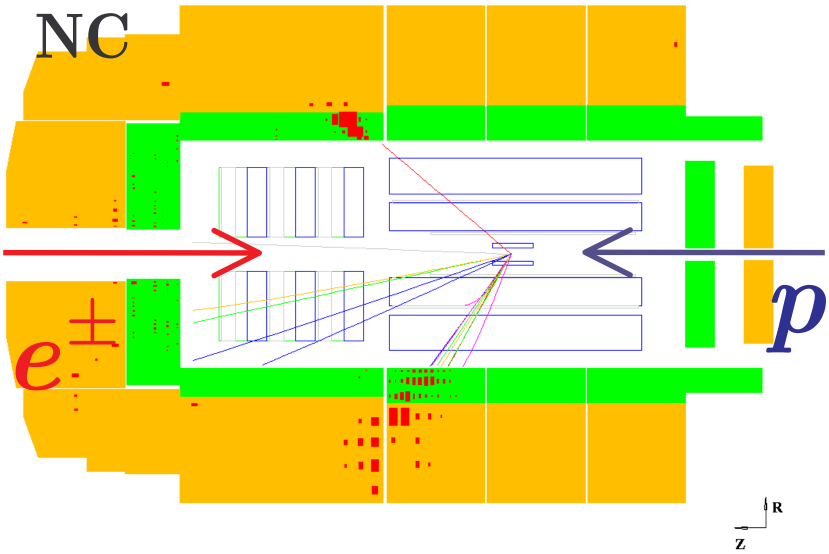
NC & CC Cross Sections and F_2, F_L and xF_3 Structure Functions

Ana Dubak
MPI for Physics Munich
on behalf of the
H1 Collaboration

- H1 detector
- e^+p NC & CC
  - Cross sections
  - Proton structure function F_2
  - Longitudinal structure function F_L
  - Structure functions $x\tilde{F}_3$, $xF_3^{\gamma Z}$
- Summary

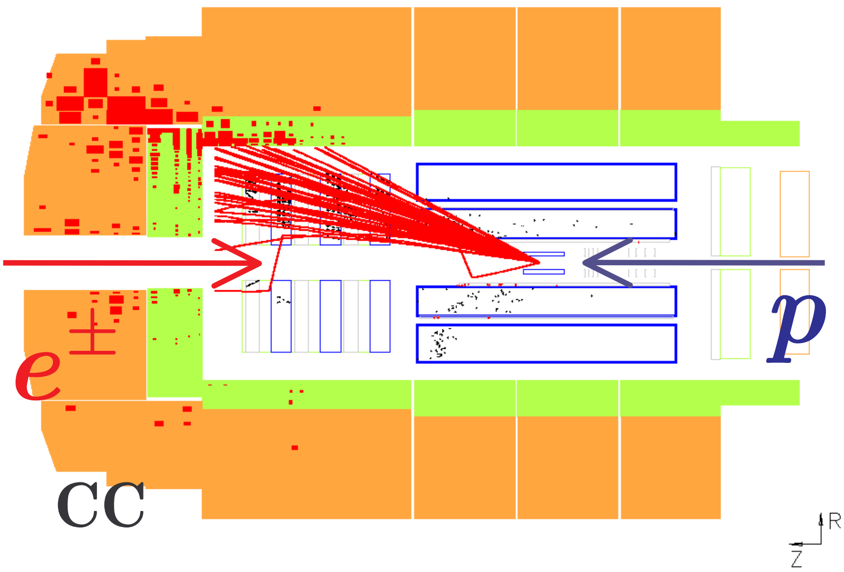
The H1 Detector

NC



$Q^2 = 10100\ \mathrm{GeV}^2$
$x = 0.177$
$y = 0.565$

$E'_e = 103\ \mathrm{GeV}$
$\theta_e = 39.2°$



CC

$Q^2 = 22500\ \mathrm{GeV}^2$

$P_T = 127\ \mathrm{GeV}$

LAr calorimeter:
High granularity 45000 cells

$$\frac{\sigma(E)}{E} : \frac{12\%}{\sqrt{E/\mathrm{GeV}}} \quad \text{LAr - EM}$$

$$\frac{50\%}{\sqrt{E/\mathrm{GeV}}} \quad \text{LAr - HAD}$$

$\sigma_{\theta_{e'}}$: 1 - 3 mrad

Systematic Uncertainties

- **common for NC & CC**
  - hadronic energy measurement $1.4 - 2\%$
  - noise subtraction in the LAr calorimeter: $\lesssim 10\%$
  - γp background estimated by MC: $\lesssim 1\%$
- **NC**
  - trigger efficiency $0.3 - 2\%$
  - electron identification efficiency $0.5 - 2\%$
  - electron energy measurement $0.7 - 3\%$
  - electron polar angle $1 - 3$ mrad
  - QED radiative corrections 1%
- **CC**
  - trigger efficiency $2 - 6\%$
  - due to cut against γp background: $< 7\%$
  - QED radiative corrections 3%

Overall systematic uncertainty of the cross section:

NC 3%, CC 6%

H1 Data Sets from HERA-I

H1 Luminosity:

e^+p **(99-00)** $\sqrt{s} = 319$ **GeV :** $\mathcal{L} = 65.3$ **pb**$^{-1}$

e^-p **(98-99)** $\sqrt{s} = 319$ **GeV :** $\mathcal{L} = 16.4$ **pb**$^{-1}$

e^+p **(94-97)** $\sqrt{s} = 301$ **GeV :** $\mathcal{L} = 35.6$ **pb**$^{-1}$

NC Cross Section $ep \to e'X$

$$\frac{d^2\sigma^{\pm}_{NC}}{dx\,dQ^2} = \frac{2\pi\alpha^2}{xQ^4}\phi^{\pm}_{NC}$$

$$\phi^{\pm}_{NC} = \left[Y_+\tilde{F}_2(x,Q^2) - y^2\tilde{F}_L(x,Q^2) \mp Y_- x\tilde{F}_3(x,Q^2)\right]$$

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

Generalised structure functions:

$$\tilde{F}_2 \equiv F_2 - v_e \frac{\kappa_w Q^2}{Q^2+M_Z^2} F_2^{\gamma Z} + (v_e^2 + a_e^2)\left(\frac{\kappa_w Q^2}{Q^2+M_Z^2}\right)^2 F_2^Z$$

$$x\tilde{F}_3 \equiv \quad - a_e \frac{\kappa_w Q^2}{Q^2+M_Z^2} xF_3^{\gamma Z} + \quad (2v_e a_e)\left(\frac{\kappa_w Q^2}{Q^2+M_Z^2}\right)^2 xF_3^Z$$

in QPM:

$$\left[F_2, \quad F_2^{\gamma Z}, \quad F_2^Z\right] = x\sum_q \left[e_q^2, \quad 2e_q v_q, \quad v_q^2 + a_q^2\right] \quad \{q + \bar{q}\}$$

$$\left[xF_3^{\gamma Z}, \quad xF_3^Z\right] = x\sum_q \quad \left[2e_q a_q, \quad v_q a_q\right] \quad \{q - \bar{q}\}$$

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

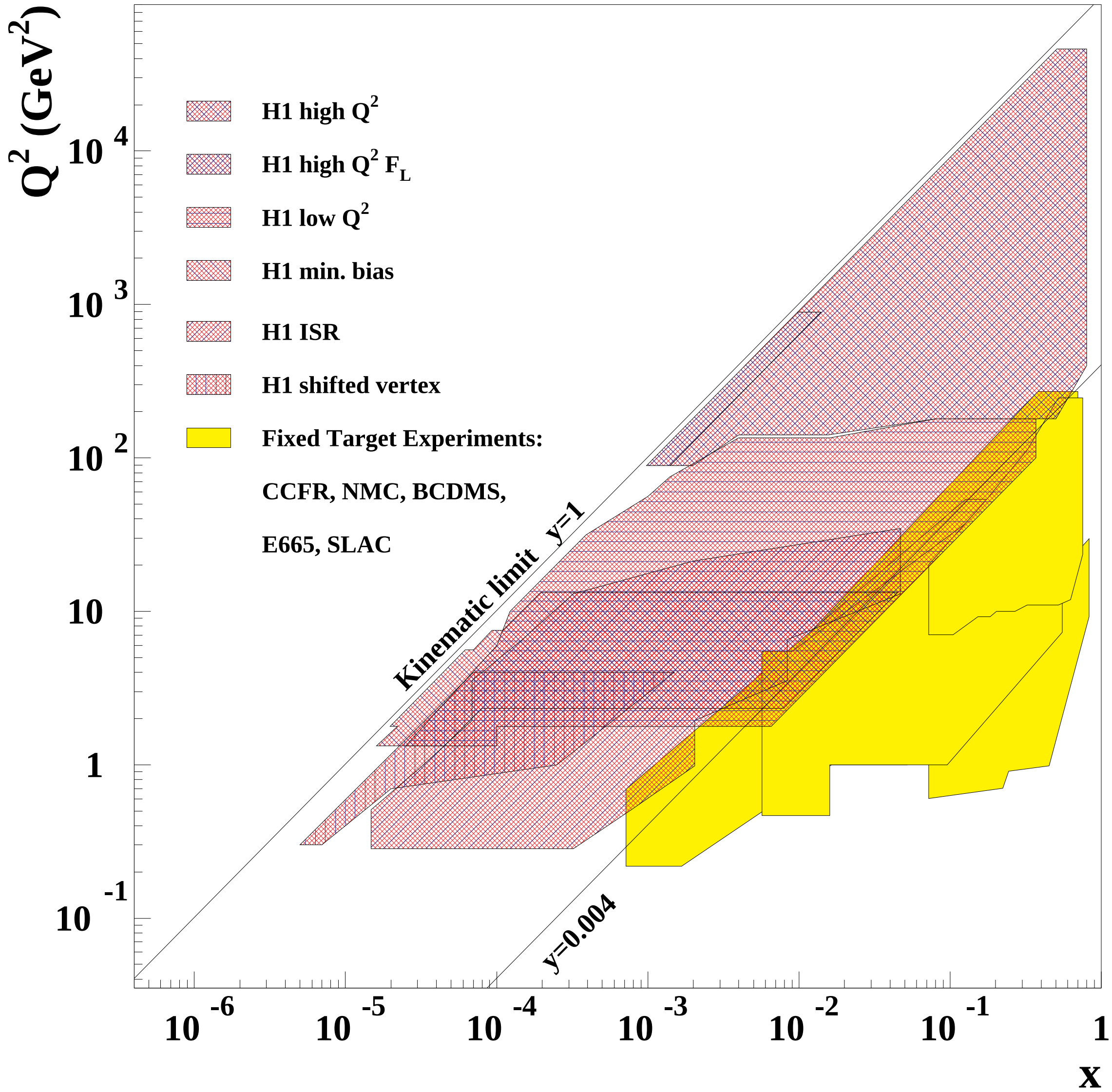
in QCD:

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

vector $v_{e,q}$ and axial $a_{e,q}$ coupling constants; $\kappa_w = \dfrac{1}{4\sin^2\theta_W \cos^2\theta_W}$

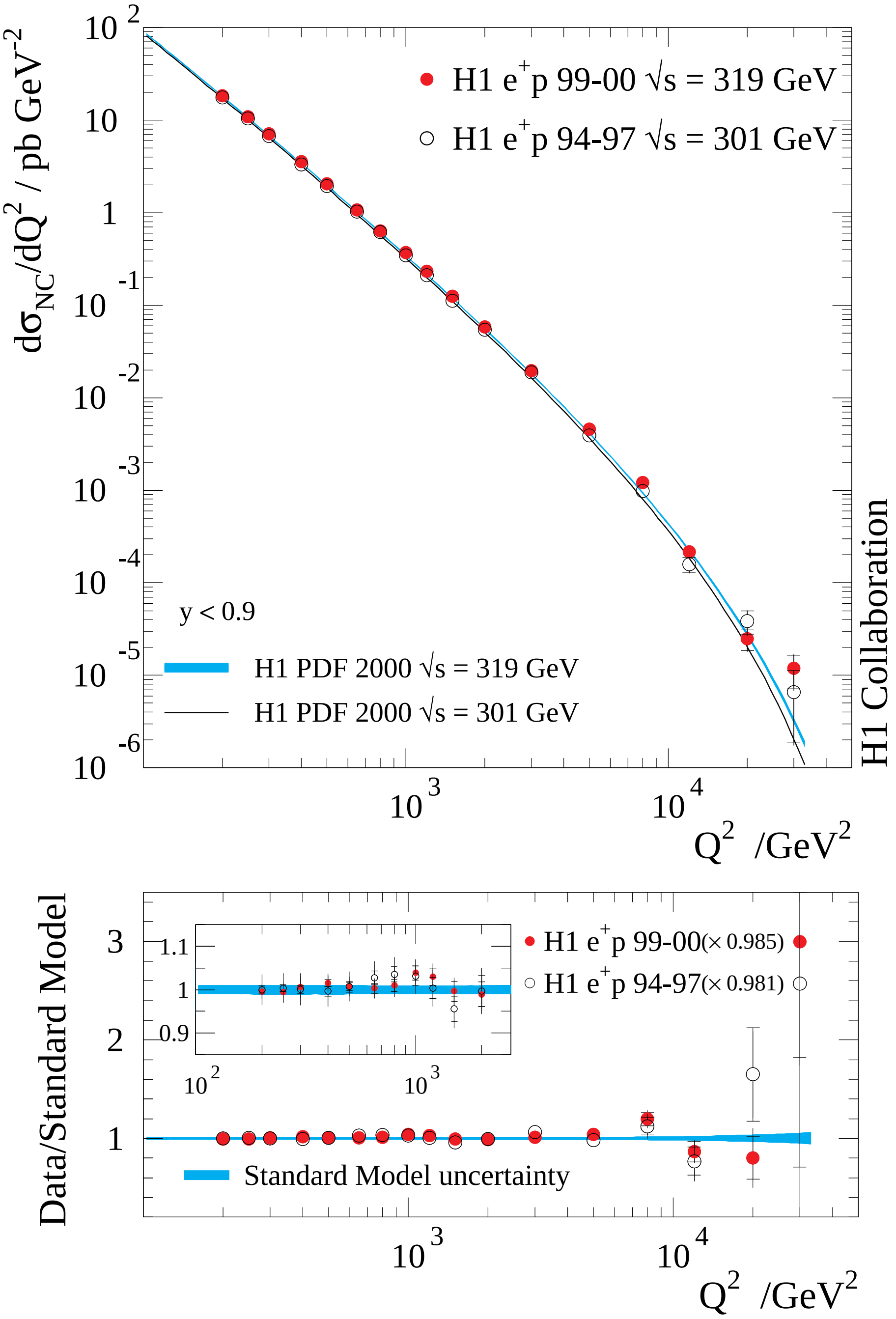
Kinematic Range

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



- $F_2 \rightarrow$ full kinematic range
- $x\tilde{F}_3 \rightarrow$ high Q^2
- $F_L \rightarrow$ high y

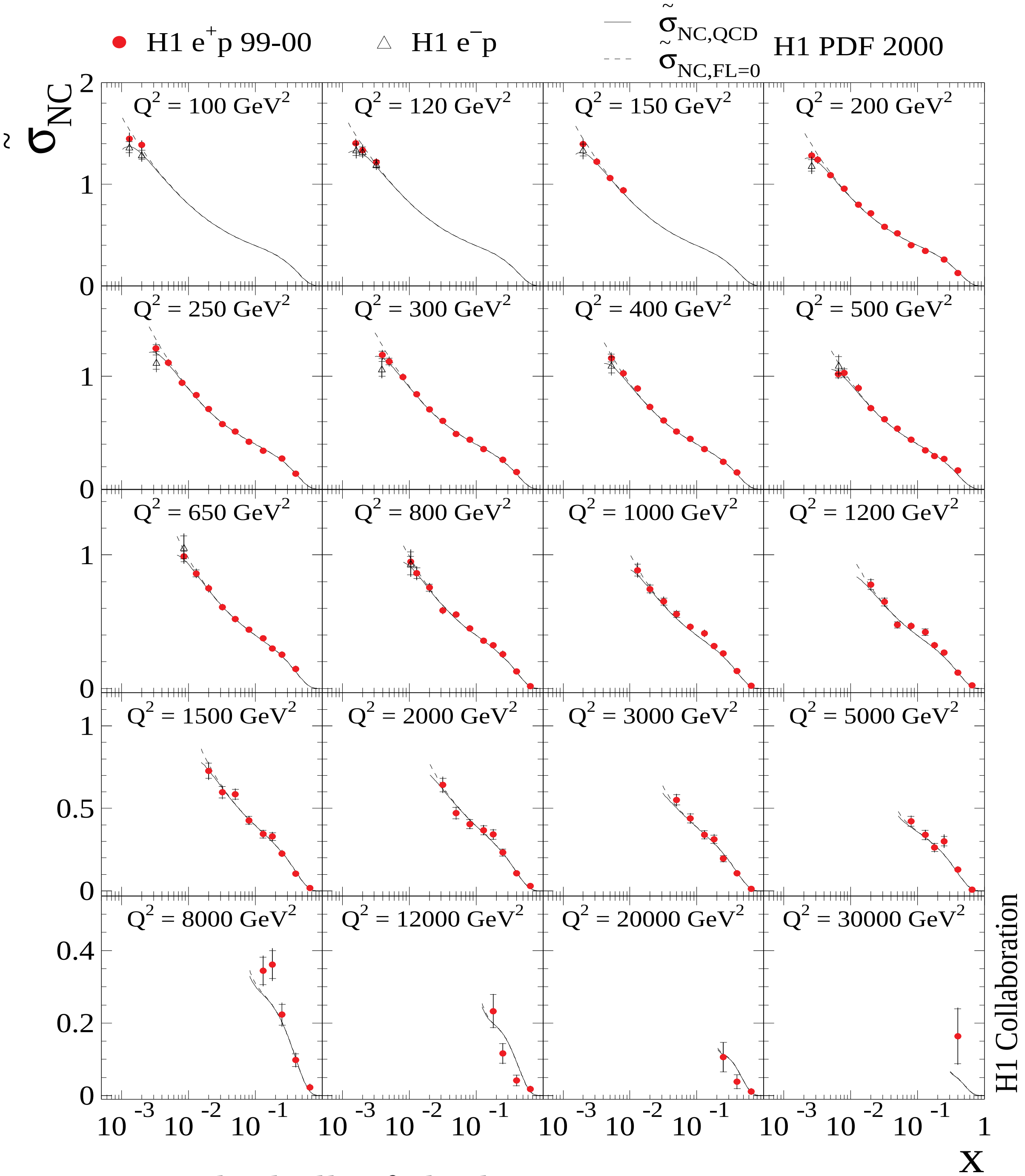
NC Single Differential Cross Section



- $d\sigma/dQ^2$ falls by 7 orders of magnitude
- well described by Standrad Model based on H1 PDF 2000 (see talk of B. Reisert)

NC Double Differential Cross Section

$$\tilde{\sigma}^{\pm}_{NC} \equiv \frac{1}{Y_+}\frac{xQ^4}{2\pi\alpha^2}\frac{d^2\sigma^{e^{\pm}p}_{NC}}{dx\,dQ^2} = \frac{\phi^{\pm}_{NC}}{Y_+}$$



In the bulk of the kinematic region:

- statistical precision of data is $1.5 - 3\%$,
- total error of data is $3 - 4\%$

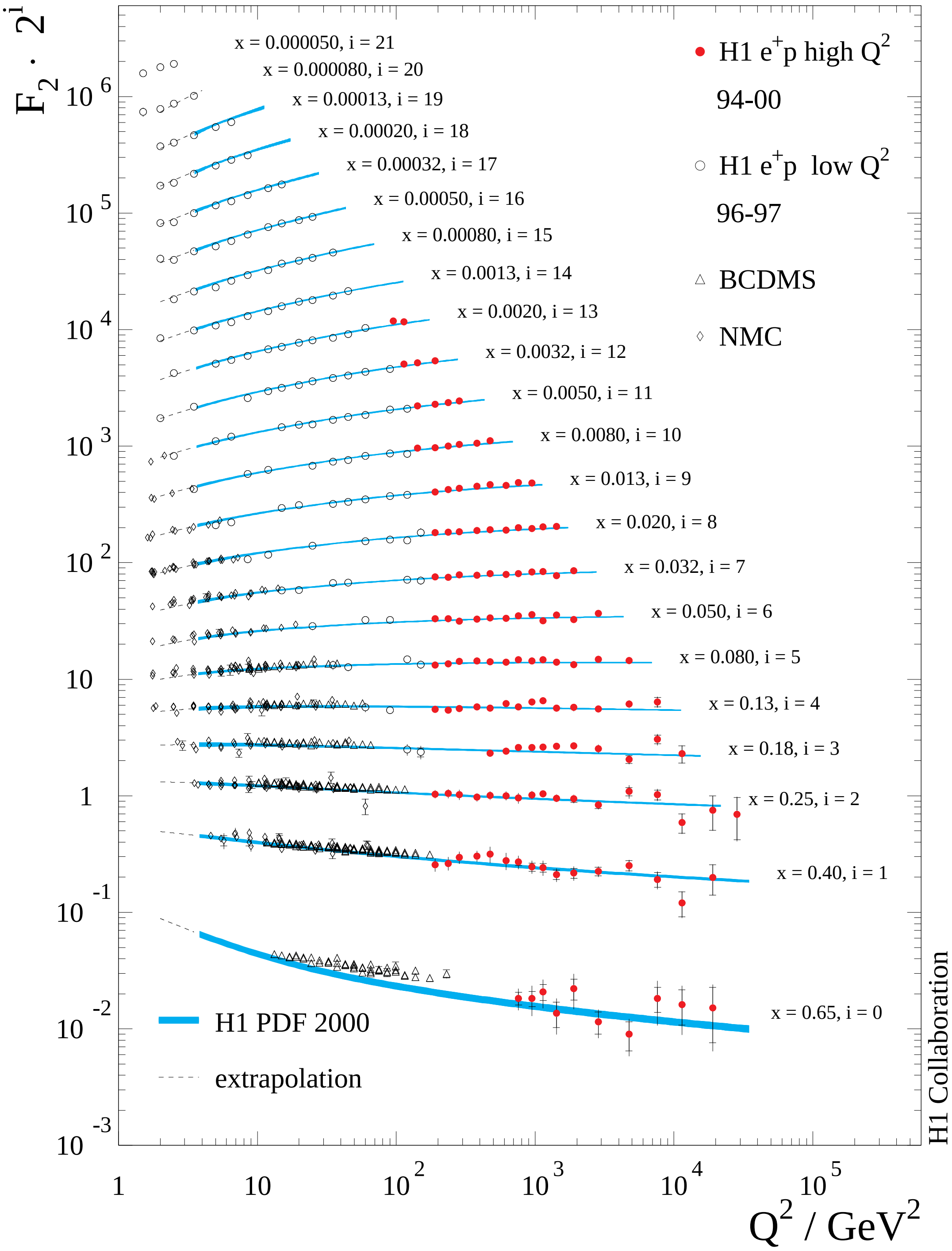
the errors are increasing at lowest y

Proton Structure Function F_2

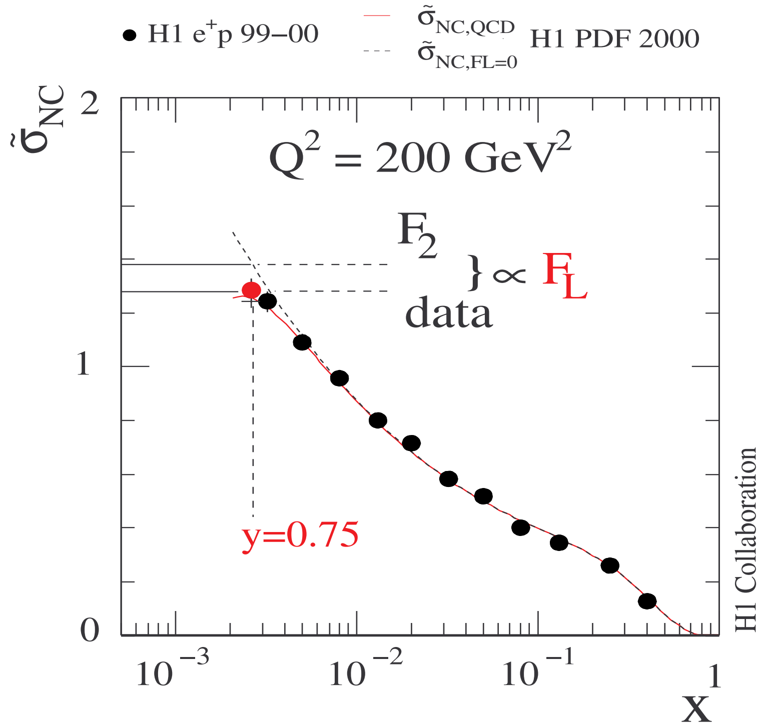
$$F_2 = \frac{\phi_{NC}}{Y_+}\left(1 + \Delta_{F_2} + \Delta_{F_3} + \Delta_{F_L}\right)^{-1}$$

for $Q^2 < 2000\ \mathrm{GeV}^2 :\ y < 0.6$

$Q^2 \geq 2000\ \mathrm{GeV}^2 :\ y < 0.9$



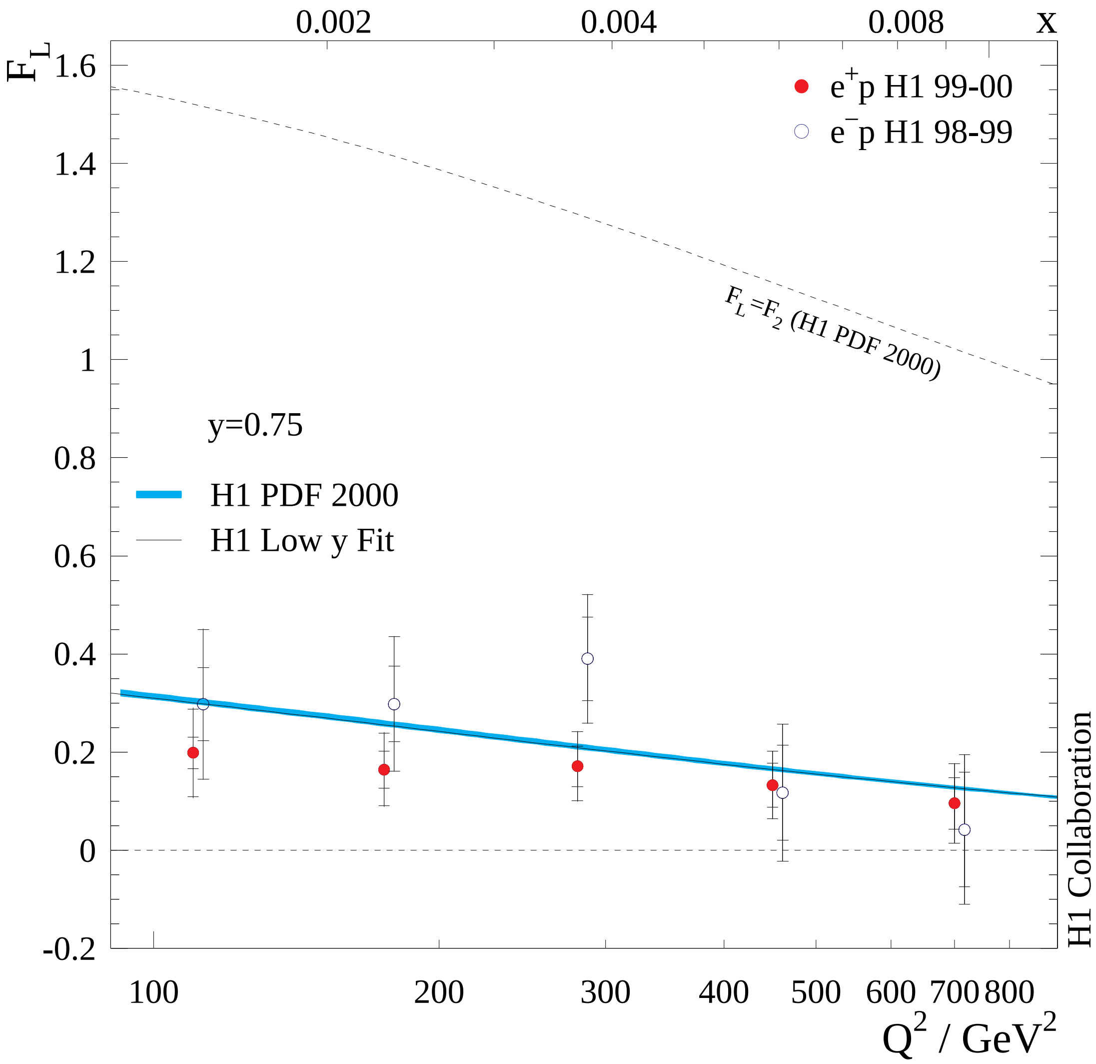
Determination of F_L



$$\tilde{F}_L = \frac{1}{y^2}\Big[\underbrace{Y_+\tilde{F}_2 \mp Y_- x\tilde{F}_3}_{\text{from fit to H1 data } y<0.35} - \underbrace{\phi^{\pm}_{NC}}_{\text{data}}\Big]$$

- Cross sections in two neighbouring Q^2 bins combined
- ϕ_{NC} shifted according to:
  - relative normalisation of data set determined by fit
  - shifts from correlated errors common to low y and high y regions
- errors of F_L:
  - statistical errors from data
  - systematic errors: from cross section measurements at high y; model uncertainties due to extrapolation

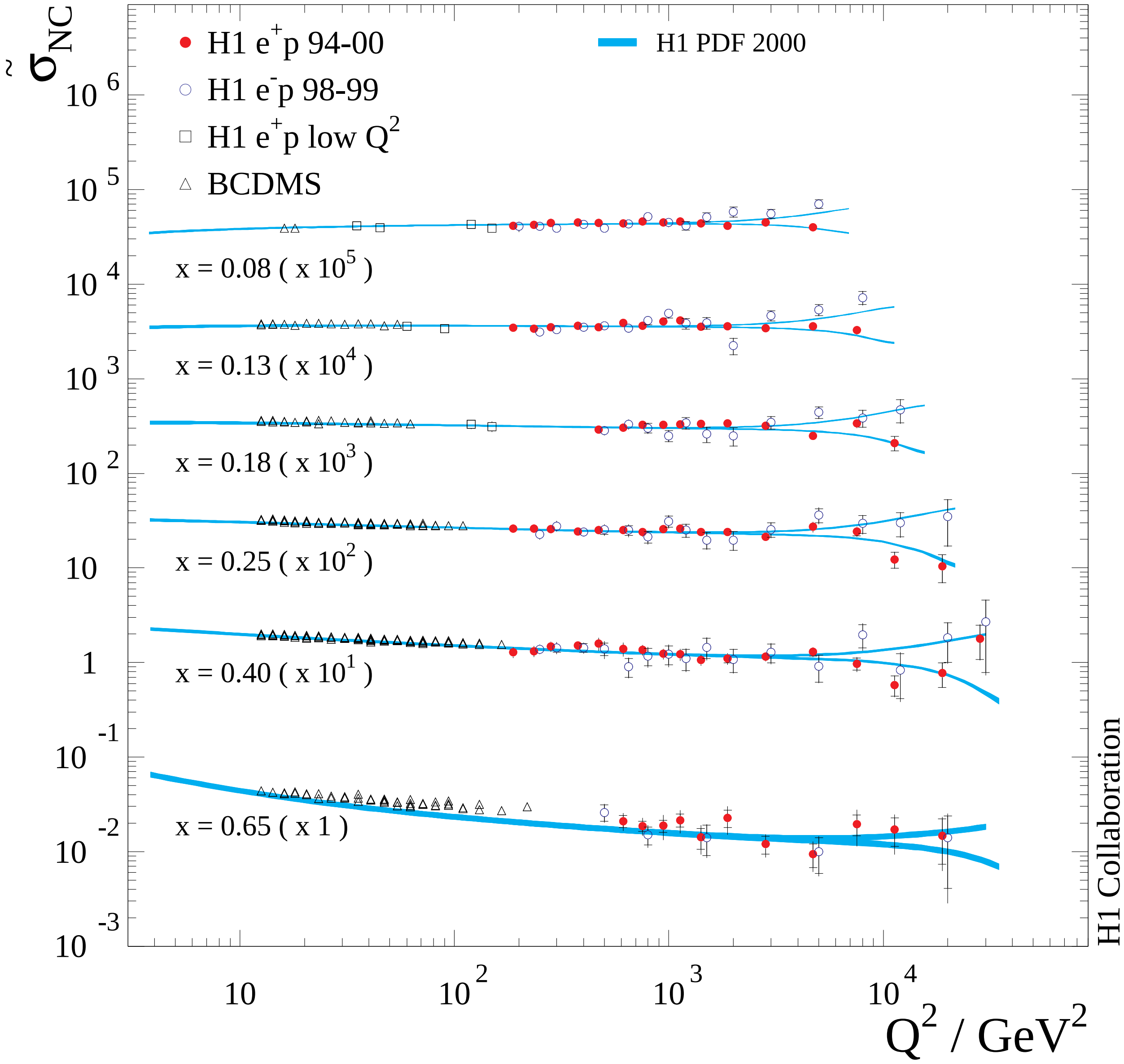
Longitudinal Structure Function F_L



- F_L from e^-p and e^+p mutually consistent
- extremes excluded: $F_L \neq 0$ and $F_L \neq F_2$
- F_L in agreement with expectation from H1 PDF 2000

Double Differential Cross Section at high x

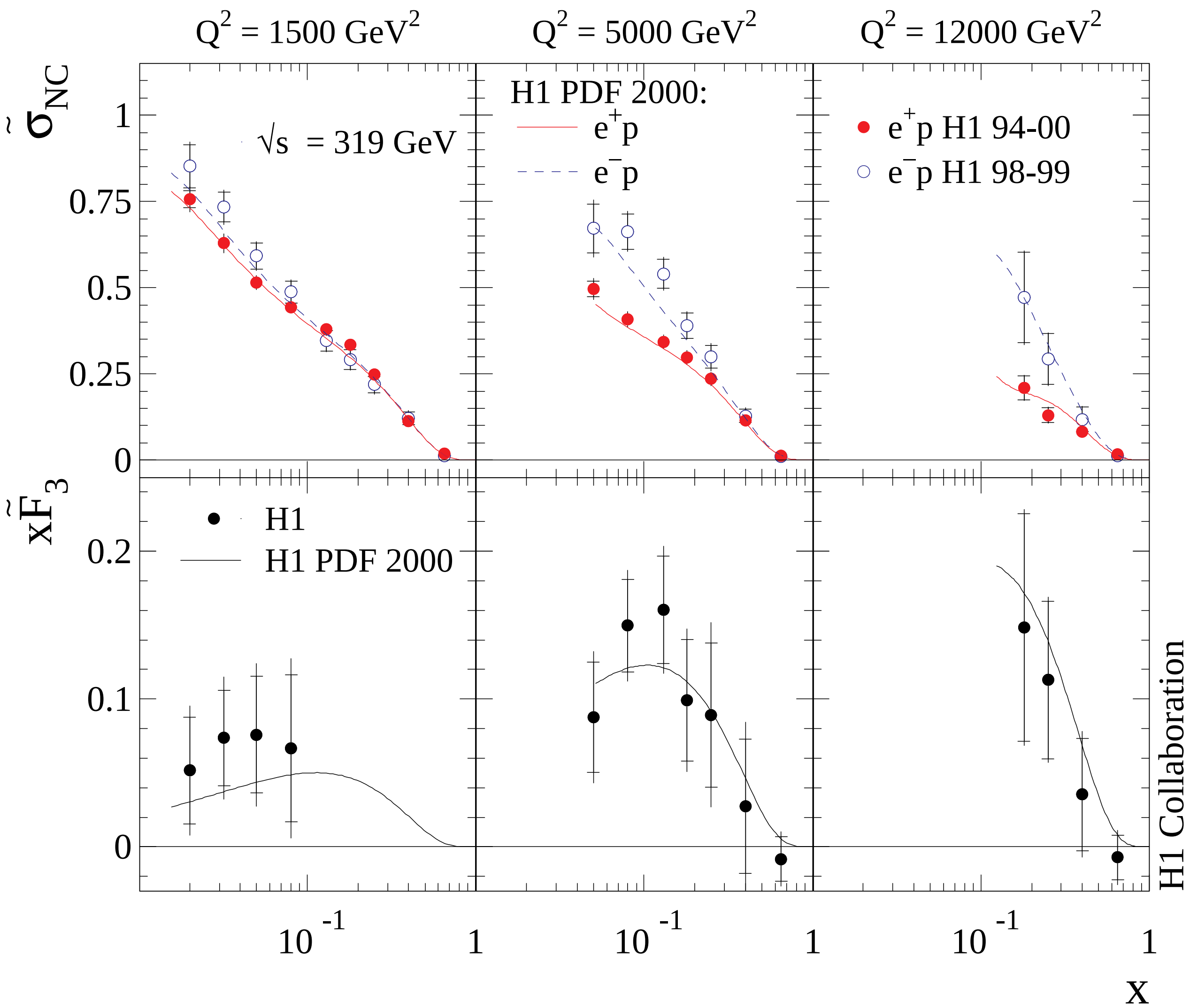
$$\tilde{\sigma}^{\pm}_{NC} = \tilde{F}_2 \mp \frac{Y_-}{Y_+} x\tilde{F}_3, \qquad Y_{\pm} = 1 \pm (1-y)^2$$



- negative (positive) contribution from $x\tilde{F}_3$ in e^+p (e^-p)

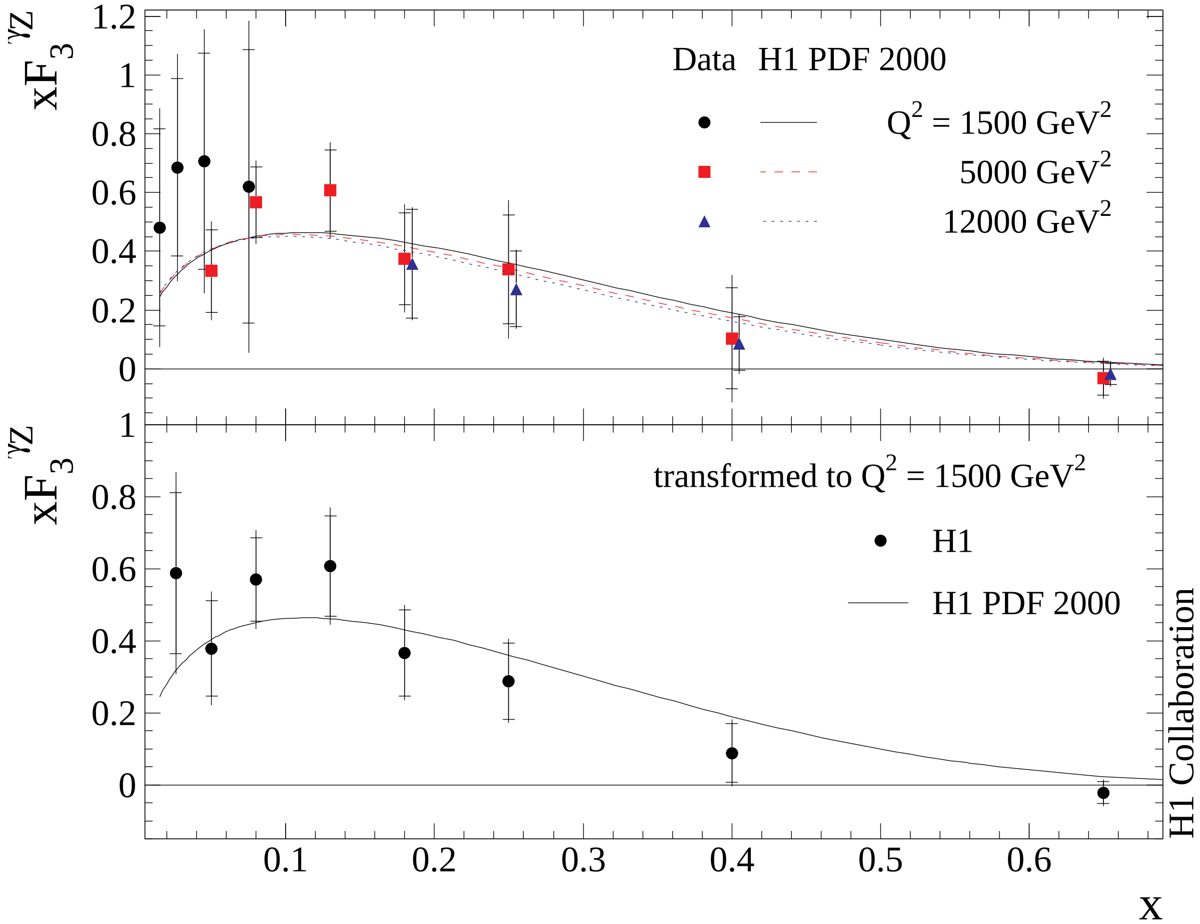
Generalised structure function $x\tilde{F}_3$

$$x\tilde{F}_3 = \frac{1}{2Y_-}\left[\phi^-_{NC} - \phi^+_{NC}\right], \qquad Y_\pm = 1 \pm (1-y)^2$$



$$x\tilde{F}_3 = -a_e \cdot \frac{\kappa_w Q^2}{Q^2 + M_Z^2} xF_3^{\gamma Z} + (2v_e a_e)\left(\frac{\kappa_w Q^2}{Q^2 + M_Z^2}\right) xF_3^Z$$

Interference Structure Function $xF_3^{\gamma Z}$



in LO: $$xF_3^{\gamma Z} = x\sum_i 2e_i a_i(q_i - \bar{q}_i)$$

Sum rule for $F_3^{\gamma Z}$:

(by analogy with *Gross Lewellyn-Smith* sum rule for νN scattering)

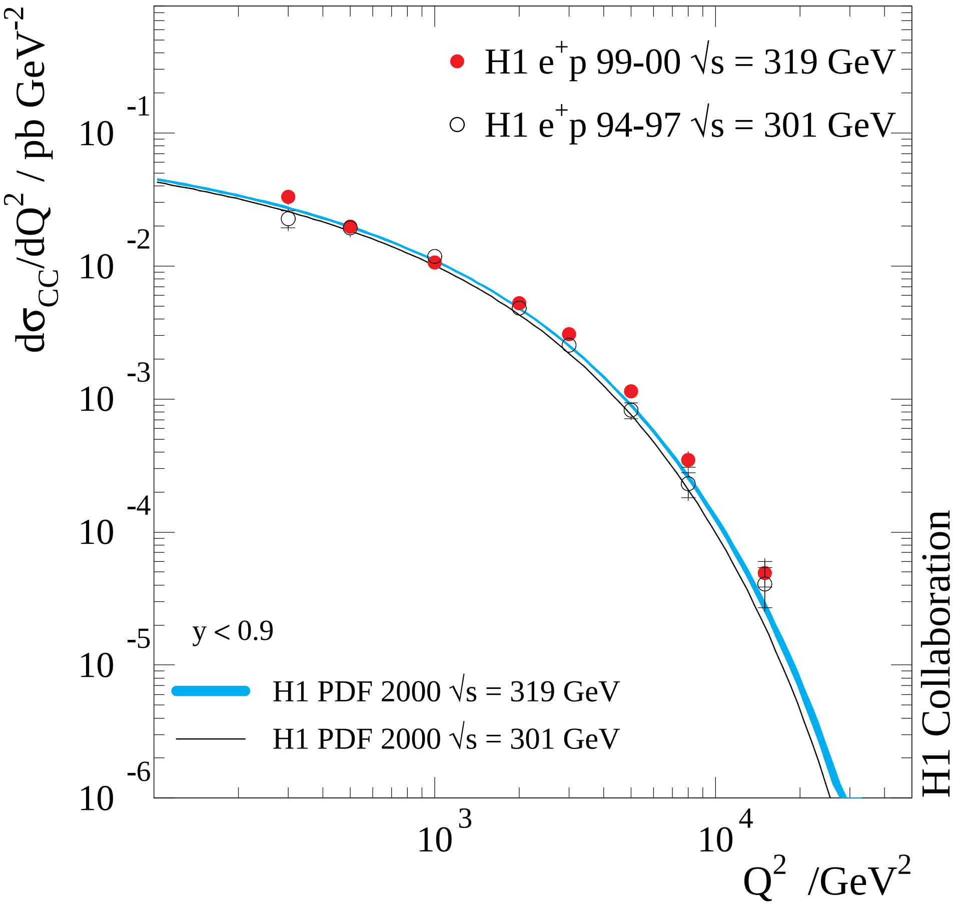
$$\int_0^1 F_3^{\gamma Z} \mathrm{d}x = \frac{5}{3} \cdot \mathcal{O}\left(1 - \frac{\alpha_s}{\pi}\right)$$

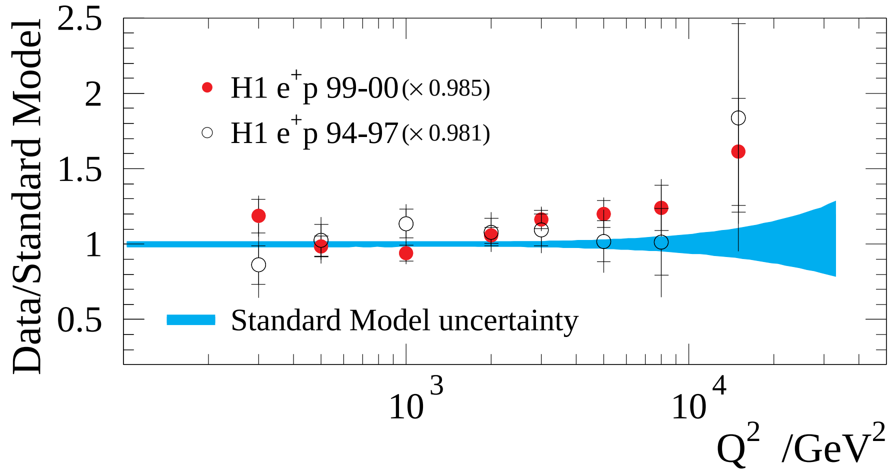
H1:

$$\int_{0.026}^{0.650} F_3^{\gamma Z}(x, Q^2 = 1500 \text{ GeV}^2)\mathrm{d}x = 1.28 \pm 0.17(\text{stat.}) \pm 0.11(\text{syst.})$$

H1 PDF 2000: $$\int_{0.026}^{0.650} F_3^{\gamma Z}\mathrm{d}x = 1.06 \pm 0.02$$

Charged Current Cross Section





94-00 e^+p ($\sqrt{s} = 319$ GeV), $Q^2 > 1000$ GeV^2, $y < 0.9$:

$$\sigma_{tot}^{CC}(e^+p) = 18.99 \pm 0.52(\text{stat.}) \pm 0.81(\text{syst.}) \ \text{pb}$$

$$\sigma_{tot}^{CC}(e^+p) \quad = 16.76 \pm 0.32 \ \text{pb} \quad (\text{H1 PDF 2000})$$

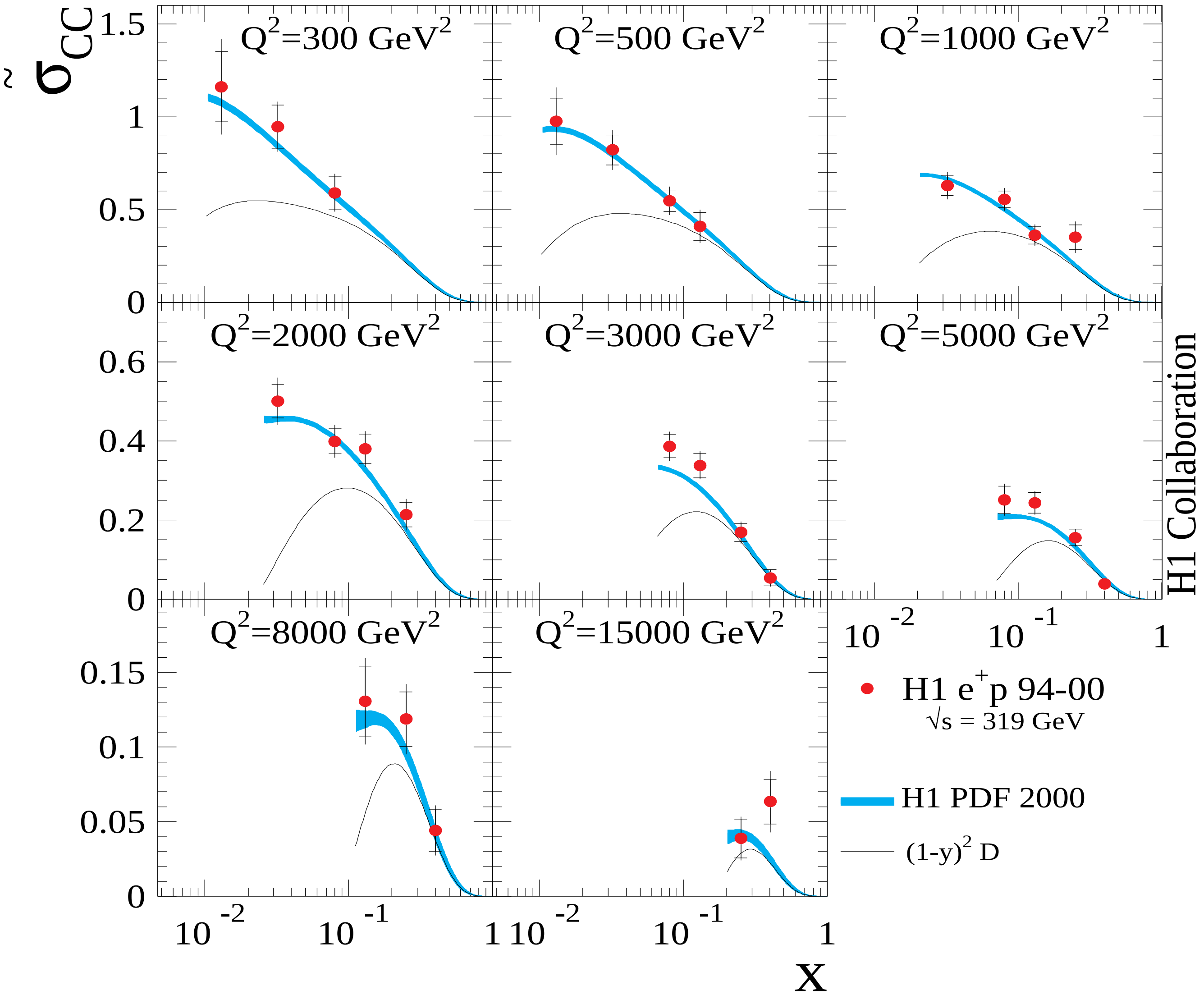
Double Differential CC Cross Section

$$\frac{d^2\sigma^{\pm}_{CC}}{dx\,dQ^2} = \frac{G_F^2}{2\pi x}\left(\frac{M_W^2}{Q^2+M_W^2}\right)^2 \phi^{\pm}_{CC}$$

$$\phi^{\pm}_{CC} = \left[Y_+ W_2^{\pm}(x,Q^2) \mp Y_- x W_3^{\pm}(x,Q^2) - y^2 W_L^{\pm}(x,Q^2)\right]$$

$$W_2^+ = x\left(D+\overline{U}\right), \quad W_3^+ = x\left(D-\overline{U}\right) \qquad xU = x(u+c)$$

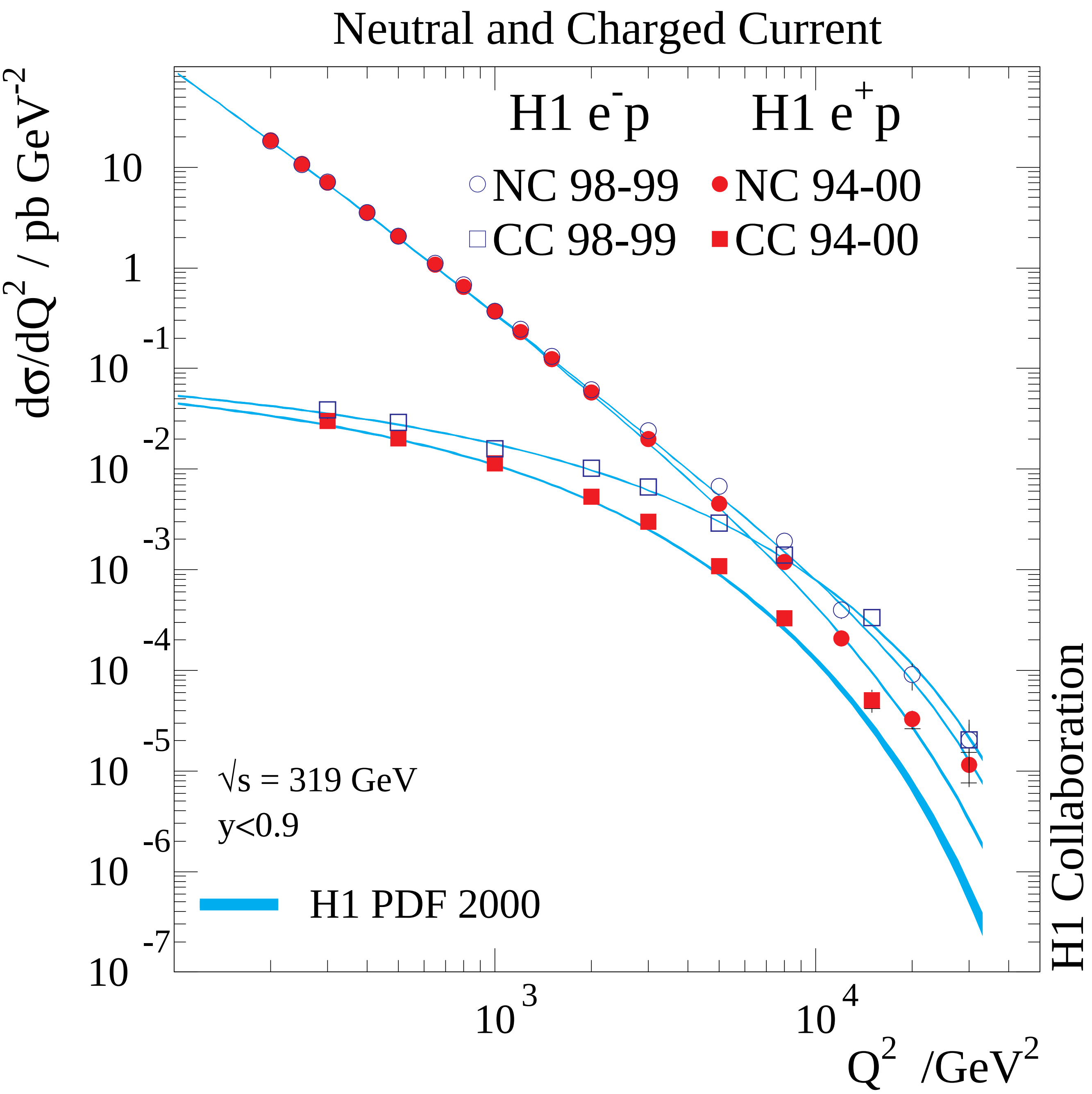
$$W_2^- = x\left(U+\overline{D}\right), \quad W_3^- = x\left(U-\overline{D}\right) \qquad xD = x(d+s+b)$$



For new 99-00 data:

- statistical errors are 10 – 15 %
- systematic errors are typically 3.5 – 6 %

HERA-I NC & CC Summary



Unification of electromagnetic and weak interactions in deep inelastic scattering

Summary

- NC & CC cross sections at high Q^2:
  $\mathrm{d}\sigma/\mathrm{d}Q^2$, $\mathrm{d}\sigma/\mathrm{d}x$, $\mathrm{d}^2\sigma/\mathrm{d}x\,\mathrm{d}Q^2$
  measured in e^+p and e^-p interactions using full HERA-I data

Extracted:

- structure function F_2 with precision of 3 – 4 %
- structure functions $x\tilde{F}_3$ and $xF_3^{\gamma Z}$
- the londitudinal structure function F_L

Standard Model (EW+QCD) provides consistent picture of all data presented

- Higher luminosity needed to access high x and high Q^2

- Polarisation will allow more detailed studies of weak sector of SM