High Q^2 results from HERA

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on behalf of the

&

Collaborations

PIC2000
Lisbon, Portugal
June 29 - July 1, 2000

Overview

HERA : **unique e-p collider**

$\hookrightarrow$ study Deep Inelastic Scattering (DIS)

(27.6 GeV) $\mathbf{e^{\pm}}$ $\Longrightarrow \bullet$ $\bullet \Longleftarrow$ **p** (820 GeV)

In 1998 proton energy : **820 GeV** $\nearrow$ **920 GeV**

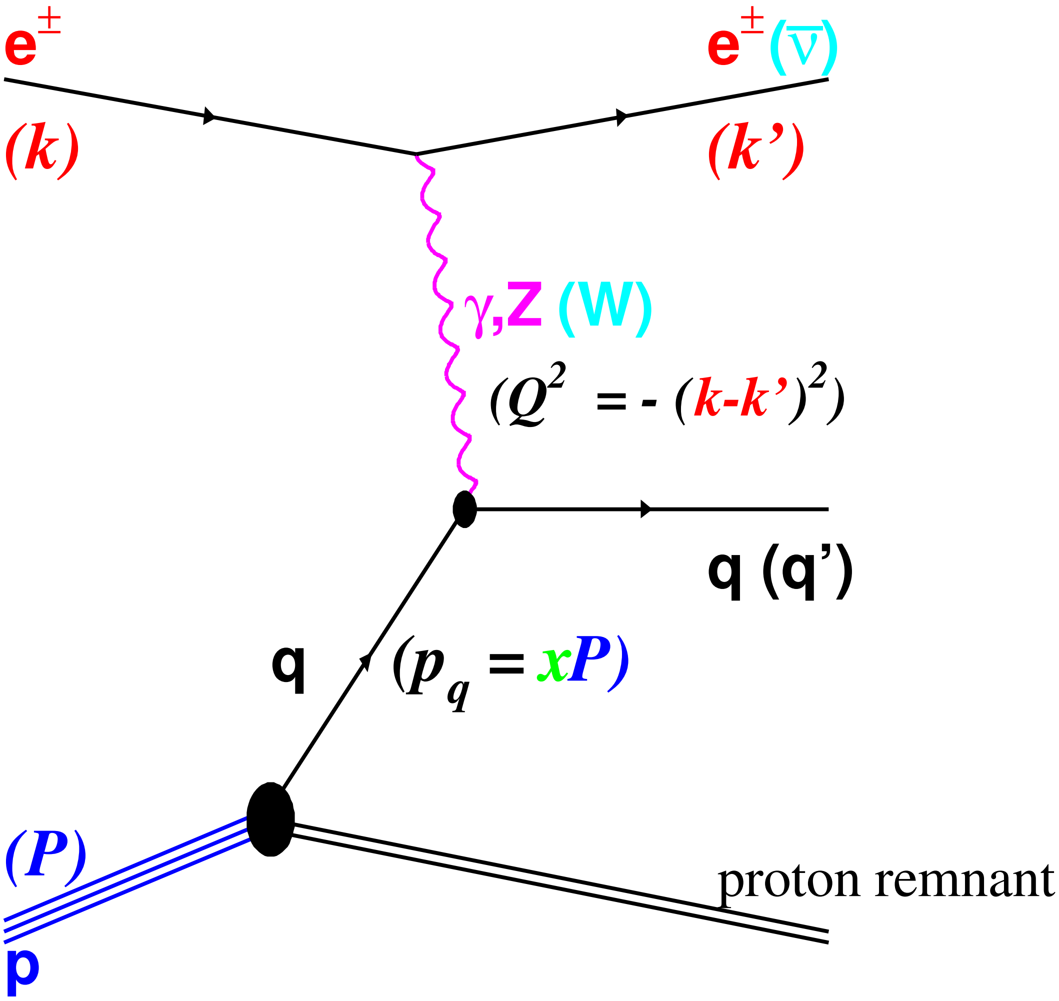
$\hookrightarrow$ $\sqrt{S}$ increased from 300 GeV to 320 GeV

H1 and ZEUS have data covering 1994 to spring 2000.
Each experiment has recorded about 100 pb^{-1} of data
(80 pb^{-1} e^{+}-p and 20 pb^{-1} e^{-}-p)

This talk : High Q^2 domain ($\geq$ 1000 GeV^2)

- Inclusive Cross-sections
  - Neutral Current (NC)
  - Charged Current (CC)
  - Attempts to interprete deviations wrt Standard Model
- W production
  - High P$_T$ isolated leptons

e - p DIS Kinematics



Variables :

- Q^2 = Squared Four Momentum Transfer
- x = Fractional parton momentum
- y = Inelasticity
- s = Squared C.M. Energy
- M^2 = Squared Lepton-parton invariant mass

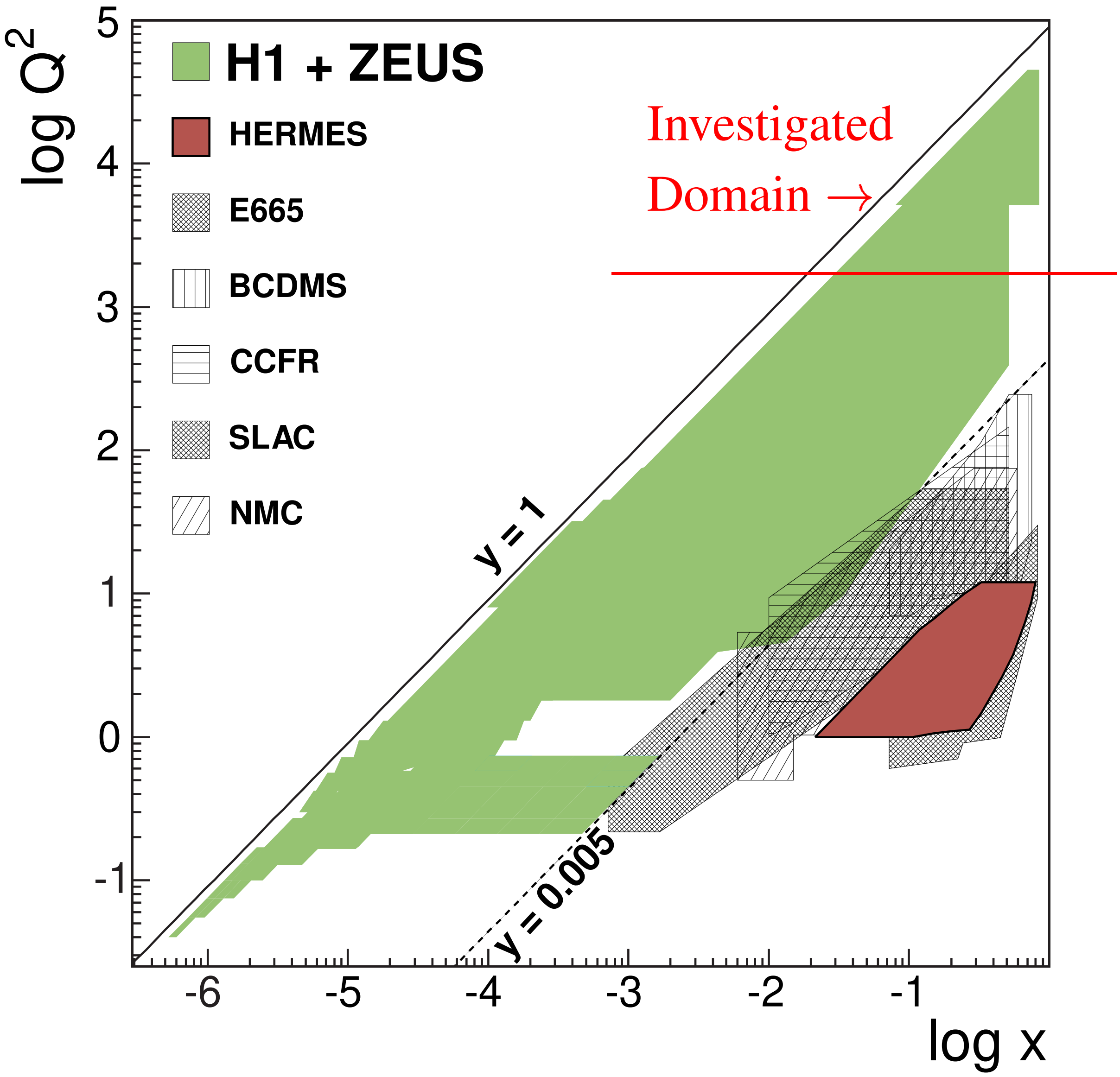
$$Q^2 = xys = My$$

Physics Motivations

- Probe the proton down to $d \sim 1/Q \sim 10^{-18}$ m
- Probe physics in a region where electromagnetic (γ) and weak (W,Z) interactions are of comparable strength

$\Longrightarrow$ Test the Standard Model with our highest Q^2 data

$\Longrightarrow$ Study eventual deviations from the SM at high Q^2



Most of kinematically accessible plane now covered

The Data

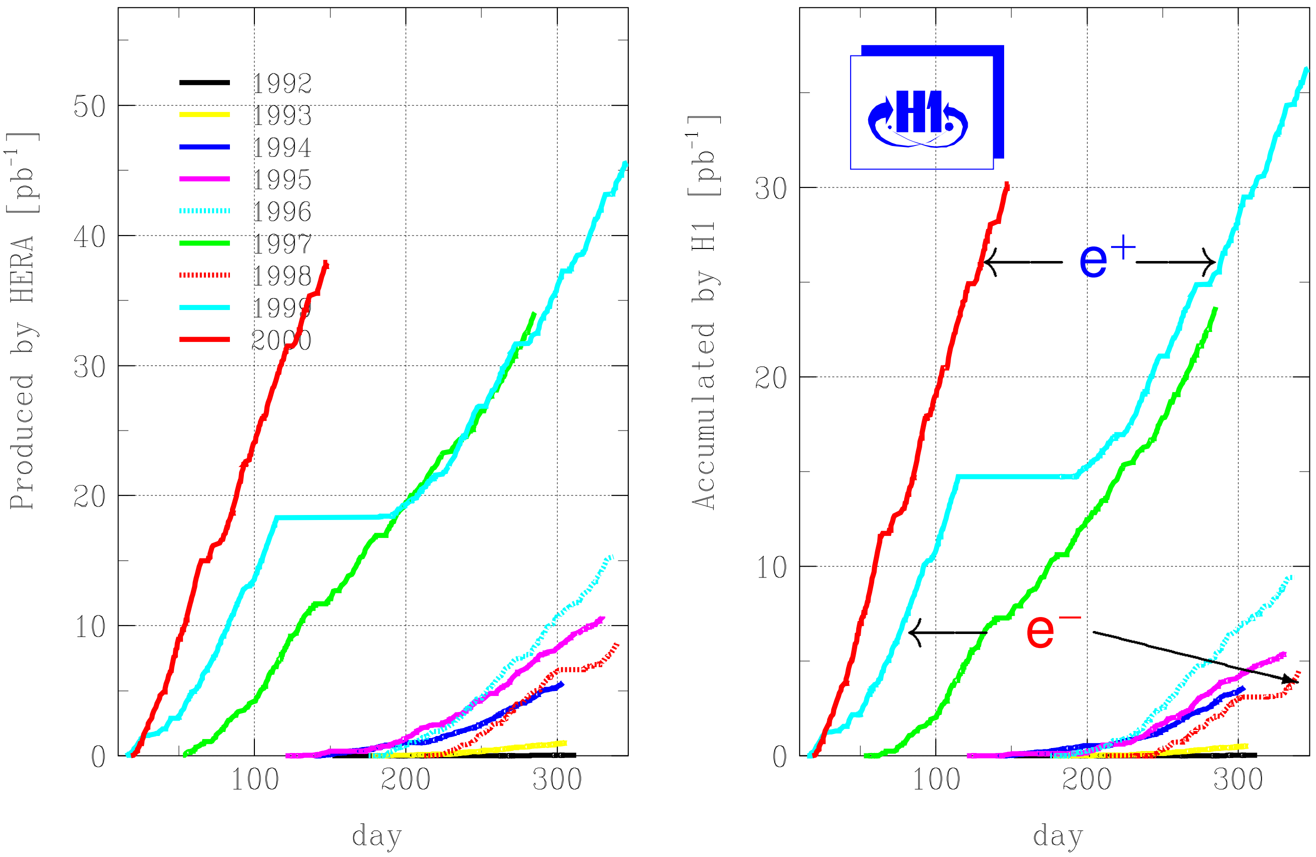
Available data sets

		H1	ZEUS
• 1994 - 1997	: e^+-p (820 GeV)	37 pb^{-1}	48 pb^{-1}
• 1998 - 05/1999	: e^--p (920 GeV)	18 pb^{-1}	16 pb^{-1}
• 07/99 - 05/2000 (continue to 09/2000)	: e^+-p (920 GeV)	$\sim$ 50 pb^{-1}	$\sim$ 50 pb^{-1}

High int. luminosities $\Rightarrow$ statistics in high Q^2 domain

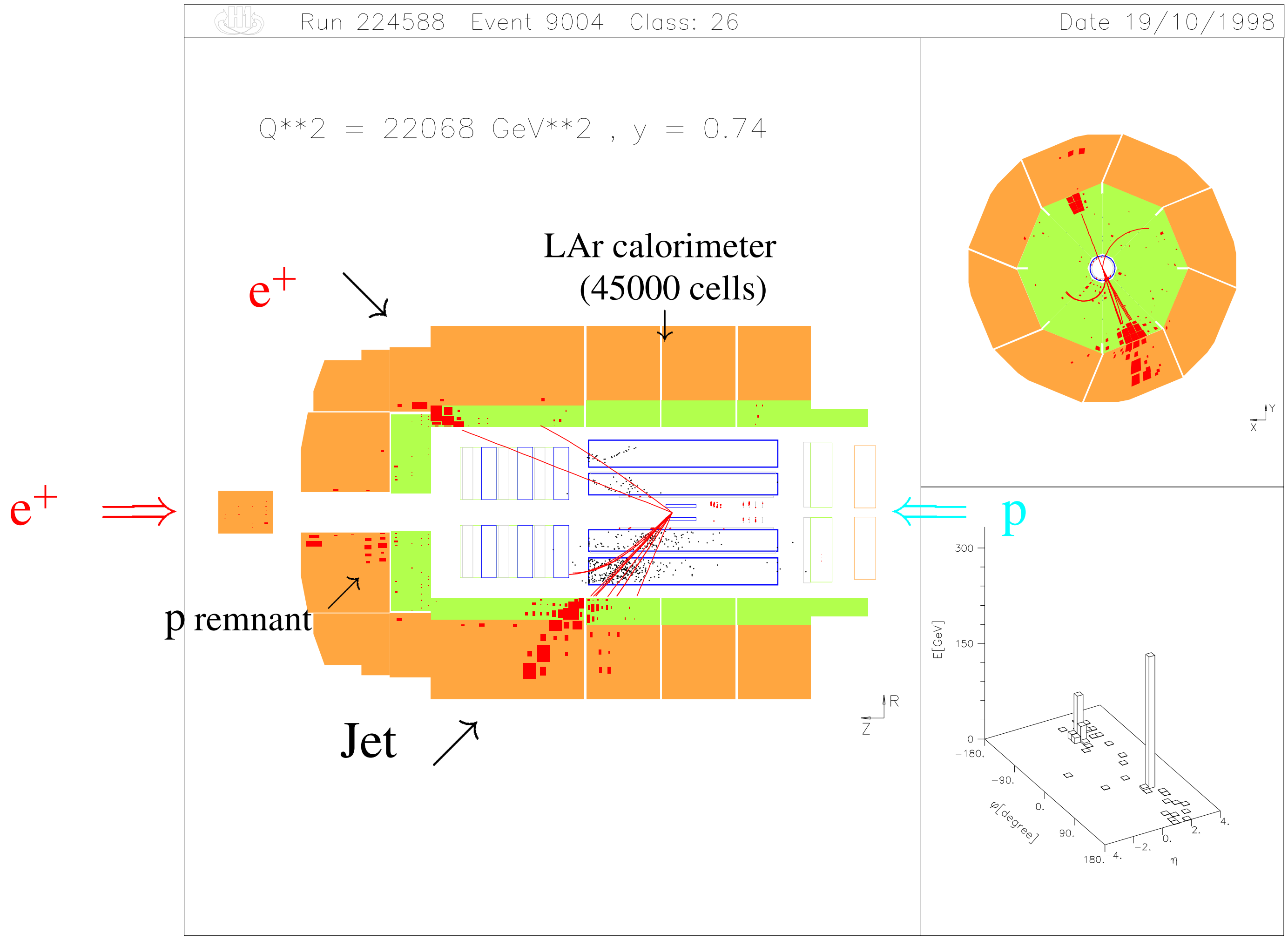
$\hookrightarrow$ study both e^+-p and e^--p interactions for 1st time

INTEGRATED LUMINOSITY (29.05.00)



NC Event Signature

- Charged track with EM energy associated to it
- Hadronic energy (jet)

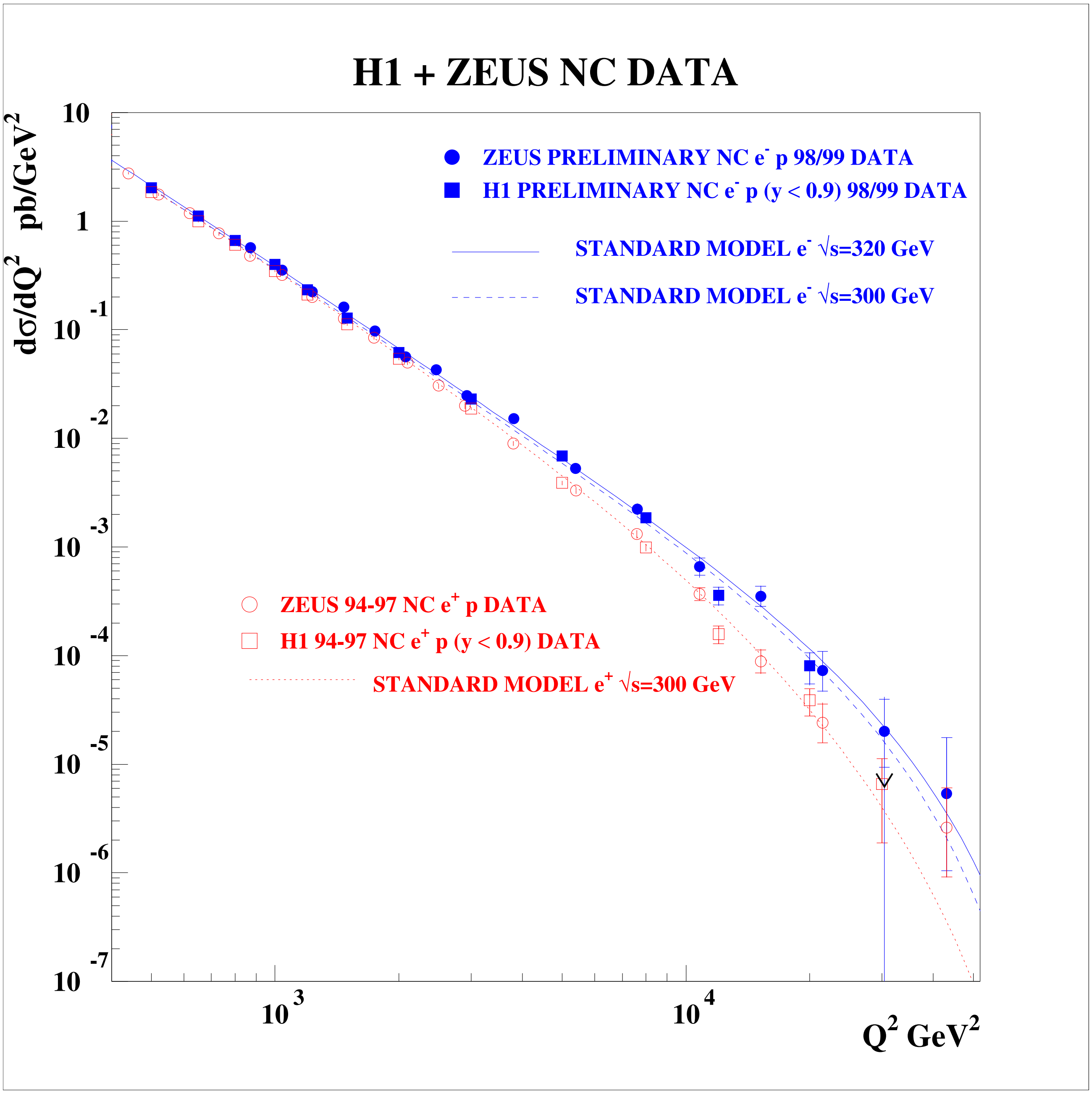


Main Event Selection Criterion :

Electromagnetic energy in LAr Calorimeter

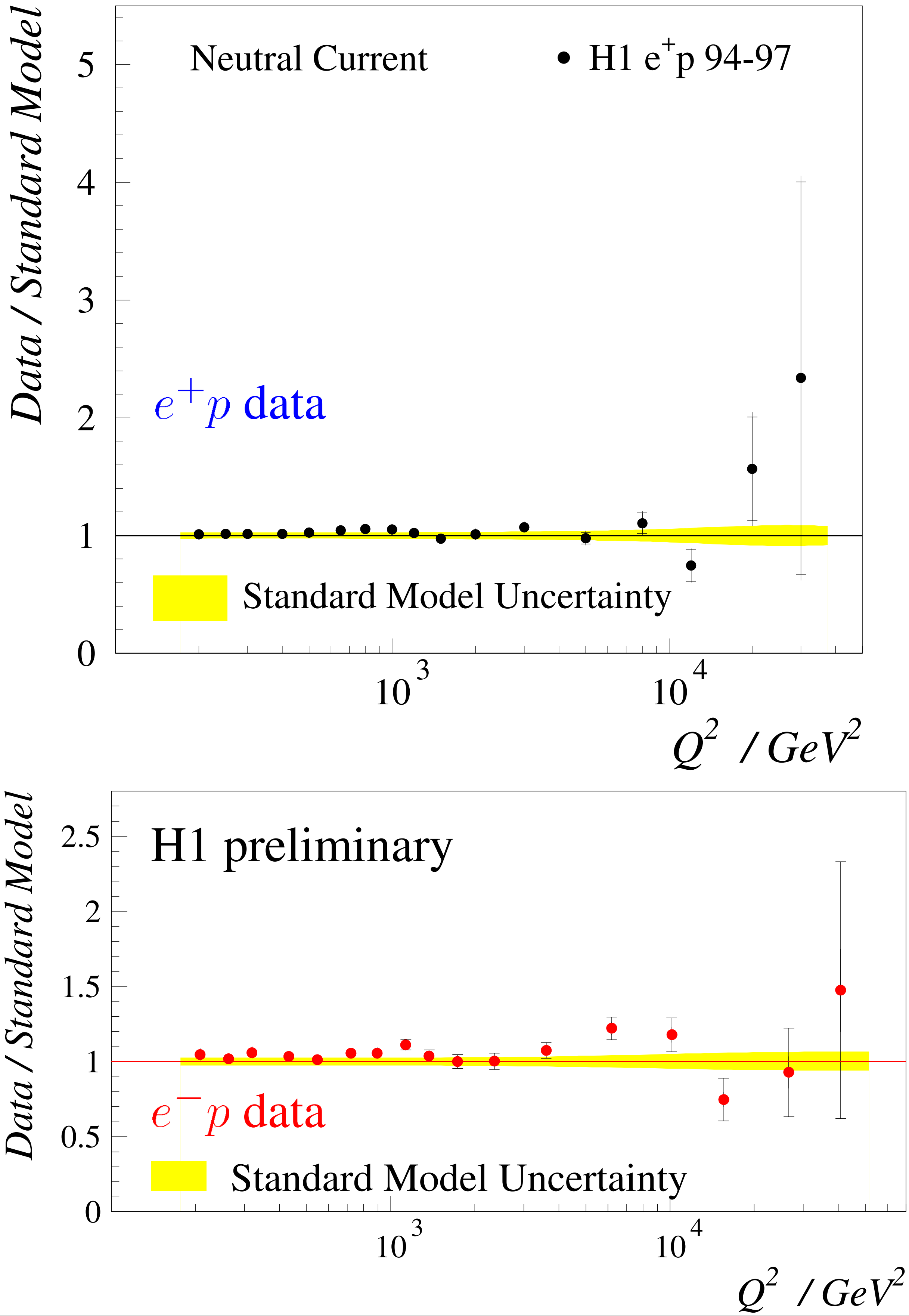
Overconstrained kinematics $\Longrightarrow$ good determination of e and jet parameters (angle, energy deposition)

$d\sigma/dQ^2$ NC : e^+-p vs e^--p data



- HERA data : agree with pQCD on wide Q^2 range
- $d\sigma/dQ^2$ drops by $\sim$ 7 orders of magn. over 2 orders in Q^2
- $\sigma(e^-\text{-p}) > \sigma(e^+\text{-p})$ at $Q^2 \geq 5000$ GeV^2, due to $\oplus\ \gamma/Z$ interference in e^--p ($\ominus$ in e^+-p)

NC $d\sigma/dQ^2$ Compared to Standard Model

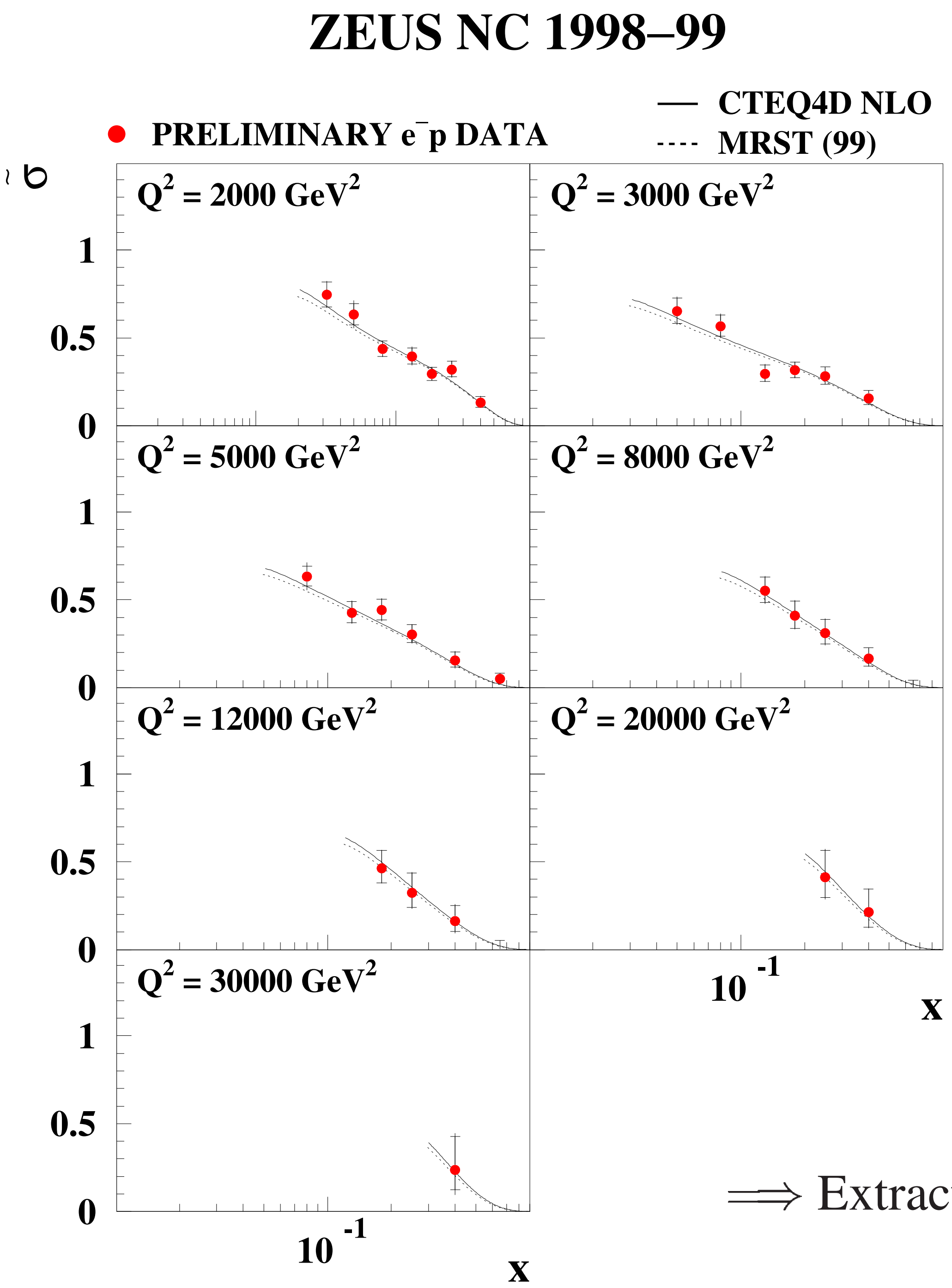


NC e^+p and e^-p $d\sigma/dx$

Define reduced NC cross section :

$$\tilde{\sigma}_{NC} = x \, \frac{Q^4}{2\pi\alpha^2 Y_+} \, \frac{d^2\sigma^{NC}}{dx dQ^2}$$

$$Y_+ = 1 + (1-y)^2$$



$\Longrightarrow$ Extract $xF_3 \rightarrow$

Extraction of xF_3 from $\tilde{\sigma}(e^+p)$ and $\tilde{\sigma}(e^-p)$

Reminder :

$$\frac{d^2\sigma^{NC}_{Born}}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4}(Y_+F_2(x,Q^2) - y^2F_L(x,Q^2) \mp Y_-xF_3(x,Q^2))$$

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

- sign of xF_3 term depends on lepton charge
- y^2F_L contribution negligible at high Q^2

Data sets used here (ZEUS Analysis) :

- σ^+ (1996 - 1997) e$^+$ -p (820 GeV) 30 pb^{-1}
- σ^- (1998 - 1999) e$^-$ -p (920 GeV) 16 pb^{-1}

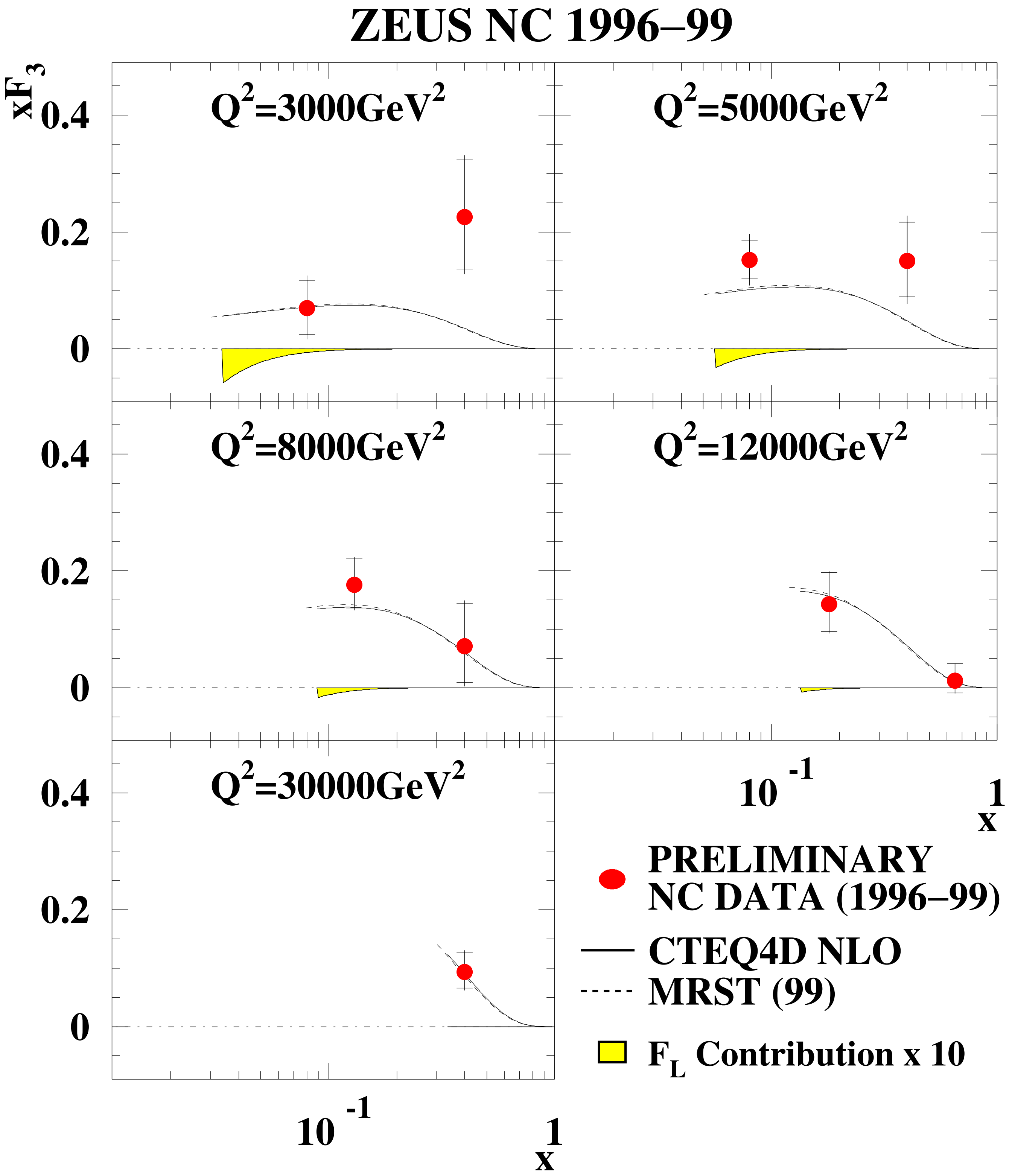
Different E_p (proton beam energies) $\Longrightarrow$ need $Y_\pm^{E_p}$

$$\sigma^+ = \frac{2\pi\alpha^2}{xQ^4} \cdot (Y_+^{820} \cdot F_2 - Y_-^{820} \cdot \mathbf{xF_3})$$

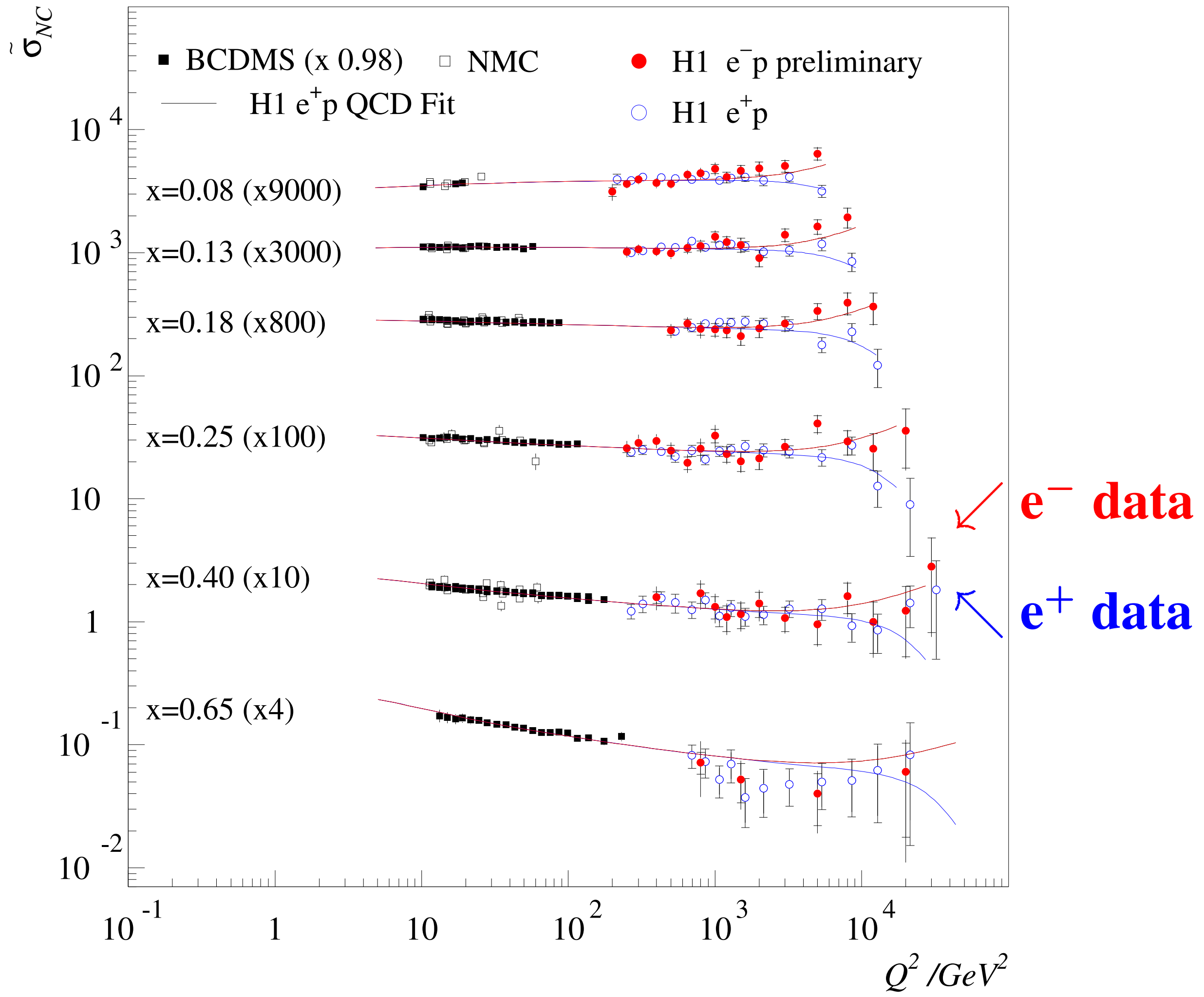
$$\sigma^- = \frac{2\pi\alpha^2}{xQ^4} \cdot (Y_+^{920} \cdot F_2 + Y_-^{920} \cdot \mathbf{xF_3})$$

$\Longrightarrow$ **Using reduced cross sections $\tilde{\sigma}$, extract xF_3 :**

$$xF_3 = \left(\frac{Y_-^{820}}{Y_+^{820}} + \frac{Y_-^{920}}{Y_+^{920}}\right)^{-1} \cdot \left(\frac{1}{Y_+^{920}} \cdot \tilde{\sigma}^- - \frac{1}{Y_+^{820}} \cdot \tilde{\sigma}^+\right)$$


ZEUS NC 1996–99
xF3
Q2=3000GeV2
Q2=5000GeV2
Q2=8000GeV2
Q2=12000GeV2
Q2=30000GeV2
0.4
0.2
0
10 -1
1
x
PRELIMINARY
NC DATA (1996–99)
CTEQ4D NLO
MRST (99)
FL Contribution x 10

QCD fit of fixed target and HERA data

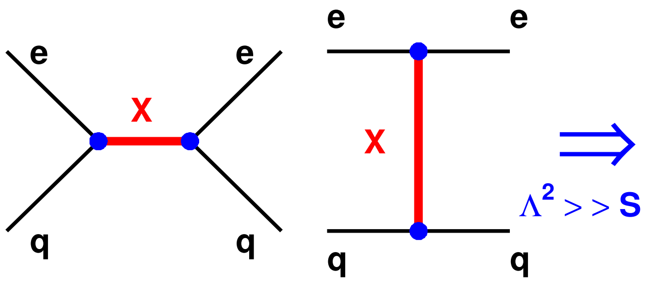


pQCD is tested over ∼4 orders of magnitude in Q^2

- in e^+ data at high Q^2, excess at $x \sim 0.4$ mainly due to events in 94-96 (e^+) data sample
- wait for more statistics !

BSM : Contact Interactions

- High Q^2 domain : **the place** to look for New Physics, Beyond the Standard Model (BSM)
- Processes with characteristic energy scale $\Lambda >> \sqrt{S}$: parameterized as Contact Interactions CI



4-Fermion ($eeqq$) CI with effective coupling $\eta_{ij}^q = \epsilon_{ij}^q \frac{4\pi}{\Lambda^2}$
(Only vector terms considered ; scalar and tensor terms beyond sensitivity of HERA)

$$\mathcal{L} = \mathcal{L}_{\mathcal{SM}} + \mathcal{L}_{\mathcal{CI}}$$

with

$$\mathcal{L}_{CI} = \Sigma \eta_{ij}^q (\overline{e}_i \gamma^\mu e_i)(\overline{q}_j \gamma_\mu q_j)$$

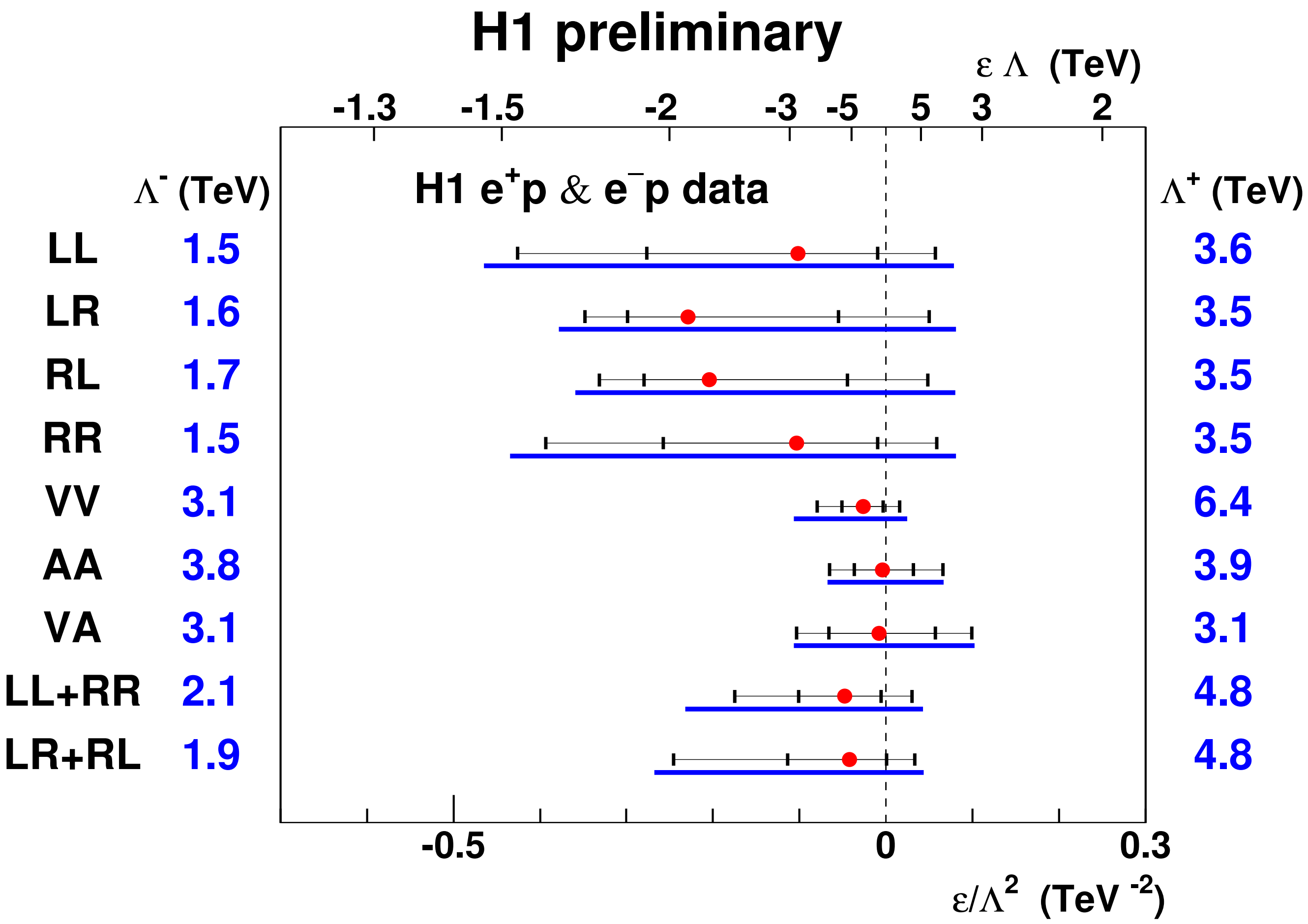
$\epsilon_{ij}^q = \pm 1$ (allows positive or negative interference)
$i, j = L, R \quad ; \quad q = u, d$

$|CI|^2$ + Interference $\Longrightarrow$ CI affect $d\sigma/dQ^2$ and $d\sigma/dx$

$\Longrightarrow$ Look for distorsions of Q^2 spectrum

$\Longrightarrow$ Fit to $d\sigma/dQ^2$ yields limits on Λ

Limits for Compositeness Models

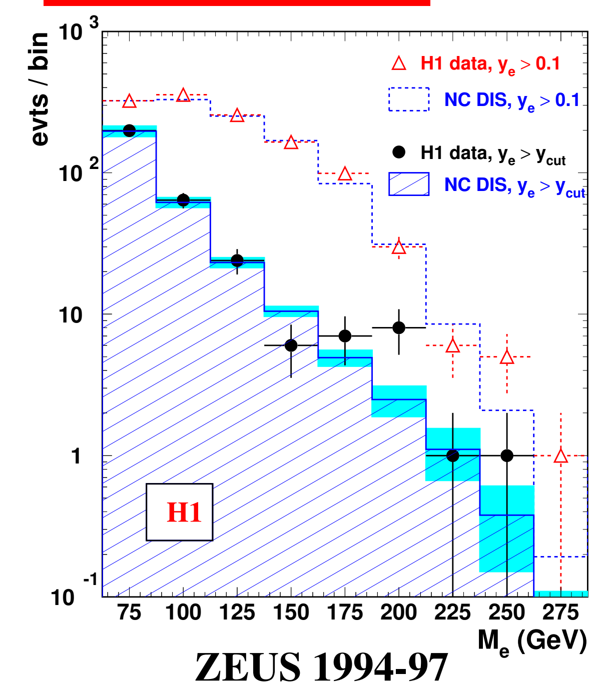


● show Λ values for best fit

- H1 limits from combined e^+p and e^-p data
- Similar results from ZEUS (e^+p) (other models also investigated)
- LEP (ALEPH) limits often more stringent (stronger hypotheses)

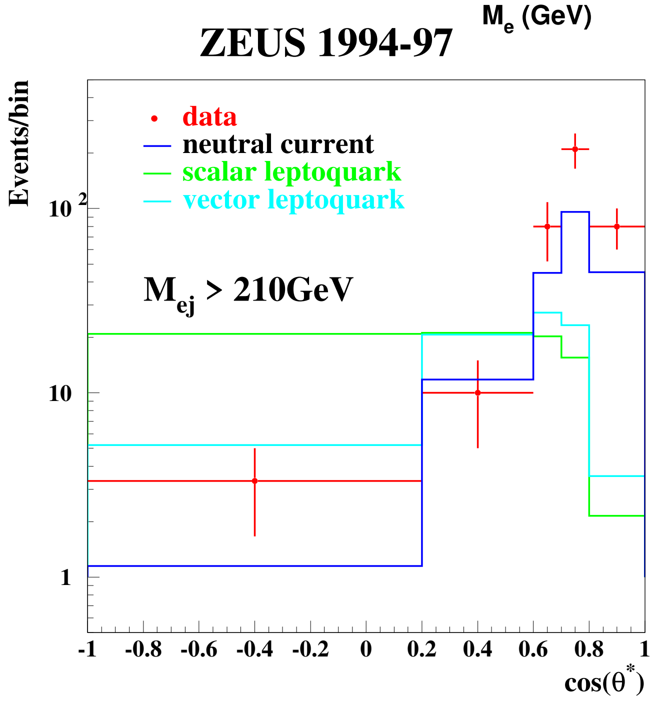
Status of HERA Searches for eq Resonances

94-97 e^+p data H1 and ZEUS analyses published



H1

- Optimised angular cut dedicated to $\nearrow S/B$ (e.g. here for scalar LQ)
- Slight excess around 200 GeV at high y, mainly due to 94-96 events



ZEUS

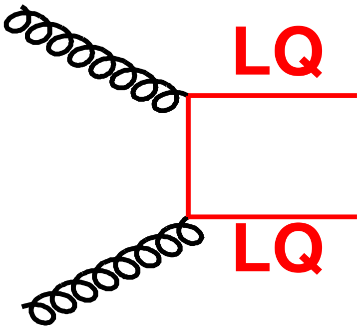
- General search for eq resonance
- slight excess at high M_{ej} and low y
- Not statistically compelling

98-99 e^-p data ZEUS and H1 $\Rightarrow$ Preliminary results

$\Longrightarrow$ e^-p data show no deviation from SM prediction

Leptoquarks : Summary of Current Limits

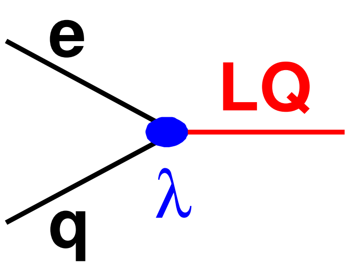
pp



Pair prod

$\sigma = f\,(M_{LQ})$

ep

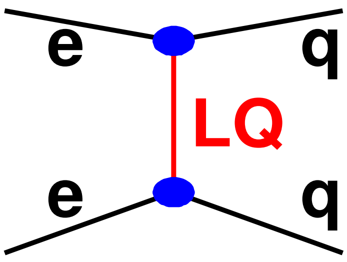


Single prod

(Resonant)

$\sigma = f\,(M_{LQ}, \lambda)$

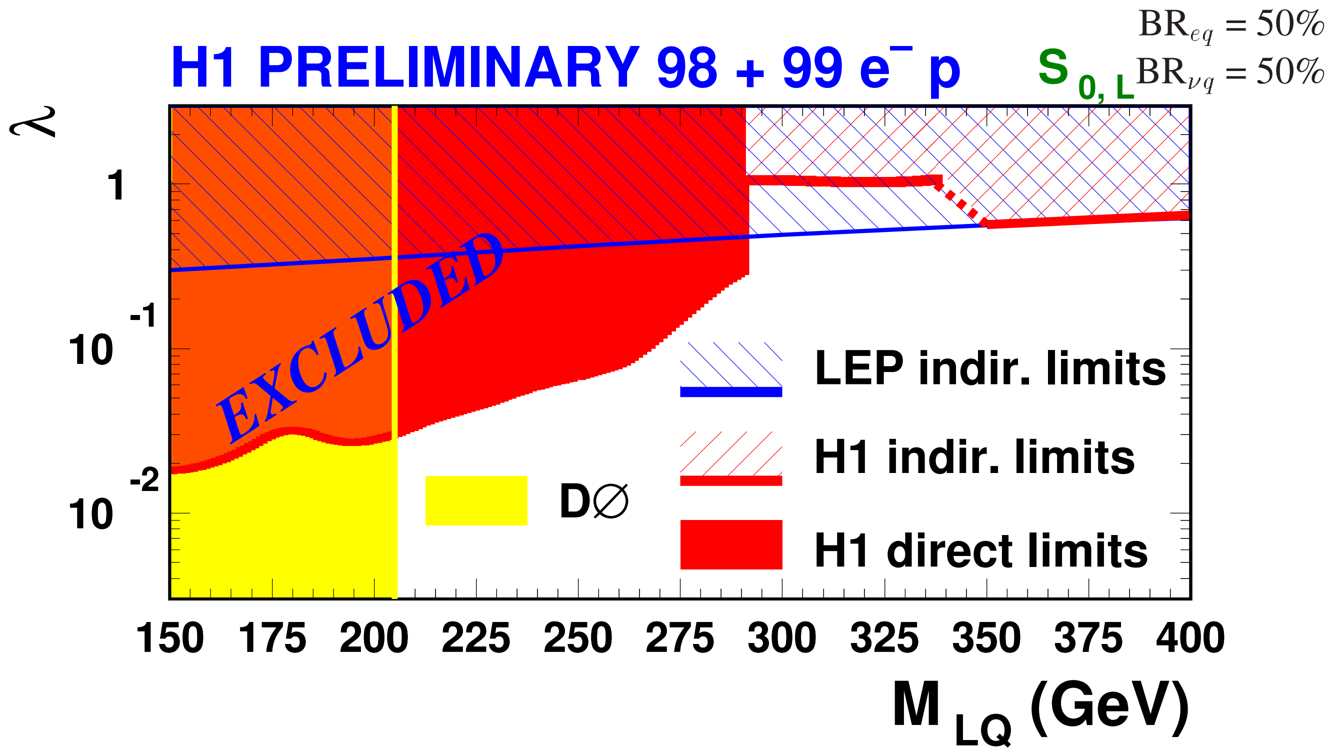
ee



affects

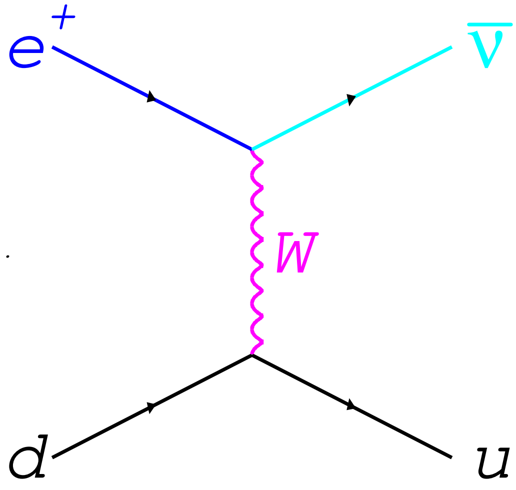
$\sigma\,(ee \rightarrow \text{had.})$

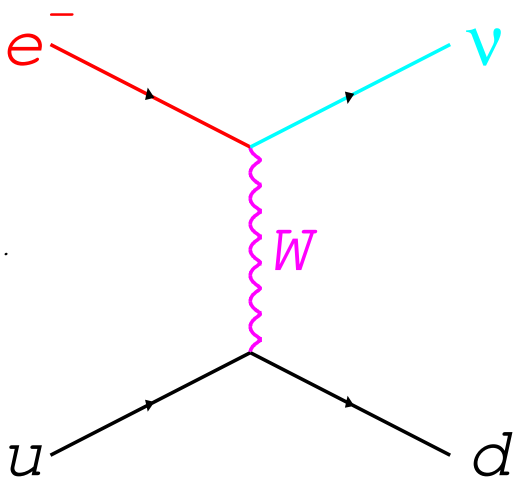
$f\,(M_{LQ}, \lambda)$



Complementarity of HERA data with LEP and TeVatron

Charged Current Interactions (CC)





$$\boxed{e^+ p \longrightarrow \overline{\nu} X}$$

$$\frac{d^2\sigma}{dx\,dQ^2} = \frac{G_F^2}{2\pi}\left(\frac{M_W^2}{M_W^2+Q^2}\right)^2\left(\overline{u} + \overline{c} + (1-y)^2(d + s)\right)$$

$$\boxed{e^- p \longrightarrow \nu X}$$

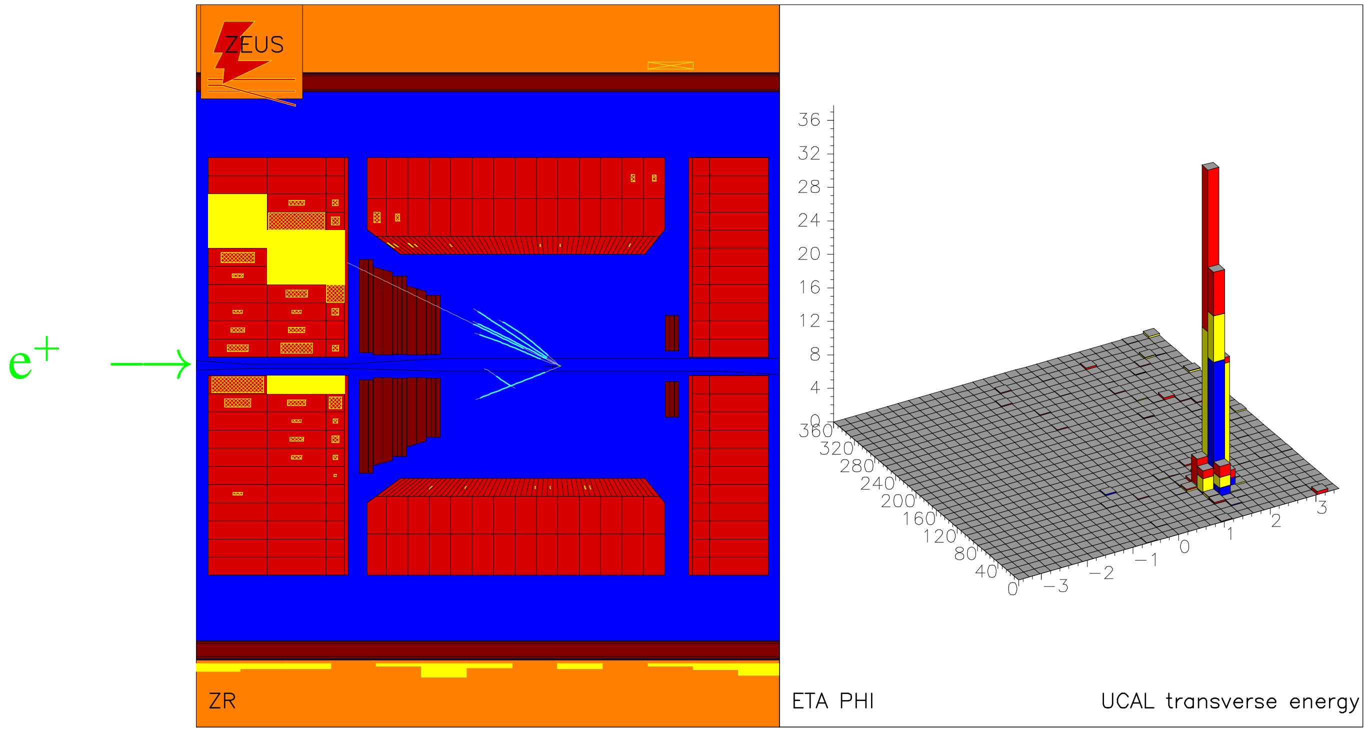
$$\frac{d^2\sigma}{dx\,dQ^2} = \frac{G_F^2}{2\pi}\left(\frac{M_W^2}{M_W^2+Q^2}\right)^2\left(u + c + (1-y)^2(\overline{d} + \overline{s})\right)$$

Focus on :

- e^+p and e^-p CC cross sections
- Propagator mass $\Longrightarrow$ determine M_W
- Quark - antiquark composition

CC event Selection

Signature : Missing P_T (ν) + Hadronic energy (jet)



Main Event Selection Criteria

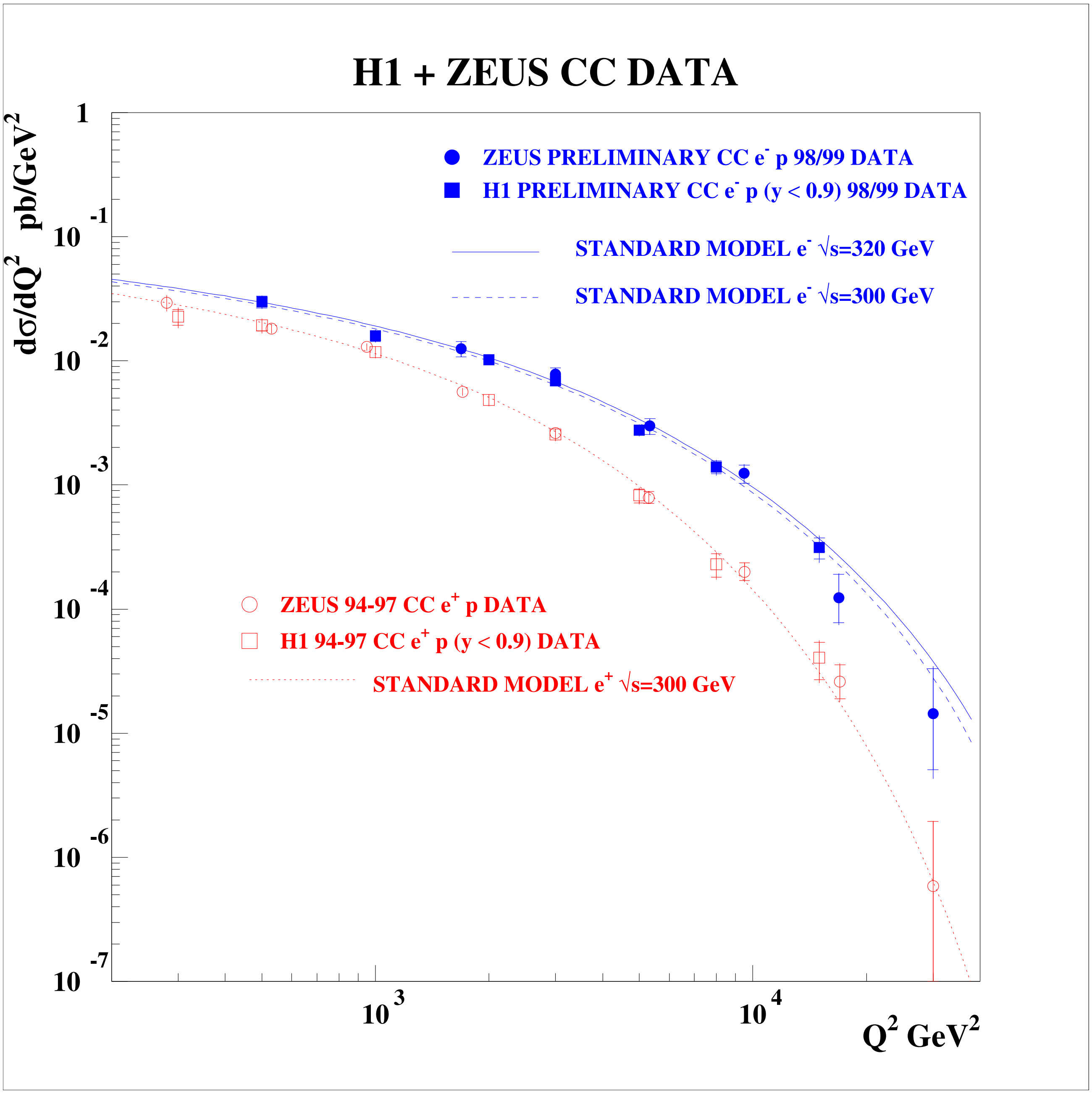
- Missing P_T : $\not{P}_T > \not{P}_{T\,min}$
- Also vertex, timing, ...

Reconstruction largely based on hadronic calorimeter data

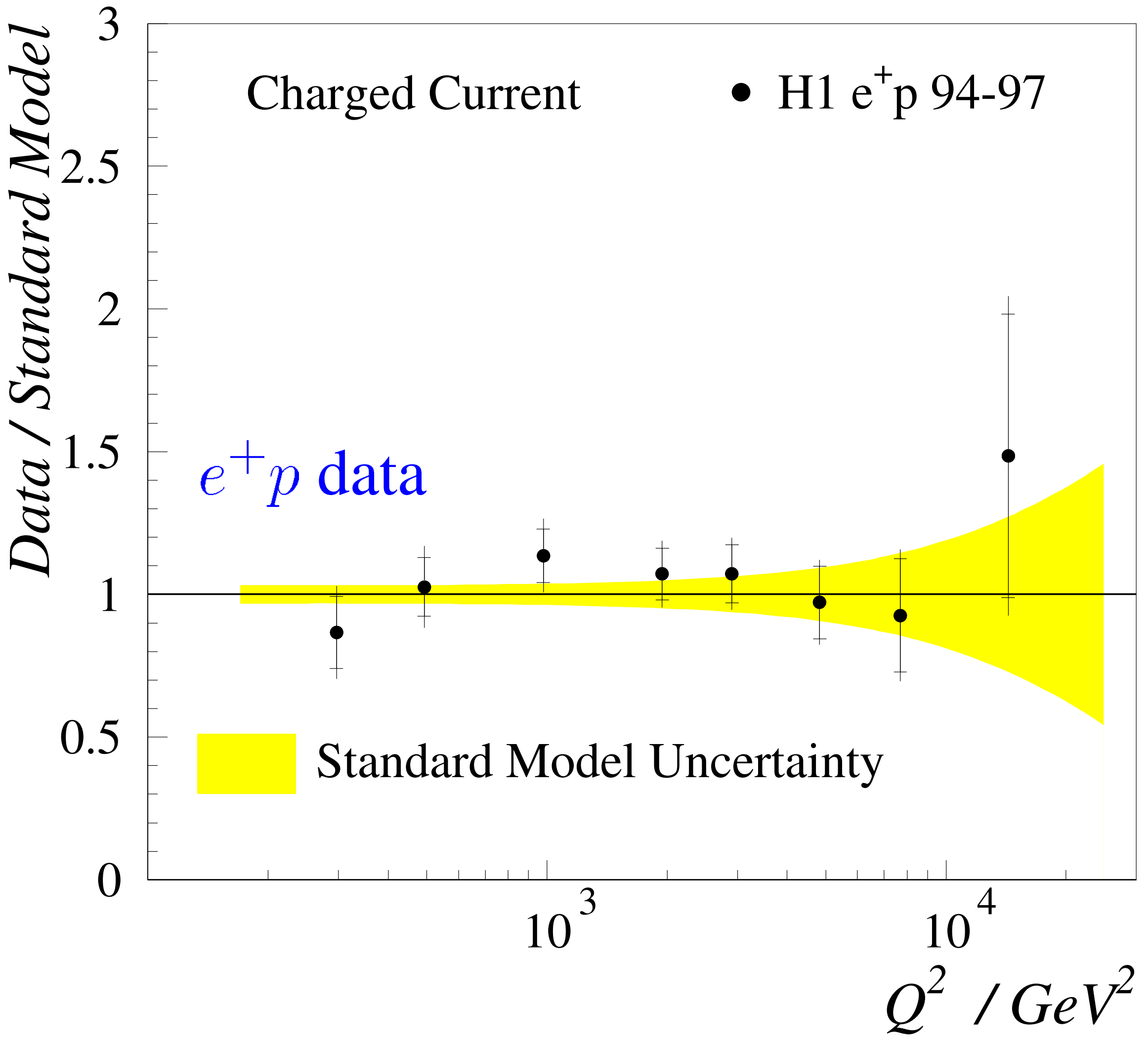
- $(E - p_z)_{had}$ and $P_{T,had} \Longrightarrow Q^2, x, y$
- Good understanding of hadronic energy scale is essential

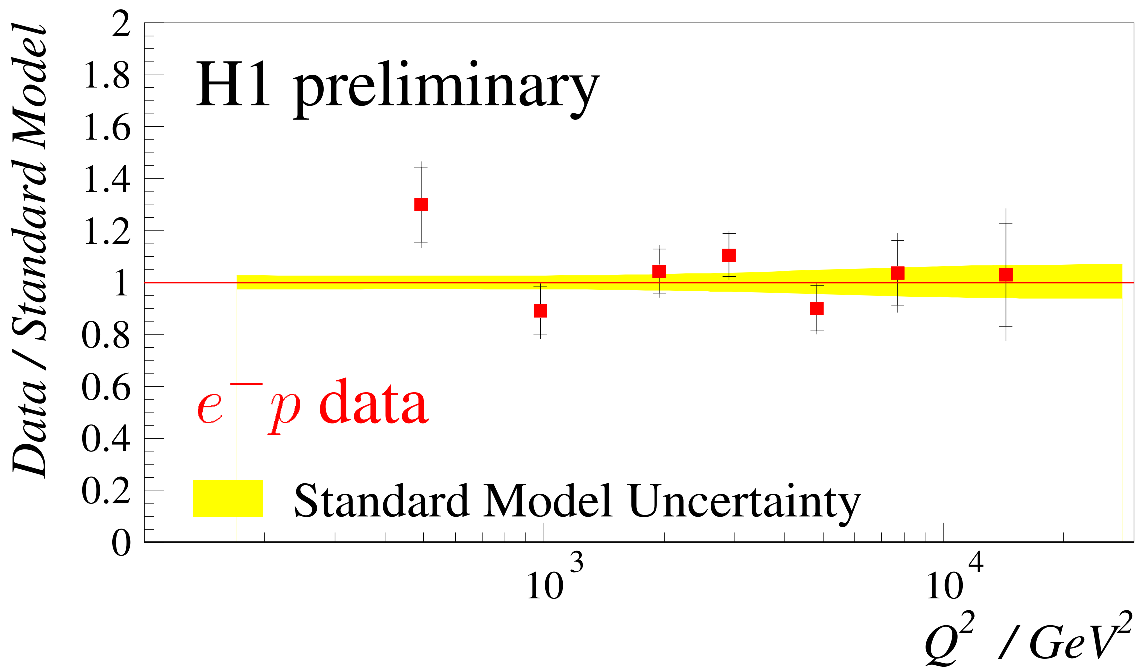
Observe good agreement MC $\Longleftrightarrow$ Data

$d\sigma/dQ^2$ CC : e^+-p vs e^--p data



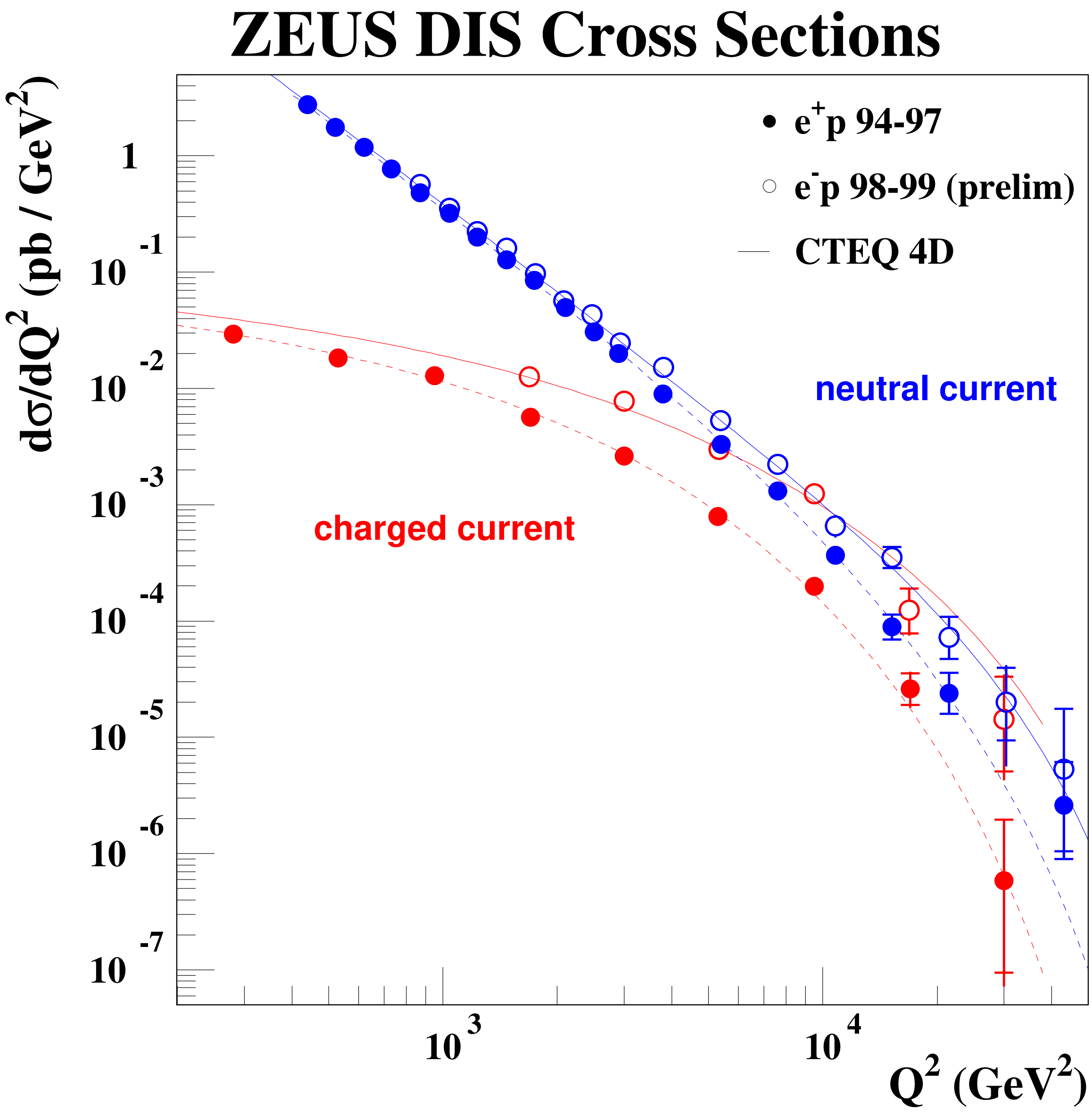
CC $d\sigma/dQ^2$ Compared to Standard Model





Electroweak Unification

Compare **NC** and **CC** cross sections for e^+-p and e^--p



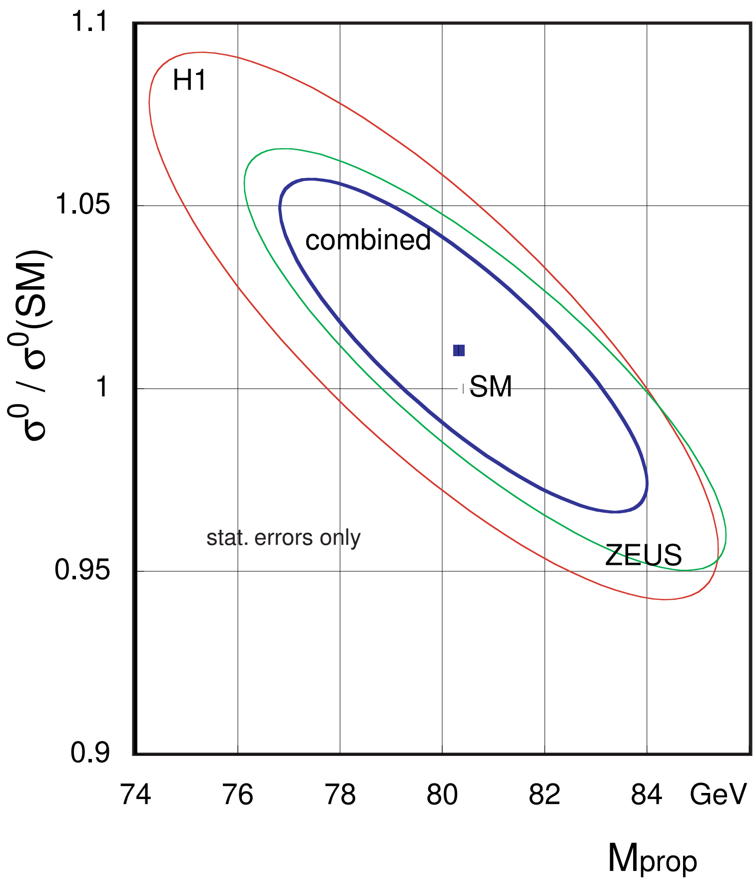
For large Q^2 NC and CC cross sections of similar size

Test of EW Theory from CC $d\sigma/dQ^2$

CC $d\sigma/dQ^2$ cross section contains propagator term :

$$\frac{d\sigma}{dQ^2} \propto G_F^2 \left(\frac{M_W^2}{M_W^2+Q^2}\right)^2$$

$\Longrightarrow$ Fit to Q^2 dependence of CC $d\sigma/dQ^2$ gives M_W



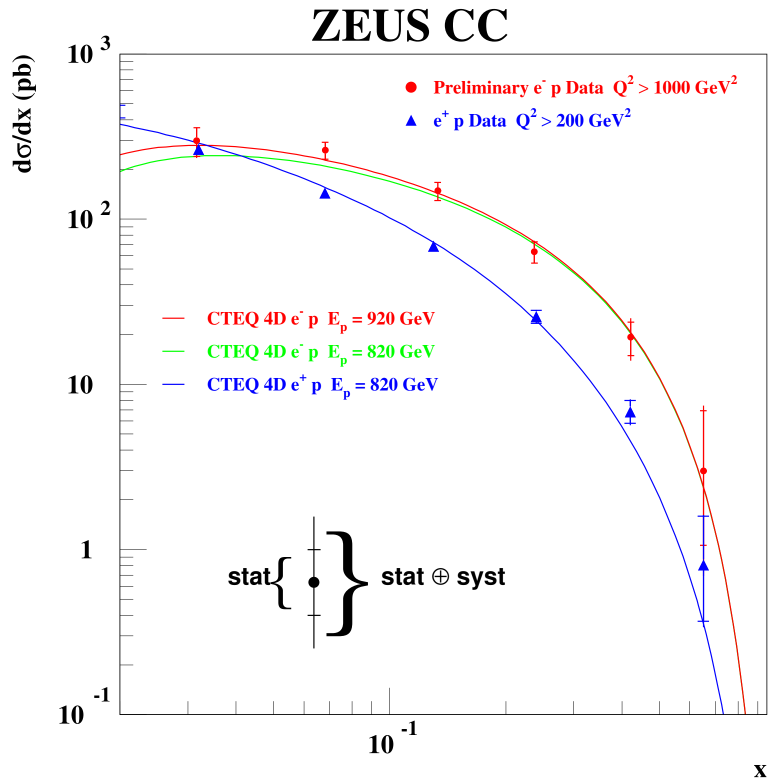
For fixed G_F (PDG value) :

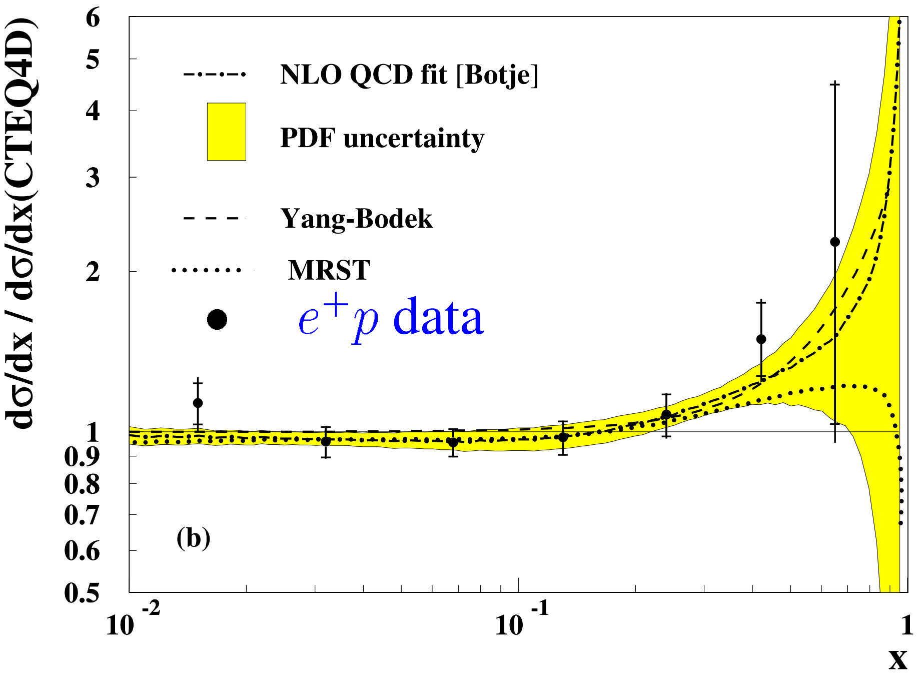
$$M_{prop} = \begin{cases} 80.9 \pm 3.3(stat) \pm 1.7(syst) \pm 3.7(pdf) & \text{H1} \\ 81.4^{+2.7}_{-2.6}(stat) \pm 2.0(syst)^{+3.3}_{-3.0}(pdf) & \text{ZEUS} \end{cases}$$

$\hookrightarrow$ Good agreement of indirect determination (W space-like) with world average from direct determinations (W time-like)

$\Rightarrow$ Important test of the universality of the SM !

CC e$^+$p and e$^-$p $\quad d\sigma/dx$





Parton densities not well constrained presently at high x

With e$^+$p and e^-p data $\Longrightarrow$ get u,d PDFs at high x

Parton Densities at High x

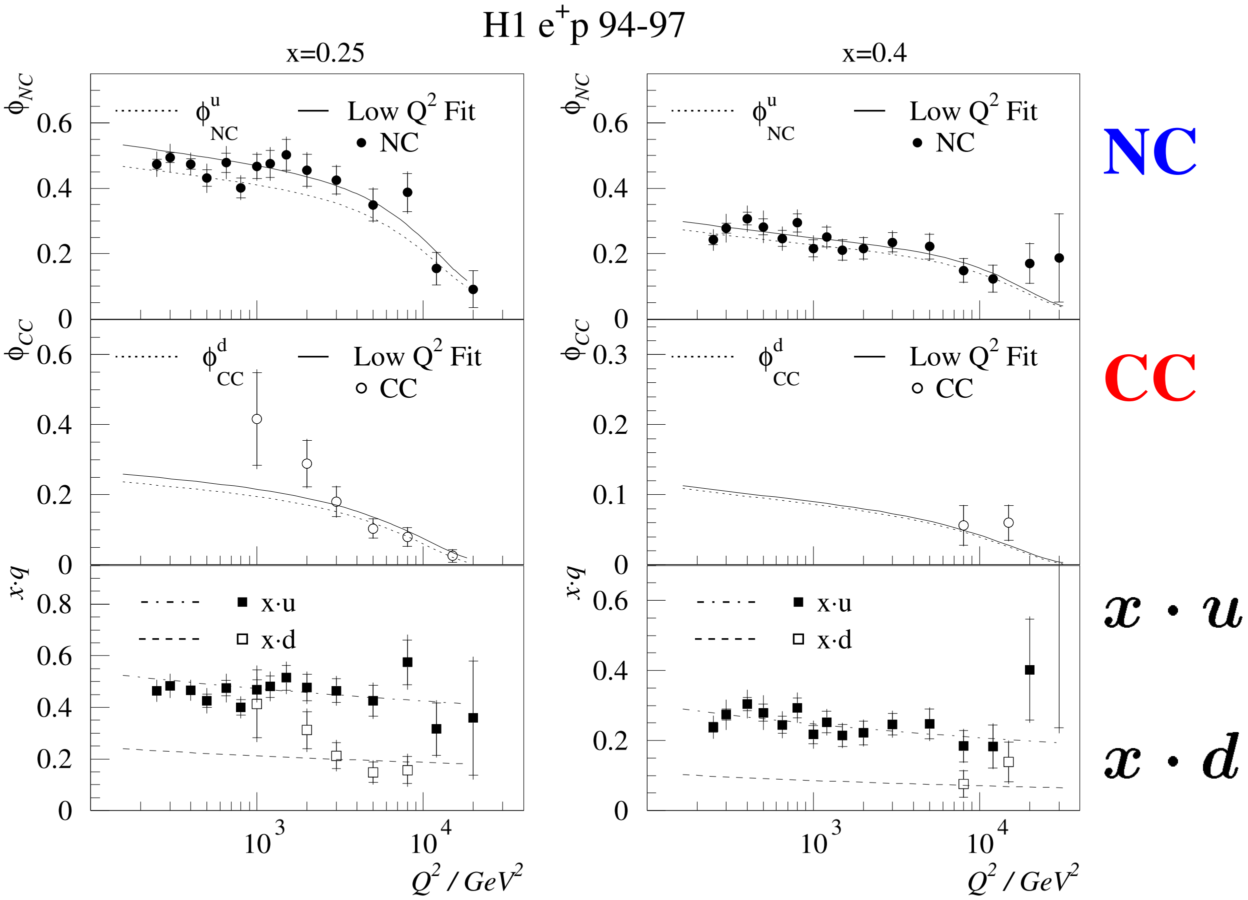
Define reduced cross section :

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

$$\tilde{\sigma}_{NC}(e^+p) \sim \Phi_{NC} \sim (1+(1-y)^2)\Sigma\, e_i^2 x q_i$$

$$\tilde{\sigma}_{CC}(e^+p) \sim \Phi_{CC} \sim x\bar{u} + (1-y)^2 xd$$

$\hookrightarrow$ Extract u and d quark densities

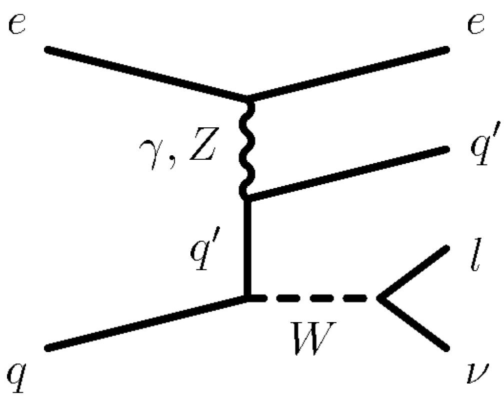


HERA upgrade welcome (more lumi)

W Production and Isolated Leptons

In the CC processes there is virtual W production.

At HERA, Ws can also be produced directly, mainly by :

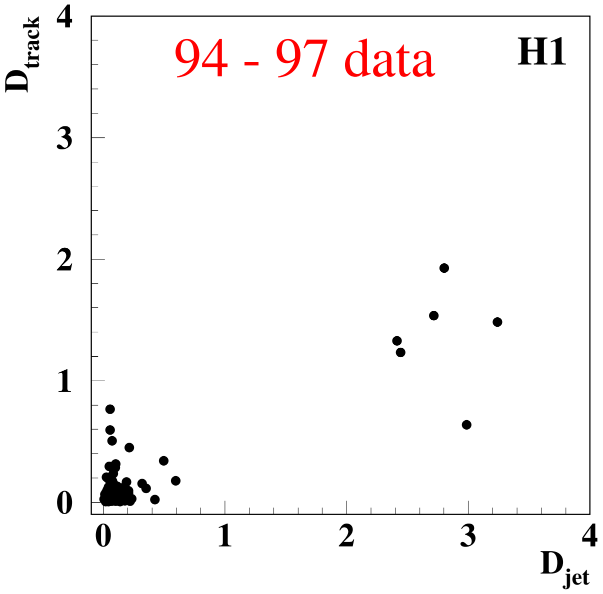


$\sigma(ep \to eW^{\pm}X) \simeq 1$ pb (SM at LO)
With current $\mathcal{L}$, expect only few events in semileptonic decay mode

$\Rightarrow$ Look for events with :
High P_T isolated lepton, missing P_T

$\hookrightarrow$ Cuts :

- $\not{P}_T$(calo) > 25 GeV
- Track P$_T$ > 10 GeV
- The track is required to be isolated

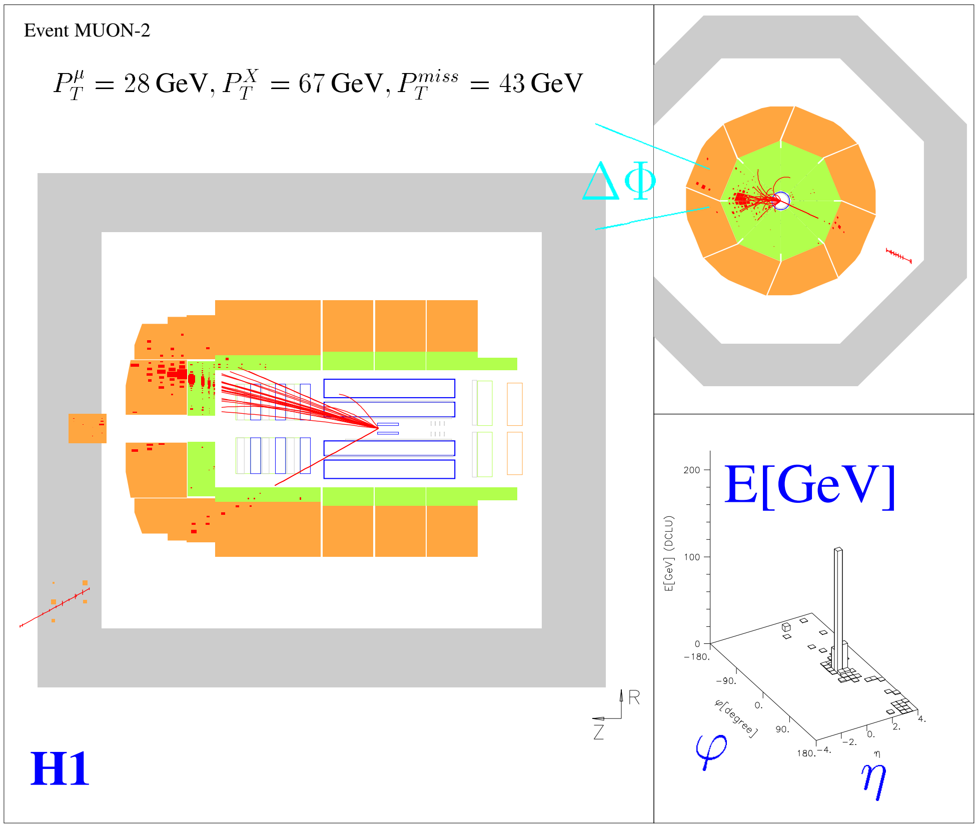


D$_{track}$: distance to closest track in $(\eta - \phi)$
D$_{jet}$: distance to closest hadron jet in $(\eta - \phi)$

$\hookrightarrow$ Cuts :
D$_{track}$ > 0.5 and D$_{jet}$ > 1

Isolated Leptons

$e^+p \to \mu^+ X$



μ^+

For this example :

$\not{P}_T = 43.2^{+6.1}_{-7.7}$ GeV
$\Delta\Phi = 23.4 \pm 4.2\ ^o$
$M_T^{\mu\nu} = 22.8^{+6.7}_{-4.2}$ GeV

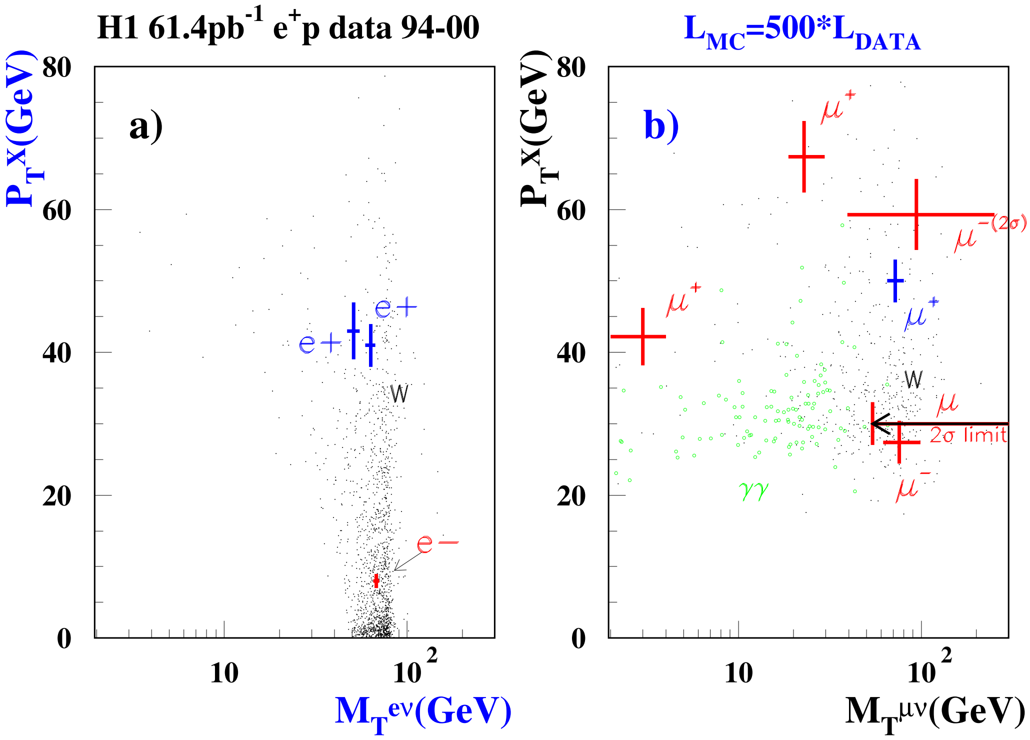
dataset	H1	ZEUS
94-97 e^+	6 $l + P_{T,miss} + X$ evts (5 μ, 1 e) 3 μ show abnormally large $P_{T,had}$ compared to SM backgrounds (W, $\gamma\gamma$)	3 e evts compatible with SM
98-99 e^-	0 evt observed	2 e evts compatible with SM

For spring 2000 conferences, updates using 99-00 e^+p data (18 pb^{-1} / 25 pb^{-1} for ZEUS/H1) $\longrightarrow$

H1 : Extended (phase space) analysis + enhanced backgroun d rejection

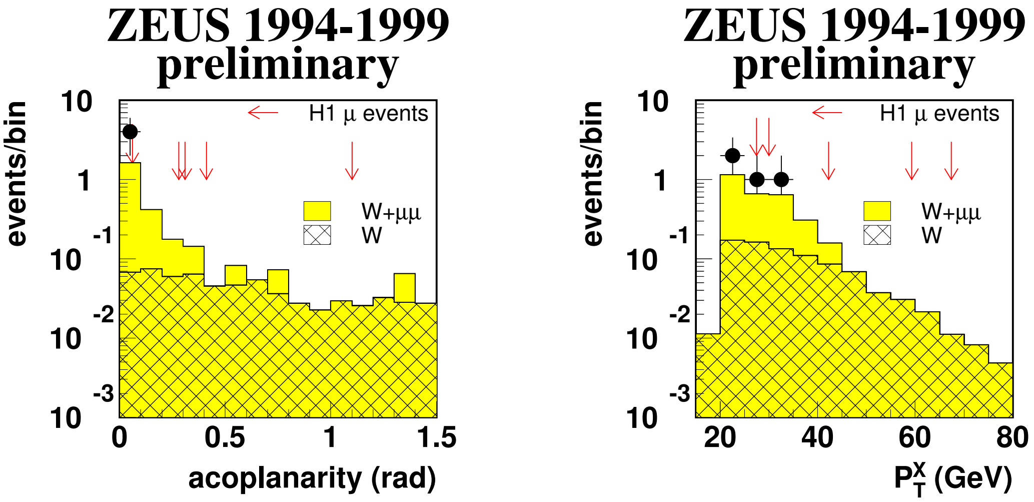
'2000' Update on W & Isolated Leptons

H1 : 3 new evts observed (1 μ, 2 e), all at large $P_{T,had}$:



H1 total (e^+ & e^-) with $P_{T,had} > 25$ GeV : Data / SM = 8 / 2.7 $\pm$ 0.6

ZEUS : 6 new evts (4 μ, 2 e) ; compatible with SM :



↓ : H1 μ events

Backgrounds shown are for ZEUS analysis

ZEUS total ($e^+ + e^-$) (Data / SM)$_e$ = 7 / 6.1 $\pm$ 0.9

(Data / SM)$_\mu$ = 4 / 3.7 $\pm$ 0.4

Summary

H1 and ZEUS have accumulated $\sim$ 100 pb^{-1} since 1994, thanks to the very good performance of HERA and the detectors in the last 2 years.

- Overall good agreement with Standard Model
  $\rightarrow$ NC and CC cross sections up to highest Q^2
  $\rightarrow$ xF_3
  $\rightarrow$ M$_W$ from CC
  $\rightarrow$ u(x) & d(x) at high x (need higher $\mathcal{L}$)
- Searches for New Physics
  $\rightarrow$ no signs of it
- Need more study of
  $\rightarrow$ NC DIS at highest Q^2 and x
  $\rightarrow$ Isolated leptons

$\Longrightarrow$ The HERA upgrade is welcome

Outlook

- HERA will stop in September for ≈ 9 months for an upgrade program aiming for a 5-fold increase in luminosity
- Both H1 and ZEUS detectors will be significantly modified to cope with the changes to the machine magnets and to upgrade their performance
- With the goal of $\simeq \mathbf{1}\ \mathbf{fb}^{-\mathbf{1}}$, achievable till ca 2006, as well as the availability of electron (positron) **polarization** the prospects for getting many exciting results in the near future look good.