Lepton-Parton Physics at Large Momentum Transfer at HERA

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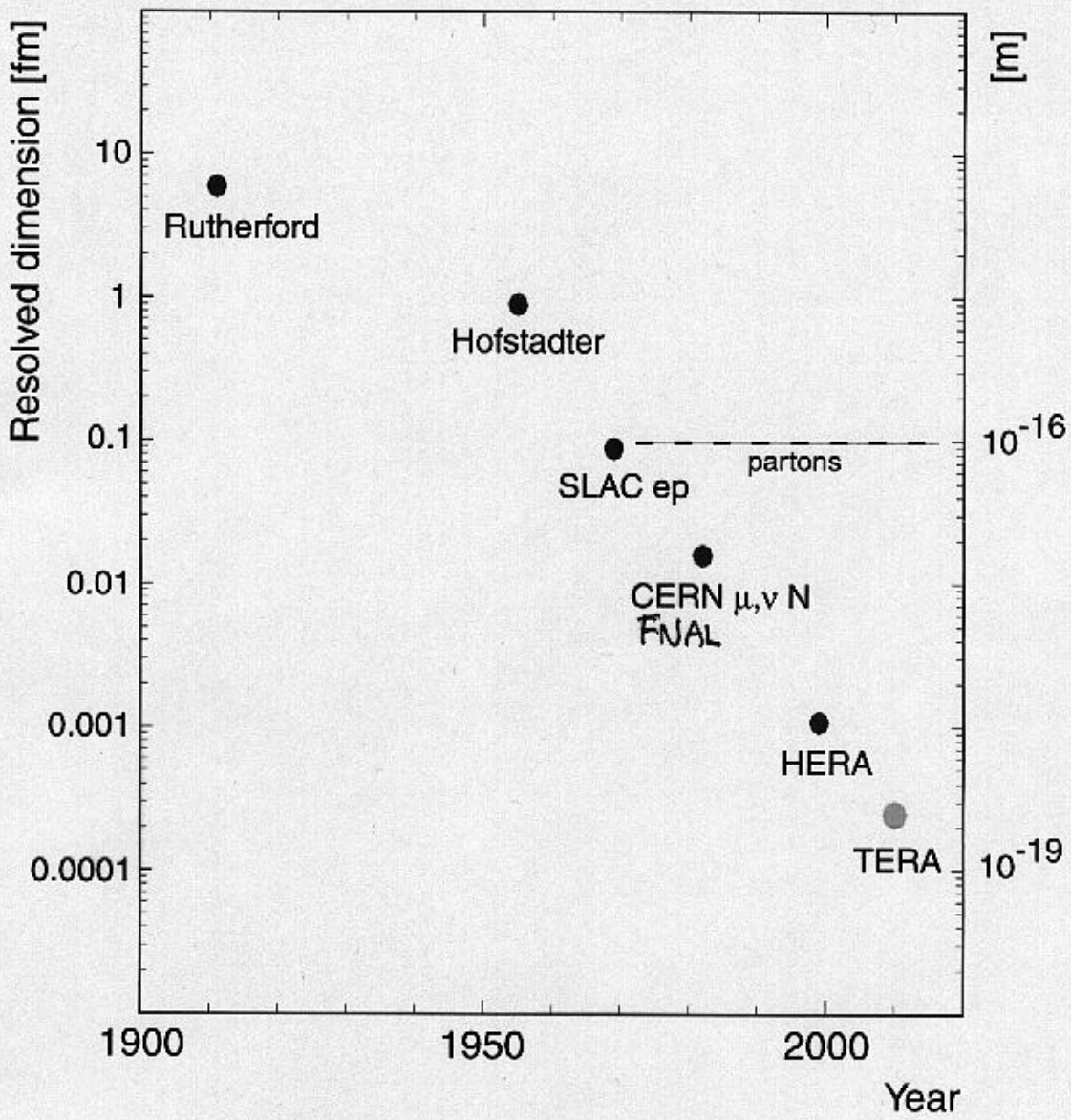
Outline

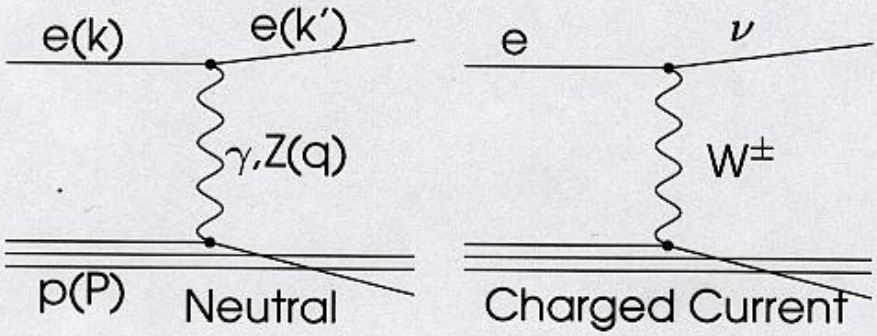
- Introduction
- From F_2 to Parton Densities
- Jets and α_s from Jets
- Highest Q^2 Neutral Currents
- Deviation from SM
- Highest Q^2 Charged Currents
- Summary and Outlook

Resolving the Structure of Matter



using Deep Inelastic Scattering experiments

Deep Inelastic Scattering



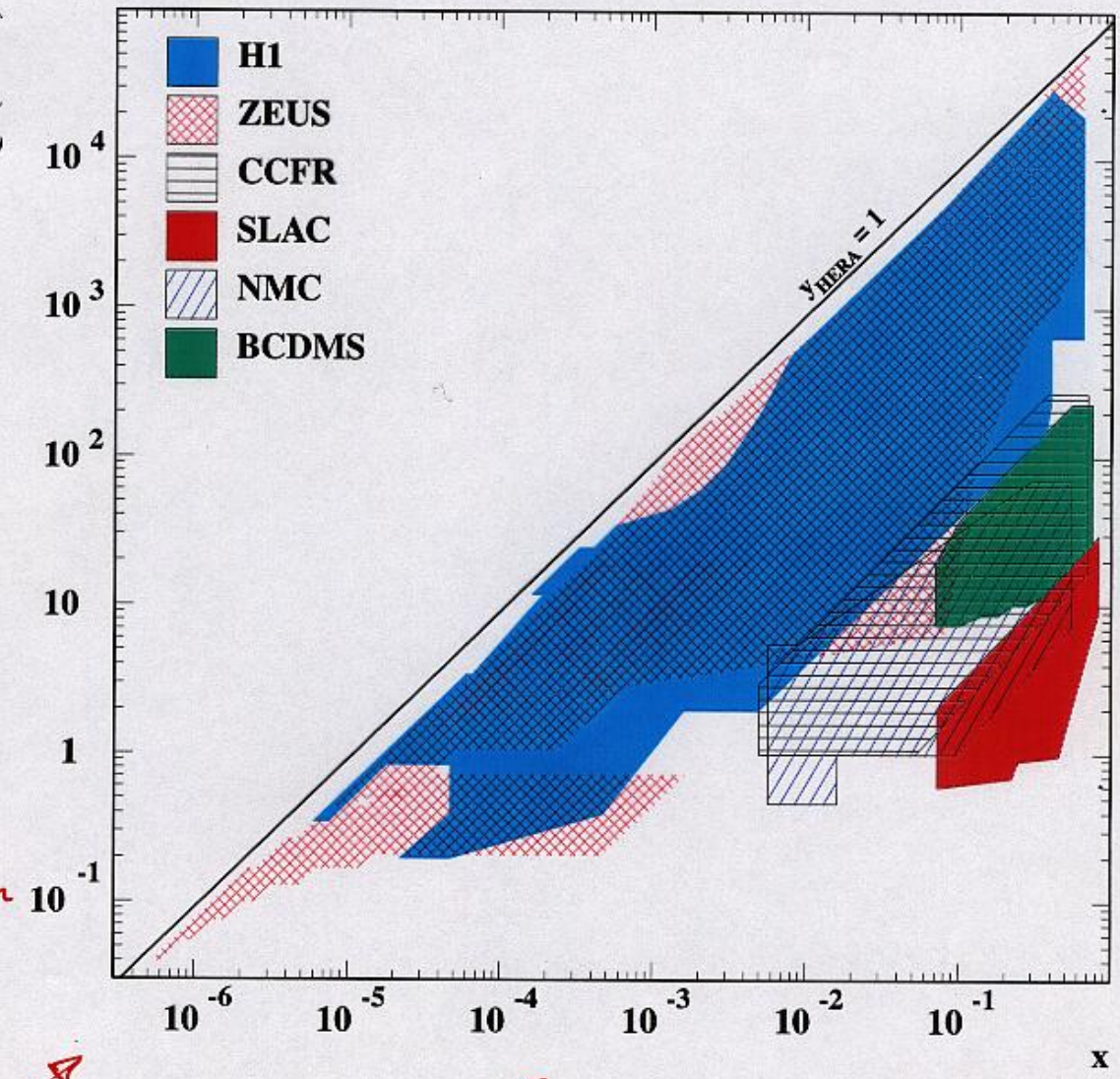
$$s = (k+P)^2$$

$$Q^2 = -q^2$$

$$x = Q^2/(2Pq)$$

$$Q^2 = xys, W^2 = ys$$

EW
Exotics



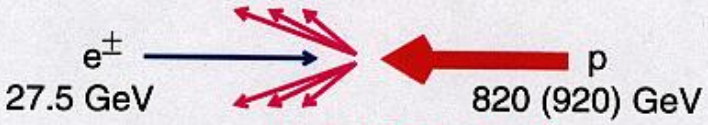
precise QCD tests

transition to PHP

F_L sensitivity

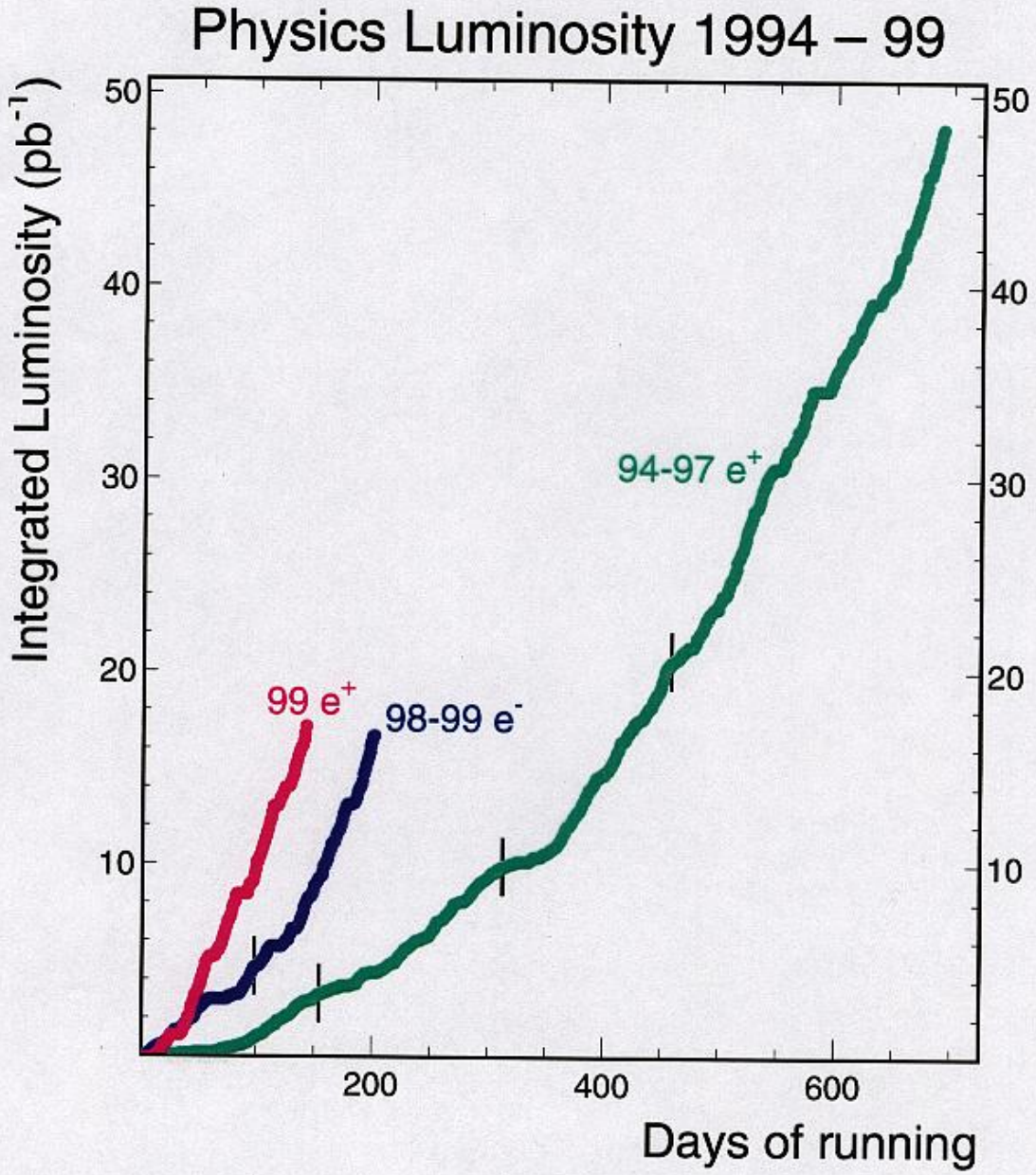
overlap w fixed target

HERA → Physics Luminosity



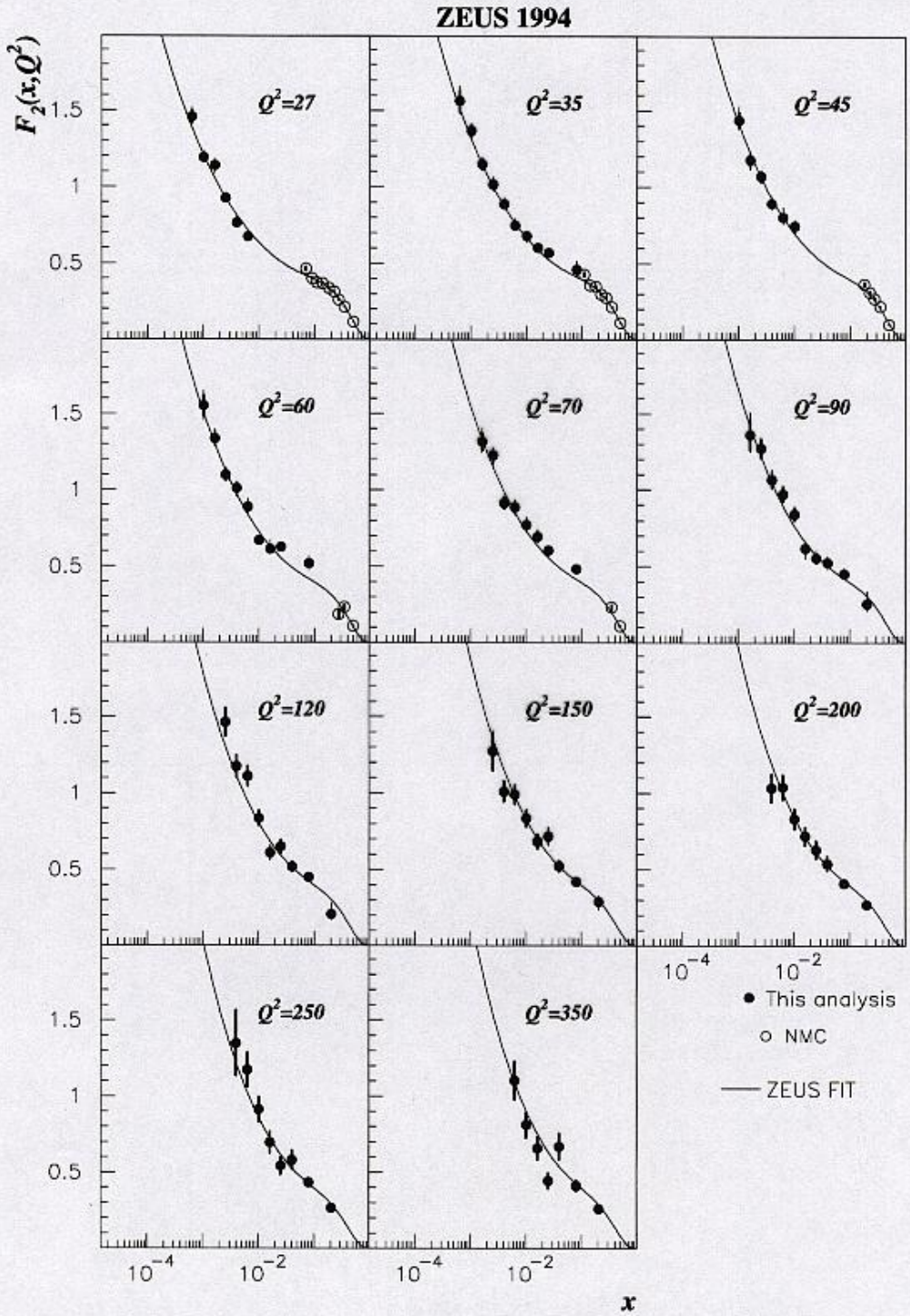
$\sqrt{s}$ = 300 GeV (320)

→ equivalent to 50 TeV fixed target energy



Proton Structure Function F_2

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



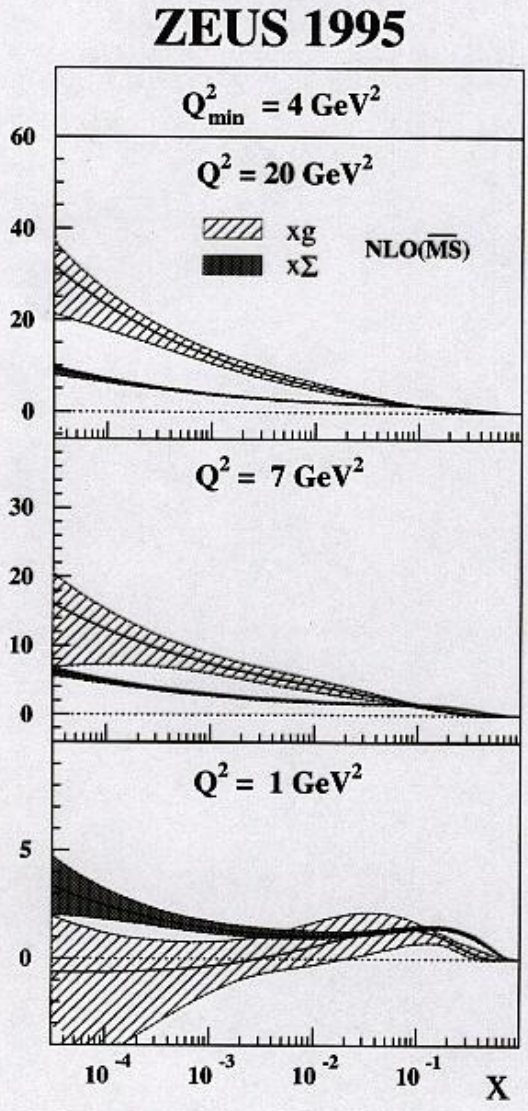
Analysis of F_2: xg(x) and $x\Sigma(x)$

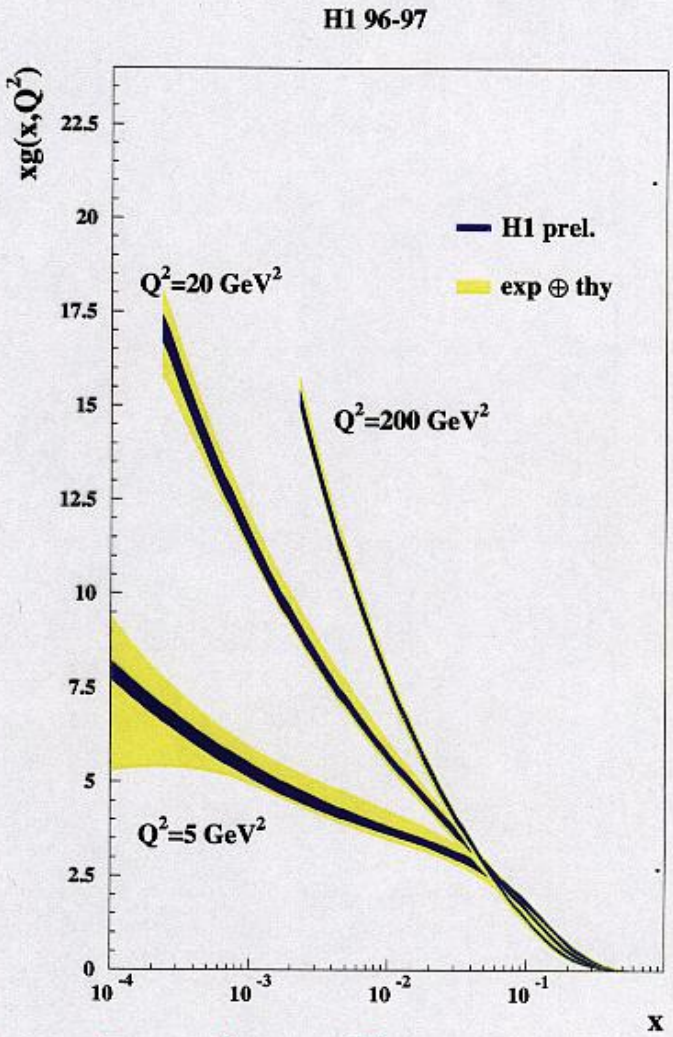
Fit to F_2 with input scale $Q_0^2 = 7$ GeV^2

$$xg(x) = A_g x^{\delta g}(1-x)^{\eta g}(1+\gamma_g x)$$

with QCDNUM: NLO in $\overline{\text{MS}}$ scheme

Singles $\times\Sigma$



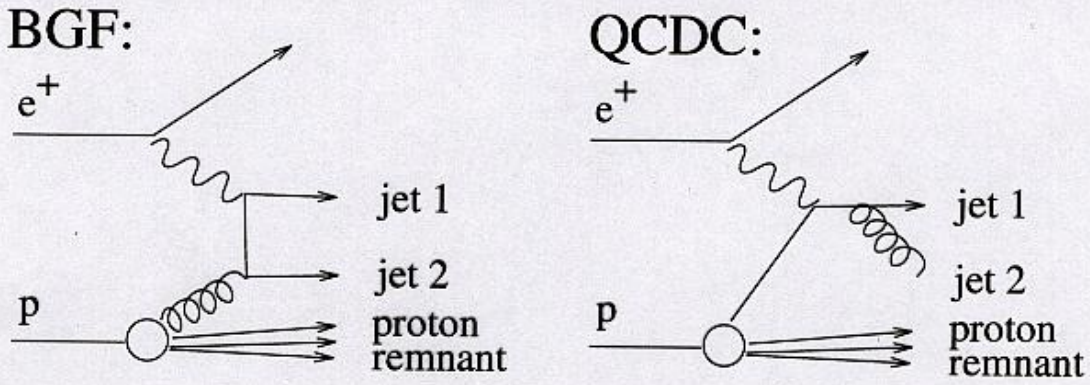


QCD is able to describe F_2 data to $Q^2 \gtrsim 1$ GeV^2 ⇒ A. Gousiou's ta

where $\alpha_s \simeq 0.46$

Measurement of α_s from Jet Cross Sections

Leading Order $O(\alpha_s)$:



Next-to-Leading Order $O(\alpha_s^2)$:

$$\sigma_{2+1}(Q^2) = \alpha_s(Q^2)c_1(Q^2,\alpha_s) + \alpha_s^2(Q^2)c_2(Q^2,\alpha_s)$$

where $c_i = c_i(PDF)$

To determine α_s use inclusive cross section or ratio of 2-jets

$$R_{2+1}(Q^2) = \sigma_{2+1}(Q^2)/\sigma_{tot}(Q^2)$$

Four Different NLO Programs now available:

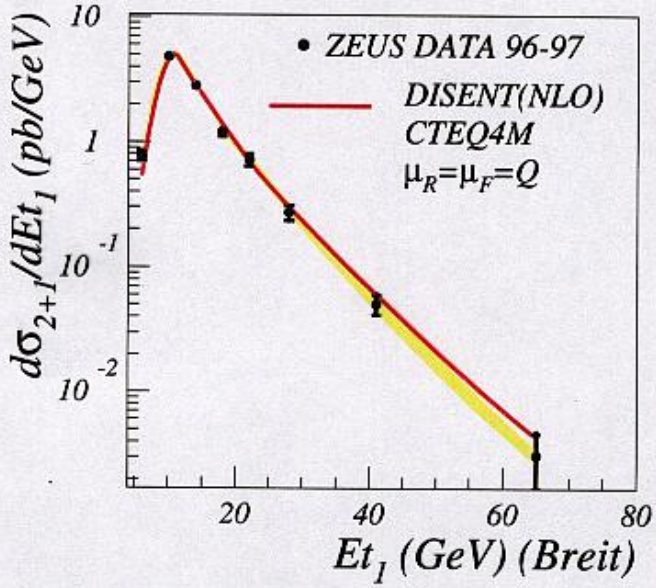
subtraction: DISASTER++ (Graudenz), DISENT (Catani/Seymour),

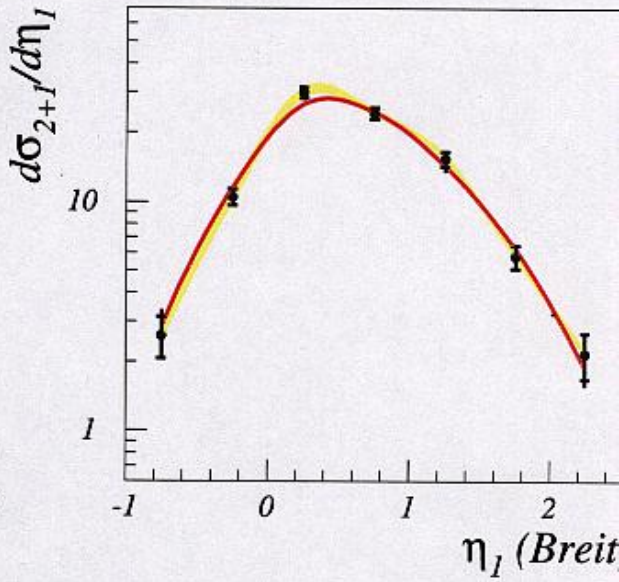
phase-space-slicing: JETVIP (Pötter), MEPJET (Mirkes/Zeppenfeld)

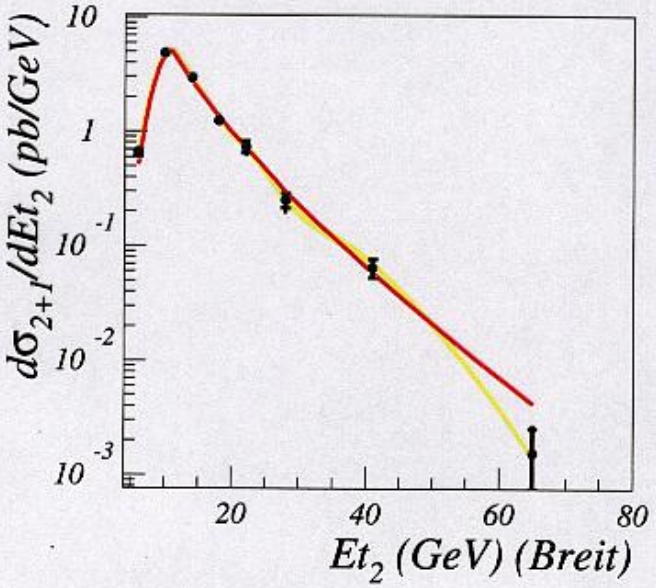
- Highly non trivial test of pQCD
- Sensitive to α_s and g(x,μ_F^2)

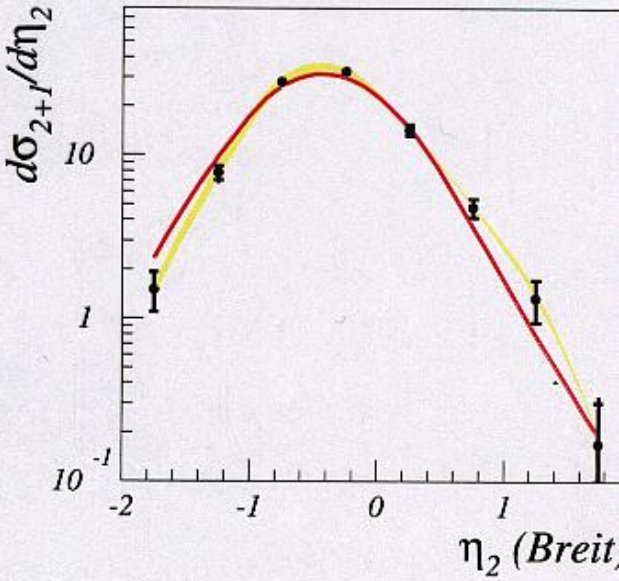
α_s cont'd

ZEUS 96-97 PRELIMINARY





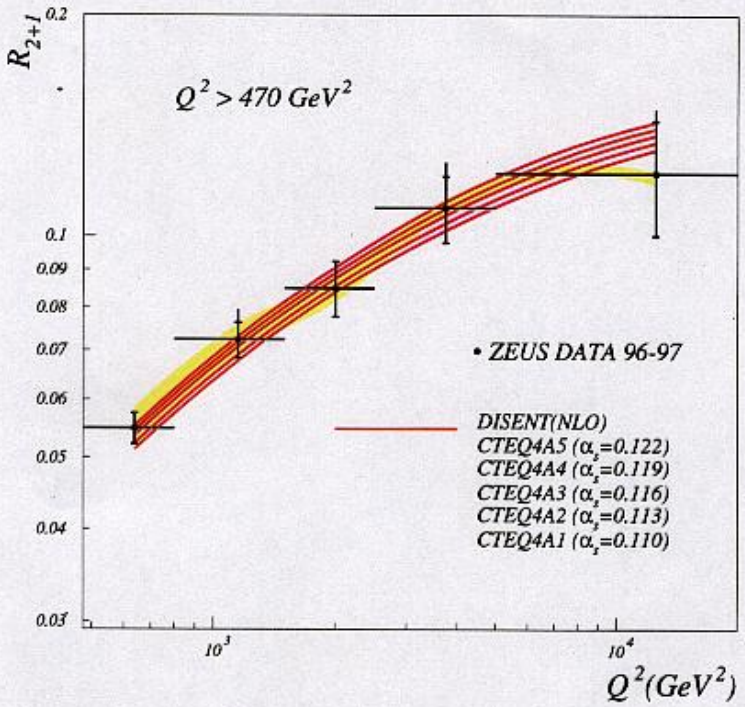


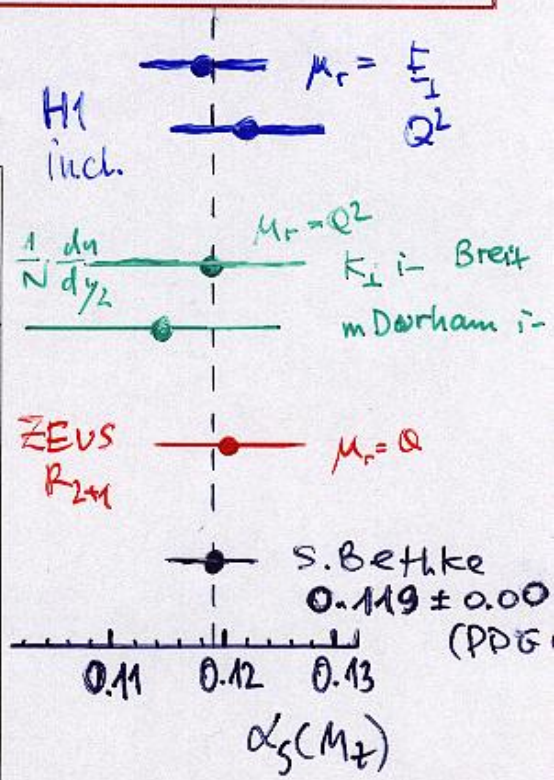


$$x_p = \frac{Q^2}{Q^2+M_{jj}^2}, \xi = \frac{x}{x_p}, z_p(i) = \frac{p\cdot p(i)}{p\cdot q} = \frac{1}{2}\cdot(1-\cos\theta^*(i))$$

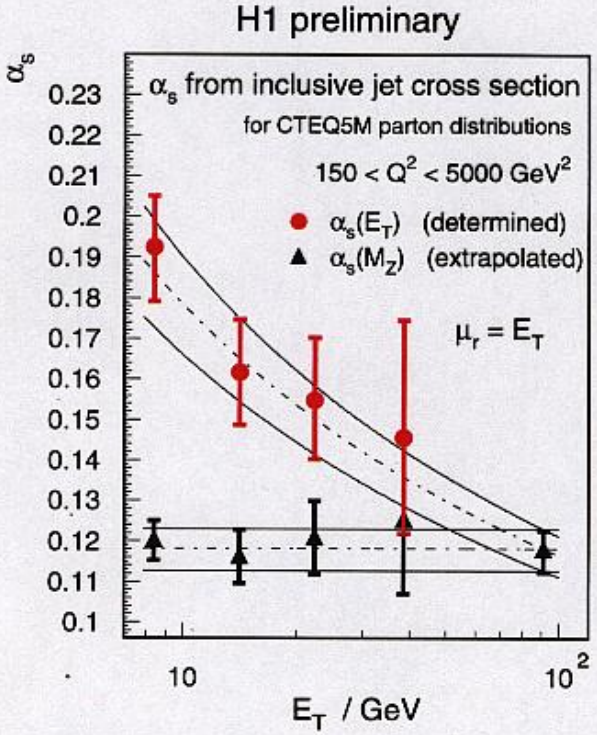
and M1 $d^2\sigma/dE_T\,dQ^2$ and $\frac{1}{\sigma}\frac{d\sigma}{d\eta}$

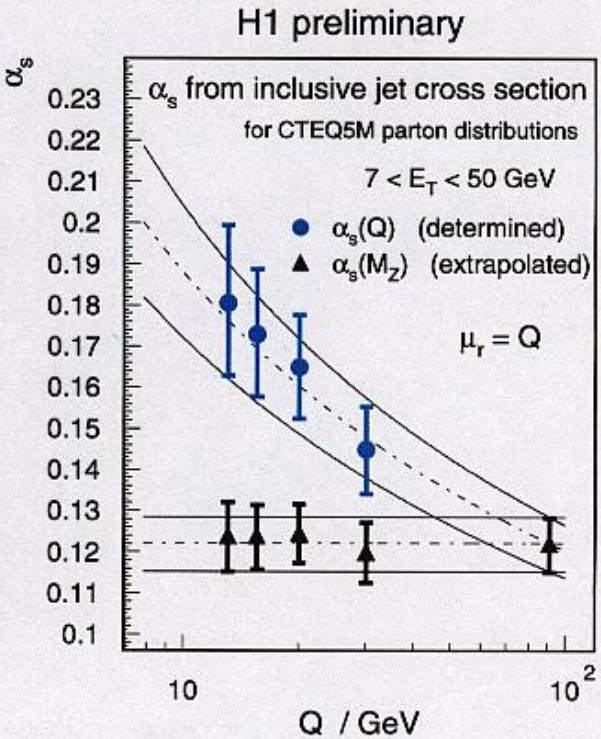
α_s cont'd





H1/ZEUS prelim (my value)
0.119 ± 0.004





$$\frac{d^2\sigma^{\pm}}{dx\,dQ^2} = \frac{2\pi\alpha^2}{xQ^4}\left[Y_+F_2 \mp Y_- xF_3\right]$$

High Q^2 Neutral Current Cross sections

SM works over >6 orders of magnitude

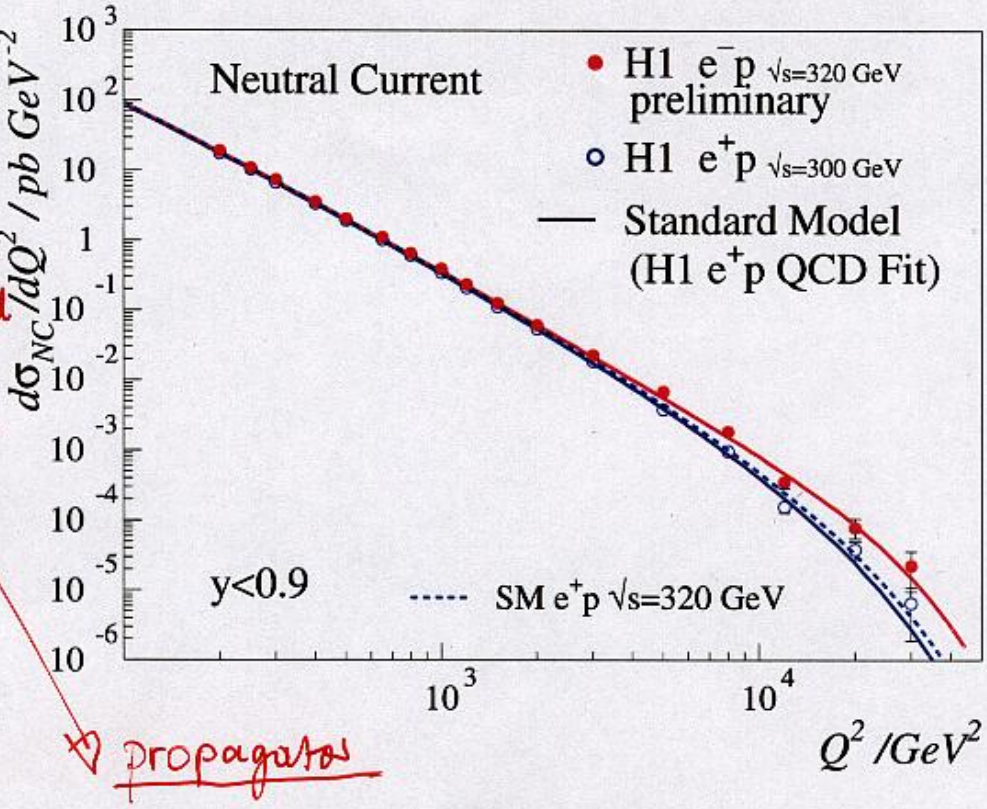
couplings

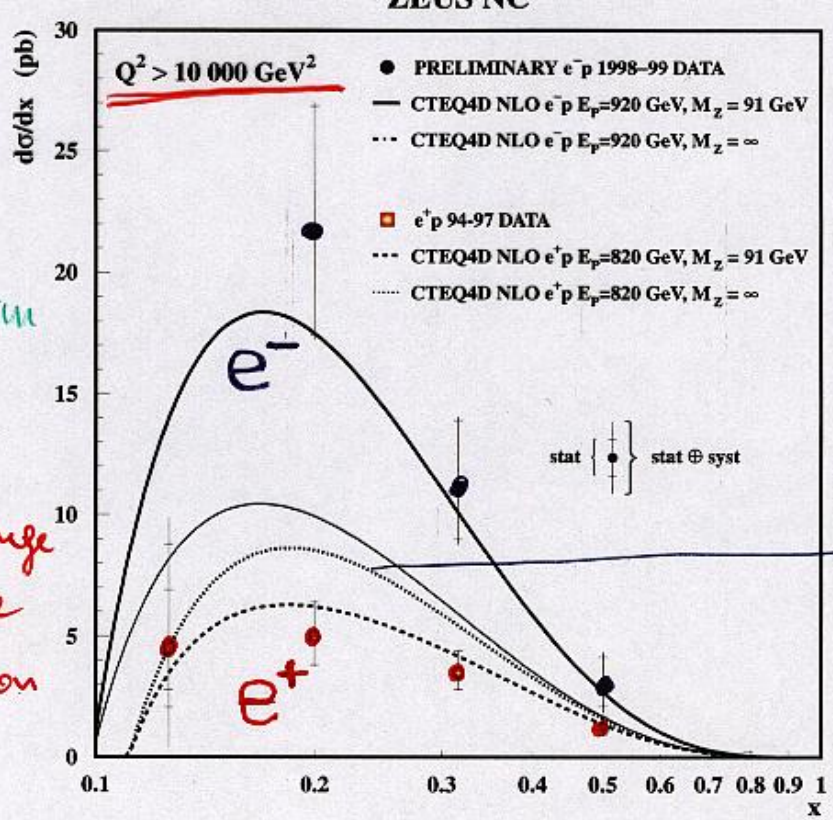
& PDF's

↳ F_2, xF_3

low Q^2 fit!

propagator





$\mp xF_3$ term

Z exchange in space like region

no M_Z-te

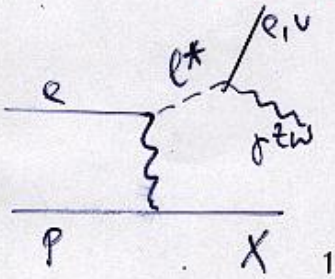
Where does the SM break down?

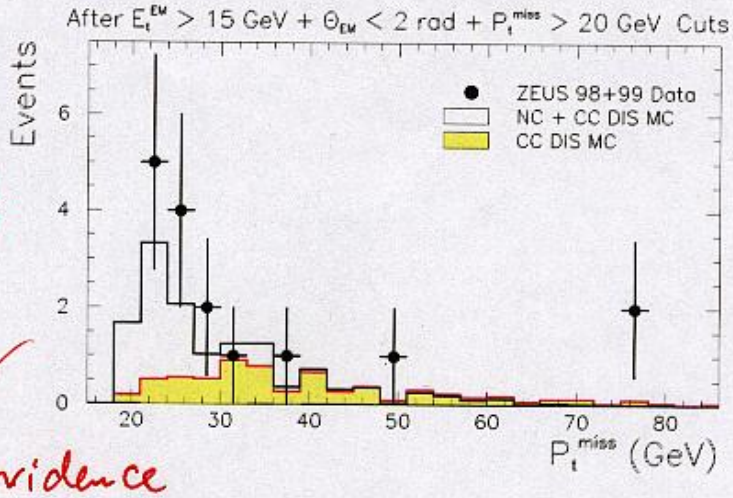
- Excited Fermions
- R-parity Violating SUSY
- Contact Interactions
- Lepton Flavour Violation
- Leptoquarks
-
-

Where does the SM break down?
Excited Fermions

Fermion substructure?

$e^* \to e\gamma, eZ \to \nu W$

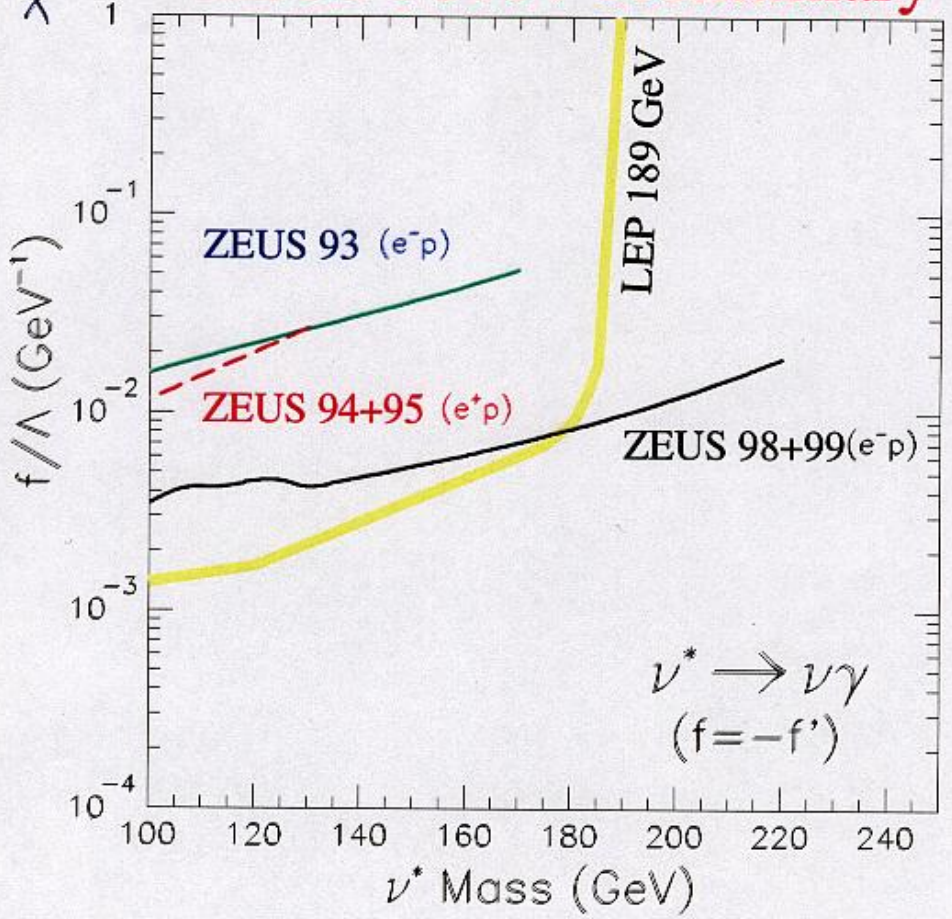




no evidence

$\gamma^* \to \nu\gamma$ search

Similar H1 result

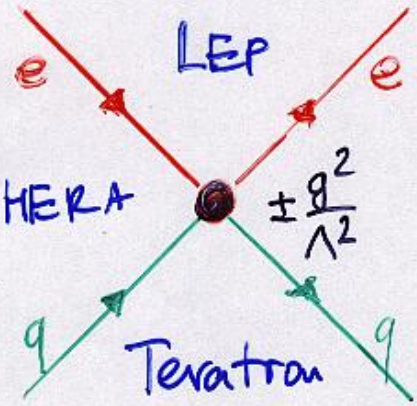


also $\nu^* \to \nu Z \to e W$

Where does the SM break down? Contact Interactions

effective phenomenological description of processes with mass scale $\Lambda \gg \sqrt{s}$

eeqq - CI examples



- exchange of heavy (gauge) bosons
- LQ (s/u exchange)
- Compositness (e, q)
- ⋮

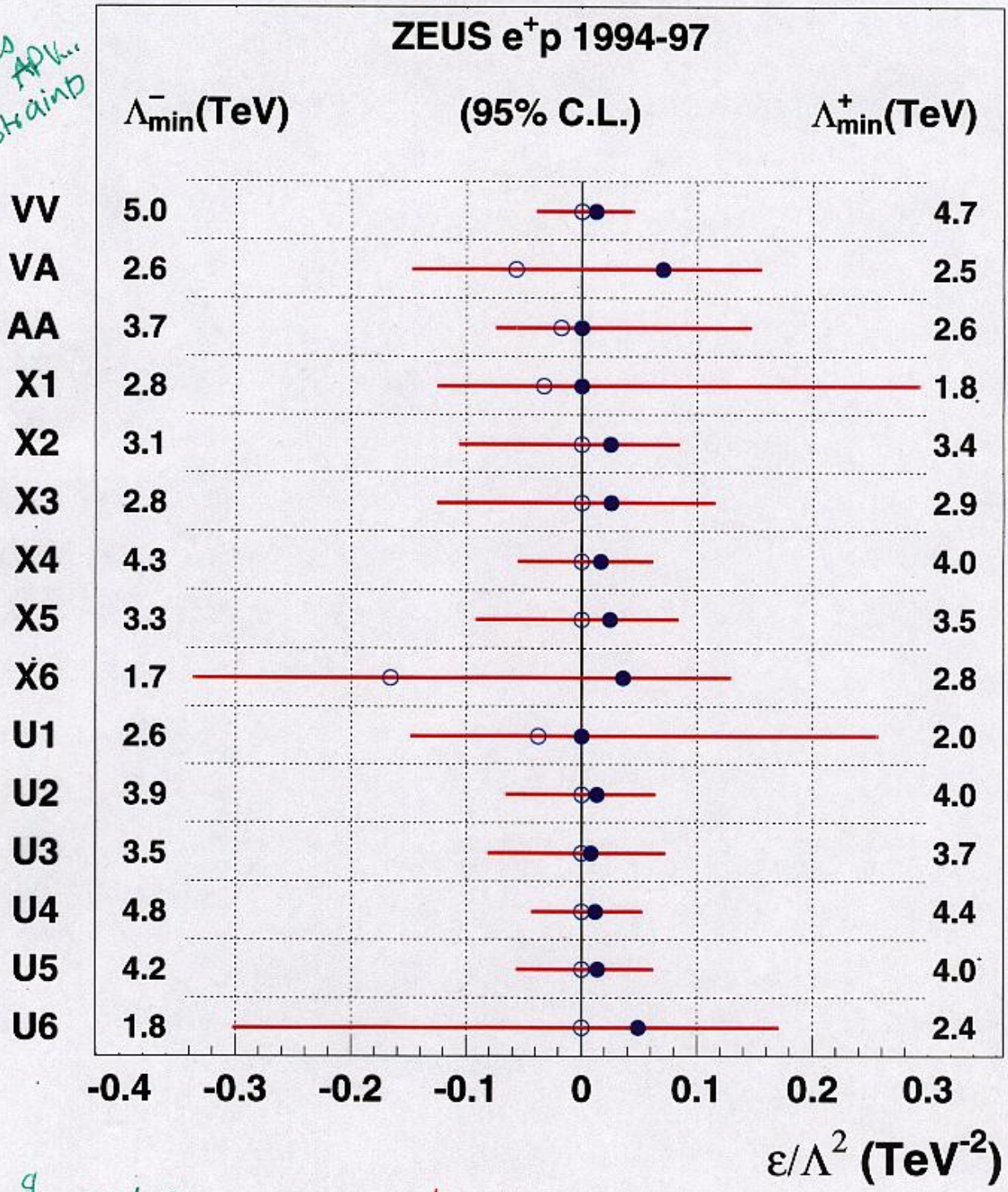
constructiv or destructive interference with the SM

$$\mathcal{L} = \frac{g^2}{\Lambda^2} \sum_{\substack{a,b = L,R \\ q = u,d}} \eta^q_{ab} (\bar{e}_a \gamma^\mu e_a)(\bar{q}_b \gamma_\mu q_b)$$

construct linear combinations of η^q_{ab} for many scenarios with strength g^2/Λ^2

Where does the SM break down? Contact Interactions

many models using APV... constraints



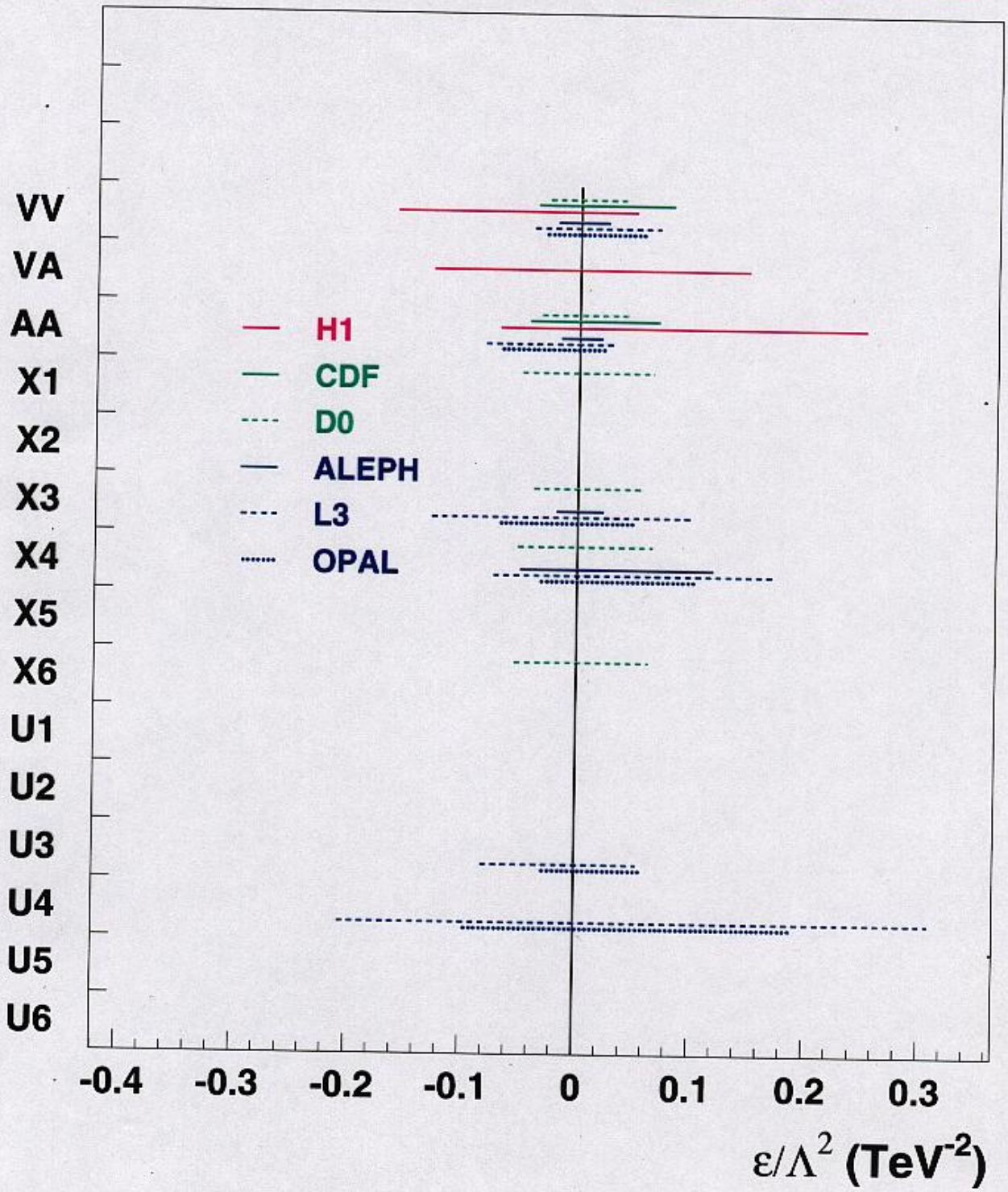
$\eta^q_{LR} = \pm 1, 0$

Combinations

— limits

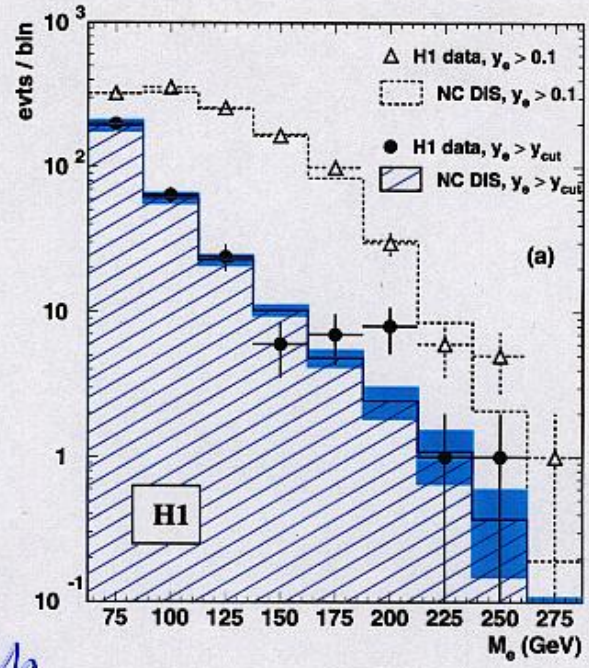
●○ best fits (95% CL)

Where does the SM break down?
Contact Interactions



Where does the SM break down? Leptoquarks

"needed" in many SM extensions

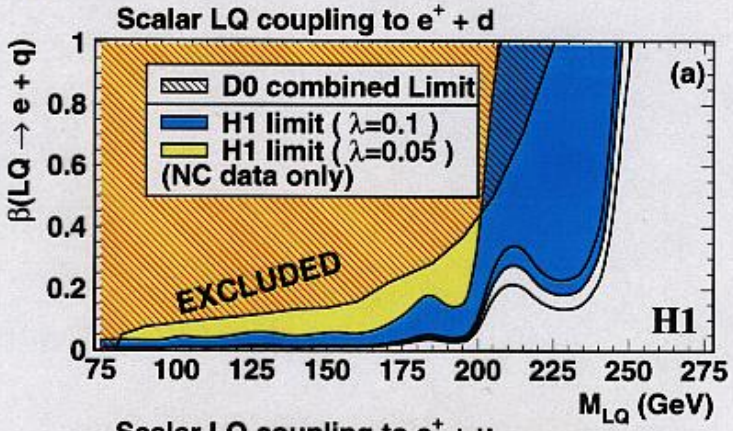


"naturally" produced at HERA

$eq \to LQ \to e$ / ν

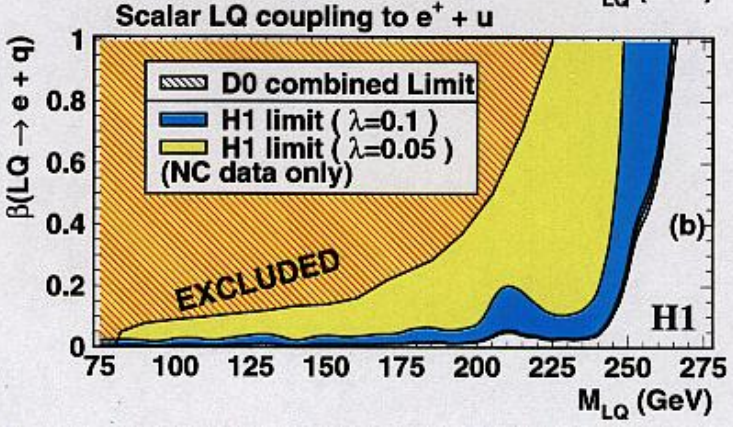
Your optimized for LQ search

e^+ data into e^+ jet

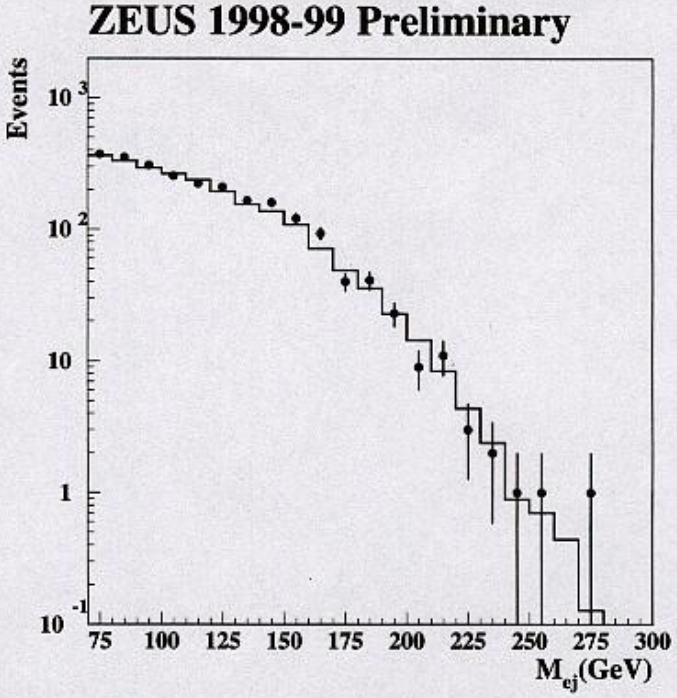


for other decays eq, $\nu q'$

Variable Branching



Where does the SM break down? Leptoquarks

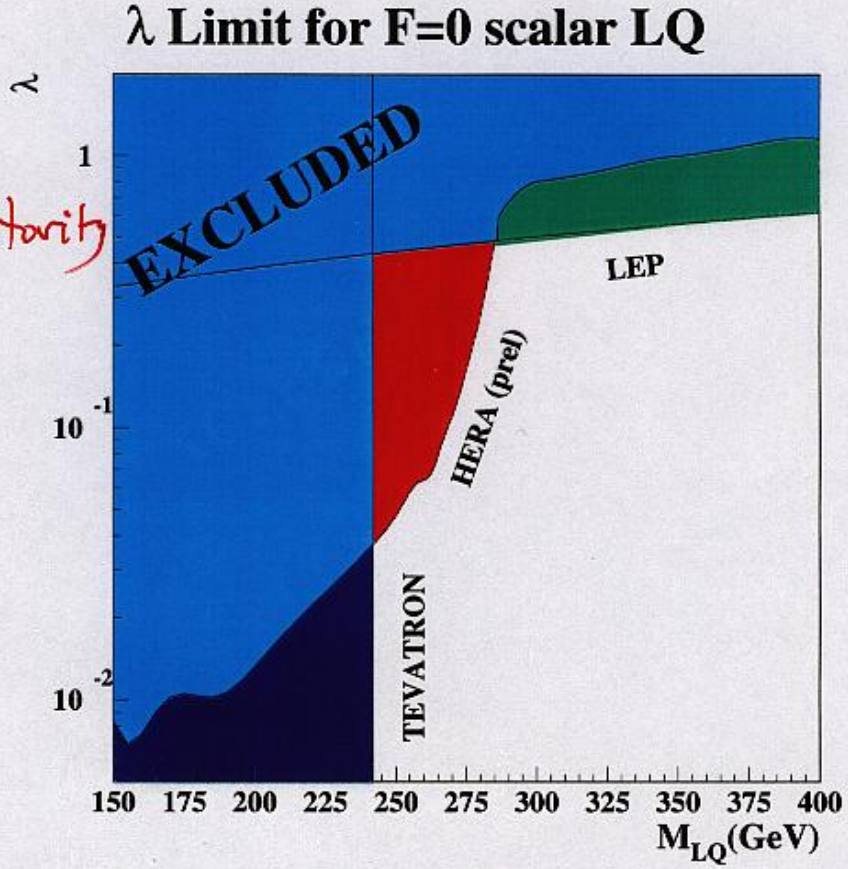


e^- data into e^- jet

$\sigma^{NWA} = (J+1) \cdot$

$\frac{\pi}{4s} \lambda \; q(x_0, Q$

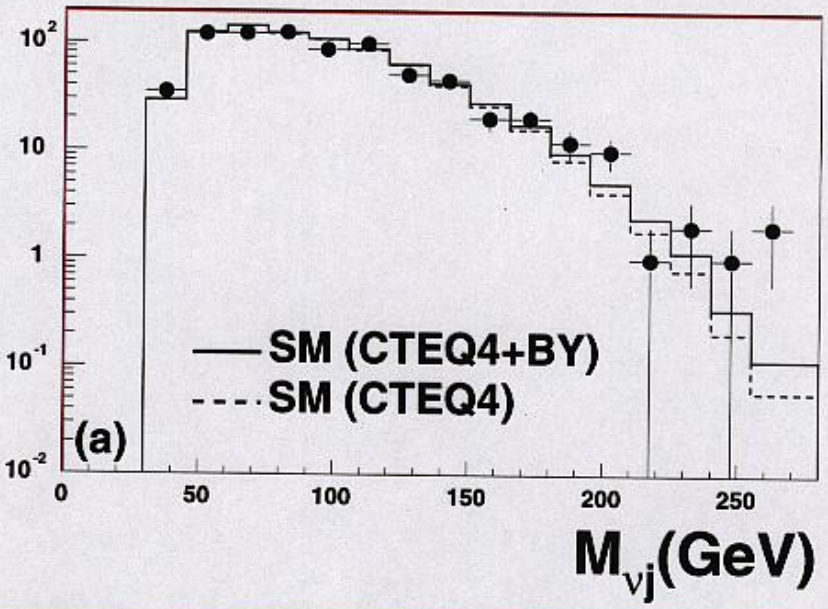
$\frac{M_{LQ}^2}{s}$ M_L



$(F = 3B + L$

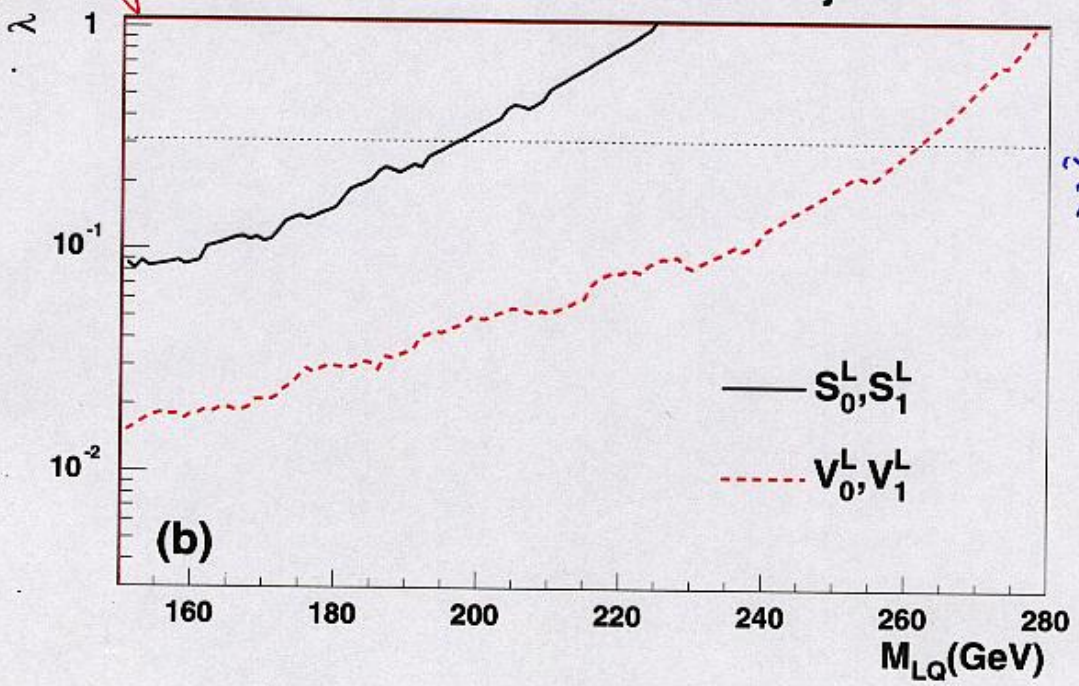
Complementarity of LEP HERA FNAL

Where does the SM break down?
Leptoquarks: ν jet



e+ data
→ $\bar{\nu}$ jet

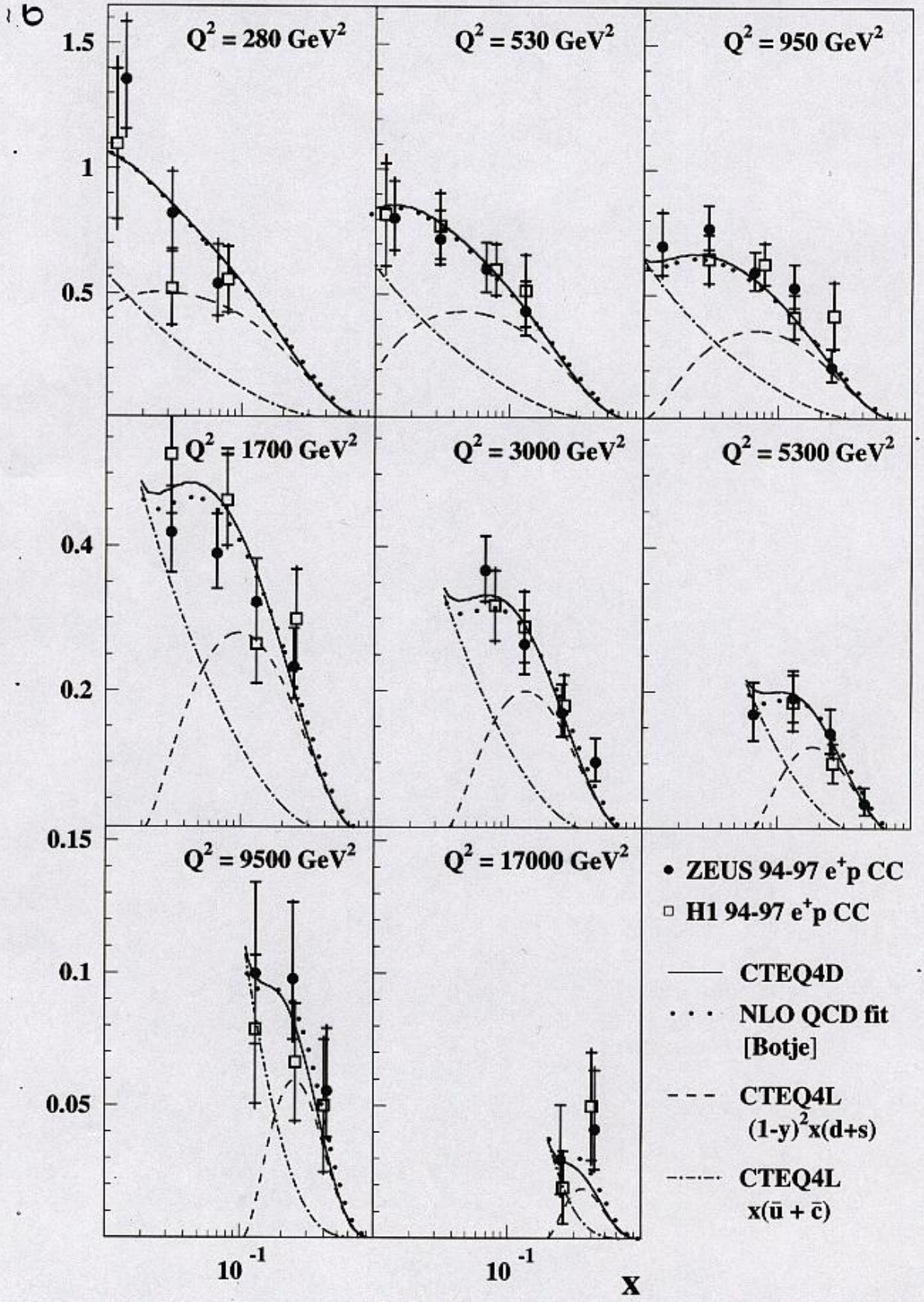
coupling limits



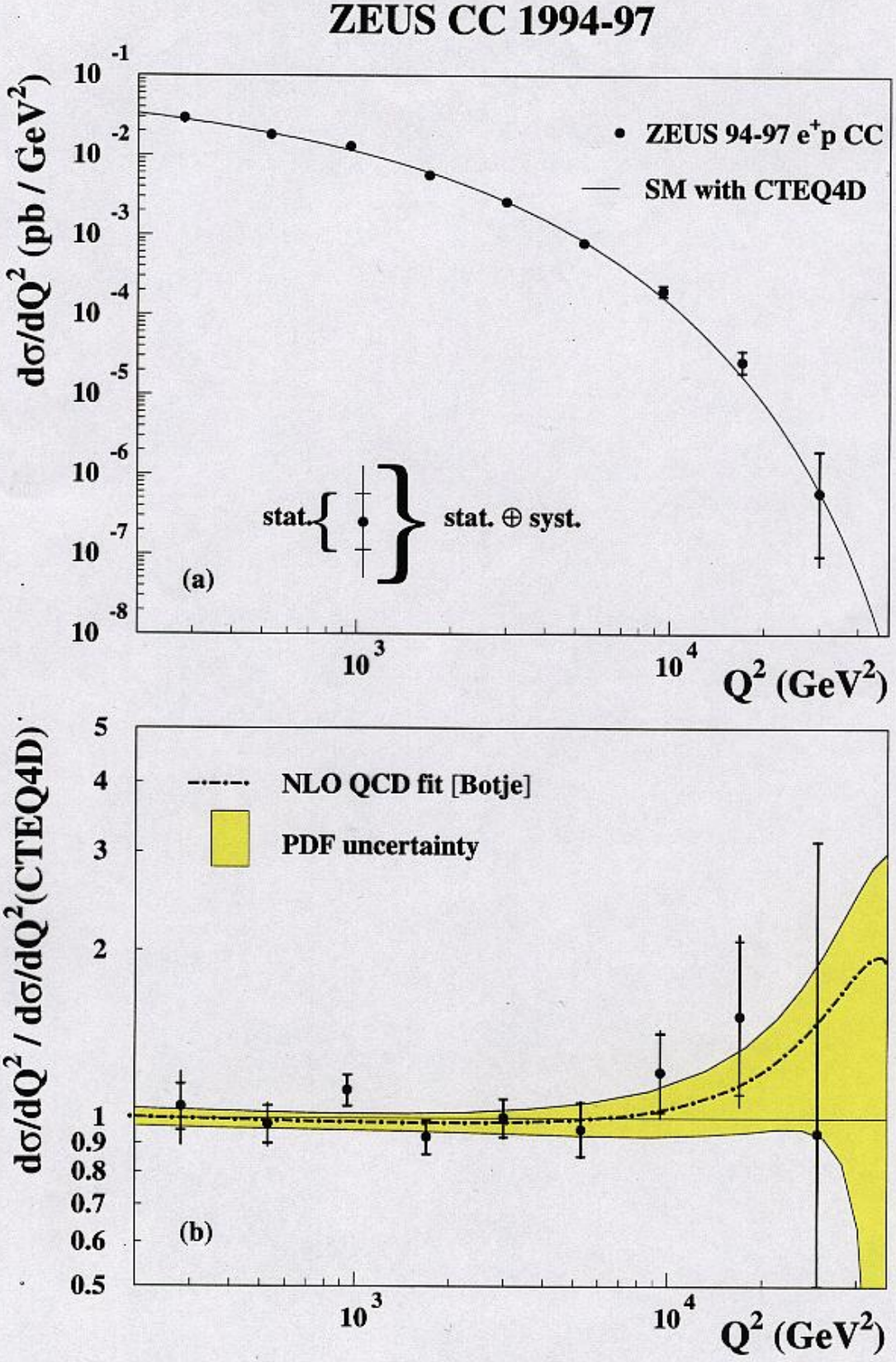
ew scale
$\lambda = \sqrt{4\pi\alpha}$

$$\frac{d^2\sigma}{dx\,dQ^2} = \frac{G_F^2}{2\pi x}\left(\frac{M_W^2}{Q^2+M_W^2}\right)^2 \Phi_{cc}(x,Q^2) \qquad \Phi_{cc}^{LO} = x\,(\bar{u}+\bar{c}) + (1-y)^2\,(u+c)$$

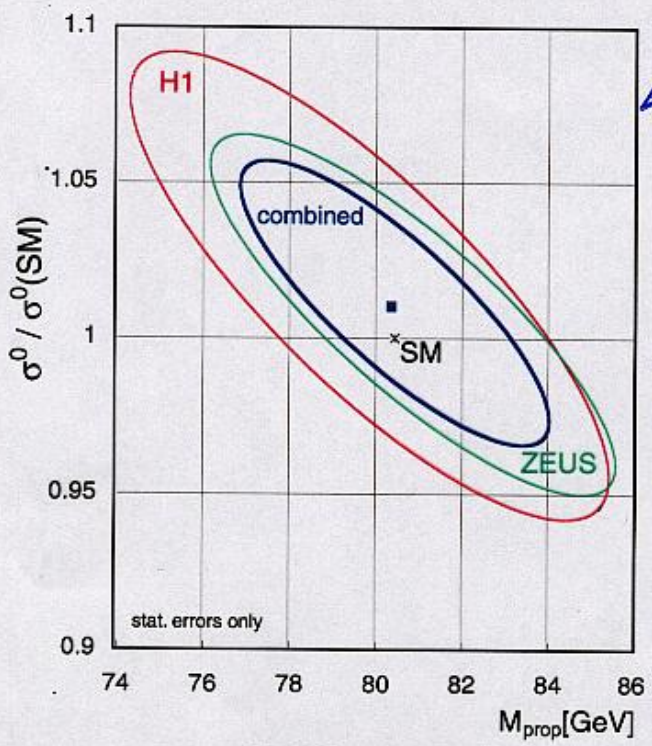
High Q^2 Charged Current Cross sections



High Q^2 CC Cross sections cont'd



High Q^2 CC Cross sections $\rightarrow M_W$



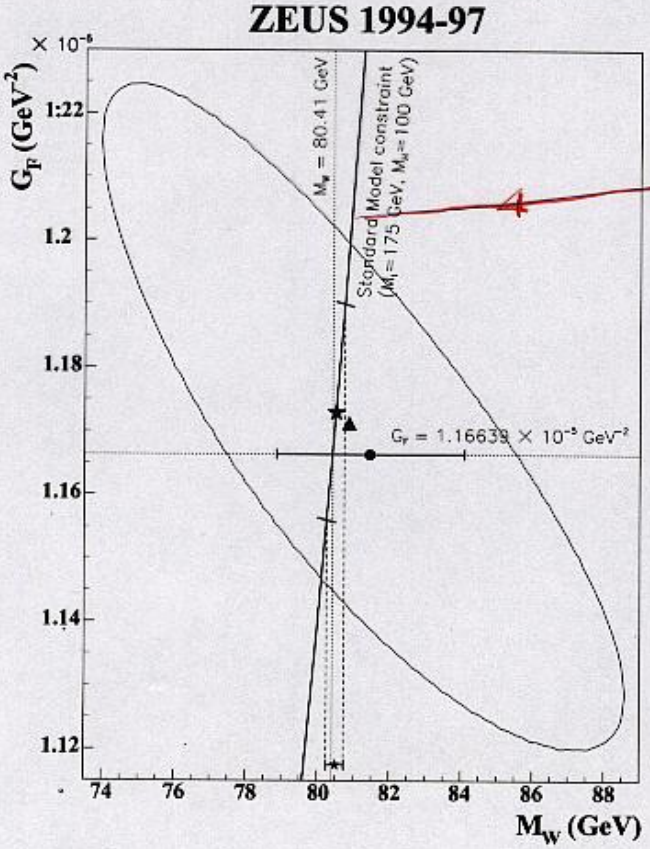
unconstrained fit

for fixed normalitat

stat syst PDF

H1 $M_W = 80.9 \pm 3.3 \pm 1.7 \pm 3.7$

ZEUS $81.4 \pm 2.7 \pm 2.0 \pm 3.3$



put SM constrain on

$G_F = G_F(M_W, M_t, \ldots)$

with $\Delta r(M_W)$

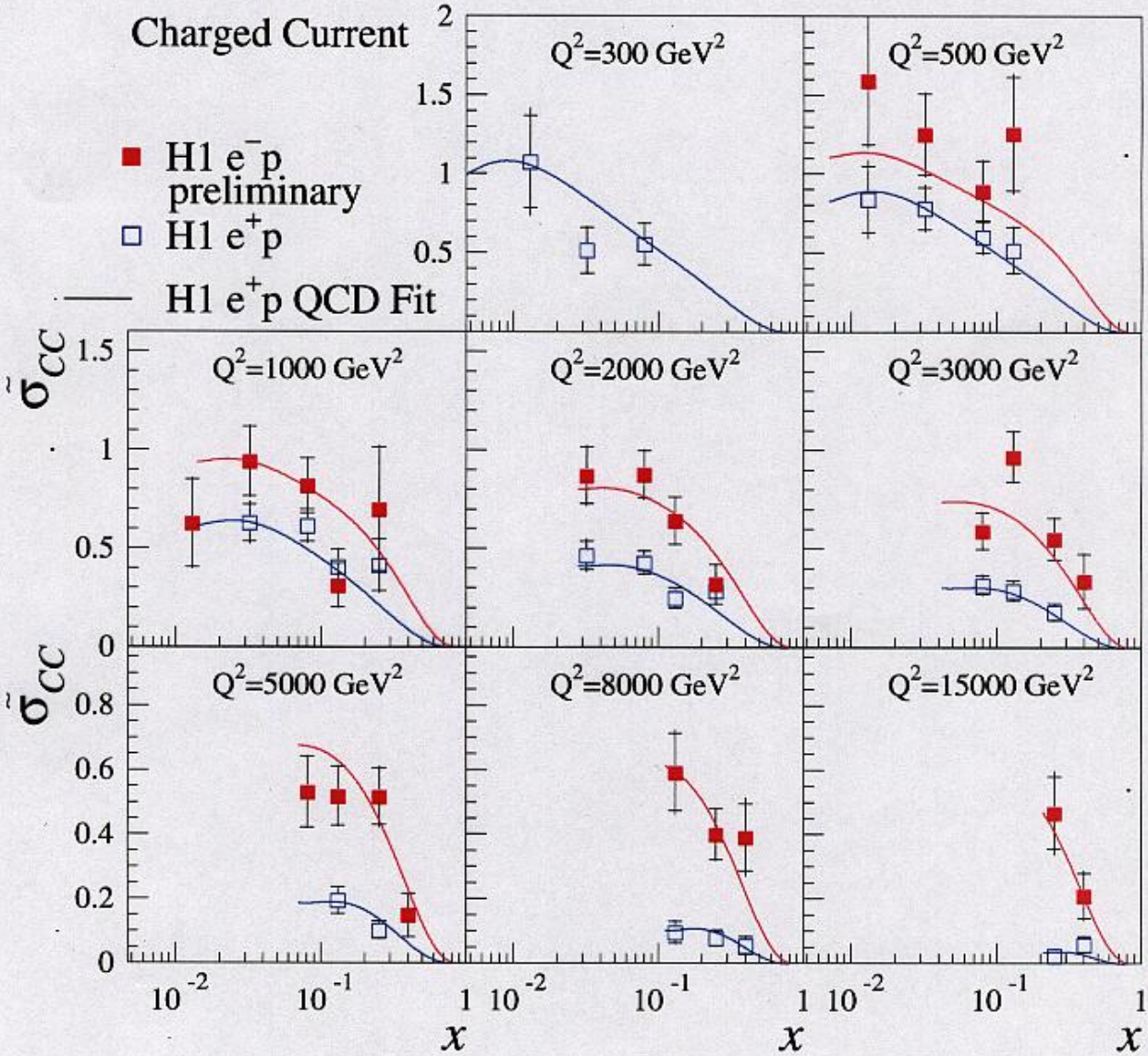
$M_W = 80.50 \pm 0.25$

$\pm 0.16 \pm 0.31 \pm 0$

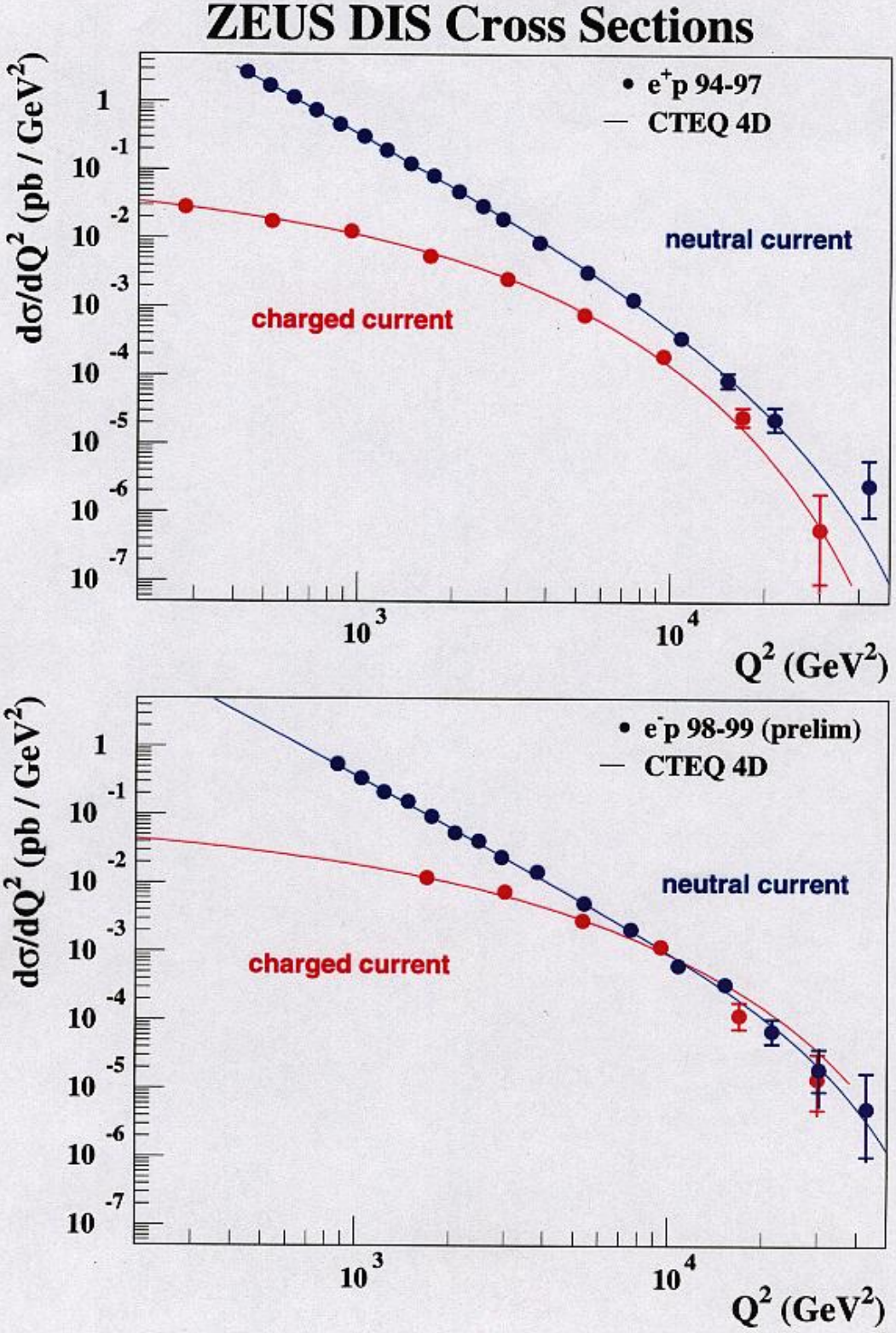
High Q^2 CC Cross sections cont'd

e^- cross section much bigger than e^+

$\sim x\bar{u}$ $\sim (1-y)^2 x d$



High Q^2 Cross sections



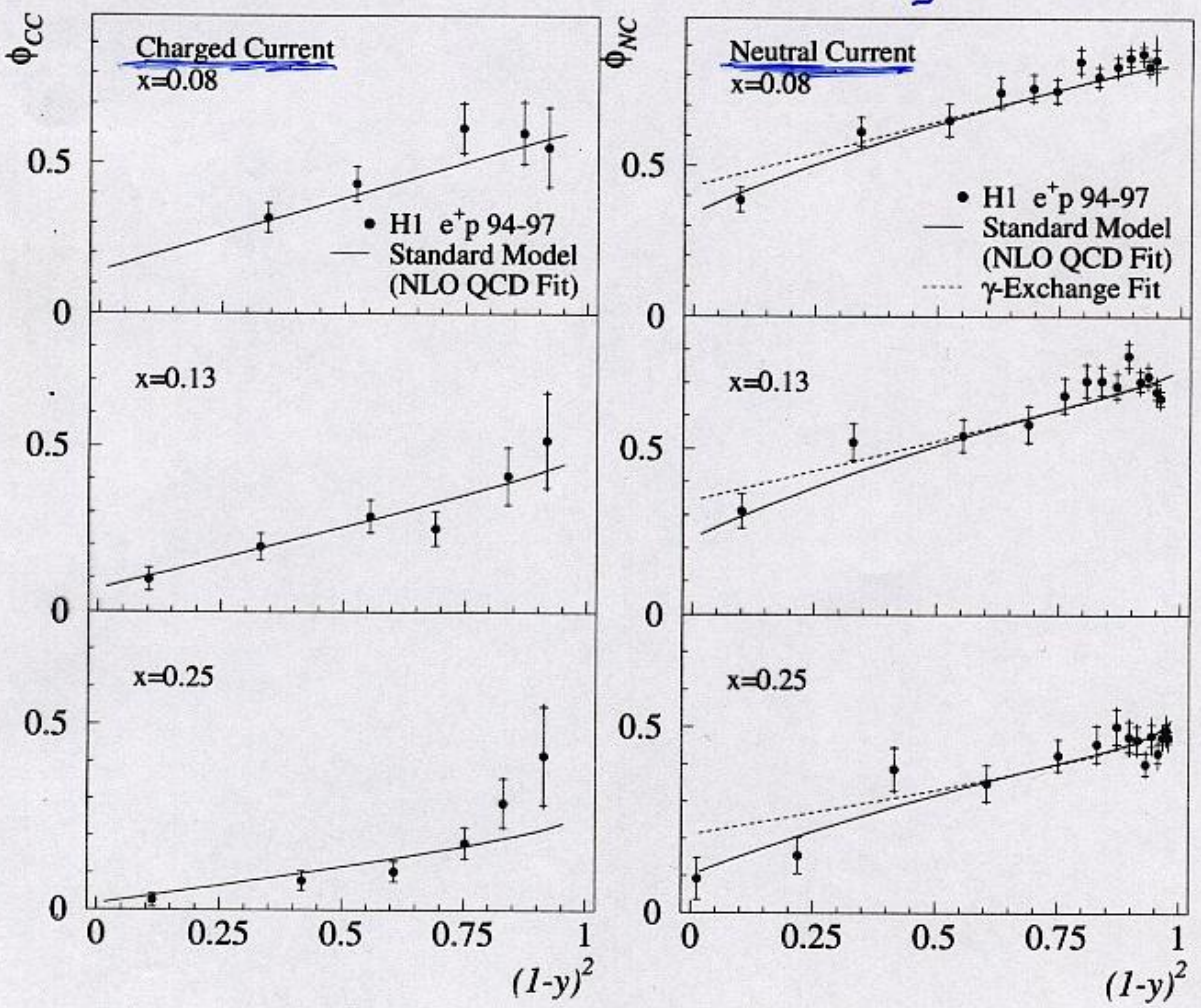
High Q^2 Cross sections: Helicity Structure

in the region of approx Bjorken scaling

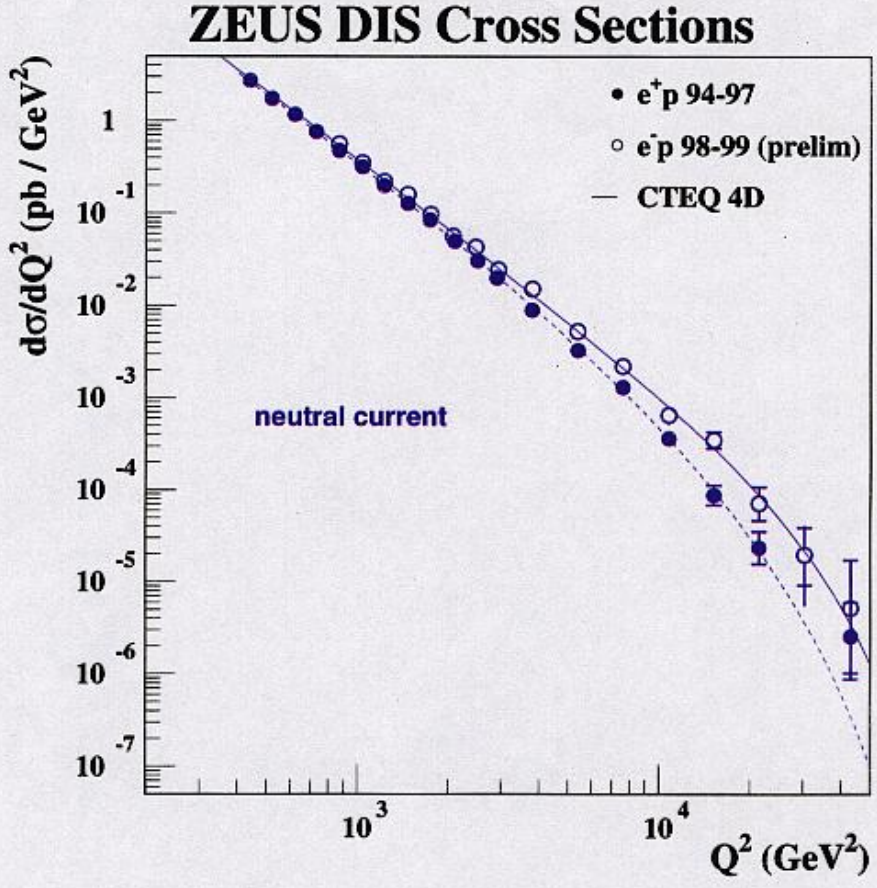
$x \simeq 0.1$

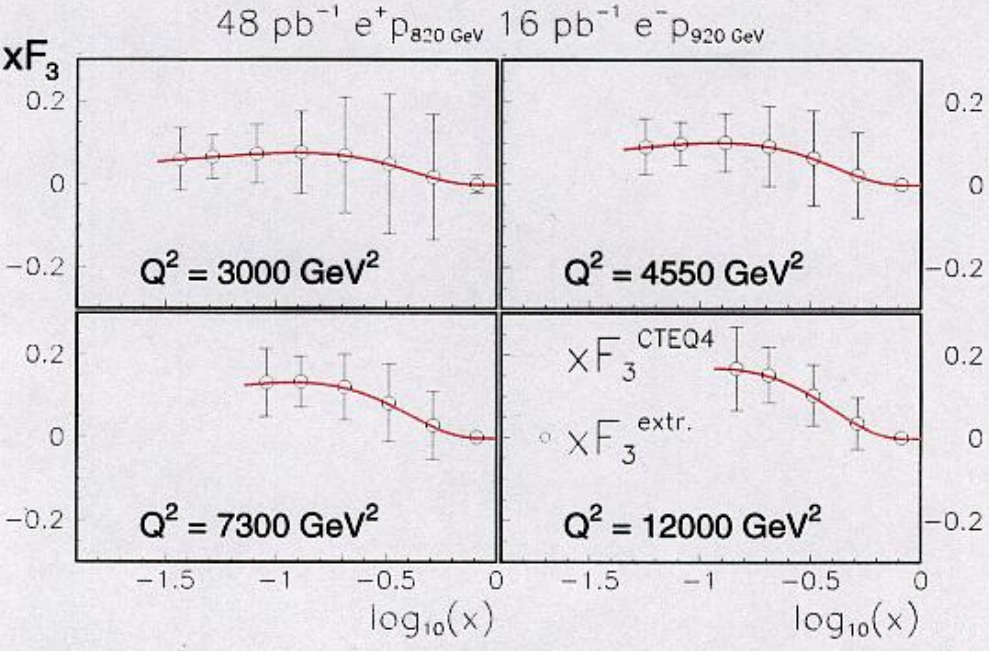
separate helicity dep from q-PDF

$\Phi_{CC} \sim x(\bar{u} + (1-y)^2 d)$ $\quad$ $\Phi_{NC} \sim (1 + (1-y)^2)x * (\frac{4}{9}(u+\bar{u}) + \frac{1}{9}(d+\bar{d}))$



Introduction to Summary





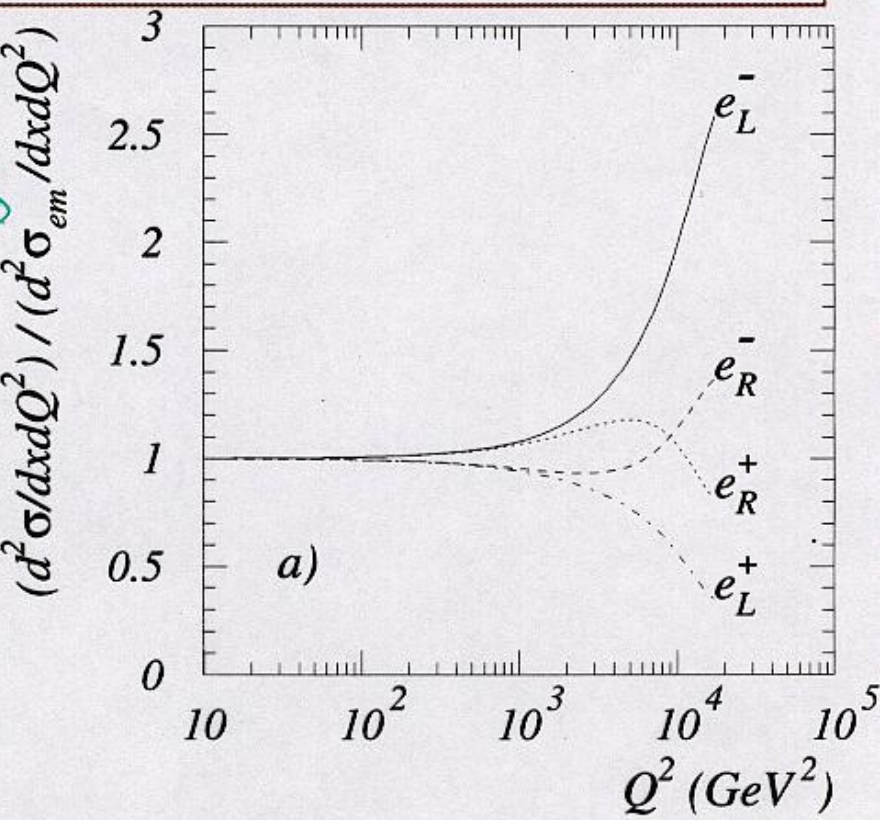
Summary and Outlook

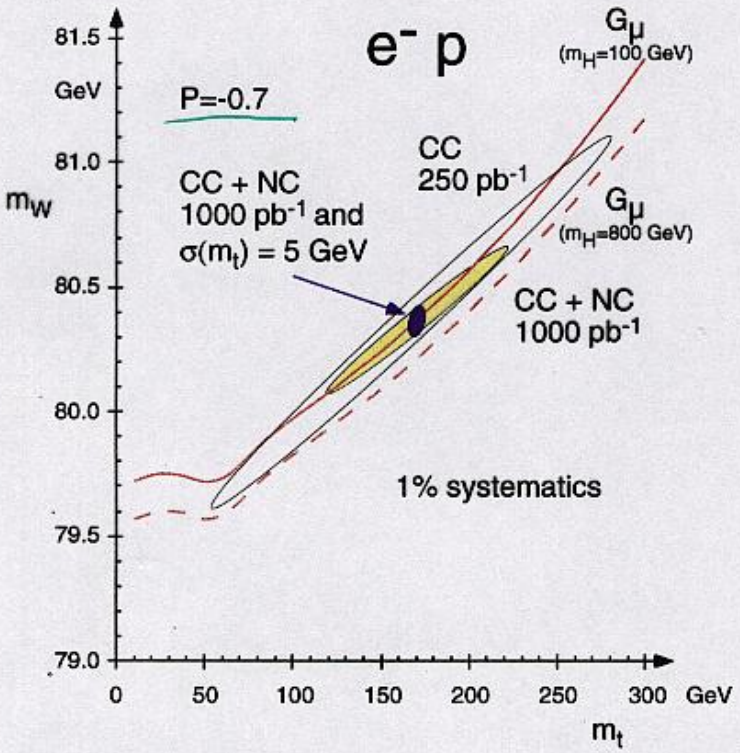
- HERA physics reveals detailed knowledge of the proton structure and of the interactions of leptons with partons
- H1 and ZEUS are good working experiments since 1992 and exploit and extend their detector(s) with better and better understanding
- The program is rich: QCD, proton and photon structure), diffraction, electroweak physics
- HERA is a good machine to look for the "unexpected"
- HERA's goal is to deliver 1 fb^{-1} with electron (positron) polarization starting 2001
- ZEUS and H1 will certainly present exciting physics until 2006

HERA luminosity upgrade - Physics examples

Sensitivity of NC DIS to ⇒ polarization

measure also (e.g.) v_u, a_u to 13, 7 %





SM analysis combining CC+NC data w 1 fb^{-1} yields

δM_W = 60 M