Measurement of $F_2^{c\bar{c}}$ and $F_2^{b\bar{b}}$ at High Q^2 using the H1 Vertex Detector at HERA

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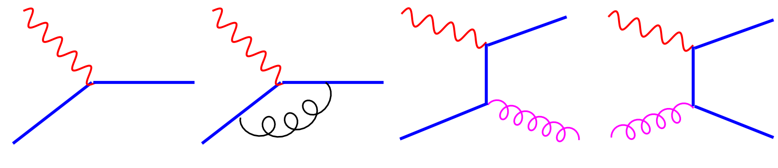
Details of recently published analysis (hep-ex/0411046 accepted Eur. Phys. J)

- Analysis Method
- Results at High Q^2
- Extending to low Q^2 - NLO QCD predictions

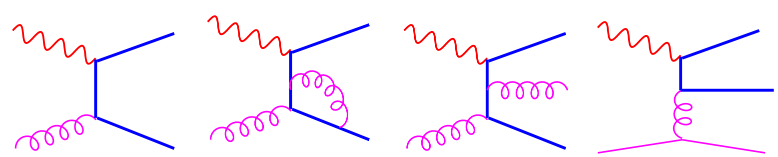
NLO QCD Treatments for Inclusive Cross Section

"massless" - Zero Mass Variable Flavour Number Scheme $Q^2 \gg M^2$



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

"massive" - Fixed Flavour Number Scheme $Q^2 \sim M^2$



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

Variable FNS: Interpolate between massive and massless avoiding double counting etc. ACOT(CTEQ), MRST.

VFNS

Why VFNS?

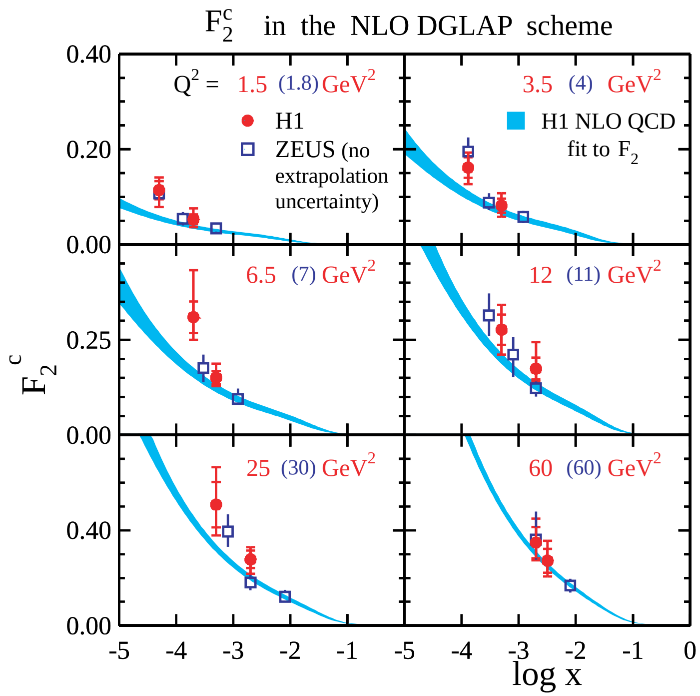
- Preferred scheme for use in precision QCD global fitting e.g. MRST,CTEQ,ZEUS of various inclusive and exclusive data
- Could use a ‘massive’ VFNS but NLO calculations of jet processes and Drell Yan do not yet exist

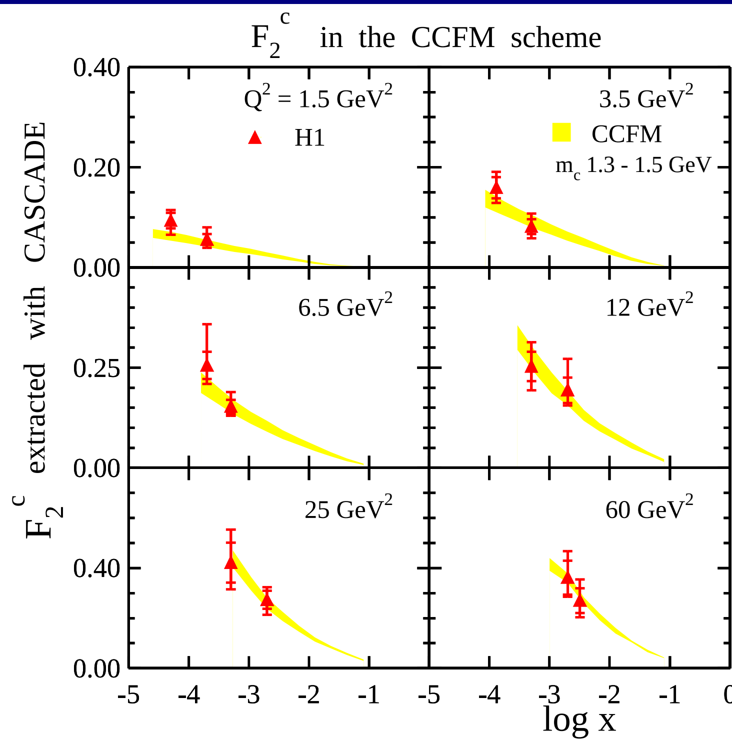
The HFS predictions are being left behind . . .

- Lack of compatible final state program to use latest VFNS PDFs
- CTEQ5F3(4) likely to be the last massive PDFs
- Massive Heavy flavour NLO QCD programs e.g. HVQDIS are technology from ~ 5 years ago
- LHC/HERA Workshop chance for progress?

Experimentalists: Use only massive PDFs in the correct scheme for HVQDIS/FMNR predictions!

Charm Production





At HERA, measurements mainly from $D^* \to (K\pi)\pi_s$

Large correction factors $(5 - 1.5)$ in p_T and η when going from hadron level to inclusive $c\bar{c}$ cross section.

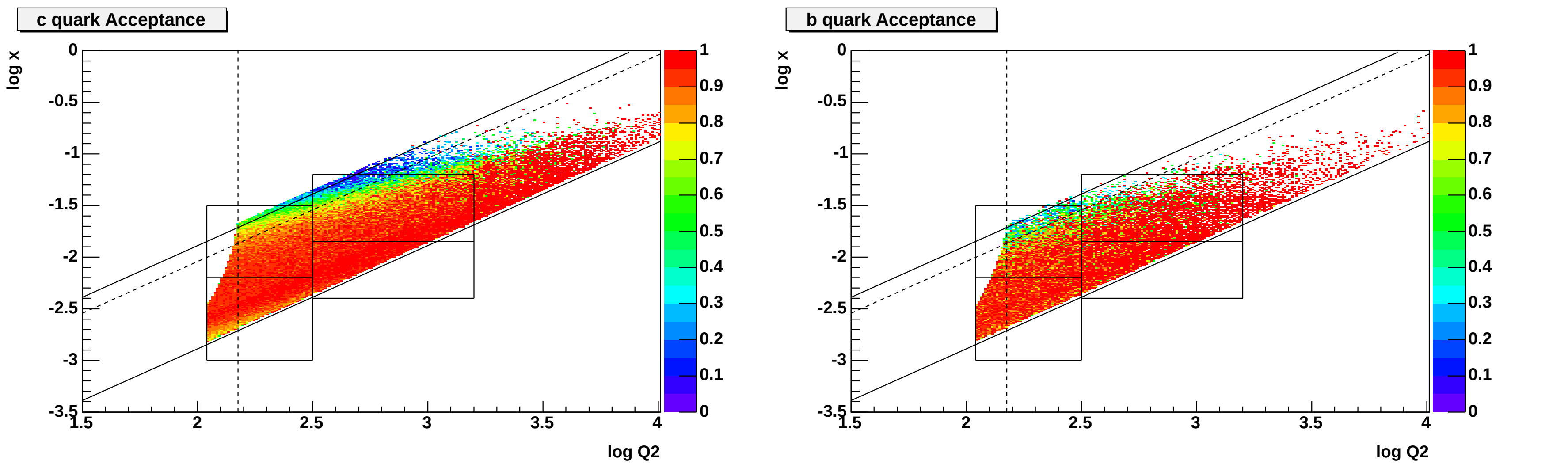
Leads to differences as large as 20% at low x and low Q^2 when using different models to extrapolate (HVQDIS/CASCADE)

Motivation for Analysis

- Aim to make a measurement of charm and beauty at high Q^2
- Exclusive method e.g. D^*, μ limited by statistics at high Q^2
- This analysis make an inclusive measurement using Jet chamber tracks with Central Silicon Tracker (CST) hits.
- Reconstructing explicitly the secondary vertex is also limited by statistics. Use CST-improved impact parameter measurements for all tracks. Similar to multi-impact parameter method from ALEPH (Phys. Lett. B 313 (1993) 535.)
- Using inclusive quatities of all tracks at low p_T means there are no large extrapolations in p_T,η.
- The technique uses fact that the lifetime of heavy flavours is largely model independent, reducing model uncertainties.
- Challenging experimentally - b typically $< 5\%$ of the cross section

Log x vs. Log Q^2 Acceptance

Acceptance for a c or b quark to be in CST acceptance ($30 < \theta < 150^{\rm o}$, $p_T > 0.5$ GeV) and generated z-vertex within ± 20 cm.



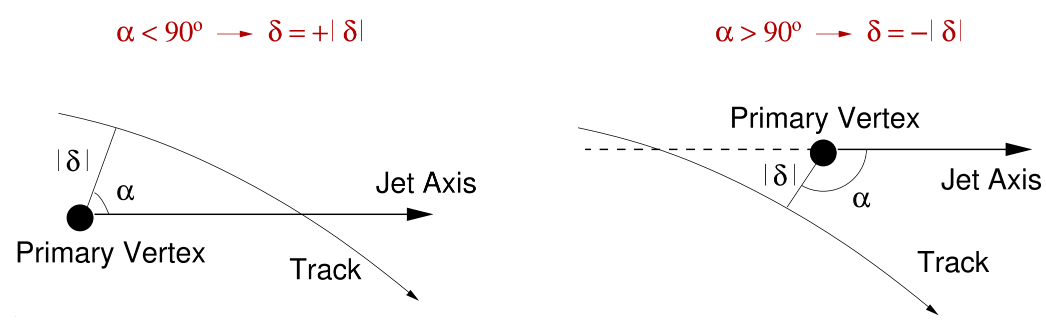
Acceptance for quarks $c \simeq b \sim 95\%$ at lower x and $c \sim 85\%$ at higher x

Acceptance for generated charged track from decay of heavy hadron $\sim 95\%$

No large extrapolations

Technique

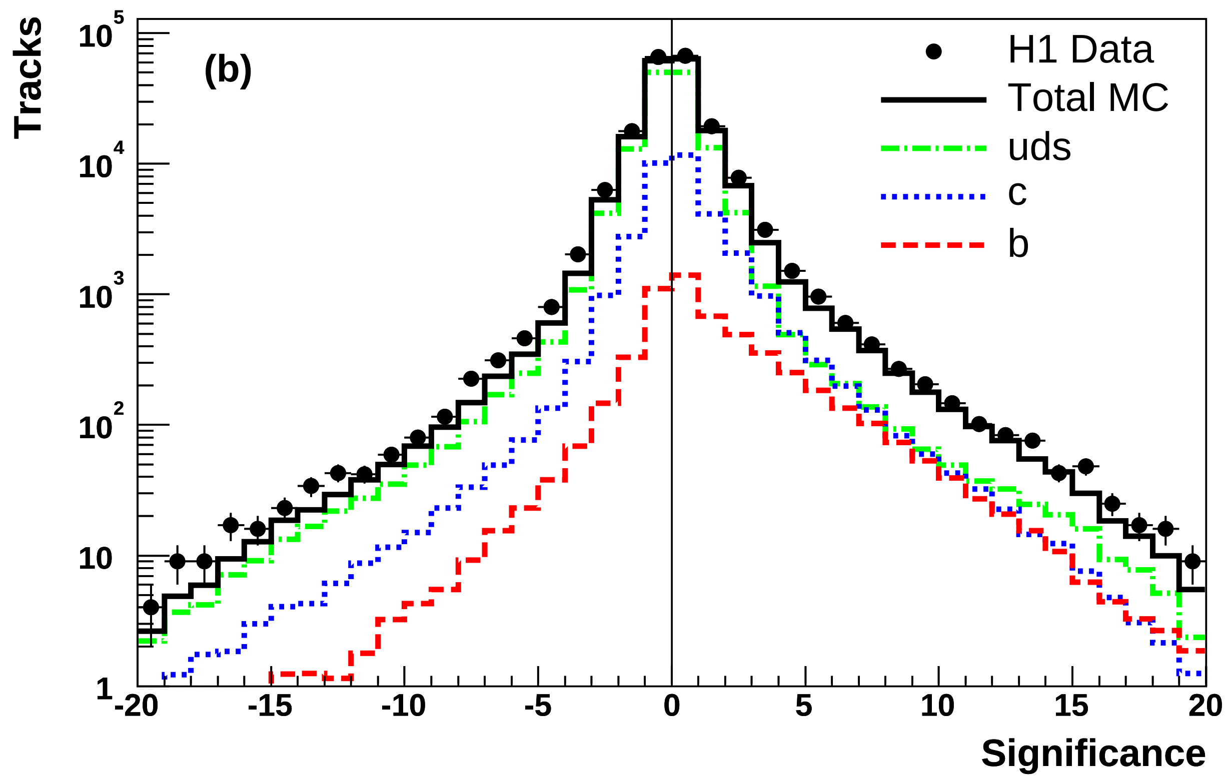
Look at the signed impact parameter for all tracks with precise measurement from central silicon tracker (CST). δ is the signed DCA to primary vertex in $r\phi$ plane



- 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
- At high Q^2, HFS has high p_T. $\sim 100\%$ of events have a jet

Significance (S_i)

For each track within each jet, plot significance given by $S_i = \frac{\delta}{\sigma(\delta)}$



More work to do to separate c and b and reduce uds . . .

S_1 and S_2

Define two independent S_1 and S_2 distributions:

S_1 highest significance track for 1 CST track events

S_2 2nd highest significance track for > 1 track events

S_1 More sensitive to charm and aids statistics

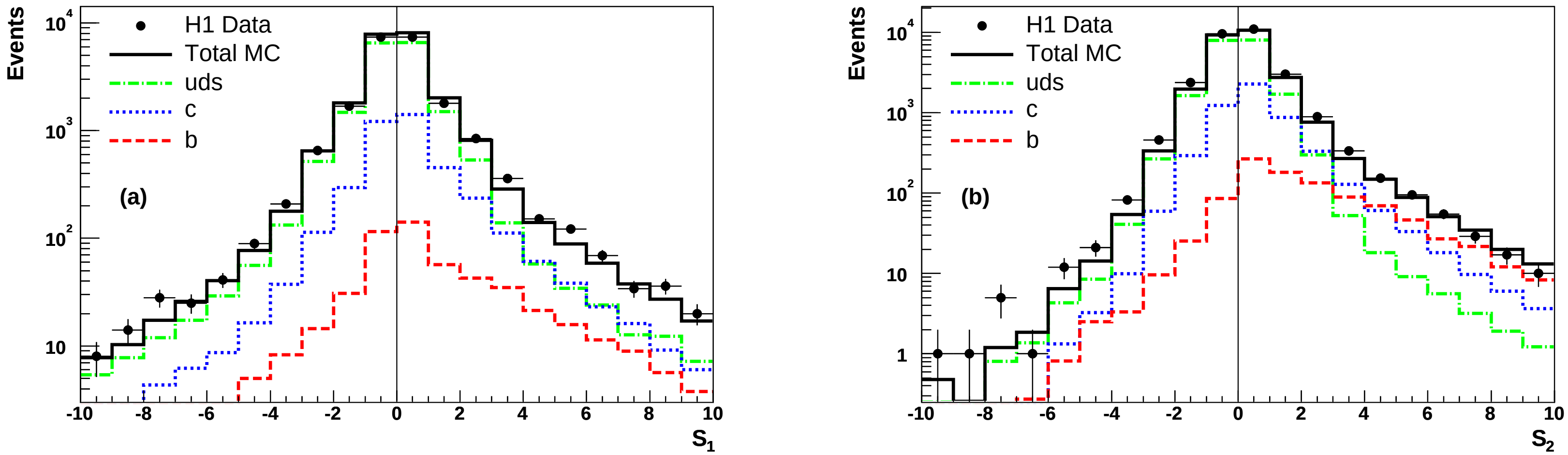
S_2 more sensitive to beauty due to higher multiplicity. Choosing the 2^{nd} highest significance track reduces contamination from light quark background.

Further reduce light quark background

$\rightarrow$ Only consider S_2 events if they have the same significance sign as S_1

S_1 and S_2

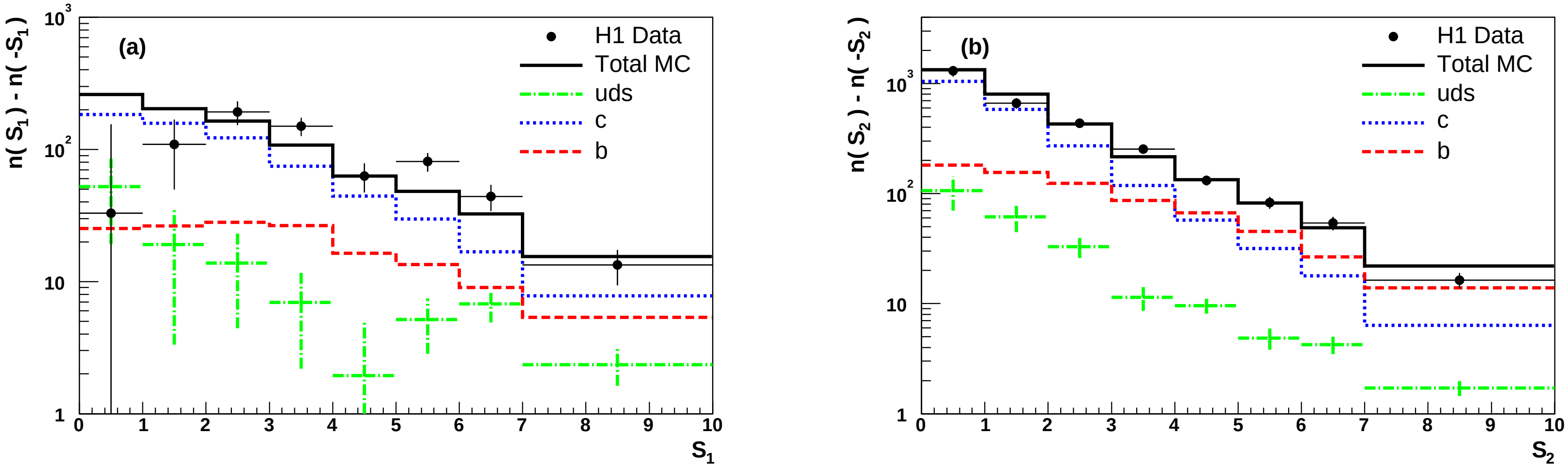
S_1 and S_2 distributions:



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

Negative Subtracted S_1 and S_2

Subtract the negative S_i bins from the positive for both data and MC



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

$P_c = 0.811 \pm 0.079$ $P_b = 1.62 \pm 0.24$ $P_l = 1.038 \pm 0.020$
$\chi^2/n.d.f. = 27.48/14$

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

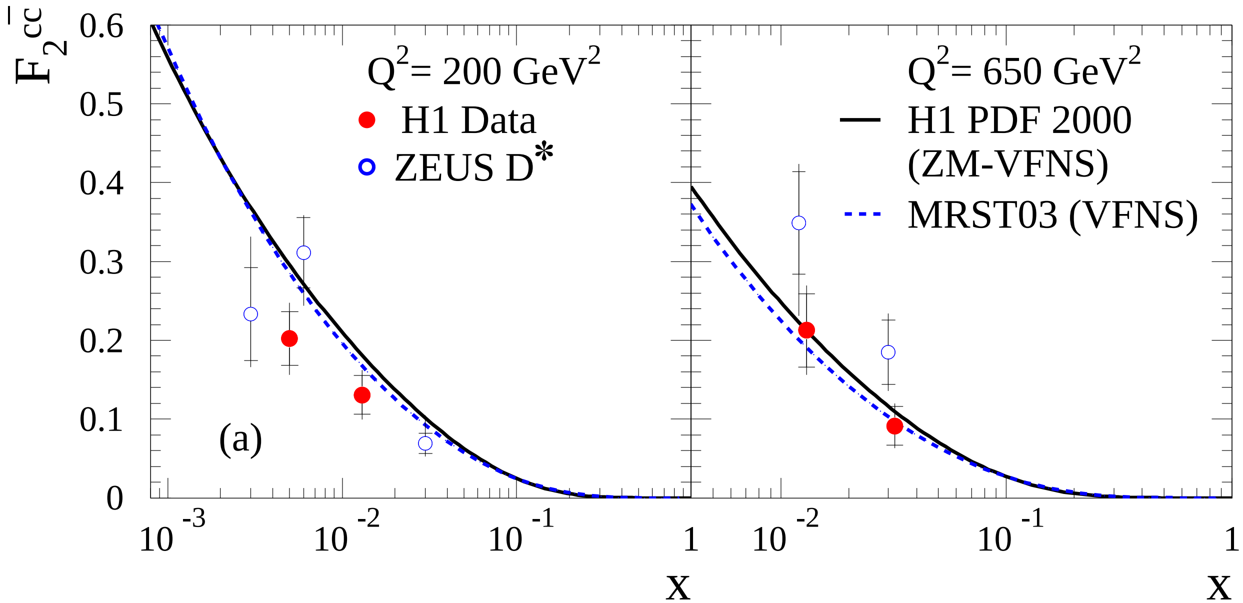
$$\frac{\mathrm{d}\sigma^{c\bar{c}}}{\mathrm{d}x\mathrm{d}Q^2} = \frac{2\pi\alpha^2}{xQ^4}((1+(1-y)^2)F_2^{c\bar{c}} - y^2 F_L^{c\bar{c}}),$$

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 (R at bin centre$/R$ integrated over bin). Corrections $2\% - 3\%$.

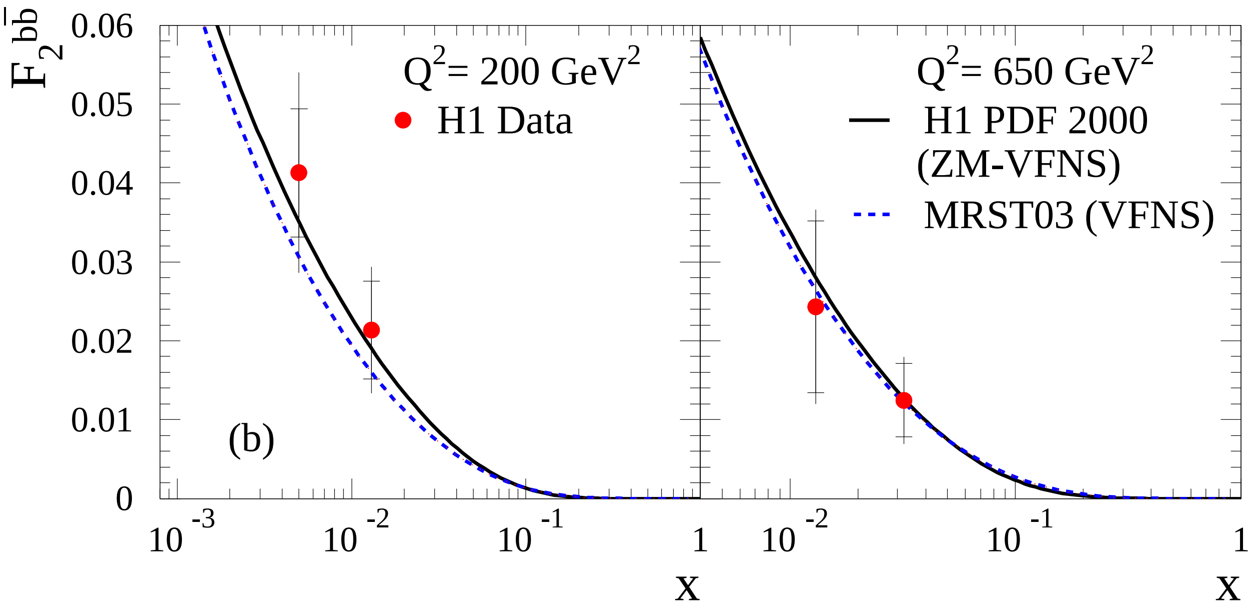
$F_2^{c\bar{c}}$



Consistent results with ZEUS D^* measurements (extrapolation factors 1.5-2.5)

Consistent with 'massless' NLO QCD predictions.

$F_2^{b\bar{b}}$

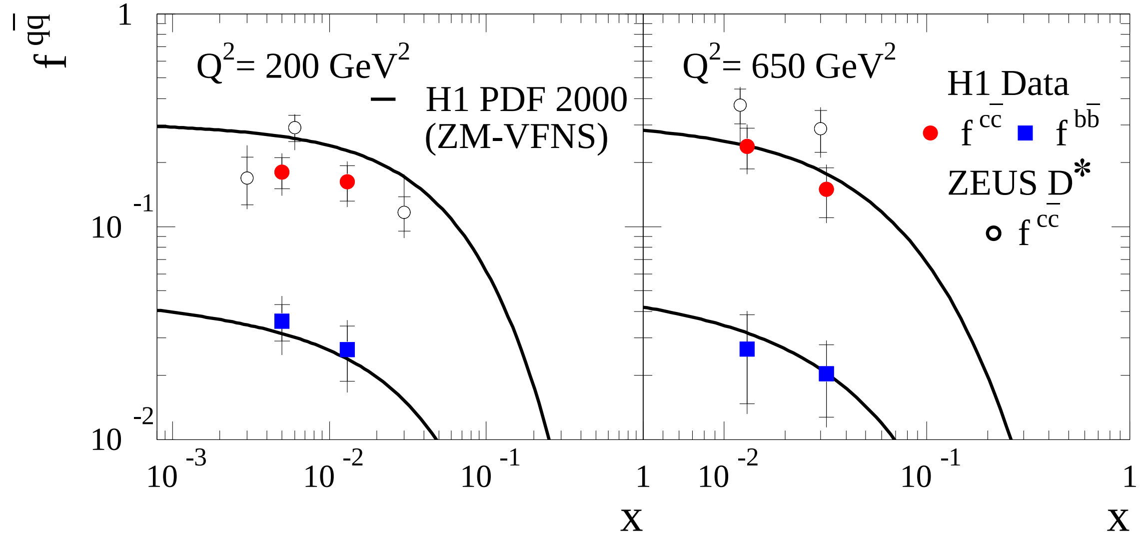


First measurement of $F_2^{b\bar{b}}$

Consistent with 'massless' NLO QCD predictions.

No large discrepancy with theory despite large errors.

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



Charm is around $15 - 25\%$ of the total cross section.

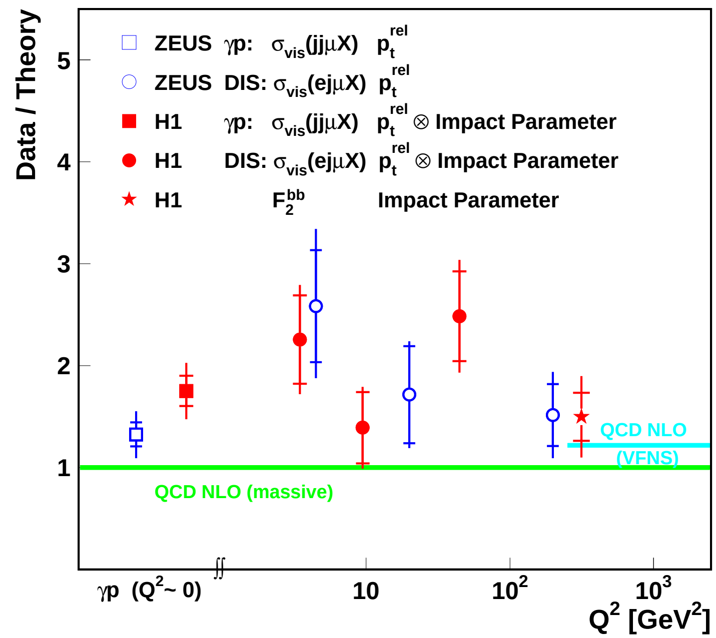
Beauty contributes $2 - 3.5\%$.

Reduced cross section, systematic errors and correlations are available

`http://www-h1.desy.de/psfiles/figures/d04-209.errortable.txt`

Please use them in your fits!

Status of HERA b Measurements



High Q^2 data consistent with 'massive' calculations.

Improved agreement with more relevant 'massless' calculations.

Different schemes (rather than the uncertainties of one model) give a feeling of the uncertainty of QCD

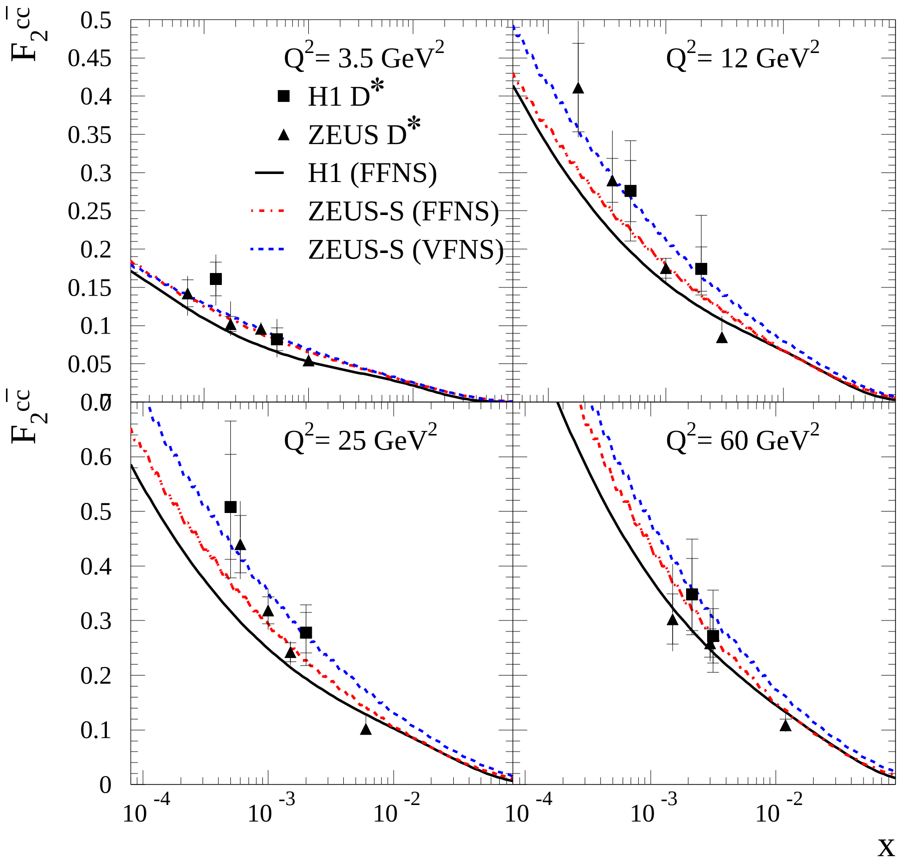
Extension to Low Q^2

Ongoing work to extend to low Q^2 using same techniques.

The challenges are

- b fraction decreases rapidly for $Q^2 < m_b^2 \rightarrow$ increases experimental difficulty
- At lower Q^2, HFS will have less p_T. Need careful consideration of phase space where we can still make inclusive measurements
- Threshold behaviour of NLO QCD predictions (next slides)

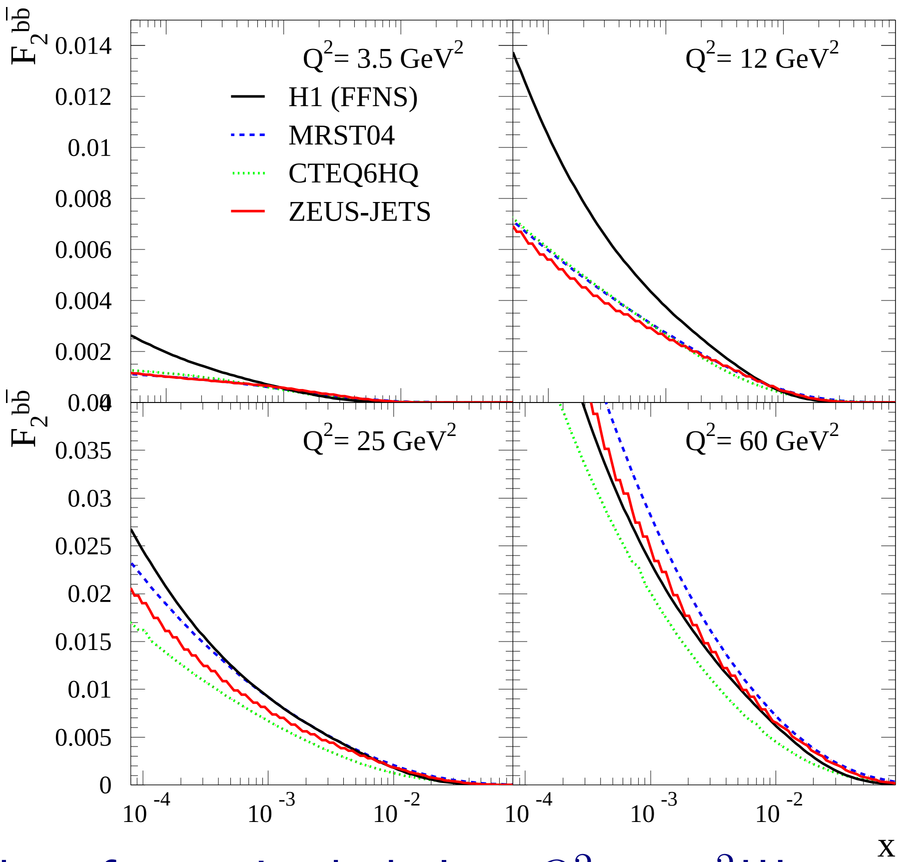
$F_2^{c\bar{c}}$ at low Q^2



VFNS tends to FFNS at low Q^2

FFNS NLO QCD predictions from ZEUS and H1 are similar

$F_2^{b\bar{b}}$ at low Q^2



$F_2^{b\bar{b}}$ falls by an order of magnitude below $Q^2 \sim m_b^2$!!!

Large differences between FFNS and VFNS are due to technical problems (work in progress!) Thanks to A. Cooper-Sarkar, C. Gwenlan, R. Thorne, S. Kretzer for identifying this.

Summary

- Measurement of Inclusive c and b cross sections using technique based on lifetime of the heavy quark decay products
- Inclusive method means no need for large model extrapolations
- $F_2^{c\bar{c}}$ results compatible with ZEUS (D^*)
- First measurement of $F_2^{b\bar{b}}$
- NLO QCD consistent with $F_2^{c\bar{c}}(x, Q^2)$ and $F_2^{b\bar{b}}(x, Q^2)$
- Extension to low Q^2, challenge experimentally. Theoretically need to be careful around threshold

Outlook

- Preliminary results looking at HFS (H1-04-173 jets in γp)
- HERA-II should improve statistics at high Q^2. Possibility to measure $F_2^{s\bar{s}}$ from c production in Charged Current events?

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