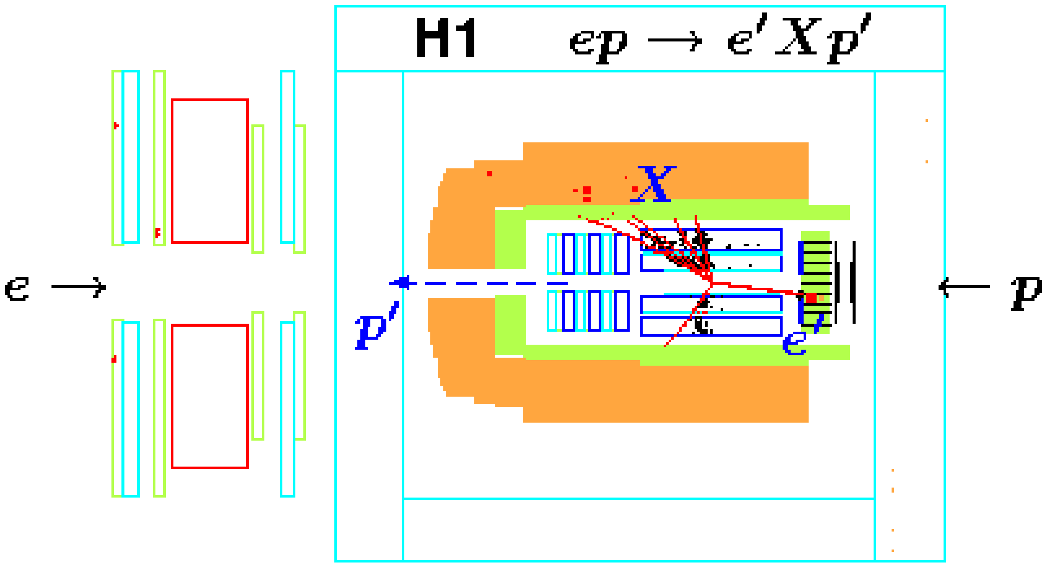
$F_2^{D(3)}$ measurements at Low, Medium and High Q^2

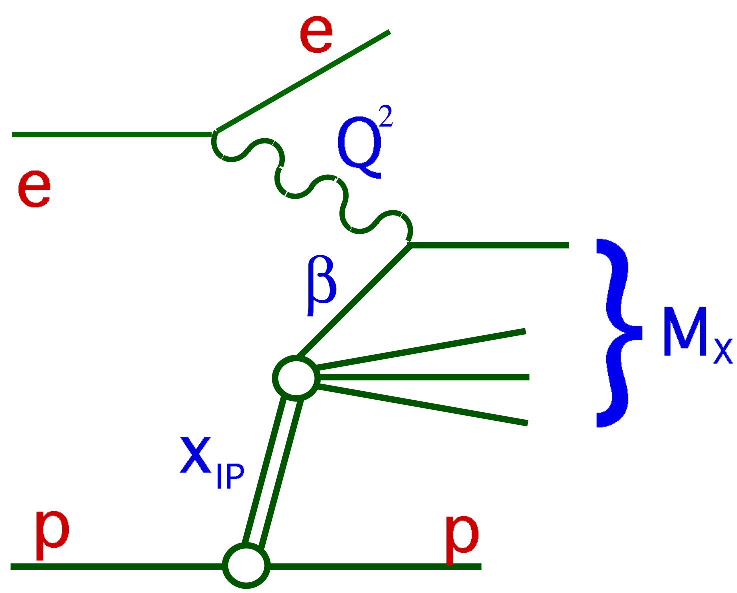
M.Kapishin, JINR, Dubna

- Diffractive DIS at HERA
- Diffractive reduced cross section
- Factorization in diffractive DIS
- Cross section measurements and QCD analysis
- Comparison with models
- Summary

Diffractive DIS at HERA

Large rapidity gap between leading proton *p´* and *X*





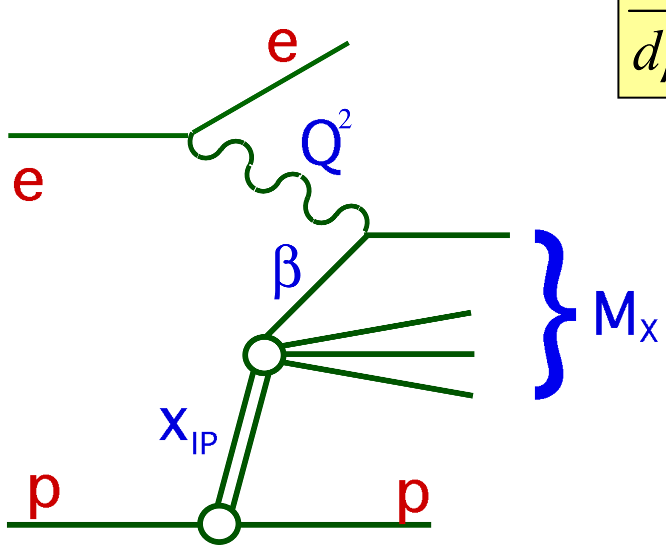
Momentum fraction of proton carried by colour singlet exchange:

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

Momentum fraction of color singlet carried by struck quark:

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

Diffractive Reduced Cross Section



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

Relation to F_2^D and F_L^D:

$$\sigma_r^{D(4)} = F_2^{D(4)} - \frac{y^2}{2(1 - y + y^2/2)} F_L^{D(4)}$$

$\sigma_r^D \approx F_2^D$ at low y $\qquad$ $\sigma_r^D = F_2^D$ if $F_L^D = 0$

Integrate over t when proton is not tagged → $\sigma_r^{D(3)}$

Factorization in Diffractive DIS

QCD hard scattering factorization:

$$\sigma^D(\gamma^* p \to Xp) = \sum_{parton\_i} f_i^D(x, Q^2, x_{IP}, t) \cdot \sigma^{\gamma^* i}(x, Q^2)$$

$\sigma^{\gamma^* i}$ - universal hard scattering cross section (same as in inclusive DIS)

f_i^D - diffractive parton distribution function → obey DGLAP, universal for diffractive *ep* DIS (inclusive, di-jets, charm)

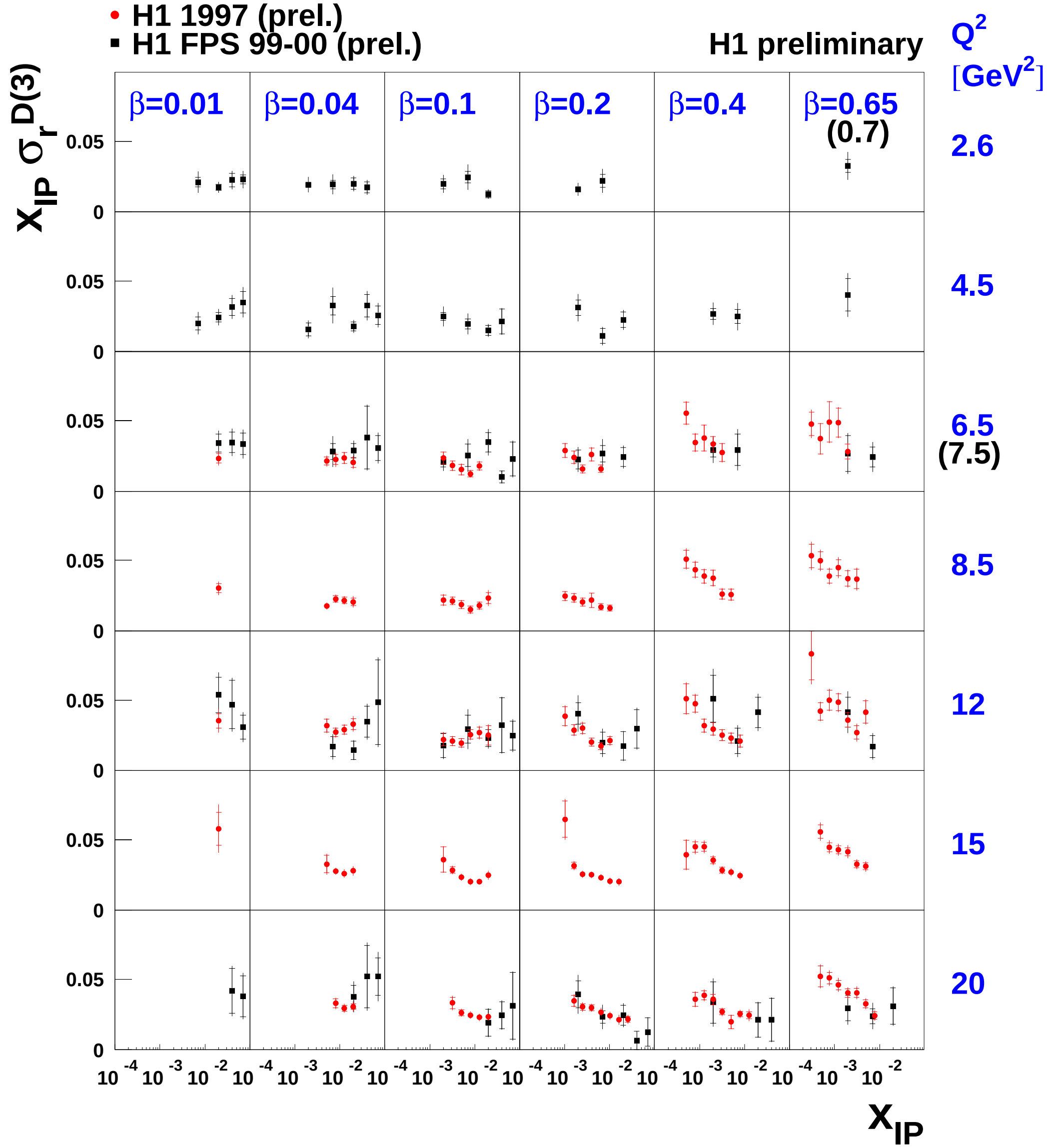
Additional assumption → Regge factorization:

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

$f_{IP/p}$ - pomeron flux factor

f_i^{IP} - pomeron parton distribution function

FPS proton vs Rapidity Gap



Rapidity gap selection:

$\sigma_r^{D(3)}$ defined in the kinematical range:

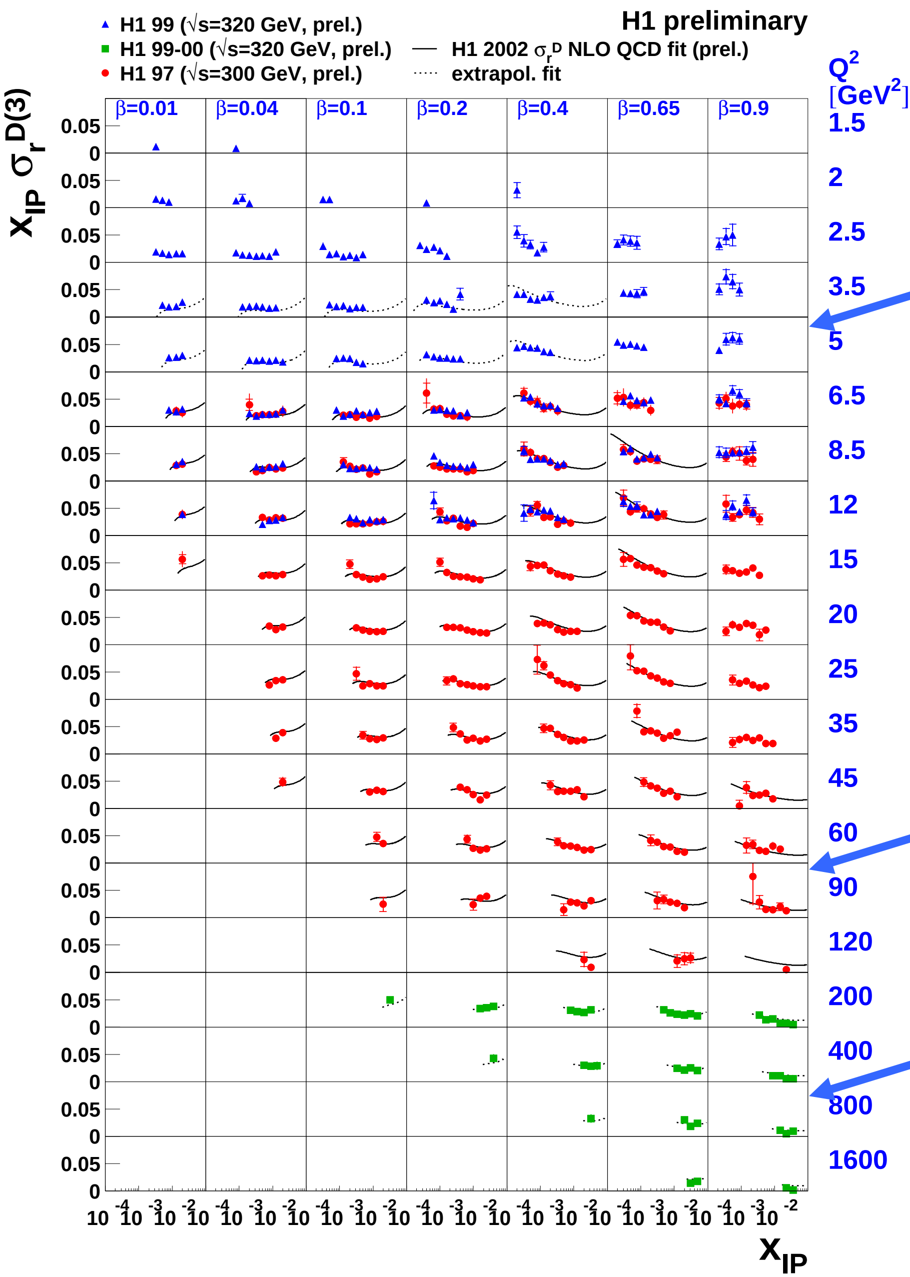
M_Y<1.6 GeV and |t|<1 GeV^2

FPS proton selection:

$\sigma_r^{D(4)}$ integrated over measured t range

➔ Good agreement between two methods

Overview of σ_r^D measurements



Data at Low Q^2, $\mathscr{L} = 3.4$ pb^{-1}

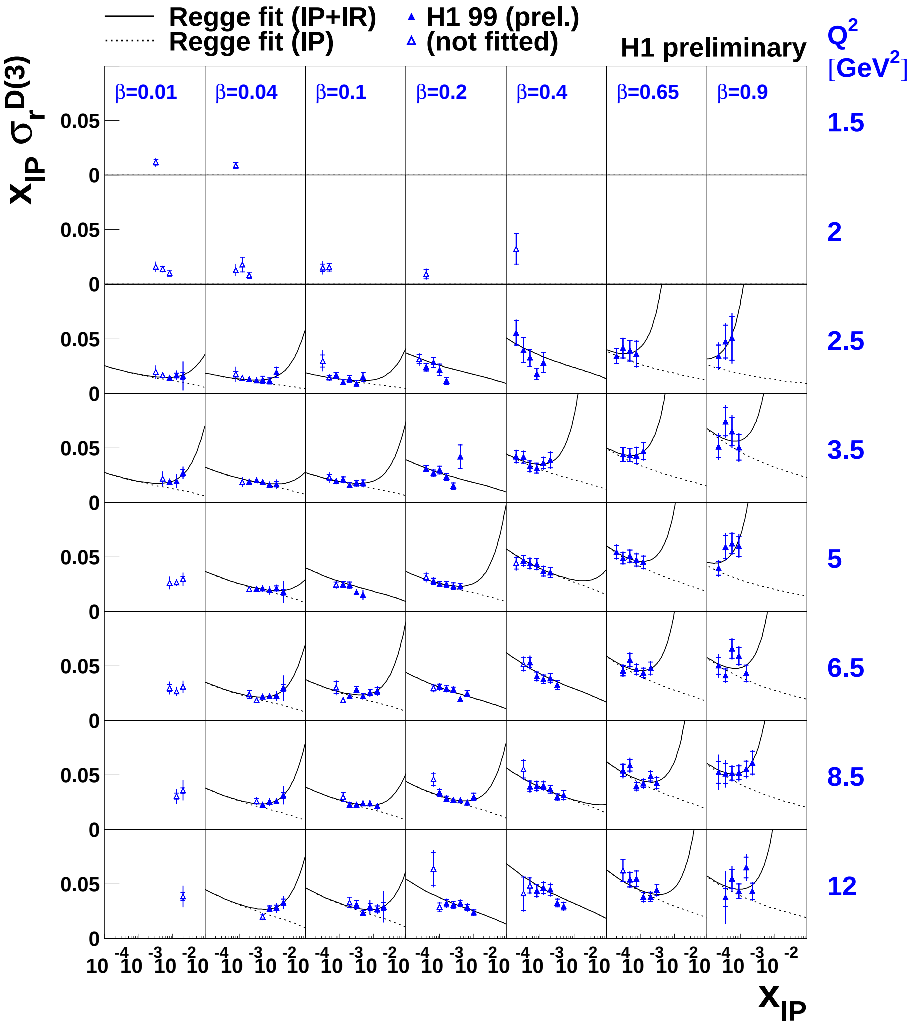
Good agreement between measurements

Data well described by QCD fit

Data at Medium Q^2, $\mathscr{L} = 10.6$ pb^{-1}

Data at High Q^2, $\mathscr{L} = 65$ pb^{-1}

Measurement at Low Q^2, Test of Regge Factorization



Fit x_{IP} dependence at fixed β, Q:

$$\sigma_r^{D(3)}(x_{IP},\beta,Q^2) = \sum_{IP,IR} f_i(x_{IP}) \cdot A_i(\beta,Q^2)$$

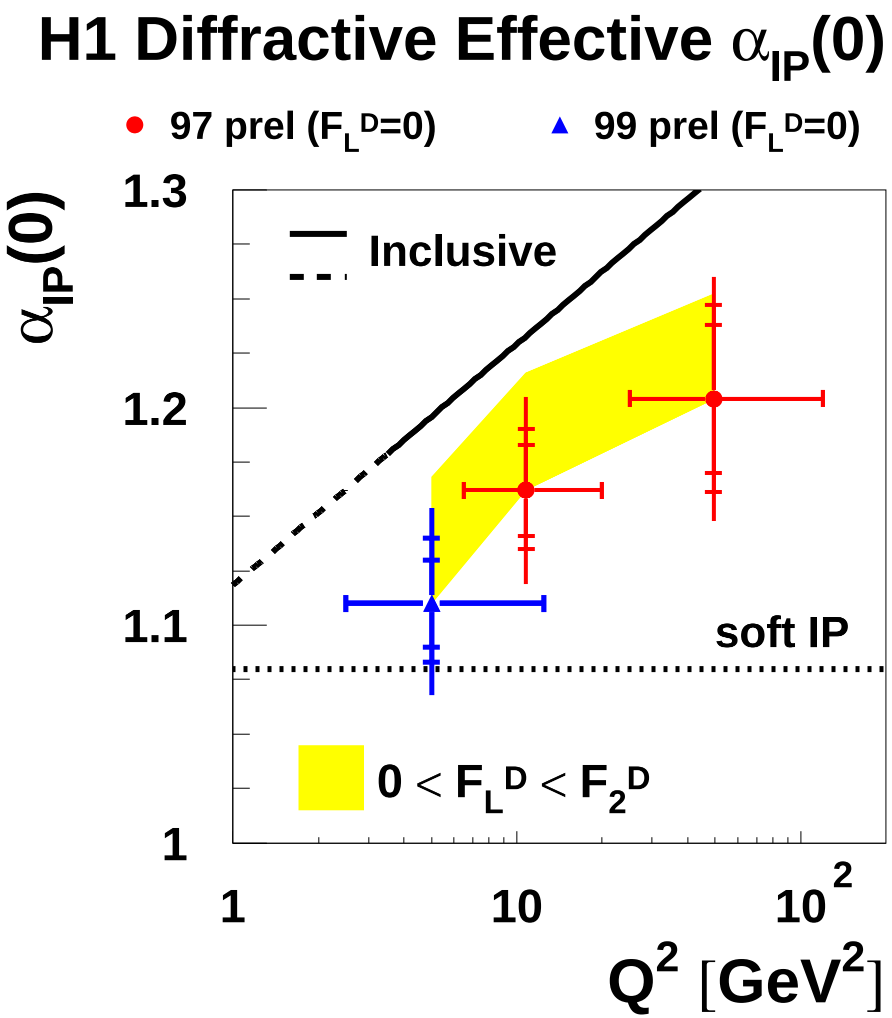
Regge Flux factor for *IP* and *IR*:

$$f_{IP}(x_{IP}) = \int_{t_{cut}}^{t_{min}} \frac{e^{B_{IP}t}}{x_{IP}^{2\alpha_{IP}-1}} dt$$

Data well described by exchange of *IP* and *IR*:

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

Effective $\alpha_{IP}(0)$ vs Q^2



Diffractive cross section:

$$x_{IP} F_2^D \sim A(\beta, Q^2)\, x_{IP}^{2-2\alpha(t)}$$

Inclusive cross section:

$$F_2 \sim B\, x^{1-\alpha(Q^2)}$$

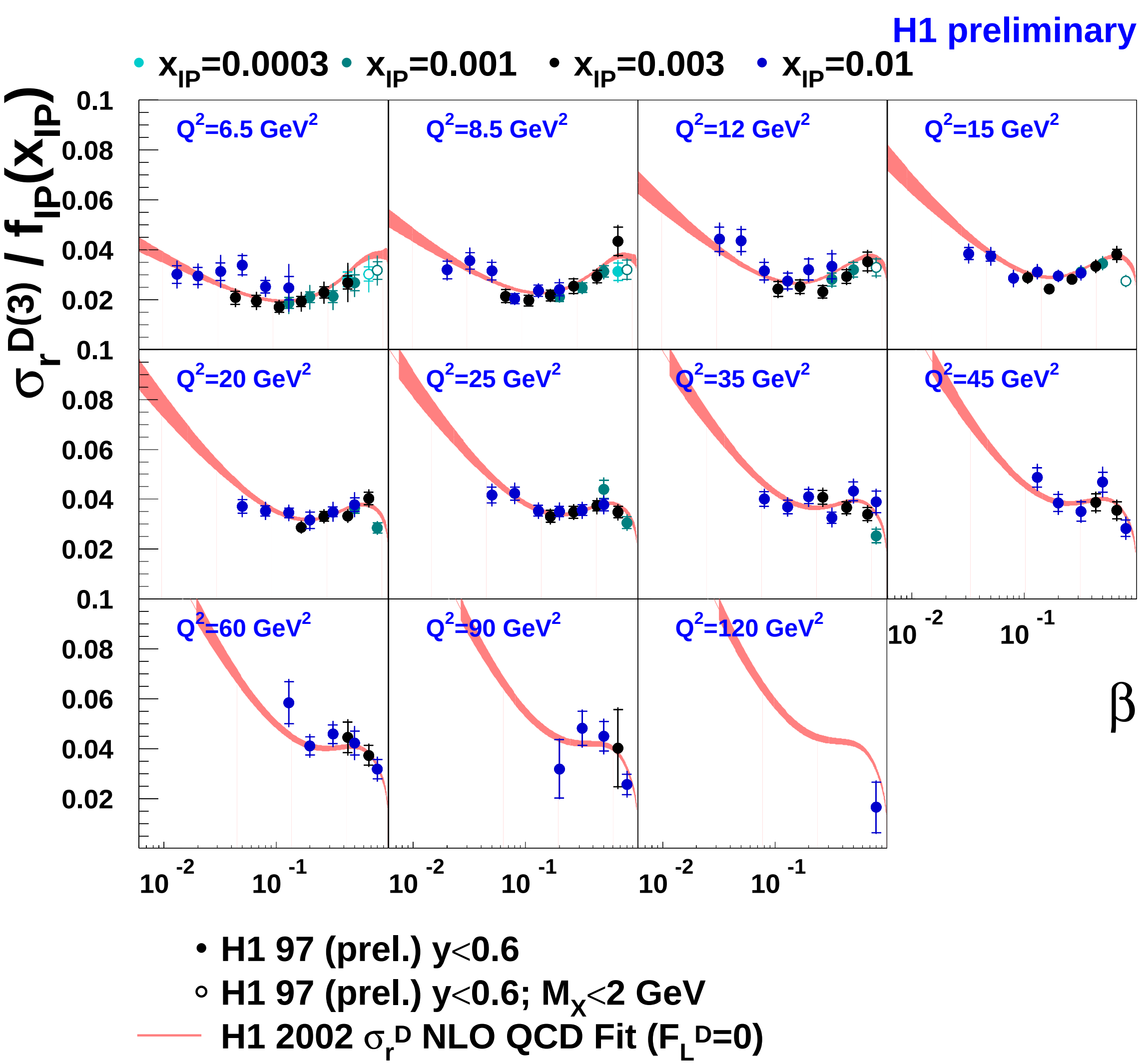
Effective $\alpha_{IP}(0)$:

- lower than for inclusive cross section
- consistent with soft IP at low Q^2
- data suggest increase with Q^2 but consistent within the errors
- uncertainty due to ignorance of F_L^D

Parameters of QCD Fit

- Singlet quark and gluon parameterised at $Q_0^2=3GeV^2$ by Chebychev polynomials, massive charm treatment via BGF
- Assume Regge factorization for x_{IP} dependence, $\alpha_{IP}(0)$ extracted from data, GRV-π sub-leading contribution at high x_{IP}
- NLO DGLAP evolution, fit Medium Q^2 data (Q^2>6.5 GeV^2)
- Full propagation of correlated experimental systematic and theoretical uncertainties

β dependence of σ_r^D



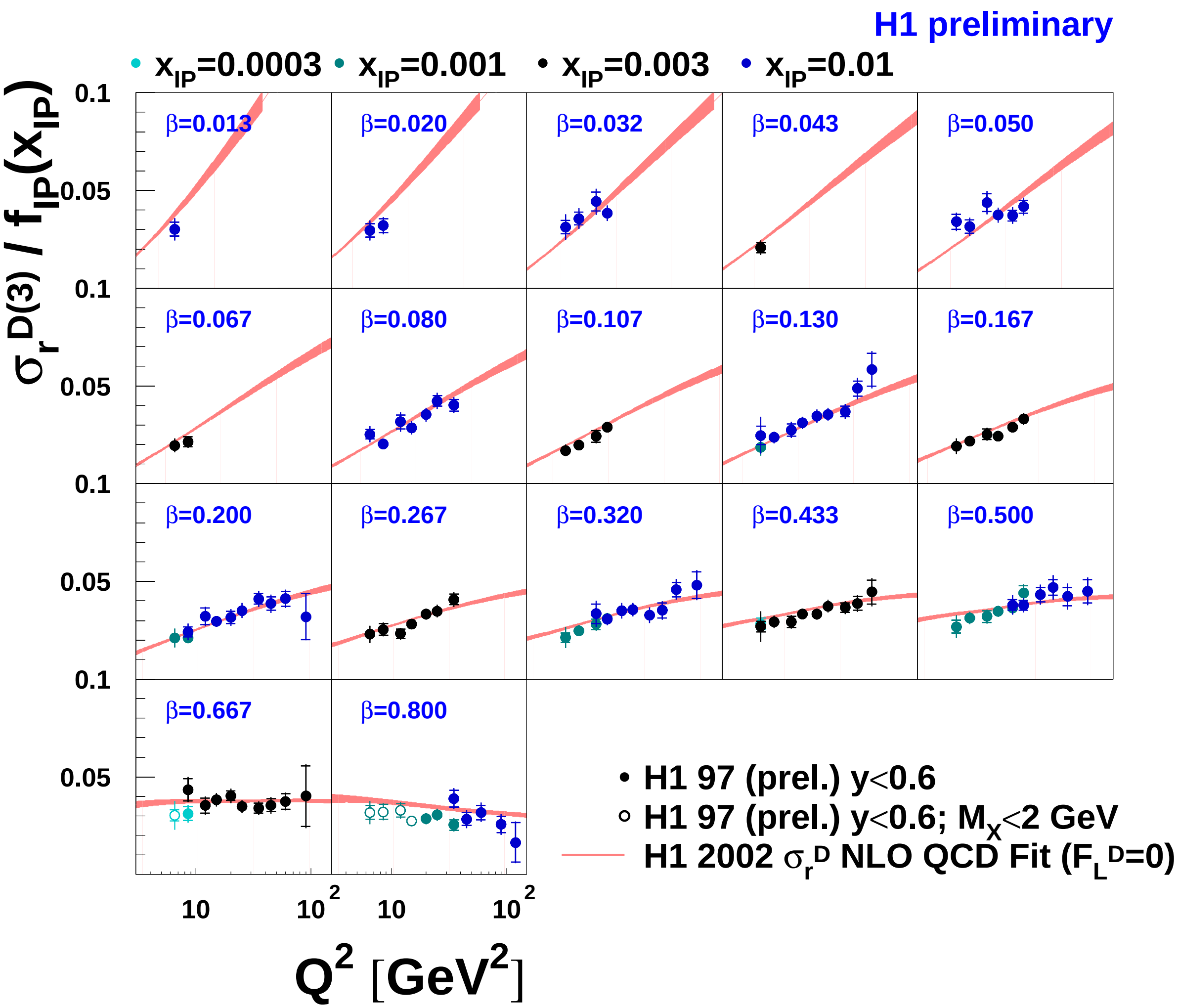
At fixed x_{IP} and Q^2:

- ❑ Data described by QCD fit
- ❑ Compare different x_{IP} bins:

➔ behavior is similar

➔ consistent with Regge factorization

Q^2 dependence of σ_r^D



At fixed x_{IP} and β:

- Large positive scaling violations except at high β

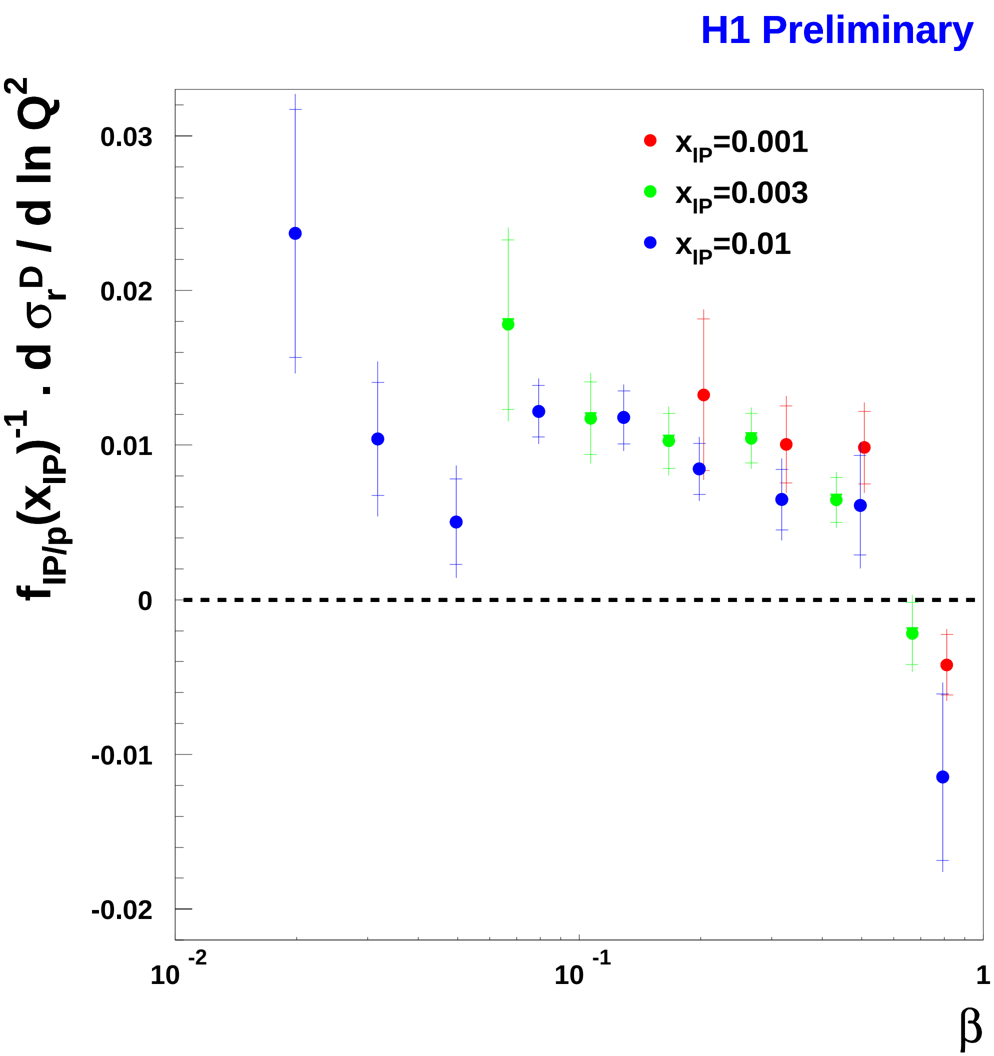
➔ Gluon dominated

- Compare different x_{IP} bins:

➔ scaling violations are similar

➔ consistent with Regge factorization

Scaling Violations



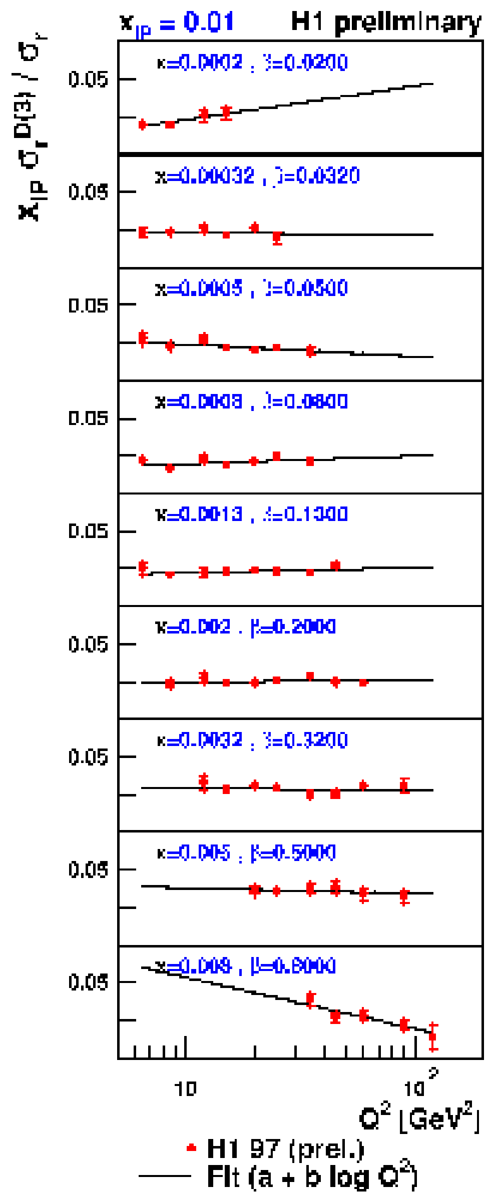
- Quantify Scaling violations at fixed x_{IP} and β:

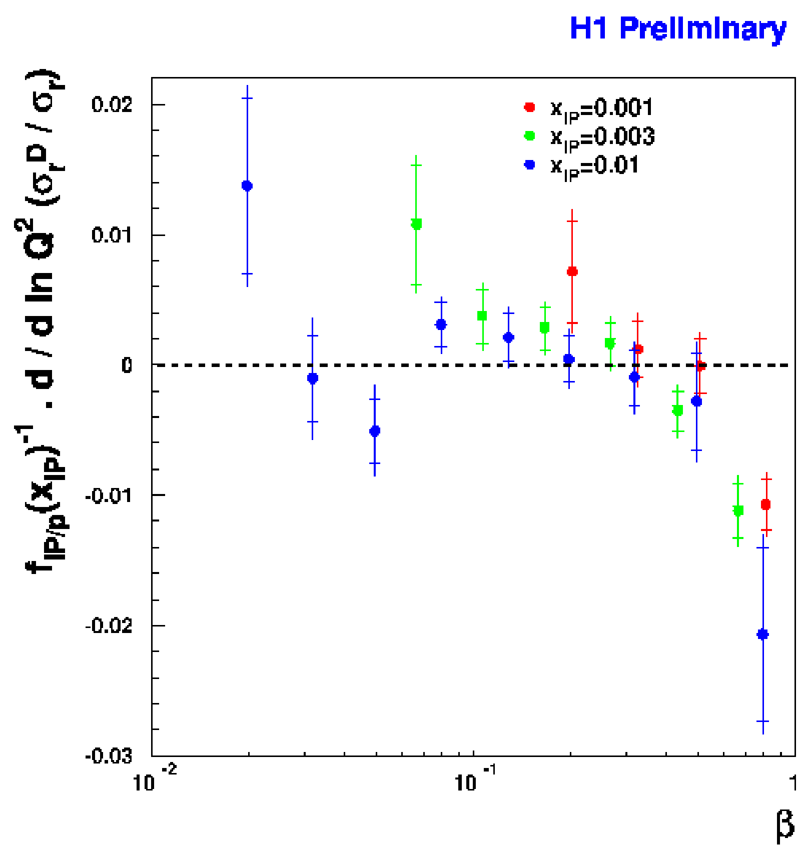
$$\sigma_r^D = A + B \ln Q^2$$

$$B = d\,\sigma_r^D / d \ln Q^2$$

- Large positive Scaling violations up to β~0.6

Comparison with inclusive DIS





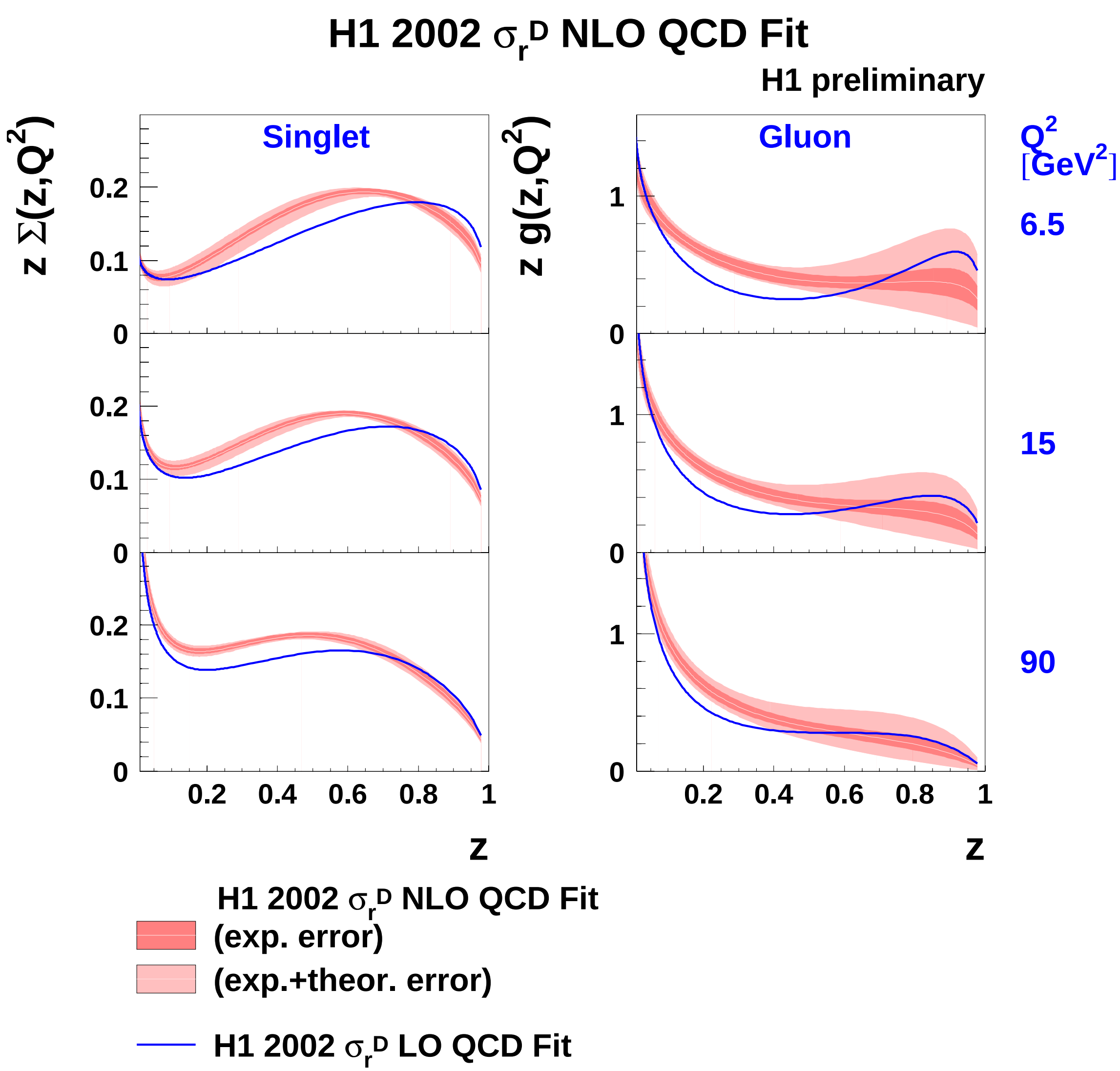
Fit Q^2 dependence at fixed x_{IP} and β:

$$R = a + b \ln Q^2$$

➔ σ_r^D / σ_r is flat vs Q^2 except at highest β

➔ similar Q^2 dynamics in diffractive and inclusive DIS?

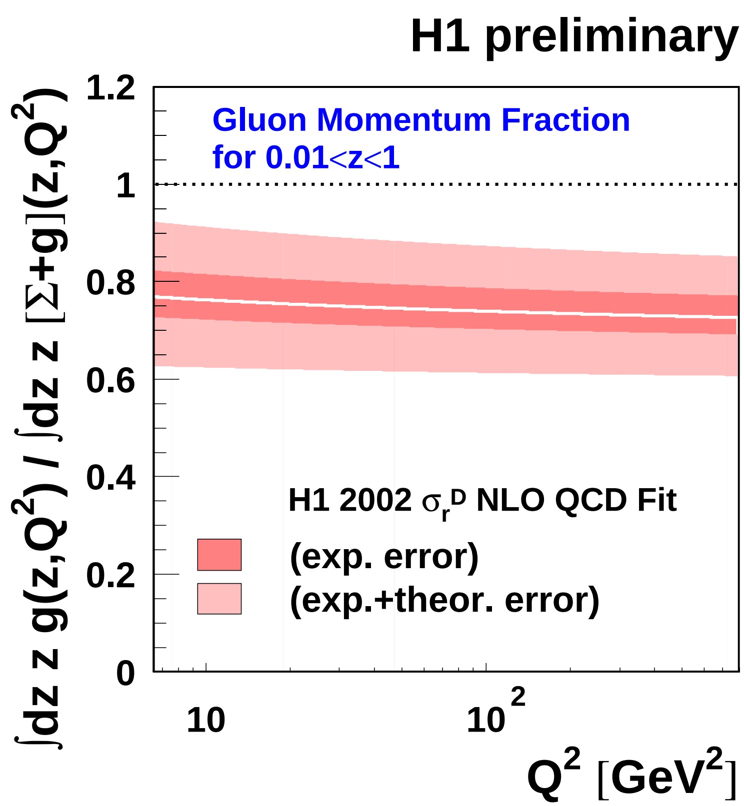
NLO DGLAP Fit → PDF

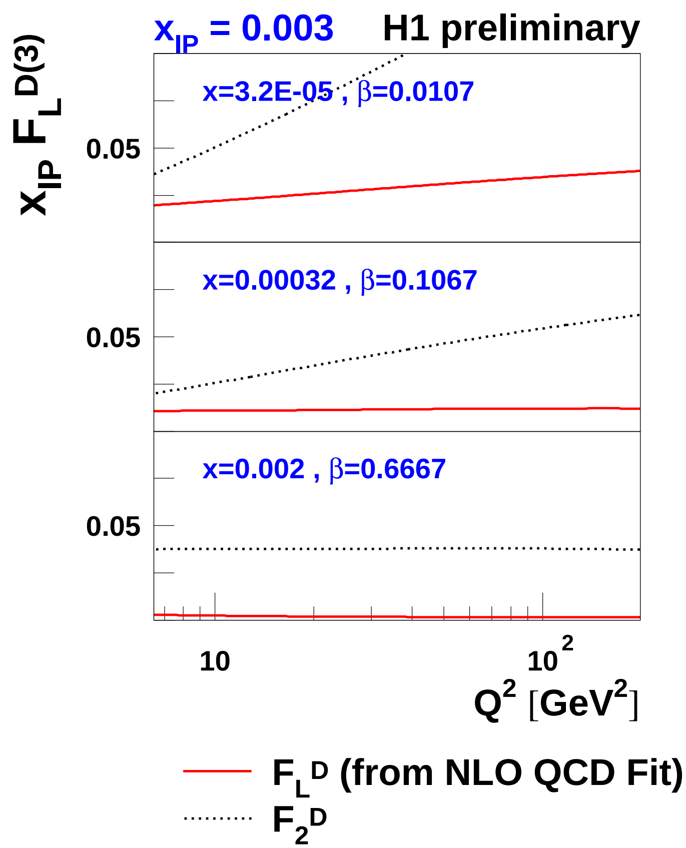


- Diffractive PDF's:
  - ✓ PDF extend to large fractional momentum *z*
  - ✓ Precise measurement of quark singlet distribution
  - ✓ Gluon distribution dominated
  - ✓ Large gluon uncertainty at high *z*

➔ Can be applied to test QCD factorization in *ep* final states (charm, di-jets) and hadron-hadron scattering

Gluon momentum fraction and F_L

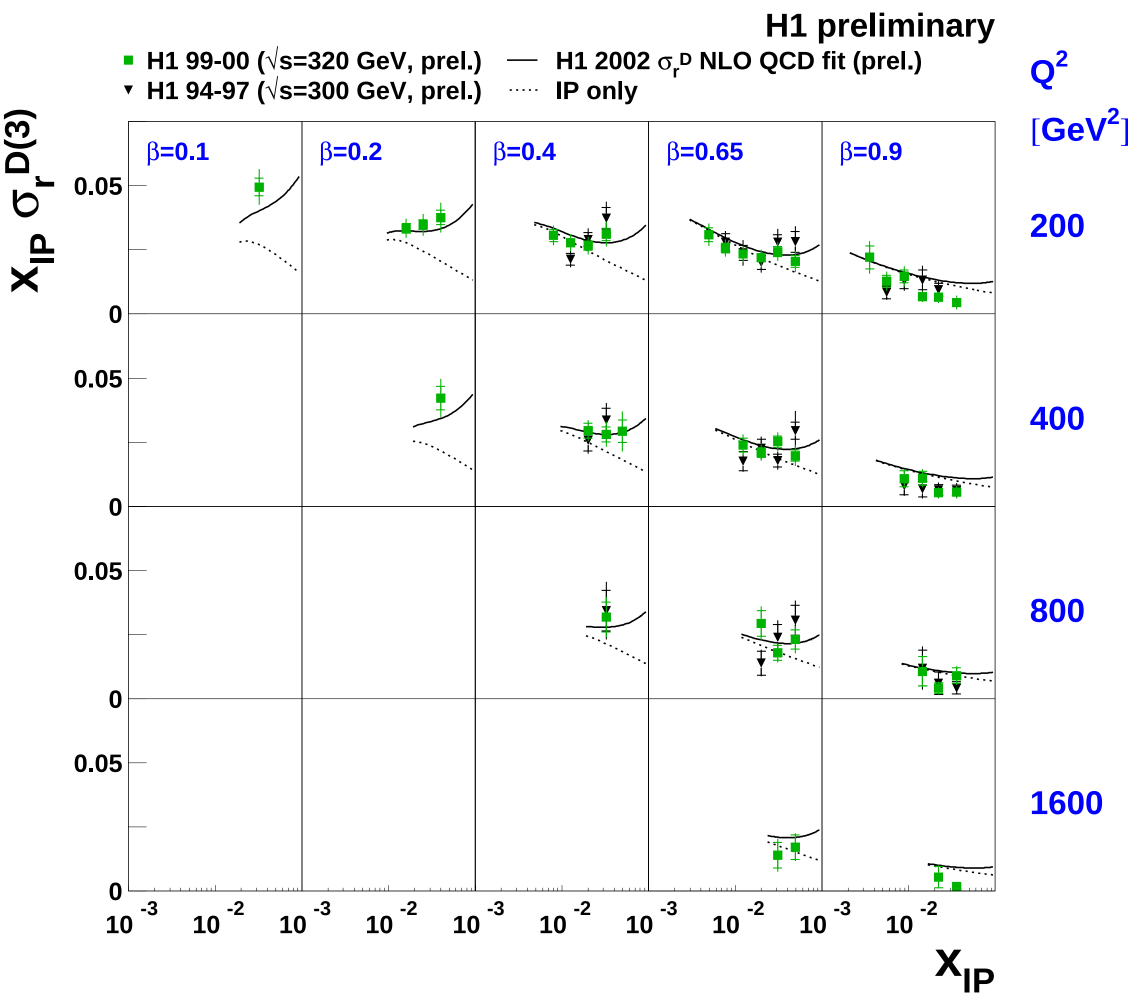




Momentum fraction of diffractive exchange carried by gluons
➔ 75 ± 15 %

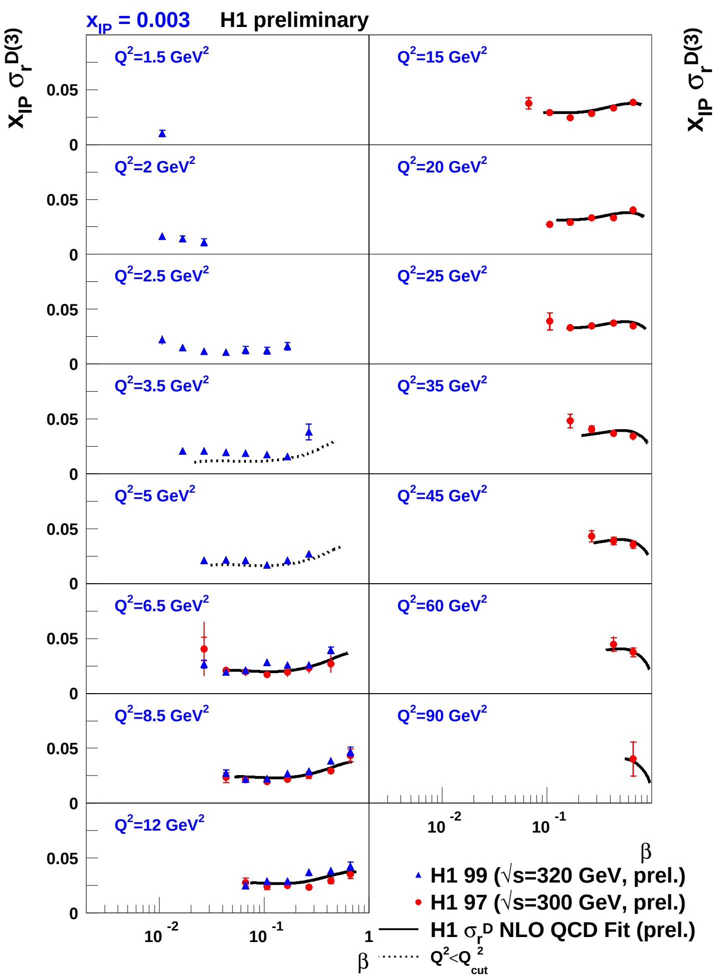
F_L^D predicted at leading twist → F_L^D is large at low Q^2 and low β

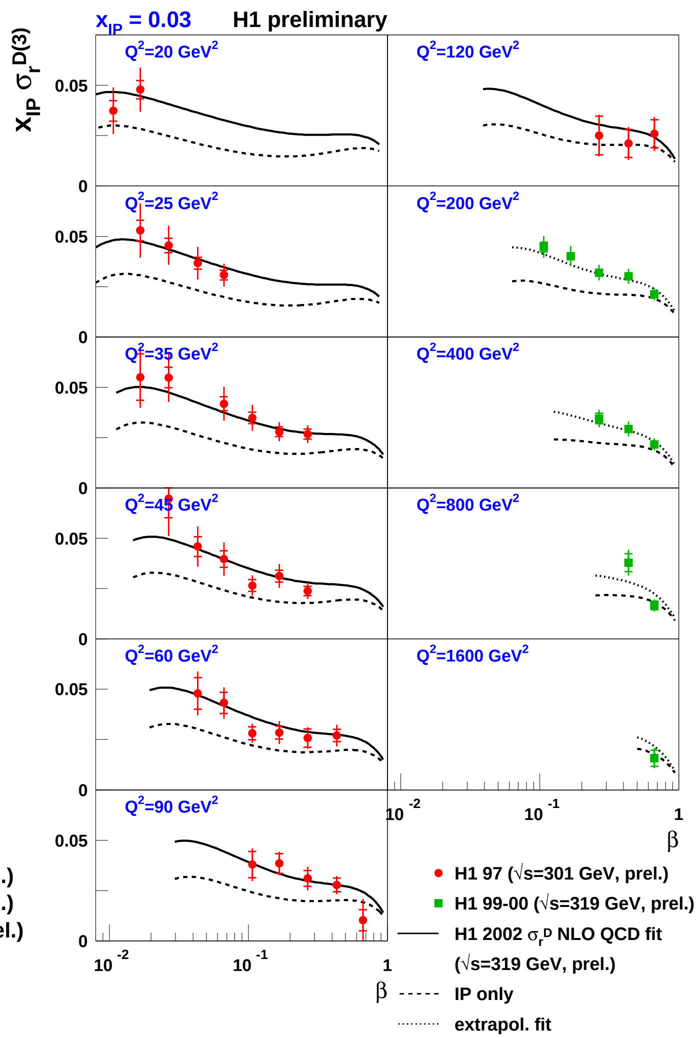
Measurement at High Q^2 vs Prediction of QCD Fit



- Improved statistics and kinematical range of new measurement compared to previous measurement
  ➔ good agreement
- Prediction of QCD Fit based on Medium Q^2 data
  ➔ good agreement
- Sub-leading trajectory needed at high x_{IP} and low β

Extrapolation of QCD Fit: β dependence



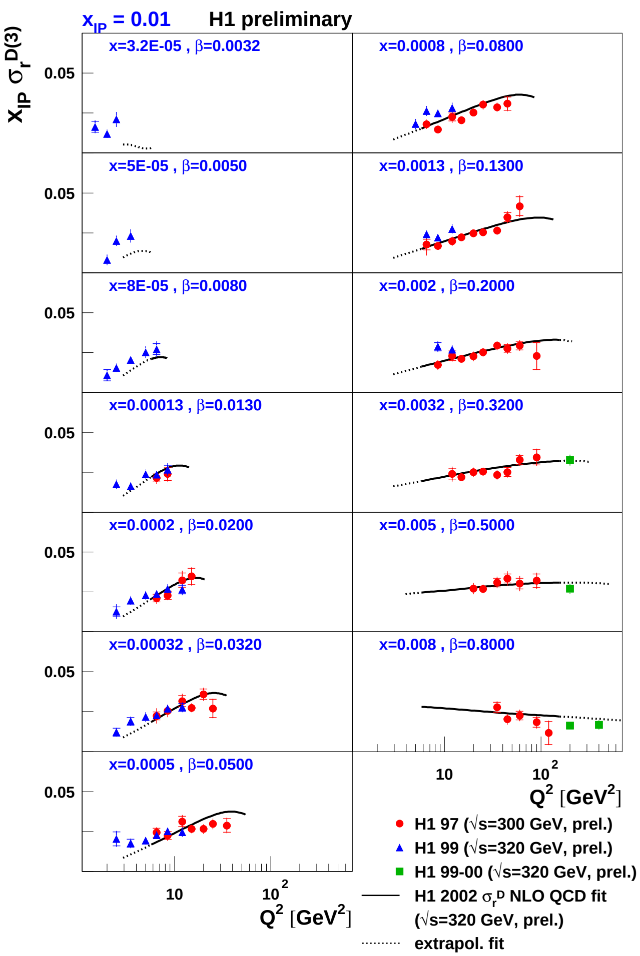


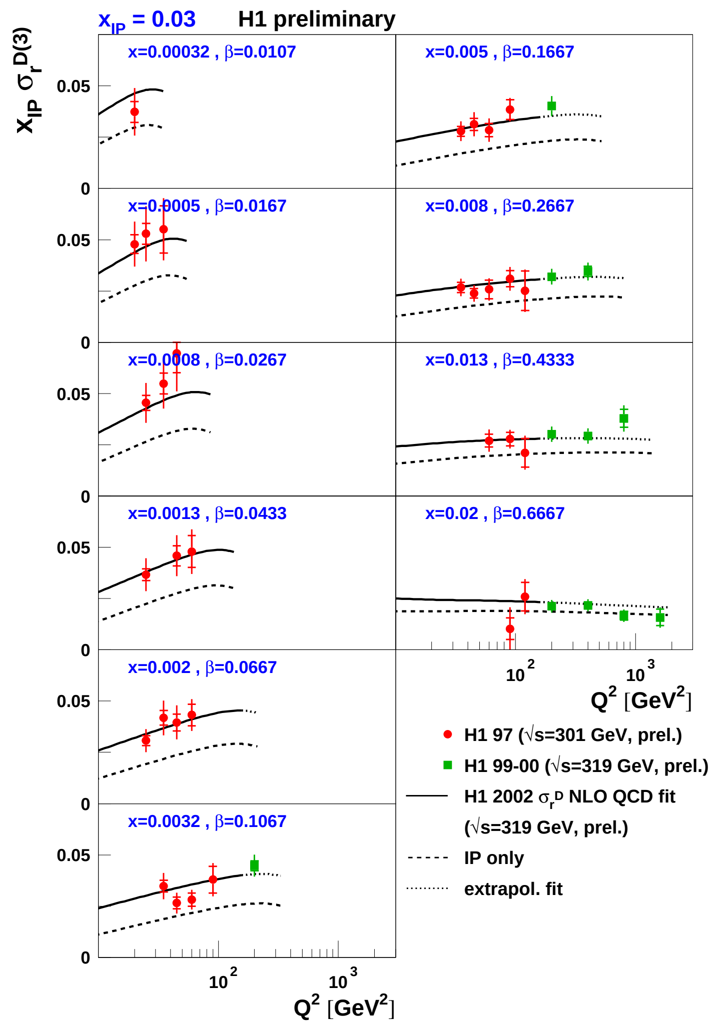
Prediction of NLO Fit based on Medium Q^2 data

➔ good agreement with Low and High Q^2 data

❑ Low and High Q^2 data will provide additional constraints on singlet and gluon distributions

Extrapolation of QCD Fit: Q^2 dependence





Extrapolation of NLO Fit over an order of magnitude in Q^2

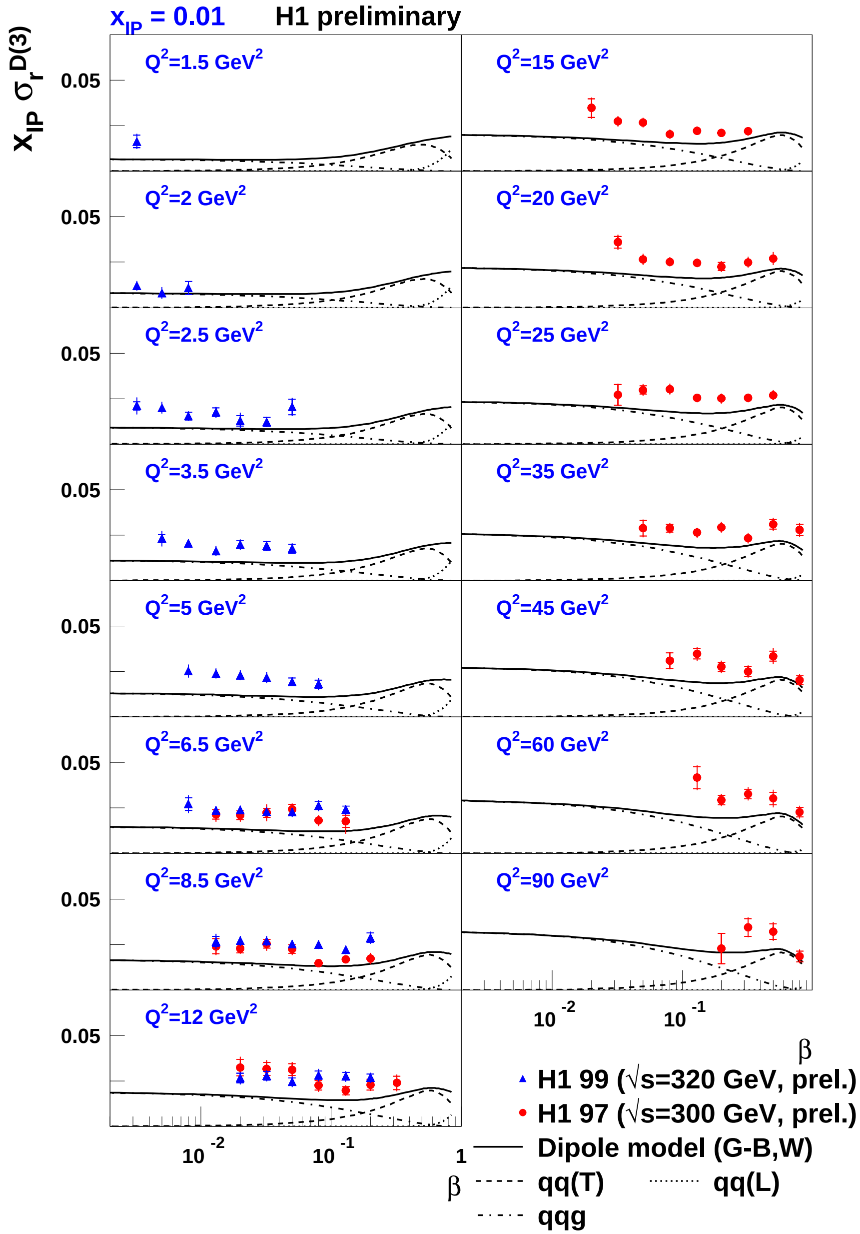
➔ good agreement with Low and High Q^2 data

❑ Low and High Q^2 data will provide additional constraints on singlet and gluon distributions

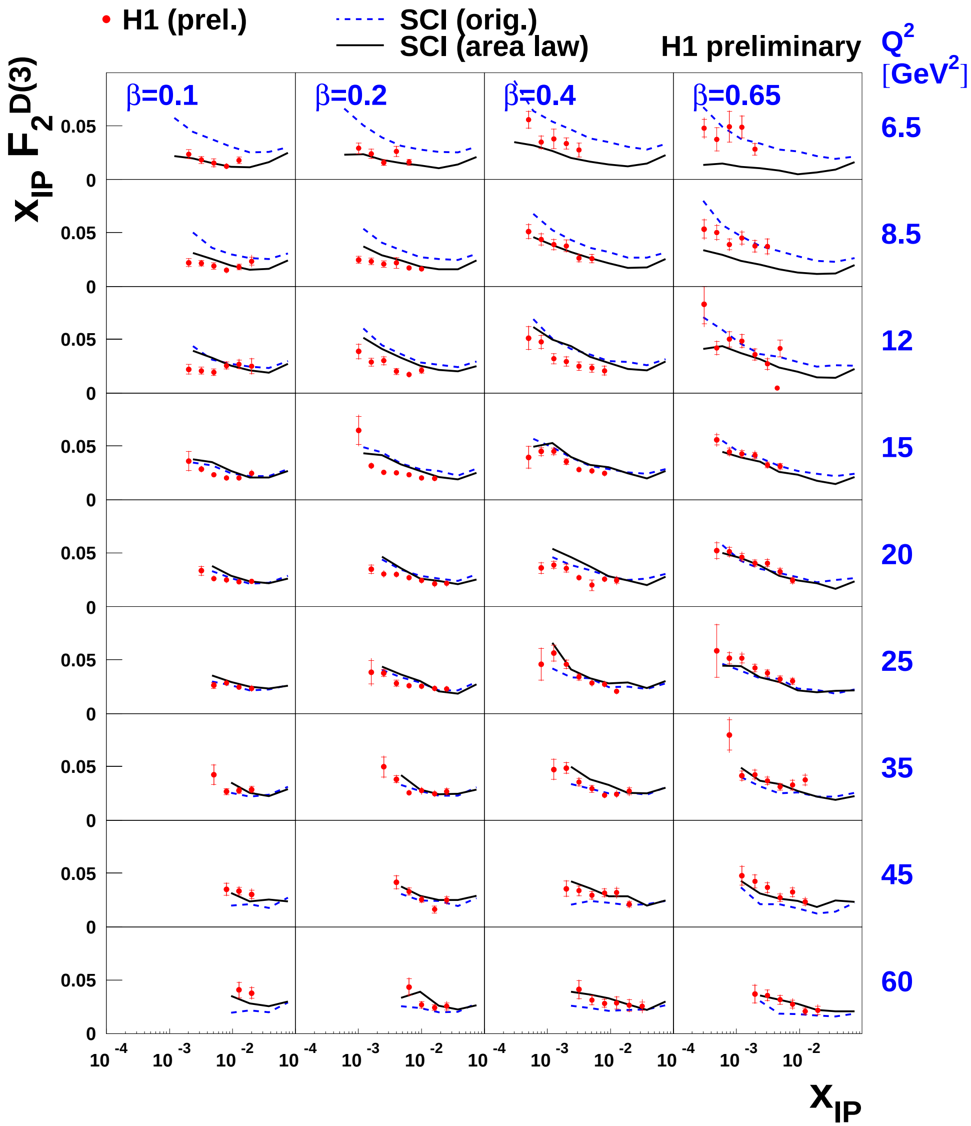
Low and Medium Q^2 data vs Colour dipole saturation model

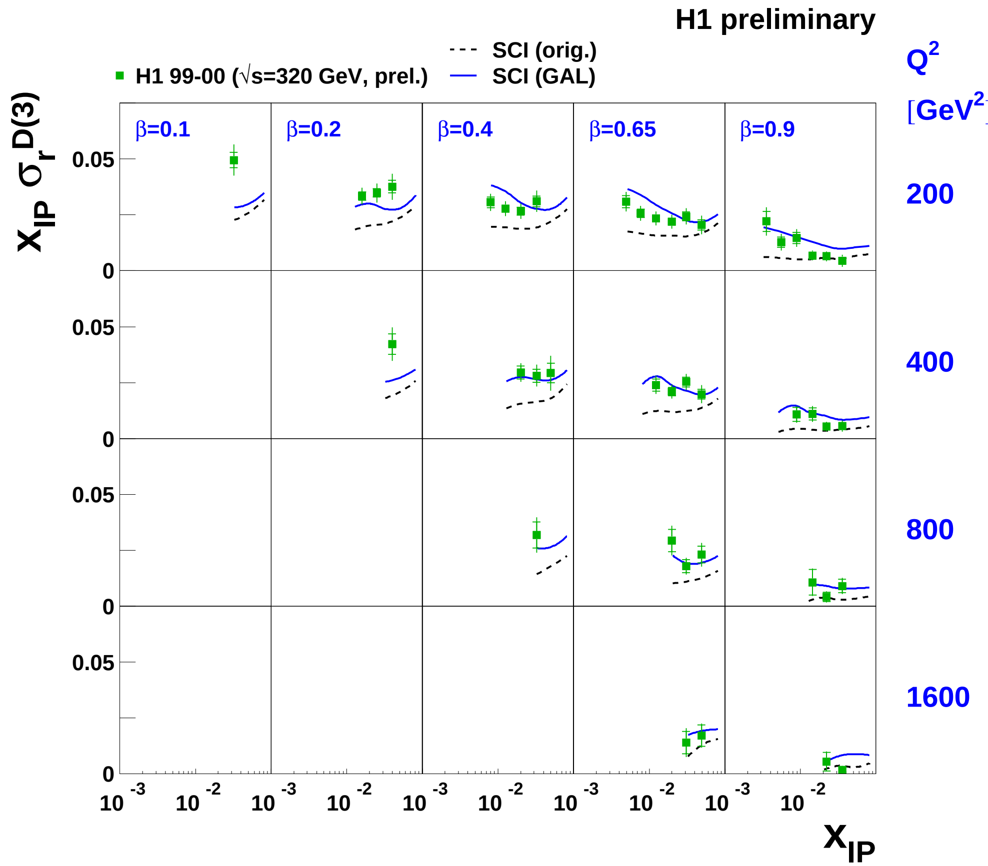
- Photon fluctuates in *qq / qqg* long before interaction with proton
- Parameterization for dipole-proton cross section:
  - ✓ color transparency for small dipole sizes
  - ✓ cross section saturation at low x / Q^2

➔ Model consistently undershoots the data



Medium and High Q^2 data vs SCI model





- Model based on Generalized Area Law describes data better than original

Summary

- ❑ High precision measurements of the diffractive reduced cross section have been performed at Low, Medium and High Q^2
- ❑ Data are consistent with Regge factorization assuming additional contribution from sub-leading trajectory
- ❑ Similar Q^2 dynamics to inclusive DIS at medium β
- ❑ NLO DGLAP fit to Medium Q^2 data:
- ✓ diffractive parton distributions (quark singlet and gluon)
- ✓ gluon distribution dominates (75±15%)
- ✓ can be used to test QCD factorization in *ep* and *hh* interactions
- ❑ High and low Q^2 measurements are in agreement with QCD Fit predictions
- ❑ Color Dipole Saturation model undershoots Low and Medium Q^2 data
- ❑ Soft Color Interaction model describes Medium and High Q^2 data except at low β