Charged Current DIS Cross Sections with a Longitudinally Polarised Positron Beam at ZEUS

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On behalf of the ZEUS collaboration

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Charged Current Interaction: Motivation

Extraction of M_W

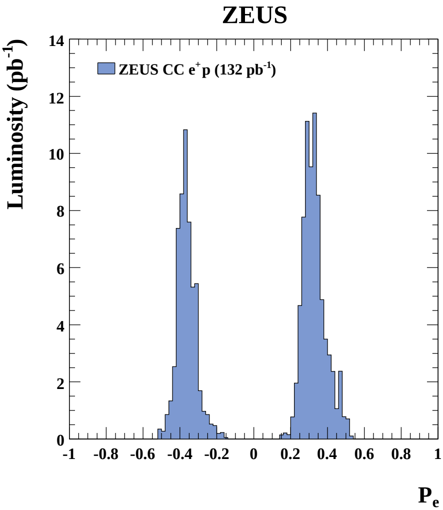
$$\frac{d^2\sigma(e^+p)}{dxdQ^2} = \boxed{(1+P)} \times \boxed{\frac{G_F^2 M_W^4}{2\pi(Q^2+M_W^2)^2}} \left[\bar{u} + \bar{c} + \boxed{(1-y)^2\,(d+s)}\right]$$

Test of the chiral nature of the Standard Model
$\sigma(P_e) = (1+P_e)\sigma(P_e=0)$

Sensitivity to the d quark PDF

Data

2006/2007 e^+p HERA data is used

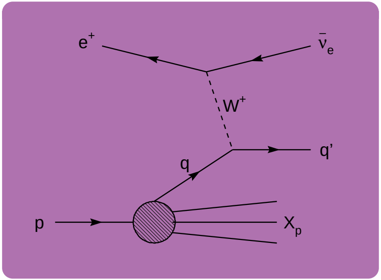


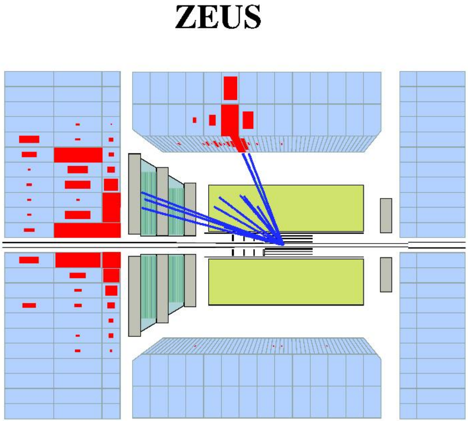
Data set	$\mathcal{L}(\text{pb}^{-1})$	P_e (%)
Total	132	$+3.4$
Right-handed	75.8	$+33$
Left-handed	56.0	-36

- Luminosity uncertainty: 2.6%
- Runs with $P_e < 15\%$ were rejected to allow reliable polarisation measurement
- Polarisation uncertainty: 4.0% (LH), 3.7% (RH)

Charged Current Event Selection I

Large missing transverse momentum (p_T) due to neutrino





Charged Current Event Selection II

Kinematic reconstruction from hadrons (Jacquet-Blondel)

$$\delta = \sum_i \left(E^i - p_z^i\right) \qquad p_T^2 = \left(\sum_i p_x^i\right)^2 + \left(\sum_i p_y^i\right)^2$$

$$y_{\mathrm{JB}} = \frac{\delta}{2E_e} \qquad x_{\mathrm{JB}} = \frac{p_T^2}{s y_{\mathrm{JB}}(1-y_{\mathrm{JB}})} \qquad Q^2_{\mathrm{JB}} = s x_{\mathrm{JB}} y_{\mathrm{JB}}$$

Kinematic Cuts

- $Q^2_{\mathrm{JB}} > 200\ \mathrm{GeV}^2$
- $y_{\mathrm{JB}} < 0.9$

CC Selection

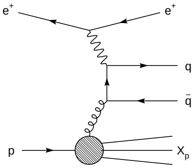
- $P_T > 12$ GeV

Background Rejection

- Tracking cuts (vertex and quality)
- Cosmic μ rejection (CAL energy fractions)
- γP & beam gas rejection (jet shape cuts)
- NC rejection (electron cuts)

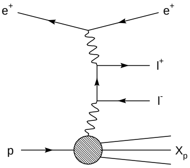
Charged Current Backgrounds

Photoproduction



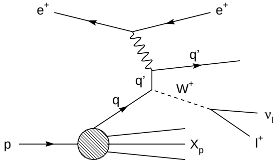
0.6%

Di-leptons



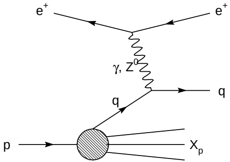
0.2%

Single-W



0.3%

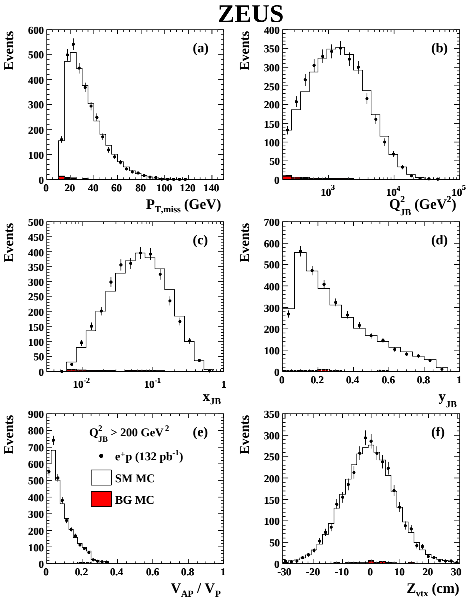
Neutral current



<0.02%

Control Plots

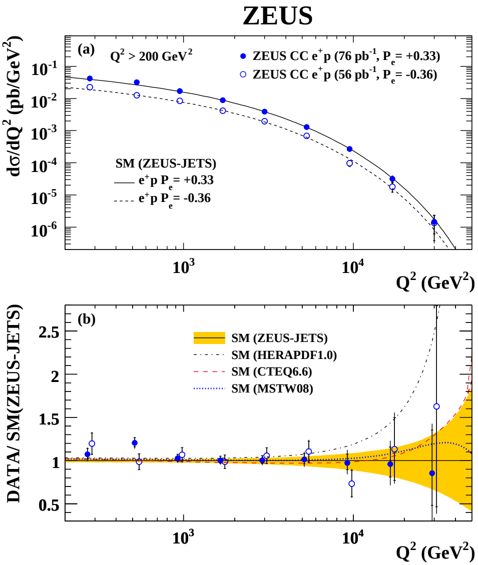
- Total data sample is shown (≈ 3000 events, 132 pb^{-1})
- Signal histograms: DJANGOH + ARIADNE with CTEQ5D PDFs.
- *ep* background contamination: $< 1.5\%$
- Data are well described by MC ⇒ MC is used to estimate efficiencies of selection and detector effects



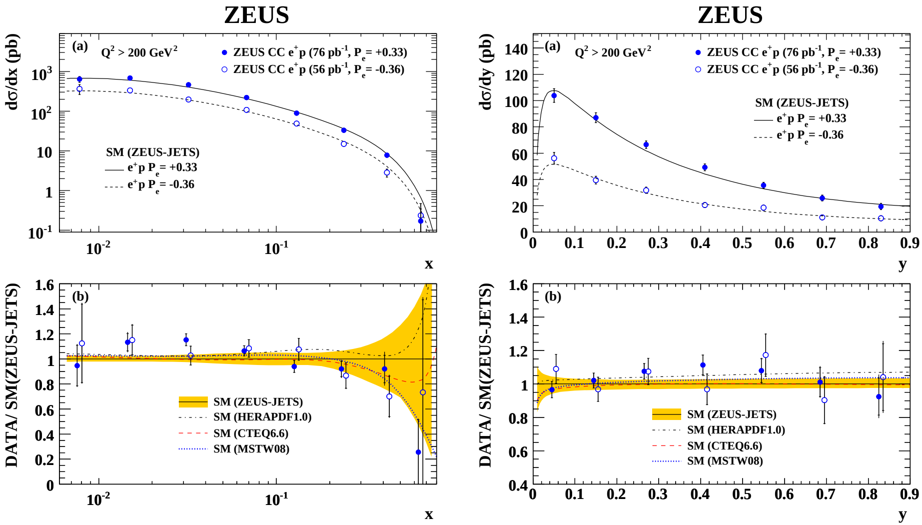
Single Differential Cross Sections I

Single differential cross sections as a function of Q^2, x and y:

- Cross sections measured at different polarisations differ in magnitude but not shape
- Consistent with SM

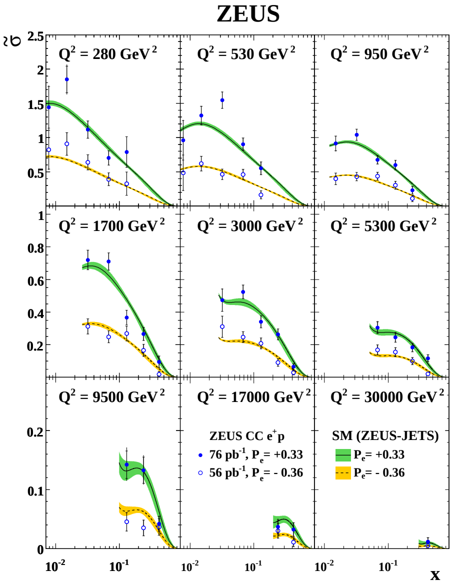


Single Differential Cross Sections II



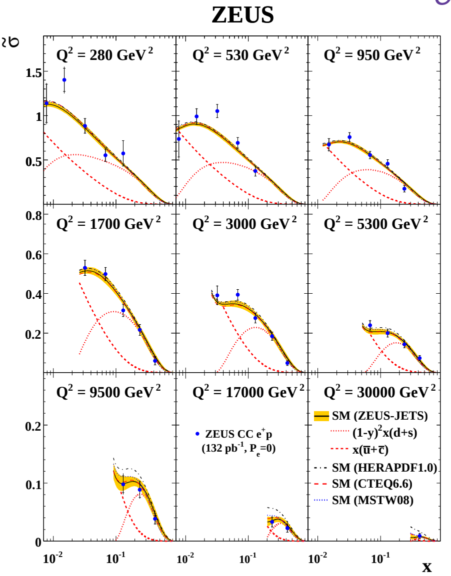
Reduced Cross Section $\tilde{\sigma}_{CC}^{e^+p}$ I

$$\tilde{\sigma} = (1 + P_e)\left[\overline{u} + \overline{c} + (1 - y)^2 (d + s)\right]$$



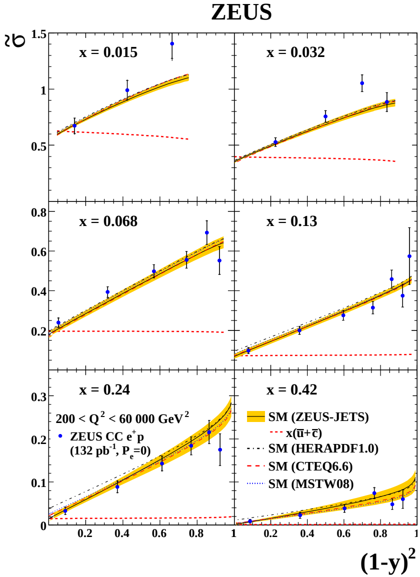
- Positron data is sensitive to d valence quark
- Precise data can further constrain PDFs

Reduced Cross Section $\tilde{\sigma}_{CC}^{e^+p}$ II



- Unpolarised reduced cross section in bins of Q^2 as a function of x
- Contributions are shown from quarks and antiquarks:
  - $x\,(\overline{u}+\overline{c})$ term dominates at low x
  - $(1-y)^2\,x\,(d+s)$ term dominates at high x (valence region)

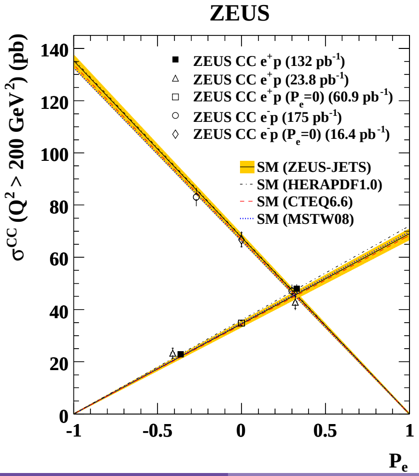
Reduced Cross Section $\tilde{\sigma}_{CC}^{e^+p}$ III



- Unpolarised reduced cross section in bins of x as a function of $(1-y)^2$ $\rightarrow$ helicity structure of CC interactions
- At leading order in QCD:
  - Intercept gives $(\overline{u}+\overline{c})$ contribution
  - Slope gives the $(d+s)$ contribution.

Total Cross Sections I

$\sigma^{CC}(P_e = -0.36) = 22.9 \pm 0.82(\text{stat.}) \pm 0.60(\text{lumi.}) \pm 0.40(\text{syst.})$ pb
$\sigma^{CC}(P_e = +0.33) = 48.0 \pm 1.01(\text{stat.}) \pm 1.25(\text{lumi.}) \pm 0.77(\text{syst.})$ pb

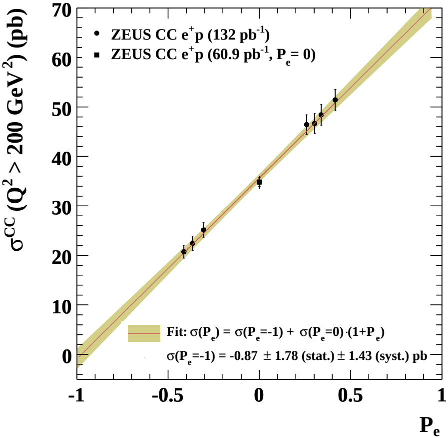


$$\sigma_{CC}^{e^\pm p}(P_e) = (1 \pm P_e) \cdot \sigma_{CC}^{e^\pm p}(P_e = 0)$$

- Test chiral nature of the SM
- Search for a non-zero cross section at $P_e = -1$ due to the existence of W bosons coupling to RH particles (W_R)

Total Cross Sections II

- Measure cross section in 8 bins of polarisation
- Do not constrain linear fit to zero at P_e = -1
- Derive upper limit on $\sigma_{CC}^{e^+p}(P_e = -1) \Rightarrow$ lower limit on mass of W_R assuming:
  - $g_L = g_R$
  - Light ν_R



$$\sigma_{CC}^{e^+p}(P_e = -1) = -0.87 \pm 1.78\ \text{(stat.)} \pm 1.43\ \text{(syst.) pb}$$
$$M_{W_R} > 198\ \text{GeV}\ \ (95\%\text{CL})$$

Summary

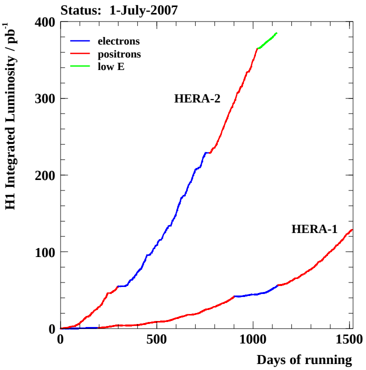
- Total, single-differential and reduced charged current DIS cross sections are presented for 2006/2007 e^+p HERA data (132 pb^{-1}) with polarised positron beams
- The Standard Model describes the data well
- The results of this analysis should help to constrain the d-quark and sea PDF $\rightarrow$ important for PDFs at LHC

Back-Up Slides

HERA and ZEUS

HERA collided protons with longitudinally polarized $e^{\pm}$

- ZEUS was a multi-purpose collider detector at HERA
- 0.5 fb^{-1} luminosity taken by ZEUS



HERA Energies

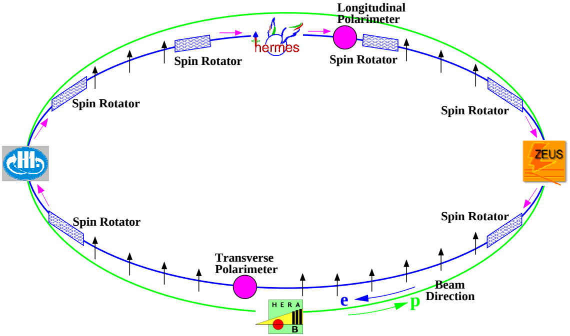
p beam: 920 GeV

$e^{\pm}$ beam: 27.5 GeV

Centre of mass energy: 318 GeV

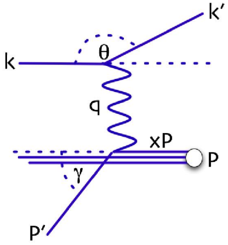
HERA: Longitudinally Polarised Positrons

- Positron beam becomes transversely polarized by emission of synchrotron radiation
- Spin rotators provide longitudinally polarized positrons at both IPs
- Mean polarization: 30 - 40%



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

Kinematics & Deep Inelastic Scattering



Neutral current
exchange of γ or Z°
Charged current
exchange of $W^{\pm}$

Probing power of the lepton:

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

Bjorken scaling variable, the fraction of the proton's momentum carried by the struck quark

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

Inelasticity, the energy fraction transferred from the lepton in the proton's rest frame

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

Centre of mass energy squared:

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

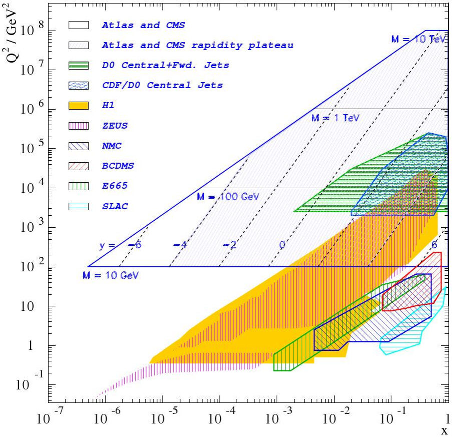
Sokolov-Ternov Effect

- Naturally-occurring transverse polarisation of lepton beams in storage rings
- When electrons are injected, spins are randomly oriented
- As they accelerate round the ring, vertical B-field is created
- The electrons emit synchrotron radiation.
- When an electron emits a photon there is a probability that the projection of the electron's spin onto the vertical axis may flip direction
- The probability per unit time that the electrons spin will flip from up to down is greater than the probability per unit time that the electrons spin will flip from down to up
- $\rightarrow$ Over time, lepton beams become transversely polarised

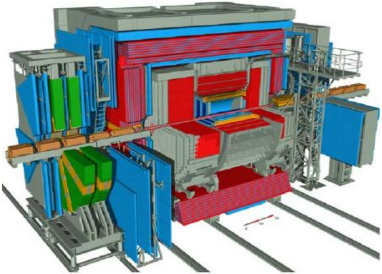
HERA Polarimeters

- HERA polarimeters use Compton scattering of circularly polarised laser beams off the lepton beam to measure the polarisation of the lepton beam.
- The polarimeters determine transvere or longitudinal components of lepton beam polarisation by measuring asymmetries between the scattered photons from circularly polarised laser beams with positive and negative helicity.

HERA and LHC Kinematic Regions



ZEUS



- Hermetic - 4π detector
- Tracking:
  - Central Tracking Detector (CTD), a cylindrical drift chamber
  - Silicon Microvertex detector (MVD) (HERA-II)
- Compensating uranium scintillator calorimeter (UCAL)
- μ chambers

Optimised for precision measurement of the hadronic final state

Charged Current Cross Sections

Charged current reduced cross section

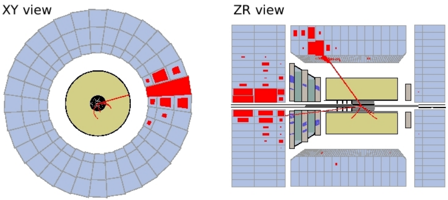
$$\tilde{\sigma}(e^- p)_{CC} = (1 - P_e)\,[u + c + (1 - y)^2(\overline{d} + \overline{s})]$$
$$\tilde{\sigma}(e^+ p)_{CC} = (1 + P_e)\,[\overline{u} + \overline{c} + (1 - y)^2(d + s)]$$

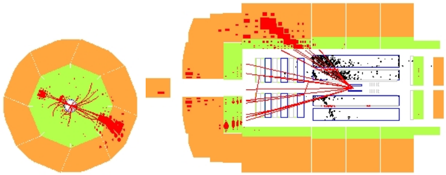
- Linear polarisation dependence
- Electron (positron) data is sensitive to u (d) valence quark
- Probes flavour structure of the proton

Charged Current & Neutral Current Events

CC Event: Large missing transverse momentum (p_T) due to neutrino

NC Event: High p_T isolated scattered electron/positron and balanced total p_T

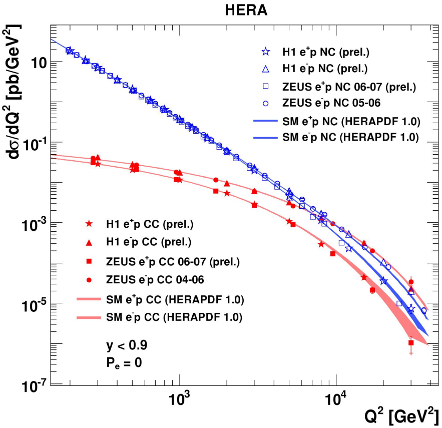




Final selection: $\sim 10^3$ events per sample

Final selection: $\sim 10^5$ events per sample

High Q^2 NC and CC Cross Sections



- NC and CC high Q^2 cross sections are measured very precisely over many orders of magnitude in Q^2

W_R Mass Limits

- Assuming $M_{\nu_R} > M_{W_R}$:
  - UA2 excluded 100-251 GeV in $W_R \rightarrow$dijets channel
  - D0 (CDF) excluded $M_{W_R} < 739$ ($M_{W_R} < 800$) GeV in search for $t\bar{b}$ final state
- Assuming $M_{\nu_R} < M_{W_R}$:
  - CDF excluded 1.00 TeV
- Cosmological limits also exist

Extraction of W Mass

- The fall in the cross section $d\sigma/dQ^2$ with increasing Q^2 depends on $M_W^4/(Q^2+M_W^2)^2$.
- Fitting $d\sigma/dQ^2$ with G_F fixed at the PDG value of $1.16639 \cdot 10^{-5}$ GeV^{-2}, using the ZEUS-S fit PDFs and M_W treated as a free parameter, gives:

$$M_W = 78.9 \pm 2.0(\text{stat.}) \pm 1.8(\text{syst.})^{+2.0}_{-1.8}\,(\text{PDF})\,\text{GeV}$$

- This measurement, in the space-like region, is in good agreement with the more precise measurements of W-boson mass in the time-like region