Measurements and QCD interpretation of the diffractive cross section at HERA

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Diffraction 2004
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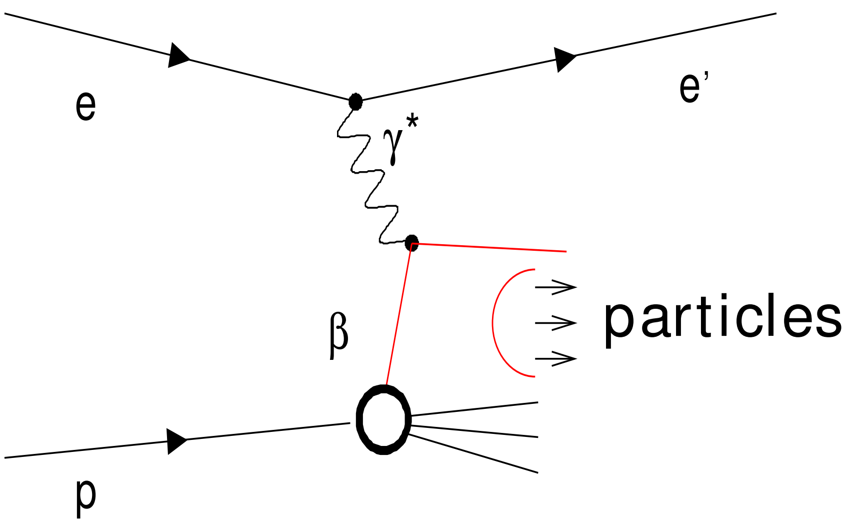
- Measurement of inclusive diffractive DIS cross section
- DGLAP QCD fit
- Diffractive parton densities
- Measurement of inclusive diffractive charged-current cross section

Diffraction at HERA

- *ep* collisions: probe proton with photon
- examine QCD structure of diffraction

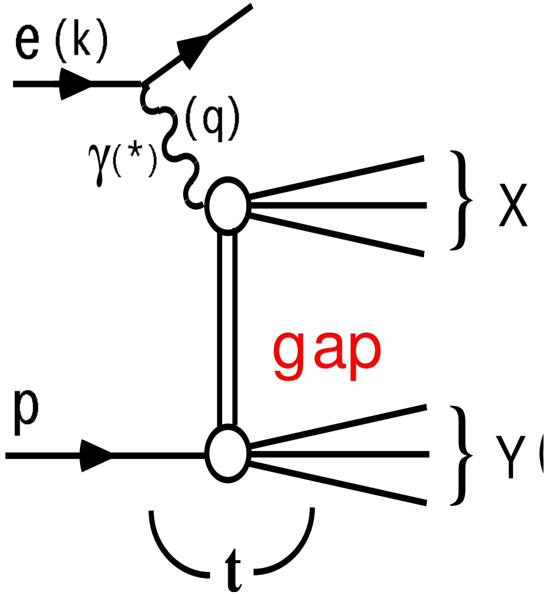
deep-inelastic ep scattering (DIS)



- colour flow
- proton breaks up

→ many particles in proton direction

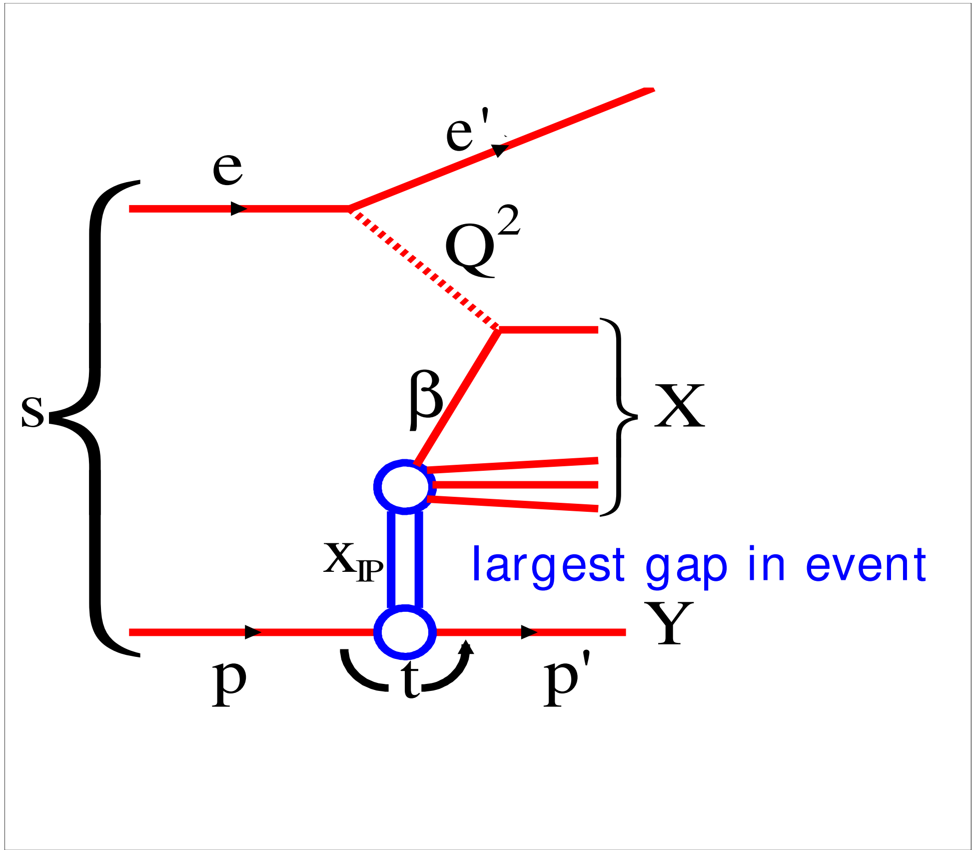
diffractive ep collision
(≈10% of DIS events)



- colour singlet exchange
- proton intact or low mass excitation

→ events with gap and/or leading proton

Kinematics



Q^2 photon virtuality

β quark momentum fraction w.r.t. colour singlet exchange

x_{IP} colour singlet momentum fraction w.r.t. proton

$x = \beta\, x_{IP}$ quark momentum fraction w.r.t. proton

t squared momentum transferred at proton vertex

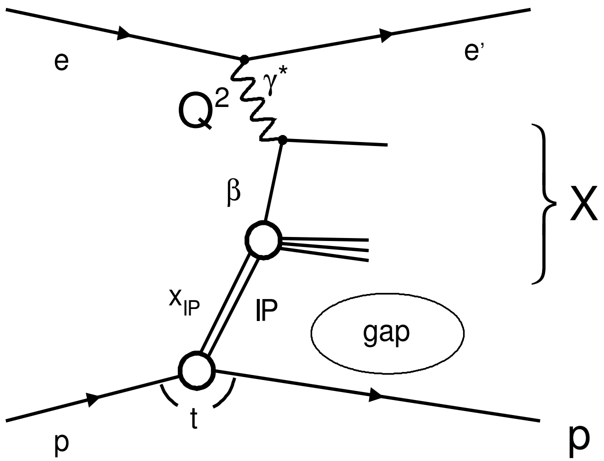
$\sqrt{s}$ *ep* centre-of-mass energy ≈300 GeV

$y = \frac{Q^2}{s\ x}$ inelasticity variable

M_Y mass of (dissociating) proton system, mostly m_p

diffraction: $x_{IP} < 0.05$, $|t| < 1$ GeV^2, $M_Y < 1.6$ GeV

Reduced diffractive cross section



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

reduced cross section

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

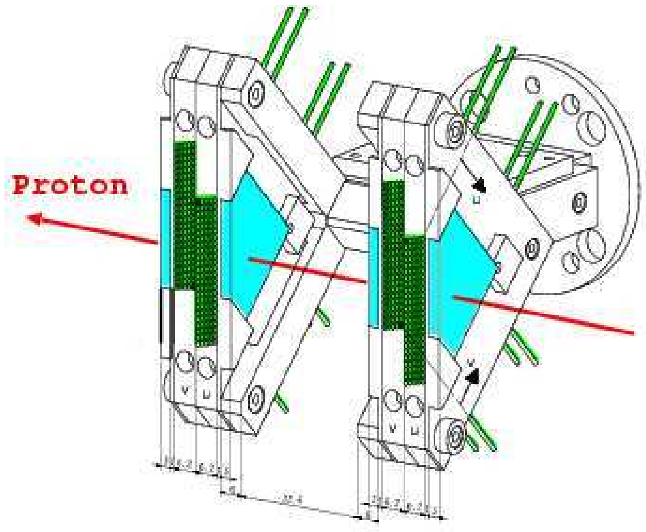
diffractive structure functions

$$F_2^{D(4)} = \frac{Q^2}{4\pi^2\alpha}\left(\sigma_{T,D}^{\gamma^* p}+\sigma_{L,D}^{\gamma^* p}\right)$$

$$F_L^{D(4)} = \frac{Q^2}{4\pi^2\alpha}\sigma_{L,D}^{\gamma^* p}$$

At LO QCD: $F_L^D = 0$

t dependence: Forward Proton Spectrometer



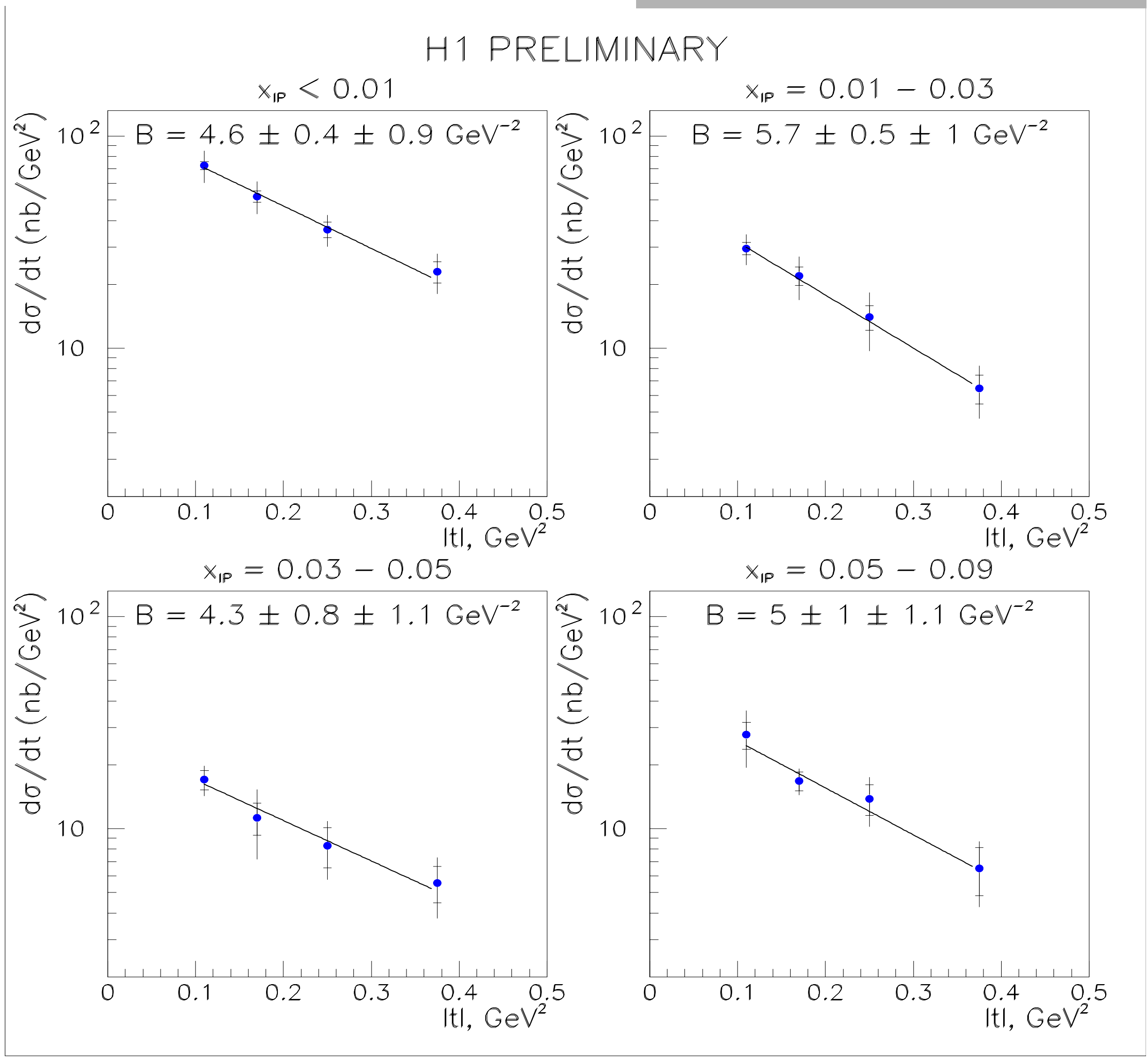
- roman pot detectors close to outgoing proton beam
- limited acceptance

$2 < Q^2 < 50$ GeV^2
$y < 0.6$
$-0.45 < t < -0.08$ GeV^2
$x_{IP} < 0.09$
$L = 28.8$ pb^{-1}

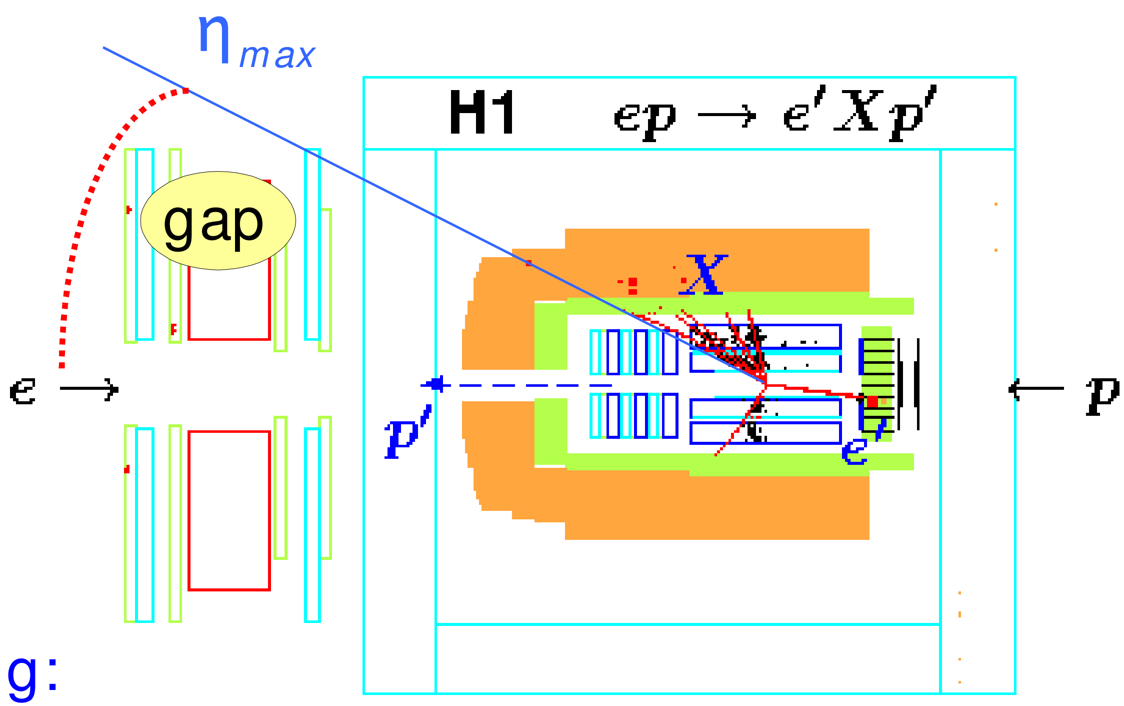
- measure t dependence
- fits to cross section

$$\frac{d\sigma^D}{dt} \propto e^{Bt}$$

$B = 5.0 \pm 0.3(\mathrm{stat}) \pm 0.8(\mathrm{syst})$ GeV^{-2}



Rapidity Gap Selection



- proton escapes undetected through beam pipe
- require no activity between proton and system in detector

Disadvantages w.r.t. proton tagging:

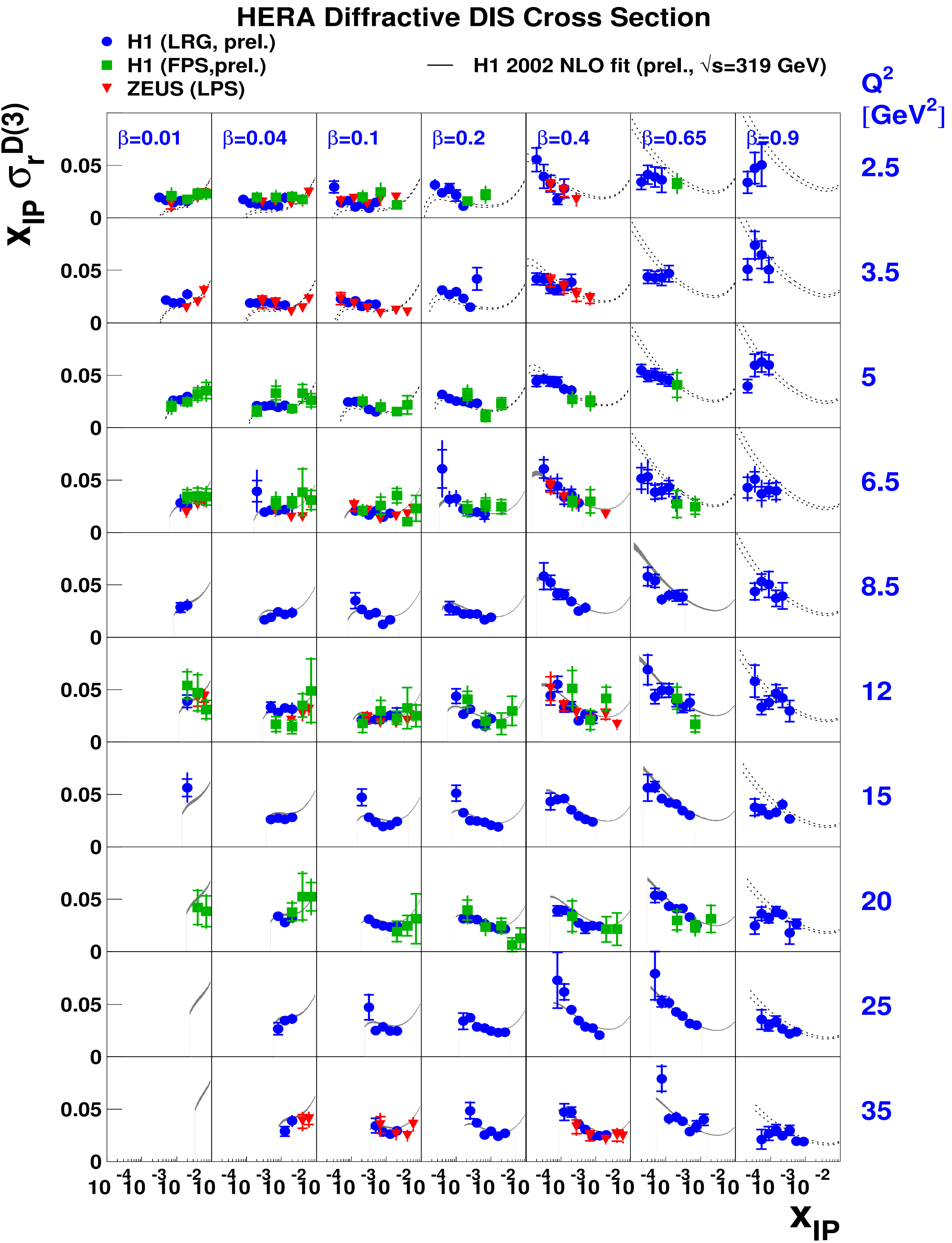
- integrate over t range:

  $|t| < 1\ \text{GeV}^2$

- proton dissociation background:

  $M_Y < 1.6\ \text{GeV}$

...but: higher statistics!



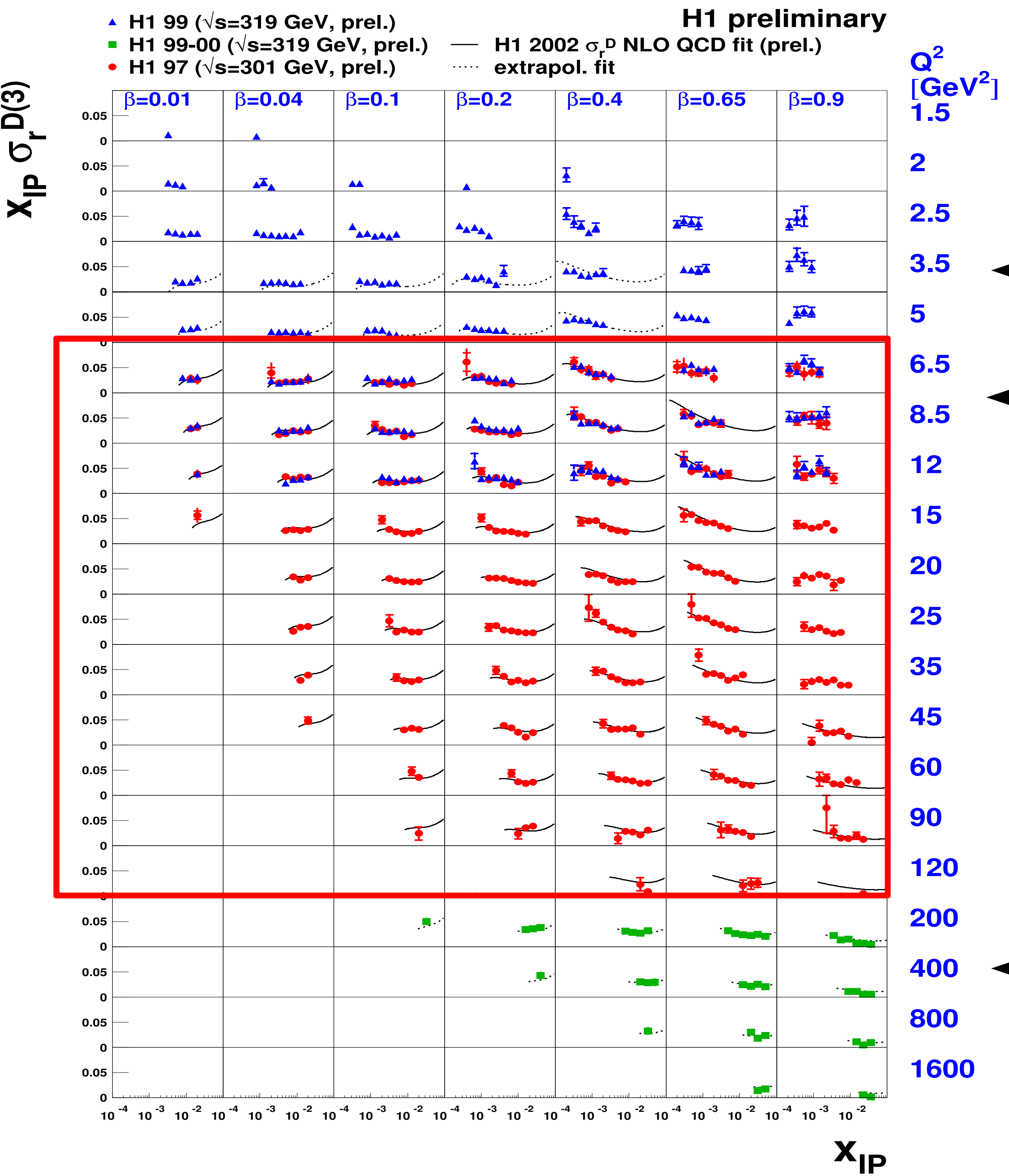
Rapidity Gap Selection vs. Proton Tagging

- $\sigma_r^{D(3)}$ measurements with rapidity gap method and proton tagging

→ good agreement

- good agreement with ZEUS proton tagging measurement

H1 $\sigma_r^{D(3)}$ measurements (rapidity gap method)

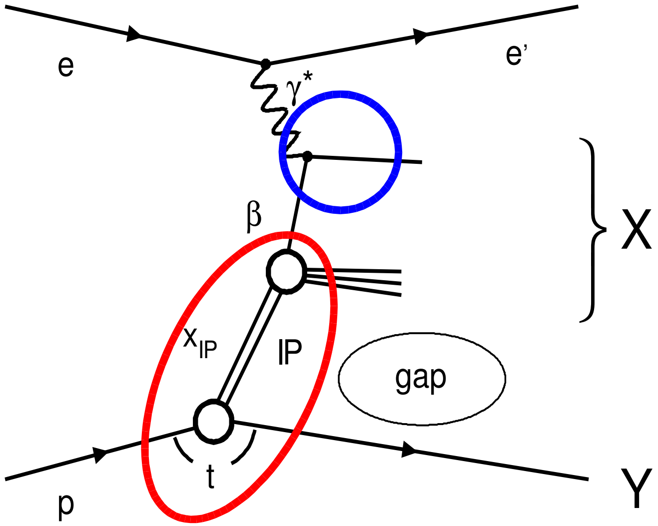


'99 low Q^2 data

'97 data shown in the following and entering DGLAP fit

'99-'00 high Q^2 data

QCD Factorisation and Diffractive Parton Densities



diffractive photon-proton cross section factorises at fixed x_{IP} and t (proof by J. Collins)

$$\sigma_{T,L}^{\gamma^* p} = \sum_{partons\ i} f_{i/p}^{D} \otimes \sigma_{T,L}^{\gamma^* i}$$

diffractive PDF

partonic cross section

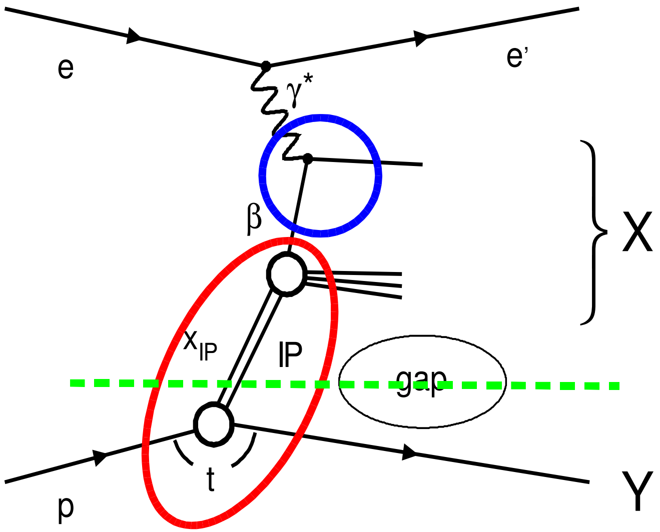
→ ep collision: diffractive structure functions factorise:

$$F_2^{D(4)} \propto \sum_{partons\ i} f_{i/p}^{D} \otimes \sigma^{\gamma^* i}$$

with $\sigma_D^{\gamma^* p} = \sigma_{T,D}^{\gamma^* p} + \sigma_{L,D}^{\gamma^* p}$

$$F_L^{D(4)} \propto \sum_{partons\ i} f_{i/p}^{D} \otimes \sigma_L^{\gamma^* i}$$

Regge Factorisation



factorise the diffractive PDF:

$$f^{D}_{i/p}(x_{IP}, t, \beta, Q^2) = f_{IP/p}(x_{IP}, t)\; f_{i/IP}(\beta, Q^2)$$
$$\left[+ f_{IR/p}(x_{IP}, t)\; f_{i/IR}(\beta, Q^2) \right]$$

'Reggeon' contribution for $x_{IP} > 0.01$

- (β, Q^2) dependence independent of (x_{IP}, t) dependence
- Regge phenomenology, no proof in QCD!

Experimental Test of Regge Factorisation

- Fit to $\sigma_r^{D(3)}$ assuming Regge factorisation (y< 0.45 to avoid F_L^D)

$$\sigma_r^{D(3)} = f_{IP/p}(x_{IP})\, A_{IP}(\beta, Q^2) + f_{IR/p}(x_{IP})\, A_{IR}(\beta, Q^2)$$

flux factor:

$$f_{IP/p}(x_{IP}) = \int dt \frac{e^{B_{IP} t}}{x_{IP}^{2\alpha_{IP}(t)-1}} \qquad \text{with } \alpha_{IP}(t) = \alpha_{IP}(0) + \alpha'_{IP}\, t$$

- fit x_{IP} distribution in every (β, Q^2) bin
- A_{IP} and A_{IR} are free parameters controlling the normalisations

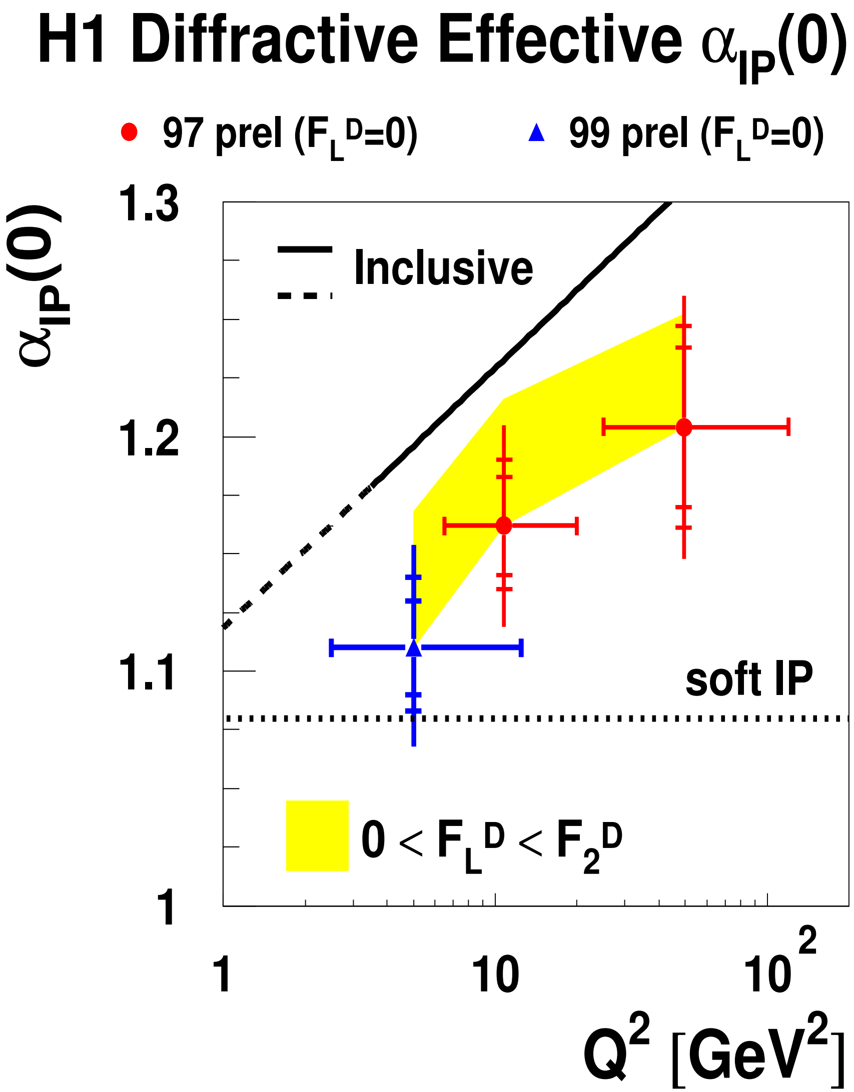
Result:

$$\chi^2/ndf = 0.95$$

$$\alpha_{IP}(0) = 1.173 \pm 0.018(stat.) \pm 0.017(syst.)\, {}^{+0.063}_{-0.035}(model)$$

→ **Regge factorisation consistent with data**

Effective $\alpha_{IP}(0)$



- Regge fit in different Q^2 ranges
  → $\alpha_{IP}(0)$ at different Q^2

- no significant dependence on Q^2
- error dominated by uncertainty on F_L^D: varied by $0 < F_L^D < F_2^D$

- $\alpha_{IP}(0)$ at high Q^2 larger than in hadron-hadron collisions

→ **no universal pomeron**

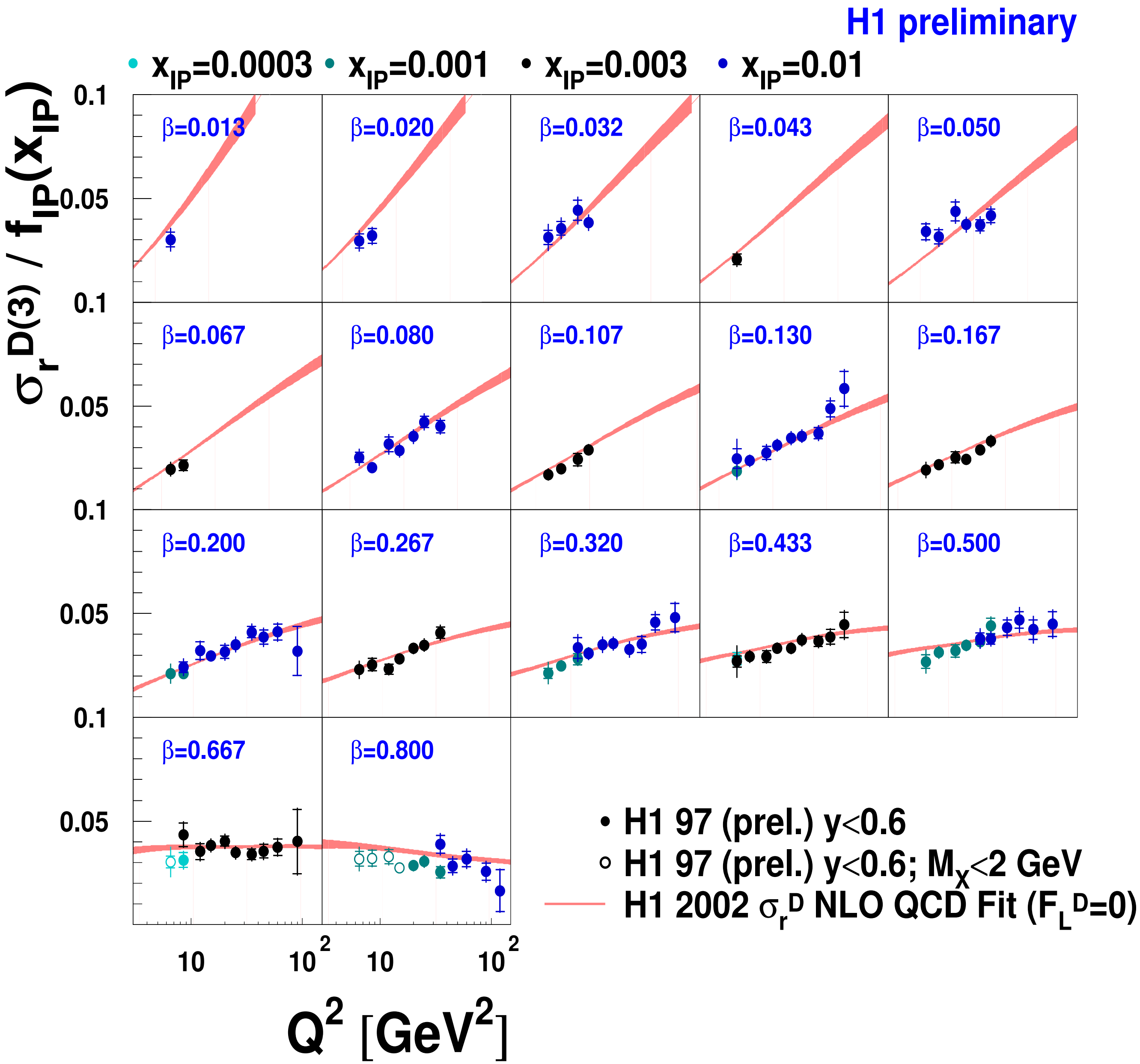
- $\alpha_{IP}(0)$ from fit to inclusive ep scattering:

$$F_2 = c\, x^{-(\alpha_{IP}(0)-1)}$$

- data suggest that at high Q2 inclusive $\alpha_{IP}(0)$ > diffractive $\alpha_{IP}(0)$

Q^2 dependence of σ_r^D - Scaling violations

- $x_{IP} < 0.01$, $y < 0.6$ to limit Reggeon and F_L^D contributions



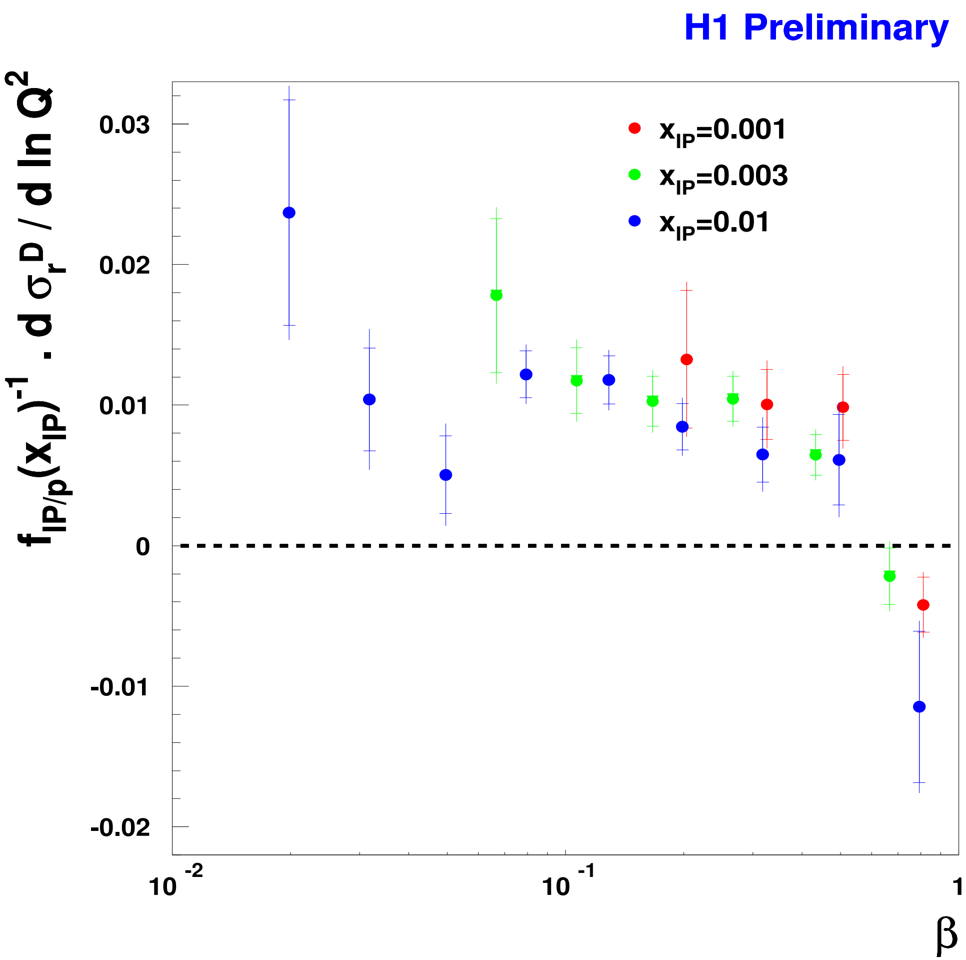
- divided by flux factor
- structure similar for all x_{IP}
  → supports Regge factorisation
- at LO:

$$\sigma_r^{D(3)} / f_{IP} = F_2^{IP}(\beta, Q^2) = \sum_i \beta\, e_i^2\, q_i(\beta, Q^2)$$

$$\frac{\partial \sigma_r^{D(3)}}{\partial \ln(Q^2)} \sim \alpha_s\, g(\beta, Q^2)$$

- positive scaling violations for $\beta < 0.65$
  → large gluon component

Scaling Violations Quantified



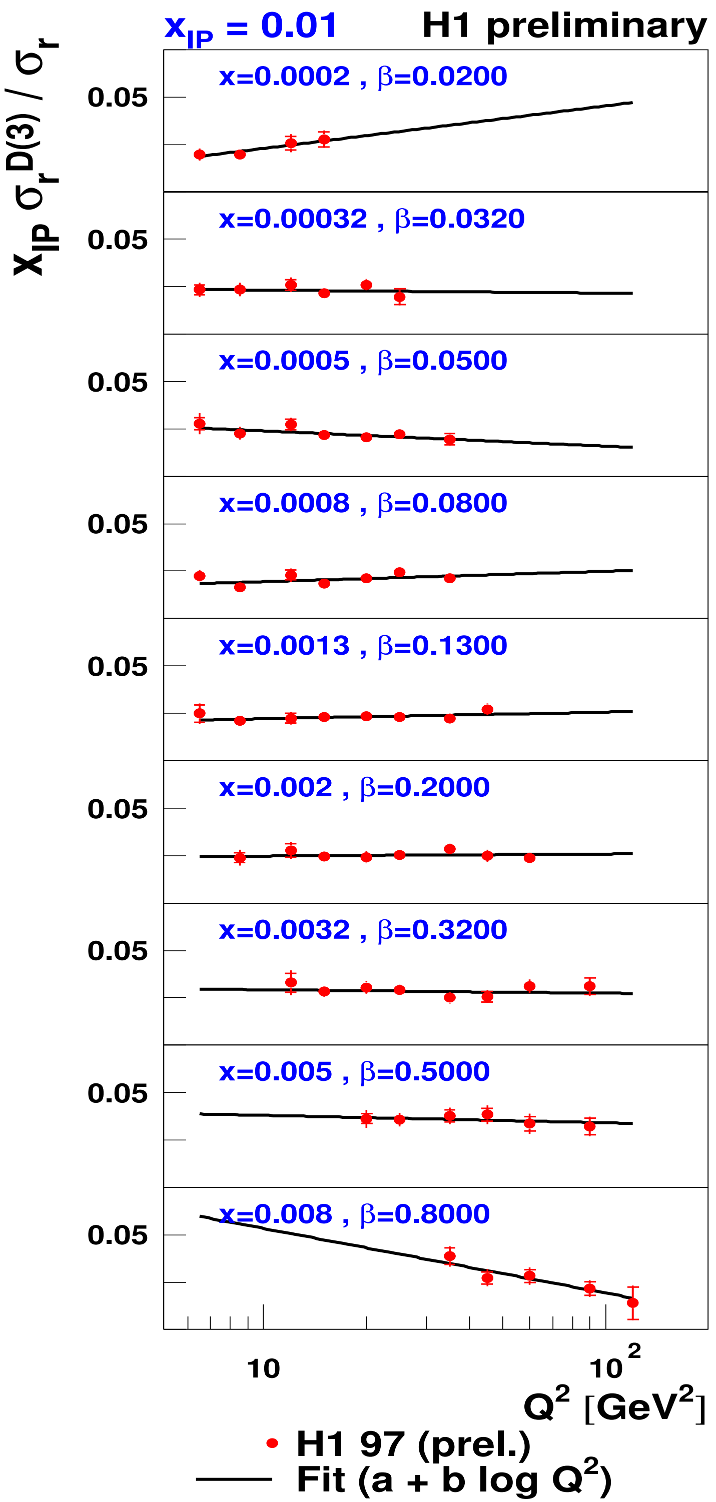
$$\frac{\partial \sigma_r^{D(3)}}{\partial \ln(Q^2)} \sim \alpha_s g^{LO}(\beta, Q^2)$$

- fit of scaling violations:

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

- scaling violations positive for $\beta < 0.65$

→ large gluon



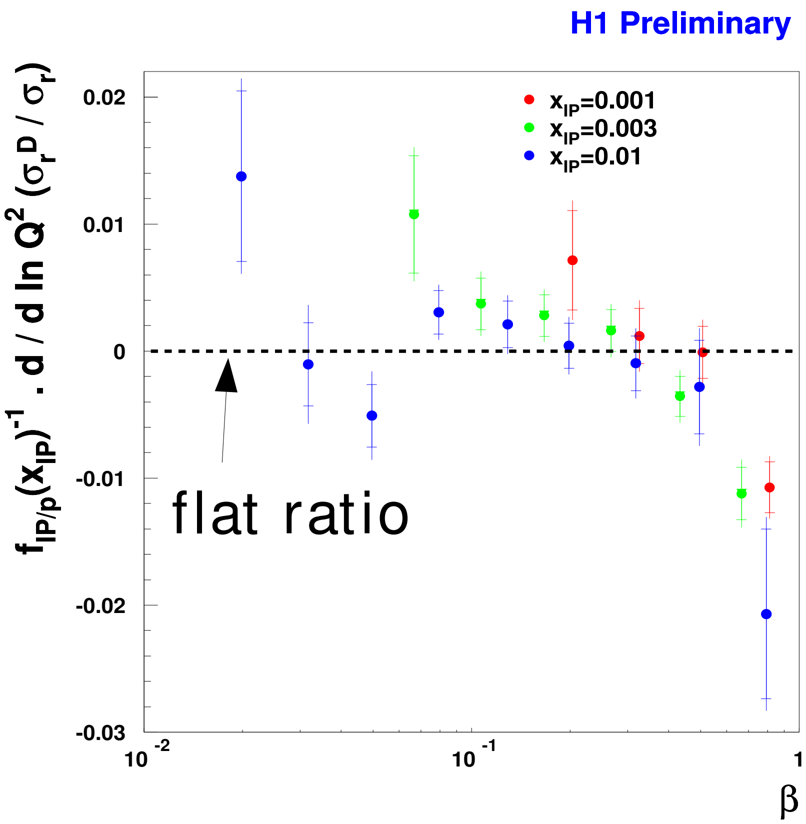
Ratio diffractive/ inclusive DIS

- ratio of reduced cross sections
- fixed x_{IP} $\rightarrow$ fixed gap size
- ratio flat for $\beta < 0.5$

similar QCD dynamics in diffraction and inclusive DIS?

- $\beta > 0.6$: diffractive contribution decreasing

?



DGLAP Fit to σ_r^D

- rapidity gap data: $6.5 < Q^2 < 800$ GeV^2 ('94-'97 data in $200 < Q^2 < 800$ GeV^2 not shown)

- avoid higher twist: $M_X > 2$ GeV

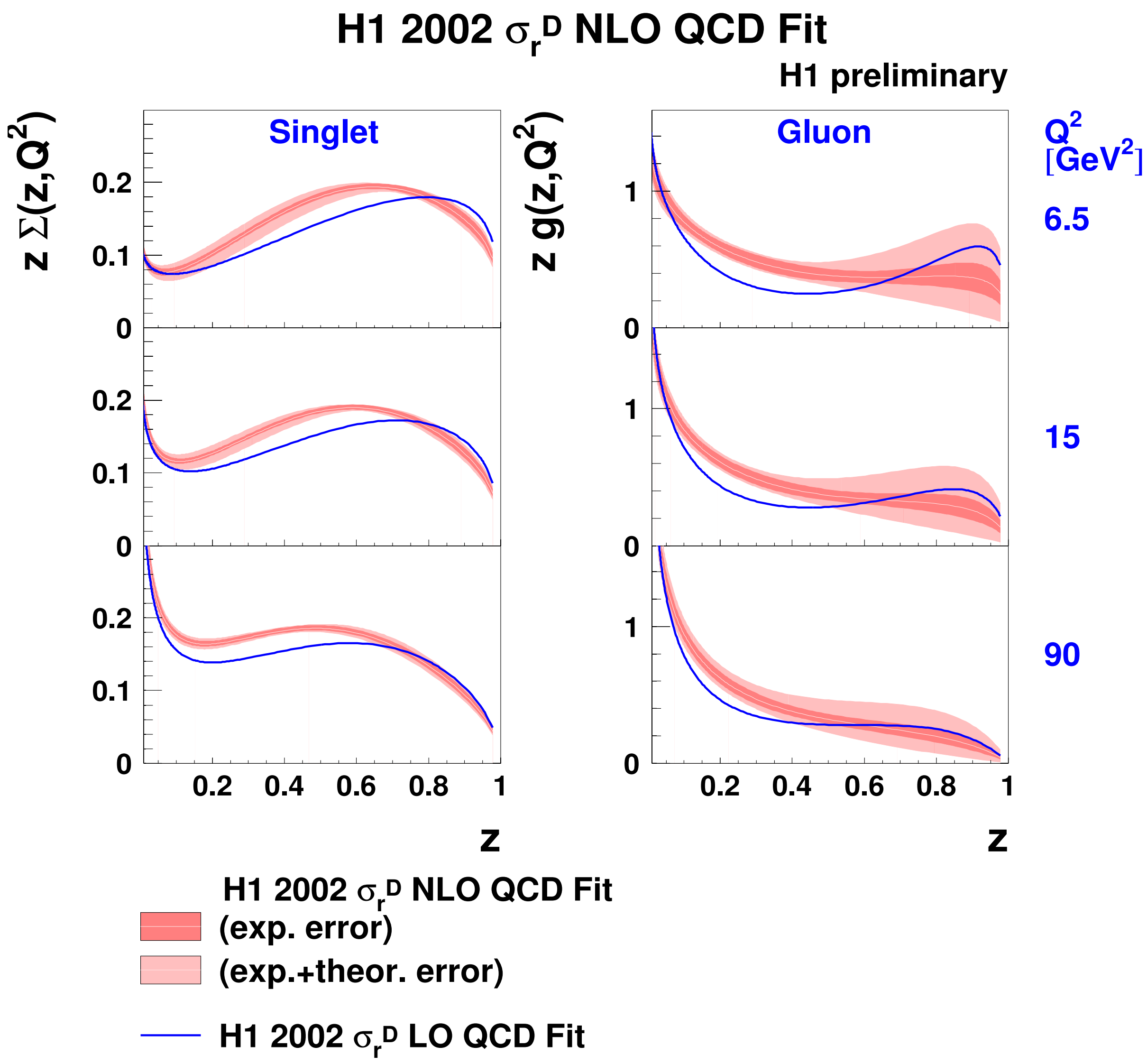
- NLO fit: F_L^D taken into account
- LO fit: $y < 0.45$ to avoid F_L^D

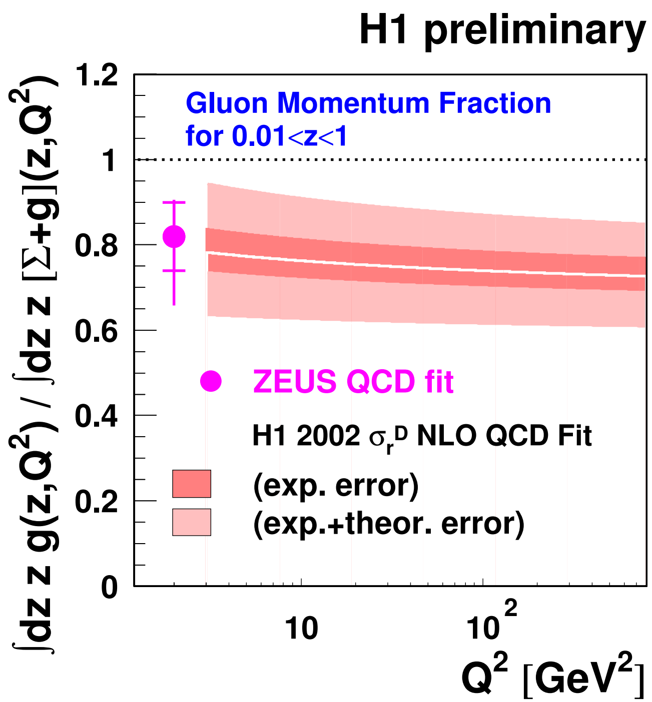
- fit diffractive parton densities:

  sum of light quarks $\Sigma = u + d + s + \bar{u} + \bar{d} + \bar{s}$
  gluon

- parameterised at starting scale $Q_0^2 = 3$ GeV
- using Chebychev polynomials + exp. damping at high fractional momentum
- (N)LO DGLAP evolution to measured Q^2

Diffractive Parton Densities



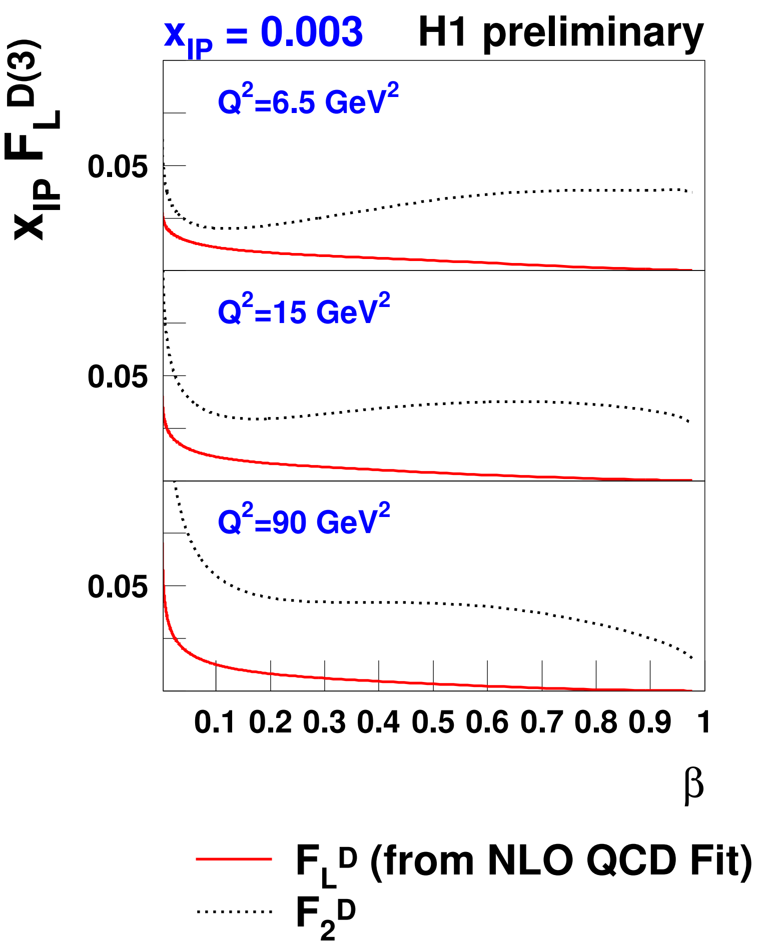


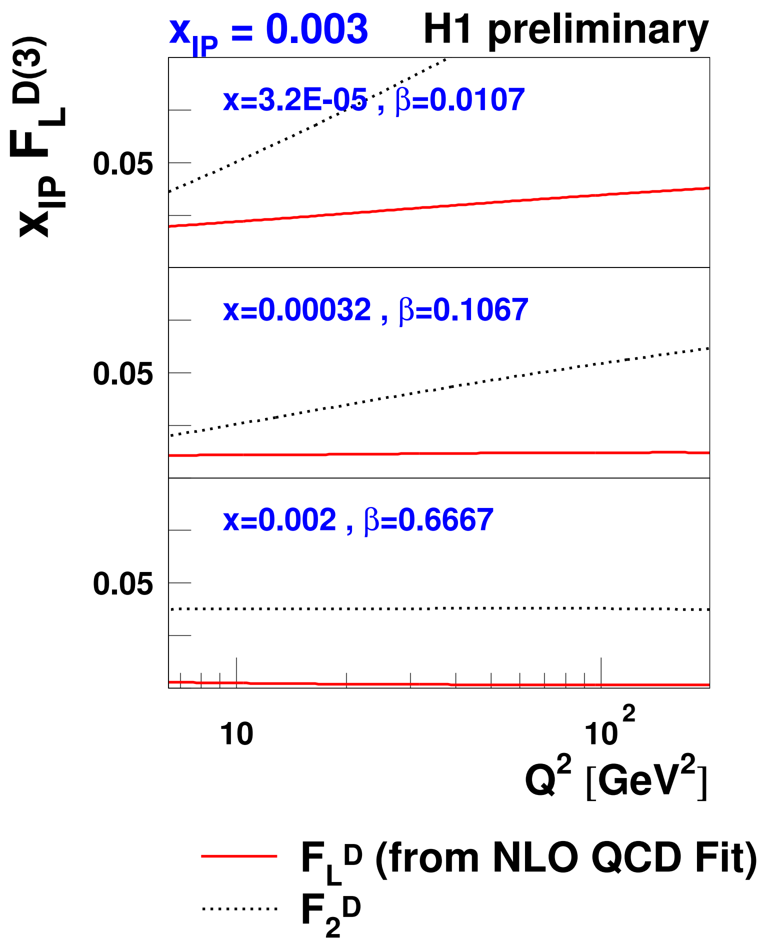
- gluon carries 75± 15% of momentum (agreement with ZEUS fit)
- large gluon uncertainty at high z

z = parton momentum fraction w.r.t. diffractive exchange

F_L^D - Longitudinal Structure Function

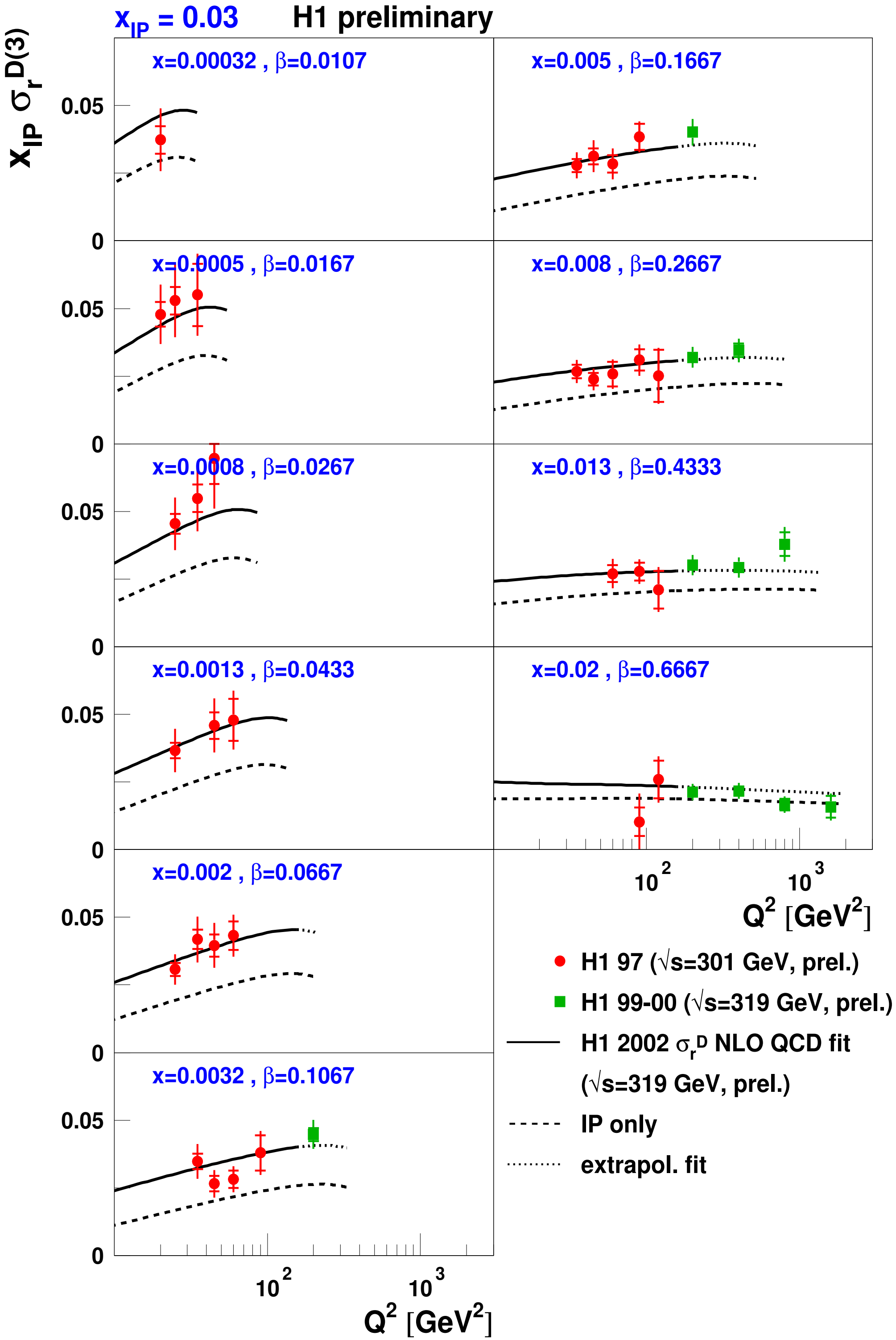
F_L^D at leading twist NLO QCD: $F_L^D \propto \frac{\alpha}{2\pi}\left[C_q^L \otimes F_2^D + C_g^L \otimes \sum_i e_i^2 z\, g^D(z, Q^2)\right]$





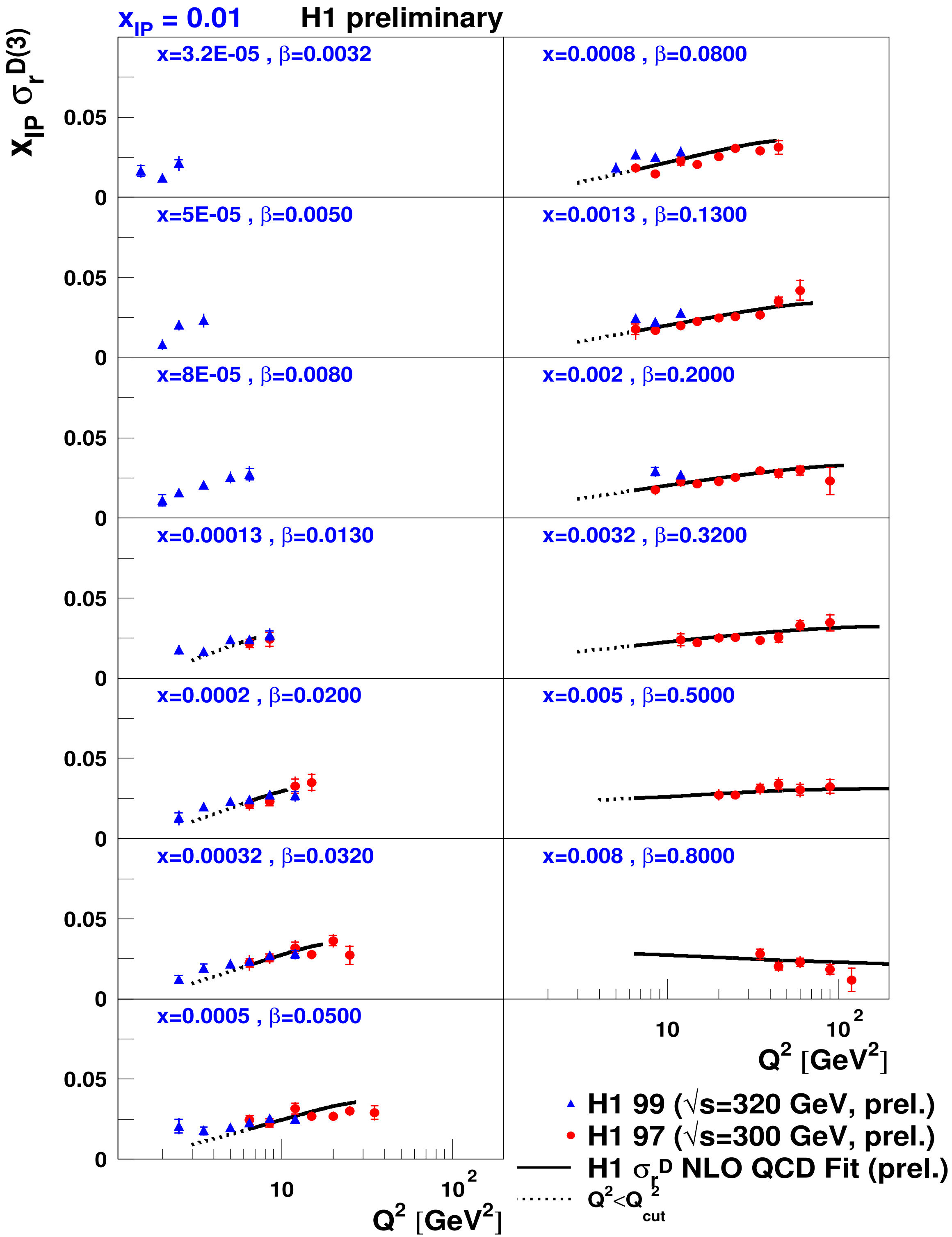
- related to NLO gluon density
  → large at low β

- large fraction of F_2^D at low Q^2 and low β



High Q^2 measurement

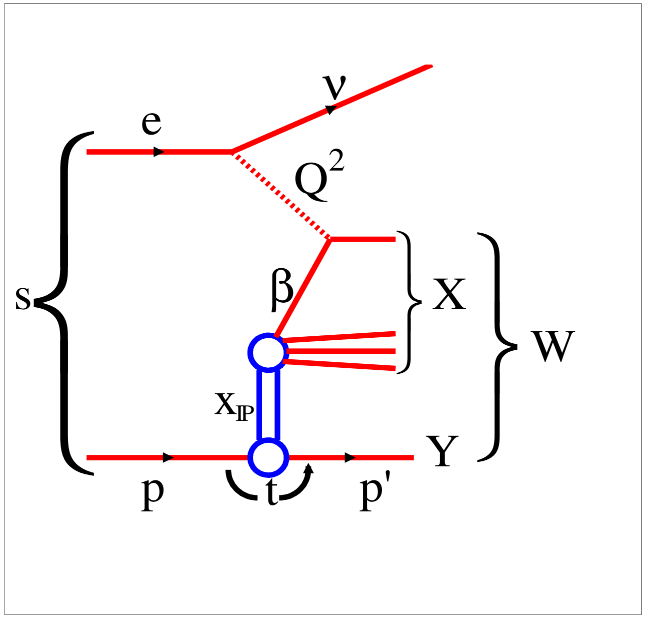
- $200 < Q^2 < 1600$ GeV^2
- L = 63 pb^{-1}, H1 99-00 data
- extrapolated NLO fit to region $6.5 < Q^2 < 800$ GeV^2 in good agreement
- shown for $x_{IP} = 0.03$
  → sizeable Reggeon contribution
- new data will provide constraint to future fit



Low Q^2 measurement

- $1.5 < Q^2 < 12$ GeV^2
- L = 3.4 pb^{-1}, H1 99 data (unbiased triggers)
- NLO fit extrapolated down to $Q^2 = 3$ GeV^2 and $\beta = 0.013$ in reasonable agreement
- new data will provide constraint to future fit

Diffractive Charged- Current DIS



- process ep $\rightarrow \nu XY$
- L = 63 pb^{-1}, H1 99-00 data
- rapidity gap selection

$Q^2 > 200$ GeV^2
$x_{IP} < 0.05$
$y < 0.9$

→ 14 diffractive CC events

H1: $\sigma^D_{CC} = 0.42 \pm 0.13(stat.) \pm 0.09(syst)\ pb$

ZEUS: $\sigma^D_{CC} = 0.49 \pm 0.20(stat.) \pm 0.13(syst)\ pb$

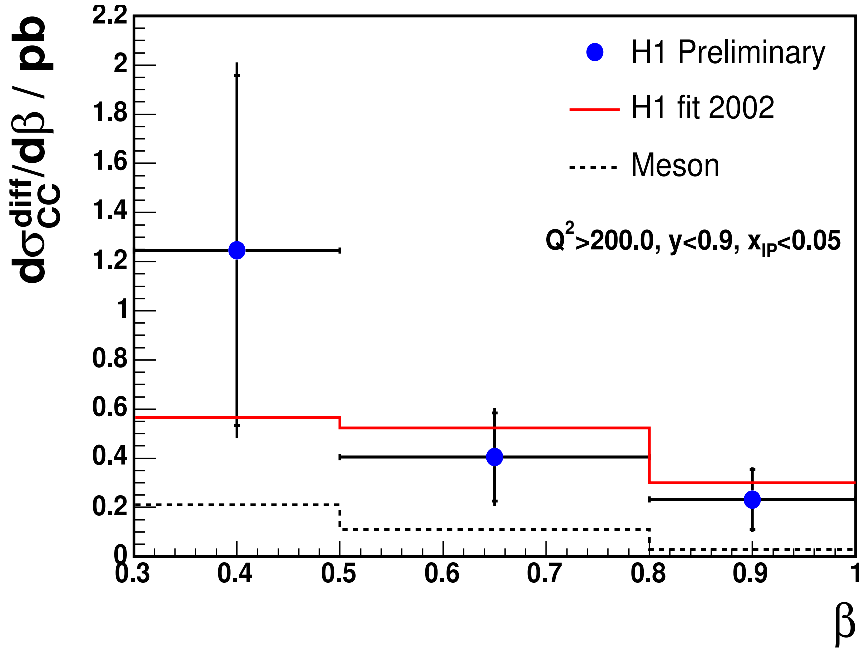
Ratio to inclusive CC cross section:

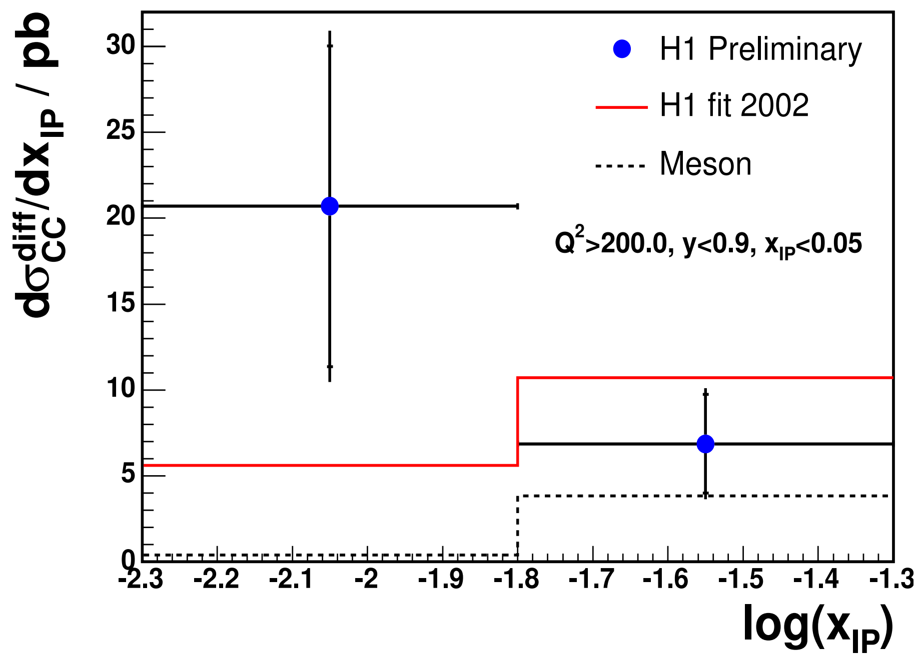
H1: $\sigma^D_{CC}/\sigma_{CC} = 2.5 \pm 0.8(stat) \pm 0.6(syst)\ \%$

ZEUS: $\sigma^D_{CC}/\sigma_{CC} = 2.9 \pm 1.2(stat) \pm 0.8(syst)\ \%$

→ good agreement between results of experiments

Diffractive CC DIS - differential cross section





- comparison with RAPGAP LO Monte Carlo + ARIADNE CDM
- prediction based on LO diffractive PDFs from H1 2002 fit (obtained in neutral current DIS)

→ cross section well described within large statistical uncertainties of data

Summary

- reduced cross section measured in diffractive DIS (neutral current) for $1.5 < Q^2 < 1600\ GeV^2$

- agreement between rapidity gap method and proton tagging

- NLO and LO DGLAP fits performed

- (N)LO diffractive parton densities extracted with uncertainties

- gluon carries $75 \pm 15\%$ of momentum of diffractive exchange

- diffractive charged-current DIS cross section measured
  - well described by LO Monte Carlo based on LO diffractive PDFs
  - H1 and ZEUS results in agreement

Diffractive PDFs can be used to obtain predictions for other final state configuration: jets, heavy flavour

→ final states talks