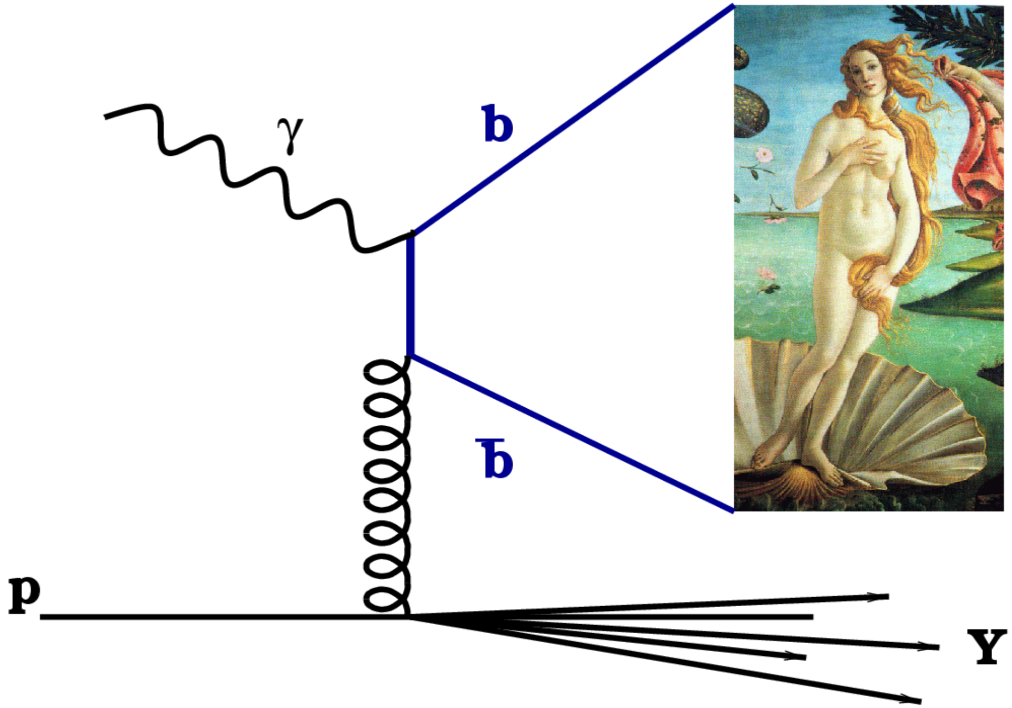
Beauty Production in DIS

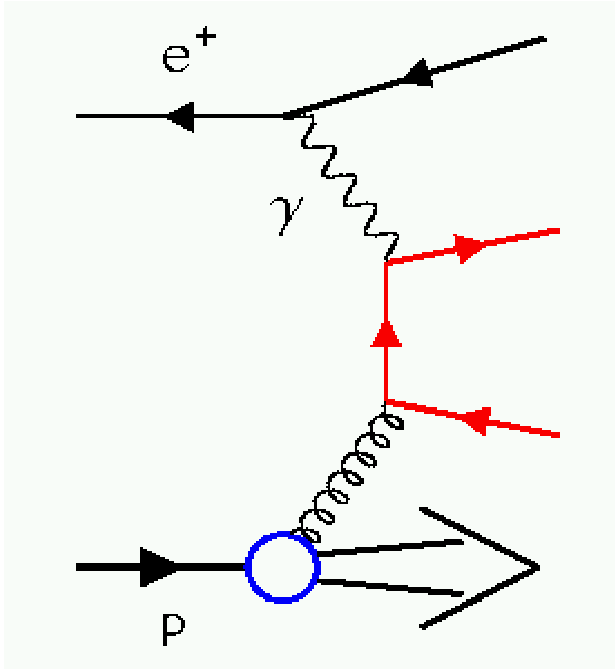
- Motivation
- Theory Predictions
- Beauty Tagging
- Results
- Summary



On Behalf ZEUS Collaboration

Beauty Physics Motivation

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



- **Beauty puzzel still present...**

What about 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 $p_T \sim m_b$**

↳ FMNR (PhP)
HVQDIS (DIS)

Resummed (massless) scheme

- **massles heavy quarks**
- **u,d,s,c,b active flavours in p and γ**
- **applicable for $p_T \sim m_b$**

Matched Calculations (FONLL)

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

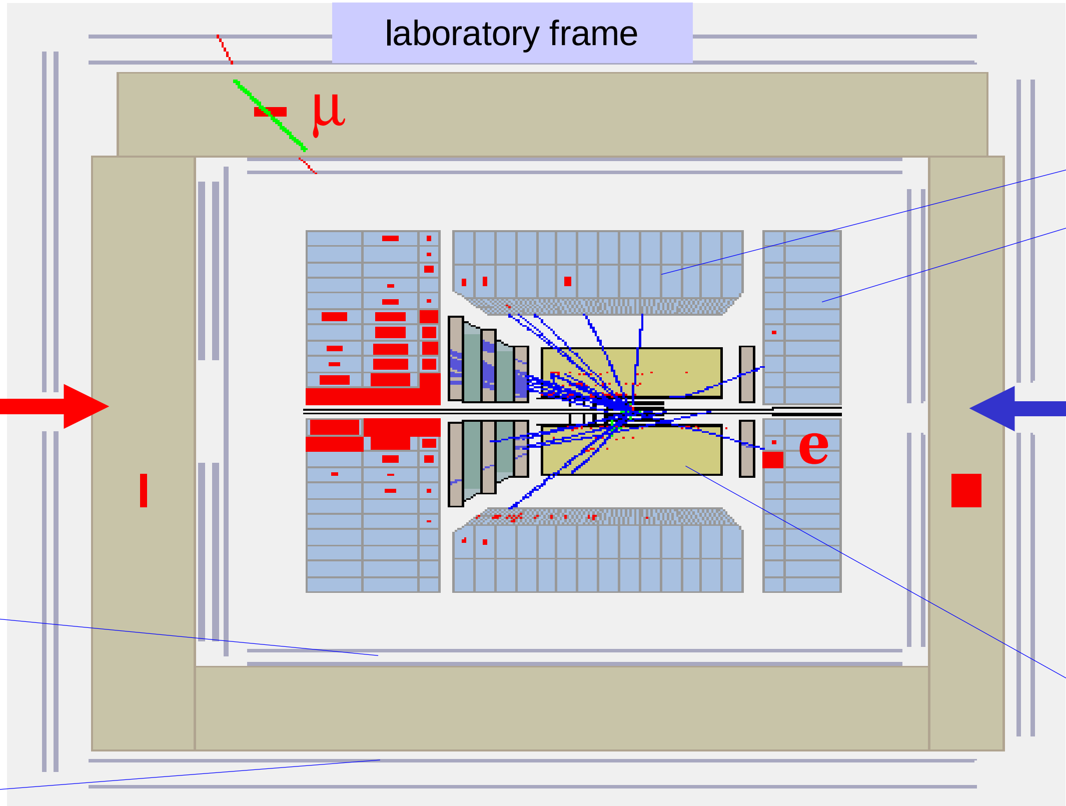
Beauty Event Topology in ZEUS

study beauty production with semileptonic B decay:

$$ep \to e b\bar{b} X \to e\,\mu^{\pm}\,\text{jet}\,X$$

electron

(forward)



proton

(rear)

Barrel and rear calorimeter

Inner muon chambers

Central tracking detector

Outer muon chambers

Event Selection

- **Data sample: ZEUS 99-00 e^+p, 72.4 pb^{-1}**
- **Standard DIS Selection in kinematic range:**

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

- **Muon Cuts:**

  $-0.9 < \eta^\mu < 1.3$ and $p_T^\mu > 2\ GeV$ (Barrel Muon Chambers region)

  $-1.6 < \eta^\mu < -0.9$ and $p^\mu > 2\ GeV$ (Rear Muon Chambers region)

- **Jet Cuts:**

  $E_T^{Breit} > 6\ GeV,\ -2 < \eta^{lab} < 2.5$

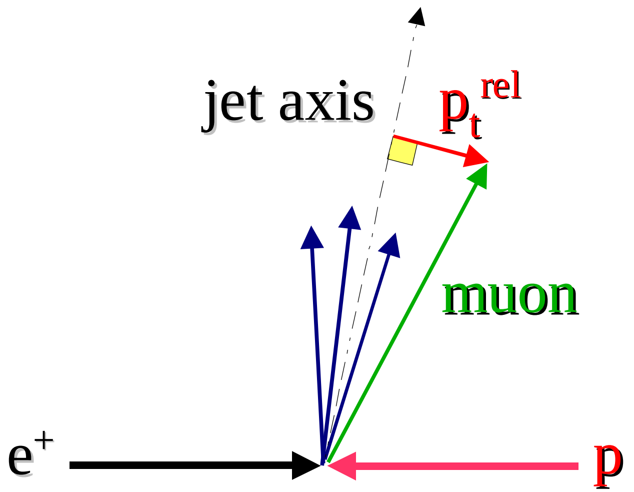
- **Jet – Muon Association:**

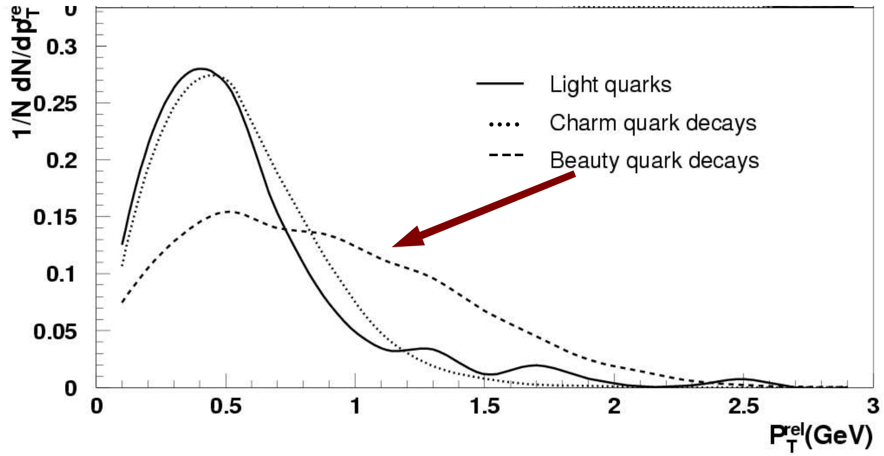
  associated jet: $E_T^{Breit} > 4\ GeV$

after all selection cuts 941 events remains

Extraction of beauty fraction (1)

- after all selection cuts data sample is a mixture of several processes:
  - semi-leptonic decays of beauty hadrons
  - semi-leptonic decays of charm hadrons
  - in-flight decays and fake muons from light quarks
- **p_T^{rel} method to tag beauty**





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

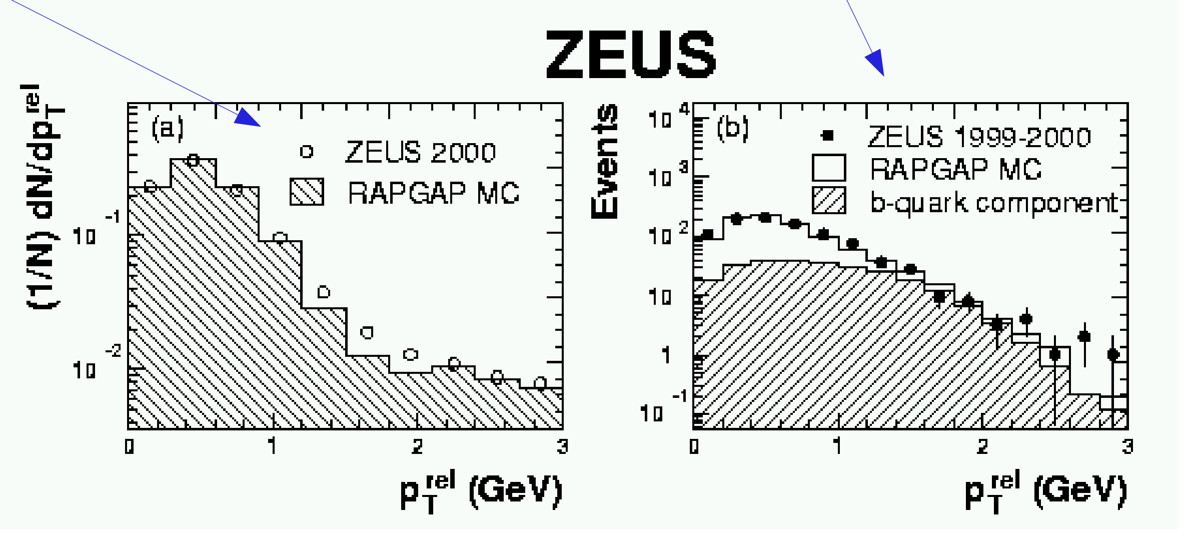
Extraction of beauty fraction (2)

- extraction depends on proper MC simulation for all processes
- cross-checked with data, using inclusive DIS data with at least one hard jet in Breit frame
- p_T^{rel} calculated for tracks passing muon selection criteria
- compared to light and charm MC
- shape generally well described
- difference between data and MC contained in systematic error obtained by reweighting amount of charm contribution in the fit

- beauty fraction extracted from $\mathbf{p_T^{rel}}$

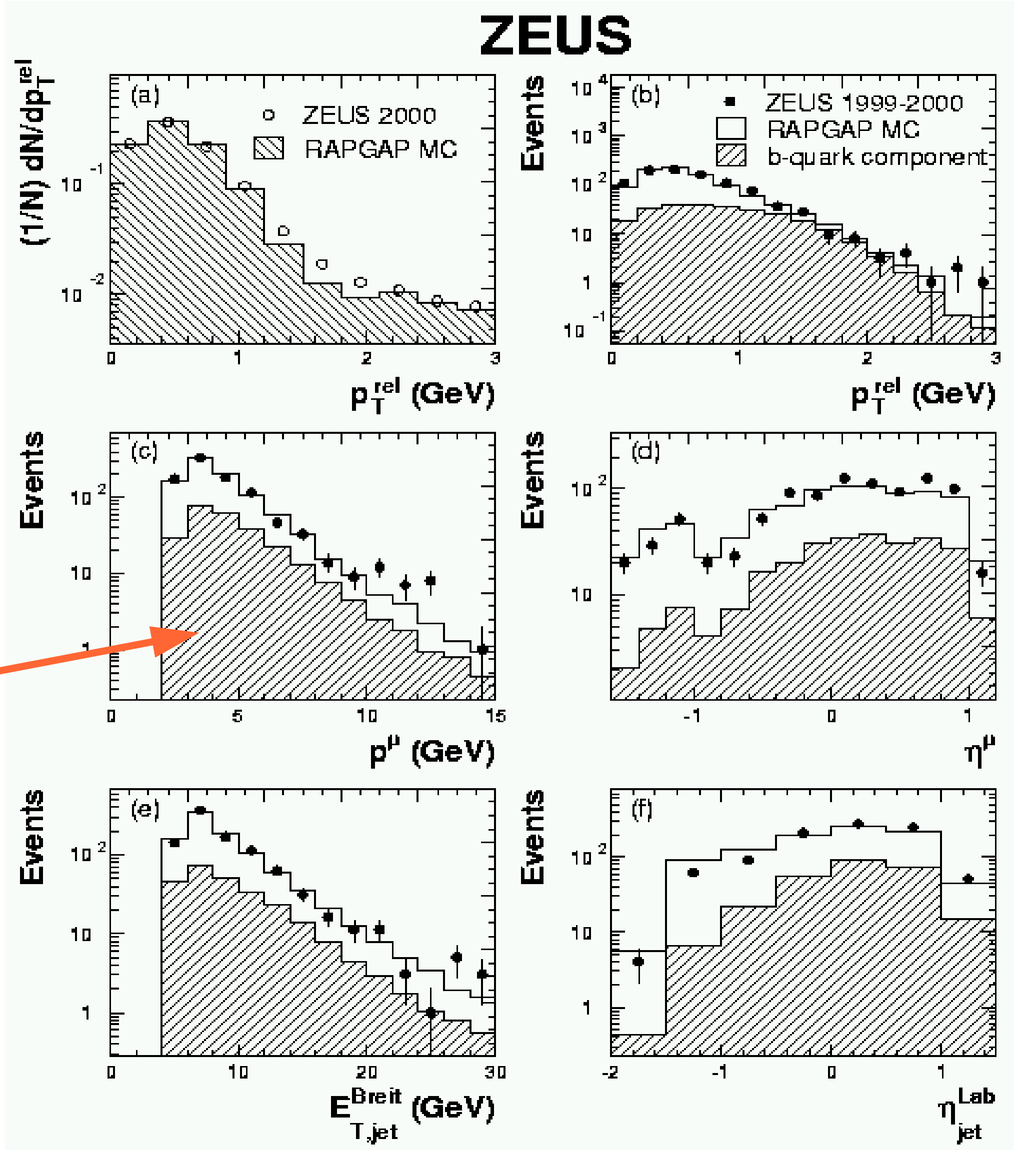
$$f_b = (30.2 \pm 4.1)\ \%$$

- p_T^{rel} well described by mixed MC



Data – MC Comparison

- muon and jet variables well described by MC samples weighted by extracted beauty fraction

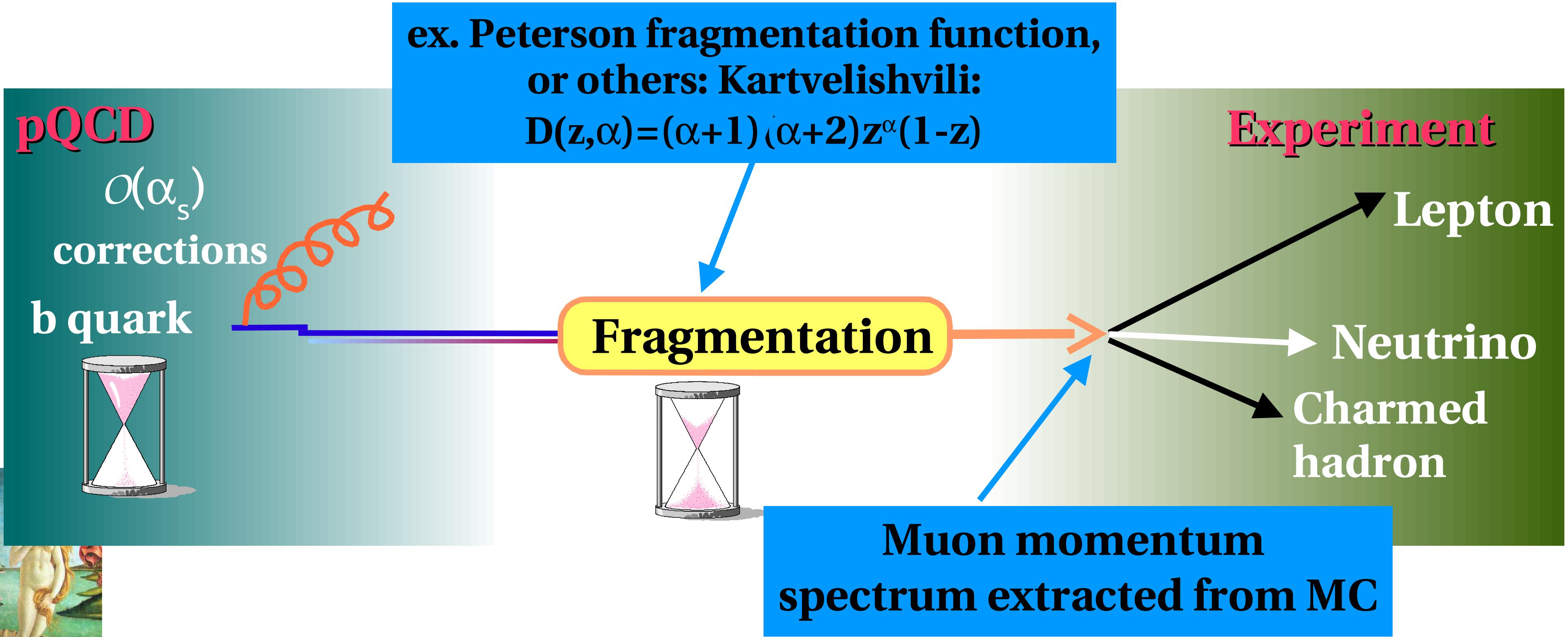


~ 30 % of events comes from b-decays (~285 events)

QCD Prediction: NLO Calculations

The calculation of the NLO QCD predictions proceeds in three steps:

- PhP: FMNR, DIS: HVQDIS: $\gamma^*g \rightarrow b\bar{b}$, $\gamma^*g \rightarrow b\bar{b}g$, $\gamma^*q \rightarrow b\bar{b}q$, etc.
- Fragmentation of the b-quark into a B-meson
- Semileptonic decay of the B-meson



Total Cross Section

ZEUS results: 99/00, ~ 72.4 pb-1

corrected for radiative effects (HERACLES)

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

kinematic region:

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

at least one jet in Breit frame with:

$E_T^{Breit} > 6$ GeV, $-2 < \eta^{lab} < 2.5$

at least one muon with:

$-0.9 < \eta^{\mu} < 1.3$, $p_T^{\mu} > 2$ GeV

$-1.6 < \eta^{\mu} < -0.9$, $p^{\mu} > 2$ GeV

Measured Cross Section:

σ = 40.9 ± 5.7 (stat.) +6.0 -4.4 (syst.) pb

NLO QCD (HVQDIS)

σ = 20.6 +3.1 -3.1 pb

Cascade (CCFM)

σ = 28 pb

RAPGAP (DGLAP)

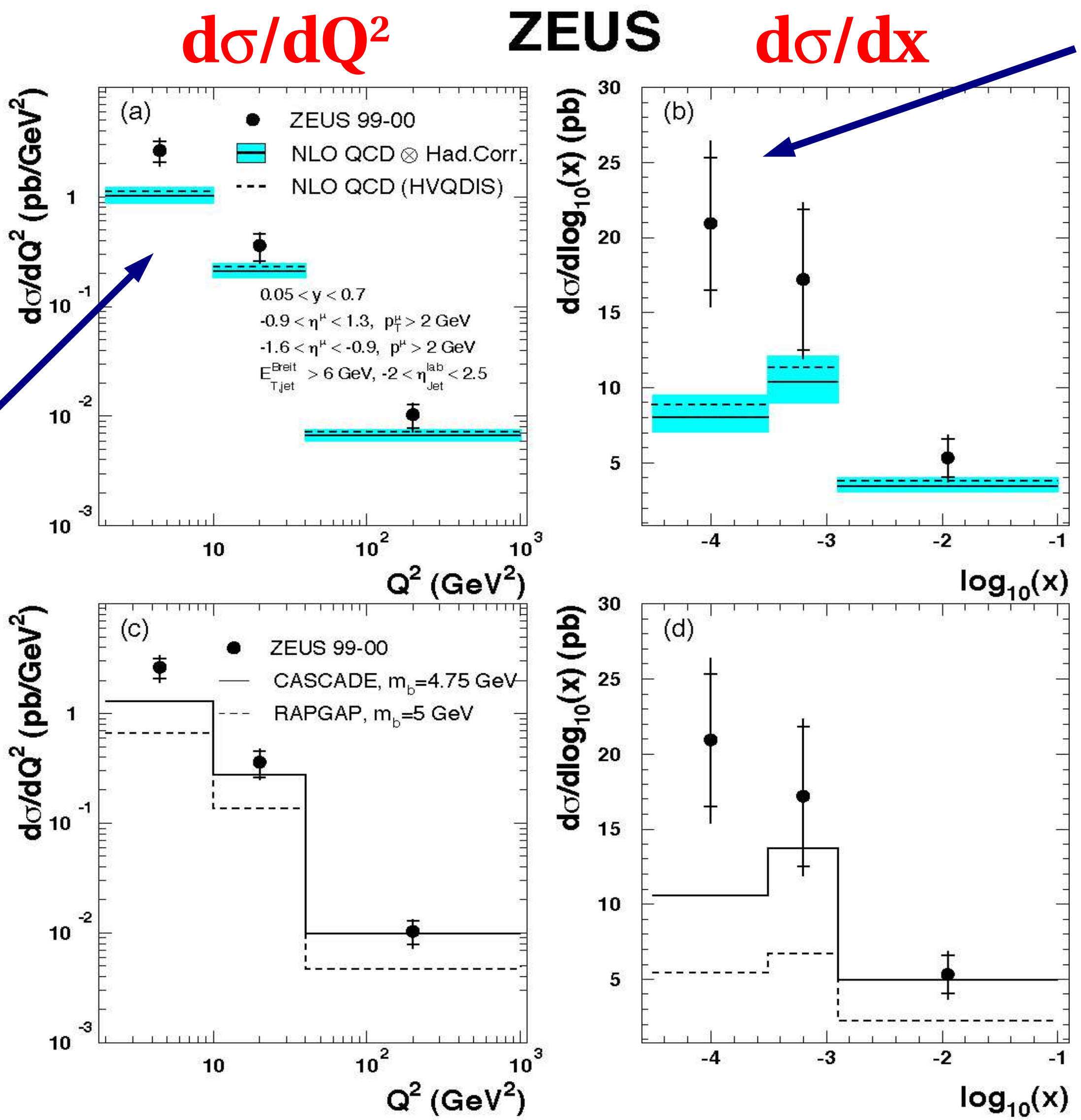
σ = 14 pb

NLO prediction is about 2.5 standard deviation lower than measured cross section

Differential Cross Sections

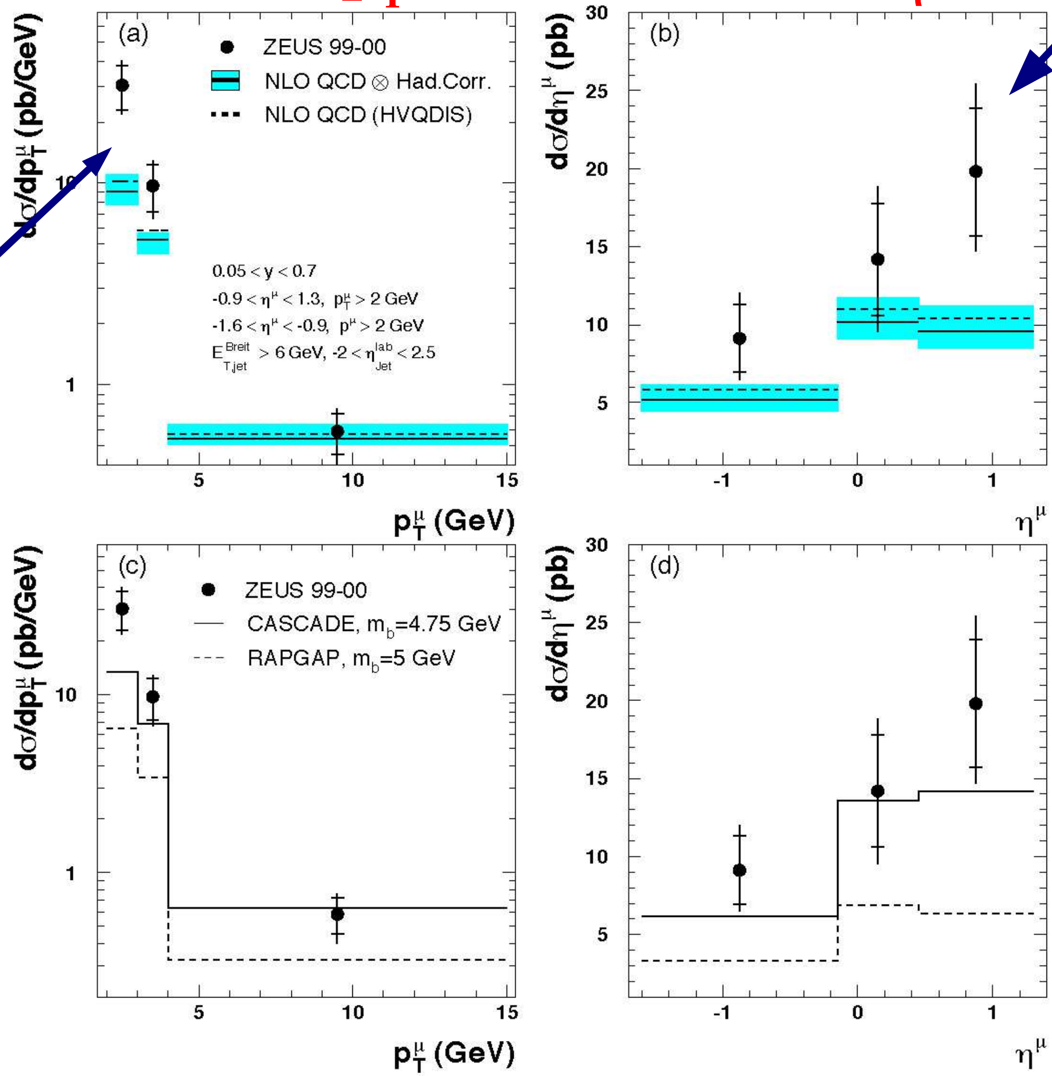
- differential cross sections calculated in the same kinematic region
- f_b extracted in each bin
- **NLO** agrees well with the data except for lowest Q^2 and lowest x bins
- the same behavior for **CASCADE**
- RAPGAP below the data

$d\sigma/dQ^2$ ZEUS $d\sigma/dx$



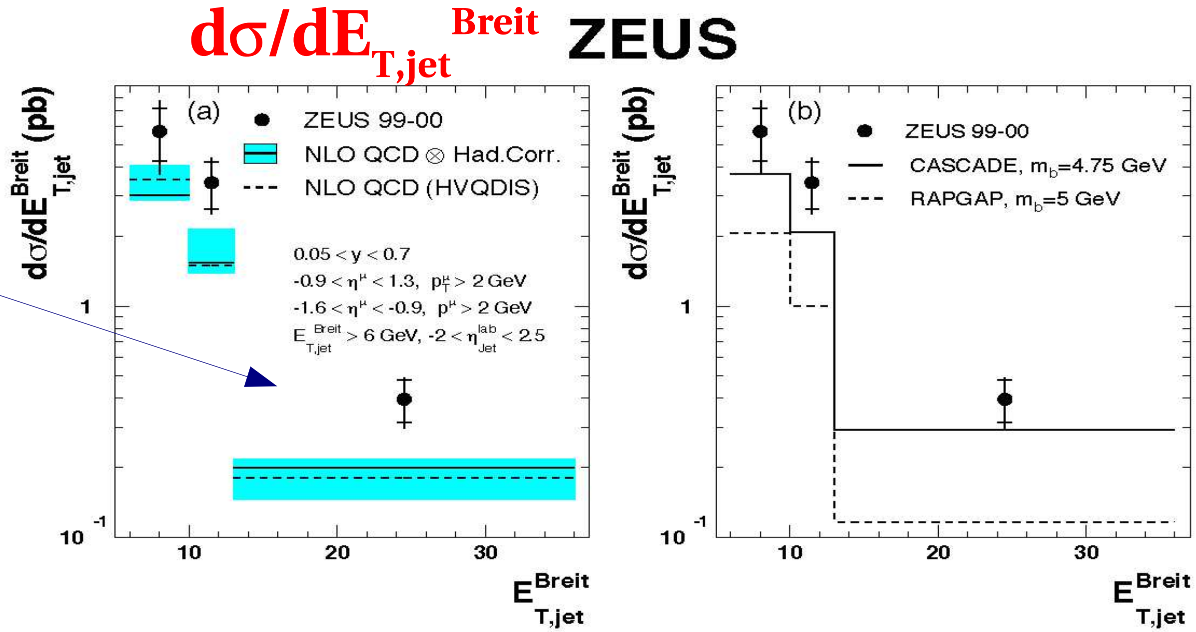
Differential Cross Sections

$d\sigma/dp_T^\mu$ **ZEUS** $d\sigma/d\eta^\mu$



- **NLO** agrees well with the data except for lowest p_T^{μ} and **highest** η^{μ} values were it lies about 2 standard deviations below the data
- similar behavior for **CASCADE** (better agreement for high η^μ)
- RAPGAP below the data

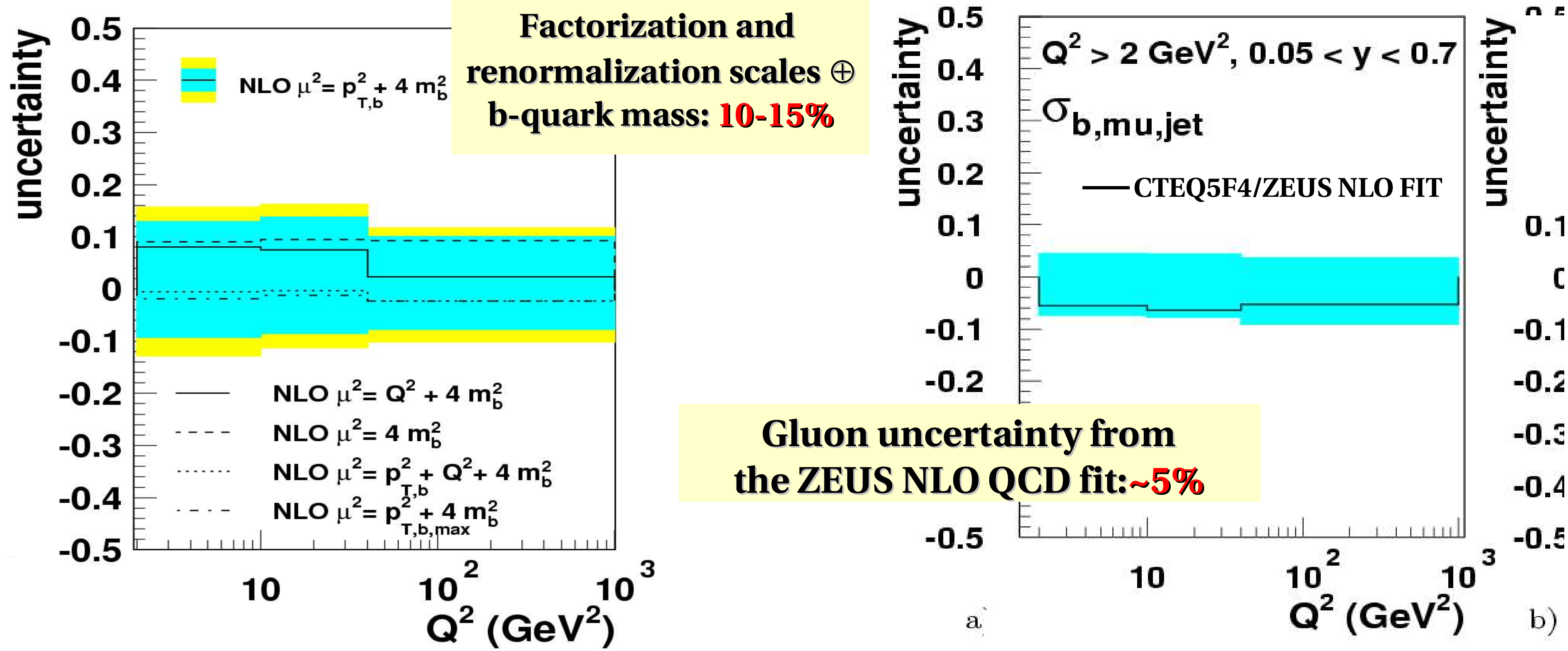
Differential Cross Section



- **NLO** agrees well with the data except for highest $E_{T,jet}^{Breit}$ values were it lies about 2 standard deviations below the data
- **CASCADE** reproduces cross section well
- RAPGAP below the data

- **b-quark production in DIS measured for the first time**
- **consistent with NLO QCD**
- **regions in phase space defined where NLO lies below the data**

NLO QCD Uncertainties



Factorization and renormalization scales ⊕ b-quark mass: 10-15%

Gluon uncertainty from the ZEUS NLO QCD fit: ~5%

more sources:

Hadronization (jet): ~ 10%

Fragmentation (muon): 5-10%

Summary & Conclusions

- Beauty production measured in DIS for the first time
  - visible cross section and differential cross sections are compared with NLO calculations and MC simulations
- NLO prediction consistent with the data but lies 2.5 standard deviations below
- RAPGAP MC well below the data
- CASCADE (CCFM) describes the data well except for low Q^2, low x and low p_T^μ values
- **NLO describes data well except for low Q^2, low x, low p_T^μ, high η^μ and high $E_{T,jet}^{Breit}$ values**