

Electroweak Physics Measurements at HERA



Les Rencontres de Physique
de la Vallée d'Aoste

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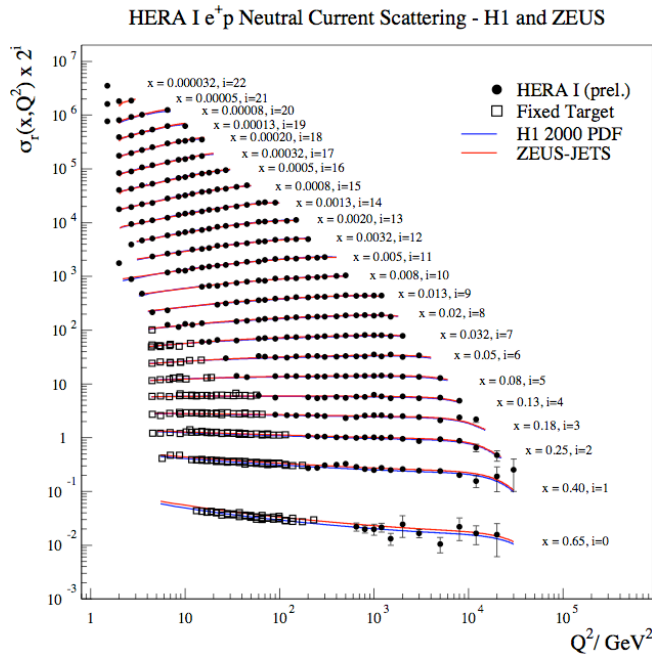


Outline

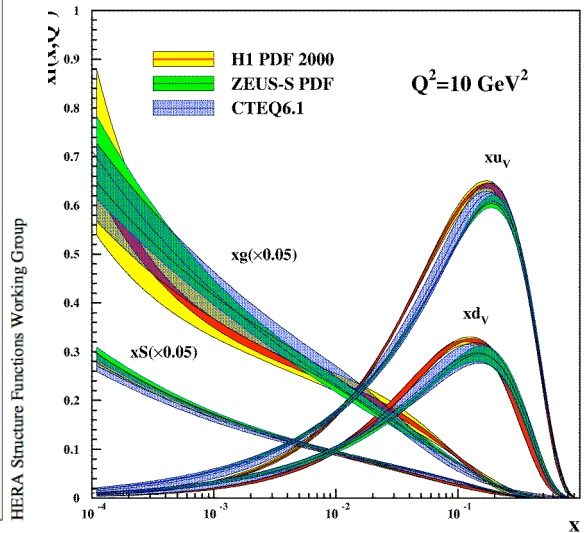
- Polarised cross sections
- Electroweak Studies

QCD and EW Studies at HERA

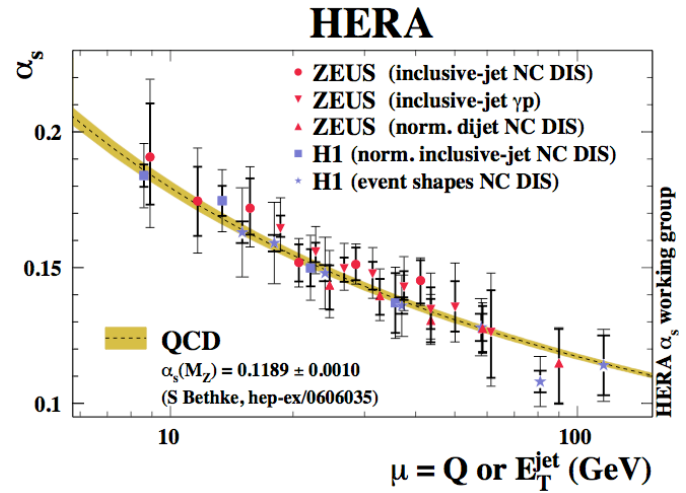
HERA as a QCD machine: proton structure and tests of pQCD...



Structure functions



Parton densities






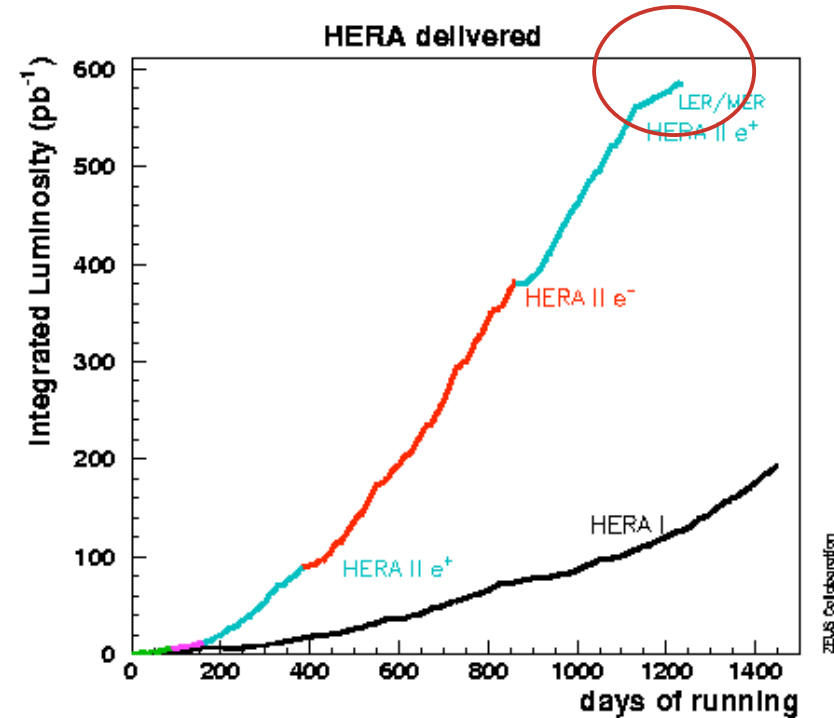
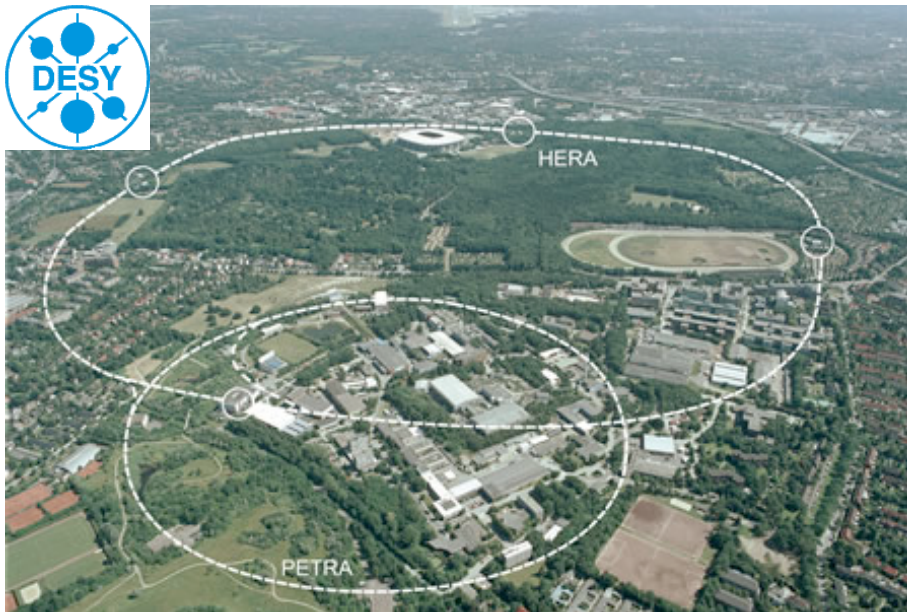
Strong coupling

But also Studies of the ElectroWeak sector of the Standard Model at High- Q^2

HERA

Only $e^\pm p$ collider in the world
Ended operation July 07

p (920 GeV)   e^\pm (27.5 GeV) 
 $\sqrt{s} = 318$ GeV



HERA I (1992-2000): 190 pb⁻¹
-unpolarised e^\pm beams

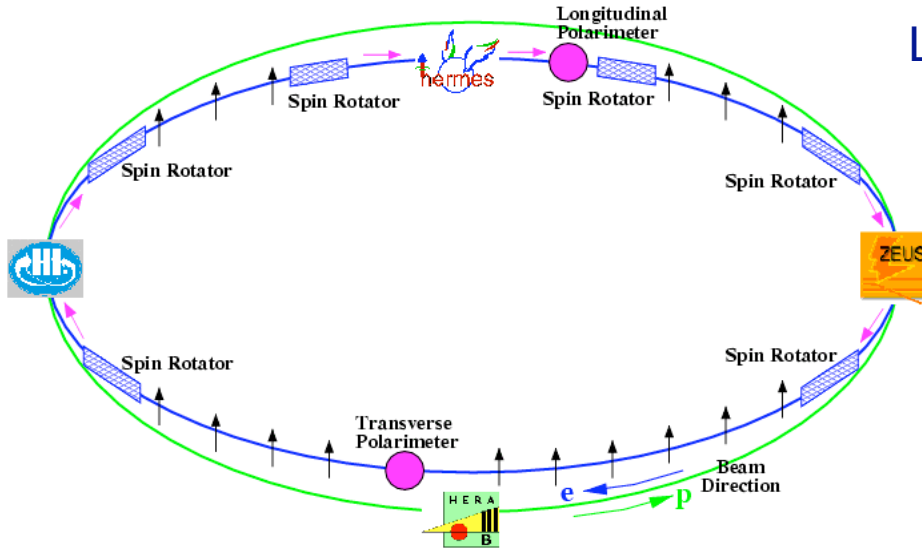
HERA II (2002-2007): 560 pb⁻¹
- longitudinally polarised e^\pm beams
- upgraded detectors
- Runs at reduced \sqrt{s} for F_L measurement

Polarization

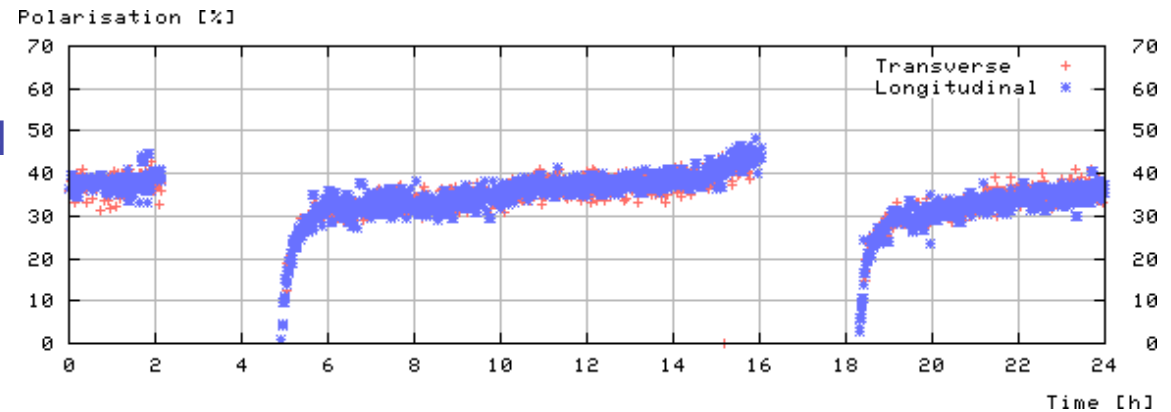
Longitudinal polarisation of the lepton beam

- Transverse polarization builds up naturally (Sokolov-Ternov effect, rise time ~30 min)
- Spin rotators before/after H1 and ZEUS
- Polarisation = Asymmetry of helicity states:

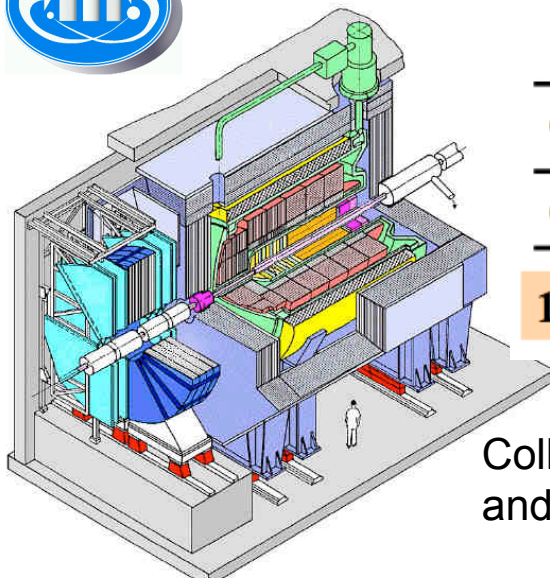
$$P_e = \frac{N_R - N_L}{N_R + N_L}$$



Polarisation build-up
 $P_e \sim 30\text{-}40\%$ routinely achieved
 Measured by two independent Compton polarimeters.



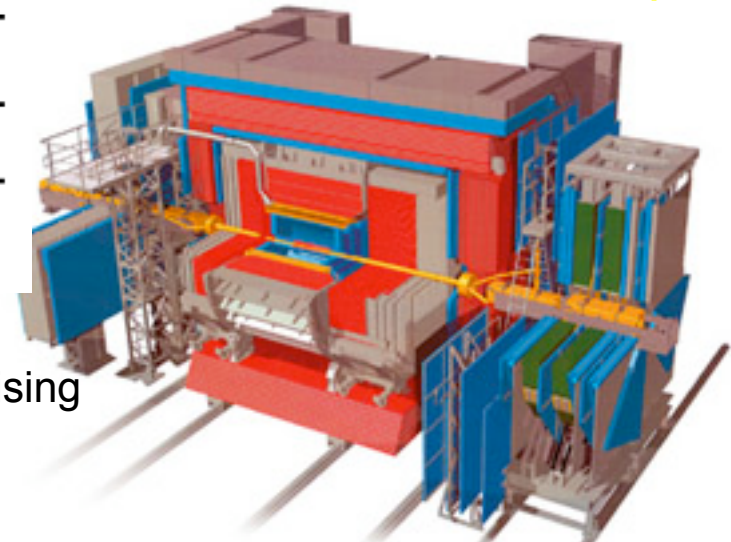
ZEUS and H1



	HERA-I	HERA-II
e^-	$\sim 20 \text{ pb}^{-1}$	$\sim 200 \text{ pb}^{-1}$
e^+	$\sim 100 \text{ pb}^{-1}$	$\sim 200 \text{ pb}^{-1}$

1 fb⁻¹ collected by H1+ZEUS

Collaborations very active in finalising and combining their results...



Complete 4 π detector

Tracking:

- central jet chamber
 - z drift chambers
 - forward track. detector
 - Silicon μ -Vtx
- (operate in a B field of 1.2 T)

Calorimeters:

- Liquid Argon cal.
- Lead-Fiber cal. (SPACAL)

Muon chambers

Complete 4 π detector

Tracking:

- central tracking detector
 - Silicon μ -Vtx
- (operate in a B field of 1.43 T)

Calorimeters:

- Uranium-scintillator (CAL)
- Instrumented-iron (BAC)

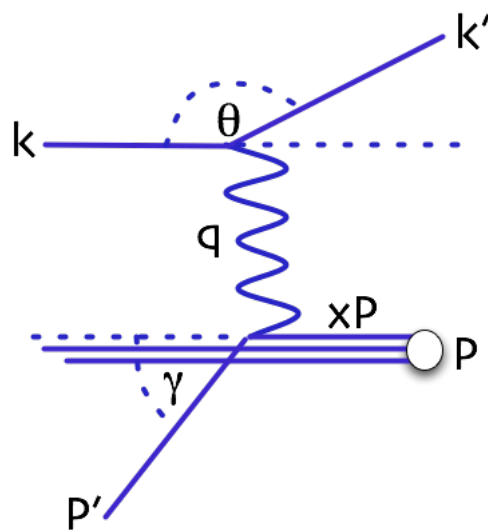
Muon chambers

Deep Inelastic Scattering at HERA

Two processes:

Neutral Current (NC) - exchange γ and Z^0 ($e^\pm p \rightarrow e^\pm X$)

Charged Current (CC) - exchange of W^\pm ($e^\pm p \rightarrow \nu X$)



$$Q^2 = -q^2 = (k - k')^2$$

Virtuality of exchanged boson

$$x = \frac{Q^2}{2p \cdot q}$$

Bjorken scaling variable

$$y = \frac{p \cdot q}{p \cdot k}$$

Inelasticity

$$Q^2 = sxy$$

Main observables of interest: double differential cross sections $d^2\sigma/dxdQ^2$

Neutral current cross sections

Reduced cross sections

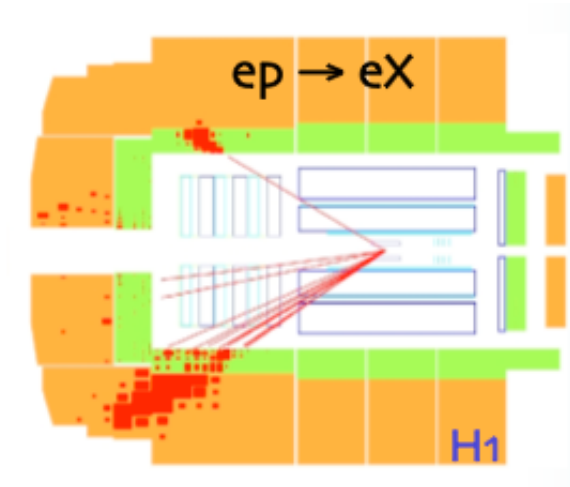
$$\tilde{\sigma}^{\pm} = \frac{d^2\sigma^{\pm}}{dx dQ^2} \frac{Q^4 x}{2\pi\alpha^2 Y_+} = \tilde{F}_2^{\pm} \mp \frac{Y_-}{Y_+} x \tilde{F}_3^{\pm} - \frac{y^2}{Y_+} \tilde{F}_L^{\pm}$$

Structure functions

$$\begin{aligned} \tilde{F}_2^{\pm} &= F_2 + k(-v_e \mp P a_e) F_2^{\gamma Z} + k^2(v_e^2 + a_e^2 \pm 2P v_e a_e) F_2^Z \\ x \tilde{F}_3^{\pm} &= k(-a_e \mp P v_e) x F_3^{\gamma Z} + k^2(2v_e a_e \pm P(v_e^2 + a_e^2)) x F_3^Z \end{aligned}$$

at leading order

$$\begin{aligned} (F_2, F_2^{\gamma Z}, F_2^Z) &= x \sum (e_q^2, 2e_q v_q, v_q^2 + a_q^2) (q + \bar{q}) \\ (x F_3^{\gamma Z}, x F_3^Z) &= 2x \sum (e_q a_q, v_q a_q) (q - \bar{q}) \end{aligned}$$



$$k = \frac{1}{4 \sin^2 \theta \cos^2 \theta} \frac{Q^2}{Q^2 + M_Z^2}$$

Charged current cross sections

Double diff. cross sections

$$\frac{d^2\sigma^\pm}{dx dQ^2} = (1 \pm P_e) \frac{G_F^2}{4\pi x} \left[\frac{M_W^2}{M_W^2 + Q^2} \right]^2 (Y_+ W_2 \mp Y_- x W_3 - y^2 W_L)$$

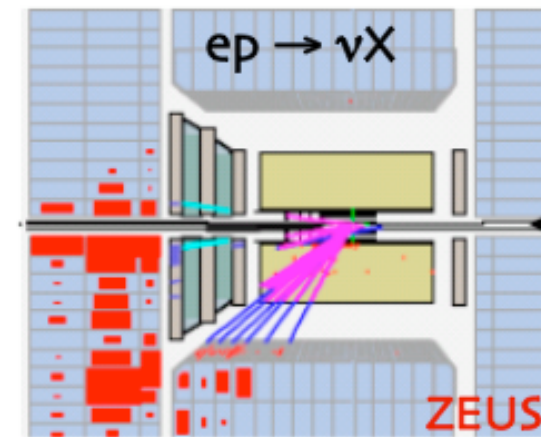
Reduced Cross Section:

$$\tilde{\sigma}^\pm = \frac{4\pi x}{G_F^2} \left[\frac{M_W^2 + Q^2}{M_W^2} \right]^2 \frac{d^2\sigma^\pm}{dx dQ^2}$$

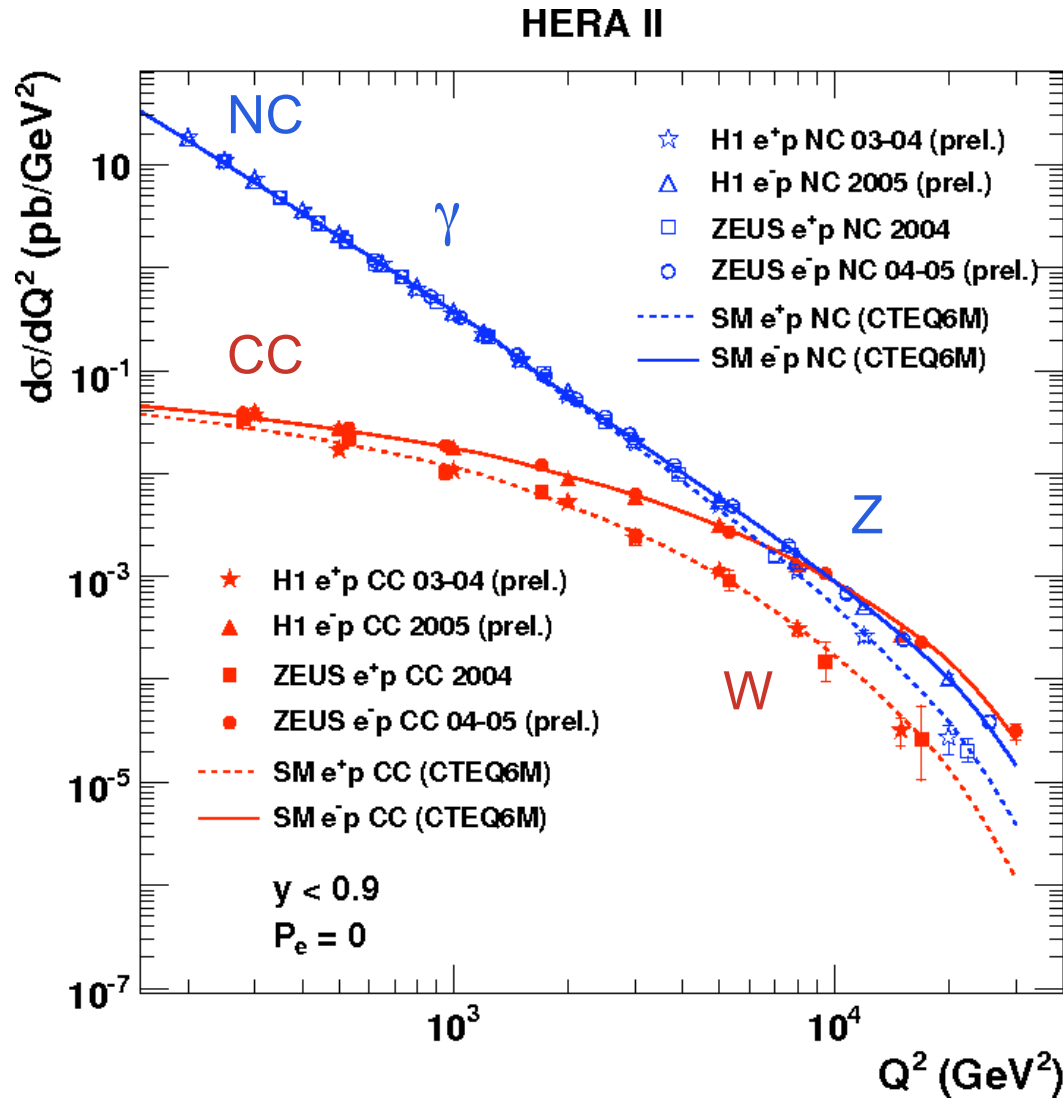
QPM Structure functions

$$W_2 = x(\bar{u} + \bar{c} + d + s)$$

$$xW_3 = x(-\bar{u} - \bar{c} + d + s)$$



NC and CC unpolarised cross sections



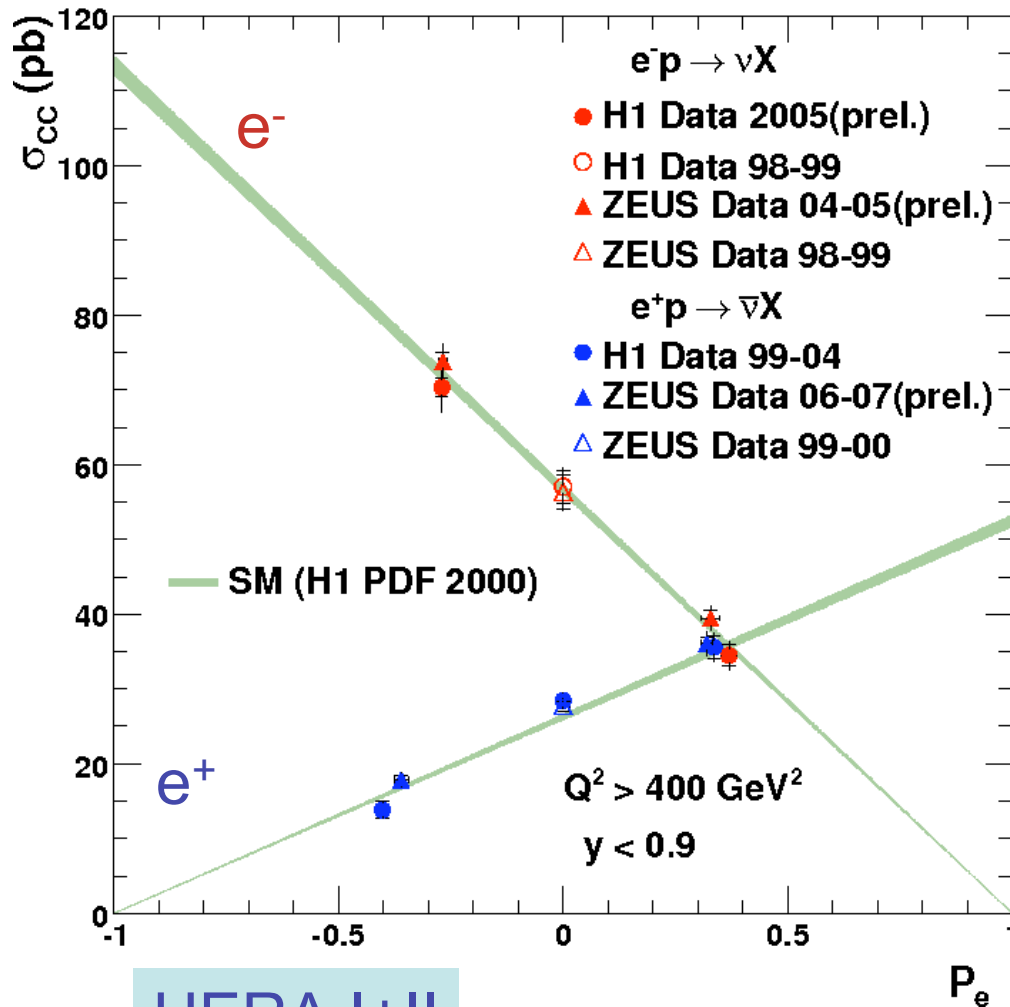
- Neutral current $\sim 1/Q^4$
 - Charged current $\sim 1/(Q^2 + M_W^2)^2$
 - NC and CC cross sections comparable at $Q^2 \approx M_{Z/W}^2$
- ➔ EW Unification

Difference between e⁺p and e⁻p:
 NC: γZ interference
 CC: (d vs u) and helicity factor

Cross sections corrected for polarisation effect

Total polarised CC cross section

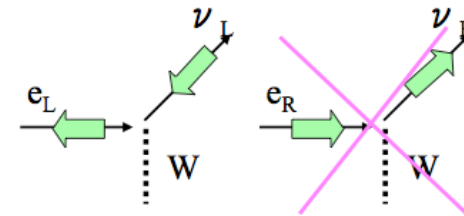
Charged Current $e^\pm p$ Scattering



HERA I+II

$$\sigma_{e^\pm p}^{CC}(P_e) = (1 \pm P_e) \sigma_{e^\pm p}^{CC}(P_e = 0)$$

Extrapolate measured cross sections to $P_e = \pm 1$:
 \Rightarrow no sign of right-handed currents



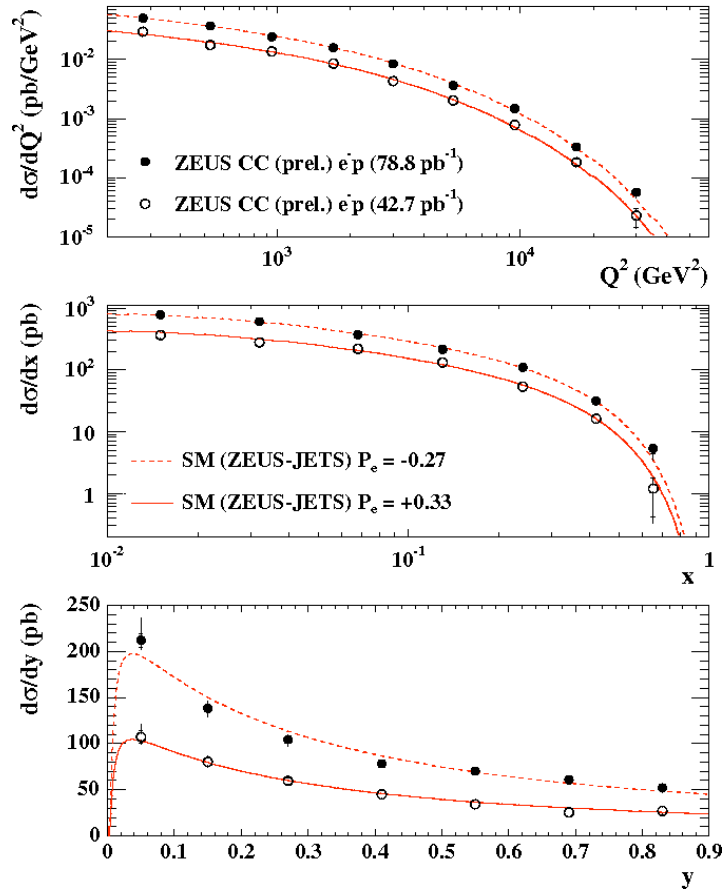
Chiral structure of the SM confirmed

Convert to 95% CL on heavy W_R :
 $m_{W,R} > 208 \text{ GeV}$ (H1)

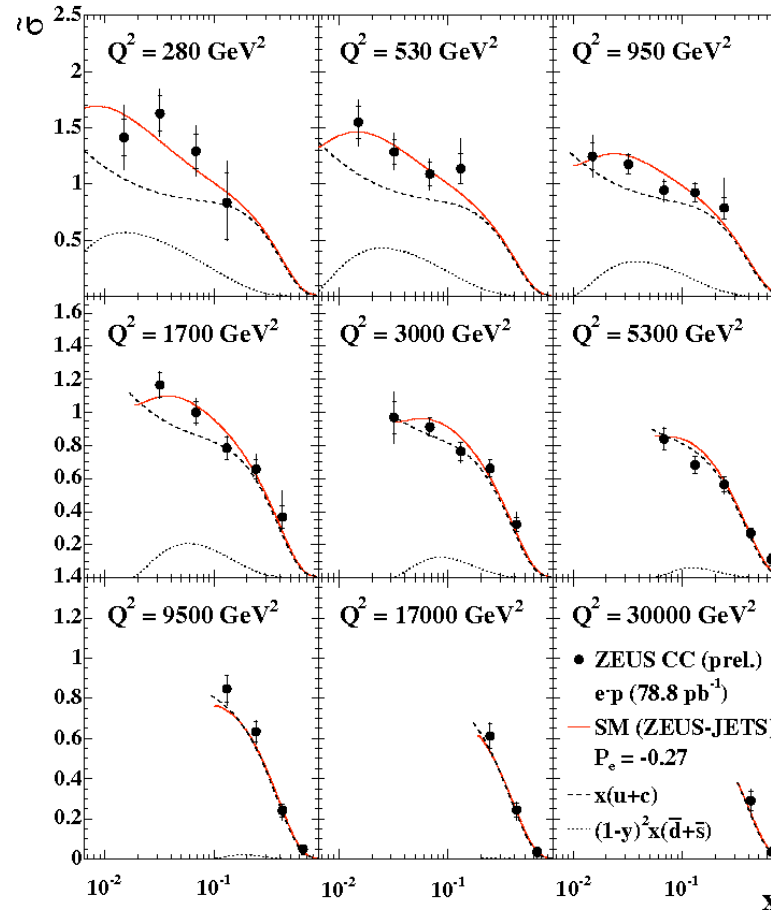
Complementary to Tevatron direct searches

CC Differential cross sections

ZEUS



ZEUS



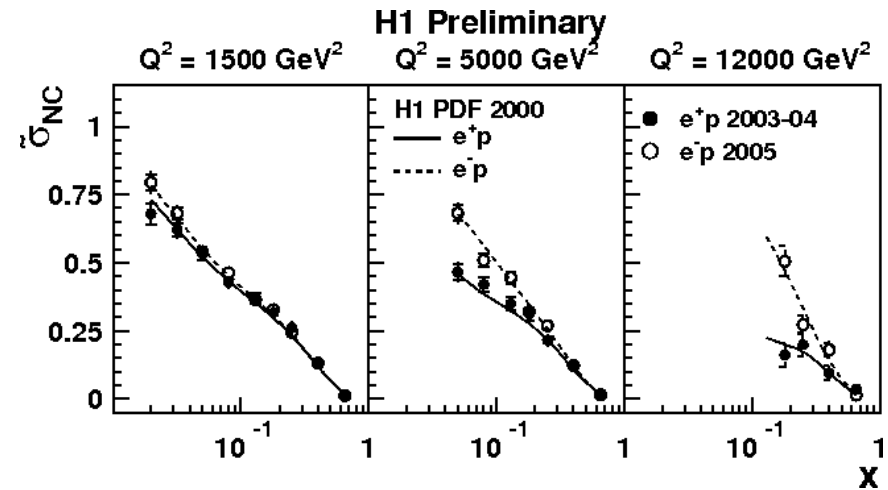
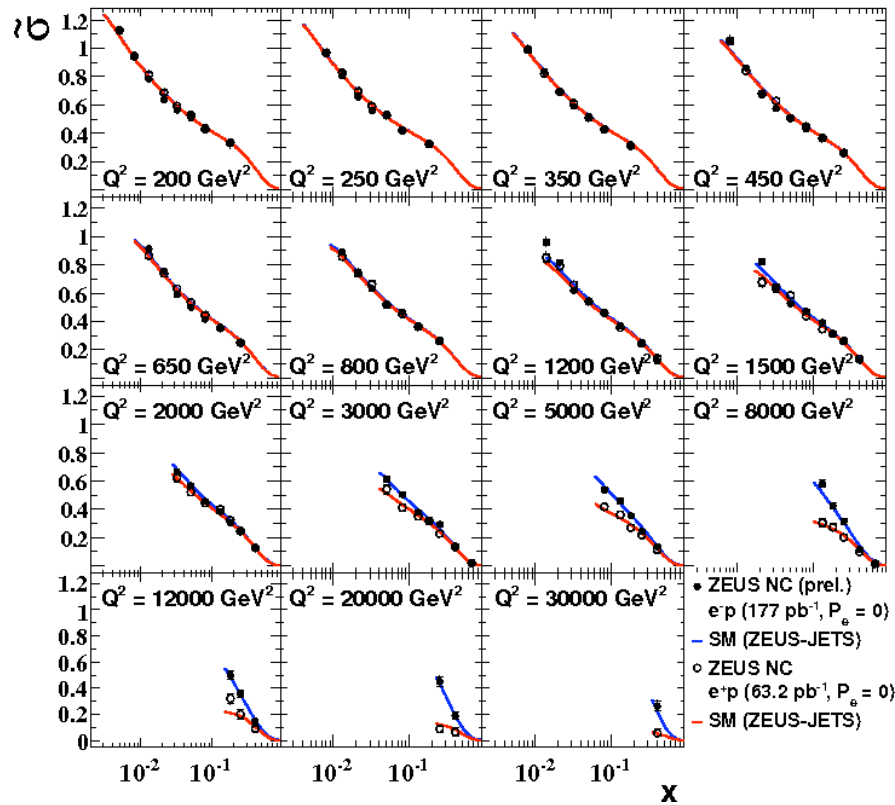
Cross sections as a function of Q^2 , x and y
Scale with polarisations independently of
kinematic variables

Higher precision than ever before in CC DIS
Input to QCD-EW fits (see later)

NC cross sections and $xF_3^{\gamma Z}$

$$\tilde{\sigma}^- - \tilde{\sigma}^+ = 2 \frac{Y_-}{Y_+} (-a_e \cdot k x F_3^{\gamma Z} + 2v_e a_e \cdot k^2 x F_3^Z)$$

ZEUS



xF_3 - H1 and ZEUS Combined

$$xF_3^{\gamma Z} = \frac{x}{3}(2u_v + d_v + \Delta)$$

- Valence quark content
- Sensitivity to a_q

Weak Q^2 dependence - transform all points to $Q^2 = 1500 \text{ GeV}^2$

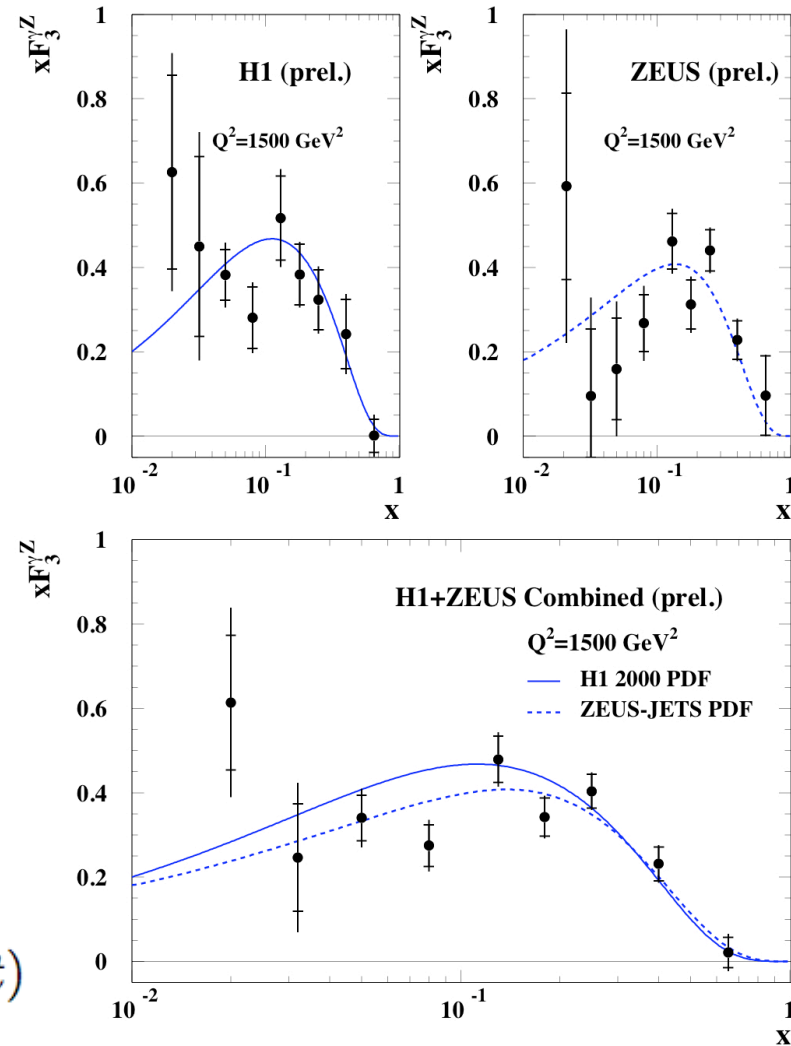
Sum rule:

$$\int_0^1 xF_3^{\gamma Z} \frac{dx}{x} = \frac{1}{3} \int_0^1 (2u_v + d_v) dx = \frac{5}{3}$$

Combined H1-ZEUS result

$$\int_{0.02}^{0.65} F_3^{\gamma Z} dx = 1.21 \pm 0.09(\text{stat}) \pm 0.08(\text{syst})$$

HERA



NC Asymmetries

$$A^{\pm} = \frac{2}{P_R - P_L} \cdot \frac{\sigma^{\pm}(P_R) - \sigma^{\pm}(P_L)}{\sigma^{\pm}(P_R) + \sigma^{\pm}(P_L)} \simeq \mp k a_e \frac{F_2^{\gamma Z}}{F_2}$$

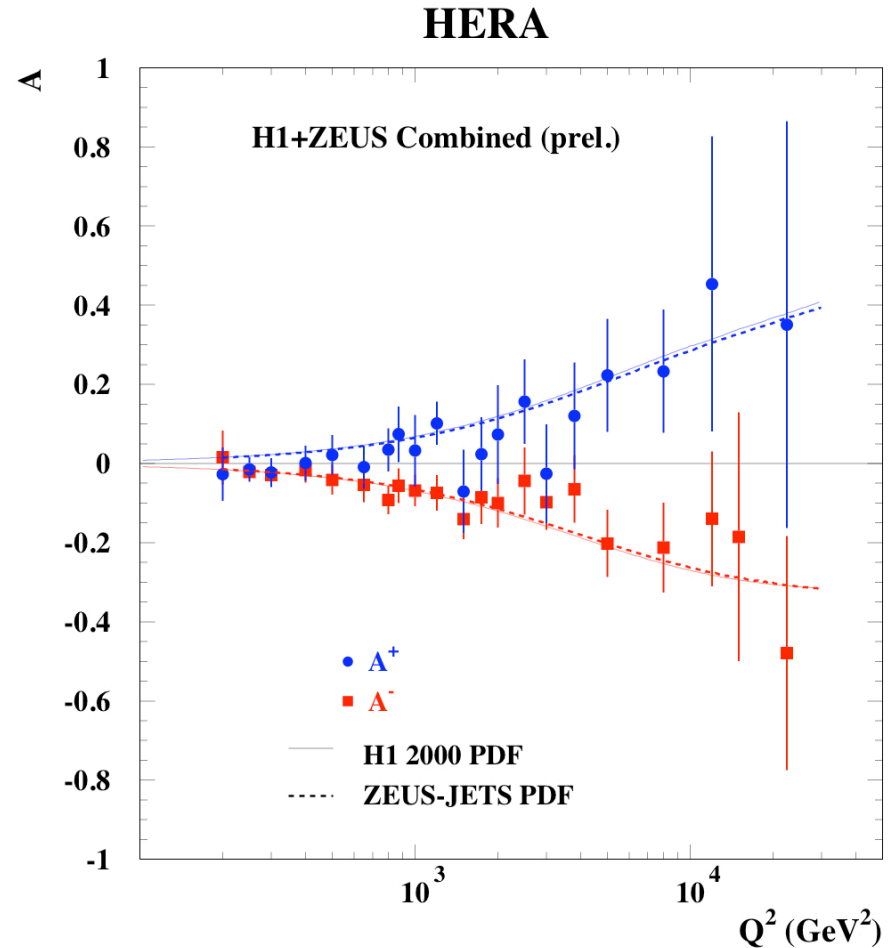
Observe $A^{\pm} \neq 0$:

First evidence of parity violation in DIS at high- Q^2 (i.e. down to distances as small as 10^{-18} m)

Expect $A^+ \approx -A^-$ within the SM

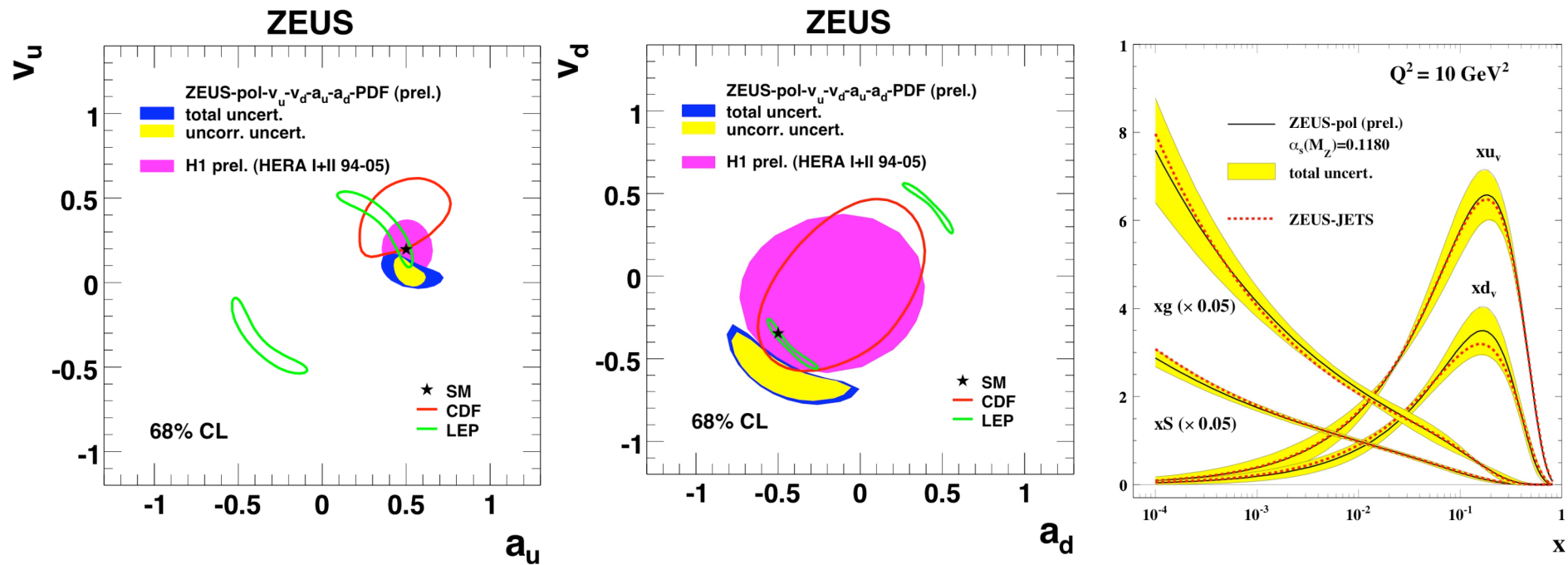
$$A^{\pm} \simeq \pm k \frac{1 + d_v/u_v}{4 + d_v/u_v}$$

Sensitivity to quark vector couplings v_q



DGLAP QCD-EW Analysis

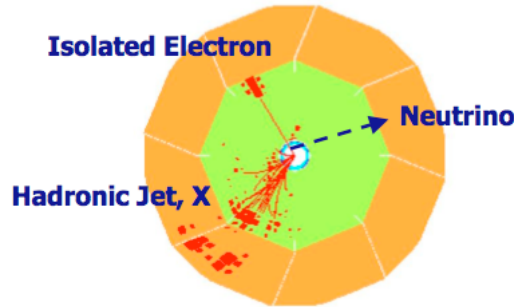
In the DGLAP QCD fit, in addition to the proton PDFs parameters, leave also free the light-quark couplings to Z (a_u, v_u, a_d, v_d):



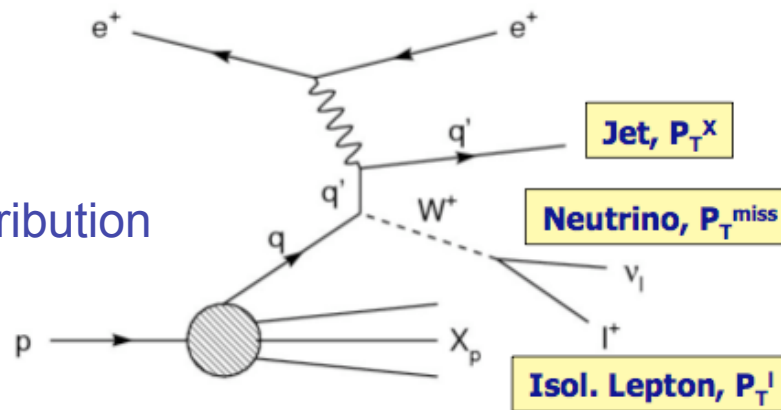
- A simultaneous test of the EW and Strong sectors of the SM
- Competitive with Tevatron and LEP results

W production

Look for events with large transverse momentum isolated Lepton and jet + miss. P_T

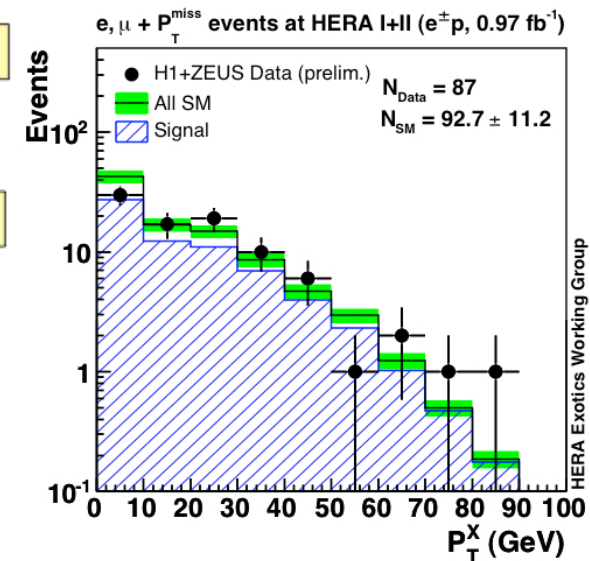
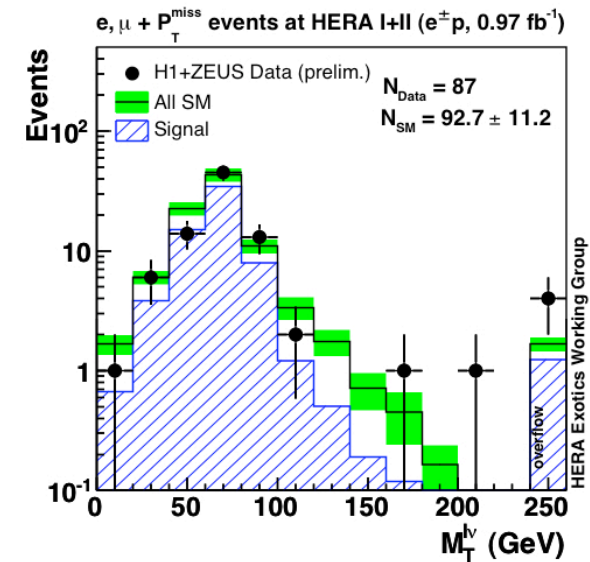


W production: dominant SM contribution



Cross section:

H1	HERA I+II Data	SM
$\sigma_{\sigma_{\ell+P_T}}$	0.24 ± 0.05 (stat) ± 0.05 (sys)	0.26 ± 0.04 (th.sys)
σ_W	1.23 ± 0.25 (stat) ± 0.22 (sys)	1.31 ± 0.20 (th.sys)



W pol. fractions

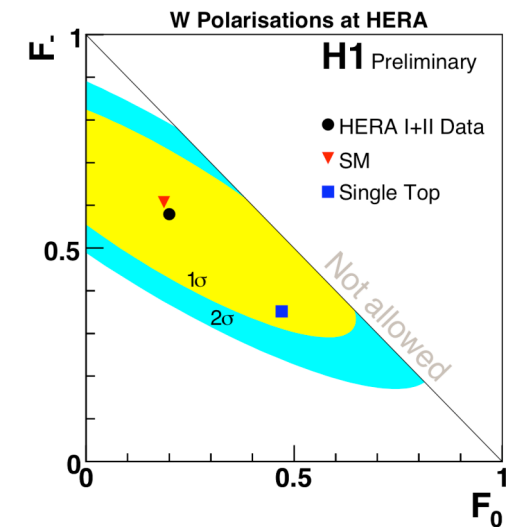
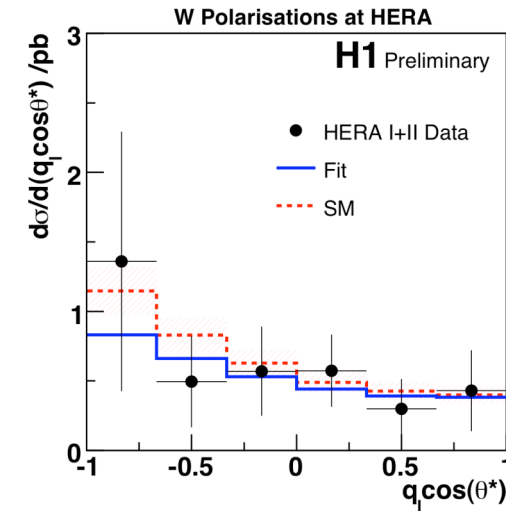
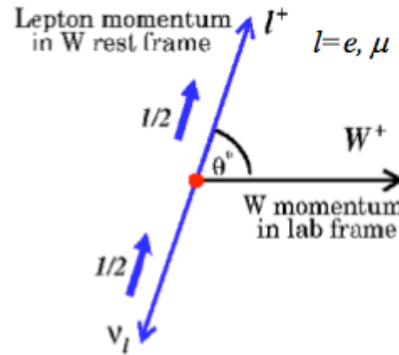
Measured $\cos\theta^*$ distribution:

W polarisation asymmetries

$$\begin{aligned} \frac{dN}{d\cos\theta^*} &\propto (1 - F_- - F_0) \cdot \frac{3}{8} (1 + \cos\theta^*)^2 \\ &+ F_0 \cdot \frac{3}{4} (1 - \cos^2\theta^*) \\ &+ F_- \cdot \frac{3}{8} (1 - \cos\theta^*)^2. \end{aligned}$$

Fit F_- and F_0 simultaneously

H1	HERA I+II Data	SM
F_-	0.58 ± 0.15 (stat) ± 0.12 (sys)	0.61 ± 0.01 (stat)
F_0	0.15 ± 0.21 (stat) ± 0.09 (sys)	0.19 ± 0.01 (stat)



Summary Outlook

Precise measurements of the polarised cross sections becoming available:

- EW unification
- Test of the chiral structure of the SM
- Limits on RH charged currents ($M_{W,R}$)
- First observation of parity violation in NC DIS at high- Q^2
- Competitive determination of the light-quark couplings to the Z boson
- W production and decays

Zeus-H1 combined EW results based on 1fb^{-1} of data will be soon available.