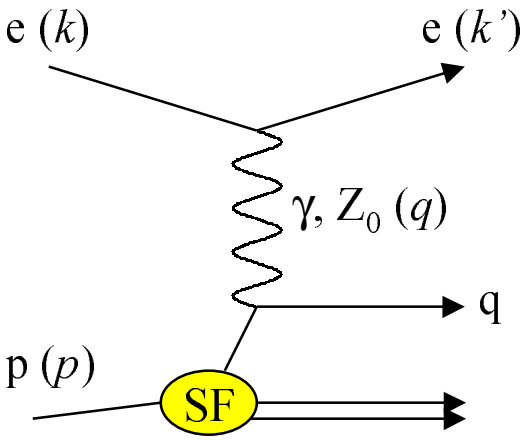
Recent Results on High-Q^2 Neutral and Charged Current Cross-Sections at HERA

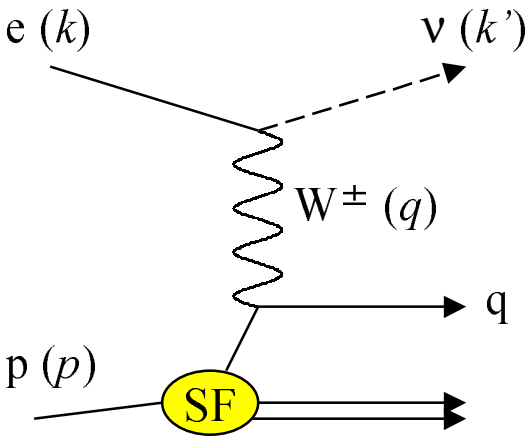
ElectroWeak Interactions and Unified Theories,
Rencontres de Moriond 2001

12/Mar/2001 T.Fusayasu (Univ. of Tokyo)

Deep Inelastic Scattering (DIS) at HERA



Neutral Current (NC)



Charged Current (CC)

$$\mathrm{DIS} = \mathrm{PDF(QCD)} \otimes \mathrm{EW}$$

Kinematic variables

- Virtuality.

  $Q^2 \equiv -(k-k')^2$ → Spatial Resolution $\lambda \sim 1/Q$.
  At HERA, $Q^2 \lesssim 10^5$ GeV^2 → $\lambda \gtrsim 10^{-3}$ fm.

- Bjorken scaling variable.

  $$x \equiv \frac{Q^2}{2p\cdot q}$$ → Fractional momentum of the proton carried by the struck quark.

- Inelasticity

  $$y \equiv \frac{p\cdot q}{p\cdot k} = \frac{Q^2}{sx}$$

NC Cross Section

$$\frac{d^2\sigma^{NC}_{BORN}(e^{\pm}p)}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4}\left[Y_+F_2^{NC}(x,Q^2) \mp Y_- xF_3^{NC}(x,Q^2) - y^2F_L^{NC}(x,Q^2)\right]$$

$$[\,Y_{\pm} = 1 \pm (1-y)^2\,]$$

$F_2^{NC} \sim \sum(xq_i + x\bar{q}_i) \otimes$ (EW coupling)

$xF_3^{NC} \sim \sum(xq_i - x\bar{q}_i) \otimes$ (EW coupling) ← γ–Z_0 interference term.

→ Visible at $Q^2 > M_Z^2$.

F_L^{NC} → Influence is small in our kinematic region.

CC Cross Section

At the QCD leading order,

$$\begin{cases} \dfrac{d^2\sigma(e^+p)}{dxdQ^2} = \dfrac{G_F^2}{2\pi}\left(\dfrac{M_W^2}{M_W^2+Q^2}\right)^2 \displaystyle\sum_{i=1}^{2}\left[\bar{u}_i(x,Q^2) + (1-y)^2\, d_i(x,Q^2)\right] \\ \dfrac{d^2\sigma(e^-p)}{dxdQ^2} = \dfrac{G_F^2}{2\pi}\left(\dfrac{M_W^2}{M_W^2+Q^2}\right)^2 \displaystyle\sum_{i=1}^{2}\left[u_i(x,Q^2) + (1-y)^2\, \bar{d}_i(x,Q^2)\right] \end{cases}$$

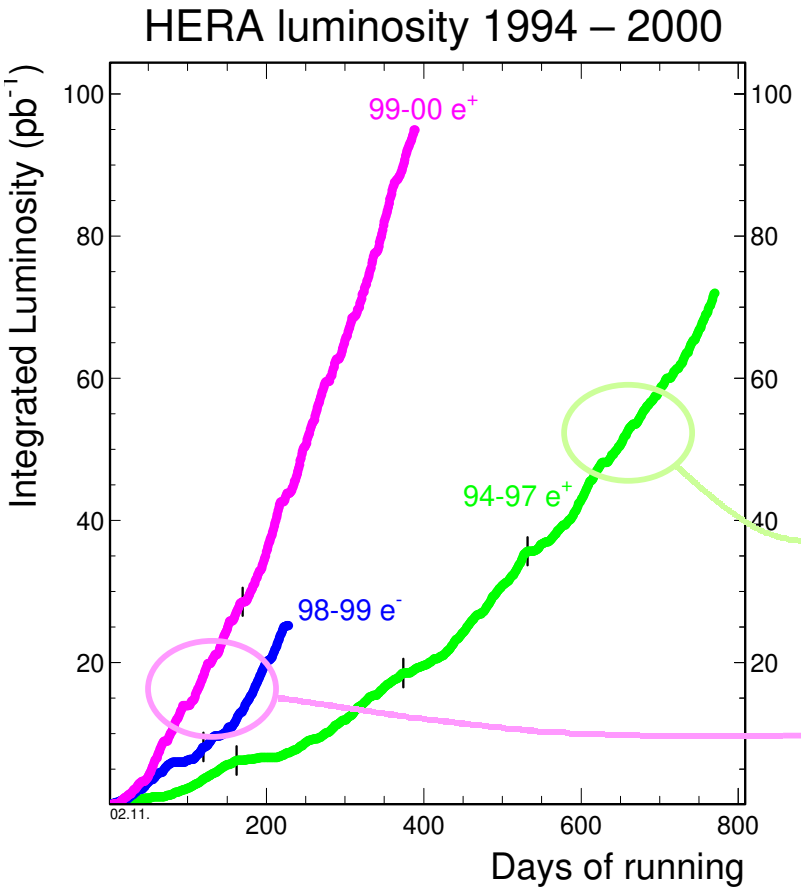
- e^+p is sensitive to d quarks, which is suppressed by $(1-y)^2$.
- e^-p is sensitive to u quarks.

→ Dissolve valence quark distributions at high-x.

NLO QCD

- Evolution of PDF predicted by pQCD : DGLAP equation.
  → Does it hold up to as high Q^2 as HERA reaches?

History of the HERA Luminosity



Utilized Luminosity
$L \sim 130$ pb^{-1}
in total.

Ee = 27.5 GeV
Ep = 820 GeV

Ee = 27.5 GeV
Ep = 920 GeV

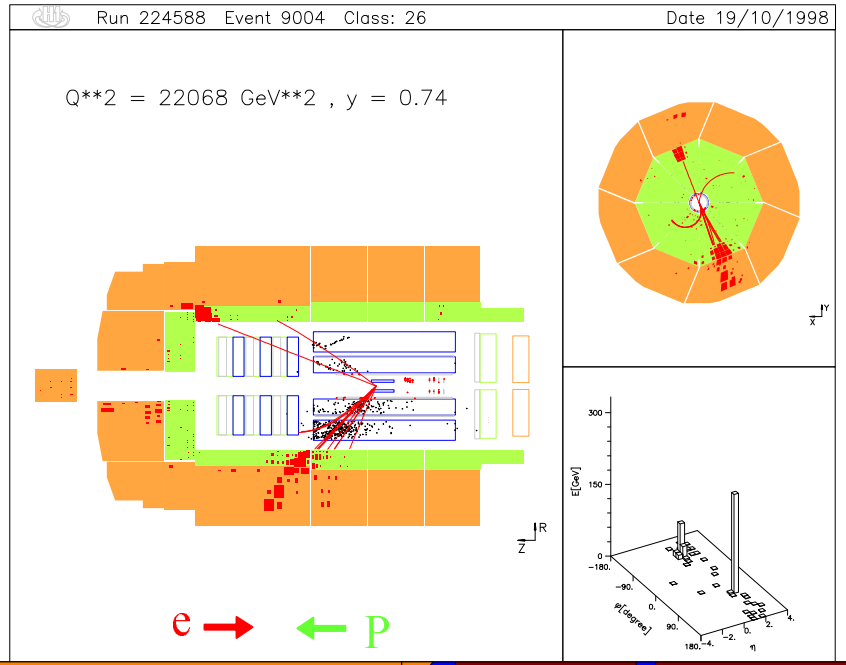
1994-1997 positron runs
H1 : 36.6 pb^{-1} → published.
ZEUS : 47.7 pb^{-1} → published.

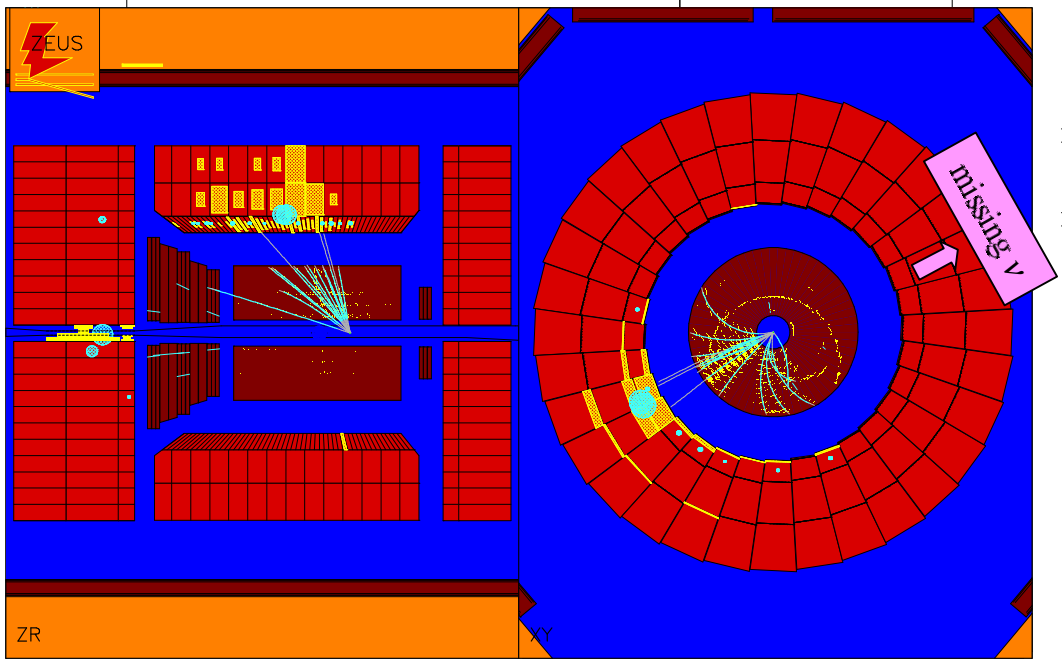
New Results

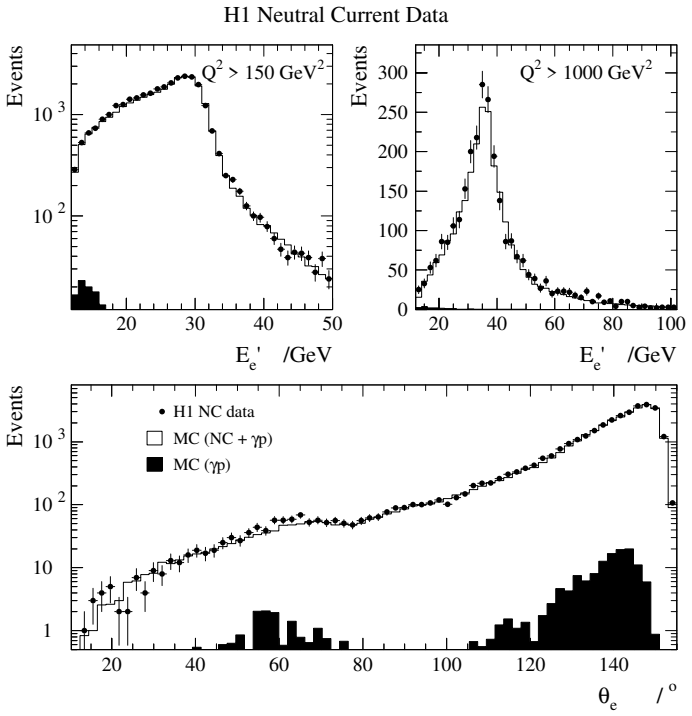
1998-1999 electron runs
H1 : 16.4 pb^{-1} → published.
ZEUS : 16.3 pb^{-1} → preliminary.

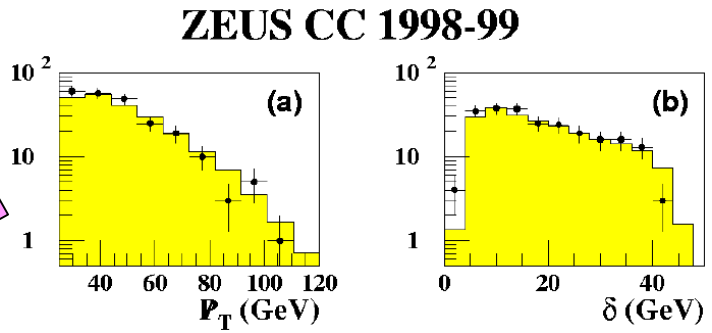
1999-2000 positron runs
H1 : 65 pb^{-1} → 45.9 pb^{-1} analyzed and preliminary.
ZEUS : 68 pb^{-1}

H1 and ZEUS detectors







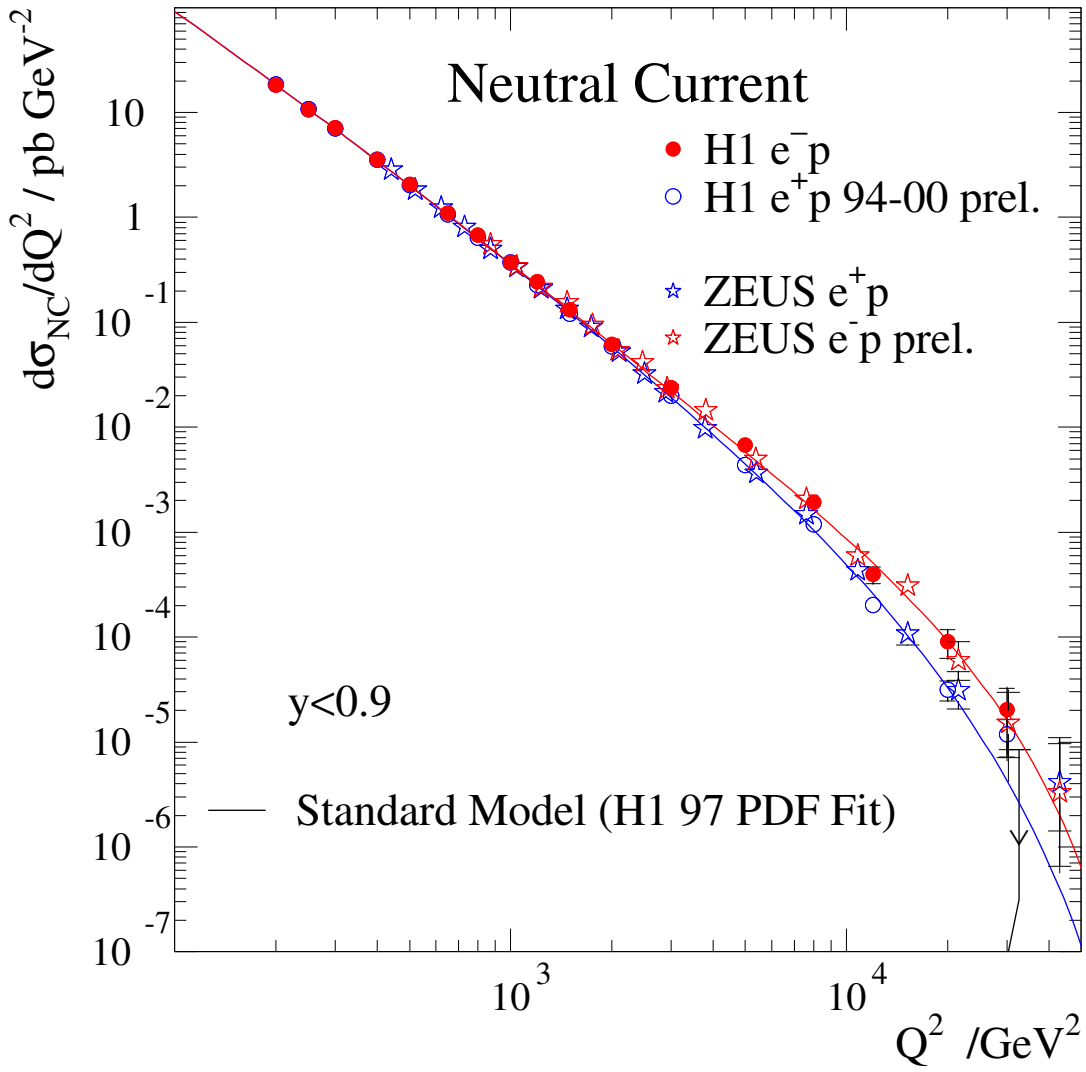


Kinematics are well understood

- NC → Electron finding
- CC → Missing P_T

NC (ep→eX) Cross-Sections

Single Differential Cross Sections dσ/dQ²

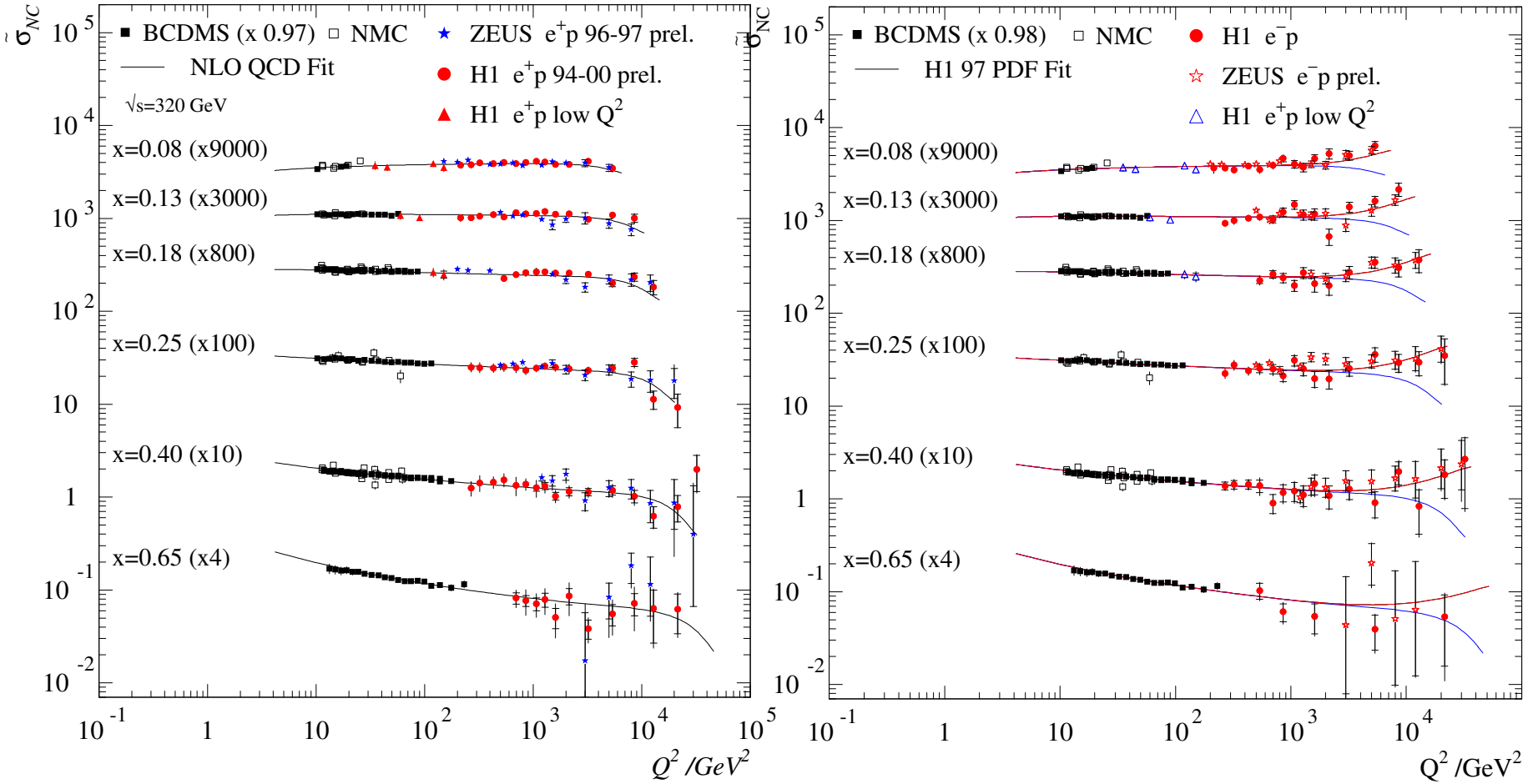


- Good agreement with SM over ~7 orders of magnitude.
- NLO QCD describes data well up to $Q^2 \sim 20{,}000\ GeV^2$.
- Small difference due to γ-Z_0 interference.

NC "Reduced" Cross-sections ($d^2\sigma/dxdQ^2$) at high x

$$\tilde{\sigma}_{NC}(e^{\pm}p) \equiv \frac{1}{Y_+}\frac{Q^4 x}{2\pi\alpha^2}\frac{d^2\sigma_{NC}}{dxdQ^2} = F_2^{NC}(x,Q^2) \mp \frac{Y_-}{Y_+} x F_3^{NC}(x,Q^2) - \frac{y^2}{Y_+} F_L^{NC}(x,Q^2)$$

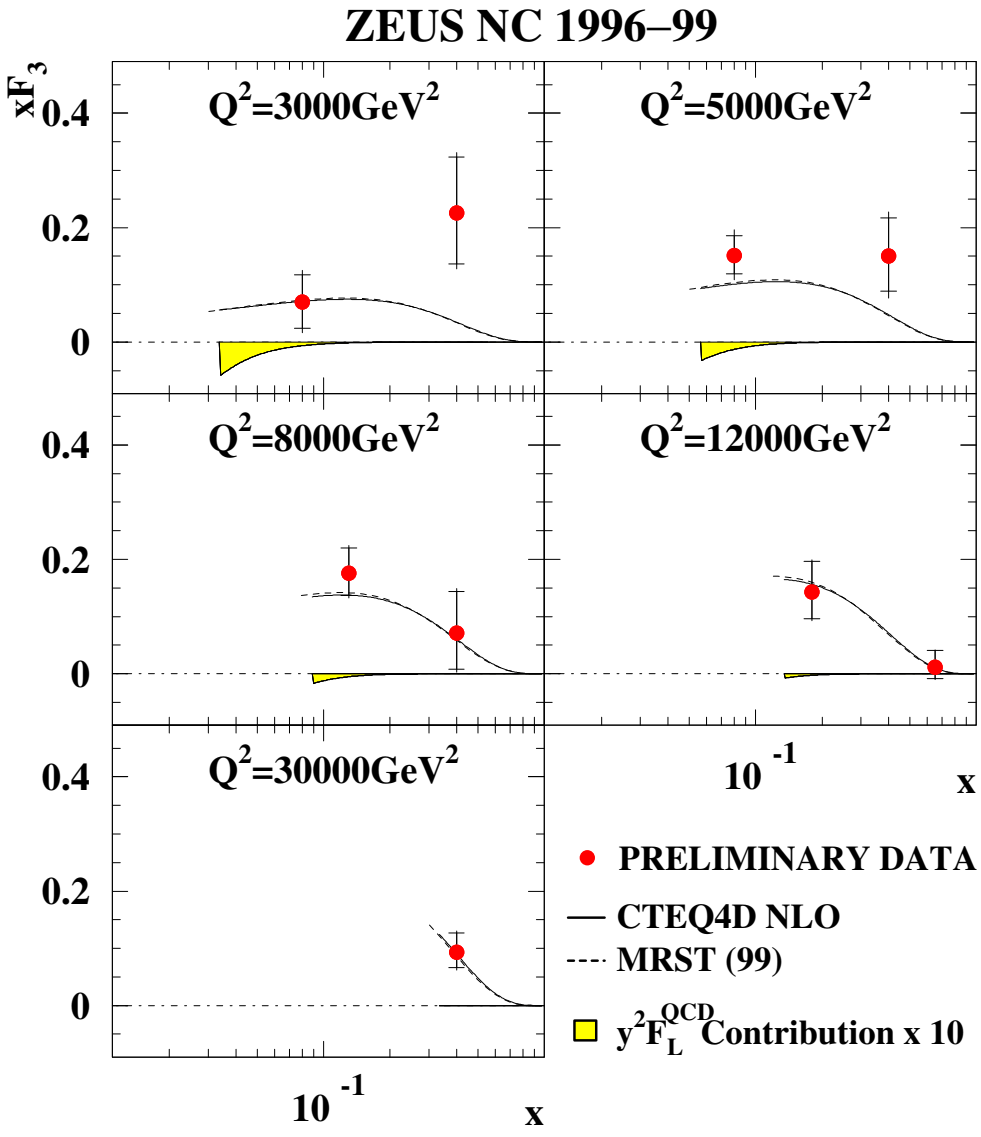
→ Structure Function component is extracted.



• Large Q^2 → Contribution from γ-Z_0 interference, xF_3

Extraction of xF_3^{NC}

- $\tilde{\sigma}^{-}_{NC} - \tilde{\sigma}^{+}_{NC} = (xF_3 + \Delta F_L)\left[\frac{Y^{920}_{-}}{Y^{920}_{+}} + \frac{Y^{820}_{-}}{Y^{820}_{+}}\right]$
- F_L correction is small enough (<10%)



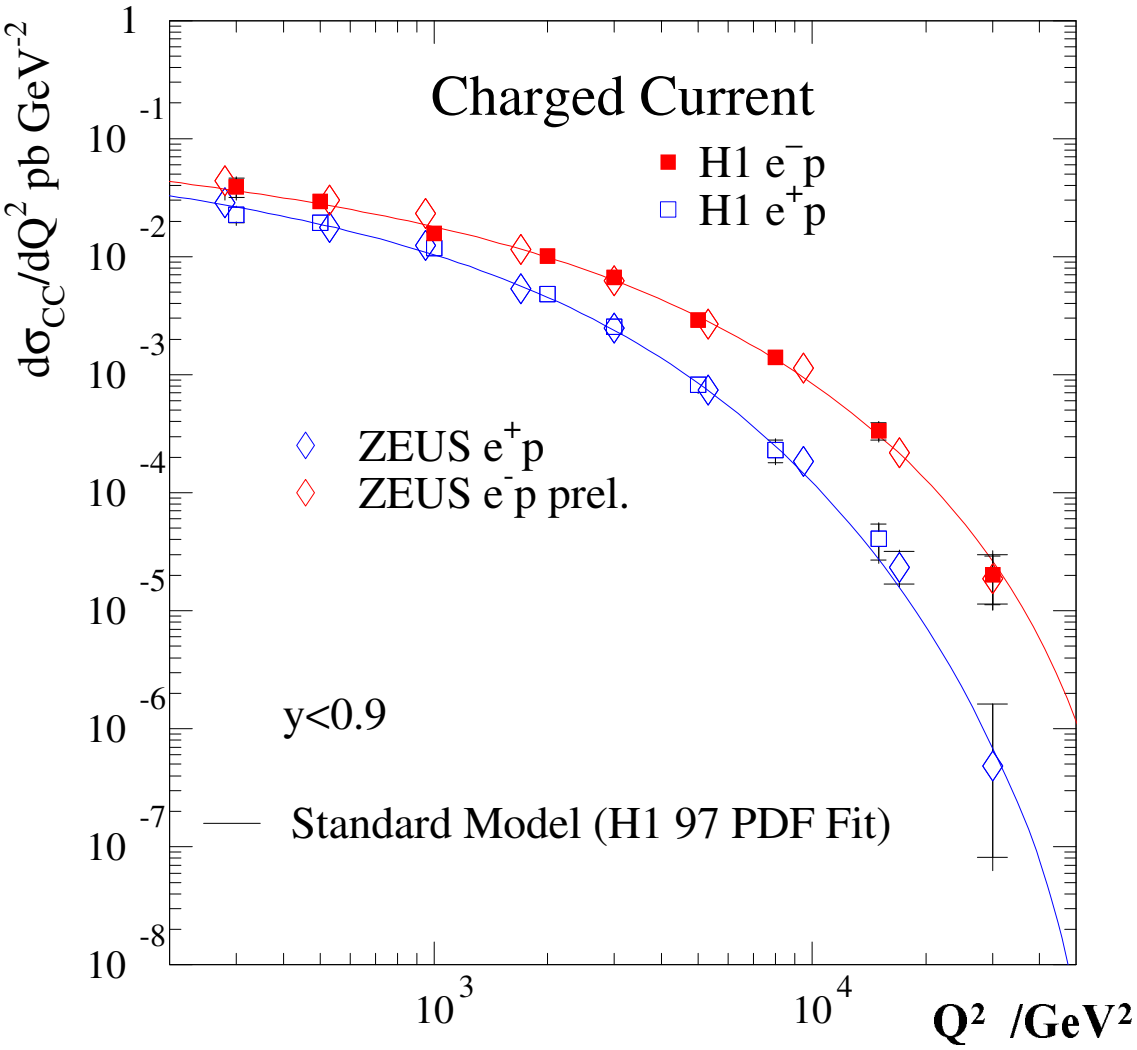
First extraction of xF_3^{NC} from HERA

CC (ep→νX) Cross-Sections

Single Differential Cross Sections dσ/dQ²

$$\frac{d^2\sigma(e^+p)}{dxdQ^2} = \frac{G_F^2}{2\pi}\left(\frac{M_W^2}{M_W^2+Q^2}\right)^2 \sum_{i=1}^{2}\left[\overline{u}_i(x,Q^2) + (1-y)^2\, d_i(x,Q^2)\right]$$

$$\frac{d^2\sigma(e^-p)}{dxdQ^2} = \frac{G_F^2}{2\pi}\left(\frac{M_W^2}{M_W^2+Q^2}\right)^2 \sum_{i=1}^{2}\left[u_i(x,Q^2) + (1-y)^2\, \overline{d}_i(x,Q^2)\right]$$



- σ(e⁻p) / σ(e⁺p) > 2, especially at high Q².
  → Contribution from different quarks (*u*/*d*),
  Helicity suppression (1-y)² on *d* quark.
- Slope is ascribed to M_W.

Extraction of M_W from CC cross sections

- Propagator term of $d\sigma/dQ^2$: $\frac{d\sigma_{CC}}{dQ^2} \propto G_{CC}^2 \left(\frac{M_W^2}{Q^2 + M_W^2} \right)^2$

  Normalization Slope

- Results of space-like measurements :

  ZEUS(e^+p) : $M_W = 81.4^{+2.7}_{-2.6}(\text{stat.}) \pm 2.0(\text{syst.})^{+3.3}_{-3.0}(\text{PDF})$ GeV

  H1(e^+p) : $M_W = 80.9 \pm 3.3(\text{stat.}) \pm 1.7(\text{syst.}) \pm 3.7(\text{PDF})$ GeV

  H1(e^-p) : $M_W = 79.9 \pm 2.2(\text{stat.}) \pm 0.9(\text{syst.}) \pm 2.1(\text{PDF})$ GeV

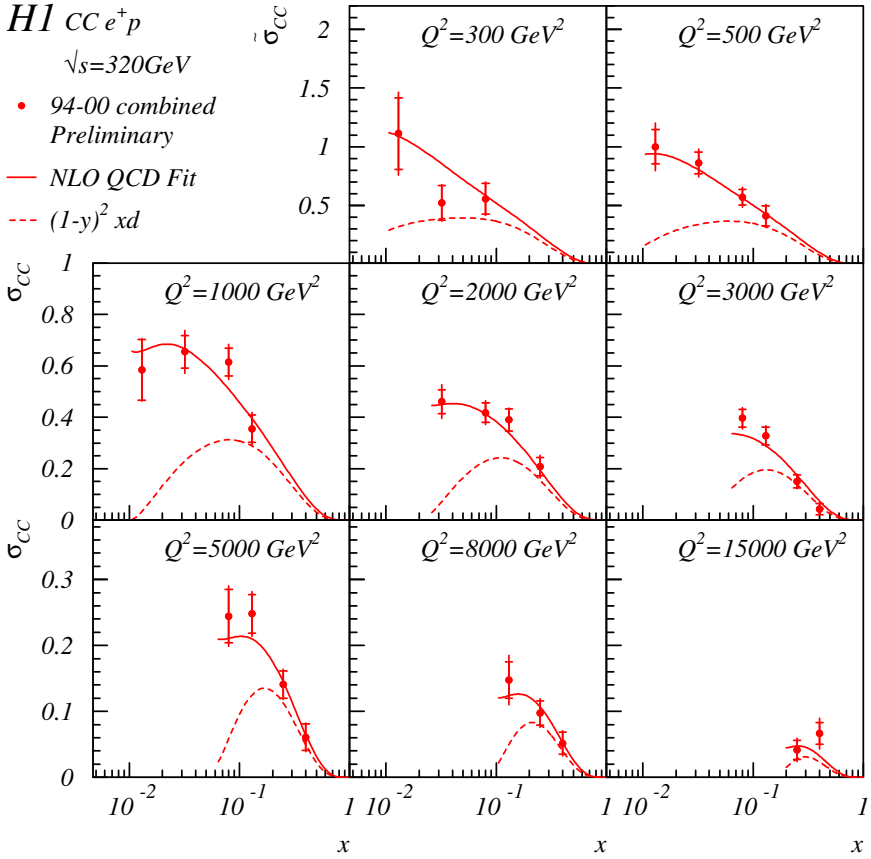
→ Consistent with time-like measurements by LEP/Tevatron. (PDG'00 : 80.419±0.038 GeV)

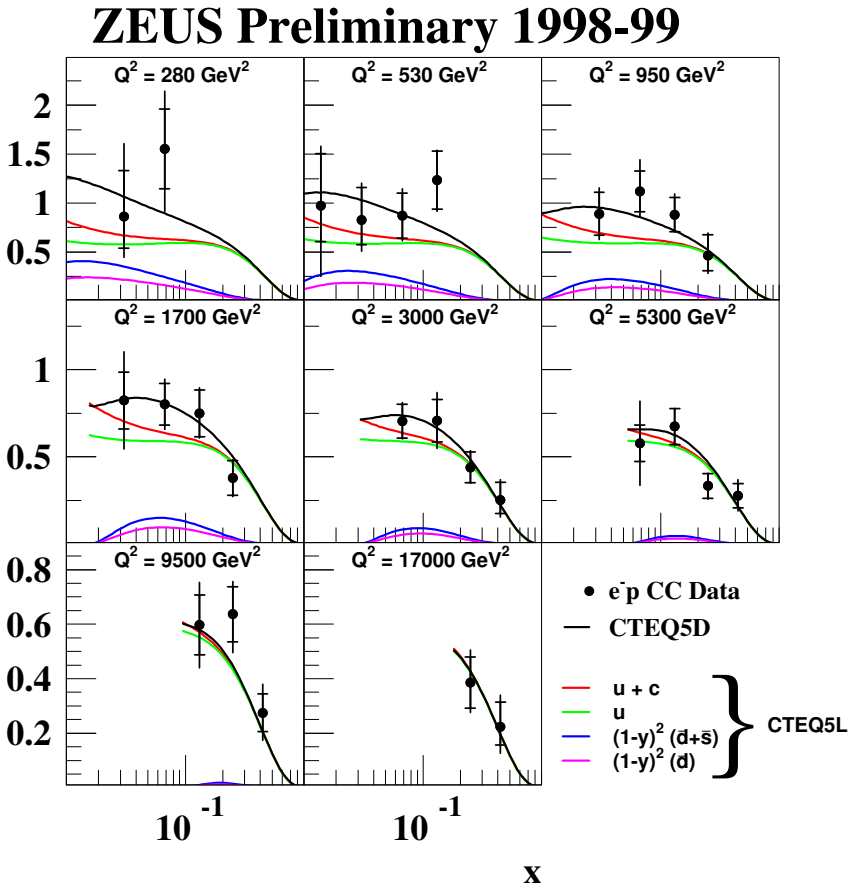
First Space-like Measurement

CC Double Differential Cross Sections

"Reduced" cross-section :

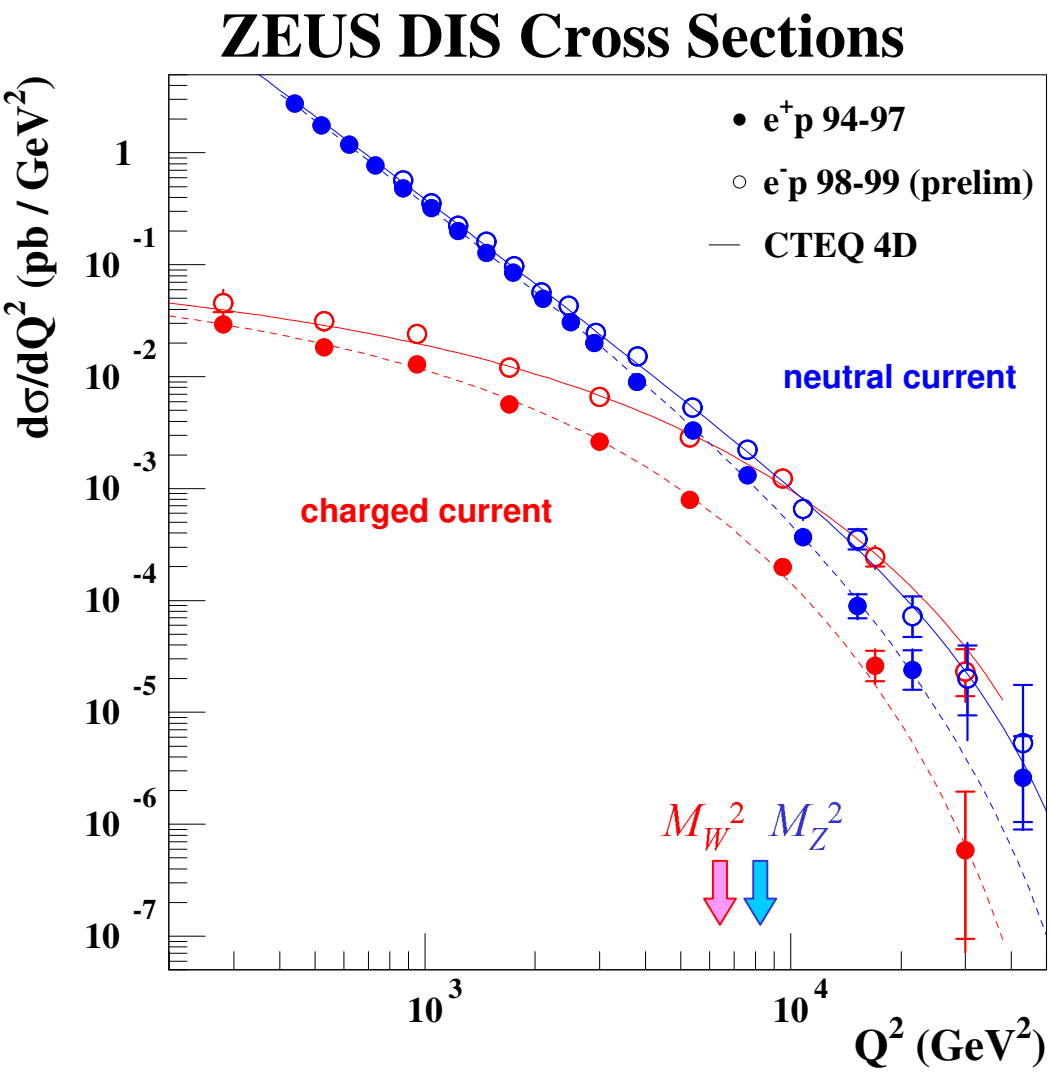
$$\tilde{\sigma}_{CC}(x,Q^2) \equiv \frac{2\pi x}{G_F^2}\left(\frac{M_W^2+Q^2}{M_W^2}\right)^2 \frac{d^2\sigma_{CC}}{dx dQ^2} \underset{(LO)}{=} \begin{cases} \sum_{i=1}^{2}\left[u_i(x,Q^2)+(1-y)^2\,\overline{d}_i(x,Q^2)\right] & \cdots (e^- p) \\ \sum_{i=1}^{2}\left[\overline{u}_i(x,Q^2)+(1-y)^2\,d_i(x,Q^2)\right] & \cdots (e^+ p) \end{cases}$$





NC and CC combined

Comparison between NC/CC, e^+p/e^-p



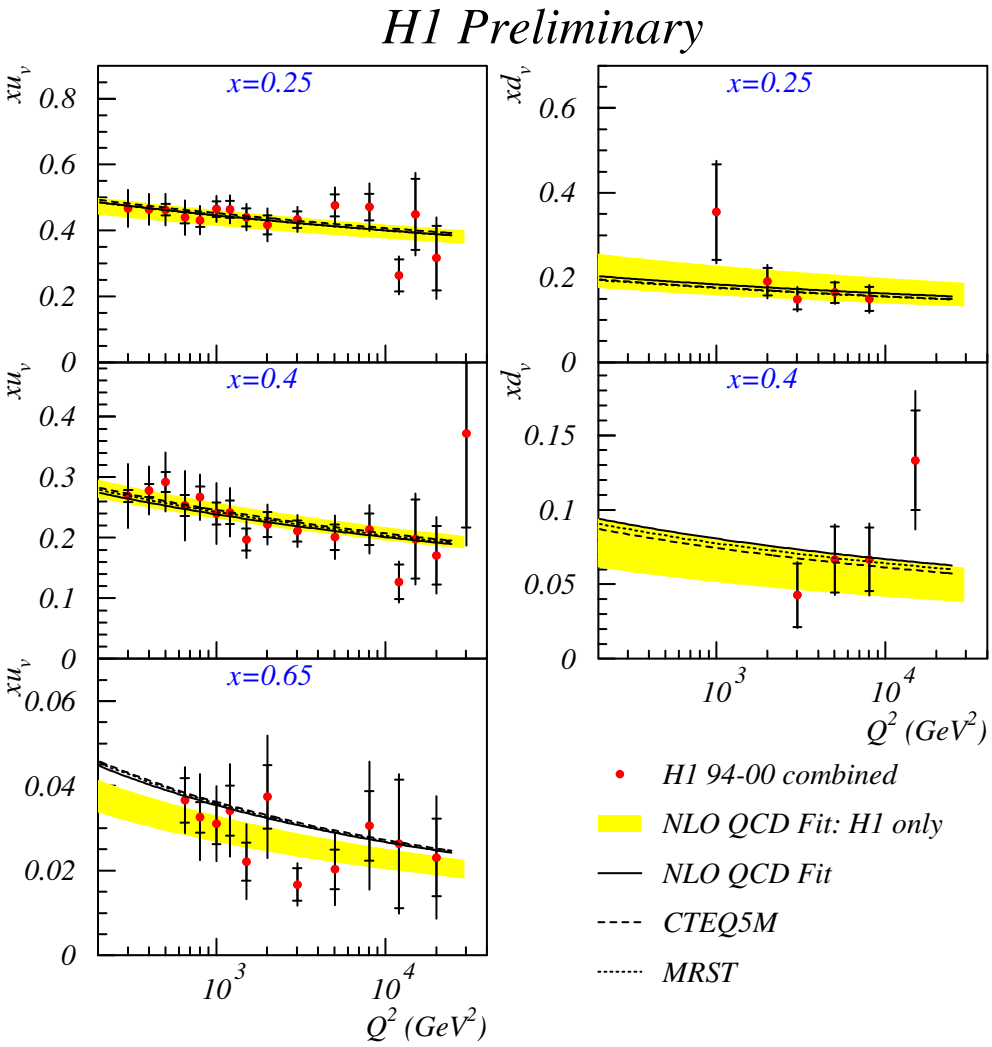
- Lower Q^2 ➡ σ(CC) is suppressed by M_W .
- $Q^2 \gtrsim 10{,}000\ \mathrm{GeV}^2$ ➡ M_Z^2 , $M_W^2 \ll Q^2$.
  → σ(NC) ~ σ(CC)

Unification of EW is observed

Extraction of valence xq (H1)

- NLO QCD fit to high-Q^2 CC/NC cross sections, according with low-Q^2 data.
- NC/CC data with >70% xq_v contribution are shown.

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



- Extracted xu_v, xd_v are in good agreement with QCD NLO.

Summary

4 sets of cross sections, NC and CC in e^-p and e^+p collisions, have been measured.

NC ($e^{\pm}p \rightarrow e^-X$)

- Consistent with SM.
- γ-Z_0 interference is observed at high-Q^2.
  → Structure function xF_3 is extracted.

CC ($e^{\pm}p \rightarrow \nu X$)

- Consistent with SM.
- $\sigma(e^-p) / \sigma(e^+p) > 2$ (>10 at Q^2>10,000) due to different involved parton flavors and $(1-y)^2$ suppression on d(x).

QCD aspects

- NLO QCD holds up to $Q^2 \sim 20{,}000$ GeV^2.
- u_v and d_v are extracted.

EW aspects

- EW unification is clearly seen.
- Space-like M_W is extracted.

Outlook

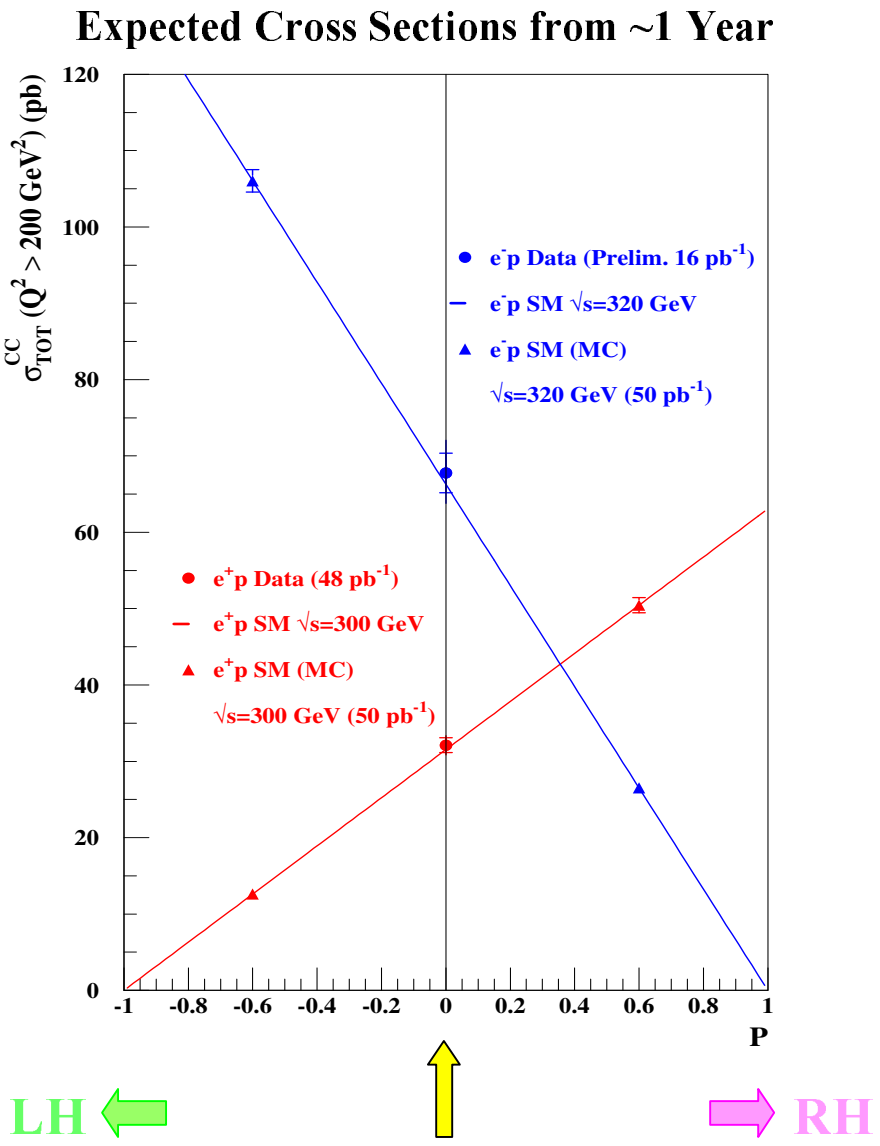
Luminosity Upgrade / Polarized Lepton Beam

→See Next Page

Outlook for HERA II

(2001 ~ 2005+)

- Luminosity upgrade : 1 fb^{-1} in total.
  (Focusing magnets inside the detectors)
- LH/RH longitudinally polarized e^+/e^- beam.



P=0
(have been measured)