

Diffraction PDFs



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University College London



Overview

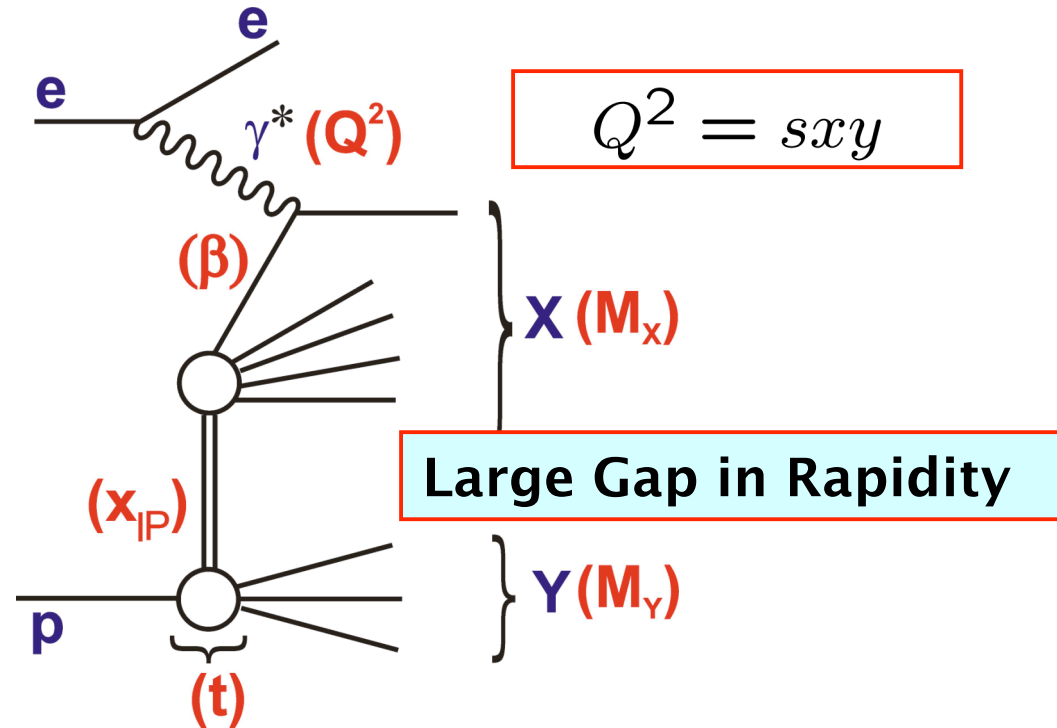
- Diffractive DIS at Hera
 - Kinematics and observables
 - Experimental techniques
- Factorisation, NLO QCD Fits and Diffractive PDFs
 - QCD and the high z gluon
- Diffractive dijets in DIS
 - Factorisation holds in diffractive DIS
 - Diffractive Dijet PDFs

Diffractive DIS Kinematics and Observables

$$x = x_{IP} \beta$$

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

$$x_{IP} = \frac{Q^2 + M_X^2}{Q^2 + W^2}$$



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

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

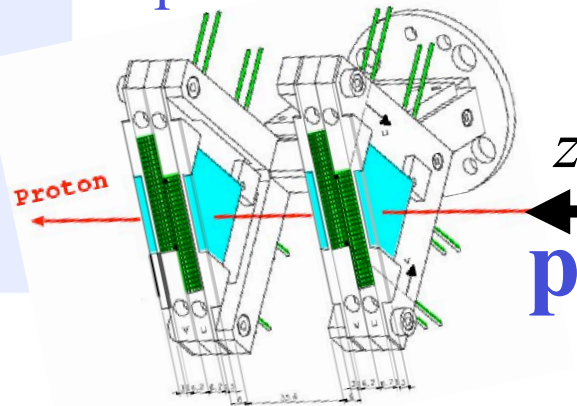
$$\sigma_r^{D(4)} = F_2^{D(4)} - \frac{y^2}{Y_+} F_L^{D(4)}$$

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

Experimentally selecting

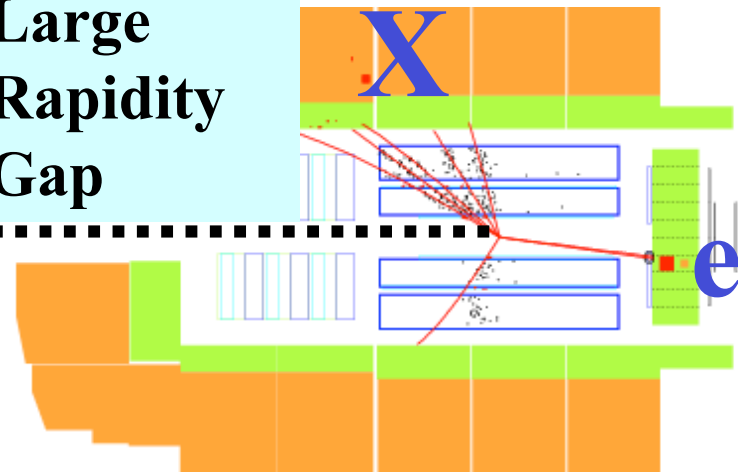
$$ep \rightarrow eXp$$

Forward Proton Spectrometer



$z = 64, z = 80m$

Large Rapidity Gap



Measure Leading Proton (FPS)

No proton dissociation

Measure the t dependence

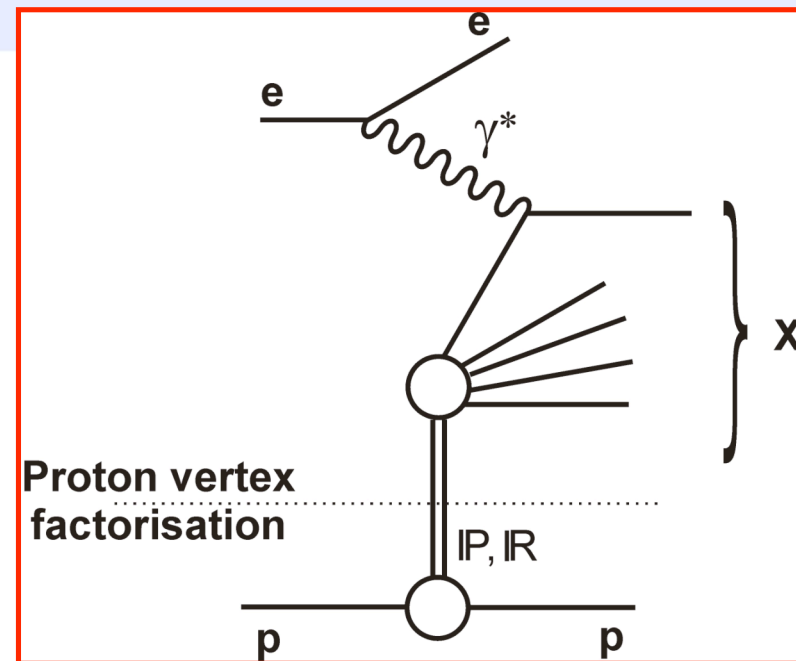
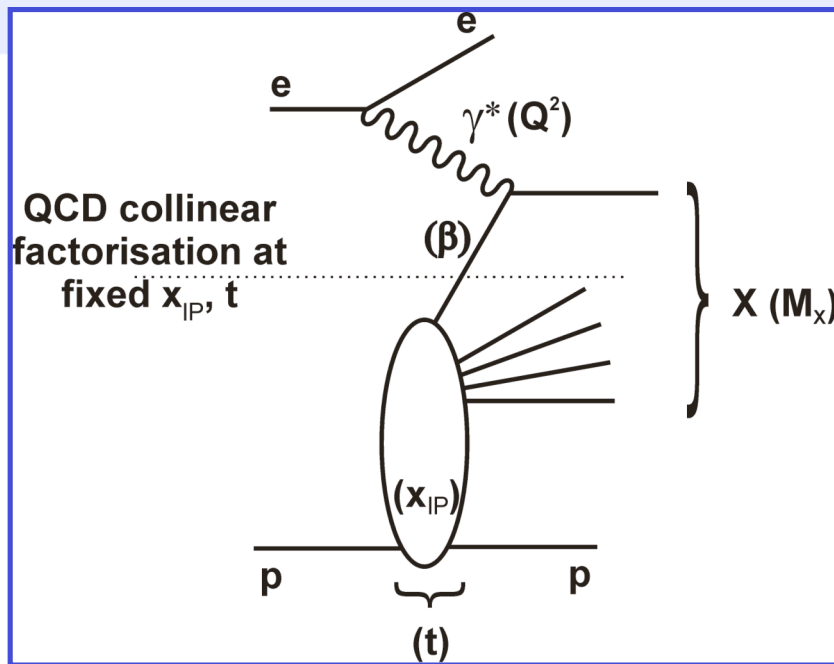
Low detector acceptance

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

Kinematics measured from X system, integrate $|t| < 1.0 \text{ GeV}^2, M_Y < 1.6 \text{ GeV}$

High detector acceptance \rightarrow precision

Two Levels of Factorisation



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

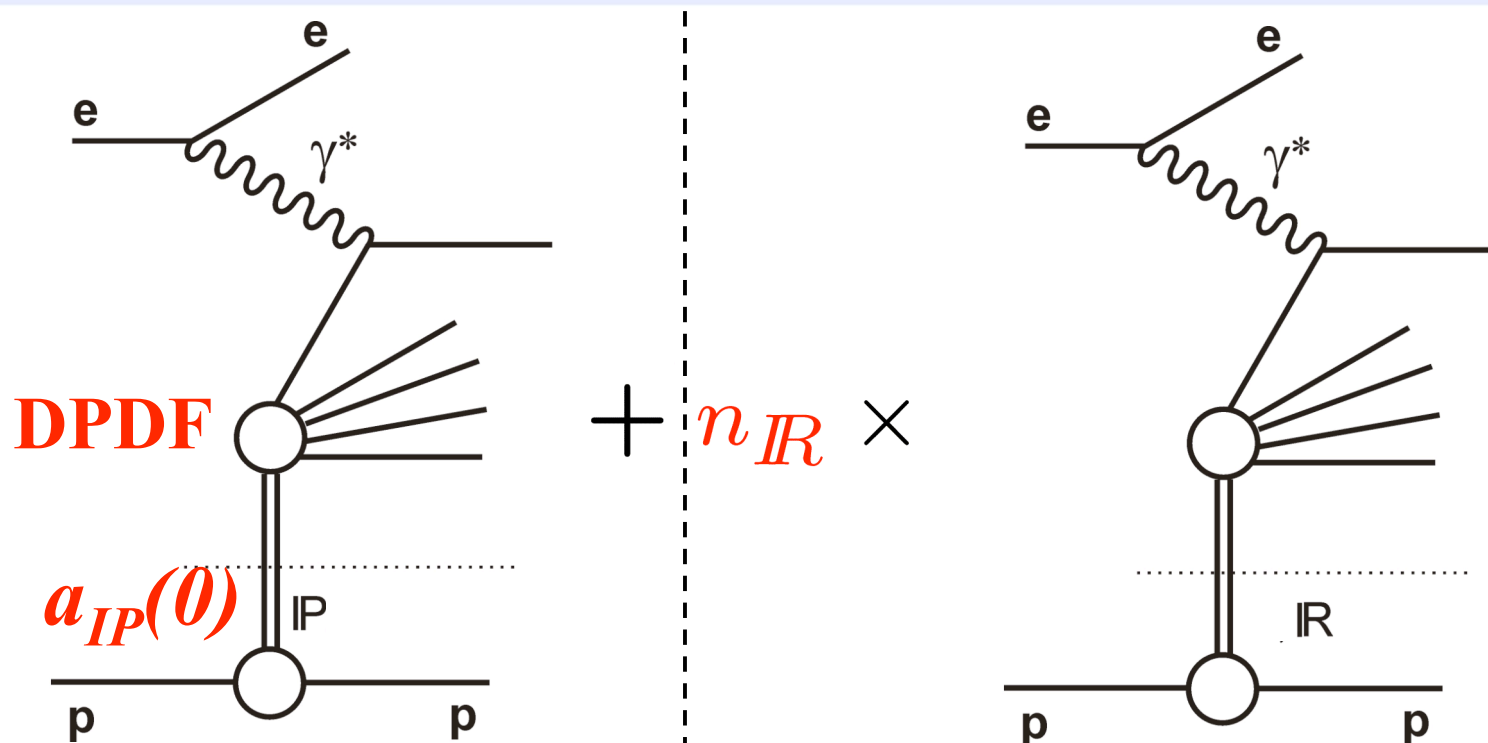
$$d\sigma_{partoni}(ep \rightarrow eXY) = f_i^D(x, Q^2, x_{IP}, t) \otimes d\sigma^{ei}(x, Q^2)$$

Applied after integration over measured M_Y and t ranges

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

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

H1 2006 DPDF Fit - Overview



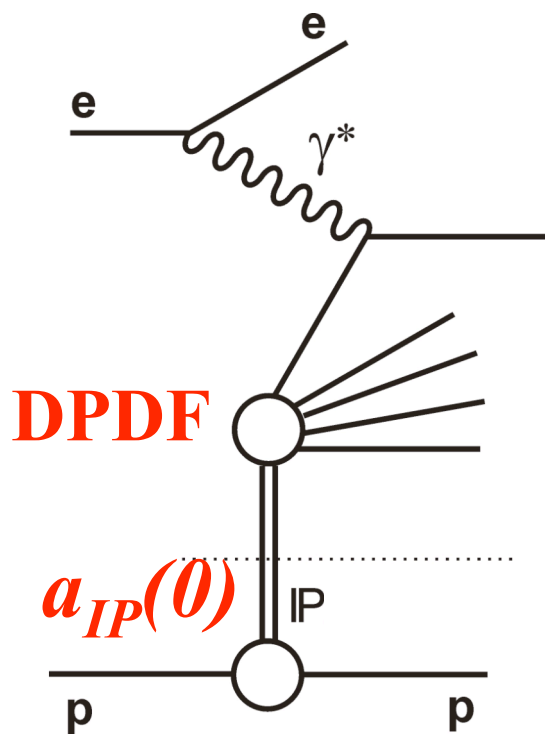
IP component:

- 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



- Parameterise quark singlet $z\Sigma(z, Q_0^2)$ and gluon $zg(z, Q_0^2)$ densities, where z is parton momentum fraction ($= \beta$ 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.

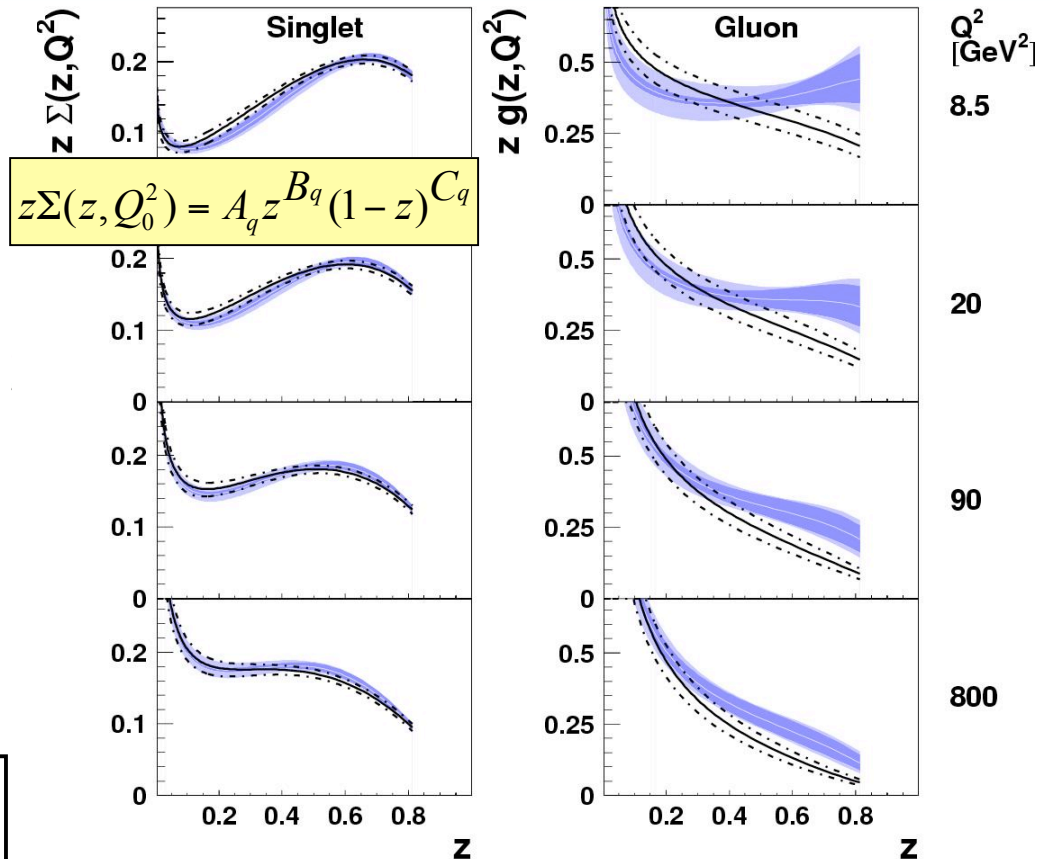
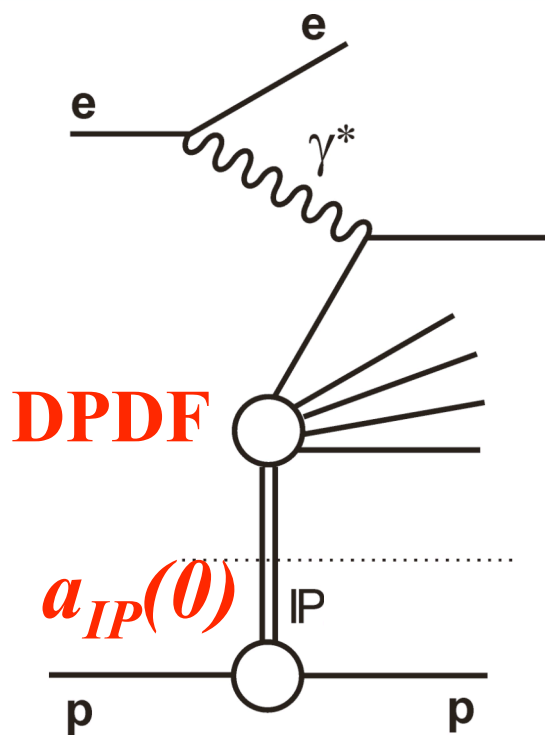
- Fit stable for $Q_{min}^2 > 8.5 \text{ GeV}^2$.

- Fit all data with: $Q^2 \geq 8.5 \text{ GeV}^2$ (and $M_x > 2 \text{ GeV}$, $\beta \leq 0.8$)

IP component:

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

H1 2006 DPDF Fit - Results



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

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

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

IP component:

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

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

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

DPDFs from inclusive data

- **Fit A**

$$Q_0^2 = 1.75 \text{ GeV}^2$$

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

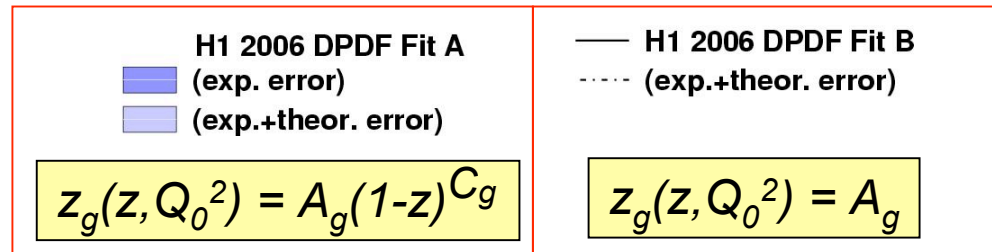
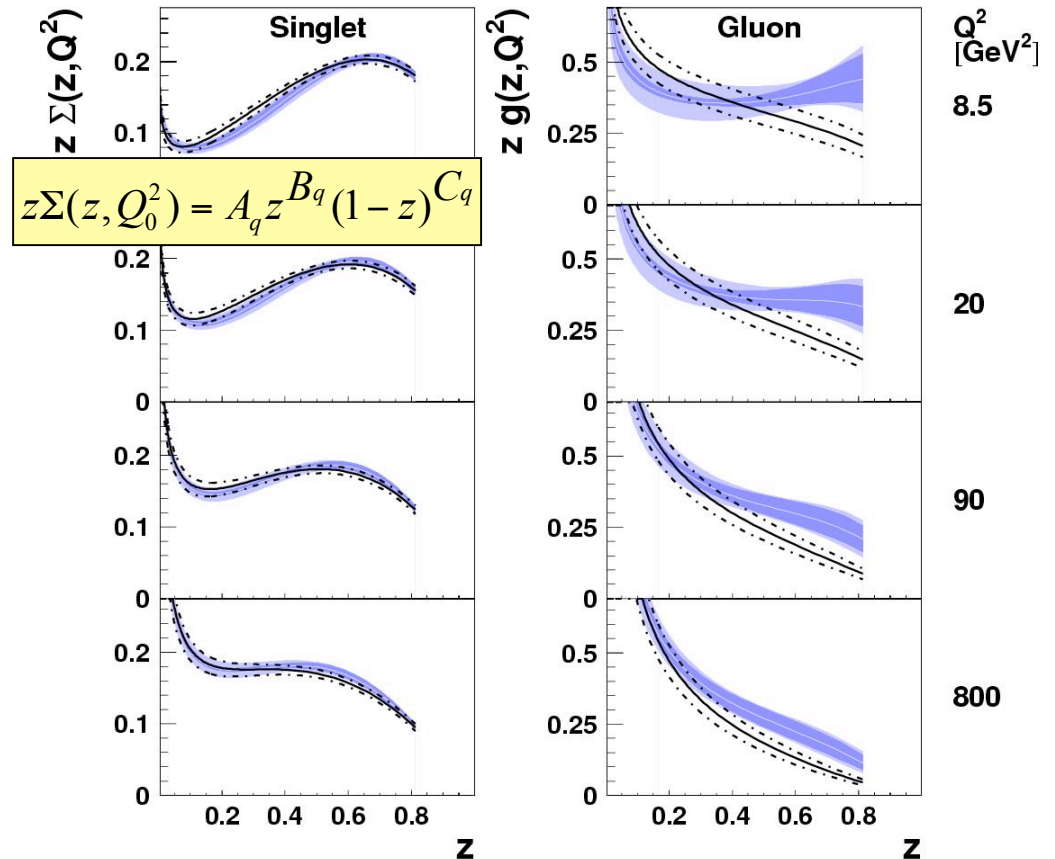
- **Fit B**

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

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

$$Q_0^2 = 2.5 \text{ GeV}^2$$

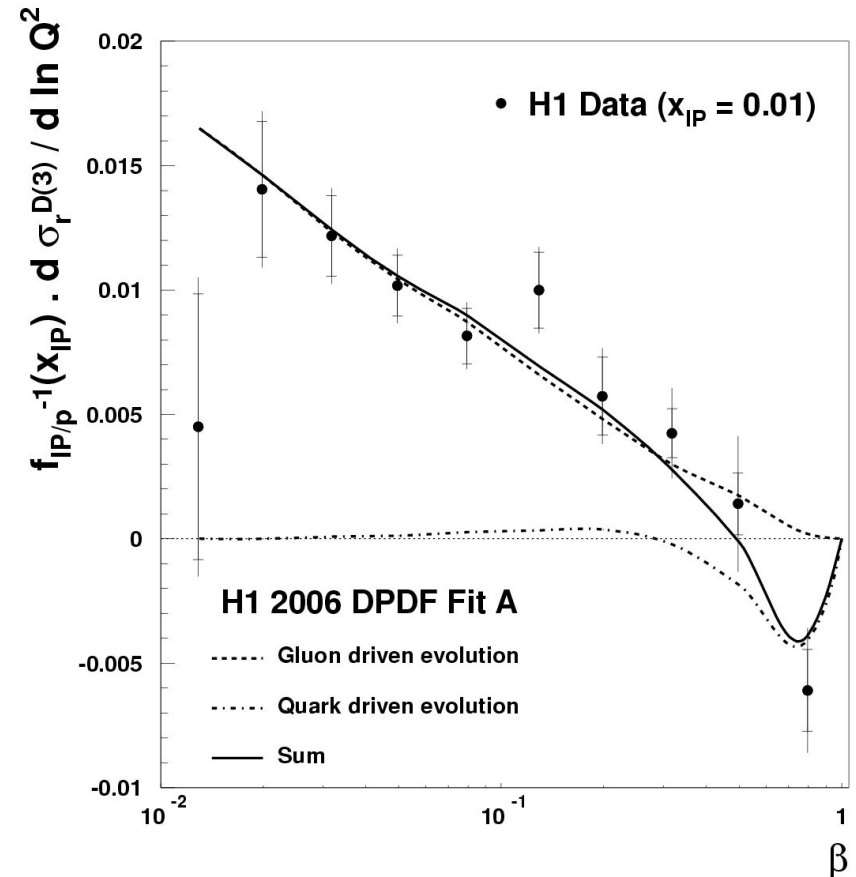
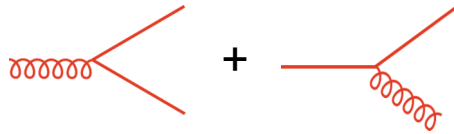
- Quarks very stable
- Gluon similar at low z
- No sensitivity to gluon at high z



A Closer Look at the High z Region

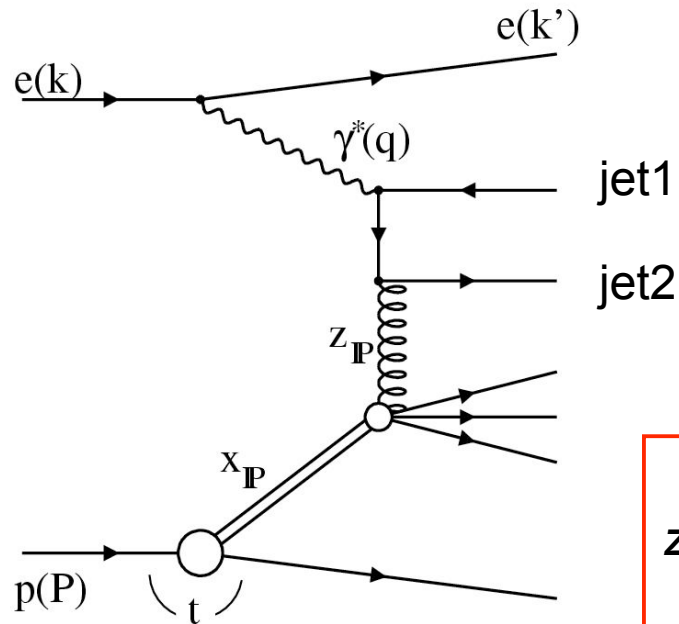
We have only singlet quarks, so DGLAP evolution equation for F_2^D

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

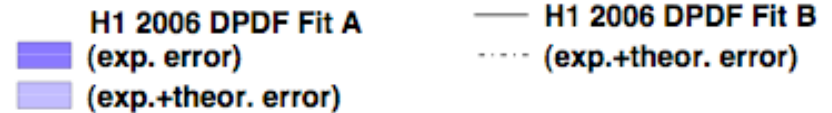
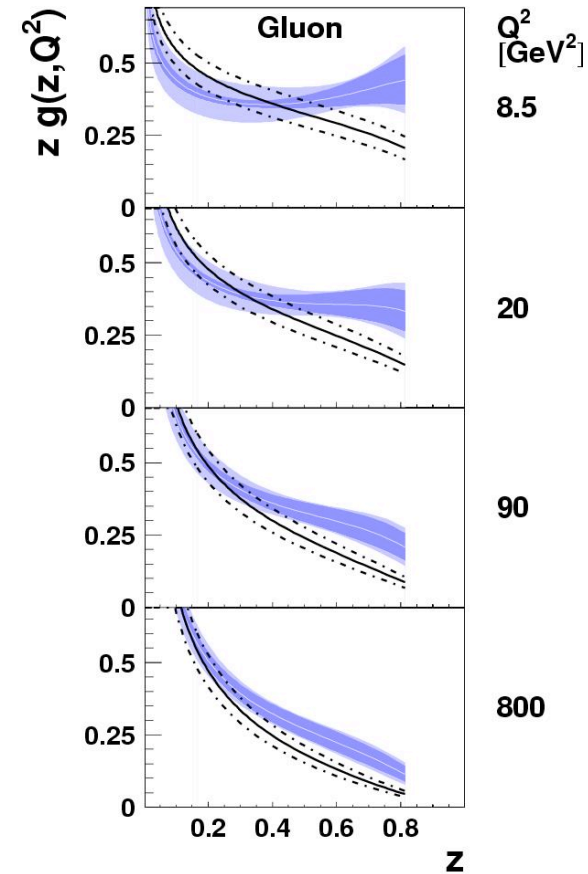


At high β , relative error on derivative grows, $q \rightarrow qg$ contribution to evolution becomes important ... sensitivity to gluon is lost

Compare to diffractive dijets in DIS



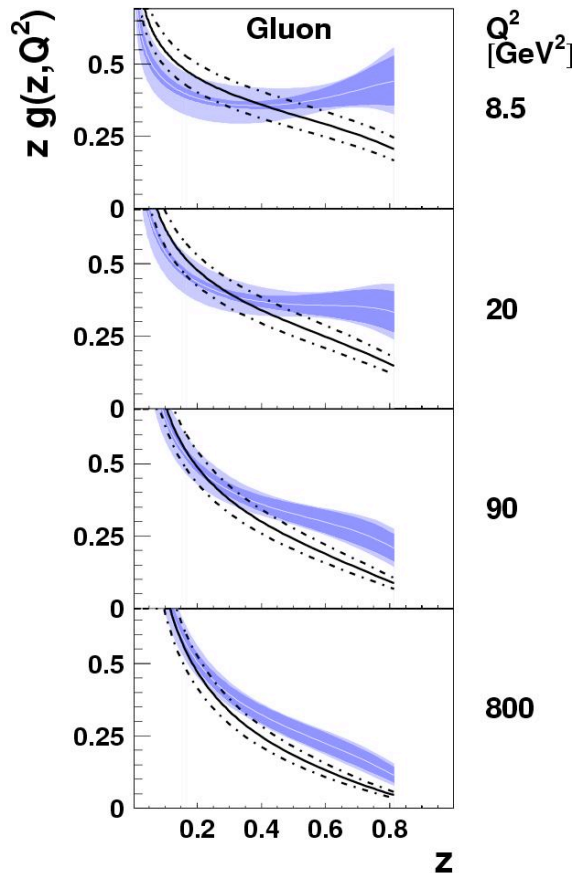
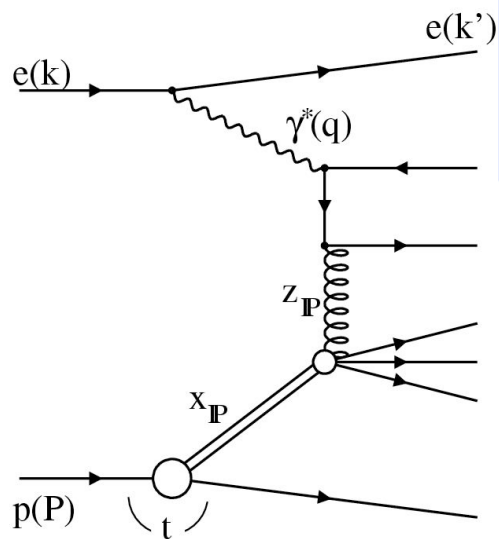
$$z_{IP} = \frac{M_{12}^2 + Q^2}{M_X^2 + Q^2}$$



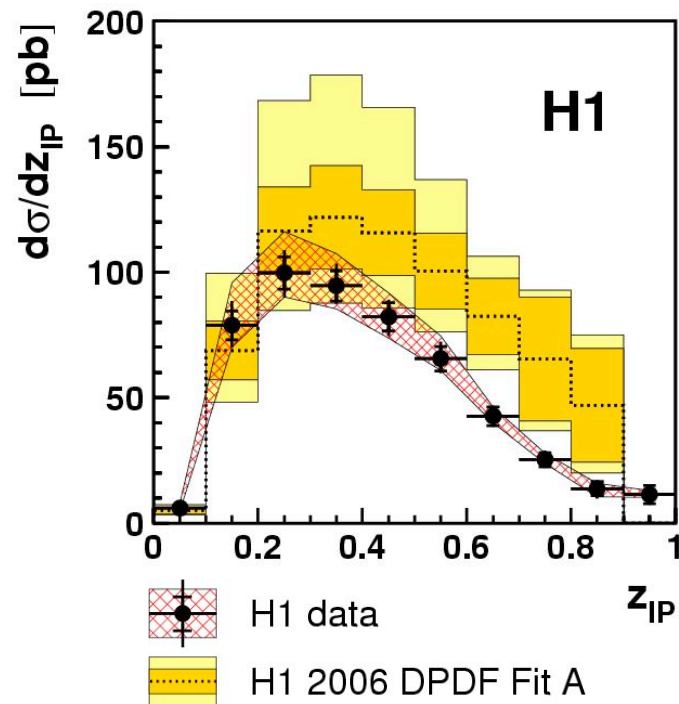
We can compare the predictions of Fit A and Fit B with the experimental measurement of diffractive dijets in DIS

This process is particularly sensitive to the gluon at large z

Compare to diffractive dijets in DIS

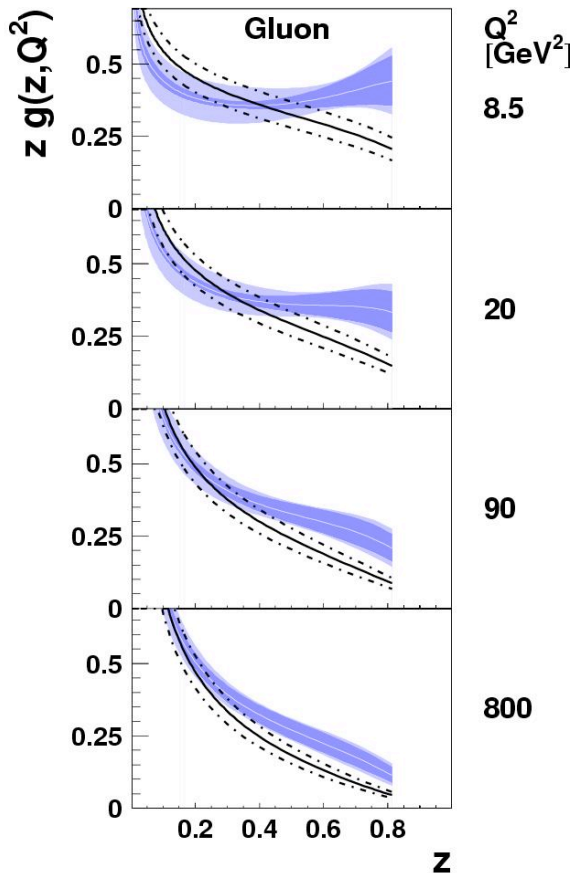
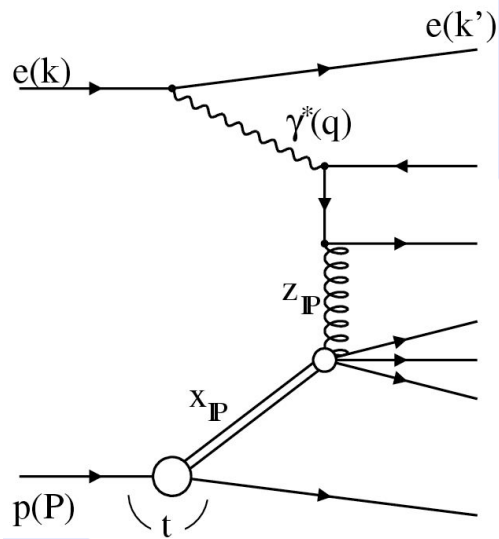


■ H1 2006 DPDF Fit A (exp. error)
■ (exp.+theor. error)
— H1 2006 DPDF Fit B
- - - (exp.+theor. error)

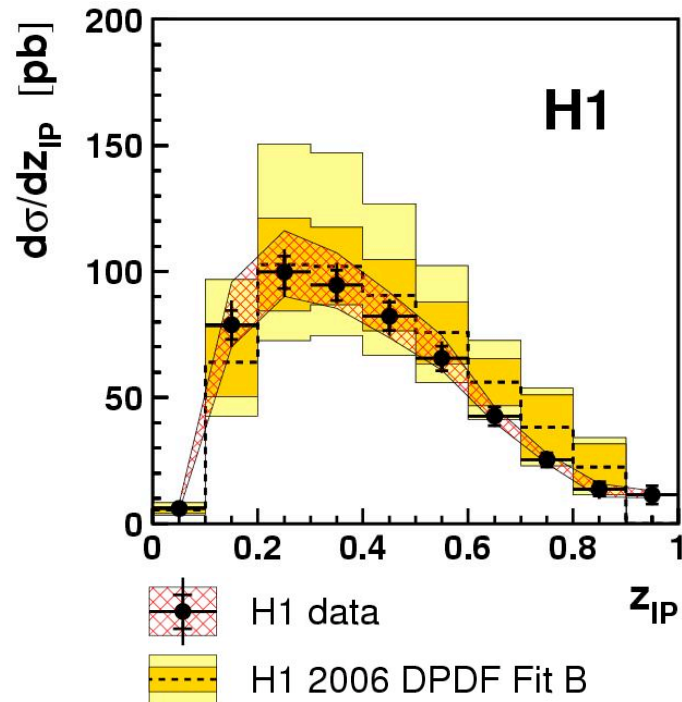


Fit A is in good agreement with the data at low z , overshooting at high z

Compare to diffractive dijets in DIS



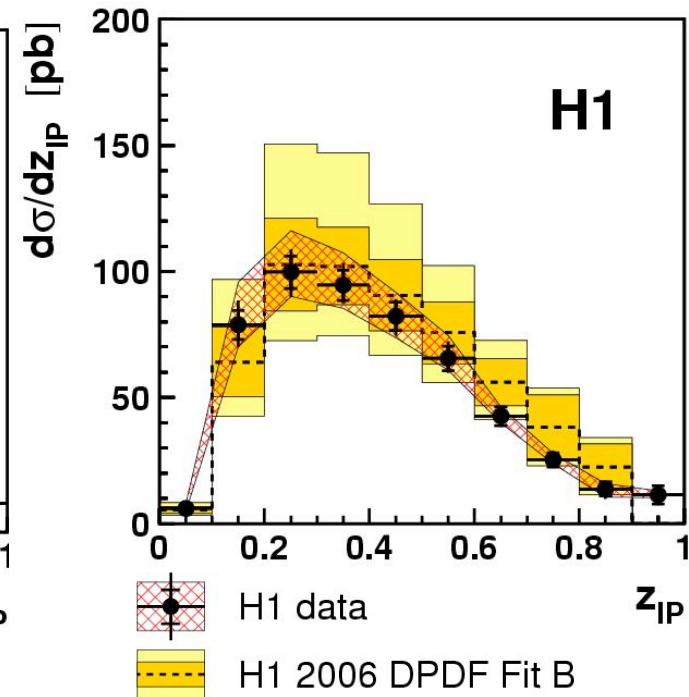
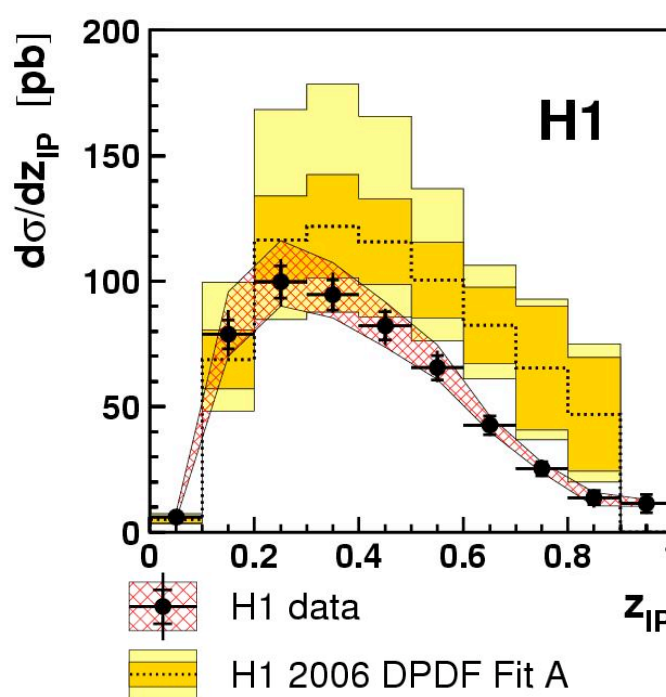
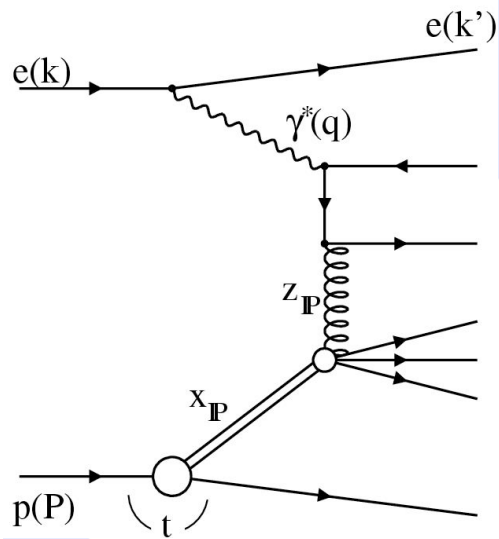
■ H1 2006 DPDF Fit A (exp. error)
■ (exp.+theor. error)
— H1 2006 DPDF Fit B (exp.+theor. error)



● H1 data
 H1 2006 DPDF Fit B

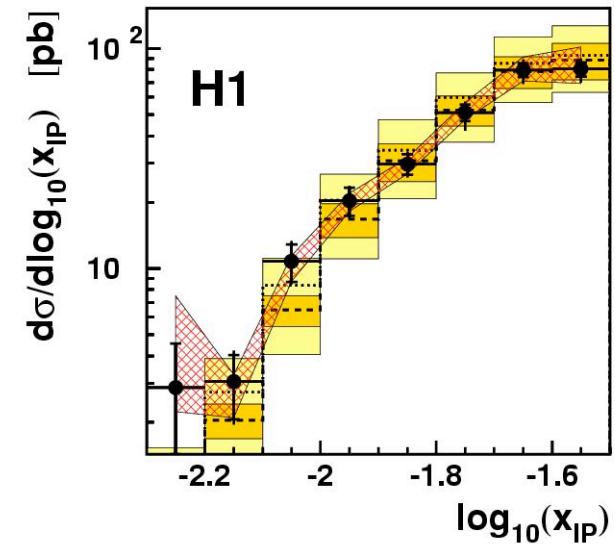
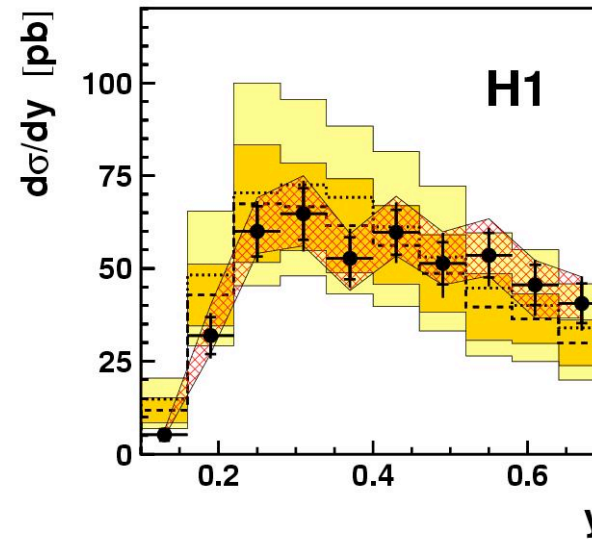
Fit B is in good agreement with the data at all z

Compare to diffractive dijets in DIS

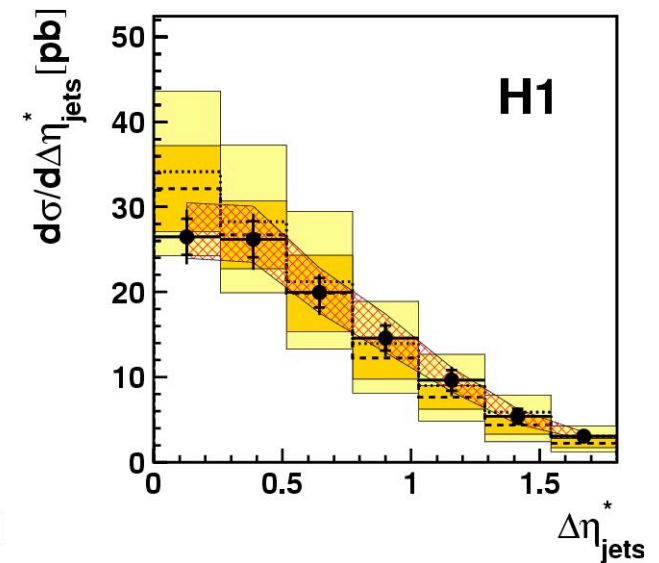
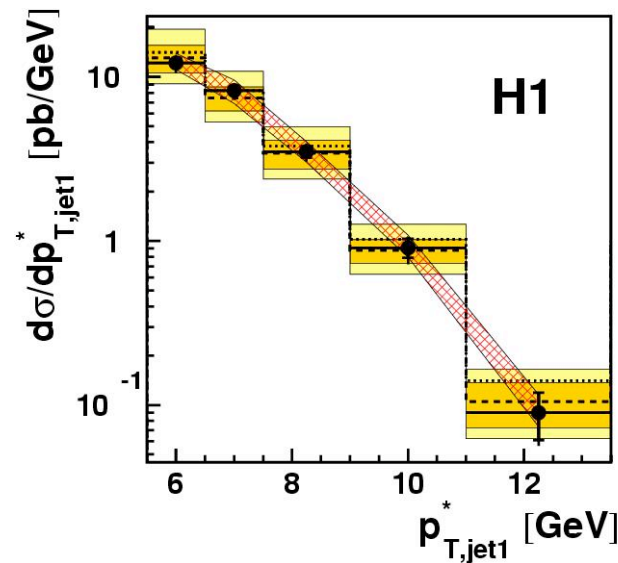


At low z_{IP} (< 0.4) Fit A and Fit B are similar / at high z_{IP} the data clearly prefer Fit B
 The data are in good agreement with the predictions, consistent with factorisation
 Include the sensitive diffractive dijet in a combined fit...

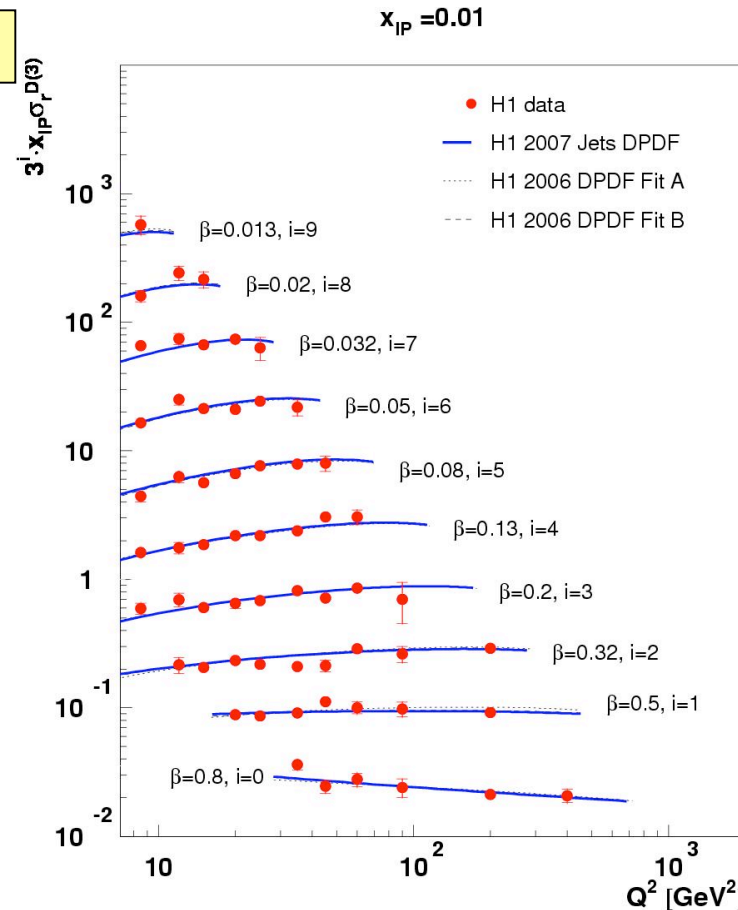
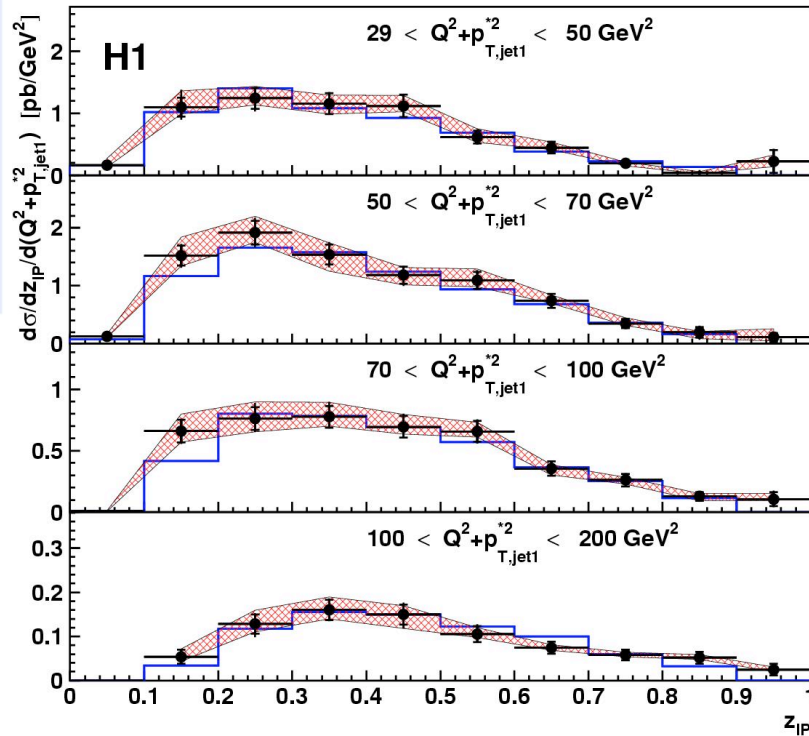
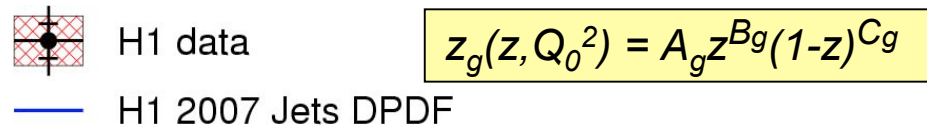
Factorisation in DIS



- Compare the dijet data to Fit A and Fit B for low $z_{IP} < 0.4$ where gluon is well constrained
- Good, detailed agreement between data and predictions
- **Factorisation holds in DIS**
- For more on factorisation in photo-production see K. Cerny's talk



Combined fit of dijet and inclusive data



- 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

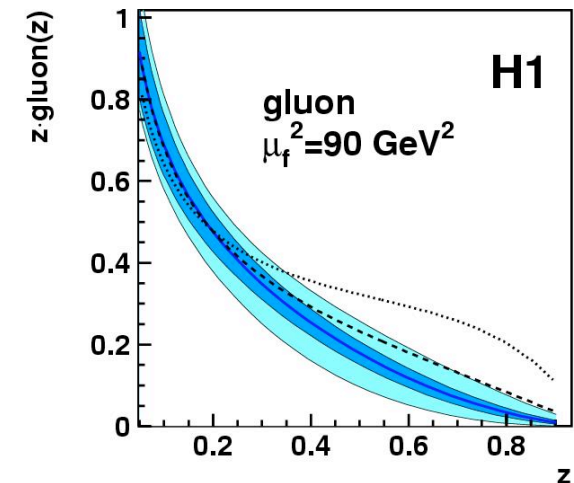
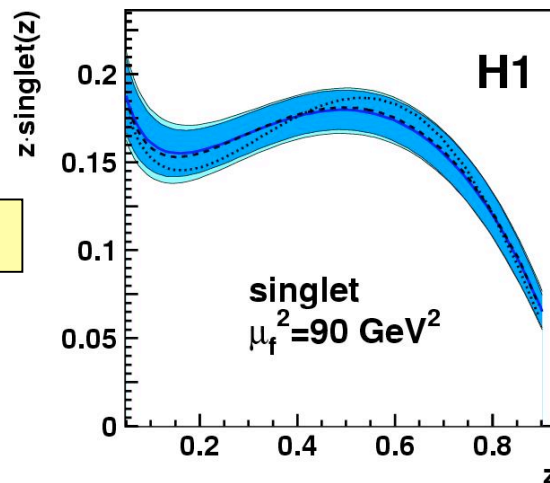
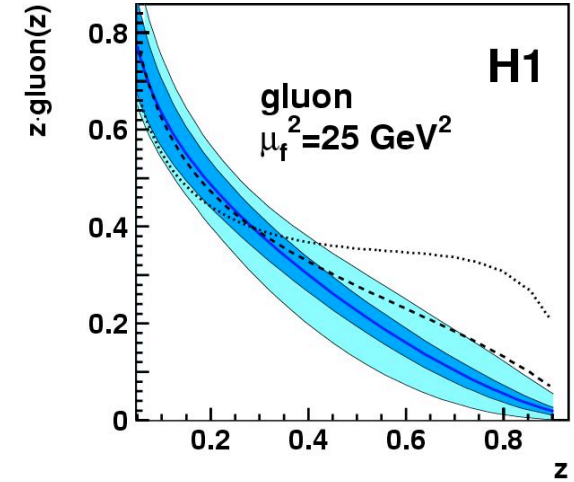
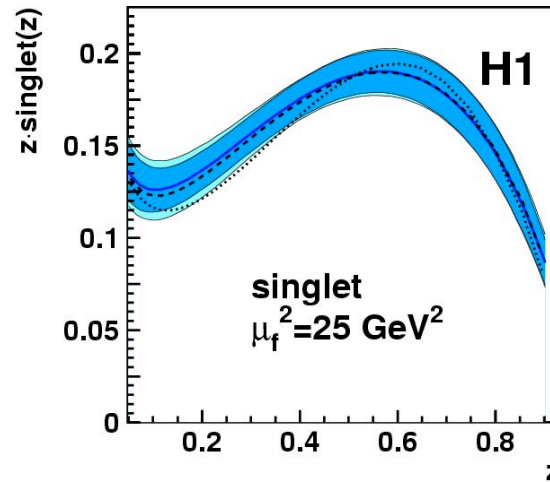
Singlet: $z\Sigma(z, Q_0^2) = A_q z^{B_q} (1-z)^{C_q}$

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



Summary

- A wealth of data from H1 using FPS and LRG methods - no time to show it all!
- DPDFs from NLO QCD fits to β , Q^2 dependences of inclusive data
 - (H1 2006 DPDF Fits A+B)
 - Quark singlet very well constrained ($\sim 5\%$)
 - Gluon constrained to $\sim 15\%$, but poorly known at high z
- Diffractive dijet data agree well with predictions of fits to inclusive data
- Combined fit to inclusive and dijet data constrains both the quark and gluon PDFs to similar good precision

H1 2007 Jets DPDF are our best knowledge of the diffractive partons

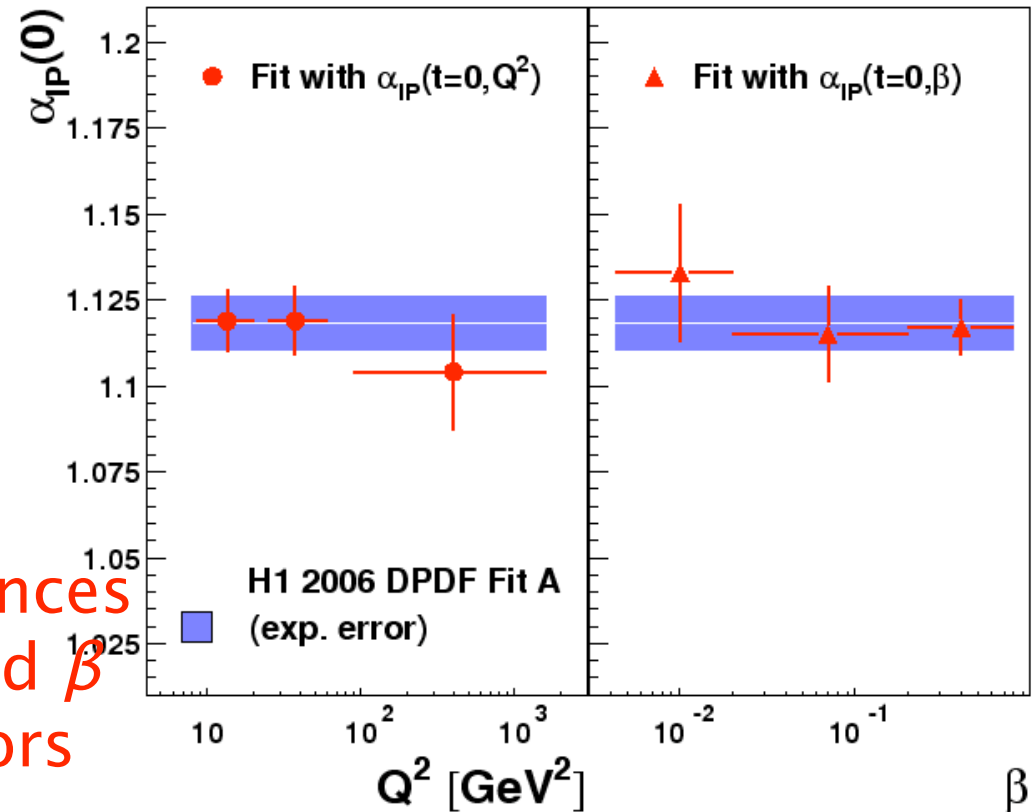


BACK-UP SLIDES FOLLOW

Effective Pomeron Intercept Independent of β and Q^2

From fit to LRG data: $\alpha_{IP}(0) = 1.118 \pm 0.008$ (exp.) $^{+0.029}_{-0.010}$ (theory)

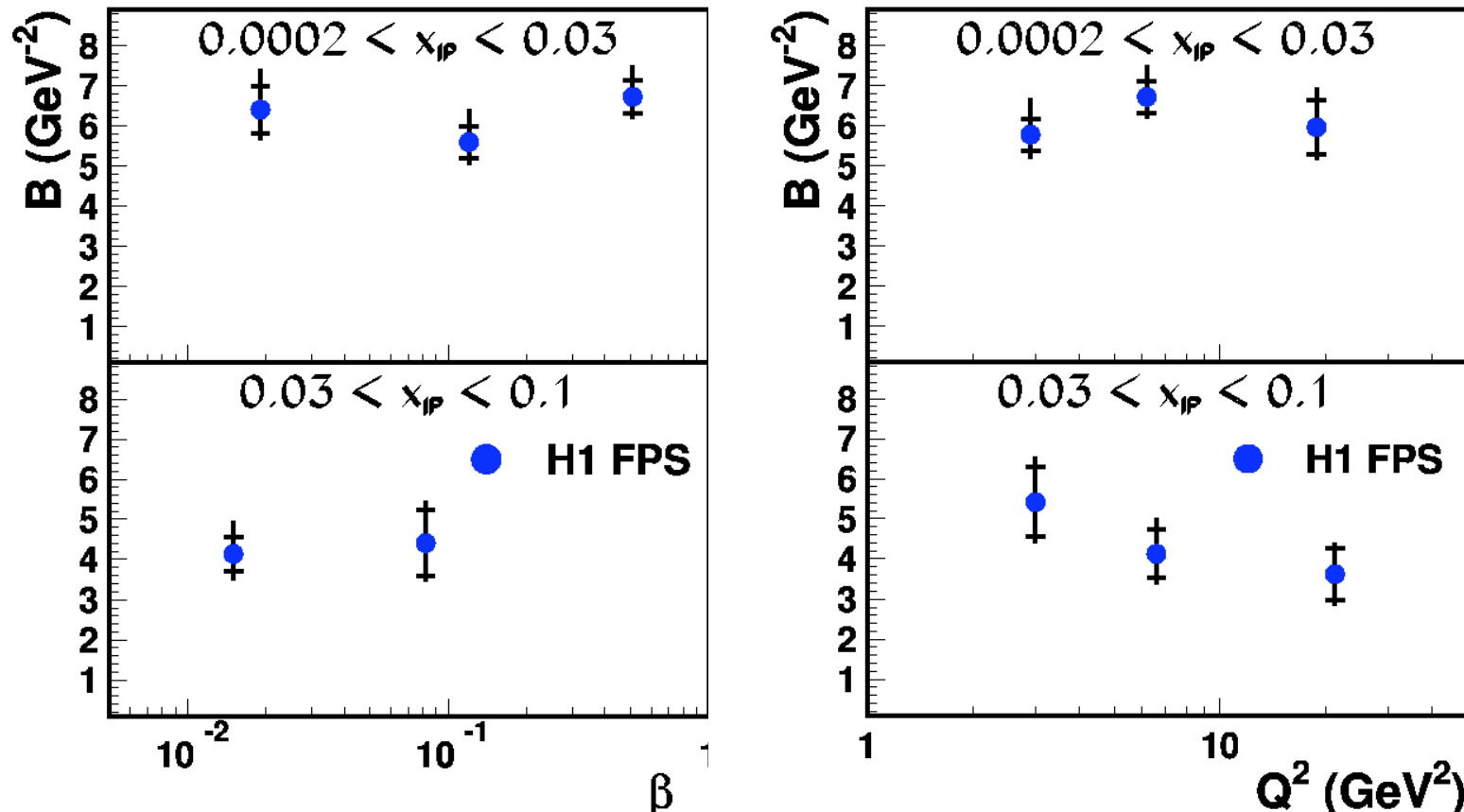
- No dependence of $\alpha_{IP}(0)$ on Q^2 or β
- The x_{IP} dependence also factorises from Q^2 and β
- x_{IP} , t and M_Y dependences factorise from the Q^2 and β dependences within errors



→ Data support Proton Vertex Factorisation

t Slope Dependence on β or Q^2 ?

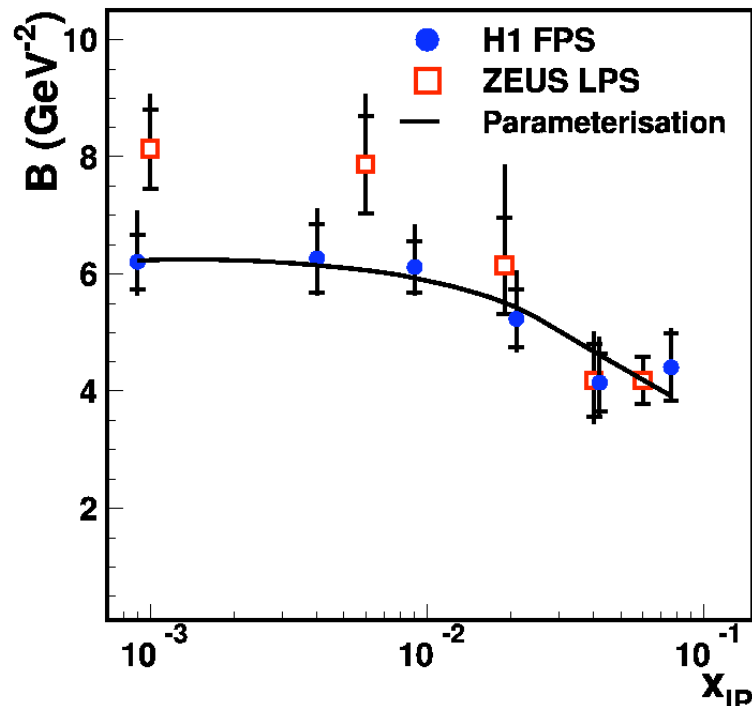
B measured double differentially in (β or Q^2) at fixed x_{IP}



- t dependence does not change with β or Q^2 at fixed x_{IP}

t dependence from FPS measurements

$B(x_{IP})$ from fit to $\frac{d\sigma}{dt} \sim \exp B|t|$



• Fitting low x_{IP} data to

$$B = B_{IP} + 2\alpha'_{IP} \ln(1/x_{IP})$$

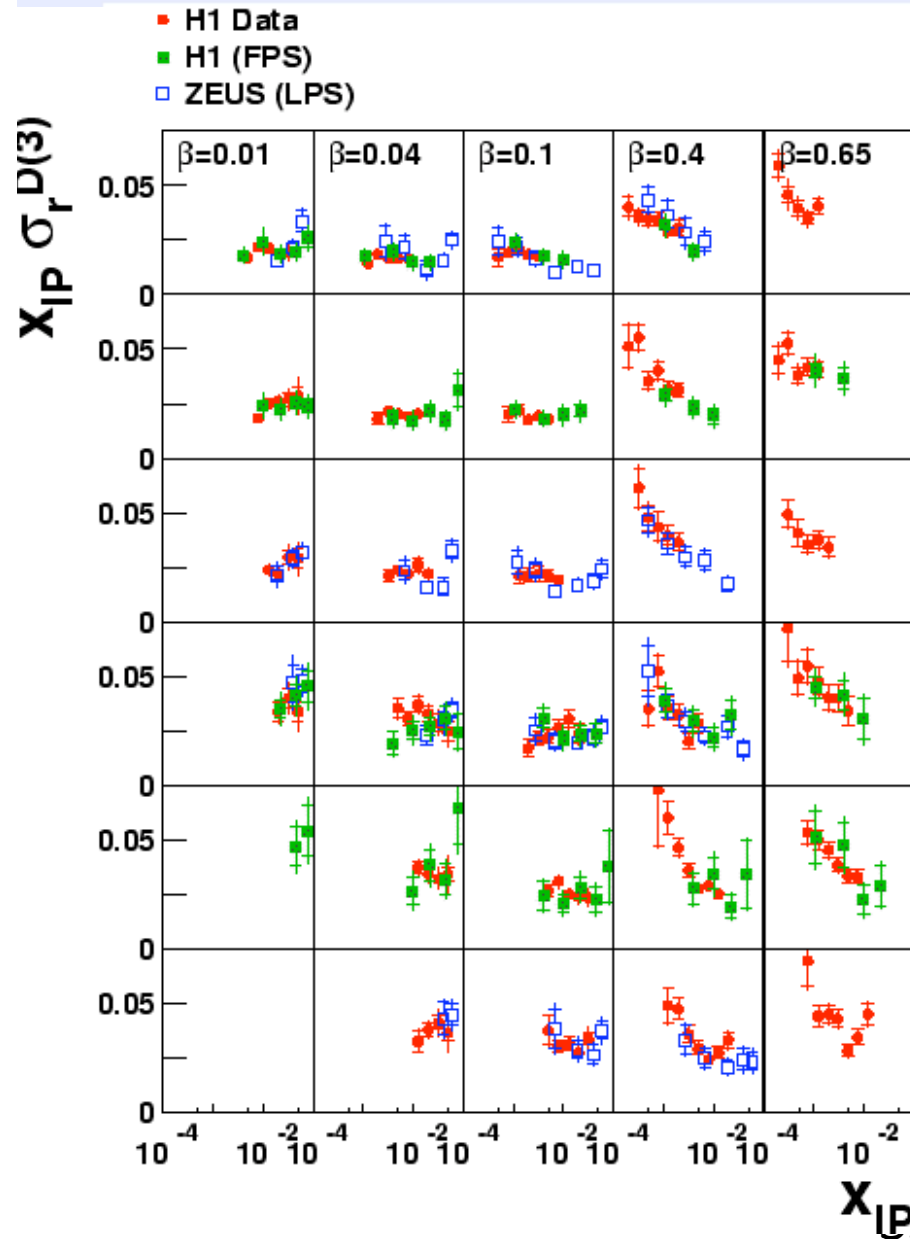
yields:

$$\alpha'_{IP} = 0.06^{+0.19}_{-0.06} \text{ GeV}^{-2}$$

$$B_{IP} = 5.5^{+2.0}_{-0.7} \text{ GeV}^{-2}$$

- $B(x_{IP})$ data constrain IP , IR flux factors in proton vertex factorisation model

Comparison of H1 LRG, H1 FPS, ZEUS LPS Data

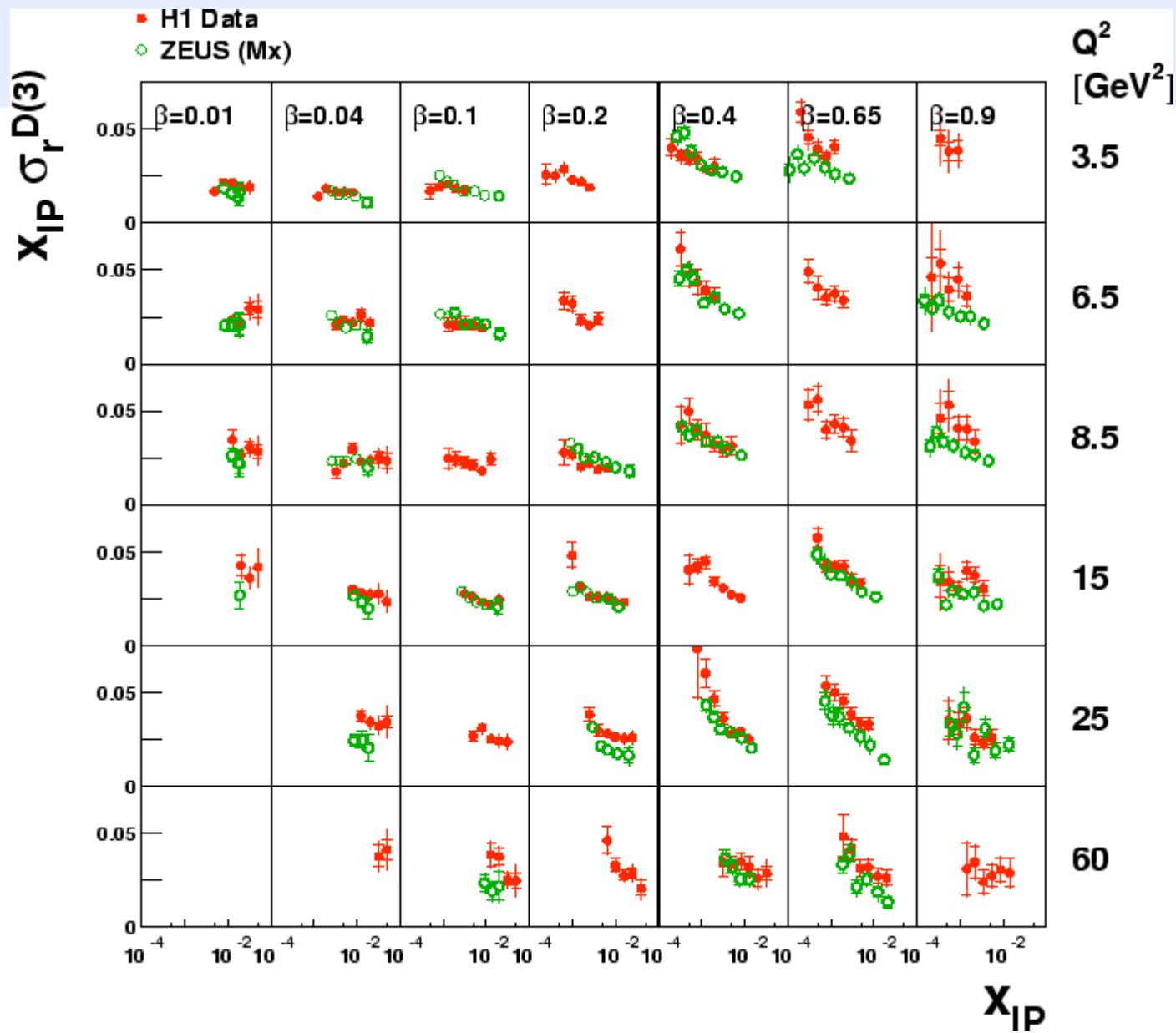


• **ZEUS (LPS)** and **H1 (FPS)**
 Leading Proton Data agree very well
 (they agree to 8% cf. 10%
 normalisation uncertainties)

• **ZEUS LPS** and **H1 FPS**
 scaled by global factor of 1.23 to
 compare with **LRG** $M_Y < 1.6$ GeV

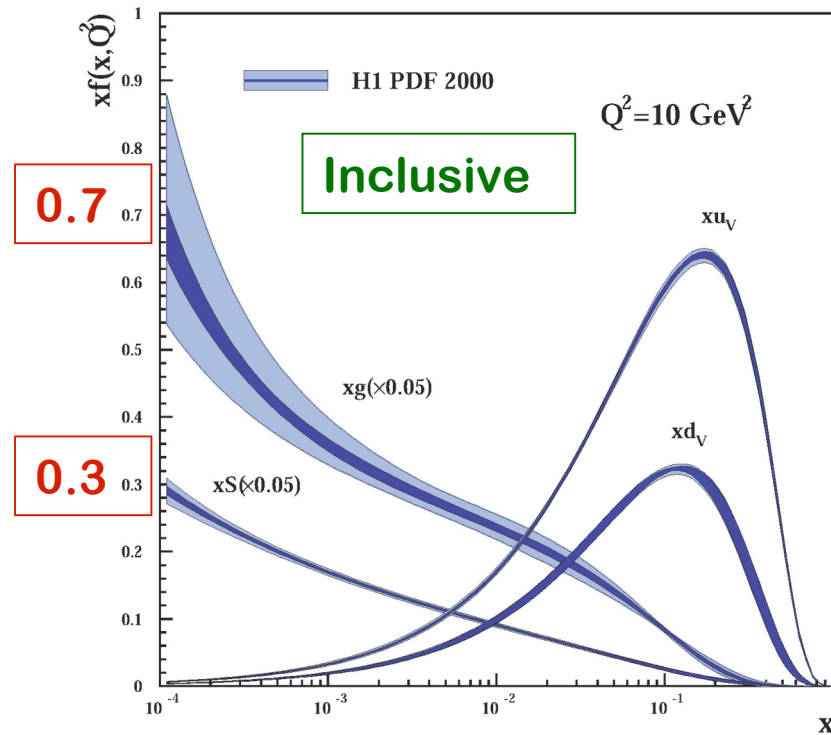
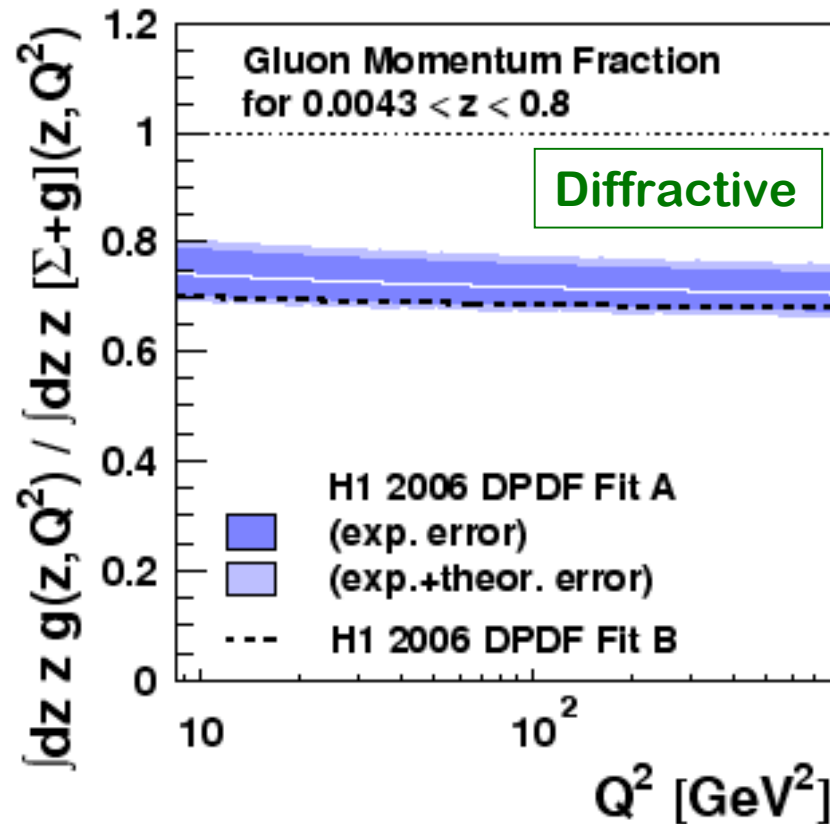
• Very good agreement between
 Leading Proton and LRG methods
 after accounting for proton diss'n

• Both experimental techniques
 measure the same cross section



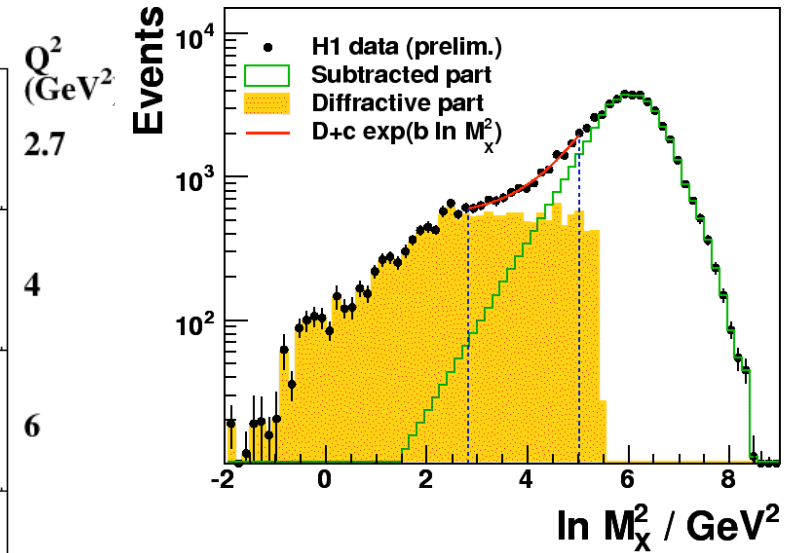
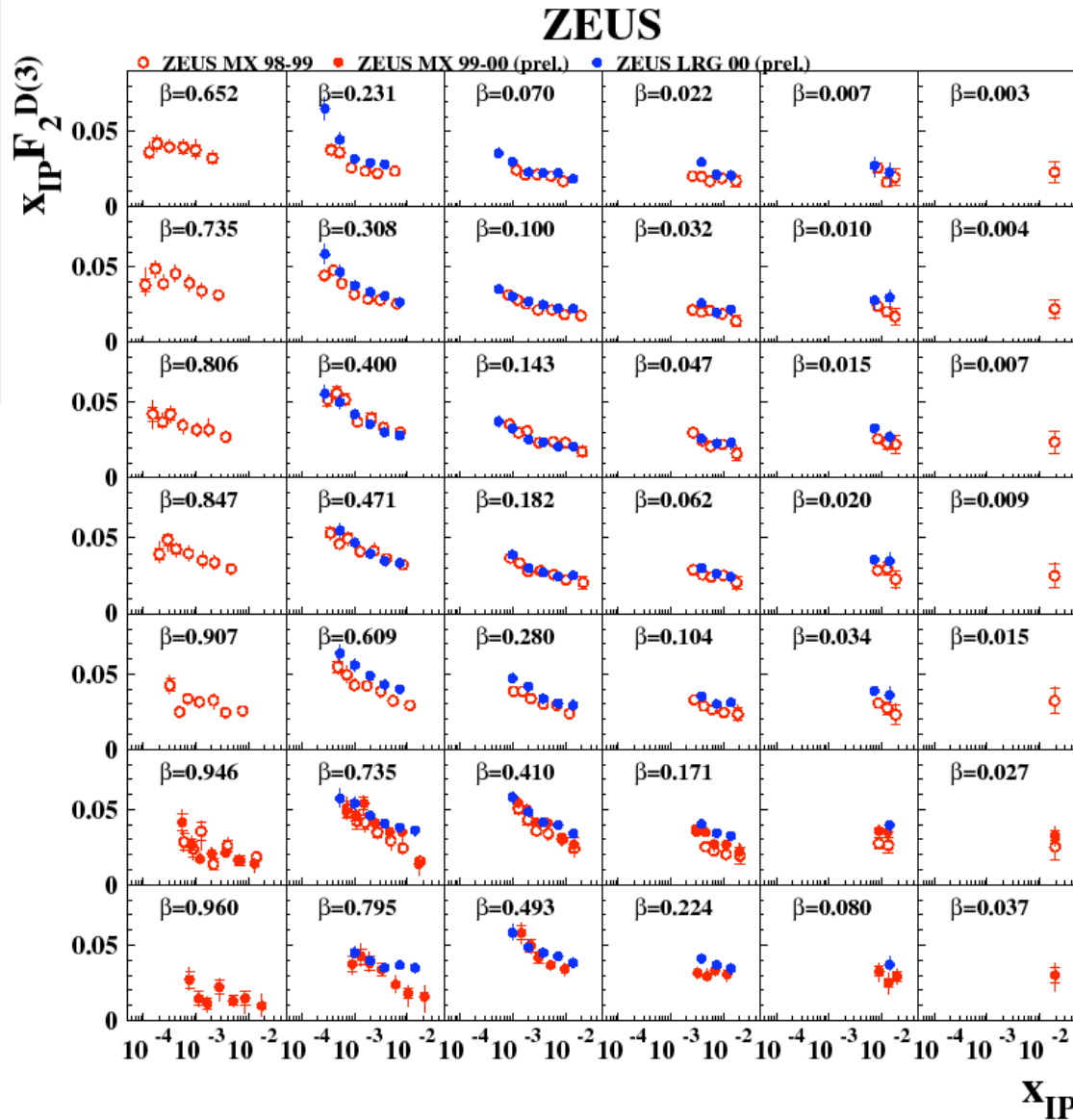
Q^2 derivative and gluon/quark ratios

$$\text{If } \frac{d(\sigma_r^D / \sigma_r)}{d \ln Q^2} \sim 0 \text{ then } \frac{1}{\sigma_r^D} \frac{d\sigma_r^D}{d \ln Q^2} \approx \frac{1}{\sigma_r} \frac{d\sigma_r}{d \ln Q^2} \rightarrow \frac{g^D}{q^D} \sim \frac{g}{q}$$



At low x , gluon:quark ratio $\sim 70\%/30\%$, common to diffractive and inclusive

Latest Zeus results – M_X and LRG



Zeus and H1 both comparing LRG and M_X methods

Shown here – Zeus LRG (blue) and Zeus M_X (red)

Reasonable agreement but ongoing work to understand the differences

A wealth of precision data to add to future diffractive PDFs

H1 Inclusive Data Overview

LRG: $M_Y < 1.6 \text{ GeV}$ \longrightarrow

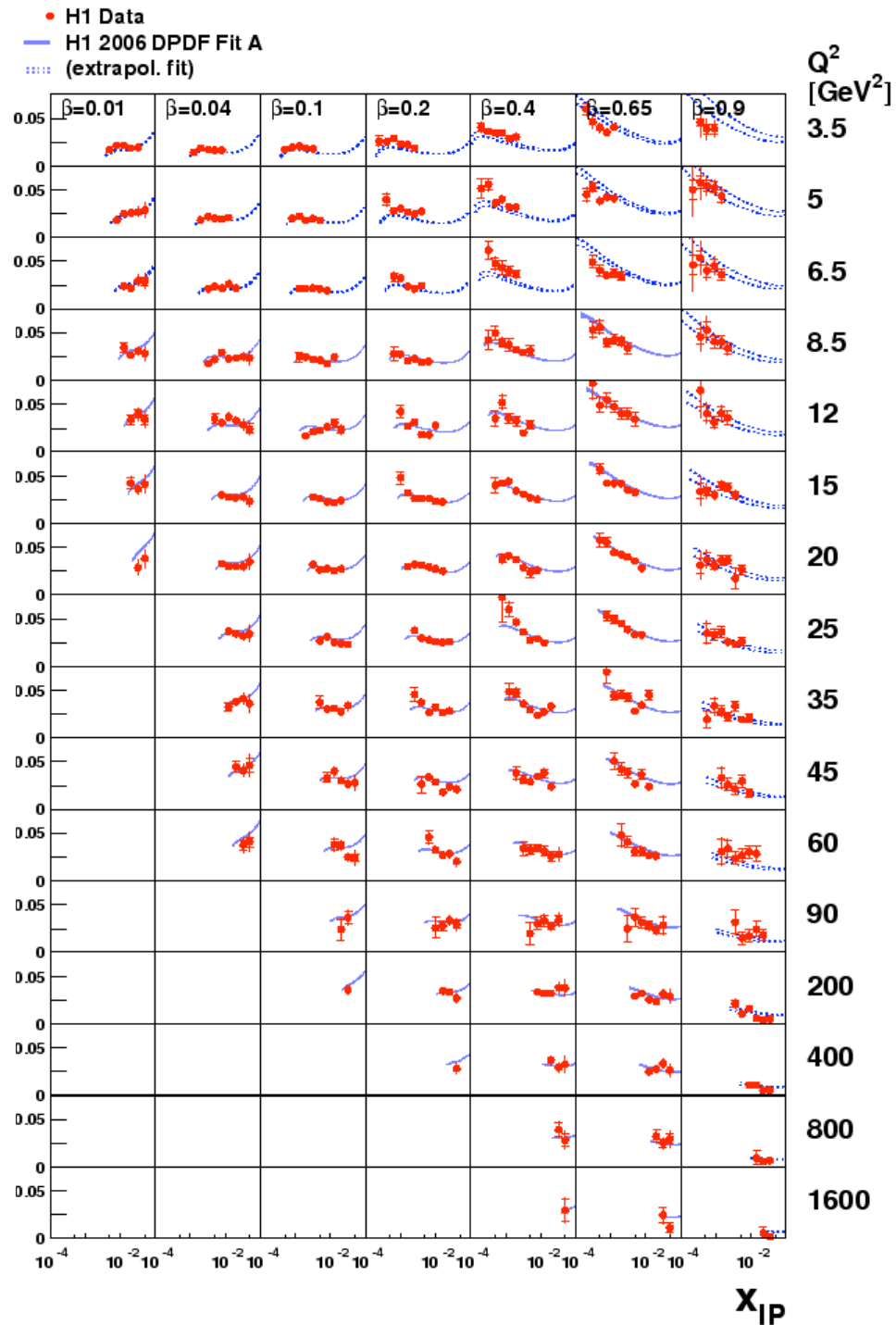
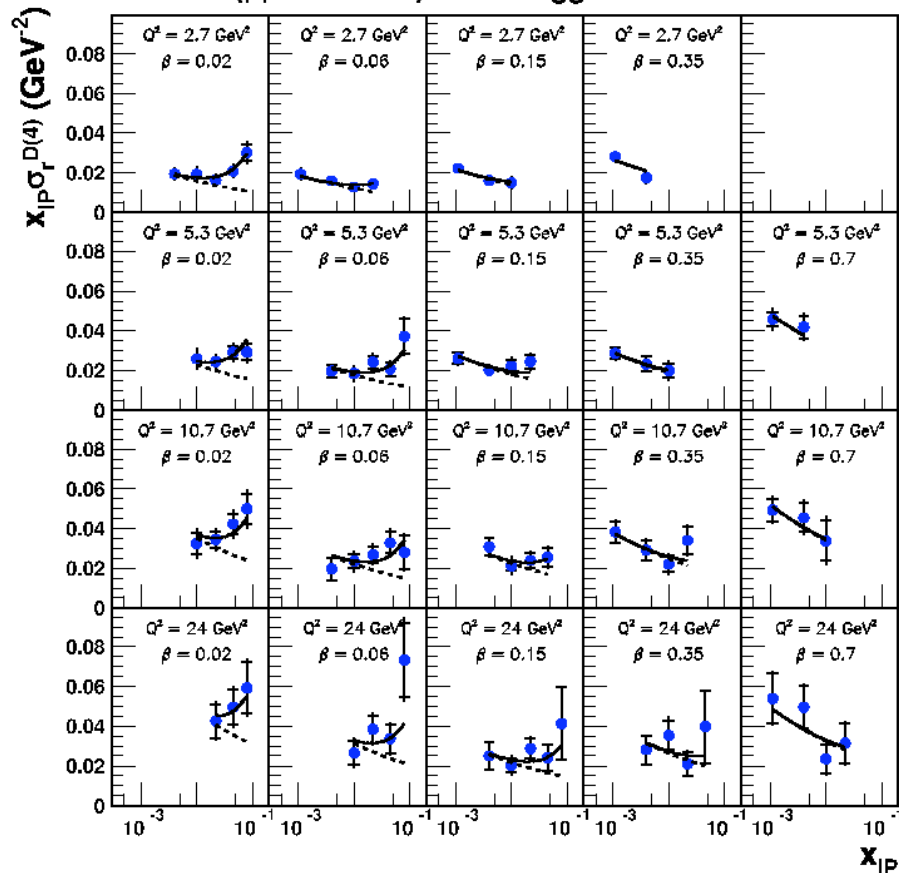
$$3.5 \leq Q^2 \leq 1600 \text{ GeV}^2$$

FPS: $Y=p$

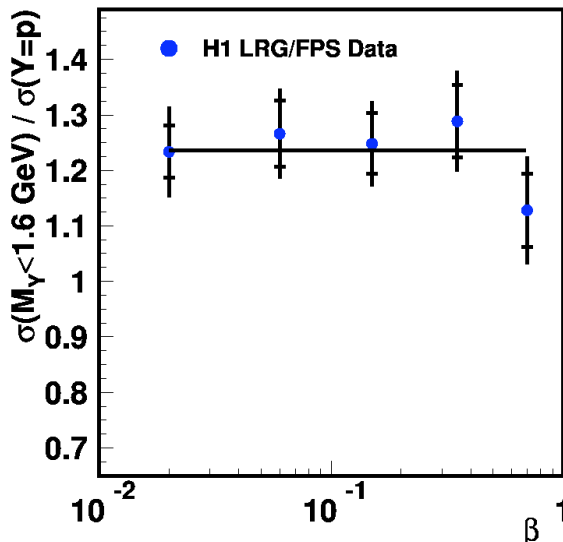
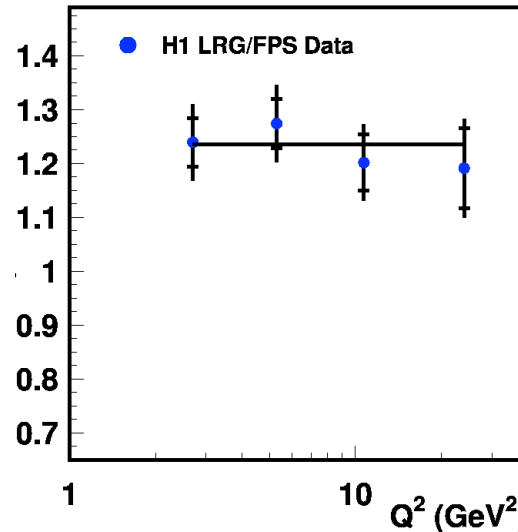
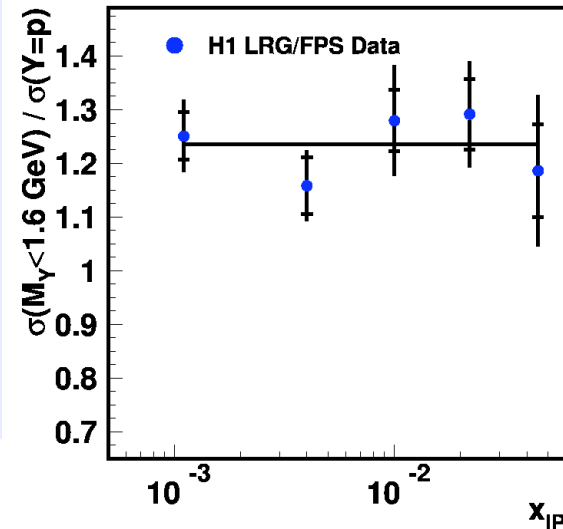
$$2.7 \leq Q^2 \leq 24 \text{ GeV}^2$$

$x_{IP} \sigma_r^{D(3)}$

• H1 FPS ($|t|=0.25 \text{ GeV}^2$) — Regge fit IP+IR IP only



Detailed Comparison LRG v FPS



• LRG measurement also done with FPS bins

• Form ratio of measurements as a function of x_{IP} , β and Q^2

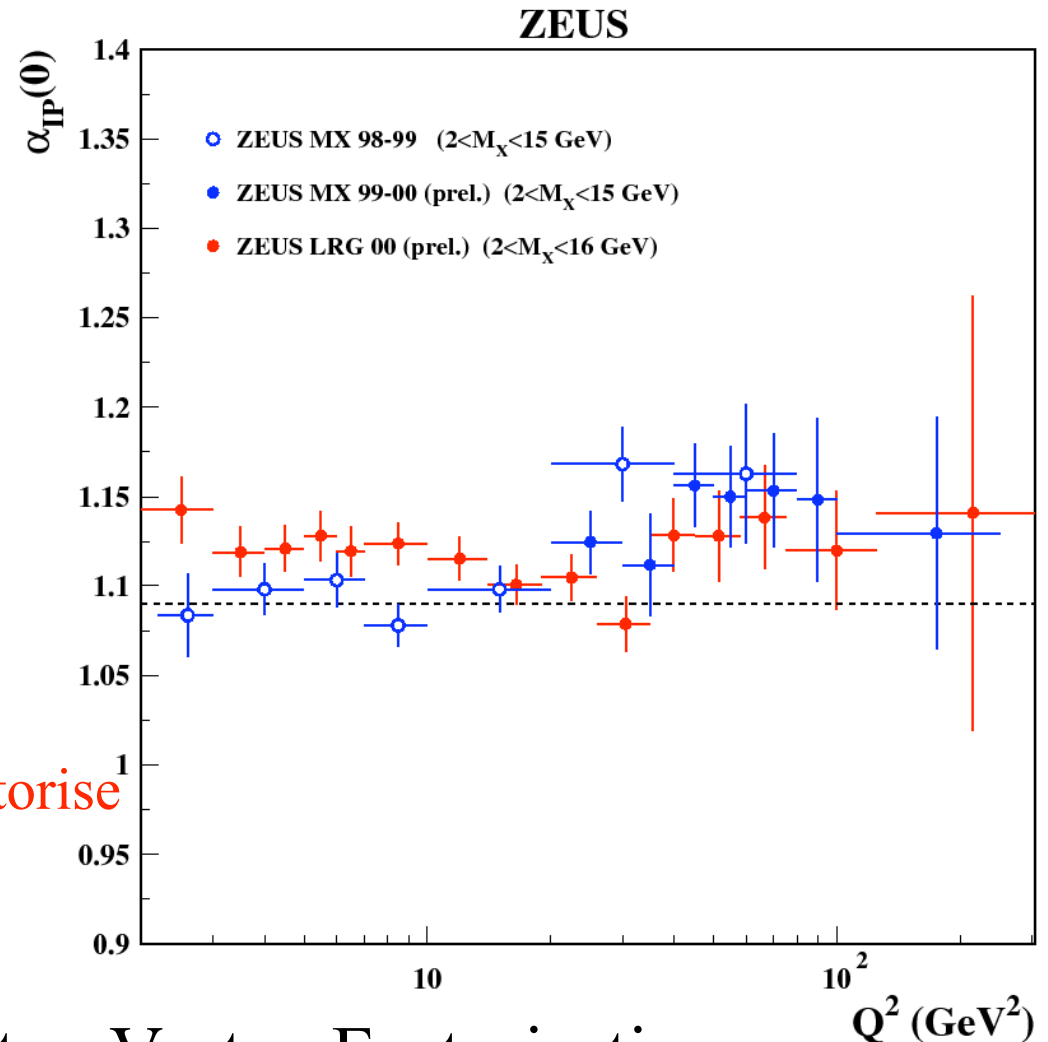
$$\frac{\sigma(M_Y < 1.6 \text{ GeV})}{\sigma(Y = p)} = 1.23 \pm 0.03 \text{ (stat.)} \pm 0.16 \text{ (syst.)}$$

M_Y dependence factorises from x_{IP} , β and Q^2 within 10% (non-normalisation) errors

Effective Pomeron Intercept Independent of β and Q^2

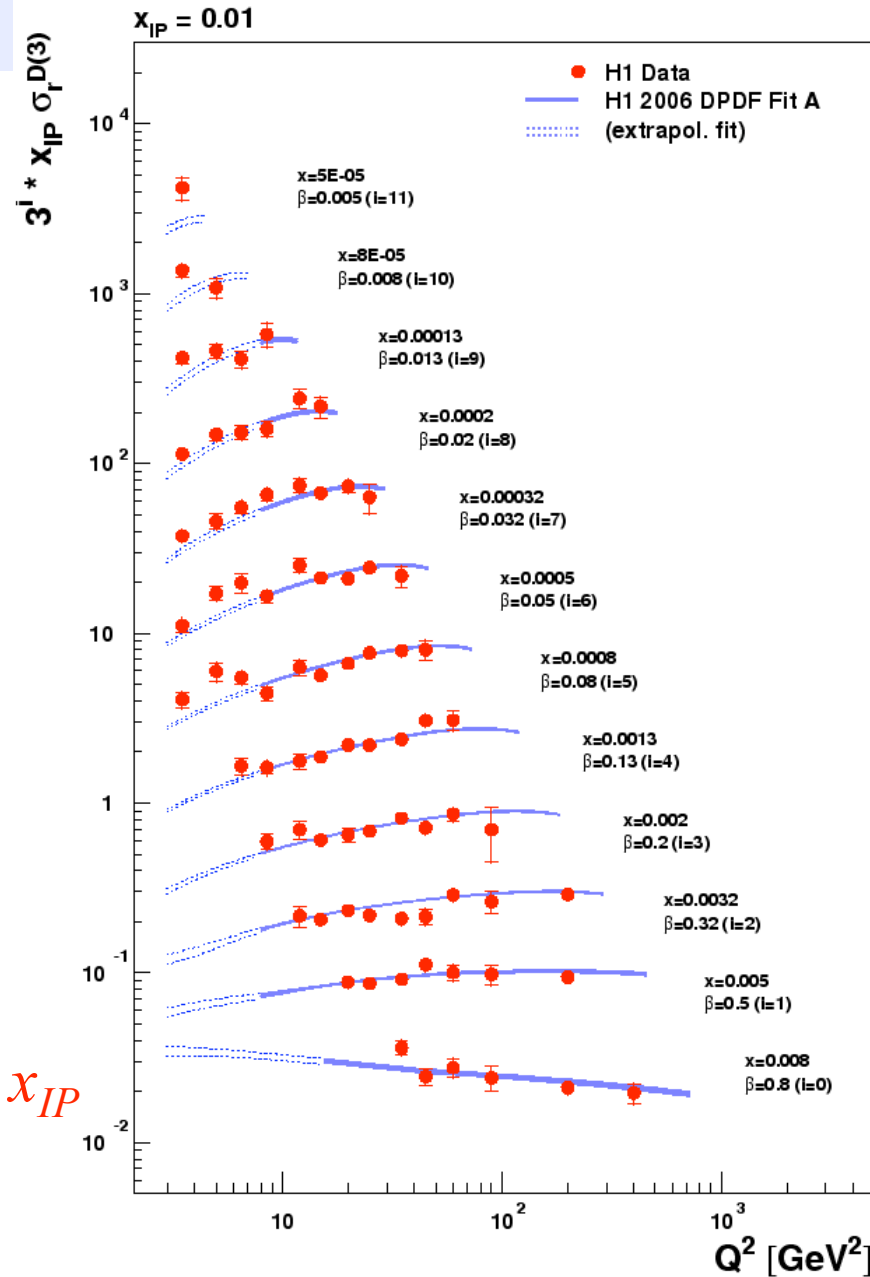
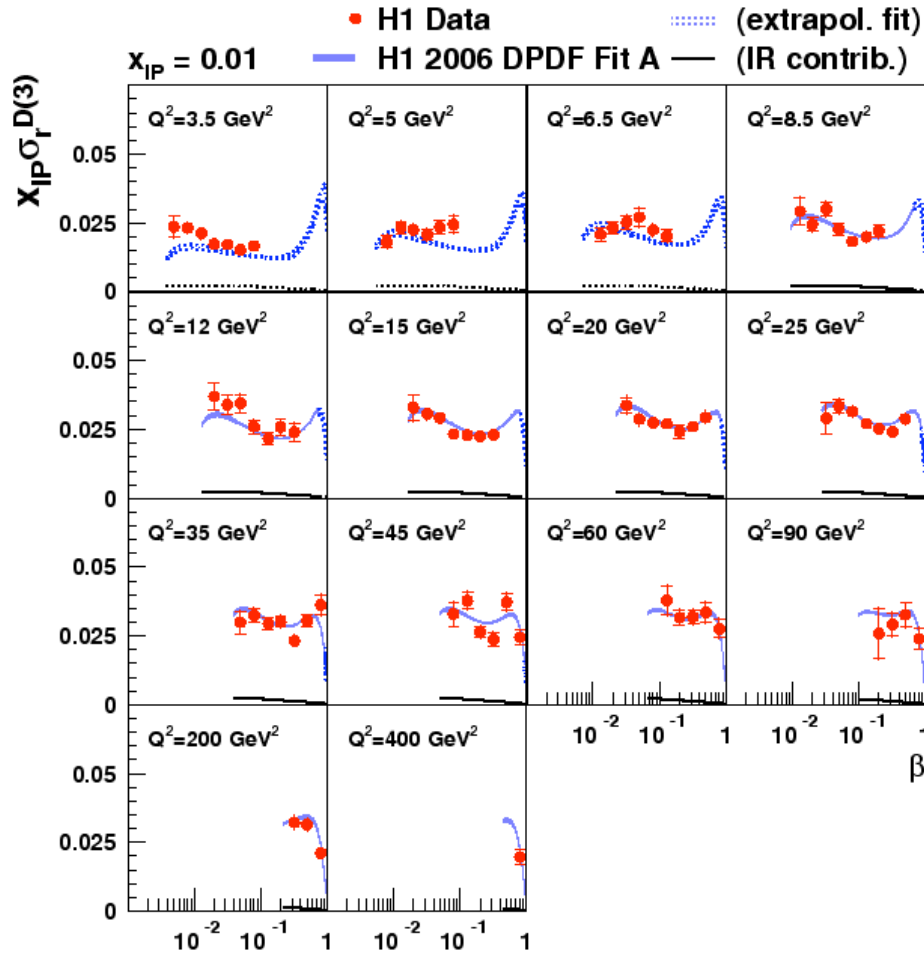
From fits to LRG and M_X data, *with current experimental precision:*

- Data compatible with no dependence of $\alpha_{IP}(0)$ on Q^2 (Zeus and H1) or β (H1)
- The x_{IP} dependence also factorises from Q^2 and β
- x_{IP} , t and M_Y dependences factorise from the Q^2 and β dependences within errors



→ Data support Proton Vertex Factorisation

$$\sigma_r^{D(3)}(\beta, Q^2, x_{IP}) \text{ at } x_{IP} = 0.01$$



Study β and Q^2 dependences at fixed x_{IP}
 Analogous to making an inclusive F_2
 measurement at each value of x_{IP}

Q^2 Dependence in More Detail

Fit data at fixed x , x_{IP} to

$$\sigma_r^D = A + B \ln Q^2$$

such that

$$B = \frac{d\sigma_r^D}{d \ln Q^2}$$

Divide results by $f_{IP/p}(x_{IP})$
to compare different x_{IP} values

Different x_{IP} measurements agree

Derivatives large and positive... suggests large gluon

