Neutral Current and Charged Current DIS at High Q^2

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On behalf of the

H1 Collaboration

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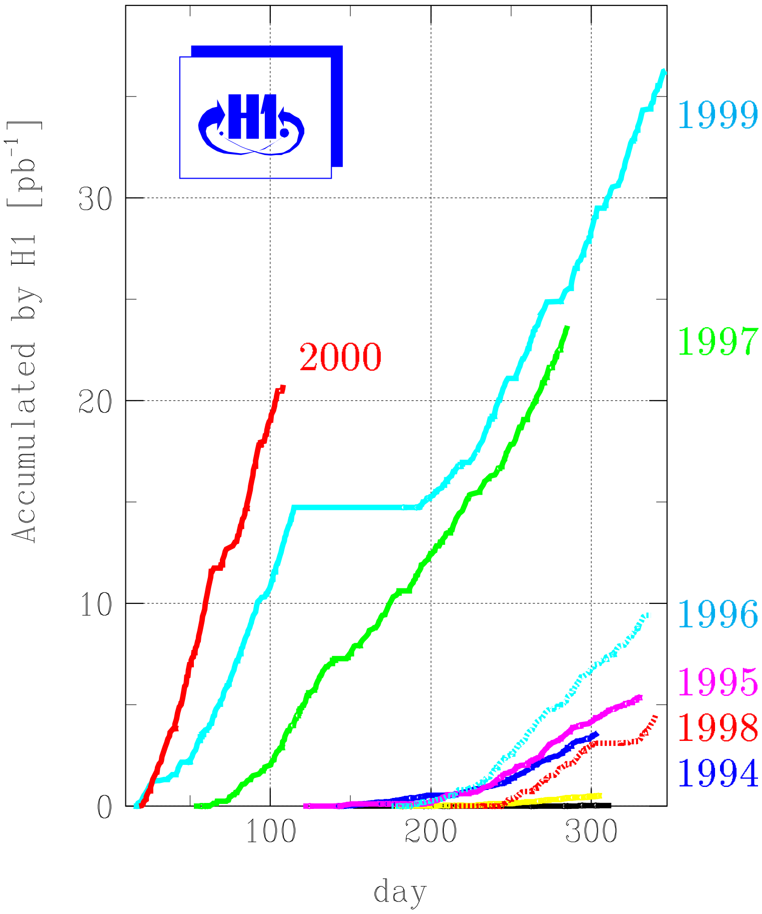
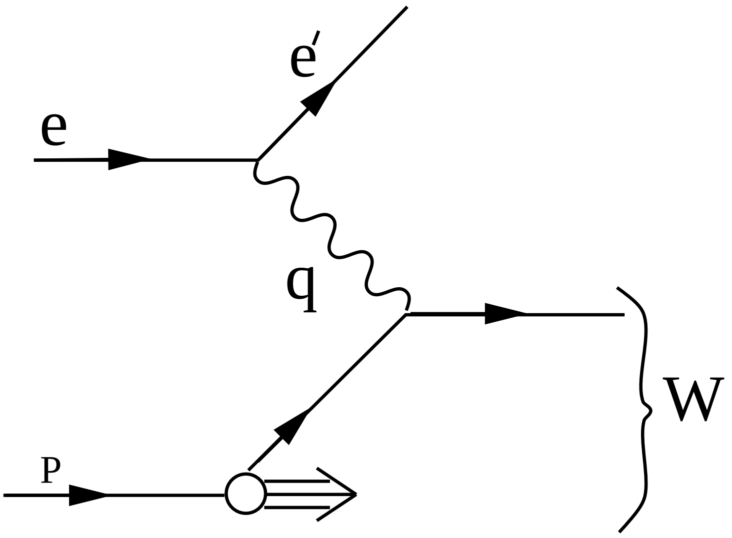


- The H1 Detector
- NC Data Selection
- CC Data Selection
- Deep Inelastic Scattering at High Q^2
- NC and CC Cross Section Measurements
- Conclusions

- e^+p $\mathcal{L} = 36pb^{-1}$ $\sqrt{s} = 300$ GeV
- e^-p $\mathcal{L} = 15pb^{-1}$ $\sqrt{s} = 320$ GeV

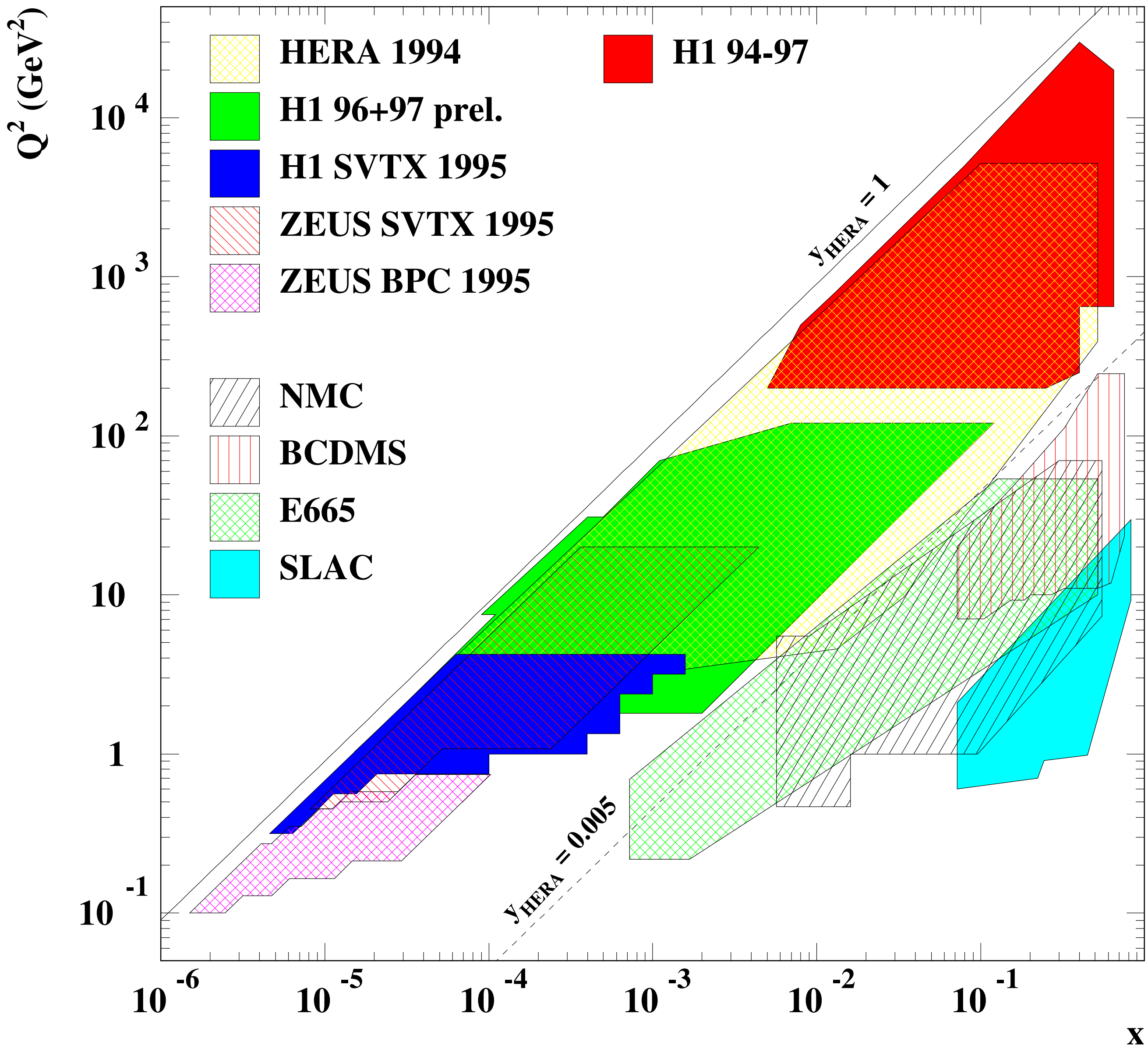
Kinematics of DIS



$$Q^2 = -q^2, \quad W^2 = (q+P)^2, \quad x = -\frac{q^2}{2P.q},$$
$$y = \frac{P.q}{P.e},$$

- Q^2 is the virtuality of the photon
- W is the virtual photon-proton CMS energy
- In the infinite momentum frame of the proton x is the fraction of proton's momentum carried by the struck quark.
- y is the inelasticity parameter.

Kinematic Range of HERA



- Accessible kinematic plane now almost completely covered
- Measurements extend range to high y, high x and high Q^2

Kinematic Reconstruction

Methods used for Measurements:

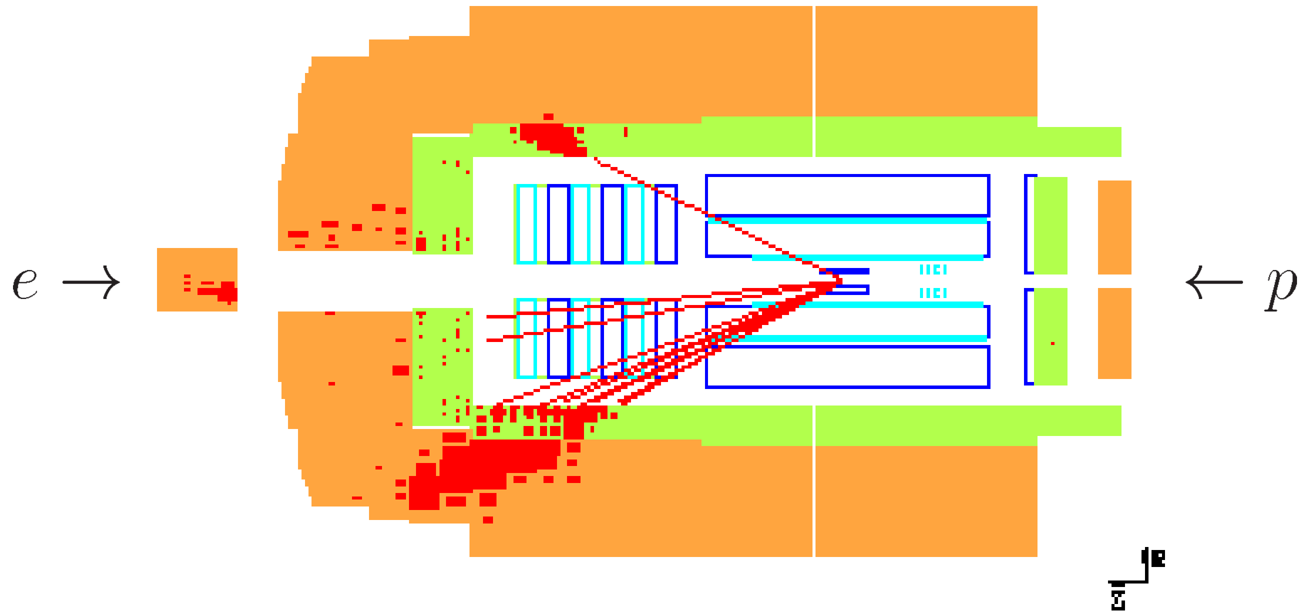
- Electron Method: $y_e = 1 - \frac{E'_e}{E_e}\sin^2\frac{\theta_e}{2}$ $\quad Q^2_e = 4E'_e E_e \cos^2\frac{\theta_e}{2}$
  - most precise at high y / low x
  - bad x resolution at low y
  - good Q^2 resolution in full range
- Hadron Method: $y_h = \frac{\Sigma}{2E_e}$ $\quad Q^2_h = \frac{p^2_{t,h}}{1-y_h}$
  - low precision, but only method for charged current
- $e\Sigma$ Method: $x_{e\Sigma} = x_\Sigma$ and $Q^2_{e\Sigma} = Q^2_e$
  - precise over the whole kinematic range
  - good resolution even at very high x

Further Methods for Calibration and Cross Checks

- Σ Method:
  - good x resolution also at low y
  - independent of QED initial state radiation
- Double Angle Method:
  - angle of scattered electron and hadronic final state
  - high precision at high Q^2, but sensitive to QED radiation
  - independent of energy scale $\Rightarrow$ used for calibration

The H1 Detector

$Q^2 = 25030\ \mathrm{GeV}^2,\quad y = 0.56,\quad M = 211\ \mathrm{GeV}$



- Fine grained liquid argon calorimeter (45 000 channels)

  EM: $\frac{\delta E}{E} = \frac{12\%}{\sqrt{E/GeV}} \oplus 0.01$ Had: $\frac{\delta E}{E} = \frac{50\%}{\sqrt{E/GeV}} \oplus 0.01$

- Backward calorimeter (SPACAL)

  EM: $\frac{\delta E}{E} = \frac{7.5\%}{\sqrt{E/GeV}} \oplus 0.01$

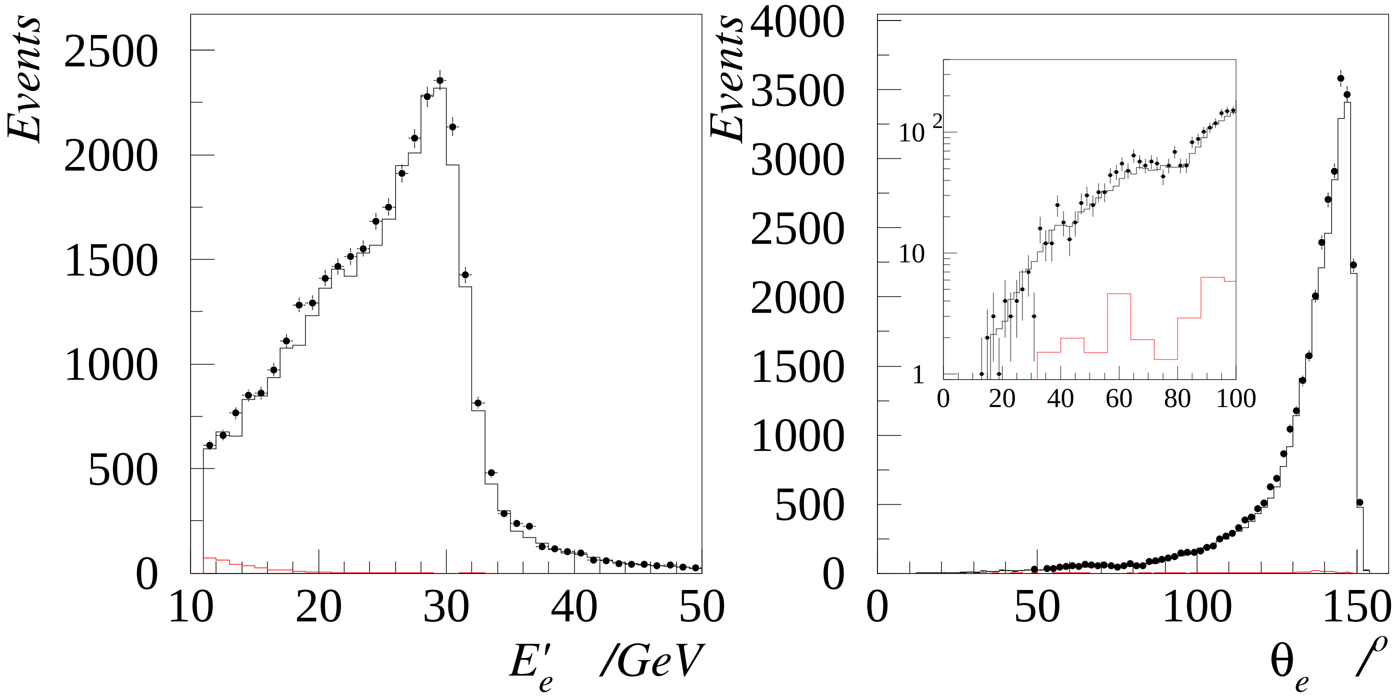
- Tracking chambers provide coverage for $8^\circ \leq \theta \leq 155^\circ$

  $\sigma_p/p \simeq 0.003p$

NC selection

- Compact EM energy trigger
- $E'_e > 11$ GeV – Ensure $\epsilon = 100\%$
- $y_e < 0.9$ – Reduce γ/p background
- $E - P_z > 35$ GeV – Reduce γ/p background
- $|Z_{vertex}| < 35$ cm – Reduce non-ep background
- Track-energy cluster link for $\theta > 40°$– Remove fake e^-
- Event timed in with ep collisions
- Topological non-ep background finders – cosmic/halo μ's
- Detector fiducial cuts to remove inefficient regions

NC e^-p event Sample

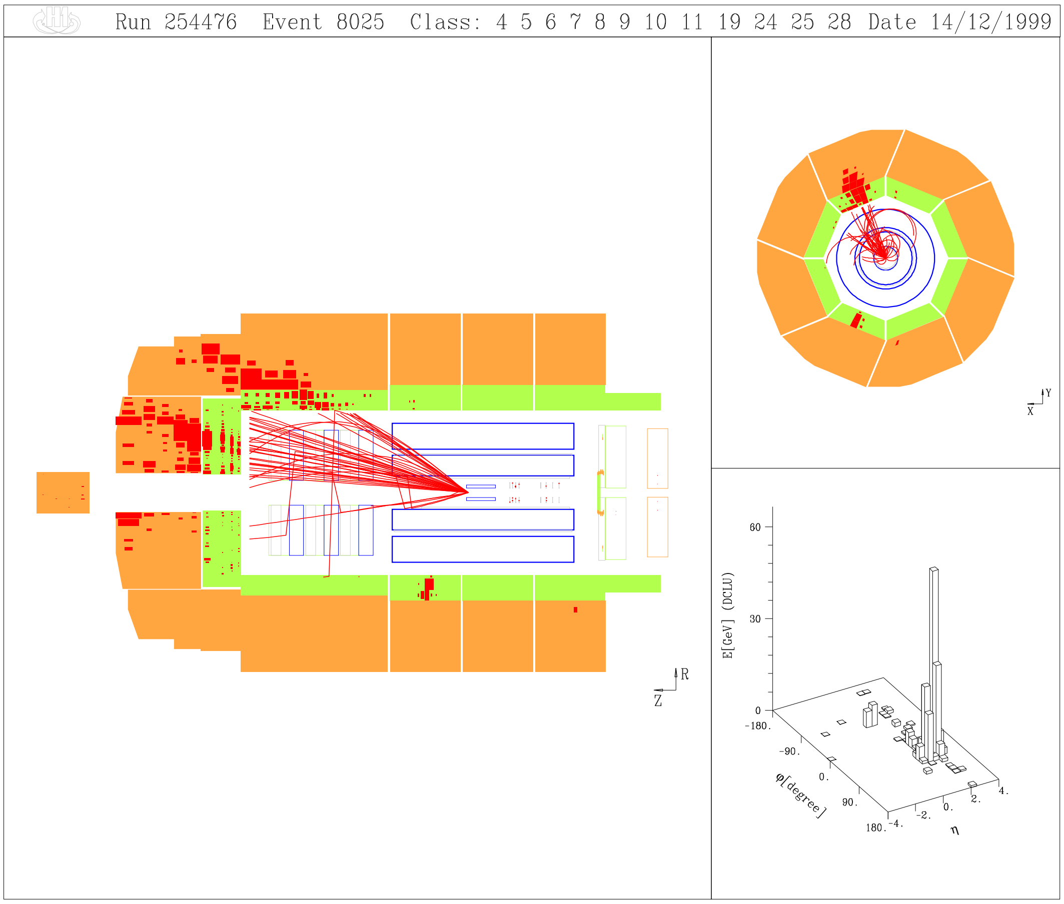


- About 30,000 selected events
- E'_e and θ_e for NC well described
- photo-production contribution $< 5\%$
- Low Q^2 precision statistical is $\simeq 4\%$
- Low Q^2 systematic uncertainty is $\simeq 7\%$
- For $Q^2 > 1000$ statistical error dominates

NC Systematic Uncertainties

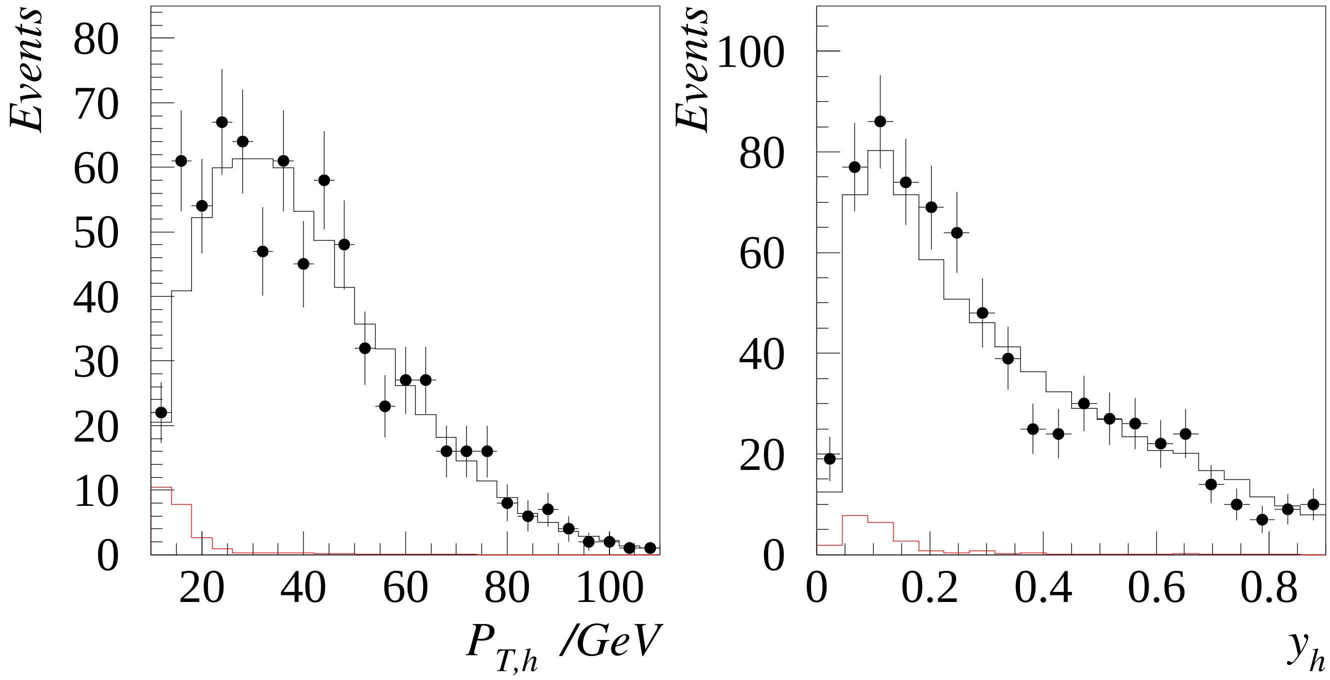
- main error sources
  - Trigger efficiency $\pm 0.5\%$
  - Electron finding efficiency $\pm 1\%$
  - e^- Track validation $\pm 2\%$
  - Electron Energy scale $\pm 1 - 3\%$
  - e^- scattering angle ± 3 mrad
  - Hadronic Energy scale $\pm 3\%$
  - Noise suppression $\pm 25\%$
  - Photoproduction background $\pm 30\%$
  - radiative corrections $\pm 2\%$
- no single error source dominates at low $Q^2 \approx 400$ GeV^2
- precision still limited statistical error for $Q^2 > 1000$ GeV^2

Selection of Charged Current Events



- Calorimeter and track based trigger $\Longrightarrow$ $\epsilon = 50 - 100\%$ depending on P_t
- $P_t > 12$ GeV
- $0.03 < y_h < 0.85$
- $|z_{vtx}| < 35$ cm
- topological non-*ep*-background filters
- γp background: $P_{t,antiparallel}/P_{t,parallel} < 0.15$
- reconstruction of kinematic variables from tracks and calorimetry
- good understanding of hadronic energy scale essential

CC e^-p event Sample



- Sample contains about 700 events
- $P_{T,h}$ and y_h for CC well described
- photo-production contribution $< 5\%$

CC Systematic Uncertainties

main error sources

- Trigger efficiency $(1-\epsilon) * 15\%$
- Vertex Efficiency $\approx \pm 1\%$
- Hadronic Energy scale $\pm 3\%$
- Noise suppression $\pm 25\%$
- Photoproduction background $\pm 50\%$

error on hadronic energy scale dominating

- Statistical precision varies 10-20%
- Systematic uncertainty varies 5-15%

Neutral Current Cross Sections and Structure Functions in DIS

$$\frac{d^2\sigma}{dx\,dQ^2} = \frac{2\pi\alpha^2}{xQ^4}\left[Y_+F_2(x,Q^2) - y^2F_L(x,Q^2) \pm Y_- xF_3(x,Q^2)\right]$$

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

F_2: generalized structure function
F_L: longitudinal structure function
F_3: parity violating term from Z° exchange

$$F_2 = F_2^{em} + \frac{Q^2}{(Q^2+M_Z^2)}F_2^{int} + \frac{Q^4}{(Q^2+M_Z^2)^2}F_2^{wk} = F_2^{em}(1+\delta_Z)$$

$$\frac{d^2\sigma}{dx\,dQ^2} = \frac{2\pi\alpha^2 Y_+}{xQ^4}F_2^{em}(1+\delta_Z-\delta_3-\delta_L)$$

$\delta_Z - \delta_3$: $< 1\%$ at $Q^2 < 1500$ GeV^2
$\approx 10\%$ at $Q^2 = 5000$ GeV^2 and x=0.08
δ_L: negligible at $y < 0.5$
$\approx 5\%$ at $y = 0.9$

In the following we will use the Reduced Cross Section:

$$\sigma \equiv \frac{xQ^4}{2\pi\alpha^2}\frac{1}{Y_+}\frac{\mathrm{d}^2\sigma}{\mathrm{d}x\mathrm{d}Q^2}$$

Charged Current Cross Sections in DIS

$e^+p \longrightarrow \bar{\nu}X$:

$$\frac{d^2\sigma}{dxdQ^2} = \frac{G_F^2}{2\pi}\left[\frac{Q^2}{Q^2+M_W^2}\right]^2 [\bar{u}+\bar{c}+(1-y)^2(d+s)]$$

$e^-p \longrightarrow \nu X$:

$$\frac{d^2\sigma}{dxdQ^2} = \frac{G_F^2}{2\pi}\left[\frac{Q^2}{Q^2+M_W^2}\right]^2 [u+c+(1-y)^2(\bar{d}+\bar{s})]$$

- Sensitivity to Propagator $\Rightarrow$ W mass determination

- Sensitivity to separate parton densities

Reduced Charged Current Cross Section:

$$\begin{aligned}
\sigma_{CC} &\equiv x \cdot \frac{2\pi}{G_F^2}\left[\frac{Q^2+M_W^2)}{Q^2}\right]^2 \frac{d^2\sigma}{dxdQ^2} \\
\sigma_{CC}^+ &= x \cdot \left[\bar{u}+\bar{c}+(1-y)^2(d+s)\right] \\
\sigma_{CC}^- &= x \cdot \left[u+c+(1-y)^2(\bar{d}+\bar{s})\right]
\end{aligned}$$

in Standard Model

- definition in analogy to Reduced Neutral Current Cross Section σ

H1 NLO-QCD Fits

- Use NLO DGLAP equations to evolve:
  - $xu_{val}(x,Q^2)$, $xd_{val}(x,Q^2)$ $xg(x,Q^2)$, $xSea(x,Q^2)$
  - Treat charm / bottom as massless partons

    more appropriate description for high Q^2
  - Assume $\bar{u} = 2\bar{s}$

    $Sea = 2x(\bar{u} + \bar{d} + \bar{s} + \bar{c})$ at Q_0^2
  - Take $x\bar{c} = 0.02 \times xSea$

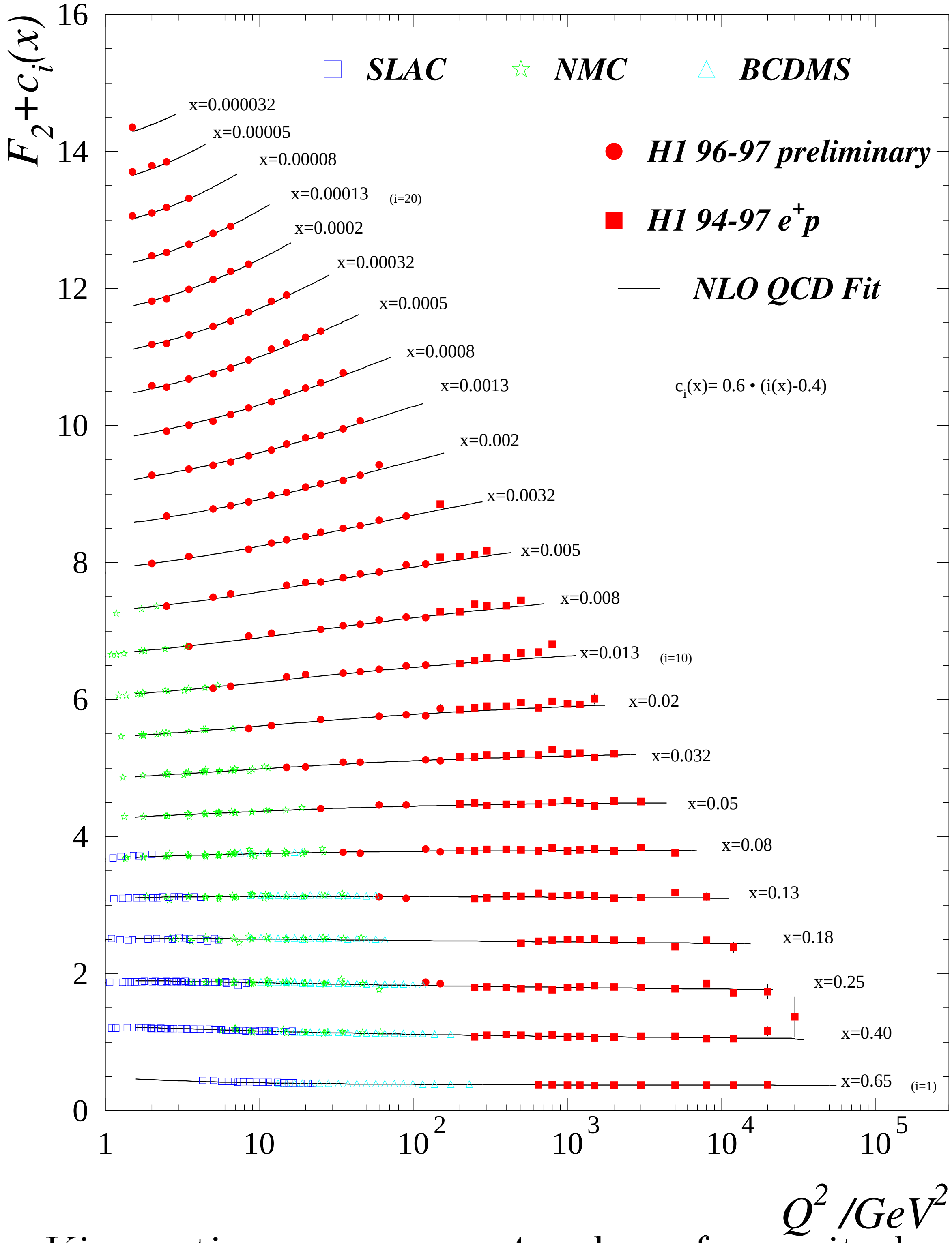
- Datasets and Cuts:
  - NMC/BCDMS p+d F_2 data
  - H1 94 F_2 data
  - H1 NC/CC e^+p reduced cross-sections (1994-1997)

    $\rightarrow$ no assumptions for F_L or xF_3
  - Require $Q^2 \geq 10$ GeV^2 and $W^2 > 20$ GeV^2
  - Require $x \leq 0.7$

- Parameters:
  - $Q_0^2 = 4$ GeV^2
  - $\alpha_s(M_Z^2)$=0.118 (fixed)

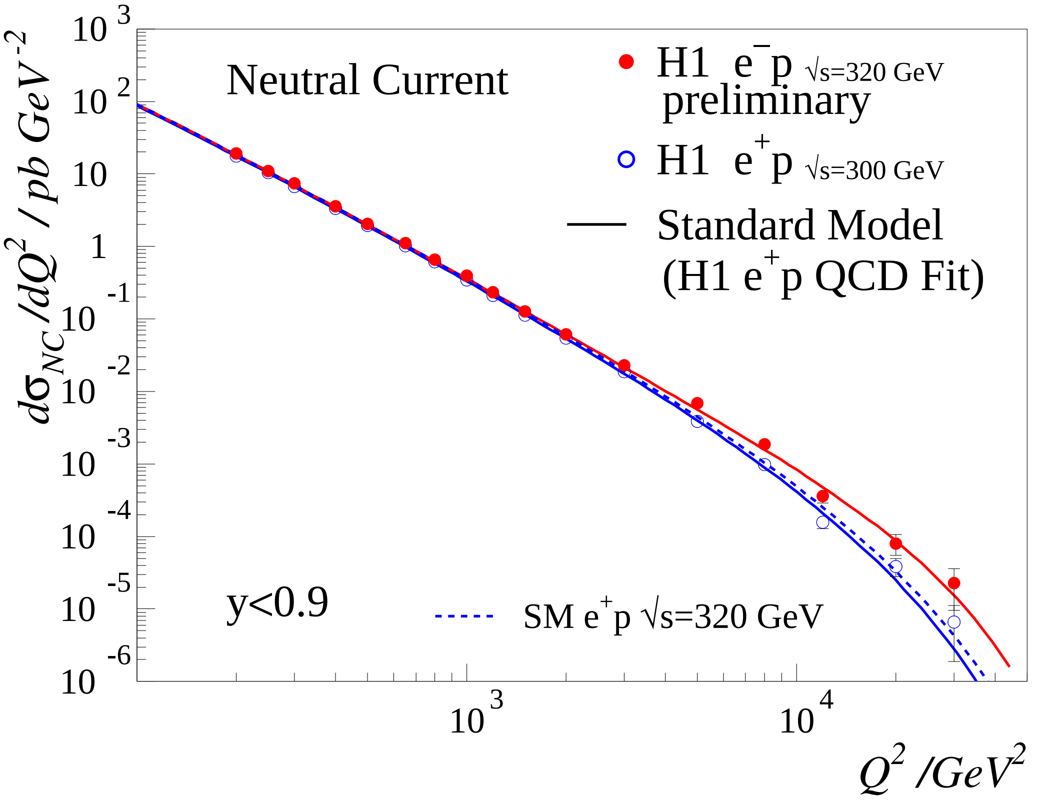
- Results:
  - Assumptions and cuts varied to estimate SM uncertainty
  - Fit statistical $\oplus$ uncorrelated syst. errors
  - Correlated systematic errors are fitted
  - Fit has $\chi^2/\mathrm{ndf} = 1.02$

Overview of F_2 Measurements

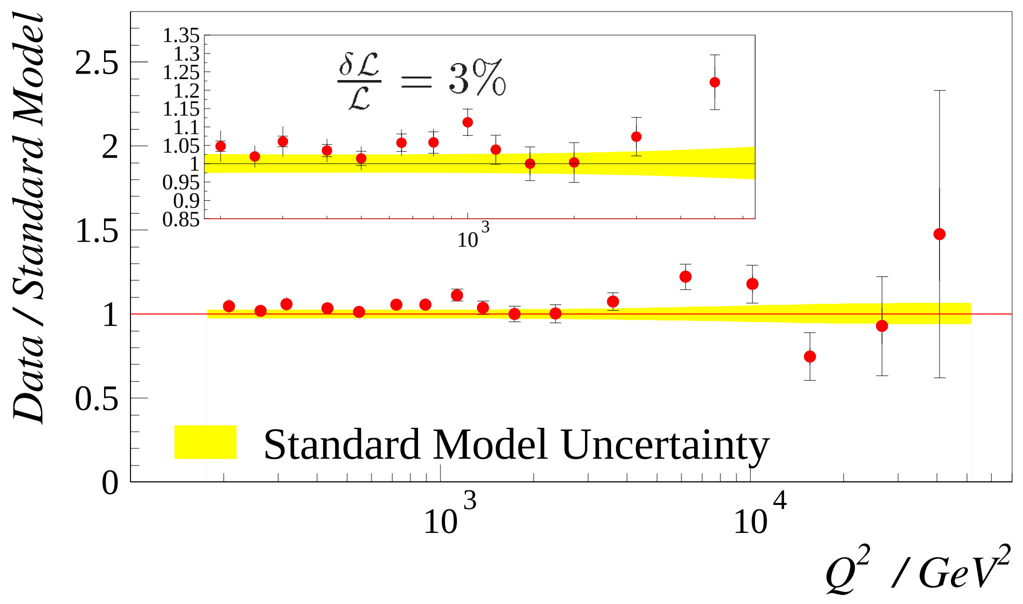


- Kinematic range covers 4 orders of magnitude in Q^2 and x
- Scaling violations: positive at low x, negative at high x
- Data described by QCD down to $Q^2 \approx 1$ GeV^2

Neutral Current $\frac{d\sigma}{dQ^2}$

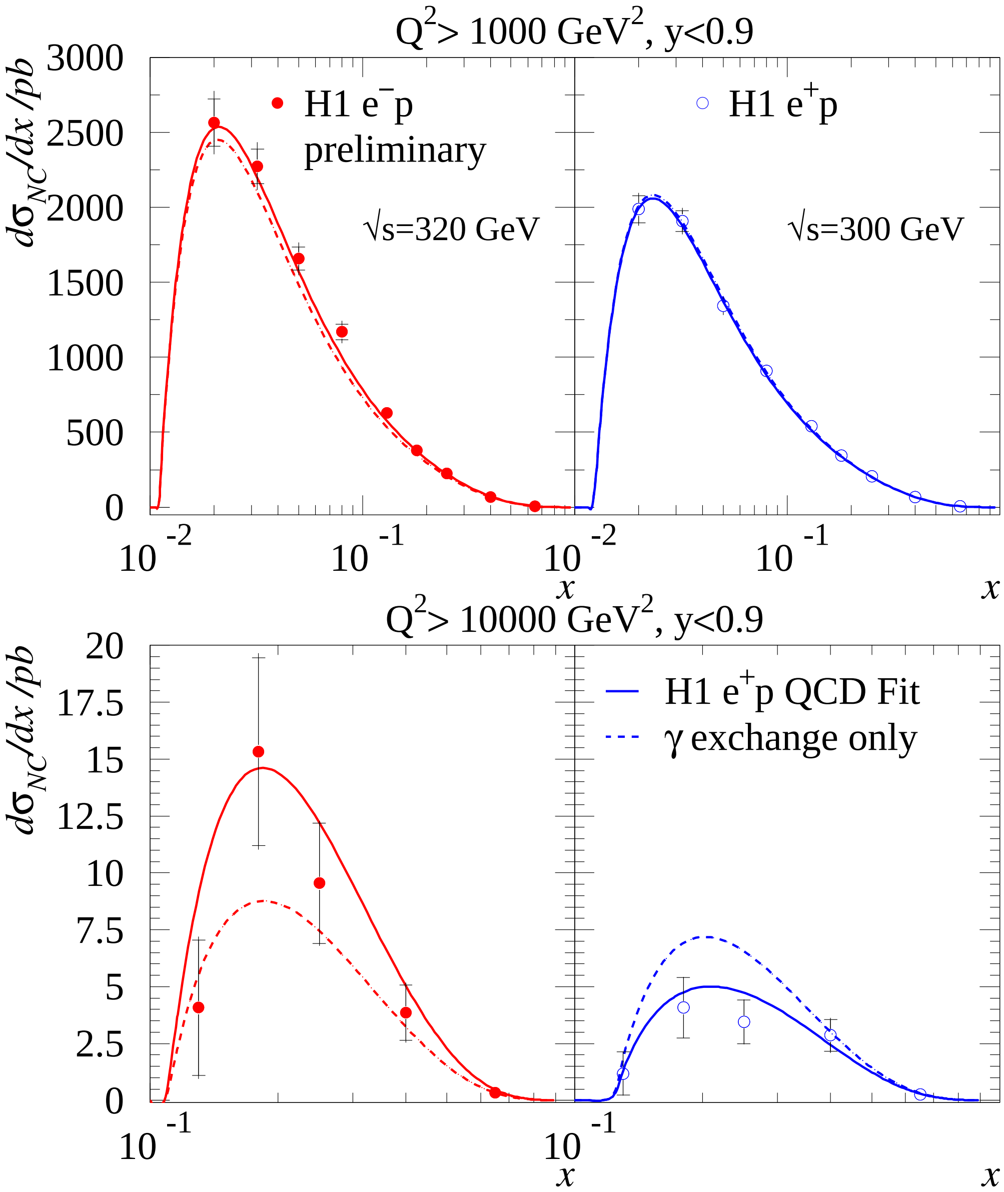


e^-p



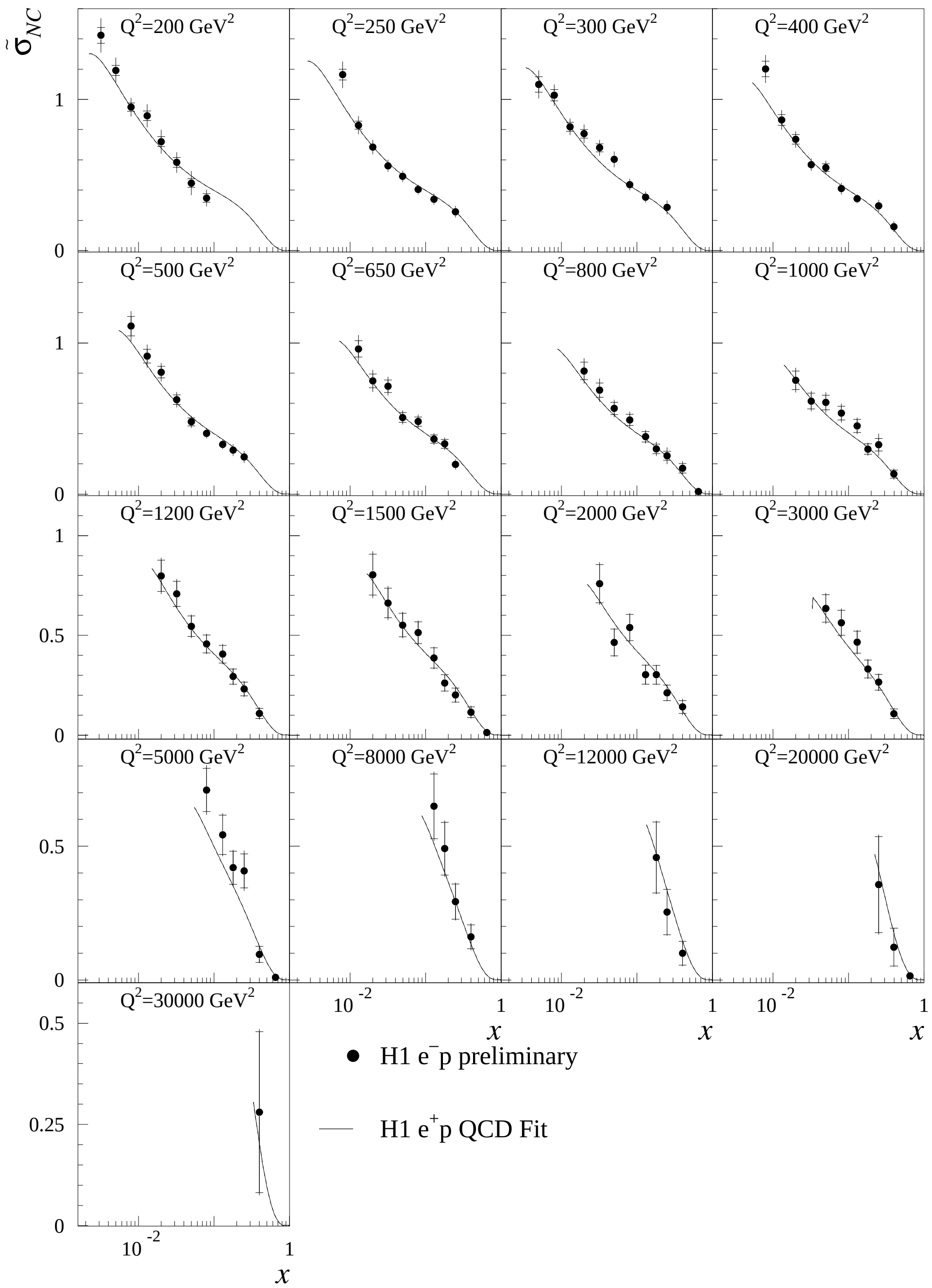
- Beam energy change causes 7% difference at medium Q^2

Neutral Current $\frac{d\sigma}{dx}$



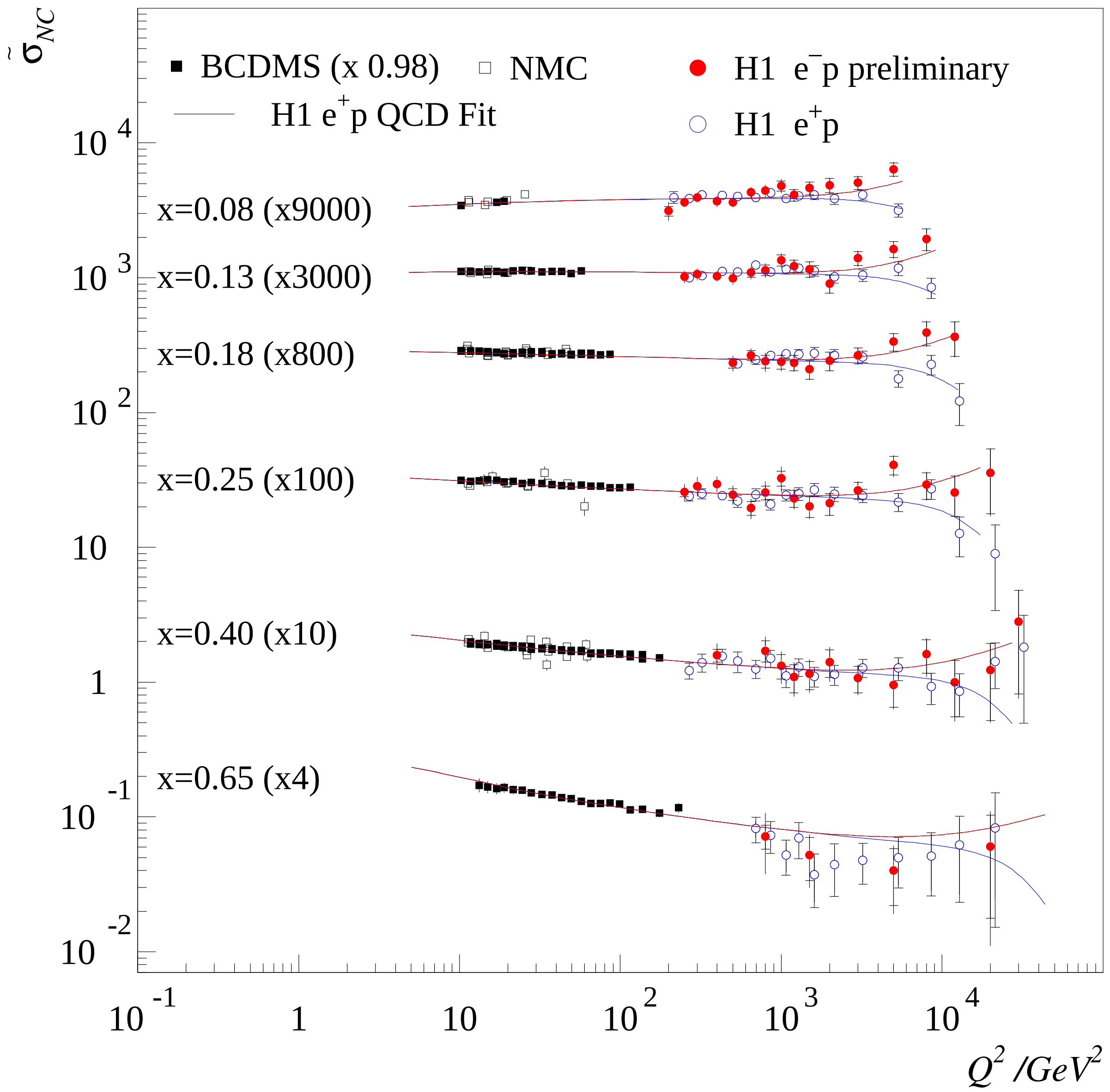
- Data sensitive to e^- enhancement of cross section

Neutral Current e^-p Reduced Cross Section



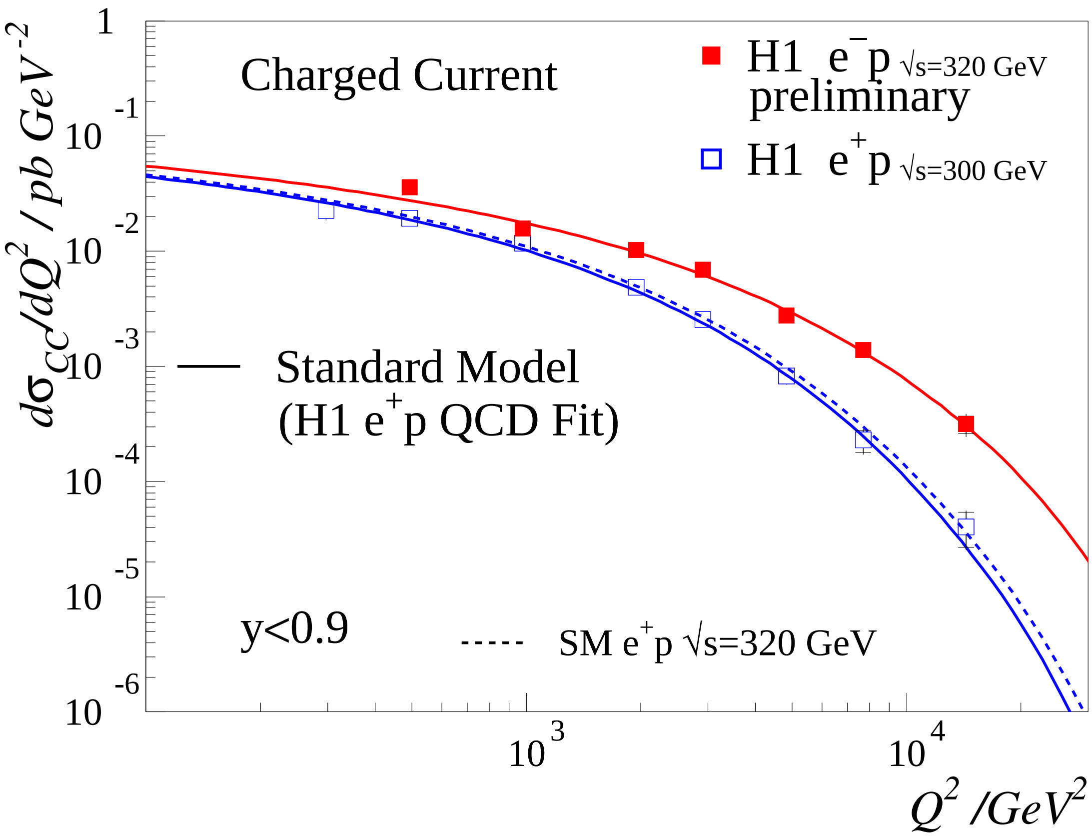
- Good agreement with SM prediction from fit to e^+p data

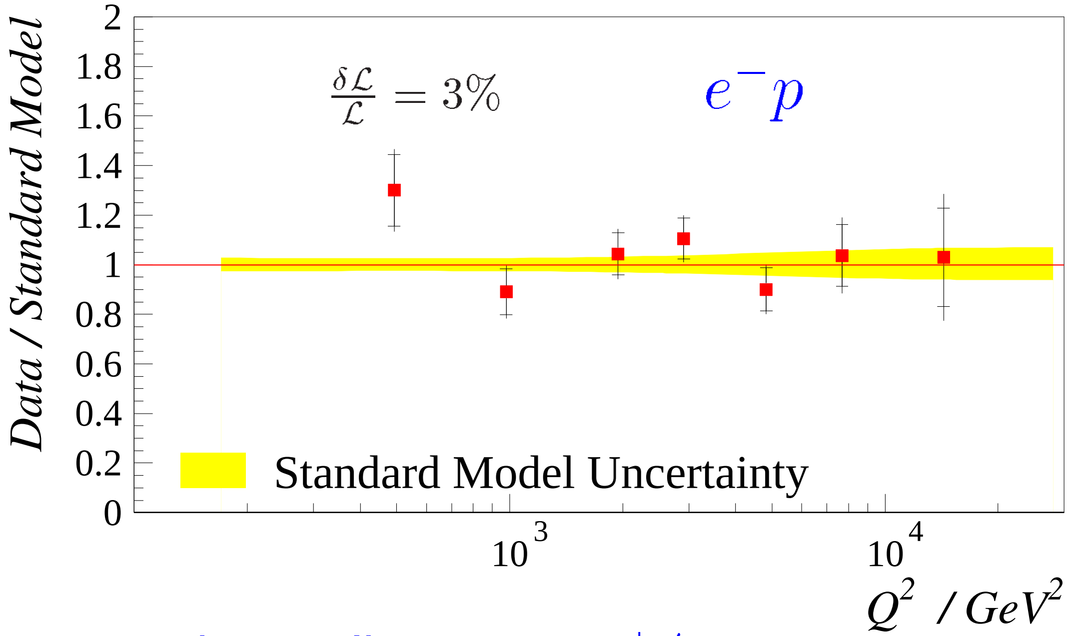
Neutral Current Reduced Cross Section



- The e^- data agree with e^+ data

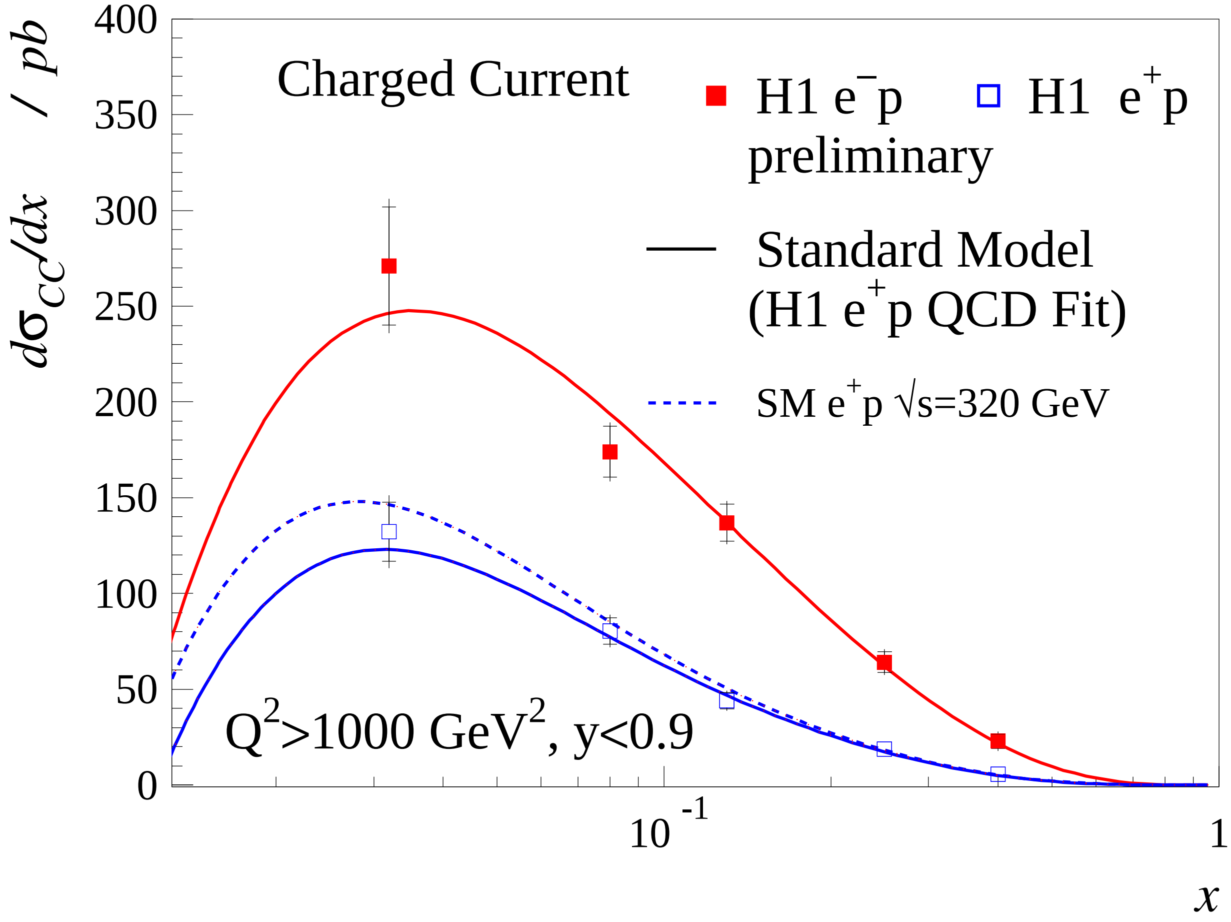
Charged Current $\frac{d\sigma}{dQ^2}$





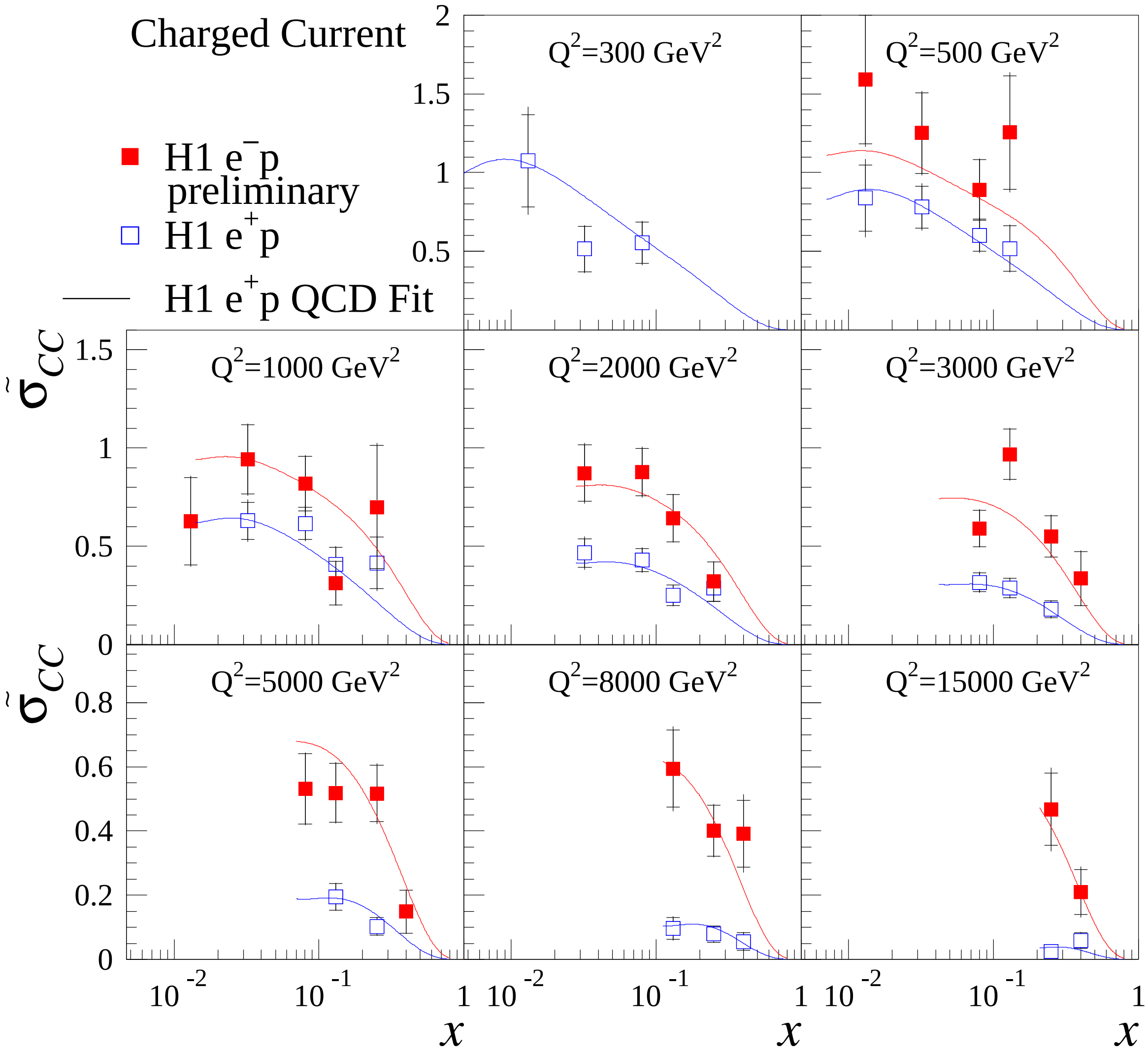
- Factor of 10 difference in e^+/e^- cross section at high Q^2

Charged Current $\frac{d\sigma}{dx}$



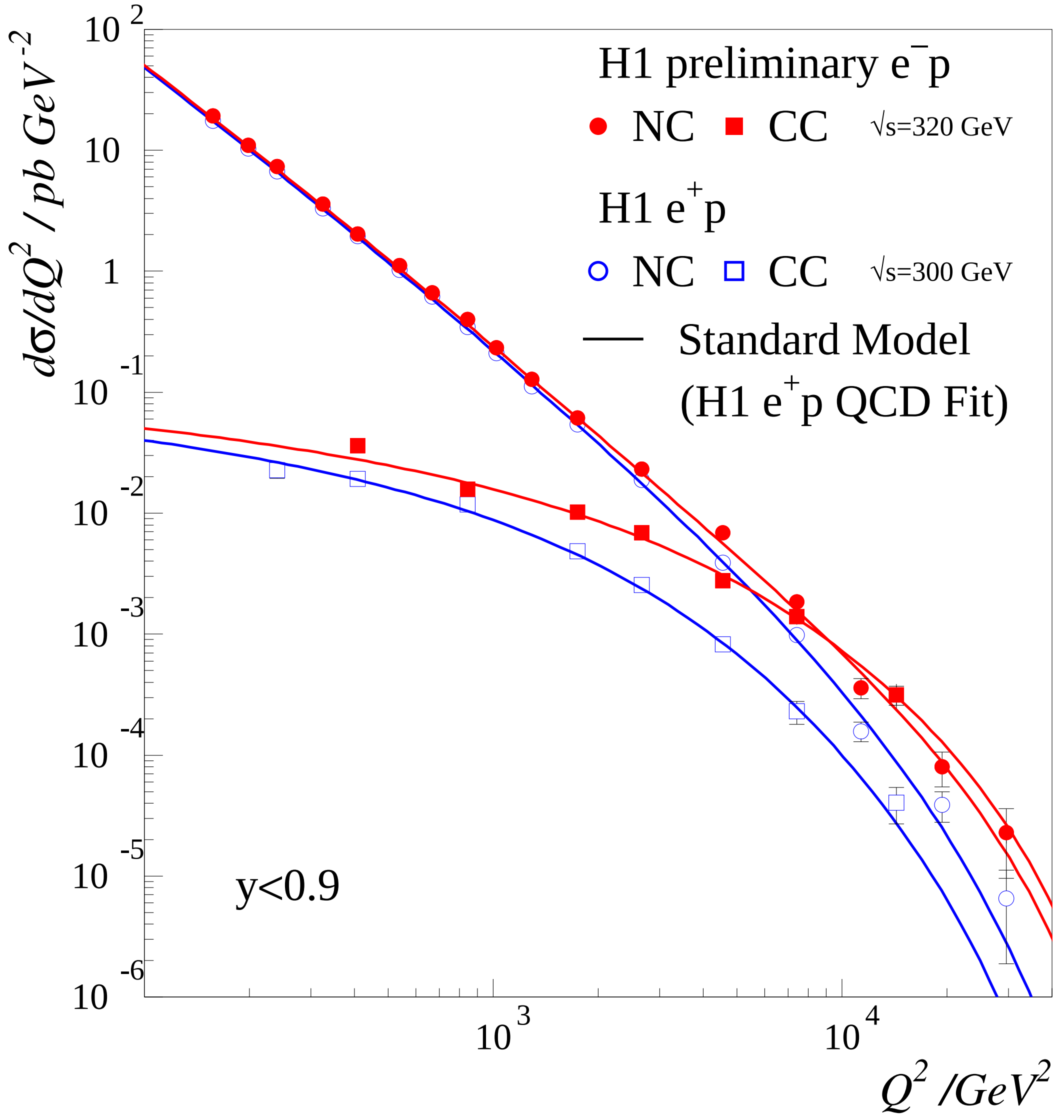
- Good agreement with SM

Charged Current Reduced Cross Section



- Access to separate quark flavours at high Q^2
  - require more $\mathcal{L}$

Summary



- Single and double-differential NC and CC cross sections have been measured for $e^{\pm}p$ scattering in the Q^2 range 200 - 30000 GeV^2 and x upto 0.65