Charm and Beauty production from semileptonic decays at HERA

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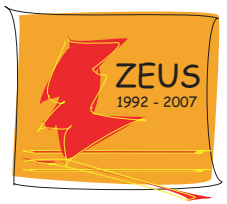
for the ZEUS Collaboration



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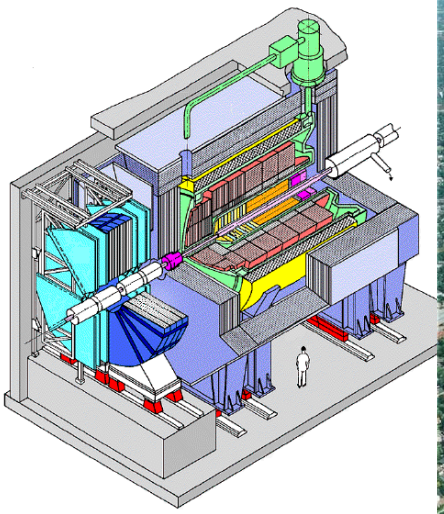
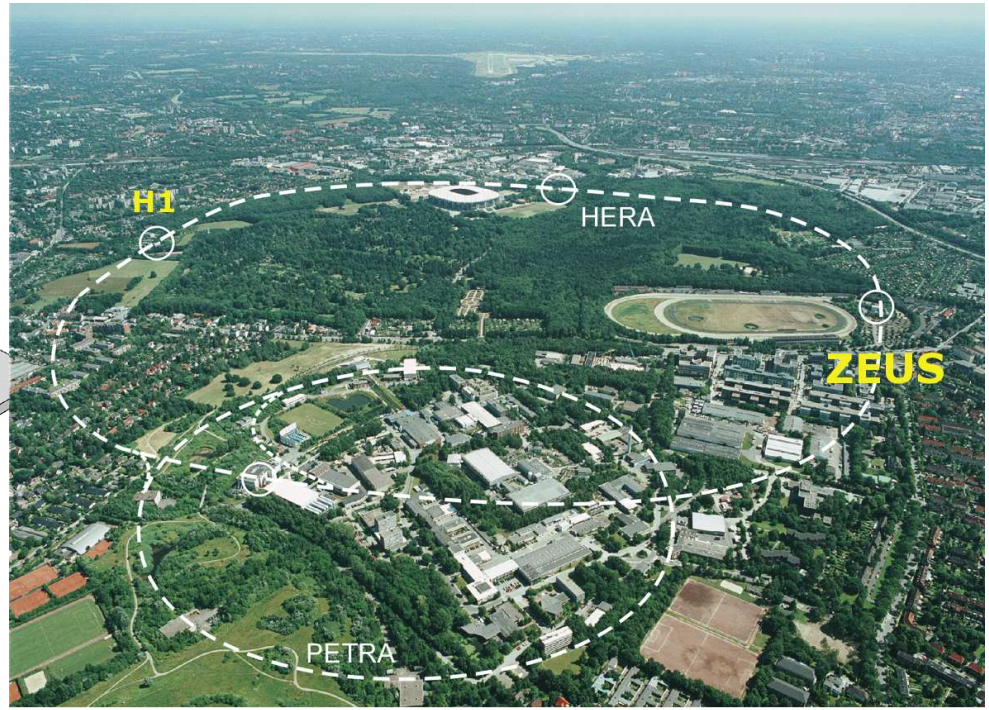
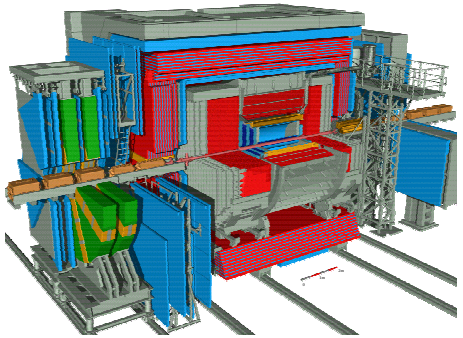
H1 and ZEUS

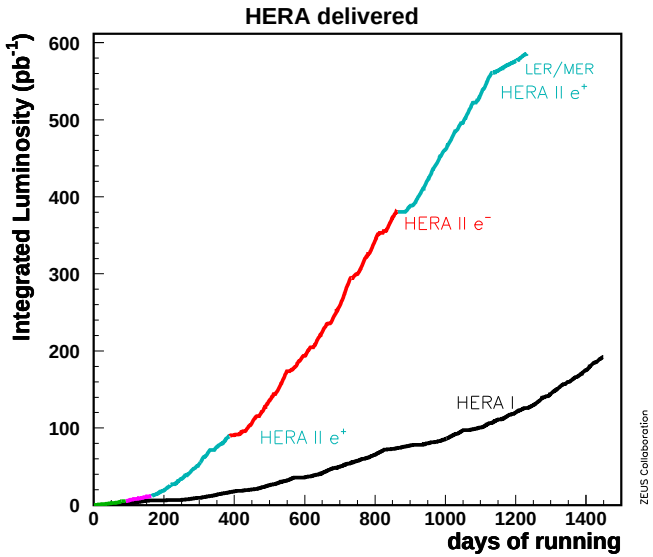






- 27.5 GeV $e^{\pm}$
  920 GeV $p \rightarrow \sqrt{s} = 318$ GeV
- HERAI: 1992-2000
- HERAII: 2003-2007

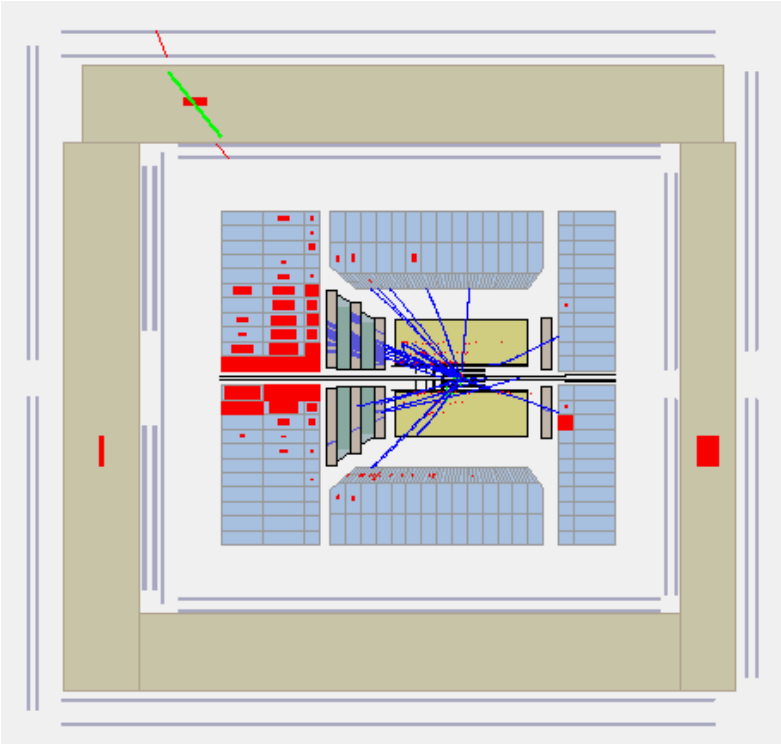
$\rightarrow \sim 0.5\,\mathrm{fb}^{-1}$ per experiment



Motivation

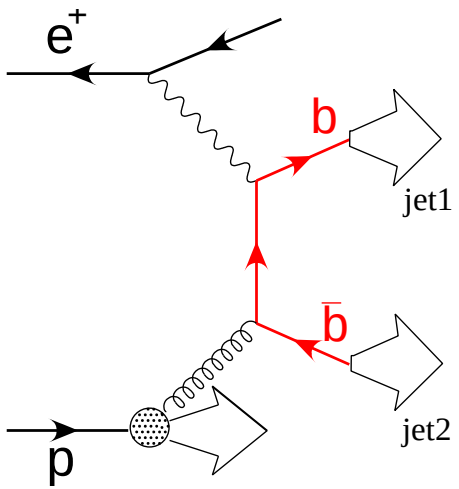
Heavy flavour production is a good probe for different production and decay mechanisms:

- Open production (pQCD)
- Resonance production (NRQCD)
- Searches for exotic bound states



► Important to use different channels to cross check with independent systematics

$\sigma_{uds} : \sigma_c : \sigma_b \sim 2000 : 200 : 1$ (HERA)



Kinematical regions:

Photoproduction (γp) $\rightarrow Q^2 \lesssim 1\,\mathrm{GeV}^2$

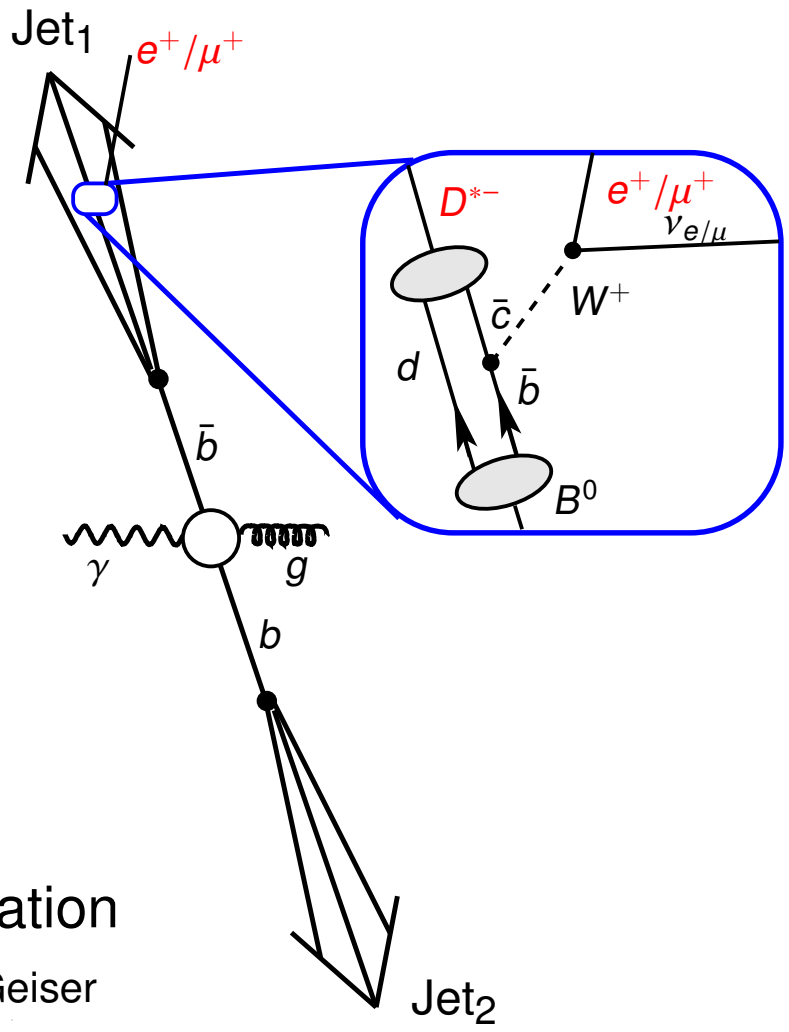
Electroproduction (DIS) $\rightarrow Q^2 \gtrsim 1\,\mathrm{GeV}^2$

Q^2 : photon virtuality, x : parton momentum fraction

Heavy flavour tagging

Different experimental techniques used (combined) for heavy flavour tagging:

- Decay spectra
  p_T^{rel} of lepton to jet axis
- Lifetime information
  Measure impact parameter with respect to primary vertex (beamspot)
- Meson identification
  $D^{*\pm}$ tagging (”Golden Decay”)



- In this talk focus on lepton identification

  → for dilepton tagging see Talk 864 by Achim Geiser

Beauty from decays into muons

Method:

- Use different shape of p_T^{rel} distributions, to extract fractions of beauty and the background
- Calculate beauty cross section down to low values of Q^2

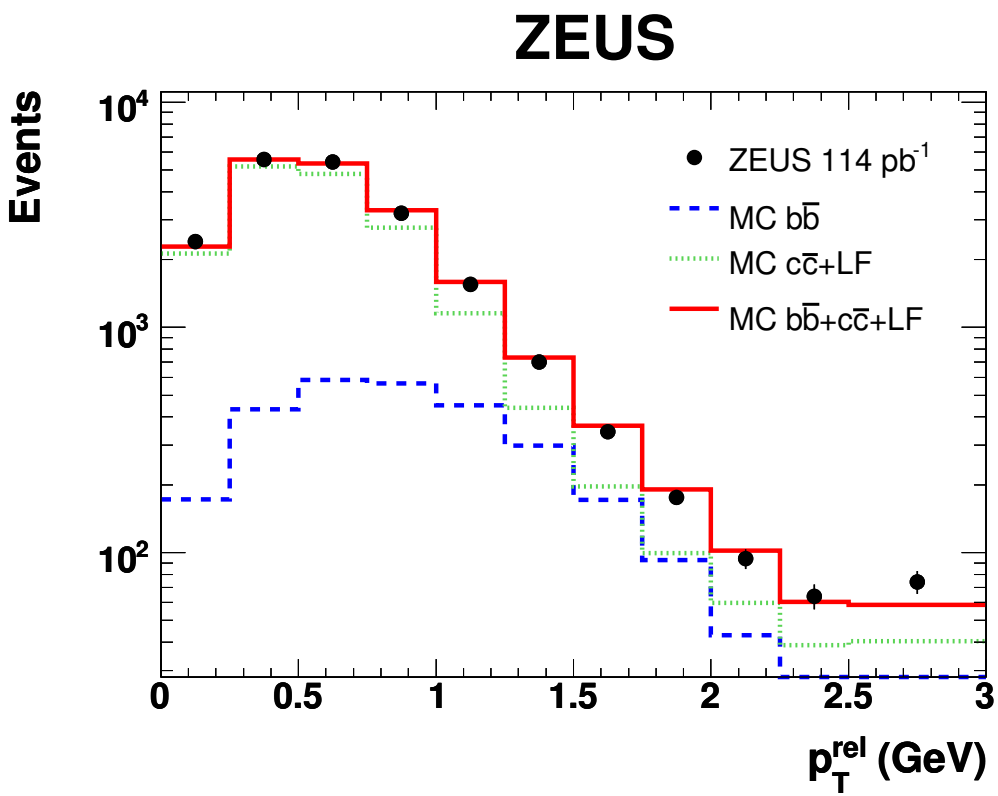
HERAI data:

1996-2000 ($\mathcal{L} \approx 114\,\text{pb}^{-1}$)

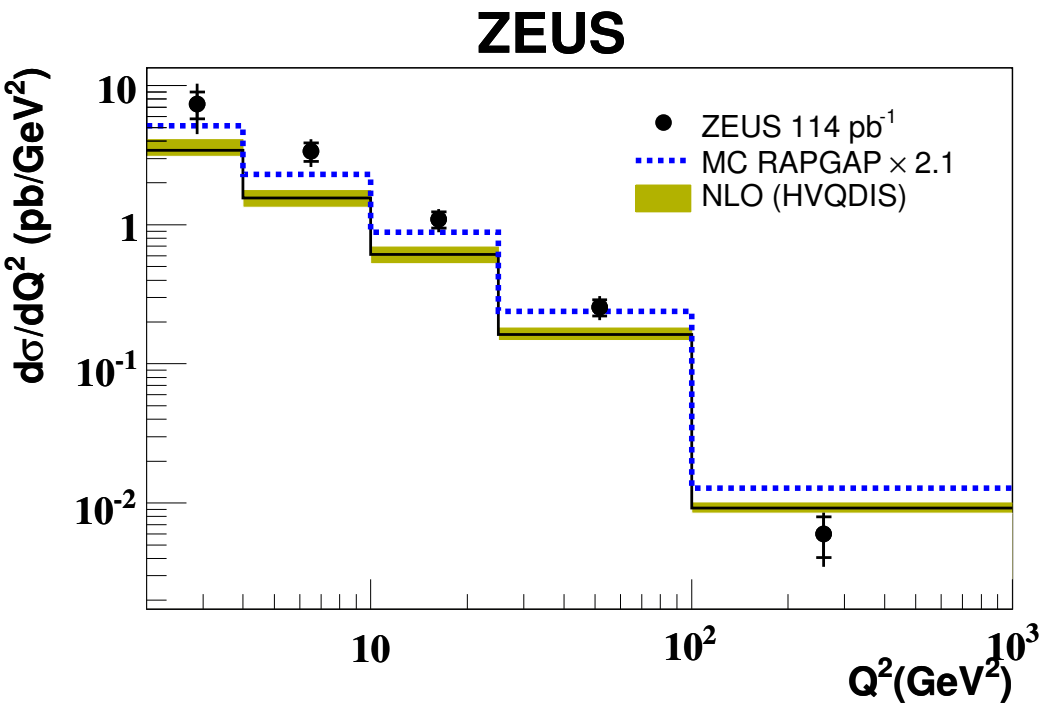
Kinematic region:

$Q^2 > \mathbf{2}\,\text{GeV}^2$, $0.05 < y < 0.7$,

$p_T^\mu > 1.5\,\text{GeV}$, $\eta^\mu > -1.6$



Beauty from decays into muons

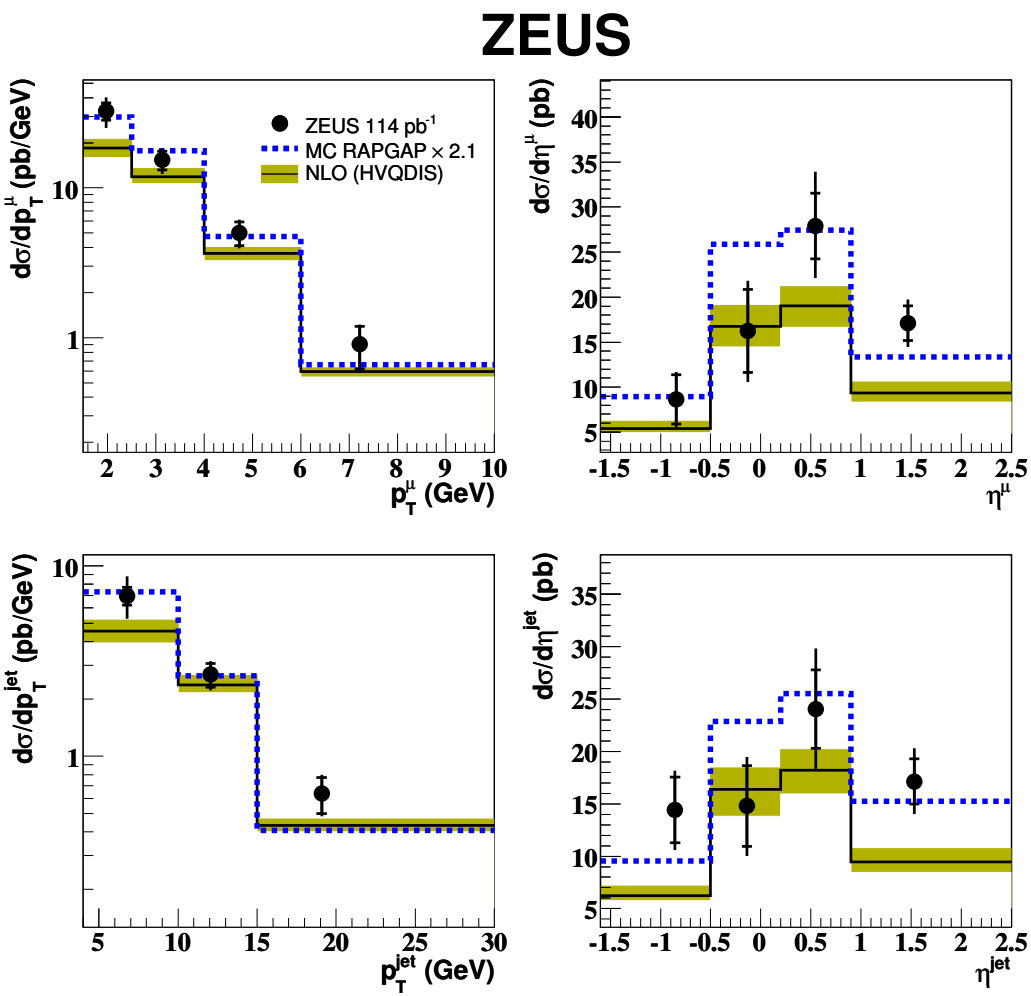


$\sigma_b = 70.4 \pm 5.6(stat.)^{+11.4}_{-11.3}(syst.)$ pb
$(\sigma_b^{NLO} = 46.4^{5.8}_{6.1}$ pb)

Scale parametrisation:
$\mu^2 = 1/4(p_T^2 + m_b^2 + Q^2)$
(Varied by a factor 2)

- Total visible and differential cross section as a function of Q^2 compared with NLO QCD calculation
- Also double-differential cross sections computed to extract F_2^b
- The largest difference can be attributed in the low x, Q^2 region ($\rightarrow$ low p_T)

Differential cross sections



- In shape, both the RAPGAP MC (scaled by 2.1) and the NLO QCD calculation reasonably describe the data

Method:

Simultaneous fit of

p_T^{rel}, δ and $p_T^{miss||\mu}$

$p_T^{miss||\mu}$:

-missing transverse momentum

-using parallel component to the muon direction

► additional variables provide sensitivity to charm

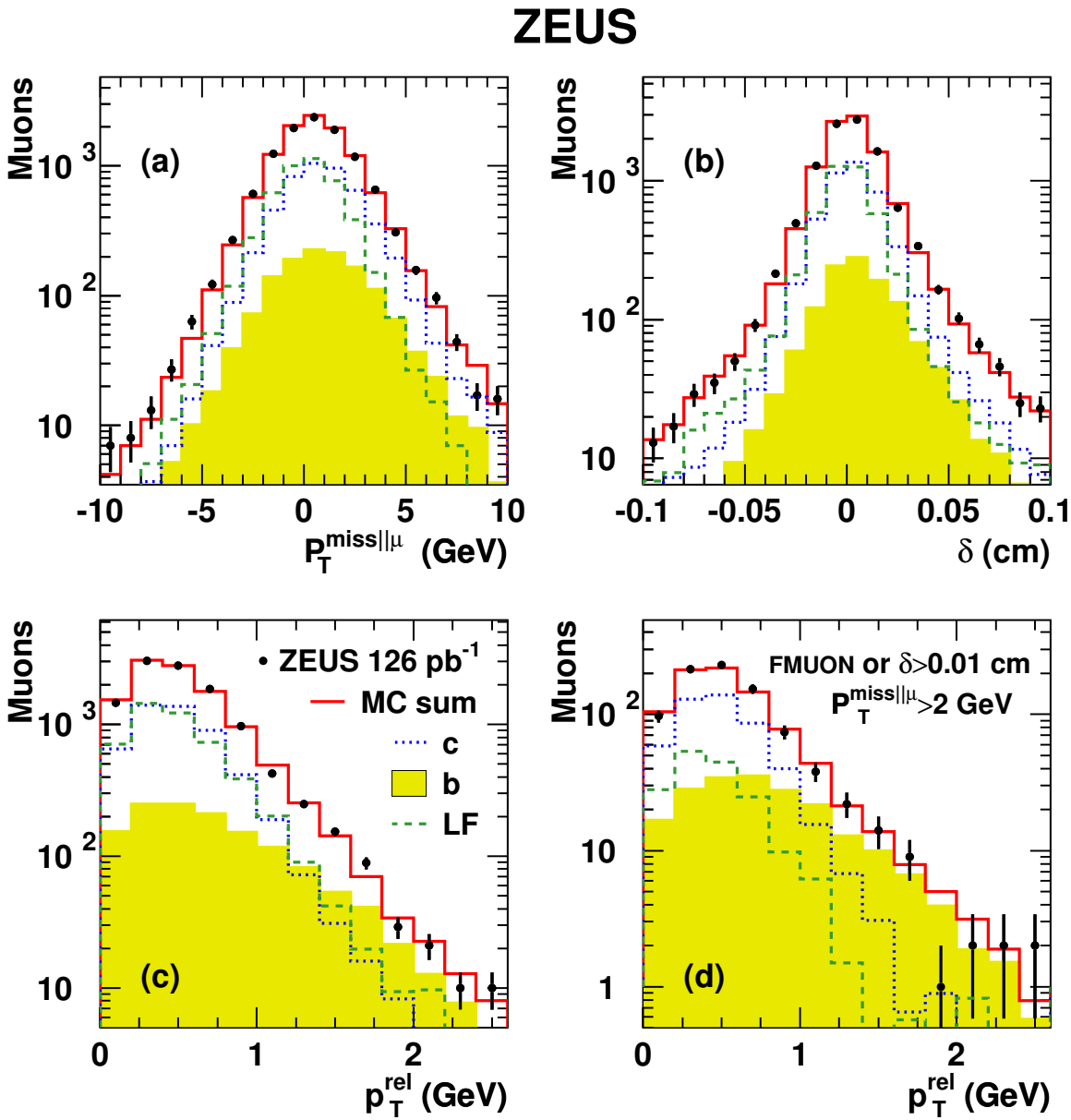
HERAII data:

2005 ($\mathcal{L} \approx 126\,\mathrm{pb}^{-1}$)

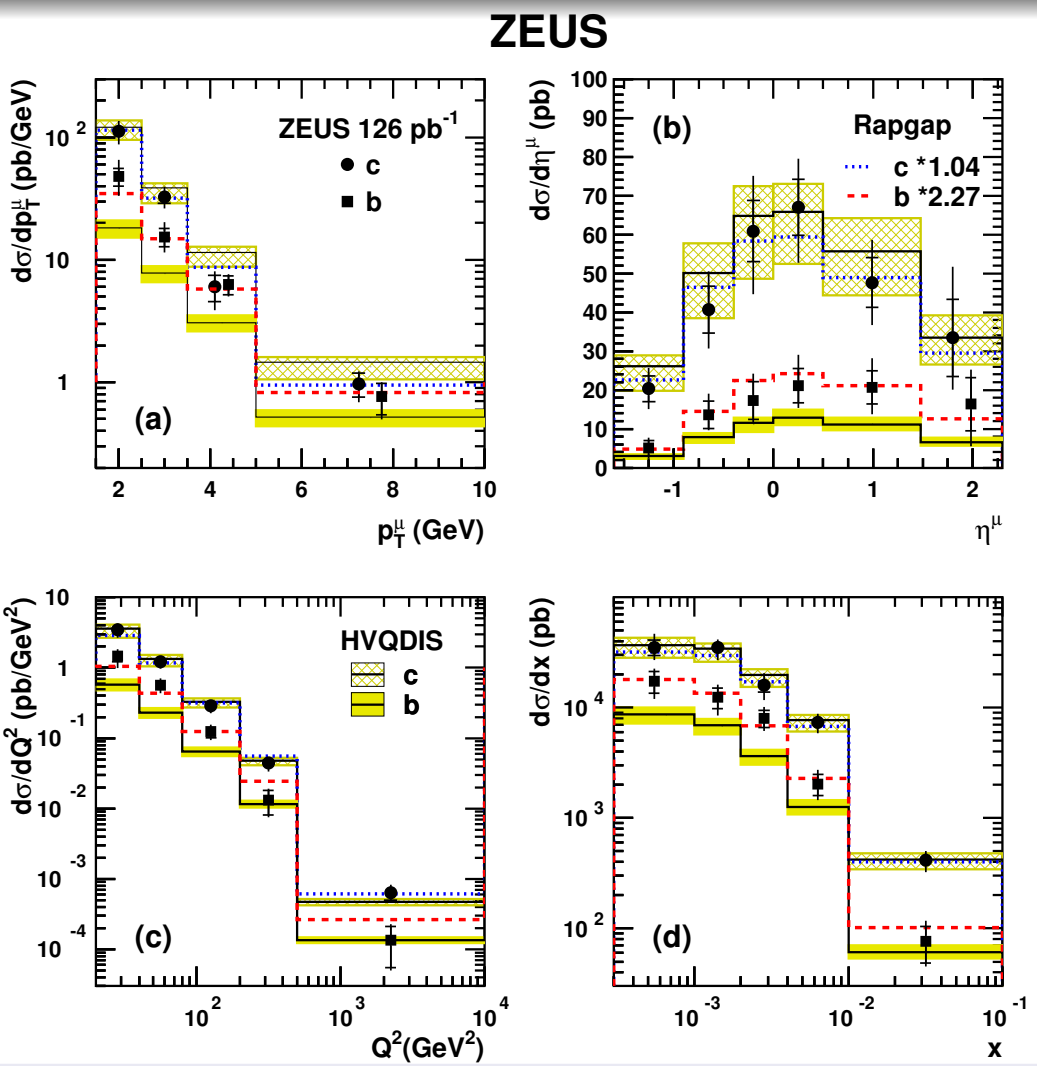
Kinematic region:

$Q^2 > 20\,\mathrm{GeV}^2$, $0.01 < y < 0.7$,

$p_T^\mu > 1.5\,\mathrm{GeV}$, $-1.6 < \eta^\mu < 2.3$



Charm and beauty cross sections



$$\sigma_c = 164 \pm 10(stat.)^{+30}_{-31}(syst.)\,\text{pb}$$
$$(\sigma_c^{NLO} = 184^{+26}_{-40}\,\text{pb})$$

$$\sigma_b = 63 \pm 7(stat.)^{+18}_{-11}(syst.)\,\text{pb}$$
$$(\sigma_b^{NLO} = 33 \pm 5\,\text{pb})$$

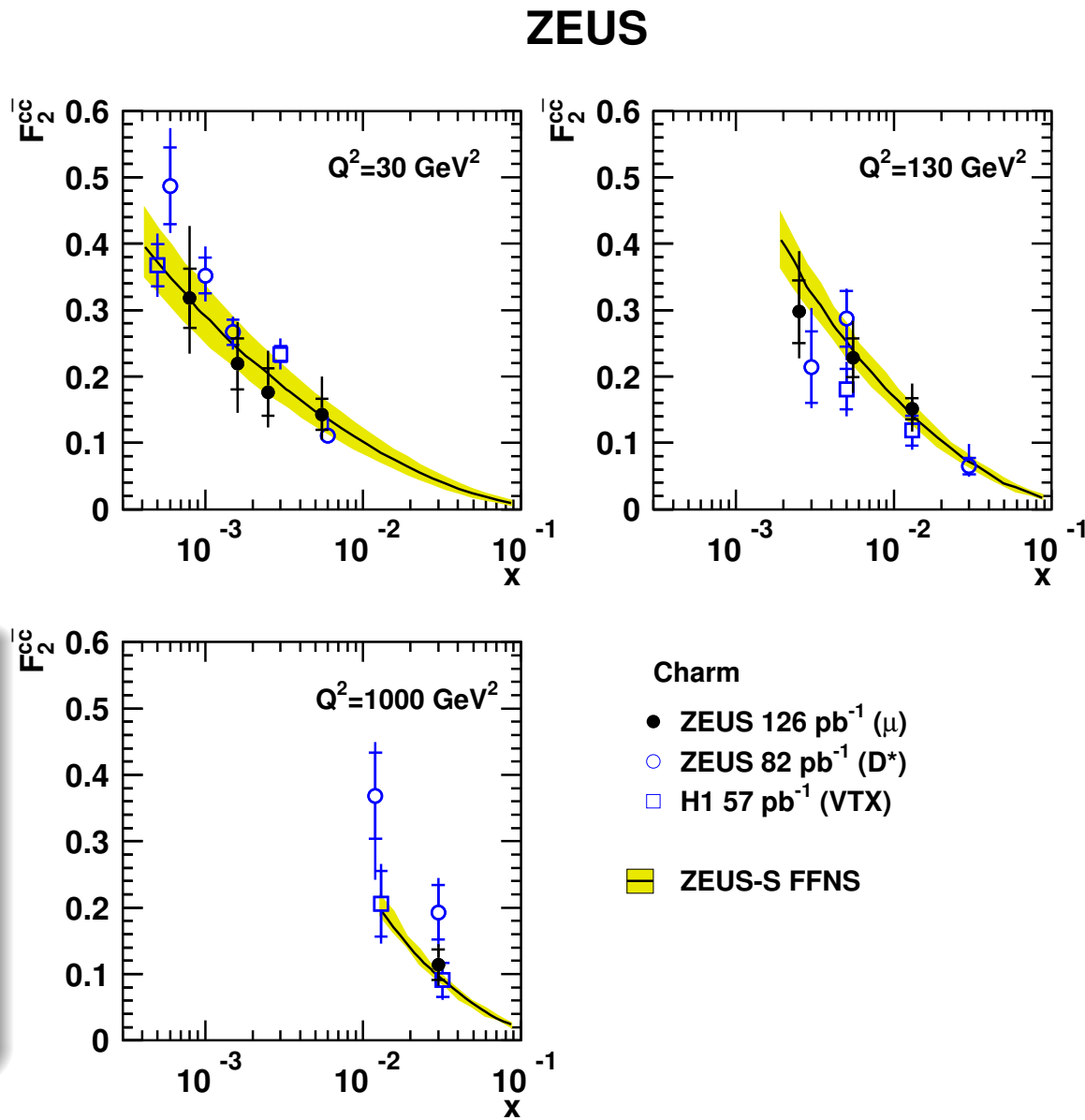
Scale in HVQDIS:
$\mu^2 = Q^2 + 4m^2_{b/c}$

- NLO QCD calculation in good agreement for charm while beauty cross section is 2.3 standard deviations above HVQDIS result
- Shapes are well described by NLO calculation and RAPGAP LO MC

Charm contribution to the structure function - $F_2^{c\bar{c}}$

Unfold cross sections:

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



- Compared with NLO QCD predictions in the FFNS using the ZEUS-S PDF fit
- Structure functions agree well with other measurements based on independent technique

→ for details on $F_2^{c\bar{c}}$ results see Talk 1159 by Massimo Corradi

Beauty contribution to the structure function - $F_2^{b\bar{b}}$

Unfold cross sections:

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

- Compared with NLO QCD predictions in the FFNS using the ZEUS-S PDF fit
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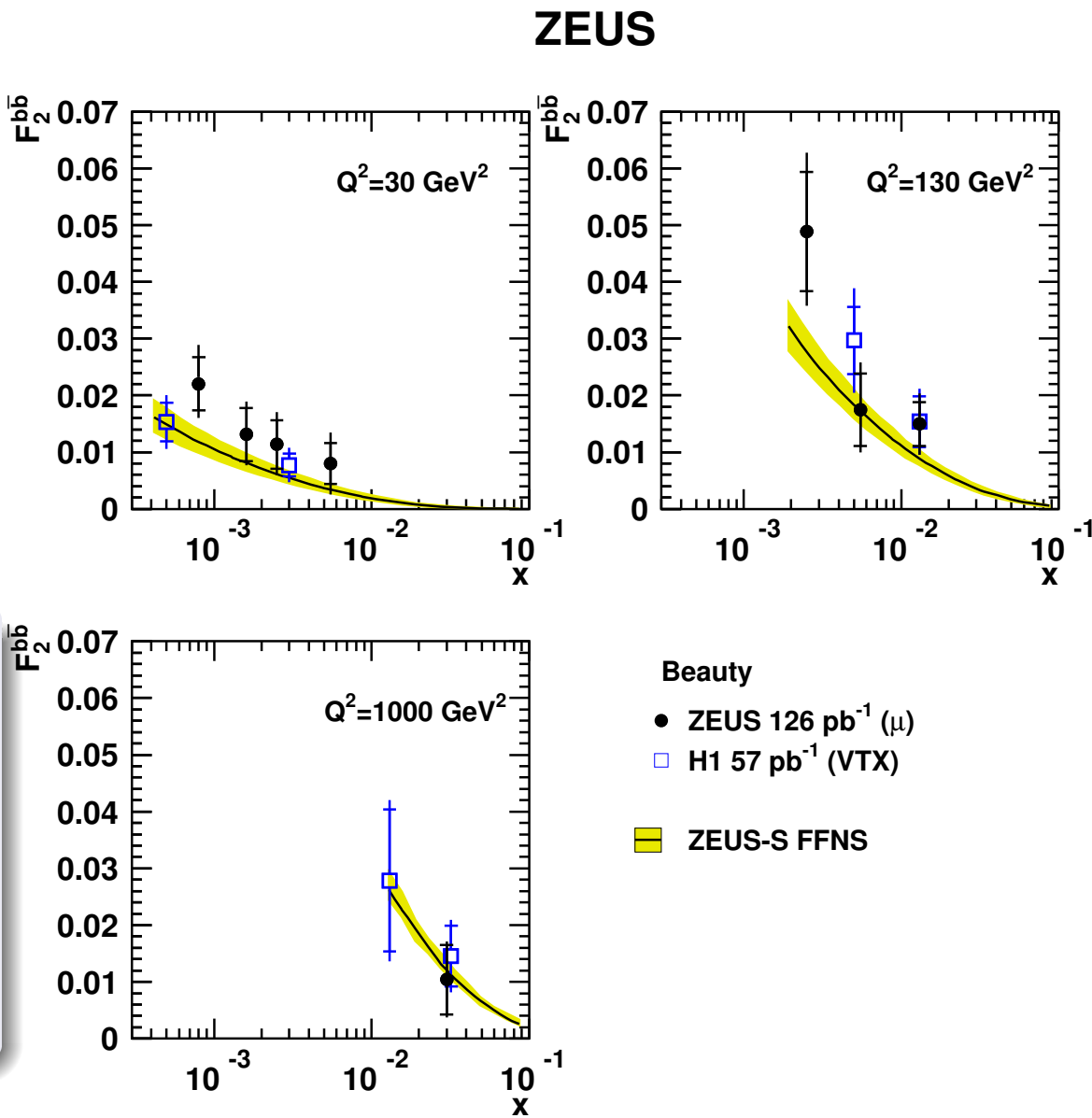


Beauty from decays into electrons

Method:

- p_T^{rel}, $\Delta\phi(\not{p},e)$ and d/δ_d combined with particle ID
- fit contribution of beauty, electron background and other background

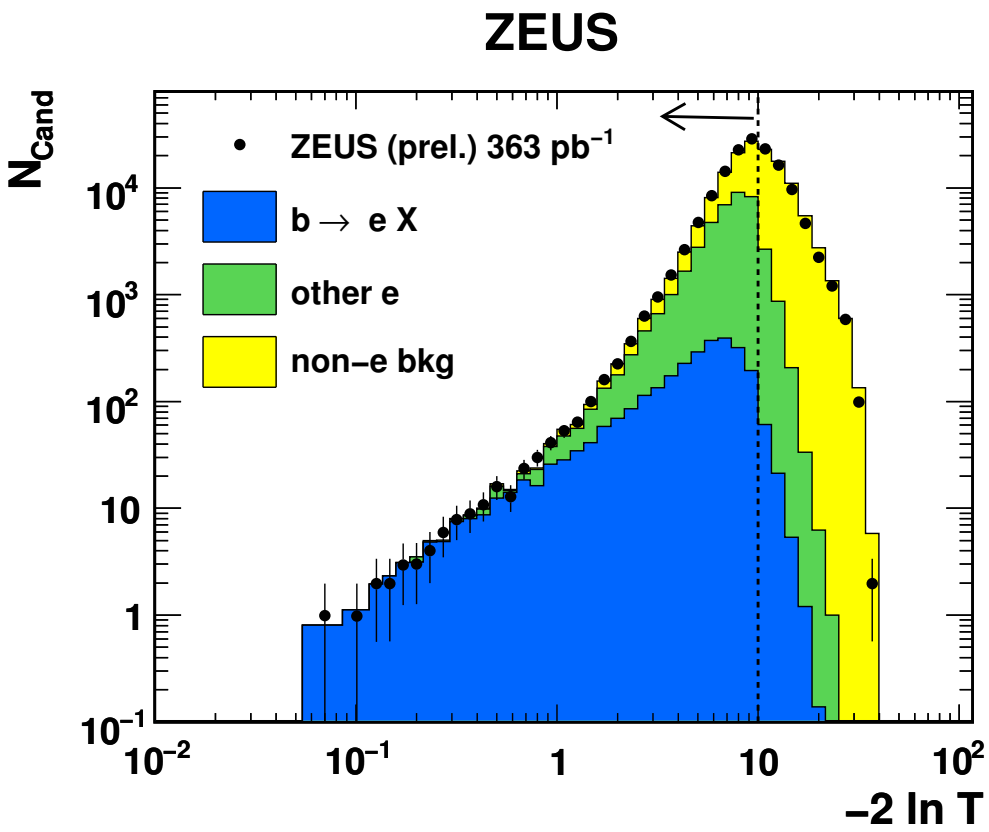
HERAII data:

2004-2007 ($\mathcal{L} \approx 363\,\text{pb}^{-1}$)

Kinematic region:

$Q^2 > 10\,\text{GeV}^2$, $0.05 < y < 0.7$,

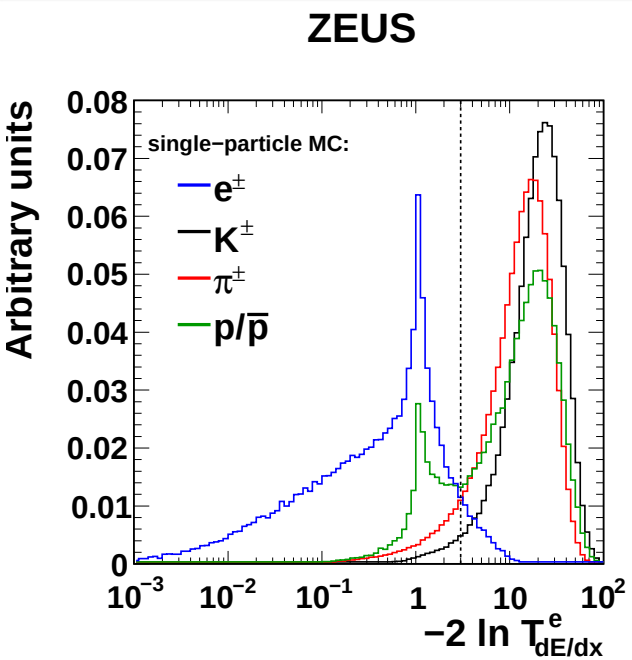
$p_T^e > 0.9\,\text{GeV}$, $|\eta^e| < 1.5$

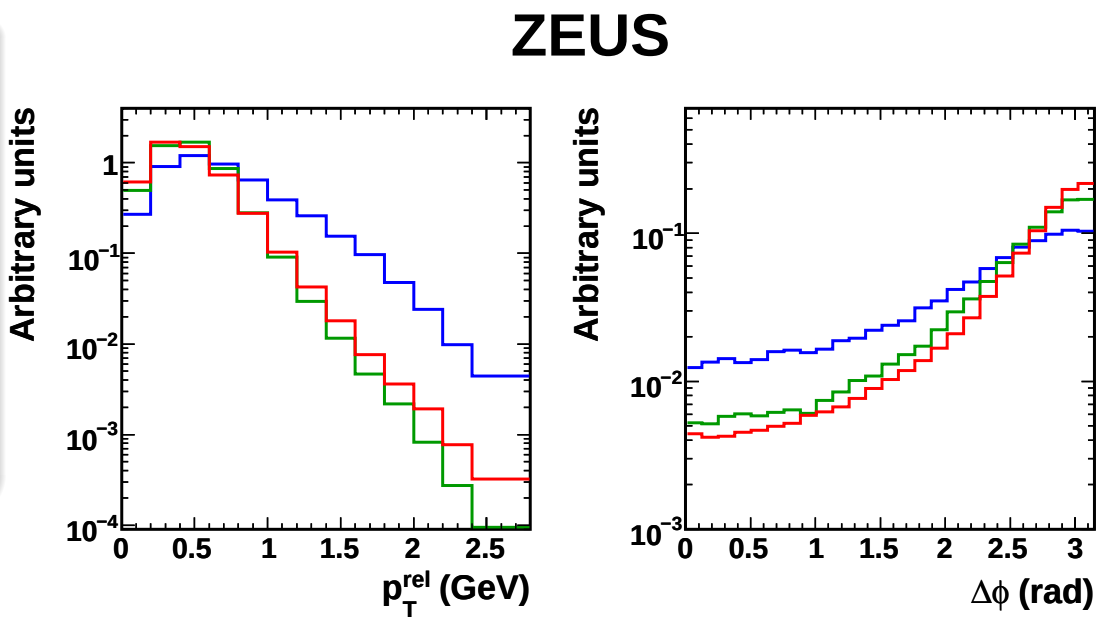


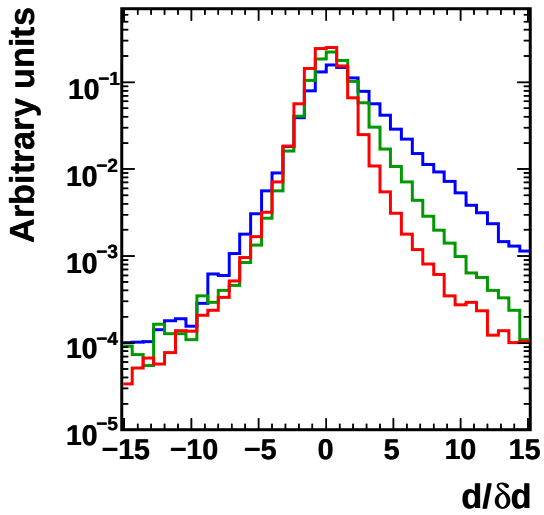
► Extract beauty cross sections fitting fractions of three contributions to data in the distribution of the hypothesis test, T

Input variables for likelihood test

- Main variable for particle ID is mean energy loss, dE/dx
- Three variables contribute to decay identification
- Probability distributions are input for likelihood hypothesis test





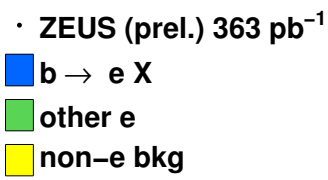


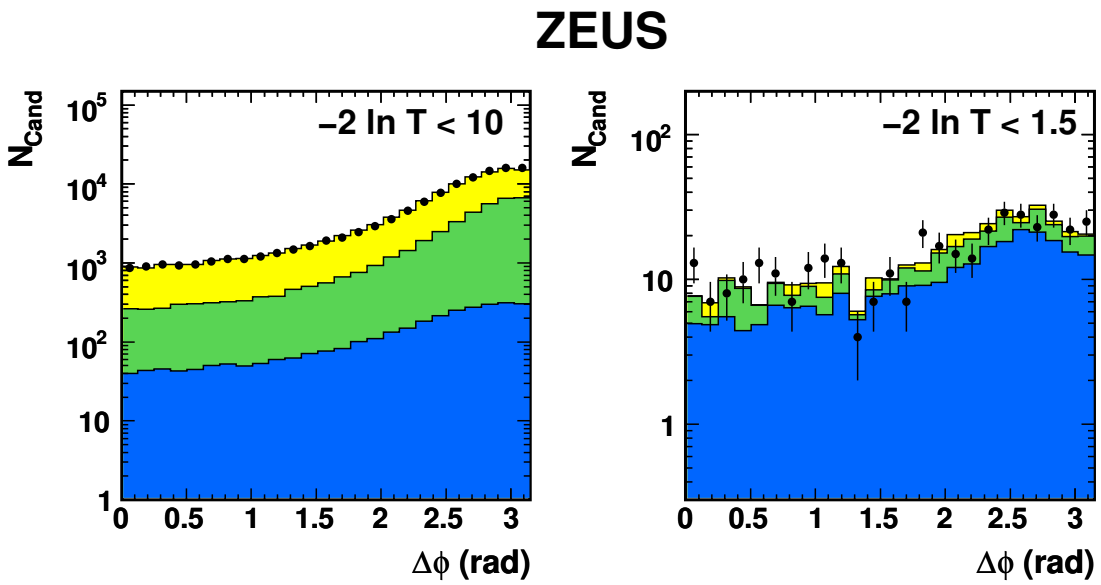
single−particle MC:

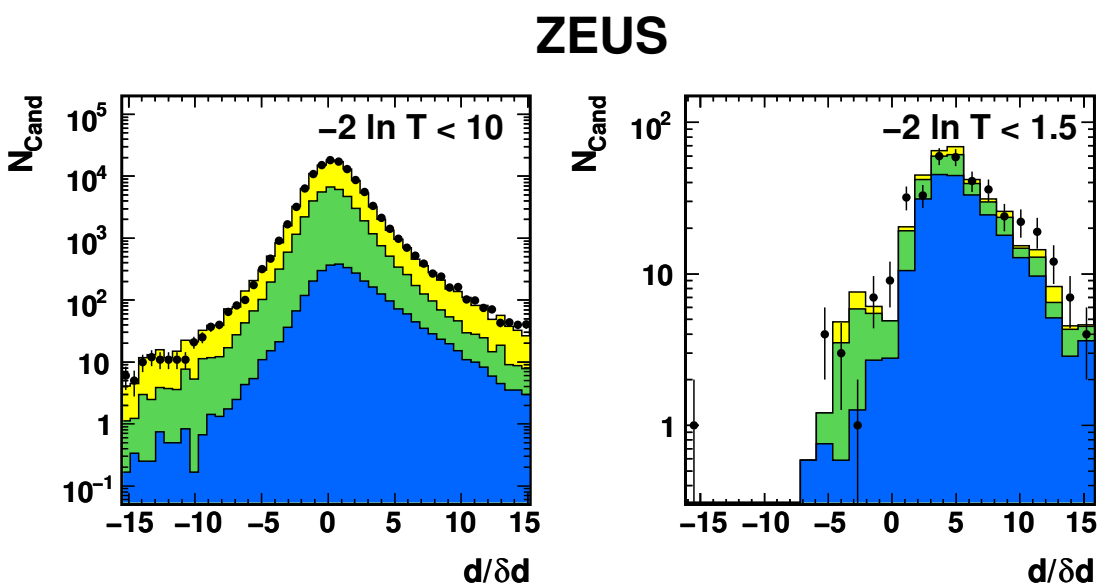
- b → e X
- c → e X
- bkg

Control Plots

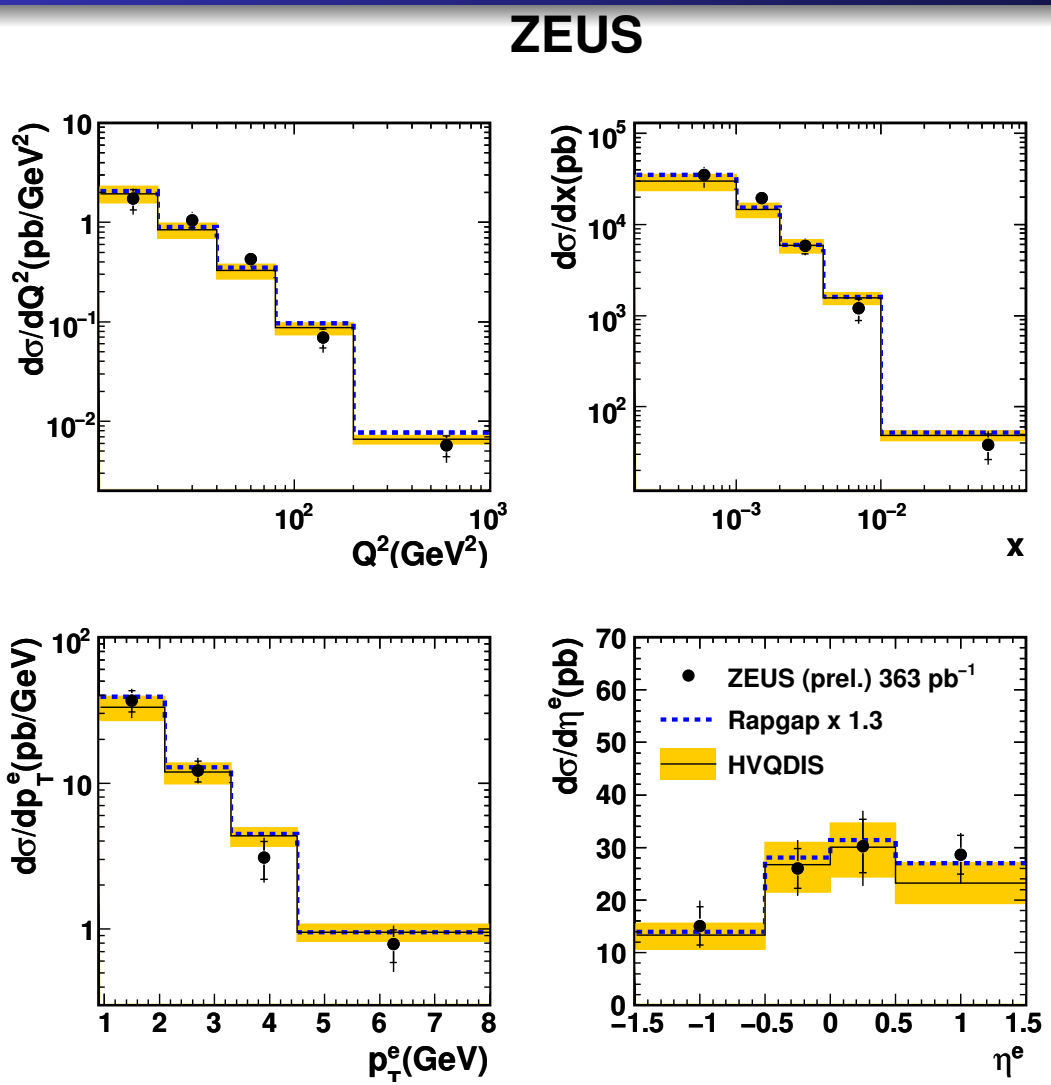
- Control plots for $\Delta\phi$ and d/δ_d
- Shown after two steps of enrichment
- Variables well described







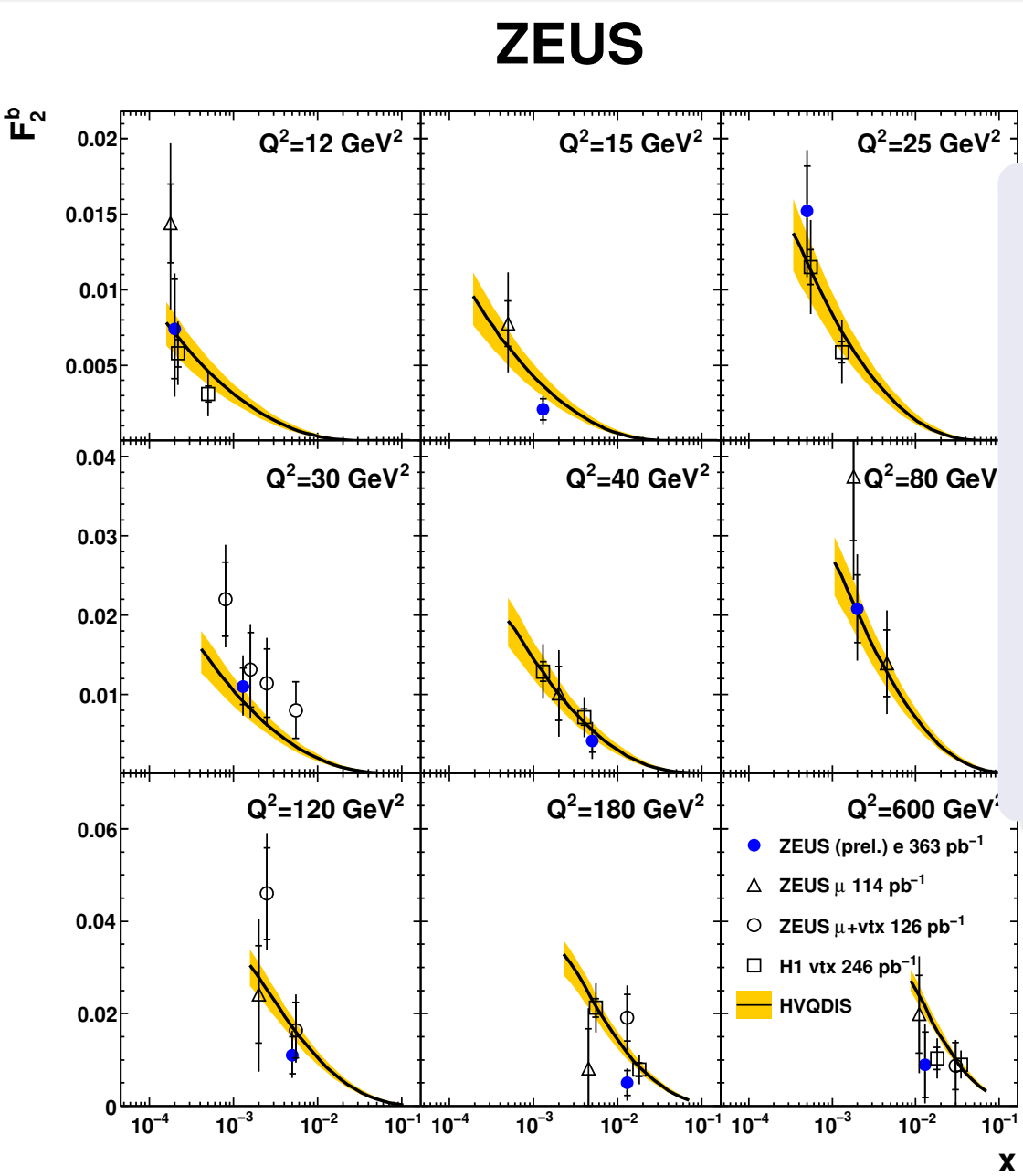
Differential cross sections



- RAPGAP prediction scaled by a factor of **1.3**
- HVQDIS prediction using $\mu^2 = Q^2 + 4m_b^2$

- NLO QCD calculation in good agreement with measured values
- Shapes are well described by NLO calculation and RAPGAP LO MC

F_2^b as a function of x

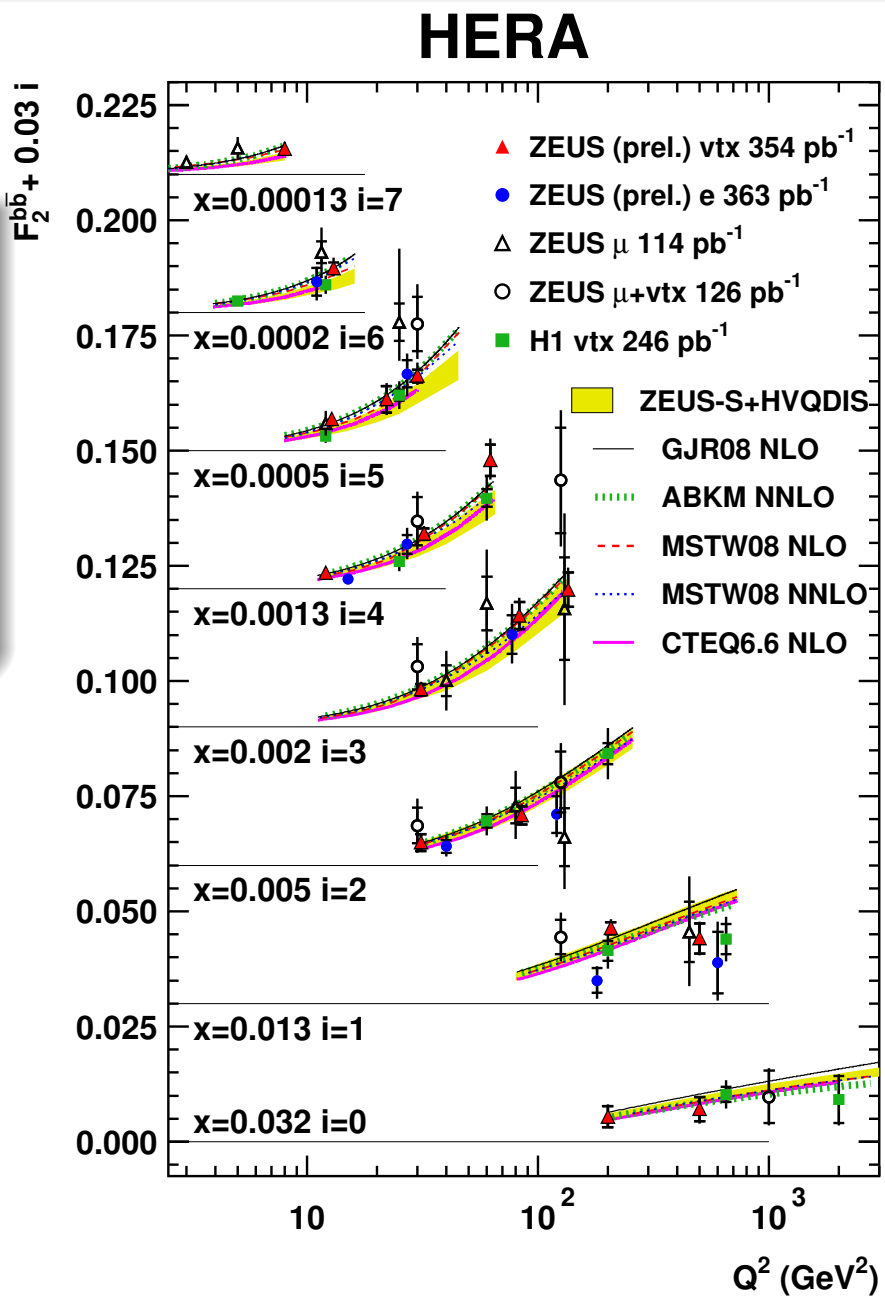


- Extract F_2^b from differential cross section in bins of x for different regions of Q^2
- Previous points corrected to the reference Q^2 values
- Measured points consistent with previous measurements and NLO QCD calculation
- Points at large Q^2 tend to be lower than previous results

F_2^b - Comparison

- Summary of all F_2^b measurements
- All measurements consistent with each other and with the NLO QCD predictions
- New preliminary results with comparable precision as for the H1 published result

→ for inclusive measurements see Talk 1169 by Paul Thompson



Summary

- Using semileptonic decays to muons or electrons the heavy quark production in DIS was measured over a wide range of Q^2
- The cross sections for charm are consistent with the NLO QCD prediction while the cross sections for beauty tend to be on the upper edge of the prediction
- The new extracted values of F_2^b have similar uncertainties compared with other measurements and give a consistent picture of beauty production in DIS

References

Measurement of beauty production in DIS and $F_2^{b\bar{b}}$ extraction at ZEUS

DESY-10-47 (April 2010)

Measurement of charm and beauty production in deep inelastic ep scattering from decays into muons at HERA

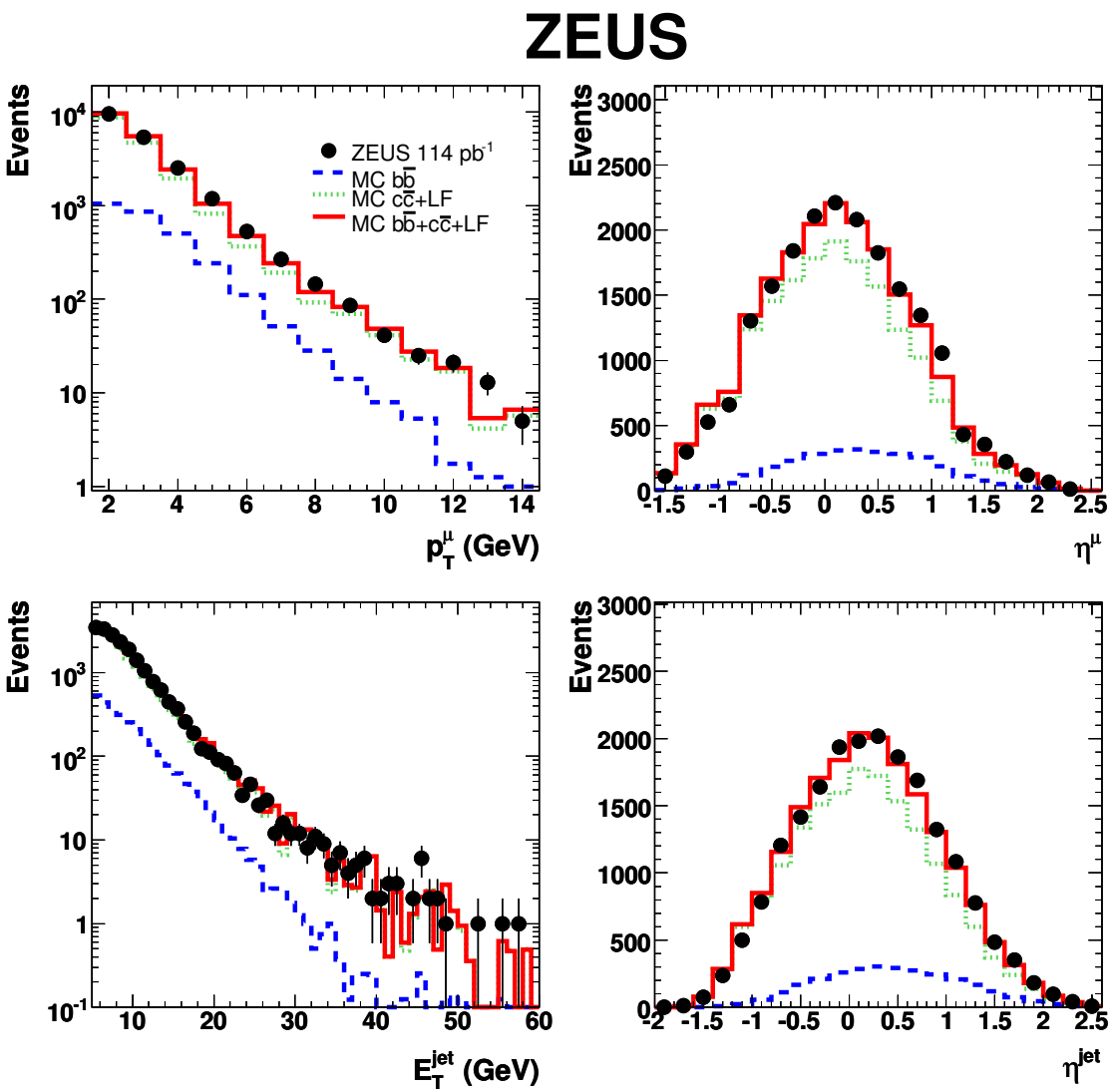
DESY-09-56 (April 2009)

Beauty production in DIS using decays into electrons at HERA

ZEUS-prel-10-010 (July 2010)

Backup

Beauty from decays into muons



Beauty from decays into muons

Monte Carlo details:

- ▶ RAPGAP 3

to simulate beauty and charm

  - HERACLES 4.6.1 for QED radiative effects
  - CTEQ5L PDFs
  - $m_b = 4.75\,\text{GeV}, m_c = 1.5\,\text{GeV}$

- ▶ ARIADNE

to simulate light flavour events

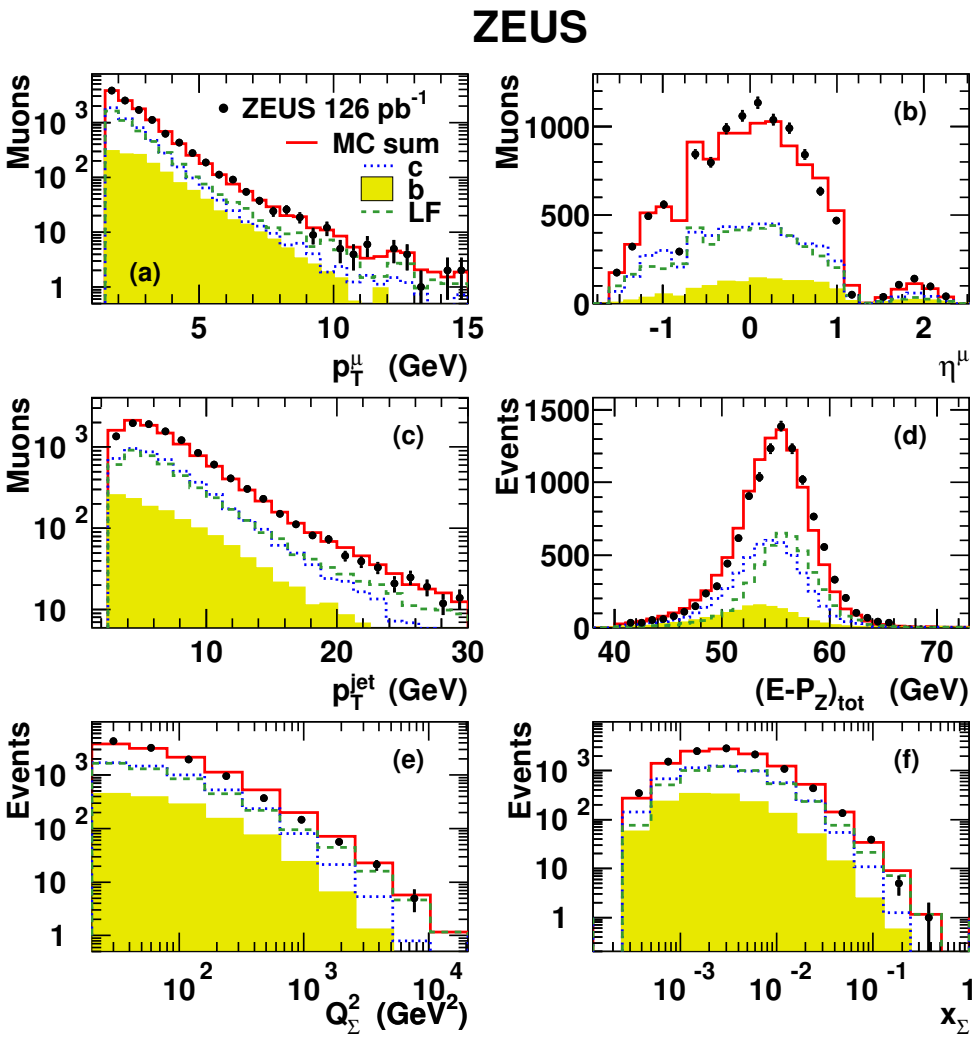
NLO calculation:

- ▶ HVQDIS

in the FFNS scheme

  - $\mu_R^2 = \mu_F^2 = 1/4(Q^2 + + p_T^2 + m_q^2)$
  - ZEUS-S PDFs
  - $m_b = 4.75\,\text{GeV}$
  - $\epsilon_b = 0.0035$

Charm and beauty from decays into muons



Charm and beauty from decays into muons

Monte Carlo details:

- ▶ RAPGAP 3.0

to simulate beauty and charm

  - HERACLES 4.6 for QED radiative effects
  - CTEQ5L PDFs
  - $m_b = 4.75\,\text{GeV}, m_c = 1.5\,\text{GeV}$

- ▶ DJANGOH 1.3

to simulate light flavour events

- ▶ CASCADE

to simulate J/Ψ production

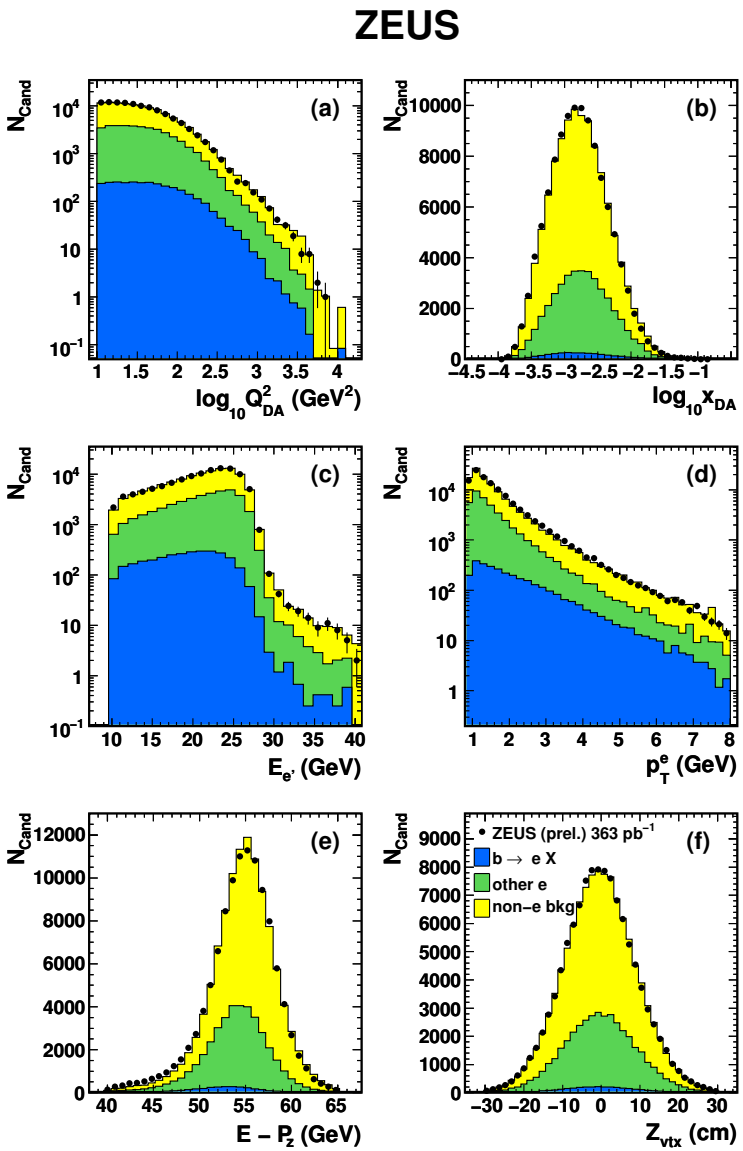
NLO calculation:

- ▶ HVQDIS

in the FFNS scheme

  - $\mu_R^2 = \mu_F^2 = Q^2 + 4m_q^2$
  - ZEUS-S PDFs
  - $m_c = 1.5\,\text{GeV}$, $m_b = 4.75\,\text{GeV}$
  - $\epsilon_c = 0.0055, \epsilon_b = 0.0035$
  - $\mathcal{B}(c \to \mu) = 0.096$, $\mathcal{B}(b \to \mu) = 0.209$

Beauty from decays into electrons



Beauty from decays into electrons

Monte Carlo details:

- RAPGAP 3.0

to simulate beauty and charm

  - HERACLES 4.6 for QED radiative effects
  - CTEQ5L PDFs
  - $m_b = 4.75\,\text{GeV}, m_c = 1.5\,\text{GeV}$

- DJANGOH 1.6

to simulate light flavour events

NLO calculation:

- HVQDIS

in the FFNS scheme

  - $\mu_R^2 = \mu_F^2 = Q^2 + 4m_q^2$
  - ZEUS-S PDFs
  - $m_b = 4.75\,\text{GeV}$
  - $\epsilon_b = 0.0035$