LOW X MEETING

YUKAWA INSTITUTE, KYOTO, JAPAN

June 17-21 2014

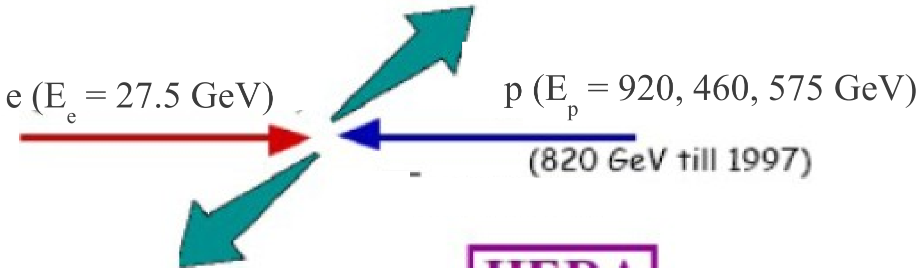
Measurement of the longitudinal structure function F_L

S. Shushkevich on behalf of H1 and ZEUS collaborations

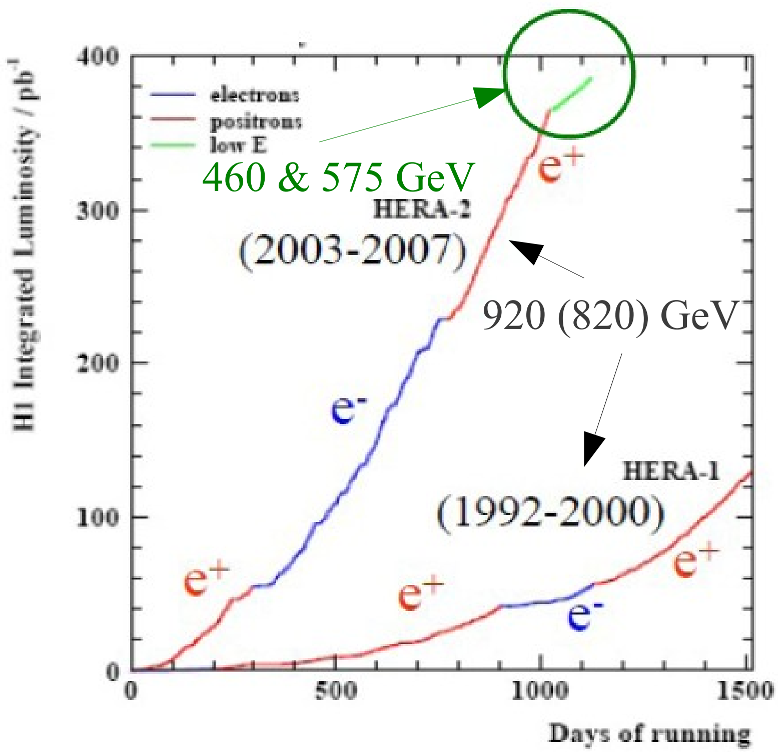
Eur. Phys. J. C 74 (2014) 2814 [arXiv:1312.4821] (H1 experiment)

DESY-14-053, submitted to Phys. Lett. B [arXiv:1404.6376] (ZEUS experiment)

HERA ep Collider

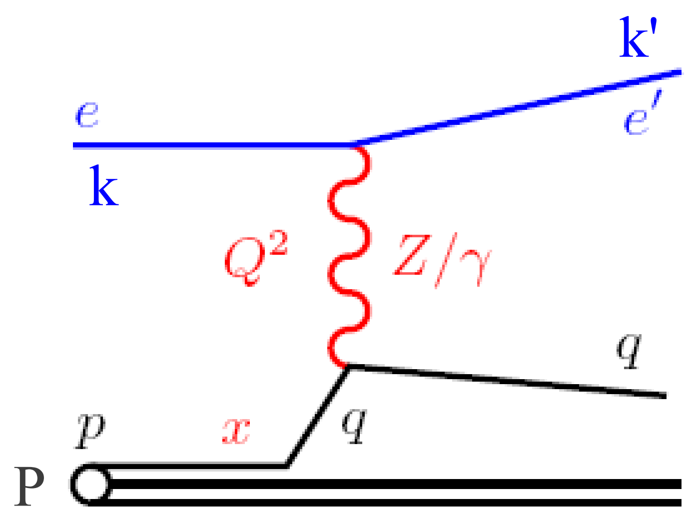


HERA



- experiments: H1 and ZEUS
- 0.5 fb^{-1} per experiment
- e$^+$ and e$^-$

Deep Inelastic Scattering (DIS) and Neutral Current (NC)



$s = (k+P)^2$	centre-of-mass energy squared
$Q^2 = -q^2 = (k-k')^2$	boson virtuality negative transferred 4-momentum squared
$x = \frac{Q^2}{2(Pq)}$	Bjorken x momentum fraction of proton carried by the struck quark
$y = \frac{(Pq)}{(Pk)}$	inelasticity

related as $Q^2 = sxy$

The Proton Structure and F_L Structure Function

At moderate Q^2

reduced cross section | cross section measurement | structure functions

$$\tilde{\sigma}_{NC}(x,Q^2,y) = \frac{d^2\sigma^{ep}_{NC}}{dxdQ^2}\cdot\frac{xQ^4}{2\pi\alpha Y_+} = F_2(x,Q^2) - \frac{y^2}{Y_+}F_L(x,Q^2)$$

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

In QPM:

$$F_2(x,Q^2) = \sum e^2_{q_i} x(q_i + \bar{q}_i)$$ Total quark content

$$F_L(x,Q^2) = F_2 - 2xF_1 = 0$$ Callan-Gross relation

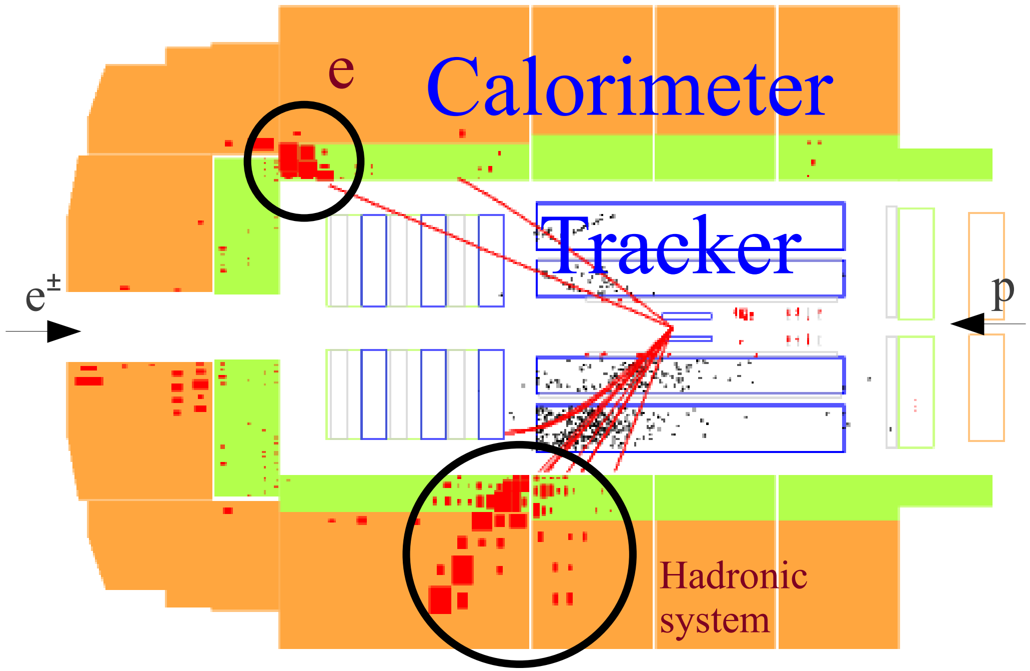
The QCD lowest order in α_s: add gluon to carry angular momentum

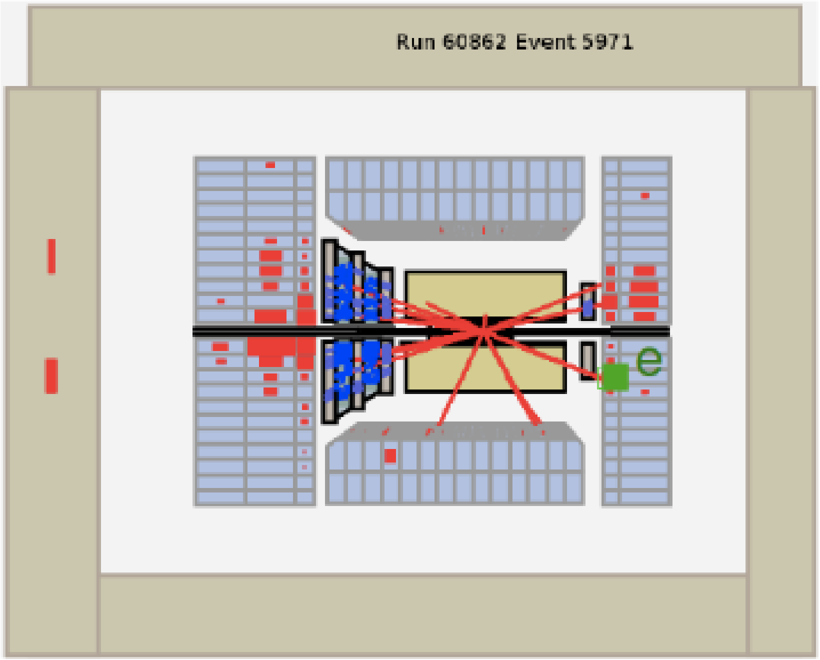
$$F_L(x,Q^2) = \frac{\alpha_s}{4\pi}x^2\int_x^1\frac{dz}{z^3}\left[\frac{16}{3}F_2 + 8\sum_q e_q^2(1-\frac{x}{z})\cdot xg\right]$$

- F_L is a QCD effect which allows for a critical test of perturbative QCD
- F_L is directly sensitive to the gluon density
- To disentangle F_2 and F_L fix x and Q^2, vary y

$$y = \frac{Q^2}{sx}$$

NC Event in the Detector





$$y_e = 1 - \frac{E'_e}{E_e} \sin^2 \frac{\Theta_e}{2} \qquad Q^2_e = \frac{E'^2_e \sin^2 \frac{\Theta_e}{2}}{1 - y_e}$$

Kinematics

$$\tilde{\sigma}_{NC}(x, Q^2, y) = F_2(x, Q^2) - \frac{y^2}{Y_+} F_L(x, Q^2)$$

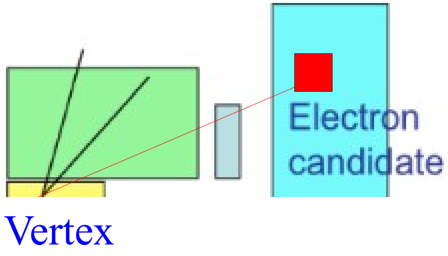
Sensitivity to F_L at high y

$$y_e = 1 - \frac{E'_e}{E_e} \sin^2 \frac{\Theta_e}{2}$$

$$Q^2_e = \frac{E'^2_e \sin^2 \frac{\Theta_e}{2}}{1 - y_e}$$

Accept scattered electron candidates down to 3 GeV (H1) / 6 GeV (ZEUS)

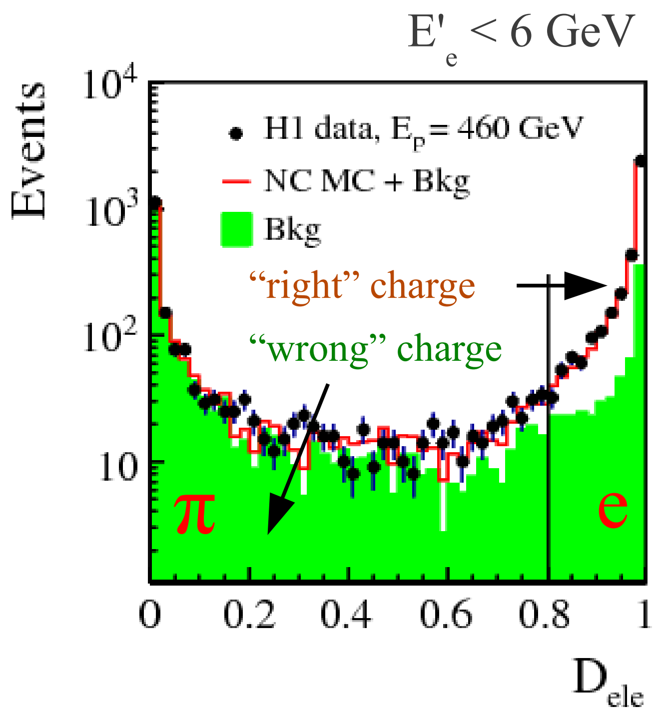
To access low Q^2 measure sample with shifted vertex (ZEUS)



Harsh background conditions due to

- $\pi^0 \rightarrow \gamma\gamma$ decays
- misidentification of charged hadrons
- semi-leptonic decays of heavy flavour hadrons

γp Background Treatment at High y



Apply neural network to select electrons for $E'_e < 10$ GeV

shower shape variables
ionisation energy loss dE/dx
momentum matched track associated to the cluster

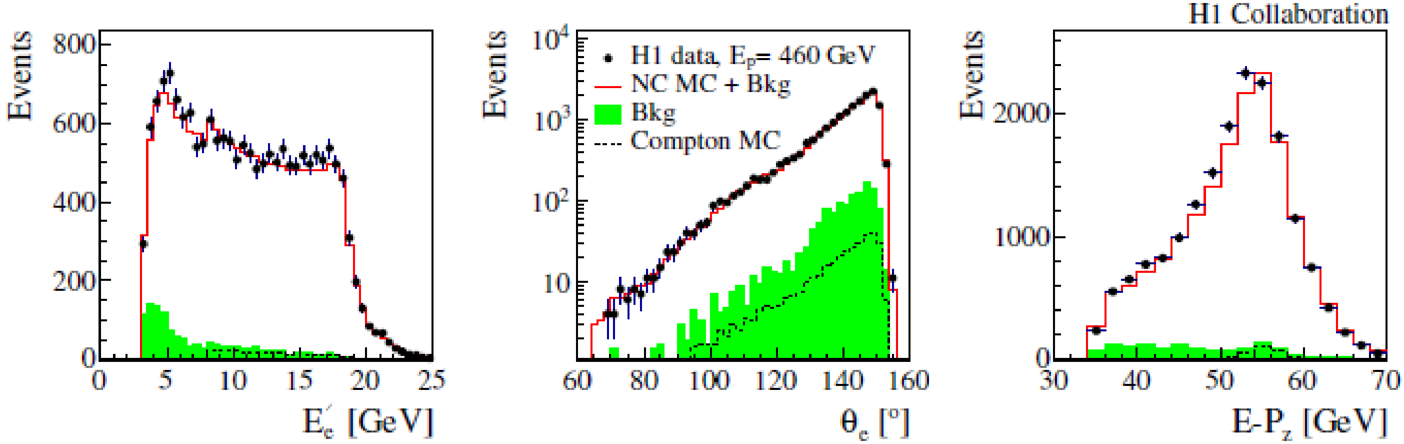
Make use of the electric charge of the electron candidate

- determine the charge from the track
- eliminate half of the background by requiring the **“right” charge** candidates
- estimate remaining half using **“wrong” charge** candidates
- take into account
  - charge asymmetry for data and MC
  - efficiency of charge determination

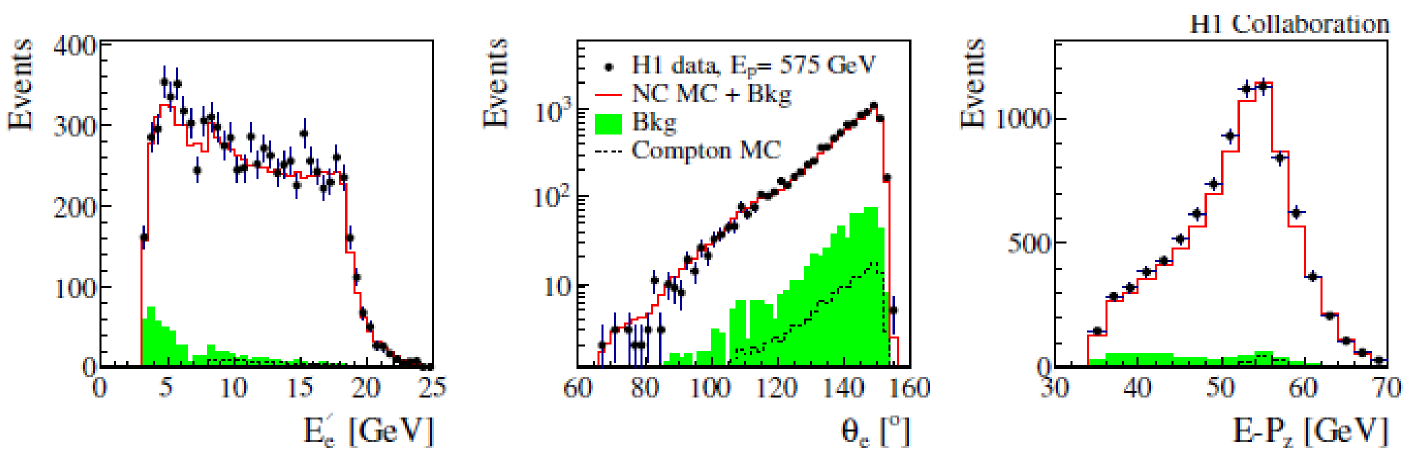
Estimate remaining non-photoproduction background using simulation

Control Plots for the High y Analysis (H1)

$0.38 < y_e < 0.90$

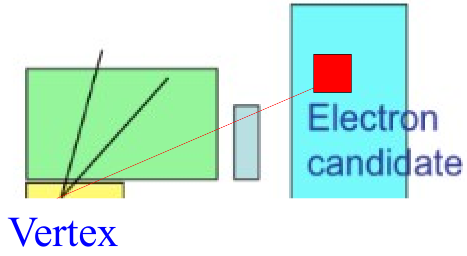


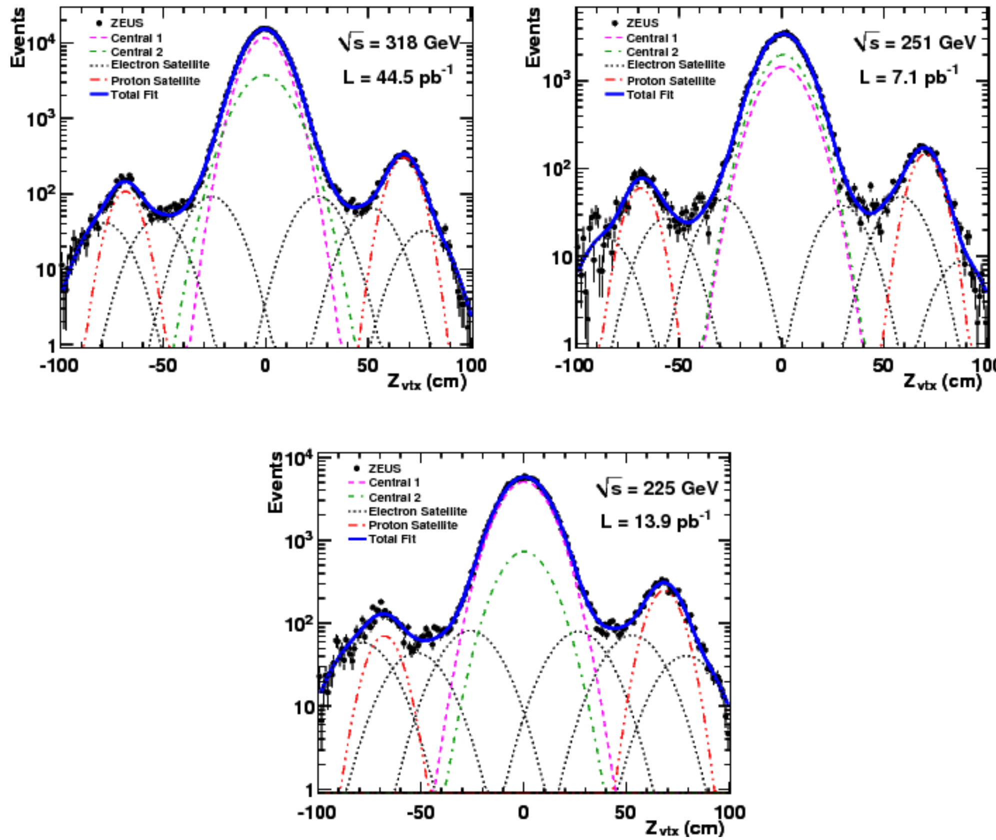
$E_p = 460$ GeV



$E_p = 575$ GeV

Vertex Distribution Description (ZEUS)





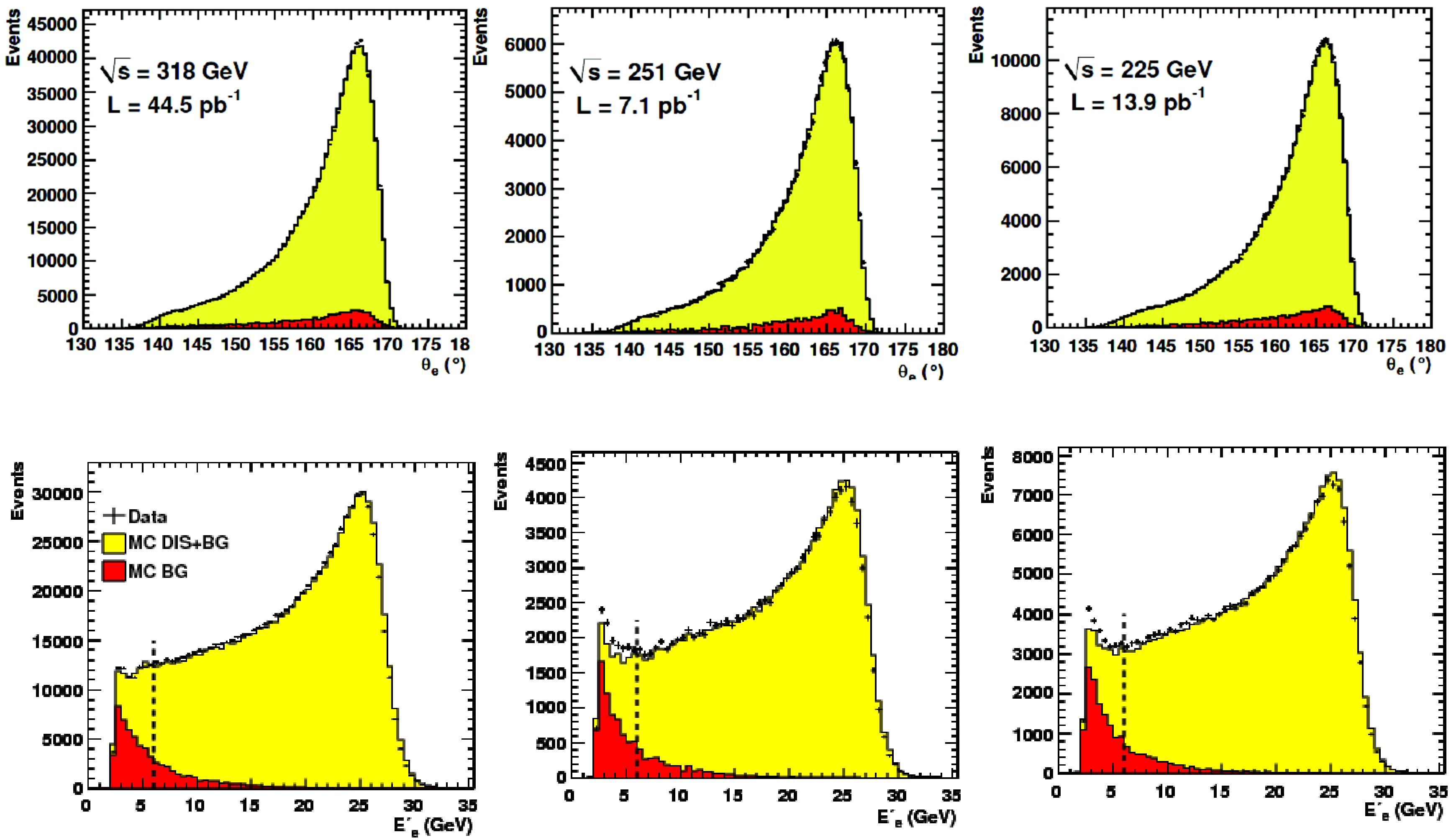
About 10% of events are in sample with shifted vertex due to presence of the satellite bunches

Make use of a special clean DIS sample and use 10 Gaussians for the accurate fit and MC reweighing

Good description of data by simulation

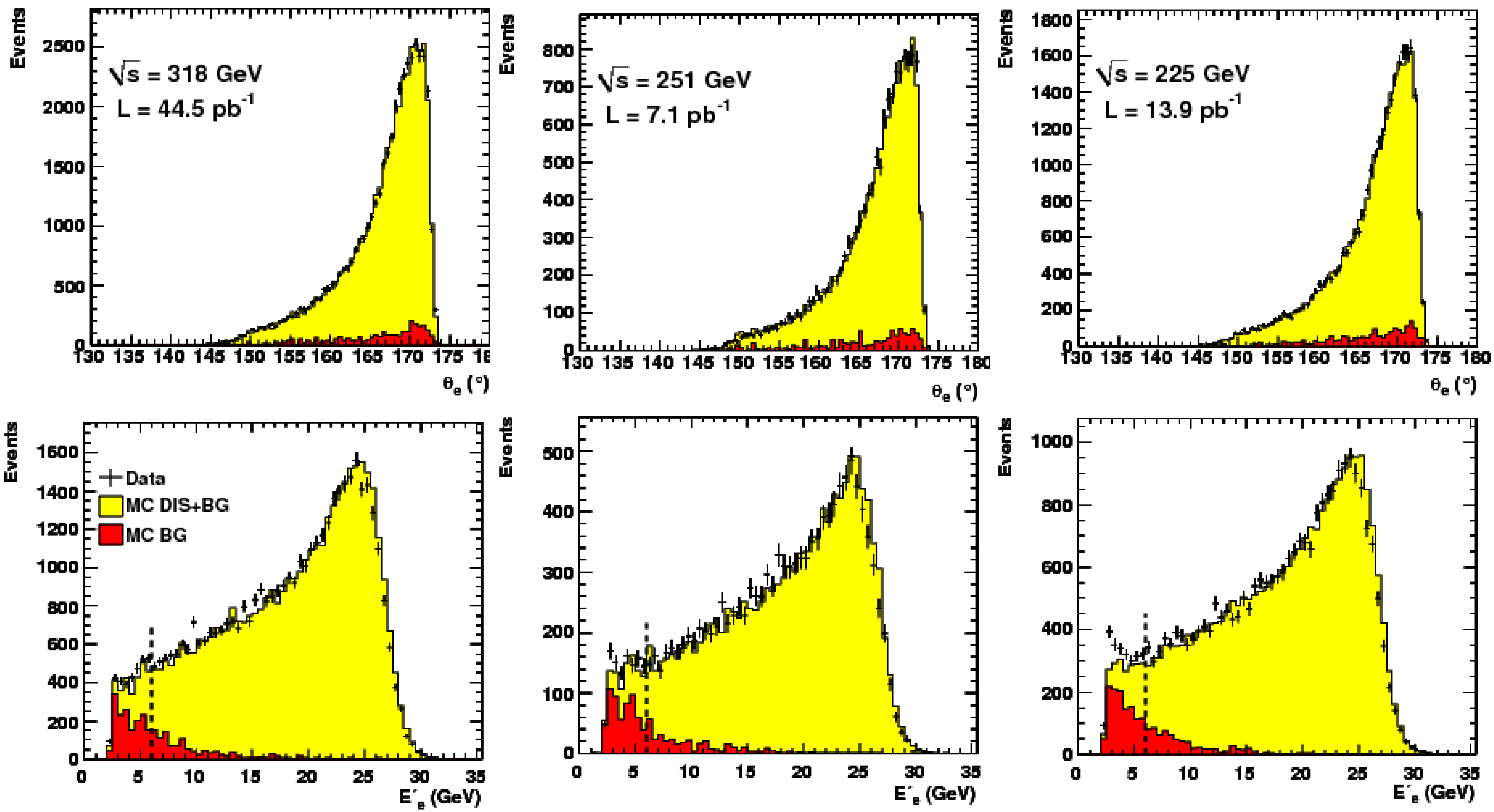
Control Plots (ZEUS)

Nominal vertex sample (-30 < Z_{vtx} < 30 cm)

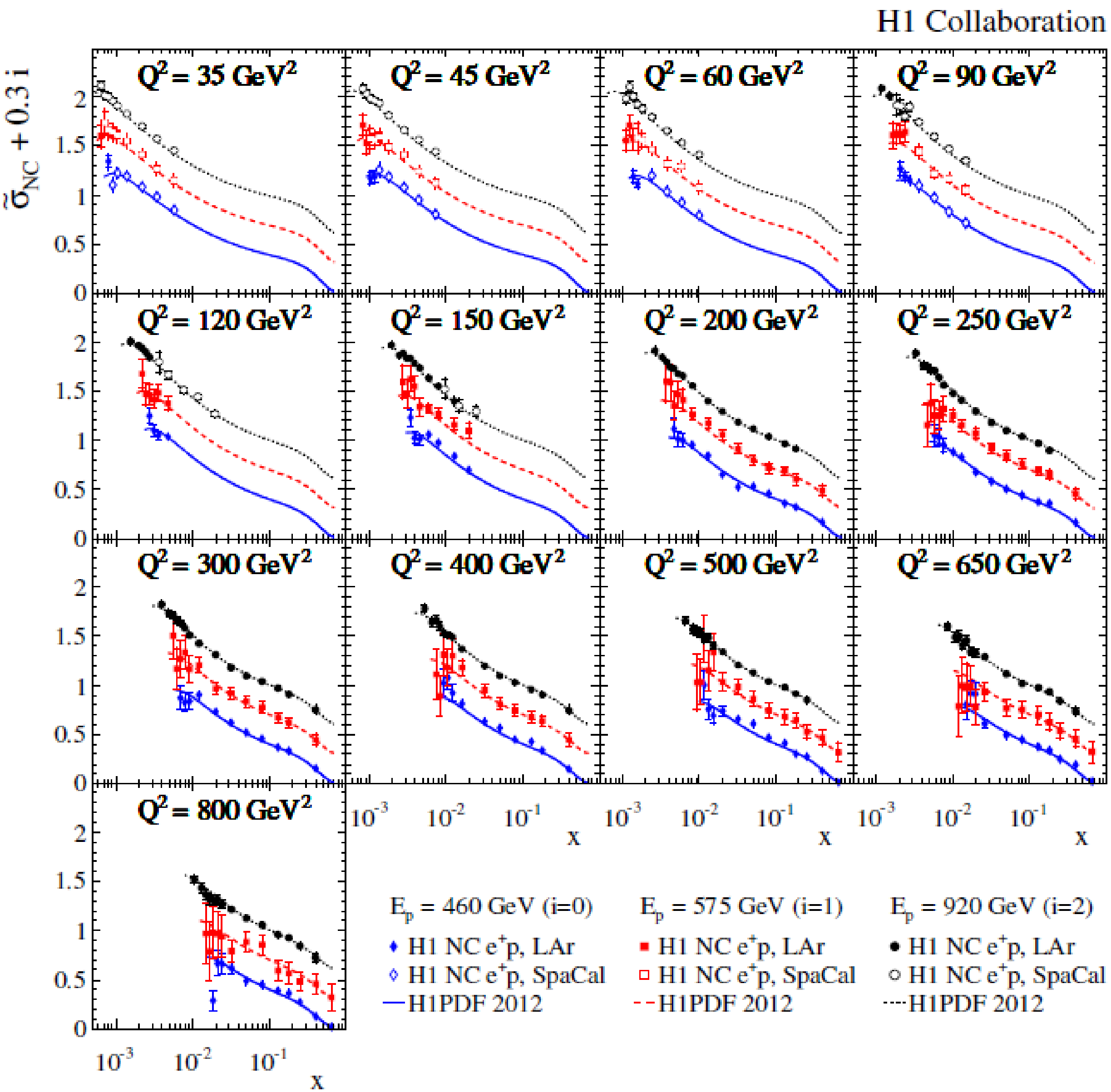


Control Plots (ZEUS)

Satellite vertex sample (30 < Z_{vtx} < 100 cm)



NC Cross Section for E_p = 460, 575, 920 GeV (H1)

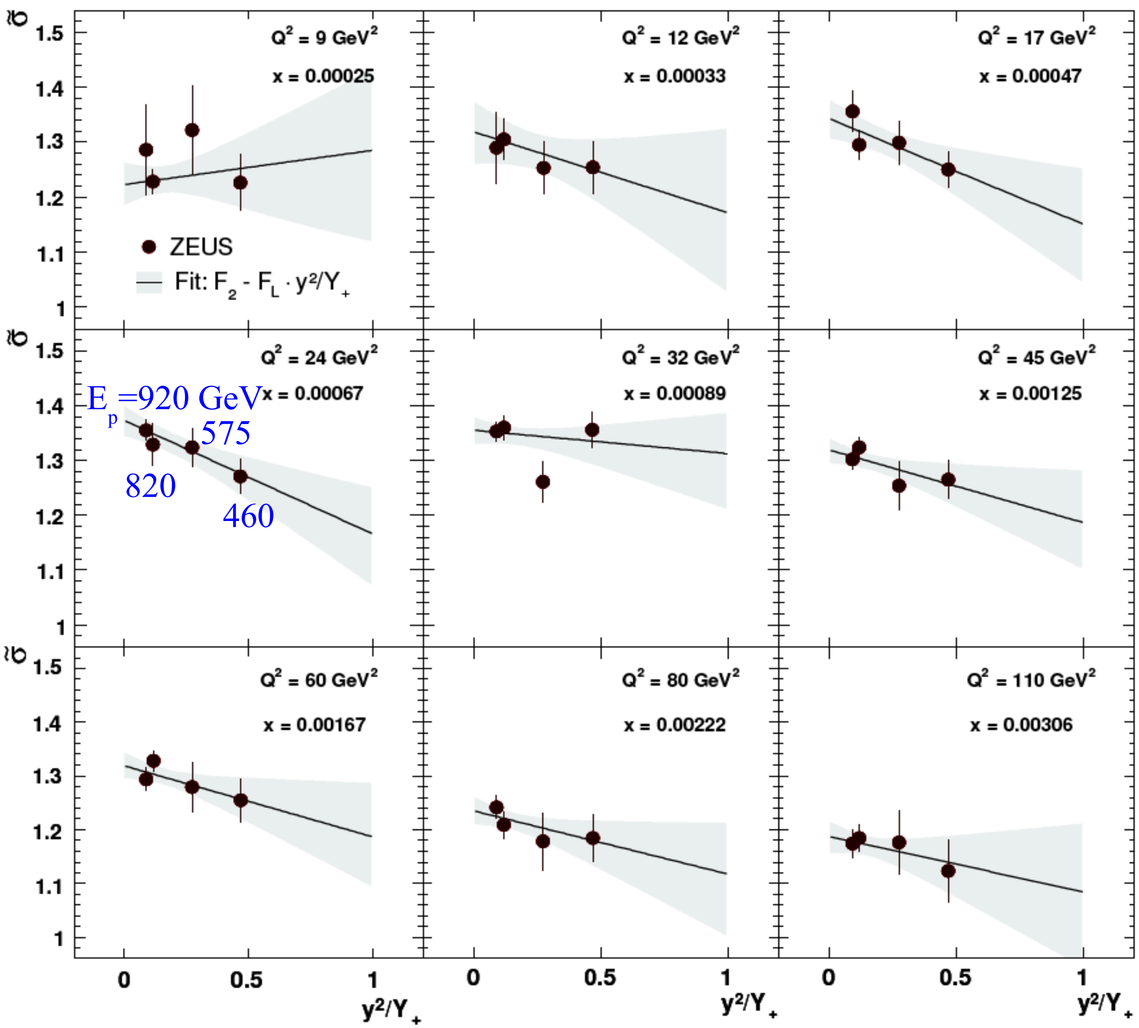


Cross section measurements at (x, Q2) points at different s

Data are from both high Q^2 and medium and low Q^2 analysis

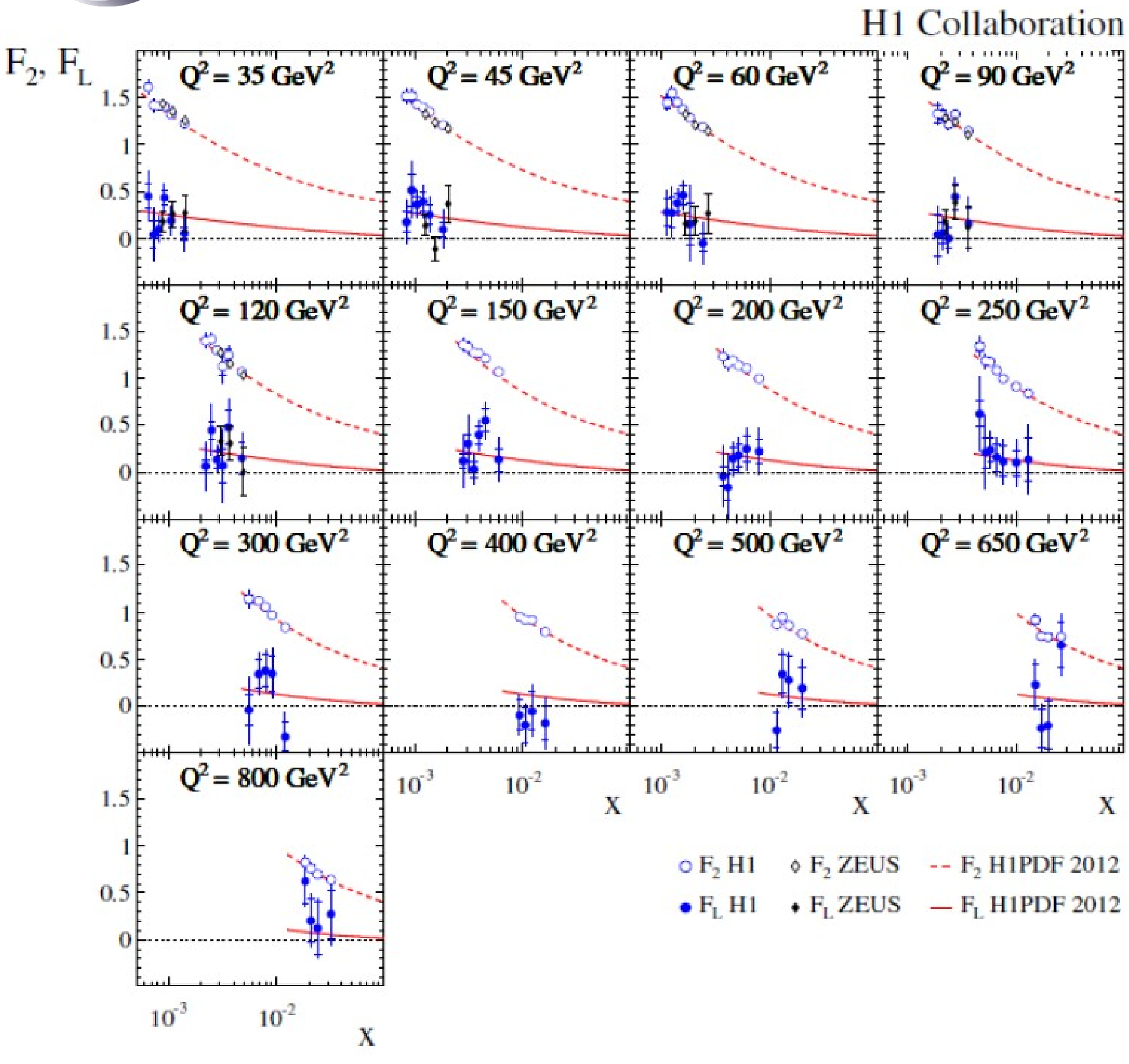
F_L Structure Function Extraction: Linear Fit

$$\tilde{\sigma}_{NC}(x,Q^2,y) = \frac{d^2\sigma^{ep}_{NC}}{dx dQ^2}\cdot\frac{xQ^4}{2\pi\alpha Y_+} = F_2(x,Q^2) - \frac{y^2}{Y_+}F_L(x,Q^2) \qquad y = \frac{Q^2}{sx}$$



- Sensitivity to F_L at high y only
- At (x, Q^2) fixed: change s → change y
- Extraction of F_L and F_2
  measure at different s and do linear fit
- Results are model independent

The Longitudinal Structure Function $F_L(x, Q^2)$

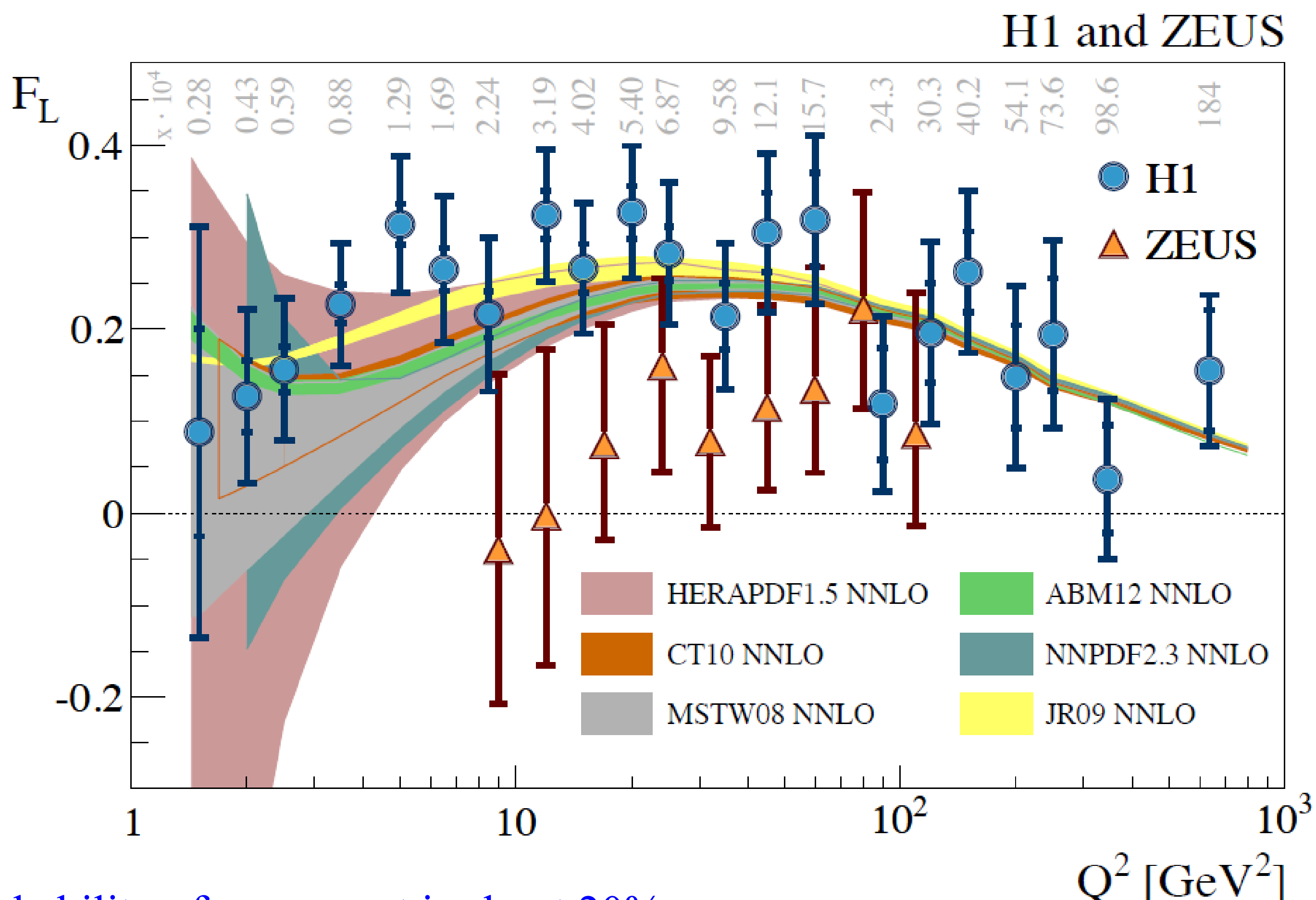


Model independent extraction

Good description by the NLO theoretical prediction

The Longitudinal Structure Function $F_L(Q^2)$

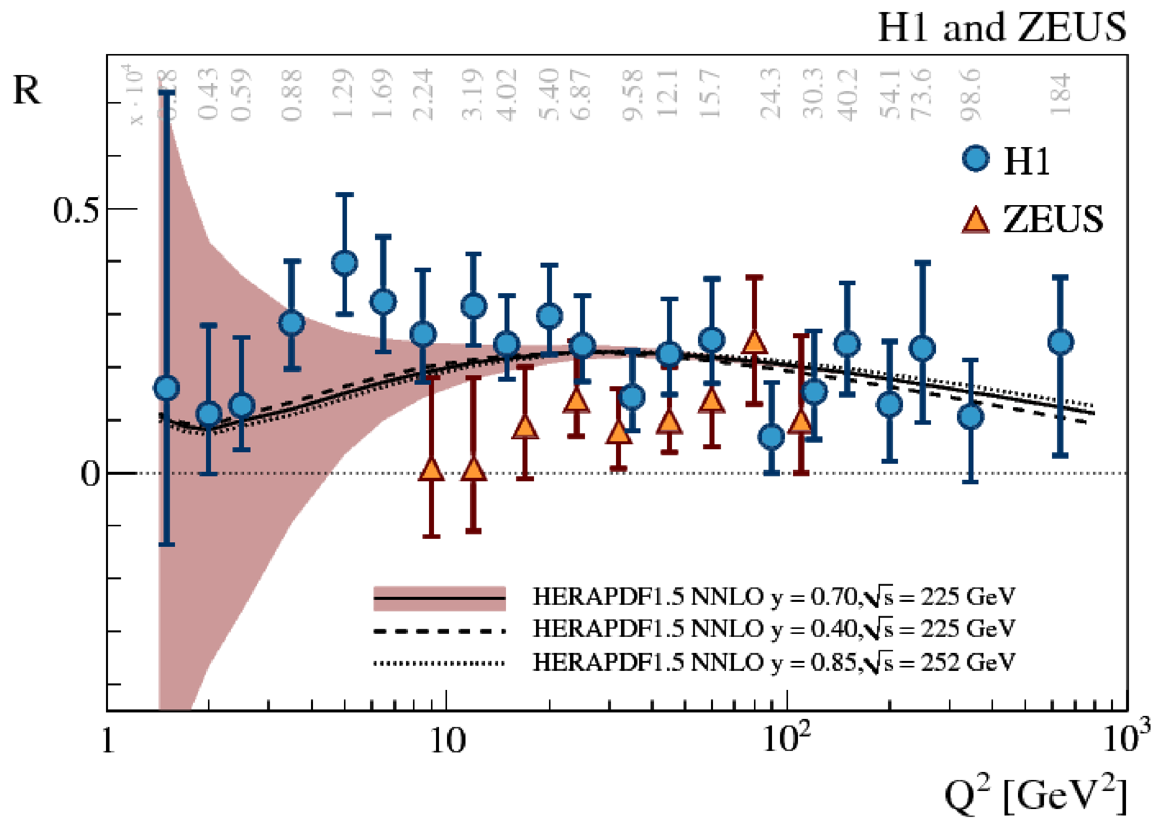
Average F_L measurement over x at each Q^2 to reduce statistical uncertainty



Probability of agreement is about 20%
Good agreement between the NNLO predictions and the measurement
Additional constraints to PDF's at low Q^2

The Ratio $R = \sigma_L / \sigma_T$ Extraction

For γ^*p R measures interaction with longitudinally polarized virtual photon.
Relation between F_L and R: $F_L = F_2 * R/(R+1)$.

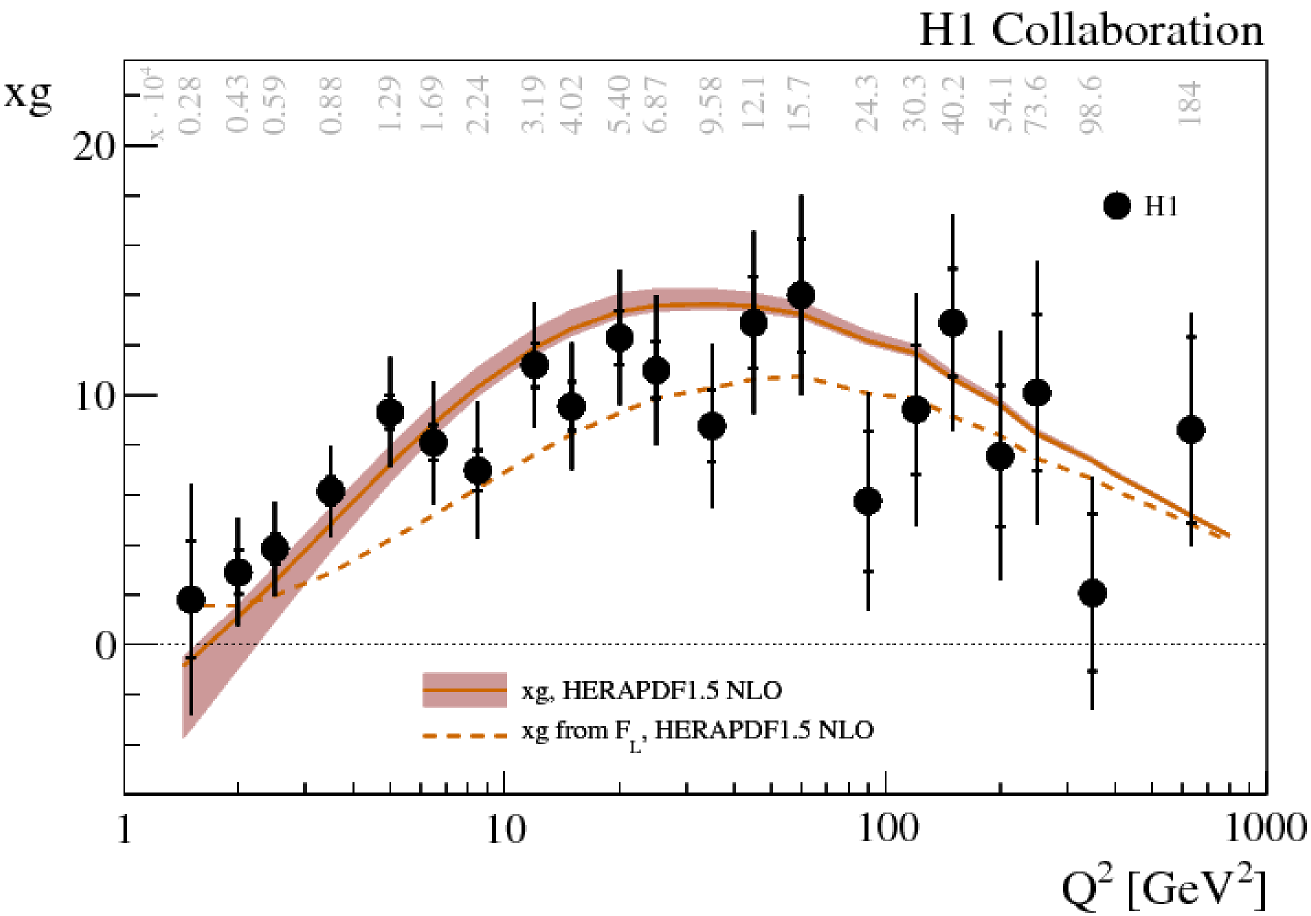


R is approximately constant. Constant value fit gives

H1 0.23 ± 0.04

ZEUS $0.105 + 0.055 - 0.037$

The Gluon Density Extraction



- Shaded area
  prediction from the QCD fit
- Data and dashed line
  extraction at order α_s from the F_L
  measurement and prediction

$$xg(x,Q^2) \approx 1.77 \frac{3\pi}{2\alpha_S(Q^2)} F_L(x,Q^2)$$

A.M. Cooper-Sarkar et al., Z. Phys. C39 (1988) 281
E.B. Zijlstra, W.L. van Neerven, Nucl. Phys. B 383 (1992) 525
G. R. Boroun, B. Rezaei, Eur. Phys. J. **C72** (2012) 2221
G. R. Boroun, B. Rezaei, arXiv:1401.7804.

Agreement between direct gluon density extraction and indirect measurement from scaling violations

Conclusions

- New measurement of NC DIS cross section at different centre-of-mass energies by H1 and ZEUS
- Model independent extraction of the F_L and F_2 structure functions
- Measurement of the ratio R of longitudinally and transversely polarized virtual photon cross sections
- Agreement of H1 and ZEUS measurements
- Direct gluon density extraction from F_L
- Theoretical predictions are in good agreement with the measurements

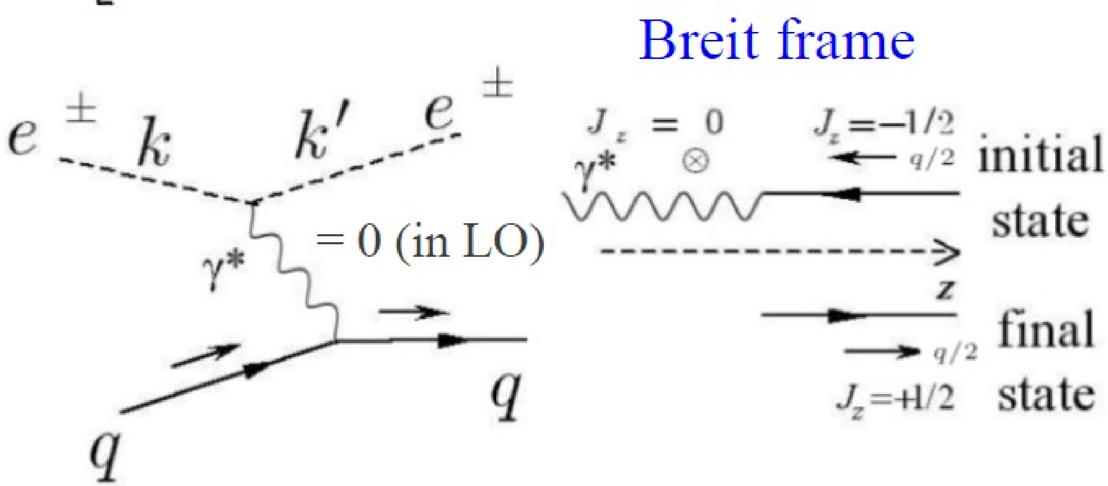
Backup

The F_L Structure Function in QPM

γ*p interaction at small x

$F_2 \sim \sigma_L^{\gamma p} + \sigma_T^{\gamma p}$, $F_L \sim \sigma_L^{\gamma p}$

→ $0 \leqslant F_L \leqslant F_2$



Interaction of a longitudinally polarized photon with a spin 1/2 quark

In QPM: can't conserve angular momentum and helicity at the same time

$$F_L = F_2 - 2xF_1 = 0 \quad \text{(Callan-Gross relation)}$$

F_L Structure Function Extraction: Accurate Treatment

- Use cross section measurements at E_p = 460, 575 and 920 GeV (ZEUS: use 820 GeV data also)

- Simultaneously obtain F_2 and F_L in the fit properly taking correlated systematic uncertainties into account

H1

$$\chi^2\left(F_{L,i}, F_{2,i}, b_j\right) = \sum_i \frac{\left[\left(F_{2,i} - f(y_i)F_{L,i}\right) - \sum_j \Gamma_{i,j} b_j - \mu_i\right]^2}{\Delta_i^2} + \sum_j b_j^2$$

$$f(y) = y^2/(1+(1-y)^2)$$

$$\Delta_i = \sqrt{\left(\Delta_{i,\mathrm{stat}}^2 + \Delta_{i,\mathrm{syst}}^2\right)}$$

ZEUS make use of Bayesian formalism (unconstrained case is equivalent to maximum likelihood)