Structure functions and electroweak studies at HERA

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(On behalf of H1 and ZEUS collaborations)

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Content

- Introduction to HERA
- Deep Inelastic Scattering
- Structure functions
- Electroweak studies
- Polarised physics
- Summary and outlook

H1 and ZEUS at HERA

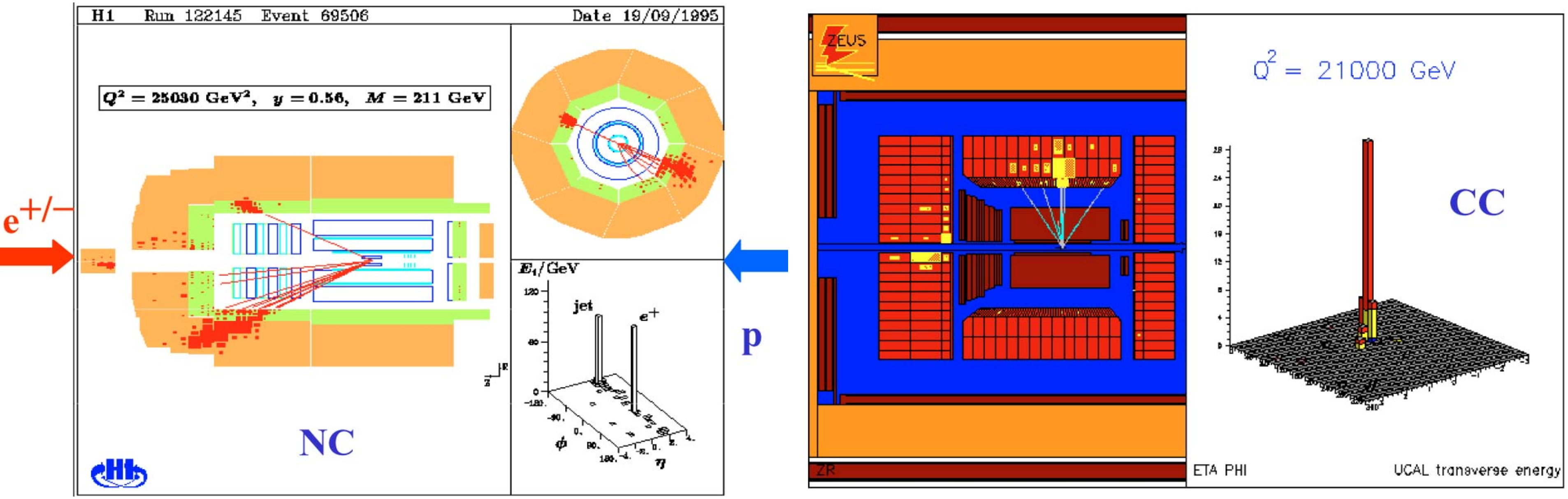
- HERA collider at DESY, Hamburg
- *ep* accelerator ring, 27.5 x 920 GeV, $\sqrt{s_{ep}} = 319$ GeV
- circumference: 6.3km
- 4 experimental halls, 2 collider experiments:

H1

ZEUS

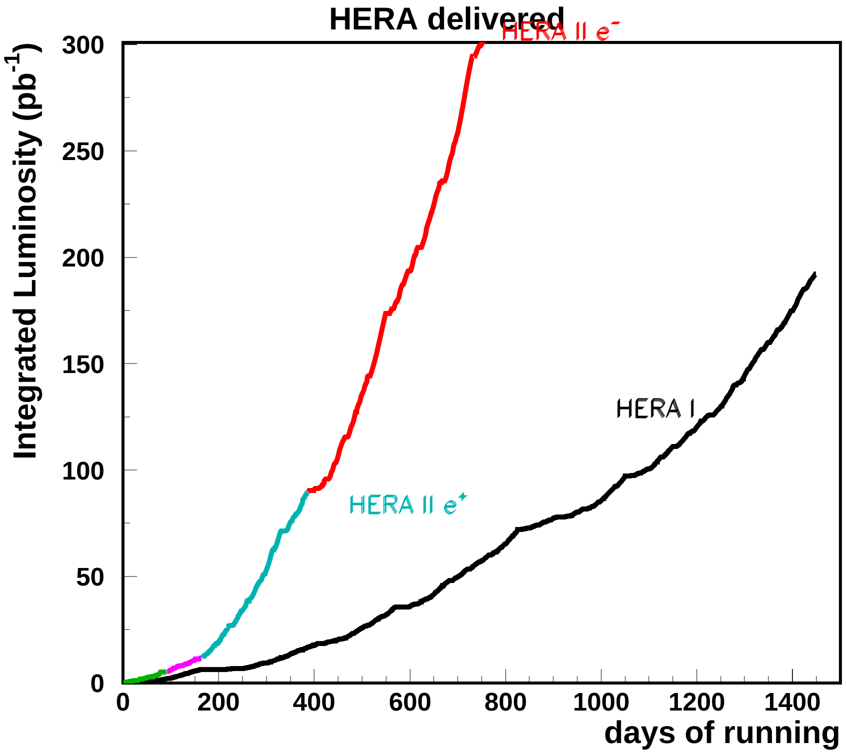
H1 and ZEUS experiments

- Nearly 4π detector coverage
- Delivering data since 1992
- HERA 2: higher luminosity since 2004

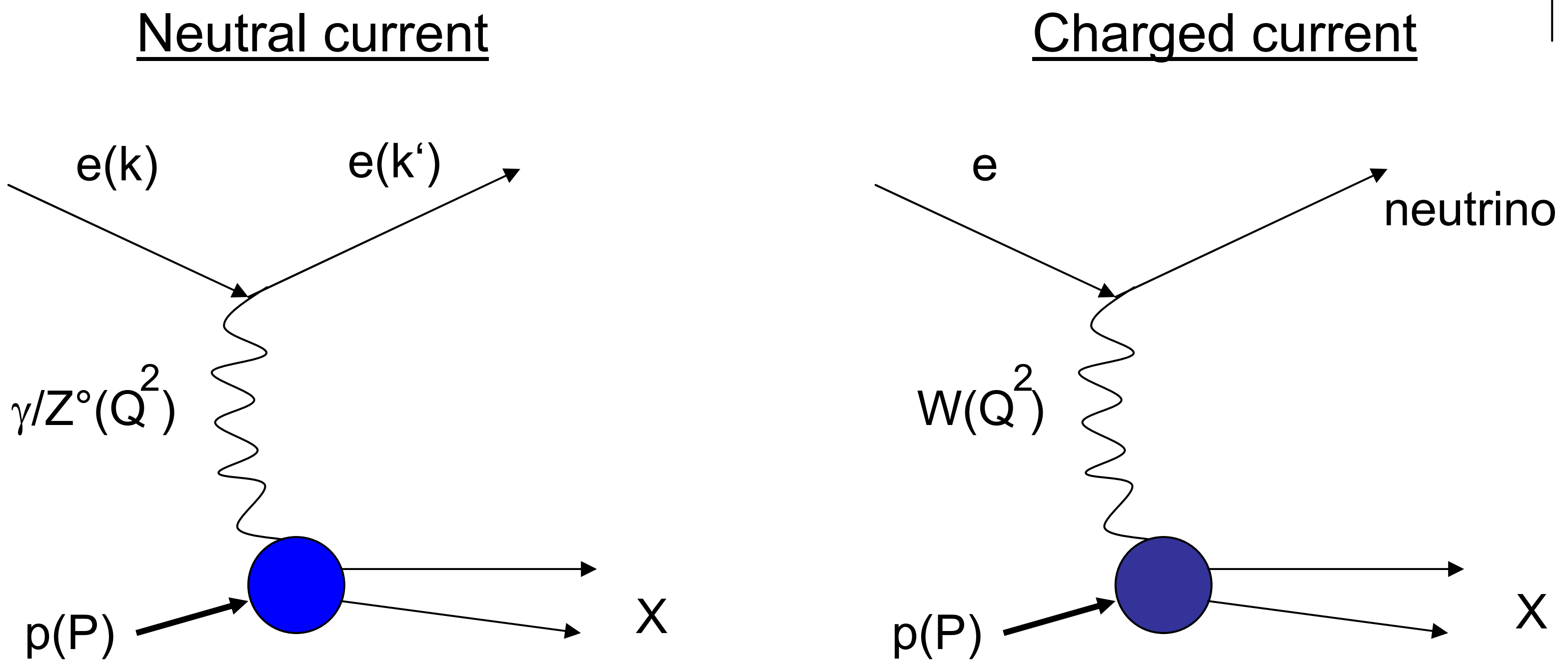


HERA luminosity and status

- Luminosity upgrade: mid 2000 – end 2001
- Longitudinal polarisation of *e*-beam for HERA 2
- Improvement in machine performance



Inclusive Deep Inelastic Scattering at HERA



$Q^2 = -(k-k')^2$ - four momentum transfer squared in the reaction

$x = \dfrac{Q^2}{2P(k-k')}$ - fraction of the proton momentum carried by the parton

$y = Q^2/sx$ - fraction of the lepton's energy loss,

$s = 4E_eE_p$ -center-of-mass energy squared

Cross sections and structure functions

NC Cross Section:

NC Reduced cross section: $\tilde{\sigma}_{NC}(x, Q^2)$

$$\frac{d^2\sigma_{NC}(e^\pm p)}{dx\,dQ^2} = \frac{2\pi\alpha^2}{xQ^4} Y_+ \overbrace{\left[\tilde{F}_2 - \frac{y^2}{Y_+}\tilde{F}_L \mp \frac{Y_-}{Y_+} x\tilde{F}_3\right]}$$

$$Y_\pm = 1 \pm (1-y)^2$$

Dominant contribution

Sizeable only at high y (y>~0.6)

Contribution only important at high Q^2

(from γZ interference)

CC Cross Section:

$$\frac{d^2\sigma_{CC}(e^\pm p)}{dx\,dQ^2} = \frac{G_F^2 M_W^4}{2\pi x} \frac{1}{(Q^2 + M_W^2)^2} \frac{1}{2} \underbrace{\left[Y_+ W_2^\pm - y^2 W_L^\pm \mp Y_- x W_3^\pm\right]}$$

CC Reduced cross section: $\tilde{\sigma}_{CC}(x, Q^2)$

Structure functions

- The proton structure function in QPM:

$$F_2 = \sum_i e_i^2 x[q_i(x) + \overline{q}_i(x)]$$

- sum of the (anti)quarks density distributions weighted with their electric charge squared

- Structure function F_L ~gluon density *g(x)* in NLO QCD and 0 in QPM

- $xF_3 \sim 2\sum_i e_i a_i x[q_i(x) - \overline{q}_i(x)]$ - determines the valence quark distributions $xq_v(x,Q^2)$

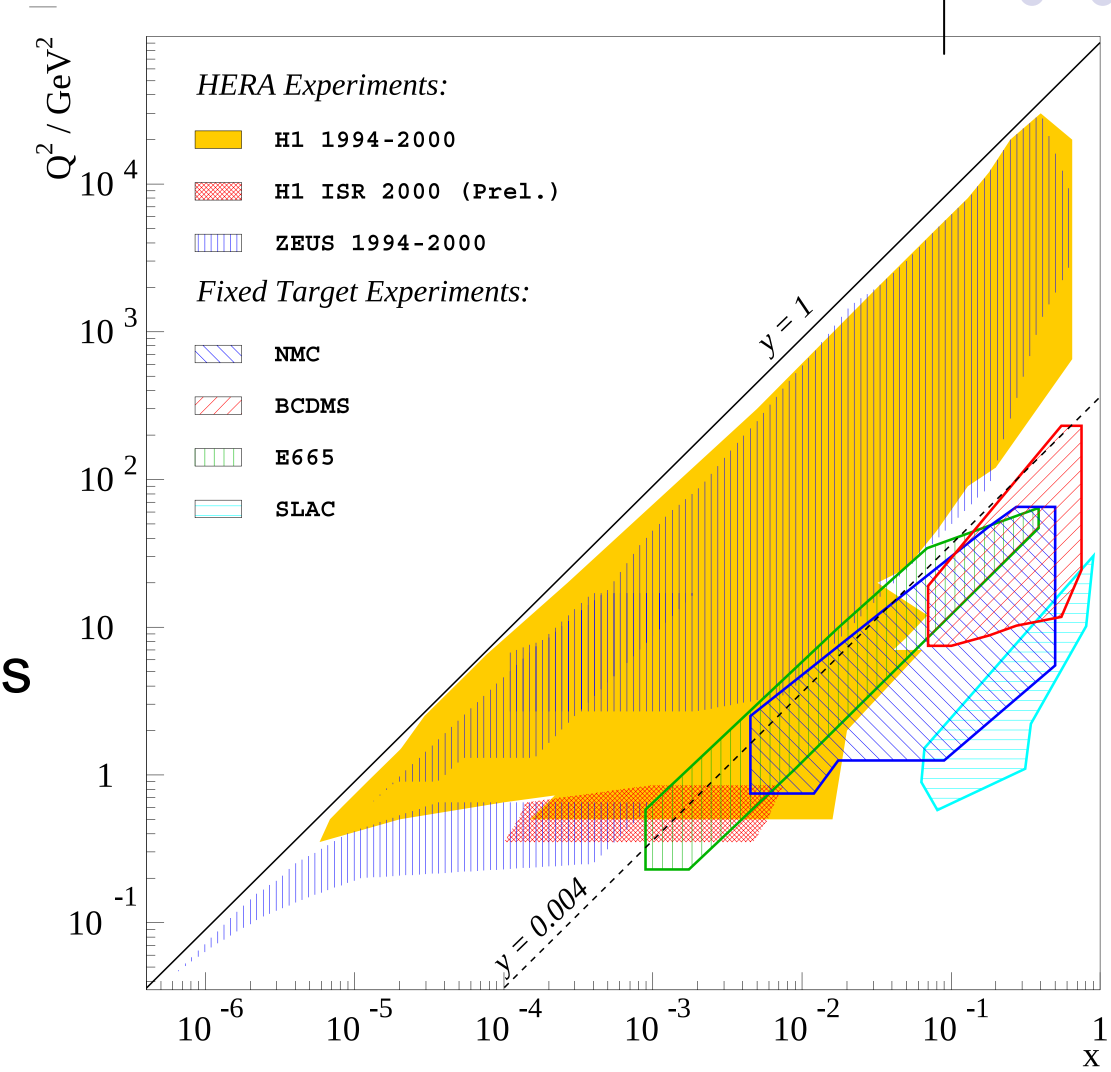
- $$\left.\begin{aligned} W_2^+ &= x(d+s+\overline{u}+\overline{c}) \\ W_2^- &= x(u+c+\overline{d}+\overline{s}) \end{aligned}\right\}$$ flavour separation at high *x*

➢ Combinations of structure functions allow to unfold PDF and check QCD as well as electroweak theory

Kinematic plane coverage

- HERA extends kinematic plane coverage to lower x and higher Q^2 by 2 orders of magnitude

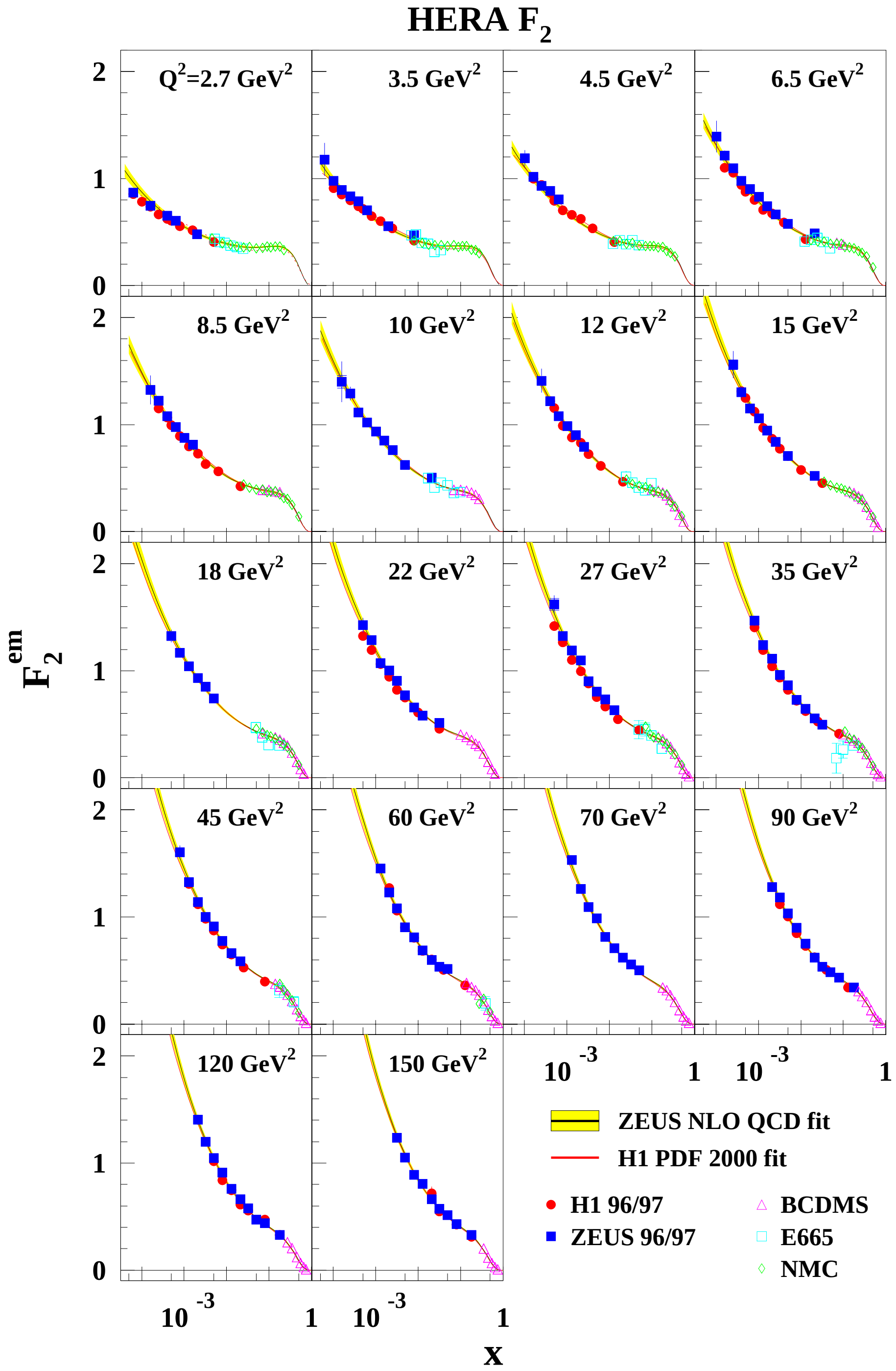
- H1 and ZEUS overlap with fixed target results in wide range of x and Q^2



Low Q^2-x physics

Structure function F_2

- Precision measuremens at low Q^2 : F_2 ~2-3%
- F_2 rises towards low x for all measured Q^2 bins
- H1 and ZEUS results are in a good agreement with fixed target data in the overlapping regions

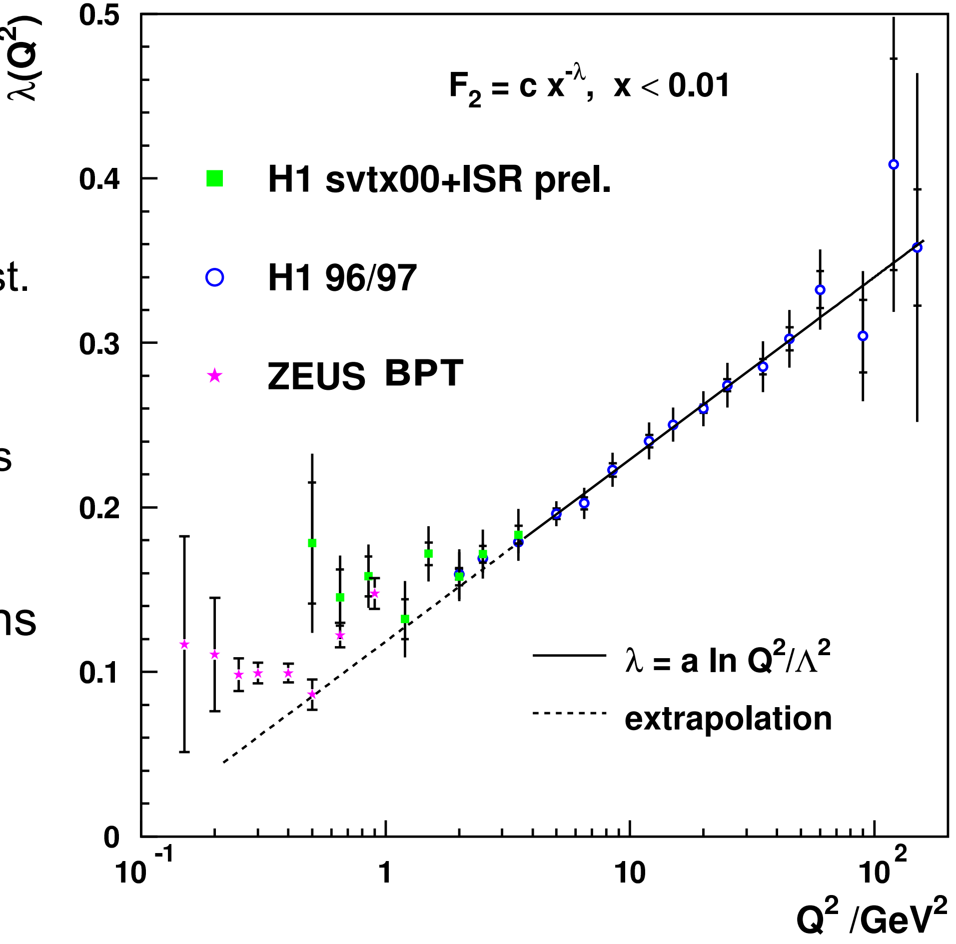


Rise of F_2 towards low x

- F_2 used to fit x-dependences in Q^2 bins for x<0.01 and W>12 GeV:

$$F_2 = c(Q^2) \cdot x^{-\lambda(Q^2)}$$

- $\lambda \sim \ln(Q^2/\Lambda^2)$ and $c(Q^2)$~const. for $Q^2 > 3.5\,\mathrm{GeV}^2$
- Around $Q^2 = 1\,\mathrm{GeV}^2$ λ deviates from log-dependence
- From soft hadronic interactions it is expected that $\lambda \to 0.08$ for $Q^2 \to 0$



F_L at low Q^2 – ‘shape’ method

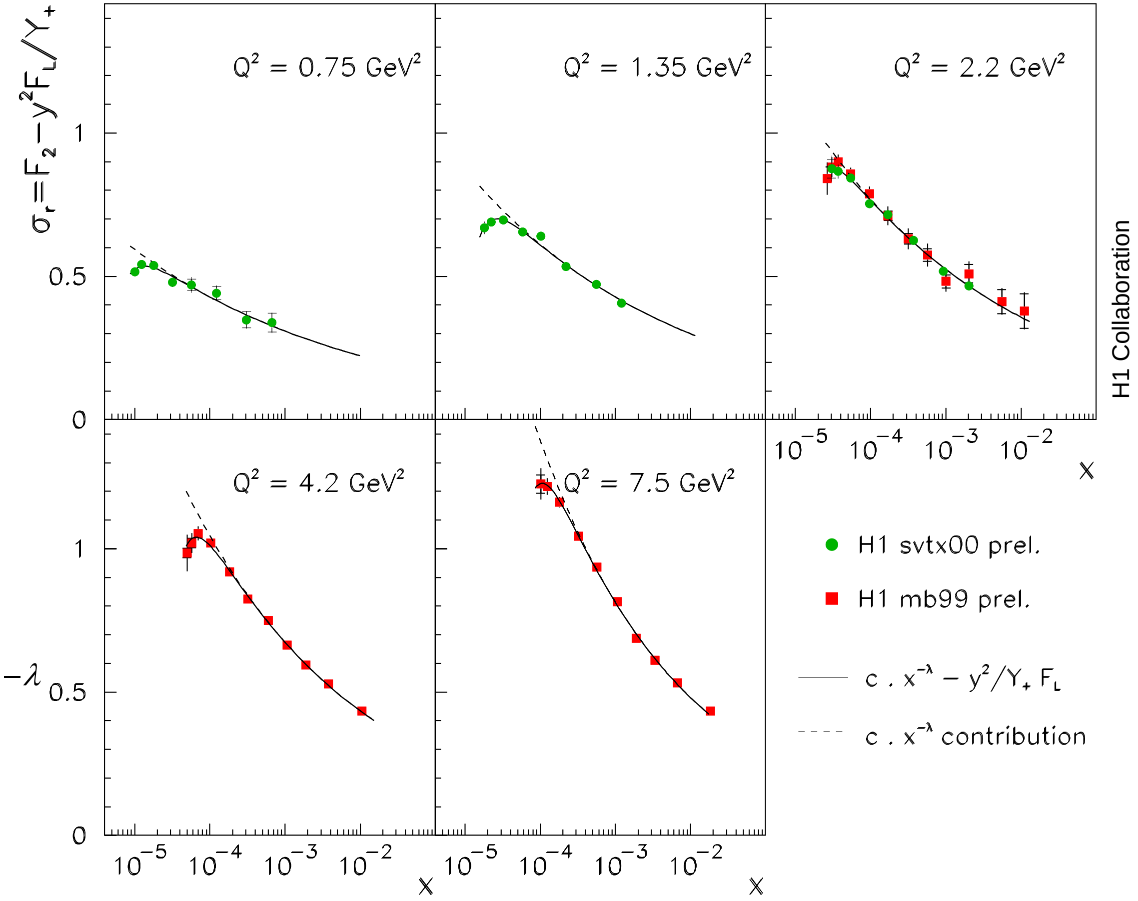
- Assume $F_2 = c \cdot x^{-\lambda}$
- Difference in the shape between σ and extrapolated F_2 vs x is driven by y^2/Y_+ mostly

↳ One F_L bin per Q^2

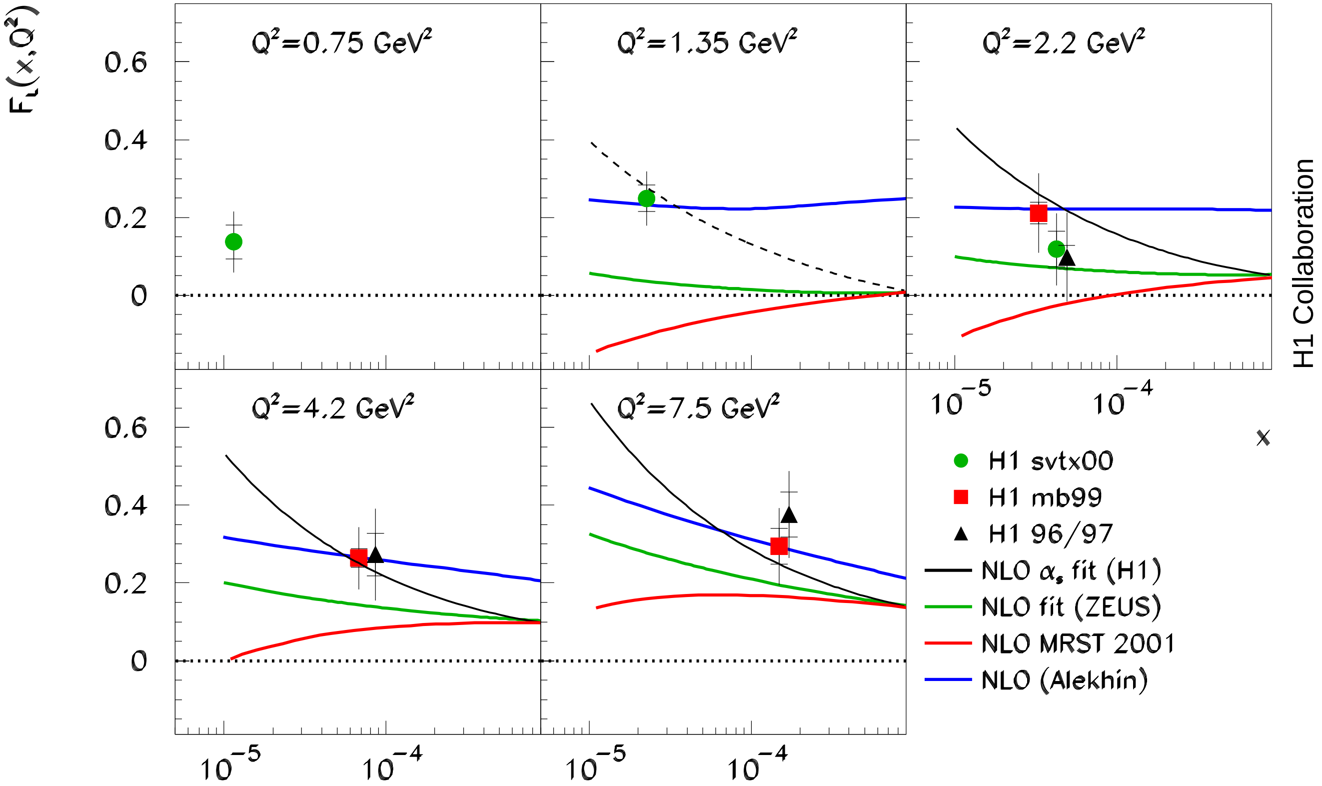
↳ Fit in Q^2 bins:

$$\sigma_{fit} = F_2 - \frac{y^2}{Y_+} F_L \ , \ F_2 = c \cdot x^{-\lambda}$$

Model dependent determination

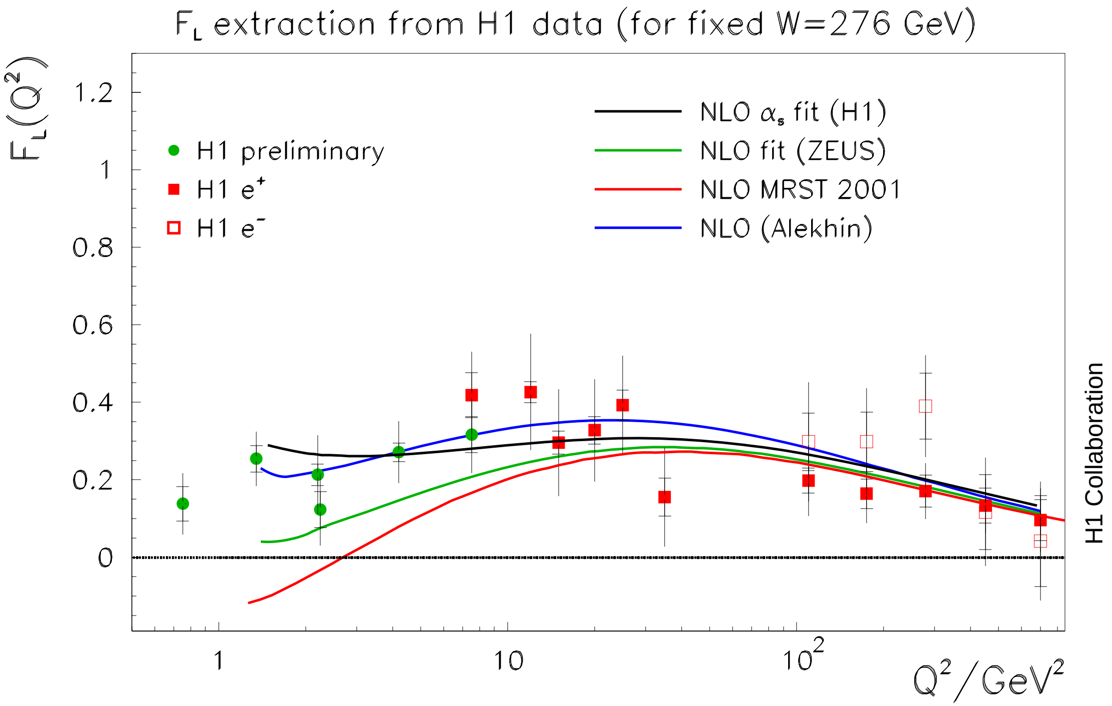


F_L extraction



- Extracted F_L is greater than 0 for all bins in Q^2

F_L extraction

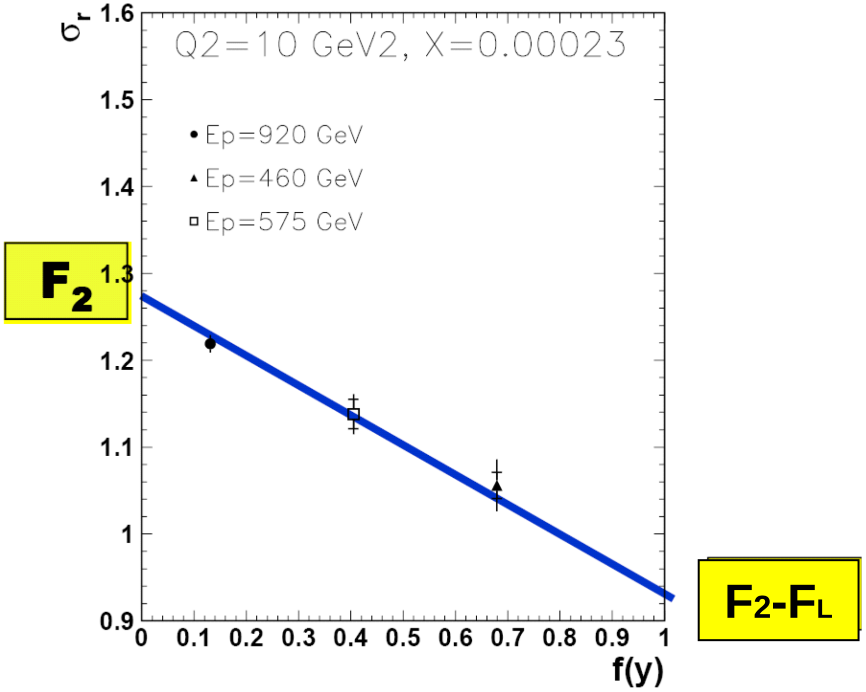


- H1 NLO QCD fit is consistent with the data for wide Q^2 range
- Alekhin fit is in agreement with the data
- MRST and ZEUS NLO fits tend to be low at low Q^2

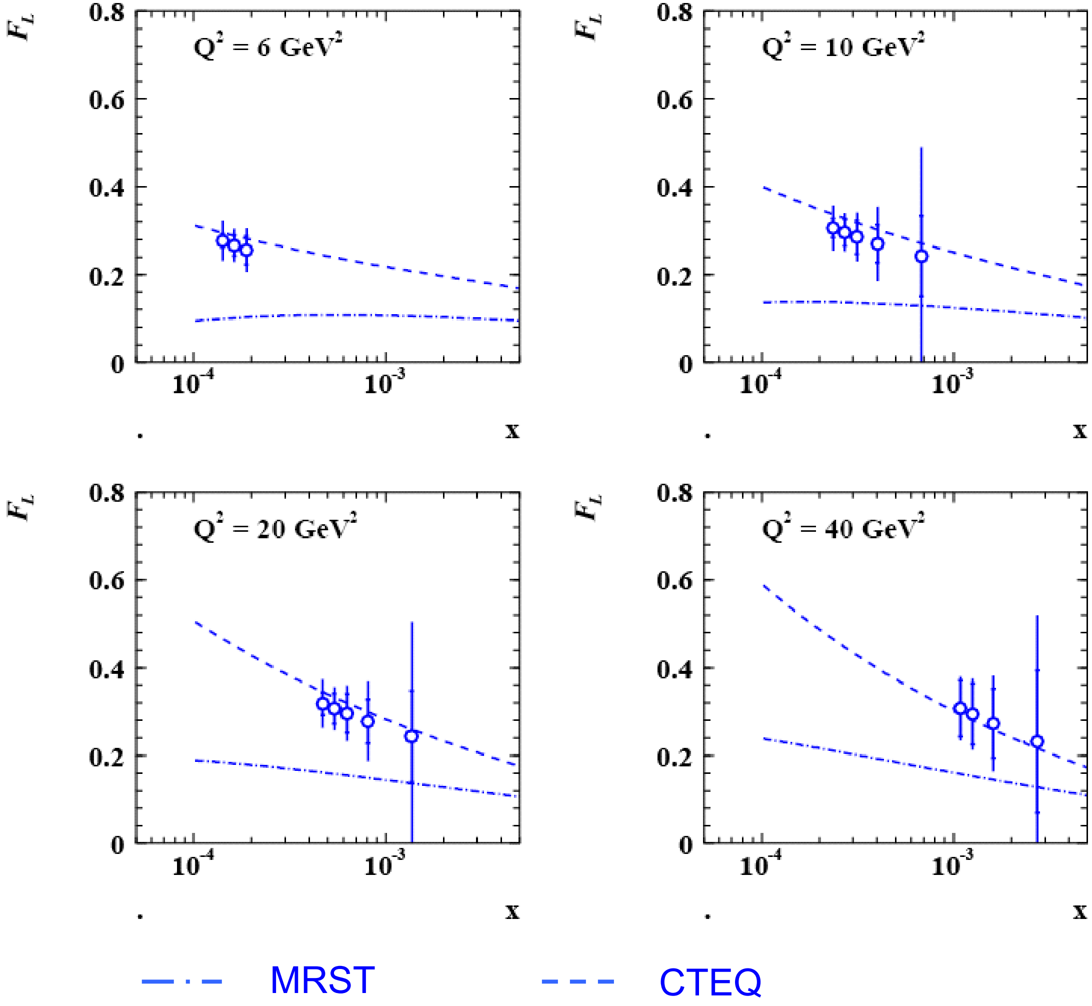
Future

- Direct measurement of F_L can be performed only by measuring cross section for the same Q^2-x but with different proton beam energies (different y):

$$\boxed{\sigma_r = F_2 - f(y)F_L}$$



Expected precision of F_L



ZEUS and H1 expressed interest to perform low energy run

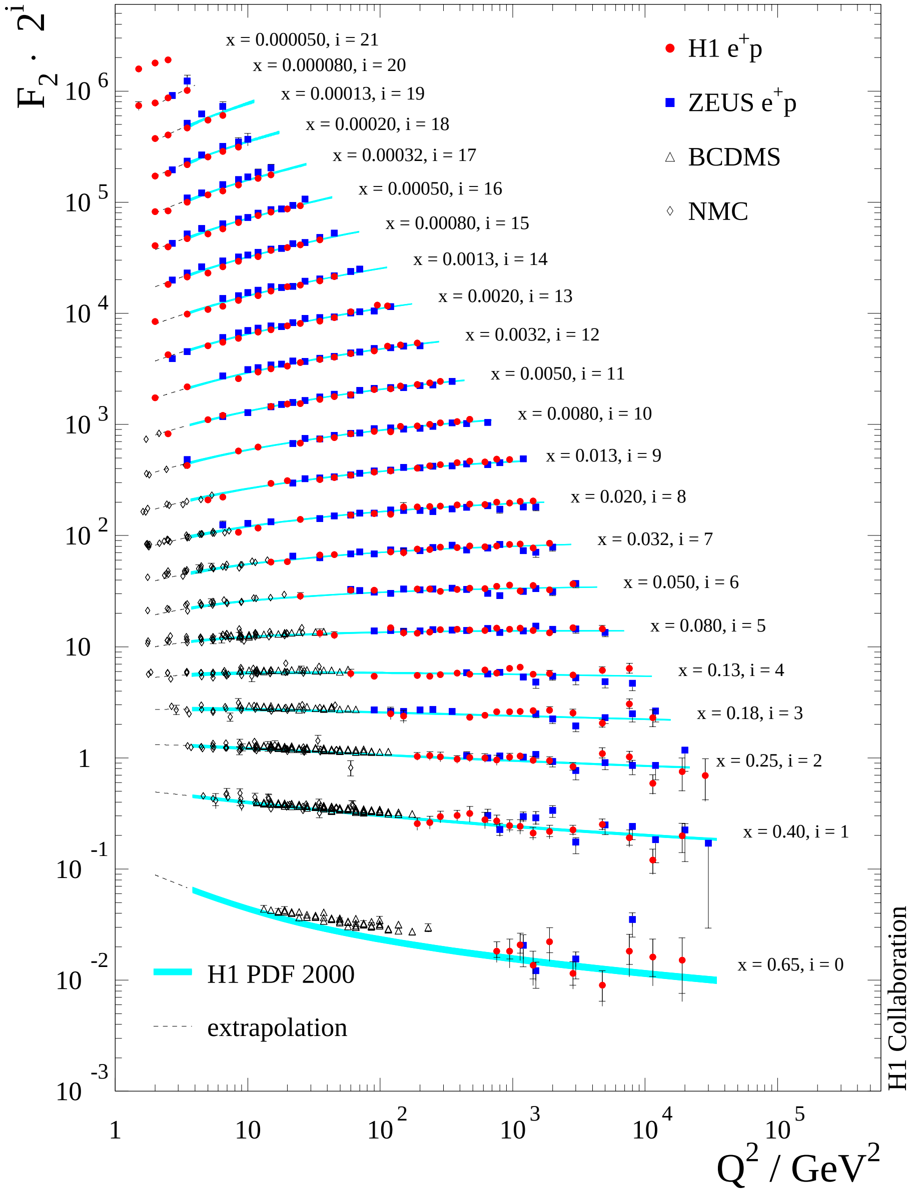
$$30\mathrm{pb}^{-1}, \mathrm{E}_\mathrm{p} = 920\mathrm{GeV}$$

$$10\mathrm{pb}^{-1}, \mathrm{E}_\mathrm{p} = 460\mathrm{GeV}$$

NC and CC unpolarised cross sections, high Q^2

F_2 measurements

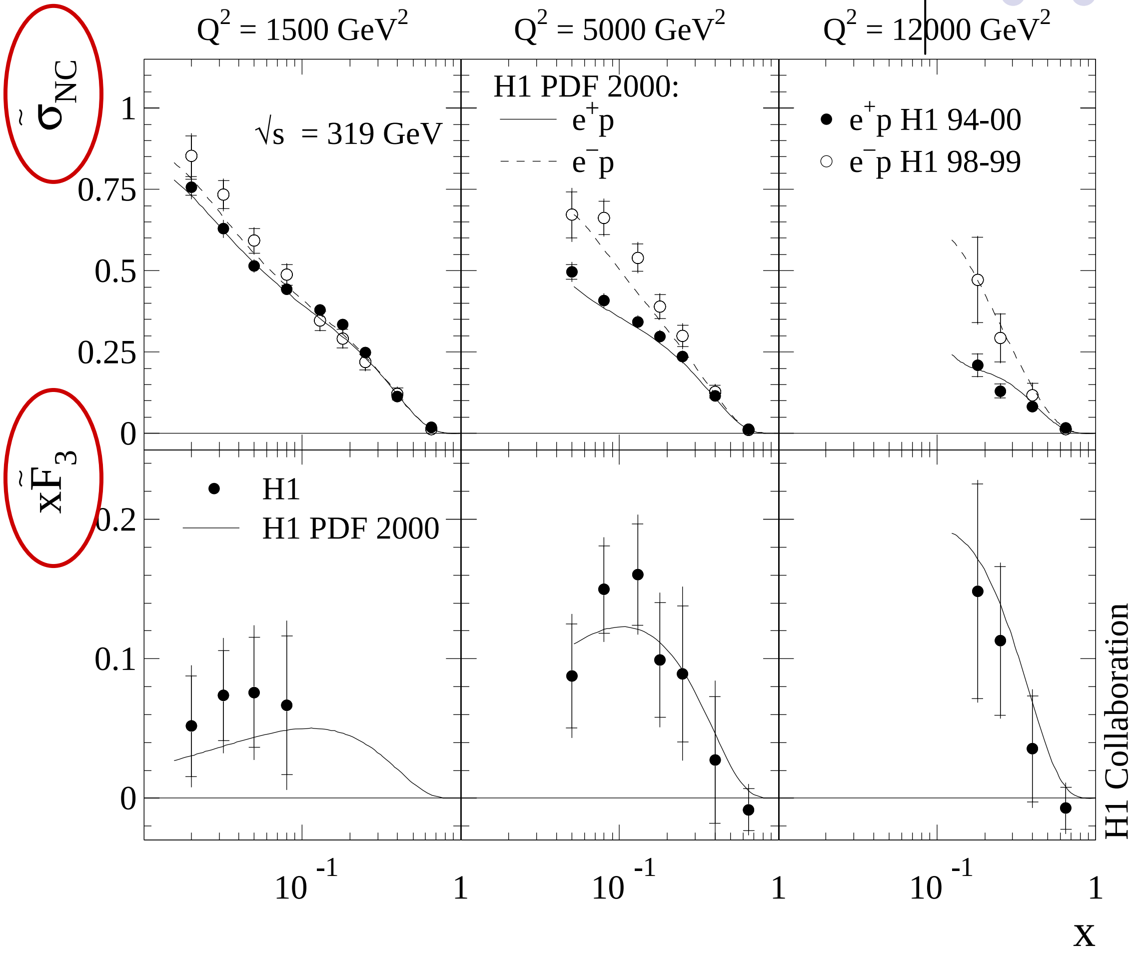
- F_2 across the whole kinematic plane
- Extend low Q^2 measurements consistent with them
- Negative scaling violation for x>0.18: running of α_s
- Positive scaling violation for x<0.1: effect of high gluon density
- Scaling violations are well described over 4 orders of magnitude in x and Q^2 by QCD fit



NC cross section and *xF₃*

- At high Q^2 the NC cross sections in e^+p and e^-p scattering are different

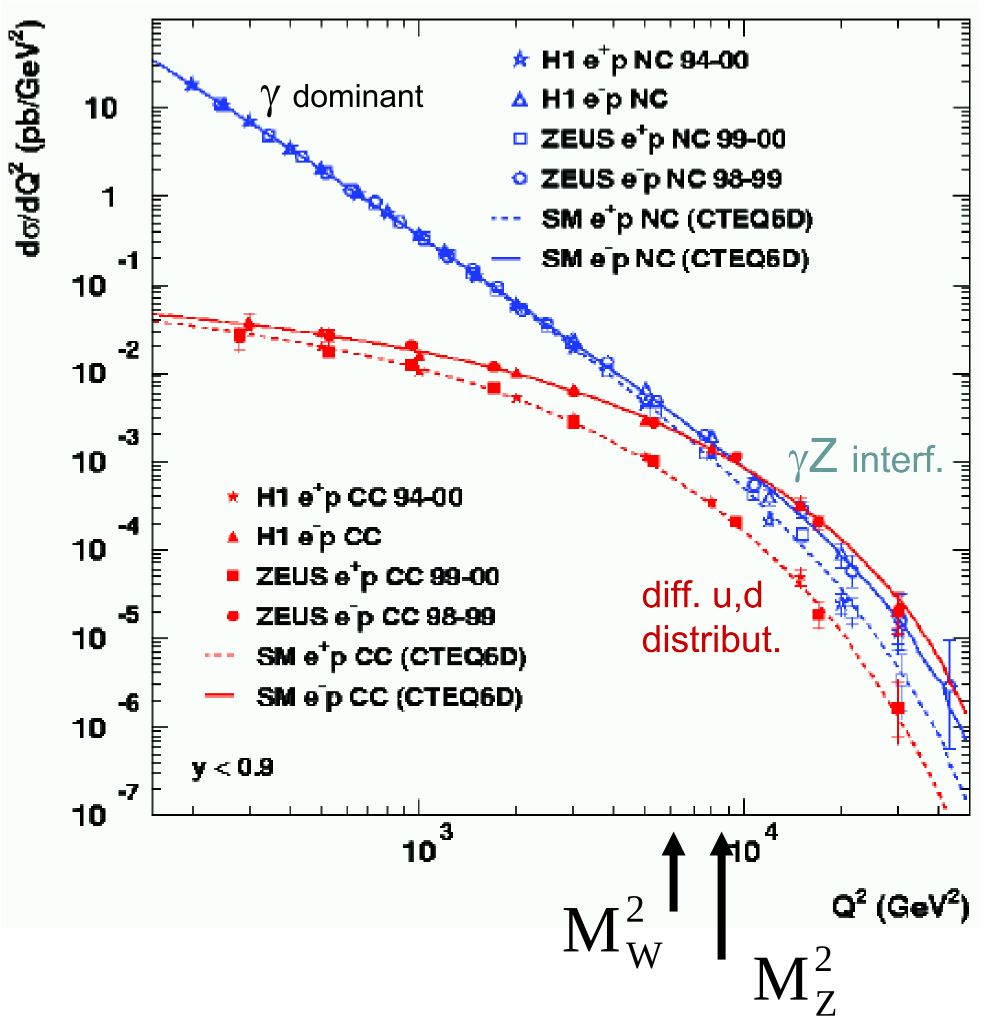
- The results of measured cross sections and structure function xF_3 are comparable with corresponding SM expectations (γZ interference)



$$x\tilde{F}_3 \sim \frac{1}{2Y_-}[\tilde{\sigma}^-_{NC} - \tilde{\sigma}^+_{NC}]$$

CC and NC cross section measurements

- Unification of EM and weak interactions in DIS for $Q^2 > M_W^2$
- NC cross section exceeds CC cross section at low Q^2
- Agreement between H1, ZEUS and QCD fit over seven orders of magnitude in cross section

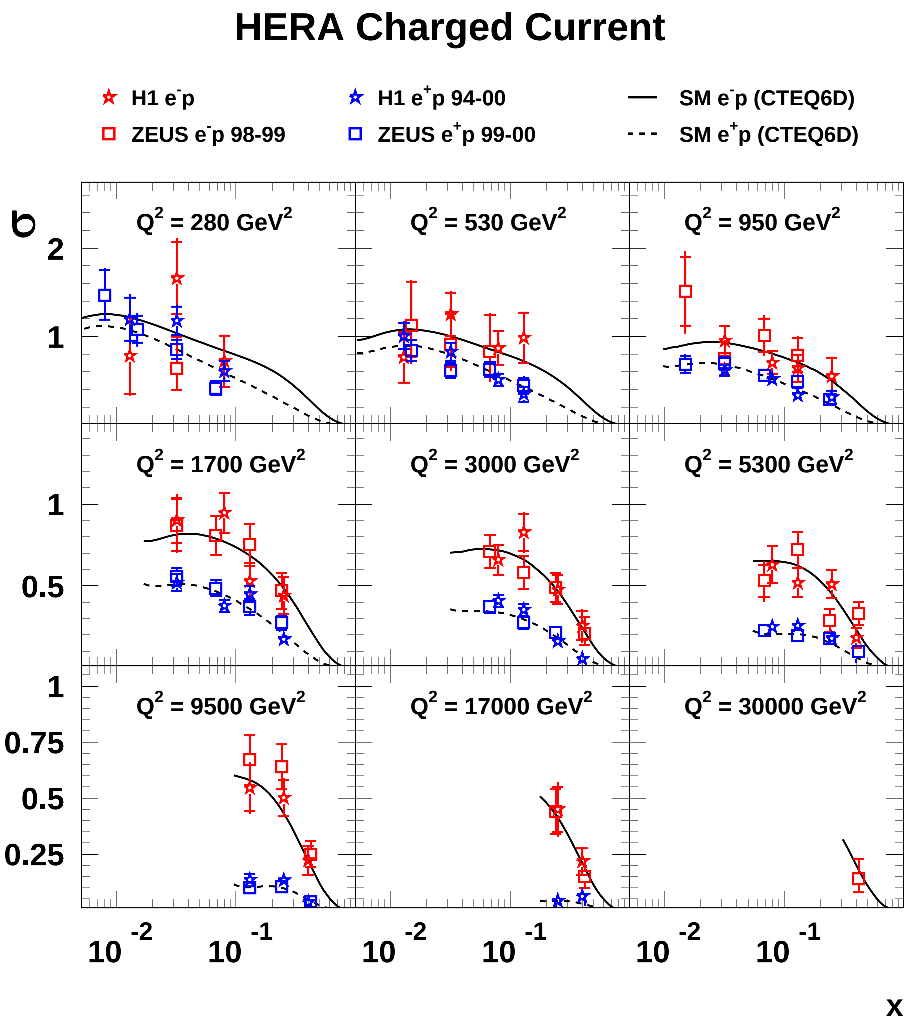


CC cross section

- CC e^+p e^-p allow to disantangle contributions of *u* and *d* quarks:

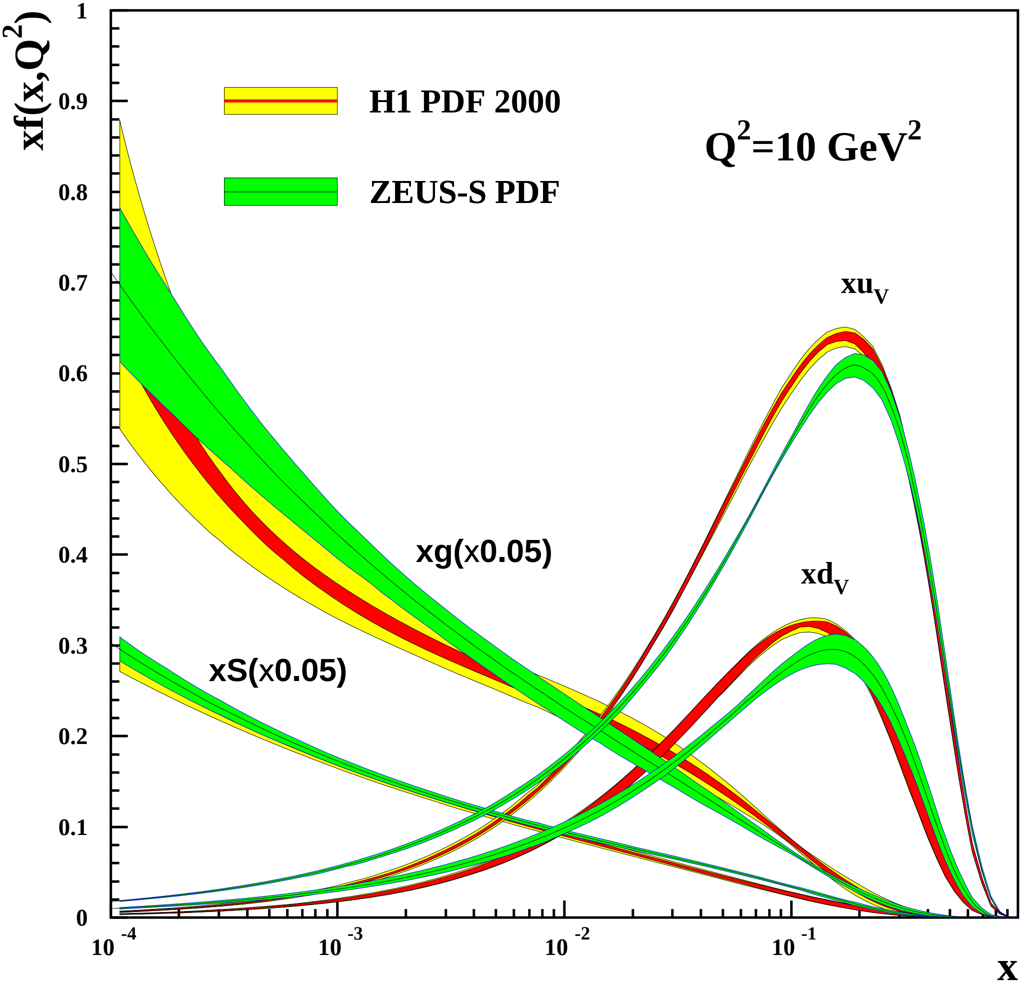
$$\tilde{\sigma}^{+}_{CC} \sim \bar{u}+\bar{c}+(1-y)^2(d+s)$$

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



- e^+p most sensitive to $d(x,Q^2)$
- e^-p most sensitive to $u(x,Q^2)$
- e^+p valence quarks suppressed by factor $(1-y)^2$

Parton density functions (PDFs)



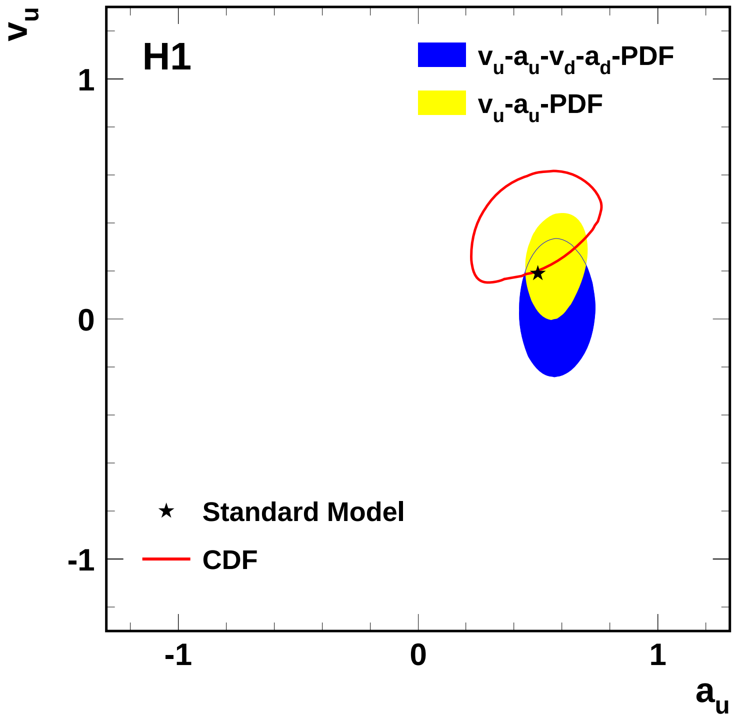
- Cross section measurements in *ep* interactions at HERA allow PDF fits
- H1 and ZEUS PDFs are in reasonable agreement though there are differences in the shape of xg

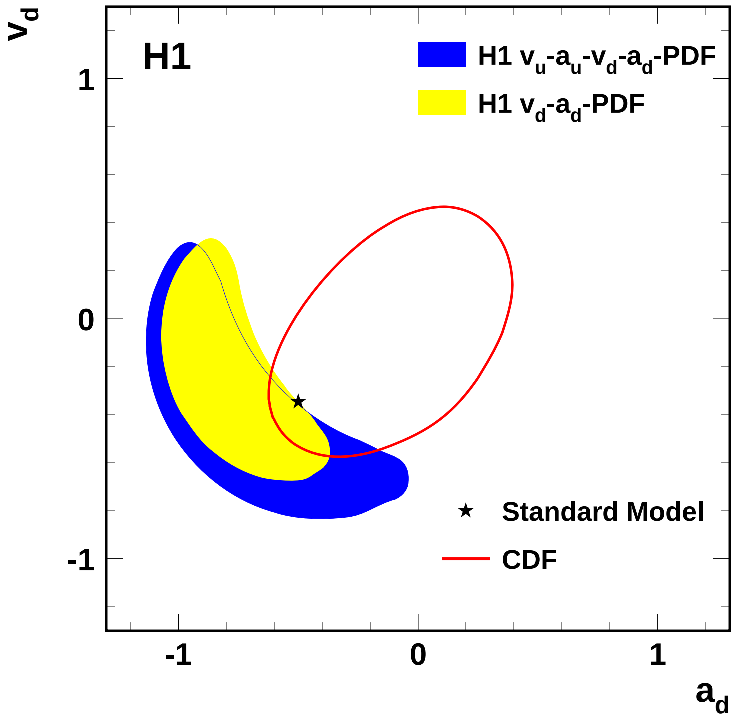
- Sea and gluon distributions are divided by a factor of 20

Electroweak physics

- Derived from NC DIS (high Q^2 and high x)
- Combined fit to determine PDFs and Z couplings to u and d quarks

- First HERA results on EW parameters
- Result consistent with SM, comparative with determination at Tevatron





Polarised physics at HERA II

Polarised CC cross section

- Linear dependence of CC cross section on polarisation:

$$\frac{d^2\sigma_{CC}(e^{\pm}p)}{dx\,dQ^2} = \frac{G_F^2 M_W^4}{2\pi x}\frac{\boxed{1\pm P_e}}{(Q^2+M_W^2)^2}\tilde{\sigma}^{\pm}{}_{CC}(x,Q^2)$$

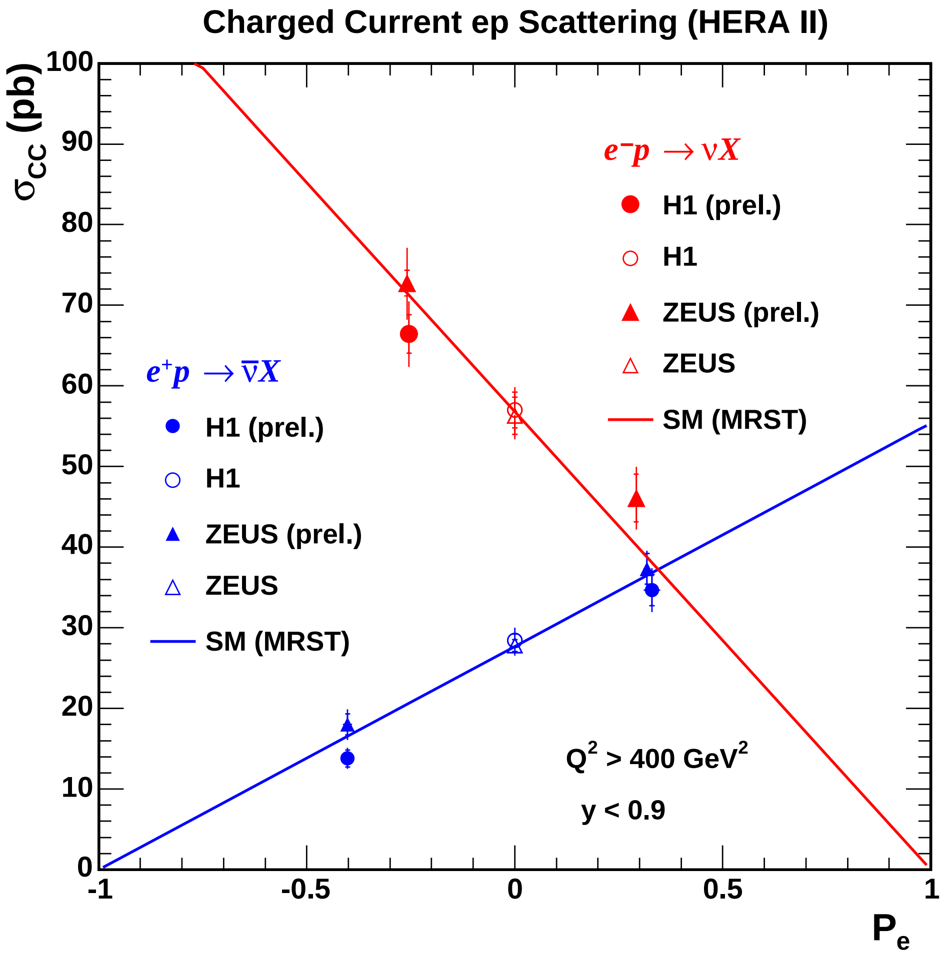
- The degree of longitudinal polarisation:

$$P_e = (N_R - N_L)/(N_R + N_L)$$

N_R(N_L) – number of right(left) handed polarised leptons in the beam

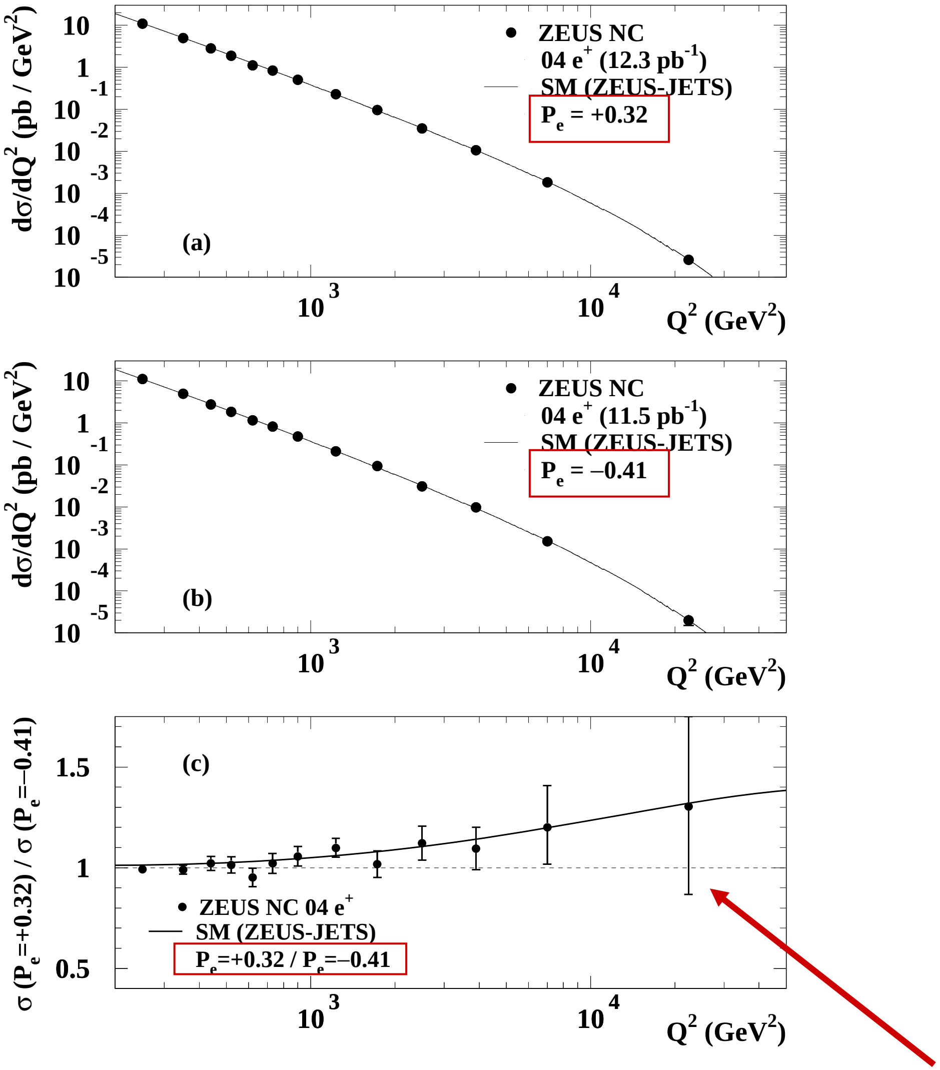
➢ Vanishing cross section for e^-_{RH} and e^+_{LH}

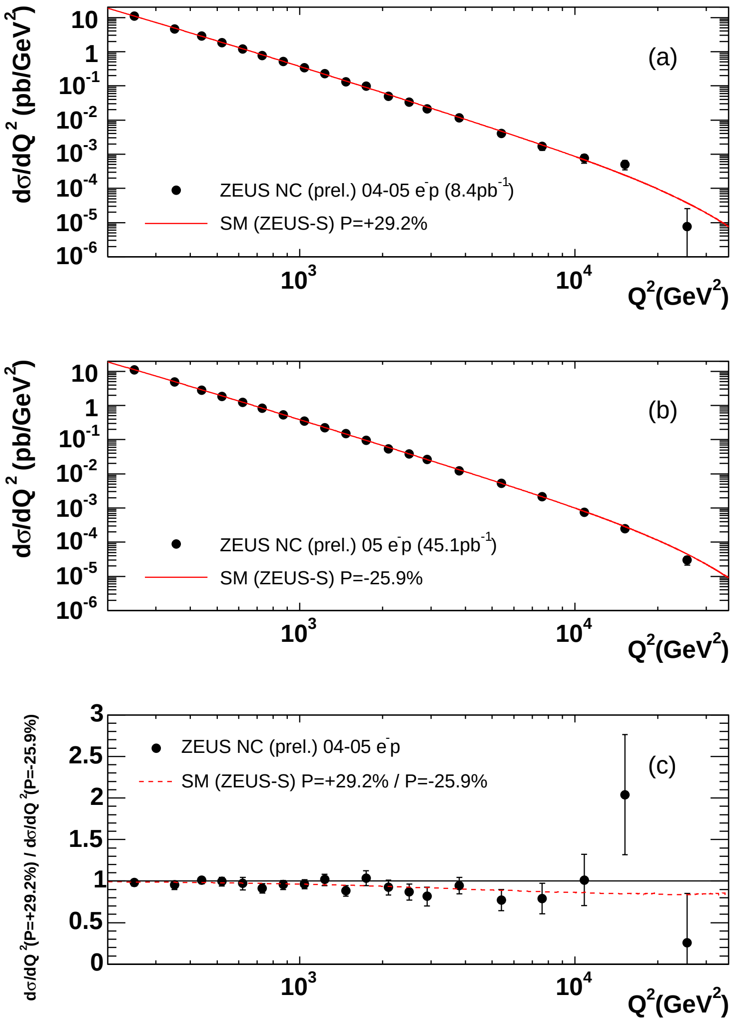
CC total cross section



- Data exhibit linear dependence with P_e and are compatible with vanishing cross sections for left(right)-handed positrons(electrons)
- Measurements of CC cross section at HERA1 and HERA2 consistent with Standard Model

Polarised NC cross section





- Above $Q^2 > 1000 GeV^2$ ratio of $\sigma(P_e = +0.32)/\sigma(P_e = -0.41)$ is above 1.
  Well consistent with SM prediction

Conclusions

- HERA continues to deliver many interesting results
- Precision of ~2−3 % achieved for F_2
- H1 and ZEUS want to measure F_L at low E_P
- The electroweak results provide consistency check of SM
- The measured NC and CC cross sections (also for longitudinally polarised lepton beam) are consistent with the Standard Model