Charm production in DIS (and $\gamma p$) at HERA

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- Introduction
- $D^*$ production in DIS
- Inclusive charm production in DIS
- Charm fragmentation fractions ($\gamma p$)
- Conclusions
The HERA ep collider and experiments

HERA I: \( \sim 130 \text{ pb}^{-1} \) (physics)

HERA II: \( \sim 380 \text{ pb}^{-1} \) (physics)

combined: \( \sim 2 \times 0.5 \text{ fb}^{-1} \)
Kinematics of Deep Inelastic Scattering (DIS)

HERA:

\[ q = \ell - \ell' \]

**kinematic variables:**

- \( Q^2 = -q^2 \): photon (or Z) virtuality, squared momentum transfer
- \( x = \frac{Q^2}{2Pq} \): Bjorken scaling variable,
  for \( Q^2 \gg (2m_q)^2 \): momentum fraction of p constituent
- \( y = \frac{qP}{\ell P} \): inelasticity,
  \( \gamma \) momentum fraction (of e)

\[ Q^2 \lesssim 1 \text{ GeV}^2: \text{photoproduction} \]
\[ Q^2 \gtrsim 1 \text{ GeV}^2: \text{DIS} \]

28. 6. 08
A. Geiser, QCD at the HERAscale, PIC08
Why are heavy flavours important?

- charm contribution to DIS data up to 40%!

- **kinematic effect of mass**

- **competing scales for perturbative expansion**

  e.g. \( m, Q^2, p_T \) -> terms \( \log \frac{Q^2}{m^2} \) \( \log \frac{p_T^2}{m^2} \) etc.

  \[ \uparrow \]

  => "massless" treatment allows resummation, but fails near "mass threshold" -> avoid!

  => "massive" treatment gets kinematics right, but does not allow resummation (fixed flavour number schemes) or induces ambiguities in QCD corrections near flavour threshold (variable flavour number schemes)

**check different schemes against HERA data**
**D* production in DIS**

\[ Q^2 > 5 \text{ GeV}^2, \ 0.02 < y < 0.7 \]

**H1**

- H1 data
- WC comb.
- Sig+Bg Fit
- \( 24705 \pm 343 \text{ D}^* \)

\[ |\eta(\text{D}^*)| < 1.8 \]
\[ p_T(\text{D}^*) > 1.25 \text{ GeV} \]

**large statistics!**


**ZEUS**

\[ D^* \rightarrow K\pi\pi_\gamma \]
- ZEUS (prel.) 357 pb\(^{-1}\)
- Wrong-sign background
- Signal region

\[ |\eta(\text{D}^*)| < 1.5 \]
\[ p_T(\text{D}^*) > 1.5 \text{ GeV} \]

**H1 slightly larger phase space**

**ZEUS slightly better mass resolution**

6. 7. 12

A. Geiser, charm at HERA, ICHEP12
good agreement between H1 and ZEUS and with NLO QCD (massive differential predictions only available in fixed flavour number scheme)
D* cross section vs. pseudorapidity $\eta$

- good agreement between experiments
- tendency for somewhat more forward D*s than NLO QCD predicts?
D* cross section vs. $Q^2$

- **H1**
  - $d\sigma / dQ^2$ [nb/(GeV$^2$)]
  - $R_{\text{norm}}$
  - $Q^2$ [GeV$^2$]

- **ZEUS**
  - $d\sigma / dQ^2$ (pb/(GeV$^2$))
  - $Q^2$ (GeV$^2$)

- Good agreement between experiments and with NLO QCD
good agreement between experiments and with massive NLO QCD calculations
massless NLO calculation (ZM-VFNS) fails at low $y$
D* double differential cross sections

now H1 in same phase space as ZEUS

\[ Q^2 = 5-9 \text{ GeV}^2 \]
\[ Q^2 = 9-14 \text{ GeV}^2 \]
\[ Q^2 = 14-23 \text{ GeV}^2 \]
\[ Q^2 = 23-45 \text{ GeV}^2 \]
\[ Q^2 = 45-100 \text{ GeV}^2 \]
\[ Q^2 = 100-158 \text{ GeV}^2 \]
\[ Q^2 = 158-251 \text{ GeV}^2 \]
\[ Q^2 = 251-1000 \text{ GeV}^2 \]

ep → e' D* X

- ZEUS (prel.) 357 pb\(^{-1}\)
- HVQDIS + RAPGAP \(b \times 1.52\)
- RAPGAP \(b \times 1.52\)
- H1 D*
- H1 D* (high \(Q^2\))

good agreement!

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Charm in DIS from inclusive secondary vertices

ZEUS

Entries

$1.4 < M_{\text{VTX}} < 2 \text{ GeV}$

- ZEUS (prel.) $354 \text{ pb}^{-1}$
- Monte Carlo
- LF
- Charm
- Beauty

asymmetry of vertex significance distribution well described
Charm cross section, incl. sec. vtx

Access higher $p_T$, $\eta$, and $Q^2$; same conclusions as from $D^*$ data

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Heavy flavour contributions to $F_2$

Measure cross section

$$\frac{d^2\sigma}{dx\,dQ^2} \approx \frac{2\pi\alpha^2}{Q^4x} \left[1 + (1 - y)^2\right] F_2(x, Q^2)$$

$e^+ \rightarrow \text{detect} \quad Q^2, \ x = Q^2/2pq$

$p \rightarrow \text{anything}$

$e^+ \rightarrow \text{flavour tagging} \quad Q^2, \ x \quad b, \ \bar{b} \text{ or } c, \ \bar{c}$

$F_2^{bb}, F_2^{cc}$

QCD

27.6 GeV

$Q^2$

$\sqrt{\alpha_s}$

$g(x)$

920 GeV

$p \rightarrow b, \ c \quad \bar{b}, \ \bar{c}$
good agreement between all data sets, and with theory

use to constrain PDFs and to measure the charm mass (in preparation)

variable flavour number scheme, works
charm fragmentation fractions

Charm Fragmentation Fractions
ZEUS-prel-12-003

precision competitive with e+e-
consistent with universality

- $f (c \rightarrow D^0)$
- $f (c \rightarrow D^+)$
- $f (c \rightarrow D^{*+})$
- $f (c \rightarrow D_s)$
- $f (c \rightarrow \Lambda_c)$

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Summary and conclusions

- different measurements of charm production in DIS yield good agreement with each other and with NLO theory
  -> allows to further constrain PDFs and measure charm mass
  (ongoing work, see also talk R. Plačakytė)
  -> better predictions for processes at HERA, Tevatron, and LHC

- recent measurement of charm fragmentation fractions in charm photoproduction competitive with $e^+e^-$ and consistent with universality

- most HERA results now available with full HERA statistics, but final results, in particular H1-ZEUS combinations, still to come.