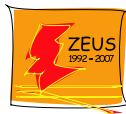


# Heavy Flavour photoproduction at HERA

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*Physikalisches Institut der Universität Bonn*

**The 2009 Europhysics Conference  
on High Energy Physics  
Cracow, Poland, 17<sup>th</sup> July 2009**



- Introduction
- Charm Production
- Beauty Production



Heavy Flavour production provides multiple hard scales:

- large mass  $m_b/m_c$
- high momenta  $p_T$

→ Should ensure reliable predictions?

→ **Test of perturbative QCD**

**Monte Carlo programs** (leading order + parton shower)

- Pythia

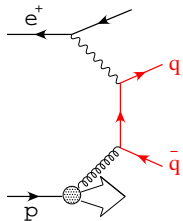
**NLO Calculations**

- General Mass Variable Flavour Number Scheme (GMVFNS)
- Fixed Flavour Number scheme (FFNS → FMNR)

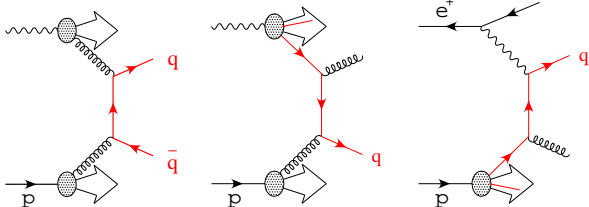
# Heavy Flavour Production Mechanism

Dominant process: **Boson-gluon fusion**

"direct"



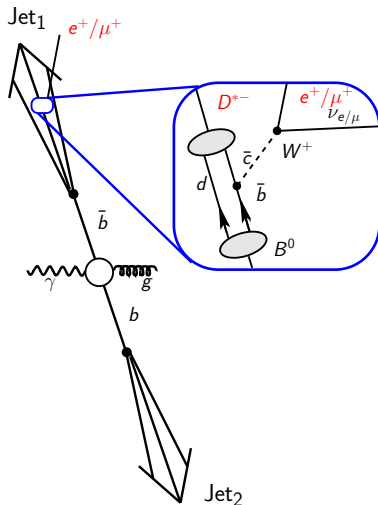
"resolved" (including flavour excitation)



# Heavy Flavour Tagging

Different experimental techniques to use (combine) for heavy flavour tagging:

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



# Part I

# Charm Production

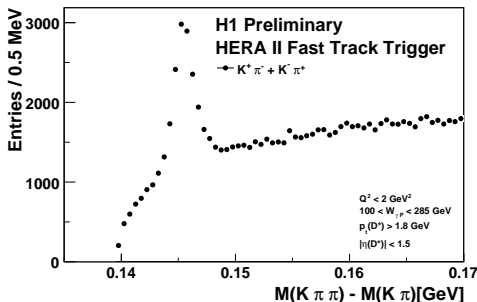
Charm quark tagged by a D\* meson decaying in the **golden channel**

$$D^{*\pm} \rightarrow D^0 \pi_{\text{slow}}^{\pm} \rightarrow K^{\mp} \pi^{\pm} \pi_{\text{slow}}^{\pm}$$

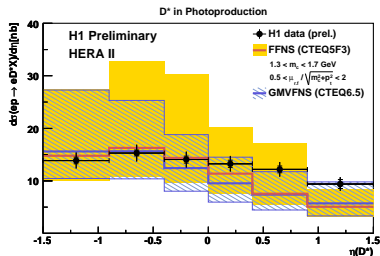
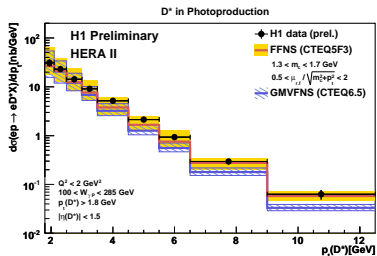
**Data:**  $\mathcal{L} = 93 \text{ pb}^{-1}$

## Kinematic range

- $Q^2 < 2 \text{ GeV}^2$
- $100 < W_{\gamma p} < 285 \text{ GeV}$
- $p_t(D^*) > 1.8 \text{ GeV}$
- $|\eta(D^*)| < 1.5$



$\Delta M$  distribution for determination of number of D\* mesons

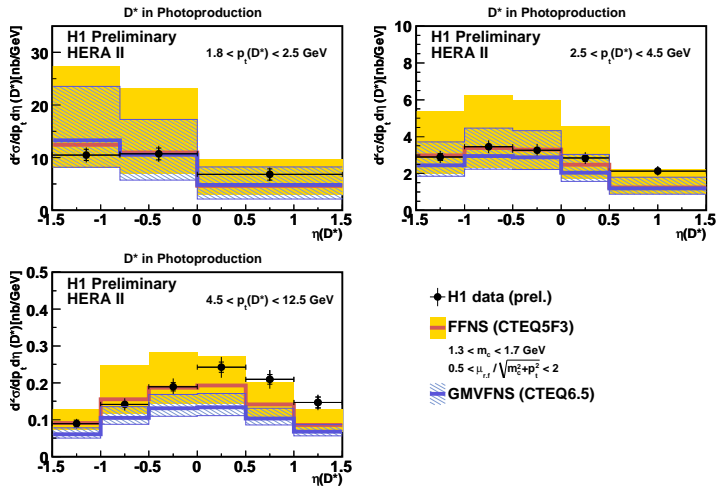


Data compared to NLO predictions:

- ▶ **FFNS**: Fixed Flavour Number Scheme (FMNR)
- ▶ **GMVFS**: General Mass Variable Flavour Number Scheme

→ Data in reasonable agreement with both predictions

→ GMVFS too steep in  $p_t$ , slightly different shape in  $\eta$



Good agreement between Data and NLO predictions  
 except for high  $p_t$  / high  $\eta$  region

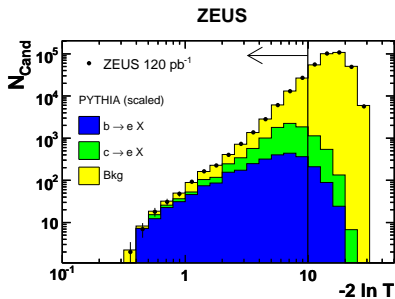
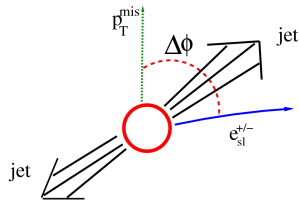


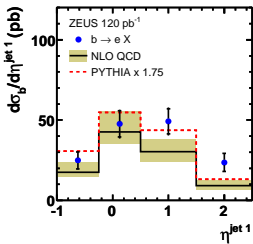
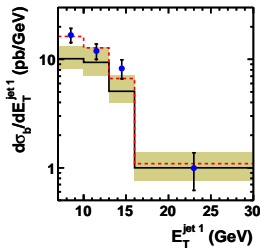
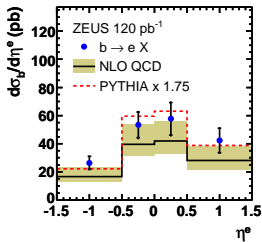
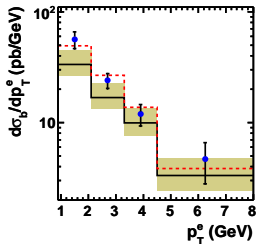
## Part II

# Beauty Production

**Data:**  $\mathcal{L} = 120 \text{ pb}^{-1}$

- Dijet events with  $E_T > 7(6) \text{ GeV}$
- Semileptonic decays to electrons
- Combine several discriminating variables in likelihood test function:
  - ▶ Electron identification:  $dE/dx$ , EMC fraction,  $E/p$
  - ▶ Decay identification:  $\Delta\phi$  and  $p_t^{\text{rel}}$





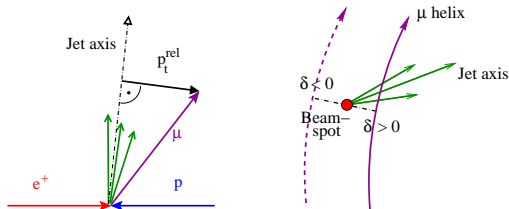
Differential cross-sections in  $p_T^e$ ,  $\eta^e$ ,  $E_T^{jet1}$ ,  $\eta^{jet1}$

- NLO prediction (FMNR) consistent with Data
- Scaled MC distributions describe the shape well

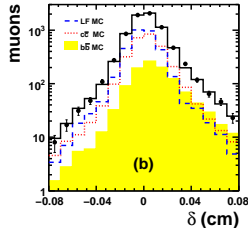
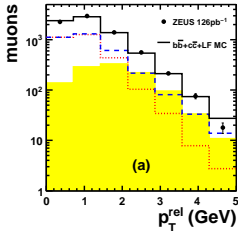
arXiv:0805.4390v3

**Data:**  $\mathcal{L} = 124 \text{ pb}^{-1}$

- Dijet PhP events with  $p_T^{\text{jet}} > 7(6) \text{ GeV}$
- Semileptonic decays to muons
  - ▶  $-1.6 < \eta^\mu < 2.3$
  - ▶  $p_t^\mu > 2.5(1.5) \text{ GeV}$
- Simultaneous fit of impact parameter and  $p_t^{\text{rel}}$



ZEUS



[arXiv:0901.2226v2](https://arxiv.org/abs/0901.2226v2)

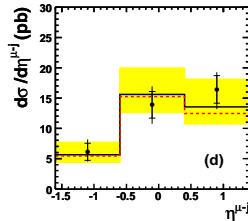
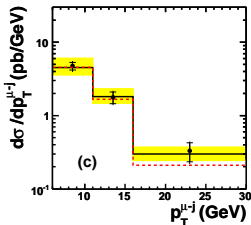
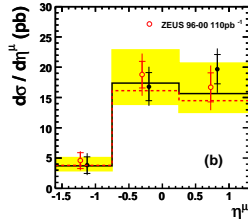
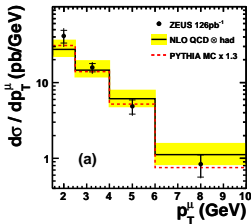
## Total cross-section

$$\sigma^{vis} = 38.6 \text{ pb} \pm 3.5 \text{ (stat.) pb} + 4.6 \text{ (syst.) pb} - 4.9 \text{ (syst.) pb}$$

$$\sigma^{NLO} = 37.0^{+11.9}_{-7.5} \text{ pb}$$

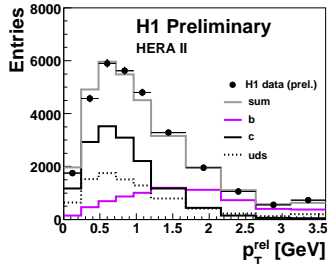
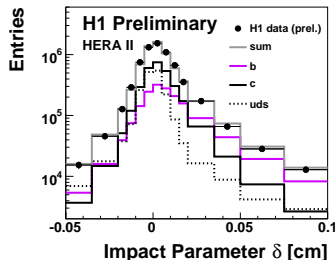
- Previous analysis (ZEUS 96-00 110 pb<sup>-1</sup>) with external constraint on charm!
- ZEUS 126 pb<sup>-1</sup> without constraint

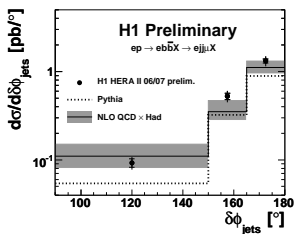
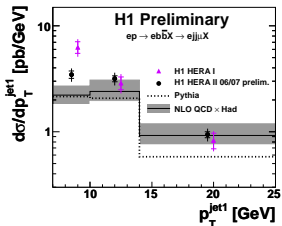
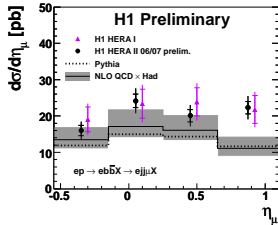
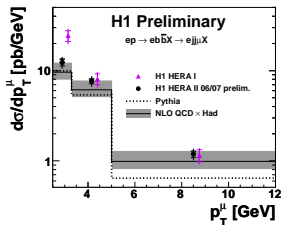
ZEUS



**Data:**  $\mathcal{L} = 170 \text{ pb}^{-1}$

- Dijet PhP events with  $p_T^{\text{jet}} > 7(6) \text{ GeV}$
- Semileptonic decays to muons
  - ▶  $-0.55 < \eta^\mu < 1.1$
  - ▶  $p_t^\mu > 2.5 \text{ GeV}$
- Simultaneous fit of impact parameter and  $p_t^{\text{rel}}$

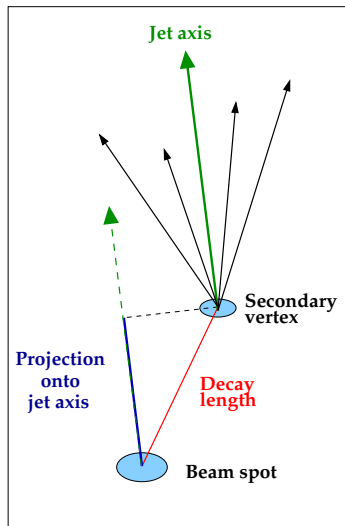




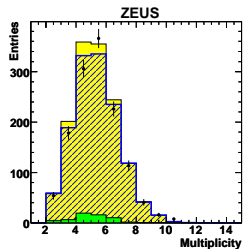
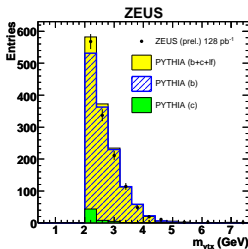
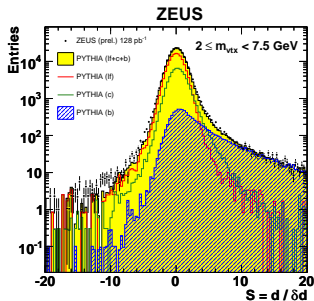
- Good agreement between Data and NLO predictions
- Shapes well-described by Pythia MC
- New measurement closer to NLO prediction than previous HERA I result

**Data:**  $\mathcal{L} = 128 \text{ pb}^{-1}$

- Dijet PhP events with  $p_T^{\text{jet}} > 7(6) \text{ GeV}$
- No specific B decay channel  
→ Inclusive measurement
- Secondary vertexing:
  - ▶ Associate tracks to jets and fit secondary vertices
  - ▶ Calculate 2D decay length as distance between beam spot and secondary vertex in x-y (projected onto jet axis)

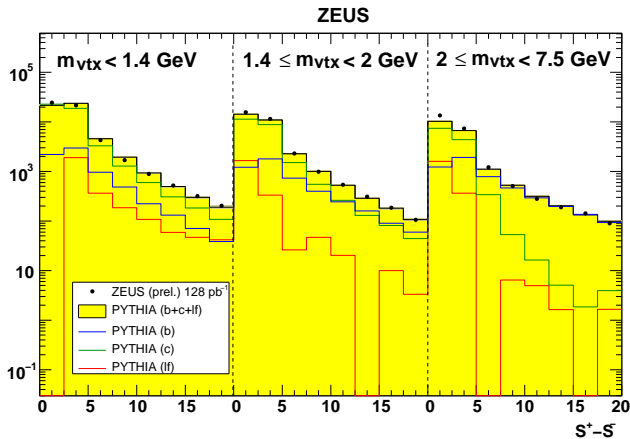




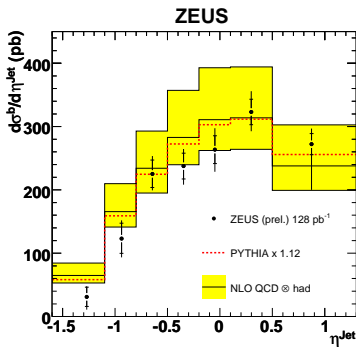
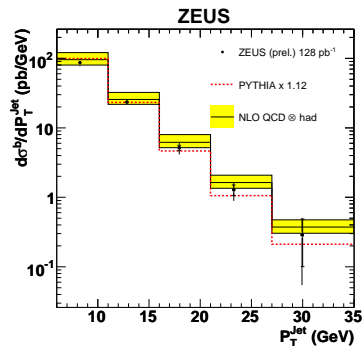


- Decay length significance  
 $S = DL / \delta DL$
- For large  $m_{vtx}$  dominated by **beauty**  
→ With cuts on  $S$  and  $m_{vtx}$  an almost **pure beauty sample** can be obtained!

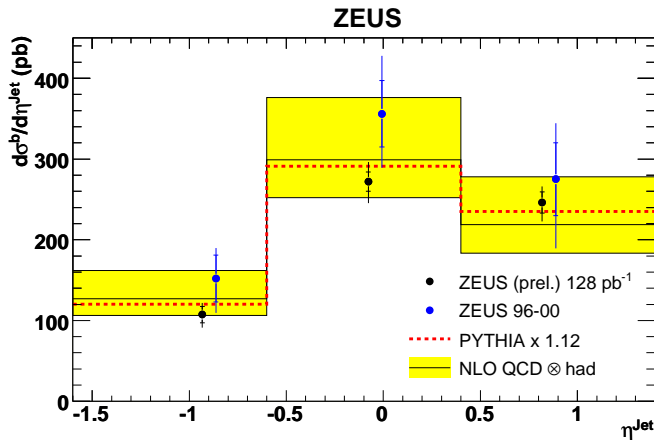
- Beauty-enriched  $m_{vtx}$  and multiplicity distributions
- Very good agreement between Data and MC



Fit mirrored and subtracted decay length significance ( $S^+ - S^-$ )  
in bins of the secondary vertex mass  $m_{\text{vtx}}$

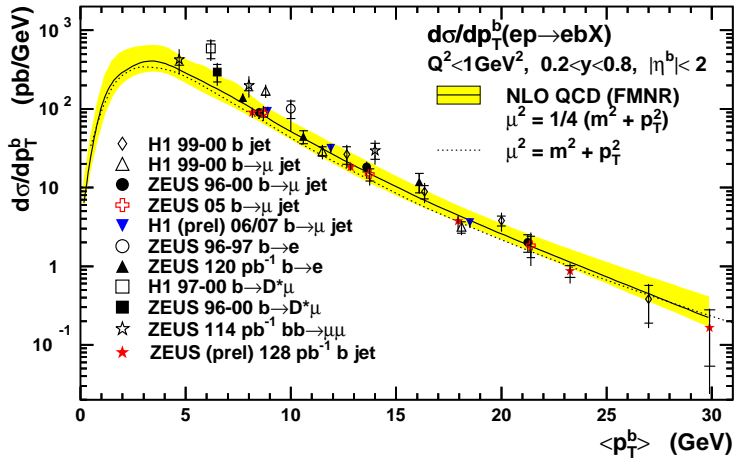


- Differential cross-sections in  $P_T^{\text{Jet}}$  and  $\eta^{\text{Jet}}$
- Good agreement between Data and Pythia / NLO predictions (FMNR)



- New measurement in good agreement with previous HERA I result
- Statistical error substantially reduced

## HERA



- Latest results of heavy flavour photoproduction at HERA presented
  - HERA II data provide large increase in statistics
  - New methods used and improved (lifetime tagging)
  - First ZEUS analysis with inclusive secondary vertexing presented
- 
- Various H1 and ZEUS measurements using different experimental techniques in very good agreement
  - General agreement with NLO QCD predictions

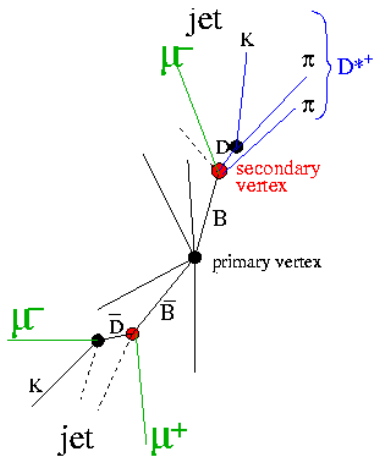
# BACKUP

**Data:** Hera I ( $\mathcal{L} = 114 \text{ pb}^{-1}$ )  
**LO:** Pythia + Rapgap  
**NLO:** FMNR

- PhP and DIS
- Two identified muons in the final state
- Extract b fraction from difference between unlike-sign and like-sign distributions

#### Advantages:

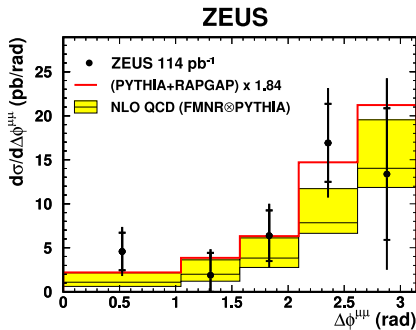
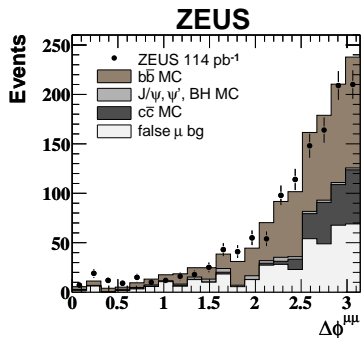
- No jet requirements
- Low  $p_t^\mu$  thresholds
- Measure bb correlations





## Method

- Sample split into different charge combinations
- 2 muons from same b quark
  - Unlike-sign muon pair
- 2 muons from different b quarks
  - Like-sign or unlike-sign muon pair
- Use difference between unlike-sign and like-sign distributions to extract beauty contribution
  - Almost free from false-muon background
  - Other background sources: Charm, heavy vector mesons, Bethe-Heitler



- $\Delta\phi^{\mu\mu}$  = angle between muons from different quarks
- Correlations expected to show higher order effects  
→ Good description, but large uncertainties