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Factorization and factorization breaking in diffraction at HERA

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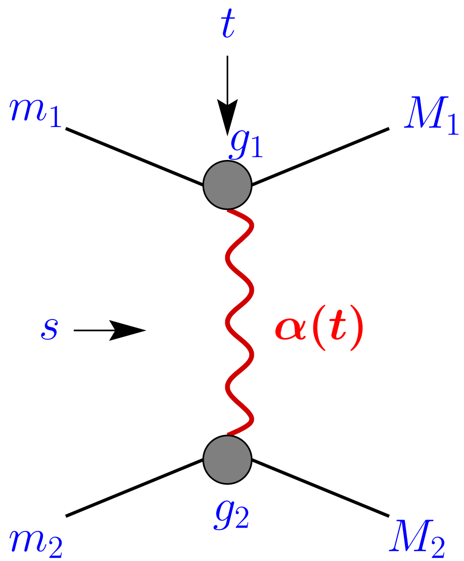
representing

ZEUS

- Introduction
- Testing Regge factorisation in inclusive diffraction
- Testing QCD factorisation in diffractive final states
- Summary

Two approaches to Strong Interactions

1. Regge Pole Model $\Rightarrow$ RFT

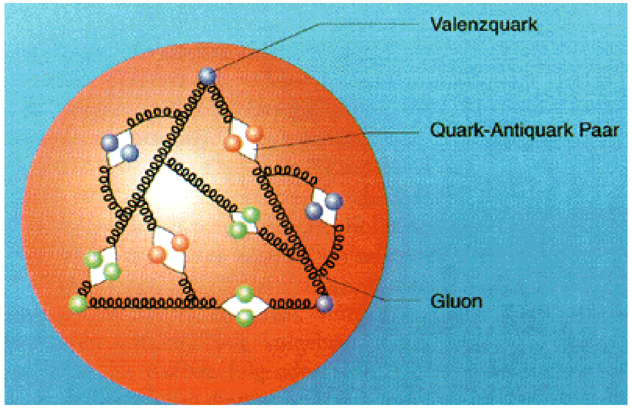


$$A(s,t) =$$

$$g_1(m_1, M_1, t) g_2(m_2, M_2, t) \frac{s^{\alpha(t)} \pm (-s)^{\alpha(t)}}{\sin(\pi\alpha(t))}$$

hadronic language

2. Quark-Parton Model $\Rightarrow$ QCD



$$\sigma_{ab} =$$

$$\int f_{i/a}(x_i, \mu^2) \cdot f_{j/b}(x_j, \mu^2) \cdot \hat{\sigma}_{ij}(x_i, x_j, \mu^2)$$

sub-hadronic language

Ultimate goal: derive (1) from (2)

RFT: soft hh scattering vs QCD: deep inelastic ep scattering

RFT	QCD
• Hadronic degrees of freedom	• Partonic degrees of freedom
• Validity: large $s \gg t$	• Low x: $W^2 \gg Q^2, t$ $(Q^2/W^2 \simeq x \ll 1)$
• $I\!P$ dominates: $\alpha_{I\!P}(0) > \alpha_{I\!R}(0)$ $\longrightarrow \sigma_{\mathrm{tot}} \propto s^{\alpha_{I\!P}(0)-1}$	• gluons dominate: $xg(x) \gg xq_{val}(x)$ $F_2(x, Q^2) \propto xg(x) \sim x^{-\lambda}$
• Unitarity corrections unavoidable $(\sigma_{\mathrm{tot}} \leq \ln^2(s/s_0)$ at $s \to \infty)$	• Saturation of the $xg(x)$ (non-linear effects, shadowing, ...)
• When? $s_{sat} = ?$	• $x_{sat}(Q_{sat}) = ?$
• First to be seen in diffraction: $\sigma_D \propto s^{2(\alpha-1)}$	• First to be seen in diffraction: $\sigma_D \propto \lvert xg(x)\rvert^2$

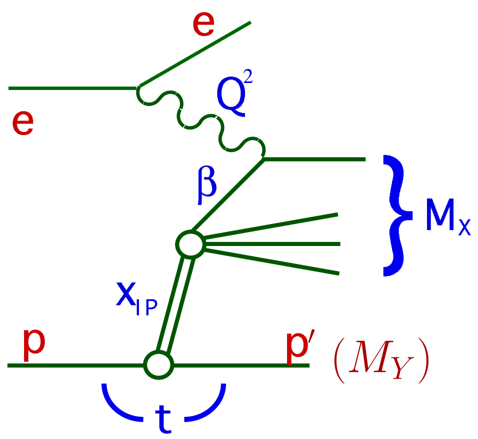
$\Rightarrow$ Diffraction $\equiv$ Physics of the Pomeron, the essence of strong interactions

$\Rightarrow$ Diffraction $\equiv$ Gluodynamics, the essence of QCD

(in high energy limit)

Diffraction at HERA

- Fundamental aim: understand high energy limit of QCD (gluodynamics; CGC ?)
- Novelty: for the first time probe partonic structure of diffractive exchange
- Practical motivations: study factorisation properties of diffraction; try to transport to hh scattering (e.g. predict diffractive Higgs production at LHC)



$$x_{I\!P} = \xi = \frac{Q^2+M_X^2}{Q^2+W^2}$$

(momentum fraction of colour singlet exchange)

$$\beta = \frac{Q^2}{Q^2+M_X^2} = x_{q/I\!P} = \frac{x}{x_{I\!P}}$$

(fraction of exchange momentum, coupling to γ^*)

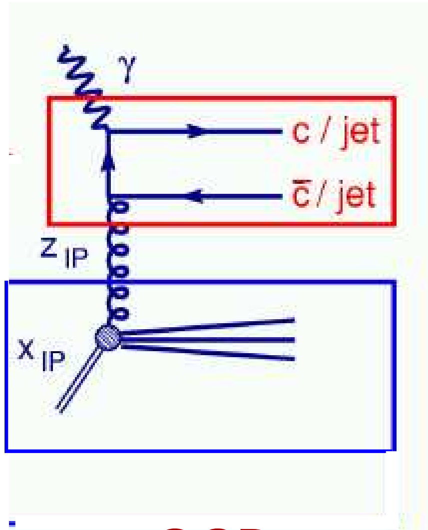
$$t = (p - p')^2$$

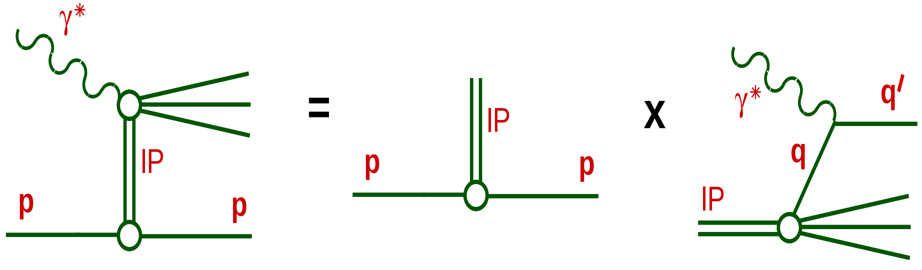
(4-momentum transfer squared)

$$\frac{d^4\sigma}{dx_{I\!P}\, dt\, d\beta\, dQ^2} = \frac{4\pi\alpha^2}{\beta Q^4}\left(1 - y + \frac{y^2}{2}\right)\sigma_r^{D(4)}(x_{I\!P}, t, \beta, Q^2)$$

$$\sigma_r^{D(4)} = F_2^{D(4)} - \frac{y^2}{2(1-y+y^2/2)}F_L^{D(4)} \quad \Rightarrow \quad F_2^{D(3)} = \int dt F_2^{D(4)}$$

Factorisation properties in diffraction





QCD versus Regge factorisation

QCD factorisation

(rigorously proven for DDIS by Collins et al.):

$$\sigma_r^{D(4)} \propto \sum_i \hat{\sigma}^{\gamma^* i}(x, Q^2) \otimes f_i^D(x, Q^2; x_{I\!P}, t)$$

- $\hat{\sigma}^{\gamma^* i}$ – hard scattering part, same as in inclusive DIS
- f_i^D – diffractive PDF's, valid at fixed $x_{I\!P}, t$ which obey (NLO) DGLAP

Regge factorisation

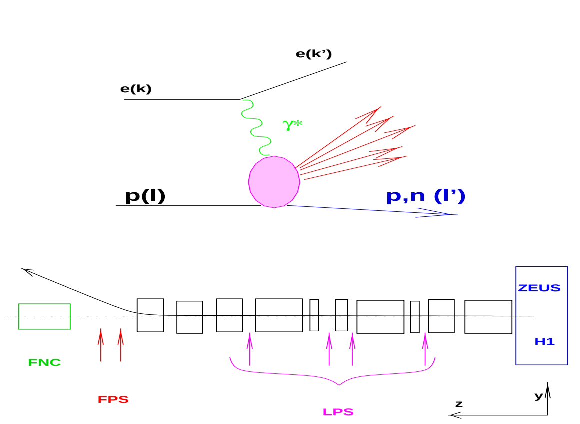
(conjecture, e.g. RPM by Ingelman,Schlein):

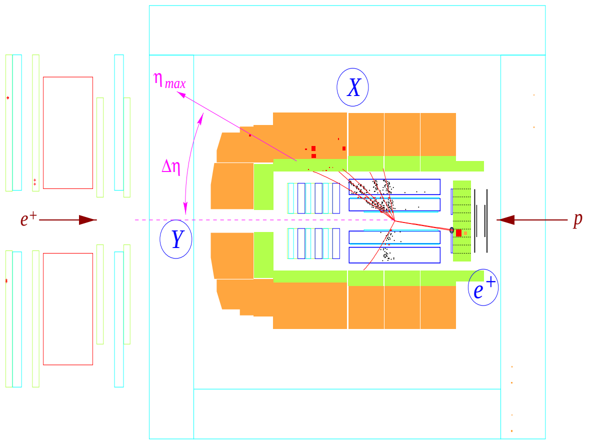
$$F_2^{D(4)}(x_{I\!P}, t, \beta, Q^2) = \Phi(x_{I\!P}, t) \cdot F_2^{I\!P}(\beta, Q^2)$$

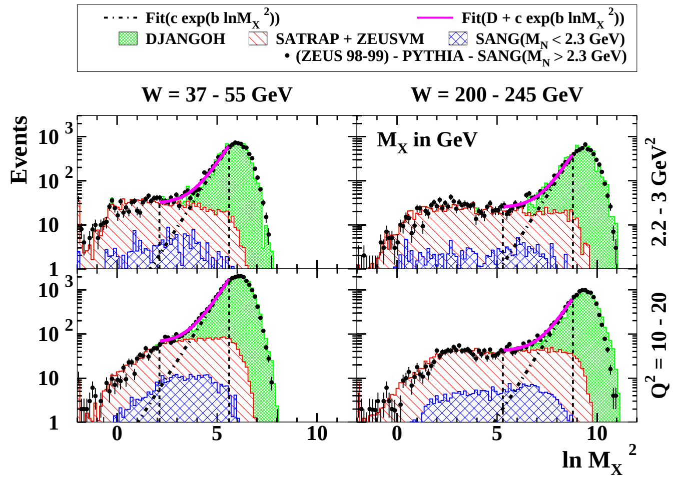
- In this case shape of diffractive PDF's is independent of $x_{I\!P}, t$ while normalization is controlled by Regge flux $\Phi(x_{I\!P}, t)$

Selecting Diffractive Events at HERA

LPS (H1,ZEUS) | **LRG** (H1) | M_X (ZEUS)







- clean sample, free of p-dissociative bgr
- provides t measurement
- limited statistics (beam cond., $x_{I\!P}, t$ acceptance)

- large statistics, bigger phase space coverage:
  $3.2 < \eta_{\text{gap}} < 7.5$ (tag) $\qquad$ $\eta_{\max} < 5.0$ (meas)
- integrate over $t > -1$ GeV^2
- some dissociative admixture remains in sample:
  $M_Y < 1.6$ GeV $\qquad$ $M_Y < 2.3$ GeV

Strategy

- obtain NLO DPDFs from inclusive DDIS (and test Regge factorisation)
- predict final states to NLO, or model them using MC technique (charm, jets)
- confront to the data (test QCD factorisation)

NLO QCD:

DIS: HQVDIS, DDISENT

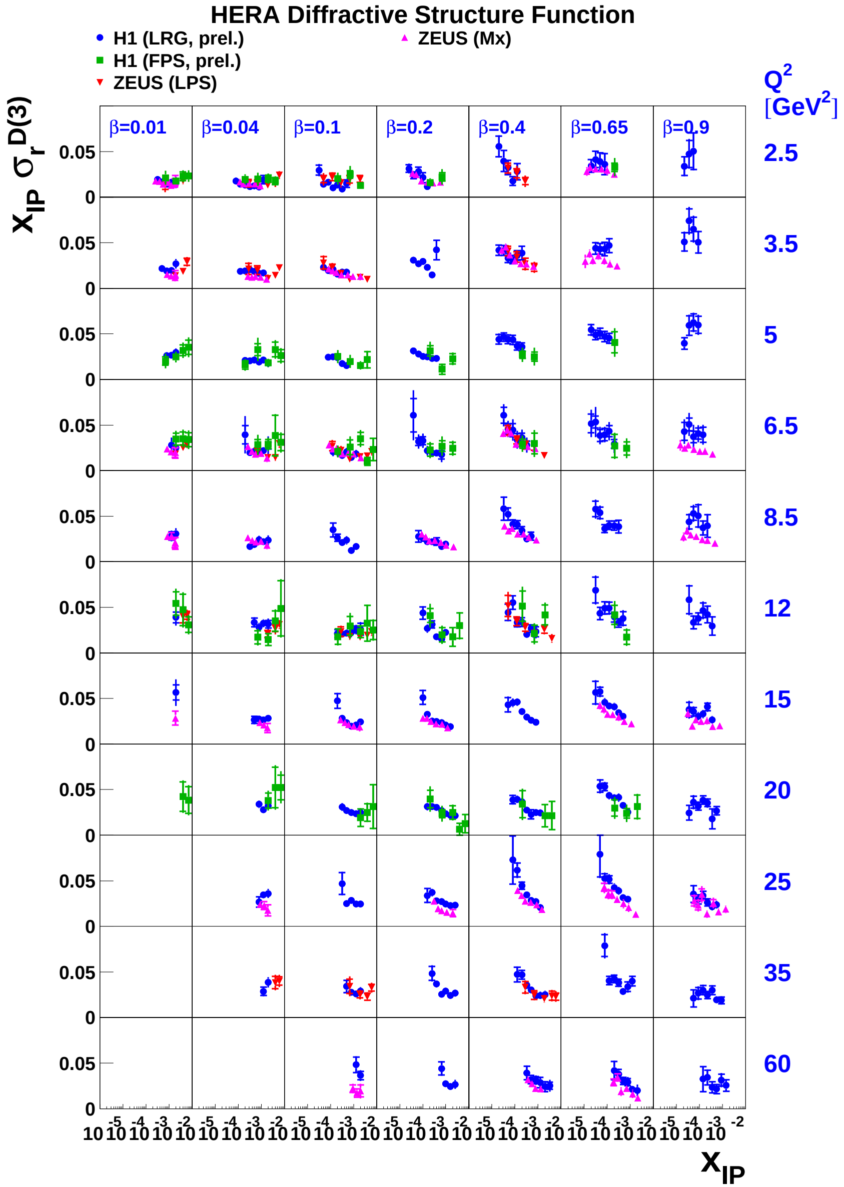
γp: Frixione, KK

Data Samples

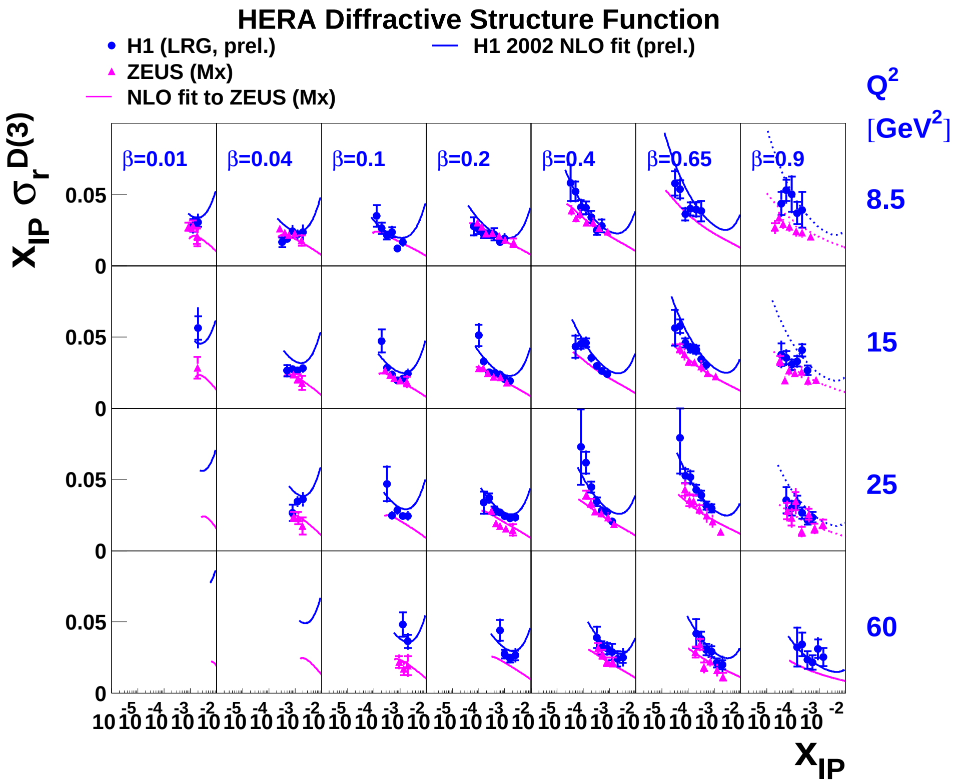
Sample	Q^2 range	$\mathcal{L}$
LPS (ZEUS)	$0.03 < Q^2 < 0.6$ GeV^2	3.6 pb^{-1}
	$2 < Q^2 < 100$ GeV^2	12.8 pb^{-1}
FPS (H1)	$2 < Q^2 < 50$ GeV^2	28.8 pb^{-1}
M_X	$2.2 < Q^2 < 80$ GeV^2	4.2 pb^{-1}
LRG	$1.5 < Q^2 < 12$ GeV^2	3.4 pb^{-1}
	$6.5 < Q^2 < 120$ GeV^2	10.6 pb^{-1}
	$200 < Q^2 < 1600$ GeV^2	63 pb^{-1}

All data analysed so far are from HERA-1 run

Inclusive diffraction: H1 vs ZEUS



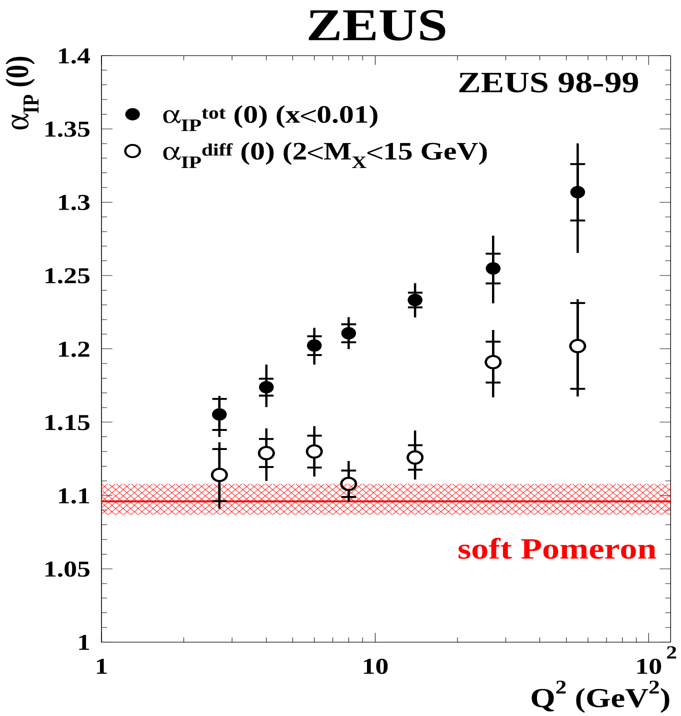
- All data are scaled to $M_Y < 1.6$ GeV
- All data are transported to H1 LRG bin centers

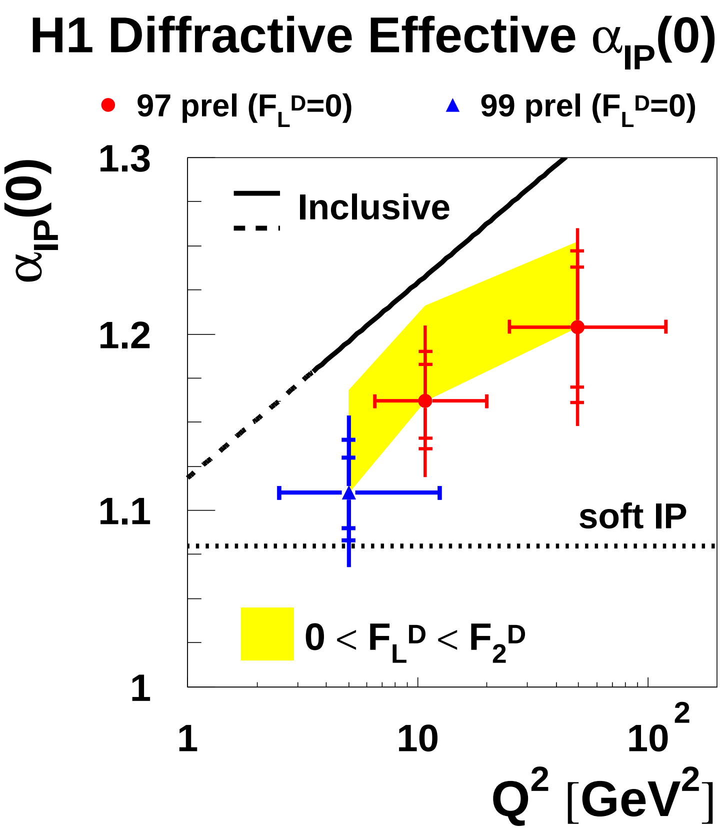


- Reasonable agreement between data sets
- Differences: (a) at low M_X, (b) Q^2 dependence

$\alpha_{I\!P}(0)$ in total vs diffractive DIS

Related via Optical theorem: $\sigma^{tot} \sim W^{2(\alpha_{I\!P}(0)-1)}$ $\sigma^{el/diff} \sim W^{4(\alpha_{I\!P}(0)-1)}$





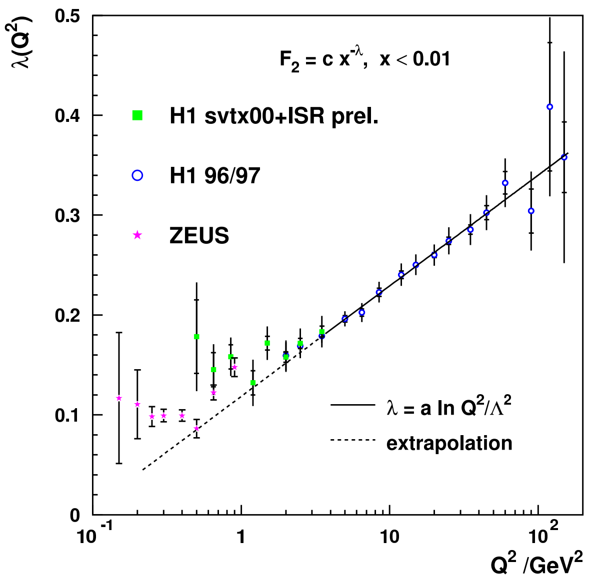
$\Rightarrow$ in DIS region $\alpha_{I\!P}(0)$ is incompartible with soft $I\!P$

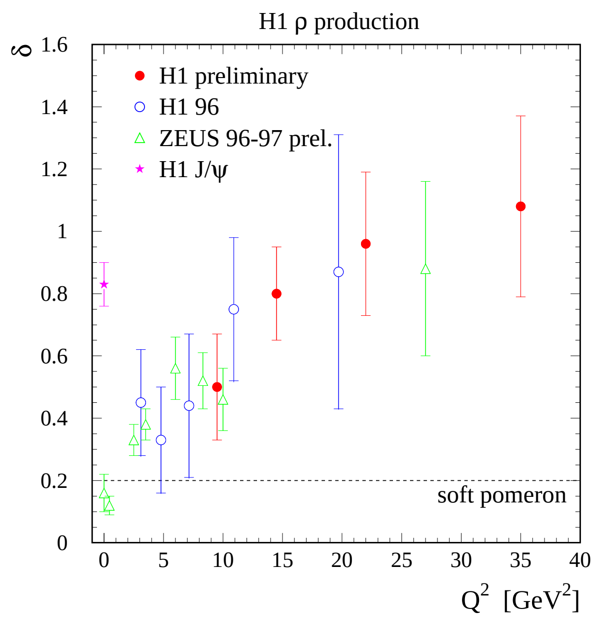
$\Rightarrow$ indication for Regge factorisation breaking

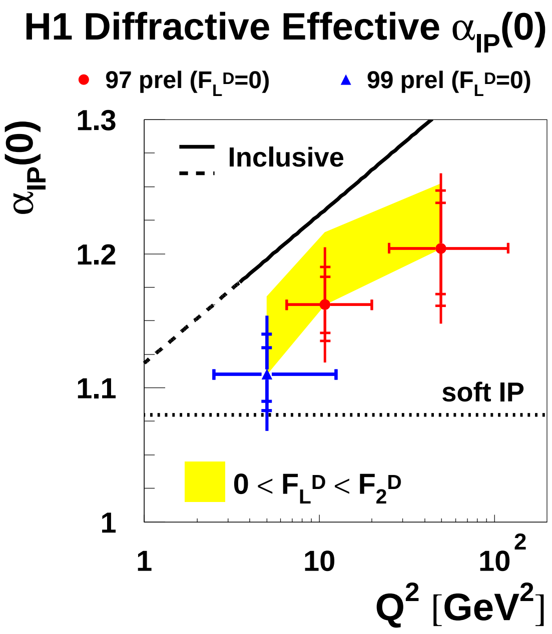
$\Rightarrow$ $\alpha_{I\!P}^{diff}(0) - 1 \simeq \frac{1}{2}(\alpha_{I\!P}^{tot}(0) - 1)$ $\rightarrow$ UC ??

Pomeron intercept in inclusive, elastic and diffractive DIS

Optical theorem







$\lambda = (\alpha_{I\!P}(0) - 1)$

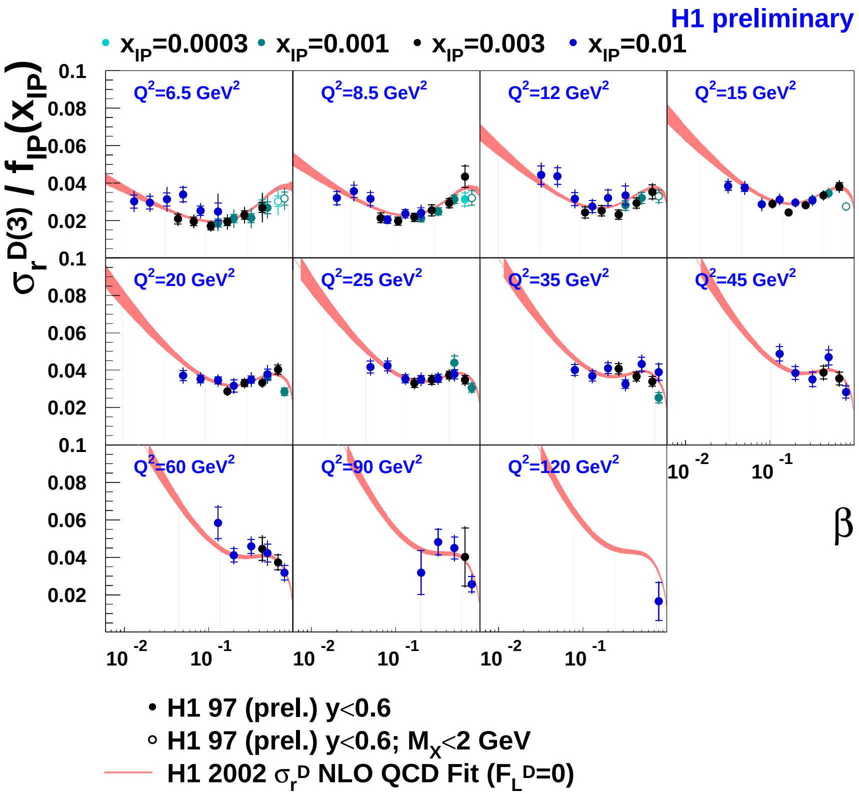
$\delta = 4(\overline{\alpha_{I\!P}(0)} - 1)$

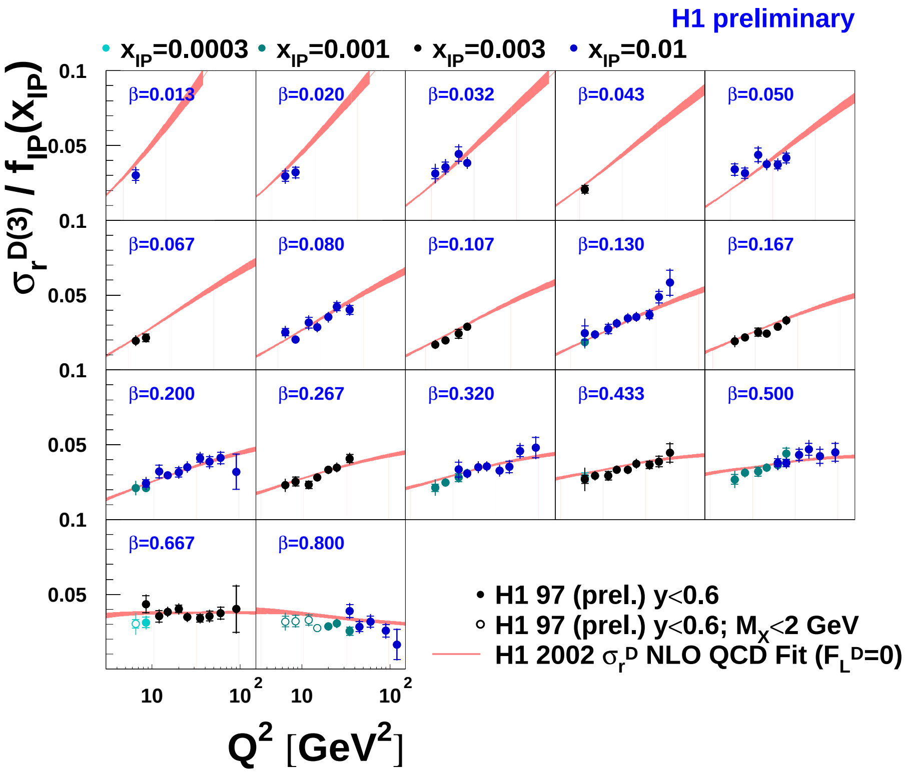
Unitarity corrections?

Understanding of colour singlet exchange remains a major challenge in QCD:

It is a complicated interplay between soft and hard phenomena

H1 $F_2^D(\beta, Q^2)$





- Regge factorisation approx. holds for $x_{I\!P} < 0.01$ $\longrightarrow$ simplifies QCD fit
- positive scaling violation except largest β $\longrightarrow$ gluon dominance

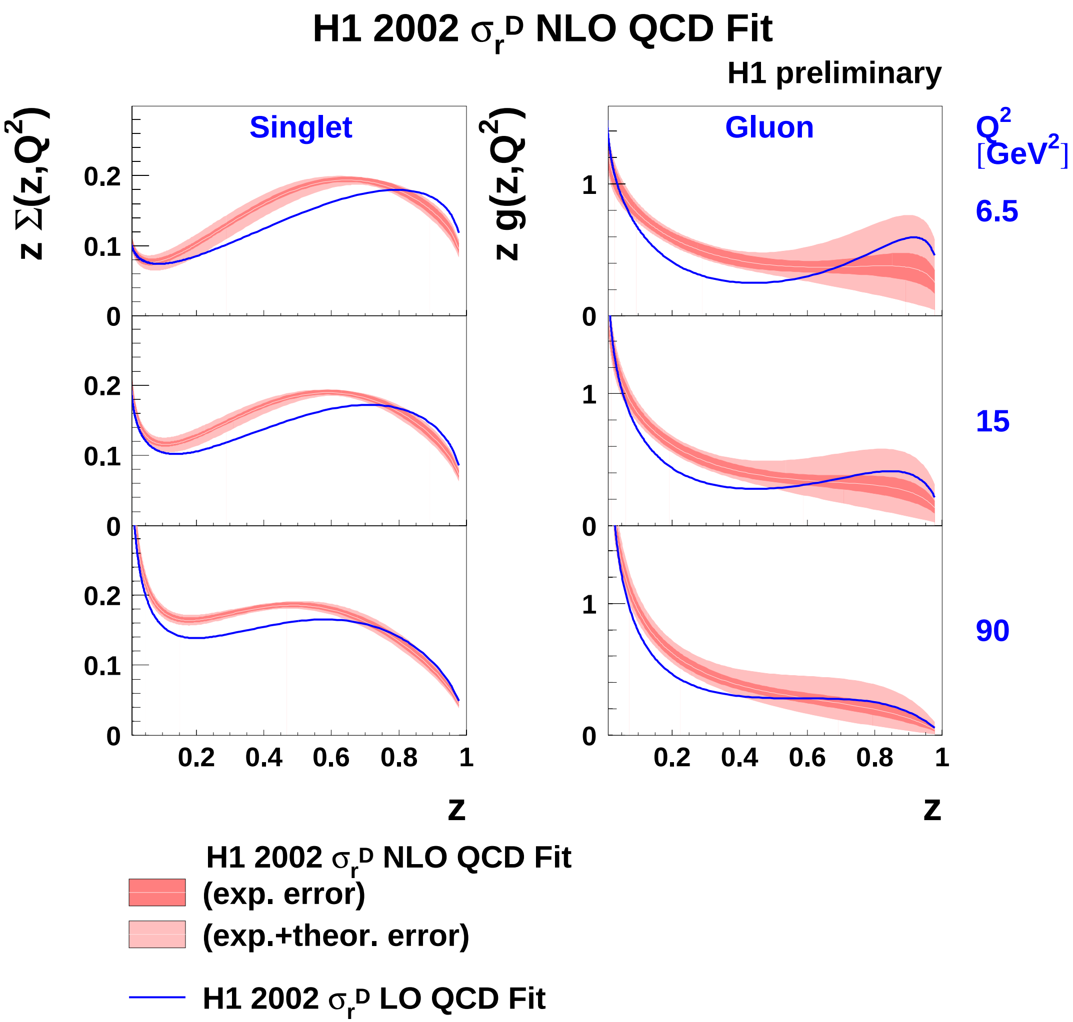
NLO DGLAP QCD fit and Diffractive PDF's

QCD fit technique

- Regge factorisation with $I\!P$, $I\!R$ terms (pion PDF (Owens) are used for $I\!R$)
- Singlet Σ and gluon g in $I\!P$ parametrized at $Q_0^2 = 3$ GeV^2
- NLO DGLAP evolution for $Q > Q_0$
- Fit 313 data points for $Q^2 > 6.5$ GeV^2 and $M_X > 2$ GeV (7 free par.)
- Propagate exp. and theor. uncertainties to obtain PDF's with error band

Resulting diffractive PDF's

- Gluon dominated
- Singlet part is well constrained
- Substantial (theor.) uncertainty for gluon at highest fractional momenta z



NLO QCD fit to ZEUS M_X data

Similar fit as for H1. Differences:

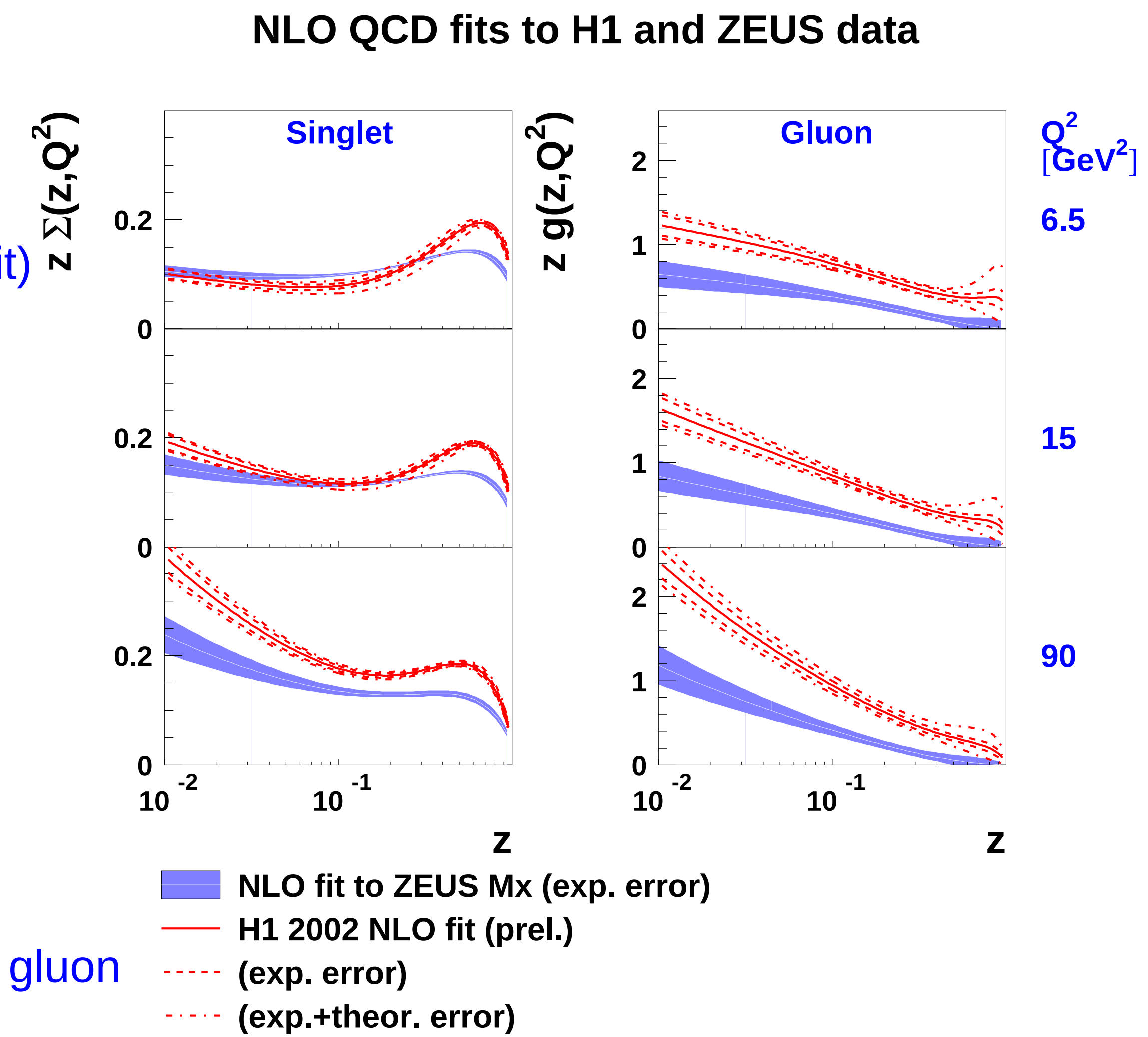
- Only $I\!P$ term, no meson component (including one does not improve the fit)
- Fit 138 data points for $Q^2 > 4$ GeV^2
- Common Pomeron intercept fitted together with pdf's

$$\chi^2/ndf = 90/131$$

$$\alpha_{I\!P}(0) = 1.132 \pm 0.006 \text{(exp.)}$$

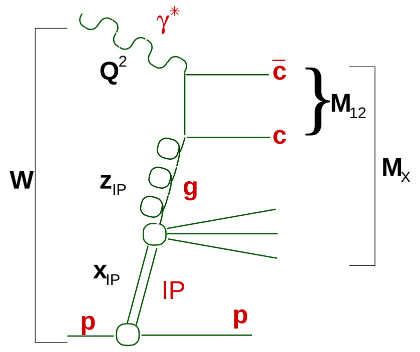
Resulting diffractive PDF's

- Singlet: similar at low Q^2
- Gluon: factor of ~ 2 smaller than H1 gluon

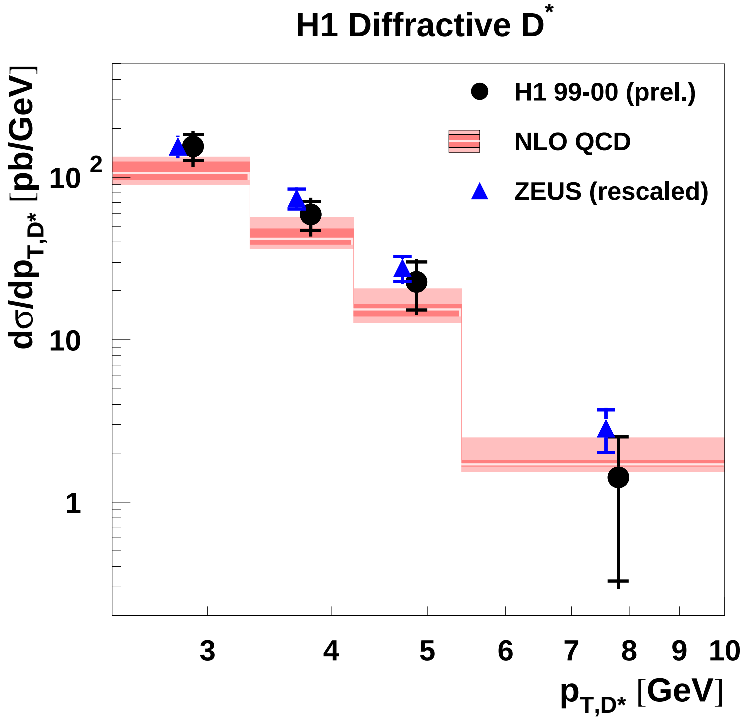


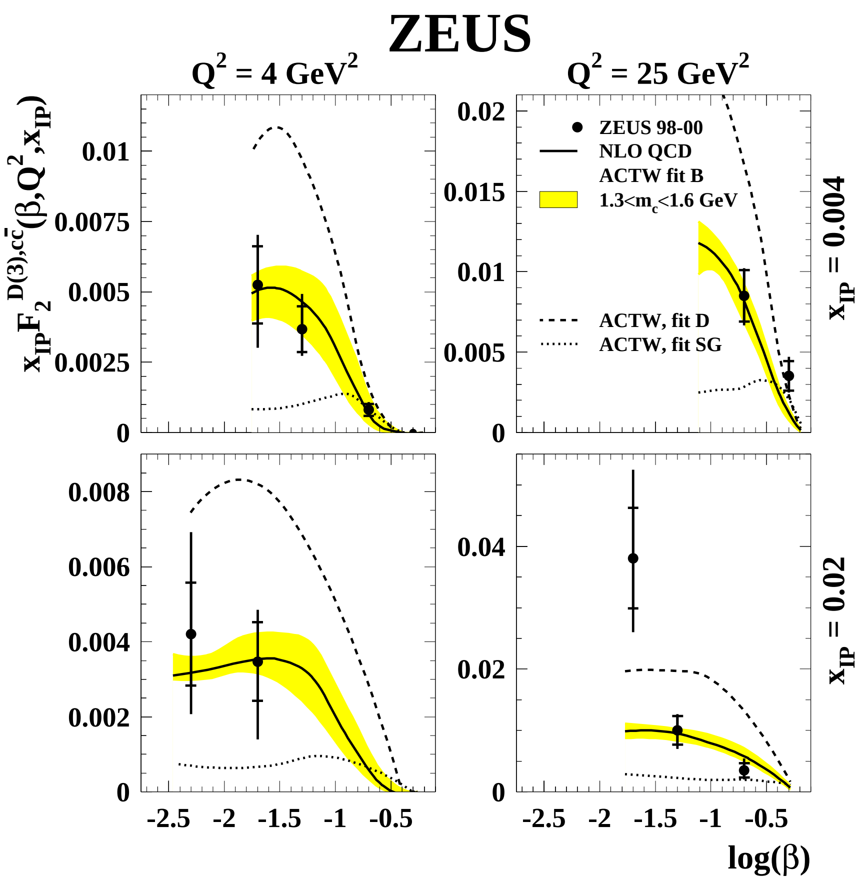
⇒ **Need more direct access to diffractive gluons**

Diffractive D^* in DIS regime



- H1 and ZEUS data are in agreement
- Consistent with QCD factorisation and H1 gluon
- Provides extra constraints to DPDFs





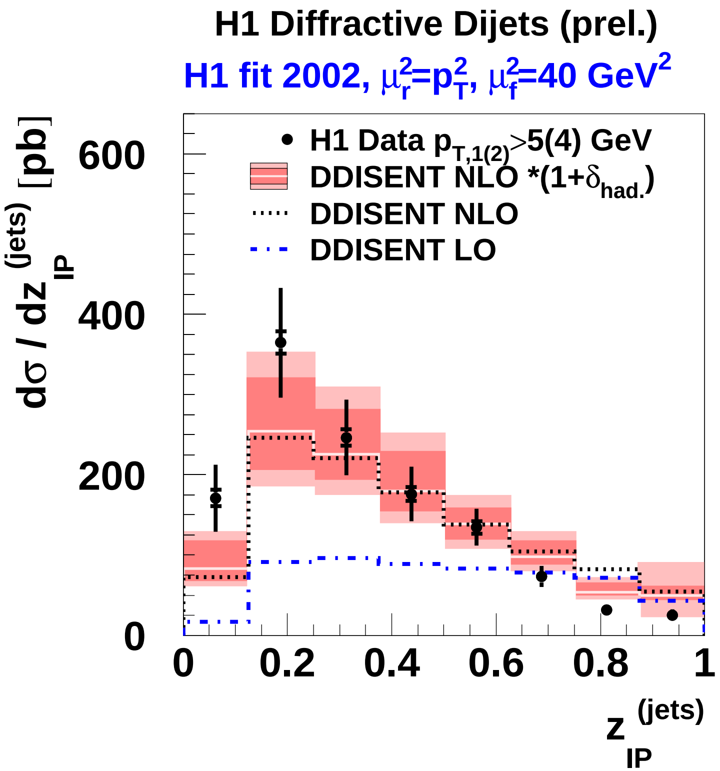
Diffractive dijets in DIS regime

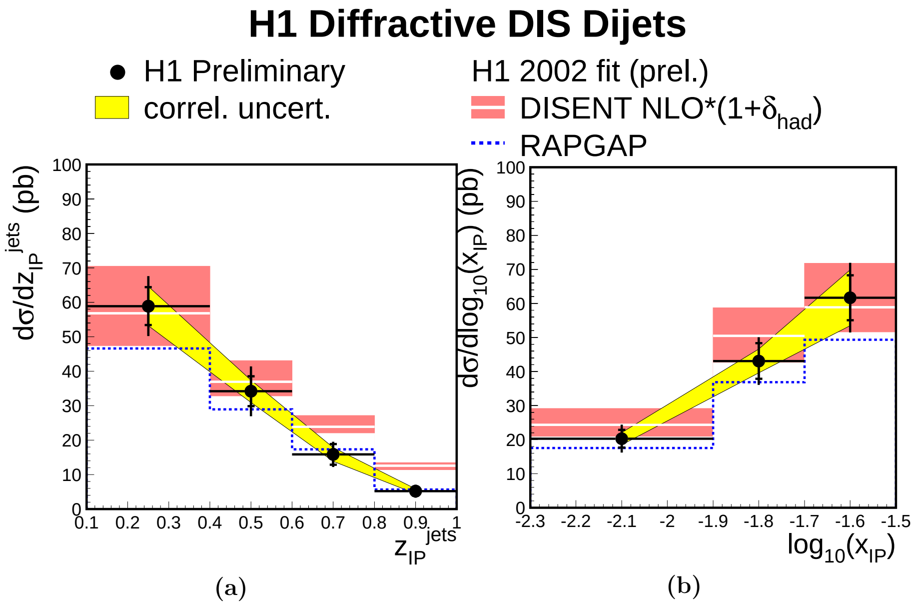
Old H1 measurement (cone jets) — New H1 measurement (k_T jets)

$4 < Q^2 < 80$ GeV^2; $E_{T1} > 5$ GeV, $E_{T2} > 4$ GeV; $-3 < \eta^*_{jet} < 0$

Old: $0.1 < y < 0.7$, $x_{I\!P} < 0.05$

New: $0.3 < y < 0.65$, $x_{I\!P} < 0.03$





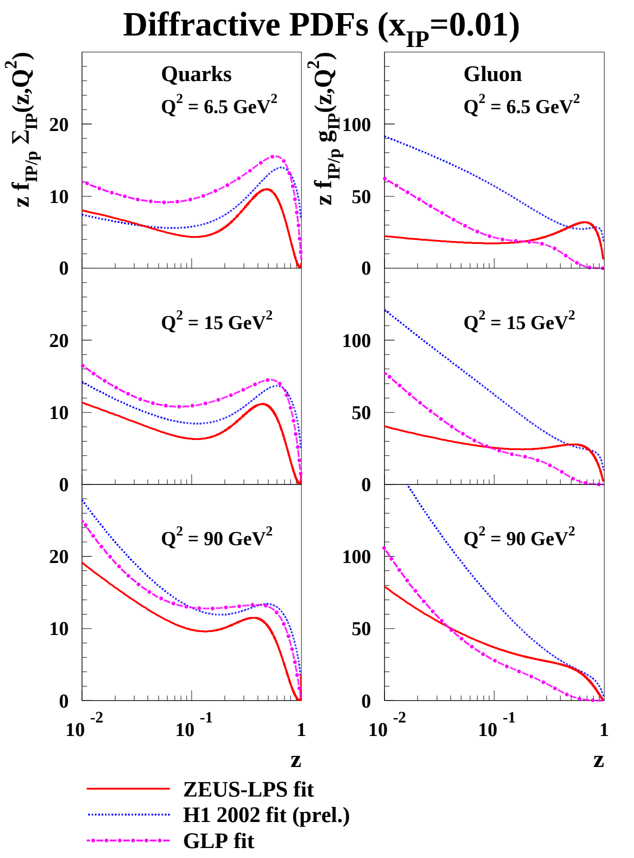
(a) (b)

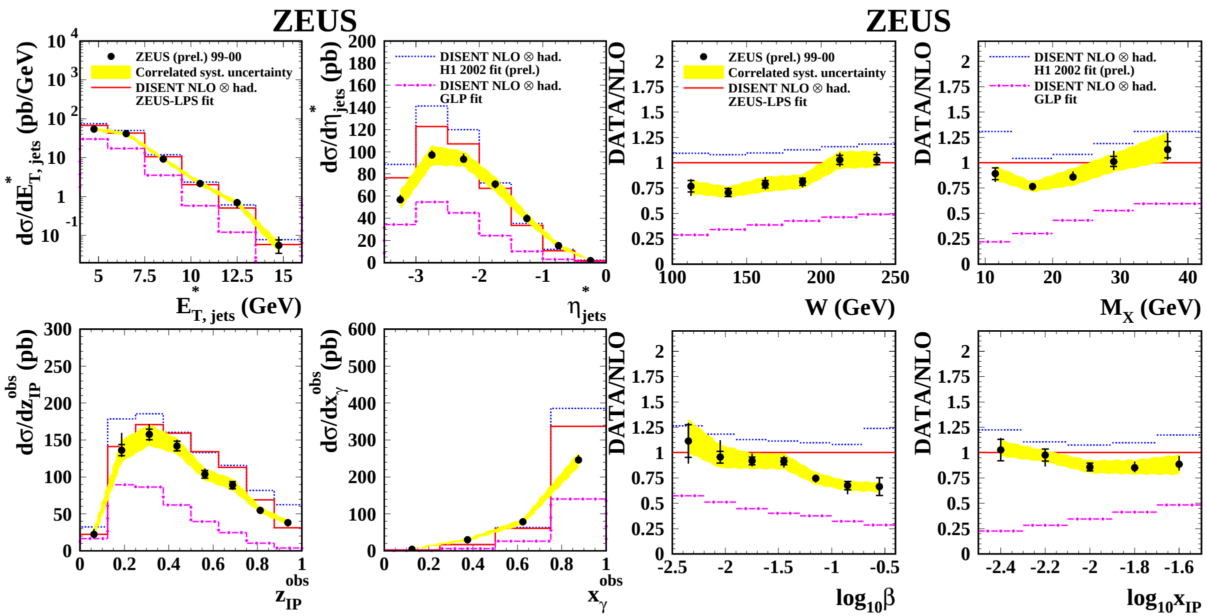
H1: Consistent picture of diffractive DIS to NLO QCD!

Diffractive dijets in DIS: sensitivity to DPDFs

New ZEUS NLO analysis
using different DPDF sets:

GLP: fit to ZEUS M_X data
ZEUS-LPS: fit to LPS data
and charm fraction in $F_2^{D(3)}$



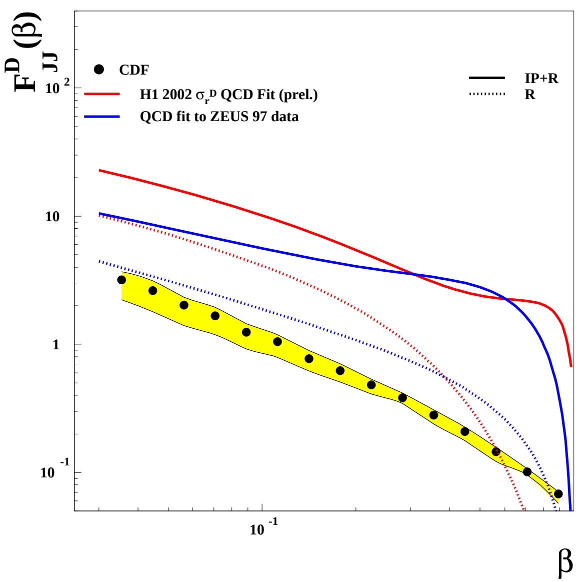


⇒ low GLP prediction due to small gluon at large z

ZEUS: "Better understanding of DPDFs and their uncertainties is required before a firm statement about validity of QCD factorisation can be made"

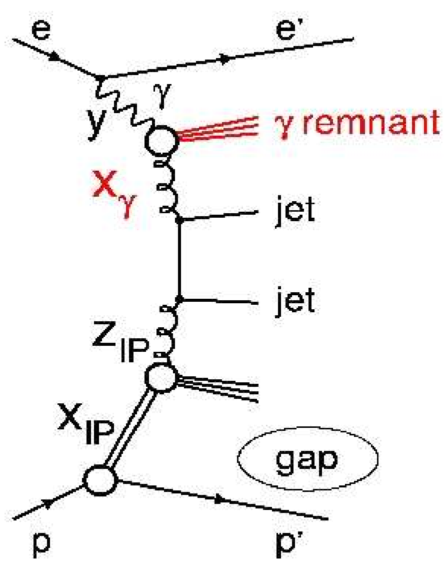
More factorisation tests: from DIS via γp to Tevatron

Tevatron vs HERA



$Q^2 \approx 0$:

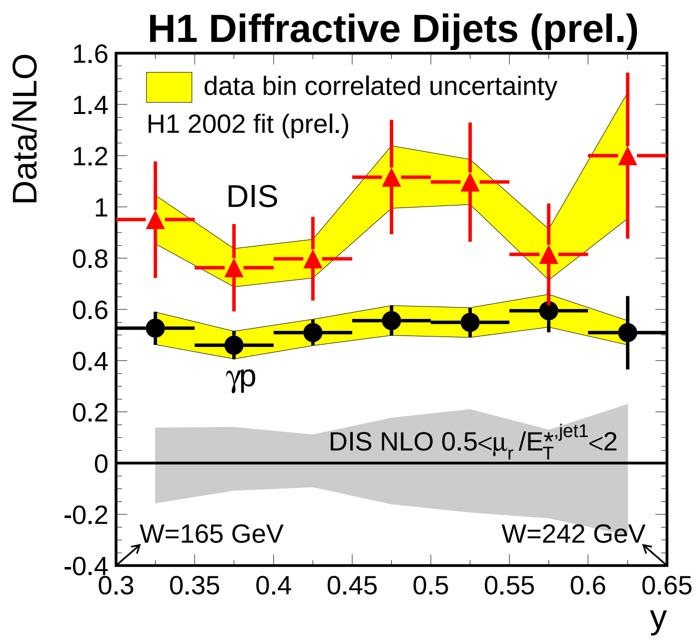
can secondary interactions fill the gap?



$x_\gamma = 1$ – direct photon coupling, DIS-like

$x_\gamma < 1$ – "resolved" photon, hadron-like

Compare γp with DIS via the ratio data/NLO using the same DPDFs:



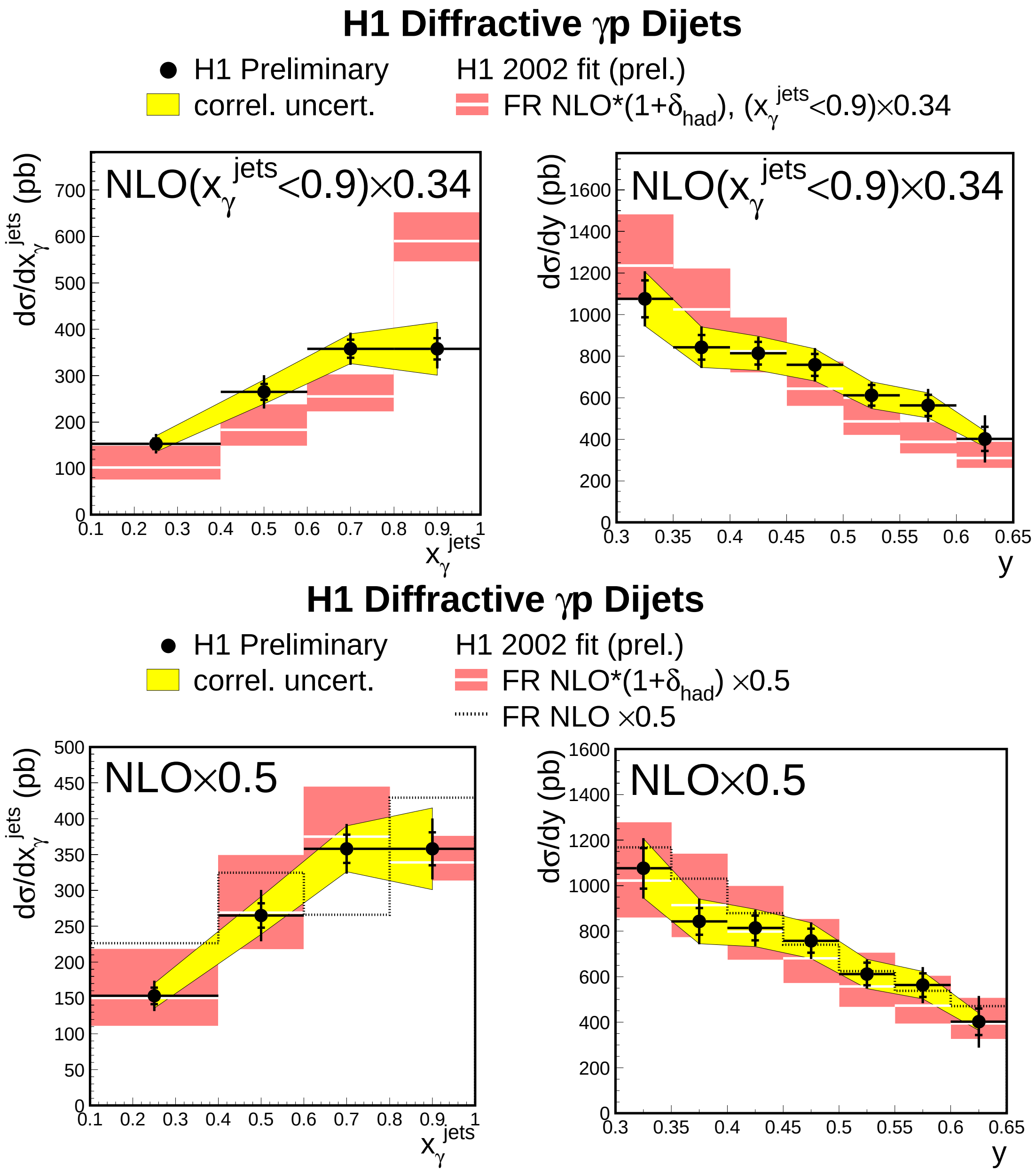
Factorisation breakdown by factor of ~ 7

(Gap survival probability; soft physics, hence hard to calculate precisely)

γp suppressed by factor ~ 2 wrt DIS

$\Rightarrow$ look in more detail...

Suppression of H1 γp dijets



Data:

k_T jets with $E_{T1} > 5,\ E_{T2} > 4$ GeV

$Q^2 < 0.01$ GeV^2, $0.3 < y < 0.65$

$x_{I\!P} < 0.03$

$$x_\gamma = \frac{\sum_{jets}(E-p_z)}{2yE_e}$$

Results:

- ”direct” unsuppressed does not describe x_γ shape
- global suppression describes data within uncertainties

Suppression of ZEUS γp dijets

Data:

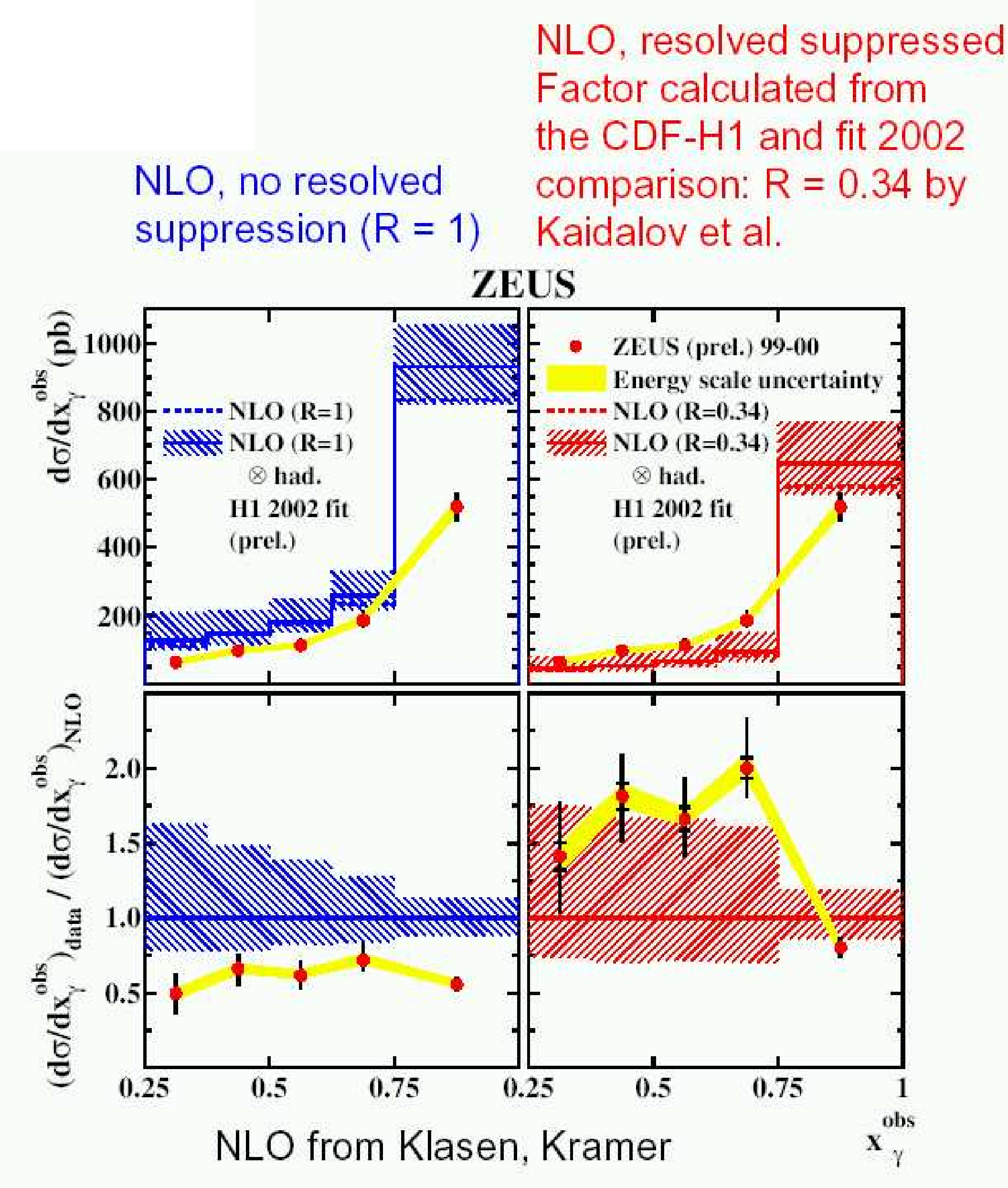
k_T jets with $E_{T1} > 7.5,\ E_{T2} > 6.5$ GeV

$Q^2 < 1$ GeV^2, $0.2 < y < 0.85$

$x_{I\!P} < 0.025$

Results:

- data/NLO is flat in x_γ
- global suppression by ~ 0.6 is clearly preferred over "resolved"-only suppression



Summary

Inclusive diffraction

- ▷ Q^2 dependence of $\alpha_{I\!P}(0)$ suggests Regge factorisation breaking in DIS regime
- ▷ Energy dependence: $\alpha_{I\!P}^{diff}(0) - 1 \simeq 0.5 \cdot (\alpha_{I\!P}^{tot}(0) - 1)$ implies either severe failure of Regge picture in $\gamma^* p$, or unitarity corrections at work
- ▷ H1 vs ZEUS: despite measured F_2^D are in fair agreement remaining differences lead to approximately 2 times different gluon in diffractive PDFs $\Rightarrow$ to be clarified with new data

Diffractive final states

- ▷ NLO predictions strongly depend upon specific choice of DPDFs
- ▷ When using H1 DPDFs both diffractive charm and dijets in DIS regime support QCD factorisation
- ▷ In diffractive photoproduction QCD factorisation is broken, showing at the moment global x_γ independent suppression factor of ~ 2, contrary to (naive) theoretical expectation

Although an important progress is made recently, understanding of colour singlet exchange remains a major challenge in QCD