H1 and ZEUS Results on $F_2^{c\bar{c}}$ and $F_2^{b\bar{b}}$

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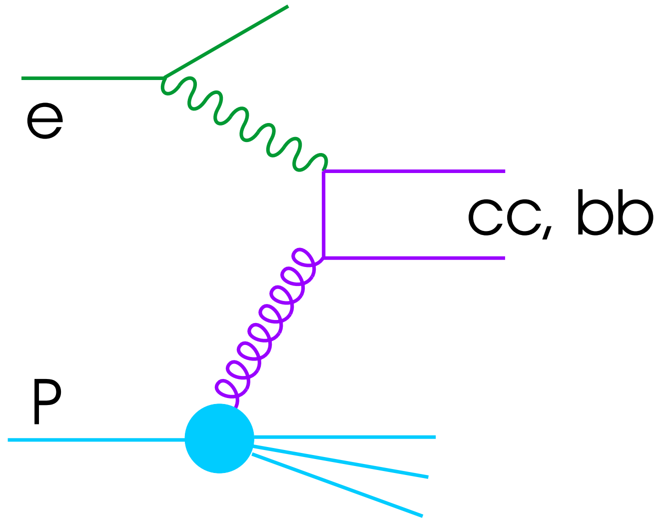
- Introduction
- Previous measurements of c and b
- Motivation for inclusive analyses
- Results

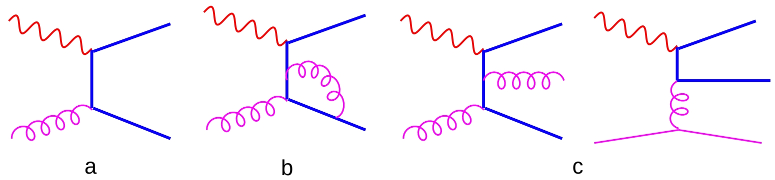
Heavy Flavour Production at HERA



- Heavy flavours directly sensitive to gluon of proton and photon. Understand production mechanisms and constrain PDFs.
- Charm and beauty contributions $F_2^{c\bar{c}}$ and $F_2^{b\bar{b}}$
- Low Q^2 DIS $Q^2 \geq 1\ \mathrm{GeV}^2$.
- High Q^2 DIS $Q^2 \geq 100\ \mathrm{GeV}^2$

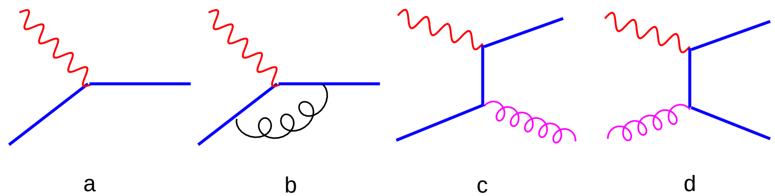
NLO QCD Treatments for Inclusive Cross Section

"massive" - Fixed Flavour Number Scheme



FFNS: $$\sigma_{ep\to HX} = \sum_{a = \text{light partons only}} f_p^a(x_a,\mu) \otimes \hat{\sigma}^{FFNS}_{ea\to HX}(\hat{s}, Q, m_H, \mu)$$

"massless" - Zero Mass Variable Flavour Number Scheme



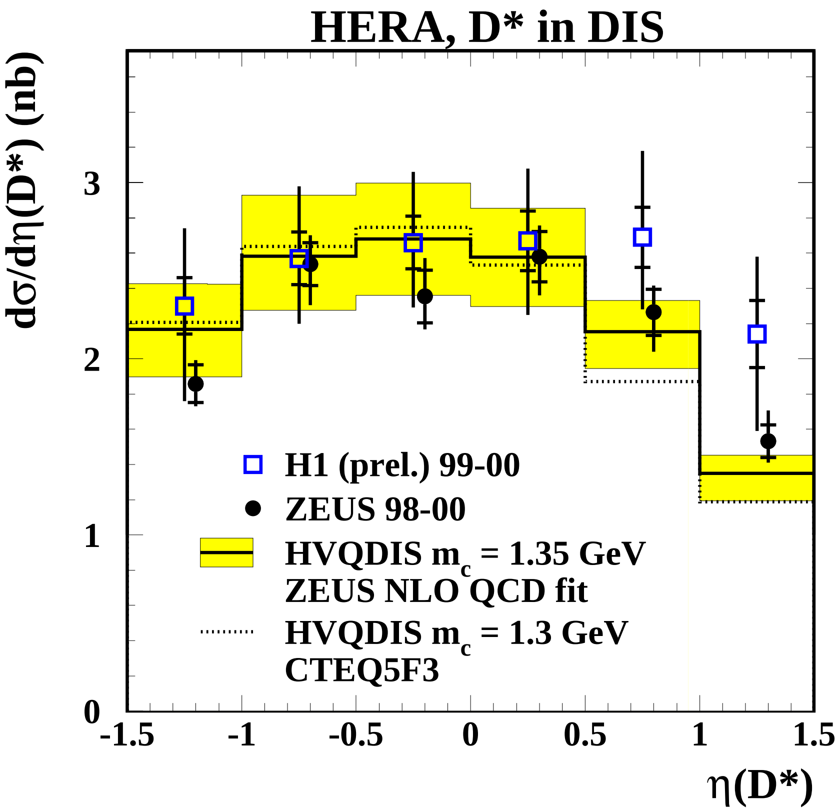
ZM-VFNS: $$\sigma_{ep\to CX} = \sum_{a = \text{all active partons}} f_p^a(x_a,\mu) \otimes \hat{\sigma}_{ea\to CX}(\hat{s}, Q, \mu)\,\Big|^{\overline{MS}}_{m_a=0}$$

Variable FNS: Interpolate between massive ($Q^2 \sim M^2$) and massless ($Q^2 \gg M^2$) avoiding double counting etc. ACOT(CTEQ), MRST.

Charm Production

- At HERA, measurements mainly from $D^* \longrightarrow K\pi\pi_s$
  Branching fraction
  $f(c \rightarrow K\pi\pi) < 1\%$
- Charm production in DIS at HERA generally well described by massive NLO QCD (BGF)

For more details on latest charm results see talk from Manuel Zambrana.

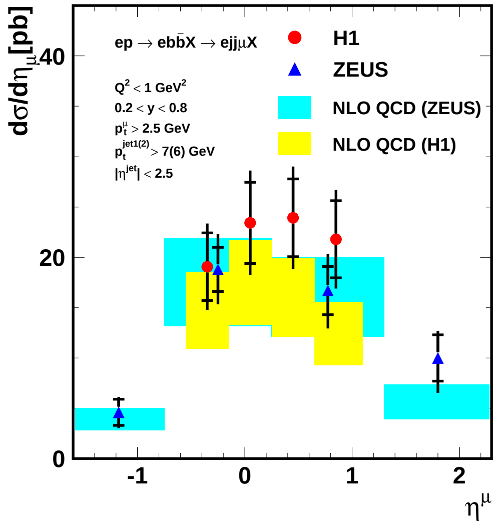


Extraction of $F_2^{c\bar{c}}$

$$F_{2\ \mathrm{meas}}^{c\bar{c}}(x,Q^2) = \frac{\sigma_{\mathrm{meas}}(ep \to D^* X)}{\sigma_{\mathrm{theory}}(ep \to D^* X)} F_{2\ \mathrm{theory}}^{c\bar{c}}(x,Q^2)$$

- Extraction of $F_2^{c\bar{c}}$ from measured cross section to full phase space using consistent 'massive' NLO QCD scheme (HVQDIS program).
- Extrapolation factors $(4.7 - 1.5)$ in p_T and η decreasing with Q^2
- Uncertainties in extrapolation due to fragmentation, charm mass, PDF are typically around 10% ($< 20\%$).

Beauty Measurements



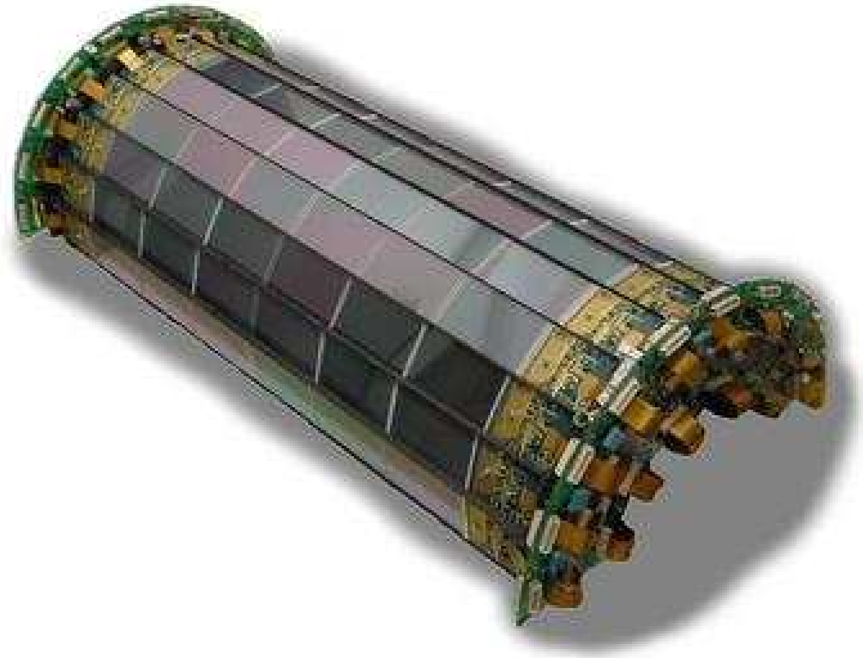
- At HERA beauty cross section measurements made using exclusive final state (typically with high p_T lepton μ,e and a jet).
- Reasonable agreement between different methods, H1 and ZEUS.
- Comparisons with with 'massive' NLO QCD calculations using CTEQ5F PDF. Data tend to be somewhat higher than theory.

For more details on latest HERA beauty measurements see talk from C. Grab

Motivation for Inclusive Analysis

- Exclusive method e.g. D^*, μ limited by statistics at high Q^2
- Reconstructing explicitly the secondary vertex is difficult considering statistics. Use the silicon-improved impact parameter measurements for all tracks. Similar to multi-impact parameter method from ALEPH (Phys. Lett. B 313 (1993) 535.)
- The technique uses fact that the lifetime of heavy flavours is largely model independent, reducing model uncertainties.
- Using inclusive quantities of all tracks at low p_T means there are smaller extrapolations in p_T,η.
- Acceptance for at least 1 generated charged track in central acceptance $> 82\%$ for c and $> 96\%$ for b.

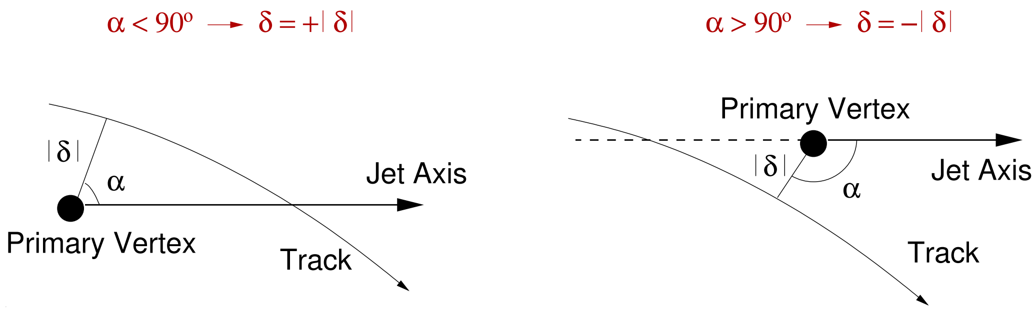
H1 Vertex Detector - CST



- Hit resolutions of $12\ \mu$m in r–ϕ and $25\ \mu$m in z.
- Momentum resolution $33\ \mu\text{m} \oplus 90\ \mu\text{m}/p_T[\text{GeV}]$
- Around 75% efficiency for a Jet Chamber track to be fitted to CST hits in both layers.

Technique

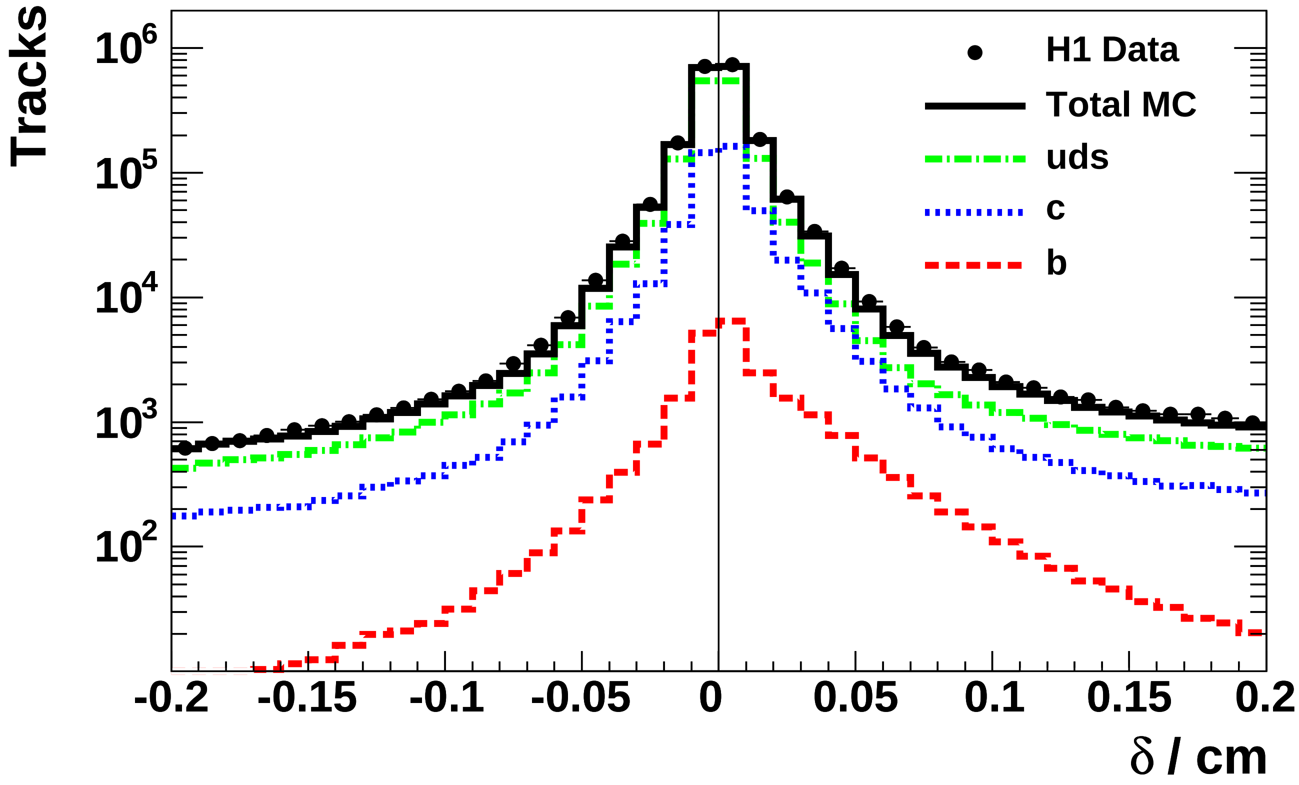
Look at the signed impact parameter for all tracks with precise measurement from central silicon tracker (CST)



- Events with secondary vertex decays from heavy flavour particles will have large positive impact parameter w.r.t. primary vertex
- Light flavour primary decays will have small negative and positive impact parameter due to resolution effects
- Jet direction given by direction of jet or estimate of struck quark direction. Restrict to regions with high jet fractions ($> 80\%$).
- Match tracks to jet axis in ϕ or $\eta - \phi$ depending on low/high Q^2.

DCA (δ)

For each track within each jet, plot DCA to primary vertex in $r\phi$ plane (δ)



Tracks required to have $|\delta| < 1$ mm (remove e.g. K^0s).

Significance Distributions $S_i = \frac{\delta}{\sigma(\delta)}$

Define 3 significance distributions as:

S_1 - highest significance track

S_2 - 2^{nd} highest absolute significance track

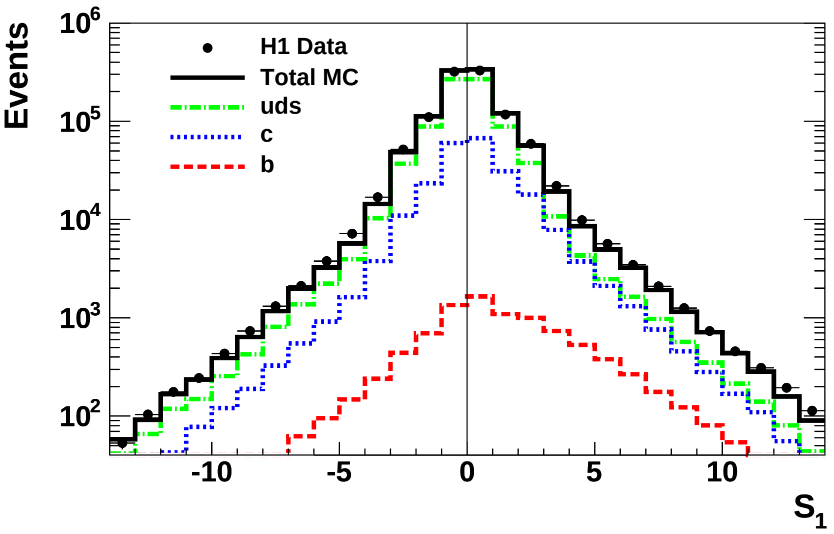
S_3 - 3^{rd} highest absolute significance track

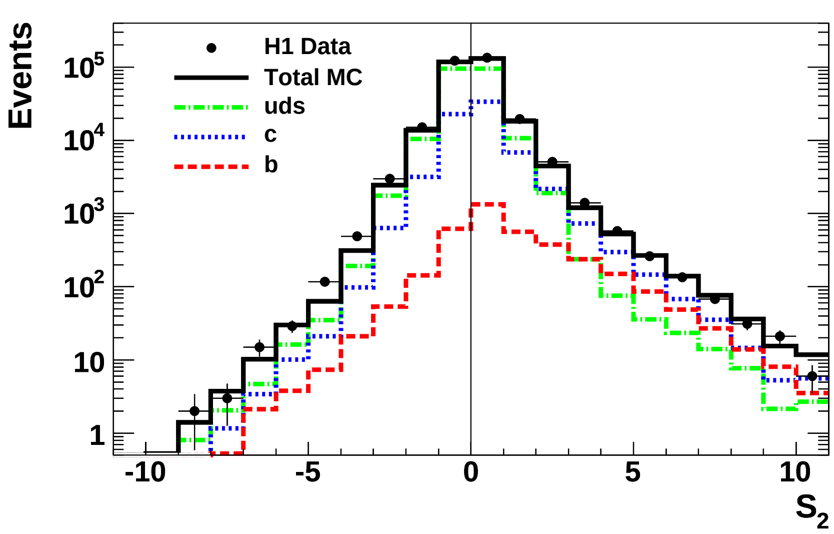
Further reduce light quark background

$\longrightarrow$ Only consider S_2 events if they have the same significance sign as S_1.
$\longrightarrow$ Only consider S_3 events if they have the same significance sign as S_1,S_2

Similar technique used at high Q^2 with S_1 and S_2 only due to higher b fraction.

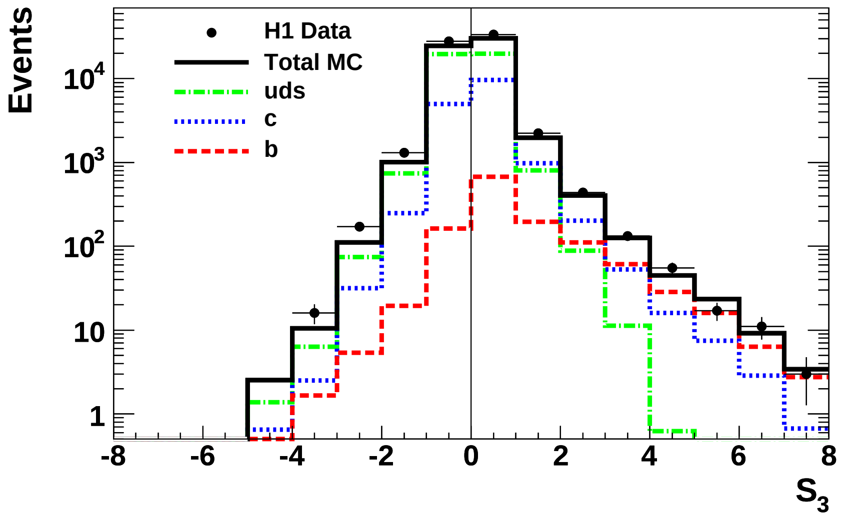
Siginificance at low Q^2



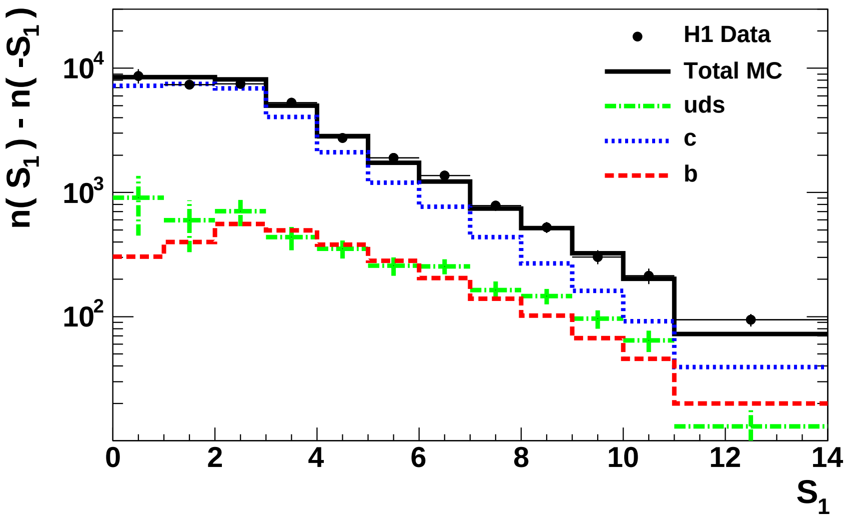


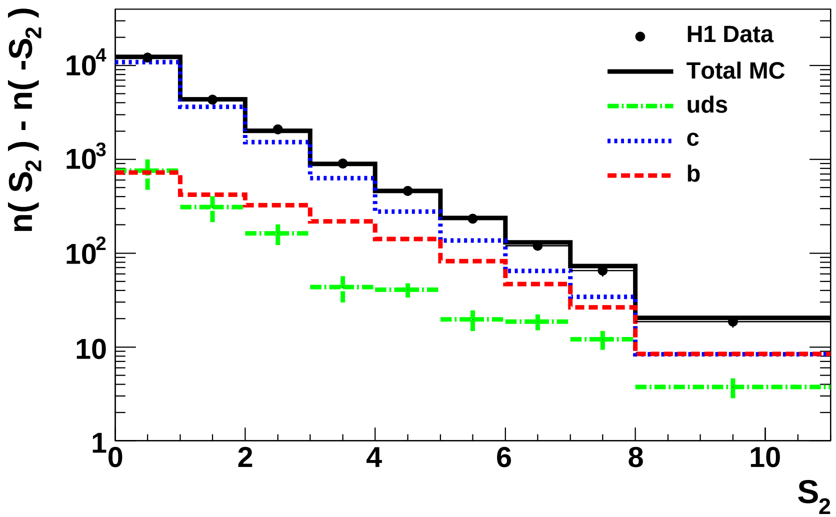
Separation improved

Could fit these distributions but would be sensitive to systematic uncertainties in resolution from dominating uds contribution.



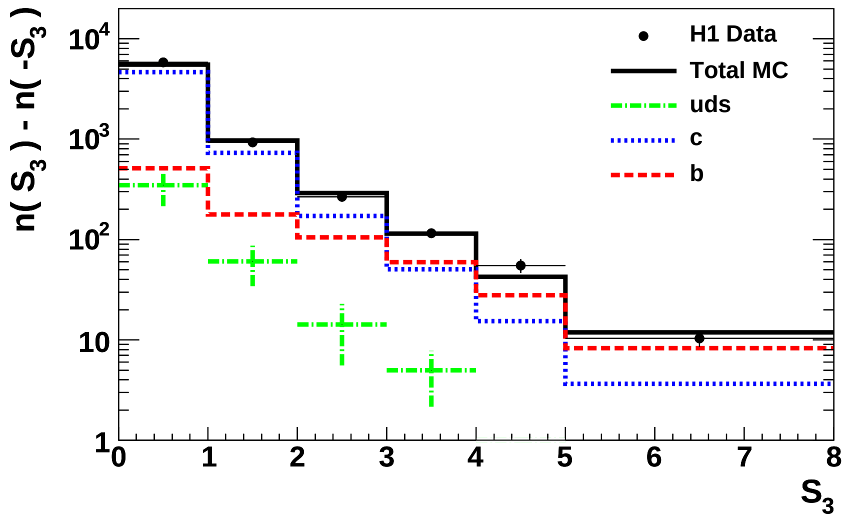
Negative Subtraction for S_i





Subtract the negative S_i bins from the positive for both data and MC to reduce sensitivity to resolution of light quarks

Small reduction in statistical accuracy for c and b



Fitting Method

Three parameter fit

- MC scale factor c - P_c
- MC scale factor b - P_b
- MC scale factor uds - P_l

to

- S_1,S_2 and S_3
- All events in each x,Q^2 bin ($N^{\mathrm{data}}_{\mathrm{TOT}}$, $N^{\mathrm{MC}}_{uds\mathrm{TOT}}$, $N^{\mathrm{MC}}_{c\mathrm{TOT}}$, $N^{\mathrm{MC}}_{b\mathrm{TOT}}$)

$$\frac{\mathrm{d}\sigma^{c\bar{c}}}{\mathrm{d}x\mathrm{d}Q^2} = \frac{\mathrm{d}\sigma}{\mathrm{d}x\mathrm{d}Q^2}\frac{P_c N_c^{\mathrm{MCgen}}}{P_c N_c^{\mathrm{MCgen}} + P_b N_b^{\mathrm{MCgen}} + P_l N_l^{\mathrm{MCgen}}}$$

'Reduced' cross section

$$\tilde{\sigma}^{c\bar{c}}(x, Q^2) = \frac{\mathrm{d}^2\sigma^{c\bar{c}}}{\mathrm{d}x\,\mathrm{d}Q^2}\frac{xQ^4}{2\pi\alpha^2(1+(1-y)^2)},$$

$\tilde{\sigma}^{c\bar{c}}$

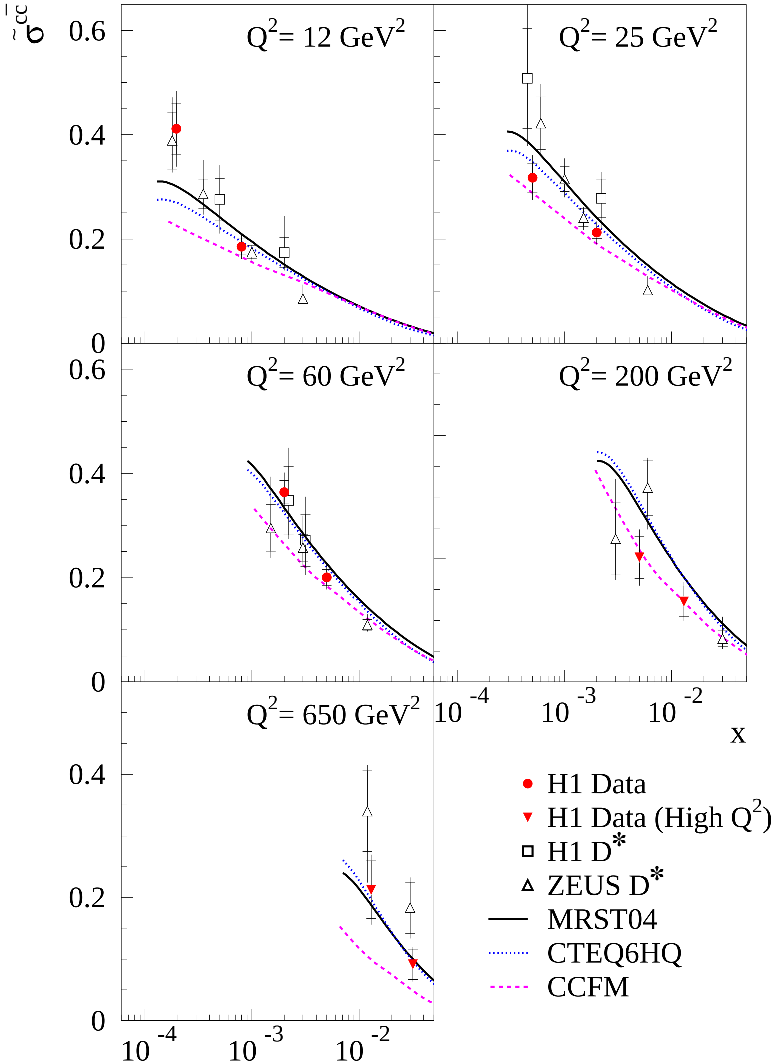
Consistent results with
H1 and ZEUS D^* measurements

Consistent with QCD predictions.

MRST04 - NLO QCD Variable FNS

CTEQ6HQ - NLO QCD Variable FNS

CCFM - Cascade MC



$\tilde{\sigma}^{b\bar{b}}$

First measurements of inclusive b cross section

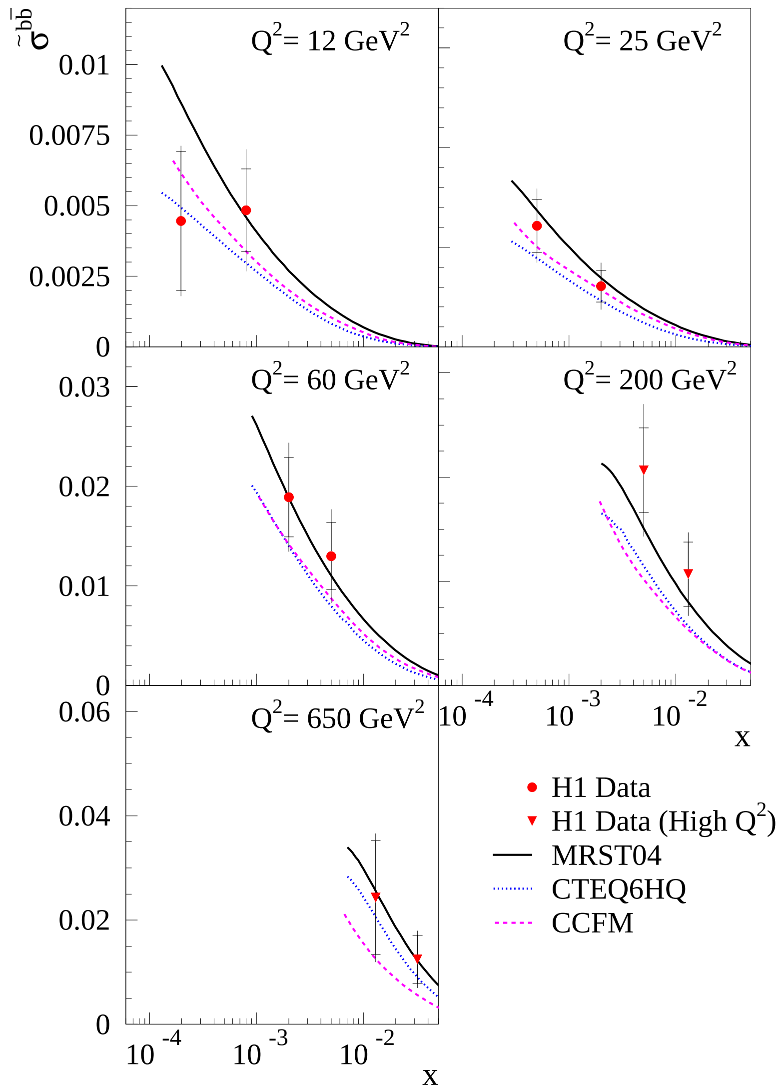
Large differences in NLO QCD predictions at low Q^2.
Threshold treatments? Gluon density?

Data errors consistent with all QCD predictions.

MRST04 - NLO QCD Variable FNS

CTEQ6HQ - NLO QCD Variable FNS

CCFM - Cascade MC



Contribution to σ

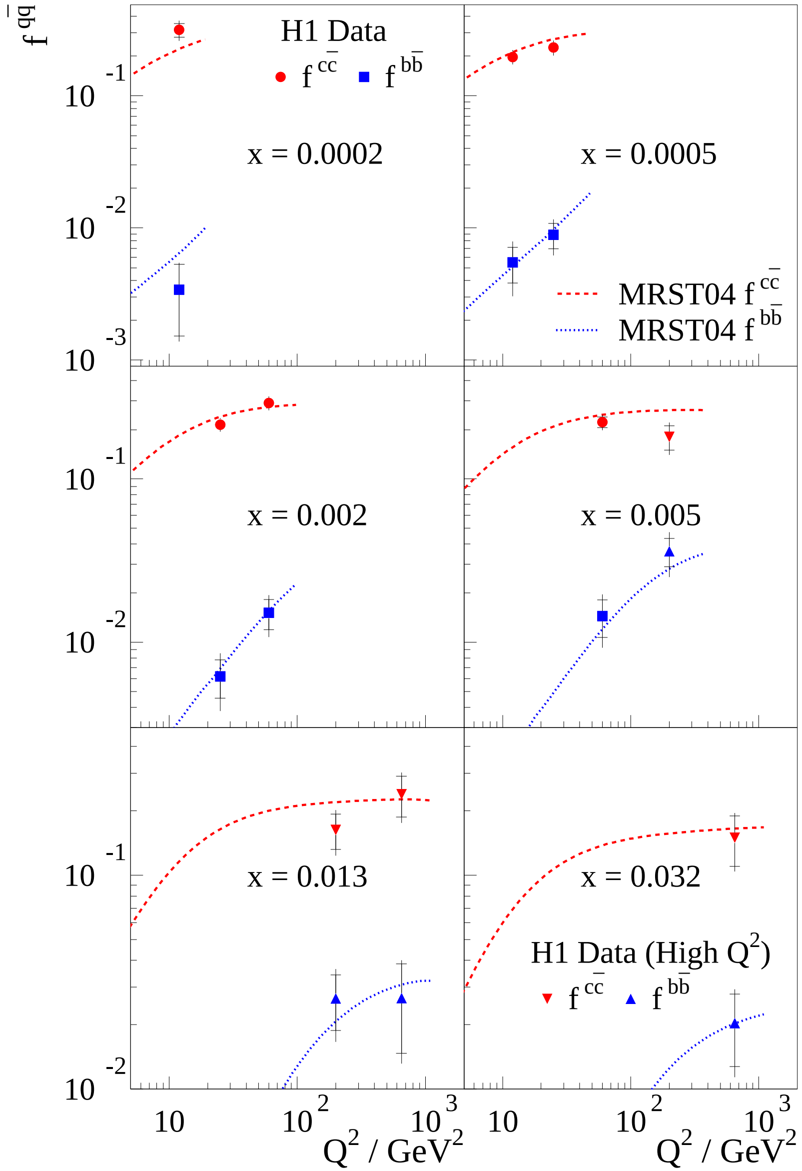
$$f_{q\bar{q}} = \frac{\mathrm{d}\sigma^{q\bar{q}}/\mathrm{d}x\mathrm{d}Q^2}{\mathrm{d}\sigma/\mathrm{d}x\mathrm{d}Q^2}$$

In this kinematic range:

Charm contributes around $15 - 30\%$ of the total cross section.

Beauty contributes $0.3 - 3.5\%$. Threshold effect!

Reasonable description by NLO QCD



Conversion to $F_2^{c\bar{c}}$ and $F_2^{b\bar{b}}$

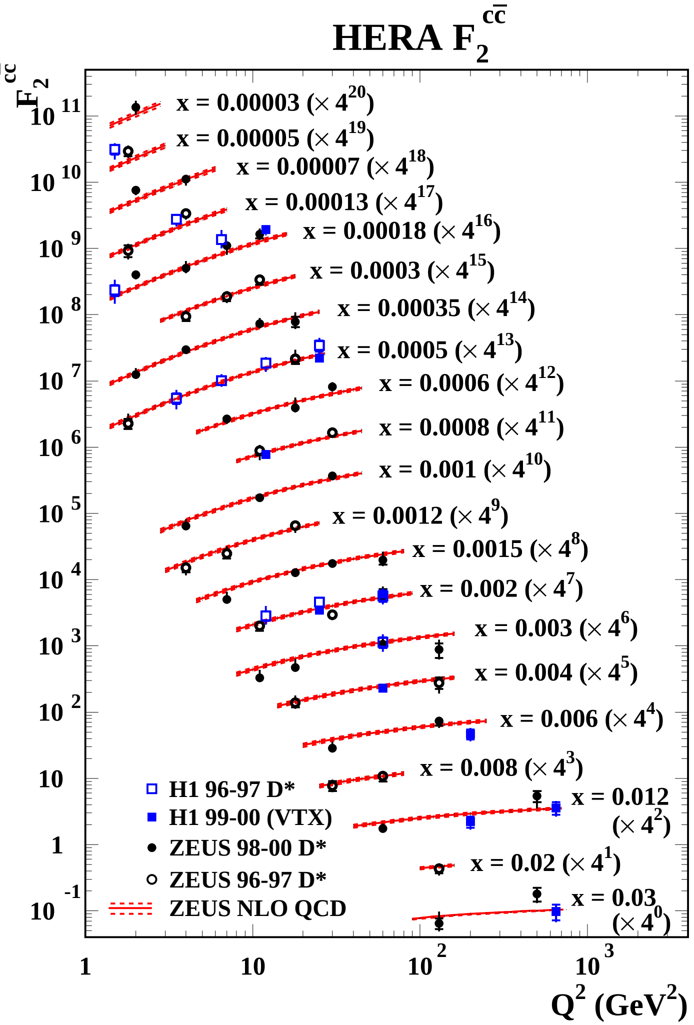
$$\frac{\mathrm{d}\sigma^{c\bar{c}}}{\mathrm{d}x\mathrm{d}Q^2} = \frac{2\pi\alpha^2}{xQ^4}((1+(1-y)^2)F_2^{c\bar{c}} - y^2 F_L^{c\bar{c}}),$$

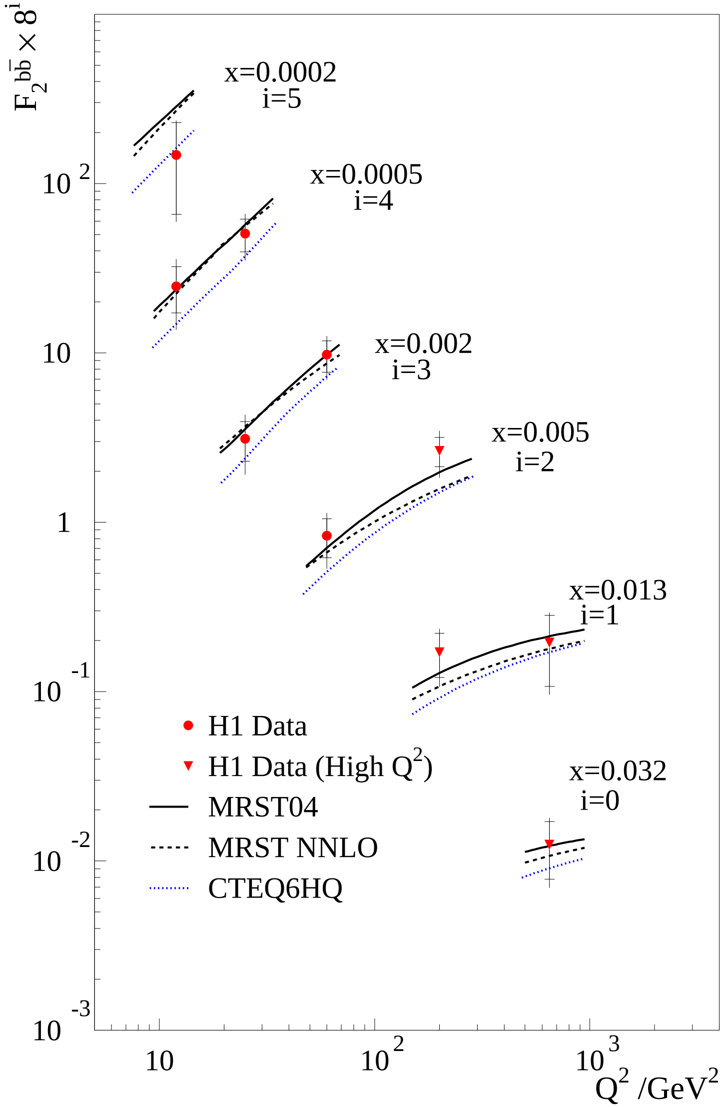
Use NLO QCD expectation for small contribution of $F_L^{c\bar{c}}$. For lower x i.e. higher y bins 3% (5%) correction for $c(b)$.

Bin centre Correction

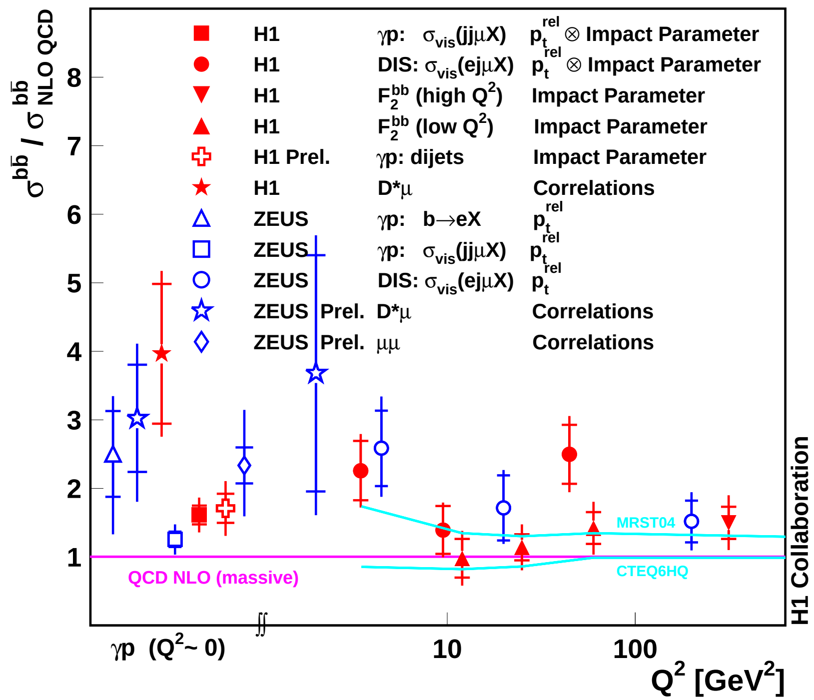
Bin centre correction using NLO fit. Corrections $2\% - 3\%$.

$F_2^{q\bar{q}}$ vs Q^2





Beauty Production at HERA



Reasonable agreement between experimental methods

Large difference in predictions from different QCD calculations for inclusive predictions.

Perhaps improves agreement for final state calculations?
As yet no final state NLO program that works with VFNS-PDFs available.

Summary

- Measurements of $F_2^{c\bar{c}}$ and $F_2^{b\bar{b}}$ at HERA
- Measurement of Inclusive c and b cross sections using technique based on lifetime of the heavy quark decay products presented
- New $F_2^{c\bar{c}}$ results compatible with D^* method
- $F_2^{c\bar{c}}(x, Q^2)$ measurements more precise than spread in NLO QCD predictions.
- Large differences in predictions for $F_2^{b\bar{b}}(x, Q^2)$. We require final state predictions using latest theory!
- HERA-II. Improve statistical precision, especially at high Q^2.