FL Measurements at Low x

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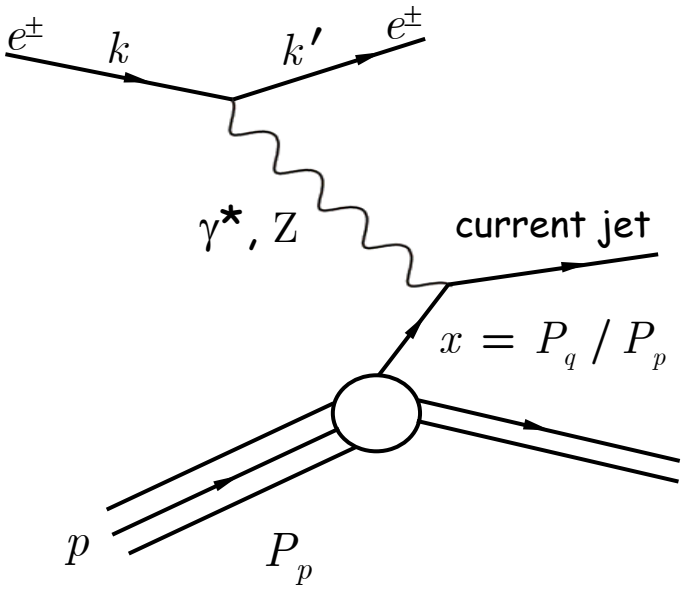
on behalf of
H1 & ZEUS Collaborations

- 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



- Q2 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 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

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

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

- **F_2 dominant contribution:**

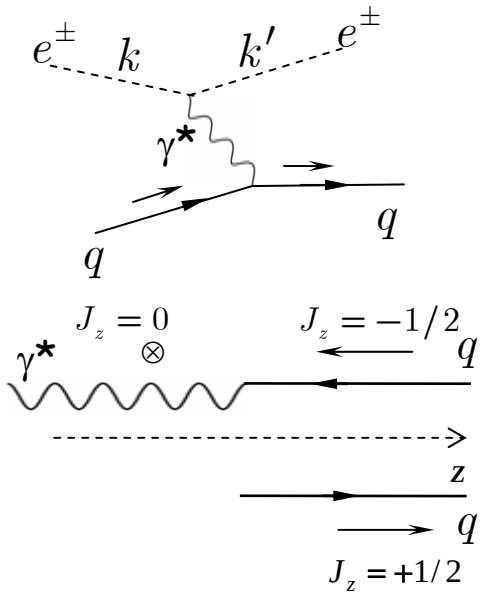
$$F_2 = \sum_q e_q^2 x \quad (q + \bar{q})$$

- **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: $F_L \propto \sigma_L^{\gamma p} = 0$
  - F_L non-zero in QCD

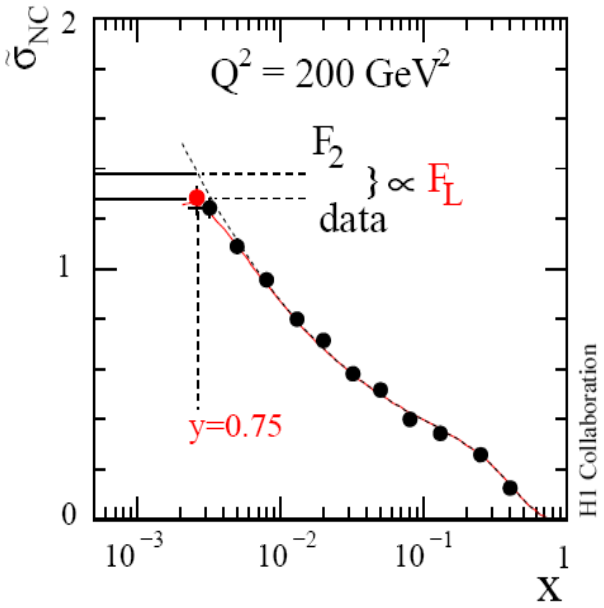
$$F_L = \frac{\alpha_s}{4\pi}x^2\int_x^1 \frac{dz}{z^3}\left[\frac{16}{3}\sum_q zF_2 + 8\sum_q e_q^2\left(1-\frac{x}{z}\right)\cdot zg\right]$$



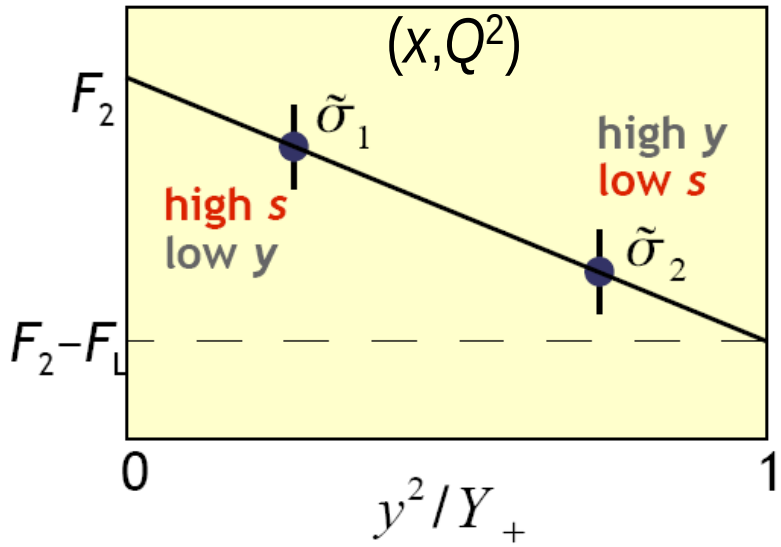
What are the ways to measure F_L?

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

- Indirect method:
  needs assumption for F2



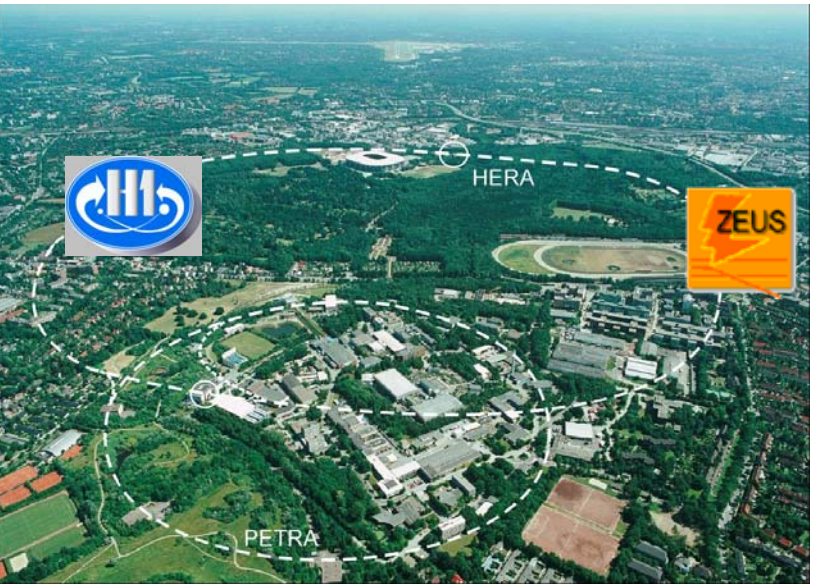
- Direct measurement:
  measure σ_r at the same x & Q^2 but different y, i.e. CME

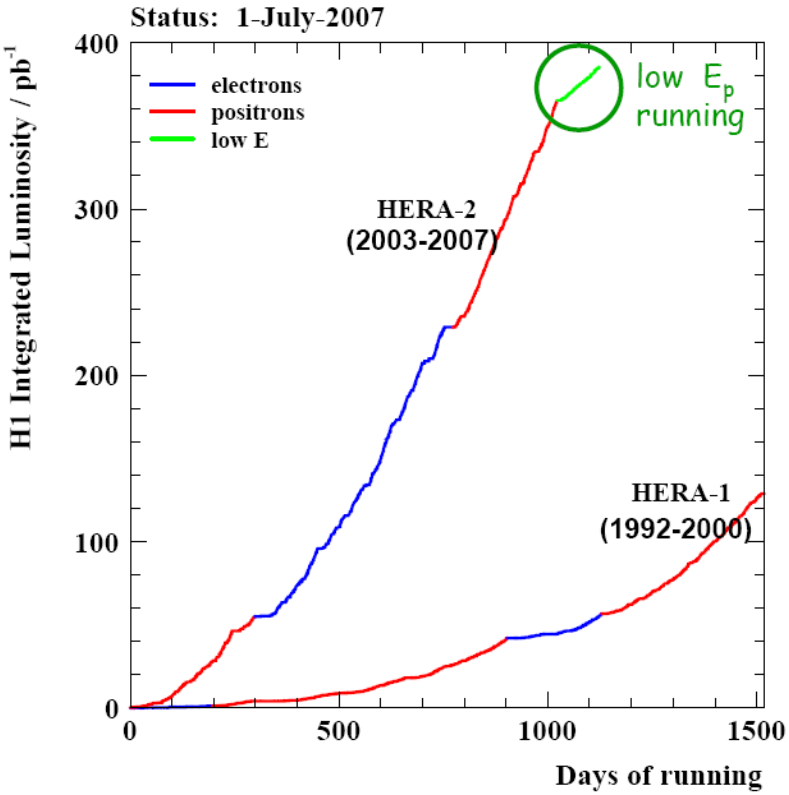


HERA

e^+ → ← p

Ee = 27.5 GeV Ep = 820,920,460,575 GeV





HERA-II since 2002 (Ep = 920 GeV):

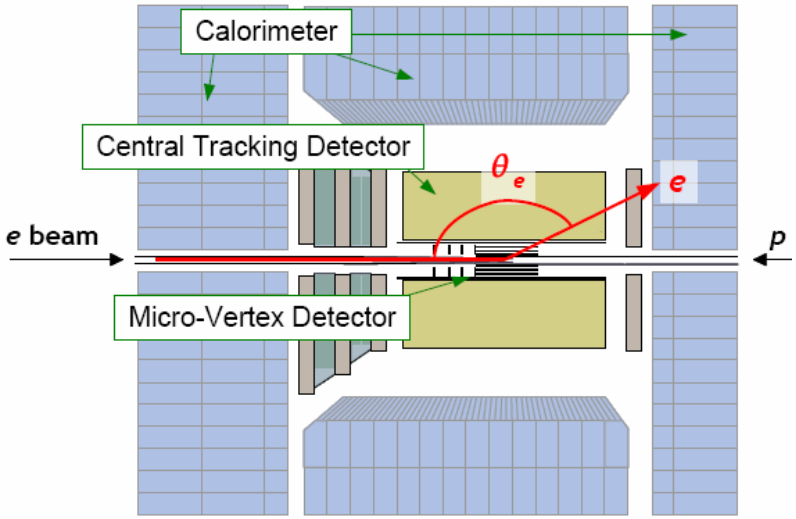
- Increased luminosity
- Polarised lepton in collider mode

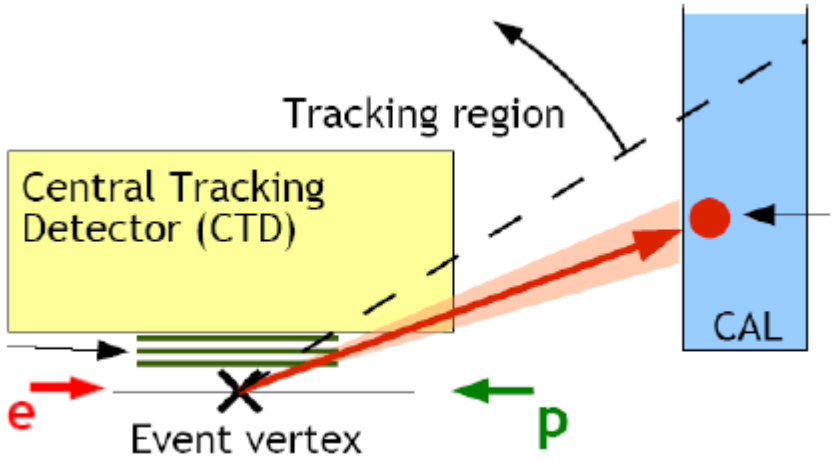
In 2007 dedicated low Ep run for FL measurement:

- Low energy run (Ep = 460 GeV) 13 pb^{-1}
- Medium energy run (Ep = 575 GeV) 7 pb^{-1}

ZEUS

$y=1-(E'_e/E_e)\sin^2(\vartheta_e/2)$ -> high y <=> low E'_e



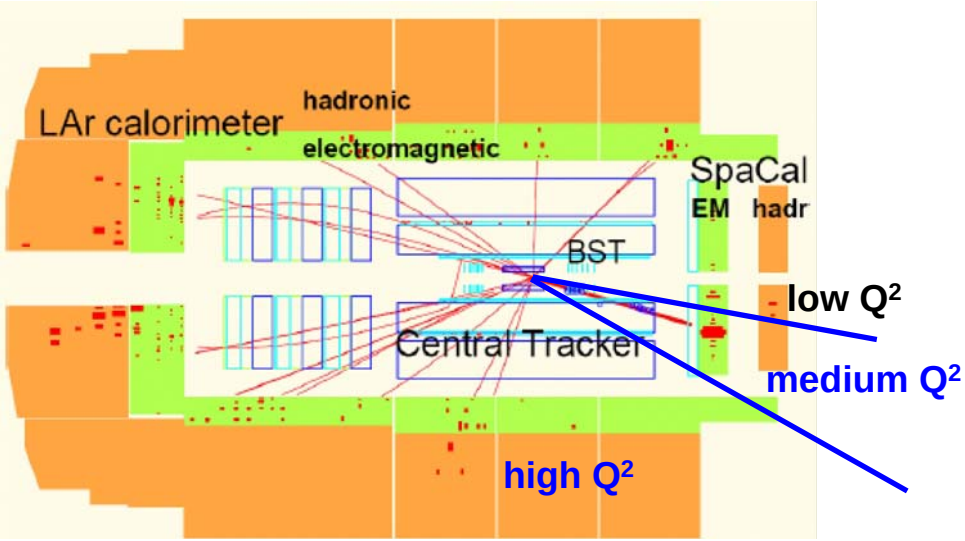


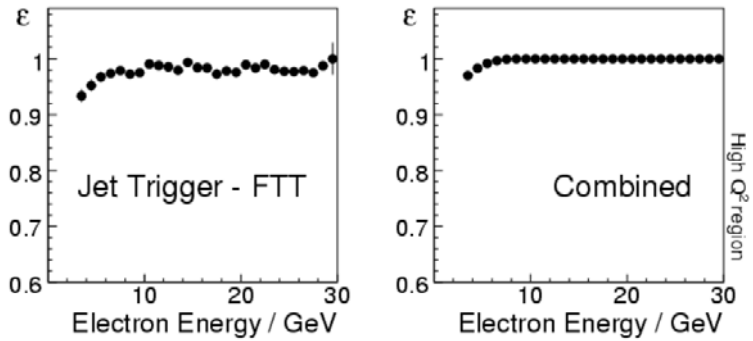
- the acceptance of the ZEUS tracking system is limited in the backward direction to $\vartheta_e > 154°$
- Tracking at the edge of phase space
  - use single hits in the tracking detectors to reject neutral particles down to $\vartheta_e = 168°$

- F_L measurements using E_p = 920, 460 GeV
  - $\vartheta < 168°$, $E'_e > 6$ GeV ($y \approx 0.76$)
  - $24 < Q^2 < 110$ GeV^2

H1 Detector

$y=1-(E'_e/E_e)\sin^2(\vartheta_e/2)$ -> high y <=> low E'_e





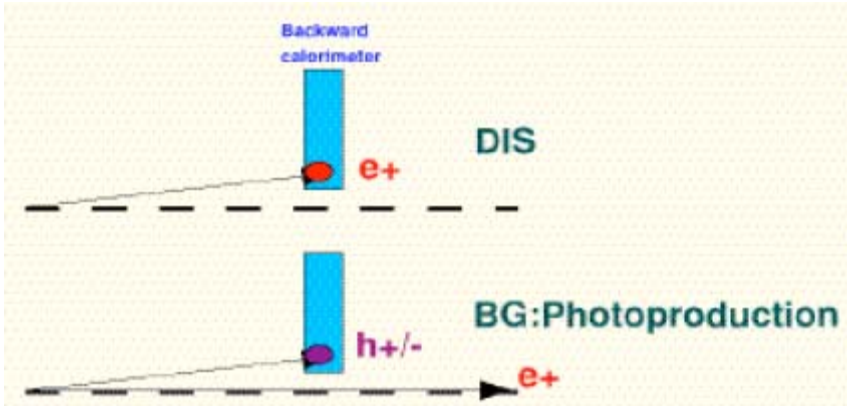
new trigger hardware used for **high Q^2** since fall 2006:

- 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 GeV,
  - E'_e > 3 GeV (y ≈0.90);
  - Medium Q^2 region 12 < Q^2 < 90 GeV² SpaCal + CT -> published
  - High Q^2 region 35 < Q^2 < 800 GeV² LAr + CT -> preliminary
  - Low Q^2 region 5 < Q^2 < 15 GeV² SpaCal + BST -> to come

High y region: photoproduction background

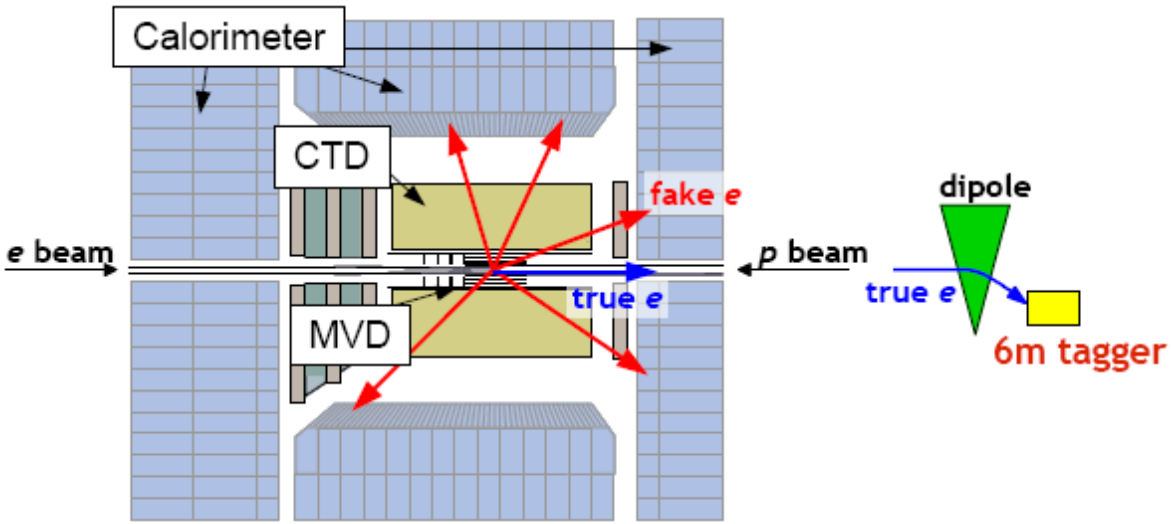
- **γp event:**
  - electron irradiates almost a real photon ($Q^2 = 0$) which then interacts with the proton
  - beam electron with lower energy goes down the beam pipe
  - one of the particles in the detector is misidentified as DIS electron (mostly γ or π)
  - problematic region: low Q^2 events with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

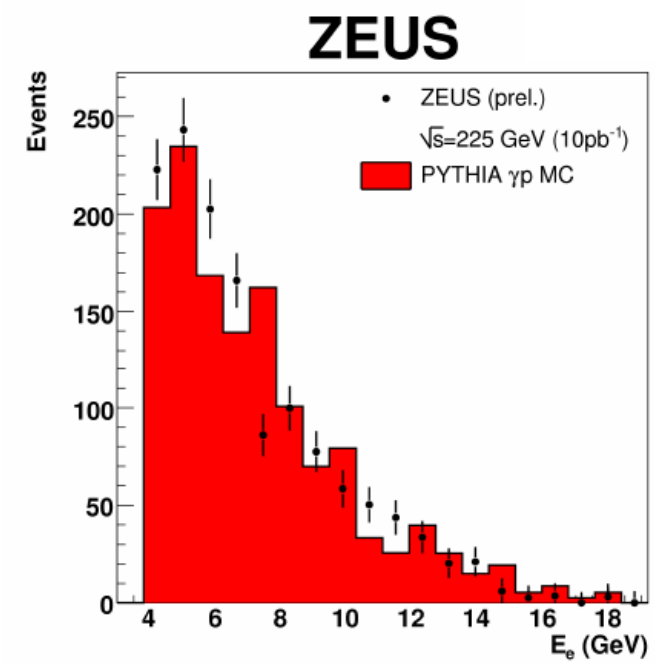


ZEUS: electron tagger

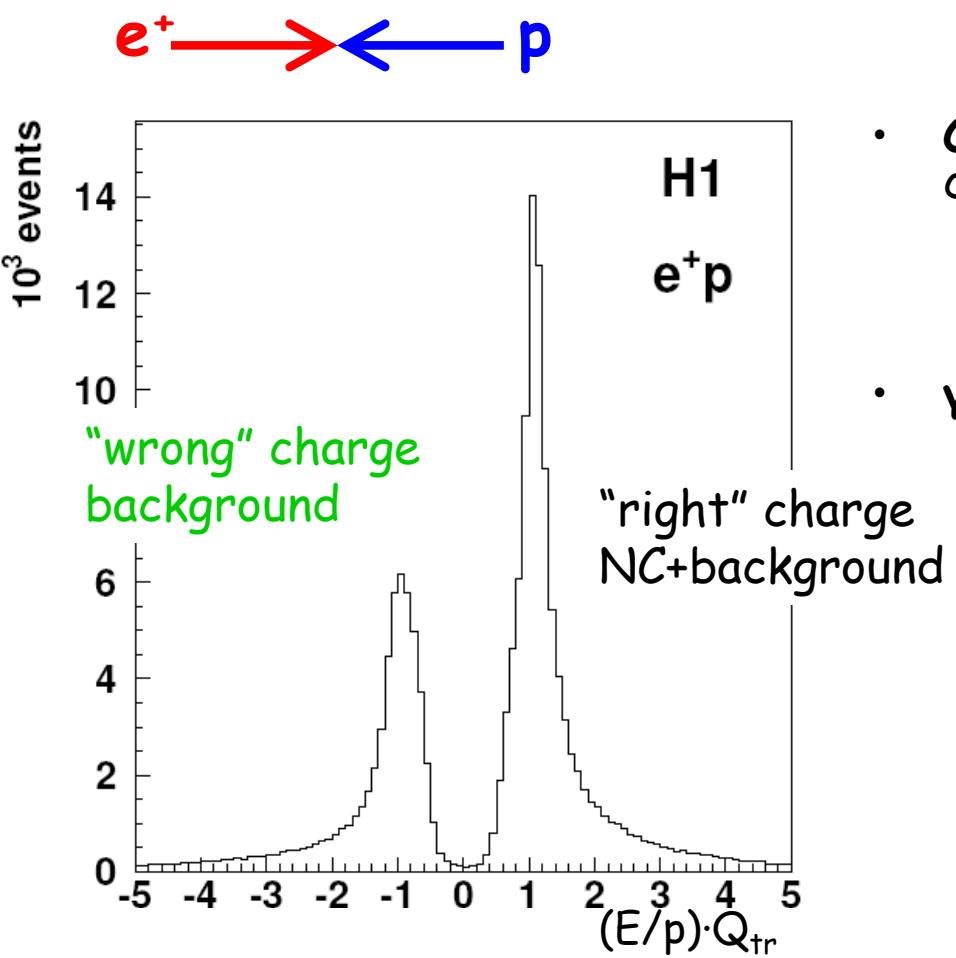
- 6m tagger:
  - downstream of the electron beam
  - detection of low energy electrons in the beam pipe
  - allows for direct tagging of γp events

- Fraction of γp events is measured in the tagger and used to normalise PYTHIA γp MC for all E_p energies



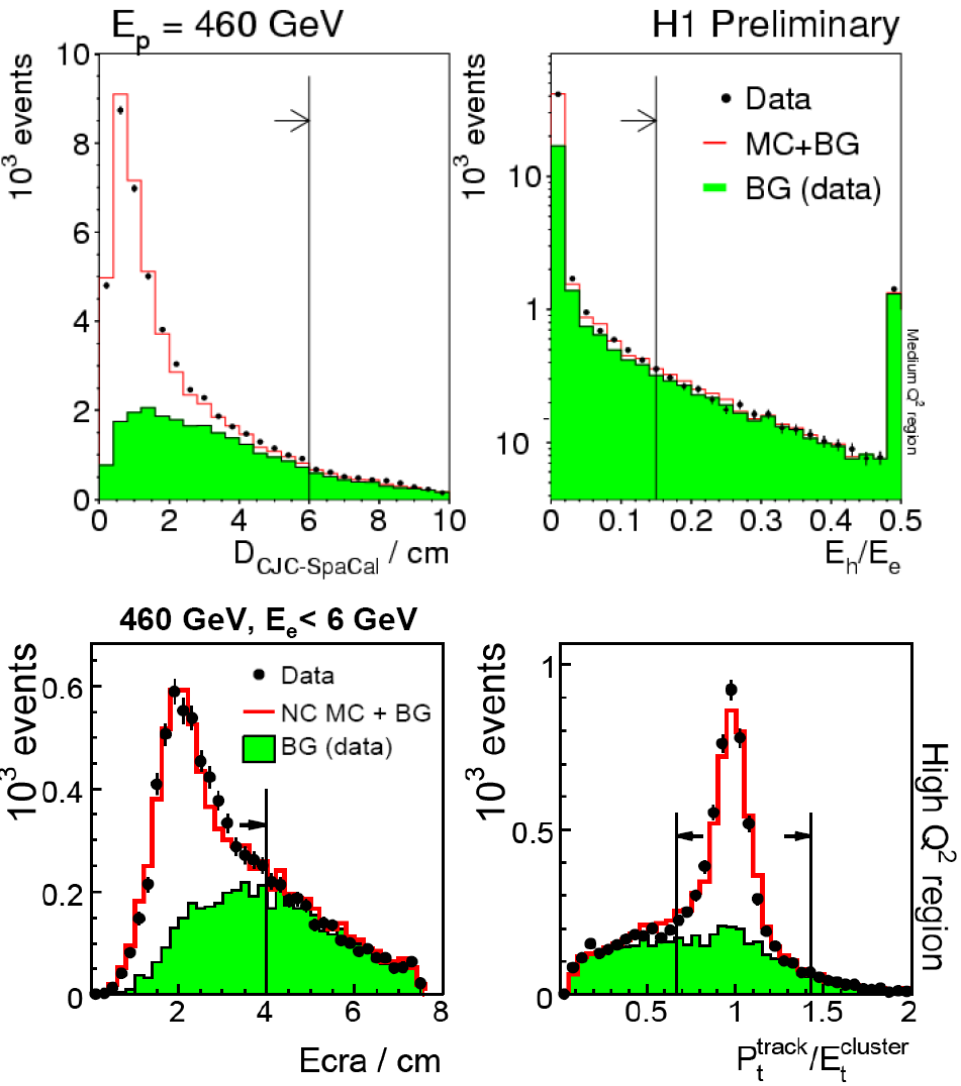


H1: γp background identification



- **Charge measurement** of the electron candidate using track
  - Good charge measurement resolution
  - Wrong assignment of the charge < 1%
- **γp 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
    - γp events identified by 6 m electron tagger

H1: Electron identification and bg supression

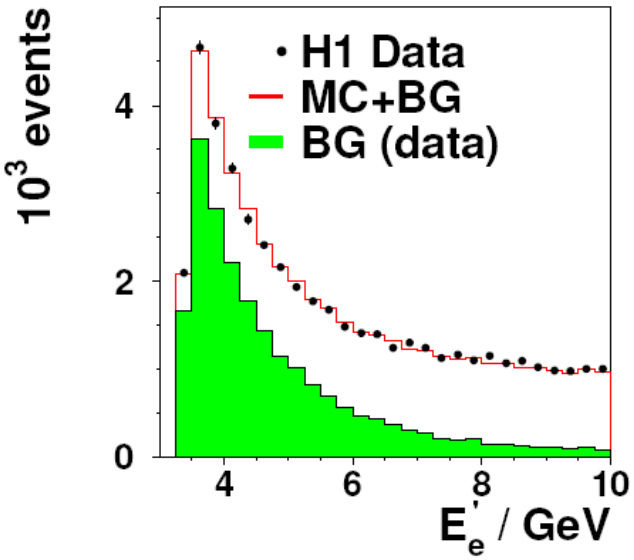


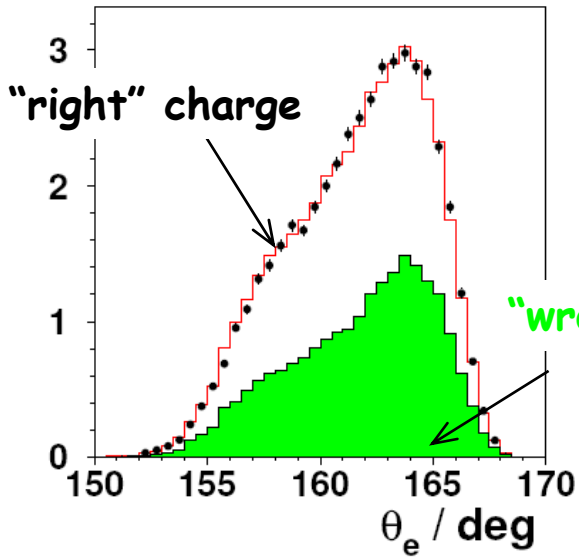
- Electron is identified by compactness of the cluster in calorimeter and track pointing to the cluster.

further reduction of γp bg:

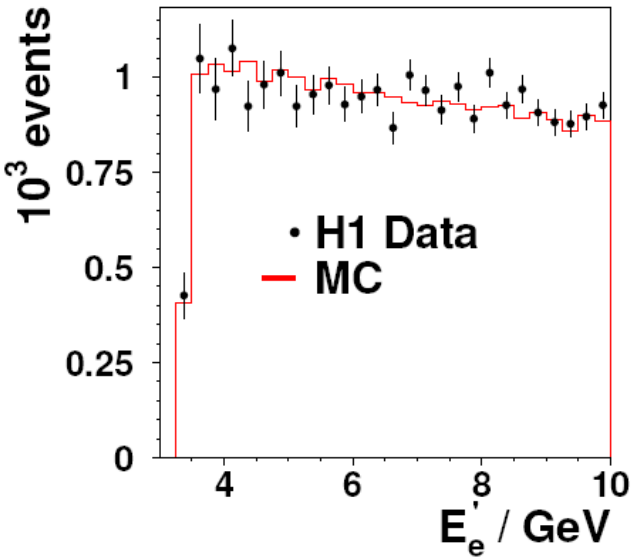
- **Spacal sample**
  - distance between extrapolated track and the electron cluster D < 6 cm
  - energy fraction behind the electron cluster E_h/E_e< 0.15
- **LAr sample at E_e < 6 GeV**
  - small transverse size of the electron cluster in LAr: Ecra< 4 cm
  - matching between track momentum and cluster energy: $0.7<E_{t,}^{cluster}/P_t^{track}<1.5$

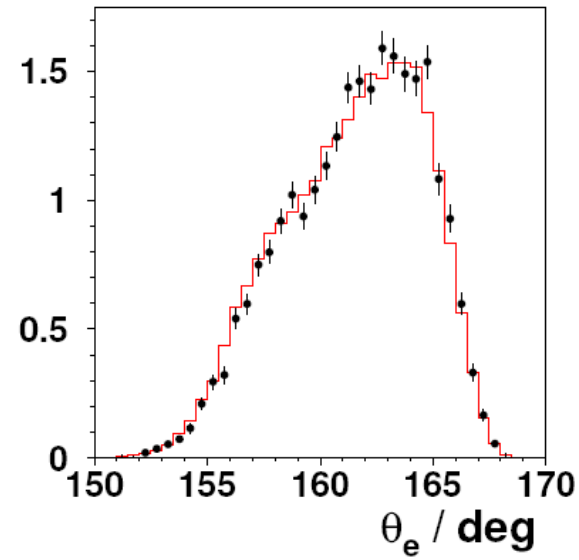
H1 Control plots: High y medium Q^2





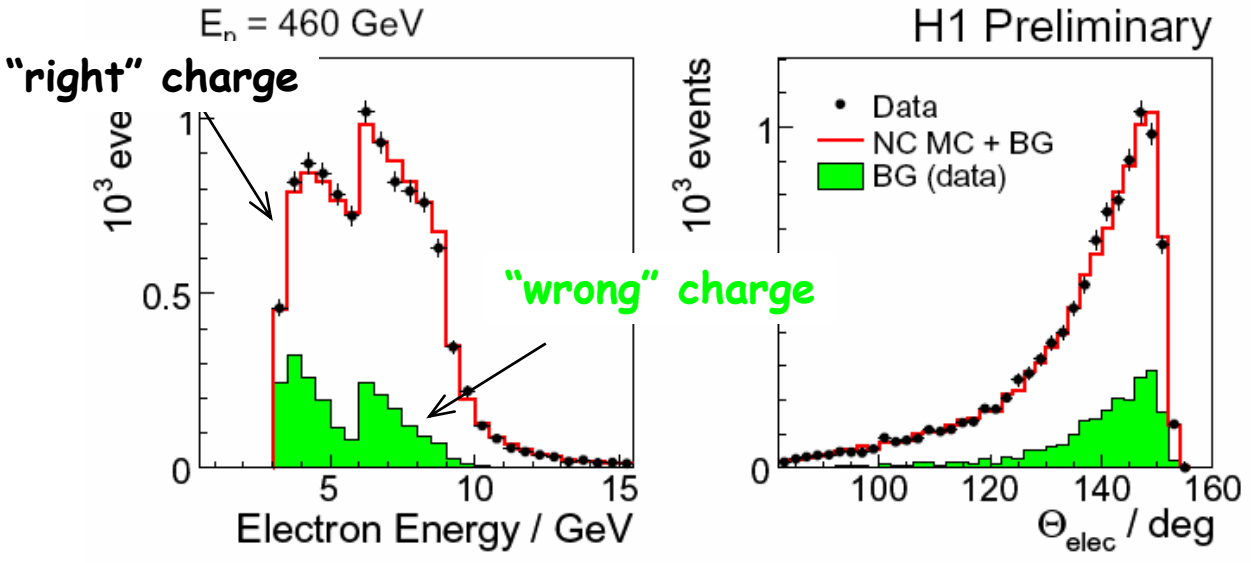
No bg subtraction



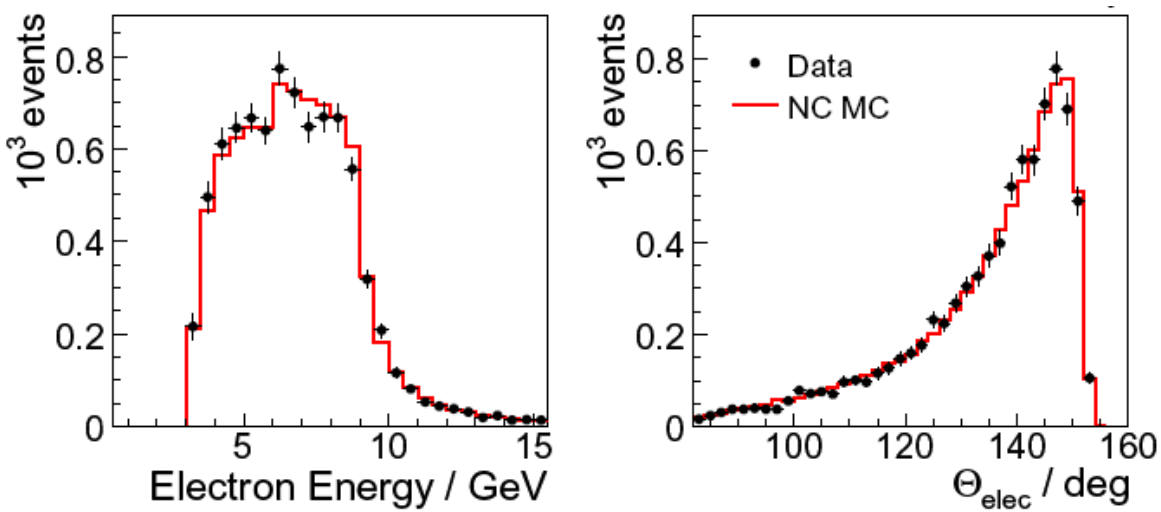


Bg subtracted

H1 Control plots: High y at high Q^2



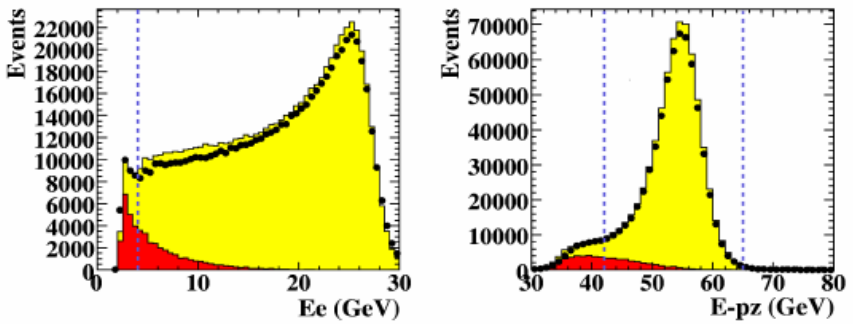
No bg subtraction

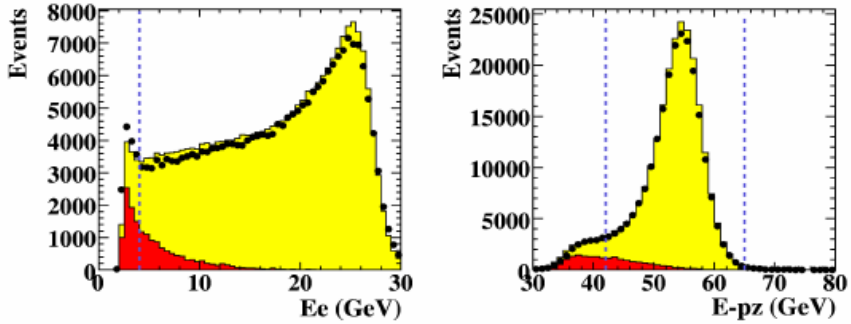


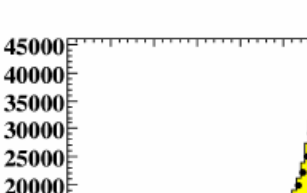
Bg subtracted

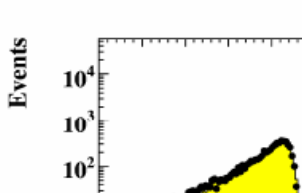
ZEUS Control plots

- The same selection is applied to both samples





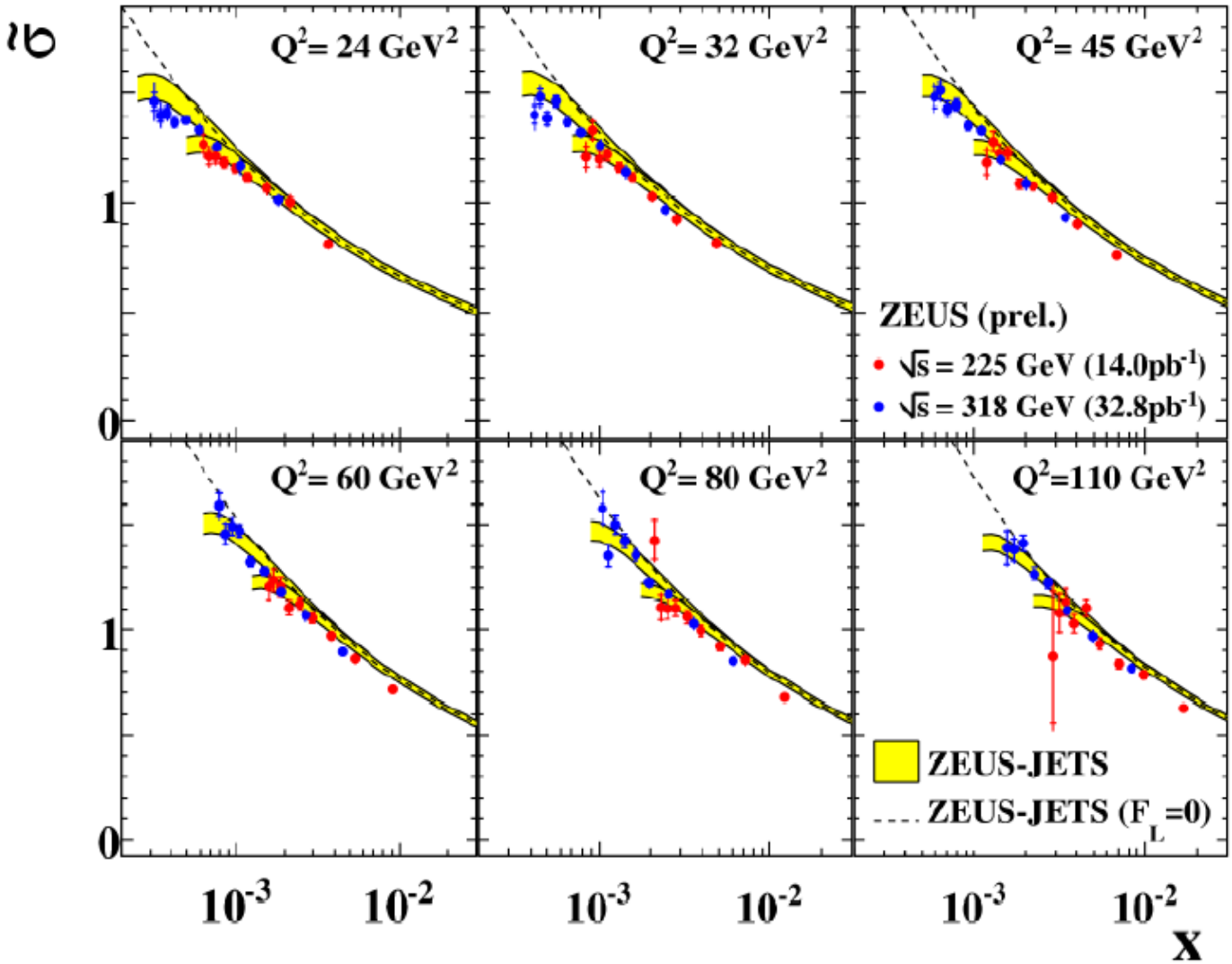




E_p = 920 GeV

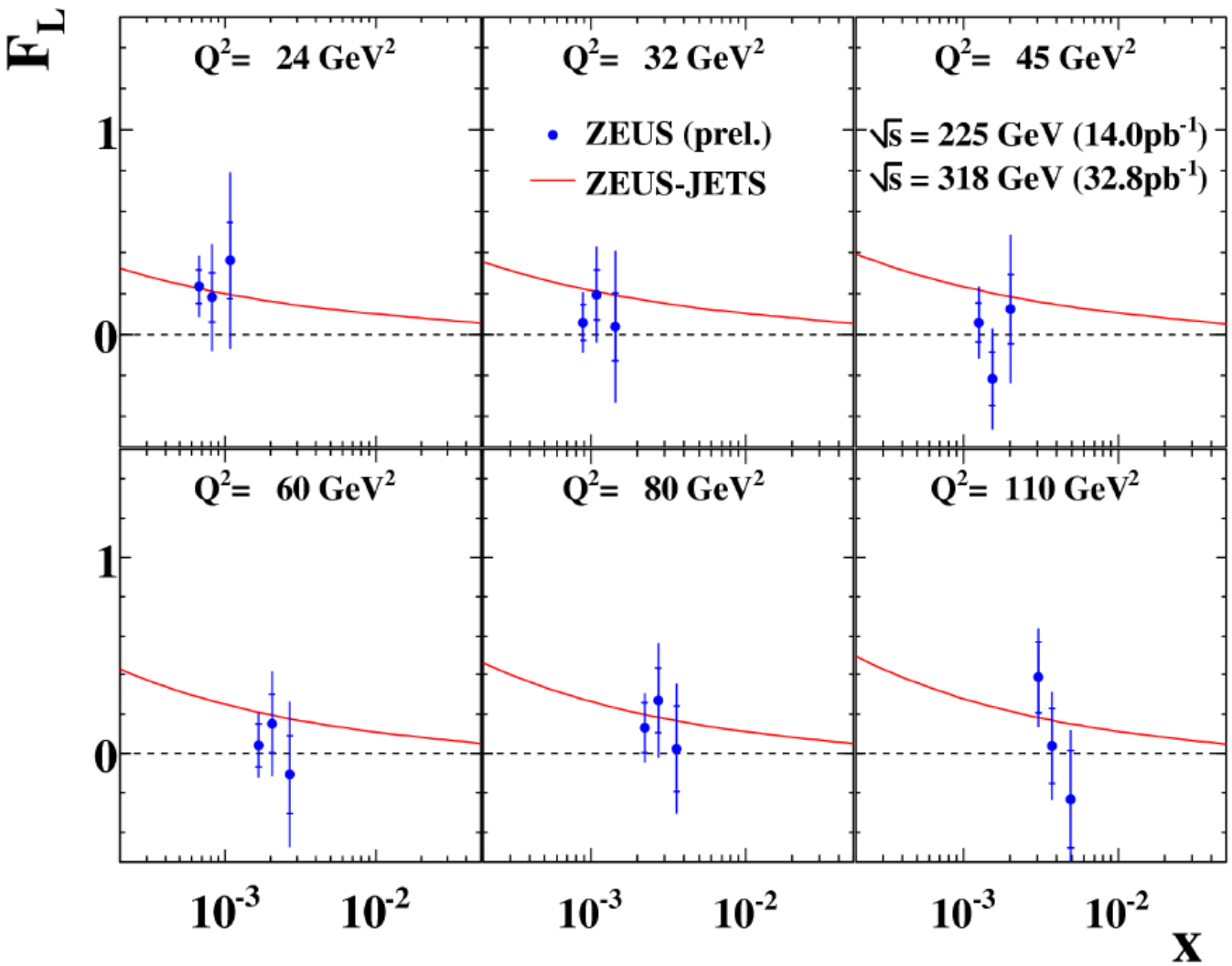
E_p = 460 GeV

ZEUS: NC cross section for E_p = 920, 460 GeV



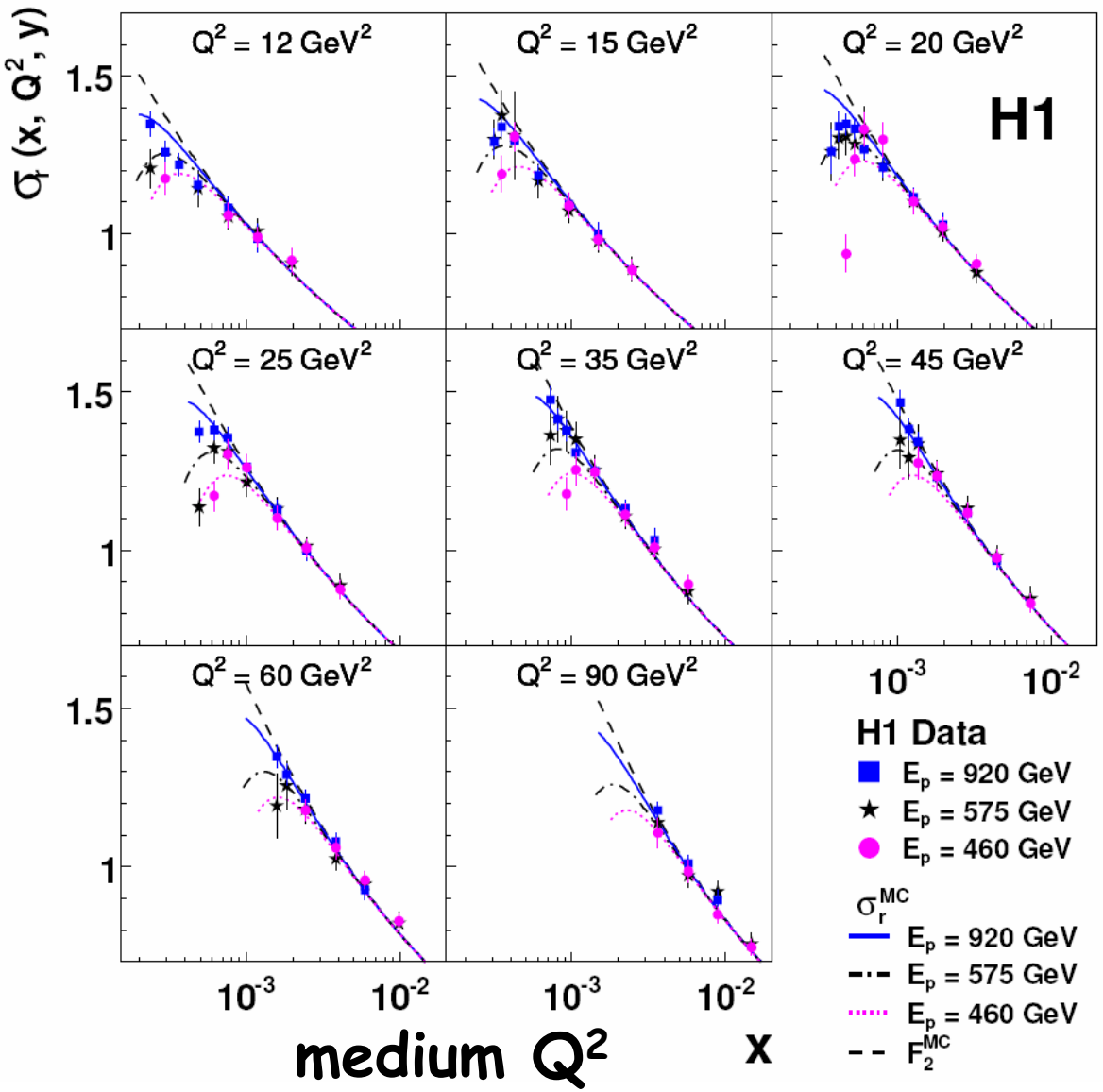
- The difference between two data sets due to F_L contribution

ZEUS: F_L measurement



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

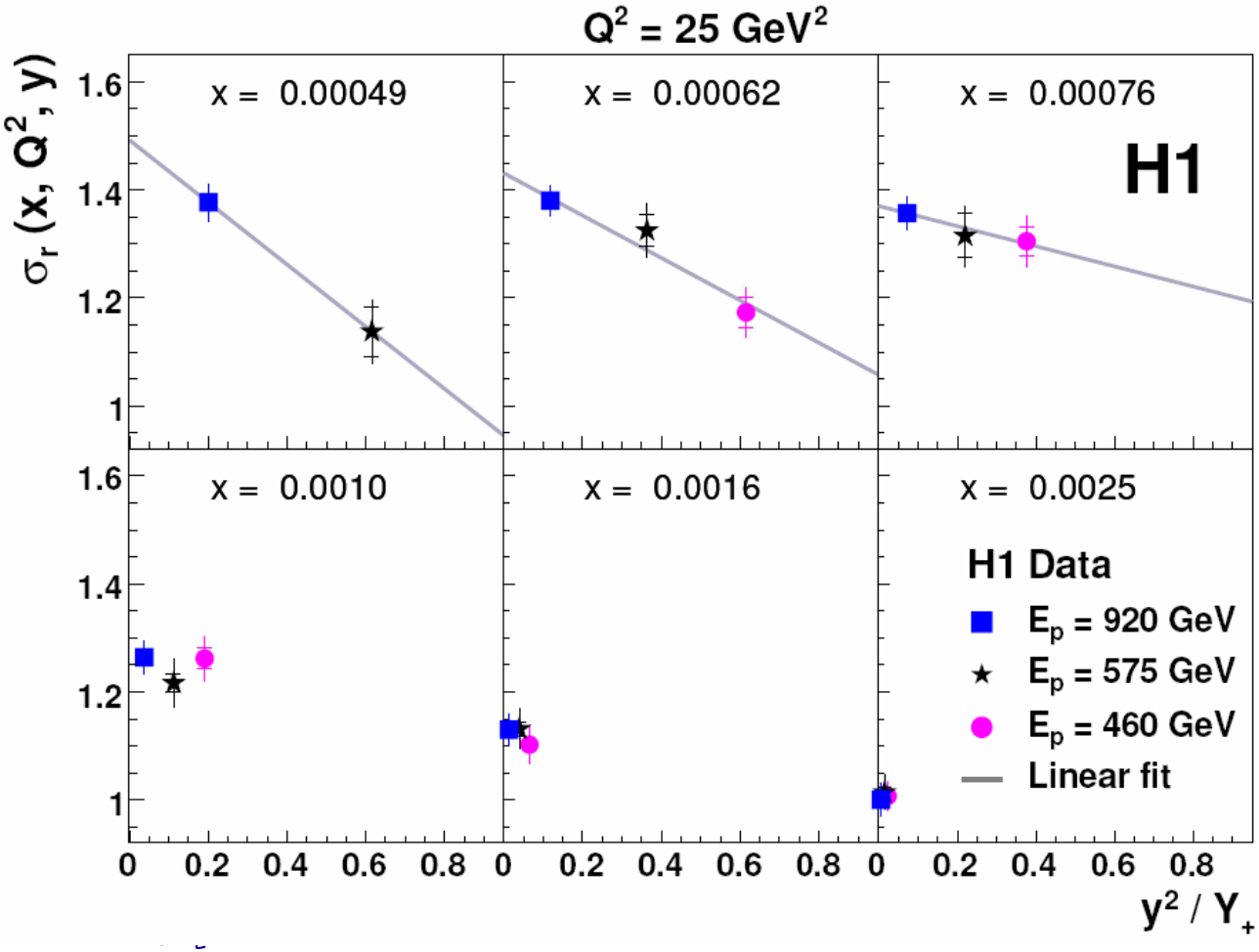
H1: NC cross section for E_p = 920, 460, 575 GeV



- The same x,Q^2 bins, different y
- Turnover due to F_L contribution
- Applied relative normalization of Ep= 460, 575, 920 GeV derived from the low y data

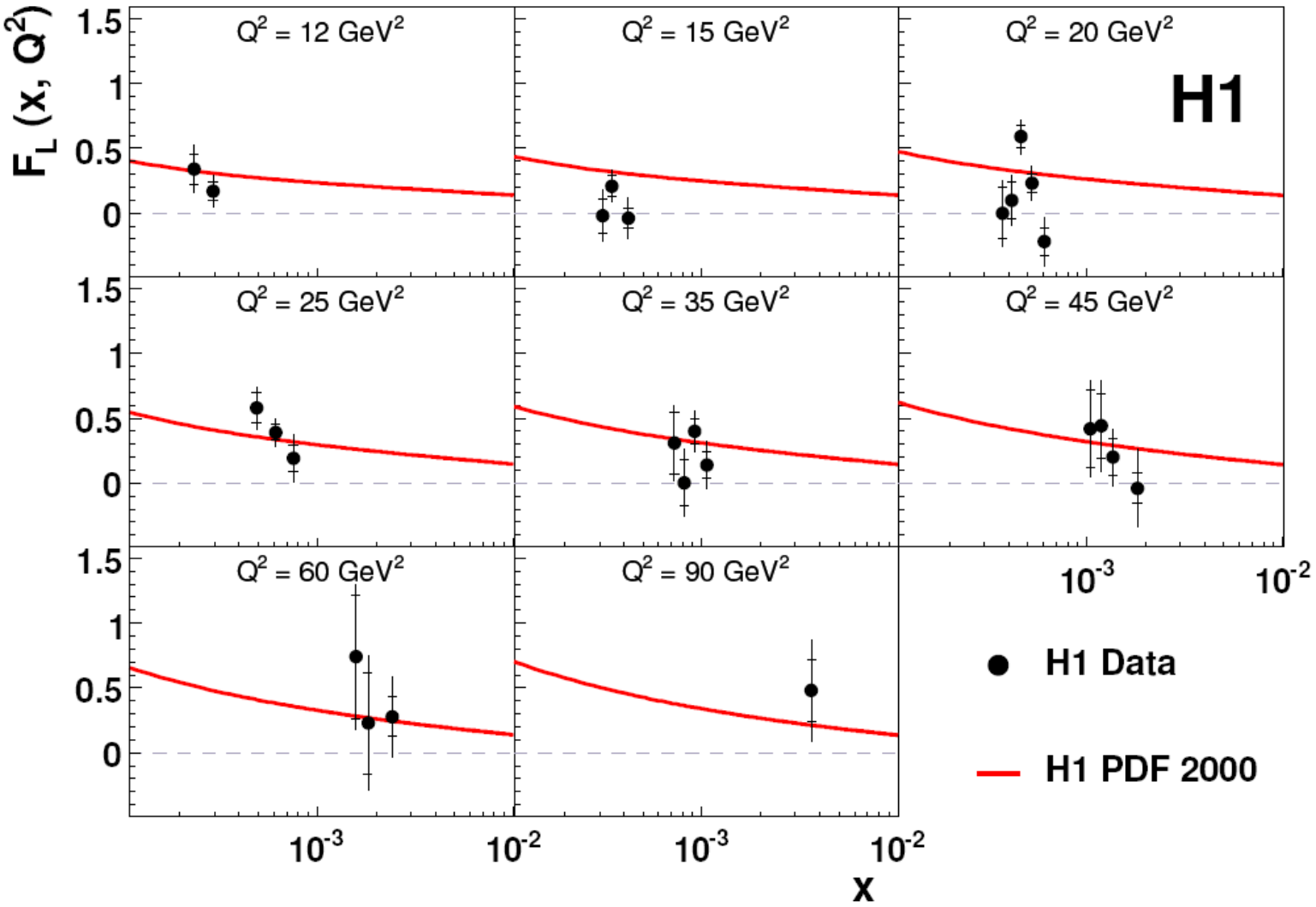
H1: Extraction of F_L

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



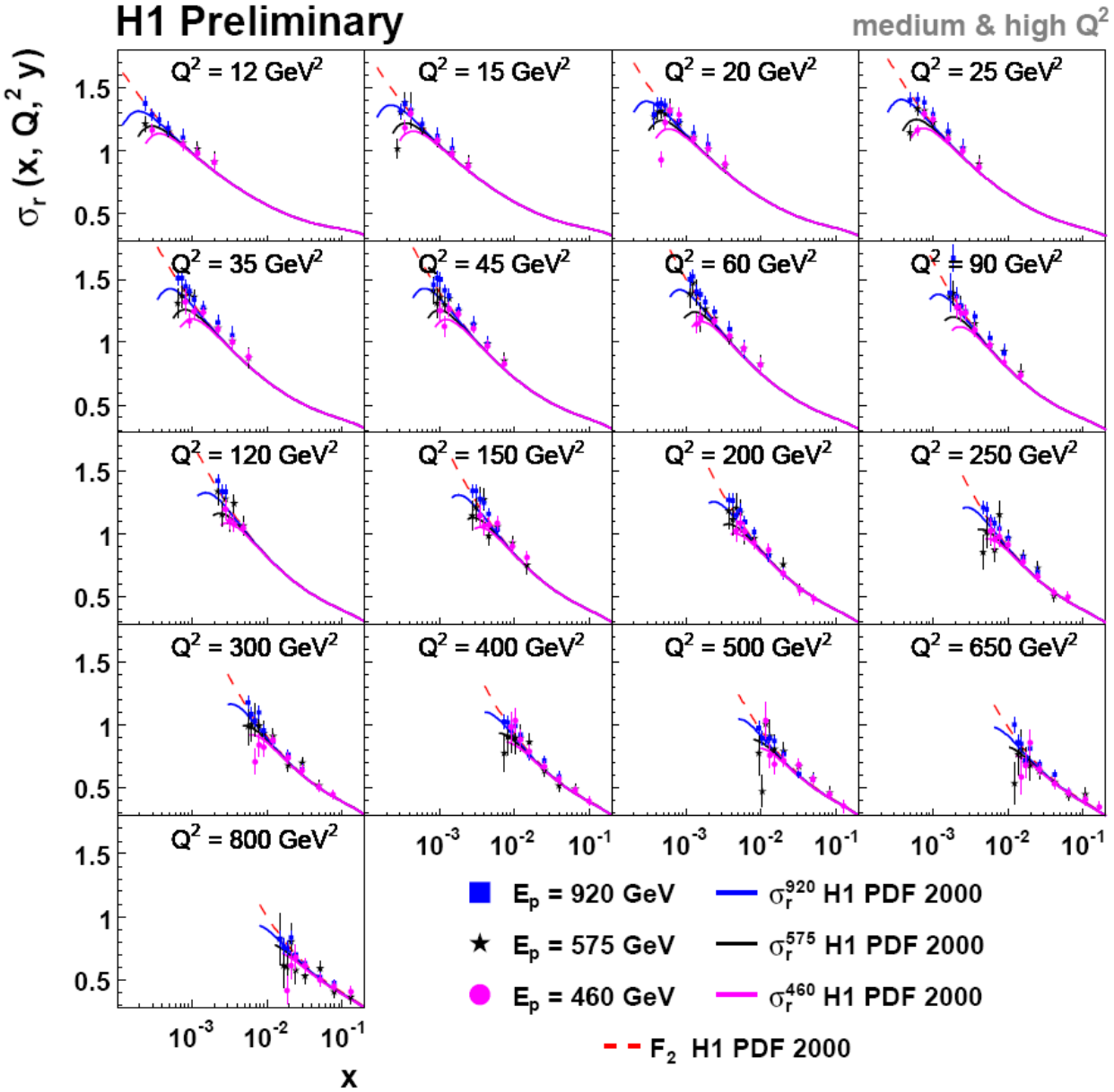
- Linear fit to points of different CME
- Intercept at y axis: F_2
- Slope: F_L
- Data at different Ep renormalized

H1: Published F_L at medium Q^2



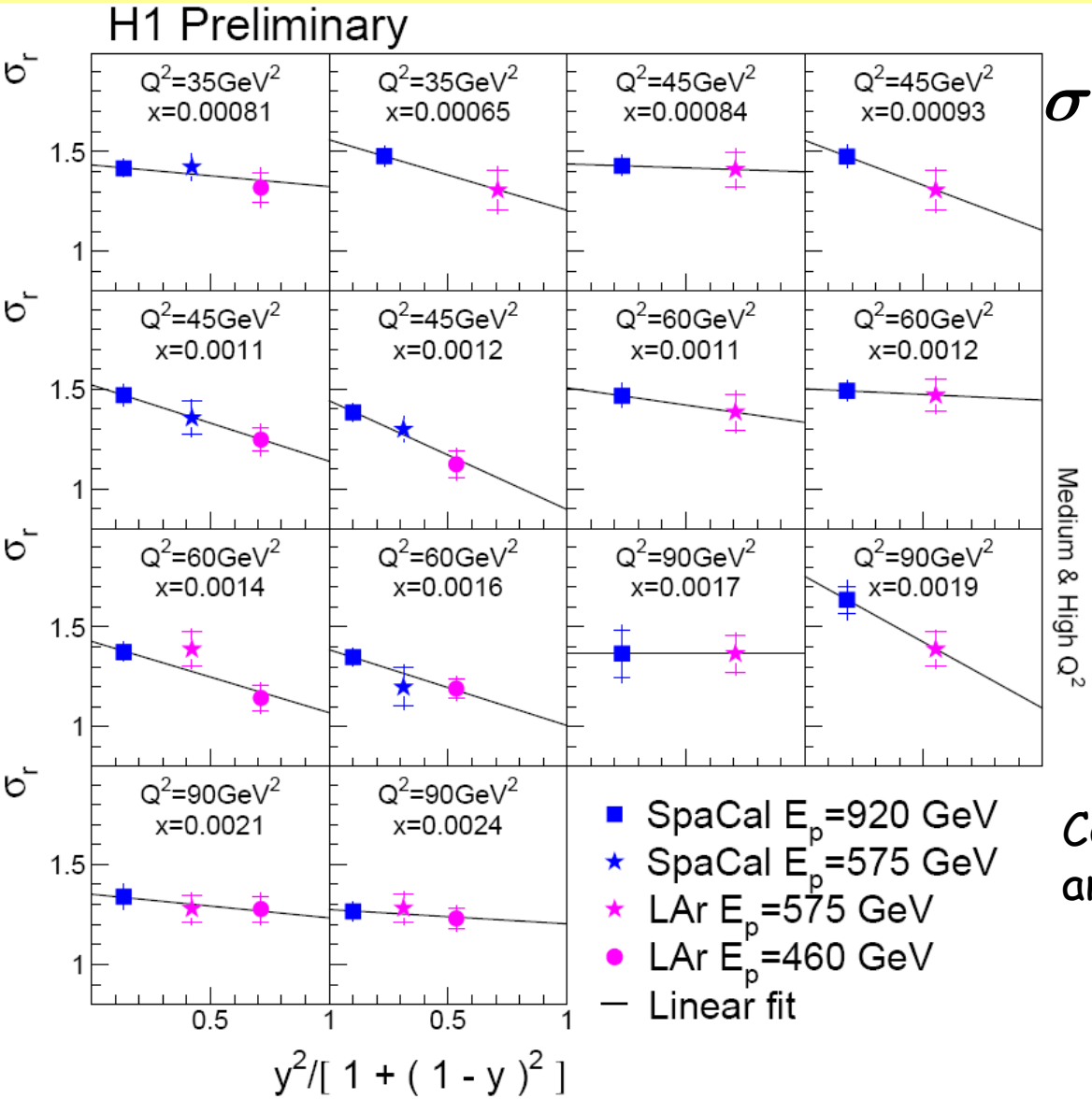
- measured F_L are above zero and consistent with QCD calculations

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

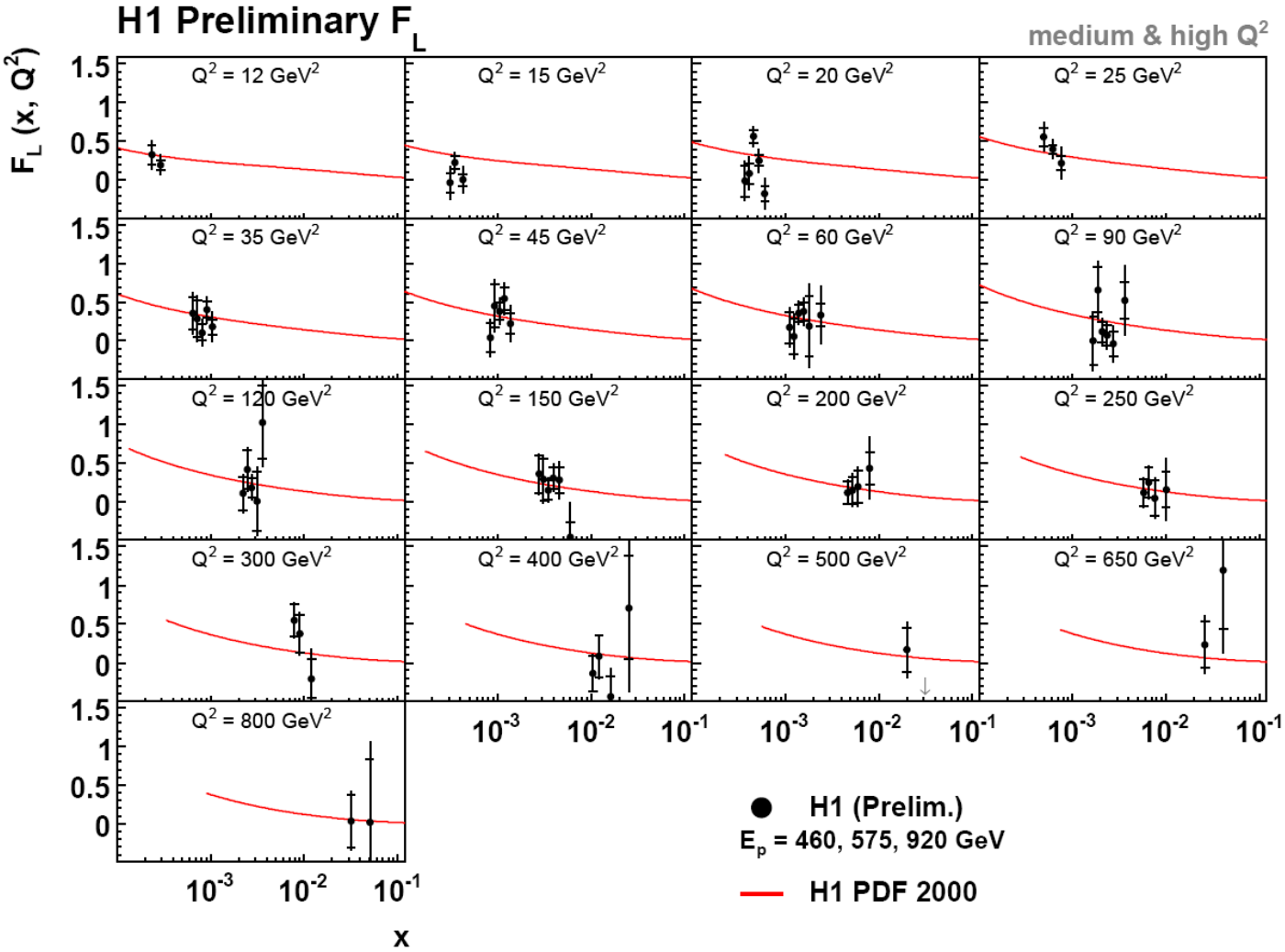


$$\sigma_r = F_2 - \frac{y^2}{1+(1-y)^2} F_L$$

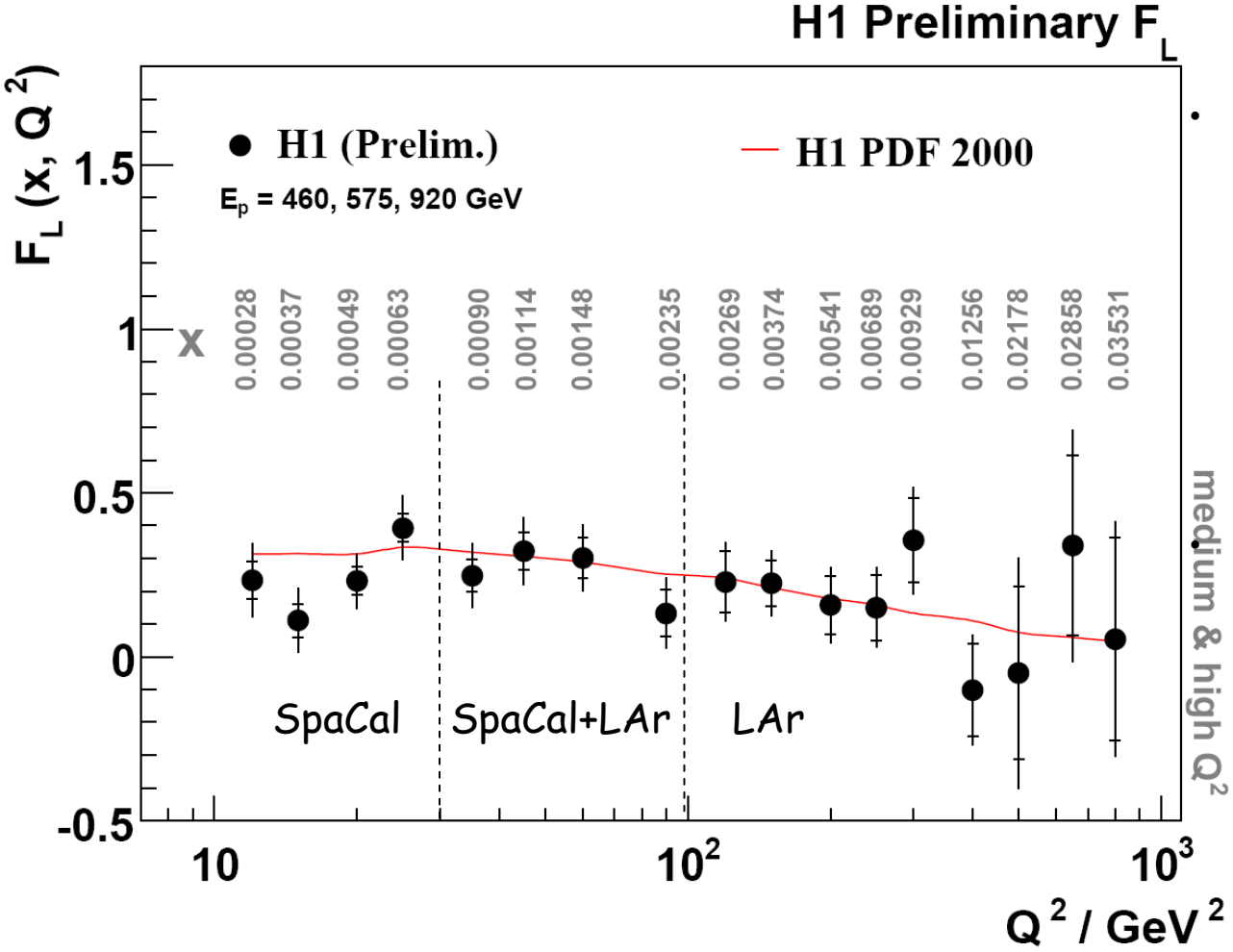
Combination of two independent analyses using different detectors

- -SpaCal
- -LAr

H1: FL in the full Q2 range

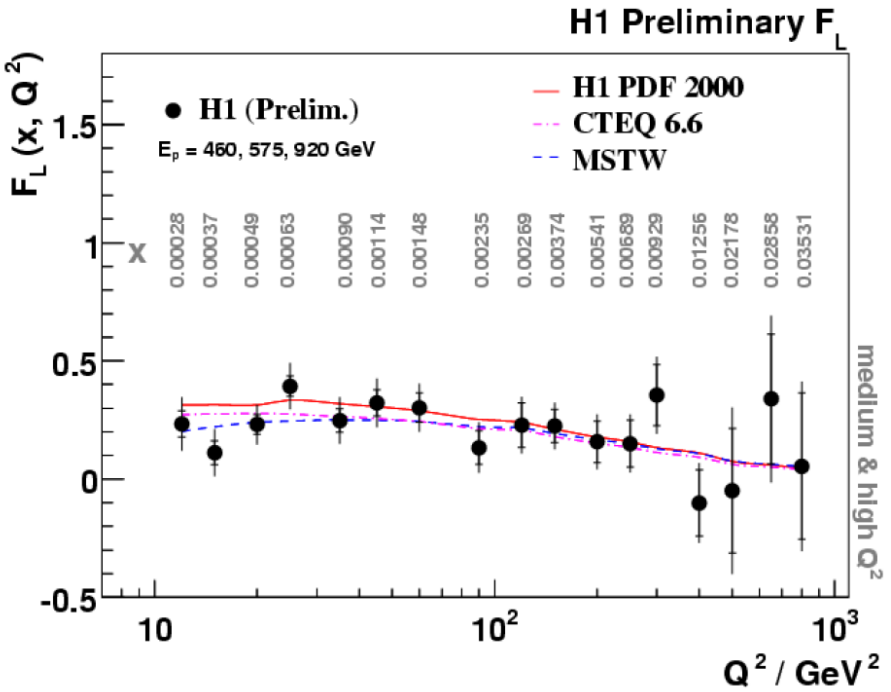


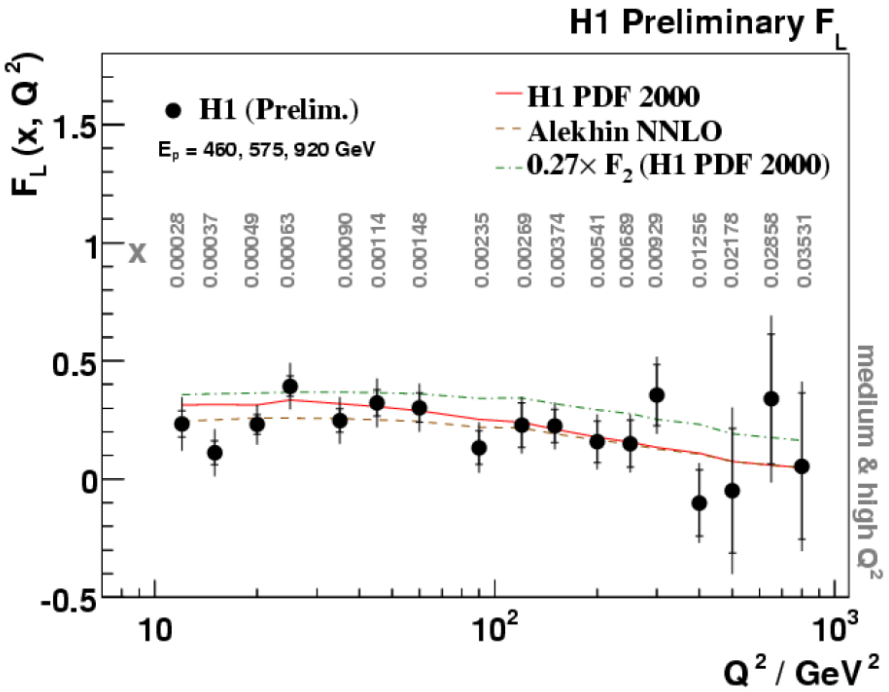
H1: Averaged FL in the full Q2 range



- 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





- FLmeasurements are in a good agreement with the QCD calculations

Summary

direct measurements of F_L

- **ZEUS:**
  - E_p = 920 GeV & E^p = 460 GeV
  - The measurement covers medium Q2 range 24 GeV2 to 110 GeV2
  - 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 GeV dataset
- **H1:**
  - E_p = 920 GeV, E_p = 460 GeV, E_p = 575 GeV
  - the full range of medium and high Q^2: 12 < Q^2< 800 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:
    - FL measurement at the lowest Q^2