HADRON PHYSICS 2002

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Bento Gonalves, Rio Grande do Sul

Diffraction at HERA

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HERA

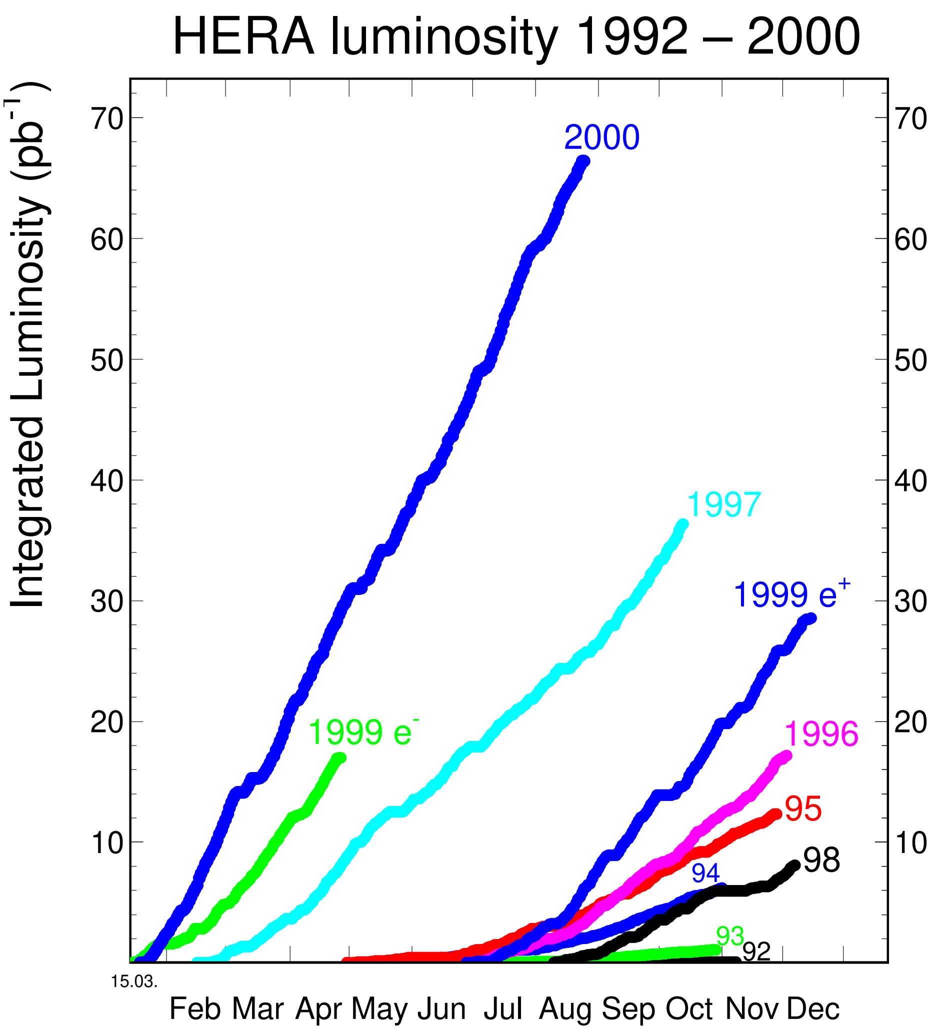
e p

$\sqrt{s} \simeq 300$ GeV

27.5 GeV 920 GeV

- separation time of bunches: 96 ns (10.4 MHz)
- Inst. Luminosity $1.5 10^{31}\ cm^{-2}s^{-1}$
- 4 experiments

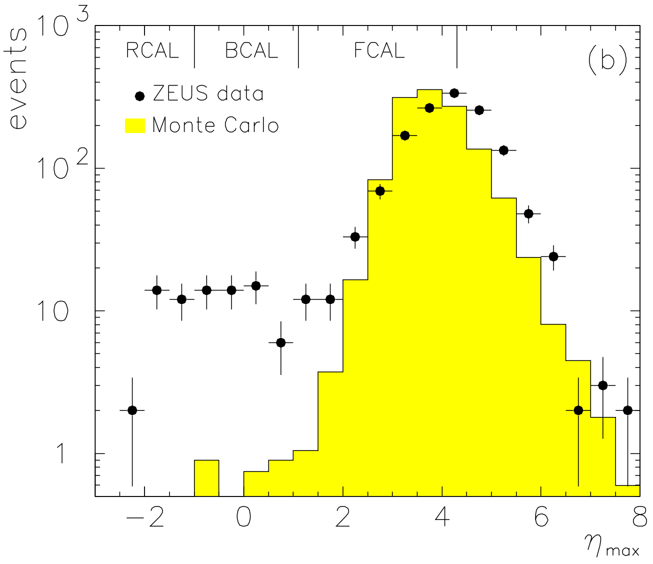
$e-p$:	H1 - ZEUS	
$e-gas$:	HERMES	(polarised e beam)
$p-wires$:	HERA-B	



- HERA II 2003-2006 : Luminosity increase x 5
  $\rightarrow 1\ \text{fb}^{-1}$
  long. polarised e beam

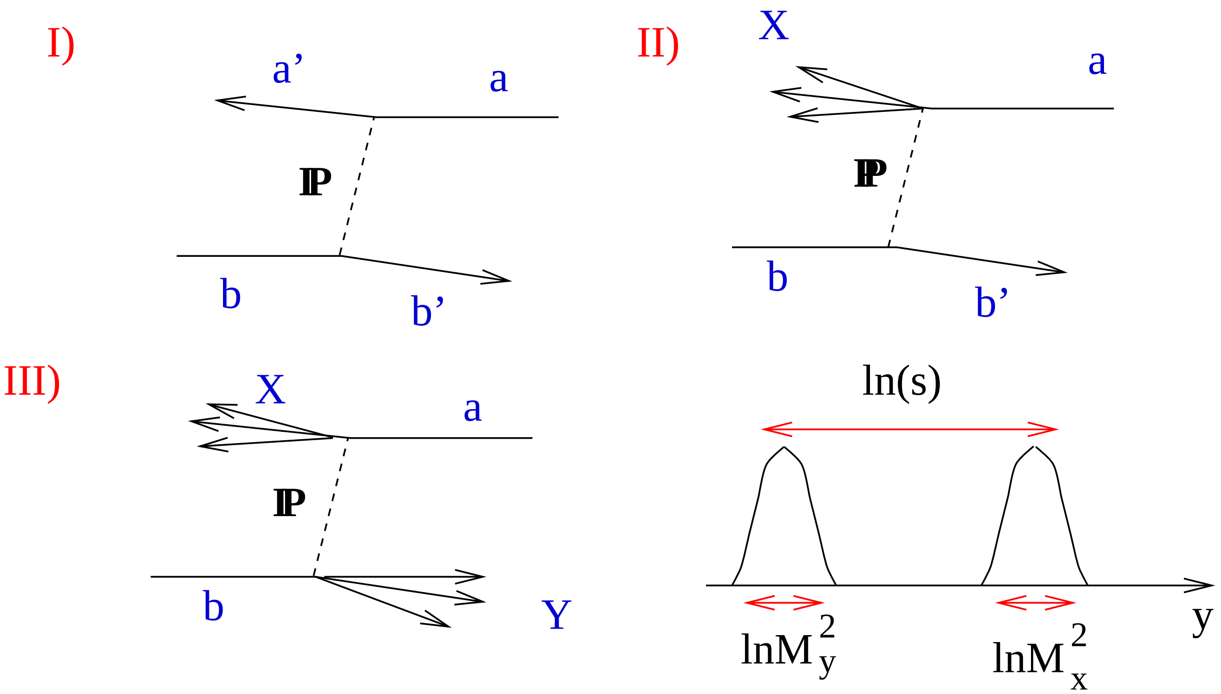
Introduction

- In first HERA data (1993) on observes:



Excess of events (10%) at high Q^2 with no energy in the forward part (proton direction) of the detector! $\Rightarrow$ first observation of hard diffraction

Diffrcation in h-h soft interactions:



- No quantum number exchanged : $I\!\!P$ (0^{++})
- Low p_T final states
- M_X and M_Y are independent $\Rightarrow$ rapidity gap.

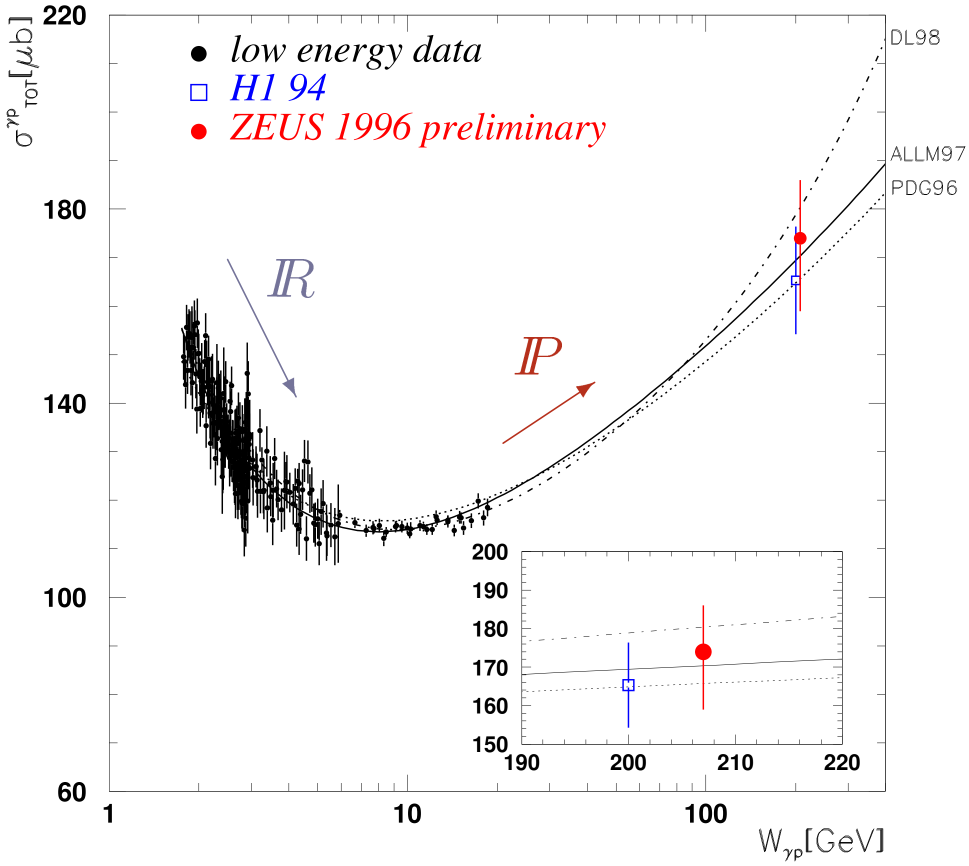
HERA: Total $\gamma^* - p$ cross sections

Optical Theorem

$$\sigma_{AB\to X} = \frac{1}{W^2} Im\{T^{AB\to AB}(W^2, t=0)\}$$

relates the Total cross section and the forward scattering, i.e diffraction.

Total Cross Section and Regge Approach



$\Rightarrow$ Good description by Regge Model

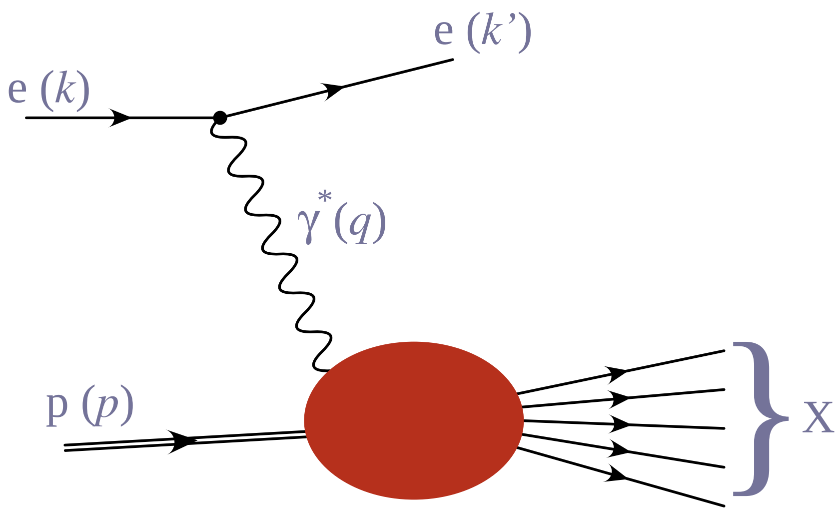
$$\sigma_{Tot} = A\ W^{2(\alpha_{\mathbb{P}}-1)} + B\ W^{2(\alpha_{\mathbb{R}}-1)}$$

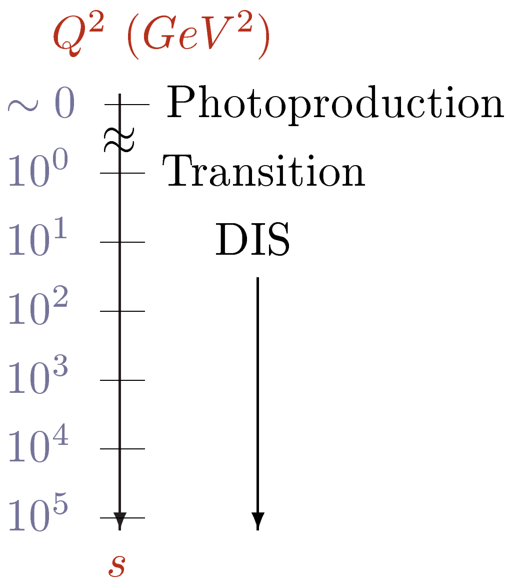
Fast fall due to Reggeon exchange: $\mathbb{R}\ :\ \alpha_{\mathbb{R}} = 0.55$
Slow rise due to Pomeron exchange: $\mathbb{P}\ :\ \alpha_{\mathbb{P}} = 1.08$

$\Rightarrow$ $\mathbb{P}$ dominates at large energy!

$\Rightarrow$ Unique opportunity to study the nature of diffraction in terms of a fundamental Theory: QCD

$e - p$ Interactions



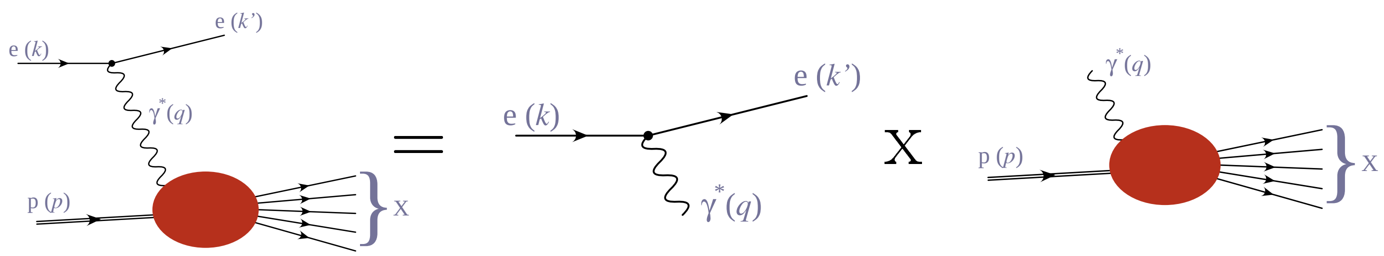


- Kinematic Variables

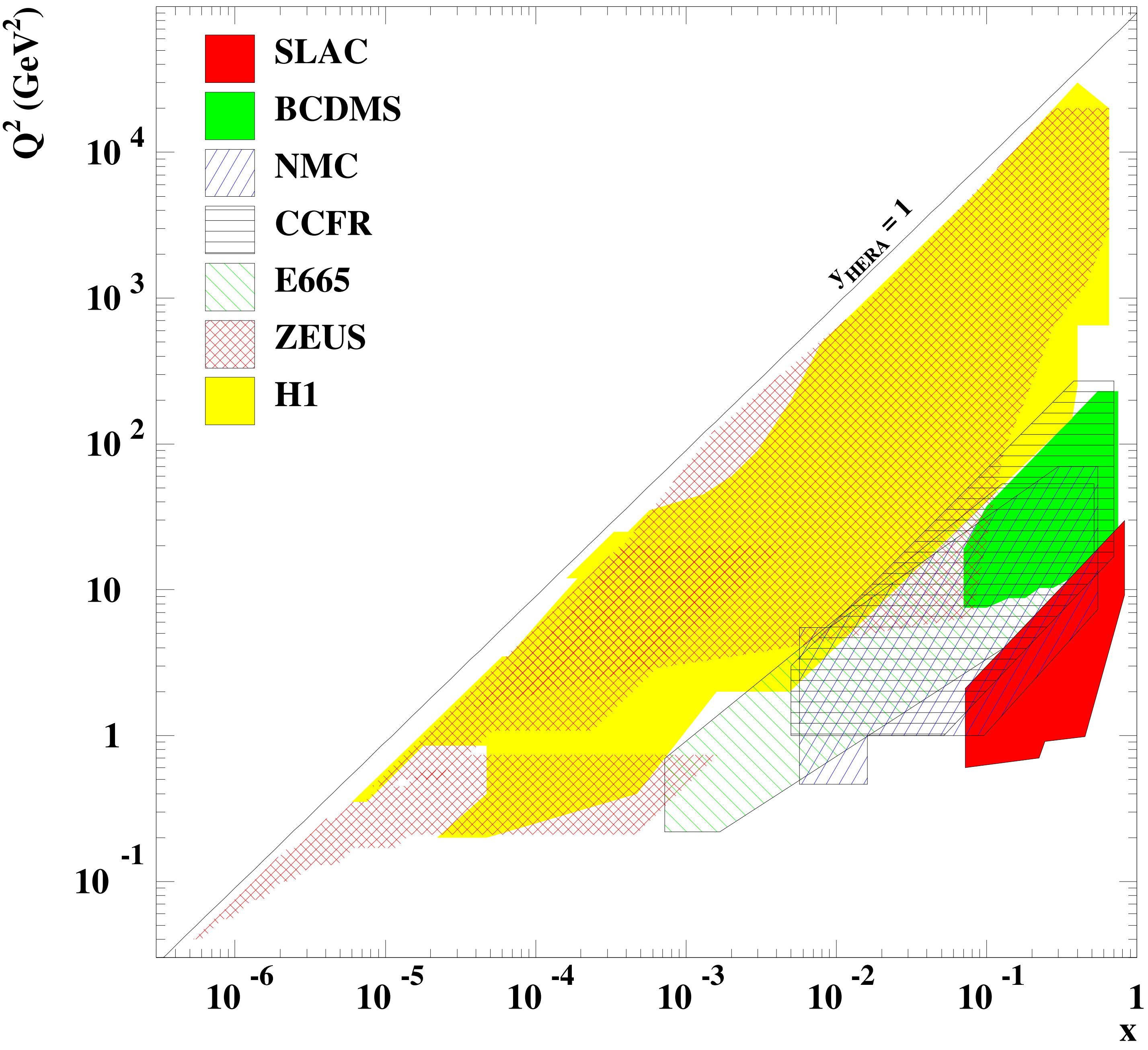
$Q^2 = -q^2 = -(k - k')^2$	squared 4-momentum transfer
$x = Q^2/(2p \cdot q)$	Bjorken-x
$y = p \cdot q/(p \cdot e)$	Inelasticity
$W = (p + q)^2$	$\gamma^* - p$ system energy

- Photon Flux factorisation

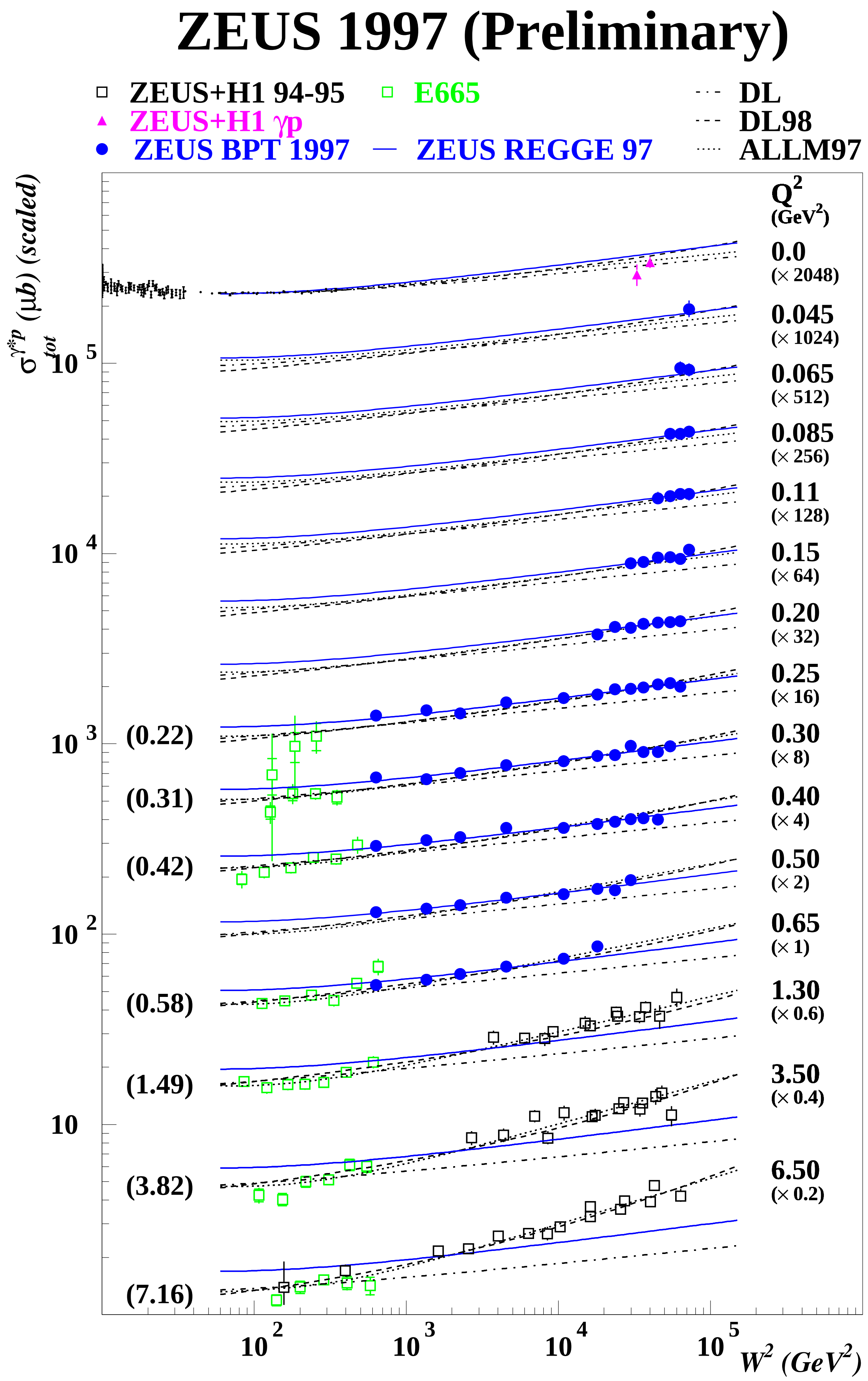
$$\sigma^{ep \to eX} = \Gamma\ \sigma^{\gamma^* p \to X}$$



Kinematic Range



Total $\gamma^* - p$ cross sections - increasing Q^2



Deep Inelastic Scattering

Q^2 increases $\rightarrow$ resolution of the probe increases

$$d \simeq \frac{0.2\ fm}{Q(GeV)}$$

In DIS : the photon probes the miscroscopic structure of the proton

- In the data: $\mathrm{d}\sigma/\mathrm{d}W$ shows soft to hard transition

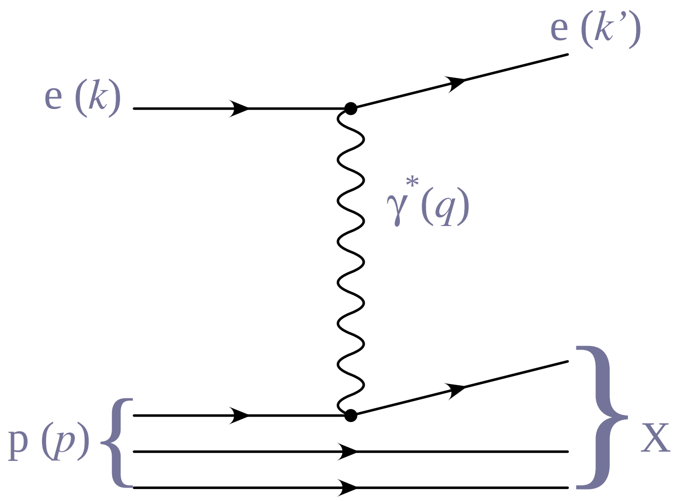
soft regime: well described by Regge model
hard regime: described by perturbative QCD ?

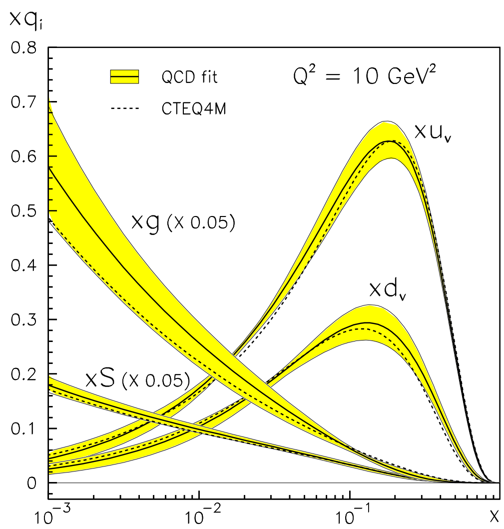
- Structure Functions:

$$\frac{\mathrm{d}^2\sigma}{\mathrm{d}x\,\mathrm{d}Q^2} \simeq \frac{2\,\pi\,\alpha^2}{x\,Q^4}\left(1+(1-y)^2\right) F_2(x,Q^2)$$

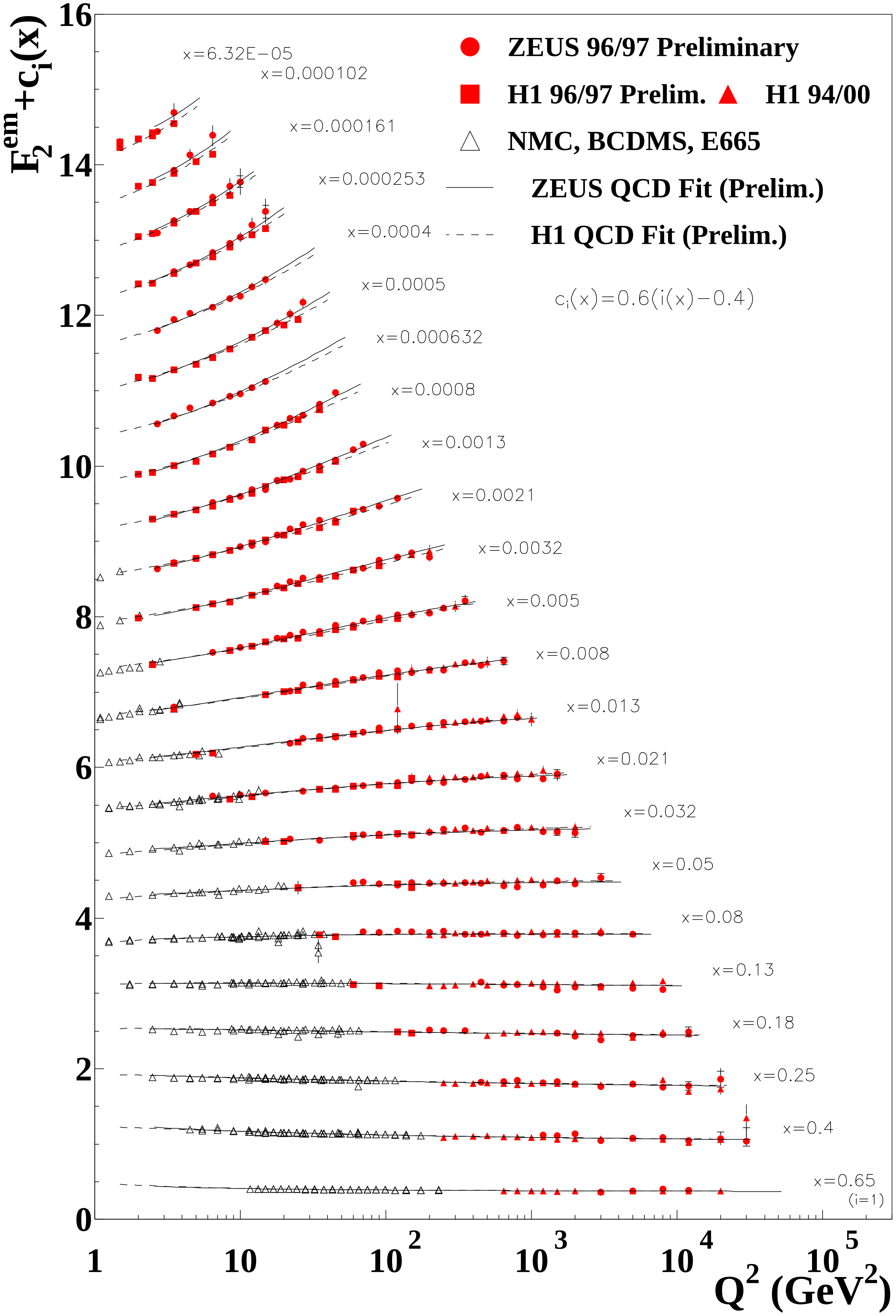
$$F_2(x,Q^2) = \sum_{quarks} e_q^2\ x\ (q+\bar{q})$$

sum of the quark densities (valence + sea) in the proton.



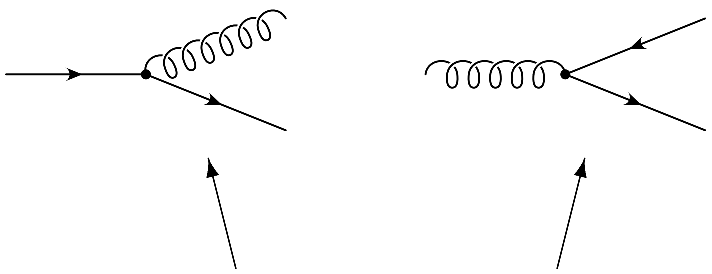


F_2 Measurements



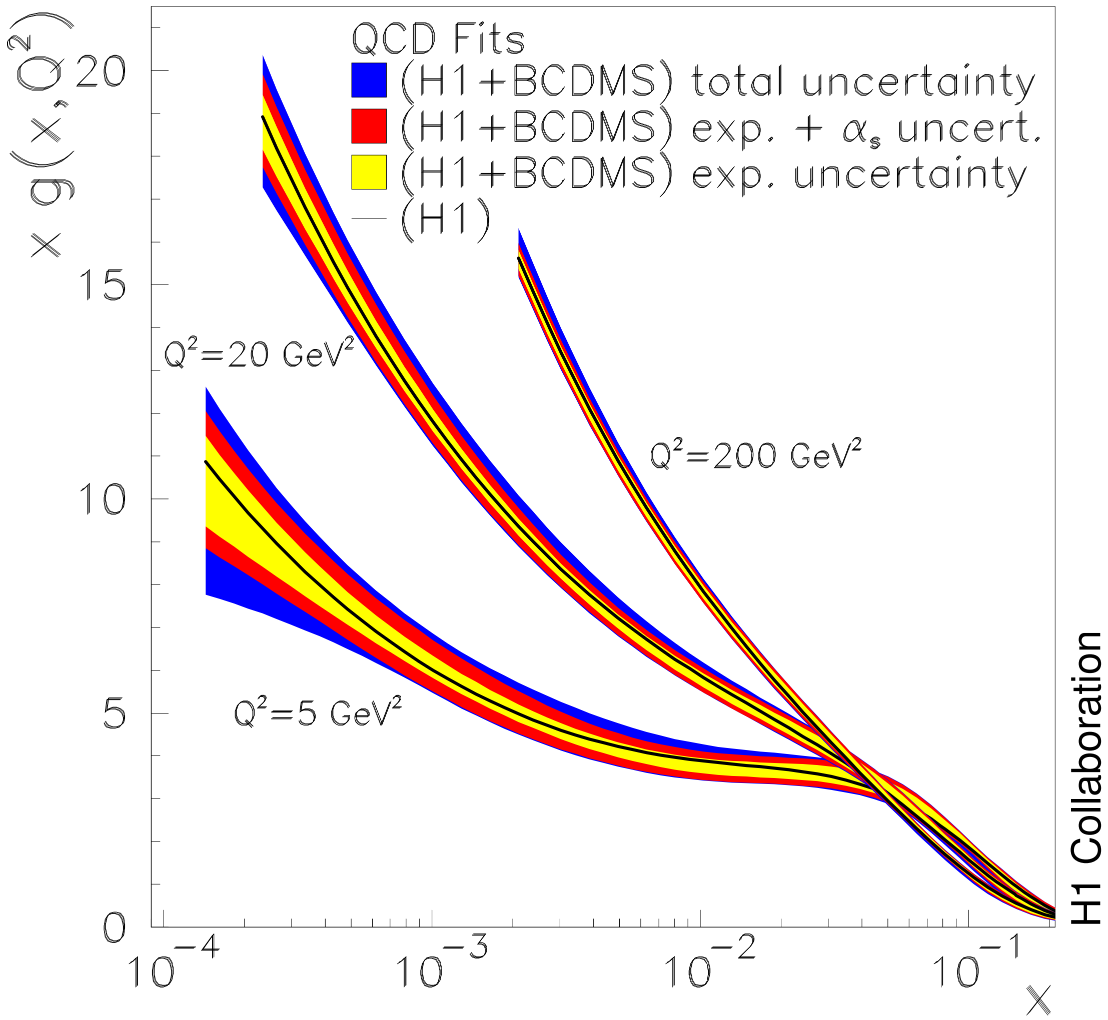
QCD: DGLAP equation

QCD predicts the evolution of F_2 in Q^2

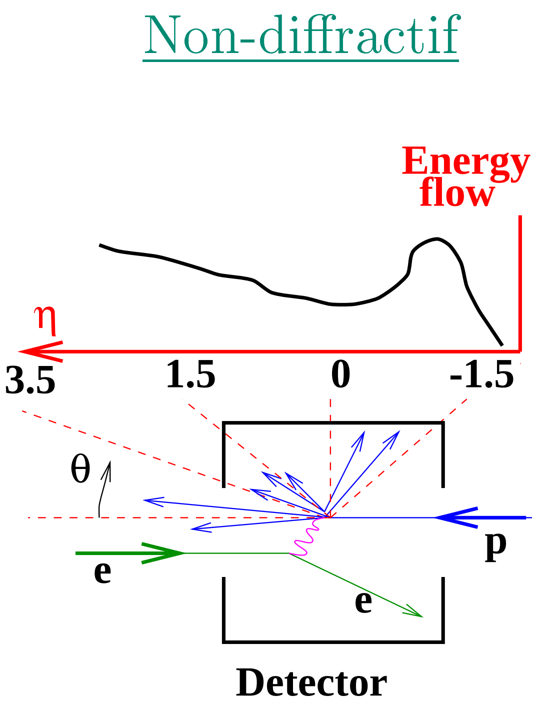


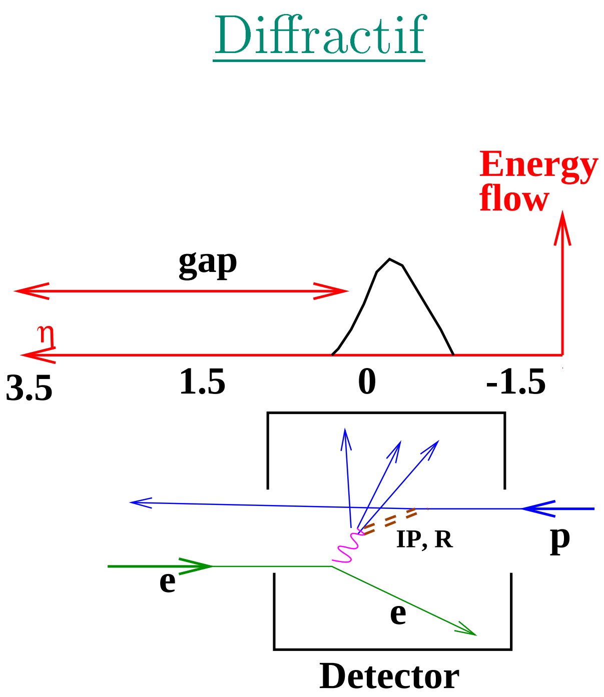
$$\frac{\mathrm{d}q(x,Q^2)}{\mathrm{dlog}Q^2} \sim \alpha_s \int_x^1 \left(q(x',Q^2)\, P_{qq} + g(x',Q^2)\, P_{qg} \right) dx'$$

- allows the Gluon density extraction (2–10 % accuracy) steep rise as Q^2 increases and x decreases



Diffraction at HERA





(Pseudo)Rapidity: $\eta = -\ln\tan(\theta/2)$

QCD interpretation of Hard Diffraction

-Pomeron structure (inclusive diffraction)
- structure function approach
- scaling violation
- PDF extraction
- dipole Model
- cross check: Eflow, di-jets

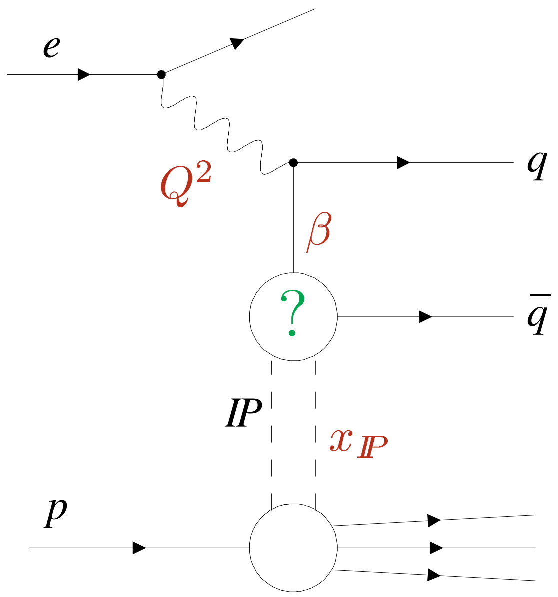
-Vector Meson production
- hard scale presence?
- skewing effect

Pomeron Structure

- If there is a hard scale $\to$ the $I\!P$ can be probed as the proton with a Structure Function approach

$$\frac{d\sigma^{ep\to eXY}}{d\beta\ dQ^2\ dx_{I\!P}} = \frac{4\pi\alpha^2}{\beta Q^4}\ (1-y+\frac{y^2}{2})\ F_2^{D(3)}(\beta, Q^2, x_{I\!P})$$

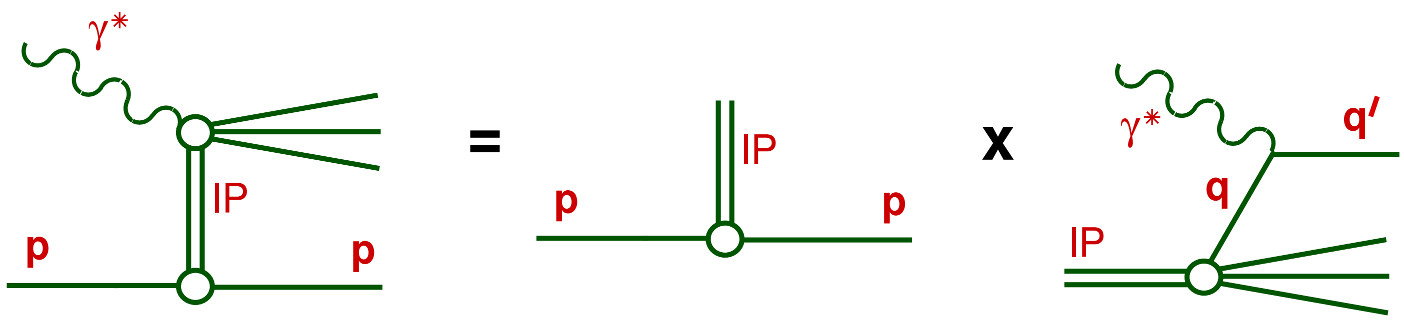
Here integrated over t



β Frac. of $I\!P$ momentum carried by quark coupling to $\gamma^\star$

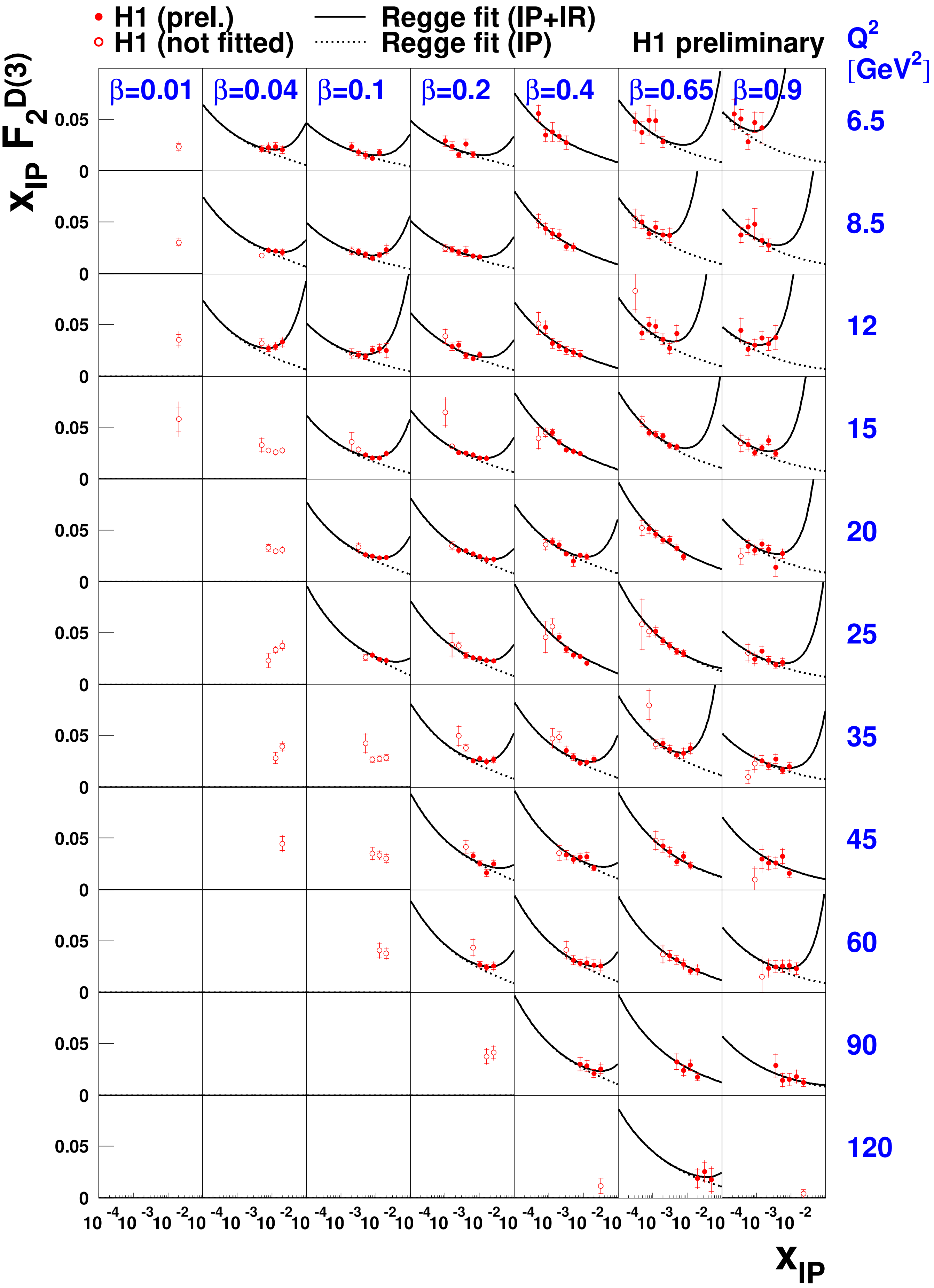
$x_{I\!P}$ Fraction of p momentum transferred to $I\!P$

- Can we factorise the $I\!P$ flux ?



$$F_2^{D(3)}(\beta, Q^2, x_{I\!P}) \propto f_{I\!P/p}(x_{I\!P}) \times F_2^{I\!P}(\beta, Q^2)$$
$$+\ f_{I\!R/p}(x_{I\!P}) \times F_2^{I\!R}(\beta, Q^2)$$

The Reggeon contribution has to be added (low β).

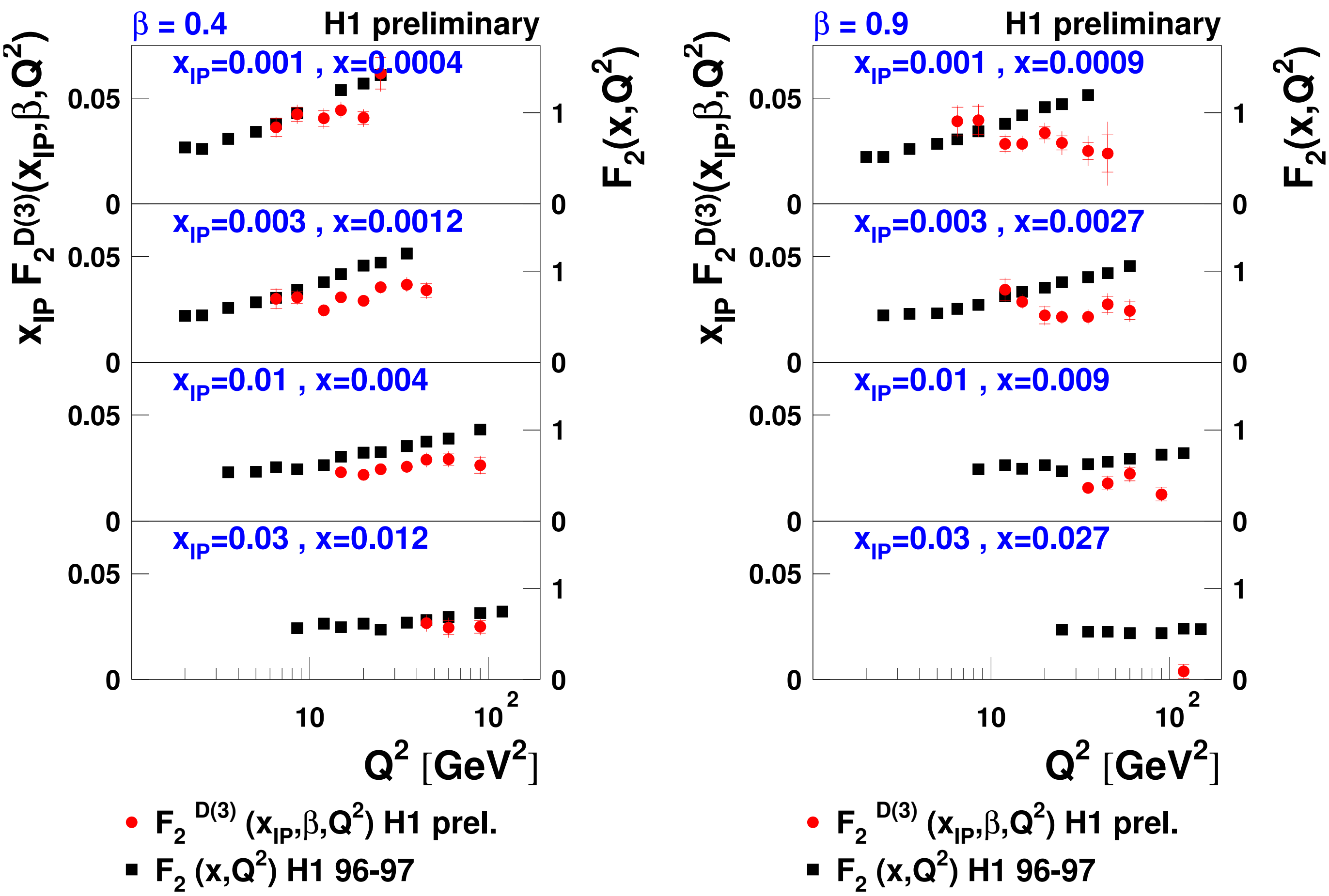


Data well described by two universal trajectories ($I\!P$ & $I\!R$)

No evidence of factorisation breaking.

Scaling Violation of F_2 and F_2^D

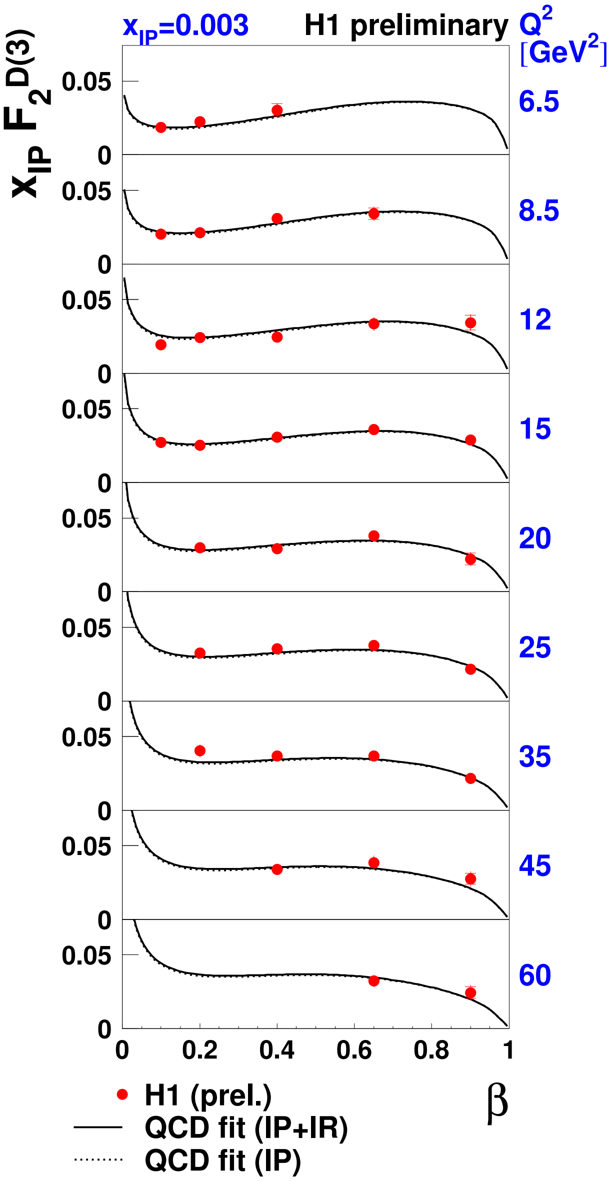
Compare scaling violations of F_2 at fixed x and F_2^D at $x = x_{I\!P} \cdot \beta$

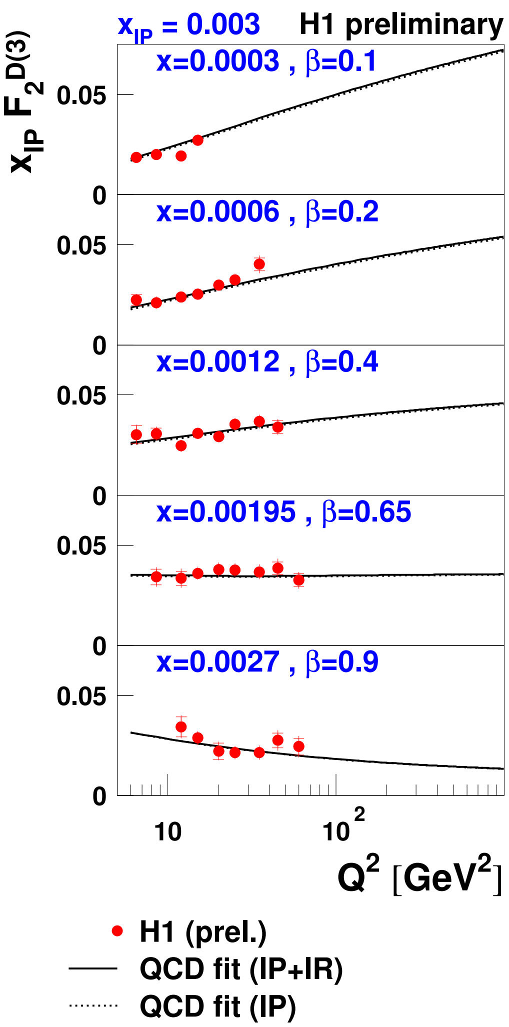


- Similar Q^2 dependence at low β
- At large β F_2 rises and F_2^D falls

$\Rightarrow$ Different dynamics at work in diffractive processes!

Q^2 and β dependence of $F_2^{D(3)}$



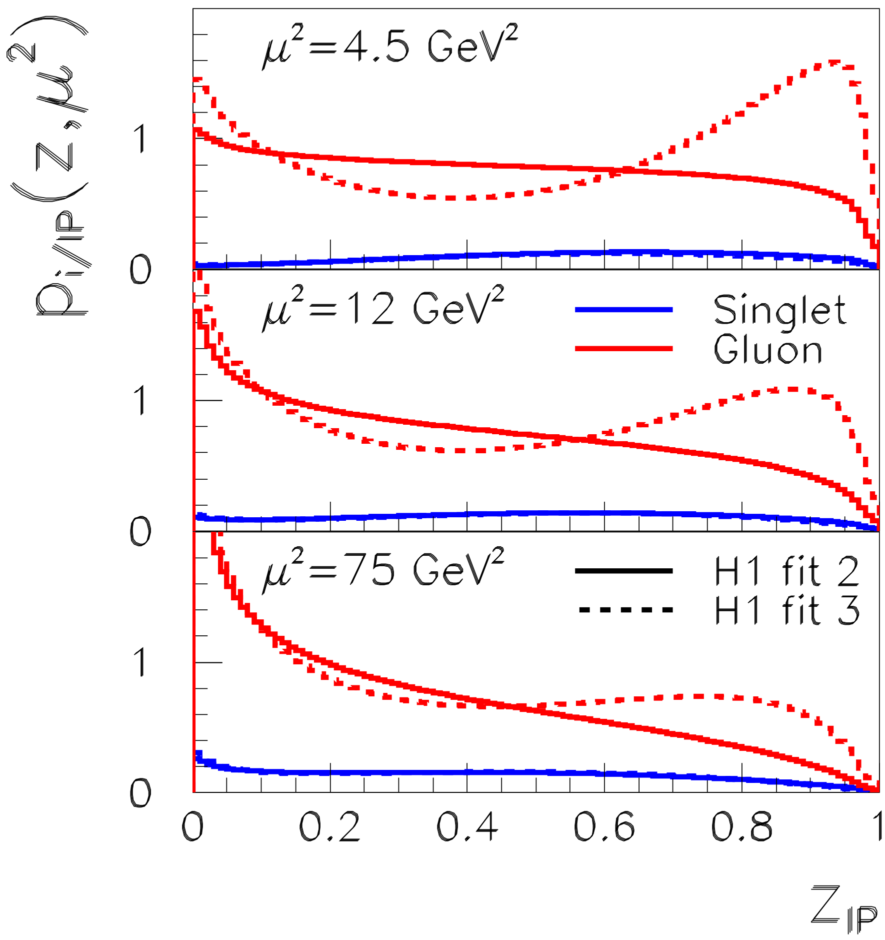


- β dependence relatively flat
- Rising scaling violation with Q^2 up to large β
- A large gluon density is required.

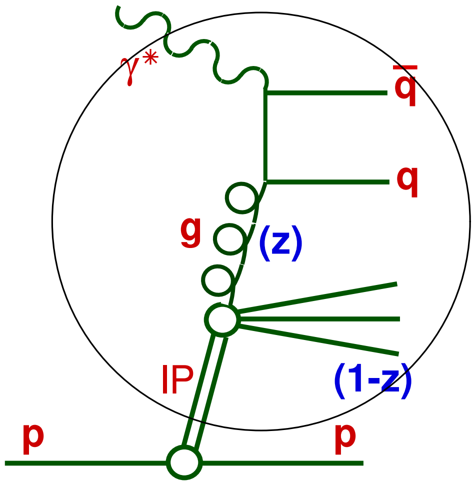
DGLAP Fits to $F_2^{D(3)}$

The β and Q^2 dependence of $F_2^{D(3)}$ can be considered in terms of the QCD evolution of structure functions for the pomeron.

- Paramterise $I\!\!P$ with q_s and g QCD motivated model at starting scale ($Q_0^2 = 3$ GeV^2) and evolve to larger Q^2.
- Assume a π structure function for $I\!\!R$.



Acceptable fits only when $I\!\!P$ is dominated by "hard" gluons.



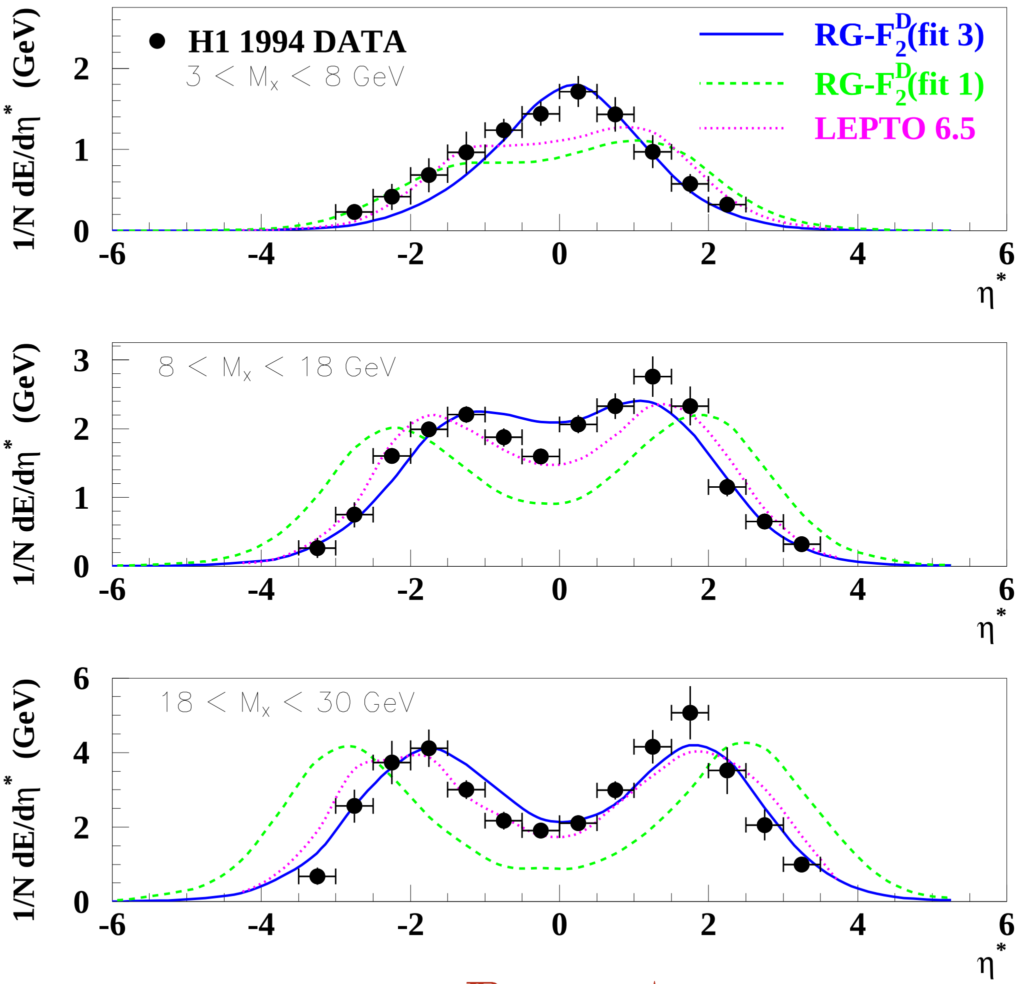
$\sim 90\%$ gluon at $Q^2 = 4.5$ GeV^2, $\sim 80\%$ at $Q^2 = 75$ GeV^2.

But large uncertainty at large z

Energy Flow in the Rest frame of X

Pseudorapidity $\eta^\star$ relative to $\gamma^\star$ direction in X rest frame.

Fit 3 Hard gluon Fit 1 quark only

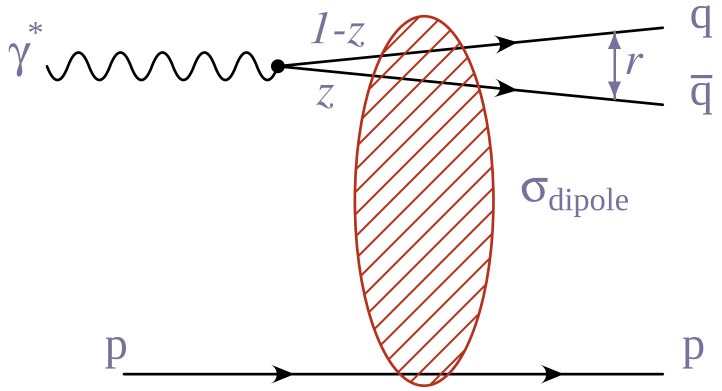


$I\!P \longleftrightarrow \gamma^\star$

- Approximately symmetric forward / backward hemispheres.
- 2-jet structure with sizeable central rapidity plateau emerges with increasing M_X.
- …Gluons are needed to model diffractive final states.

Dipole Model

In the proton rest frame:



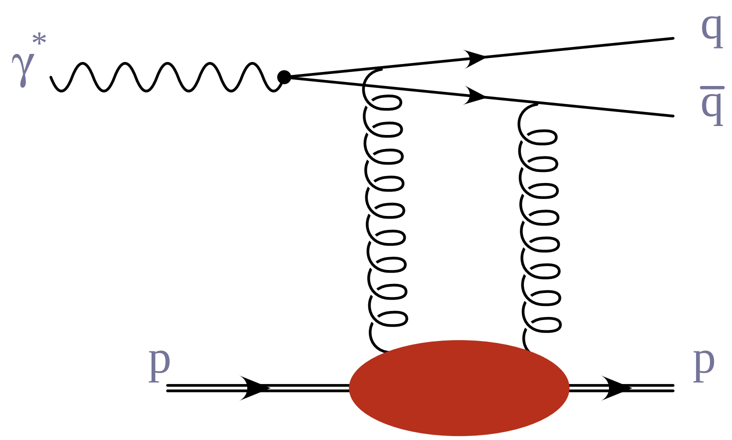
- γ^* fluctuates in $q\bar{q} + q\bar{q}g + \ldots$

$$\sigma = \int dr^2 \psi^{in}(r, z, Q^2)\ \sigma^2_{\text{dipole}}\ \psi^{out}(r, z, Q^2)$$

- ψ^{in} calculable
- σ_{d} is modelised
- integrated over trans. $q\bar{q}$ separation r

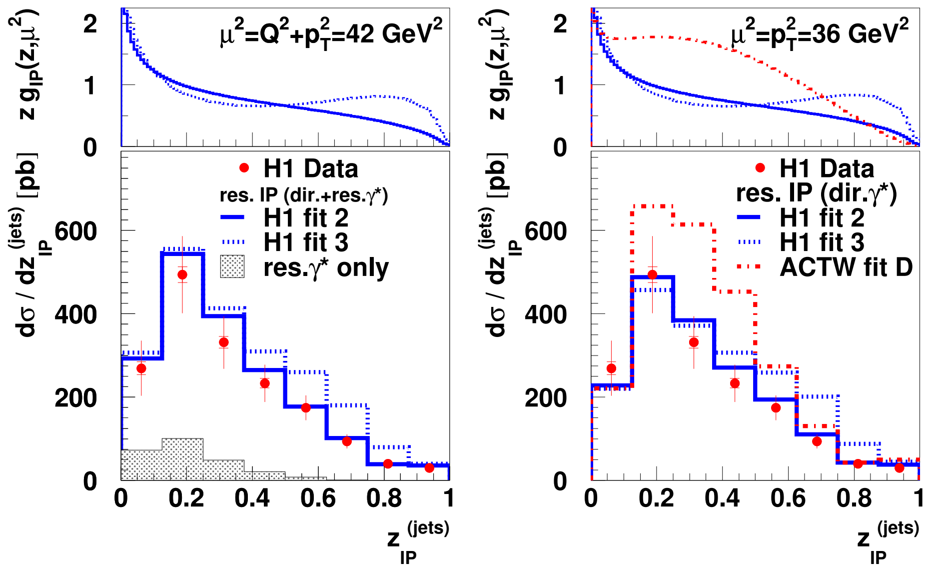
Diffraction: colour singlet exchange

$\Rightarrow \sigma_{\text{dipole}}$ modelled at lowest order in pQCD as two gluon exchange.

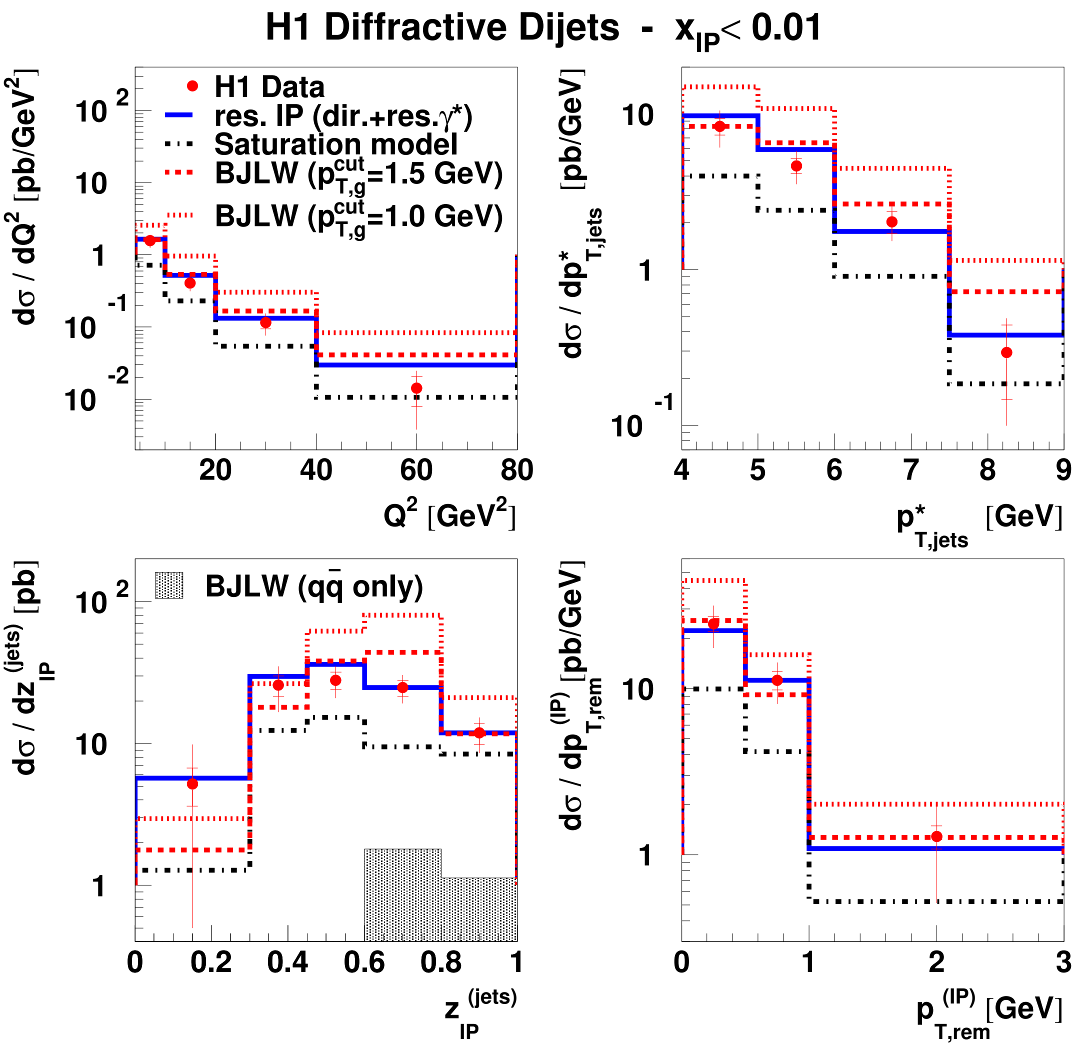


Dijet production in diffractive events

Dijets directly constrain shape and normalisation of the gluon content in the $I\!P$ $\Rightarrow$ need of P_T in the scale!.

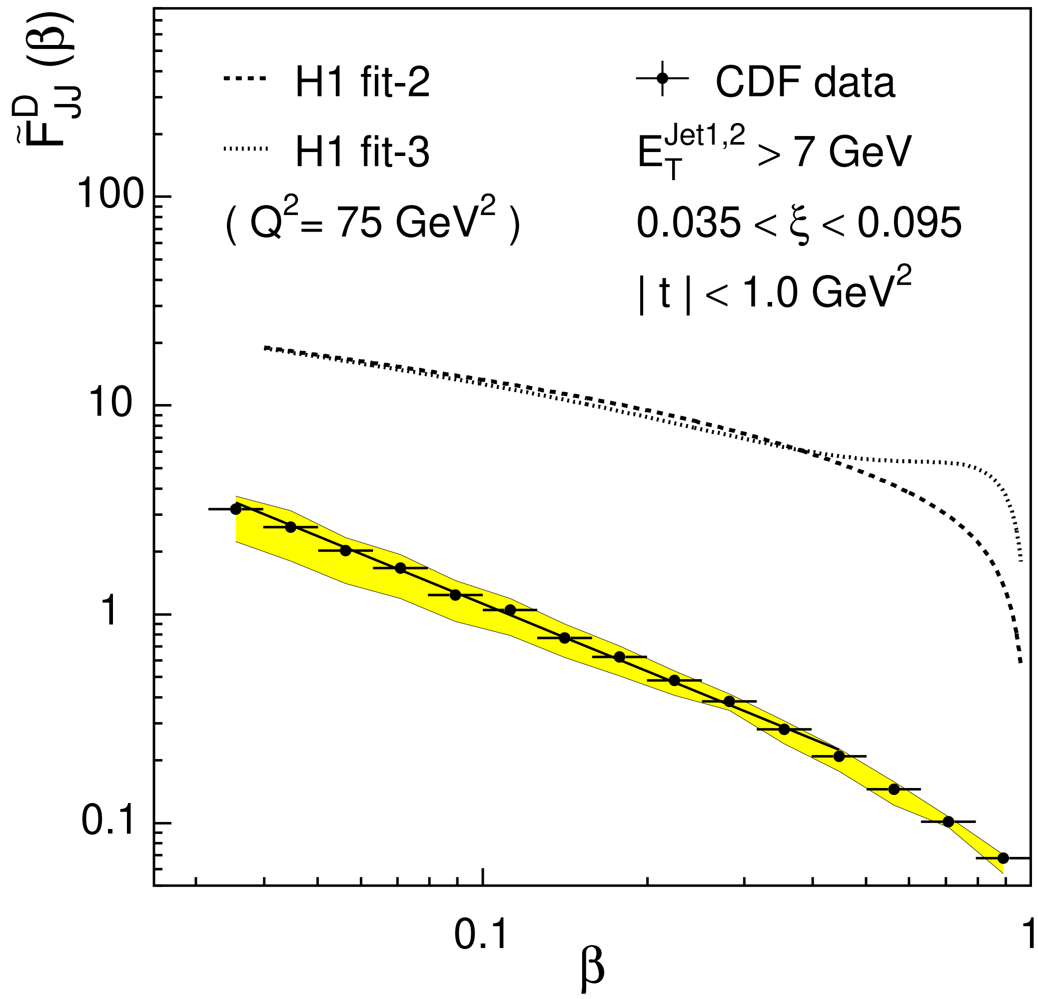


success of the Dipole Model:



Factorisation breacking at the Tevatron

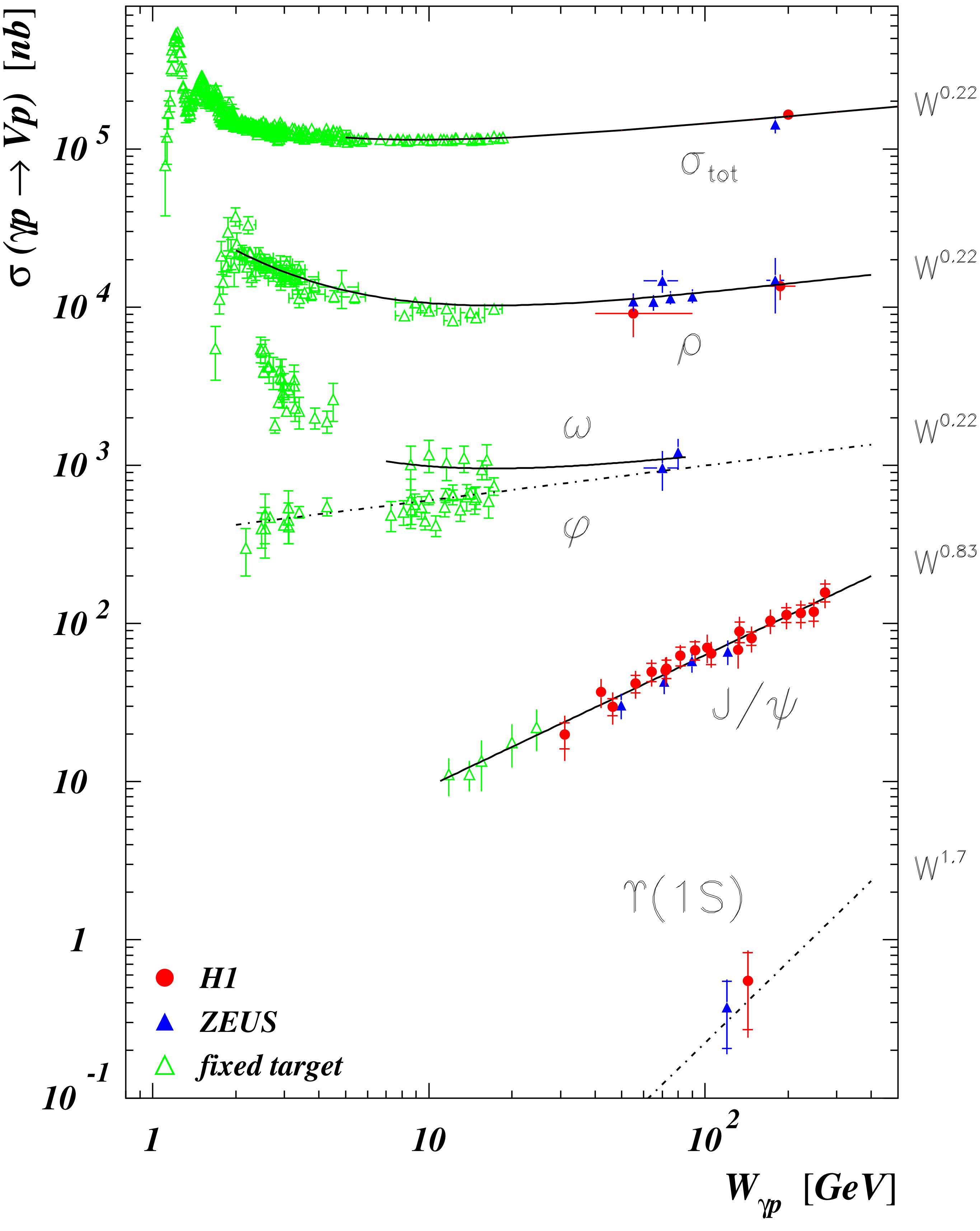
CDF measurement of the diffractive dijet production:



The prediction based on diffractive PDF's extracted at HERA are one order of magnitude above the measures cross section!

⇒ Important to get a unified picture for *ep* and *pp* collisions.

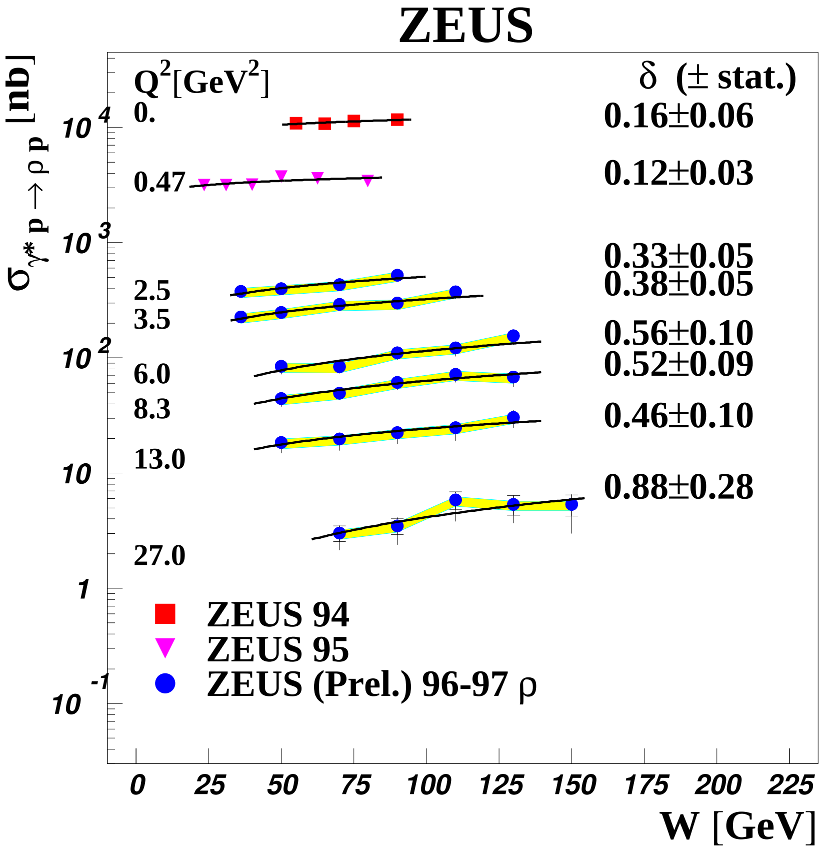
Diffractive Vector Meson cross sections



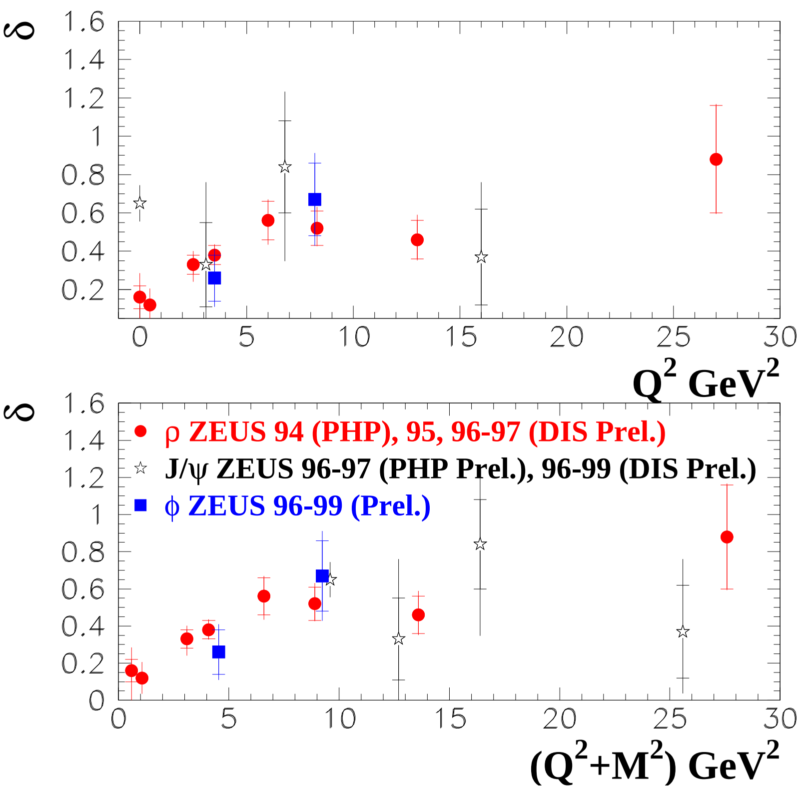
Low $\rightarrow$ high mass $\Leftrightarrow$ soft $\rightarrow$ hard regime

Q^2 evolution of ρ^o Production

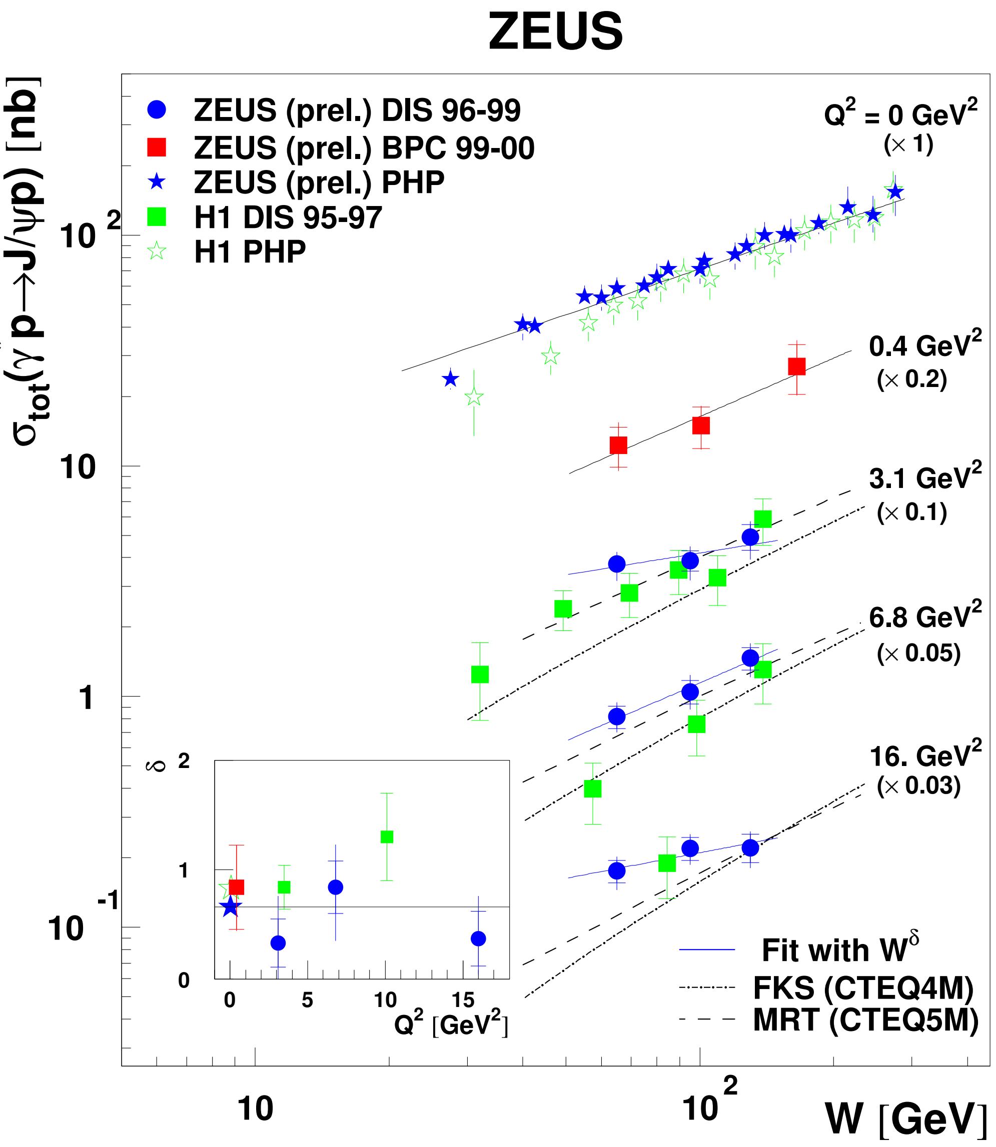
$e\ p \rightarrow e\ \rho^o p$ fit in W^δ



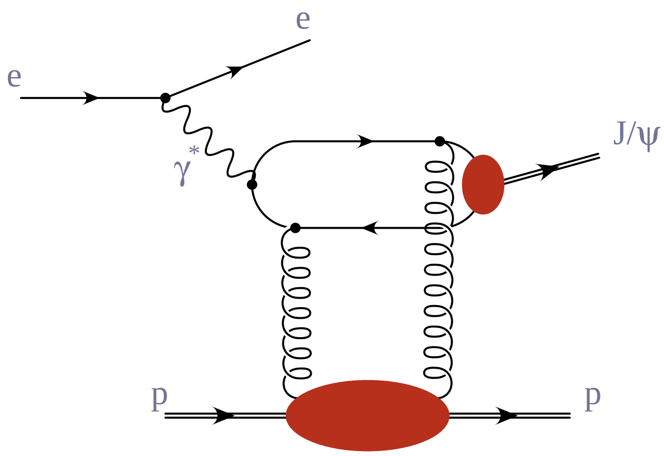
When Q^2 increases, also soft $\rightarrow$ hard transition



Diffractive J/Ψ cross section



- steep rise already at $Q^2 \sim 0$
- increasing with Q^2 ? no effect seen



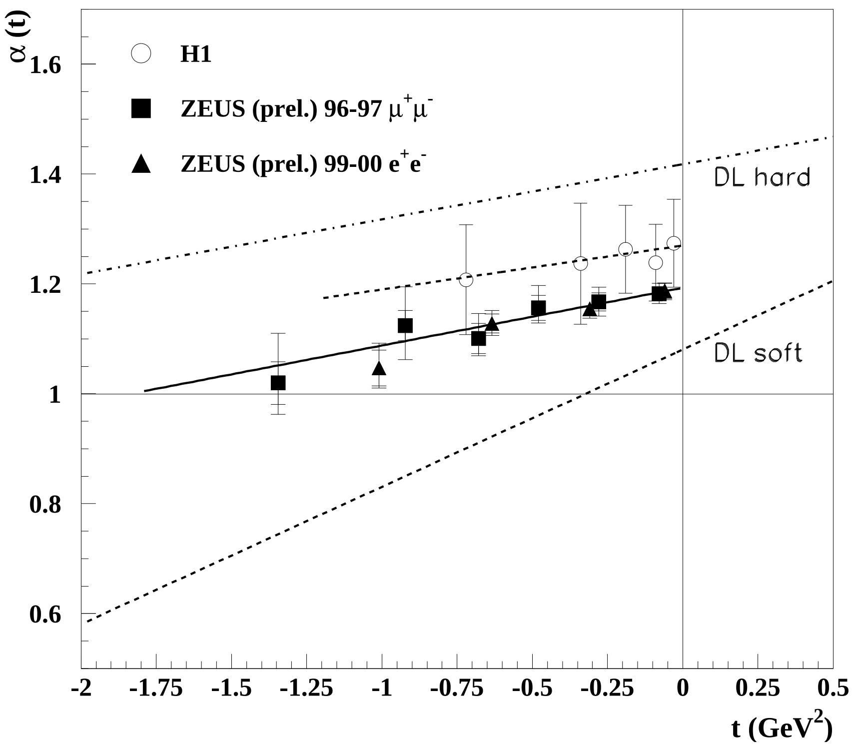
pQCD approach:

- $\int_x [x\ g(x', Q^2)]^2\ dx$
- with g from F_2 fit
- J/Ψ wave function

Good description of W dependence

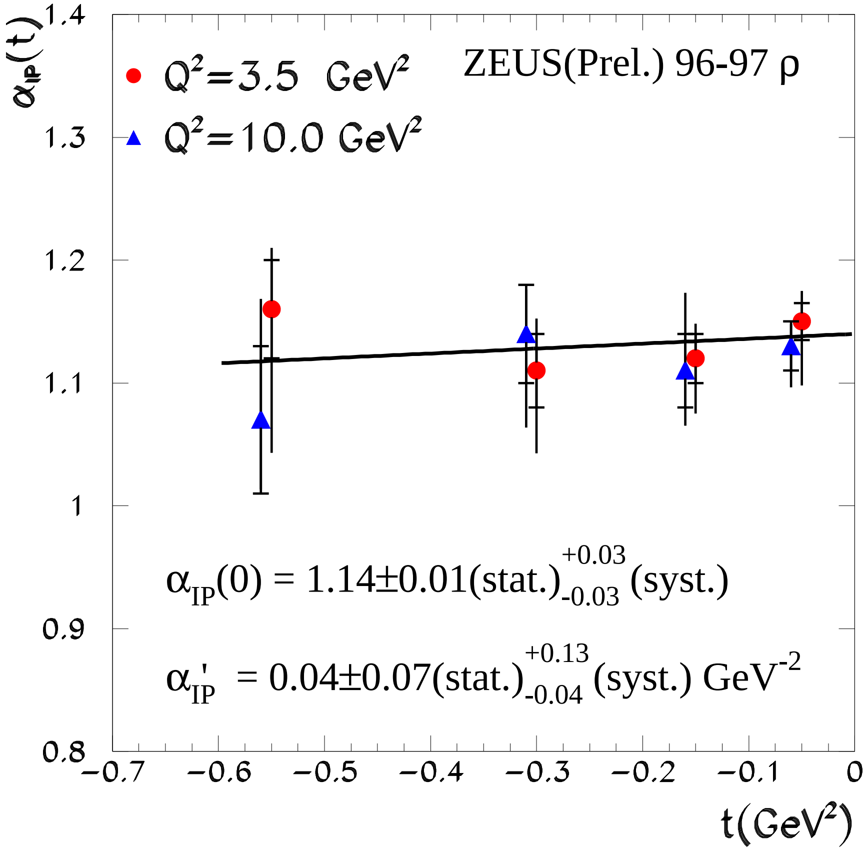
Trajectories at Large Mass or Q^2

Photoproduction $\gamma\, p \to J/\Psi\, p$



$$\alpha_{I\!P} = 1.201 \pm 0.013^{+0.003}_{-0.011}$$
$$\alpha'_{I\!P} = 0.126 \pm 0.029^{+0.015}_{-0.028}\ \mathrm{GeV}^{-2}$$

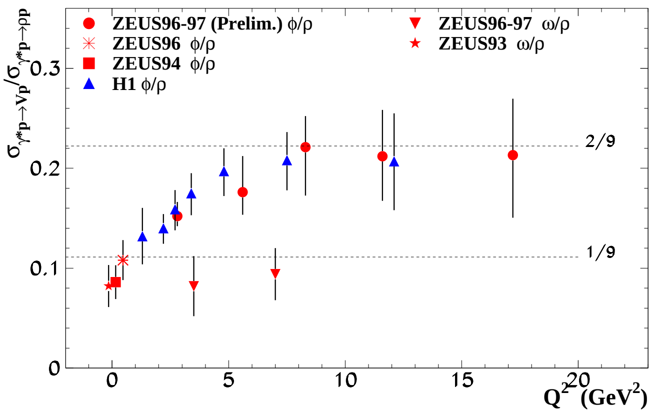
Electroproduction $\gamma^*\, p \to \rho\, p$

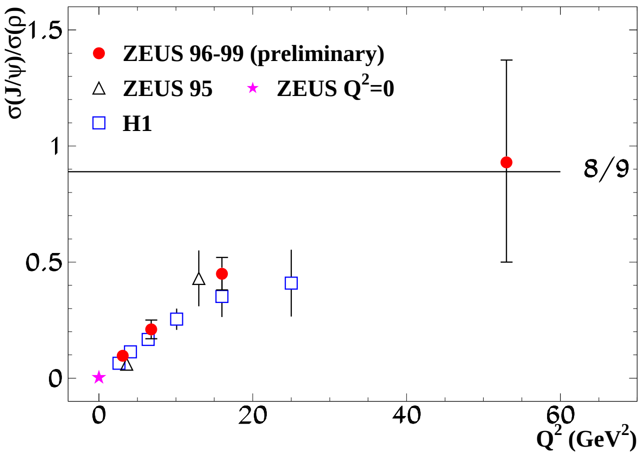


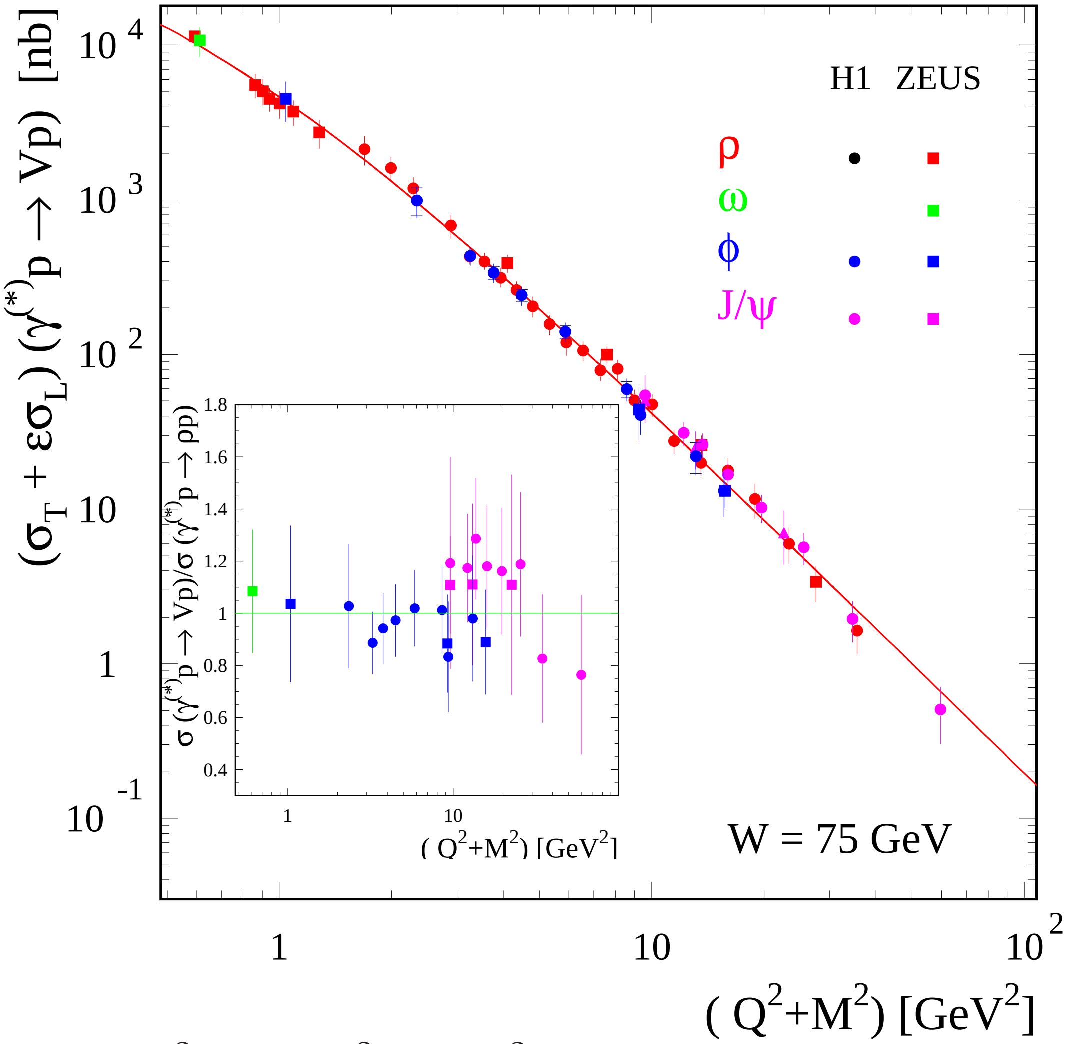
Measured values of $\alpha'_{I\!P}$ smaller than soft Pomeron $\alpha'_{soft\, I\!P} = 0.25\ \mathrm{GeV}^{-2}$

ρ-electroproduction: still large uncertainties

SU(4) prediction, from el.magn. coupling $\rho^\circ : \omega : \phi : J/\Psi$
$9 : 1 : 2 : 8$







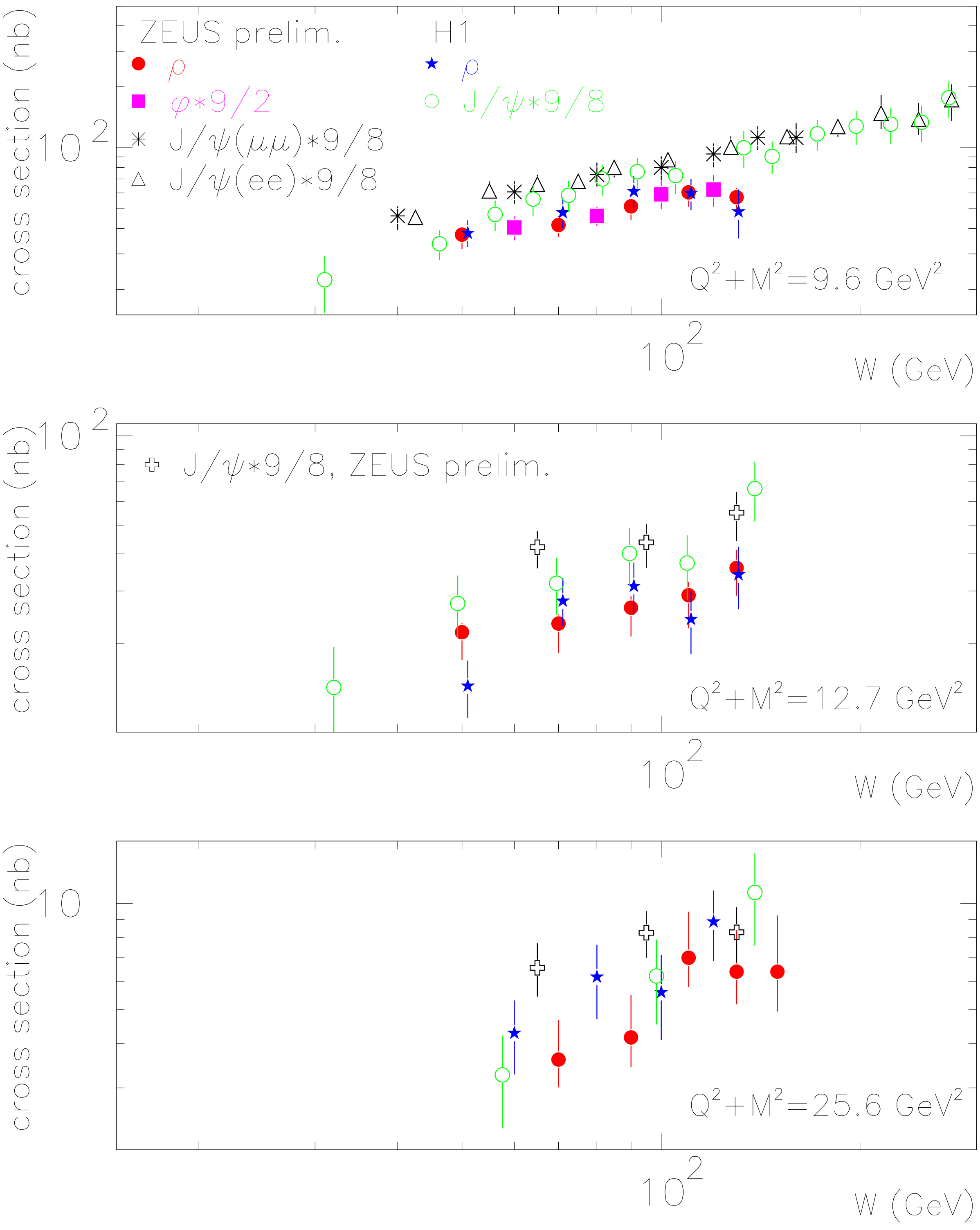
Fit $\sigma = a(Q^2 + M_V^2 + c^2)^n$

Extrapolated to W = 75 GeV

$\rho, \omega, \phi, J/\Psi$ behave universally in $(Q^2 + M_V^2)$ scale

$\Rightarrow$ approximate flavour independance

What is the good Scale?



If good scale used $\rightarrow$ same W dependence

but still: $(Q^2 + M^2_{VM})$??
$(Q^2 + M^2_{VM} + t)$??
$(Q^2 + M^2_{VM})/4$??

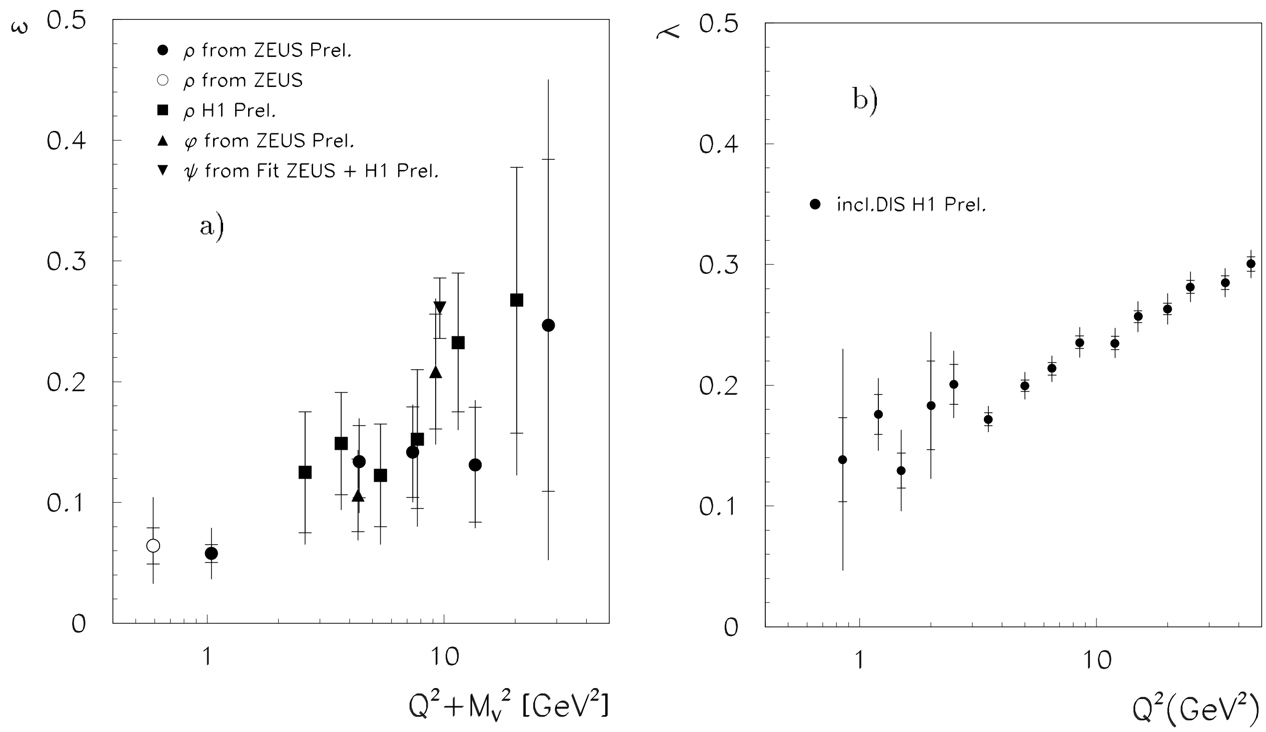
Diffractive VM and DIS Comparison

DIS: $F_2^p \;\sim\; x^{-\lambda} \qquad\qquad \sim\; W^{2\lambda}$ (at fixed Q^2)

$$\sigma^2_{\gamma^* p}(Q^2, W) \;\sim\; (F_2^p(Q^2, x))^2 \sim d\sigma/dt(Q^2, W, t=0)$$

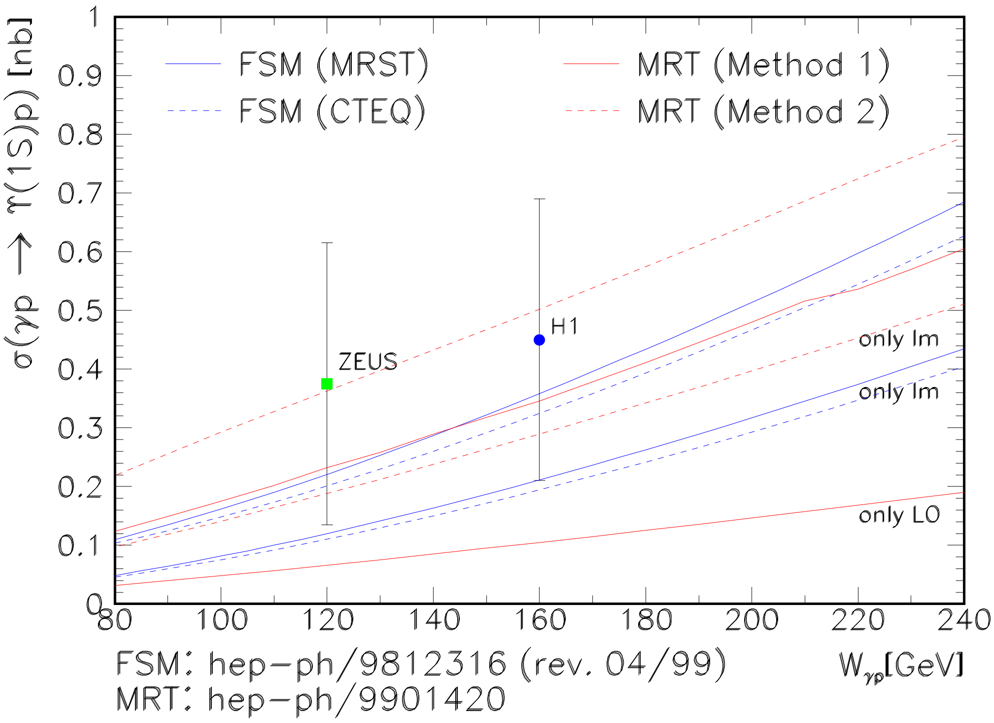
DIS $\Leftrightarrow$ Diffraction
$W^{4\lambda} \Leftrightarrow W^{(\delta = 4\,\epsilon)}$

The increase of $\boldsymbol{F_2^p}$ with decreasing x and the increase of the VM production with increasing $\boldsymbol{W}$ have a common origin: the Gluon density in the proton

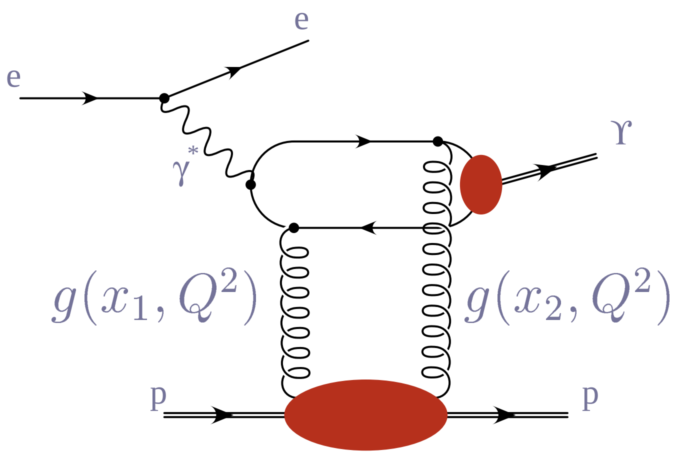


$\boldsymbol{\epsilon}$ and $\boldsymbol{\lambda}$ have similar $\boldsymbol{Q^2(+M_V^2)}$ dependences

Skewing effect

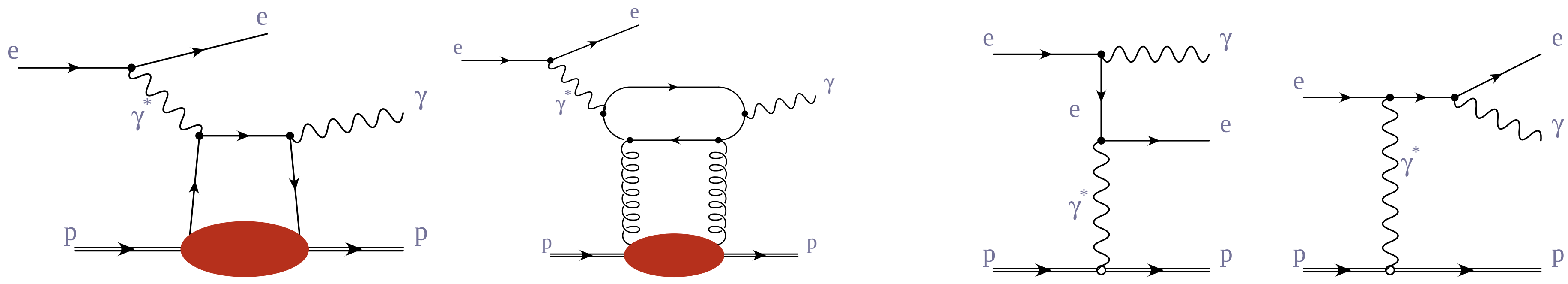


pQCD calculations has to include skewed gluon distributions and real parts for the amplitude to describe the data

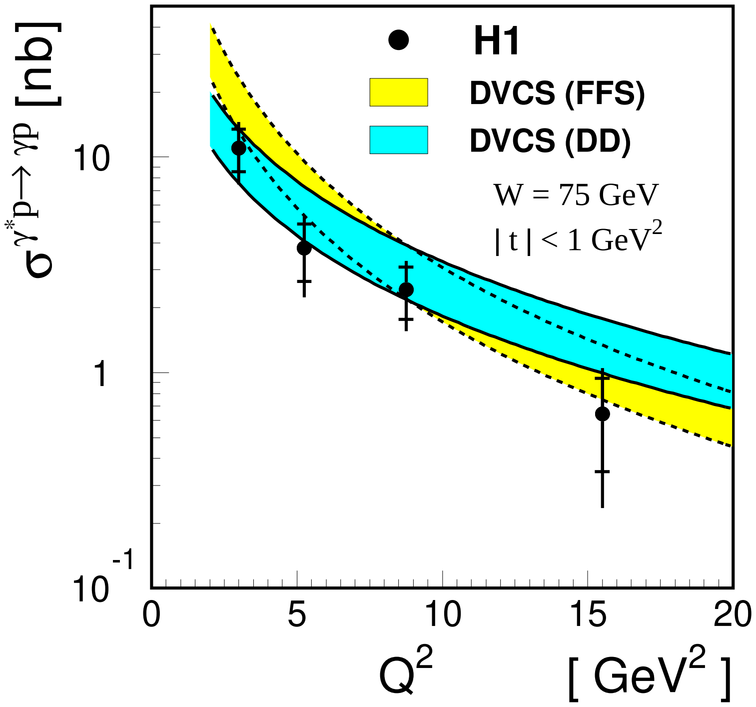


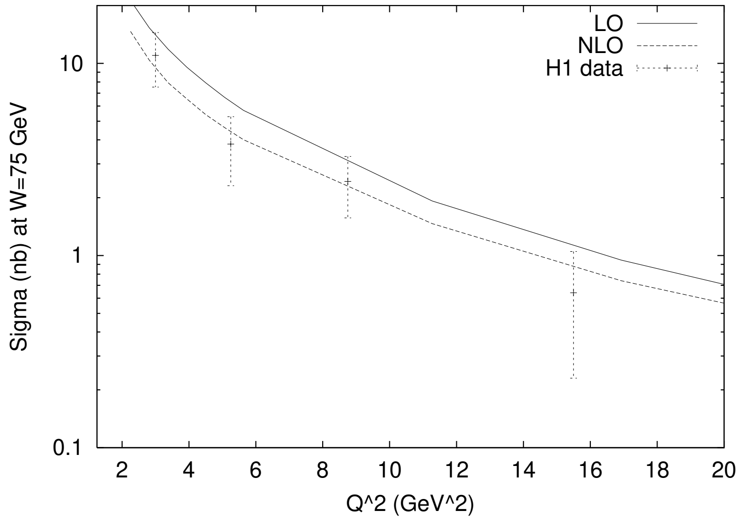
$x1 \neq x_2$

Deep Virtual Compton Scattering



Cleanest diffractive process - fully calculable in pQCD.
Sensitive to skewed effect through the interference term with Bethe-Heitler.





Newest NLO QCD calculation in good agreeement

Conclusions

- Diffraction at HERA shed a new light on the proton structure and hadronic interactions

- Study (in a wide W range) the transition between non-perturbative physics (Regge) and pQCD, using different scales:
  Q^2 Incl. Measurement and Vector Meson
  M_x Vector Meson
  t ? Incl. and Vector Meson - Not yet clear (not shown)

- With a Structure Function approach, the partonic structure of the $I\!P$ has been extracted.
  $I\!P$ largely dominated by the gluon density
  F_2 and F_2^D have similar behaviour except at large β
  (i.e. small M_x)

- Important success of Dipole Models
  Di-jet production
  J/Ψ cross section from $[xG(x,Q^2)]^2$

- First fully caculated process measured : DVCS
  In good agreement with NLO pQCD calculation