New Trends in HERA Physics
Ringberg Castle, Tegernsee,
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Factorisation issues in Diffraction

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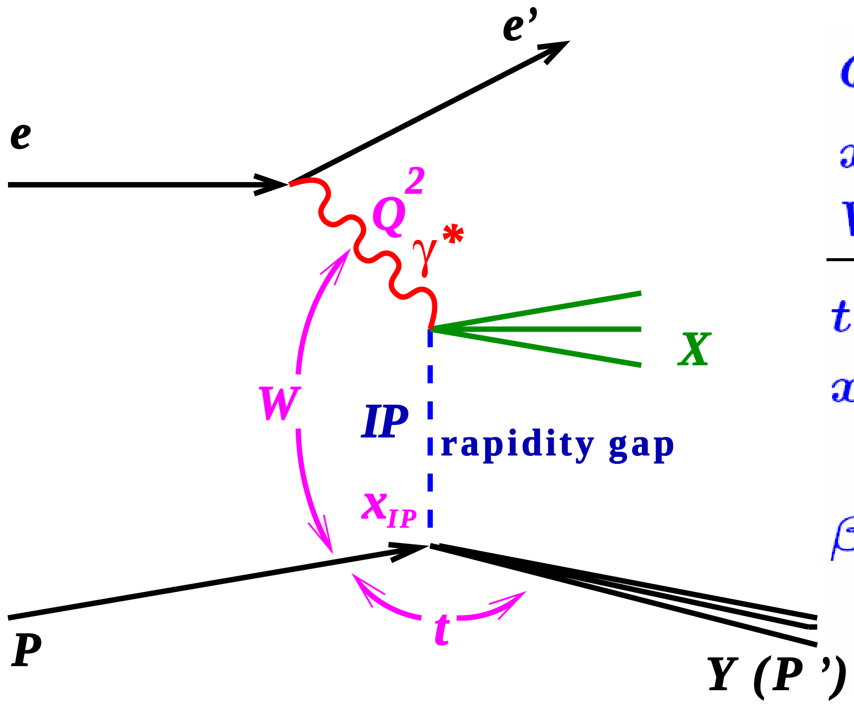
for the H1 and ZEUS Collaborations

Outline:

- Introduction
- Tests of QCD factorisation in diffraction with jets and D*
- E_T dependence of rapidity gap survival probability
- Factorisation in jet production with leading neutron
- Conclusions



$Q^2 = -q^2$	photon virtuality
$x = \frac{Q^2}{2q \cdot p}$	Bjorken scaling variable
$W^2 = (p+q)^2$	$\gamma^* p$ CM energy squared
$t = (p - p_Y)^2$	4-momentum transfer squared
$x_{I\!P} = \frac{q \cdot (p-Y)}{q \cdot p}$	fraction of p momentum transferred to $I\!P$ ($x_{I\!P} \simeq 1 - E_Y/E_p$)
$\beta = \frac{Q^2}{2q \cdot (p-Y)}$	fraction of $I\!P$ momentum carried by struck quark ($x_{I\!P}\beta = x$)
M_X	Inv. mass of system X

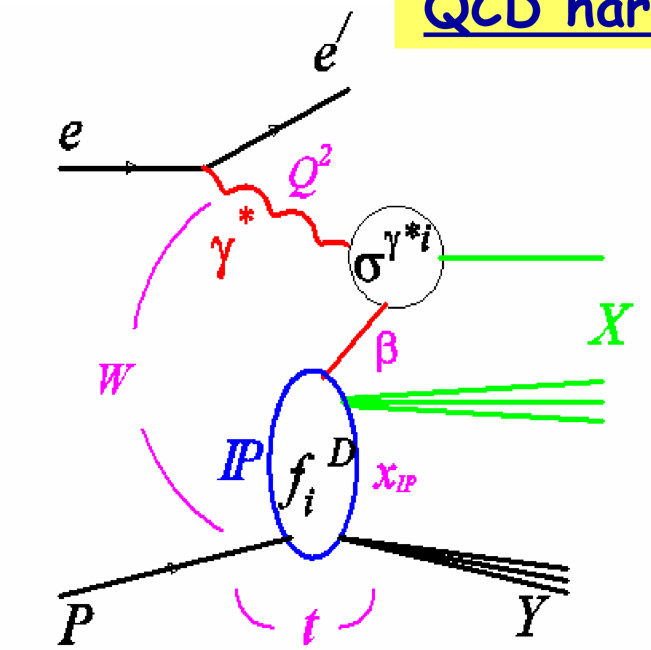
- t-channel exchange of vacuum quantum numbers
- proton survives the collision intact or dissociates to low mass state, $M_Y \sim O(m_p)$
- large rapidity gap
- small t (four-momentum transfer) and x_{IP} (fraction of proton momentum); $M_X \ll W$

~10% of low-x DIS events at HERA are diffractive

distinguish two classes of events depending on photon virtuality:
$Q^2 \sim 0$ → **photoproduction**
$Q^2 \gg 0$ → **deep inelastic scattering (DIS)**

Factorisation in diffraction

QCD hard scattering collinear factorisation in diffractive DIS



(J.Collins; Phys.Rev.D57 (1998) 3051)

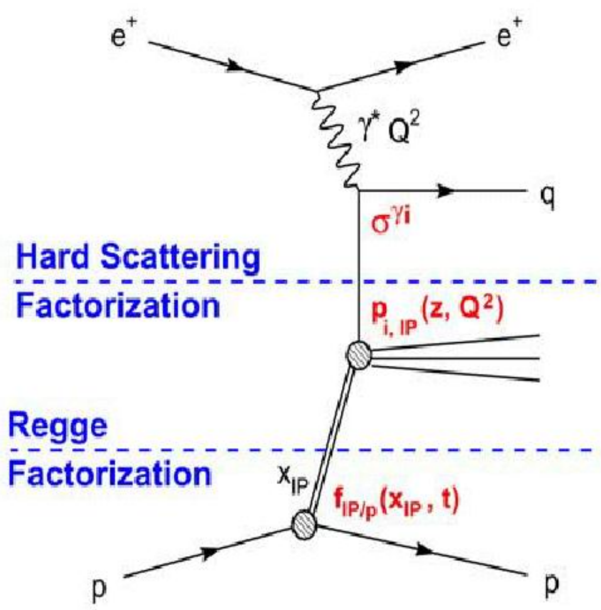
$$\sigma^D(\gamma^* p \to Xp) \propto \sum_i f_i^D(x_{IP}, t, x, Q^2) \otimes \sigma^{\gamma^*, i}(x, Q^2)$$

f_i^D -diffractive parton distribution function – conditional proton parton probability distributions with final state proton at fixed x_{IP},t

$\sigma^{\gamma^*, i}$-universal hard scattering cross section

Should work in diffractive DIS (Collins; Berera, Soper; Trentadue, Veneziano; Kunszt, Steerling)

Proton vertex factorisation (Regge factorisation)



β and Q^2 dependences factorise from x_{IP},t and M_Y

PDF = Pomeron-flux × Pomeron-PDF

$$f_i^D(x_{IP}, t, x, Q^2) = f_{IP/p}(x_{IP}, t) \times f_i^{IP}(\beta = x/x_{IP}, Q^2)$$

$$f_{IP/p}(x_{IP}, t) = \frac{e^{Bt}}{x_{IP}^{2a(t)-1}}, a(t) = a(0) + a'(t)$$

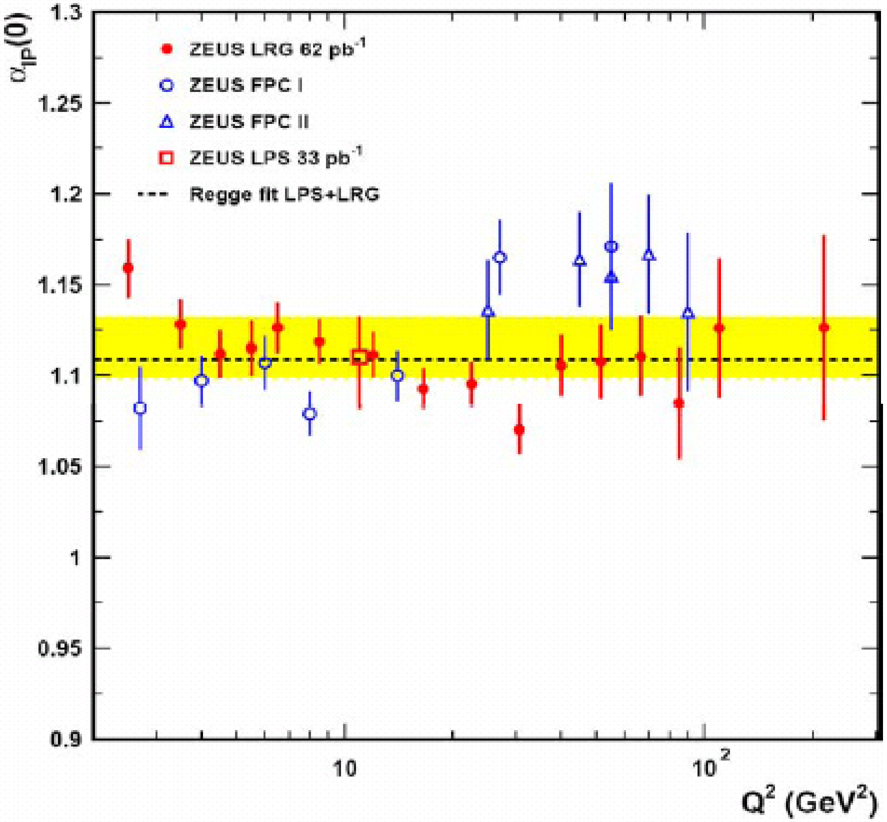
Pomeron flux

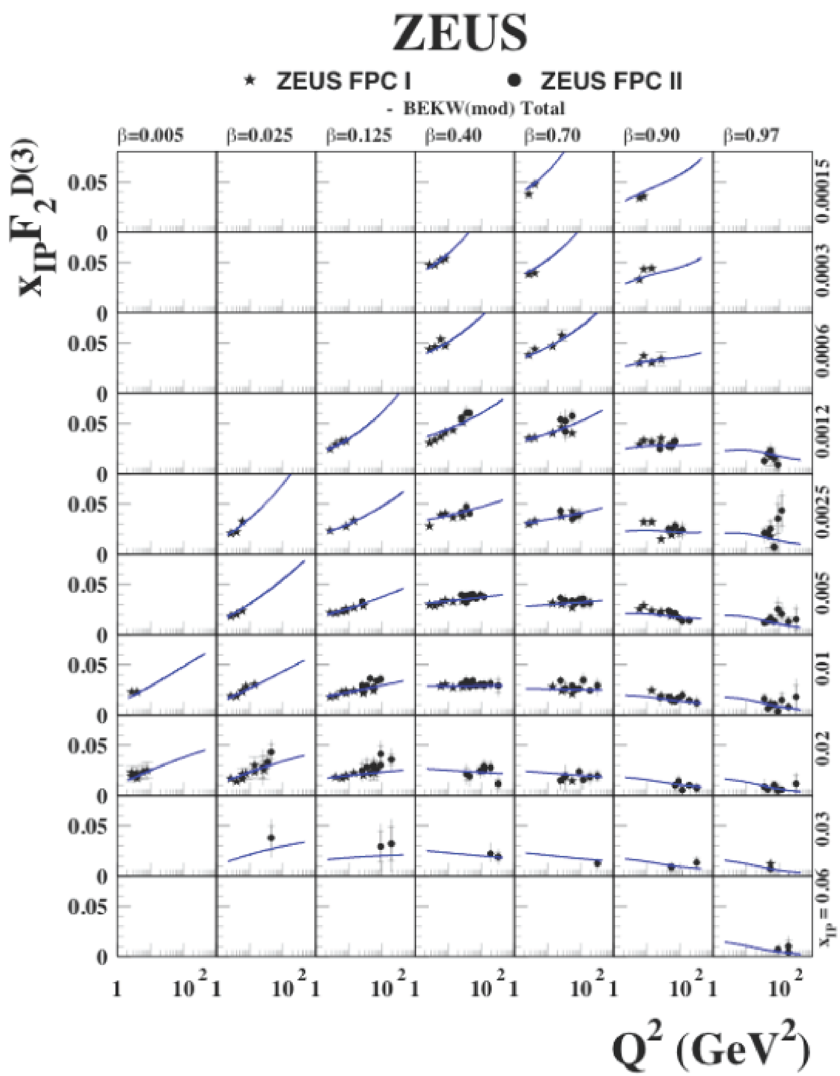
➔ assumption; no firm basis in QCD

Is proton vertex (Regge) factorisation supported by data ?

within errors $\alpha_{IP}(0)$ independent on Q^2
→support Regge factorisation

$F_2^{D(3)}$ data (Mx method): for fixed β shape of $F_2^{D(3)}$ depends on x_{IP} (e.g. β=0.4)
→contradicts the Regge factorisation

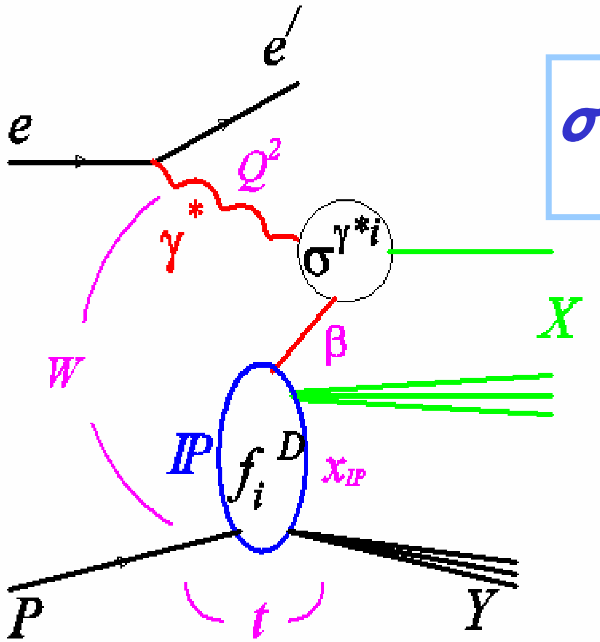




Within uncertainties, no essential violation of proton vertex factorisation

QCD hard scattering collinear factorisation in diffractive DIS

(J.Collins; Phys.Rev.D57 (1998) 3051)



$$\sigma^D(\gamma^* p \to Xp) \propto \sum_i f_i^D(x_{IP}, t, x, Q^2) \otimes \sigma^{\gamma^*,i}(x, Q^2)$$

f_i^D -diffractive parton distribution function – conditional proton parton probability distributions with final state proton at fixed x_{IP}, t

$\sigma^{\gamma^*,i}$ -universal hard scattering cross section

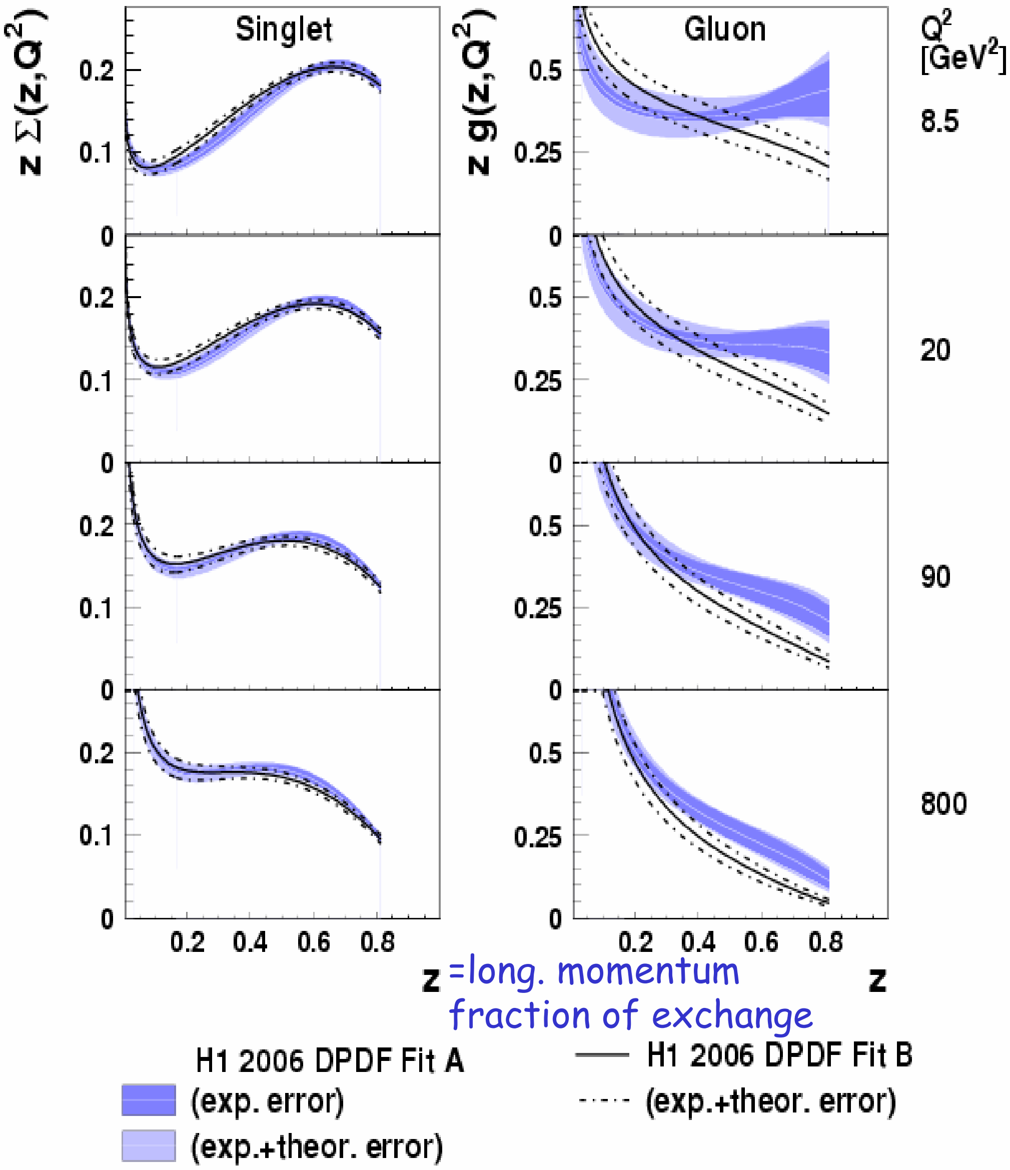
Proven for diffractive DIS.
Is not necessarily true for hadron-hadron collisions

How the QCD factorisation can be studied/tested ?

- measure F_2^D from inclusive measurement,
- extract diffractive PDFs from NLO DGLAP fit
- measure an exclusive diffractive final states, open charm and dijets; in pp, DIS and γp
- compare the measurement to theory predictions

Diffractive PDFs: H1 NLO QCD fit

(details in L.Schoeffel's talk)



z =long. momentum fraction of exchange

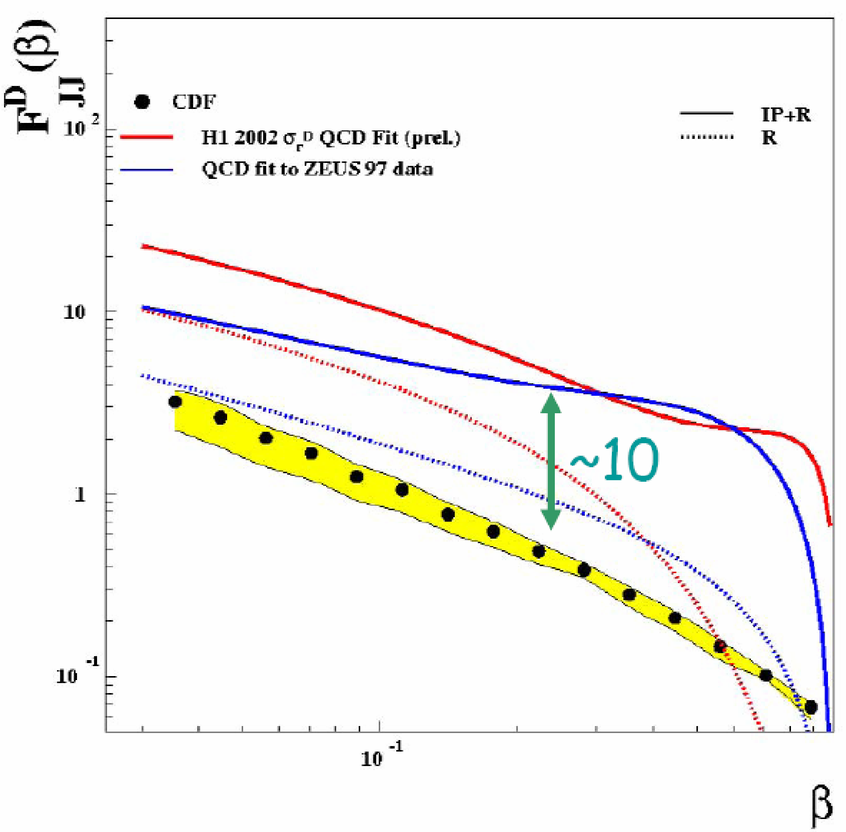
- **assume Regge factorisation**
- **apply NLO QCD DGLAP analysis technique to Q^2 and β dependencies of F_2^D**

→quark density from F_2^D, gluon density from scaling violation

- **H1 2006 DPDFs FitA, FitB**
  (different starting parameterizations)
  - **Well constrained singlet**
    Weakly constrained gluons (at high β)
  - **low *z* behavior similar to F_2**
  - **hard gluon distribution extended to high *z***
  - **gluon carries ~70% of diffractive exchange**

- also parameterisations from **Martin, Ryskin, Watt ; ZEUS LPS+charm**

Factorisation in diffraction: diffractive jet production at TeVatron

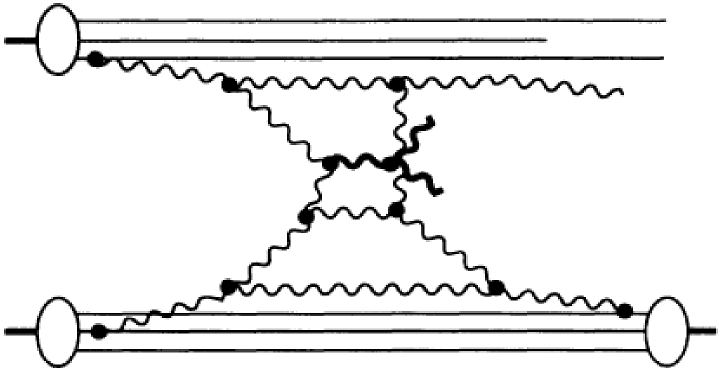


huge difference between the predictions based on the F_2^D fits from HERA and the measurements !

Factorisation is broken in pp

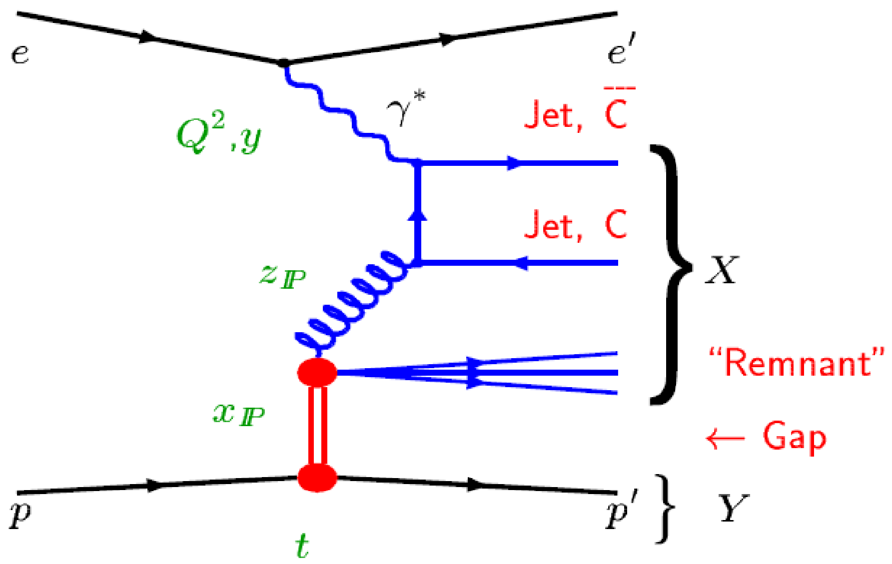
Violation of factorisation can be understood in terms of (soft) rescattering between the two hadrons and their remnants, in initial and final state, suppressing the large rapidity gap

Berera,Soper Phys.Rev.D53 (1996) 6162



Very essential for the predictions for Diffractive Higgs production at the LHC

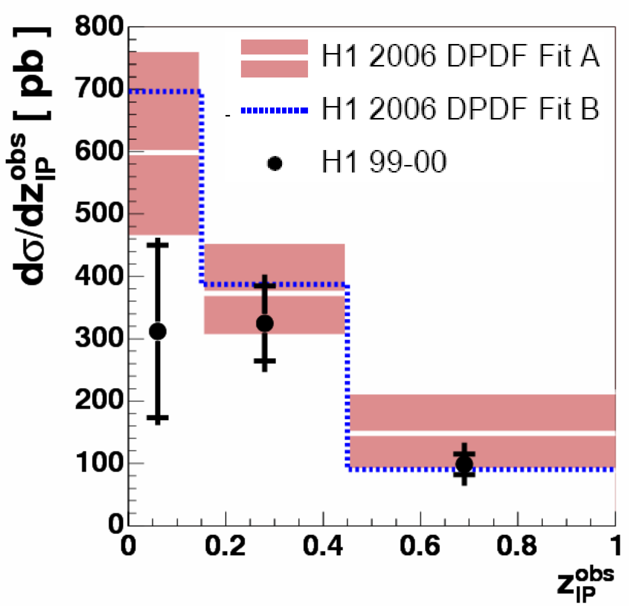
Factorisation tests with jets and charm at HERA

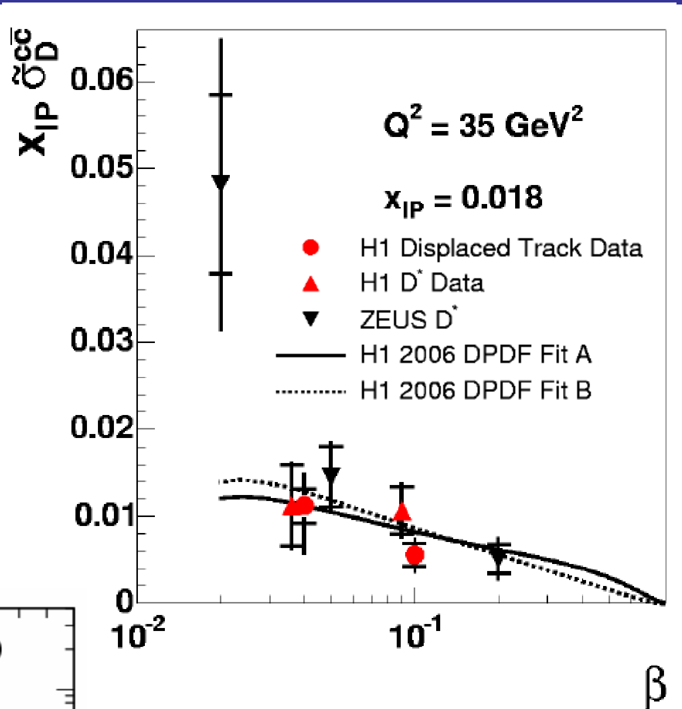


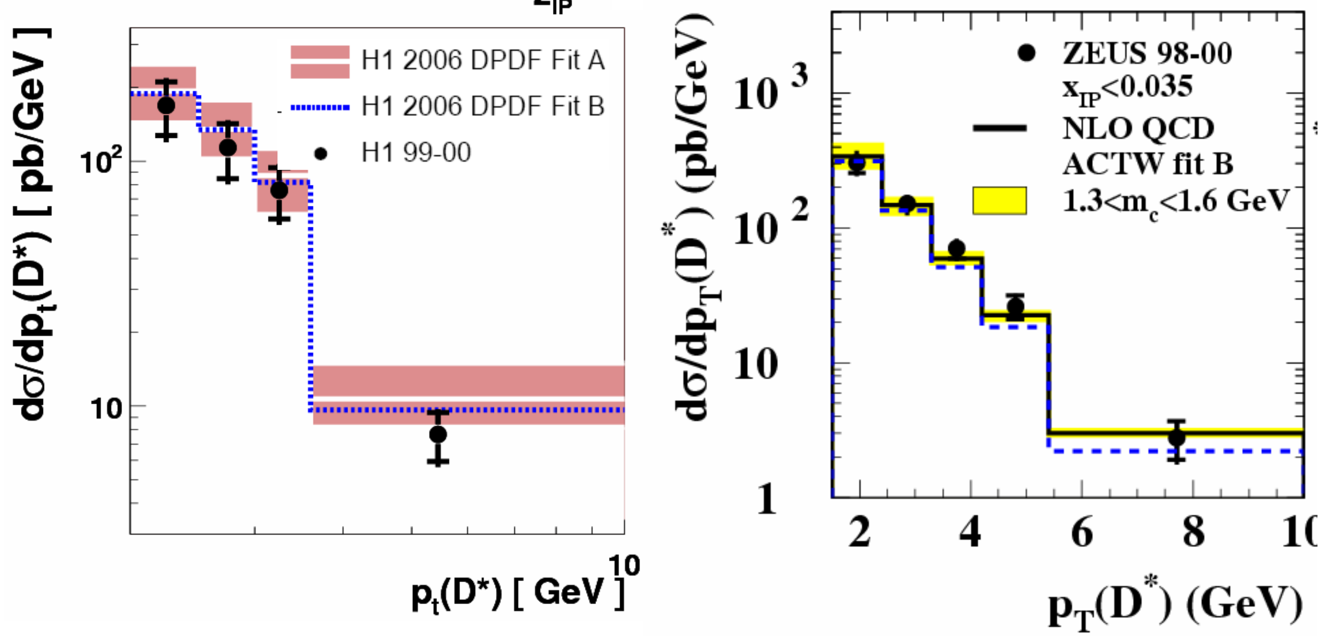
Ideal test of underlying dynamics of diffraction:

- Cross sections calculable in pQCD (hard scales: Q^2, p_T^{jet}, m_Q)
- Production mechanism is directly sensitive to the gluon content of colour singlet exchange ! → provides constrain of shape and normalisation of gluon density in diffractive exchange
- Test universality of parton distributions (extracted from F_2^D)

D* production in Diffractive DIS



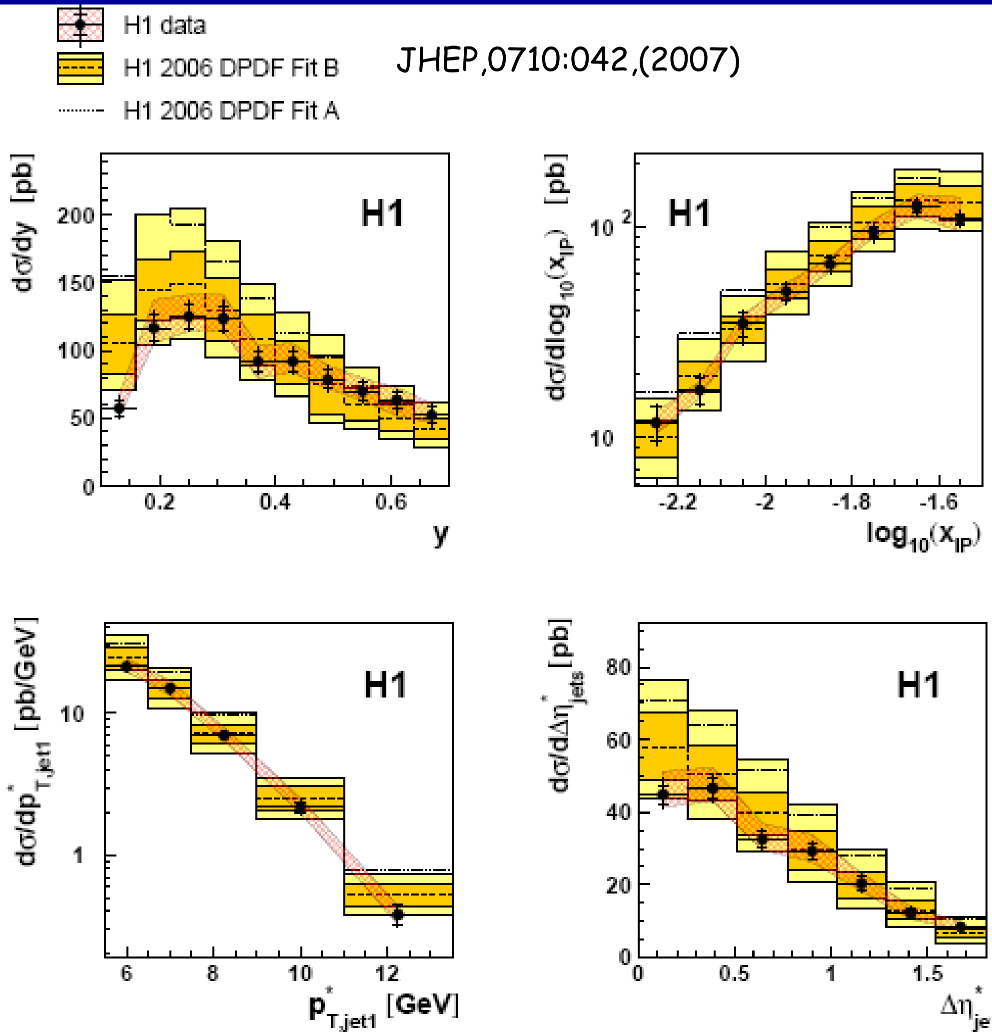




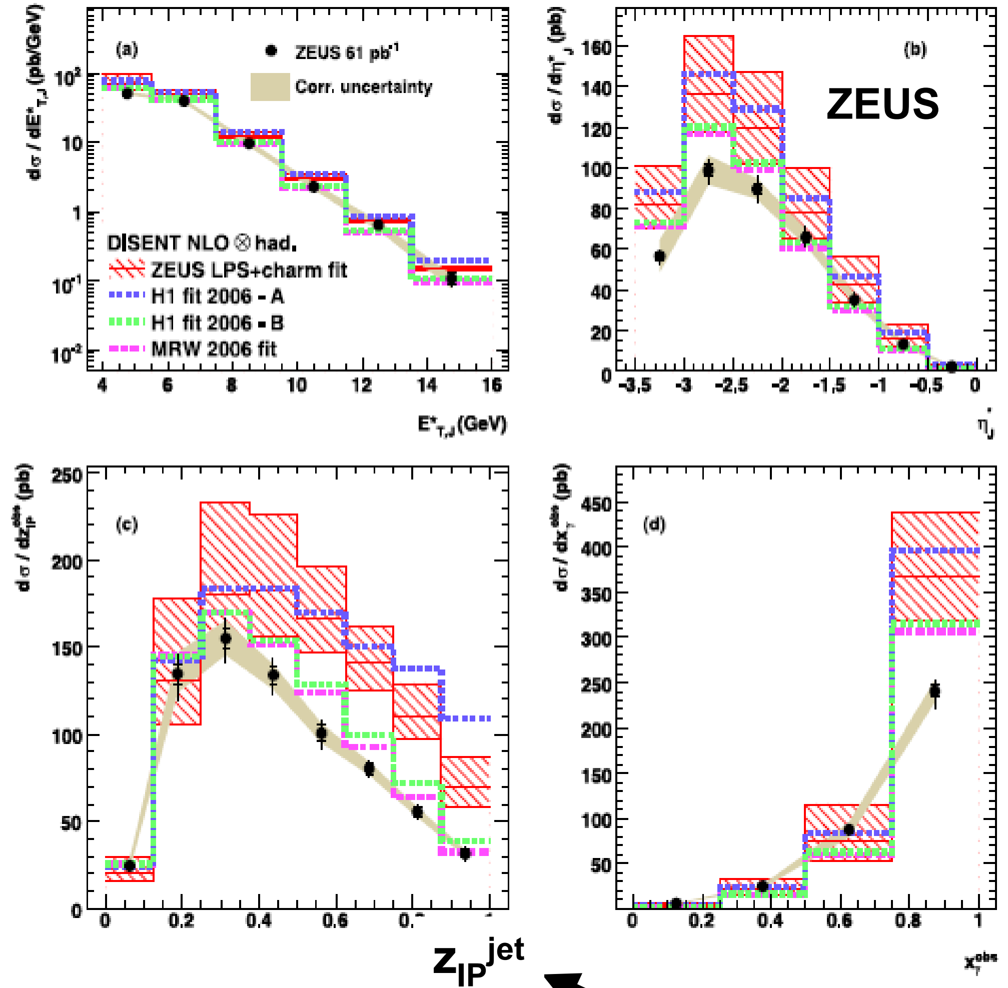
NLO calculations (HVQDIS) provide good description of diffractive charm data
→ support QCD factorization

Dijets in diffractive DIS

JHEP,0710:042,(2007)



Eur.Phys.J.C52: 83 (2007)



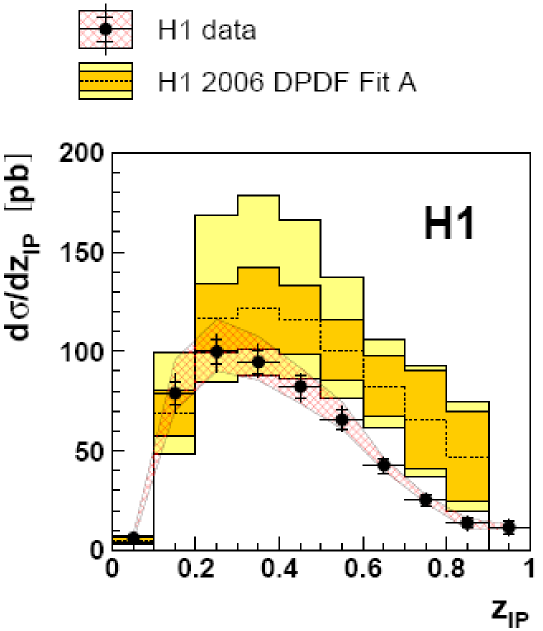
Data agree with NLO predictions within uncertainties

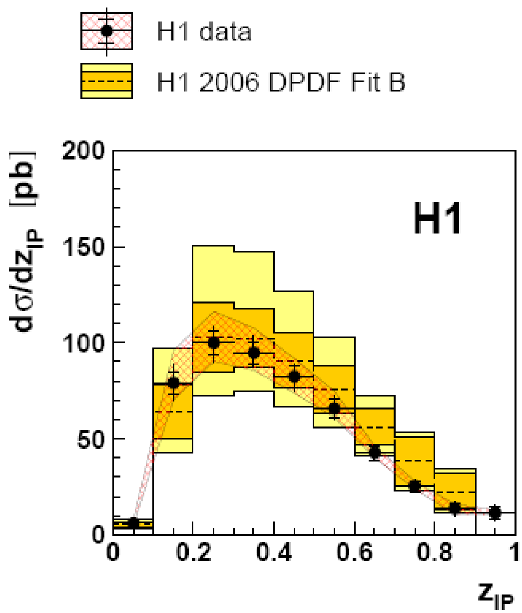
→ **consistent with QCD factorisation**

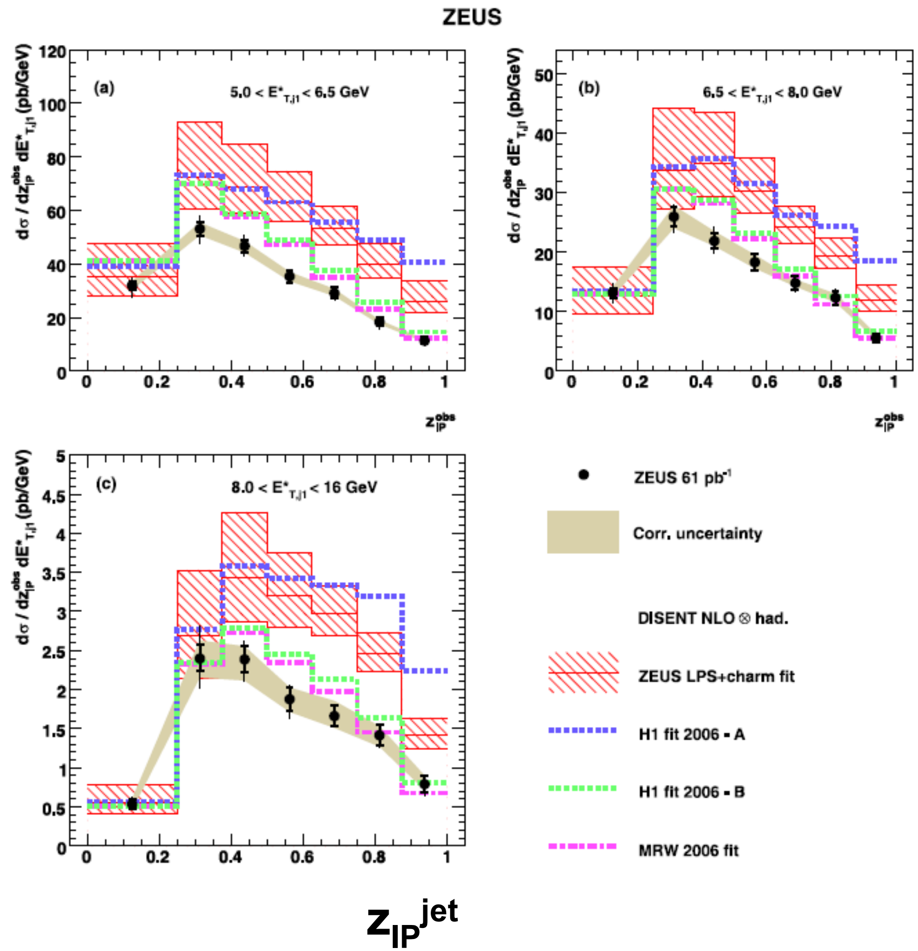
The differences between the different PDFs are visible, in particular at high z_{IP} (>0.4)

H1-2006-fit B and MRW-2006 are closest to the data

Dijets in diffractive DIS







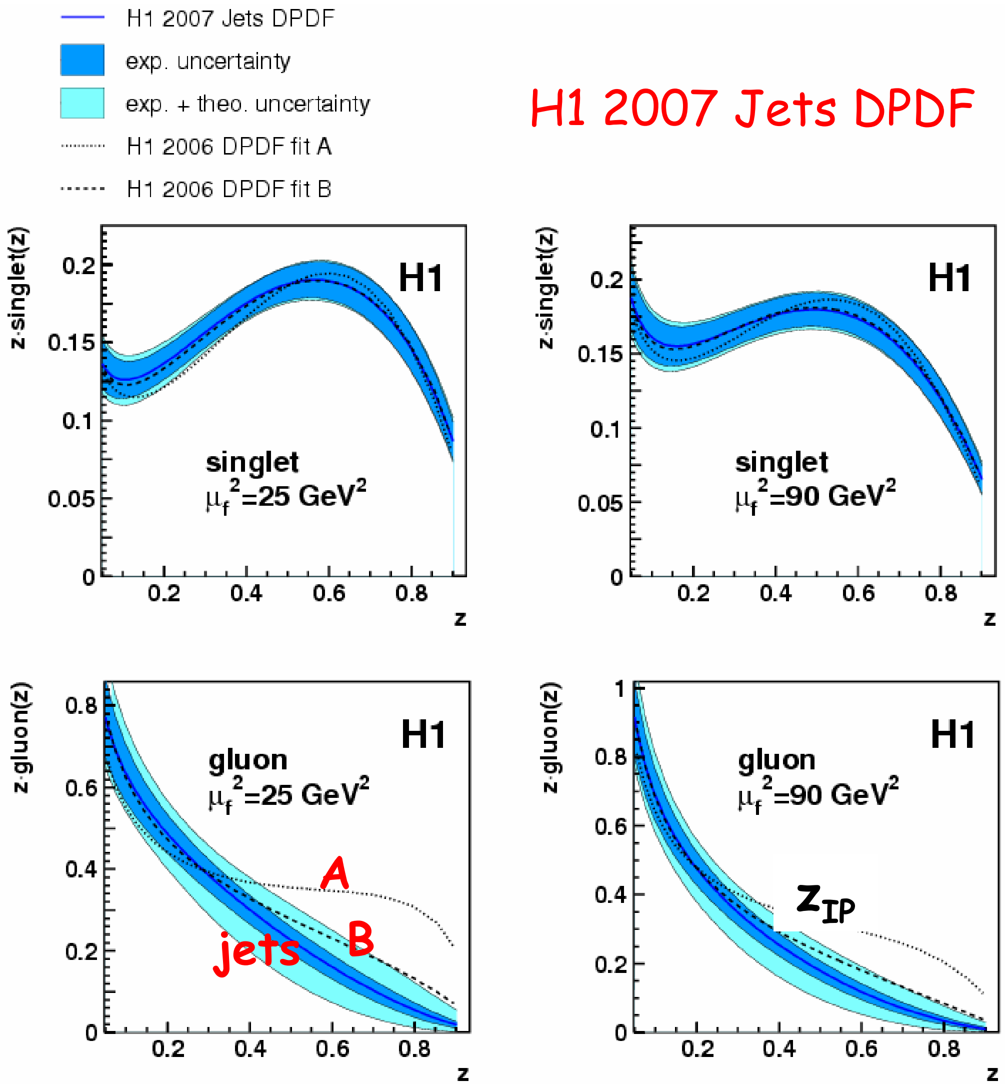
The data prefer H1-2006-fit B over fit A (e.g. less gluons)

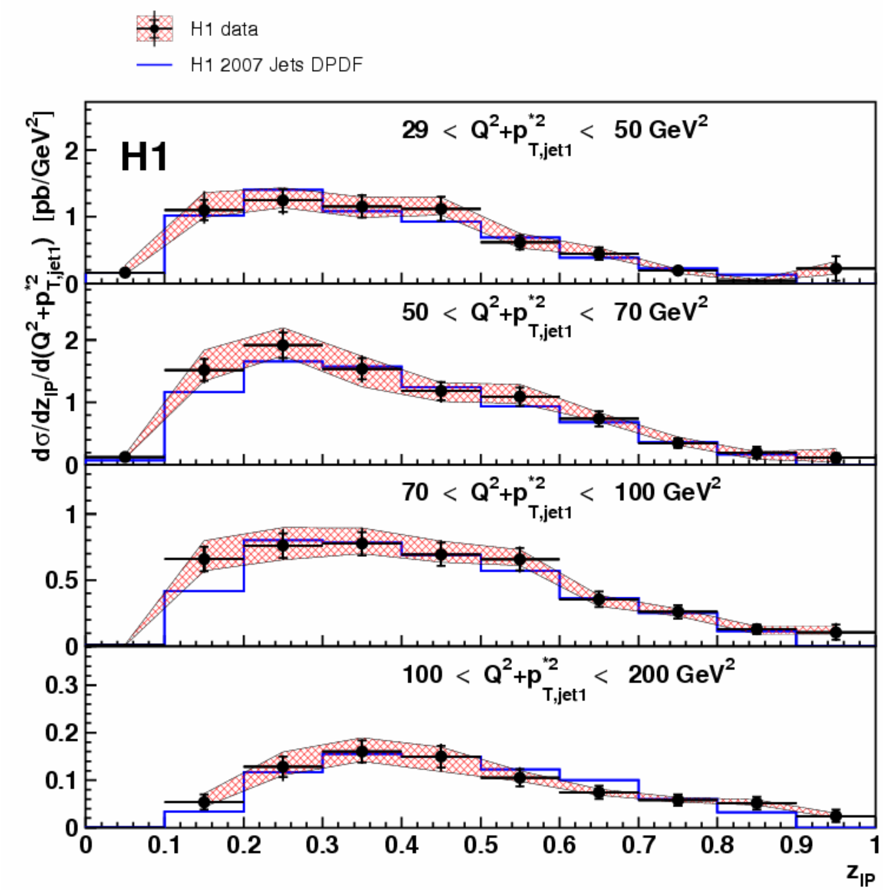
➔ dijet data constrain gluon PDF

Dijets in diffractive DIS: combined QCD fit

Combined QCD fit for inclusive and dijet DIS data, constrain PDFs over a wide range ($0.05<z<0.9$) ➔ Reduce uncertainty on $g(\beta,Q^2)$

H1 2007 Jets DPDF





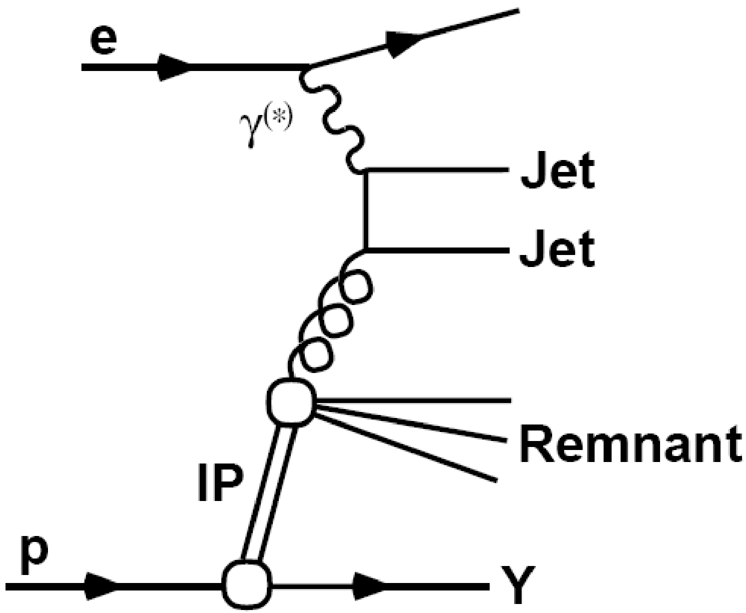
Conclusion: in diffractive DIS, factorisation holds for jets and for charm

Factorisation test with jets and charm in diffractive photoproduction

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

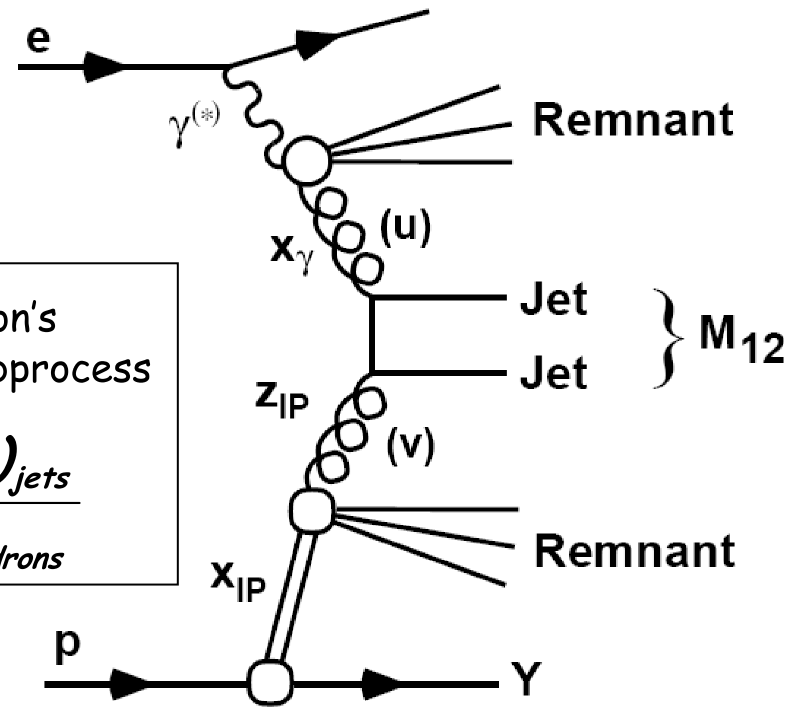
Pointlike (direct) photon

Resolved photon



x_γ - fraction of photon's momentum in hard subprocess

$$x_\gamma^{OBS} = \frac{\sum (E - p_z)_{jets}}{(E - p_z)_{hadrons}}$$



•photon (virtual/real) is directly involved in hard scattering

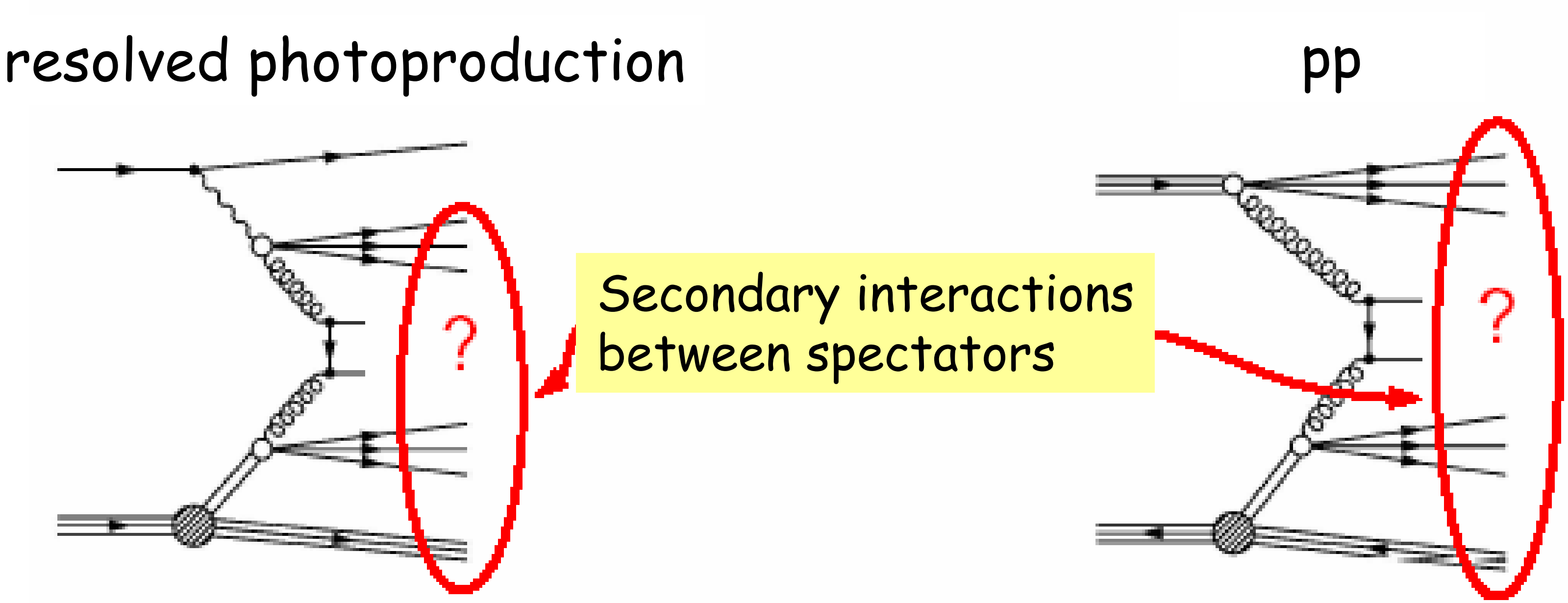
$x_\gamma = 1$

(due to hadronization and resolution not exactly true for measured x_γ)

•photon fluctuates into hadronic system. which takes part into hadronic scattering

$x_\gamma < 1$

factorisation: γp – pp analogy

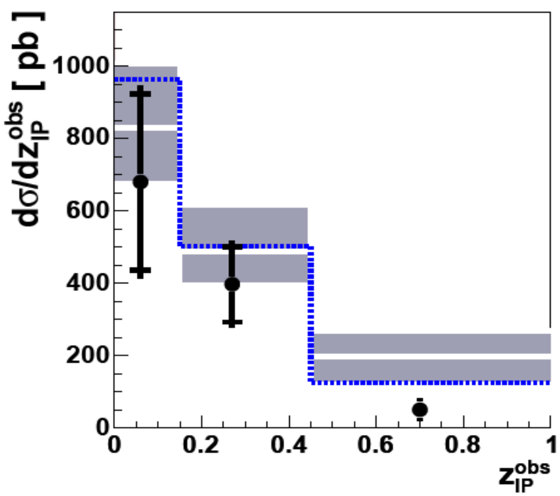


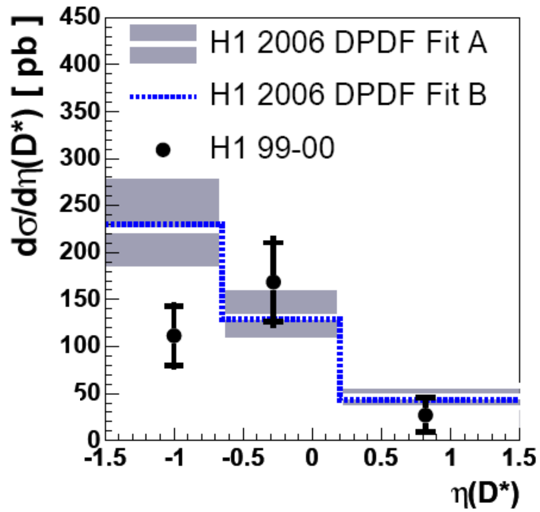
Rescattering leads to factorization breaking and rapidity gap fill up

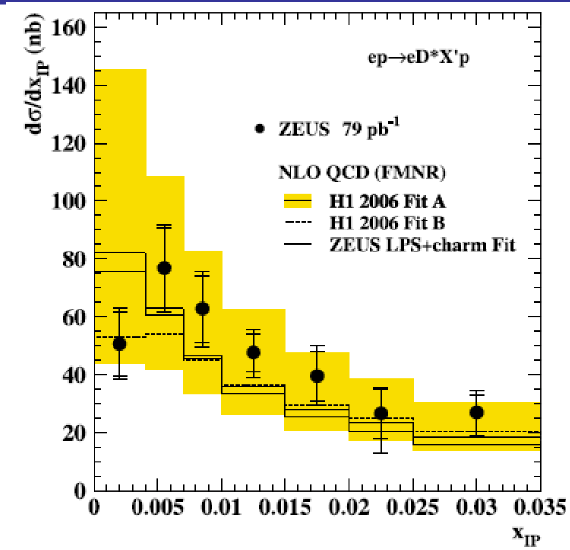
suppression of cross section = 1–"rap.gap.survival probability"

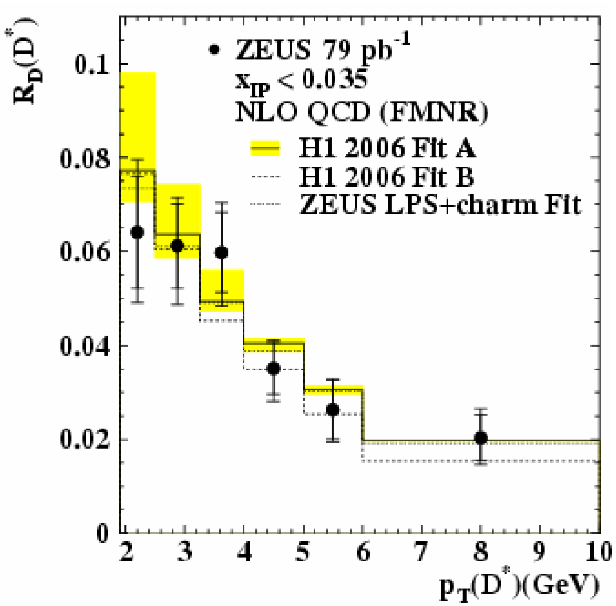
In photoproduction resolved contribution expected to be suppressed
(e.g. suppression~0.34   Kaidalov,Khoze,Martin,Ryskin:Phys.Lett.B567 (2003),61)

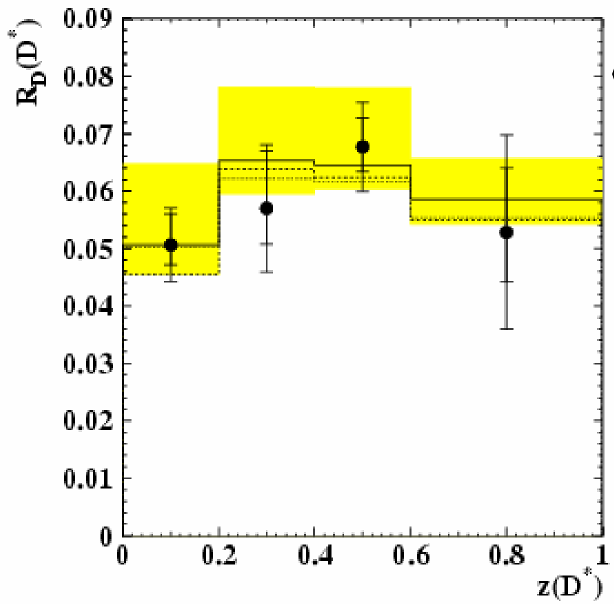
check factorisation with D* in diffractive photoproduction











Ratio diffractive/inclusive

R_D = 5.7 ±0.5%

Ratio from NLO calculations:

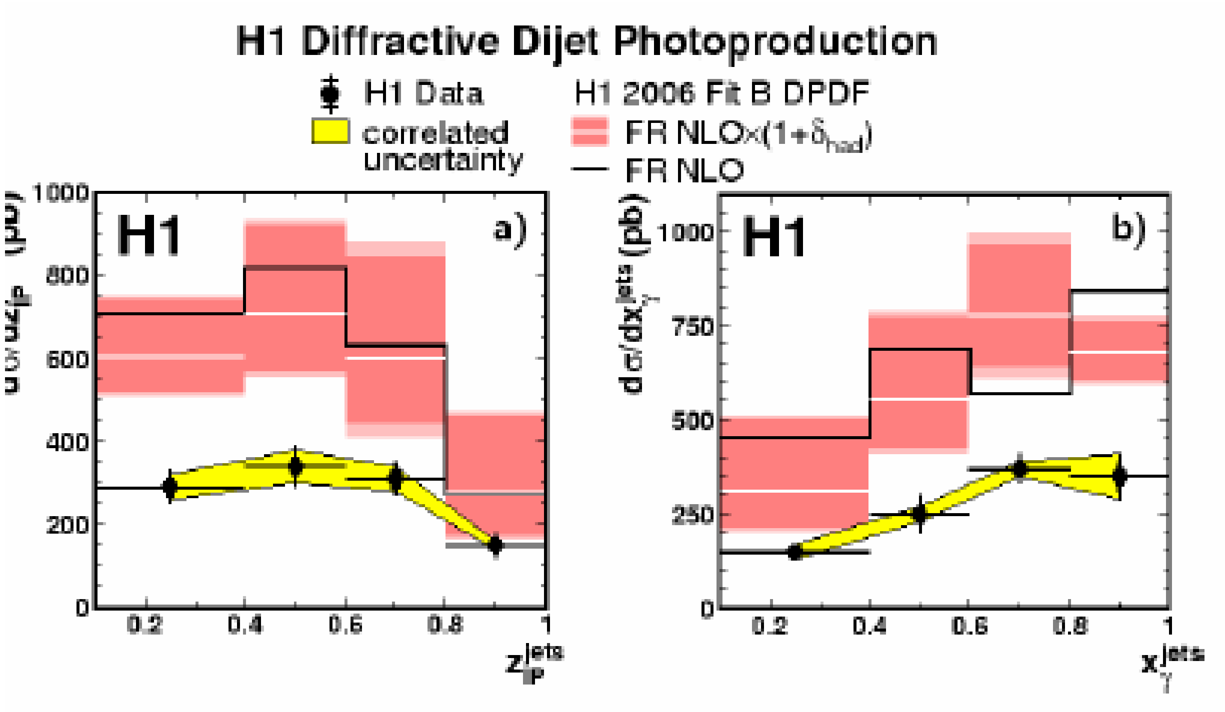
H1 fit 2006 B ➔ 5.7%

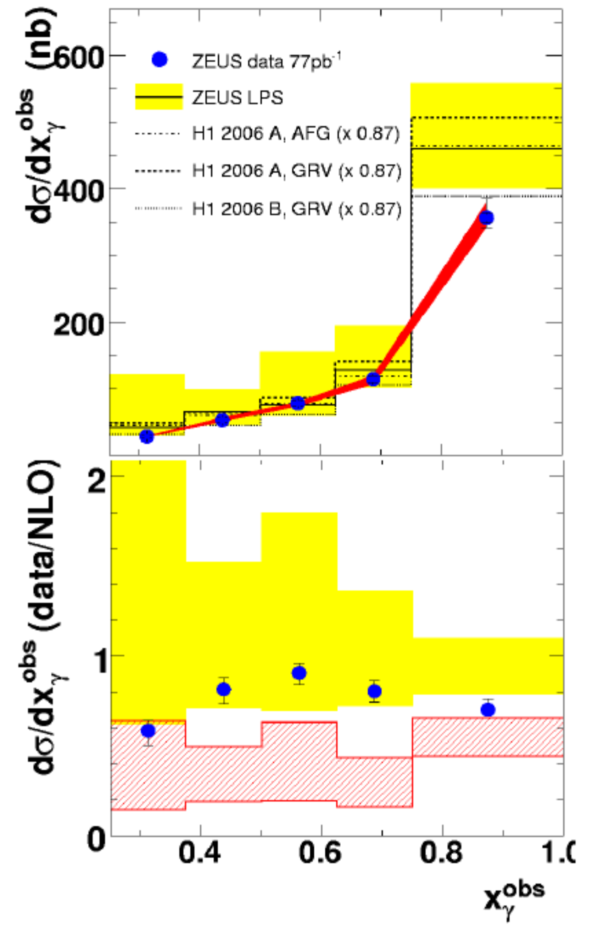
ZEUS fit LPS + charm: ➔ 5.8%

➔ **no evidence of factorisation breaking**

NLO calculation (FMNR) provides satisfactory description of diffractive charm data
➔ support QCD factorization

Dijets in diffractive photoproduction



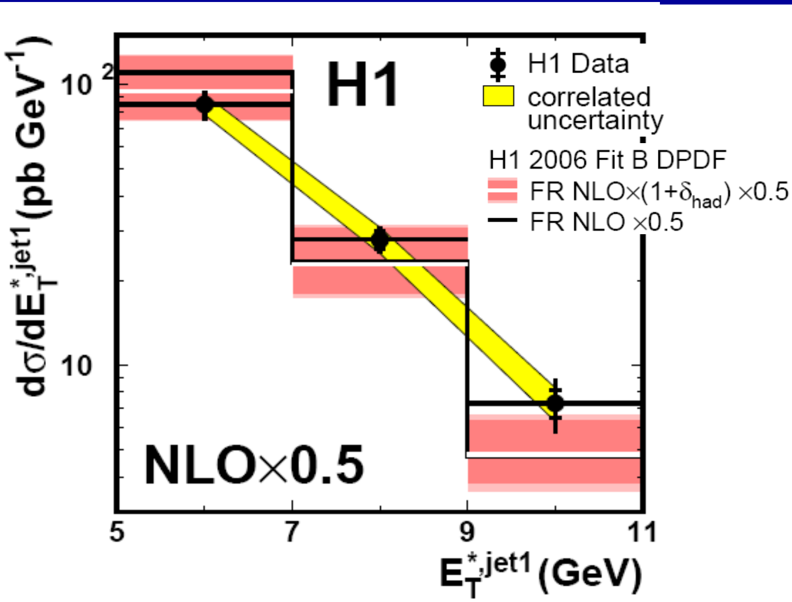


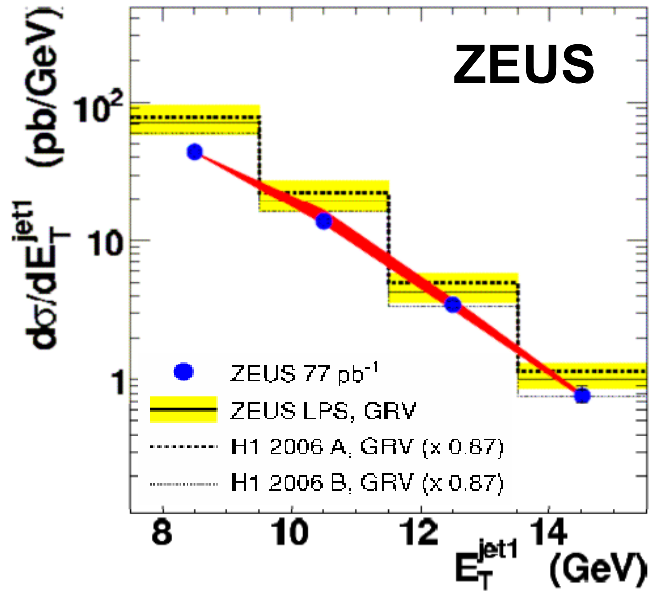
H1: suppression of factor ~0.5
ZEUS: weak (if any) suppression 0.6÷0.9

Both, H1 and ZEUS, don't see differences between the resolved and direct regions, in contrast to theory expectation !

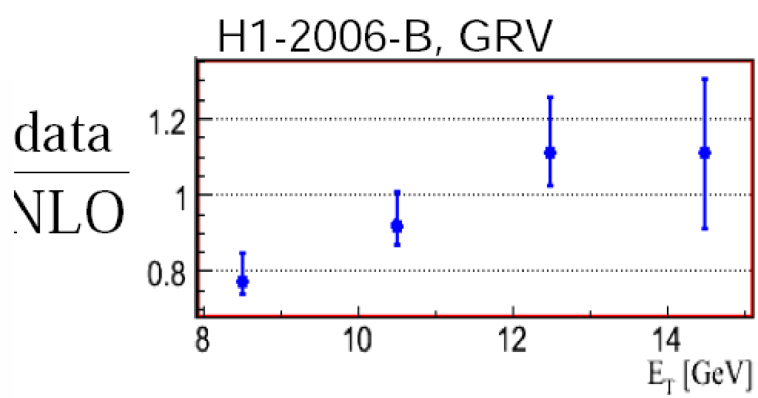
Possible explanation of differences between H1 and ZEUS - different phase space of both analyses **(H1: E_T^{jet} > 5 GeV, ZEUS: E_T^{jet} > 7.5 GeV)**

E_T dependence of suppression ?



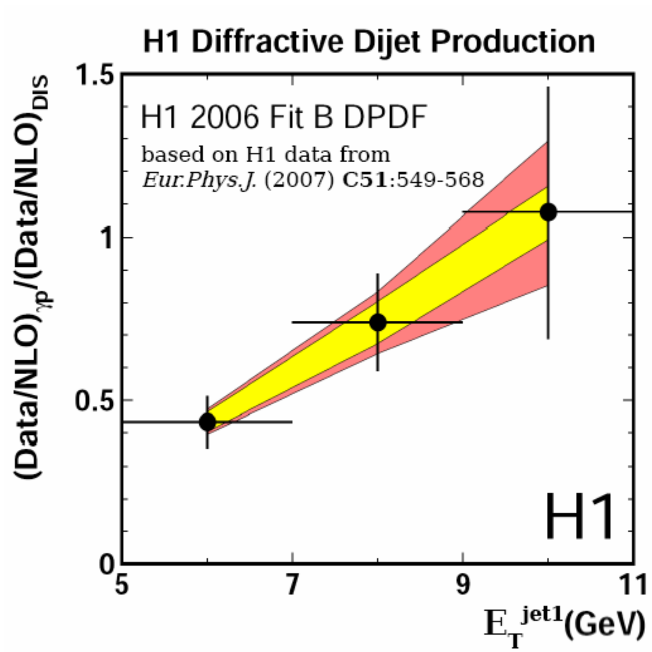


the data have harder E_T slope than NLO



suggestion of E_T^{jet} dependence is even stronger when look at double ratio

$$ratio = \frac{(Data/NLO)^{\gamma p}}{(Data/NLO)^{DIS}}$$



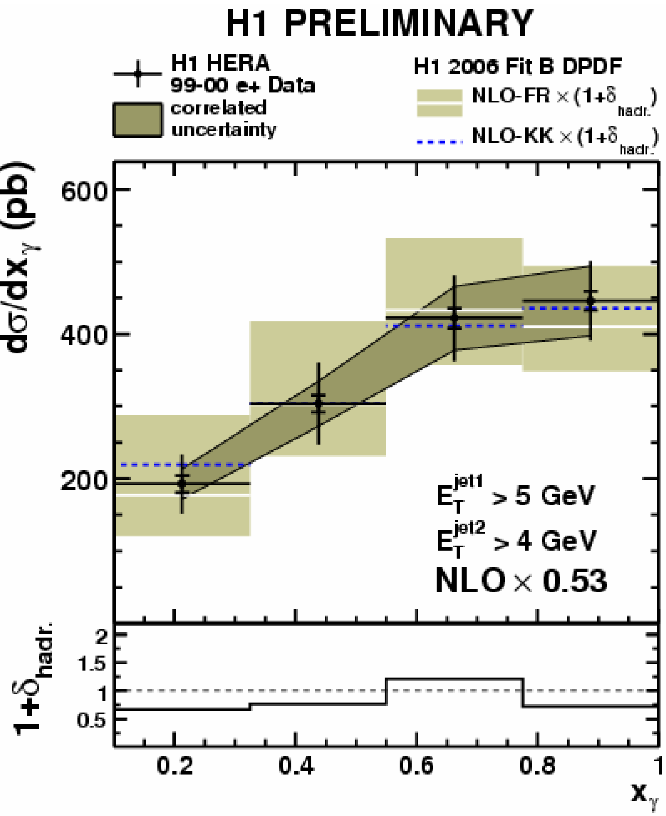
New H1 analysis with two E_T cut scenario

- try to understand difference in suppression factors H1-ZEUS
- data 99/00, luminosity 3x compared to previous results

low E_T scenario → cross-check of old H1 results	high E_T scenario → similar to ZEUS analysis	
$E_T^{jet1} > 5$ GeV	$E_T^{jet1} > 7.5$ GeV	
$E_T^{jet2} > 4$ GeV	$E_T^{jet2} > 6.5$ GeV	
$-1 < \eta(\text{jet 1 or 2}) < 2$	$-1.5 < \eta(\text{jet 1 or 2}) < 1.5$	
$x_{IP} < 0.03$	$x_{IP} < 0.025$	
$0.3 < y_e < 0.65$	$0.3 < y_e < 0.65$	(ZEUS $0.2<y<0.85$)
$Q^2 < 0.01$ GeV^2	$Q^2 < 0.01$ GeV^2	(ZEUS $Q^2<1$ GeV^2)
$\|t\| < 1$ GeV^2	$\|t\| < 1$ GeV^2	
$M_Y < 1.6$ GeV	$M_Y < 1.6$ GeV	

different from ZEUS (applies to the high E_T cuts on y_e, Q^2, $|t|$, M_Y)

Lower E_t cut scenario



$E_T^{jet1\ (jet2)} > 5\ (4)$ GeV, $-1 < \eta^{jet} < 2$

- 2 programs for NLO calculations (Frixione/Ridolfi and Klasen/Kramer)
- 3 sets of DPDFs: H1 2006- Fit A; Fit B; Jets

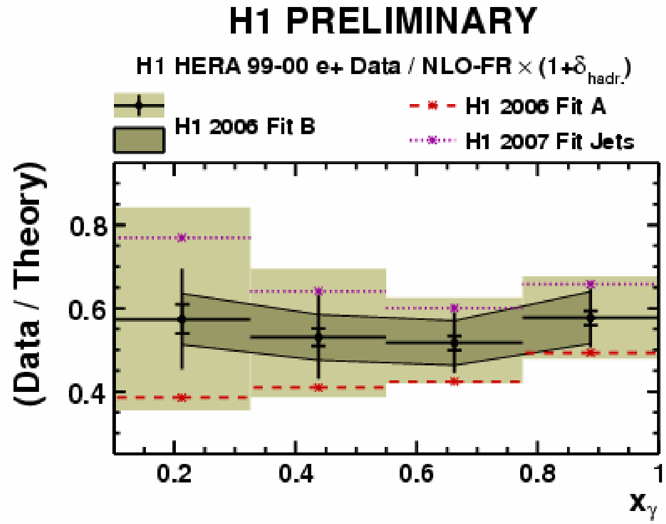
-good agreement with previous H1 measurement
-integrated survival probabilities 0.43÷0.65 depending on dPDFs;
-Within uncertainties similar for different dPDFs

$$S^{FR}_{fit\,B} = 0.54 \pm 0.01(stat.) \pm 0.10(syst.)^{+0.14}_{-0.13}(scale)$$

$$S^{KK}_{fit\,B} = 0.51 \pm 0.01(stat.) \pm 0.10(syst.)$$

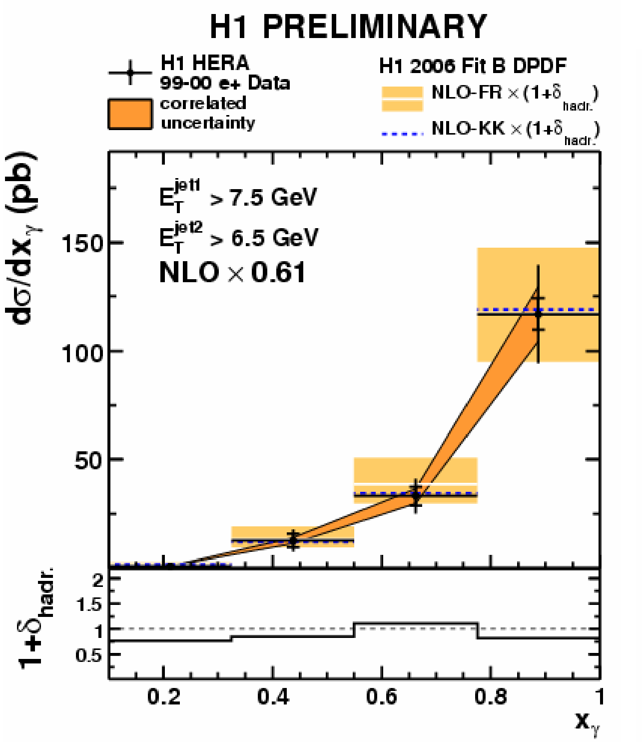
$$S^{FR}_{fit\,A} = 0.43 \pm 0.01(stat.) \pm 0.10(syst.)$$

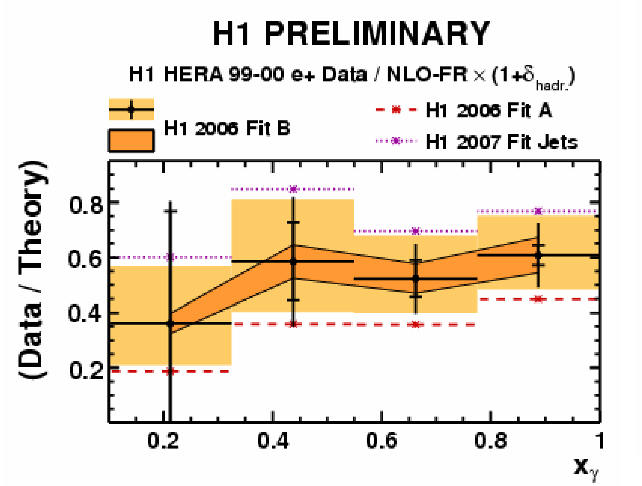
$$S^{FR}_{fit\,Jets} = 0.65 \pm 0.01(stat.) \pm 0.11(syst.)$$



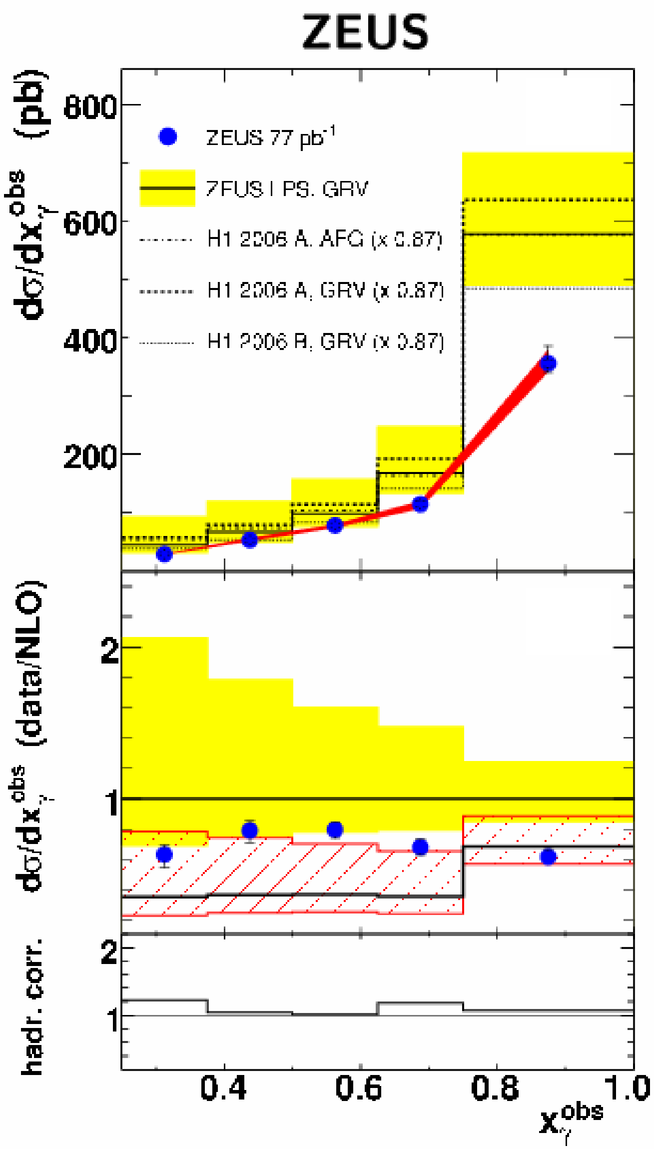
No difference in survival probabilities for resolved and direct regions of x_γ, like in previous H1 and ZEUS analyses

Higher E_t cut scenario





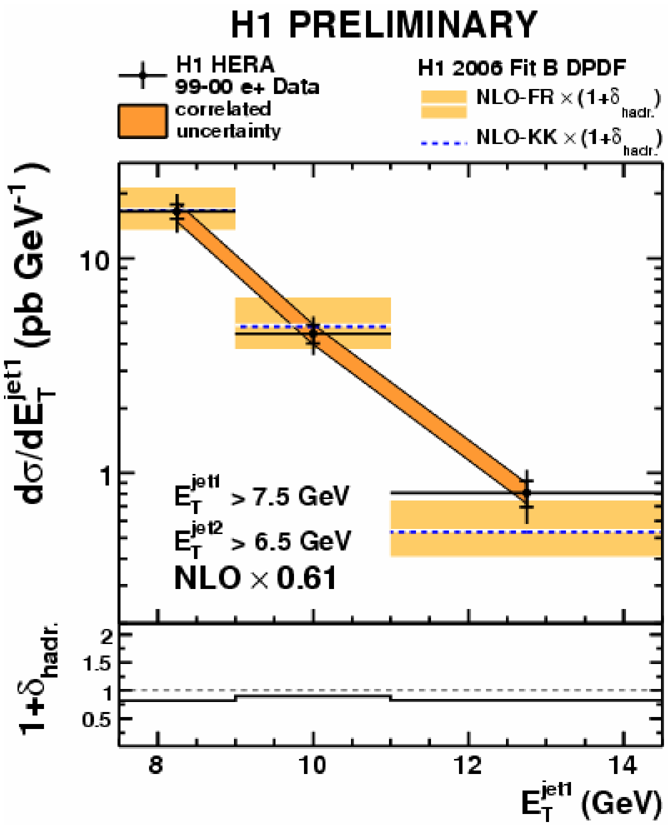
$E_T^{jet1\ (jet2)} > 7.5\ (6.5)$ GeV, $-1.5 < \eta < 1.5$



higher E_T
→more "direct-like" events
→ peak at higher x_γ

→ larger integrated survival probability than for lower E_T cut

Higher E_t cut scenario



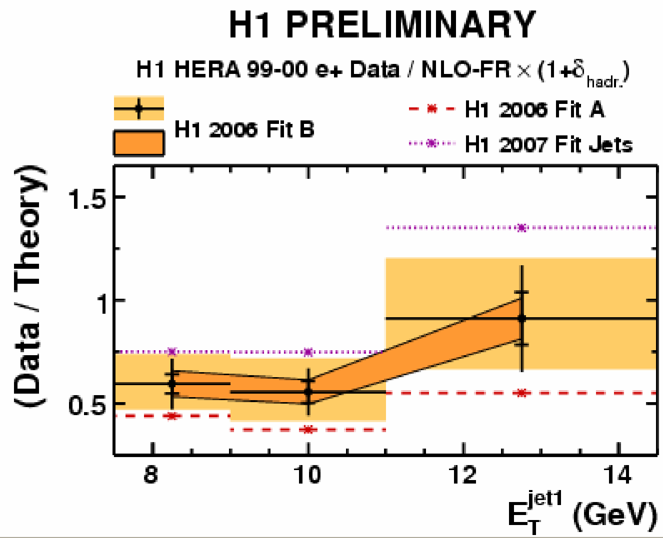
$$S^{FR}_{fit\,B} = 0.61 \pm 0.03(stat.) \pm 0.13(syst.)^{+0.16}_{-0.14}(scale)$$

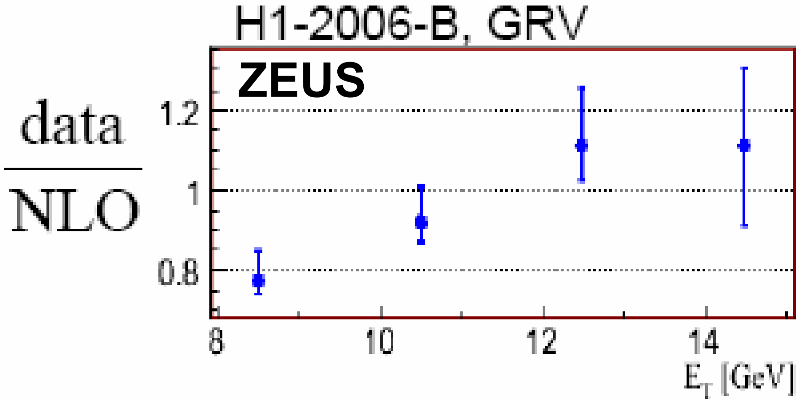
$$S^{KK}_{fit\,B} = 0.62 \pm 0.03(stat.) \pm 0.14(syst.)$$

$$S^{FR}_{fit\,A} = 0.44 \pm 0.02(stat.) \pm 0.16(syst.)$$

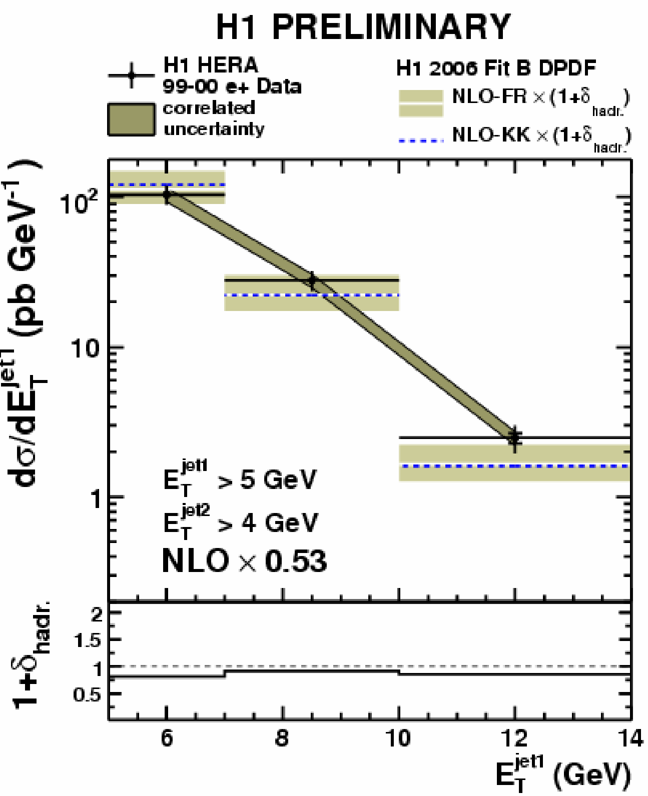
$$S^{FR}_{fit\,Jets} = 0.79 \pm 0.04(stat.) \pm 0.09(syst.)$$

With higher E_t^{jet} cut the H1 data require higher survival probabilities, i.e. move closer to the ZEUS results

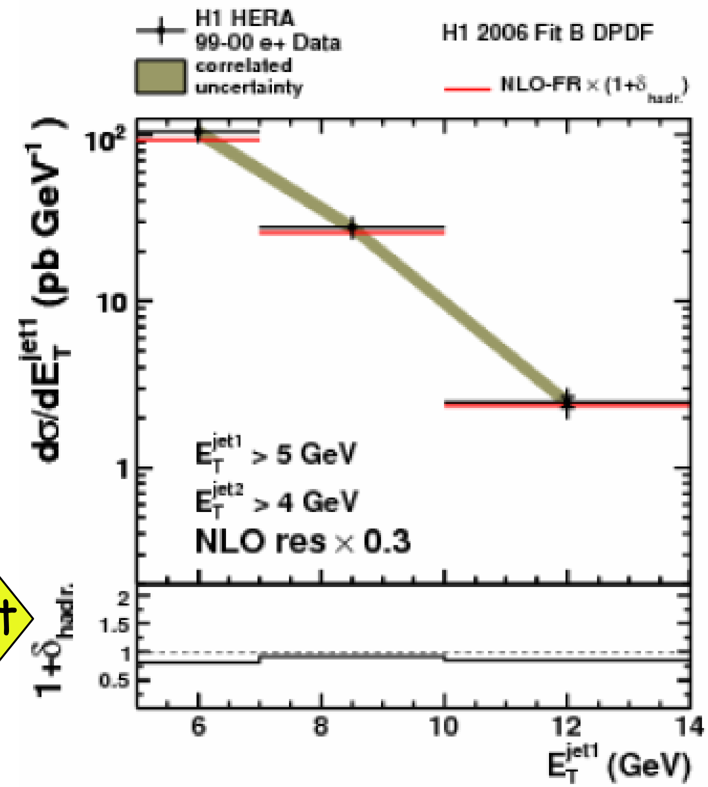




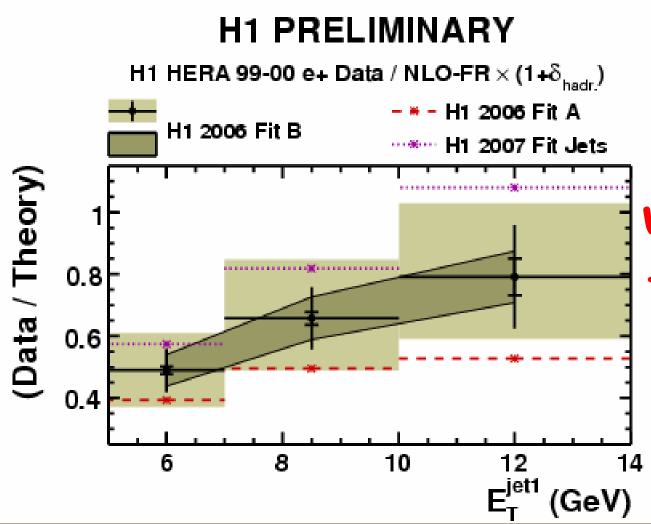
Global suppression or only for resolved component ?



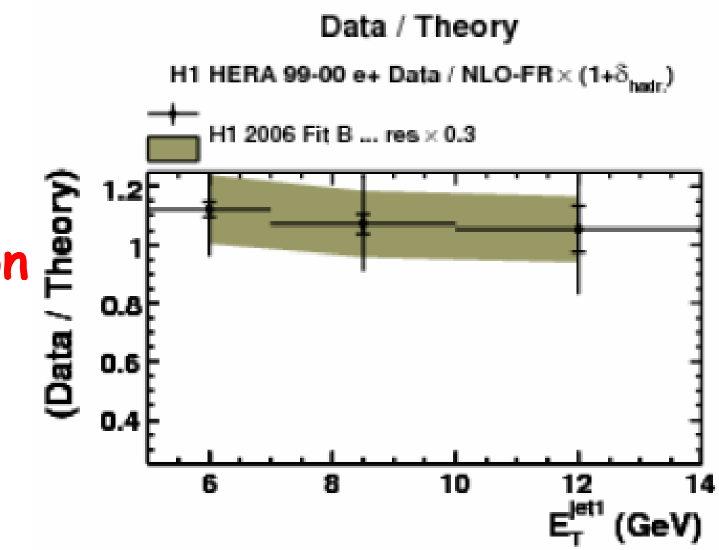
global suppression 0.53



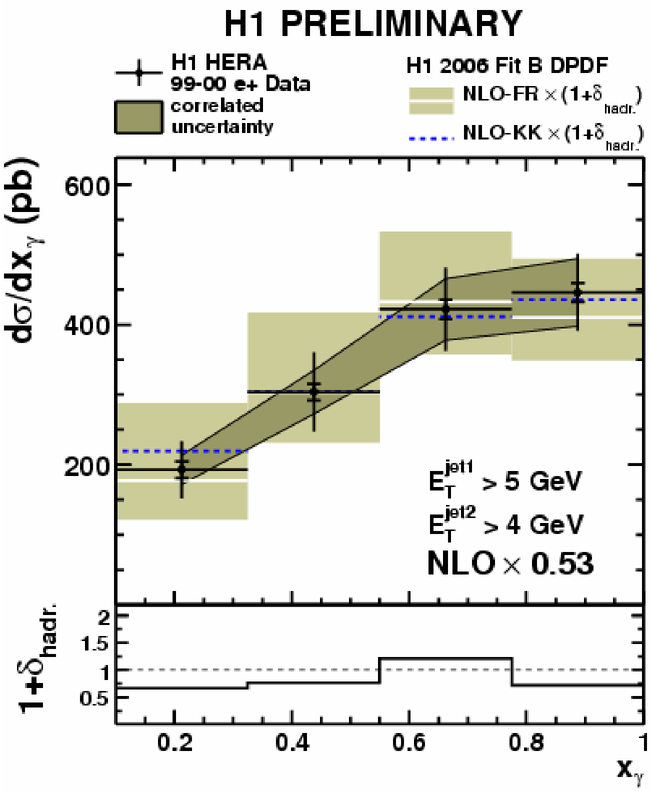
suppression of only NLO resolved component by 0.3



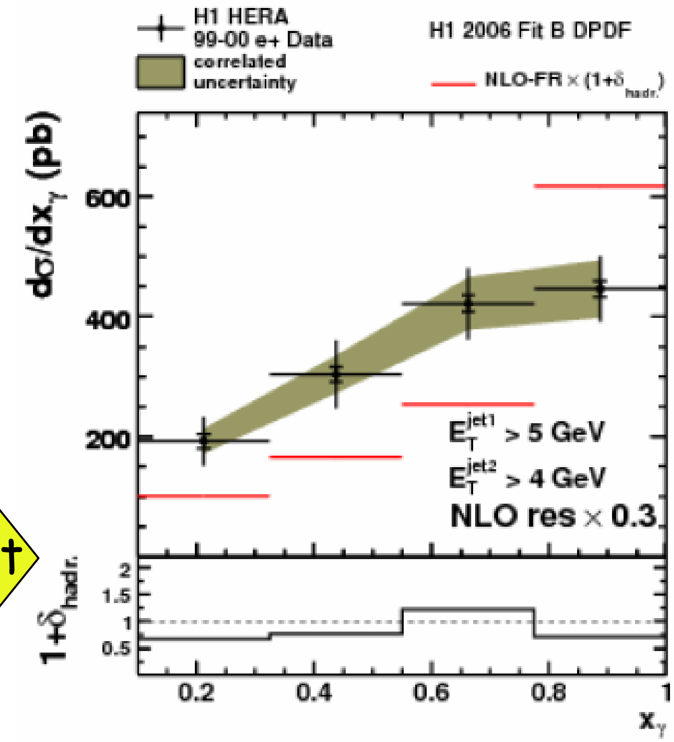
with resolved only suppression - no E_T dependence



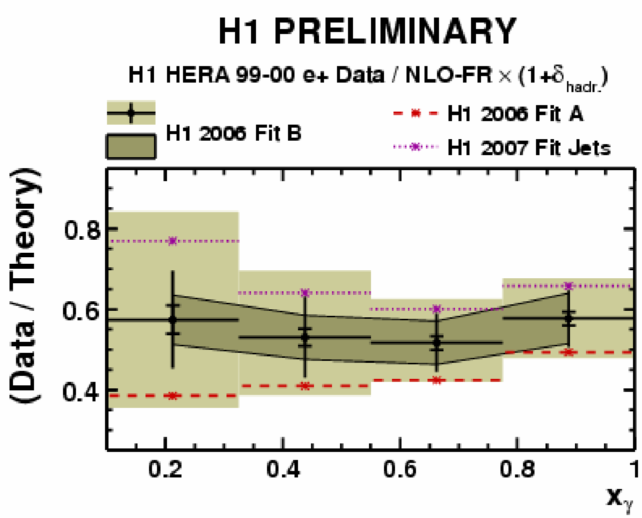
Global suppression or only for resolved component ?



global suppression
0.53

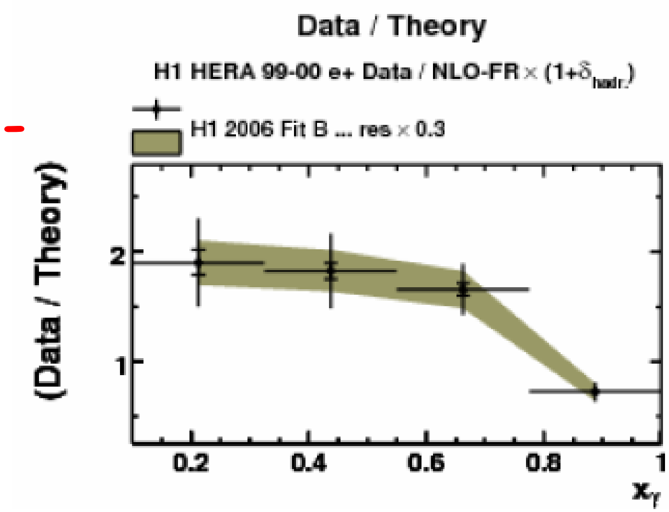


suppression of only
NLO resolved component
by 0.3



with resolved only suppression-
no E_T dependence, but worse
agreement between data and
NLO in x_γ distribution

experiments seem to prefer
global suppression

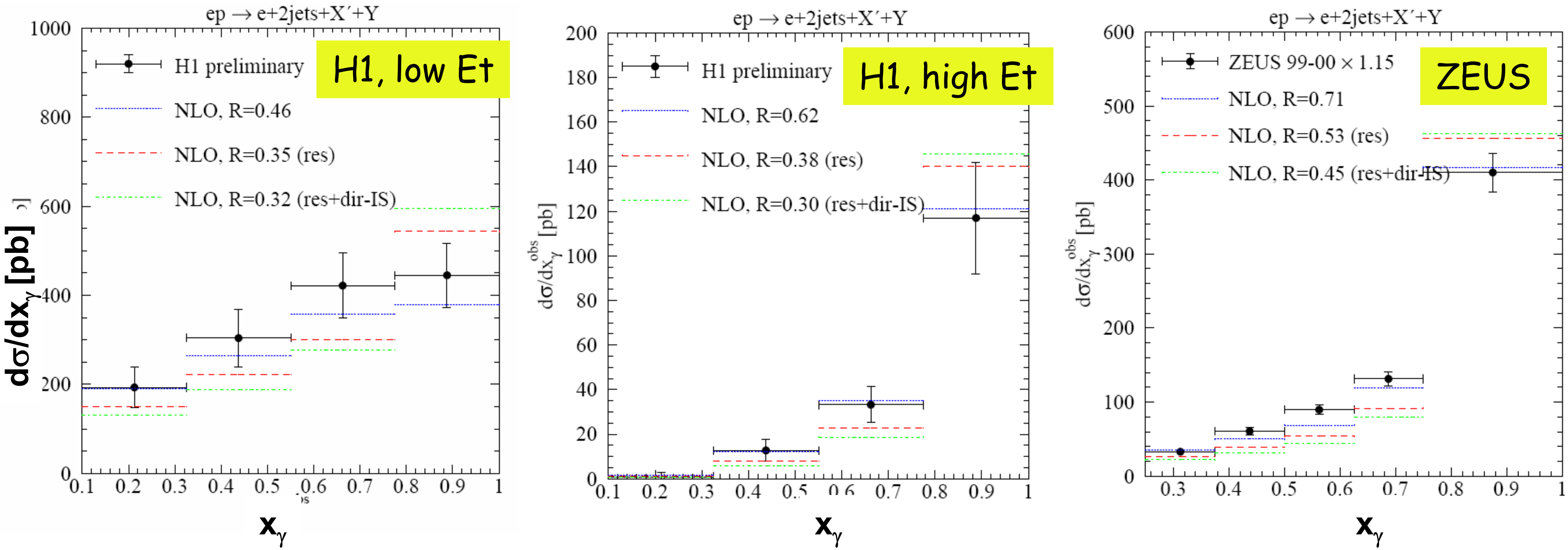


Global suppression or only for resolved component ?

M.Klasen,G.Kramer: DESY 08-074; LPSC-08-115

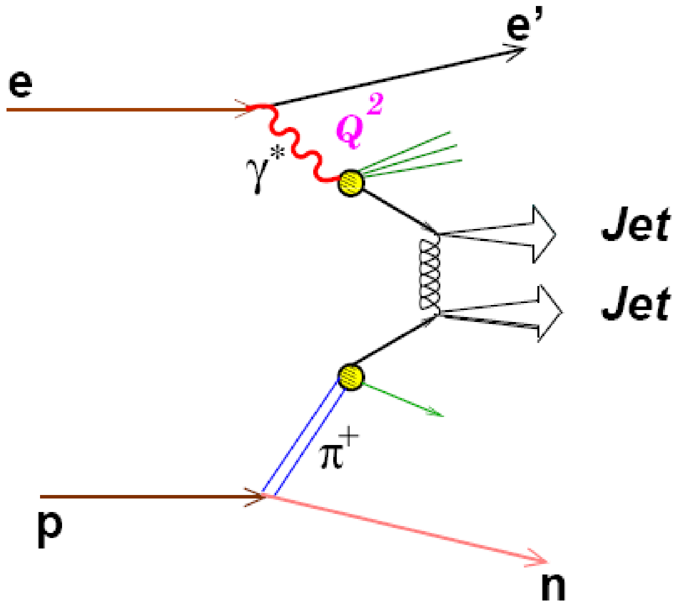
NLO calculations ; quantify suppression for global & resolved_only suppression hypotheses

	Global suppression	Resolved only suppression
H1 low Et	0.46	0.35
H1 high Et	0.62	0.38
ZEUS (high Et)	0.71	0.53

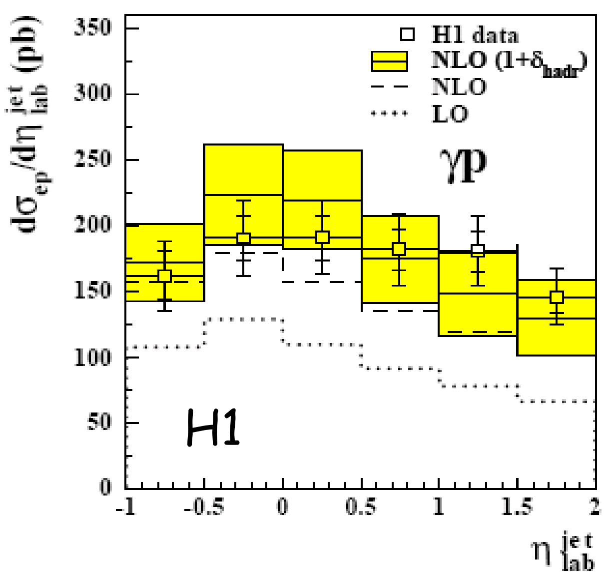


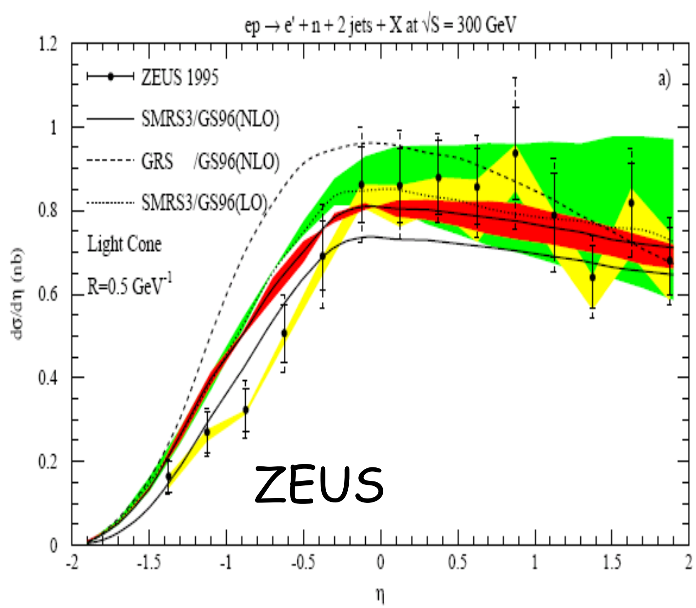
for resolved_only hypothesis the suppression is E_T-independent
(however the global suppression seem to be somewhat better w.r.t. to the data)

Another test of factorisation – dijet photoproduction with leading neutron



- Study the jet production in event with leading neutron in the final state ($\gamma^*p \rightarrow$ jet+jet+n+X)
- at high x_L=(En/Ep) dominant production mechanism- pion exchange
- Similar to diffractive jet production, the factorisation is expected to work in DIS and be broken in photoproduction (soft rescattering between the γ remnant and the neutron)





H1 and ZEUS γp jet cross sections compared to NLO calculations of Klasen&Kramer $\rightarrow$ good agreement !?

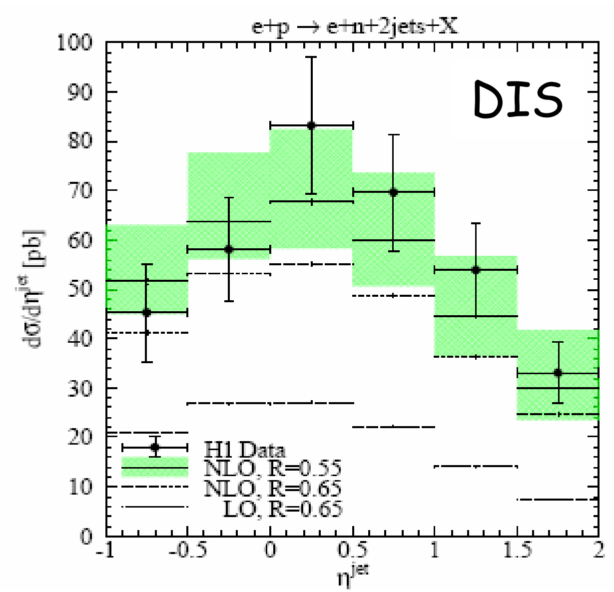
π-exchange different from diffraction ?
No factorisation breaking ?

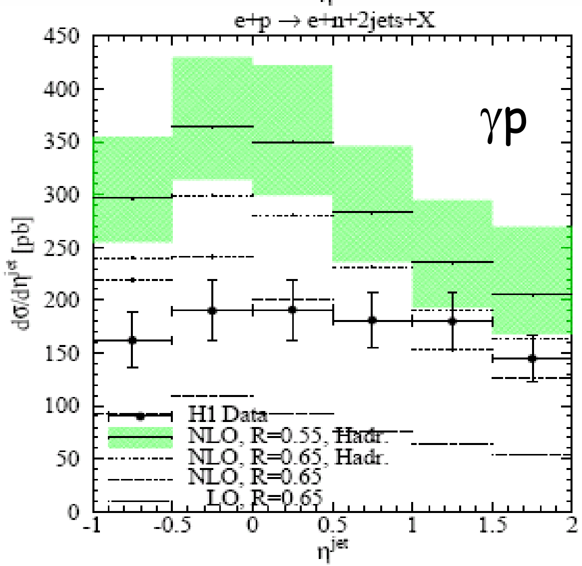
The normalisation of NLO predictions strongly depends on the choice of pion PDF and flux (rather arbitrary) !

Another test of factorisation – dijet photoproduction with leading neutron

New calculations (Klasen & Kramer, Eur.Phys.J.C49:957-965,2007)

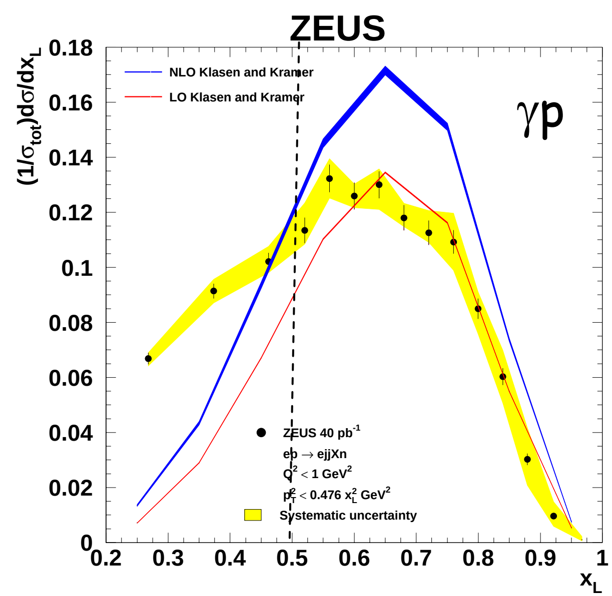
- **normalise NLO (fix pion PDF, adjust pion flux) to H1-DIS data ($\gamma^* p \rightarrow jjnX$)**
- **compare to H1-γp data ($\gamma p \rightarrow jjnX$) , look for suppression**





NLO vs H1 photoproduction data (E_T^{jet}>7 GeV) needs ~0.48 suppression of resolved component (or 0.64 global suppression)

Suppression seen also in ZEUS data (E_T^{jet} >7.5 GeV) for x_L>0.5



Summary

•QCD factorisation in diffraction investigated at HERA in hadronic final states and over a wide kinematic range

• In diffractive DIS, the measurements of jet and charm production confirm validity of QCD factorisation

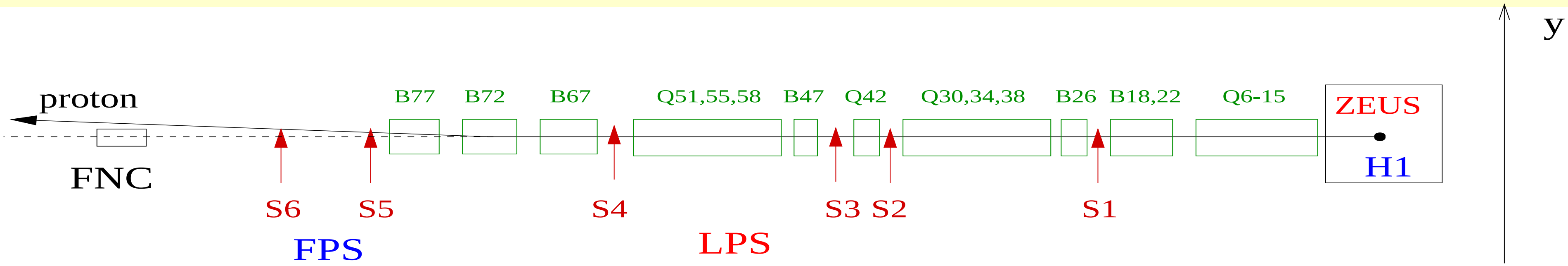
• In the photoproduction of jets the large violation of factorisation is observed: the measured rapidity gap survival probability (overall factor): 0.5 (H1 – low E_T^{jet}), 0.65 (H1- high E_T^{jet}), 0.8 (ZEUS)

➔ suppression is dependent on E_T^{jet}
➔ the H1/ZEUS difference gets smaller for the same E_T^{jet} cut (but still there)

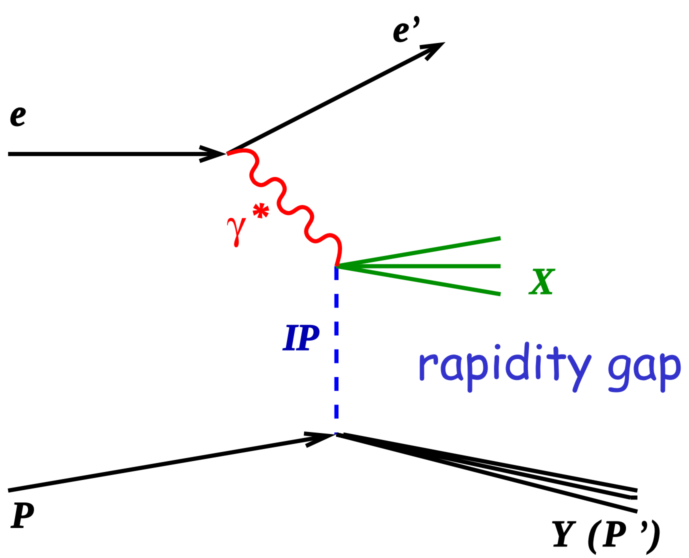
• the H1 and ZEUS data prefer the suppression which is independent on x_γ (i.e. same for direct/resolved)
➔ explanation is far not obvious

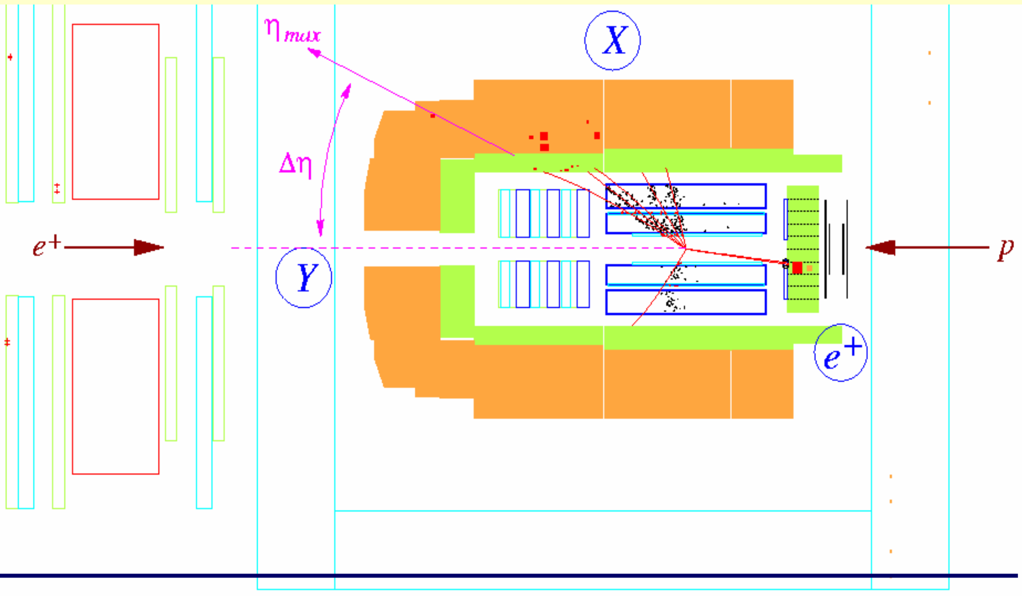
• limitation: experimental systematics, theoretical uncertainties

- **'Leading proton' method (LPS)– scattered proton detected in 'Roman Pots' (LPS, FPS)**
  free of p-diss. background, t and x_{IP} measurement, but low acceptance/statistics



- **Large Rapidity Gap' method (LRG)**
  t is not measured, some p-diss. background

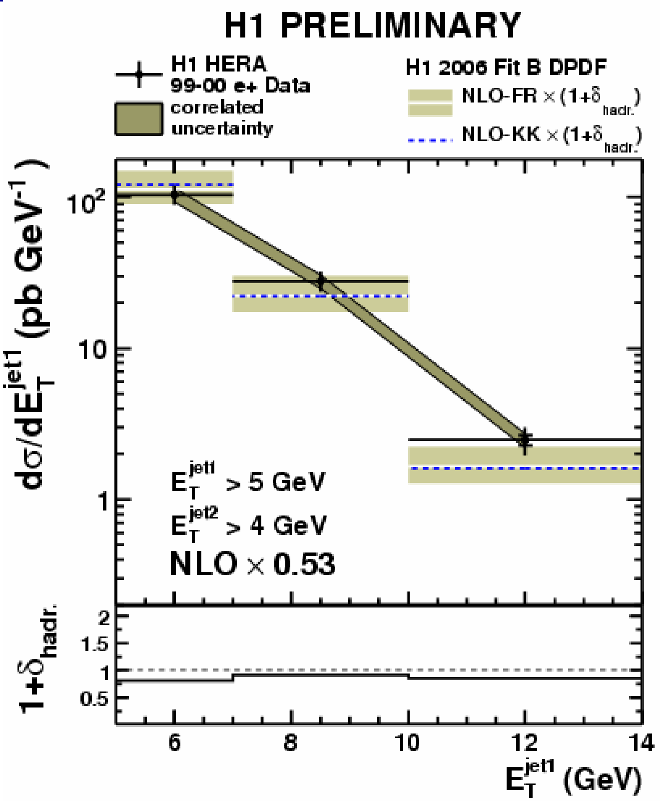




- **'M_X' method- non-diffractive contribution subtracted from fit to M_X distribution**

Lower E_t cut scenario

$E_T^{jet1\ (jet2)} > 5\ (4)$ GeV, $-1 < \eta^{jet} < 2$



E_T^{jet} :harder slope for data than for NLO