

Leading Baryons at HERA

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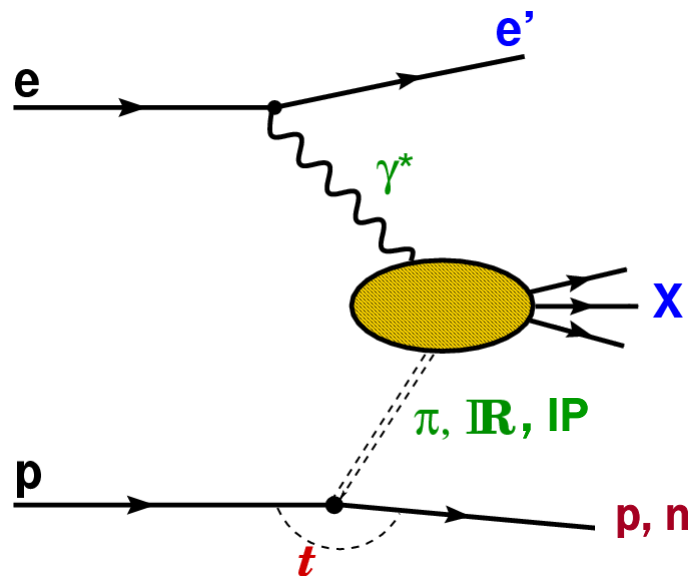
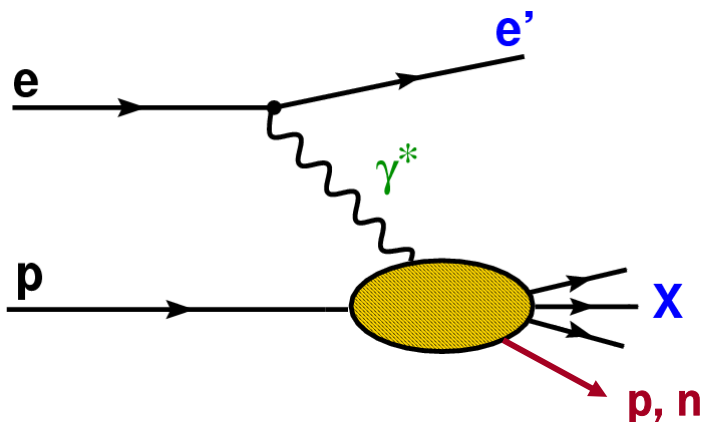
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on behalf of the H1 and ZEUS Collaborations

- Introduction
- Diffractive structure function measured in events with a leading proton
(See also M. Kapishin's talk)
- D^* photoproduction with a leading neutron
- Dijet with a leading neutron
- Summary

Introduction

- A significant fraction of ep scattering events contains a leading baryon produced at small t (soft process).



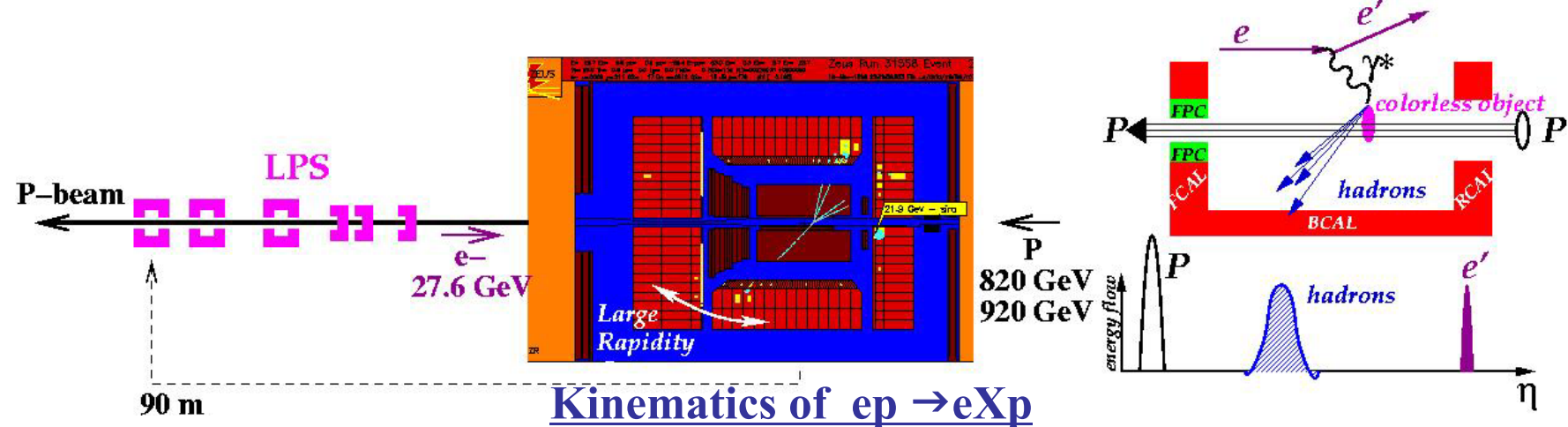
Standard fragmentation :

- p or n appears in fragmentation of target jet

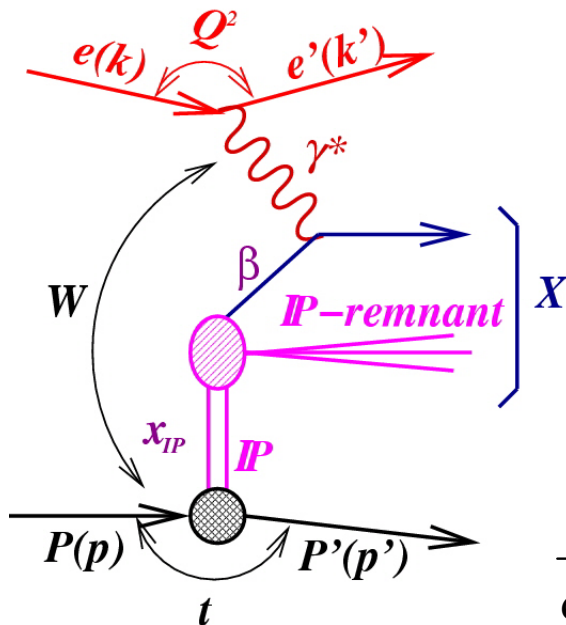
In exchange models :

- p from exchange of neutral iso-scalar or iso-vector ($\pi^0, \mathbb{R}, \mathbb{P}$)
- n from exchange of charged iso-vector (π^+, ρ^+, \dots)

Diffractive structure function measured with a leading proton



Kinematics of $ep \rightarrow eXp$



$$Q^2 = -(k - k')^2$$

$$W = \sqrt{(p + q)^2}$$

$$x_{IP} \approx \frac{Q^2 + M_X^2}{Q^2 + W^2}$$

$$t = (p - p')^2$$

$$M_X^2 = (k - k' + p - p')^2$$

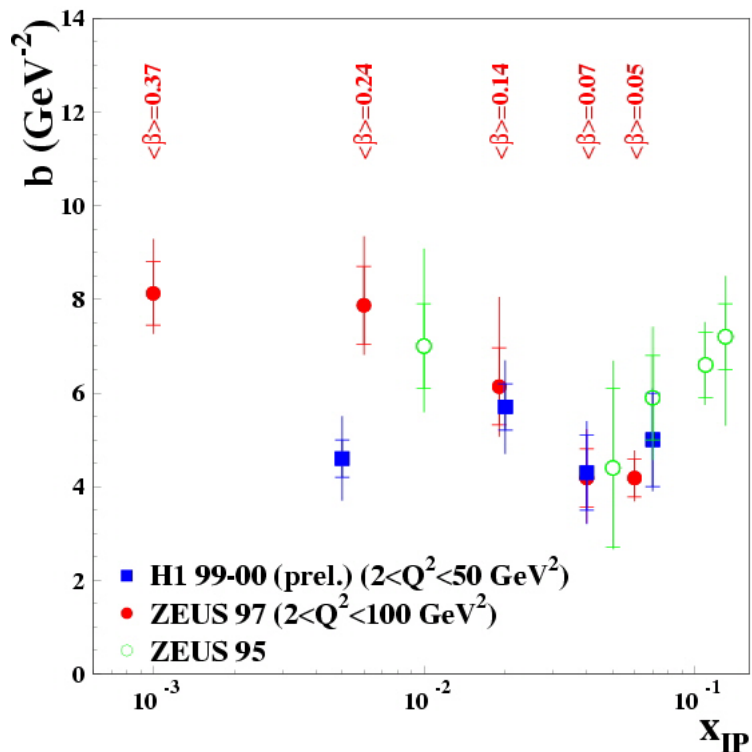
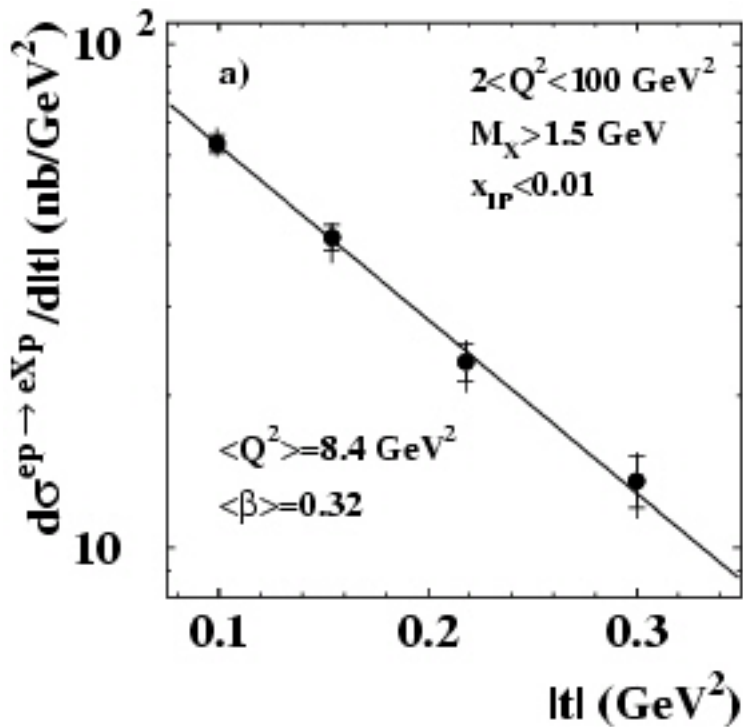
$$\beta \approx \frac{Q^2}{M_X^2 + Q^2} = \frac{x}{x_{IP}}$$

$$x_L = p'_Z / E_p = 1 - x_{IP}$$

Diffractive structure function of proton

$$\frac{d\sigma^{ep \rightarrow eXp}}{d\beta dQ^2 dx_{IP} dt} = \frac{4\pi\alpha^2}{\beta Q^4} \left[1 - y + \frac{y^2}{2(1 + R^D)} \right] F_2^{D(4)}(\beta, Q^2, x_{IP}, t)$$

t dependence from LPS



- H1 b-value considerably below ZEUS result.
- Regge phenomenology predicts “shrinkage” of the diffractive peak:

$$b = b_0 + 2\alpha' \ln \frac{W^2}{M_X^2} \approx b_0 + 2\alpha'_{IP} \ln \frac{1}{x_{IP}}$$

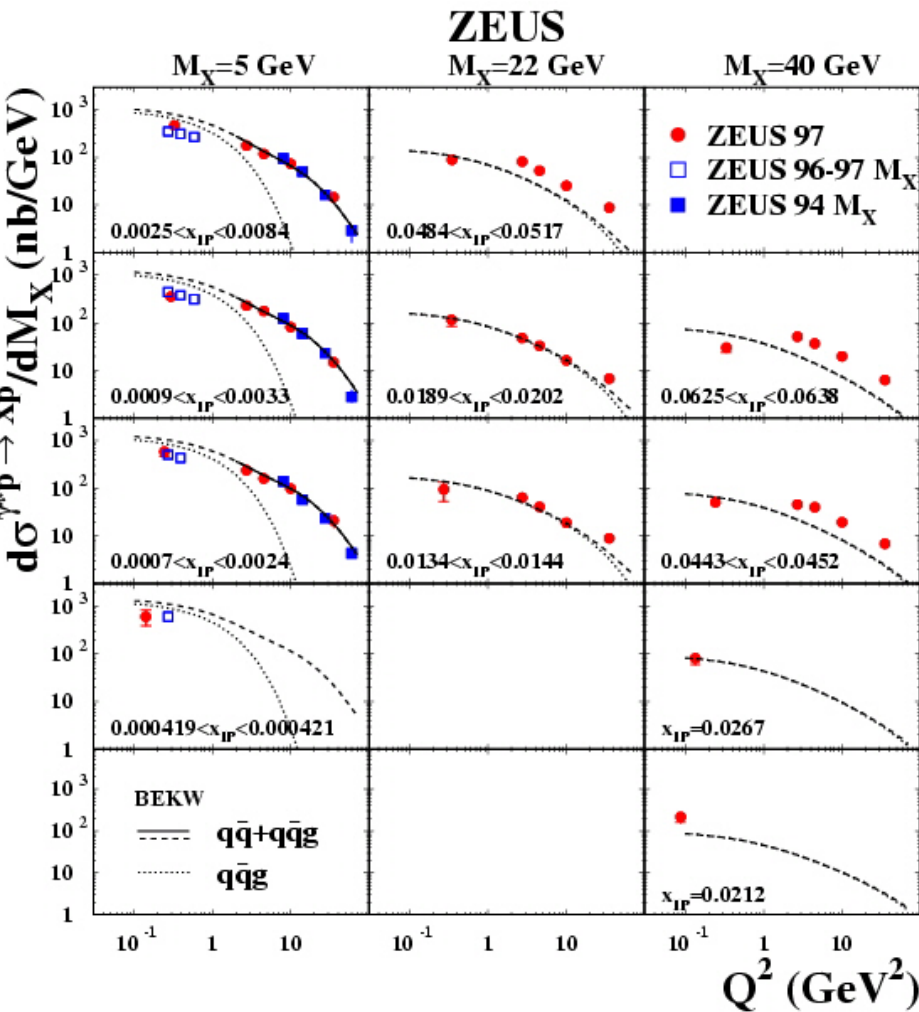
Additional β dependence expected in models. Data not yet precise enough to show presence/absence of α'_{IP} term.

- Fit t distribution to $d\sigma/d|t| \propto \exp(-b|t|)$

$$b = 7.9 \pm 0.5(\text{stat.})_{-0.5}^{+0.9}(\text{syst.}) \text{ GeV}^{-2}$$

→ $d\sigma/d|t|$ shows steep fall-off with t as in elastic hadron-hadron scattering.

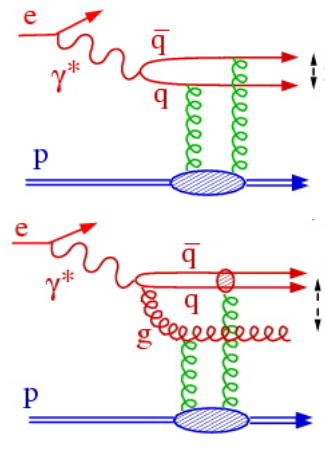
Q^2 dependence of cross section with LPS



- At high Q^2 , $d\sigma/dM_X$ falls with Q^2 .
- As $Q^2 \rightarrow 0$, $d\sigma/dM_X$ depends weakly on Q^2 .

- Data are compared with the color dipole model (BEKW parametrization).

(Bartels, Ellis, Kowalski and Wüsthoff)



For **medium** β ,

$$F_{q\bar{q}}^T \propto \beta(1 - \beta)$$

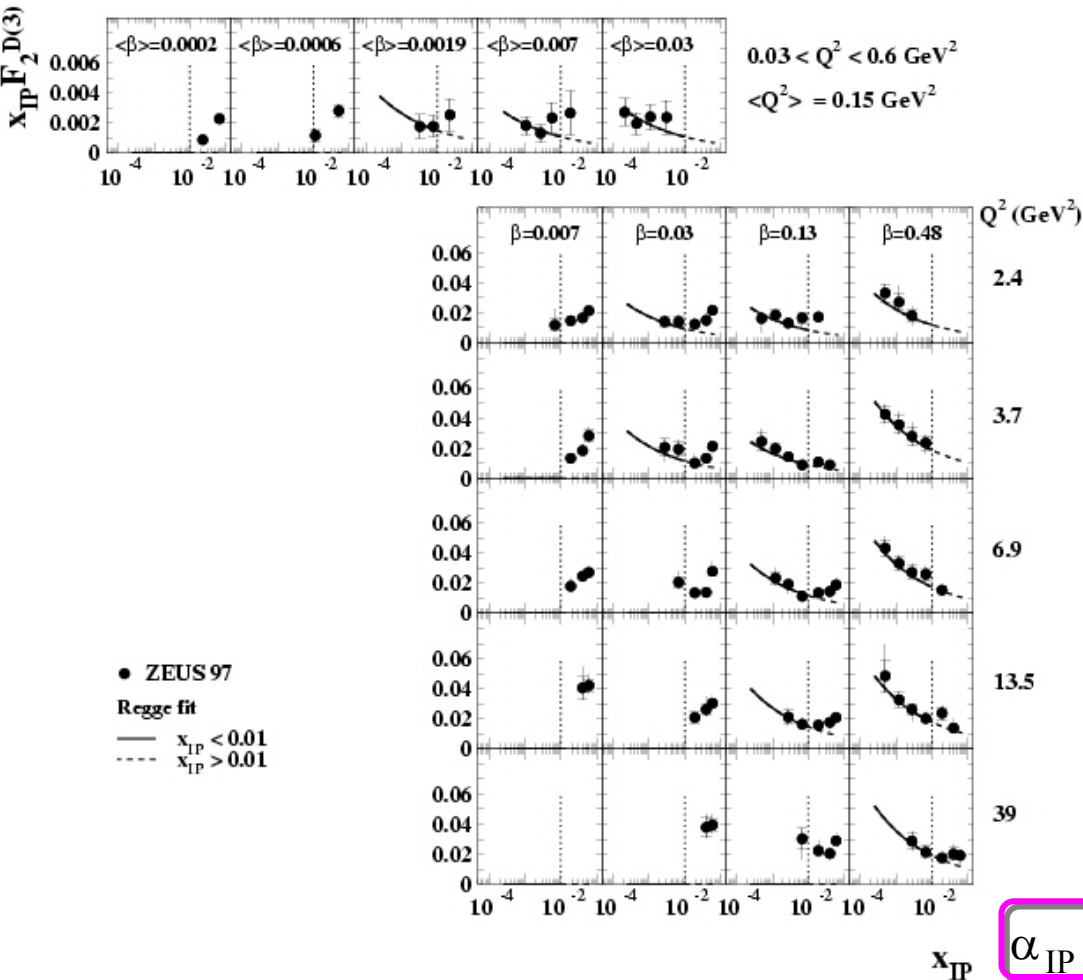
For **small** β ,

$$F_{q\bar{q}g}^T \propto (1 - \beta)^\gamma$$

- At high Q^2 in high M_X bins,
 - ✓ Data above BEKW.
 - ✓ Expect this region ($x_{IP} > 0.01$) to be dominated by Reggeon exchange.

Diffractive structure function of the proton

$x_{IP}F_2^{D(3)}(x_{IP}, \beta, Q^2)$ with LPS



- $x_{IP} > 0.01$
 $x_{IP}F_2^{D(3)}$ increases as $x_{IP} \rightarrow 1$
 \rightarrow **Reggeon** contributions
- $x_{IP} < 0.01$
 $x_{IP}F_2^{D(3)}$ increases as $x_{IP} \rightarrow 0$
 \rightarrow **Parton evolution** as $x_{IP} \rightarrow 0$

- Regge fit ($x_{IP} < 0.01$) with common Pomeron flux factor

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

$$\text{with } f_{IP}(x_{IP}) \propto \int \frac{e^{b_0^{IP}t}}{x_{IP}^{2\alpha_{IP}(t)-1}} dt$$

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

$$\alpha_{IP}(0) = 1.16 \pm 0.02(\text{stat.}) \pm 0.02(\text{syst.})$$

Diffractive hard scattering factorization

[Collins (1998); Trentadue, Veneziano (1994); Berera, Soper (1996)...]

$$\sigma^D(\gamma^* p \rightarrow Xp) = \underline{f_{i/p}^D(z, Q^2, x_{IP}, t)} \otimes \underline{\hat{\sigma}_{\gamma^* i}(z, Q^2)}$$

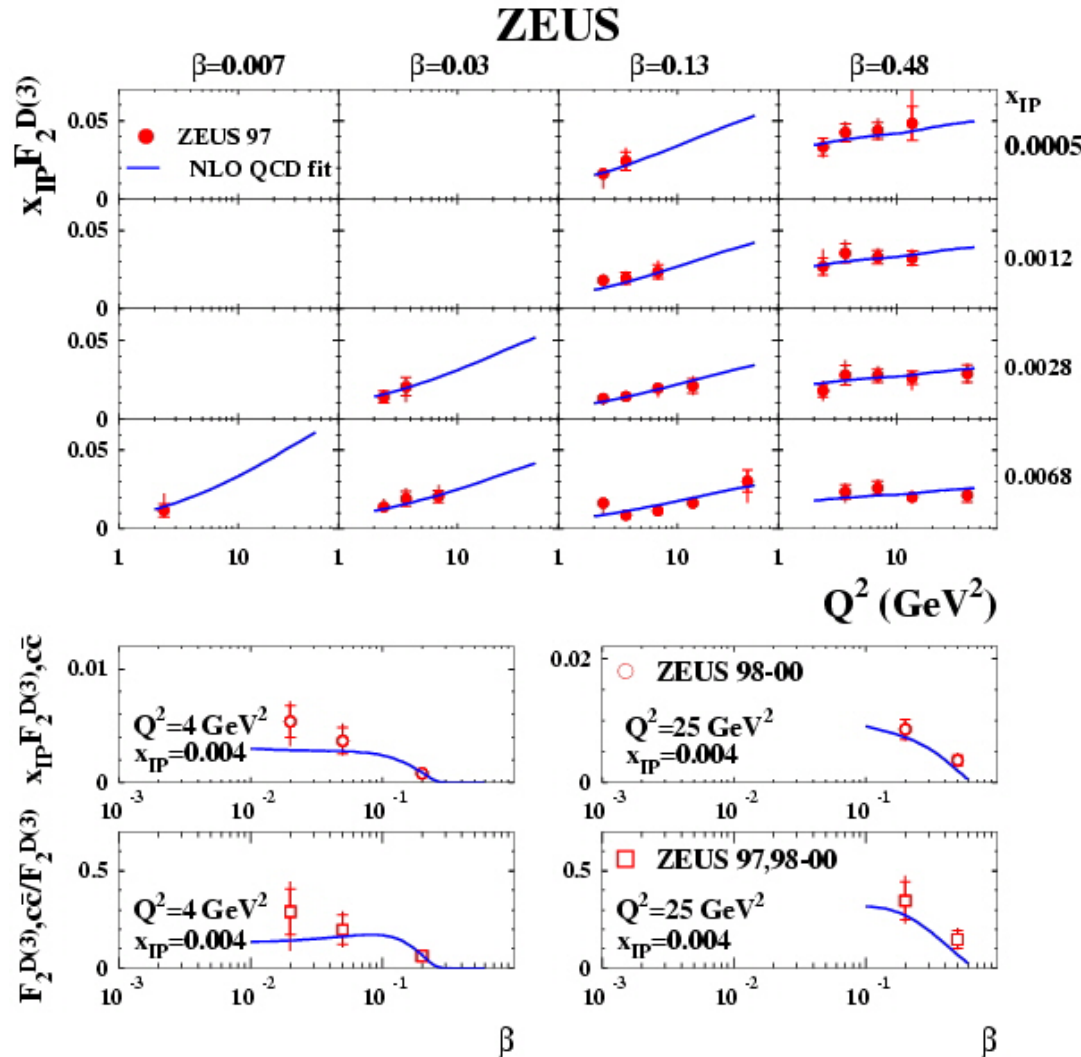
Diffractive parton distribution function **Universal partonic cross section**

$f_{i/p}^D(z, Q^2, x_{IP}, t)$: Probability to find in a proton, with a probe of resolution Q^2 , parton i with momentum fraction z , under the condition that the proton remains intact and emerges with small energy loss, x_{IP} , and momentum transfer, t .

NLO QCD fits to the ZEUS data

- Perform fit to the results from LPS and from diffractive charm in DIS.
 - ✓ $x_{IP} < 0.01$ and $Q^2 > 2 \text{ GeV}^2$
- Regge factorisation assumption, $F_2^{D(3)}(\beta, Q^2, x_{IP}) = f_{IP}(x_{IP}) \cdot F_2^{IP}(\beta, Q^2)$
- Donnachie and Landshoff Pomeron flux
- Parametrise PDFs (quark flavour singlet and gluon) using $\underline{zf(z)} = (a_1 + a_2 z + a_3 z^2)(1-z)^{a_4}$
 - ✓ For light quark distribution, assuming $u = d = s = \bar{u} = \bar{d} = \bar{s}$
 - ✓ Charm quarks were treated in Thorne-Roberts variable flavor number (TRVFN) scheme with $m_c = 1.45 \text{ GeV}$.
- NLO evolution : QCDNUM

NLO QCD fit on LPS+charm data



- QCD fit describes data with $\chi^2/\text{ndf} = 37.8/36$

- Fraction of the t-channel momentum carried by gluons

ZEUS at $Q^2=2 \text{ GeV}^2$

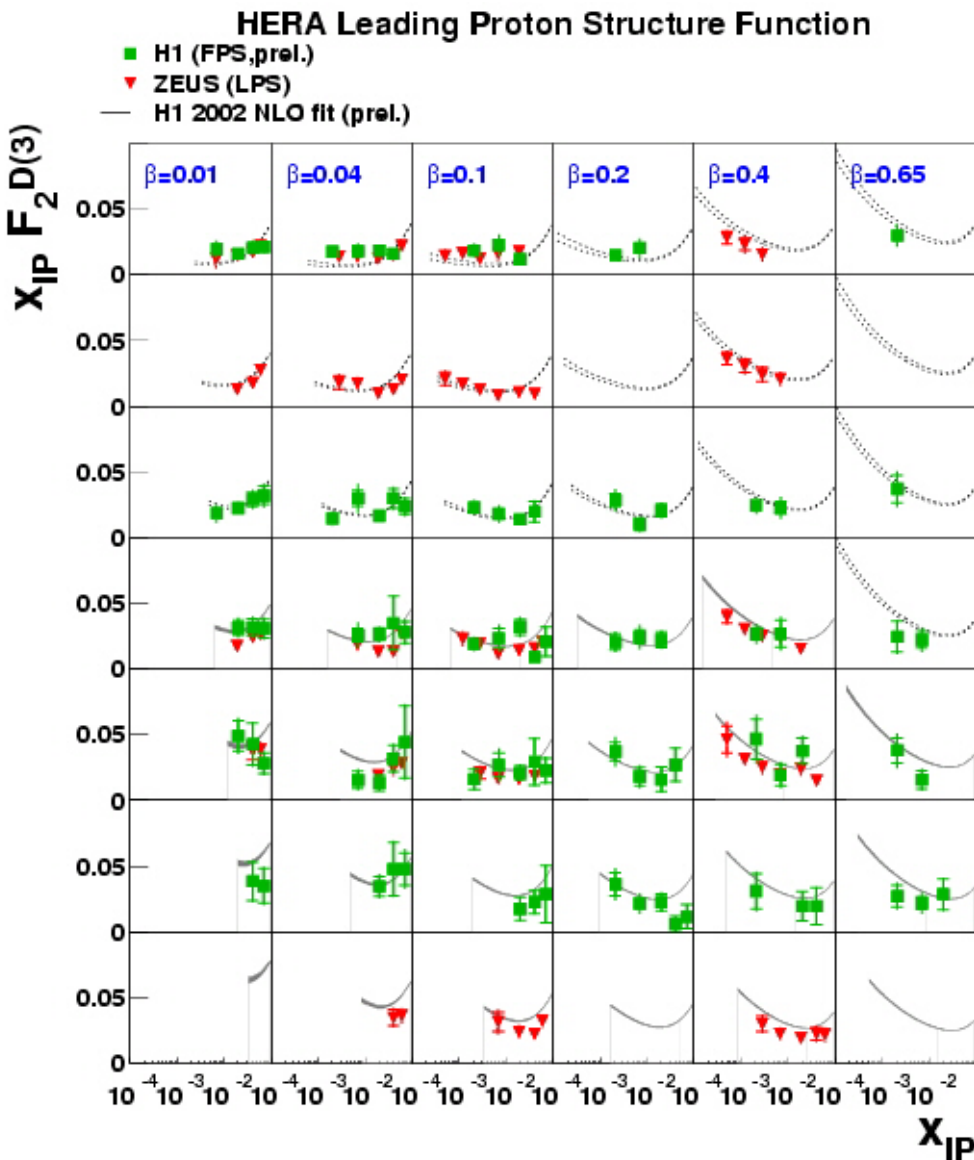
$$82 \pm 8(\text{stat.})_{-16}^{+5} (\text{syst.})\%$$

H1(2002) at $Q^2=10 \text{ GeV}^2$.

$$75 \pm 15\%$$

→ consistent with H1.

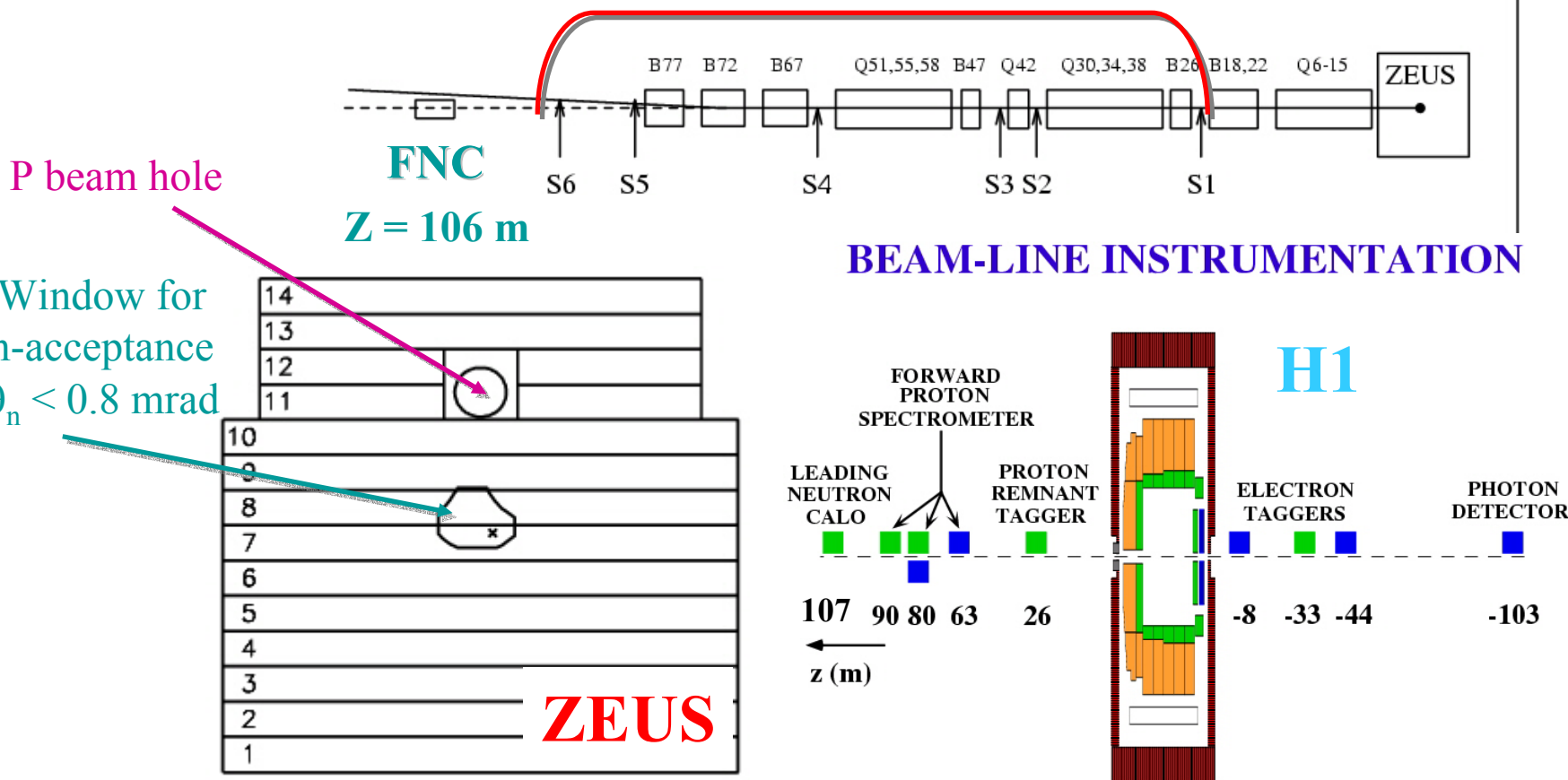
Comparison of LPS and H1-FPS



- Good agreement between the two experiments.
- H1 QCD fit (from large rapidity gap data, see M. Kapishin's talk) describes the results of ZEUS(LPS) and H1(FPS).

Forward neutron calorimeter

Leading Proton Spectrometer



- ZEUS FNC consists of 10 λ_1 Pb-scintillator sandwich calorimeter.
- H1 FNC consists of Pb-scintillator fibers.

- $\sigma(E_n)/E_n = 0.65/\sqrt{E_n}$

Factorization hypothesis

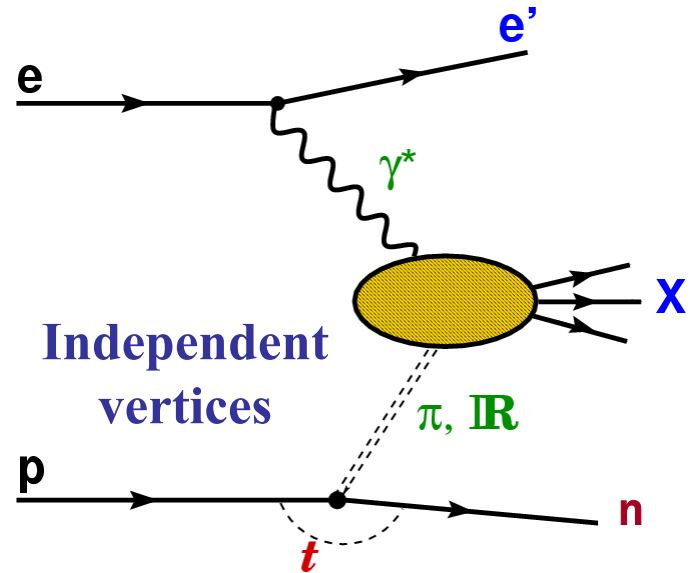
- Study relationship between soft and hard interactions :
 - ✓ Hard scale : m_c^2 for charm production
 E_T for dijet events
 Q^2 for DIS.
 - ✓ Soft scale : p_T of the neutron
- Study vertex factorization hypothesis.

$$\frac{d\sigma_{\gamma p \rightarrow Xn}}{dx_L dt} = f_{\pi/p}(x_L, t) \sigma^{\gamma\pi}(s')$$

with $s' = s(1-x_L)$

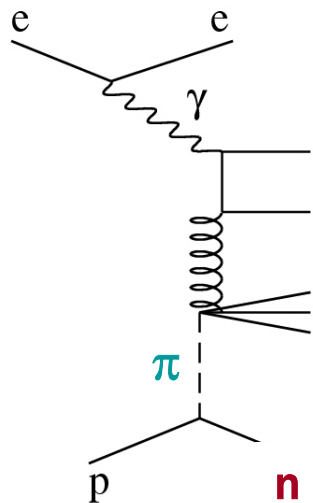
pion form-factor

parton distribution in pion

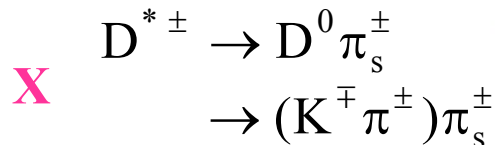


- Ratios $(d\sigma/dY \text{ neutron tagged}) / (d\sigma/dY \text{ inclusive})$ are flat with Y kinematic variables of the event.

D* photoproduction with a leading neutron



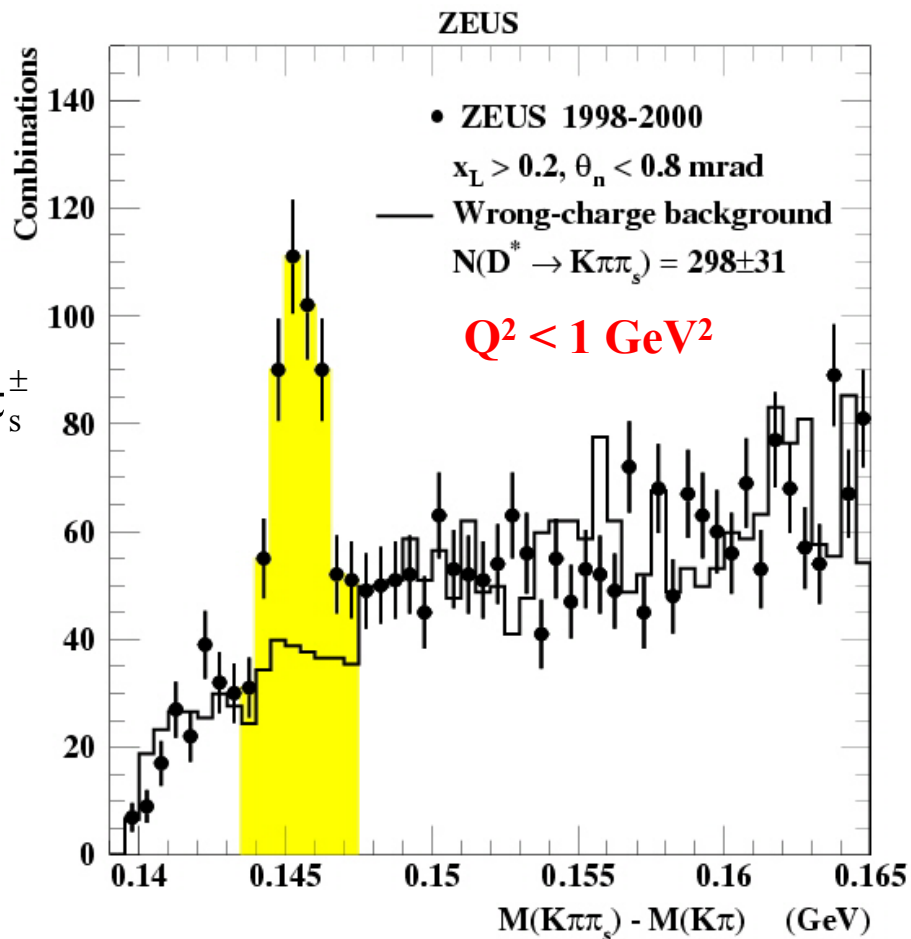
$$ep \rightarrow eXn \rightarrow eD^* X'n$$



n tagged in FNC :

$$\checkmark 0.2 < x_L < 1$$

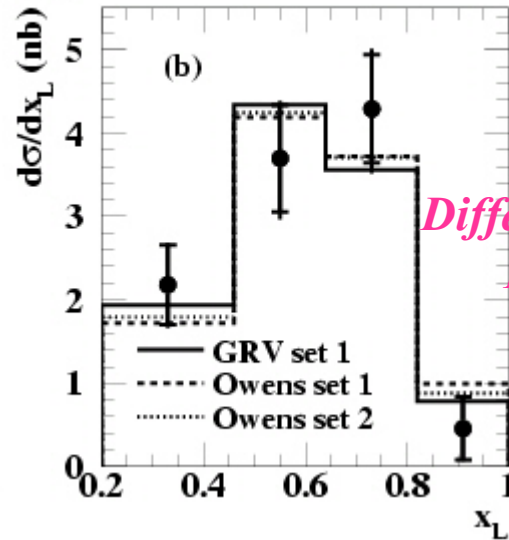
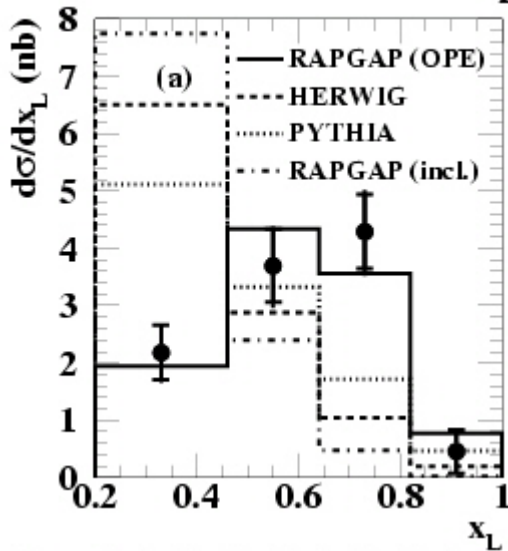
$$\checkmark \theta_n < 0.8 \text{ mrad}$$



$$\sigma_{LN}^{D^*} = 2.08 \pm 0.22(\text{stat.})_{-0.18}^{+0.12}(\text{syst.}) \pm 0.05(\text{B.R.})\text{nb}$$

Differential cross sections of D^* production with a leading neutron

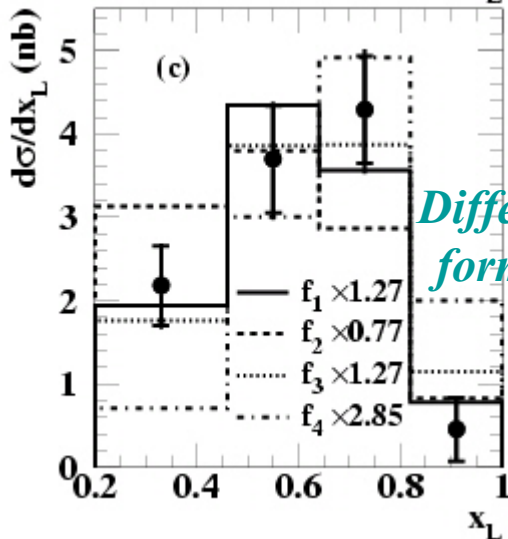
ZEUS



Different pion PDFs

- Standard fragmentation (HERWIG, PYTHIA, RAPGAP(inc)) and RAPGAP(OPE) describe W , p_T and η dist.

→ **Only OPE describes x_L dist.**



Different pion form factors

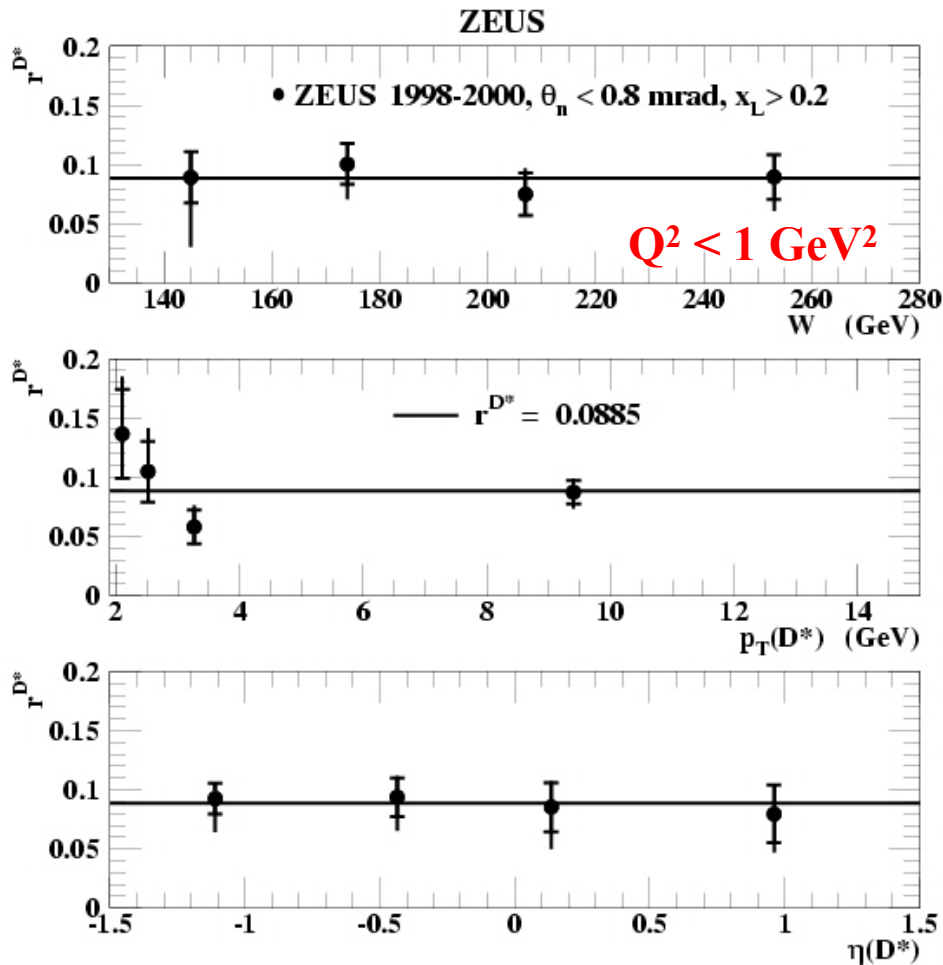
- ZEUS 1998-2000
 $x_L > 0.2$, $\theta_n < 0.8$ mrad

$Q^2 < 1 \text{ GeV}^2$

- Data is not sensitive to the different variants of the pion structure function.

- Light-cone(f_1) and exponential(f_3) pion form factors are compatible with data in shape.

Ratio if D^* yield with and without a neutron



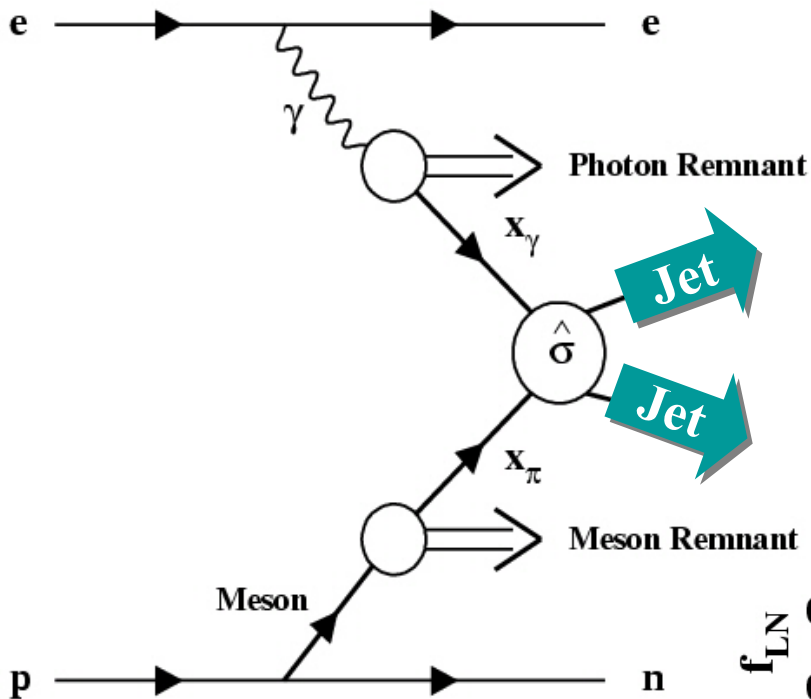
$$r^{D^*} = \left(\sigma_{LN}^{D^*} / \sigma_{inc}^{D^*} \right)$$

$$= 8.85 \pm 0.93(\text{stat.})_{-0.61}^{+0.48} (\text{syst.})\%$$

- Ratio is flat with respect to W , $p_T(D^*)$ and $\eta(D^*)$.

Agreement with factorization hypothesis.

Dijet with a leading neutron

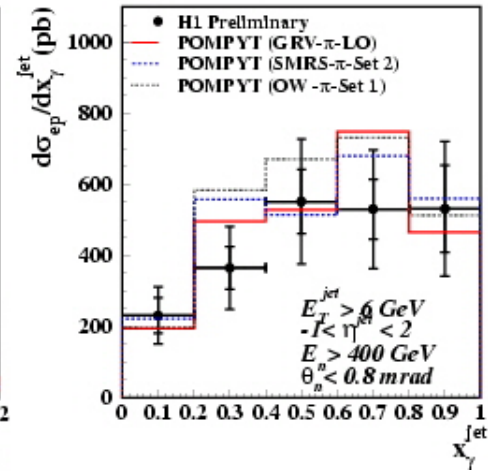
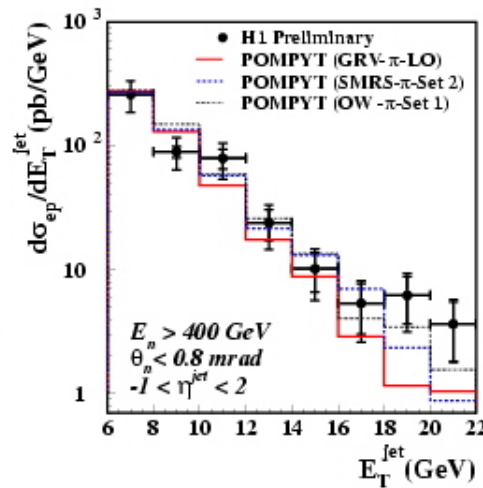


- $f_{LN} = r^{jj} = (\sigma_{LN}^{jj} / \sigma_{inc}^{jj})$

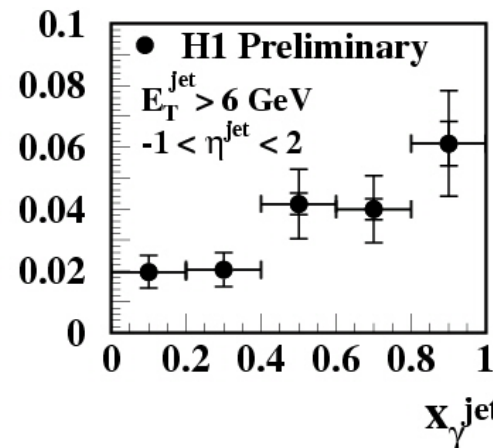
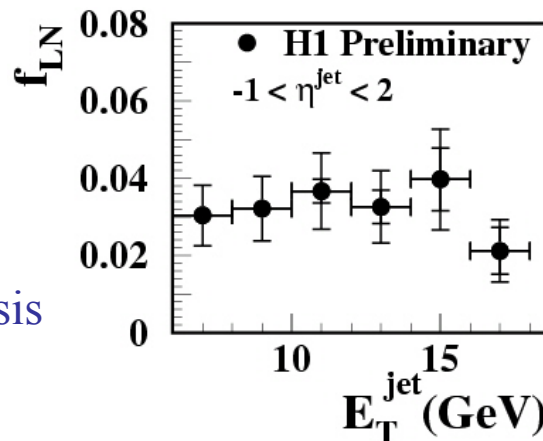
- ✓ flat with E_t^{jet}

- ➔ Support factorization hypothesis

- ✓ rising with x_{γ}^{jet}



Dijet cross sections compared to pion exchange MC (POMPYT) with different pion PDFs. ➔ Not sensitive.



Summary

- **Diffractive structure function measured with a leading proton in DIS**

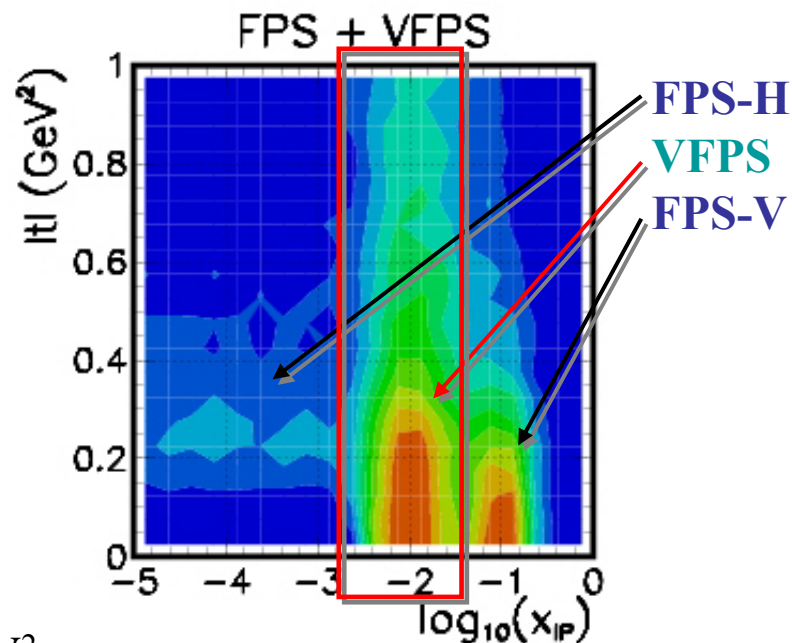
- ✓ Recent data from ZEUS with improved precision and extended kinematic range.
- ✓ Slope of $d\sigma/d|t|$ is compatible with soft interaction at the proton vertex.
- ✓ Data can be described by color dipole model (e.g. BEKW parameterisation).
- ✓ Data described by a NLO QCD fit

- **D* and dijet with a leading neutron**

- ✓ Data described by one-pion-exchange model.
- ✓ Data agree with the factorization hypothesis.

- **H1 Very Forward Proton Spectrometer (VFPS)**

- ✓ Tag the scattered proton at HERA II for high rate studies of diffraction
- ✓ Large acceptance for low x_{IP} and $0 < |t| < 0.5 \text{ GeV}^2$
- ✓ Expect physics data soon.



Acceptance :

Red : 90-100 %, Blue:0-10%