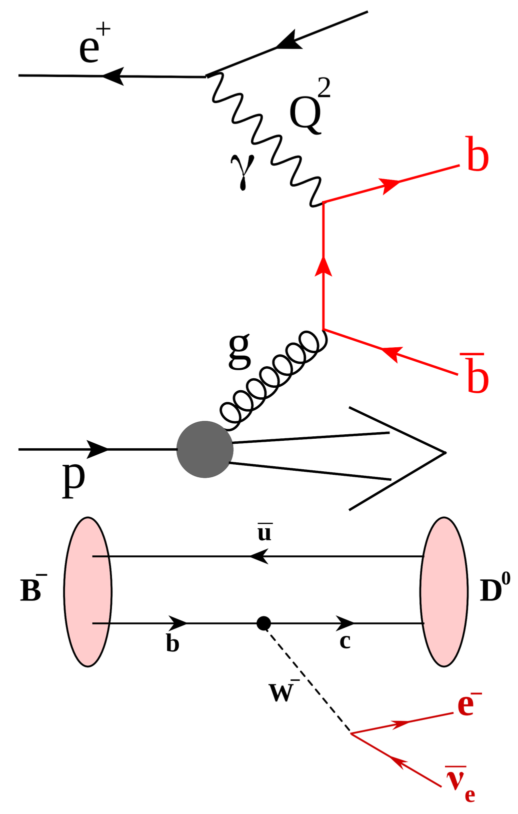
Beauty Production in Deep Inelastic Scattering at HERA using Decays into Electrons

ZEUS Collaboration

Motivation

- Beauty production in ep collisions at HERA provides a powerful tool for testing the proton structure and perturbative Quantum Chromodynamics (pQCD).
- The dominant production process is boson gluon fusion between the incoming virtual photon and a gluon in the proton
- b quark identification is possible using semileptonic decays of B hadrons

$$ep \to e'bX \to e'e_{sl}\nu_e X'$$



Event Selection

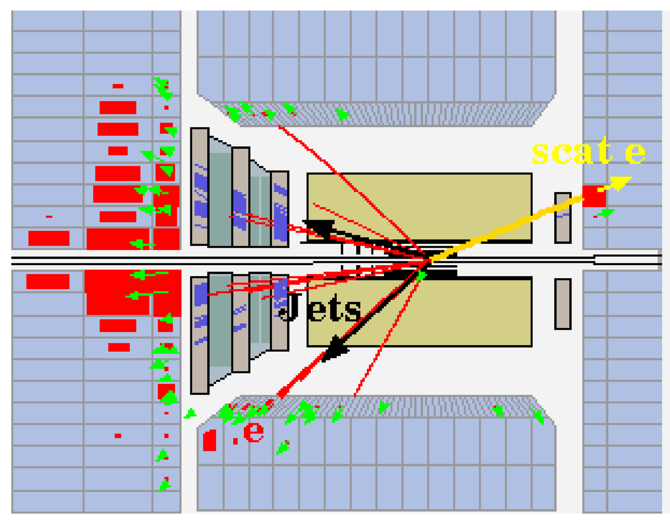
Data:

2004 − 2007($\mathcal{L} = 263\,\mathrm{pb}^{-1}$)

Monte Carlo:

RAPGAP 3.0, DJANGOH 1.6

- DIS events: $Q^2 \geq 10\,\mathrm{GeV}^2$, $0.05 < y < 0.7$
- Scattered electron in the calorimeter: $E' > 10\,\mathrm{GeV}$, $\mathcal{P}_e > 90\%$
- At least one jet in the event: $p_T^{jet} > 2.5\,\mathrm{GeV}$
- One candidate for semileptonic electron: $0.9 < p_T^e < 8\,\mathrm{GeV}$, $|\eta^e| < 1.5$



Discriminating Observables

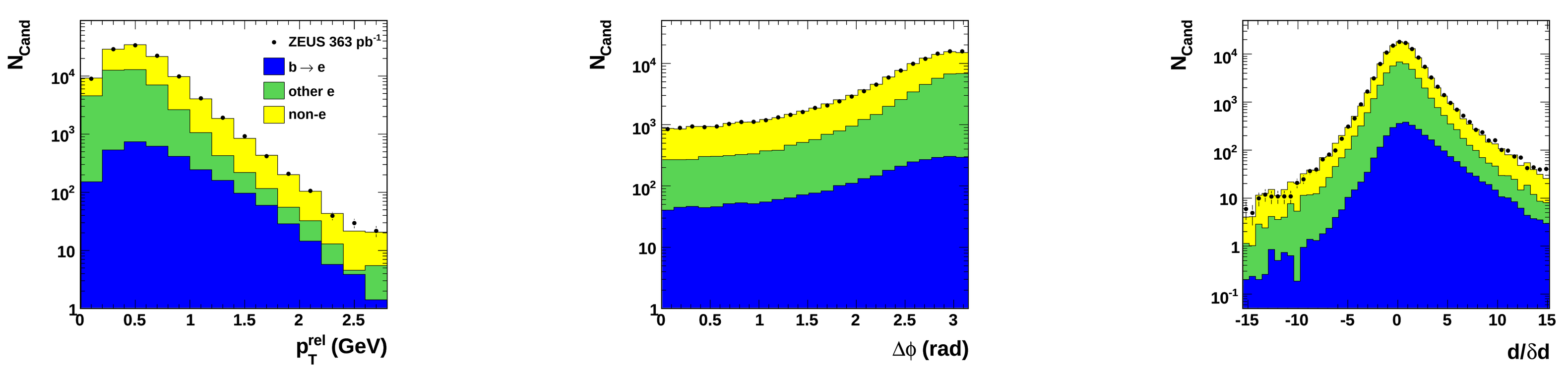
Several discriminating variables sensitive to electron identification as well as to semileptonic decay kinematics were used to separate beauty signal from background.

Particle Identification:

- **dE/dx :** average energy loss per unit length of the track measured in the central tracking detector (CTD)
- $\mathbf{E^{cal}/p^{trk}}$ **:** calorimeter energy divided by track momentum. The clustering and energy distribution affects this ratio such that the ratio is shifted to lower values for heavier particles with respect to pions.
- $\mathbf{d_{cell}}$ **:** the penetrating depth of the energy deposited in the calorimeter. Different shower shapes of hadrons and leptons result in different penetrating depths in the calorimeter.

Decay Identification:

- $\mathbf{p_T^{rel}}$ **:** relative transverse momentum of the e to the corresponding jet. This variable is sensitive to b decays, since electrons from b decays tend to have large p_T^{rel} due to large b mass.
- $\mathbf{\Delta\phi}$ **:** the difference of azimuthal angles of e and $\nu_e(p_T^{miss})$. This variable is sensitive to semileptonic decays of b and c hadrons due to presence of neutrino.
- $\mathbf{d/\delta d}$ **:** decay length of b hadron relative to vertex divided by its error. This variable is sensitive to the decay of b and c hadrons due to their long lifetimes.



Shown above are variables which are sensitive to decay identification. In all distributions a reasonable agreement between data and Monte Carlo is observed.

Signal Extraction

Different variables for particle and decay identification were combined into one discriminating test-function variable using a likelihood hypothesis

For a given hypothesis of particle, i, and source j, the likelihood, $\mathcal{L}_{ij}$, is

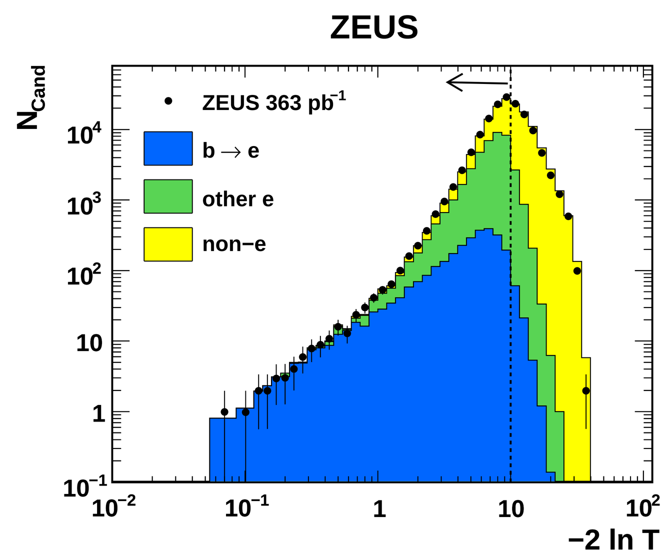
$$\mathcal{L}_{ij} = \prod_l \mathcal{P}_{ij}(d_l)\,,$$

where $\mathcal{P}_{ij}(d_l)$ is the probability to observe particle i from source j with value d_l of a discriminating variable. The particle hypotheses $i \in \{e, \pi, K, p\}$ and the sources, j, for electrons from semileptonic b decays, electrons from other sources and non-electrons were considered. The test function T_{ij} was defined

$$T_{ij} = \frac{\alpha_i \alpha'_j \mathcal{L}_{ij}}{\sum_{k,l} \alpha_k \alpha'_l \mathcal{L}_{kl}}$$

where α_i, α'_j are the prior probabilities taken from Monte Carlo

- Fit distribution of test function using $b \to e$ hypothesis
- Determine relative contributions of beauty, other electrons and non-electrons
- Use fit results to calculate cross sections



Theoretical Predictions

Next-to-leading order (NLO) QCD predictions were obtained from the HVQDIS program. This program is based on the fixed-flavor-number scheme, in which heavy flavors are generated dynamically in the hard subprocess.

Parameter set:

Parameter	Value	Variation
m_b	4.75GeV	[4.5, 5.0] GeV
$\mu_{R,F}$	$\mu_0 = \sqrt{Q^2 + 4m_b^2}$	$[0.5, 2.0]\mu_0$
ϵ_b	0.0035	[0.0015, 0.0055]
PDF	ZEUS-S-FF NLO	within exp. error
$\mathcal{B}(b \to e)$	0.217	*

*: uncertainty due to variation of $\mathcal{B}(b \to e)$ was negligible

Cross Sections

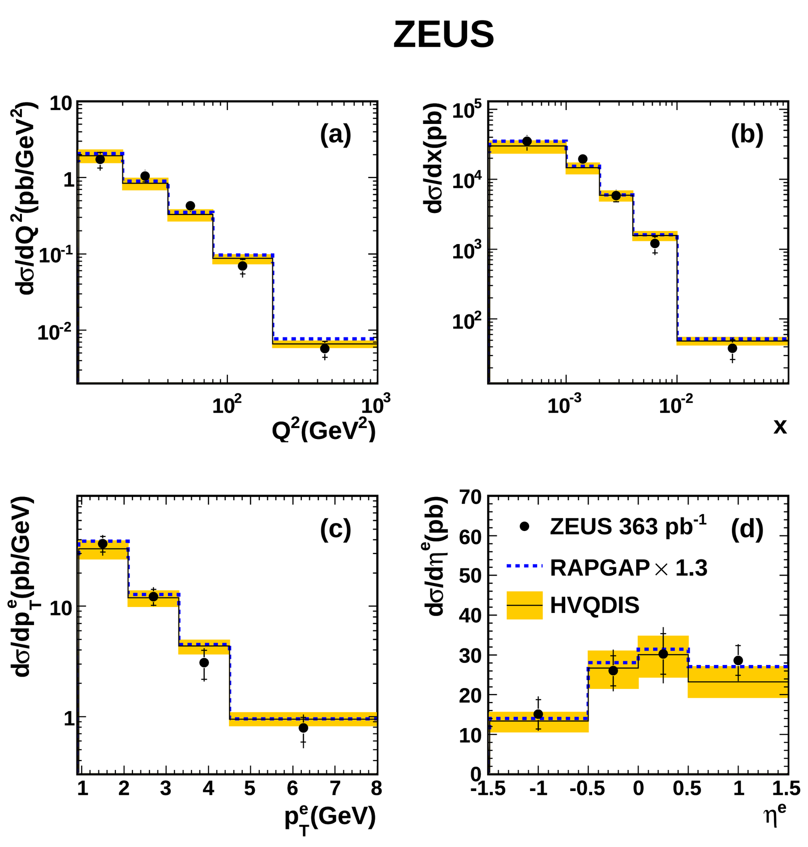
Visible cross-section:

$$\sigma_{b\to e} = (71.8 \pm 5.5\,(\mathrm{stat.})^{+5.3}_{-5.5}\,(\mathrm{syst.}))\,\mathrm{pb}$$

NLO prediction:

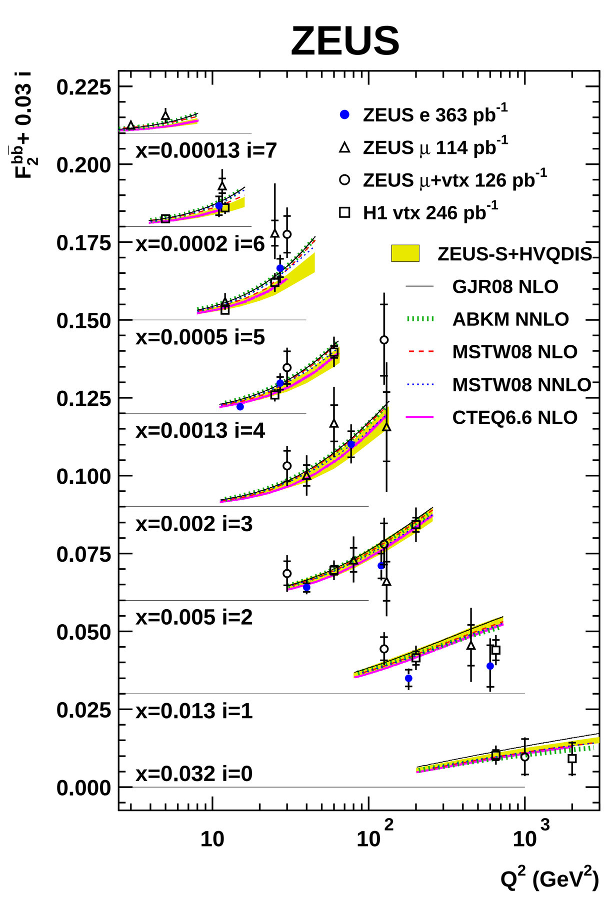
$$\sigma^{NLO}_{b\to e} = (67^{+10}_{-11})\,\mathrm{pb}$$

- Differential cross sections as a function of Q^2, x, p_T^e and η^e have been measured
- Shapes of cross-section distributions are well described by leading-order plus parton-shower Monte Carlo
- Good agreement with NLO QCD predictions is observed



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

- Double-differential cross sections measured in bins of x and Q^2, were used to extract $F_2^{b\bar{b}}$
- $F_2^{b\bar{b}}$ results from this measurement have been compared with the previous H1 and ZEUS measurements and also with several NLO and NNLO QCD predictions
- The different measurements are consistent with each other and the data are reasonably well described by the different theory predictions.



Conclusions

- Beauty production was measured in deep inelastic scattering at HERA using decays into electrons
- To extract beauty signal, variables sensitive to particle and decay identification were combined in a likelihood hypothesis
- Total visible cross section and differential cross sections were measured in bins of different variables
  → The predictions from the NLO QCD calculations and scaled RAPGAP cross sections describe the data well
- $F_2^{b\bar{b}}$ was extracted from double differential cross sections
  → Consistent picture of $F_2^{b\bar{b}}$ was observed using different analyses in DIS from the H1 and ZEUS collaborations
  → NLO and approx. NNLO QCD calculations give a reasonable description of data

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