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

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on behalf of the **ZEUS Collaboration**

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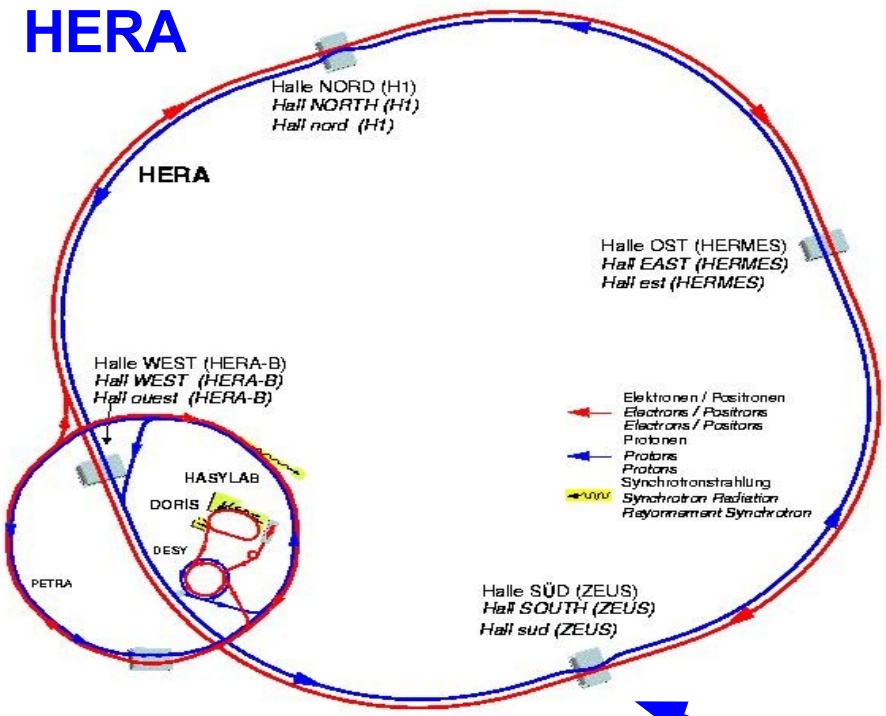
Outline

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

ZEUS @ HERA

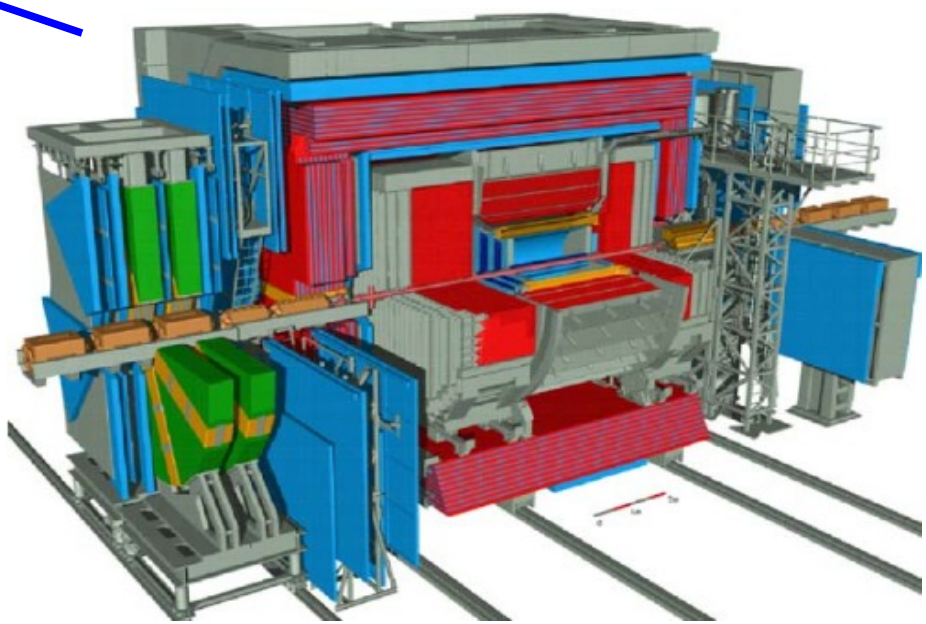
HERA



- Protons 920 GeV,
- Electrons 27.6 GeV

$\sqrt{s} = 318\,GeV$

- Operational: 1992-2007
- **ZEUS** – general purpose hermetic detector
- ~500 pb^{-1} accumulated during HERA I and HERA II running periods



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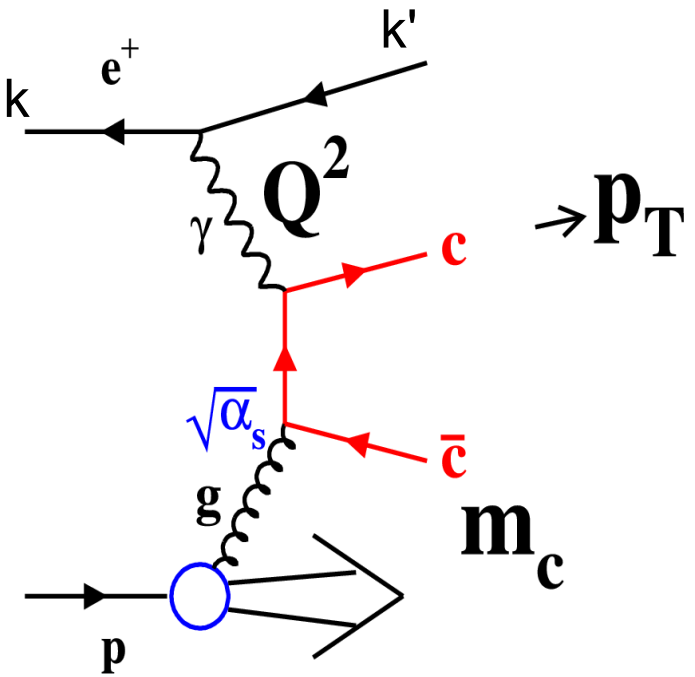
Charm physics at HERA

- 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



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

Kinematics of ep scattering:

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

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

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

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

Secondary vertex method

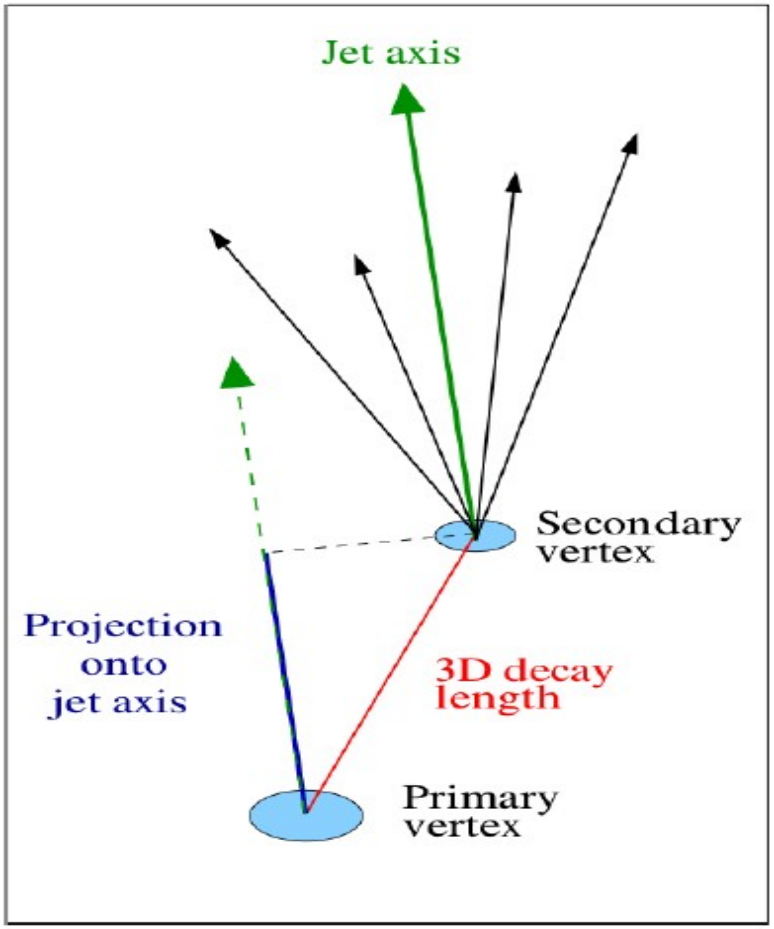
- Employs long lifetime of HQ
- No specific decay mode requirement → increase statistics
- Select tracks belonging to a jet
  - p_T(track)>500 MeV
- Fit a secondary vertex
- Project decay length onto a jet axis
- Calculate decay length significance

$5 < Q^2 < 1000\ GeV^2$

$0.02 < y < 0.7$

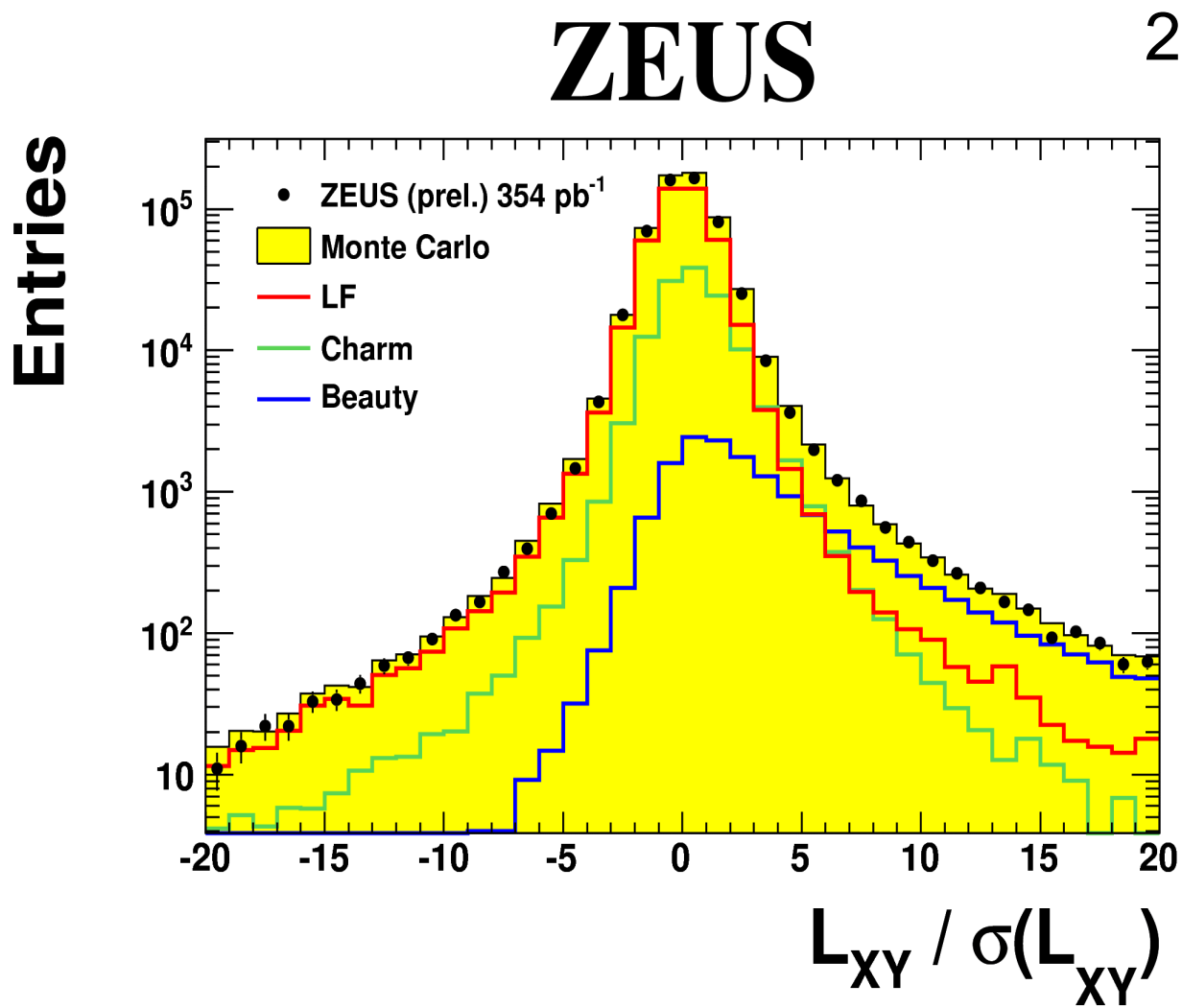
E_T(jet)>4.2 GeV

$-1.6 < \eta(jet) < 2.2$



Secondary vertex method (cont'd)

- Decay length significance:



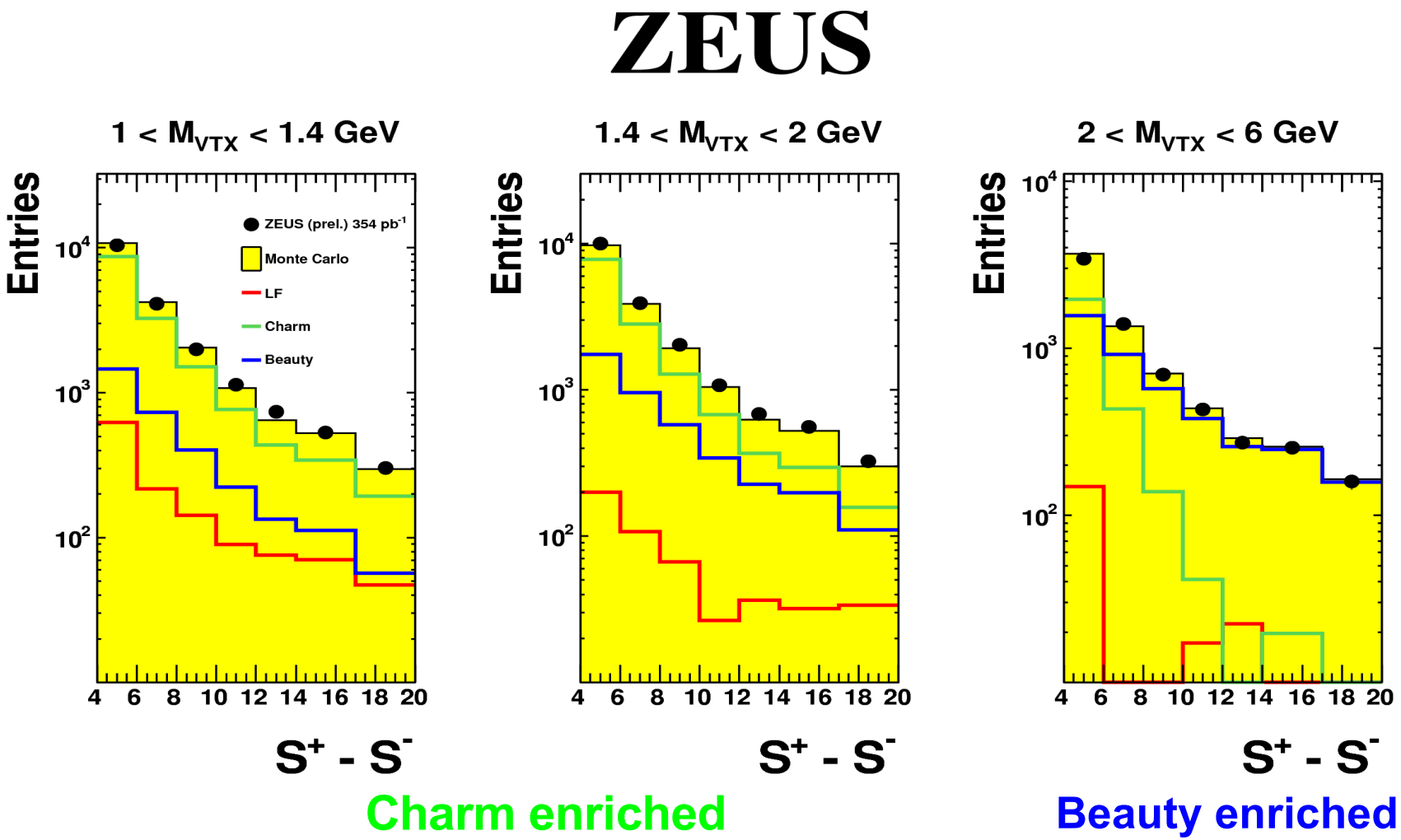
$2 < M_{vtx} < 6$ GeV

- 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



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

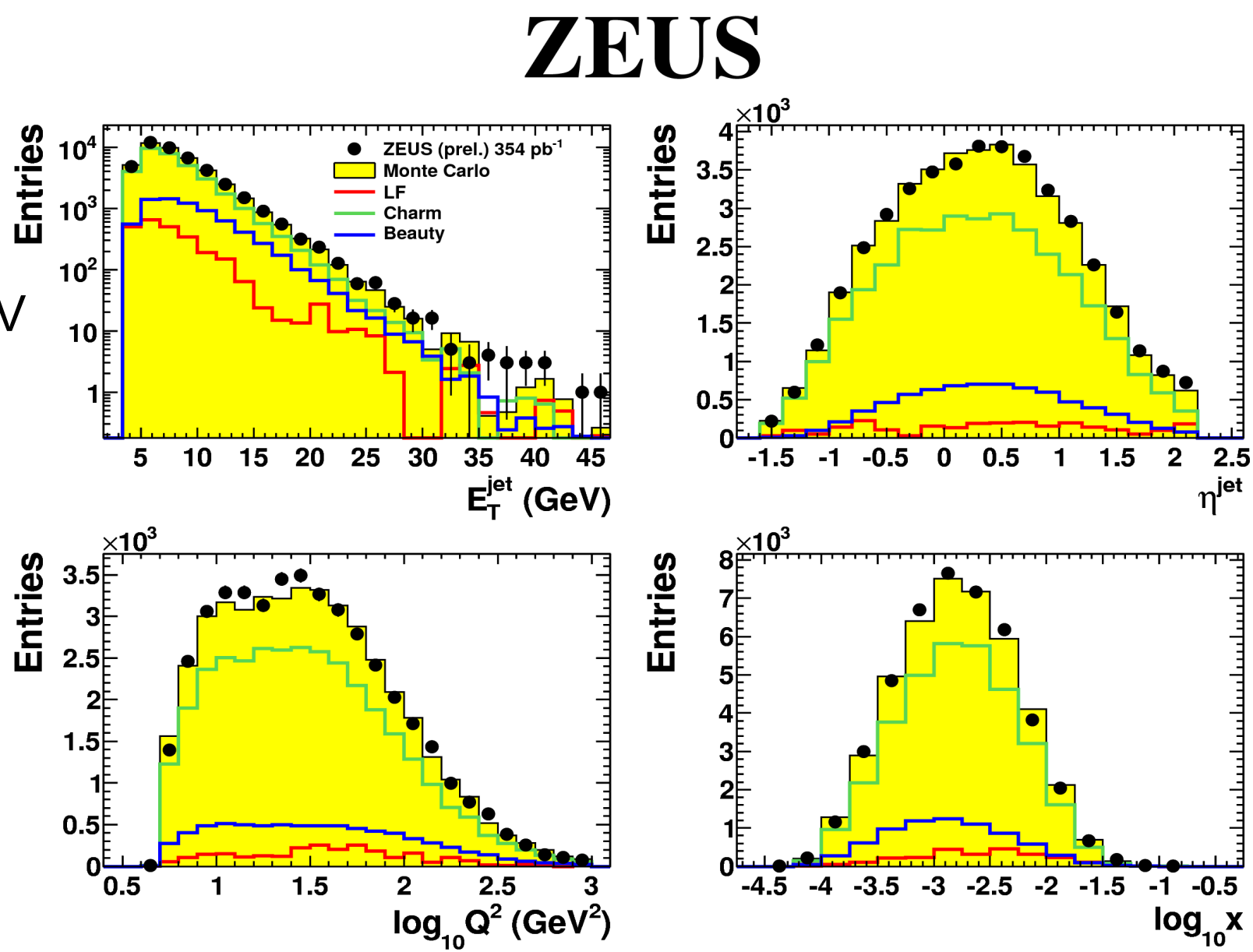
Control distributions

- Charm enrichment:

  $S^+ - S^- > 4$

  $1 < M_{vtx} < 2$ GeV

- High purity charm sample!



- Good description of the data by the Monte Carlo

Systematic uncertainties

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

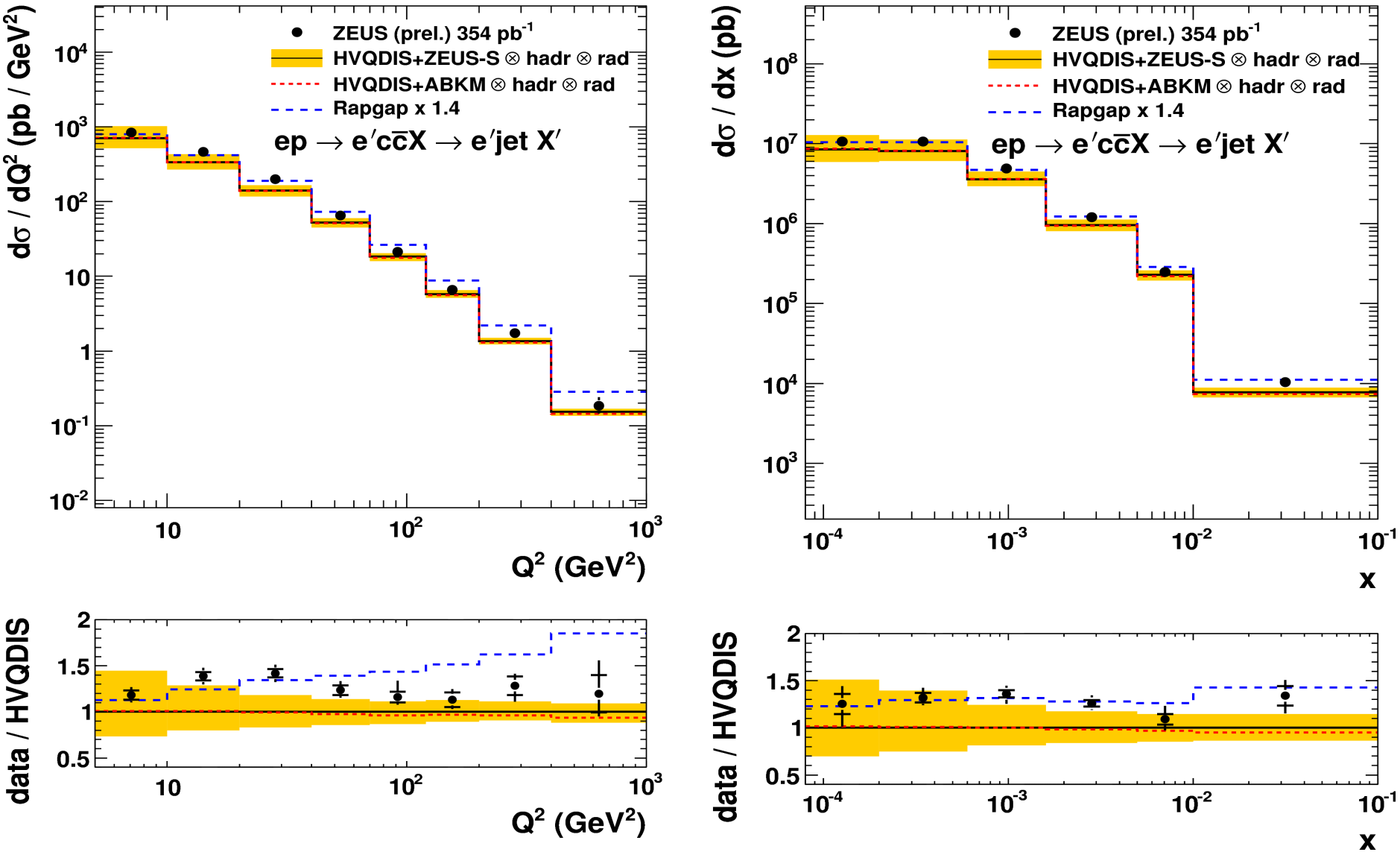
HVQDIS predictions

- NLO massive scheme

- ZEUS-S and ABKM NLO PDFs
- $\mu_R = \mu_F = \sqrt{Q^2 + 4 m_c^2}$
- m_c=1.5 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

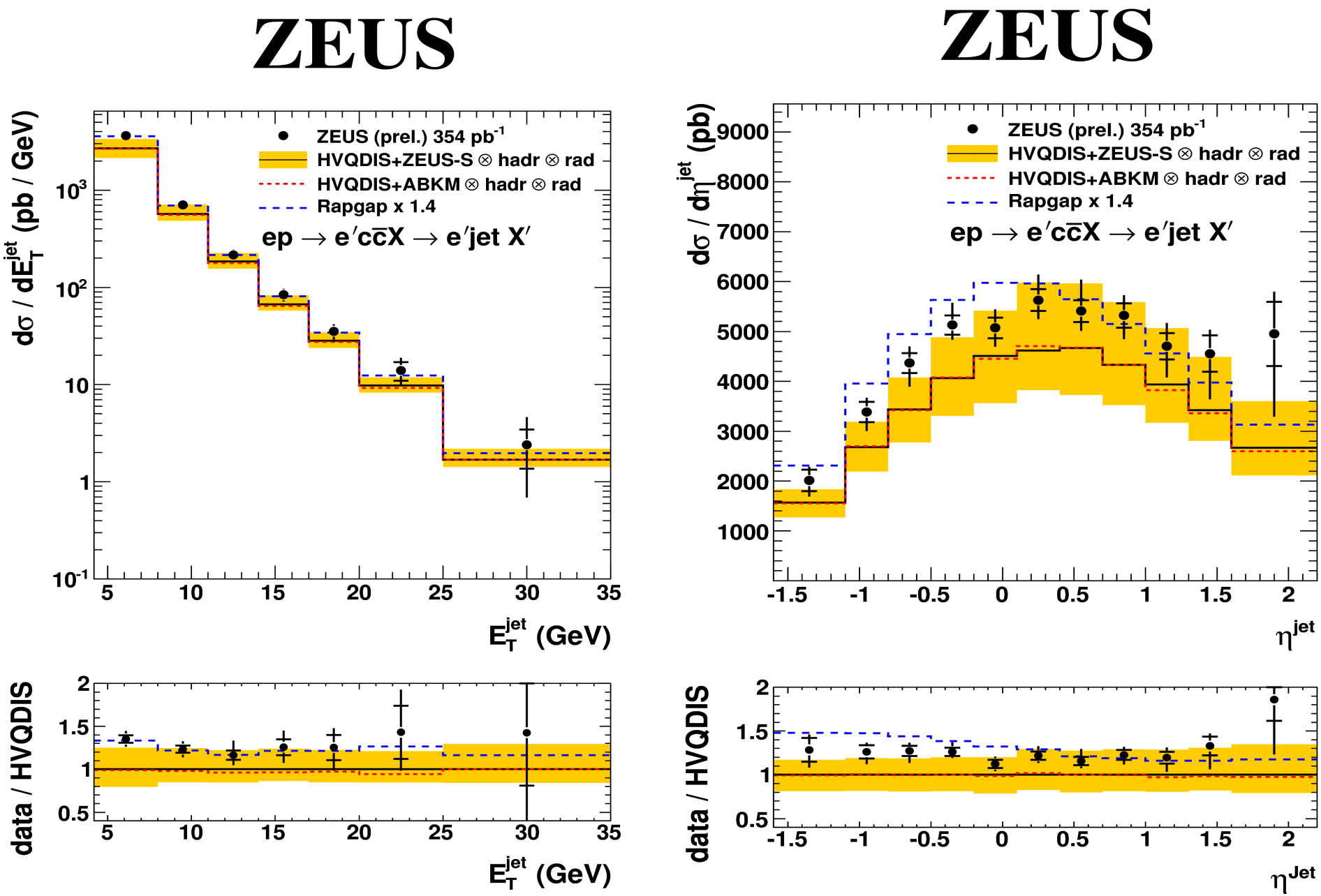
Differential cross-sections

ZEUS **ZEUS**



- Reasonable description by HVQDIS NLO QCD

Differential cross-sections



- Reasonable description by HVQDIS NLO QCD

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

- Charm contribution to the proton structure function F_2:

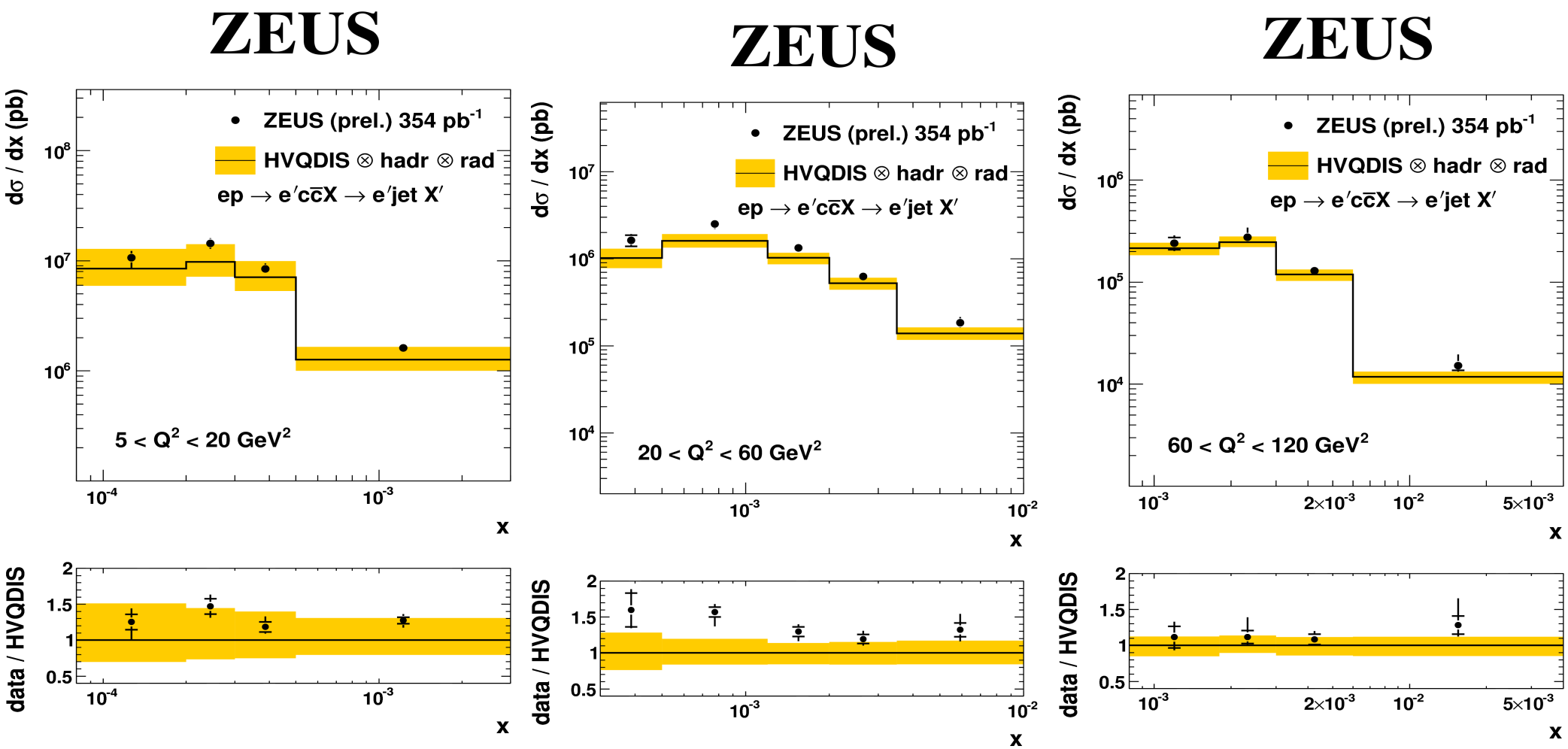
$$\frac{d^2\sigma^{ep\to c\bar{c}x}}{dQ^2\,dx}=\frac{2\pi\alpha^2}{Q^4 x}\left[\left(1+(1-y)^2\right)\cdot F_2^{c\bar{c}}(x,Q^2)-y^2 F_L^{c\bar{c}}\right]$$

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

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

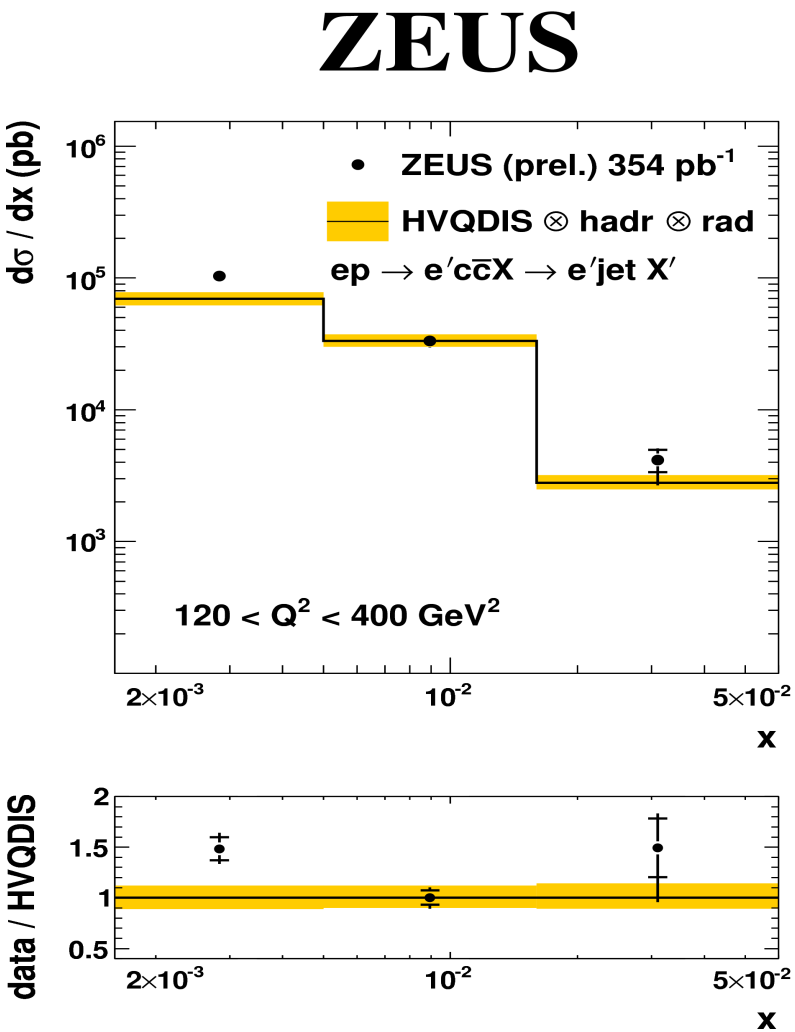
- Typical extrapolation factors: ~1 at high Q^2, up to ~4 at low Q^2 (due to jet E_T cut)

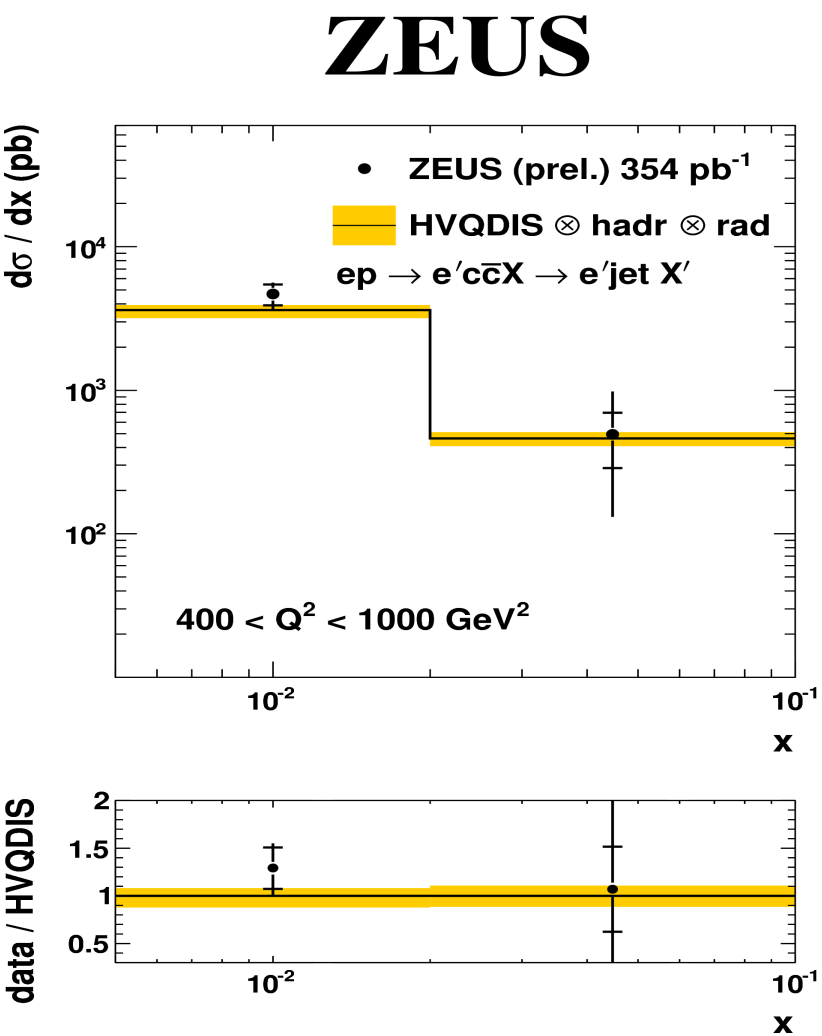
Double-differential cross-sections



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

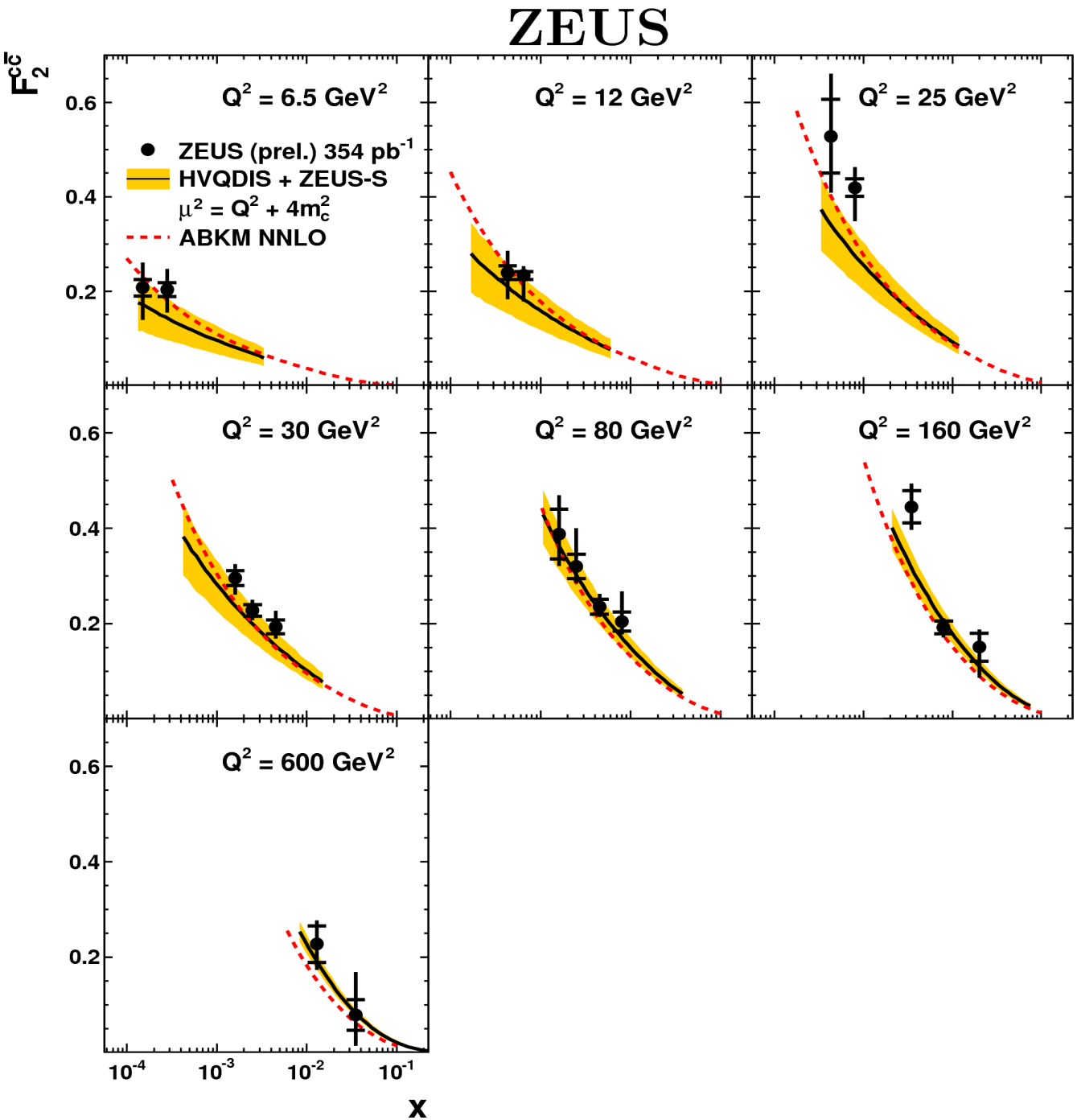
Double-differential cross-sections (cont'd)





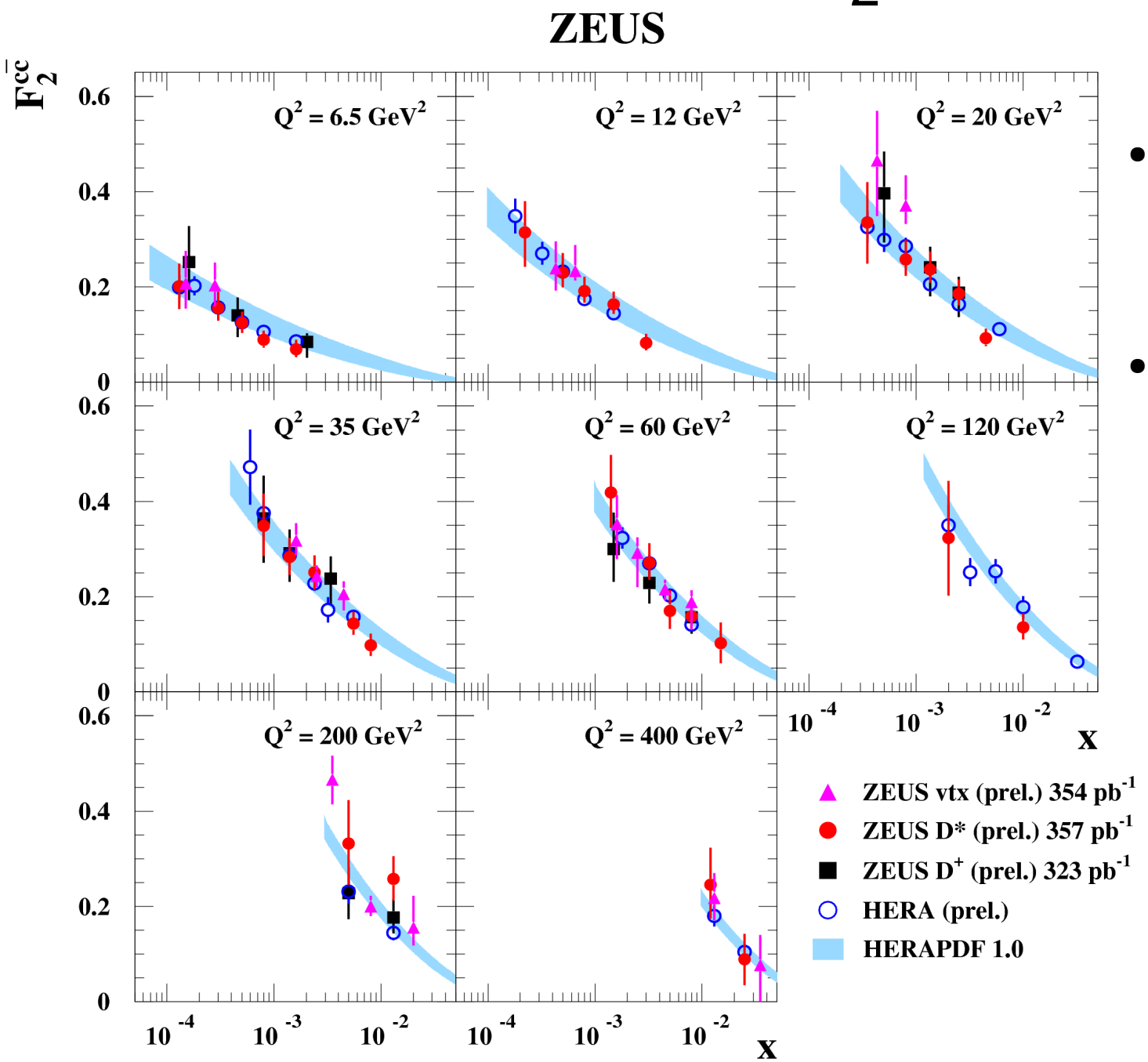
- Reasonable description by NLO QCD
- Input to $F_2^{c\bar{c}}$

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



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

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



- 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!!