CIPANP 2006
Puerto-Rico
29/5-4/6/2006

Diffraction at HERA

Pierre Marage
Univ. Libre de Bruxelles

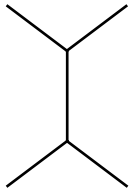
On behalf of the H1 and ZEUS collaborations

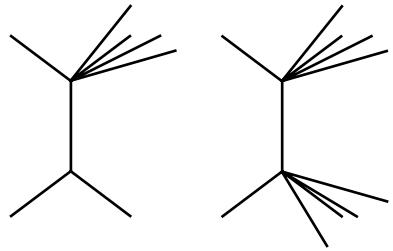
Content

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

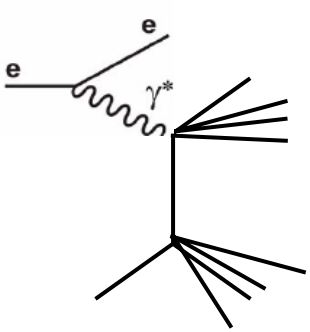
elastic scattering 

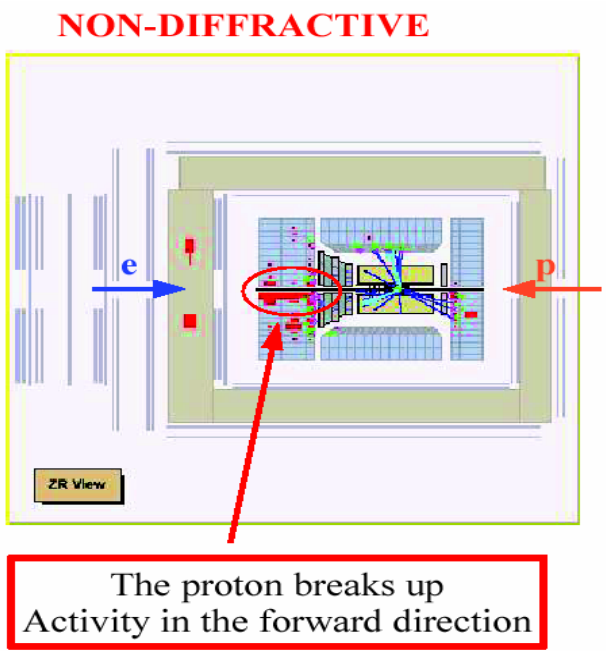
diffractive dissociation
(differential absorption
of hadronic components) 

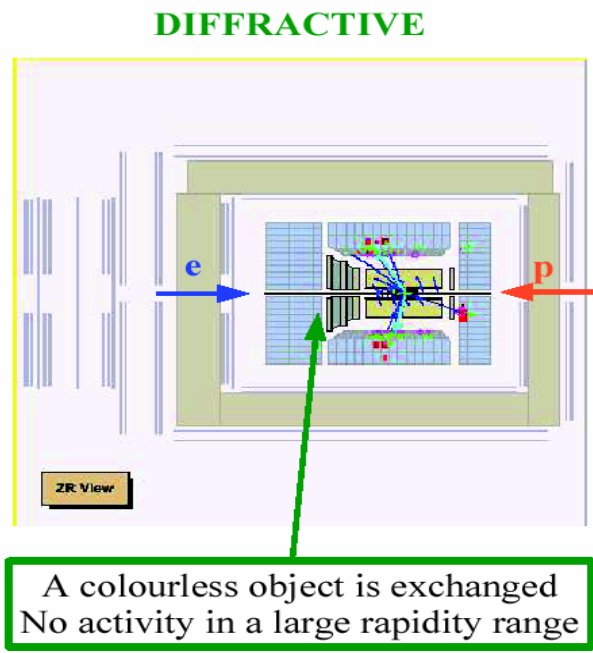
high energy $\sigma(h-h) \propto s^{\alpha_{IP}(0)-1}$ $\alpha_{IP}(0) \approx 1.08$ *soft* pomeron - unitarity !

HERA

some 10% of cross section
in electroproduction !







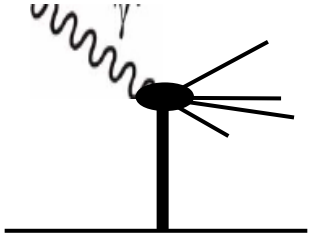
Diffraction at HERA and QCD

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.

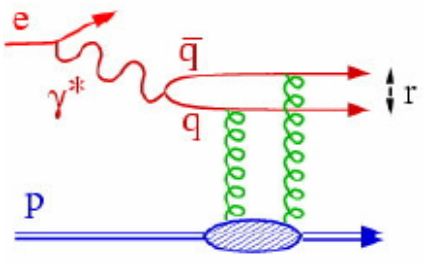
✓ pomeron structure



diffractive parton densities

factorisation theorem

✓ colour dipole

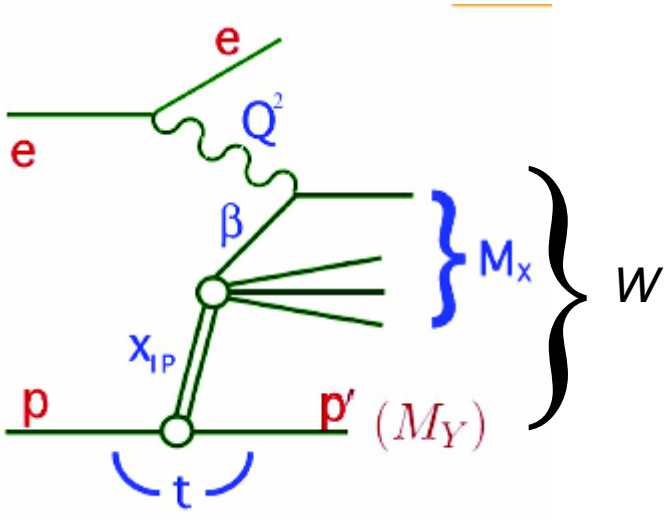


dipole – proton cross section

lowest order = 2 gluon exchange

small dipoles in presence of hard scale

Diffractive variables



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

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

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

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

$$M_Y$$

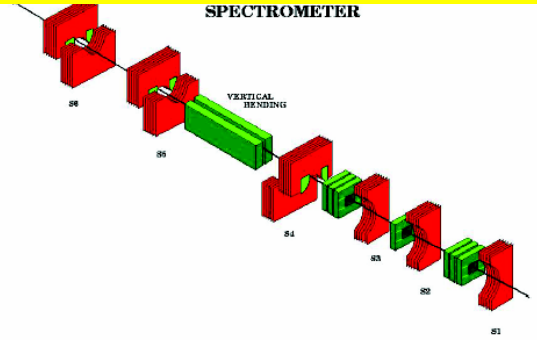
Inclusive cross section

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

Inclusive diffraction : 3 measurement methods

1. **Proton spectrometers**

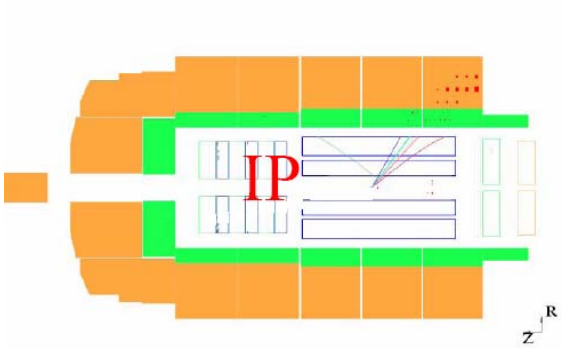
-> *t* measurement

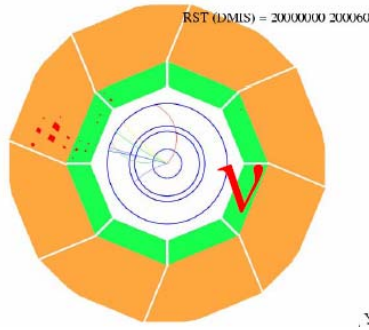


2. **Large rapidity gap**

NC and CC diffraction

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



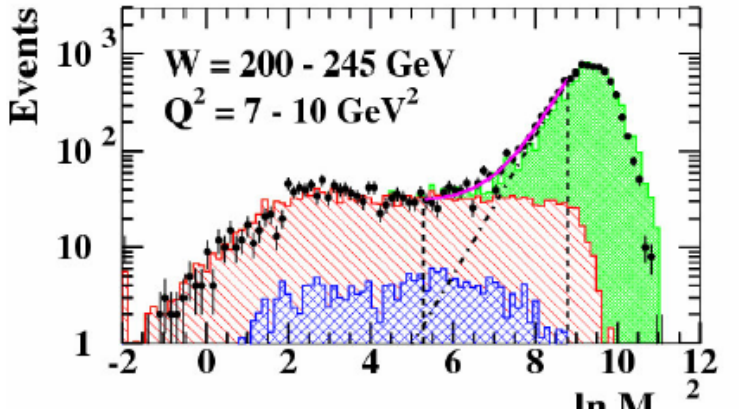


3. **Non-exponential fall off**

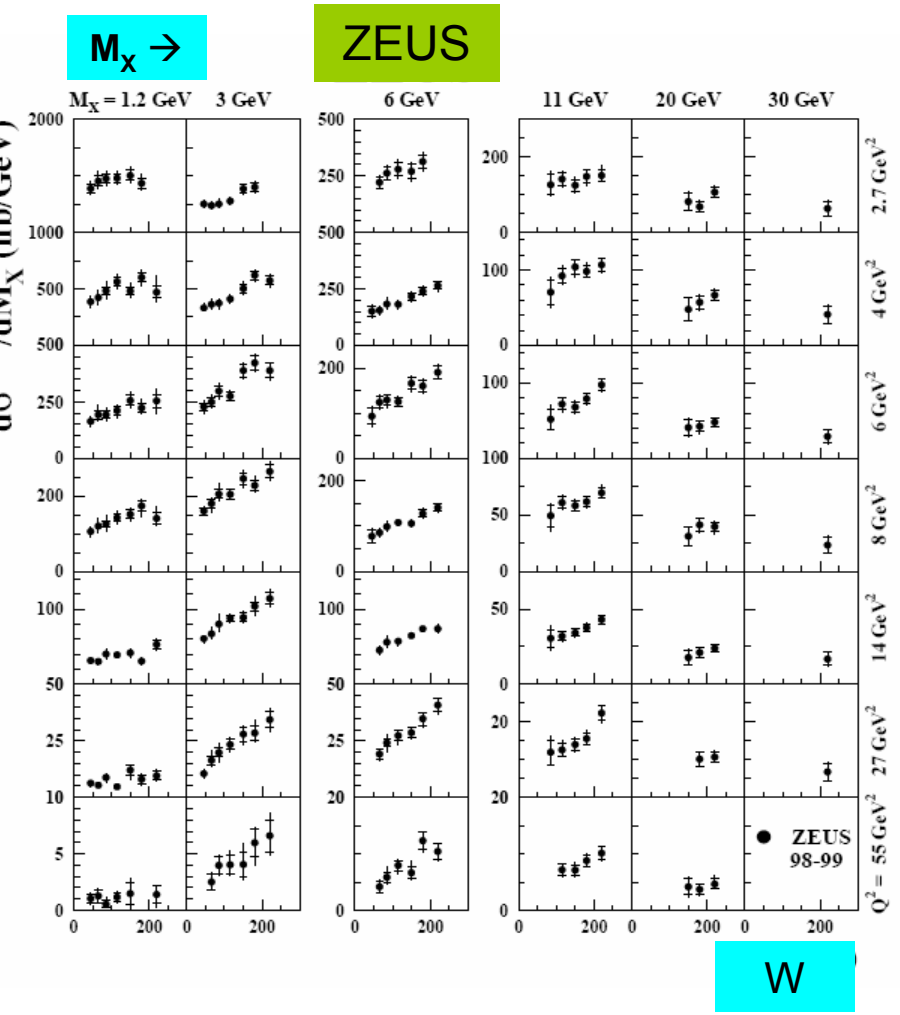
of ln M_X^2 distribution :

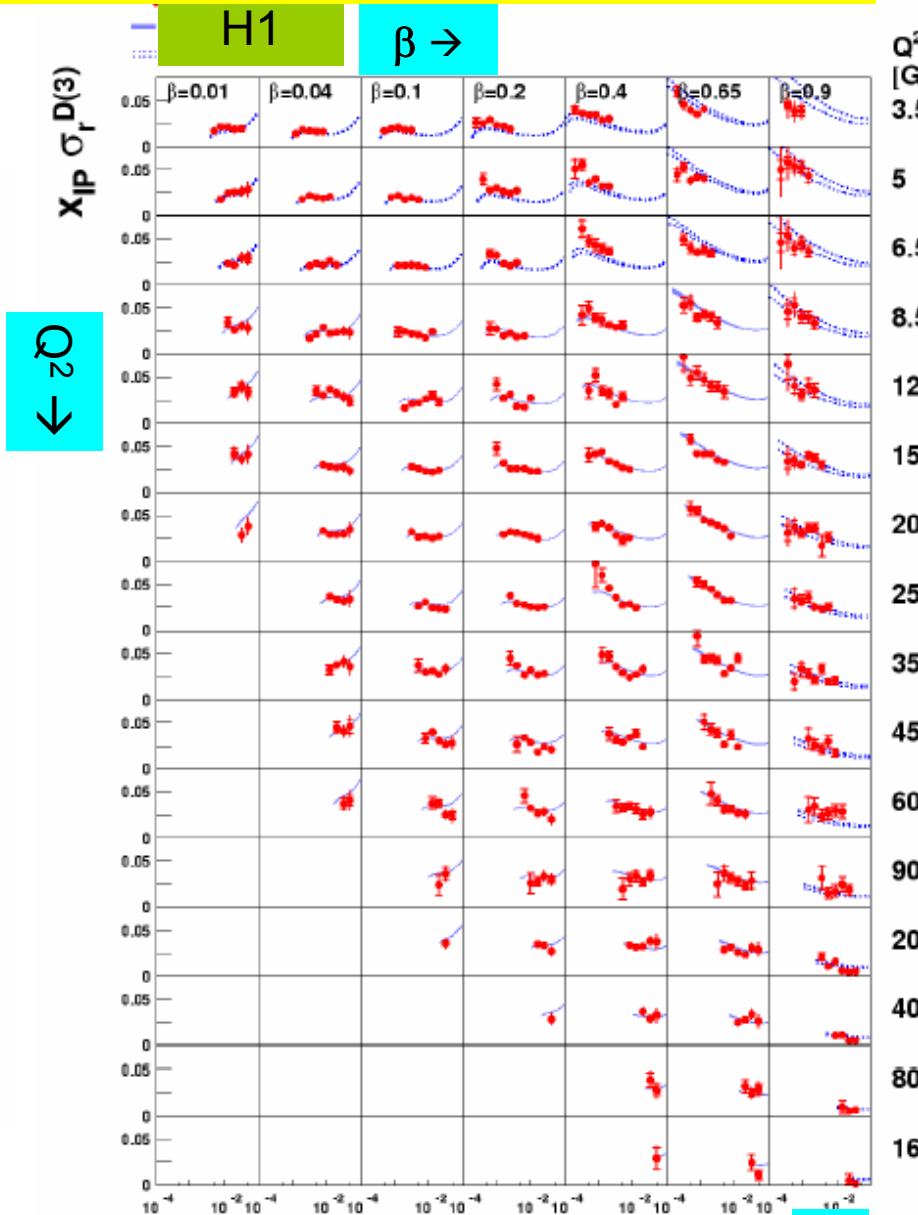
$$\frac{dN}{d\ln M_X^2} \propto D + C\, e^{B \ln M_X^2}$$

diffr. non-diffr.



Cross sections measurements





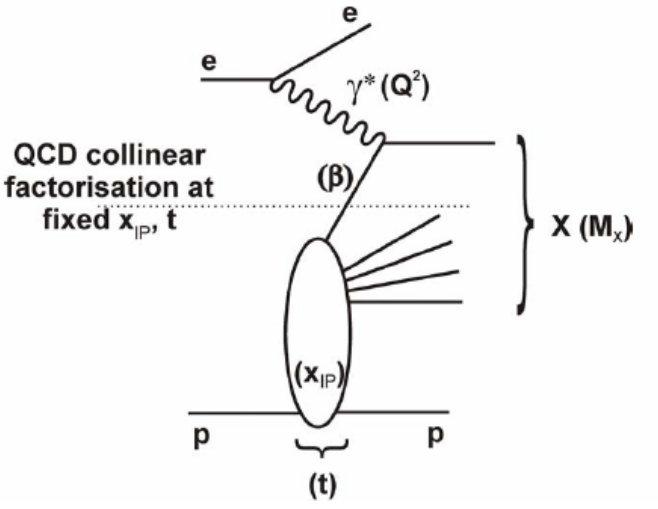
Factorisation and pdf's

Collinear factorisation

cf. total ep cross section

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

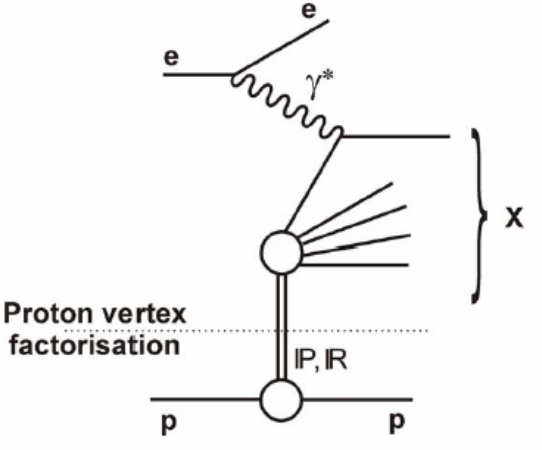
for fixed x_{IP}, t (M_Y)



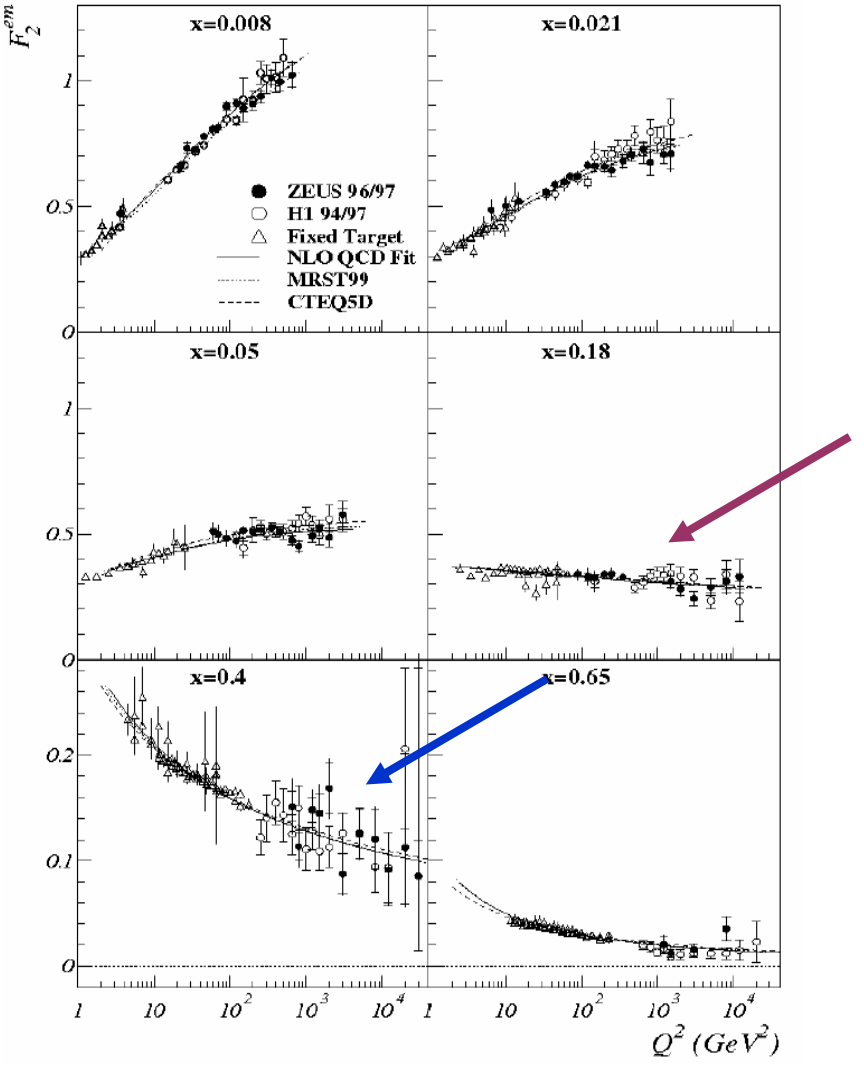
Vertex factorisation

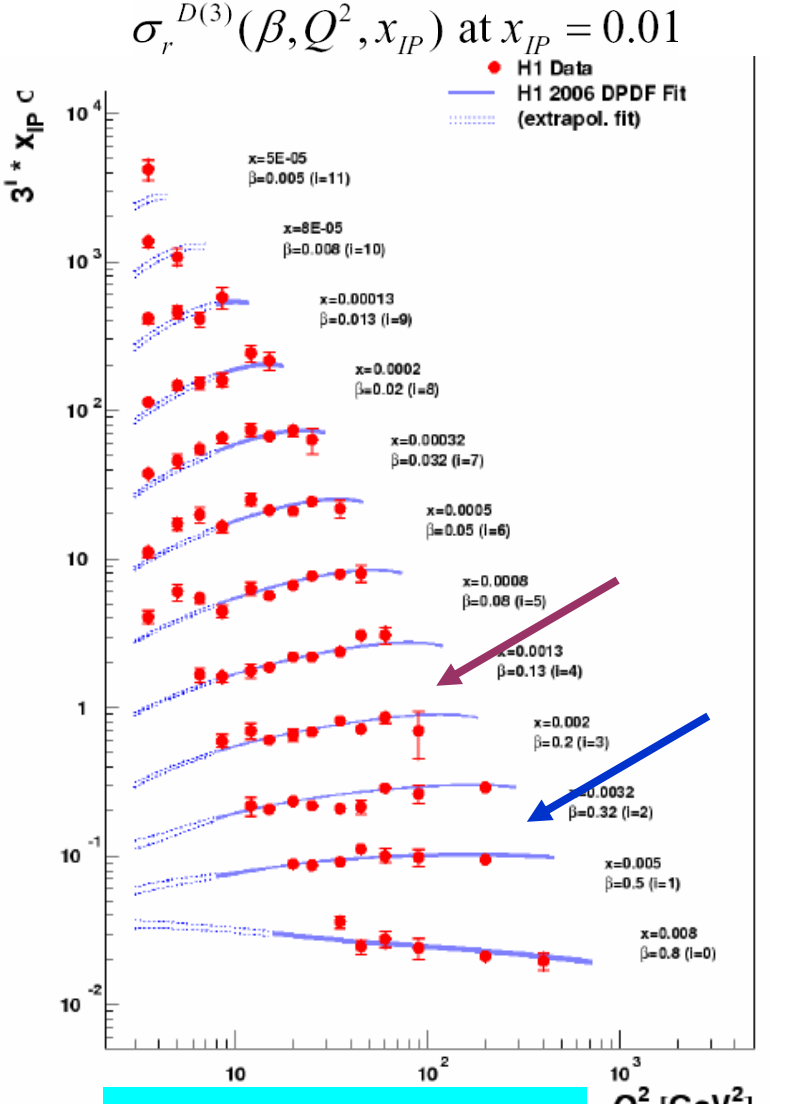
$$f_i^D(x, Q^2, x_{IP}, t) = f_{IP/p}(x_{IP}, t) \cdot f_i^{IP}(\beta, Q^2) \quad (\beta = x \,/\, x_{IP})$$

usefull hypothesis (Regge inspired)



Scaling violations





large gluon content !

Parton distribution function parameterisations

- **Fit A**

$$z\Sigma(z,Q_0^2) = A_q z^{B_q}(1-z)^{C_q} \quad \text{and} \quad zg(z,Q_0^2) = A_g(1-z)^{C_g}$$

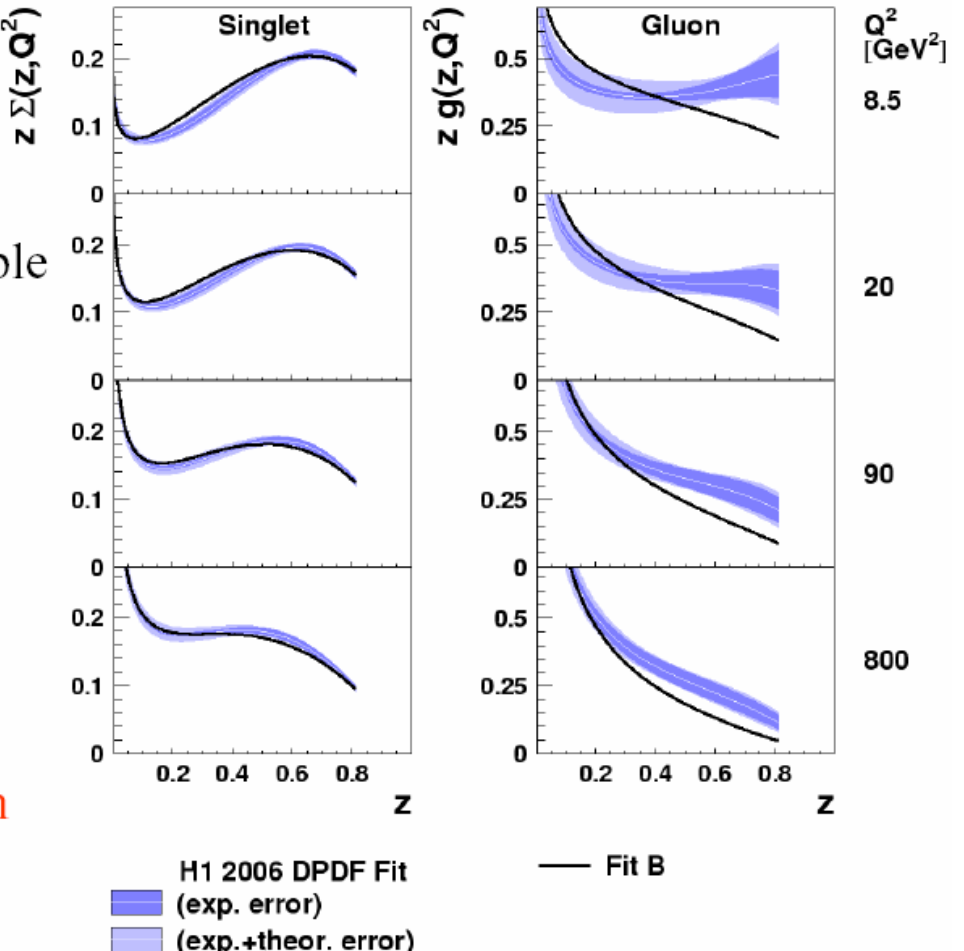
$Q_0^2 = 1.75\ \text{GeV}^2$
$\chi^2 \sim 158 / 183$ d.o.f.

- 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**

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

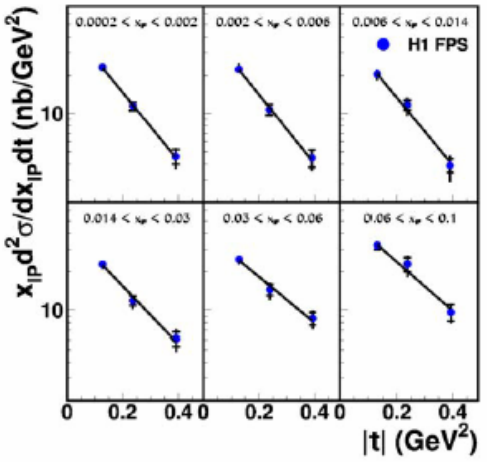
- Quarks very stable
- Gluon similar at low z
- Substantial change to gluon at high z

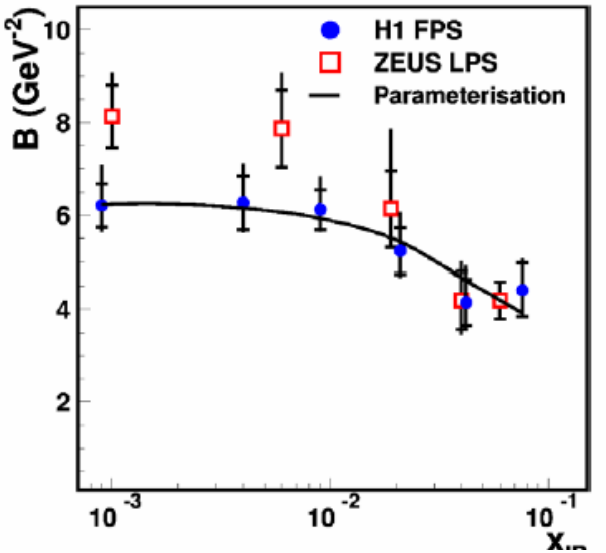


H1

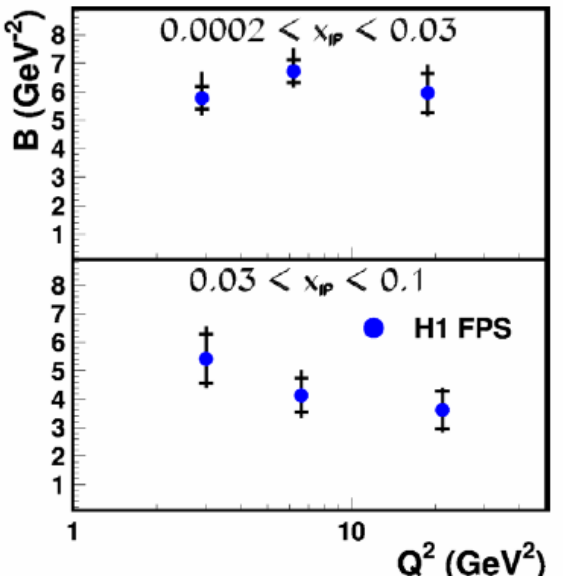
$F_2^{D(4)}(x_{IP}, \beta, Q^2, t)$

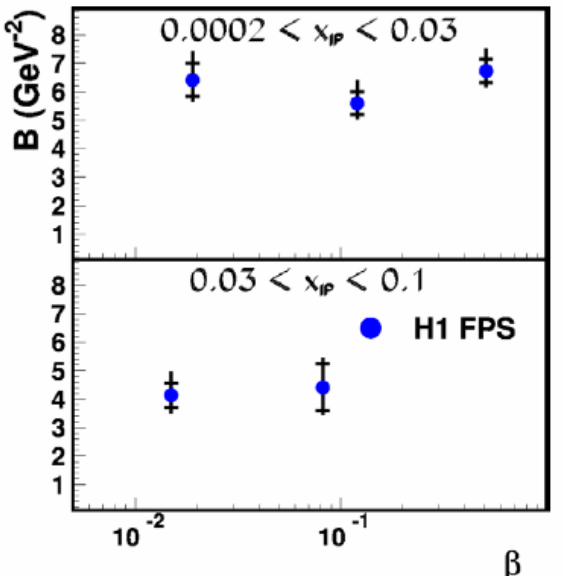
Fit to *exp(Bt)* in bins of x_{IP}





Vertex factorisation :

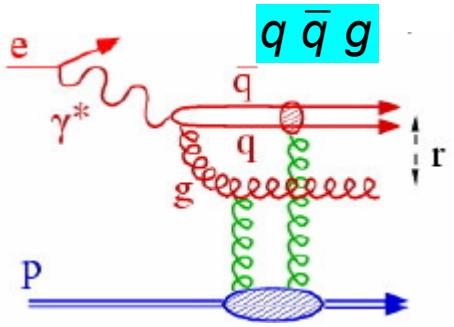




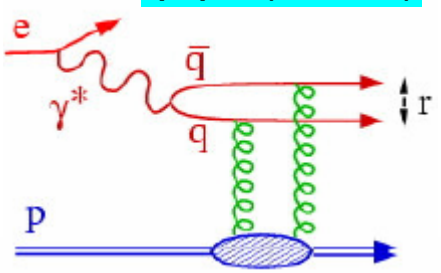
2-gluon exchange model

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

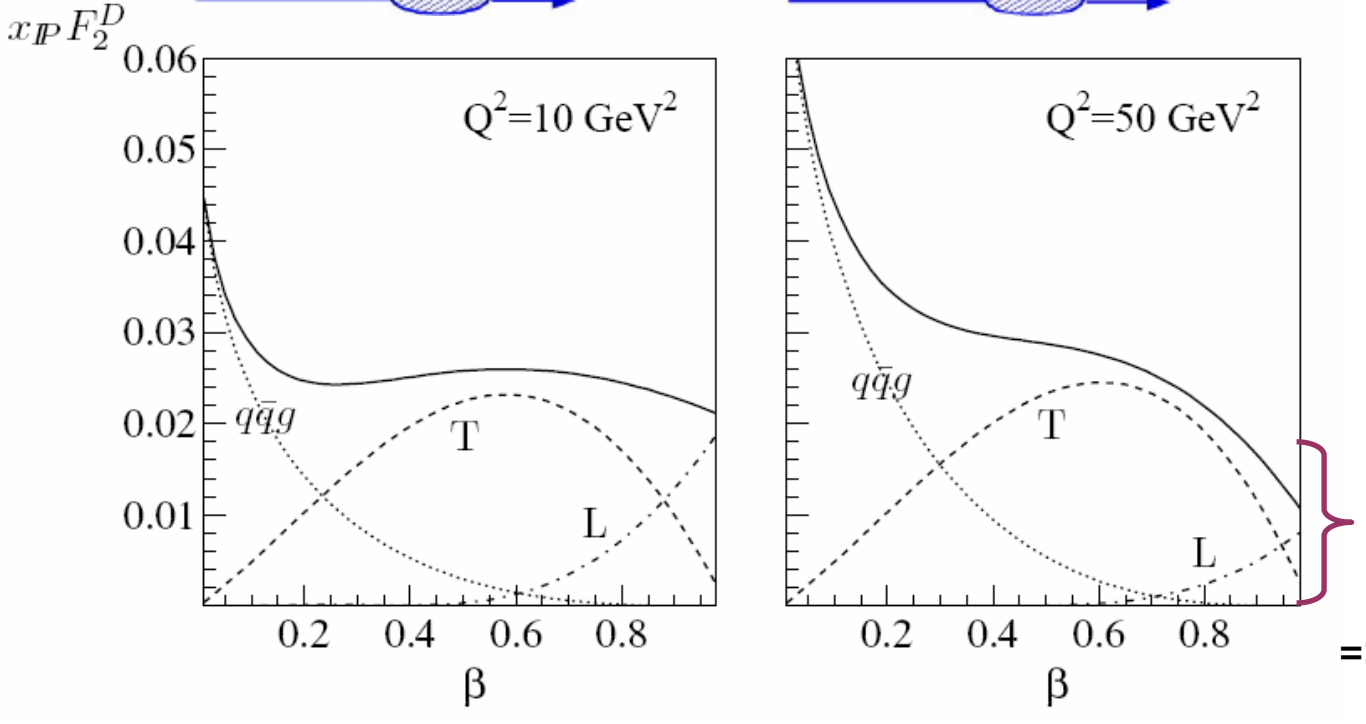
Colour dipole



$q\bar{q}\,g$

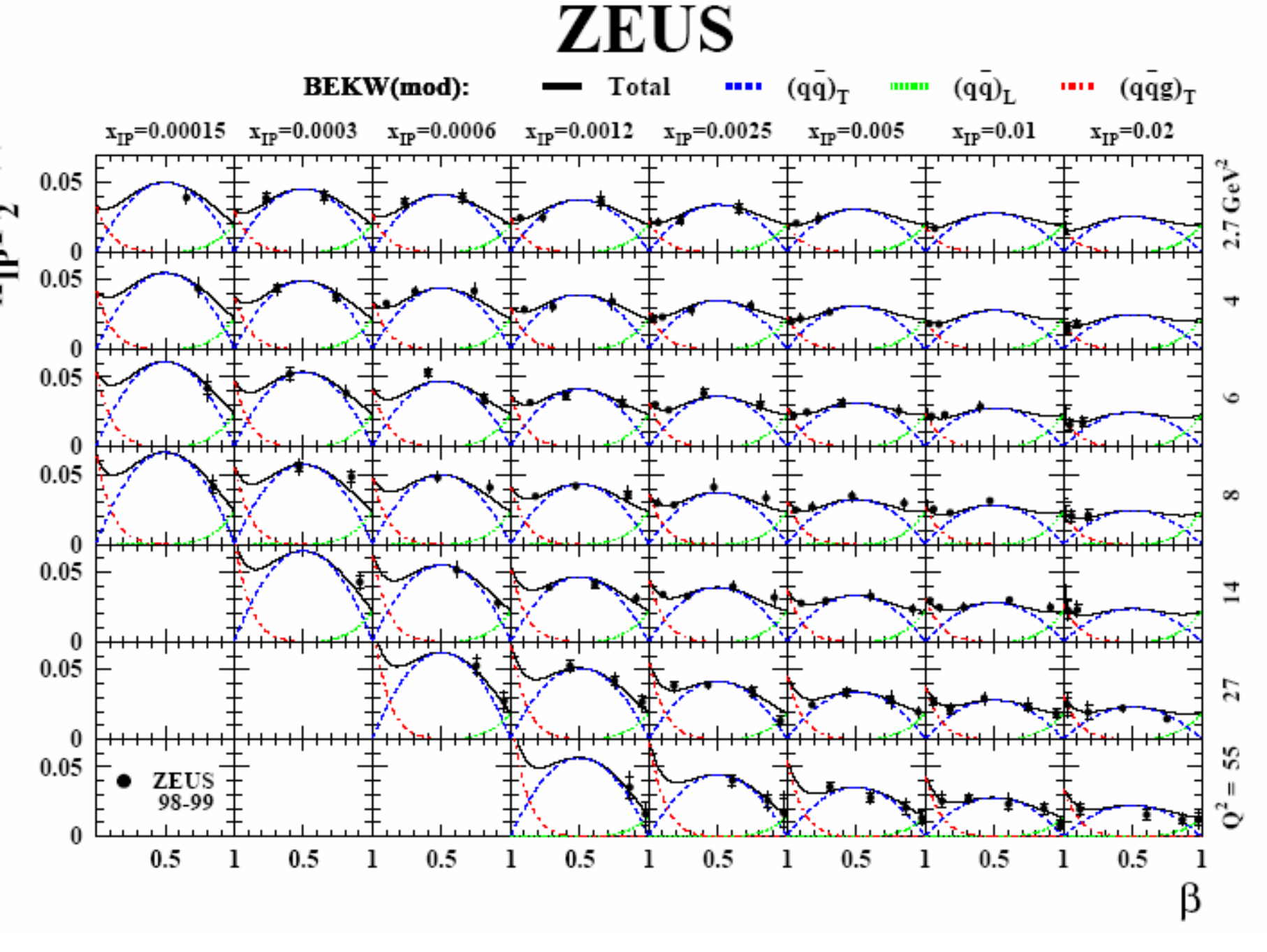


$q\bar{q}$ (L or T)



~1/Q²
at large β

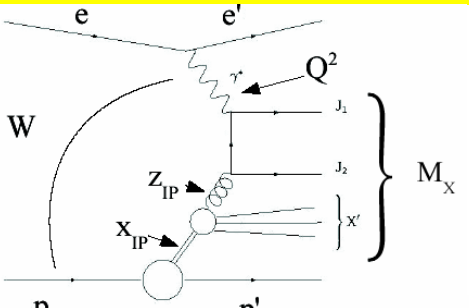
=> HigherTwist behaviour

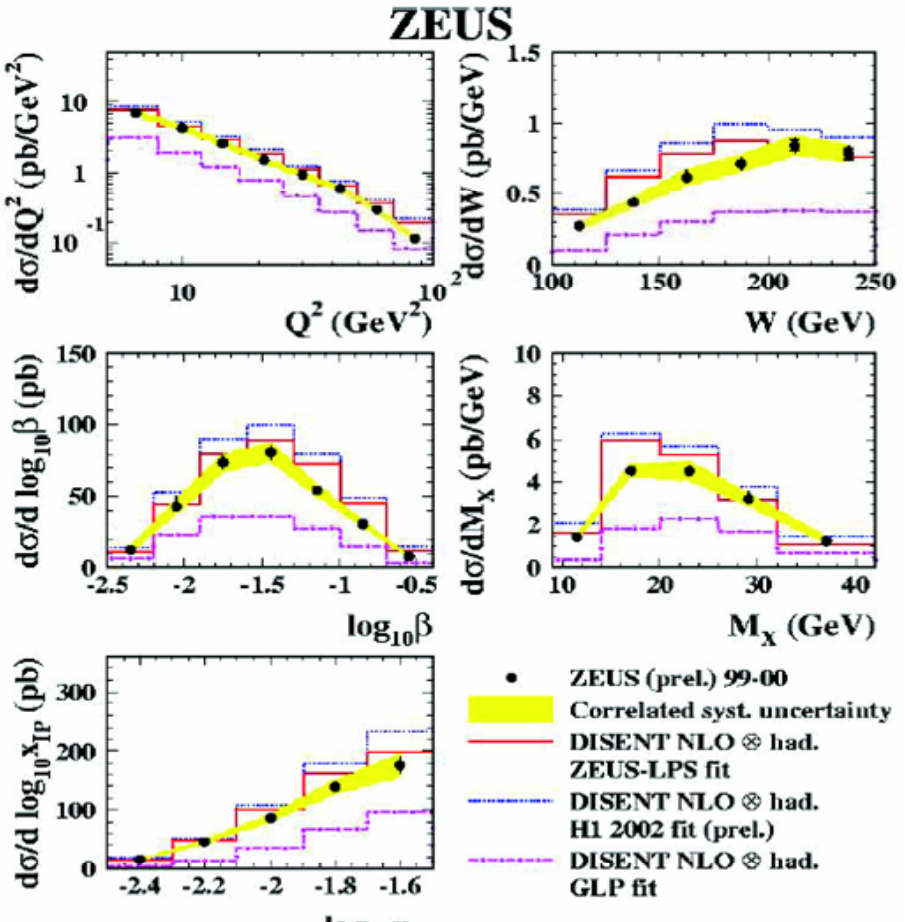

ZEUS
BEKW(mod):
Total
$(q\bar{q})_T$
$(q\bar{q})_L$
$(q\bar{q}g)_T$
x_{IP}=0.00015
x_{IP}=0.0003
x_{IP}=0.0006
x_{IP}=0.0012
x_{IP}=0.0025
x_{IP}=0.005
x_{IP}=0.01
x_{IP}=0.02
F_2^{IP}
2.7 GeV^2
4
6
8
14
27
Q^2 = 55
ZEUS
98-99
β

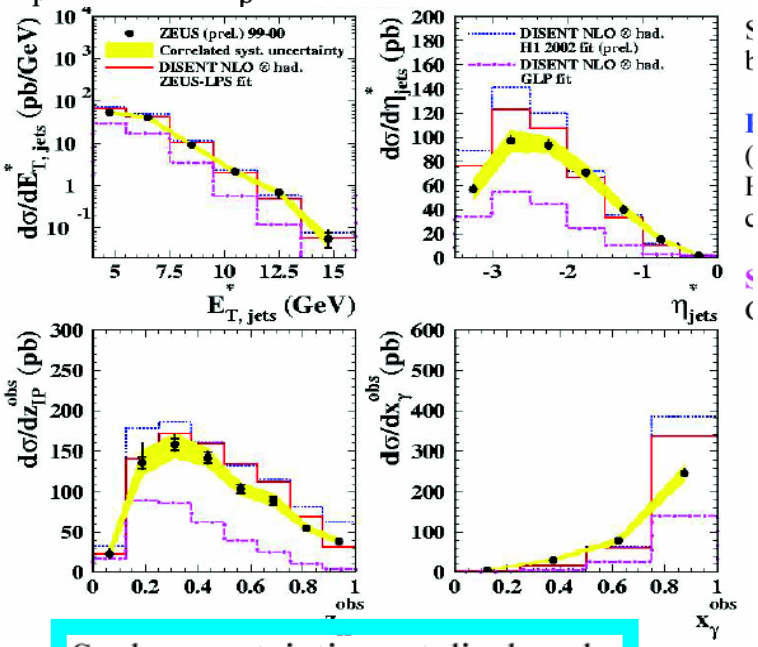
Dijets in diffractive DIS : factorisation ?

hard scales (Q^2, p_T) → pdf evolution
(perturbative QCD)

sensitivity to gluon distr. fct. (z_{IP} var.)



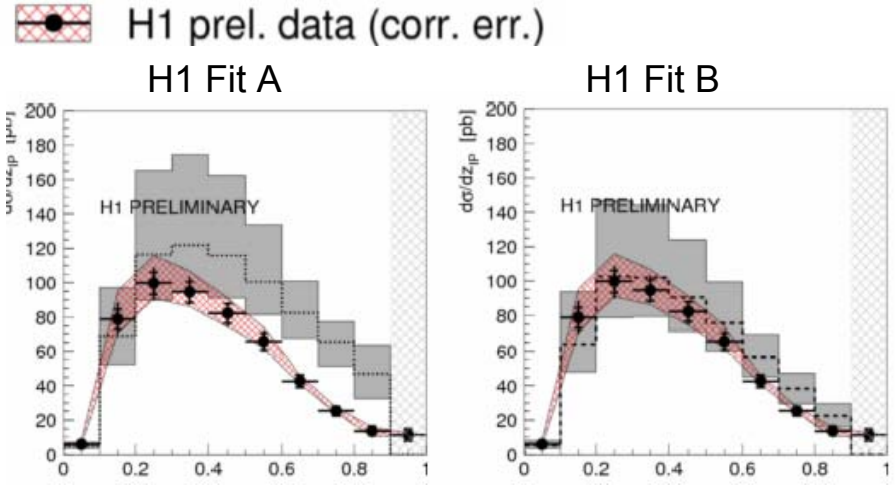




Scale uncertainties not displayed but large (~20%)

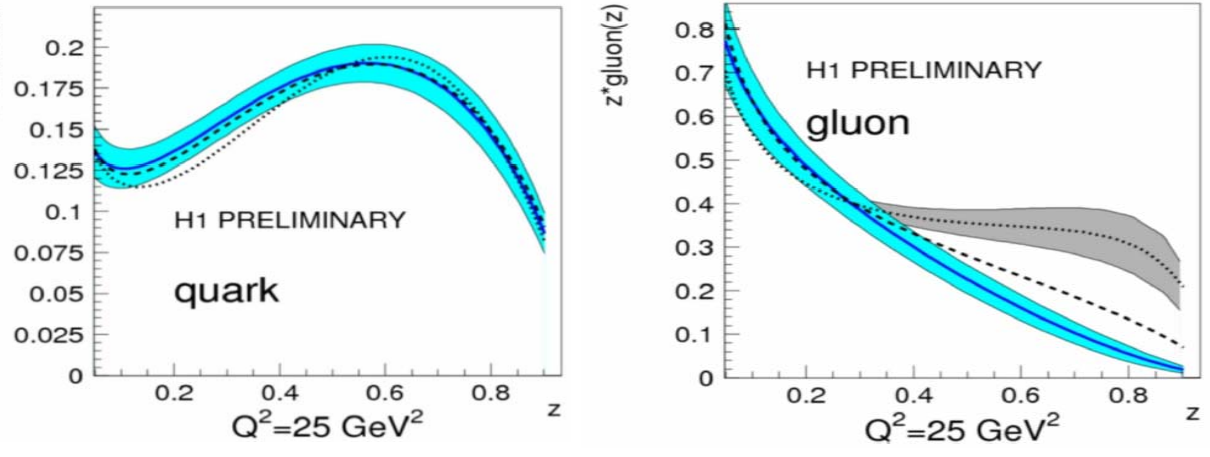
Reasonable description of data (slightly overestimating) by H1fit2002 and ZEUS-LPS

Joint (inclusive + jets) pdf fits



Low sensitivity of fits to inclusive cross section to gluon pdf, especially at large z_{IP}

→ use jets in combined fits

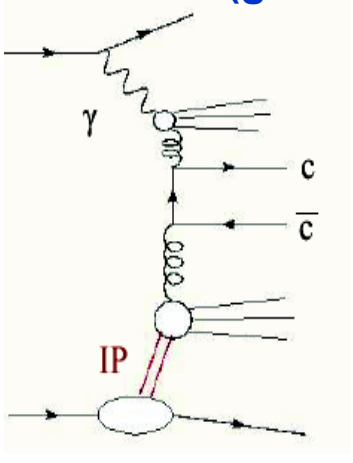


Combined fit close to Fit B;
dijets provide significant constraints on high β gluons !

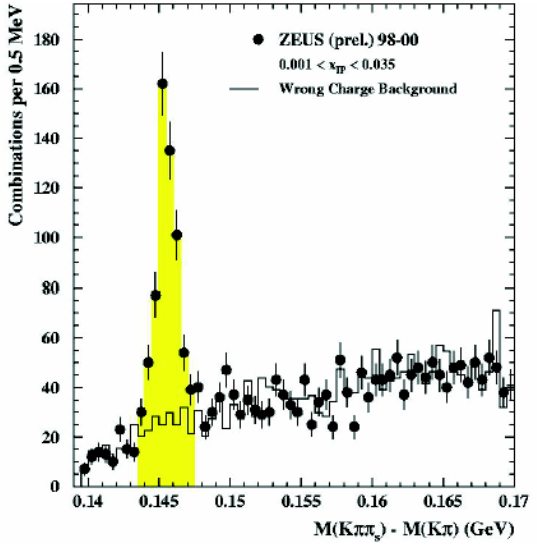
Diffractive charm production (photoprod.)

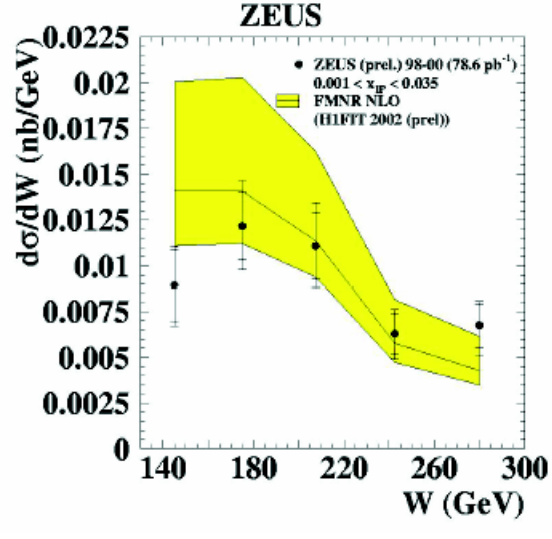
hard scale

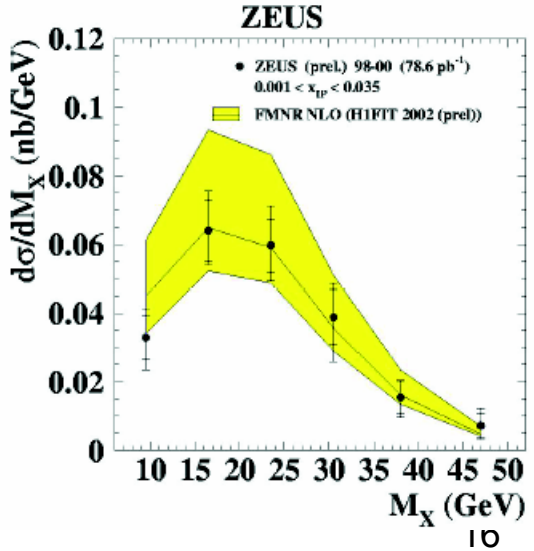
pdf evolution (gluons)



ZEUS photoproduction

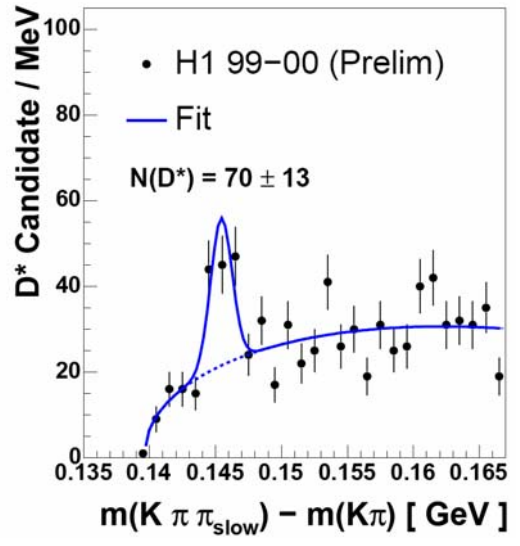


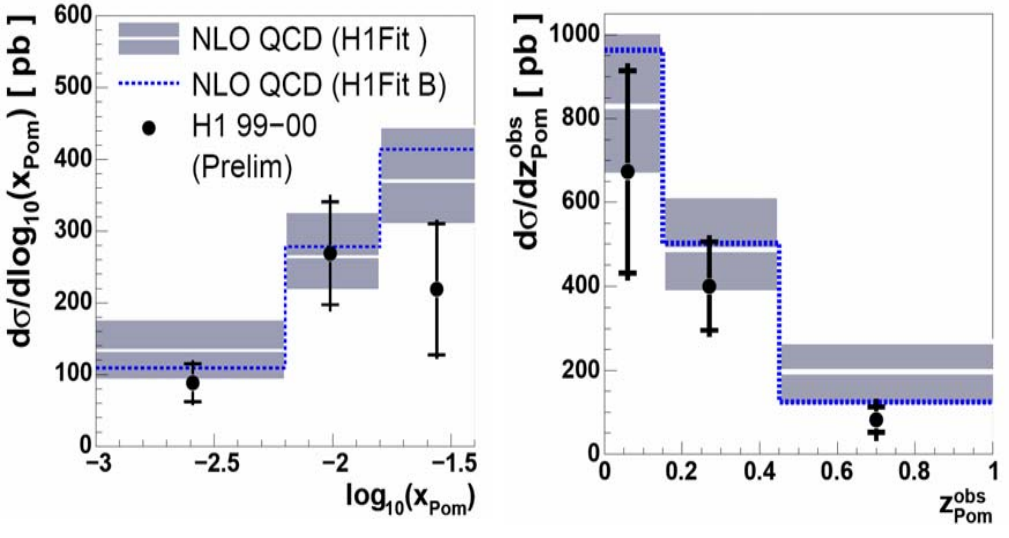




Diffractive charm production (DIS)

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 β** →joint fits important

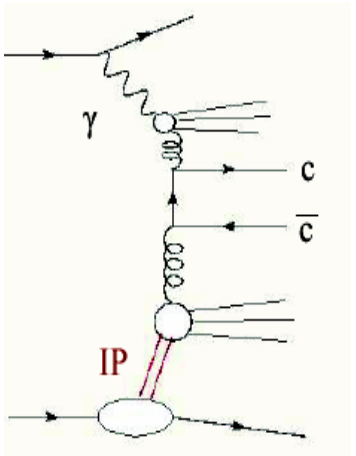
Factorisation breaking

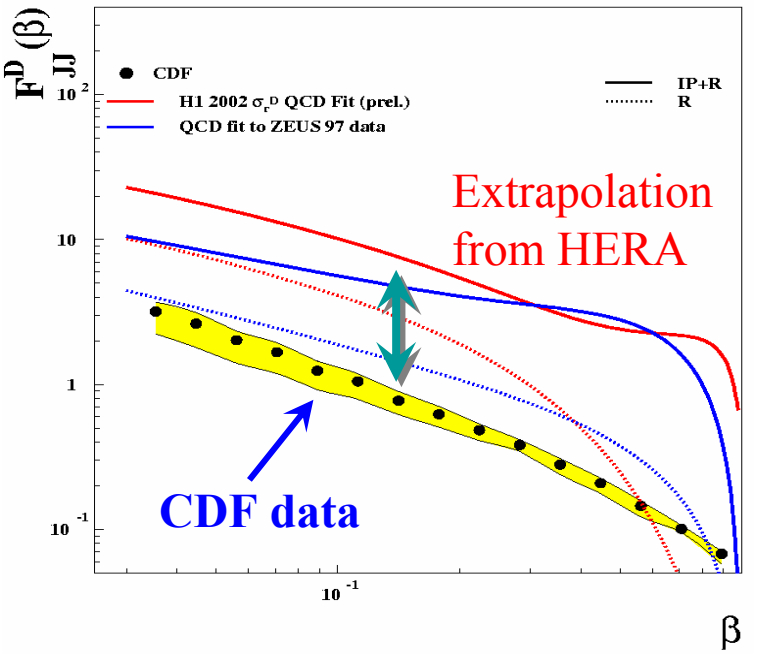
by underlying interactions

in hadron-hadron (Tevatron, LHC)

and for resolved photons

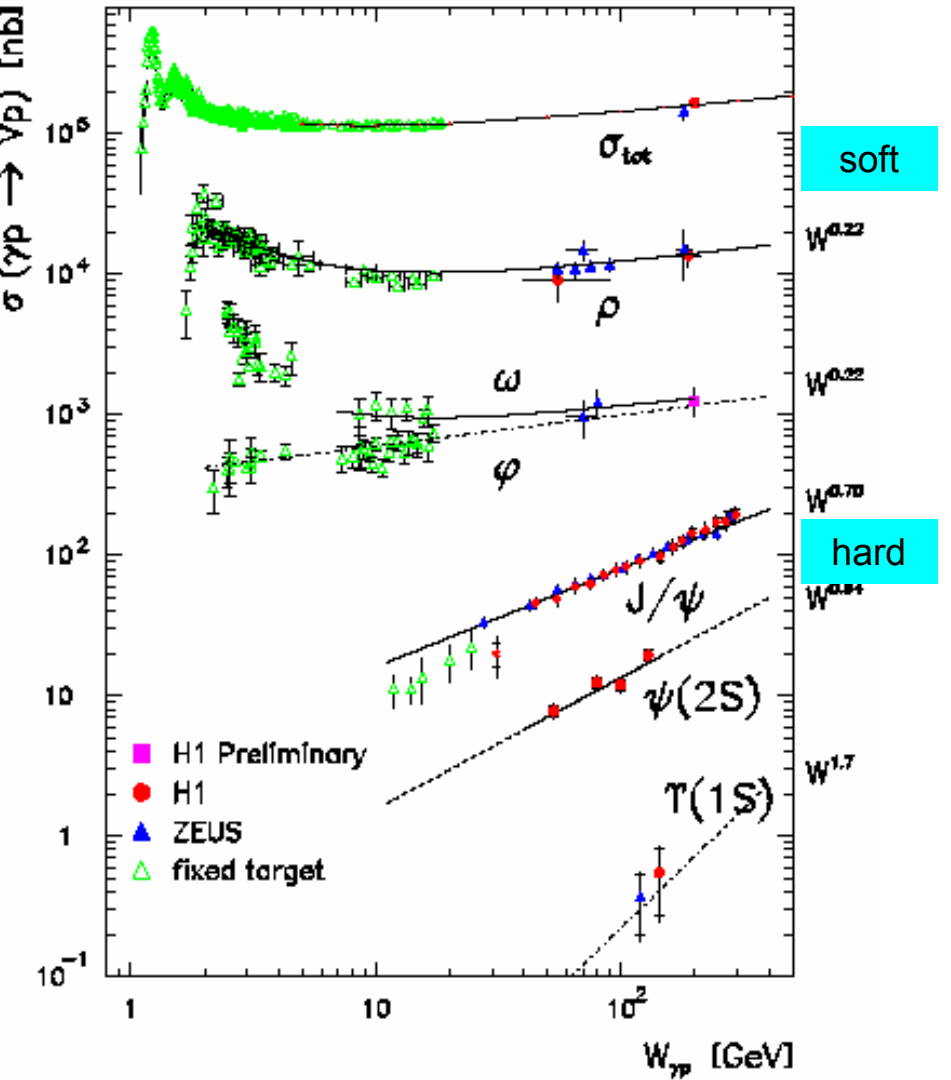
→ gap survival probability





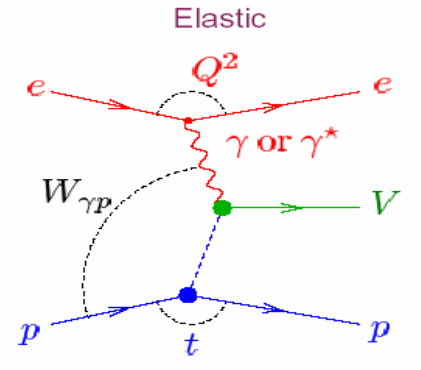
Vector meson production

photoproduction



soft

hard



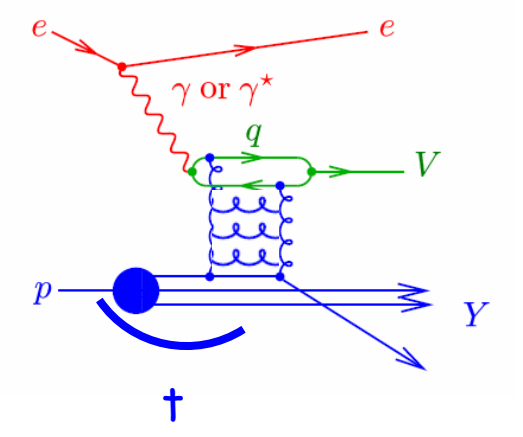
soft diffraction (ex. ρ photoprod.)

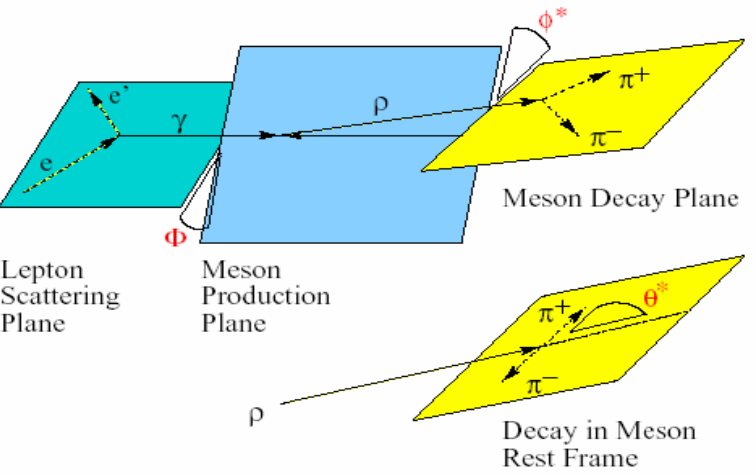
- low cross section increase with energy (soft pomeron)
- fast fall of t distribution $\frac{d\sigma}{dt} \propto e^{B\,t}$

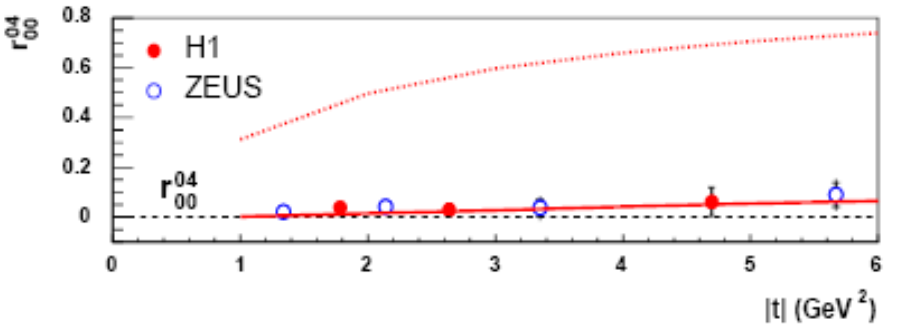
hard diffraction (J/Ψ, large Q^2)

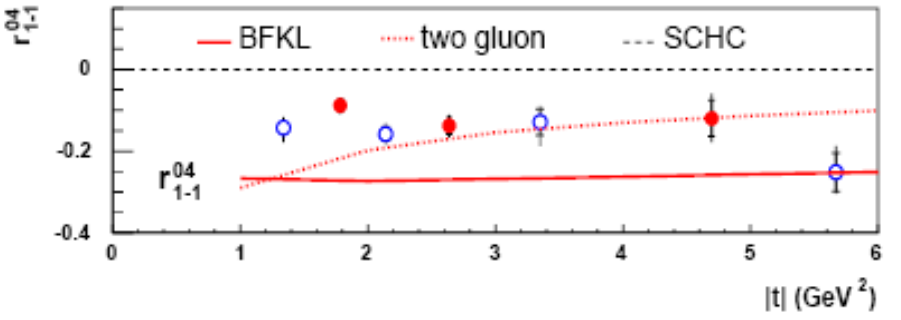
- stronger energy dependence
  large gluon density at small x
- flatter *t* distribution
  small dipole size

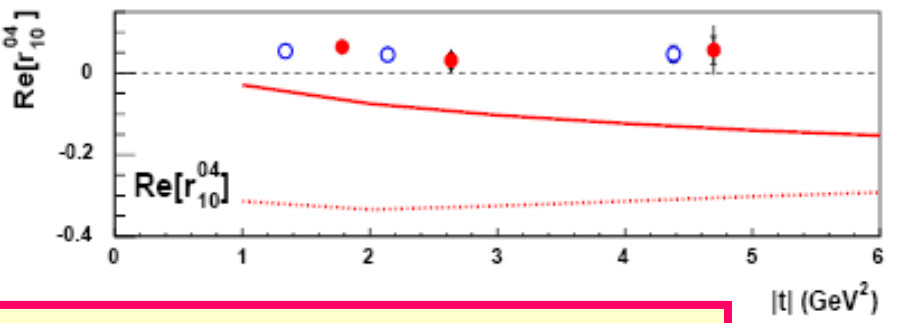
Large |t| ρ photoproduction and BFKL





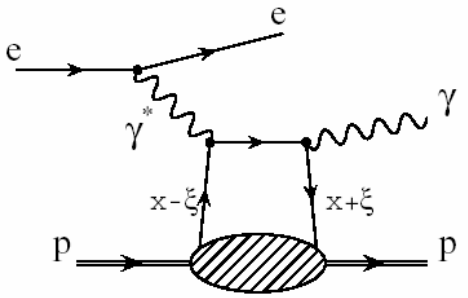


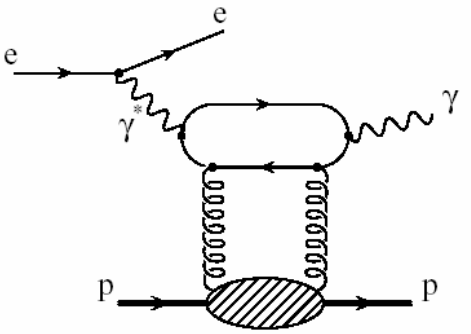




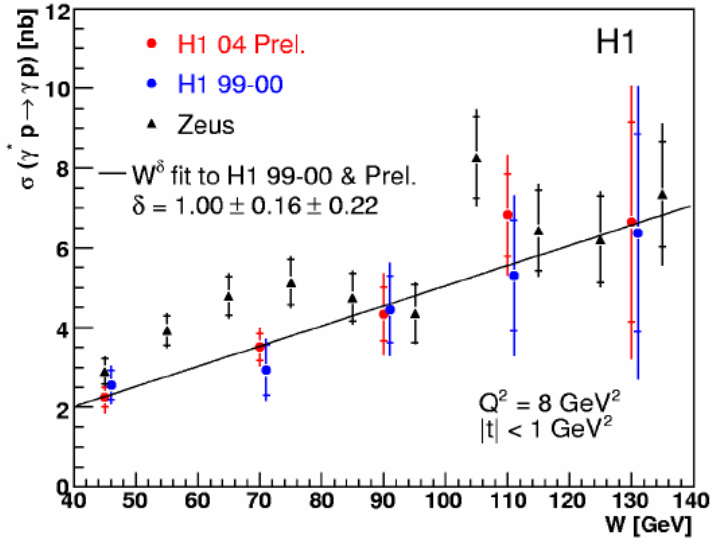
helicity flips best described by BFKL-like approach

DVCS

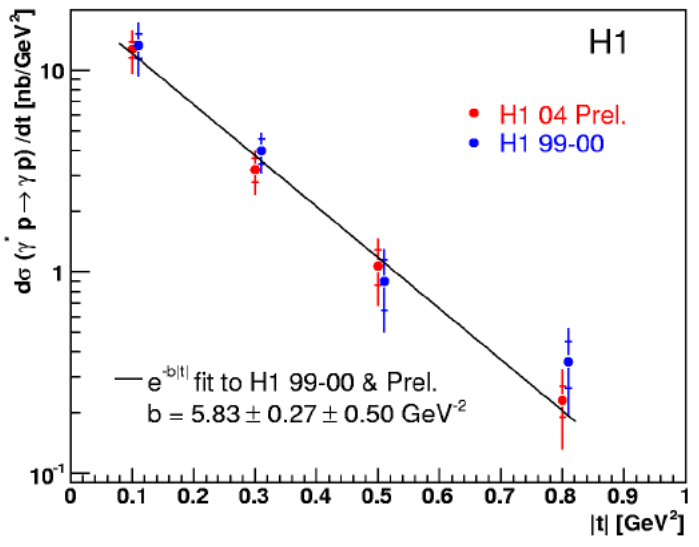




Generalised Parton Distributions



rather ``hard´´
energy dependence



rather ``soft´´
t dependence

Conclusions

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

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

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

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

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

QCD understanding of diffraction