On behalf of H1 and ZEUS Collaborations

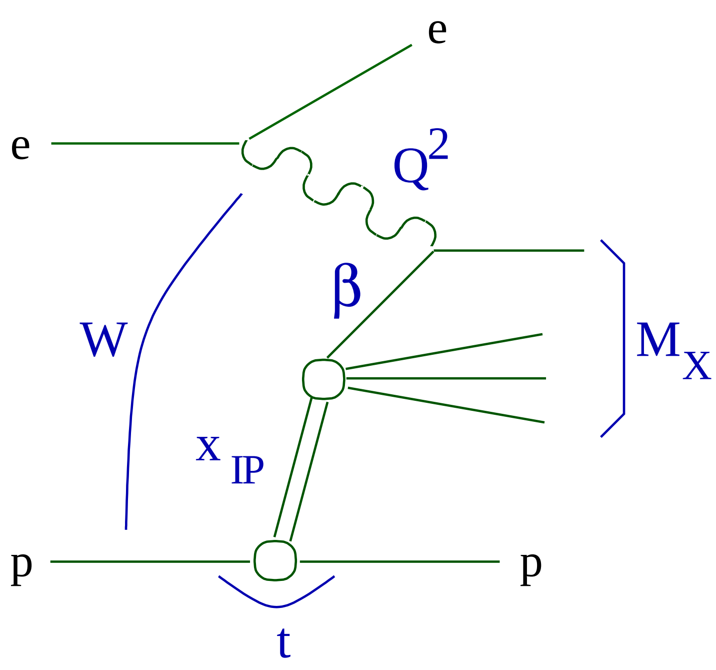
Inclusive diffraction at HERA and factorisation issues

LOW X MEETING

Helsinki, Finland, 29th Sept., 2007

Inclusive diffraction at HERA

$$e + p \longrightarrow e + X + p$$



Proton stays intact and loses small momentum fraction

Q^2	Photon virtuality
x	Bjorken-x
$x_{I\!P}$	Momemtum fraction of colour singlet exchange
β	Fraction of exchange momemtum of struck q
t	4-momemtum transfer squared
W	Photon-proton cms energy

$$x = x_{I\!P}\,\beta\,;\, W = Q^2\,(\tfrac{1}{x} - 1)$$

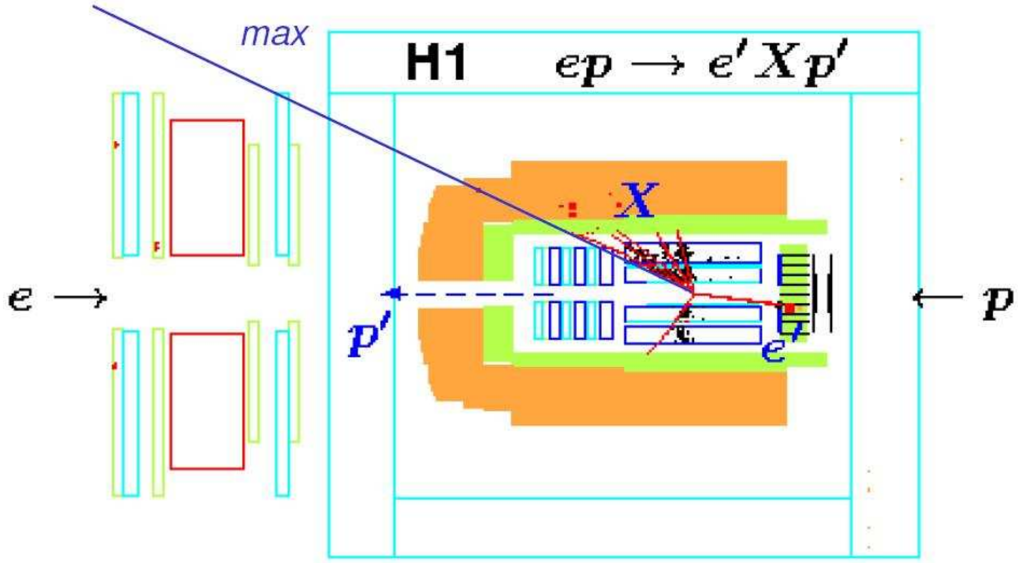
Main observable: Reduced cross section σ_r^D

$$\frac{d^4\sigma^{ep\rightarrow eXp}}{dx\,dQ^2\,dx_{I\!P}\,dt} = \frac{4\pi\alpha^2}{xQ^4}\; Y_+\; \sigma_r^{D(4)}(x, Q^2, x_{I\!P}, t)$$

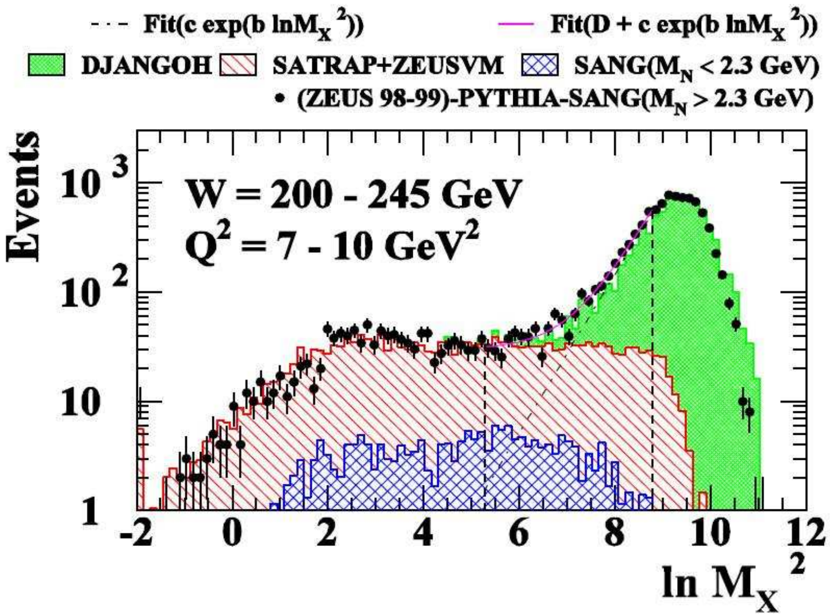
$$\sigma_r^{D(4)}(x, Q^2, x_{I\!P}, t) = F_2^{D(4)} - \frac{y^2}{Y_+} F_L^{D(4)} \approx F_2^{D(4)}$$

Selection Methods

H1: Large Rapidity Gap Method



ZEUS: M_X Method



- Gap spanning $3.3 < \eta < 7.5$
- Measure kinematic from hadrons in central detector
- Some proton dissociation $\longrightarrow$ Correct to $M_Y < 1.6$ GeV

- Flat vs ln M_X^2 for diffractive events
- non-diffracive events substracted from fit
- Proton dissociation $ep \to eXY$ corrected to $M_Y < 2.3$ GeV

Selection Methods

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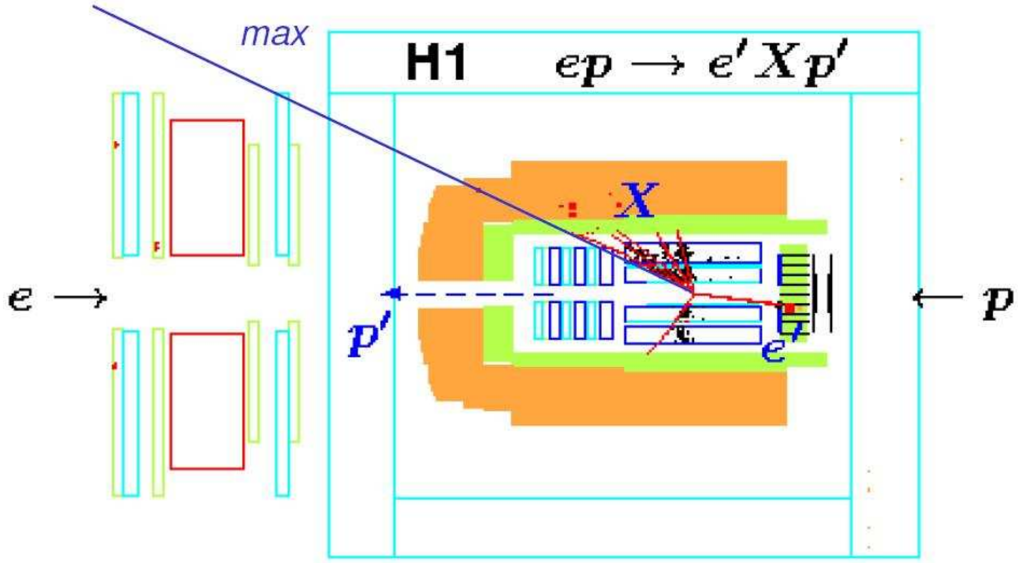

- Gap spanning $3.3 < \eta < 7.5$
- Measure kinematic from hadrons in central detector
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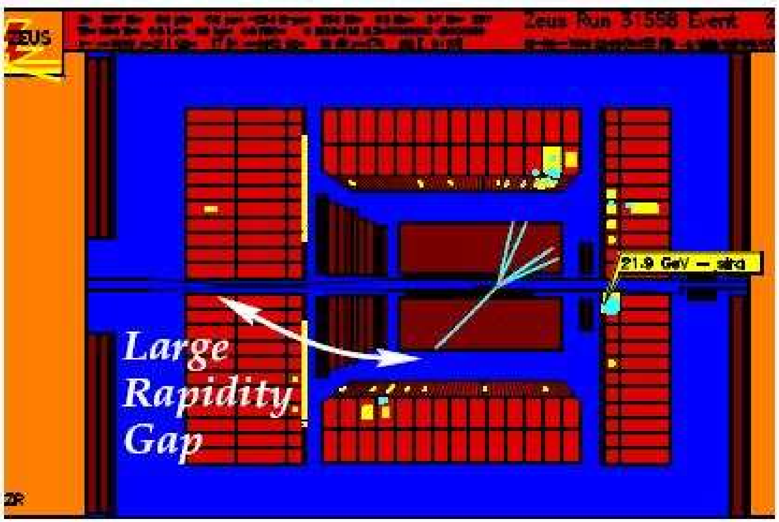
  $\longrightarrow$ Correct to $M_Y < 1.6$ GeV

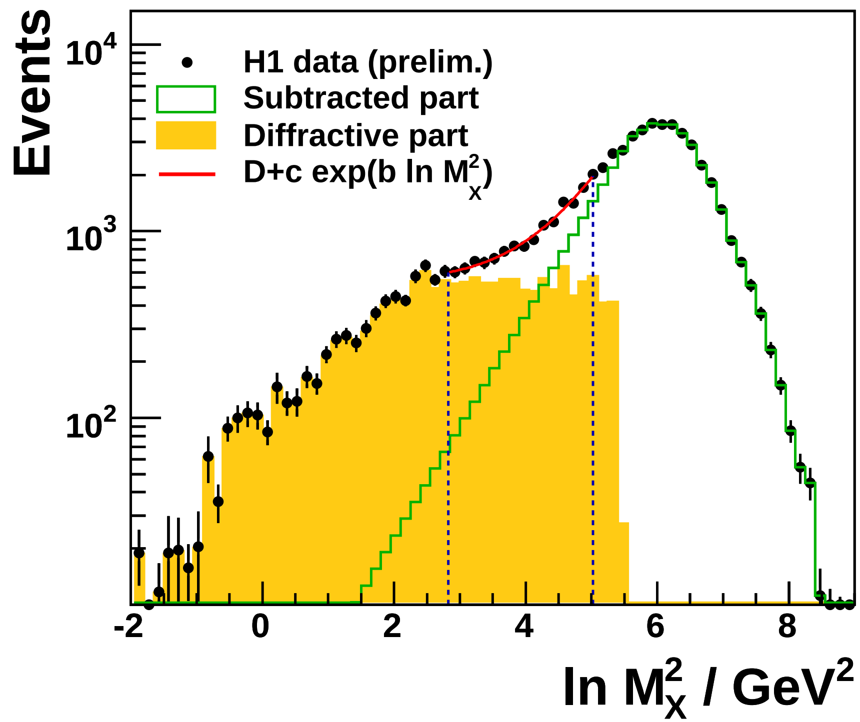
ZEUS: LRG Method



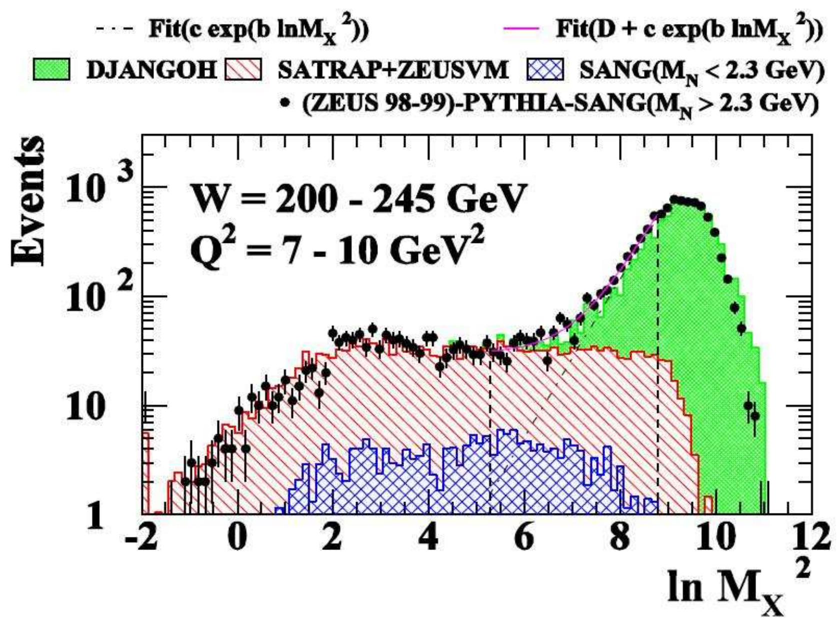
- $\eta_{max} < 3.0$
- $E_{FPC} < 1$ GeV
  (FPC covers $4 < \eta < 5$)
- Some proton dissociation
  $\longrightarrow$ Correct to $M_Y < 2.3$ GeV

Selection Methods

H1: M_X Method



ZEUS: M_X Method

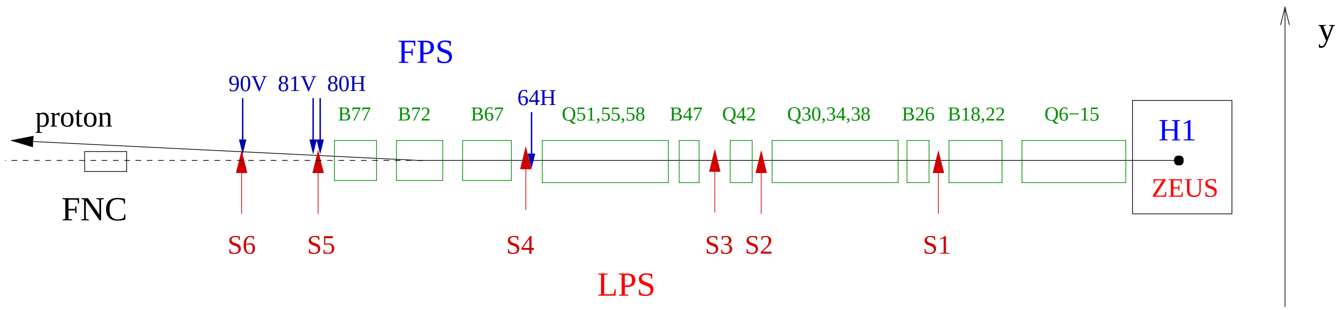


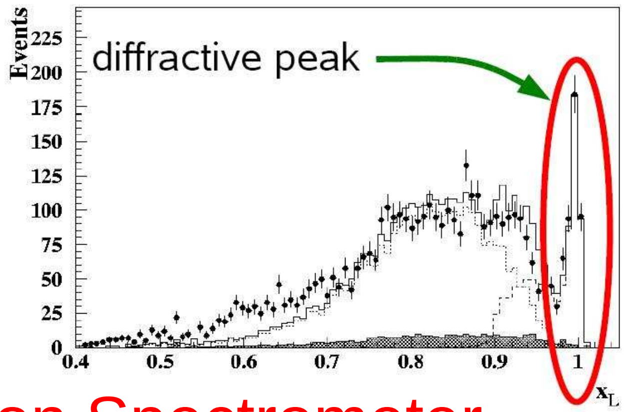
- M_X Method possible in H1

BUT lower acceptance in fwd direction $\rightarrow$ larger sytematic error on substraction for H1 $\rightarrow$ Restricted W range

- Flat vs ln M_X^2 for diffractive events
- non-diffracive events substracted from fit
- Proton dissociation $ep \rightarrow eXY$ corrected to $M_Y < 2.3$ GeV

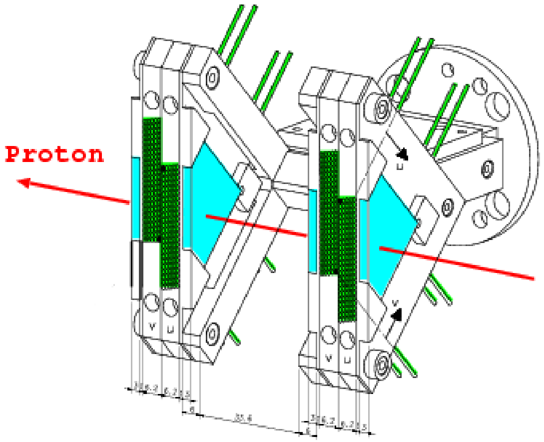
Selection Methods

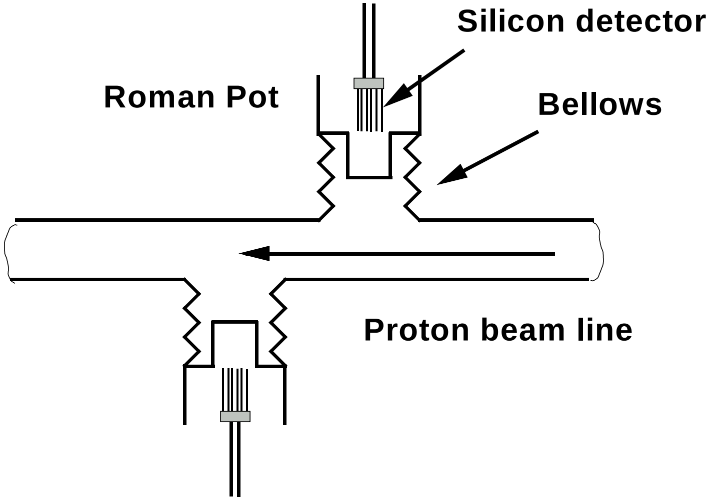




Forward Proton Spectrometer

Leading Proton Spectrometer





Scintillating fibre detector

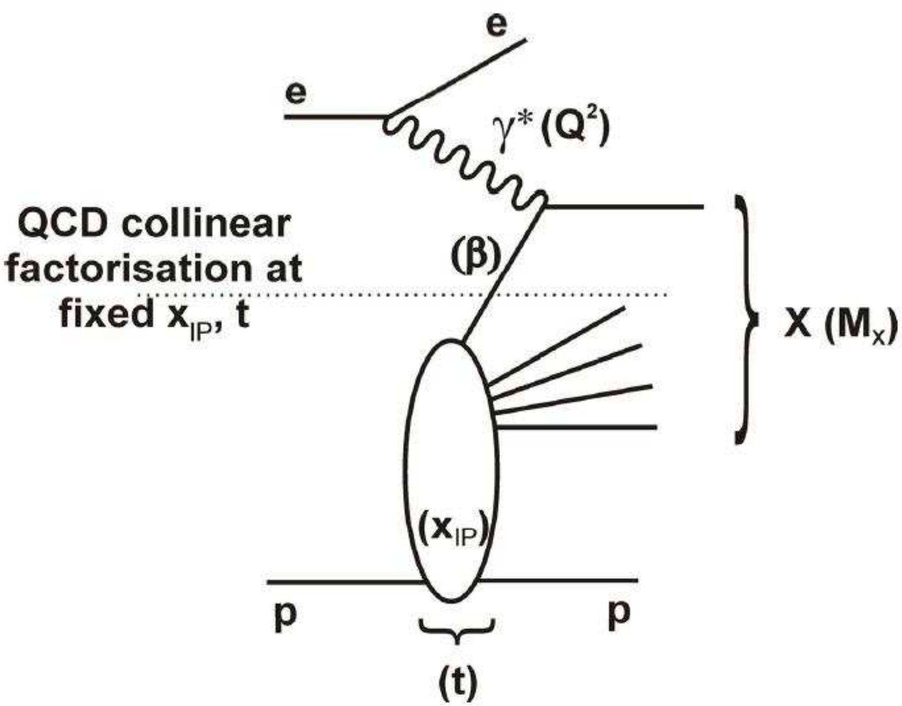
Silicon Micro-Strip Detector

- Free of proton dissociation bkgd
- p 4-momemtum measurment $\rightarrow t$
- Low statistic (acceptance)

Factorisation Properties

- QCD hard scattering collinear factorisation (Collins) at fixed $x_{I\!P}$ and t

$\rightarrow$ DGLAP applicable for Q^2 evolution.

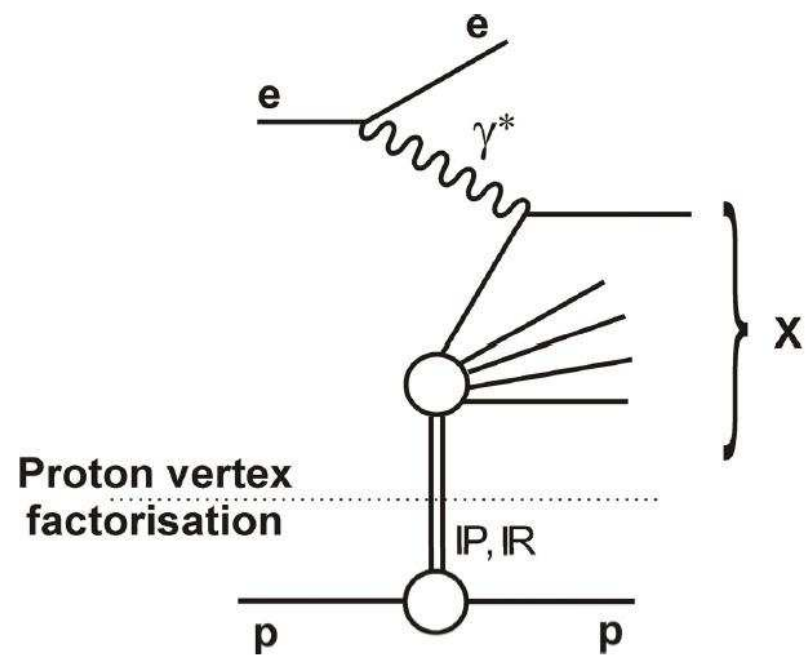


$$\mathrm{d}\sigma_{\mathrm{i}}(\mathrm{ep} \rightarrow \mathrm{eXp}) =$$

$$f_i^D(x, Q^2, x_{I\!P}, t) \otimes \mathrm{d}\hat{\sigma}^{\mathrm{i}}(\mathrm{x}, \mathrm{Q}^2)$$

- "Proton vertex" factorisation of x, Q^2 from $x_{I\!P}$, t (and M_Y) dependences

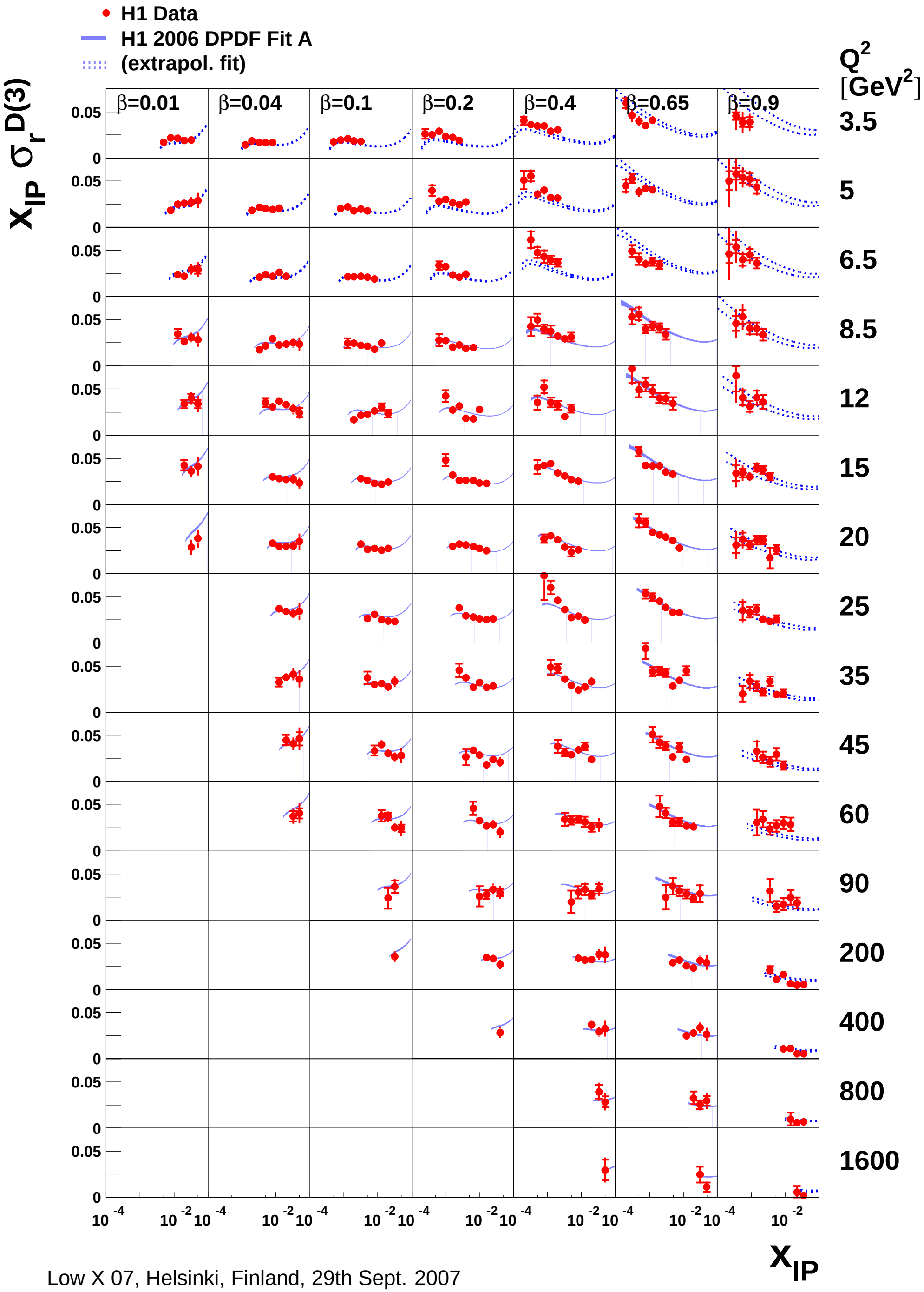
No firm basis in QCD !



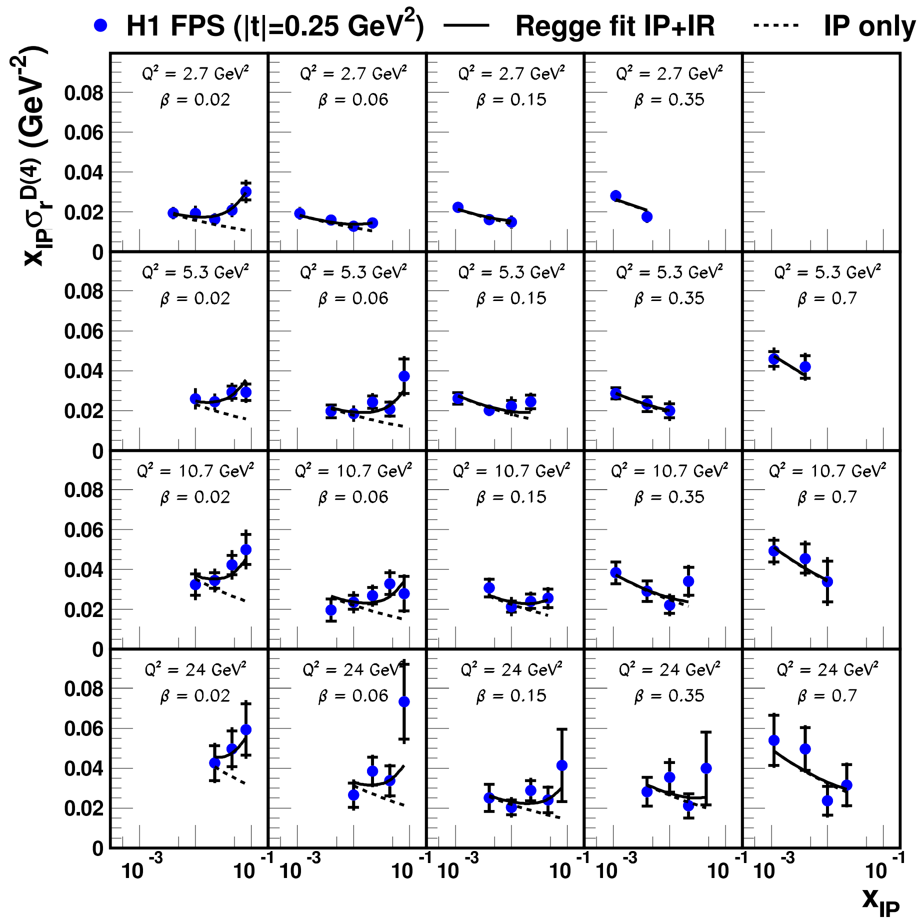
$$f_i^D(x, Q^2, x_{I\!P}, t) =$$

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

H1 Published Data Overview

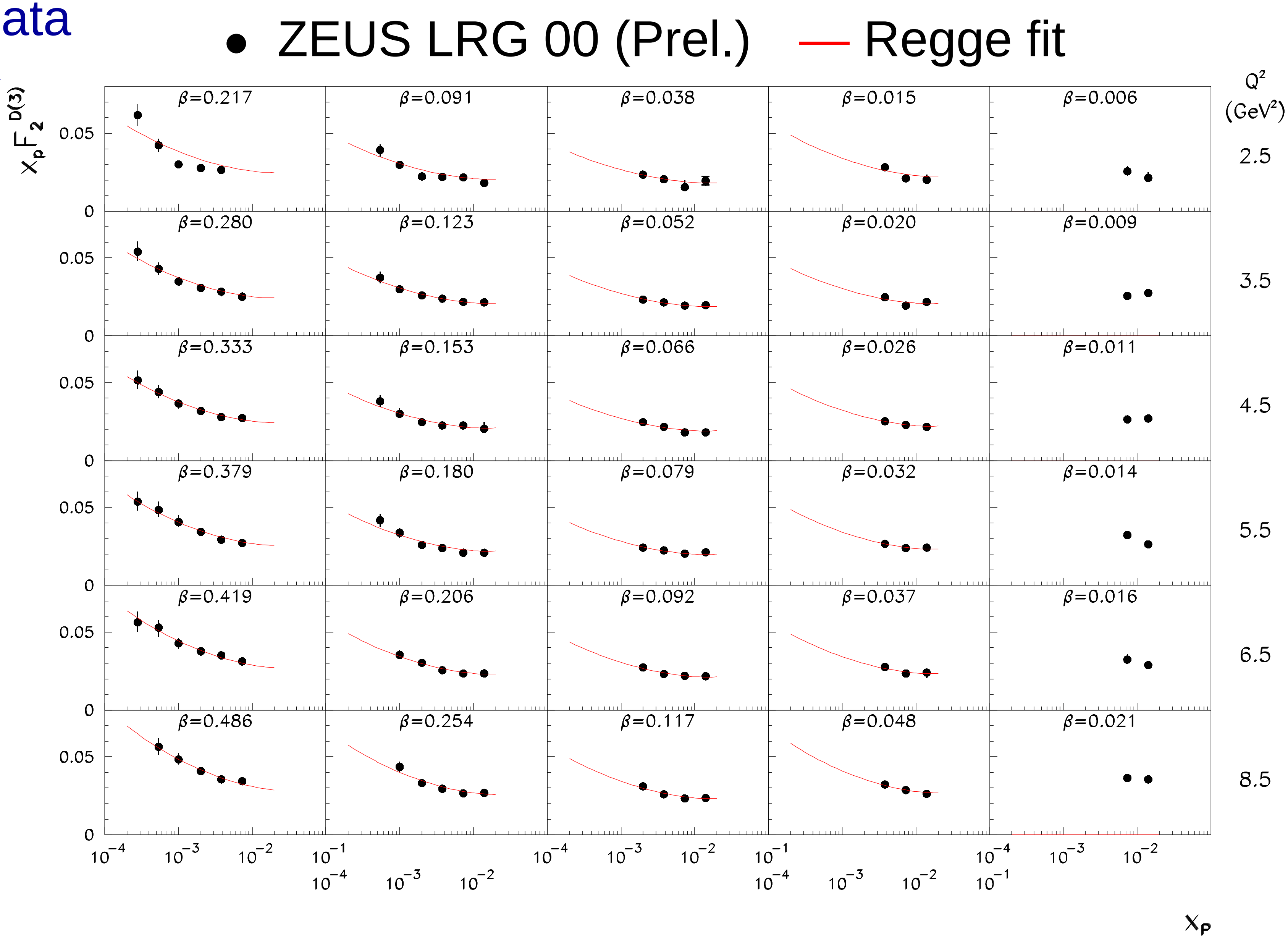


- LRG: $M_Y < 1.6$ GeV
  $3.5 < Q^2 < 1600\ \mathrm{GeV}^2$
- FPS: $Y = p$
  $2.7 < Q^2 < 24\ \mathrm{GeV}^2$



New ZEUS Data with Rapidity Gap Method

2000e+ data
45.3 pb^{-1}



Fit: $\alpha_{I\!P}(0) = 1.117 \pm 0.005$ (stat.) $^{+0.024}_{0.007}$ (model)

New ZEUS Data with Proton Tag

- ZEUS LPS 00 (Prel.) $t = 0.13\ \mathrm{GeV}^2$
- ZEUS LPS 00 (Prel.) $t = 0.3\ \mathrm{GeV}^2$

2000e+ data

32.6 pb^{-1}

$x_{I\!P} < 0.1$

$2 < Q^2 < 120\ \mathrm{GeV}^2$

— Regge fit

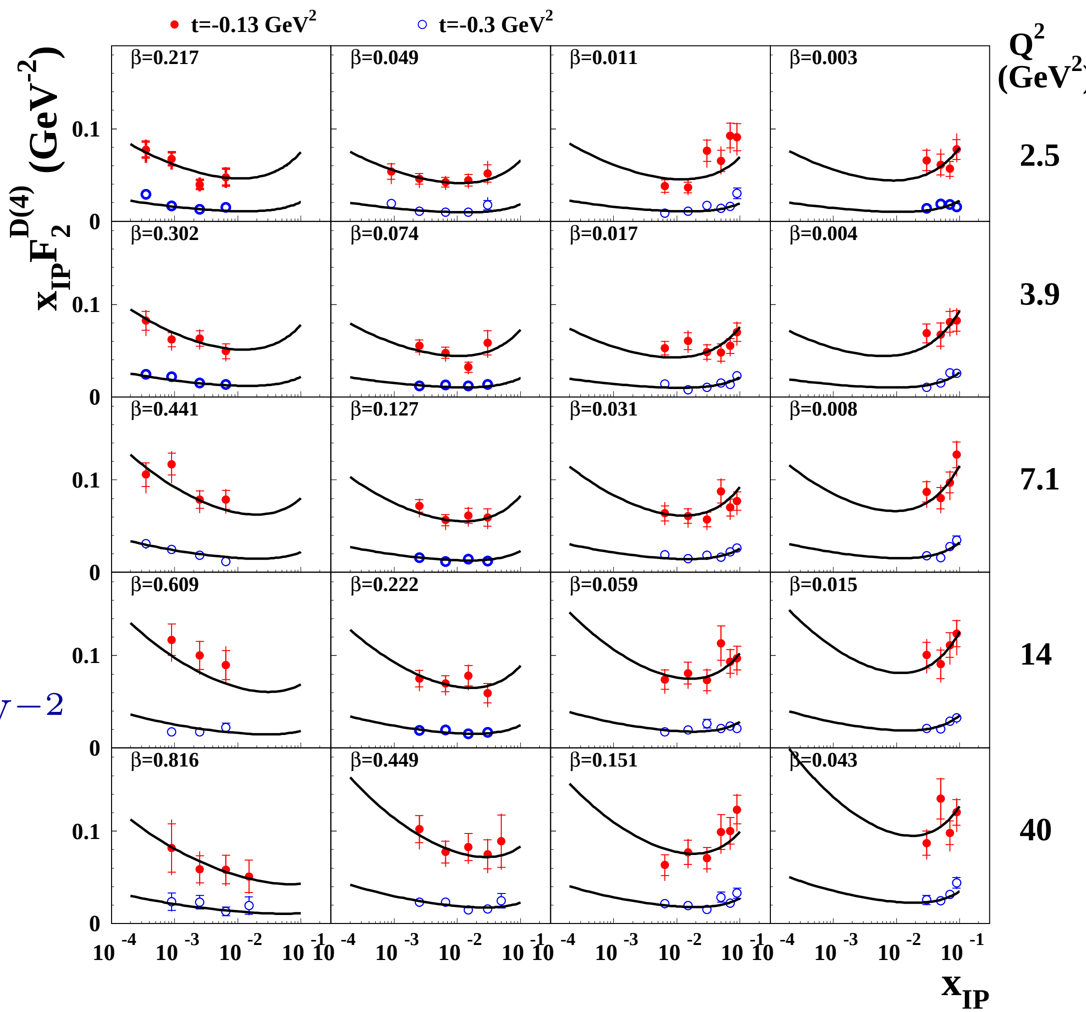
$\alpha_{I\!P}(0) = 1.1 \pm 0.02(\mathrm{stat})^{+0.01}_{-0.02}(\mathrm{syst}) \pm 0.02(\mathrm{mod})$

$\alpha'_{I\!P} = -0.03 \pm 0.07(\mathrm{stat})^{+0.04}_{-0.08}(\mathrm{syst})\ \mathrm{GeV}^{-2}$

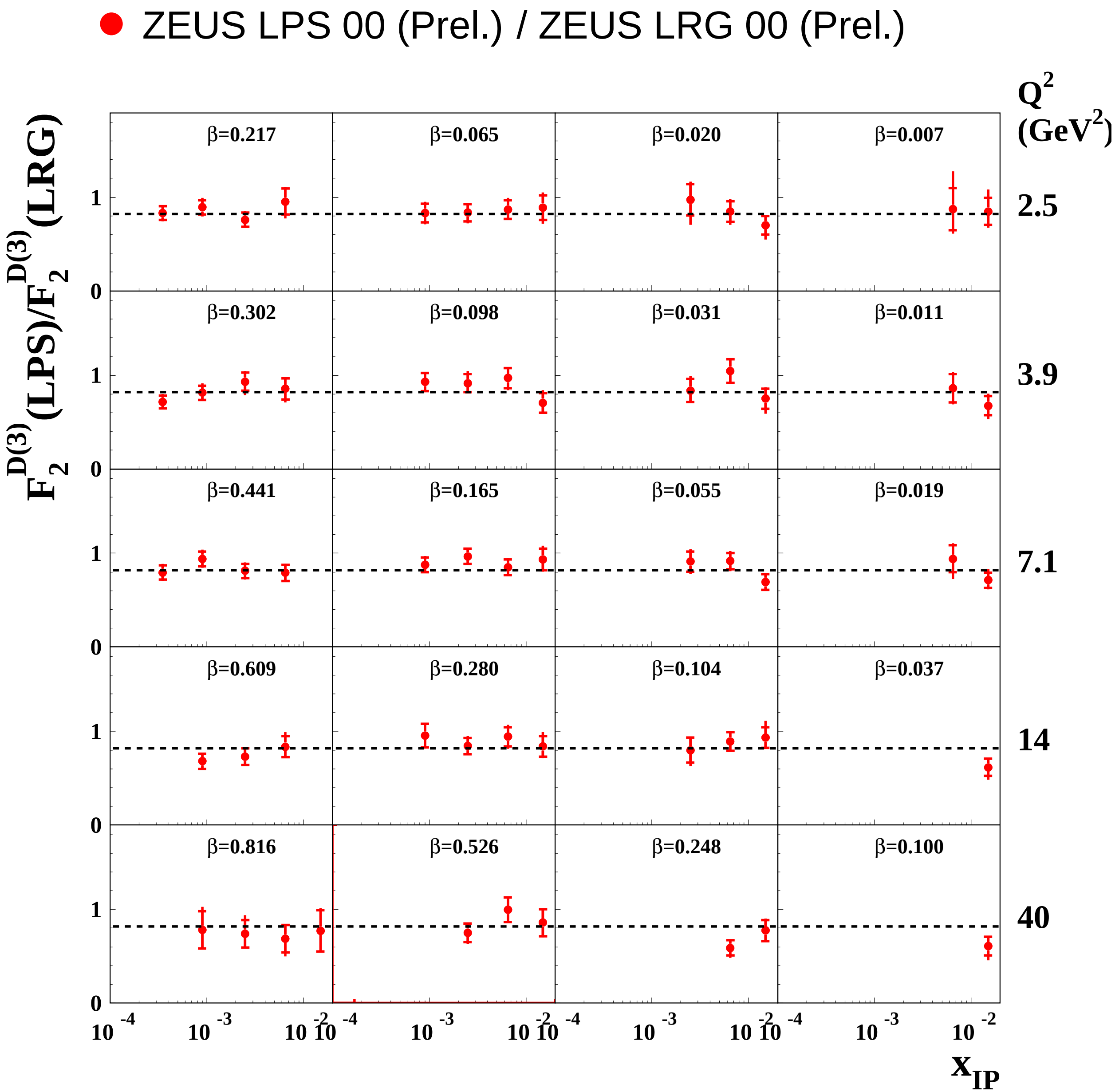
$B_{I\!P} = 7.2 \pm 0.7(\mathrm{stat})^{+1.4}_{-0.7}(\mathrm{syst})\ \mathrm{GeV}^{-2}$

$\alpha_{I\!R}(0) = 0.75 \pm 0.07(\mathrm{stat})^{+0.02}_{-0.04}(\mathrm{syst}) \pm 0.05(\mathrm{mod})$

$\chi^2/ndf = 172.5/153 = 1.13$



ZEUS: Rapidity Gap vs Leading Proton data



LPS/LRG =
0.82 ± 0.01 (stat.)
± 0.03 (syst.)
± 0.08 (norm.)

$\rightarrow (22 \pm 14)\%$ of p-diss

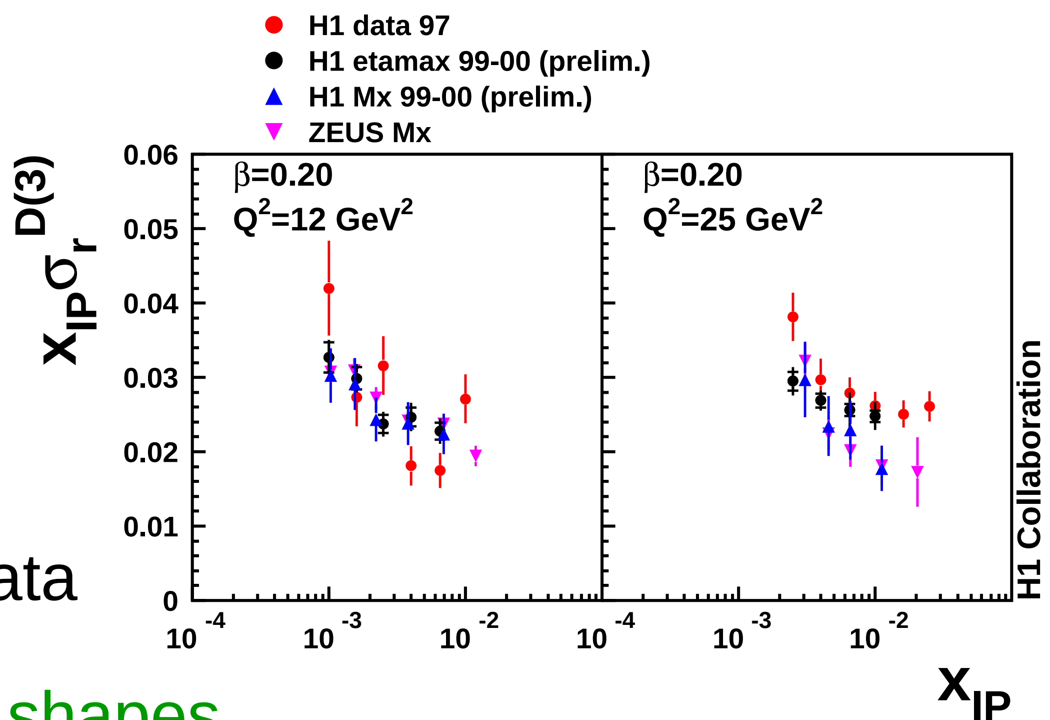
Independent of Q^2 and β

Comparaison between data sets

- H1 LRG/H1 FPS = $1.23 \pm 0.03 \pm 0.16$
  with shape agreement
  $\rightarrow 19 \pm 11\%$ of p-diss in H1 LRG data
- H1 FPS and ZEUS LPS data
  agrees within 8% normalisation
- Good agreement between
  H1 and ZEUS M_X data
  but H1 W range limited !
- Relative agreement between
  LRG and M_X / H1 and ZEUS data

New M_X data from H1:

Prelim. 99-00, 34 pb^{-1}
$M_Y < 2.3$ GeV, $|t| < 1$ GeV^2

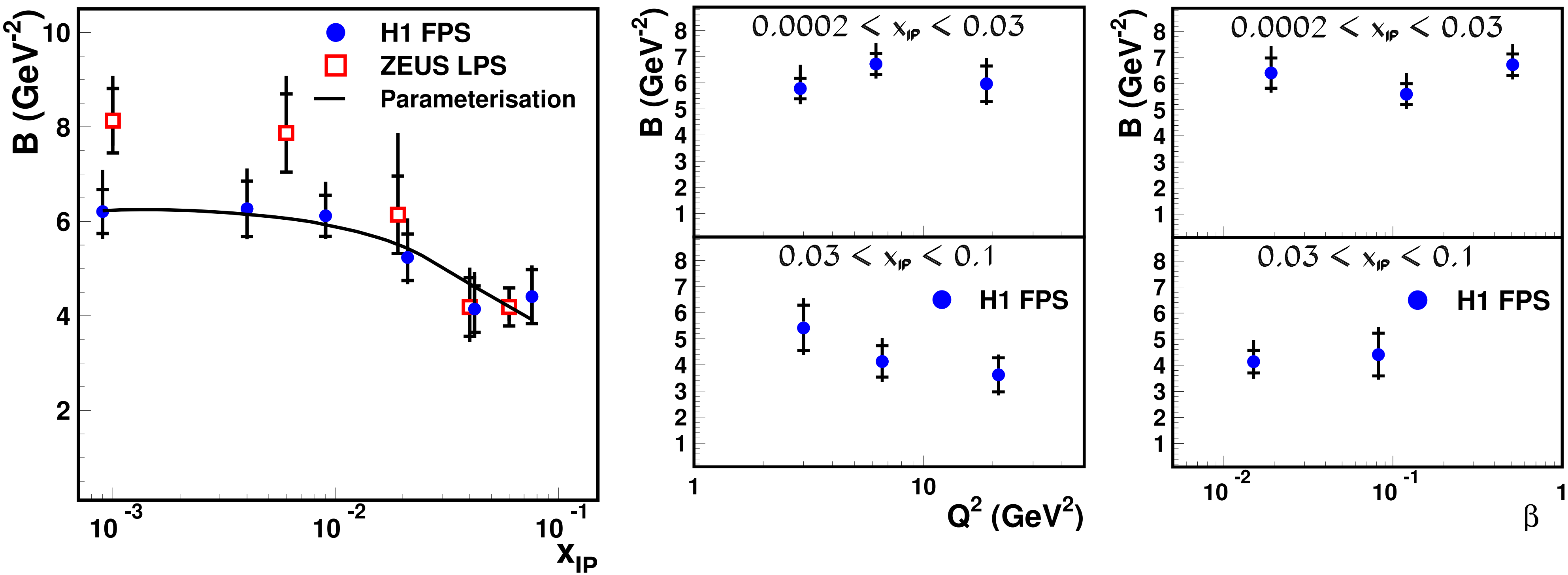


$\longrightarrow$ Coherent data sets respecting shapes

$\longrightarrow$ Common H1/ZEUS investigation on p-dissociation normalisation

t dependence from FPS and LPS data

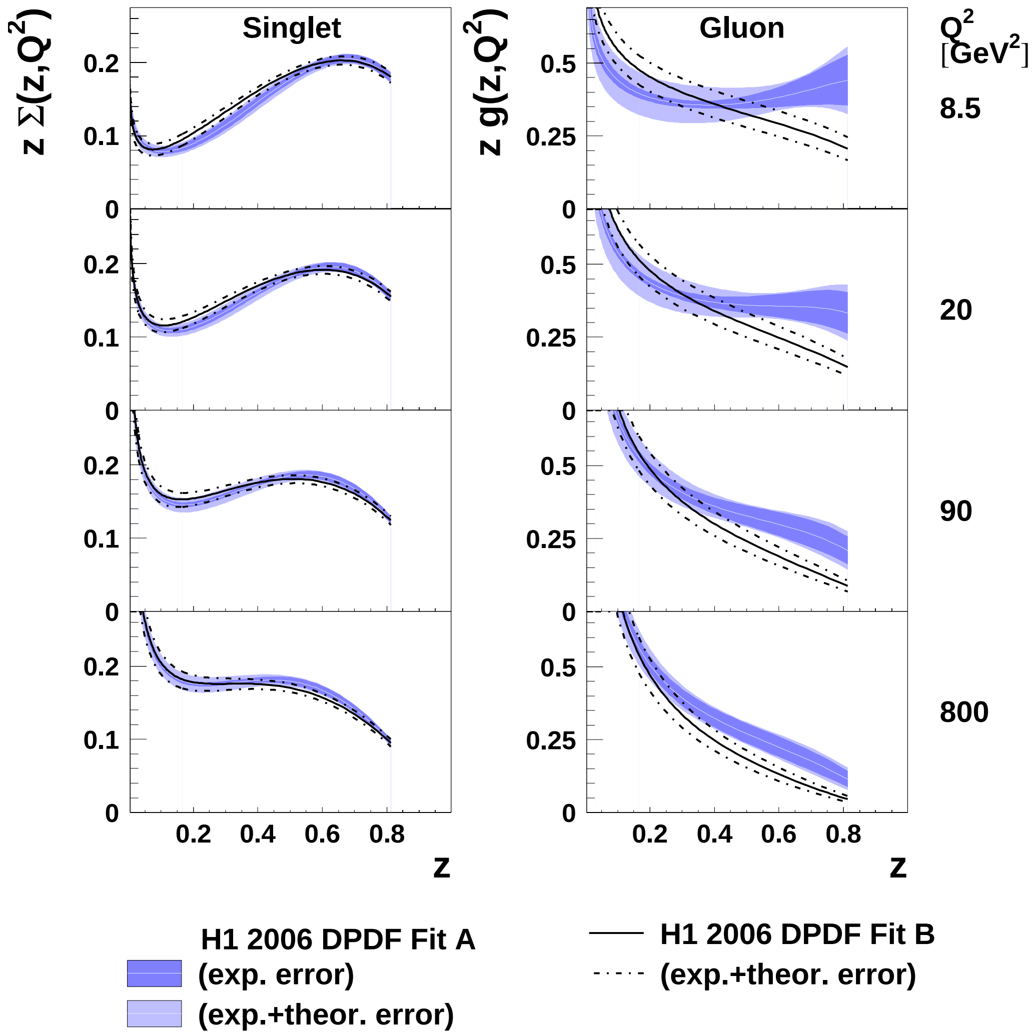
- $B(x_{I\!P})$ from fit $\mathrm{d}\sigma/\mathrm{dt} \propto \exp(\mathrm{B}|\mathrm{t}|)$
- Independent of β, Q^2 within errors



- $B(x_{I\!P})$ data constrain $I\!P$, $I\!R$ flux in proton vertex factorisation model
- Regge motivated form: $f_{I\!P/p}(x_{I\!P}, t) = \frac{e^{B_{I\!P} t}}{x_{I\!P}^{2\alpha_{I\!P}(t)-1}}; \alpha_{I\!P}(t) = \alpha_{I\!P}(0) + \alpha'_{I\!P} t$
- Fitting H1 data to $B = B_{x_{I\!P}} + 2\alpha'_{I\!P} \ln(1/x_{I\!P})$ gives:

$$B_{x_{I\!P}} = 5.5^{-2.0}_{+0.7} \mathrm{GeV}^{-2} \qquad \alpha'_{I\!P} = 0.06^{+0.19}_{-0.06} \mathrm{GeV}^{-2}$$

H1 2006 DPDF fit results

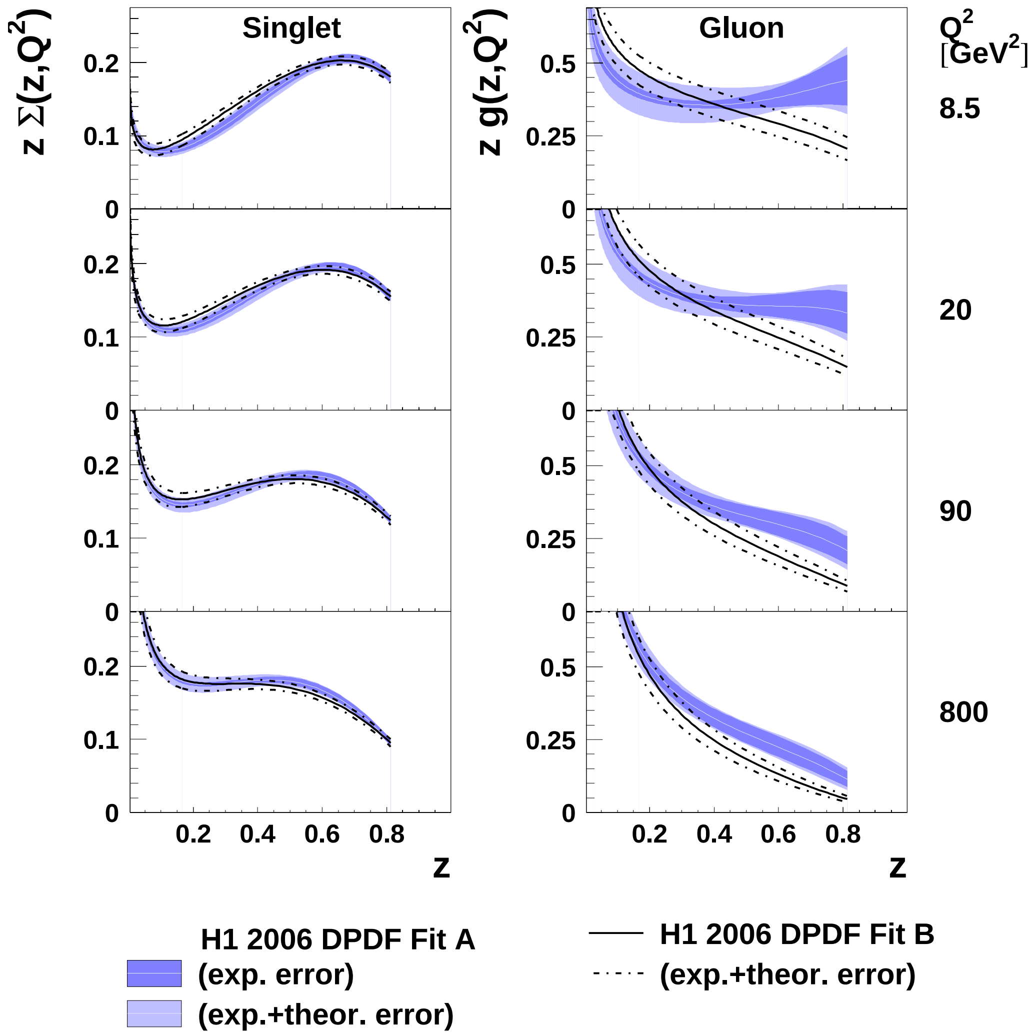


- **Fit A:** $Q_0^2 = 1.45\ \mathrm{GeV}^2$
  $\chi^2 \sim 158/183$ dof
  - Singlet constrained to $\sim 5\%$
  - Gluon to $\sim 15\%$ at low z
  - Gluon error band blowing up at highest z
- **Fit B:** $zg(z, Q_0^2) = A_g$
  $\chi^2 \sim 164/184$ dof
  - Singlet very stable
  - Gluon similar at low z
  - Gluon change at high z

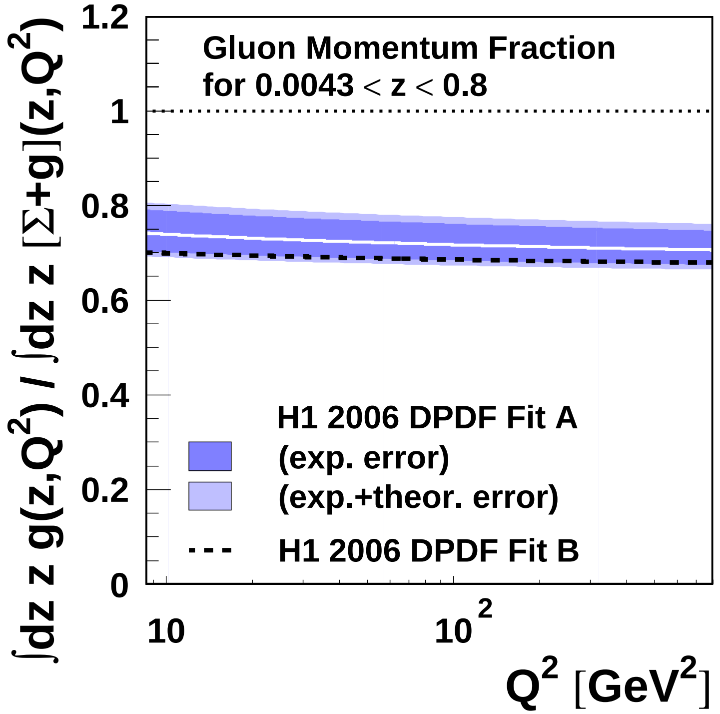
$\longrightarrow$ New Diffractive PDFs available

$\longrightarrow$ Lack of sensitivity to gluon at high z

H1 2006 DPDF fit results



Gluon Momentum Fraction



gluon:quark ratio $\sim 70\%/30\%$

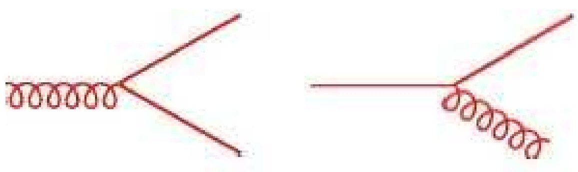
$\longrightarrow$ New Diffractive PDFs available

$\longrightarrow$ Lack of sensitivity to gluon at high z

H1 Fit: High z sensitivity to gluon

- As there are only singlet quarks, the evolution eq. for F_2^D is

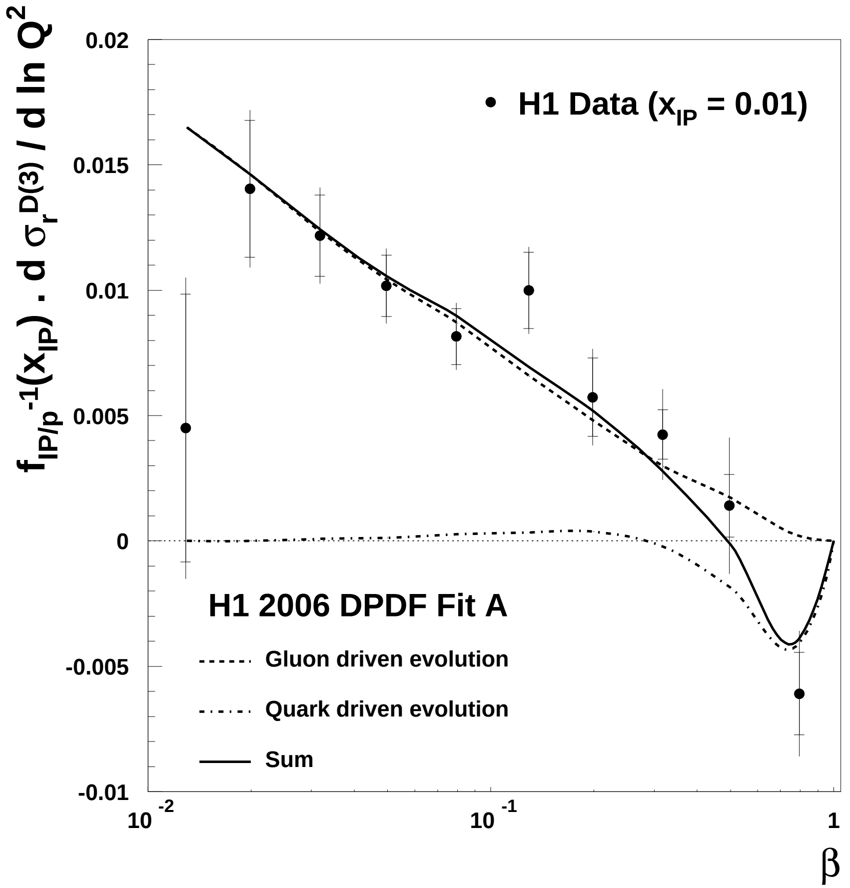
$$\frac{\mathrm{dF_2^D}}{\mathrm{dlnQ^2}} \sim \frac{\alpha_s}{2\pi}\left[\, P_{qg} \otimes g + P_{qq} \otimes \Sigma \,\right]$$



- At low β, evolution driven by $g \longrightarrow q\bar{q}$
  $\longrightarrow$ strong sensitivity to gluon

- At high β, relative error on derivative grows, $q \longrightarrow qg$ contribution becomes important
  $\longrightarrow$ sensitivity to gluon is lost

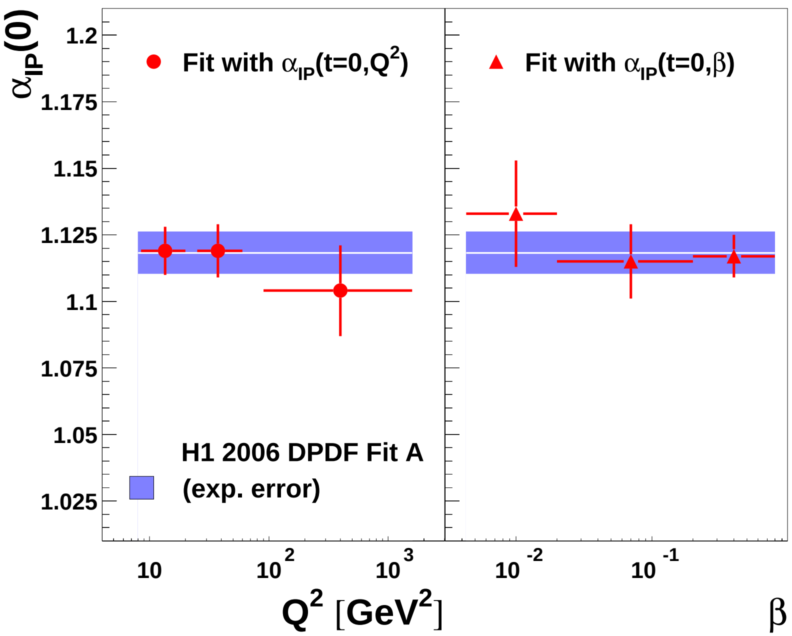
Log. Derivative wrt Q^2



Effective Pomeron Trajectory Intercept

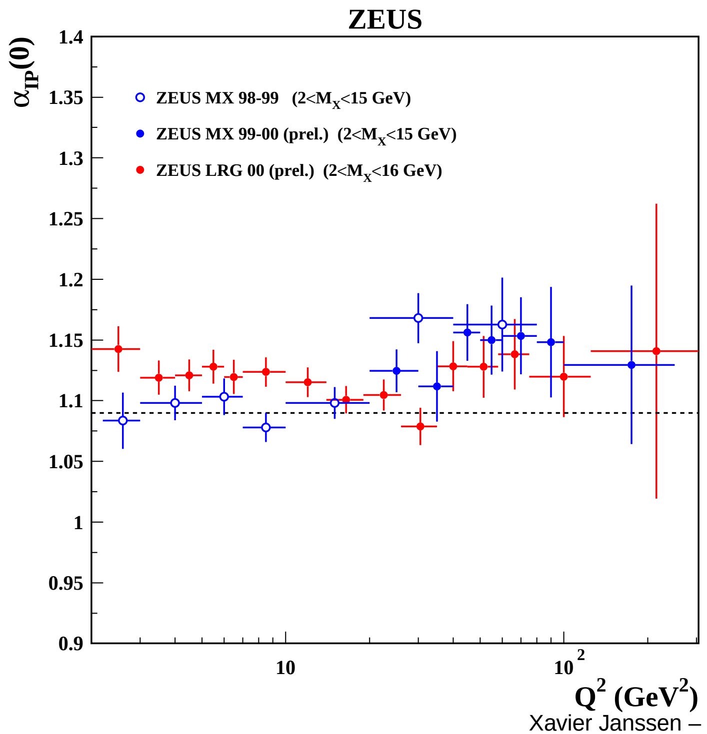
H1 Pomeron Intercept from QCD fits:

- $\alpha_{I\!P}(0) = 1.118 \pm 0.008(\mathrm{exp.})^{+0.029}_{-0.10}(\mathrm{th.})$
- Dominant uncertainty from strong correlation with $\alpha'_{I\!P}$
- No variation in Q^2 or β
  $\rightarrow$ support p vertex factorisation



ZEUS $I\!P$ Intercept from Regge fits:

- Data from M_X and LRG methods
- No variation with Q^2 within errors



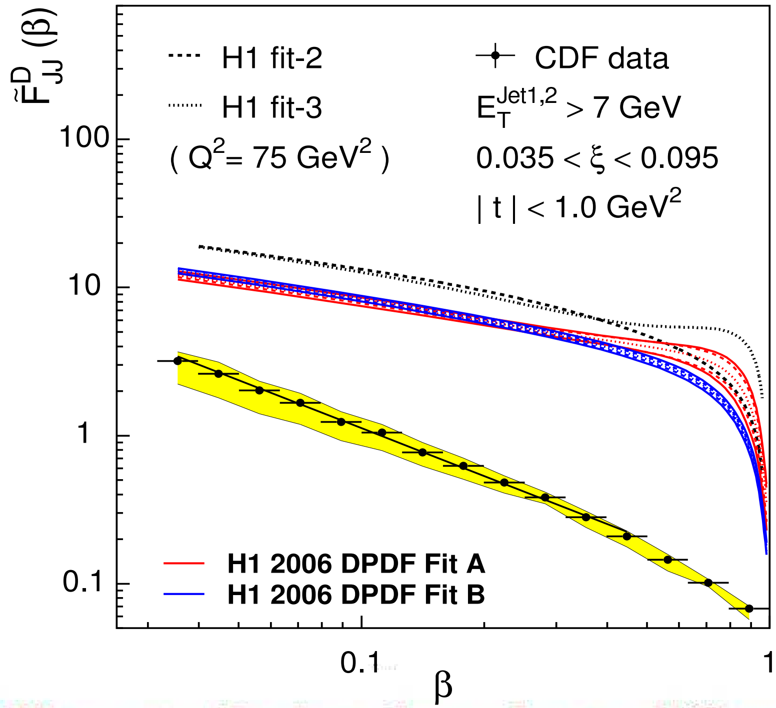
Consistent with proton tag results:

H1: $\alpha_{I\!P}(0) = 1.114 \pm 0.018(\mathrm{stat.}) \pm 0.012(\mathrm{syst.})^{+0.040}_{-0.020}(\mathrm{th.})$

ZEUS: $\alpha_{I\!P}(0) = 1.1 \pm 0.02(\mathrm{stat.})^{+0.01}_{-0.02}(\mathrm{syst.}) \pm 0.02(\mathrm{th.})$

Factorisation breaking at the Tevatron

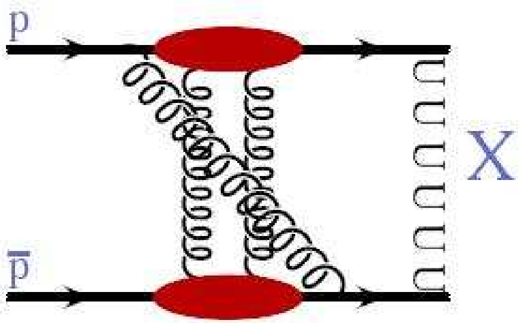
CDF measurement of the diffractive dijet production (using ratio SD/ND):



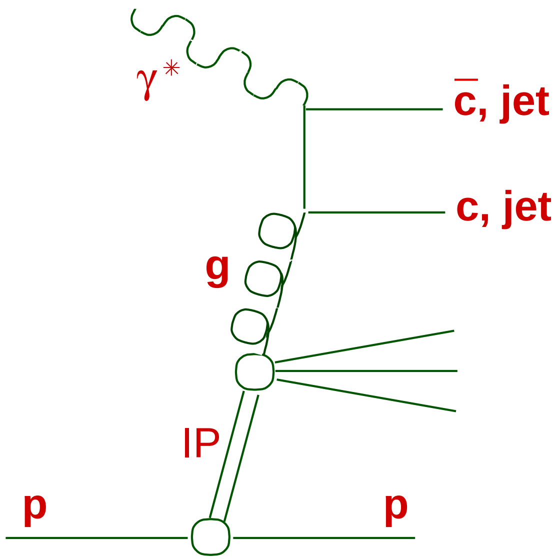
- The prediction based on diffractive PDF's extracted at HERA are one order of magnitude above the measures cross section!

- 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...

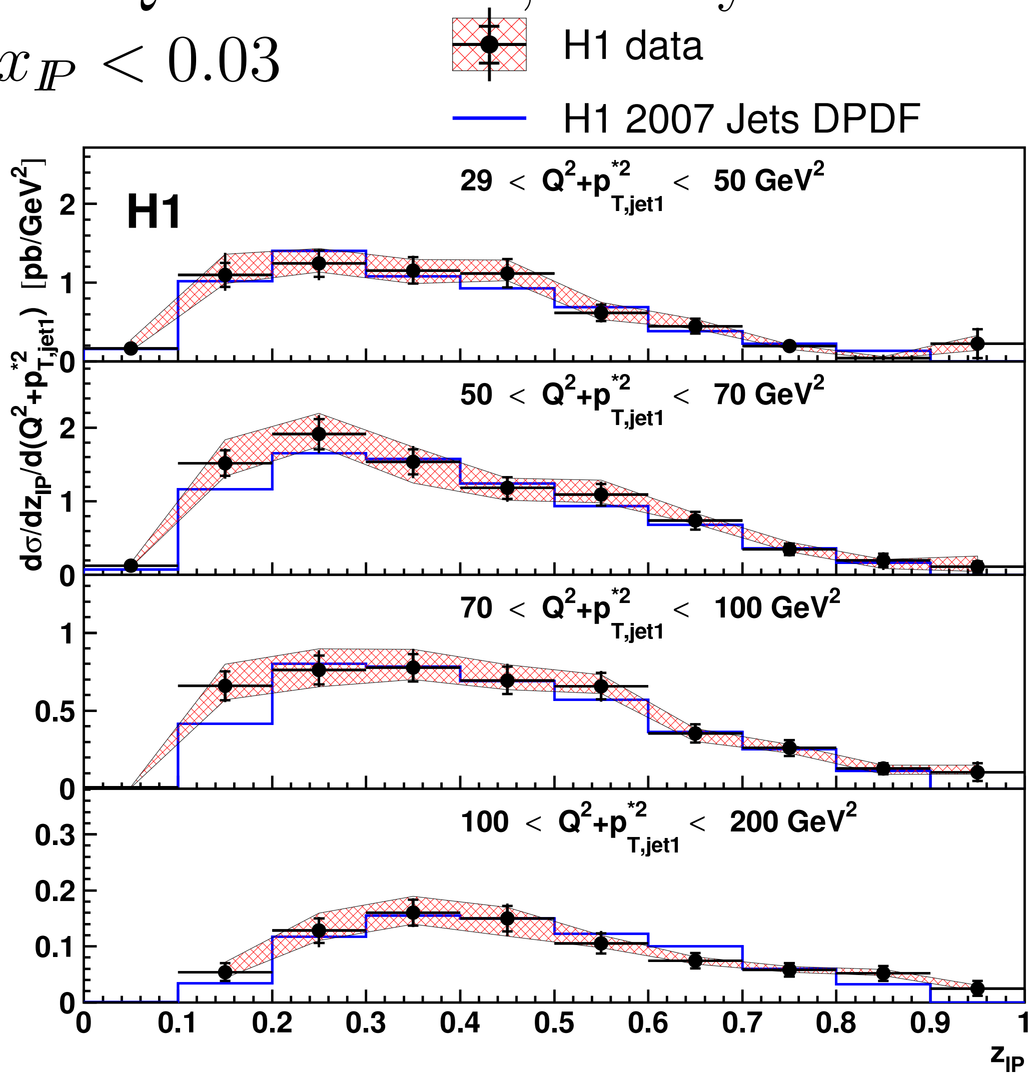


H1 Diffractive Dijets in DIS



New H1 Publication on Diffractive dijets

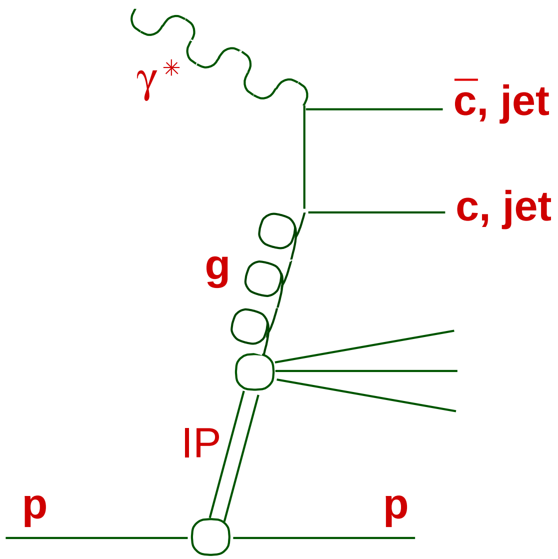
- 99-2000 data (50 pb^{-1})
- $4 < Q^2 < 80\ \text{GeV}^2, 0.1 < y < 0.7$
- $x_{I\!P} < 0.03$

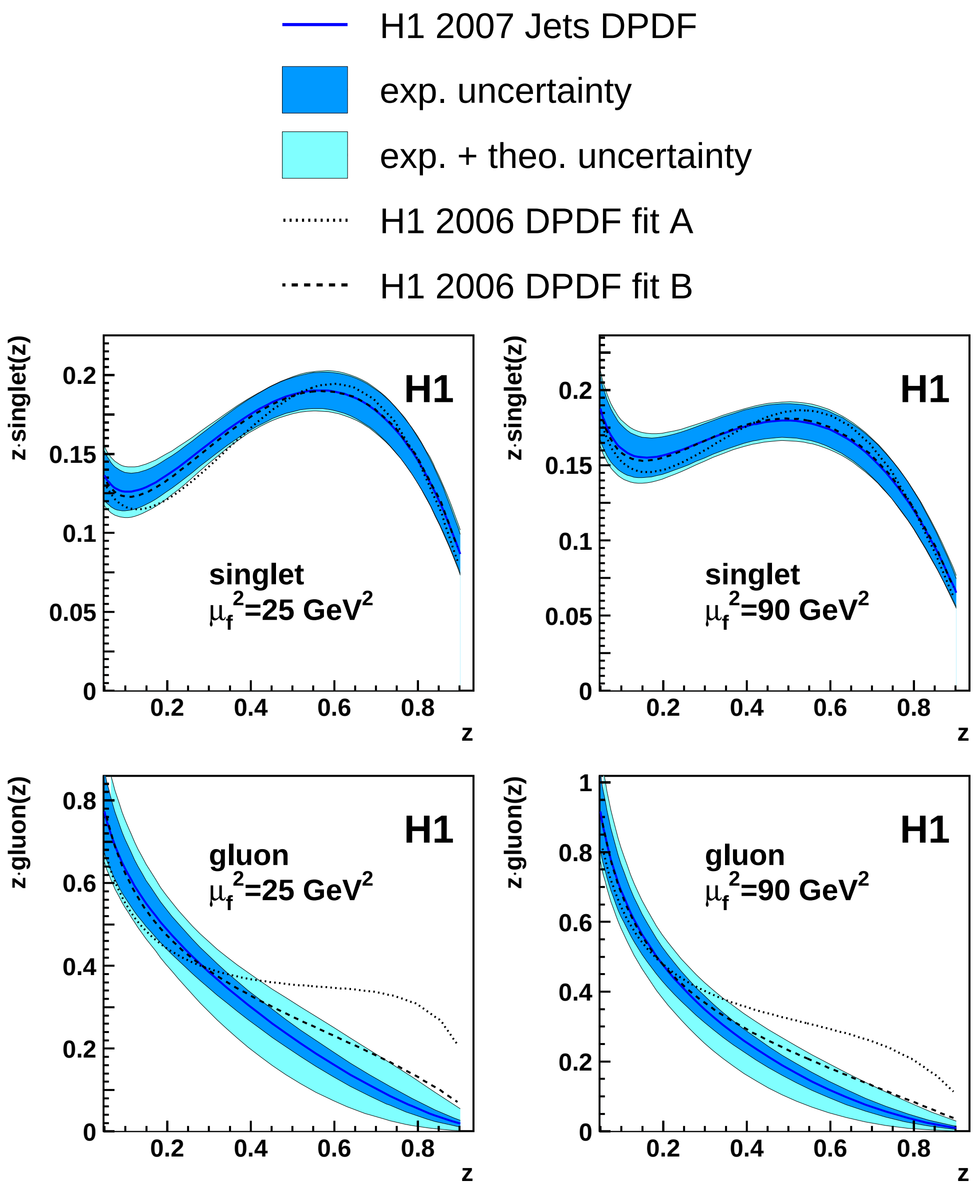


- Sensitivity to gluon at high z

$\rightarrow$ Combined QCD fit to dijets and inclusive data to constrain gluon at high z

H1 Diffractive Dijets in DIS





- Sensitivity to gluon at high z

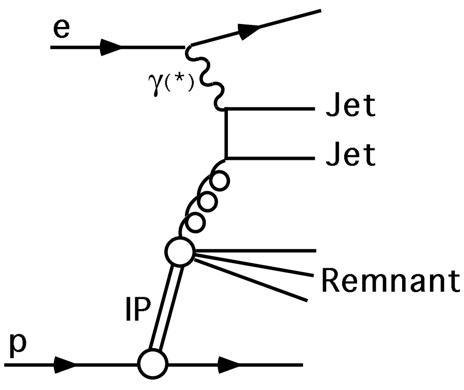
  $\rightarrow$ Combined QCD fit to dijets and inclusive data to constrain gluon at high z

- Fit successfull: $\chi^2 = 196/217$

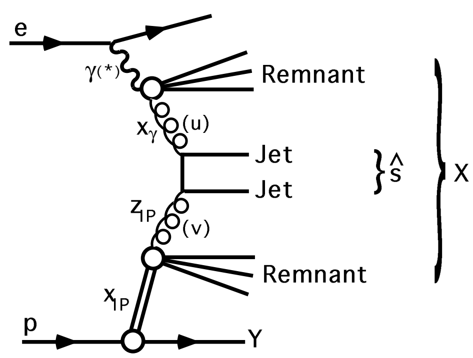
Common $F_2^{D(3)}$ and DIS Jets Diff. PDFs $\rightarrow$ Factorisation holds

H1: Dijets in DIS and Photoproduction

DIS and direct γp | **Resolved γp**



x_γ = 1



x_γ < 1

x_γ = fraction of photon momentum in hard scattering

Resolved γ can behave as a hadron

$\longrightarrow$ Factorization braking expected

for resolved case ($x_\gamma < 1$)

- Factorisation holds in DIS
- Factorisation breaking in Photoprod. both for direct and resolved

$\longrightarrow$ Global factor: ~ 0.5

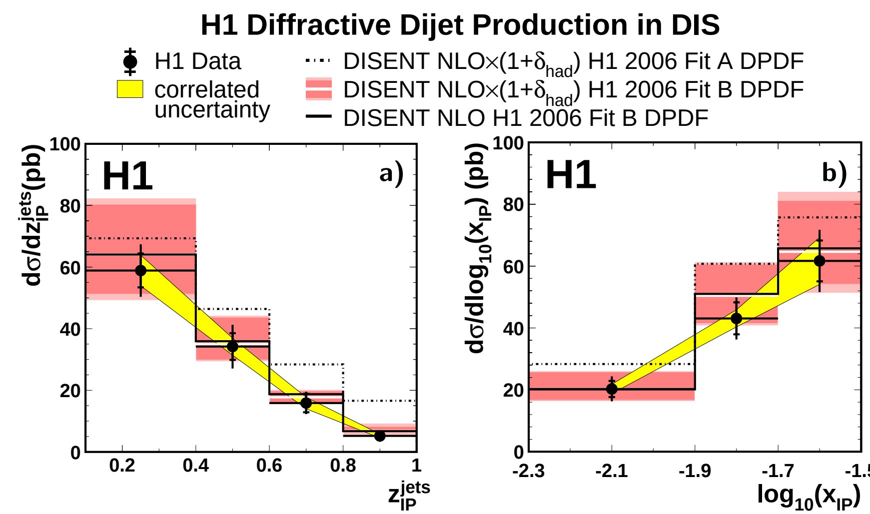
H1 97 Data: $E_{T,jet1(2)} > 5(4)$ GeV

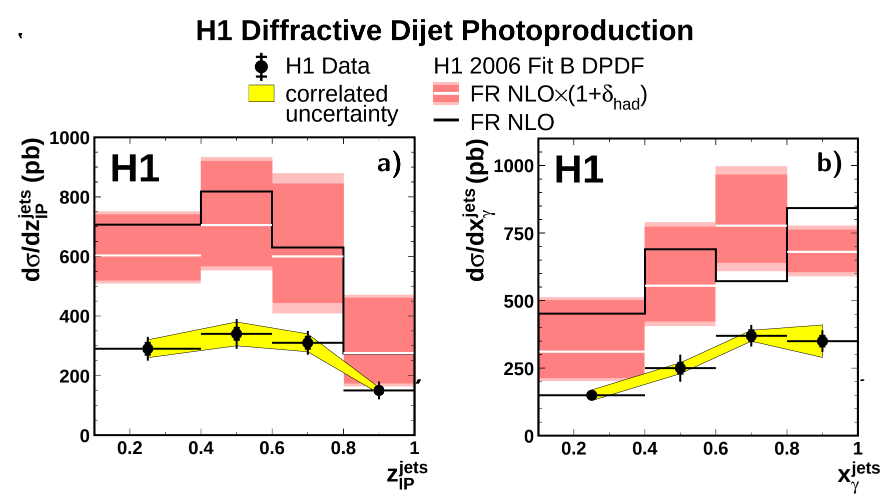
$Q^2 < 0.01\ \mathrm{GeV}^2$

$165 < W < 242$ GeV

$x_{I\!P} < 0.03$

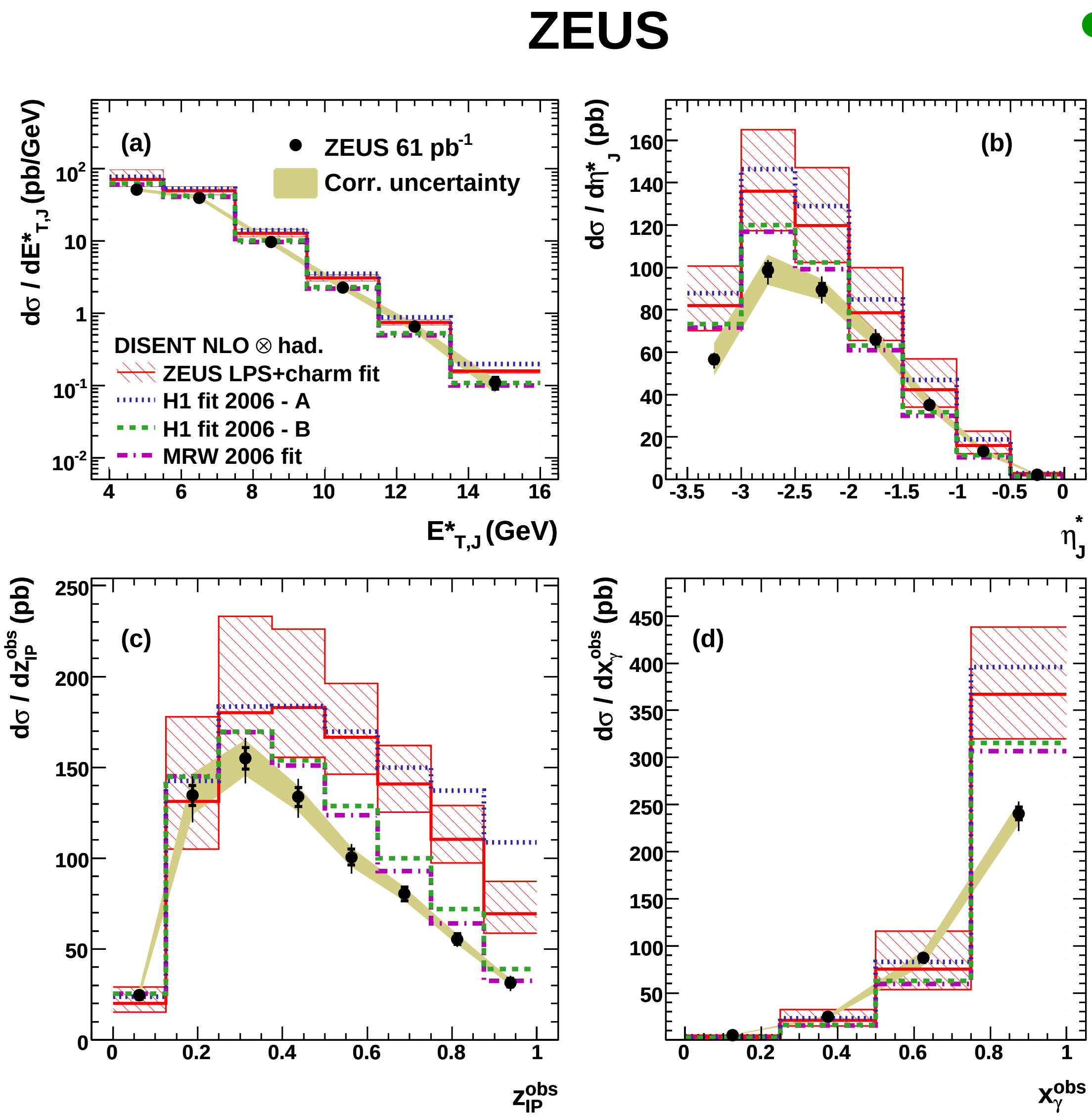
NLO : Frixione code + H1 2006 Fit B





ZEUS: Dijets in DIS

96-00 Data: $E_{T,jet1(2)} > 5(4)$ GeV
$5 < Q^2 < 100\ \mathrm{GeV}^2$
$100 < W < 250$ GeV
$x_{I\!P} < 0.03$



NLO Predictions:

- DISENT code (Catani-Seymour)
- Diffractive PDFs:
  - NLO Fits to ZEUS FPS + charm
  - H1 NLO Fit 2006 A
  - H1 NLO Fit 2006 B
  - Martin-Ryskin-Watt 2006 Fit

Discrimination between PDF's

H1 NLO Fit 2006 B and MRW06 give reasonable data description

→ QCD factorisation holds for Dijets in DIS

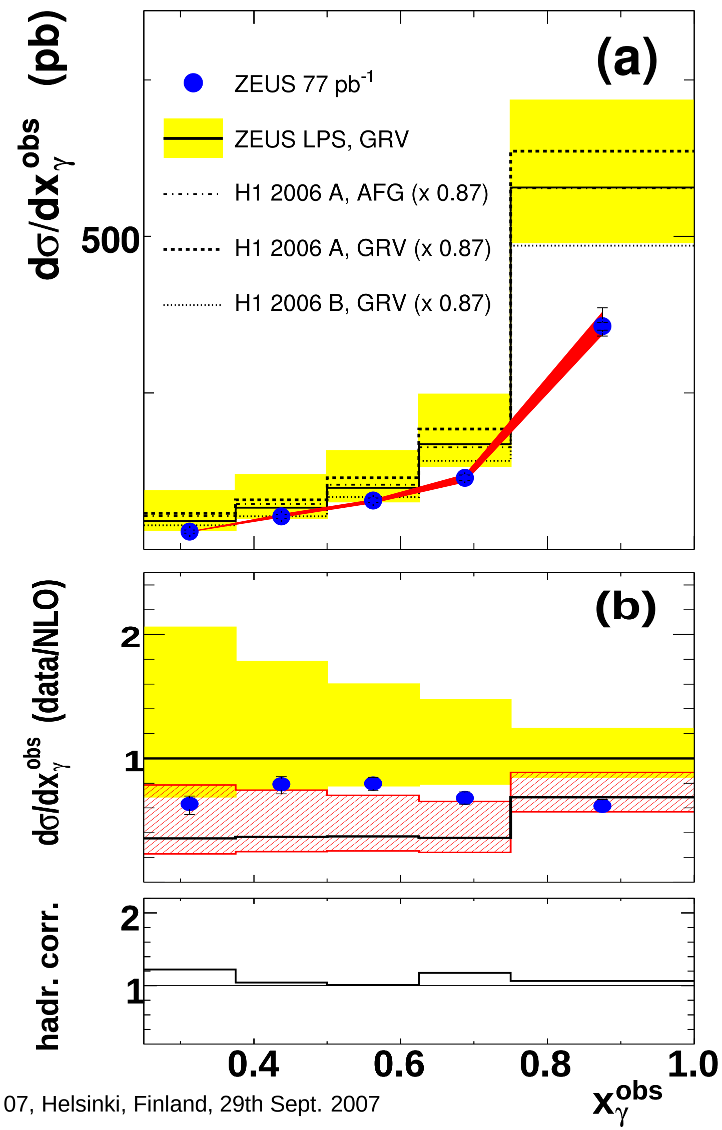
ZEUS: Dijets in Photoproduction

99-00 Data: $E_{T,jet1(2)} > 7.5(6.5)$ GeV ⟵ Higher E_T cuts vs H1

$< Q^2 >= .02\ \mathrm{GeV}^2$

$142 < W < 293$ GeV

$x_{I\!P} < 0.025$



NLO Predictions:

- Klasen-Kramer code
- Diffractive PDFs:
  - NLO Fits to ZEUS FPS + charm
  - H1 NLO Fit 2006 A
  - H1 NLO Fit 2006 B

- Data/NLO(FPS Fit) $\sim$ 0.7
- Data/NLO(H1 Fit B) $\sim$ 0.8-0.9

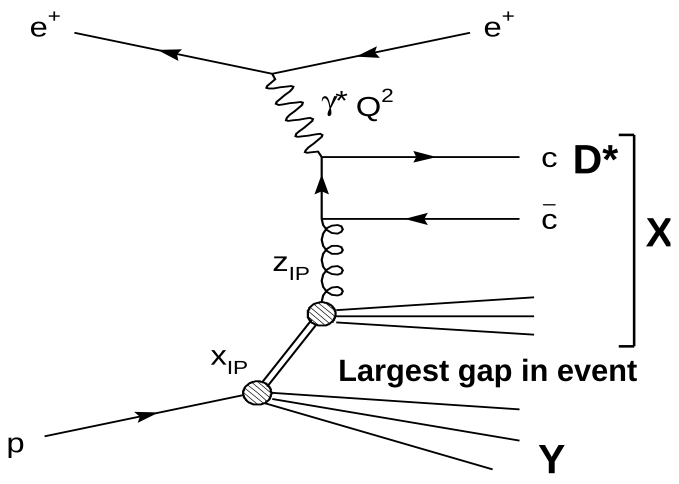
⟶ Factorisation breaking not seen in ZEUS Photoproduction Dijet within large theoretical errors

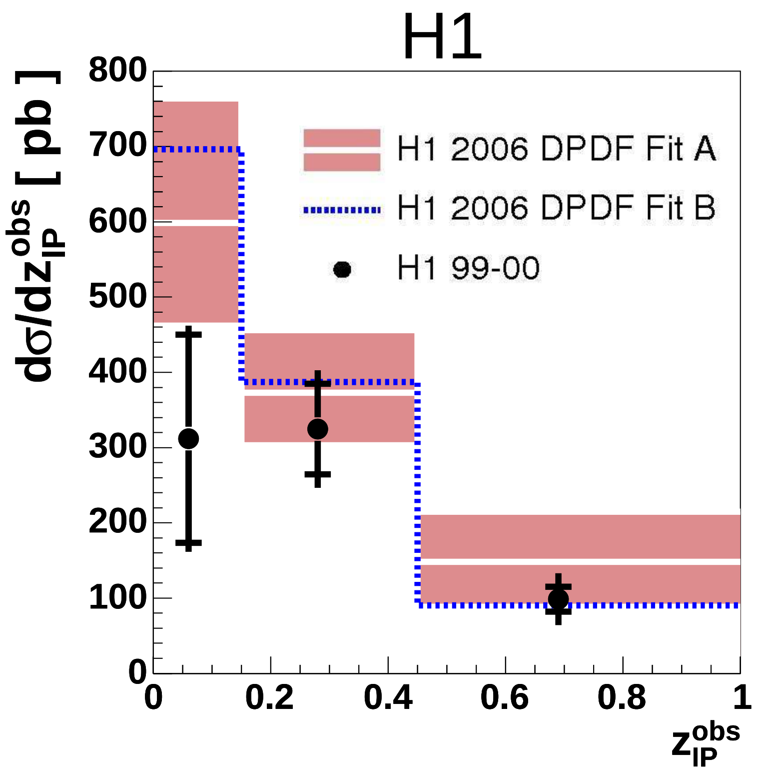
Ongoing investigation on possible sources of difference vs H1 (E_T cut, theory treatments,...)

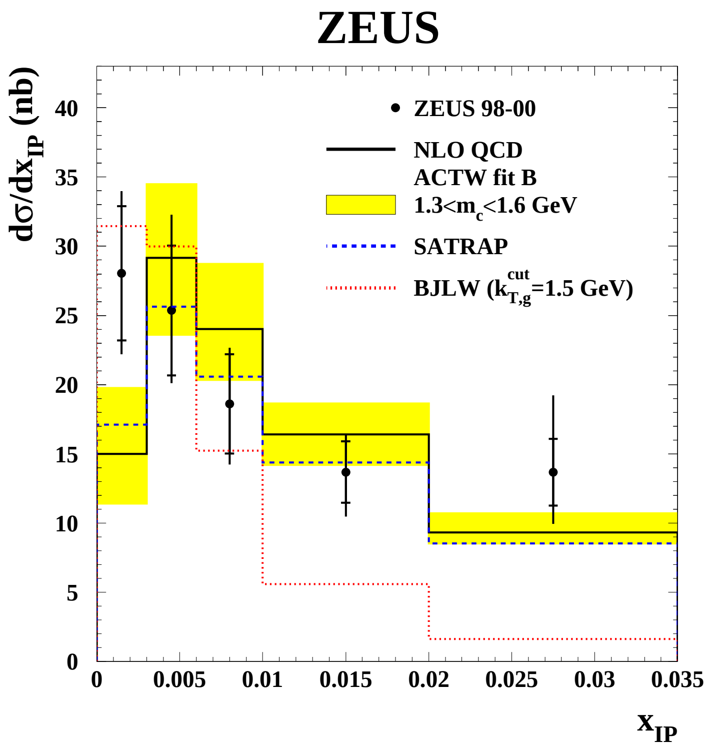
D^* in Diffractive DIS

- Charm offers direct access to gluon PDF
- Overall Good description by NLO QCD

  $\longrightarrow$ Factorisation valid for D^* in DIS



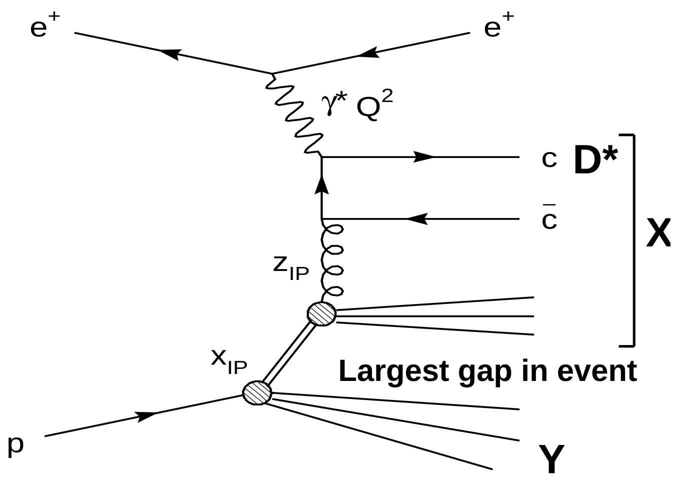


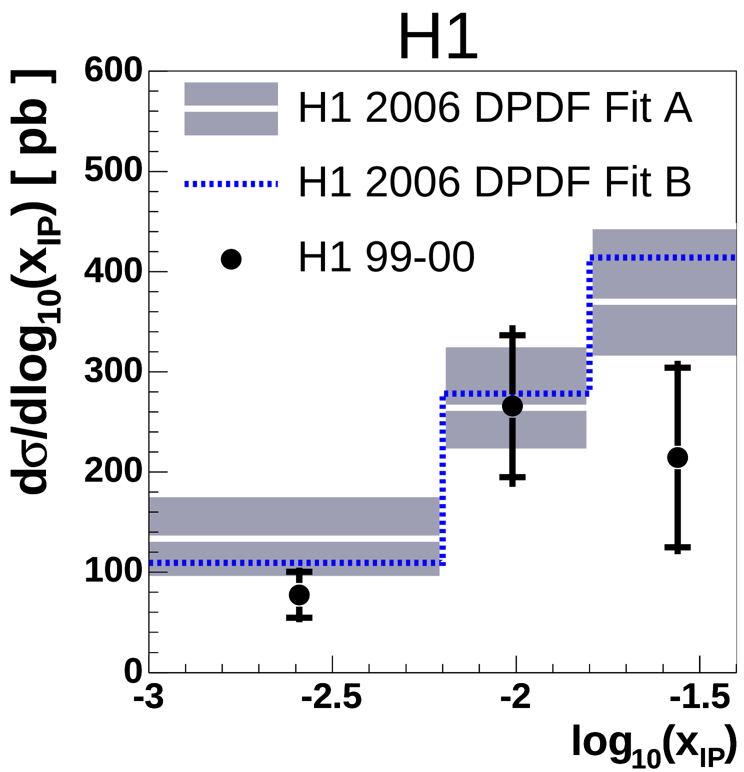


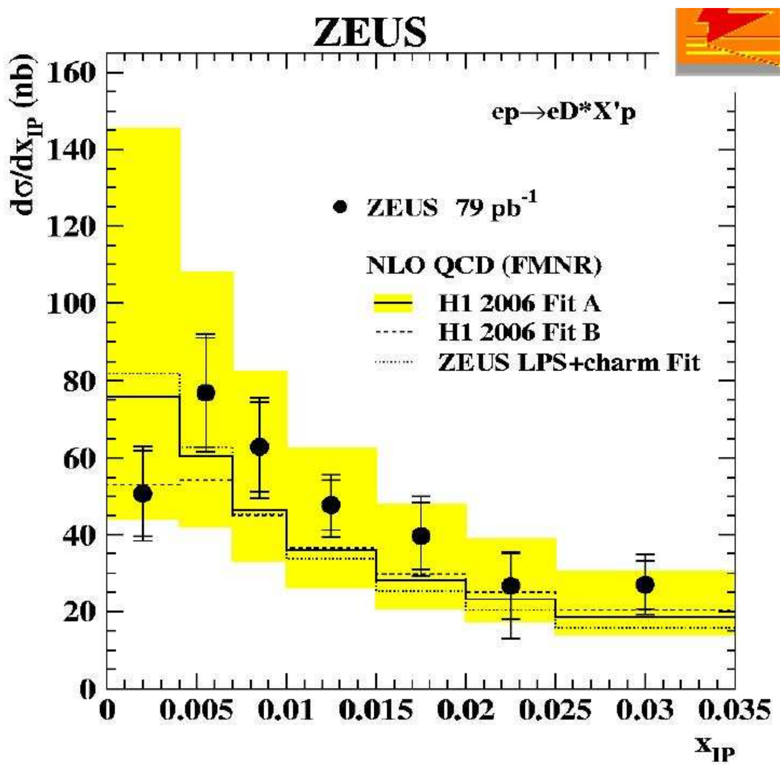
D^* in Diffractive Photoproduction

No evidence for factorisation breaking in D^* Photoproduction within errors

H1: $$\frac{(Data/NLO)_{php}}{(Data/NLO)_{DIS}} = 1.15 \pm 0.40 \text{ (stat.)} \pm 0.09 \text{ (syst.)}$$







QCD Analysis of H1 Data

- Fit H1 LRG data in fixed $x_{I\!P}$ binning using NLO DGLAP evolution of DPDFs (massive scheme) to describe x, Q^2 dependences
- Proton vertex factorisation framework assumed
- Fit all H1 LRG data with $Q^2 \geq 8.5\ \mathrm{GeV}^2, \mathrm{M_X} > 2\ \mathrm{GeV}, \beta \leq 0.8$
  $\longrightarrow$ Ensure stability of fit with variations of kinematic boundaries
- Parametrize:
  - quark singlet: $z\Sigma(z, Q_0^2) = A_q\ z^{B_q}\ (1-z)^{C_q}$
  - gluon density: $zg(z, Q_0^2) = A_g\ (1-z)^{C_g}$
    gluon insensitive to B_g
  - $\alpha_{I\!P}(0)$ (describes $x_{I\!P}$ dependence)
- Fix:
  - use world average for $\alpha_s(M_Z) = 0.118$
  - sub-leading $I\!R$ flux parameters taken from previous data
  - sub-leading $I\!R$ PDFs from Owens-π but free normalization
- Small number of parameters in DPDFs
  $\longrightarrow$ Need to optimize Q_0^2 wrt χ^2

SUMMARY

Inclusive Diffraction:

- Studied within the QCD framework by H1 and ZEUS with several methods (LRG, M_X and Proton Tag)
- Global agreement but some open points (p-diss, M_X vs LRG)
- Proton vertex factorisation provides a good approximation for the $x_{I\!P}$ dependence $\leftrightarrow$ $\alpha_{I\!P}(0)$ constant vs Q^2
- New Diffractive PDFs extracted from NLO QCD fits to H1 data

Final states and factorisation tests:

- Diffractive charm and dijets in DIS consistent with NLO predictions based on Diffractive PDFs $\leftrightarrow$ support factorisation
- Diffractive dijets in DIS constraint further Diffractive PDFs
- H1 data on dijets in PhP indicates factorisation breaking for both direct and resolved components by a factor 0.5
- However, ZEUS data on dijets in PhP do not confirms this factorisation breaking (but large theory uncertainties)

New H1 Data with Rapidity Gap Method

- H1 published data
- H1 Prelim. 99-00, 34 pb^{-1}

  $10 < Q^2 < 105$ GeV^2
- H1 Prelim. 2004, 34 pb^{-1}

  $17.5 < Q^2 < 105$ GeV^2
- Large increase in statistics
- Consistent with publised data