Beauty photoproduction at ZEUS

HERA and the LHC workshop

4th workshop on the implications of HERA on the LHC

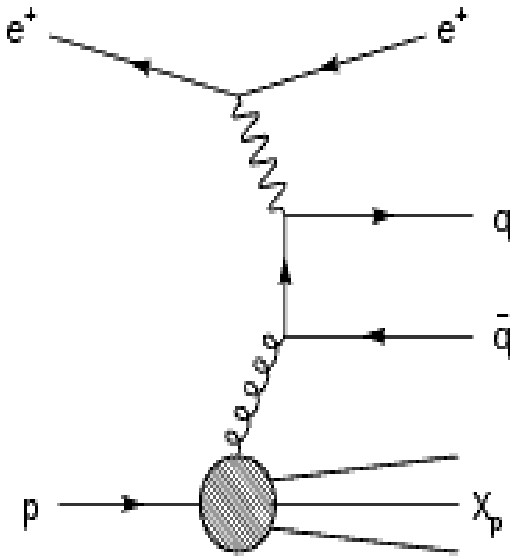
Sarah Boutle

Introduction

- Beauty quarks are predominantly produced at HERA by Boson-Gluon fusion

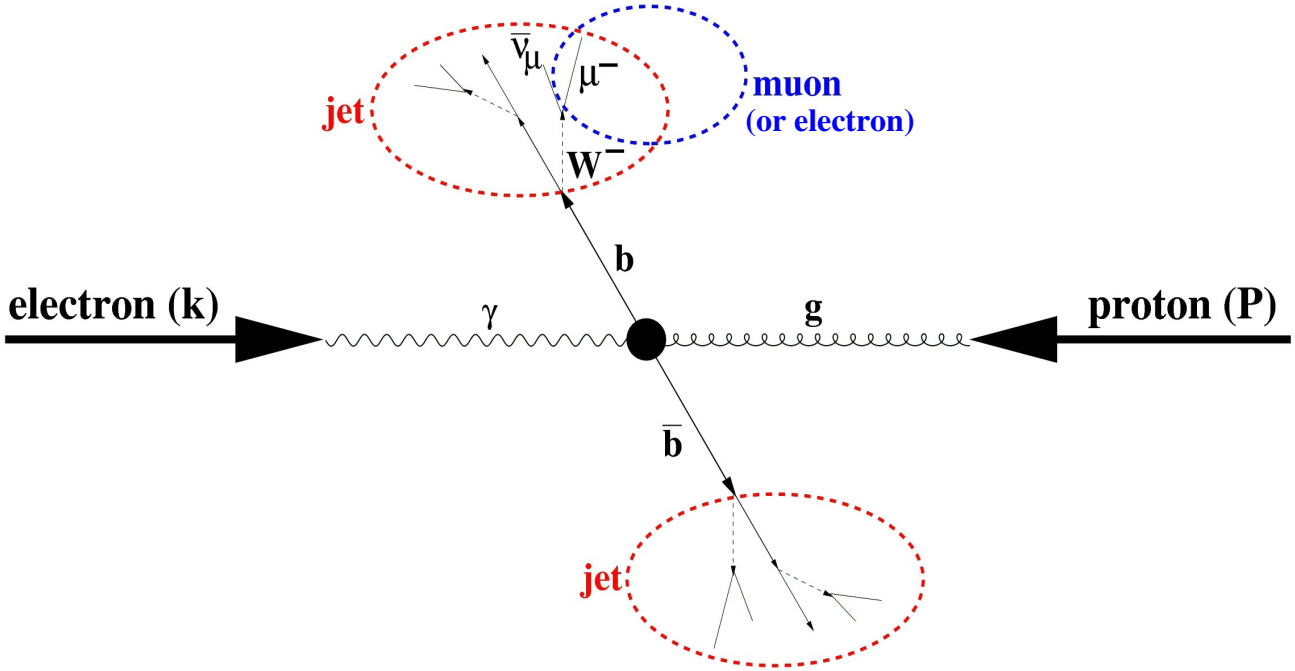
- Why measure beauty photoproduction at HERA?
  - Test of QCD due to large beauty mass
  - Important to understand backgrounds for LHC measurements

- In this talk I will present 3 ZEUS measurements:
  - Semileptonic decay into muons – HERA II
  - Semileptonic decay into electrons – HERA I (final)
  - Dimuon analysis – HERA I (final)



Semi-leptonic decay channels

- Signature of lepton and two jets
- Semi-leptonic decay allows 2 complimentary methods of b-quark measurement
  - Muon provides clean signature
  - Electron allows measurements to lower p_T of the lepton



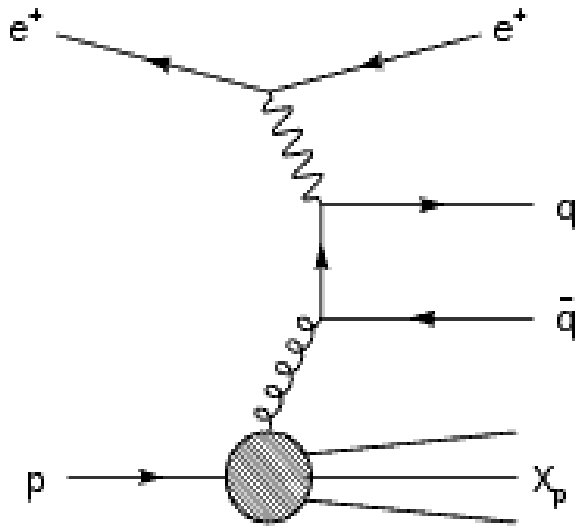
Theoretical model used in NLO comparison

- Massive approach
- Heavy quarks have mass and are not part of structure functions
- c and b are produced perturbatively in the hard interaction
- Appropriate for $p_T^2 \sim M_b^2$, if $p_T^2 >> M_b^2$ then large $\ln(p_T^2/M_b^2)$ appe
- Program used in photoproduction is FMNR (Frixione et al.)

$\mu^2 = \mu_0^2 = (p_T^b)^2 + (m_b)^2$ $\quad 0.5\,\mu_0 < \mu < 2\mu_0$

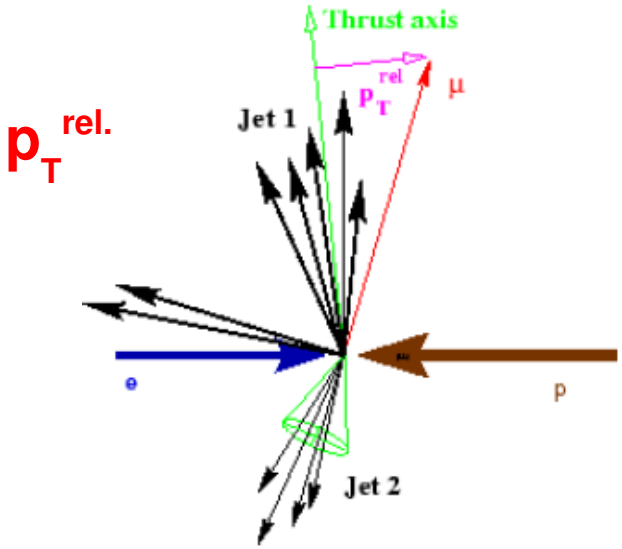
$m_b = 4.75\text{GeV}$ $\quad 4.5\text{GeV} < m_b < 5\text{GeV}$

Proton PDF: CTEQ5M, Photon PDF GRV-G HO



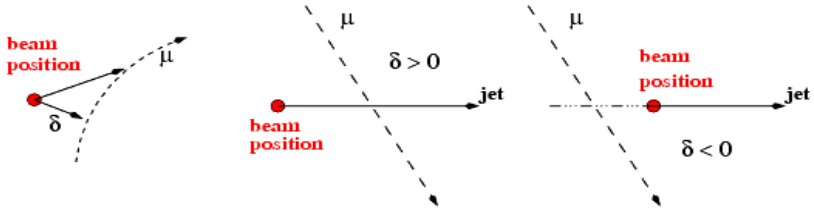
Muon tag analysis - finding beauty quarks

- Use two variables to discriminate b from lighter quarks
- Properties of the b-quark:
  - Large mass $m_b \sim 5$GeV → Larger $p_T^{rel.}$
  - Long lifetime → Larger positive δ

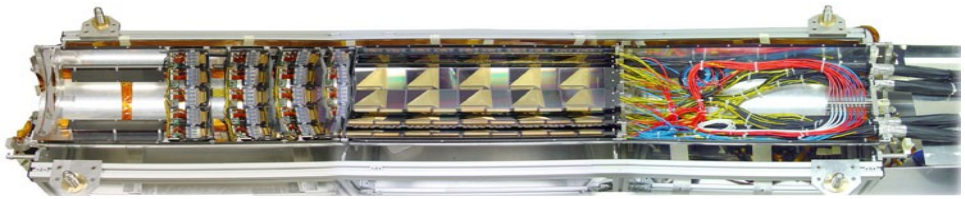


$p_T^{rel.}$

- One of the first analyses to use the MicroVertex Detector
- This analysis uses e^-p data collected in 2005: ~124pb^{-1}
- $-2.5 < \eta^{jet} < 2.5$, $p_T^{jet1,2} > 7{,}6$ GeV
- $-1.6 < \eta^{\mu} < 2.3$, $p_T^{\mu} > 2.5$ GeV
- The muon must be associated with a jet
- Photoproduction $Q^2 \sim 0$GeV^2

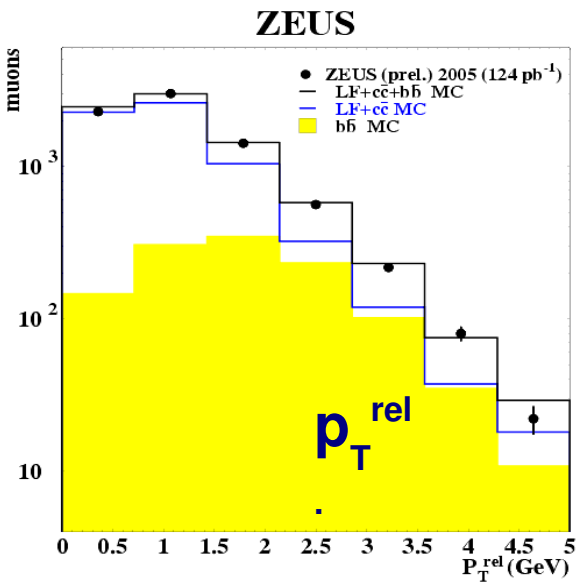


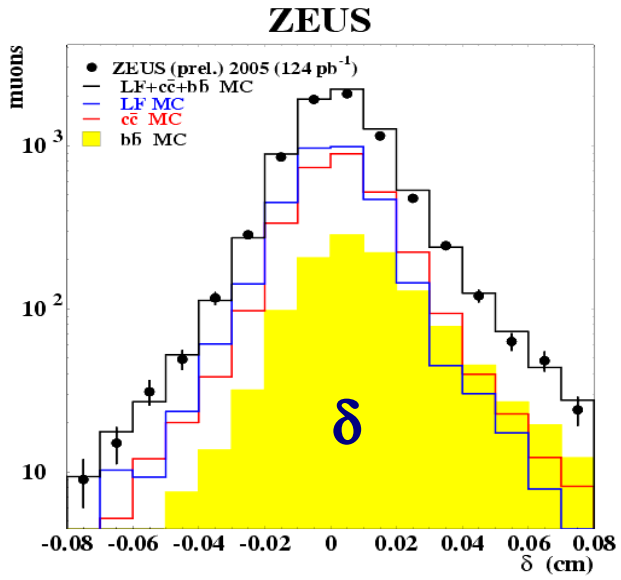
Signed Impact Parameter δ



MVD

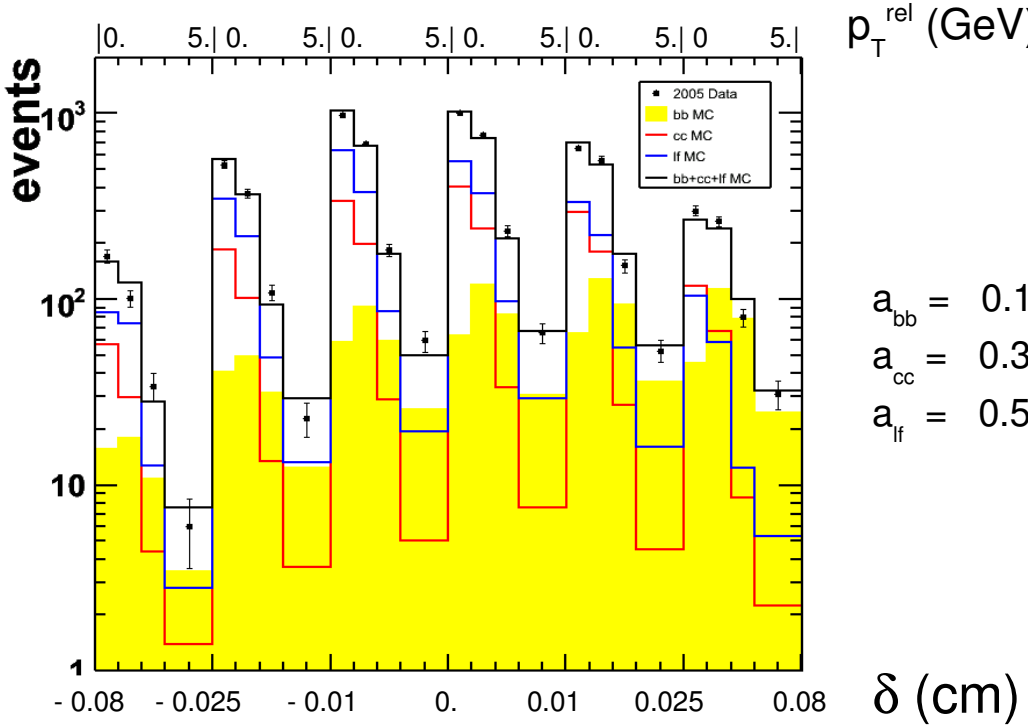
Extracting the beauty (dijet + muon)





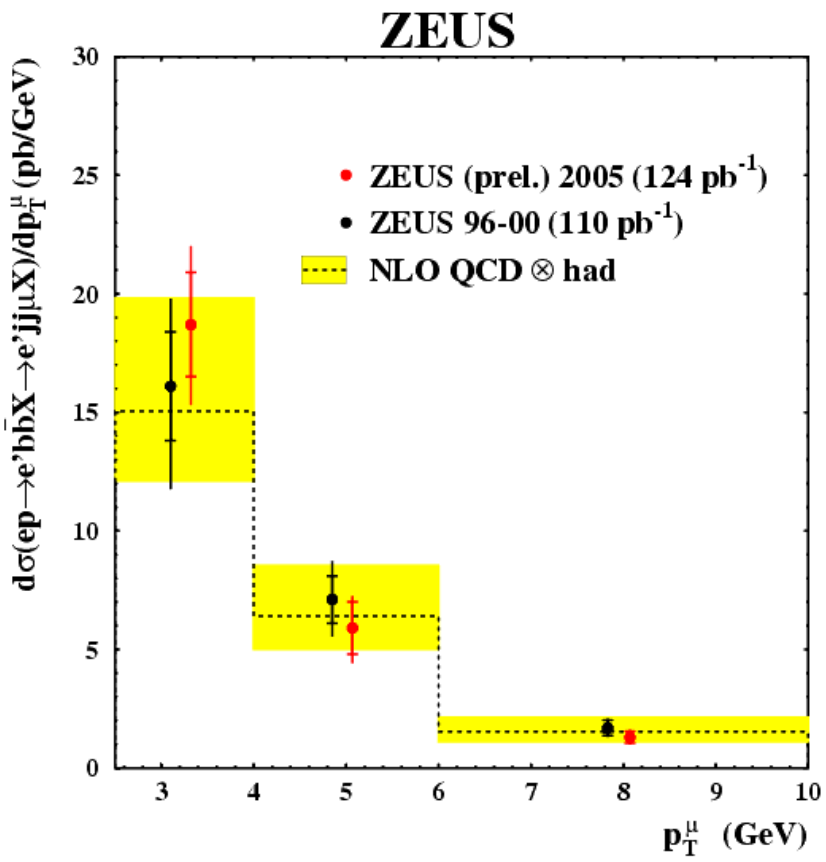
- Fraction of beauty events in the sample is extracted statistically
- Simultaneous 2-d fit of the data with the MC distributions

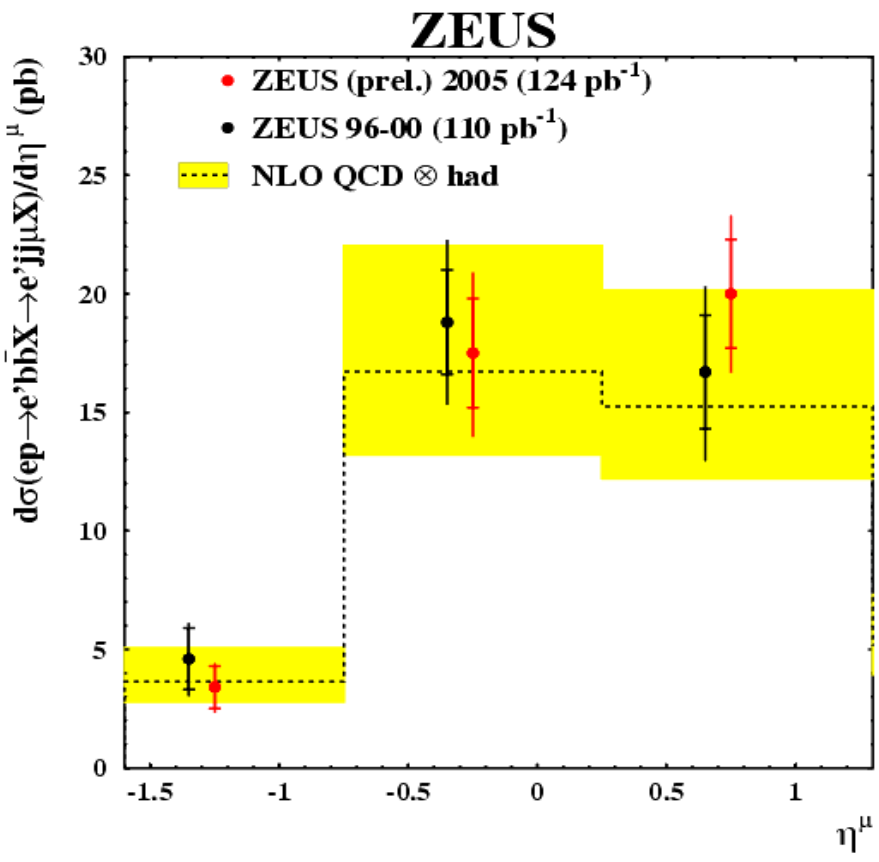
$$f = a_{b\bar{b}} f_{b\bar{b}} + a_{c\bar{c}} f_{c\bar{c}} + a_{lf} f_{lf}$$



a_{bb} = 0.175 ± 0.013
a_{cc} = 0.316 ± 0.057
a_{lf} = 0.509 ± 0.055

Preliminary for EPS 2007

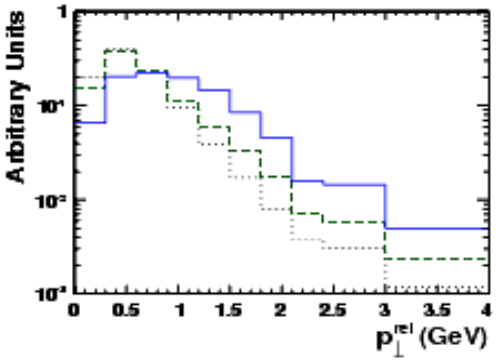




- Differential cross sections w.r.t muon p_T and η measured
- Compared to HERA I measurement made with $p_T^{rel.}$ fit only
- Also compared to NLO QCD prediction made with FMNR program – found to be well described

Dijet + electron analysis

- This analysis uses $e^{\pm}p$ data collected in 96-00: ~120pb^{-1}
- $-2.5 < \eta^{jet} < 2.5$, $E_T^{jet1,2} > 7,6$ GeV
- $-1.5 < \eta^{e} < 1.5$, $p_T^{e} > 0.9$ GeV
- b fraction extracted from a likelihood fit using variables sensitive to e-identification and semi-leptonic decays:



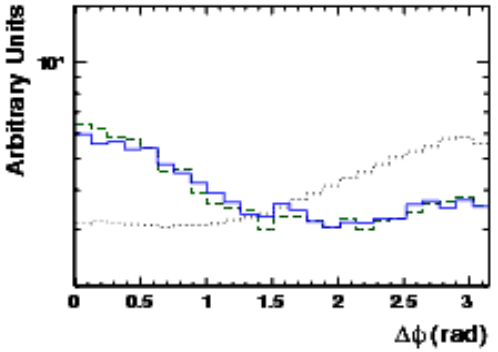
dE/dx the average energy loss per unit length of track

E_{EMC}/E_{CAL} fraction of energy in EM part of the calorimeter

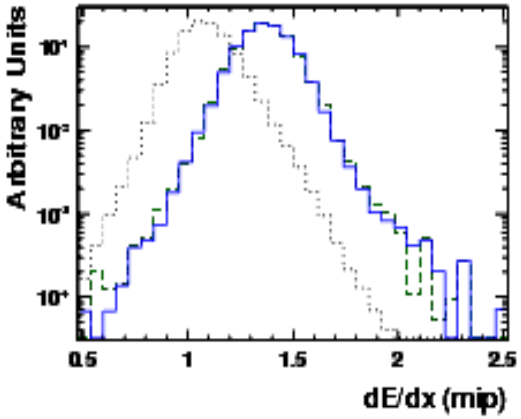
E_{CAL}/p_{track} energy in the calorimeter divided by track momentum

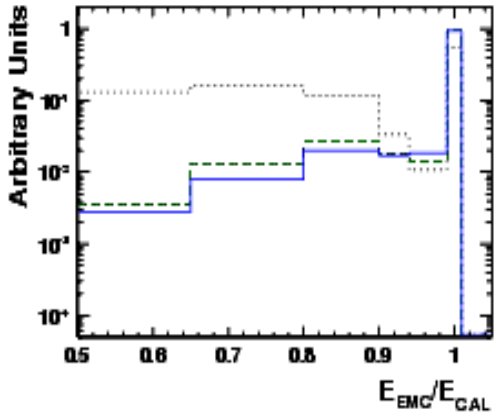
$p_T^{rel.}$ transverse momentum of the electron relative to the jet axis

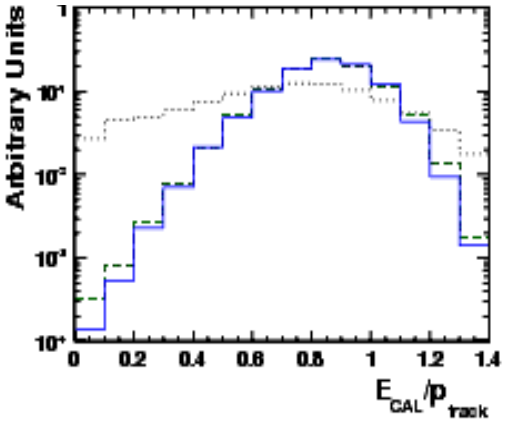
$\Delta\phi$ difference in azimuthal angle between the e^- and missing p_T vector



$b \rightarrow e\ X$
$c \rightarrow e\ X$
Bkg







Electron tag analysis – fit method

- Hypothesis test for particle type i, decay j:

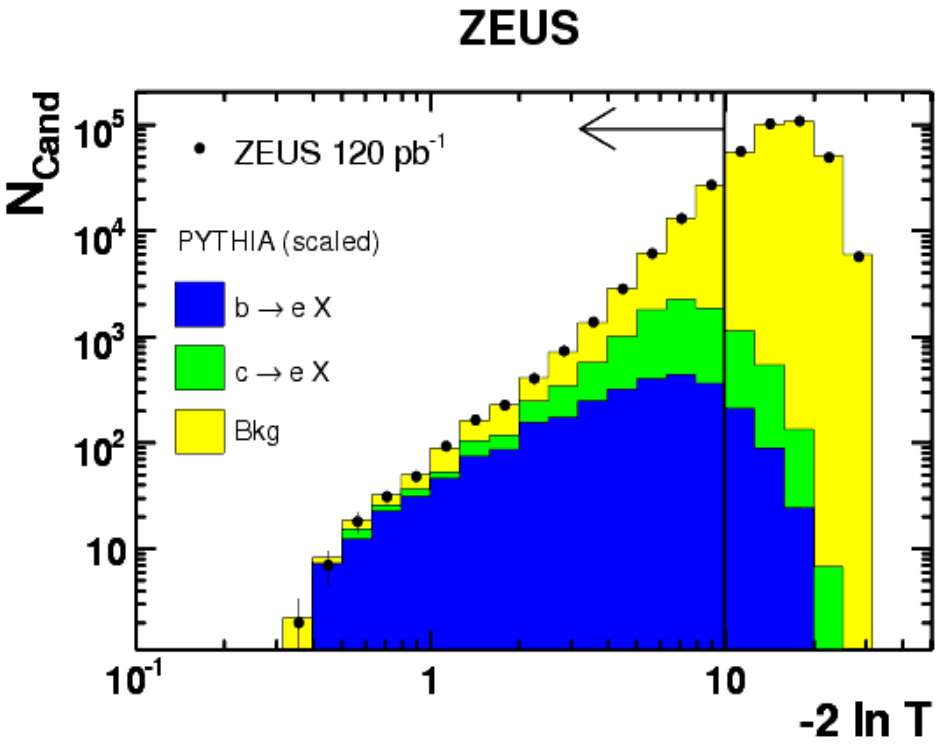
$$A_{ij} = \alpha_i \cdot P(dE/dx) \cdot P(E_{EMC}/E_{CAL}) \cdot P(E_{CAL}/p\,track) \cdot \tilde{\alpha}_j \cdot P(\Delta\phi) \cdot P(p_T^{rel.})$$

Particle abundance
$i\,A\{\pi^B, K^B, p, \bar{p}, e^B, \mu^B\}$

Decay abundance
$j\,A\{e^B_{SL}, e^B_{other}\}$

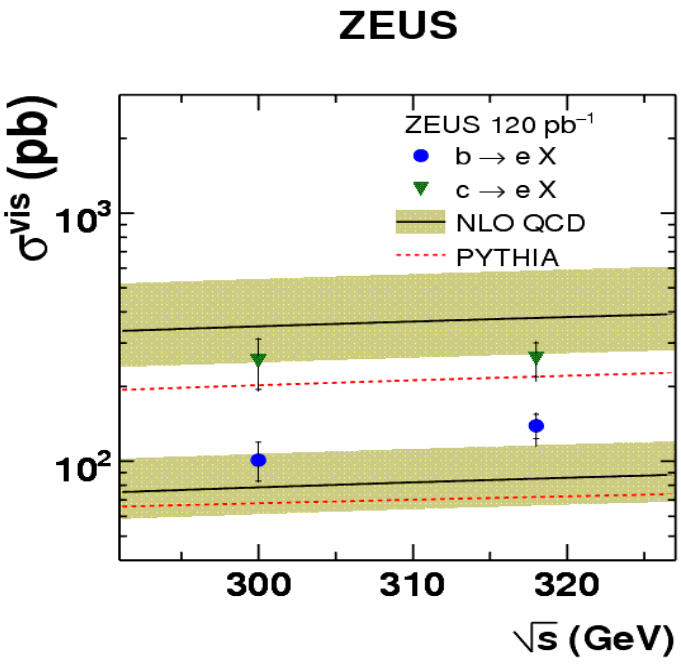
- Test function: $T_{ij} = \dfrac{A_{ij}}{\sum_{kl} A_{kl}}$

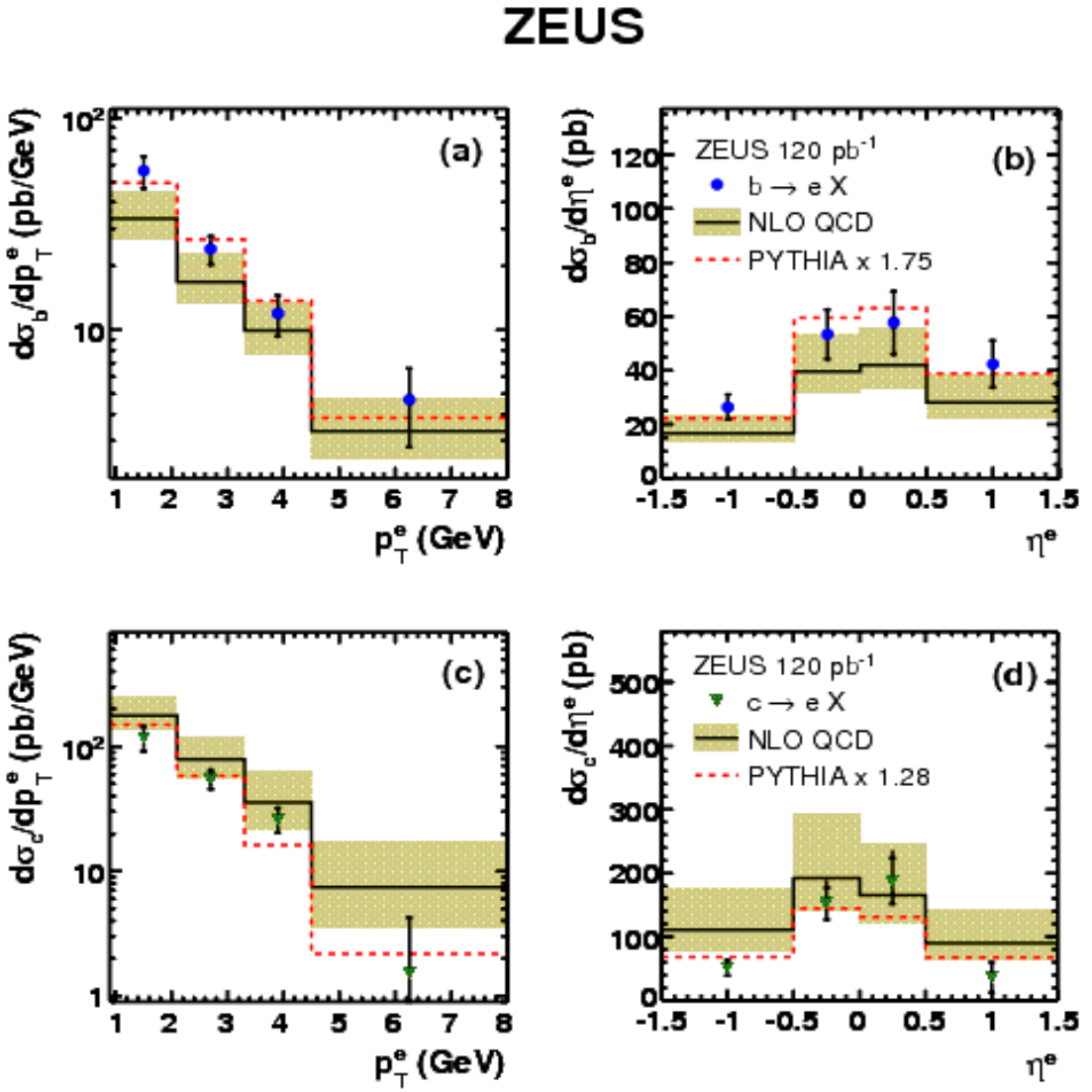
- Range of fit restricted to -2lnT < 1
- PYTHIA scale factors:
  - beauty: 1.75 ± 0.16
  - charm: 1.28 ± 0.13



Electron differential cross sections

- Charm cross sections have also been extracted using a likelihood ratio optimised for b-quark production

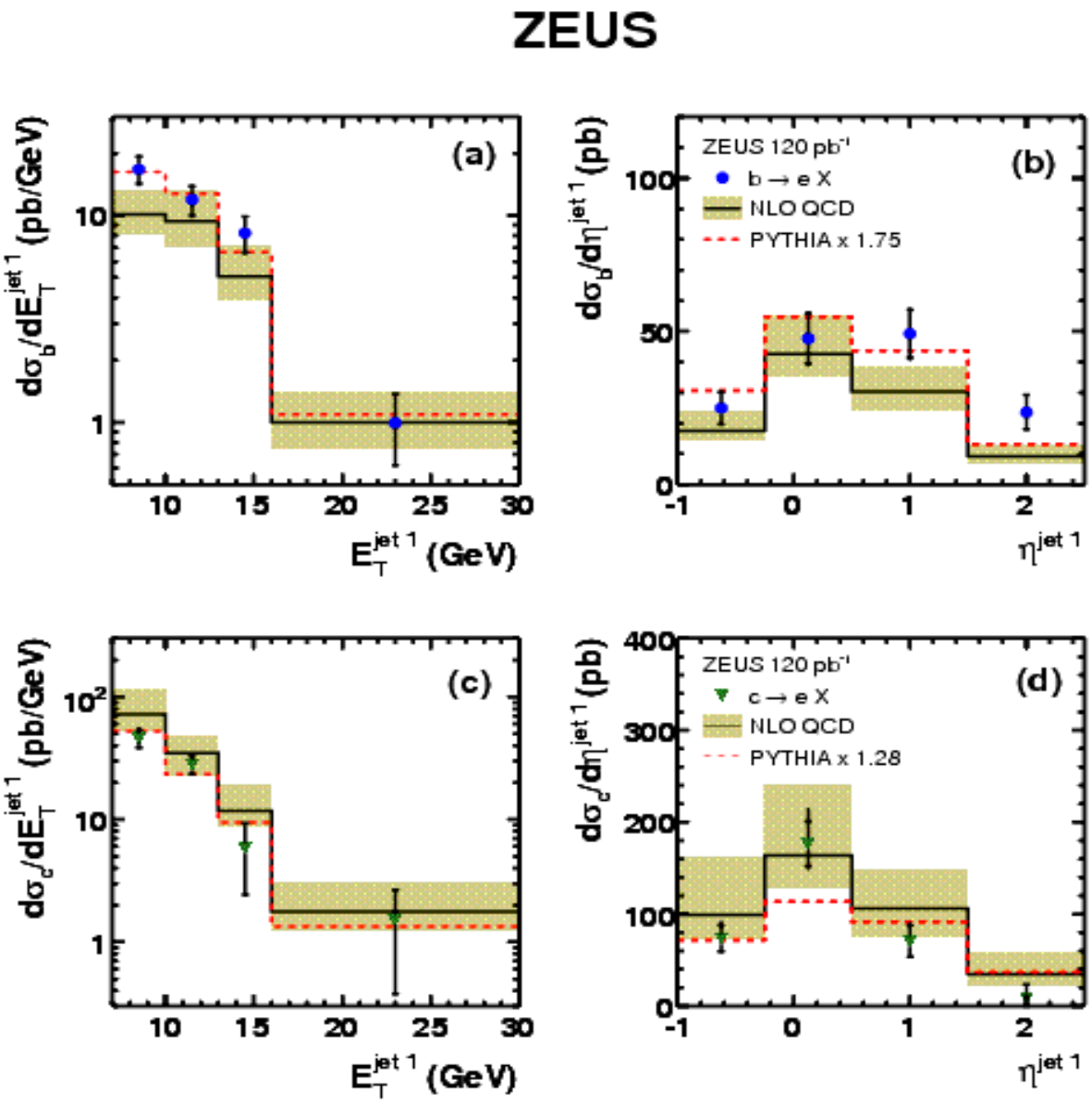




Jet differential cross sections

Beauty

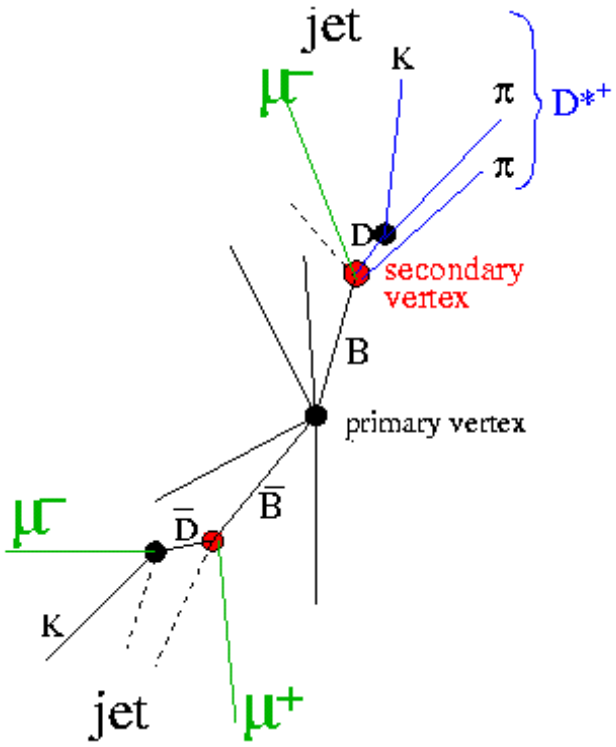
Charm



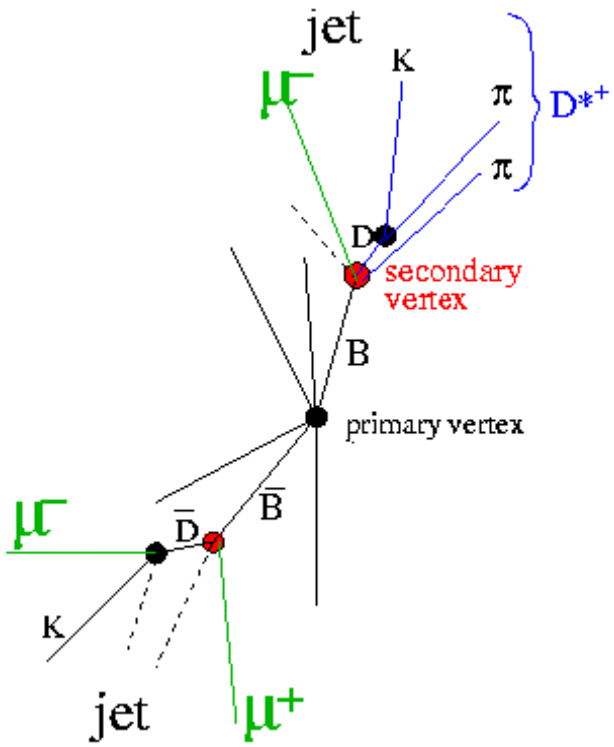
Dimuon analysis – method overview

- The data is organised into 4 subsamples
- Beauty is the only source of genuine like-sign muon pairs
- physics background: unlike sign only (from MC)
- fake muon background: like sign=unlike sign (from data)
- Determine the beauty contribution from difference between like and unlike sign muons

  (if the backgrounds are known)



m < 4 GeV	m > 4 GeV
++/--	++/--
m < 4 GeV	m > 4 GeV
+-	+-



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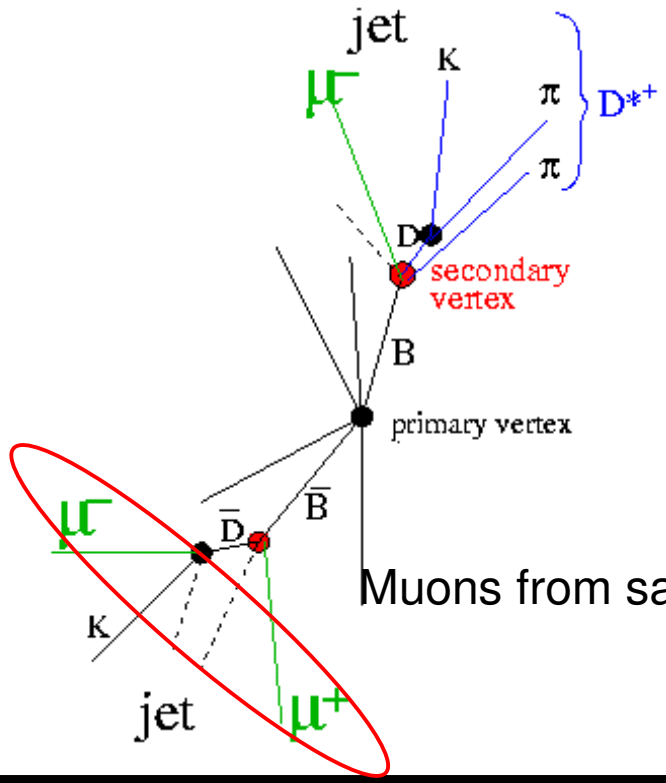

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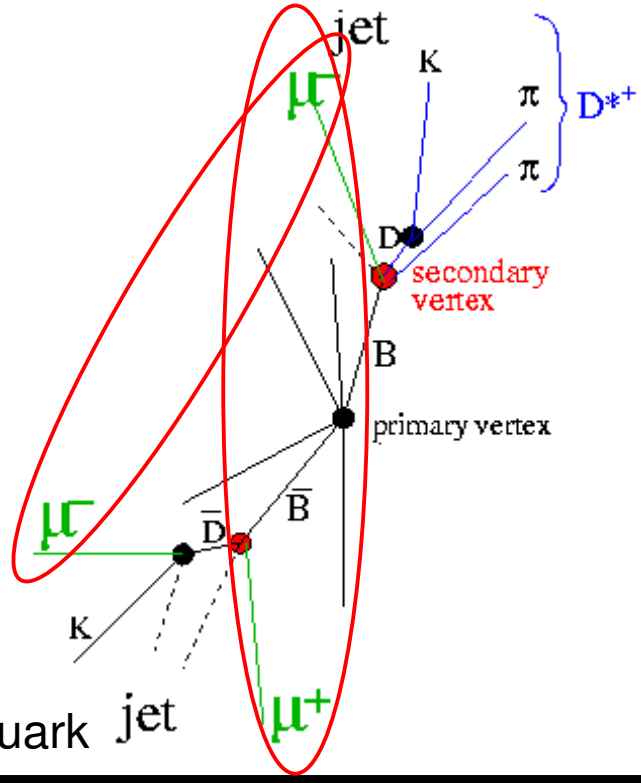
Muons from same b-quark



Muons from different b-quark

Dimuon analysis

- This analysis uses $e^{\pm}p$ data collected in 96-00: ~$114pb^{-1}$
- $-2.2 < \eta^{\mu} < 2.5$, $p_T^{\mu} > 1.5$ GeV and $p_T^{\mu} > 0.75$ GeV for higher quality muons, no jet requirement

Backgrounds:

- Open charm (high mass, unlike sign)

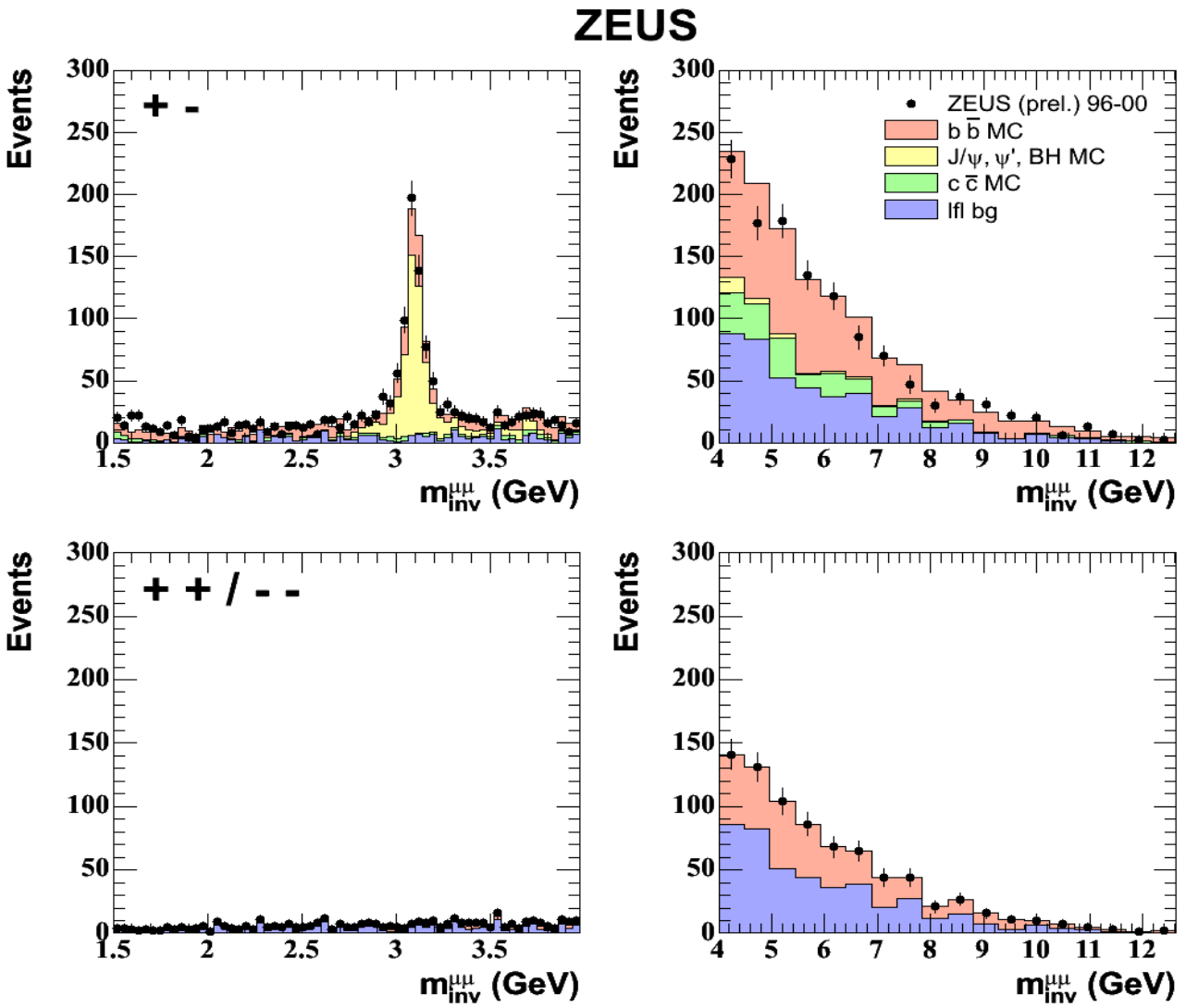
  Normalisation from D*μ analysis
- Hidden charm (J/ψ, ψ')

  (low mass, unlike sign)

  Isolation cut
- Bethe-Heitler (high mass, unlike sign)

  Isolation cut
- Light flavour all regions

  From data



Theoretical model used in NLO comparison

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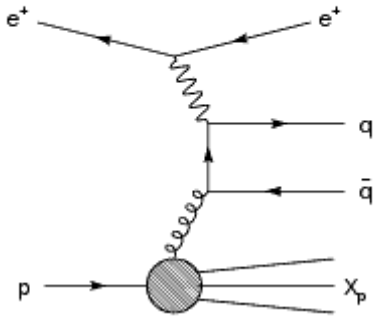
- Appropriate for $p_T^2 \sim M_b^2$, if $p_T^2 >> M_b^2$ then large $\ln(p_T^2/M_b^2)$ appear
- Program used in photoproduction is FMNR (Frixione et al.)

$\mu = \mu_0/2 = 1/2 \sqrt{((p_T^b)^2 + (m_b)^2)}$ $\quad 0.25\,\mu_0 < \mu < \mu_0$

$m_b = 4.75\text{GeV}$ $\quad 4.5\text{GeV} < m_b < 5\text{GeV}$

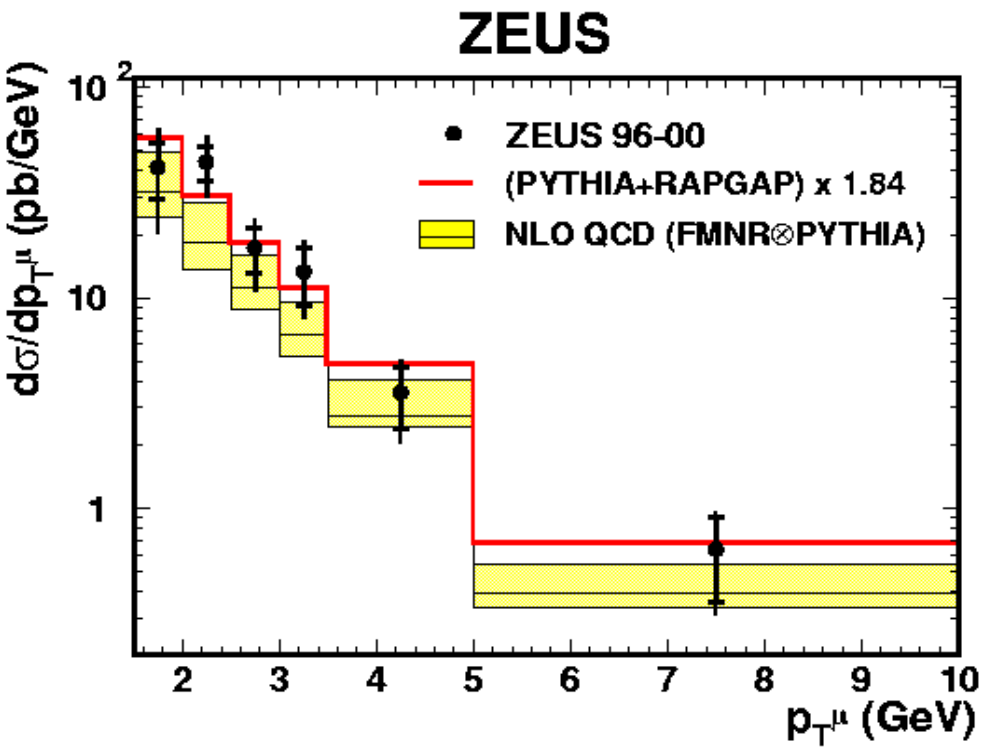
Proton PDF: CTEQ5M, Photon PDF GRV-G HO

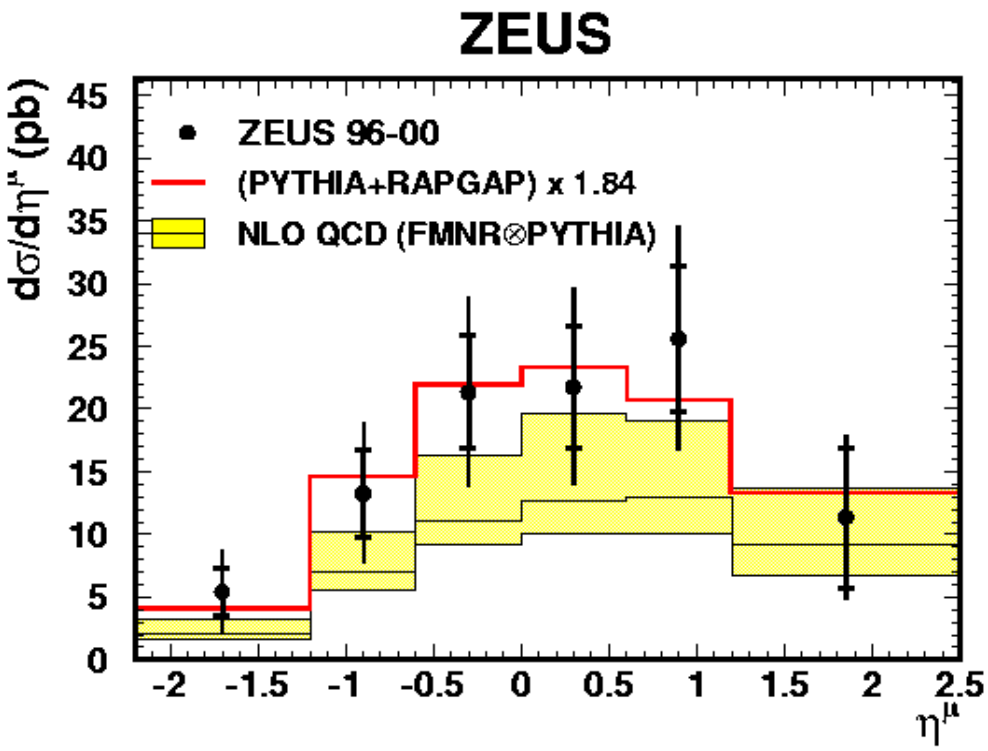


- WW approximation $Q^2 = 25\text{GeV}$ to include DIS contribution
- FMNR x PYTHIA interface for visible $\mu\mu$ cross sections

Muon differential cross sections

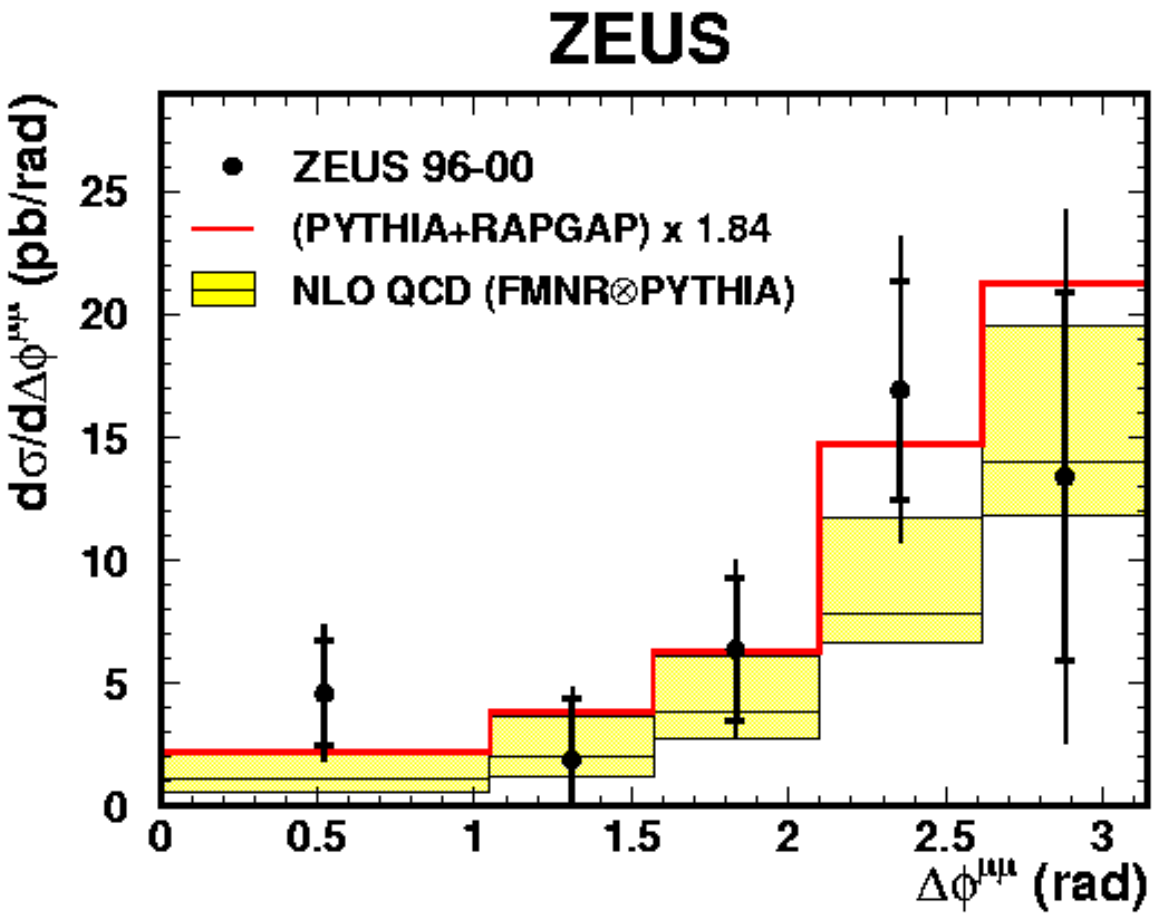
- Both muons $p_T^\mu > 1.5$ GeV, $-2.2 < \eta^\mu < 2.5$
- Good agreement in shape and reasonable agreement in normalisation

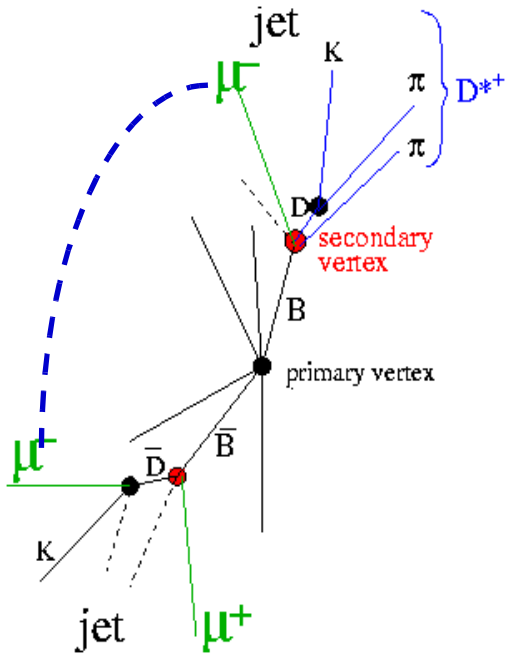




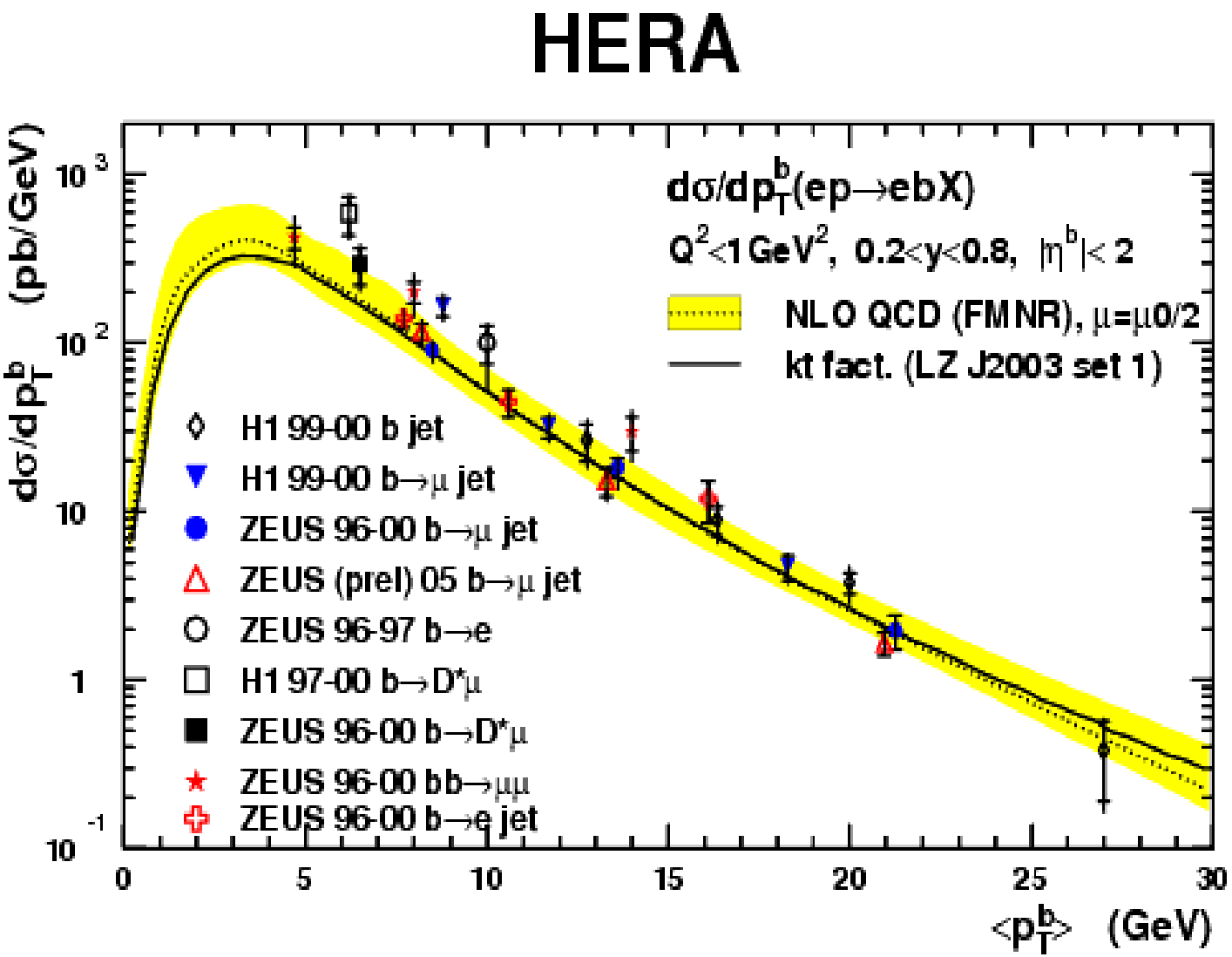
Beauty correlations

- $\Delta\phi = (\phi^{\mu 1} - \phi^{\mu 2})$ between muons form different quarks ($m^{\mu\mu} > 3.25$GeV)
- b-correlations are well described





Beauty summary plot



Conclusions

- Three complimentary analyses in beauty photoproduction at ZEUS have been presented:

- Semi-muonic tag in HERA II
  - Analysis uses MVD for the first time to extract beauty
  - p_T^{rel} and impact parameter method gives results which agree with HERA I p_T^{rel} only measurement
- Electron tag analysis with HERA I data
  - Beauty and charm cross sections have been measured using a likelihood ratio test
  - Agreement had been found with NLO
- Dimuon analysis at HERA I
  - Beauty extracted using muon double tag
  - bb correlations measured and are in agreement with NLO (within large errors)

- beauty production at HERA is in reasonable agreement with NLO
- theory is appropriate for cross section calculation at LHC