Neutral and Charged Current Cross Sections and Measurements of F_2, xF_3 and F_L at high Q^2 at HERA

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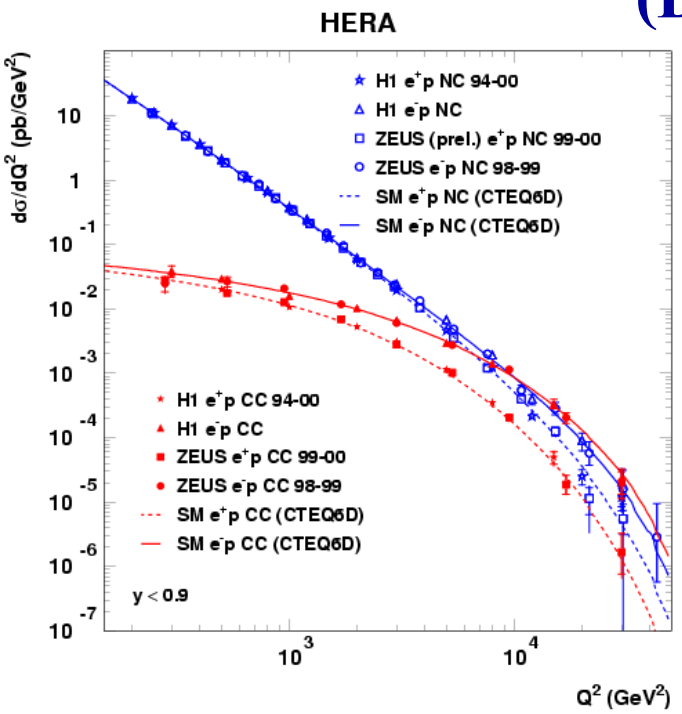
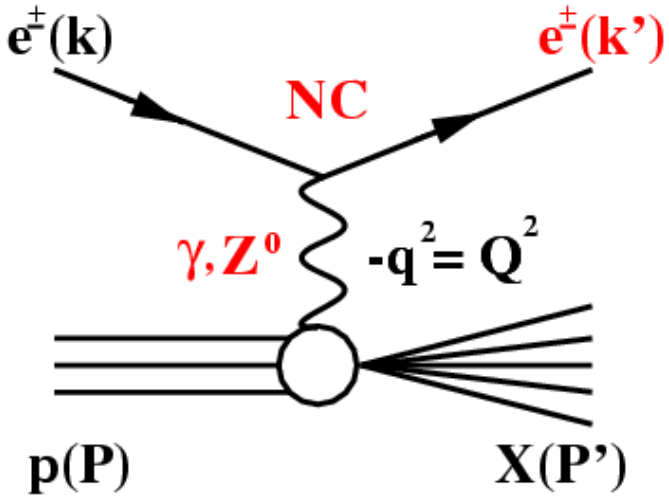
(DESY, now at CERN)



- DIS and kinematics at HERA
- proton structure with highest resolution → new physics at high Q^2?
- test QCD PDF evolution
- study EW sector of SM

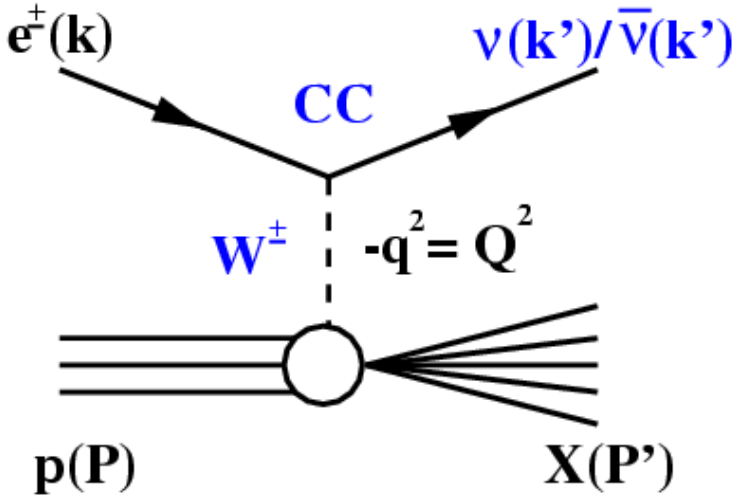
DIS at HERA



$Q^2 = -q^2 = -(k - k')^2$ negative 4-momentum transfer squared, carried by boson

$\longrightarrow \lambda \approx \hbar c / \sqrt{Q^2} \longrightarrow 1/1000 r_P$

$x = \dfrac{Q^2}{2P \cdot q}$ QPM: fraction of proton momentum, carried by struck quark



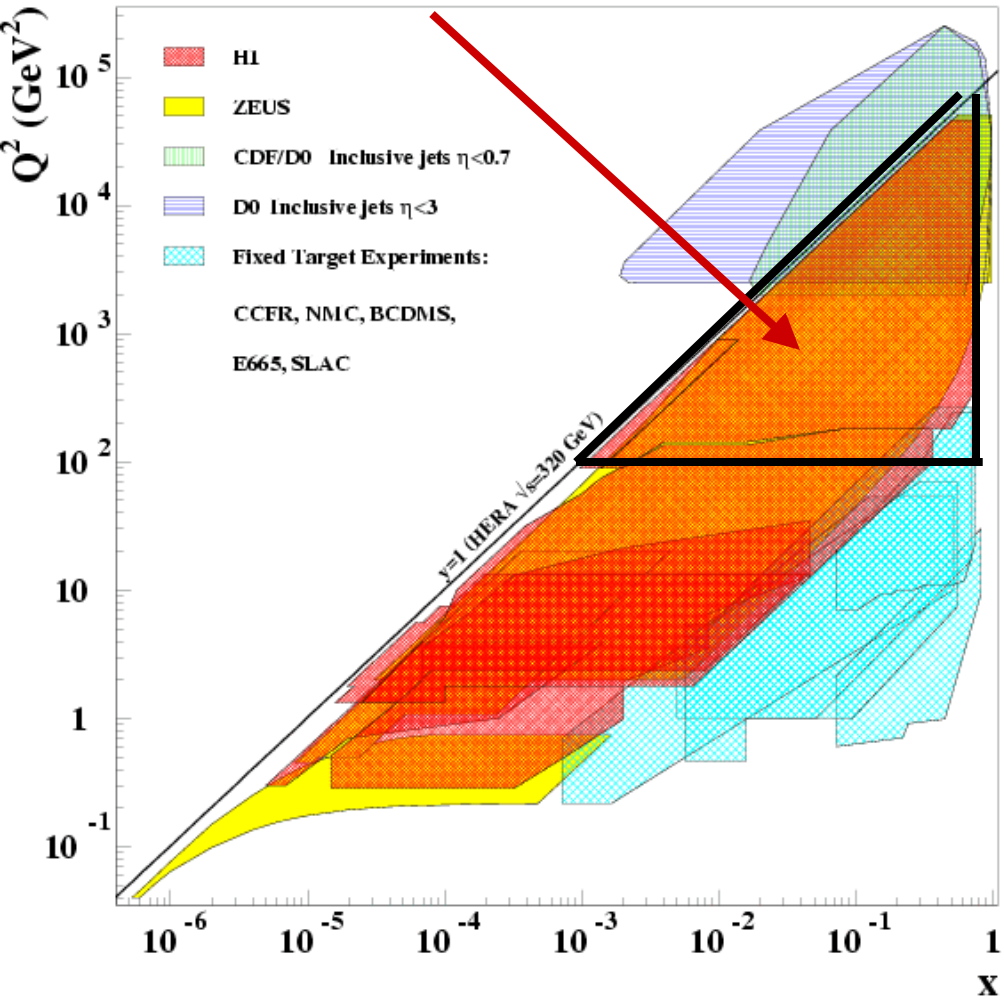
$y = \dfrac{P \cdot q}{P \cdot k}$ Inelasticity, in eq cms: related to lepton scattering angle θ^*:

$\longrightarrow y = (1 - \cos\theta^*)/2$

$s = (k + P)^2 = \dfrac{Q^2}{xy}$ Squared cms energy $\longrightarrow$ only 2 independent variables

Kinematic Plane and Data Samples

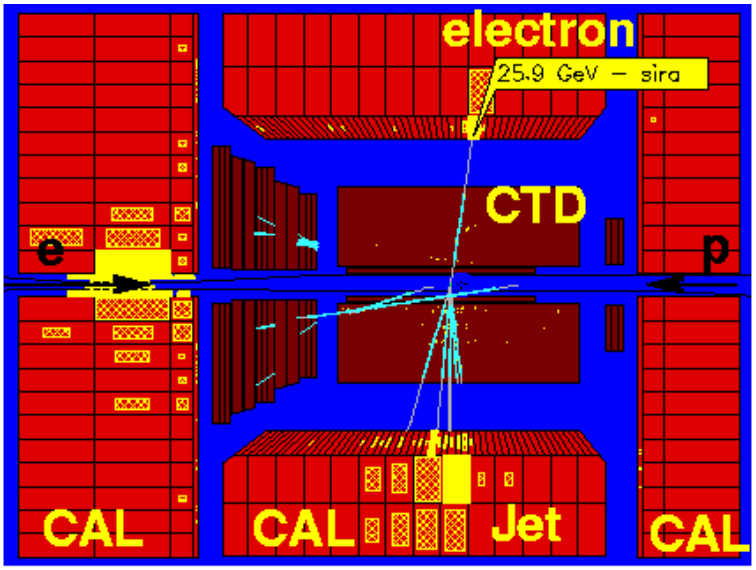
this talk!

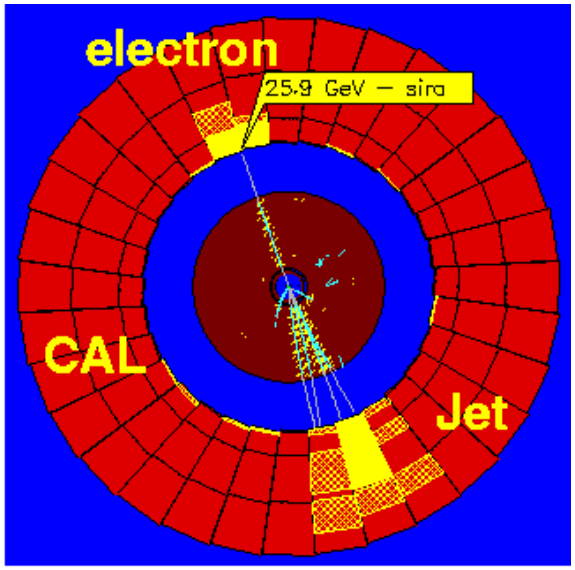


HERA run periods:

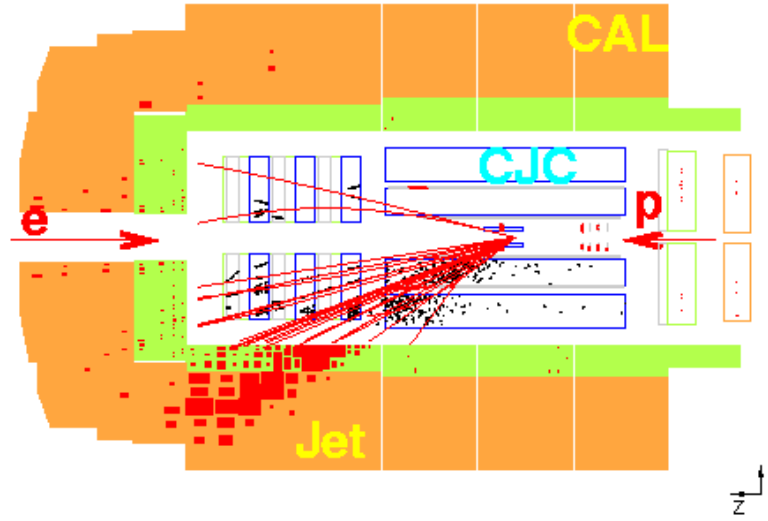
y	94-97	98-99	99-00
data	e^+p	e^-p	e^+p
E_e	27.5	27.5	27.5
E_p	820	920	920
$\sqrt{s}$	300	318	318
$\mathcal{L}$(1/pb) H1	36	16	65
$\mathcal{L}$(1/pb) ZEUS	48	16	61

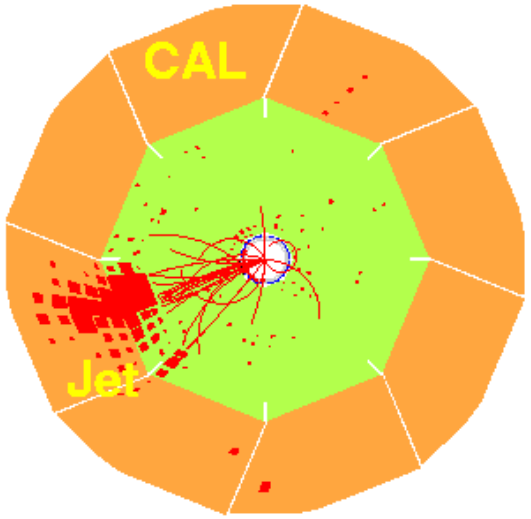
NC Event in ZEUS, CC Event in H1





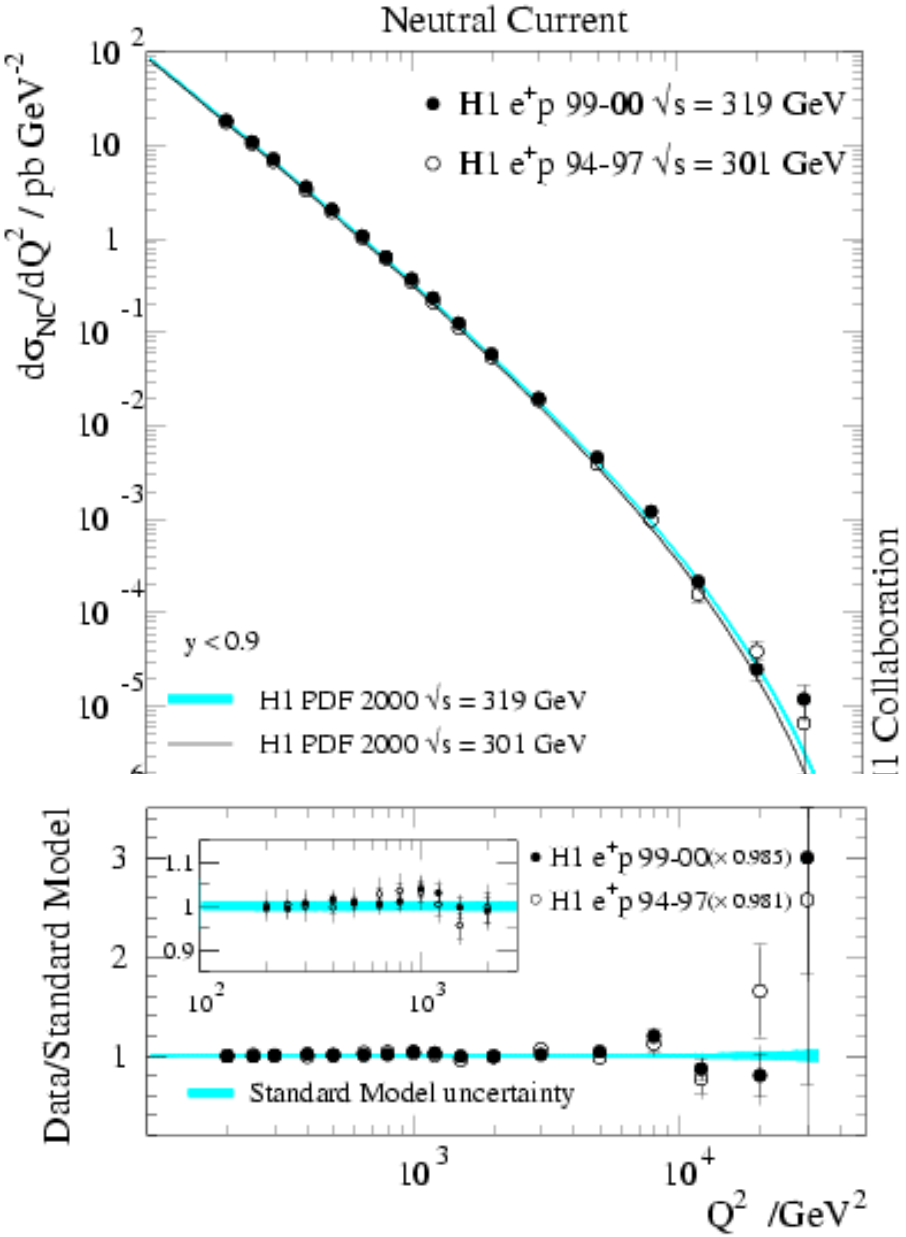
NC:
-e backscattered, high E_t
- balance in P_t





CC:
- missing ν
- no balance in P_t

NC Cross Section

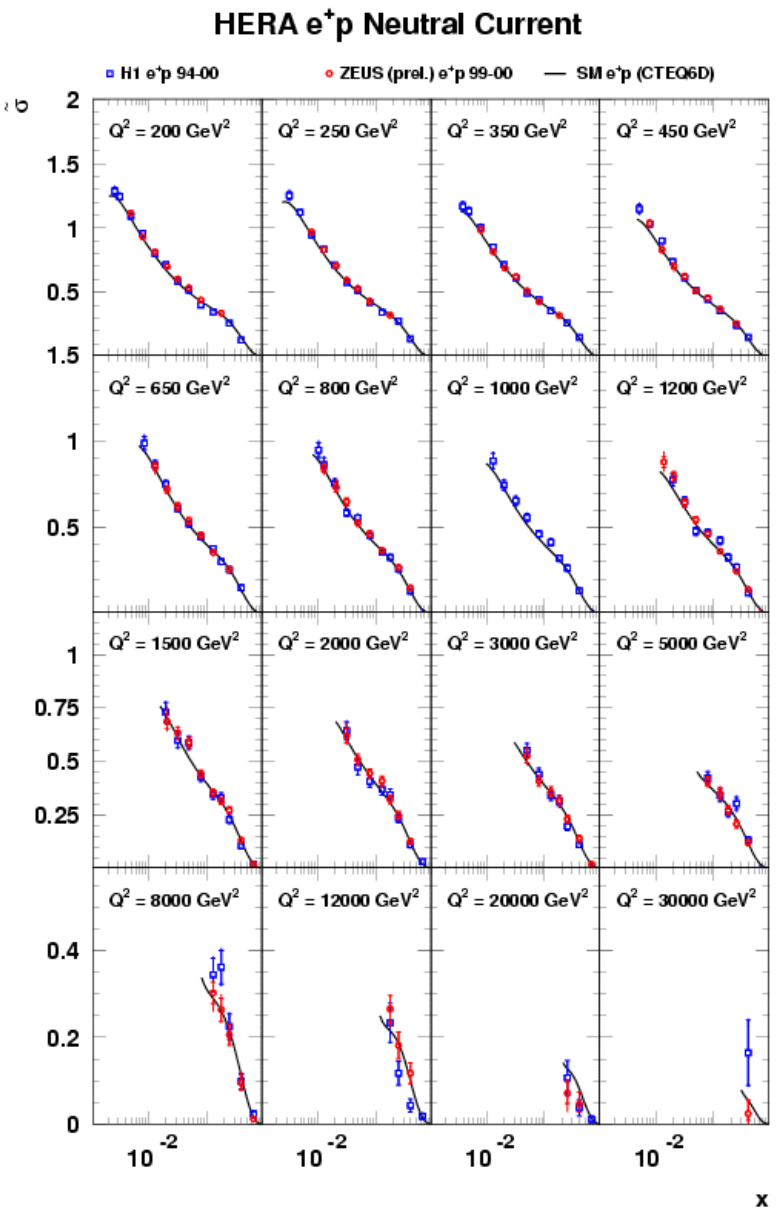


$$\frac{d^2\sigma_{NC}^{e^{\pm}p}}{dxdQ^2} = \frac{2\pi\alpha^2}{Q^4 x}\left[Y_+ F_2 \mp Y_- xF_3 - y^2 F_L\right]$$

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

- dominant γ exchange
- spans 7 orders of magnitude
- insight in proton at smallest distance scales
- well described by SM

NC Reduced Cross Section



$$\frac{d^2\sigma_{NC}^{e\pm p}}{dxdQ^2} = \frac{2\pi\alpha^2}{Q^4 x}\left[Y_+ F_2^{NC} \mp Y_- xF_3^{NC} - y^2 F_L^{NC}\right]$$

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

reduced cross section:

$$\tilde{\sigma}_{NC}^{e\pm p} = \left[F_2^{NC} \mp \frac{Y_-}{Y_+} xF_3^{NC} - \frac{y^2}{Y_+} F_L^{NC}\right]$$

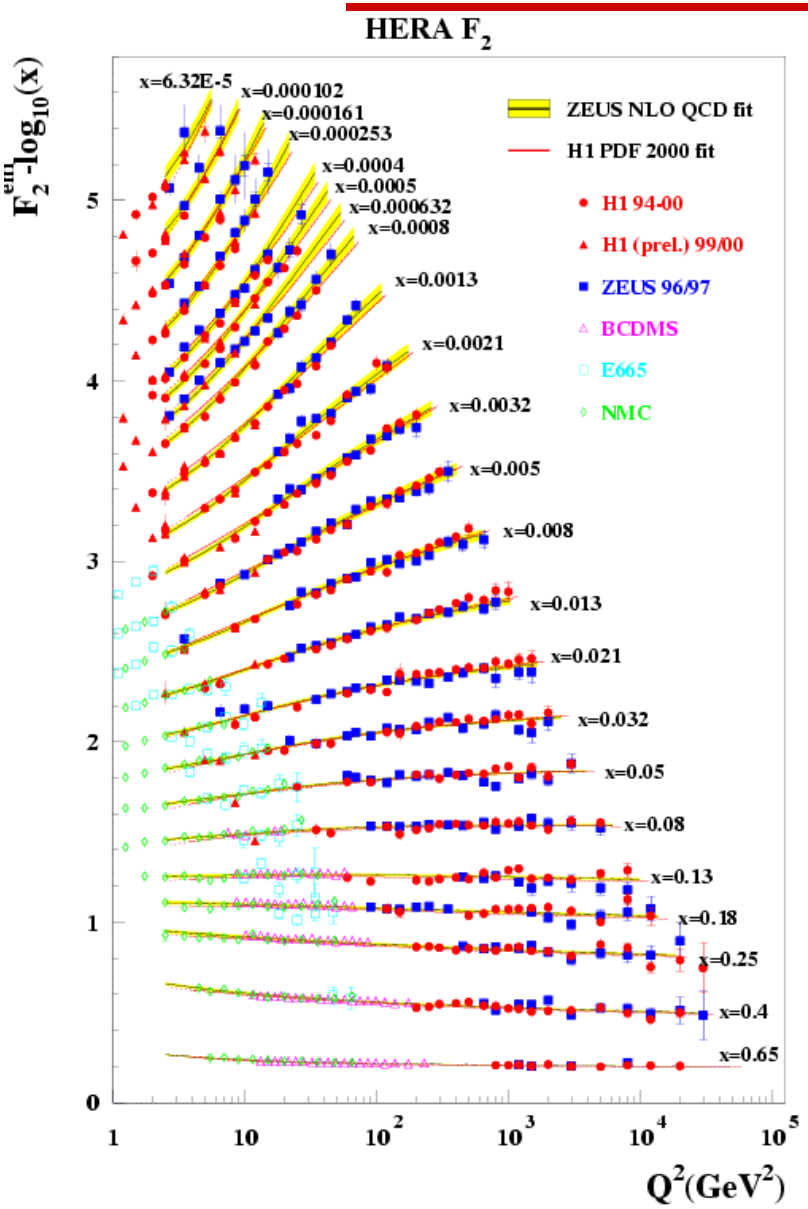
- **precise cross section determination**

(bulk of data:

stat.: 1.5-3%, tot.: 3-4%)

- **in agreement with SM**

The Structure Function F_2



in QPM:

$$F_2 = \sum_i x(q + \bar{q})A_i$$

sensitive to valence and sea quarks

$$F_2 = F_2^{em} - v_l \left[\frac{\kappa_W Q^2}{Q^2 + M_Z^2}\right] G_2 + \ldots$$

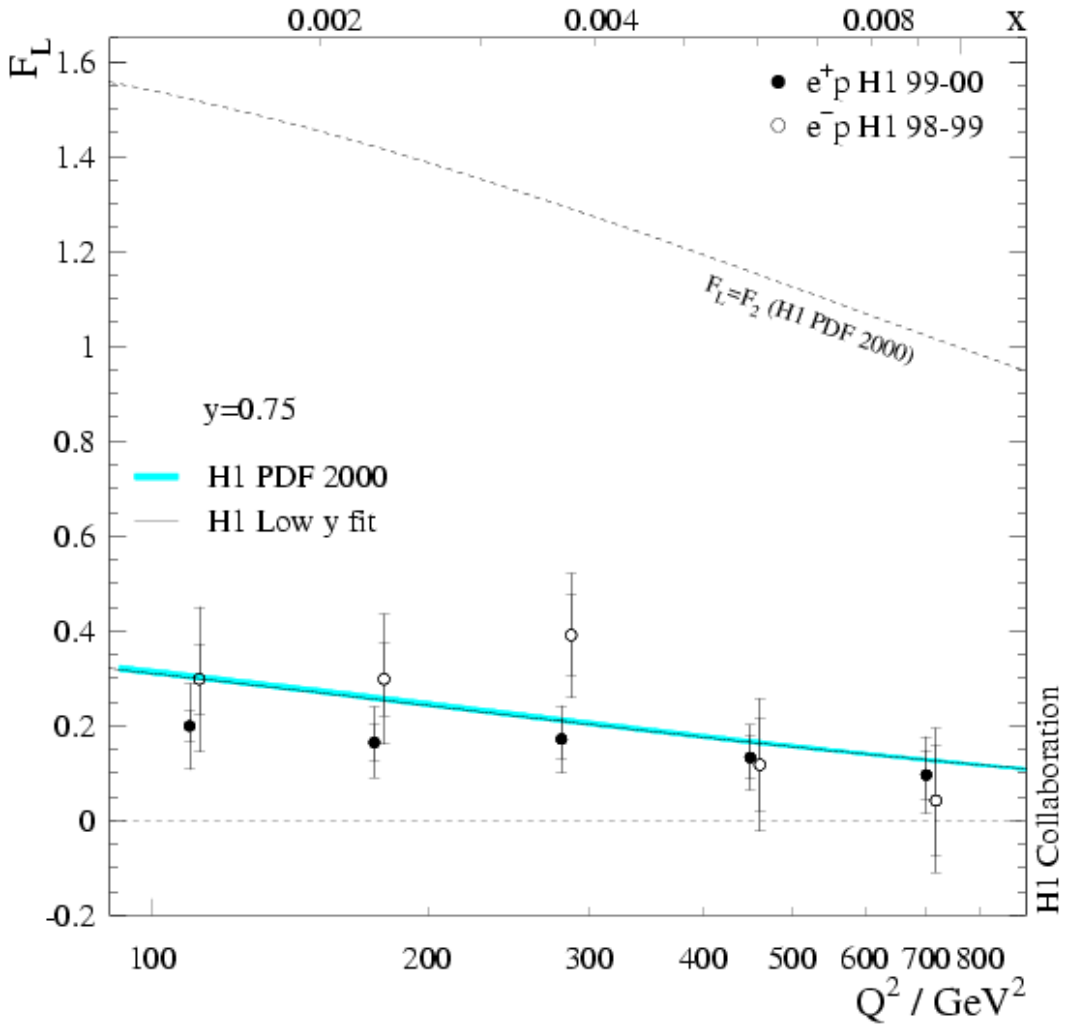
γ-Z

$$\ldots (v_l^2 + a_l^2)\left[\frac{\kappa_W Q^2}{Q^2 + M_Z^2}\right]^2 H_2$$

Z

- **test quark content up to highest Q^2**
- **QCD evolution of PDFs (see talk by E. Rizvi)**

The Structure Function F_L



describes absorption of longitudinal pol. photons

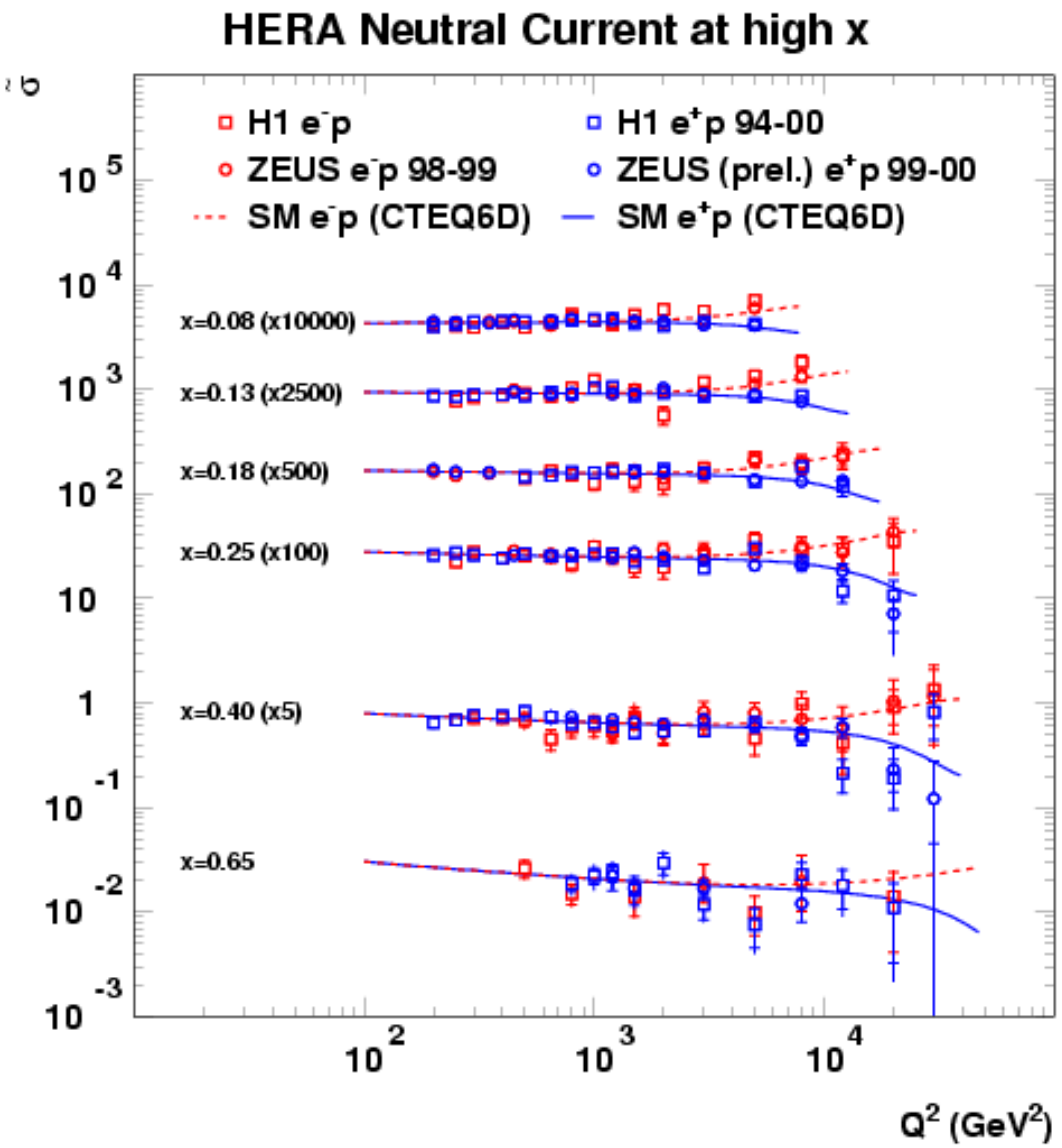
neglecting EW effects:

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

- **extrapolation for F_2 into high y region (dedicated low y fit)**
- **$F_L = 0$ and $F_L = F_2$ clearly excluded**

(F_L at low Q^2 see talk of T.Lastovicka)

NC e^+p and e^-p data sets

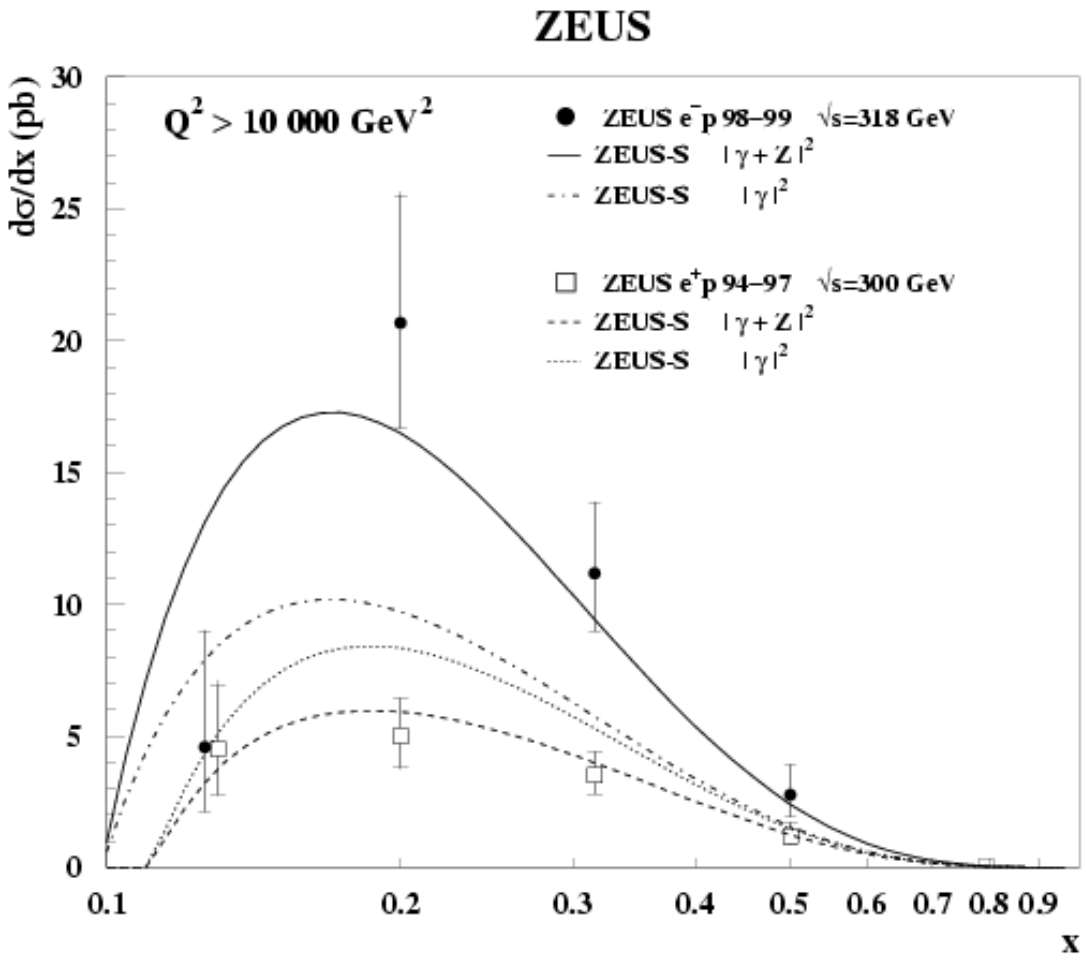


$$\tilde{\sigma}_{NC}^{e^{\pm}p} \sim F_2 \mp xF_3$$

- e^+p and e^-p cross section similar at low Q^2
  → photon exchange
- differ from $Q^2 \geq 3000 GeV^2$
  → γ-Z interference

- combining the data sets
  → extract xF_3

NC at very high Q^2

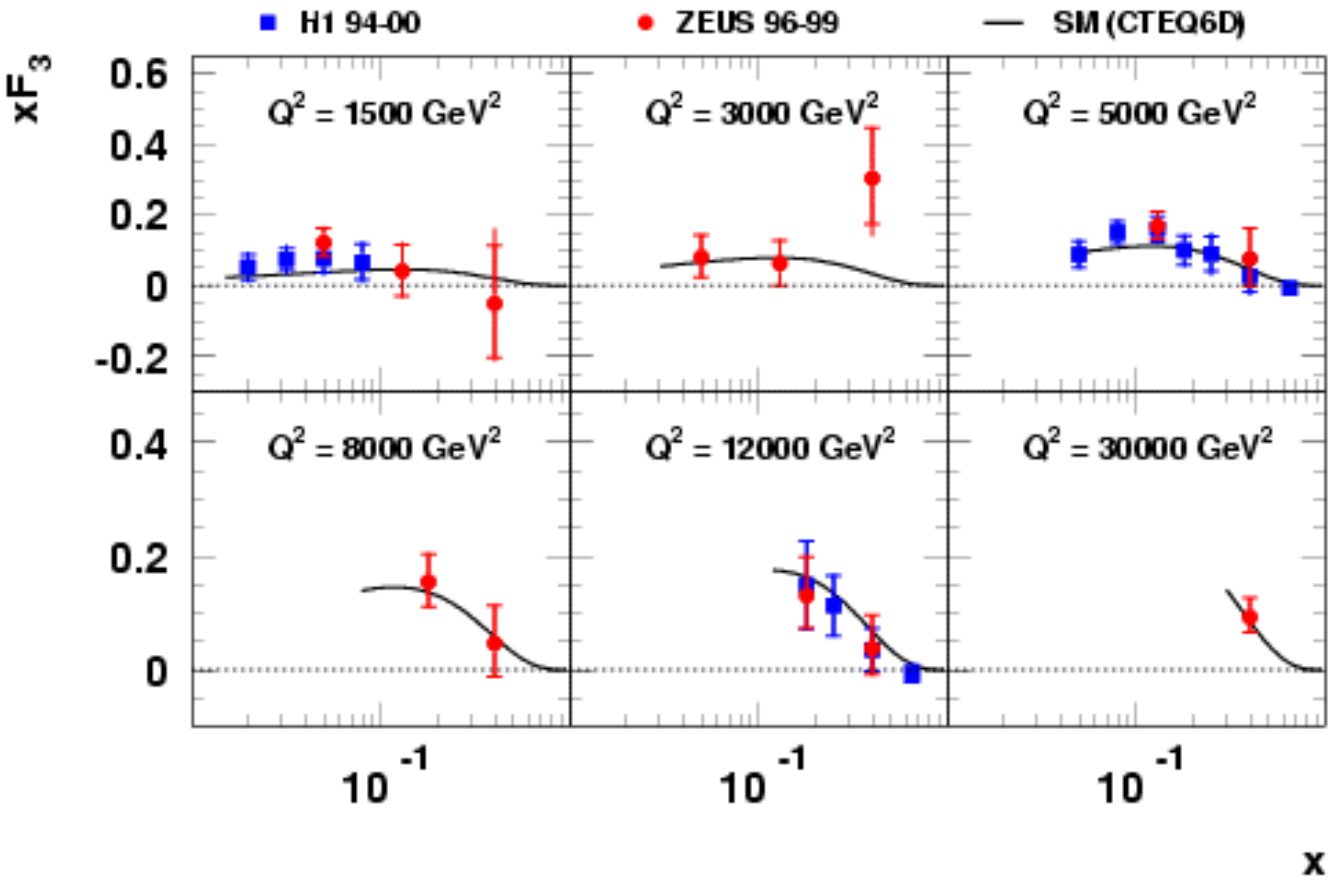


Z exchange visible!

different contribution to e^+p and e^-p cross section

The Structure Function xF_3

$$xF_3 = \sum_i x\left(q - \bar{q}\right)B_i$$ sensitive to valence quarks



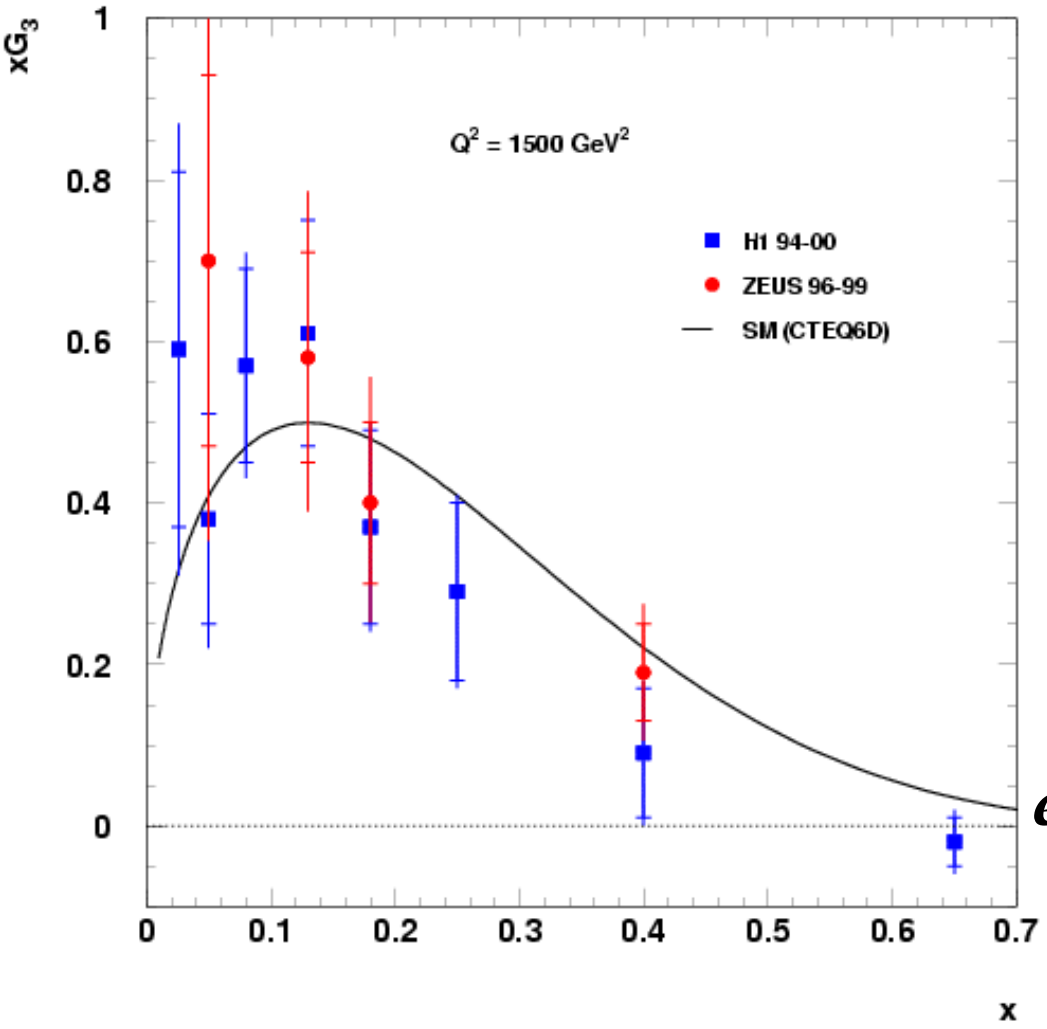
Interference Structure Function xG_3

$$xF_3 = -a_l \left[\frac{\kappa_W Q^2}{Q^2 + M_Z^2} \right] xG_3 + \ldots$$

γ-Z

$$\ldots 2a_l v_l \left[\frac{\kappa_W Q^2}{Q^2 + M_Z^2} \right]^2 xH_3$$

Z



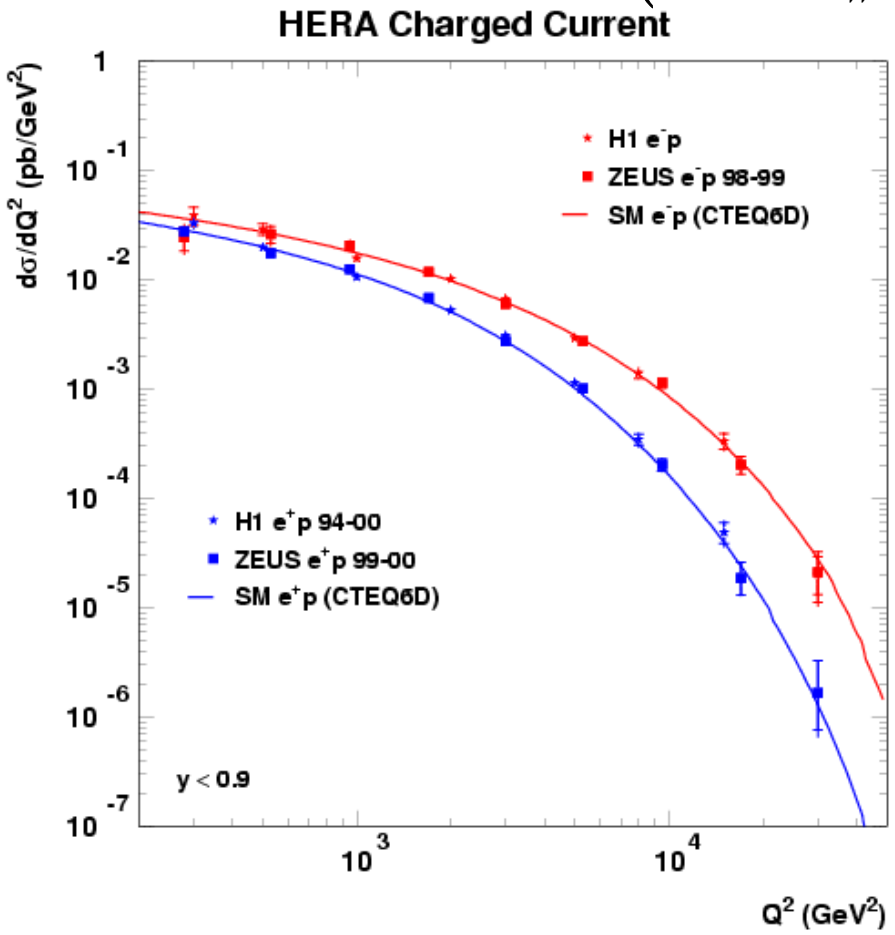
measurement agrees with SM, however, statistically limited

($e^- p$ data $\mathscr{L} \sim 16\ pb^{-1}$ $e^+ p$ combined $\mathscr{L} \sim 100\ pb^{-1}$)

CC Cross Section

$$\frac{d^2\sigma_{CC}^{e^{\pm}p}}{dxdQ^2} = \frac{G_F^2}{4\pi x}\frac{M_W^4}{\left(Q^2+M_W^2\right)^2}\left[Y_+F_2^{CC} \mp Y_- xF_3^{CC} - y^2F_L^{CC}\right]$$

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



H1,94-00, $Q^2 \geq 1000 GeV^2$

$\sigma_{tot}^{CC} = 19.0 \pm 0.5(stat.) \pm 0.8(sys.)\,pb$

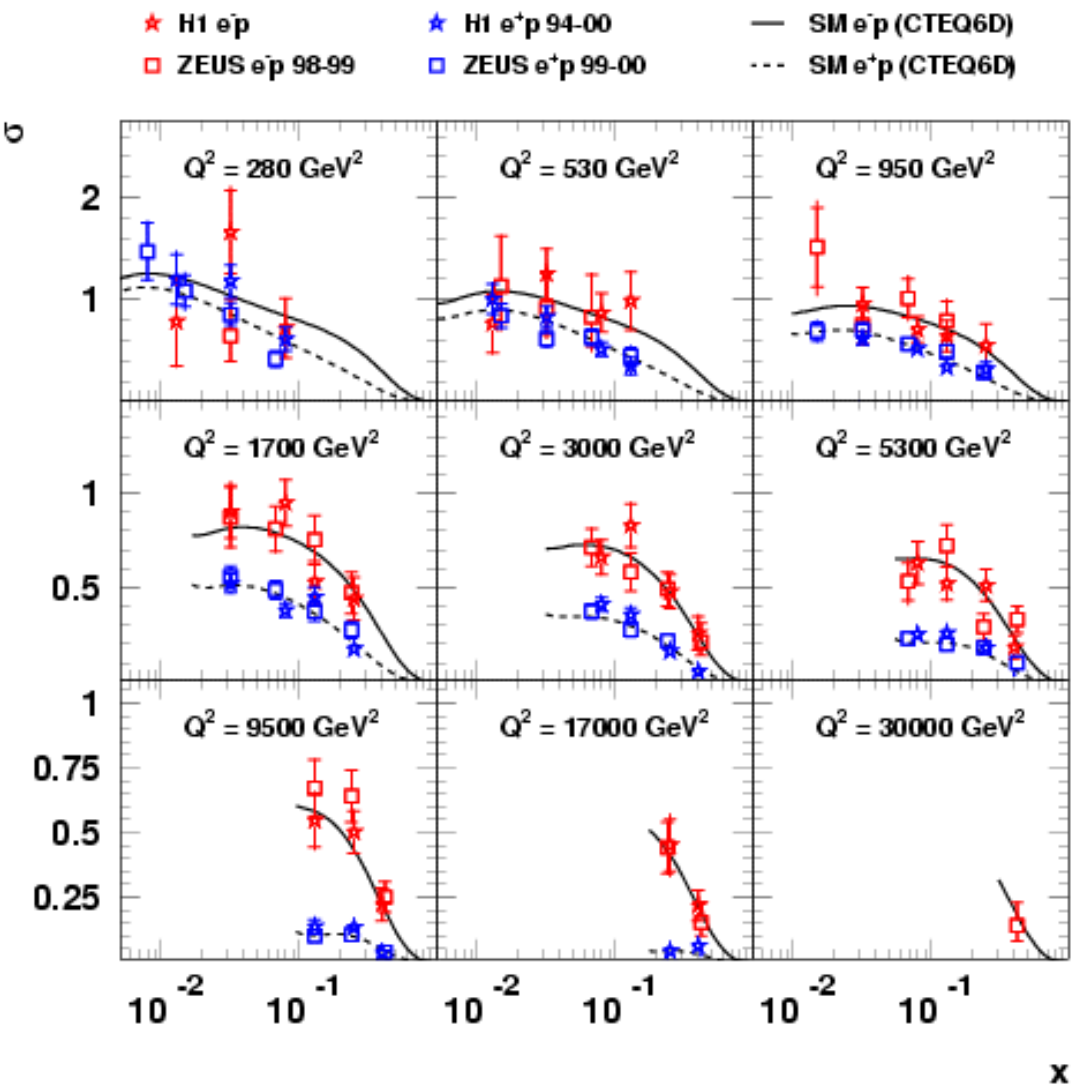
$(H1-PDF2000 : 16.8 \pm 0.3\,pb)$

ZEUS,99-00, $Q^2 \geq 200 GeV^2$

$\sigma_{tot}^{CC} = 34.8 \pm 0.9(stat.) \pm 1.0(sys.)\,pb$

$(ZEUS-S : 37^{+1.7}_{-0.8}\,pb)$

CC Reduced Cross Section



$$\tilde{\sigma}_{CC}^{e^{\pm}p} = \frac{2\pi x}{G_F^2}\frac{\left(Q^2+M_W^2\right)^2}{M_W^4}\frac{d^2\sigma_{CC}^{e^{\pm}p}}{dxdQ^2}$$

$$F_{2,e^+p}^{CC} = x\left[d+s+\bar{u}+\bar{c}\right]$$

$$xF_{3,e^+p}^{CC} = x\left[d+s-\left(\bar{u}+\bar{c}\right)\right]$$

$$F_{2,e^-p}^{CC} = x\left[u+c+\bar{d}+\bar{s}\right]$$

$$xF_{3,e^-p}^{CC} = x\left[u+c-\left(\bar{d}+\bar{s}\right)\right]$$

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

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

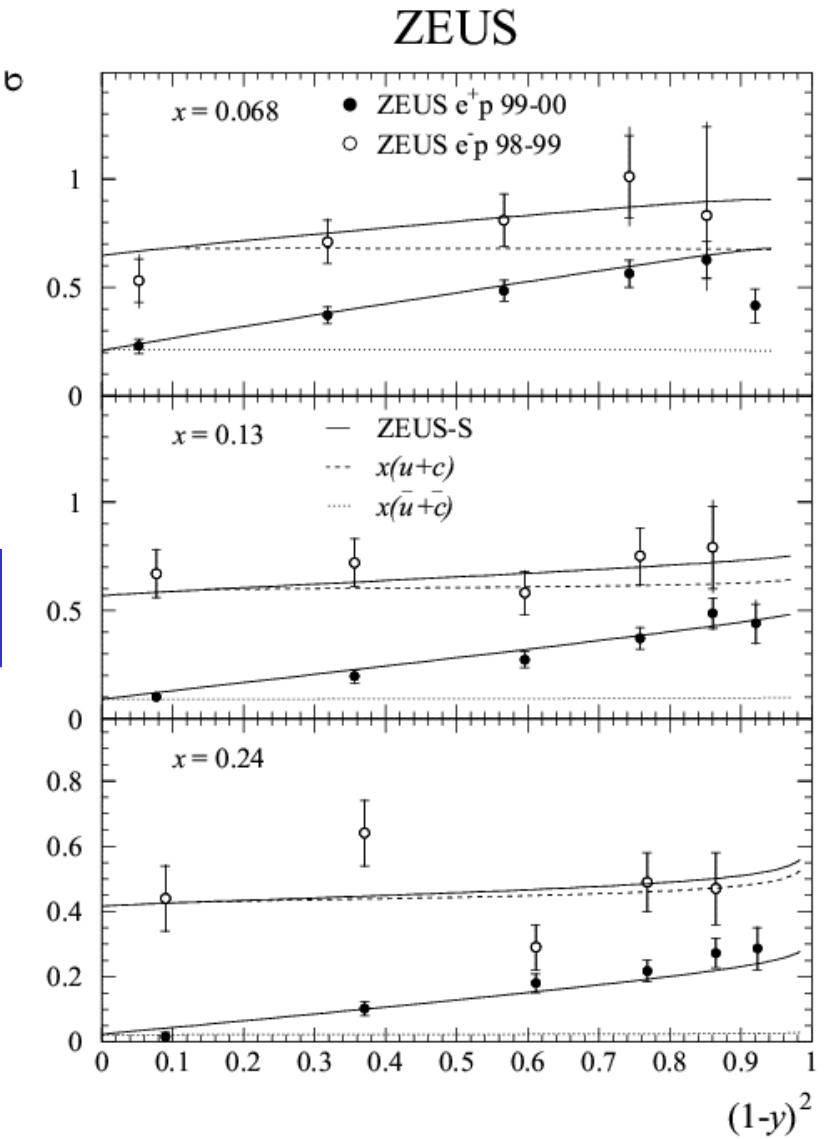
CC e^+p and e^-p : Helicity Structure

e^-q	e^+q
L.H. + L.H	R.L.+L.H.
CMS: $\sum s_i = 0$	$=1$
isotropic in θ_{CMS}	peaked forward

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

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

- **helicity structure of EW confirmed**

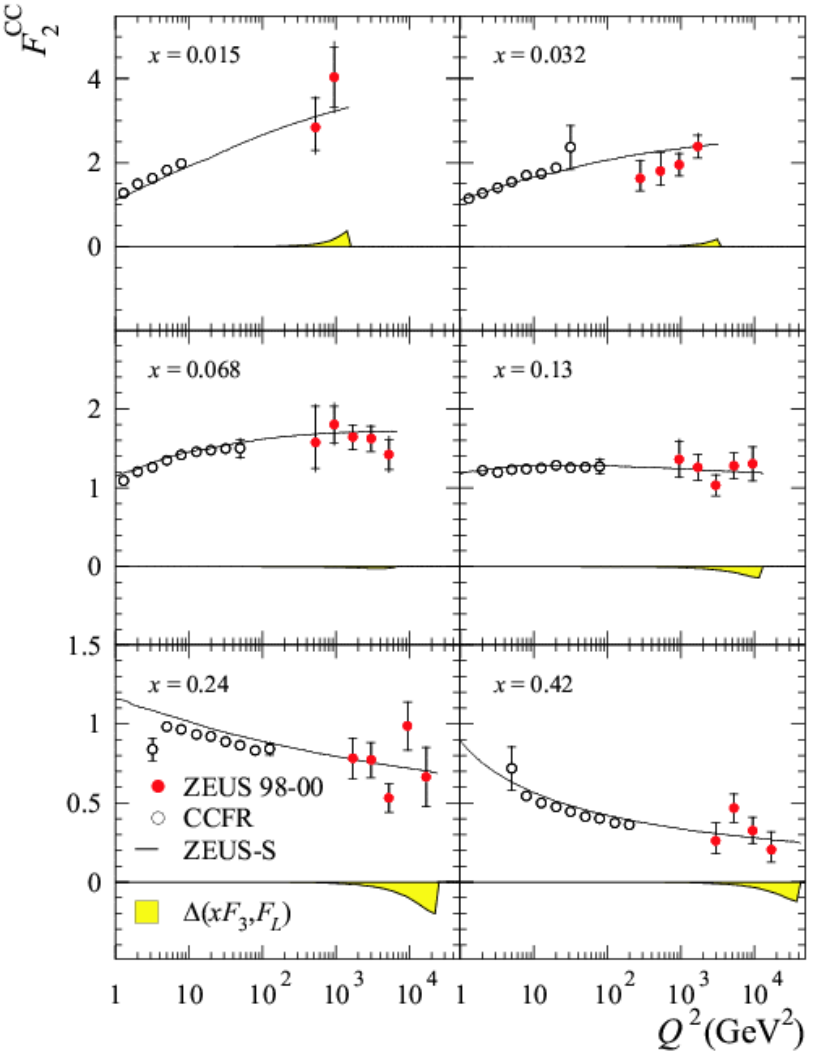


CC e^+p and e^-p : F_2^{CC}

ZEUS

$$F_2^{CC} = \frac{2}{Y_+}\left(\tilde{\sigma}_{CC}^{e^+p} + \tilde{\sigma}_{CC}^{e^-p}\right) + \Delta\left(xF_3^{CC}, F_L^{CC}\right)$$

- all quark flavours contribute
- new kinematic area
- well described by SM
- uncertainty due to limited e^-p sample



Summary and Outlook

- NC and CC cross sections measured up to highest Q^2 ⟶ insight into proton at smallest distance scales
- Extraction of $F_2^{NC}, xF_3^{NC}, F_L^{NC}, F_2^{CC}$

⟶ successfully tested QCD and EW sector of SM

- HERA II: increased statistics (in particular $e^- p$) and longitudinally polarized leptons