XXII International Workshop on Deep-Inelastic Scattering and Related Subjects

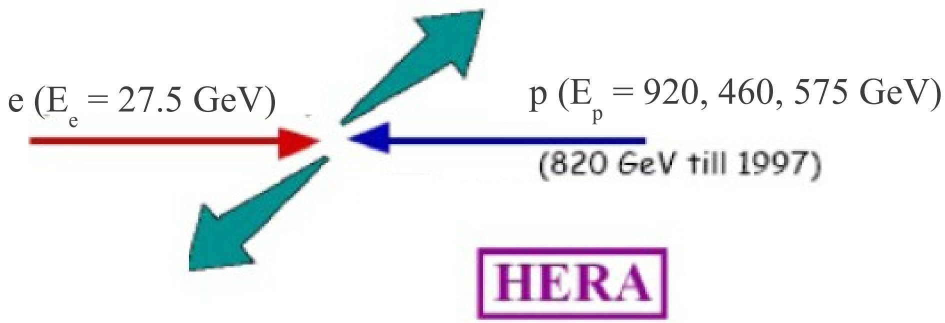
Warsaw, 28 April to 2 May 2014

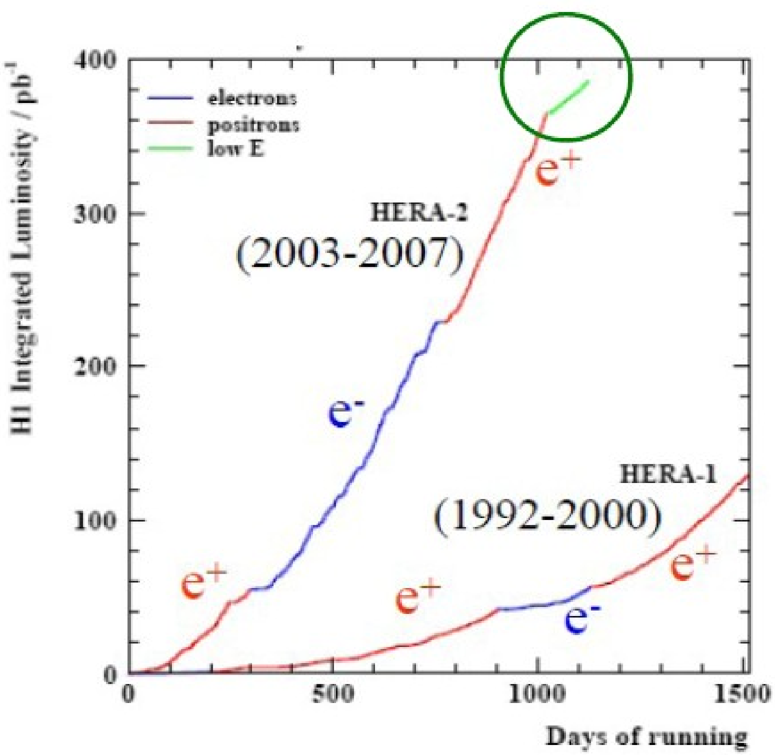
Measurement of Inclusive ep Cross Sections at High Q^2 at $\sqrt{s} = 225$ and 252 GeV and of the Longitudinal Proton Structure Function F_L at HERA

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

S. Shushkevich, DESY

HERA Collider





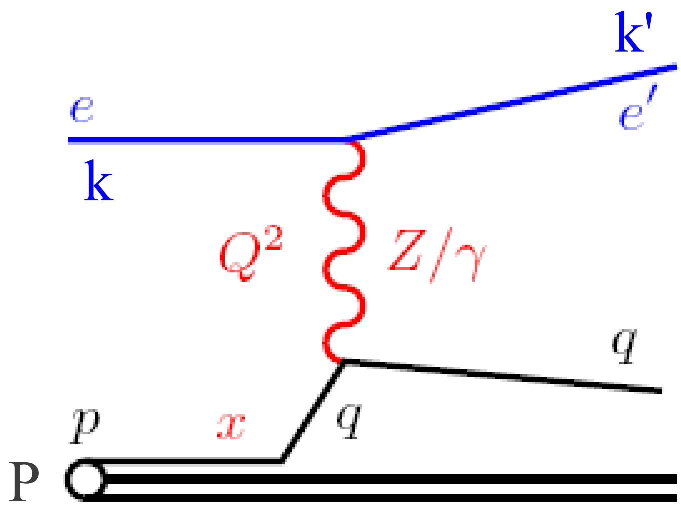
- experiments: (H1, ZEUS)
- e^+ and e^-
- polarization P_e

Low proton energy runs for direct F_L measurement

E_p = 460 GeV 11.8 pb^{-1}

E_p = 575 GeV 5.4 pb^{-1}

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
$x = \dfrac{Q^2}{2(Pq)}$	Bjorken x momentum fraction of proton carried by the struck quark
$y = \dfrac{(Pq)}{(Pk)}$	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

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

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

In QPM:

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

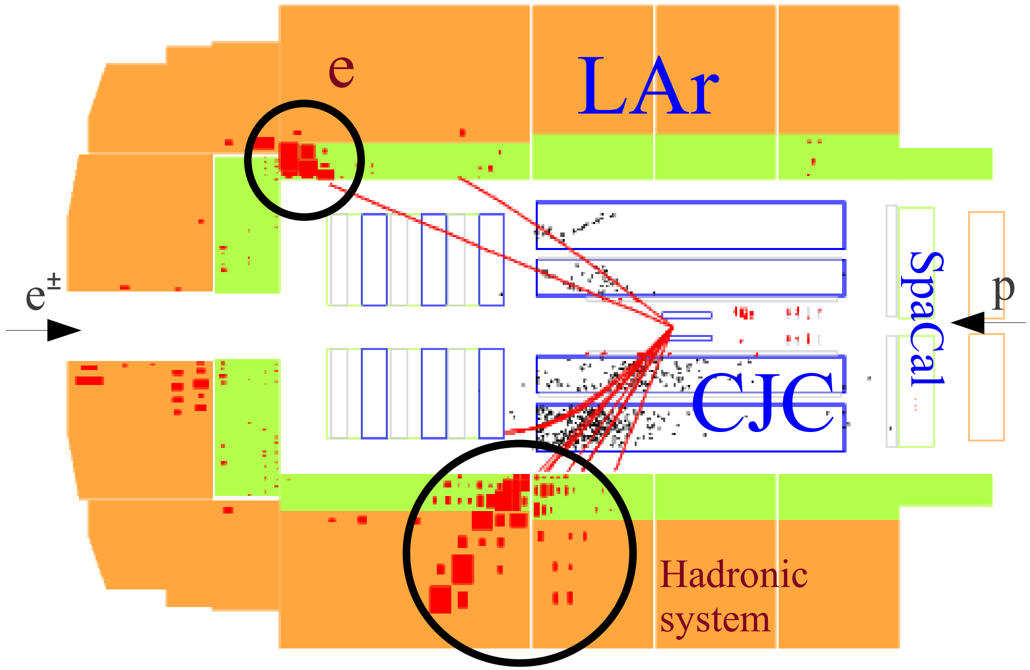
$$F_L(x,Q^2) = F_2 - 2xF_1 = 0 \quad \text{Callan-Gross relation}$$

In QCD: add particle to carry angular momentum, gluon is needed

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

- F_L is a QCD effect which allows to make a critical test of perturbative QCD
- F_L is directly sensitive to the gluon density
- F_L is a structure function is measured at HERA at high y

Main Detector Components



LAr   Liquid Argon Calorimeter

This measurement (large Θ → high Q^2)
Electron identification
Scattered electron energy $E'_e > 3$ GeV
Background suppression with NN

CJC   Central Jet Chamber

Electron candidate verification with track
Electron candidate charge measurement
Background suppression with NN

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

SpaCal   Spaghetti Calorimeter

F.D. Aaron *et. al.* [H1 Collaboration],
Eur. Phys. J. C71 (2011) 1579

Accept electron candidates down to 3 GeV
→ harsh background conditions

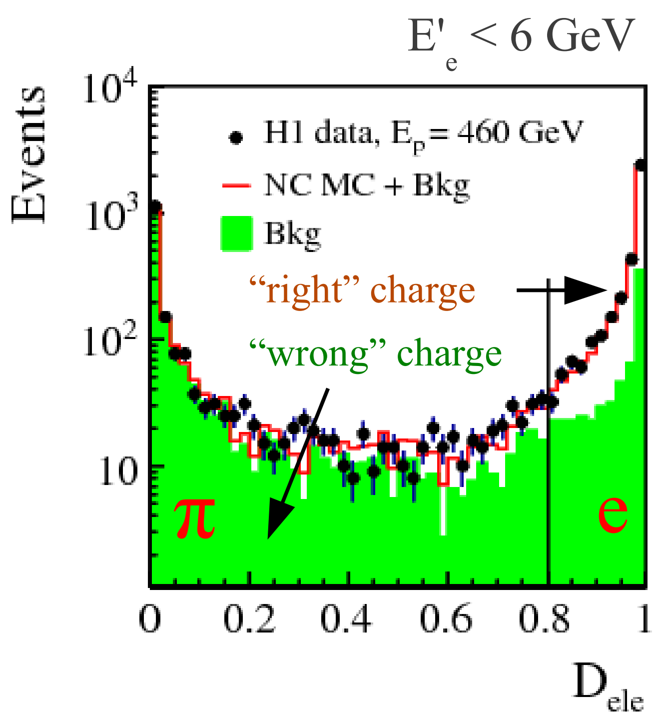
γp Background Treatment at High y

Photoproduction background arise from

$\pi^0 \to \gamma\gamma$ decays

misidentification of charged hadrons

semi-leptonic decays of heavy flavour hadrons



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

shower shape variables

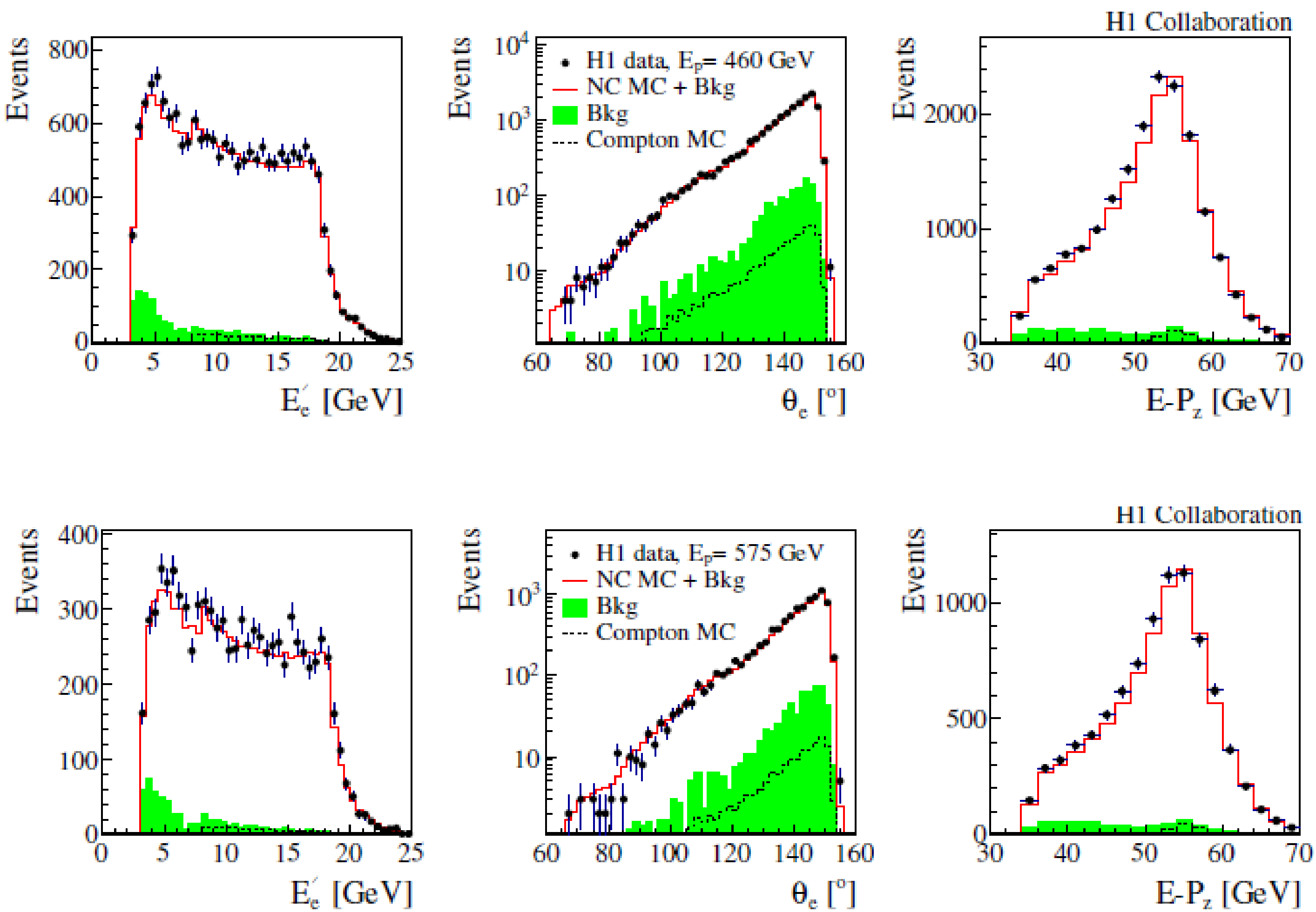
ionisation energy loss dE/dx

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

Control Plots for the High y Region

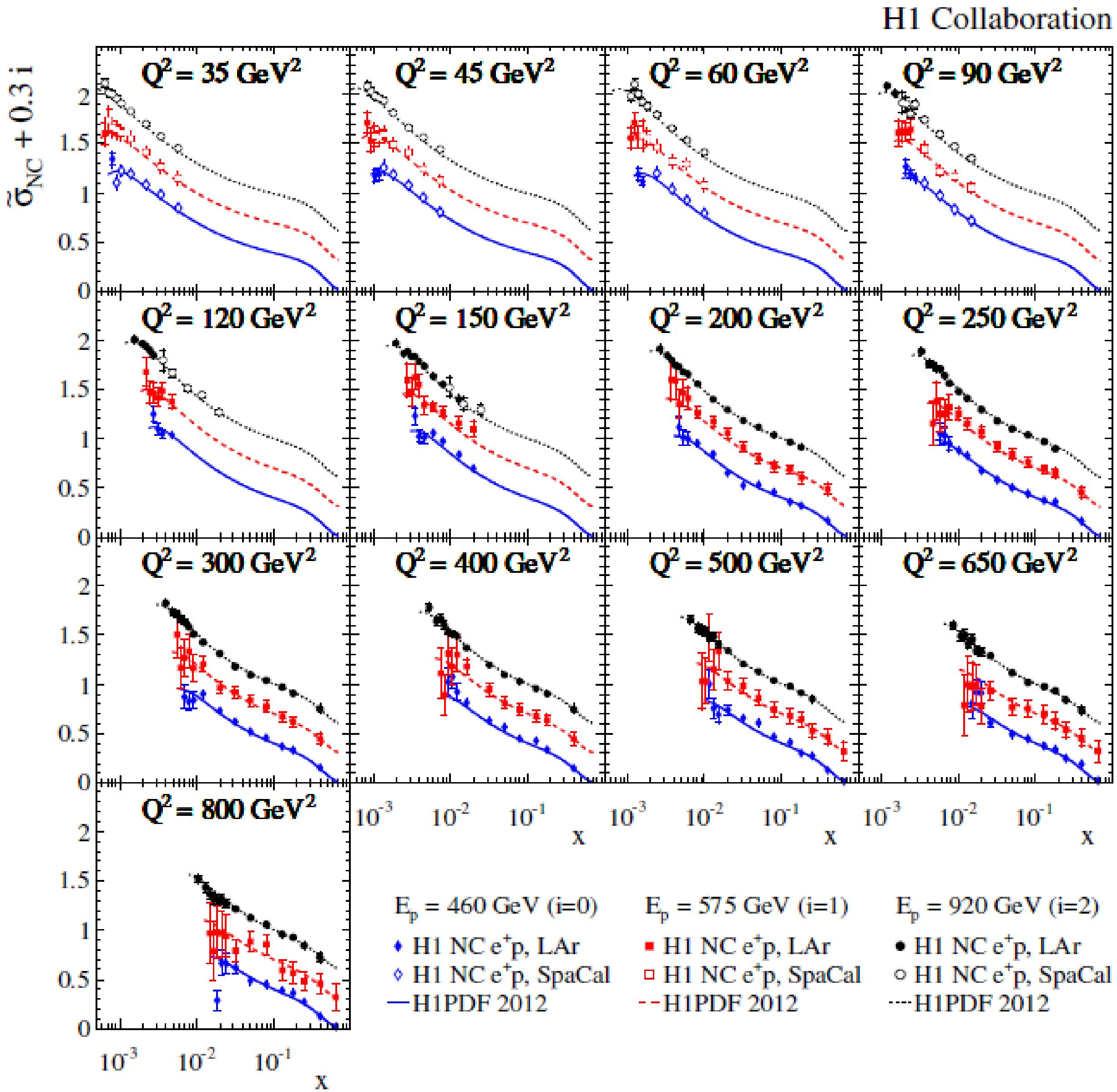


E_p = 460 GeV

E_p = 575 GeV

$0.38 < y_e < 0.90$

NC Cross Section for $E_p = 460, 575, 920$ GeV

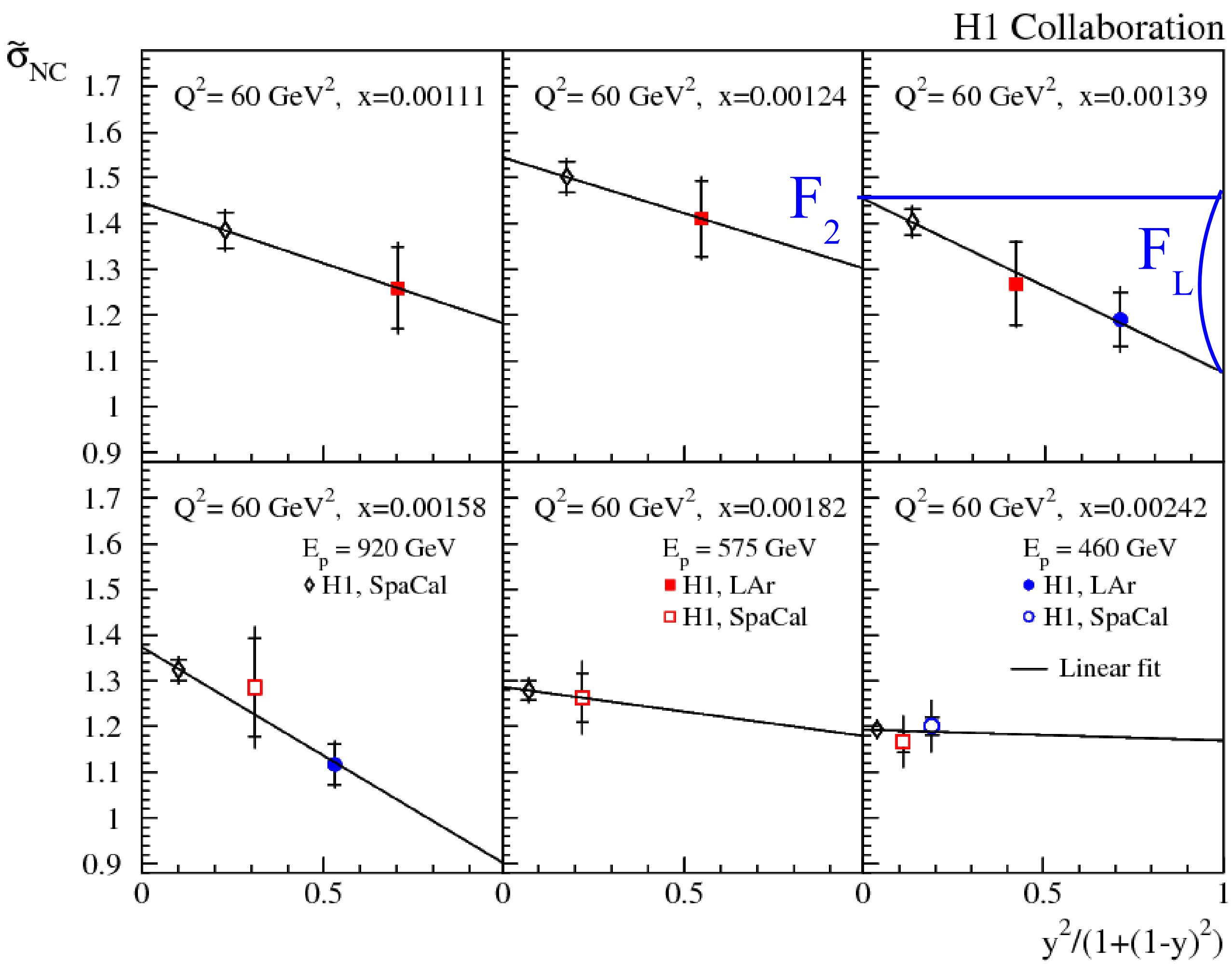


Cross section measurements at (x, Q2) points at different s

Data from both LAr and SpaCal

F_L Structure Function Extraction: Linear Fit

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



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

F_L Structure Function Extraction: Accurate Treatment

- Use cross section measurements at E_p = 460, 575 and 920 GeV in LAr and SpaCal

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

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

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

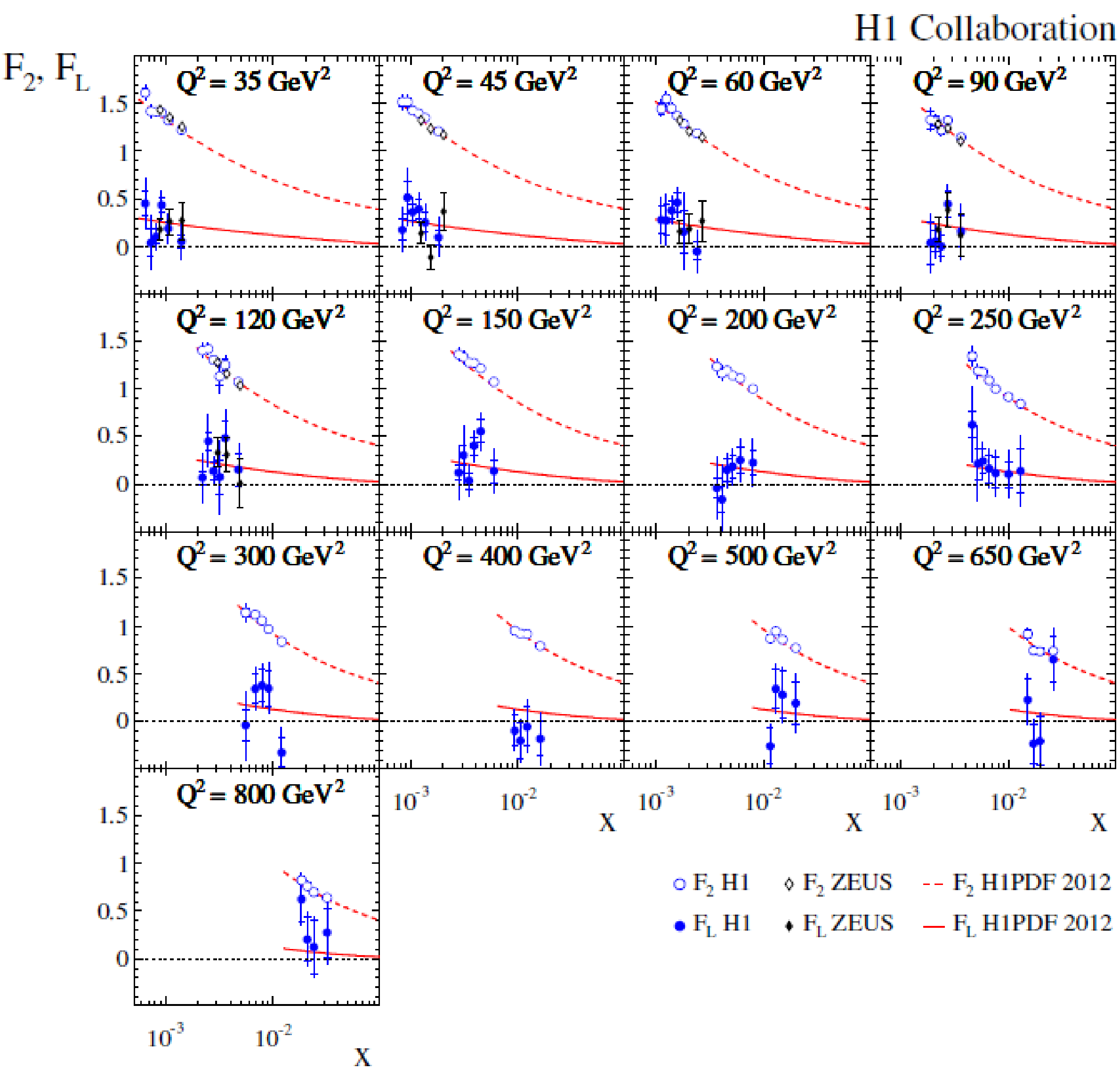
$$\Delta_i = \sqrt{\left(\Delta_{i,\mathrm{stat}}^2 + \Delta_{i,\mathrm{syst}}^2\right)}$$

- Fit goodness: χ^2/ndf = 184/210

(Neglecting correlations yields back to the naive linear fit)

F.D. Aaron *et. al.* [H1 Collaboration],
Eur. Phys. J. C **71** (2011) 1579 [arXiv: 1012.4355]

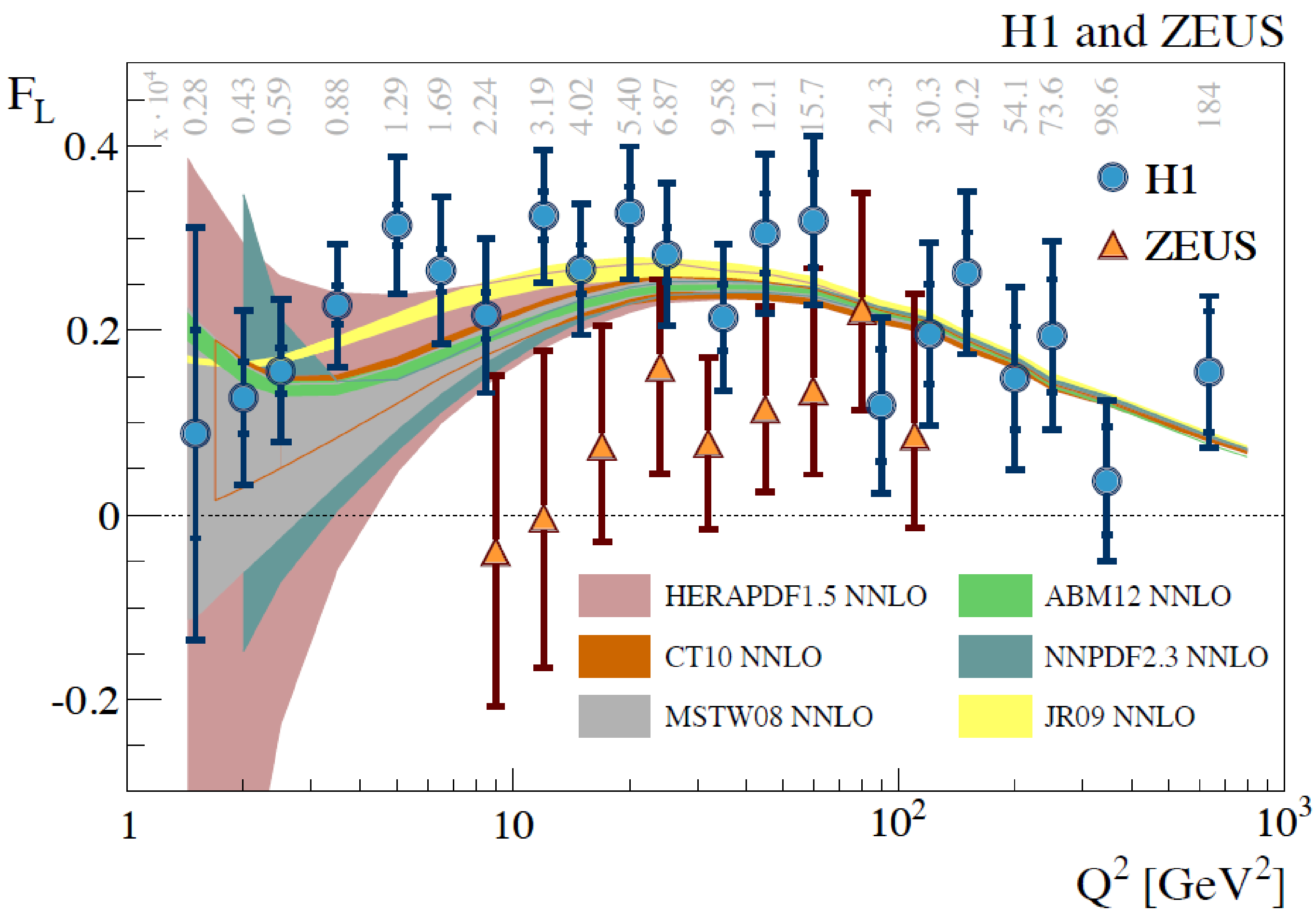
The Longitudinal Structure Function $F_L(x, Q^2)$ at high Q^2



- Main contributions are from
  - $1.5 < Q^2 < 25$ GeV^2 SpaCal
  - $35 < Q^2 < 90$ GeV^2 SpaCal & LAr
  - $Q^2 > 120$ GeV^2 LAr
- F_L measurement is extended to $Q^2 = 800$ GeV^2
- Model independent extraction
- Good description by the NLO theoretical prediction

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

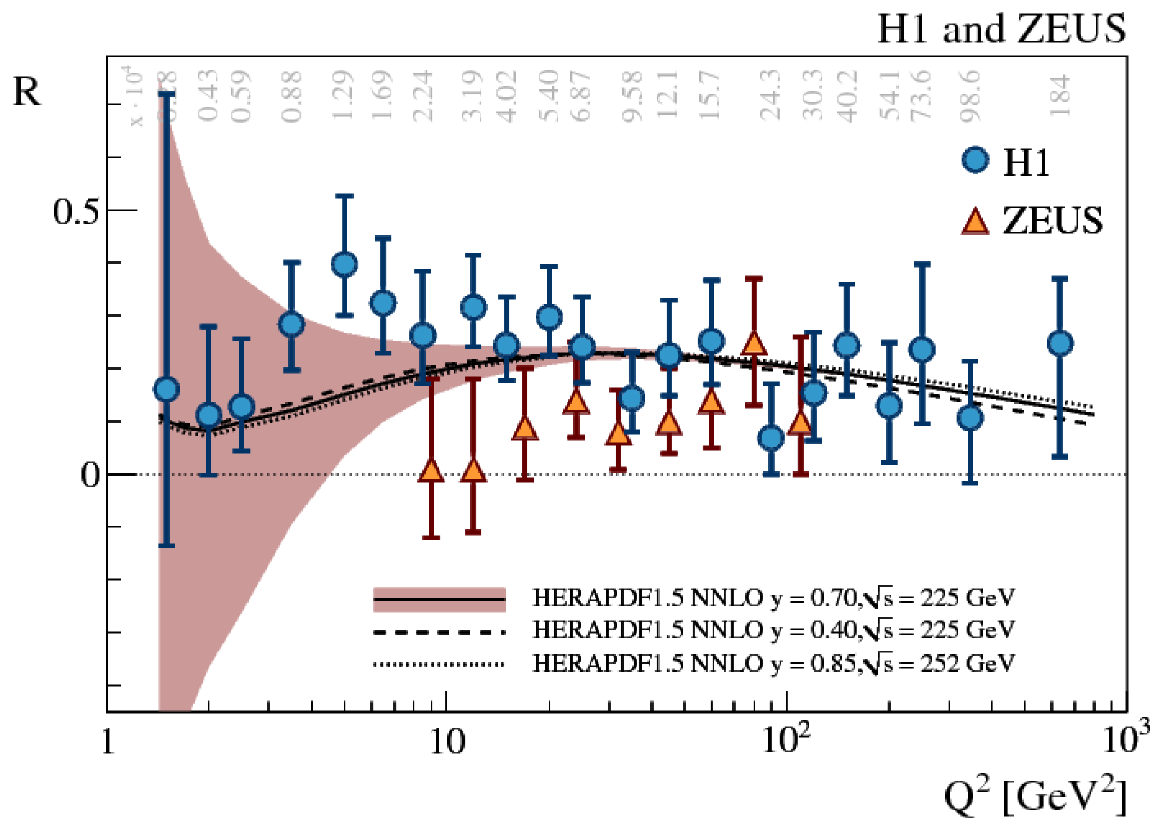
Average F_L measurement over x at each Q^2 to reduce statistical uncertainty



Good agreement between the NNLO predictions and the measurement
Additional constraints to PDF's at low Q^2

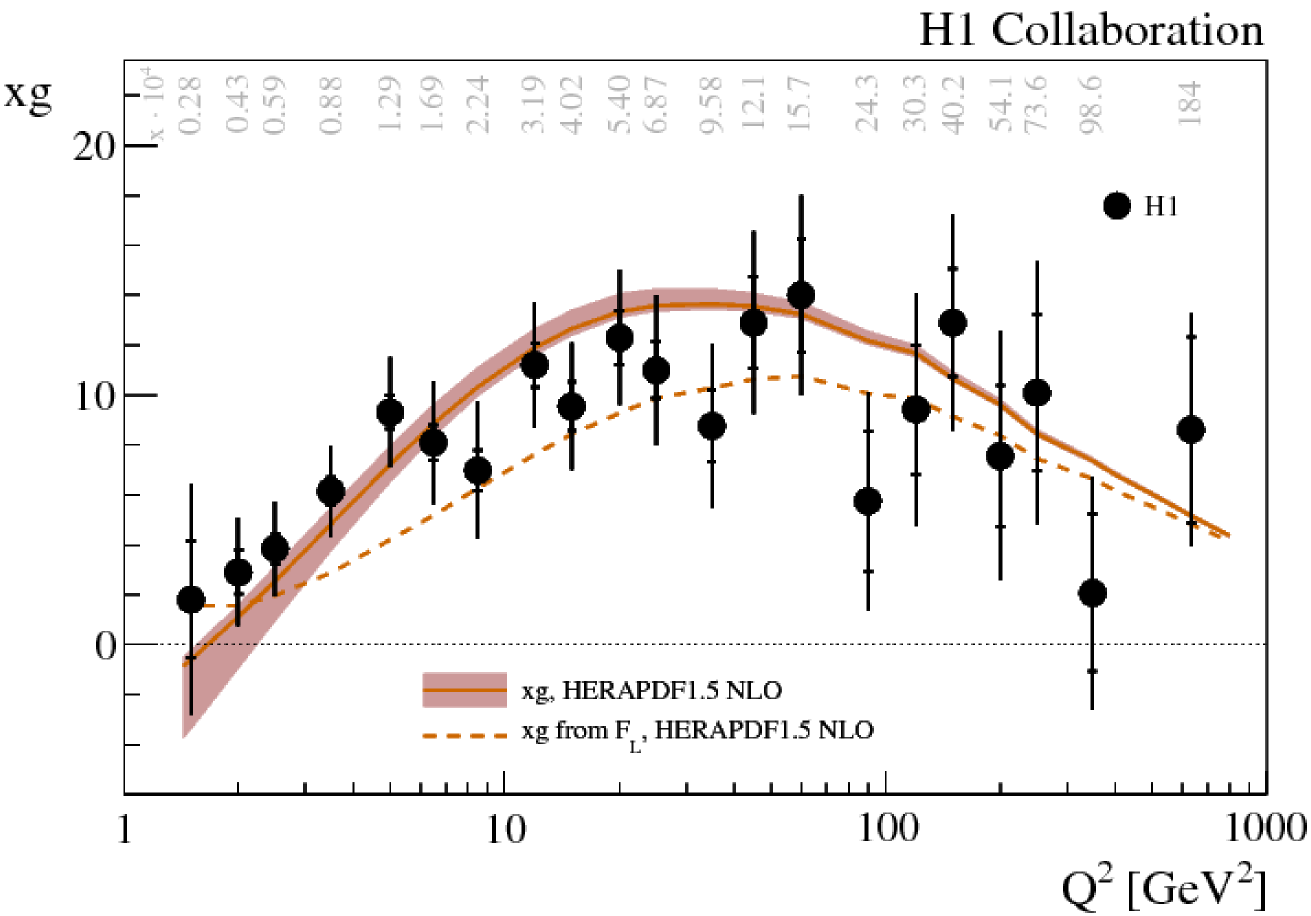
The Ratio $R = \sigma_L / \sigma_T$ Extraction

For γ^*p R measures interaction with longitudinally polarized virtual photon
Express F_L with F_2 and R from $R = F_L / (F_2 - F_L)$. Extraction is done with the similar minimization procedure obtaining asymmetric uncertainties.



R is approximately constant. Fit for R – fixed yields $R = 0.23 \pm 0.04$
Agrees well with previous measurement at low Q^2 and reasonable with ZEUS result

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 / prediction

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

A. M. Cooper-Sarkar *et al.*, Z. Phys. C **39** (1988)

E. B. Zijlstra and W. L. van Neerven, Nucl. Phys. B **383** (1992)

G. R. Boroun, B. Rezaei, Eur. Phys. J. **C72** (2012) 2221
G. R. Boroun, B. Rezaei, arXiv:1401.7804.

Reasonable agreement between direct gluon density (approximate) extraction and indirect measurement from scaling violation

Conclusions

- Measurement of the NC DIS cross section at two centre-of-mass energies of $\sqrt{s}$ = 225 and 252 GeV
- Model independent extraction of the F_L and F_2 structure functions with the use of previous measurement at $\sqrt{s}$ = 319 GeV
- Measurement of the ratio R of longitudinally and transversely polarized virtual photon cross sections
- Gluon density extraction based on NLO approximation
- Theoretical predictions demonstrates good agreement with the measurement
- The agreement between H1 and ZEUS results is within one standard deviation

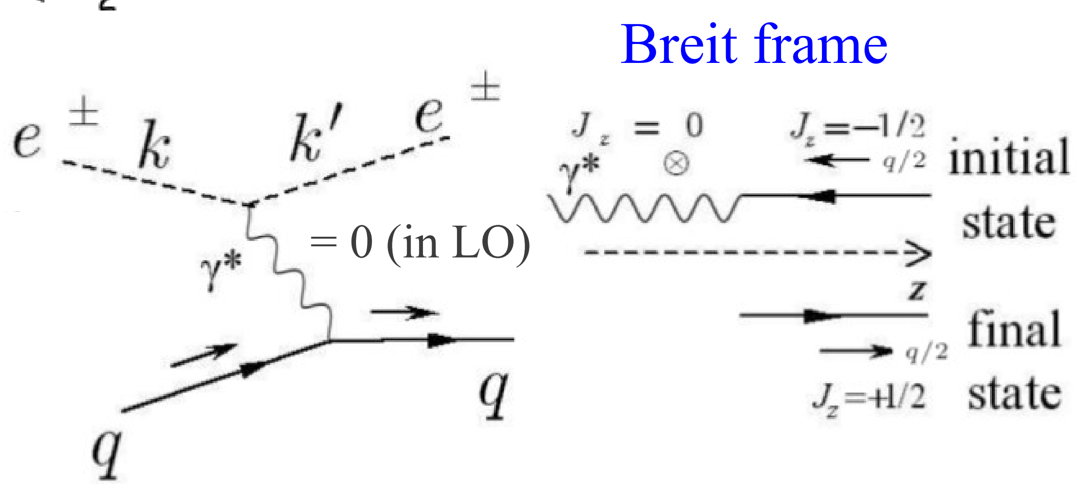
Backup

The F_L Structure Function in QPM

γ*p interaction at small x

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

$\rightarrow \quad 0 \leqslant F_L \leqslant F_2$



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

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

Analysis Strategy

High y analysis	Nominal analysis
$0.38 < y_e < 0.90$ $E'_e > 3$ GeV → hard background conditions	$0.076 < y < 0.38$ $E'_{e\,min} \approx 18$ GeV from kinematics
Claim for track pointing to the cluster Use neural network for scattered electron energy below 10 GeV to suppress the photoproduction background : shower shapes, dE/dx, track-cluster momentum matching Make use of electric charge of the candidate require "right charge" for the em candidates estimate the remaining bkg with the "wrong charge" candidates take charge asymmetry into account	Validate electron cluster with the CIP hits → optimized vertex treatment → very good ID efficiency simulation Simulate and subtract the background (mainly QED Compton)

In common
- $|Zvtx| < 35$ cm for good reconstruction quality
- $E-Pz > 35$ GeV to suppress initial state ration
- exclude insensitive LAr regions
- suppress QED Compton background