

# Measurement of the Longitudinal Structure Function in Diffraction

$$F_L^D$$

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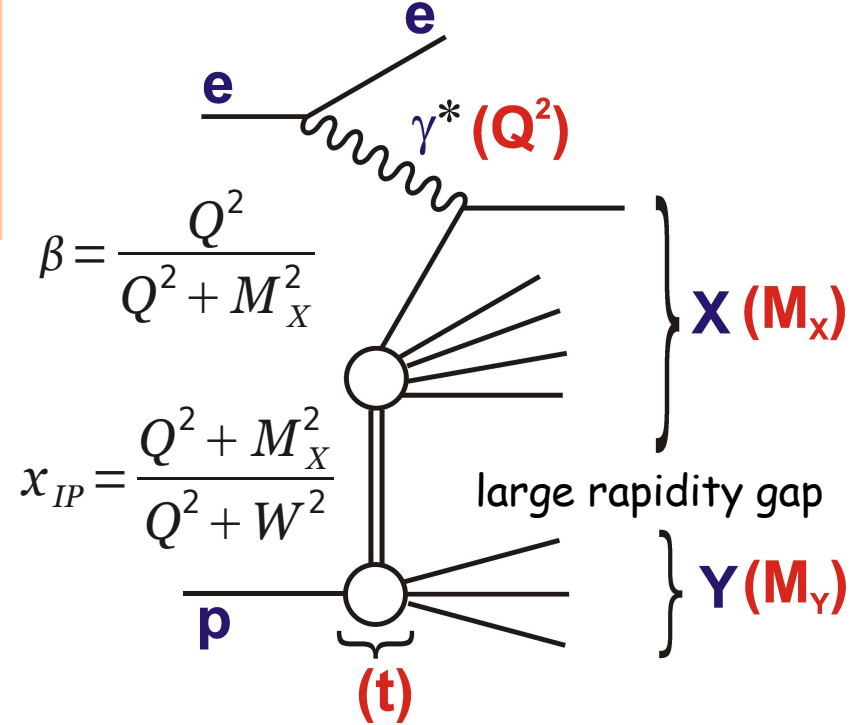
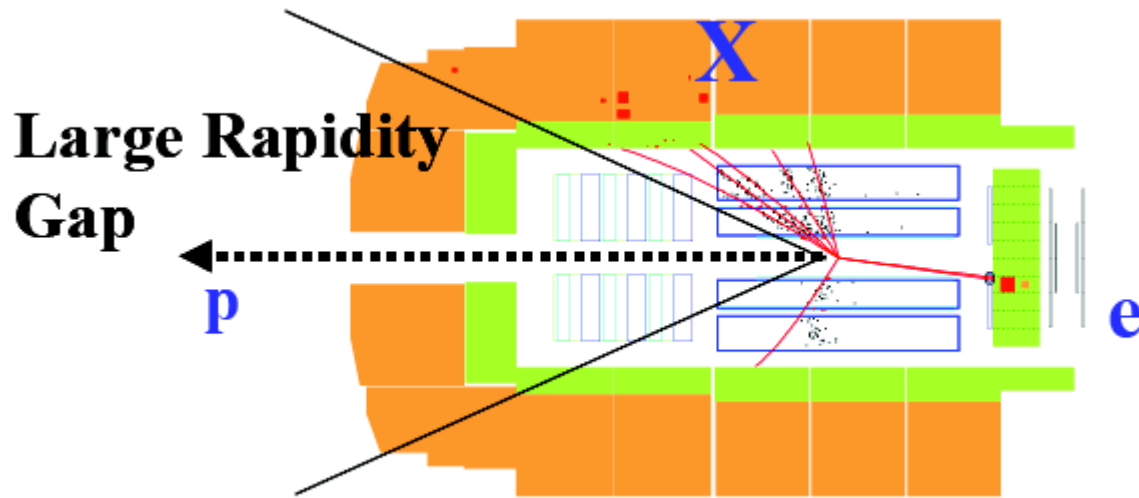
Diffraction Conference

Otranto, Italy

September 10 - 15, 2010



# Diffractive DIS



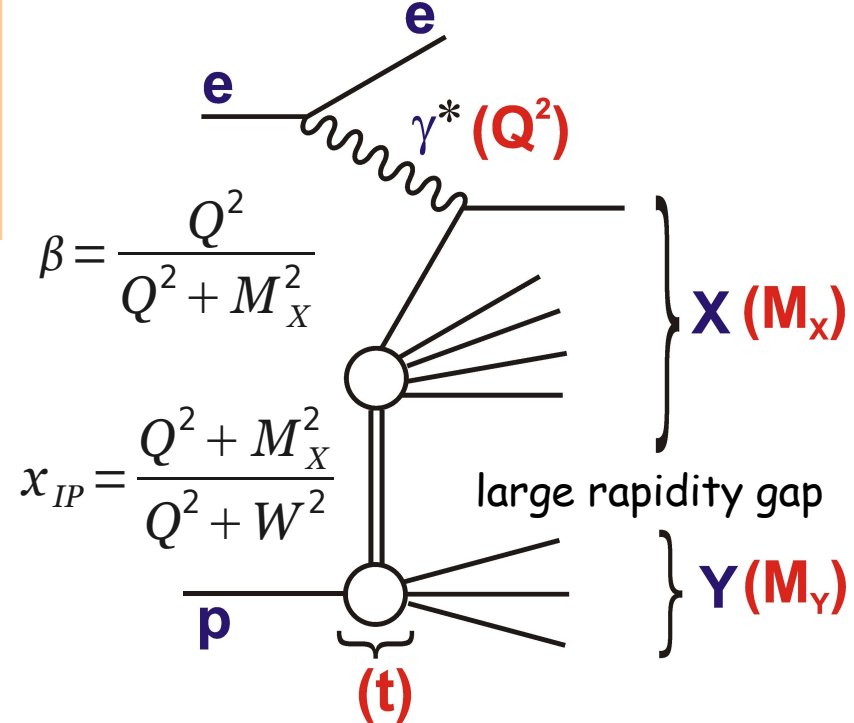
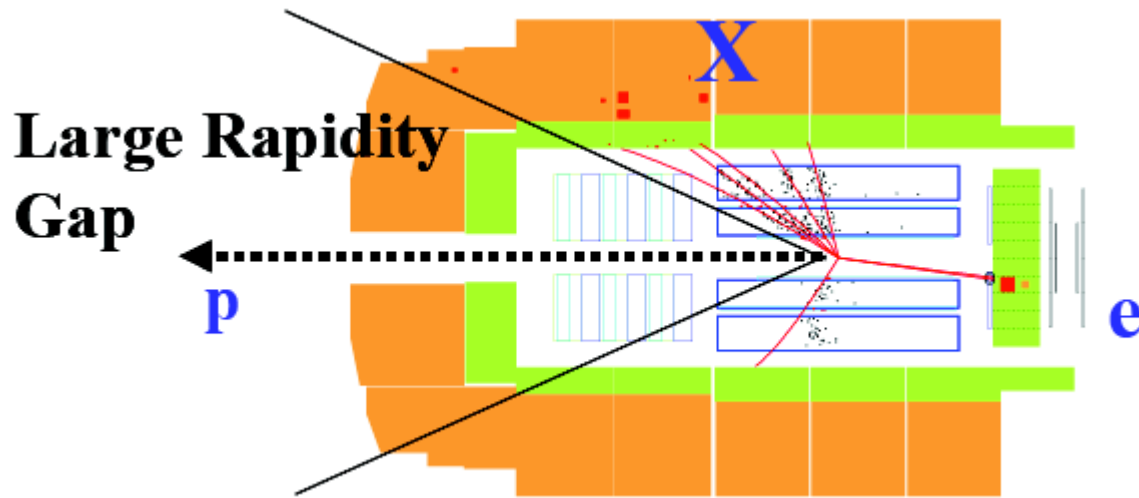
- diffractive reduced cross section

$$\sigma_r^D = F_2^D - \frac{y^2}{Y_+} F_L^D$$

$$Y_+ = 1 + (1 - y)^2$$

$$\frac{d^3 \sigma^{ep \rightarrow eXY}}{dx_{IP} d\beta dQ^2} = \frac{2\pi\alpha^2}{\beta Q^4} Y_+ \sigma_r^D(x_{IP}, \beta, Q^2)$$

# Diffractive DIS



- diffractive reduced cross section

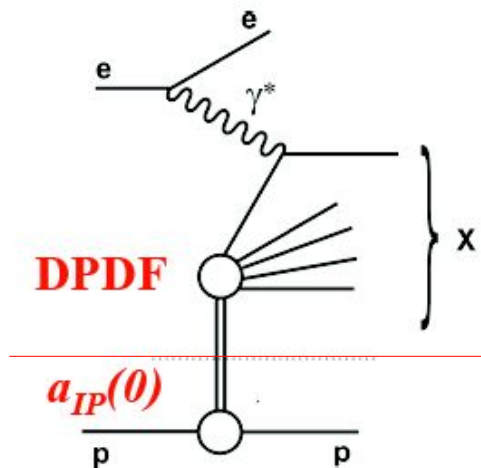
$$\sigma_r^D = F_2^D - \frac{y^2}{Y_+} F_L^D$$

$$Y_+ = 1 + (1 - y)^2$$

- this analysis focuses on the diffractive longitudinal proton structure function

# QCD Factorisation in Diffraction

- diffractive parton densities
  - extracted from the inclusive measurements
  - $x_{IP}$  dependence factorised



→ H1 2006 DPDF Fits

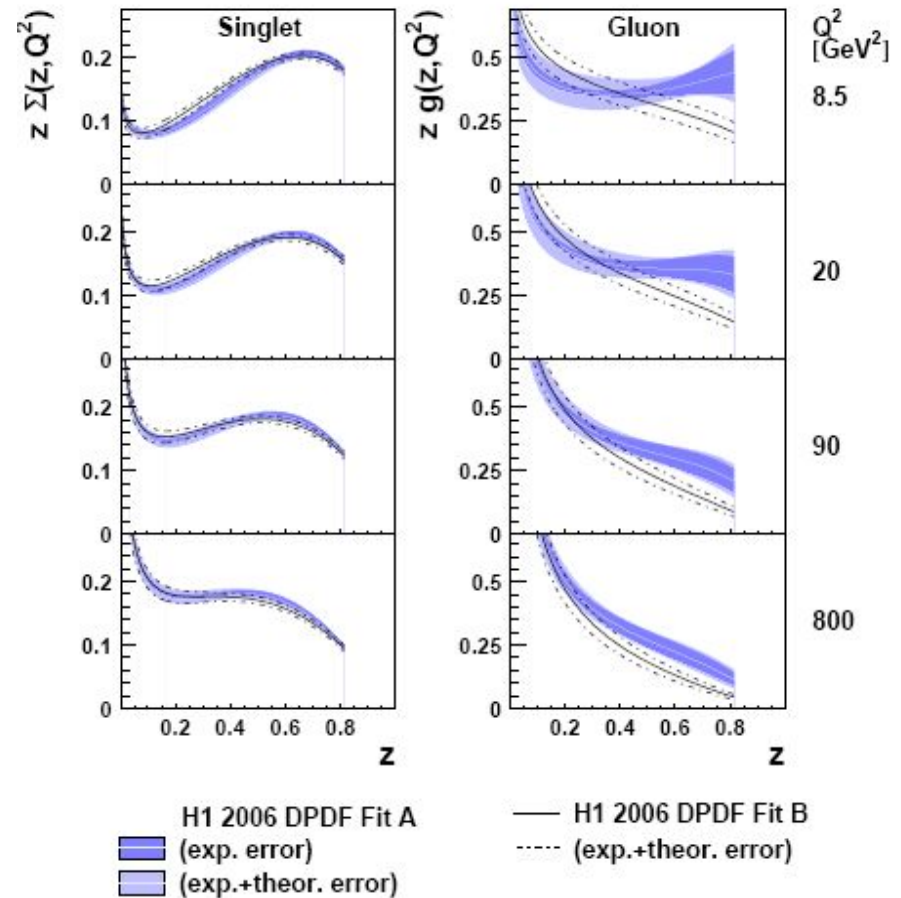
- NLO QCD fit ( $\beta$  and  $Q^2$  dependence)
- singlet parametrisation:

$$z\Sigma(z, Q_0^2) = A_q z^{B_q} (1-z)^{C_q}$$

- 2 gluon parametrisations:

- Fit A  $z_g(z, Q_0^2) = A_g (1-z)^{C_g}$

- Fit B  $z_g(z, Q_0^2) = A_g$

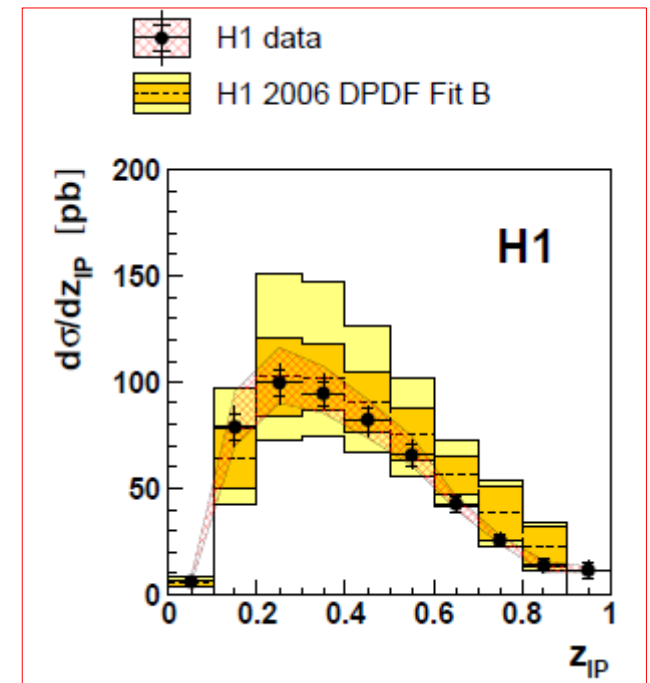
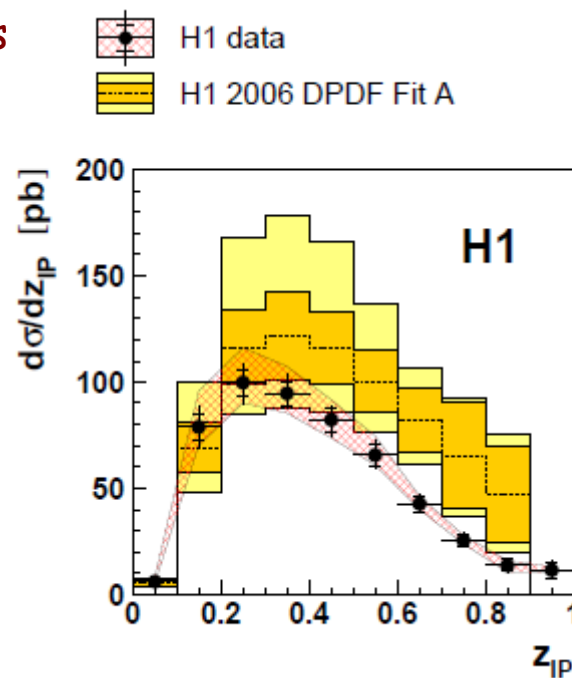


# QCD Factorisation in Diffraction

- inclusive measurements constrain quarks
- gluons are constrained weakly from the scaling violations

$$\frac{d\sigma_r^D}{d\ln Q^2}$$

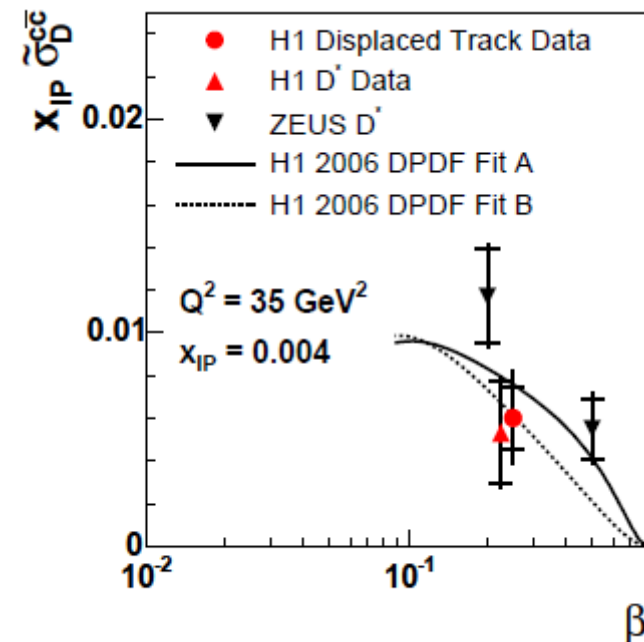
- diffractive dijets in DIS
  - compatible with the parton densities from H1 2006 DPDF Fits
  - QCD factorisation holds
  - Fit B preferred



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- diffractive charm production
  - low statistics

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# QCD Factorisation in Diffraction

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  - QCD factorisation holds
  - Fit B preferred
- diffractive charm production
  - low statistics
- FLD measurement
  - probes low  $x_{IP}$  and  $\beta$  region inaccessible by dijets and  $D^*$

$$\frac{d\sigma_r^D}{d\ln Q^2}$$

$$F_L^D \sim x g(x)$$

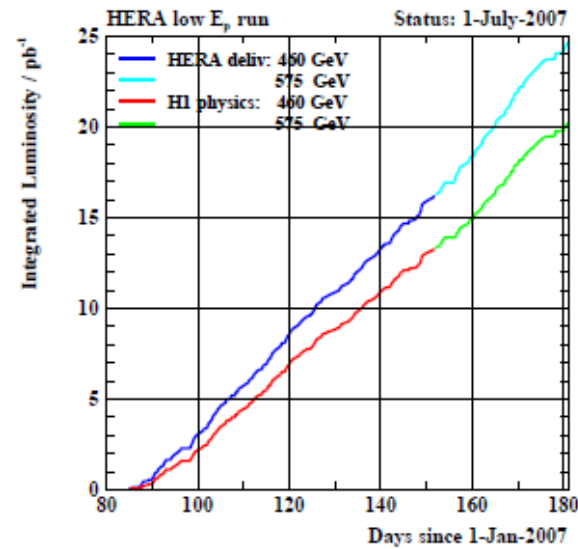
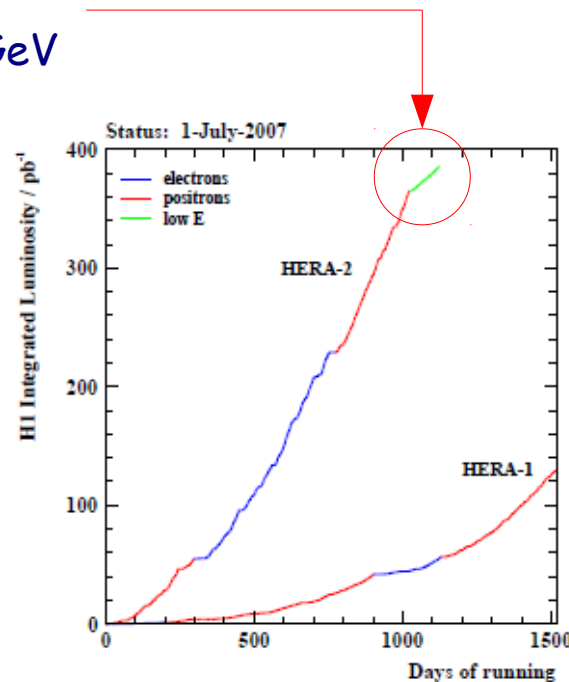
# HERA Low Energy Runs

- last months of HERA running were dedicated to the measurements of  $F_L$  and  $F_L^D$

→ low energy runs

- $E_p = 460 \text{ GeV}$

- $E_p = 575 \text{ GeV}$



- nominal proton beam energy

- $E_p = 820 \text{ GeV}$

- $E_p = 920 \text{ GeV}$



# Measurement Strategy

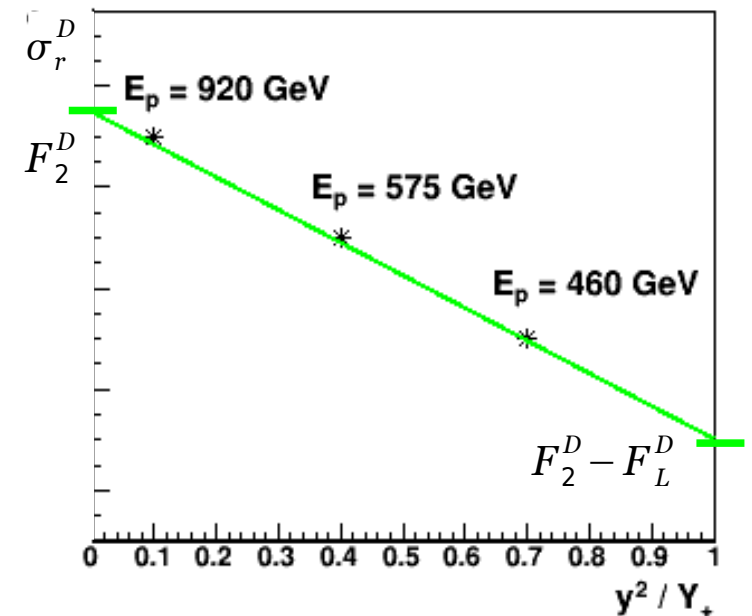
- analysis closely follows the measurement of the inclusive  $F_L$  by H1 (published as DESY-08-053)
- Rosenbluth plots
  - separate the structure functions  $F_L^D$  and  $F_2^D$  by combining measurements at different  $y$  (for the fixed  $x_{IP}, \beta, Q^2$ )

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

$$Q^2 = x_{IP} \beta y s$$

- data at different centre-of-mass energy needed

- $2 \text{ pb}^{-1}$       $E_p = 820 \text{ GeV}$
- $21 \text{ pb}^{-1}$      $E_p = 920 \text{ GeV}$
- $6 \text{ pb}^{-1}$       $E_p = 460 \text{ GeV}$
- $4 \text{ pb}^{-1}$       $E_p = 575 \text{ GeV}$



# Data Selection and H1 Detector

- diffractive selection:

- large rapidity gap  $\rightarrow \eta_{max} < 3.3$

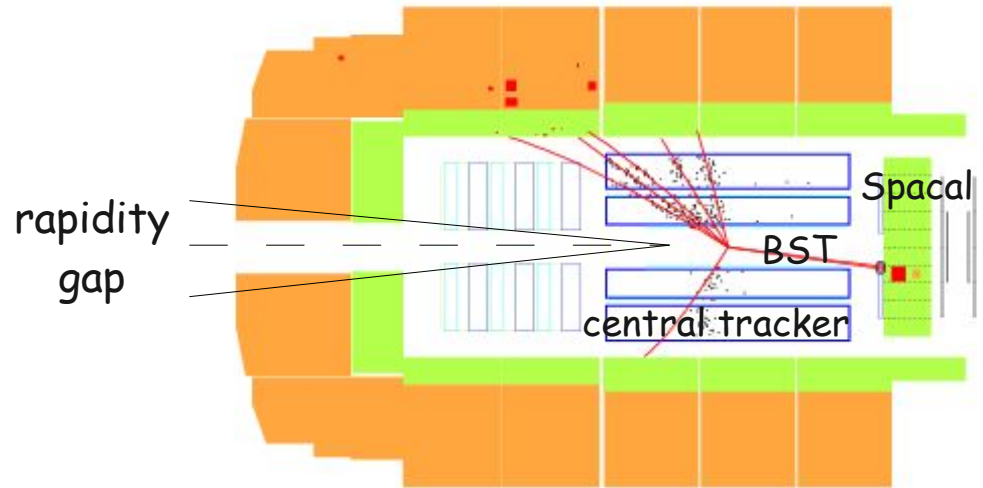
- $F_L^D$  selection:

- $Q^2 > 2.5 \text{ GeV}^2$
- high  $y$  region sensitive to  $F_L^D \rightarrow y < 0.9$

- kinematic variables reconstructed from the scattered positron

$$Q^2 = 4 E_e E_e' \cos^2 \frac{\theta_e}{2} \quad y = 1 - \frac{E_e'}{E_e} \sin^2 \frac{\theta_e}{2} \approx 1 - \frac{E_e'}{E_e}$$

- low scattered positron energy  $\rightarrow E_e' > 3.4 \text{ GeV}$
- high level of photoproduction background
- challenging measurement requiring precise positron identification
  - cluster (Spacal calorimeter)
  - track (central tracker and/or Backward Silicon Tracker)



# Background at High $y$

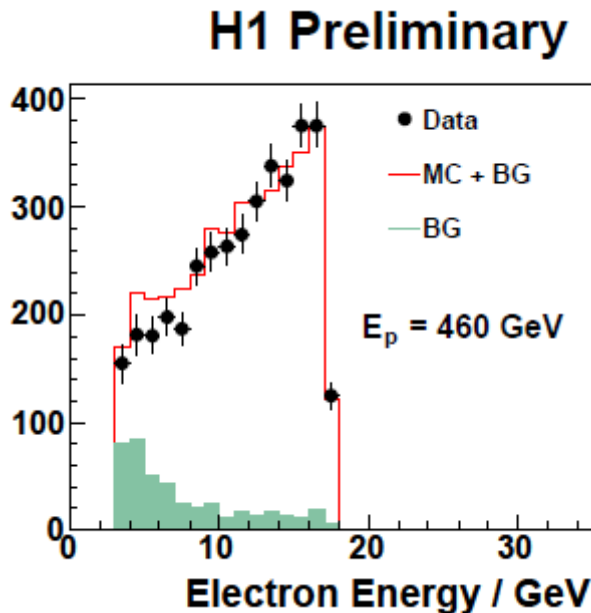
- data at high  $y$  contain photoproduction background
  - scattered positron escapes the central detector through the beam-pipe
  - one of the hadronic final state particles is mis-identified as the scattered positron
  - background from hadronic particles is almost charge symmetric  $\frac{N_{bg}^+}{N_{bg}^-} \sim 1$
- background subtraction using the charge of the scattered positron candidate

$$N^+ = \text{signal events} + \text{background from } \pi^+$$

$$N^- = \text{background from } \pi^-$$

$$N_{\text{signal}} = N^+ - N^-$$

# Monte Carlo Simulation



data with positive charge

background determined from the data with negative charge

signal Monte Carlo (based on H1 2006 DPDF Fit B) + background from data

- Monte Carlo does not simulate  $F_L^D \rightarrow$  it overshoots data at high  $y$

$$\sigma_r^D(F_L^D = 0) = F_2^D$$

# Normalisation of Data Sets

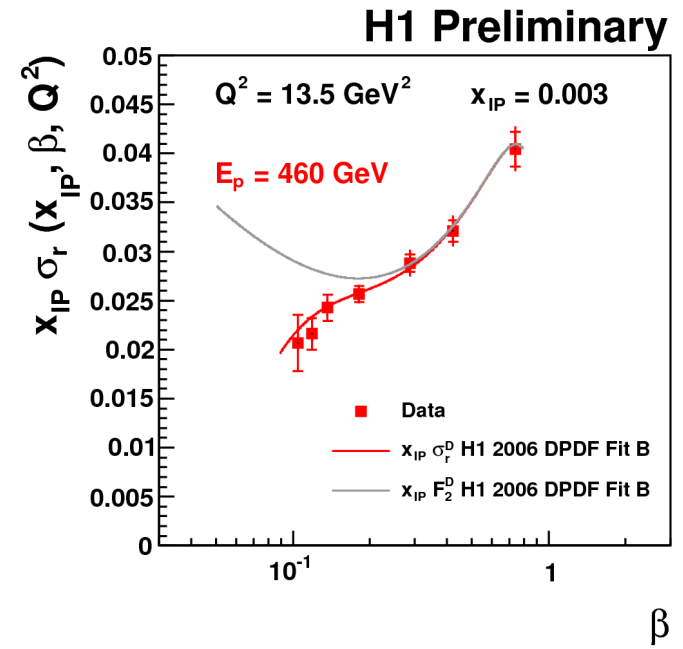
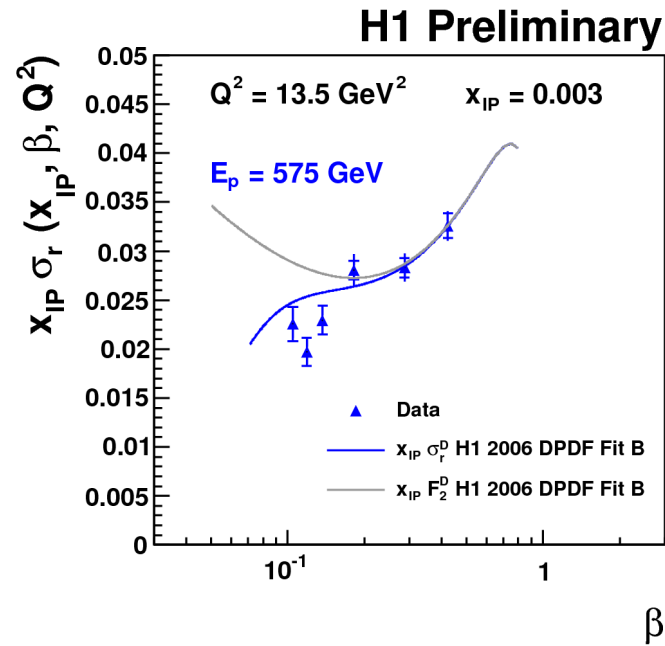
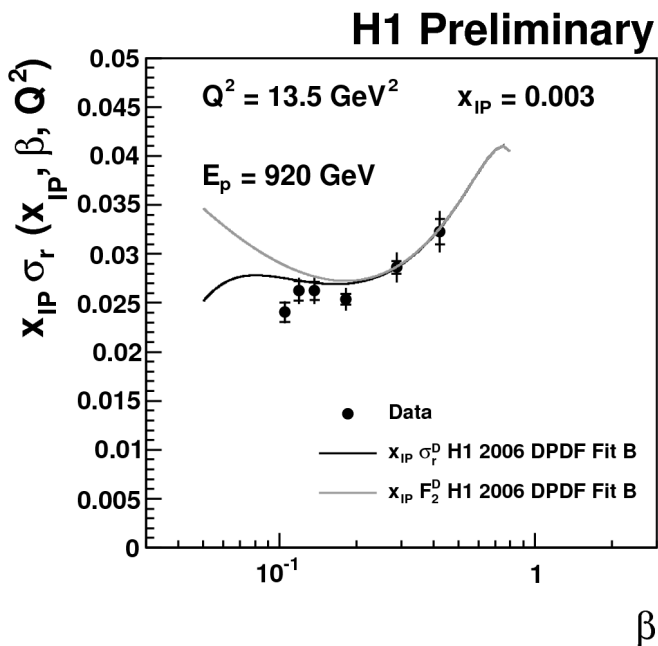
- data cross section is corrected for proton dissociation
  - rapidity gap selection accepts events with dissociated protons up to  $M_Y = 1.6 \text{ GeV}$  (acceptance of the forward detectors near the beam pipe)
  - 7% uncertainty → can it be reduced?
- use as constraint that  $F_2^D$  is independent of the beam energy
  - no significant contribution from  $F_L^D$  at low  $y$  (high  $\beta$ )
  - data cross sections normalised to H1 2006 DPDF Fit B at  $Q^2 = 13.5 \text{ GeV}^2$ ,  $0.28 < \beta < 0.42$  in order to give the same  $F_2^D$
  - normalisation changed by  $< 4\%$
  - uncertainty reduced to 2.5%

$$\sigma_r^D = F_2^D - \frac{y^2}{Y_+} F_L^D$$

$$Q^2 = x_{IP} \beta y s$$

# Diffraction Reduced Cross Sections

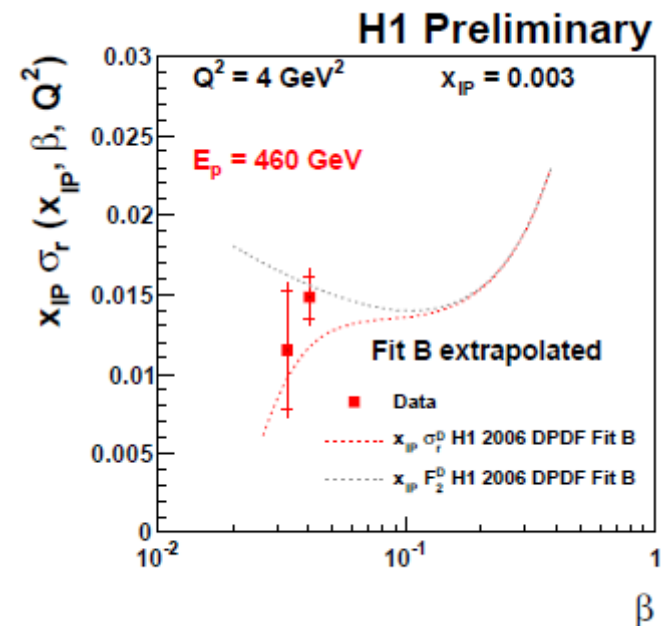
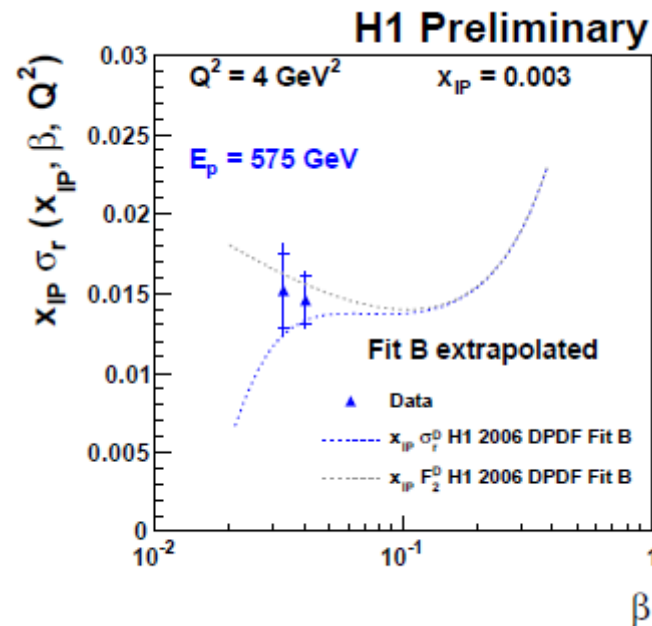
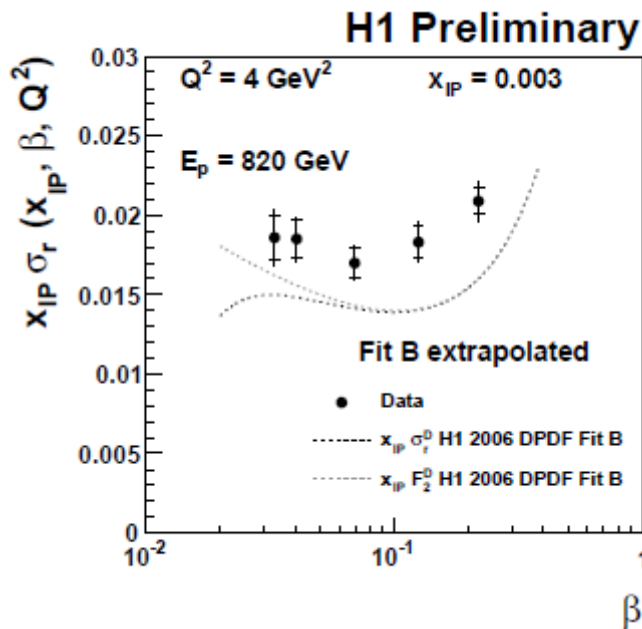
- $7 < Q^2 < 32 \text{ GeV}^2$
- $E_p = 920, 575, 460 \text{ GeV}$



- cross sections agree with H1 2006 DPDF Fit B
- contribution of non-zero  $F_L^D$  observed  $\rightarrow$  fall at low  $\beta$
- prediction for  $\sigma_r^D (F_L^D = 0) = F_2^D$  overestimates data

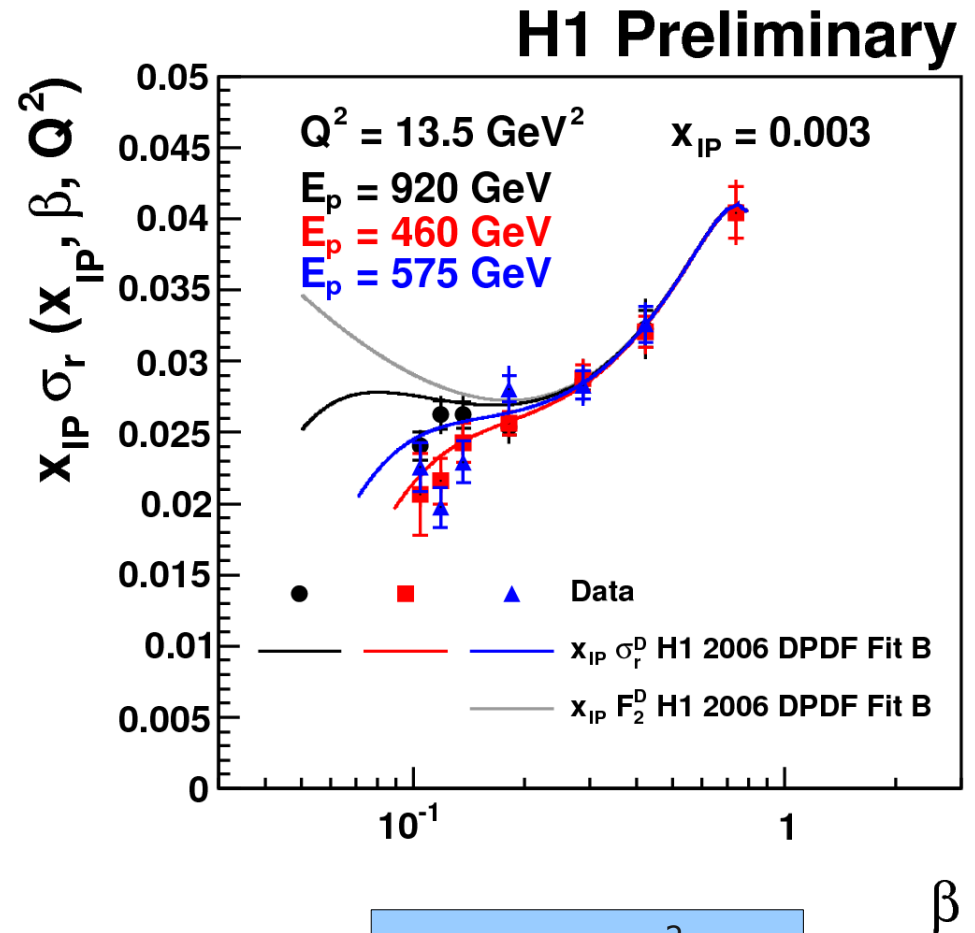
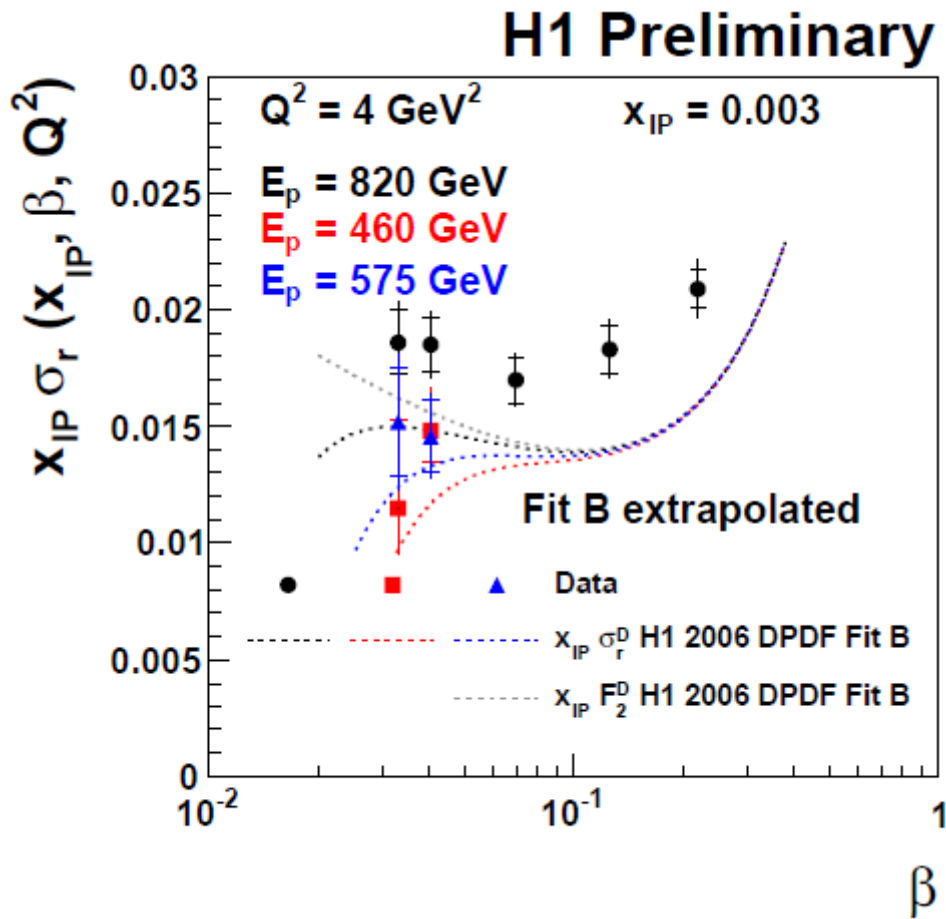
# Diffractive Reduced Cross Sections

- $2.5 < Q^2 < 7 \text{ GeV}^2$
- $E_p = 820, 575, 460 \text{ GeV}$



- data at  $E_p = 820 \text{ GeV}$  from the publication DESY-06-049
  - cover larger  $\beta$  range
  - used to determine H1 2006 DPDF Fit A and Fit B
  - the Fits are known to underestimate data at  $Q^2 < 8.5 \text{ GeV}^2$

# Sensitivity to $F_L^D$



- data cross sections are sensitive to  $F_L^D$

$$\sigma_r^D = F_2^D - \frac{y^2}{Y_+} F_L^D$$

$$Q^2 = x_{IP} \beta y s$$

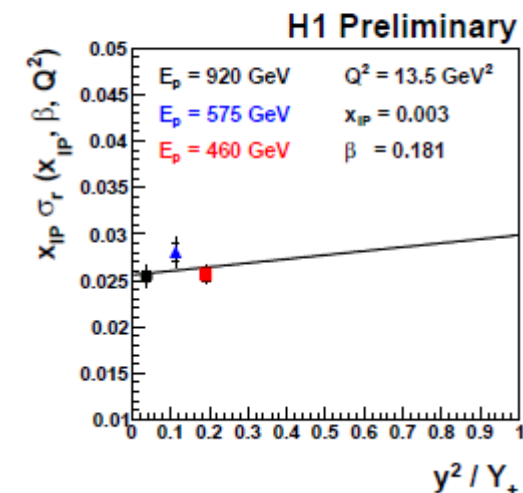
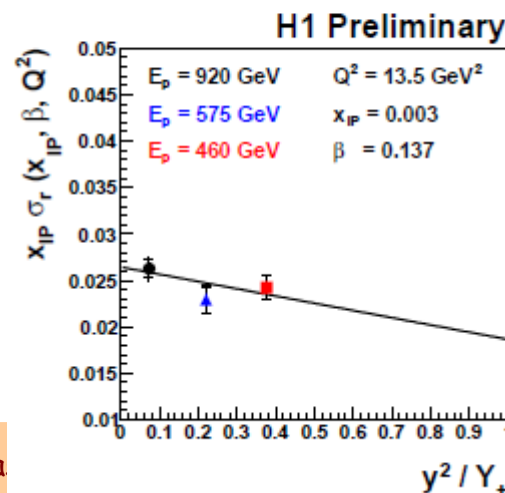
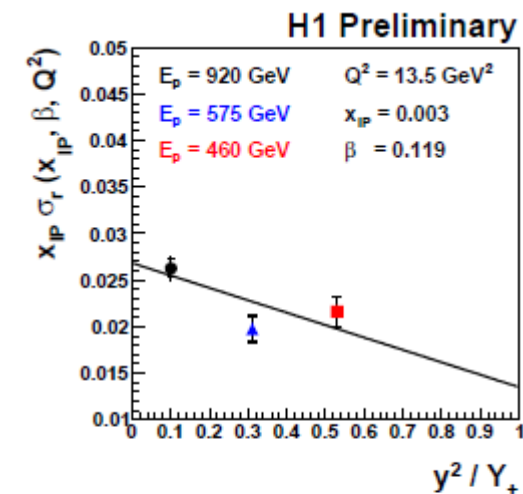
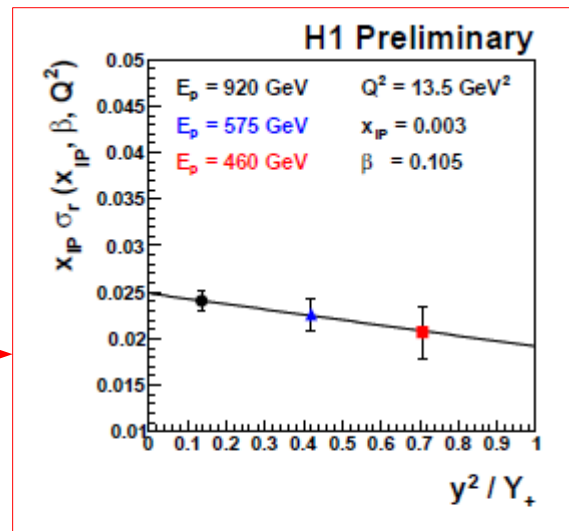
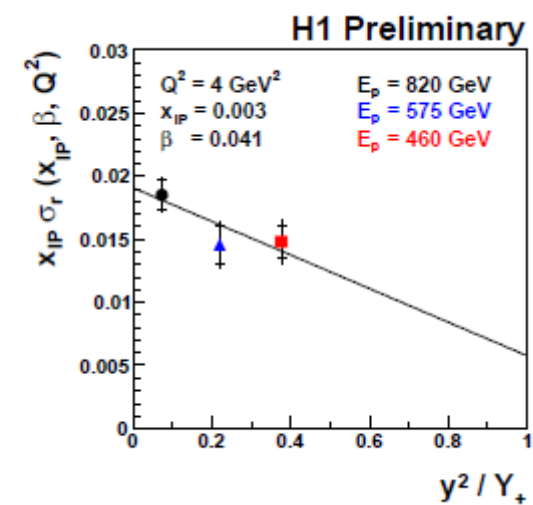
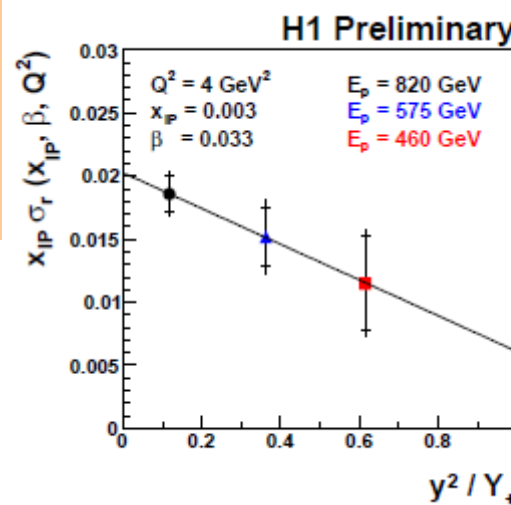


# $F_L^D$ Fits

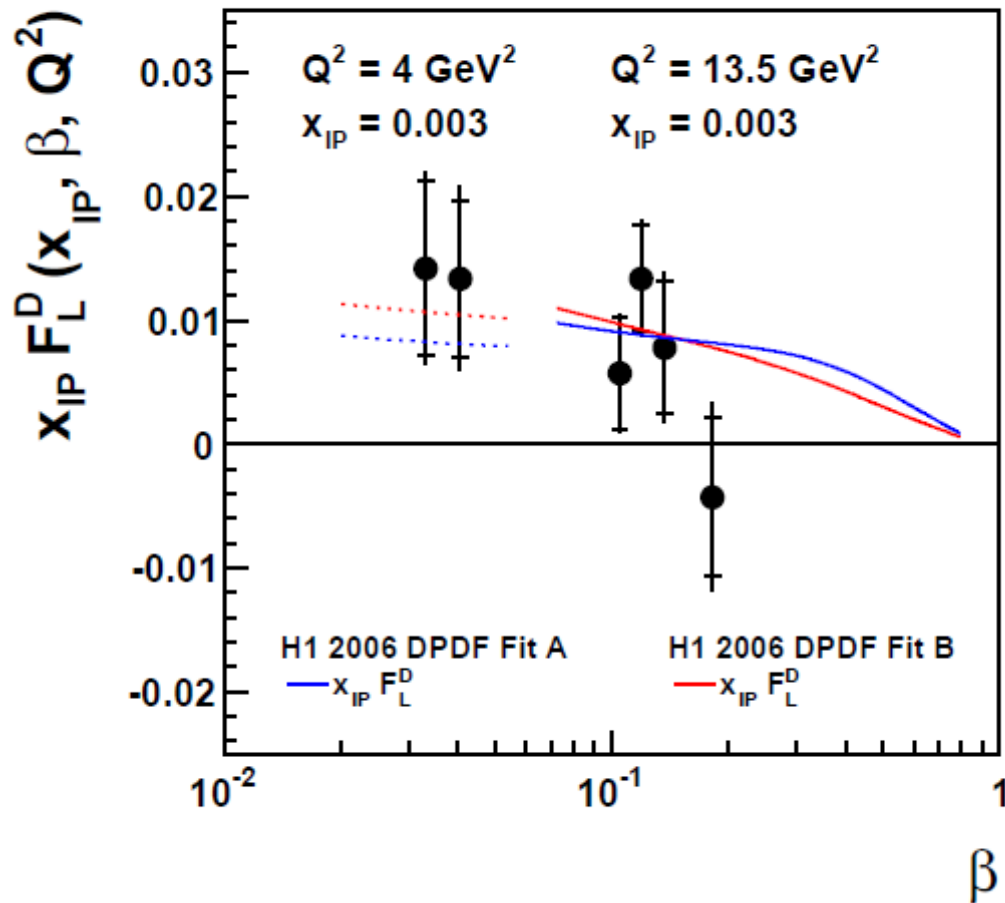
- linear fit in the Rosenbluth plots to obtain  $F_2^D$  and  $F_L^D$

$$\sigma_r^D = F_2^D - \frac{y^2}{Y_+} F_L^D$$

- highest sensitivity to  $F_L^D$  at high  $y$  (low  $\beta$ )



# H1 Preliminary $F_L^D$

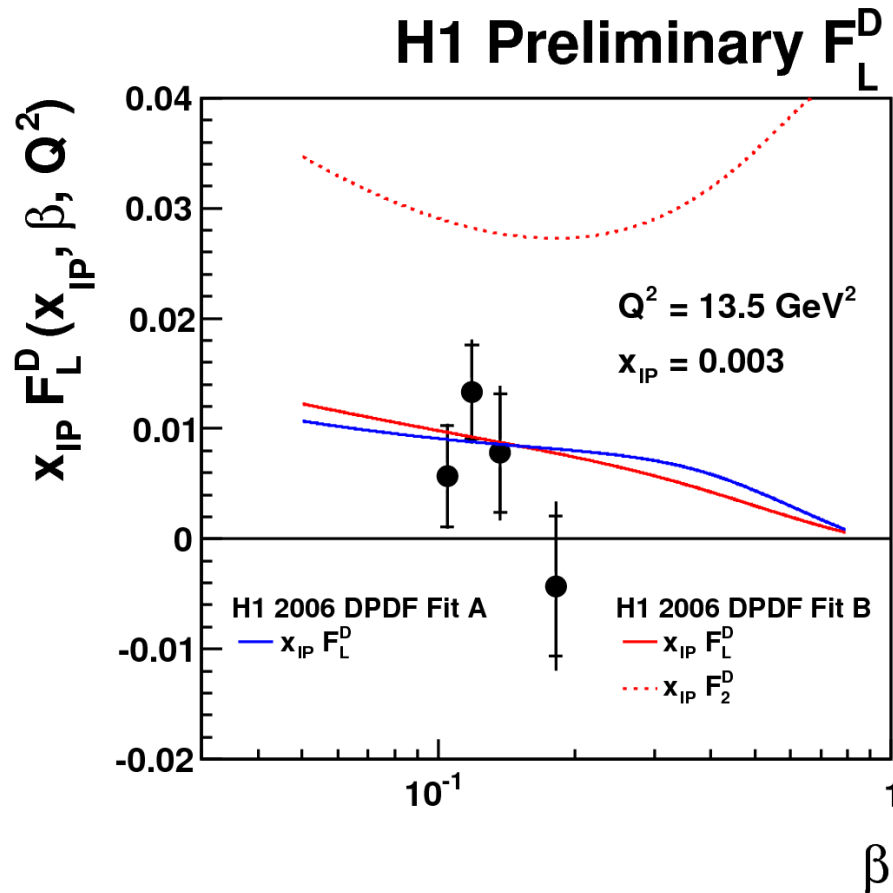


## $F_L^D$ Results

- $F_L^D$  is measured in the kinematic region:
  - $2.5 < Q^2 < 32 \text{ GeV}^2$
  - $0.001 < x_{IP} < 0.01$
- measurements are corrected to:
  - $Q^2 = 4 \text{ and } 13.5 \text{ GeV}^2$
  - $x_{IP} = 0.003$

- significantly non-zero results (more than  $5\sigma$ )
- consistent with the H1 2006 DPDF Fits
  - based on DPDF's and factorisation
  - extrapolation of the Fits shown for  $Q^2 = 4 \text{ GeV}^2$

# $F_L^D$ Results



- $F_2^D$  prediction gives the upper bound for  $F_L^D$  in the range of validity of the Fits

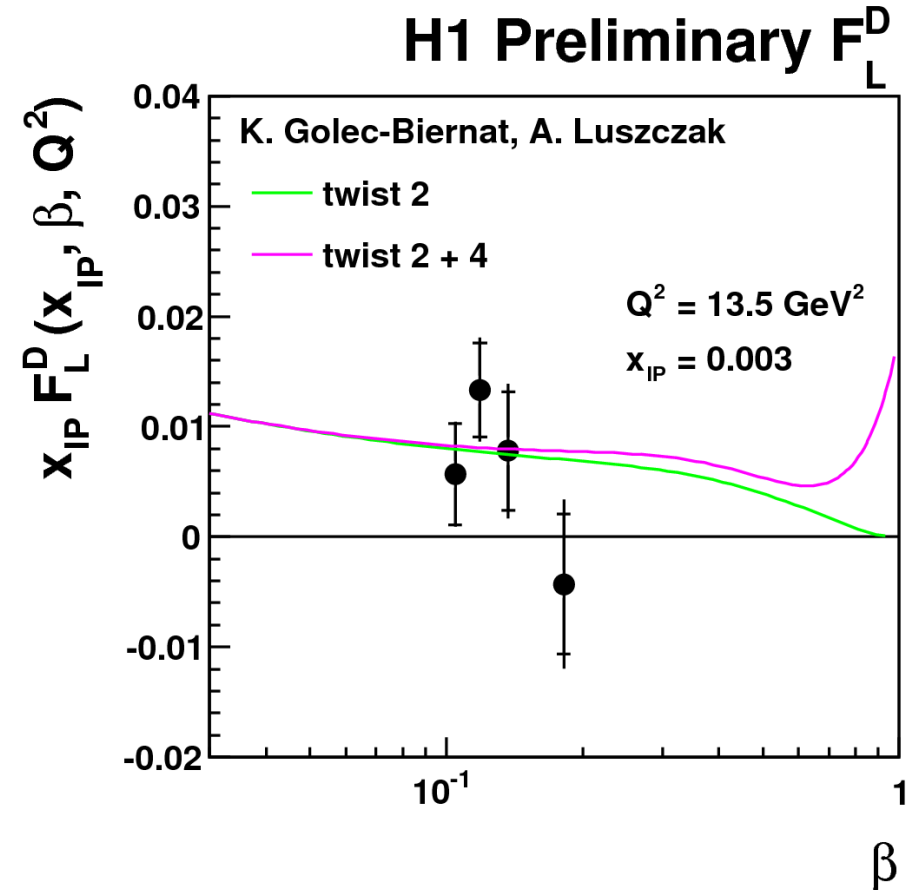
# QCD Fits and Higher Twist Effects

- higher twist longitudinal contribution to diffraction at high  $\beta$  implies large  $F_L^D$  (e.g. BEKW)

- $F_2^D$  dominated by  $F_L^D$  at high  $\beta$  and low  $Q^2$

$$F_2 = F_T + F_L$$

- QCD fits from H1 only consider the leading twist and do not predict large  $F_L^D$



- measurement is also consistent with K. Golec-Biernat et al.
- no sensitivity to the twist 4 contribution in the current  $\beta$  range

# Summary

- **the first  $F_L^D$  measurement**
- significant non-zero value (more than  $5\sigma$ )
- a new, independent test of the diffractive gluon density
- verification of the QCD factorisation in diffractive DIS
  - dijets
  - $D^*$
  - $F_L^D$
- $F_L^D$  measured at  $Q^2 = 13.5 \text{ GeV}^2$ ,  $x_{IP} = 0.003$  and  $\beta \sim 0.1$   
 $Q^2 = 4 \text{ GeV}^2$ ,  $x_{IP} = 0.003$  and  $\beta \sim 0.03$