

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

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on behalf of the **ZEUS Collaboration**

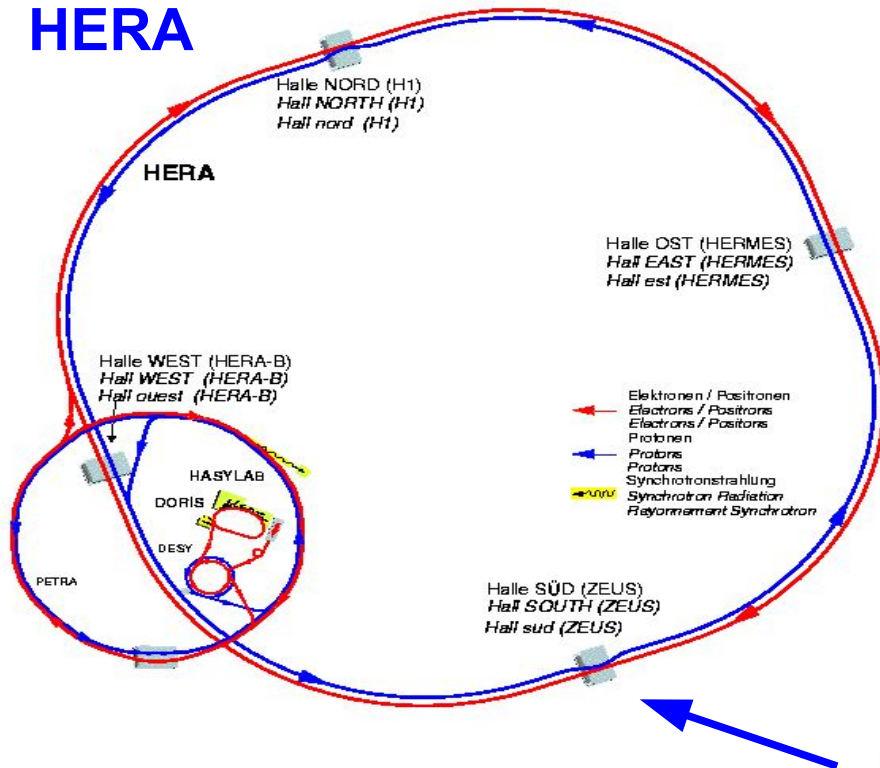
**XIX International Workshop on
Deep-Inelastic Scattering and Related Subjects**
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Outline

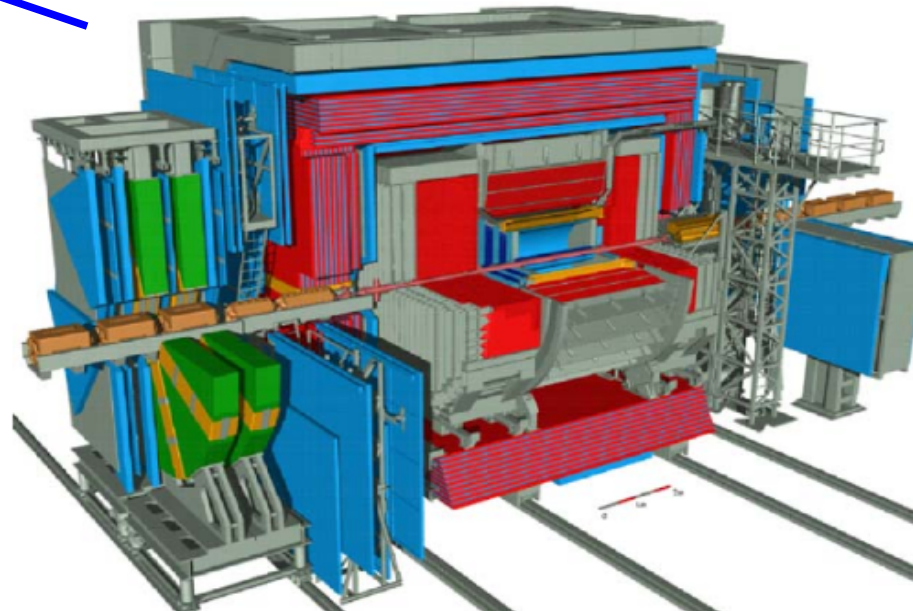
- Beauty production at HERA
- Inclusive secondary vertexing at ZEUS
- Differential cross-sections
- $F_2^{b\bar{b}}$ measurement
- Summary and outlook

ZEUS @ HERA

HERA



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

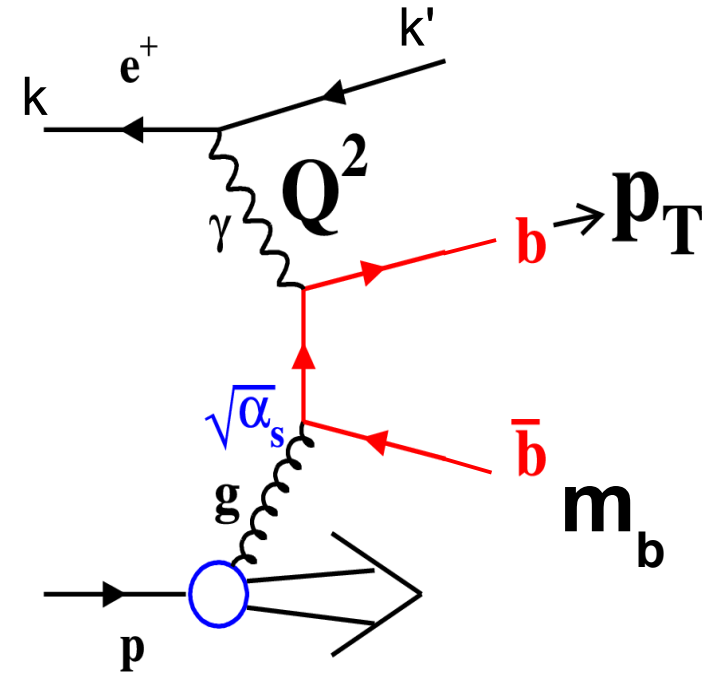


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Beauty physics at HERA

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

Secondary vertex method

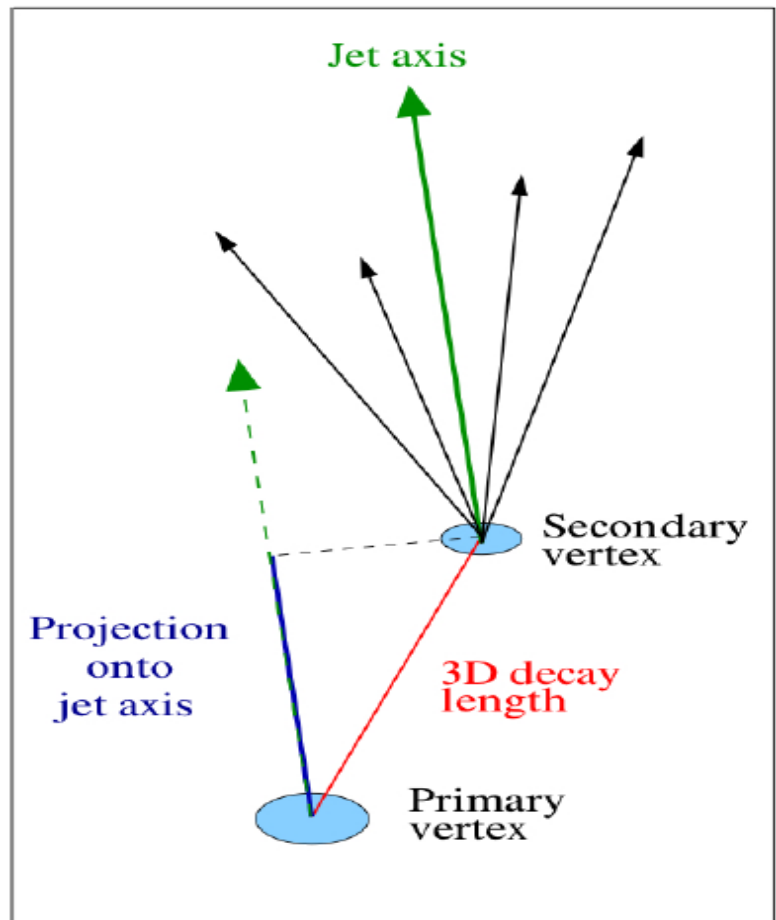
- Employs long lifetime of HQ
- No specific decay mode requirement → increase statistics
- Select tracks belonging to a jet
 - $p_T(\text{track}) > 500 \text{ MeV}$
- Fit secondary vertex if at least two tracks found
- Project decay length onto a jet axis
- Calculate decay length **significance**

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

$$0.02 < y < 0.7$$

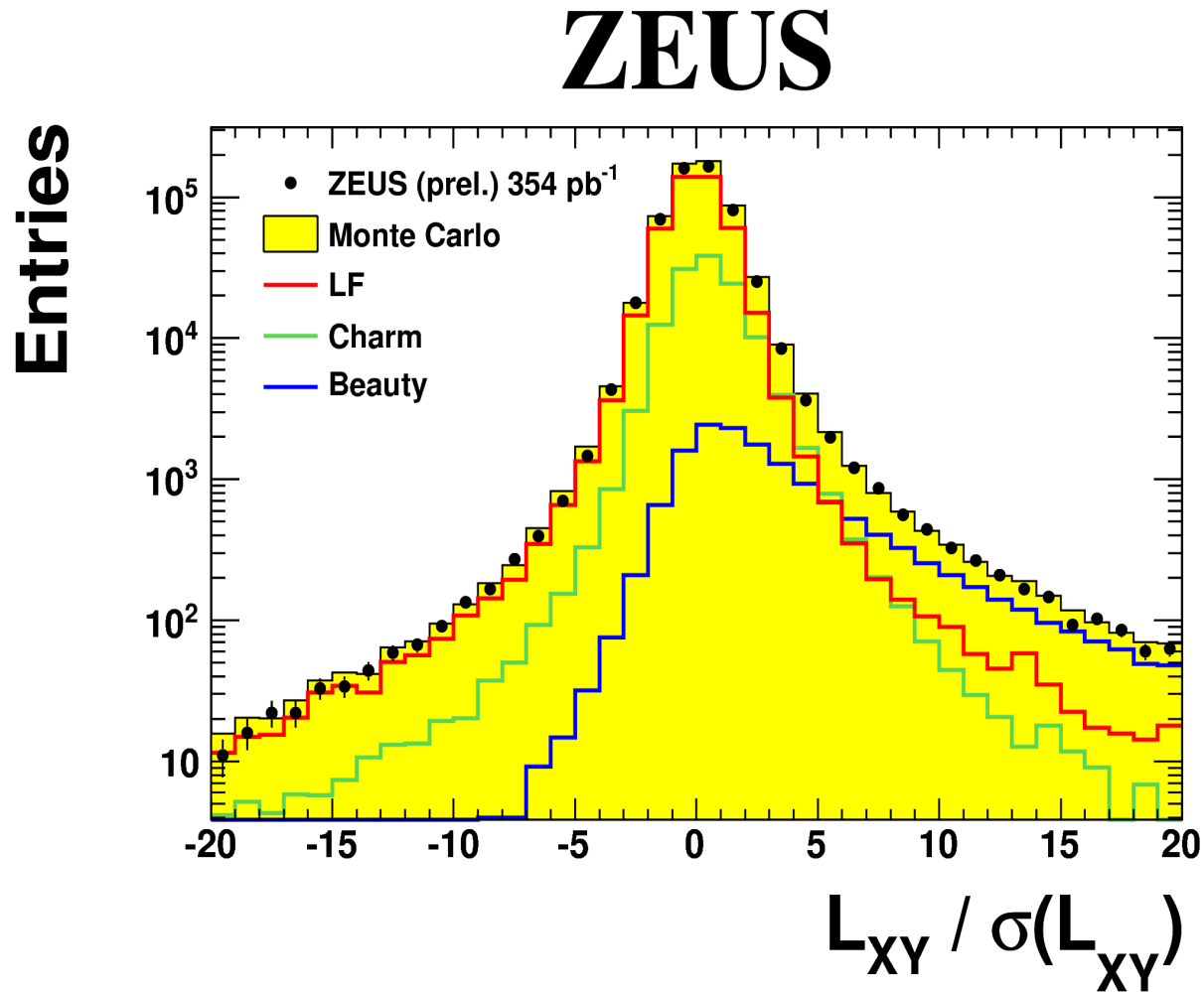
$$E_T(\text{jet}) > 5 \text{ GeV}$$

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



Secondary vertex method (cont'd)

- Decay length significance:

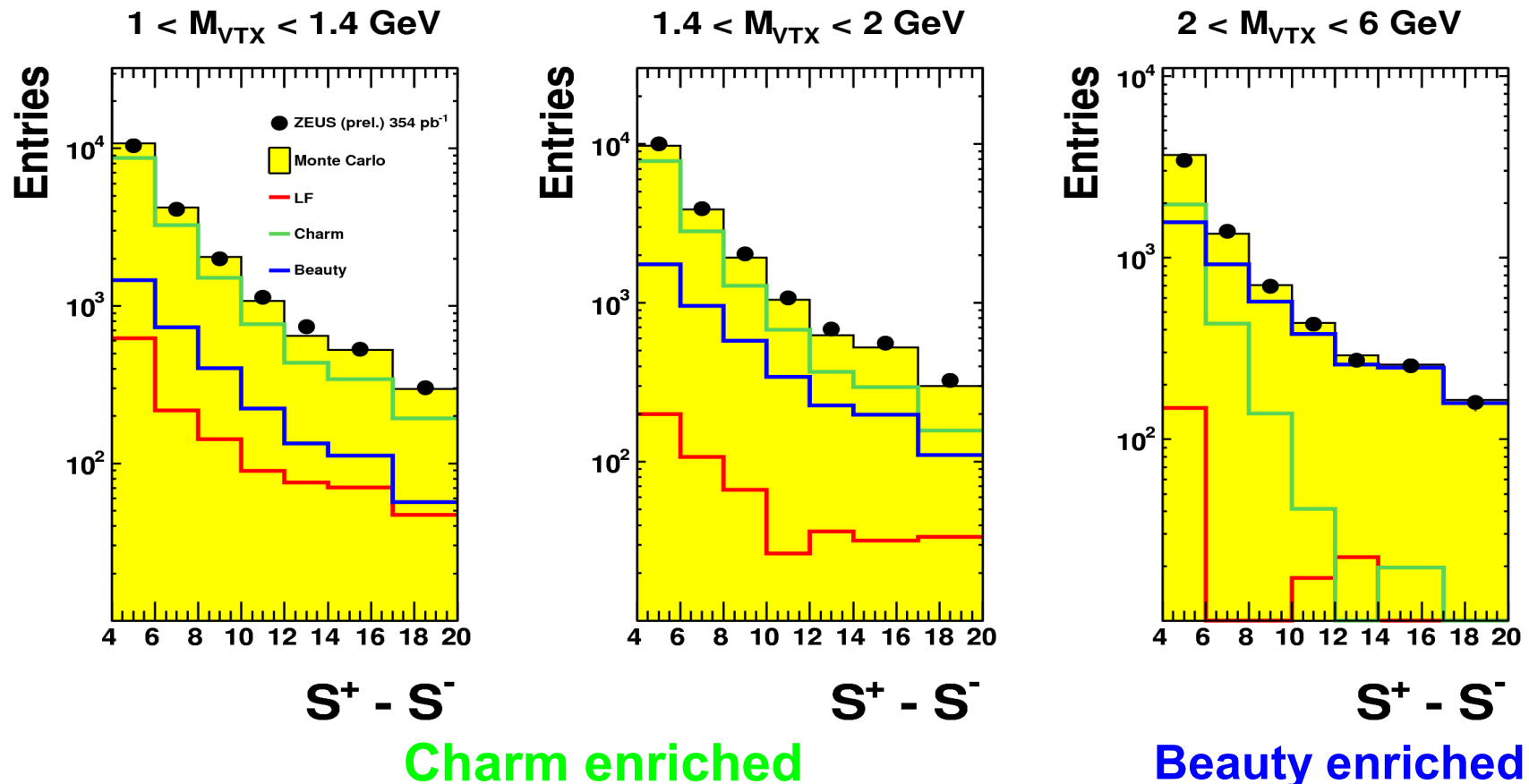


- Get rid of symmetric part by “mirroring”

Secondary vertex method (cont'd)

- Discriminating variables: mirrored significance and mass

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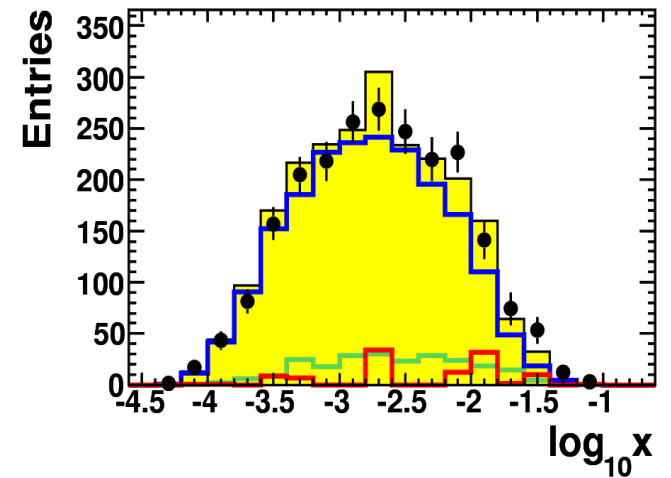
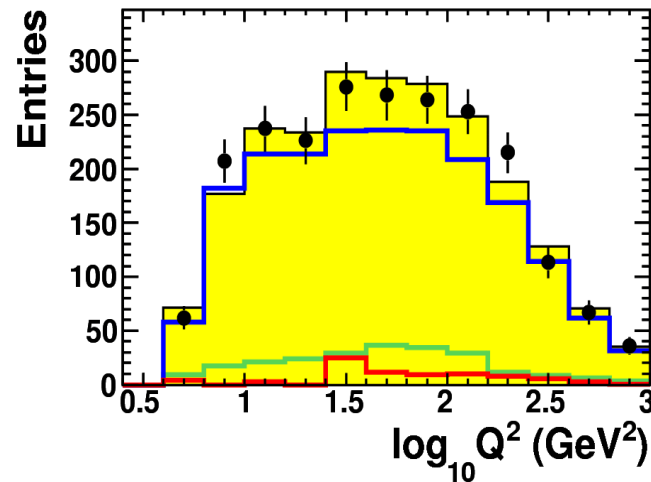
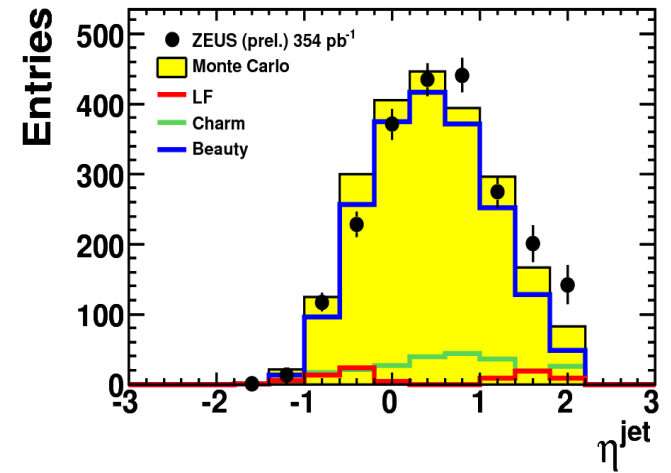
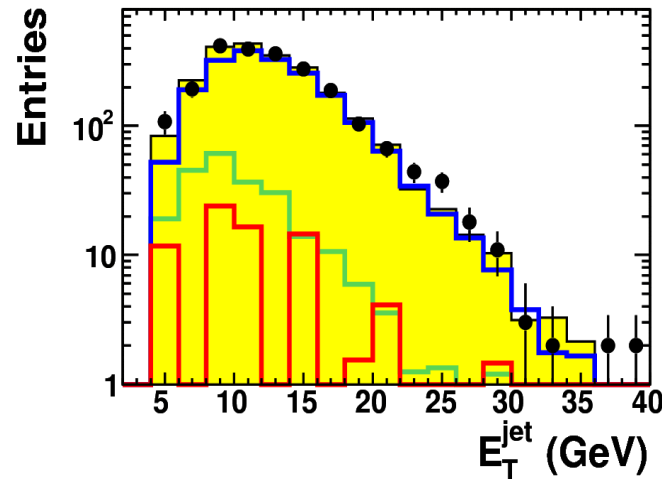


- Three bins are fitted simultaneously
- Total light flavour normalization is fixed by unmirrored significance

Control distributions

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- Beauty enrichment:
 $S^+S^- > 8$
 $2 < M_{\text{vtx}} < 6 \text{ GeV}$
- Almost pure beauty sample!



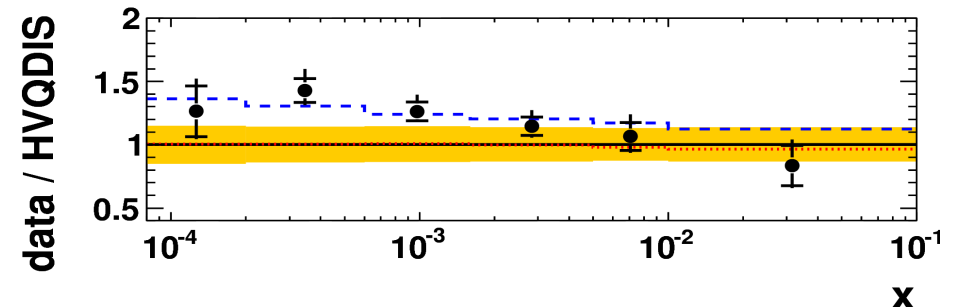
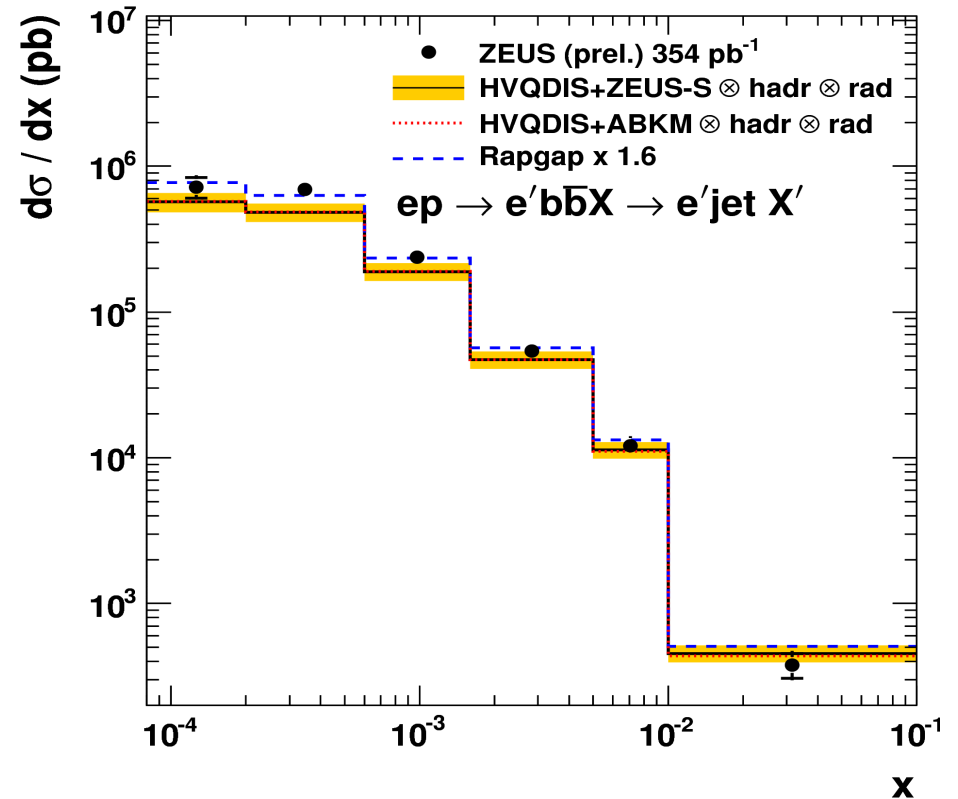
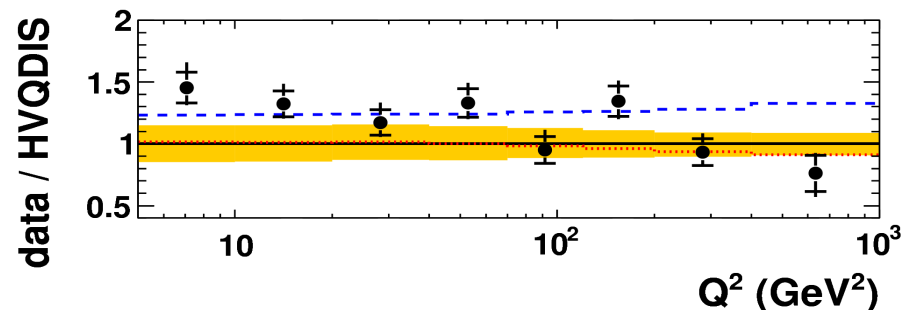
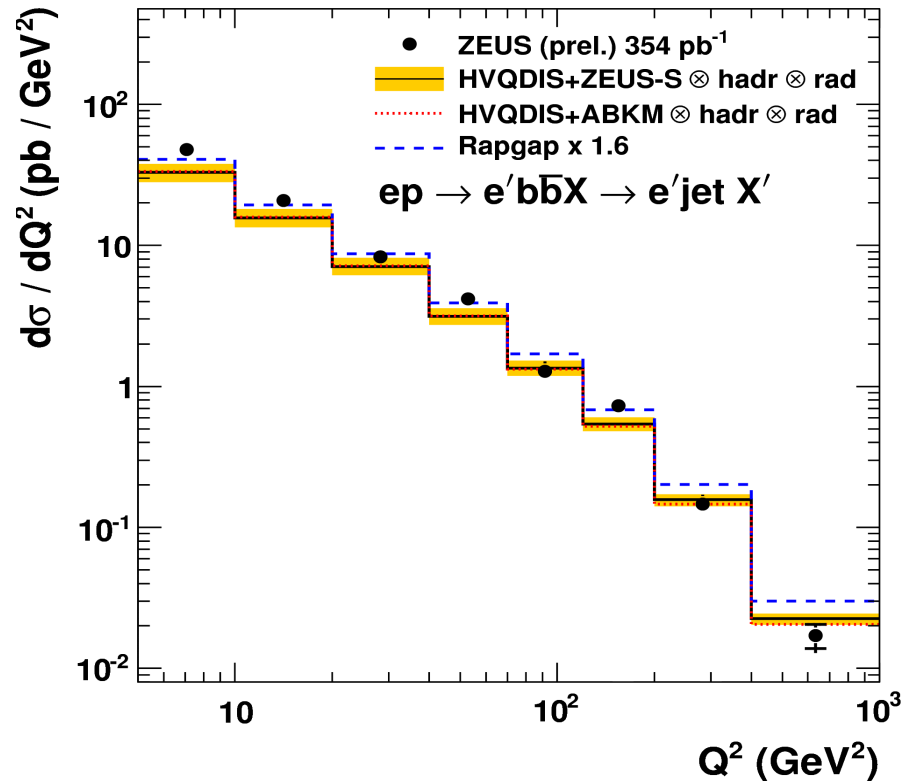
- Good description of the data by the Monte Carlo

HVQDIS predictions

- NLO massive scheme
- ZEUS-S and ABKM NLO PDFs
- $\mu_R = \mu_F = \sqrt{Q^2 + 4m_b^2}$
- $m_b = 4.75$ 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

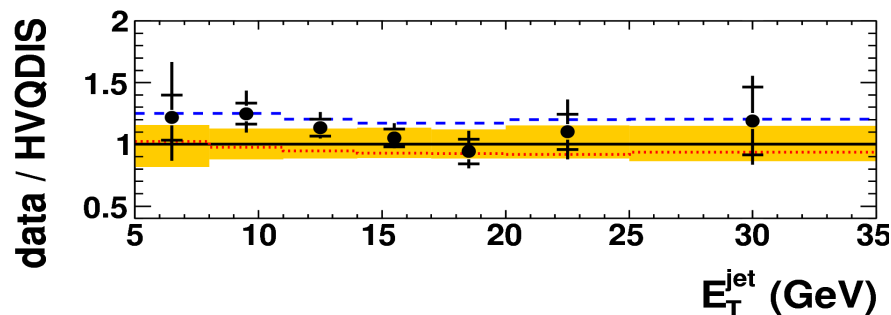
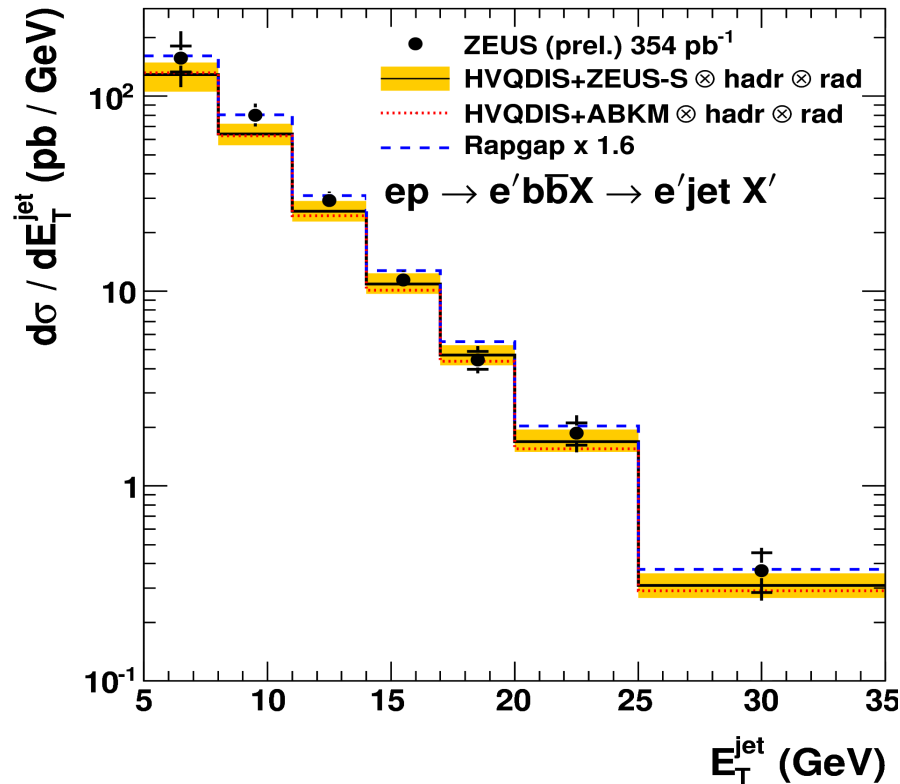
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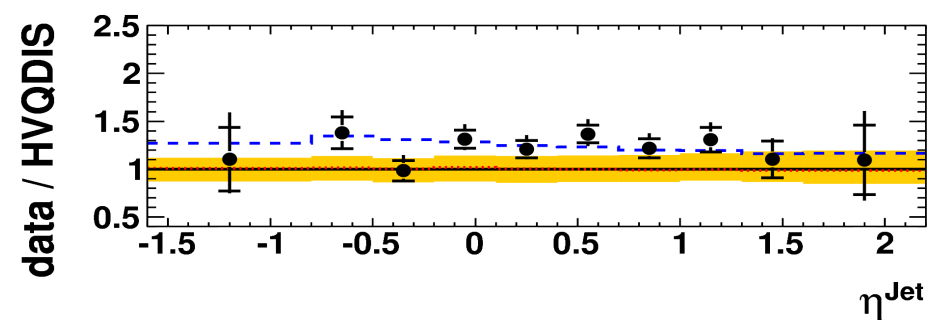
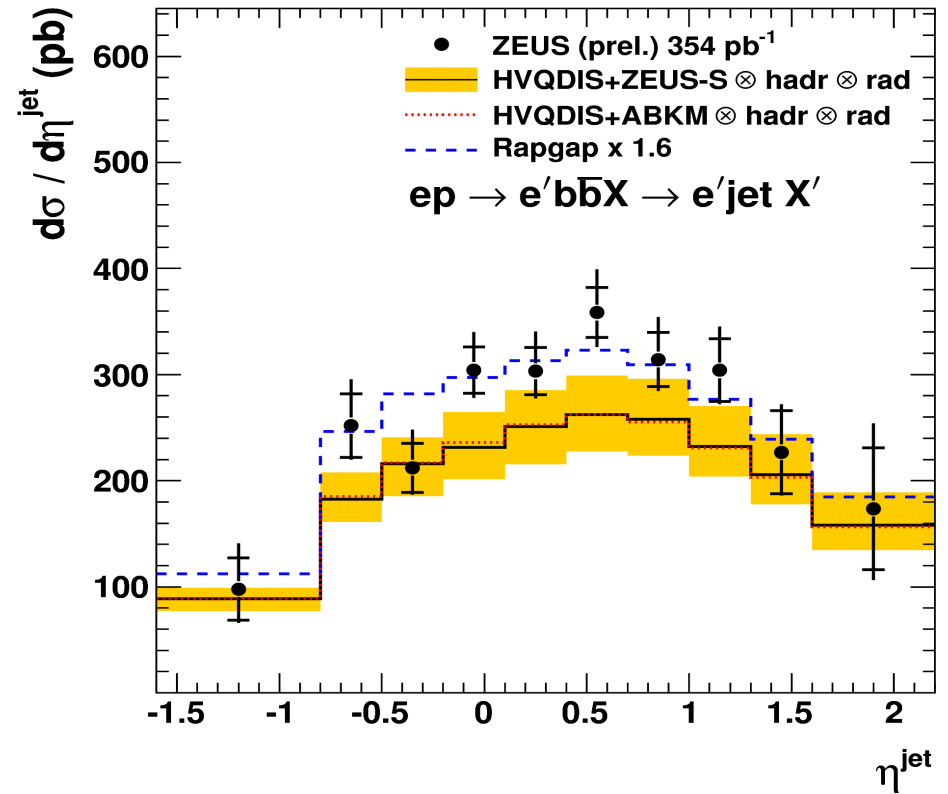
- Reasonable description by HVQDIS NLO QCD

Differential cross-sections

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- Reasonable description by HVQDIS NLO QCD

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

- Beauty contribution to the proton structure function F_2 :

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

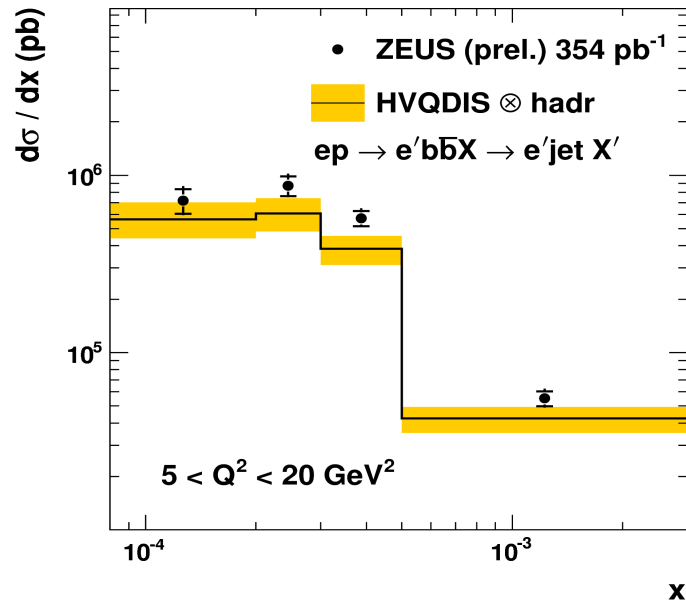
- NLO QCD to extrapolate from visible cross-section to full phase space:

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

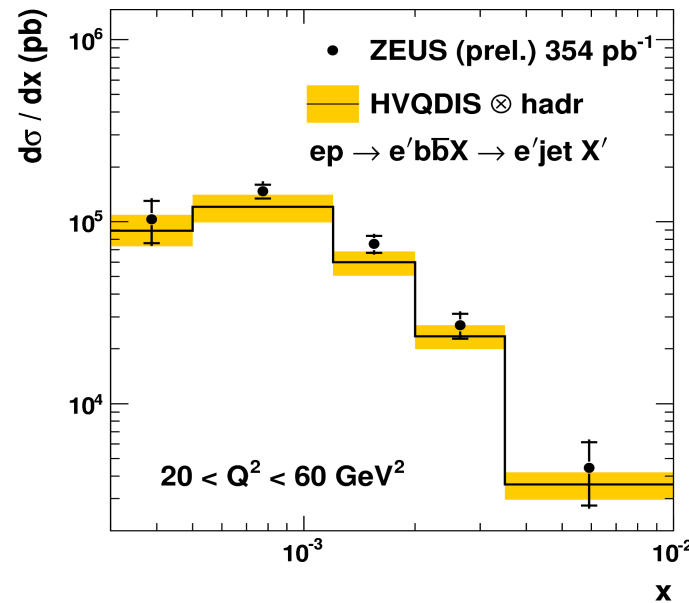
- Typical extrapolation factors: 1.0 - 1.3

Double-differential cross-sections

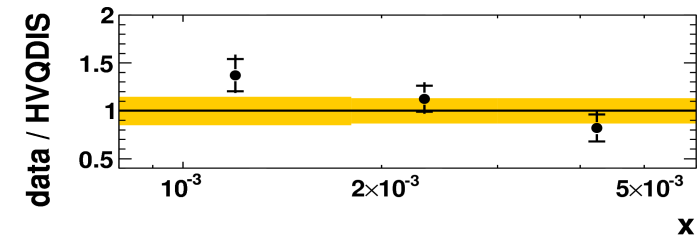
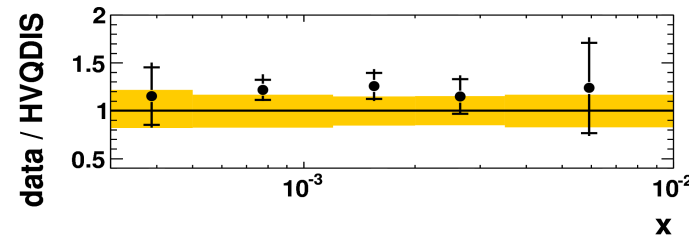
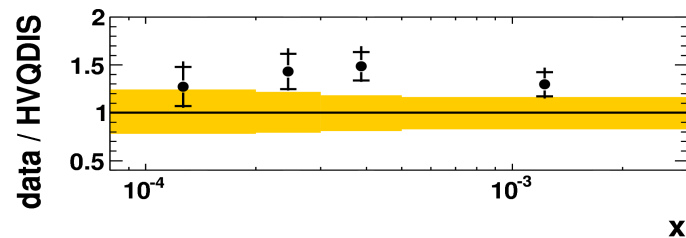
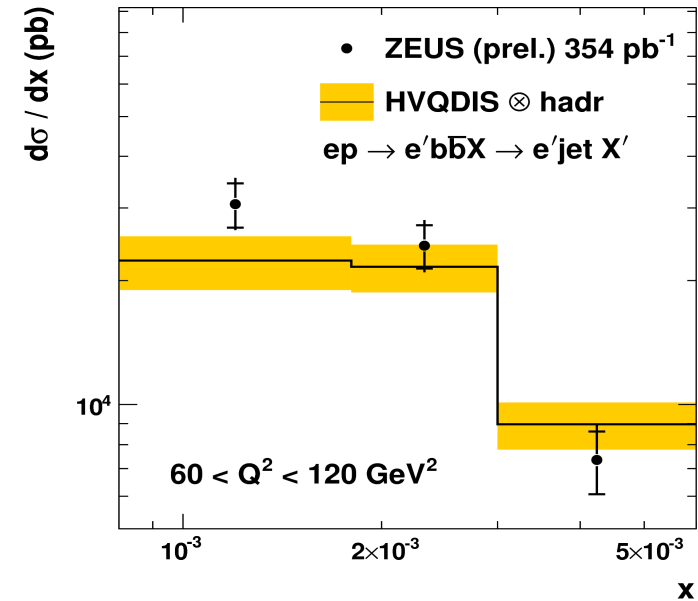
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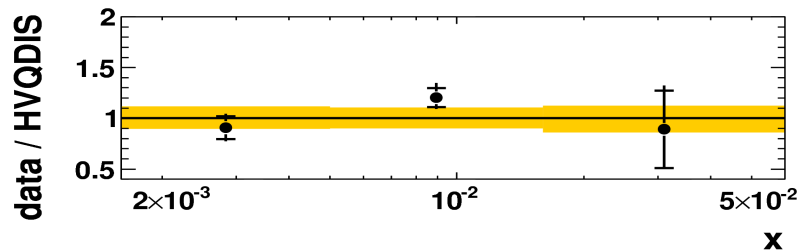
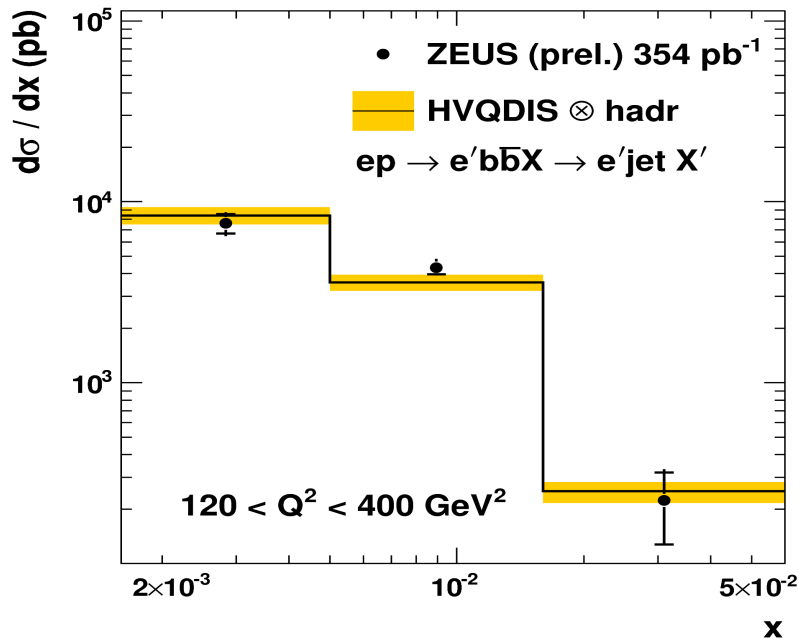
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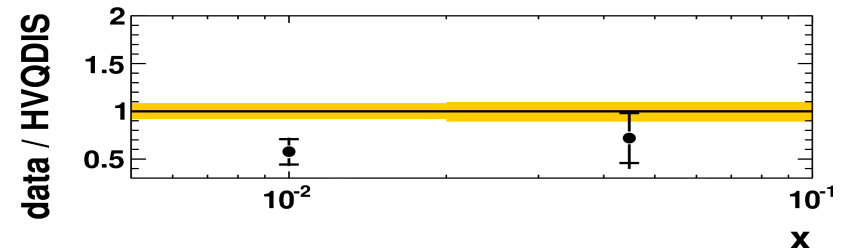
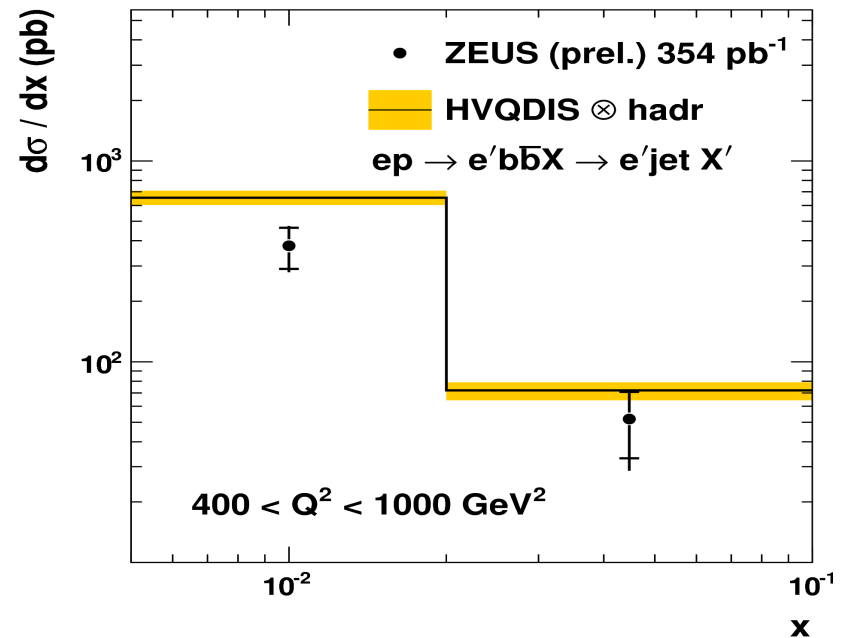
- Reasonable description by NLO QCD ($\mu_R = \mu_F = \frac{1}{2} \sqrt{Q^2 + p_T^2 + m_b^2}$)
- Input to $F_2^{b\bar{b}}$

Double-differential cross-sections (cont'd)

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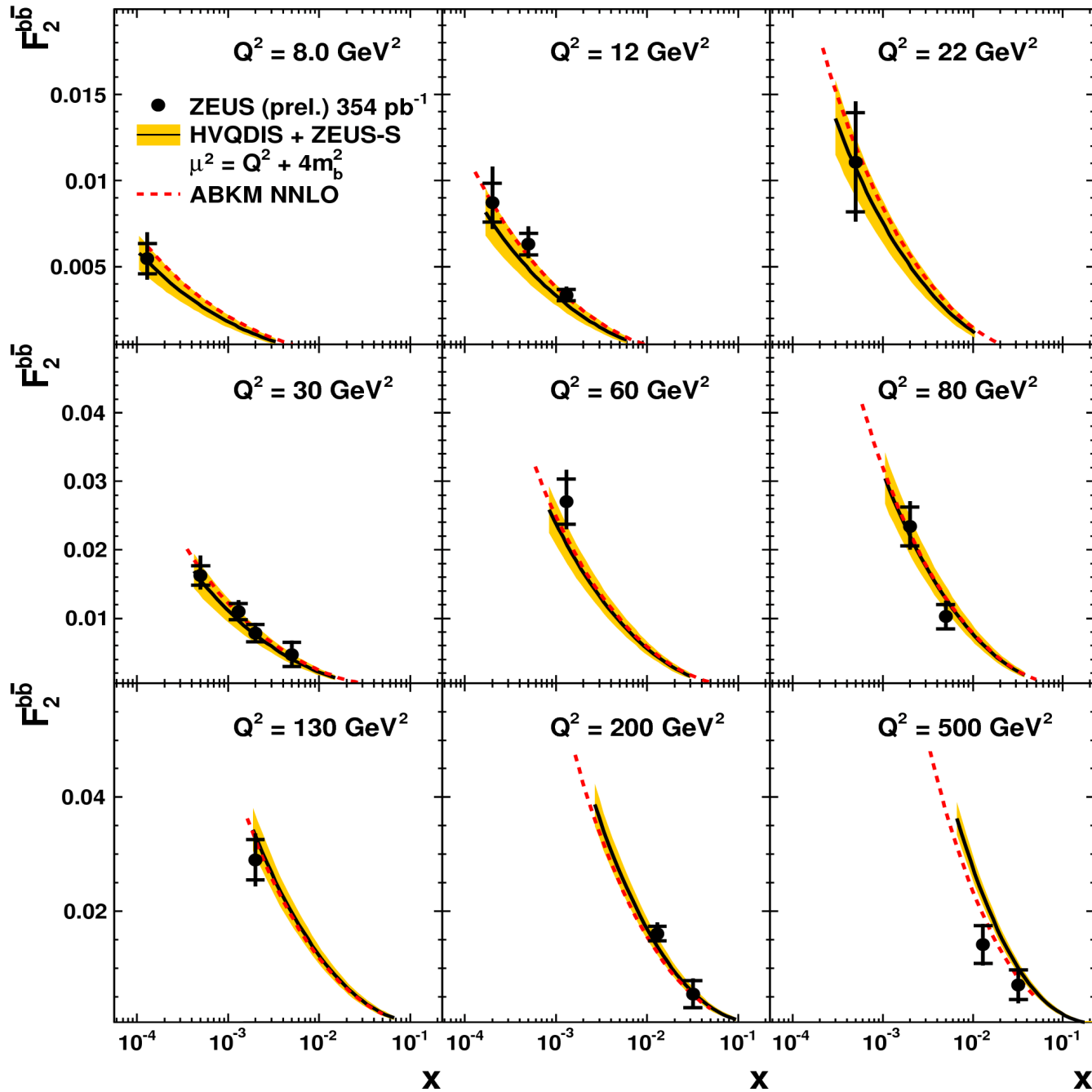
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- Reasonable description by NLO QCD ($\mu_R = \mu_F = \frac{1}{2} \sqrt{Q^2 + p_T^2 + m_b^2}$)
- Input to $F_2^{b\bar{b}}$

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

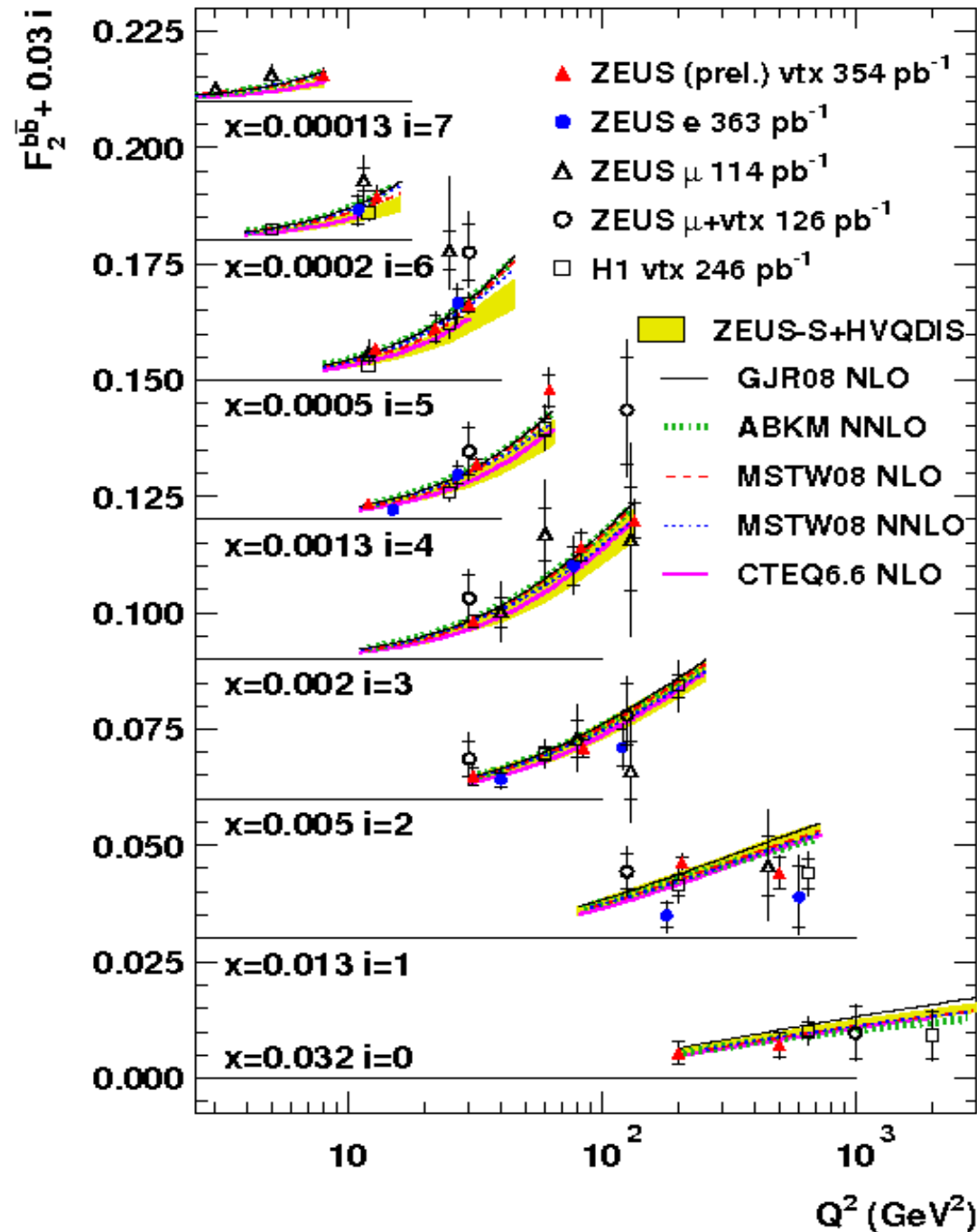
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- Good agreement with NLO and NNLO

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



- 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...



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...and for the great conference!