$F_2^{b\bar{b}}$ measurement with inclusive secondary vertices at ZEUS

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on behalf of the **ZEUS Collaboration**

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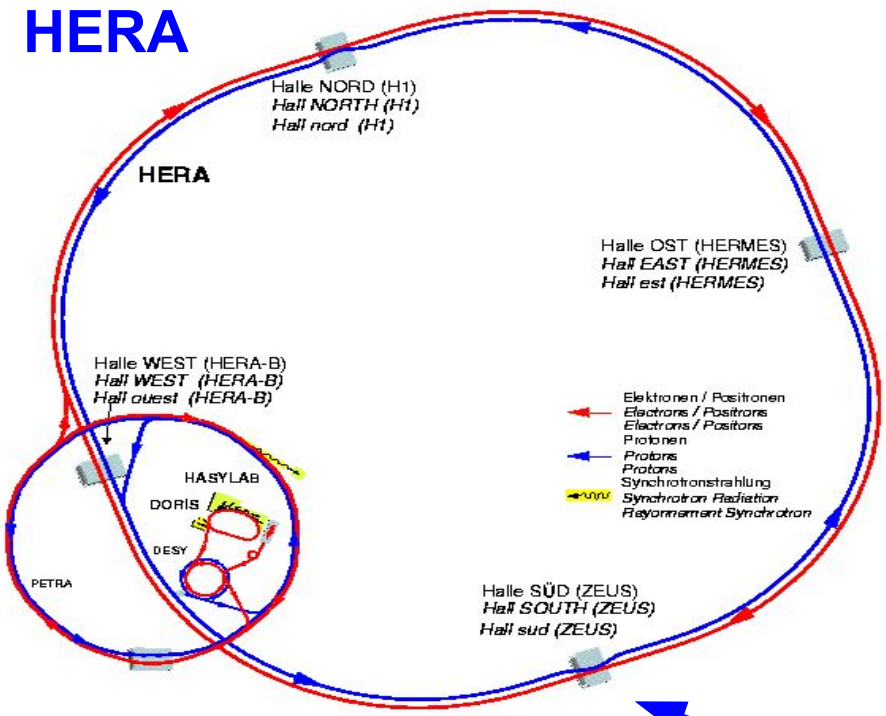
Outline

- Beauty production at HERA
- Inclusive secondary vertexing at ZEUS
- Differential cross-sections
- $F_2^{b\bar{b}}$ measurement
- Summary and outlook

ZEUS @ HERA

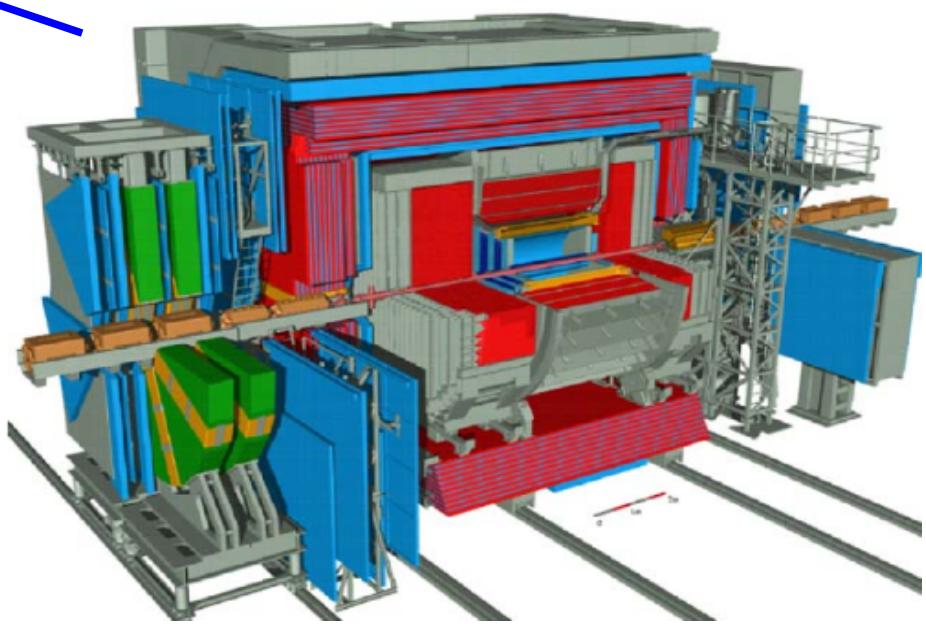
HERA



- Protons 920 GeV,
- Electrons 27.6 GeV

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

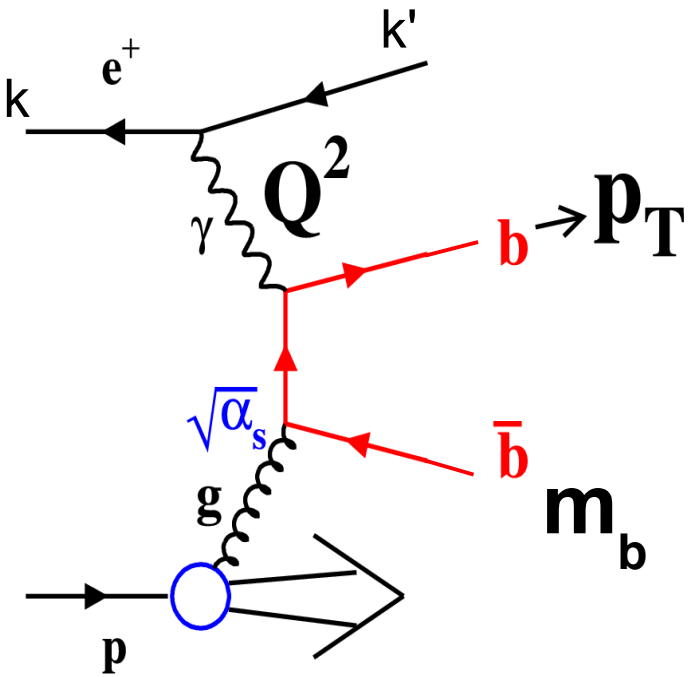
- Operational: 1992-2007
- **ZEUS** – general purpose hermetic detector
- ~500 pb^{-1} accumulated during HERA I and HERA II running periods



ZEUS

Beauty physics at HERA

- Heavy flavours are produced in the LO via Boson-Gluon Fusion (BGF)
- Sensitivity to the gluon density in the proton
- High beauty mass allows pQCD calculations to be performed and tested by comparing with data
- Multiple-hard-scale problem (m_b, p_T, Q^2)



- 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

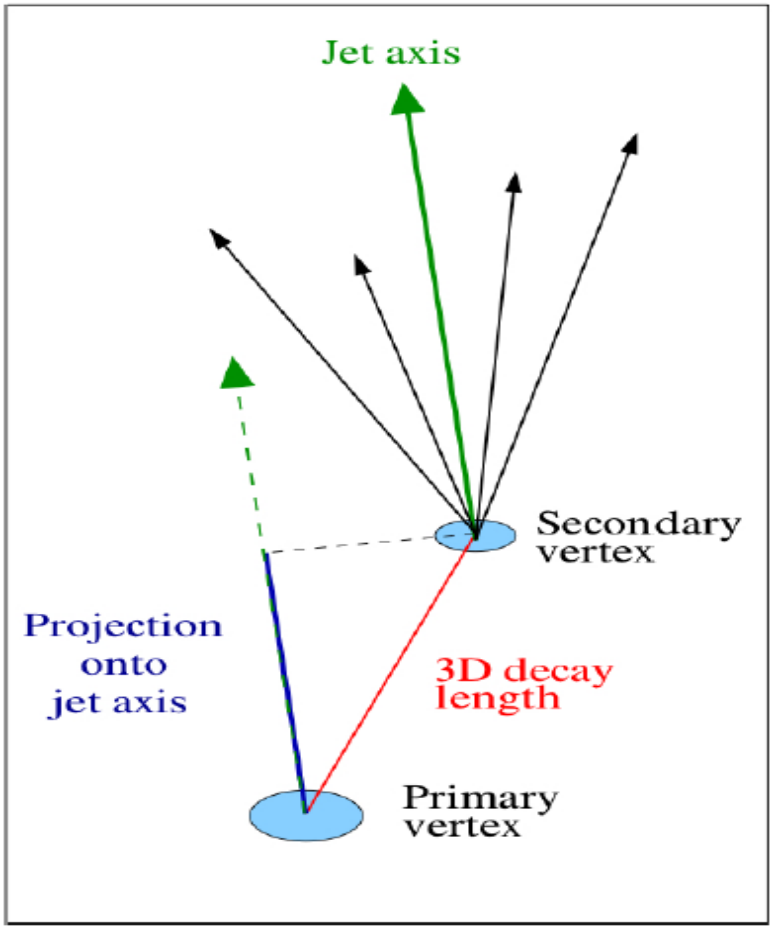
- Employes long lifetime of HQ
- No specific decay mode requirement → increase statistics
- Select tracks belonging to a jet
  - p_T(track)>500 MeV
- Fit secondary vertex if at least two tracks found
- Project decay length onto a jet axis
- Calculate decay length significance

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

$0.02 < y < 0.7$

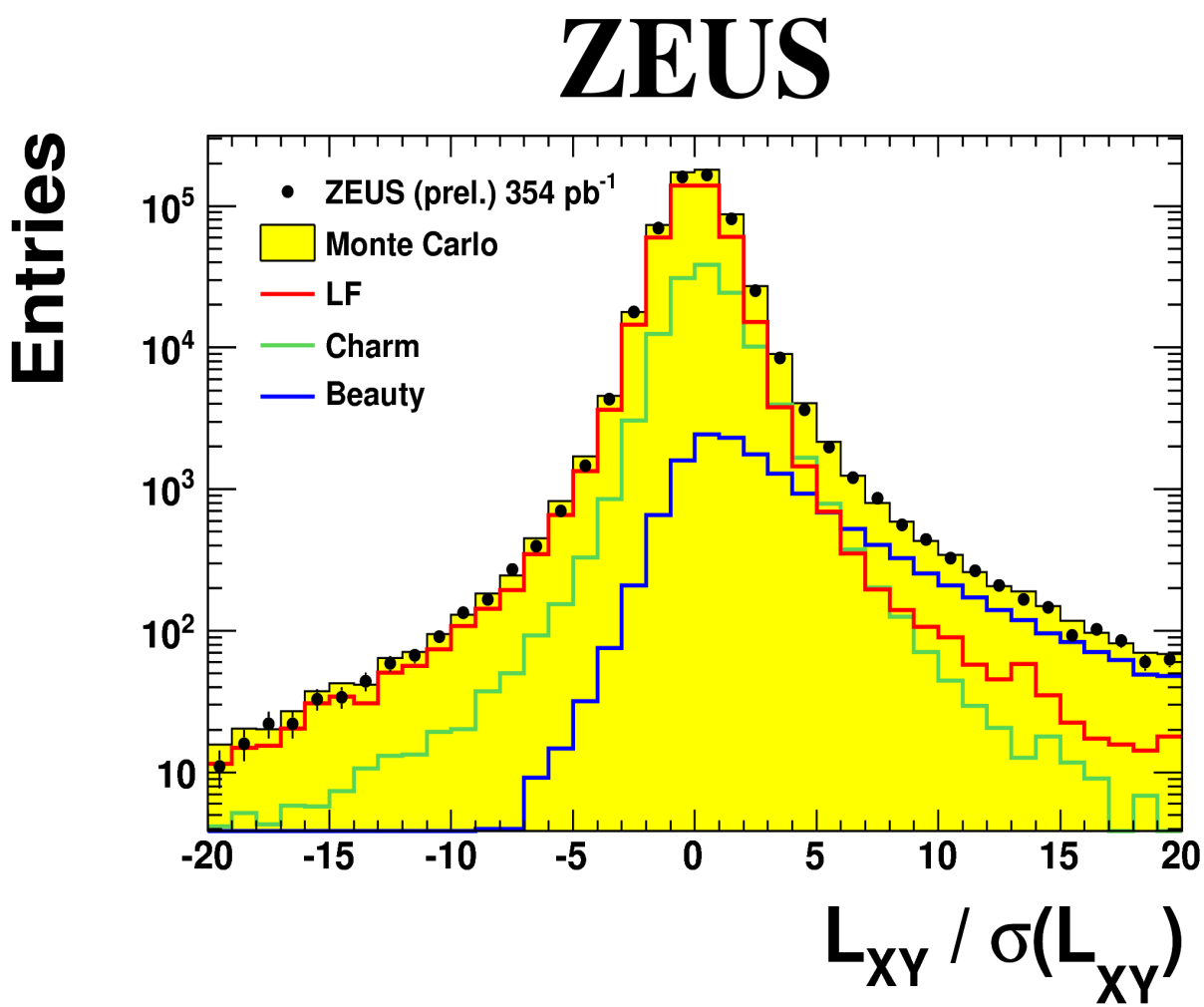
E_T(jet)>5 GeV

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



Secondary vertex method (cont'd)

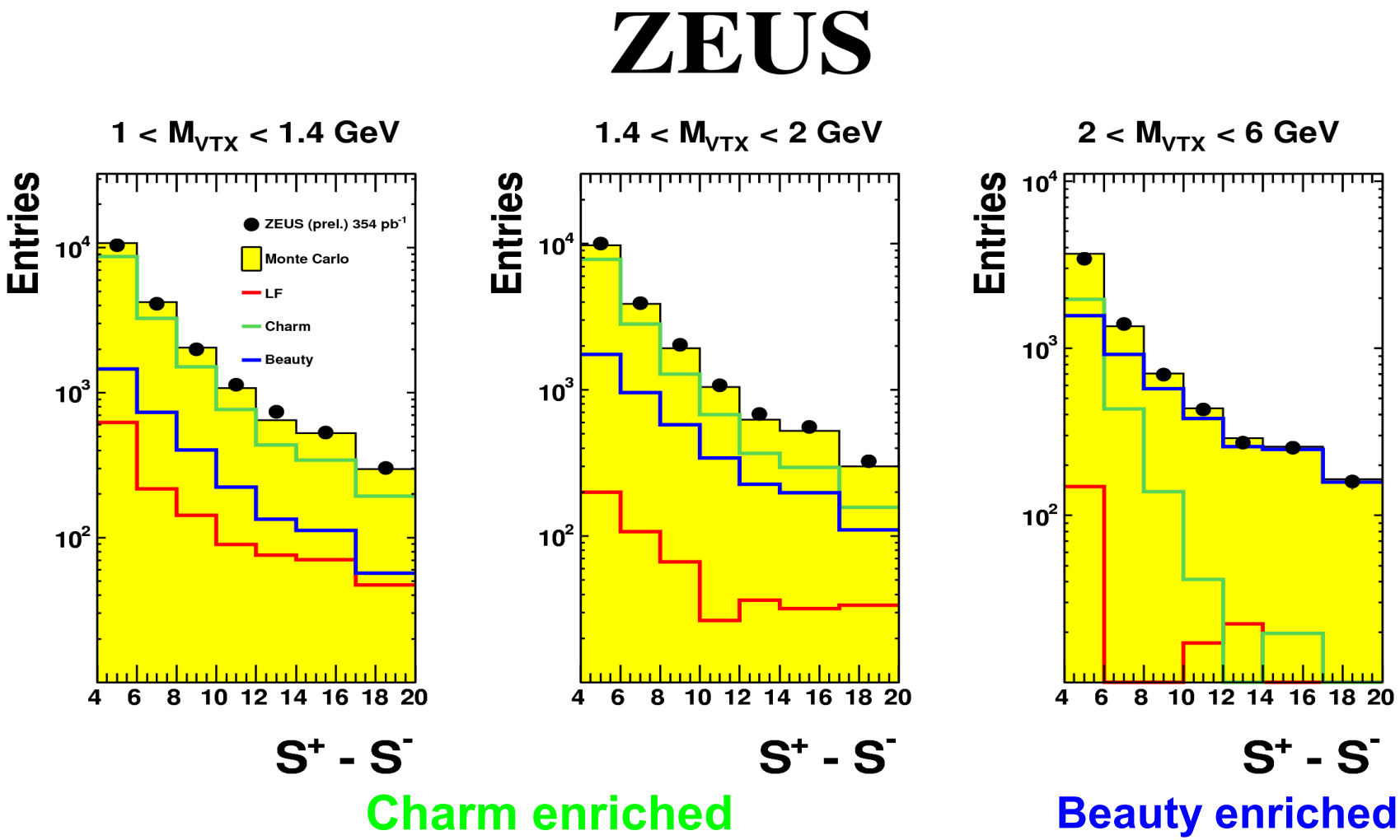
- Decay length significance:



- 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

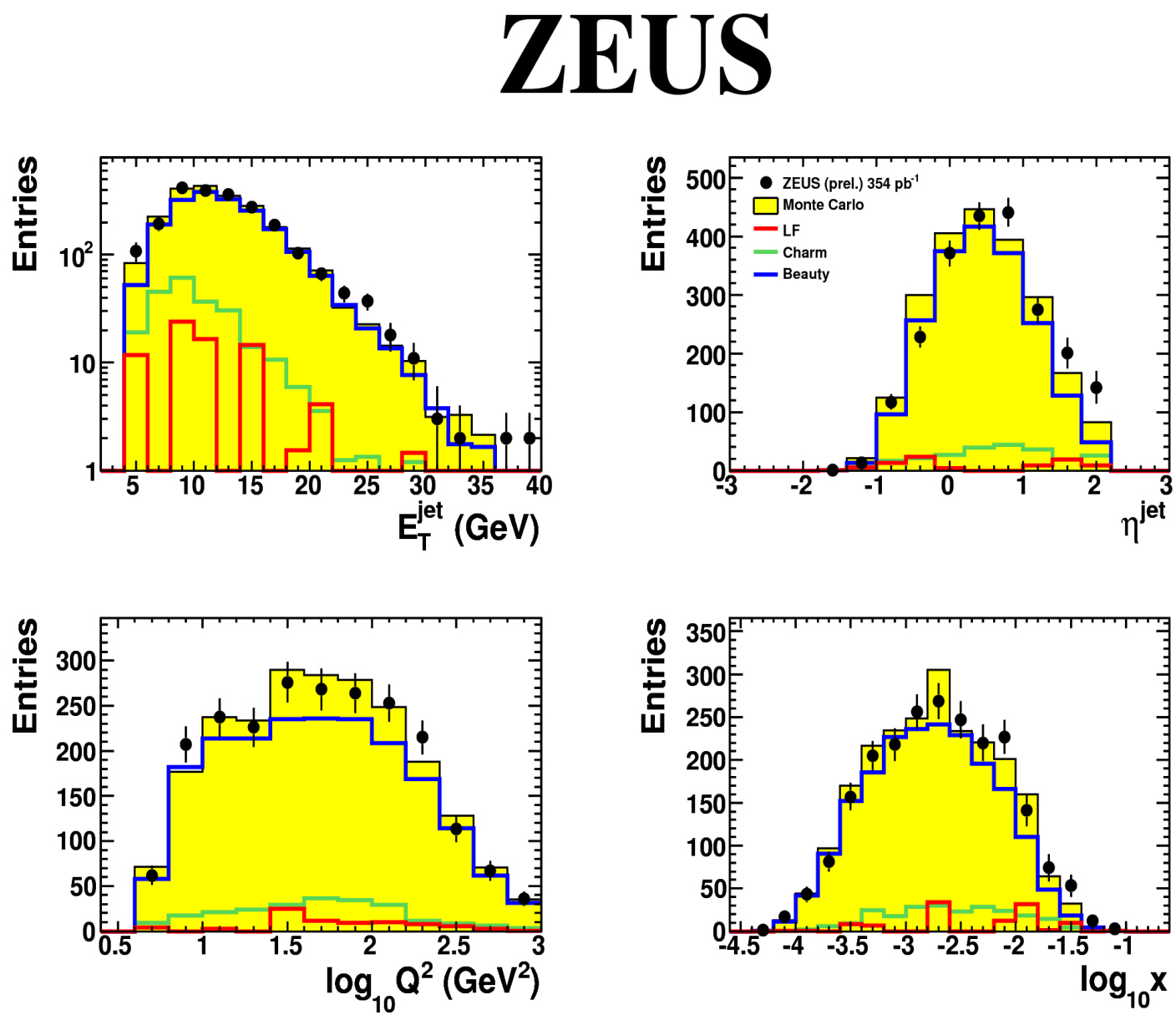
Control distributions

- Beauty enrichment:

  $S^+ - S^- > 8$

  $2 < M_{vtx} < 6$ GeV

- Almost pure beauty sample!



- Good description of the data by the Monte Carlo

HVQDIS predictions

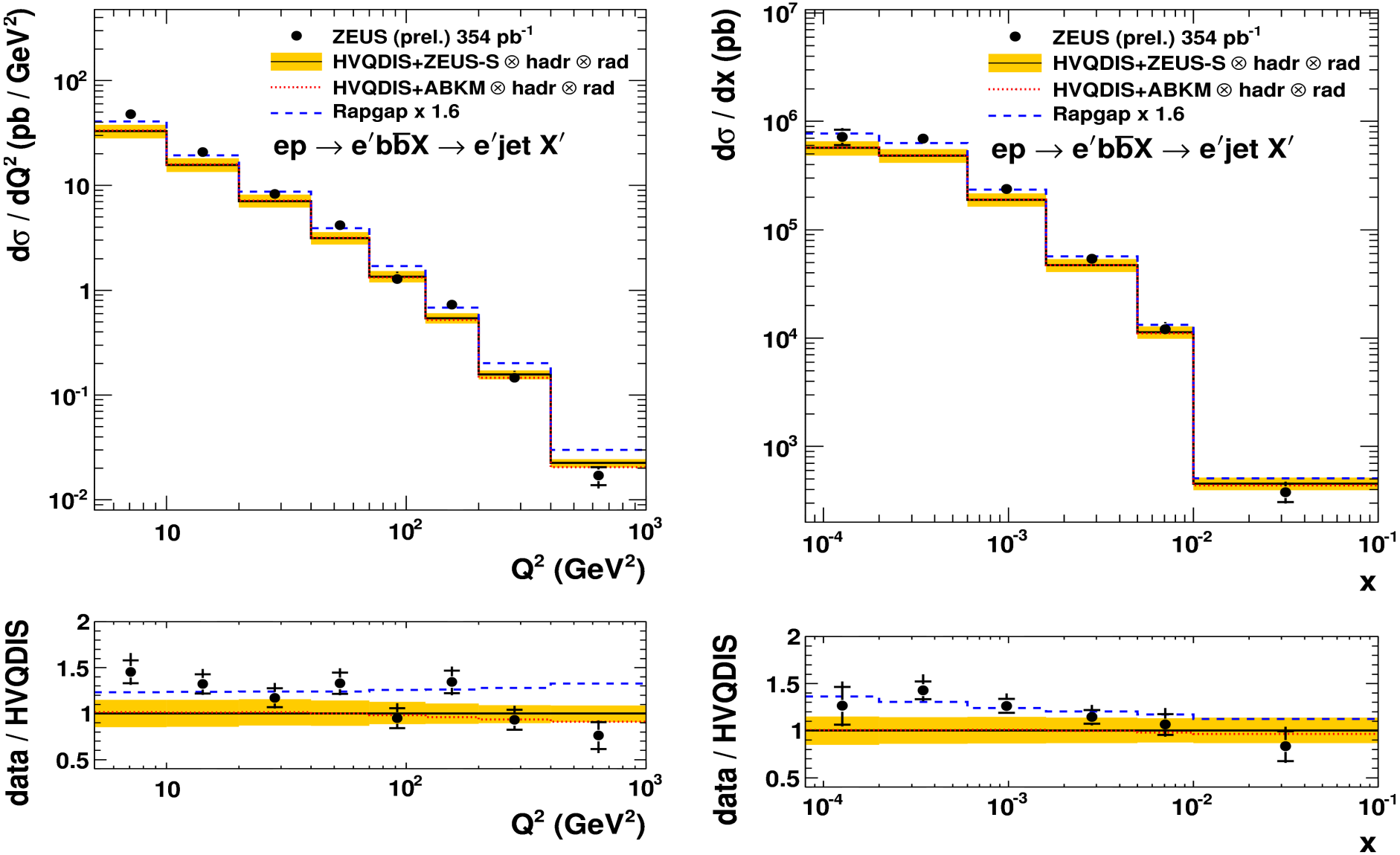
- NLO massive scheme

- ZEUS-S and ABKM NLO PDFs
- $\mu_R = \mu_F = \sqrt{Q^2 + 4 m_b^2}$
- m_b=4.75 GeV (ZEUS-S), m_b=4.5 GeV (ABKM)
- Hadronization and QED corrections obtained with RAPGAP MC

- Uncertainties (for ZEUS-S):
  - μ_R and μ_F varied independently by 0.5 and 2
  - m_b varied from 4.0 GeV to 5.0 GeV

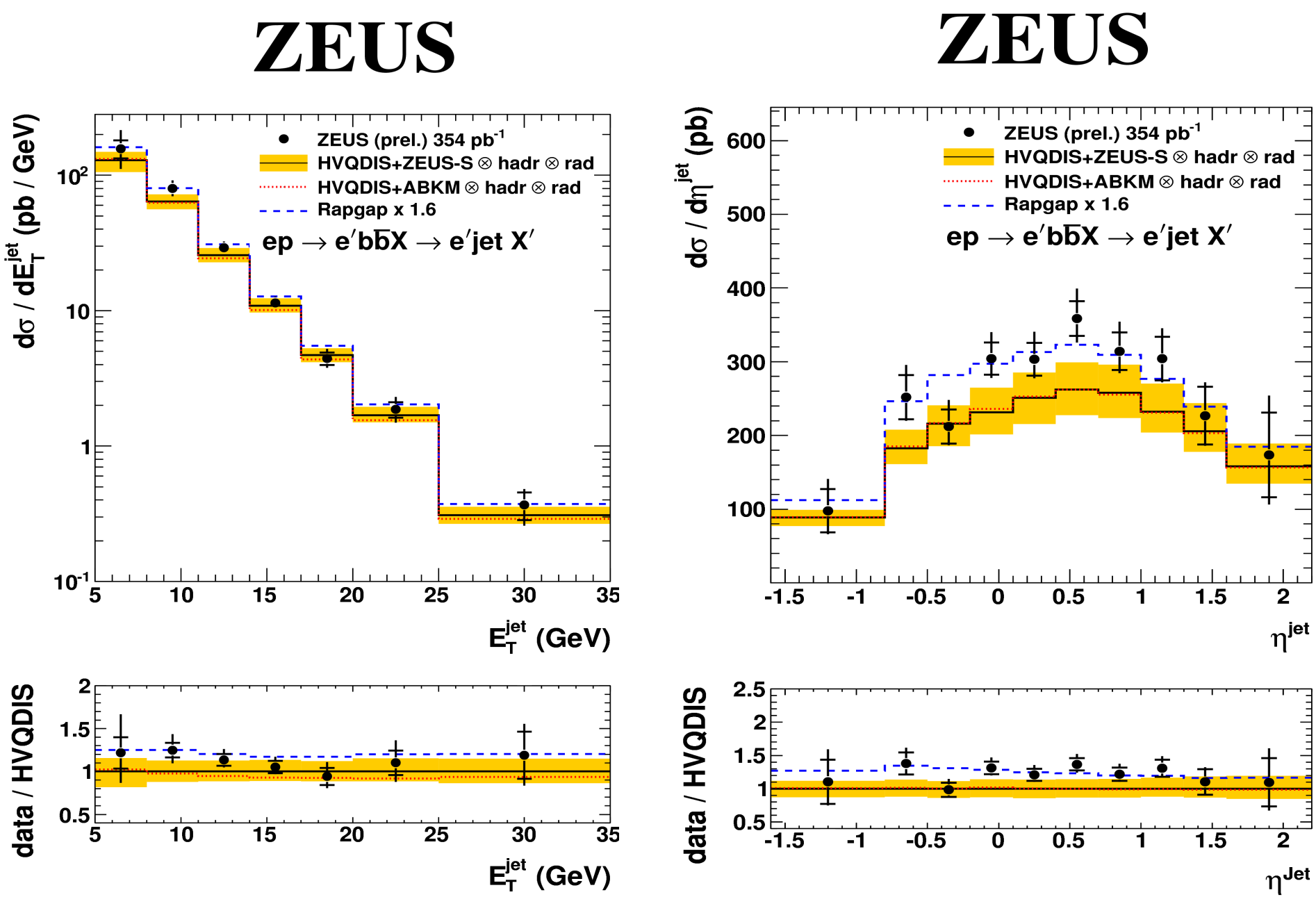
Differential cross-sections

ZEUS **ZEUS**



- Reasonable description by HVQDIS NLO QCD

Differential cross-sections



- Reasonable description by HVQDIS NLO QCD

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

- Beauty contribution to the proton structure function F_2:

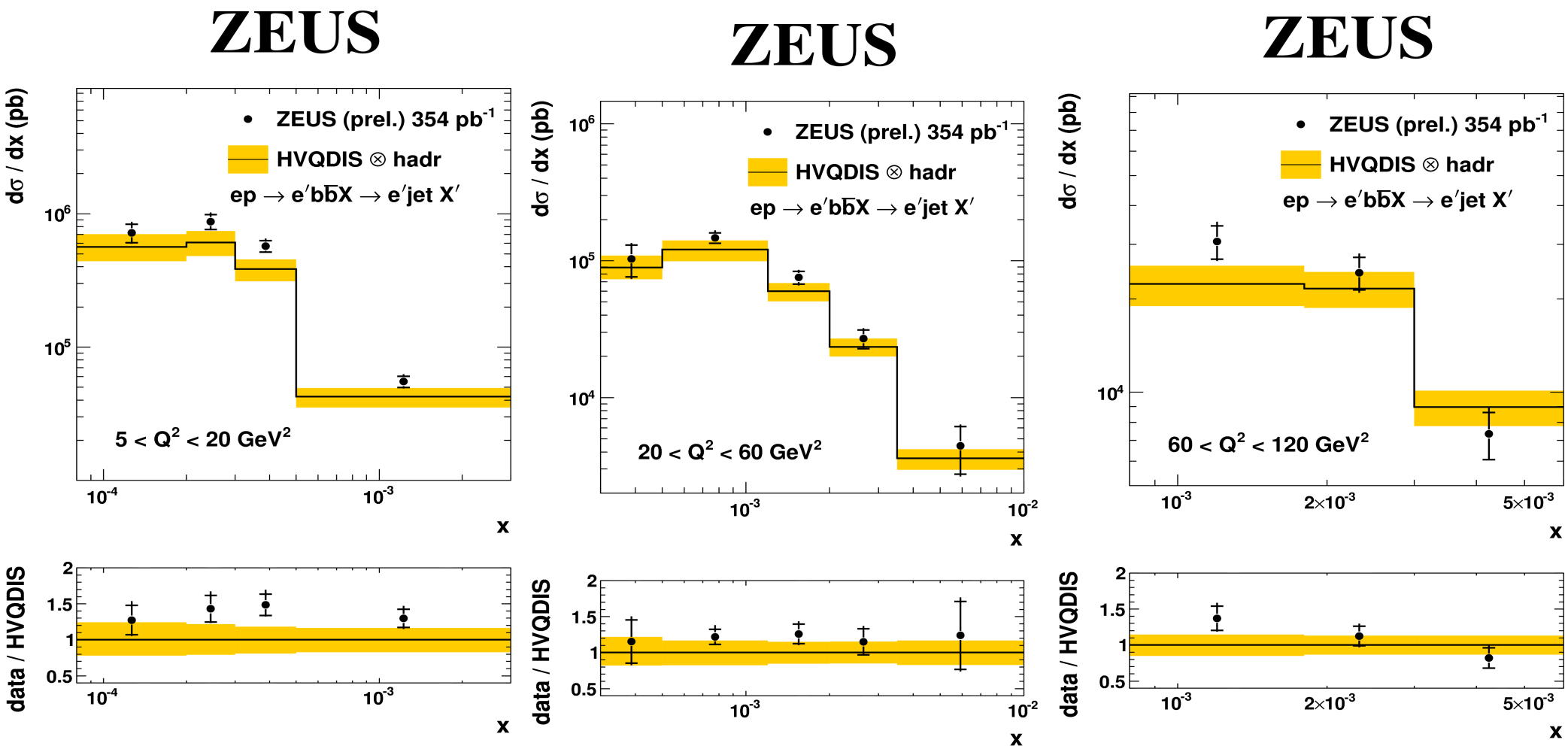
$$\frac{d^2\sigma^{ep\to b\bar{b}x}}{dQ^2\,dx} = \frac{2\pi\alpha^2}{Q^4 x}\left[\left(1+(1-y)^2\right)\cdot F_2^{b\bar{b}}(x,Q^2) - y^2 F_L^{b\bar{b}}\right]$$

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

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

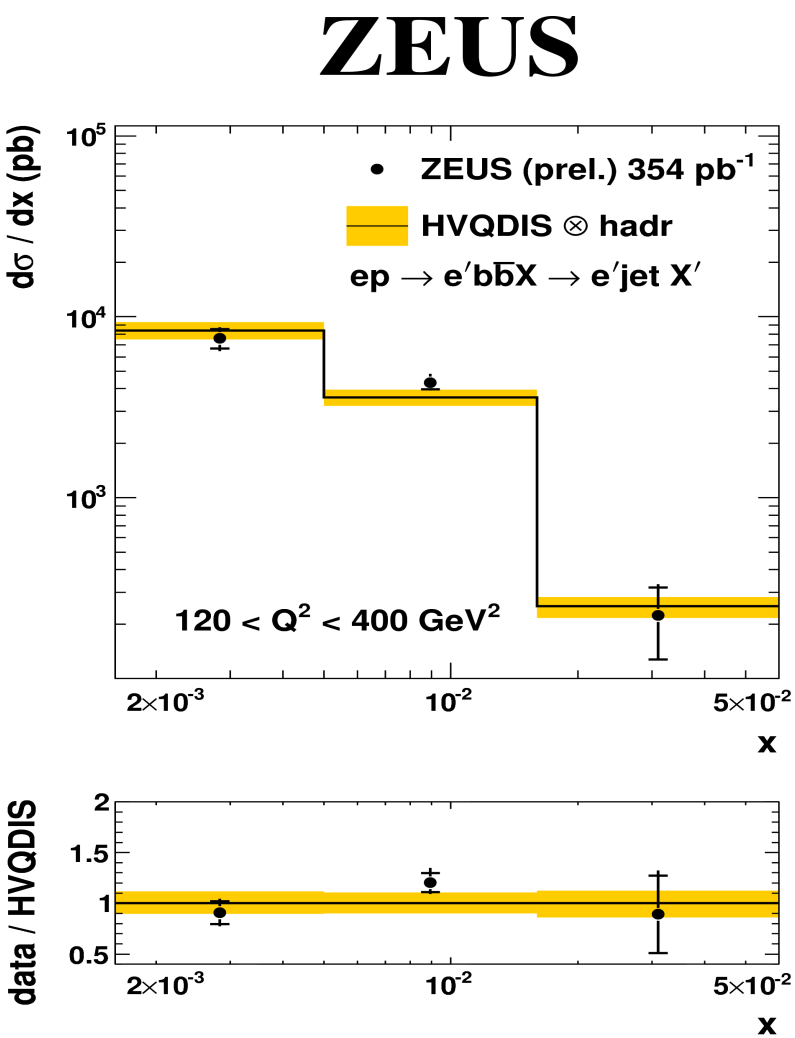
- Typical extrapolation factors: 1.0 - 1.3

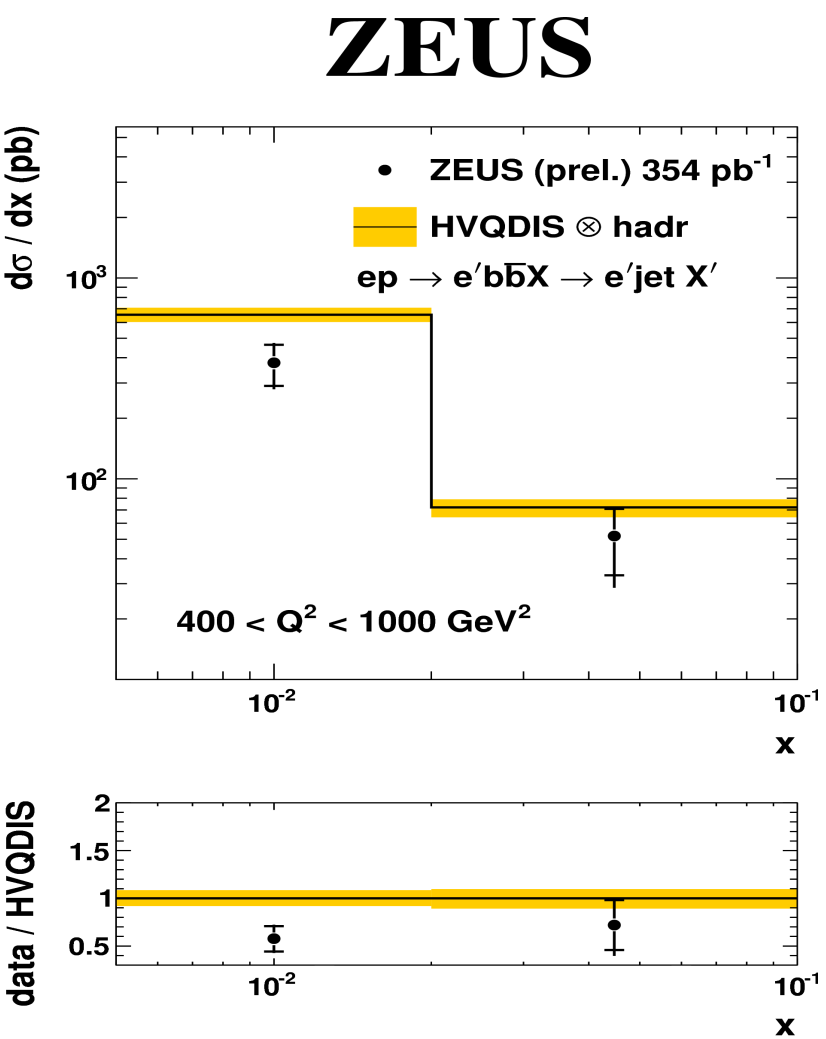
Double-differential cross-sections



- Reasonable description by NLO QCD ($\mu_R = \mu_F = \frac{1}{2}\sqrt{Q^2 + p_T^2 + m_b^2}$)
- Input to $F_2^{b\bar{b}}$

Double-differential cross-sections (cont'd)





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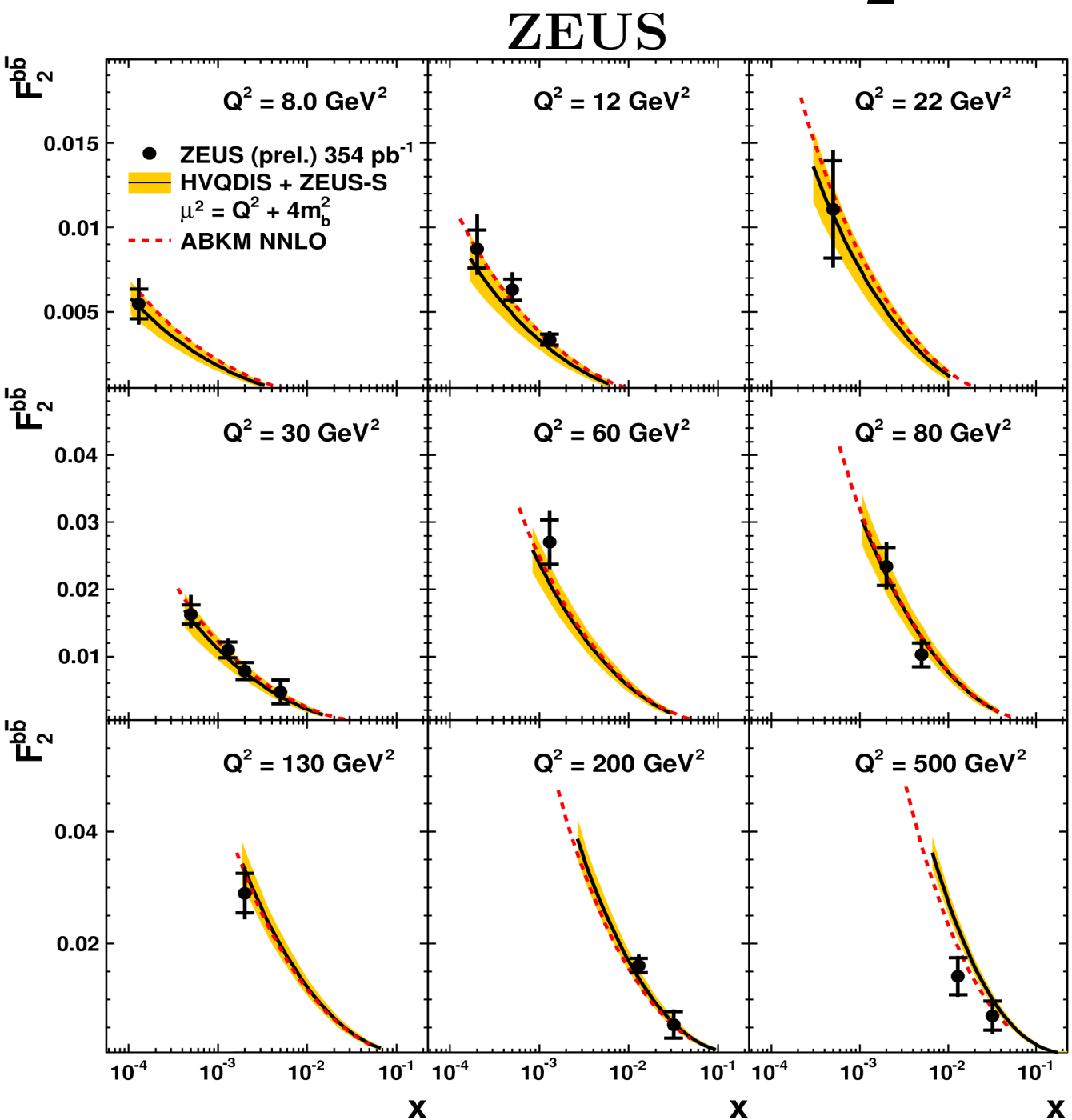
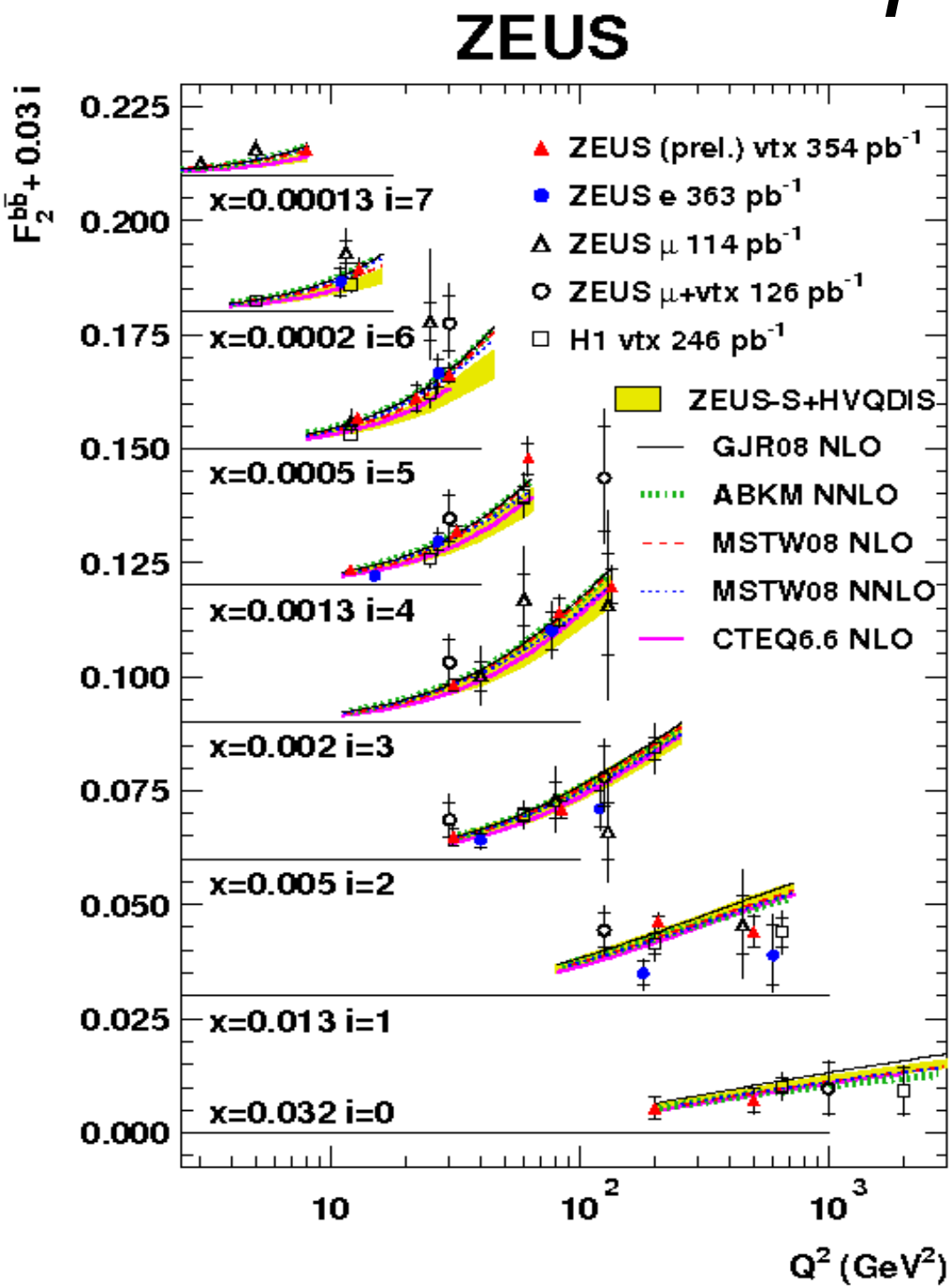
$F_2^{b\bar{b}}$



- Good agreement with NLO and NNLO

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



- Consistent with previous measurements
- Improved precision due to higher statistics (inclusive analysis)

Summary and outlook

- Beauty measurements at HERA provide unique means to test pQCD, validity of gluon PDFs, multiple-scale problem
- Beauty production was measured with inclusive secondary vertices method
- Cross-sections are reasonably described by HVQDIS
- $F_2^{b\bar{b}}$ contribution to the proton structure function was extracted
- Competitive precision due to inclusive nature of the method
- $F_2^{c\bar{c}}$ analysis using this method is underway

Thank you very much for your attention...

...and for the great conference!