Inclusive diffraction and DVCS

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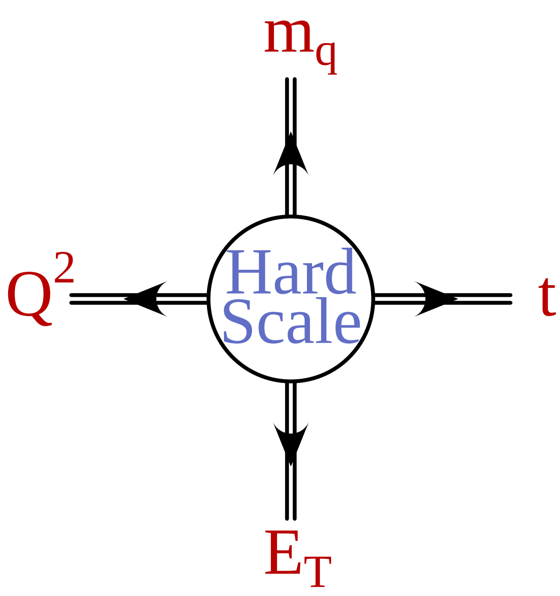
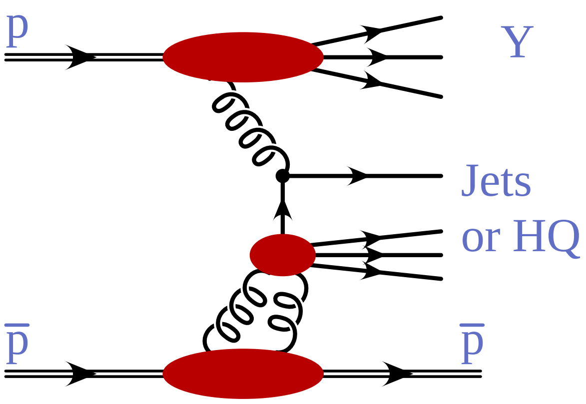
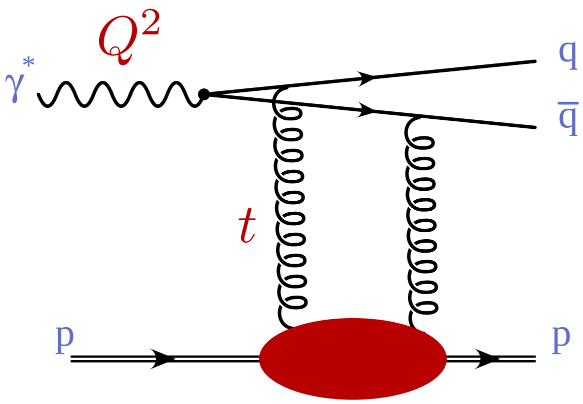
Ringberg Workshop 2005
2-7$^{\mathrm{th}}$ of October 2005

Interest of Hard Diffraction

- Understanding of Diffractive phenomena in terms of QCD
  - two gluon exchange
  - Several possible hard scales

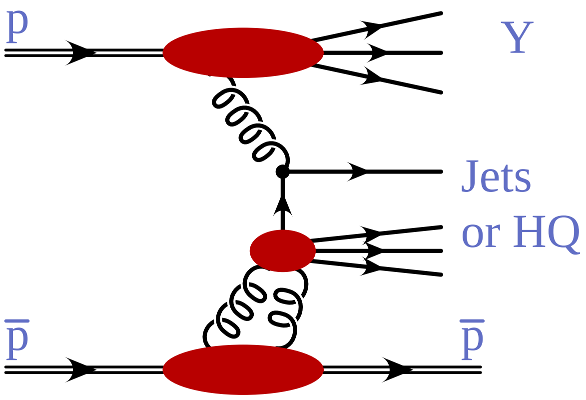


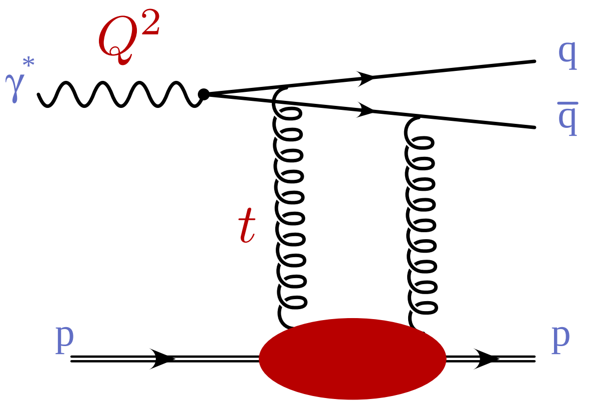




Interest of Hard Diffraction

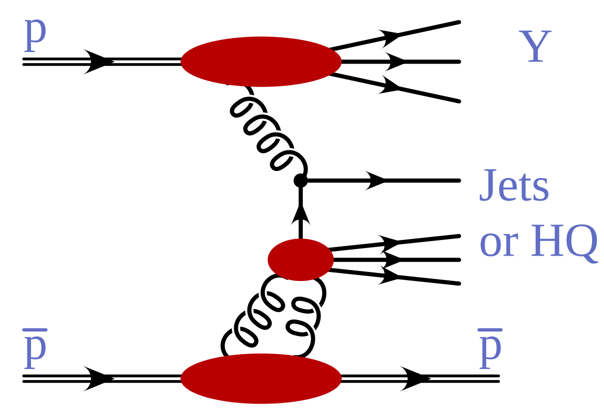
- Understanding of Diffractive phenomena in terms of QCD
  - → two gluon exchange
  - → Several possible hard scales
  - → probing the exchange partonic structure - like in inclusive structure functions
  - → typical signature of hard scale presence: steep rise with W (cms energy)

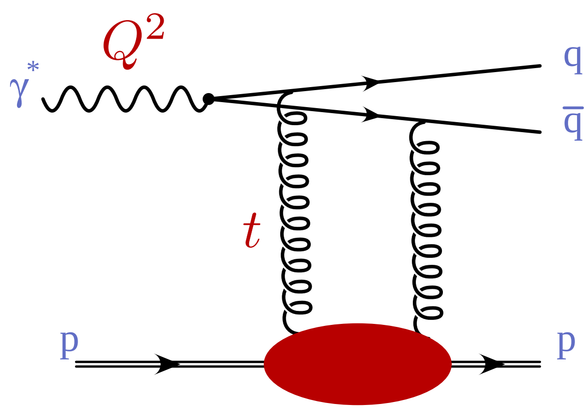




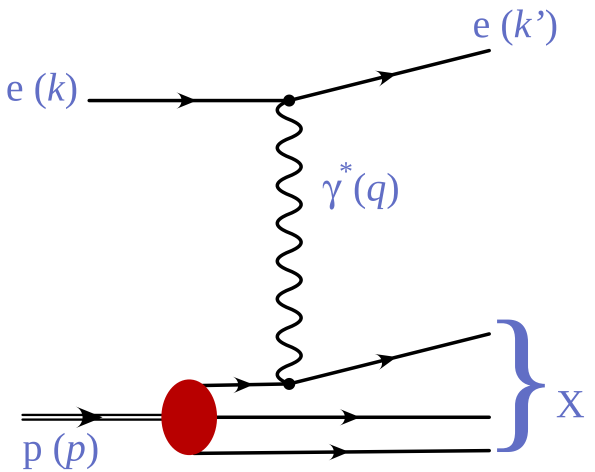
Interest of Hard Diffraction

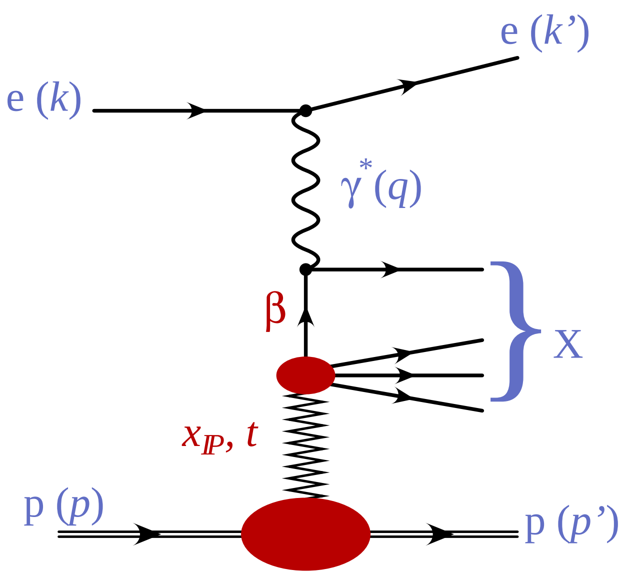
- Understanding of Diffractive phenomena in terms of QCD
  - ➜ two gluon exchange
  - ➜ Several possible hard scales
  - ➜ probing the exchange partonic structure - like in inclusive structure functions
  - ➜ typical signature of hard scale presence: steep rise with W (cms energy)
- Access to very low x of nucleon structure function and parton correlations ➜ the Generalized Parton Distributions (GPDs).
- Test of DGLAP and BFKL asymptotic behaviour dynamics
- Colour Dipole model approach: transition to non pQCD, saturation





Kinematic





Deep Inelastic Scattering

Q^2	$= -q^2$ - virtuality of the exchanged photon
W	$\gamma^* - p$ system energy
x	Bjorken-x: fraction of proton's momentum carried by the struck quark
y	γ^* inelasticity : $y = Q^2/s\ x$

Diffractive Scattering

$x_{I\!P}$	fraction of proton's momentum of the colour singlet exchange (also named ξ) $x_{I\!P} \simeq \frac{Q^2+M_X^2}{Q^2+W^2}$
β	fraction of $I\!P$ carried by the quark "seen" by the γ^* $\beta = x/x_{I\!P}$
t	$= (p-p')^2$, 4-momentum squared at the p vertex

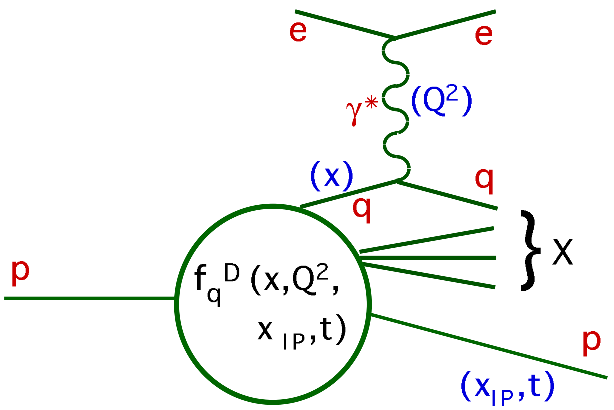
Factorisation Properties

QCD Hard Scattering Fact.

$$\sigma_{\text{DIS}}^{\text{Dif}} \sim f_q^D(x_{I\!P}, t, x, Q^2) \otimes \hat{\sigma}_{\text{pQCD}}$$

Diffractive parton densities $f_q^D(x_{I\!P}, t, x, Q^2)$ $\rightarrow$ *conditional* proton parton probability distributions for particular $x_{I\!P}, t$.

DGLAP applicable for Q^2 evolution.

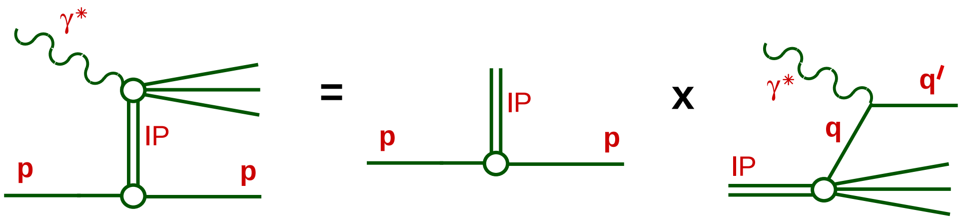


Rigorous for leading Q^2 dependence but not in hadron-hadron collisions

Regge Factorisation

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

Diffractive parton densities factorise into "pomeron flux factor" and "pomeron parton densities"



$I\!P$ flux factor from Regge theory ...

$$f_{I\!P/p}(x_{I\!P}, t) = \frac{e^{Bt}}{x_{I\!P}^{2\alpha(t)-1}} \quad \text{where} \ \ldots$$

$$\alpha(t) = \alpha(0) + \alpha' t$$

No firm basis in QCD

Recent Diffractive DIS Data

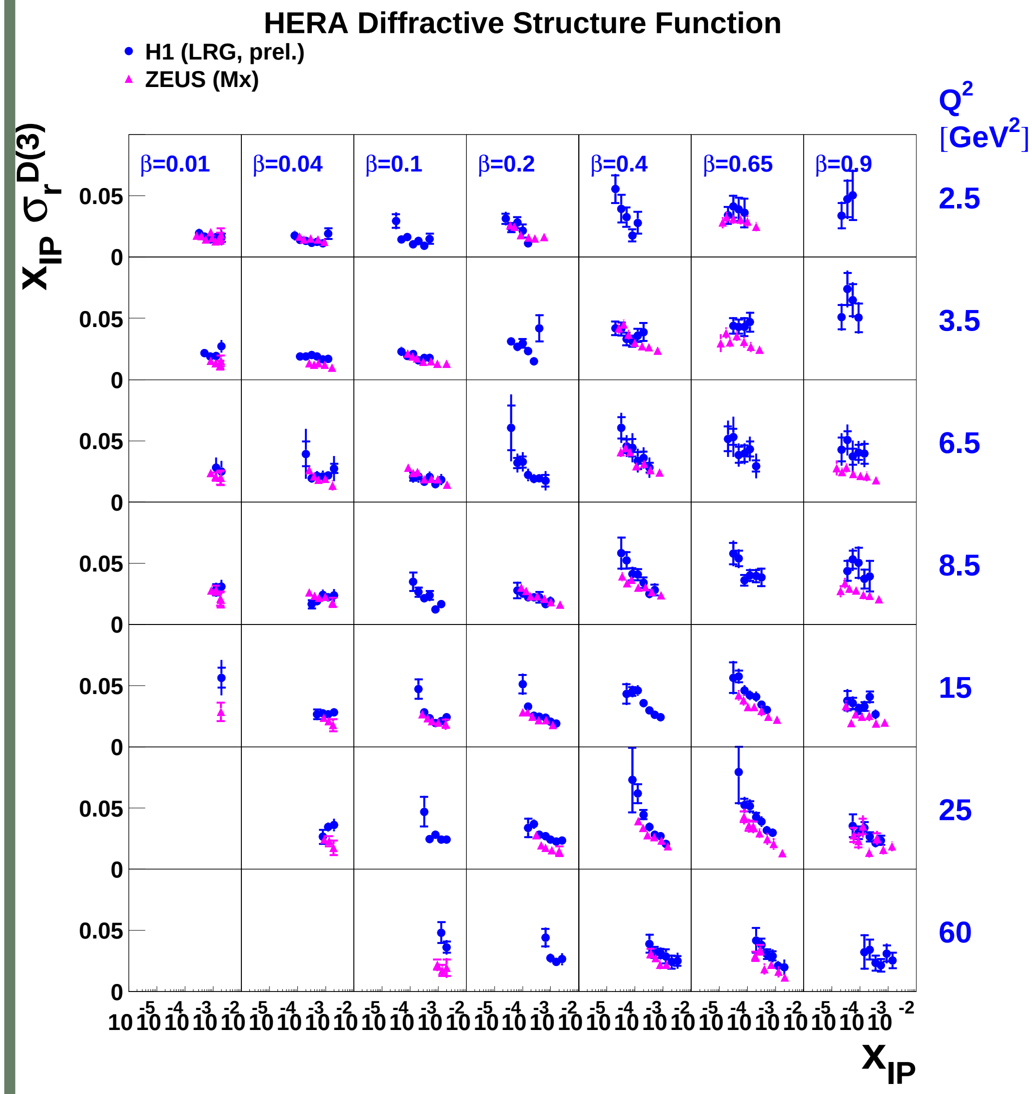
ZEUS Data:

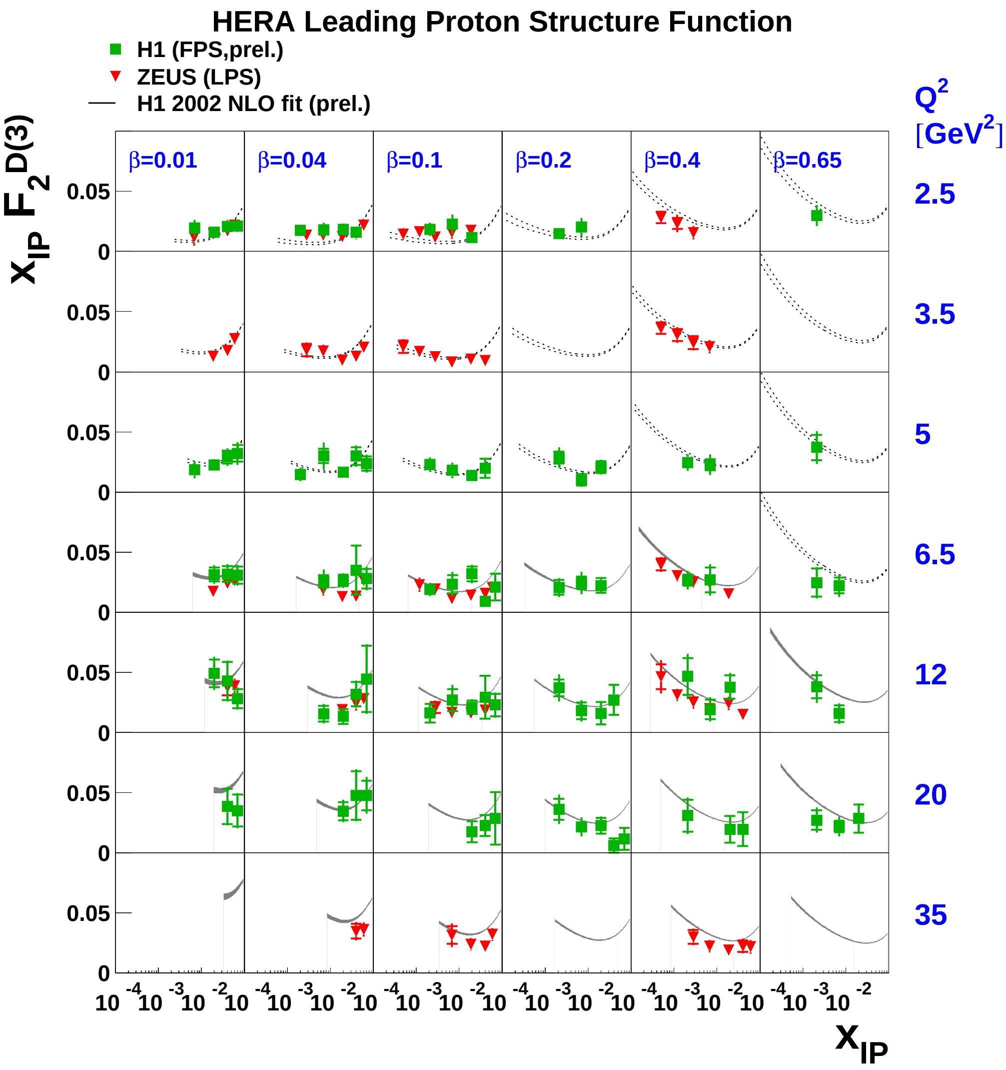
- "Study of Deep Inelastic Inclusive and Diffractive Scattering with the ZEUS Forward Plug Calorimeter" (Mx method)
  DESY-05-011, accepted by Nucl. Phys. B $2.4 < Q^2 < 39$ GeV^2 (98-99)
- "Dissociation of virtual photons in events with a leading proton at HERA" (Leading Proton)
  Eur. Phys. J C38 (2004) 43 $2.7 < Q^2 < 55$ GeV^2 (97)

H1 Data:

- "Measurement of semi-inclusive diffractive deep-inelastic scattering with a leading proton at HERA" (Leading Proton)
  Paper 6-984 subm. to ICHEP 2002, H1prelim-01-112 $2.6 < Q^2 < 20$ GeV^2 (99-00)
- "Measurement of the Diffractive DIS Cross Section at low Q^2 " (LRG method)
  Paper 981 subm. to ICHEP 2002, H1prelim-02-112 $1.5 < Q^2 < 12$ GeV^2 (99)
- "Measurement and NLO DGLAP QCD Interpretation of Diffractive Deep-Inelastic Scattering at HERA" (LRG method)
  Paper 980 subm. to ICHEP 2002, H1prelim-02-012 $6.5 < Q^2 < 120$ GeV^2 (97)
- " Measurement of the Inclusive Diffractive Cross Section $\sigma_r^D(3)$ at high Q^2" (LRG method)
  Paper 5-090 subm. to EPS 2003, H1prelim-03-011 $200 < Q^2 < 1600$ GeV^2 (99-00)

H1 and ZEUS Measurements





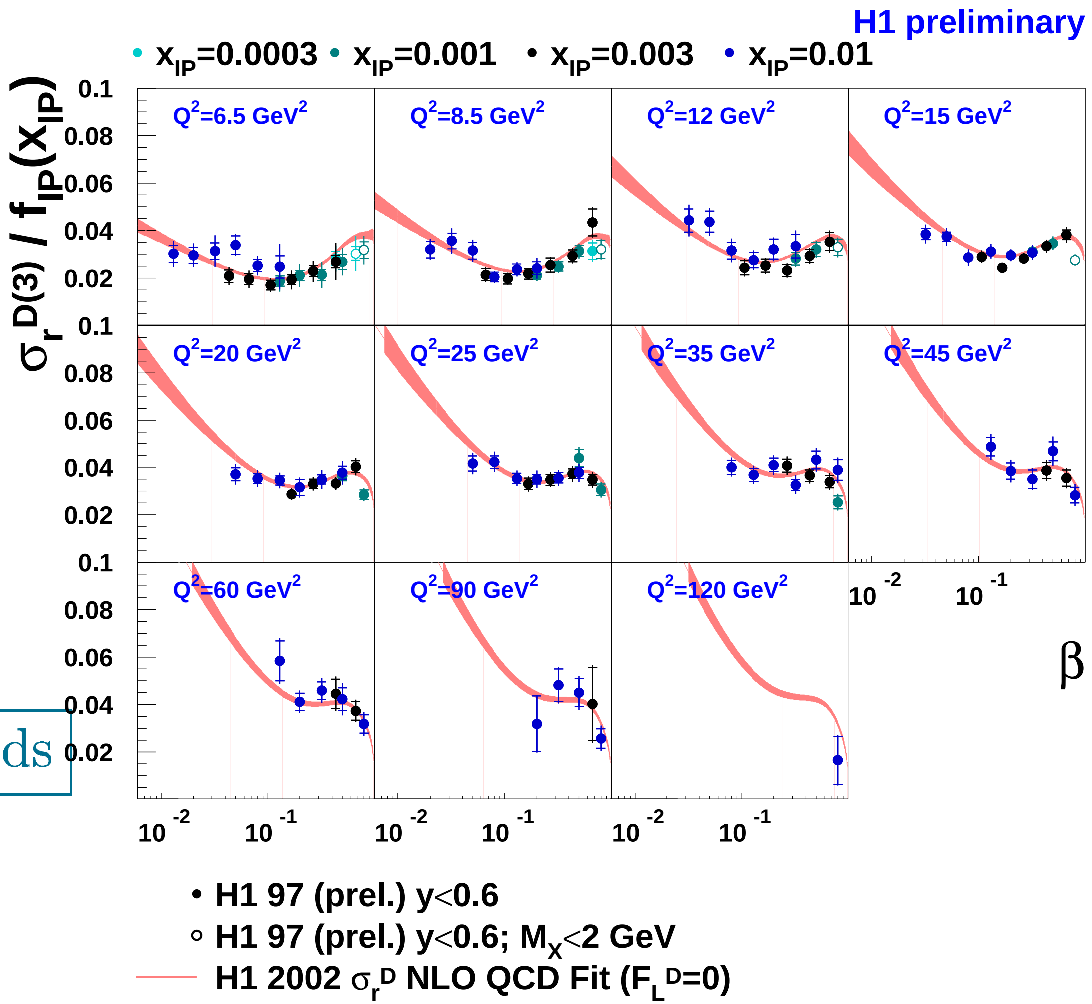
Regge factorisation: β Dependence of F_2^D

Does Regge factorisation work ?

i.e. is $F(\beta, Q^2)$ dependent of $x_{I\!P}$ after factoring out the flux dependence ?

$$f_{I\!P/p}(x_{I\!P}, t) = \frac{e^{Bt}}{x_{I\!P}^{2\alpha(t)-1}}$$

Take experimentally measured B, $\alpha(0)$

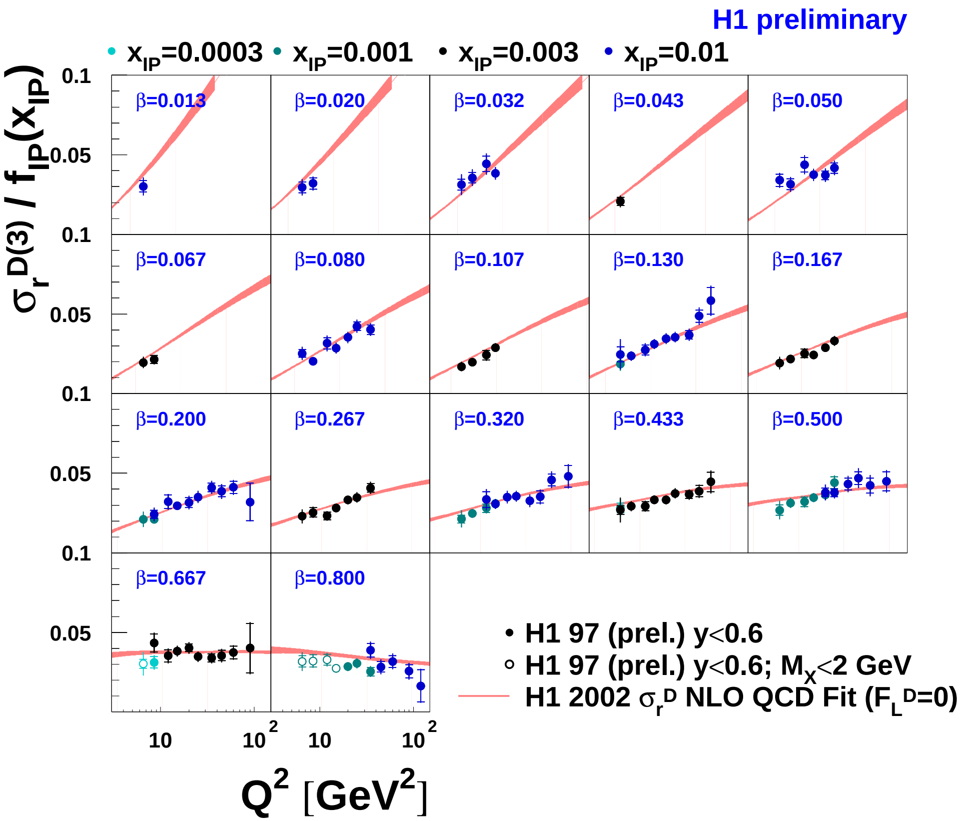


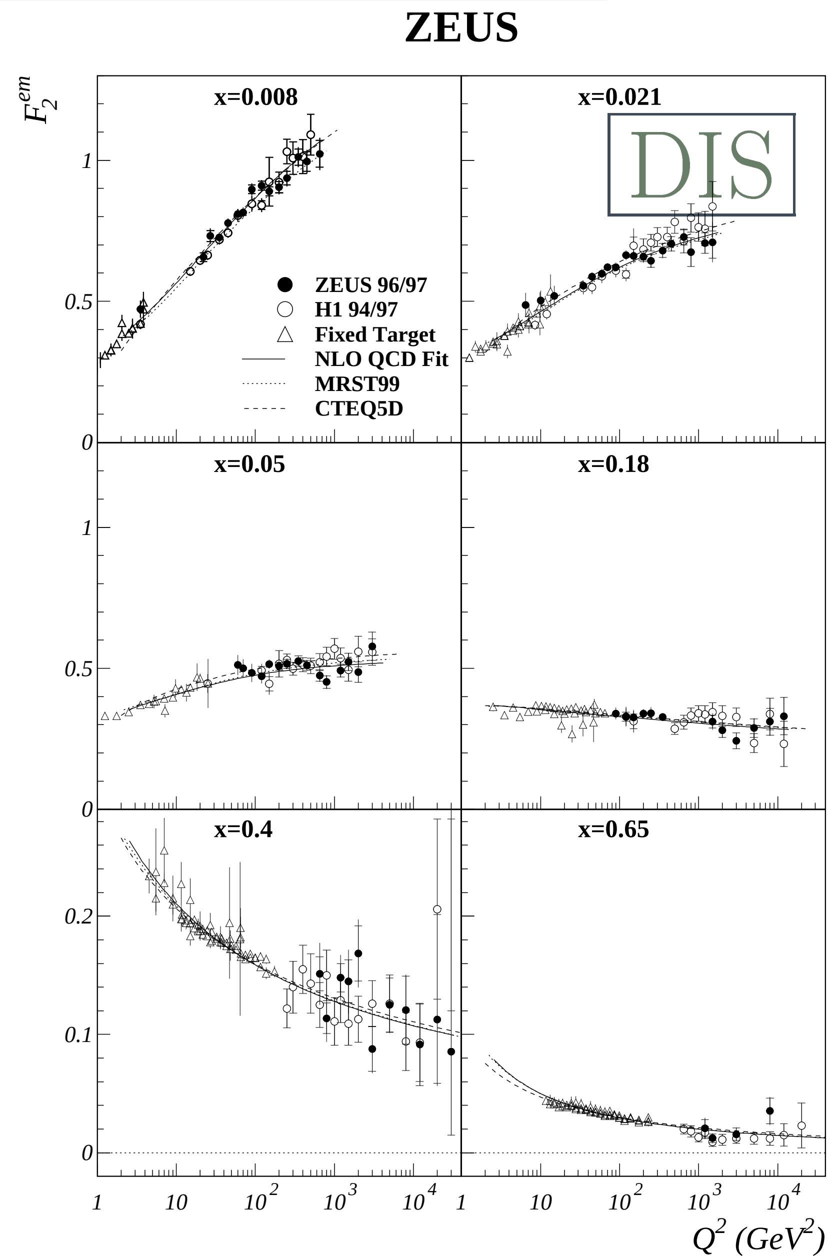
→ Regge factorisation basicaly holds

Measures parton density over wide β range.

Q^2 Dependence of F_2^D

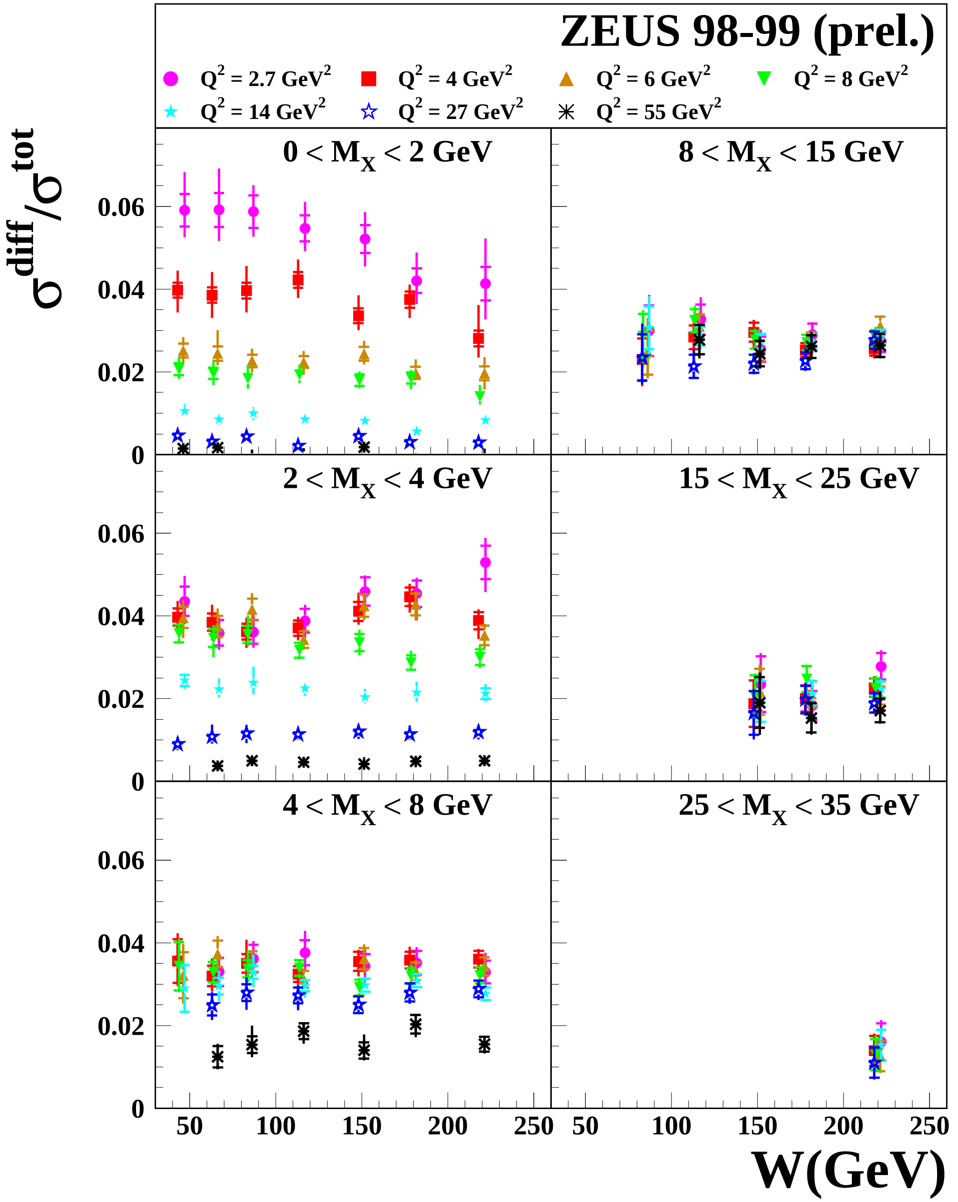
Q^2 dependence displays strong scaling violations with positive $\partial\sigma_r^D/\partial \ln Q^2$ up to high β





Not like a "normal" hadron

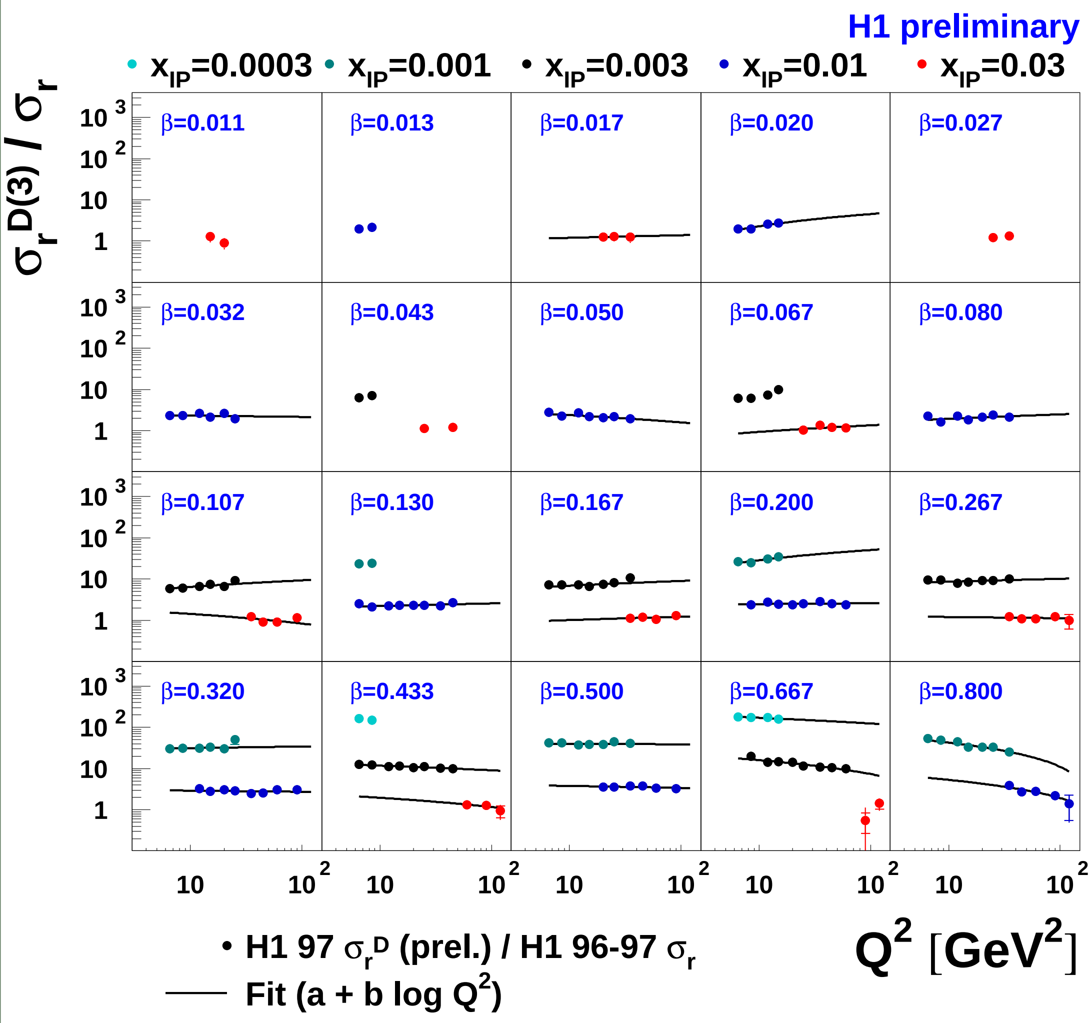
Ratio of Diffractive to inclusive cross-sections

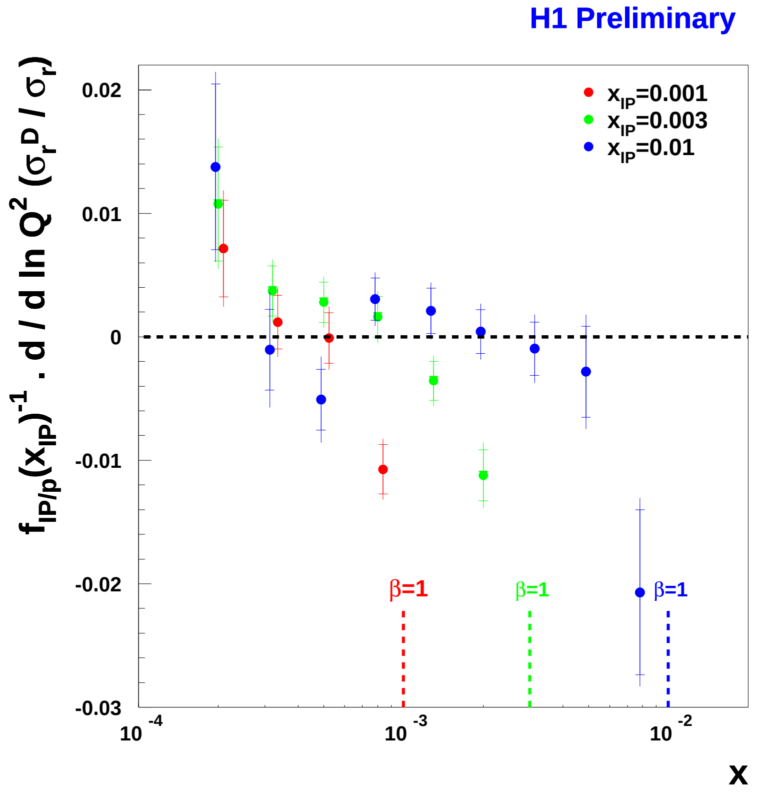


$W^2 \simeq Q^2/x$ $\quad$ $\beta \simeq Q^2/(Q^2 + M_X^2)$

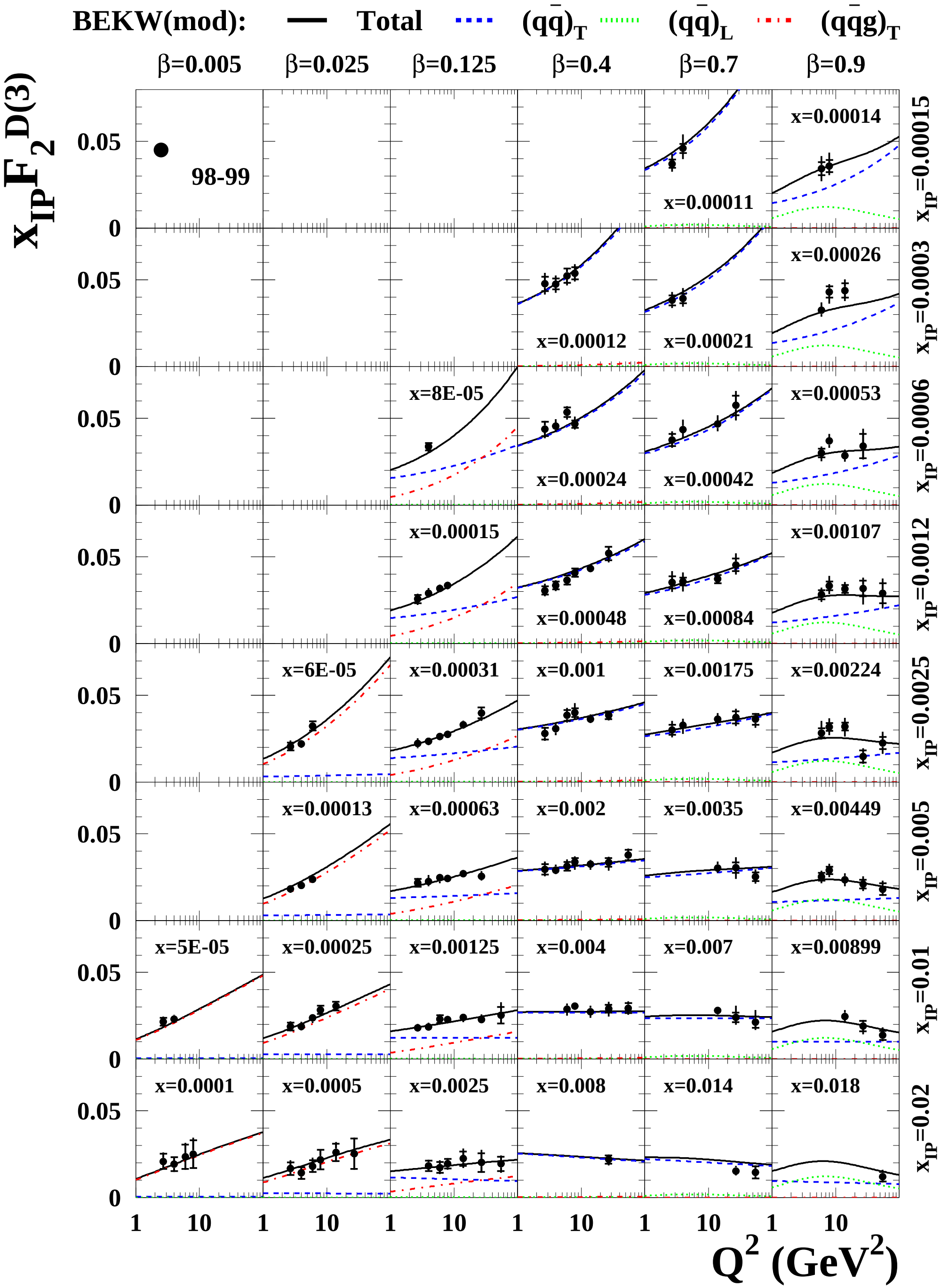
- For $M_X > 2$ GeV: flat in W
  - → same W dependence as σ_{tot}
  - → Not consistent with naive 2 gluon exchange:
    $$R = \frac{|x\ g(x,Q^2)|^2}{x\ g(x,Q^2)} = x\ g(x,Q^2)$$
- $M_X > 8$ GeV: no Q^2 dependence
  - → same DGLAP evolution
  - → γ^* sees: 1 gluon that can radiate
- If $M_X \searrow, \beta \nearrow$ → γ^*: more and more of the exchanged object (2 g)
- $M_X < 2$ GeV (large β): falling with W
  - → contribution of Vector Meson production (higher twist)
  - → no g radiation allowed
  - → "closed" gluon object

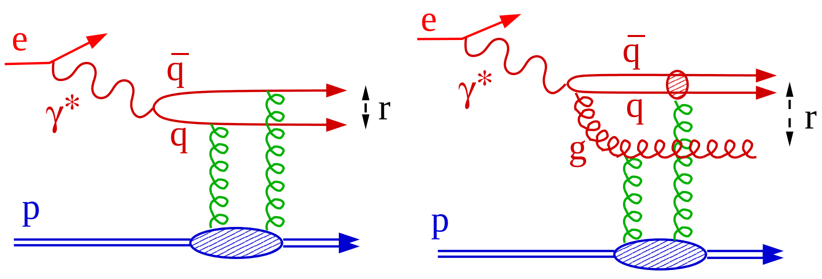
Ratio of Diffractive to inclusive cross-sections





Colour Dipole approach





- Dominated by $(q\bar{q}g)_L$ for $\beta < 0.1$
- Dominated by $(q\bar{q})_T$ for $\beta > 0.1$
- Importance of $(q\bar{q})_L$ for $\beta > 0.8$

- $\beta \to 1$ ➜ exclusive final state

NLO QCD fit: H1 Measurement

QCD Fit Technique:

- factorize $f(x_{I\!P})f(z,Q^2)$
- Singet Σ and gluon g
- NLO DGLAP evolution

$$\frac{1}{f_{I\!P/p}}\frac{\partial\sigma_r^D}{\partial\ln Q^2}\sim xg(x)\otimes\alpha_s\otimes P_{qg}$$

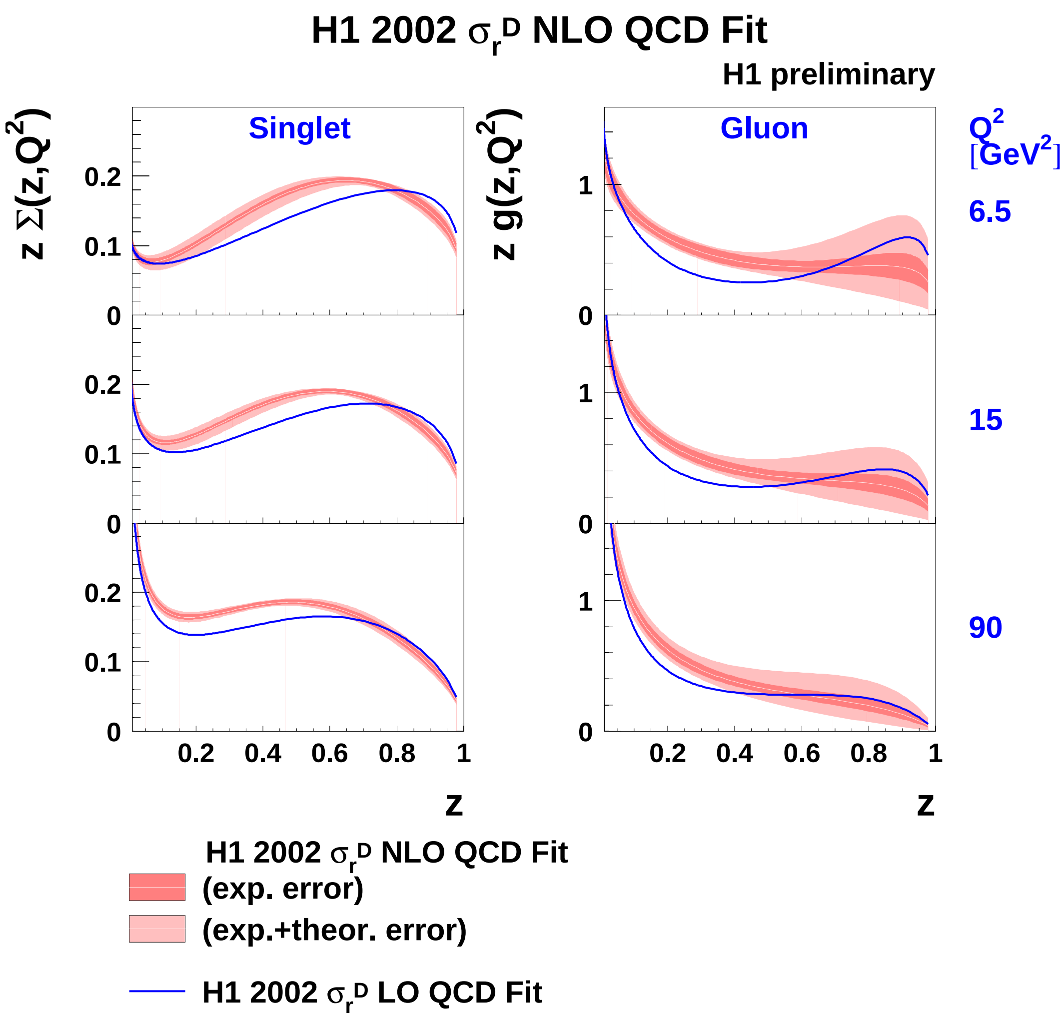
- parametrised at $Q_0^2 = 3$ GeV^2
- Fit data for $Q^2 \geq 6.5$ GeV^2, $M_X > 2$ GeV

PDF's of Diffractive exchange

- z is the fract. mom. of the parton in $I\!P$
- Σ well constrained
- a lot of gluons (75 ± 15 % of mom.)

$\chi^2/ndf = 308/306$

$\alpha_{I\!P}(0) = 1.173$ **(Regge fit)**



NLO QCD fit: ZEUS Measurement

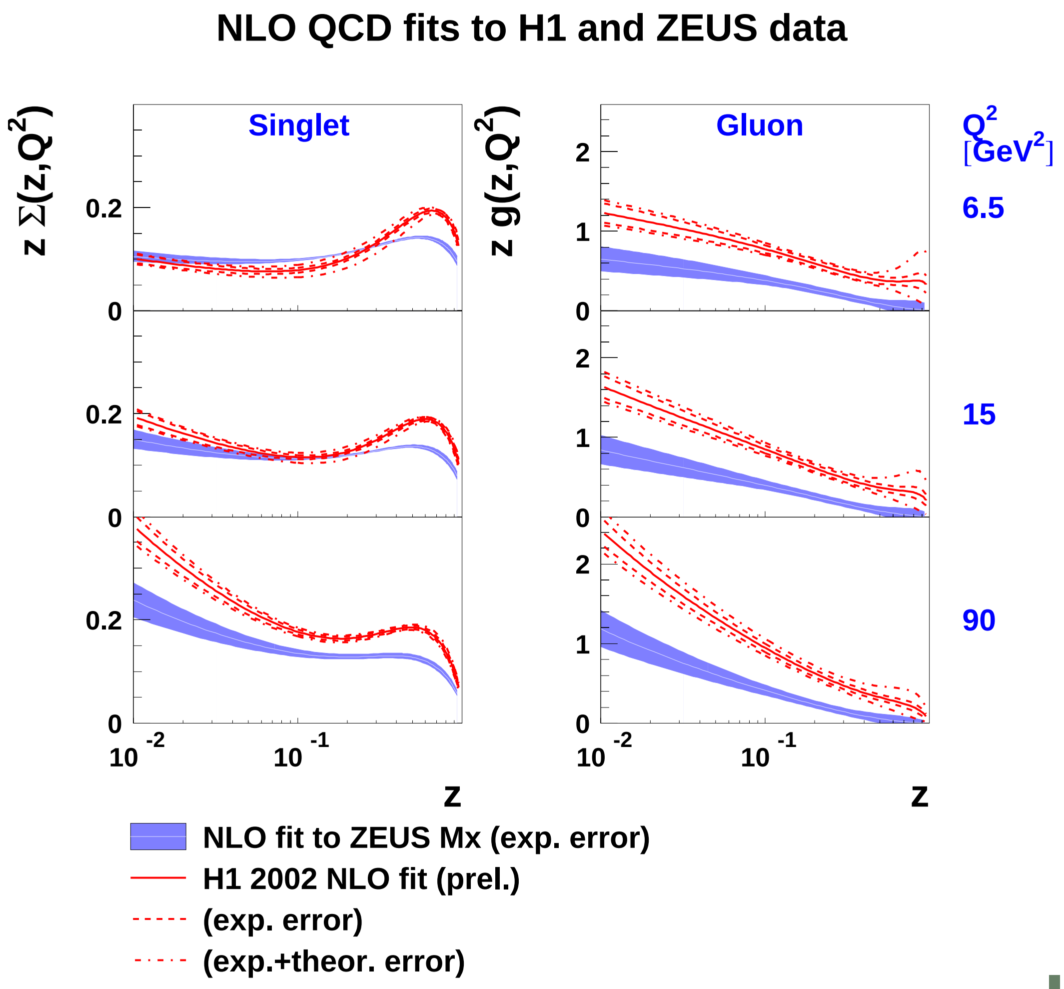
same Fit procedure applied

- results of the HERA-LHC Workshop

- Fit data for $Q^2 \geq 4\ \text{GeV}^2$
- no meson componant (including one doesnot improve the fit)
- $\alpha_{I\!P}(0)$ fit in the same time

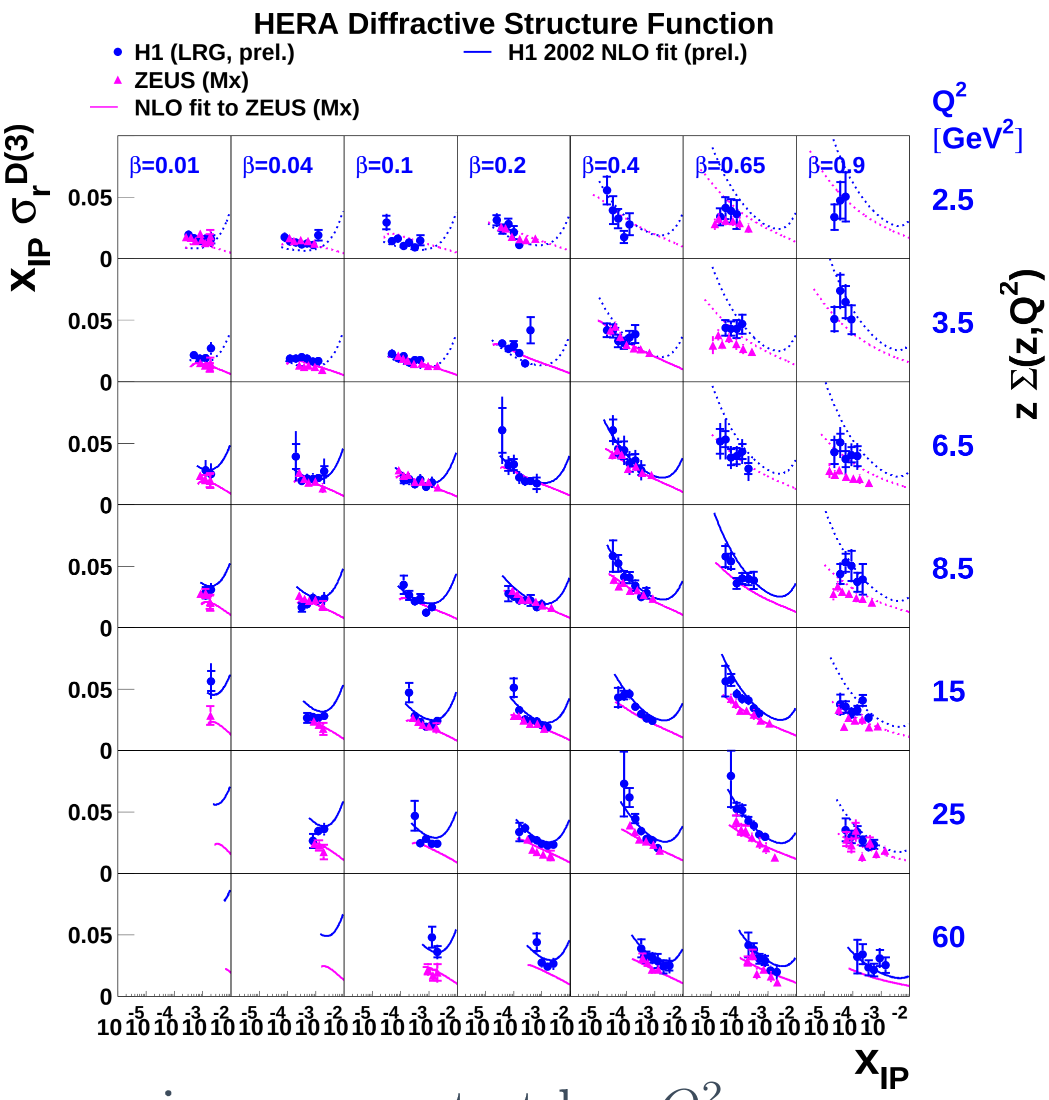
$\chi^2/ndf = 90/131$

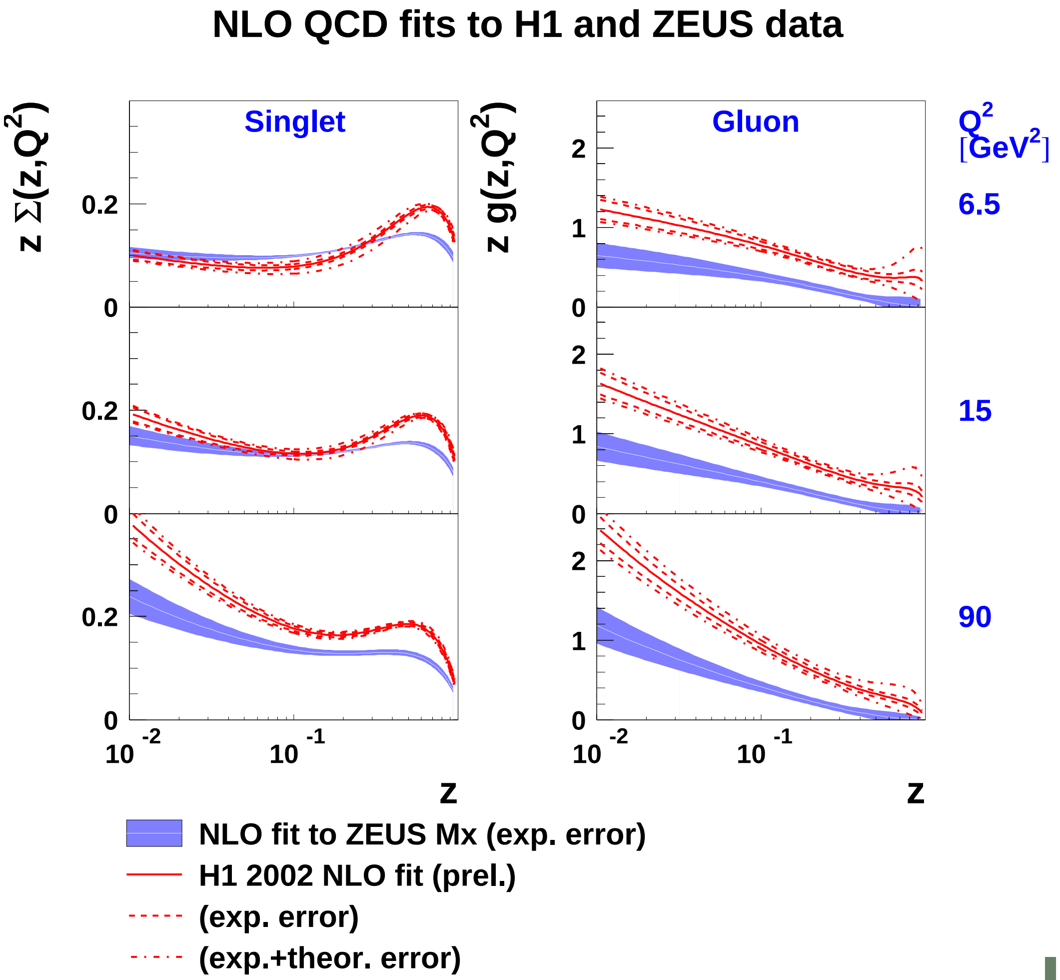
$\alpha_{I\!P}(0) = 1.132 \pm 0.006$



- Singet similar at low Q^2
- Gluon factor ~ 2 smaller than H1's

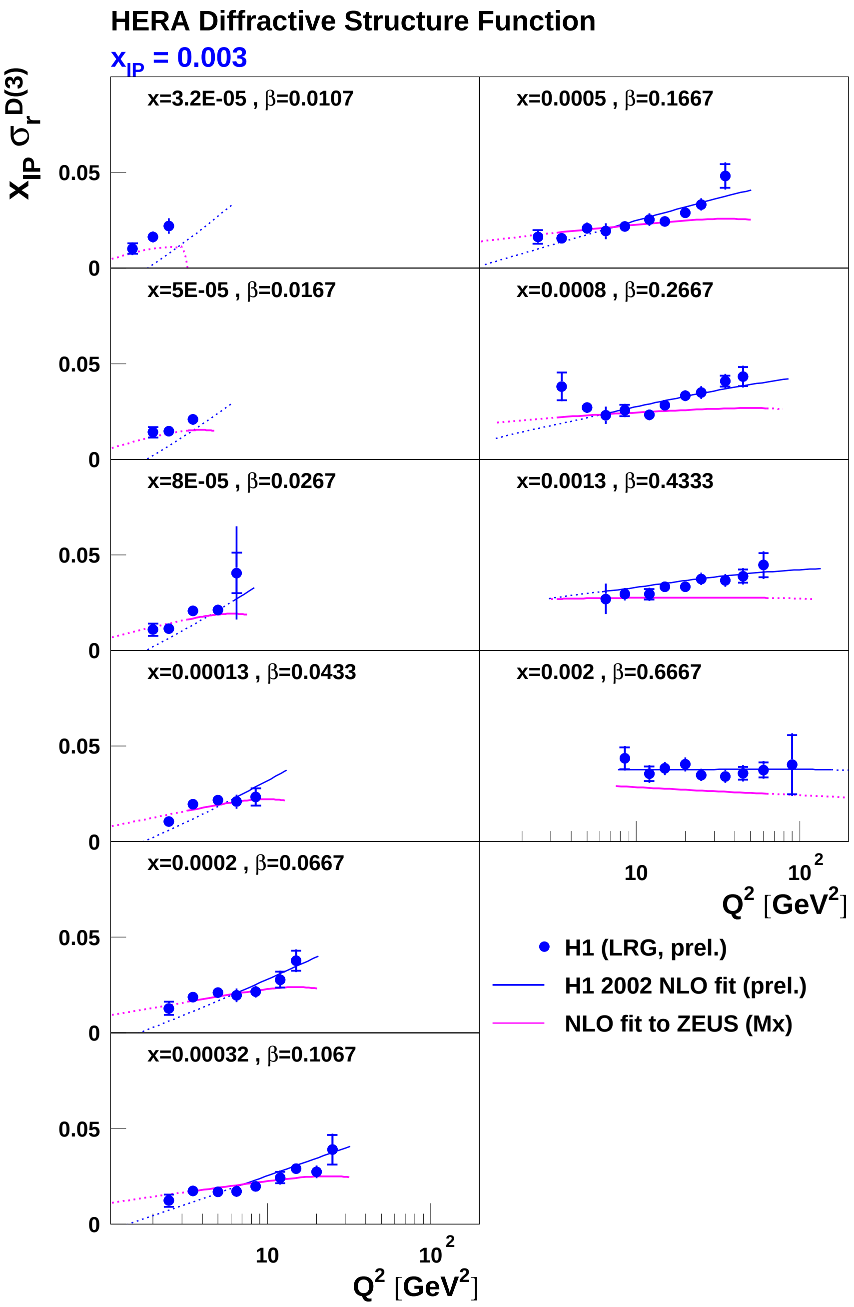
NLO QCD fit: ZEUS Measurement

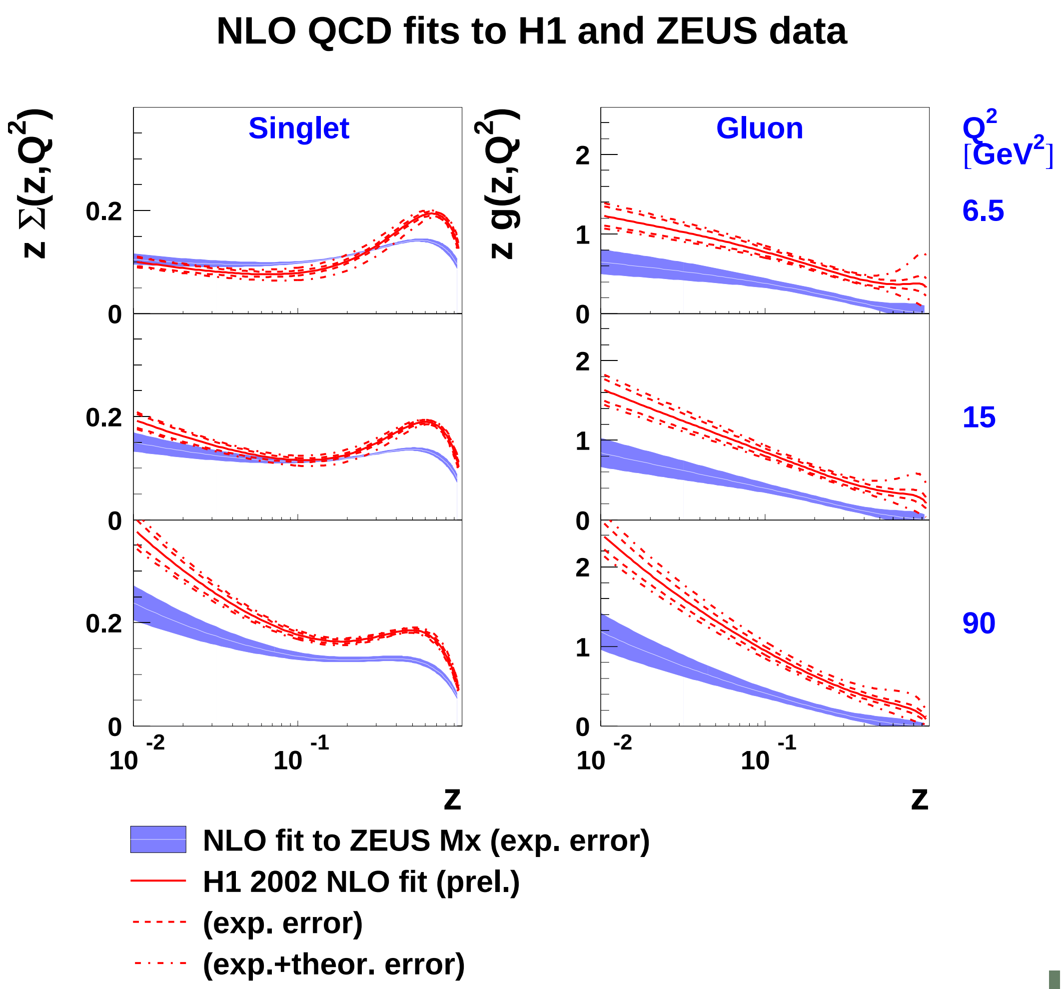




- in agreement at low Q^2
- difference H1-ZEUS at larger Q^2

NLO QCD fit: ZEUS Measurement

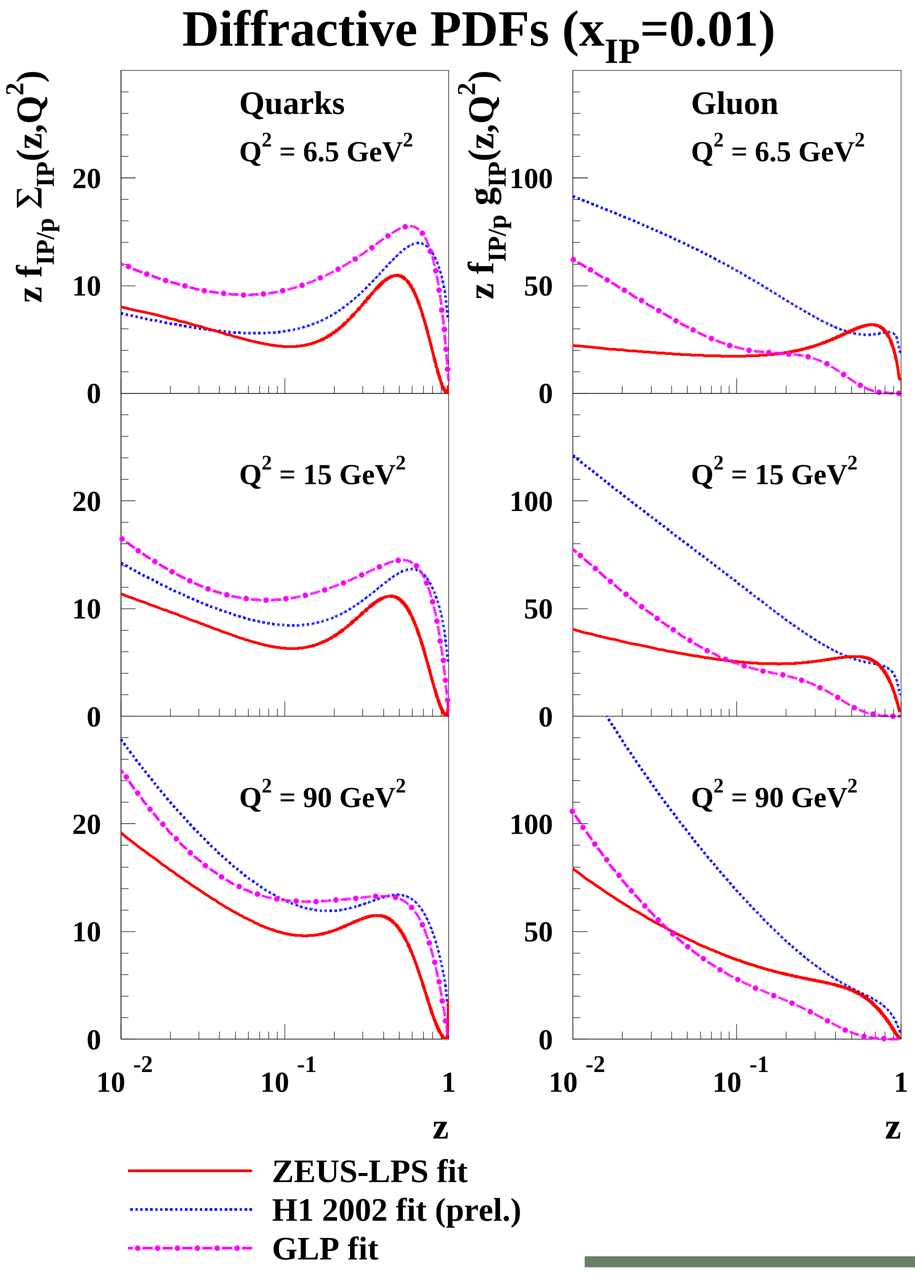




More NLO QCD fits

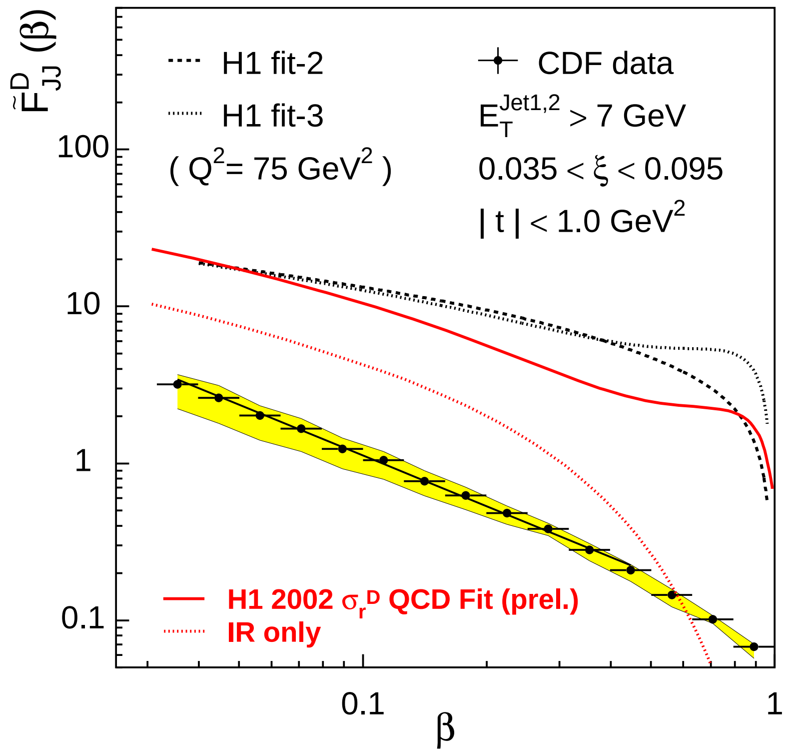
- ZEUS-LPS
  fitting LPS data and Diffractive charm
- GLP : Groys, Levy and Proskuryakov
- MRW: Martin, Ryskin, Watt
  (icluding inhomogeneous terms, direct sea contrib,...)
  $\longrightarrow$ see Graeme Watt talk.
- ...

→ quite unclear situation



Factorisation breaking at the Tevatron

CDF measurement of the diffractive dijet production (using ratio SD/ND):



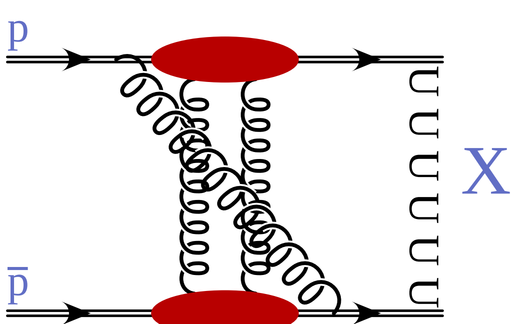
- The prediction based on diffractive PDF's extracted at HERA are one order of magnitude above the measures cross section!

- same to factorisation breaking in soft diffraction (Tevatron RUN I).

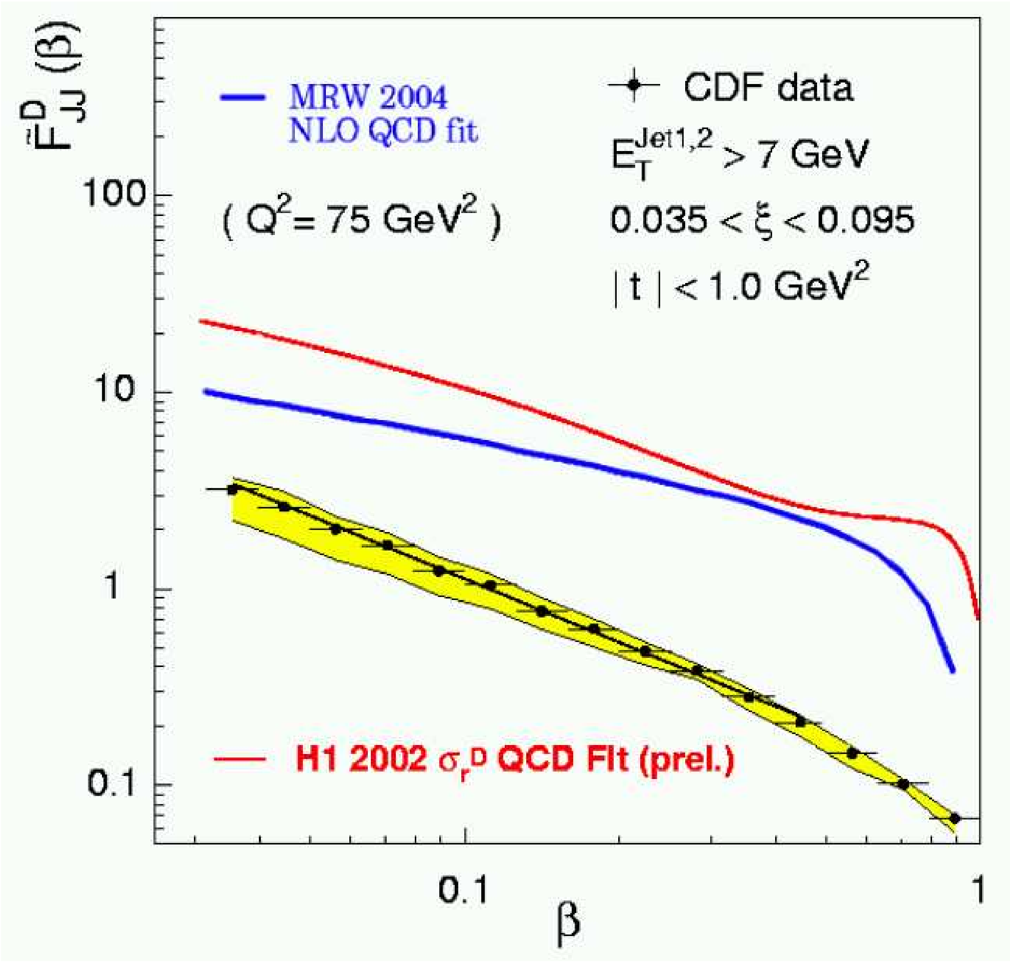
- also seen in $W\&Z$ production (sensitive to quark) and J/Ψ and b-mesons (sensitive to gluons)

- Factorization not expected to hold in pp. Violation of factorization understood usually in terms of (soft) rescattering corrections of the spectator partons

But other approaches exist...

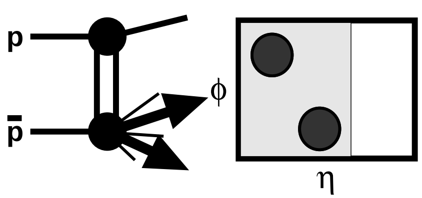


Factorisation breaking at the Tevatron

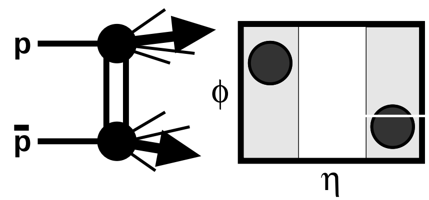


- does not change the conclusion with other DPDF

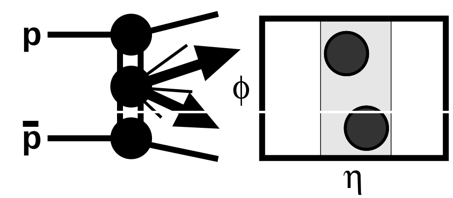
Factorisation breaking at the Tevatron



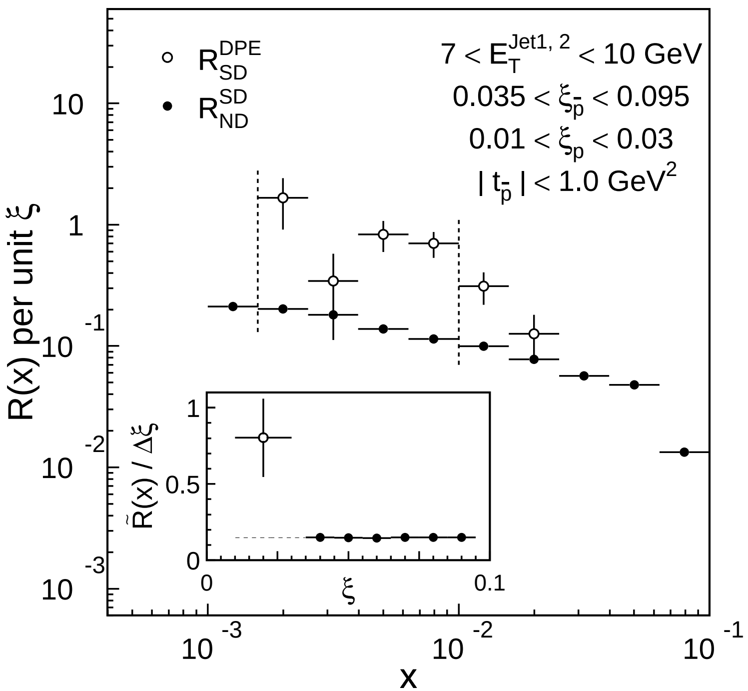
Single Diffraction

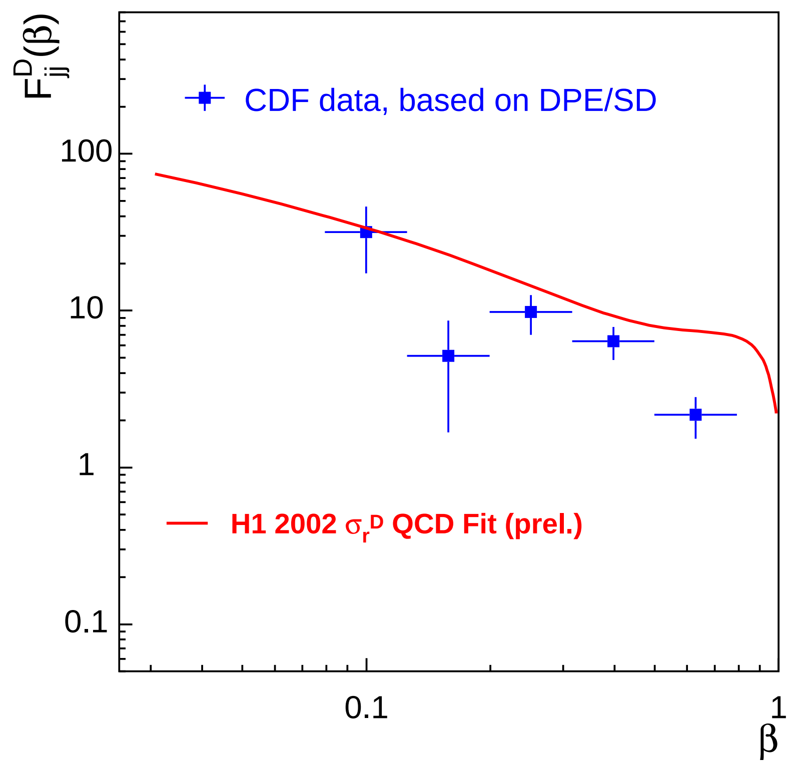


Double Diffraction



Double Pomeron Exchange





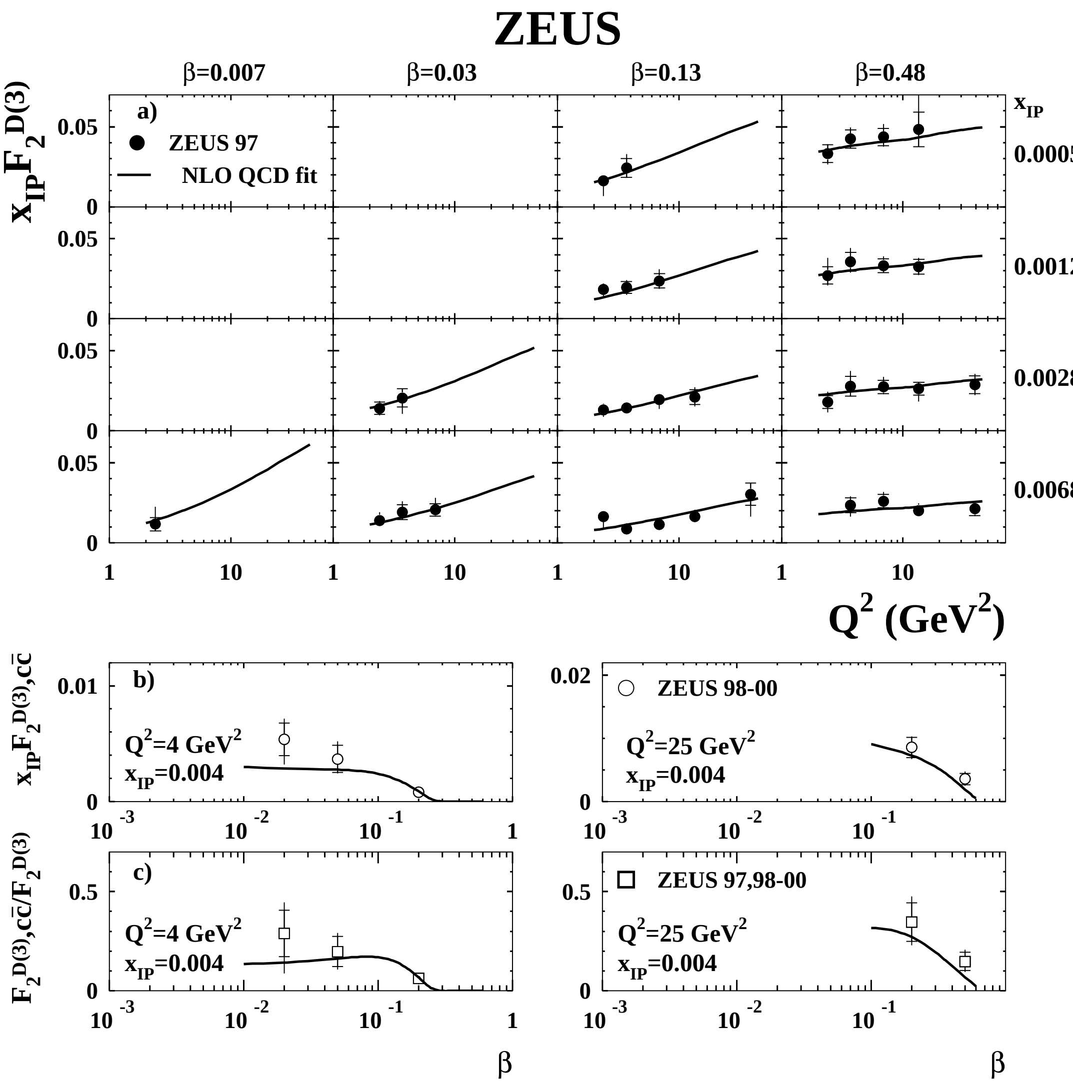
CDF measurement of R_{ND}^{SD} and R_{SD}^{DPE}

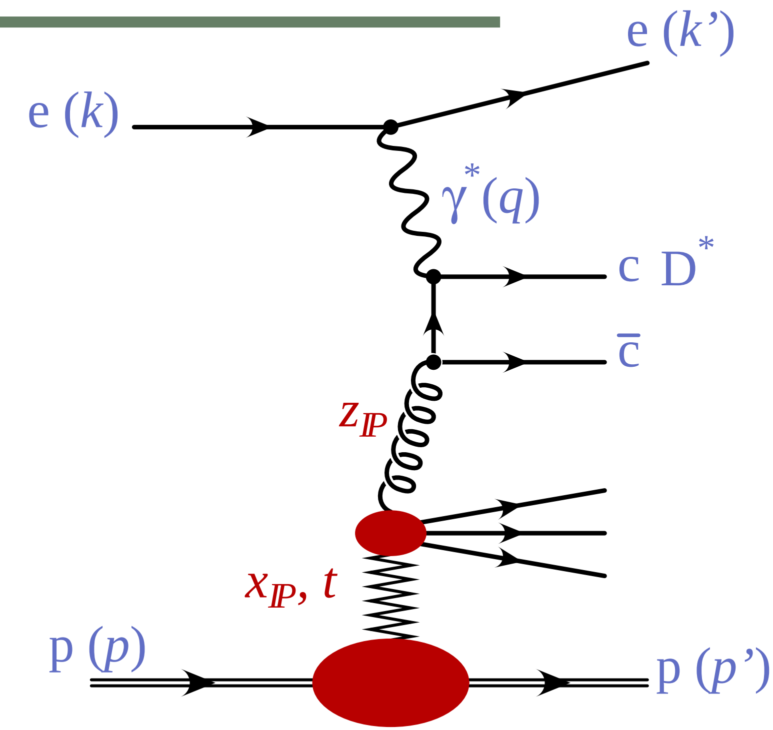
$$R_{ND}^{SD} / R_{SD}^{DPE} = 0.19 \pm 0.07$$

Second gap formation unsuppressed

DPE compatible with expectation from H1 PDFs

Test of QCD factorisation: Charm



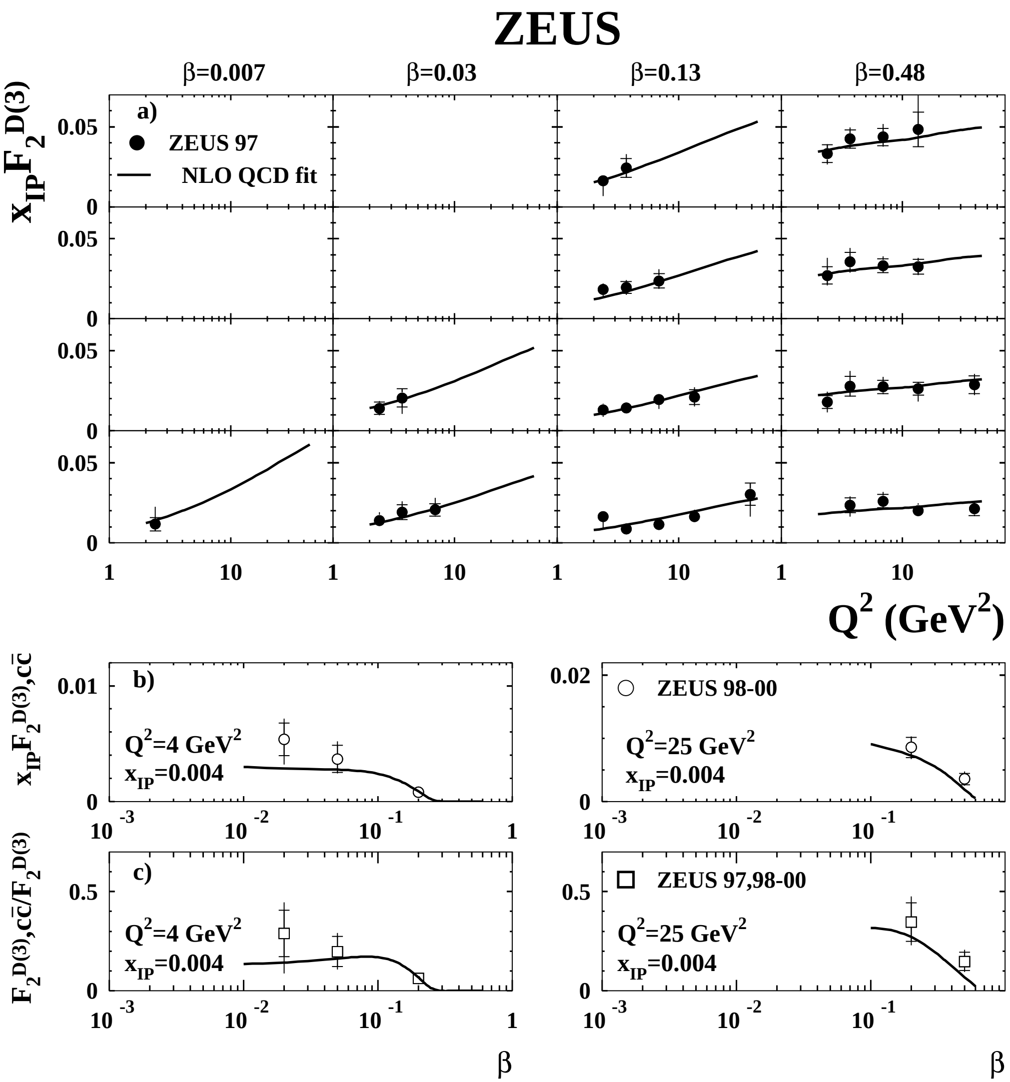


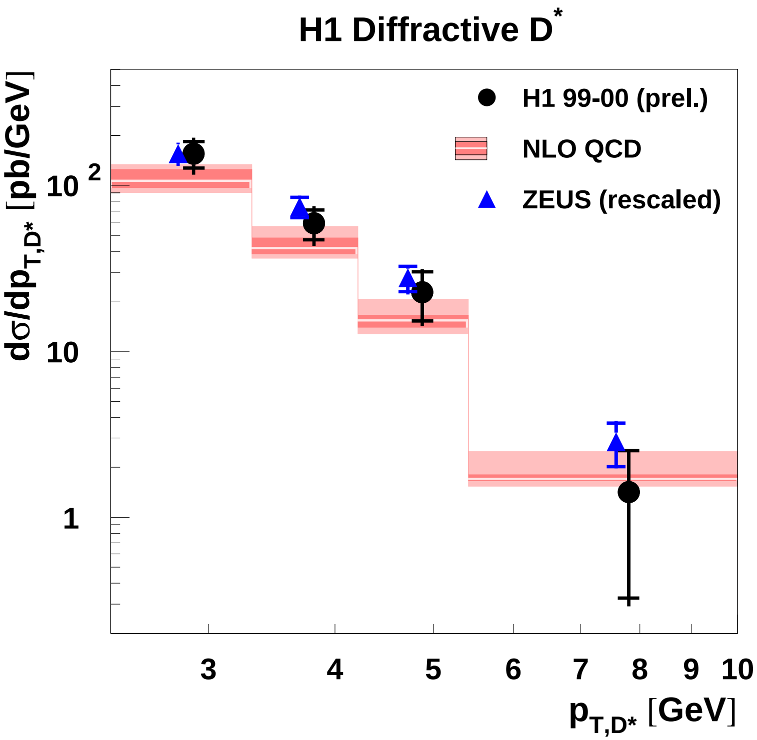
- Data using tagged leading proton
- NLO QCD fit

→ charm prediction

→ QCD factorization works for Charm in Diffraction with $Q^2 > 4$ GeV^2

Test of QCD factorisation: Charm





- Data using tagged leading proton
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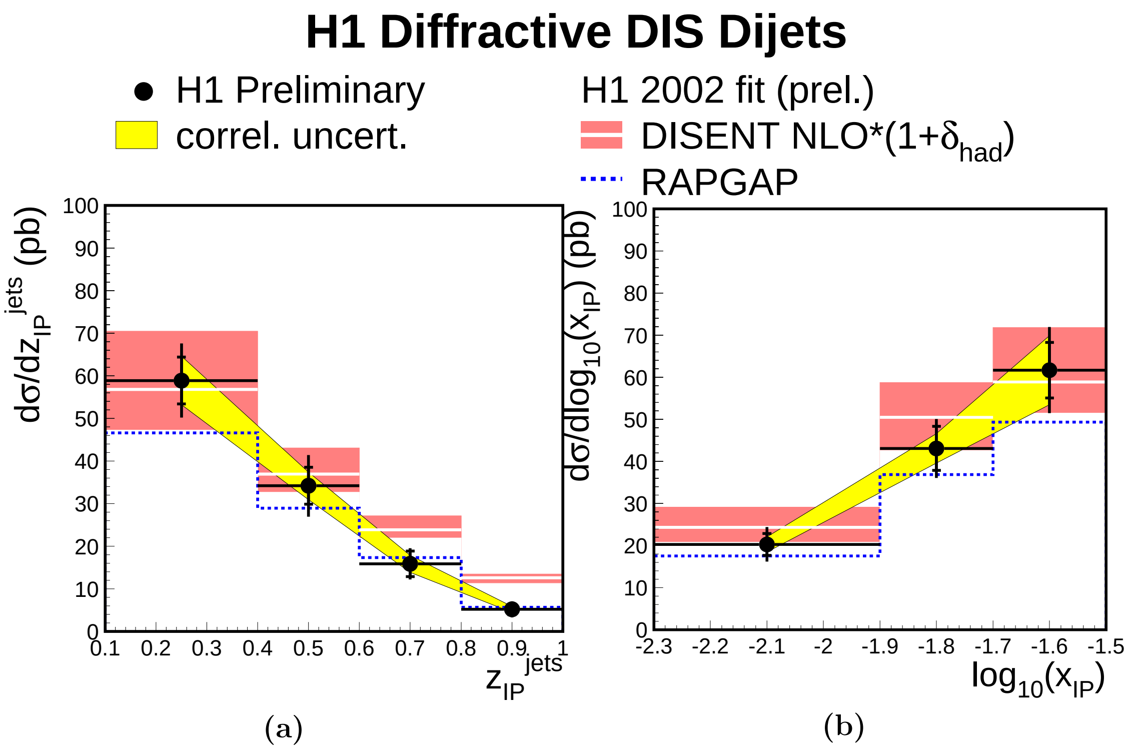
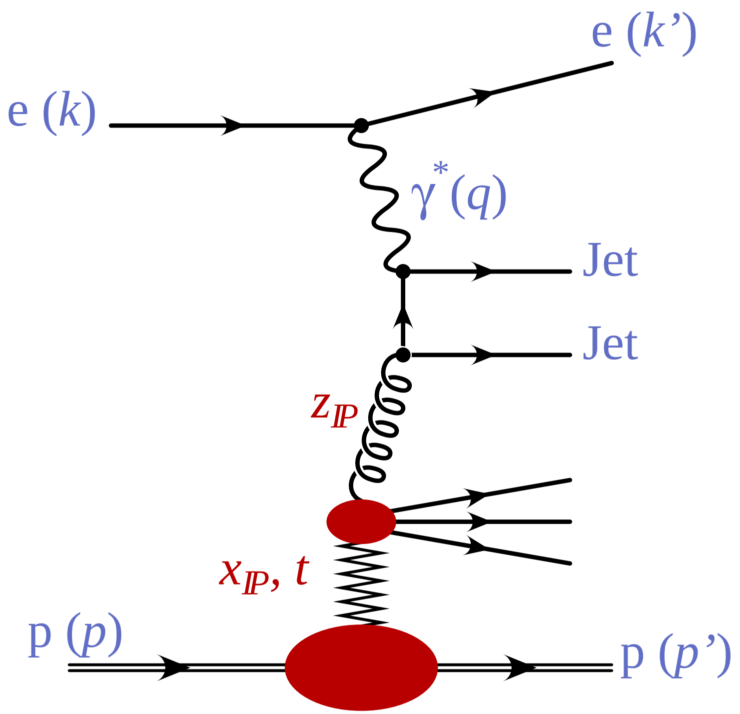
→ charm prediction

→ QCD factorization works for Charm in Diffraction with $Q^2 > 4$ GeV^2

Test of QCD factorisation: Dijet

Use diff PDFs to predict Dijet production

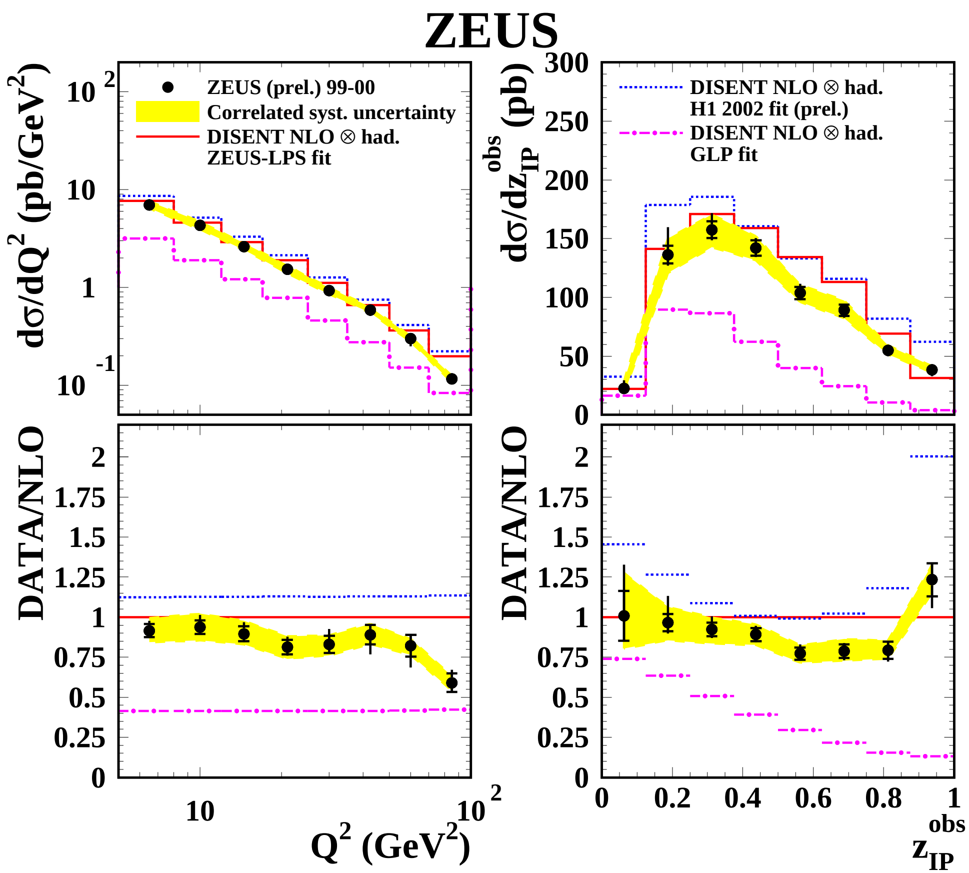


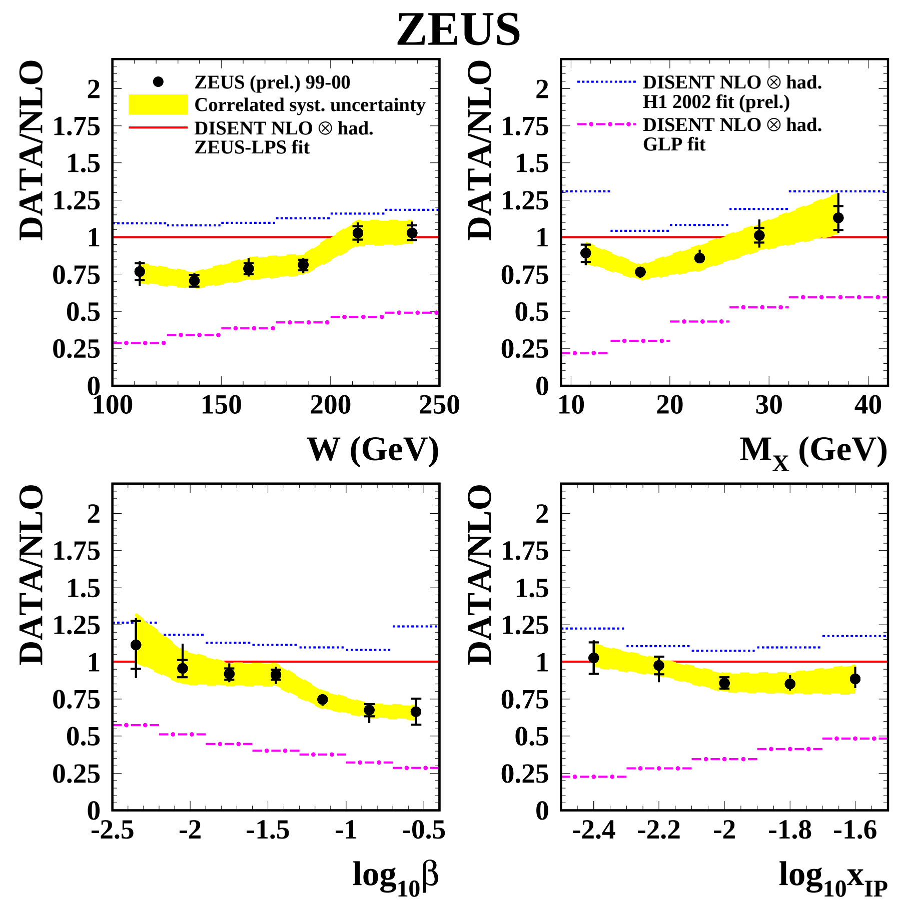


- $Q^2 > 4$ GeV^2, $P_T^{jet1(2)} > 5(4)$ GeV
- Normalisation and shape OK.

→ QCD factorization works within hard Diffraction (in DIS regime)

Test of QCD factorisation: ZEUS Dijet



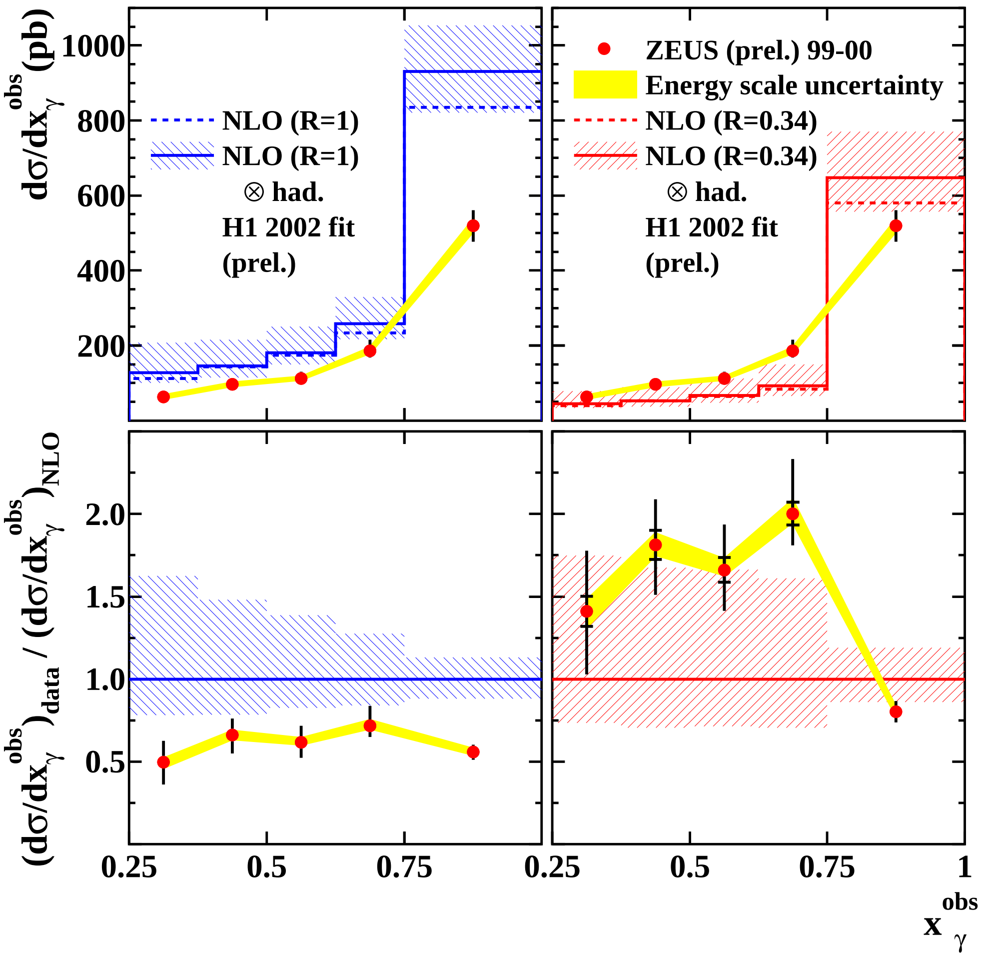


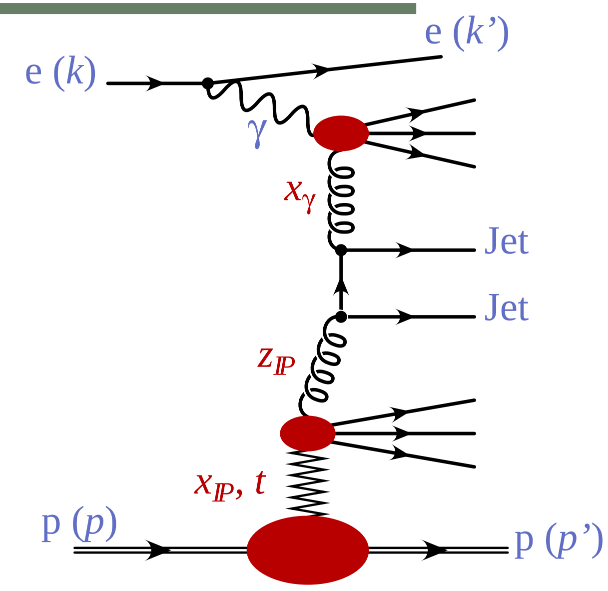
ZEUS concludes: "...differences between PDF predictions may be interpreted as an estimate of the uncertainty..."

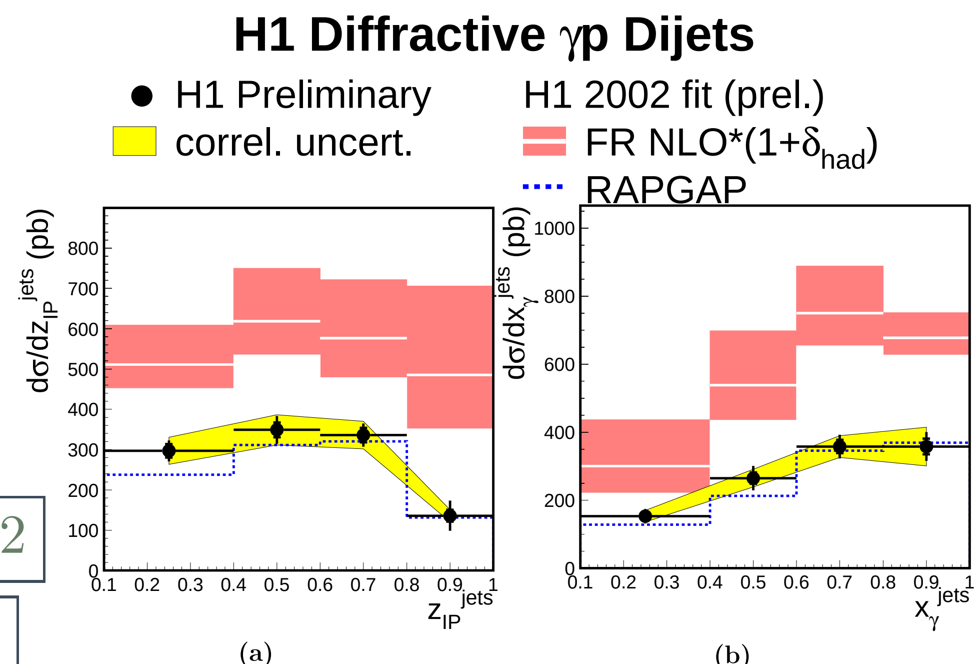
"A better understanding of the PDFs and their uncertainties is required before a firm statement about the validity of the QCD factorisation"

HERA: Factorisation test: Dijet in Photoproduction

Real photon ($Q^2 \simeq 0$) can develop a hadronic structure



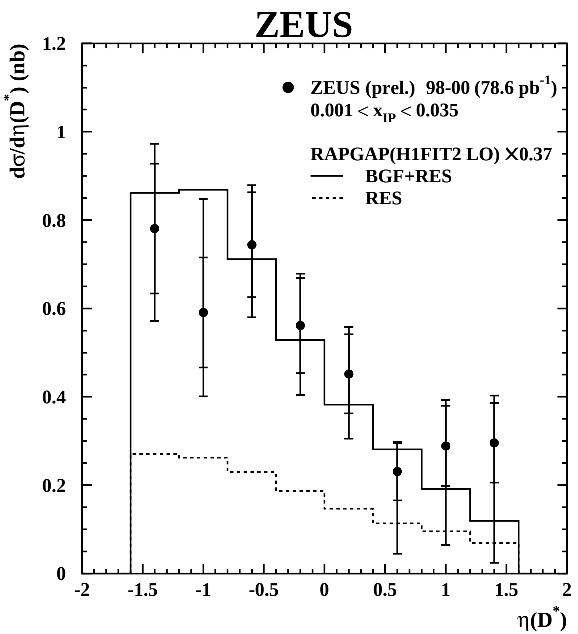


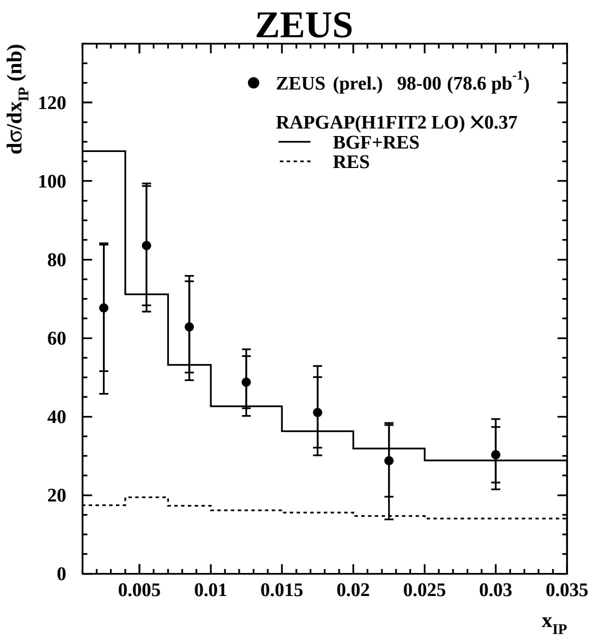


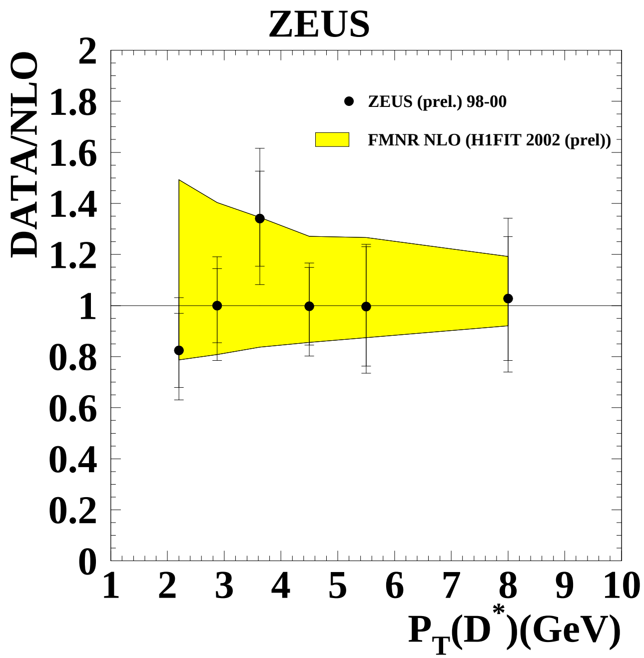
→ NLO prediction above by a factor $\simeq 2$

Suppression of both resolved and direct

Test of QCD factorisation: Charm in Photoprod.







- $Q^2 < 4$ GeV^2, $P_T^{D^*} > 1.9$ GeV, $\eta_{D^*} < 1.6$
- $130 < W < 300$ GeV $0.001 < x_{I\!P} < 0.035$
- Shape OK but not normalisation.

→ factorisation broken as for Dijets

Summary of QCD Factorization tests

Assuming H1Fit 2002 is correct

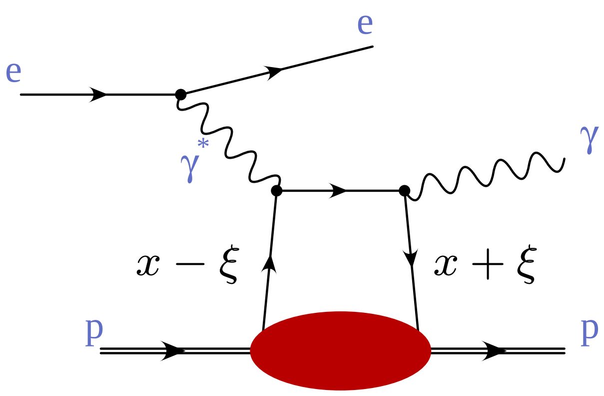
- **HERA - Diffraction in DIS regime**
  - → D^* (H1 and ZEUS) validate
  - → Di-jets (H1 and ZEUS) validate
- **Tevatron**
  - → Di-jets in single Diff. (CDF) factor 10 lower than expected from HERA PDFs
  - → Double Pomeron exchange (CDF) factor 2-1 lower (OK?)
  - → same in soft and hard diffraction
- **HERA - Diffraction in photoproduction**
  - → Di-jets (H1 and ZEUS) data below NLO QCD (factor 0.34).
  - → Di-jets: global suppression of both resolved and direct component
  - → D^* (ZEUS) data below NLO QCD (factor 0.37).

=> Better understanding of PDFs and their uncertainties needed for firm statements

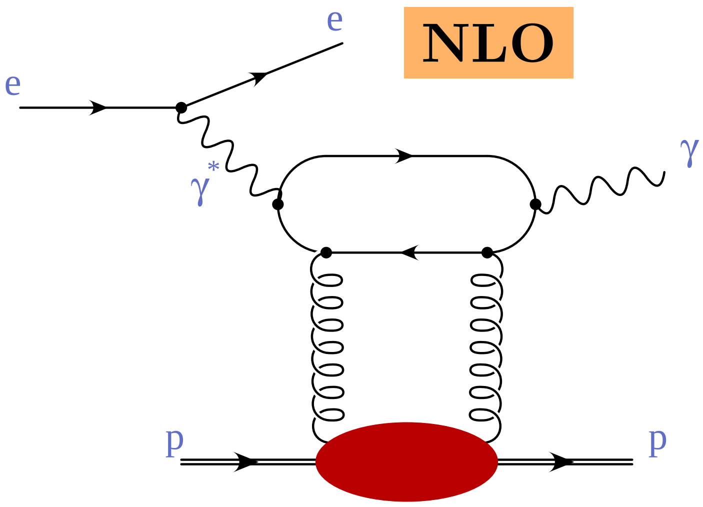
DVCS - QCD predictions

- Fully calculable in QCD

LO



NLO



- NLO leading twist (+ twist three) calc. by A. Freund and M. McDermott
  Eur.Phys.J. **C23** (2002) 651. Input: GPDs

DGLAP region: $|x| > \xi$

$\mathcal{H}^q(x, \xi, t; \mu^2) = q(x; \mu^2)\, e^{-b|t|}$ q singlet

$\mathcal{H}^g(x, \xi, t; \mu^2) = x\ g(x; \mu^2)\, e^{-b|t|}$ gluons

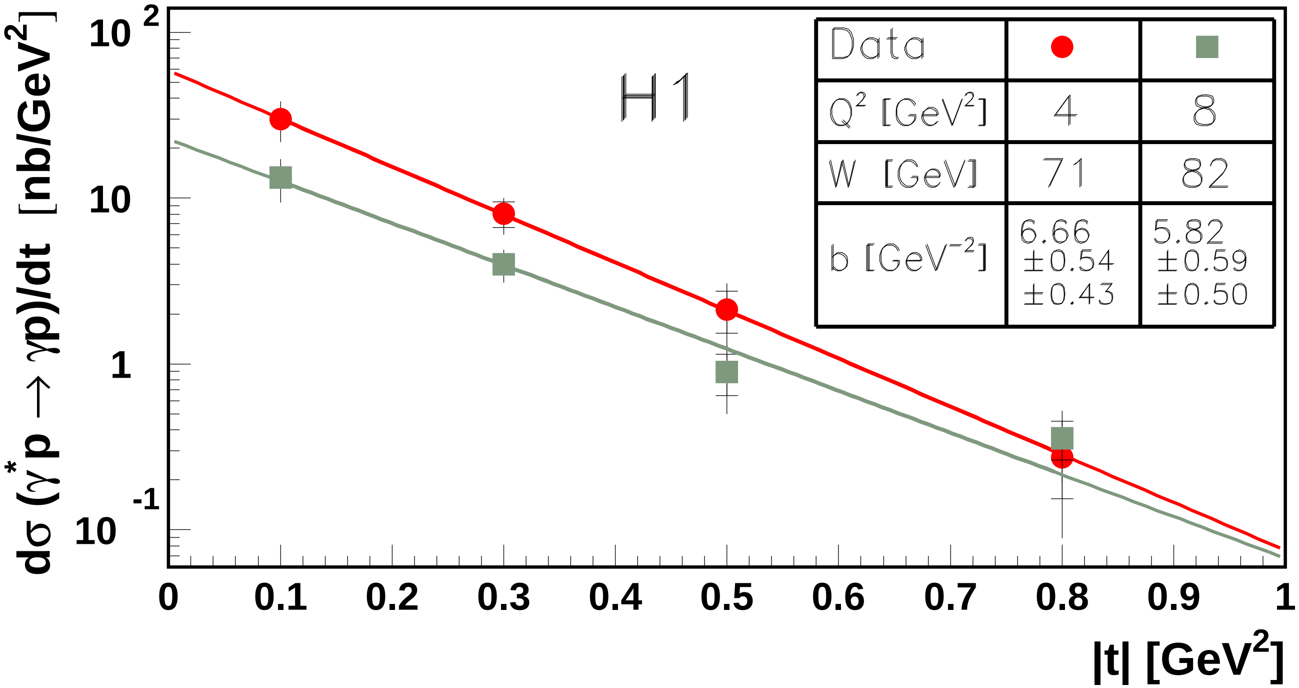
MRST2001 and CTEQ6

ERBL region: $|x| < \xi$

simple analytic function

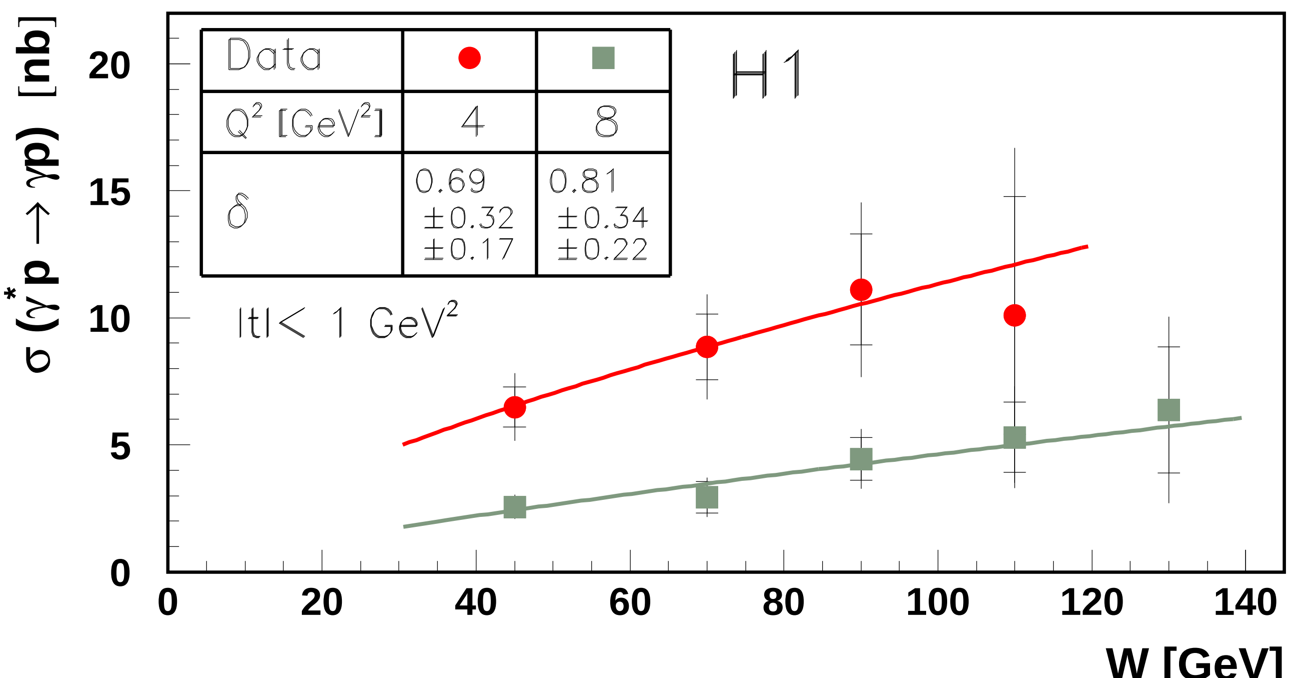
$\rightarrow Q^2$ and ξ generated dynamically

b from the data

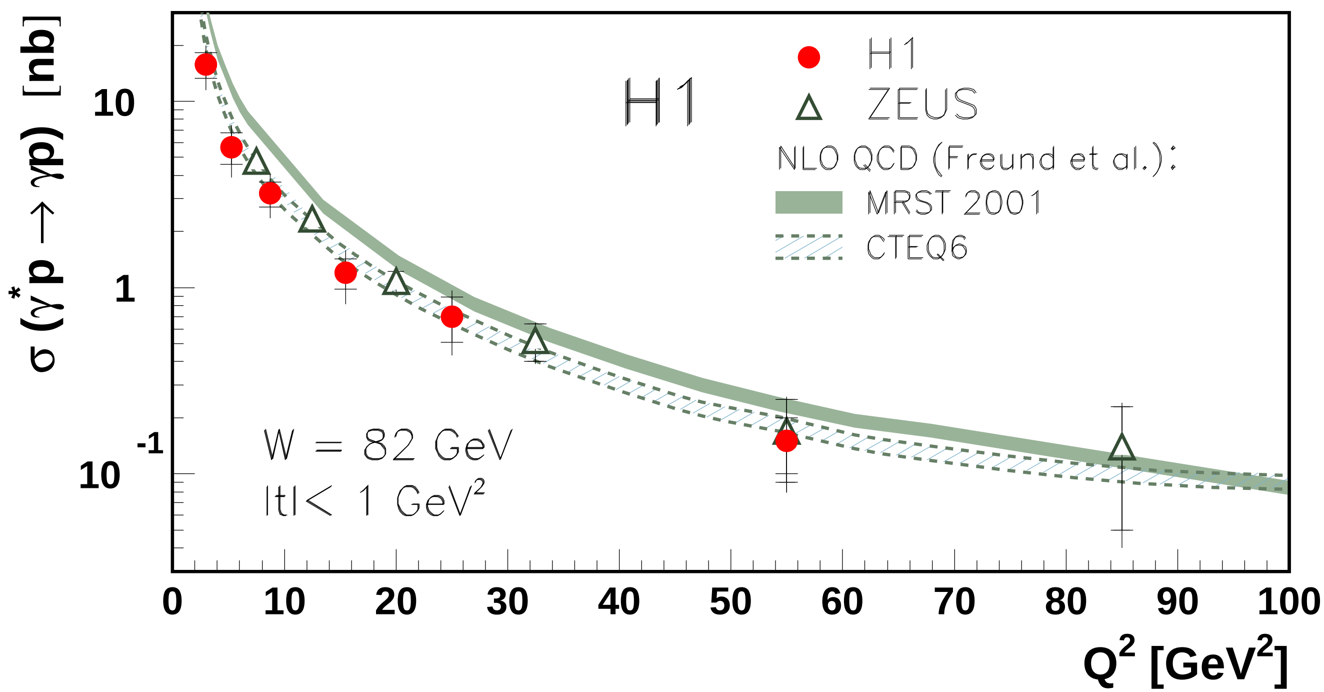


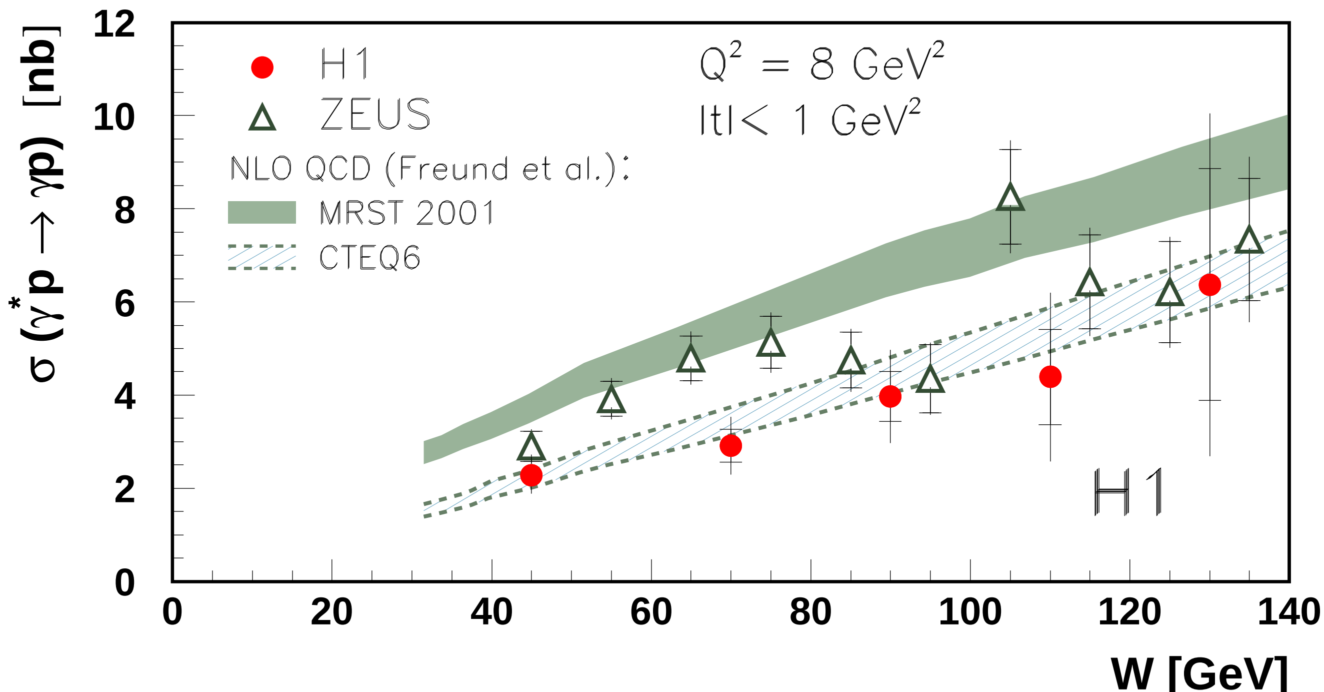
- First measurement of the t slope

combined samples:
$b = 6.02 \pm 0.35 \pm 0.39\ \mathrm{GeV}^{-2}$



- W dependence for two Q^2 values
  - Fit W^δ:
- indication of a hard regime (comparable to J/Ψ)





H1-ZEUS Comparison

→ Agreement

Fit in Q^2: $(Q^2)^{-n}$

→ $n = 1.54 \pm 0.09 \pm 0.04$

→ n smaller than for VM ($n(\rho) = 2.60 \pm 0.04$)

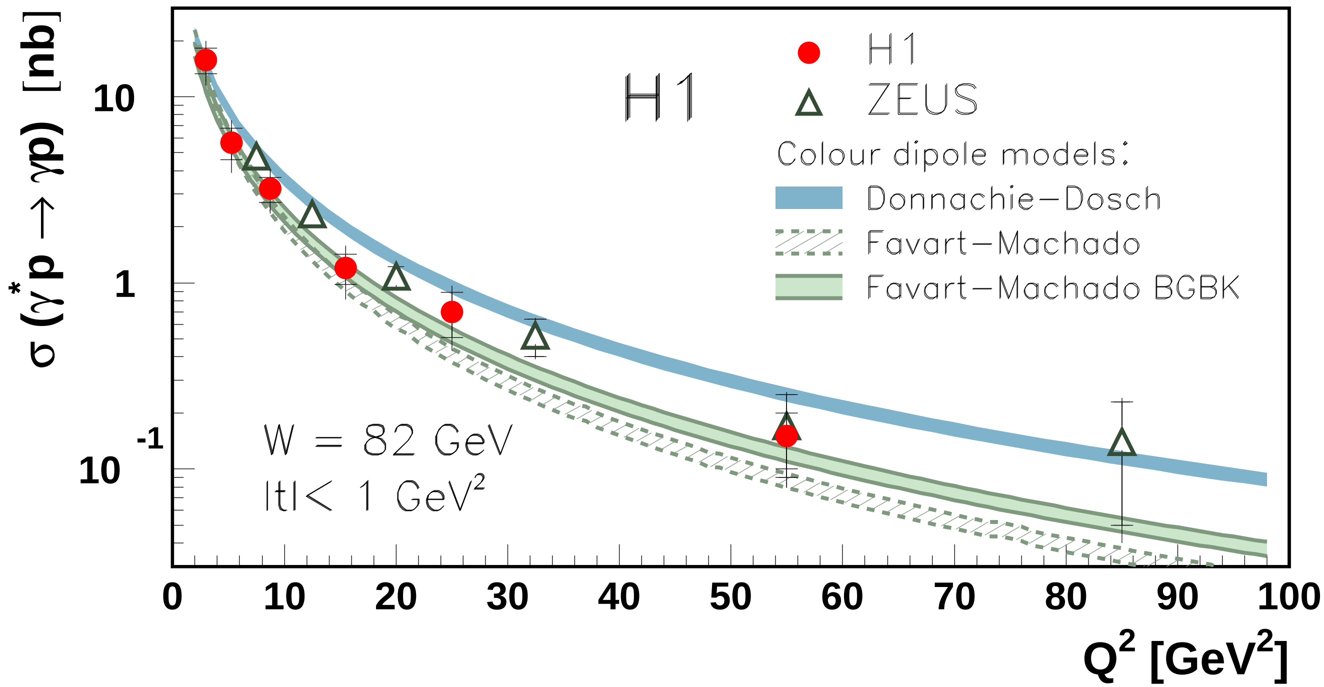
Comparison to NLO QCD:

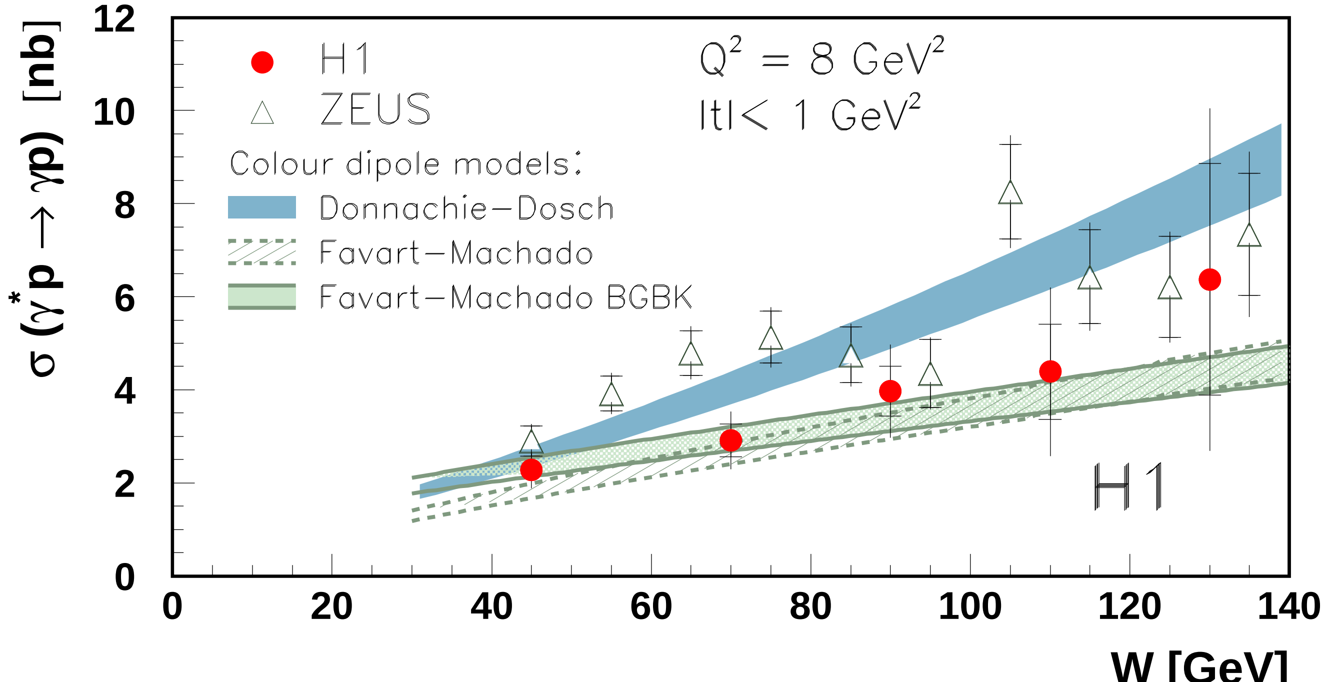
- Band width provided by b measurement.

→Good description by QCD-NLO calculations

→No need for intrinsic skewing

Comparison to Dipole Models





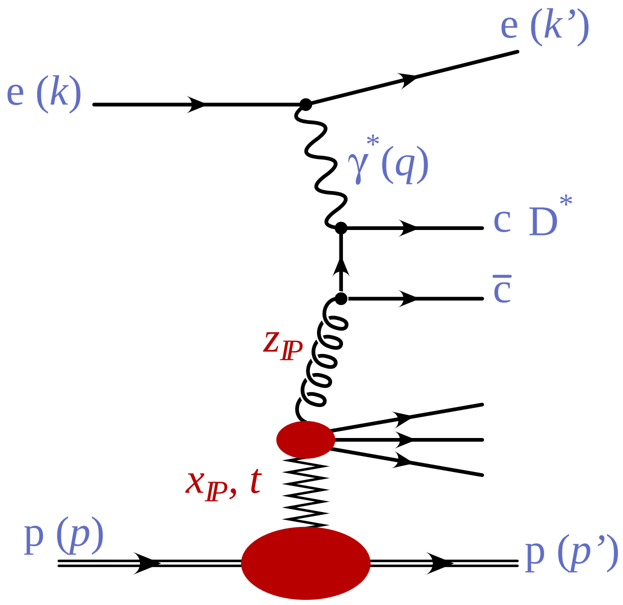
- Good normalisation and shape description

- Improvement in FM when DGLAP evol. included

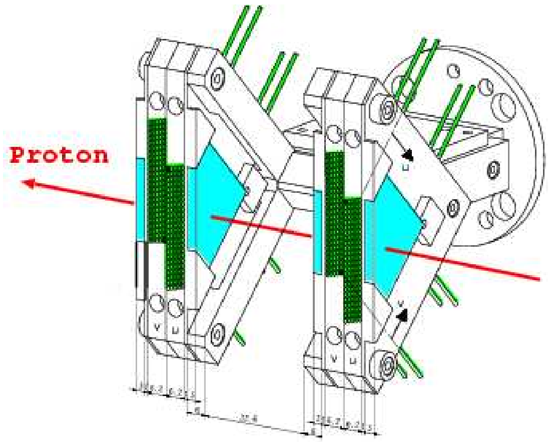
- Still improved if $b(Q^2)$ used as observed for ρ

Future

- HERA - more data - in part. D^*, VM, DVCS
- $F_2^{D(3)}(\beta, Q^2, x_{I\!P})$, $F_2^{D(4)}(\beta, Q^2, x_{I\!P}, t)$
- measure the t slope of D^* and Di-jet in both electro and photoprod.
- ratio of incl. di-jet to diff di-jet in photoprod.
- same for $D*$

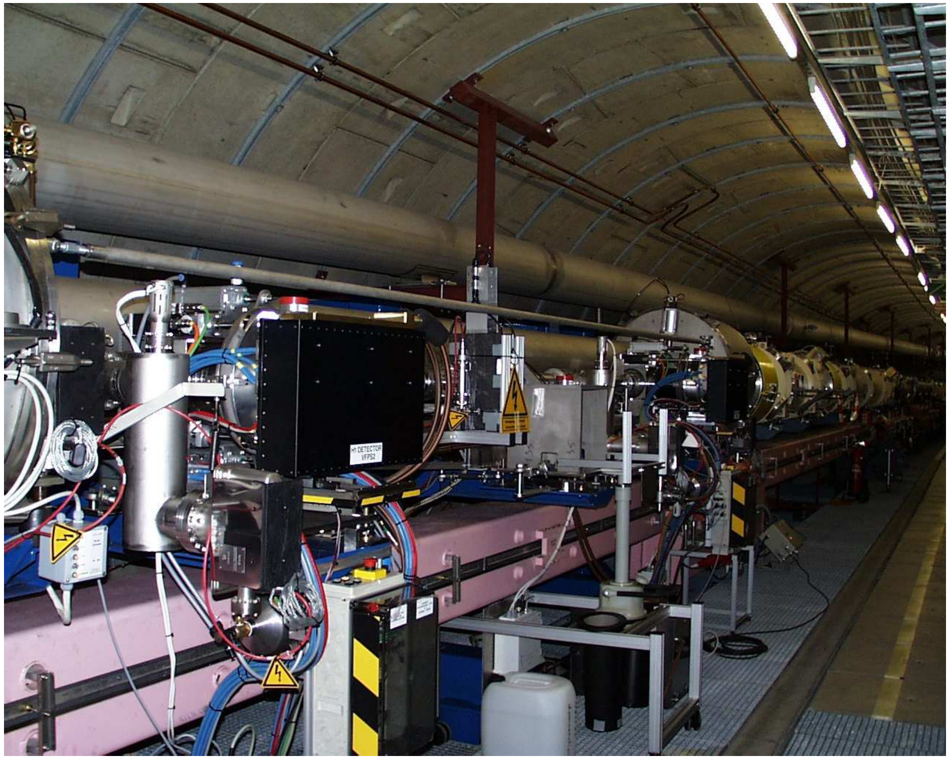


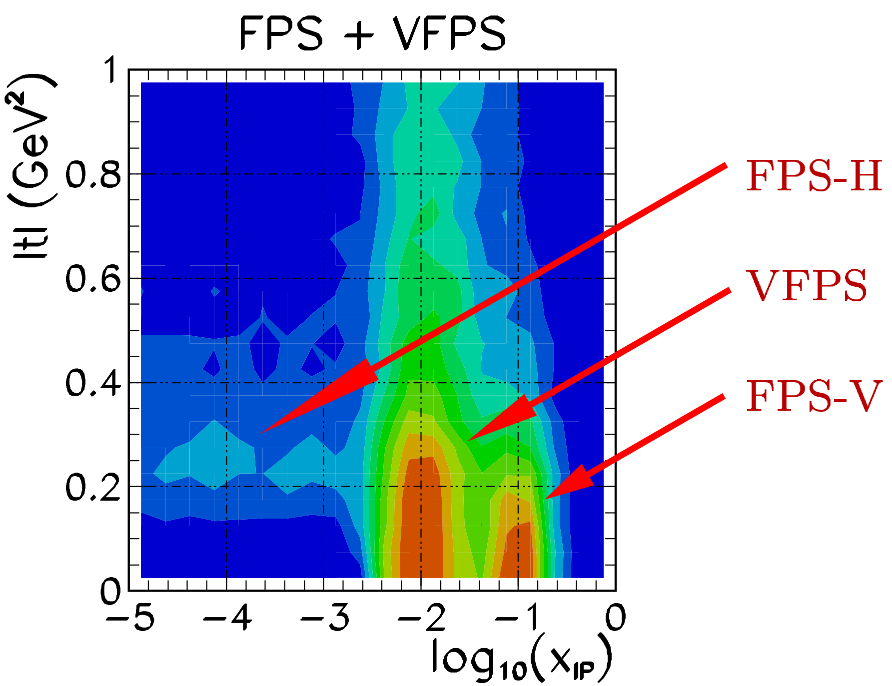
H1 at HERA II



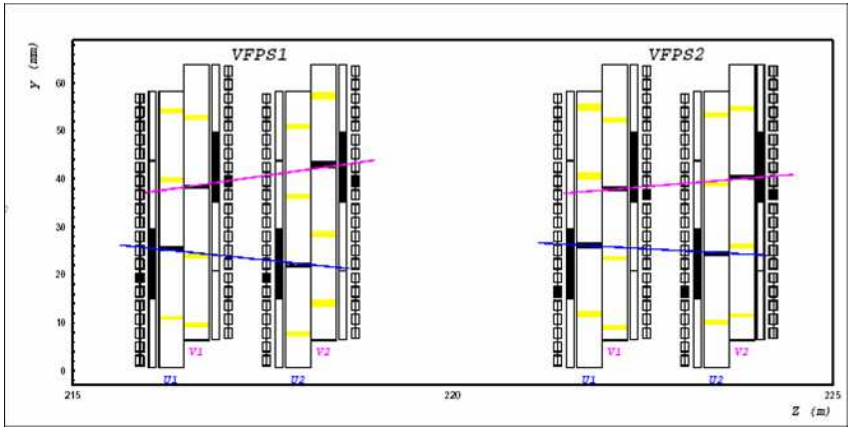
- Scintillating fiber detector
- Free of proton dissociation bkgd
- proton 4-momentum measurement $\rightarrow$ t

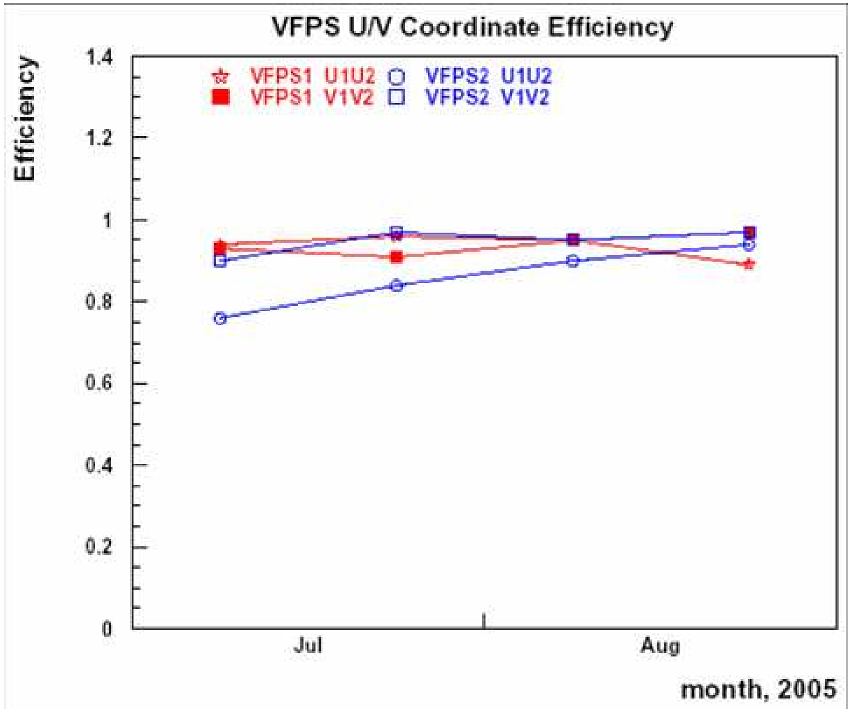
$\longrightarrow$ commissioning January 2004



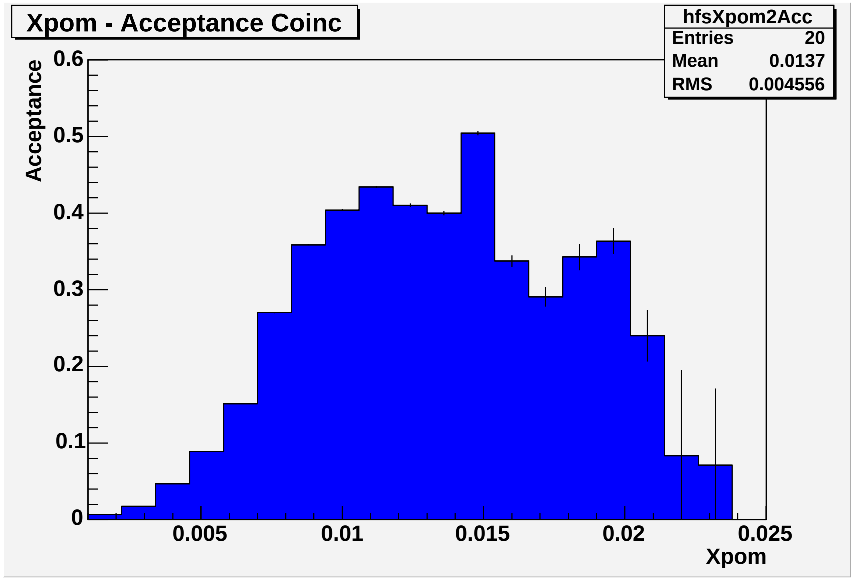


VFPS - First year of data





- High efficiency
- Acceptance in the expected $x_{I\!P}$ region
- High acceptance



Conclusion

- Diffraction is a subtle QCD process.
- the partonic structure of the exchanged object in diffraction has been measured.
- it is dominated by gluons.
- Diffractive Structure functions can be factorised in DIS regime (large Q^2) in $\gamma^* - p$ interactions
- Factorisation broken $pp*$ (Tevatron)).
- Factorisation broken in photoproduction (dijets and D^*).
- better measurement and understanding of DPDFs are needed

- DVCS: first t slope measurement
- very good agreement with NLO QCD (absolute) prediction
- Sensitivity to gluon density and parton correlations (GPDs).