Combined F_2^{cc} Mesurement at HERA

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on behalf of the
H1 and ZEUS collaborations

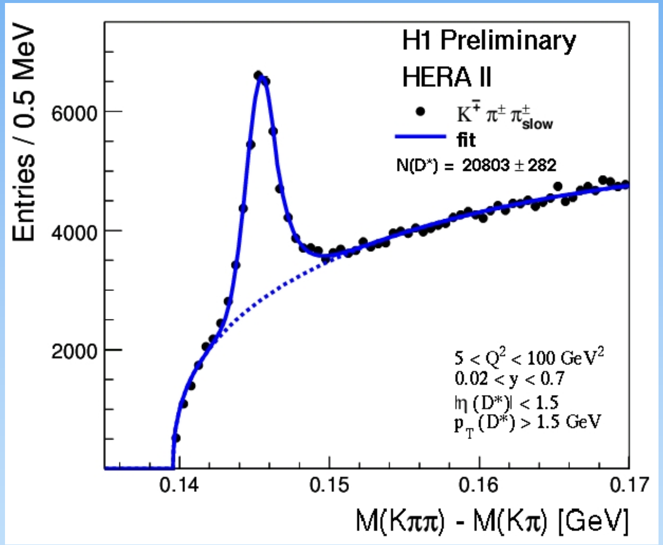
Outline:

- Heavy quark tagging methods
- Theory approaches for charm production
- Heavy quark production cross sections in DIS
- Charm contribution F_2^{cc} to the proton structure function
- Conclusions

Heavy quark tagging methods at HERA

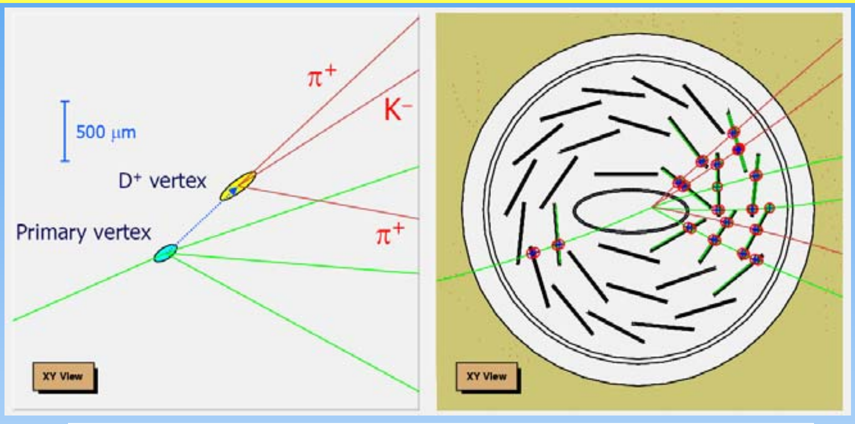
Using fully reconstructed charmed mesons: $D^*, D^\pm, D^0$

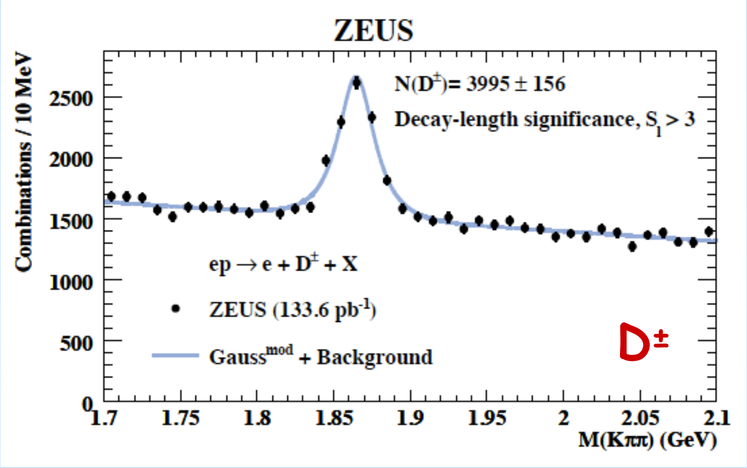
$D^* \to D^0\pi \to K\pi\pi$



$\Delta m\ (D^*) = M_{inv}(K\pi\pi) - M_{inv}(K\pi)$

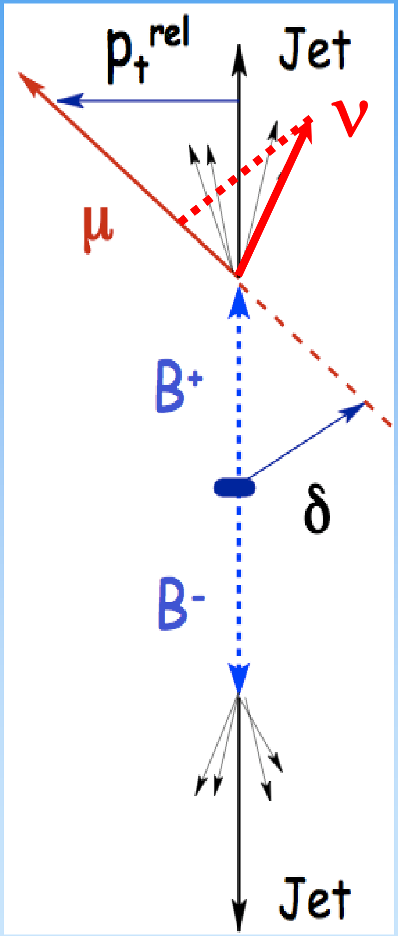
Secondary vertex reconstruction (MVD)



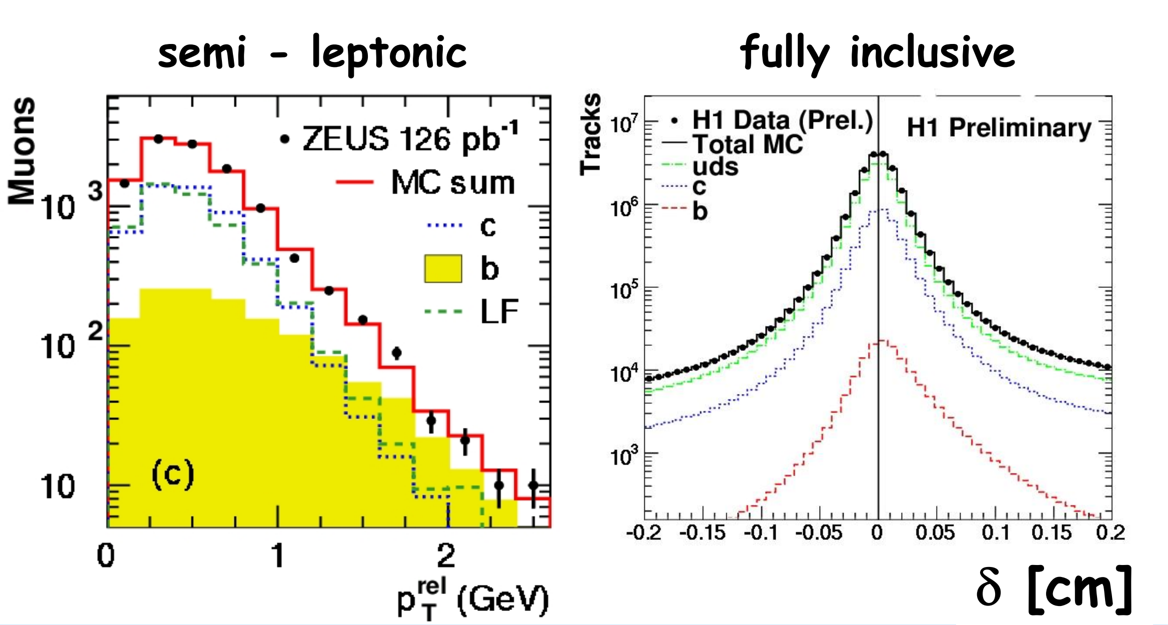


Heavy quark tagging methods at HERA

Large mass, long lifetime of heavy hadrons for charm and/or beauty



- Semi-leptonic decays (e,μ) or fully inclusive
- Large mass ⇒ large p_t^{rel} w.r.t. jet axis
- Large lifetime ⇒ large impact parameter δ w.r.t. primary vertex



Theory approaches for charm production

Massive fixed order QCD calculation, FFNS

- heavy flavours generated dynamically via BGF
- correct threshold treatment
- valid for $\mu^2 \approx O(m_c^2)$
- expected to fail at some scale $\mu^2 >> m_c^2$

Model for charm production in DIS and inclusive charm meson production available : HVQDIS

is used for data

Massless calculation (ZM-VFNS)

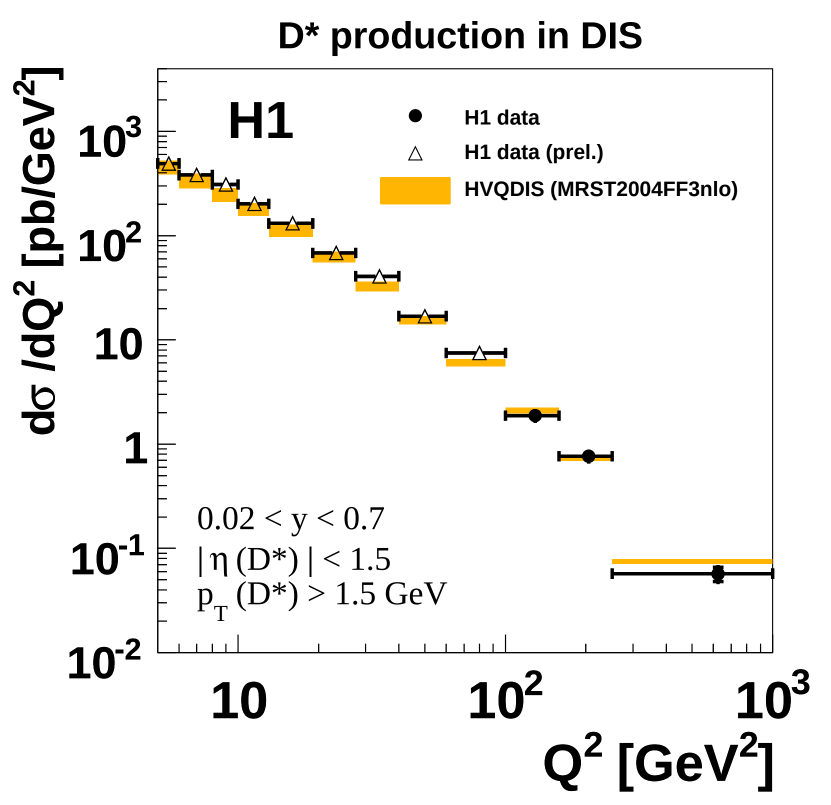
- massless charm as part of the proton
- not valid at threshold
- expected to work at HERA at large p_t

Generalized mass calculation (GM-VFNS)

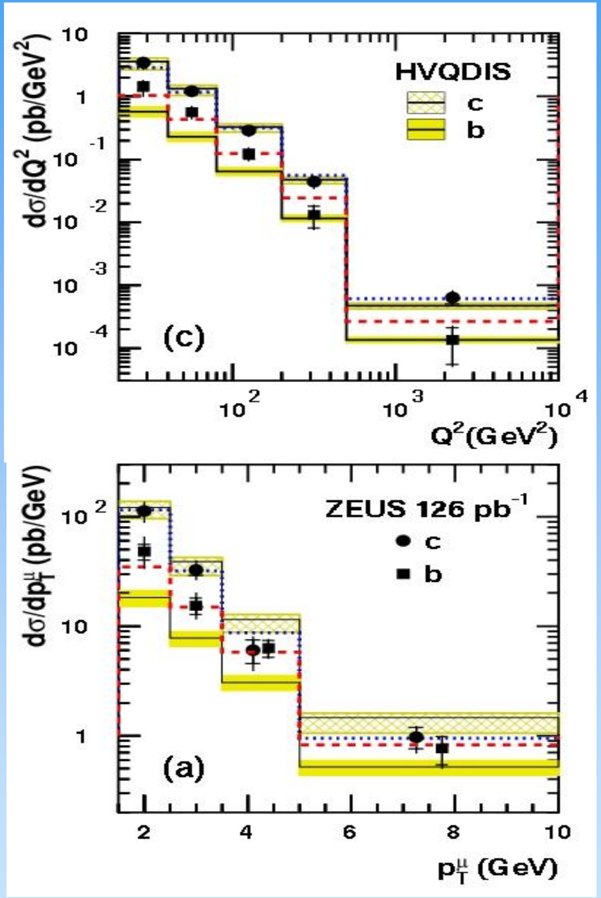
- massive at $\mu^2 \approx m_c^2$ and massless at $\mu^2 \gg m_c^2$
  - various F_2^{cc} predictions
  - no predictions yet for the final state in DIS

Heavy Quarks in Deep Inelastic Scattering

Charm from D*



HQ from semi-leptonic decays



Charm: NLO QCD agrees with data
Beauty: NLO lower in normalization for μ data

Theory uncertainties:
HQ mass, scales, fragmentation model

Charm contribution to F_2 (charm via D,μ)

Experimental procedure:

$$F_2^{c\bar{c}}(\exp) = \frac{\sigma_{vis}(\exp)}{\sigma_{vis}(theory)} F_2^{c\bar{c}}(theory)$$

Visible meson cross section: $p_T(D^*)>1.5$ GeV, $|\eta(D^*)|<1.5$

Problem: only ~30% of the D meson phase space accessible

→ introduces model dependences due to extrapolation

Extrapolation models: HVQDIS / CASCADE

Considered uncertainties: mass of charm quark, scales, fragmentation model (Parameters from experiment)

Charm contribution to F_2 (lifetime)

Experimental procedure:

Quark fractions $\rho_c, \rho_b, \rho_{uds}$ from fits of MC templates to observables sensitive to lifetime/mass of heavy flavoured hadrons

Normalization: inclusive reduced cross section $\sigma_{red}(x,Q^2)$

Bin center corrections δ_{BCC}: via FFNS NLO calculation

$$\sigma_{red}^{c\bar{c}}(x,Q^2) = \sigma_{red}(x,Q^2) \cdot \frac{\rho_c \cdot N_c^{MC}}{\rho_c \cdot N_c^{MC} + \rho_b \cdot N_b^{MC} + \rho_{uds} \cdot N_{uds}^{MC}} \cdot \delta_{BCC}$$

Connection to F_2^{cc}:

$$\sigma_{red}^{c\bar{c}} = F_2^{c\bar{c}} - \frac{y^2}{1+(1-y)^2} F_L^{c\bar{c}}$$

Averaged F_2^{cc}: H1-ZEUS Combination

- H1 data:
  - D* HERA I (1999-2000) 47 pb^{-1}
  - HERA II (2004-2007) 340 pb^{-1} (prel.)
  - Lifetime tag: HERA I + HERA II(prel.)
- ZEUS data:
  - semi-leptonic events (muons) (2005)
  - D^0, $D^\pm$ (2005)
  - D* HERA I (1996-2000)
- Correlations of systematic uncertainties taken into account

Extrapolation uncertainties correlated between H1 and ZEUS

Variations of m_c, $\mu_r=\mu_f$, fragmentation parameters in HVQDIS (D-mesons)

Averaging

Similar procedure as used for combining inclusive cross sections

correlated systematic errors

$$\chi^2(\vec{m},\vec{b}) = \sum_i \frac{\left(m^i - \sum_j \gamma^i_j m^i b_j - \mu^i\right)^2}{(\delta_{i,stat}\,\mu^i)^2 + (\delta_{i,unc}\, m^i)^2} + \sum_j b_j^2$$

statistical errors

uncorrelated systematic errors

μ^i **measured value at point i**

δ_i **statistical, uncorrelated systematic error**

γ_j^j **– correlated systematic error**

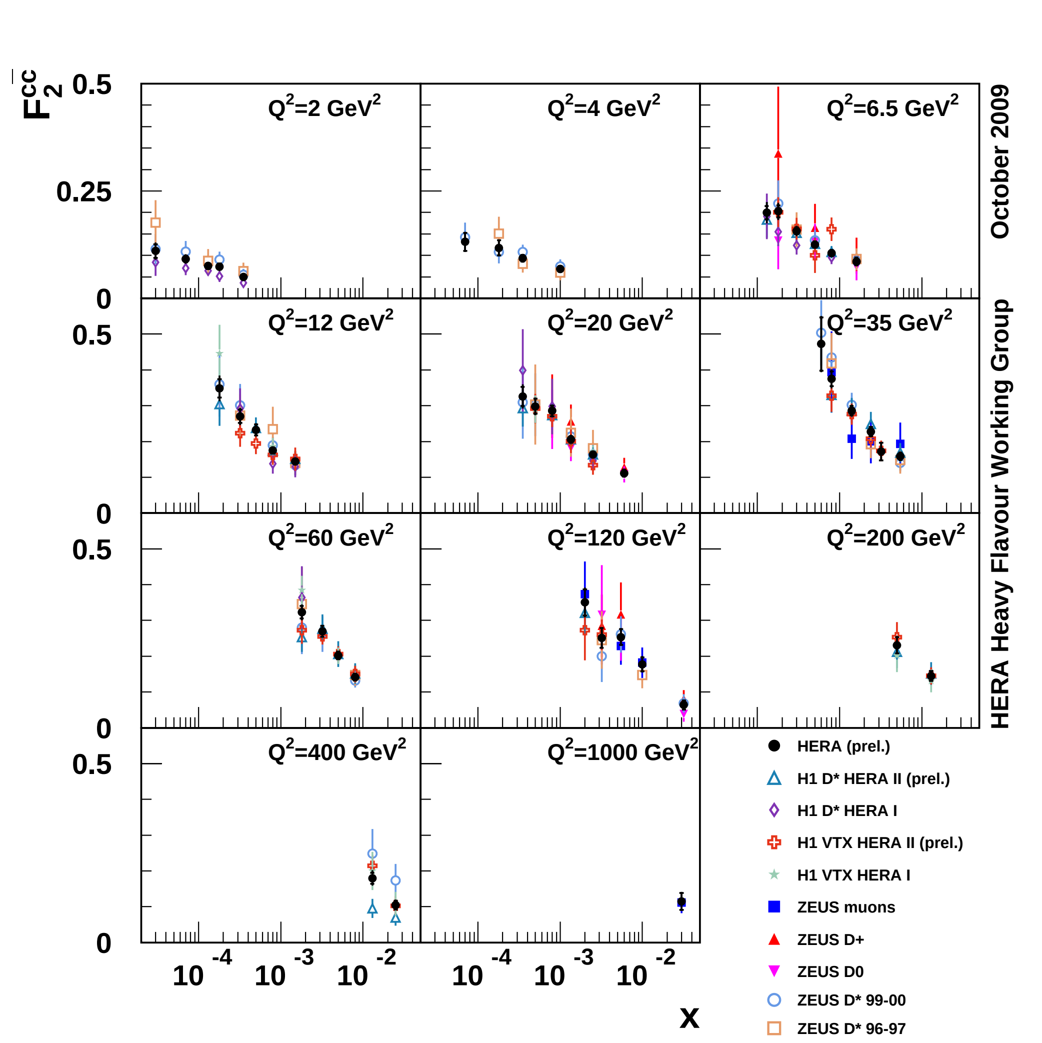
b_j **– shift of correlated systematic error sources**

m^i **– true value (corresponds to min** χ^2**)**

54 sources of systematic errors

swimming to common (x,Q^2) points via FFNS NLO (Riemersma *et al*)

Averaging Result

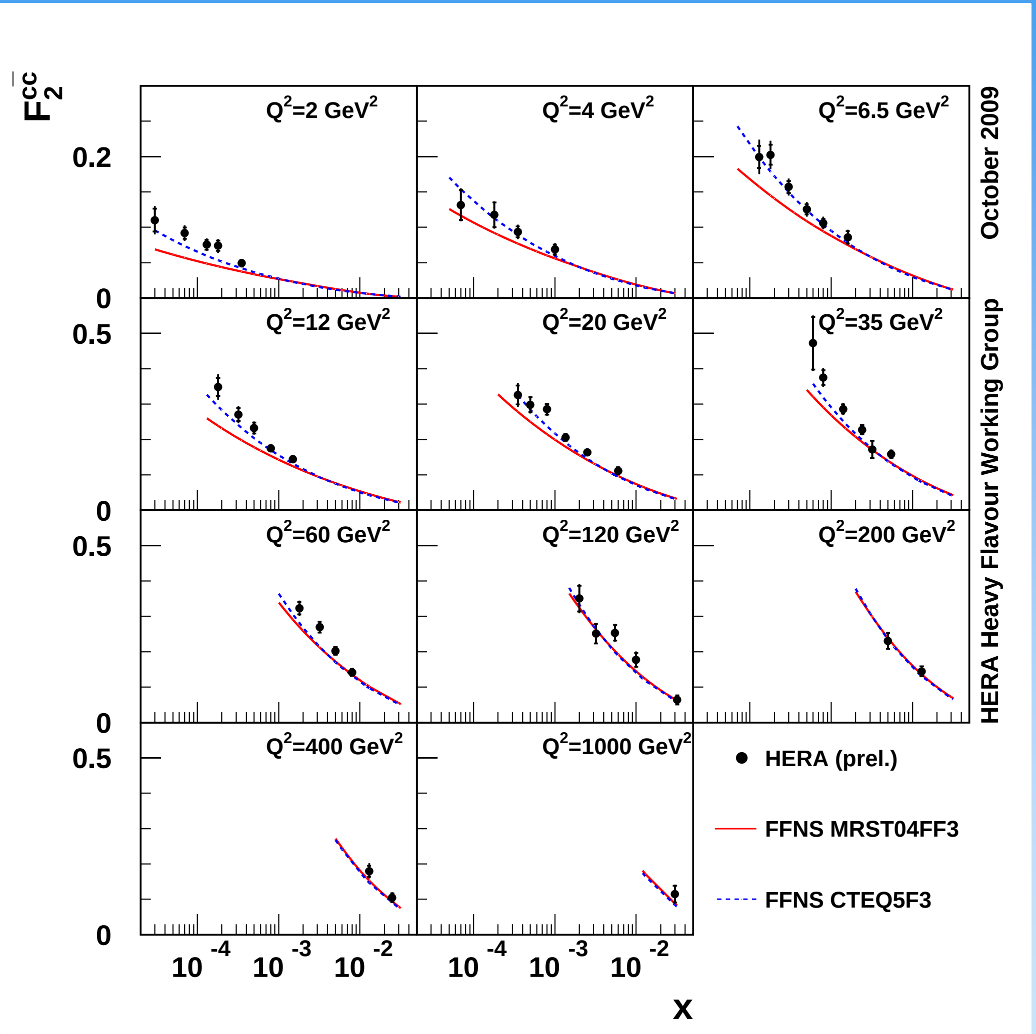


Input:
9 different data sets

(measurements are swum to common (x,Q^2) points)

Precision of combined result: 5-10%

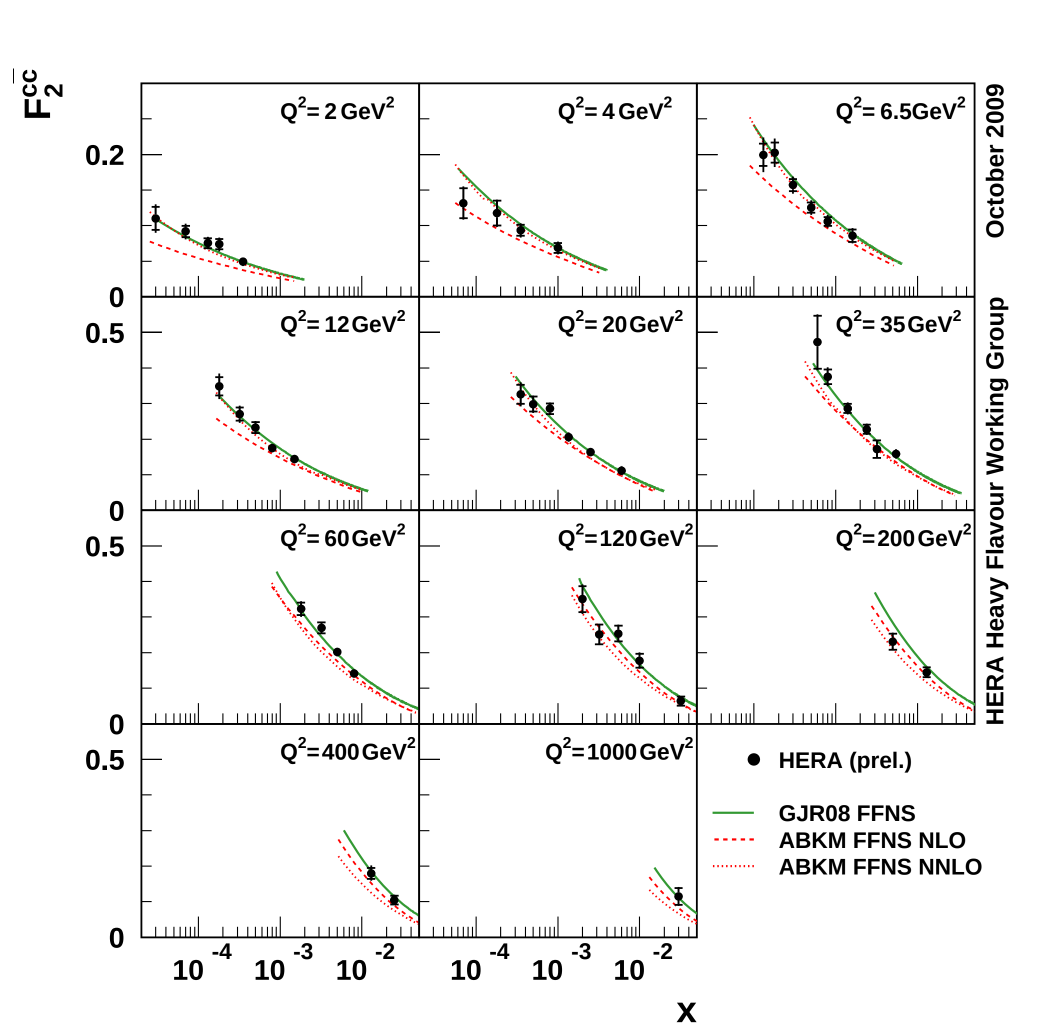
F_2^{cc} vs FFNS NLO



FFNS NLO only scheme available for extrapolating measurement

Calculations based on Riemersma et al.

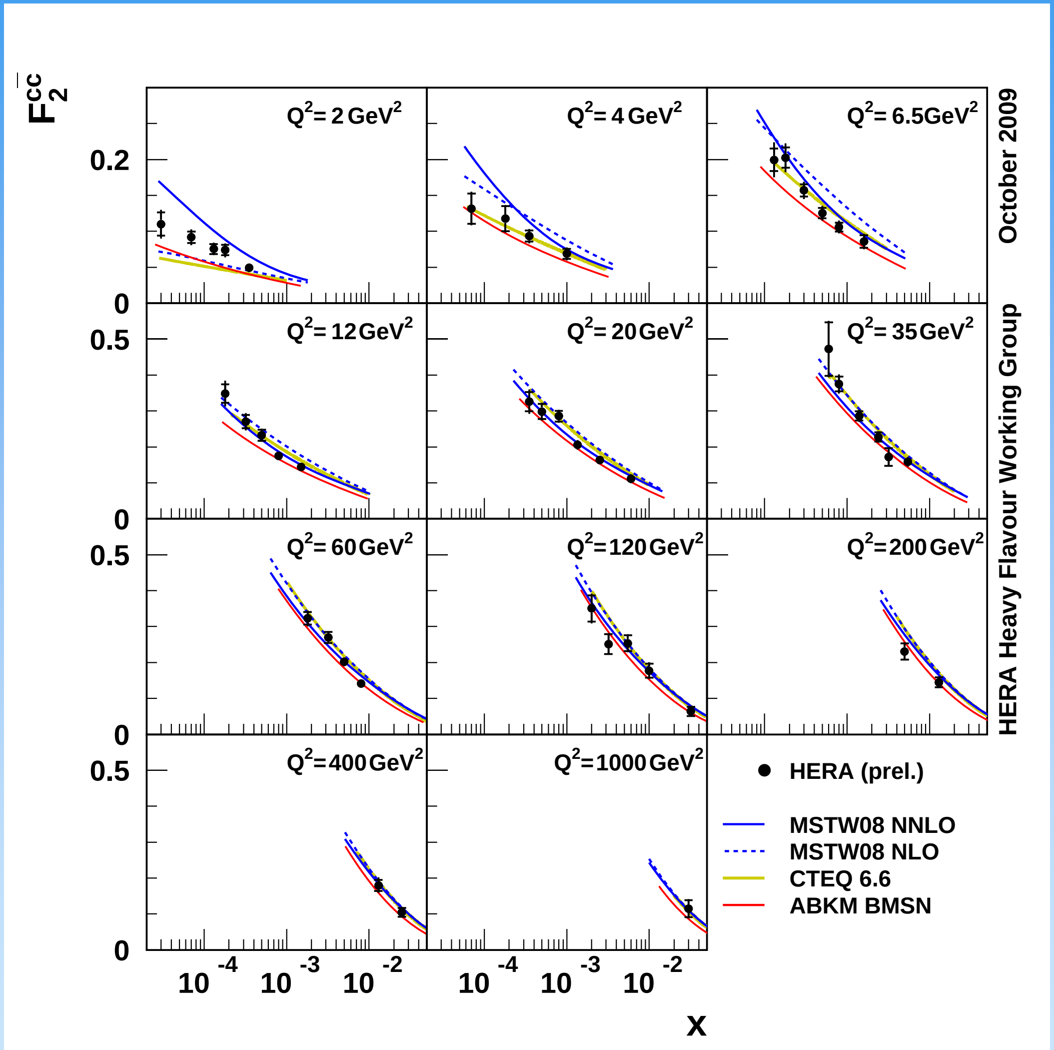
F_2^{cc} vs. FFNS



- GJR in good agreement with data @ all Q^2 (m_c=1.3 GeV is used)
- ABKM NLO below data @ low Q^2
- ABKM NNLO below data @ high Q^2 (both with m_c=1.5 GeV)

GJR: Glück, Jimienez-Delgado, Reya
ABKM: Alekhin, Blümlein, Klein, Moch

F_2^{cc} vs. GMVFNS



Medium to high Q^2:
Very similar predictions (differences of same size than exp. errors)

Small Q^2:
Larger differences Among calculations

Very small Q^2:
Calculations deviate significantly from data

Conclusions

- Preliminary HERA averaged results on F_2^{cc} from the combination of 9 different data set from H1 and ZEUS have be presented for $2<Q^2<1000$ GeV^2 , $10^{-5}<x<10^{-1}$
- Average uncertainty 10%, in some bins 5%
- Experimental precision will further improve with final HERA measurements on charm production
- Current precision on F_2^{cc} already good enough to
  - -discriminate among different theoretical F_2^{cc} calculations and PDFs
    - -FFNS does describe the data best
    - -GMVFNS NLO does not fit the data at low Q^2
  - -make impact on the HERA PDF (see next talk)