

# FL Measurements at Low $x$

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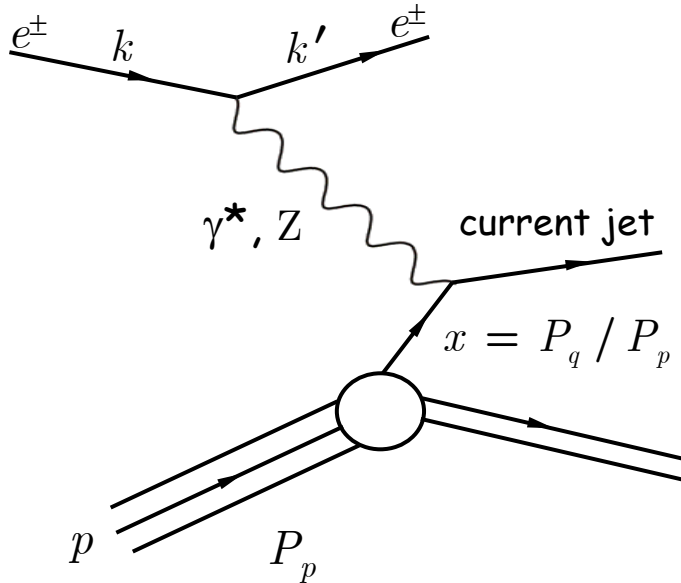
University of Montenegro  
on behalf of  
H1 & ZEUS Collaborations



- Deep Inelastic Scattering
- Proton structure functions  $F_2$  &  $F_L$
- $F_L$  measurement strategy
- HERA and H1 and ZEUS experiments
- Experimental details
- Results
- Summary

# Deep Inelastic Scattering (DIS)

## Neutral Current DIS



- $Q^2$  Virtuality of the intermediate boson

$$Q^2 = -q^2 = -(k - k')^2$$

- Bjorken scaling variable

$$x = Q^2 / (2 P \cdot q)$$

- Inelasticity of the interaction

$$y = (P \cdot q) / (P \cdot k)$$

- $Q^2 = sxy$ ,  $s = ep \text{ CME}$

## Deep Inelastic Scattering the key tool for

- Measurement of the substructure of the proton: quark and gluon content (PDFs)
- Tests of QCD

# Proton Structure Functions

$$\frac{d^2\sigma_{\text{NC}}^{\pm}}{dx dQ^2} = \frac{2\pi\alpha^2 Y_{\pm}}{xQ^4} \sigma_r^{\pm} = \frac{2\pi\alpha^2 Y_{\pm}}{xQ^4} \left[ F_2(x, Q^2) - \frac{y^2}{Y_{\pm}} F_L(x, Q^2) \mp \frac{Y_{\mp}}{Y_{\pm}} xF_3(x, Q^2) \right]$$

$$Y_{\pm} \equiv 1 \pm (1-y)^2$$

- **$F_2$  dominant contribution:**

$$F_2 = \sum_q e_q^2 x (q + \bar{q})$$

- **$xF_3$  contributes only at high  $Q^2$**

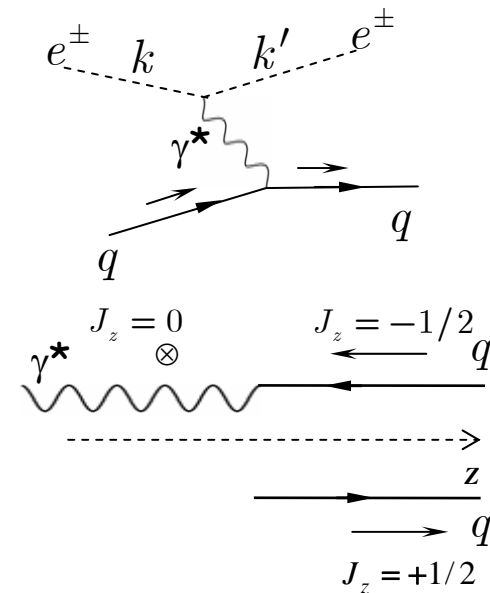
$$xF_3 = x \sum_q B_q x (q - \bar{q})$$

- **$F_L$  contributes at high  $y$**

- In QPM, due to angular momentum and helicity conservation:  $F_L \propto \sigma_L^{\text{YP}} = 0$

- $F_L$  non-zero in QCD

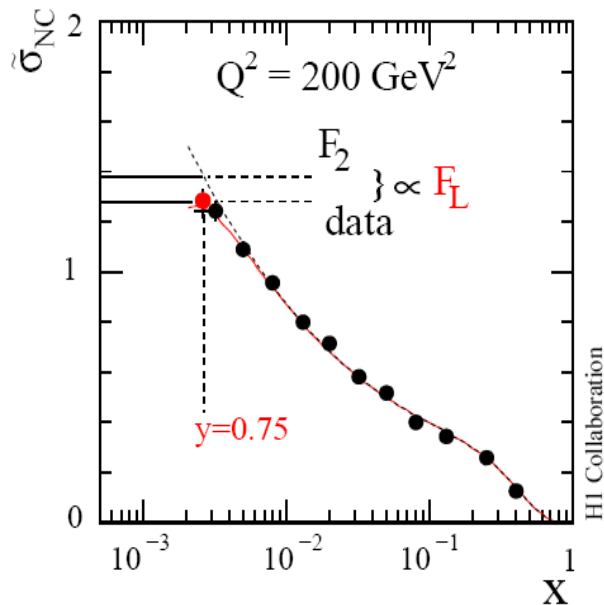
$$F_L = \frac{\alpha_s}{4\pi} x^2 \int_x^1 \frac{dz}{z^3} \left[ \frac{16}{3} \sum_q z F_2 + 8 \sum_q e_q^2 \left( 1 - \frac{x}{z} \right) \cdot zg \right]$$



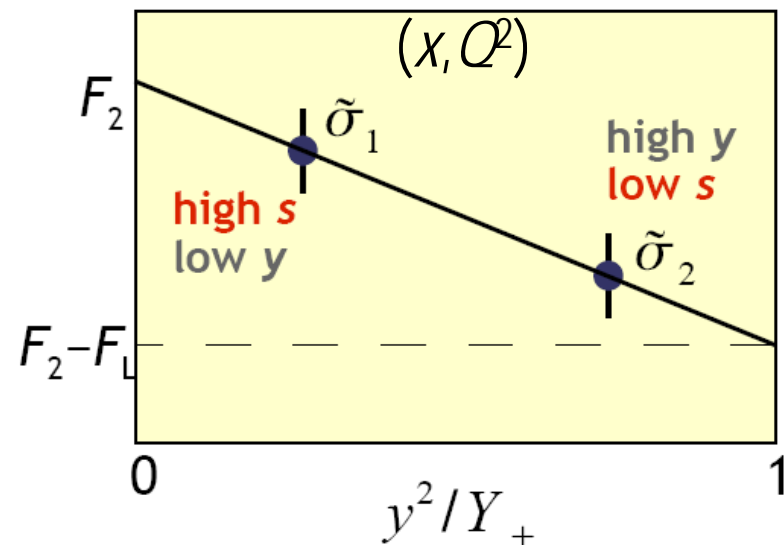
# What are the ways to measure $F_L$ ?

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

- Indirect method:  
needs assumption for  $F_2$



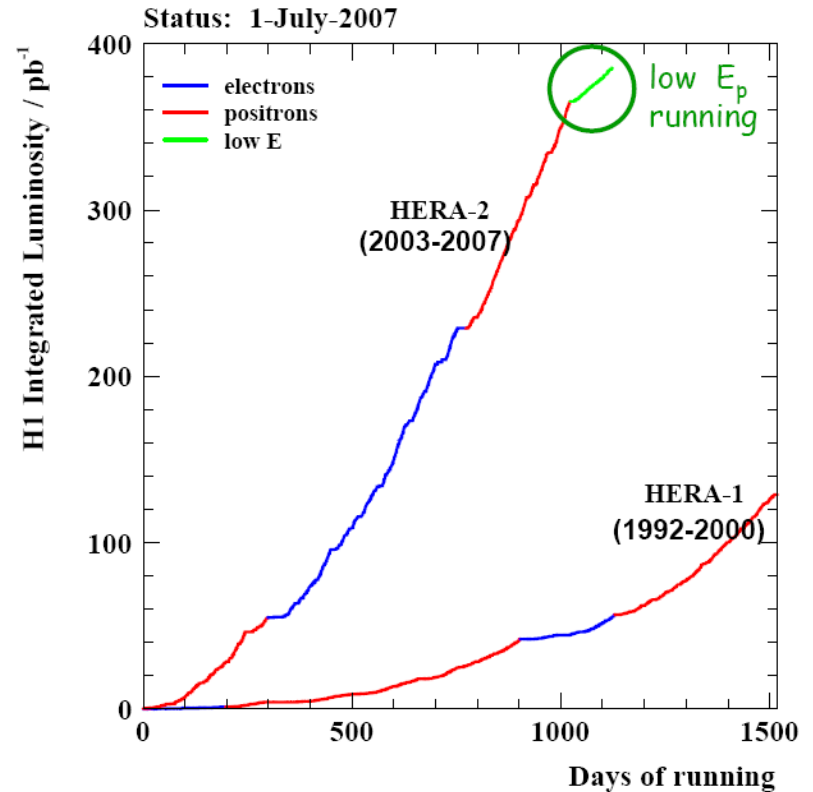
- Direct measurement:  
measure  $\sigma_r$  at the same  $x$  &  $Q^2$   
but different  $y$ , i.e. CME



# HERA

$$e^+ \longrightarrow \longleftarrow p$$

$E_e = 27.5 \text{ GeV}$        $E_p = 820,920,460,575 \text{ GeV}$



HERA-II since 2002 ( $E_p = 920 \text{ GeV}$ ):

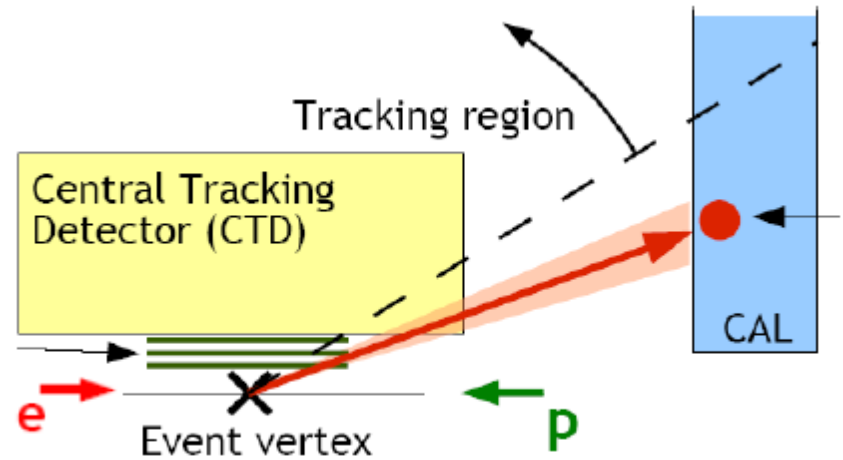
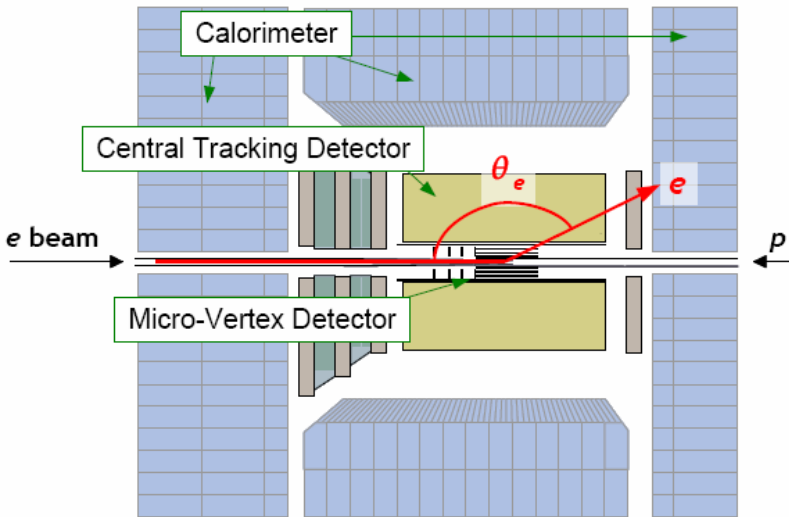
- Increased luminosity
- Polarised lepton in collider mode

In 2007 dedicated low  $E_p$  run for FL measurement:

- Low energy run ( $E_p = 460 \text{ GeV}$ )       $13 \text{ pb}^{-1}$
- Medium energy run ( $E_p = 575 \text{ GeV}$ )       $7 \text{ pb}^{-1}$

# ZEUS

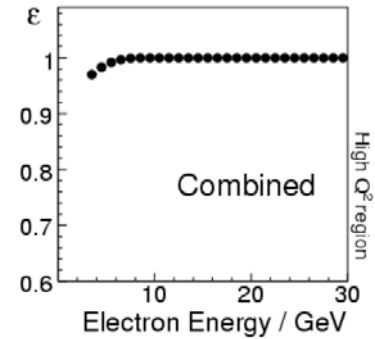
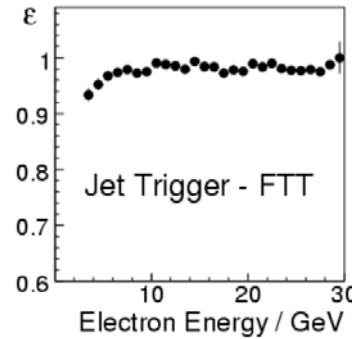
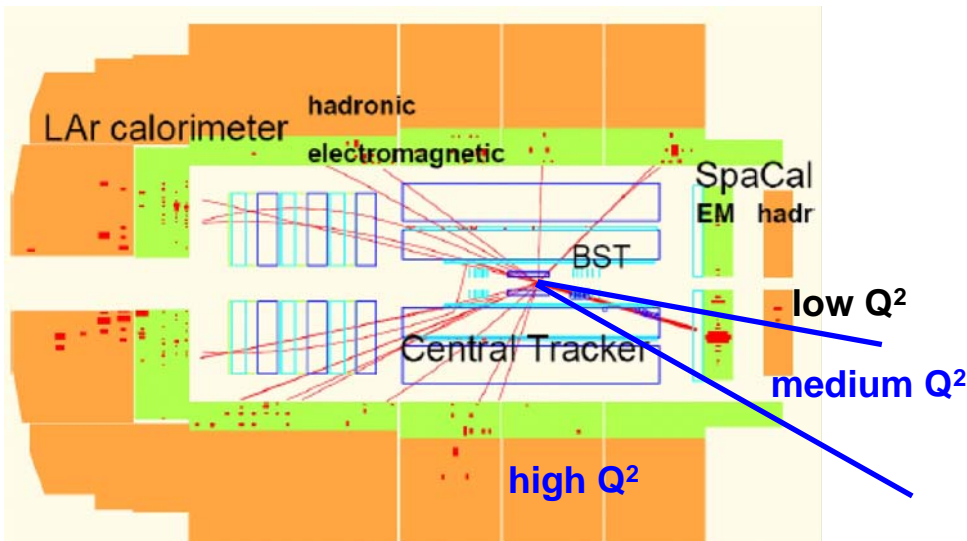
$$y = 1 - (E'_e/E_e) \sin^2(\vartheta_e/2) \rightarrow \text{high } y \Leftrightarrow \text{low } E'_e$$



- the acceptance of the ZEUS tracking system is limited in the backward direction to  $\vartheta_e > 154^\circ$
- Tracking at the edge of phase space
  - use single hits in the tracking detectors to reject neutral particles down to  $\vartheta_e = 168^\circ$
- $F_L$  measurements using  $E_p = 920, 460 \text{ GeV}$ 
  - $\vartheta < 168^\circ$ ,  $E'_e > 6 \text{ GeV}$  ( $y \approx 0.76$ )
  - $24 < Q^2 < 110 \text{ GeV}^2$

# H1 Detector

$$y = 1 - (E'_e/E_e) \sin^2(\vartheta_e/2) \rightarrow \text{high } y \Leftrightarrow \text{low } E'_e$$



new trigger hardware used for **high  $Q^2$**  since fall 2006:

- Jet Trigger (real time clustering in LAr)
- Fast Track Trigger (FTT)
- High trigger efficiency down to low  $E_e$

•  $F_L$  measurements using  $E_p = 920, 460, 575 \text{ GeV}$ ,

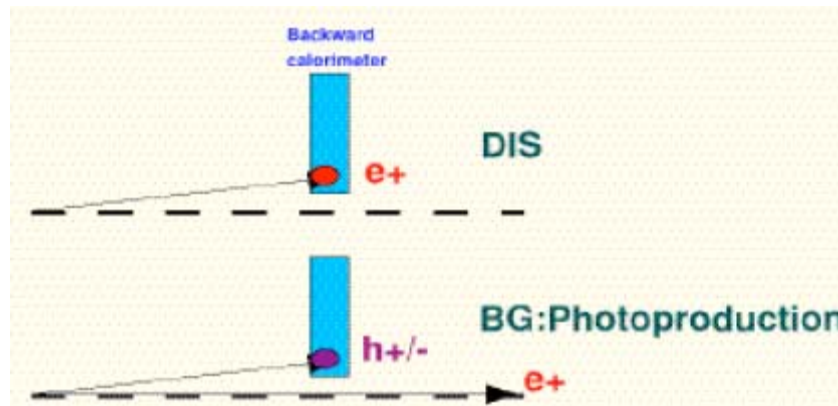
-  $E'_e > 3 \text{ GeV}$  ( $y \approx 0.90$ );

- Medium  $Q^2$  region  $12 < Q^2 < 90 \text{ GeV}^2$  SpaCal + CT  $\rightarrow$  published
- High  $Q^2$  region  $35 < Q^2 < 800 \text{ GeV}^2$  LAr + CT  $\rightarrow$  preliminary
- Low  $Q^2$  region  $5 < Q^2 < 15 \text{ GeV}^2$  SpaCal + BST  $\rightarrow$  to come

# High $\gamma$ region: photoproduction background

- $\gamma p$  event:

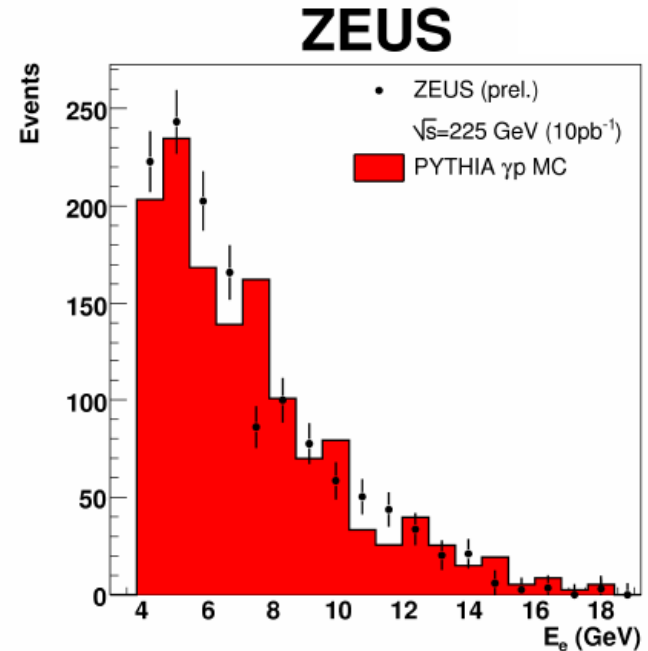
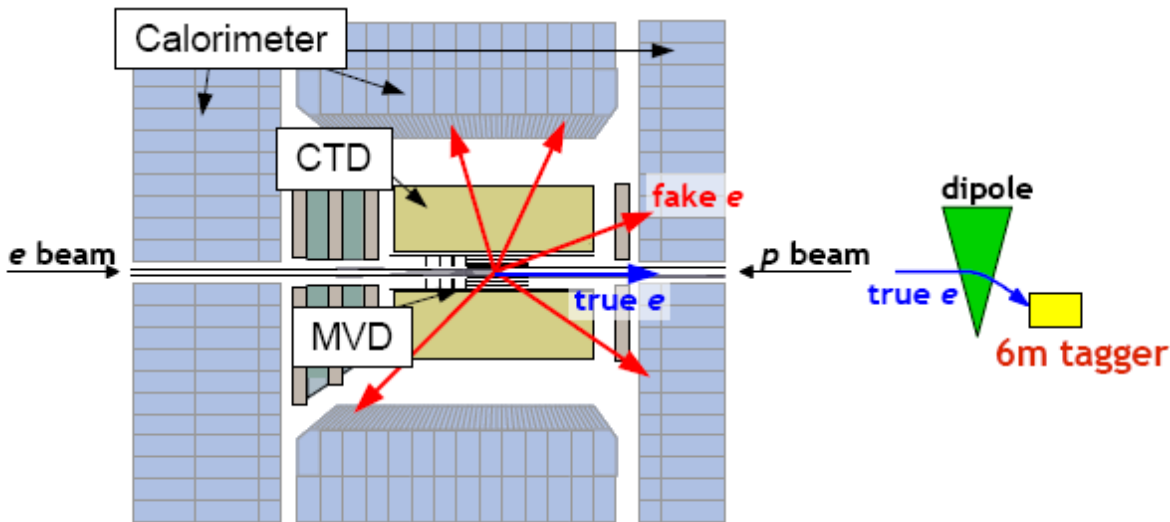
- electron irradiates almost a real photon ( $Q^2 = 0$ ) which then interacts with the proton
- beam electron with lower energy goes down the beam pipe
- one of the particles in the detector is misidentified as DIS electron (mostly  $\gamma$  or  $\pi$ )
- problematic region: low  $Q^2$  events with electron candidate close to the beam pipe



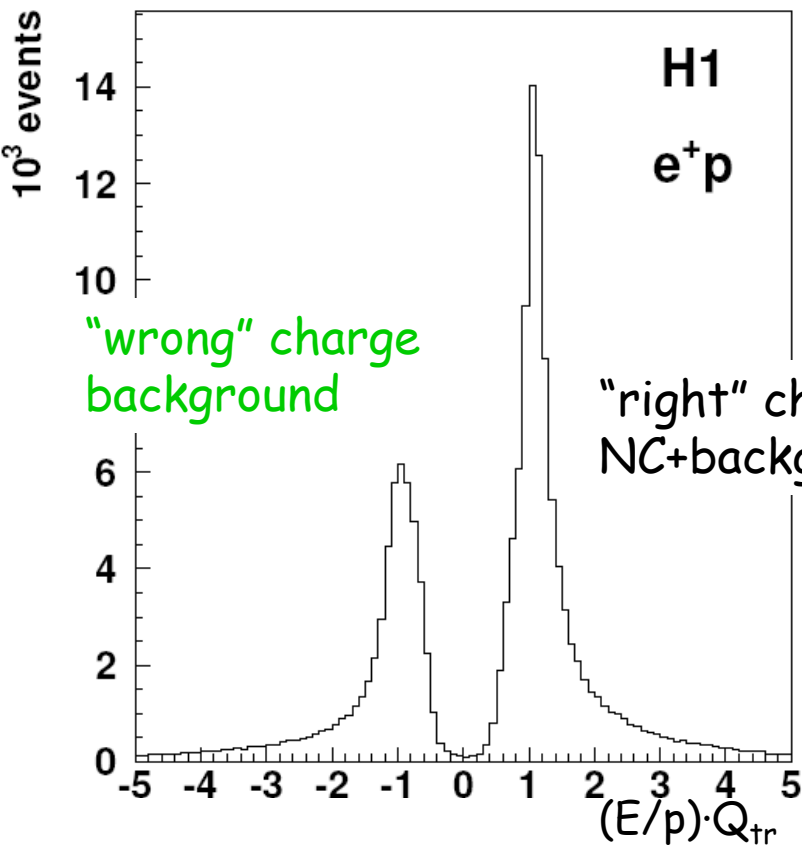


# ZEUS: electron tagger

- 6m tagger:
  - downstream of the electron beam
  - detection of low energy electrons in the beam pipe
  - allows for direct tagging of  $\gamma p$  events
- Fraction of  $\gamma p$  events is measured in the tagger and used to normalise PYTHIA  $\gamma p$  MC for all  $E_p$  energies

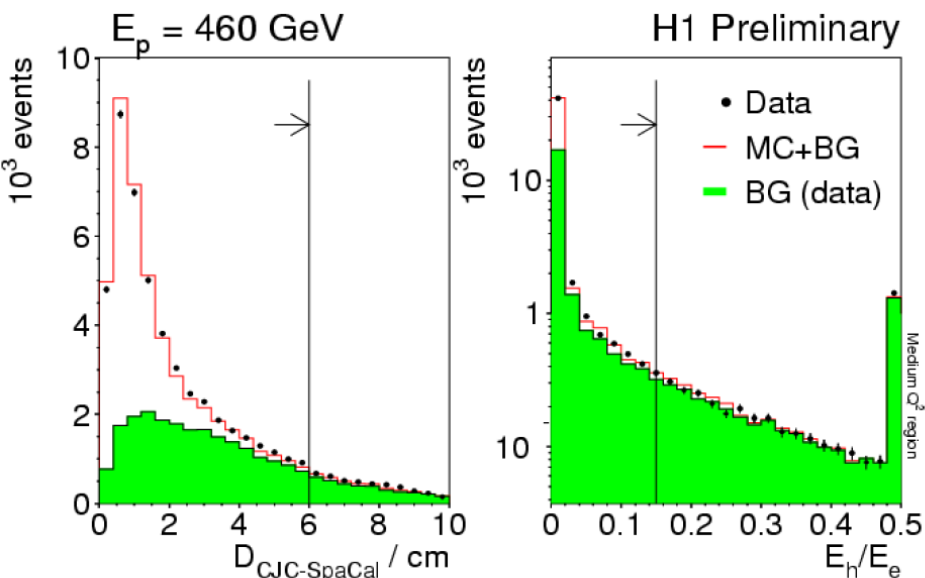


# H1: $\gamma p$ background identification



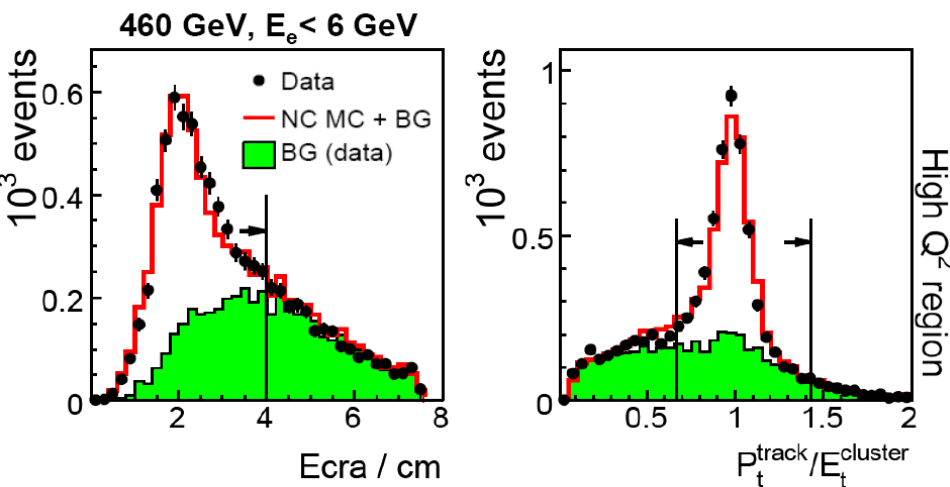
- **Charge measurement** of the electron candidate using track
  - Good charge measurement resolution
  - Wrong assignment of the charge  $< 1\%$
- **$\gamma p$  background reduction:**
  - Accept only "right" charge for electron candidates
  - Remaining background estimated using "wrong" charge electron candidates
  - In statistical subtraction of background take into account charge asymmetry, determined
    - using "wrong" charge electron candidates in  $e^+p$  and  $e^-p$  data
    - $\gamma p$  events identified by 6 m electron tagger

# H1: Electron identification and bg suppression



- Electron is identified by compactness of the cluster in calorimeter and track pointing to the cluster.

further reduction of  $\gamma p$  bg:



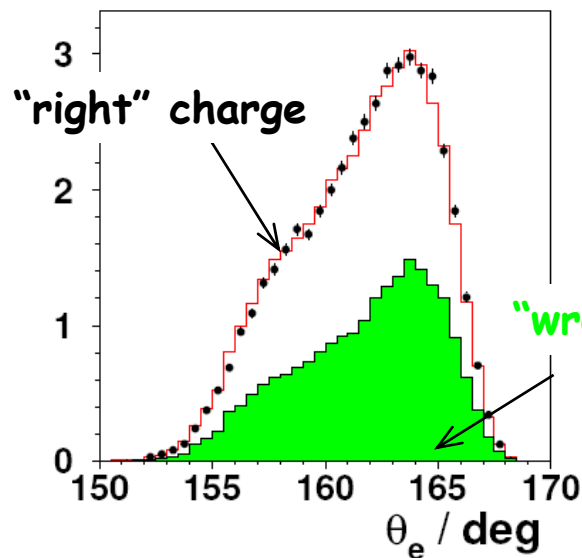
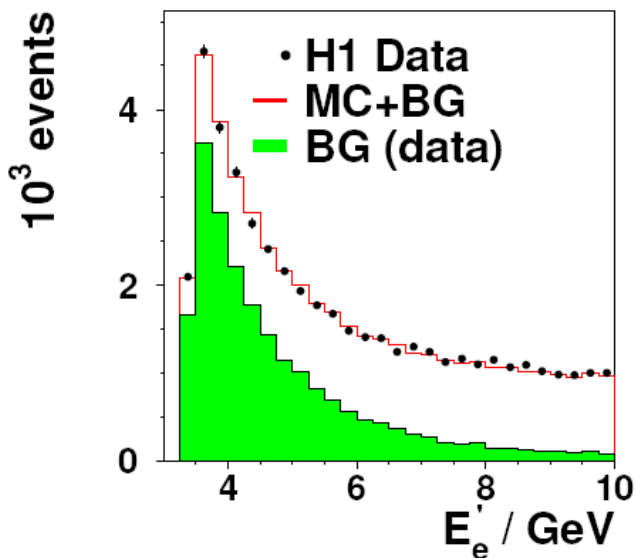
## • Spacal sample

- distance between extrapolated track and the electron cluster  $D < 6$  cm
- energy fraction behind the electron cluster  $E_h/E_e < 0.15$

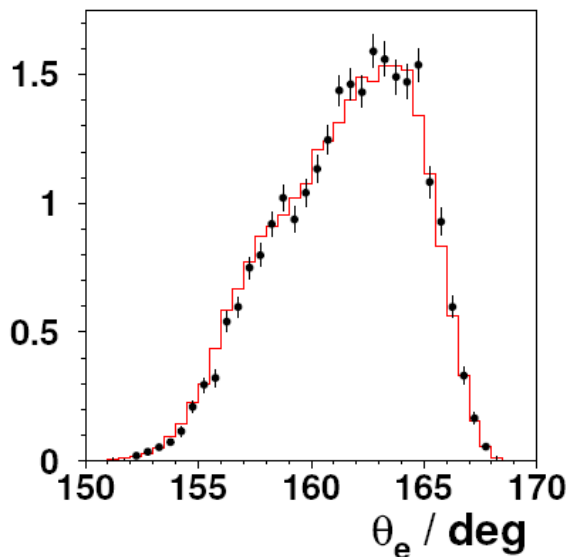
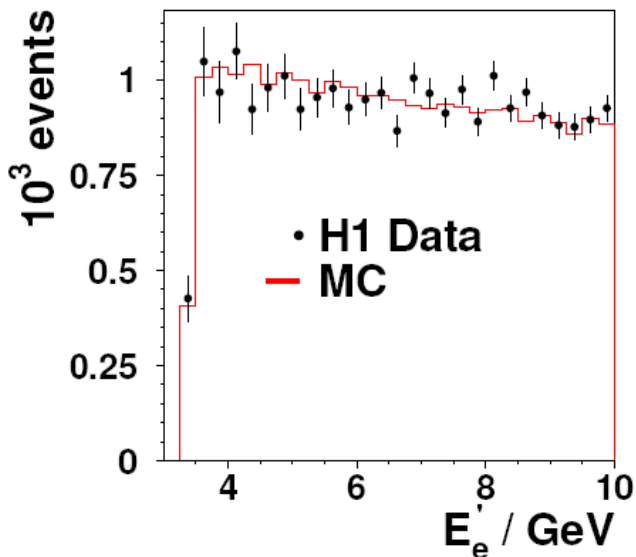
## • LAr sample at $E_e < 6$ GeV

- small transverse size of the electron cluster in LAr:  $E_{cra} < 4$  cm
- matching between track momentum and cluster energy:  
 $0.7 < E_{t, cluster} / P_t^{track} < 1.5$

# H1 Control plots: High $y$ medium $Q^2$



No bg subtraction

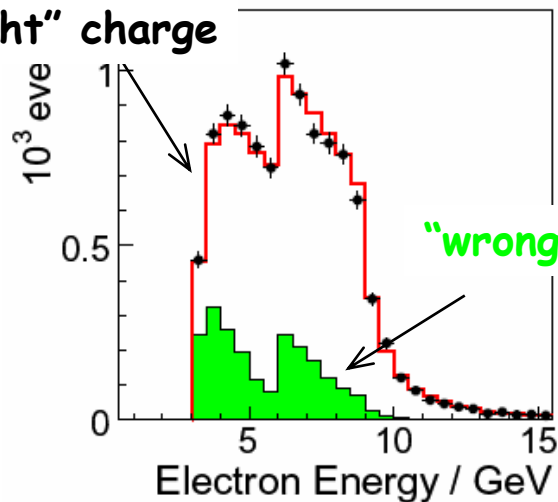


Bg subtracted

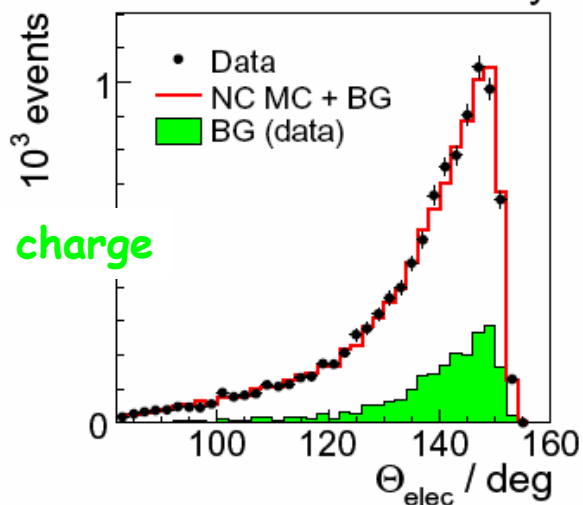
# H1 Control plots: High $\gamma$ at high $Q^2$

$E_n = 460$  GeV

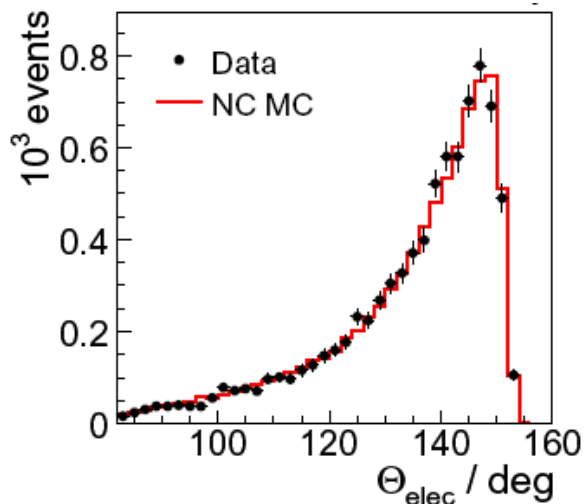
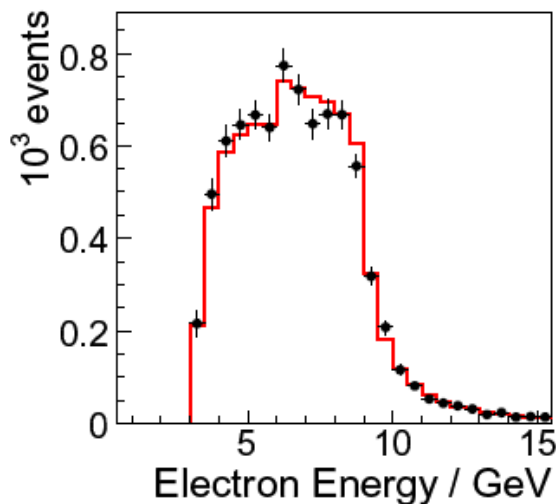
"right" charge



H1 Preliminary



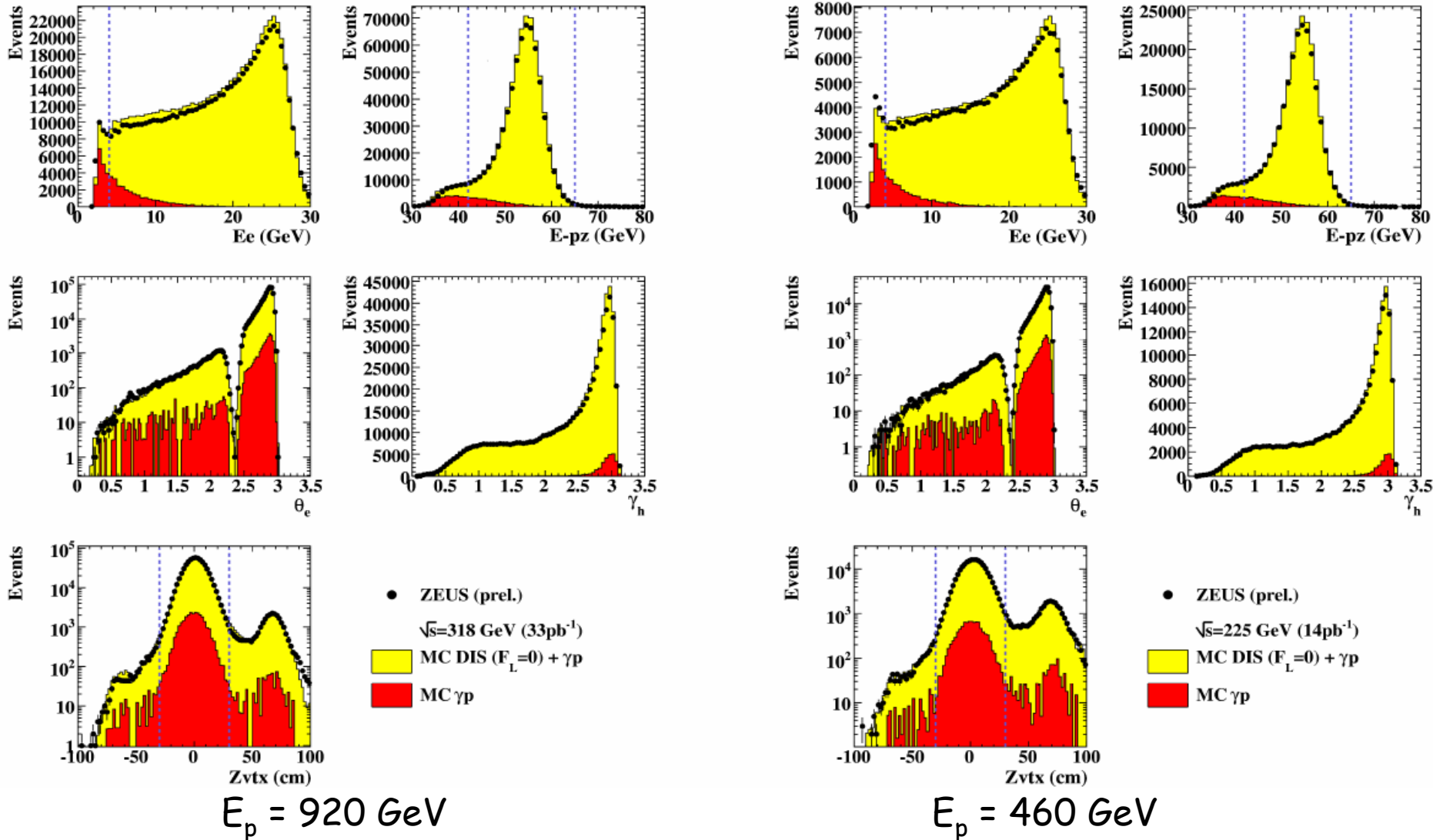
No bg subtraction



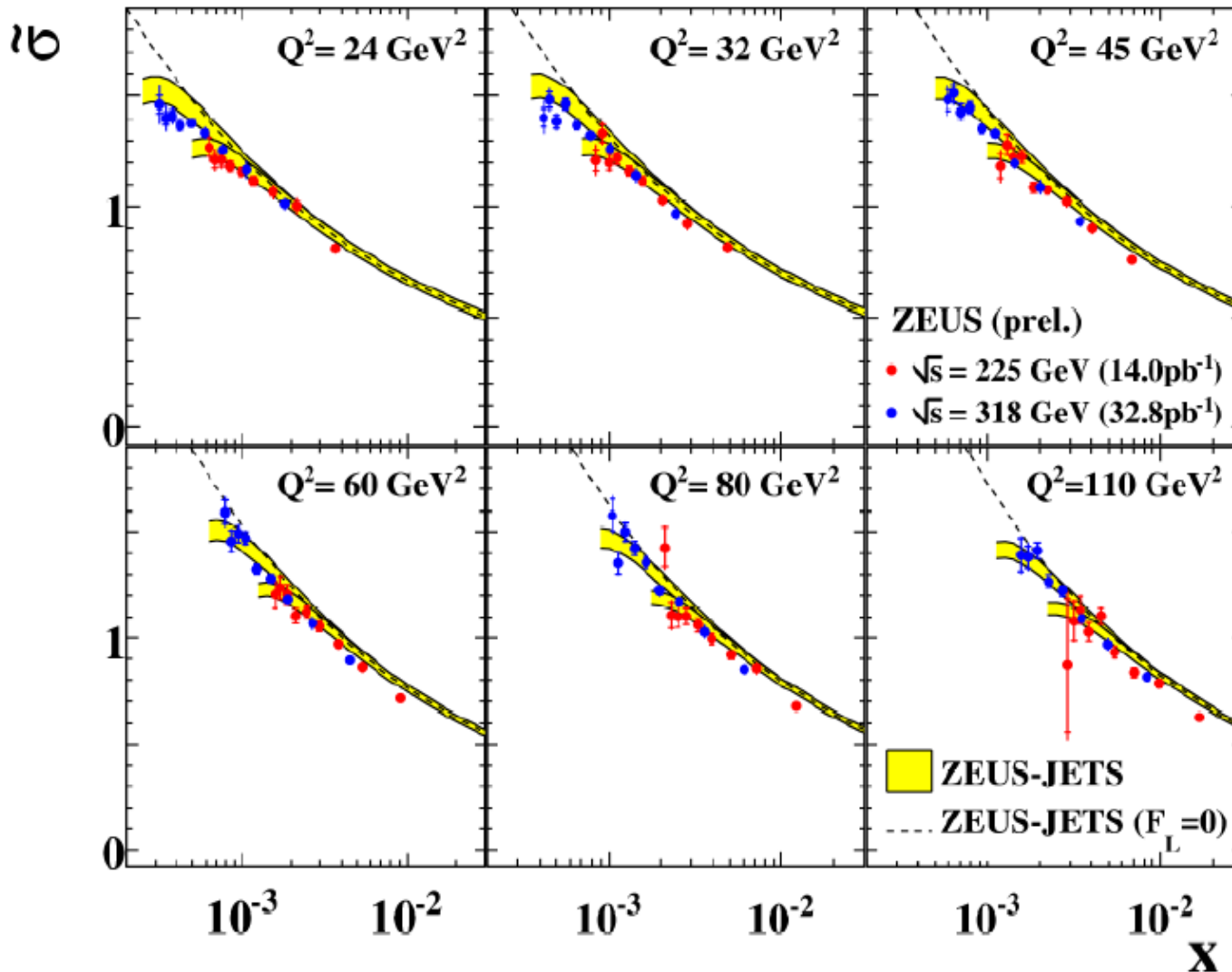
Bg subtracted

# ZEUS Control plots

- The same selection is applied to both samples

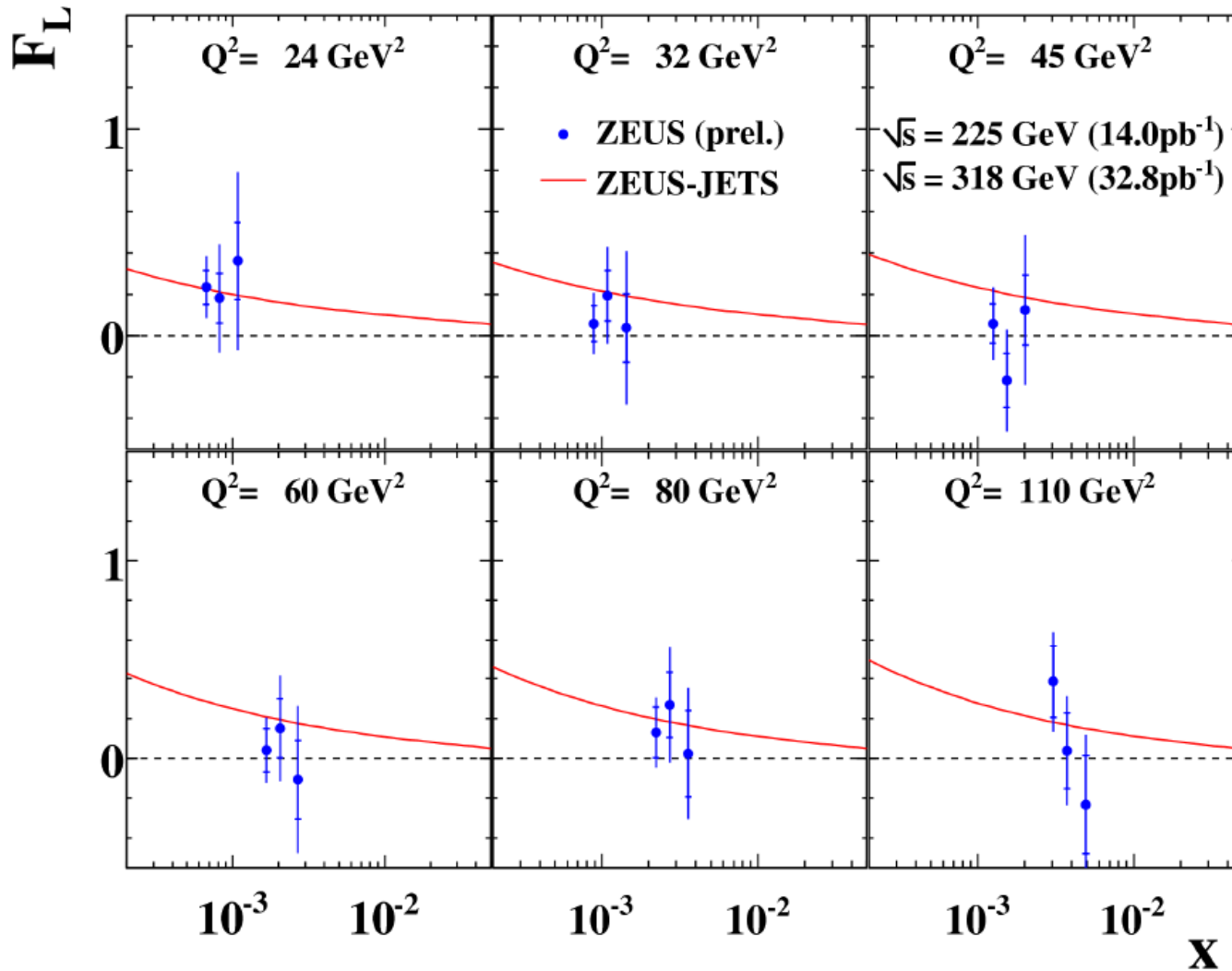


# ZEUS: NC cross section for $E_p = 920, 460 \text{ GeV}$



- The difference between two data sets due to  $F_L$  contribution

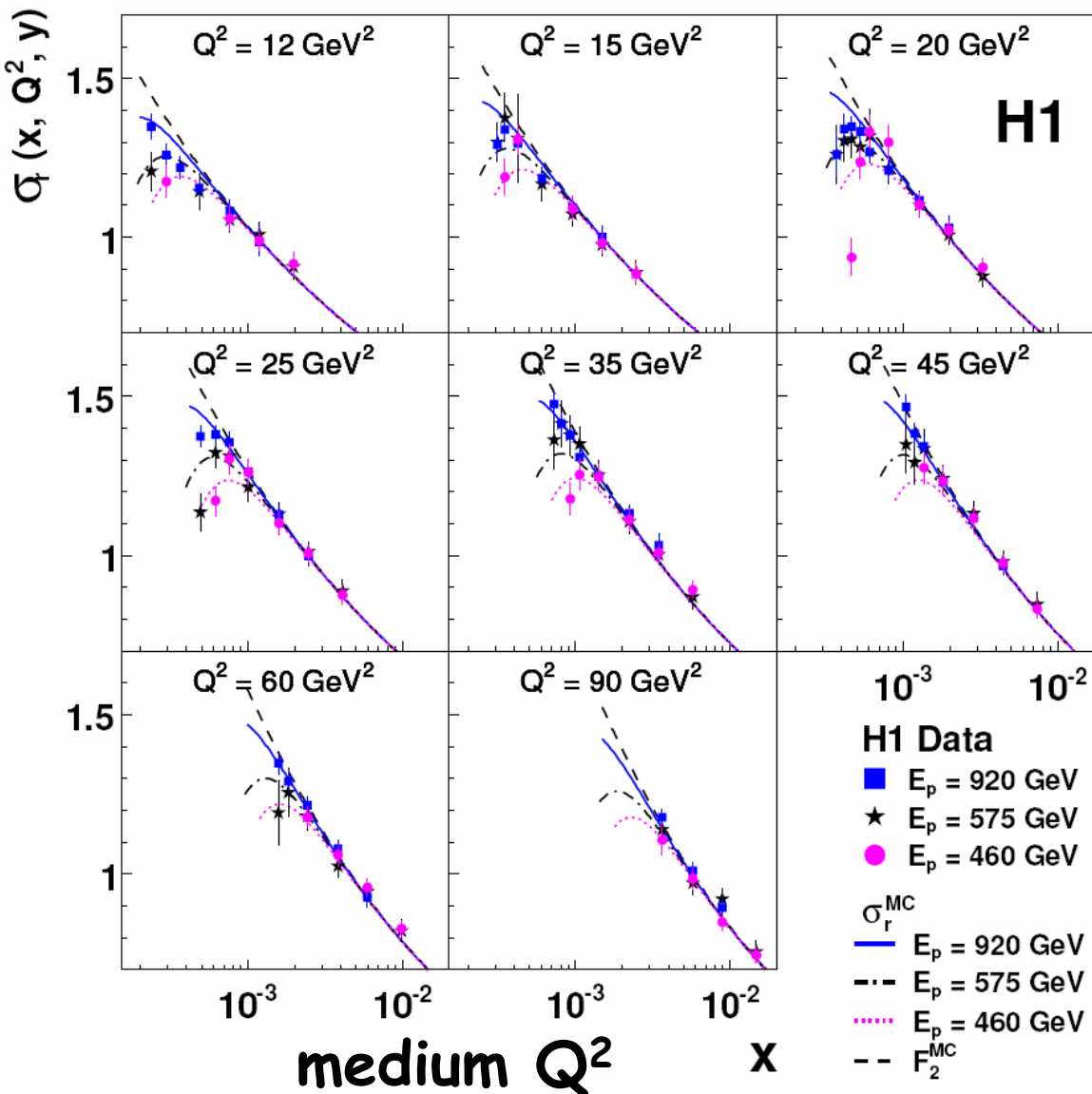
# ZEUS: $F_L$ measurement



- Measurement consistent with QCD calculation as well as with  $F_L=0$



# H1: NC cross section for $E_p = 920, 460, 575 \text{ GeV}$



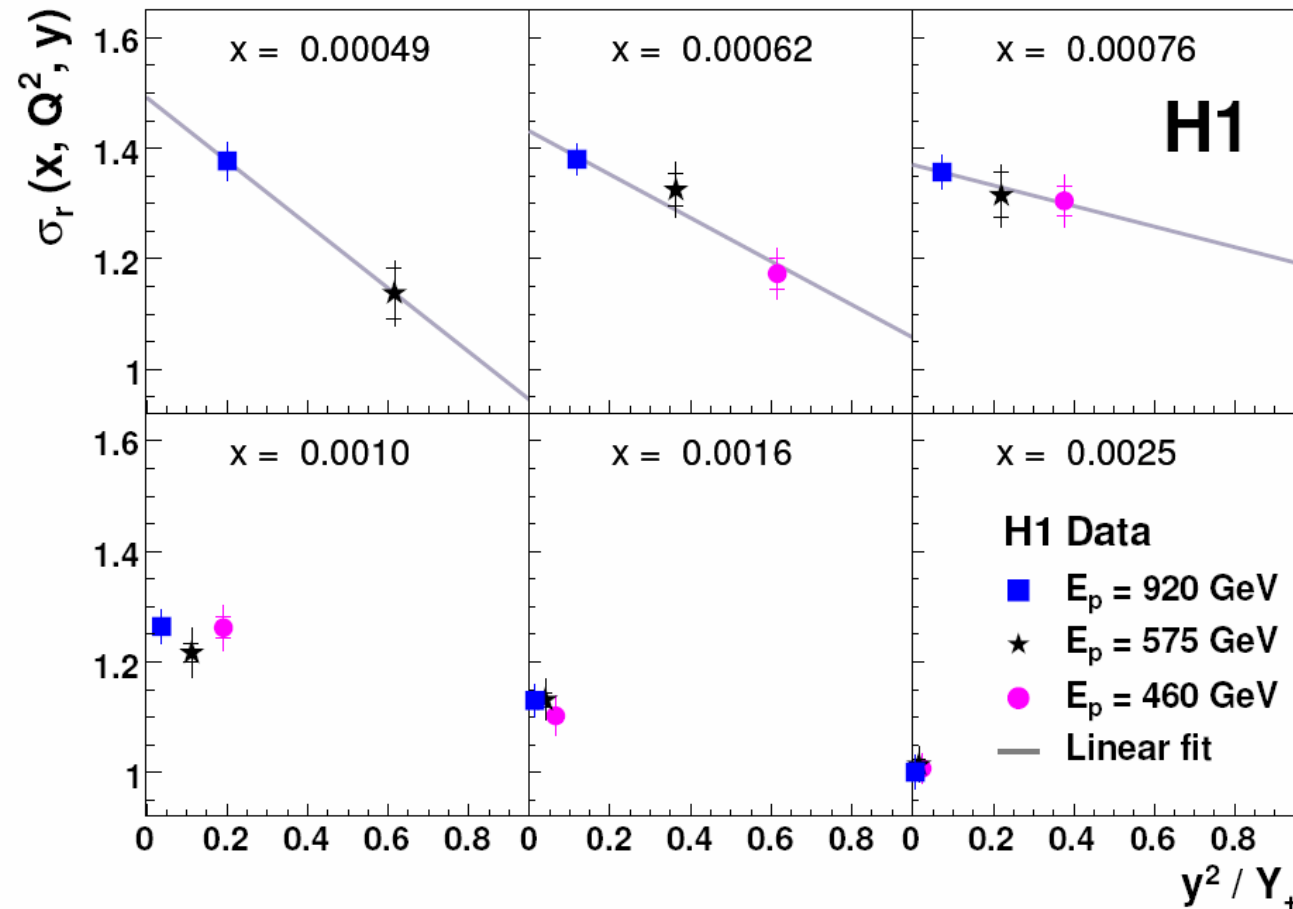
- The same  $x, Q^2$  bins, different  $y$
- Turnover due to  $F_L$  contribution

- Applied relative normalization of  $E_p = 460, 575, 920 \text{ GeV}$  derived from the low  $y$  data

# H1: Extraction of $F_L$

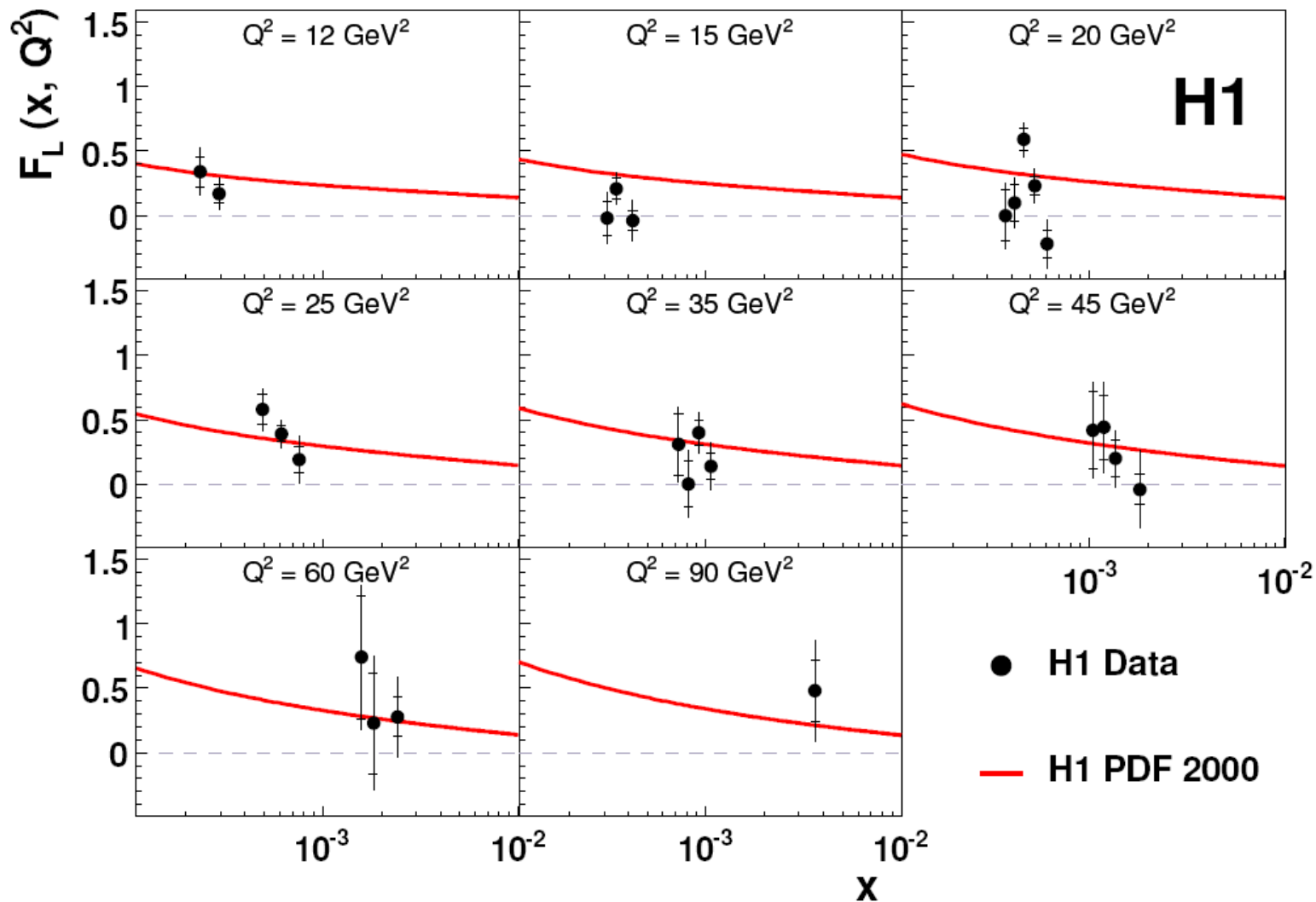
$$\sigma_r = F_2 - \frac{y^2}{Y_+} F_L$$

$Q^2 = 25 \text{ GeV}^2$



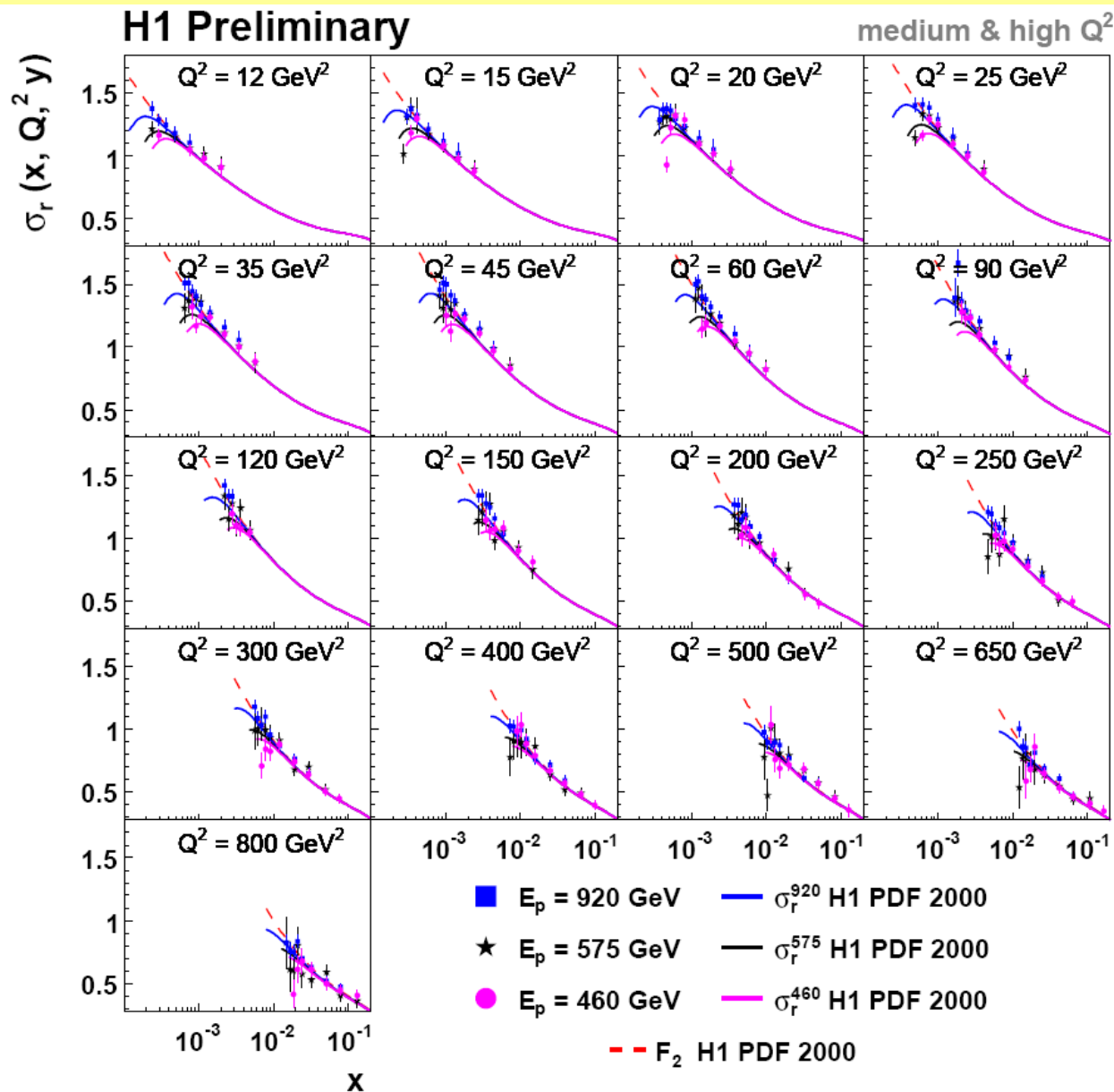
- Linear fit to points of different CME
- Intercept at  $y$  axis:  $F_2$
- Slope:  $F_L$
- Data at different  $E_p$  renormalized

# H1: Published $F_L$ at medium $Q^2$



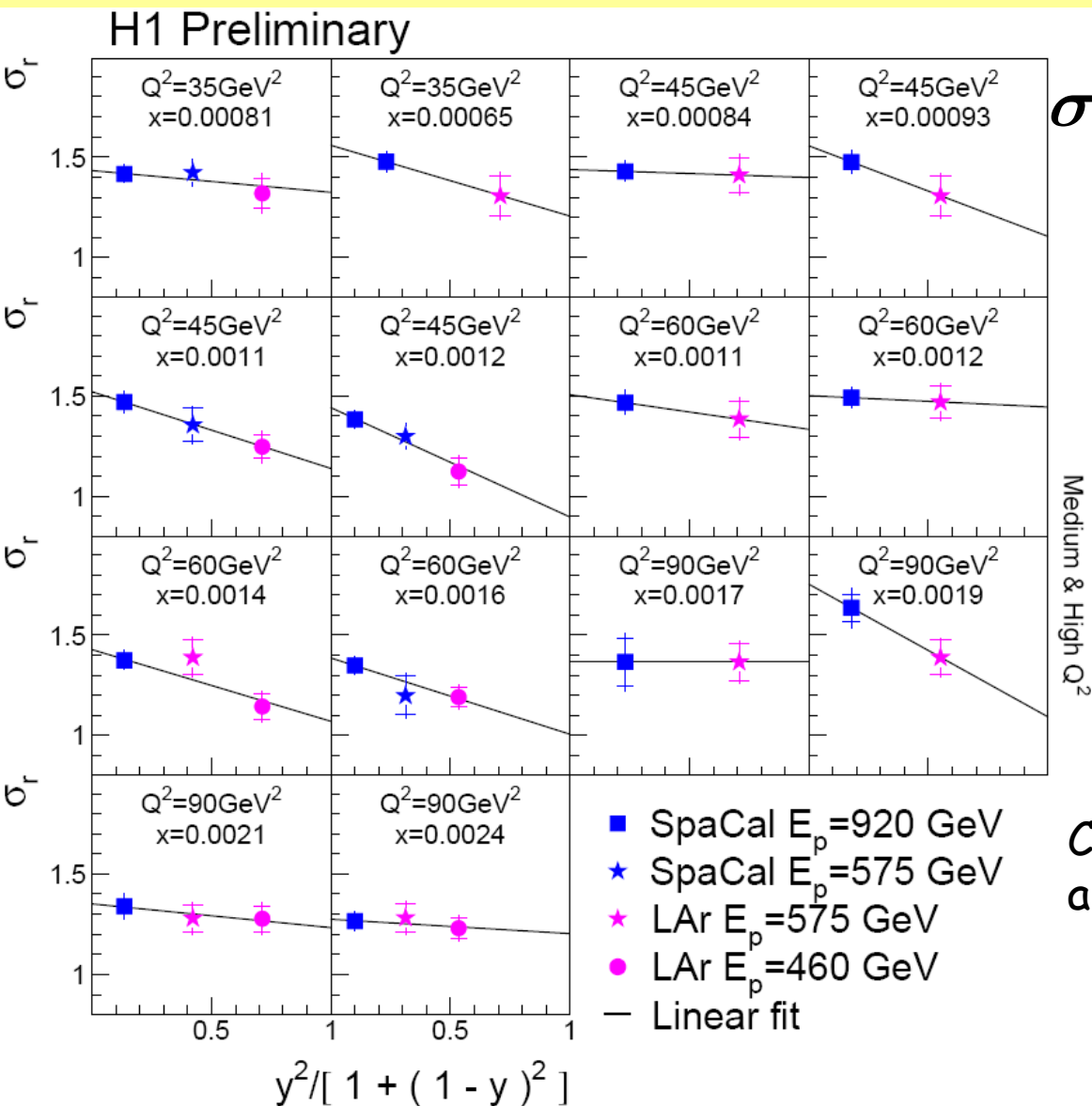
- measured  $F_L$  are above zero and consistent with QCD calculations

# H1: NC cross section in the full $Q^2$ range



- The full range of medium and high  $Q^2$  obtained using SpaCal and LAr data

# H1: Extraction of $F_L$

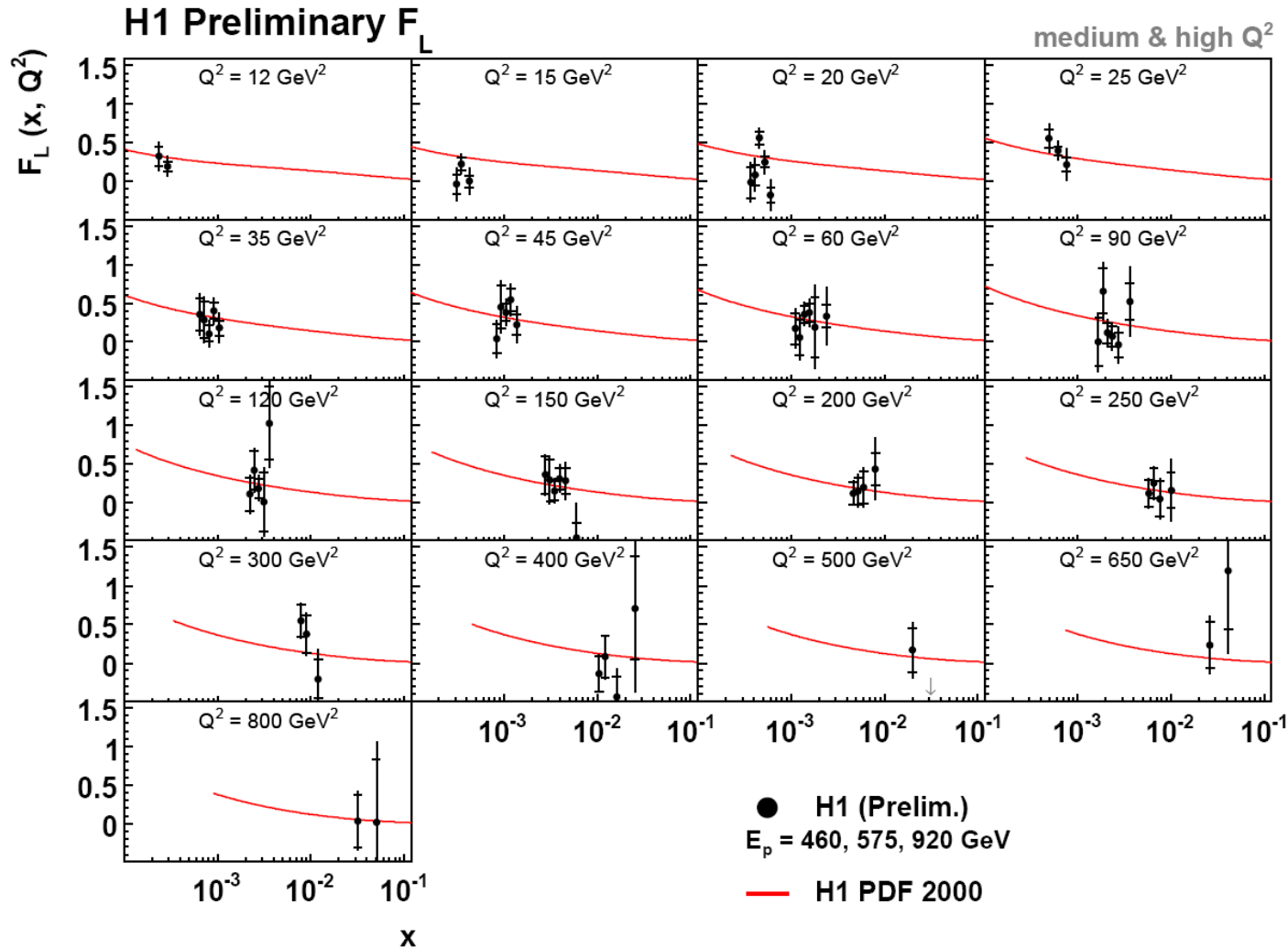


$$\sigma_r = F_2 - \frac{y^2}{1 + (1 - y)^2} F_L$$

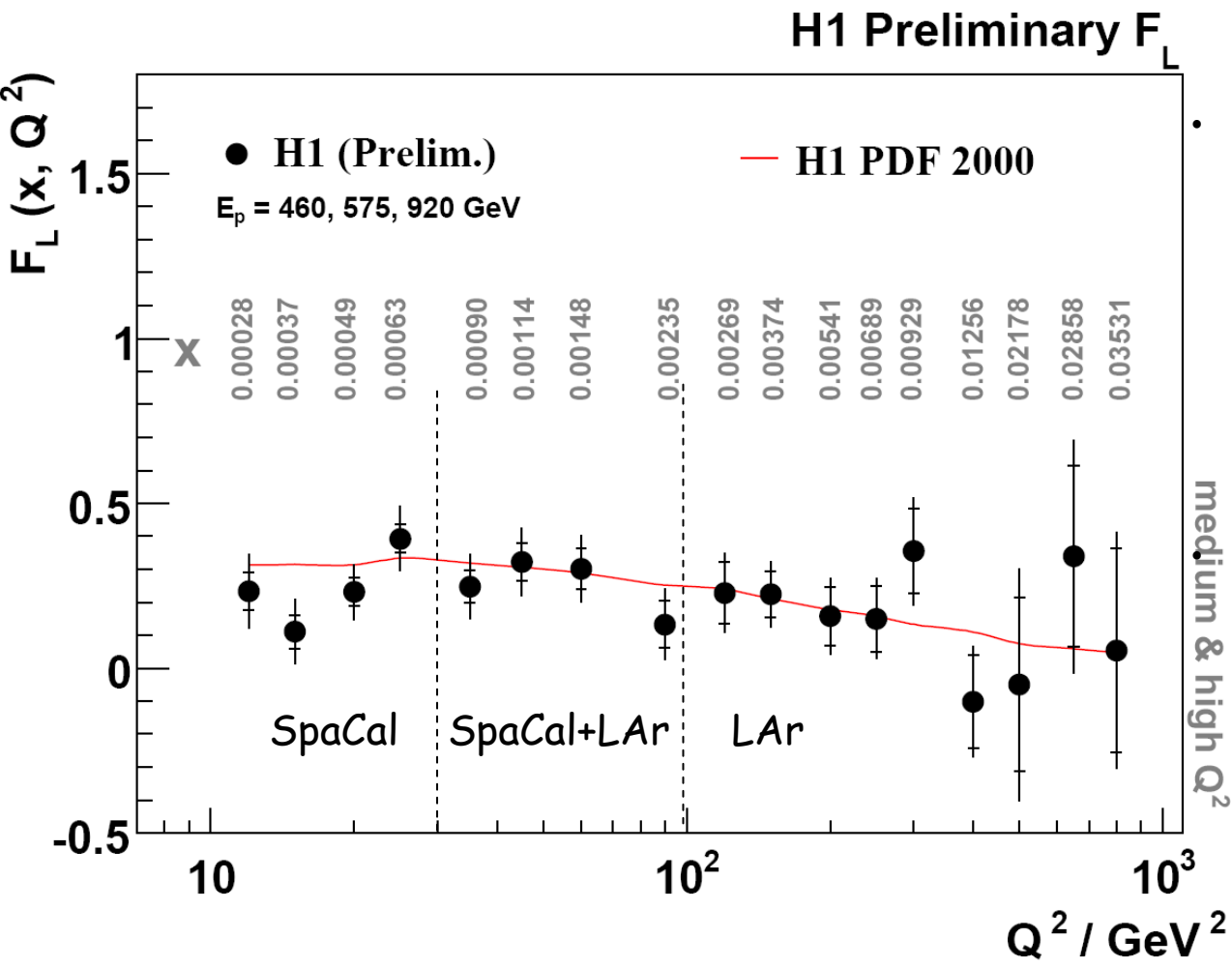
Combination of two independent analyses using different detectors

- SpaCal
- LAr

# H1: FL in the full Q<sup>2</sup> range



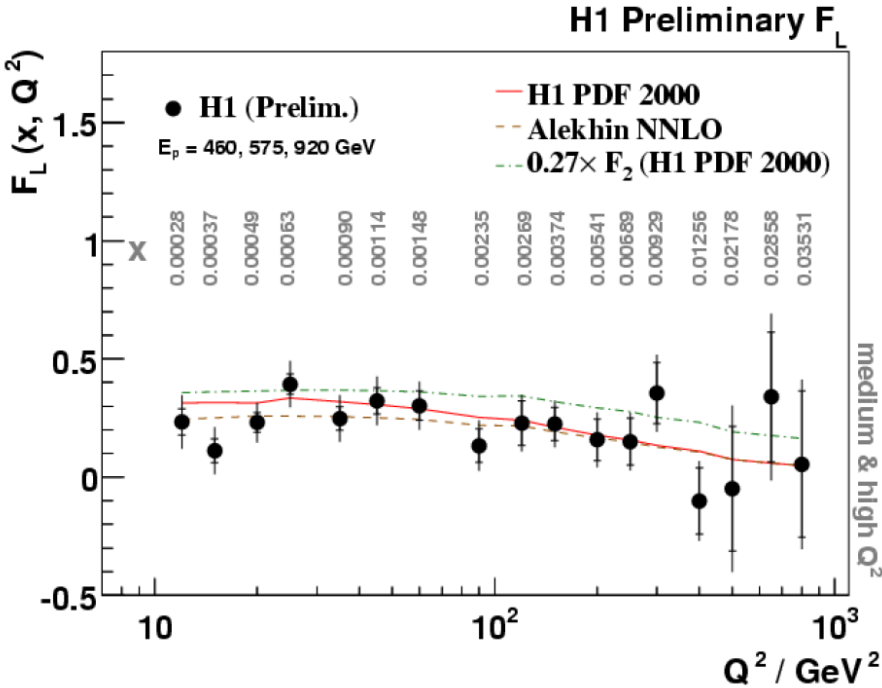
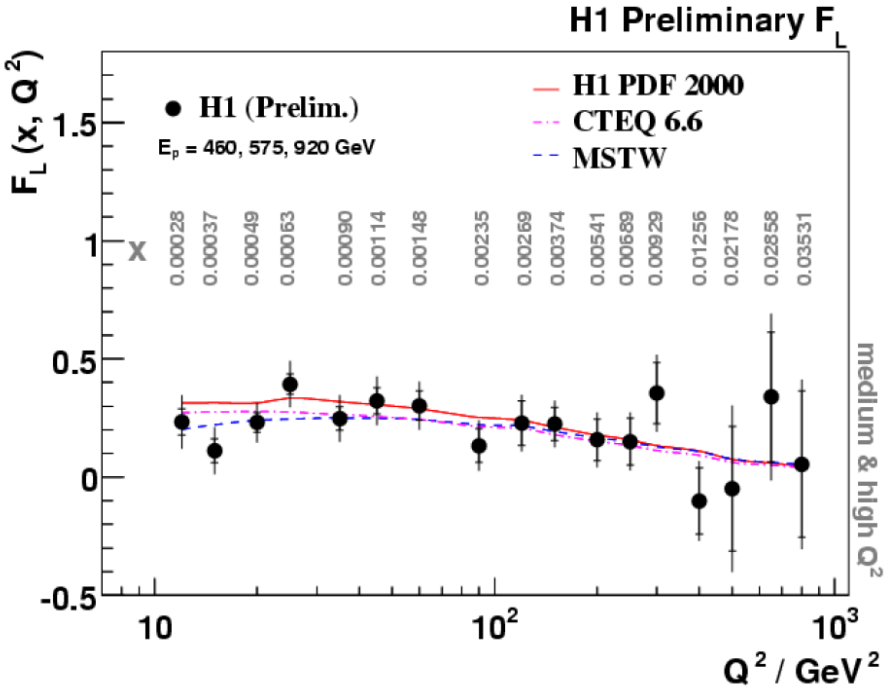
# H1: Averaged $F_L$ in the full $Q^2$ range



SpaCal and LAr provide a cross check of the  $F_L$  measurements

Overall correlated systematics between  $F_L$  points is  $\delta F_L \approx 0.05-0.10$

# Comparisons with different QCD calculations



- $F_L$  measurements are in a good agreement with the QCD calculations



# Summary

## direct measurements of $F_L$

### • ZEUS:

- $E_p = 920 \text{ GeV}$  &  $E^p = 460 \text{ GeV}$
- The measurement covers medium  $Q^2$  range  $24 \text{ GeV}^2$  to  $110 \text{ GeV}^2$
- Measured  $F_L$  values are consistent with ZEUS-Jets PDF prediction as well as with  $F_L=0$
- To come:
  - Extend measurement to higher  $y$  (more sensitive to  $F_L$ )
  - Include  $E_p = 575 \text{ GeV}$  dataset

### • H1:

- $E_p = 920 \text{ GeV}$ ,  $E_p = 460 \text{ GeV}$ ,  $E_p = 575 \text{ GeV}$
- the full range of medium and high  $Q^2$ :  $12 < Q^2 < 800 \text{ GeV}^2$ ,
- Combinations of two independent measurements
- The measured  $F_L$  is in agreement with the recent theoretical calculations in the QCD framework
- To come:
  - $F_L$  measurement at the lowest  $Q^2$