

Measurement of the Longitudinal Structure Function in Diffraction

$$F_L^D$$

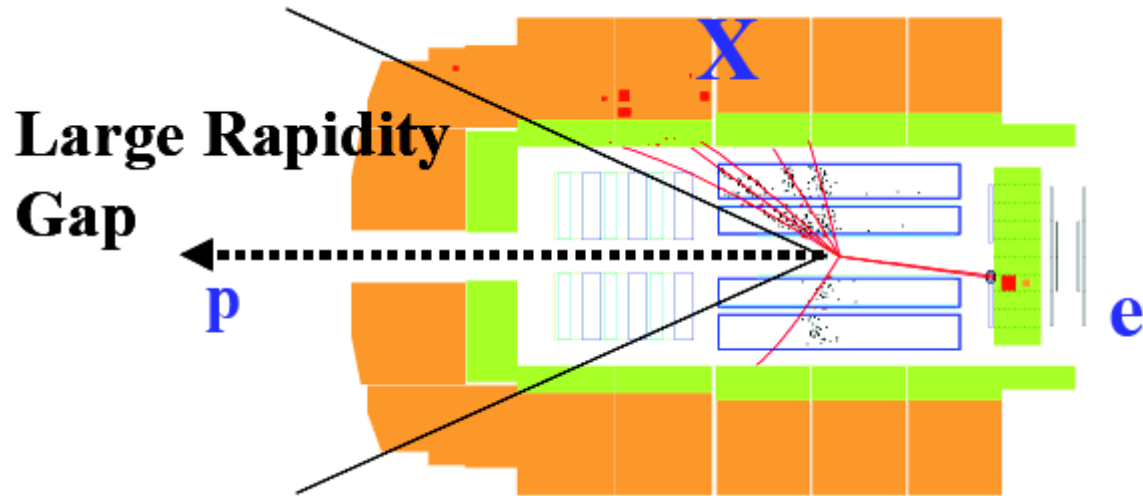
David Šálek

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Charles University, Prague

Low x Workshop, Italy, September 2009



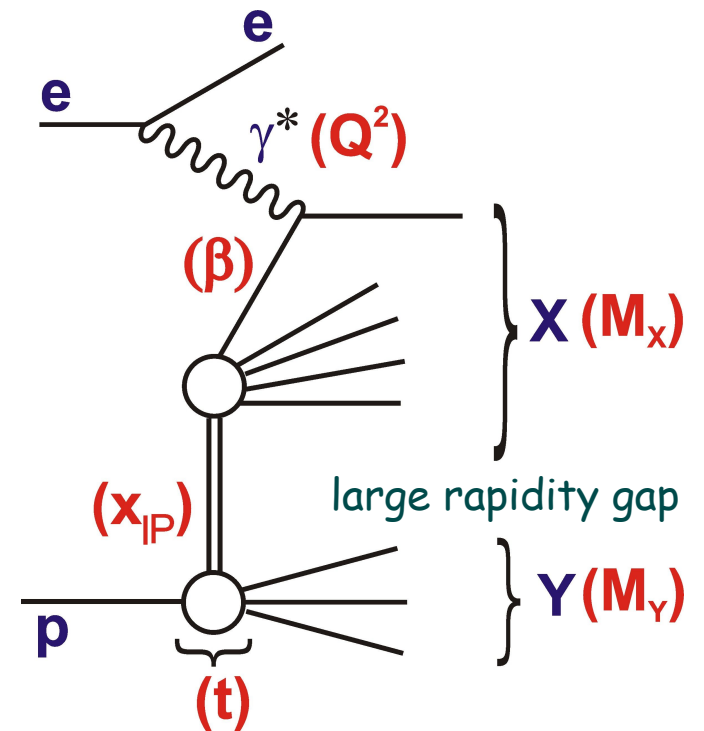
Diffractive Kinematics and Rapidity Gap



$$x = x_{IP} \beta$$

$$\beta = \frac{Q^2}{Q^r + M_X^2}$$

$$x_{IP} = \frac{Q^2 + M_X^2}{Q^r + W^2}$$



Proton Structure Functions in Diffraction

- structure functions F_2^D and F_L^D (similar to inclusive F_2 and F_L)

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

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

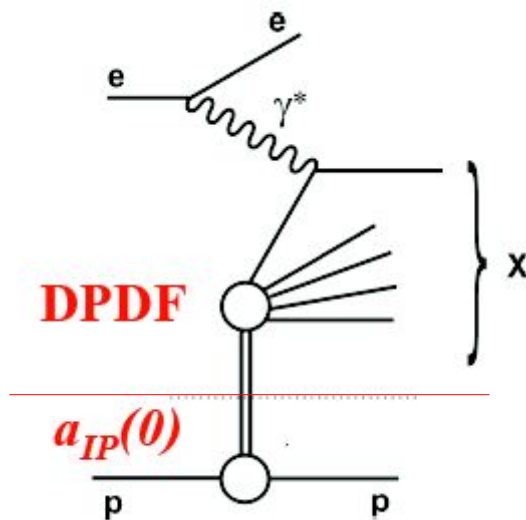
$$Y_+ = 1 + (1 - y)^2$$

- F_L^D contributes to the reduced cross section mainly at high y (low β)

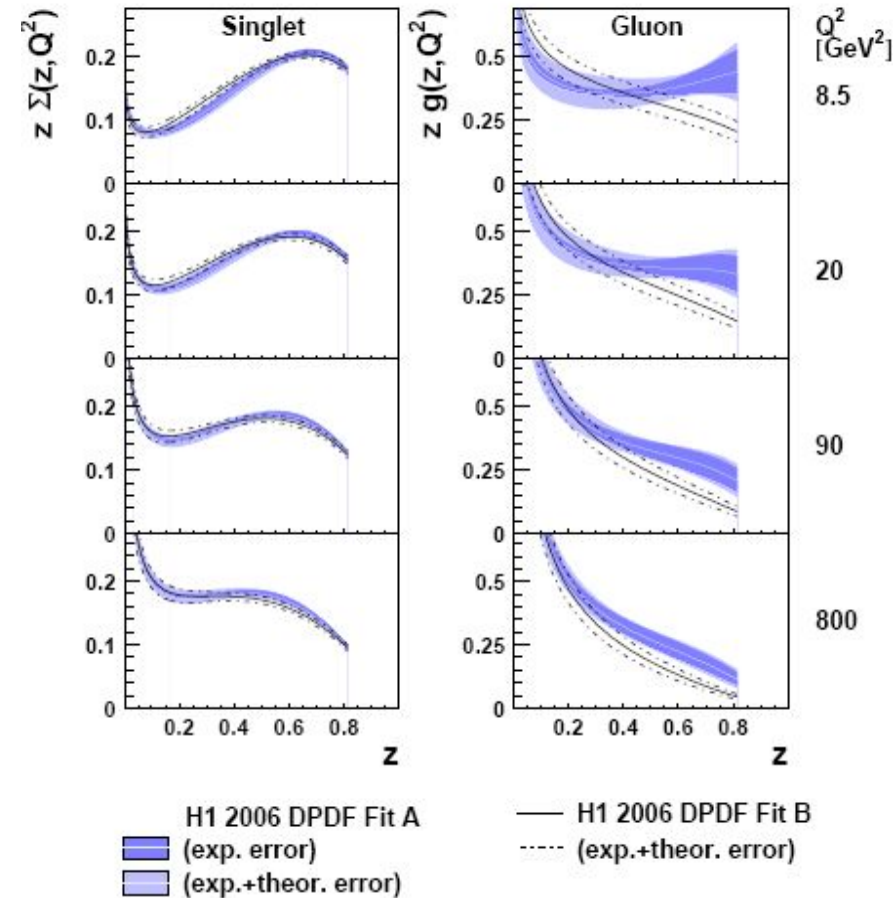
$$Q^2 = x_{IP} \beta y s$$

QCD Factorisation in Diffraction

- diffractive parton densities are extracted from the inclusive measurements from the NLO QCD fit (β and Q^2 dependence)
 - singlet: $z\Sigma(z, Q_0^2) = A_q z^{B_q} (1-z)^{C_q}$
 - gluon: 2 parametrisations (Fit A and Fit B)



x_{IP} dependence is factorised in the pomeron flux $\alpha_{IP}(0)$



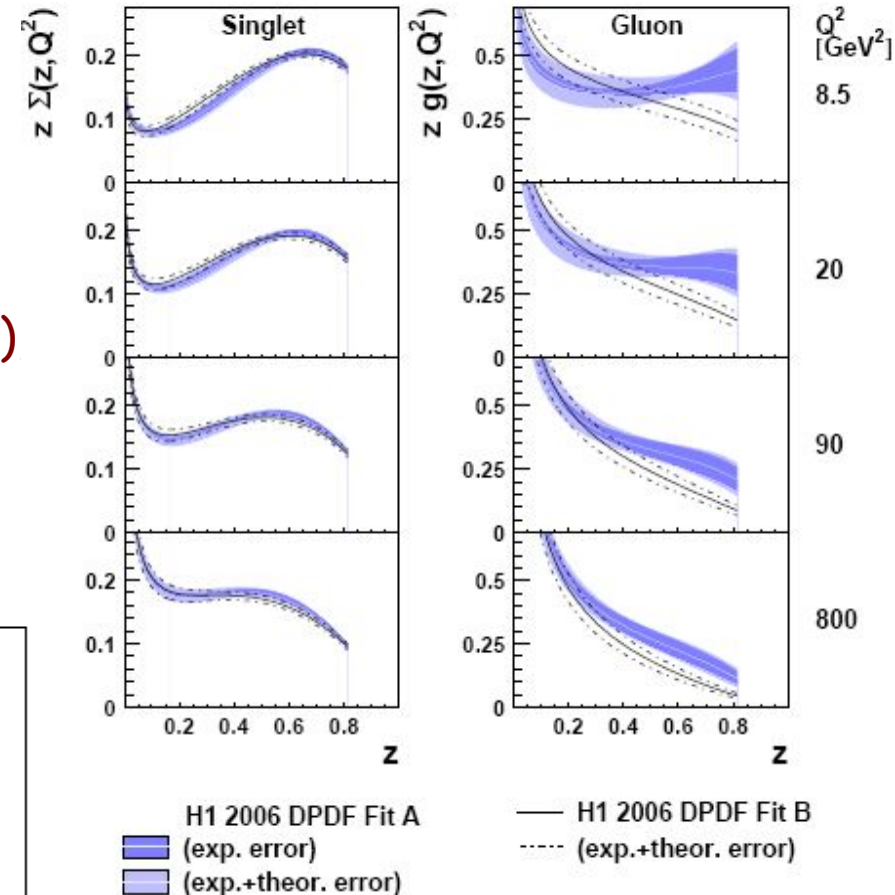
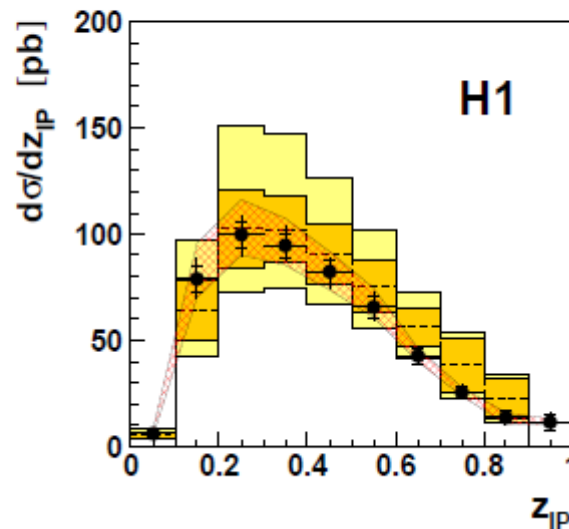
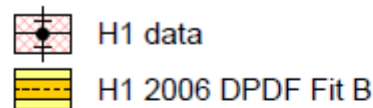
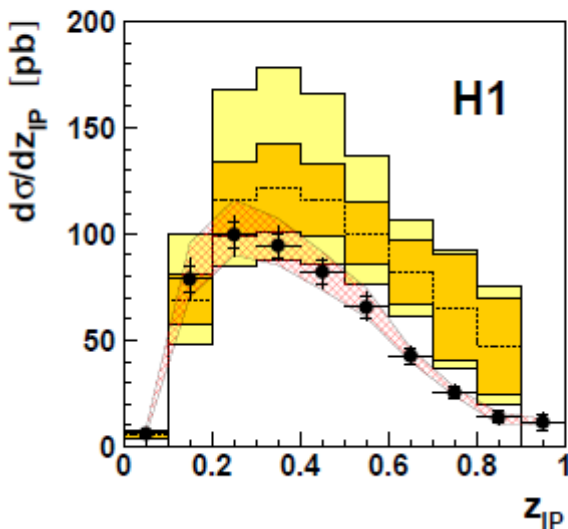
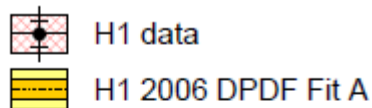
$$z_g(z, Q_0^2) = A_g (1-z)^{C_g}$$

$$z_g(z, Q_0^2) = A_g$$

H1 NLO QCD DPDF fit to F_2^D

QCD Factorisation in Diffraction

- diffractive parton densities are extracted from the inclusive measurements from the NLO QCD fit (β and Q^2 dependence)
- diffractive dijet measurement is compatible with the gluon densities extracted from the inclusive analyses are correct (Fit B preferred) and shows that the QCD factorisation holds



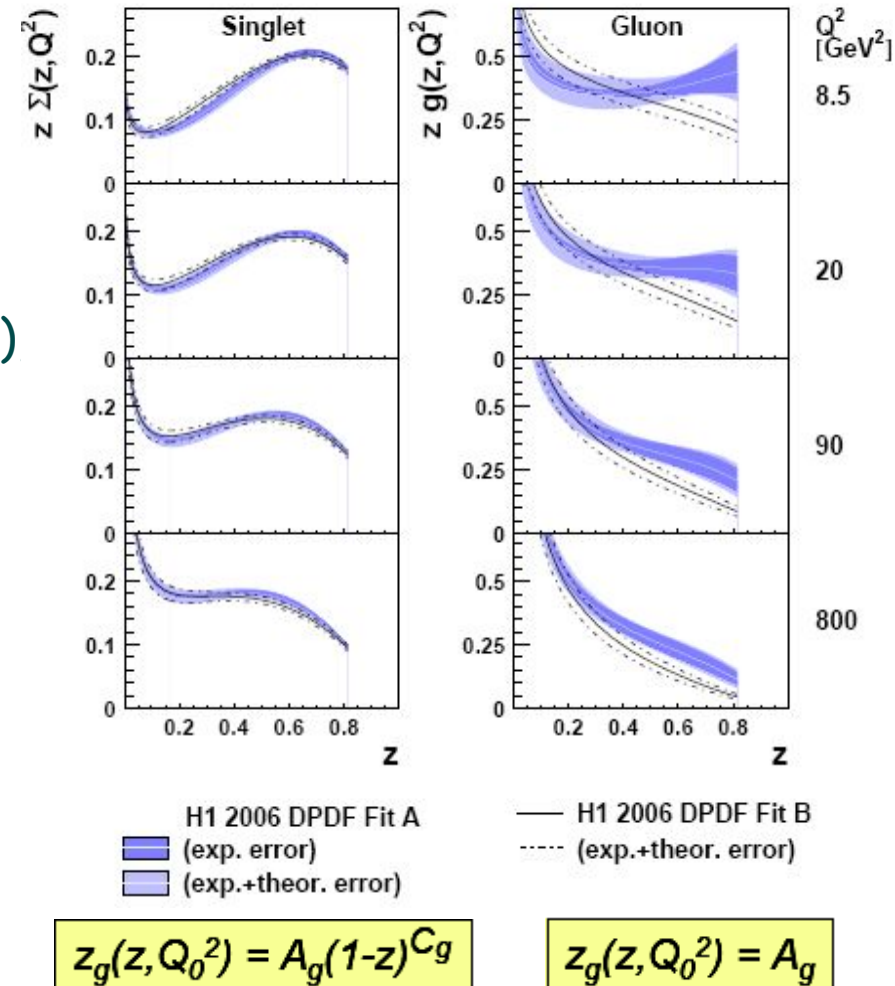
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- inclusive measurements constrain quarks, gluons are constrained weakly from the scaling violations



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QCD Factorisation in Diffraction

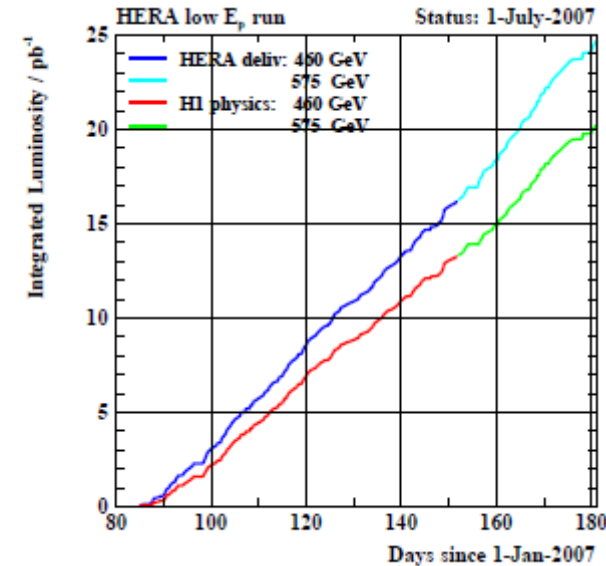
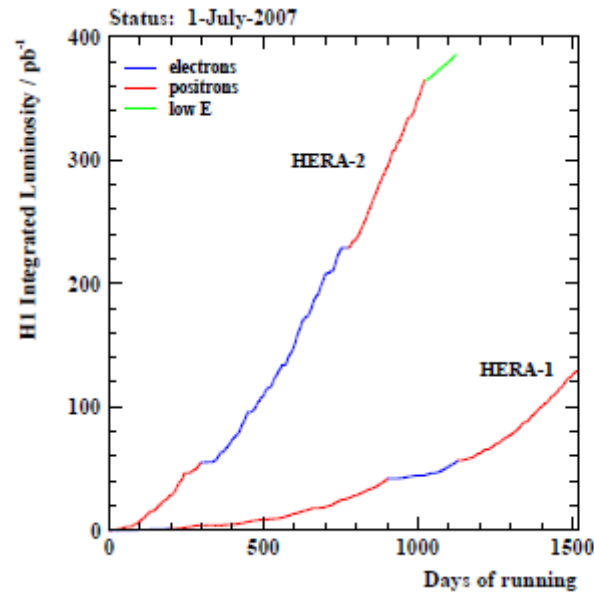
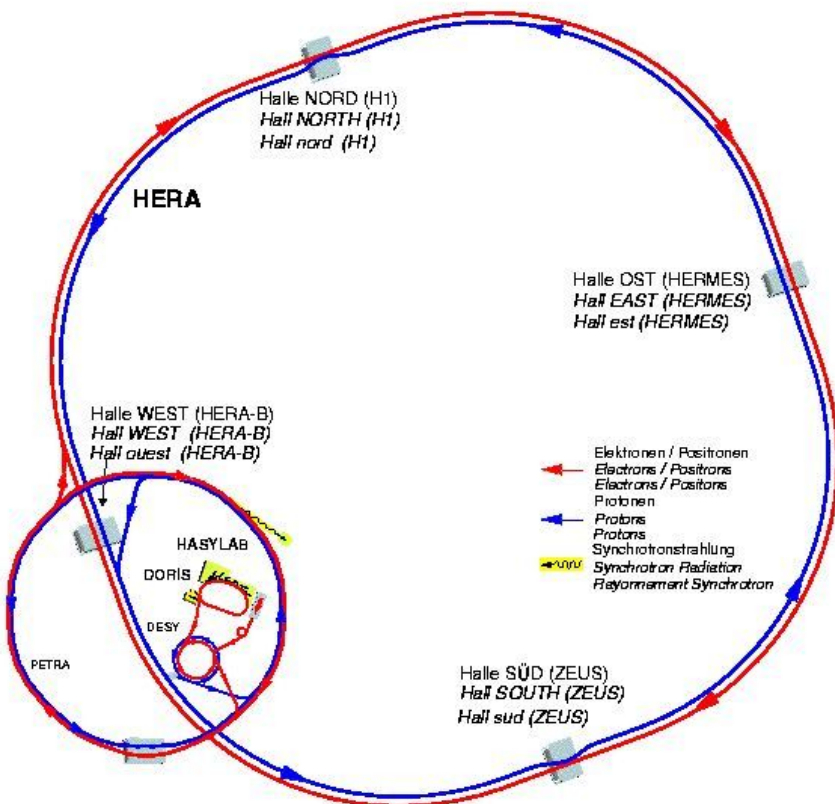
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- diffractive dijet measurement is compatible with the gluon densities extracted from the inclusive analyses are correct (Fit B preferred), and shows that the QCD factorisation holds
- inclusive measurements constrain quarks, gluons are constrained weakly from the scaling violations
- **observables sensitive to the gluons provide crucial tests of the theory and important extra constraints on the gluon**

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

→ F_L^D is sensitive to gluons

HERA Low Energy Runs

- HERA ep collider stopped operating in 2007
- nominal $E_p = 920 \text{ GeV}$
- $E_e = 27.5 \text{ GeV}$



- last months of HERA running were dedicated to the data for F_L and F_L^D measurements
- runs with the reduced proton beam energies of 460 and 575 GeV

Measurement Strategy

- analysis closely follows the measurement of the inclusive F_L (recently done by H1)
- diffractive reduced cross sections are determined in fixed x_{IP}, β, Q^2 bins
- in order to distinguish between F_L^D and F_2^D we need to measure at different y (for the fixed x_{IP}, β, Q^2)
- combine the cross section measurements from runs with different centre-of-mass energy

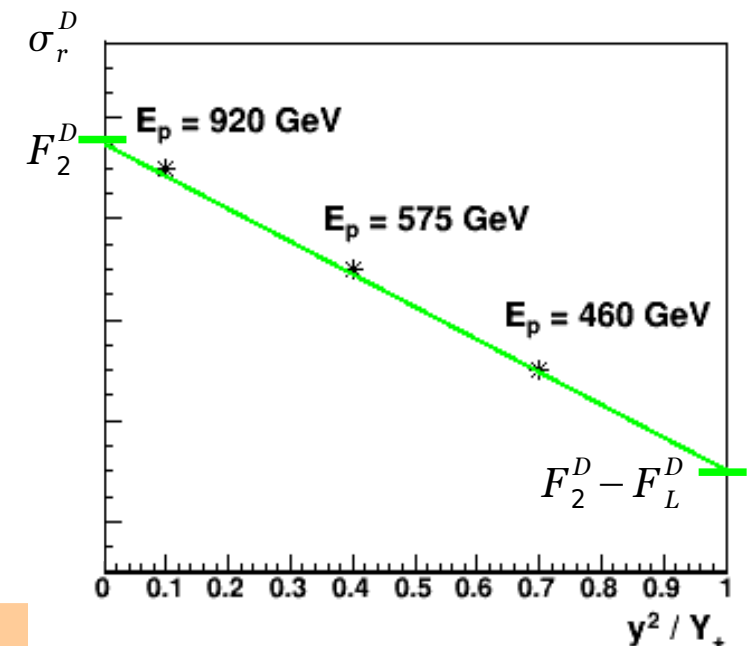
$$\sigma_r^D = F_2^D - \frac{y^2}{Y_+} F_L^D$$

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

- H1 2007 e^+ data

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

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

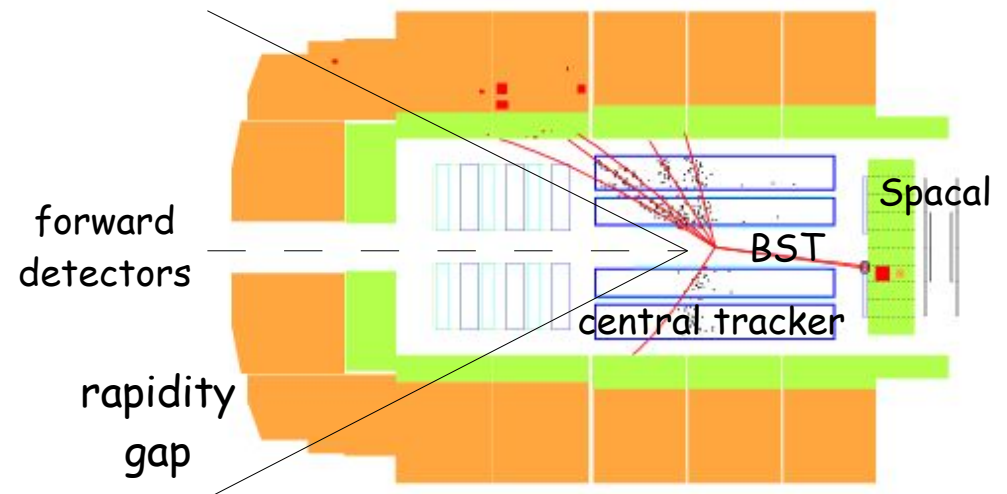


Data Selection and H1 Detector

- rapidity gap selection
- $Q^2 > 7 \text{ GeV}^2$
- $y < 0.9$
 - high y region sensitive to F_L^D
 - $E_e' > 3.4 \text{ GeV}$ $y \approx 1 - \frac{E_e'}{E_e}$
 - more photoproduction background at lower electron energies (challenging measurement)
- $E - p_z > 35 \text{ GeV}$
- kinematic variables reconstructed from the scattered electron

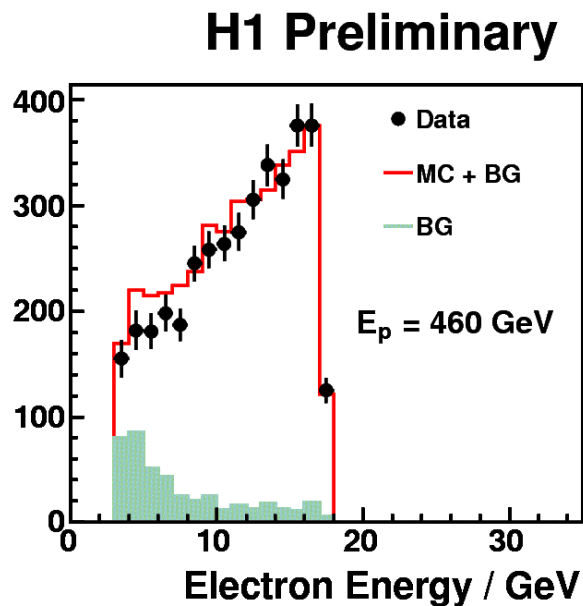
$$y = 1 - \frac{E_e'}{E_e} \sin^2 \frac{\theta_e}{2} \quad Q^2 = 4 E_e E_e' \cos^2 \frac{\theta_e}{2}$$

- forward detectors
 - forward muon detector
 - forward plug calorimeter
 - forward scintillators
- electron identification
 - Spacal calorimeter
 - central tracker
 - Backward Silicon Tracker



Background at High y

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

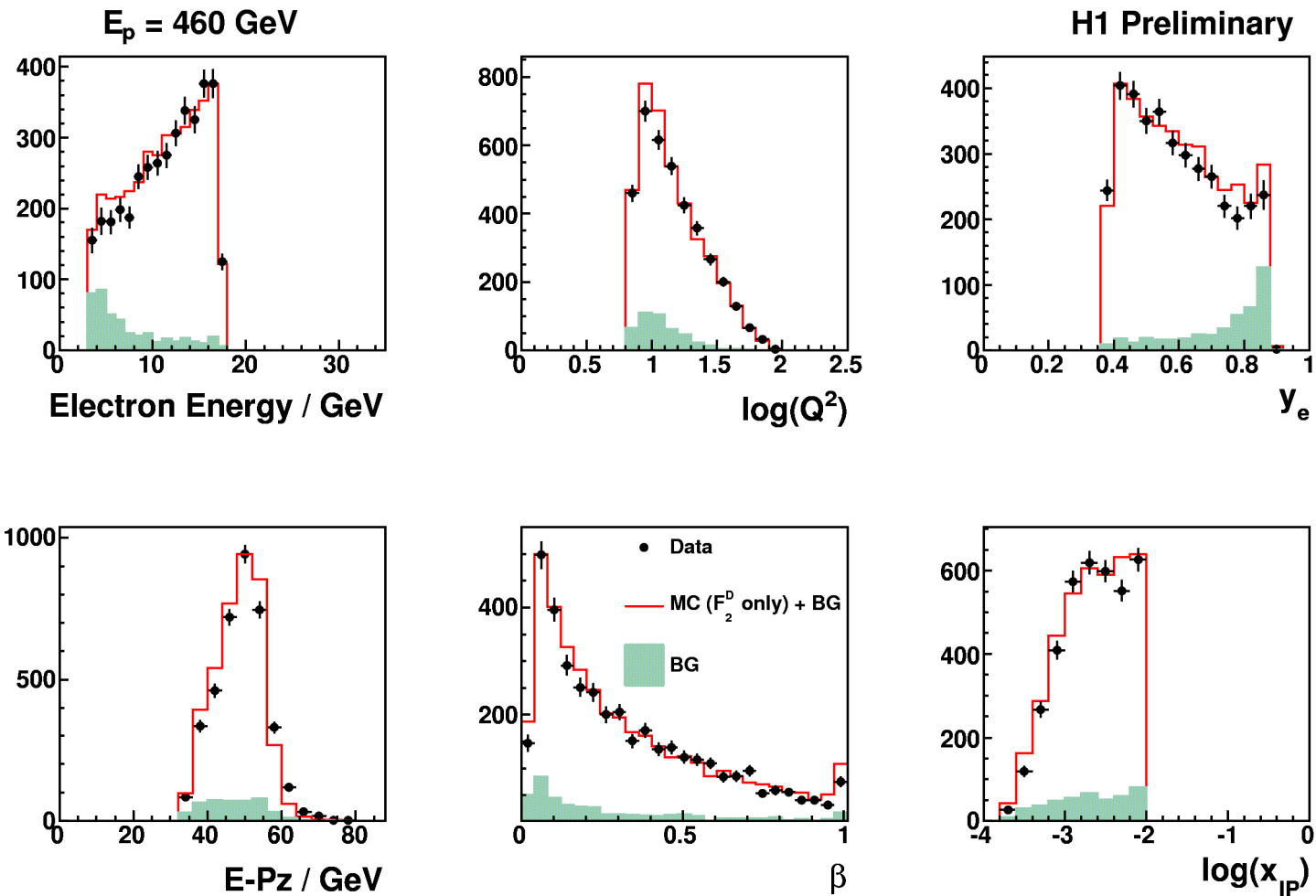


- background subtraction
 - require positive charge of the scattered lepton candidate in the signal data
 - estimate the background using the negative sample and the measured asymmetry factor

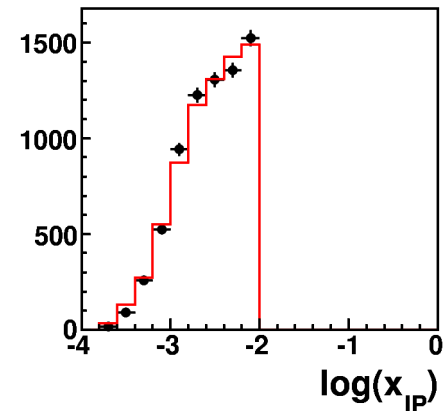
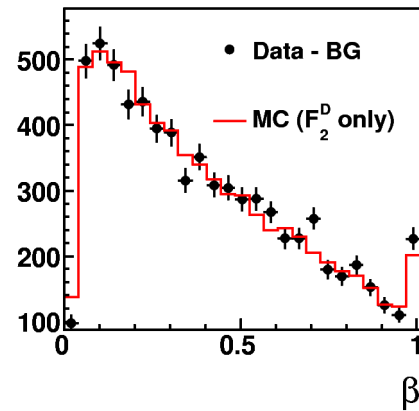
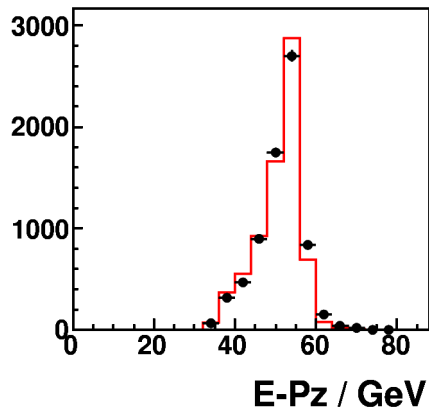
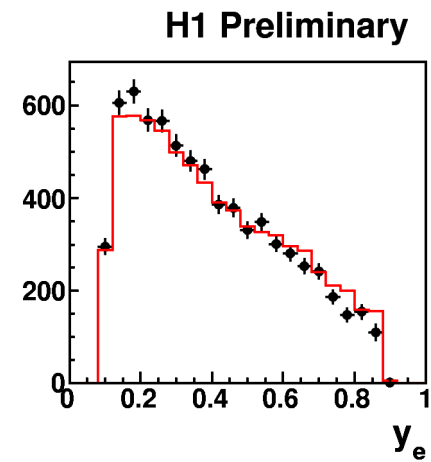
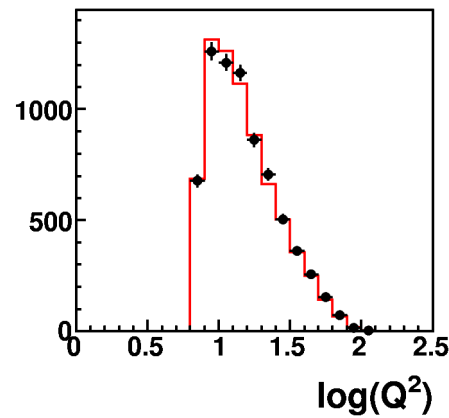
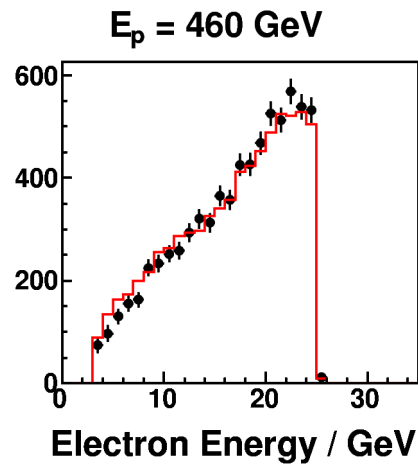
$$N_{signal} = N^+ - asym N^-$$

background in the plot determined from the data
MC includes F_2^D only

Control Plots for $E_p = 460 \text{ GeV}$ ($y > 0.38$)

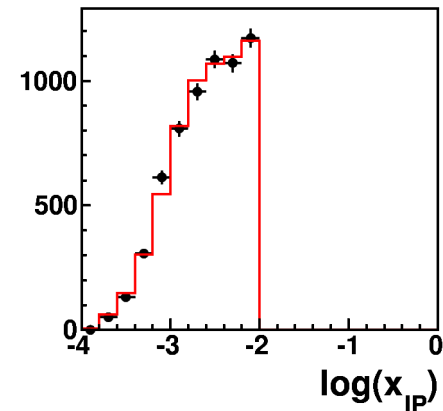
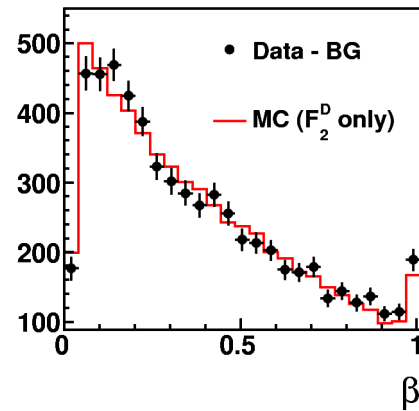
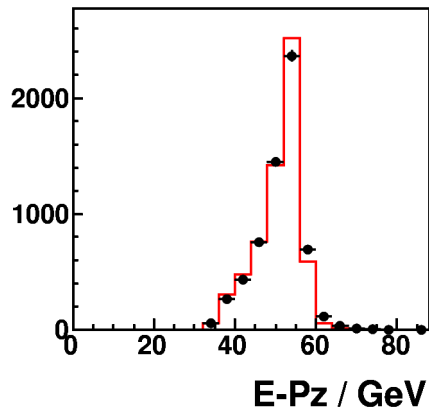
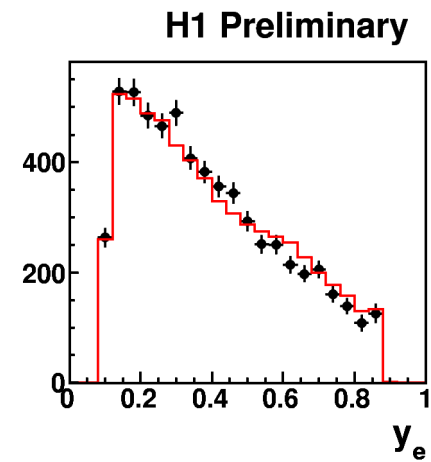
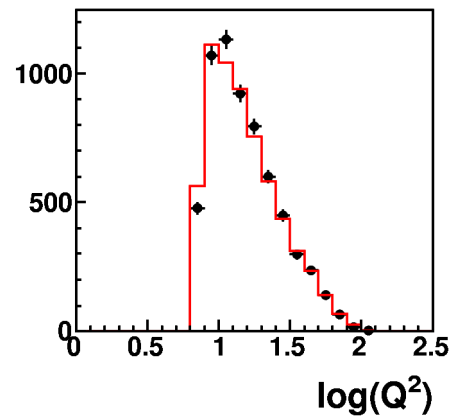
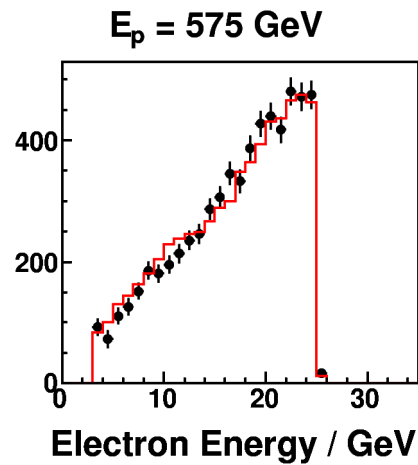


460 GeV Data after Background Subtraction (all y)



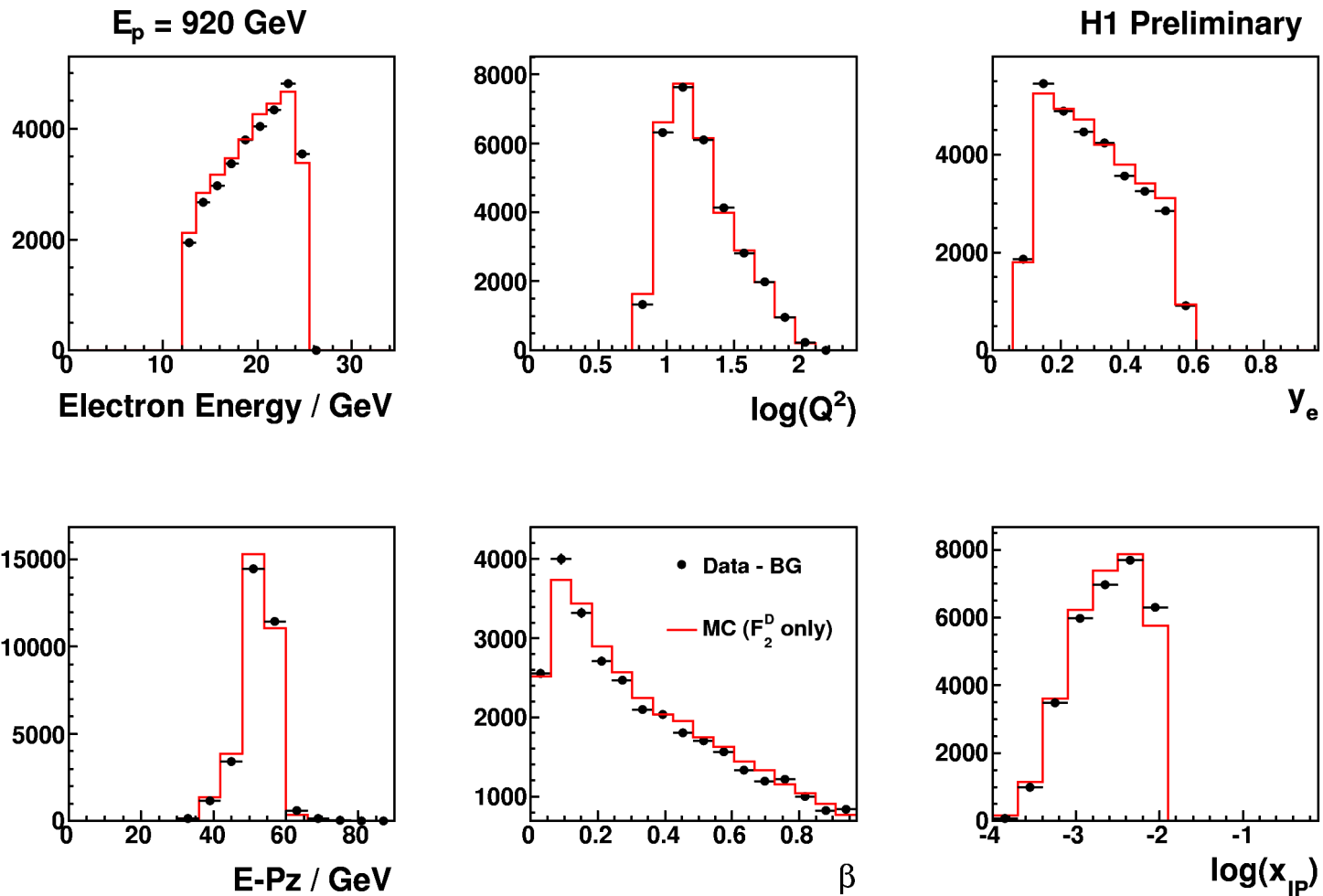
- data well described by the simulation

575 GeV Data after Background Subtraction (all y)



- data well described by the simulation

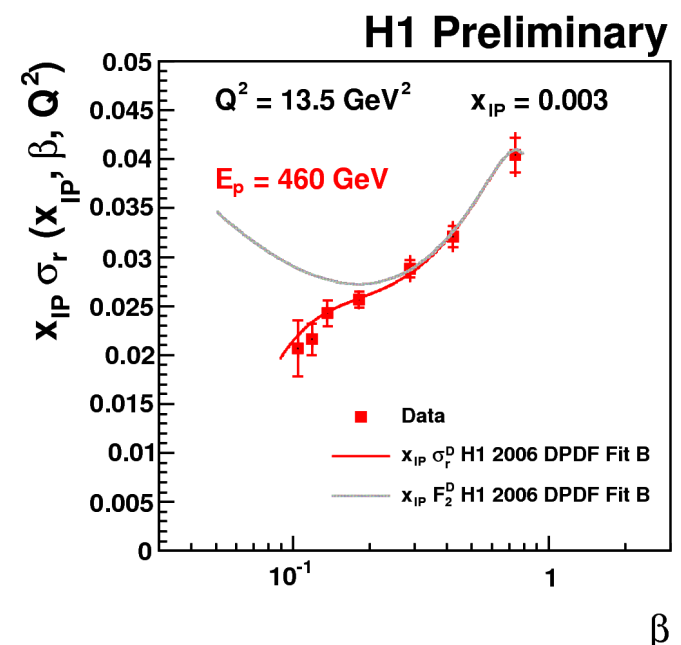
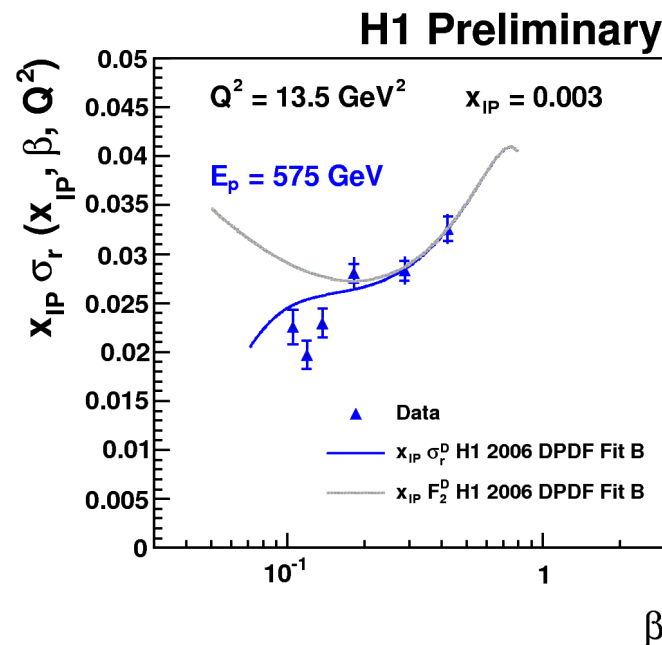
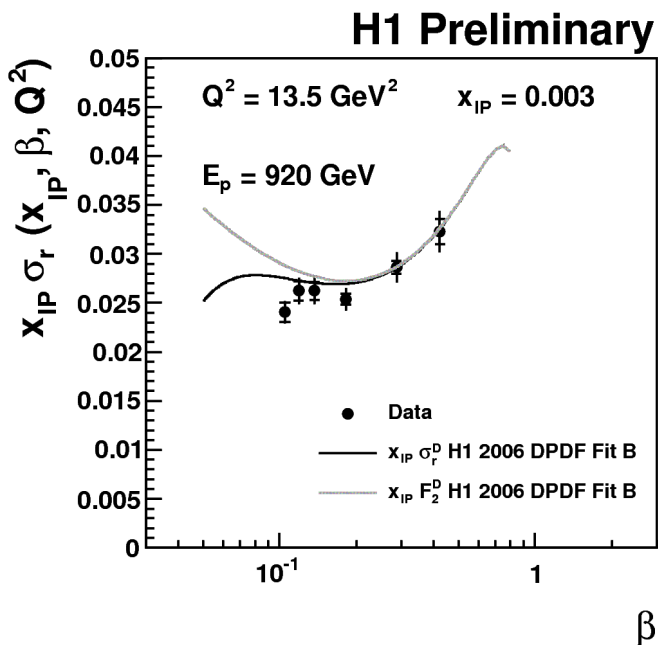
920 GeV Data after Background Subtraction (all y)



- data well described by the simulation

Diffractive Reduced Cross Sections

- data cross section corrected for proton dissociation
 - rapidity gap selection accepts events with dissociated protons up to about $M_Y = 1.6 \text{ GeV}$ (acceptance of the forward detectors near the beam pipe)
- use as constraint that F_2^D is independent of the beam energy
 - no significant contribution from F_L^D at high β (low y)
 - data cross sections re-normalised at $0.28 < \beta < 0.42$ in order to give the same F_2^D

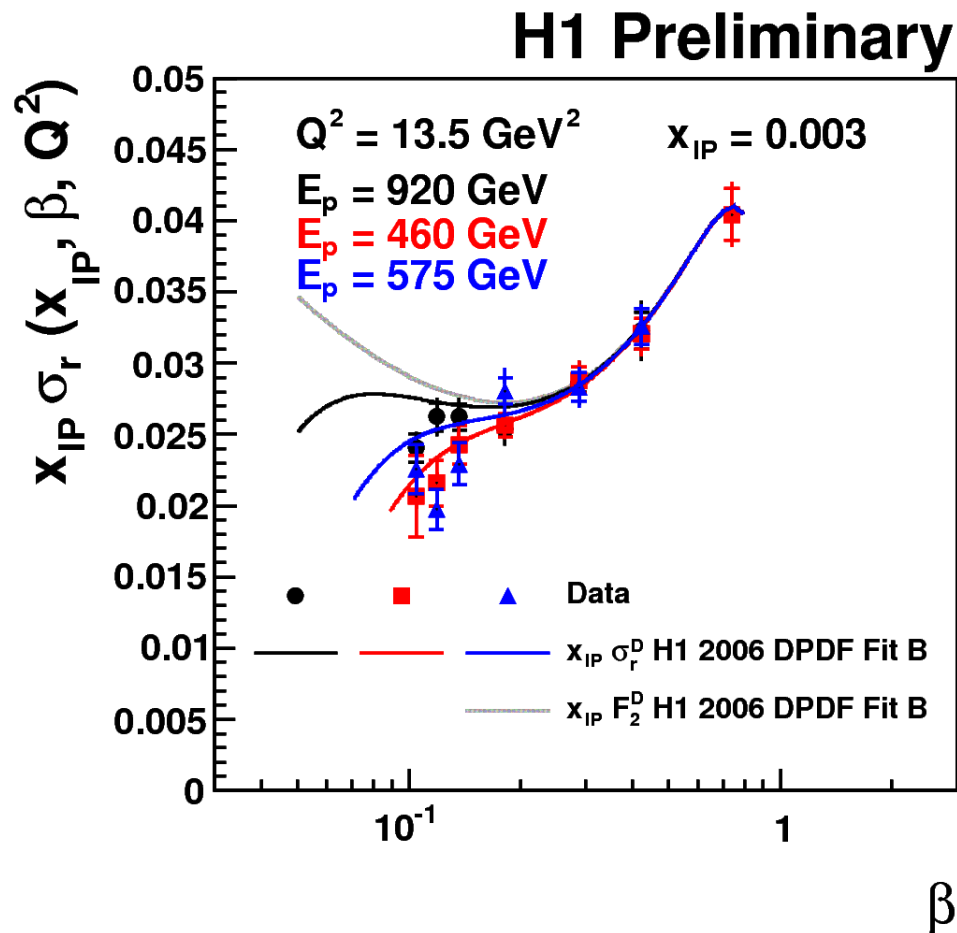


Diffractive Reduced Cross Sections

- data cross sections sensitive to F_L^D

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

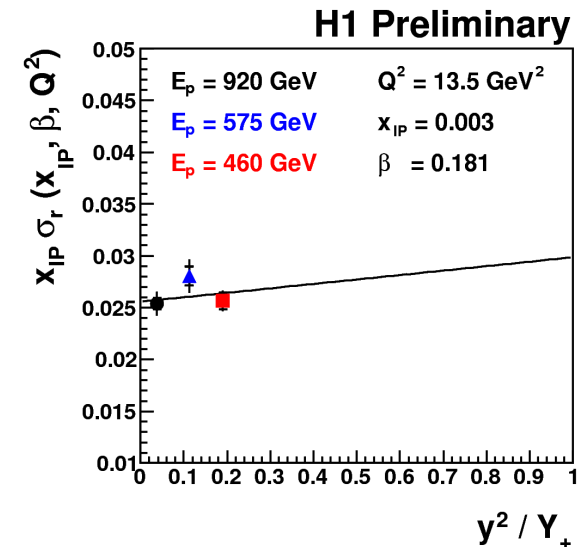
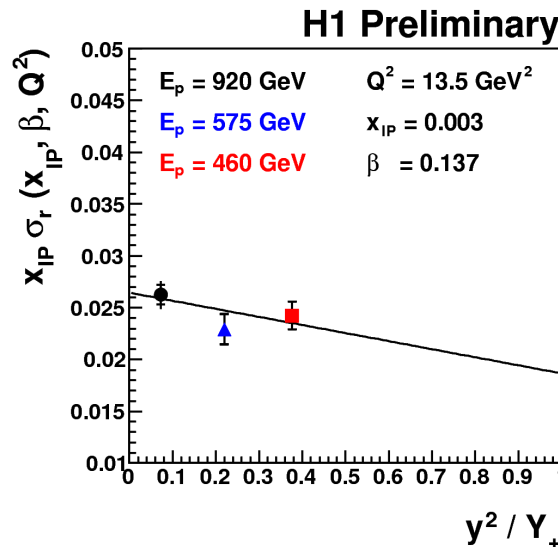
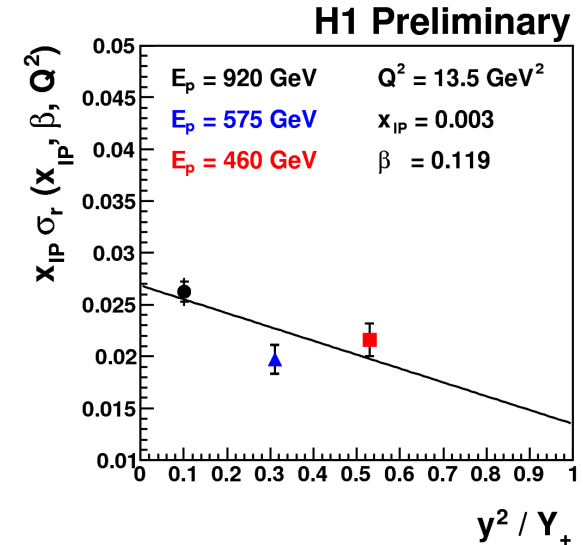
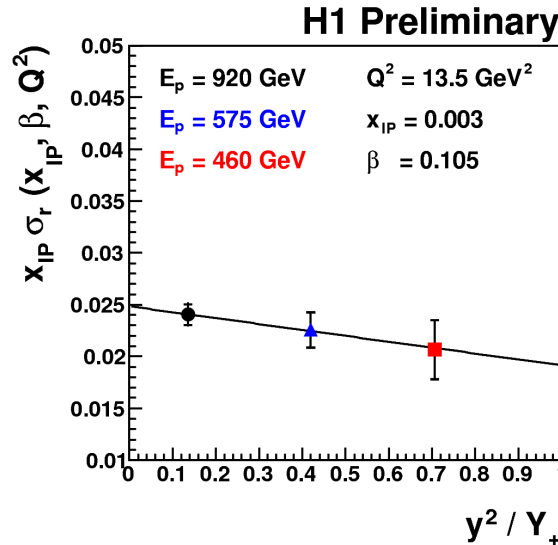
$$\sigma_r^D = F_2^D - \frac{y^2}{Y_+} F_L^D$$



F_L^D Fits

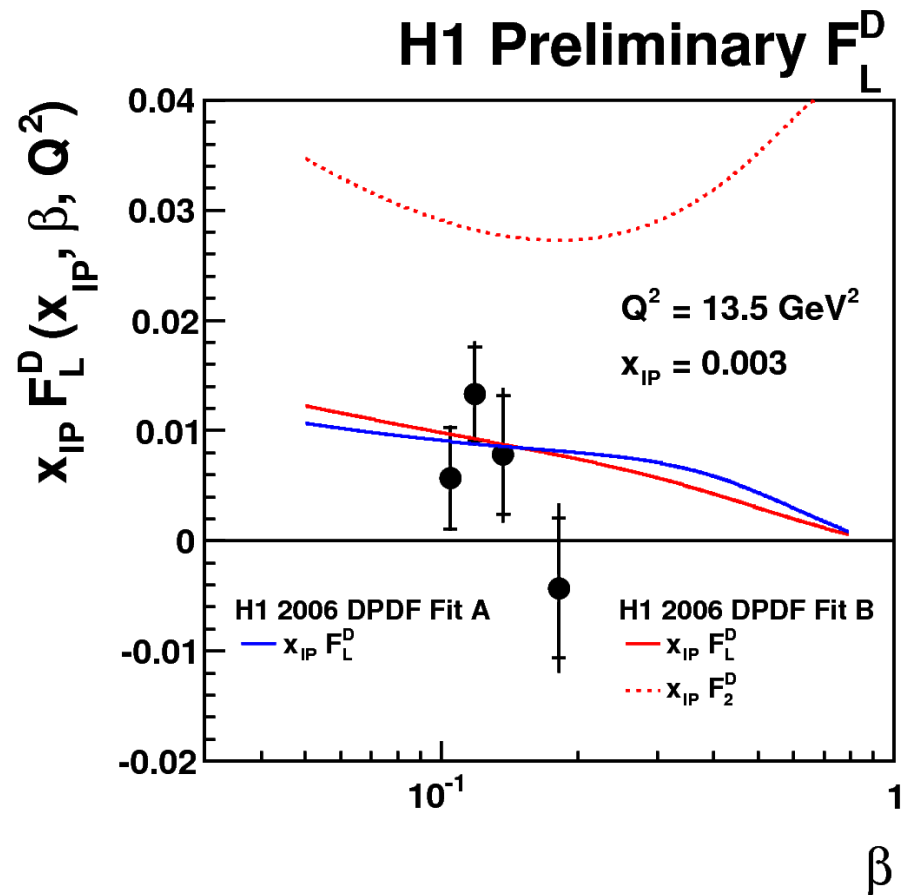
- highest sensitivity to F_L^D at low β (high y)
- linear fit to obtain F_2^D and F_L^D

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



F_L^D Results

- F_L^D measured in the kinematic region:
 $7 < Q^2 < 32 \text{ GeV}^2$
 $0.001 < x_{IP} < 0.01$
- measurement corrected to:
 $Q^2 = 13.5 \text{ GeV}^2$
 $x_{IP} = 0.003$
- the measurement represents non-zero value with more than 3σ significance
- results consistent with the H1 2006 DPDF Fits (based on DPDF's and factorisation)

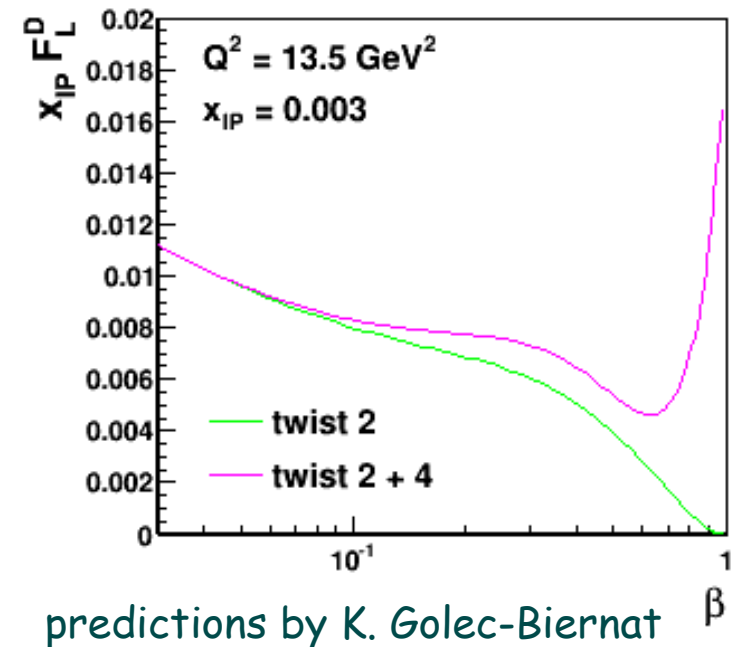
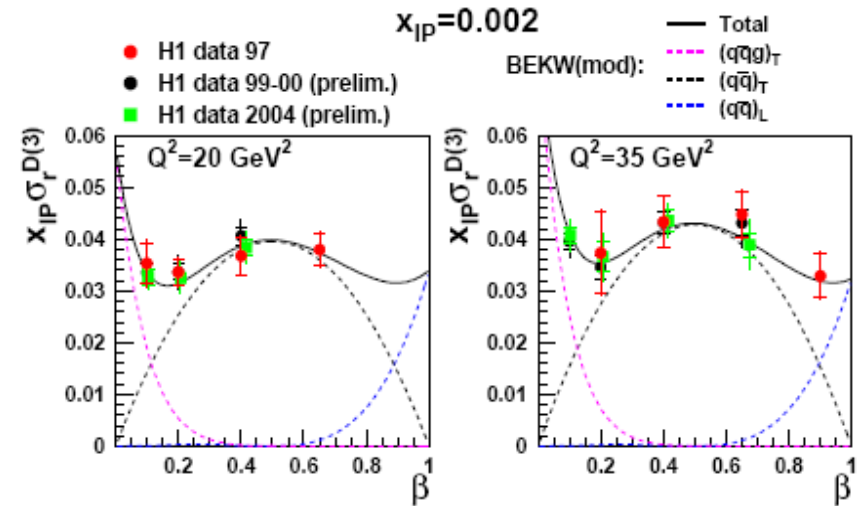


QCD Fits and Higher Twist Effects

- higher twist longitudinal contribution to diffraction at high β (e.g. BEKW) implies large F_L^D
(F_2^D dominated by F_L^D at high β and low Q^2)

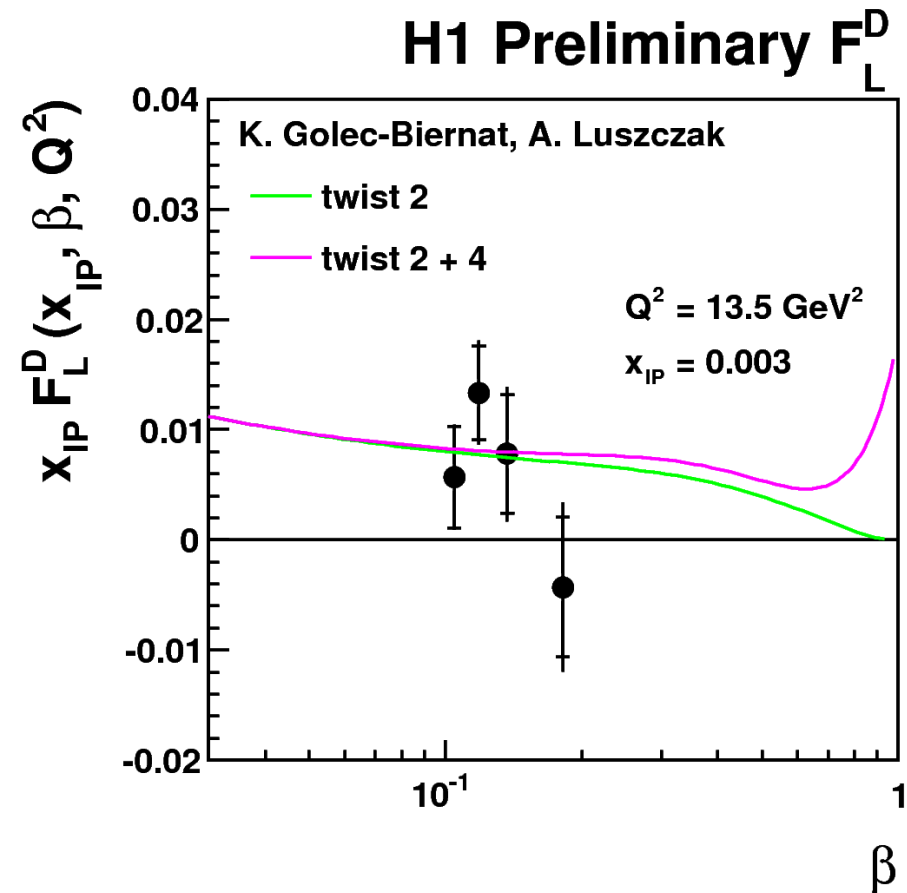
$$F_2 = F_T + F_L$$

- QCD fits from H1 only include the leading twist and do not predict large F_L^D
- e.g. Golec-Biernat fits data with both F_L^D twist 2 and twist 4
- a measurement of F_L^D can give insight into an as yet unexplored area of diffraction



F_L^D Results

- measurement also consistent with Golec-Biernat et al.
- no sensitivity in the current β range to the twist 4 contribution



Summary

- **the first F_L^D measurement**
- F_L^D measured at $Q^2 = 13.5 \text{ GeV}^2$, $x_{IP} = 0.003$ and $\beta \sim 0.1$
- the measurement represents a significant non-zero value (3σ)
- the measurement explores new territory in diffraction
- a new, independent test of the diffractive gluon density and verification of the QCD framework as applied to diffraction