

# High $Q^2$ NC & CC Cross Sections and Structure Functions

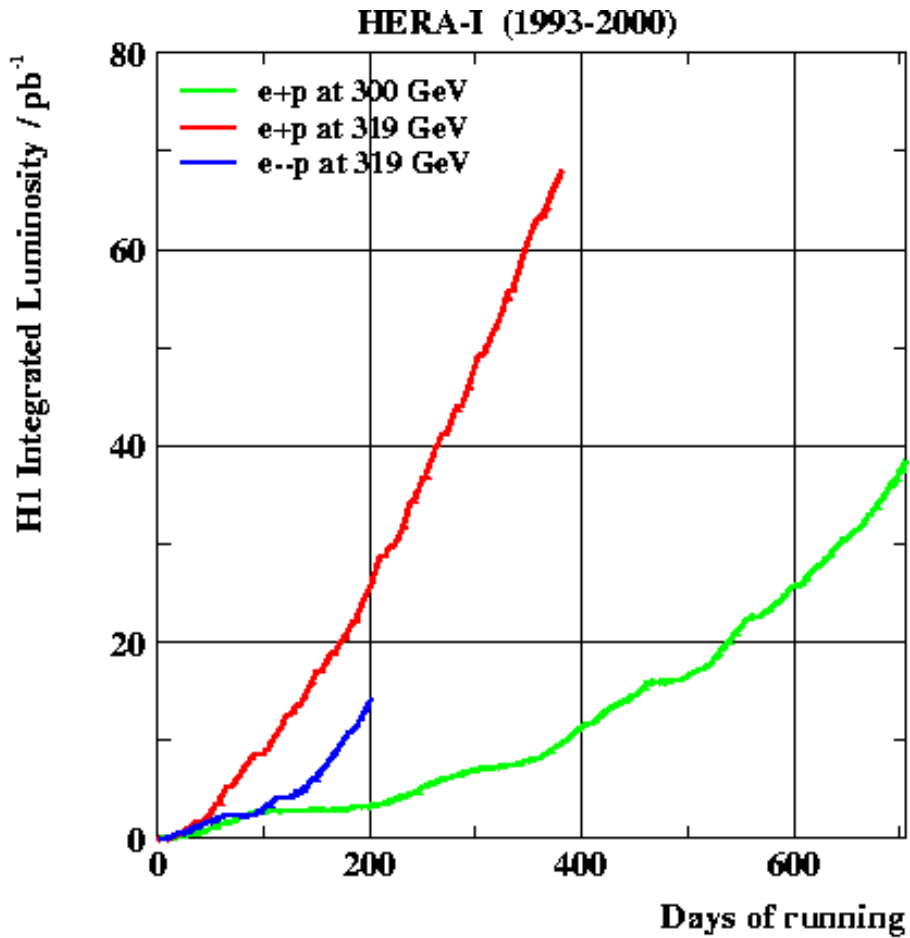
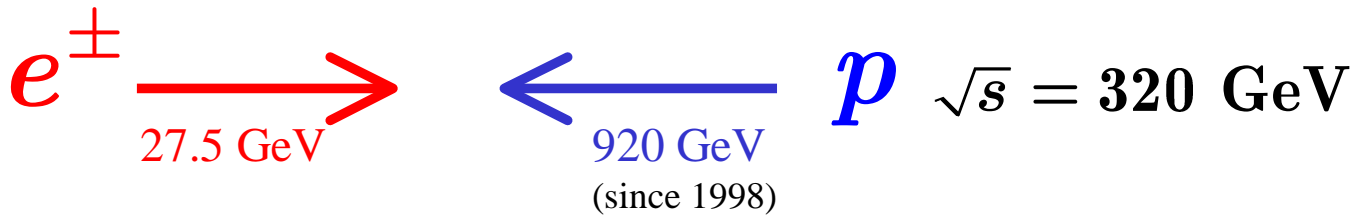


Ana Dubak  
MPI for Physics Munich  
on behalf of the  
H1 Collaboration



- HERA, H1, DIS
- NC & CC ( $e^+p$  and  $e^-p$ )
  - Cross sections
  - Proton structure function  $F_2$
  - Structure function  $x\tilde{F}_3$
  - Sum rule for  $F_3^{\gamma Z}$
  - Longitudinal structure function  $F_L$
  - Valence quark distributions
  - W propagator mass
- Summary

# HERA

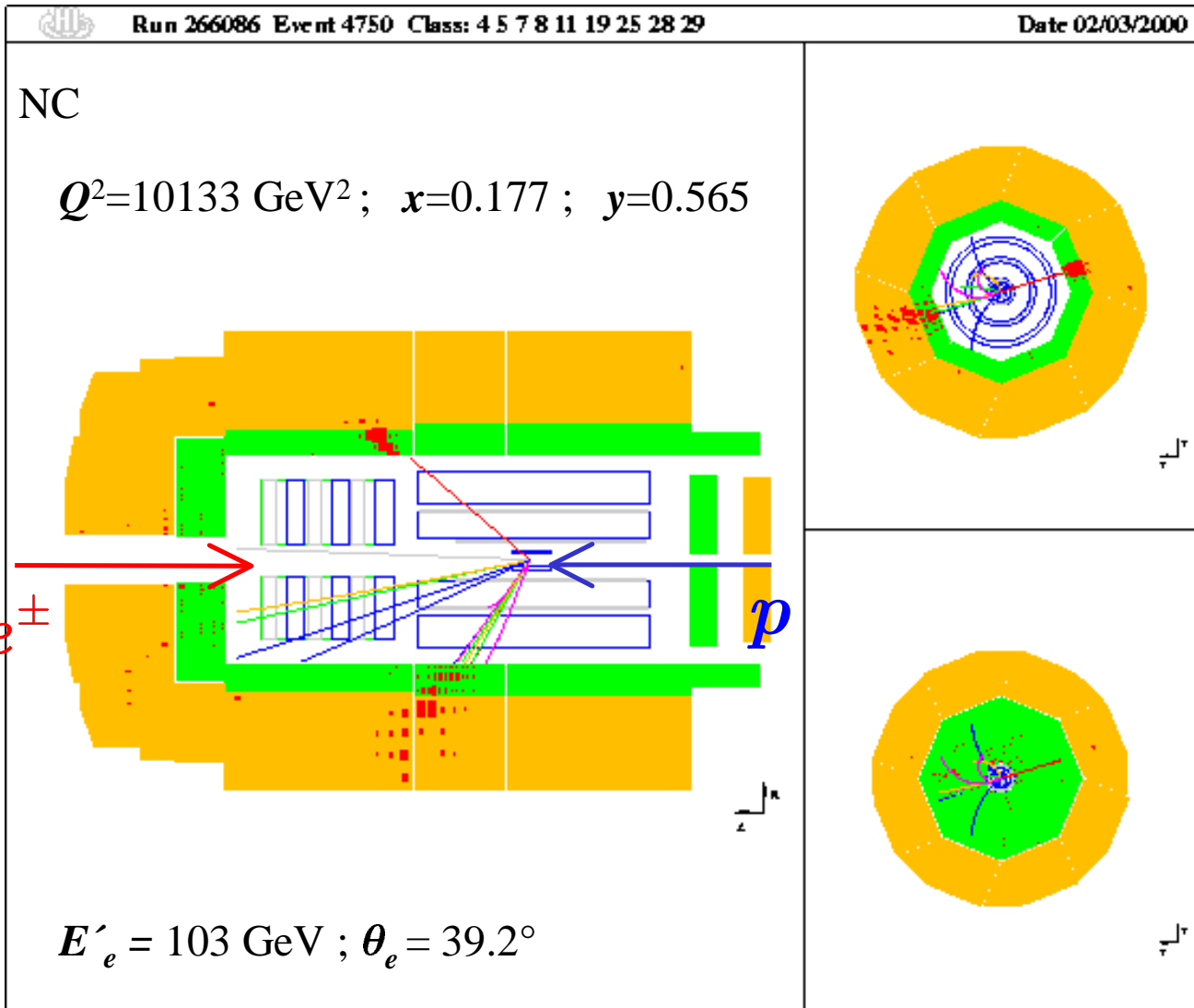


H1 Luminosity:

$$e^-p \text{ (98/99): } \mathcal{L} = 16.4 \text{ pb}^{-1}$$

$$e^+p \text{ (99/00): } \mathcal{L} = 65.3 \text{ pb}^{-1}$$

# The H1 Detector



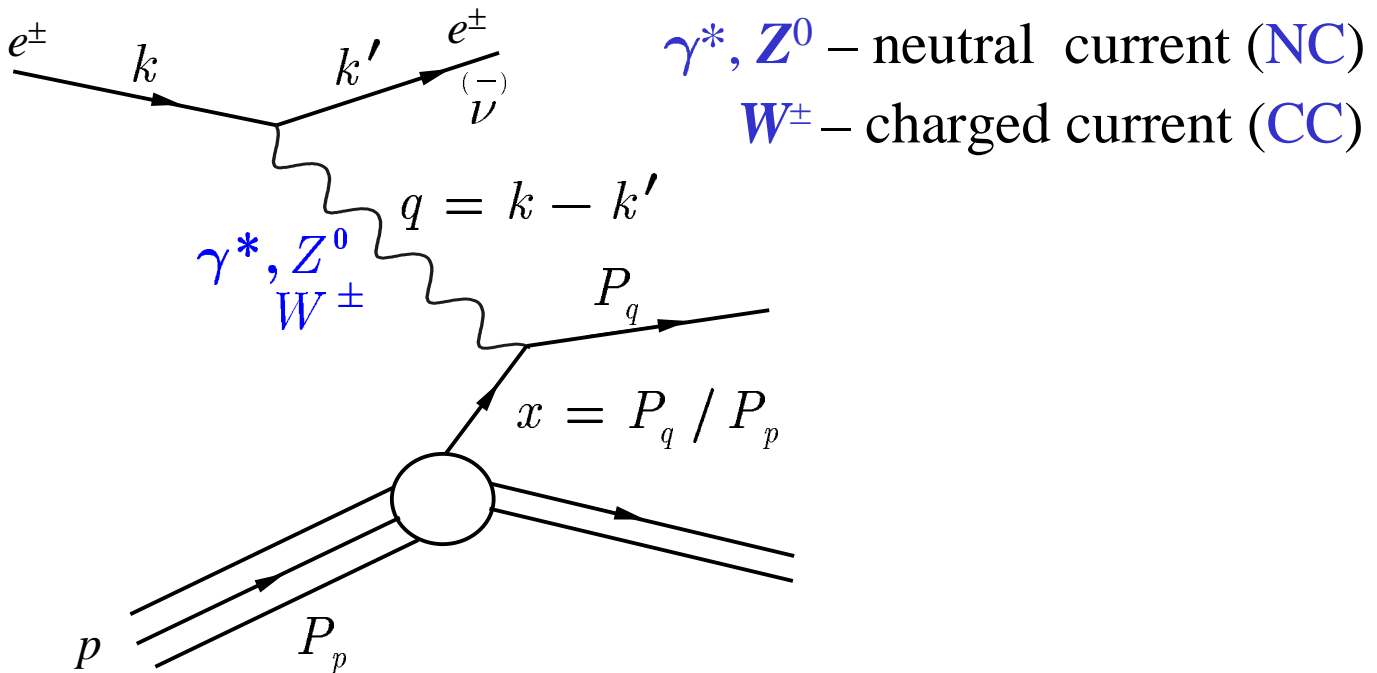
LAr calorimeter:  
High granularity 45000 cells

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

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

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

# Deep Inelastic Scattering



4-momentum transfer squared:

$$Q^2 = -q^2$$

Bjorken scaling variable:

$$x = Q^2 / (2P \cdot q)$$

Inelasticity:

$$y = q \cdot P / (k \cdot P)$$

$$Q^2 = xys,$$

$\sqrt{s}$  is center of mass energy

# NC Cross Section $ep \rightarrow e'X$

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

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

Generalised structure functions:

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

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

in QPM:

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

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

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

in QCD:

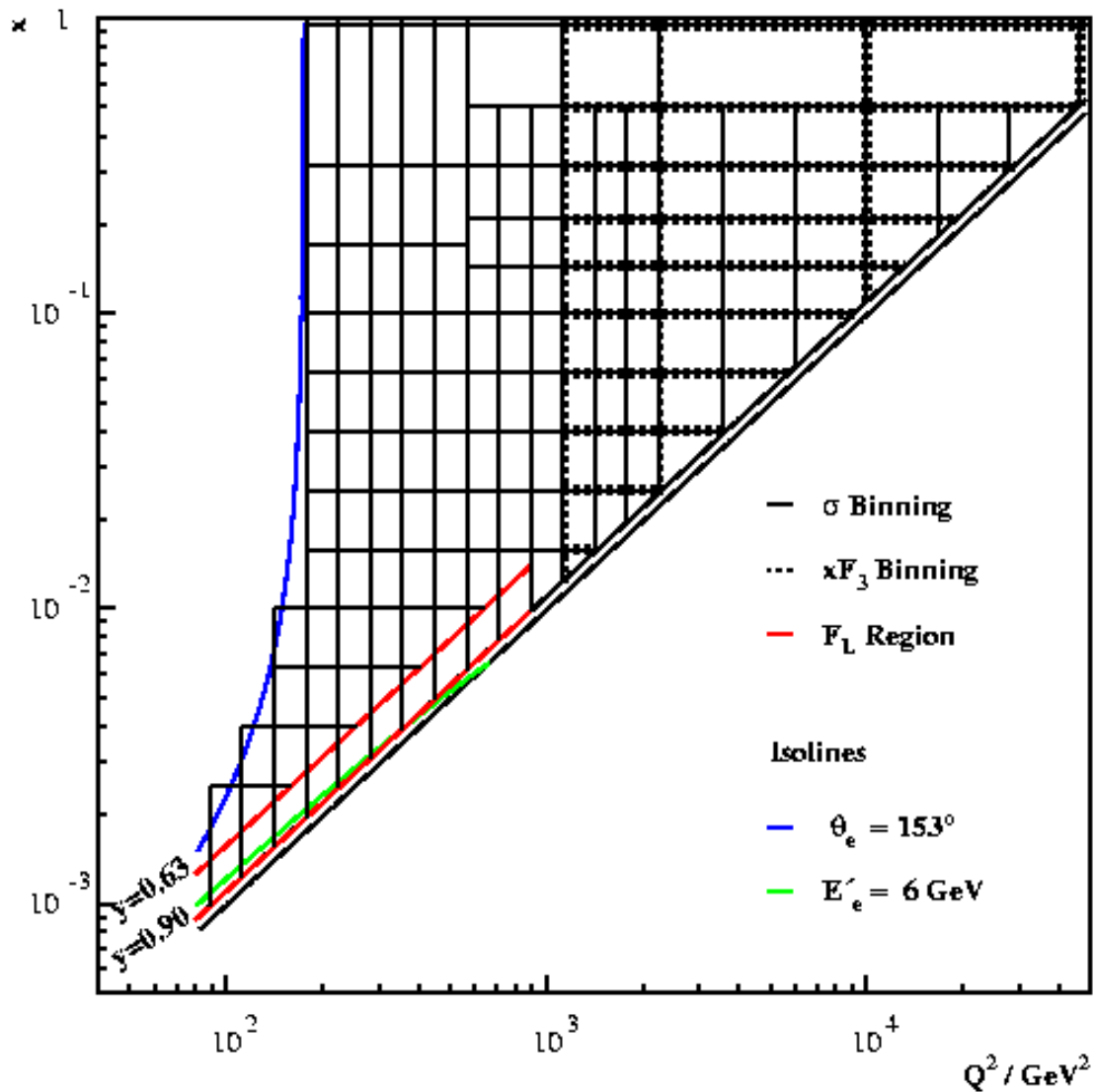
$$F_L = \frac{\alpha_s}{4\pi} x^2 \int_x^1 \frac{dz}{z^3} \left[ \frac{16}{3} \sum_q z e_q^2 (q + \bar{q}) + 8 \sum_q e_q^2 \left(1 - \frac{x}{z}\right) \cdot zg \right]$$

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

SM = EW + QCD

# Kinematic Range

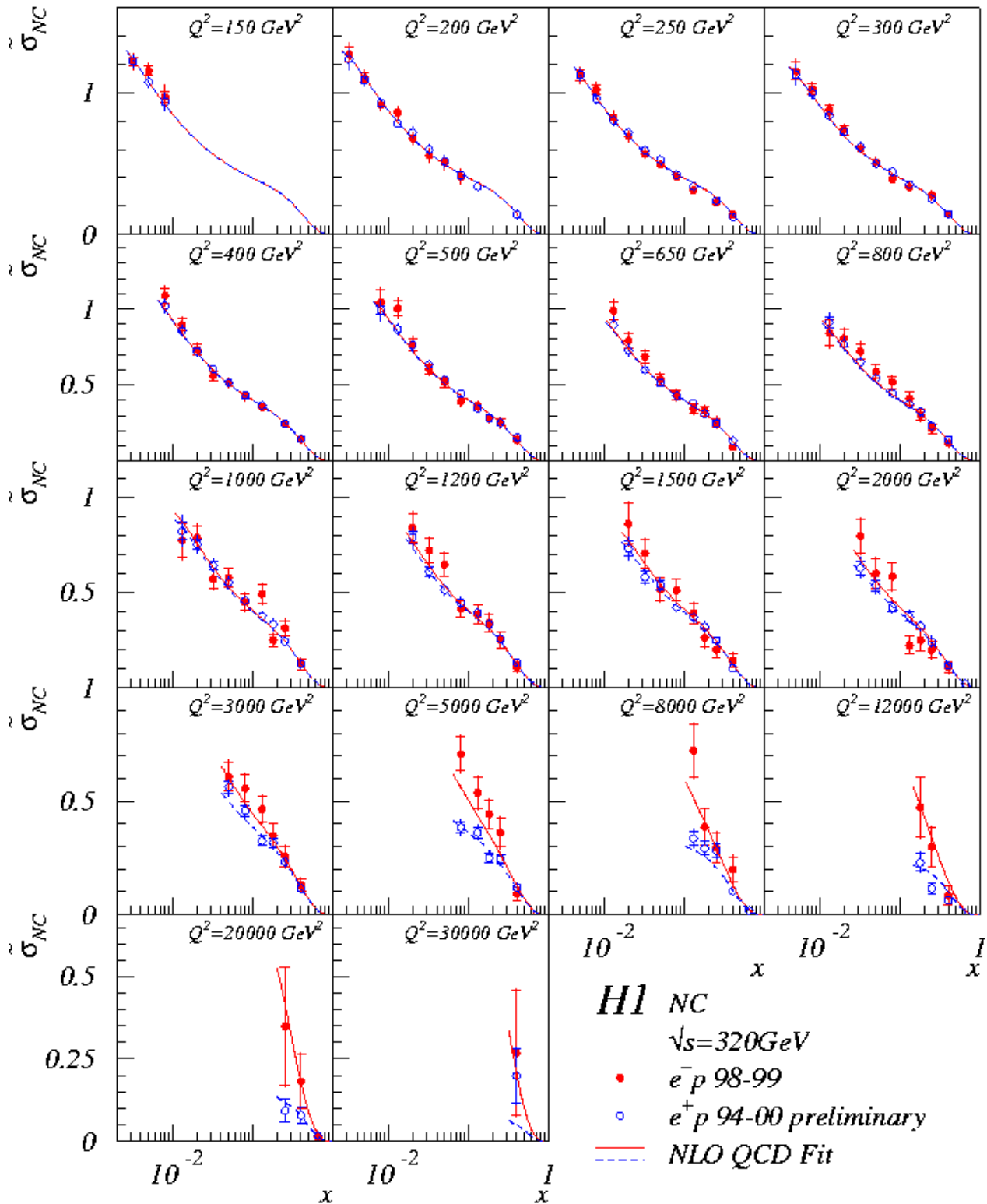
$$\frac{d\sigma_{\text{NC}}^{e^\pm p}}{dx dQ^2} = \frac{2\pi\alpha^2}{xQ^4} \left[ Y_+ \tilde{F}_2 \mp Y_- x\tilde{F}_3 - y^2 \tilde{F}_L \right]$$



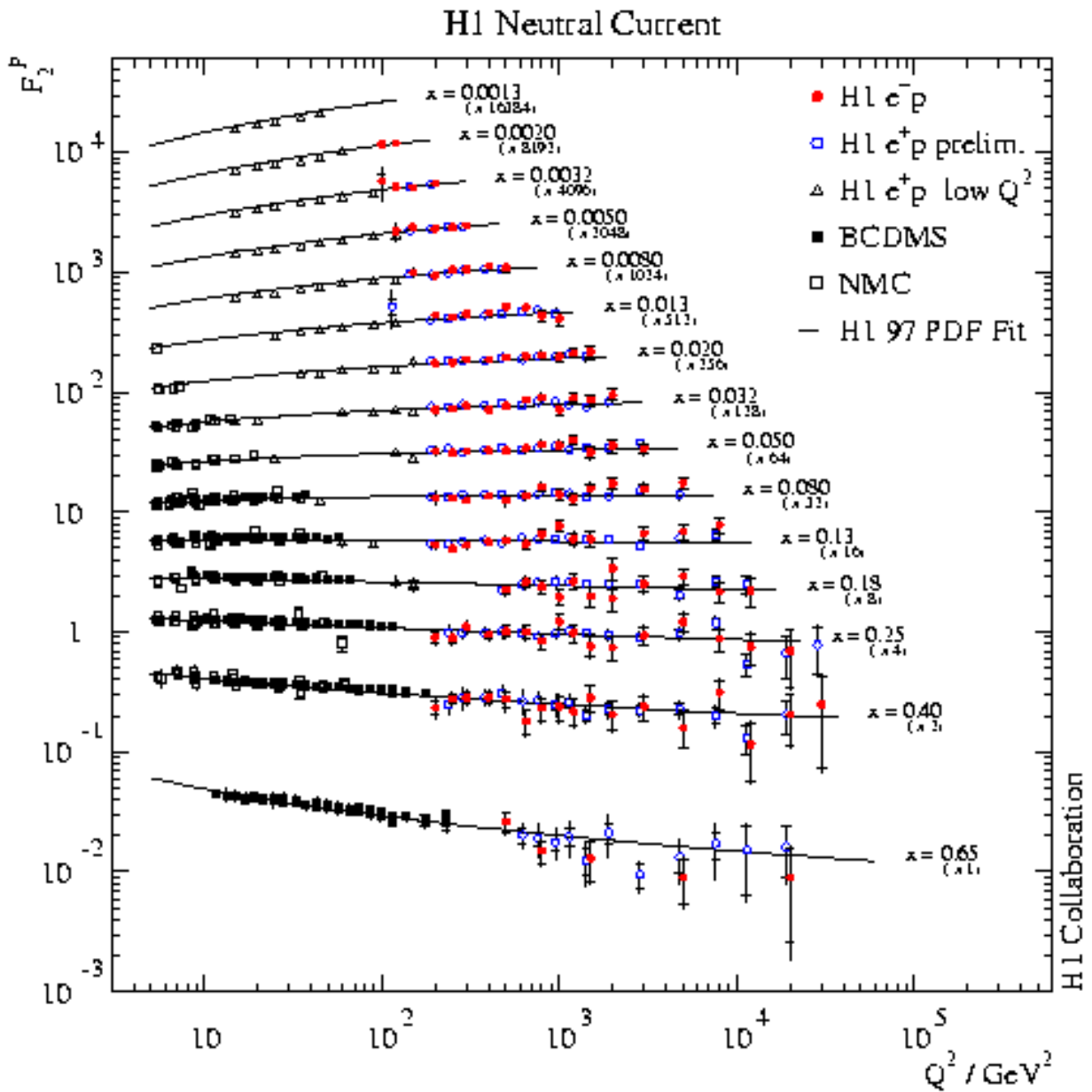
- $F_2 \rightarrow$  full kinematic range
- $x\tilde{F}_3 \rightarrow$  high  $Q^2$
- $F_L \rightarrow$  high  $y$

# NC Double Differential Cross Section

$$\tilde{\sigma}_{\text{NC}}^{e^\pm p} \equiv \frac{1}{Y_+} \frac{xQ^4}{2\pi\alpha^2} \frac{d\sigma_{\text{NC}}^{e^\pm p}}{dx dQ^2} = \tilde{F}_2 \mp \frac{Y_-}{Y_+} x\tilde{F}_3$$



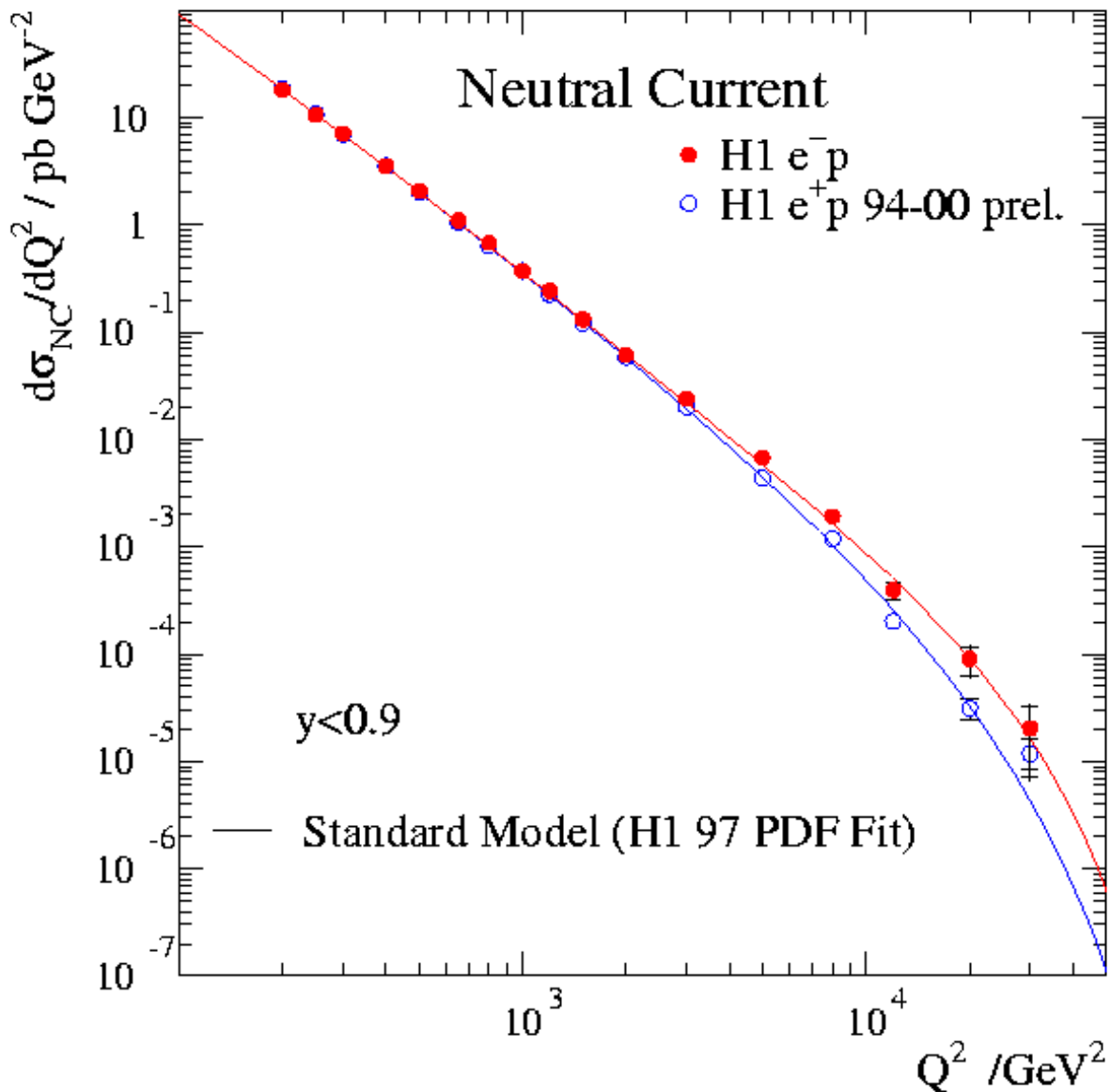
# Proton Structure Function $F_2$



- consistent measurements from  $e^-p$  and  $e^+p$



# NC Single Differential Cross Section

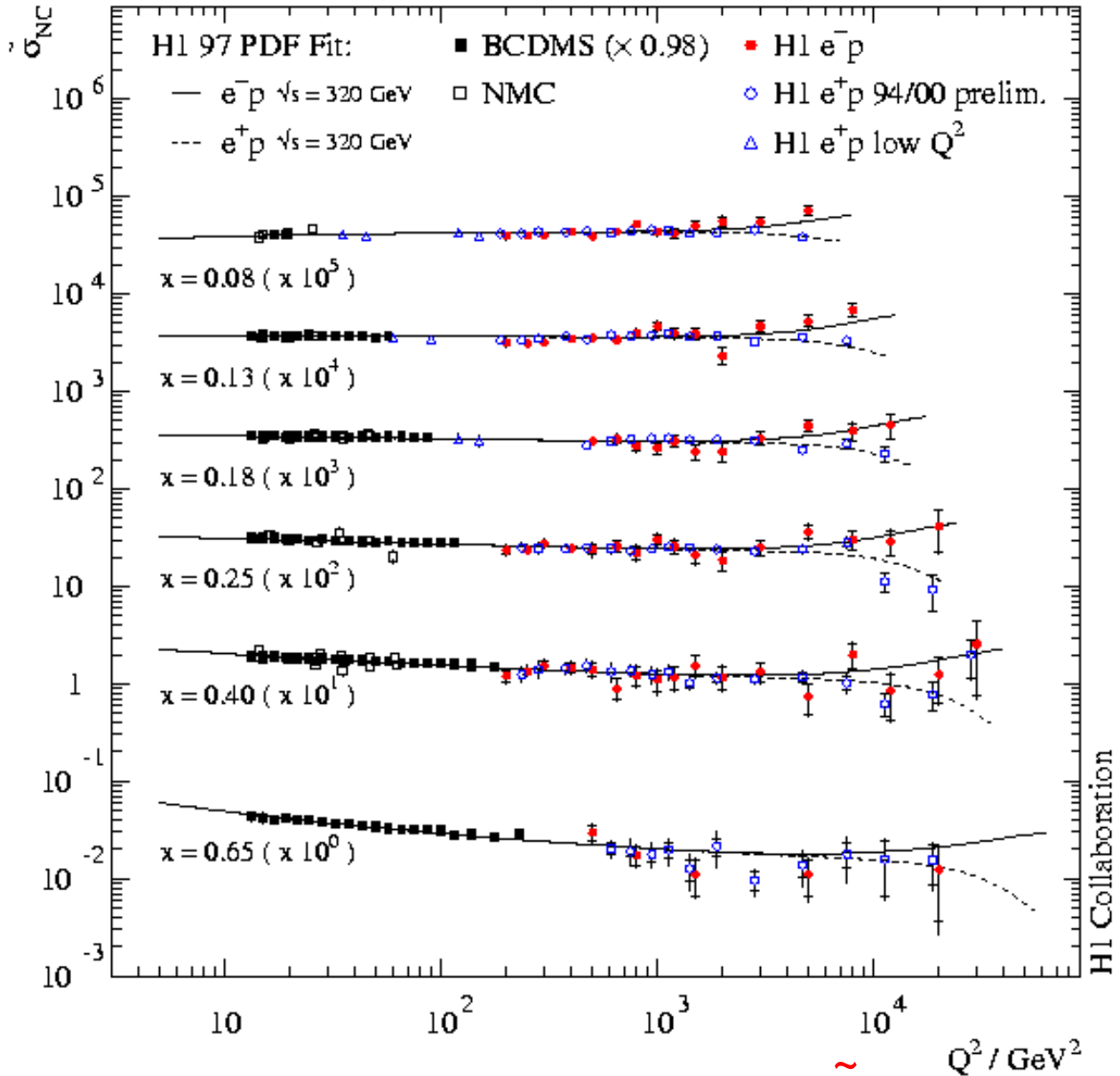


- $d\sigma/dQ^2$  falls by 7 orders of magnitude
- well described by SM
- $d\sigma/dQ^2$  for  $e^+p$  and  $e^-p$  the same at low  $Q^2$ , differ at high  $Q^2$

# Double Differential Cross Section at high $x$

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

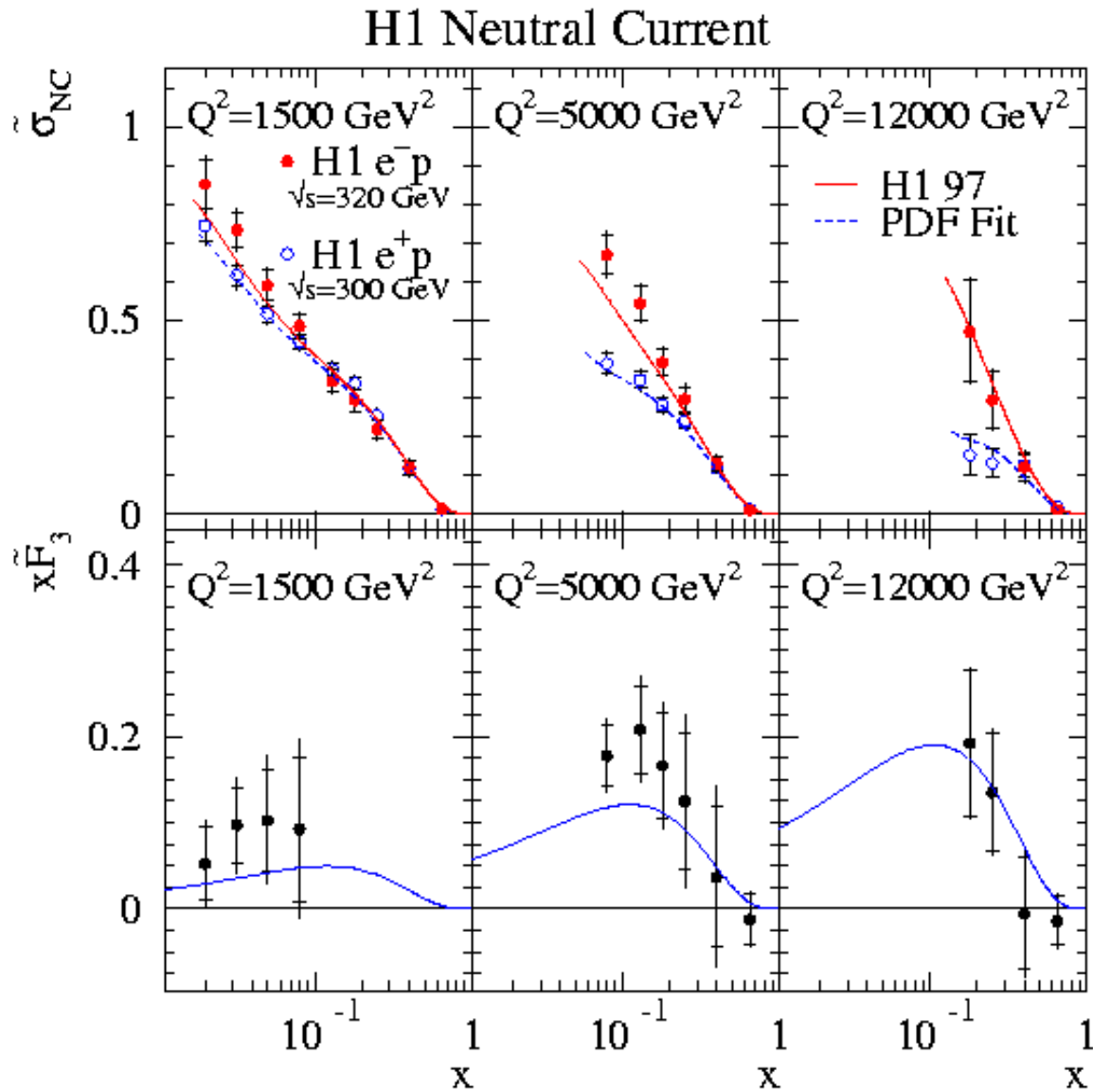
H1 Neutral Current



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

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

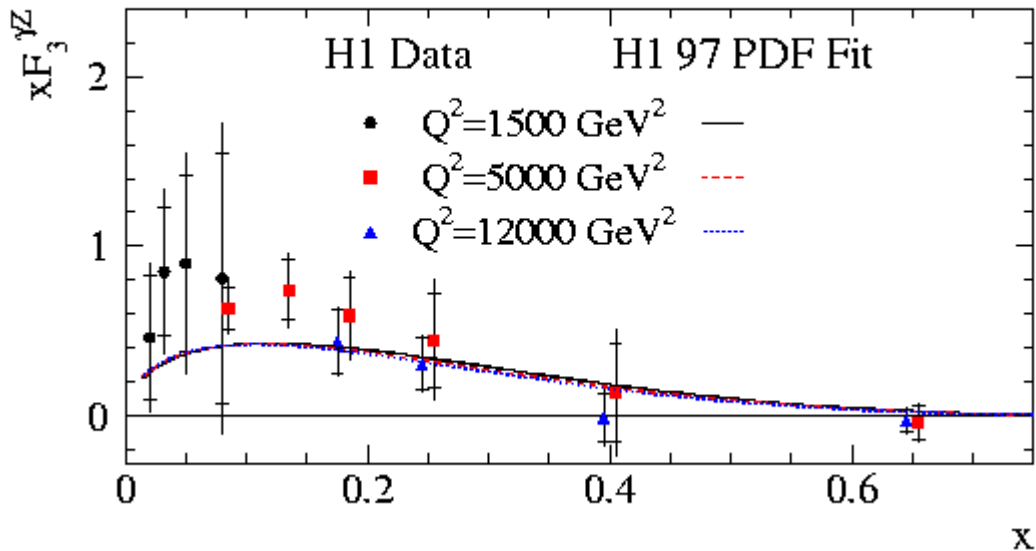
$$x\tilde{F}_3 = \frac{Y_+}{2Y_-} (\tilde{\sigma}_{\text{NC}}^- - \tilde{\sigma}_{\text{NC}}^+), \quad Y_{\pm} = 1 \pm (1-y)^2$$



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

## Sum Rule for $F_3^{\gamma Z}$

in LO :  $x F_3^{\gamma Z} = x \sum_i 2e_i a_i (q_i - \bar{q}_i)$



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

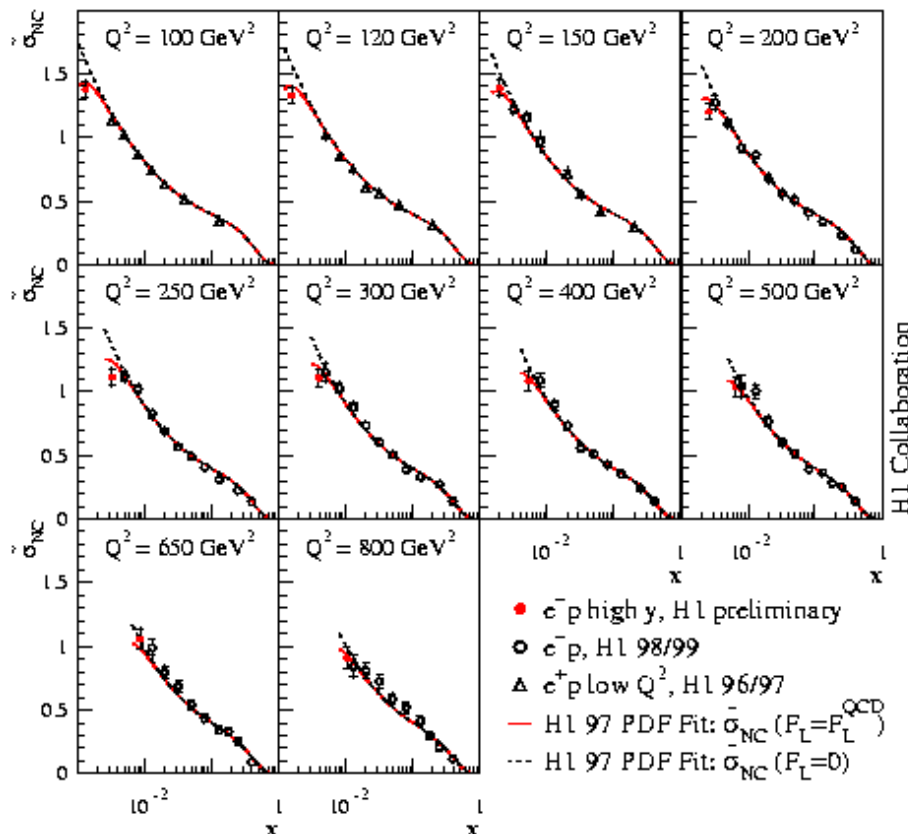
(by analogy with *Gross Lewellyn-Smith* sum rule for  $\nu N$  scattering)

$$\int_0^1 F_3^{\gamma Z} dx \approx 2e_u a_u N_u + 2e_d a_d N_d = \frac{5}{3}$$

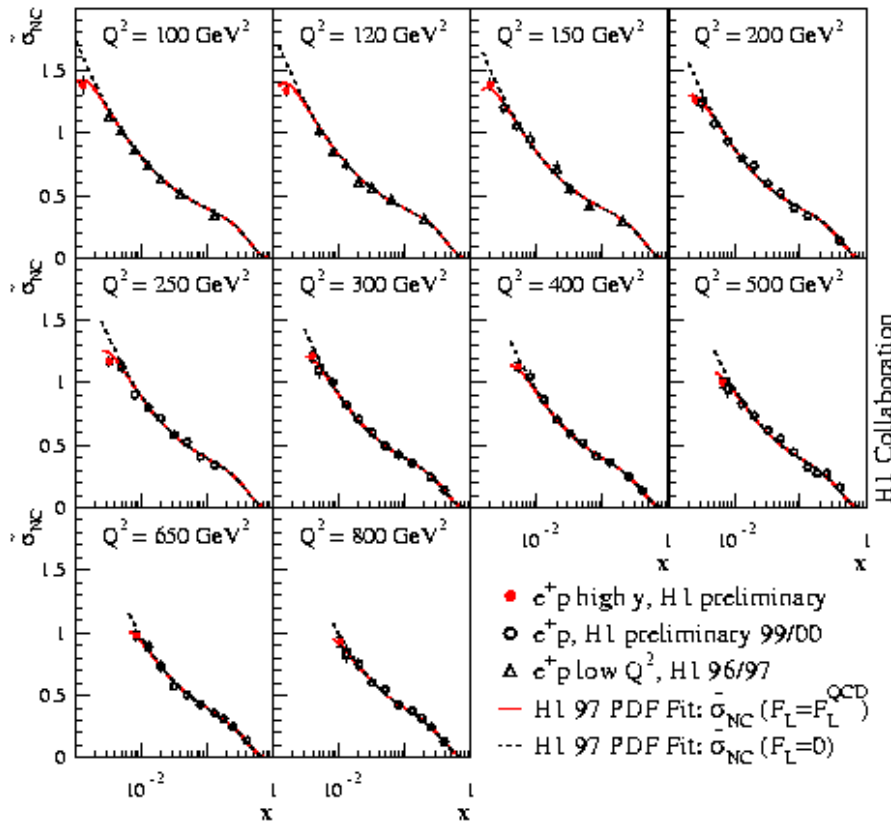
H1:  $\int_{0.02}^{0.65} F_3^{\gamma Z} dx = 1.88 \pm 0.35(\text{stat.}) \pm 0.27(\text{syst.})$

(H1 97 PDF fit:  $\int_{0.02}^{0.65} F_3^{\gamma Z} dx = 1.11$ )

# Extension of Cross Section Measurement to high $y=0.75$



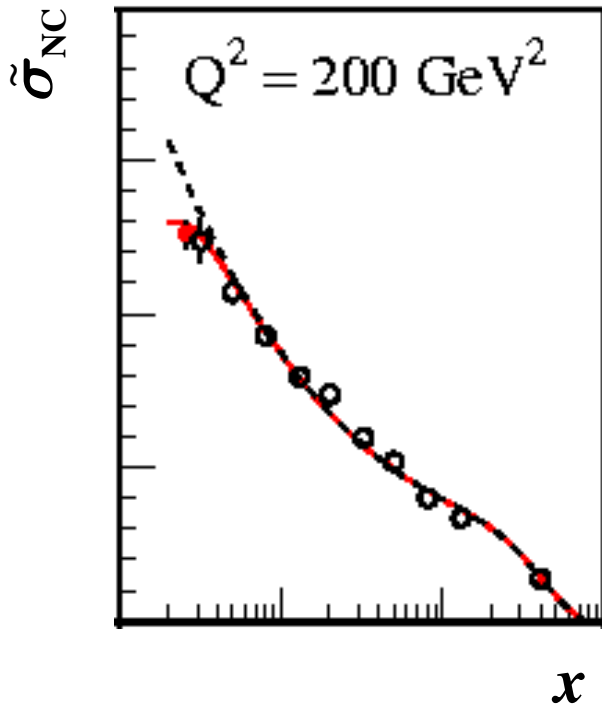
*e-p 98/99*



*e+p 99/00*

## Determination of $F_L$

$$\tilde{\sigma} = F_2 - \frac{y^2}{Y_+} F_L, \quad Y_{\pm} = 1 \pm (1 - y)^2$$



- e<sup>+</sup>p high y, H1 preliminary
- e<sup>+</sup>p, H1 preliminary
- H1 97 PDF Fit :  $\tilde{\sigma}_{\text{NC}} (F_L = F_L^{\text{QCD}})$
- - - H1 97 PDF Fit :  $\tilde{\sigma}_{\text{NC}} (F_L = 0)$

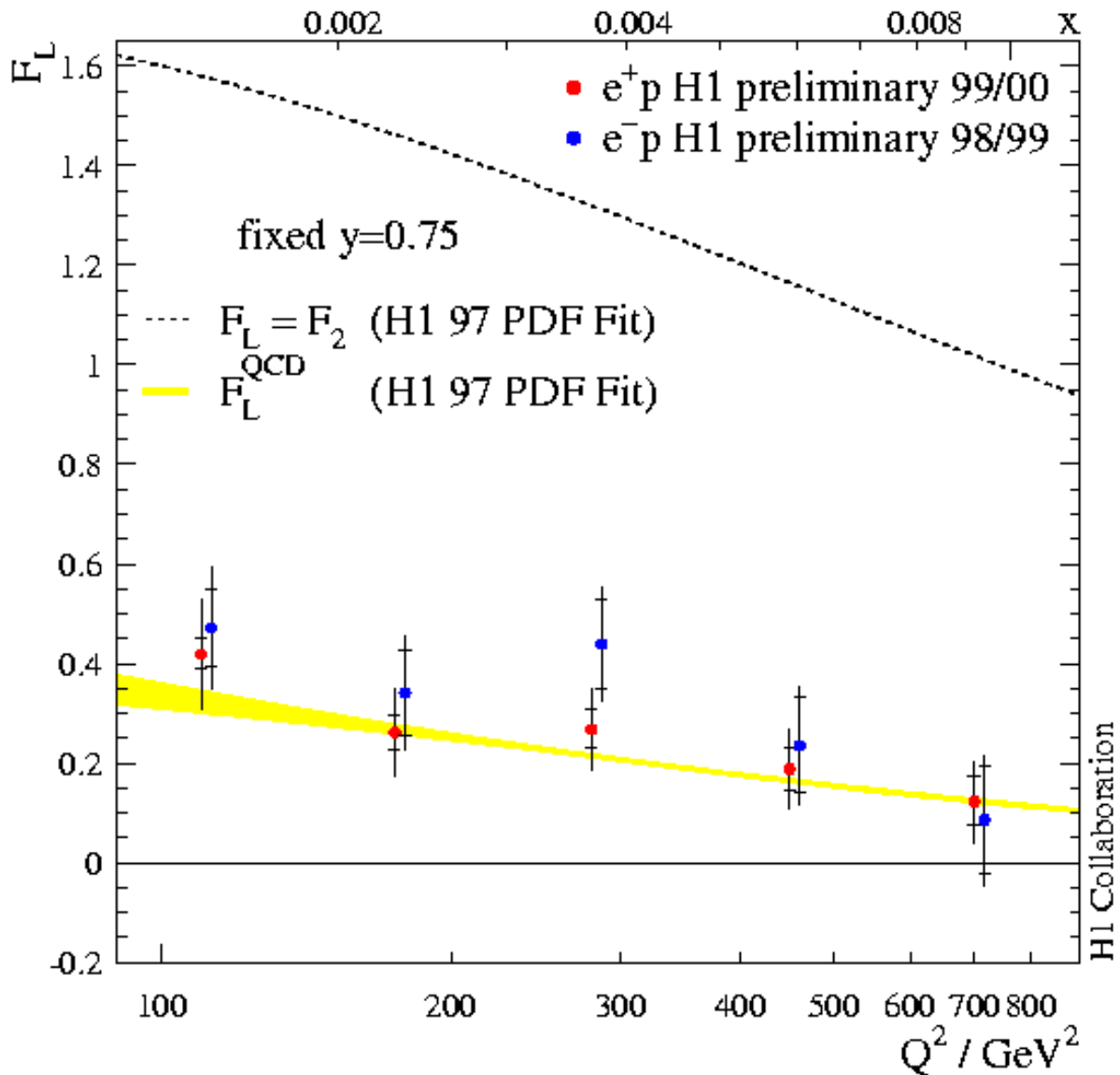
$$F_L = \frac{Y_+}{y^2} (F_2^{\text{fit}} - a\tilde{\sigma})$$

$F_2^{\text{fit}}$  – using H1 97 PDF fit  
 – relative normalisation of data ( $y < 0.4$ )  
 w.r.t. QCD fit:

$$e^- \text{ (98/99)} \quad a = 1. / 1.014 \pm 0.010$$

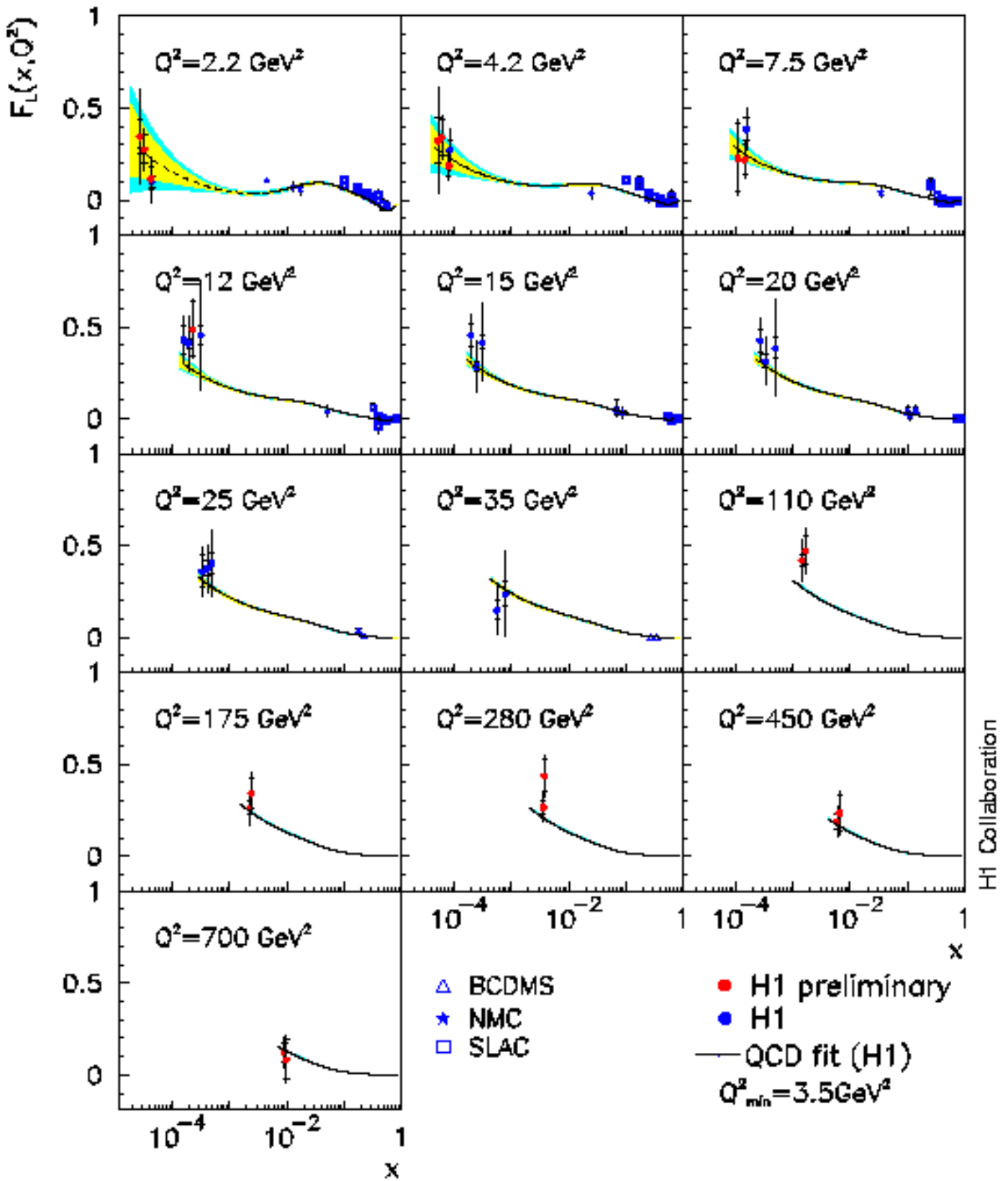
$$e^+ \text{ (99/00)} \quad a = 1. / 0.999 \pm 0.006$$

## F<sub>L</sub> Results at High Q<sup>2</sup>



- the two measurements in agreement
- agreement with QCD

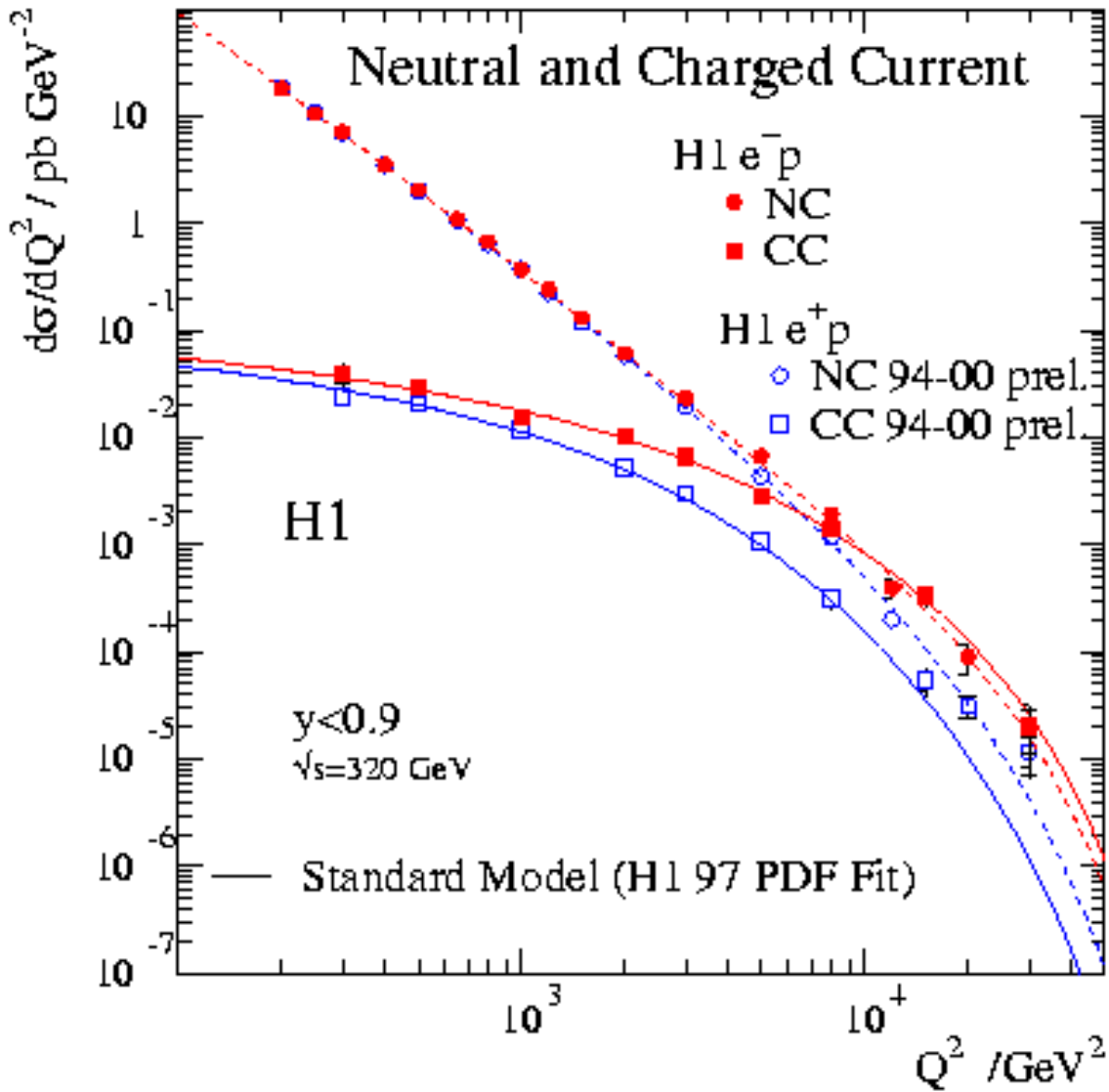
# H1 Results for $F_L$





# Charged Current Cross Section

Unification of weak and electromagnetic forces



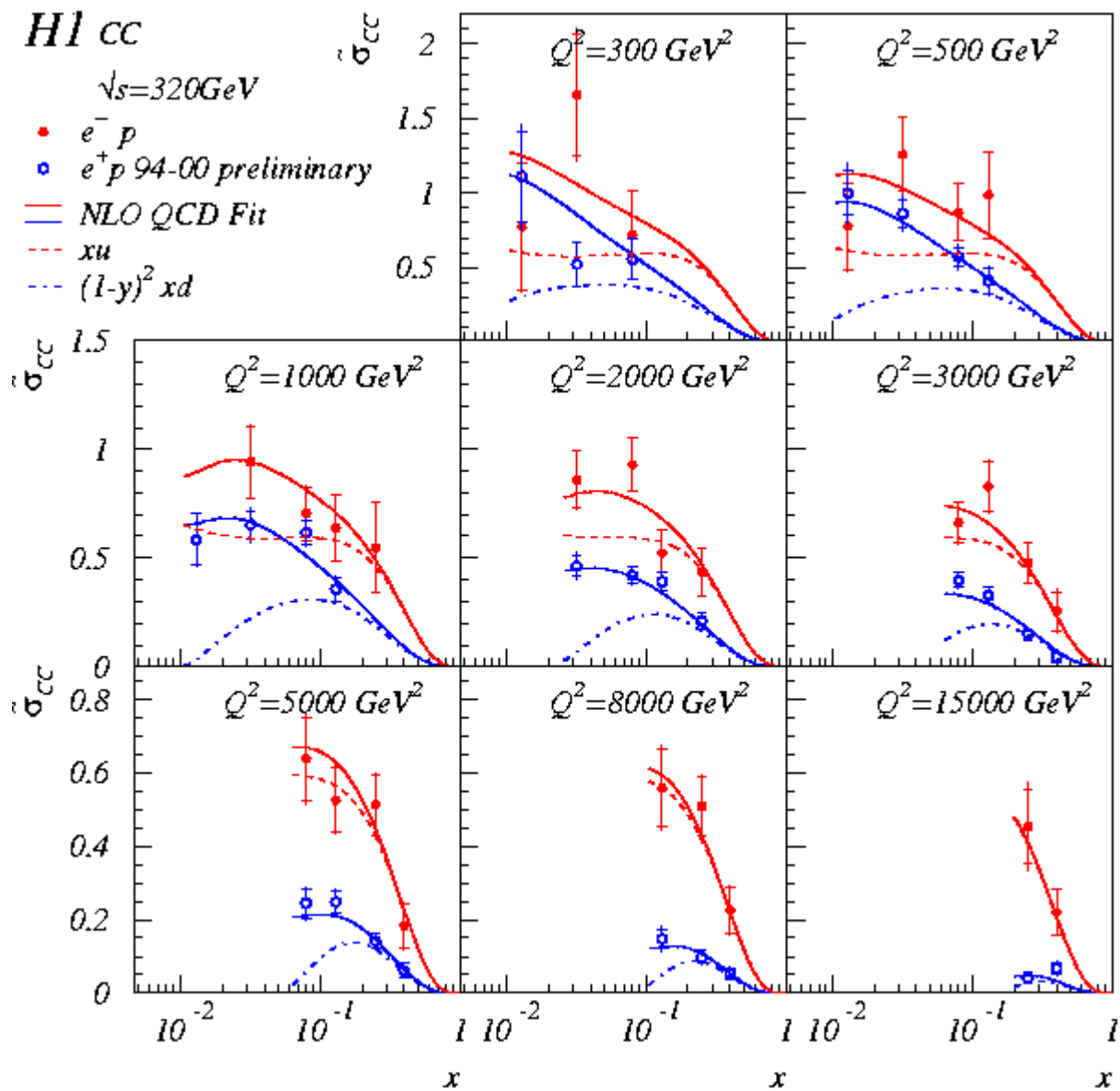
$$\sigma_{\text{tot}}^{\text{CC}}(e^-p) = 43.08 \pm 1.84(\text{stat.}) \pm 1.74(\text{syst.}) \text{ pb}$$

# Double Differential CC Cross Section

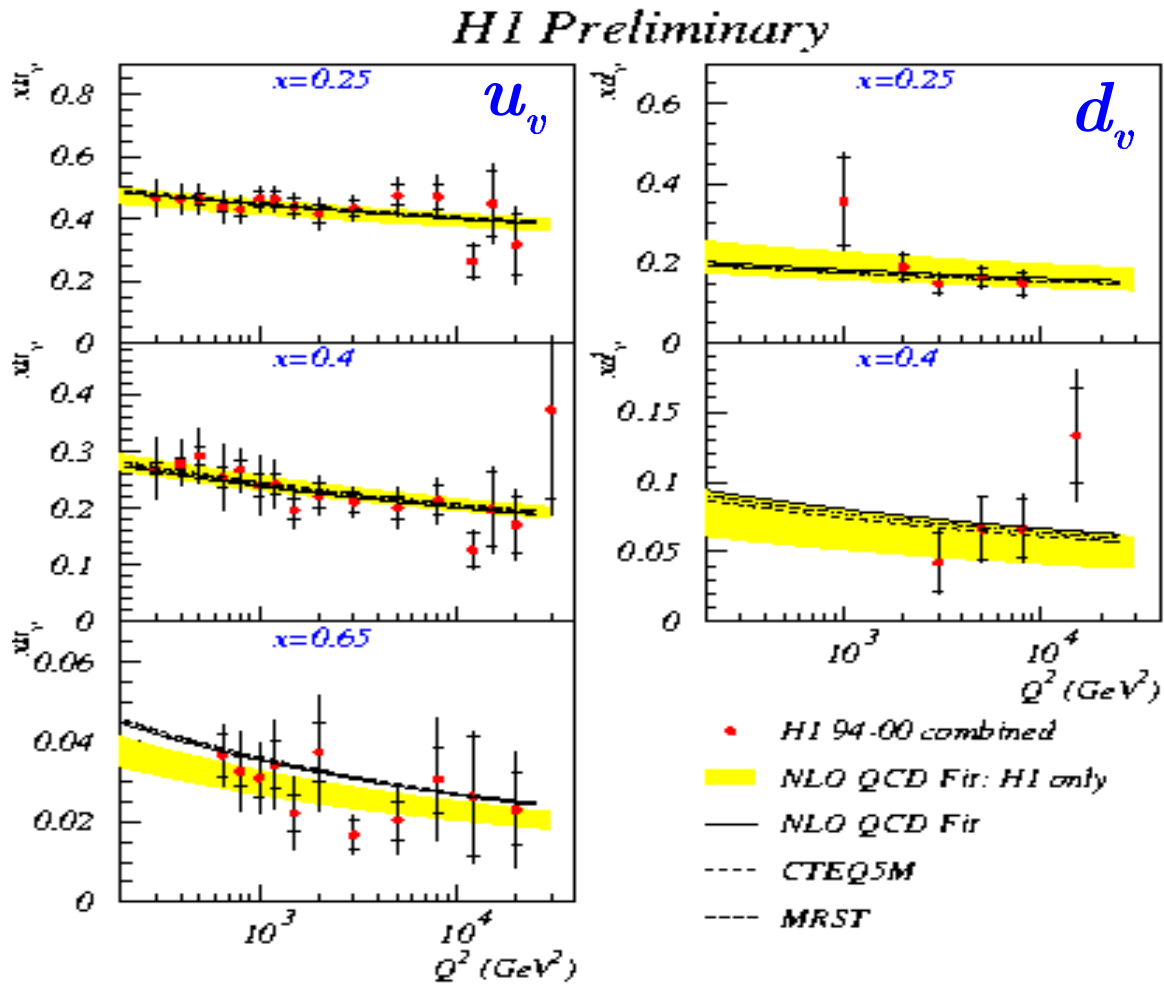
$$\frac{d\sigma_{CC}^{e^\pm p}}{dx dQ^2} = \frac{G_F^2}{2\pi x} \left( \frac{M_W^2}{Q^2 + M_W^2} \right)^2 \tilde{\sigma}_{CC}^\pm$$

$$\tilde{\sigma}_{CC}^+ = x \left[ (\bar{u} + \bar{c}) + (1-y)^2 (d + s) \right] \simeq (1-y)^2 x d_v \quad x \rightarrow 1$$

$$\tilde{\sigma}_{CC}^- = x \left[ (u + c) + (1-y)^2 (\bar{d} + \bar{s}) \right] \simeq x u_v$$



# Valence Quark Flavour Decomposition at High $x$



- Extraction of  $xu_v$  and  $xd_v$  from  $\tilde{\sigma}_{\text{NC}}^{e^\pm p}$  and  $\tilde{\sigma}_{\text{CC}}^{e^\pm p}$

local extraction method:

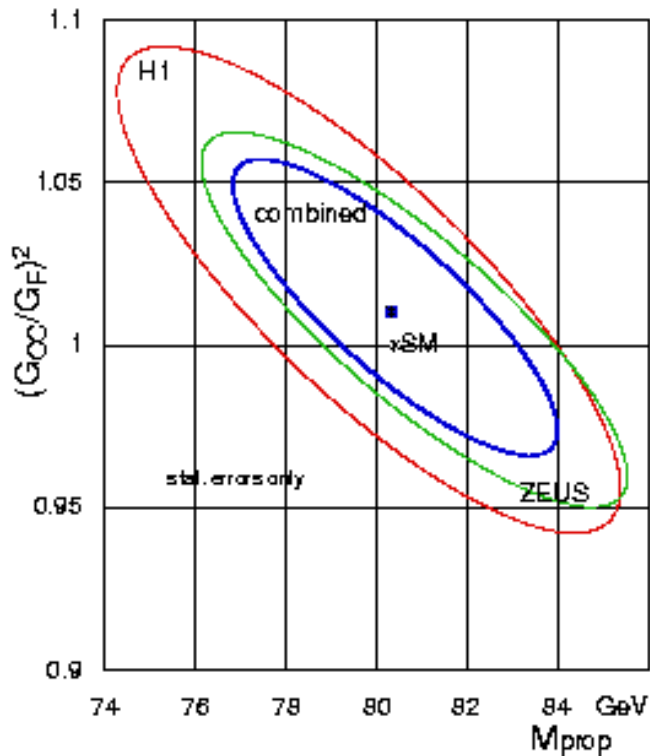
$$xq_v(x, Q^2) = \sigma_{\text{meas}}(x, Q^2) \left( \frac{xq_v}{\sigma} \right)_{\text{fit}}$$

$$\text{only if } \left( \frac{\sigma(xq_v)}{\sigma} \right)_{\text{fit}} > 0.7$$

almost model independent

- $xu_v, xd_v$  consistent with NLO QCD fit

# W Propagator Mass



$$\frac{d^2\sigma_{CC}}{dx dQ^2} \propto G_{CC}^2 \left( \frac{M_{prop}^2}{Q^2 + M_{prop}^2} \right)^2$$

*normalisation* given by coupling  $G_{CC}$  ( $G_F$ )

*shape* given by propagator mass  $M_{prop}$  ( $M_W$ )

from the constrained fit with  $G_{CC} \equiv G_F$ :

94/97  $e^+p$  :  $M_W = 80.9 \pm 3.3(\text{stat.}) \pm 1.7(\text{syst.}) \pm 3.7(\text{pdf})$

98/99  $e^-p$  :  $M_W = 79.9 \pm 2.2(\text{stat.}) \pm 0.9(\text{syst.}) \pm 2.1(\text{pdf})$

# Summary

- Neutral and charged current single and double differential cross sections measured in  $e^-p$  and  $e^+p$  interactions:  $d\sigma/dQ^2$ ,  $d\sigma/dx$ ,  $d^2\sigma/dxdQ^2$
- all three structure functions  $F_2$ ,  $xF_3$ ,  $F_L$  extracted:
  - $F_2$  from  $e^-p$  and  $e^+p$  interactions are in agreement
  - $\gamma Z$  interference is observed and sum rule for  $F_3^{\gamma Z}$  is checked
  - $F_L$  measured for the first time at high  $Q^2$
- local extraction of quark densities  $xu_v$ ,  $xd_v$  consistent with global QCD fit
- $W$  propagator mass – a cross-check of the electroweak theory in the space-like regime

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