

Charm production in DIS using inclusive secondary vertices and extraction of $F_2^{c\bar{c}}$

Vladyslav Libov (DESY / Hamburg University)
on behalf of the **ZEUS Collaboration**

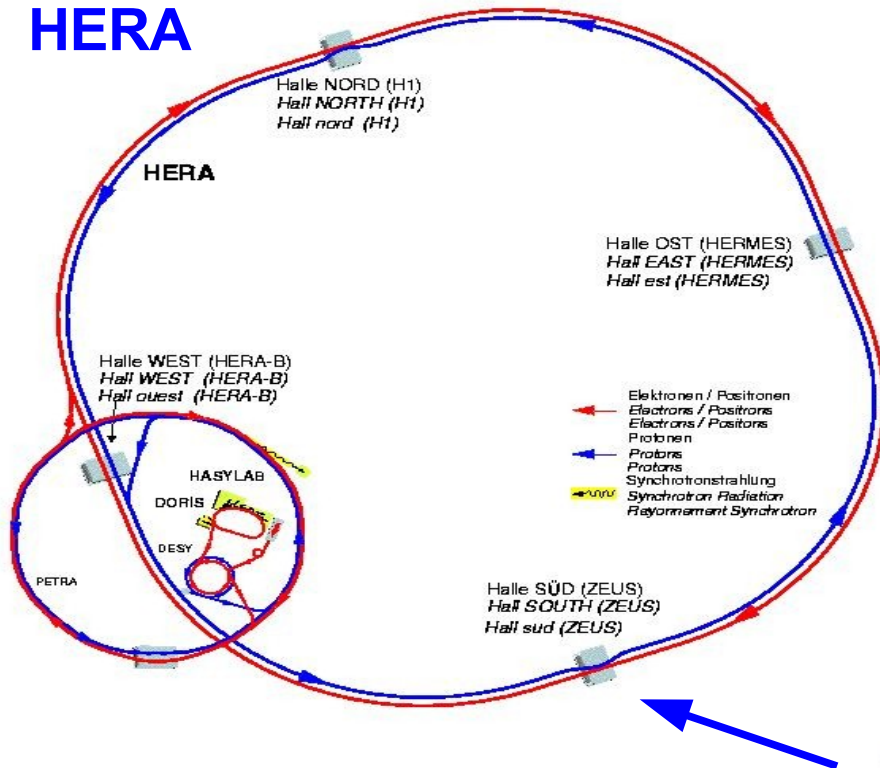
**XX International Workshop on
Deep-Inelastic Scattering and Related Subjects**
Bonn, Germany, 26-30 March 2012

Outline

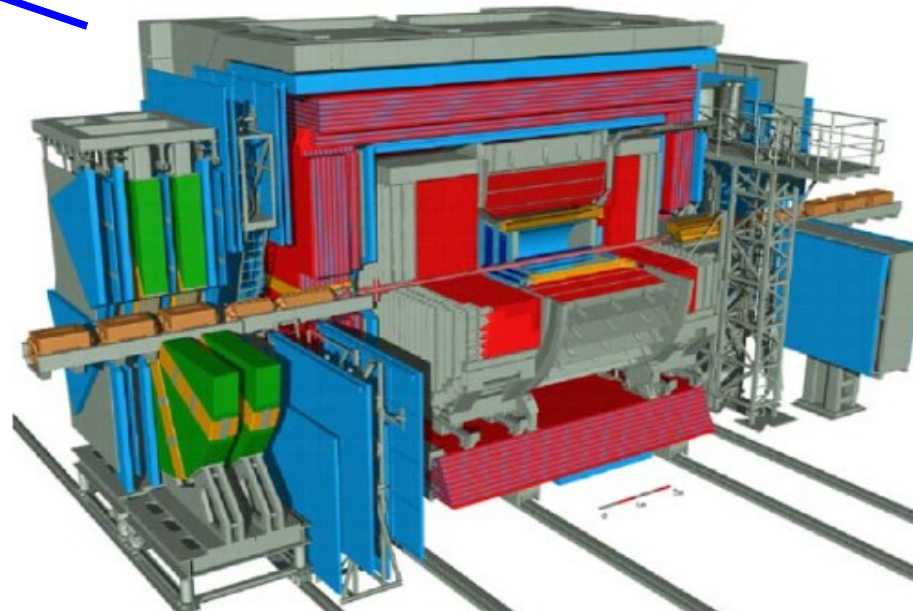
- Charm production at HERA
- Inclusive secondary vertexing at ZEUS
- Differential cross-sections
- $F_2^{c\bar{c}}$ measurement

ZEUS @ HERA

HERA



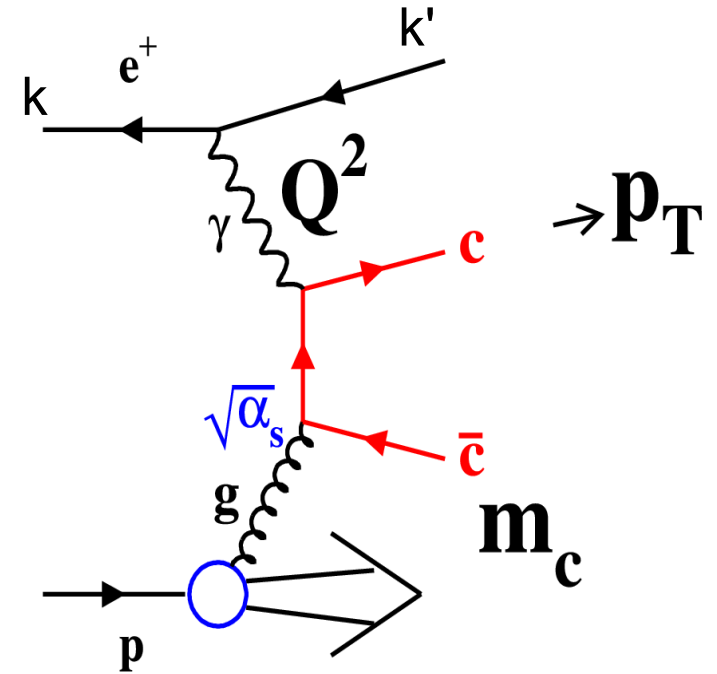
- Protons 920 GeV,
- Electrons 27.6 GeV $\left. \vphantom{\begin{matrix} \text{Protons 920 GeV,} \\ \text{Electrons 27.6 GeV} \end{matrix}} \right\} \sqrt{s} = 318 \text{ GeV}$
- Operational: 1992-2007
- **ZEUS** – general purpose hermetic detector
- $\sim 500 \text{ pb}^{-1}$ accumulated during HERA I and HERA II running periods



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Charm physics at HERA

- Heavy flavours are produced in the LO via Boson-Gluon Fusion (BGF)
- Sensitivity to the gluon density in the proton
- Multiple-hard-scale problem (m_c , p_T , Q^2)
- Sensitivity to the charm mass



Kinematics of ep scattering:

$$Q^2 = -q^2 = -(k - k')^2$$

$$x = \frac{Q^2}{2P \cdot q}$$

$$y = \frac{P \cdot q}{P \cdot k}$$

- NLO QCD calculations
 - Massive scheme (FFNS): **HVQDIS**
 - Massless scheme (ZMVFNS)
 - Mixed schemes (GMVFNS)
- NNLO partially available

- PHP: $Q^2 \sim 0 \text{ GeV}^2$
- **DIS: $Q^2 > 1 \text{ GeV}^2$**

Secondary vertex method

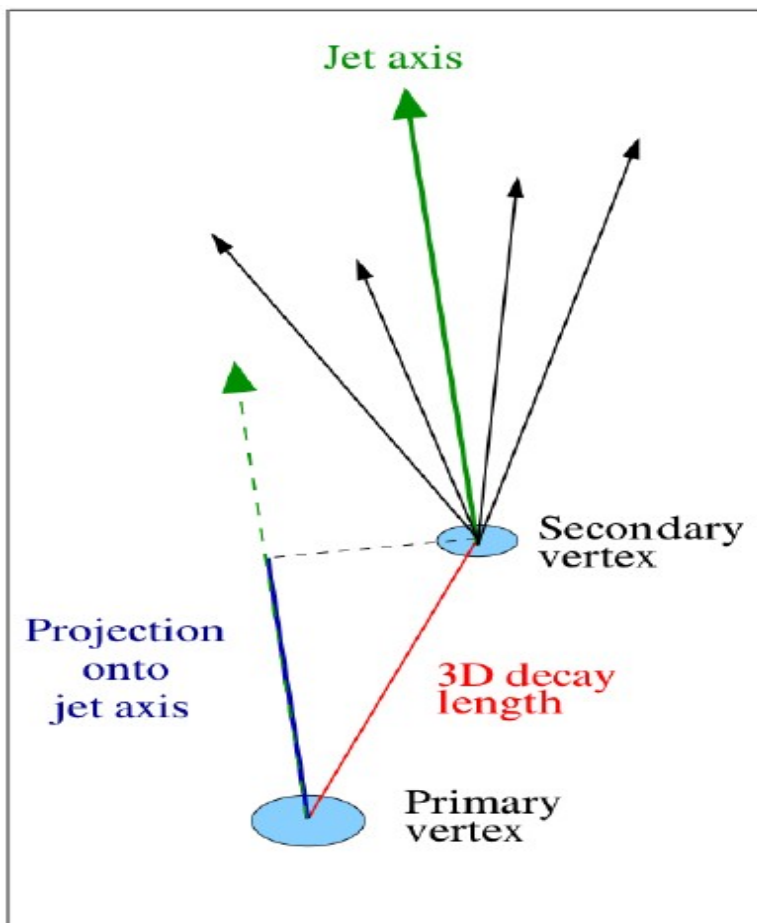
- Employs long lifetime of HQ
- No specific decay mode requirement → increase statistics
- Select tracks belonging to a jet
 - $p_T(\text{track}) > 500 \text{ MeV}$
- Fit a secondary vertex
- Project decay length onto a jet axis
- Calculate decay length **significance**

$$5 < Q^2 < 1000 \text{ GeV}^2$$

$$0.02 < y < 0.7$$

$$E_T(\text{jet}) > 4.2 \text{ GeV}$$

$$-1.6 < \eta(\text{jet}) < 2.2$$

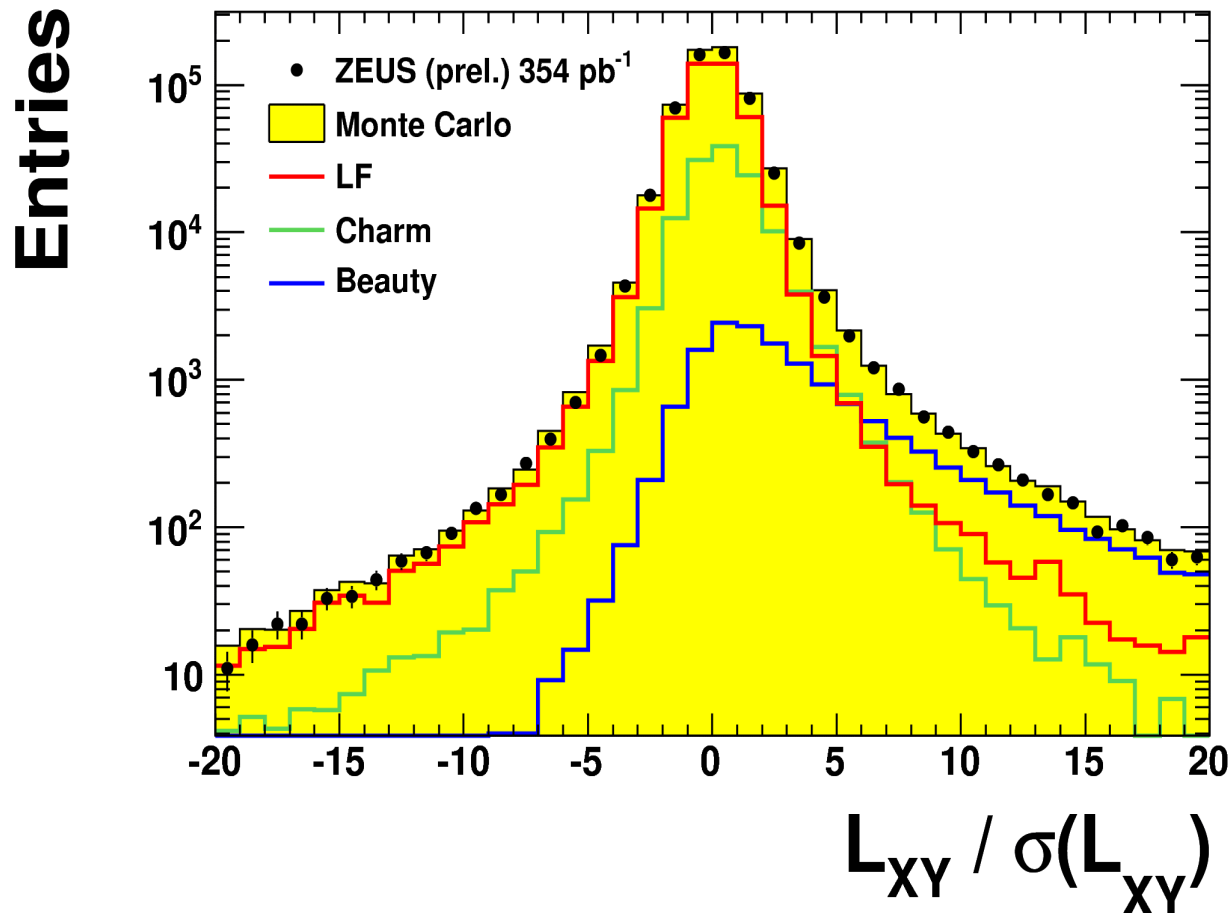


Secondary vertex method (cont'd)

- Decay length significance:

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$$2 < M_{\text{vtx}} < 6 \text{ GeV}$$



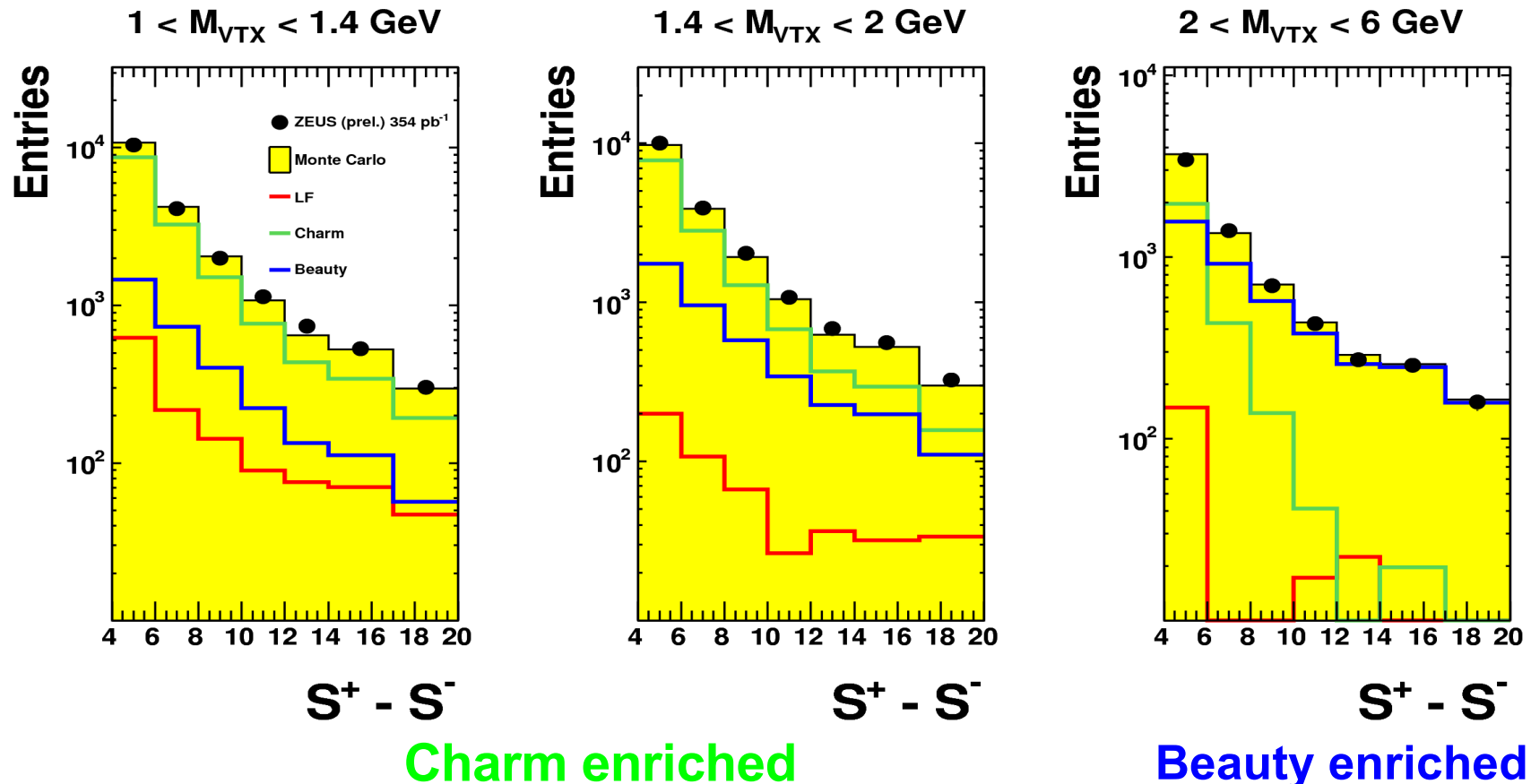
- Charm & Beauty MC: RAPGAP
- Light Flavour (LF) MC: ARIADNE

- Get rid of symmetric part by “mirroring”

Secondary vertex method (cont'd)

- Discriminating variables: mirrored significance and mass

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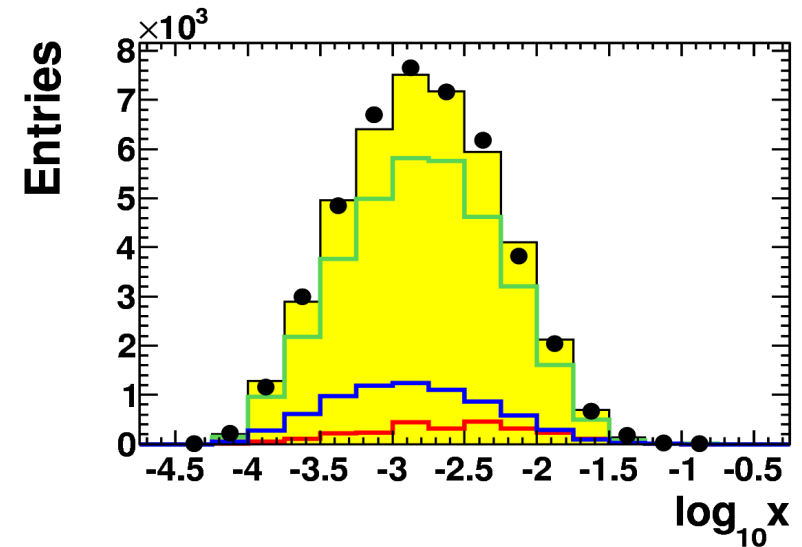
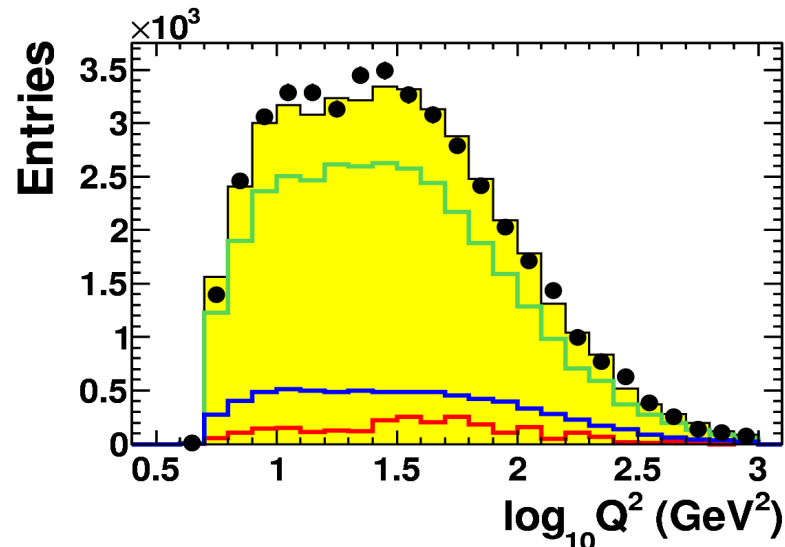
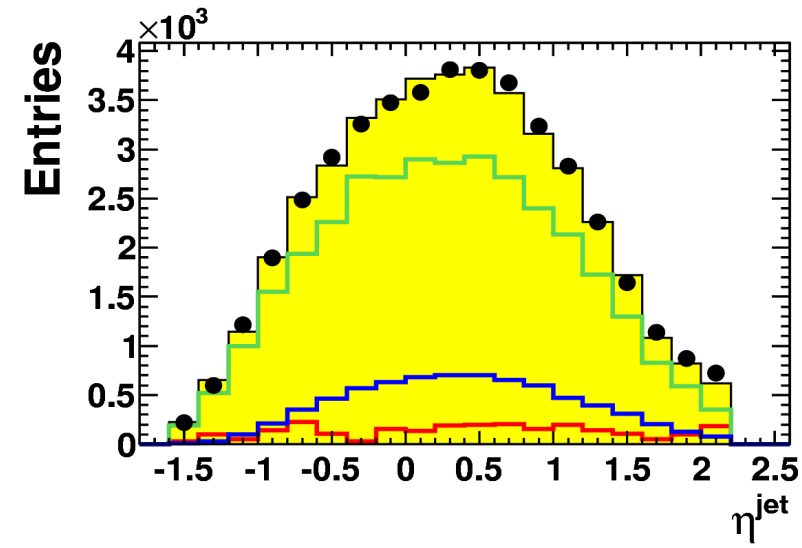
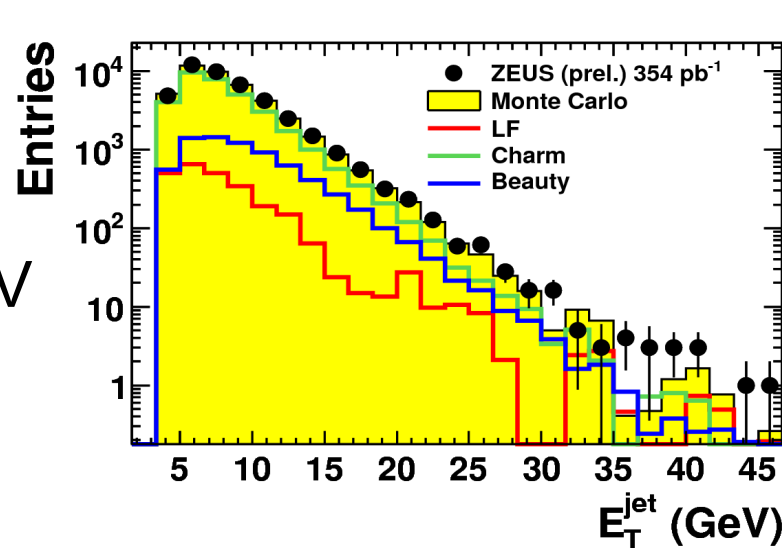


- Three bins are fitted simultaneously
- Total light flavour normalization is fixed by unmirrored significance

Control distributions

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- Charm enrichment:
 $S^+ - S^- > 4$
 $1 < M_{\text{vtx}} < 2 \text{ GeV}$
- High purity charm sample!



- Good description of the data by the Monte Carlo

Systematic uncertainties

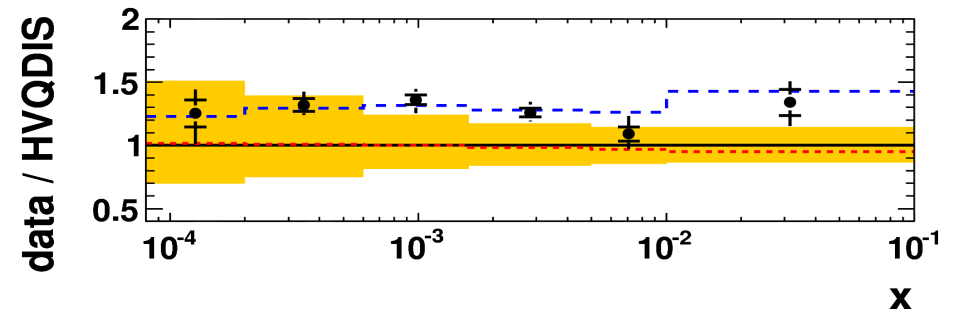
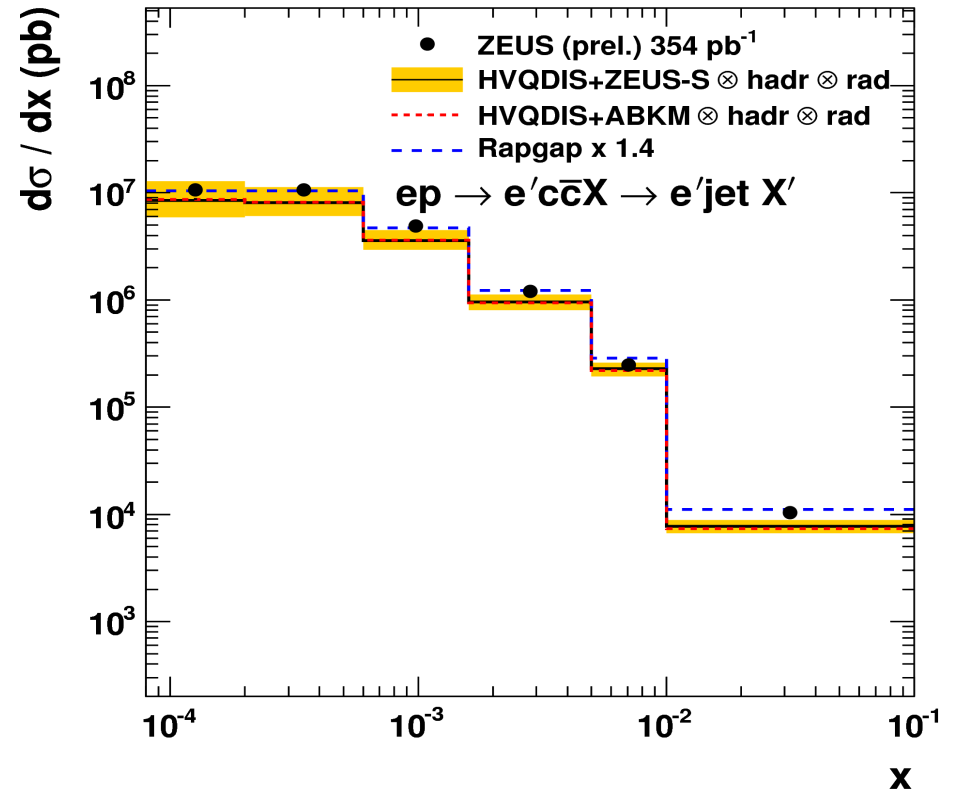
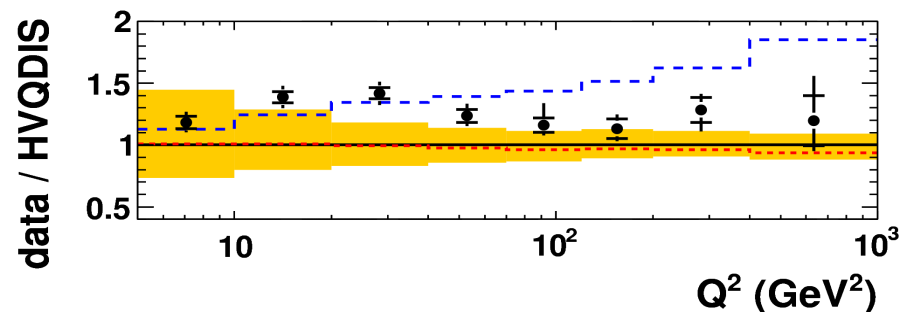
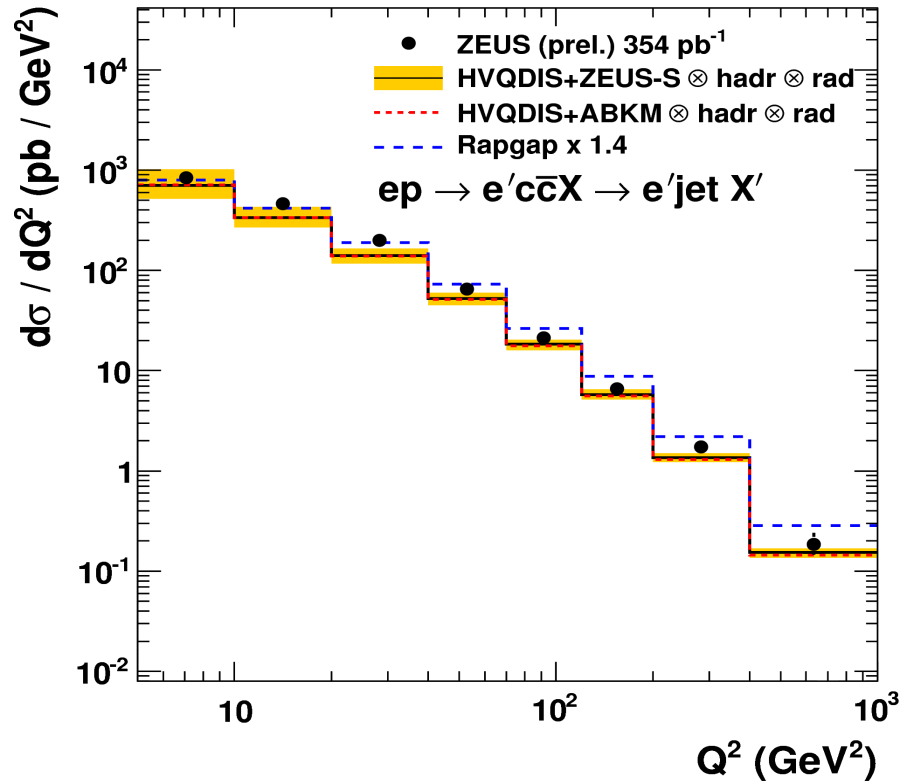
- Luminosity: $\pm 2\%$
- DIS selection: $^{+1\%}_{-2\%}$
- Signal extraction: $^{+3\%}_{-2\%}$
- EM scale: $< 1\%$
- FLT efficiency: $+1\%$
- Q^2 reweighting: $\pm 2\%$
- Branching ratios: $\pm 3\%$
- Fragmentation fractions: $\pm 1\%$
- Tracking efficiency: $+3\%$
- Charm fragmentation fraction: $+1\%$
- Jet energy scale: $\pm 1\%$
- Significance smearing: $\pm 1\%$
- Light flavour background: $\pm 2\%$
- Charm η reweighting: $^{+1.5\%}_{-1\%}$
- Charm E_T reweighting: $^{+2\%}_{-1.7\%}$

HVQDIS predictions

- NLO massive scheme
- ZEUS-S and ABKM NLO PDFs
- $\mu_R = \mu_F = \sqrt{Q^2 + 4m_c^2}$
- $m_c = 1.5 \text{ GeV}$
- Hadronization and QED corrections obtained with RAPGAP MC
- Uncertainties:
 - μ_R and μ_F varied independently by 0.5 and 2
 - m_c varied from 1.3 GeV to 1.7 GeV
 - PDFs varied within uncertainties

Differential cross-sections

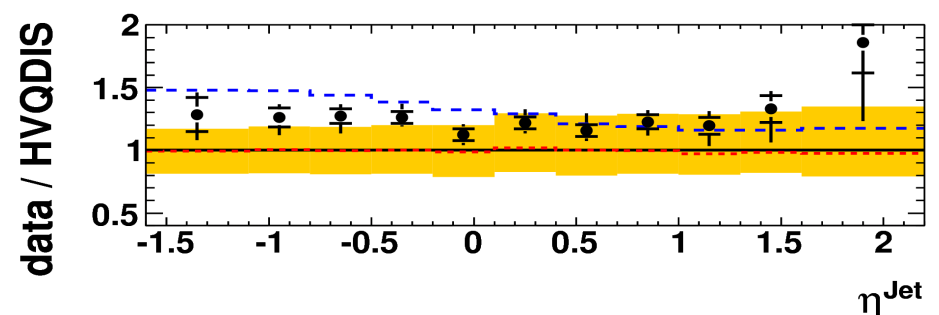
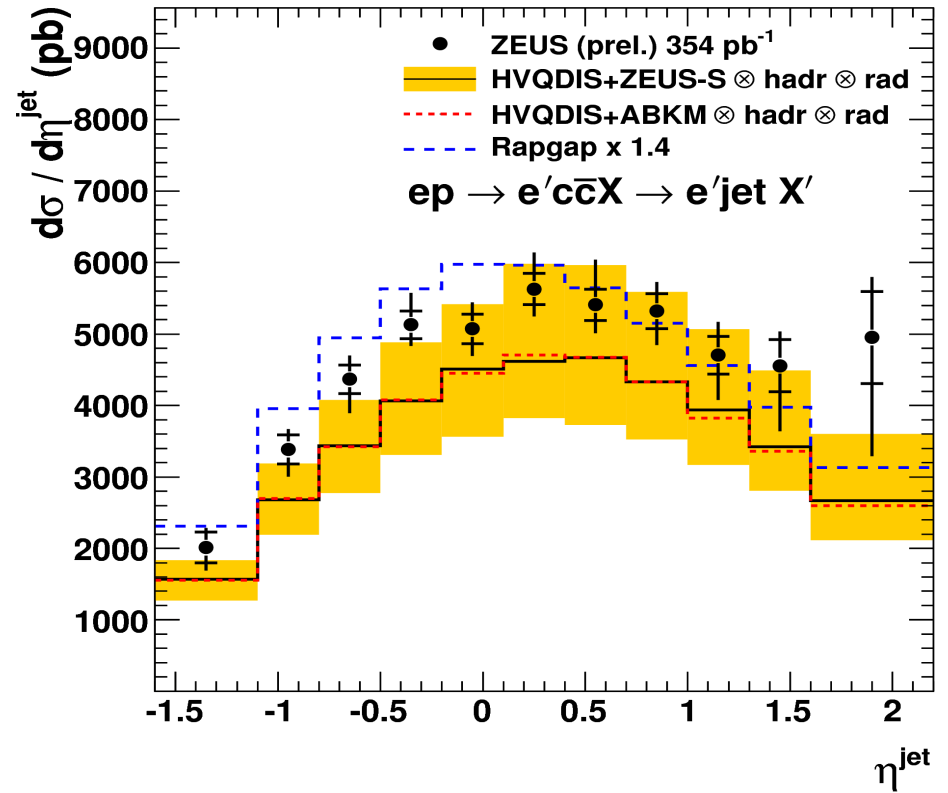
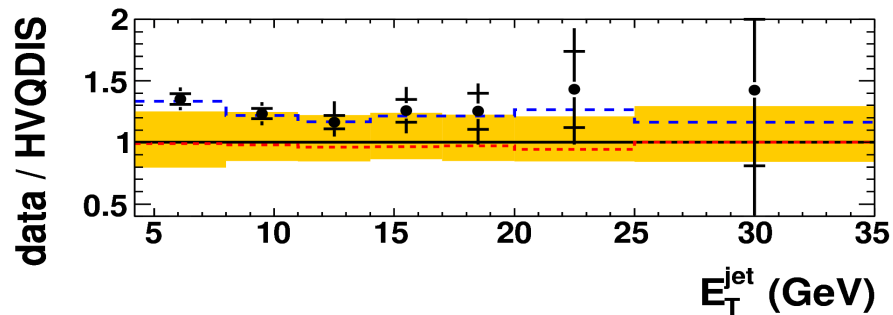
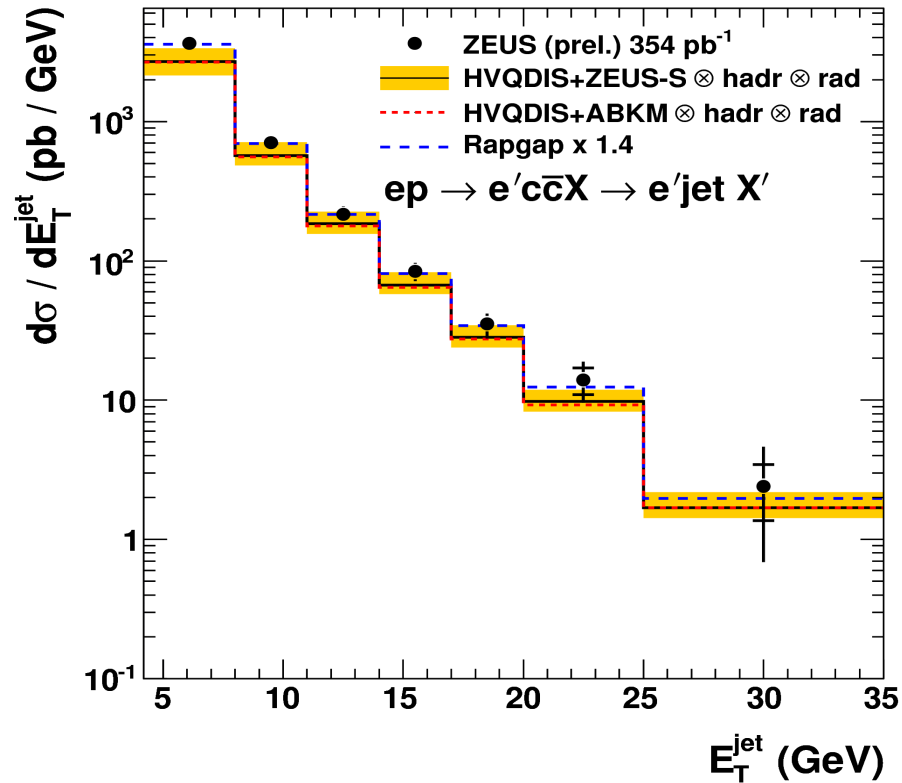
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- Reasonable description by HVQDIS NLO QCD

Differential cross-sections

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- Reasonable description by HVQDIS NLO QCD

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

- Charm contribution to the proton structure function F_2 :

$$\frac{d^2 \sigma^{ep \rightarrow c\bar{c}x}}{dQ^2 dx} = \frac{2\pi\alpha^2}{Q^4 x} [(1 + (1-y)^2) \cdot F_2^{c\bar{c}}(x, Q^2) - y^2 F_L^{c\bar{c}}]$$

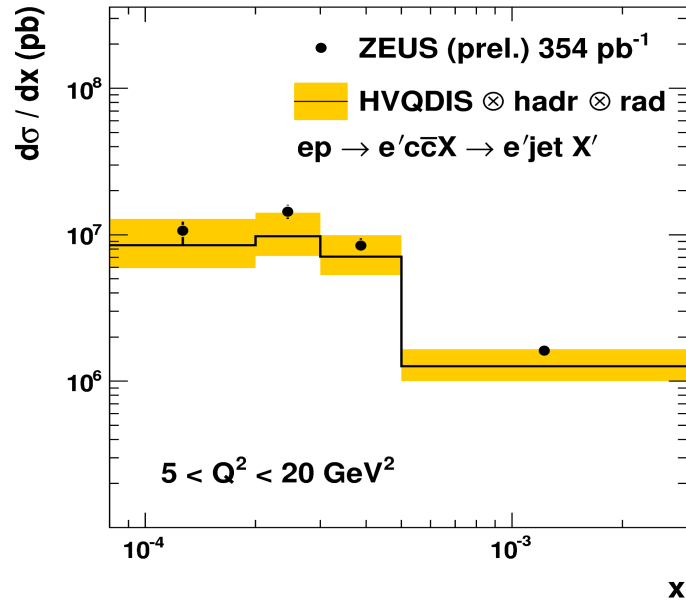
- NLO QCD to extrapolate from visible cross-section to full phase space:

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

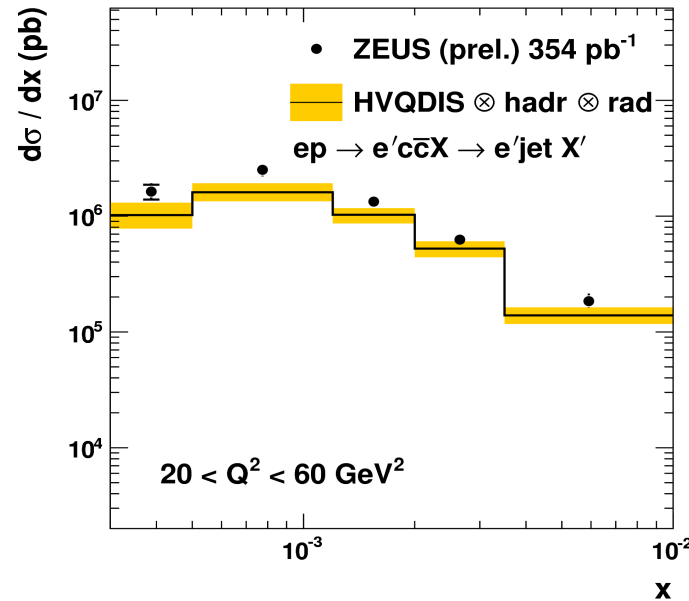
- Typical extrapolation factors: ~ 1 at high Q^2 , up to ~ 4 at low Q^2 (due to jet E_T cut)

Double-differential cross-sections

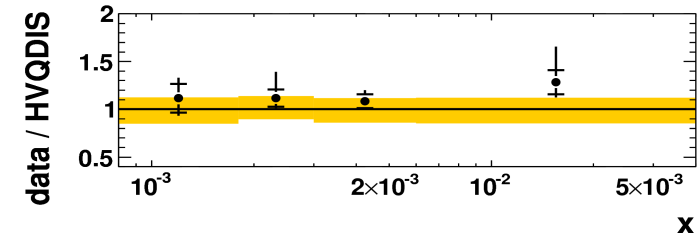
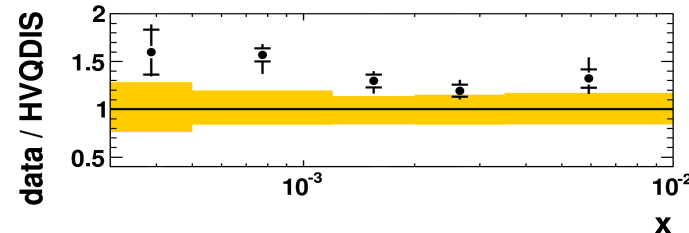
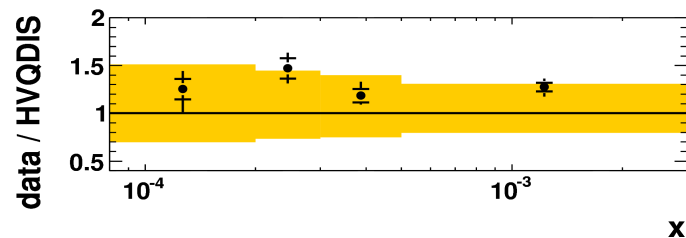
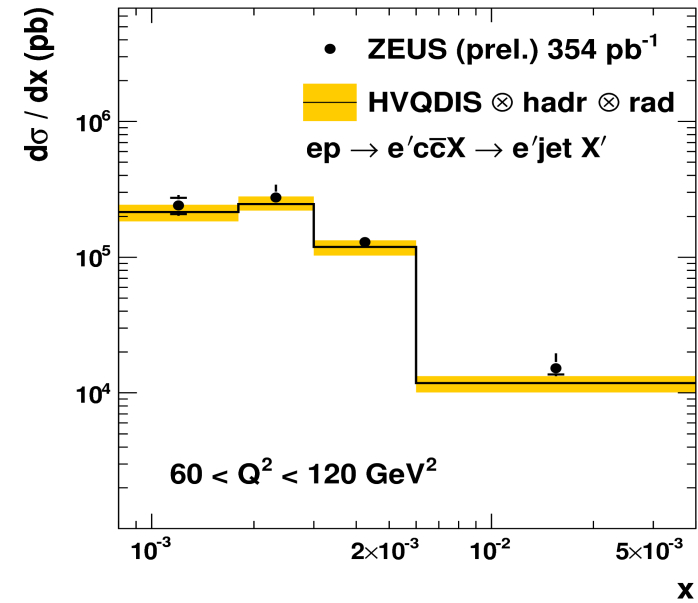
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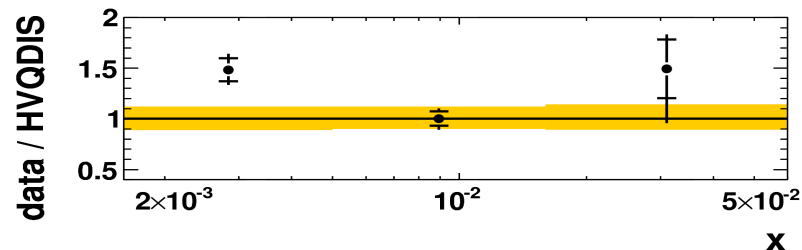
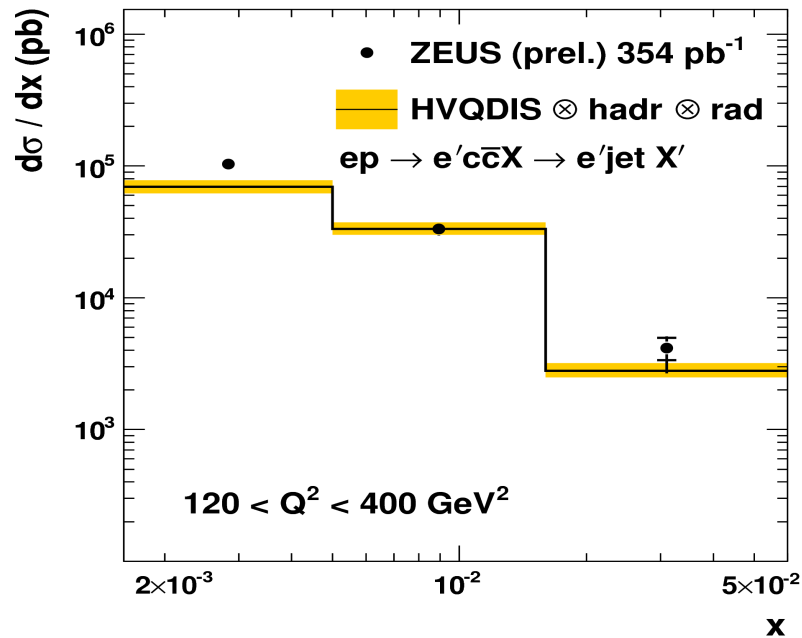
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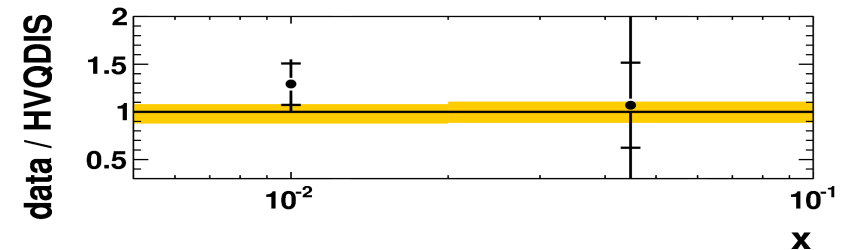
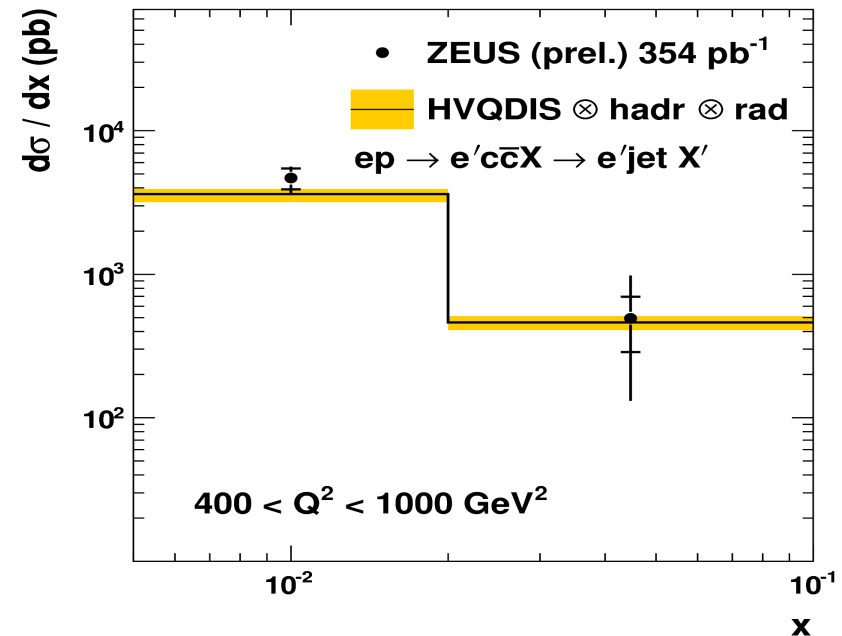
- Reasonable description by NLO QCD
- Input to $F_2^{c\bar{c}}$

Double-differential cross-sections (cont'd)

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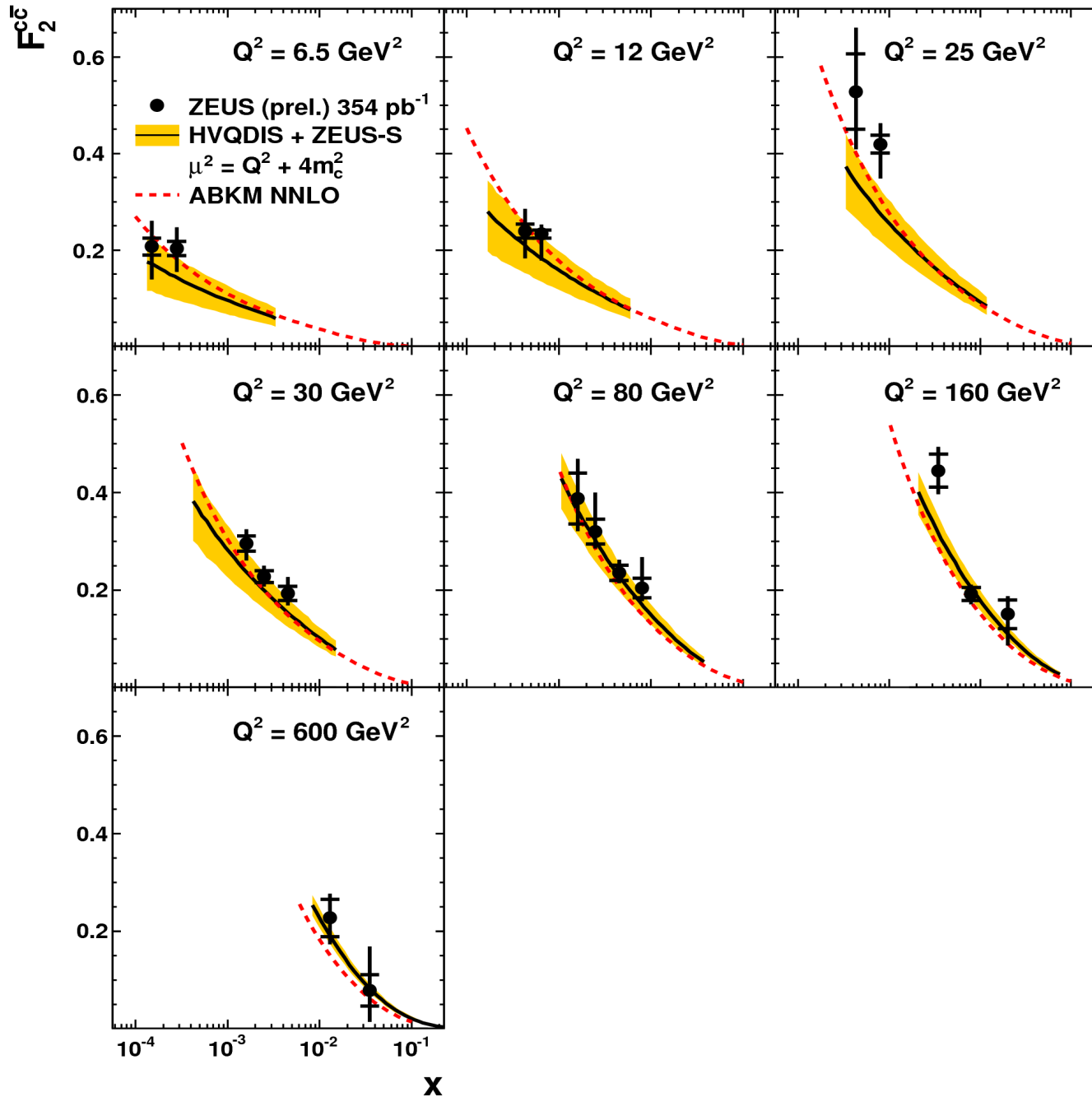
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- Reasonable description by NLO QCD
- Input to $F_2^{c\bar{c}}$

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

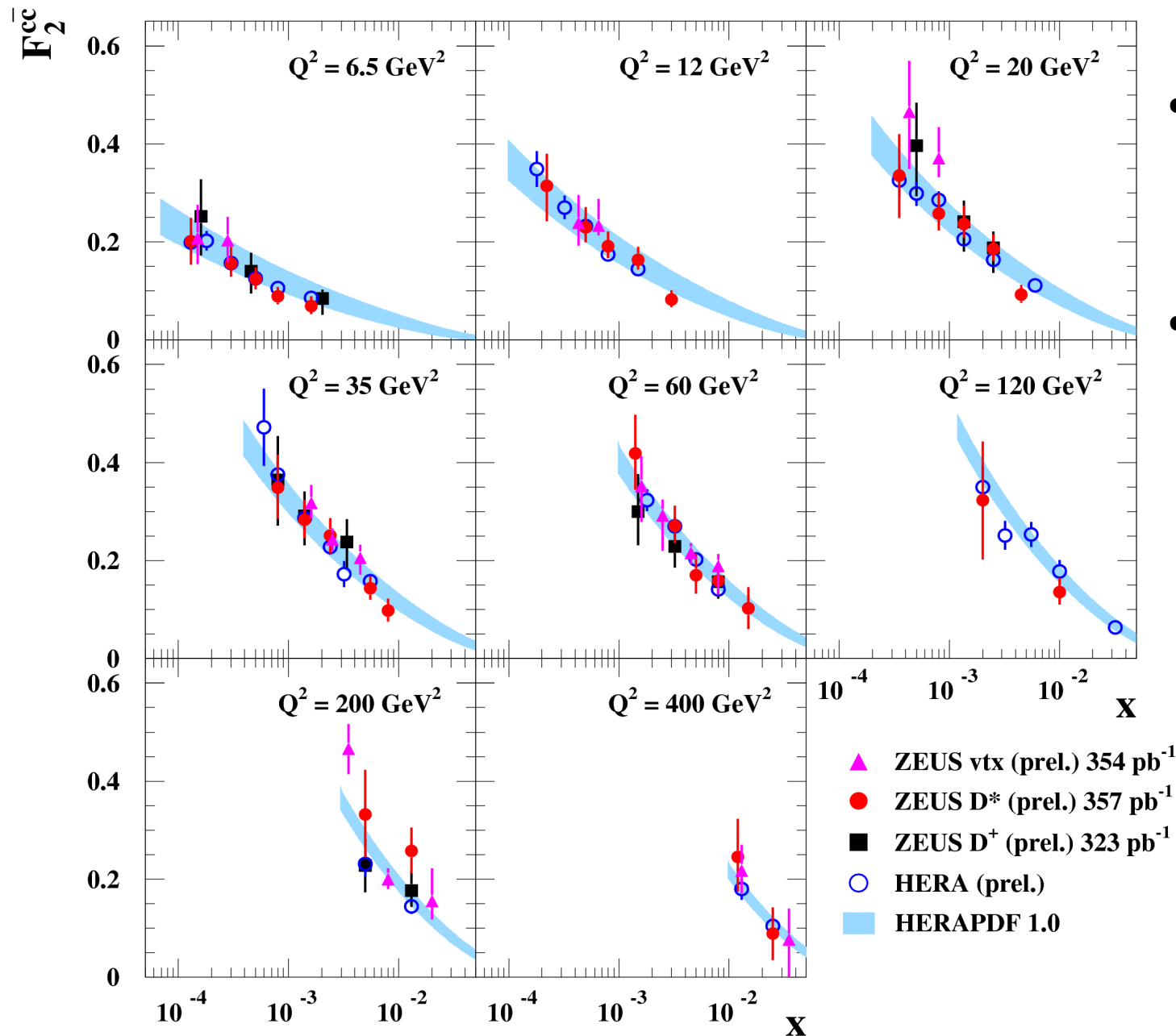
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- Good agreement with NLO and NNLO
- Large extrapolation uncertainties at low Q^2 due to jet E_T cut

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

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- Consistent with previous measurements
- Good precision, will contribute to combined results

Summary

- Charm measurements at HERA provide unique means to test pQCD, validity of gluon PDFs, multiple-scale problem, charm mass
- Charm production was measured with inclusive secondary vertices method
- Cross-sections are reasonably described by HVQDIS
- $F_2^{c\bar{c}}$ contribution to the proton structure function was extracted
- Competitive precision due to inclusive nature of the method, will contribute to the combination

Thank you very much for your attention!!

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