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# Diffraction at HERA

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On behalf of the H1 and ZEUS collaborations

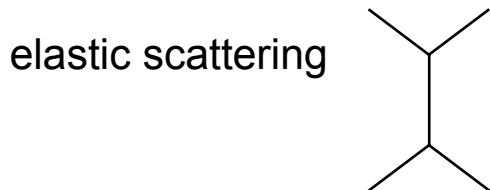


# Content

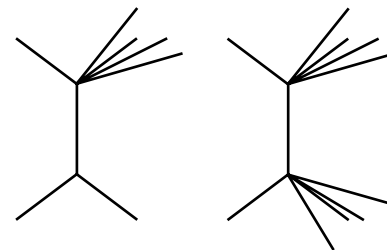
1. Introduction : diffraction and QCD at HERA
2. Inclusive diffraction measurements
3. Diffractive parton distribution functions (dpdf)
4. Semi-inclusive diffraction and comparison with dpdf
  - jets
  - charm
5. Exclusive production
  - vector mesons: rho photoproduction - BFKL
  - DVCS -GPD

# Diffraction

## Hadronic interactions



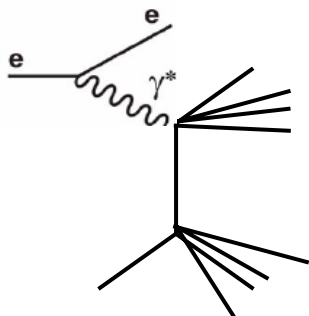
diffractive dissociation  
(differential absorption  
of hadronic components)



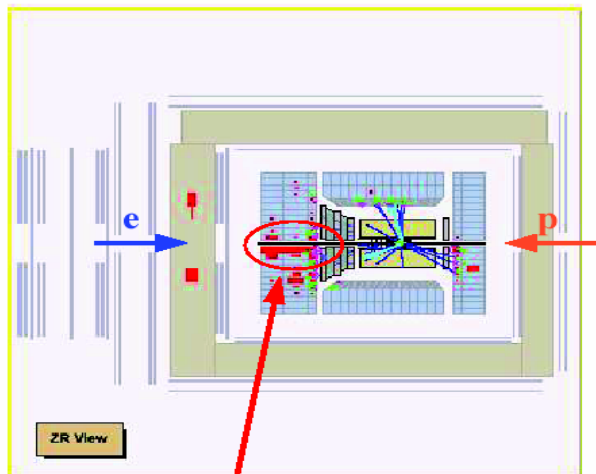
high energy  $\sigma(h-h) \propto s^{\alpha_{IP}(0)-1}$   $\alpha_{IP}(0) \approx 1.08$  *soft pomeron* - unitarity !

## HERA

some 10% of cross section  
in electroproduction !

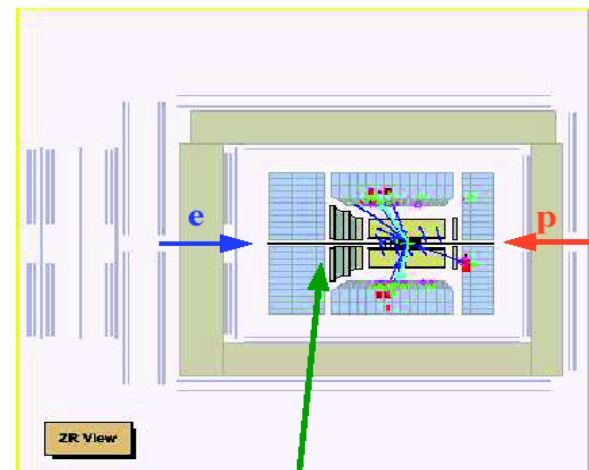


### NON-DIFFRACTIVE



The proton breaks up  
Activity in the forward direction

### DIFFRACTIVE



A colourless object is exchanged  
No activity in a large rapidity range

# Diffraction at HERA and QCD

**Hard scales** :  $Q^2$ , large  $p_t$  (jets), large quark mass (charm), large  $t$

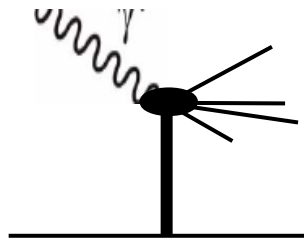
→ QCD analyses

challenge : quark and gluon understanding of diffraction, unitarity mechanisms, etc.

## ✓ pomeron structure

diffractive parton densities

factorisation theorem

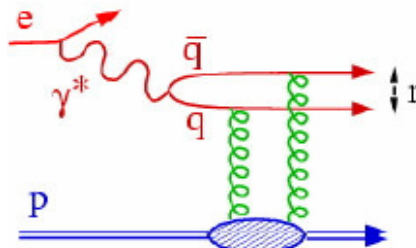


## ✓ colour dipole

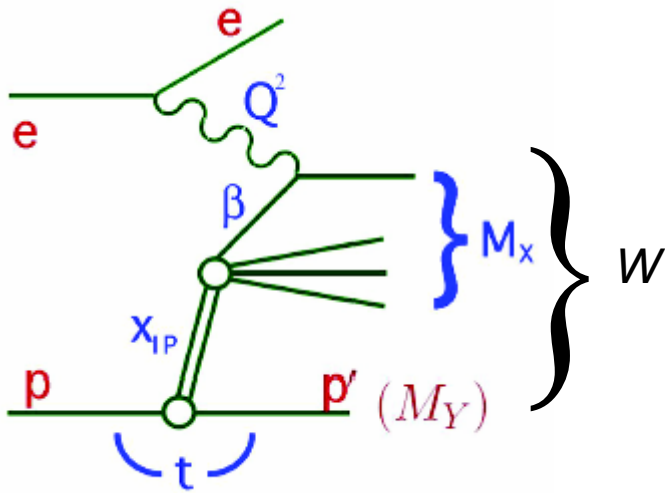
dipole – proton cross section

lowest order = 2 gluon exchange

small dipoles in presence of hard scale



# Diffractive variables



$$Q^2 = -q^2$$

$$x_{IP} = (1 - x_L) = \frac{Q^2 + M_X^2}{Q^2 + W^2}$$

$$\beta = \frac{Q^2}{Q^2 + M_X^2} \quad x = \beta x_{IP}$$

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

$$M_Y$$

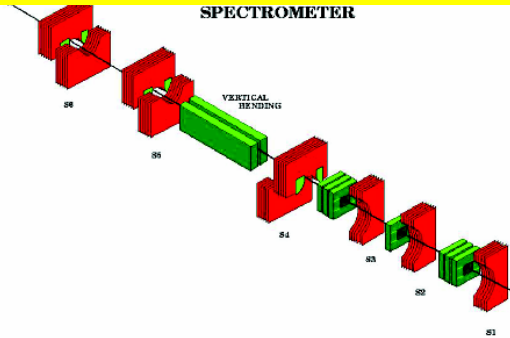
Inclusive cross section

$$\frac{d^5 \sigma^D}{dx_{IP} d\beta dQ^2 dM_Y dt} = \frac{2\pi\alpha_{em}^2}{\beta Q^4} \left(1 - y + \frac{y^2}{2}\right) \sigma_r^{D(5)}(x_{IP}, \beta, Q^2, M_Y, t)$$

# Inclusive diffraction : 3 measurement methods

## 1. Proton spectrometers

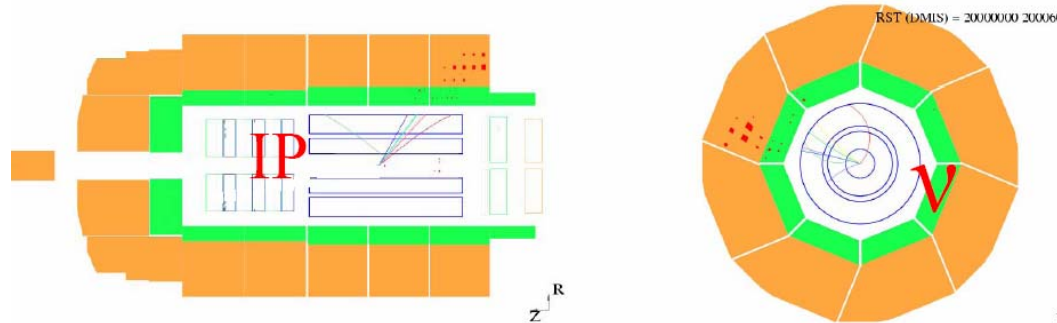
->  $t$  measurement



## 2. Large rapidity gap

NC and CC diffraction

$$e + p \rightarrow \nu + X + p$$



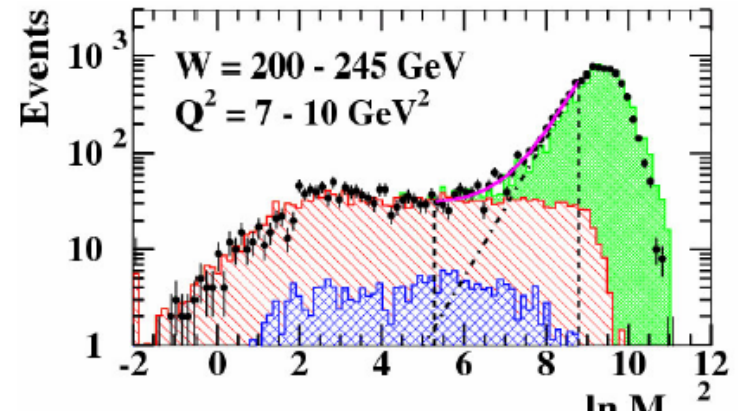
## 3. Non-exponential fall off

of  $\ln M_X^2$  distribution :

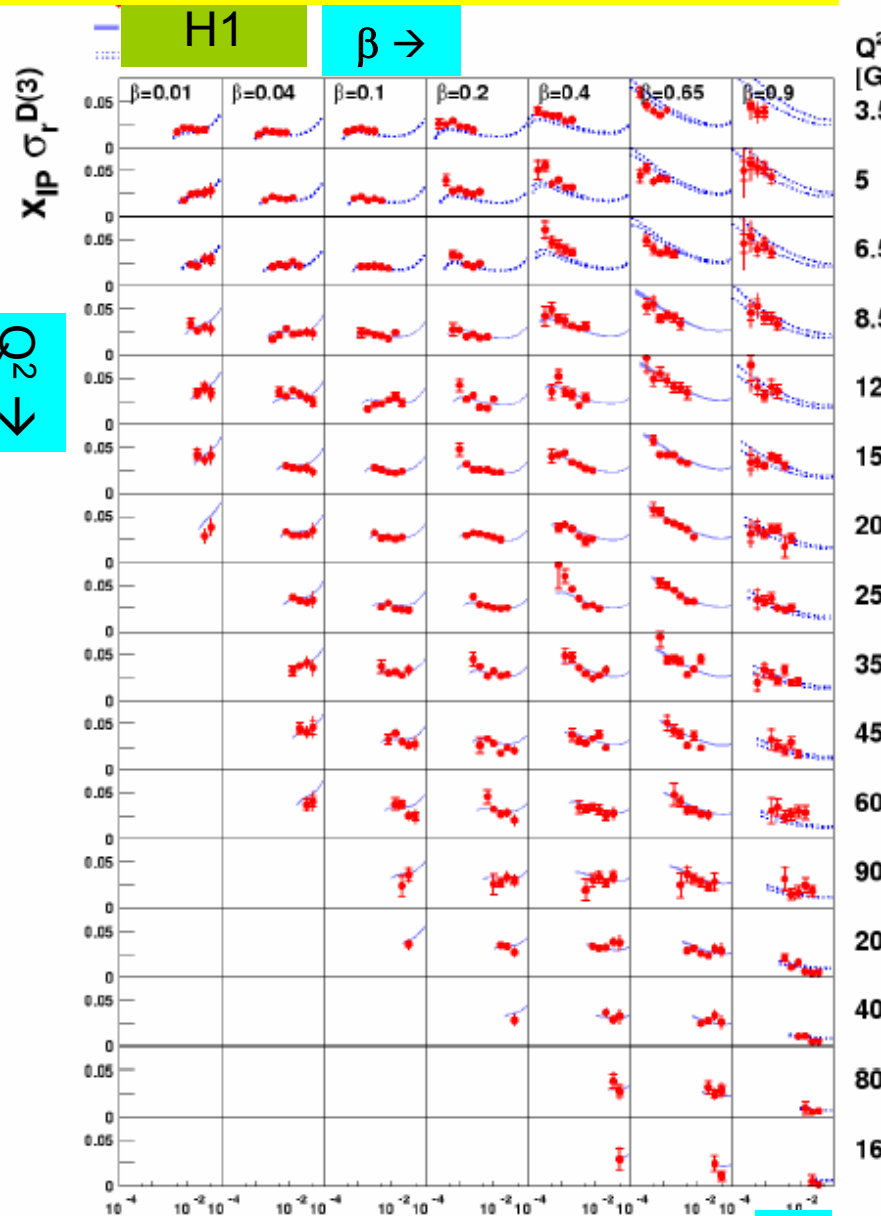
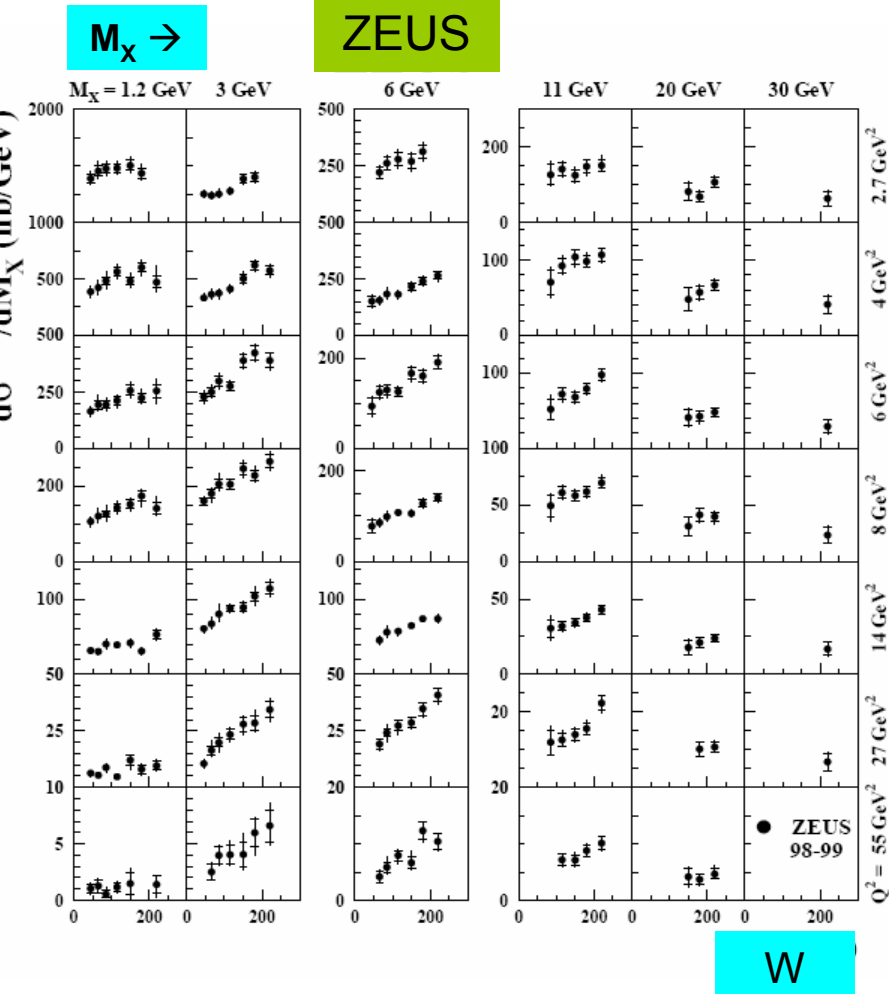
$$\frac{dN}{d \ln M_X^2} \propto D + C e^{B \ln M_X^2}$$

diffr.

non-diffr.



# Cross sections measurements



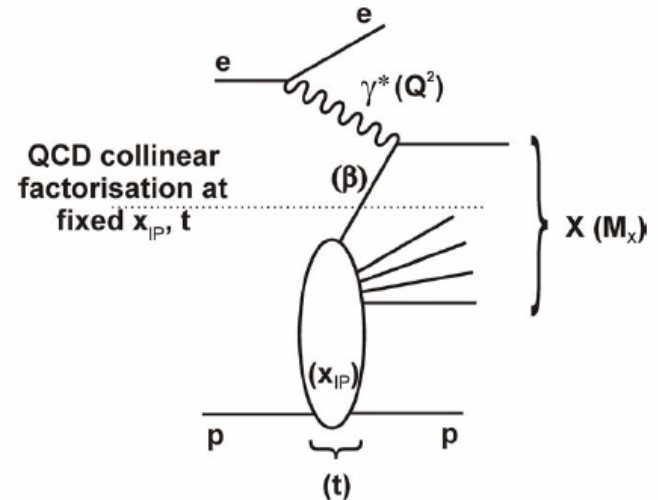
# Factorisation and pdf's

## Collinear factorisation

cf. total ep cross section

$$d\sigma_i(ep \rightarrow eXY) = f_i^D(x, Q^2, x_{IP}, t) \otimes d\hat{\sigma}_{ei}(x, Q^2) \quad (i = q, g)$$

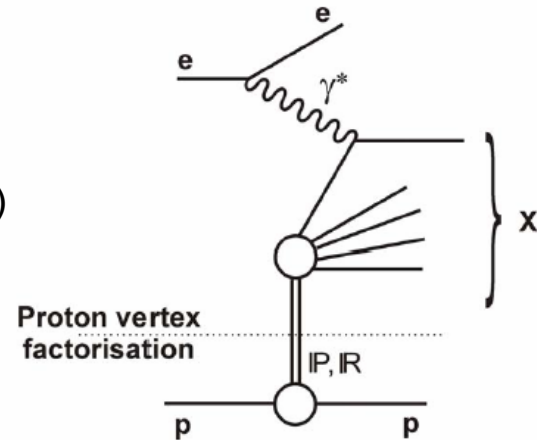
for fixed  $x_{IP}, t (M_Y)$



## Vertex factorisation

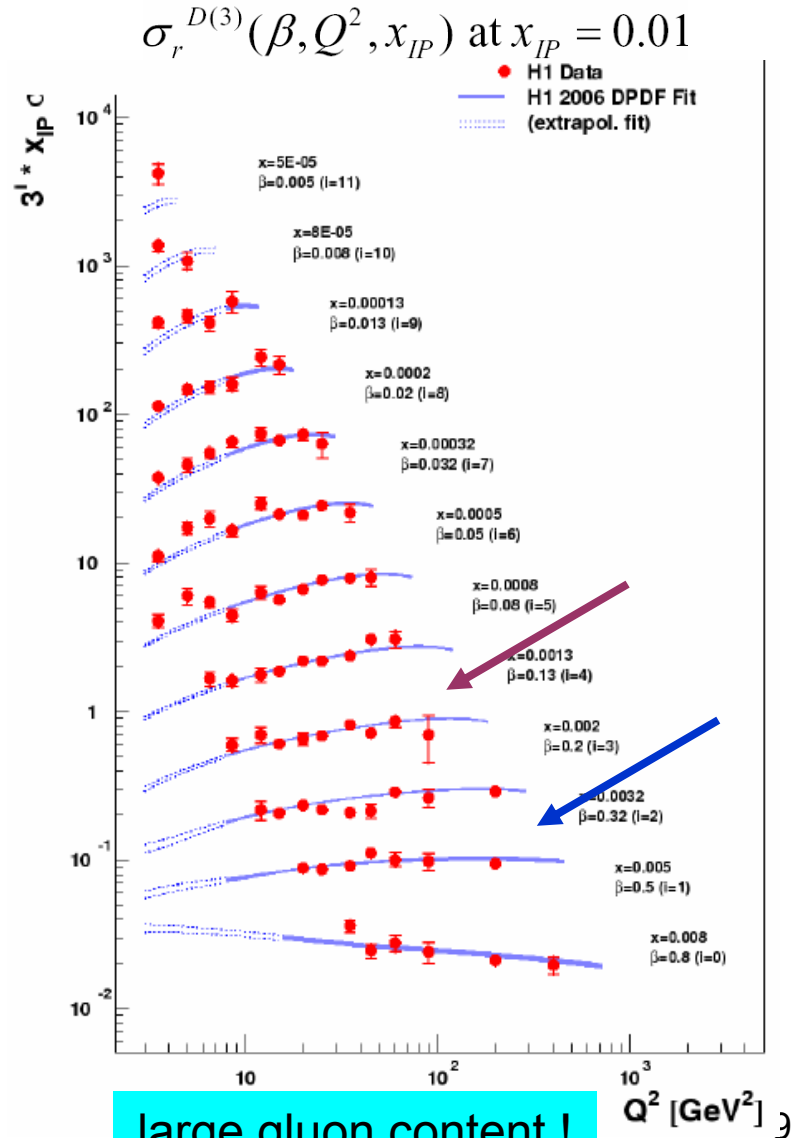
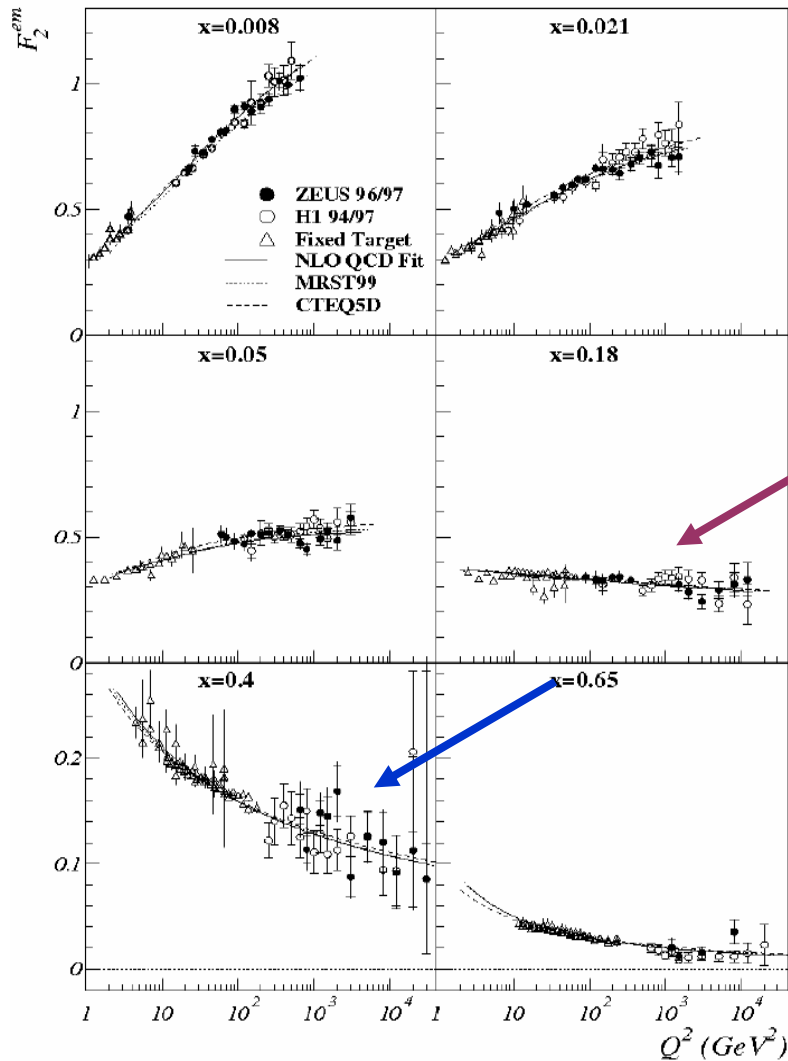
$$f_i^D(x, Q^2, x_{IP}, t) = f_{IP/p}(x_{IP}, t) \cdot f_i^{IP}(\beta, Q^2) \quad (\beta = x / x_{IP})$$

usefull hypothesis (Regge inspired)





# Scaling violations



large gluon content !

# Parton distribution function parameterisations

## • Fit A

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

$$\text{and } zg(z, Q_0^2) = A_g (1-z)^{C_g}$$

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

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

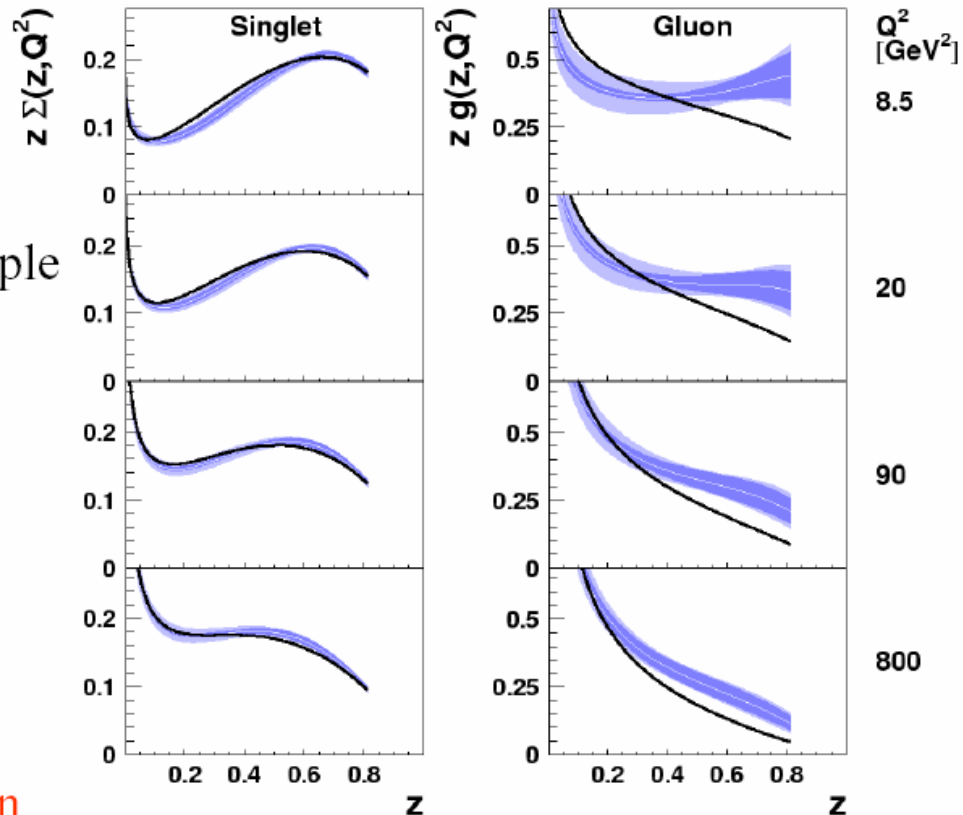
- Lack of sensitivity to high  $z$  gluon confirmed by dropping (high  $z$ )  $C_g$  parameter, so gluon is a simple constant at starting scale!

## • Fit B

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

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

- Quarks very stable
- Gluon similar at low  $z$
- Substantial change to gluon at high  $z$



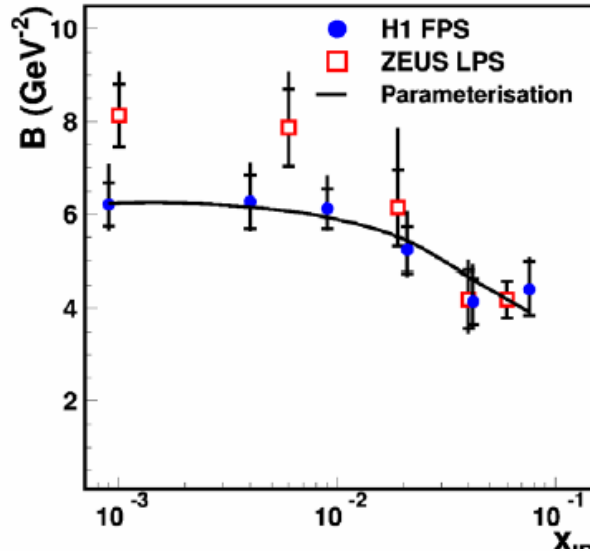
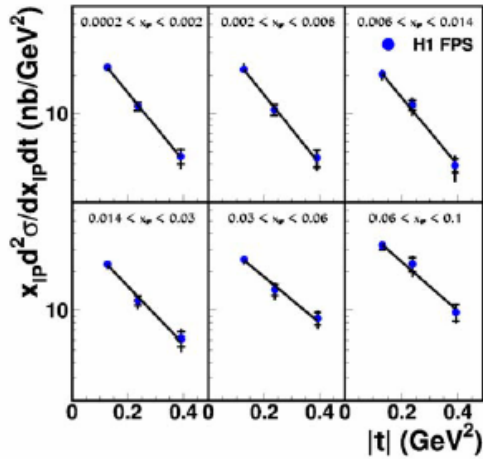
H1

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

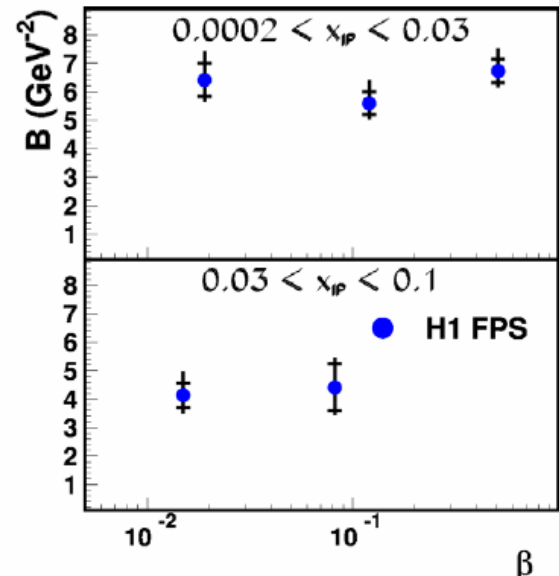
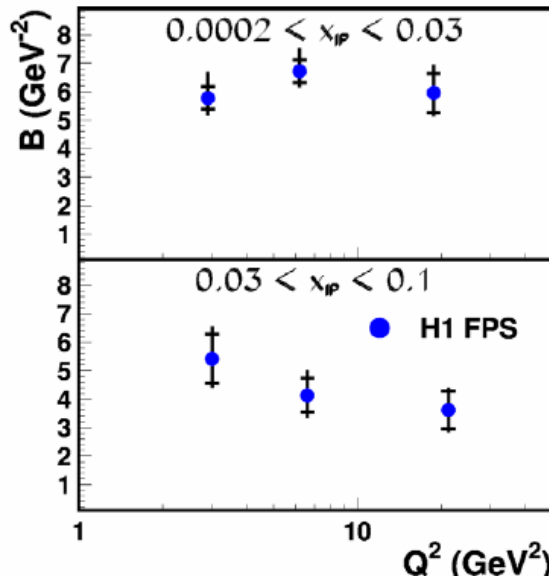
— Fit B

$$F_2^{D(4)}(x_{IP}, \beta, Q^2, t)$$

Fit to  $\exp(Bt)$  in bins of  $x_{IP}$



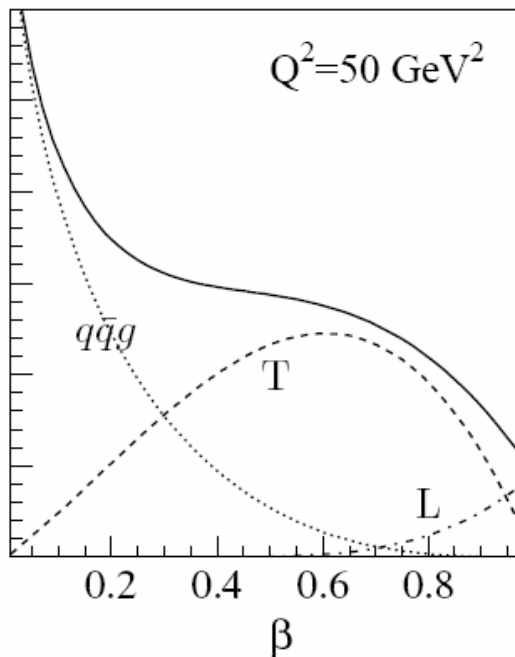
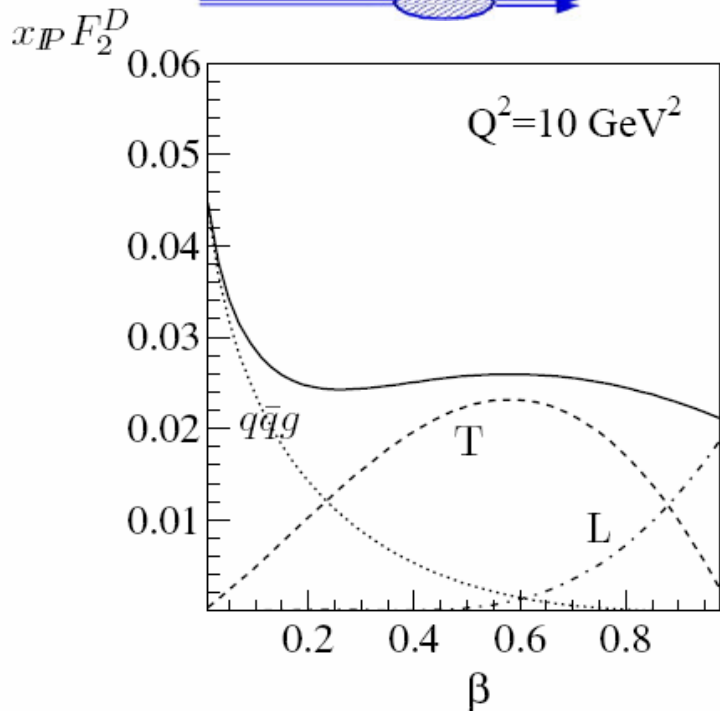
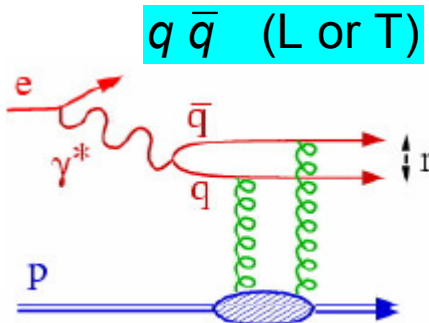
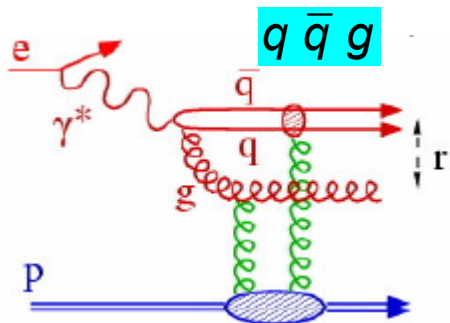
Vertex  
factorisation :



# 2-gluon exchange model

J. Bartels et al., Eur. Phys. J. C7, 443 (1999).

## Colour dipole



$\sim 1/Q^2$   
at large  $\beta$

=> HigherTwist  
behaviour 12

# ZEUS

BEKW(mod):

— Total

⋯ (qq)<sub>T</sub>

⋯ (qq)<sub>L</sub>

⋯ (qqg)<sub>T</sub>

$x_{IP}=0.00015$

$x_{IP}=0.0003$

$x_{IP}=0.0006$

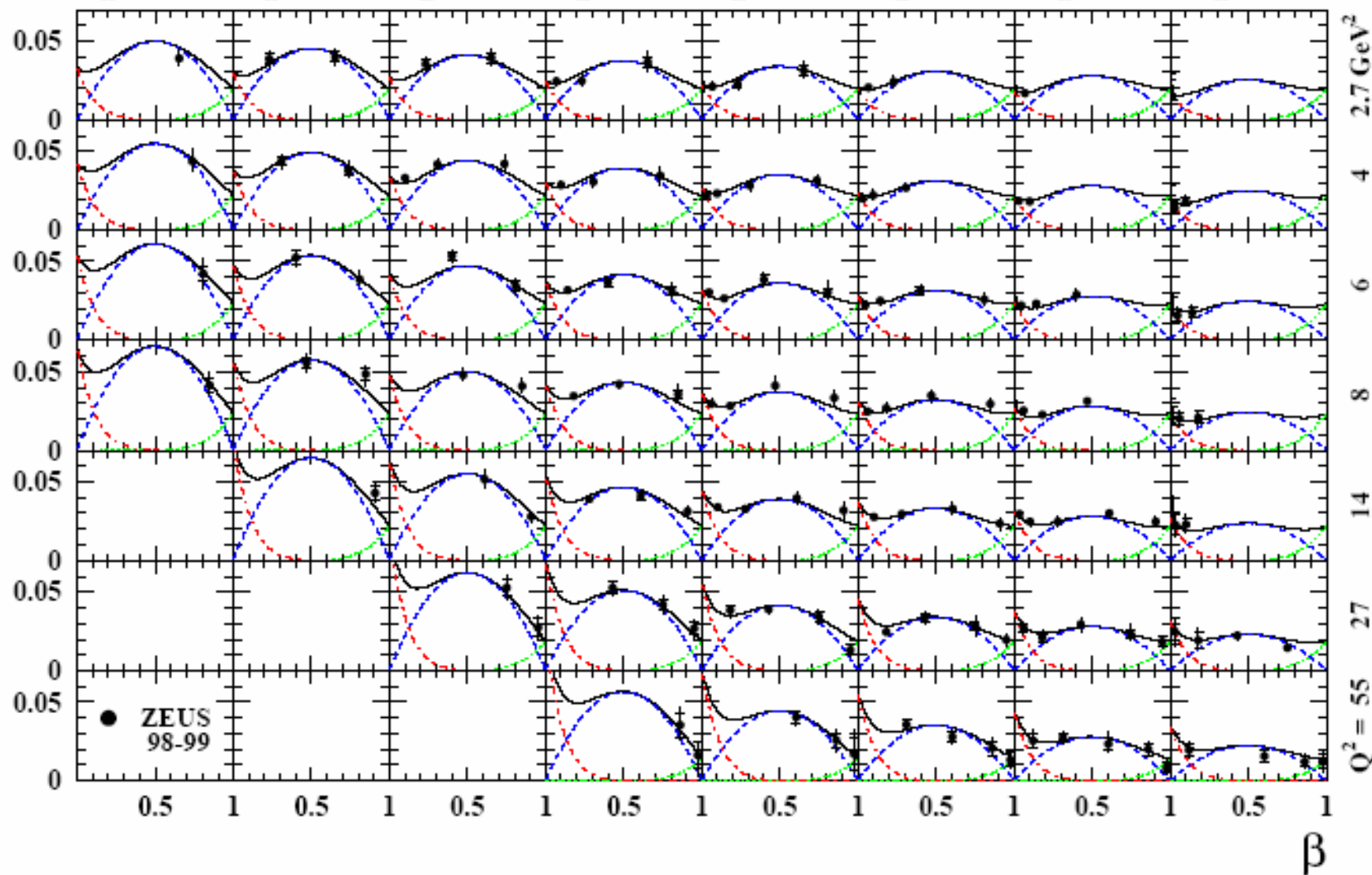
$x_{IP}=0.0012$

$x_{IP}=0.0025$

$x_{IP}=0.005$

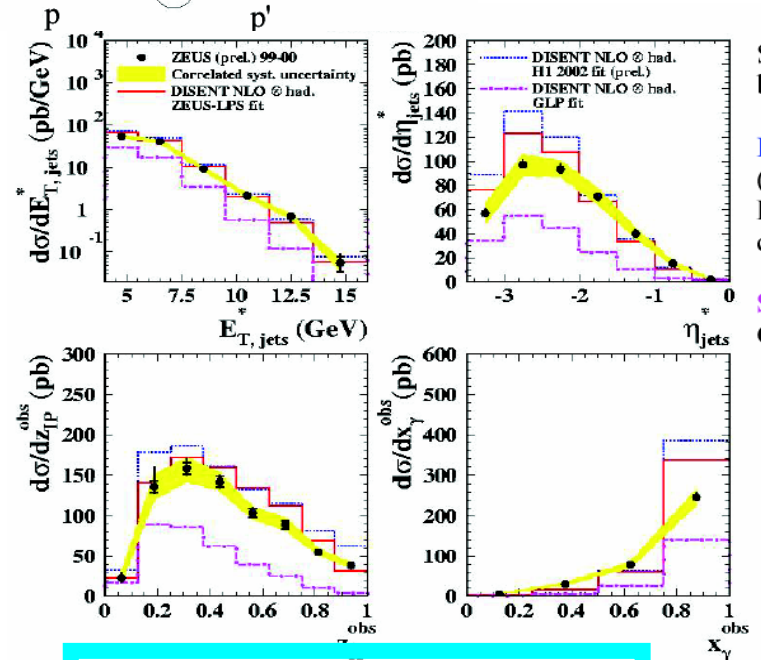
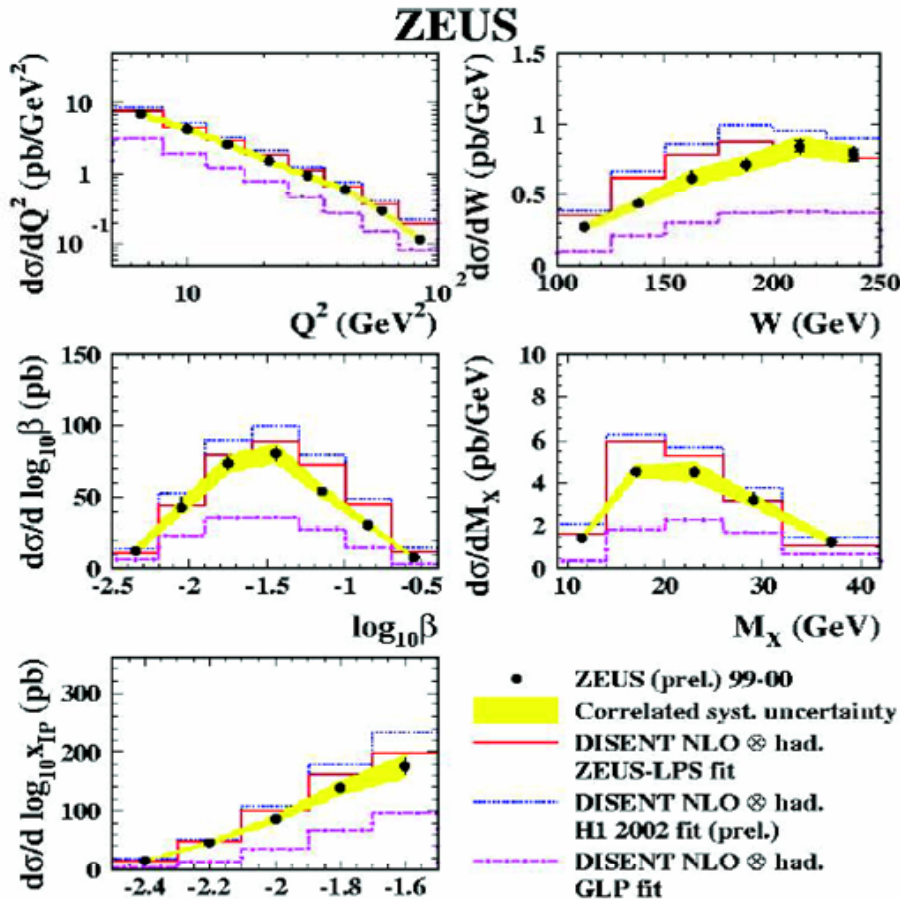
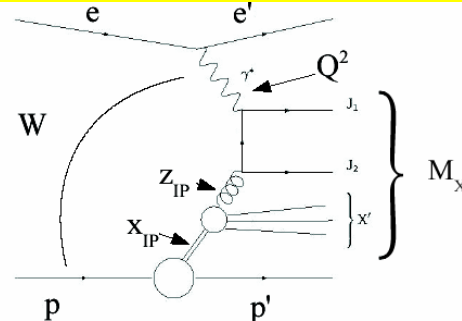
$x_{IP}=0.01$

$x_{IP}=0.02$



# Dijets in diffractive DIS : factorisation ?


hard scales ( $Q^2, p_T$ )  $\rightarrow$  pdf evolution  
 (perturbative QCD)  
 sensitivity to gluon distr. fct. ( $Z_{IP}$  var.)



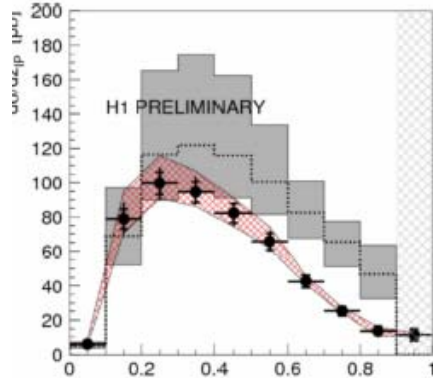
Scale uncertainties not displayed but large (~20%)

Reasonable description of data (slightly overestimating) by H1 fit2002 and ZEUS-LPS

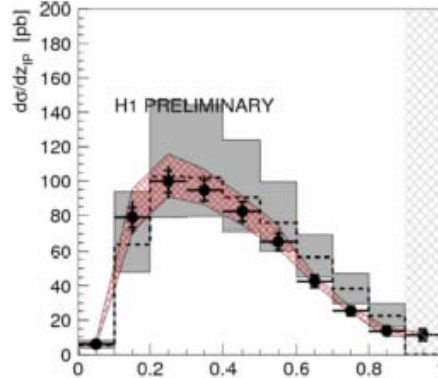
# Joint (inclusive + jets) pdf fits

 H1 prel. data (corr. err.)

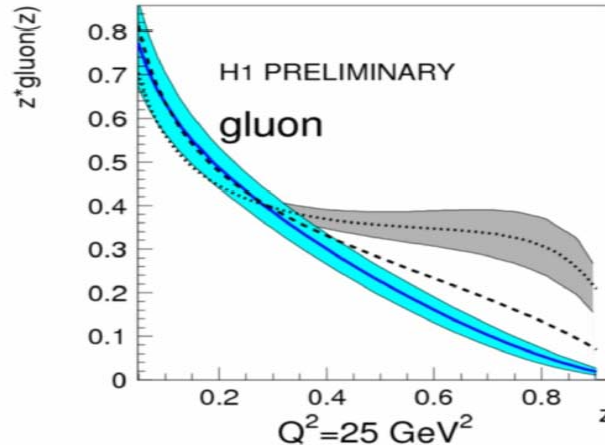
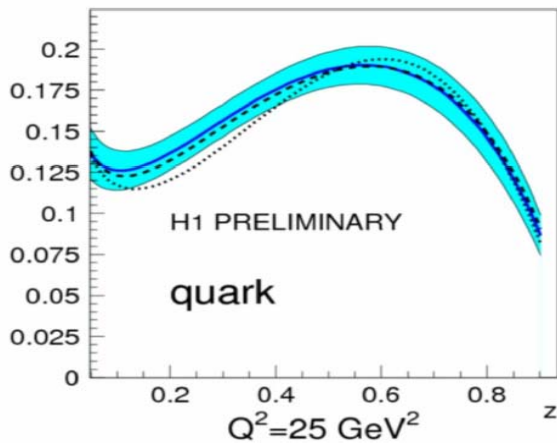
H1 Fit A



H1 Fit B



Low sensitivity of fits to inclusive cross section to gluon pdf, especially at large  $z_{IP}$   
 → use jets in combined fits

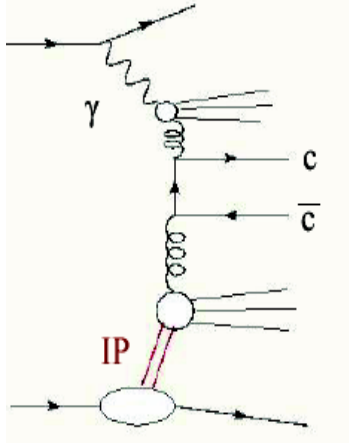


Combined fit close to Fit B;  
 dijets provide significant constraints on high  $\beta$  gluons !

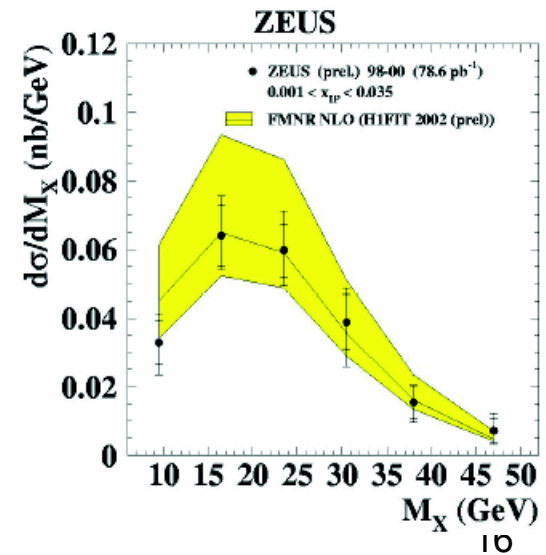
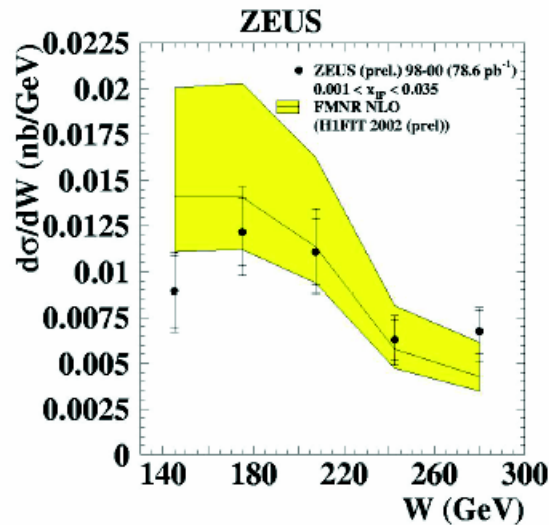
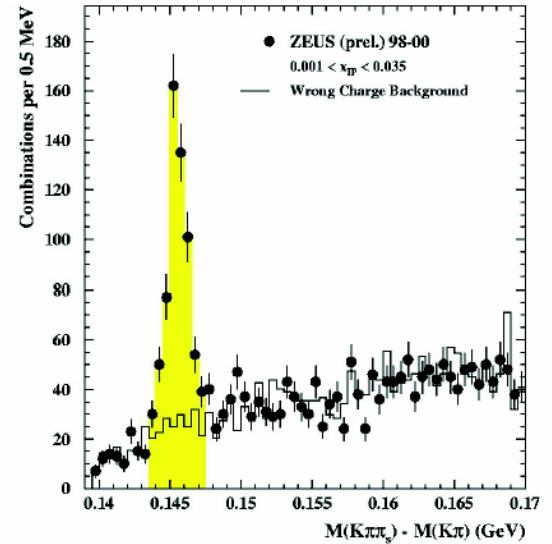


# Diffractive charm production (photoprod.)

hard scale  
pdf evolution (gluons)



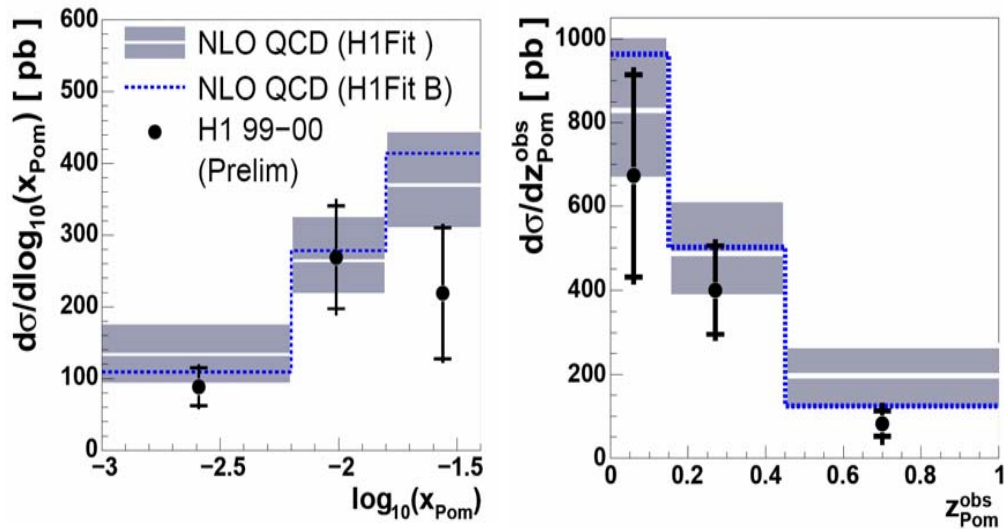
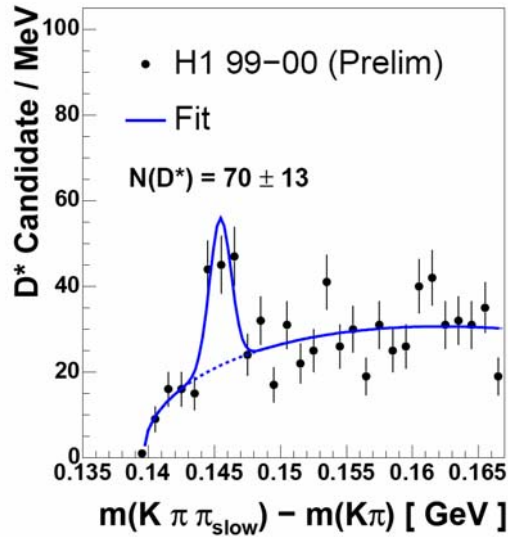
ZEUS photoproduction





# Diffraction charm production (DIS)

H1 DIS



Agreement with NLO calc.  
within the (large) errors.

# Factorisation

## Factorisation tested with jets, charm

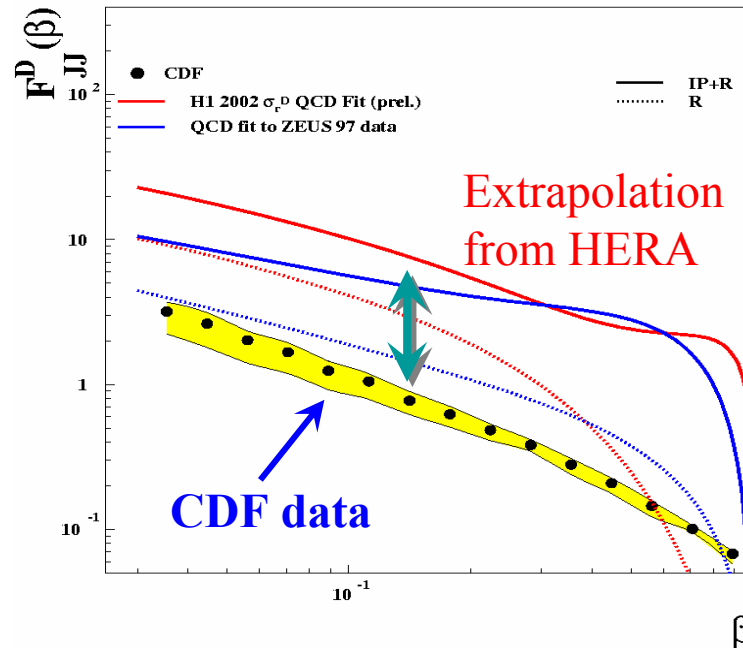
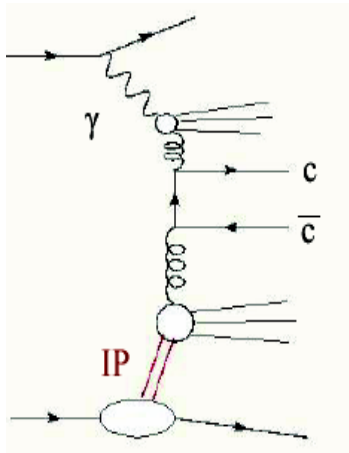
But still large errors.

NB low sensitivity of inclusive pdf's to **gluons at high  $\beta$**   $\rightarrow$  joint fits important

## Factorisation breaking

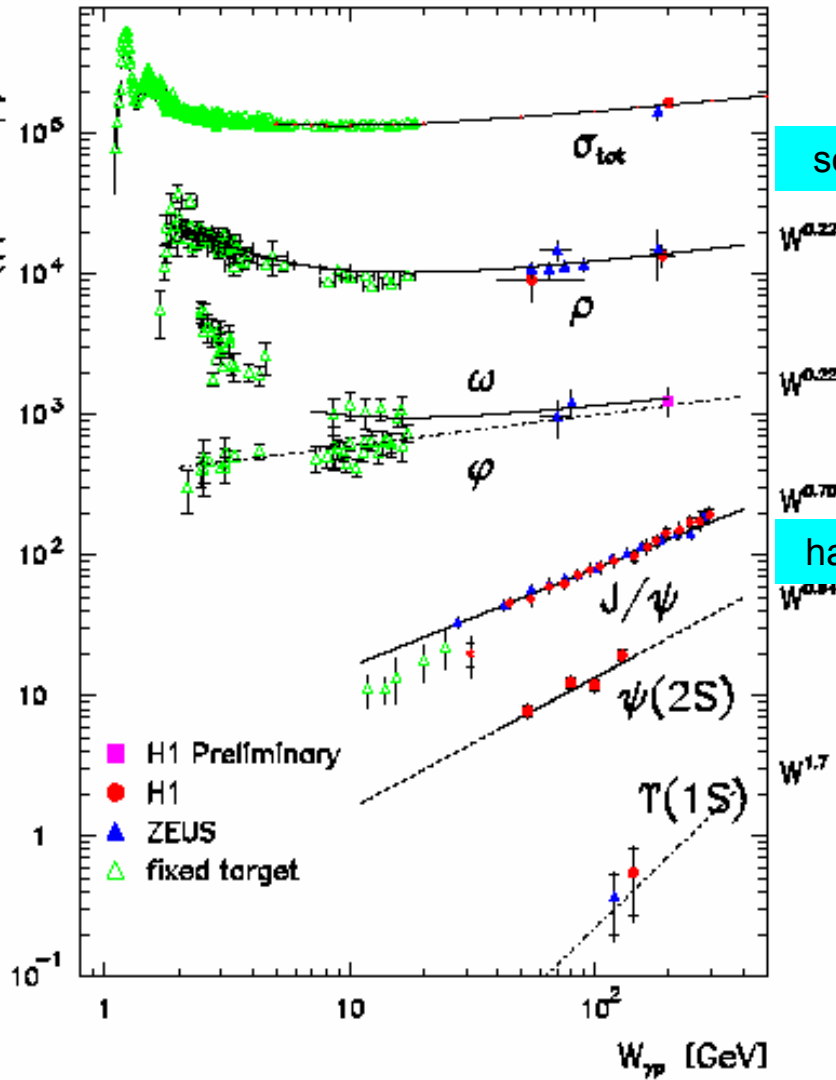
by underlying interactions  
in hadron-hadron (Tevatron, LHC)  
and for resolved photons

$\rightarrow$  **gap survival probability**



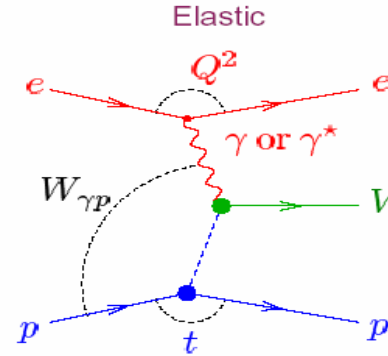
# Vector meson production

photoproduction



soft

hard



**soft diffraction** (ex.  $\rho$  photoprod.)

- low cross section increase with energy (soft pomeron)

- fast fall of  $t$  distribution  $\frac{d\sigma}{dt} \propto e^{Bt}$

**hard diffraction** ( $J/\Psi$ , large  $Q^2$ )

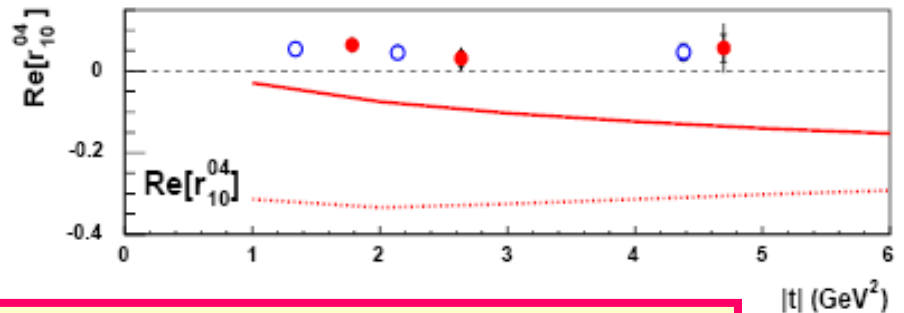
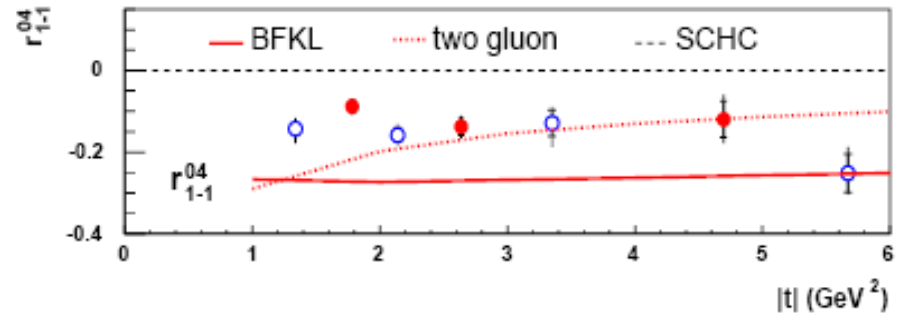
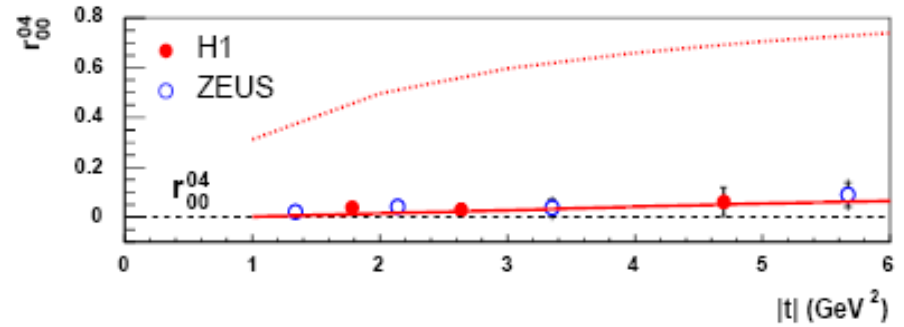
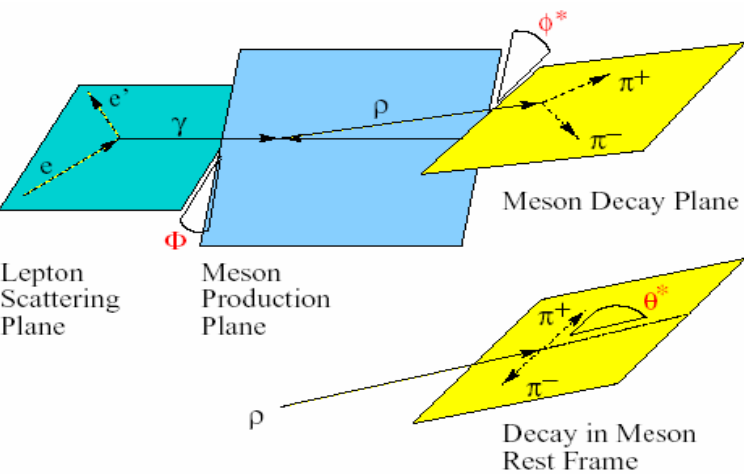
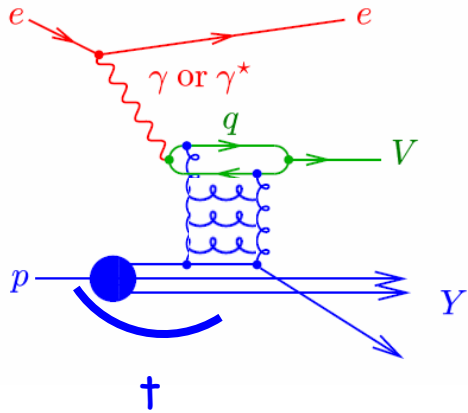
- stronger energy dependence

large gluon density at small  $x$

- flatter  $t$  distribution

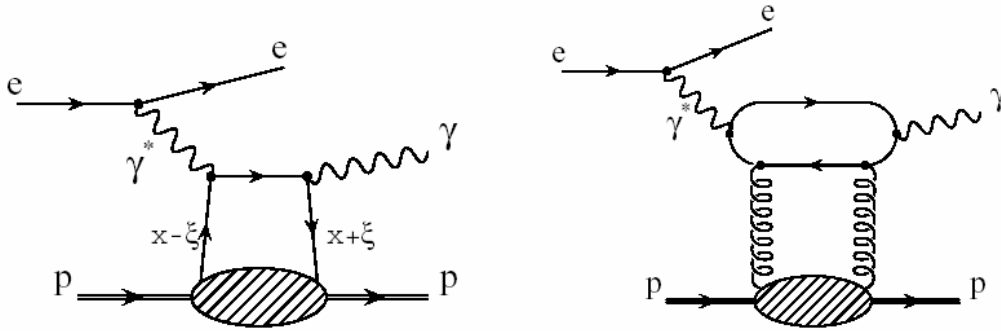
small dipole size

# Large $|t|$ $\rho$ photoproduction and BFKL

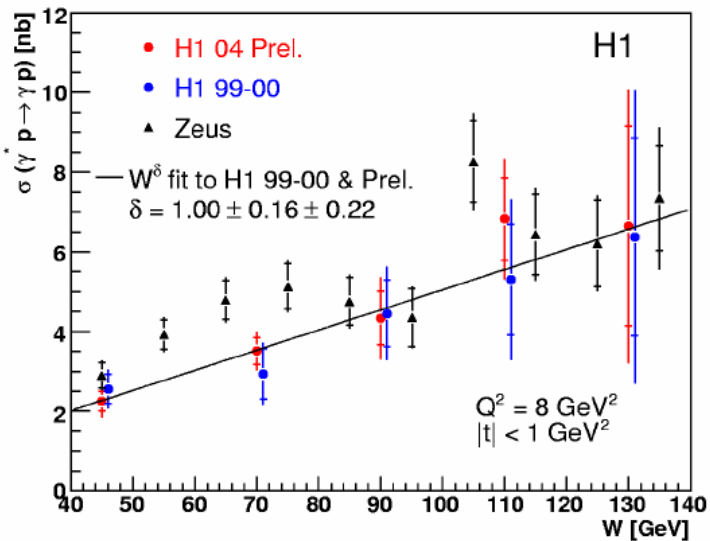


helicity flips best described by BFKL-like approach

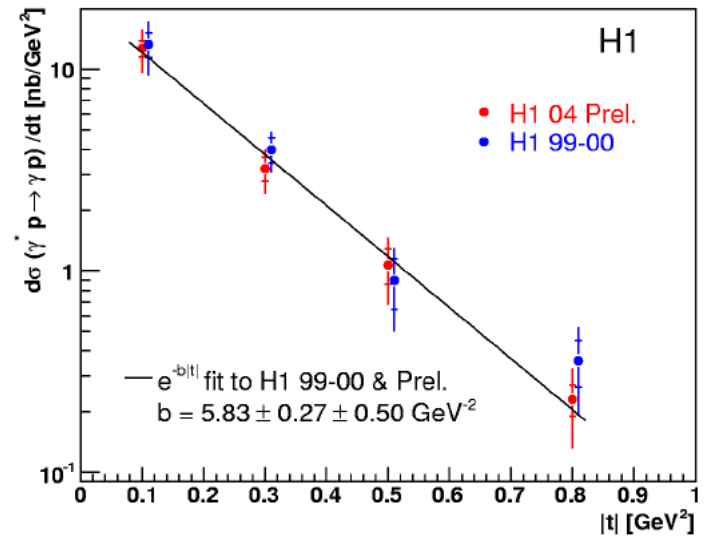
# DVCS



## Generalised Parton Distributions



rather "hard"  
energy dependence



rather "soft"  
 $t$  dependence

# Conclusions

- ✓ **Measurement precision of inclusive cross section**

$$F_2^{D(3)}(x_{IP}, \beta, Q^2) \quad F_2^{D(4)}(x_{IP}, \beta, Q^2, t)$$

- ✓ **Extraction of diffractive pdf's**

- ✓ **Factorisation tests / joint fits with jets, charm**  
(especially for gluon at large  $\beta$ )

- ✓ **Exclusive processes : vector mesons, DVCS, etc.**

**QCD understanding of diffraction**