



$F_2^{b\bar{b}}$ measurement at ZEUS

U+H



DIS 2010
<http://www.fi.infn.it/dis10>

XVIII INTERNATIONAL WORKSHOP ON DEEP INELASTIC SCATTERING AND RELATED SUBJECTS

19-23 April 2010, Convitto della Calza, Firenze

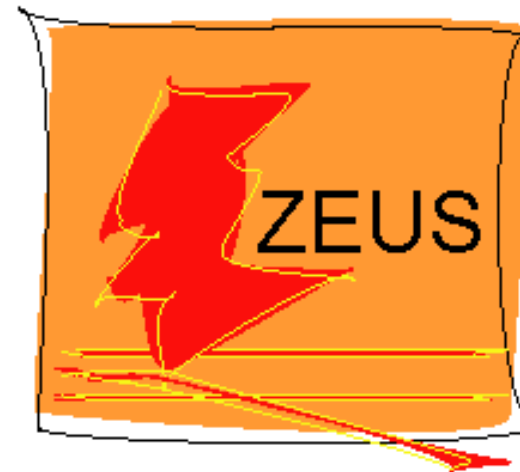
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Outline

This talk:

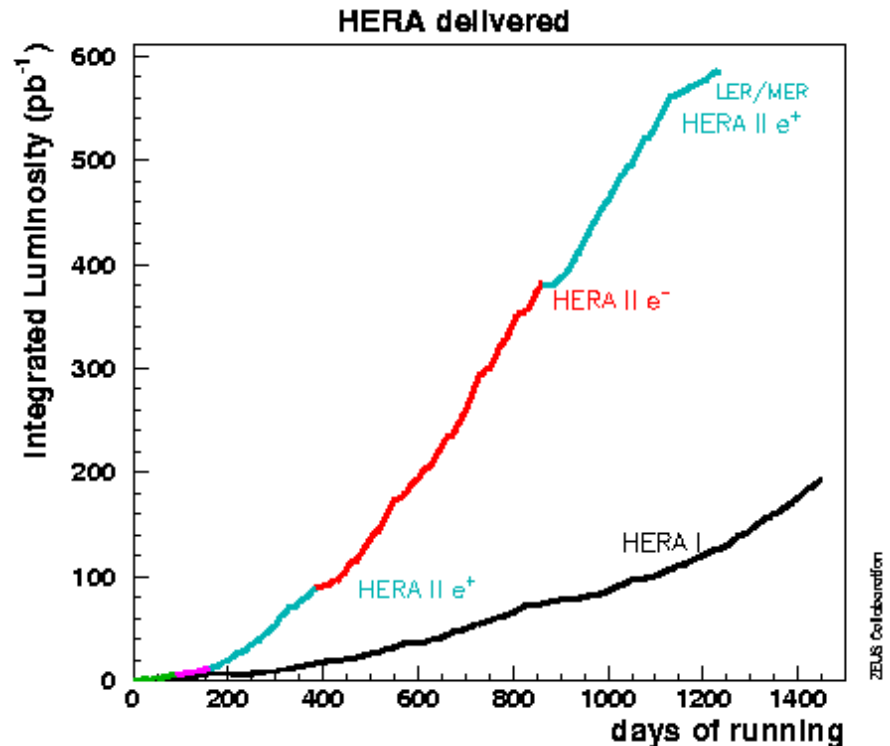
Two measurements of beauty production in DIS at HERA:

- $F_2^{b\bar{b}}$ using events with a muon and a jet (DESY 10-047)

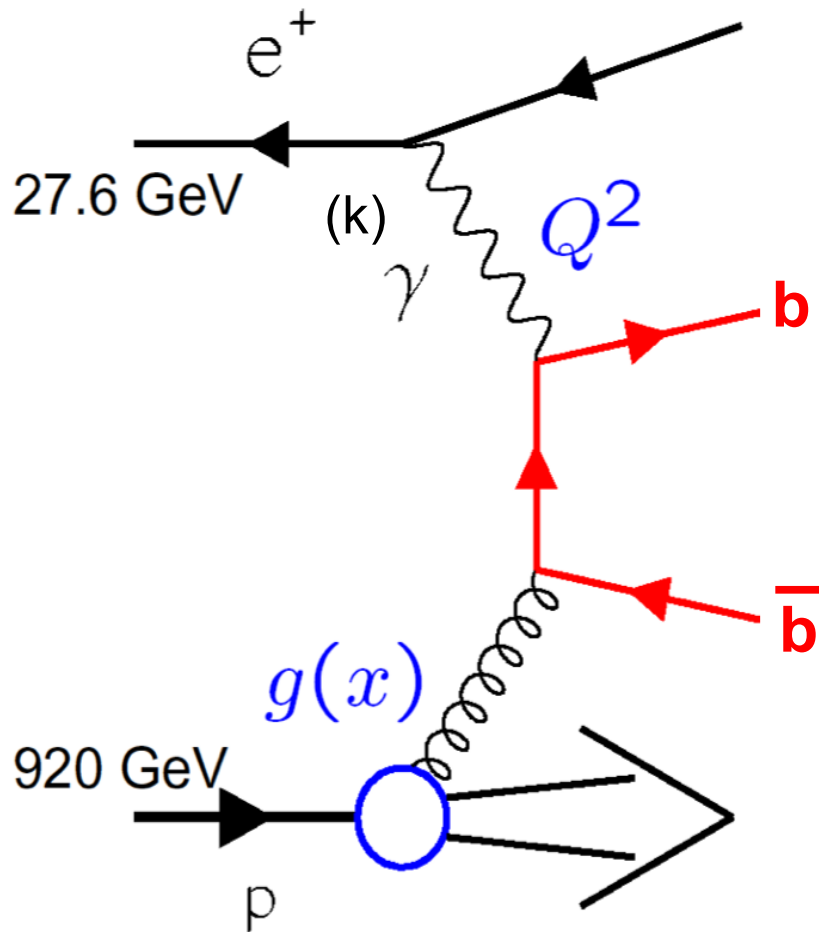
→ Full HERA I dataset

- (Double) differential cross sections using inclusive secondary vertices (ZEUS-prel-10-004)

→ Full HERA II dataset



Beauty production at HERA



- Dominant process for beauty production in DIS ($Q^2 > \text{a few GeV}^2$): **Boson-Gluon-Fusion (BGF)**

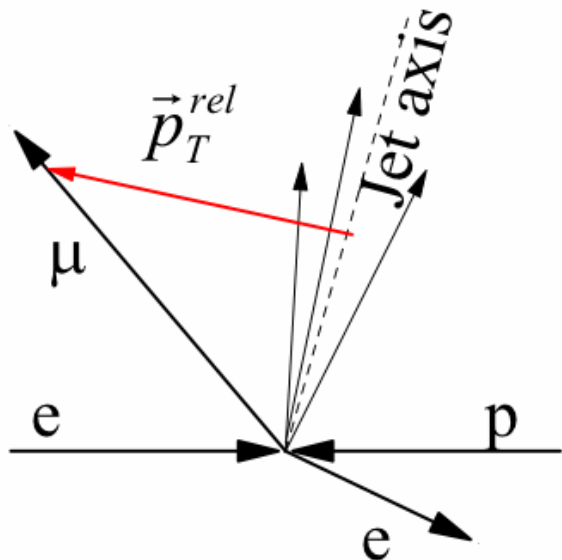
- Multiple hard scales: $\mu^2 = m_b^2, p_b^2, Q^2$

- Mass effects are relevant in a large part of the phase space accessible at HERA

- The double differential cross section for the production of open beauty can be written as:

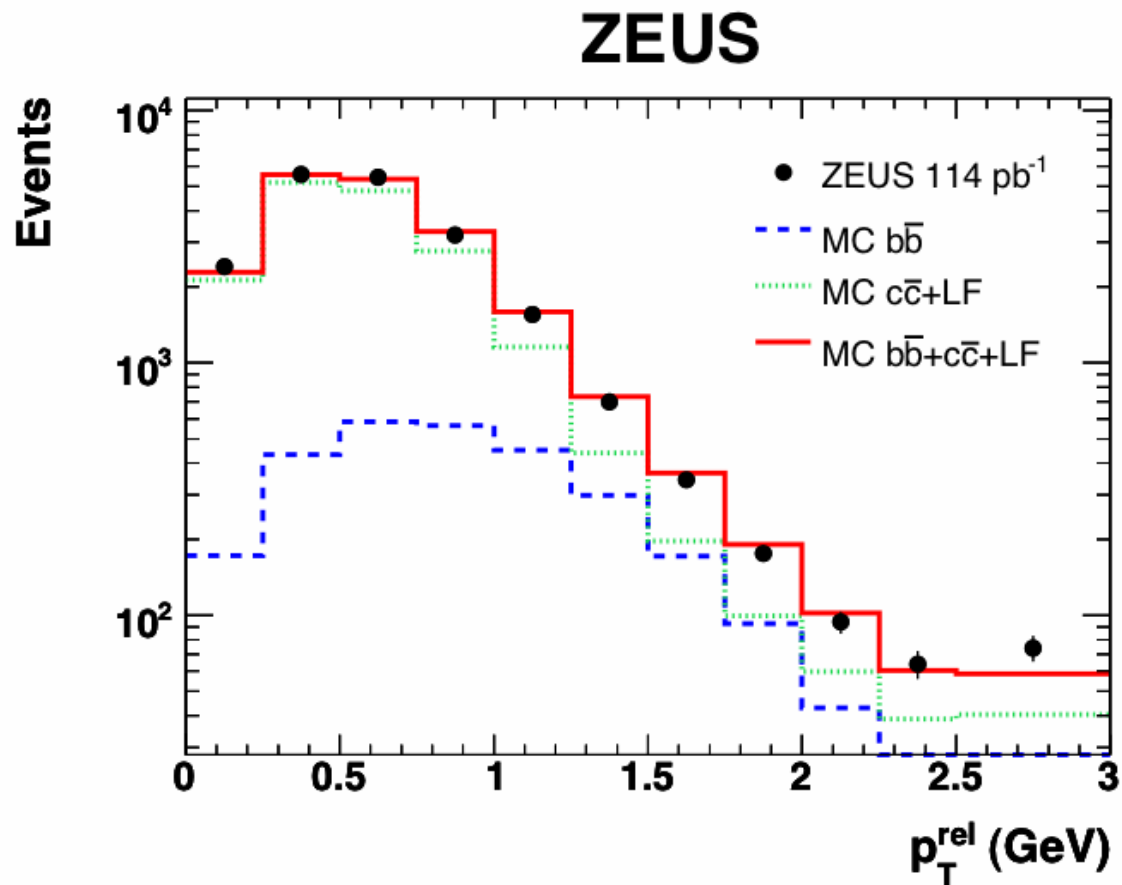
$$\frac{d^2\sigma^{b\bar{b}}}{dx dQ^2} = \frac{2\pi\alpha^2}{Q^4 x} \left([1 + (1-y)^2] F_2^{b\bar{b}}(x, Q^2) - y^2 F_L^{b\bar{b}}(x, Q^2) \right)$$

Beauty identification using the p_T^{rel} method (HERA I)



- p_T^{rel} : the muon momentum component transverse to the jet axis

- The p_T^{rel} spectrum is harder for **beauty** than for charm or light flavours → statistical separation using MC templates



Control distributions

- Kinematic range:

$$Q^2 > 2 \text{ GeV}^2$$

$$0.05 < y < 0.7$$

$$p_T^\mu > 1.5 \text{ GeV}$$

$$\eta^\mu > -1.6$$

$$E_T^{\text{jet,lab}} > 5 \text{ GeV}$$

$$-2.0 < \eta^{\text{jet}} < 2.5$$

- Data sample: 114 pb⁻¹
HERA I (1996 - 2000)

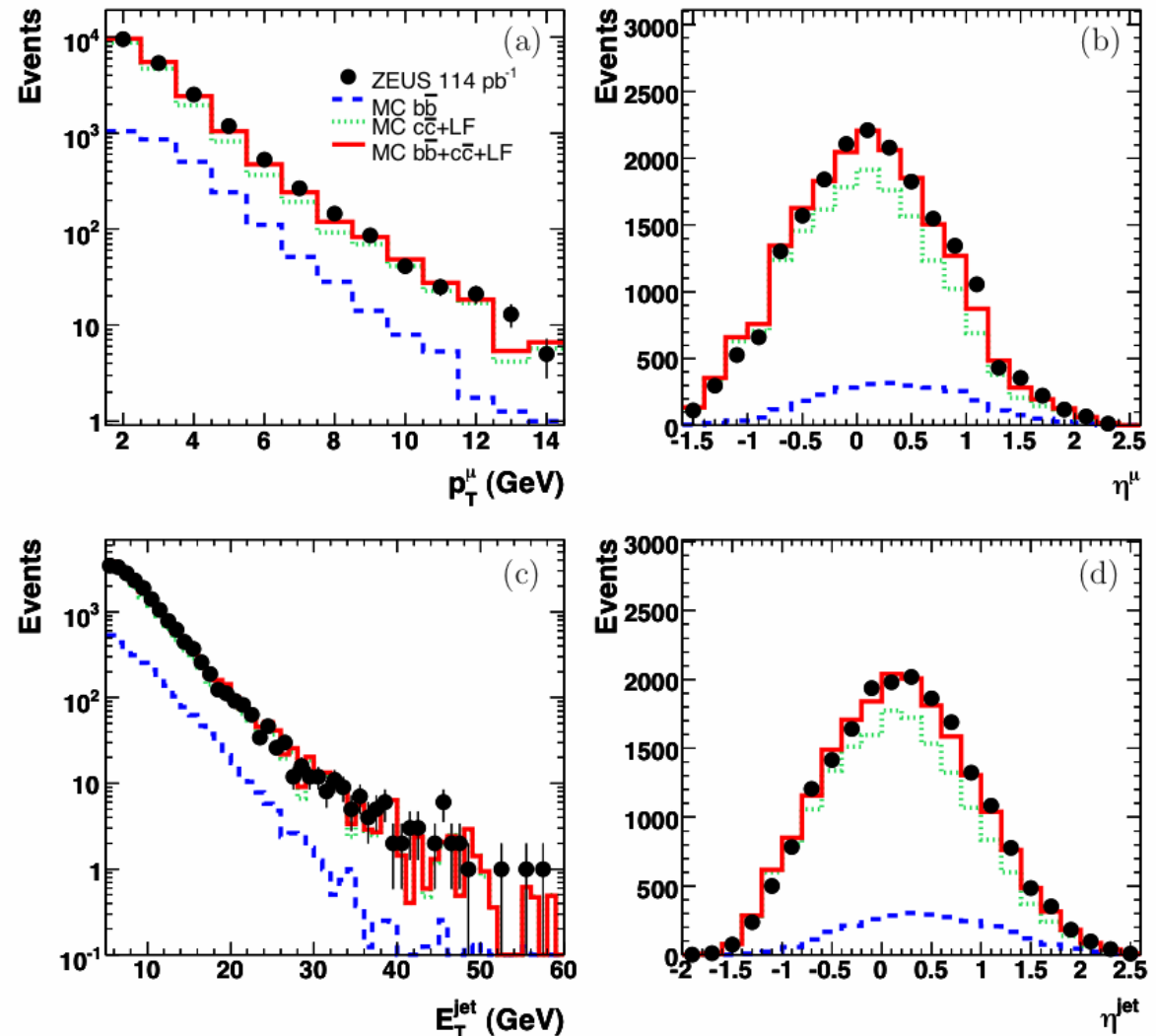
- ZEUS 114 pb⁻¹

- MC $b\bar{b}$

- MC $c\bar{c}+\text{LF}$

- MC $b\bar{b}+c\bar{c}+\text{LF}$

ZEUS

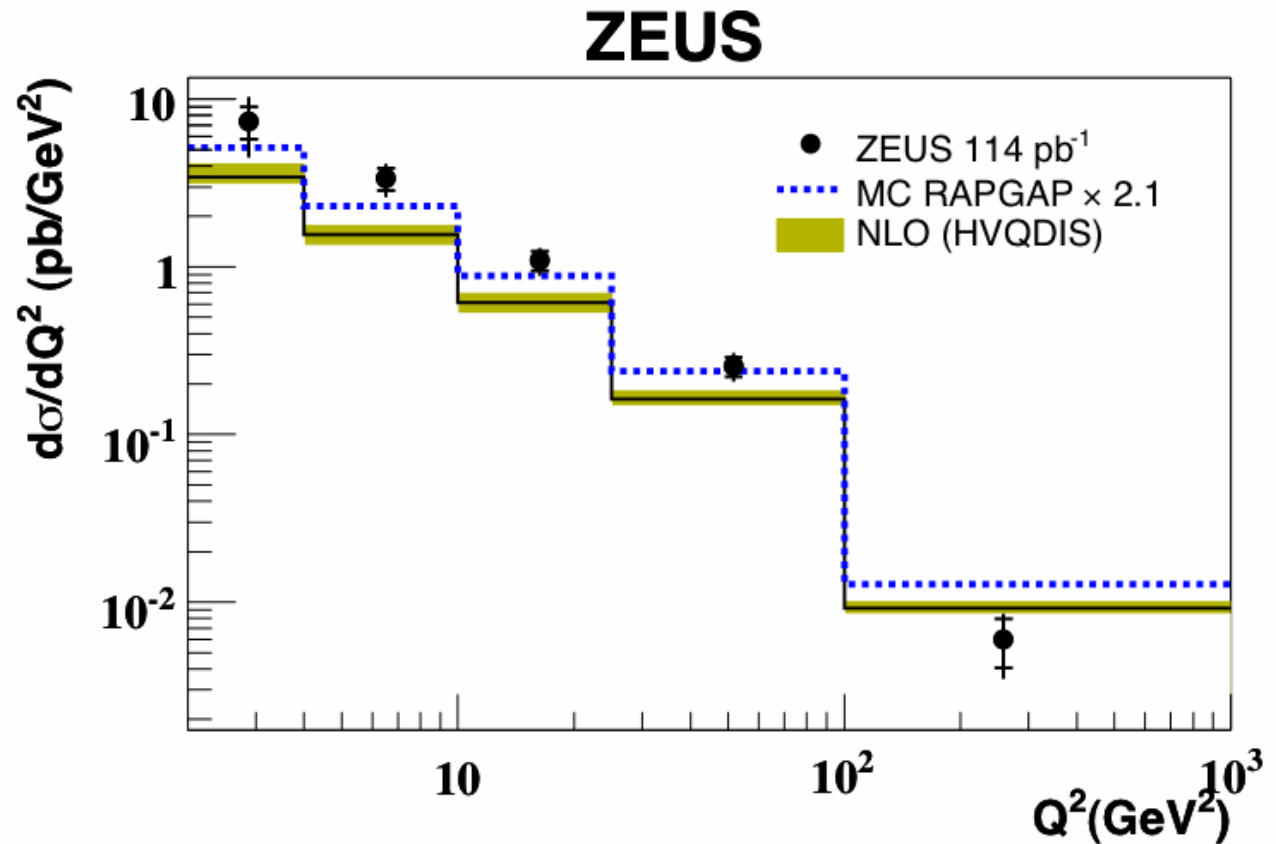


Cross sections: Q^2

- The **low Q^2 region** can only be measured at HERA I

- The HVQDIS NLO prediction (FFNS) and the RAPGAP LO+PS MC describe the shape of the data reasonably well

- ZEUS 114 pb⁻¹
- MC RAPGAP × 2.1
- NLO (HVQDIS)



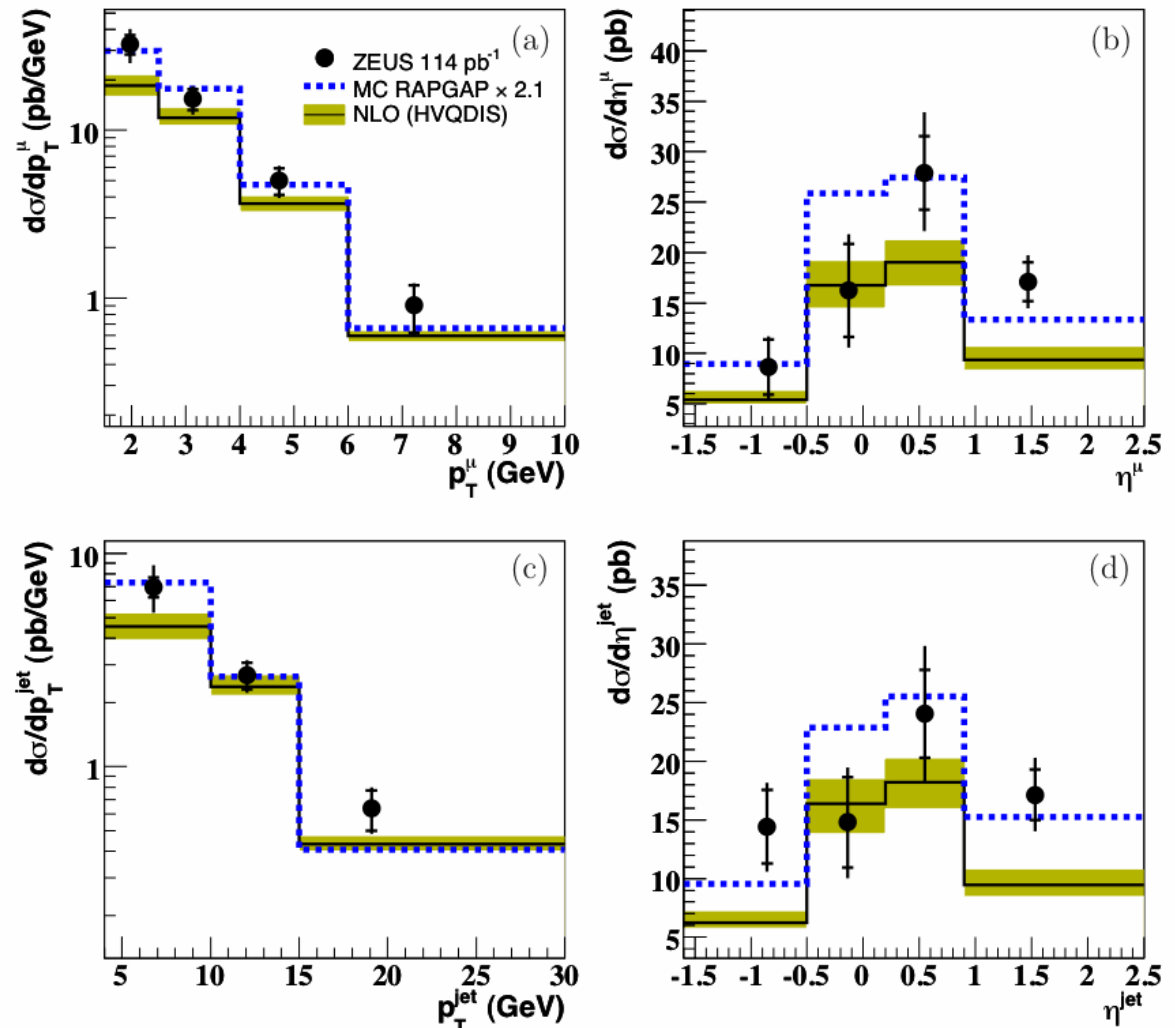
Cross sections: p_T and η

- The HVQDIS NLO prediction (FFNS) and the RAPGAP LO+PS MC describe the shape of the data reasonably well

- In the low Q^2 , and therefore low p_T , region HVQDIS tends to underestimate the data

- ZEUS 114 pb⁻¹
- MC RAPGAP × 2.1
- NLO (HVQDIS)

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

Extrapolation needed:

Measured cross section
in bin i

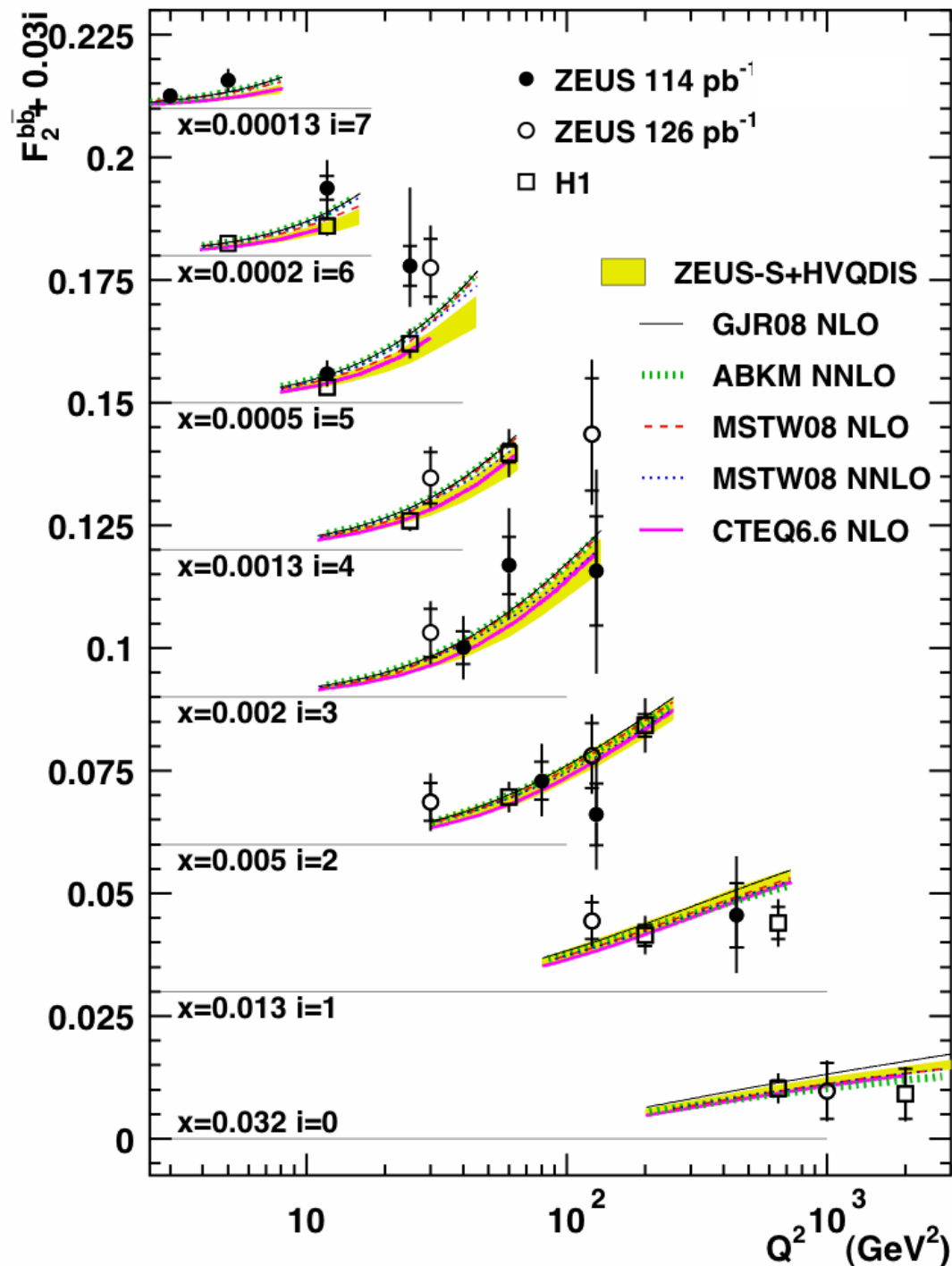
$$F_{2,meas}^b(x_i, Q_i^2) = \frac{\sigma_{meas,i}}{\sigma_{theo,i}} \times F_{2,theo}^b(x_i, Q_i^2)$$

Calculated using
HVQDIS (FFNS)

Calculated at NLO
in FFNS

$F_L^{b\bar{b}}$ small in the measured Q^2 and x ranges \rightarrow neglected

ZEUS

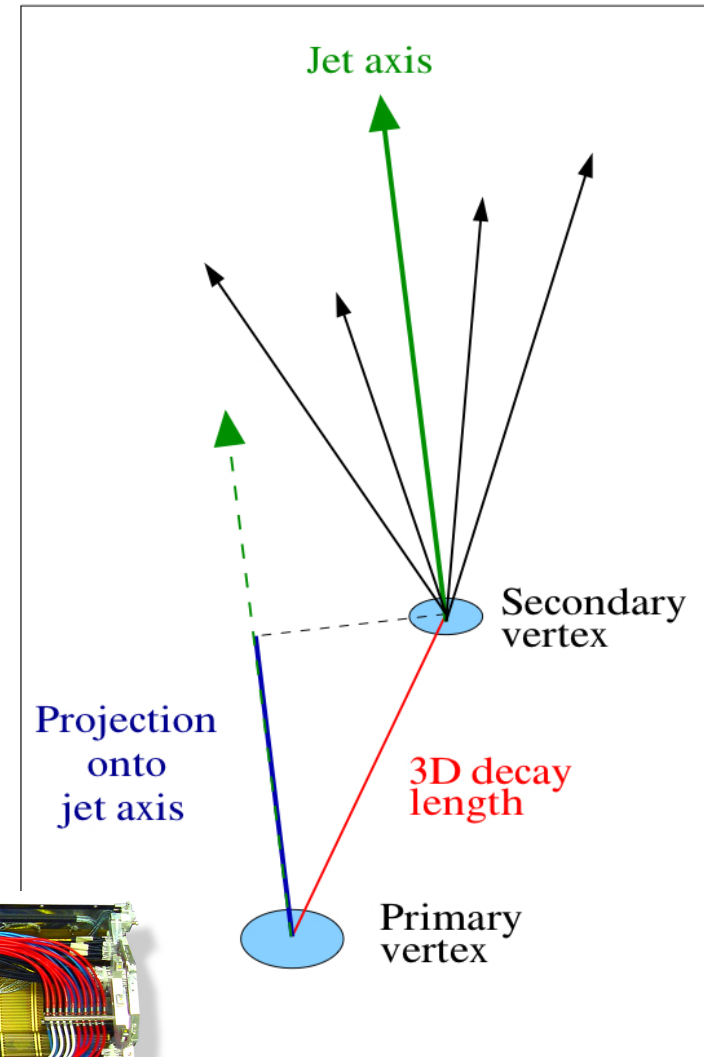


$F_2^{b\bar{b}}$ as a function of Q^2

- The data are all compatible
- At low x the ZEUS data are slightly above H1
- QCD predictions in **FFNS** (ZEUS-S+HVQDIS, GJR08, ABKM NNLO) and the **GM-VFNS** (MSTW08 NLO, MSTW08 NNLO, CTEQ6.6) are shown
- At low Q^2 and x HVQDIS is somewhat lower than the ZEUS data, at higher Q^2 the data are described by all predictions

Beauty measurements using secondary vertices (HERA II)

- During the HERA II period ZEUS was equipped with a silicon Micro Vertex Detector (MVD)
→ **Allows the reconstruction of charm and beauty decay vertices**
- Procedure:
 - Associate tracks with $p_T > 500$ MeV to jets and fit secondary vertices in 3D
 - Calculate the 2D decay length L_{XY} and project onto the jet axis



BOTTOM MICRO VERTEX DETECTOR

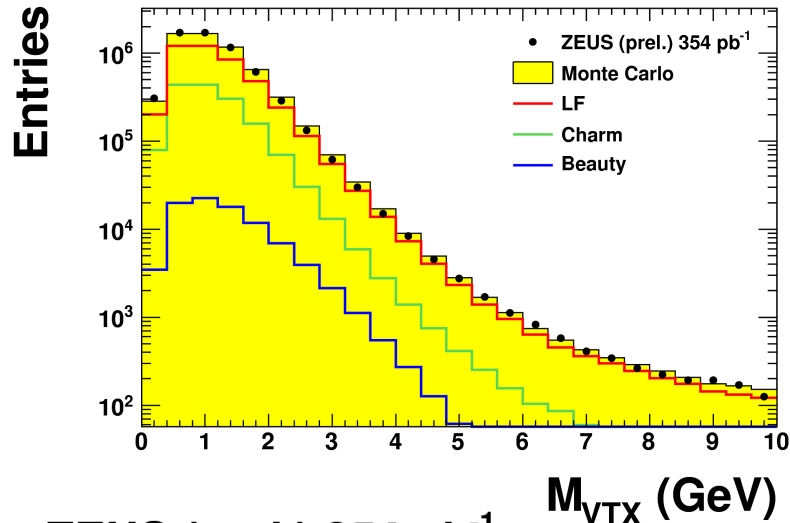
Discriminating variables

Discriminating variables:

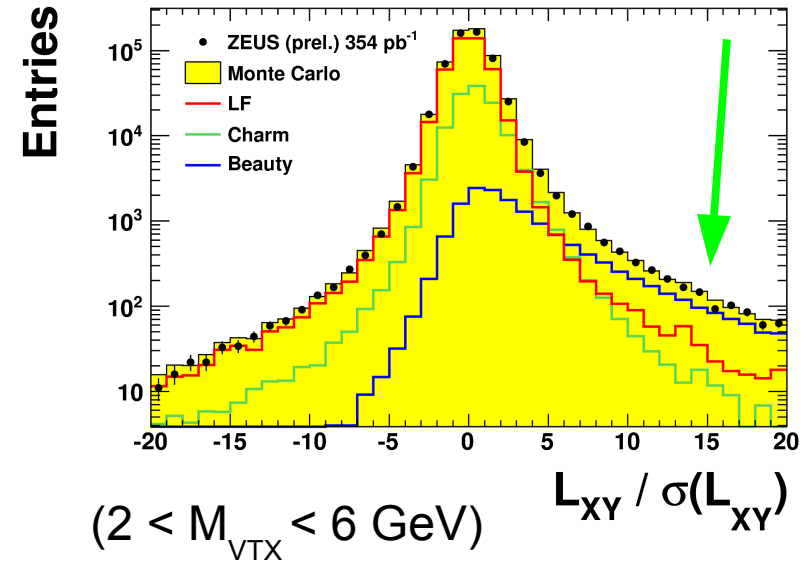
- Vertex mass

- Significance $S = L_{XY} / \sigma(L_{XY})$

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- ZEUS (prel.) 354 pb⁻¹

- Monte Carlo
- LF
- Charm
- Beauty

→ Beauty dominant at high mass and high significance

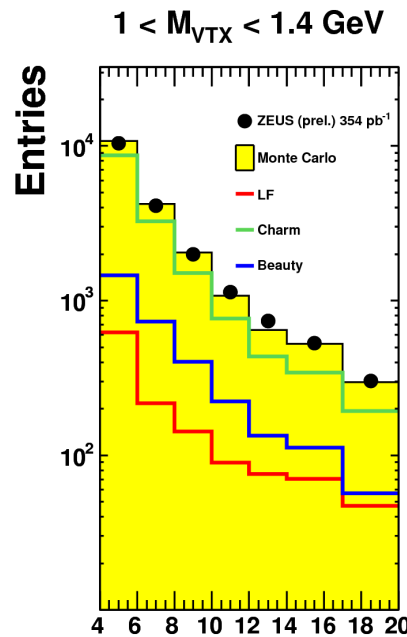
Beauty extraction

- The beauty fraction is extracted using a fit to the mirrored significance in bins of the vertex mass using MC templates

- The overall normalisation is fixed using the unmirrored distributions

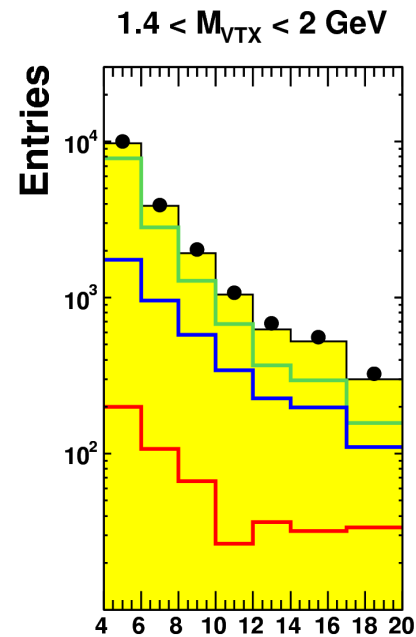
- ZEUS (prel.) 354 pb⁻¹
- Monte Carlo
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ZEUS



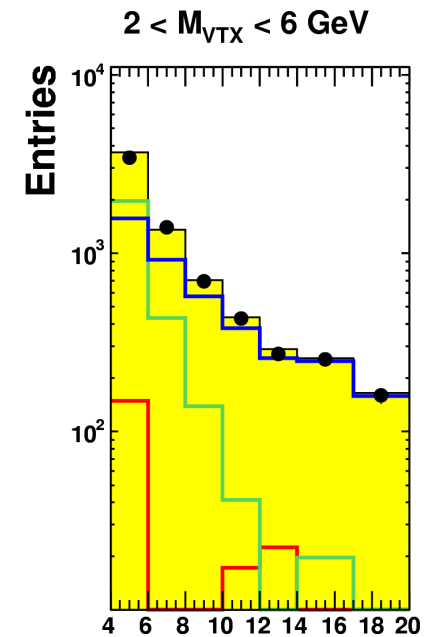
← S⁺ - S⁻

Charm dominant



← S⁺ - S⁻

Beauty dominant



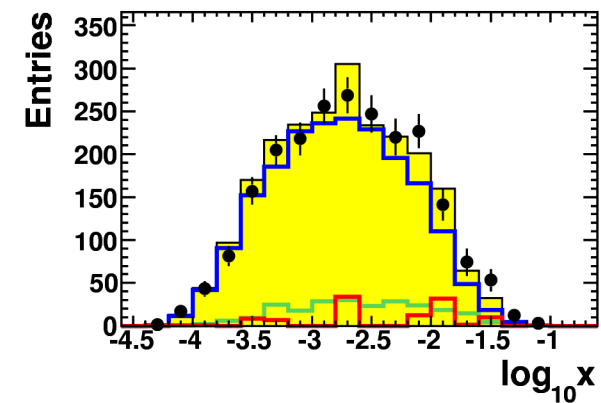
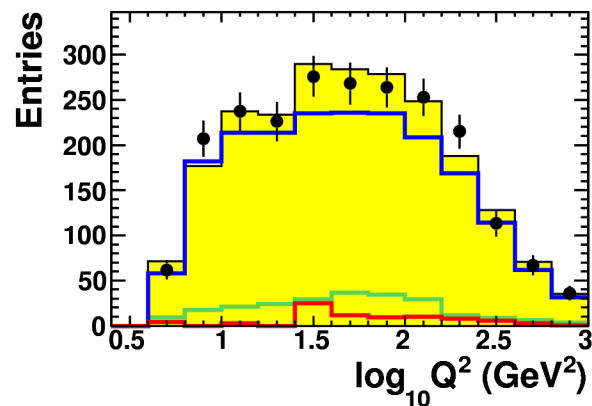
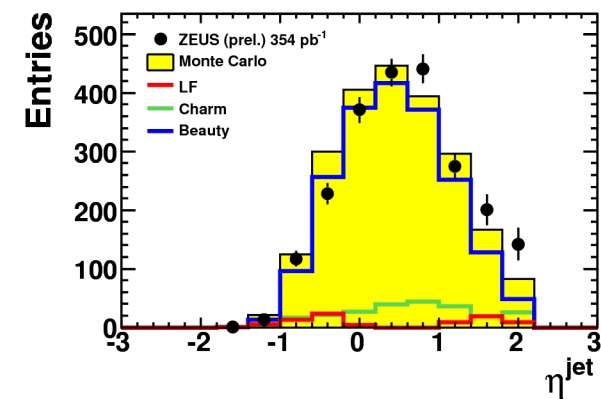
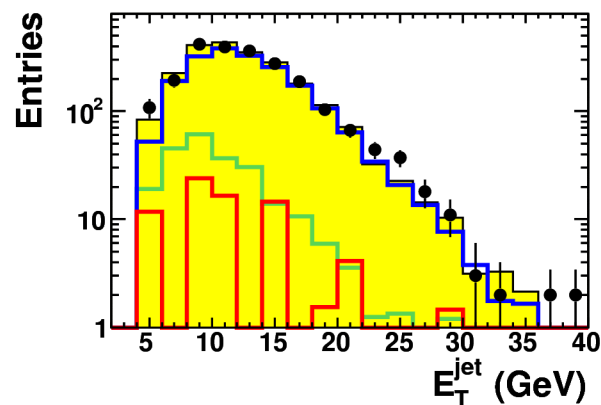
← S⁺ - S⁻

Control plots in the beauty enriched region

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It is possible to obtain an almost pure beauty sample:

- $M_{VTX} > 2 \text{ GeV}$
- $S^+ - S^- > 8$



- ZEUS (prel.) 354 pb⁻¹
- Monte Carlo
- LF
- Charm
- Beauty

Cross sections: E_T^{jet} and η^{jet}

- Kinematic

range:

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

$$0.02 < y < 0.7$$

$$E_T^{\text{jet,lab}} > 5 \text{ GeV}$$

$$-1.6 < \eta^{\text{jet}} < 2.2$$

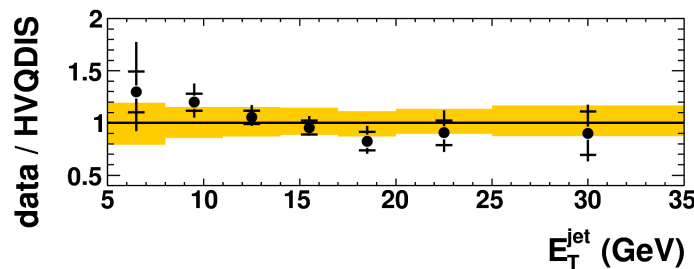
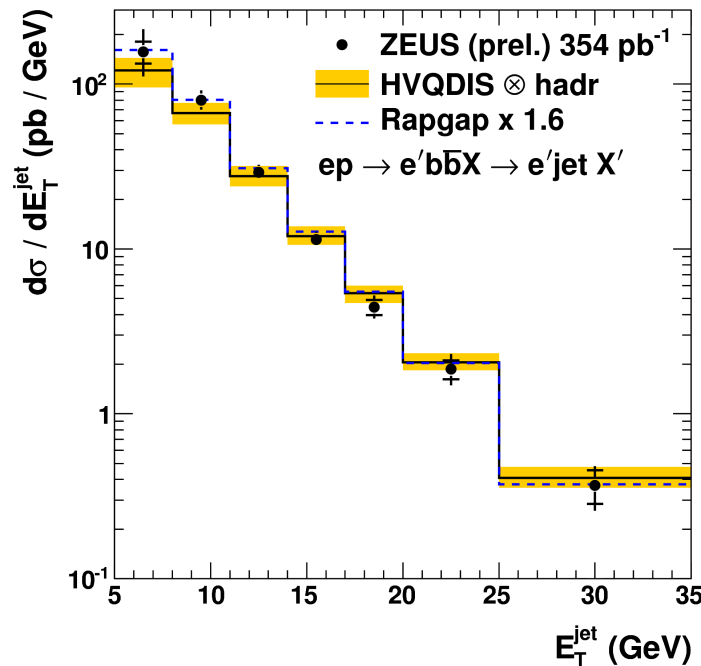
- Data sample:

354 pb⁻¹

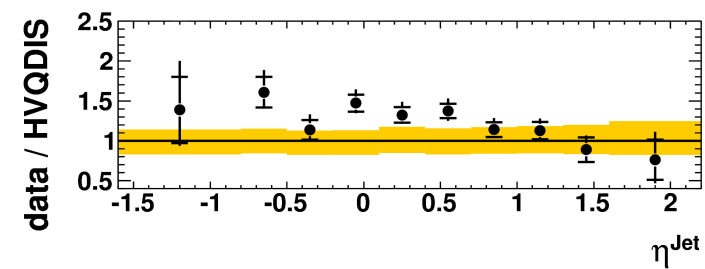
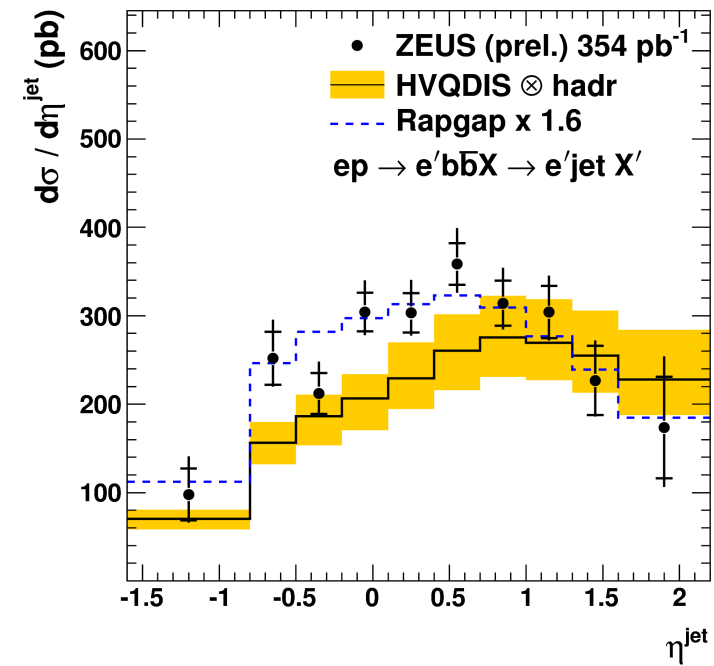
HERA II

(2004 – 2007)

ZEUS



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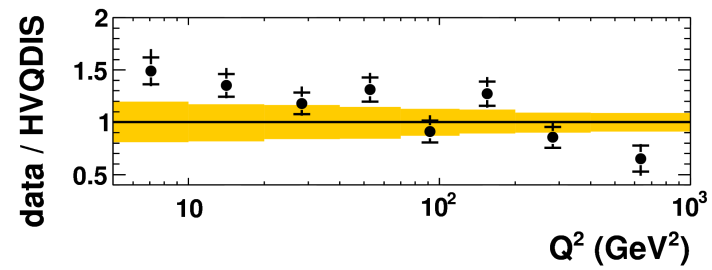
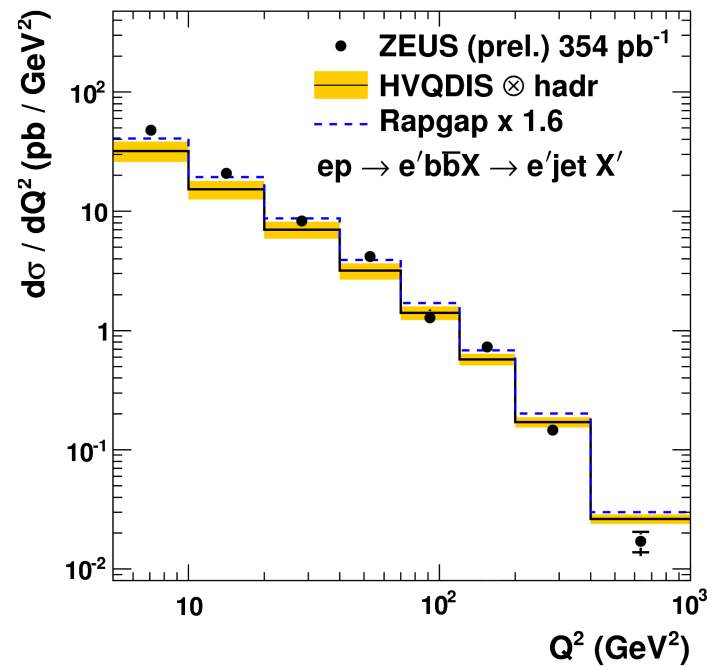


Cross sections: Q^2 and x

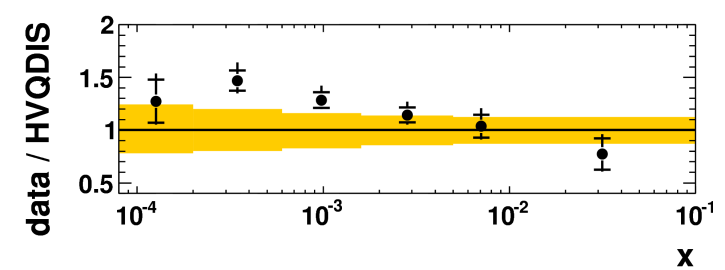
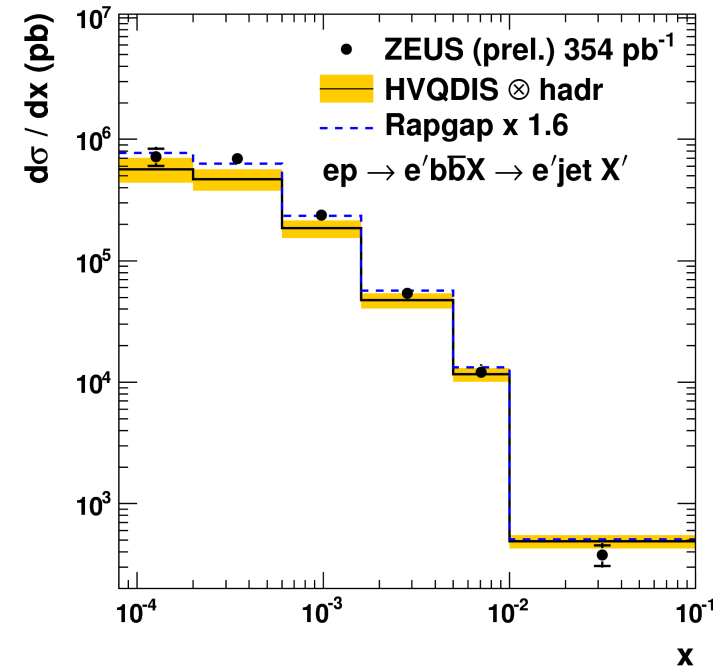
- The shapes of the data are described by HVQDIS and the Rapgap MC program

- The data are typically 20-30% above the HVQDIS NLO QCD prediction

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ZEUS



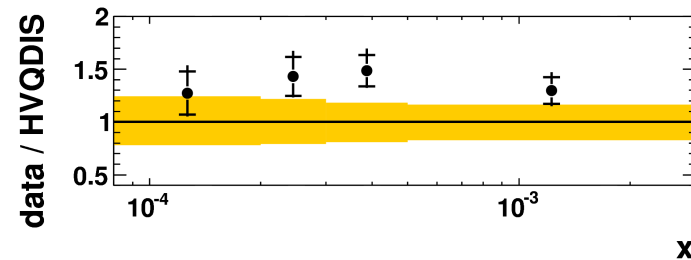
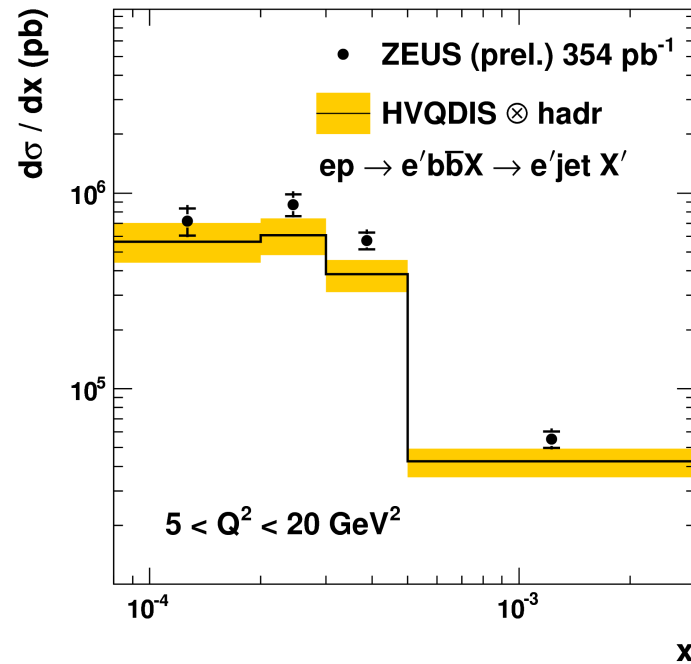
Towards $F_2^{b\bar{b}}$: $d\sigma/dx$ in bins of Q^2

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

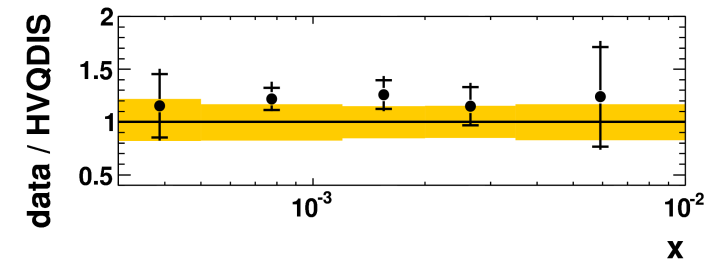
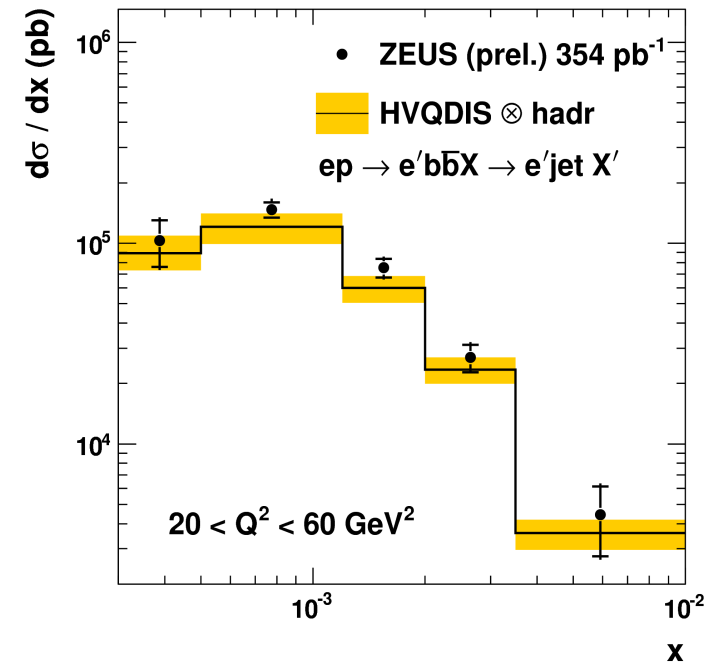
imminent

→ Precision will improve dramatically compared to HERA I

ZEUS



ZEUS

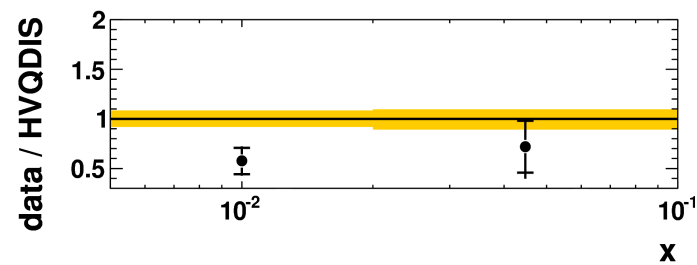
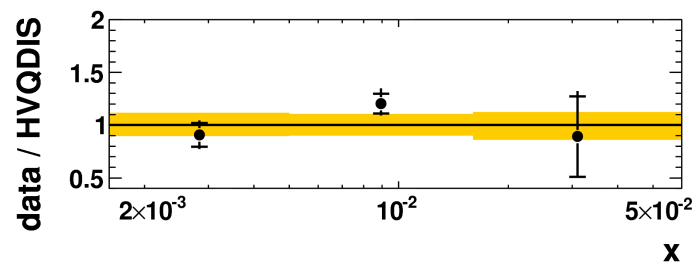
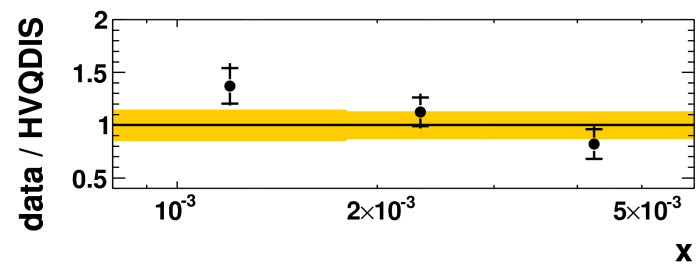
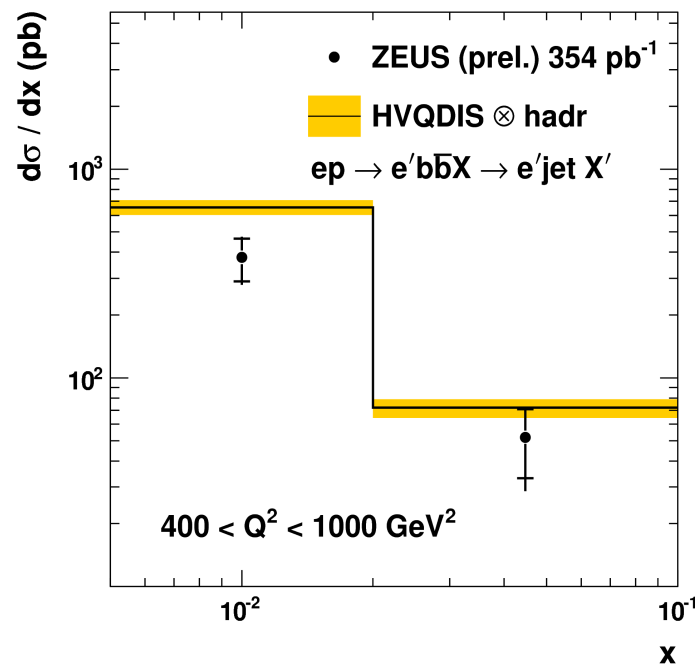
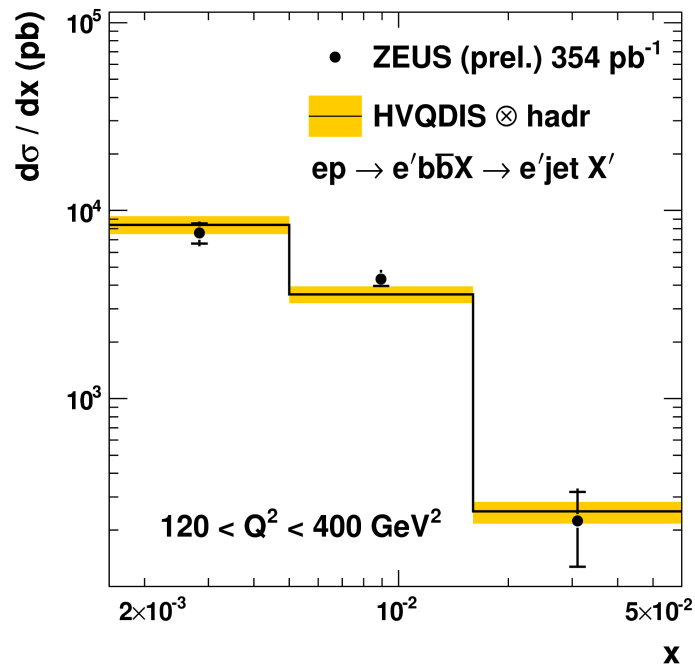
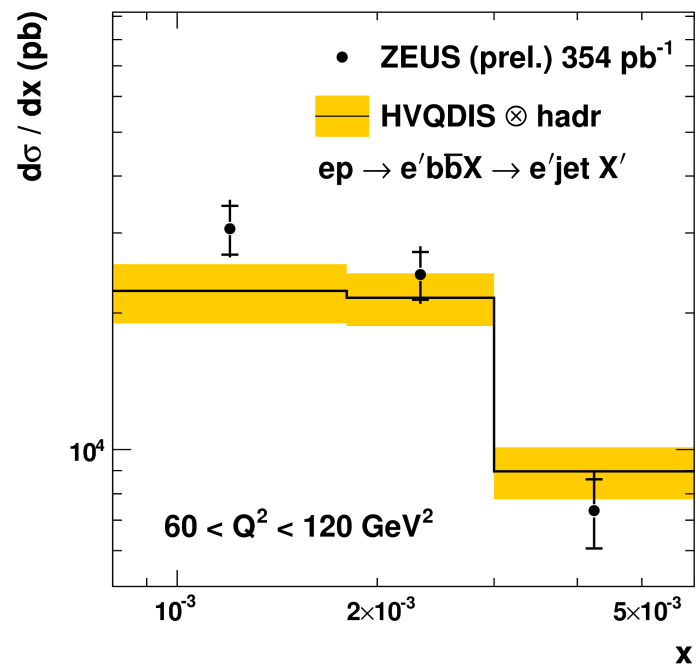


$d\sigma/dx$ in bins of Q^2

ZEUS

ZEUS

ZEUS



Summary and outlook

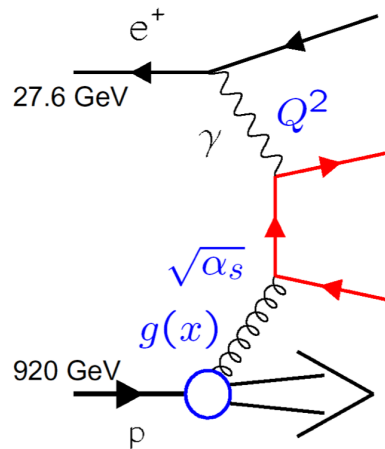
- Beauty production has been measured using events with a jet and a muon and using secondary vertices associated to jets
- Single and double differential cross sections are in reasonable agreement with predictions from HVQDIS
- $F_2^{b\bar{b}}$ was extracted for in the jet+muon analysis and is in agreement with previous measurements
- The precision on $F_2^{b\bar{b}}$ will improve using the secondary vertex measurement

pQCD Treatment of (charm and) beauty production in DIS

Massive, FFNS:

c and b produced dynamically
(not part of proton or photon)

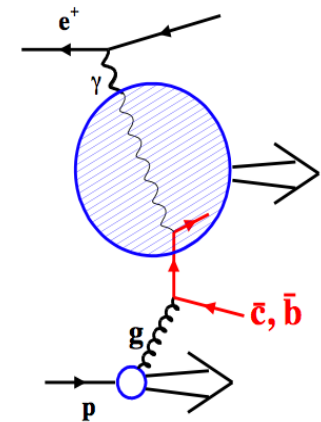
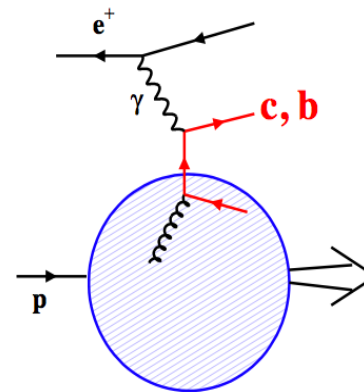
- c, b massive
- Neglects $[\alpha_s \ln(\mu^2 / m^2)]^n$
- Valid at threshold



Massless, ZM-VFNS:

c and b massless partons in proton and photon

- c, b massless
- Resums $[\alpha_s \ln(\mu^2 / m^2)]^n$
- Valid for $\mu^2 \gg m^2$



Variable Flavour Number Scheme, (GM)-VFNS:

Interpolates / matches between both approaches

- **Massive at low Q^2 , massless at high Q^2**

HVQDIS parameters

- **FFNS version of ZEUS-S** Fit (varied within errors)
- $m_b = 4.75 \text{ GeV}$ (4.5 – 5.0 GeV)
- $\mu_R = \frac{1}{2} (m_b^2 + p_T^2 + Q^2)^{1/2}$ (changed by 0.5 and 2)
- $\mu_F = \frac{1}{2} (m_b^2 + p_T^2 + Q^2)^{1/2}$ (changed by 0.5 and 2)
- Hadronisation corrections obtained using RAPGAP

Only HERA I analysis:

- Peterson fragmentation with $\varepsilon = 0.0035$
- Semileptonic decay spectrum for beauty hadrons taken from JETSET