Charm at HERA II

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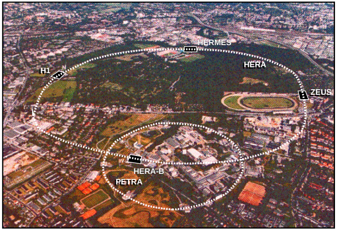
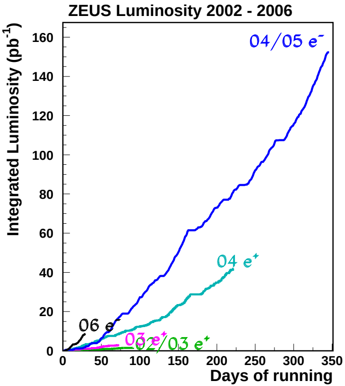
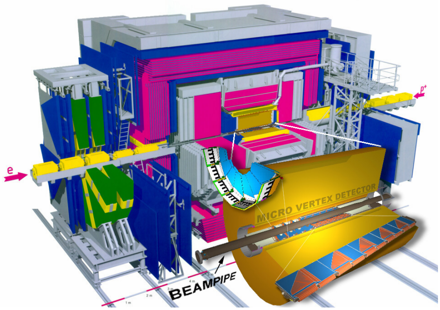
HERA



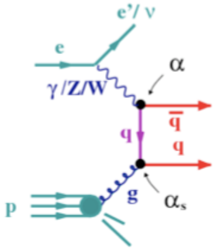


- World's only lepton-proton collider
- Collides leptons at 27.5 GeV with protons at 920 GeV
- Collisions are studied at ZEUS and H1
- Upgraded in 2000 to deliver luminosity at a faster rate
  - HERA I measurement: 82 pb^{-1}
  - HERA II: 200 pb^{-1} now, $>$ 400 pb^{-1} by end of running

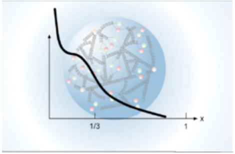


- During the HERA upgrade ZEUS was installed with a high precision silicon microvertex detector
- This device permits precision tracking near vertex
- Designed to make measurements of heavy quark production with minimal background.

Why measure $F_2^{c\bar{c}}$?



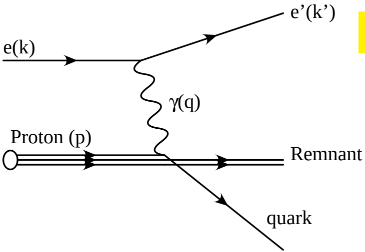
- The dominant source of charm production is Boson Gluon Fusion (BGF). $F_2^{c\bar{c}}$ measurements are therefore a sensitive probe of the poorly understood gluon content of the proton.
- Precise test of QCD and can be used to estimate hadronic σ
- New measurements will exploit ZEUS's new Micro-Vertex Detector to improve precision and will benefit from HERA II's superior luminosity.



- $F_2^{c\bar{c}}(x, Q^2)$ is the charm fraction of the proton structure function F_2. This is related to $\sigma^{c\bar{c}}$ by:

$$\frac{d^2\sigma^{c\bar{c}}(x,Q^2)}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4}\left[\left(1+(1-y)^2\right)F_2^{c\bar{c}}(x,Q^2) - y^2 F_L^{c\bar{c}}(x,Q^2)\right]$$

- $F_2^{c\bar{c}}(x, Q^2)$ dominates the cross section.
- $F_L^{c\bar{c}}(x, Q^2)$: QCD correction significant only at large y.
- $F_L^{c\bar{c}}(x, Q^2)$ will be ignored in our kinematic region.



Characterised by any 2 of:

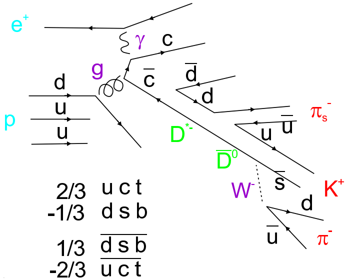
$$Q^2 = -\mathbf{q}^2 = (\mathbf{k} - \mathbf{k}')^2$$
$$W^2 = (\mathbf{P} + \mathbf{q})^2$$
$$x = \frac{\mathbf{Q}^2}{2\mathbf{P}\cdot\mathbf{q}}$$
$$y = \frac{\mathbf{P}\cdot\mathbf{q}}{\mathbf{P}\cdot\mathbf{k}}$$

- In the QPM a deep inelastic scatter may be expressed:

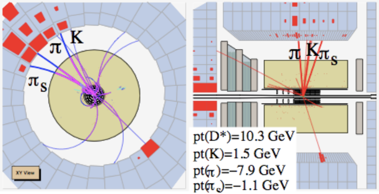
$$e(\mathbf{k}) + p(\mathbf{P}) \rightarrow e'(\mathbf{k}') + X(\mathbf{P}' = \mathbf{P} + \mathbf{q})$$

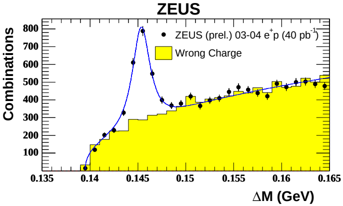
- Lorentz invariants may be interpreted as
  - Q^2: the resolving power of the exchange photon
  - x: fraction of proton momentum carried by struck quark
  - y: measure of the elasticity of the event.
    $1 =$ completely elastic and the proton has remained intact.

Principle



- Boson-gluon fusion is the dominant source of c quarks
- D^* decay is the channel used to measure $\sigma_{c\bar{c}}$
  - D^*'s are tagged by finding $D^* \longrightarrow (D^0 \longrightarrow k\pi)\pi_{\text{slow}}$
  - σ_{D^*} is obtained using
    - branching ratio for $D^* \longrightarrow k\pi\pi$ decay channel ≈ 0.026
  - $\sigma_{c\bar{c}}$ is obtained by extrapolating from the σ_{D^*}
    - fragmentation fraction $f(c \longrightarrow D^{*\pm}) \approx 0.200$



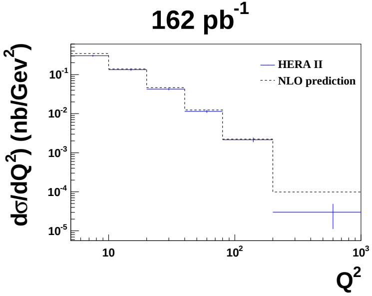


To evaluate $N(D^*)$

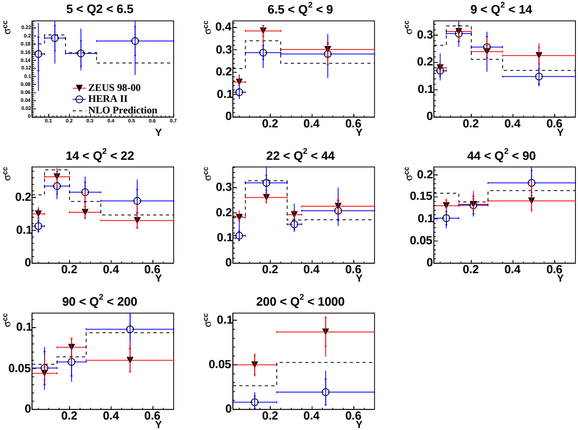
- The difference in energy between D^* and D^0 is *only just* sufficient to produce a (low momentum) π and little else.
- This is exploited by histogramming M(D^*)-M(D^0)
- A resonance is observed close to the threshold
- The number of D^* is obtained by counting entries in peak
- Combinatorial (like sign) background is shown in yellow

$\sigma_{c\bar{c}}$ is measured in the following kinematic region:

- $5 < Q^2 < 1000\mathrm{GeV}^2$
- $0.02 < y < 0.7$
- $|\eta(D^*)| < 1.5$
- $1.5 < P_T(D^*) < 15GeV$



- Q^2 variable covers 4 orders of magnitude
- Distribution looks close to NLO prediction



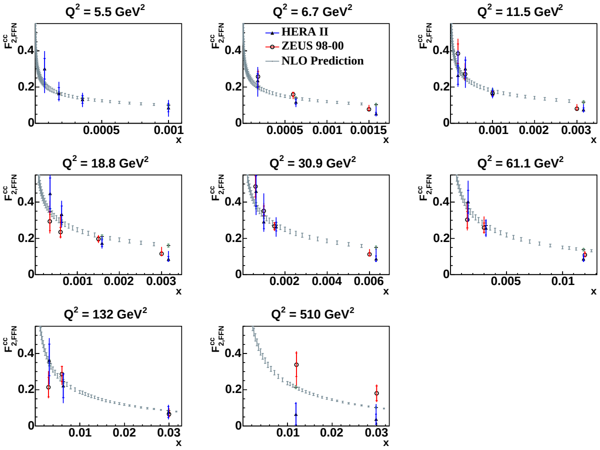
Each (Q^2, y) bin is used to interpolate an $F_2^{c\bar{c}}$ point
HERA II measurement is statistically limited by MC
NLO, published HERA I and new HERA II are in agreement

- $F_2^{c\bar{c}}(x, Q^2)$ is interpolated at the (x, Q^2) point at the center of gravity in each (Q^2, y) bin.
- This extraction is performed using

$$F^{c\bar{c}}_{2,\text{meas}}(x_i, Q_i^2) = \frac{\sigma^{c\bar{c}}_{i,\text{meas}}(ep \rightarrow D^*X)}{\sigma^{c\bar{c}}_{i,\text{theo}}(ep \rightarrow D^*X)} F^{c\bar{c}}_{2,\text{theo}}(x_i, Q_i^2)$$

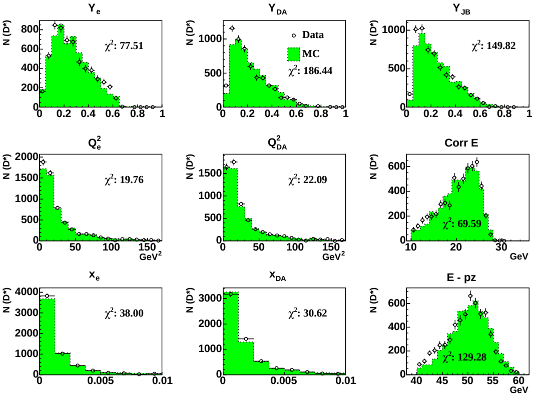
- The $\sigma^{c\bar{c}}_{i,\text{theo}}$ is generated by NLO QCD using the Fixed Flavour Number Scheme.
  - In FFNS charmed quarks are generated only by BGF.
- $F^{c\bar{c}}_{2,\text{theo}}$ is NLO QCD prediction with uncertainties arising from DGLAP evolved gluon PDFs

Extraction



HERA II agrees well with FFNS prediction and HERA I results.

Control plots of the DIS event parameters

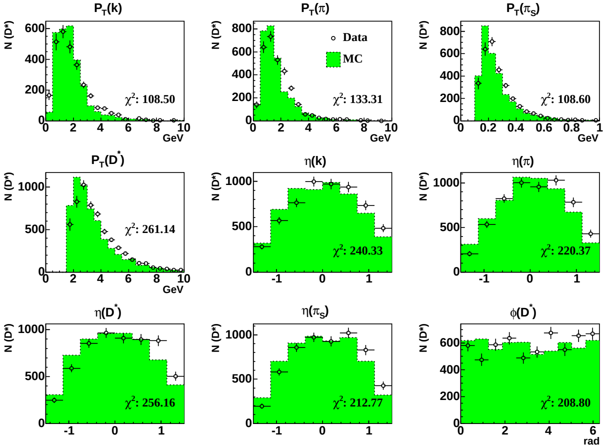


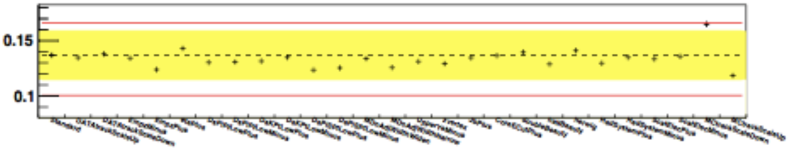
A complete measurement requires systematic errors

Will gauge the degree to which the data is understood

These parameters represent estimates of the event kinematics

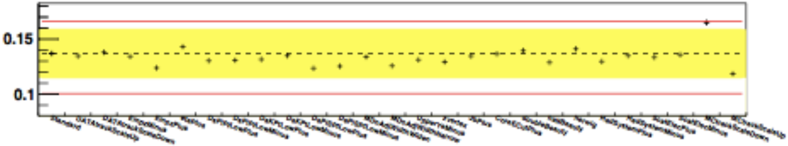
Control plots of the D^* parameters





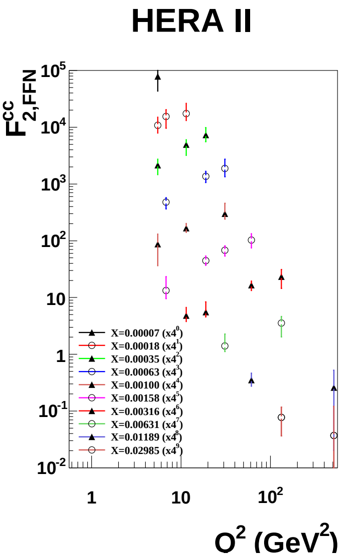
To measure systematics

- Adjustments are made to a number of parameters (track resolution, energy distributions etc) and the effect on $F_2^{c\bar{c}}$ is recorded.
- These shifts are separated into $+$ve and $-$ve contributions and added in quadrature separately.
- This is then combined with the statistical error to form an overall uncertainty.



To measure systematics

- 26 systematics have been looked at so far which can be classified according to those associated with
  - Event reconstruction
  - Track reconstruction
  - Agreement between Data and MC



If there were no gluons in the proton:

- Proton = $uu\bar{d}$ only
- Structure function will scale at high Q^2

The presence of gluons in the proton:

- Contribution to $F_2^{c\bar{c}}$ at low x
- $F_2^{c\bar{c}}(x) \longrightarrow F_2^{c\bar{c}}(x, Q^2)$

This measurement confirms scaling violations occur at low x and so the presence of gluons in the proton is confirmed

Conclusions and outlook...

- $F_2^{c\bar{c}}$ has been measured at HERA II with statistical errors
  - Work is underway to evaluate and reduce systematic errors
- Tools are being constructed to increase statistics by measuring $F_2^{c\bar{c}}$ in other ways using
  - Impact parameters
  - Other decay modes
- These measurements of $F_2^{c\bar{c}}$ can be fed back into theoretical fits to further constrain our knowledge of gluon PDFs.