Diffractive PDF fits and factorisation tests at HERA

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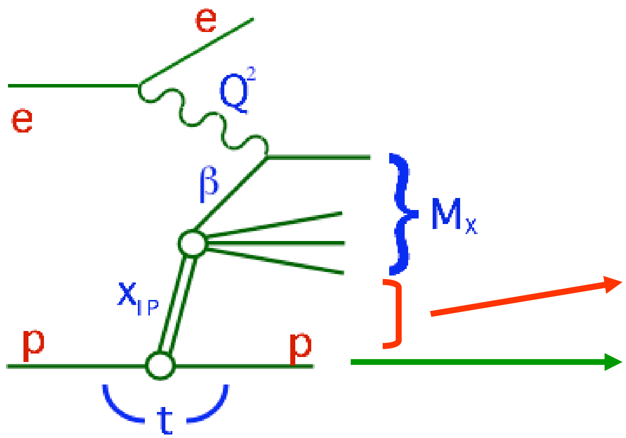
DIFFRACTION 2010

Outline:

- Introduction
- QCD analysis of ZEUS diffractive DIS data and extraction of the DPDFs
- H1 data on diffractive dijets and factorisation
- Summary

Diffractive DIS



Diffraction is a significant fraction of the inclusive cross section

Characterised by:

Large Rapidity Gap (LRG)

Fast proton (or small mass system Y)

Deep inelastic scattering on an object with vacuum quantum numbers ('pomeron').

pQCD framework as long as a hard scale is present.

In analogy with inclusive DIS:

$$\frac{d^4\sigma^{ep\to e'Xp'}}{d\beta dQ^2 dx_{IP} dt} = \frac{2\pi\alpha^2}{\beta Q^4} Y_+ \underbrace{\left[F_2^{D(4)}(\beta,Q^2,x_{IP},t) - \frac{y^2}{Y_+} F_L^{D(4)}(\beta,Q^2,x_{IP},t)\right]}_{= \sigma_r^{D(4)}(\beta,Q^2,x_{IP},t)}$$

→ Use inclusive diffractive data to extract DPDFs via NLO QCD fits, where:

DPDFs = proton PDFs when a fast proton is in the final state

Theoretical framework

QCD factorisation theorem, proven for DDIS by **J.Collins [PR D57 (1998) 3051]**

$$\sigma^D(\gamma^* p \to Xp) = \sum_i \hat{\sigma} \otimes f_i^D(x_{IP}, t, z, Q^2)$$

Hard subprocess ME
pQCD calculable

DPDFs, universal for diffractive DIS processes

Proton-vertex factorisation assumption, supported by H1 and ZEUS data

$$f_i^D(x_{IP}, t, z, Q^2) = f_{IP}(x_{IP}, t) f_i^{IP}(z, Q^2) + f_{IR}(x_{IP}, t) f_i^{IR}(z, Q^2)$$

Flux parametrisation

$$f(x_{IP}, t) = \frac{Ae^{Bt}}{x_{IP}^{2\alpha(t)-1}}$$

with $\alpha(t) = \alpha(0) + \alpha' t$

Pomeron PDFs

Reggeon PDFs taken from pion (GRV)

→ Fit z and Q^2 dependence at fixed x_{IP} and t

(z = momentum fraction of the diffr exchange entering the hard scattering)

Fitting procedure and data sets

Pomeron PDFs parametrised at initial $Q_o^2 = 1.8$ GeV^2, Q^2 evolution with DGLAP :

$$zf_k^{IP}(z,Q^2) = A_k z^{B_k}(1-z)^{C_k}$$ with k = g,S

- for all flavours q = qbar
- assume d = u = s
- heavy quarks dynamically generated above thresholds: $m_c = 1.35$ GeV, $m_b = 4.3$ GeV using the General-Mass Variable-Flavour-Number-Scheme of Thorne and Roberts

⟶ 6 parameters + $\alpha_{IP}(0)$, $\alpha_{IR}(0)$, A_{IR} (b and α' fixed by Regge fits to ep and pp data)

Gluons expected to be poorly constrained by inclusive data (lnQ^2 dependence of F_2^D)

⟶ two cases: "Standard": fit S with B_g and C_g free
"Constant": fit C with $B_g = C_g = 0$ (as for H1 2006 fit B)

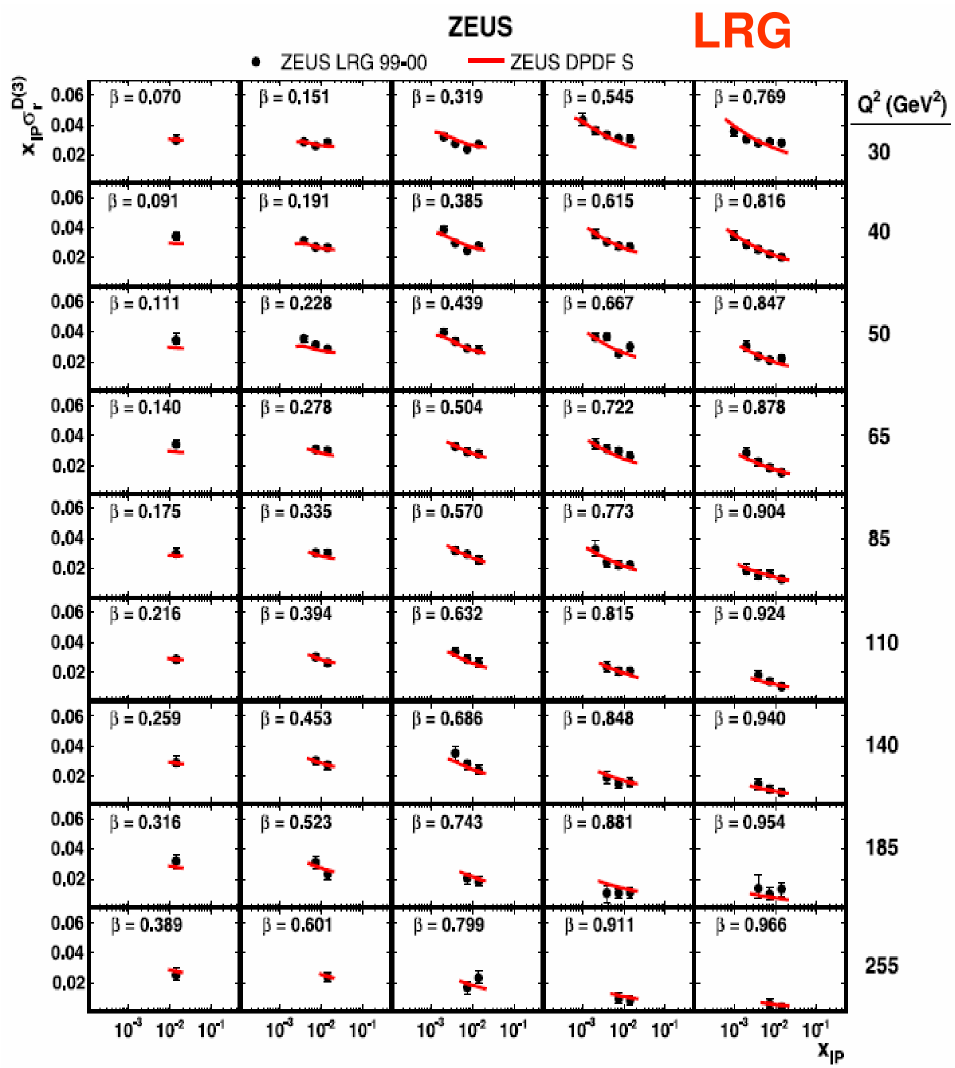
Latest inclusive ZEUS data: - LRG and LPS (229 + 36 points)

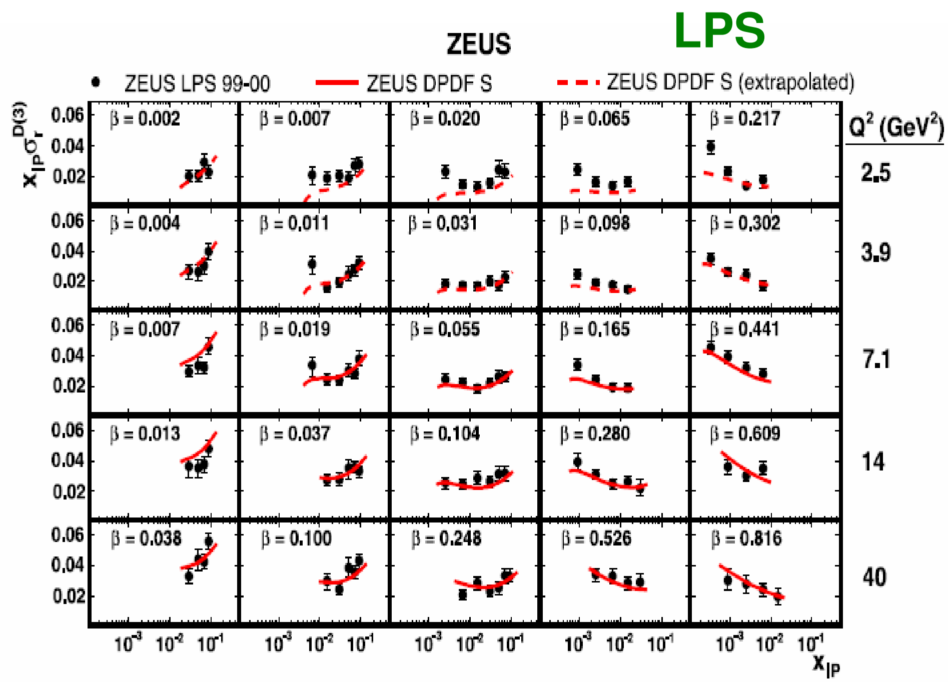
ZEUS, NP B816 (2009) 1

- only data with $Q^2 > 5$ GeV^2 used
- overlapping LPS data not used

Fit vs data

ZEUS, NP B831 (2010) 1

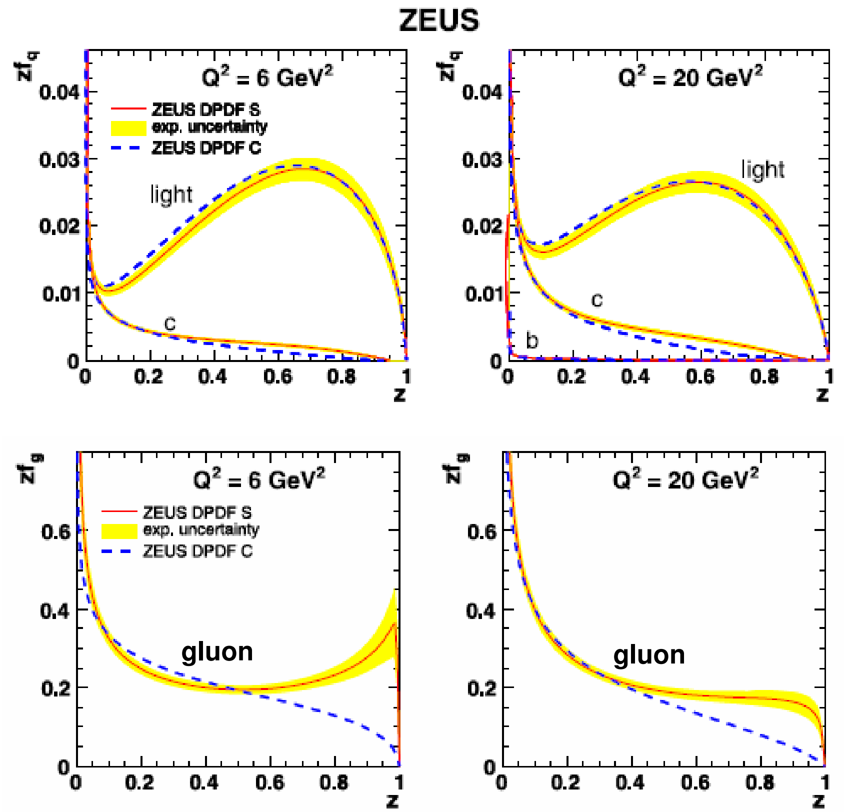




Both fits give a comparably good description of inclusive data for $Q^2 > 5$ GeV^2

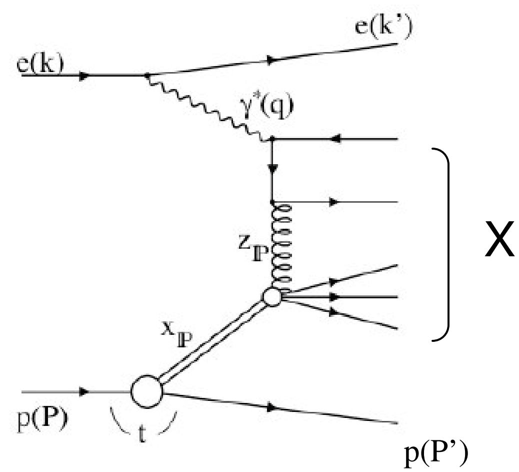
Values of $\alpha_{IP}(0)$, $\alpha_{IR}(0)$, A_{IR} are consistent with Regge fits

DPDFs



Quark densities well constrained by reduced cross sections

Gluon density constrained indirectly by scaling violations: large uncertainty at high z

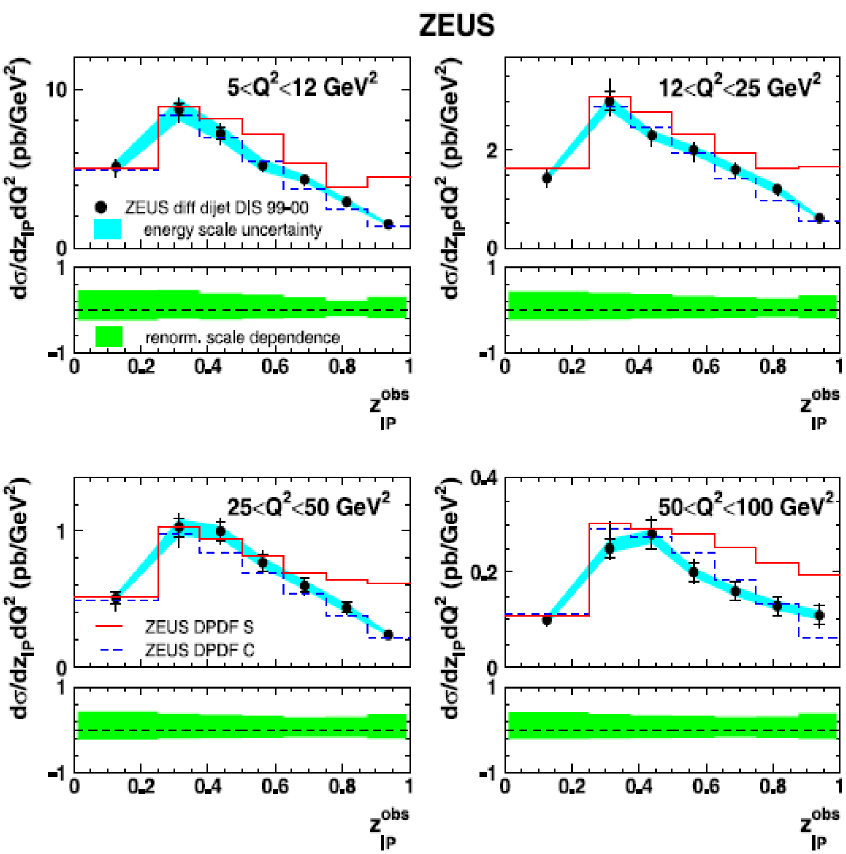


Use dijet data in diffractive DIS to constrain the gluon density (photon-gluon fusion at LO)

$$z_{IP} = (Q^2+M_{jj}^2)/(Q^2+M_X^2)$$

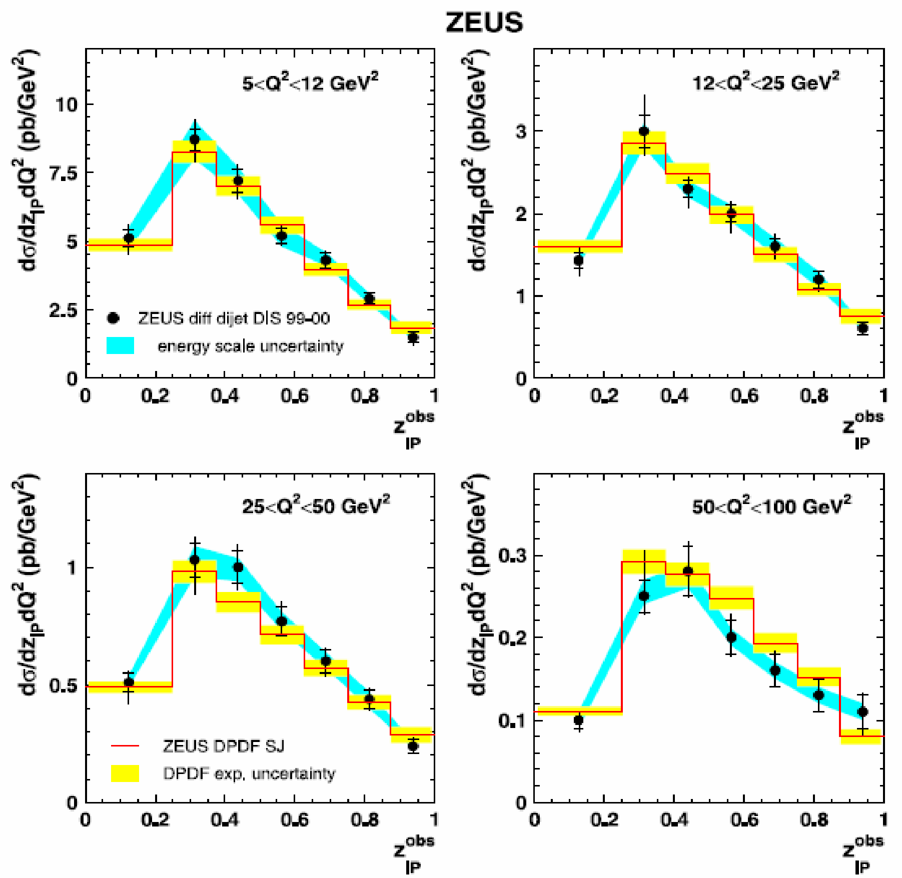
Comparison with DIS dijet data

ZEUS, EPJ C52 (2007) 813



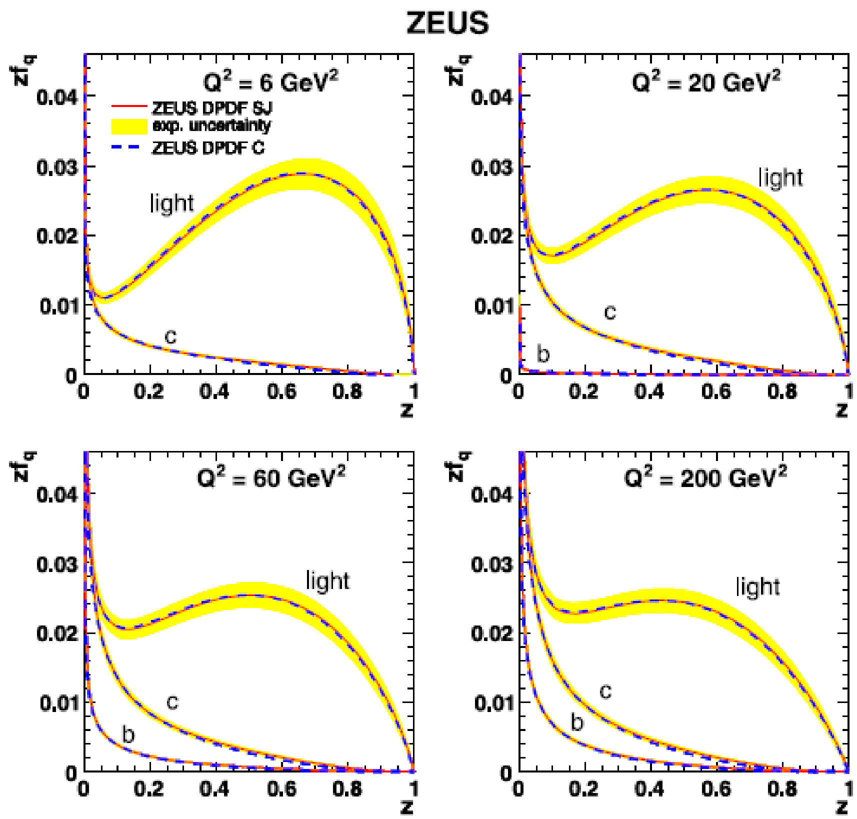
Fit C better than fit S when comparing NLO predictions (DISENT) with DDIS dijet data

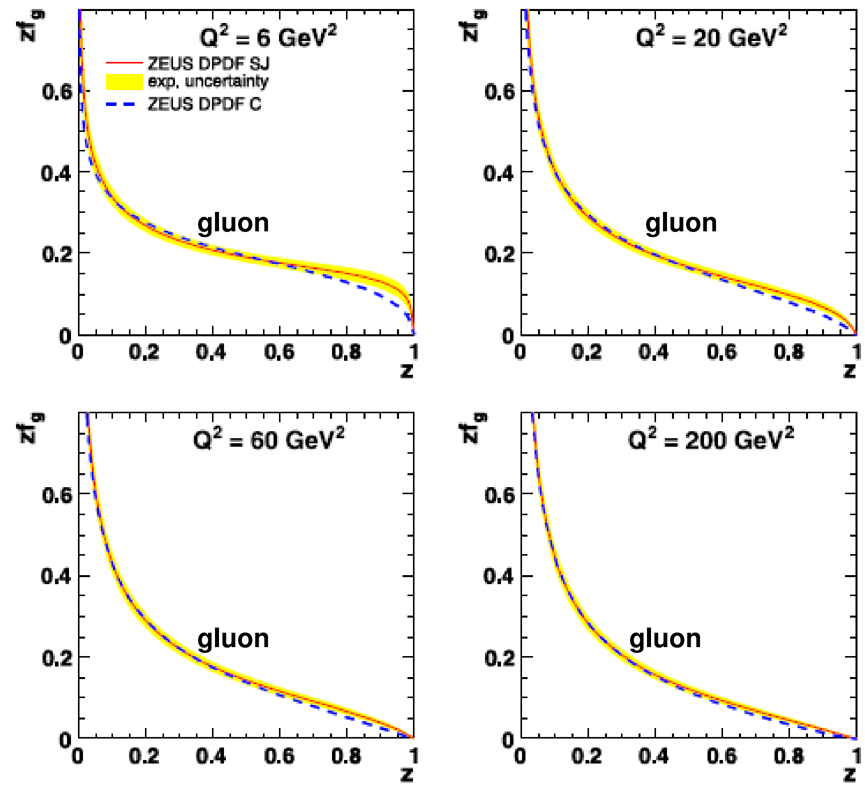
Factorisation holds in DDIS: use dijet data for a combined **fit S inclusive+dijets (SJ)**

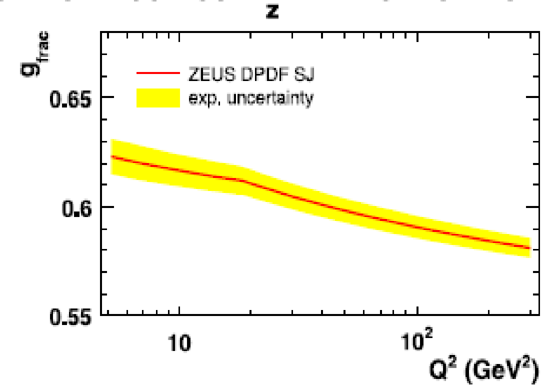


→ Good data description

DPDFs from fit SJ





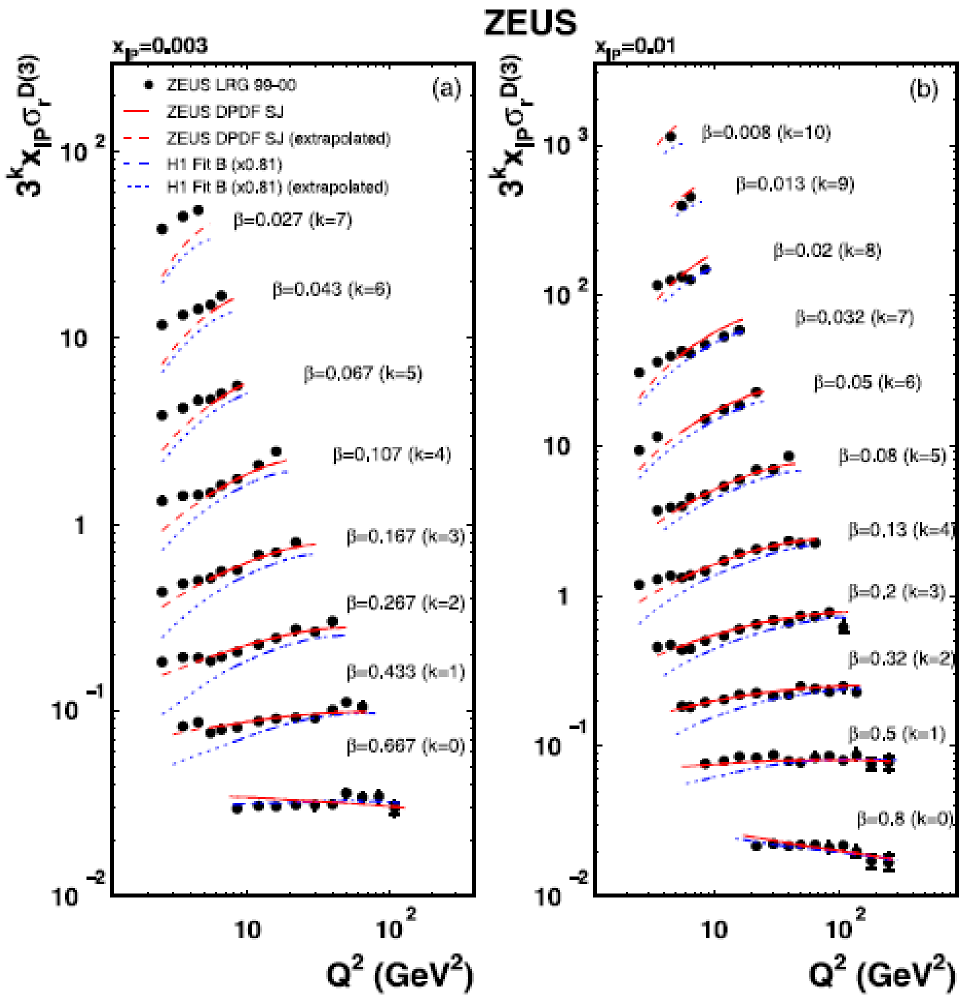


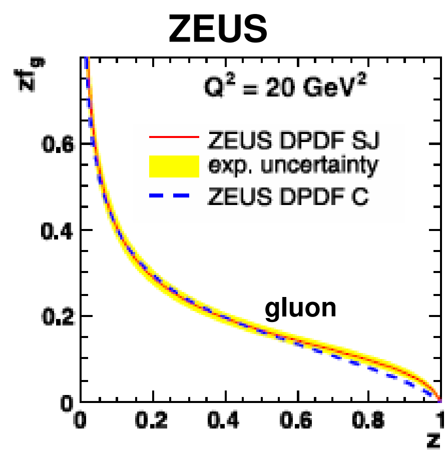
Fit SJ and fit C give very similar results

Diffractive PDFs are **gluon dominated**: ~ 60%

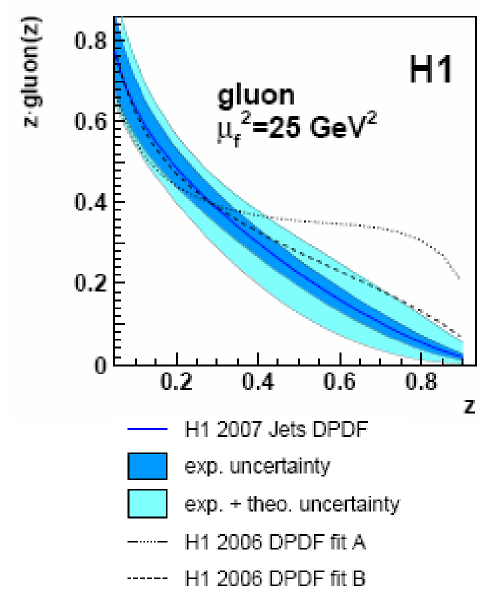
Comparison with H1 2006 fit B

H1, EPJ C48 (2006) 715





H1, JHEP 0710:042 (2007)



Plan to extract HERA DPDFs from H1+ZEUS final combined data

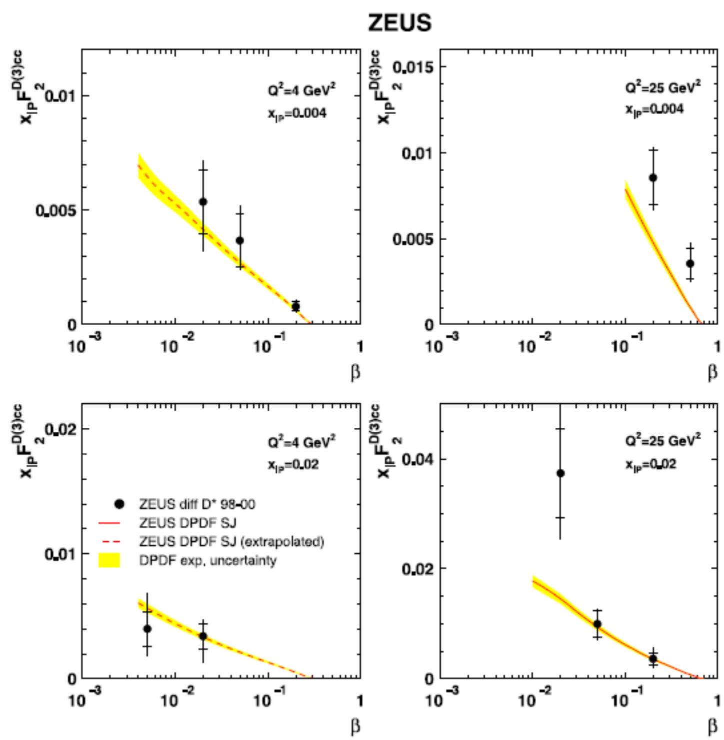
H1 predictions corrected to $M_Y = M_P$ as for ZEUS via the scaling factor 0.81

D* and dijets in diffractive DIS

Use DPDFs extracted from inclusive DDIS for calculating NLO predictions to semi-inclusive final states: **test universality of DPDFs**

→ Open charm and dijets in DIS: hard scales in the process ensure use of pQCD

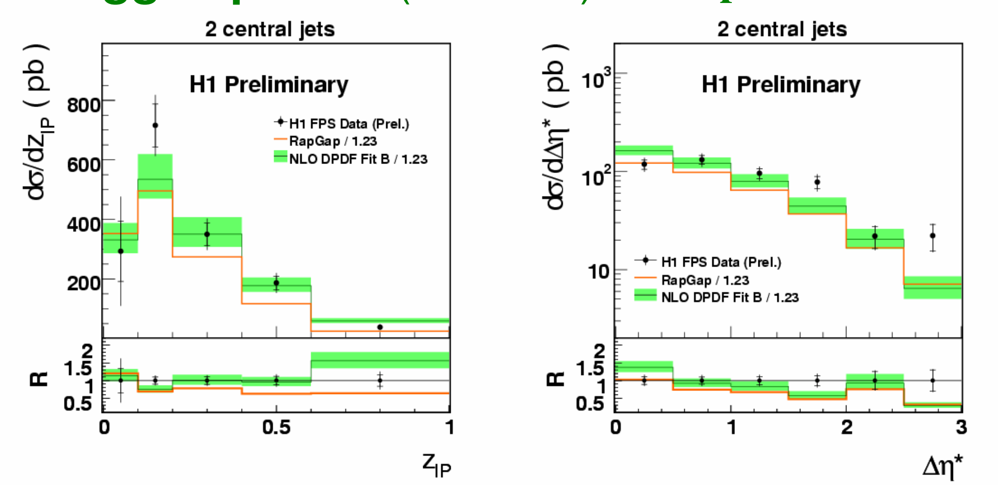
Open charm: H1, EPJ C50 (2007) 1
ZEUS, NP B672 (2003) 3



→ **QCD factorisation holds in DDIS!**

Dijets: H1, JHEP 0710:042 (2007)
ZEUS, EPJ C52 (2007) 813

First measurement of dijets in DDIS with a **tagged proton** (H1 FPS) - **H1prelim-10-013**



Deviations might be related to missing pomeron remnant in NLO predictions (NLOJET++)
Deviations at high $\Delta\eta^*$ → interesting to look at forward jets

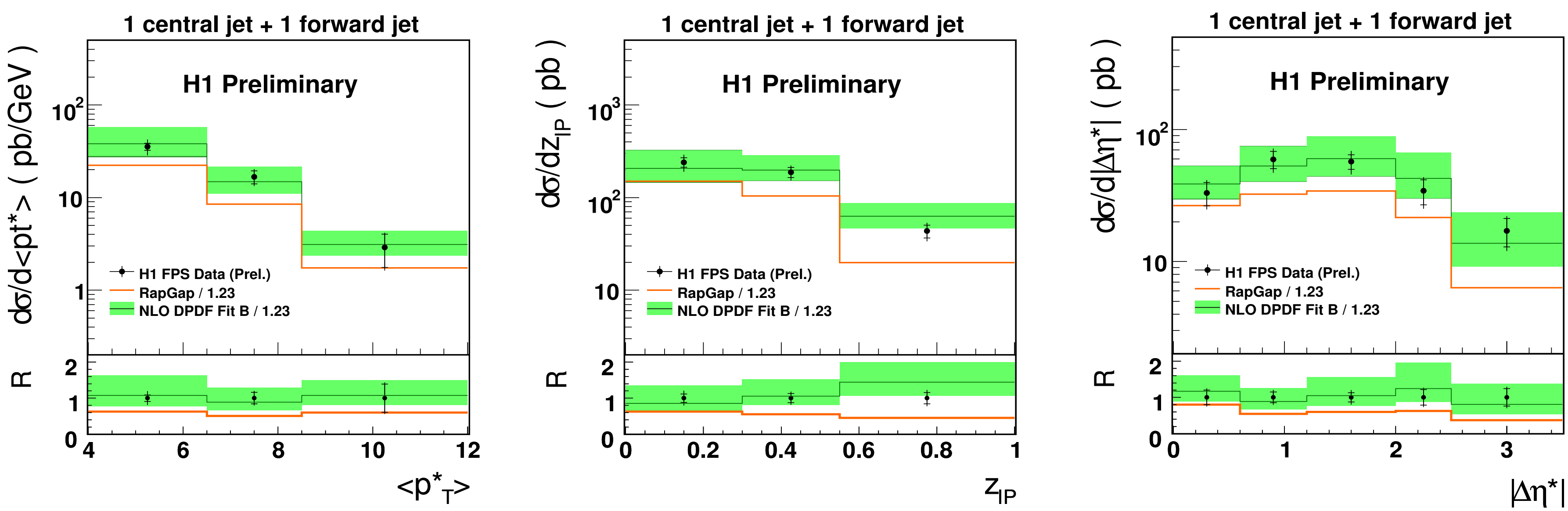
Forward jets in DDIS with proton tag

Dijet system: **Forward jet**: $p_T^* > 4.5$ GeV, $1 < \eta_{fwd} < 2.8$

Central jet: $p_T^* > 3.5$ GeV, $-1 < \eta_{cen} < \eta_{fwd}$

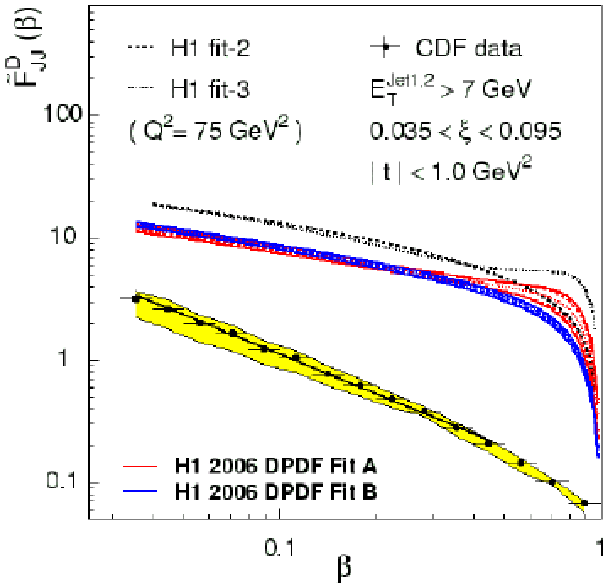
(previous 2 central jets: $p_{T1}^* > 5$ GeV, $p_{T2}^* > 4$ GeV, $-1 < \eta < 2.5$)

Predictions scaled by 1.23 due to proton dissociation not present in FPS data



NLO DGLAP with H1 fit B DPDFs gives a good description of the data

Factorization breaking at Tevatron and gap survival probability



CDF, PRL 84 (2000) 5043 + P.Newman/H1

Diffractive dijet measurement in ppbar by CDF

Comparison with NLO predictions with **HERA DPDFs as input**:

Significant **overestimation** (~ factor 10) of the data by NLO calculations and **different shape**

Factorisation not expected to hold for diffractive hadron-hadron collisions

- Violation of factorisation is understood in terms of (soft) rescattering between spectator partons, in initial and final states, suppressing the large rapidity gap: suppression ⟷ '**rapidity gap survival probability**'

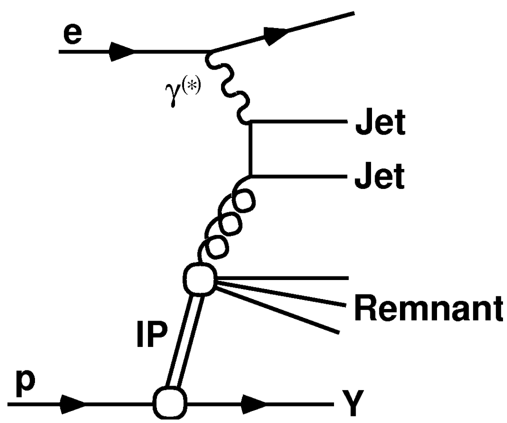
- Models including rescattering corrections via multi-pomeron exchanges are able to describe the suppression observed **[KKMR, EPJ C21 (2001) 521]**

- **Of great interest for LHC!**

Hadron-hadron and photoproduction

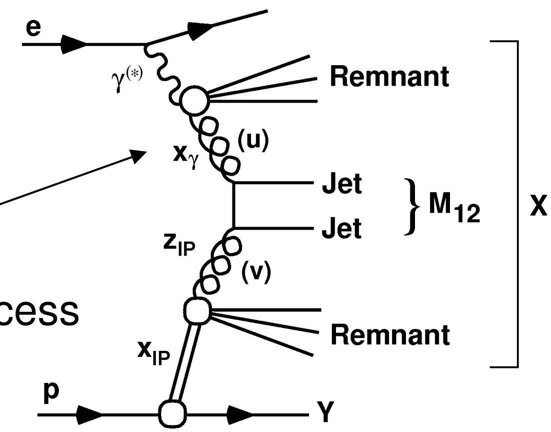
At HERA we have something similar to a hadron:
quasi-real photons ($Q^2 \sim 0$) can develop a **hadronic structure**

Direct photon ($x_\gamma \sim 1$) (at LO) **Resolved photon ($x_\gamma < 1$)**



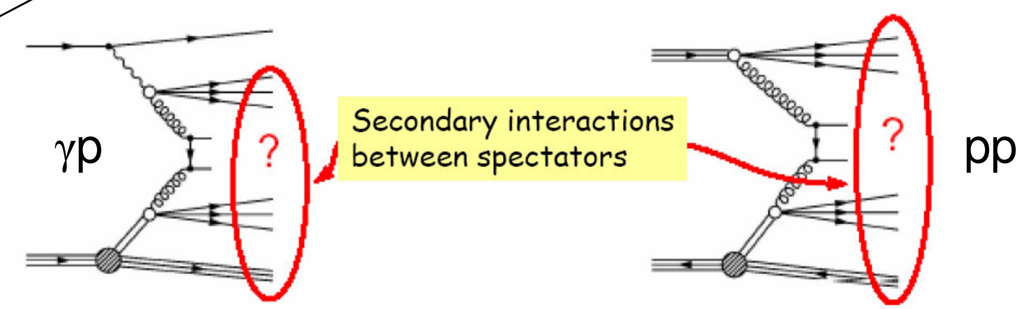
High E_T of the jets provides the hard scale

x_γ = fraction of photon's momentum in hard subprocess



QCD factorisation is expected to hold like in DIS

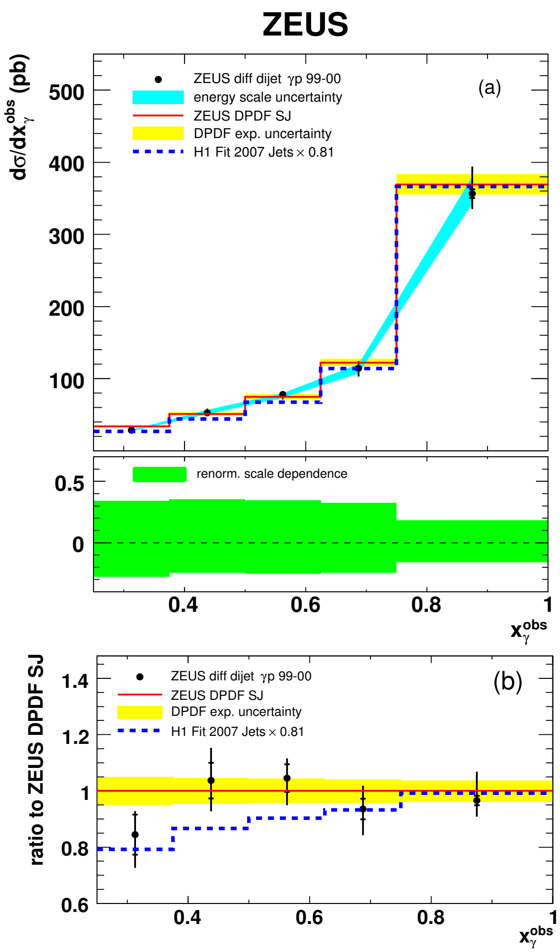
QCD factorisation is expected to break like in hadron-hadron:



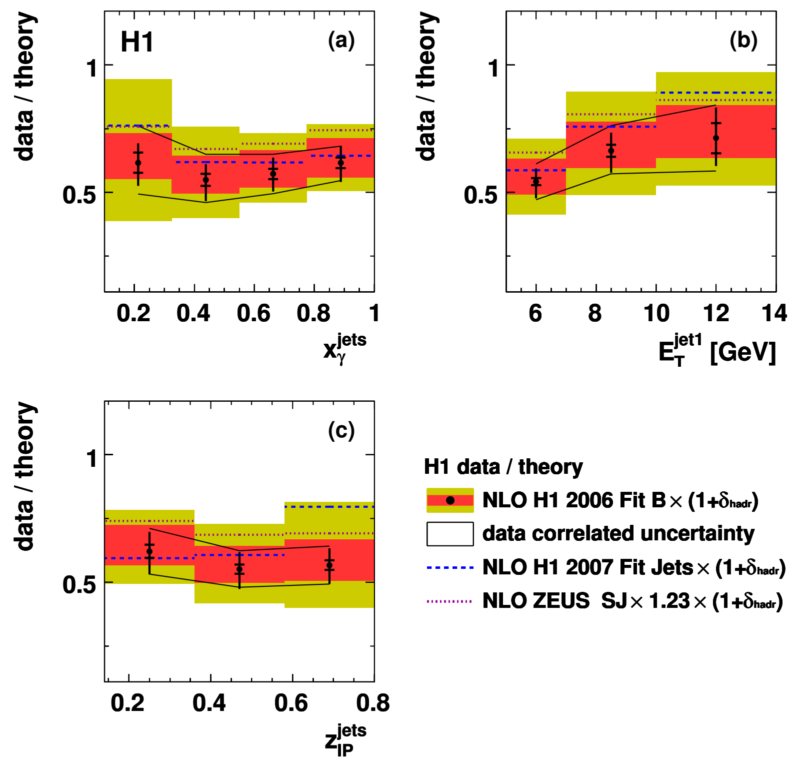
Expected suppression ~ 0.34 for resolved γ [KKMR, PL B567 (2003) 61]

Dijets in diffractive photoproduction

ZEUS, NP B831 (2010) 1



H1, DESY 10-043



Dependence on jet E_T ?

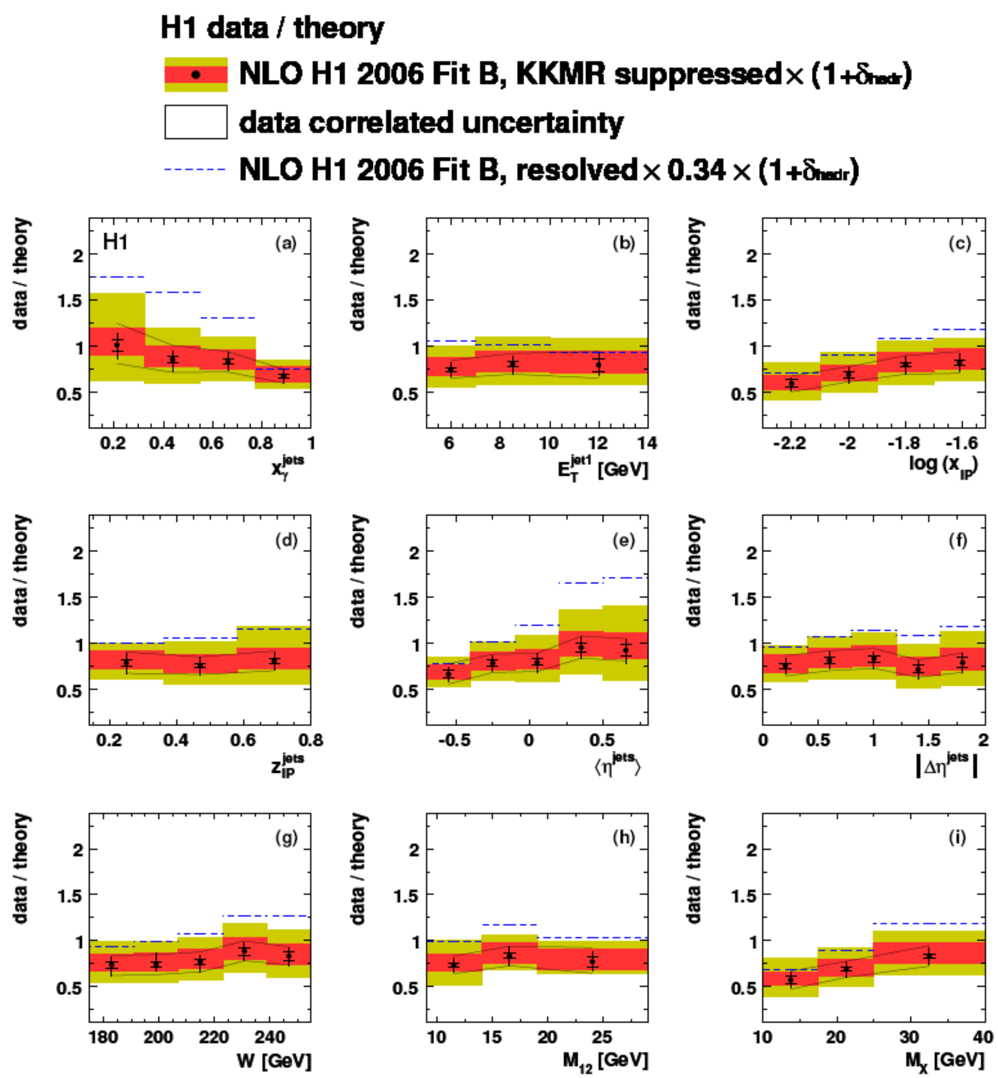
H1: data/NLO = 0.58 ± 0.12(exp) ± 0.14(scale) ± 0.09(DPDF)

Both H1 and ZEUS see **no difference between direct and resolved regions**

ZEUS: no evidence for a gap suppression

ZEUS has higher jet-E_T cuts than H1: $E_T^{1(2)}$ >7.5(6.5) GeV^2

Dijets in diffractive photoproduction



Refined gap survival model (KKMR, **hep-ph/0911.3716**) predicts a significantly **weaker suppression:**

- **direct** γ unsuppressed
- **hadron-like part of resolved** γ suppressed by ~0.34 (only $x_\gamma < 0.1$)
- **point-like part of resolved** γ less suppressed, ~0.7-0.8

E_T dependence: lower E_T cuts on the jets increase hadronisation corrections and absorptive effects, producing a higher suppression

Both H1 and ZEUS data prefer a global suppression factor

Summary

- **Diffractive PDFs** have been extracted from continuously improving diffractive data by both H1 and ZEUS

  A combined fit to inclusive and dijet data allows to constrain both the quark and gluon densities to similar good precision

  NLO predictions based on diffractive PDFs agree well with charm and dijet data in diffractive DIS, proving QCD factorisation

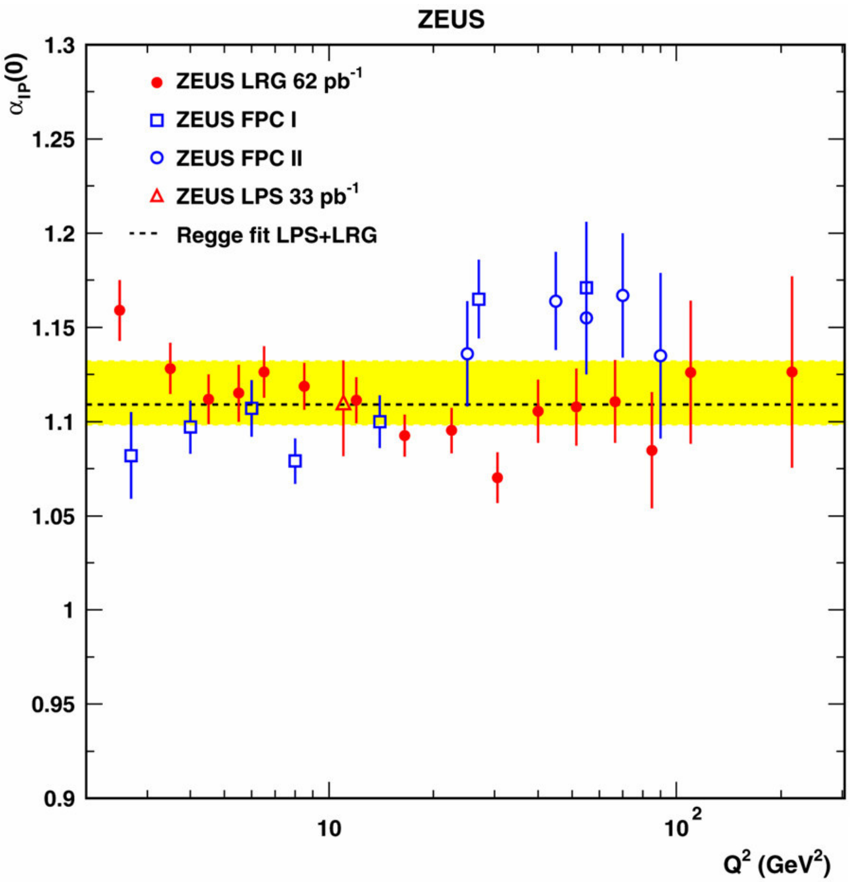
- **Diffractive dijet photoproduction** has been studied to test possible factorisation breaking as in proton-antiproton collisions at Tevatron

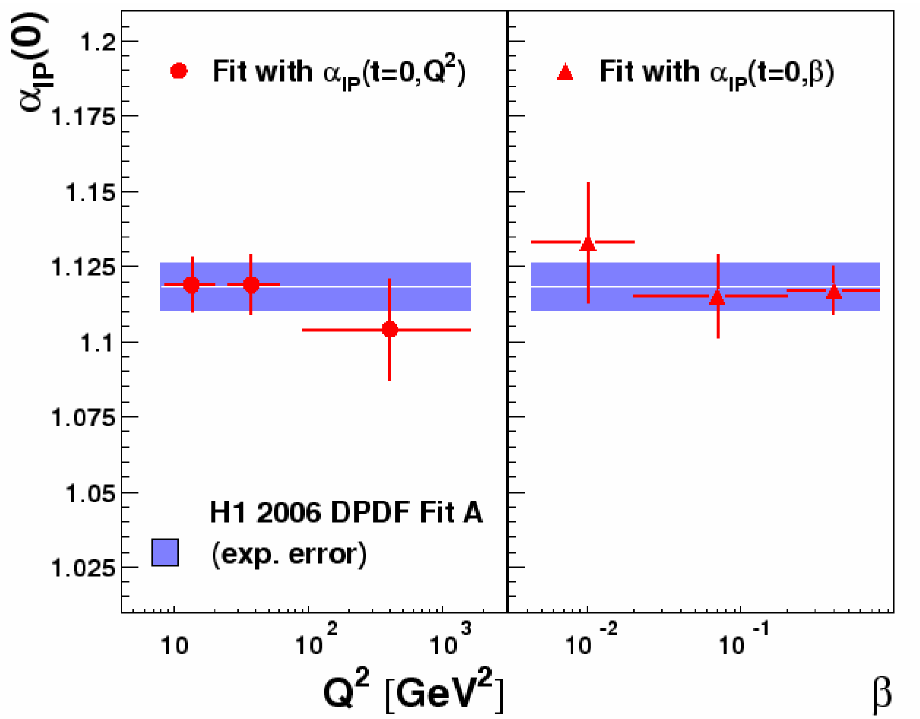
  Gap survival probabilities ~ 0.6 – 1, higher than in ppbar, have been measured

  Both H1 and ZEUS data prefer a global suppression for both the direct and resolved components of the photon, with a possible E_T dependence of the suppression factors

Backup slides

Proton vertex factorisation





Measure the x_{IP} dependence of the data as a function of β and Q^2

The proton vertex factorisation approximation holds within the experimental precision ⟶ allow NLO QCD analysis of the β and Q^2 dependences

Fit parameters and χ^2/ndf

Table 3
Parameters obtained with the different fits and their experimental uncertainties.

Parameter	Fit value DPDF S	Fit value DPDF C	Fit value DPDF SJ
A_q	0.135 ± 0.025	0.161 ± 0.030	0.151 ± 0.020
B_q	1.34 ± 0.05	1.25 ± 0.03	1.23 ± 0.04
C_q	0.340 ± 0.043	0.358 ± 0.043	0.332 ± 0.049
A_g	0.131 ± 0.035	0.434 ± 0.074	0.301 ± 0.025
B_g	-0.422 ± 0.066	0	-0.161 ± 0.051
C_g	-0.725 ± 0.082	0	-0.232 ± 0.058
$\alpha_{\mathbb{P}}(0)$	1.12 ± 0.02	1.11 ± 0.02	1.11 ± 0.02
$\alpha_{\mathbb{R}}(0)$	0.732 ± 0.031	0.668 ± 0.040	0.699 ± 0.043
$A_{\mathbb{R}}$	2.50 ± 0.52	3.41 ± 1.27	2.70 ± 0.66
χ^2/ndf	$315/265 = 1.19$	$312/265 = 1.18$	$336/293 = 1.15$

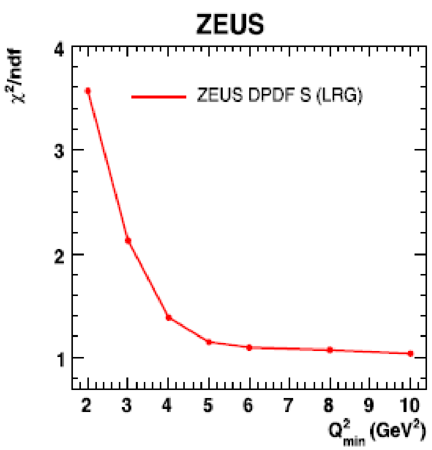
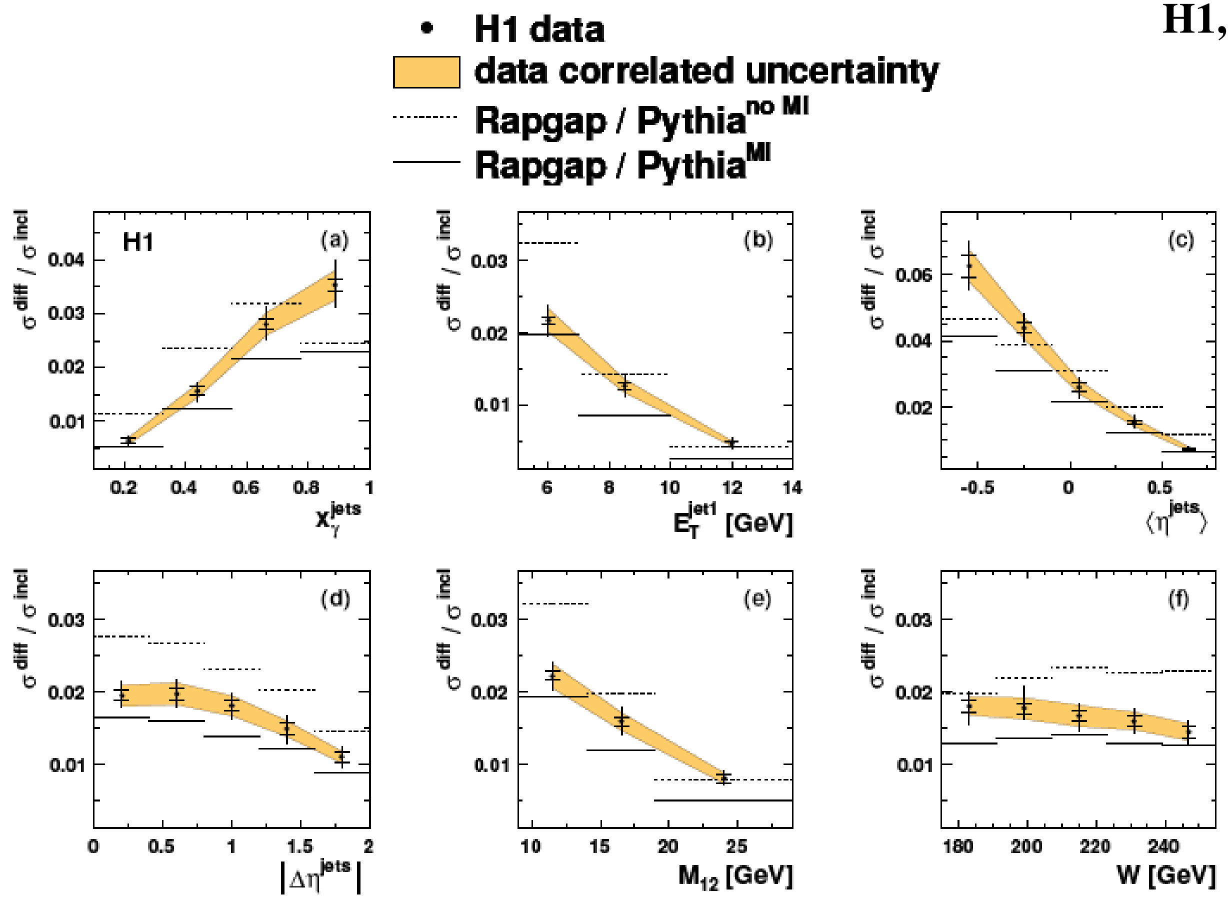


Table 1
The values of the parameters fixed in the fits and the measurements providing this input.

Parameter	Fixed to (GeV^{-2})	Measurement (GeV^{-2})	Ref.
$\alpha'_{\mathbb{P}}$	0	-0.01 ± 0.06 (stat.)$^{+0.04}_{-0.08}$ (syst.) ± 0.04 (model)	[10]
$\alpha'_{\mathbb{R}}$	0.9	0.90 ± 0.10	[32]
$B_{\mathbb{P}}$	7.0	7.1 ± 0.7 (stat.)$^{+1.4}_{-0.7}$ (syst.)	[10]
$B_{\mathbb{R}}$	2.0	2.0 ± 2.0	[32]

Diffractive/inclusive dijet γp cross sections

H1, DESY 10-043



Influence of **multiple interactions** in inclusive data is large in the kinematic range of the analysis, which preclude strong conclusions about rapidity gap survival

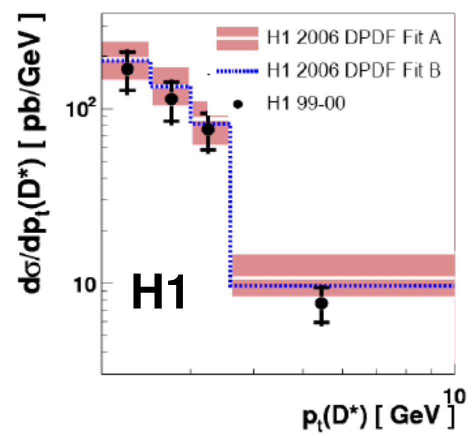
D* and dijets in diffractive DIS

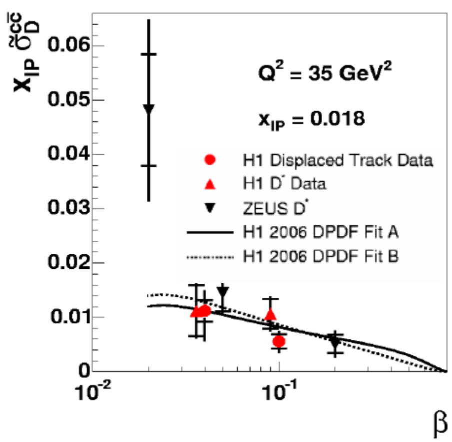
Use DPDFs extracted from inclusive DDIS for calculating NLO predictions to semi-inclusive final states: **test universality of DPDFs**

→ Open charm and dijets in DIS: hard scales in the process ensure use of pQCD

Open charm:

H1, DESY 06-164
ZEUS, NP B672 (2003) 3

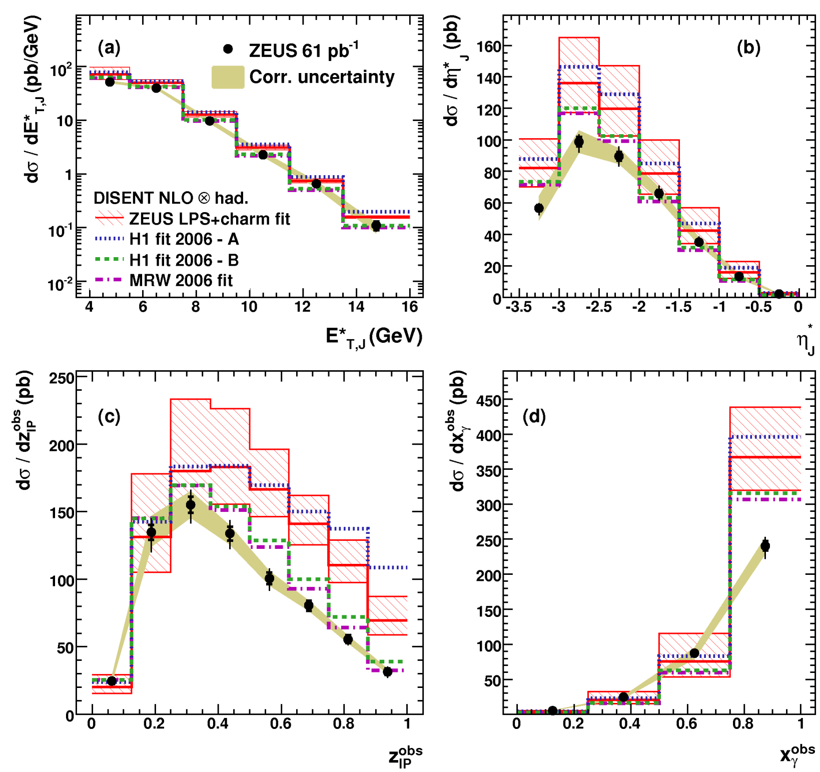




Dijets:

H1, JHEP 0710:042 (2007)
ZEUS, EPJ C52 (2007) 813

ZEUS



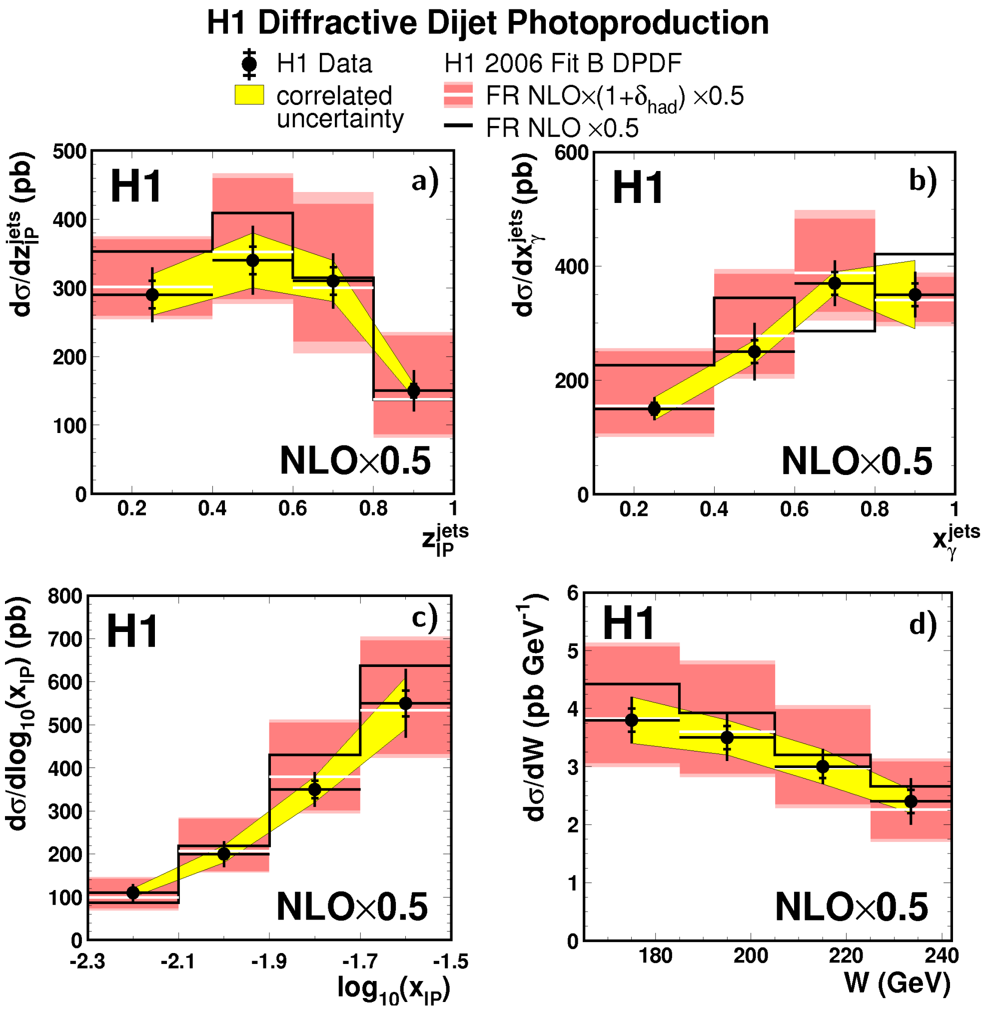
H1 and ZEUS data agree with NLO predictions within uncertainties

→ **QCD factorization holds in DDIS!**

Use D* and jet data to better constrain DPDFs

Dijets in diffractive photoproduction

H1, EPJ C51 (2007) 549



- $E_T^{jet1} > 5$ GeV, $E_T^{jet2} > 4$ GeV
- Cross section include p dissoc. with $M_Y < 1.6$ GeV
- Cross section corrected at hadron level

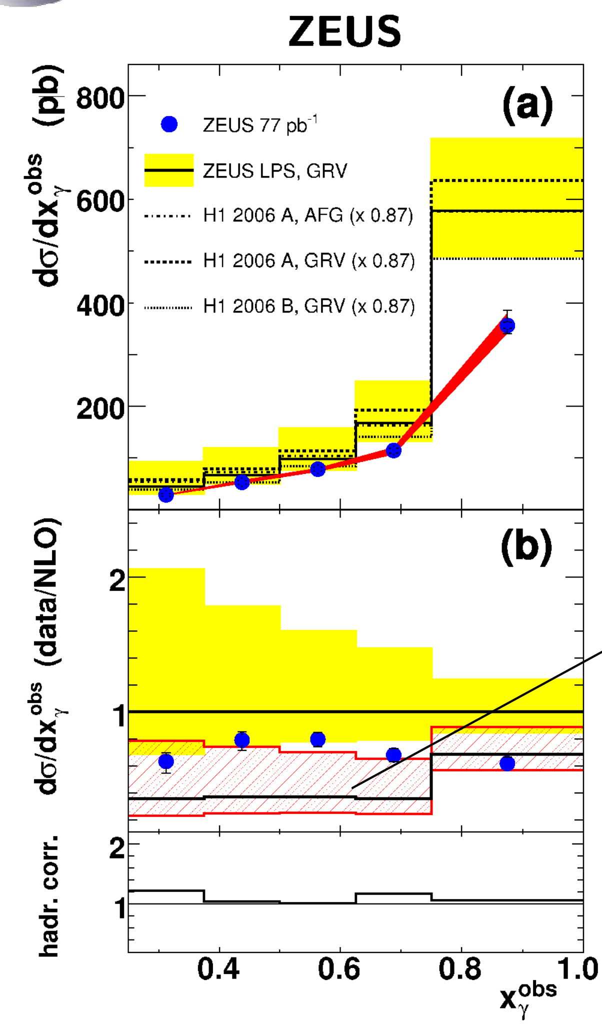
NLO overestimates the measured cross section by a factor ~ 2, both in the direct and resolved region

Suppression in γp is much smaller than in ppbar

NLO predictions assuming factorization with Frixione et al. program [NP B467 (1996) 399; B507 (1997) 295]

Dijets in diffractive photoproduction

ZEUS, EPJ C55 (2008) 177



- $E_T^{jet1} > 7.5$ GeV, $E_T^{jet2} > 6.5$ GeV
- Cross section scaled down for p-dissoc. contribution: (16±4)%
- Cross section corrected at hadron level

Suppression factor 0.34 applied to resolved component only

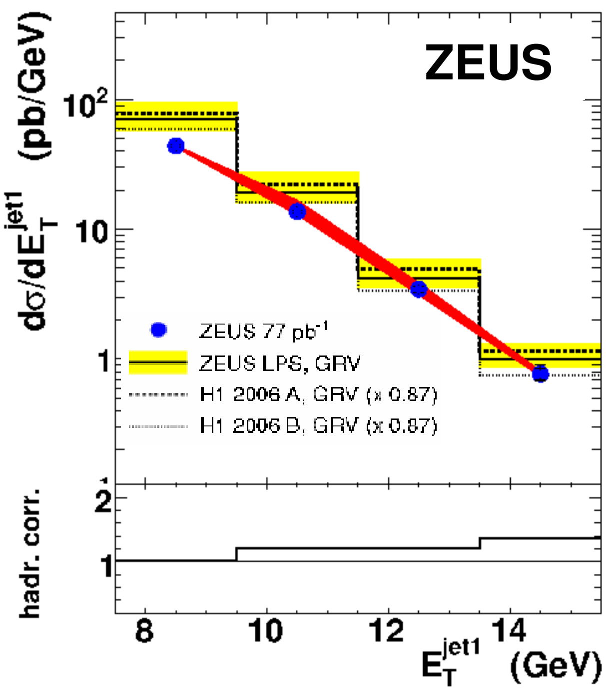
Within uncertainties data show a weak (if any) suppression: 0.6-0.9

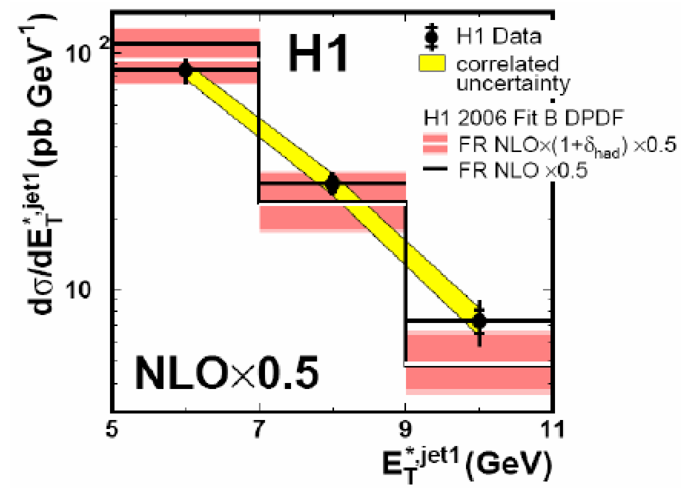
ZEUS as H1 do not see any difference between the resolved and direct regions, in contrast to theory!

NLO predictions assuming factorization with Klasen & Kramer program [EPJ C38 (2004) 9]

E_T dependence of suppression?

Difference between H1 and ZEUS possibly due to different E_T regions?



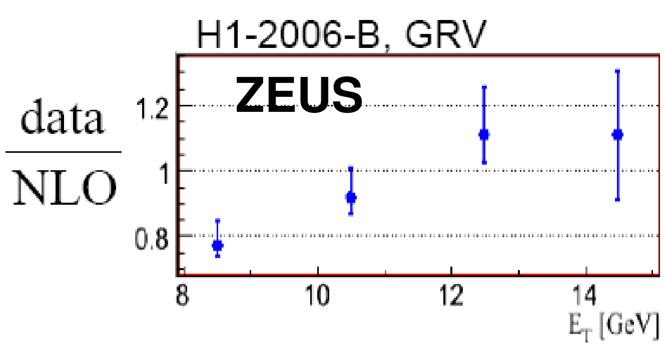


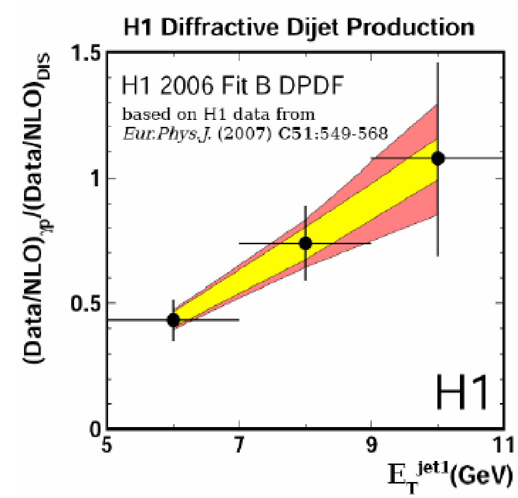
Data have a harder E_T slope than NLO

Better seen with

$$\textit{Double ratio} = \frac{(\,Data\,/\,NLO\,)_{\gamma p}}{(\,Data\,/\,NLO\,)_{DIS}}$$

to cancel DPDFs uncertainty





A signal that gap survival probability might increase with E_T