

Electroweak Physics at HERA

Ytsen de Boer (DESY)



On behalf of the

H1 & ZEUS

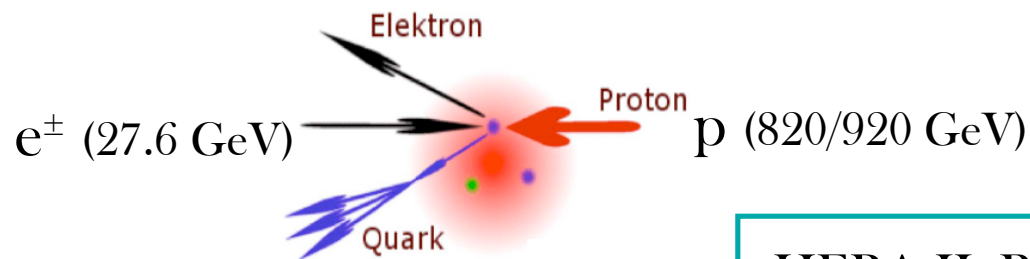
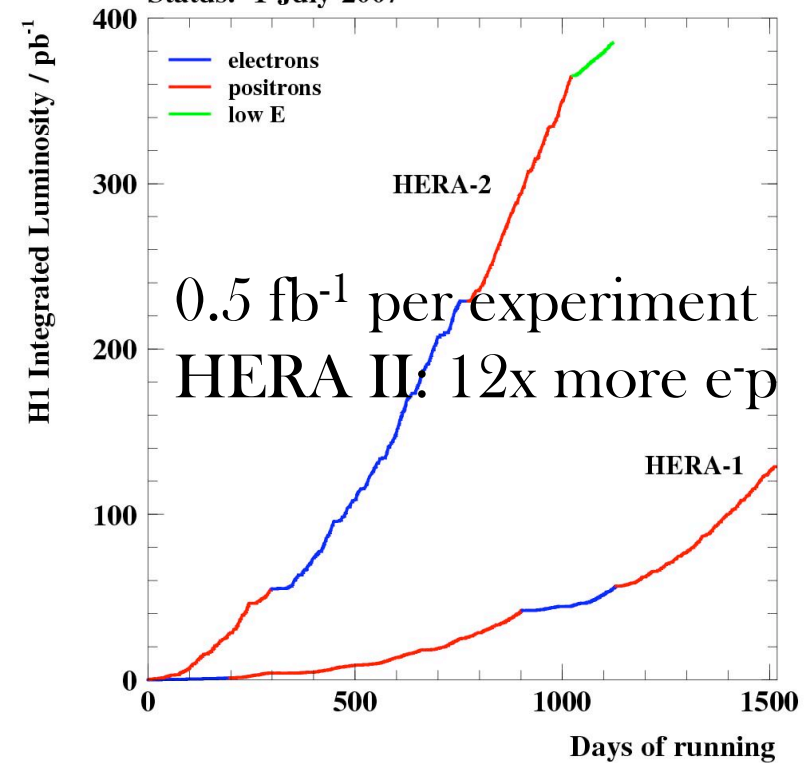
Collaborations



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

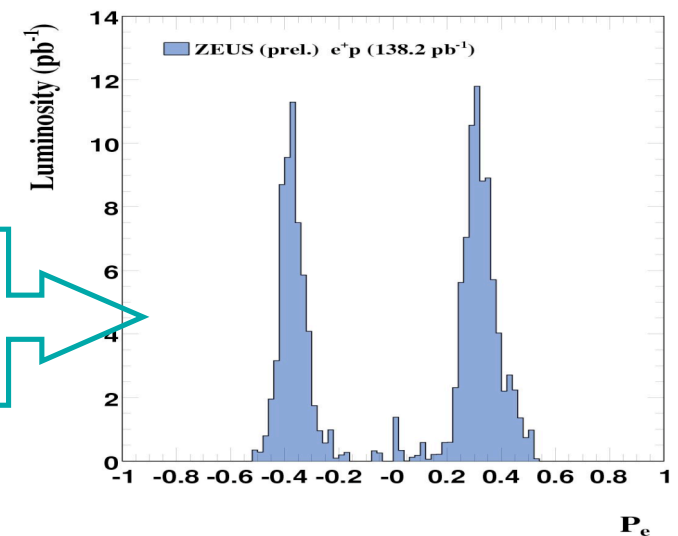
The HERA Electron-Proton Collider

Status: 1-July-2007



$$\sqrt{s} = 320 \text{ GeV}$$

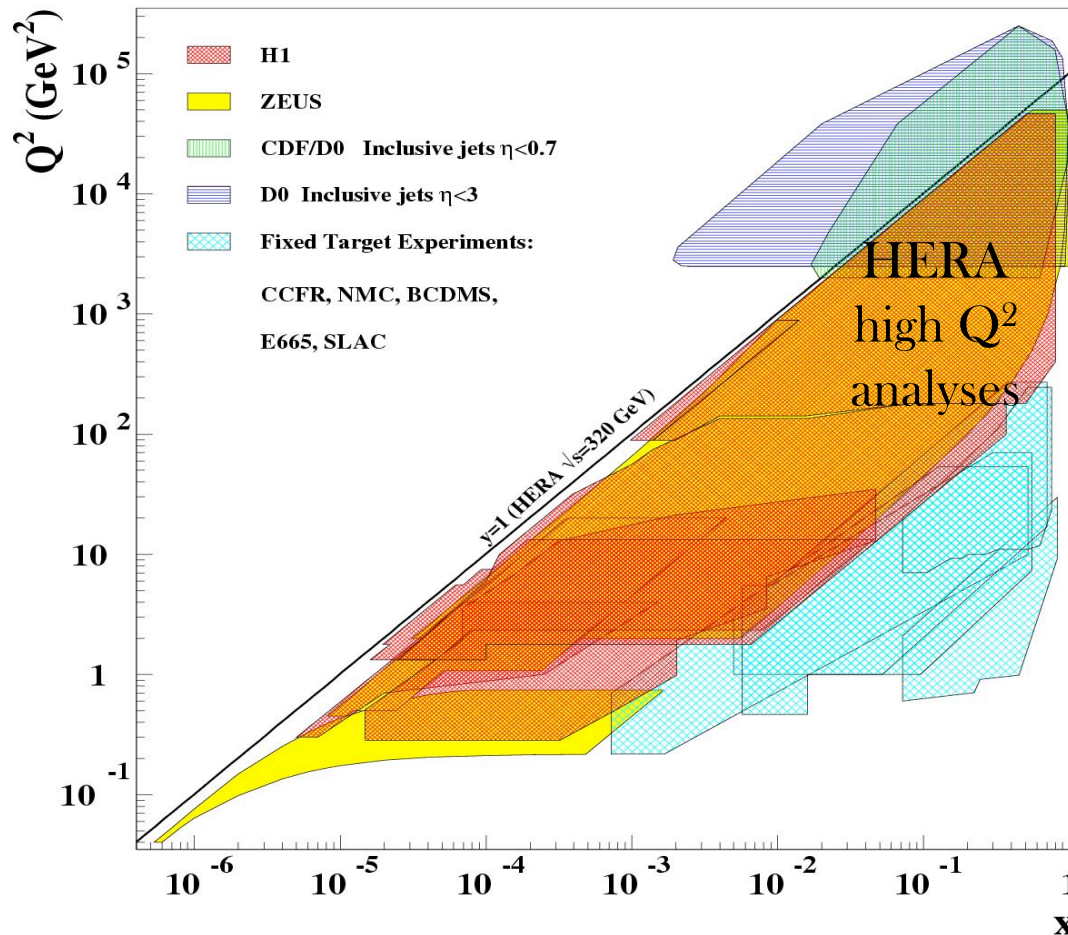
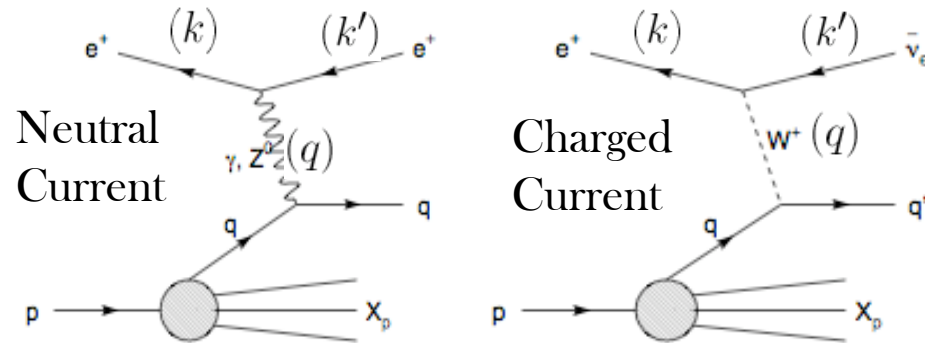
HERA II: Polarised
Lepton beam



1-8 March 2008

Moriond EW - Ytsen R. de Boer

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:

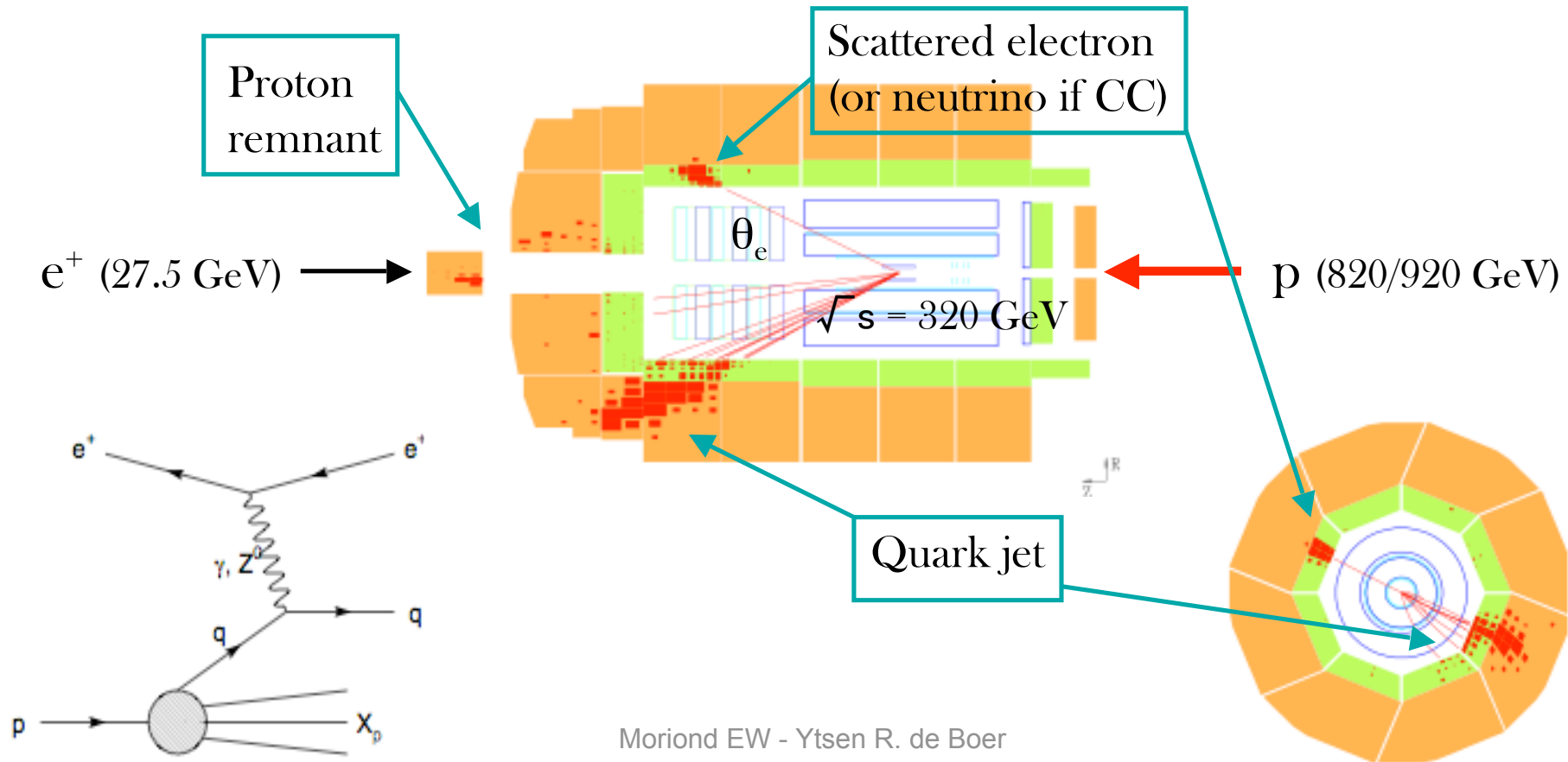
$$Q^2 = 10^{-1} - 10^5 \text{ GeV}^2$$

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

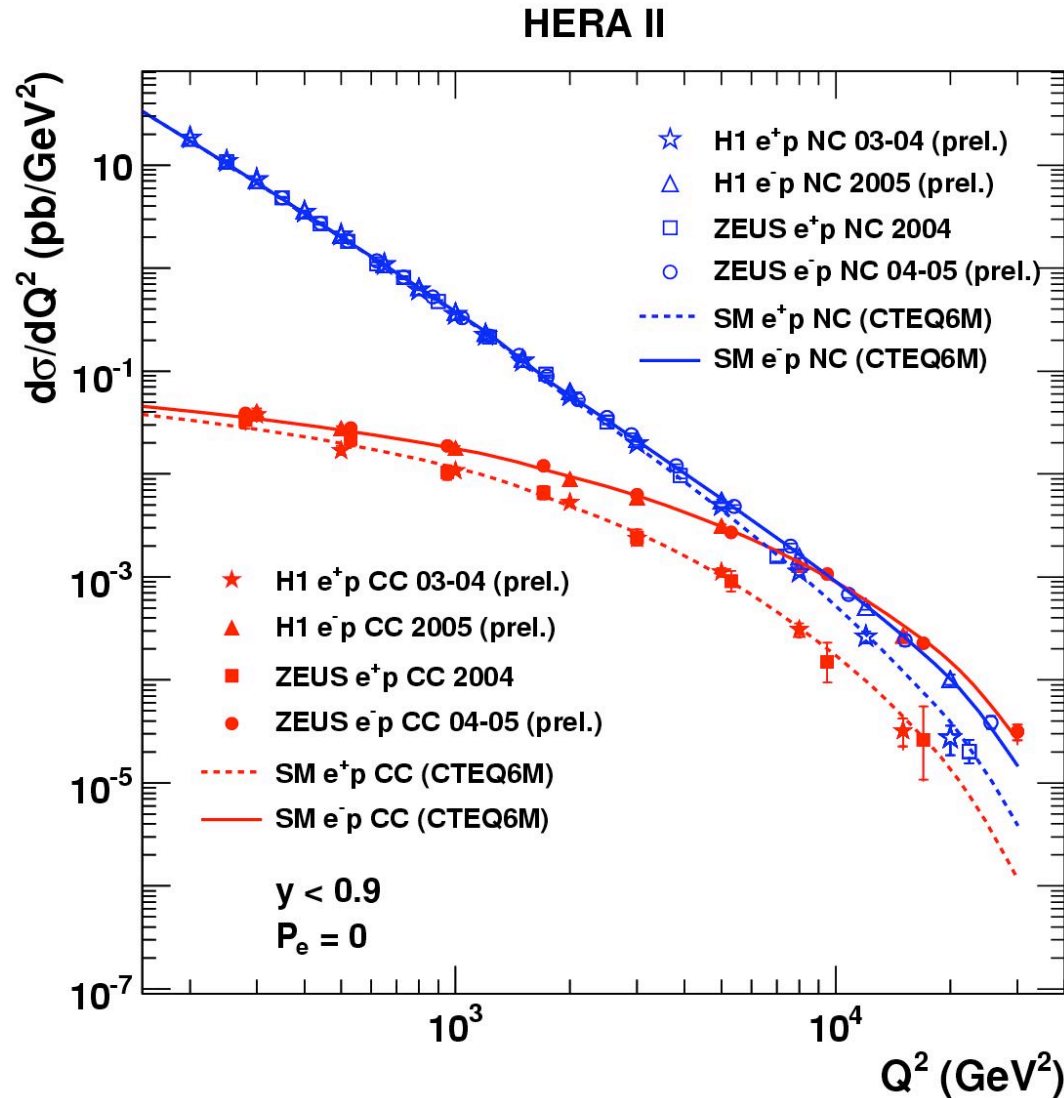
Measuring DIS Events at HERA

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

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



Neutral and Charged Current Cross Sections



HERA II data H1 and ZEUS

CC suppressed by heavy W propagator

At $Q^2 > M_{Z/W}^2$ 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

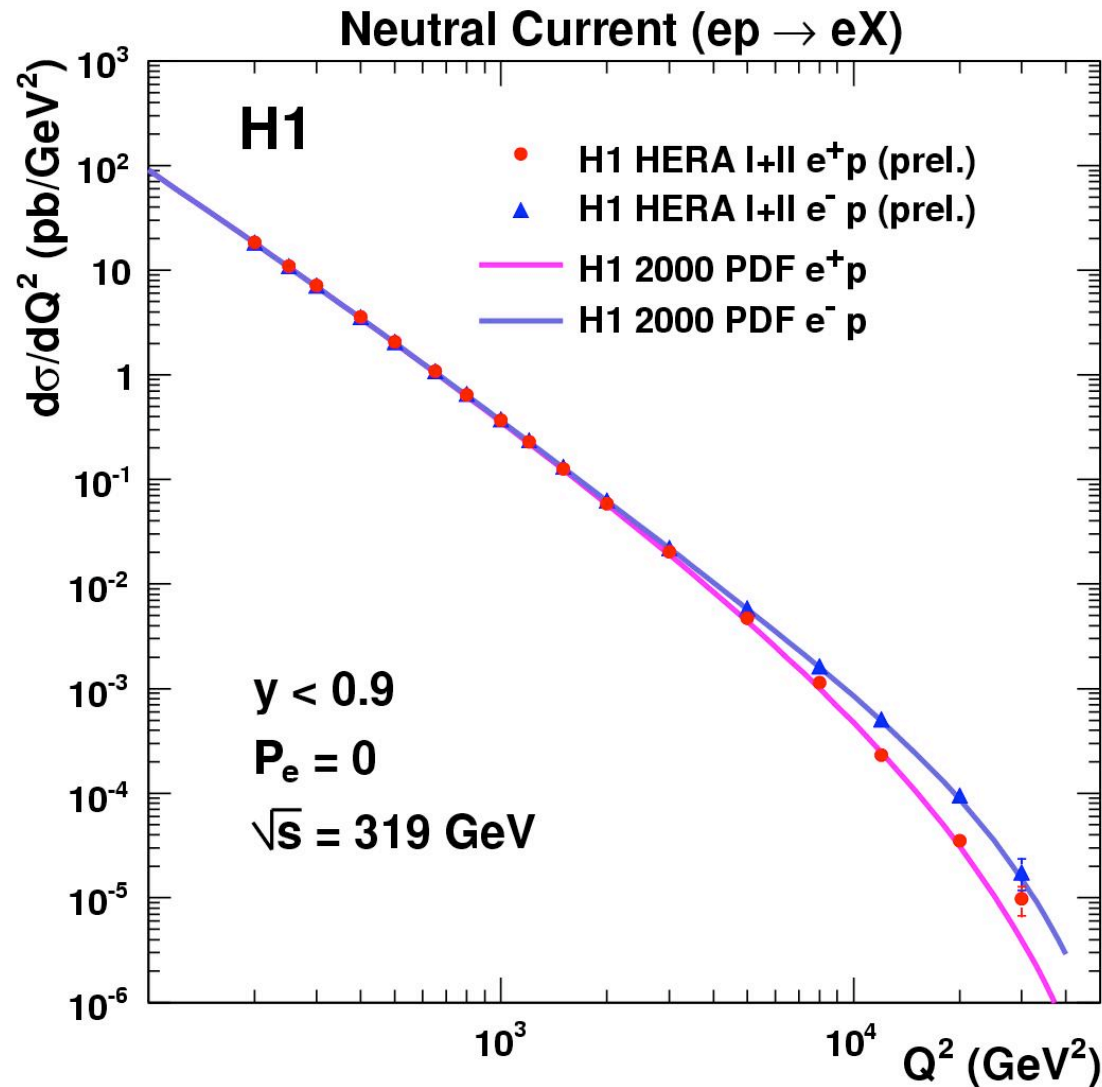


$$Q^2 > 200 \text{ GeV}^2$$

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 GeV²

Good agreement with QCD
predictions



Quark Radius

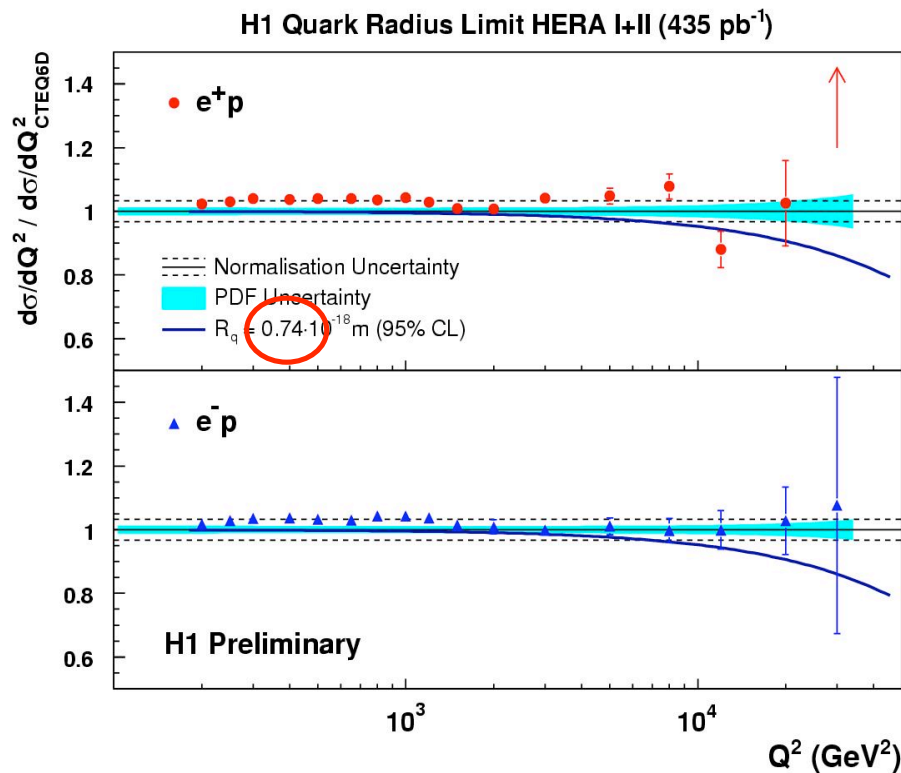
HERA I+II neutral current high Q^2

Form factor f_q modifies cross section

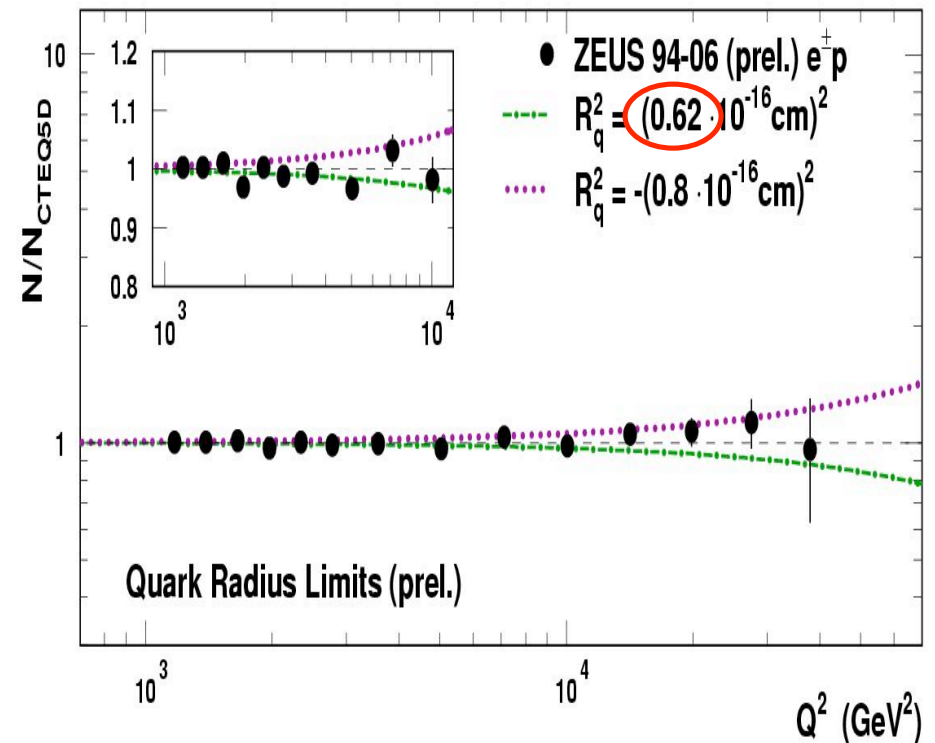
Extract 95% CL limits on quark radius assuming point like lepton

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

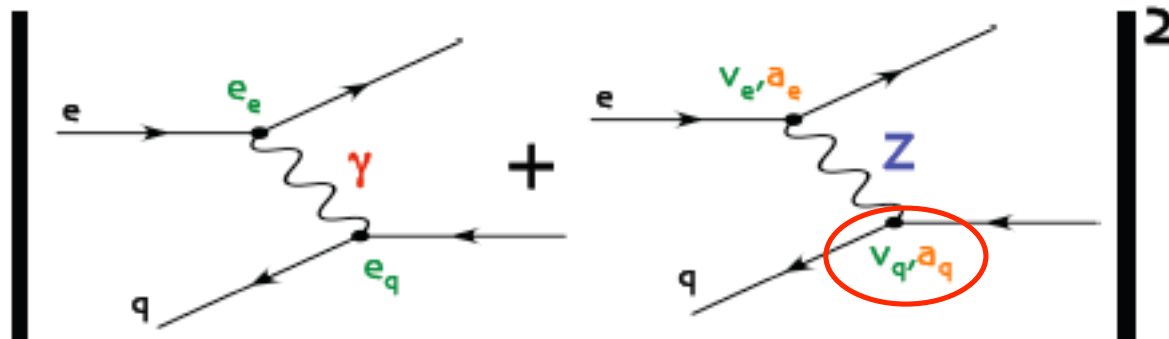
$$\frac{d\sigma}{dQ^2} = \frac{d\sigma^{SM}}{dQ^2} f_q(Q^2)$$



ZEUS



Quark - Z Coupling



| | v | a | SM |
|---|-------|------|----|
| 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

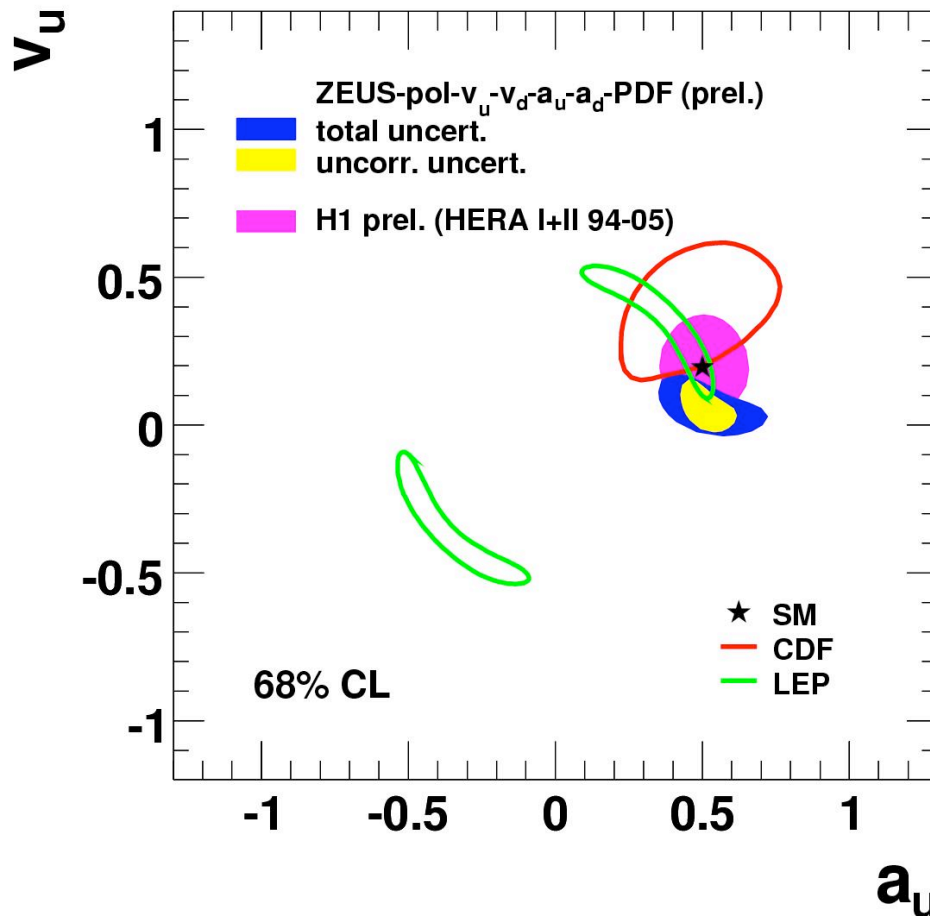
But γZ interference terms
sensitive to the couplings

Quark - Z Coupling

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

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

ZEUS



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: $q\bar{q} \rightarrow Z \rightarrow l^+l^-$

Tevatron: $e^+e^- \rightarrow Z \rightarrow l^+l^-$

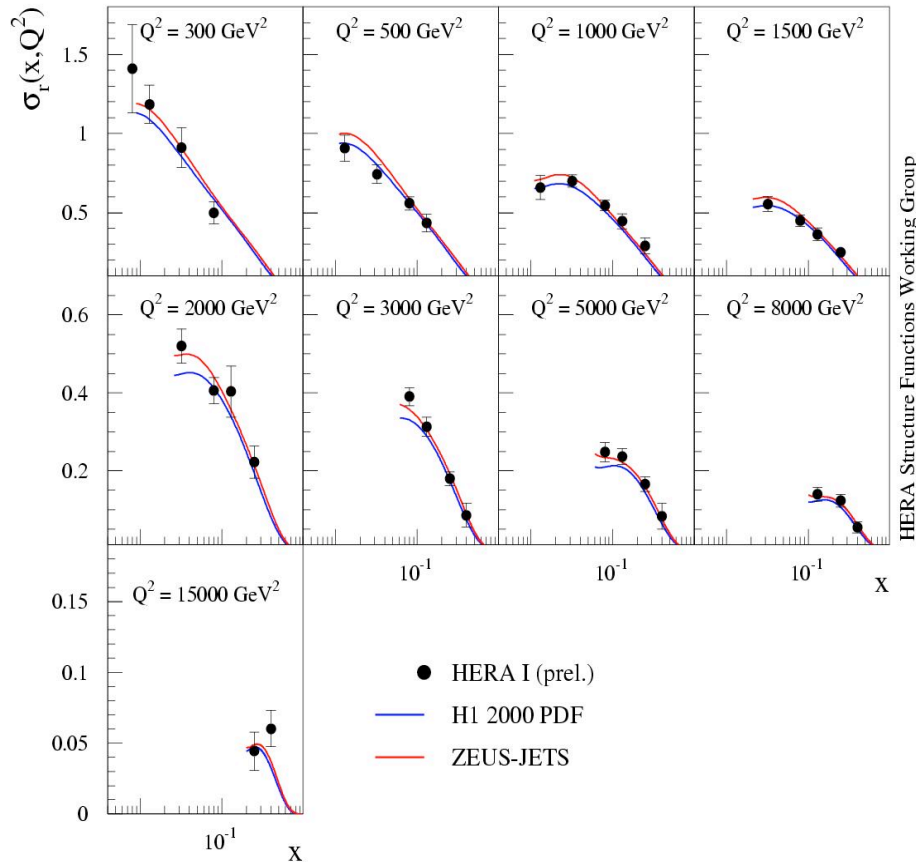
HERA/Tevatron similar limits

HERA I Combined H1+ZEUS Charged Current

H1+ZEUS published results coherently combined to maximise precision

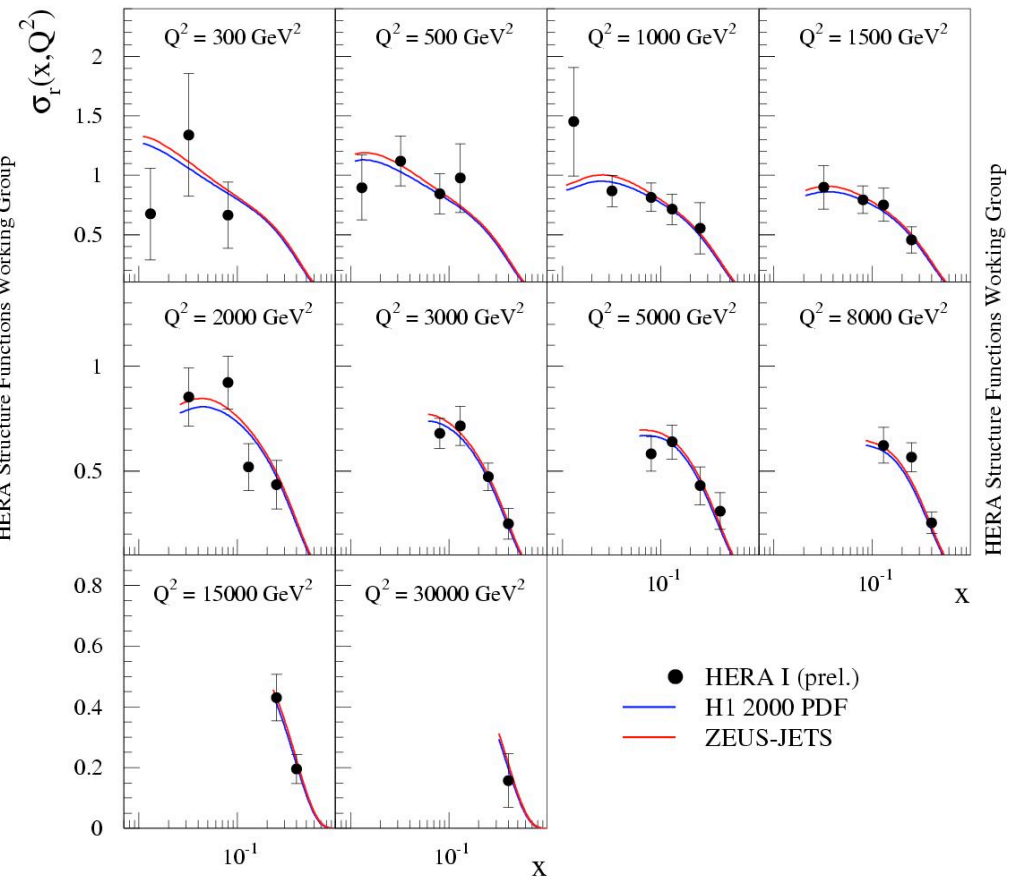
$$e^+p : \pm 200 \text{ pb}^{-1}$$

HERA I e^+p Charged Current Scattering - H1 and ZEUS



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

HERA I e^-p Charged Current Scattering - H1 and ZEUS



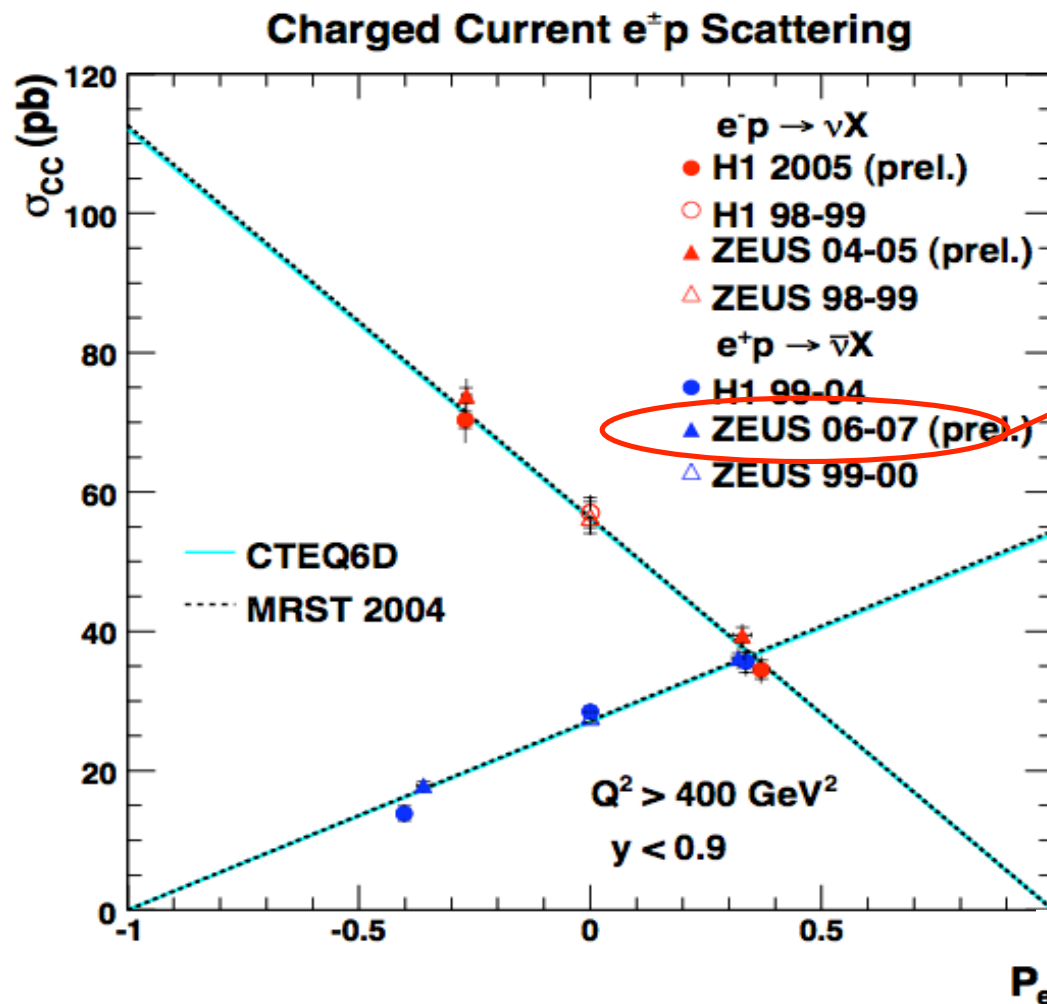
CC Cross Section with Polarised Lepton Beam

SM chiral structure predicts:

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

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

HERA I

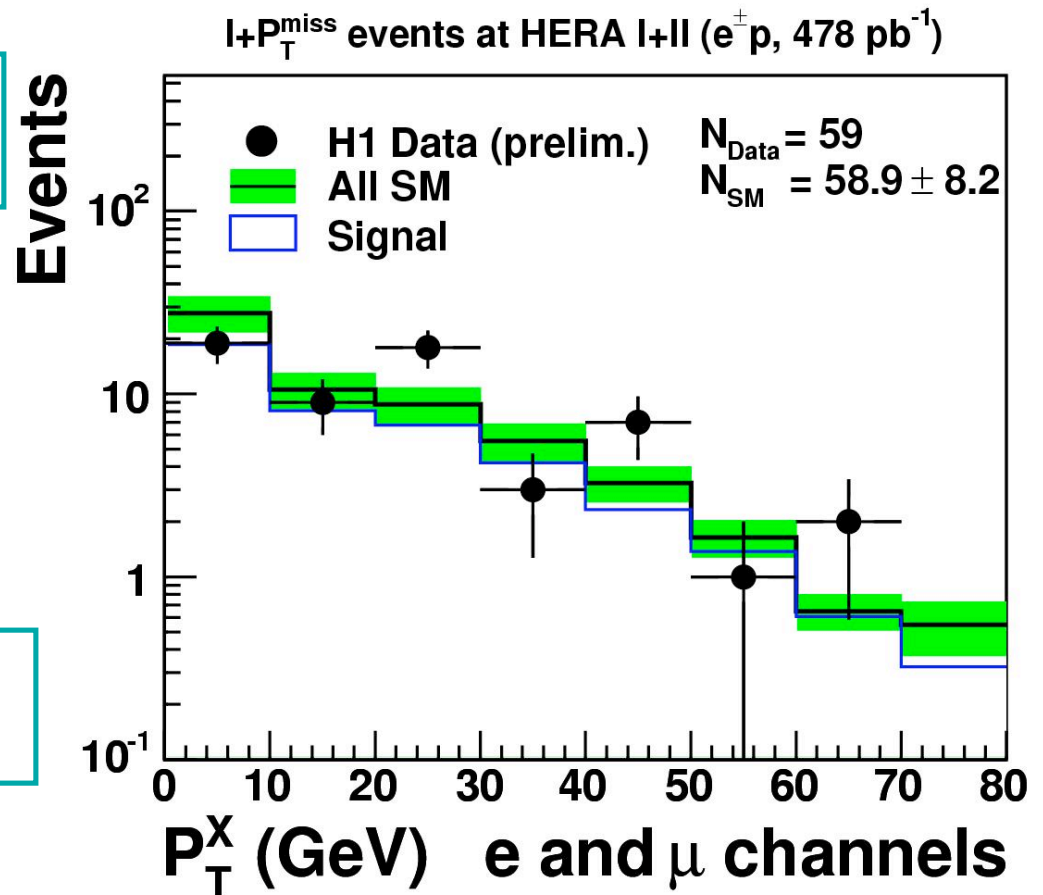
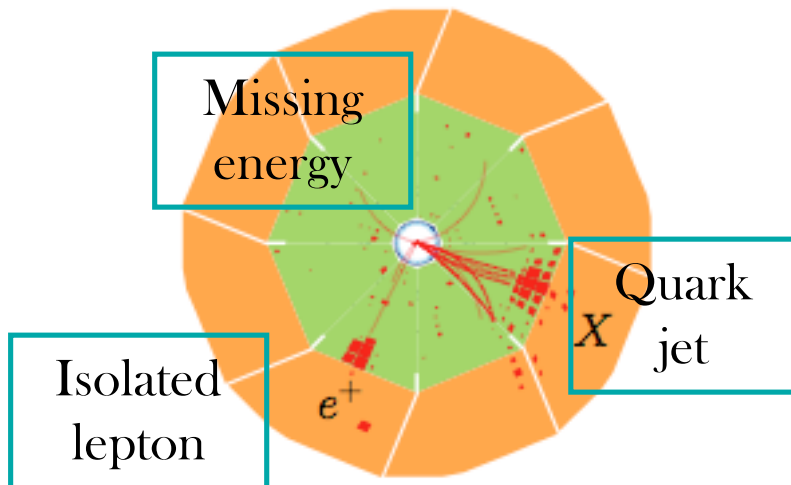
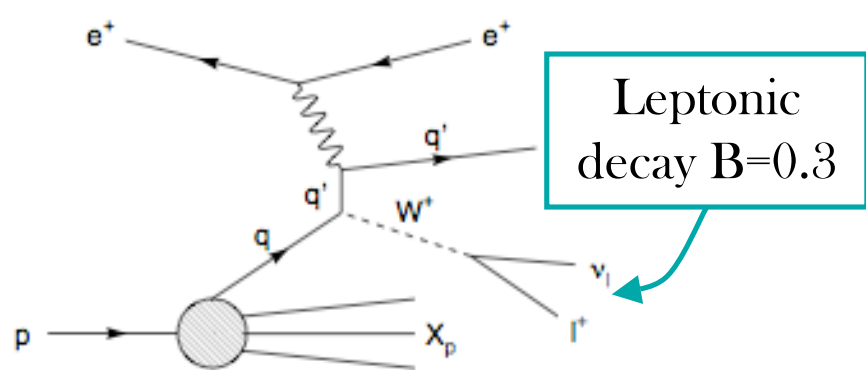


New:
ZEUS' 2006-2007
preliminary

Agreement with SM and
within experiments and
data sets

Exclude parity
conservation

Single W Boson Production



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

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^*

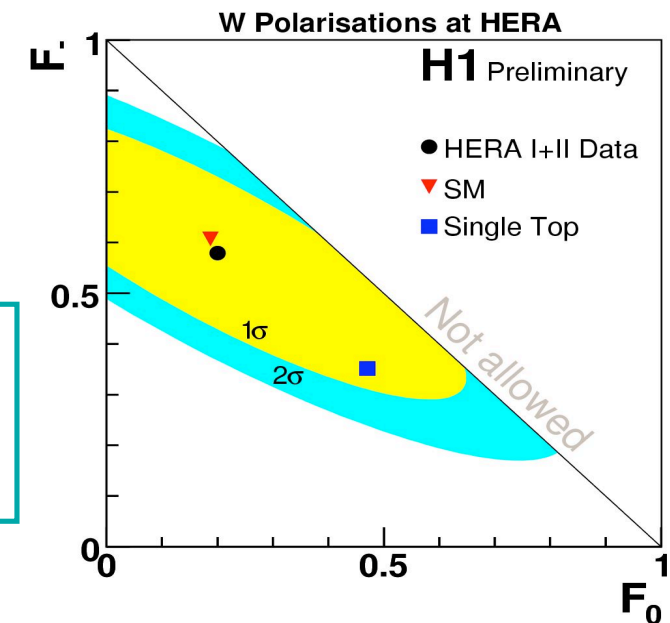
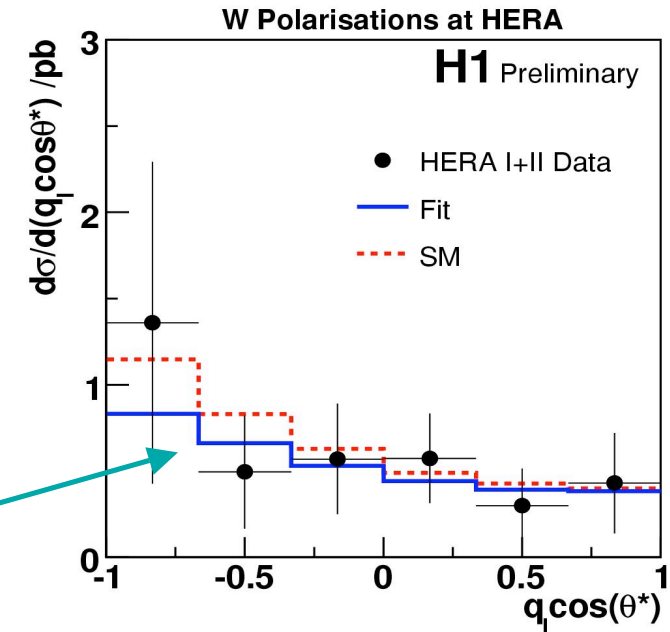
Fit differential cross section

Extract polarisation fractions F_- and F_0

Single parameter fits:

| H1 | HERA I+II Data | SM |
|-------|---|------------------------|
| F_- | 0.58 ± 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) |

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 $< 0.001 \times$ 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

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

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

$$F_2(Q^2, x) = x \sum_f A_f(Q^2) [q(Q^2, x) + \bar{q}(Q^2, x)]$$

F_2 : All quarks (dominant)

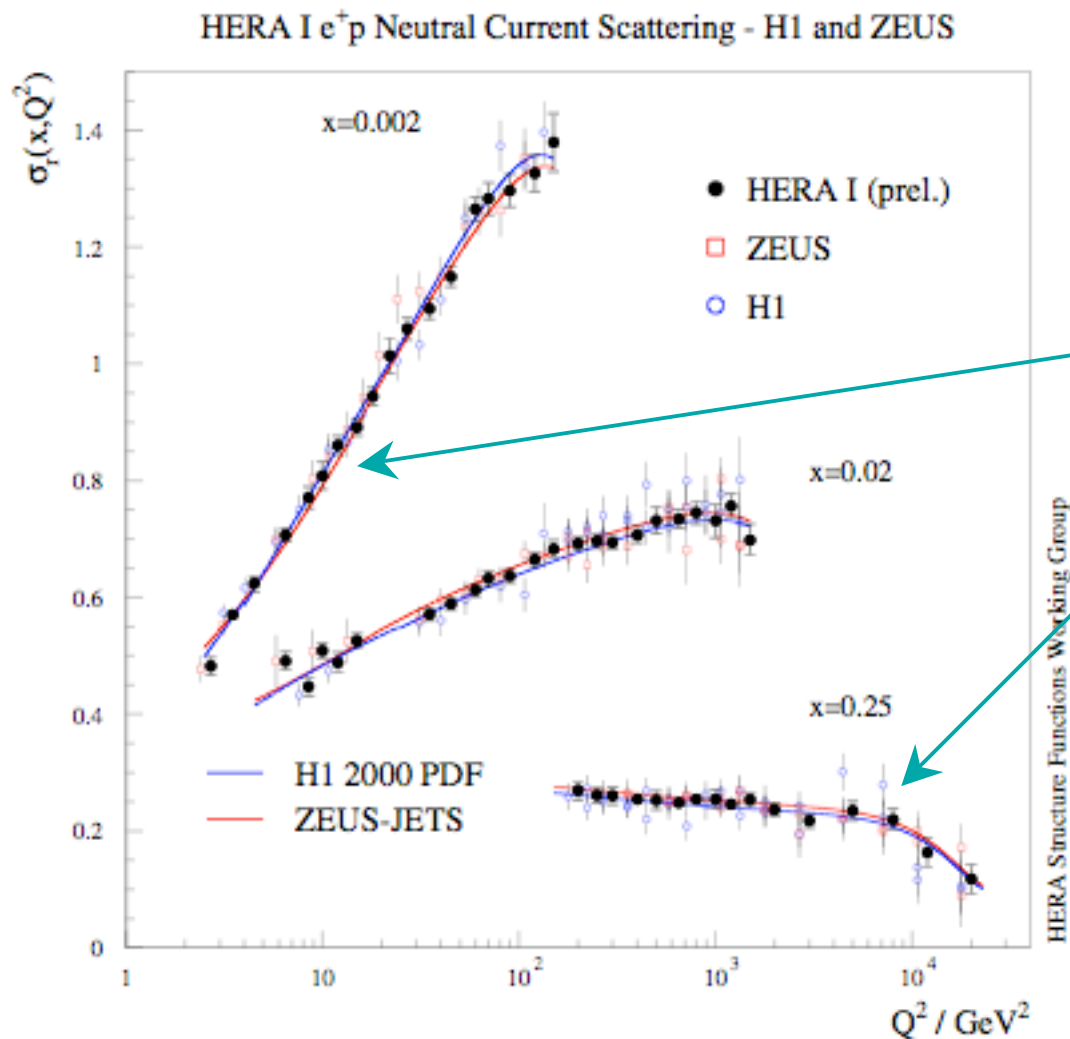
xF_3 : Valence quarks

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

Qualitatively for cross section:

- NC \gg CC
- $Q^2 > M_W^2 / M_Z^2 \rightarrow$ NC \approx CC
- $e^+p \neq e^-p$

HERA I: NC Cross Sections H1+ZEUS



H1+ZEUS published results
coherently 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