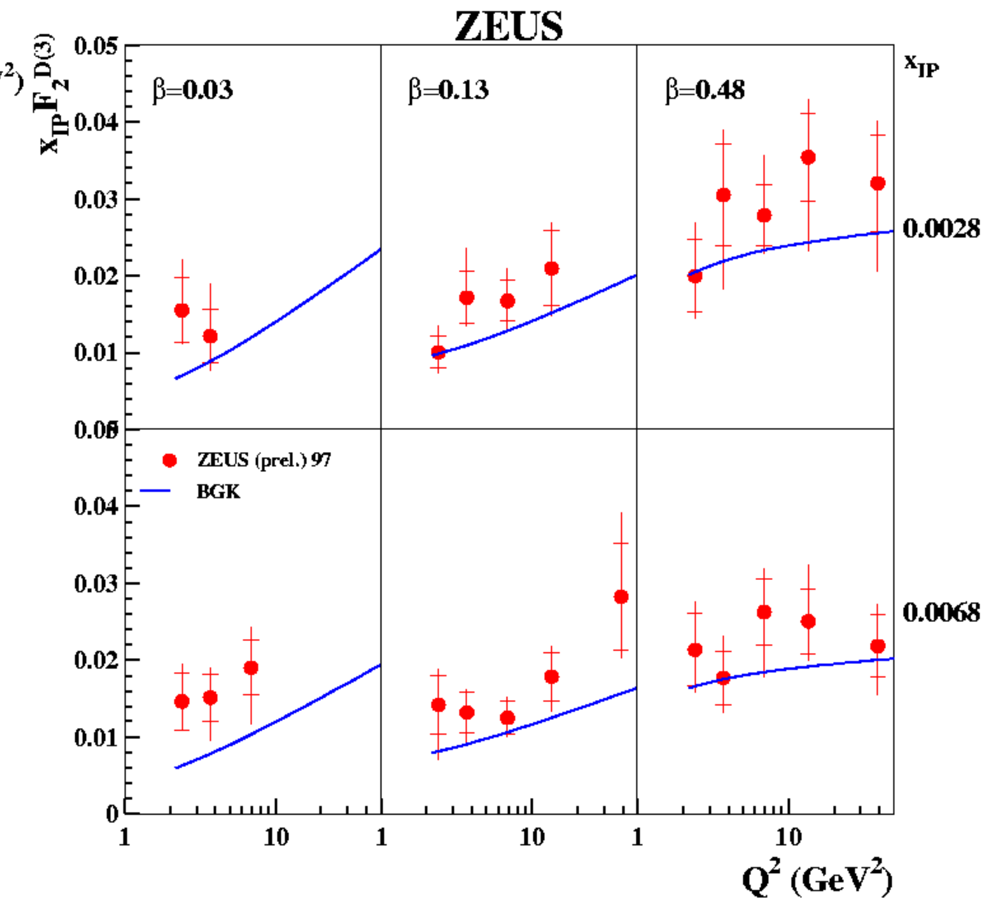
Within the uncertainties there is no evidence of a change of $a_{IP}(0)$ with Q^2

The line $\alpha_{IP}(0)=\lambda+1$ is obtained from fits to the inclusive small x proton structure function data



Q^2 dependence of σ^{DIFF}





BGK = Bartels, Golec-Biernat and Kowalski

Summary

Leading baryons (below diffractive peak):

- ✓ standard fragmentation models fail to describe baryon production;
- ✓ particle exchange models describe rate and spectra (x_L and p_t^2);
- ✓ π dominant for *n* → F_2^π – need multiple exchanges for *p*;
- ✓ vertex factorization:
  - ✓ approximately valid at high Q^2 is broken at low Q^2;
  - ✓ form of violation varies w/ x_L (*n* case);
  - ✓ violation consistent w/ re-scattering in particle exchange (any further suggestion?)
- ✓ F_2^π and $\overline{F}_2^{LP(2)} \propto F_2^p$;

Diffraction:

- ✓ New results covering wide kinematical range;
- ✓ Features of σ^{diff} consistent w/ γ fluctuations into $q\bar{q}$ and $q\bar{q}g$.
- ✓ Ratio $\sigma^{diff}/\sigma_{tot}$ flat over large kinematical ranges.