Deep inelastic diffractive scattering at HERA

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(on behalf of the H1 and ZEUS Collaborations)

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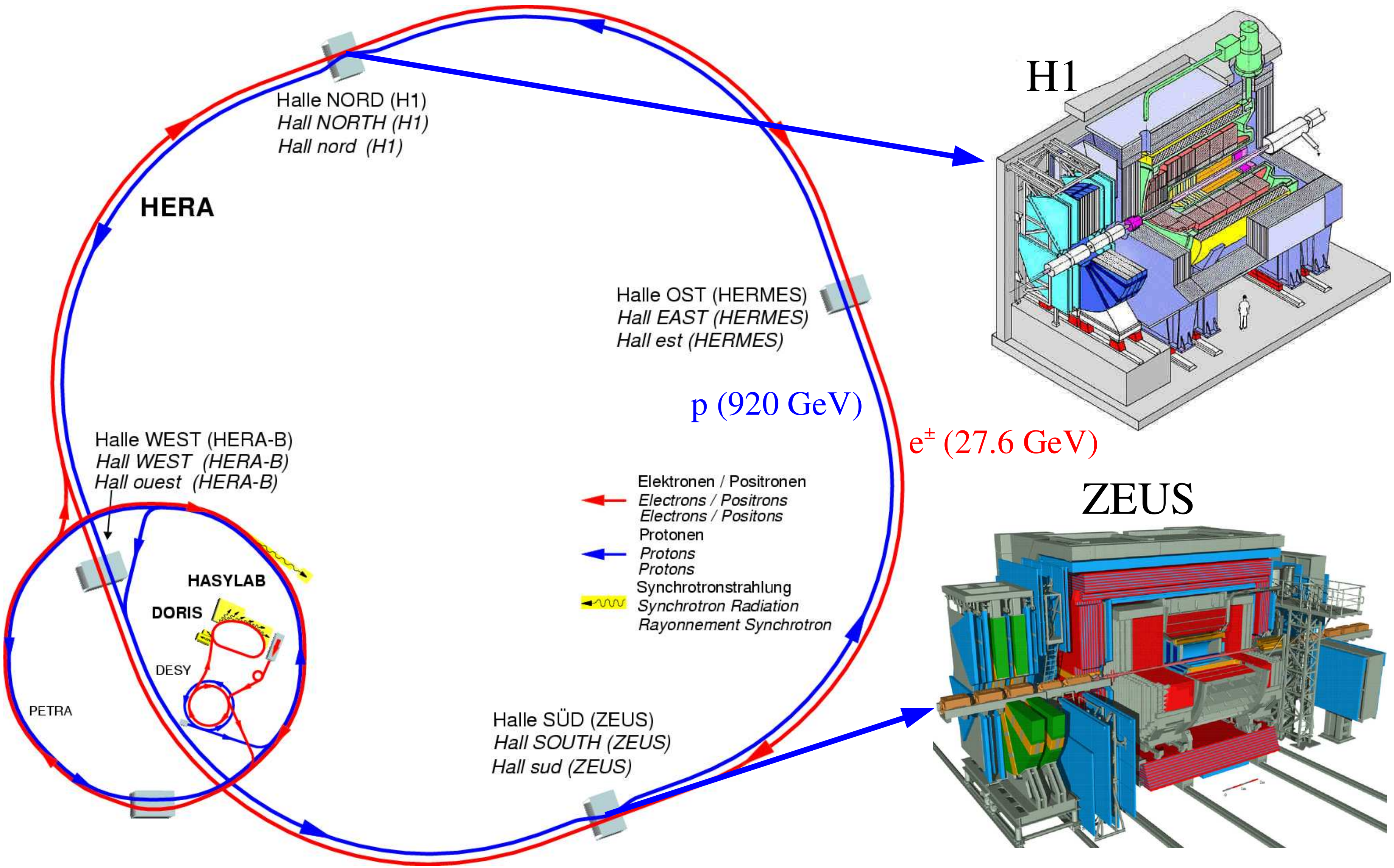
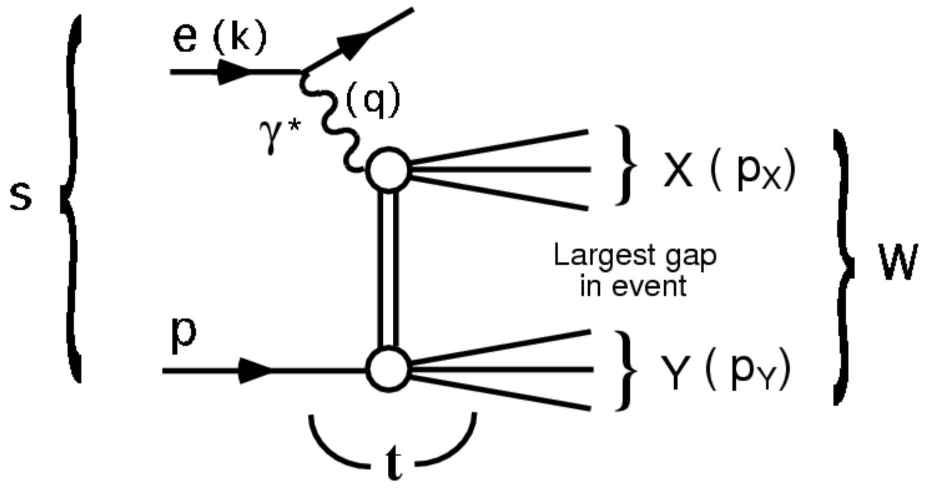
Outline

- Introduction
- Measurement of the cross section for deep inelastic diffraction
- Regge-QCD analysis
- Model comparisons
- Ratio of diffractive to inclusive DIS

HERA, H1 and ZEUS



The process $ep \rightarrow eXY$



Kinematics:

- longitudinal momentum fraction of the proton carried by the colourless exchange:

$$x_{IP} = \frac{q \cdot (P - p_Y)}{q \cdot P} \approx \frac{Q^2 + M_X^2}{Q^2 + W^2}$$

- longitudinal momentum fraction of the colourless exchange carried by the struck quark:

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

Cross section:

- reduced cross section defined through:

$$\frac{d^3 \sigma^D}{d x_{IP}\, d x\, d Q^2} = \frac{4 \pi \alpha^2}{x Q^4} (1 - y + \frac{y^2}{2}) \sigma_r^{D(3)}(x_{IP}, x, Q^2)$$

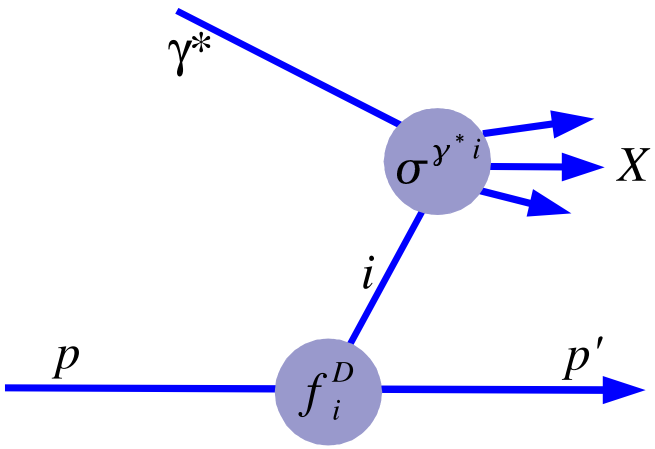
- relation to $F_2^{D(3)}$ and $F_L^{D(3)}$:

$$\sigma_r^{D(3)} = F_2^{D(3)} - \frac{y^2}{1 + (1 - y)^2} F_L^{D(3)}$$

QCD and Regge factorization

QCD hard scattering factorization:

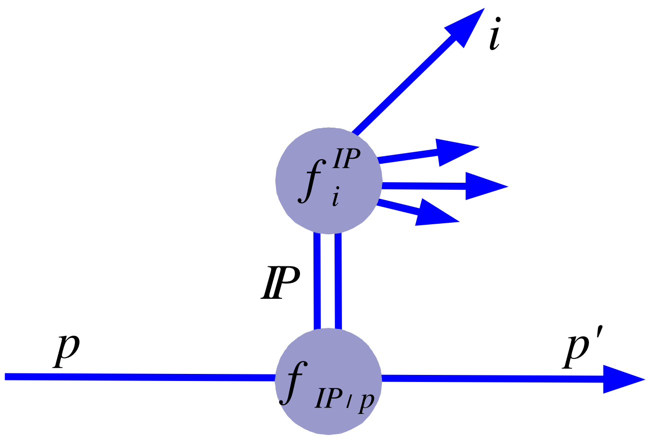
$$\sigma^{\gamma^* p \to p'X} = \sigma^{\gamma^* i} \otimes f_i^D$$



- $\sigma^{\gamma^* i}$ the universal partonic cross section (same as in inclusive DIS)
- f_i^D the parton distribution function for a parton i under the constraint that the proton survives the diffractive scattering (f_i^D should obey the DGLAP evolution equations)

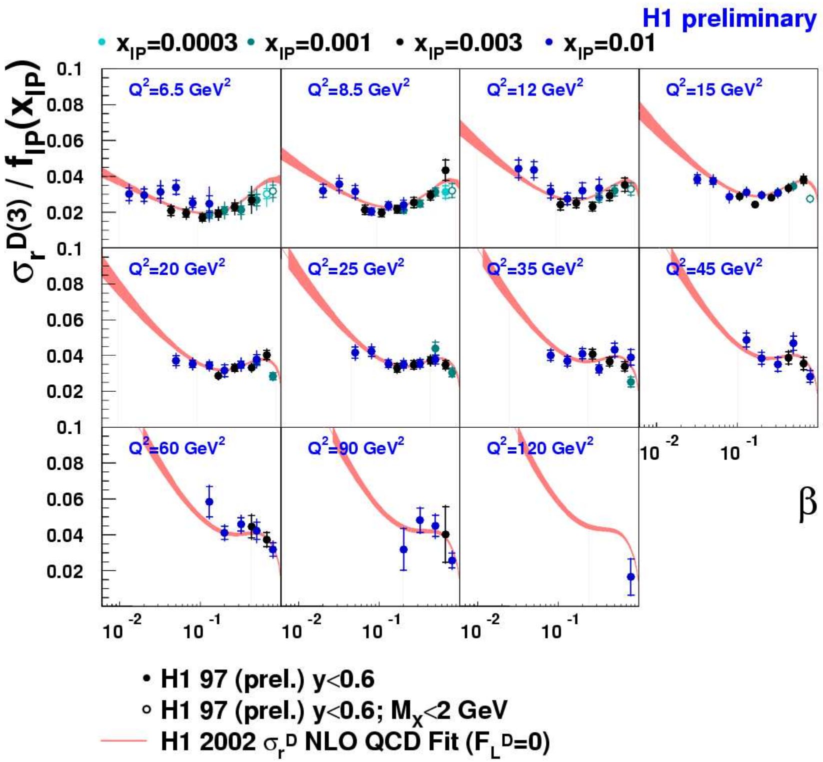
Regge factorization:

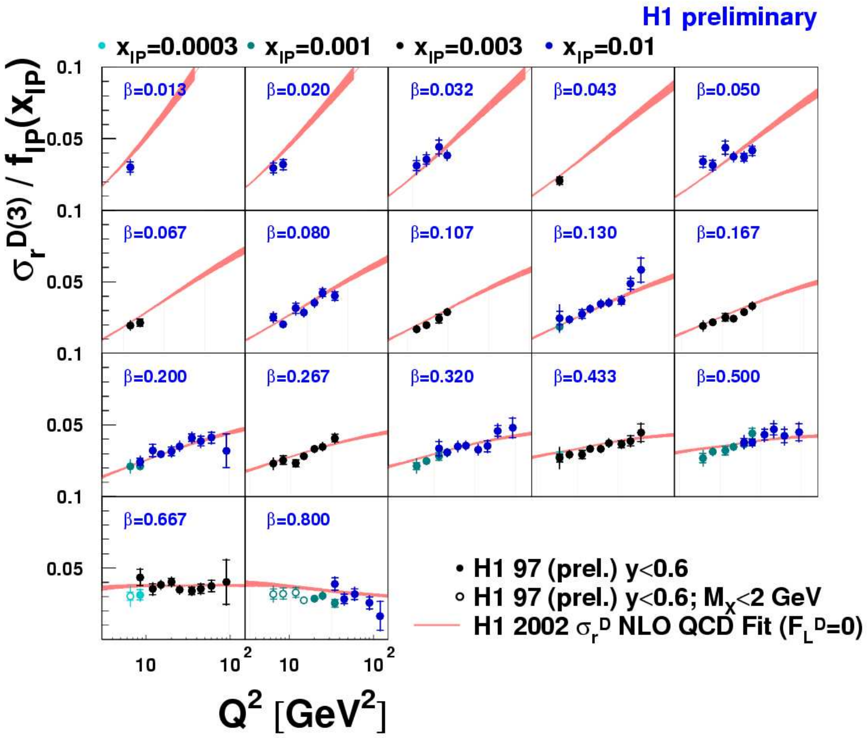
$$f_i^D(x, Q^2, x_{IP}, t) = f_{IP/p}(x_{IP}, t) \,.\, f_i^{IP}(\beta = x/x_{IP}, Q^2)$$



- $f_{IP/p}$ "pomeron flux factor" (can be parameterized according to Regge theory)
- f_i^{IP} "pomeron parton distribution"

Diffractive cross section at medium Q^2





Regge fit: parameters: $\alpha_{I\!P}(0)$, $A_{I\!P}(\beta,Q^2)$, $A_{I\!R}(\beta,Q^2)$

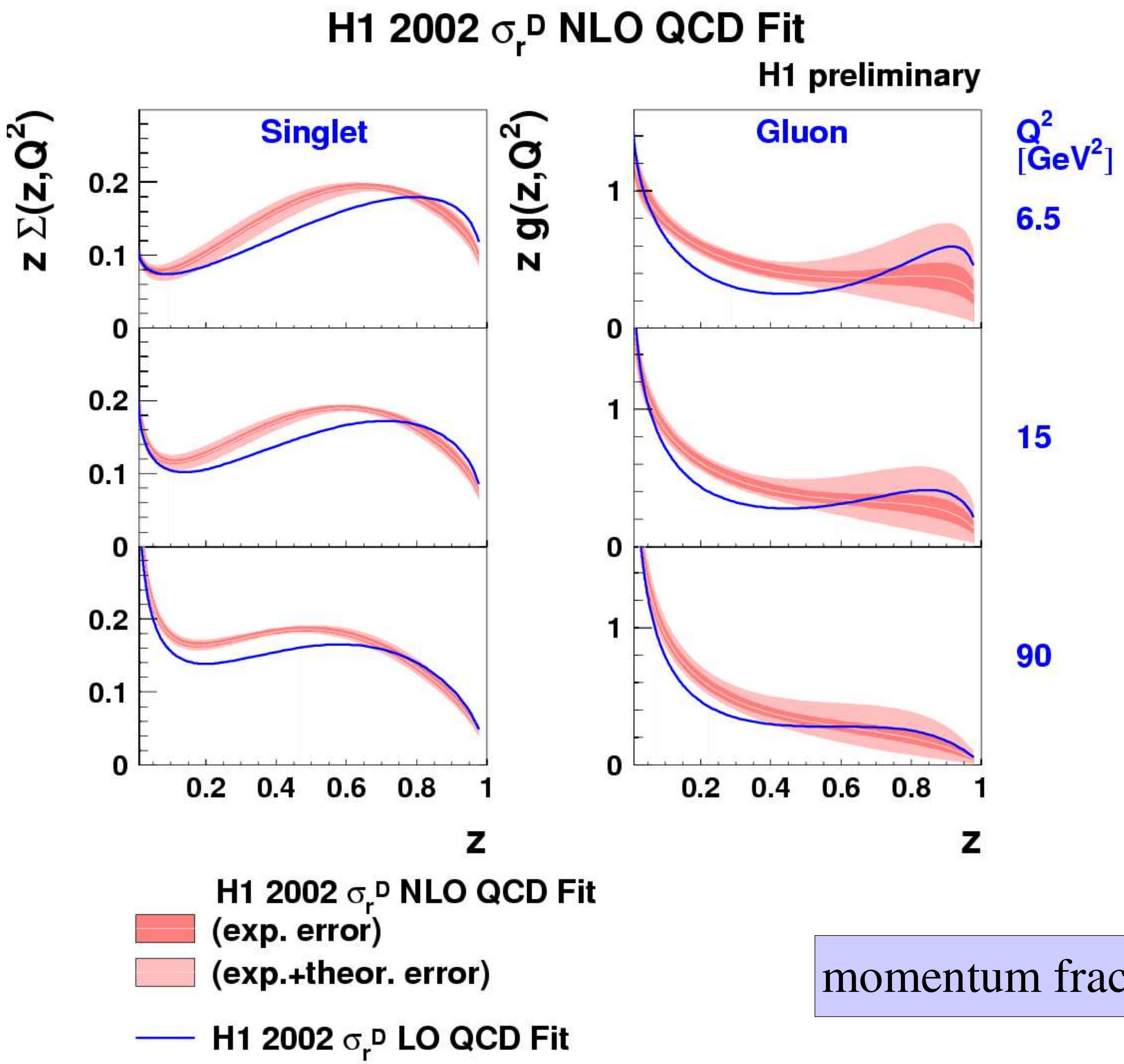
$$\sigma_r^{D(3)}(x_{I\!P},\beta,Q^2)=f_{I\!P}(x_{I\!P})\cdot A_{I\!P}(\beta,Q^2)(+I\!R)$$

$$f_{I\!P}(x_{I\!P})=\int_{t_{cut}}^{t_{min}} \mathrm{e}^{B_{I\!P}t}/(x_{I\!P}^{2\alpha_{I\!P}(t)-1})\,\mathrm{d}t$$

- σ_r from different $x_{I\!P}$ regions overlap nicely
- positive scaling violations in most of the phase space

$$\alpha_{I\!P}(0)=1.173\pm0.018\,(\text{stat.})\pm0.017\,(\text{syst.})^{+0.063}_{-0.035}\,(\text{model})$$

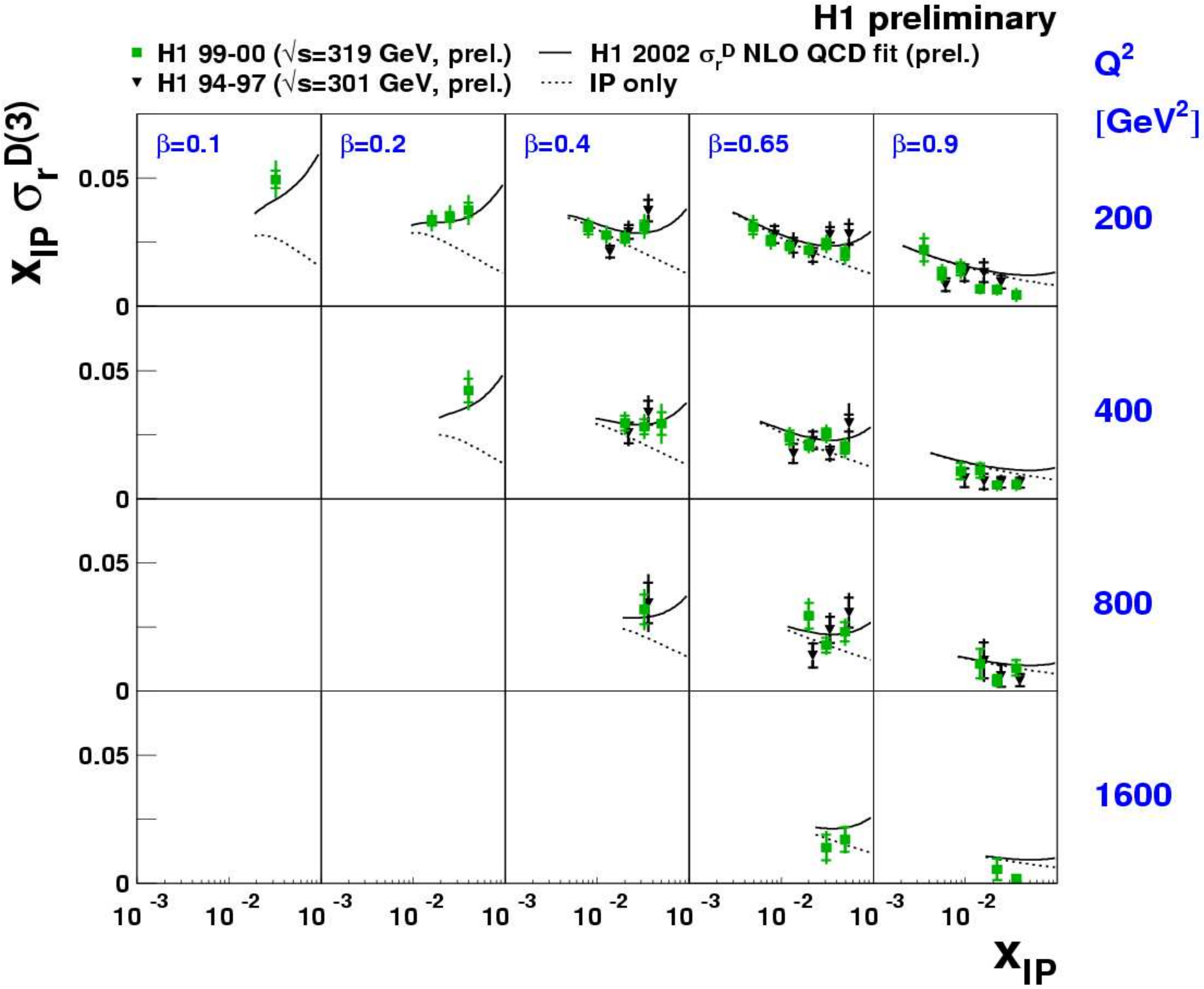
NLO DGLAP QCD fit



- quark and gluon densities are parameterized as Chebychev polynomials at starting scale $Q_0^2 = 3$ GeV^2
- fit also includes high Q^2 data ($200 < Q^2 < 800$ GeV^2)
- subleading reggeon exchange is included using the pion structure function
- χ^2/ndf = 308.7/306
- propagation of statistical, systematic experimental and theoretical errors

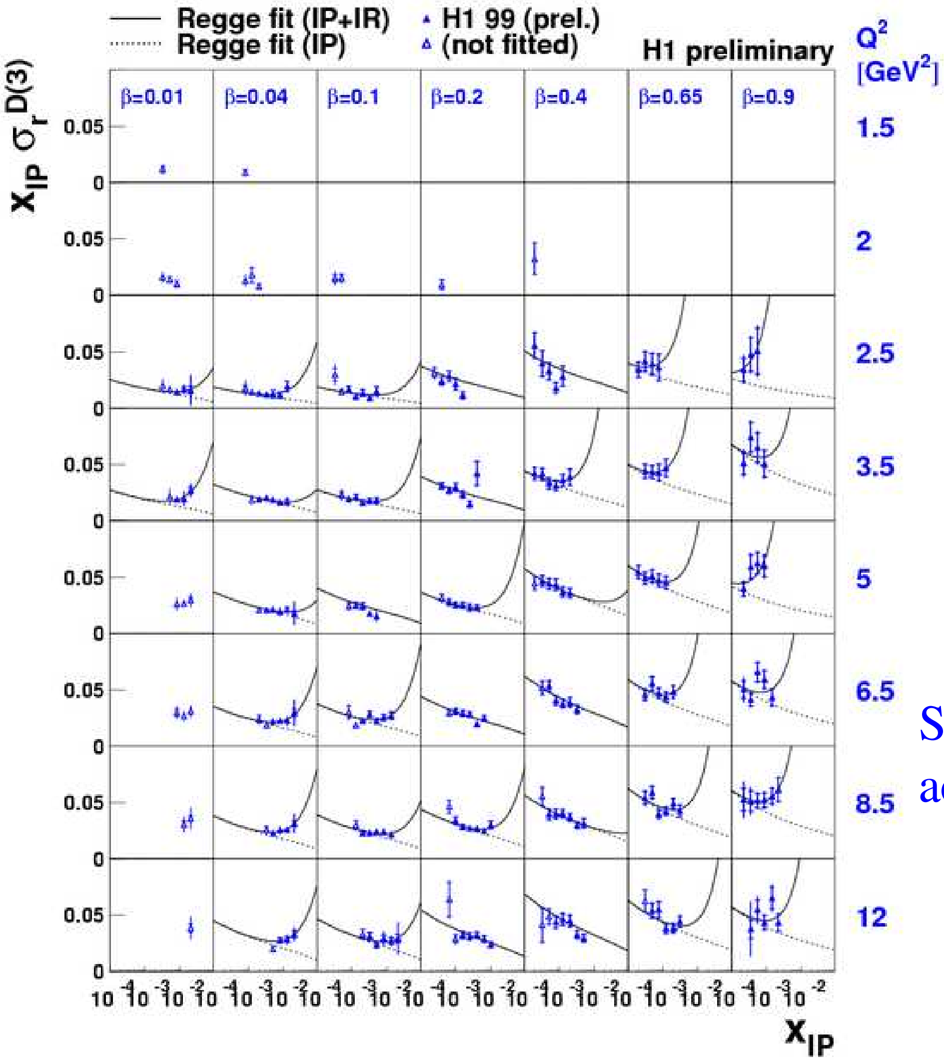
momentum fraction carried by gluons: 75 ± 15%

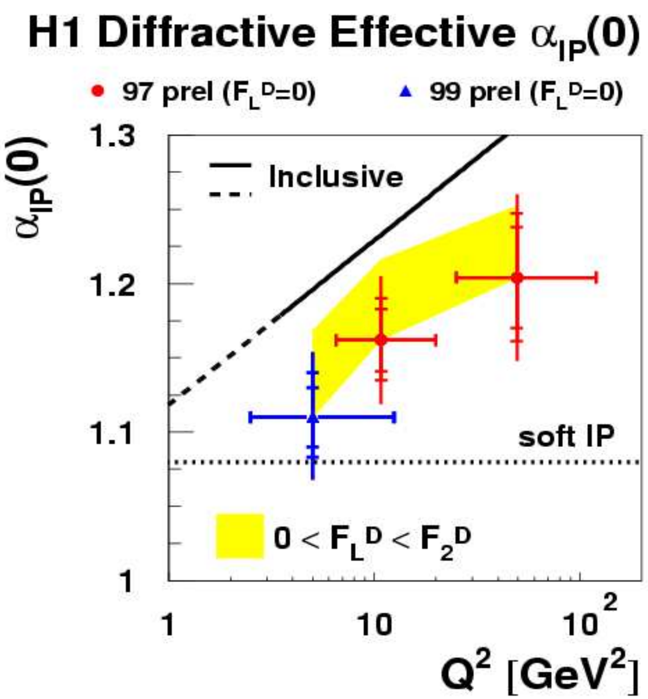
Diffractive cross section at high Q^2



- improved statistics and kinematic range compared to previous measurement
- good agreement between data sets
- extrapolation of NLO fit to medium Q^2 data works fine
- subleading trajectory needed at high $x_{I\!P}$ and low β

Diffractive cross section at low Q^2





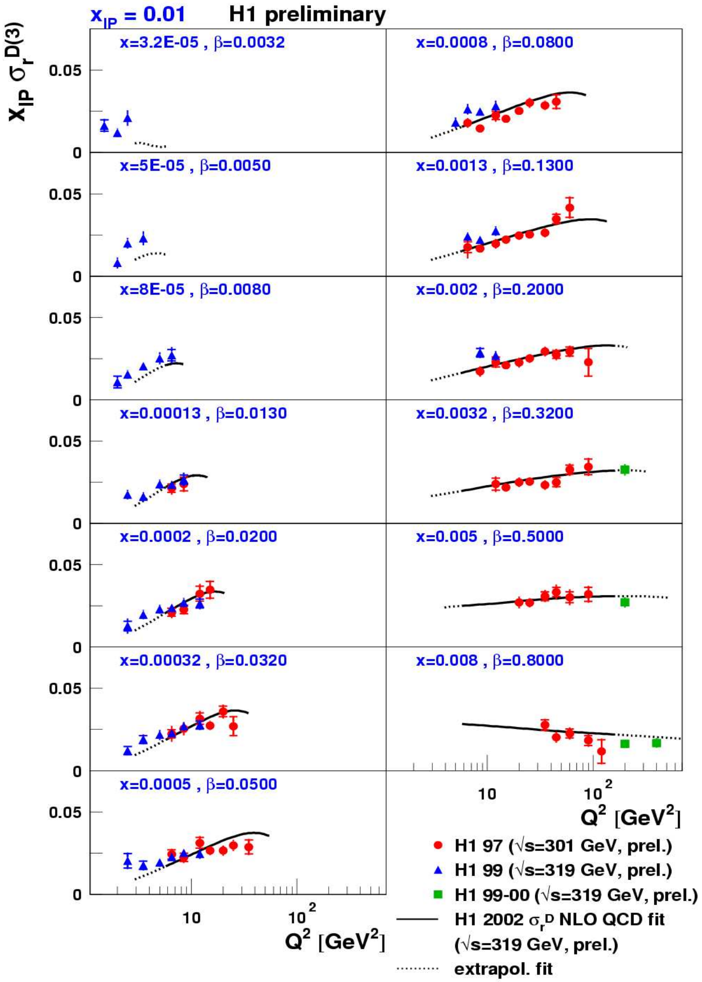
Special run with minimally biased triggers to access low Q^2:

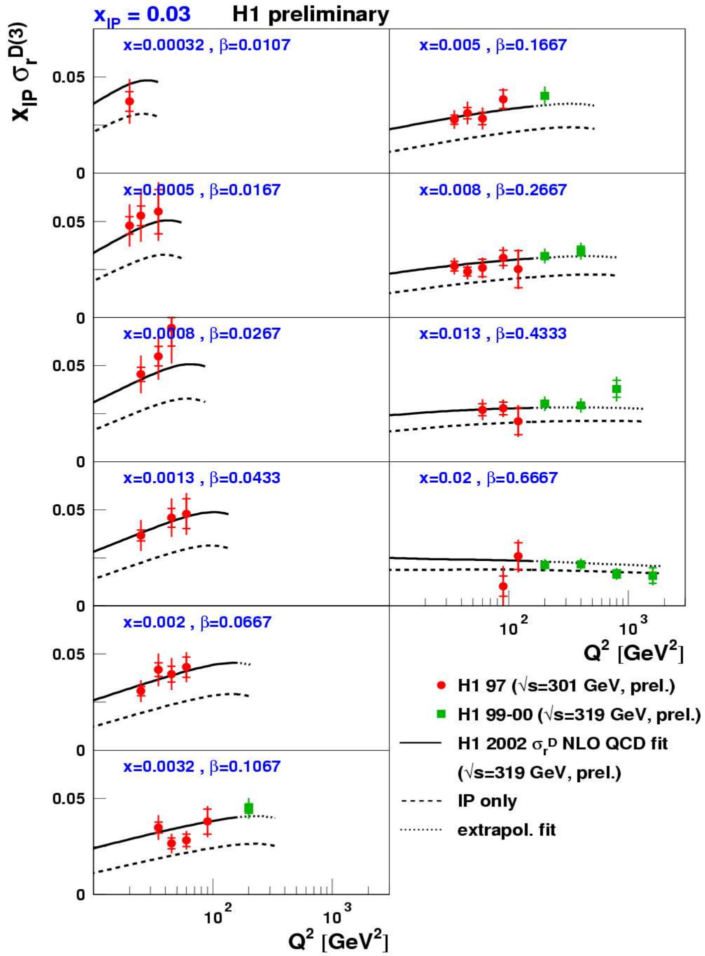
- at low Q^2, $\alpha_{I\!P}(0)$ is consistent with the soft pomeron intercept of 1.08
- H1 data suggest a rise of $\alpha_{I\!P}(0)$ with Q^2

$$\alpha_{IP}(0) = 1.110 \pm 0.020\,(\text{stat.}) \pm 0.024\,(\text{syst.})^{+0.068}_{-0.033}\,(\text{model})$$

→ uncertainties still very large

Extrapolation of QCD fit



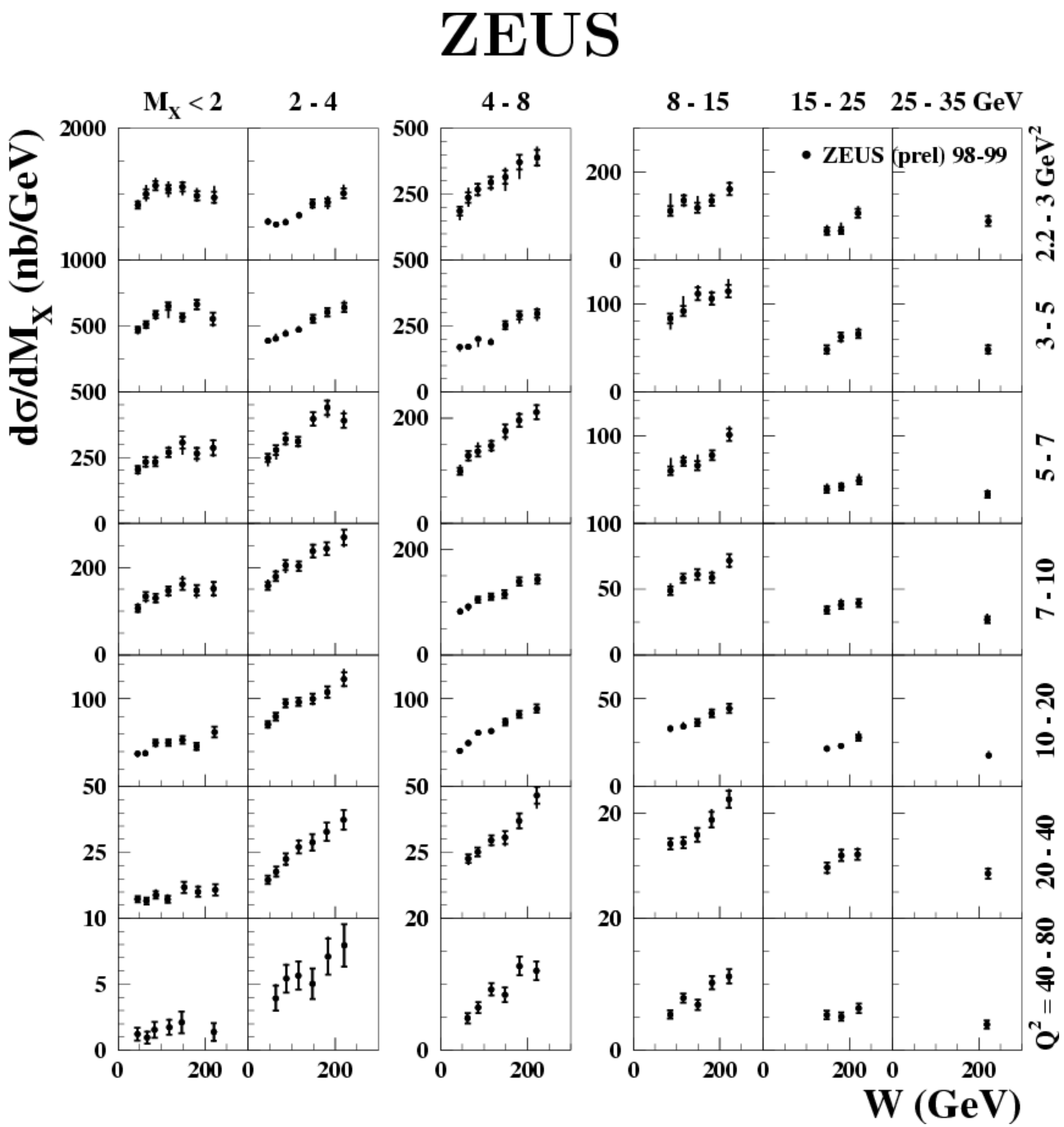


scaling violations → large gluon content

extrapolation works fine in large Q^2 range

low and high Q^2 data provide additional constraints on the singlet and gluon distributions

Differential cross section $d\sigma/dM_X$



New Forward Plug Calorimeter :

- covers pseudorapidities $4 < \eta < 5$
- increases measurable range in M_X ($M_X < 35$ GeV)
- reduces the mass of the dissociation system Y ($M_Y < 2.3$ GeV)

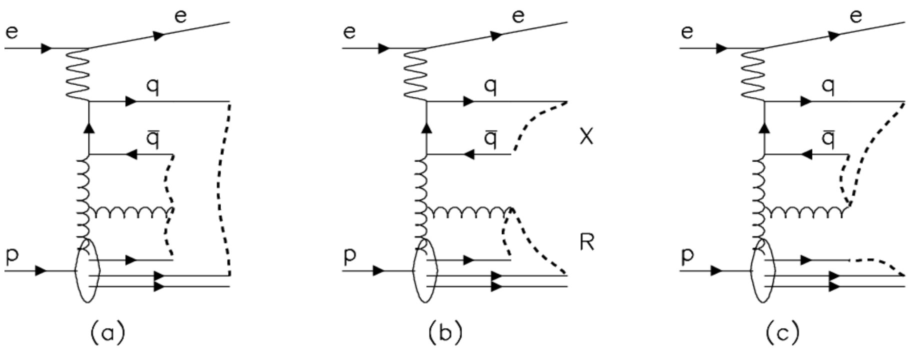
Observations:

- for $M_X < 2$ GeV (resonance production) there is little dependence on W
- at higher M_X, a strong rise with W is observed at all Q^2, compatible with the energy dependence of inclusive data

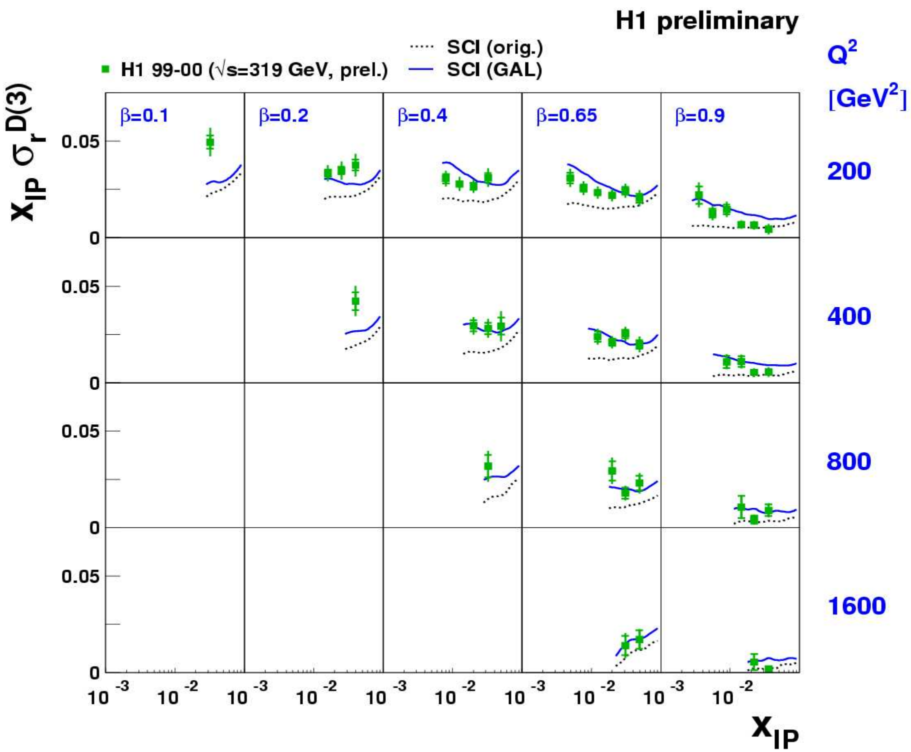
Comparison of SCI model to high Q^2 data

Soft Colour Interaction model:

(Edin, Ingelman, Rathsmann)



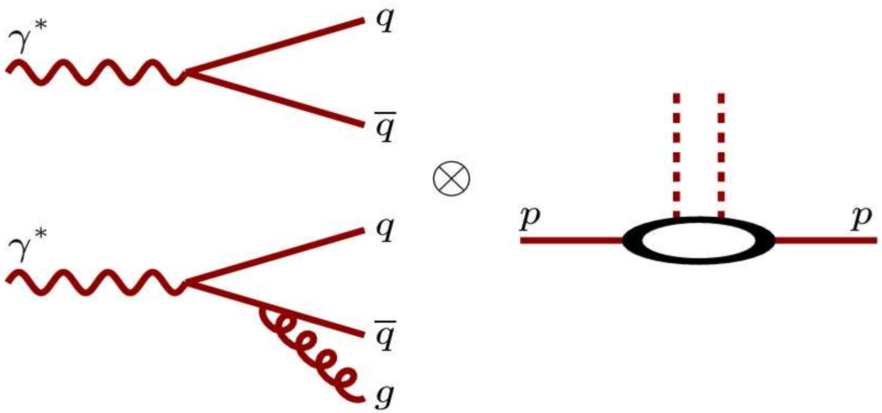
- standard prescription for DIS + soft re-arrangement of colour strings
- "Generalized Area Law" (GAL) tends to favour interactions that make colour strings shorter
- free parameter: probability for a soft interaction to occur (tuned to lower Q^2 data)



- model with GAL better than original
- failure at low β / high Q^2 ?

Saturation model vs. low Q^2 data

(Golec-Biernat, Wüsthoff)



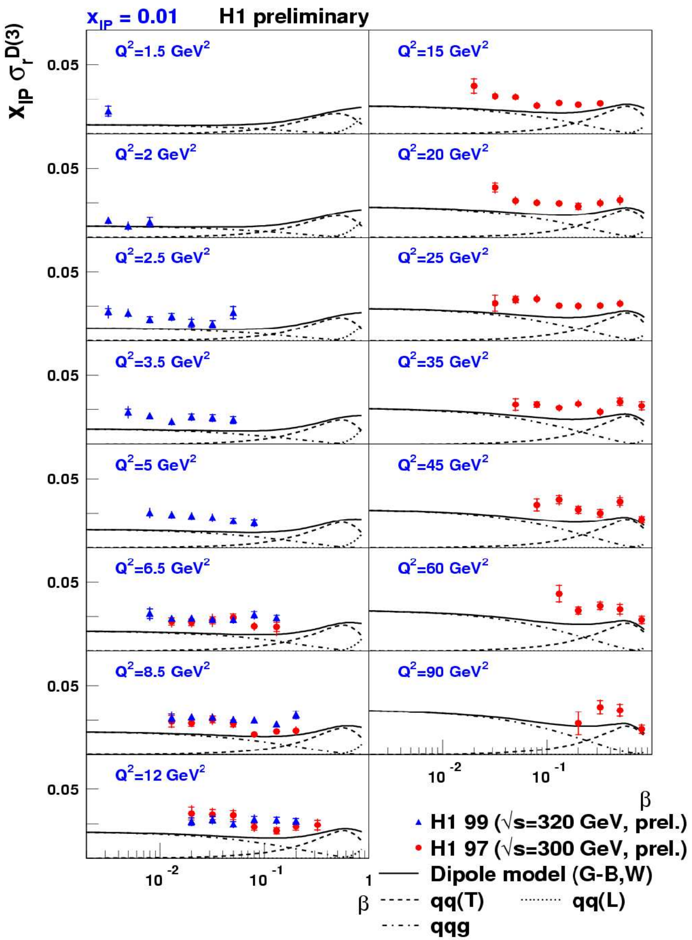
- at low x, the proton fluctuates in *qq*/*qqg* dipoles long before the interaction with the proton
- the Saturation model proposes a parameterization for the dipole-proton cross section:

$$\sigma(x, r^2) = \sigma_0 [1 - \exp(-\frac{r^2}{4 R_0^2(x)})]$$

$$R_0(x) = \frac{1}{GeV} (\frac{x}{x_0})^{\lambda/2}$$

➔ colour transparency for small dipole sizes

➔ saturation of the cross section towards low x/low Q^2

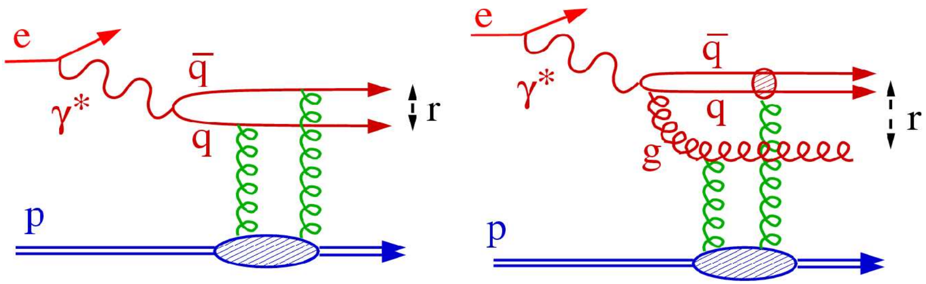


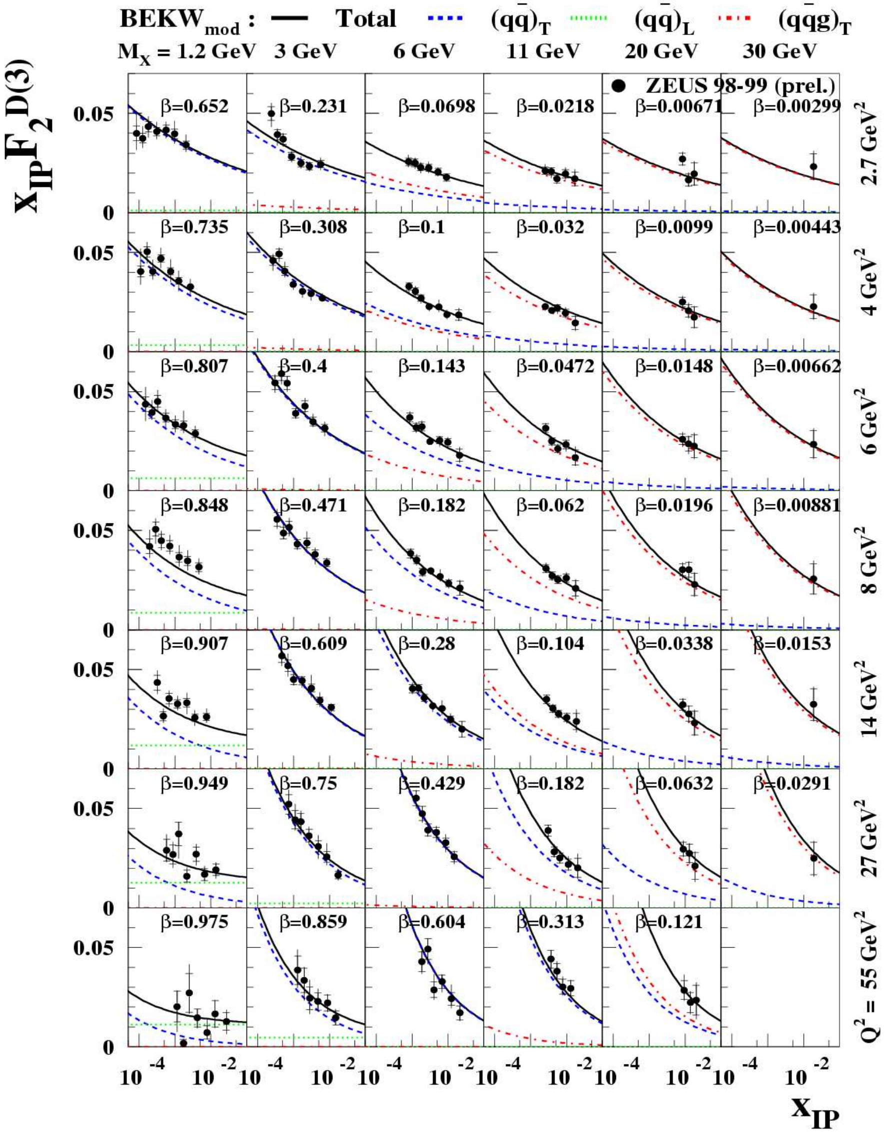
model consistently undershoots the data !

2-gluon exchange model

BEKW model:

(Bartels-Ellis-Kowalski-Wüsthoff)

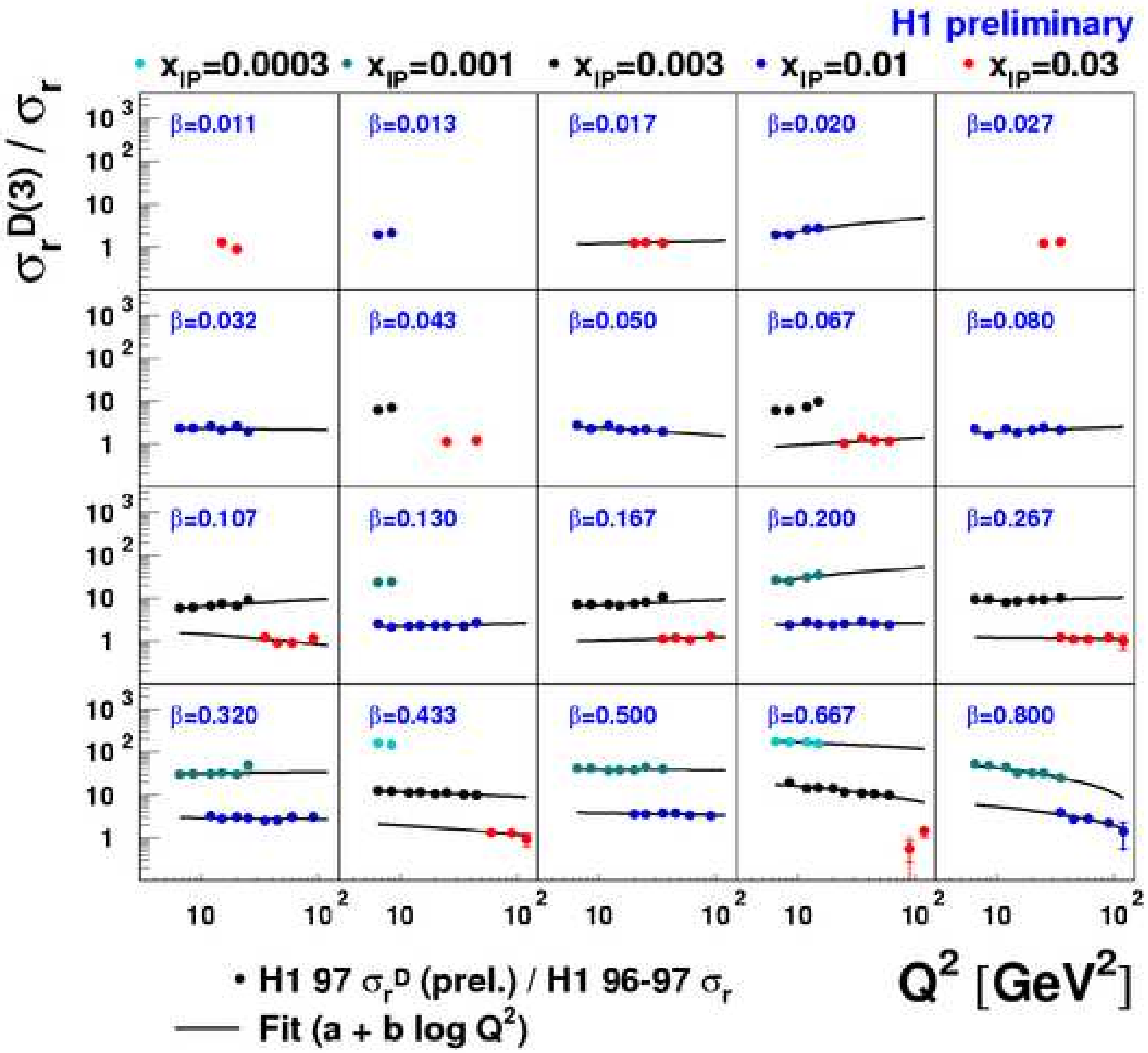




- elastic scattering of *qq*/*qqg* off the proton through the exchange of two gluons in a net colour-singlet configuration

- full pQCD calculation that requires large transverse momentum for all outgoing partons $x_{I\!P} < 0.01$ to avoid valence quark region

Ratio of diffractive to inclusive σ_r



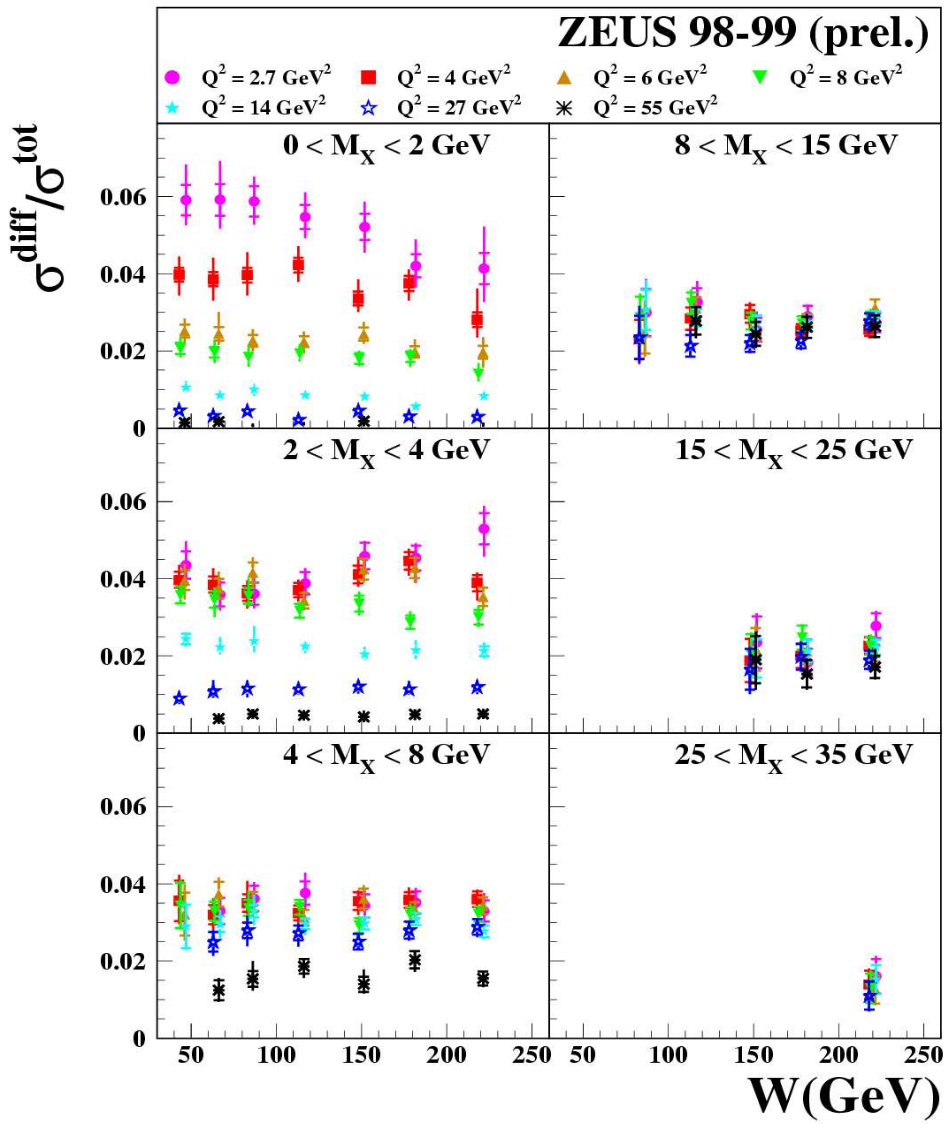
$$R = \frac{\sigma_r^D(x_{IP}, x, Q^2)}{\sigma_r(x, Q^2)}$$

ratio is reasonably flat as function of Q^2

↓

same scaling violations are observed in diffractive and inclusive DIS

W dependence of $\sigma^{diff}/\sigma^{tot}$



- for $M_X < 2$ GeV, $\sigma^{diff}/\sigma^{tot}$ is falling with W
- for $M_X > 2$ GeV, $\sigma^{diff}/\sigma^{tot}$ is constant with W

↓

the diffractive cross section has the same W-dependence as σ^{tot}

- the low M_X bins exhibit a strong decrease of $\sigma^{diff}/\sigma^{tot}$ with increasing Q^2
- for $M_X > 8$ GeV, no Q^2 dependence is observed

Summary

- High precision measurements of the diffractive reduced cross section in DIS have been performed by H1 and ZEUS in an increased region of phase space
- The data supports Regge factorisation (provided subleading trajectories can contribute) with a value for the pomeron intercept which is larger than for the soft pomeron
- New NLO QCD fits are available of the diffractive parton densities and can be used to test QCD hard scattering factorisation
- Models describe the data in general, but some new discrepancies are uncovered with the increased accessible phase space
- The ratio of diffractive to inclusive cross sections sugggest similar (W, Q^2) dynamics in both processes