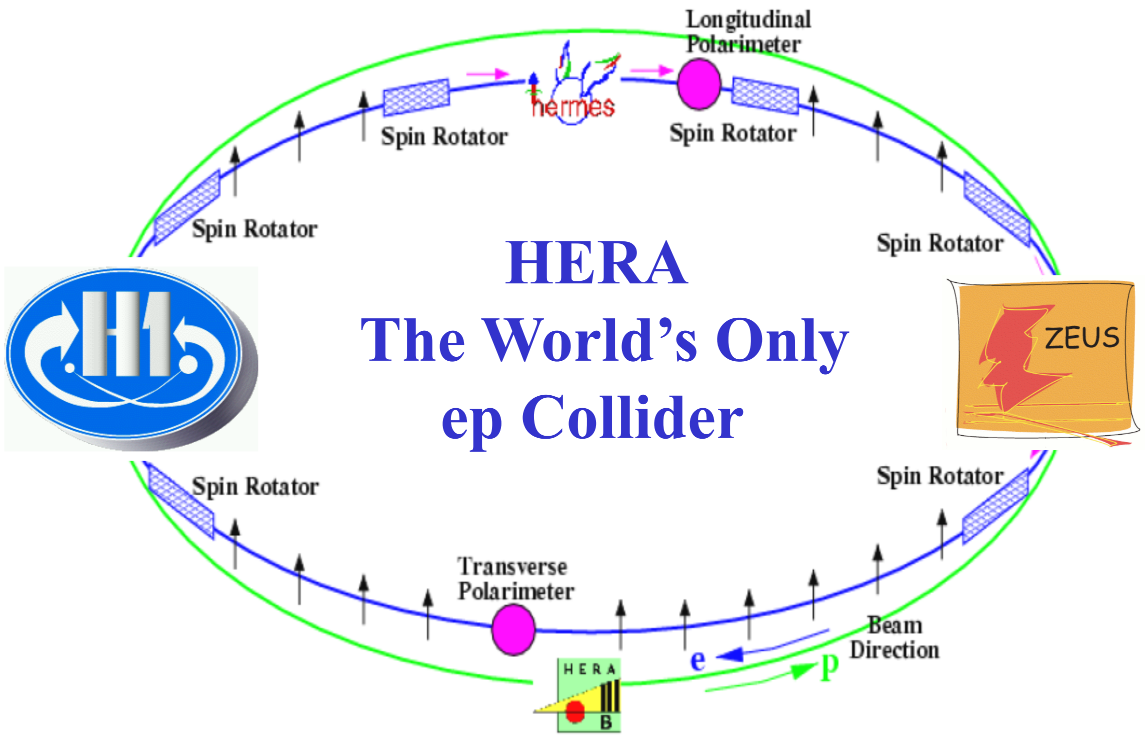
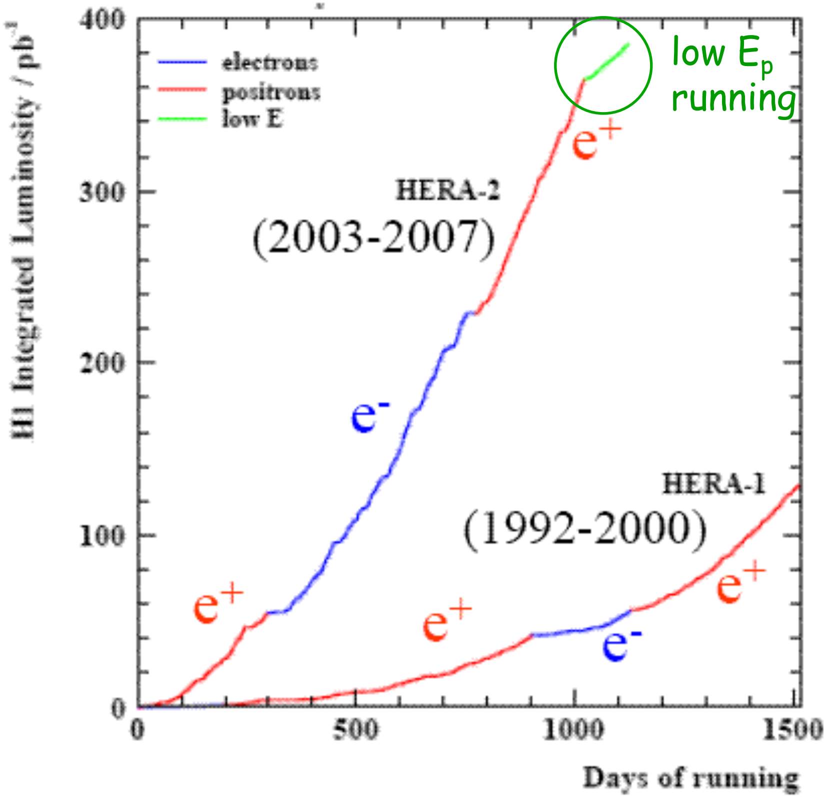
Inclusive Cross Sections at HERA and Determinations of F_L

Vladimir Chekelian (MPI for Physics, Munich)
on behalf of the H1 and ZEUS Collaborations

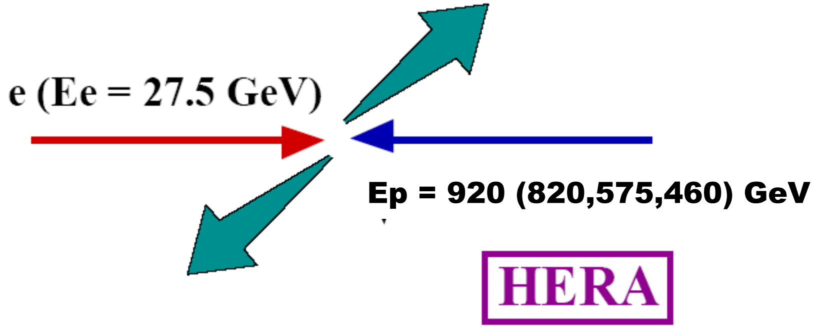


- HERA / DIS / NC / CC
- Combination of H1 & ZEUS
  - HERA I
  - HERA I+II
- Longitudinal sf $F_L(x,Q^2)$
- Summary

HERA: 15 years of operation (1992–2007)



HERA I	1992-2000	~120 pb-1
HERA II	2003-2007	~380 pb-1

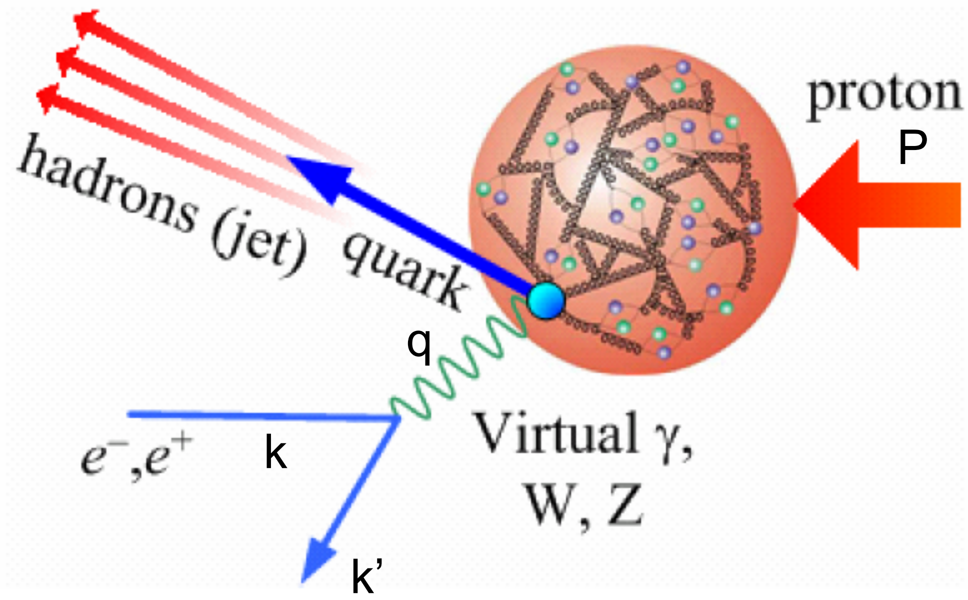


located at DESY, Hamburg
peak luminosity 5 10^{31} cm^{-2} sec^{-1}
$Q^2_{max} = 10^5$ GeV^2
λ_{min} ~ 1/1000 r_{proton}
longitudinal e-beam polarisation

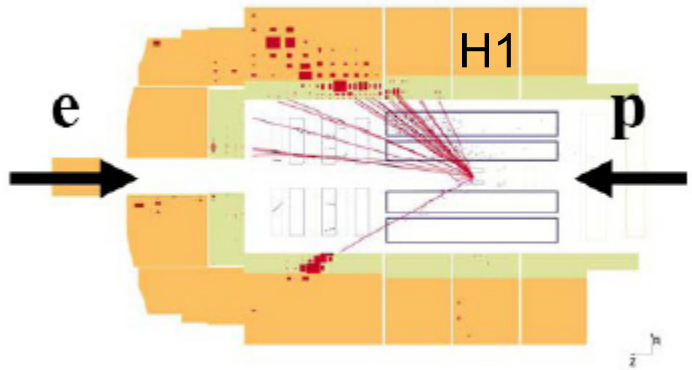
H1+ZEUS in total ~ 1 fb^{-1}
about equally shared between
- **experiments (H1, ZEUS)**
- **e^+ and e^-,**
- **positive and negative P_e**

low proton energy running for F_L

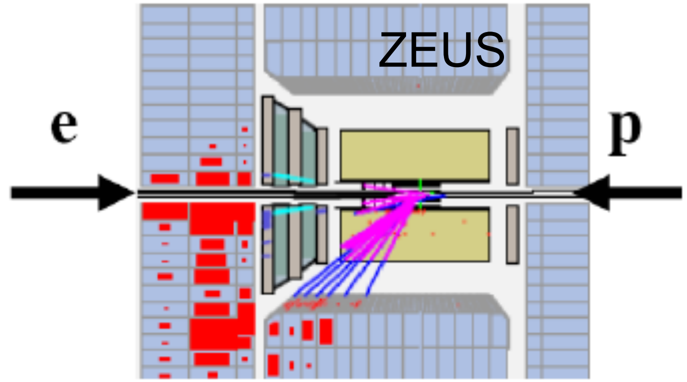
Deep Inelastic Scattering (DIS)



Neutral Current (NC): $e^{\pm}p \rightarrow e^{\pm}X$



Charged Current (CC): $e^{\pm}p \rightarrow \nu X$



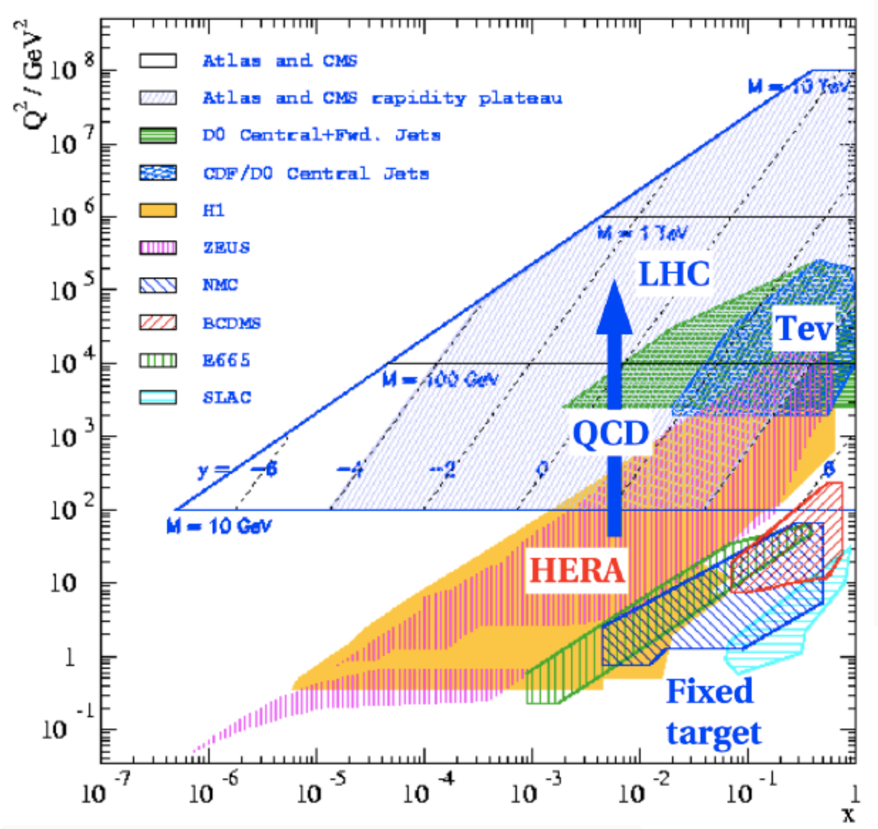
$Q^2 = -q^2 = -(k-k')^2$	virtuality of γ^*, Z^0, W
$x = Q^2/2(Pq)$	Bjorken x
$y = (Pq)/(Pk)$	inelasticity
$Q^2 = sxy$	$s=(k+P)^2$

Factorisation: $\sigma_{DIS} \sim \hat{\sigma} \otimes pdf(x)$

$\hat{\sigma}$ – perturbative QCD cross section
pdf – universal parton distribution functions

Inclusive NC and CC at HERA

HERA: span 6 orders of magnitude in x and Q^2



$$\tilde{\sigma}^{\pm}_{NC} \equiv \frac{d^2\sigma^{e^\pm p}_{NC}}{dxdQ^2}\,\frac{xQ^4}{2\pi\alpha^2}\,\frac{1}{Y_+} \equiv \tilde{F}_2 - \frac{y^2}{Y_+}\tilde{F}_L \mp \frac{Y_-}{Y_+}x\tilde{F}_3$$

$$F_2(x,Q^2) = x\sum A_i(q_i+\bar{q}_i) \qquad xF_3(x,Q^2) = x\sum B_i(q_i-\bar{q}_i)$$

$$F_L = F_2 - 2xF_1 = 0 \quad \text{(QPM)} \qquad Y_{\pm} = 1 \pm (1-y)^2$$

$$\tilde{\sigma}_{CC} = \frac{2\pi x}{G_F^2}\left[\frac{M_W^2+Q^2}{M_W^2}\right]^2 \frac{d^2\sigma_{CC}}{dxdQ^2}$$

$$\tilde{\sigma}^{+}_{CC} \sim (x\bar{u} + x\bar{c}) + (1-y)^2(xd + xs)$$

$$\tilde{\sigma}^{-}_{CC} \sim (xu + xc) + (1-y)^2(x\bar{d} + x\bar{s})$$

Large number of individual data sets from H1 and ZEUS, covering different parts of the phase space, obtained in different periods, using different detector components, different beam energies, …

→ combine

Combination of H1 and ZEUS

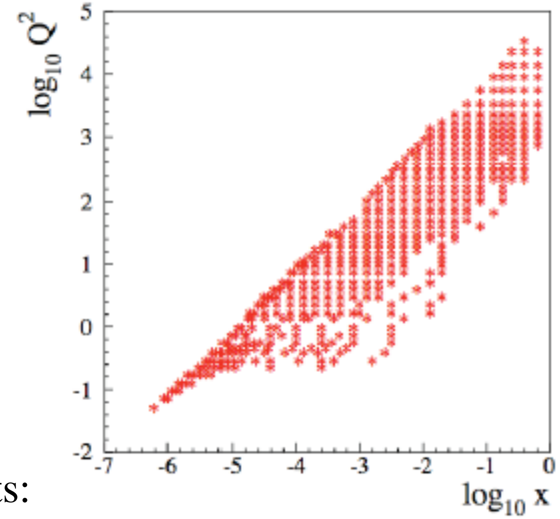
The goal is to have "the unique HERA data set" which includes expert knowledge in the treatment of the correlations between many individual data sets from H1 and ZEUS

→ most precise, complete and easy in use

Combine inclusive unpolarised NC & CC cross sections from H1 and ZEUS at HERA I (1994-2000)

→ all HERA I analyses are completed and published.

Exploit differences between H1 and ZEUS in detectors, methods and systematics to "cross-calibrate" and hence to reduce the systematic uncertainties.



- for each channel move measured points to a common x-Q^2 grid
- correct E_{pbeam}=820 GeV data to E_{pbeam}=920 GeV
- average H1 and ZEUS points at given x,Q^2 at y < 0.35
- keep all data points at y > 0.35, modifying them to account for the determined shifts in the correlated systematic sources.

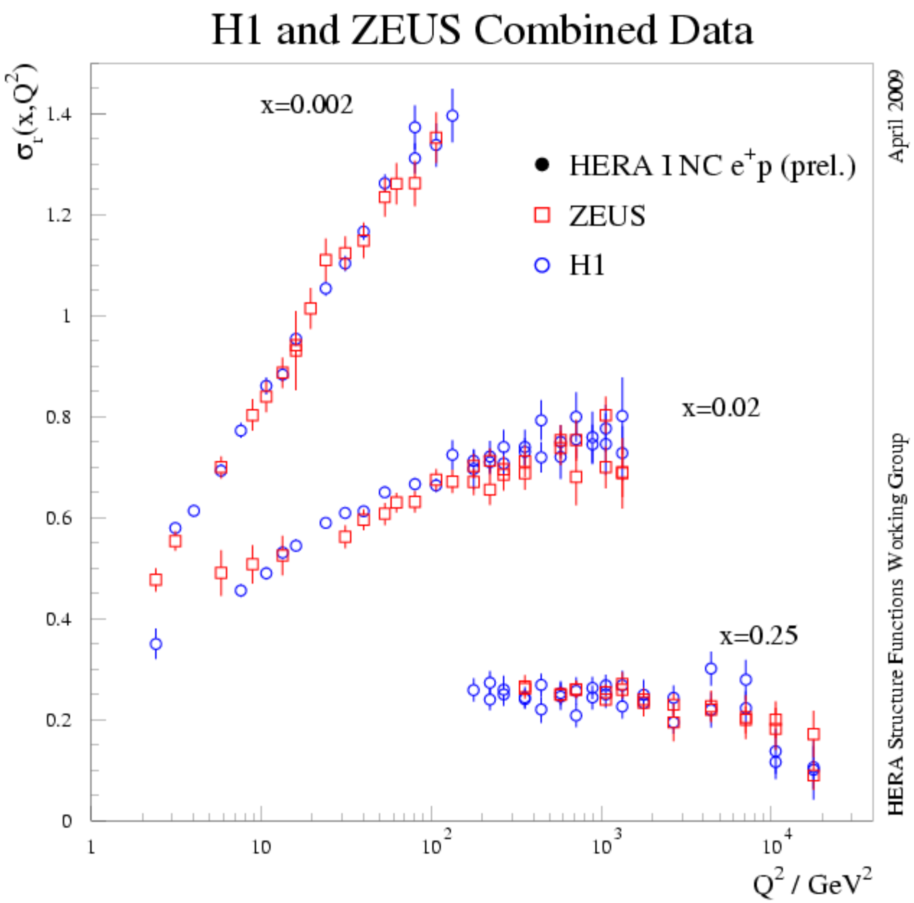
The averaging exploits a concept of correlated syst. errors, assuming that systematic uncertainties are proportional to expected values and statistical uncertainties are defined by √ of expected number of events:

$$\chi^2_{\rm exp}(\boldsymbol{m},\boldsymbol{b}) = \sum_i \frac{\left[m^i - \sum_j \gamma^i_j m^i b_j - \mu^i\right]^2}{\delta^2_{i,{\rm stat}}\,\mu^i\left(m^i - \sum_j \gamma^i_j m^i b_j\right) + \left(\delta_{i,{\rm uncor}}\, m^i\right)^2} + \sum_j b_j^2$$

$$\gamma^i_j = \Gamma^i_j/\mu^i$$
$$\delta_{i,{\rm stat}} = \Delta_{i,{\rm stat}}/\mu^i$$
$$\delta_{i,{\rm uncor}} = \Delta_{i,{\rm uncor}}/\mu^i$$

Combination of H1 and ZEUS data from HERA I

JHEP01(2010)109



1402 points are combined to 741 unique cross section measurements

χ^2/ndf = 636.5/656

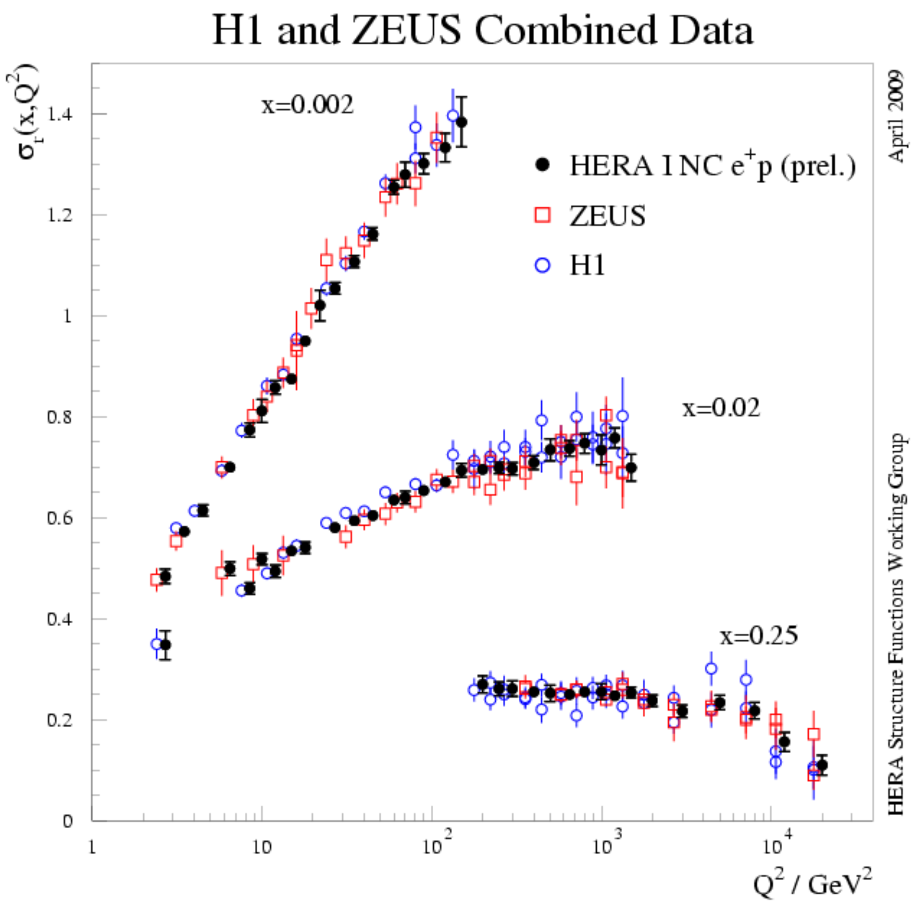
→ the original H1 and ZEUS data are fully consistent

combined data set:
110 corr. syst. sources from individual data sets
3 correlated errors from averaging procedure:
- difference between "multiplicative" treatment of errors and "additive"
- photoproduction background
- hadronic energy scale

more than just double statistics:
→ significant reduction of systematics and little difference then how to treat 110 corr. syst. sources in QCD fits - the simplest approach is to added them in quadrature to the uncorrelated errors

Combination of H1 and ZEUS data from HERA I

JHEP01(2010)109



1402 points are combined to 741
unique cross section measurements

χ^2/ndf = 636.5/656

→ the original H1 and ZEUS data
are fully consistent

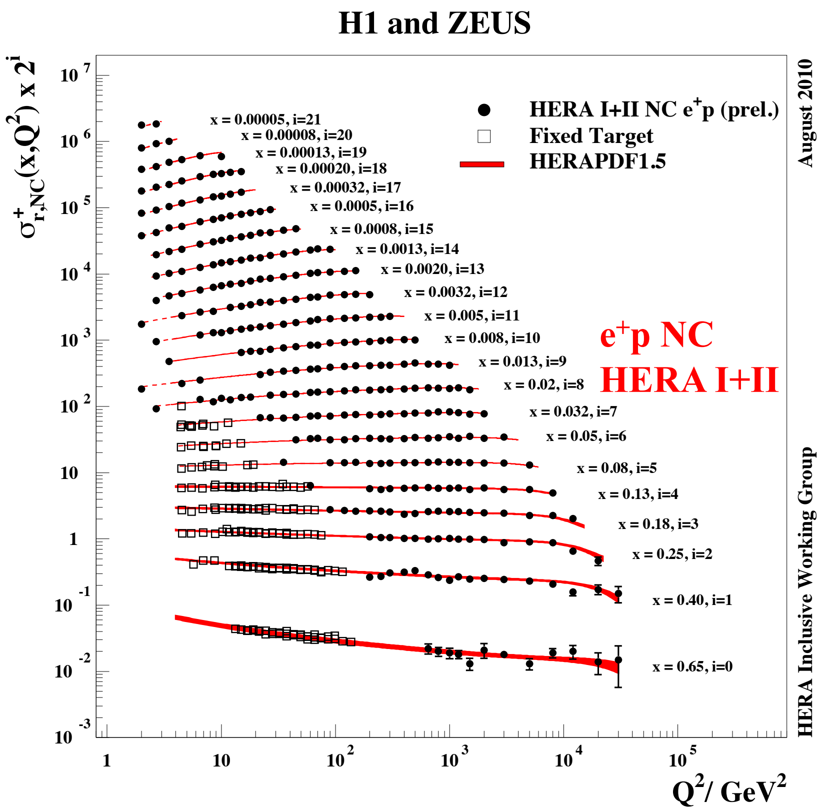
combined data set:
110 corr. syst. sources from individual data sets
3 correlated errors from averaging procedure:
- difference between "multiplicative" treatment of errors and "additive"
- photoproduction background
- hadronic energy scale

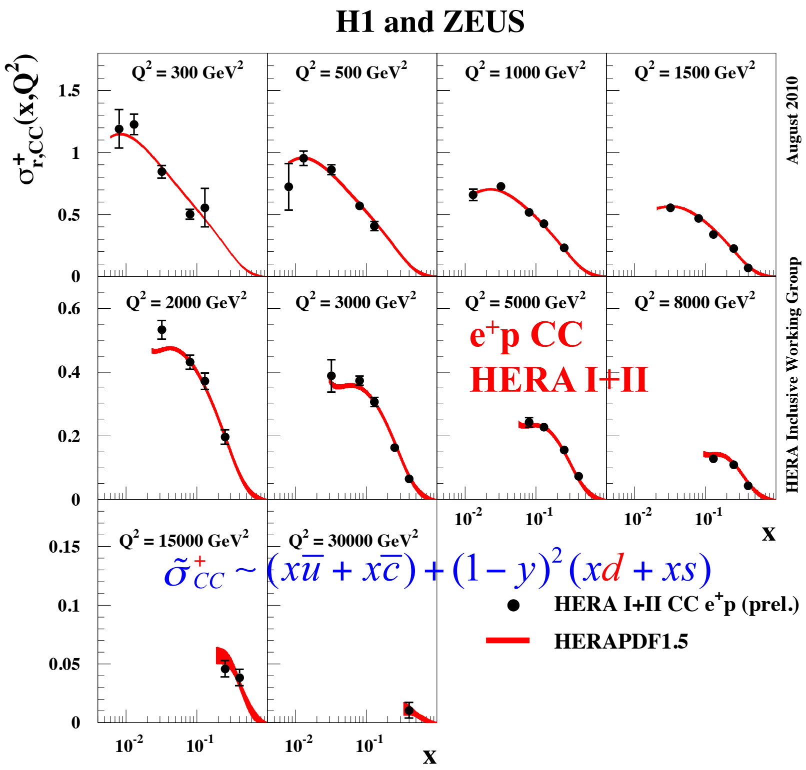
more than just double statistics:
→ significant reduction of systematics and little difference then how to treat 110 corr. syst. sources in QCD fits - the simplest approach is to added them in quadrature to the uncorrelated errors

Combination of HERA I and HERA II

The combination is extended to include unpolarised NC, CC high Q^2 data from HERA II :
HERA I+II, $e^{\pm}p$ NC, CC $\chi^2/ndf = 967/1032$

→ for polarised effects in NC, CC and xF_3 see talks of S. Habib, T. Stewart
→ for EW&QCD fit of polarised data see talk of E. Rizvi

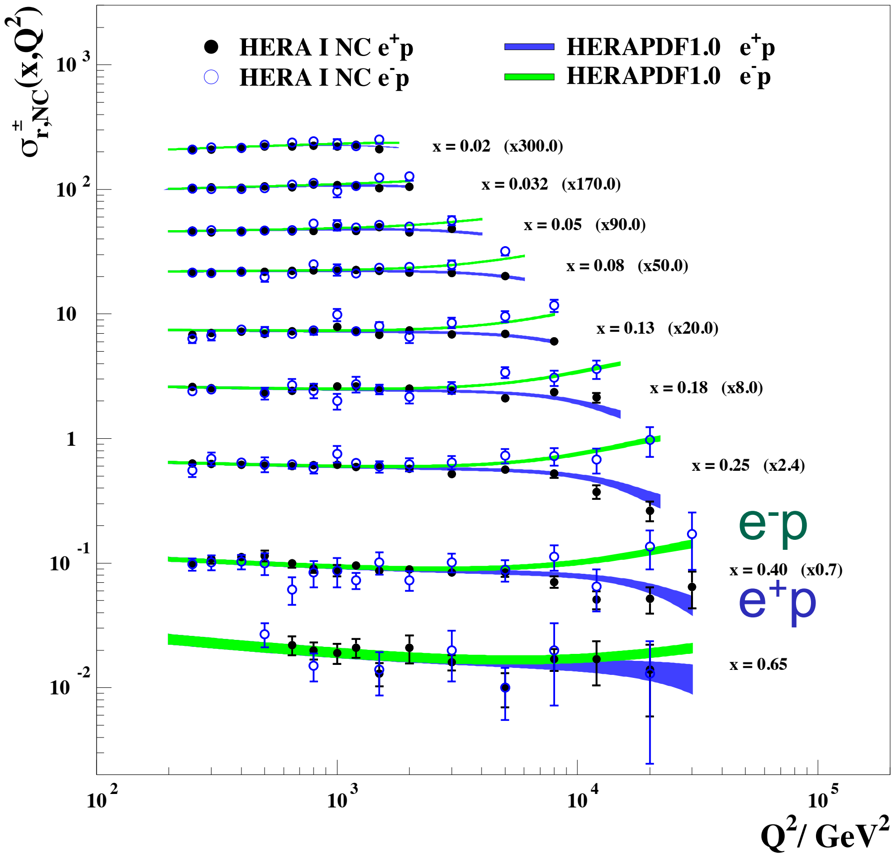




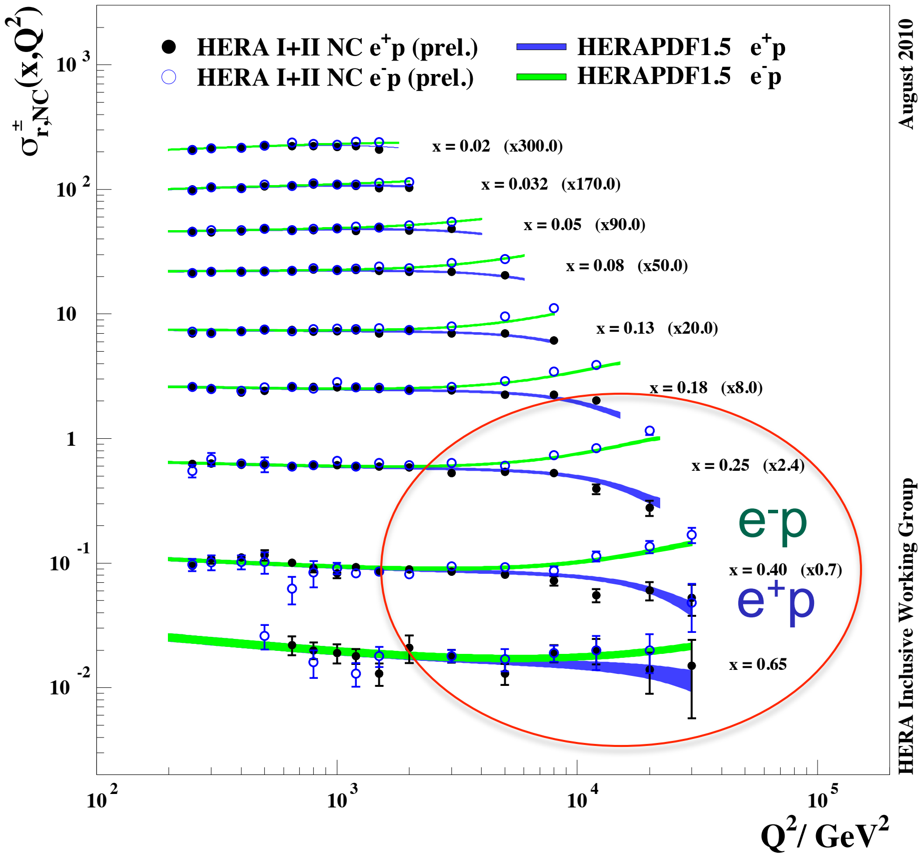
NLO QCD fits of the combined HERA data:	HERA I	HERAPDF1.0
	HERA I+II	HERAPDF1.5

HERA I vs HERA I+II

HERA I vs. HERAPDF1.0



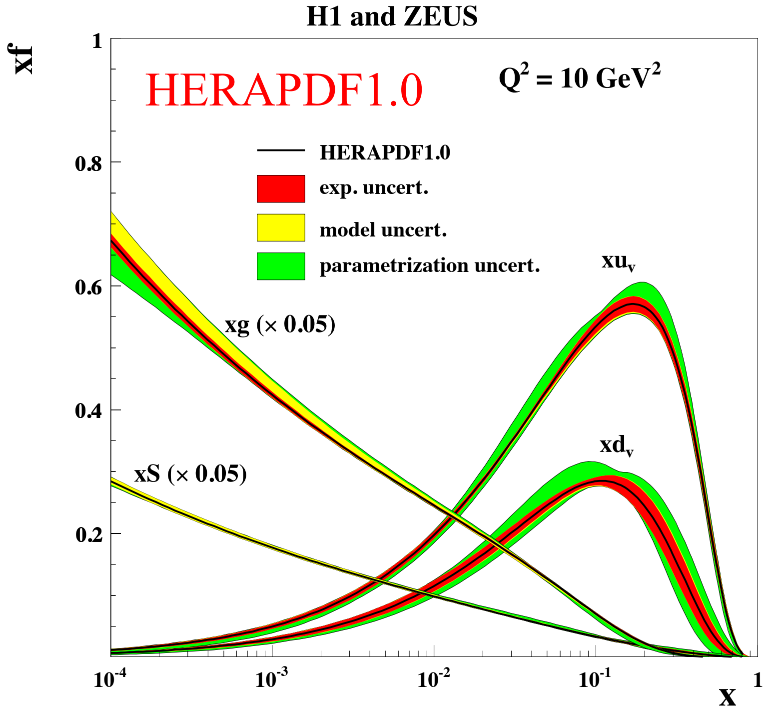
HERA I+II vs. HERAPDF1.5

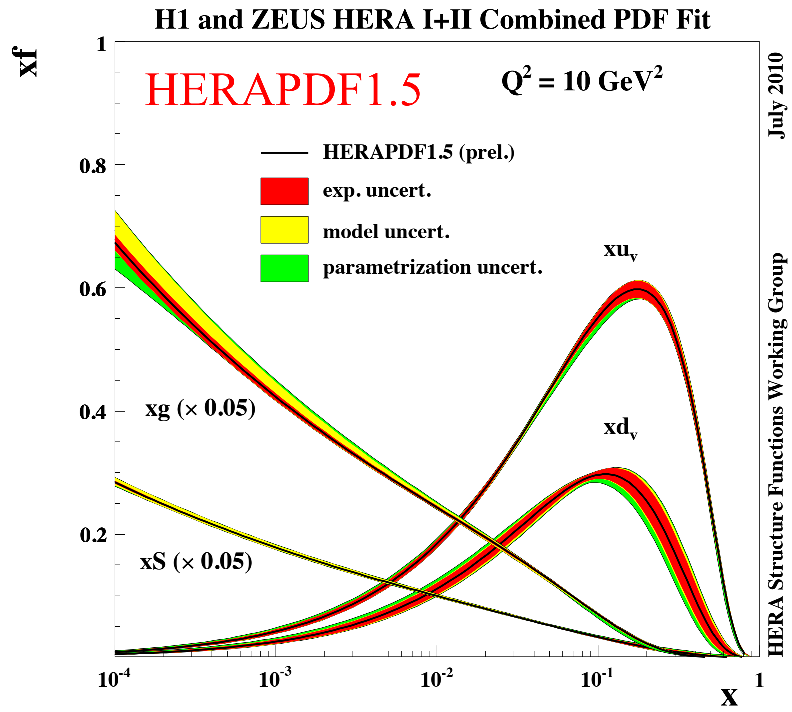


- inclusion of the HERA II high Q^2 data improves precision at high Q^2 and high x

HERAPDF: QCD Fits using HERA data only

PDFs : xg, xuv, xdv, xS (xS=xUbar+xDbar) at the scale Q^2 = 10 GeV2





- inclusion of the HERA II high Q^2 data improves uncertainties of PDFs in the high x region especially visible for the valence quark distributions

→ for HERAPDF NLO/NNLO inclusive, with jets, and with F_2^{cc} see talk of A. M. Cooper-Sarkar

The longitudinal structure function $F_L(x,Q^2)$

- F_L is a pure QCD effect which allows to make critical tests of the perturbative QCD framework used for pdf determinations
- F_L is directly sensitive to gluon density

$$\tilde{\sigma}_{NC} = F_2 - \frac{y^2}{1+(1-y)^2} F_L$$

→ F_L and F_2 can be determined from linear fits at each x and Q^2

in QPM

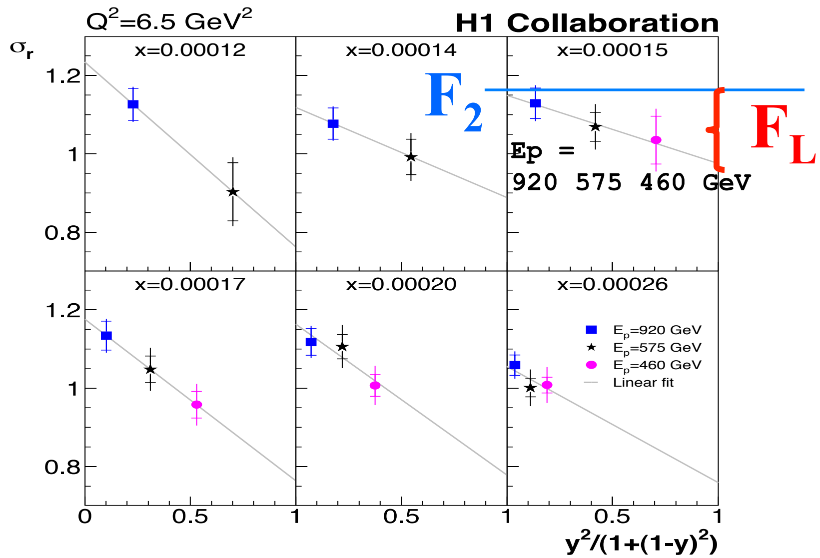
due to helicity and angular momentum conservation for spin ½ quarks

$F_L = F_2 - 2xF_1 = 0$

Callan-Gross relation

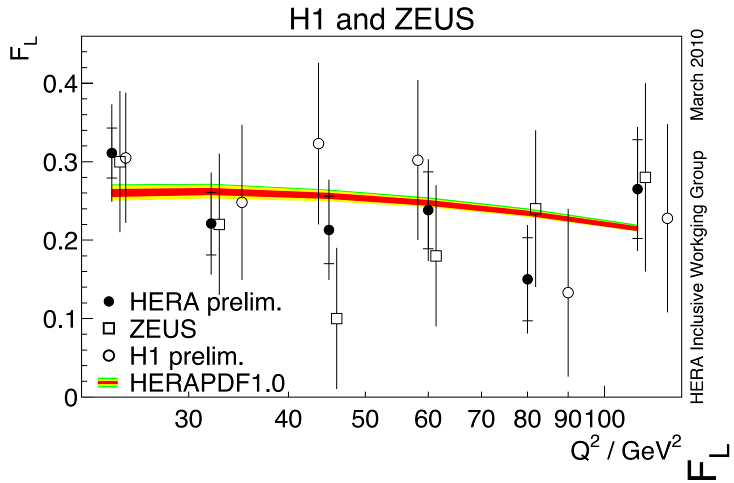
in QCD:

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



→ improved determination procedure takes into account correlation of systematic errors

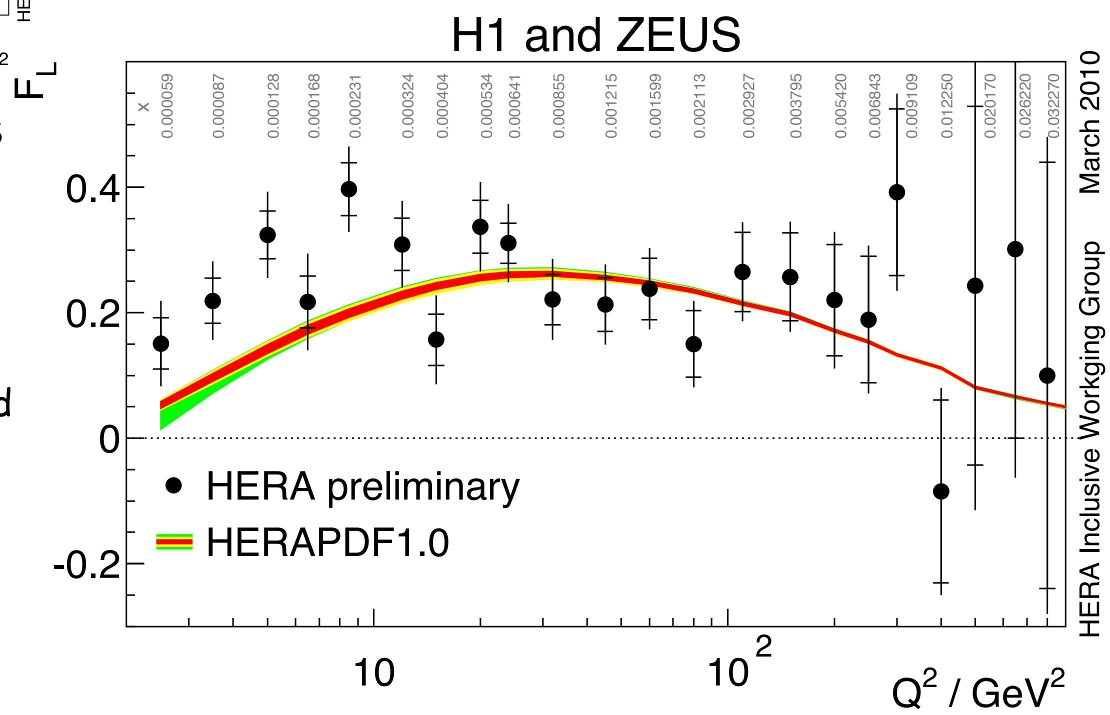
Combination of the H1 and ZEUS F_L data



Good agreement between H1 and ZEUS

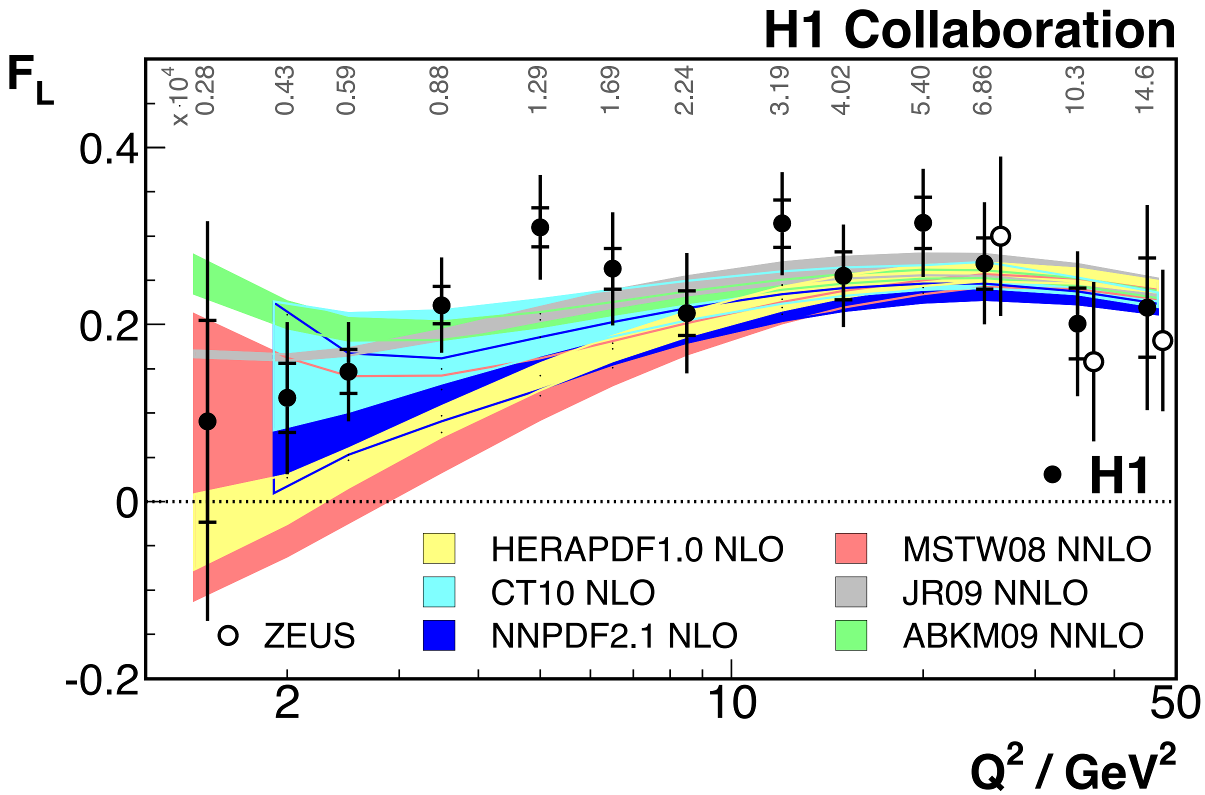
To obtain combined F_L from H1 and ZEUS, the NC cross section data at different proton beam energies (E_p = 460, 575, 920 GeV) were combined

The combined HERA F_L is measured in the region $2.5 \leq Q^2 \leq 800$ GeV^2



F_L measurements at HERA and QCD predictions

Using backward silicon tracker (BST) H1 extended F_L measurements down to $Q^2 \geq 1.5$ GeV^2

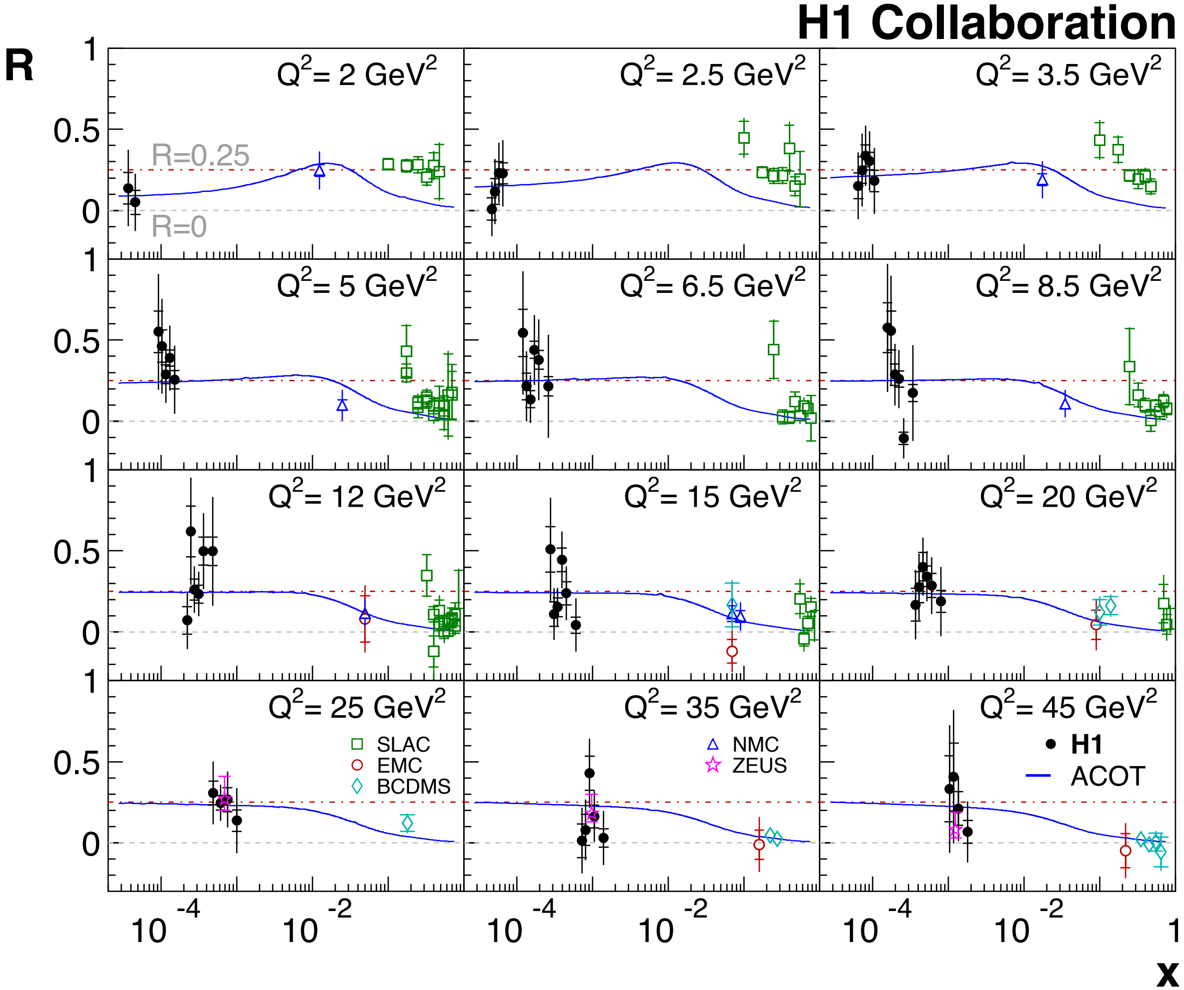


EPJ C71(2011)1579

- perfect description of the F_L data by QCD at $Q^2 \geq 10$ GeV^2
- large spread/uncertainty of the QCD predictions at low Q^2

→ *F_L data are a valuable input to the QCD fits*

The Ratio $R = F_L / (F_2 - F_L)$



HERA F_L data are consistent with constant value of R = 0.26 ± 0.05

Summary

- Combination of the H1 and ZEUS inclusive NC and CC $e^{\pm}p$ data
  - *HERA I: all inclusive results are published and combined using a model independent approach leading to significant reduction of systematic uncertainties*
  - *HERA I+II: extension of the combination to include HERA II data leads to improved precision at high Q^2 and high x*

→ *the combined data sets have small errors (down to ~1%) and used to make HERAPDF fits (HERAPDF1.0, HERAPDF1.5, …) with inclusive HERA data alone and including jets and charm data*

- The low proton beam energy data are used to measure the longitudinal structure function F_L
  - *combination of the H1 and ZEUS F_L data for* $2.5 \leq Q^2 \leq 800$ GeV^2
  - *H1 extended the F_L measurement down to $Q^2 \geq 1.5$ GeV^2*

→ *HERA data are consistent with $R = F_L /(F_2-F_L) = 0.26$ +- 0.05*

The European Physical Journal

volume 71 · number 3 · march · 2011

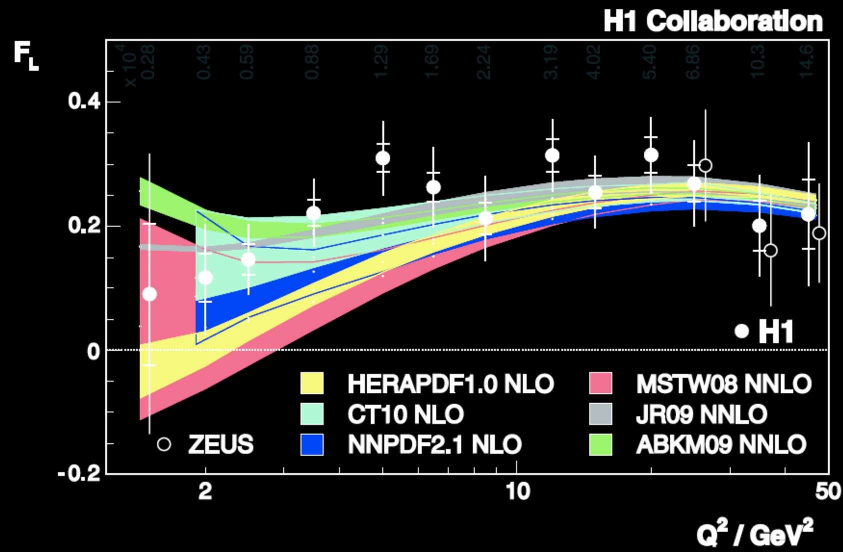
EPJ C

Recognized by European Physical Society

Particles and Fields

The European Physical Journal C

volume 71 · number 3 · march · 2011



An improved determination and extended measurement range of the proton structure function F_L—shown as a function of Q^2 and the corresponding average x values—and comparison with relevant theoretical calculations. From the H1 Collaboration: Measurement of the inclusive $e^{\pm}p$ scattering cross section at high inelasticity y and of the structure function F_L

Società Italiana di Fisica

Springer