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

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

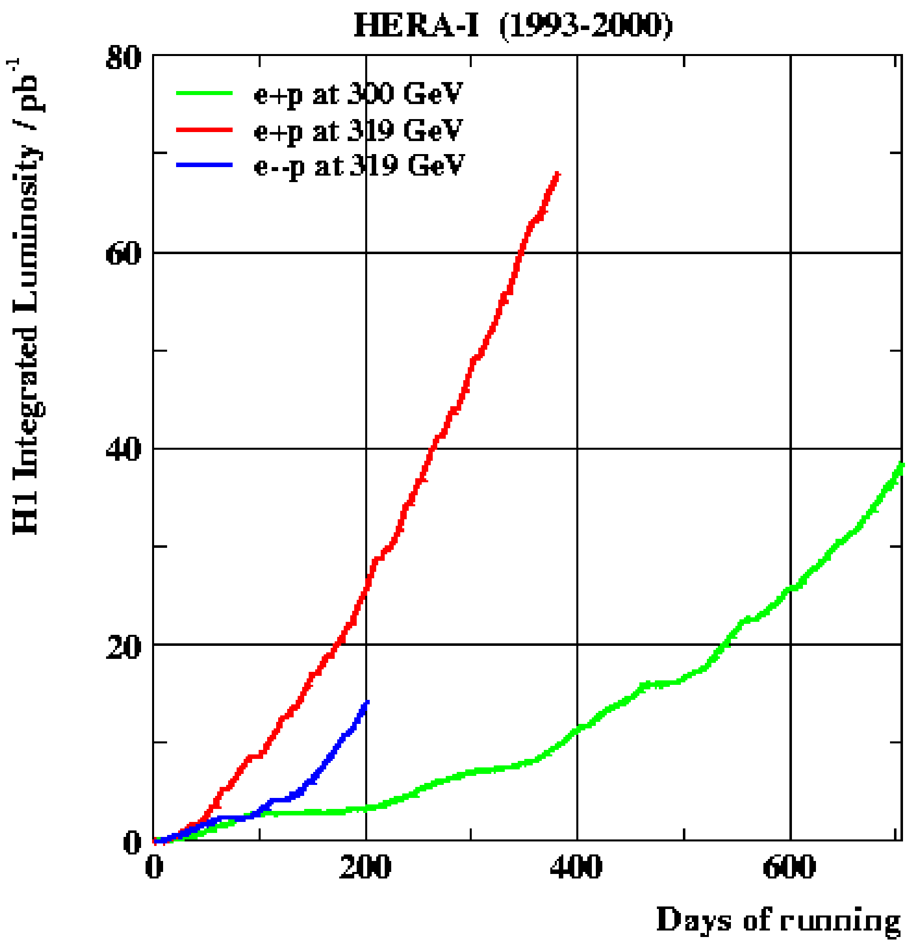
- **HERA, H1, DIS**
- **NC & CC (e^+p and e^-p)**
  - **Cross sections**
  - **Proton structure function F_2**
  - **Structure function $x\tilde{F}_3$**
  - **Sum rule for $F_3^{\gamma Z}$**
  - **Longitudinal structure function F_L**
  - **Valence quark distributions**
  - **W propagator mass**
- **Summary**

HERA

$e^{\pm}$ → ← p $\sqrt{s} = 320\ \mathrm{GeV}$

27.5 GeV

920 GeV
(since 1998)

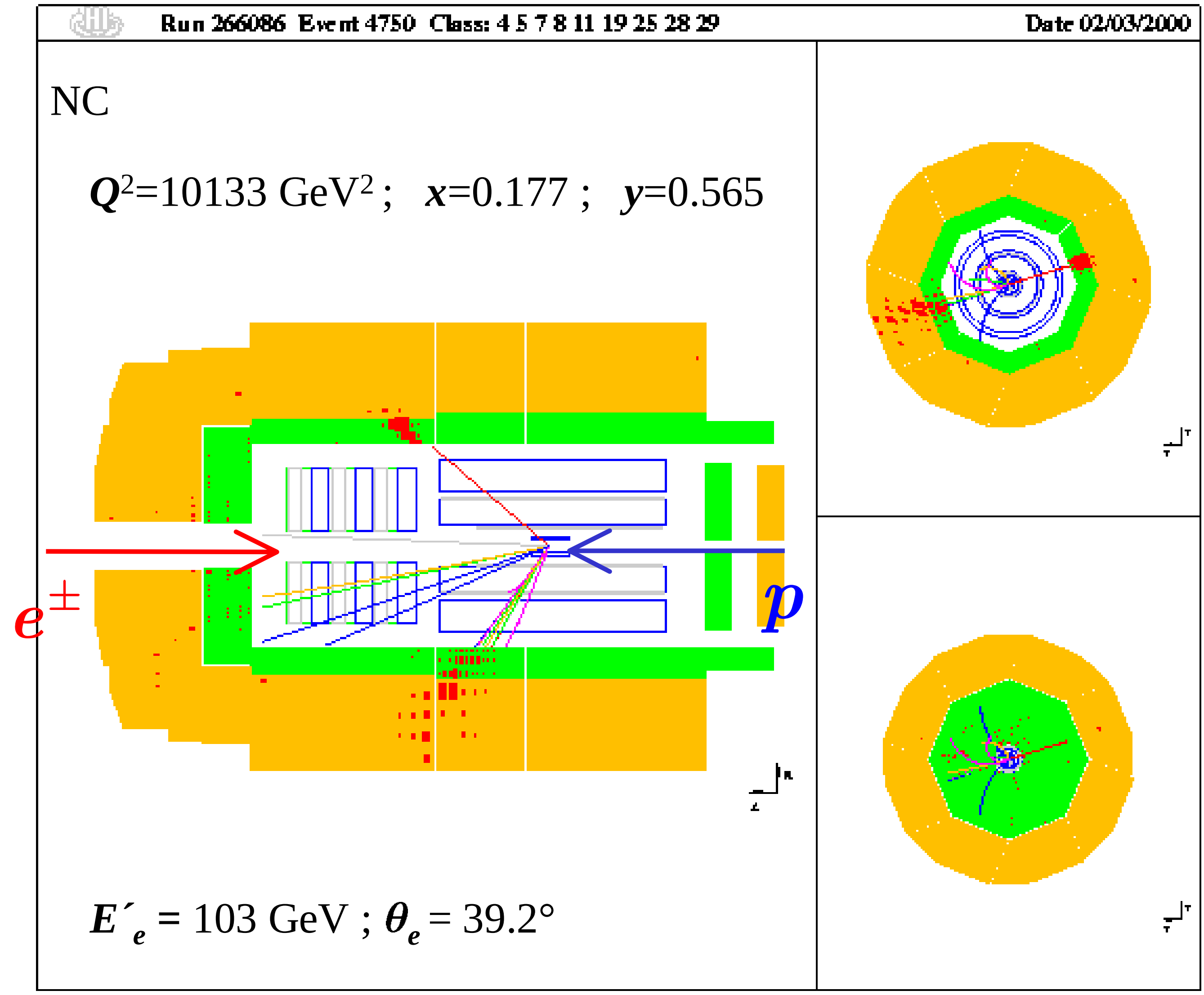


H1 Luminosity:

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

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

The H1 Detector



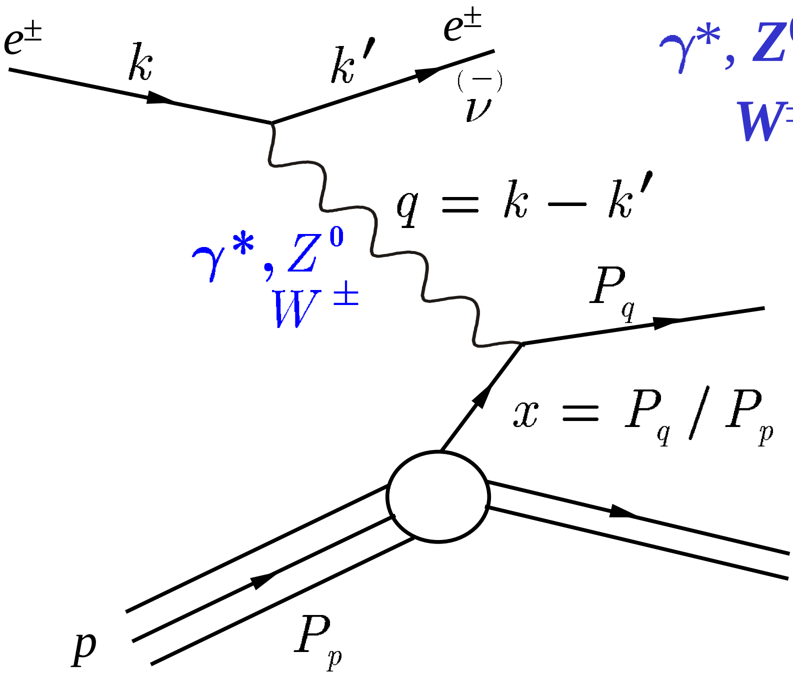
LAr calorimeter:
High granularity 45000 cells

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

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

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

Deep Inelastic Scattering



γ^*, Z^0 – neutral current (NC)

$W^{\pm}$ – charged current (CC)

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 $ep \to e'X$

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

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

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:

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

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

$$F_L = F_2 - 2xF_1 = 0$$ (Callan-Gross relation)

in QCD:

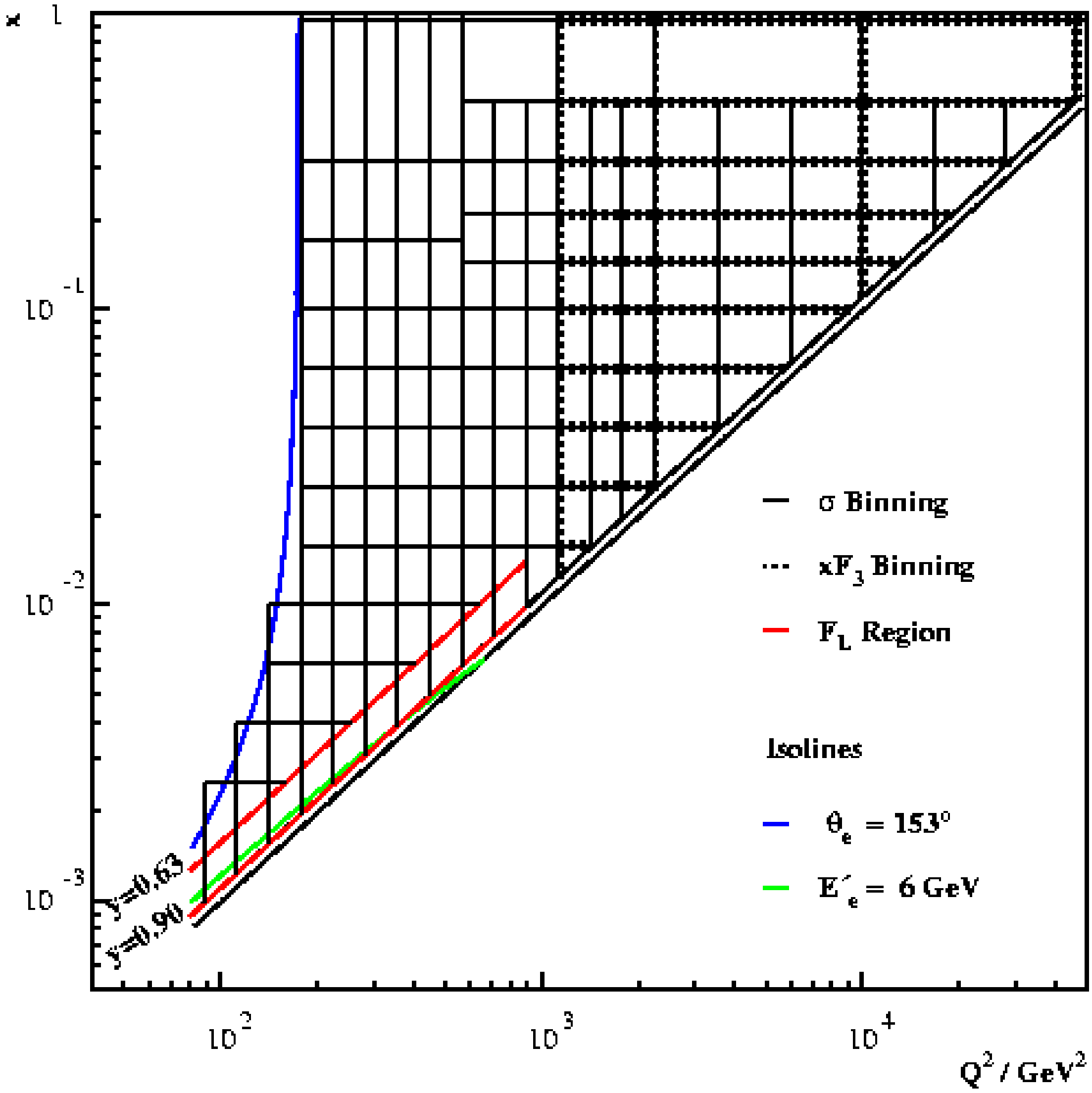
$$F_L = \frac{\alpha_s}{4\pi}x^2\int_x^1 \frac{dz}{z^3}\left[\frac{16}{3}\sum_q z e_q^2 (q+\bar{q}) + 8\sum_q e_q^2\left(1-\frac{x}{z}\right)\cdot zg\right]$$

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

SM = EW + QCD

Kinematic Range

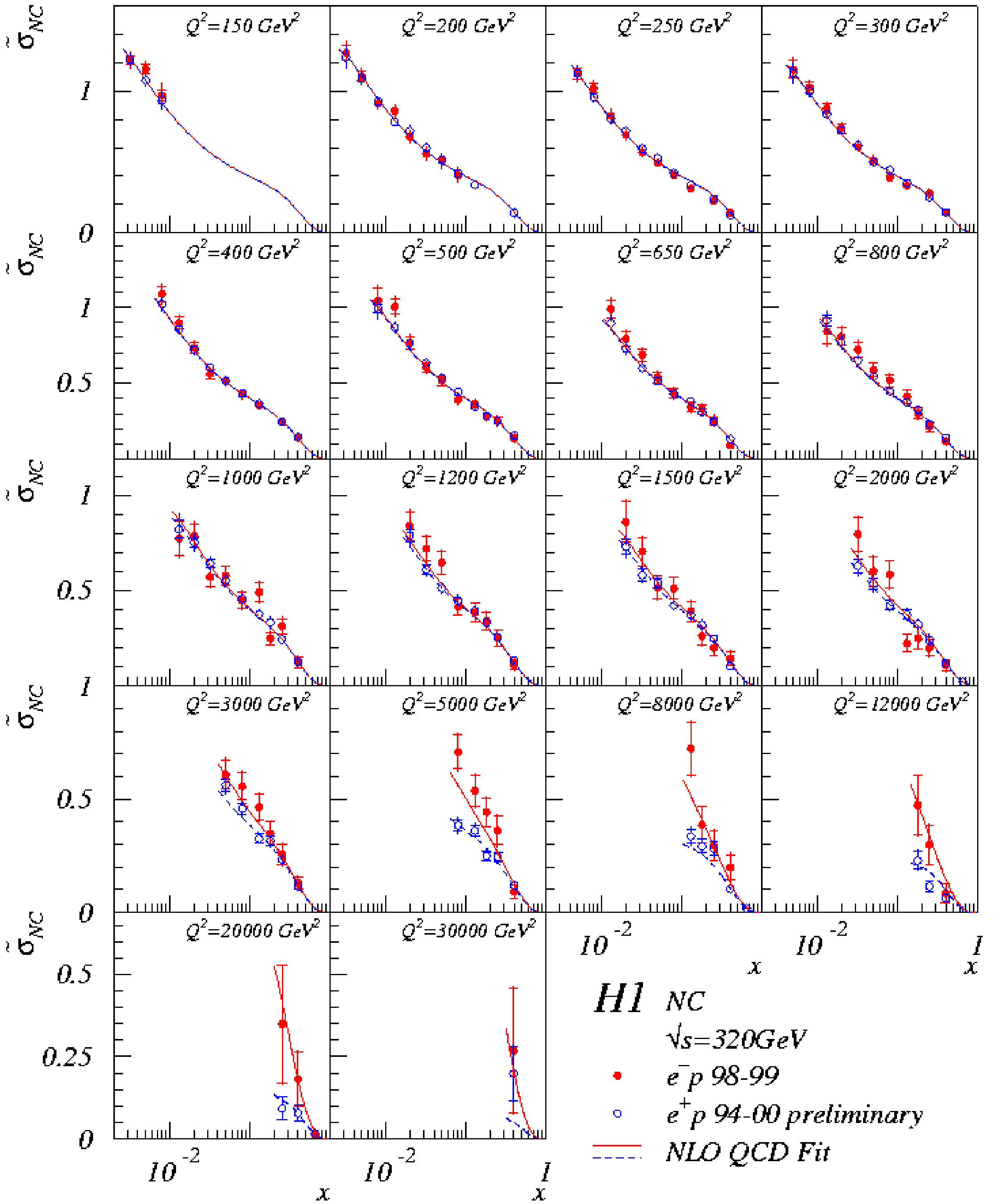
$$\frac{d\sigma_{NC}^{e^{\pm}p}}{dx\,dQ^2} = \frac{2\pi\alpha^2}{xQ^4}\left[Y_+\tilde{F}_2 \mp Y_- x\tilde{F}_3 - y^2\tilde{F}_L\right]$$



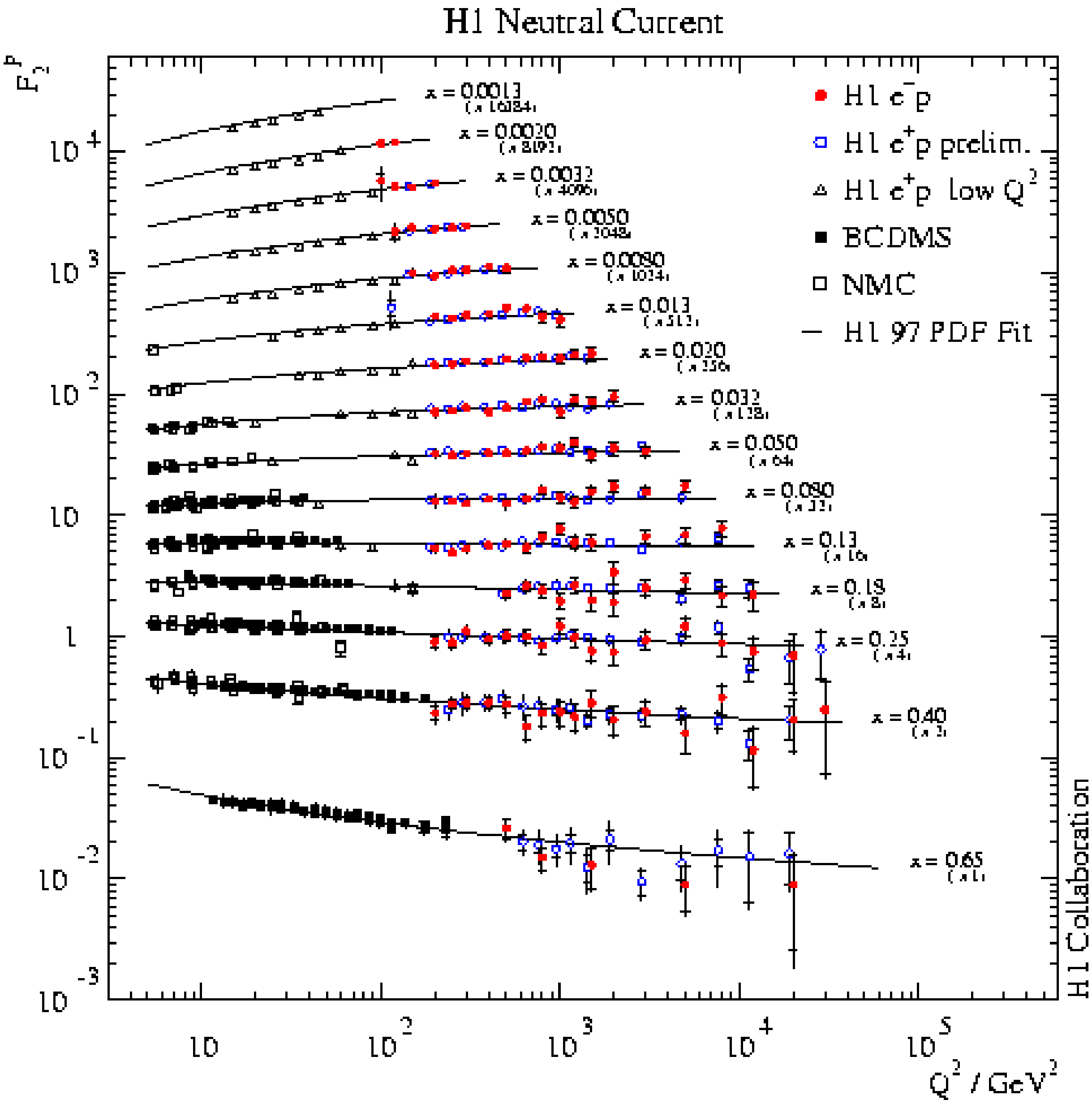
- $F_2 \quad \rightarrow \quad$ full kinematic range
- $x\tilde{F}_3 \quad \rightarrow \quad$ high Q^2
- $F_L \quad \rightarrow \quad$ high y

NC Double Differential Cross Section

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

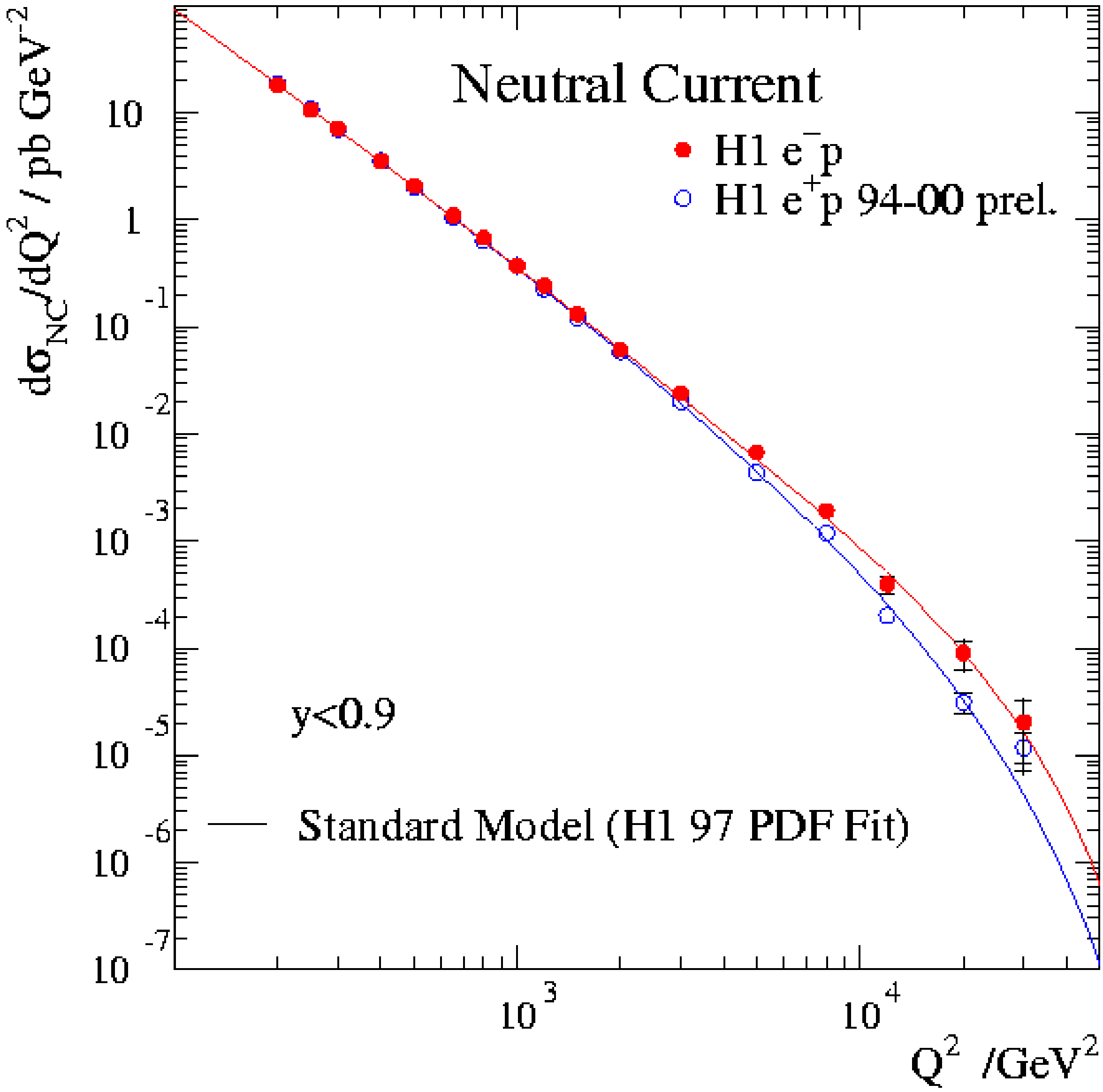


Proton Structure Function F_2



- consistent measurements from $\boldsymbol{e^-p}$ and $\boldsymbol{e^+p}$

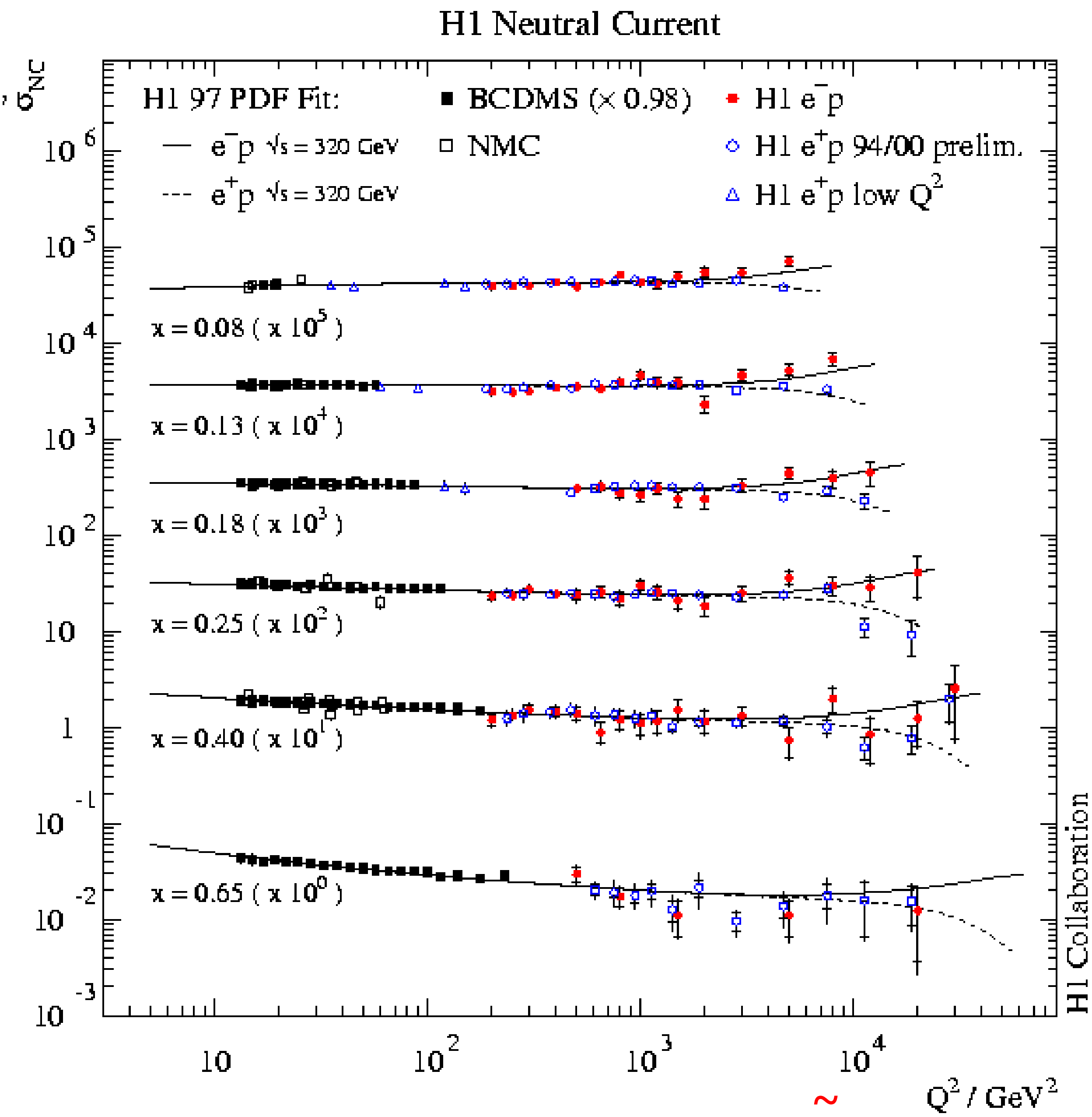
NC Single Differential Cross Section



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

Double Differential Cross Section at high x

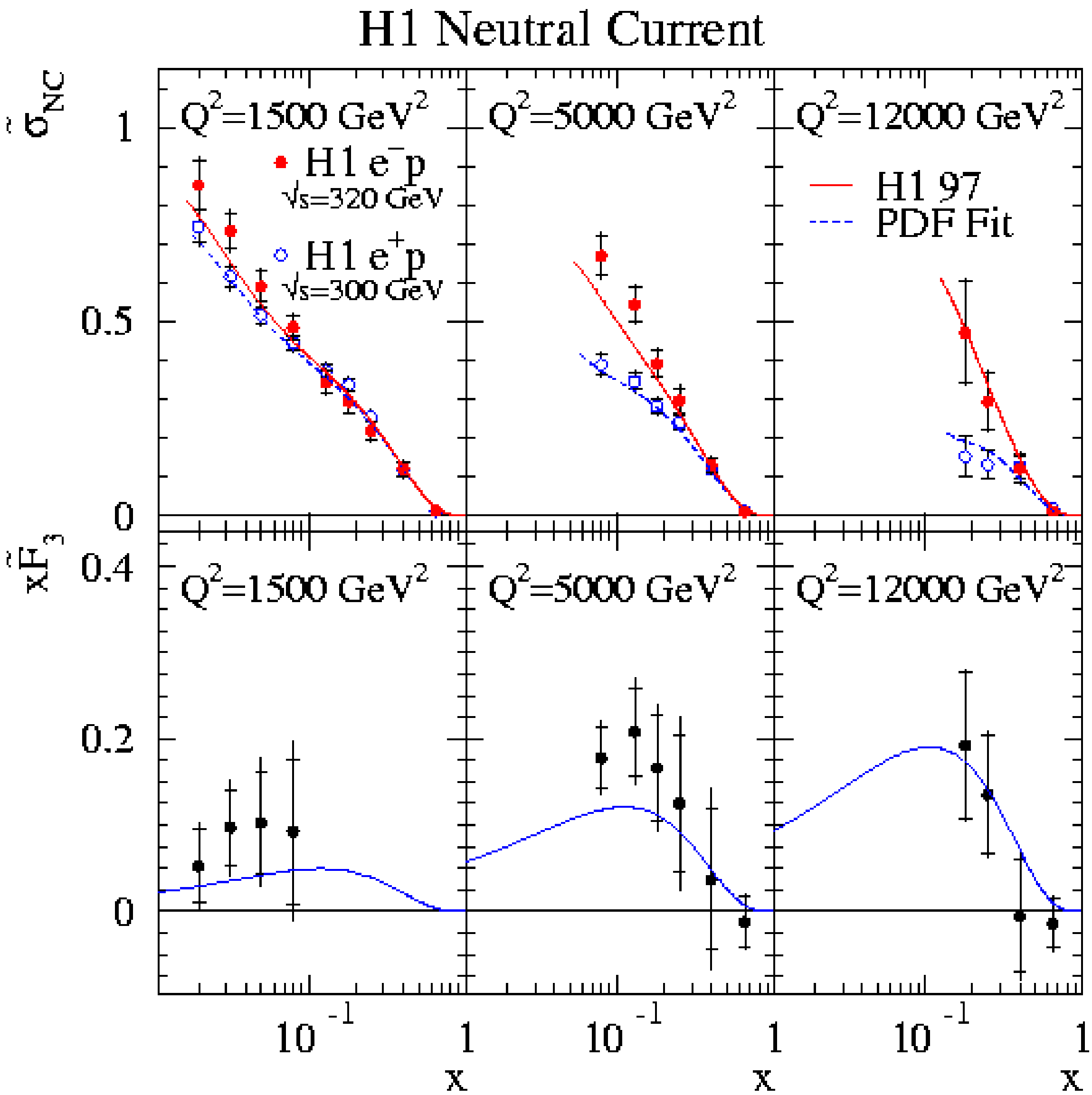
$$\tilde{\sigma}_{NC}(e^{\pm}p) = \tilde{F}_2 \mp \frac{Y_-}{Y_+} x\tilde{F}_3, \qquad Y_\pm = 1 \pm (1-y)^2$$



- negative (positive) contribution from xF_3 in e^+p (e^-p)

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

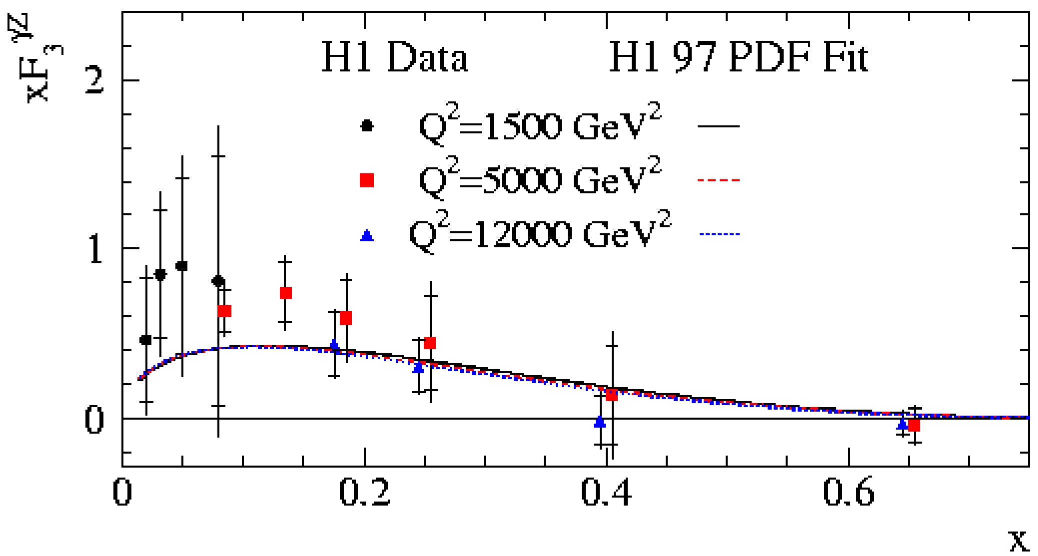
$$x\tilde{F}_3 = \frac{Y_+}{2Y_-}\left(\tilde{\sigma}^-_{NC} - \tilde{\sigma}^+_{NC}\right), \qquad Y_\pm = 1 \pm (1-y)^2$$



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

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

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



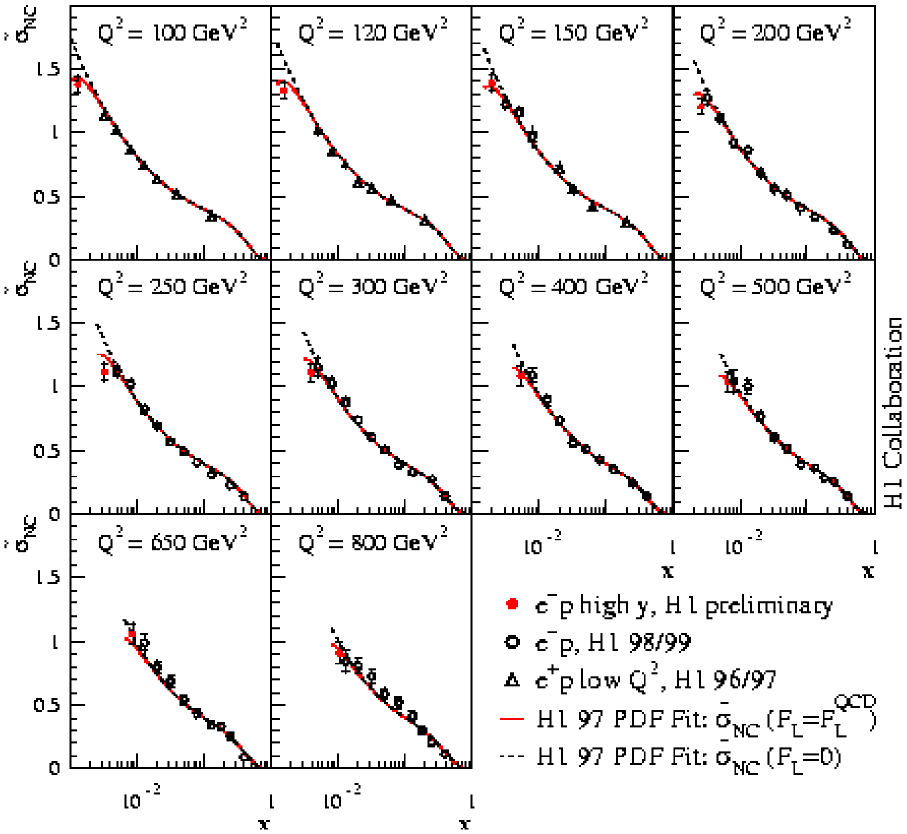
Sum rule for $F_3^{\gamma Z}$:
(by analogy with *Gross Lewellyn-Smith* sum rule for νN scattering)

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

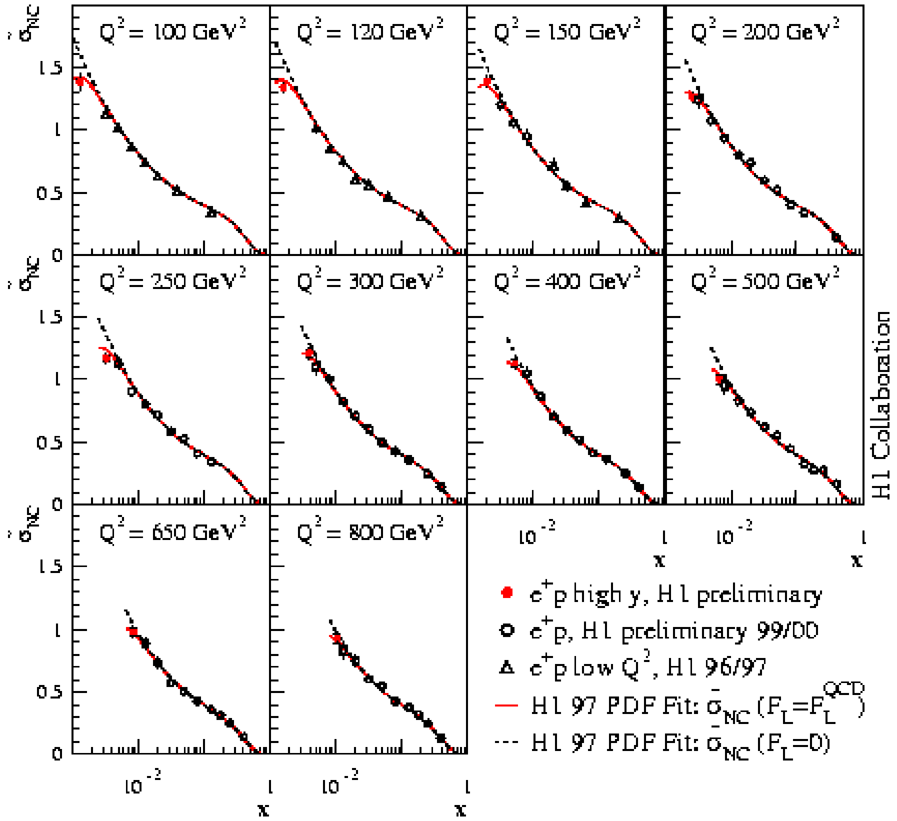
H1: $$\int_{0.02}^{0.65} F_3^{\gamma Z} \mathrm{d}x = 1.88 \pm 0.35(\text{stat.}) \pm 0.27(\text{syst.})$$

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

Extension of Cross Section Measurement to high y=0.75



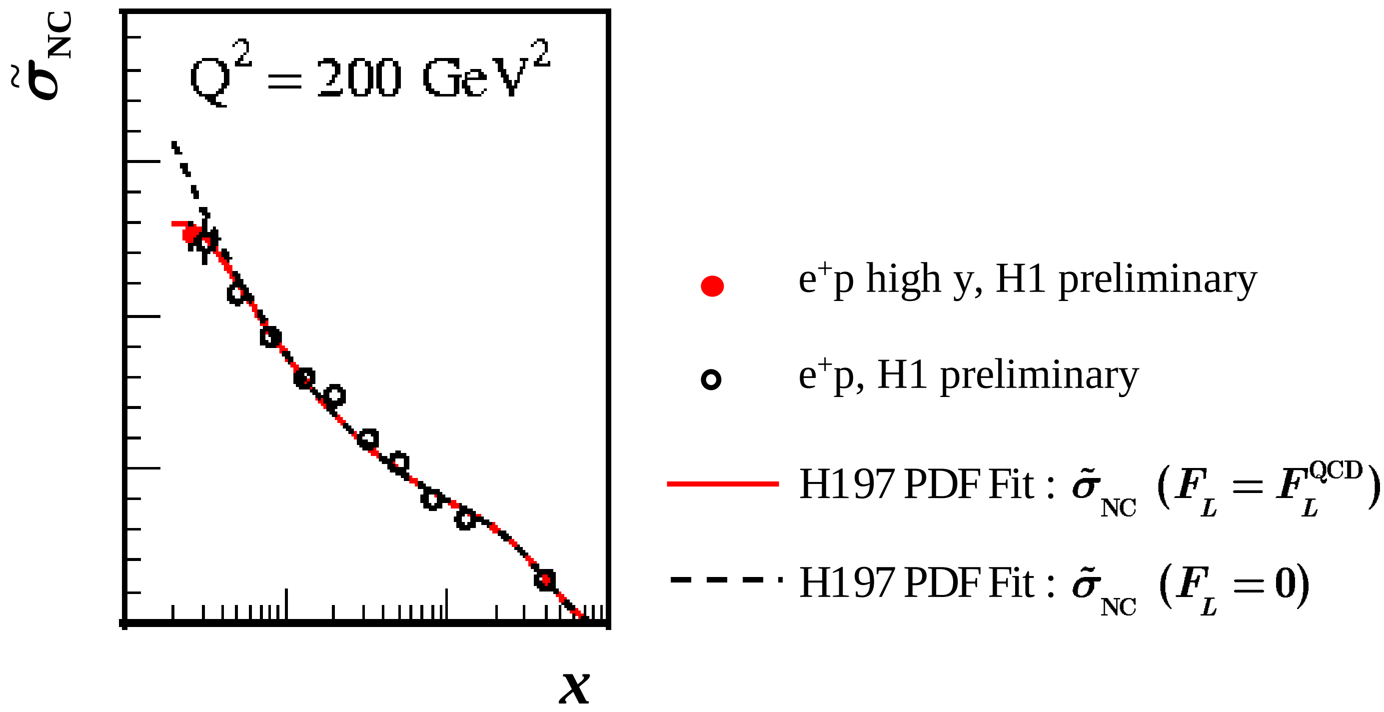
***e^-p* 98/99**



***e^+p* 99/00**

Determination of F_L

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



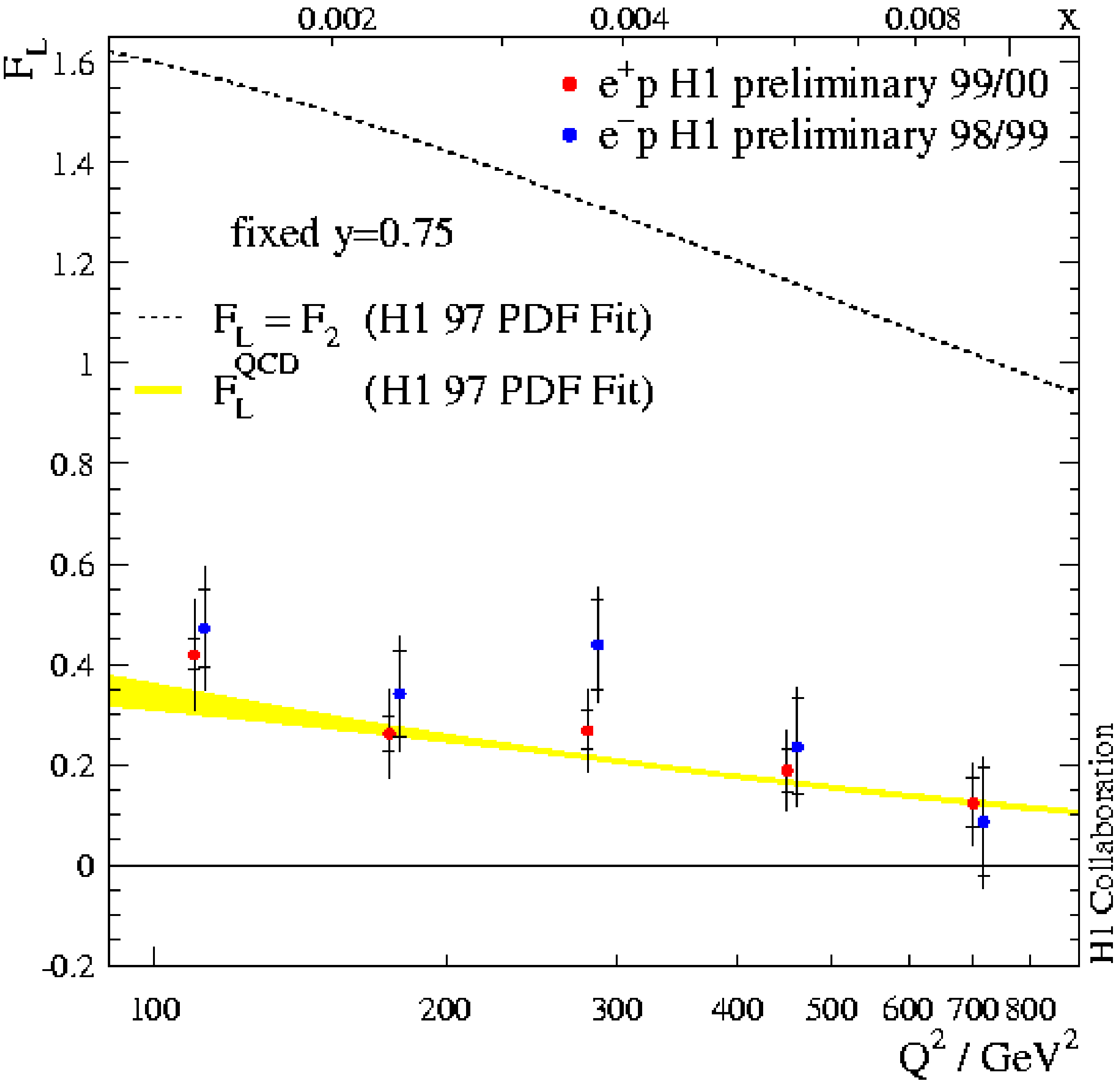
$$F_L = \frac{Y_+}{y^2}\left(F_2^{fit} - a\tilde{\sigma}\right)$$

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

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

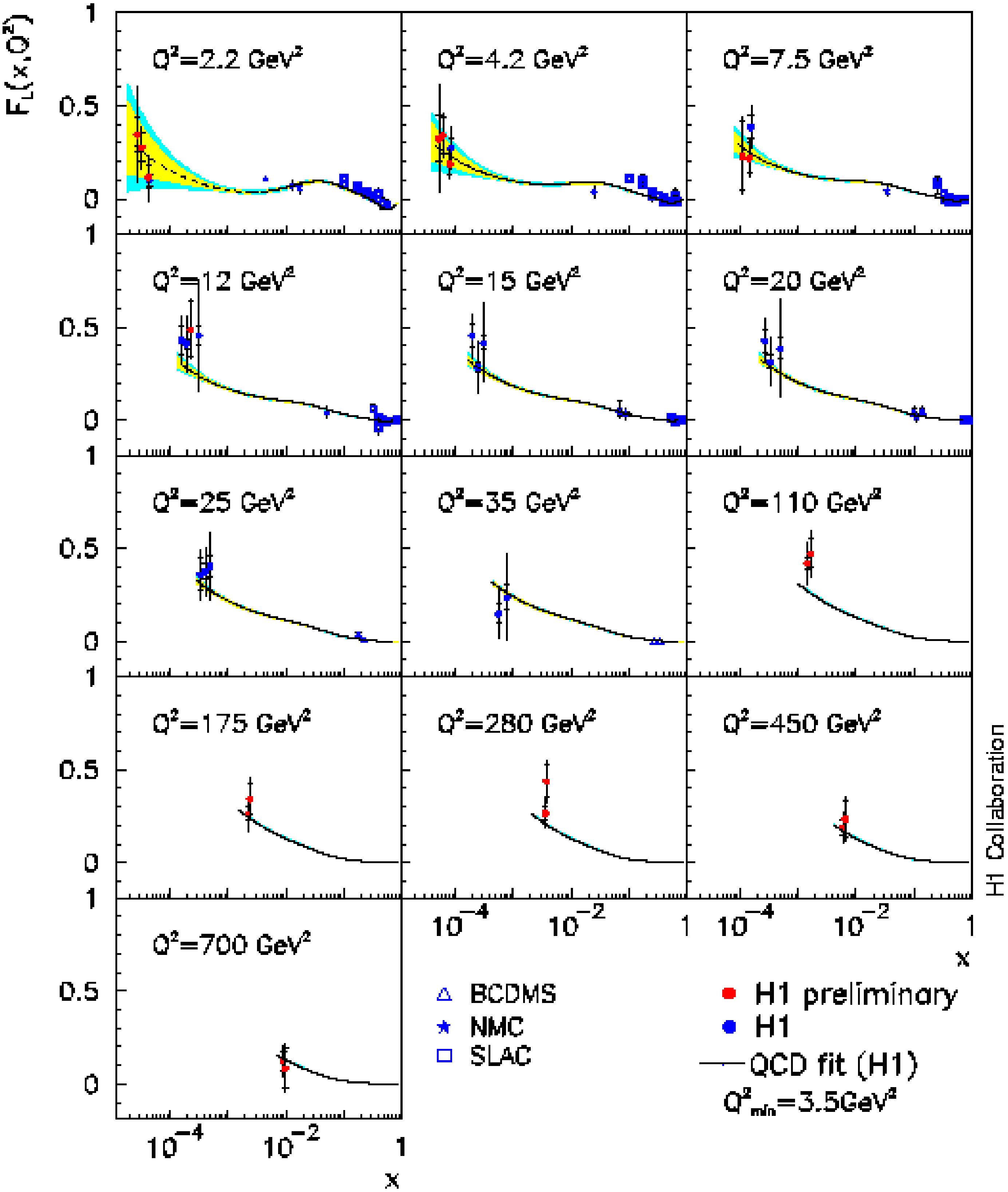
e^+ (99/00) $a = 1./0.999 \pm 0.006$

F_L Results at High Q^2



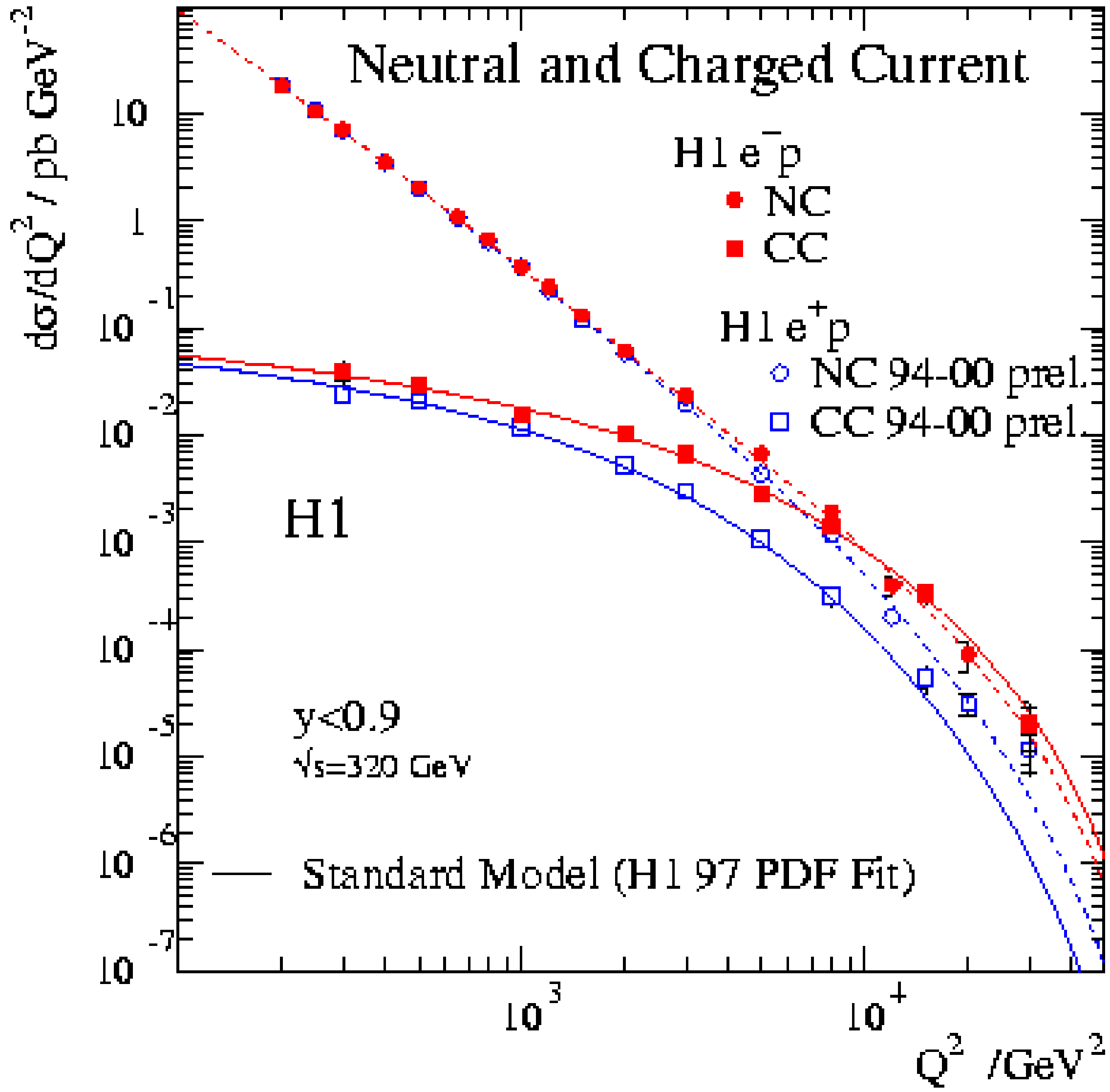
- the two measurements in agreement
- agreement with QCD

H1 Results for F_L



Charged Current Cross Section

Unification of weak and electromagnetic forces



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

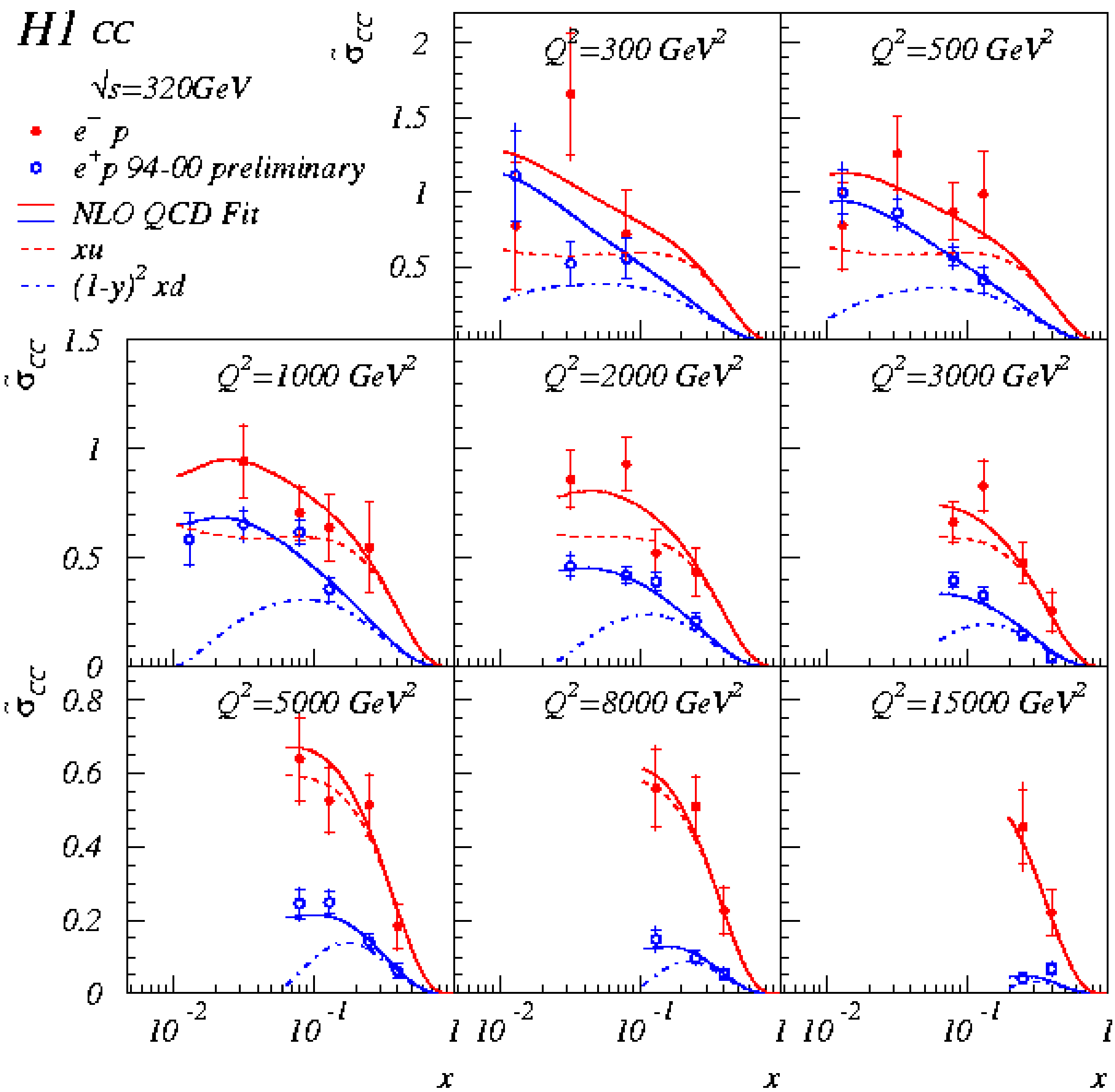
Double Differencial CC Cross Section

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

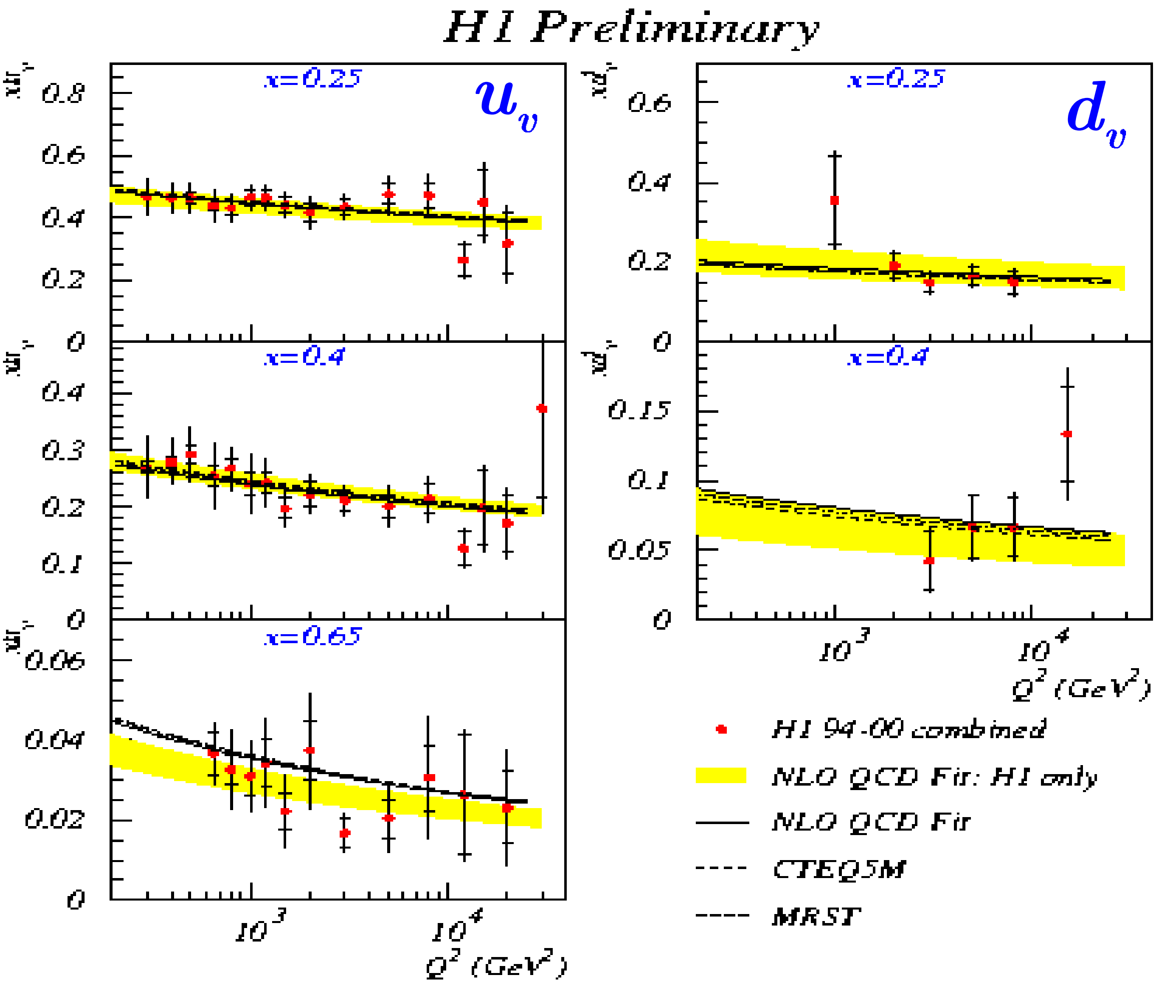
$$\tilde{\sigma}_{CC}^{+} = x\left[(\bar{u}+\bar{c}) + (1-y)^2(d+s)\right] \simeq (1-y)^2 x d_v$$

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

$$x \to 1$$



Valence Quark Flavour Decomposition at High x



- Extraction of xu_v and xd_v from $\tilde{\sigma}^{e^\pm p}_{\mathrm{NC}}$ and $\tilde{\sigma}^{e^\pm p}_{\mathrm{CC}}$ local extraction method:

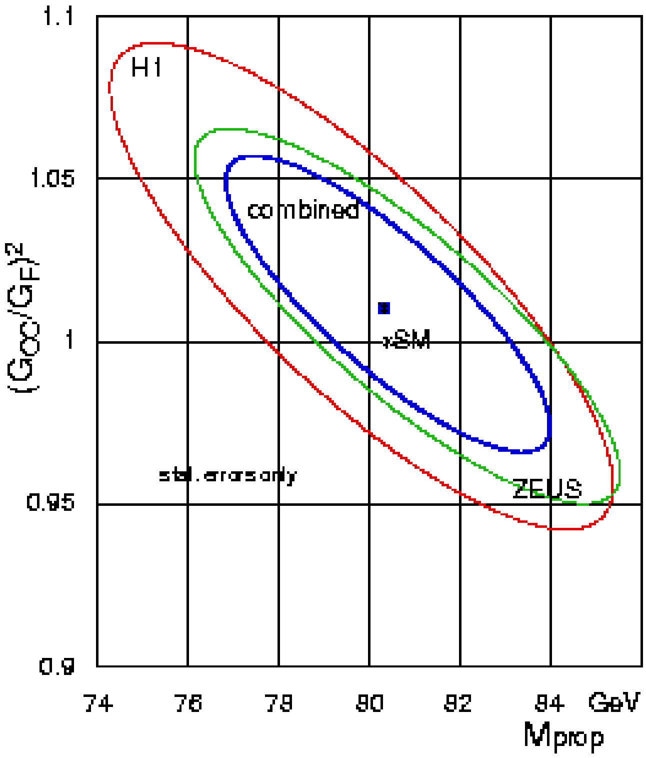
$$xq_v(x,Q^2) = \sigma_{\mathrm{meas}}(x,Q^2)\left(\frac{xq_v}{\sigma}\right)_{\mathrm{fit}}$$

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

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**
  - **γZ 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