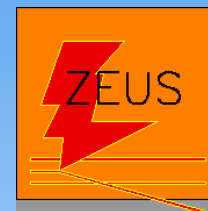


Combined F_2^{cc} Measurement at HERA



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on behalf of the
H1 and ZEUS collaborations*



Outline:

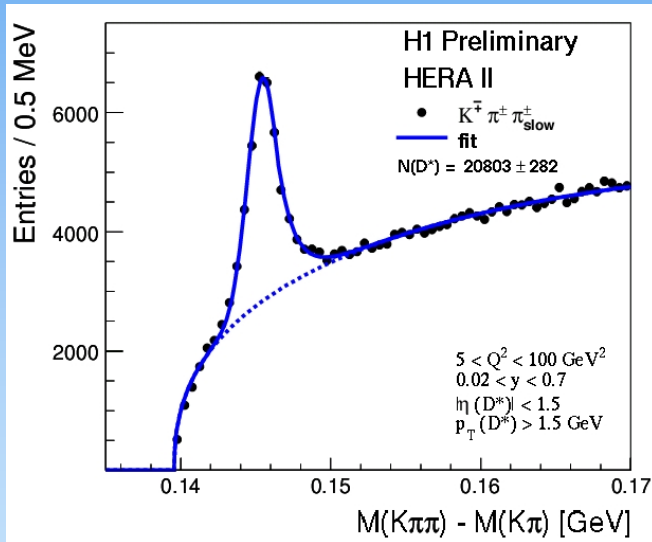
- Heavy quark tagging methods
- Theory approaches for charm production
- Heavy quark production cross sections in DIS
- Charm contribution F_2^{cc} to the proton structure function
- Conclusions

Heavy quark tagging methods at HERA

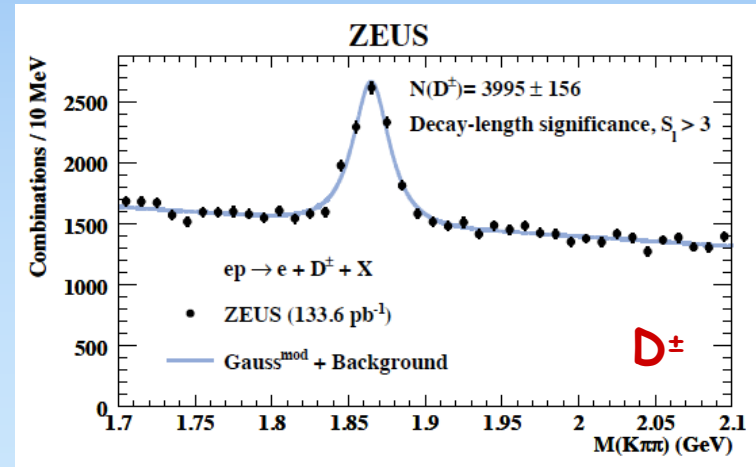
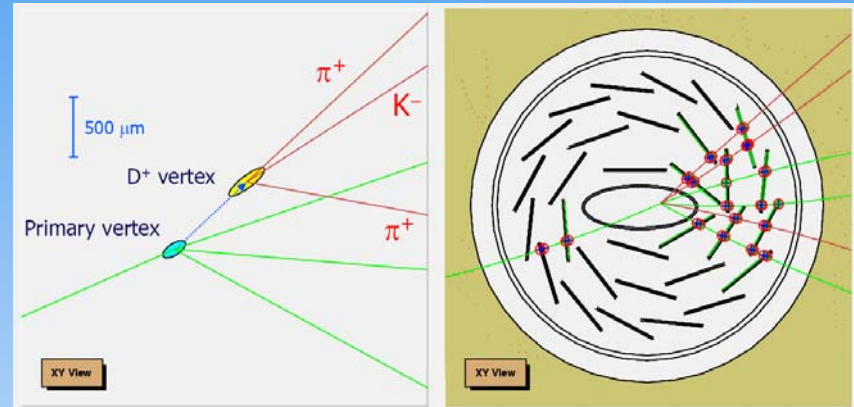
Using fully reconstructed charmed mesons: D^* , D^\pm , D^0

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

Secondary vertex reconstruction (MVD)

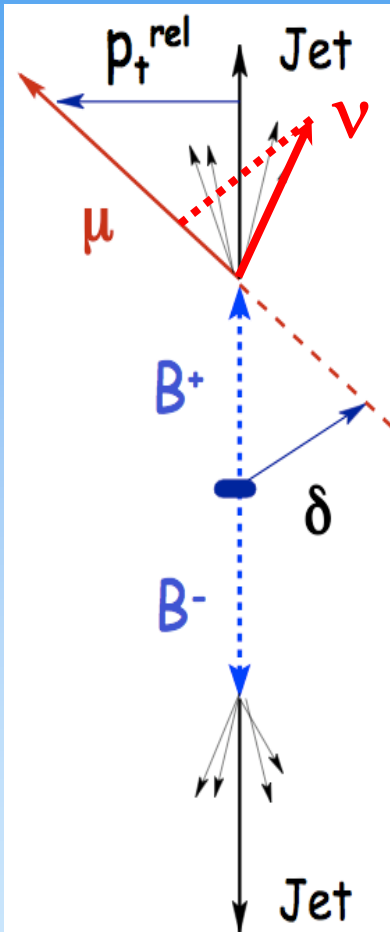


$$\Delta m(D^*) = M_{\text{inv}}(K\pi\pi) - M_{\text{inv}}(K\pi)$$

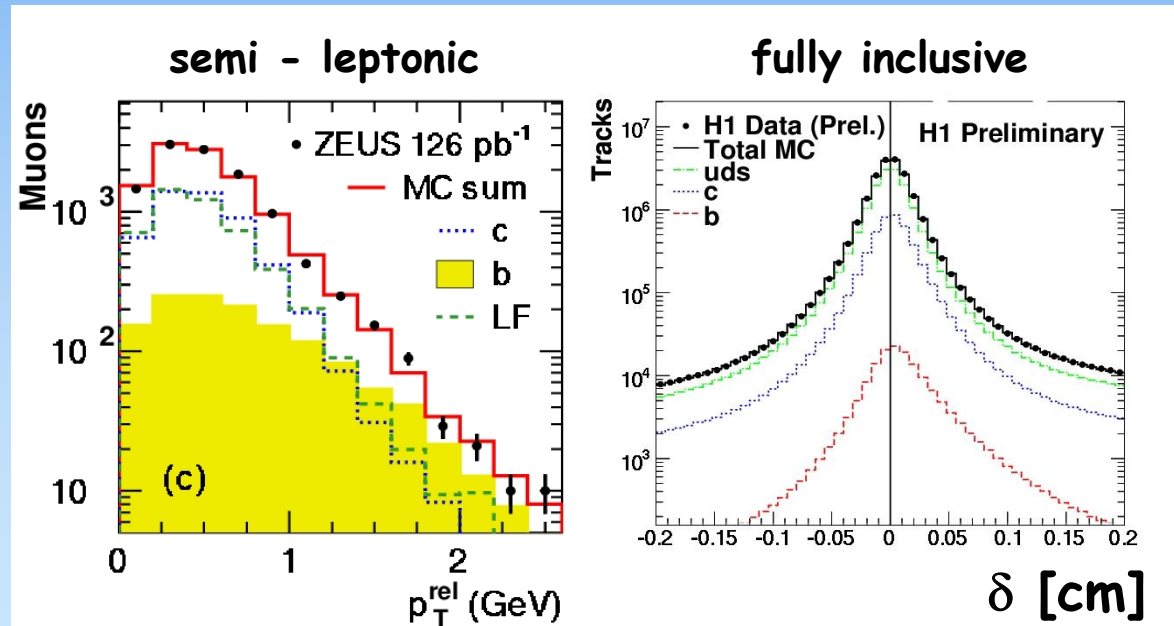


Heavy quark tagging methods at HERA

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



- Semi-leptonic decays (e, μ) or fully inclusive
- Large mass \Rightarrow large p_T^{rel} w.r.t. jet axis
- Large lifetime \Rightarrow 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 $\mu^2 \gg m_c^2$

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

Massless calculation (ZM-VFNS)

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

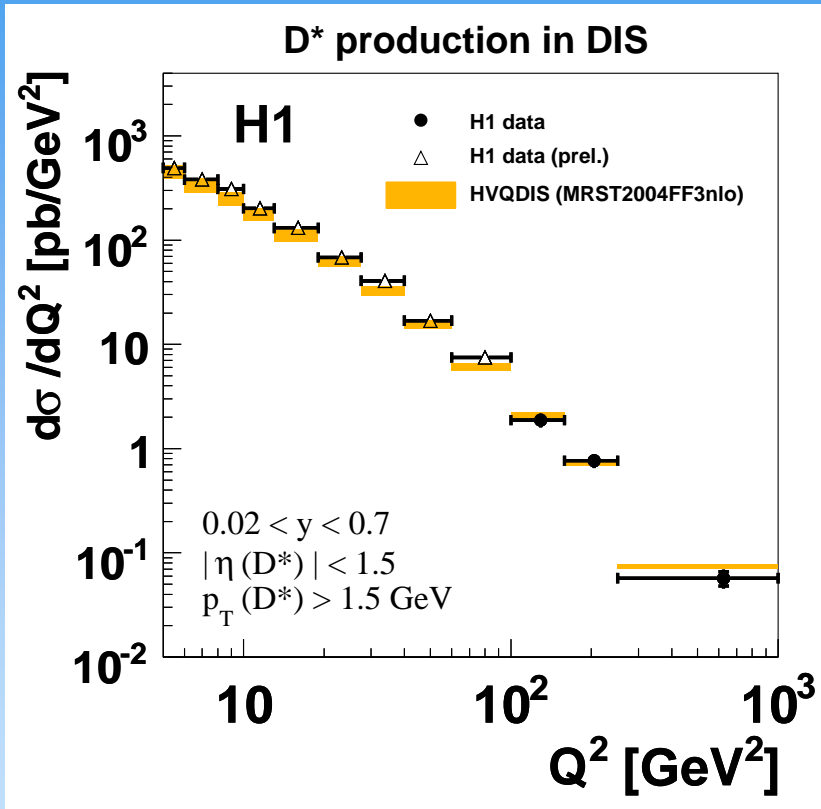
is used for data

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

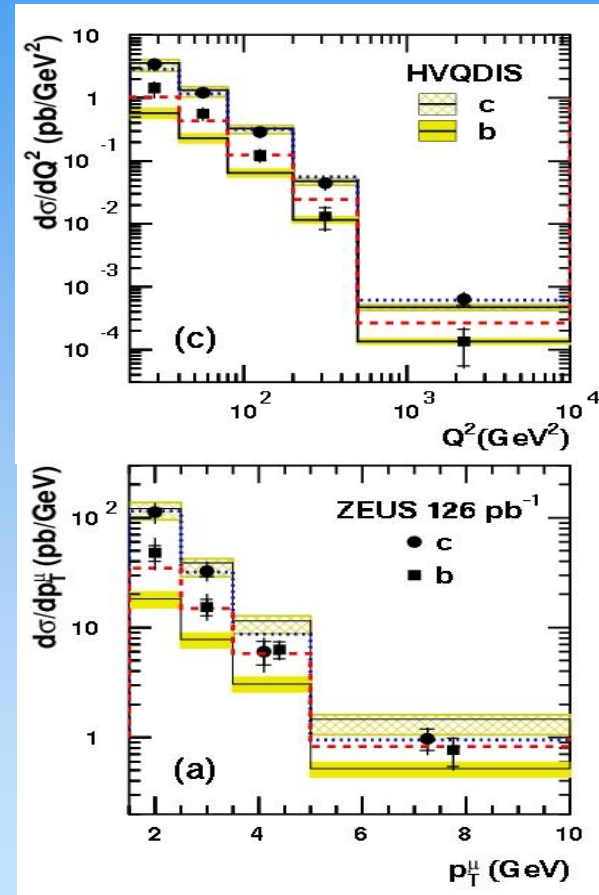
Heavy Quarks in Deep Inelastic Scattering

Charm from D^*



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

HQ from semi-leptonic decays



Theory uncertainties:
 HQ mass, scales, fragmentation model

Charm contribution to F_2 (charm via D, μ)

Experimental procedure:

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

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

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

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

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)
 - D⁰, D[±] (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

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

statistical errors

uncorrelated systematic errors

μ^i measured value at point i

δ_i statistical, uncorrelated systematic error

γ_j^i - correlated systematic error

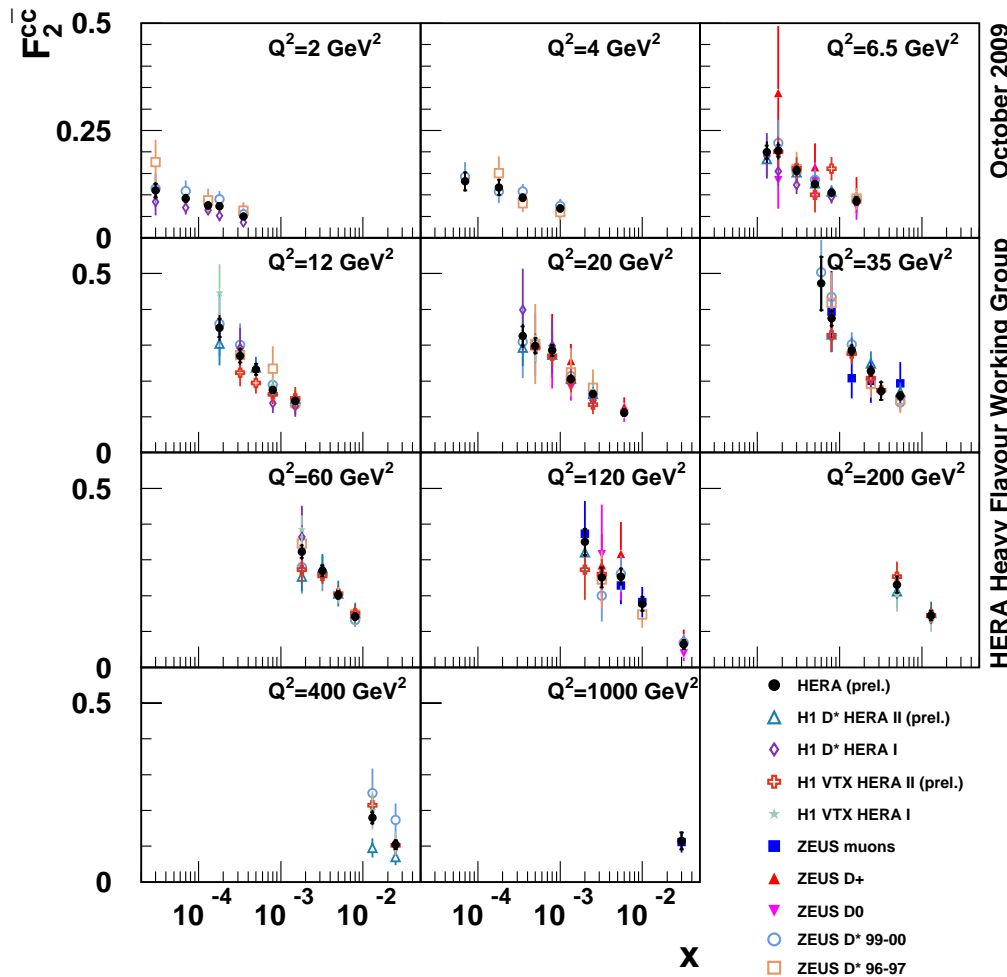
b_j - shift of correlated systematic error sources

m^i - true value (corresponds to $\min \chi^2$)

54 sources of systematic errors

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

Averaging Result

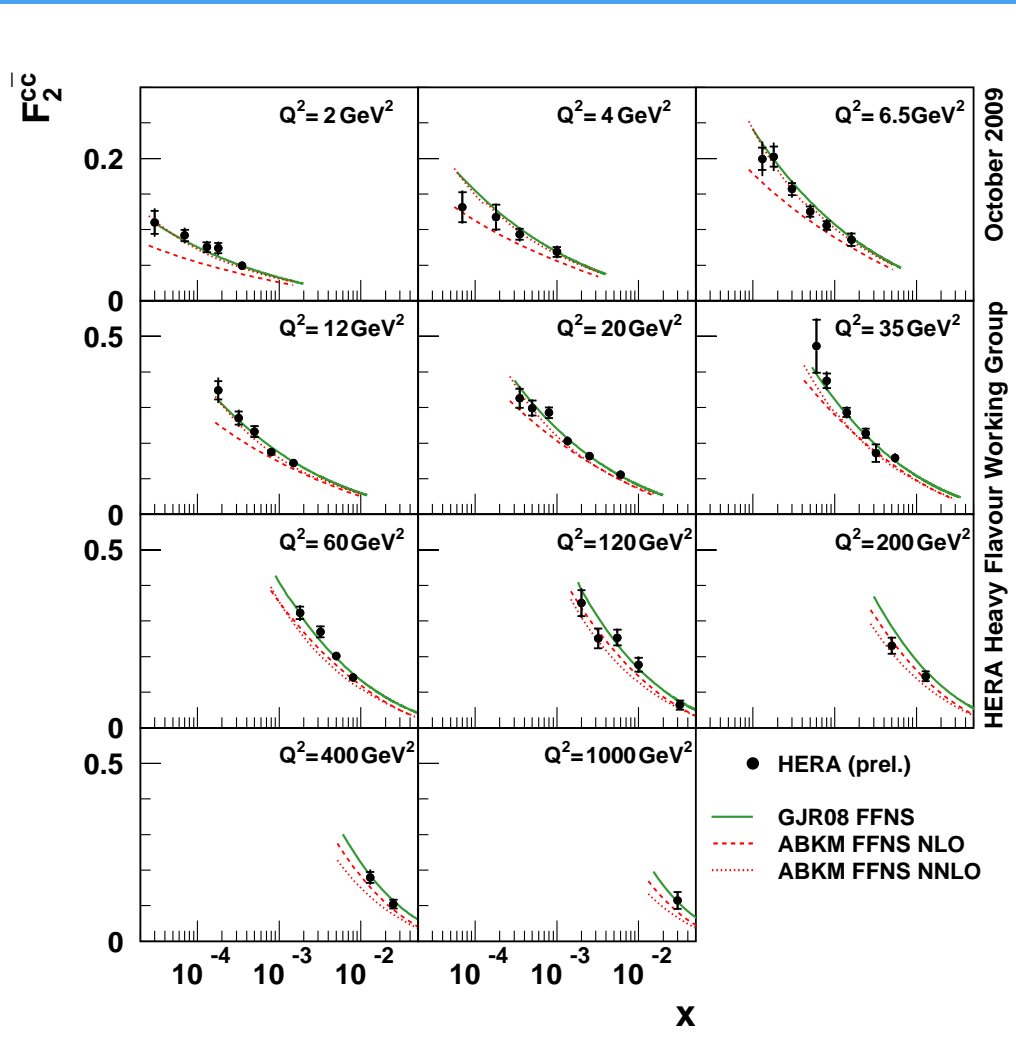


Input:
9 different data sets

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

Precision of
combined result:
5-10%

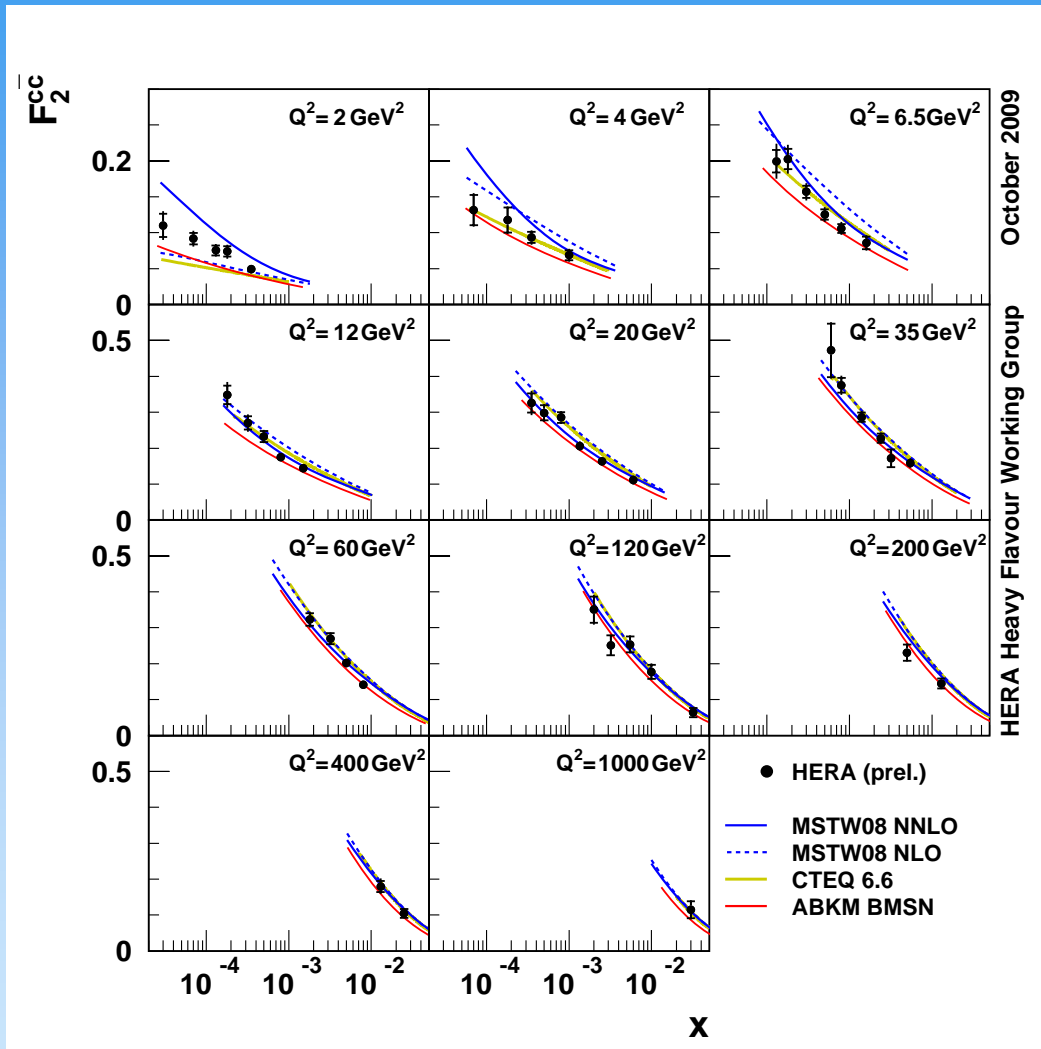
F_2^{cc} vs. FFNS



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

GJR: Glück, Jimenez-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 $2 < Q^2 < 1000 \text{ GeV}^2$, $10^{-5} < x < 10^{-1}$
- 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)