Inclusive diffraction and DVCS

$\mathcal{L}$. *Favart*

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ULB

Ringberg Workshop 2005
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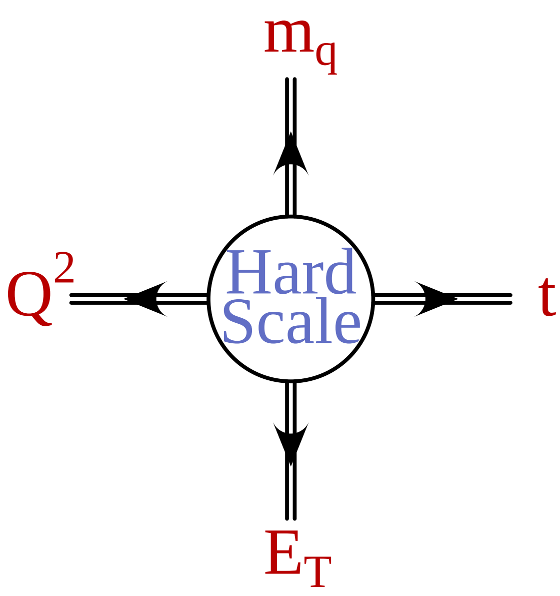
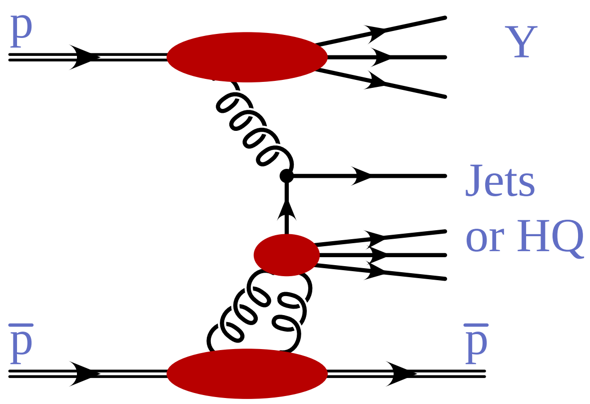
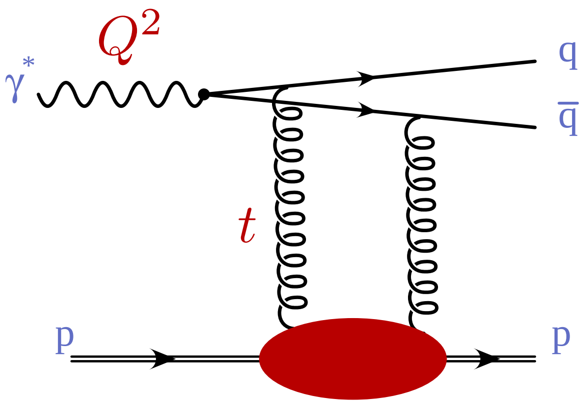
Interest of Hard Diffraction

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







Interest of Hard Diffraction

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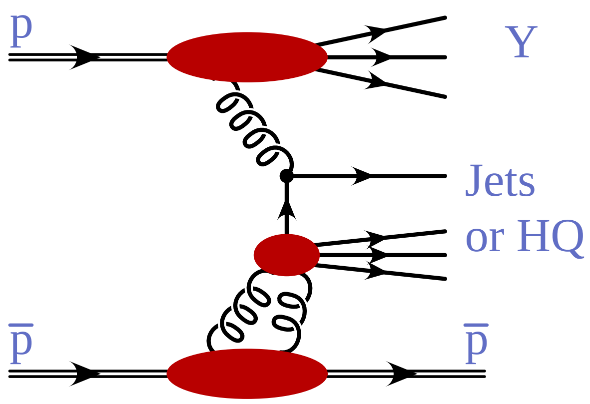
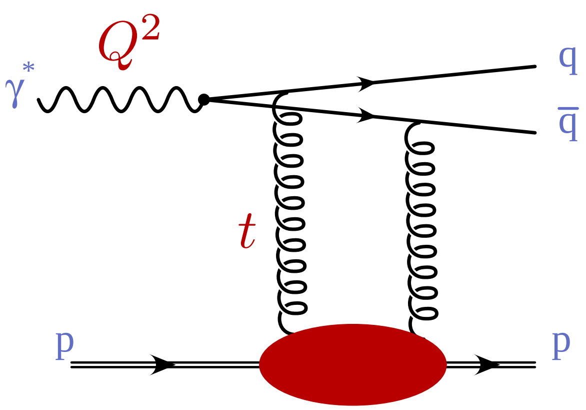
  - → Several possible hard scales
  - → probing the exchange partonic structure - like in inclusive structure functions
  - → typical signature of hard scale presence: steep rise with W (cms energy)





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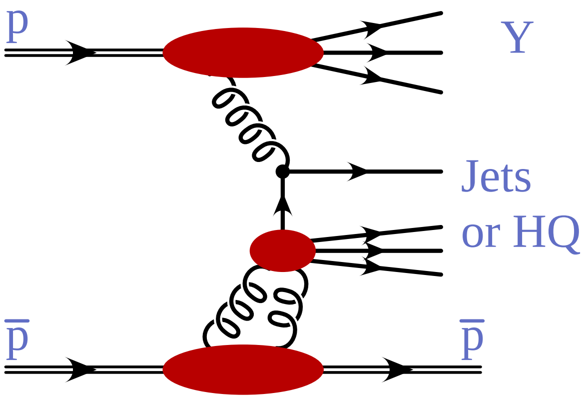
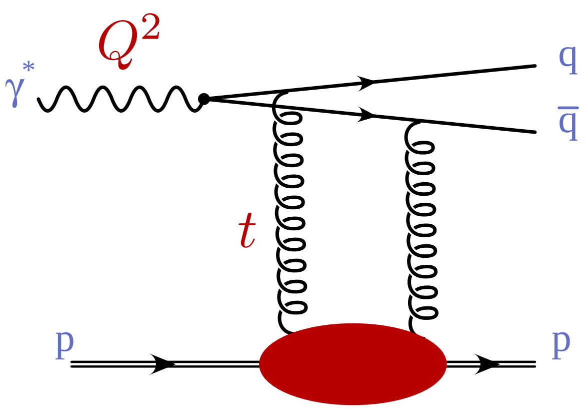
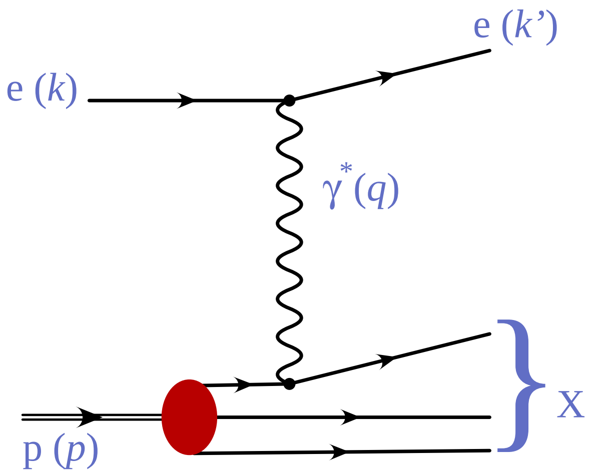
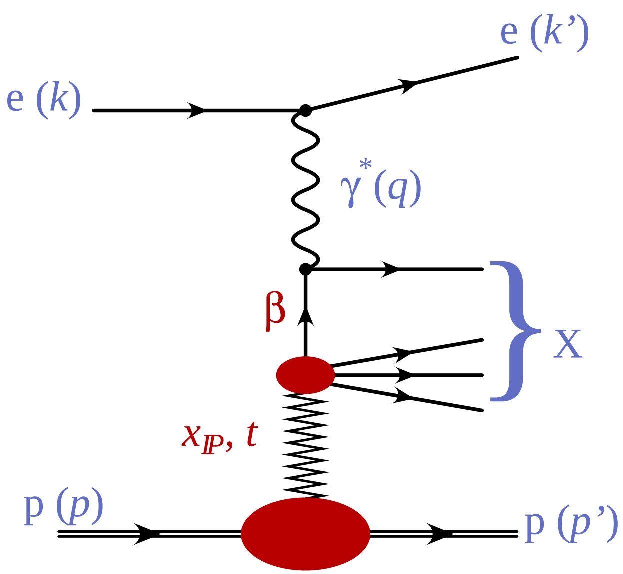
  - → two gluon exchange
  - → Several possible hard scales
  - → probing the exchange partonic structure - like in inclusive structure functions
  - → typical signature of hard scale presence: steep rise with W (cms energy)
- Access to very low x of nucleon structure function and parton correlations → 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

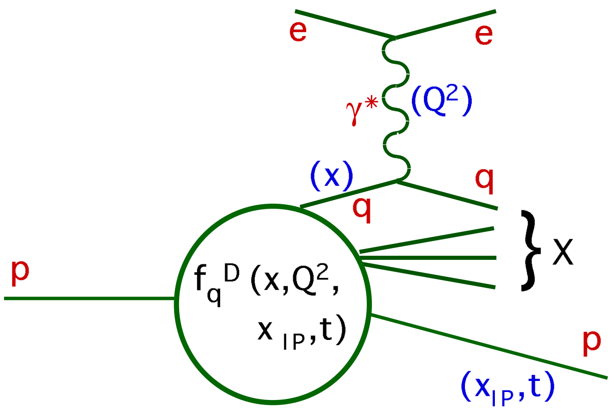
Factorisation Properties

QCD Hard Scattering Fact.

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

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.

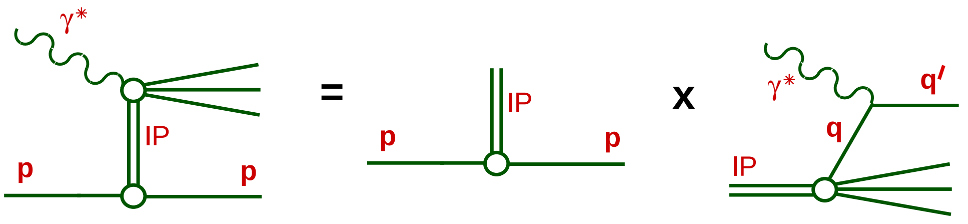


Rigorous for leading Q^2 dependence
but not in hadron-hadron collisions

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 ...

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

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

No firm basis in QCD

Recent Diffractive DIS Data

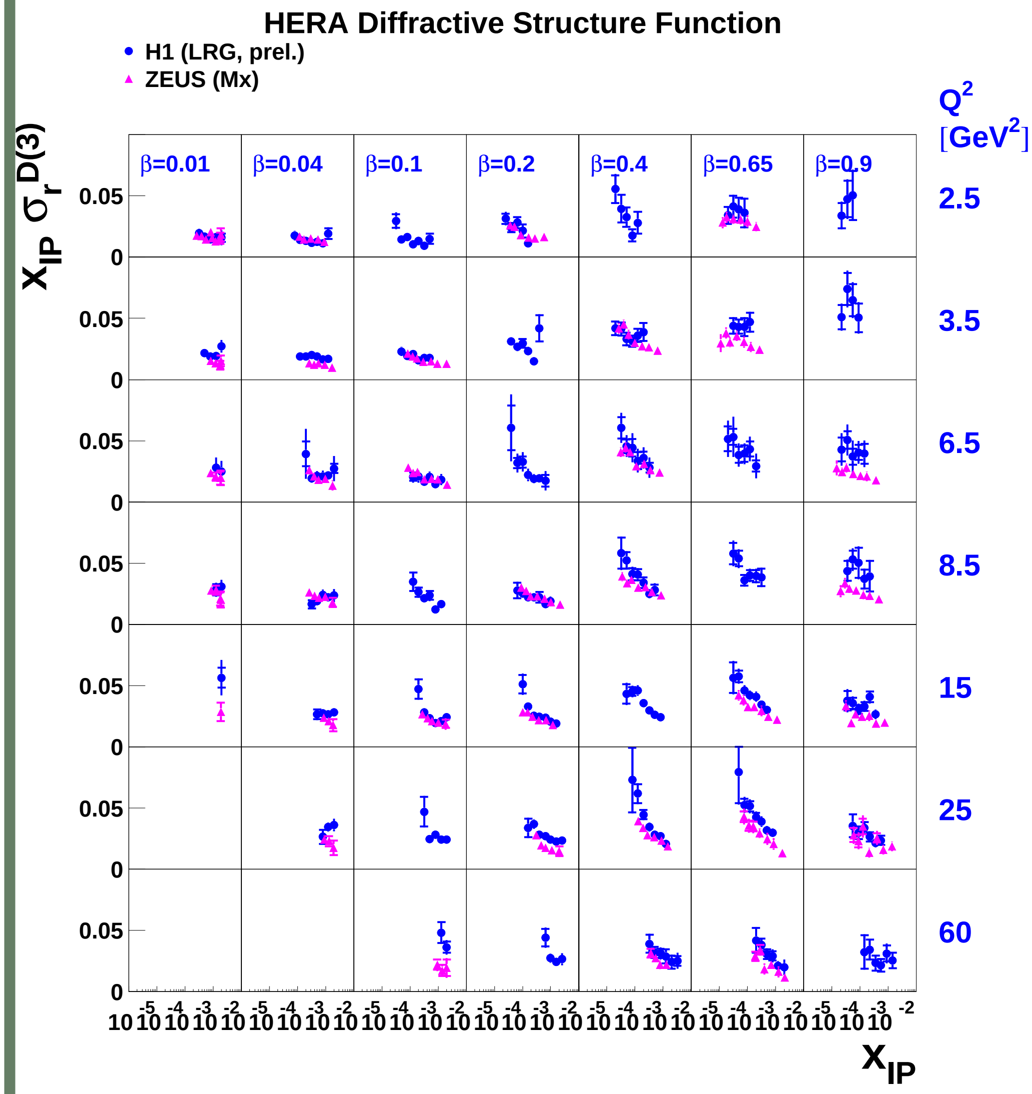
ZEUS Data:

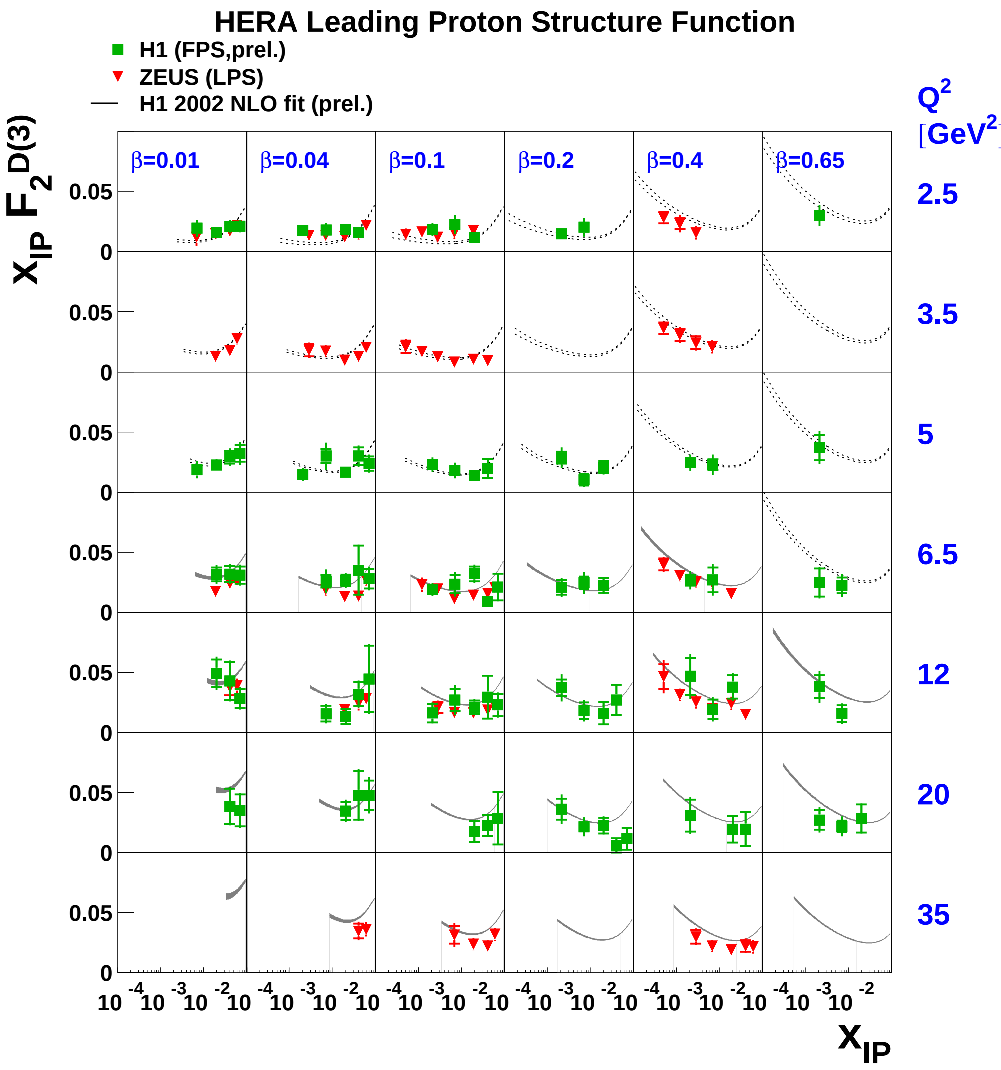
- "Study of Deep Inelastic Inclusive and Diffractive Scattering with the ZEUS Forward Plug Calorimeter" (Mx method)
  DESY-05-011, accepted by Nucl. Phys. B $2.4 < Q^2 < 39$ GeV^2 (98-99)
- "Dissociation of virtual photons in events with a leading proton at HERA" (Leading Proton)
  Eur. Phys. J C38 (2004)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





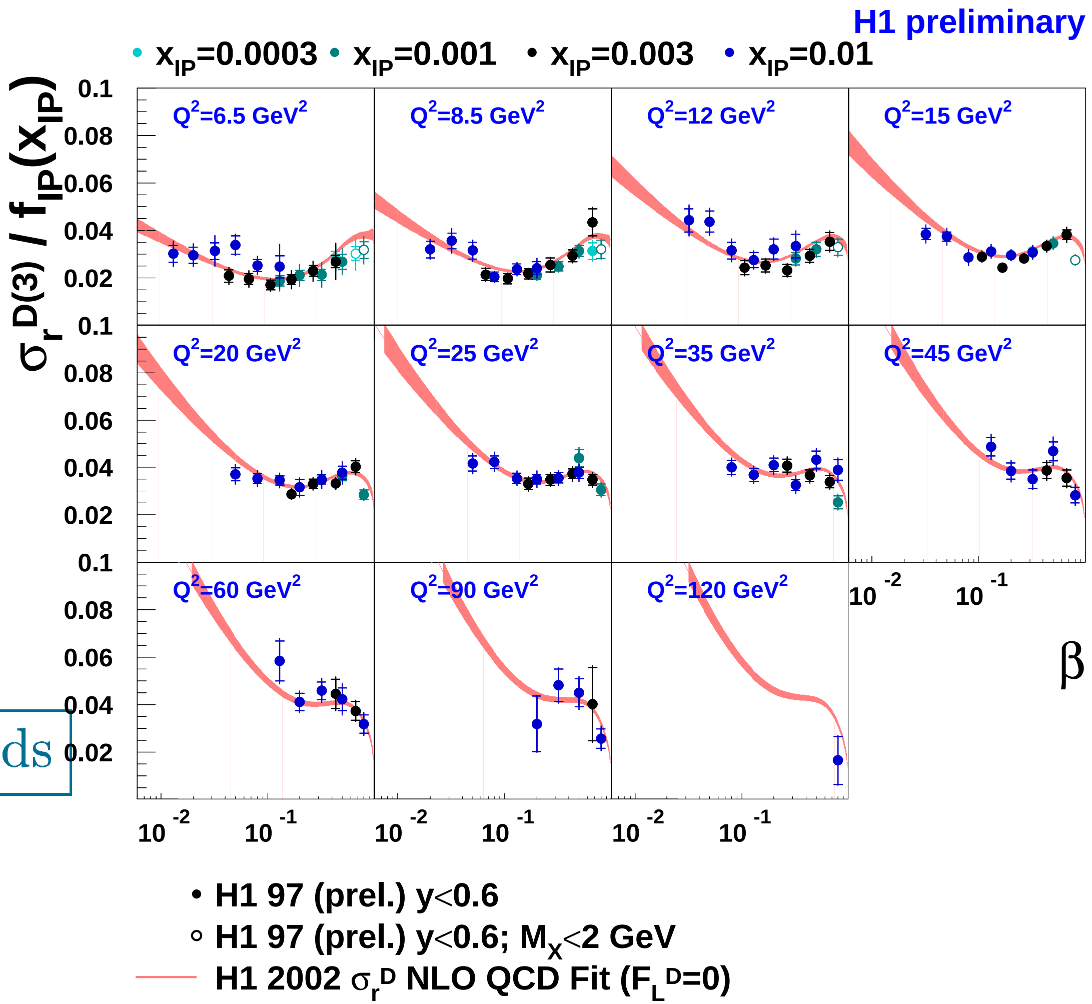
Regge factorisation: β Dependence of F_2^D

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, $\alpha(0)$

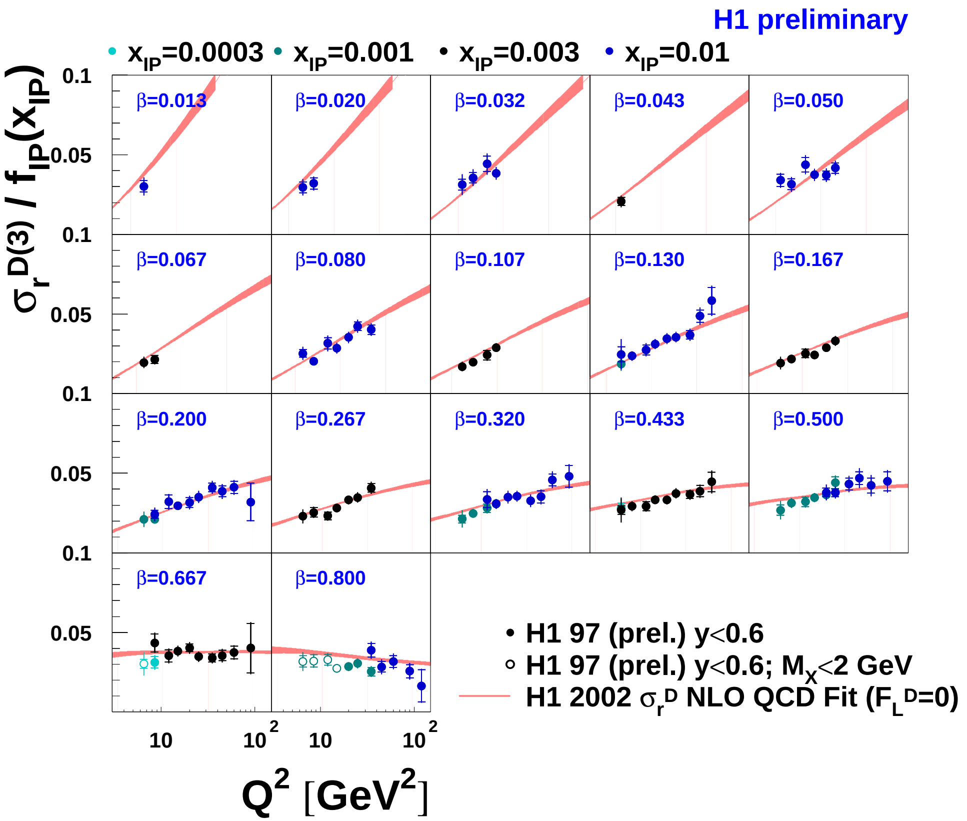


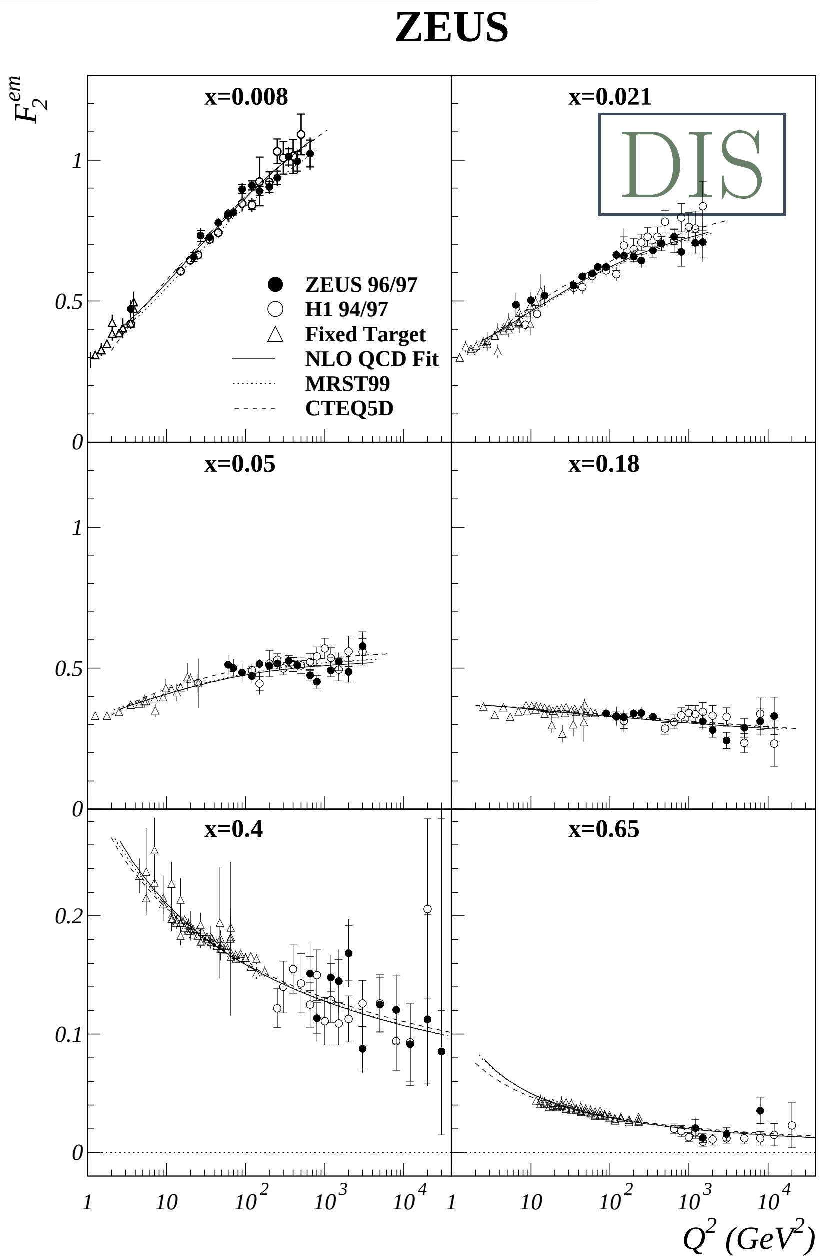
→ Regge factorisation basicaly holds

Measures parton density over wide β range.

Q^2 Dependence of F_2^D

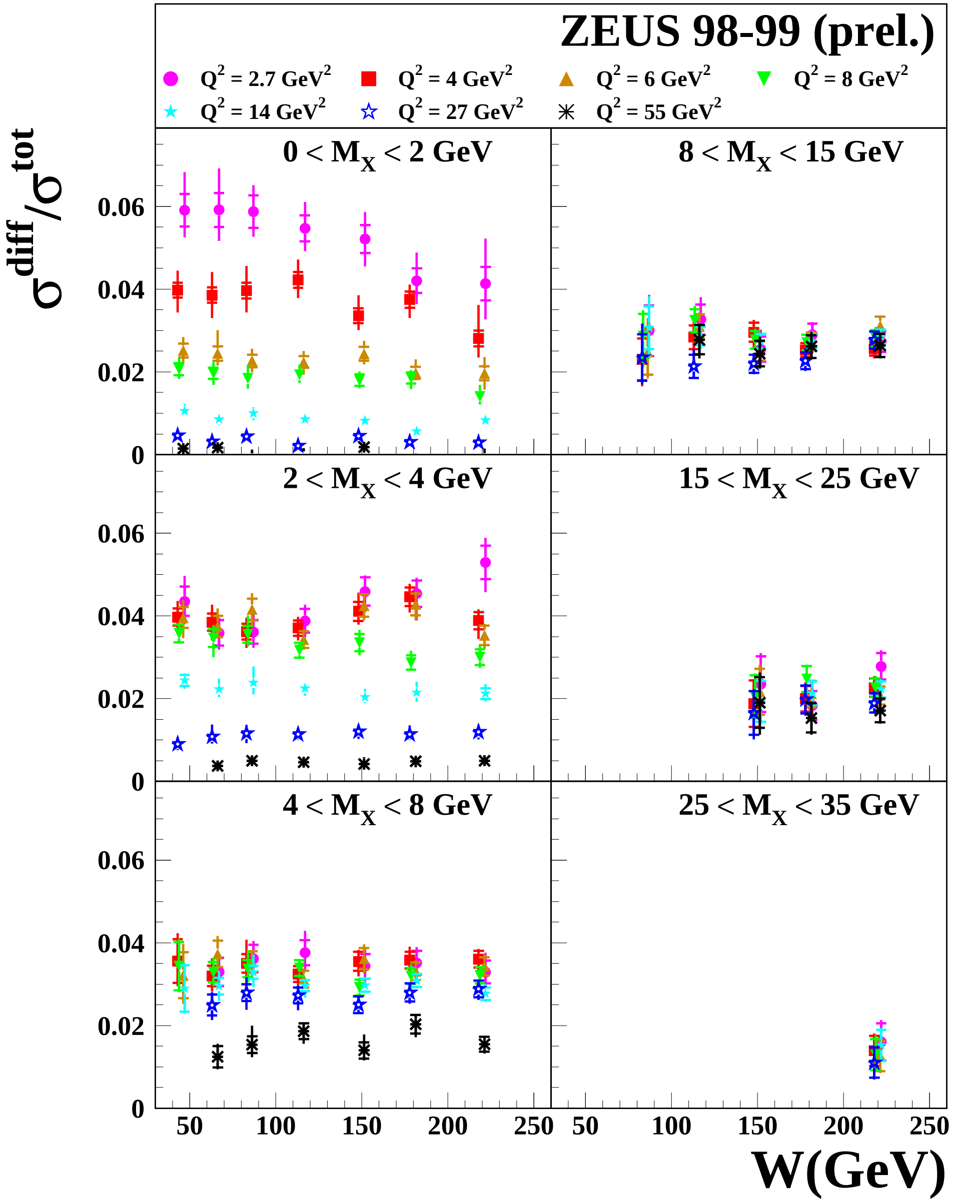
Q^2 dependence displays strong scaling violations with positive $\partial\sigma_r^D/\partial \ln Q^2$ up to high β





Not like a "normal" hadron

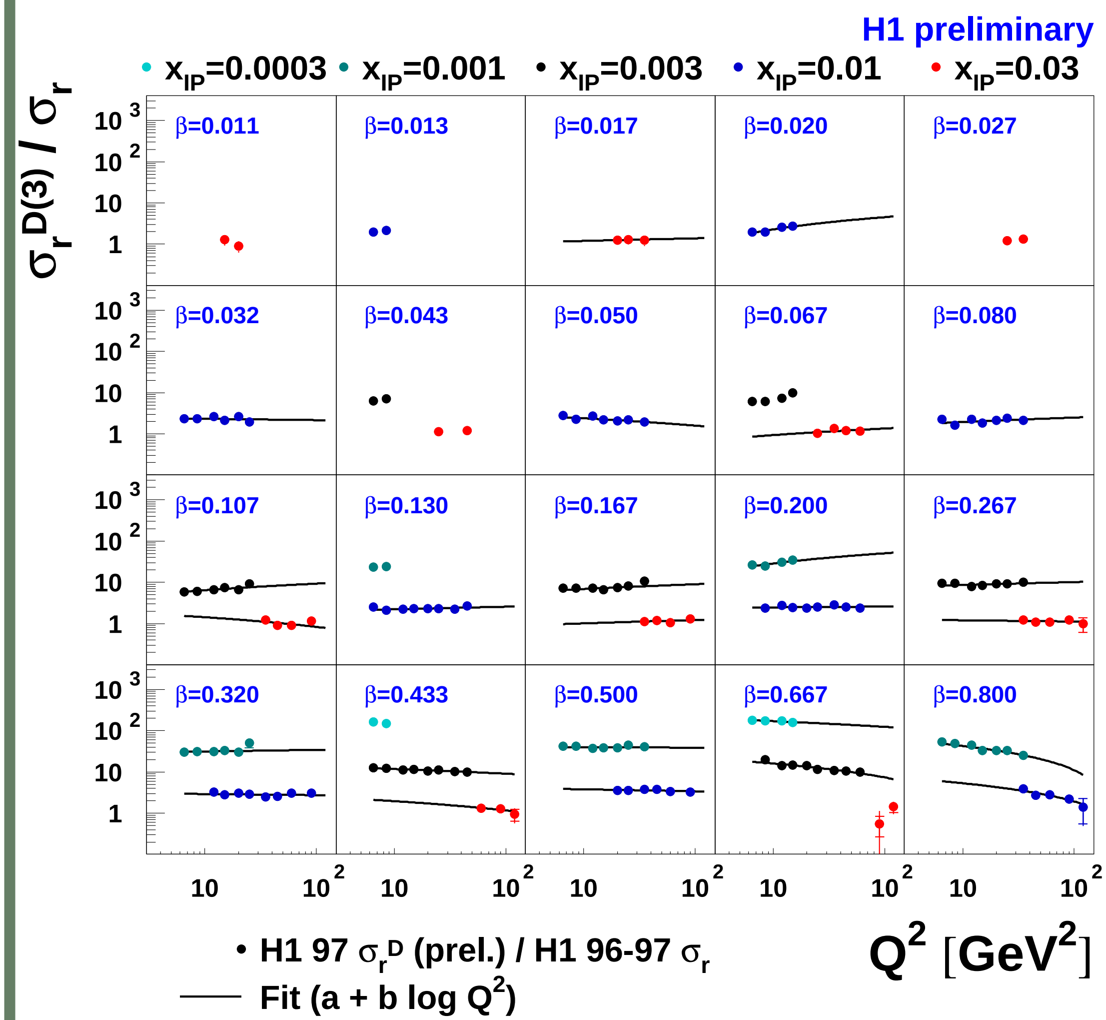
Ratio of Diffractive to inclusive cross-sections

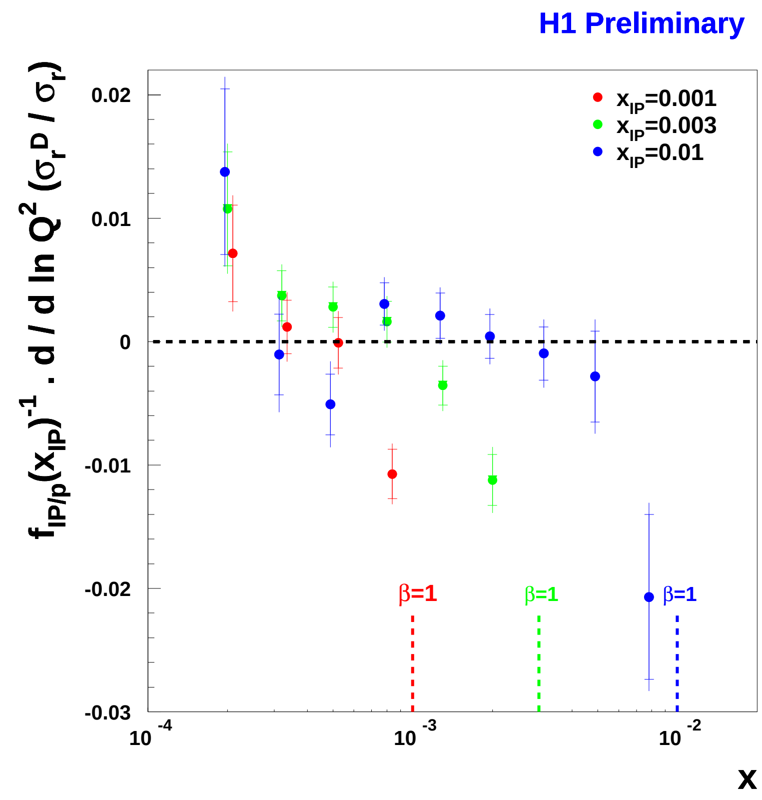


$W^2 \simeq Q^2/x$ $\beta \simeq Q^2/(Q^2 + M_X^2)$

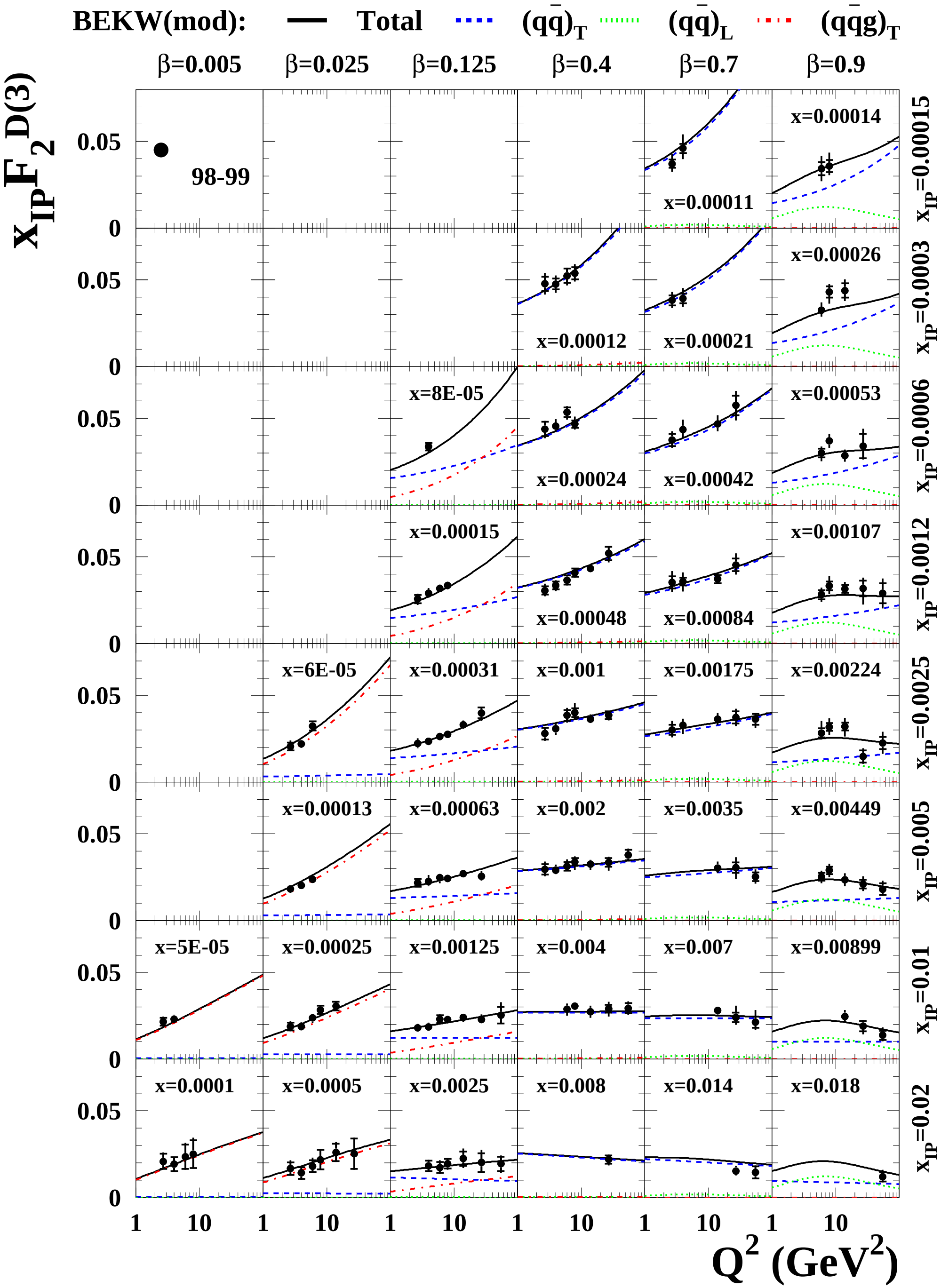
- For $M_X > 2$ GeV: flat in W
  - → same W dependence as σ_{tot}
  - → Not consistent with naive 2 gluon exchange:
    $$R = \frac{|x\ g(x,Q^2)|^2}{x\ g(x,Q^2)} = x\ g(x,Q^2)$$
- $M_X > 8$ GeV: no Q^2 dependence
  - → same DGLAP evolution
  - → γ^* sees: 1 gluon that can radiate
- If $M_X \searrow, \beta \nearrow$ → 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

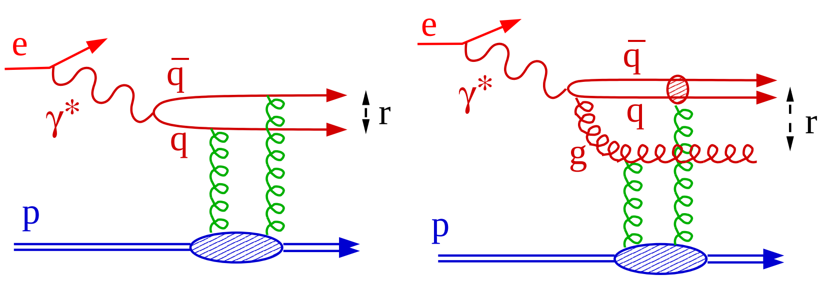
Ratio of Diffractive to inclusive cross-sections





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

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

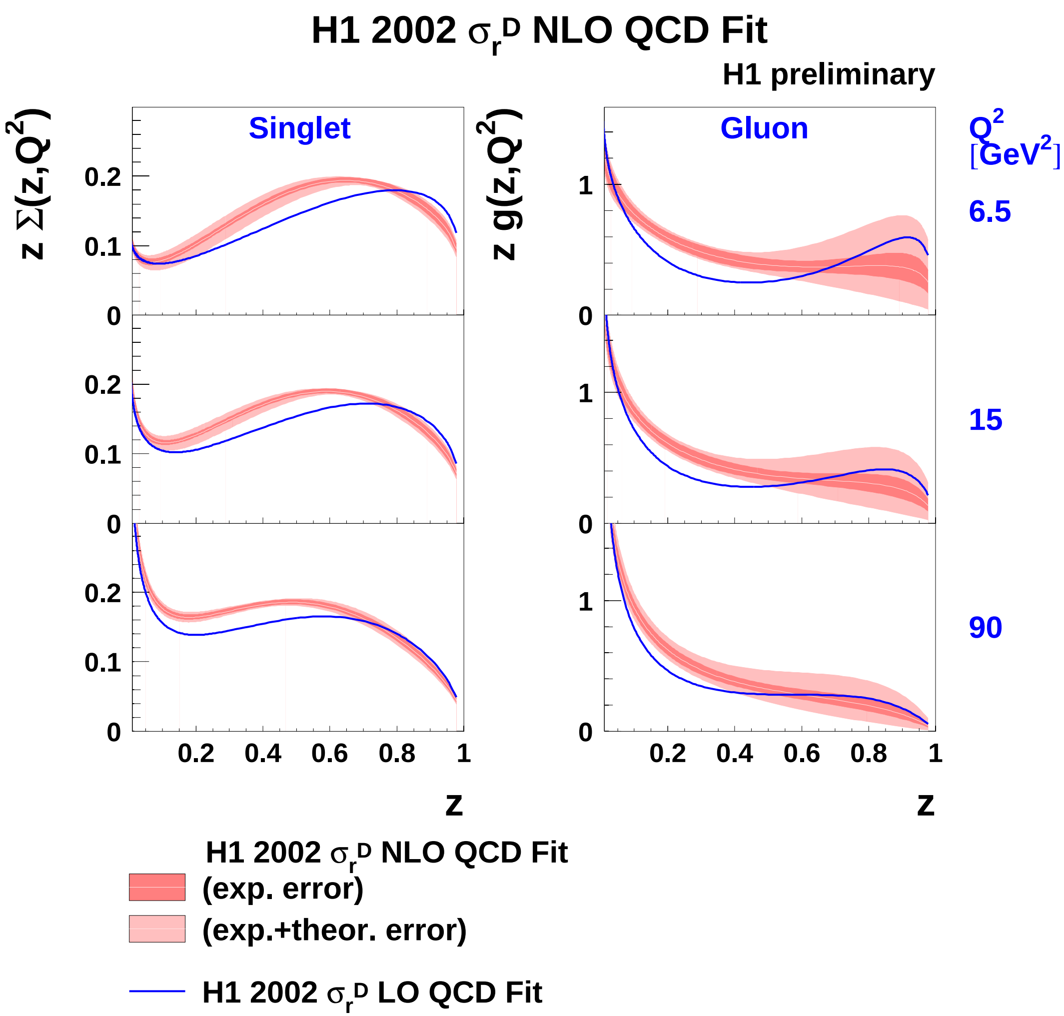
- parametrised at $Q_0^2=3\ \mathrm{GeV}^2$
- Fit data for $Q^2\geq 6.5\ \mathrm{GeV}^2$, $M_X>2$ GeV

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

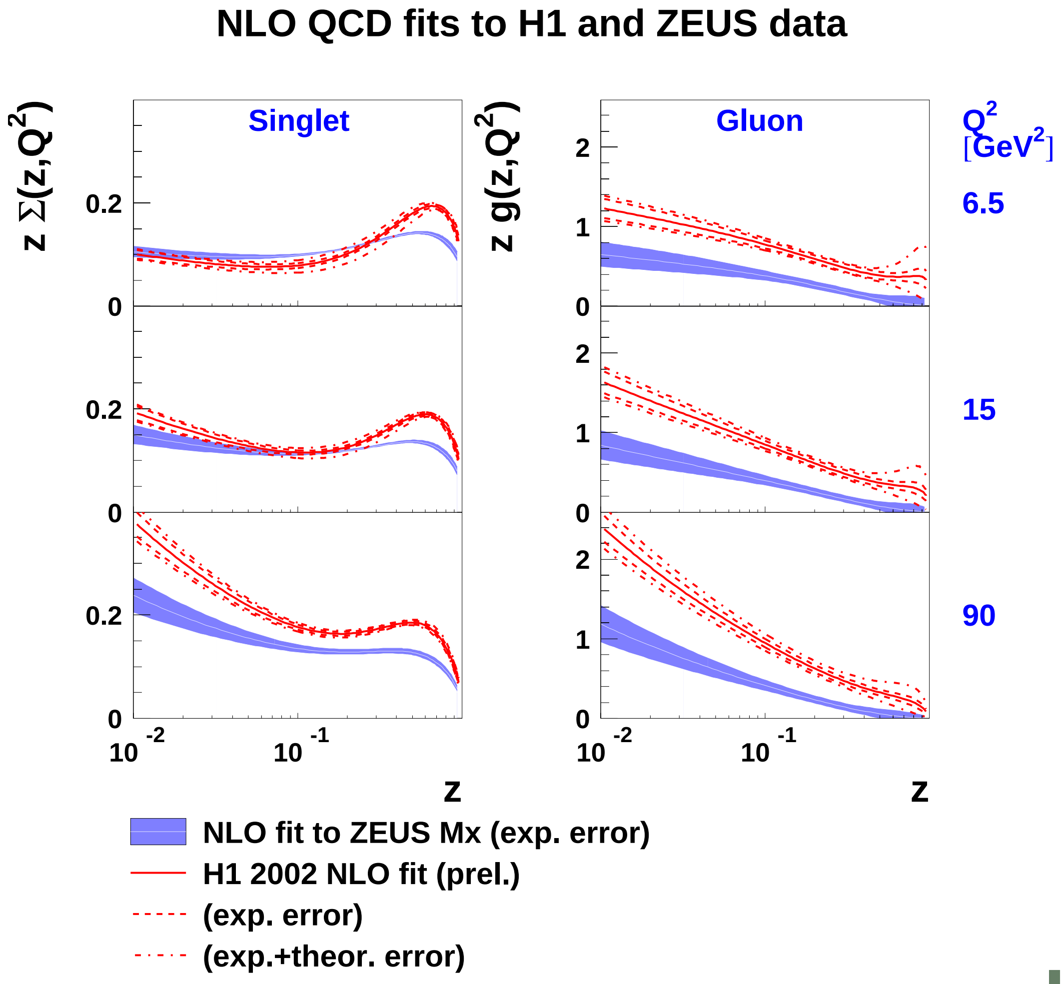
same Fit procedure applied

- results of the HERA-LHC Workshop

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

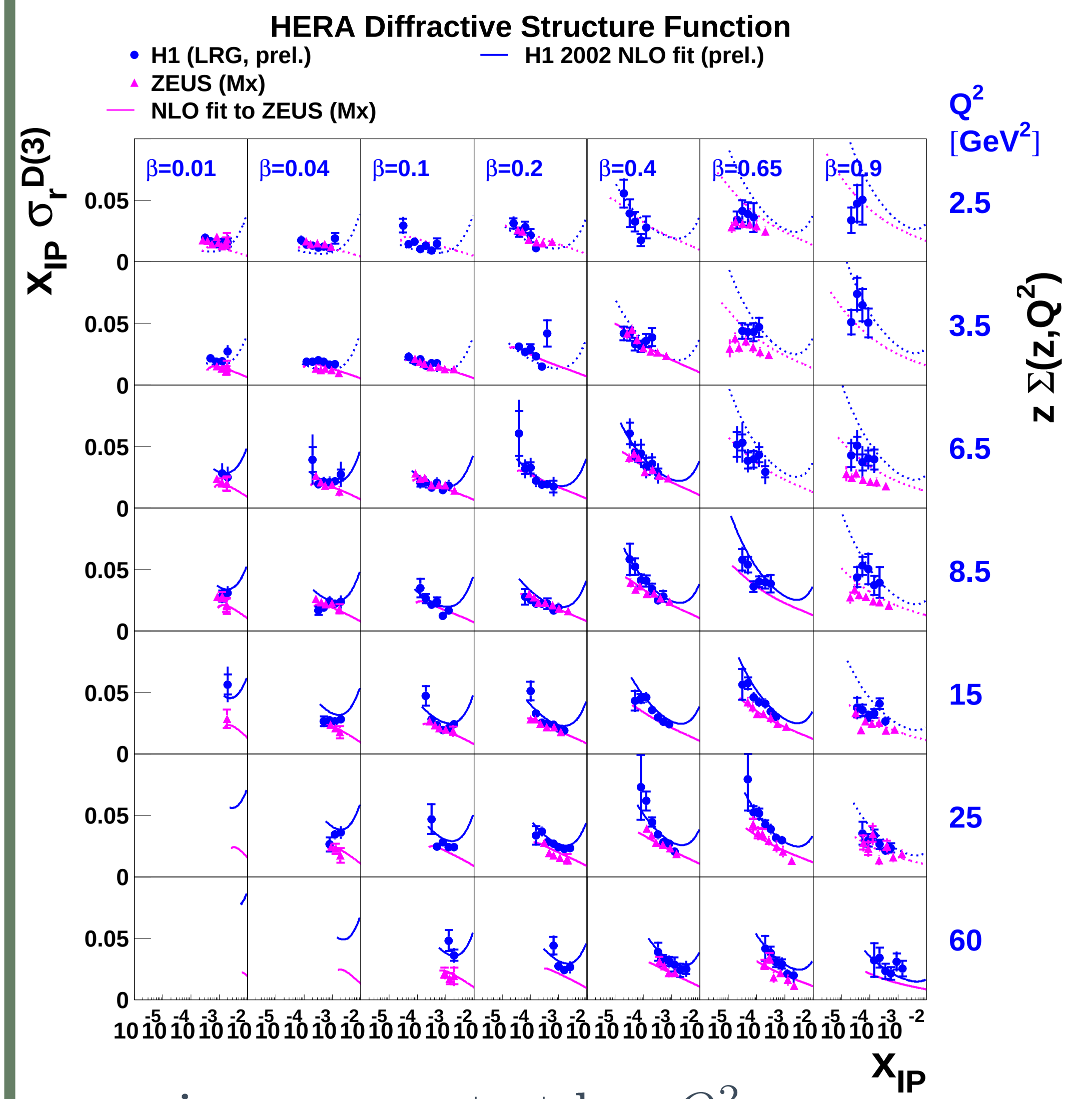
$\chi^2/ndf = 90/131$

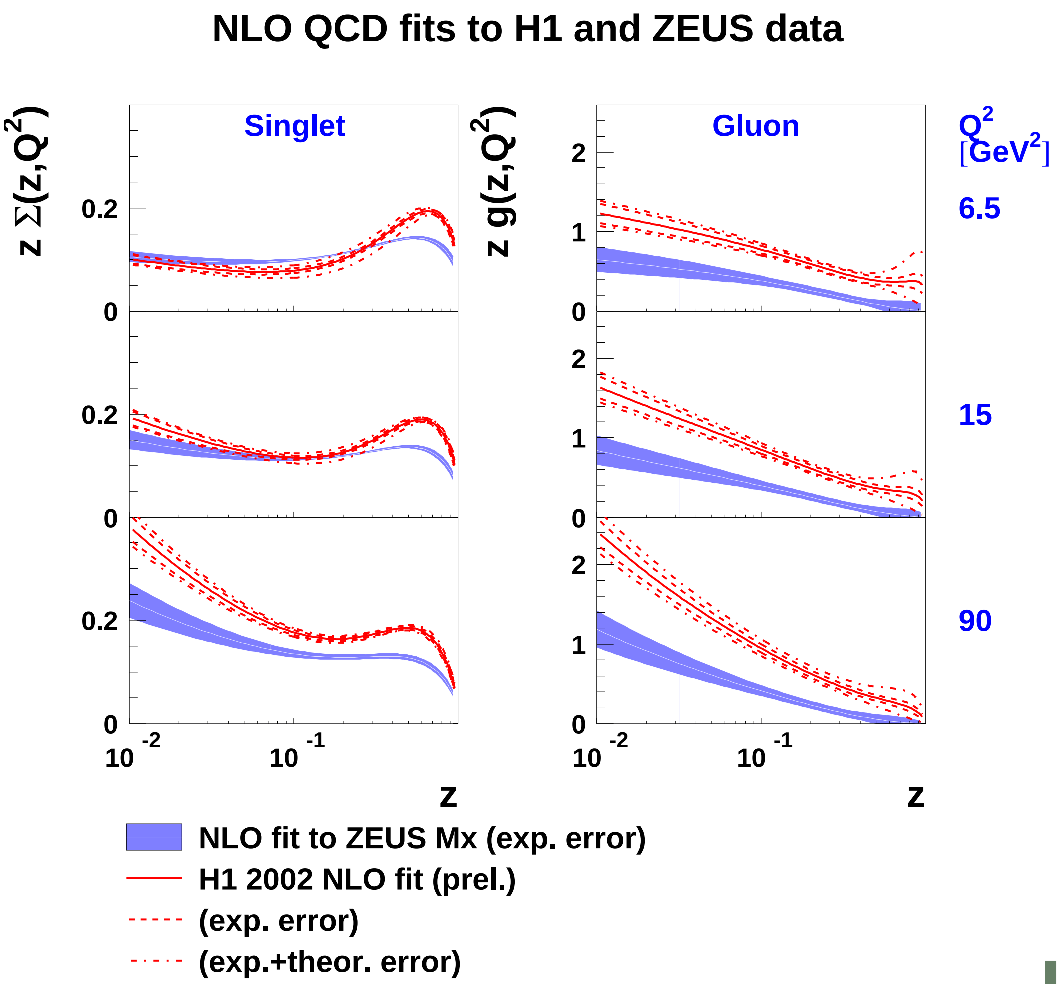
$\alpha_{I\!P}(0) = 1.132 \pm 0.006$



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

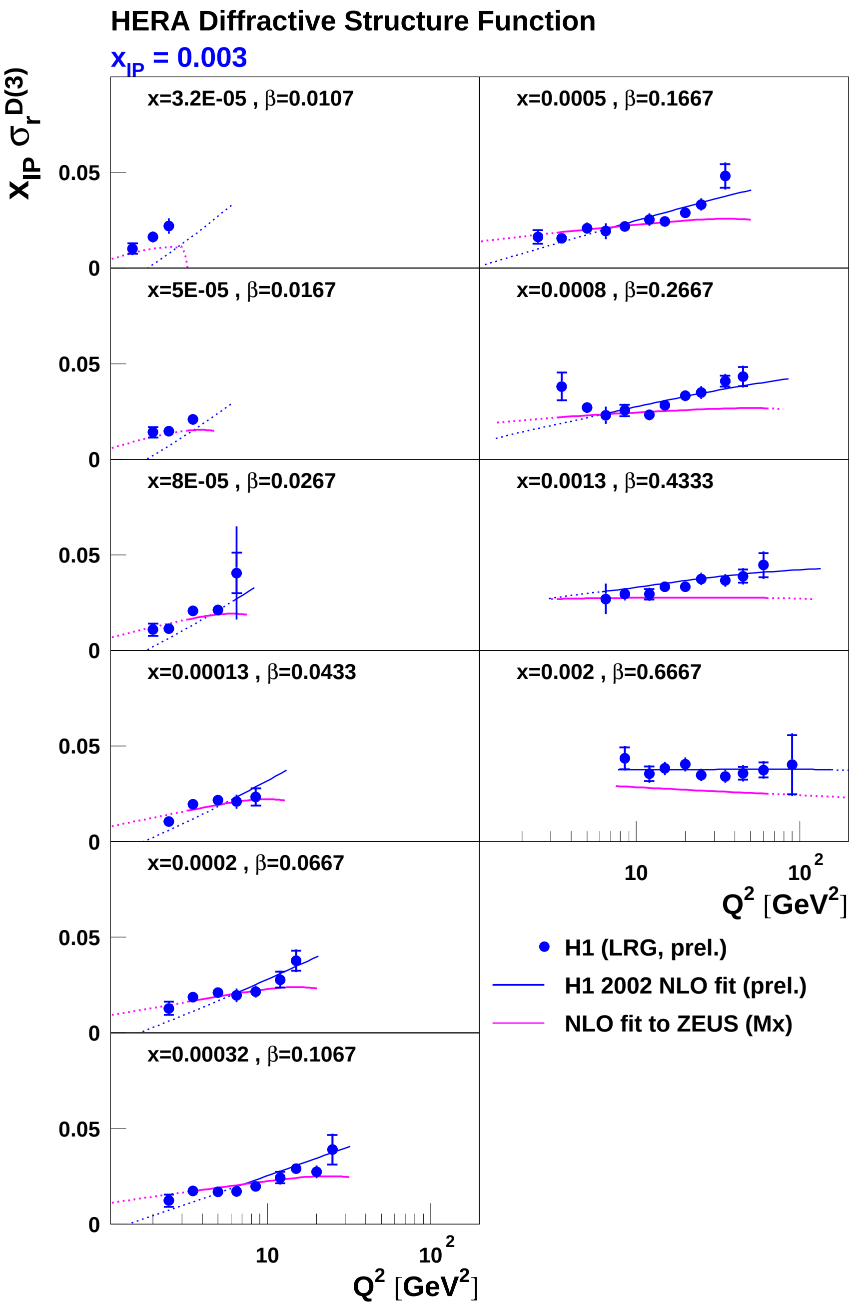
NLO QCD fit: ZEUS Measurement

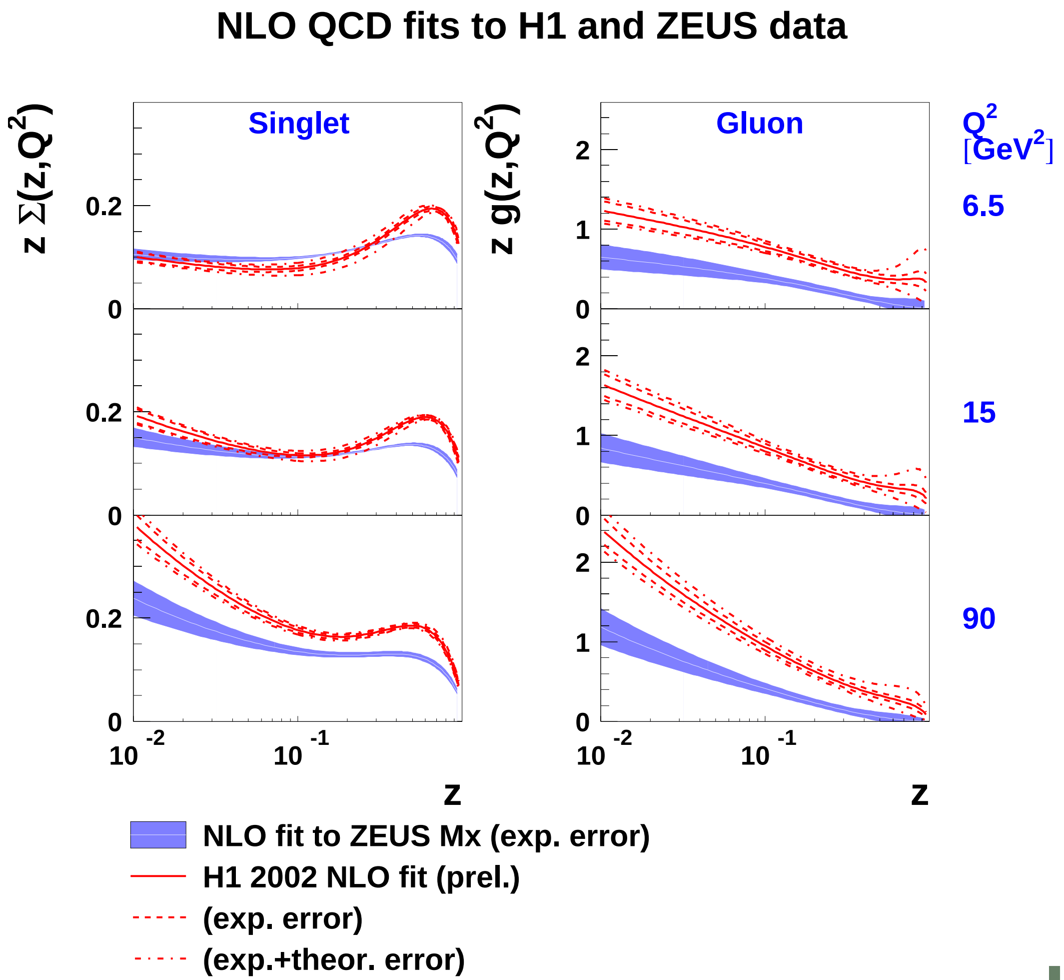




- in agreement at low Q^2
- difference H1-ZEUS at larger Q^2

NLO QCD fit: ZEUS Measurement

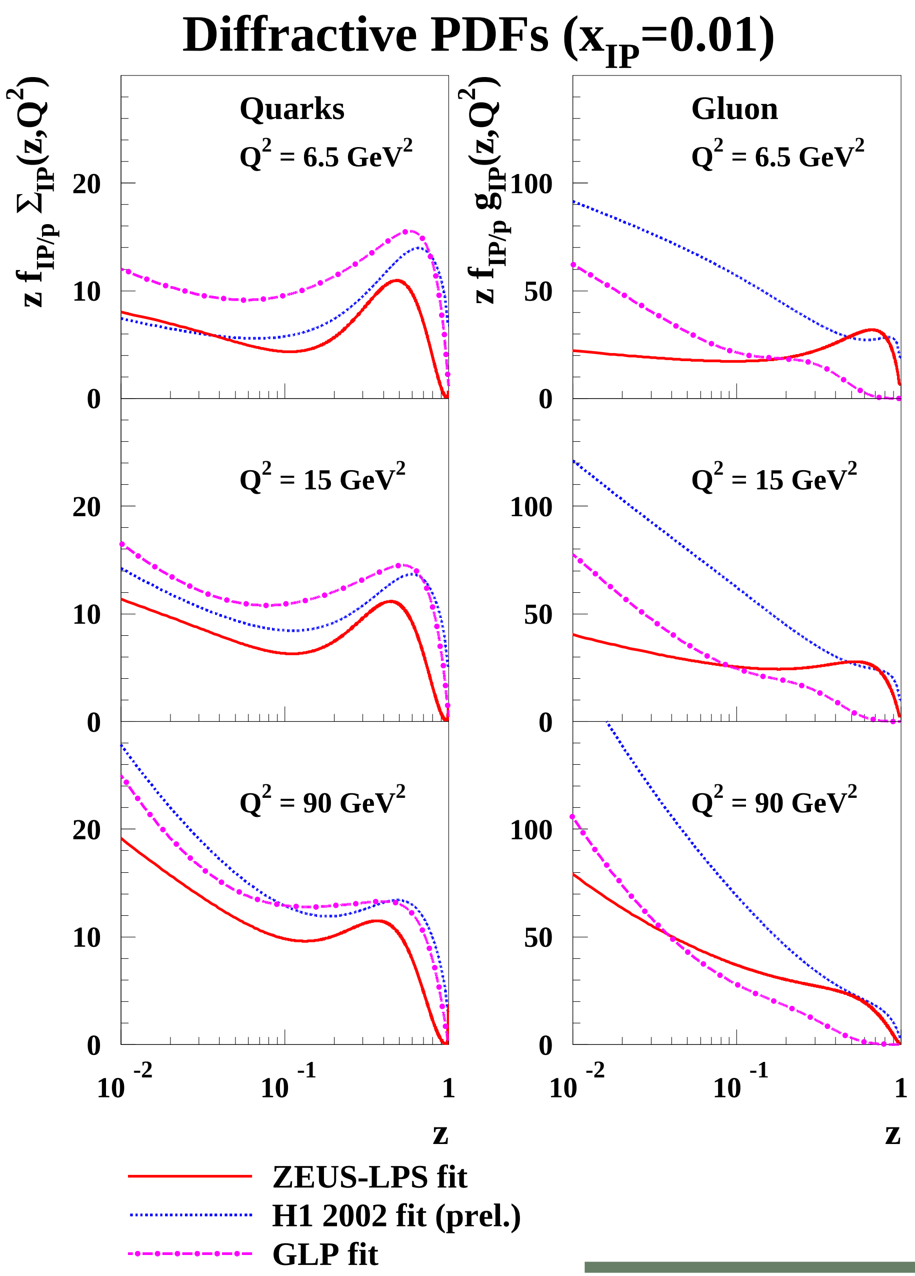




More NLO QCD fits

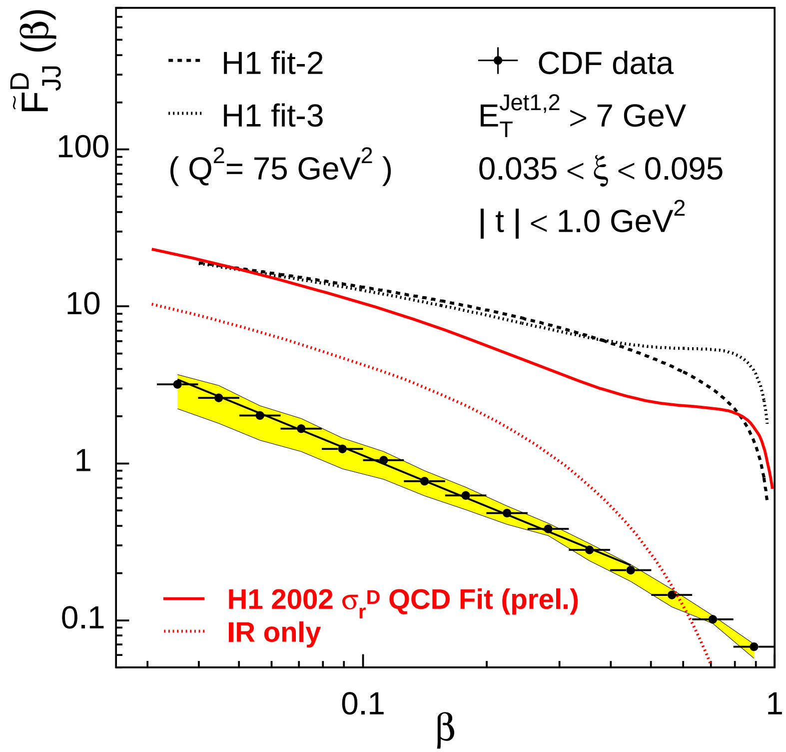
- ZEUS-LPS
  fitting LPS data and Diffractive charm
- GLP : Groys, Levy and Proskuryakov
- MRW: Martin, Ryskin, Watt
  (icluding inhomogeneous terms, direct sea contrib,...)
  → see Graeme Watt talk.
- ...

→ quite unclear situation



Factorisation breaking at the Tevatron

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



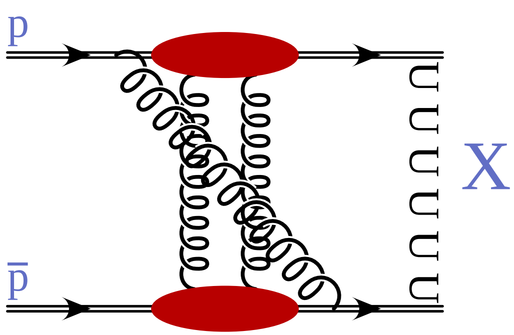
• The prediction based on diffractive PDF's extracted at HERA are one order of magnitude above the measures cross section!

• 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...



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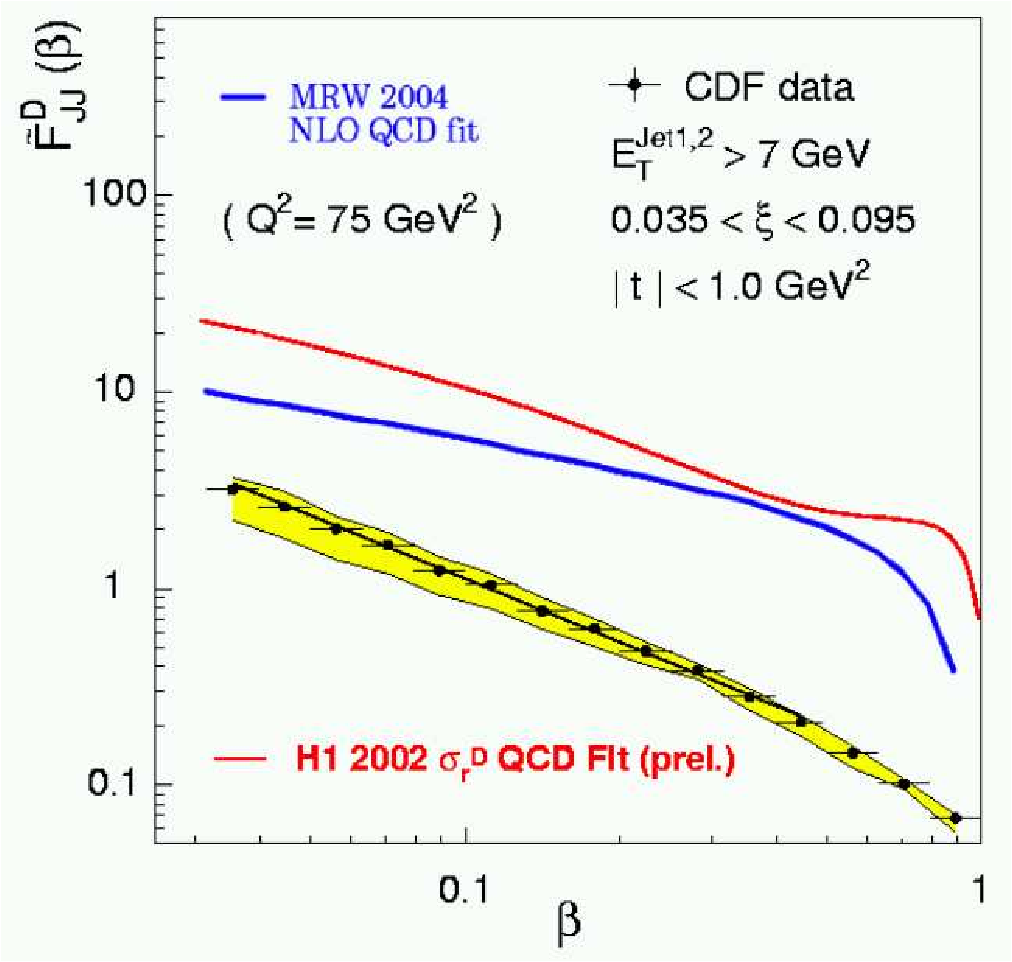
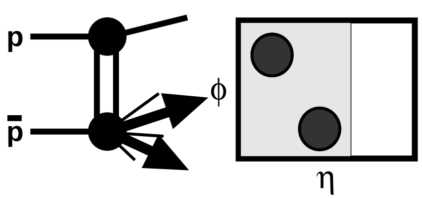
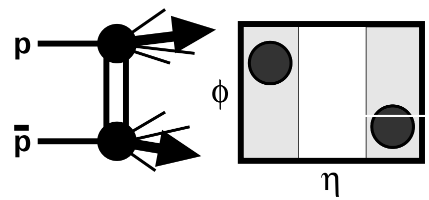


- does not change the conclusion with other DPDF

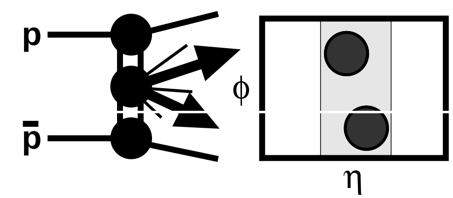
Factorisation breaking at the Tevatron



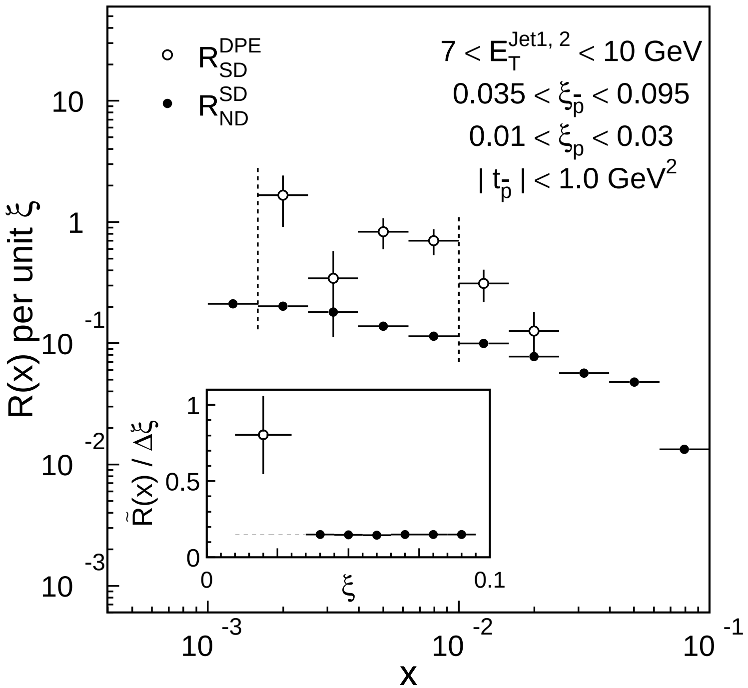
Single Diffraction

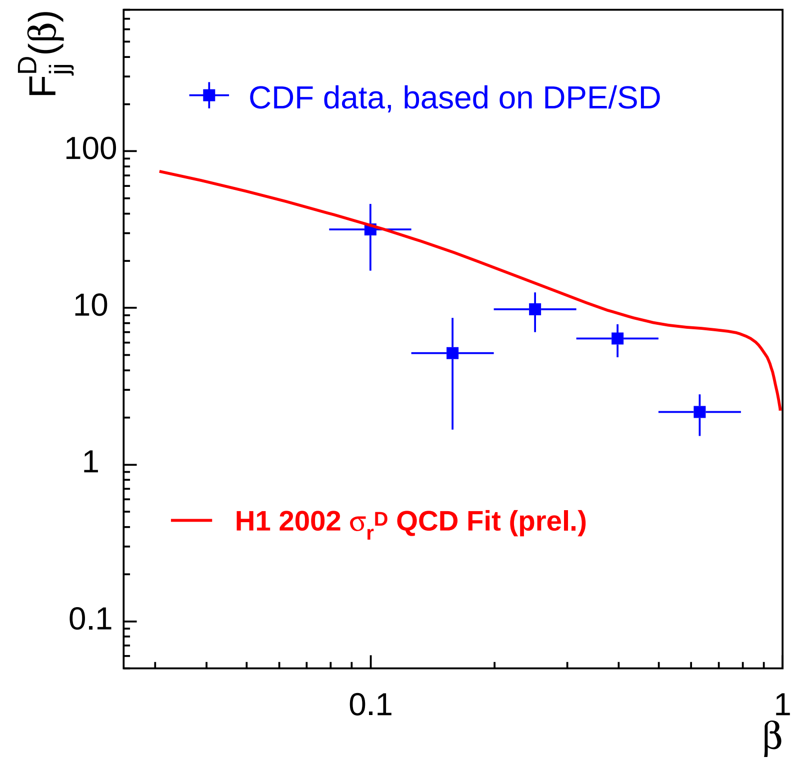


Double Diffraction



Double Pomeron Exchange





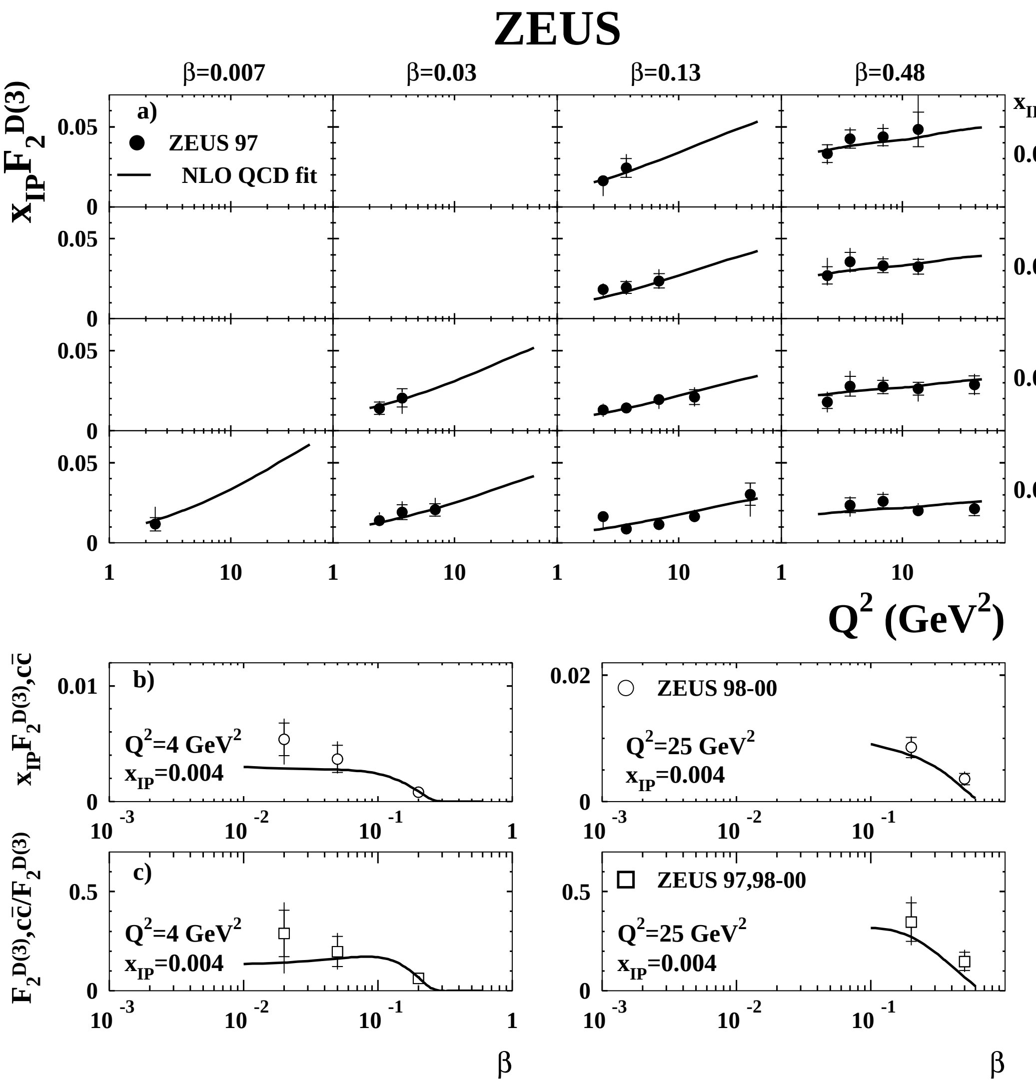
CDF measurement of R_{ND}^{SD} and R_{SD}^{DPE}

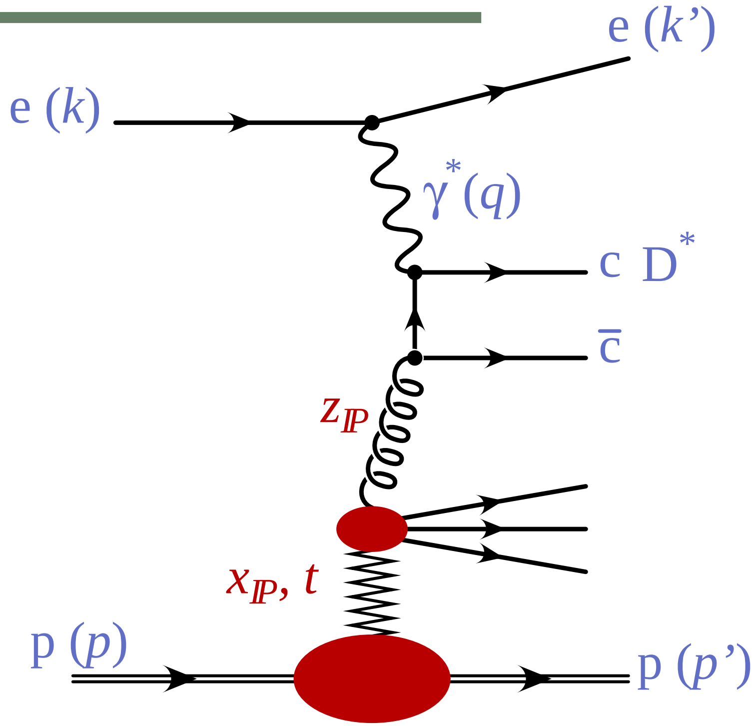
$$R_{ND}^{SD}/R_{SD}^{DPE} = 0.19 \pm 0.07$$

Second gap formation unsuppressed

DPE compatible with expectation from H1 PDFs

Test of QCD factorisation: Charm



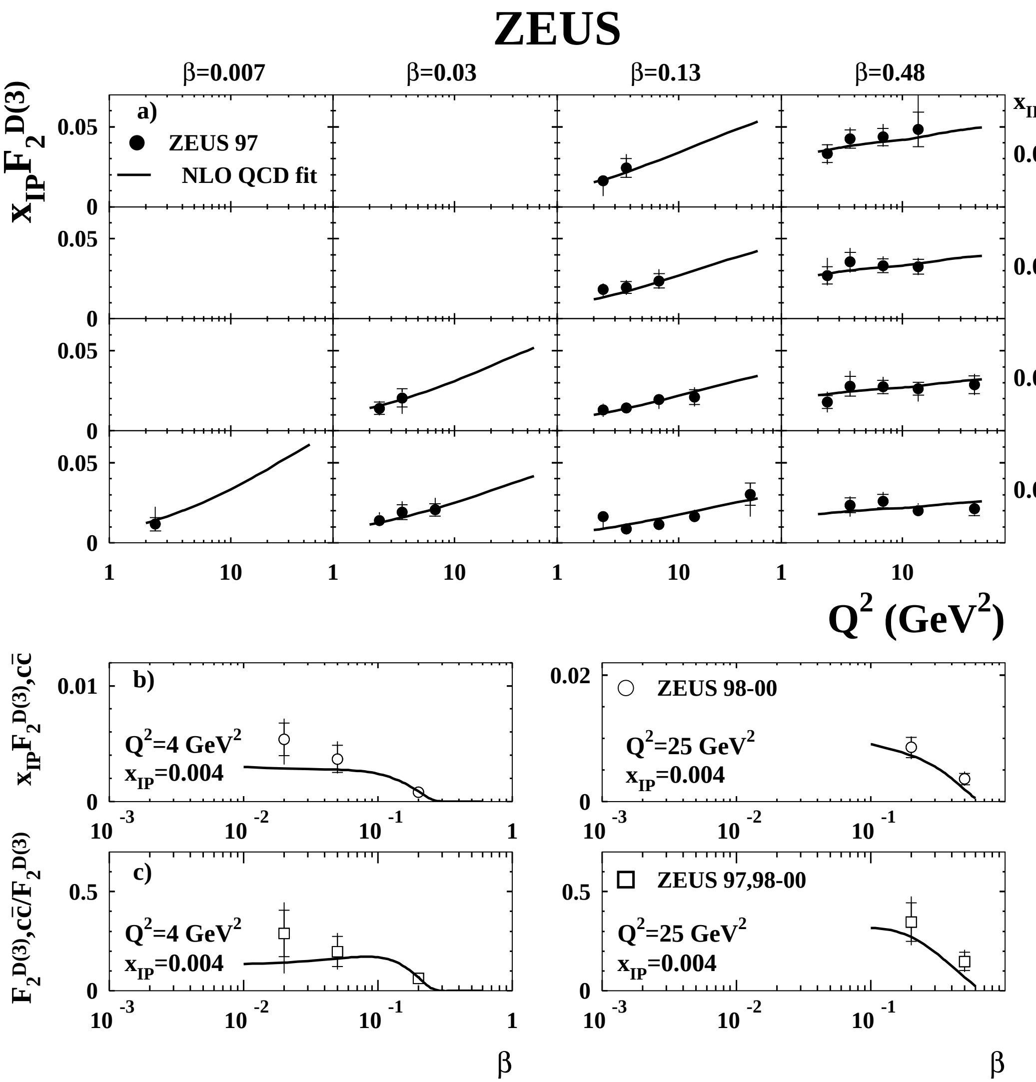


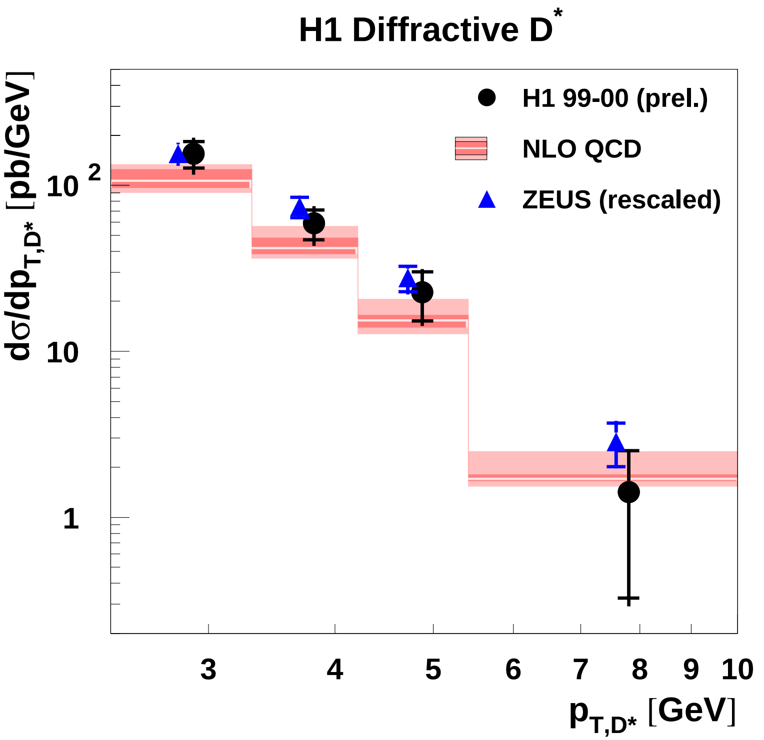
- Data using tagged leading proton
- NLO QCD fit

→ 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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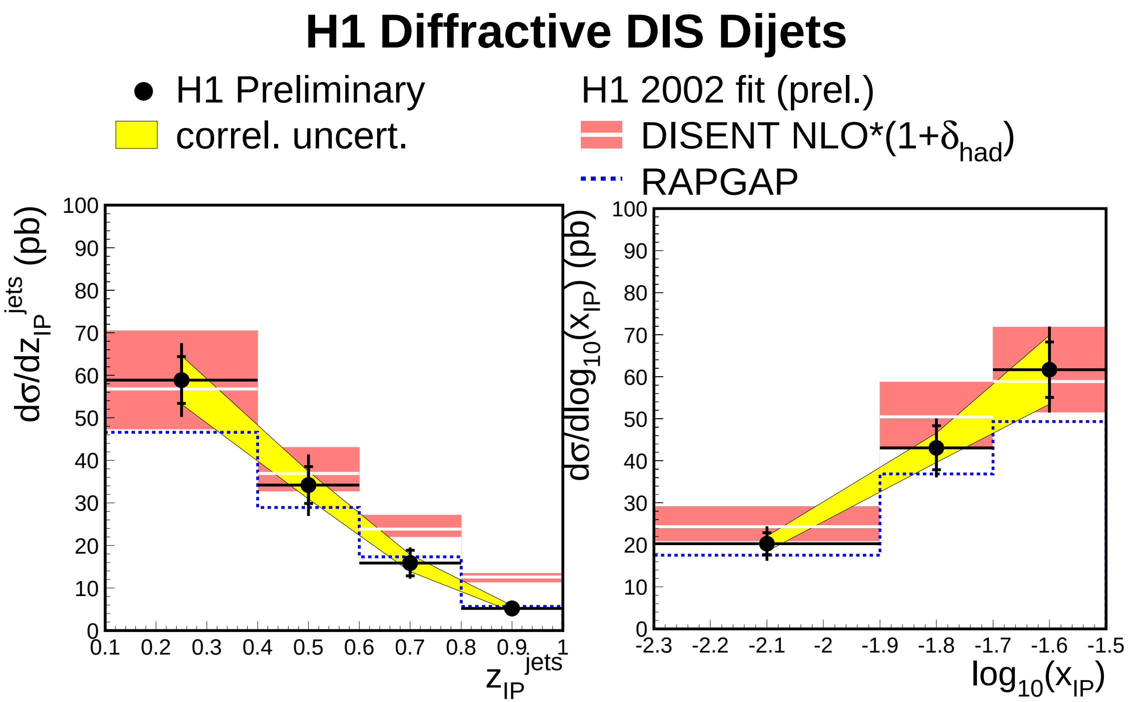
→ charm prediction

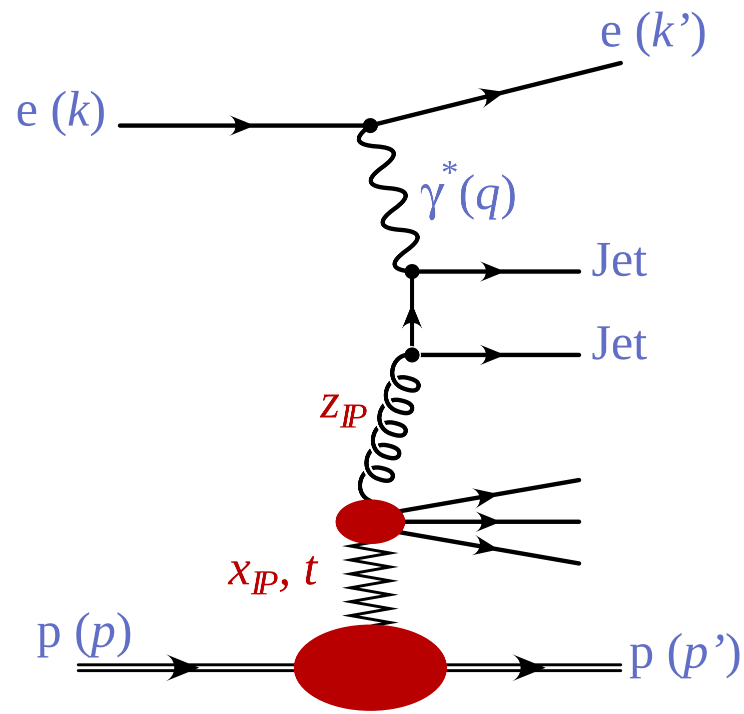
→ QCD factorization works for Charm in Diffraction with $Q^2 > 4$ GeV^2

Test of QCD factorisation: Dijet

Use diff PDFs to predict Dijet production



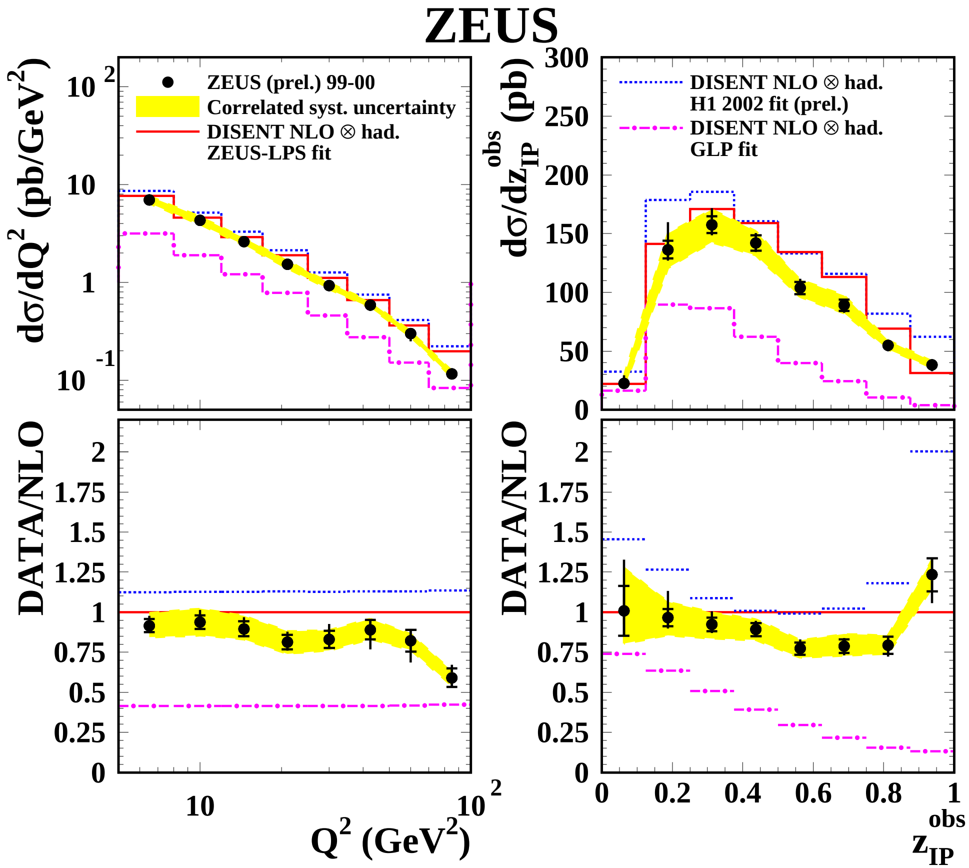
(a) (b)

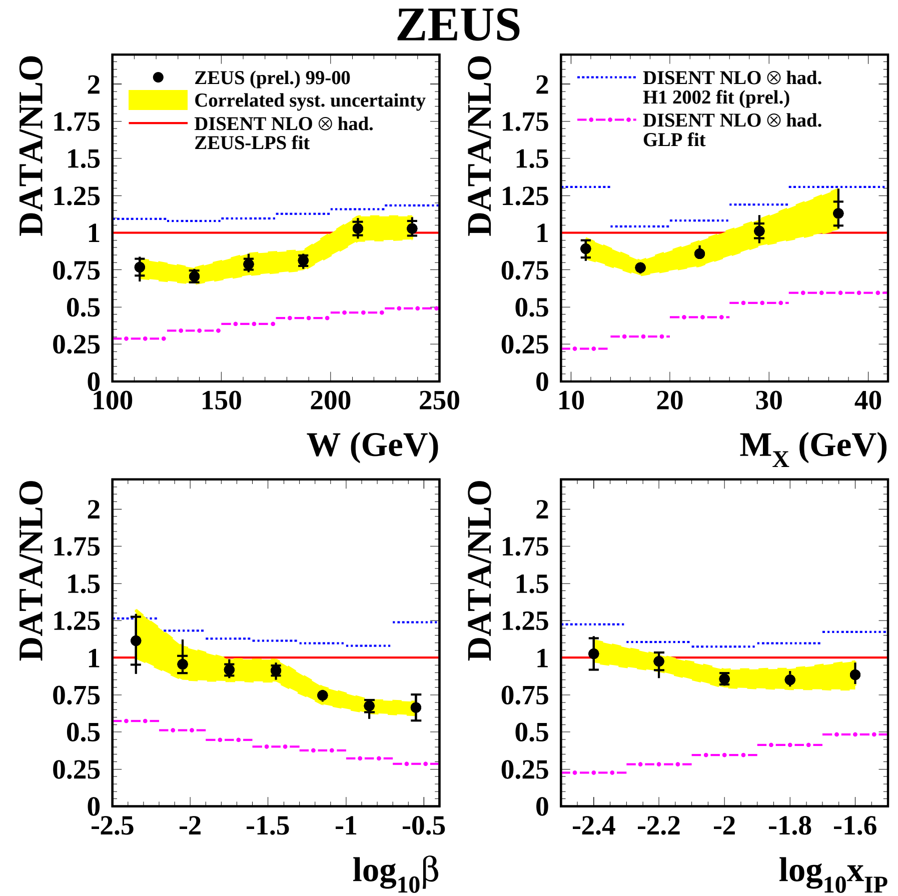


- $Q^2 > 4\ \mathrm{GeV}^2$, $P_T^{jet1(2)} > 5(4)\ \mathrm{GeV}$
- Normalisation and shape OK.

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

Test of QCD factorisation: ZEUS Dijet



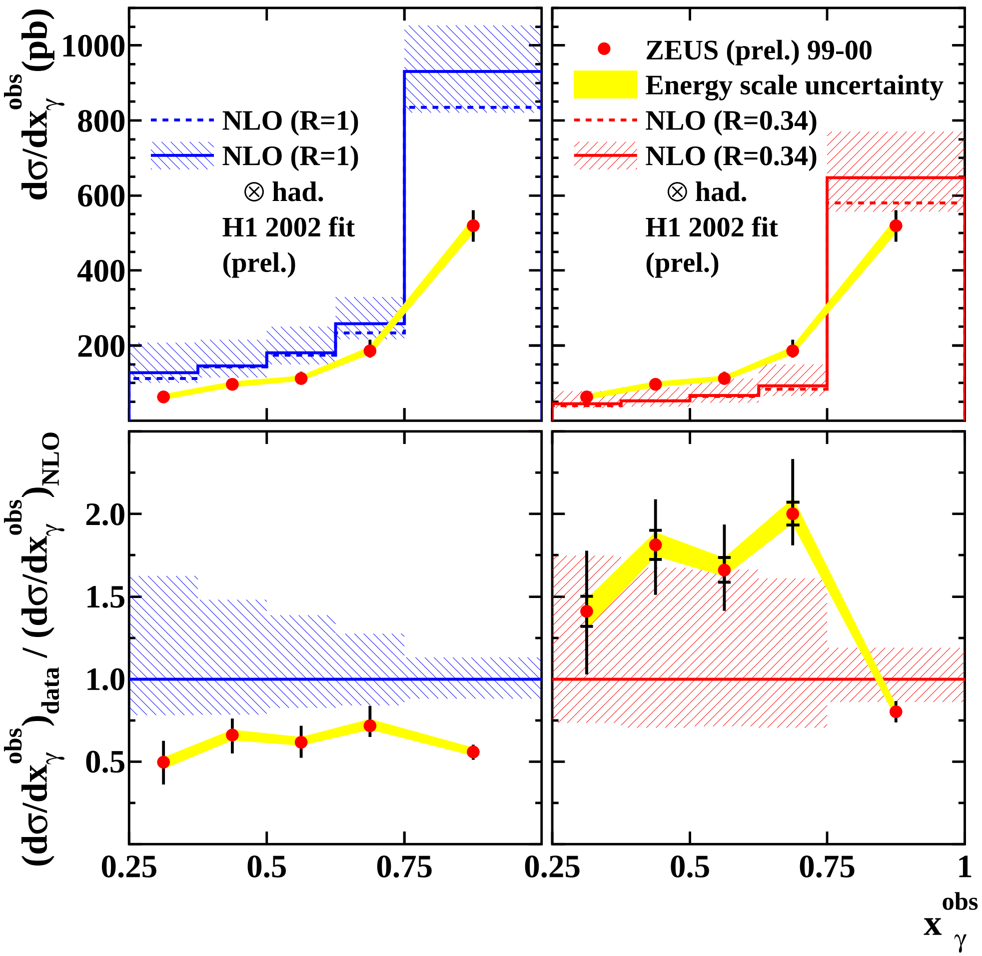


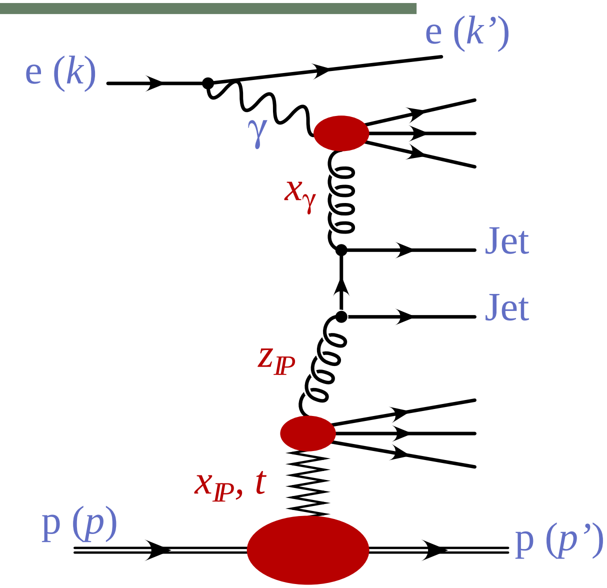
ZEUS concludes: "...differences between PDF predictions may be interpreted as an estimate of the uncertainty..."

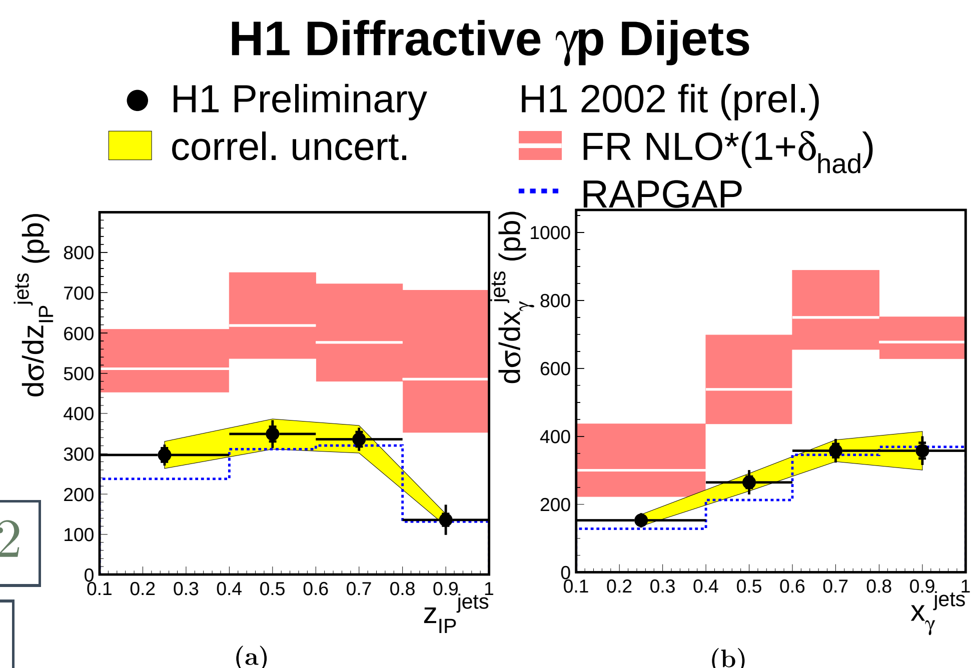
"A better understanding of the PDFs and their uncertainties is required before a firm statement about the validity of the QCD factorisation"

HERA: Factorisation test: Dijet in Photoproduction

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



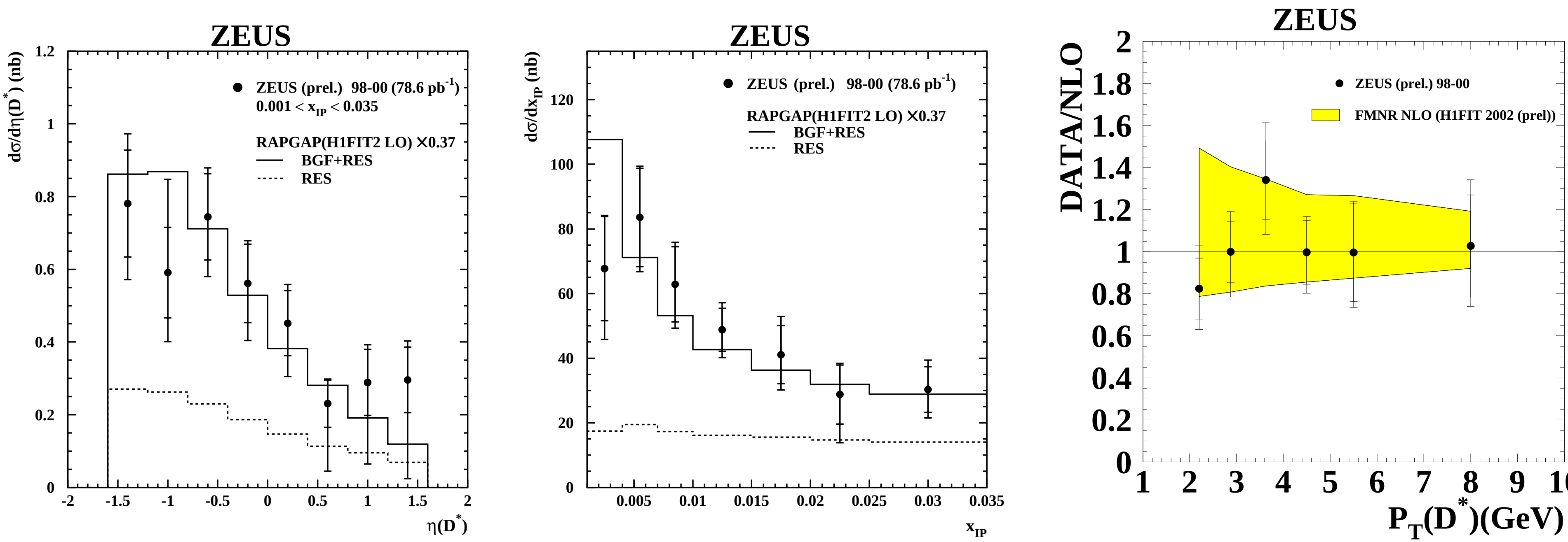




→ NLO prediction above by a factor $\simeq 2$

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

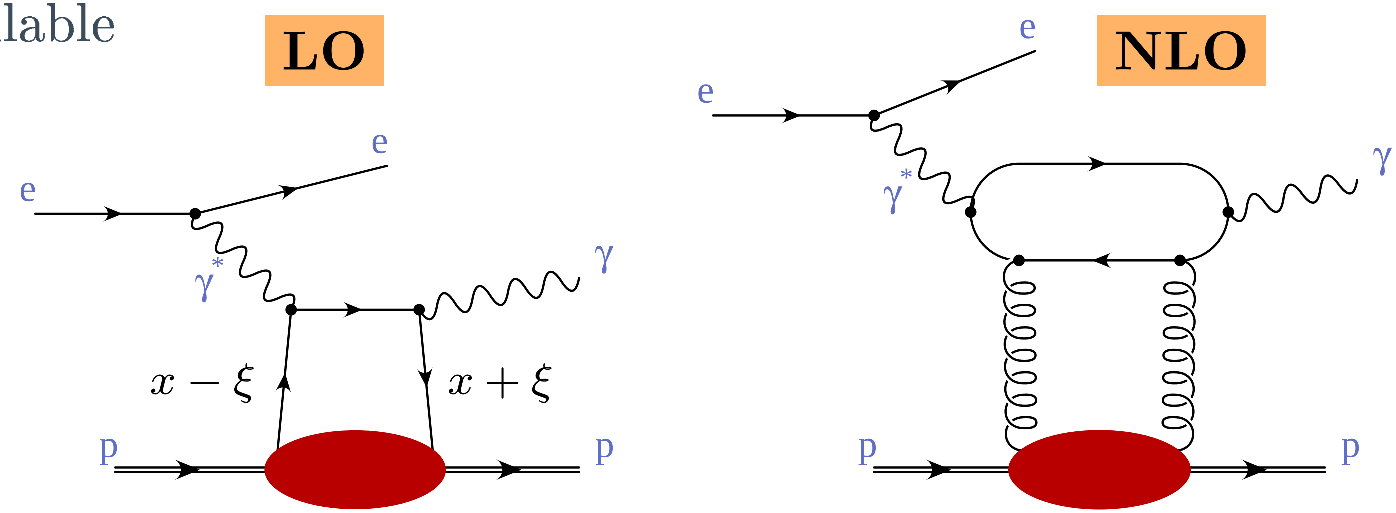
Assuming H1Fit 2002 is correct

- **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



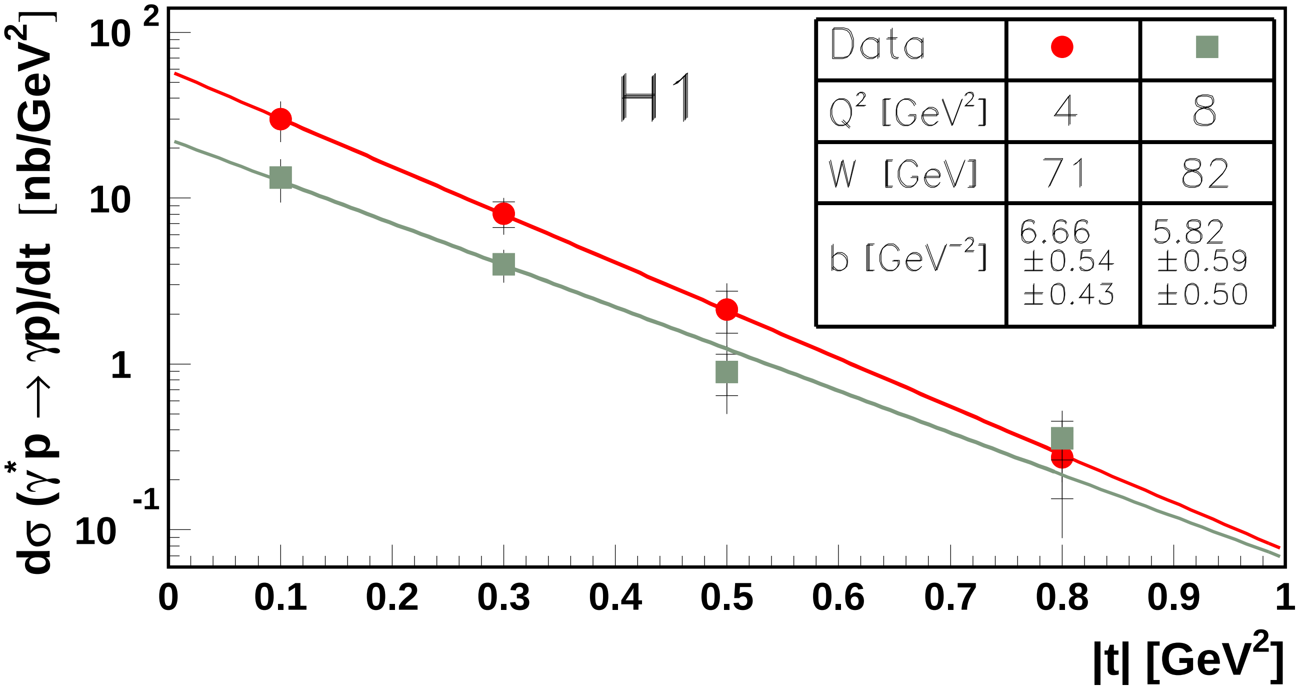
- NLO leading twist (+ twist three) calc. by A. Freund and M. McDermott Eur.Phys.J. **C23** (2002) 651. Input: GPDs

DGLAP region: $\|x\| > \xi$		ERBL region: $\|x\| < \xi$
$\mathcal{H}^q(x,\xi,t;\mu^2) = q(x;\mu^2)\, e^{-b\|t\|}$	q singlet	simple analytic function
$\mathcal{H}^g(x,\xi,t;\mu^2) = x\; g(x;\mu^2)\, e^{-b\|t\|}$	gluons	
MRST2001 and CTEQ6		

$\rightarrow Q^2$ and ξ generated dynamically

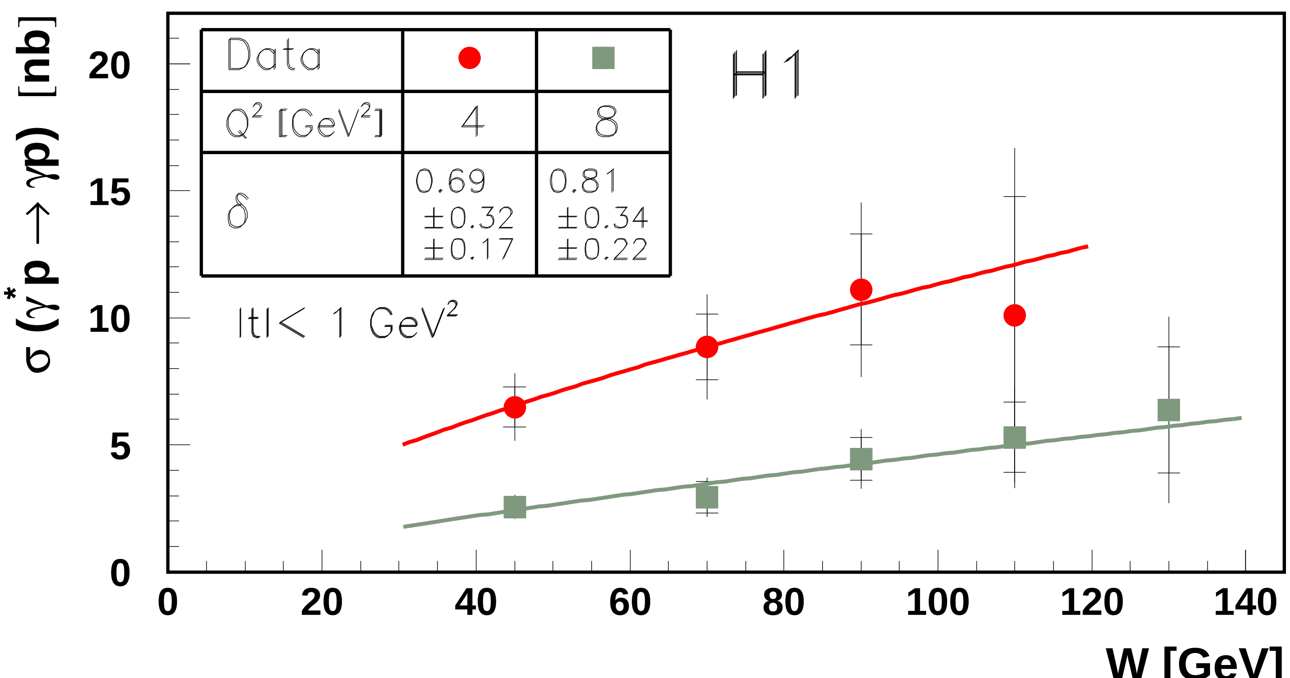
b from the data

DESY-05-065



→ First measurement of the t slope

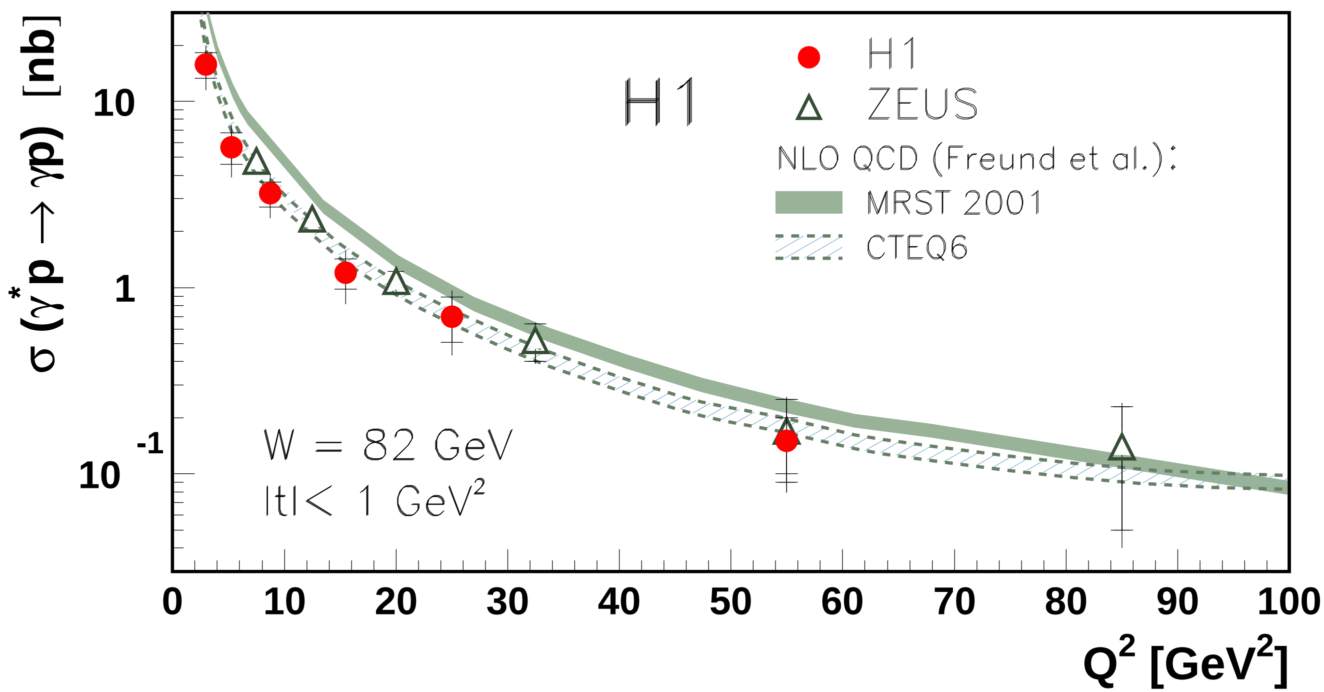
combined samples:
$b = 6.02 \pm 0.35 \pm 0.39$ GeV^{-2}

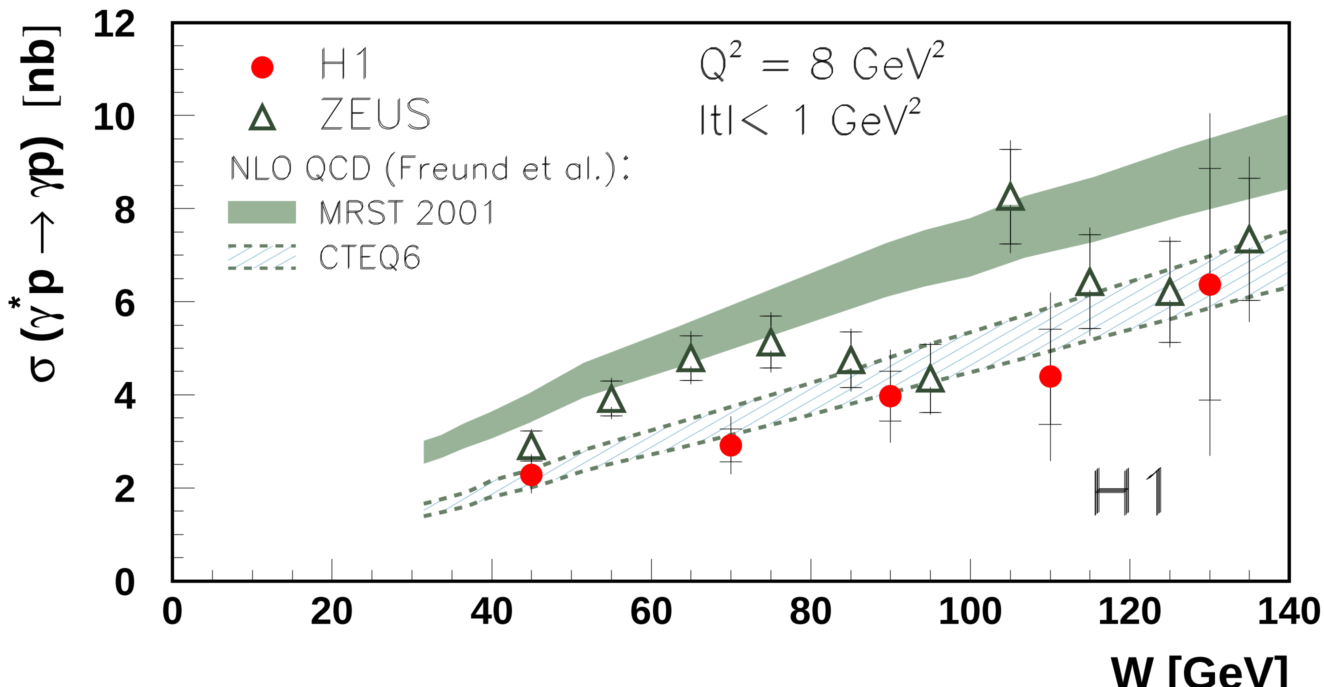


→ W dependence for two Q^2 values

→ Fit W^δ:

→ indication of a hard regime (comparable to J/Ψ)





H1-ZEUS Comparison

→ Agreement

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

→ $n = 1.54 \pm 0.09 \pm 0.04$

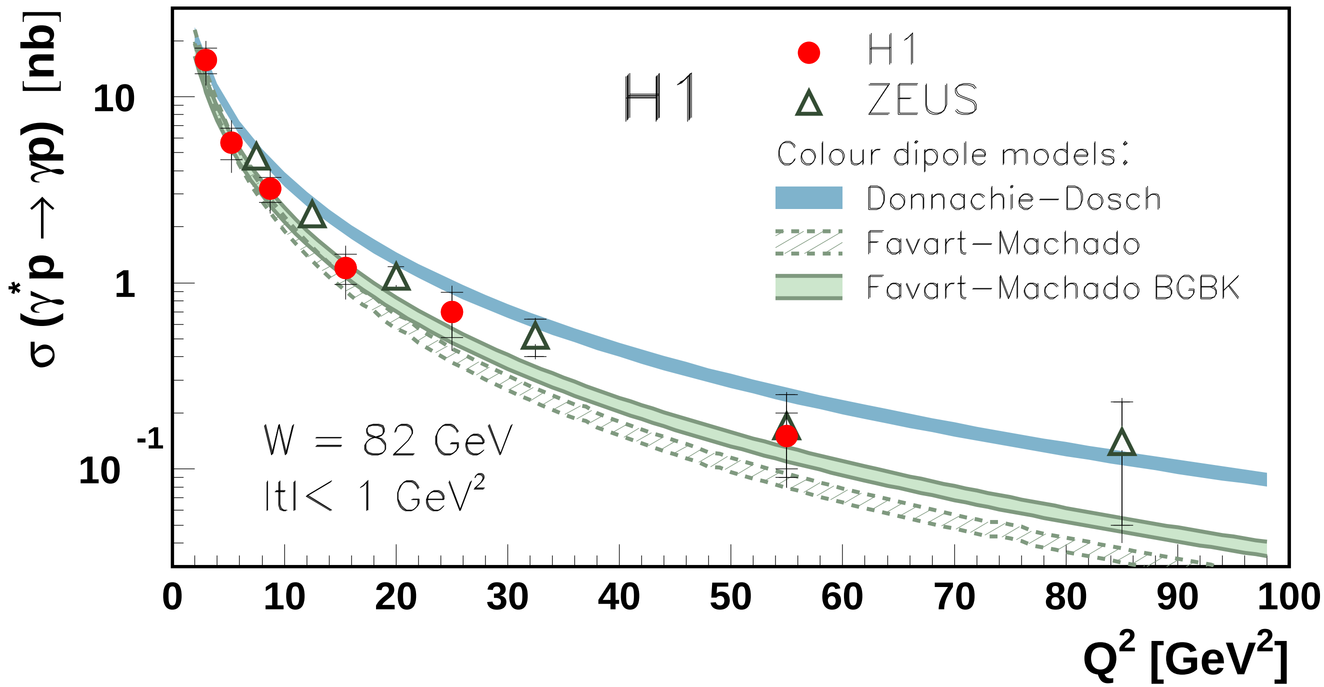
→ n smaller than for VM ($n(\rho) = 2.60 \pm 0.04$)

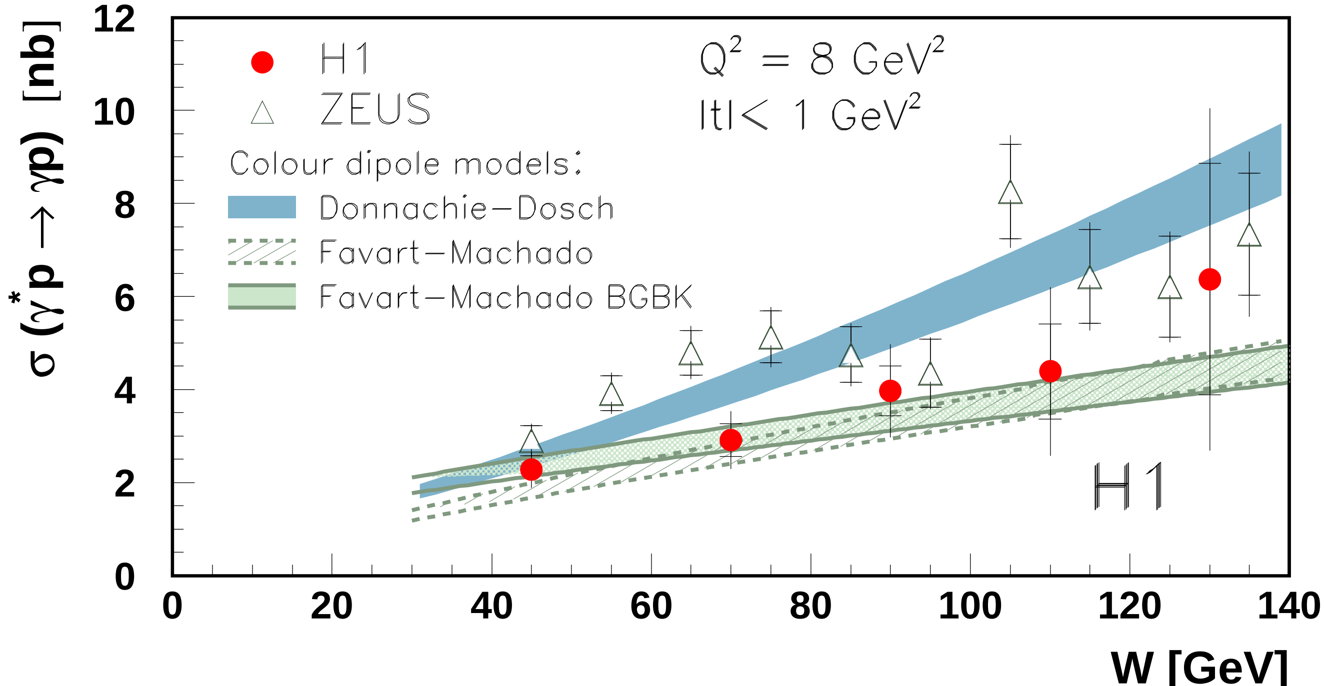
Comparison to NLO QCD:

- Band width provided by b measurement.

→Good description by QCD-NLO calculations

→No need for intrinsic skewing





Comparison to Dipole Models

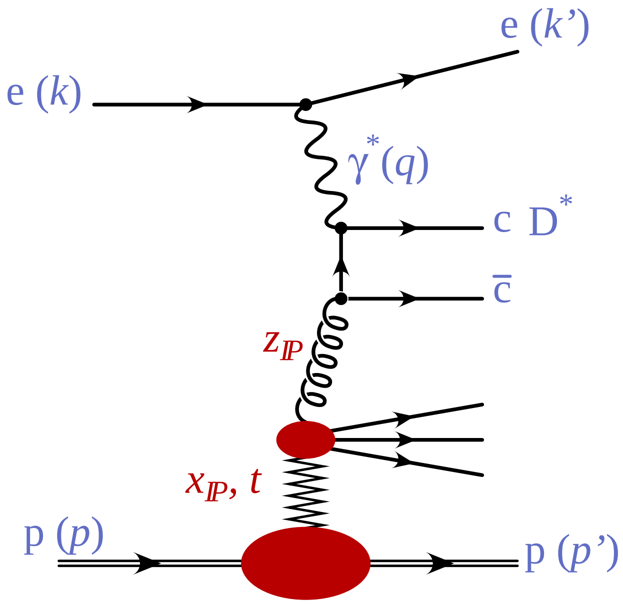
- Good normalisation and shape description

- Improvement in FM when DGLAP evol. included

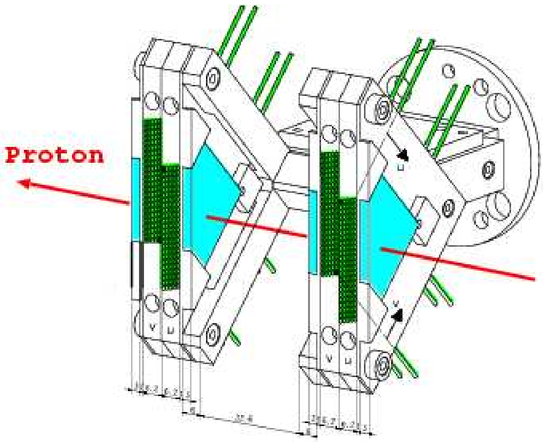
- Still improved if $b(Q^2)$ used as observed for ρ

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 $D*$

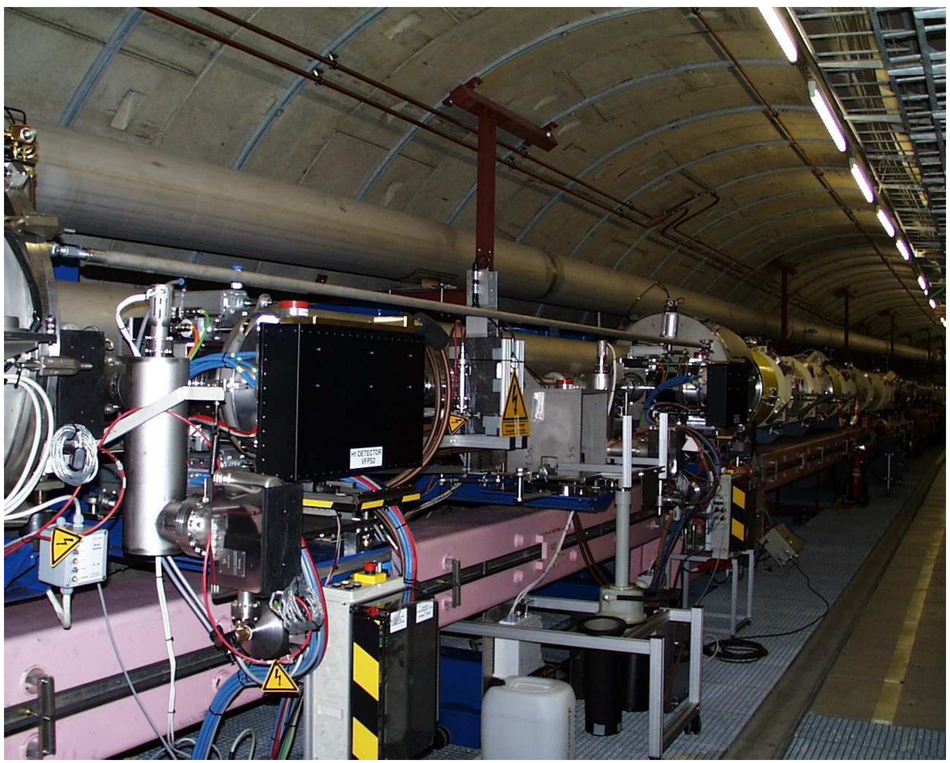


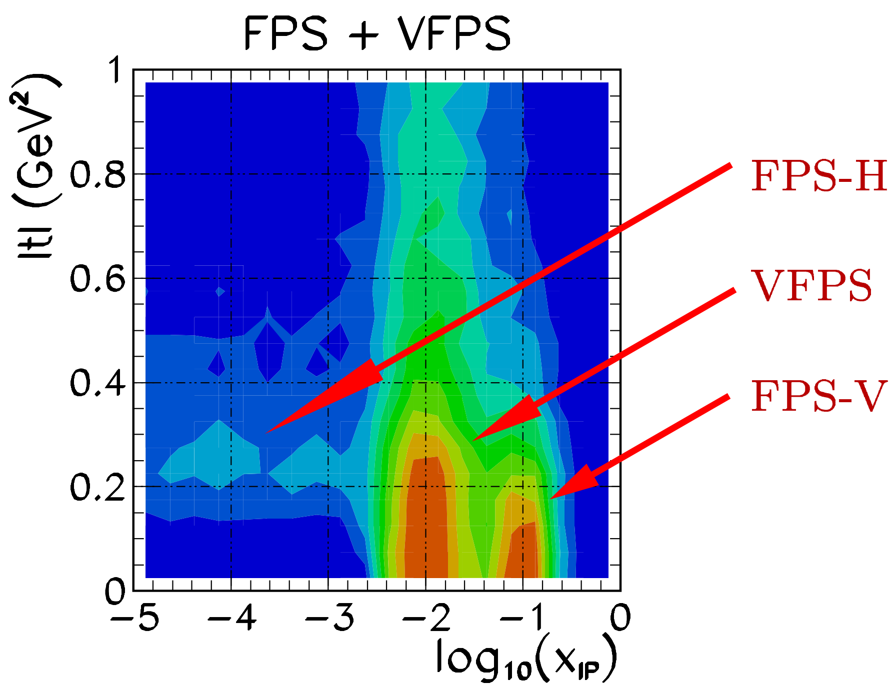
H1 at HERA II



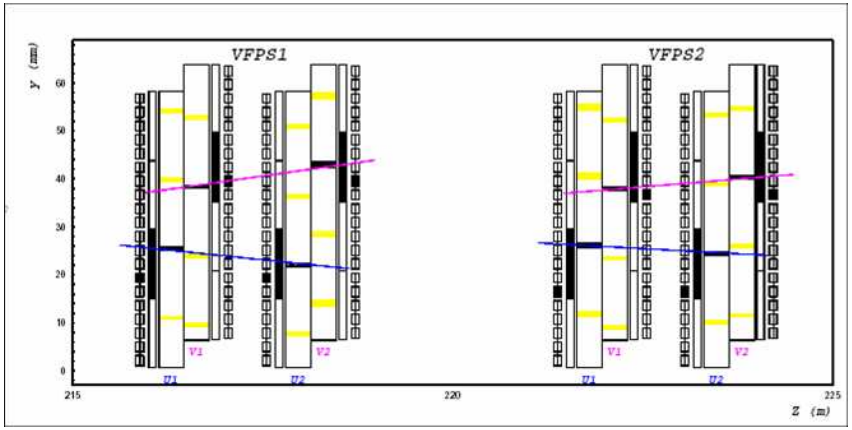
- Scintillating fiber detector
- Free of proton dissociation bkgd
- proton 4-momentum measurement $\rightarrow$ t

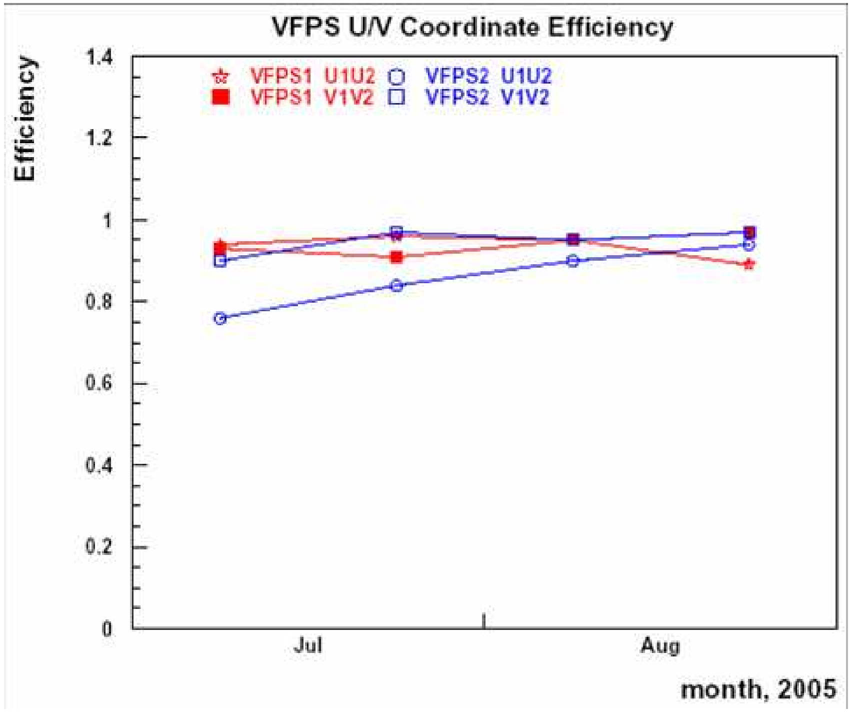
$\longrightarrow$ commissioning January 2004



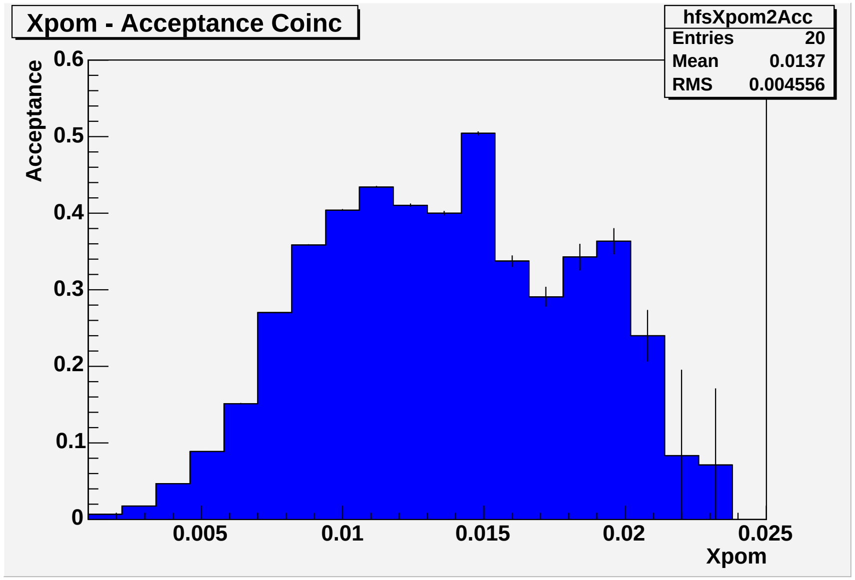


VFPS - First year of data





- 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).