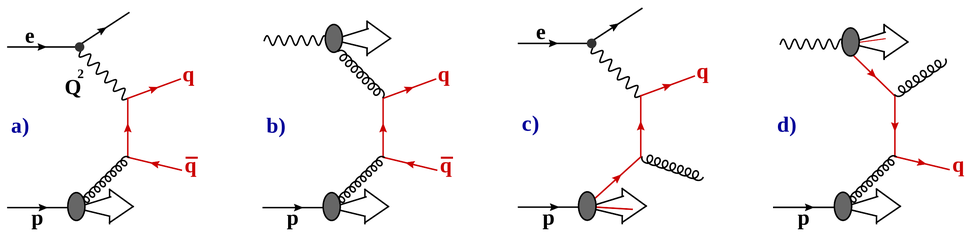
Measurement of Heavy-Quark Jet Photoproduction at HERA

ZEUS Collaboration

Heavy Flavor Production

The study of heavy flavor production in *ep* collisions at HERA provides an important test for perturbative Quantum Chromodynamics (pQCD)

The production mechanisms at leading order in photoproduction ($Q^2 < 1\,\mathrm{GeV}^2$) are

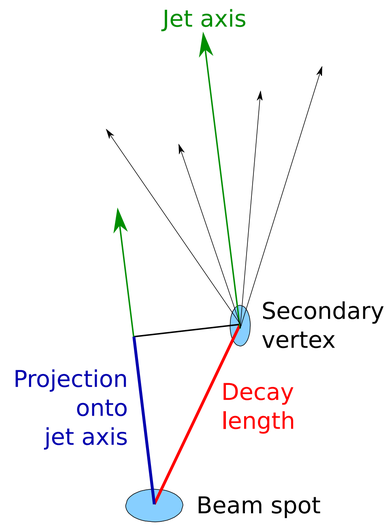


a) Direct BGF: in the so-called boson-gluon-fusion (BGF) process, a virtual photon emitted by incoming electron interacts with a gluon from the proton
b) Resolved BGF: the photon fluctuates into $q\bar{q}$ pairs and one of the quarks then participates in the hard interaction
c-d) Proton (photon) excitation: a single quark can originate directly from the proton or from the hadronic structure of the photon

Secondary Vertexing

The presence of the microvertex detector in the HERA II dataset made it possible to do a measurement using inclusive secondary vertexing, which allowed a large increase in statistics with respect to previous (exclusive) measurements.

- Tracks are associated to jets ($-1.6 \leq \eta^{\mathrm{jet}} < 1.4$), if $\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2} < 1$ and $p_{\mathrm{T}} > 0.5\,\mathrm{GeV}$
- A candidate secondary vertex is fitted if at least two tracks are matched to a jet
- The vertex fit is performed in 3D and provides the vertex position including its error matrix as well as the invariant mass, m_{vtx} of the charged tracks associated with the reconstructed vertex
- The decay length, d, is calculated in 2D (X-Y) plane as the distance between beam spot and secondary vertex and is further projected onto the jet axis



Event and Candidate Selection

Data:
2005($\mathcal{L} = 133\mathrm{pb}^{-1}$)

Monte Carlo:
PYTHIA 6.2

Dijet photoproduction (γp)

- $N_{\mathrm{jets}} \geq 2$
  ($E_{\mathrm{T}}^{\mathrm{jet}} > 7(6)\,\mathrm{GeV}, |\eta^{\mathrm{jet}}| < 2.5$)
- $0.2 < y_{\mathrm{JB}} < 0.8$
- no DIS electron candidate
- $|Z_{\mathrm{vtx}}| < 30\,\mathrm{cm}$

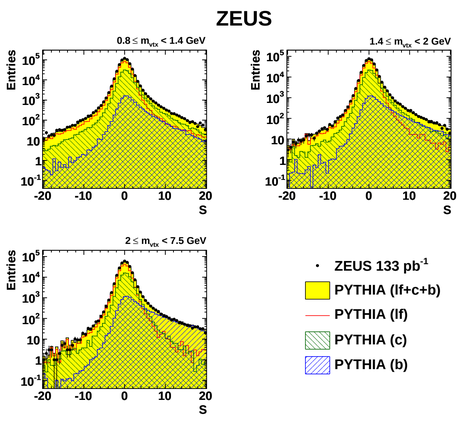
Secondary Vertex Candidates

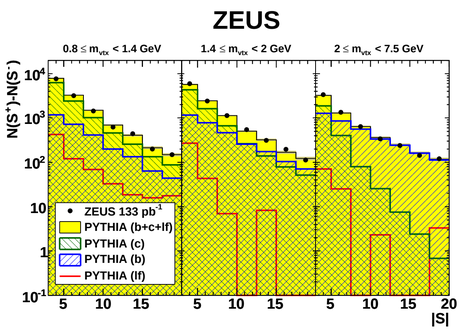
- $\chi^2/\mathrm{ndf} \leq 6$
- Distance from the interaction point $d_{XY} < 1\,\mathrm{cm}$ in X-Y
- Distance from the interaction point $d_Z < 30\,\mathrm{cm}$ in Z
- $0.8 \leq m_{\mathrm{vtx}} < 7.5\,\mathrm{GeV}$

Extraction of Heavy Quark Content

Discriminating Observables:

- Decay length significance $S = d/\delta d$ and m_{vtx}
- ▶ Divide S into three mass bins
- Beauty, charm and light flavor dominates in different mass bins and significance regions





Signal Extraction:

- Minimize light-flavor background by subtracting negative from positive significance and applying a significance cut of $|S| > 3$
- Fit beauty, charm and light flavor fractions to the data to determine the beauty and charm contributions
- Use unsubtracted distribution to constrain overall normalization

Systematic Uncertainties

Systematic uncertainties were evaluated by varying the analysis procedure and then repeating the fit to the subtracted significance distribution. The table summarizes the uncertainties on the total cross sections determined for each source.

Source	Uncertainty (%) Beauty	Charm
Trigger efficiency	$^{+4.2}_{-3.9}$	$^{+4.5}_{-3.2}$
Jet energy scale	± 0.6	± 4.3
Tracking/decay length	$^{+6.0}_{-1.0}$	$^{+1.2}_{-0.7}$
Jet reweighting	-5.6	-1.5
Charm mesons	-1.8	$^{+0.6}_{-2.2}$
Fragmentation	$^{+1.8}_{-2.1}$	$^{+1.2}_{-1.3}$
Luminosity	± 1.8	± 1.8
Total	$^{+7.8}_{-7.7}$	$^{+6.7}_{-7.0}$

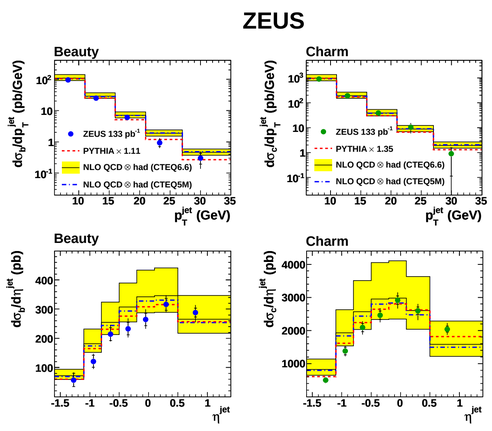
No single dominant contribution is found

Theory Predictions and Results

- FMNR program is used to obtain the next-to-leading order (NLO) QCD predictions
  - $m_b = 4.75\,\mathrm{GeV}, m_c = 1.5\,\mathrm{GeV}$
  - $\mu_F = \mu_R = 0.5\sqrt{(m_{b(c)}^2 + p_{\mathrm{T}}^2)}$
  - Proton PDFs: CTEQ6.6 (CTEQ5M); photon PDFs: GRV-G HO
- Vary masses and scales to get theory uncertainty

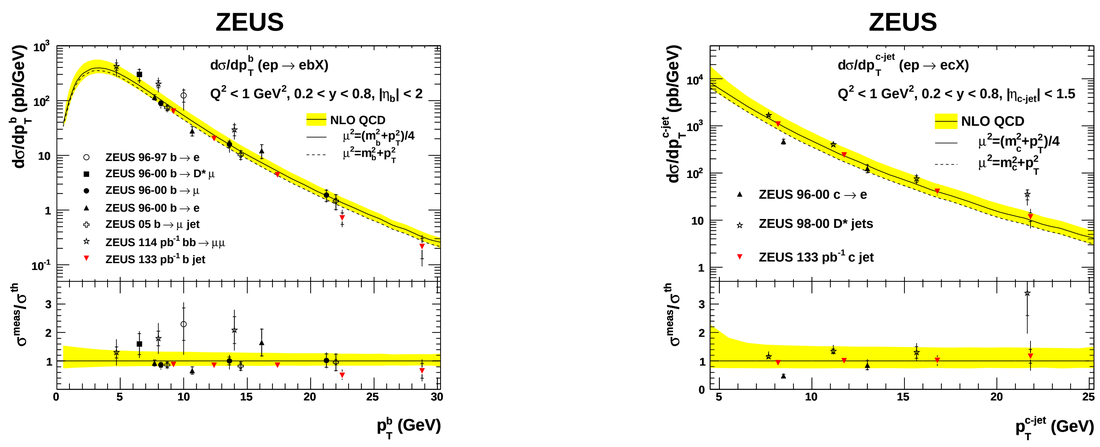
Results:

- Differential cross sections as a function of $p_{\mathrm{T}}^{\mathrm{jet}}$ and η^{jet} for beauty (left) and charm (right) have been measured
- Shapes of cross-section distributions are well described by scaled PYTHIA
- Good agreement with NLO QCD predictions is observed



Comparison with Other Analyses

Cross sections as a function of transverse momentum of the b quark and of the c-quark jet have been determined and compared with previous ZEUS measurements using different complementary methods (inclusive, semileptonic, double tag).



The measurements agree with each other and give a consistent picture of heavy-quark photoproduction over a wide kinematic range

Conclusions

- Beauty and charm production was measured in dijet photoproduction using inclusive secondary vertexing
- Mirrored decay-length significance and mass of secondary vertex were used to extract heavy quark content
- Total visible cross section and differential cross sections as a function of $p_{\mathrm{T}}^{\mathrm{jet}}$ and η^{jet} were determined
- The predictions from the NLO QCD calculations and scaled PYTHIA cross sections describe the data well
- Results are consistent with other ZEUS and H1 measurements
- Charm cross sections are more precise than previous measurements made by the ZEUS collaboration and have similar accuracy to measurements made by H1
- Beauty cross sections represent the most precise measurements of b-quark photoproduction made at HERA

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