Diffraction at HERA

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Overview

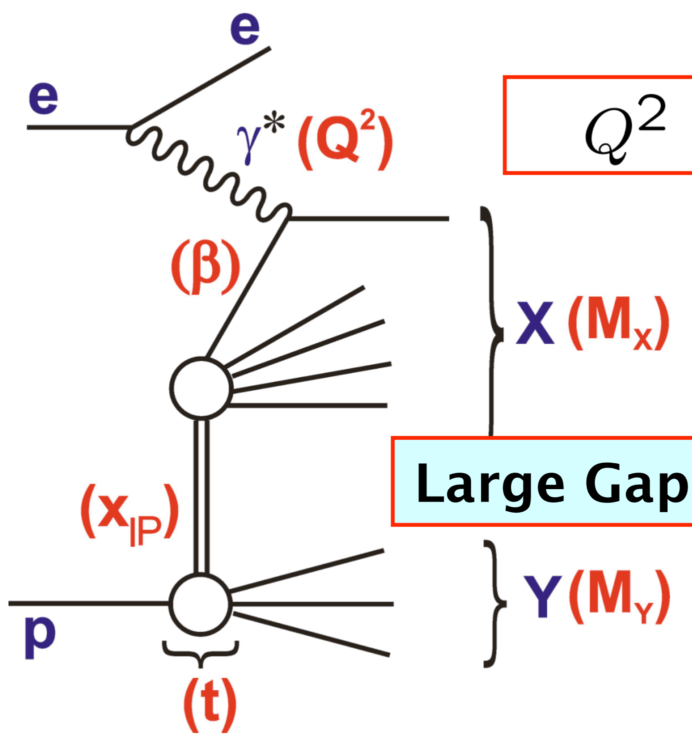
- Inclusive Diffraction at HERA
  - Factorisation in Diffraction
  - Experimental techniques
  - Data to data comparisons
- QCD Fits and Diffractive PDFs
- Diffractive dijets in DIS
  - Diffractive PDFs from a Combined Fit
- Diffractive dijets in Photoproduction
  - Suppression or not of the cross section
- Summary

Diffractive DIS Kinematics and Observables

$$x = x_{I\!P}\beta$$

$$\beta = \frac{Q^2}{Q^2+M_X^2}$$

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



$$Q^2 = sxy$$

Large Gap in Rapidity

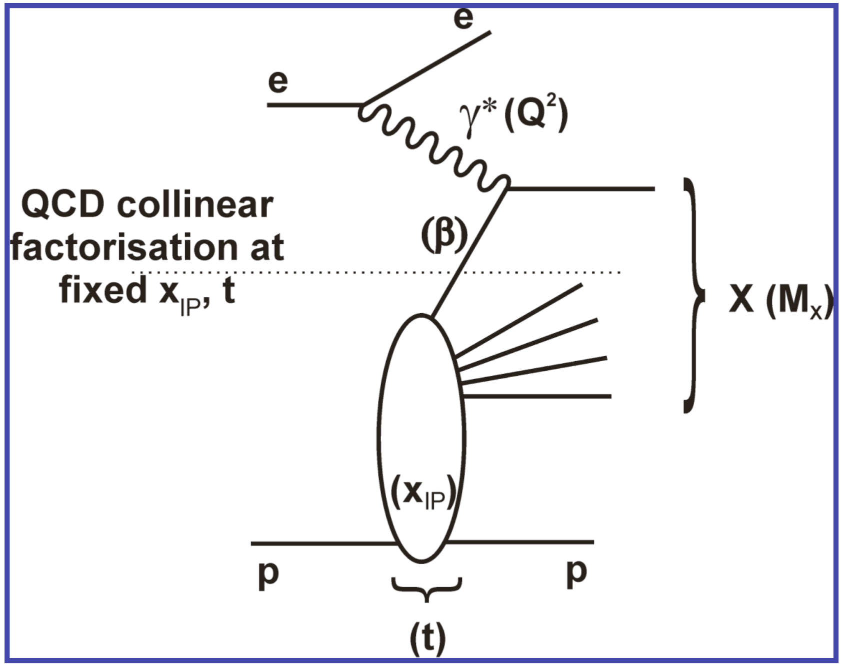
$$Y_+ = 1 + (1-y)^2$$

Cross section: $\frac{d^4\sigma^{ep\to eXp}}{dx dQ^2 dx_{I\!P} dt} = \frac{4\pi\alpha^2}{xQ^4} Y_+ \, \sigma_r^{D(4)}(x, Q^2, x_{I\!P}, t)$

$$\sigma_r^{D(4)} = F_2^{D(4)} - \frac{y^2}{Y+} F_L^{D(4)}$$

$$\sigma_r^{D(3)} = \int_{-1}^{t_{min}} \sigma_r^{D(4)} dt$$

Factorisation in Diffractive DIS

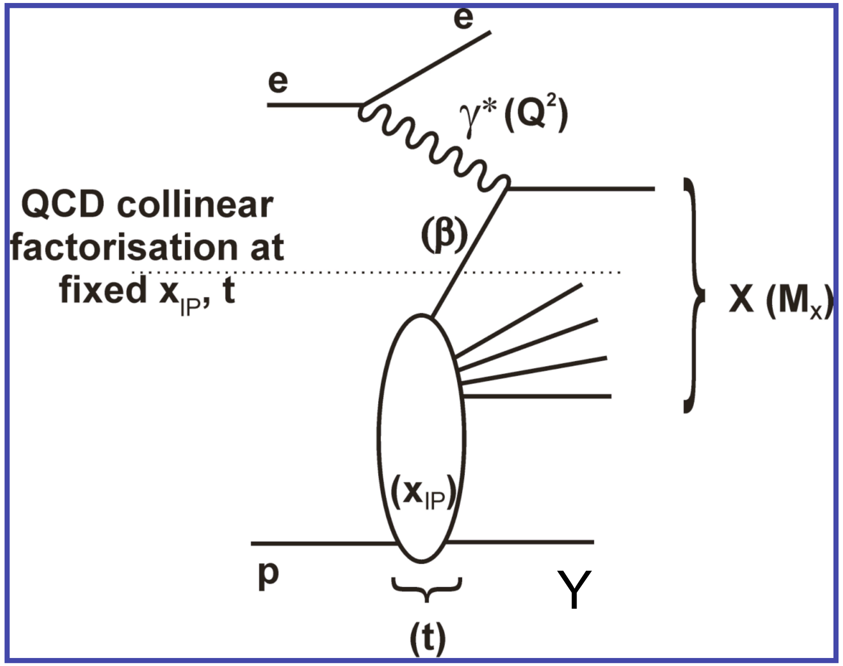


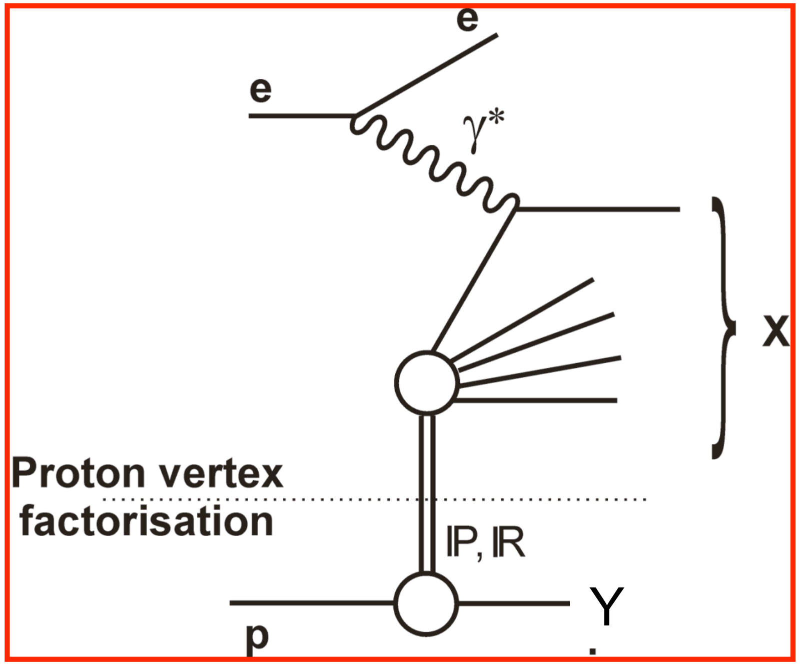
QCD hard scattering collinear factorisation (Collins) at fixed x_{IP} and t

$$d\sigma_{parton\,i}(ep \rightarrow eXY) = f_i^D(x, Q^2, x_{I\!P}, t) \;\otimes\; d\sigma^{ei}(x, Q^2)$$

Applied after integration over measured M_Y and t ranges

Factorisation in Diffractive DIS





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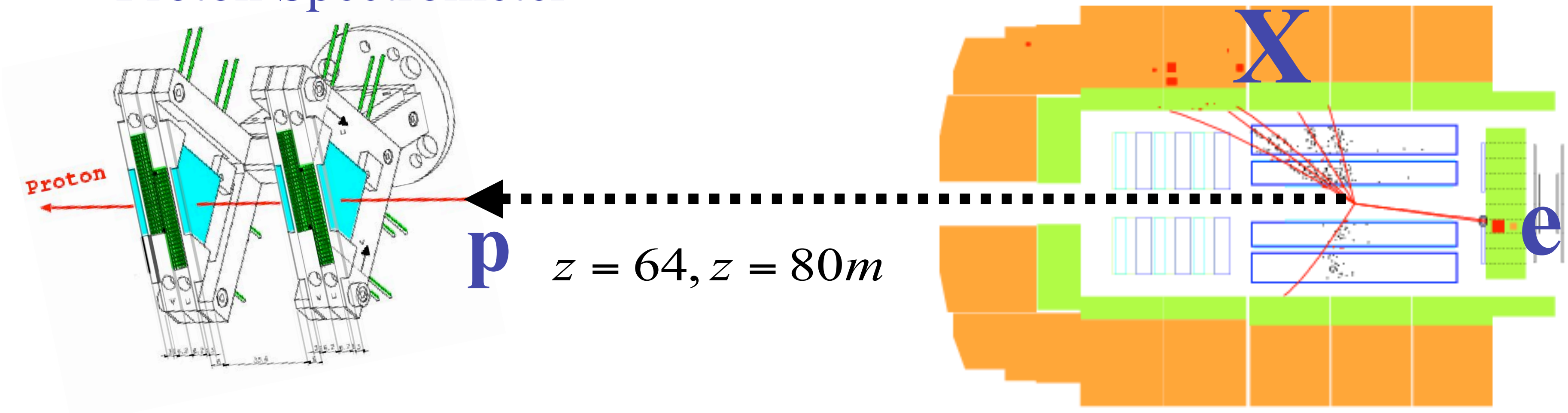
`Proton vertex' factorisation of β and Q^2 from x_{IP}, t, and M_Y dependences

$$f_i^D(x, Q^2, x_{I\!P}, t) = f_{I\!P/p}(x_{I\!P}, t) \cdot f_i^{I\!P}\left(\beta = \frac{x}{x_{I\!P}}, Q^2\right)$$

Experimentally selecting $ep \rightarrow eXp$

I Forward/Leading
Proton Spectrometer



Measure Leading Proton (FPS/LPS)

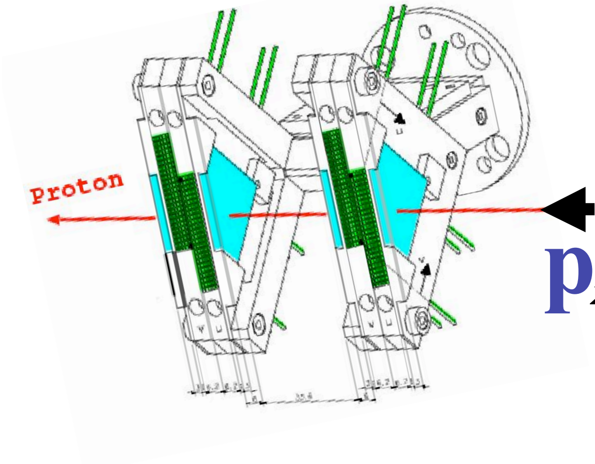
No proton dissociation

Measure the t dependence

Low detector acceptance

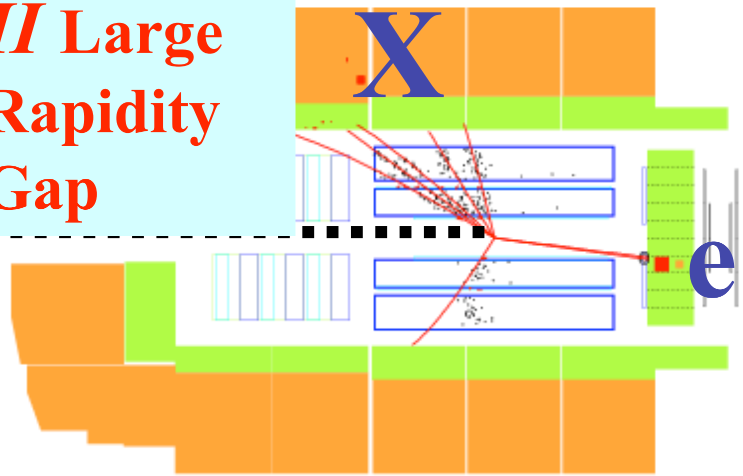
Experimentally selecting $ep \rightarrow eXp$

I Forward/Leading Proton Spectrometer



$\mathbf{p}_z = 64, z = 80m$

II **Large Rapidity Gap**



Measure Leading Proton (FPS/LPS)

No proton dissociation

Measure the *t* dependence

Low detector acceptance

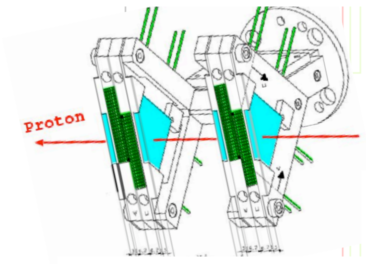
Require Large Rapidity Gap (LRG) spanning at least $3.3 < \eta < \sim 7.5$

Kinematics measured from *X* system, integrate $|t| < 1.0$ GeV^2, $M_Y < 1.6$ GeV

High detector acceptance → precision

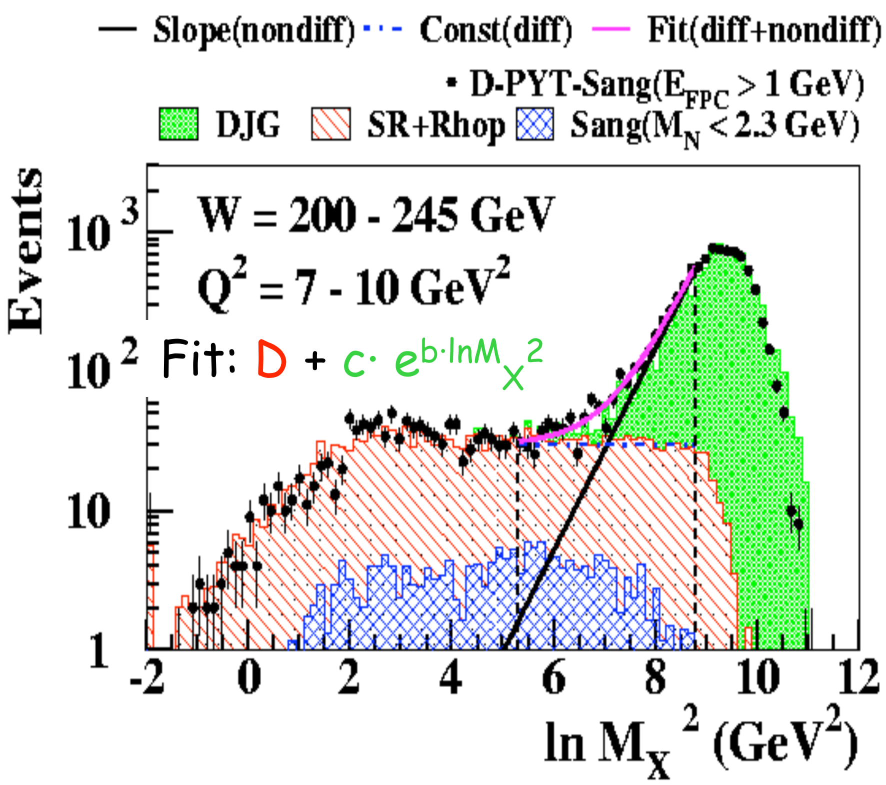
Experimentally selecting $ep \rightarrow eXp$

I LPS/FPS



II Large Rapidity Gap

III M_x method



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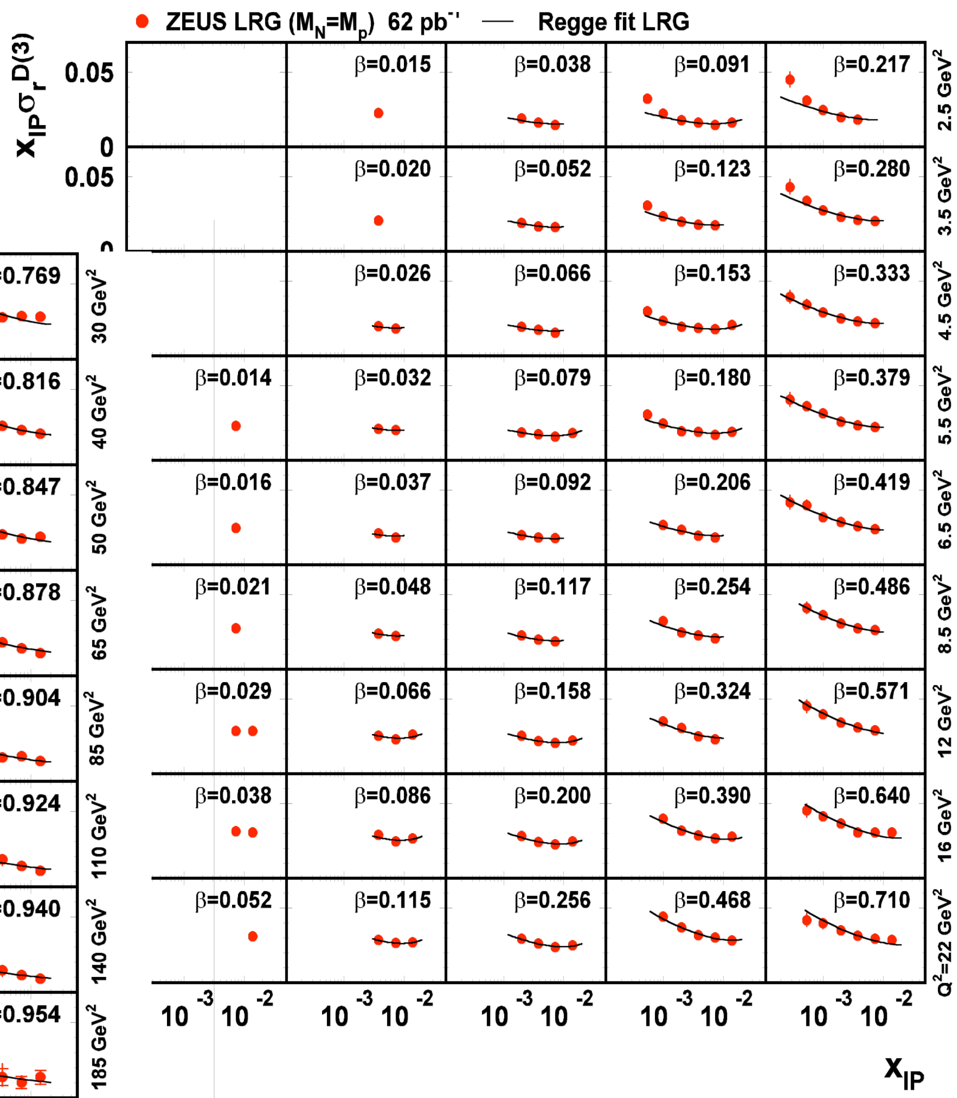
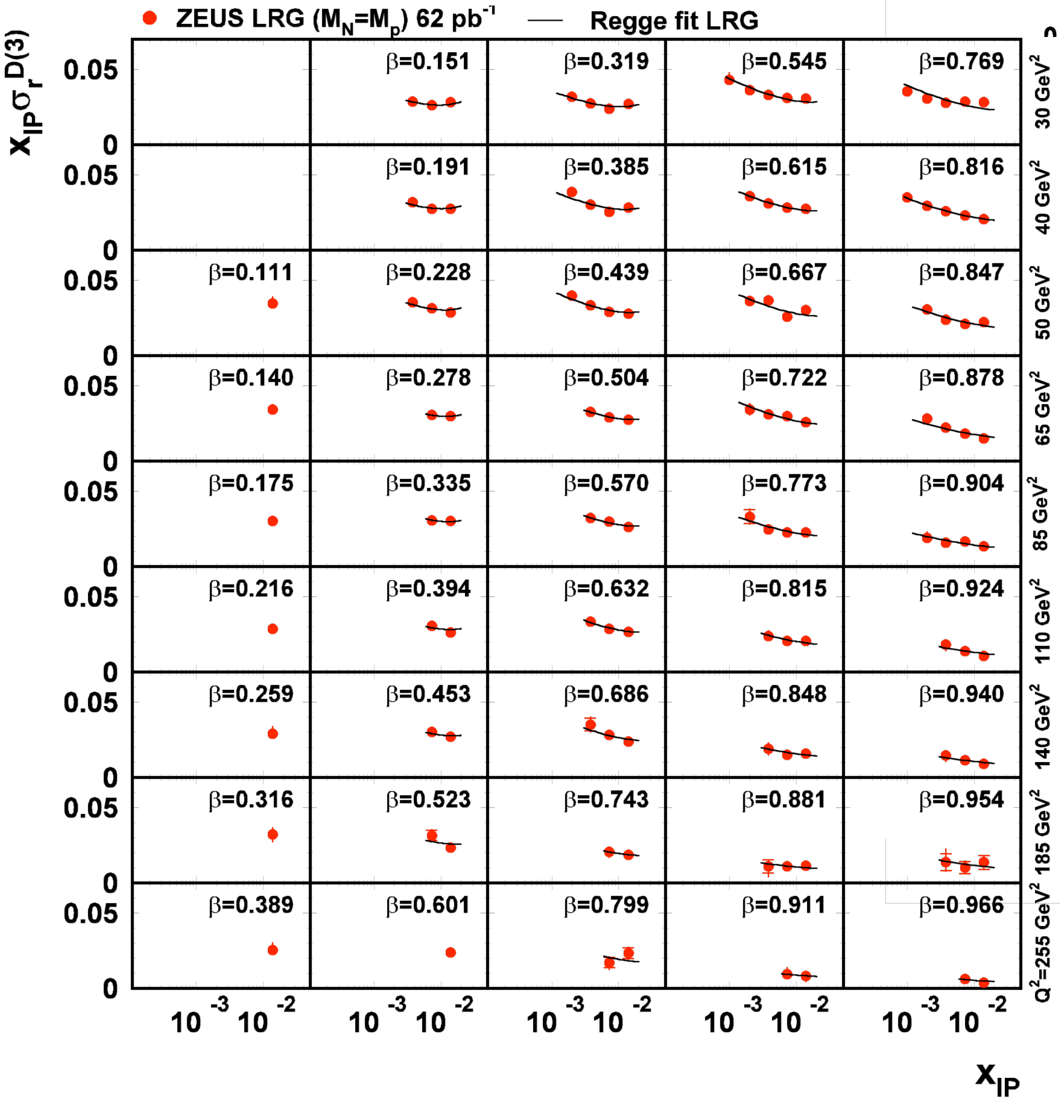
High detector acceptance → precision

How do the three experimental techniques compare?

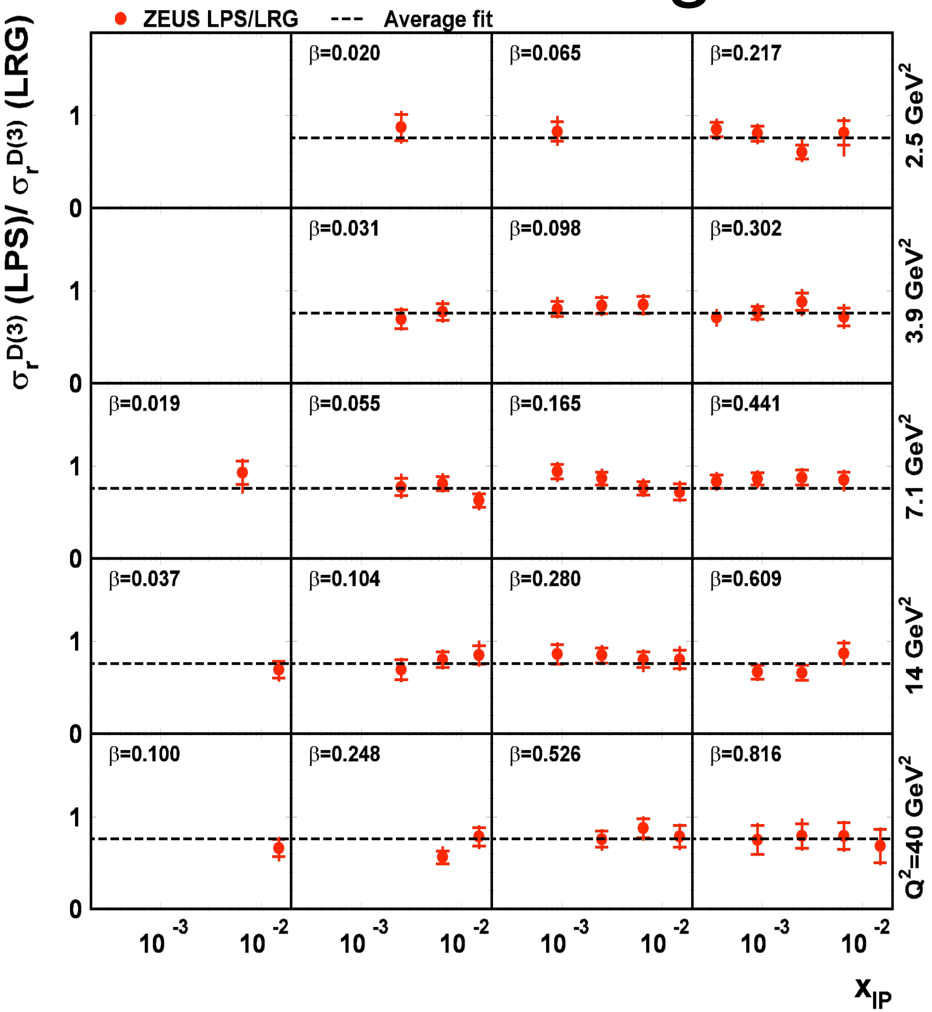
New Large Rapidity Gap Data from ZEUS





The new LRG data from ZEUS is very precise, covering a large phase space

Ratio of Leading Proton / Large Rapidity Gap



The LRG data contains a sizeable proton dissociation background (esimated to be 24% at ZEUS, cf. 23% at H1)

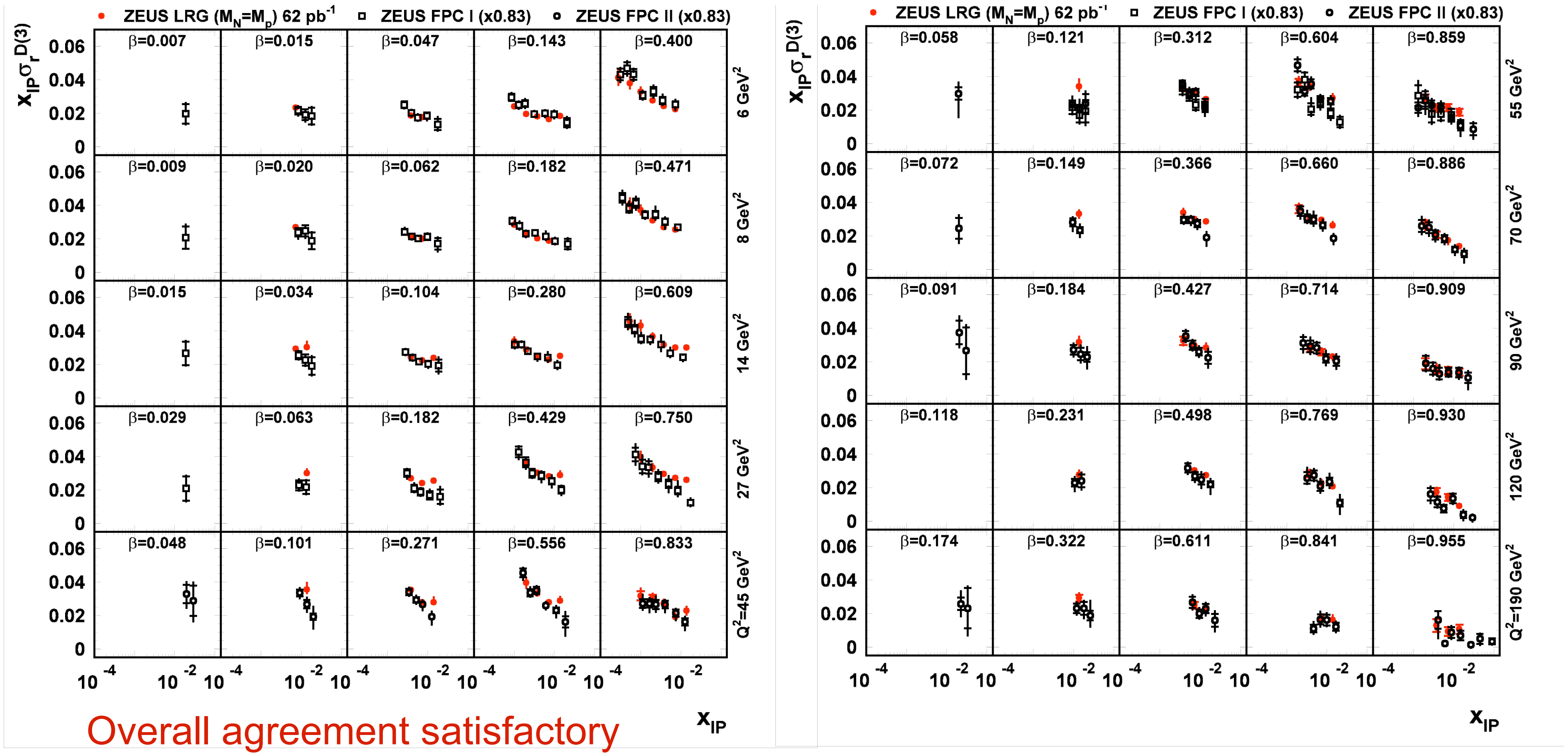
The ratio of LPS/LRG cross sections is *independent* of Q^2, x_{IP}, β

ZEUS LPS / ZEUS LRG = 0.76 +-0.01(stat) +0.03-0.02(sys) +0.08-0.05 (norm)

→ p-diss. background in LRG data: [24 +-1(stat) +2-3(sys) +5-8(norm)]%

ZEUS LRG vs ZEUS M_x

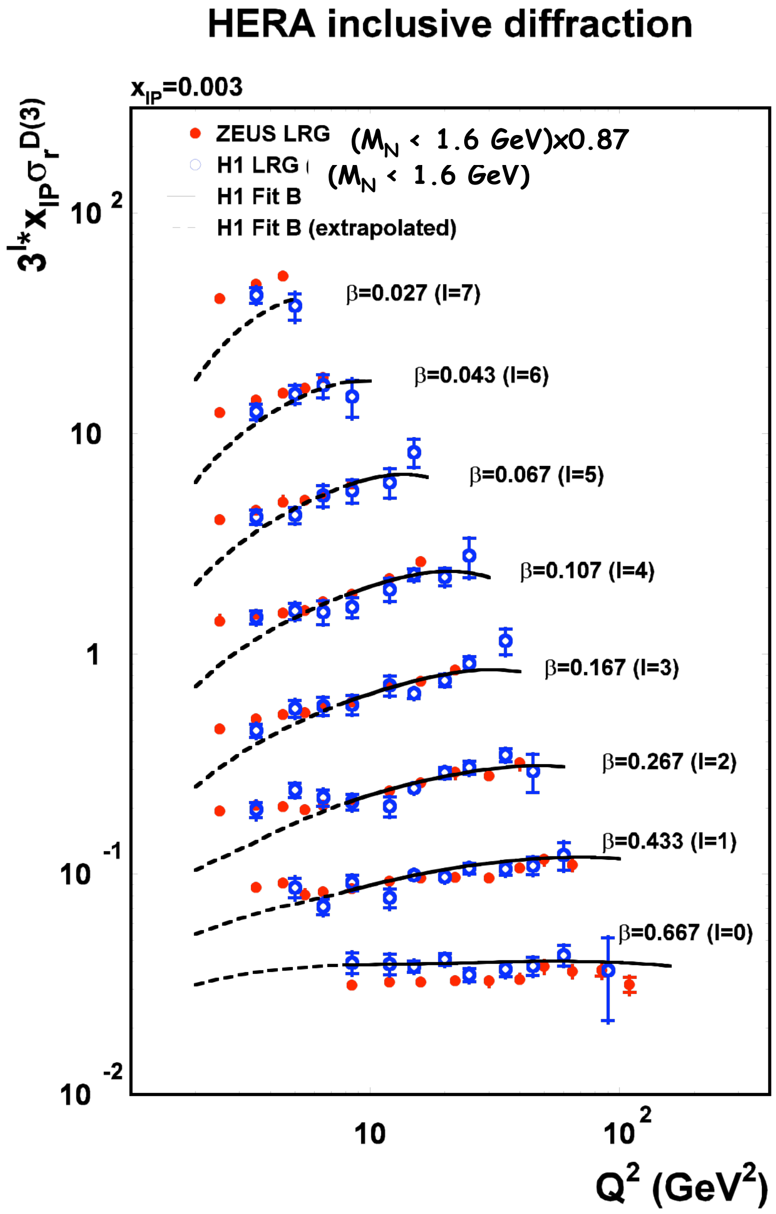
M_x data (M_N < 2.3 GeV) normalised to LRG (M_N=m_p): factor 0.83 ± 0.04 (determined via a global fit) estimates residual p-diss. background in M_x sample

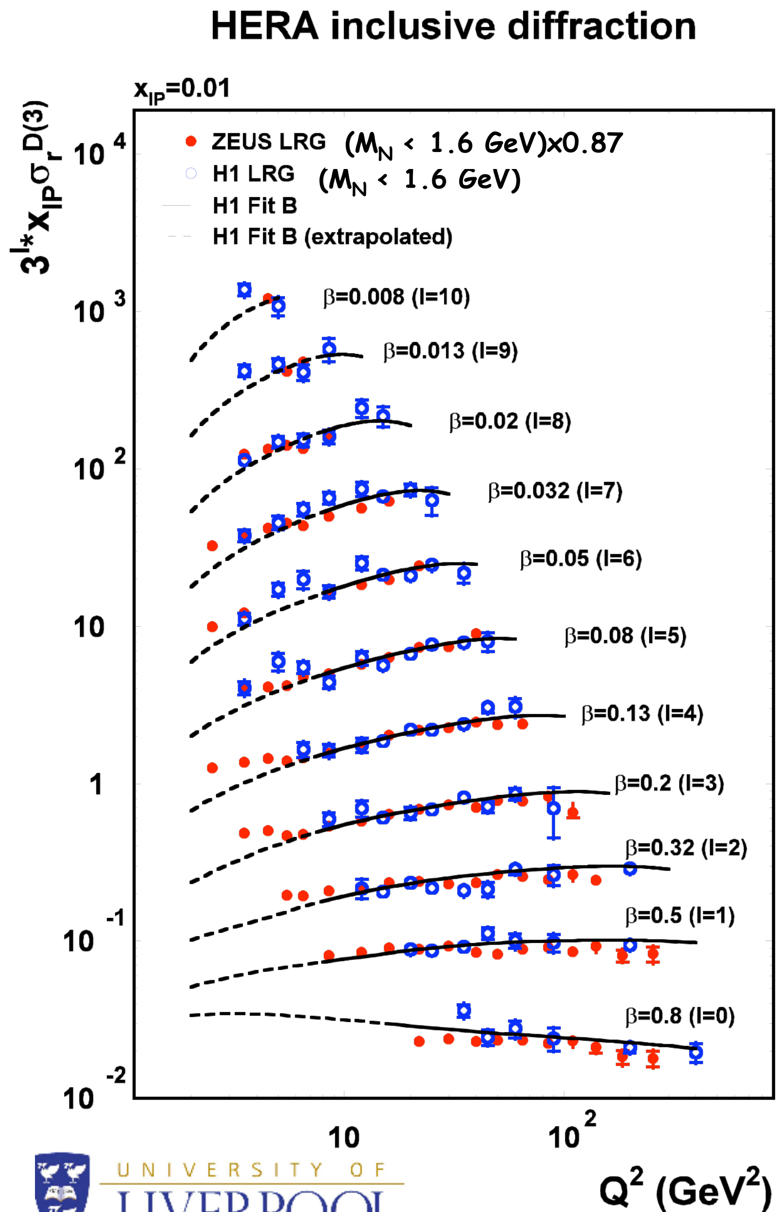


Overall agreement satisfactory

Different x_{IP} dependence ascribed to IR suppressed in M_x data

HERA Large Rapidity Gap Data

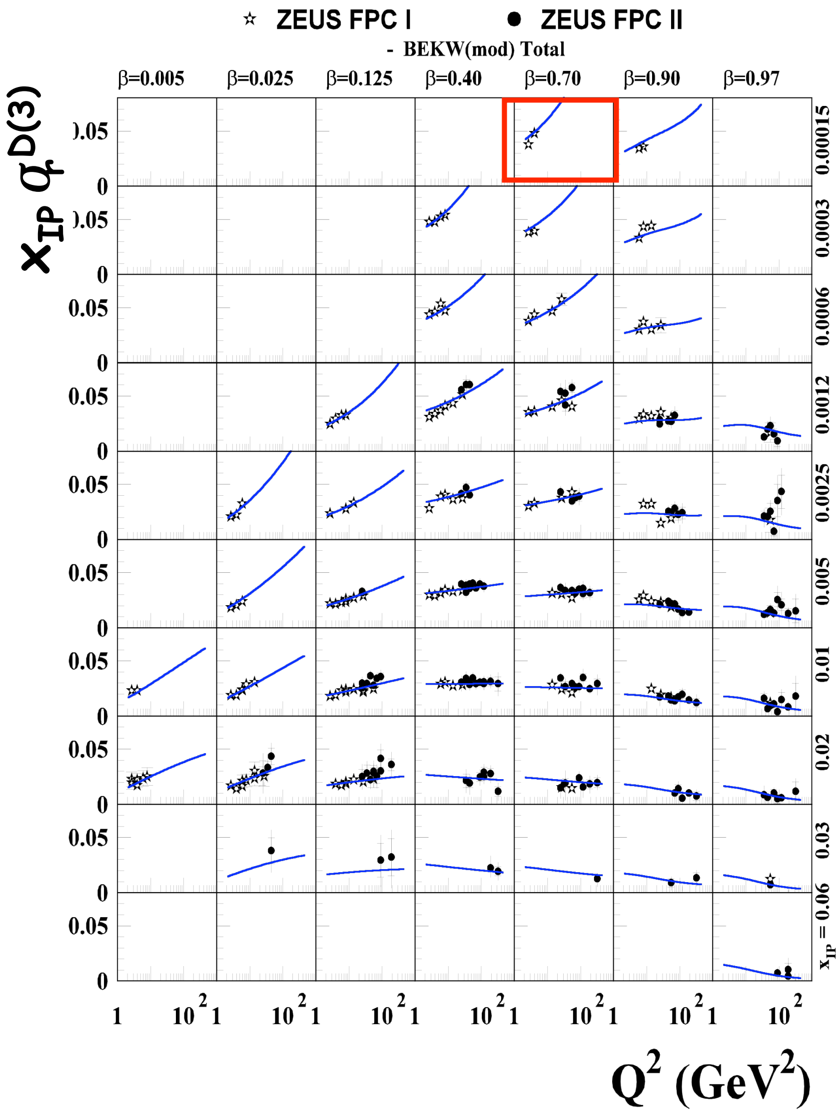


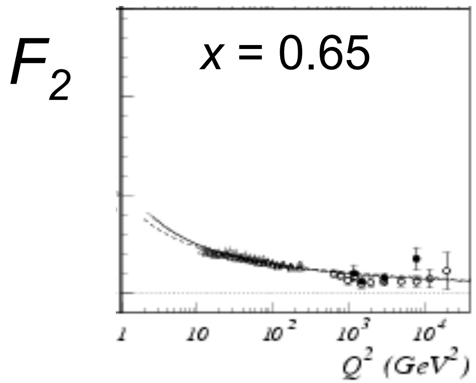


Good agreement between H1 and ZEUS

(ZEUS scaled by 0.87, covered by norm. unc.)

Q^2 dependence of $\sigma_r^{D(3)}$ ZEUS M_x data



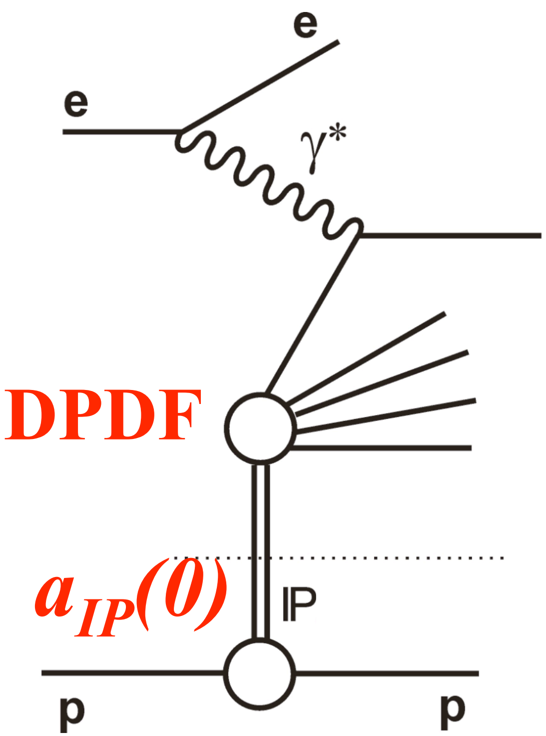


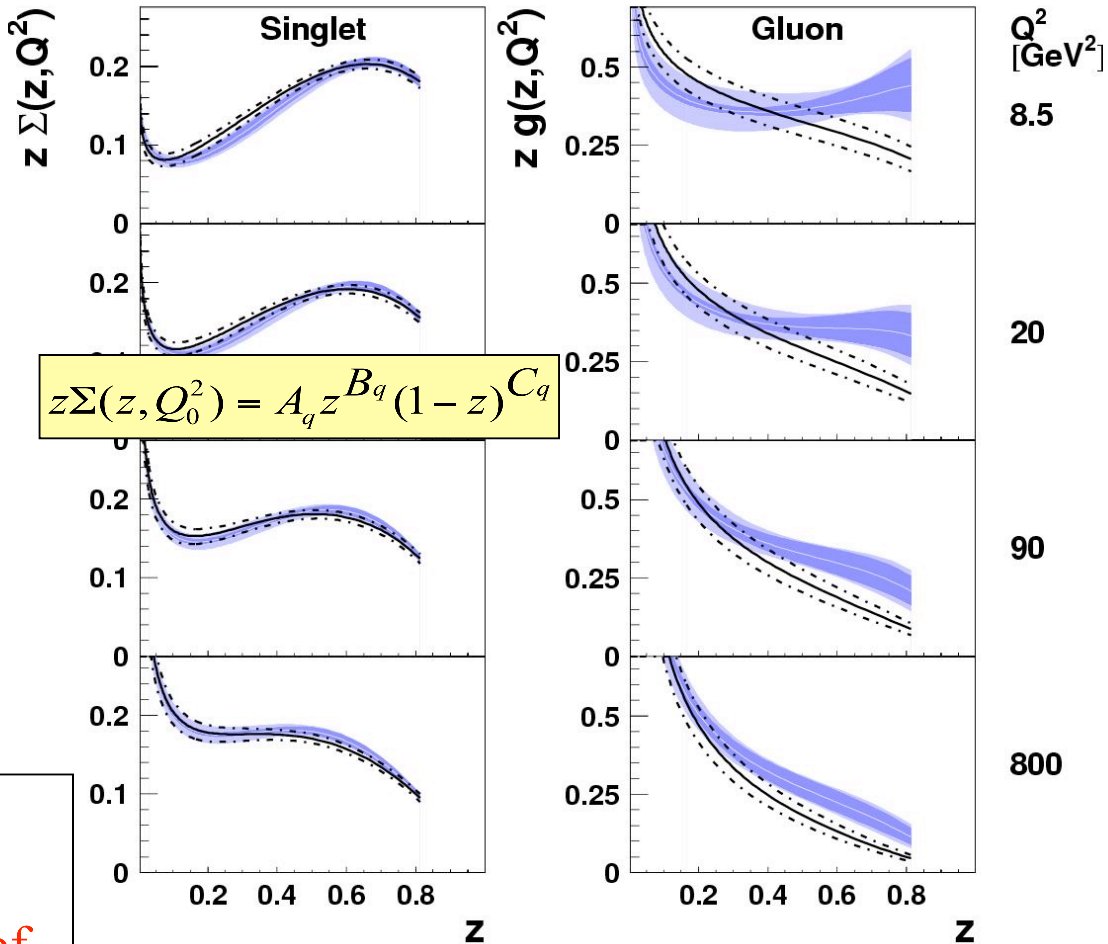
Large positive scaling violations up to high-β values implies that the diffractive exchange is gluon-dominated

At fixed β the reduced cross section depends on x_{IP} - these data seem to contradict Regge factorisation

Regge factorisation is only a useful approximation but fits made thus far are insensitive to this mild breaking

H1 2006 DPDF Fit





$$z\Sigma(z,Q_0^2) = A_q z^{B_q}(1-z)^{C_q}$$

H1 2006 DPDF Fit A
(exp. error)
(exp.+theor. error)

$$z_g(z,Q_0^2) = A_g(1-z)^{C_g}$$

H1 2006 DPDF Fit B
(exp.+theor. error)

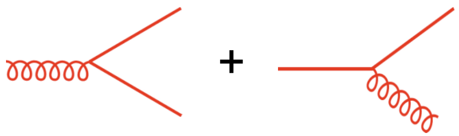
$$z_g(z,Q_0^2) = A_g$$

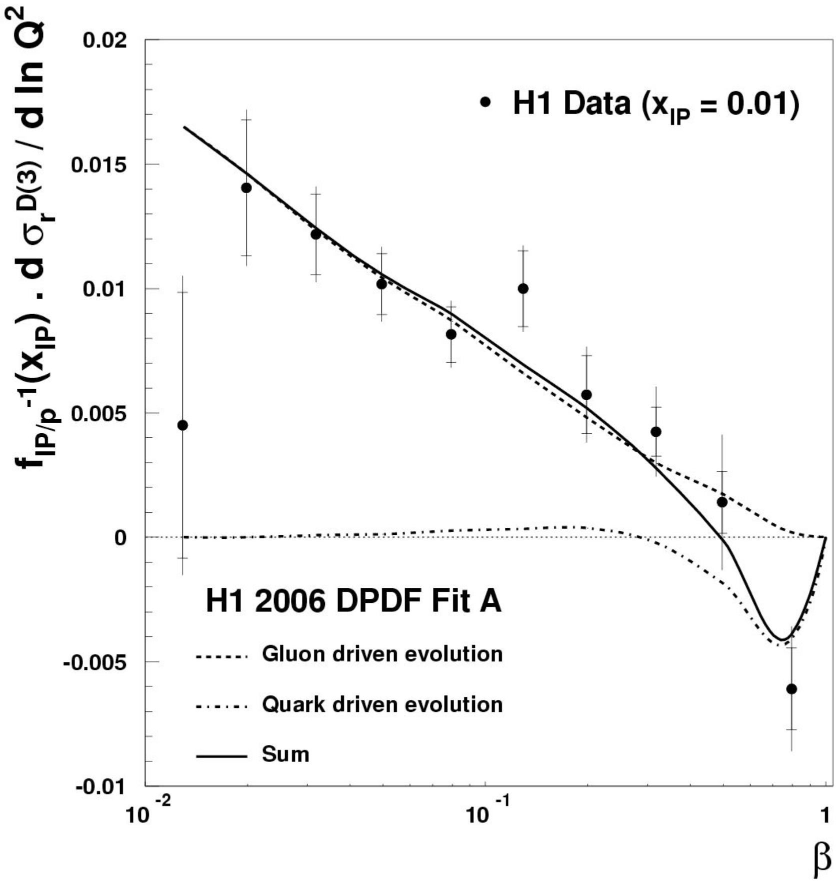
IP component*:*
- Fit $\alpha_{IP}(0)$ (x_{IP} dependence).
- Simultaneously, fit 5 parameters of DPDFs (β and Q^2 dependences) using NLO QCD.

A Closer Look at the High z Region

We have only singlet quarks, so DGLAP evolution equation for F_2^D ….

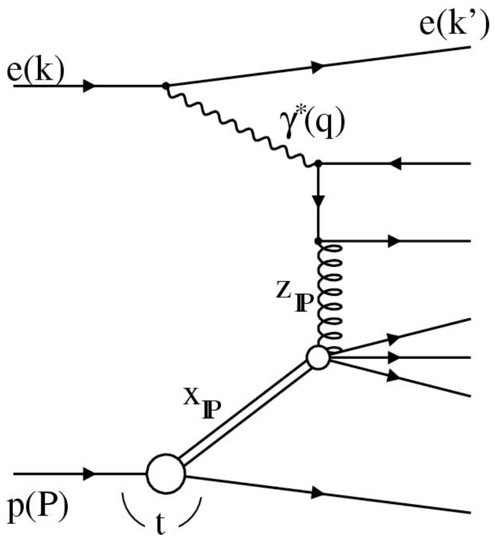
$$\frac{dF_2^D}{d\ln Q^2} \sim \frac{\alpha_s}{2\pi}\left[P_{qg}\otimes g \; + P_{qq}\otimes\Sigma\right]$$



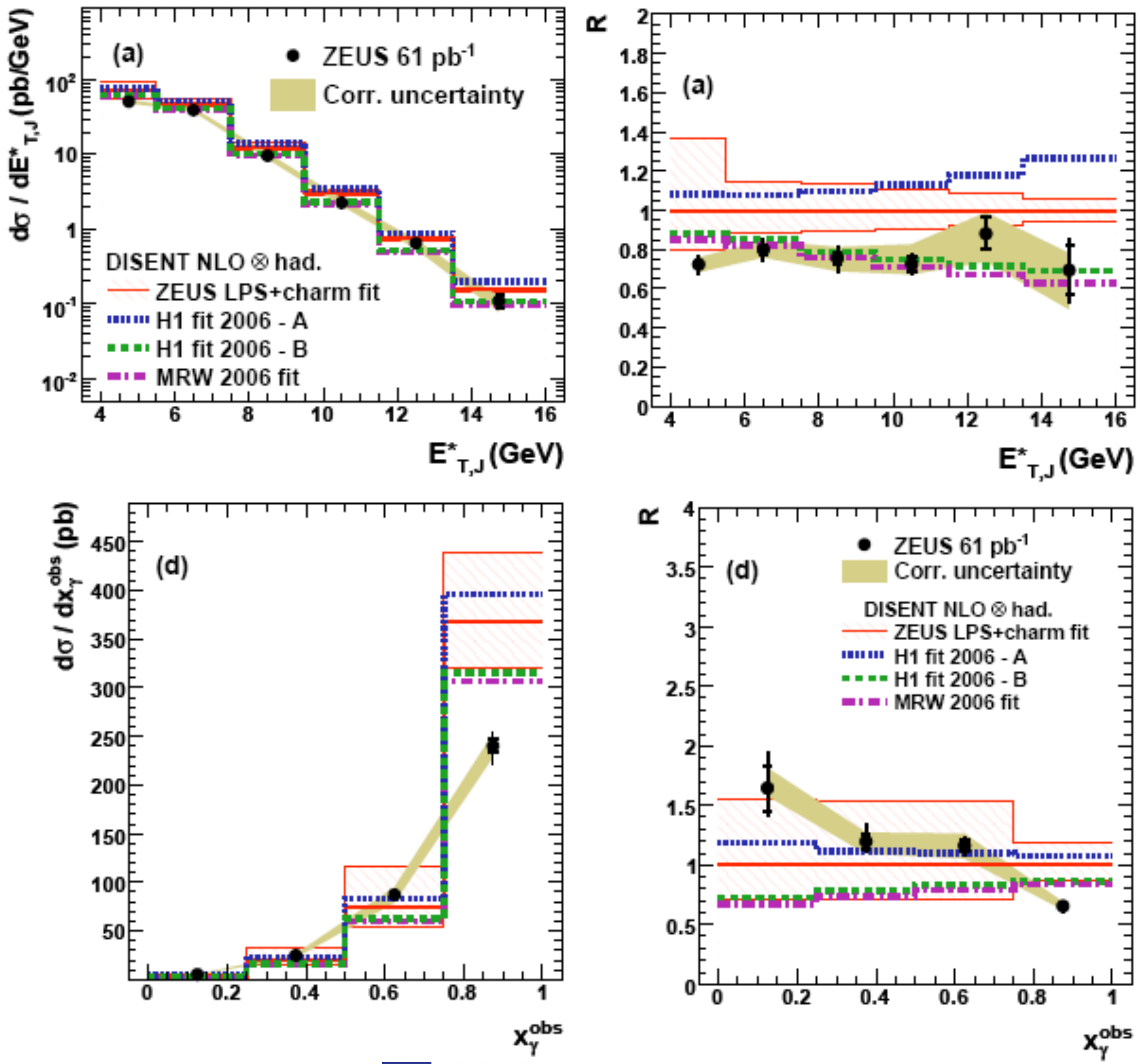


At high β, relative error on derivative grows, $q \rightarrow qg$ contribution to evolution becomes important … sensitivity to gluon is lost

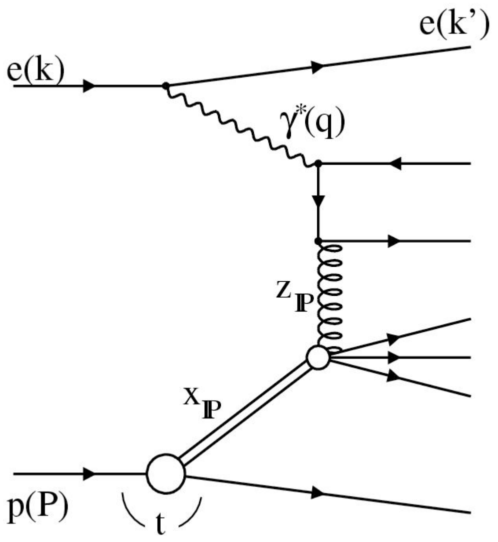
Compare to diffractive dijets in DIS



$$z_{IP} = \frac{M_{12}^2 + Q^2}{M_X^2 + Q^2}$$



- Compare the ZEUS dijet data to H1 Fit A and Fit B
- Best agreement for H1 Fit B
- ***Factorisation holds in DIS***



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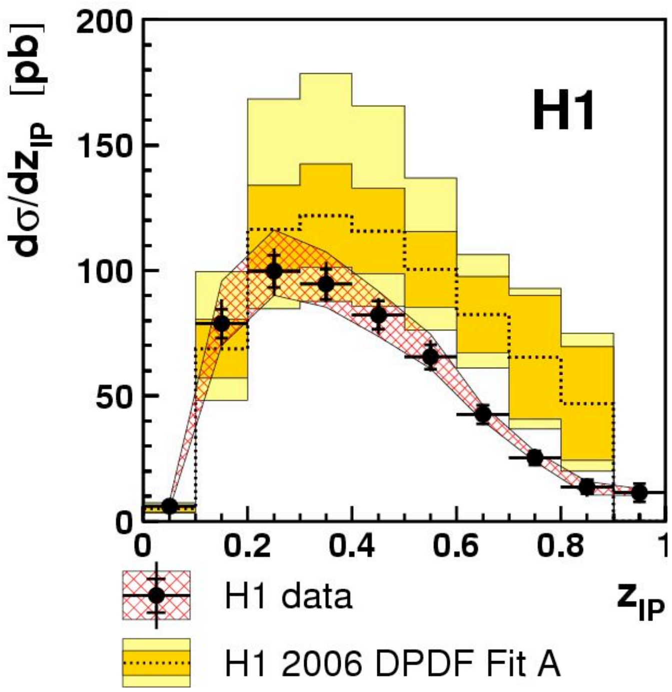
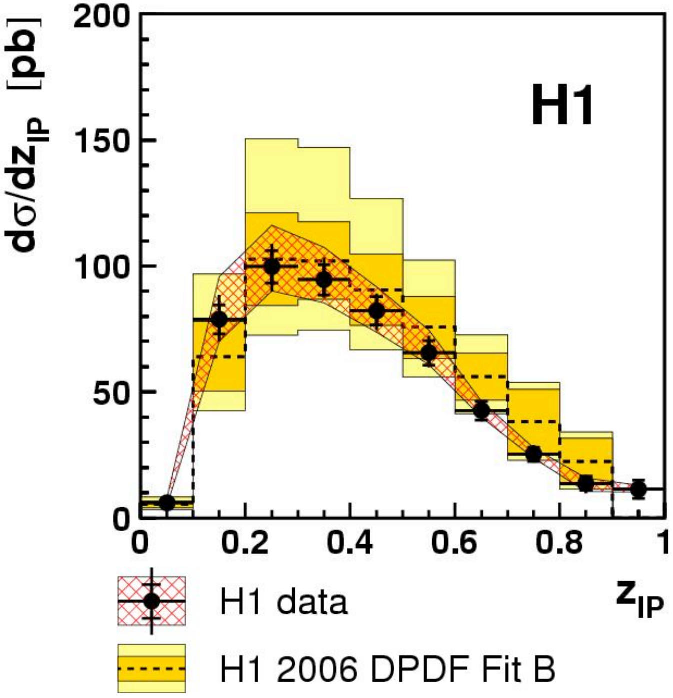




At low z_{IP} (< 0.4) Fit A and Fit B are similar

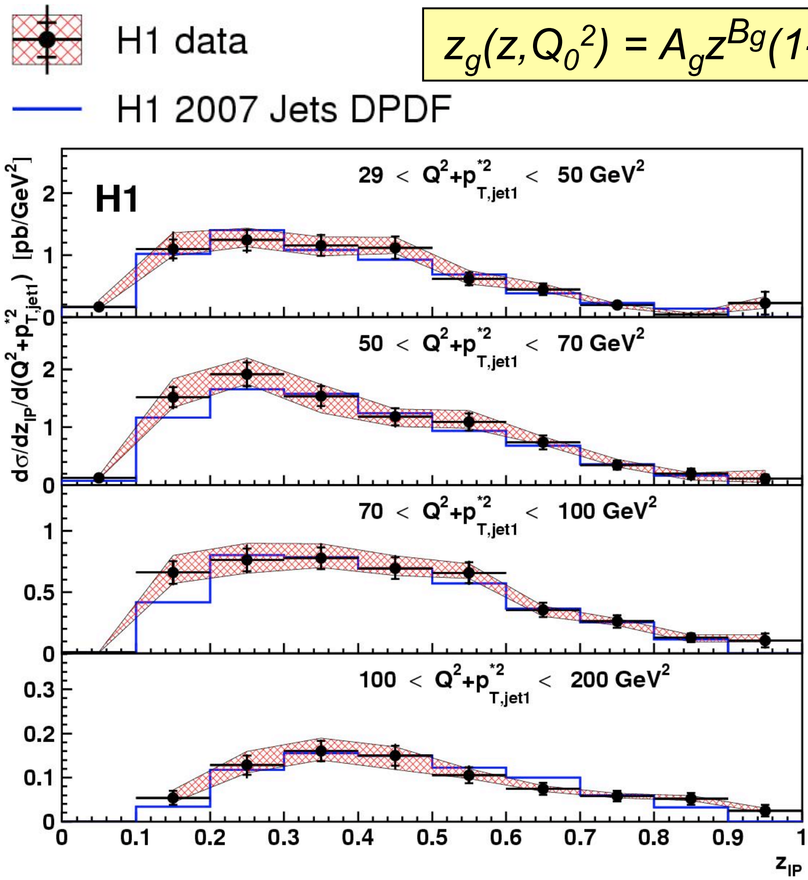
The data are in good agreement with the predictions, consistent with factorisation

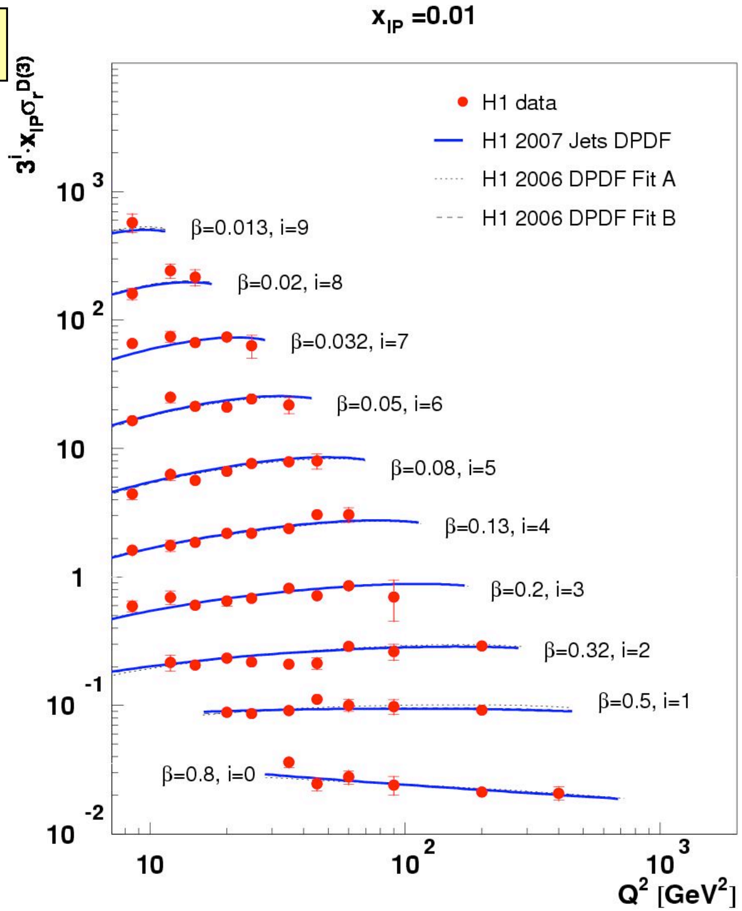
At high z_{IP} the data clearly prefer Fit B

Include the diffractive dijet in a combined fit with the inclusive H1 LRG data

Combined fit of dijet and inclusive data

$$z_g(z,Q_0^2) = A_g z^{B_g}(1-z)^{C_g}$$





- The diffractive dijet data can be used as an additional constraint in a NLO QCD fit procedure
- Details similar to the inclusive case but can now constrain 3 parameters for the gluon

Very good simultaneous fit of both inclusive and dijet data achieved

Combined fit DPDFs from H1

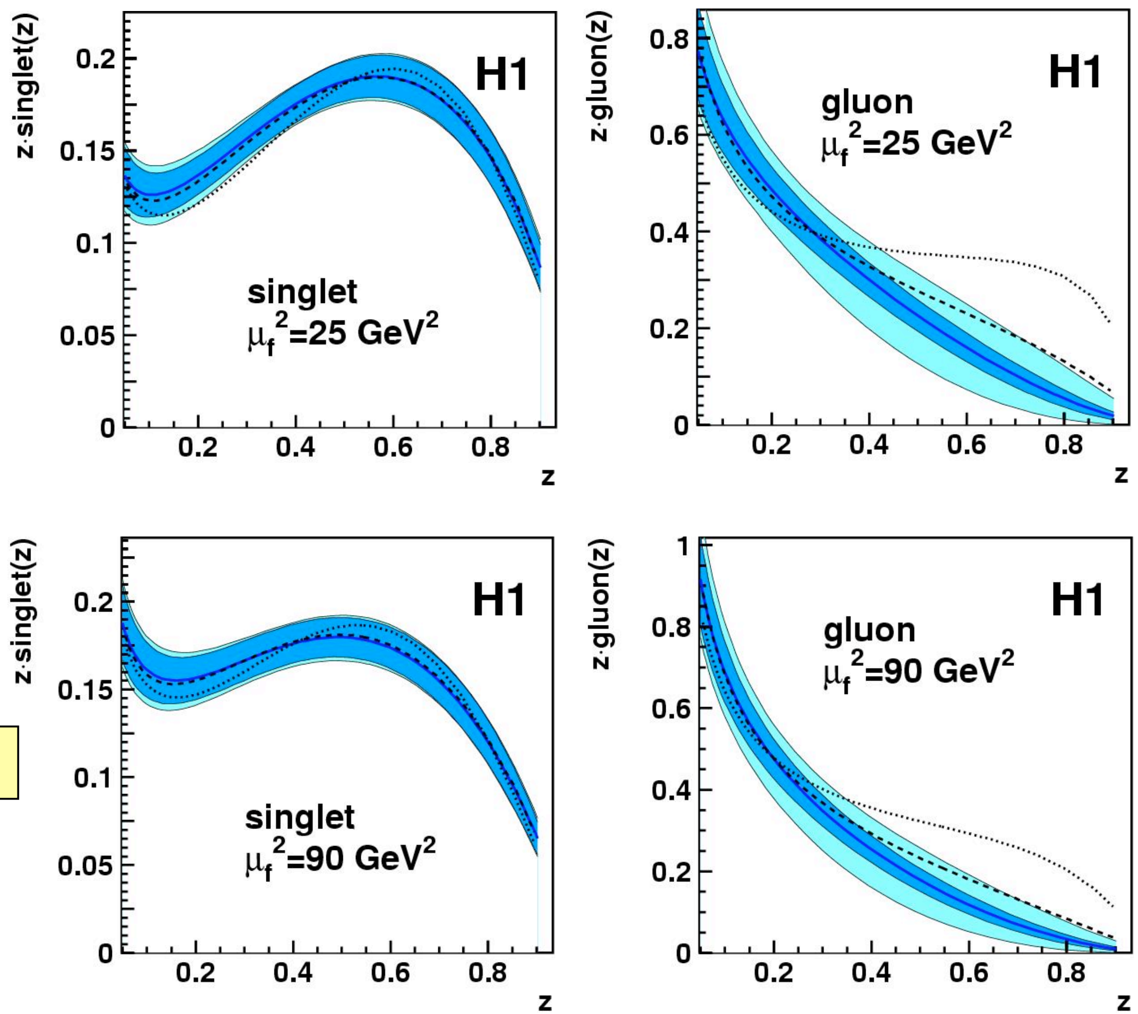
- H1 2007 Jets DPDF
- exp. uncertainty
- exp. + theo. uncertainty
- H1 2006 DPDF fit A
- H1 2006 DPDF fit B

Singlet: $z\Sigma(z,Q_0^2) = A_q z^{B_q}(1-z)^{C_q}$

Gluon Fit A: $z_g(z,Q_0^2) = A_g(1-z)^{C_g}$

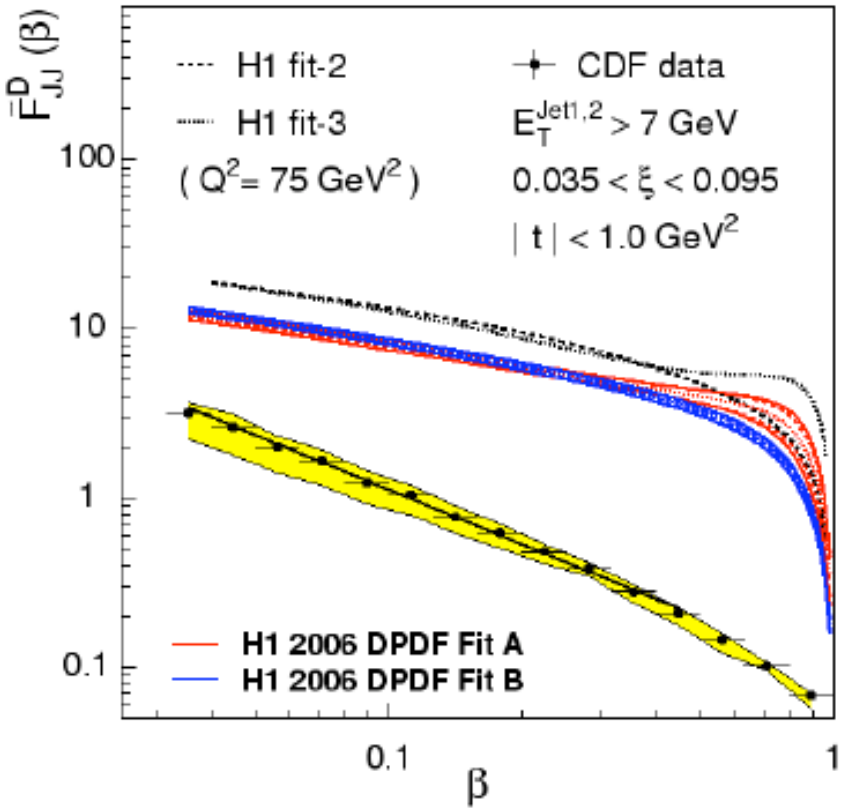
Fit B: $z_g(z,Q_0^2) = A_g$

Jets: $z_g(z,Q_0^2) = A_g z^{B_g}(1-z)^{C_g}$



The singlet and gluon are constrained with similar precision across the whole kinematic range

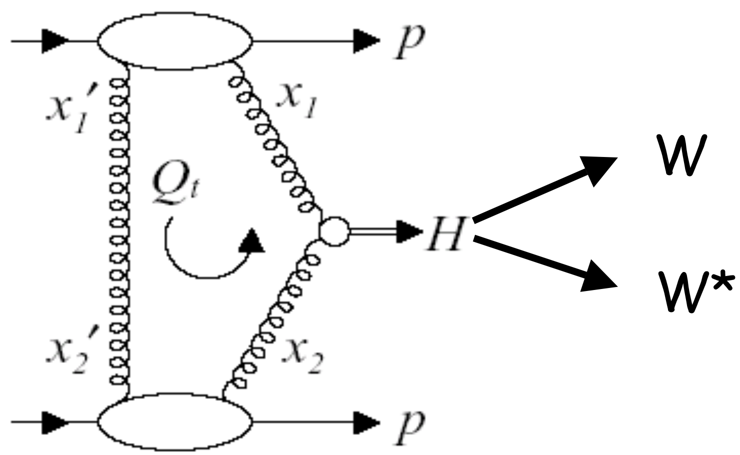
Exporting DPDFs to Hadron-Hadron machines



When trying to use DPDFs extracted at HERA to predict diffractive dijets at CDF…

… it simply doesn't work!

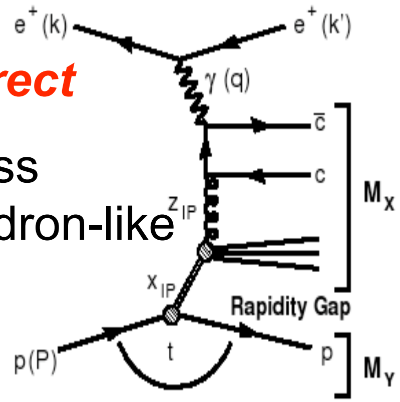
That's a big problem when trying to make predictions for Diffractive Higgs production at the LHC



Factorisation tests at HERA

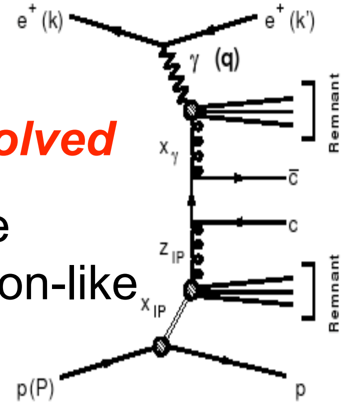
Direct

Less hadron-like



Resolved

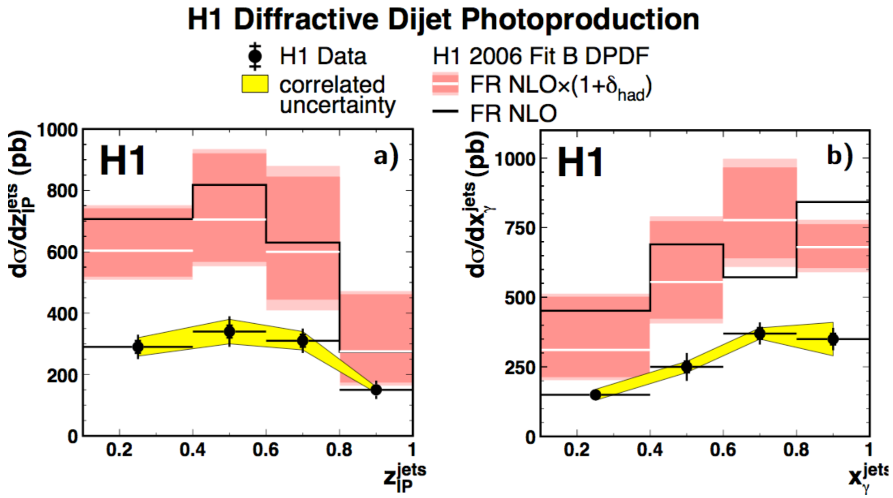
More hadron-like

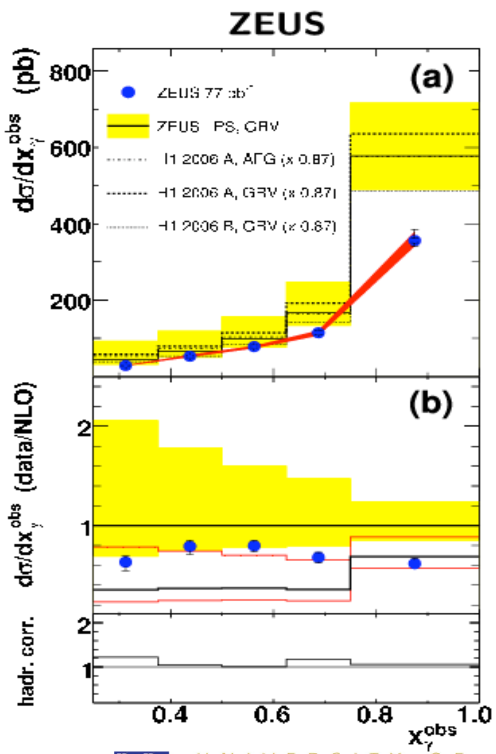


Use photoproduction at HERA as a hadron-hadron collider

How hadron-like the photon is depends on the x_γ variable

Expect *Resolved* (low x_γ)to be more suppressed than *Direct* (high x_γ)

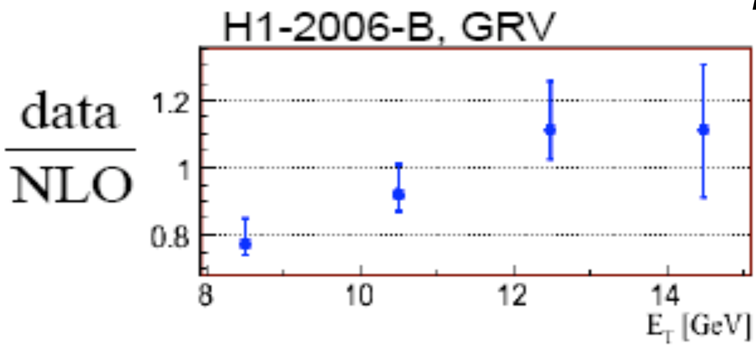


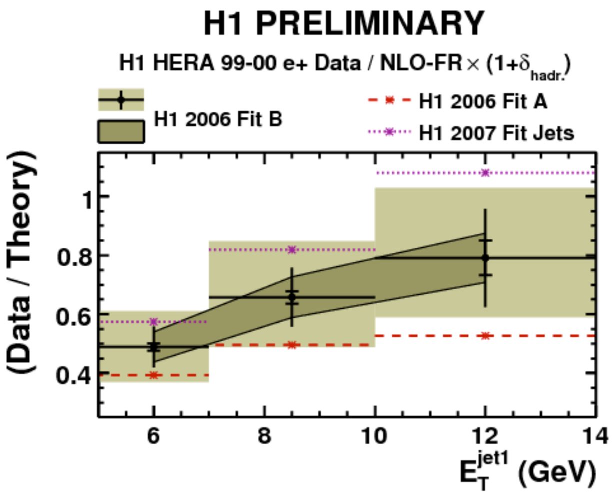


H1 saw that the cross section was suppressed in photoproduction, but independent of x_γ

ZEUS saw consistency with no suppression but did confirm the absence of dependence of x_γ

ZEUS - W.Slomiński

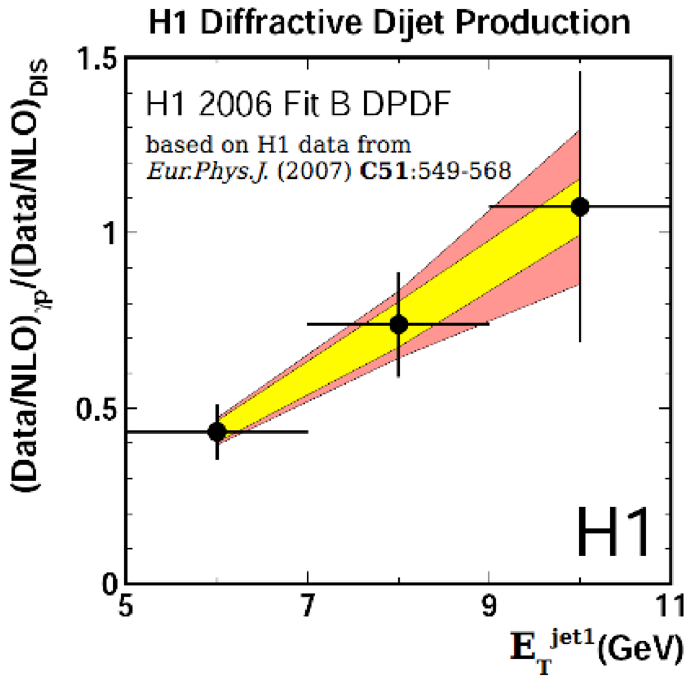




E_T dependence of the suppression

The H1 and ZEUS dijets in photoproduction analyses have different analysis cuts on jet E_T with ZEUS being at higher E_T than H1

Looking at the Data/Theory ratio as a function of jet E_T suggests that there is an *E_T dependence of the suppression*



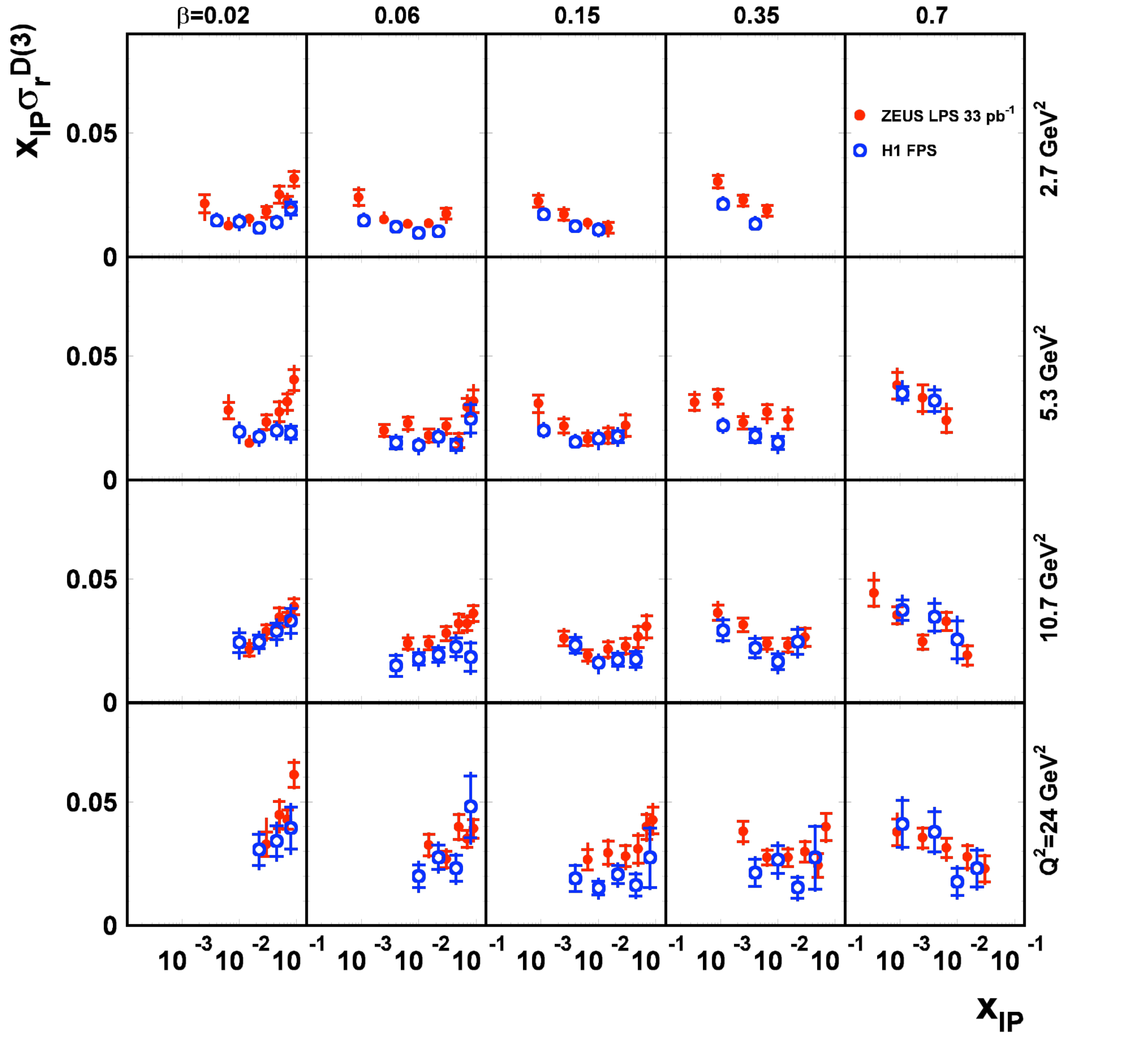
The suggestion of an E_T dependence is even stronger when looking at the double ratio of Data/Theory γp / DIS where some systematic uncertainties cancel

Summary

- A wealth of data from both the H1 and ZEUS collaborations using the Leading Proton, LRG and M_X methods
  - the experimental techniques are largely consistent
- Proton vertex factorisation is a good enough approximation of the data to allow extraction of DPDFs from NLO QCD fits to β, Q^2 dependences of inclusive data
- Diffractive dijet data in DIS agree well with predictions of fits to inclusive data
- Diffractive dijet data in photoproduction show evidence of a suppression wrt predictions that is consistent with
  - No x_γ dependence
  - An E_T dependence
- Combined fit to inclusive and dijet data constrains both the quark and gluon PDFs to similar good precision2

BACK-UP SLIDES FOLLOW

LPS vs FPS



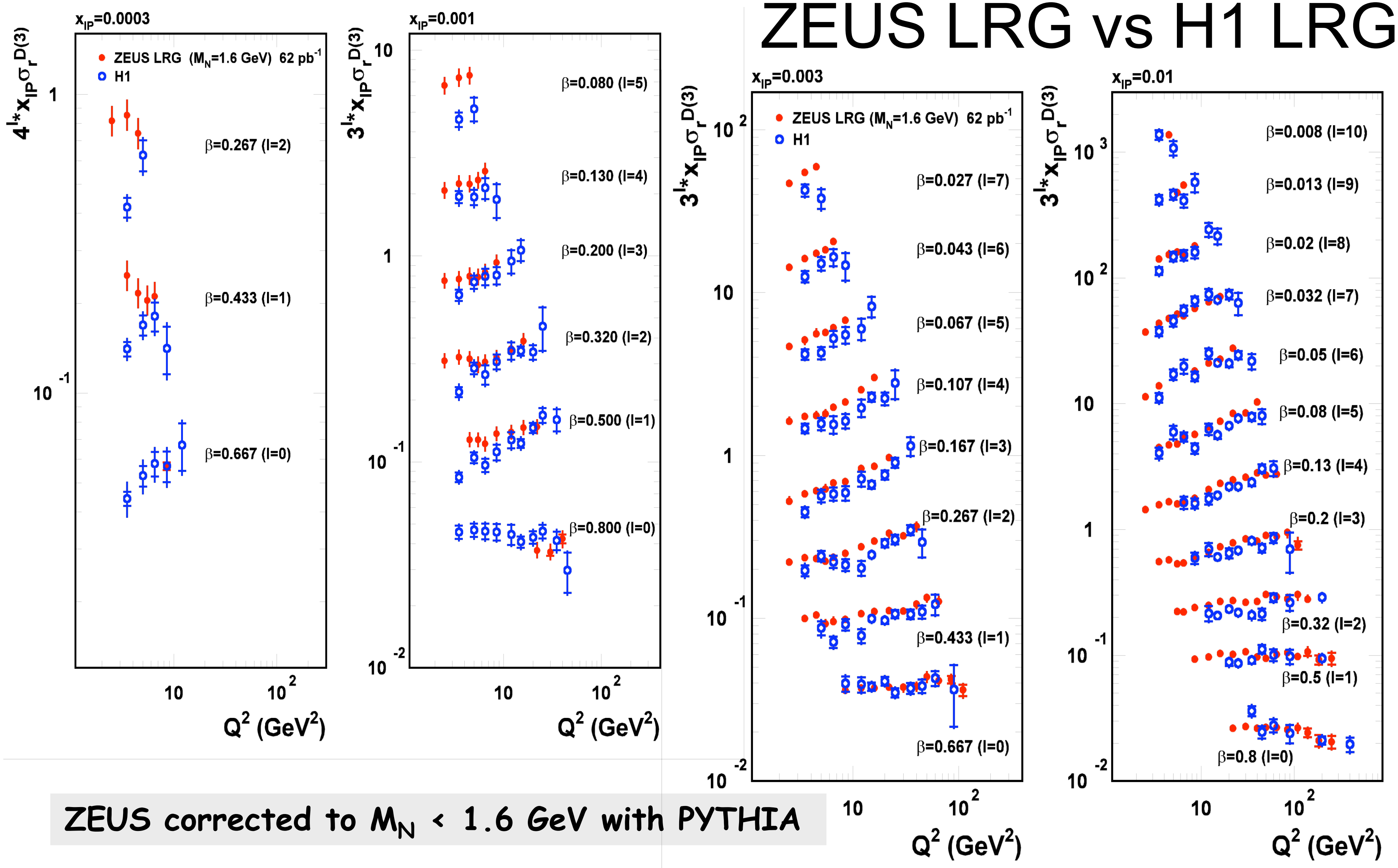
The cleanest possible comparison in principle…

…but large normalisation uncertainties:

(LPS:+11-7%, FPS: +-10%)

ZEUS and H1 proton-tagged data agree within normalisation uncertainties

ZEUS LRG vs H1 LRG

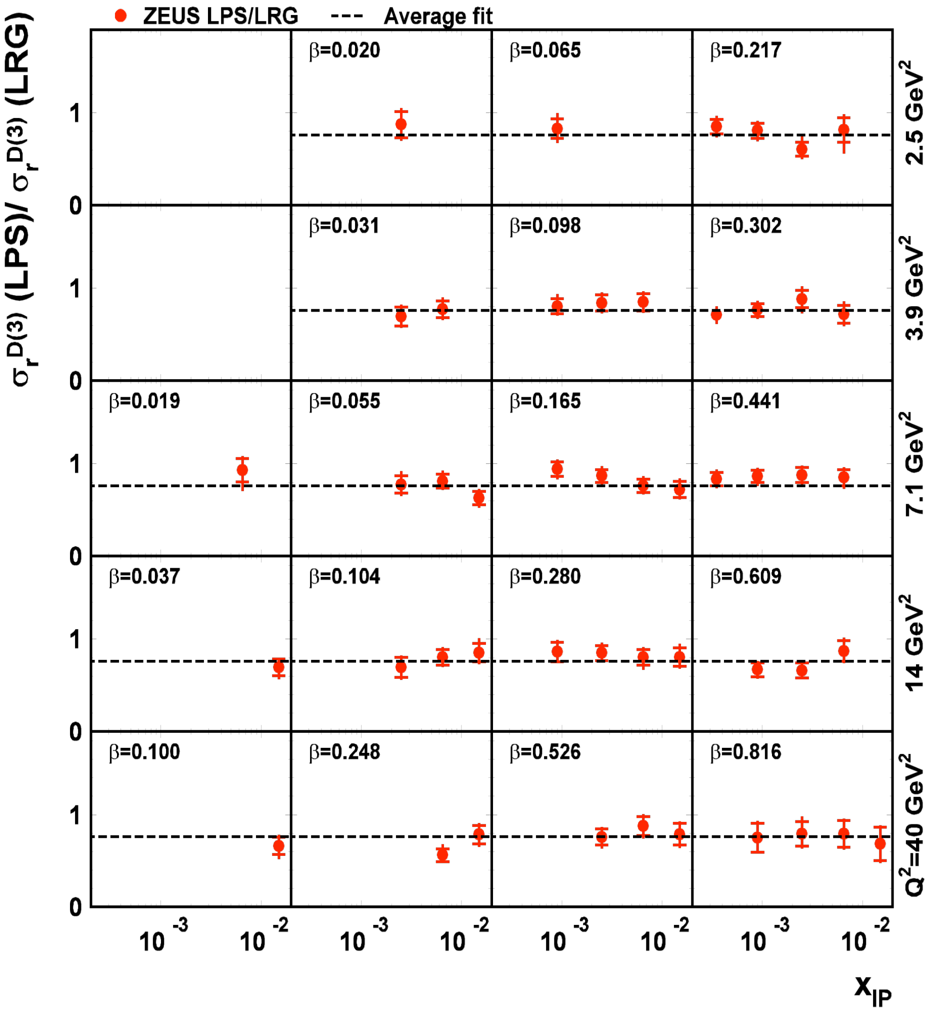


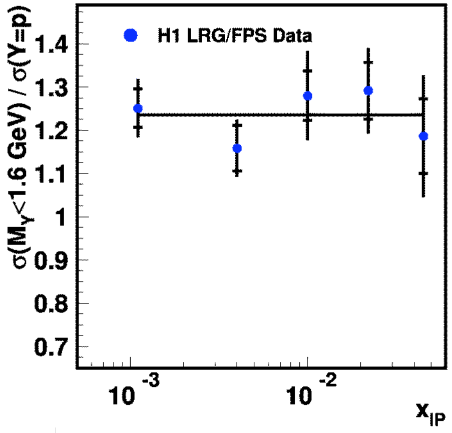
ZEUS corrected to M_N < 1.6 GeV with PYTHIA

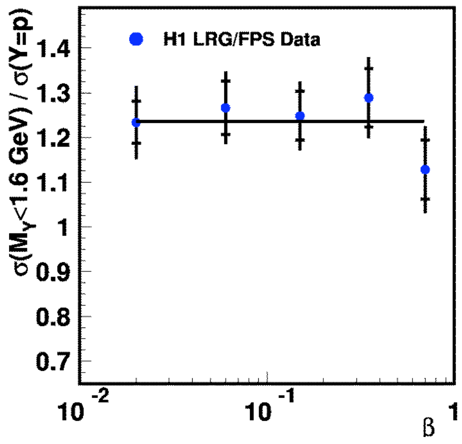
→ Remaining normalisation difference of 13% (global fit) covered by uncertainty on p-diss. correction (8%) and relative normalisation uncertainty (7%)

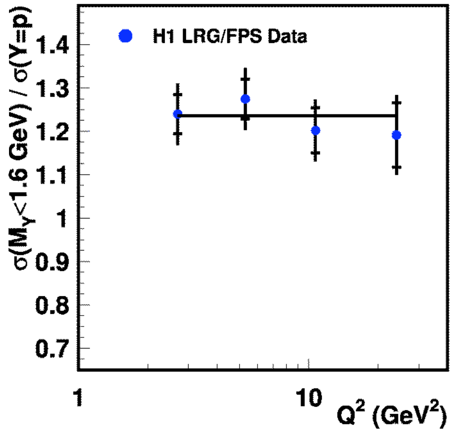
→ Shape agreement ok except low Q^2

Ratio of LPS / LRG









The ratio LPS/LRG cross sections is independent of Q^2, x_{IP}, β

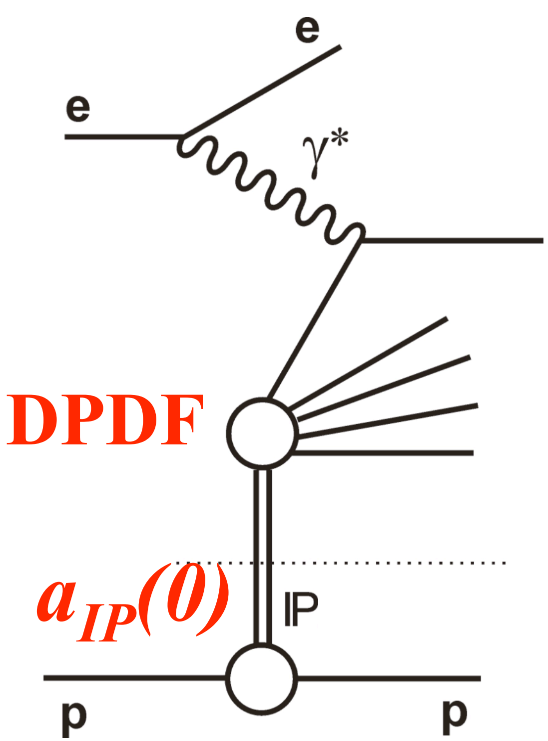
ZEUS LPS / ZEUS LRG = 0.76 +-0.01(stat) +0.03-0.02(sys) +0.08-0.05 (norm)

→ p-diss. background in LRG data: [24 +-1(stat) +2-3(sys) +5-8(norm)]%

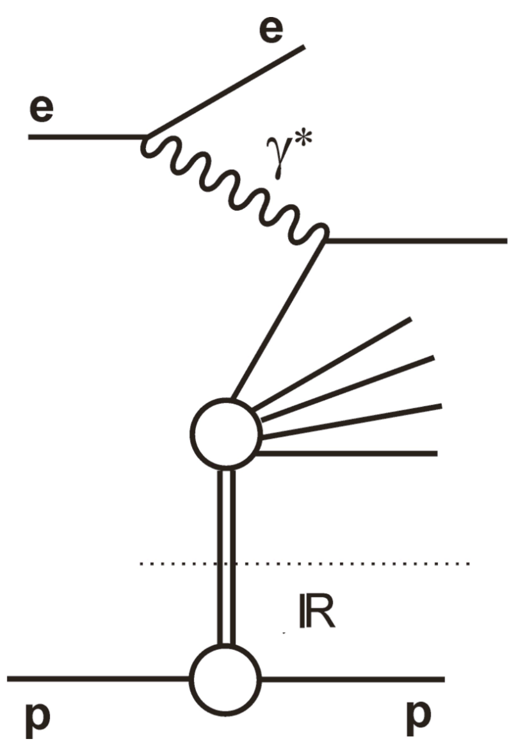
H1 LRG /H1 FPS = 1.23 +-0.03(stat) +-0.16(sys)

→ Proton dissociation left in H1 LRG data : [+11]%

H1 2006 DPDF Fit - Overview



$+\ n_{I\!R}\ \times$



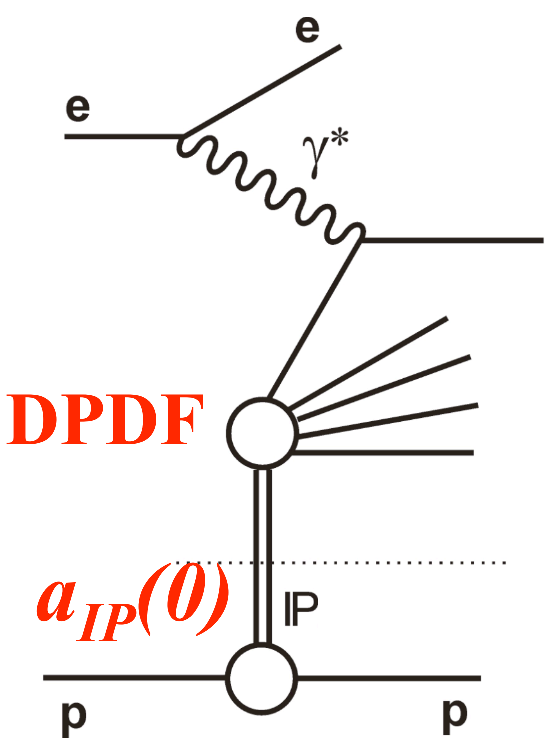
IP component*:*

- Fit $\alpha_{IP}(0)$ (x_{IP} dependence).
- Simultaneously, fit 5 parameters of DPDFs (β and Q^2 dependences) using NLO QCD.

IR component*:*

- Fit n_{IR} one parameter for normalisation.
- All flux parameters taken from previous H1 data. PDFs taken from Owens-pion

H1 2006 DPDF Fit - Details



IP component:

- Fit $\alpha_{IP}(0)$ (x_{IP} dependence).
- Simultaneously, fit 5 parameters of DPDFs (β and Q^2 dependences) using NLO QCD.

- Parameterise quark singlet $z\Sigma(z,Q_0^2)$ and gluon $zg(z,Q_0^2)$ densities, where z is parton momentum fraction (= β for QPM).
- Parameterisation used is $z\Sigma(z,Q_0^2) = A_q z^{B_q}(1-z)^{C_q}$ and $zg(z,Q_0^2) = A_g(1-z)^{C_g}$ (gluon insensitive to B_g)
- Results reproducible with Chebyshev polynomials.
- Fit is stable with variations of, e.g. β_{max} – the maximum value of β allowed in the fit.
- Fit stable for $Q^2_{min} > 8.5$ GeV².
- Fit all data with:
  $Q^2 \geq 8.5\ \text{GeV}^2$ (and $M_X > 2$ GeV, $\beta \leq 0.8$)

H1 2006 DPDF Fit - Results

- **Fit A**

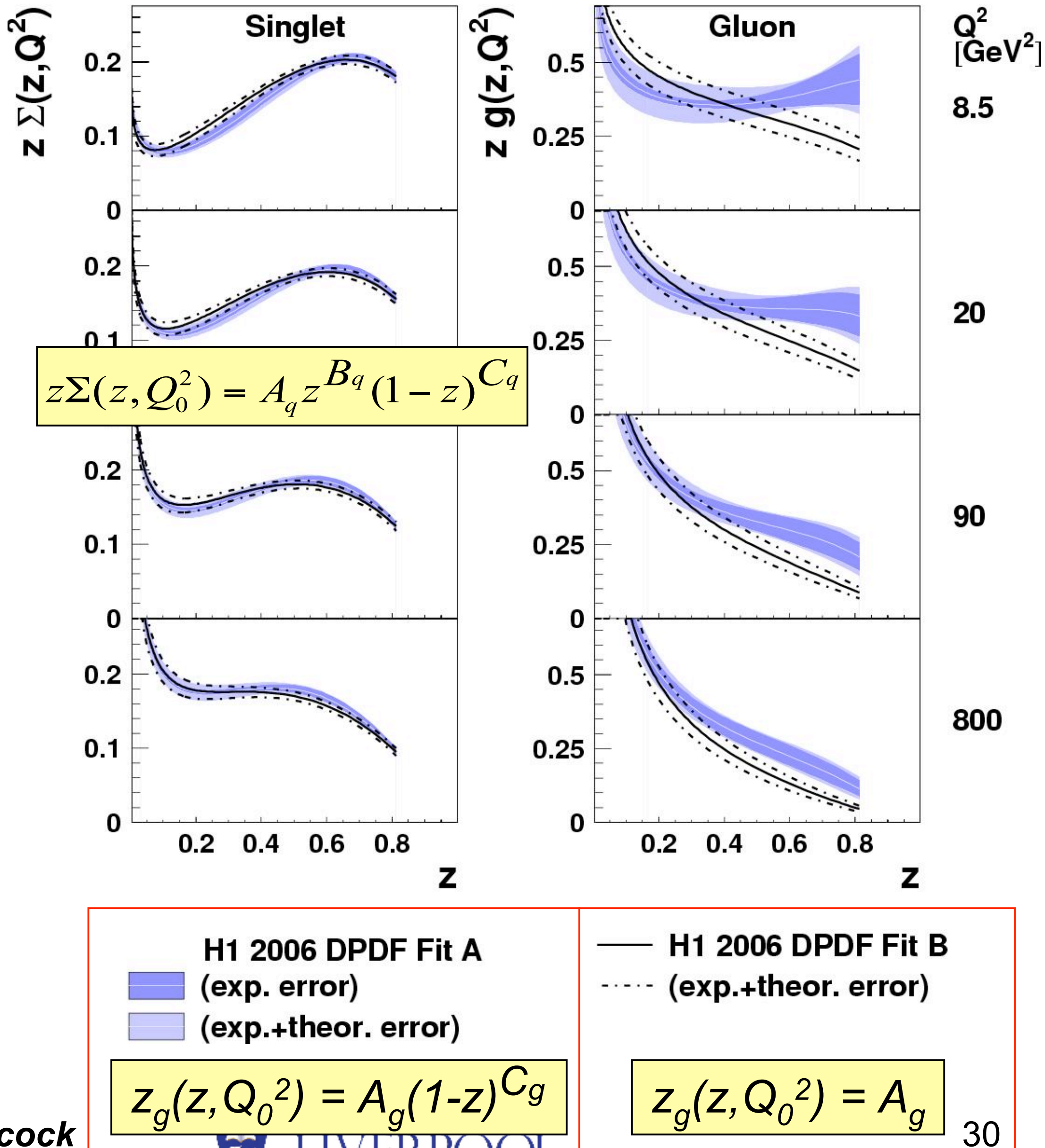
  $Q_0^2 = 1.75\ \text{GeV}^2$
  $\chi^2 \sim 158 / 183$ d.o.f.

- **Fit B**

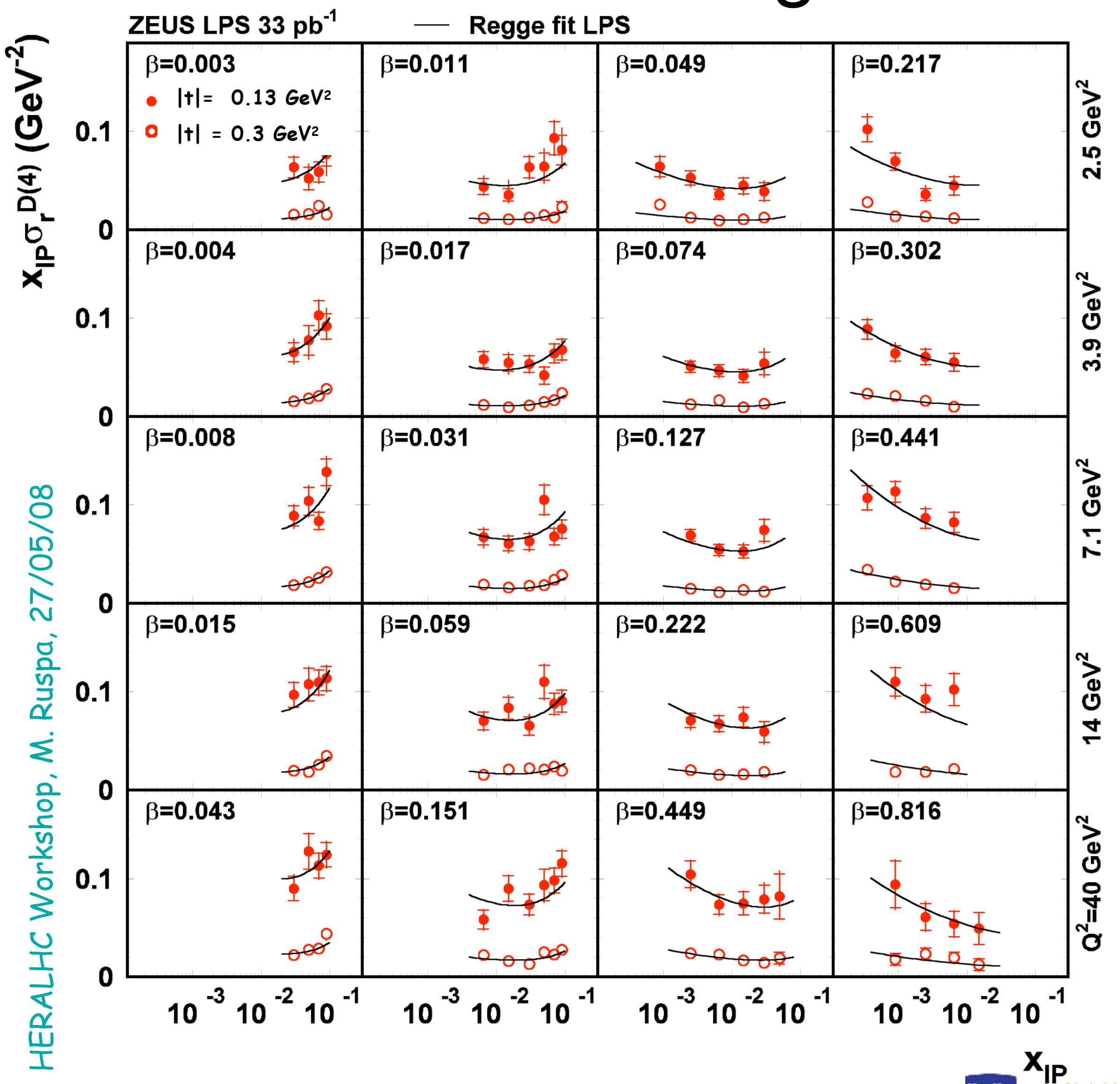
Drop C_g - gluon is parameterised as a constant at the starting scale!

$\chi^2 \sim 164 / 184$ d.o.f.
$Q_0^2 = 2.5\ \text{GeV}^2$

- Quarks very stable
- Gluon similar at low z
- No sensitivity to gluon at high z



x_{IP} dependence of $\sigma_r^{D(4)}$ Leading Proton data



First measurement in two t bins

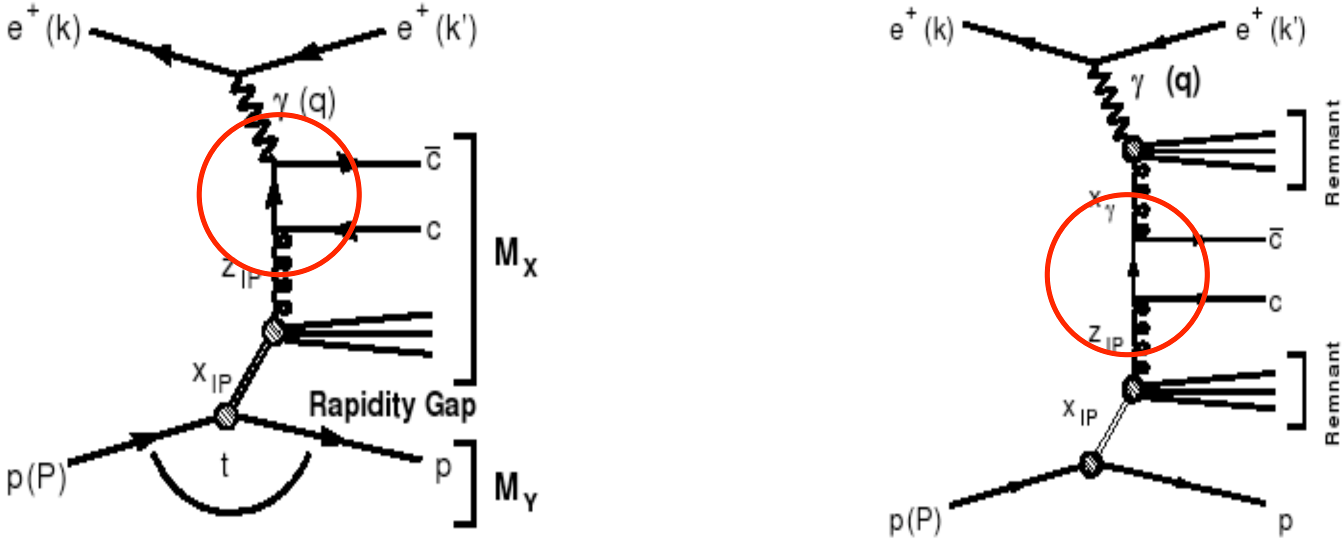
Same x_{IP} dependence in two t bins

Low x_{IP}: $\sigma_r^{D(4)}$ falls with x_{IP} faster than $1/x_{IP}$

High x_{IP}: $x_{IP}\sigma_r^{D(4)}$ flattens or increases with x_{IP}

(Reggeon and π)

Suppression



- It was predicted that the suppression would depend on the configuration of the photon in photoproduction - it doesn't
- It seems we only need a hard scale to resolve the scatter
- That can be provided by the Q^2 of the photon in DIS or by the E_T of the jets in photoproduction
- The latter seems to require playing the hard interaction backwards, but there is no time-ordering of that hard interaction