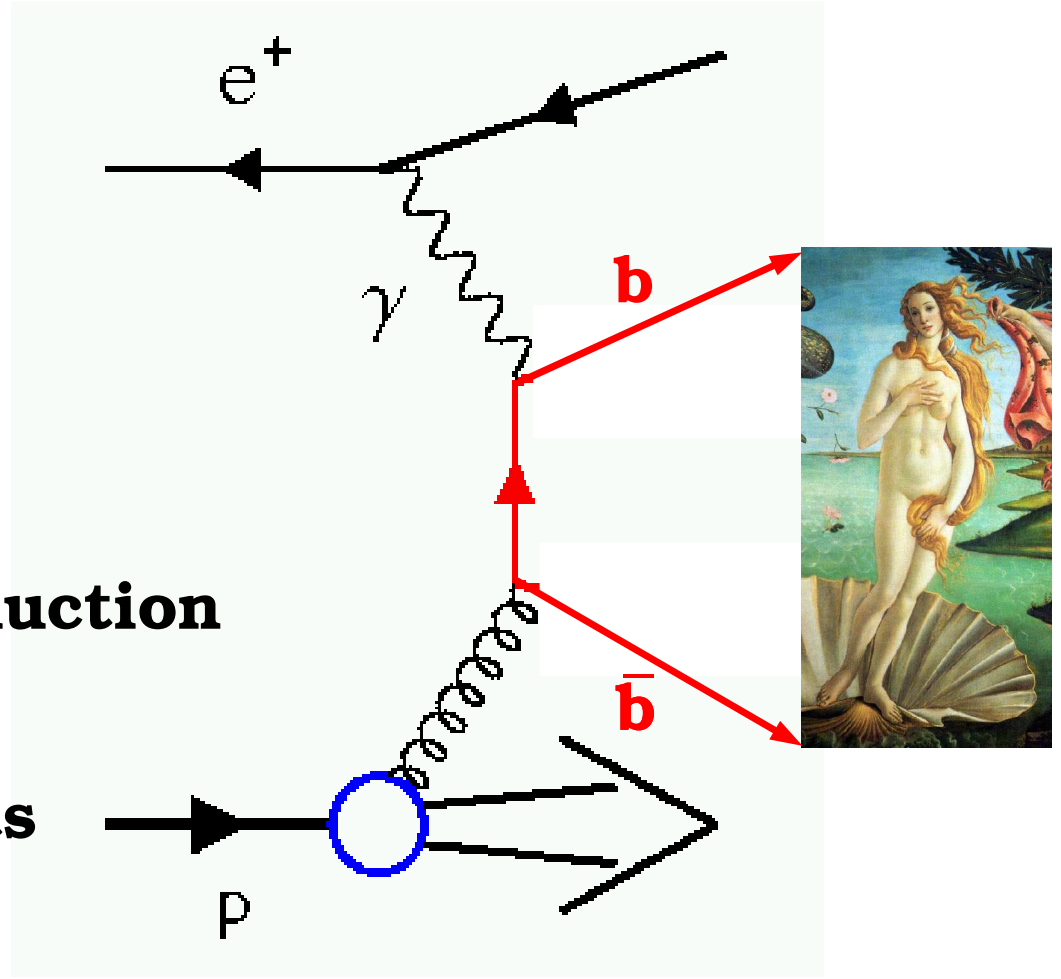
Open Beauty Production at HERA

- Motivation
- Theory Predictions
- Results
  - Beauty in Photoproduction
  - Beauty in DIS
  - Double-tagged Events
- Summary



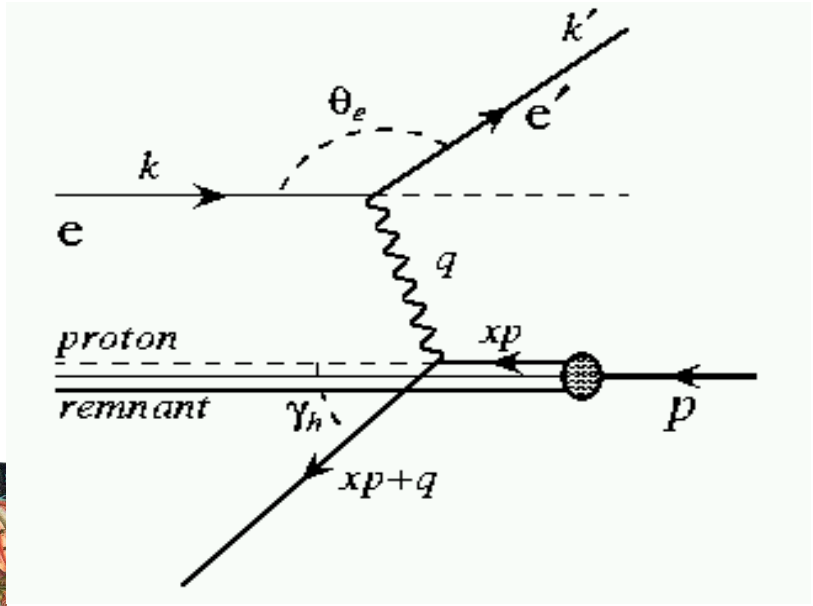
On Behalf of H1 and ZEUS Collaborations

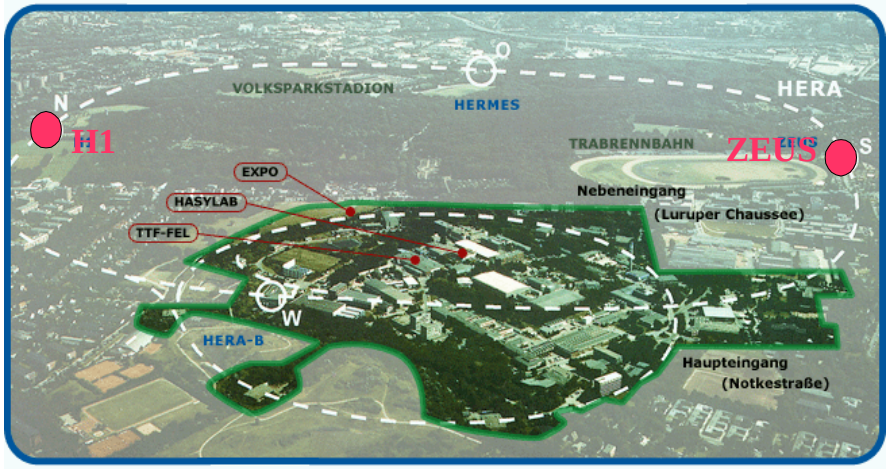
Short Introduction to HERA

- **HERA collides 27.5 GeV e± with 920 (820) GeV protons**

  $\sqrt{s}$ = 320 (300) GeV

- **Example: Neutral Current Exchange**





- **photon virtuality: Q^2**

  Deep Inelastic Scattering (DIS):

  $Q^2 \gtrsim 1\ \mathrm{GeV}^2$

  Photoproduction (PhP):

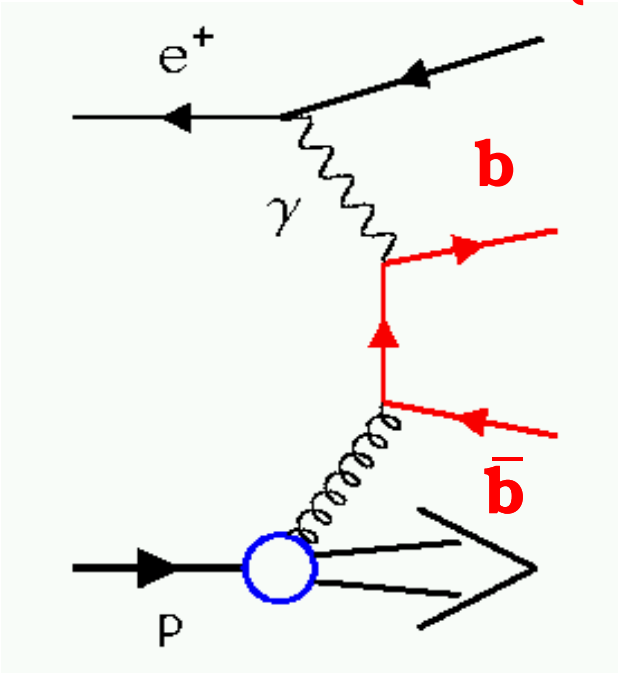
  $Q^2 \approx 0\ \mathrm{GeV}^2$

- **Bjorken *x***

Beauty Physics Motivation

- **Heavy quark production:**
  - test of QCD
  - probing photon and proton structure
- **Heavy quark masses:**
  - hard scale for calculations
  - testing pQCD
  - multi-scale problem
- **Studying non-perturbative issues such as fragmentation**

Boson Gluon Fusion (BGF)



- **Beauty production in $p\bar{p}$ and $\gamma\gamma$ above predictions**

Now let's look at ep data

pQCD Calculations & Monte Carlos

NLO Calculations on the market:

- **Fixed order (massive) scheme**
  - massive b quark produced via BGF
  - u,d,s,c – active flavours in p and γ
  - applicable for $p_T \sim m_b$
- **Resummed (massless) scheme**
  - massless heavy quarks
  - u,d,s,c,b active flavours in p and γ
  - applicable for $p_T \gg m_b$
- **Matched Calculations (FONLL)**

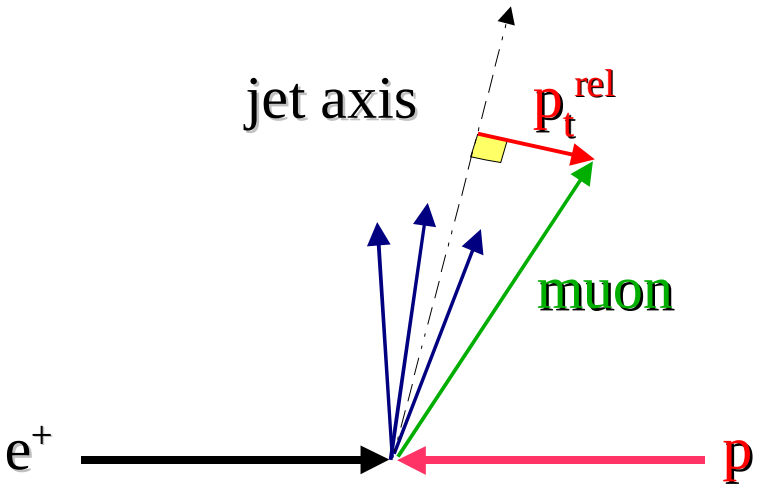
→ **FMNR (PhP)**

→ **HVQDIS (DIS)**

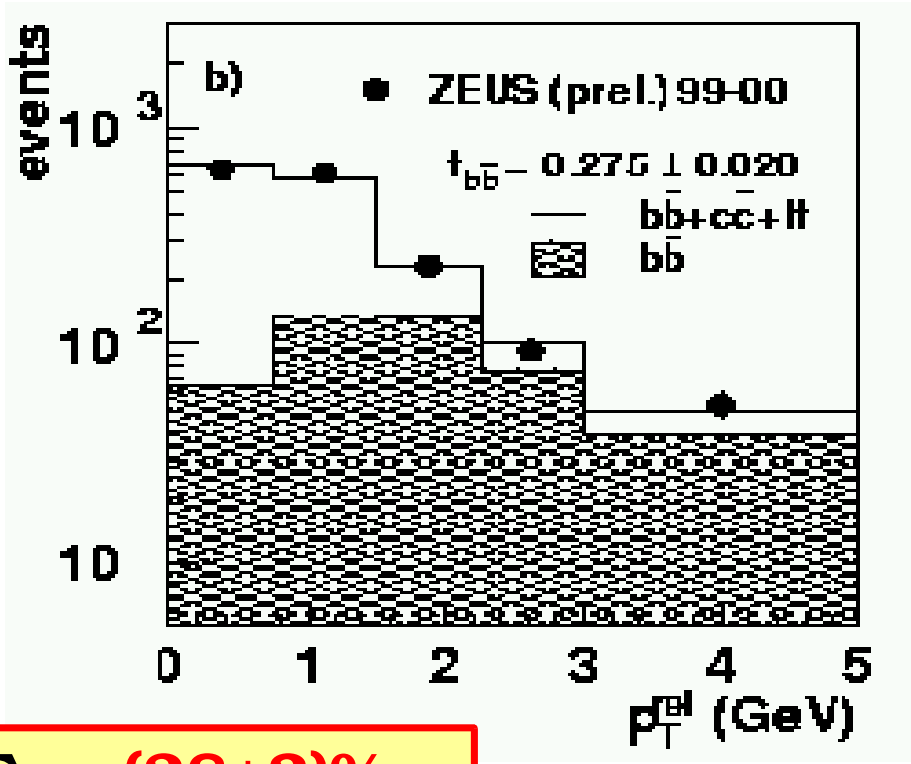
- **Parton shower with DGLAP evolution MC models:**
  - **AROMA, RAPGAP, PYTHIA, HERWIG**
- **Parton shower with CCFM evolution MC models:**
  - **CASCADE**

Beauty in Photoproduction

- p_T^{rel} method to tag beauty **in semi-leptonic b decays**



- p_T^{rel} fit to data of different flavour MC



$F_b = (28 \pm 3)\%$

Beauty in Photoproduction

ZEUS: 96/00 ~ 98 pb-1

σ (ep $\rightarrow$ bb X$\rightarrow$ Jet Jet X)

- μ **extrapolated using PYTHIA**

$Q^2 < 1$ GeV^2, $0.2<y<0.8$
At least 2 jets in the Lab frame:
$p_{t,Jet1(Jet2)} > 7\ (6)$ GeV, $|\eta_{Jet}| < 2.5$
At least 1 muon with:
$p_{T,\mu} > 2.5$ GeV, $-1.6 < \eta_{\mu} < 2.3$

Total visible dijet cross section:

σ (ep $\rightarrow$ bb $\rightarrow$ Jet Jet X) =

733 $\pm$ 61 (stat.) $\pm$ 104 (syst.) pb

NLO QCD (FMNR) = 381 +117 -78 pb

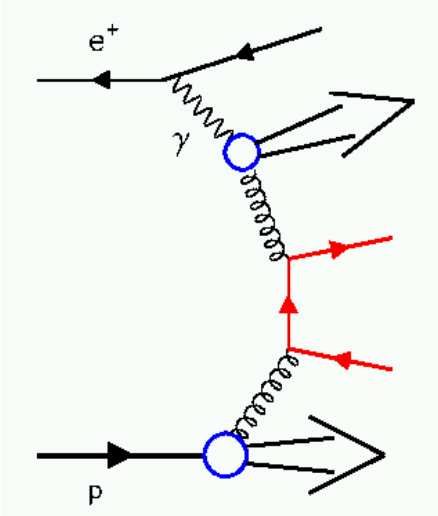
pQCD below data

Beauty in Photoproduction

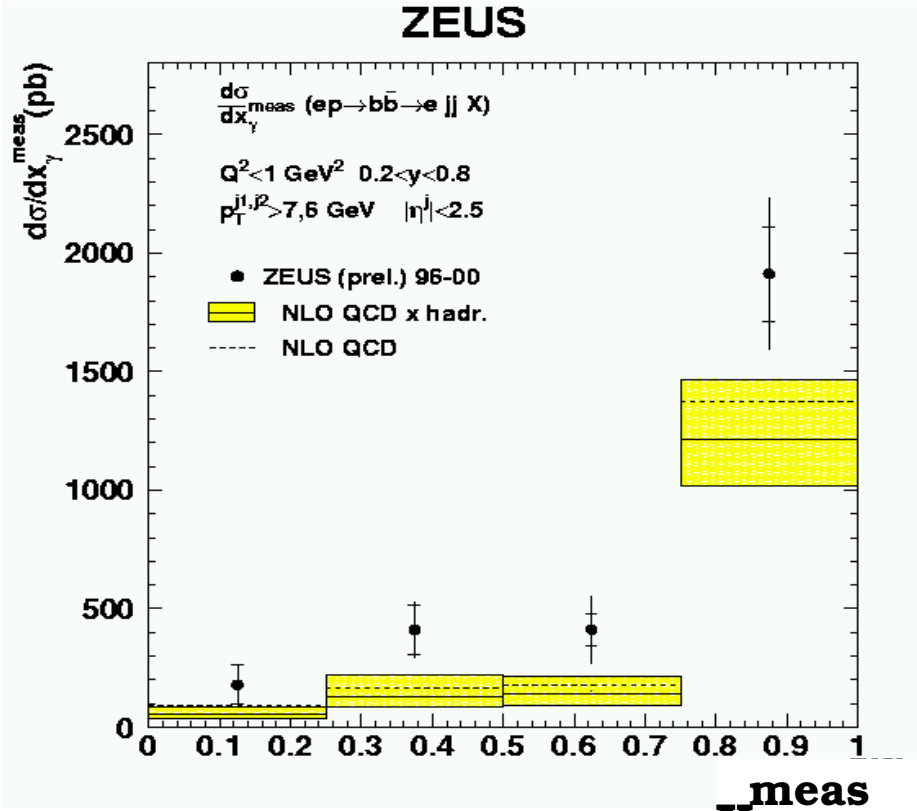
ZEUS: 96/00 ~ 98 pb-1

F_b = 22±3% (96-97), 27±3% (99-00)

- **x_γ distribution measured**



resolved γ ($x_\gamma < 1$)



- **significant resolved component in b PhP**

NLO underestimates both direct and resolved beauty PhP

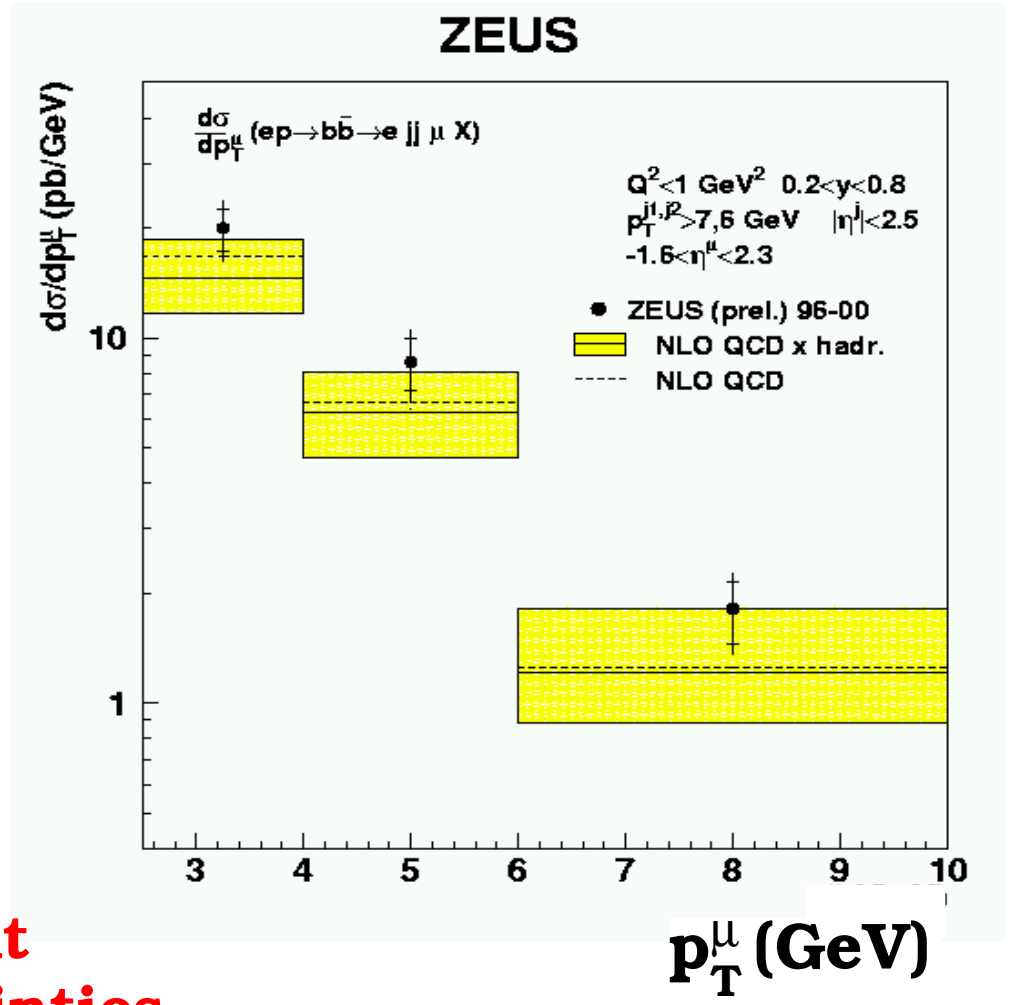
Beauty in Photoproduction

ZEUS: 96/00 ~ 98 pb-1

- **different kinematic range**
- **different x-section definition:**

  $\sigma(ep \rightarrow bb\,X \rightarrow Jet\ Jet\ \mu\ X)$

- **differential x-sections as a function of μ variables**



data above NLO but agrees within uncertainties

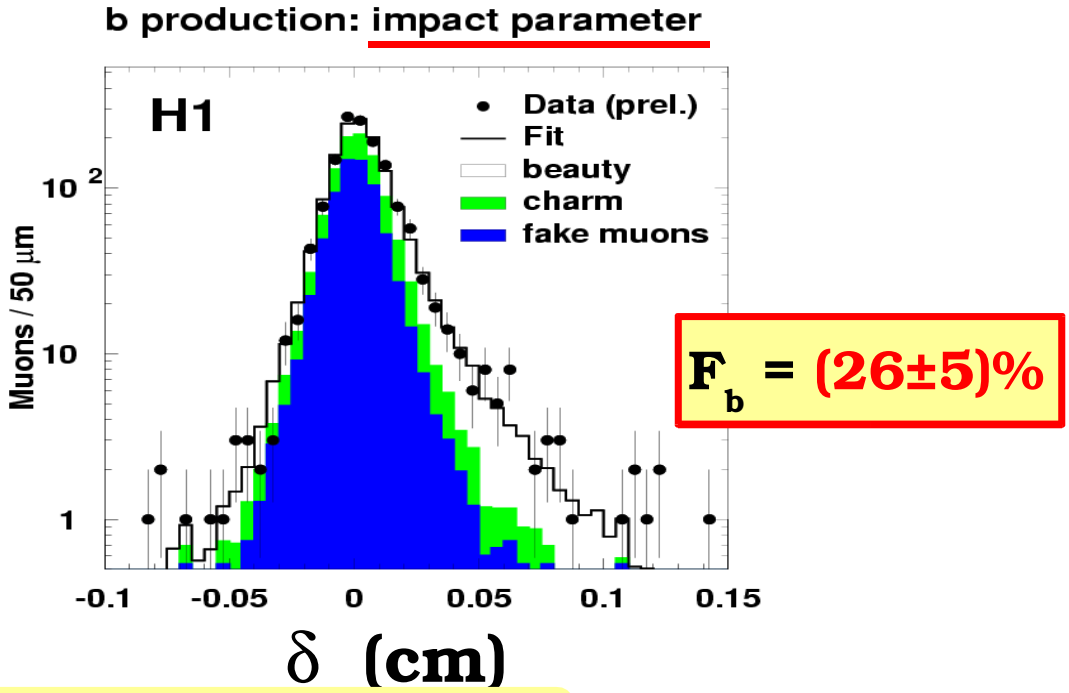
Beauty in Photoproduction

H1: 1997 ~15 pb^{-1}

P_T^{rel} + Lifetime information

$\sigma(ep \rightarrow bb\,X \rightarrow \mu\,X)$

$Q^2 < 1$ GeV^2, $0.1 < y < 0.8$
At 1 one muon with:
$p_{T,\mu} > 2$ GeV, $35° < \theta_\mu < 130°$



F_b = (26±5)%

'97 data (2D-Fit): 160 ± 16 (stat.) ± 29 (syst.) pb

H1 Combined 96+97: 170 ± 25 pb

NLO QCD (FMNR) = 54 ± 9 pb

O(α_s) QCD⊗CCFM (CASCADE) = 67 pb

O(α_s) QCD⊗DGLAP (AROMA) = 38 pb

pQCD below PhP data

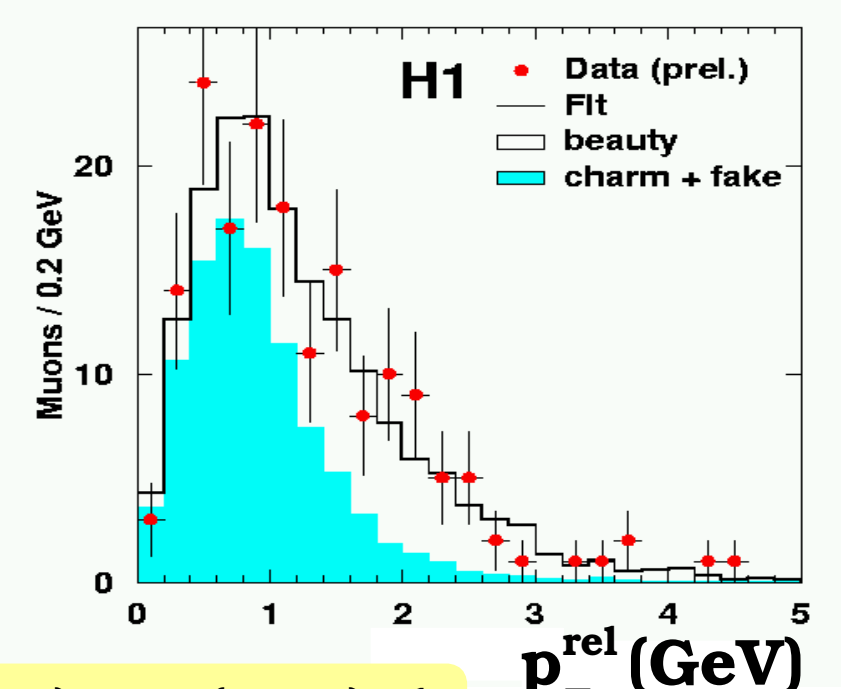
Beauty in Deep Inelastic Scattering

H1: 1997 ~10 pb^{-1}
P_T^{rel} + Lifetime

$\sigma(ep \rightarrow bb\,X \rightarrow \mu\,X)$

$2 < Q^2 < 100\ GeV^2,\ 0.05 < y < 0.7$
At least 1 muon with:
$p_{T,\mu} > 2\ GeV,\ 30° < \theta_\mu < 160°$

(P_t^{rel},δ) 2D Fit $\rightarrow$ F_b = 43±8 %



'97 data (2D-Fit): 39 ± 8 (stat.) ± 10 (syst.) pb

NLO QCD (HVQDIS) = 11 ± 2 pb
O(α_s) QCD⊗CCFM (CASCADE) = 15 pb
O(α_s) QCD⊗DGLAP (AROMA) = 9 pb

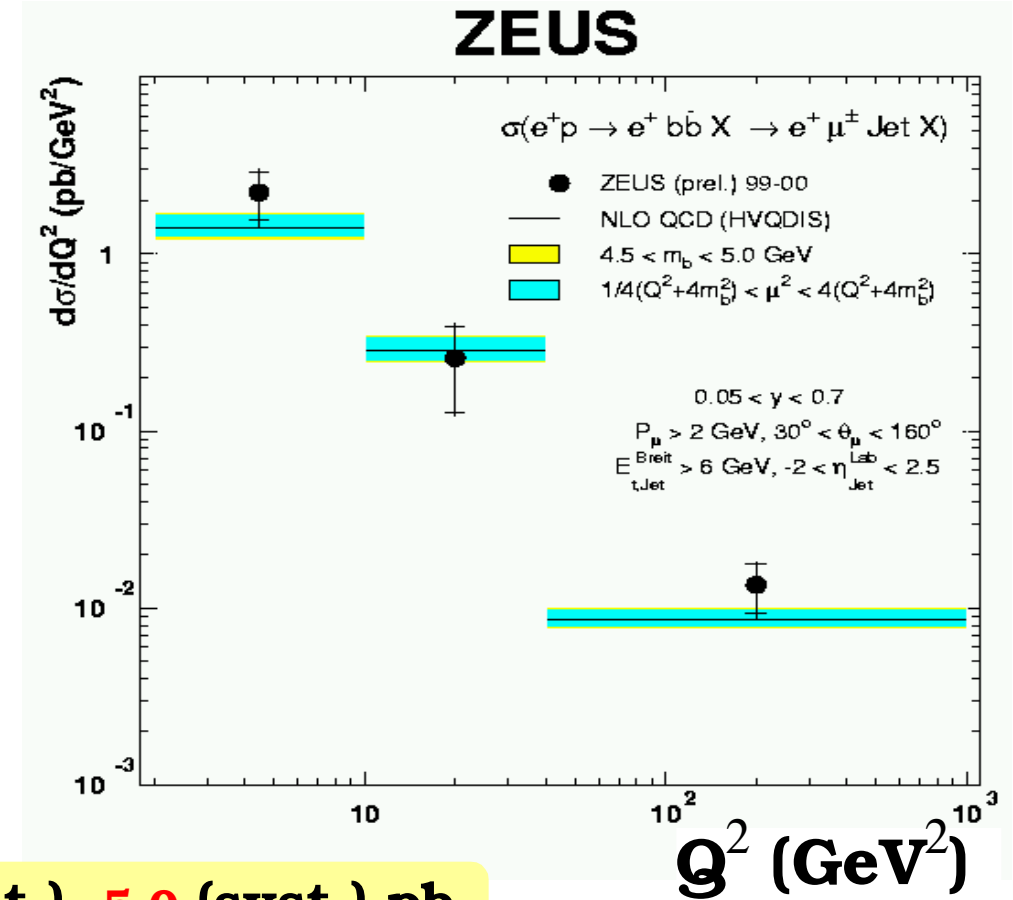
pQCD below H1 DIS data

Beauty in Deep Inelastic Scattering

ZEUS: 99/00 ~ 60 pb-1

σ (ep $\rightarrow$ e bb X$\rightarrow$ e Jet μ X)

first differential x-sections in DIS



data above NLO but agrees within uncertainties

σ = **38.7**$\pm$**7.7** (stat.) +**6.1** (syst.) -**5.0** (syst.) pb

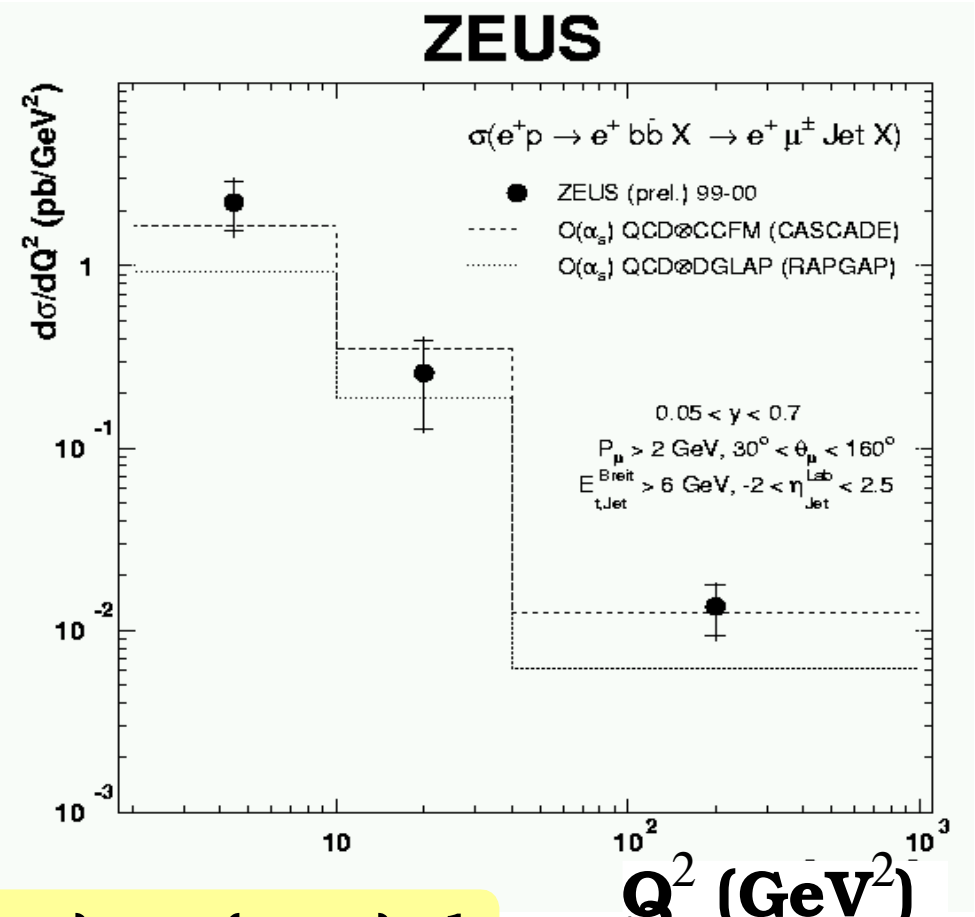
NLO QCD (HVQDIS) = **28.1** +**5.3** -**3.9** pb

Beauty in Deep Inelastic Scattering

ZEUS: 99/00 ~ 60 pb-1

σ **(ep** $\rightarrow$ **e bb X** $\rightarrow$ **e Jet** μ **X)**

- **CASCADE (with CCFM evolution) describes data well**
- **RAPGAP (with DGLAP evolution) underestimates data**



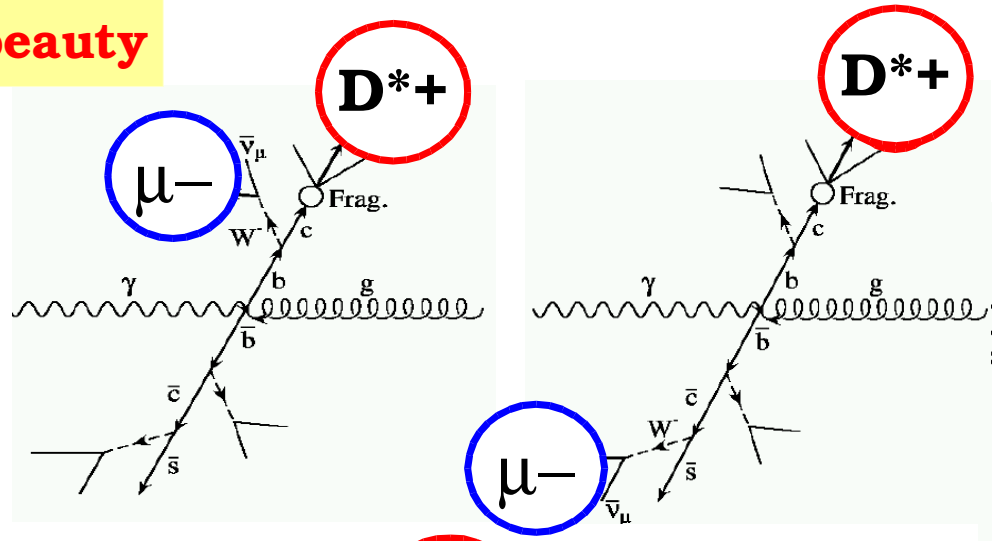
σ = **38.7±7.7 (stat.) +6.1 (syst.) -5.0 (syst.) pb**

O(α_s) QCD⊗CCFM (CASCADE) = 35 pb

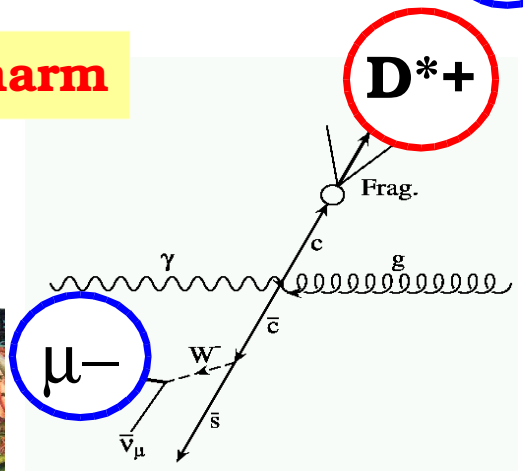
Double-Tagged Beauty Events

D* + μ final state

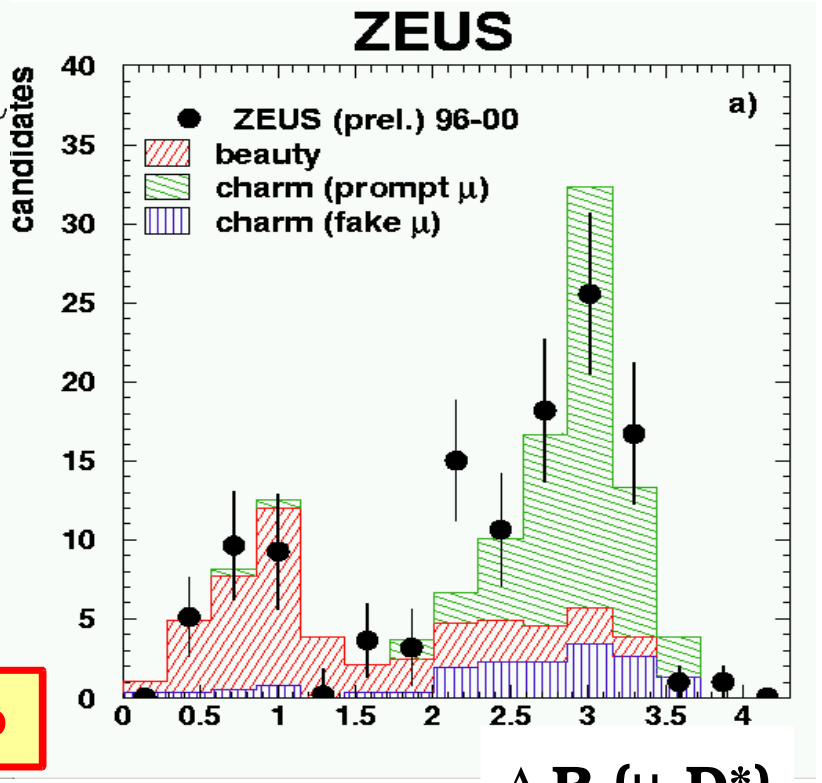
beauty



charm



- **method exploits charge & angular correlations to separate charm and beauty**
- **sensitive down to p_{Tb}~ 0 GeV**



F_b = (36±8)%

Double-Tagged Beauty Events

ZEUS: 96/00 ~114 pb^{-1}

pQCD below data

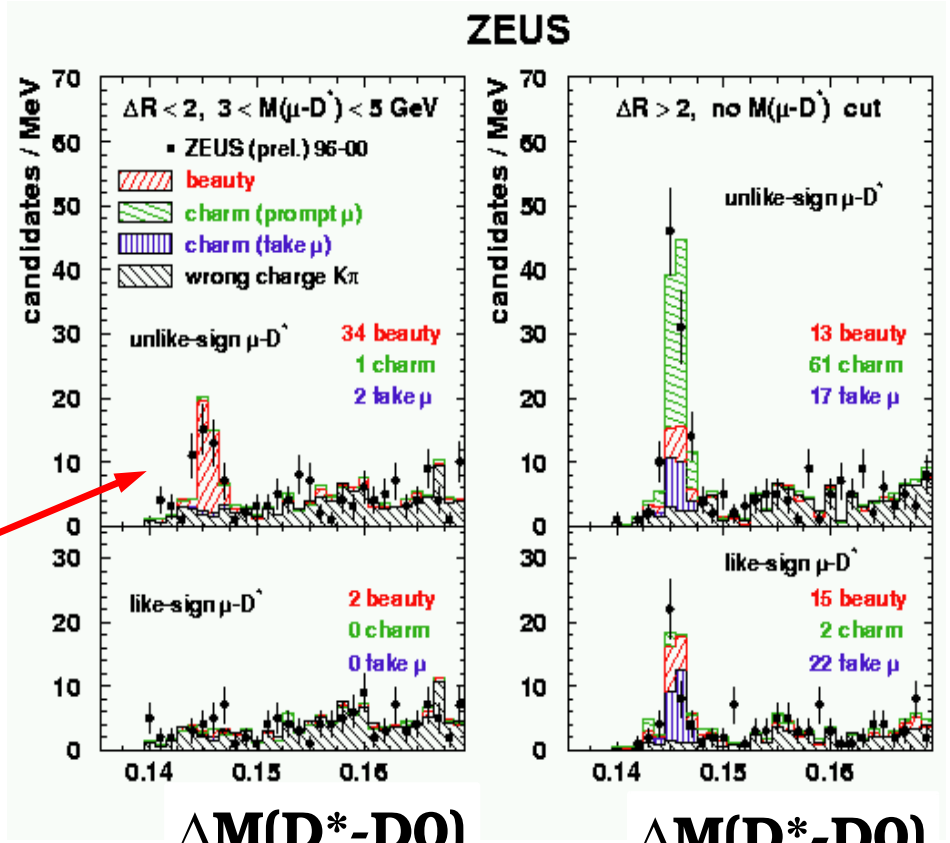
Photoproduction region:

$y_{rap}(b)<1$, $Q^2<1$ GeV^2, $0.05< y < 0.85$

$$\sigma(ep \rightarrow e\, b(\bar{b})\, X) =$$

15.1 ± **3.9** (stat.) +**3.8** -**4.7** (syst.) pb

NLO QCD (FMNR) = **5.0** +**1.7** -**1.1** pb



beauty signal

Double-Tagged Beauty Events

H1 results: 97/00 ~91 pb^{-1}

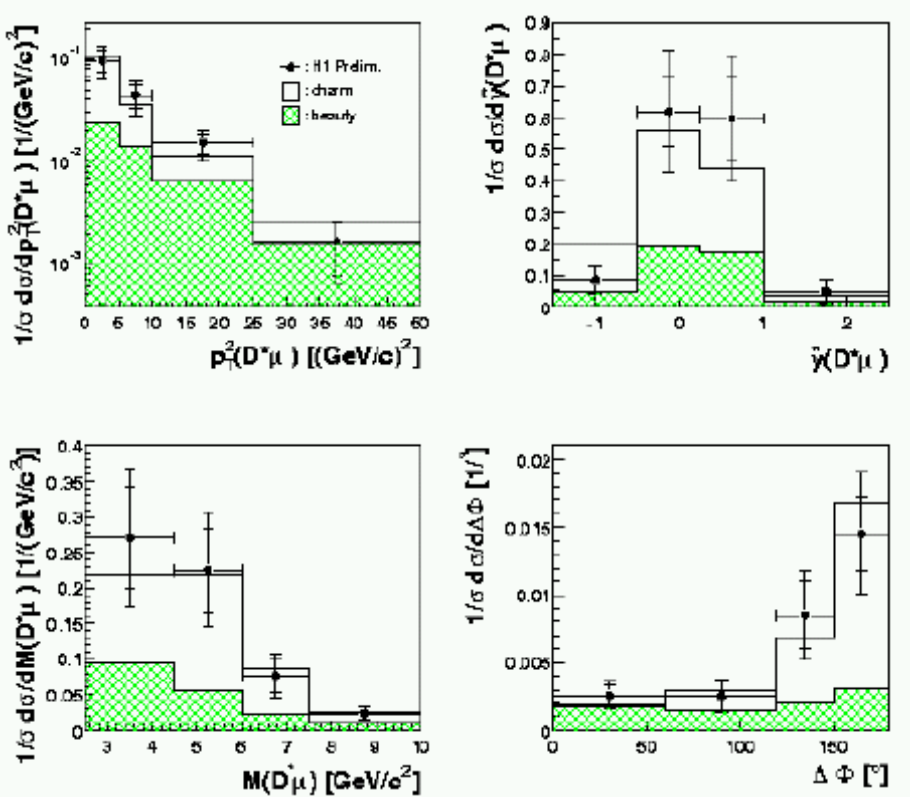
σ (ep $\rightarrow$ e qq X$\rightarrow$ eD*μ X)

p_T (D*)>1.5 GeV, -1.5< η(D*)<1.5

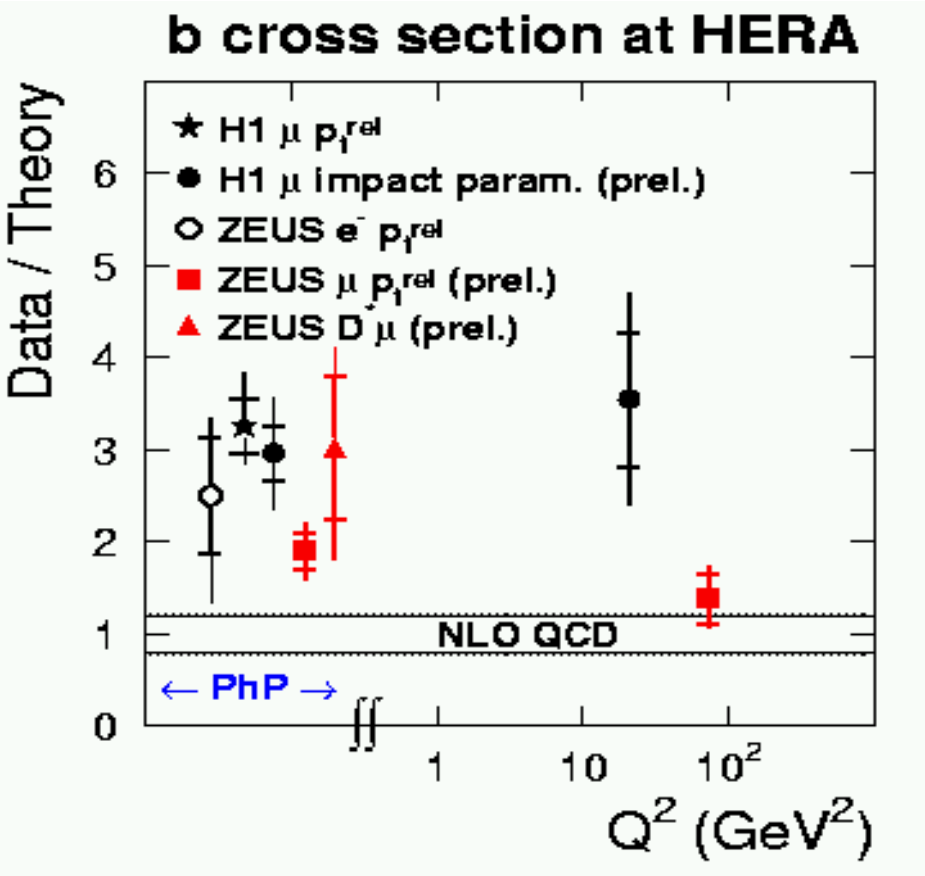
$p_{T,\mu}$>1 GeV, -1.74<η_μ<1.74

Charm: DATA/LO (AROMA) = 1.8
Beauty: DATA/LO (AROMA) = 3.6

Charm scaled by 1.8
Beauty scaled by 3.6
shapes agree well between data and LO



Summary & Conclusions



- **beauty production in e-p collisions: good test of pQCD**
- **beauty puzzle remains**
  - **data mostly above NLO QCD**
  - **for some measurements NLO QCD calculations agree with data**
  - **different phase-space, different approches to pQCD, decay, fragmentation, …**
  - **more data needed!** ⇒
- **HERA II: higher luminosity, new detectors (ZEUS: Microvertex Detector)**