Workshop on high-energy photon collisions at LHC, 2008
CERN, April 22-25

Factorisation breaking in diffraction

Alessia Bruni, INFN Bologna
on behalf of the H1 and ZEUS collaborations

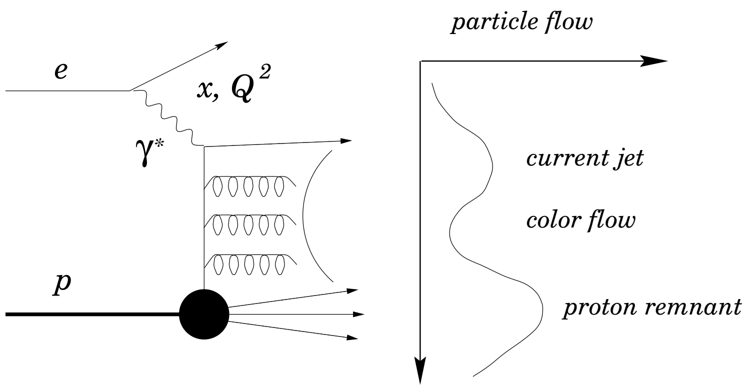
OUTLINE

- **Diffractive hard selection**
- **Hard diffraction in QCD**
- **Diffractive Parton Density Functions**
- **Diffractive final states (open charm, jets)**
- **Events with leading neutrons**

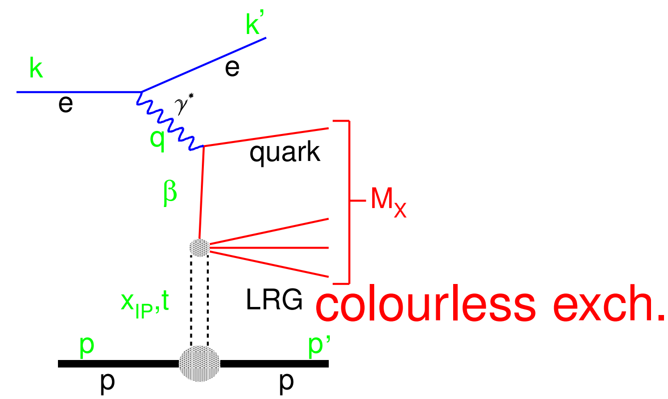
Diffractive event selection

HERA: 27.5 GeV e + 920 GeV p, $\sqrt{s} = 318$ GeV

A large fraction (10% - 20%) of DIS events is diffractive



DIS



DIS -Diffraction

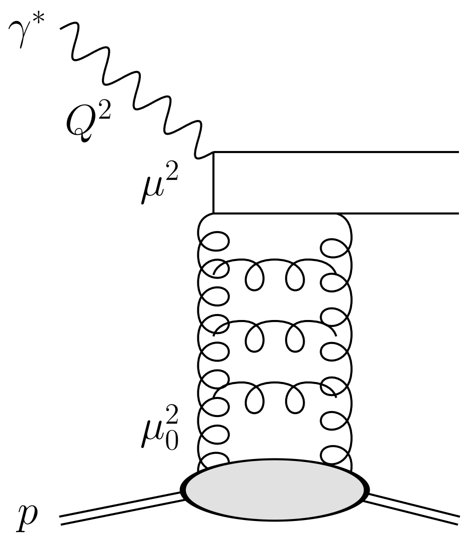
- Beam particles emerge intact or dissociated into low-mass states; energy $\simeq$ beam energy (within a few %)
- Final-state particles separated by Large Rapidity Gap (LRG)
- Interaction mediated by t-channel exchange of object with vacuum quantum numbers: colour siglet exchange or Pomeron

Hard diffraction in QCD

Diffractive processes with one or several large scales are called hard

Hard diffraction is the interplay of systems with small size configurations (quark and gluon) and large size configurations (set by the size of the protons)

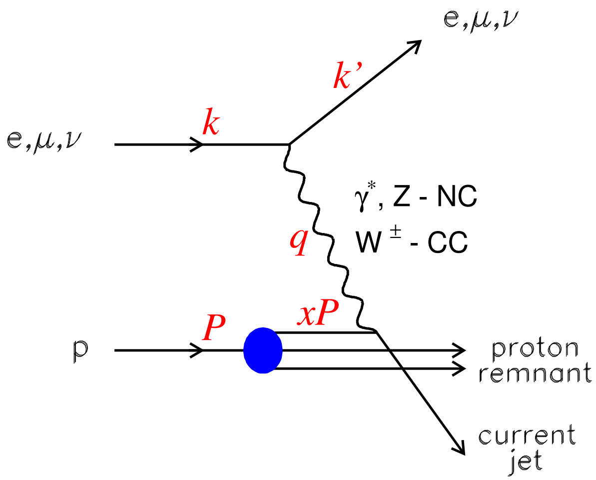
Application of pQCD relies on the ability to separate small (hard) from large configurations (soft)

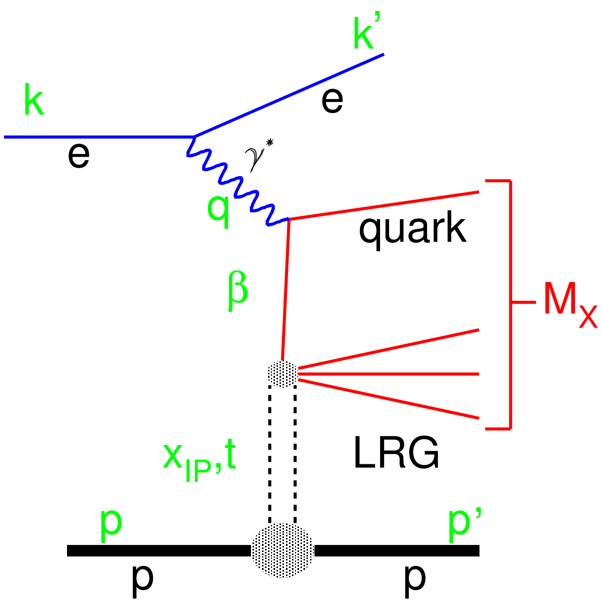


2-gluon diagram

Hard diffraction is a laboratory for QCD studies:

- scale transition soft-hard
- factorisation tests
- dynamics of hard processes





Kinematic variables

DIS

Q^2	$= -q^2$, virtuality of exchanged boson
x_B	$= Q^2/2p \cdot q$, Bjorken variable
	fraction of proton's momentum carried by struck quark
y	$= Q^2/sx$, γ inelasticity
W	photon-proton centre of mass energy

Diffractive DIS

$x_{I\!P}$	fraction of proton's momentum of colour singlet
	exchange $= \frac{q\cdot(p-p')}{q\cdot p} \simeq \frac{Q^2+M_X^2}{Q^2+W^2}$
β	fraction of Pomeron's momentum carried by quark
	coupling to $\gamma^* = \frac{Q^2}{2q\cdot(p-p')} \simeq \frac{Q^2}{Q^2+M_X^2} = x_B/x_{I\!P}$
t	$= (p-p')^2$, 4-momentum transfer squared at p-vertex

QCD factorisation theorem

Breit rest frame (fast proton)

DIS

$$F_2(x,Q^2) = \sum_{i=q,g} \int dz \quad f_i(z,Q^2) \quad C_i(x,Q^2)$$

structure functions	parton distribution function (universal, dglap)	hard scattering coefficients (pqcd)

at LO, coefficients $C_q(x) = e_q^2 \delta(1-x)$, $C_g(x) = 0$

Diffractive DIS

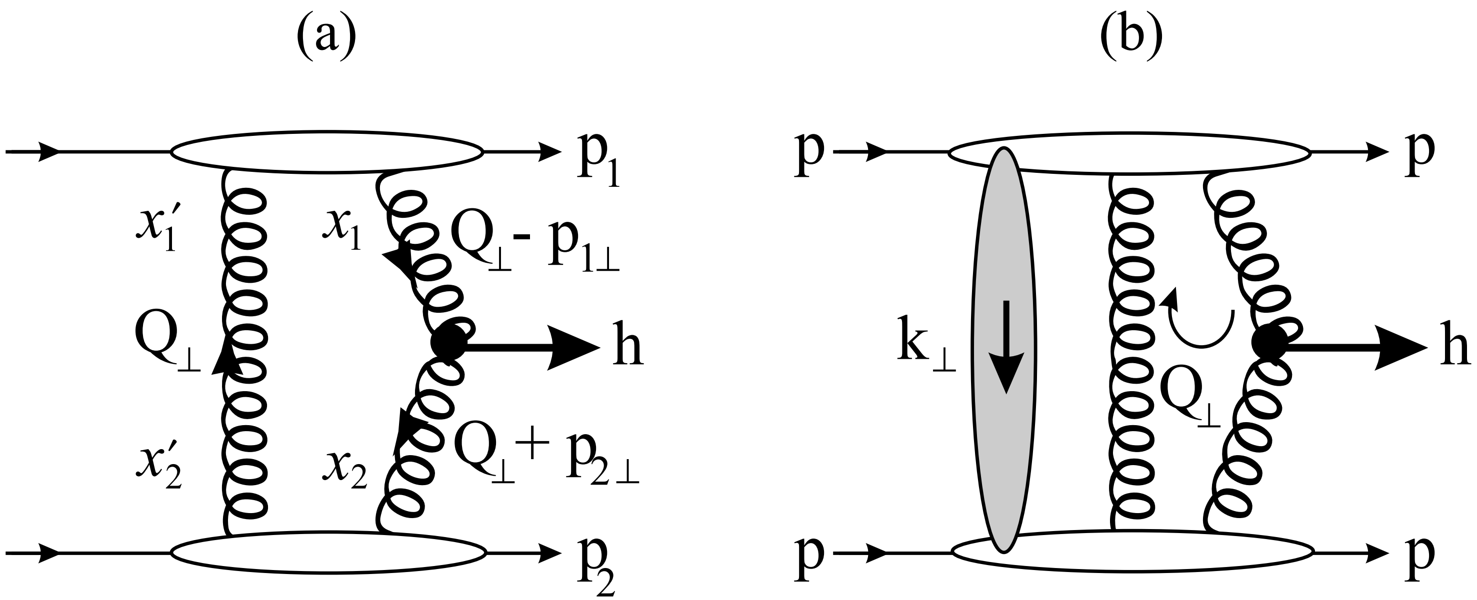
$$F_2^{D(4)} = \frac{d^2 F_2^D(x_{I\!P}, t, x, Q^2)}{dx_{I\!P}\, dt} = \sum_{i=q,g} \int dz \quad \frac{d^2 f_{i/p}^D(x_{I\!P}, t, z, \mu_F^2)}{dx_{I\!P}\, dt} \quad C_i\left(\frac{x}{z}, \frac{Q^2}{\mu_F^2}\right)$$

Diffractive PDF	same as F_2

- Factorisation proved for DDIS and exclusive hard diffraction for large μ_F (Collins, Berera &Soper, Trentadue & Veneziano)
- Not true for diffr. hadron-hadron collisions

Factorisation not expected to hold for pp

- Violation of factorization understood in terms of (soft) rescattering between the 2 hadrons and their remnants, in initial and final state, suppressing the large rapidity gap



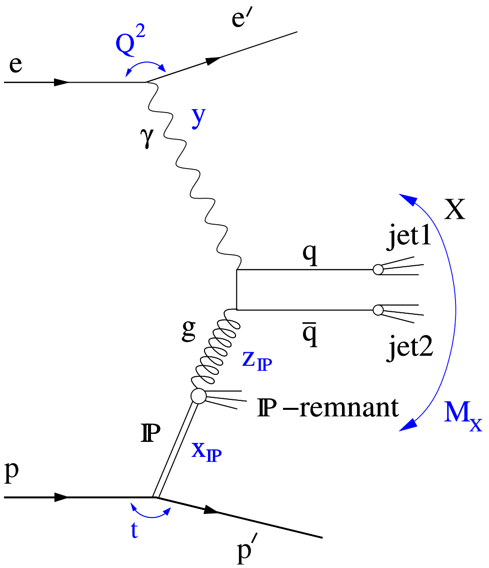
- Suppression observed for diffractive dijet production at Tevatron
- Interest for LHC diffractive production

Factorisation tests in $\gamma^* p$ and γp

Real photon ($Q^2 \simeq 0$) can develop hadronic structure

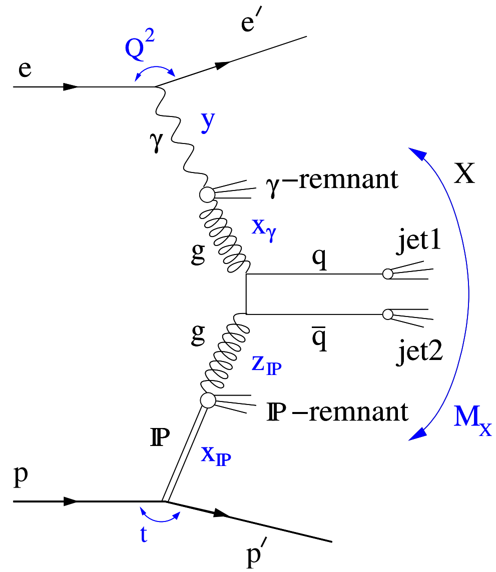
$\Rightarrow$ study fact. breaking at HERA

- direct γ ($x_\gamma \simeq 1$)



small γ couples directly to parton, dominant contribution in DIS and for high E_T jets

- resolved γ (hadron like, at low x_γ)



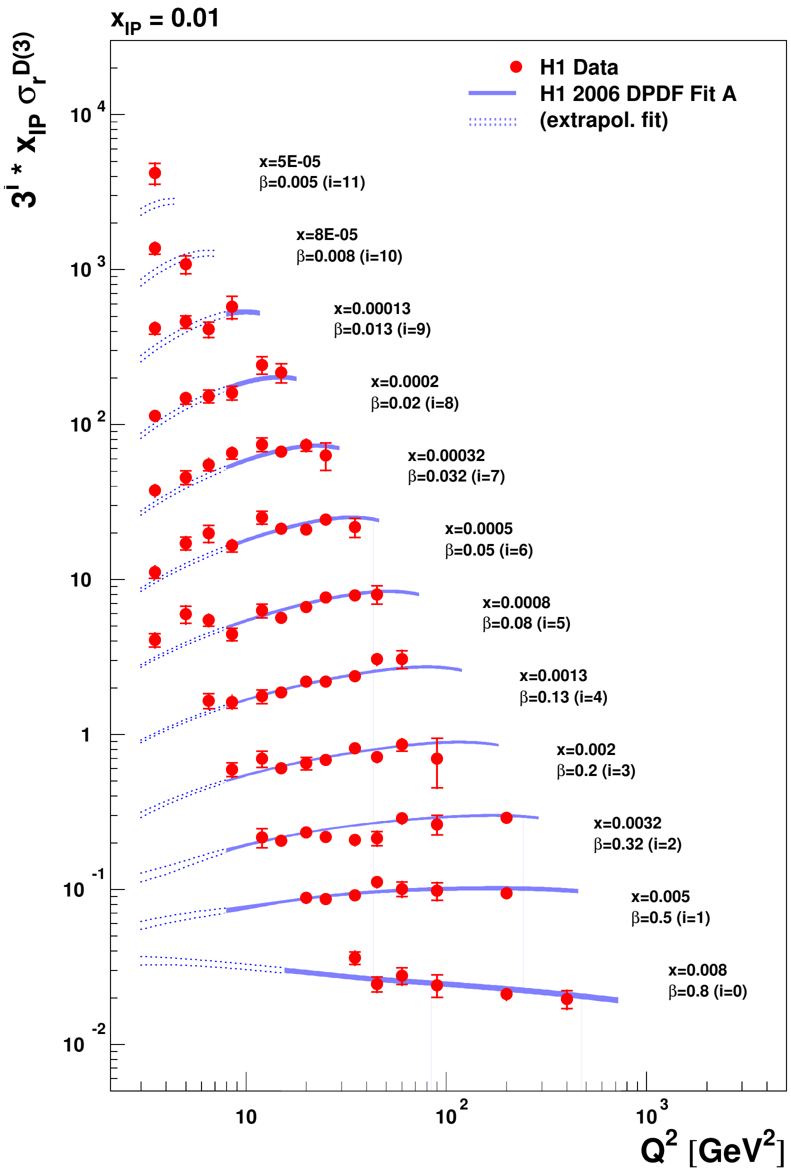
large γ, soft rescattering expected, dominant contribution for low E_T jets

- Theory: direct and resolved processes well separated only at LO
- Experimentally: x_γ reconstructed by jets, $x_\gamma = x_\gamma^{OBS} = \frac{\sum (E-p_z)_{jets}}{\sum (E-p_z)_{hadrons}}$

Diffractive final states, factorisation tests

- Basic strategy
  - measure F_2^D from inclusive measurement,
  - extract diffractive PDFs from NLO DGLAP fit
  - measure an exclusive diffractive final state, open charm and dijets, in DIS and PHP
  - compare the measurement to NLO calculation

Diffractive structure functions, inclusive data



$$\frac{d^3\sigma^{ep\to eXp}}{d\beta dQ^2 dx_{I\!P}} = \frac{4\pi\alpha_{em}^2}{\beta Q^4} Y^+ \sigma_r^{D(3)}(\beta, Q^2, x_{I\!P})$$

$$Y^+ = 1 + (1-y)^2$$

$$\sigma_r^{D(3)} = F_2^{D(3)} - \frac{y^2}{Y^+} F_L^{D(3)}$$

$F_L^{D(3)} = 0$ at LO

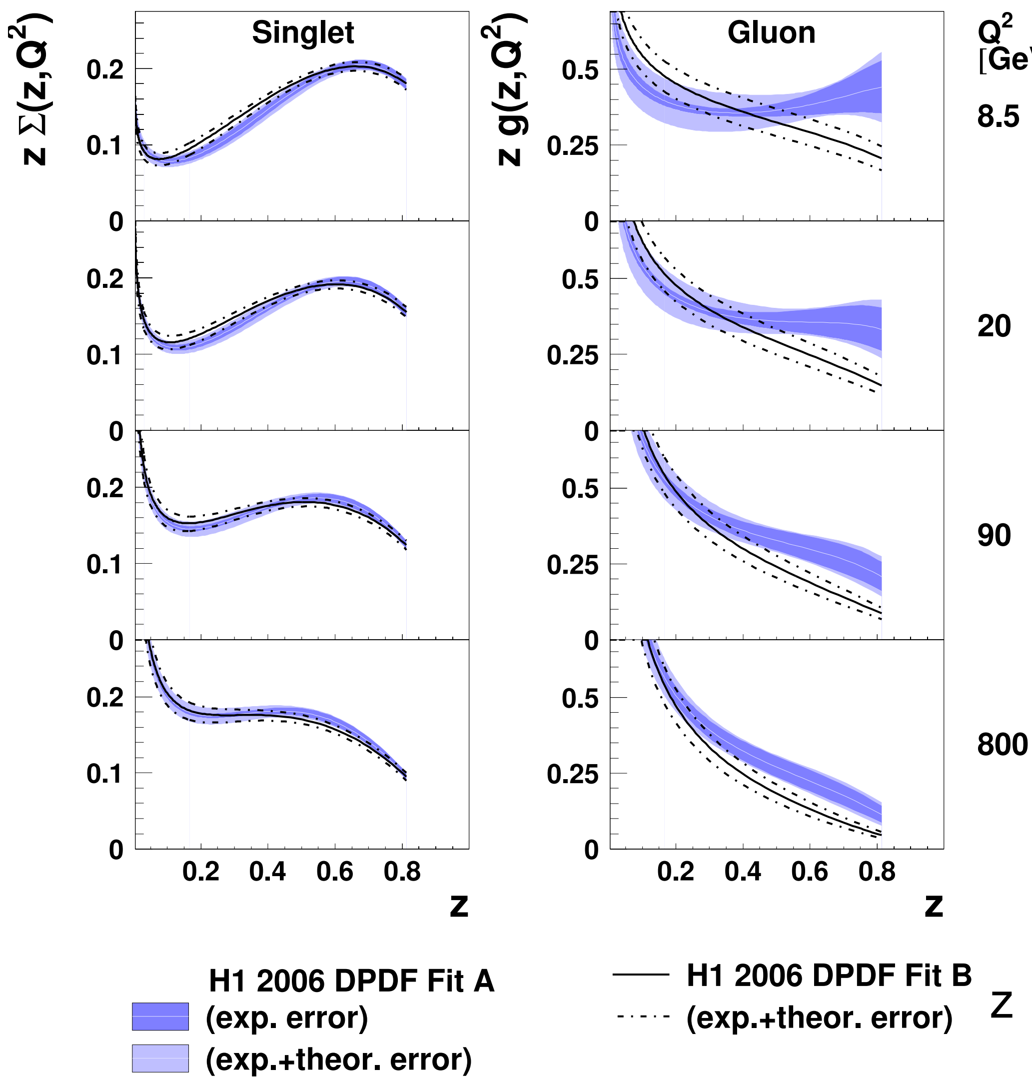
Reduced cross section constrains quark density

gluon density from $\log Q^2$ dependence

- Positive scaling violations up to high β

$\Rightarrow$ lot of gluons in diffractive exchange

Diffractive PDFs from inclusive data



- Additional assumption: proton vertex factorisation

$$\frac{d^2F_2^D(x_{I\!P},t,x,Q^2)}{dx_{I\!P}\,dt} = f_{I\!P/p}(x_{I\!P},t)F_2^{I\!P}(\beta,Q^2)$$

- NLO DGLAP fits:

- parametrise Flavour Singlet (q, $\bar{q}$) and Gluons at $Q^2 \simeq 3$ GeV^2

- evolve with NLO DGLAP and fit

- Different parametrisations:

H1 2006 fit A: $zg(z,Q_0^2) = A(1-z)^B$

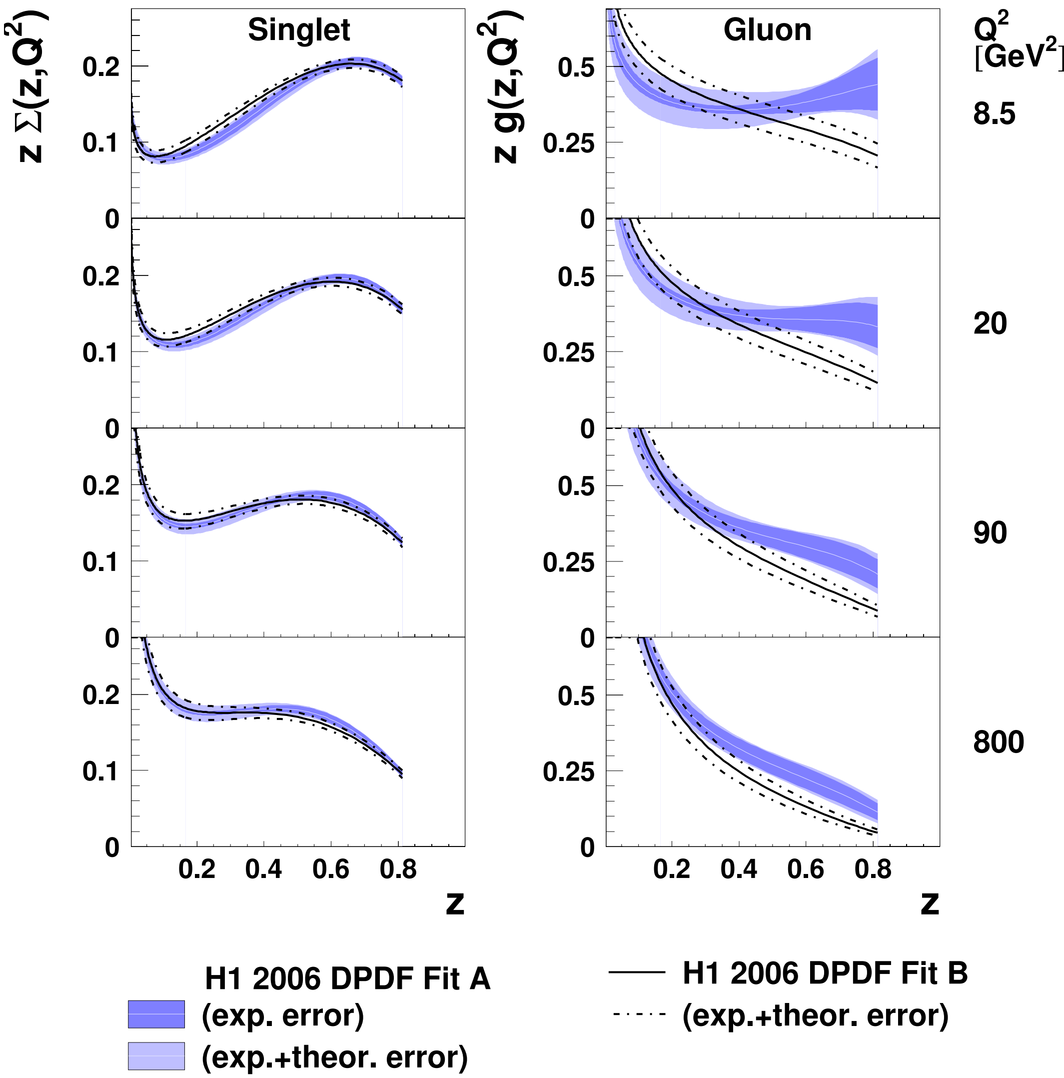
H1 2006 fit B: $zg(z,Q_0^2) = A(1-z)$

but also Martin Ryskin Watt,

ZEUS fit LPS + charm ...

z = fractional momentum of parton participating in hard scattering

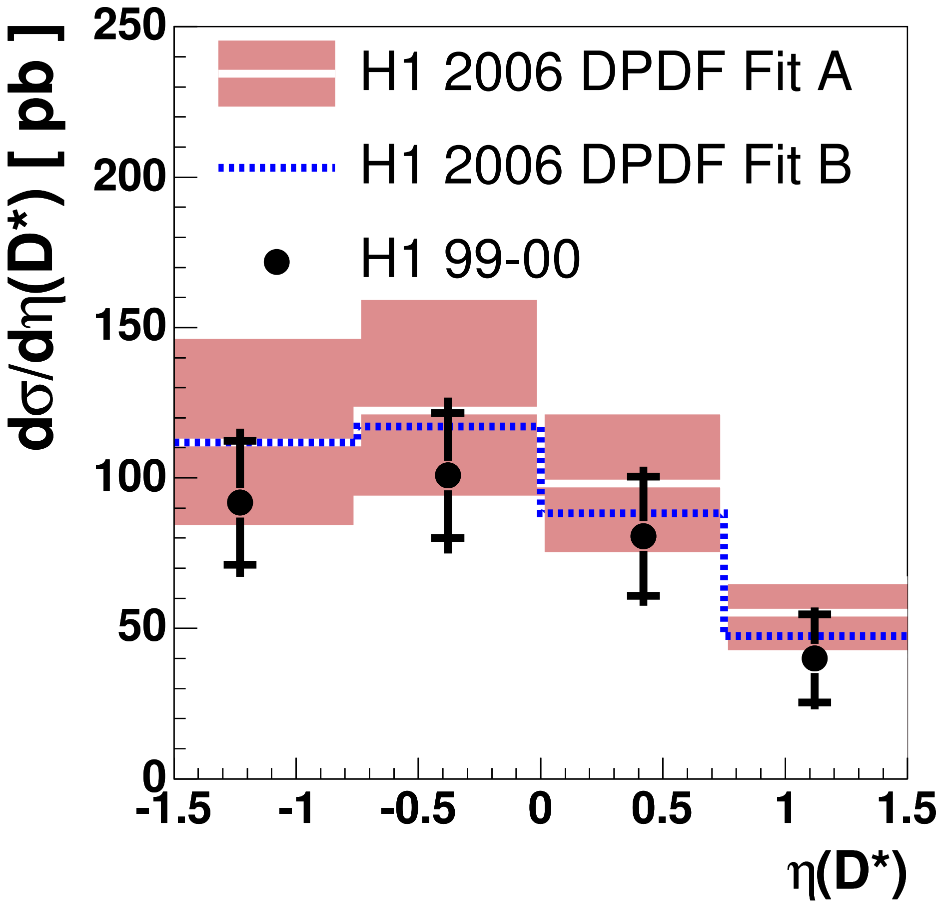
Diffractive PDFs from inclusive data



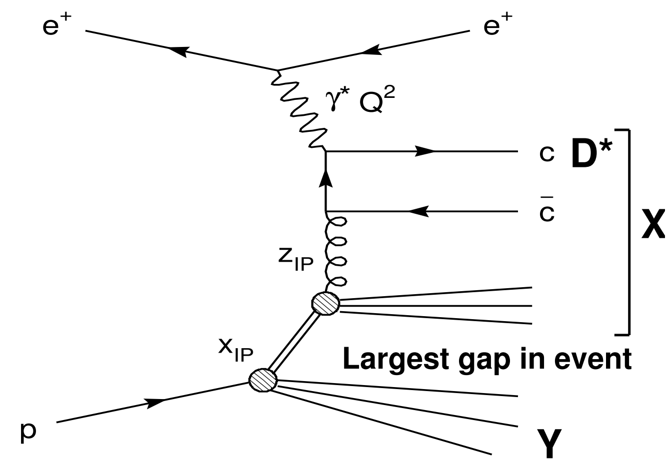
- Well constrained singlet
- Gluon dominated, 75% of exchanged momentum carried by gluons. Gluons weakly constrained, exp. at high values of z = fractional momentum of parton participating in hard scattering

  - Low z: evolution driven by $g \to q\bar{q}$ strong sensitivity to gluons
  - High z: $q \to qg$ contribution to evolution dominant, relative error on derivative grows

Factorisation tests: D* in DIS



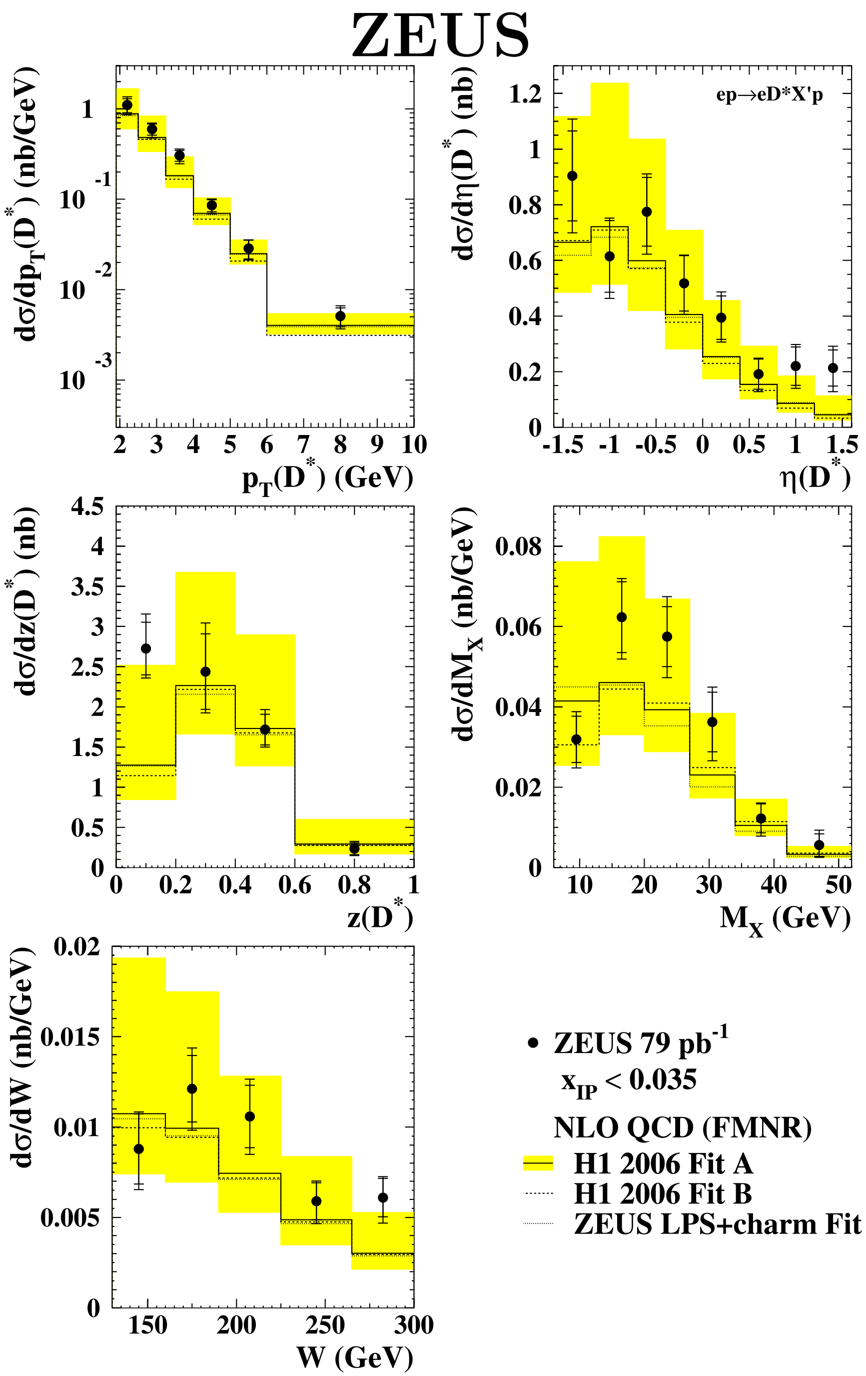
- Use diffractive PDFs from NLO DGLAP fits of F_2^D to predict rate of charm production



Kinematic range:
$2 < Q^2 < 100$ GeV^2, $p_T(D^*) > 2$ GeV,
$|\eta(D^*)| < 1.5$, $0.05 < y < 0.7$,
150 diffractive D^*

- NLO calc. + diffractive PDFs describe data

$\Rightarrow$ Within uncertainties, QCD factorisation works



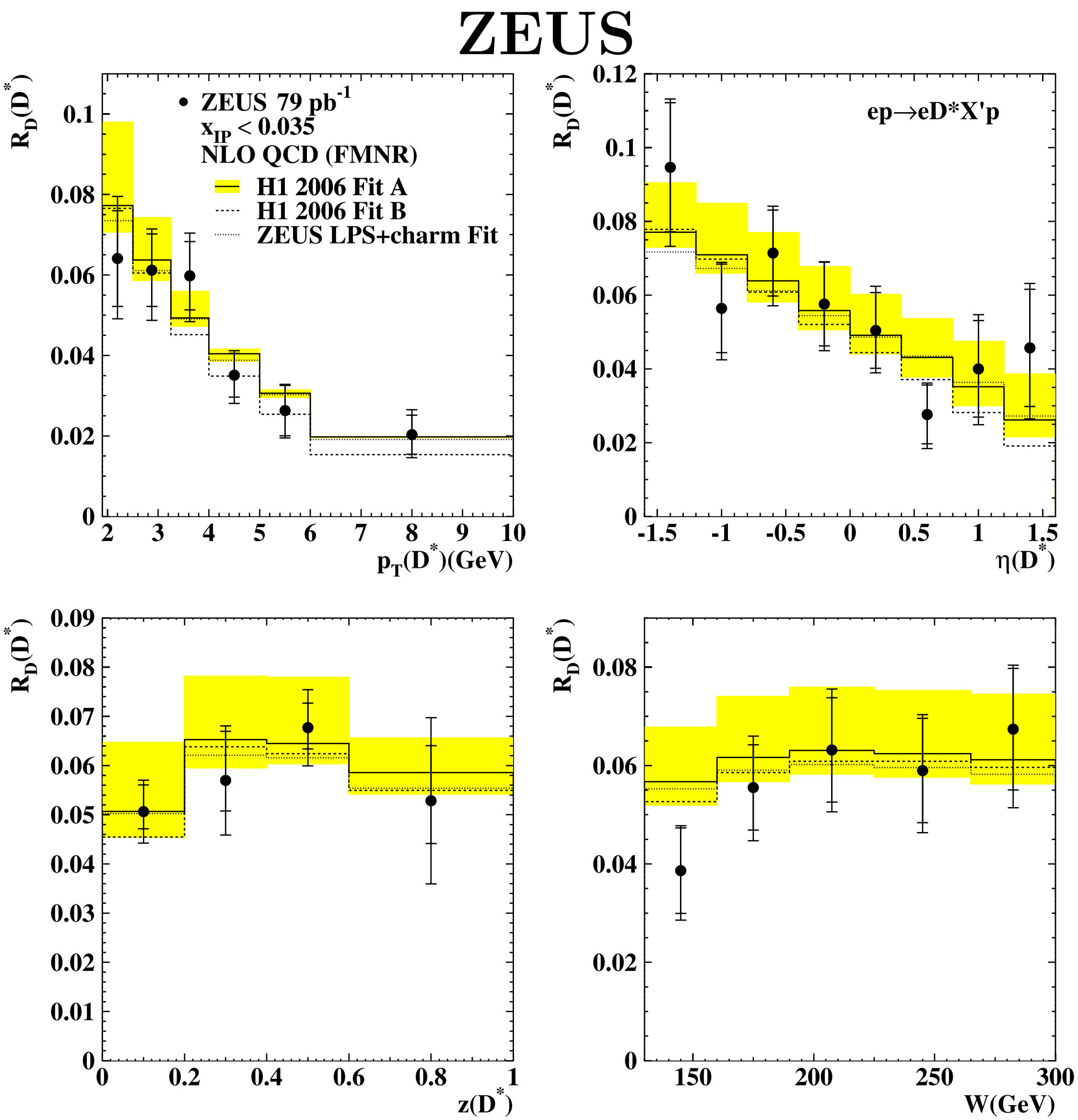
Factorisation tests: D* in γp

Kinematic range:
$130 < W < 300$ GeV, $p_T(D^*) > 1.9$ GeV, $|\eta(D^*)| < 1.6$
12500 D^*, 200 diffractive D^*

In the kin. region of the measurement, D^* production mainly produced in direct photon processes → no suppression expected

- NLO calc. + diffractive PDFs describe data

⇒ No evidence of factorisation breaking



Factorisation tests: D* in γp

- Ratio diffractive/inclusive

$R_D = 5.7 \pm 0.5\%$

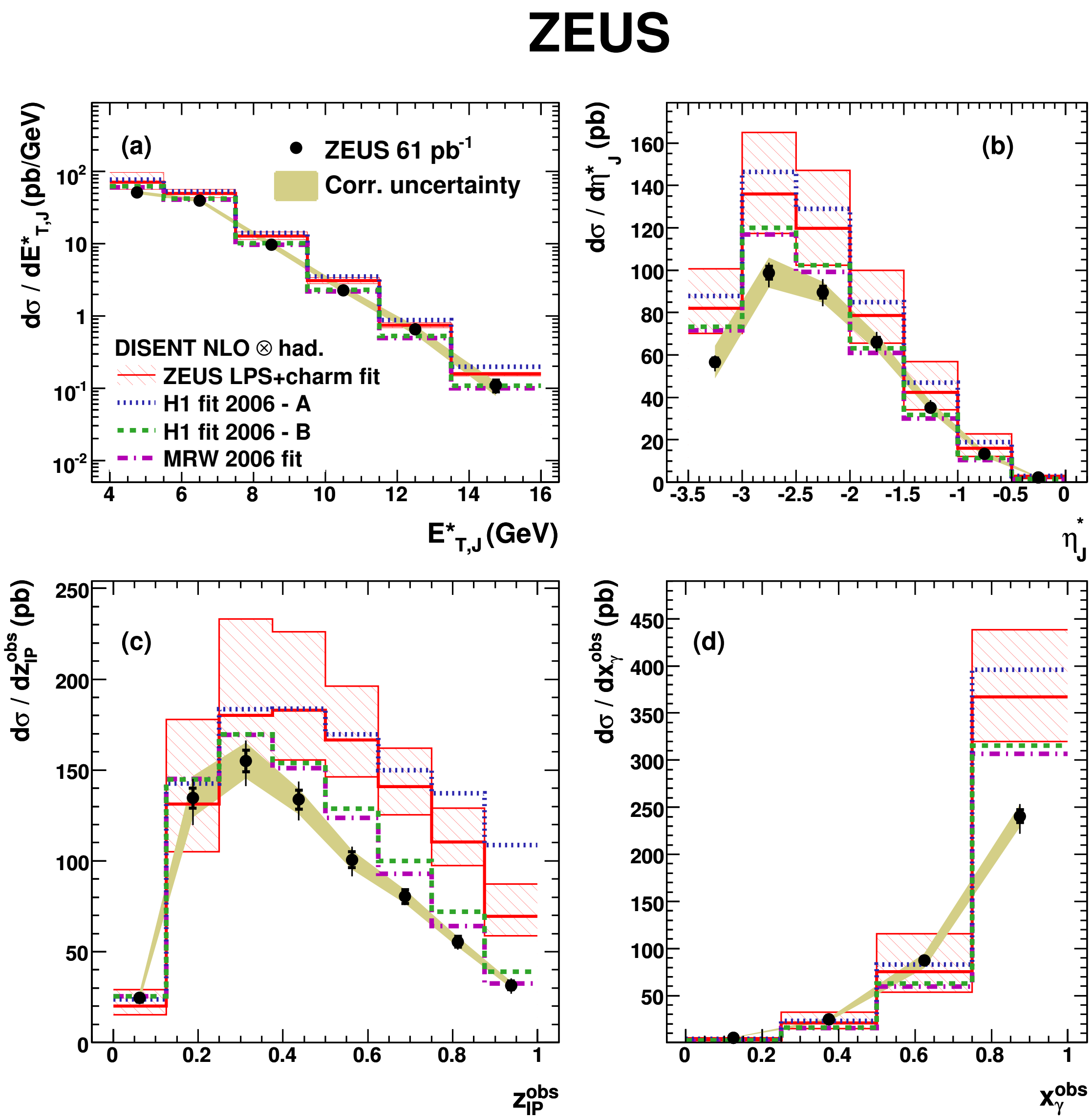
- Ratio from NLO calculations:

  H1 fit 2006 B $\Rightarrow 5.7\%$

  ZEUS fit LPS + charm: $\Rightarrow 5.8\%$

$\Rightarrow$ No evidence of factorisation breaking

Factorisation tests: dijet in DIS



Kinematic range:

$5 < Q^2 < 100$ GeV^2,

$E_{Tjet1(jet2)} > 4.(5.)$ GeV

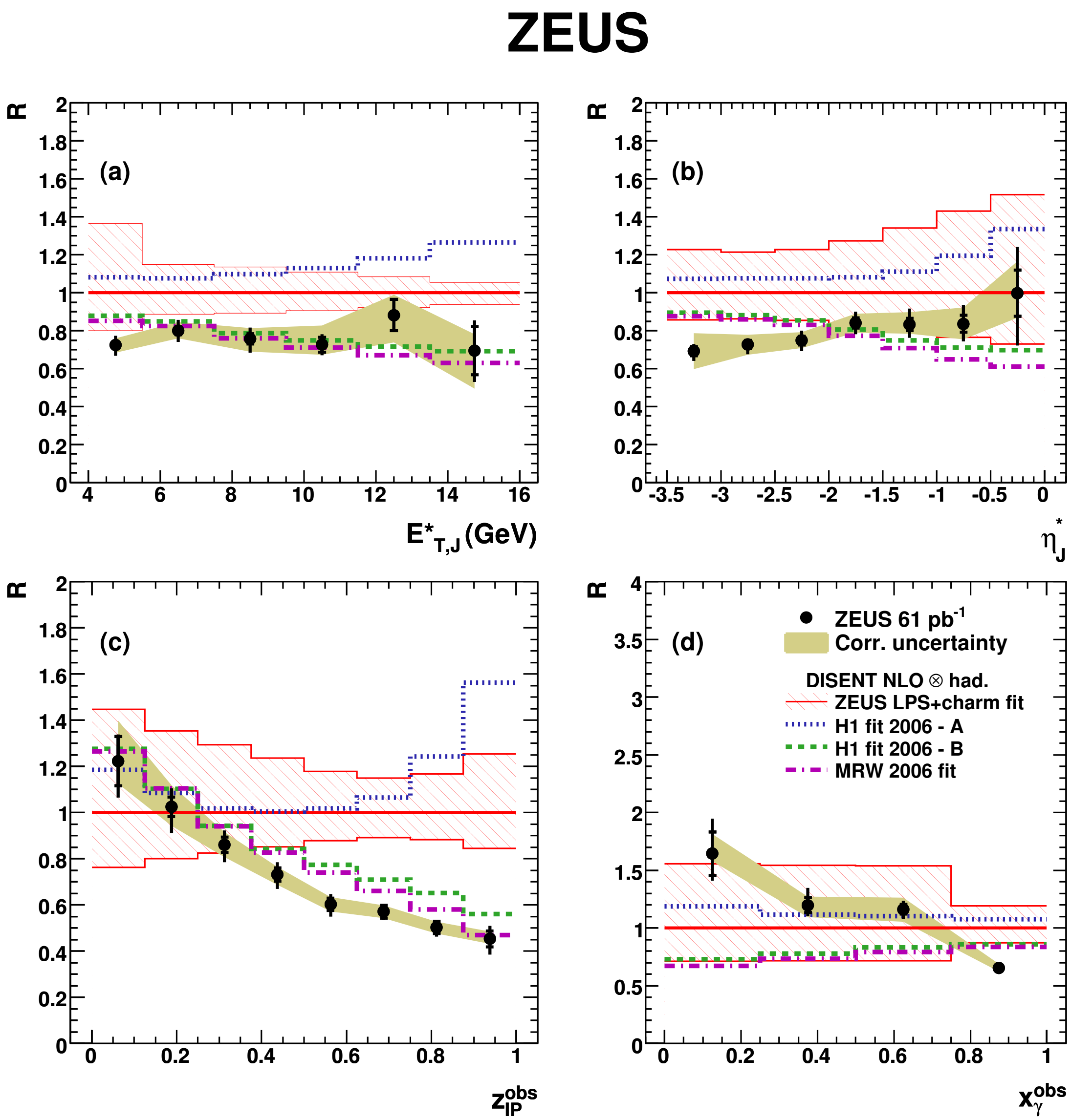
- NLO predictions using diffractive PDFs describes data within theoretical uncertainties
- Agreement depends on kinematic region $(0 - 25\%)$
- Large discrepancy between different diffractive PDFs,

best agreement for

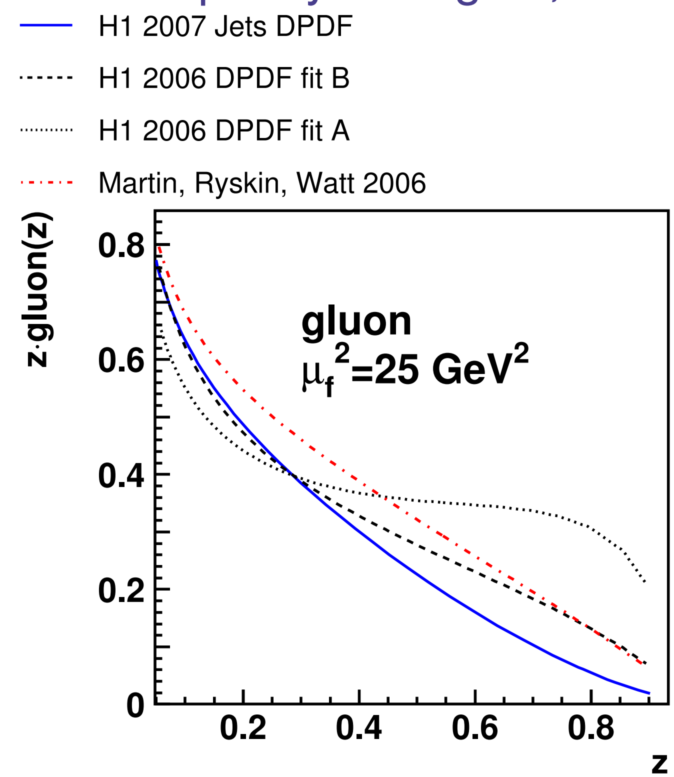
H1 2006 fit B

and Martin Ryskin Watt

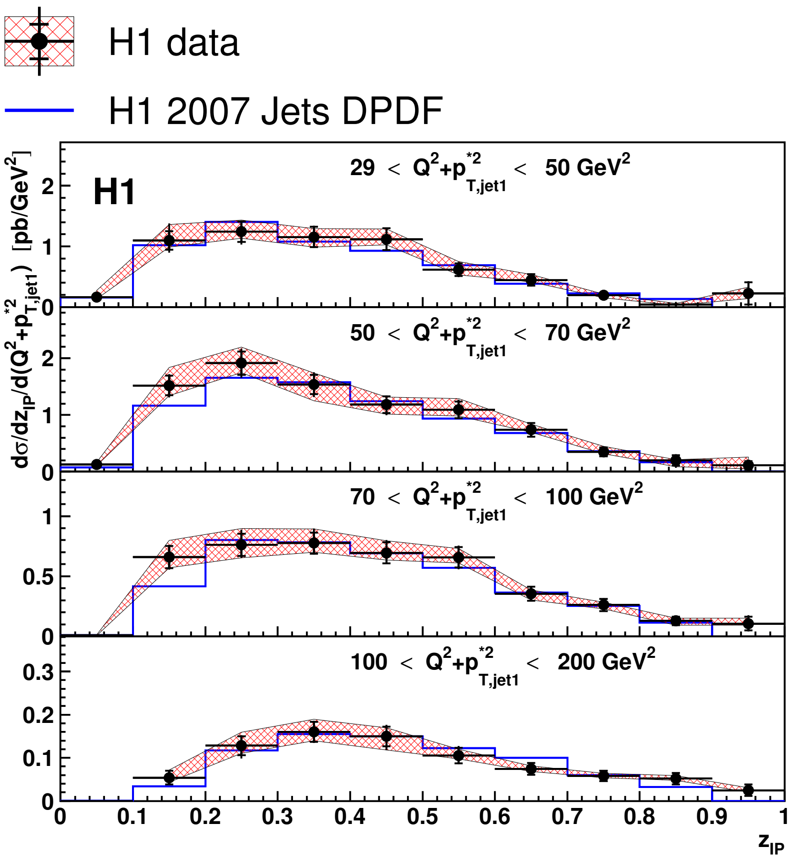
Factorisation tests: dijet in DIS

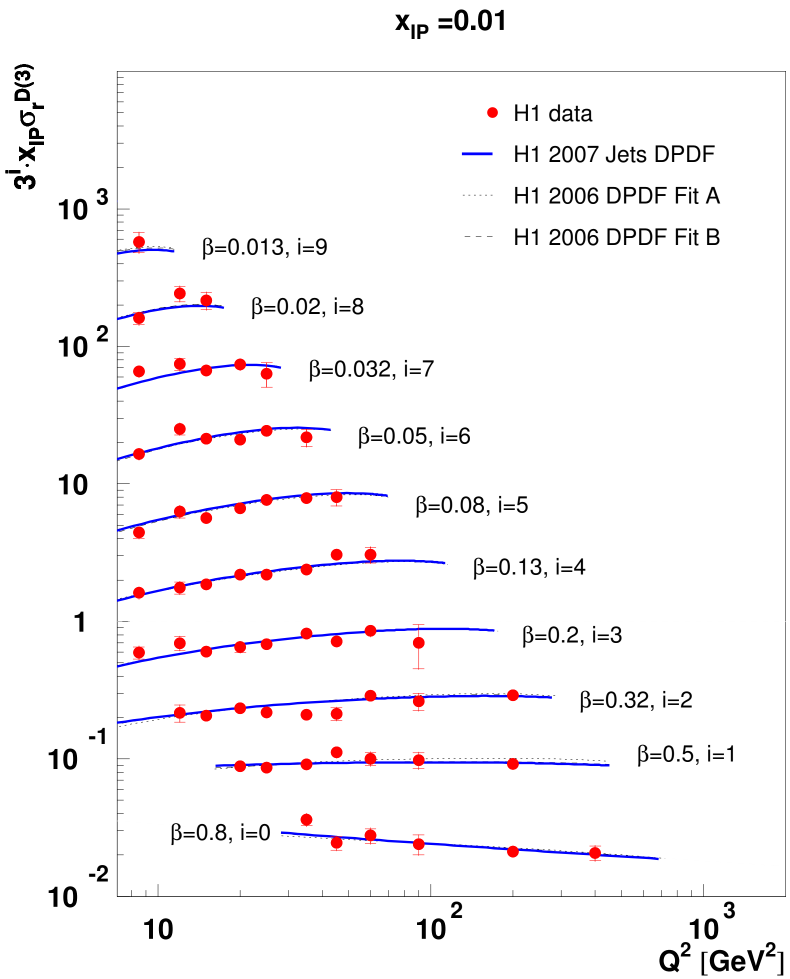


- R = data/NLO (LPS + charm)
- Discrepancy at large z, new fits:



Combined fit to inclusive and dijet DIS data





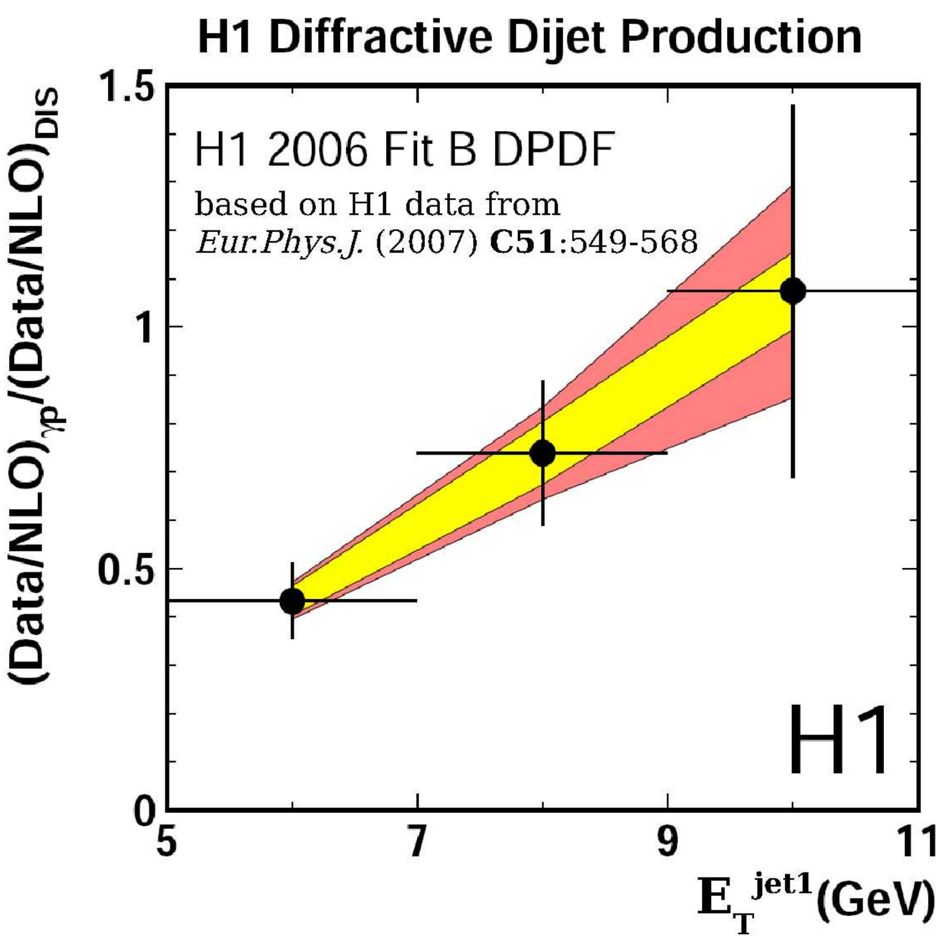
- Combined fit constrains quark and gluon densities over a wide range

$0.05 < z < 0.9$

$\Rightarrow$ Uncertainty on gluon density reduced

Factorisation tests in γp

Double ratio of (data/NLO)$^{\gamma p}$/ (data/NLO)^{DIS}, to cancel diffractive PDF uncertainty

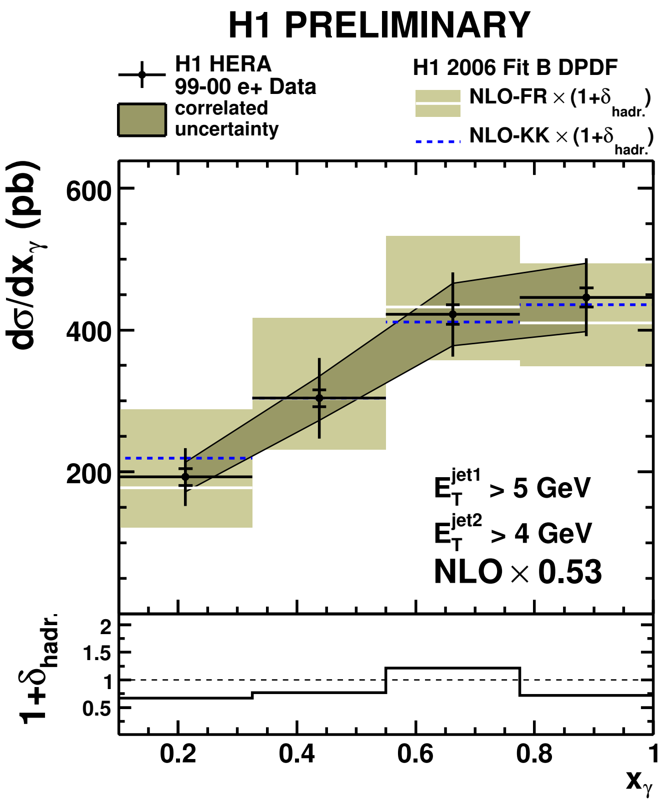


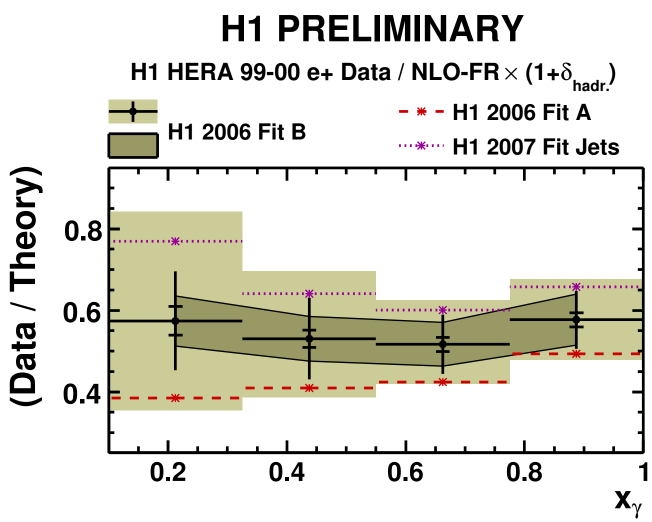
Factorisation breaking expected vs x_γ

HERA data:
global suppression vs x_γ
possible dependence of gap survival on E_T range

$\Rightarrow$ Measurement investigated vs x_γ
in different E_T region

Factorisation tests in γp





•Low E_T

$E_{T\,jet1(jet2)} > 5.(4.)$ GeV

$-1. < \eta^{jet} < 2$

$0.3 < y < 0.65$

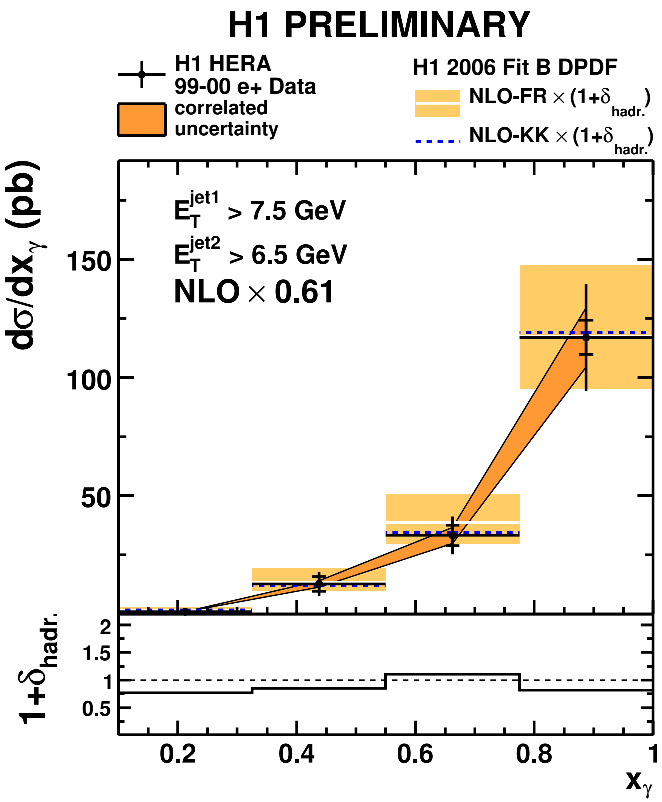
•Prediction extrapolated at high z, beyond the range of the diffractive PDF

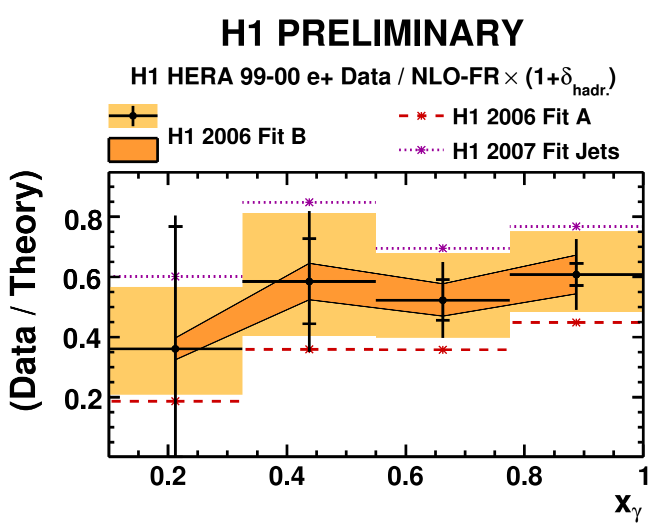
⇒ No evidence of suppression of resolved contribution only

⇒ Global suppression

data / NLO(H1 fit B) $= 0.54 \pm 0.10(syst) \pm 0.14(scale)$

data / NLO(H1 fit jets) $= 0.65 \pm 0.11(syst)$





Factorisation tests in γp

•High E_T

$E_{T\,jet1(jet2)} > 7.5(6.5)$ GeV

$-1.5 < \eta^{jet} < 1.5$

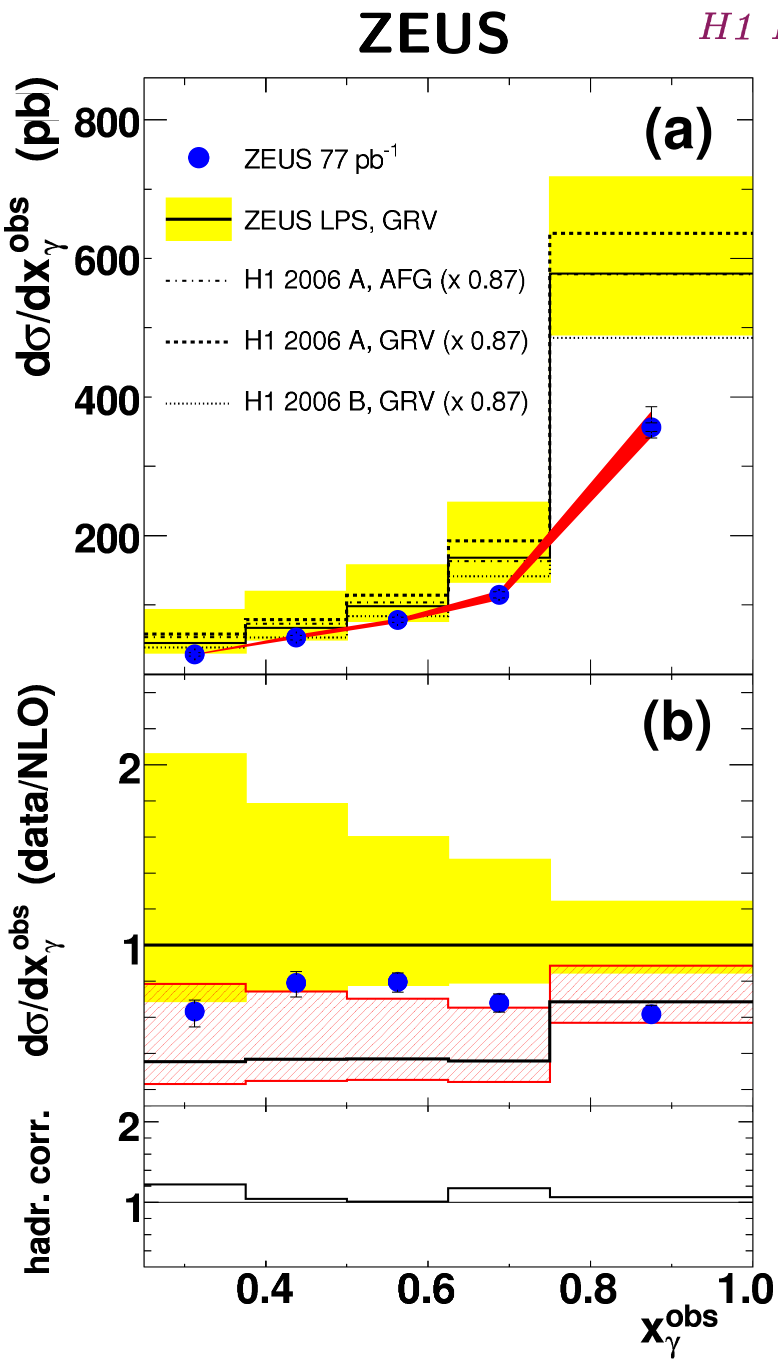
$0.3 < y < 0.65$

$\Rightarrow$ No evidence of suppression of resolved contribution only

$\Rightarrow$ Global suppression

data / NLO(H1 fit B) $= 0.61 \pm 0.13(syst) \pm 0.15(scale)$

data / NLO(H1 fit jets) $= 0.79 \pm 0.16(syst)$



Factorisation tests in γp

•High E_T

$E_{Tjet1(jet2)} > 7.5(6.5)$ GeV

$-1.5 < \eta^{jet} < 1.5$

$0.2 < y < 0.85$

$\Rightarrow$ Large theoretical uncertainty

$\Rightarrow$ No suppression of resolved contribution only

$\Rightarrow$ Global suppression

data / NLO(ZEUS LPS + charm) $\simeq 0.6$

data / NLO(H1 fit B) $\simeq 0.9$

$\rightarrow$ data compatible with no or small suppression, depending on diffractive PDFs

$\rightarrow$ Indication of possible suppression at small E_T

Uncertainties for predictions

- Large scale dependence
  - higher QCD order important
- Flavour scheme dependence

DIS, PHP

  - dPDF fitted using 3-flavour FFNS + massive c,b
  - dijets calculated with all flavours massless ZM-VFNS
- Gluon content of the Pomeron
  - poorly constrained at high z
- Proton dissociation correction factor
  - 10% uncertainty when using H1 dPDF to ZEUS

PHP

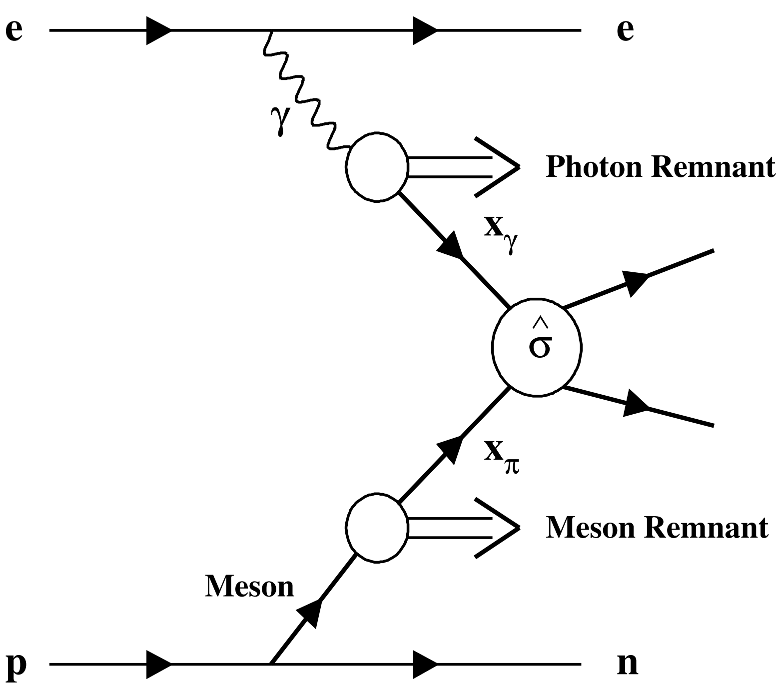
- Factorisation scheme dependence for the photon
- quark/gluon content of the photon

$\Rightarrow$ up to $\sim 30\%$ uncertainty

Another test of factorisation breaking:

Dijet photoproduction with a leading neutron

Dijet photoproduction with a leading neutron

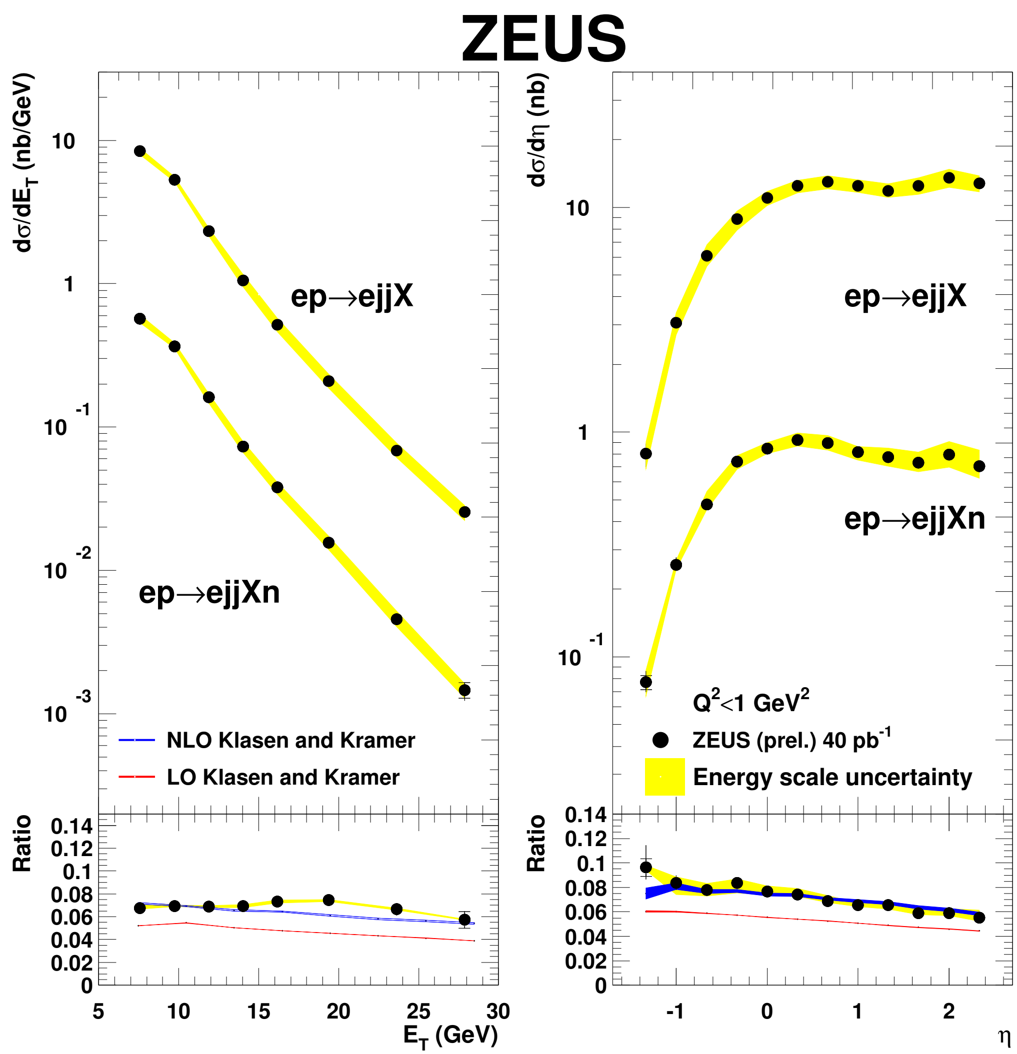


- Factorisation breaking expected in dijet photoproduction with a leading neutron $\gamma p \to jjnX$; • events whith a non-diffractive exchange (pion exchange)

- Soft rescattering expected between γ remnant and n

- NLO predictions (non-perturbative pion flux factor) normalised to DIS $ep \to ejjXn$ data and compared to photoproduction data, looking for suppression

Dijet photoproduction with a leading neutron



kinematic range:

$E_{T\,jet1(jet2)} > 7.5(6.5)$ GeV

$-1.5 < \eta^{jet} < 2.5$

$130 < W < 280$ GeV

$E_n > 184$ GeV

- Ratio $(ep \rightarrow ejjXn)/(ep \rightarrow ejjX)$ compared to NLO (hadronisation corr. cancel in ratio)

⇒ NLO predictions describe data

- data consistent with factorisation of lepton and hadron vertices and one-pion-exchange model

⇒ no sign of factorisation breaking

QCD factorisation tests summary

Factorisation studied within QCD framework:

• New diffractive PDFs available:

• inclusion of dijet data in the fits provides a better constraint on gluon density

Diffractive charm in PHP and DIS:

• within low statistics and large NLO uncertainties no hint of factorisation breaking observed

Diffractive dijets:

• diffractive dijet production measured in wide range of photon virtualities (0-100 GeV^2)

• experimental errors much smaller than theoretical uncertainties

• NLO predictions based on dPDFs from inclusive data describes data in shape

• in PHP, data favor a global suppression of NLO QCD rather than a suppression of only the resolved component

Factorisation breaking observed at low E_T

Conclusions

- QCD factorisation investigated at HERA in many final states and over a wide kinematic range
- Indications of factorisation breaking observed in dijets photoproduction at low E_T (where resolved processes dominate), but not clearly vs x_γ

- Exp: cross-section ratios can be useful, i.e. ratio diffractive/inclusive production vs E_T, x_γ
- Better QCD prediction needed (consistent flavours/masses treatement, showering ...) to quantify the suppression