

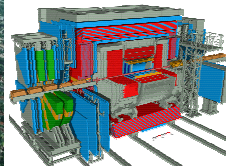
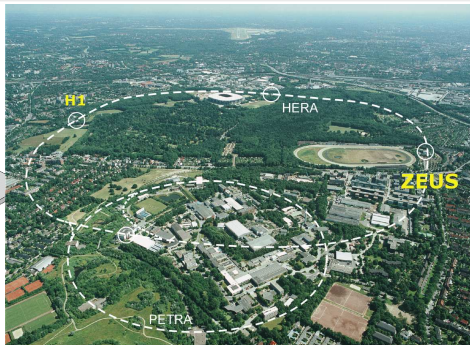
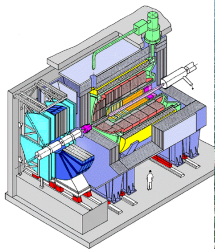
Charm and Beauty production from semileptonic decays at HERA

Markus Jüngst
for the ZEUS Collaboration

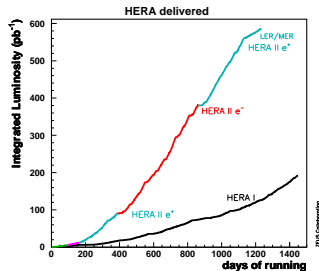


35th International Conference on High Energy Physics, Paris
22nd - 28th July 2010

H1 and ZEUS



- $27.5 \text{ GeV } e^\pm$
 $920 \text{ GeV } p \rightarrow \sqrt{s} = 318 \text{ GeV}$
 - HERA I: 1992-2000
 - HERA II: 2003-2007
- $\sim 0.5 \text{ fb}^{-1}$ 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

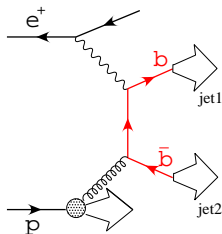
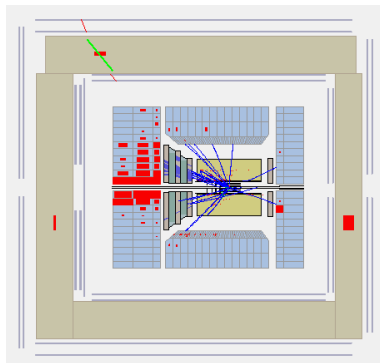
$$\sigma_{uds} : \sigma_c : \sigma_b \sim 2000 : 200 : 1 \quad (\text{HERA})$$

Kinematical regions:

$$\text{Photoproduction } (\gamma p) \rightarrow Q^2 \lesssim 1 \text{ GeV}^2$$

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

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**

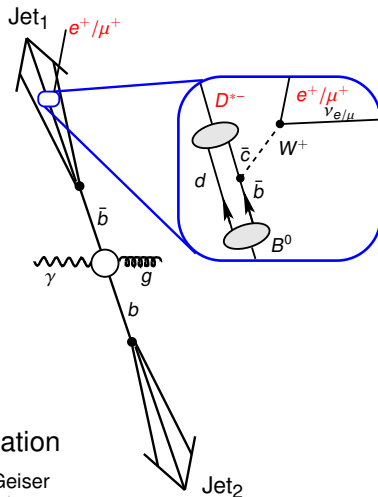
Measure impact parameter with respect to primary vertex (beamspot)

- **Meson identification**

$D^{*\pm}$ tagging ("Golden Decay")

- ▶ **In this talk focus on lepton identification**

→ for dilepton tagging see [Talk 864](#) by Achim Geiser



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

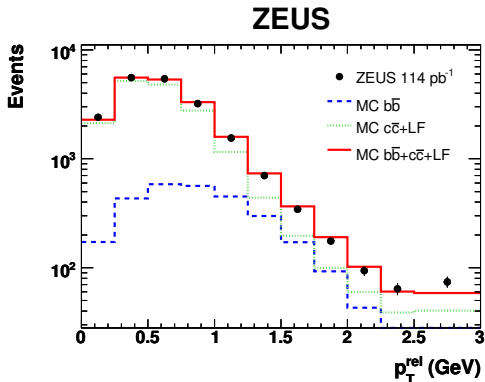
HERAI data:

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

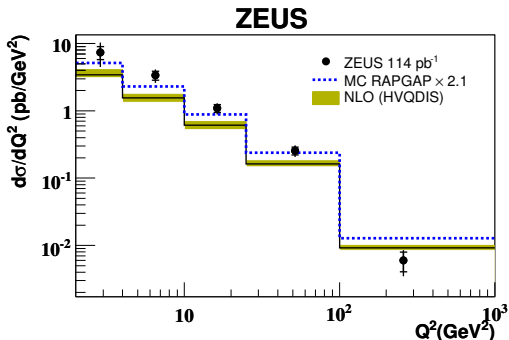
Kinematic region:

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

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



Beauty from decays into muons



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

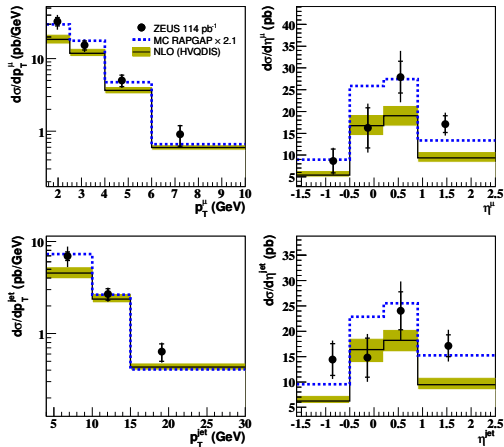
Scale parametrisation:

$$\mu^2 = 1/4(p_T^2 + m_b^2 + Q^2)$$

(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)

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

Method:

Simultaneous fit of

$$p_T^{rel}, \delta \text{ and } p_T^{miss||\mu}$$

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

-missing transverse momentum

-using parallel component to the muon direction

► additional variables provide sensitivity to charm

HERAII data:

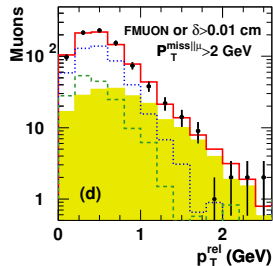
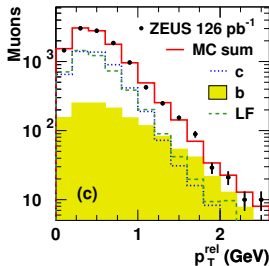
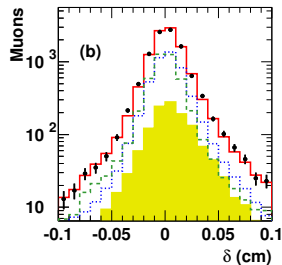
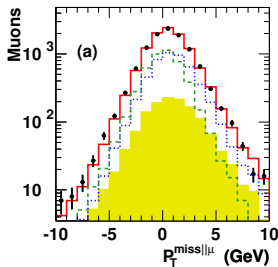
2005 ($\mathcal{L} \approx 126 \text{ pb}^{-1}$)

Kinematic region:

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

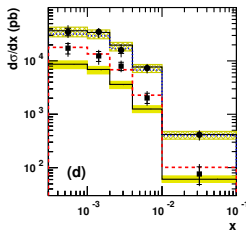
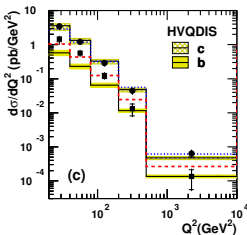
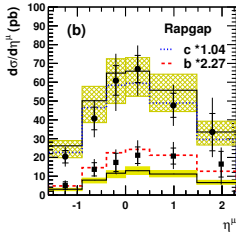
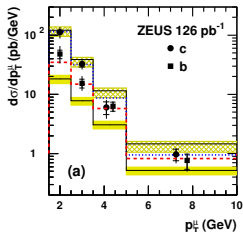
$$p_T^\mu > 1.5 \text{ GeV}, -1.6 < \eta^\mu < 2.3$$

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Charm and beauty cross sections

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

$$(\sigma_c^{NLO} = 184_{-40}^{+26} \text{ pb})$$

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

$$(\sigma_b^{NLO} = 33 \pm 5 \text{ pb})$$

Scale in HVQDIS:

$$\mu^2 = Q^2 + 4m_{b/c}^2$$

- ▶ 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

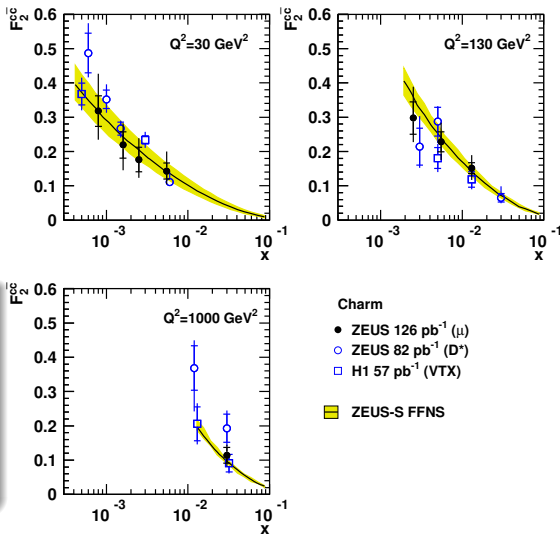
Charm contribution to the structure function - $F_2^{c\bar{c}}$

Unfold cross sections:

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

- ▶ 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

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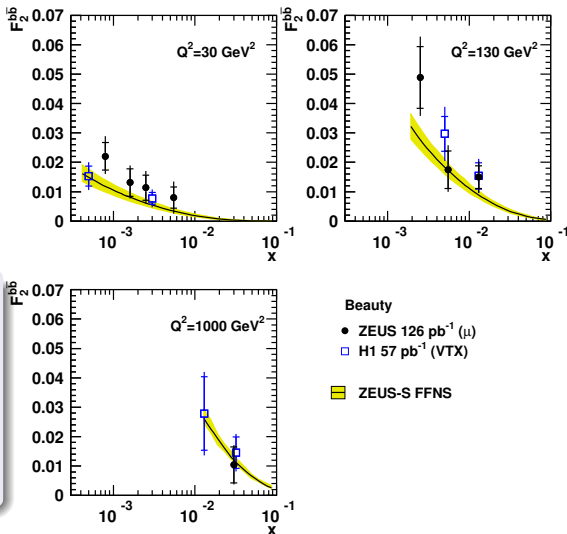
→ for details on $F_2^{c\bar{c}}$ results see [Talk 1159](#) by Massimo Corradi

Unfold cross sections:

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

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

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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

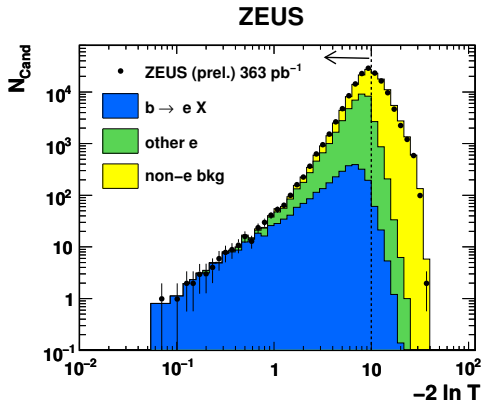
HERAII data:

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

Kinematic region:

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

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

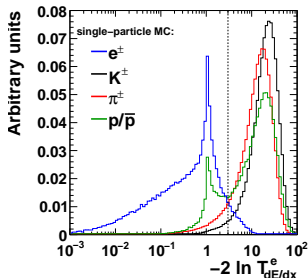


- Extract beauty cross sections fitting fractions of three contributions to data in the distribution of the hypothesis test, T

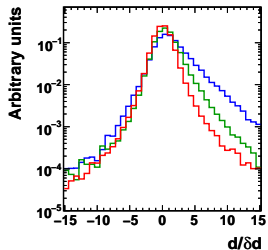
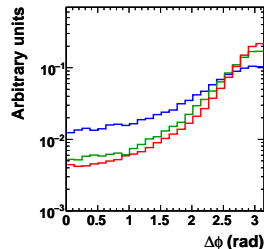
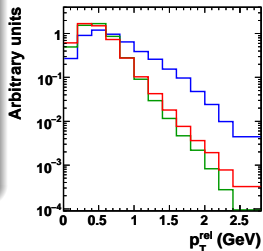
Input variables for likelihood test

- 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

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Control Plots

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

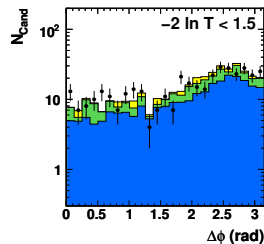
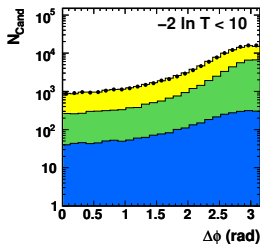
• ZEUS (prel.) 363 pb⁻¹

■ $b \rightarrow e X$

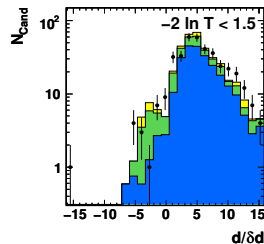
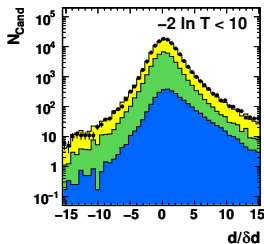
■ other e

■ non-e bkg

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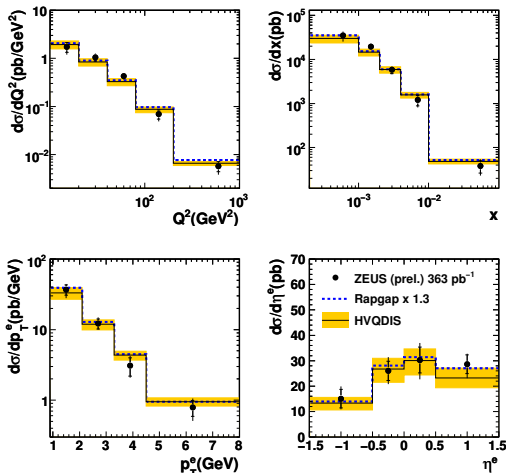


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Differential cross sections

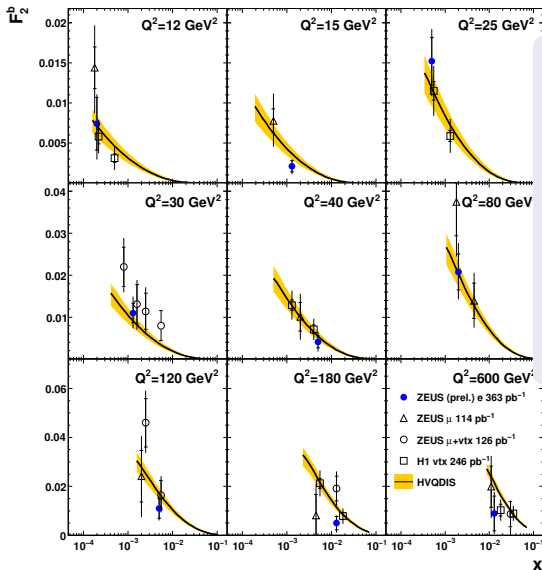
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- RAPGAP prediction scaled by a factor of 1.3
- HVQDIS prediction using $\mu^2 = Q^2 + 4m_b^2$

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

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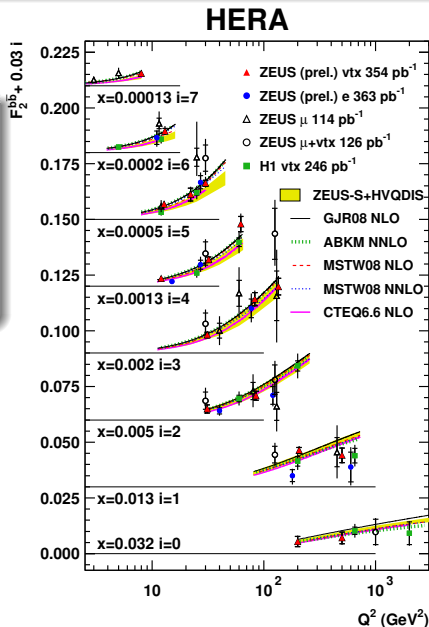


- Extract F_2^b from differential cross section in bins of x for different regions of Q^2
- Previous points corrected to the reference Q^2 values
- Measured points consistent with previous measurements and NLO QCD calculation
- Points at large Q^2 tend to be lower than previous results

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



- 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



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)

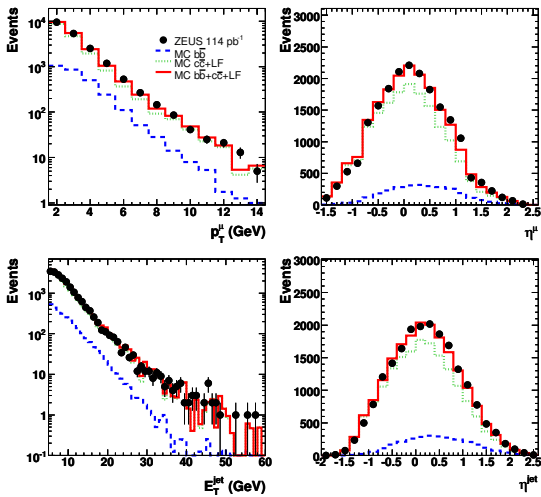


Beauty production in DIS using decays into electrons at HERA

ZEUS-prel-10-010 (July 2010)

Backup

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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:

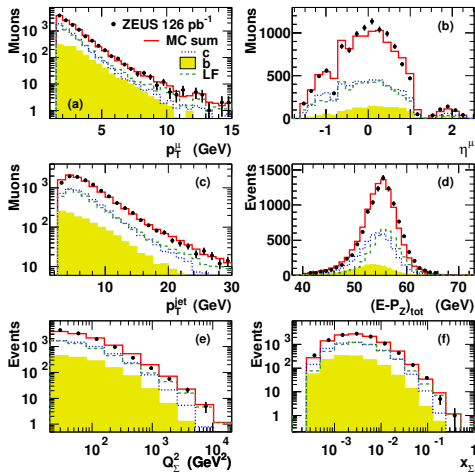
► HVQDIS

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

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Monte Carlo details:

▶ RAPGAP 3.0

to simulate beauty and charm

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

▶ DJANGO 1.3

to simulate light flavour events

▶ CASCADE

to simulate J/ψ production

NLO calculation:

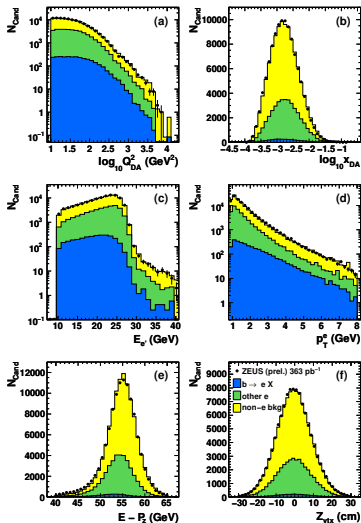
▶ HVQDIS

in the FFNS scheme

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

Beauty from decays into electrons

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Monte Carlo details:

▶ RAPGAP 3.0

to simulate beauty and charm

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

▶ DJANGO 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
- $m_b = 4.75 \text{ GeV}$
- $\epsilon_b = 0.0035$