Measurements of the Proton F_L and F_2 Structure Functions at Low x at HERA

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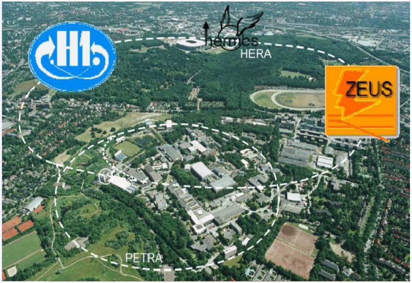
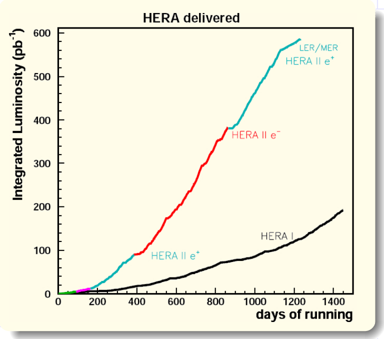
on behalf of the H1 and ZEUS collaborations

Moriond QCD, La Thuile, 13 March 2008

- HERA is a unique *ep* collider. Located at DESY, Hamburg
- Two collider experiments
- HERA II: after luminosity and detector upgrade in 2000-2002

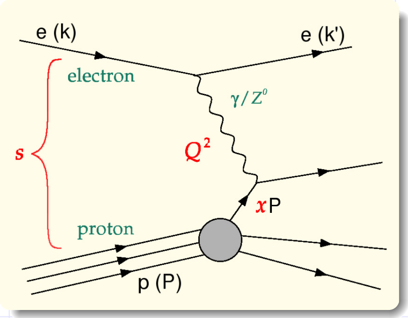
HERA operation: $E_e = 27.5$ GeV, $E_p = \begin{cases} 820 \text{ GeV}, & 1992\text{-}1998 \\ 920 \text{ GeV}, & 1998\text{-}2007 \\ 460 \text{ GeV}, & 3\text{-}5 / 2007 \\ 575 \text{ GeV}, & 5\text{-}6 / 2007 \end{cases}$





Deep Inelastic Scattering at HERA

Neutral Current DIS: $e^{\pm}p \rightarrow e^{\pm}X$



Kinematics:

- $Q^2 = -(k - k')^2 = -q^2$ *virtuality of* γ^*, Z^0
- $x = Q^2/2(Pq)$ *momentum fraction of proton carried by struck quark*
- $y = (Pq)/(Pk)$ *inelasticity*
- $Q^2 = sxy$

- Deep Inelastic Scattering (DIS) is best suited tool for
  - Measurement of the substructure of the proton: quark and gluon content (PDFs)
  - Testing QCD dynamics: validity of DGLAP evolution equations at low Q^2 and low x

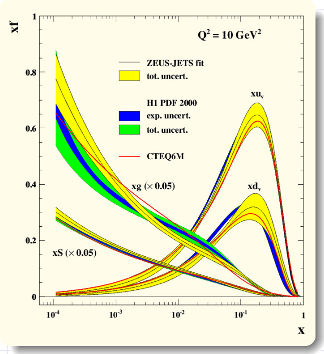
Structure Functions F_2 and F_L

At low Q^2 DIS cross section can be written via structure functions F_2 and F_L:

$$\frac{d^2\sigma^{ep}}{dxdQ^2} = \frac{2\pi\alpha^2 Y_+}{Q^4 x}\left(F_2(x,Q^2) - \frac{y^2}{Y_+}F_L(x,Q^2)\right), \qquad Y_+ = 1 + (1-y)^2$$

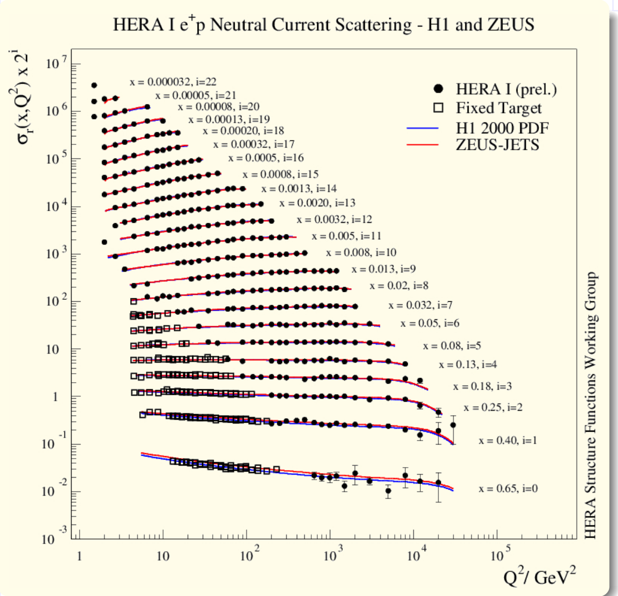
reduced cross section: $\sigma_r = \frac{Q^4 x}{2\pi\alpha^2 Y_+}\frac{d^2\sigma^{ep}}{dxdQ^2} = F_2 - \frac{y^2}{Y_+}F_L$

- F_2 is dominant ($\sigma_r \sim F_2$)
  - $F_2 = x\sum e_q^2(q+\bar{q})$
  - Sensitive to $4u + d$
  - Gluon PDF extraction from scaling violation of F_2: $\frac{\partial F_2}{\partial \ln Q^2} \propto xg$
- F_L is sizable only at high y
  - $F_L = 0$ in QPM
  - Direct sensitivity to gluons at low x



QCD: $F_L = \frac{\alpha_s}{4\pi}x^2\int_x^1 \frac{dz}{z^3}\left[\frac{16}{3}F_2 + 8\sum_q e_q^2\left(1-\frac{x}{z}\right)zg(z)\right]$

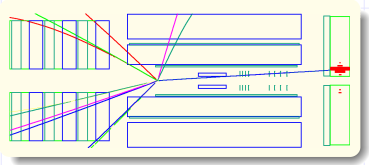
- New preliminary H1 and ZEUS combined results (submitted to EPS07, Manchester)
- 1.5-3% precision data
- 5 decades in x
- 5 decades in Q^2

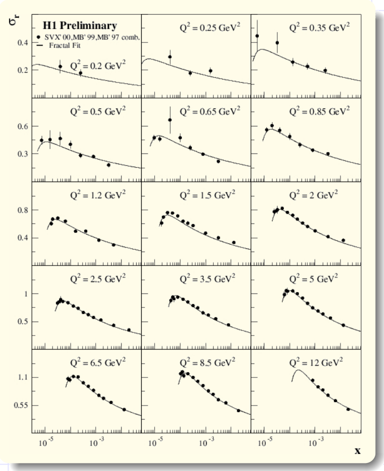


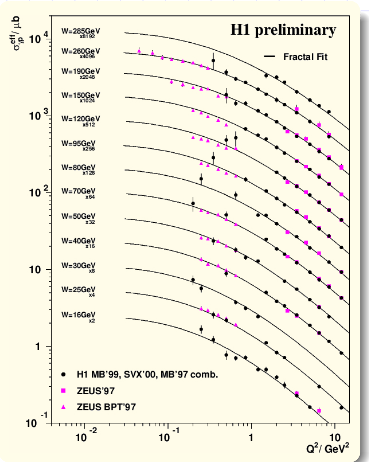
Lowest Q^2 Region

- Transition to non-perturbative region $Q^2 \to 0$ is of theoretical interest
- The lowest $Q^2 < 10$ GeV^2 region is accessed using specialised techniques to detect scattered lepton at very small angles:
  - Shifted collision vertex to increase acceptance at lowest Q^2 (H1)
  - Events with tagged (ZEUS) or untagged (H1) Initial State Radiation
  - Special low angle calorimeter + tracker (BPT, ZEUS)
  - Minimum Bias Trigger data + Backward Silicon Tracker (H1)

Shifted vertex BST event (H1) at low $Q^2 = 2.7$ GeV^2 and $x = 0.0003$







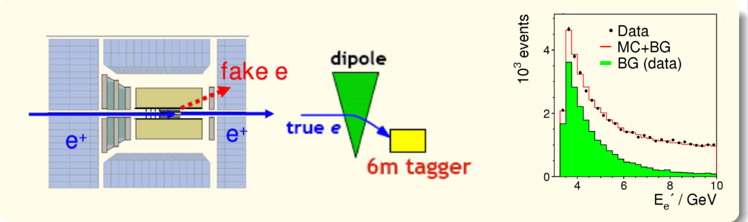
- New precision of preliminary H1 data: 1.5% for $Q^2 > 5$ GeV^2
- $\sigma^{eff}_{\gamma^* p}$, effective virtual $\gamma^* p$ cross section: $\sigma^{eff}_{\gamma^* p} = \sigma_T + [1 - f(y)]\sigma_L$
- H1 combined data cover the gap between published ZEUS results and agree with them in regions of overlap

The High y Measurements

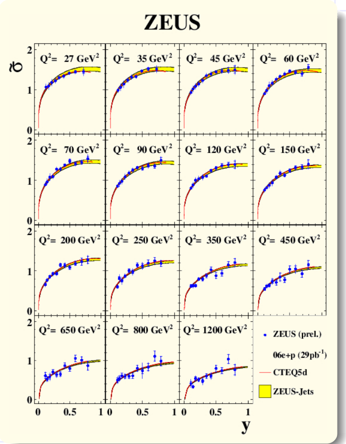
- Results are interesting because of sensitivity to F_L
- Analysis in the high $y > 0.6$ region especially challenging: difficult to identify the scattered lepton with low E'_e and high γp background
- H1 and ZEUS have released the preliminary high y results:
  - ZEUS: Measurement uses γp MC for BG subtraction, can be studied using tagged events. Analysis down $E'_e = 5$ GeV and up to $y = 0.8$
  - H1: Background determined directly from data using the track charge. Analysis down to $E'_e = 3.3$ GeV and up to $y = 0.9$

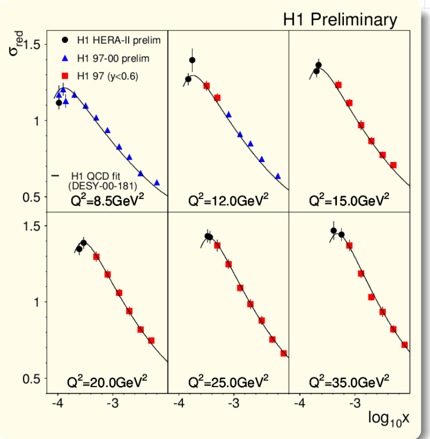
$$\sigma_r = F_2 - \frac{y^2}{Y_+} F_L$$

$$y \approx 1 - \frac{E'_e}{E_e}$$



The High y Results

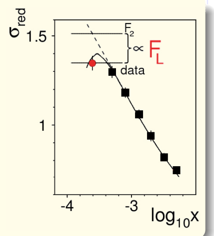


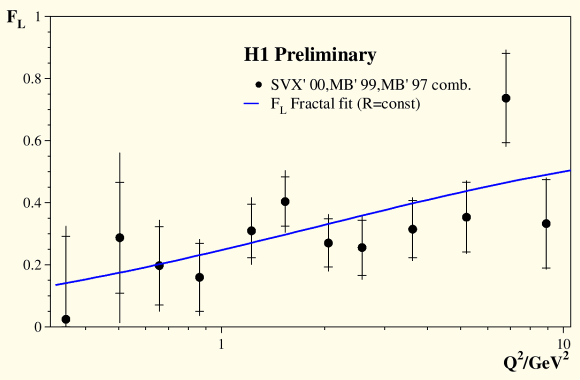


$$x = \frac{Q^2}{sy}$$

- First measurement at high y by ZEUS, covers the whole kinematic range, at higher Q^2 statistics limited
- H1 uncertainties improved by a factor 2 over former publication (hep-ex/0012053), total errors 2-3%

- Extrapolate F_2 from the low y region to the high y
- F_L: Compare σ_r with extrapolated F_2





$F_L \propto F_2 - \sigma_r$

- Strong model dependence

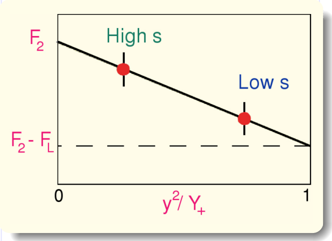
Drawback: extraction of F_L requires assumption on F_2

Direct Measurement of F_L by H1 Collaboration

Direct F_L Measurement

- Direct measurement of F_L can be performed by measuring cross section for the same (x, Q^2) but with different centre mass energies $\sqrt{s}$ (different y):

$$\sigma_r = F_2(x, Q^2) - \frac{y^2}{Y_+} F_L(x, Q^2)$$



Higher y at low s

$\downarrow$

Larger difference of $\frac{y^2}{Y_+}$

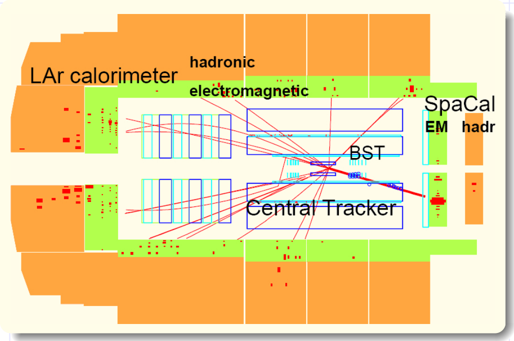
$\downarrow$

Better F_L precision

- Use 2007 e^+p data of different p-beam energy runs
- For same x, Q^2: low s high y corresponds to high s low y

E_p	Lumi
460 GeV	12.4 pb^{-1}
575 GeV	6.2 pb^{-1}
920 GeV	21.9 pb^{-1}

Analysis Strategy



Electron method:

$$Q_e^2 = 4E_e E'_e \cos^2\left(\frac{\theta_e}{2}\right)$$
$$y_e = 1 - \frac{E'_e}{E_e}\sin^2\left(\frac{\theta_e}{2}\right)$$
$$x_e = \frac{Q_e^2}{s y_e}$$

- Scattered electron produces isolated and compact energy deposition
- Identified using shape and size of e/m shower profile

"High Y"

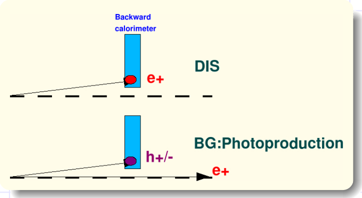
- High background contribution
- Require track link, higher R_{SpaCal}
- Estimate background from wrong charged tracks

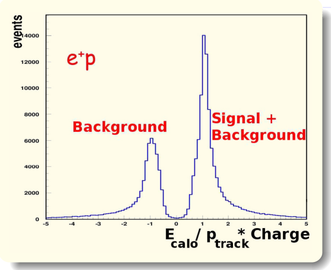
"Low Y"

- Background free area
- $R_{SpaCal} > 20$ cm. Do not require track match
- γp MC to estimate residual background

Background Determination

- At high y there is a large photoproduction background in which hadronic final state can mimic the signature of the scattered lepton with low energy



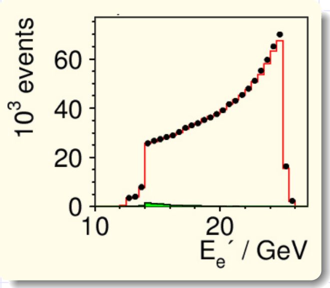


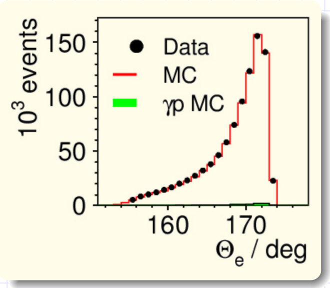
- Background is measured using data events with the charge opposite to lepton beam charge
- A small charge asymmetry ($\approx$ 5%) at low energies is generated by the difference of pA and $\bar{p}A$ cross sections
- Background charge asymmetry is determined using e^+p and e^-p 2003-07 data

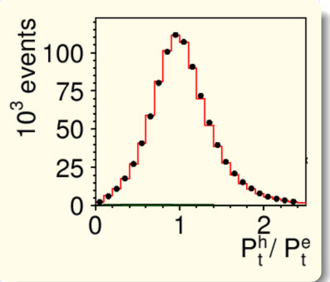
$$N^{signal} = N^+ - kN^-$$

Charge asymmetry factor: $k = \frac{N^+_{bkg}}{N^-_{bkg}}$

Low y Control Plots: $E_p = 920$ Data





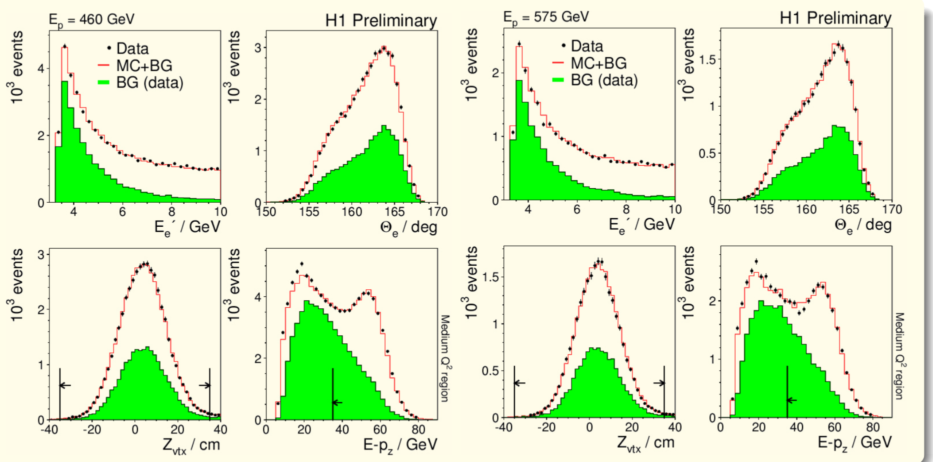


- Low background contribution
- Good control on the e/m and hadronic energy scales
- Electron energy (E_e'), scattering angle (θ_e), etc. are well described by MC

High y Control Plots

$E_p = 460$ Data

$E_p = 575$ Data



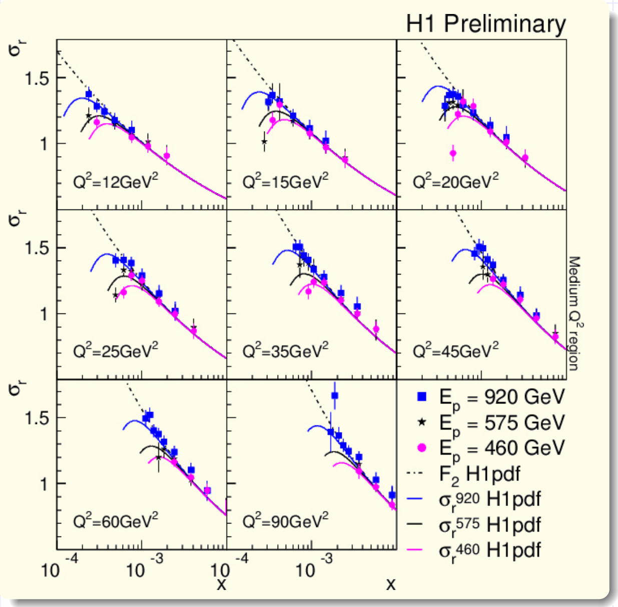
- Good description of the data by MC

Same Q^2, x range, different CME $\longrightarrow$ different y ranges

$$y = Q^2/(xs)$$

lower $s \rightarrow$ higher y

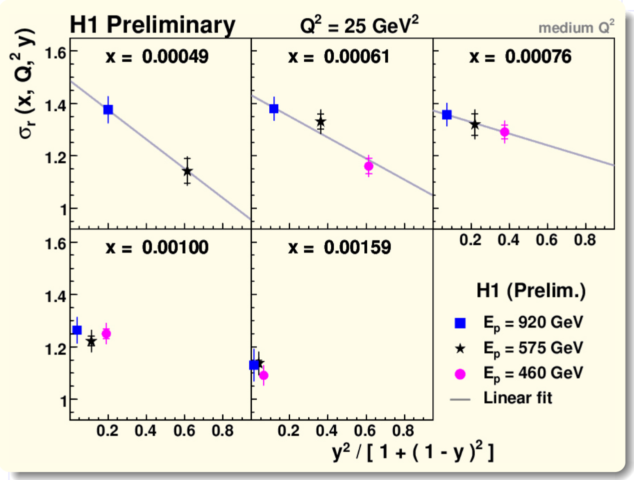
σ_r turns over at low x due to F_L



F_L Extraction

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

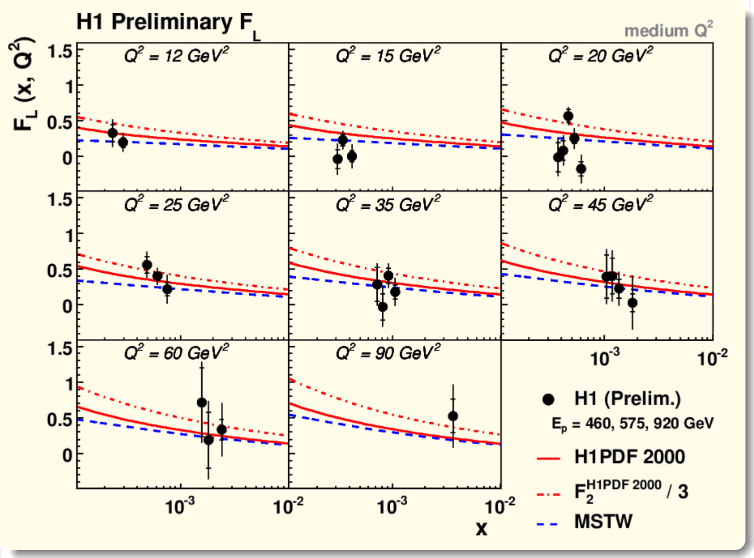
- Linear fit to points of different s
- Slope determines F_L
- Intercept at $y = 0$ gives F_2



$E_p = 575$ data:

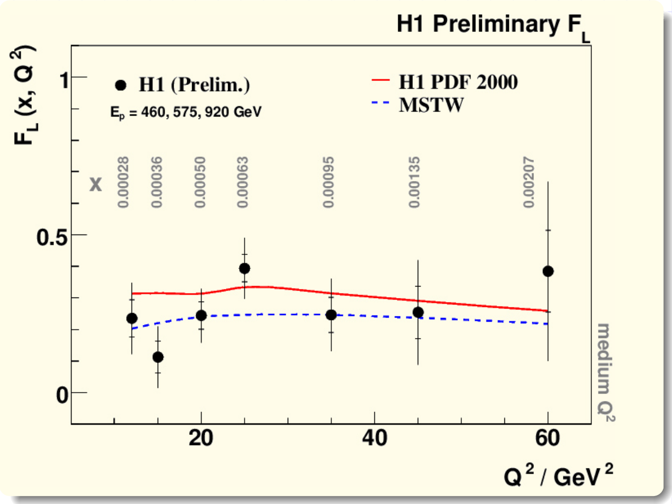
- cross check of γp background control
- additional x bins

F_L Structure Function



First direct measurement $F_L(x, Q^2)$ at low x at HERA

F_L Structure Function in Averaged x Bins



- F_L predicted by higher order QCD using gluon that was derived from scaling violations of F_2 is consistent with the measurement

Summary

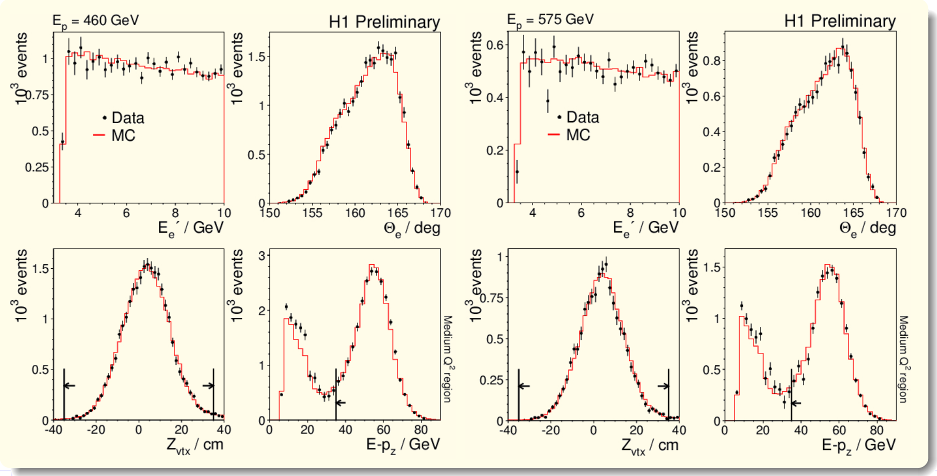
- HERA performs precision measurements of the proton structure
- New results on inclusive measurements at lowest Q^2 and in the high inelasticity y domain
- **First direct measurement of F_L at HERA has been presented, based on data taken in 2007**
  - Measured F_L is in agreement with higher order QCD expectations, based on HERA low x measurements of the scaling violations of F_2
  - The extension of the measurement to the lower and higher Q^2 regions is expected using other detection capabilities of H1. ZEUS measurement is also in progress.
- Novel precision measurements at HERA will improve the proton structure understanding

  ...and prepare LHC era

Back-up Slides

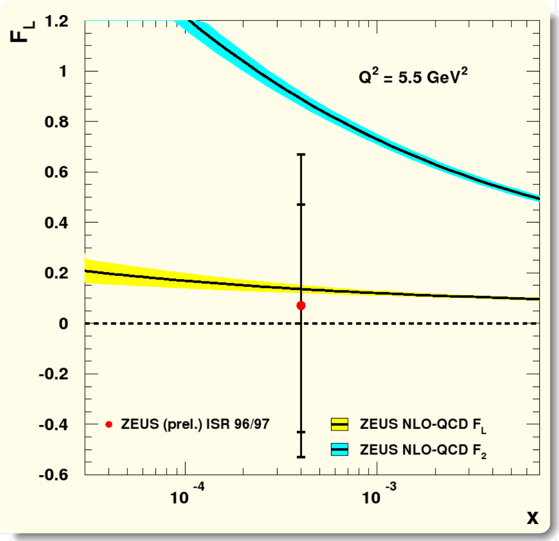
High y Control Plots

$E_p = 460$ Data　　　　$E_p = 575$ Data



- Good description of the data by MC

Measurement of F_L Using ISR



- Direct method but limited by statistical precision