Electroweak Physics at HERA

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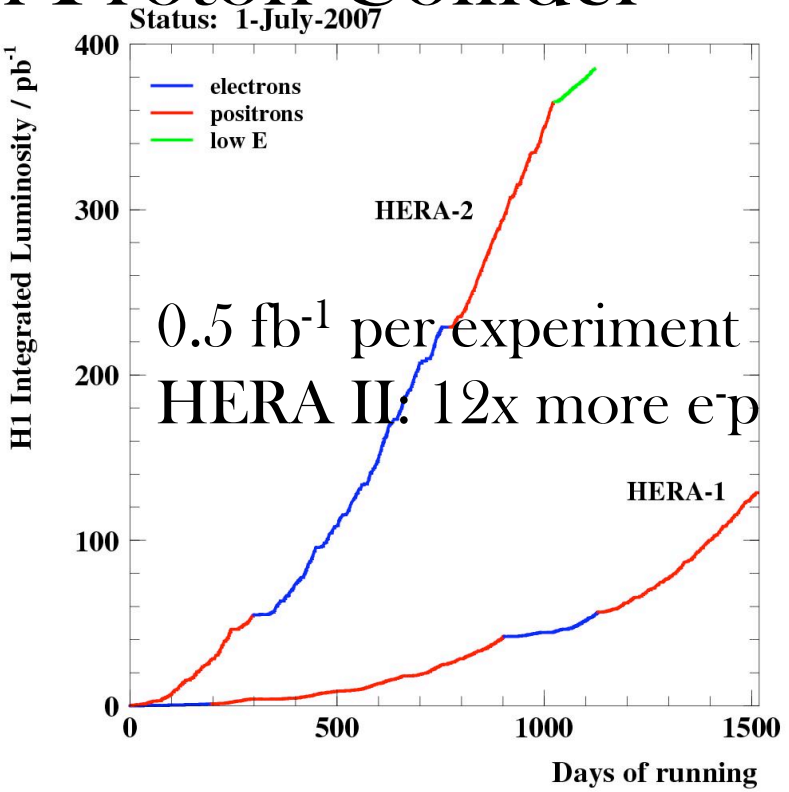
On behalf of the

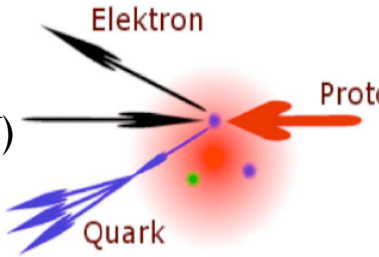
H1 & ZEUS

Collaborations

- Introduction
- Cross Section Measurements
- Quark Size
- Quark - Z Boson Coupling
- Single W Boson Production

The HERA Electron-Proton Collider

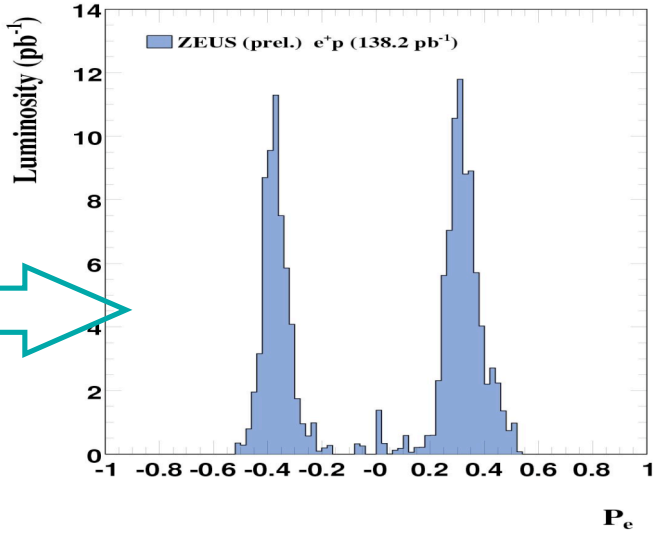




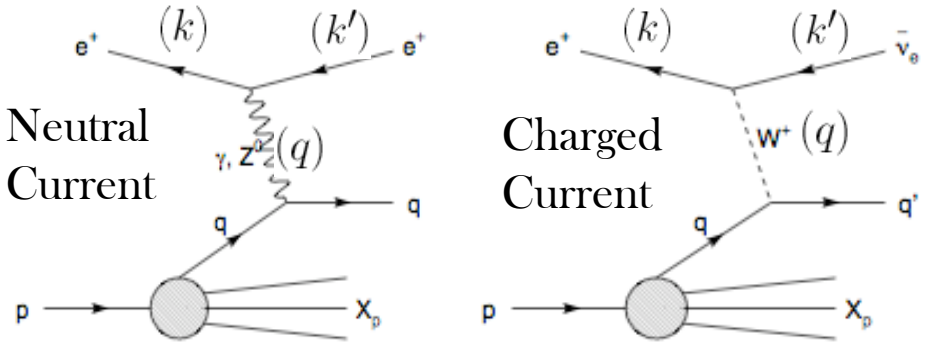
$e^{\pm}$ (27.6 GeV) p (820/920 GeV)

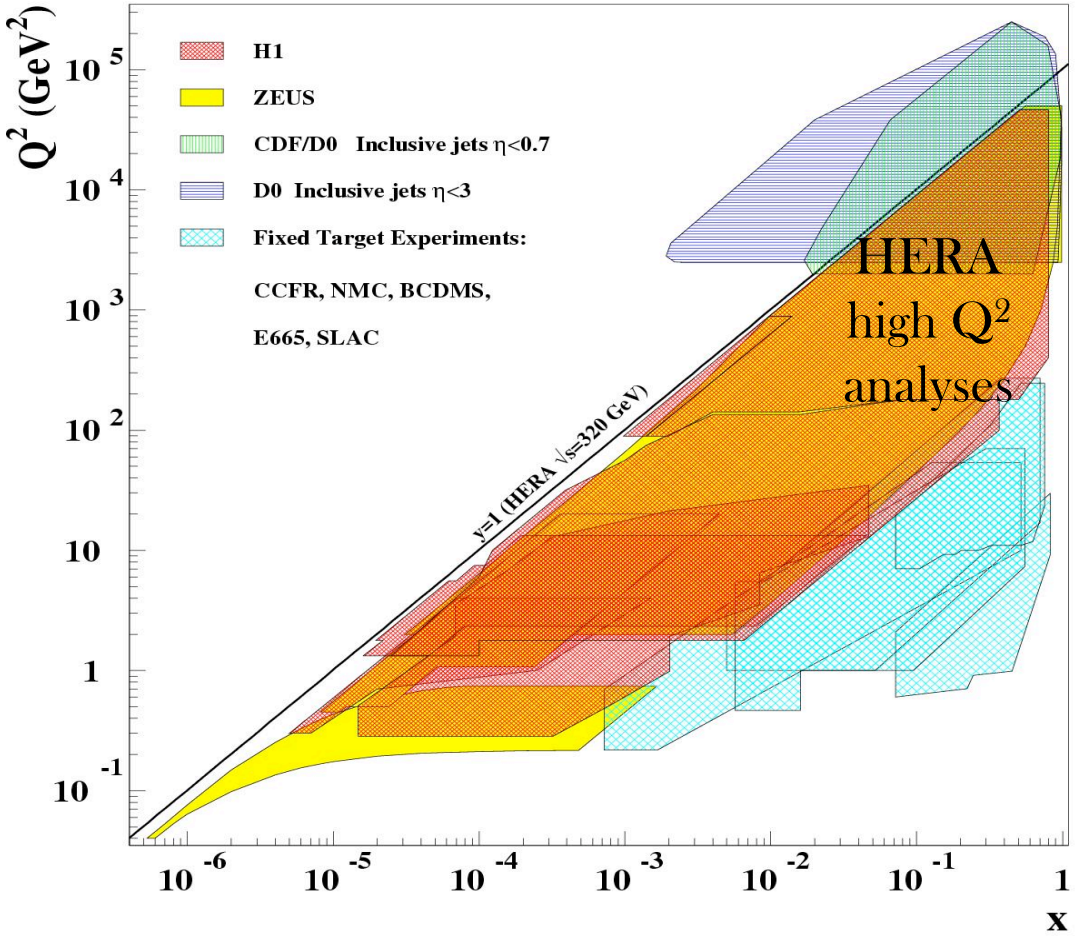
$\sqrt{s} = 320$ GeV

HERA II: Polarised Lepton beam



Deep Inelastic Scattering at HERA





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

$$x = \frac{Q^2}{2\,p \cdot q}$$ ← Bjorken-x

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

$$Q^2 = sxy = 2E_e E_e'(1+\cos\theta_e)$$

- Kinematics fixed by two variables
- Q^2 and x mostly used
- HERA range:

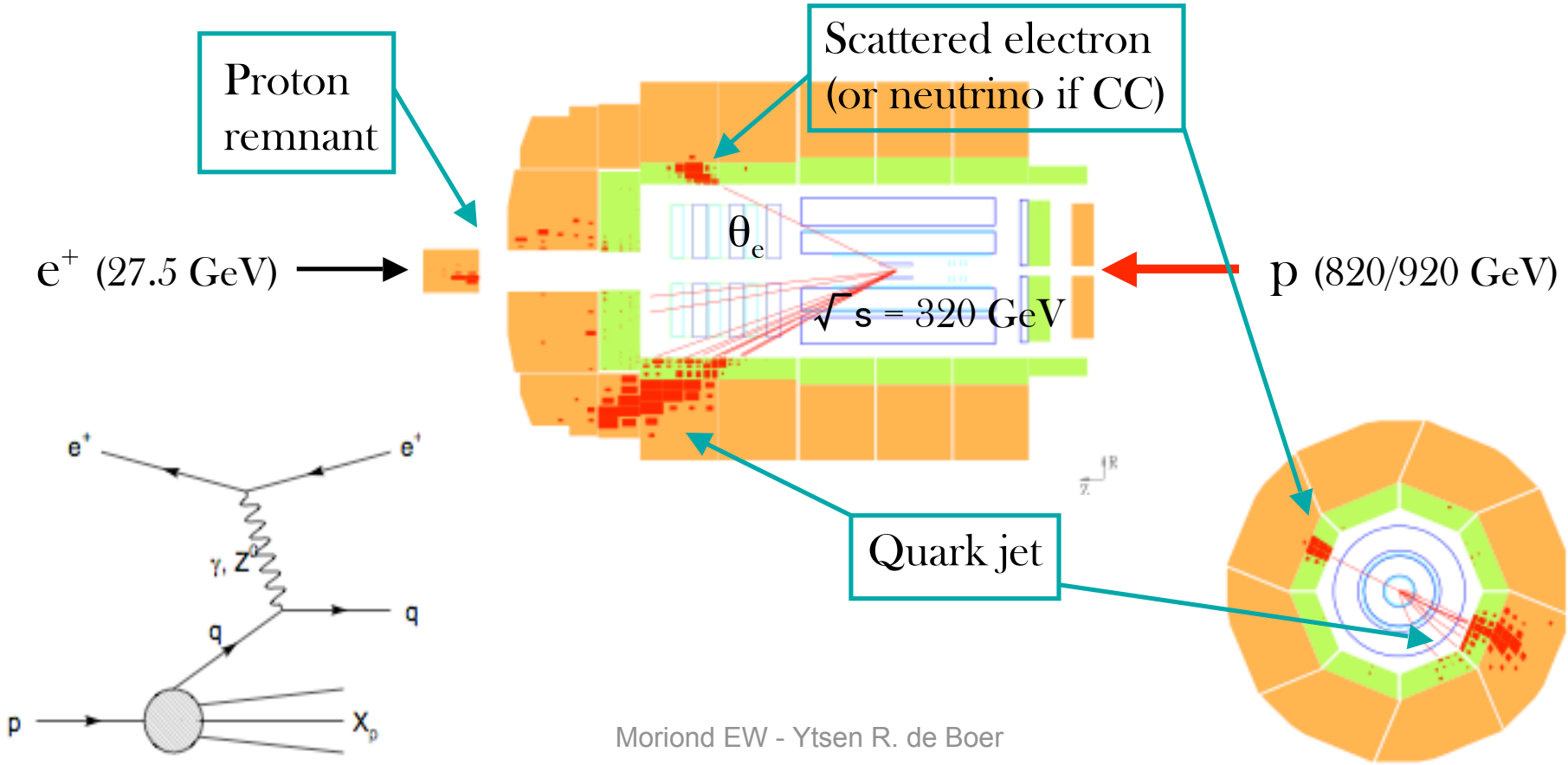
  $Q^2 = 10^{-1} - 10^5$ GeV^2

  $x = 10^{-6} - 10^0$

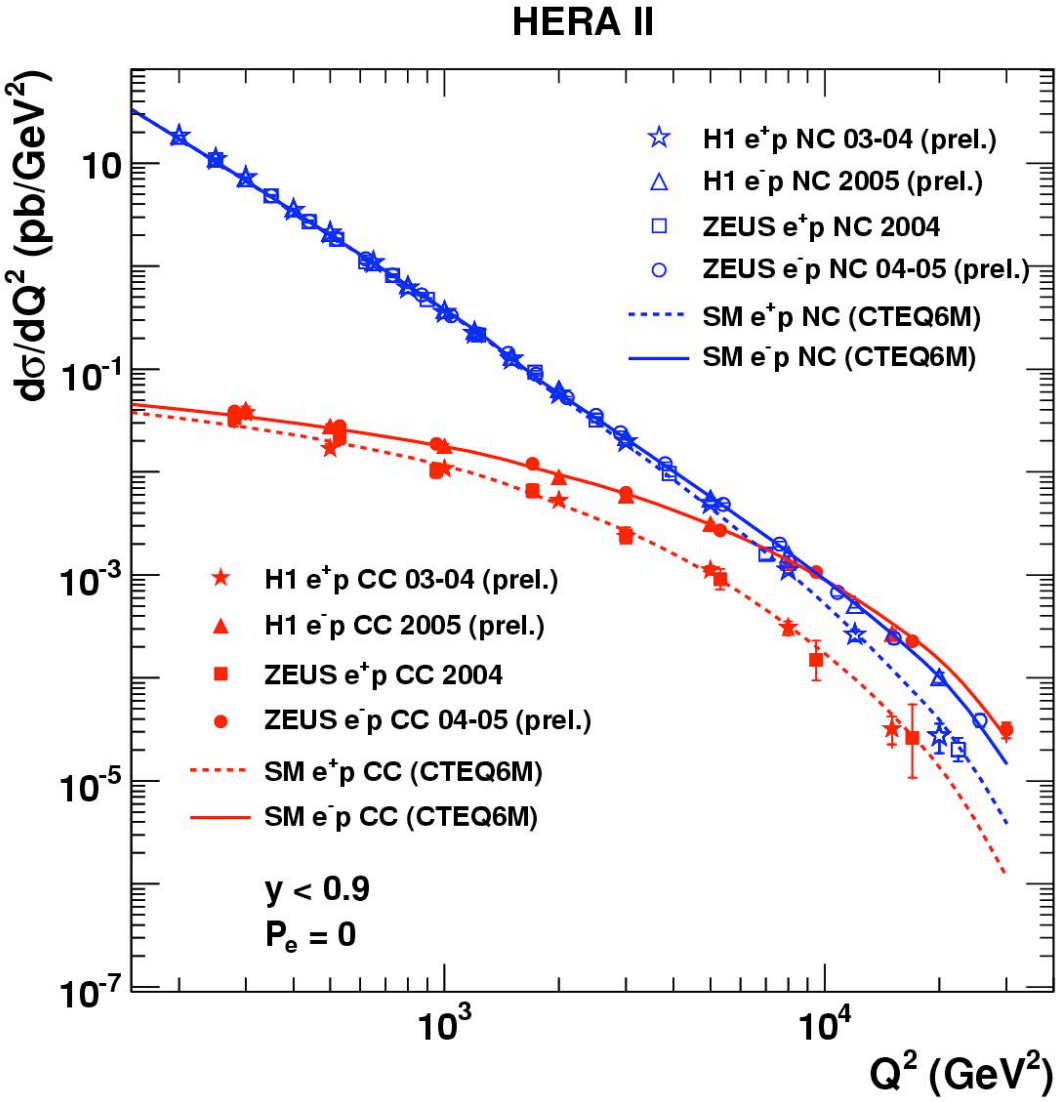
Measuring DIS Events at HERA

- Two hermetic detectors H1 and ZEUS
- Use tracking and calorimetry
- H1 example e^+p event: Q^2=25000 GeV^2 y = 0.6

$$Q^2 = sxy = 2E_e E_e'(1+\cos\theta_e)$$



Neutral and Charged Current Cross Sections



HERA II data H1 and ZEUS

CC suppressed by heavy W propagator

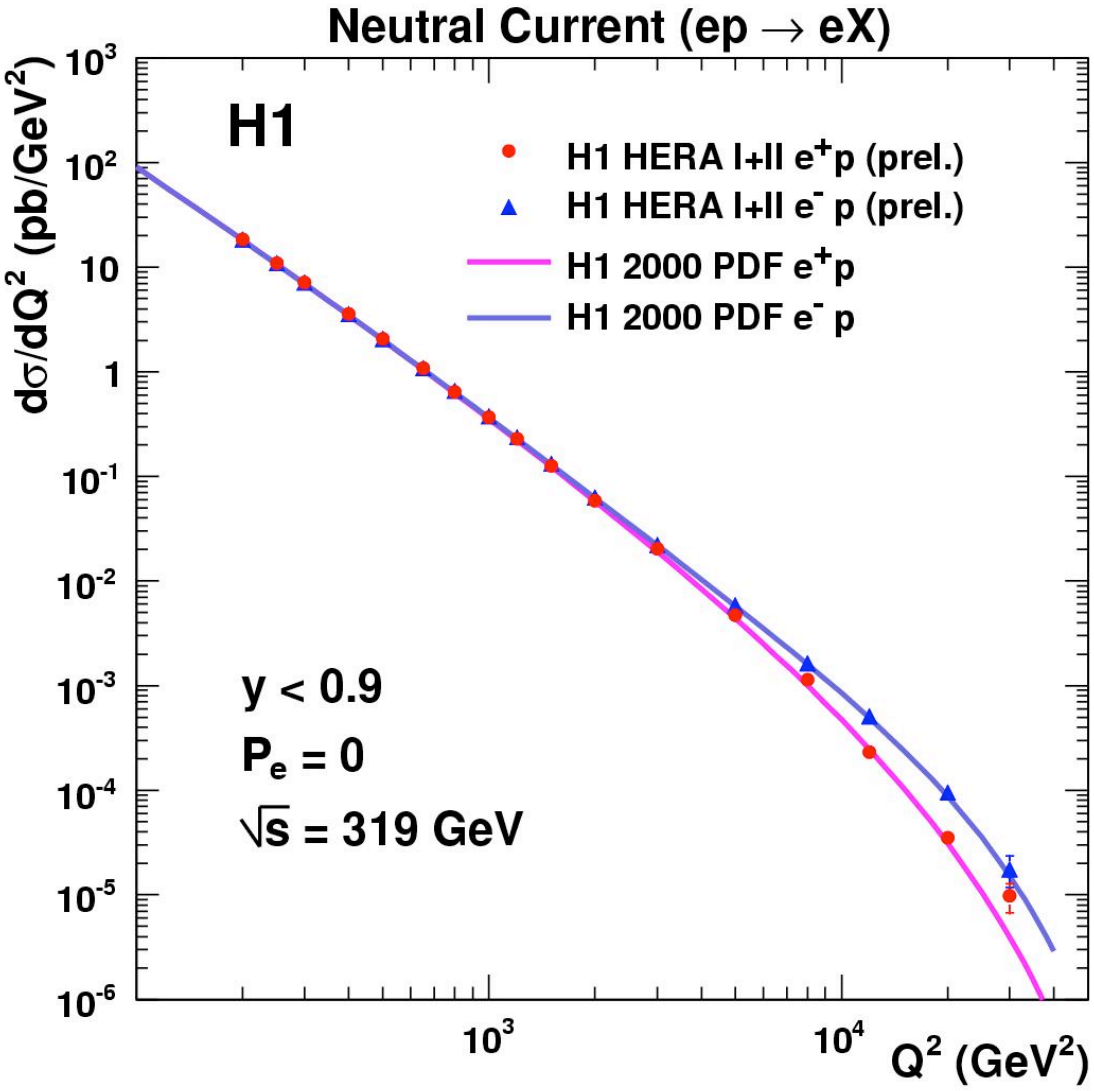
At $Q^2 > M^2_{Z/W}$ NC and CC cross sections become of same order

e^-p cross sections larger than e^+p

High Q^2: resolution $\approx 10^{-18}$ m

QCD describes HERA II data

HERA I+II Neutral Current at High Q^2



$Q^2 > 200$ GeV^2

Full HERA I+II data analysed
270 pb^{-1} e^+p and 165 pb^{-1} e^-p data

Total uncertainty < 10%
for Q^2 up to 20000 GeV^2

Good agreement with QCD predictions

Quark Radius

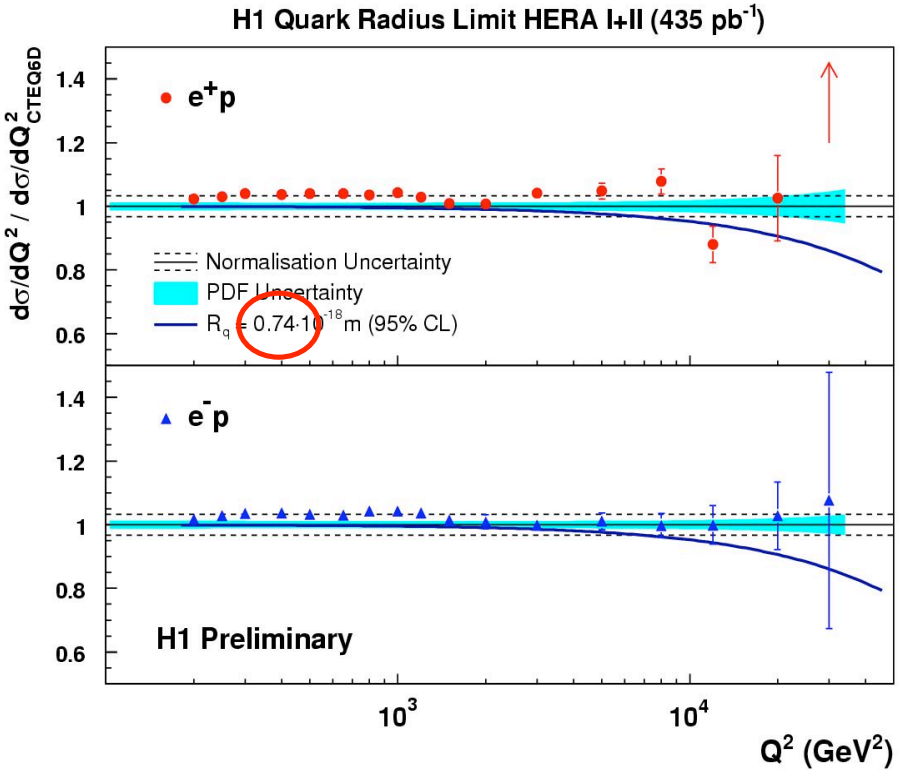
HERA I+II neutral current high Q^2

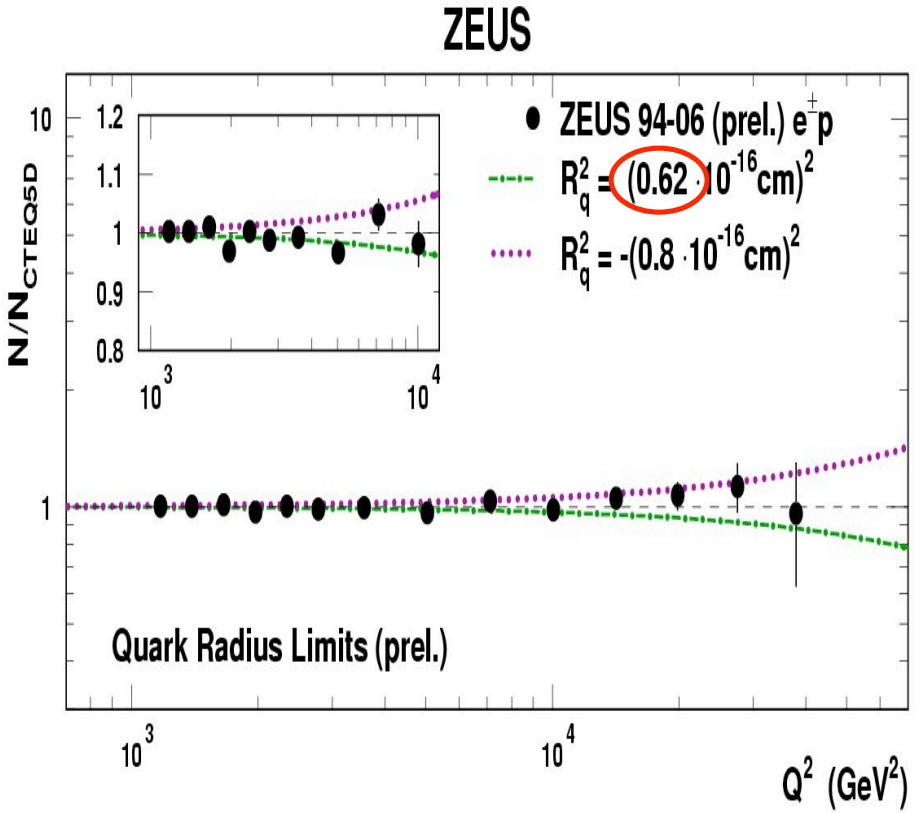
Form factor f_q modifies cross section

Extract 95% CL limits on quark radius assuming point like lepton

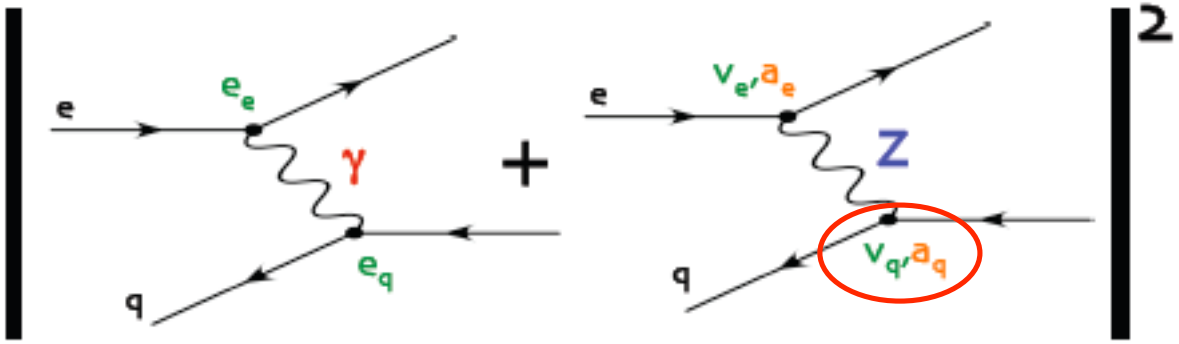
$$f_q\left(Q^2\right) = 1 - \frac{\left\langle r^2 \right\rangle}{6} Q^2$$

$$\frac{d\sigma}{dQ^2} = \frac{d\sigma^{SM}}{dQ^2} f_q\left(Q^2\right)$$





Quark - Z Coupling



SM

	v	a
e	−0.04	−0.5
u	0.2	0.5
d	−0.3	−0.5

$$F_2^{\gamma Z}(\pm P_e) = 2e_q v_q \sum_f x(q+\bar{q})$$

$$xF_3^{\gamma Z}(\pm P_e) = 2e_q a_q \sum_f x(q-\bar{q})$$

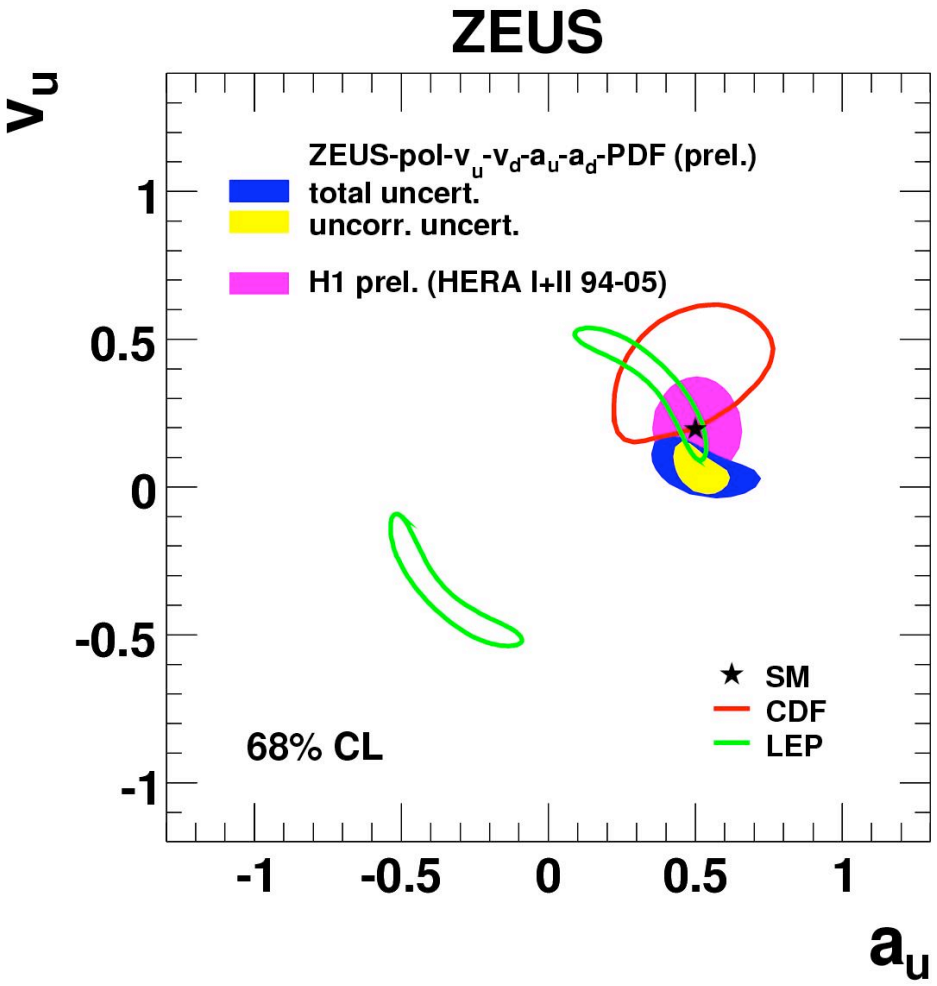
Pure Z contribution small

But γZ interference terms sensitive to the couplings

Quark - Z Coupling

$$F_2^{\gamma Z}(\pm P_e) = 2e_q v_q \sum_f x(q+\bar{q})$$

$$xF_3^{\gamma Z}(\pm P_e) = 2e_q a_q \sum_f x(q-\bar{q})$$



Combined EW/QCD fit makes use of all datasets

$$\sigma(e^+p) - \sigma(e^-p) \rightarrow xF_3^{\gamma Z}$$

$$\sigma(P_R) - \sigma(P_L) \rightarrow F_2^{\gamma Z}$$

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

HERA resolves LEP ambiguity

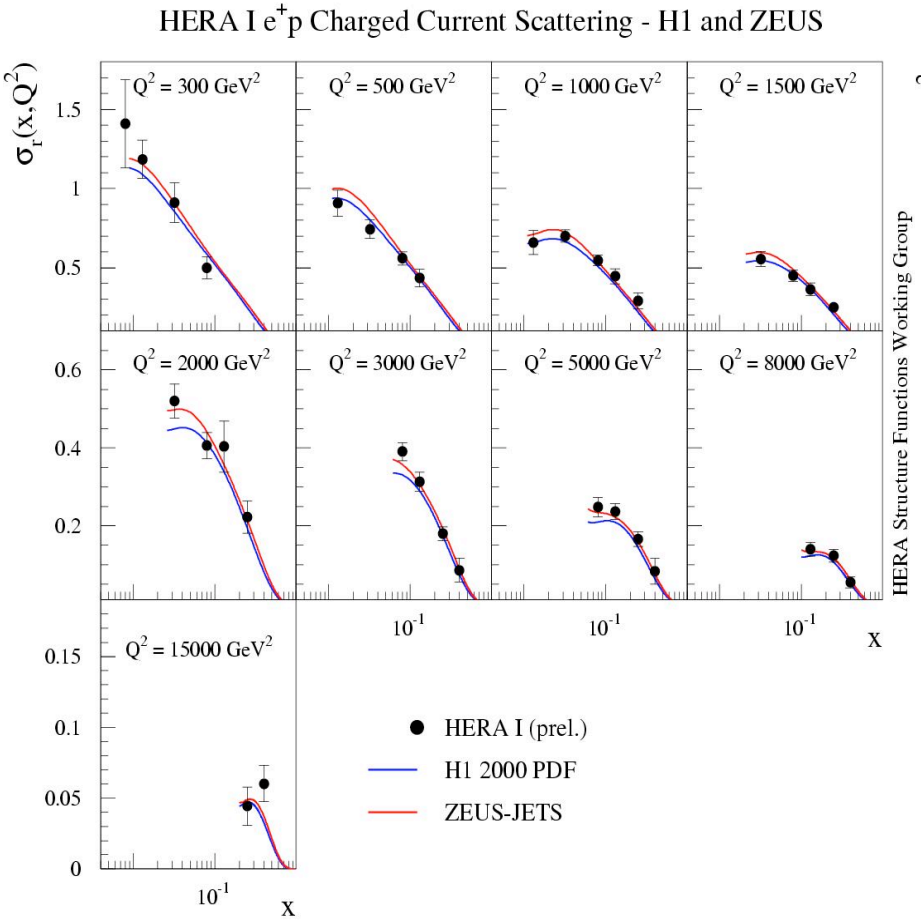
LEP: qqbar → Z → l^+l^-
Tevatron: e^+e^- → Z → l^+l^-

HERA/Tevatron similar limits

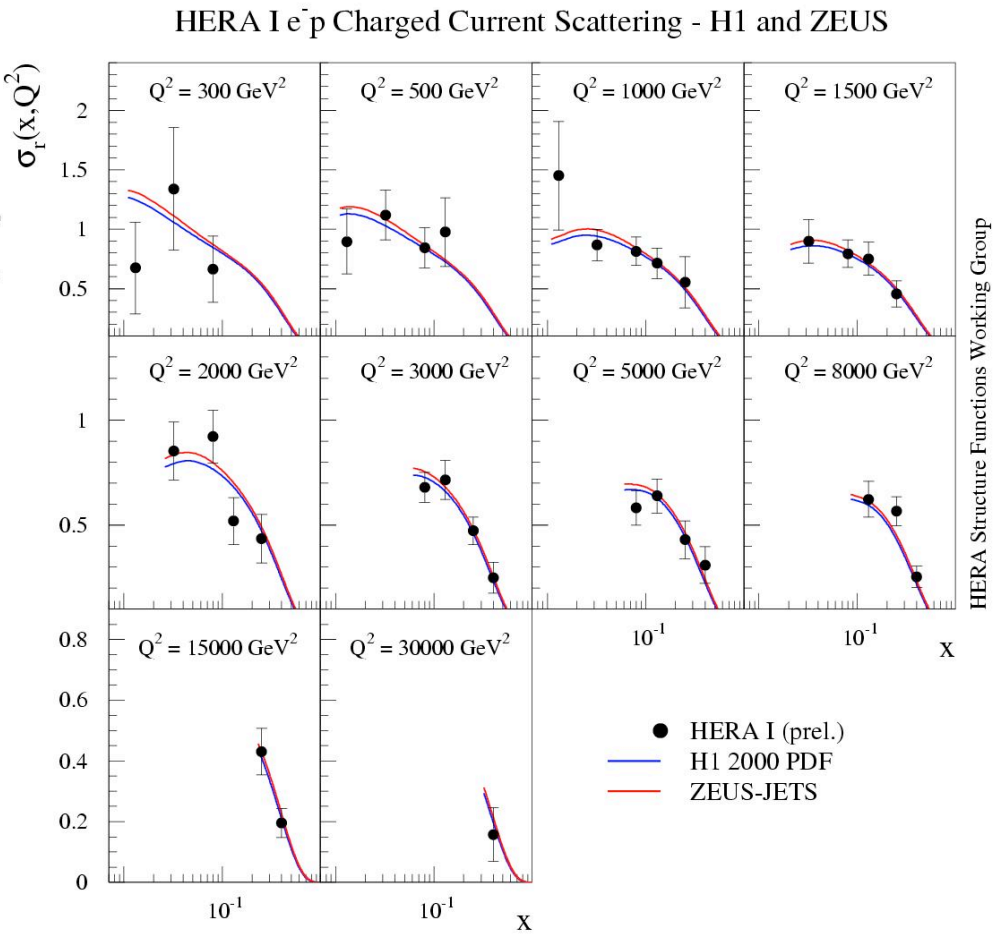
HERA I Combined H1+ZEUS Charged Current

H1+ZEUS published results coherenty combined to maximise precision

$e^+p: \pm 200\,\mathrm{pb}^{-1}$



$e^-p: \pm 30\,\mathrm{pb}^{-1}$



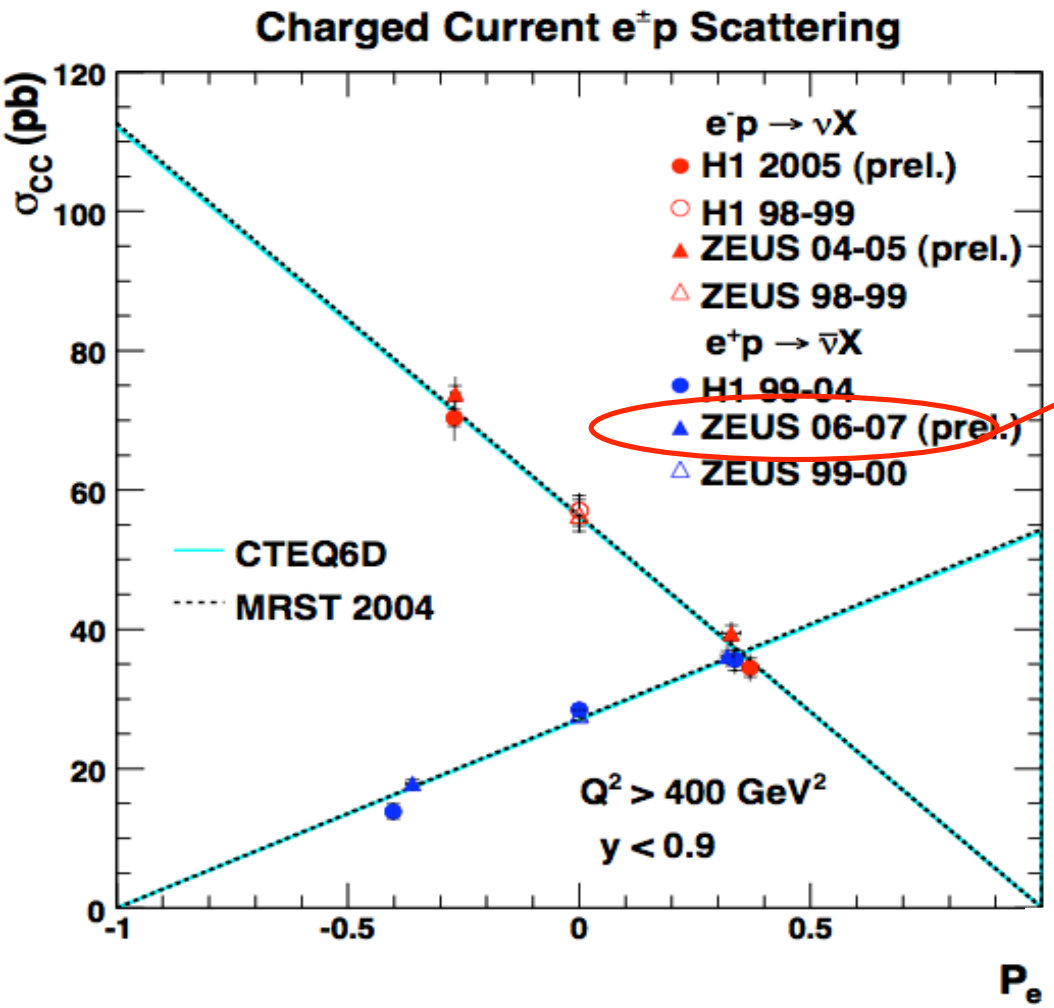
CC Cross Section with Polarised Lepton Beam

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

SM chiral structure predicts:

$$\sigma^{\pm}_{CC}(P_e) = (1 \pm P_e)\,\sigma^{\pm}_{CC}(0)$$

HERA I

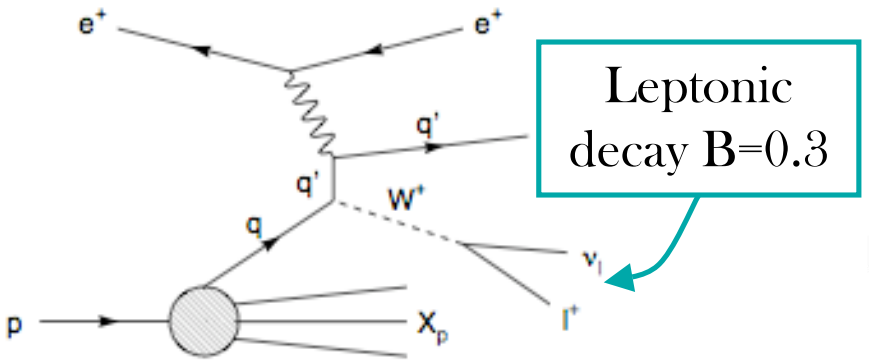


New:
ZEUS' 2006-2007
preliminary

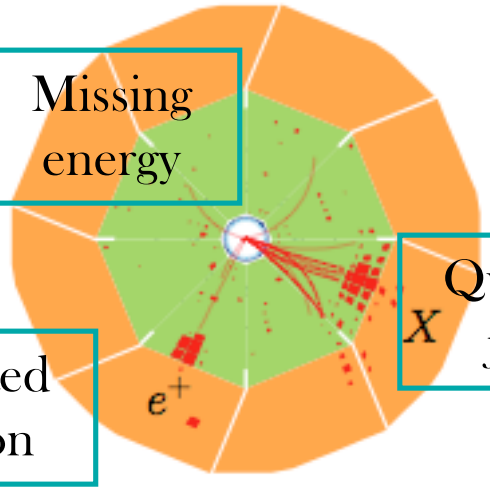
Agreement with SM and within experiments and data sets

Exclude parity conservation

Single W Boson Production



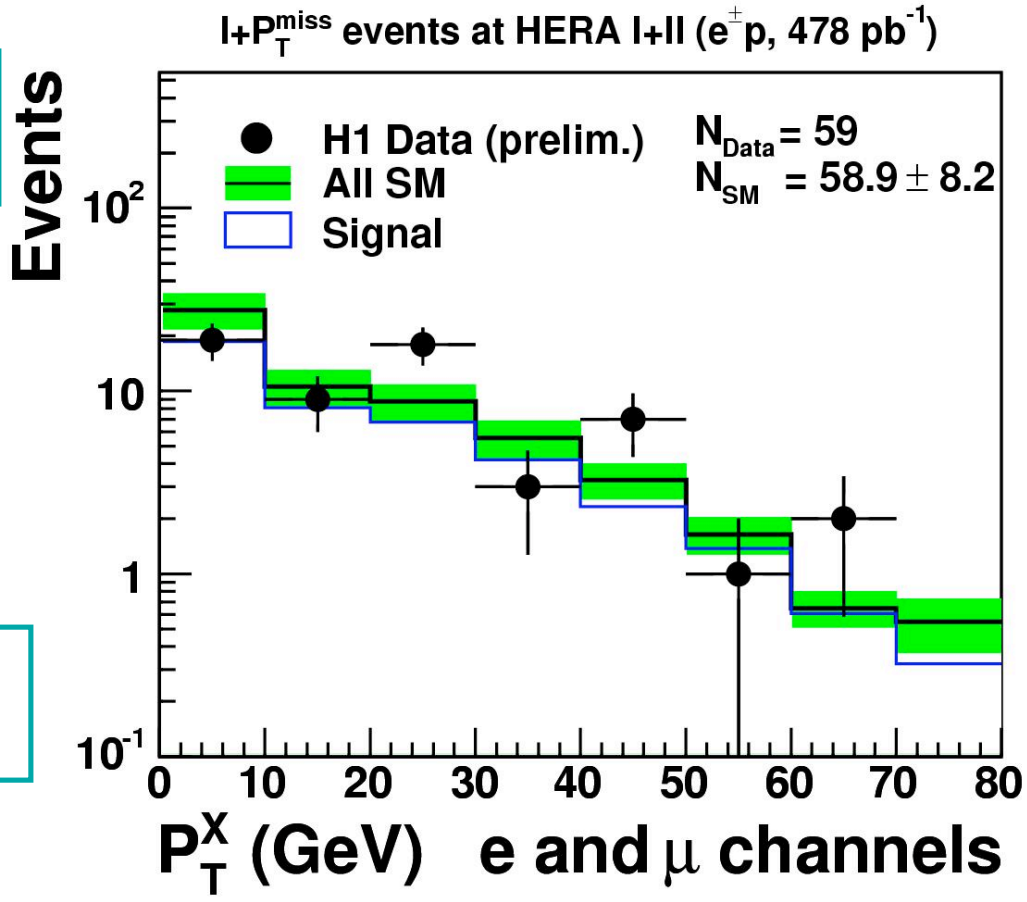
Leptonic decay B=0.3



Missing energy

Isolated lepton

Quark jet



$$\sigma_W^{\text{data}} = 1.2 \pm 0.3\,(\text{stat}) \pm 0.2\,(\text{sys})\ \text{pb} \quad (\text{SM}: 1.3 \pm 0.2)$$

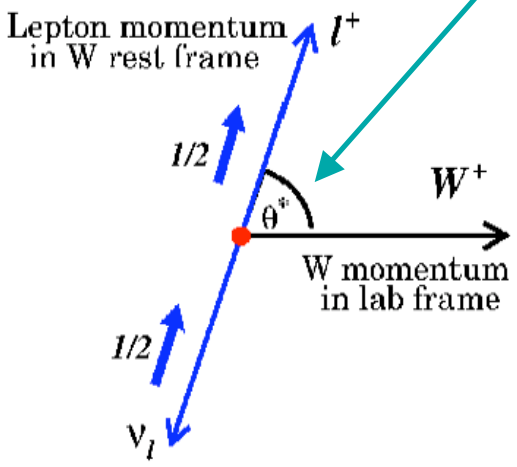
(NLO)

Good overall agreement with SM

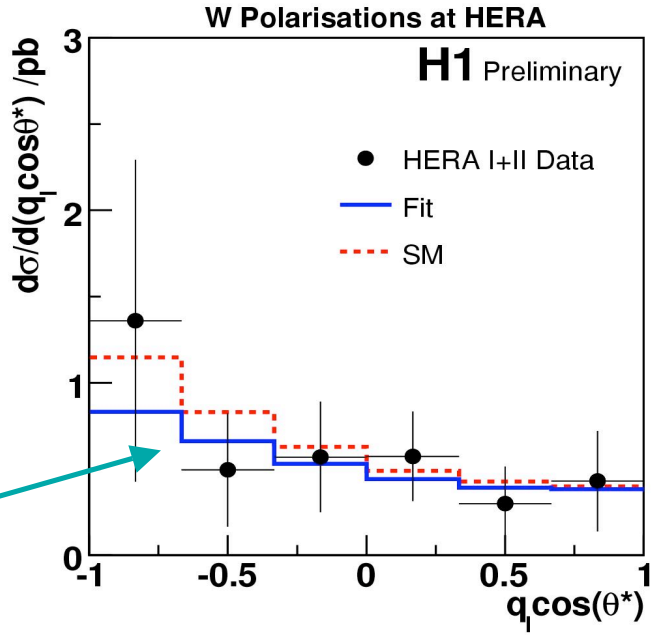
W Boson Polarisation

$$\frac{d\sigma_W}{d\cos\theta^*} \propto (1 - F_- - F_0) \cdot \frac{3}{8}(1+\cos\theta^*)^2 + F_0 \cdot \frac{3}{4}(1-\cos^2\theta^*) + F_- \cdot \frac{3}{8}(1-\cos\theta^*)^2$$

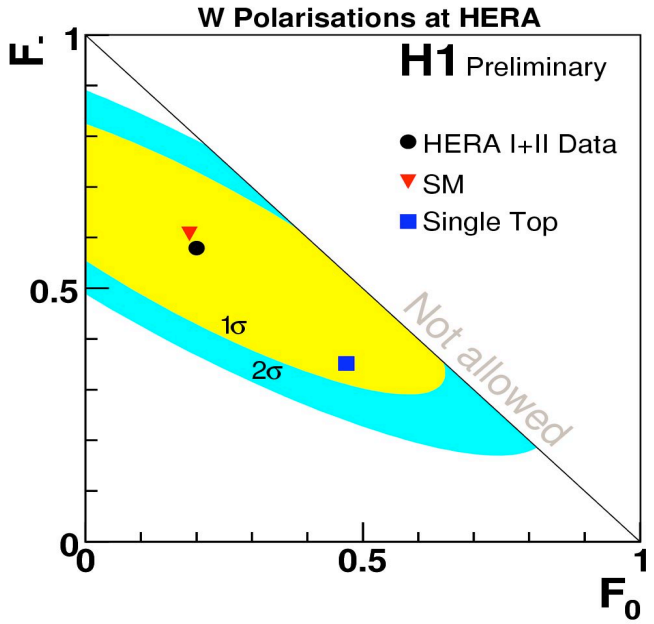
Cross section as a function of decay angle θ*



Fit differential cross section



Extract polarisation fractions F_- and F_0



Single parameter fits:

H1	HERA I+II Data	SM
F_-	$0.58 \pm 0.15\,(\text{stat}) \pm 0.12\,(\text{sys})$	$0.61 \pm 0.01\,(\text{stat})$
F_0	$0.15 \pm 0.21\,(\text{stat}) \pm 0.09\,(\text{sys})$	$0.19 \pm 0.01\,(\text{stat})$

Good agreement with SM

Summary

HERA operation stopped in June 2007, collider experiments collected together 1 fb^{-1} of data (e^+p and e^-p)

High Q^2 NC analyses allow to extract limits on quark radius < 0.001x proton radius

Competitive quark-Z couplings measured

Updated ZEUS CC cross section results HERA II

H1 measures single W production cross section at 4σ level and W polarisation for the first time

H1+ZEUS combined 1 fb^{-1} results well underway

Backup Slides

DIS Unpolarised Cross Sections in *ep* Scattering

Beam charge

Boson mass

Electron or positron

Only at high y

$$\frac{d\sigma^{\pm}}{dxdQ^2} \propto \left[\frac{1}{Q^2+M^2}\right]^2 \left[Y_+ F_2\left(Q^2,x\right) \mp Y_- x F_3\left(Q^2,x\right) - y^2 F_L\left(Q^2,x\right)\right]$$

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

F_2: All quarks (dominant)

xF$_3$: Valence quarks

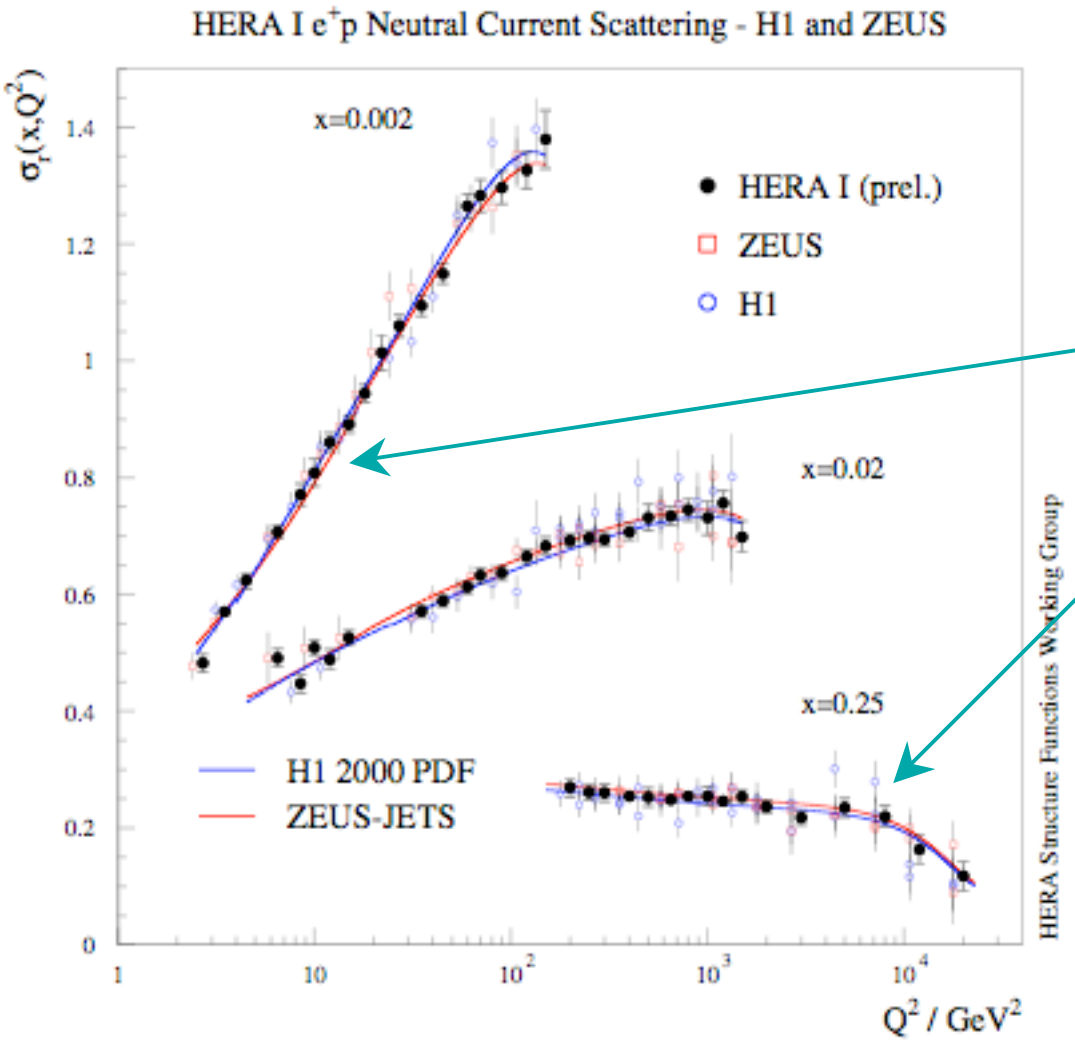
$$F_2\left(Q^2,x\right) = x\sum\nolimits_f A_f\left(Q^2\right)\left[q\left(Q^2,x\right) + \bar{q}\left(Q^2,x\right)\right]$$

$$xF_3\left(Q^2,x\right) = x\sum\nolimits_f B\left(Q^2\right) A_f\left(Q^2\right)\left[q\left(Q^2,x\right) - \bar{q}\left(Q^2,x\right)\right]$$

<u>Qualitatively for cross section</u>:

- NC >> CC
- $Q^2 > M^2_W/M^2_Z \rightarrow$ NC ≈ CC
- $e^+p \neq e^-p$

HERA I: NC Cross Sections H1+ZEUS



H1+ZEUS published results coherenty combined to maximise precision

Low Q^2 systematic uncertainties reduced

High Q^2 statistical fluctuations reduced

Combined data agree well with fits

Next:
Include HERA II data
Extract HERA's best pdfs

Method for combining: S.Glazov XIII International Workshop on Deep Inelastic Scattering