Imperial College London

Charged current deep inelastic scattering at HERA with a polarised lepton beam

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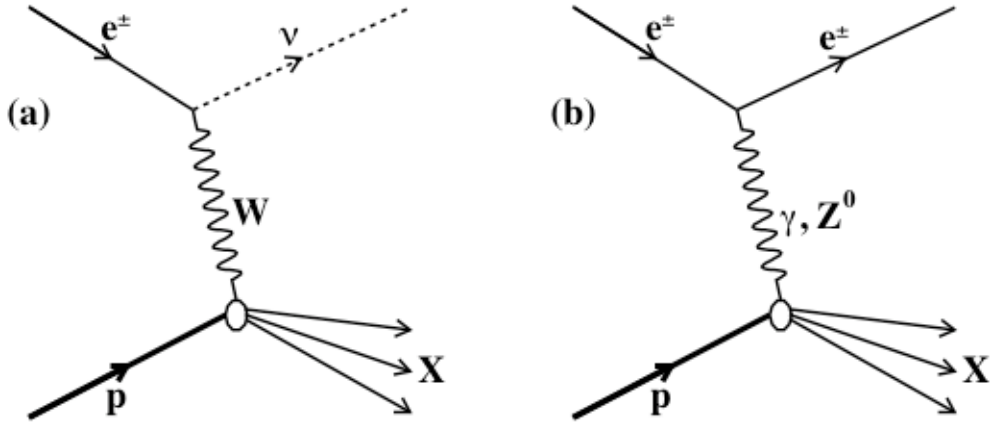
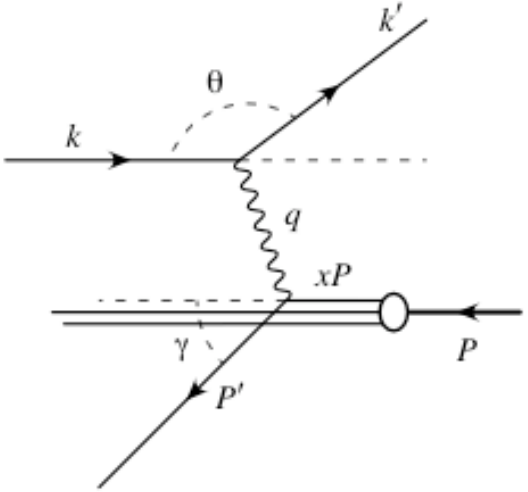
Outline

- Deep inelastic scattering
- Why use polarised leptons?
- HERA and the ZEUS detector
- Charged current event selection
- Cross section measurements
  - σ_{RH} and limit on M_{WRH}
  - Summary and outlook

Deep inelastic scattering

(a) Charged current - $W^{\pm}$ exchange
(b) Neutral current - γ/Z exchange





$Q^2 = xys$

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

- Measure of probing power
- High Q^2 ➔ small distance

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

- Bjorken scaling variable
- Fraction of proton's momentum carried by struck parton

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

- Inelasticity variable
- Fraction of electron's energy transferred to proton

What can we measure with DIS?

- Lots!
- Proton structure functions
  - $\mathbf{F_2}$ dominant term
    - Well measured over large range in x and Q^2
  - $\mathbf{xF_3}$ from Z exchange and Z-γ interference
    - Important at high Q^2
  - $\mathbf{F_L}$ zero at LO
    - Important at low Q^2 and high y
- Test of QCD
  - F_2 scaling
- Parton distribution functions
  - CC sensitive to u (e^-) and d (e^+) valence quarks
- M_W and G_F from fitting CC cross sections

$$\frac{d^2\sigma^{\pm}_{NC}}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4} Y_+ \left(F_2 - \frac{y^2}{Y_+} F_L \mp \frac{Y_-}{Y_+} xF_3 \right)$$

$$F_2 \propto \sum x(q + \bar{q}) \qquad Y_\pm = 1 \pm (1-y)^2$$

$$xF_3 \propto \sum x(q - \bar{q})$$

$$F_L \propto \alpha_s xg(x, Q^2)$$

NC

$$\frac{d^2\sigma_{CC}(e^-p)}{dxdQ^2} = \frac{G_F^2}{2\pi} \frac{M_W^4}{(Q^2 + M_W^2)^2} \left((u + c) + (1-y)^2 (\bar{d} + \bar{s}) \right)$$

$$\frac{d^2\sigma_{CC}(e^+p)}{dxdQ^2} = \frac{G_F^2}{2\pi} \frac{M_W^4}{(Q^2 + M_W^2)^2} \left((\bar{u} + \bar{c}) + (1-y)^2 (d + s) \right)$$

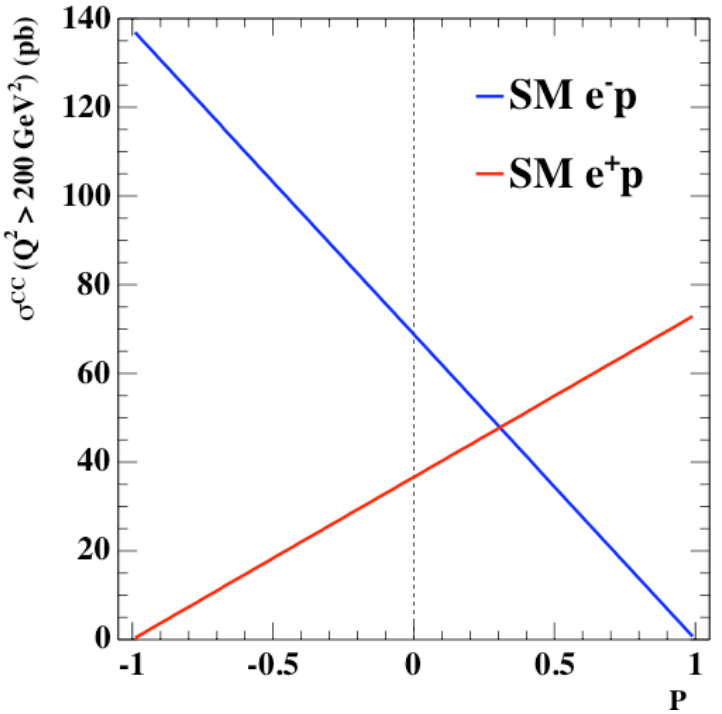
CC

What more can we learn with polarised leptons?

- Split **NC** cross section into terms with and without P dependence
  - P-dependent terms involve Z exchange and Z-γ interference
    - Only important at high Q^2
  - Quark couplings to Z boson
    - Without P - only measure **axial couplings** accurately
    - With P - can also measure **vector couplings**
    - More precise than LEP or Tevatron
    - Results coming soon…
- **CC** cross section is linearly dependent on P
  - **No RH CC in the SM**

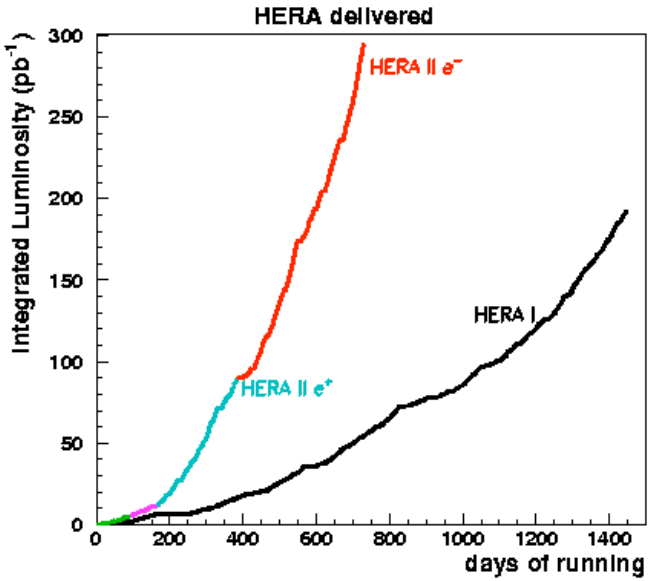
$$\sigma^{\pm}_{CC}(P) = (1 \pm P)\,\sigma^{\pm}_{0,CC}$$

- Measuring CC cross section vs. P
  - **Direct test of the EW part of the SM**
  - Search for RH CC



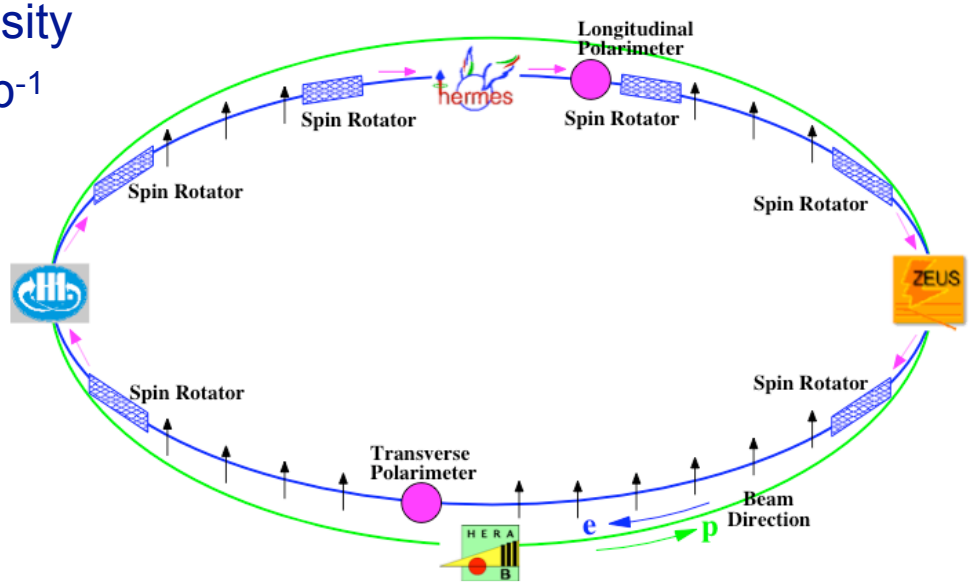
- **In this talk I will explain the CC measurement and present the latest results**

The HERA *ep* collider



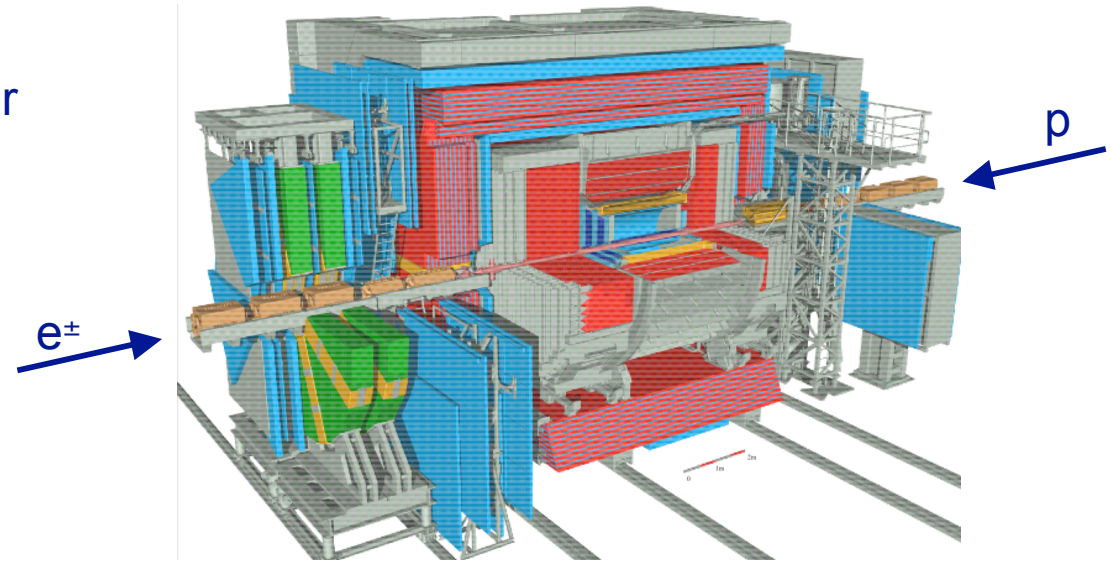
- Centre of mass energy = **320 GeV**
- HERA upgraded 2000-2002:
  - Increased luminosity
  - Polarised leptons
- Aim for ~ 700 pb^{-1} of HERA-II luminosity
- Measurements in this talk use 122 pb^{-1} of 04-05 e-p data:

Polarisation	L (pb^{-1})
-27%	78.8
+33%	42.7



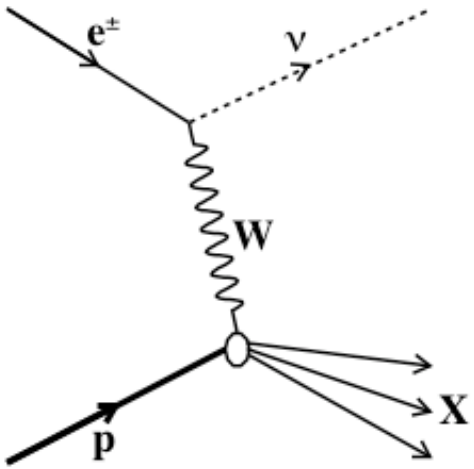
The ZEUS detector

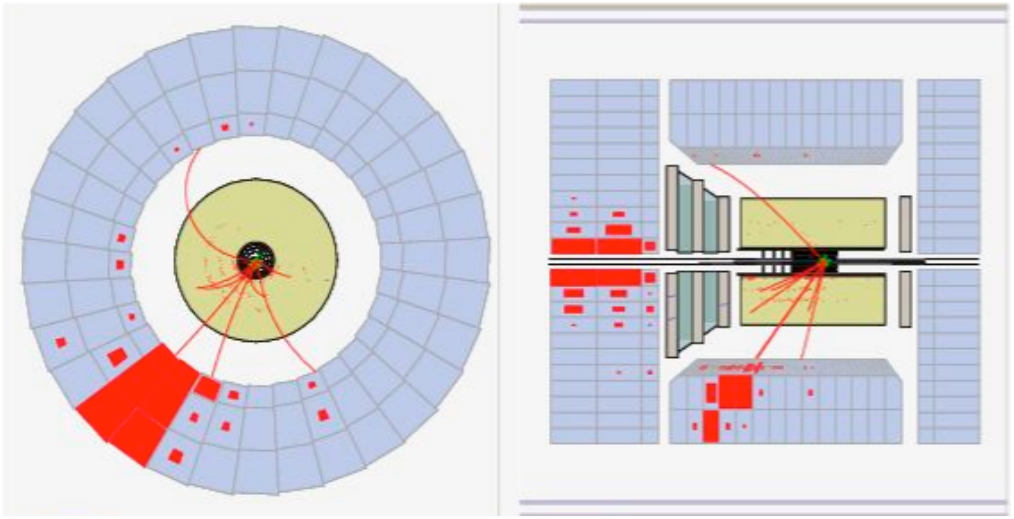
- General purpose detector
- Uranium-scintillator calorimeter
  - 99.7% solid angle coverage
  - Hadronic energy resolution
    - $35\% / \sqrt{E} \oplus 2\%$
  - Electromagnetic energy resolution
    - $18\% / \sqrt{E} \oplus 1\%$
- Central tracking detector
  - Cylindrical drift chamber
  - Radius: 18.2 cm ➔ 79.4 cm
  - 1.43 T solenoidal magnetic field
  - 72 layers of sense wires
- Silicon micro-vertex detector
  - Improved vertex measurement



- Muon chambers
- Luminosity monitor
- 3-level trigger

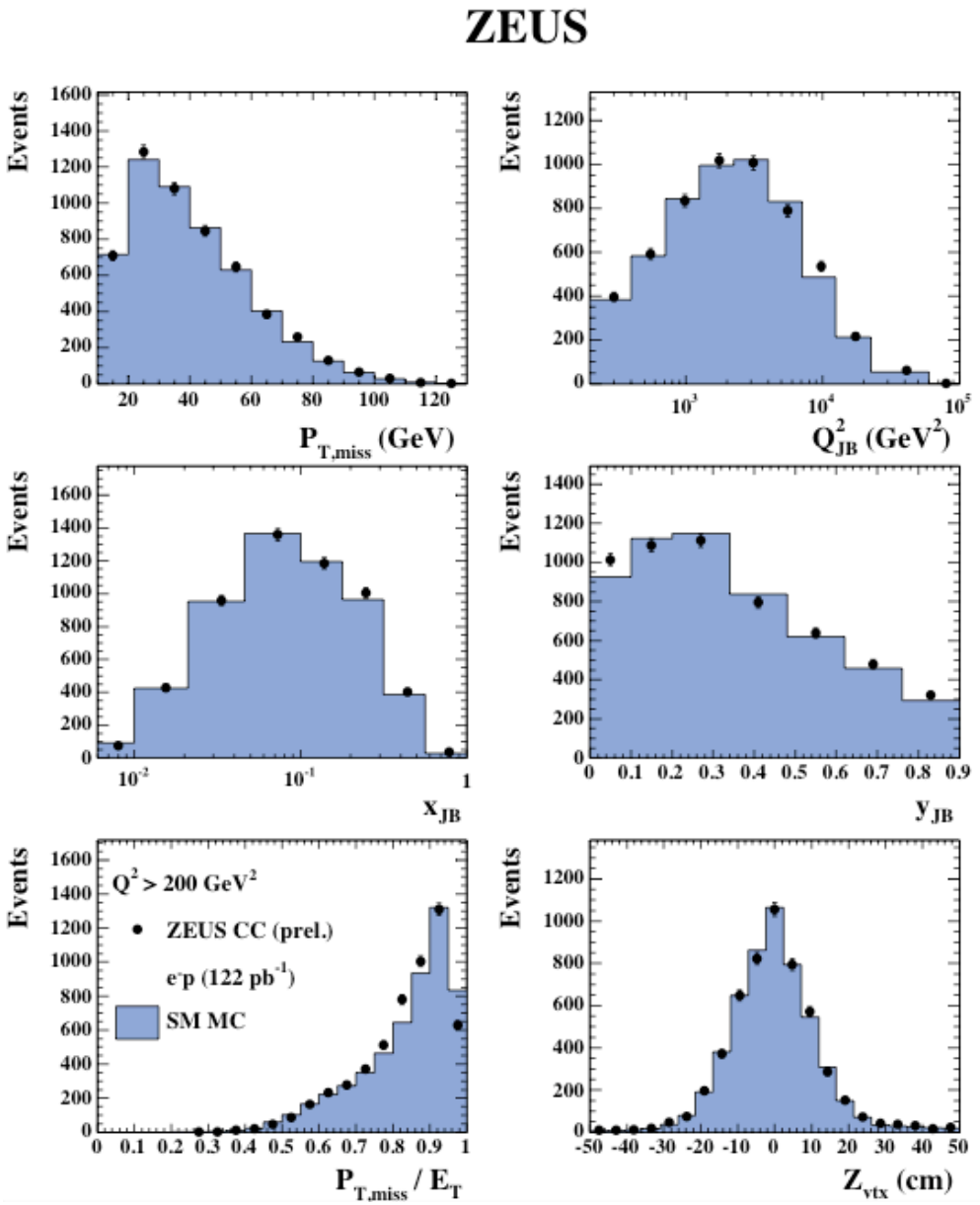
Charged current events





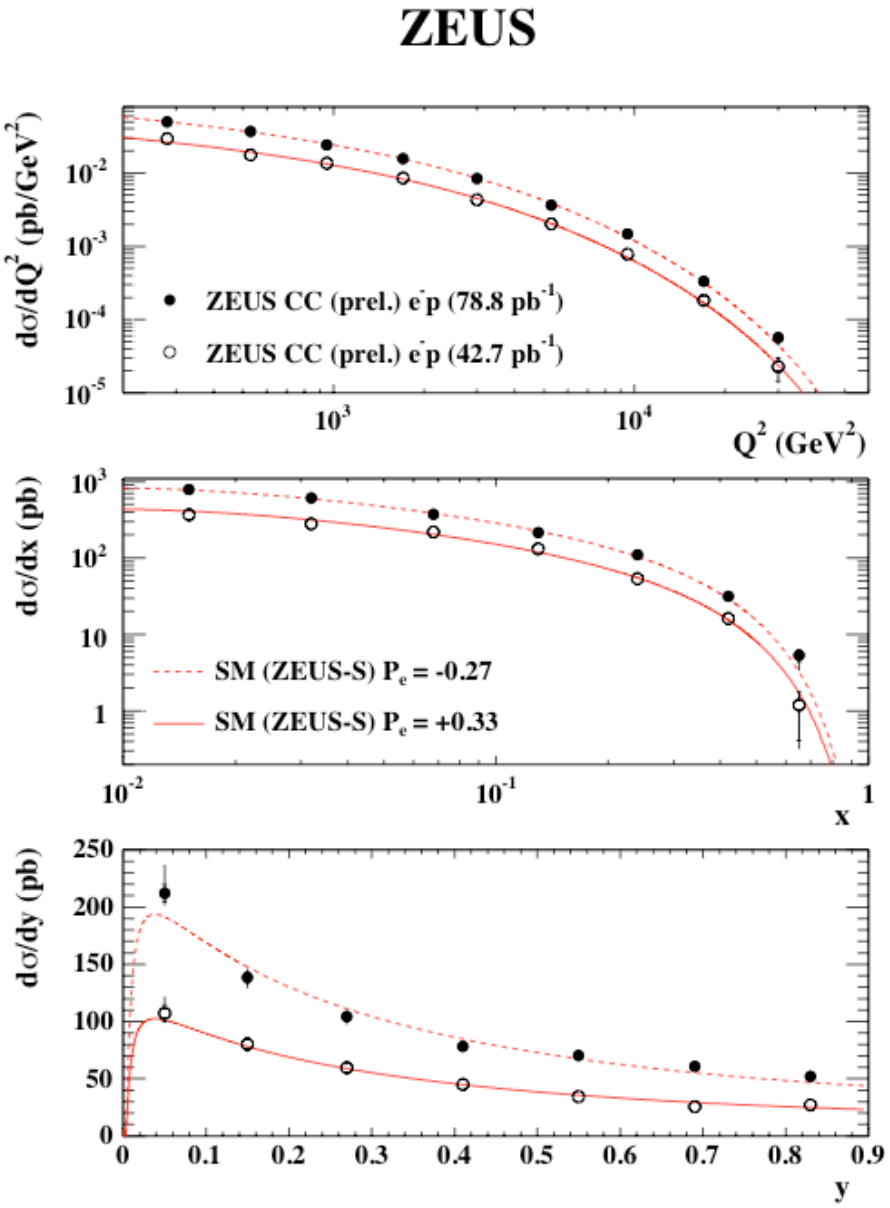
- Signature: hadronic energy with ν in final state
  - **Missing transverse momentum**
- $P_T > 12$ GeV or $P_T > 14$ GeV for very forward events
- $Q^2 > 200$ GeV^2
- Various cuts to reject SM and beam-related backgrounds

Control plots after CC selection



- 122 pb^{-1} 04-05 e$^-$p data
- After cuts have ~ 5500 events
- Good agreement between data and MC
  - ZEUS detector is well-understood
  - Can use these distributions to extract cross section measurements using MC for the acceptance correction

Single differential cross sections



- Cross sections extracted bin-by-bin:

$$\left.\frac{d\sigma}{dQ^2}^{\text{meas}}_{\text{Born}}\right|_{Q_0^2} = \left.\frac{d\sigma}{dQ^2}^{\text{theory}}_{\text{Born}}\right|_{Q_0^2} \cdot \frac{N_{\text{data}} - N_{\text{background}}}{N_{CC}}$$

- Polarisation dependence observed uniformly across Q^2, x and y
- Good agreement with SM
- Can now integrate and measure total cross sections

Total cross sections

- Extract Born level cross sections:

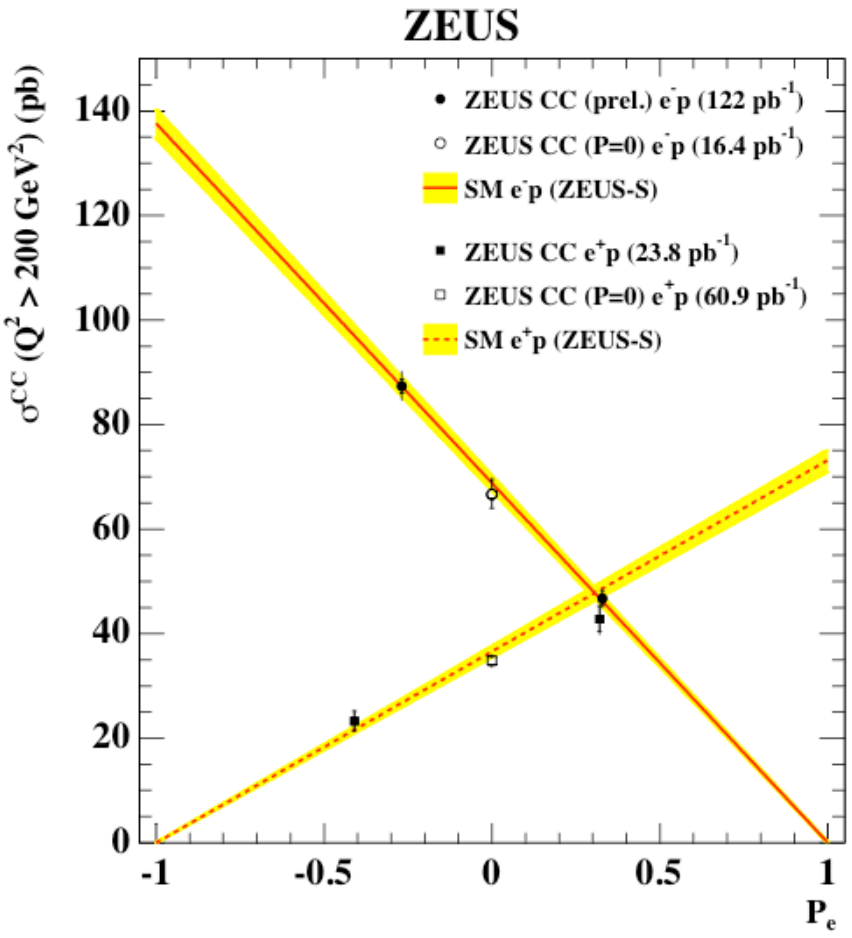
$$\sigma_{Born}^{meas} = \sigma_{Born}^{theory} \frac{N_{data} - N_{background}}{N_{CC}}$$

- Which gives:

$$\sigma_{CC}^{-}(P = -0.27) = 87.4 \pm 1.3\,(stat.)\,^{+2.6}_{-2.5}\,(sys.)\,pb$$

$$\sigma_{CC}^{-}(P = +0.33) = 46.7 \pm 1.3\,(stat.)\,^{+1.5}_{-1.3}\,(sys.)\,pb$$

- Clear dependence on P observed for both $e^{-}p$ and $e^{+}p$ with positive and negative P
- $e^{+}p$ points from previous analysis

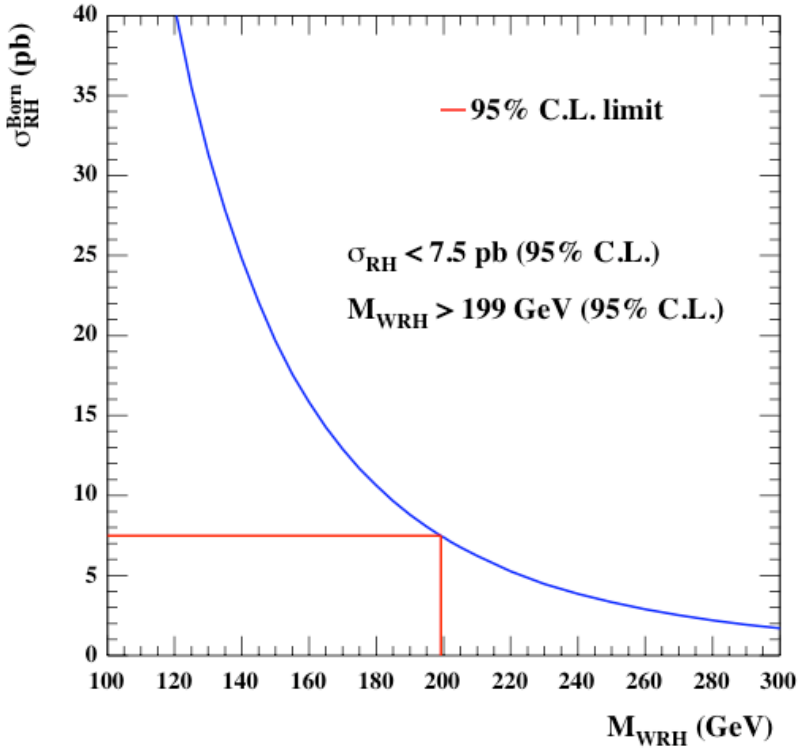


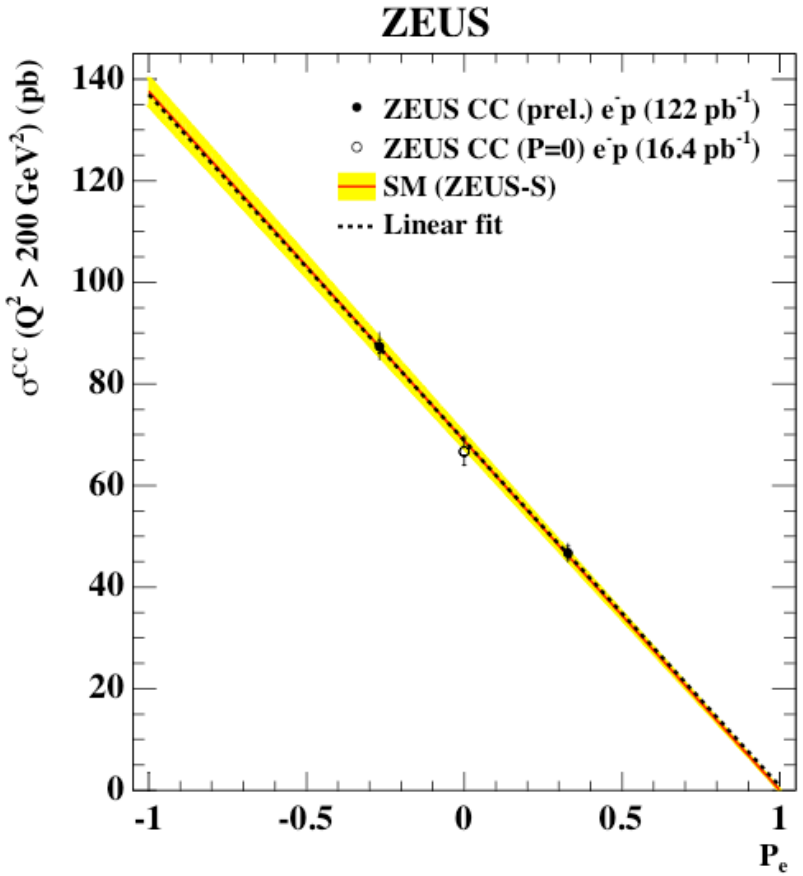
σ_{RH} and limit on M_{WRH}

- Fit straight line to total cross sections to find σ_{RH}

$$\sigma_{RH} = 0.8 \pm 3.1(\text{stat.}) \pm 2.6(\text{sys.})\,\text{pb}$$

- Consistent with zero, no RH CC
- σ_{RH} < 7.5 pb at 95% C.L.





- Convert to limit on M_{WRH} assuming:
  - Same coupling and propagator dependence as for LH CC
  - $\sigma^{-}_{CC}(P) = (1+P)\sigma_{RH}/2 + (1-P)\sigma_{LH}/2$
- **M_{WRH} > 199 GeV at 95% C.L.**

Summary and outlook

- CC DIS with polarised leptons provides direct test of EW part of SM
  - Search for RH CC

- HERA-II is operating well and have already collected considerable luminosity
- ZEUS detector also performing very well and is well-understood

- Have measured CC total cross sections with e^+p and e^-p data with both positive and negative lepton polarisations
  - Fit to find σ_{RH} consistent with zero, SM value
  - No sign of RH CC
  - Set limit of $M_{WRH} > 199$ GeV at 95 % C.L.

- Looking forward to even more HERA-II e^+p and e^-p data to further improve the precision of these measurements!

Extra slides

Reduced cross sections

$$\tilde{\sigma} = \left[\frac{G_F^2}{2\pi x}\left(\frac{M_W^2}{M_W^2 + Q^2}\right)^2\right]^{-1} \frac{d^2\sigma}{dx dQ^2}$$