Inclusive Measurements of Charm Cross Sections at HERA

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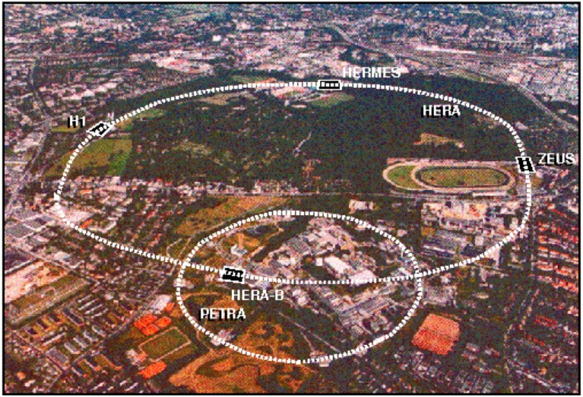
Outlook

1. Motivation
2. HERA and the ZEUS Detector
3. Event Selection and Signal Extraction
4. Differential Cross Sections
5. Summary and Outlook

Motivation

- Why do we study heavy flavour production at HERA?
- HERA physics allows for stringent tests of perturbative QCD and constrains the quark and gluon density inside the proton
- heavy flavour production might help to distinguish between different theoretical approaches to include mass effects in perturbative QCD
- inclusive measurements of charm and beauty cross sections provide more statistics and allow for the most precise measurements of the proton structure

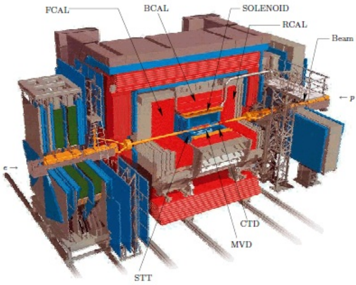
The HERA Accelerator at DESY



- HERA was the world's first and to date only lepton-proton collider, operating between 1992 and 2007
- e^-, e^+ and p were accelerated to and brought to collision at centre-of-mass energy $\sqrt{s} \approx 318\text{GeV}$

The ZEUS detector

- The ZEUS detector was a multipurpose particle detector designed to measure final state particles from $e^- p$ collisions
- The detector was composed of:
  - Microvertex Detector (MVD):
    - reconstruction of impact parameter and secondary vertices
  - Central Tracking Detector (CTD):
    - measurement of tracks, charges and momenta of particles
  - Uranium Scintillator Calorimeter (CAL):
    - measurement of the energy deposit of particles



Deep Inelastic Scattering (DIS)

- DIS occurs when the electron emits an off-shell boson that interacts with the constituents of the proton causing the proton to break up
- The scattering process is described in terms of four Lorentz scalars:
  - $s = (k + P)^2$
  - $Q^2 = -(k - k')^2$
  - $x = Q^2/(2P \cdot q)$
  - $y = (P \cdot q)/(P \cdot k)$,
- related in the following way:
  - $Q^2 = sxy$.

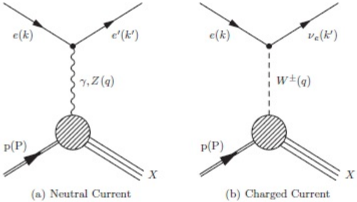


Figure: Feynman diagram of neutral and charged current DIS

Structure Functions and PDF's

- In Neutral Current DIS the cross sections can be written in terms of three structure functions F_2, F_3 and F_L:
  - $\frac{d^2\sigma}{dxdQ^2} = \frac{2\pi\alpha^2}{Q^4 x}\left(Y_+ F_2(x,Q^2) \mp x\,Y_- F_3(x,Q^2) - y^2 F_L(x,Q^2)\right),$
- where the coefficients $Y_{\substack{+\\-}}$ are given by:
  - $Y_\pm = 1 \mp (1-y)^2$
- Factorisation Theorem: $F_2(x,Q^2)$ convolution of Wilson coefficients C_2^i and parton density functions f_i :
  - $F_2(x,Q^2) = \sum_i \int_x^\infty C_2^i(\frac{x}{\xi}, \frac{Q^2}{\mu^2}, \alpha_S(\mu))\, f_i(\xi,\mu)\, d\xi$
- where ξ is the momentum fraction of the struck parton, and μ the renormalisation scale.

Heavy Flavour Production

- At HERA the dominant production mechanism for heavy quarks was boson-gluon fusion (BGF)
- Measurement of the charm and beauty fractions allows to draw conclusions about the heavy quark and gluon density inside the proton
- However, this analysis applies inclusive techniques to detect heavy quarks, e.g. via the reconstruction of impact parameter and secondary vertices

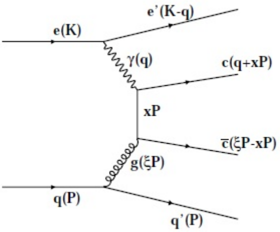


Figure: Direct boson gluon fusion (BGF)

Reduced Cross Sections in NC DIS

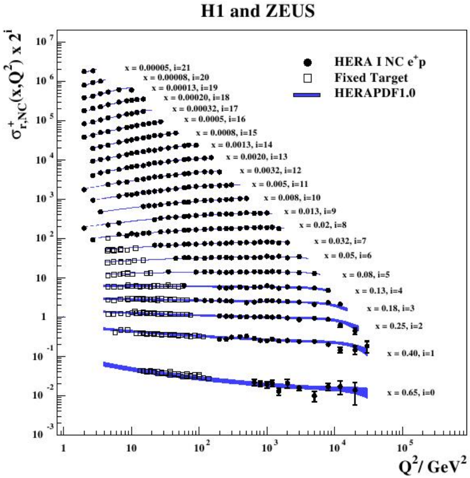


Figure: NC Cross Sections $\sigma_{r,NC}$ as a function of Q^2 for fixed values of x from combinations of ZEUS and H1 data and fixed target experiments

Structure Functions

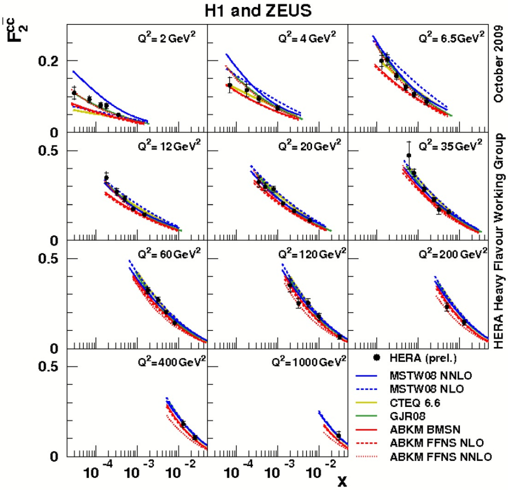


Figure: Structure Function $F_2^{c\bar{c}}$ as a function of Bjorken x in various bins of the photon virtualiy Q^2

Data Sample and Kinematic Region

Data Sample

- HERA II data sample correspondig to an integrated luminosity of $\mathcal{L} \approx 331\text{pb}^{-1}$

Trigger

- Heavy Flavour Triggers
- Inclusive DIS Triggers

Kinematic Region

- $5.0\,\text{GeV}^2 < Q^2 < 1000.0\,\text{GeV}^2$, $0.02 < y < 0.7$
- $E_T^{jet} > 4.2\,\text{GeV}$, $-1.6 < \eta^{jet} < 2.2$

Track Impact Parameter and Track Significance

- Track impact parameter calculated as distance between primary vertex and point of closest approach (pca)
- Positive/negative sign assigned depending on the angle between the line joining the primary vertex and the pca and the unit vector in the direction of the selected jet
- Track significance given by the impact parameter divided by the error on the impact parameter

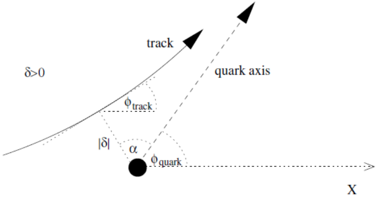


Figure: Diagram of tracks in x-y plane, in case the angle $\alpha < 90^0$ δ is defined positive, otherwise δ is defined negative

Track Selection

The track selection aims to obtain three statistically independent samples of tracking variables for the signal extraction. One distinguishes three different scenarios:

Scenario 1:

- 1 track passes the selection criteria
- track significance is stored in a histogram

Scenario 2:

- 2 tracks pass the selection criteria
- second highest track significance is stored in a separate histogram

Scenario 3:

- 3 or more tracks pass the selection criteria
- three highest track significance values are stored in three separate histograms

Track Impact Parameter

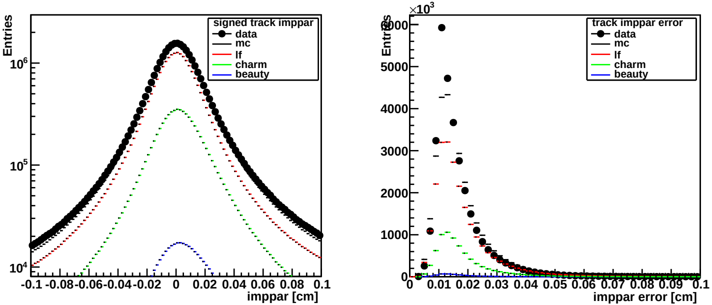


Figure: signed track impact parameter on logarithmic scale, impact parameter error on linear scale - slight dicrepancy betw MC and data

Track Significance, Scenario 3

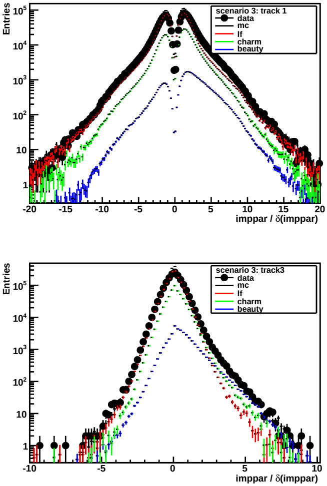


Figure: track significance for the highest, second and third highest significance track of scenario 3, note: asymmetry for heavy flavours

Track Significance, Scenario 3

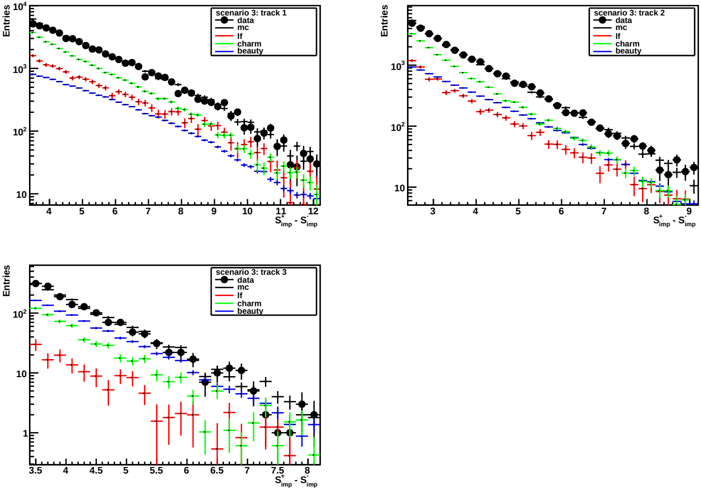


Figure: mirrored track significance for the highest, second and third highest significance track of scenario 3, note: c and b enrichment

Extraction of Differential Cross Sections

- Technique of mirroring and subtracting impact parameter significance distributions in order to minimise light flavour background
- Perform simultaneously a binned χ^2 fit of the MC to the data for the three different scenarios of track selection
- The differential cross section is then defined as:

$$\frac{d\sigma}{dv} = \frac{k_c \; N_c^{HL}}{\mathcal{L} \; \Delta v}, \qquad (1)$$

where k_c is the charm scaling factor, N_c^{HL} is the number of events generated on hadron level, $\mathcal{L}$ is the luminosity of the data sample and Δv refers to the width of the differential bin.

Differential Cross Sections $d\sigma/dQ^2$, $d\sigma/dx$

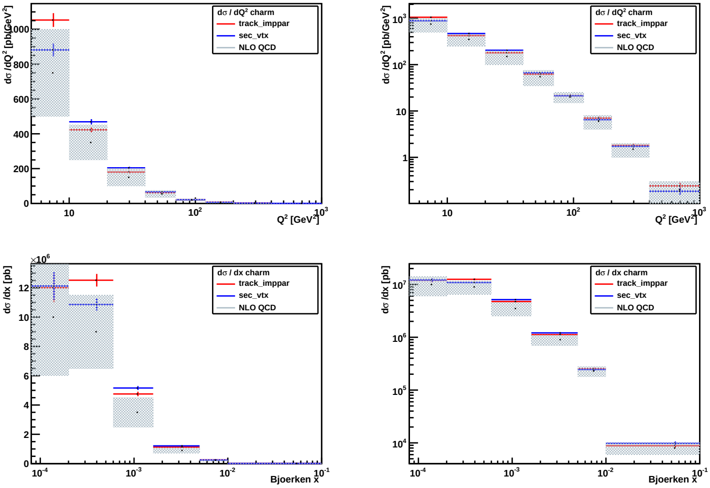


Figure: differential charm cross sections $d\sigma/dQ^2$ and $d\sigma/dx$ on linear and logarithmic scale, note: reasonable agreement with previous analysis

Differential Cross Sections $d\sigma/dx$ in bins of Q^2

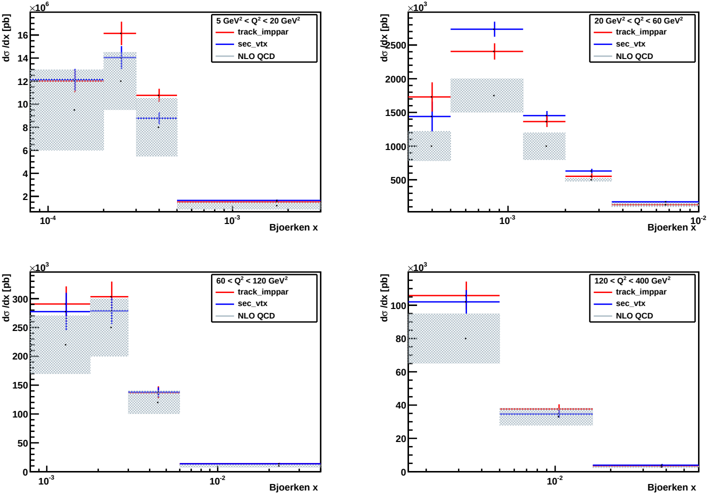


Figure: differential charm cross sections $d\sigma/dx$ in bins of Q^2

Summary

- A novel technique based on the track impact parameter has been developed to extract the charm content in DIS events
- Differential charm jet production cross sections as a functions of Q^2 and x have been measured with the ZEUS detector
- The measurement has been found to be in agreement with previous ZEUS measurements and HVQDIS predictions
- Extensions of the present analysis:
  - lower E_T^{jet} cut to 2.5 GeV
  - combine secondary vertex and tracking information
  - consider additional variables to be fed into neural network
- Aiming to make the ultimate $F_2^{c\bar{c}}$ measurement

Thank you very much for your attention!