Inclusive Diffraction at HERA

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[DESY]

Representing the

Collaborations at HERA

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Parallel Session:
QCD - Soft Interactions

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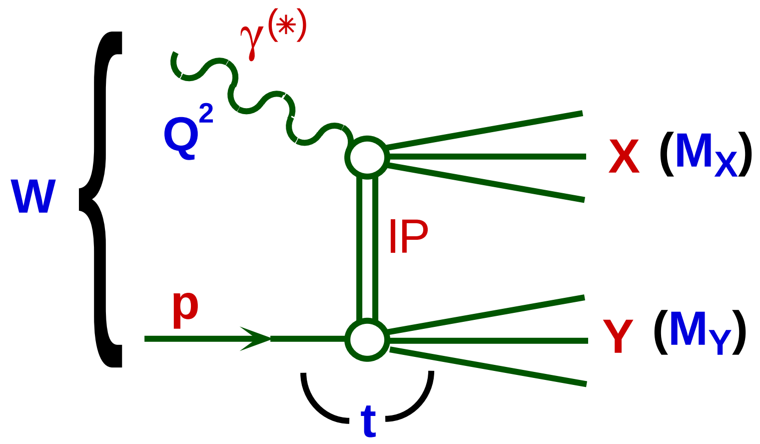


Highlights:

- **New generation of high precision data from H1 and ZEUS**
- **NLO QCD interpretation: diffractive parton distributions with uncertainties**

Introduction

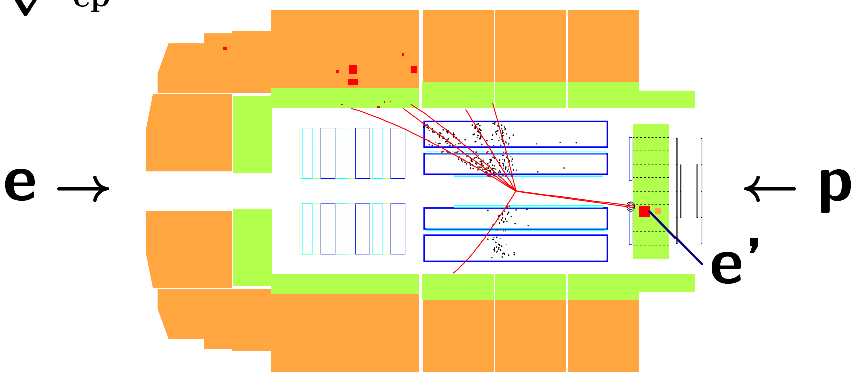
A challenge in QCD at high energies:

- **Description of colour singlet exchange or diffractive processes**
- **Closely related to rising total cross sections and confinement**

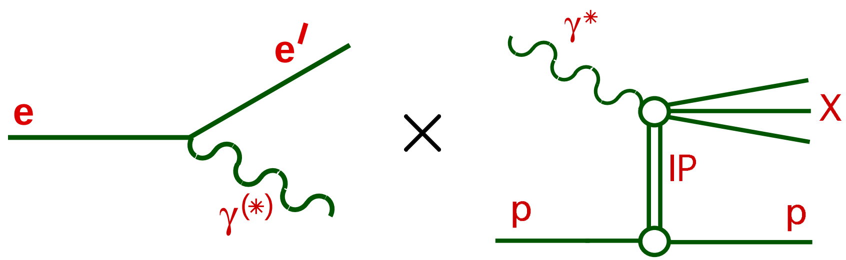
HERA: An ideal laboratory to study hard diffraction:

10% of low-x DIS events are diffractive:

$\sqrt{s_{ep}} = 320$ GeV



Can be viewed as diffractive $\gamma^* p$ interaction:

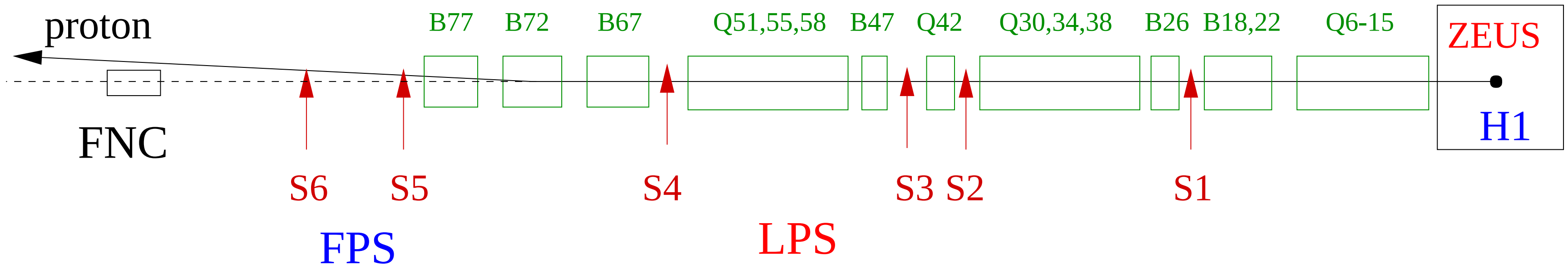


- **Probe QCD structure of colour singlet exchange with virtual photon**

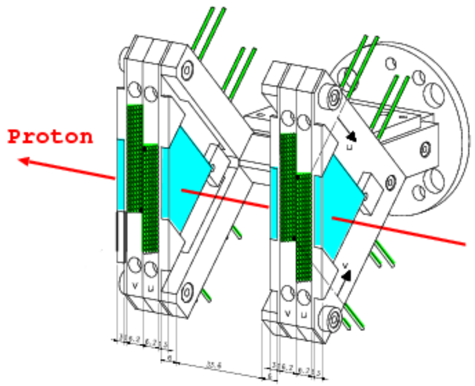
$$W^2_{\gamma p} \sim \frac{1}{x_{bj}}$$

- **In QCD: at least two partons in net colour singlet state (e.g. 2 gluons)**
- **Increased sensitivity to low-x limit of proton structure**

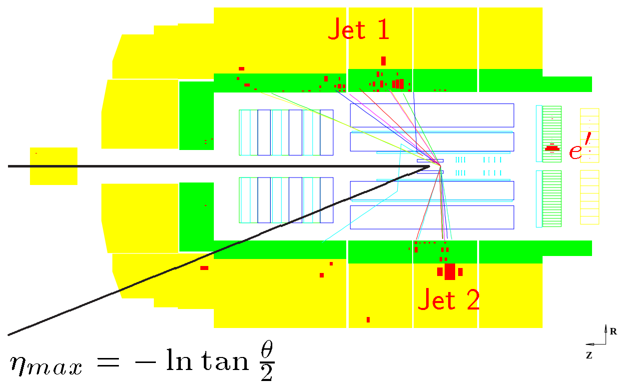
Experimental Techniques



Forward Proton Spectrometers at $z = 24 \ldots 90$ m



Rapidity Gap Selection in central detector



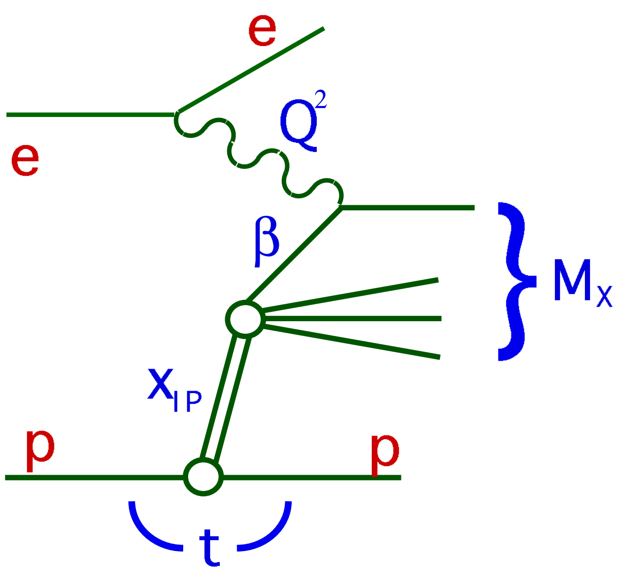
Measure leading proton

- Free of dissociation bkgd.
- Measure p 4-momentum
- low statistics (acceptance)

Require large rapidity gap

- $\Delta\eta$ large when $M_{\mathrm{central}} \ll W_{\gamma p}$
- integrate over outgoing p system
- high statistics

Diffractive Cross section and Structure Functions



$x_{\mathbb{P}} = \xi = \frac{Q^2+M_X^2}{Q^2+W^2} = x_{\mathbb{P}/p}$
(momentum fraction of colour singlet exchange)

$\beta = \frac{Q^2}{Q^2+M_X^2} = x_{q/\mathbb{P}}$
(fraction of exchange momentum of q coupling to γ^*, $x = x_{\mathbb{P}}\beta$)

$t = (p - p')^2$
(4-momentum transfer squared)

Diffractive reduced cross section σ_r^D:

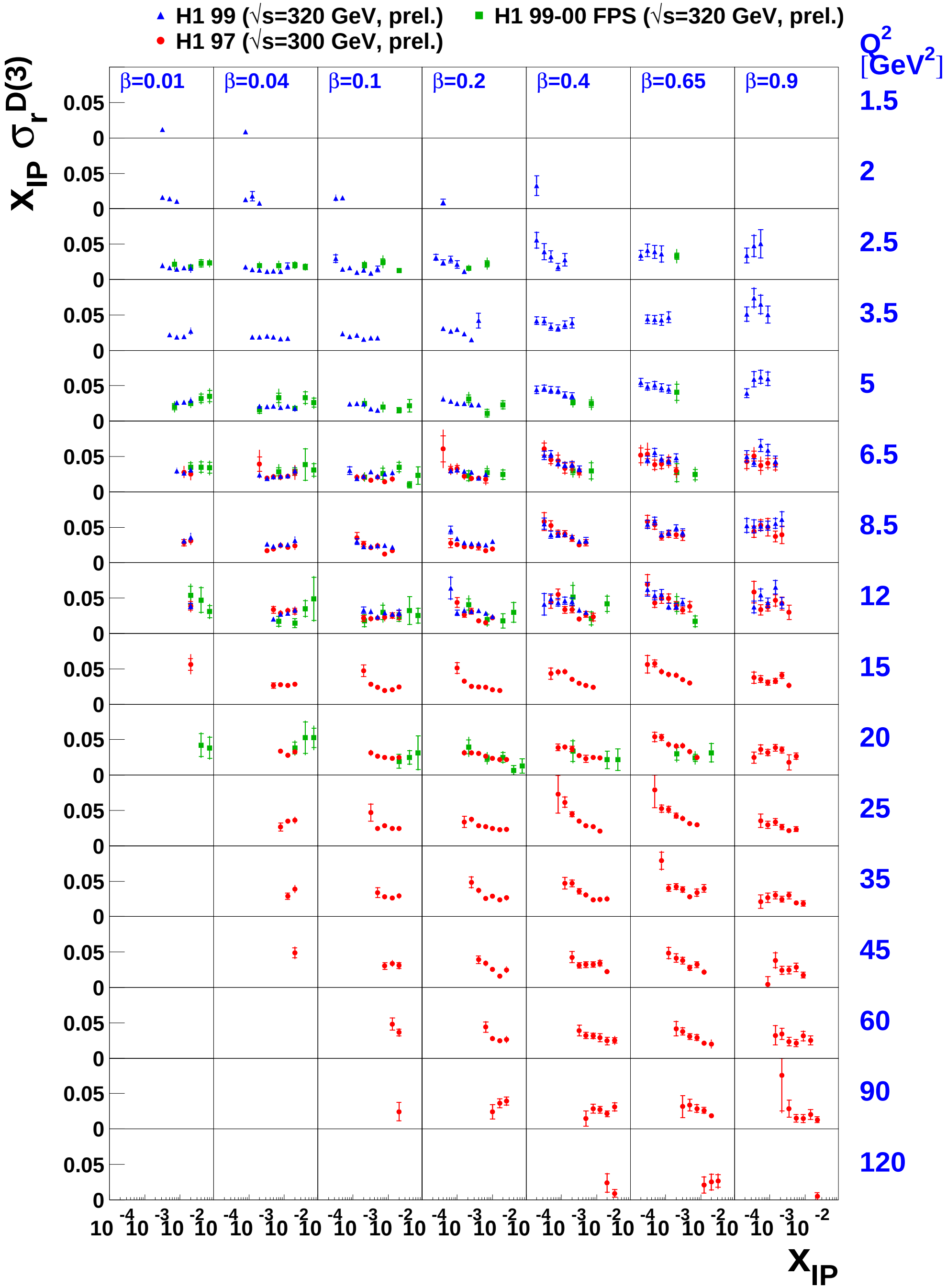
$$\frac{d^4\sigma}{dx_{\mathbb{P}}\ dt\ d\beta\ dQ^2} = \frac{4\pi\alpha^2}{\beta Q^4}\left(1 - y + \frac{y^2}{2}\right)\sigma_r^{D(4)}(x_{\mathbb{P}}, t, \beta, Q^2)$$

Structure functions F_2^D and F_L^D:

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

Integrated over t: $F_2^{D(3)} = \int dt\ F_2^{D(4)}$

– Longitudinal F_L^D: affects σ_r^D at high y [γ inelasticity $y = Q^2/sx$]
– If $F_L^D = 0$: $\sigma_r^D = F_2^D$



New Measurements: H1

- $1.5 < Q^2 < 12$ GeV^2
- $6.5 < Q^2 < 120$ GeV^2

  New measurements based on rapidity gap method

– Statistics improved by factor 5

- $2.5 < Q^2 < 20$ GeV^2

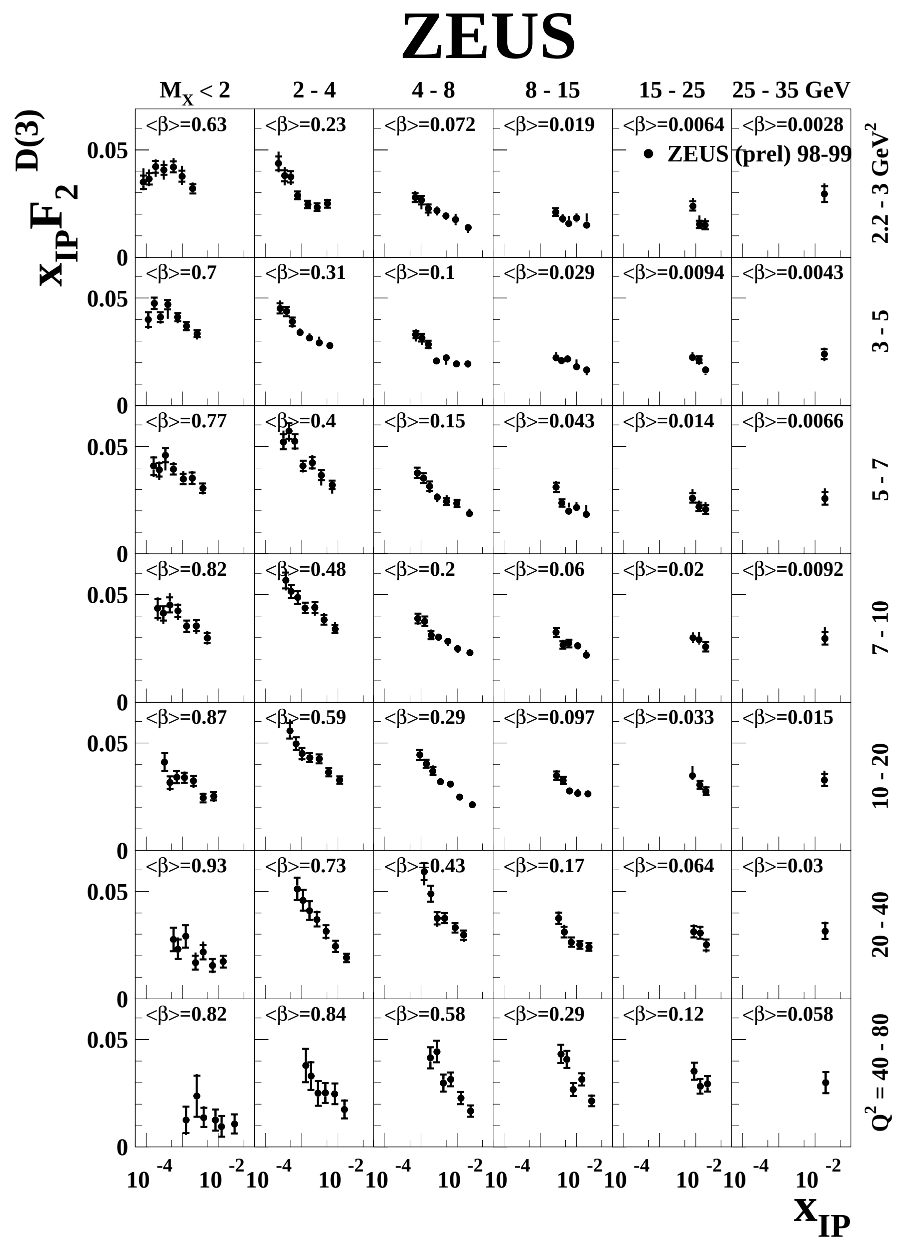
  New measurement using H1 FPS (Forward Proton Spectrometer)

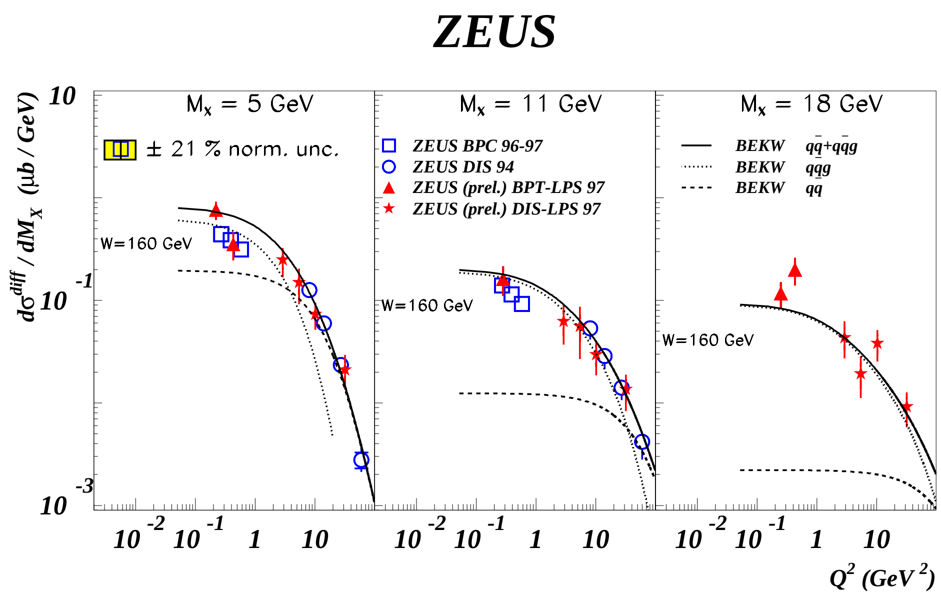
– Agreement between methods

High precision measurements of β (or x) and Q^2 dependences

$\Rightarrow$ DGLAP QCD interpretation

New Measurements: ZEUS





- **(top) New LPS data**
  (Leading Proton Spectrometer)
  In transition region (γp – DIS)
  $0.03 < Q^2 < 0.6\ \mathrm{GeV}^2$

- **(left) New data using improved forward calorimeter**
  $2.2 < Q^2 < 80\ \mathrm{GeV}^2$

Factorization in Diffraction

Proof of QCD Factorization for diffractive DIS:

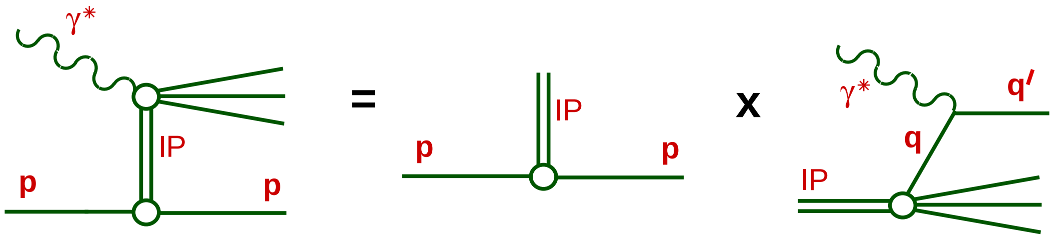
- Diffractive parton distributions (Trentadue, Veneziano, Berera, Soper, Collins, ...):

$$\frac{d^2\sigma(x,Q^2,x_{I\!P},t)^{\gamma^* p \rightarrow p' X}}{dx_{I\!P}\ dt} = \sum_i \int_x^{x_{I\!P}} d\xi \hat{\sigma}^{\gamma^* i}(x, Q^2, \xi)\ p_i^D(\xi, Q^2, x_{I\!P}, t)$$

- $\hat{\sigma}^{\gamma^* i}$ hard scattering part, as in incl. DIS
- p_i^D diffractive PDF's in proton, conditional probabilities, valid at fixed $x_{I\!P}, t$, obey (NLO) DGLAP

Regge Factorization / 'Resolved Pomeron' model:

$x_{I\!P}, t$ dependence factorizes out (Donnachie, Landshoff, Ingelman, Schlein, ...):



- additional assumption, no proof !
- consistent with present data if sub-leading $I\!R$ included

$$F_2^D(x_{I\!P}, t, \beta, Q^2) = f_{I\!P/p}(x_{I\!P}, t)\ F_2^{I\!P}(\beta, Q^2)$$

Shape of diffr. PDF's indep. of $x_{I\!P}, t$, normalization controlled by Regge flux $f_{I\!P/p}$

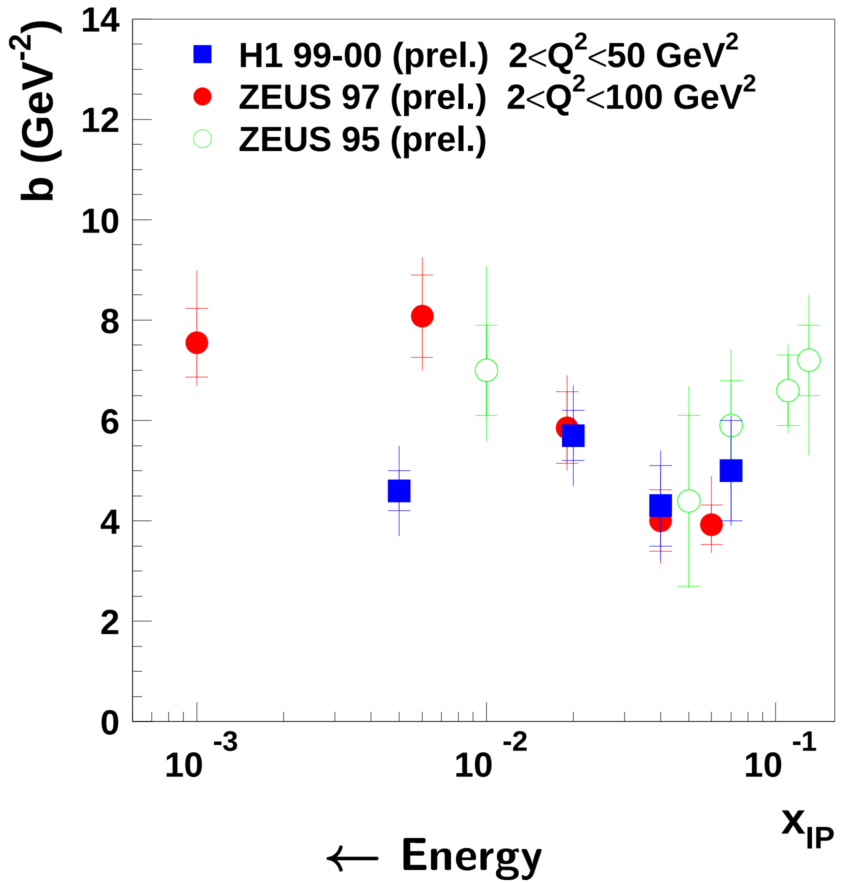
Forward Proton Detectors: t Measurement

$\frac{d\sigma}{d|t|}$ measured for $-0.4 \lesssim t < |t|_{\min}$

Exponential fit to t distribution:

$$\frac{d\sigma}{d|t|} \sim e^{-b|t|}$$

b is related to
the interaction radius: $b = R^2/4$

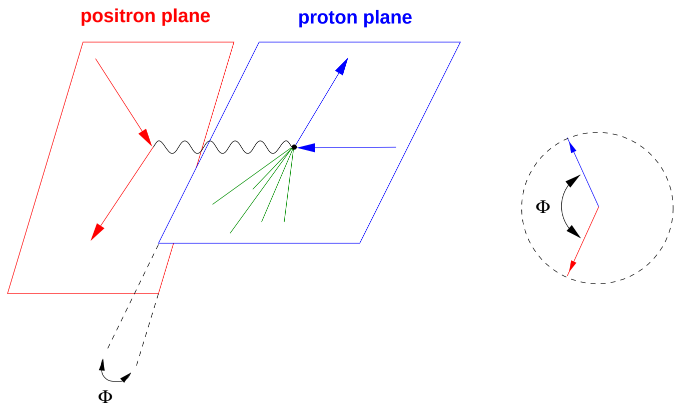


In Regge phenomenology expect 'shrinkage':
(proton gets 'bigger' with increasing energy) $b = b_0 + 2\alpha' \log \frac{1}{x_{I\!P}}$ $x_{I\!P} \sim M_X^2/W_{\gamma p}^2$

So far inconclusive ...

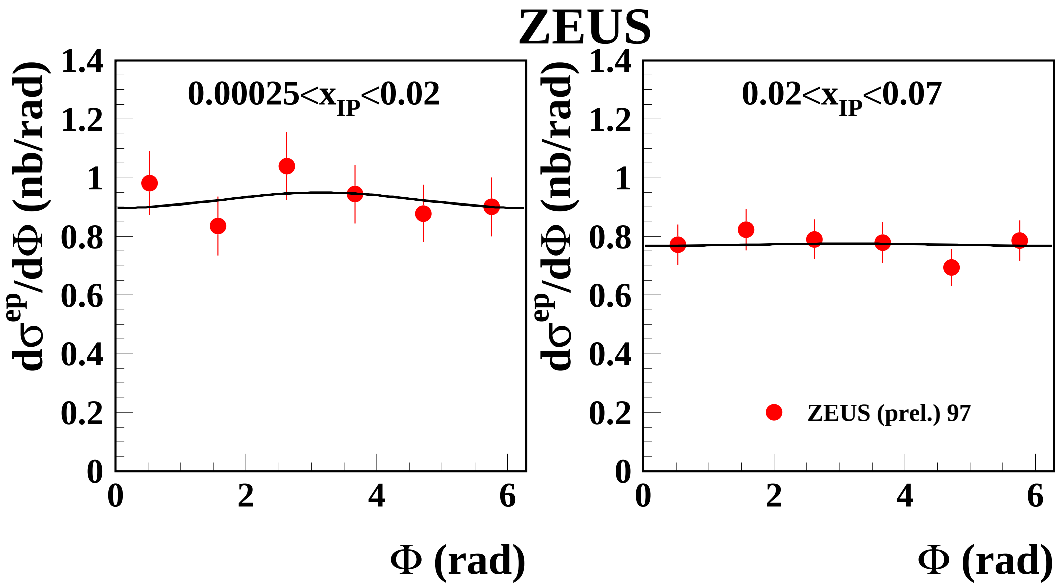
Forward Proton Detectors: ϕ Measurement

Φ: Azimuthal angle between electron and proton scattering planes



$\frac{d\sigma^D}{d\Phi}$ sensitive to σ_L^D through interf. term:

$$\frac{d\sigma^D}{d\Phi} \sim \sigma_T^D + \epsilon\sigma_L^D - 2\sqrt{\epsilon(1+\epsilon)}\sigma_{LT}^D \cos\Phi - \epsilon\sigma_{TT}^D \cos 2\Phi$$



Measured asymmetries from fit $\frac{d\sigma}{d\Phi} \sim 1 + A_{LT}\cos\Phi$:

$A_{LT} = -0.029 \pm 0.066^{+0.026}_{-0.047}$
$(0 \lesssim x_{I\!P} < 0.02\ ;\ \beta \approx 0.32)$

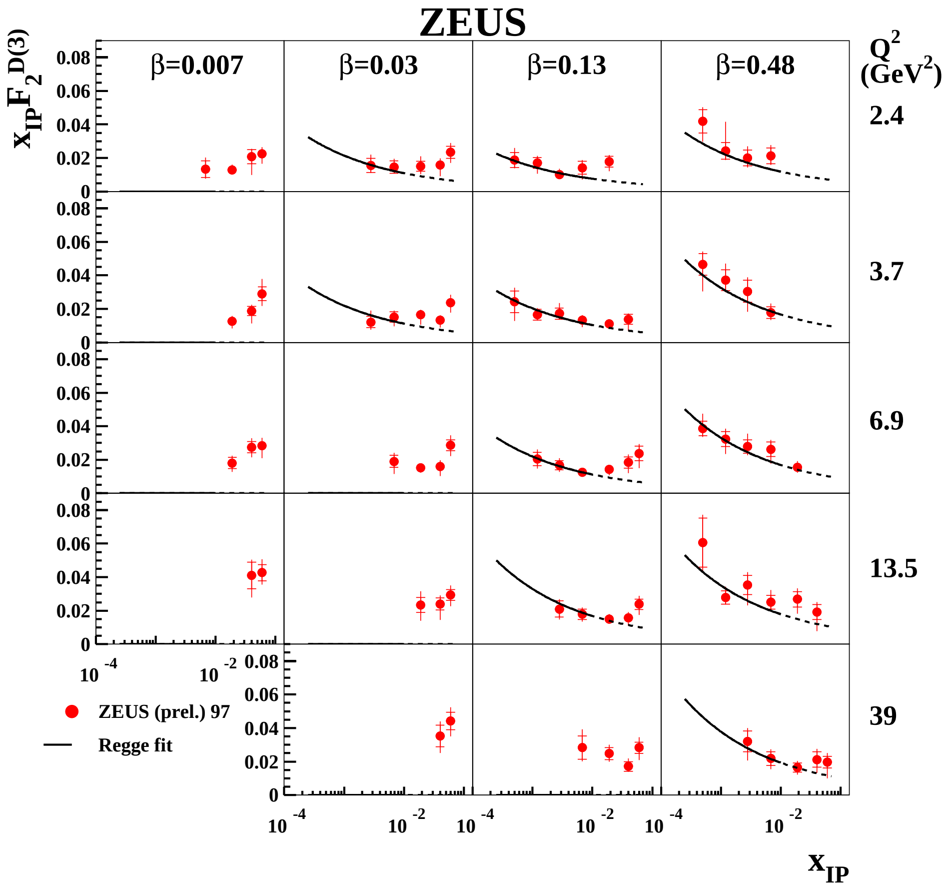
$A_{LT} = -0.005 \pm 0.052^{+0.048}_{-0.047}$
$(0.02 < x_{I\!P} < 0.07\ ;\ \beta \approx 0.1)$

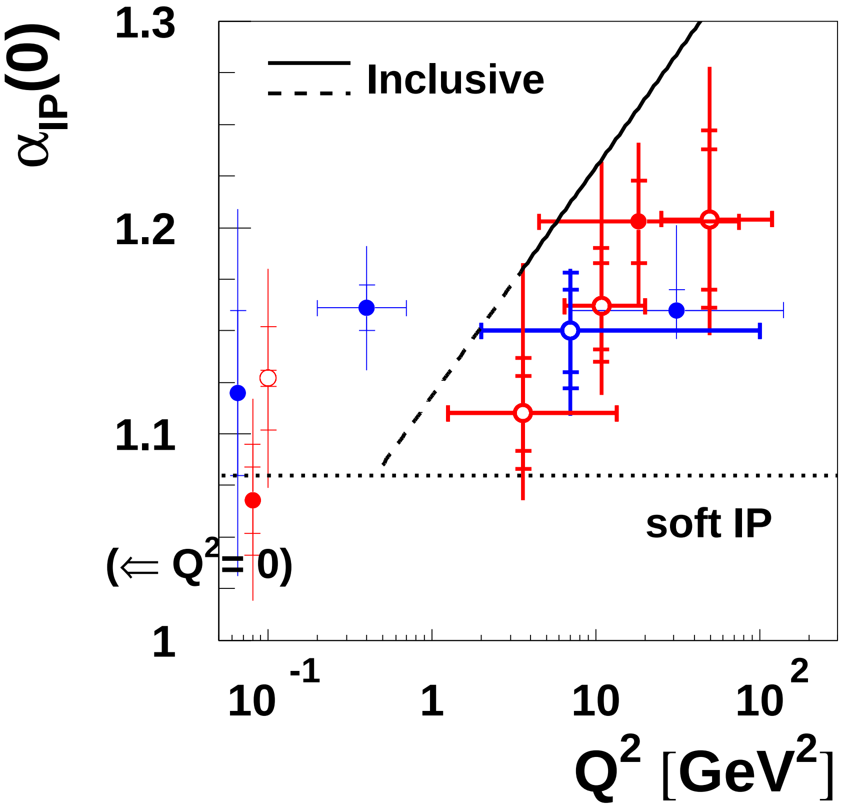
$\Rightarrow$ Interference term small in measured region

[Interesting high β region (pert. 2-gluon exch. predicts large asymmetry) not yet explored]

Energy dependence and $\alpha_{I\!P}(0)$

Example: ZEUS LPS data





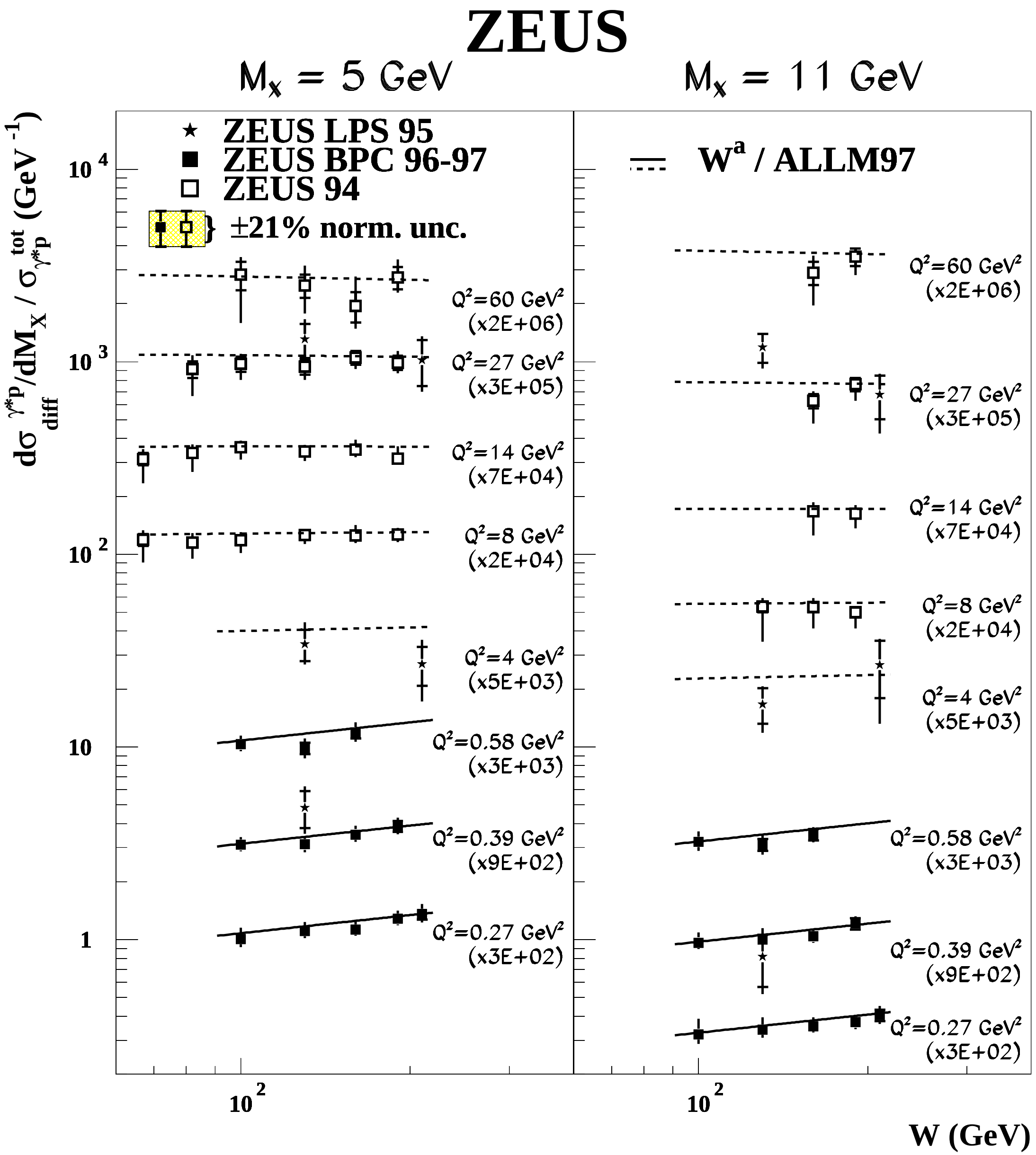
Fit to $x_{I\!P}$ dependence:

$$F_2^D(x_{I\!P}, \beta, Q^2) = \left(\frac{1}{x_{I\!P}}\right)^{2\overline{\alpha_{I\!P}}-1} \cdot A(\beta, Q^2)$$

Indications for increase with Q^2 ?

Naive expectation $\alpha_{I\!P}^{\mathrm{diff.}}(0) = 2\ \alpha_{I\!P}^{\mathrm{inc}}(0)$ fails in DIS region?

Ratio Diffractive / Inclusive: Energy Dependence



Study Ratio $R(W)|_{Mx,Q^2}$:

$$R = \frac{\int \mathrm{d}t\ (\mathrm{d}\sigma_D^{\gamma p}/\mathrm{d}M_X)}{\sigma_{tot}^{\gamma p}}$$

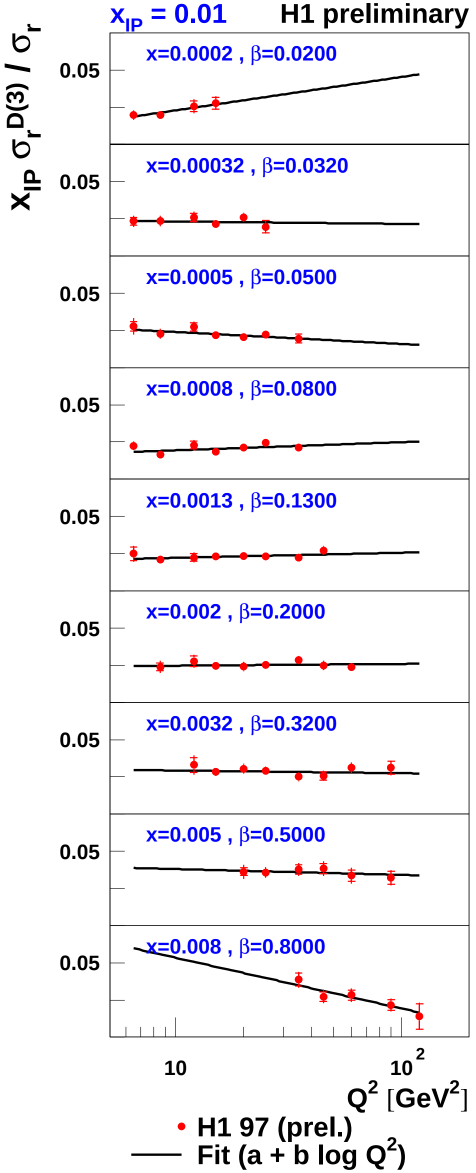
$$\sim \frac{(W^2)^{2(\overline{\alpha_{I\!P}}-1)}}{(W^2)^{(\alpha_{I\!P}-1)}} \sim W^\rho$$

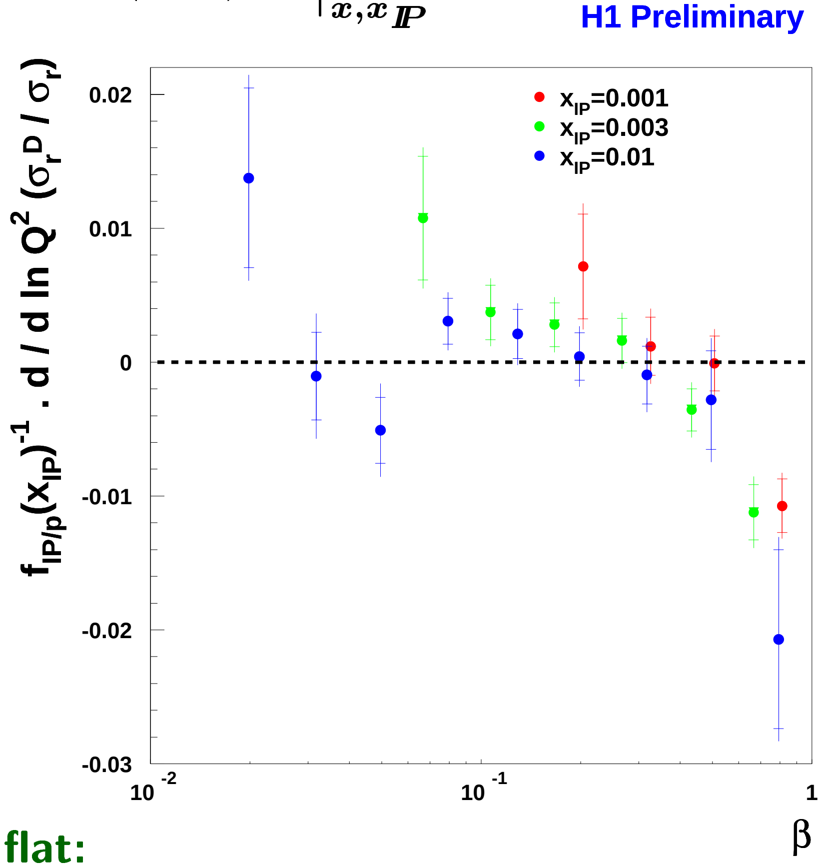
– transition region:
$\rho = 0.24 \pm 0.07$ **(stat.)**
Steeper for diffractive than inclusive
→ Regge-like

– DIS regime:
$\rho = 0.00 \pm 0.03$ **(stat.)**
Same energy dependence
→ not Regge-like

Diffractive / Inclusive: Q2 dependence from H1

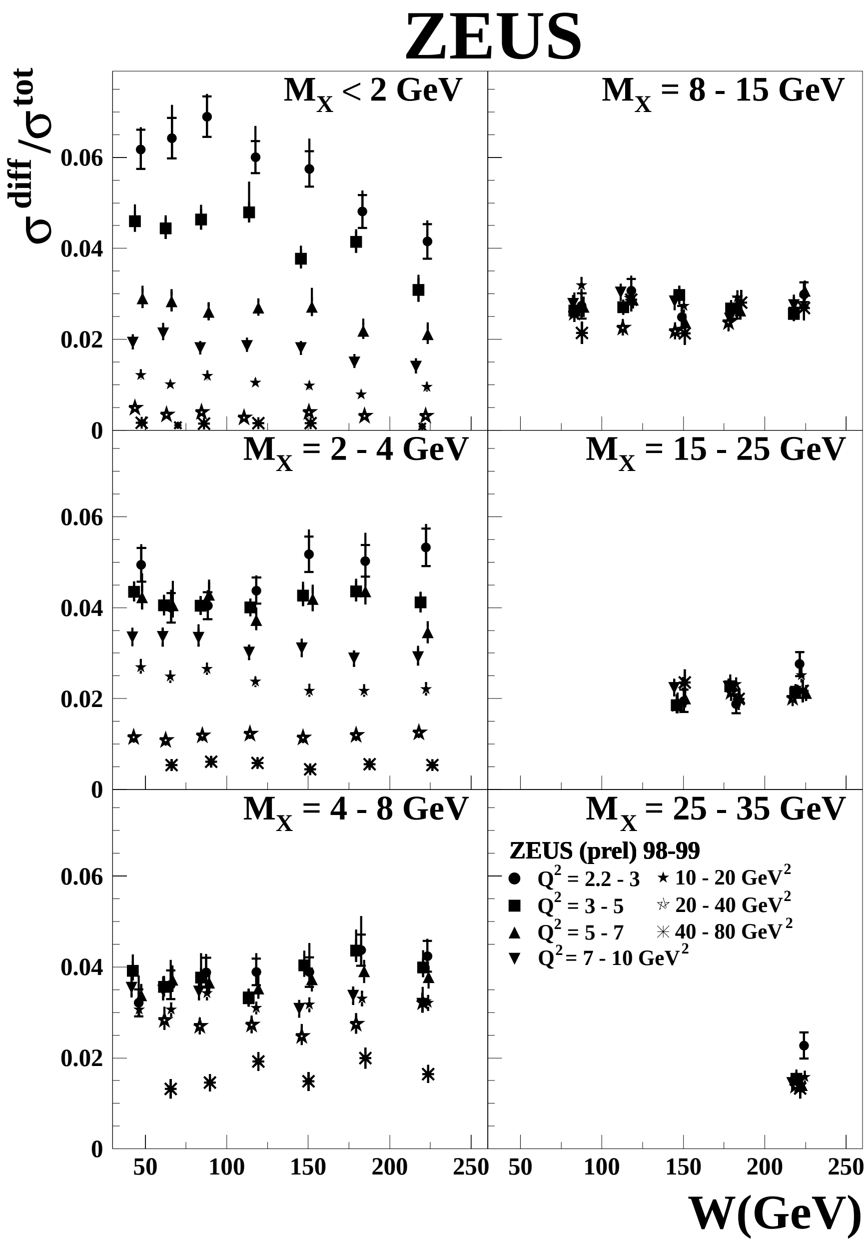
Logarithmic Q^2 dependence of the ratio $\left.\frac{\sigma_r^{D(3)}(x,Q^2,x_{I\!P})}{\sigma_r(x,Q^2)}\right|_{x,x_{I\!P}} \sim A_R + B_R \log Q^2$





Low β: rel. flat:
- **ratio of diffr. to incl. $g(x, Q^2)$ constant**
- **diple models (IF $\sigma_{dipole} \propto R$)**

As $\beta = 1$: falling:
- **Q^2-suppressed higher twist (pert. 2-gluon exchange)**
- **DGLAP evolution (gluon radiation)**



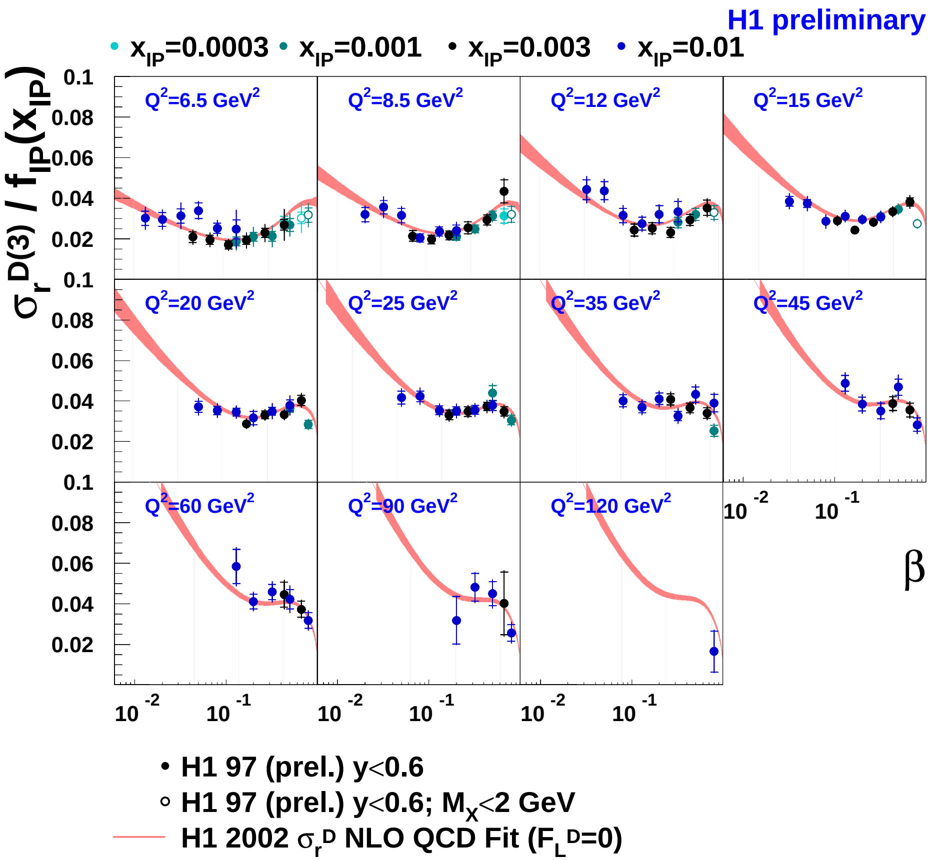
Ratio from ZEUS

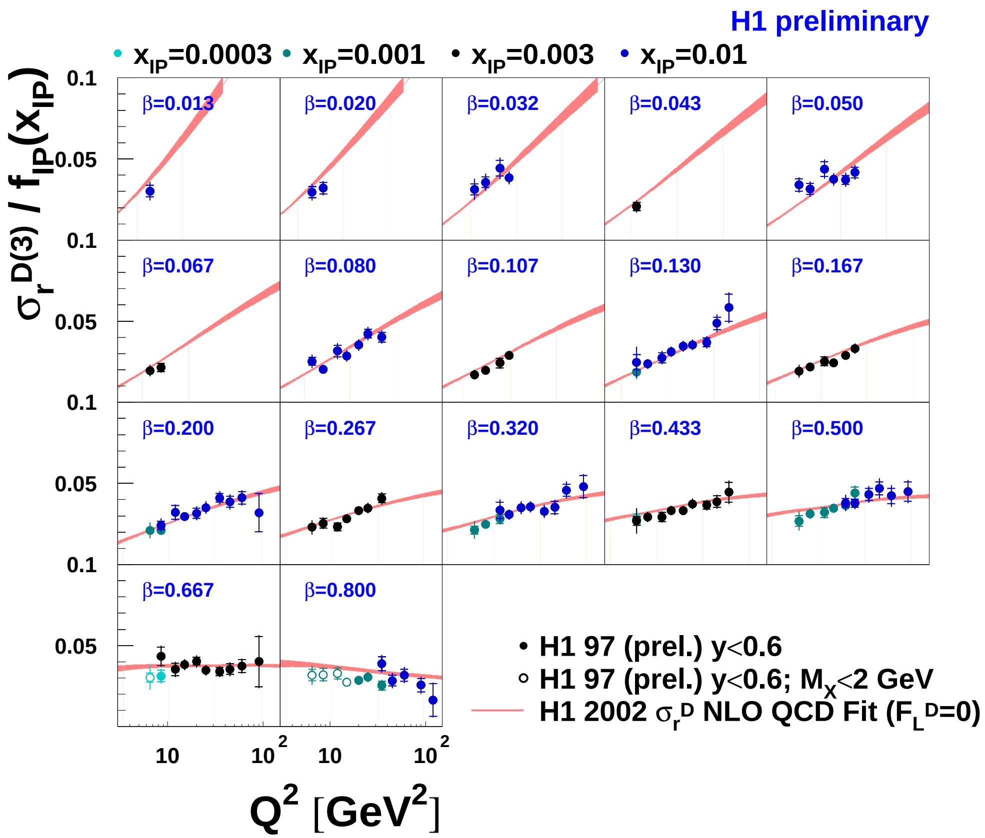
Similar features observed:

- little Q^2 dependence at high M_X ($\sim$ low β)
- strong (negative) Q^2 dependence at small M_X ($\sim$ high β)

Precise H1 Measurement of β, Q^2 dependences

Prerequisite for NLO DGLAP QCD fit:





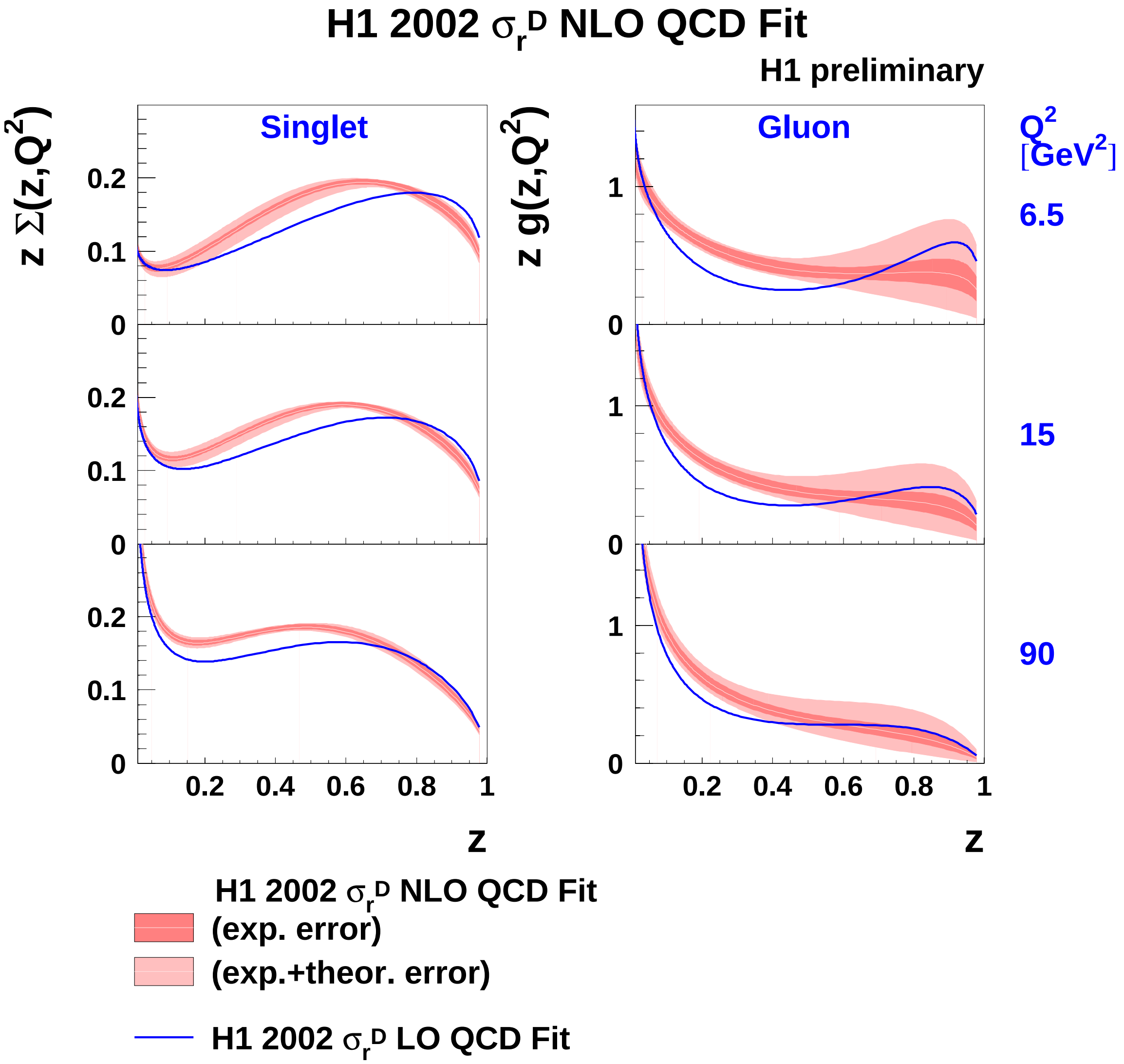
β **dep.:** $\sim \sum_i e_i^2 (q_i^D + \bar{q}_i^D)$ Q^2 **dep.:** $\sim \alpha_s \otimes g^D(\beta, Q^2)$

- $x_{\mathbb{P}}$ **dep. taken out: factorization holds for** $x_{\mathbb{P}} < 0.01$
- **rising for** $\beta \rightarrow 1$ **at low** Q^2
- **positive scaling violations expect for largest** β **(gluon dominance)**

New NLO DGLAP QCD Fit from H1

QCD Fit Technique:

- Regge factorization (c.f. data)
- Singlet Σ and gluon g parameterized at $Q_0^2 = 3\ \mathrm{GeV}^2$
- NLO DGLAP evolution
- Fit data for $Q^2 > 6.5\mathrm{GeV}^2$, $M_X > 2\ \mathrm{GeV}$
- For first time propagate exp. and theor. uncertainties !

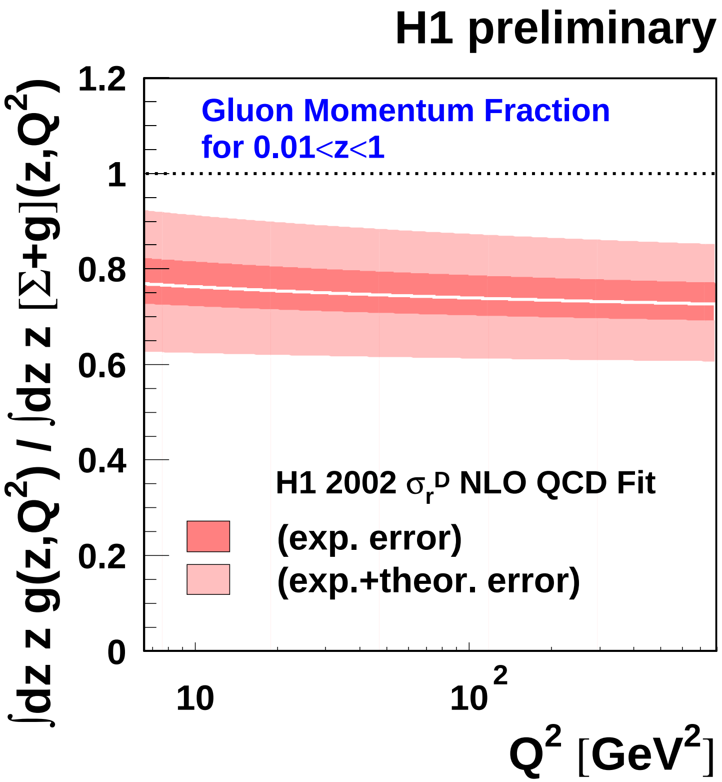


PDF's of diffractive exchange:

- Extending to large fractional momenta z
- Gluon dominated
- Σ well constrained
- substantial uncertainty for gluon at highest z
- Similar to previous fits

H1 NLO QCD Fit: Gluon fraction and F_L^D

Integrate PDF's over measured range:

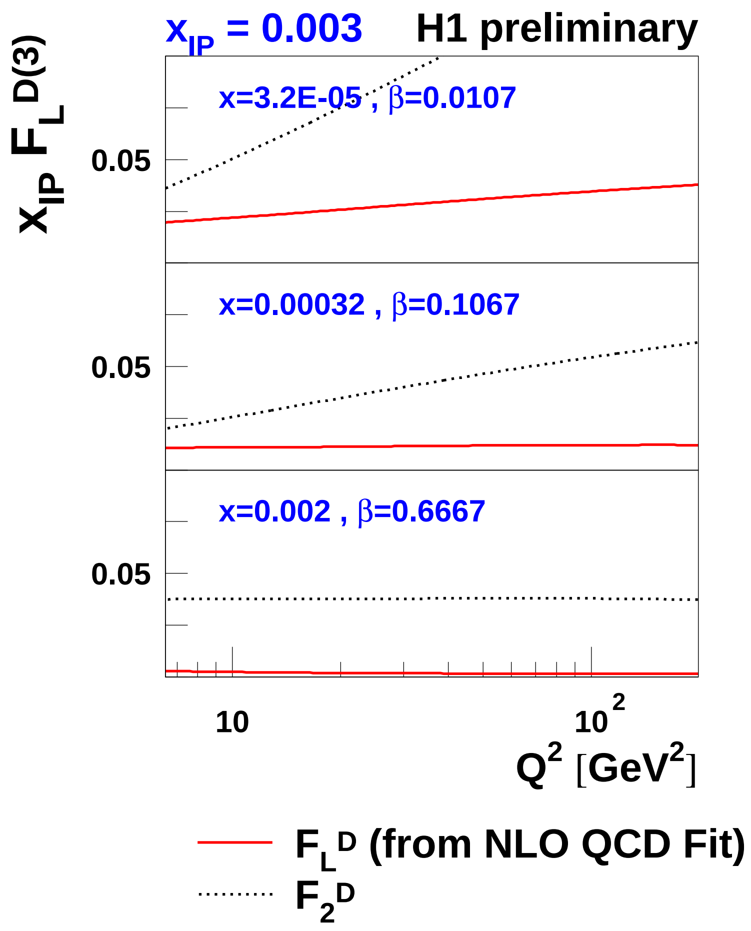


Momentum fraction of diffractive exchange carried by gluons:

$$75 \pm 15\%$$

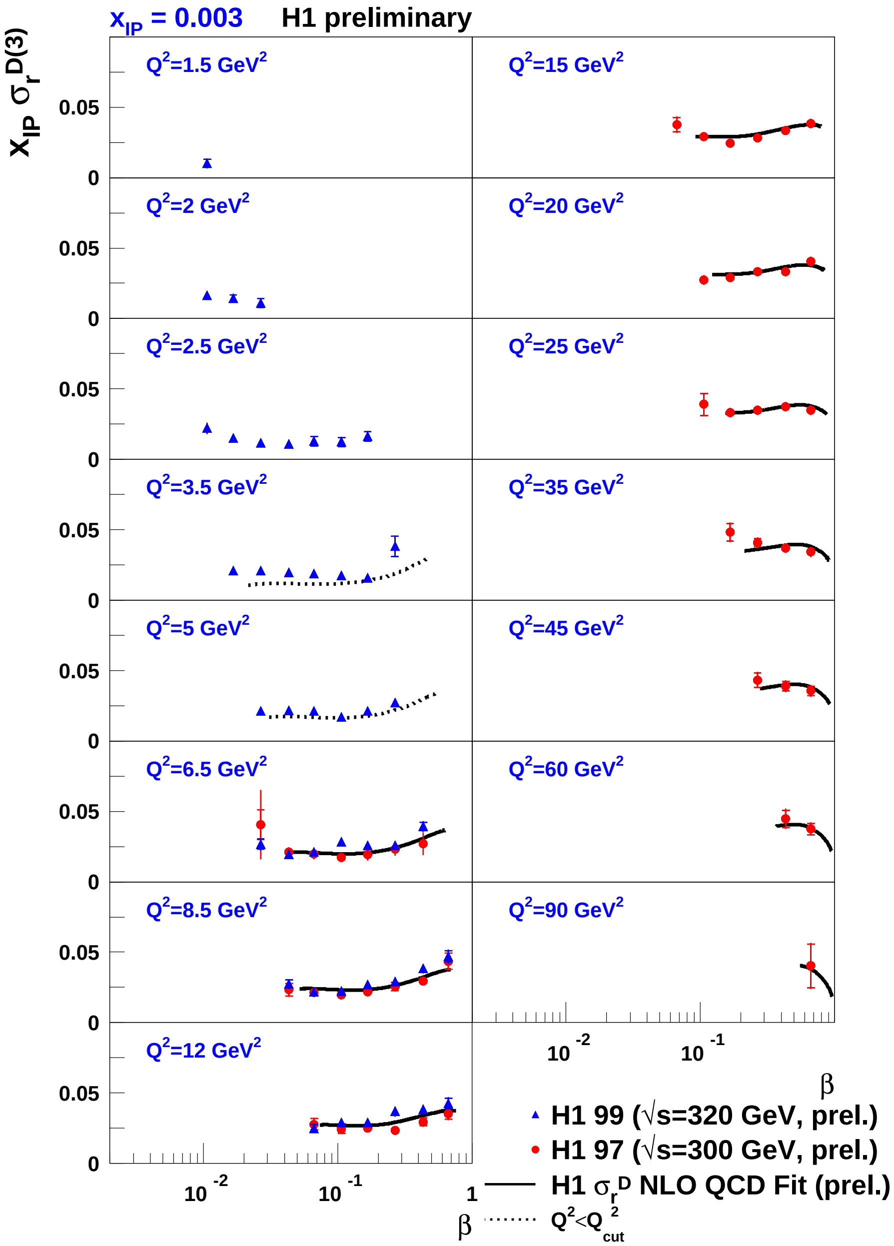
Longitudinal F_L^D:

$$F_L^D \sim \frac{\alpha_s}{2\pi}\left[C_q^L \otimes F_2^D + C_g^L \otimes \sum_i e_i^2\, zg^D(z,Q^2)\right]$$



$\Rightarrow$ F_L^D large at low Q^2, low β

H1 NLO QCD fit: β dependence

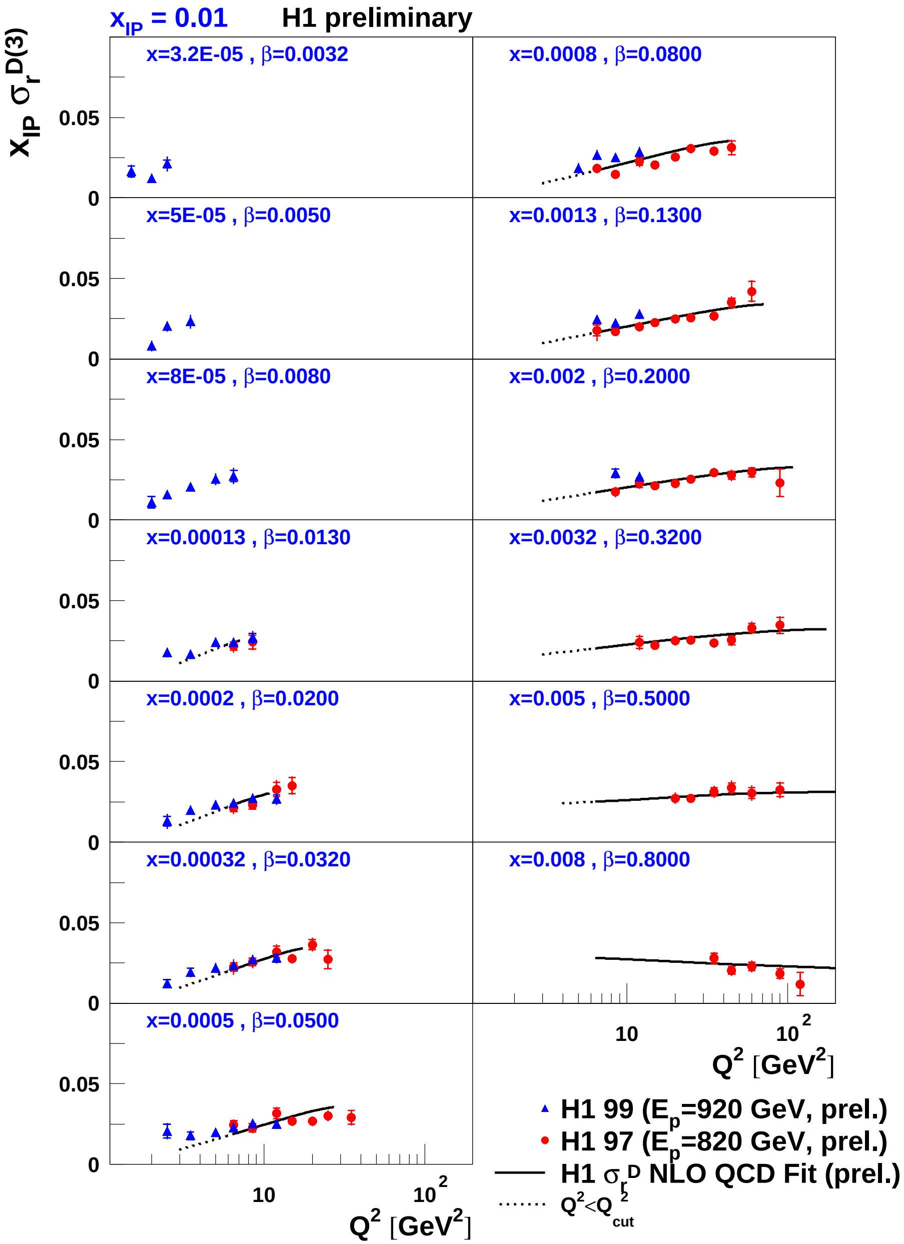


Example data at $x_{I\!P} = 0.003$:

- **Rising behaviour for $\beta \to 1$ at low Q^2, reflected by $\Sigma(\beta, Q^2)$**
- **QCD fit to data for $Q^2 > 6.5$ GeV^2**
- **Extension to lower β, Q^2 with new 99 data! (blue points)**
- **Indication of breakdown of QCD fit at $Q^2 = 3.5$ GeV^2**

$\Rightarrow$ new low Q^2 data as additional constraint in future fits!

H1 NLO QCD fit: Q^2 dependence



Example data at $x_{I\!P} = 0.01$:

- Q^2 scaling violations well constrained by data
- Rising except at highest β
- Well reproduced by QCD fit for $Q^2 > 3.5\ \mathrm{GeV}^2$
- New low Q^2 data (blue points) above fit at low Q^2 (not included in fit)

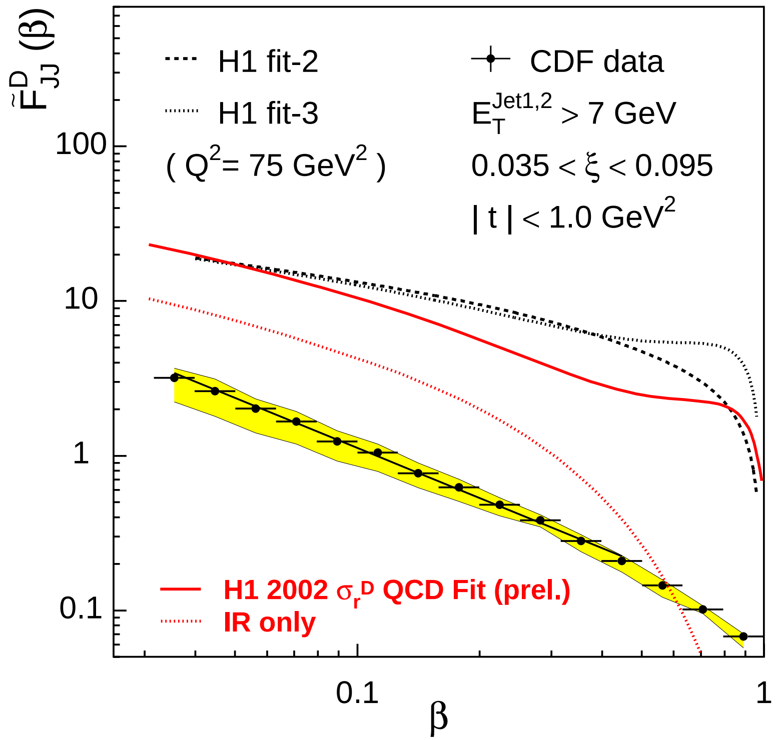
Factorization Tests

Use diffractive PDF's to predict diffractive final state cross sections:

HERA:

- **Updated comparisons with dijet and charm production in diffractive DIS:**
  Consistent with factorization $\Rightarrow$ **See next talk (A. Savin)**

Diffractive dijets at the TEVATRON:



- **Prediction based on H1 PDF's one order of magnitude below CDF data**
- **Result of new H1 fit confirms serious breakdown of factorization in diffraction between $\bar{p}p$ and ep**

Summary

Understanding colour singlet exchange - a major challenge in QCD

Diffractive DIS at HERA enables studies of quark / gluon (QCD) structure of diffraction

- **Several new data samples from H1 and ZEUS:**
  – **Entering an era of high precision in extended kinematic range**

- **Energy dependence: $\alpha_{I\!P}(0)$ in DIS higher than at $Q^2 = 0$**
  – **Diffractive vs inclusive: Simple expectation does not work in DIS**

- **Ratios diffractive to inclusive cross section:**
  – **remarkably flat over wide kinematic range**
  – **high β: complicated structure (higher twist?)**

- **New H1 NLO DGLAP QCD fit: Diffractive parton distributions including error estimate, dominated by gluon distribution**
  – **used for tests of QCD factorization**

Further information in contributed papers
980, 981, 984, 985 (H1) and 821, 822, 823, 828 (ZEUS)