

Beauty Photoproduction at ZEUS

XVI International Workshop on Deep-Inelastic
Scattering and Related Subjects

7-11 April 2008

University College London

-On Behalf of the ZEUS Collaboration-
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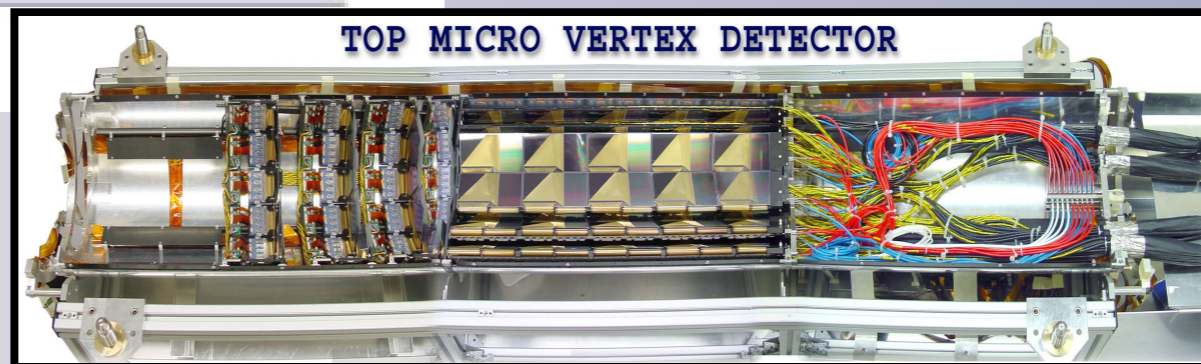
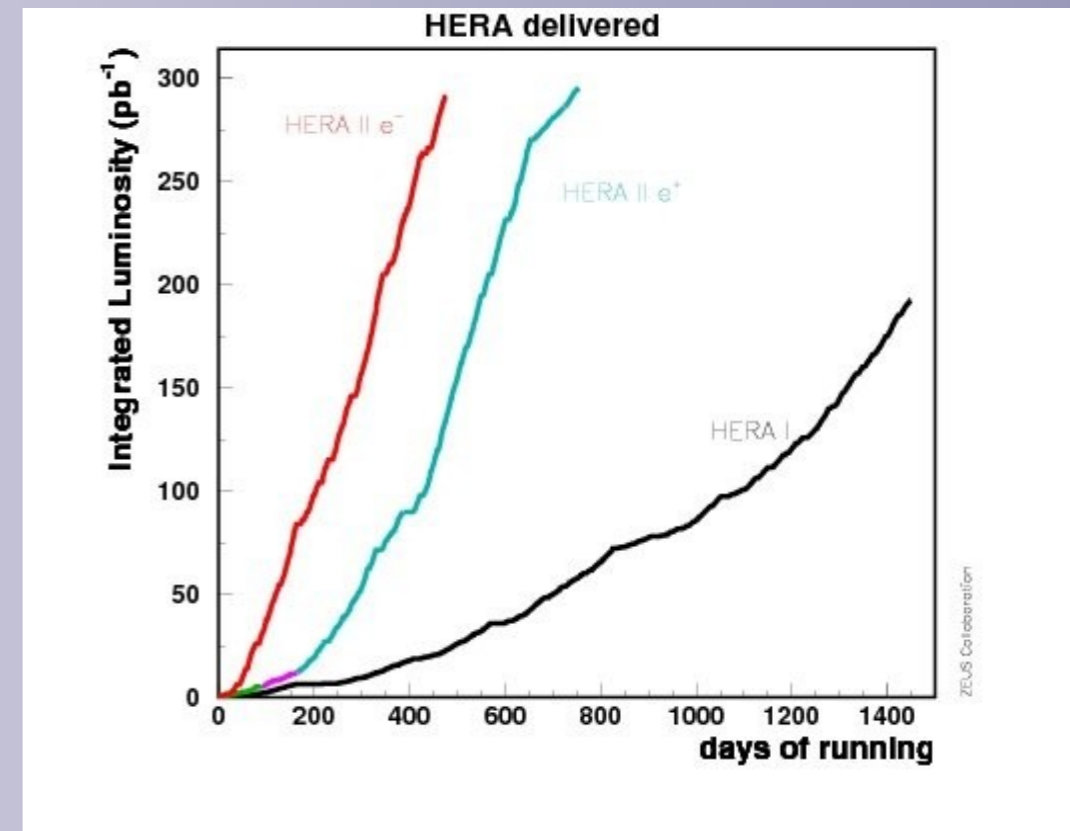
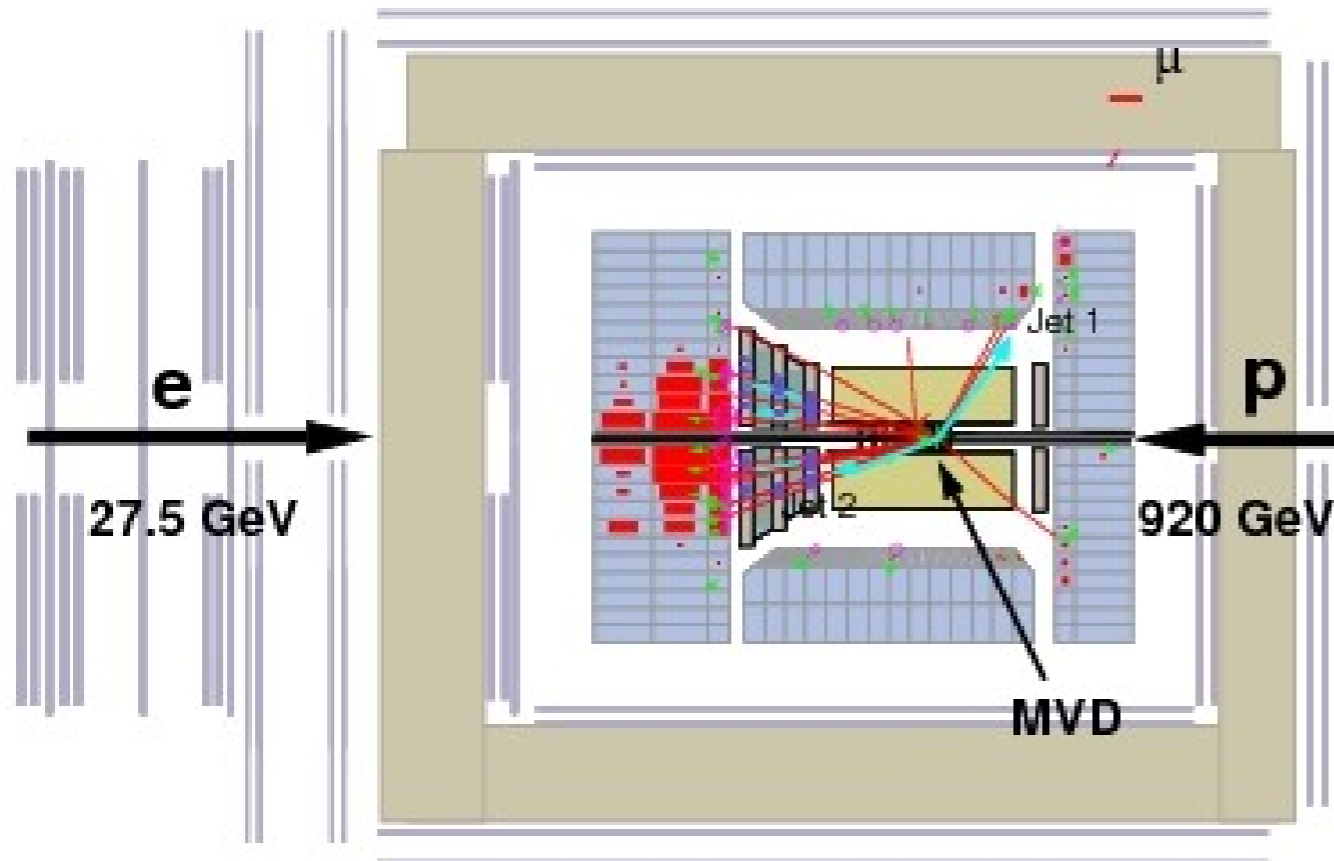
Physikalisches Institut
der Rheinischen Friedrich-Wilhelms-Universität Bonn

Introduction

Three analyses will be presented:

- Dijet PhP, semi-leptonic decays into muons, preliminary results using 124 pb^{-1} **HERA II data**
 - lifetime tagging available
- Dijet PhP, semileptonic decays into electrons, **final HERA I result** (120 pb^{-1})
 - Increase of kinematic range wrt muon analysis (lower jet-energy and $p_{\text{T}}^{\text{lepton}}$ cuts), charm cross-section measured as well
- Dimuon analysis, **final HERA I result** (114 pb^{-1})
 - both beauty quarks tagged, low background, almost full rapidity range

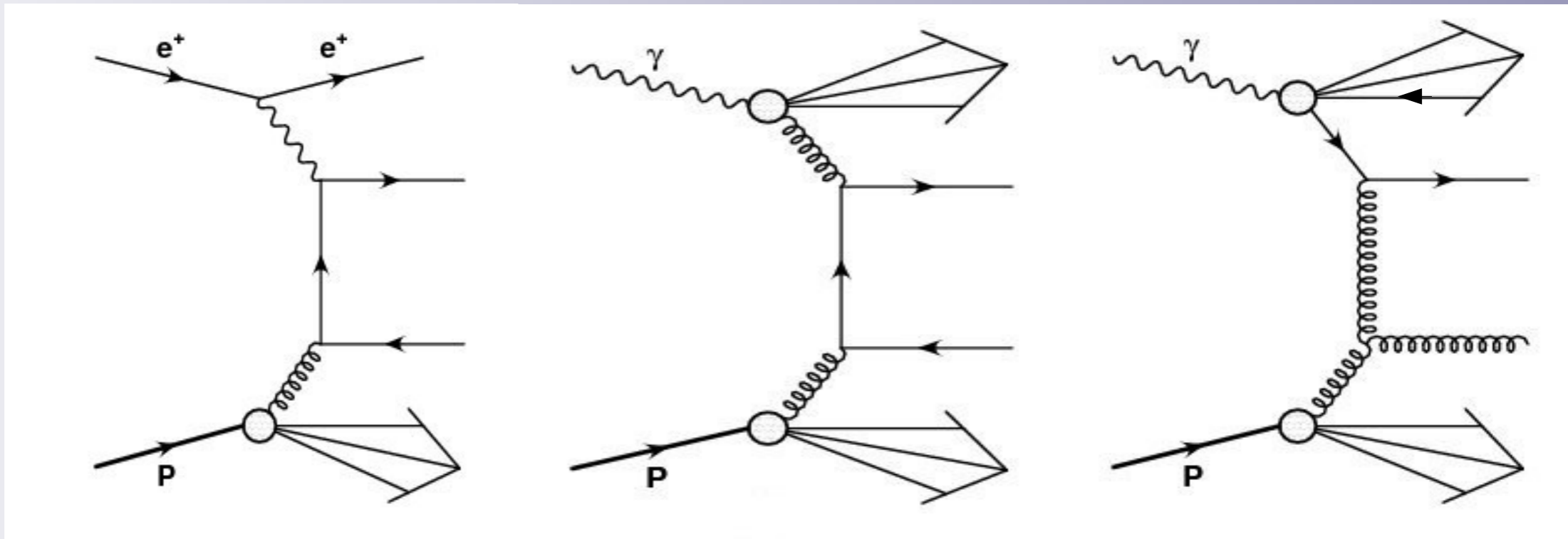
HERA & ZEUS



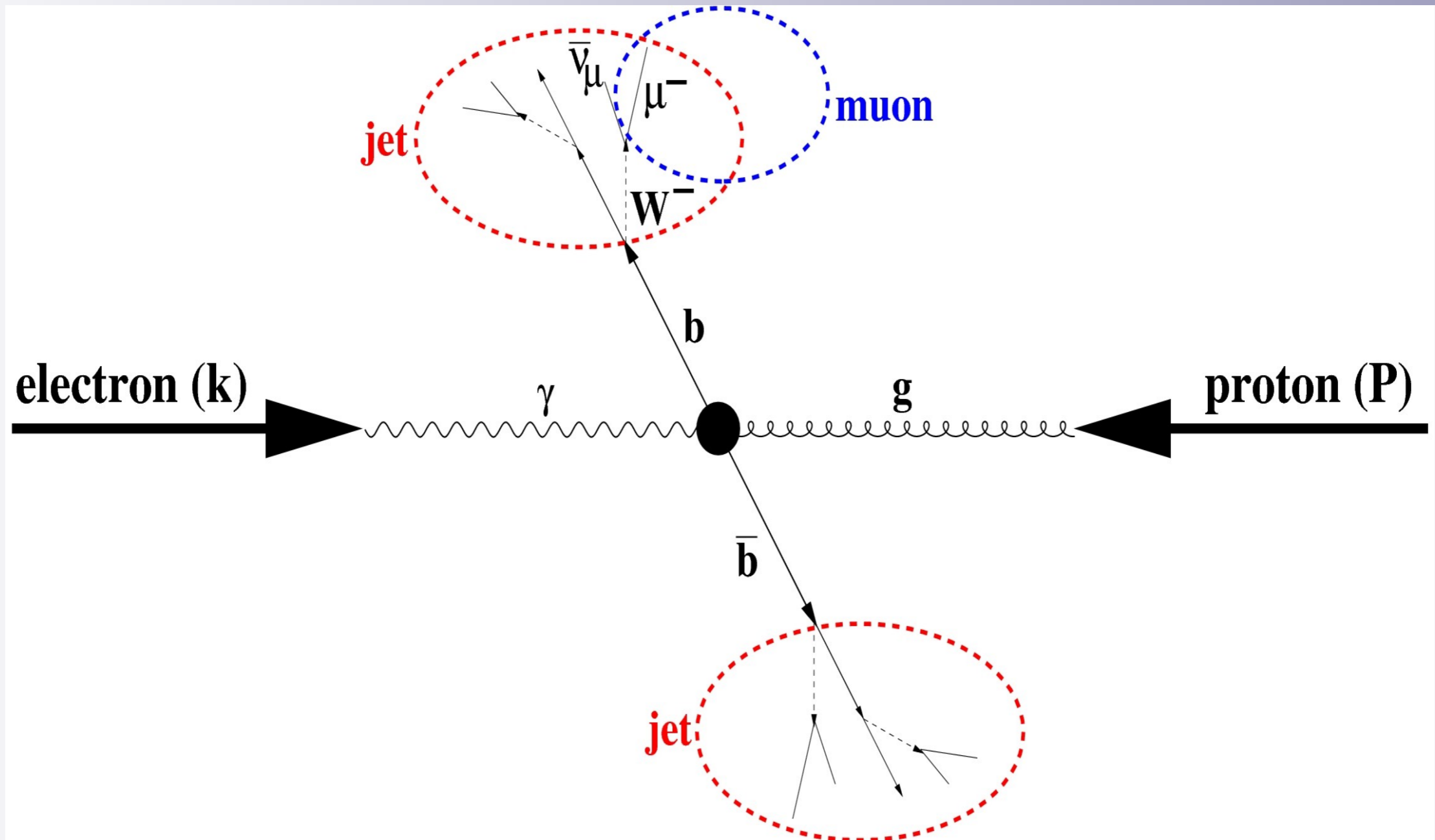
HERA integrated luminosity 96-07: 0.5 fb^{-1}
Since 2002 micro-vertex detector for lifetime tagging

Motivation

- Beauty production at HERA is good testing ground for pQCD
- Test of multiple-scale problem: $m_b, p_T^b, (Q^2)$
- LO+PS Monte Carlo (including flavour excitation)
 - PYTHIA for dijet in PhP analyses
 - PYTHIA & RAPGAP for dimuon analysis

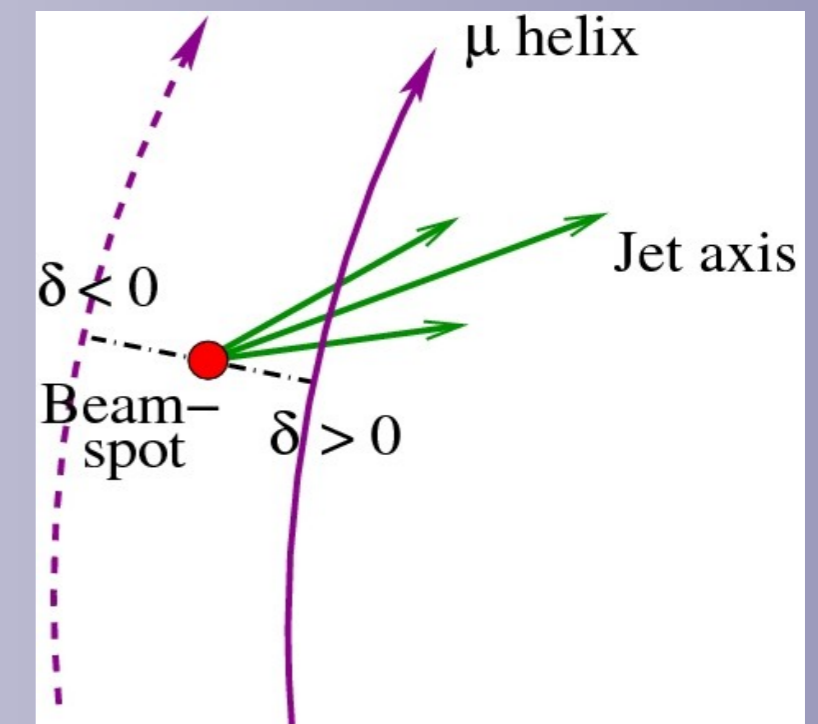
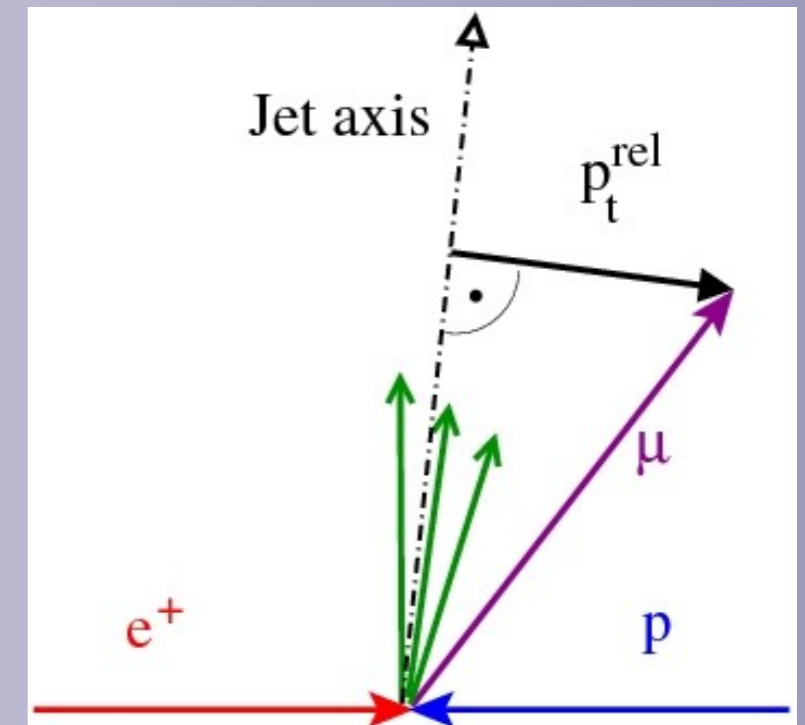


Dijet PhP Analyses



Dijet PhP $b \rightarrow \mu$ – Beauty Extraction

- Component of μ momentum transverse to jet axis, p_T^{rel}
- Harder spectrum for B decays because of large B mass
- Signed μ impact parameter, δ
- Symmetrically distributed around zero for light flavour
- Positive tail for beauty and charm due to longer life-time



Dijet PhP $b \rightarrow \mu$ – Event Selection

2005 e^+p data: $\mathcal{L} = 124 \text{ pb}^{-1}$

Photoproduction:

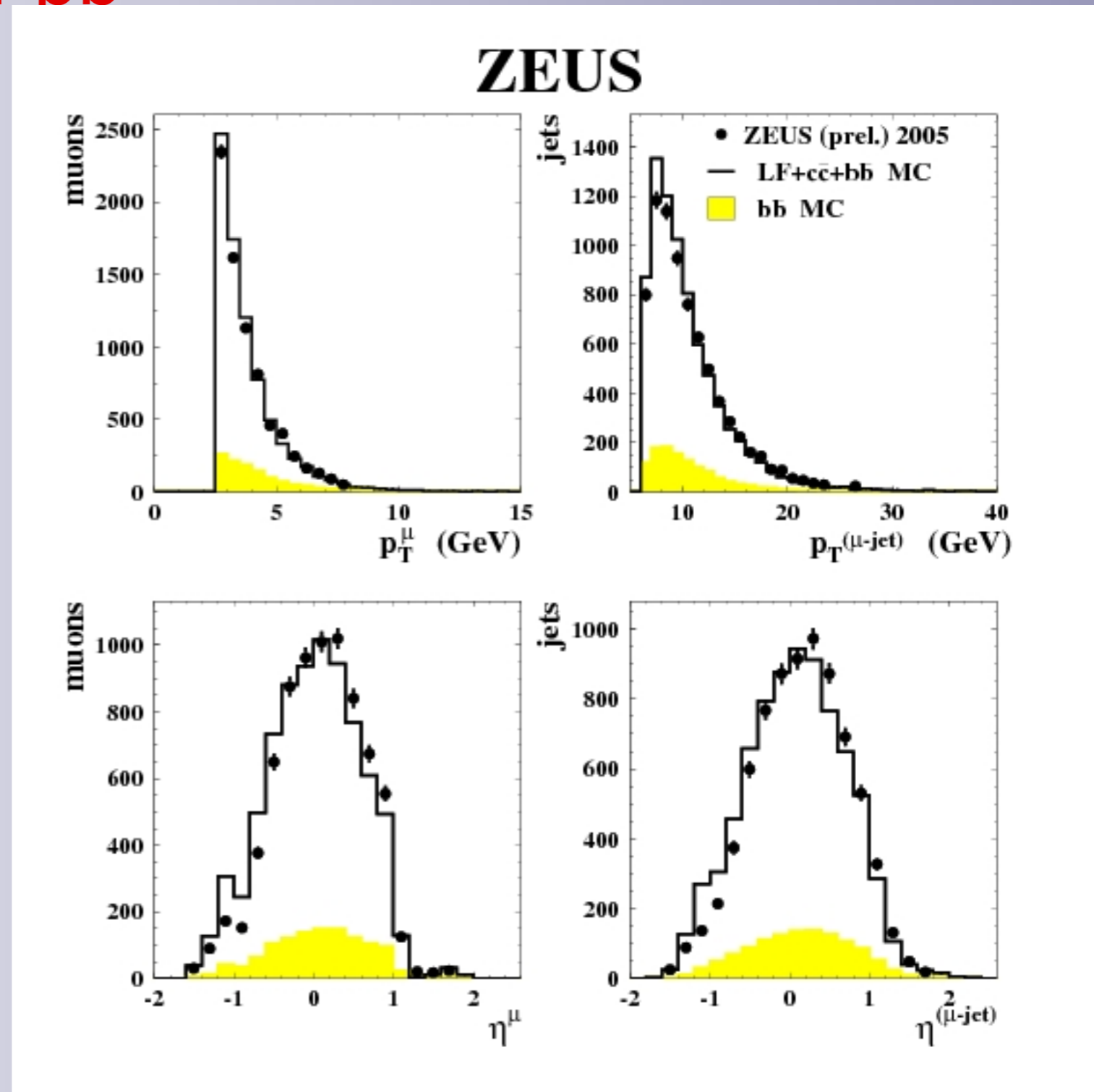
- Veto on scattered e^+ $0.2 < y_{JB} < 0.8$

Jet finding:

- k_T -clustering (massive), $N_{jet} \geq 2$
- $p_T > 7(6) \text{ GeV}$
- $|\eta| < 2.5$

μ selection:

- $p_T^\mu > 2.5 \text{ GeV}$
- $-1.6 < \eta < 2.3$

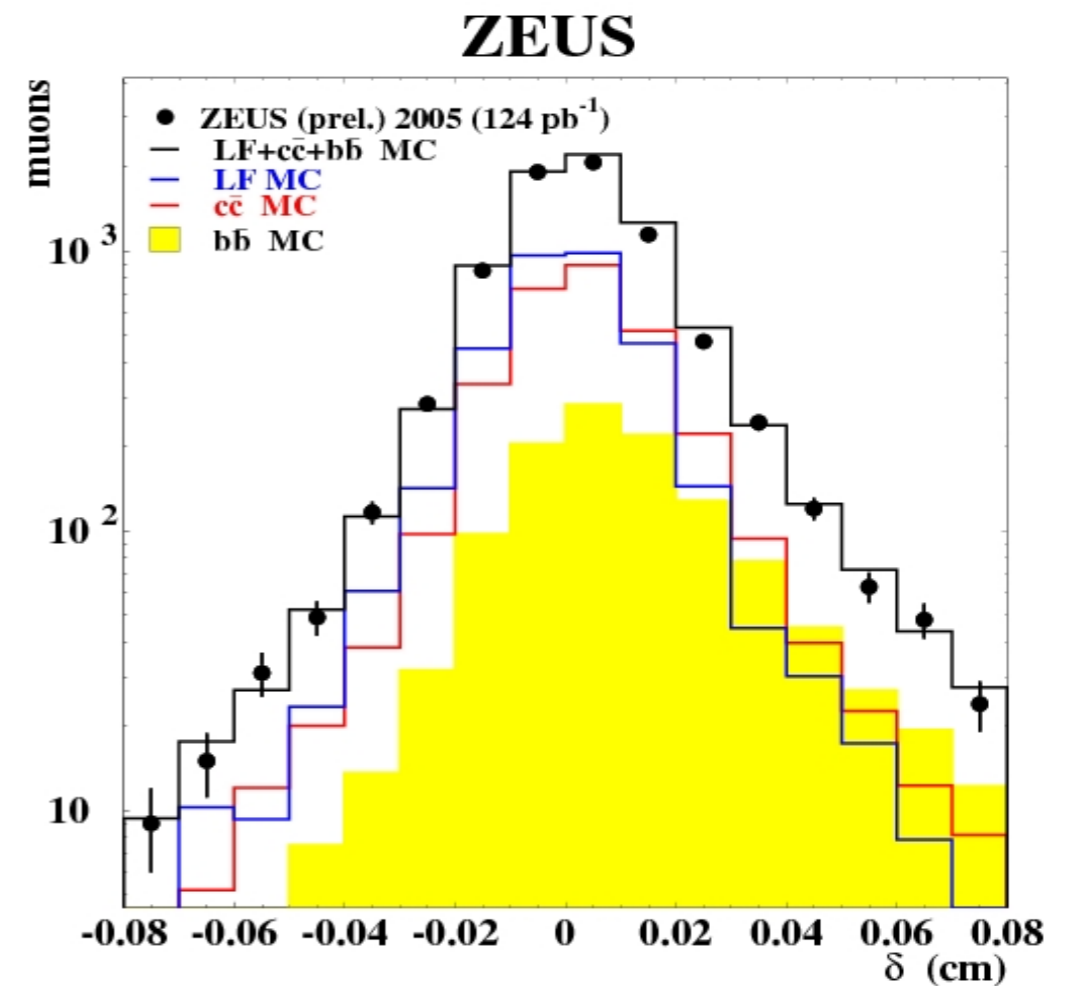
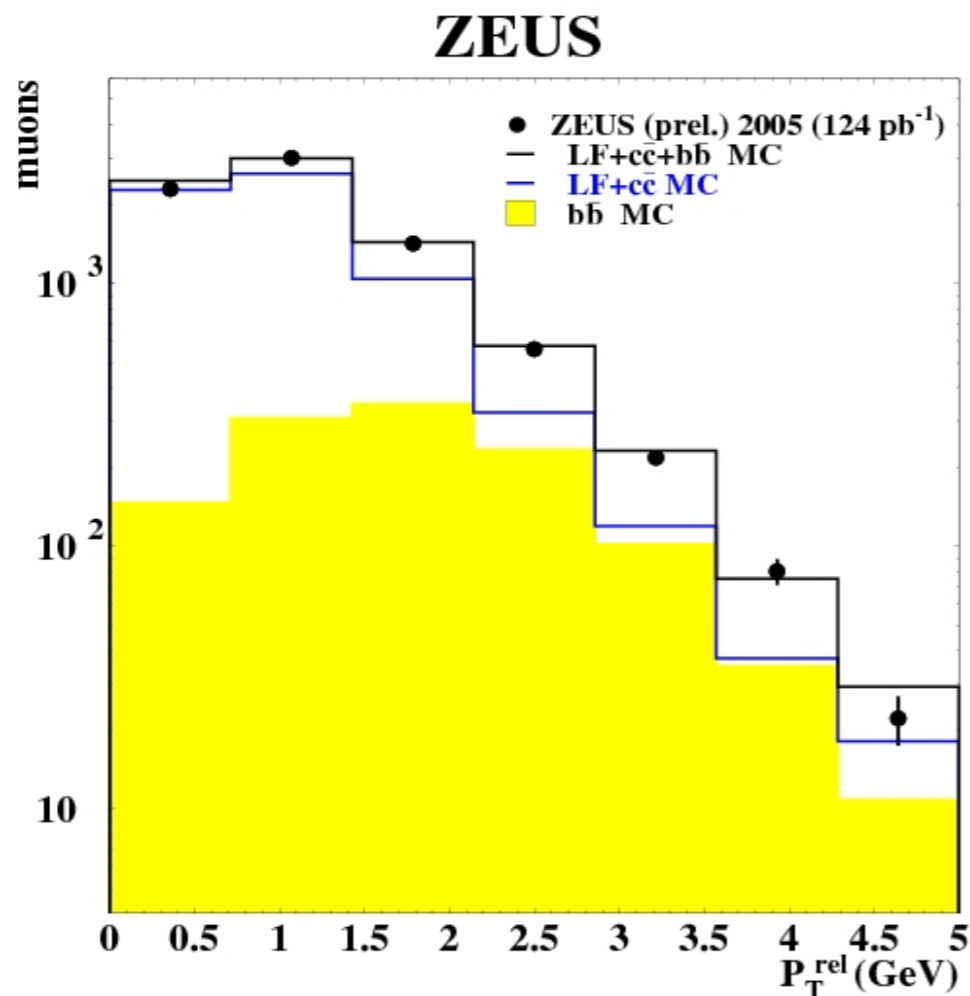


Dijet PhP $b \rightarrow \mu$ – Fit

Combined fit of p_T^{rel} and δ

$$f_b = 15.5 \pm 1.3\%, f_c = 40.1 \pm 4.8\%$$

- p_T^{rel} shape of LF MC corrected using inclusive data sample
- Beam position: Event vertex averaged over event ranges
- Resolution of δ modeled on incl. data sample



NLO QCD Predictions Dijet Analyses

Massive scheme

b massive

reliable for $p_T \sim m_b$

FMNR Program used

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

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

$$\text{PDF}(P) = \text{CTEQ5M}; \quad \text{PDF}(\gamma) = \text{GRV-G HO}$$

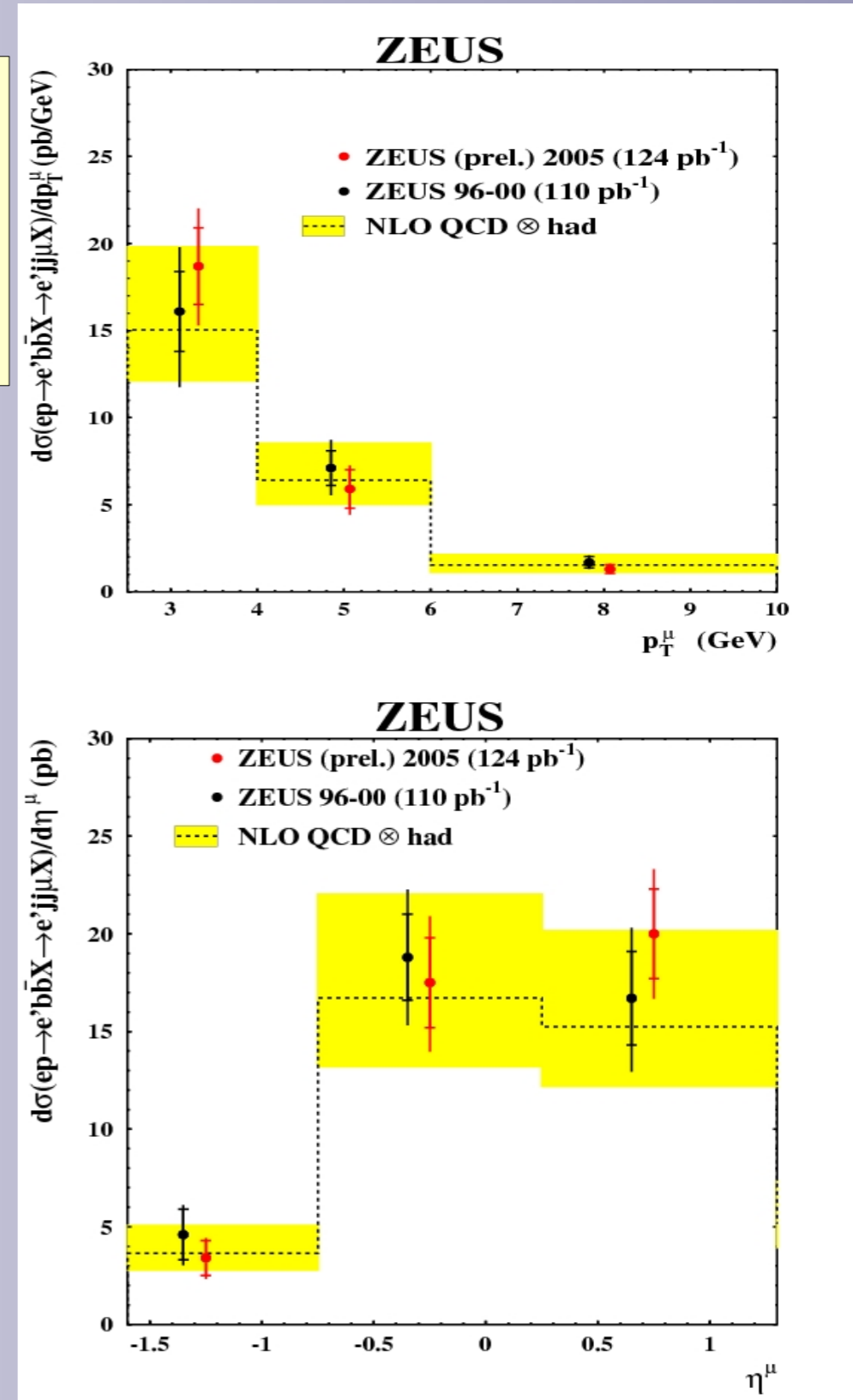
hadronisation corrections from PYTHIA

Dijet PhP $b \rightarrow \mu$ – Results

$$\sigma^{vis} = 46.8 \pm 4.0 (stat.) \pm_{7.2}^{6.1} (syst.) pb$$

$$\sigma^{NLO} = 41.5 \pm_{8.9}^{13.9} pb$$

- Good agreement with QCD NLO
- Good agreement with HERA I analysis (p_T^{rel} only)



Dijet PhP $b \rightarrow \mu$ Summary

- Beauty photoproduction has been measured in the 2005 data using semi-leptonic decays into muons
- The beauty fraction has been determined using a combined $p_T^{rel} - \delta$ fit
- The visible cross-sections are in agreement with the NLO QCD predictions and the results of the analysis of the HERA I data using a p_T^{rel} -only fit
- Only 1/3 of HERA II statistics used so far

Dijet PhP $b \rightarrow e$ Event Selection

96-00 e^+p data: $\mathcal{L} = 120 \text{ pb}^{-1}$

Photoproduction:

- Veto on scattered e^+ , $0.2 < y_{JB} < 0.8$

Jet finding:

- k_T -clustering (massive), $N_{\text{jet}} \geq 2$

- $E_T > 7(6) \text{ GeV}$

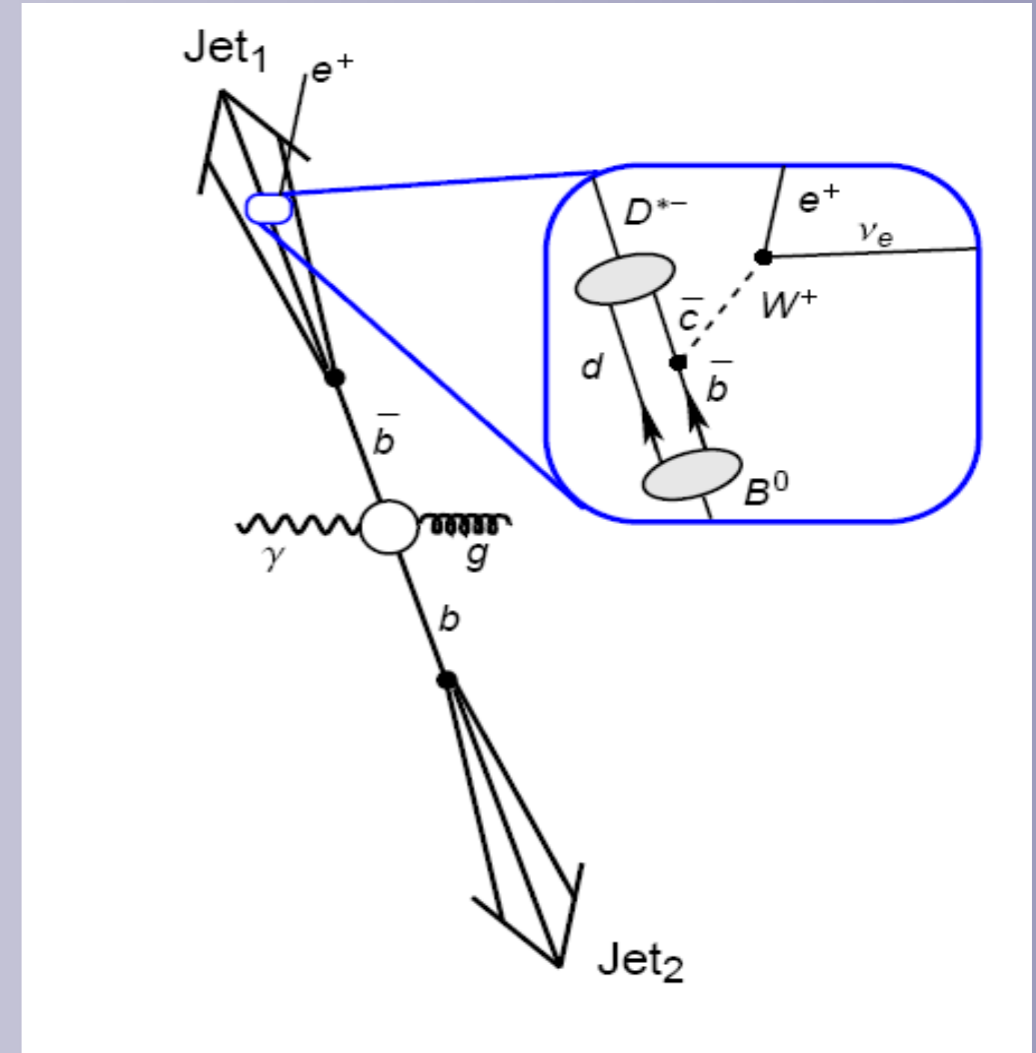
- $|\eta| < 2.5$

e_{SL}^\pm candidate

- $p_T^e > 0.9 \text{ GeV}$

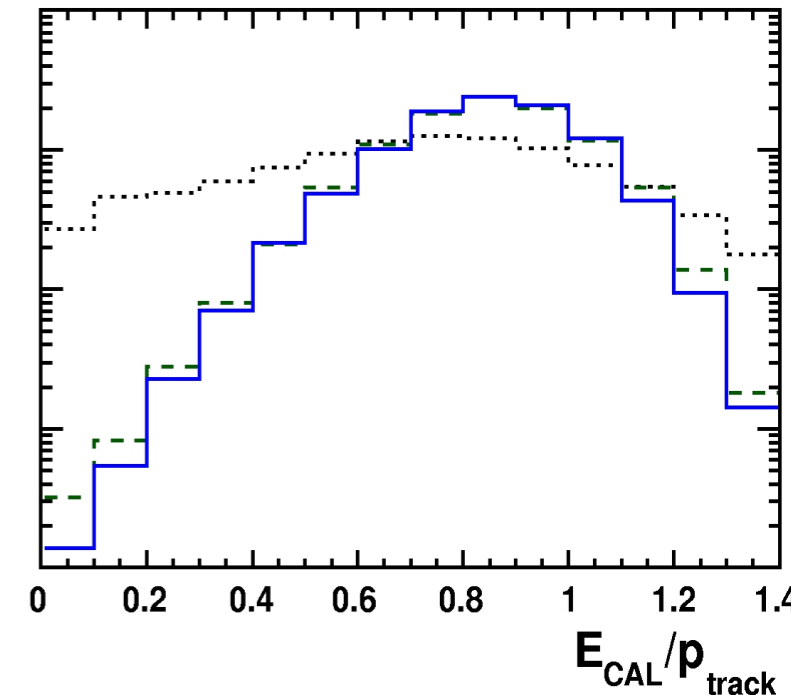
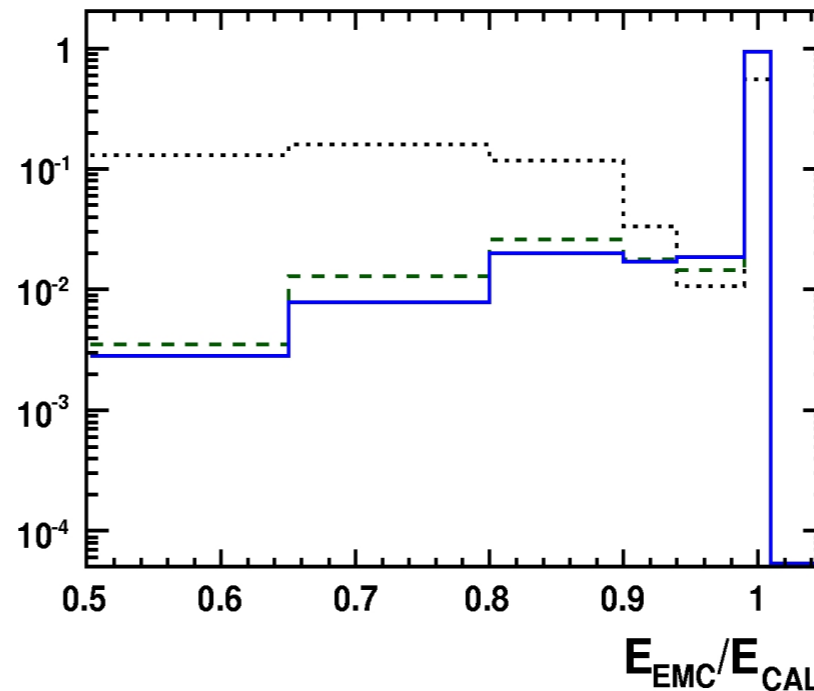
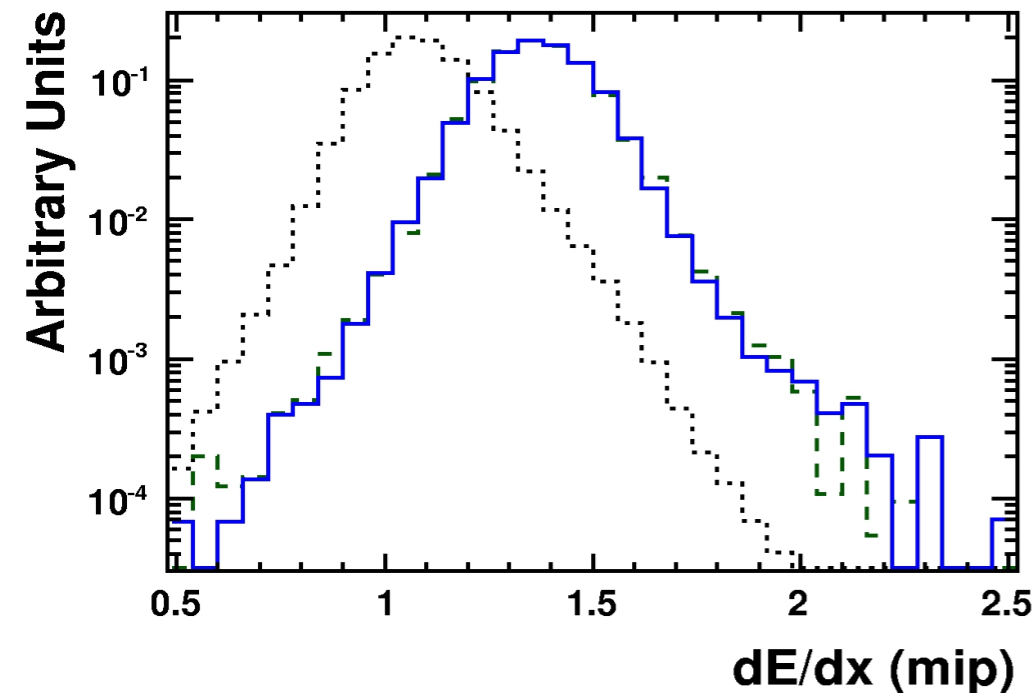
- $|\eta| < 1.5$

- $dE/dx > 1.1 \text{ mip}$, $\text{EMCfraction} > 0.9$



Dijet PhP $b \rightarrow e$ Beauty Extraction I

- b-fraction extracted from likelihood fit using variables sensitive to e-identification and semileptonic decays
- Electron variables: dE/dx , $E_{\text{EMC}}/E_{\text{tot}}$, $E_{\text{CAL}}/p_{\text{trk}}$



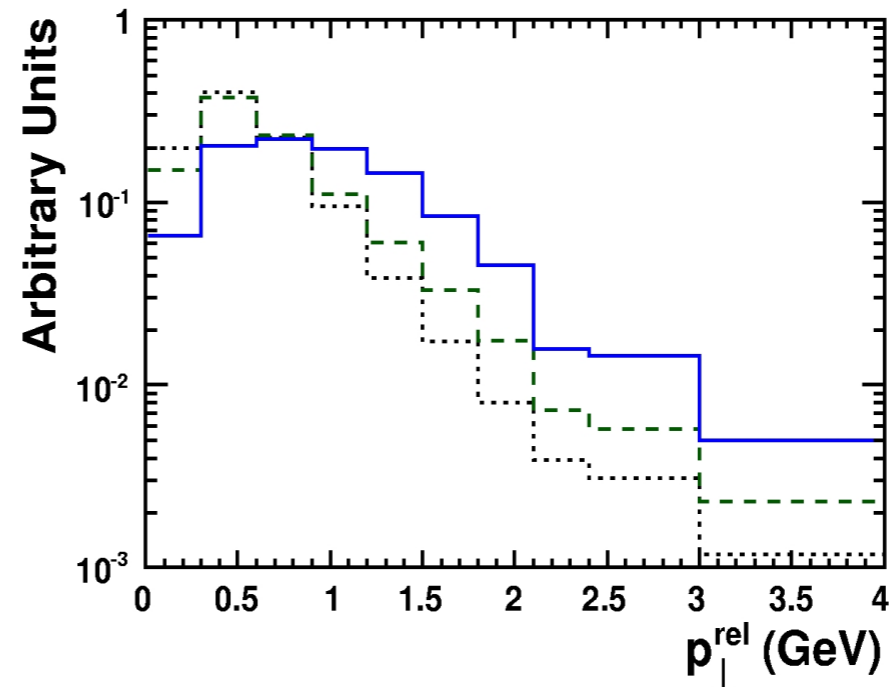
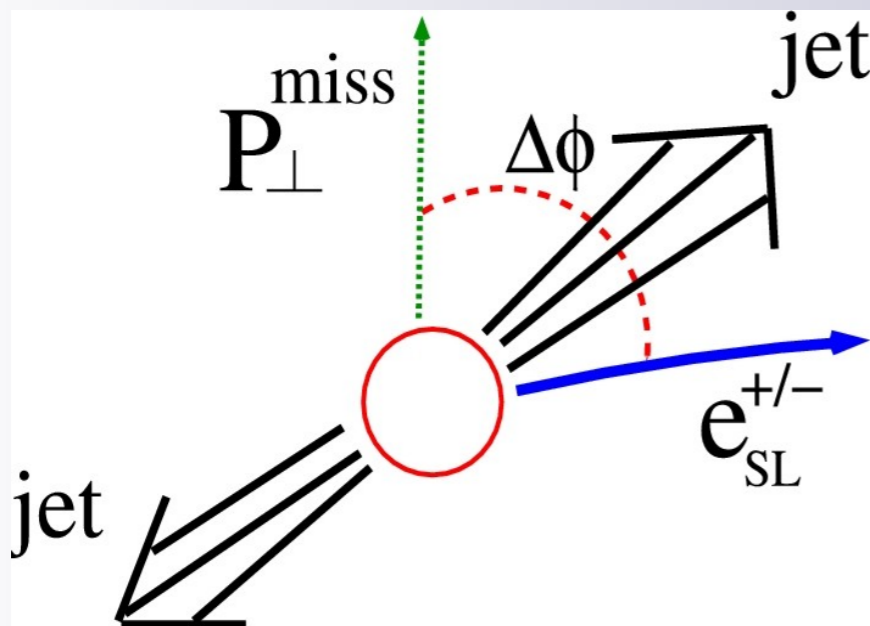
— $b \rightarrow e X$
- - $c \rightarrow e X$
... Bkg

Dijet PhP $b \rightarrow e$ Beauty Extraction II

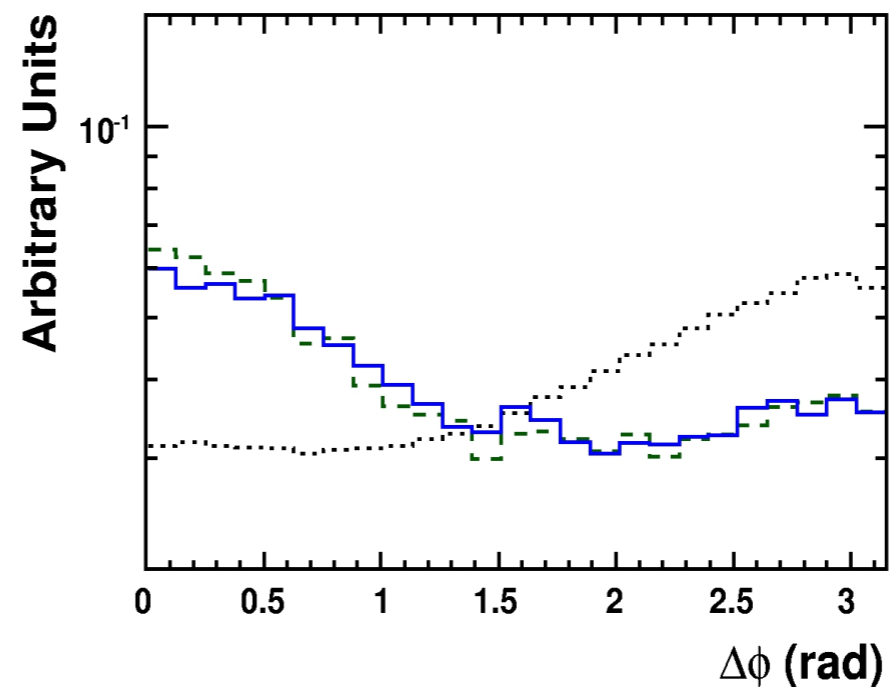
- Semileptonic decay variables:

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

$$\Delta \phi = \phi(p^e; p_T^{\text{miss}})$$



p_T^{rel}



$\Delta\phi$

Dijet PhP $b \rightarrow e$ Fit Method

- Hypothesis test for particle of sort i (decay j)

$$\mathcal{L}_{ij} = \alpha_i \cdot P(dE/dx) \cdot P(E_{CAL}/E_{tot}) \cdot P(E_{CAL}/p_{trk}) \cdot \tilde{\alpha}_j \cdot P(\Delta\phi) \cdot P(p_T^{rel})$$

α_i particle abundance

$\tilde{\alpha}_j$ decay abundance

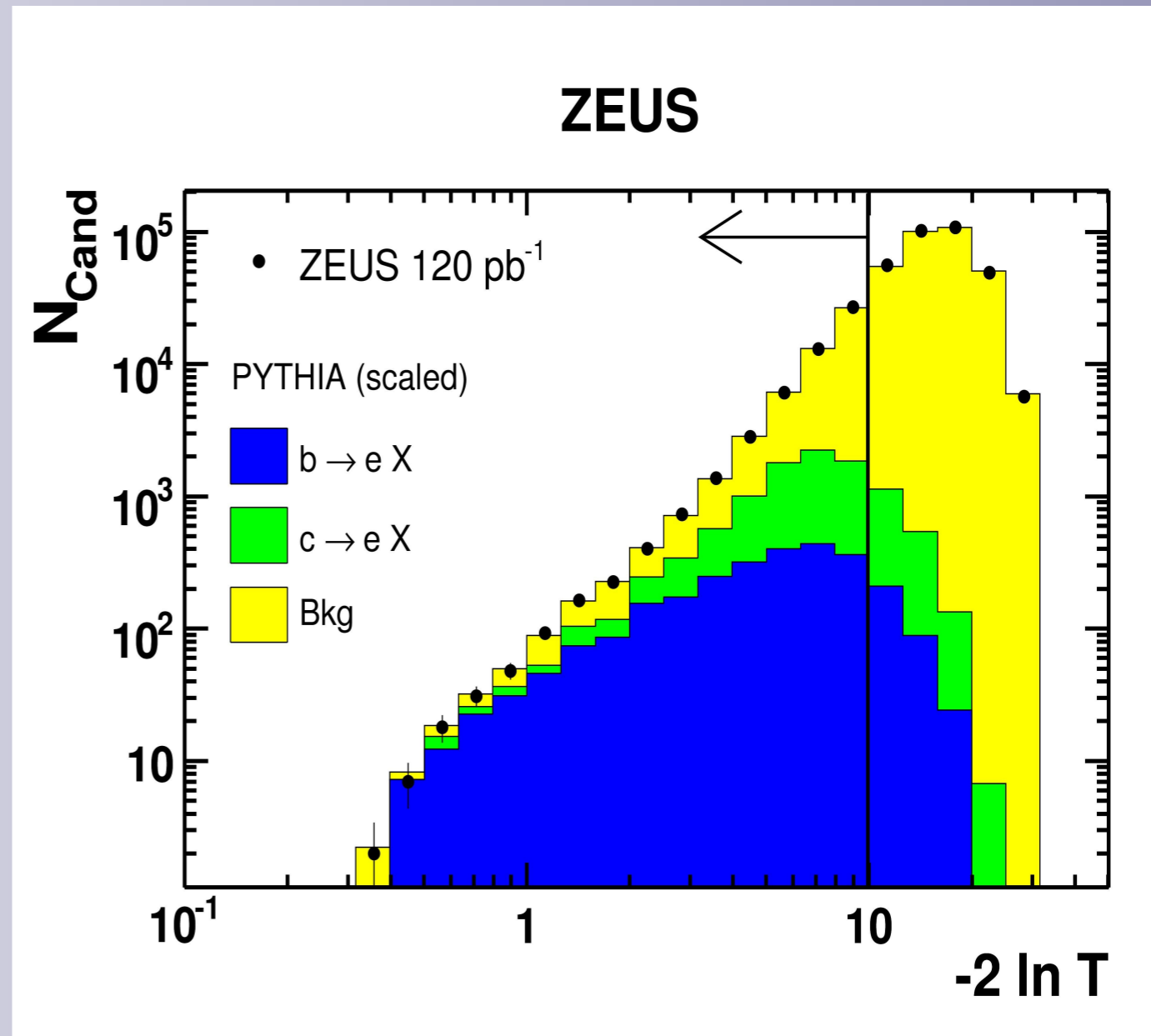
$i \in \{\pi^\pm, K^\pm, p, \bar{p}, e^\pm, \mu^\pm\}$

$j \in \{e^\pm \text{ from sl. decay, other } e^\pm\}$

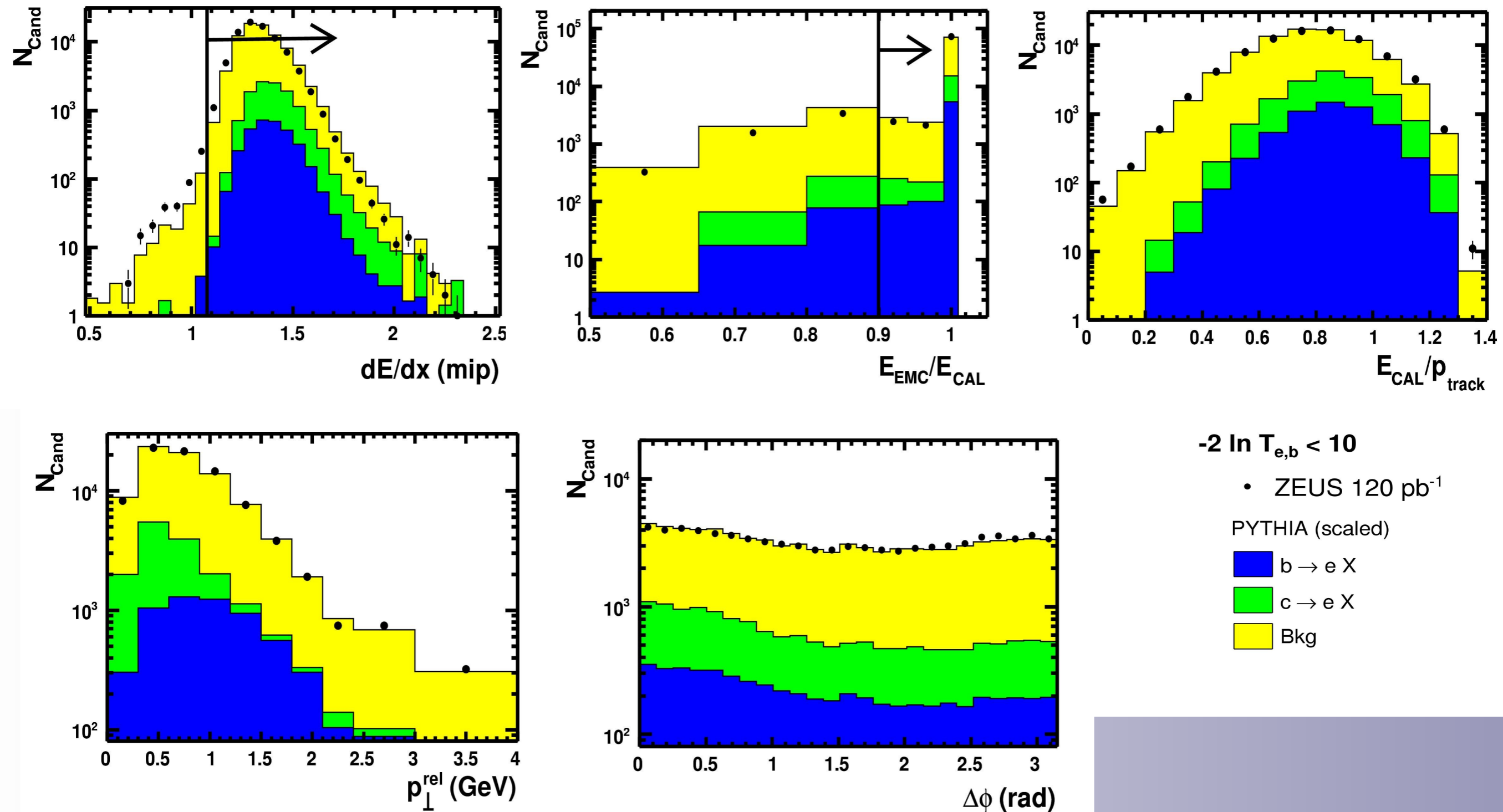
$$\text{Test Function } T_{ij} = \frac{\mathcal{L}_{ij}}{\sum_{kl} \mathcal{L}_{kl}}$$

Dijet PhP $b \rightarrow e$ Fit

- Beauty hypothesis
 - Fit contributions to $T_{e,b}$ in region up to $-2\ln T < 10$
 - PYTHIA scale factors
beauty: 1.75 ± 0.16 ,
charm: 1.28 ± 0.13



Dijet PhP $b \rightarrow e$ Control Plots



Dijet PhP $b \rightarrow e$ Total Cross-Section

Total visible cross-section for beauty and charm:

- $E_T^{\text{jet}} > 7(6) \text{ GeV}, |\eta^{\text{jet}}| < 2.5, p_T^e > 0.9 \text{ GeV}, |\eta^e| < 1.5$

$$\sigma_b^{\text{vis}} = 125 \pm 11 \text{ (stat.)} \pm_{11}^{10} \text{ (syst.) pb}$$

$$\sigma_b^{\text{tot}} = 88 \pm_{13}^{22} \text{ pb}$$

$$\sigma_c^{\text{vis}} = 278 \pm 33 \text{ (stat.)} \pm_{24}^{48} \text{ (syst.) pb}$$

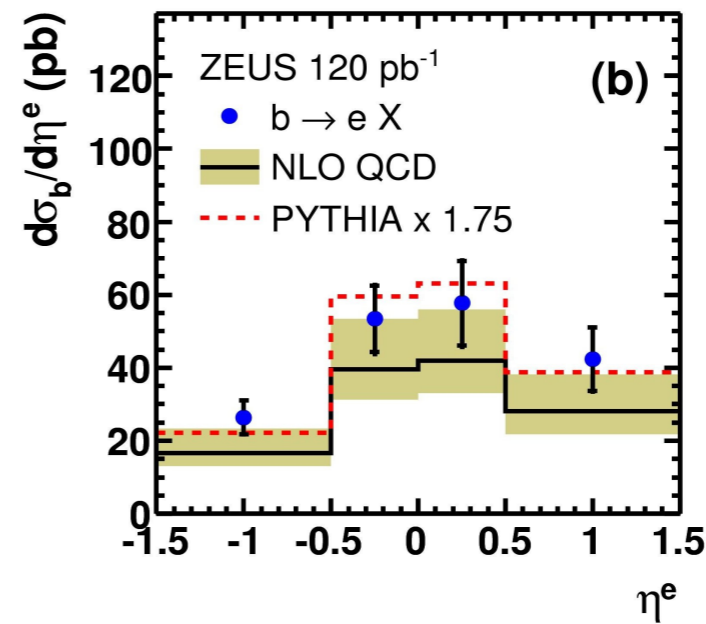
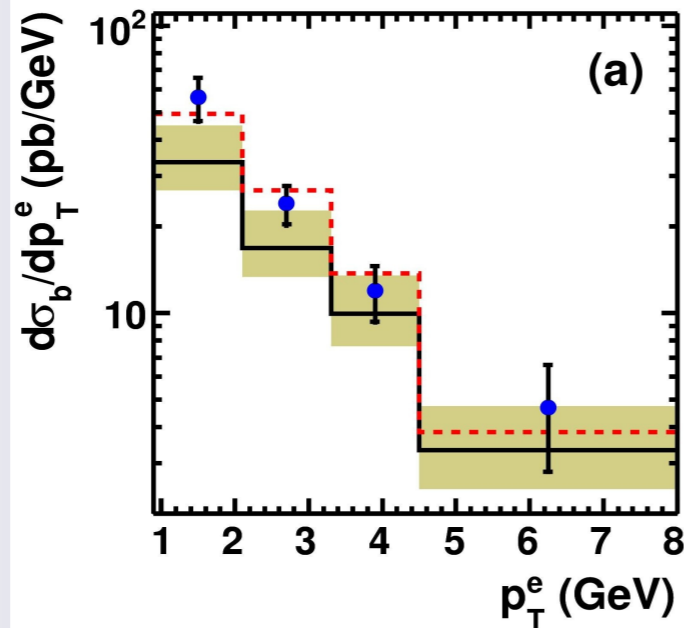
$$\sigma_c^{\text{tot}} = 382 \pm_{107}^{172} \text{ pb}$$

Dijet PhP $b,c \rightarrow e$ Results

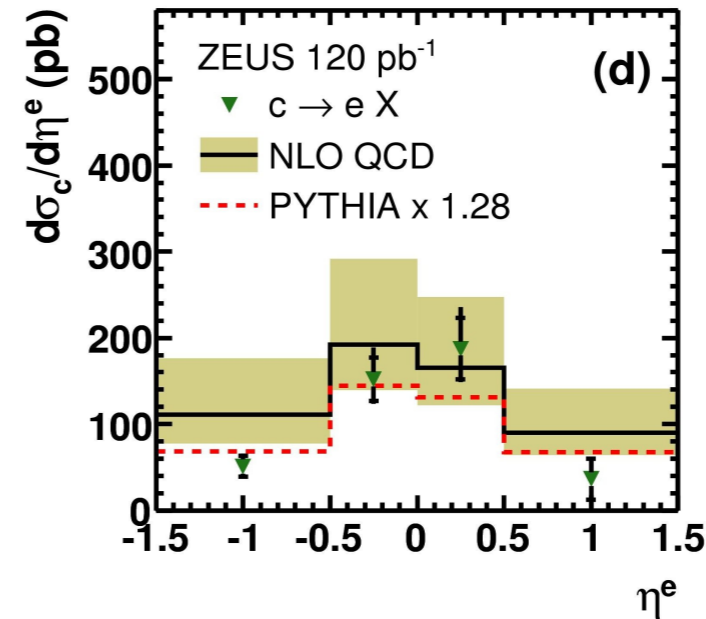
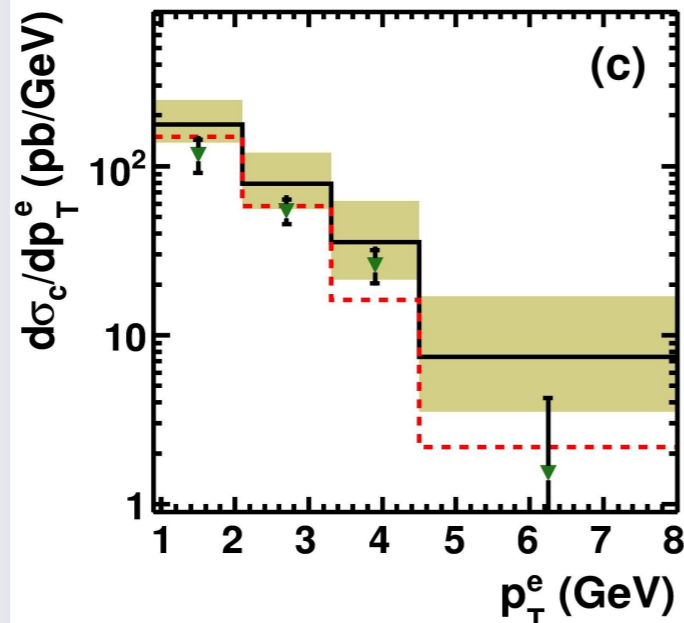
Differential electron cross-sections

Beauty

ZEUS



Charm

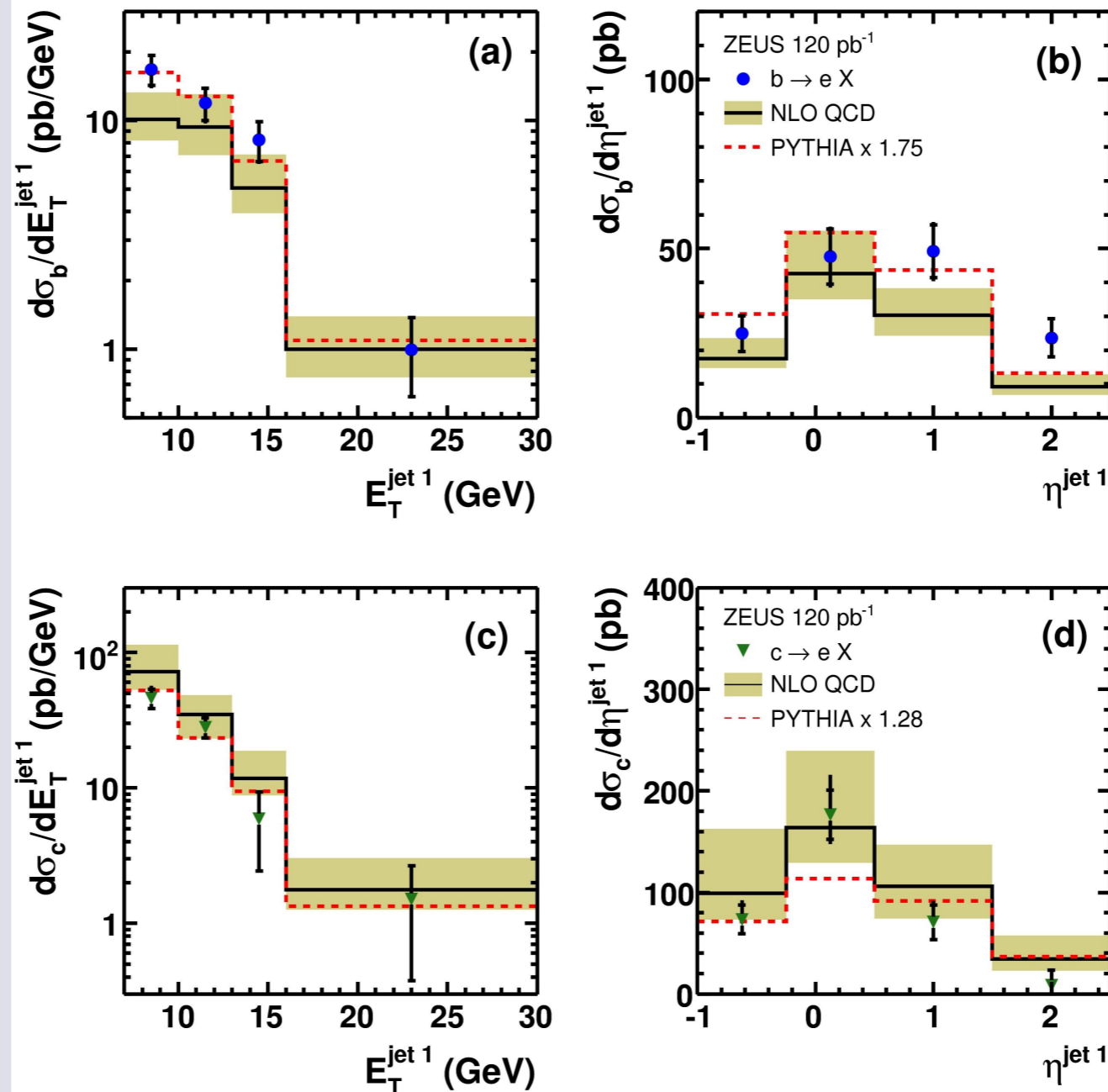


Dijet PhP b,c \rightarrow e Results

Differential jet cross-sections

Beauty

ZEUS



Charm

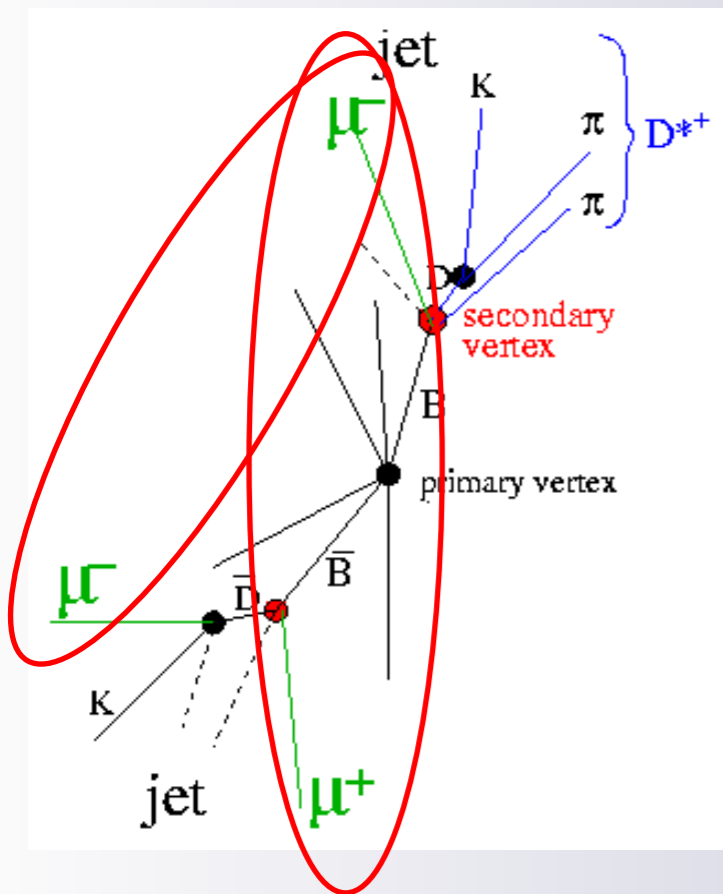
Dijet PhP $b \rightarrow e$ Summary

- Beauty and charm photoproduction has been measured in the HERA I data using semi-leptonic decays into electrons
- Using electrons cross-sections can be determined down to lower momenta ($p_T^e > 0.9 \text{ GeV}$)
- The beauty and charm fractions have been determined using a likelihood ratio test
- The measured beauty and charm cross-sections are in agreement with the NLO QCD predictions

$b \rightarrow \mu\mu$ Analysis Goal

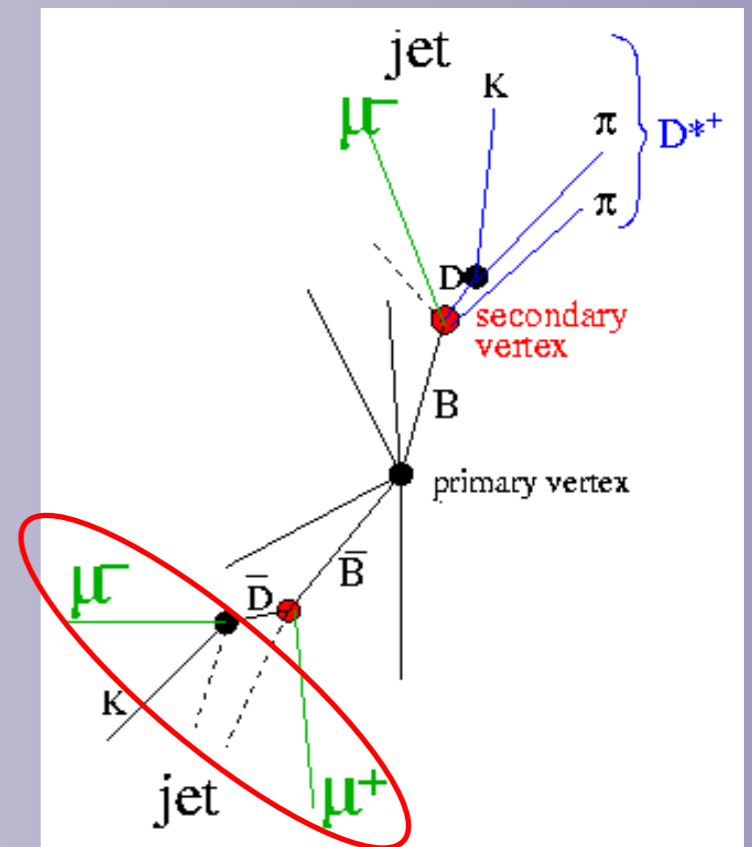
- Multitagged $b\bar{b}$ events (two muons)
- tag both beauty quarks
→ explicitly measure $b\bar{b}$ correlations
- low background
→ low muon p_T cuts
→ sensitive even to B mesons at rest
- almost full rapidity coverage
→ directly measure total $b\bar{b}$ cross-section (ep)
- measure differential cross-sections

$b \rightarrow \mu\mu$ Event Signature



Muons from different b

- **unlike sign or like sign**
- opposite hemispheres**
- **high dimuon mass**



Muons from same b

- **unlike sign**
- same hemispheres**
- **low dimuon mass**

classify data into subsamples

$m < 4 \text{ GeV}$	$m < 4 \text{ GeV}$
$+-$	$++/--$
$m > 4 \text{ GeV}$	$m > 4 \text{ GeV}$
$+-$	$++/--$

$b \rightarrow \mu\mu$ Event Selection

96-00 e^+p data: $\mathcal{L} = 114 \text{ pb}^{-1}$

Calorimeter:

- Cal E_T -10° cone $> 8 \text{ GeV}$

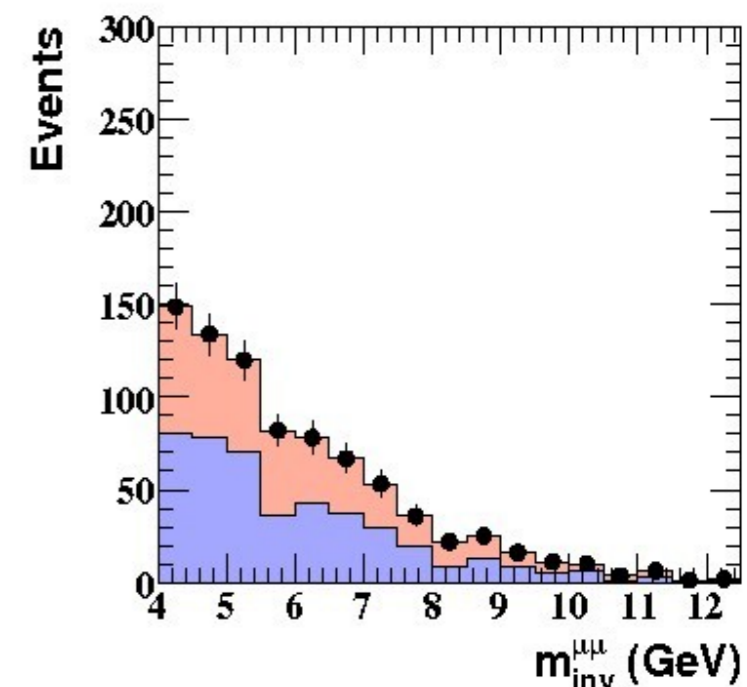
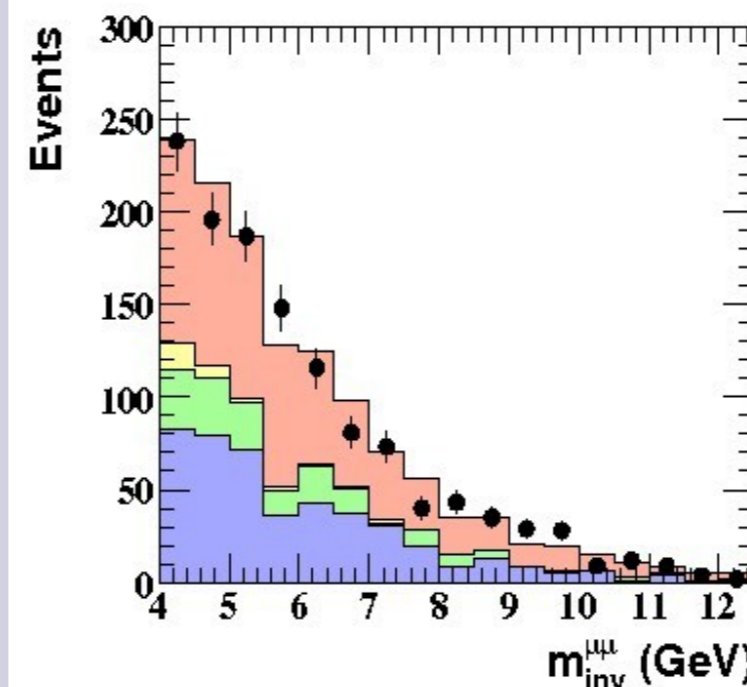
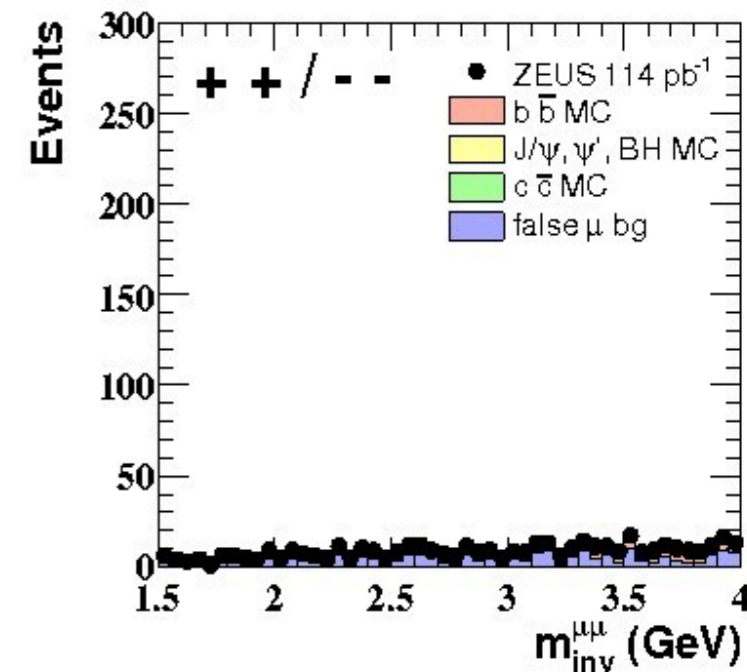
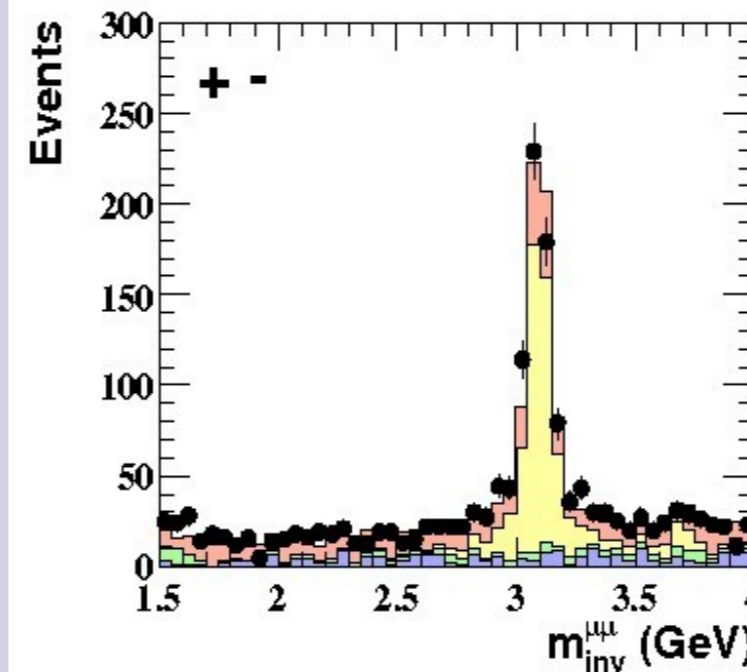
Muon Selection:

- $p_T^\mu > 1.5 \text{ GeV}$
- $p_T^\mu > 0.75 \text{ GeV}$
(high quality muons)

Further cleaning cuts

Dimuon Mass

ZEUS



$b \rightarrow \mu\mu$ Background

- Open $c \rightarrow$ high mass, unlike-sign
 - Normalisation from $D^*\mu$ analysis
- Hidden c ($J/\psi, \psi'$) \rightarrow low mass, unlike sign
 - Isolation cut
- Bethe-Heitler, hidden $b \rightarrow$ high mass, unlike sign
 - Isolation cut
- Light Flavour \rightarrow all regions
 - From data

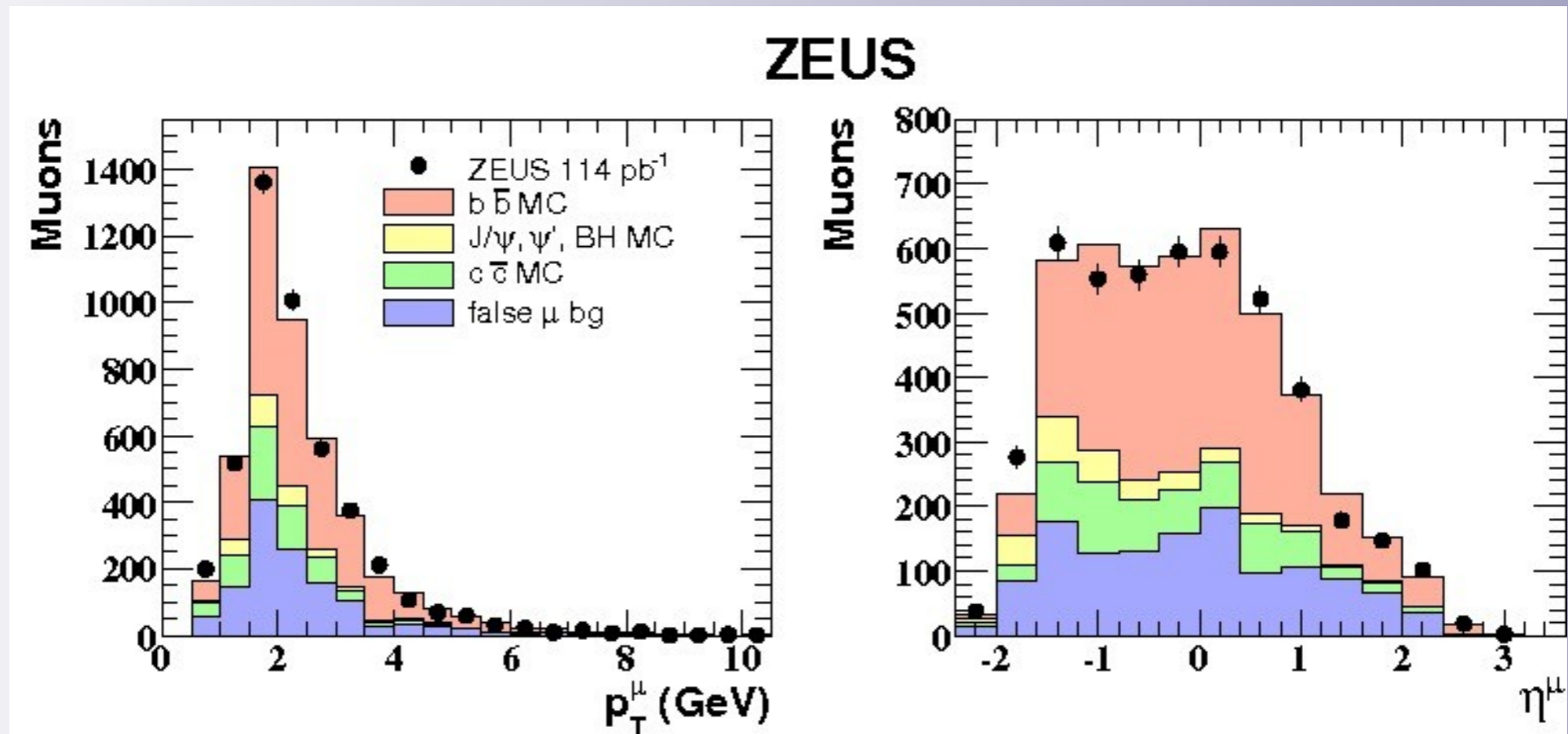
$b \rightarrow \mu\mu$ Signal Extraction

- Beauty production is only source of genuine like-sign muon pairs
- Difference of like and unlike sign muons free from fake-muon (LF) background
→ determine beauty contribution from difference
(if all other backgrounds are known)

$$N_{b\bar{b} \rightarrow \mu\mu} = (N_{data}^u - N_{data}^l - (N_{charm} + N_{VM} + N_{BH})) \times \left(\frac{N_{b\bar{b}}^u + N_{b\bar{b}}^l}{N_{b\bar{b}}^u - N_{b\bar{b}}^l} \right)^{MC}$$

Fake muon bg: should be the same for like and unlike sign
like sign free of charm
→ mirror like sign distribution to unlike sign

$b \rightarrow \mu\mu$ Control Plots



p_T^μ, η^μ for dimuon events in the non-isolated unlike-sign sample

NLO QCD Predictions - Dimuon Analysis

- FMNR program used

- $\mu = \frac{1}{2} \mu_0 = \frac{1}{2} \sqrt{(p_T^b)^2 + (m_b)^2} \quad \left(\frac{1}{4} \mu_0 < \mu < \mu_0 \right)$

- PDF(P)= CTEQ5M; PDF(γ)= GRV-G HO

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

- WW approximation $Q_{\text{max}}^2 = 25 \text{ GeV}$ to include DIS contribution($\sim 15\%$) (FMNR+HVQDIS for comparison)

- FMNR x PYTHIA interface for visible $\mu\mu$ cross-sections

$b \rightarrow \mu\mu$ Tot WQ

Visible cross-section:

$$\sigma^{vis} = 55 \pm 7 (stat.) \pm_{15}^{14} (syst.) pb$$

$$\sigma_{NLO}^{vis} = 33_{-8}^{+18} (NLO)_{-3}^{+5} (frag \oplus br)$$

$$R_{data/NLO}^{vis} = 1.7_{-1.1}^{+0.7}$$

Visible range:

$$1^{st} \mu : p_T > 1.5 \text{ GeV}$$

$$2^{nd} \mu : \begin{aligned} & (p > 1.8 \text{ GeV} \quad \text{for } \eta < 0.6 \\ & p > 2.5 \text{ or } p_T > 1.5 \text{ GeV for } \eta > 0.6) \\ & \text{and } p_T > 0.75 \text{ GeV} \end{aligned}$$

$$\text{both } \mu: -2.2 < \eta < 2.5$$

Total ep cross-section for bb production:

$$\sigma^{tot} = 13.9 \pm 1.5 (stat.)_{-4.3}^{+4.0} (syst.) nb$$

extrapolated to quark level using PYTHIA

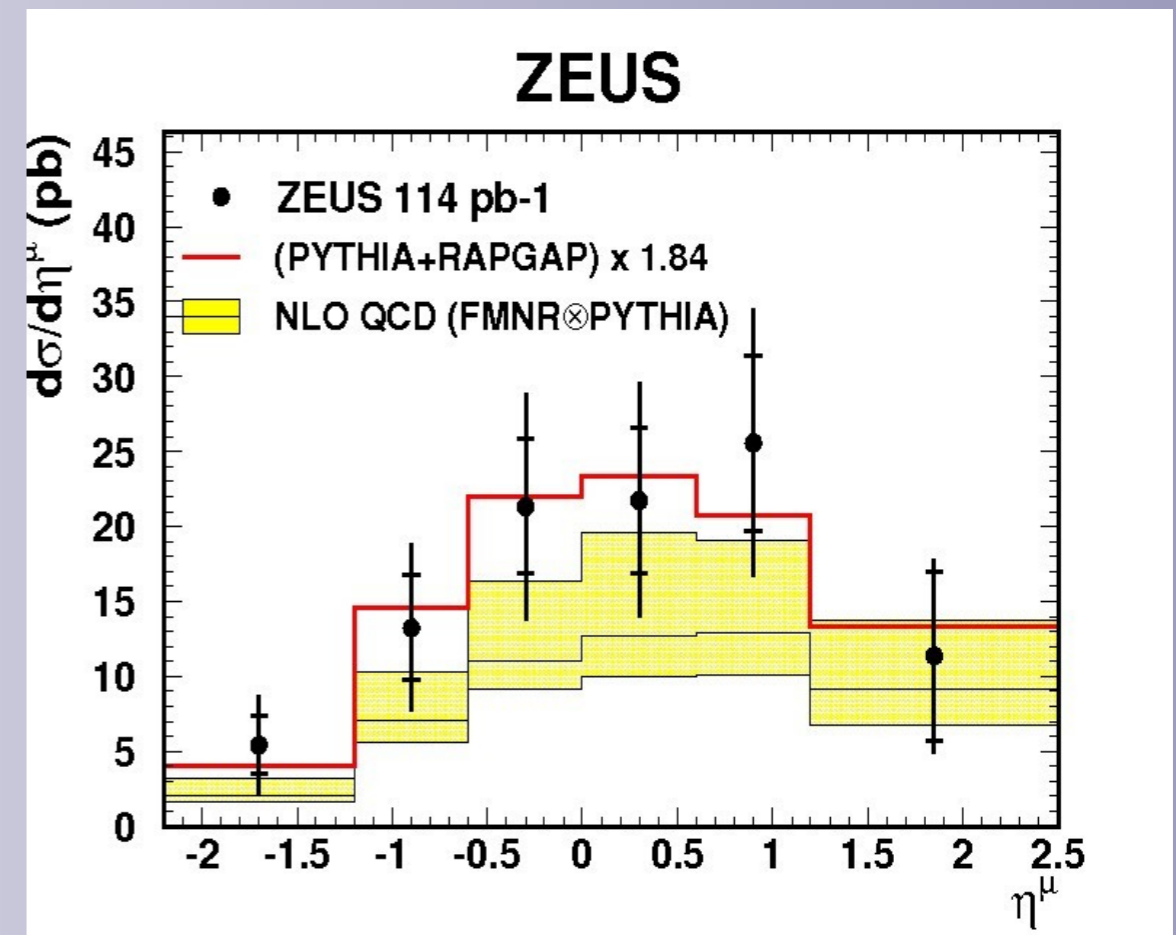
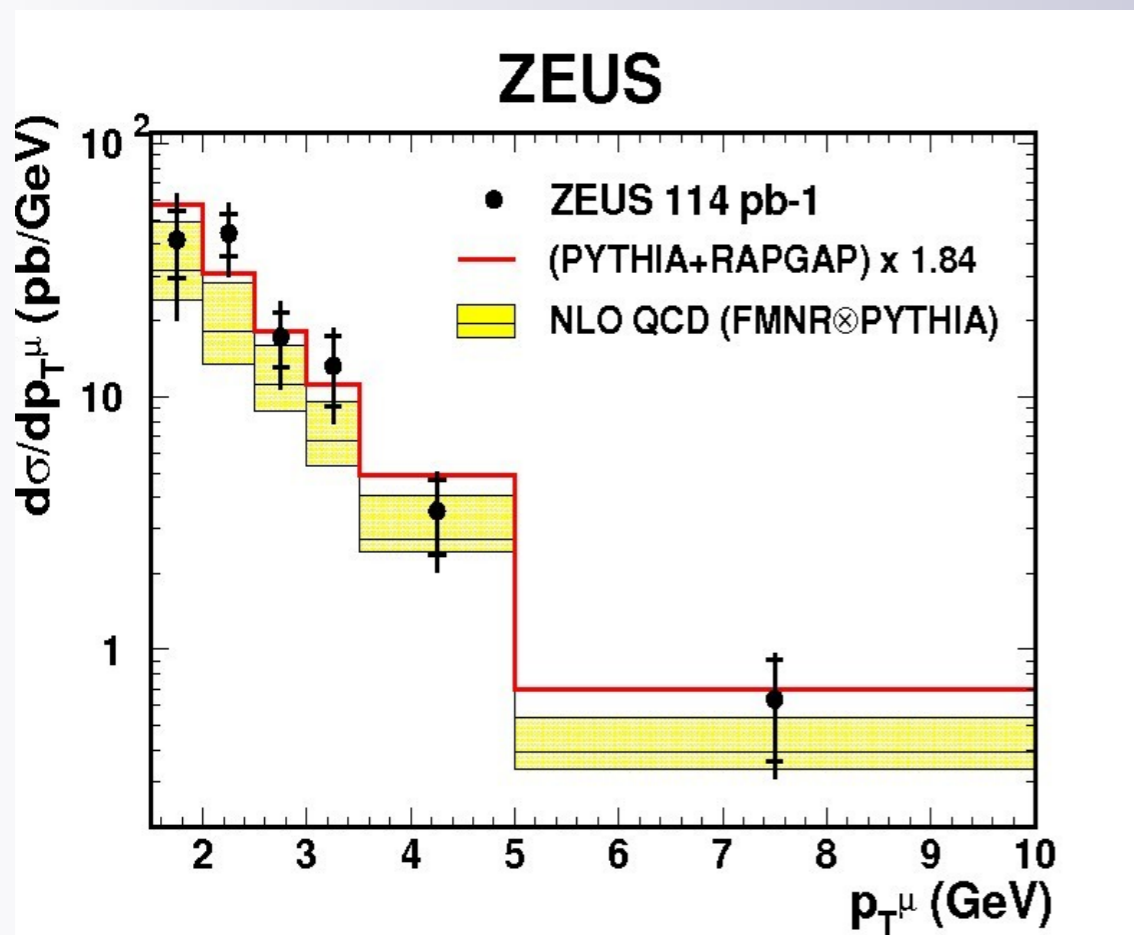
$$\sigma_{NLO}^{tot} = 7.5_{-2.1}^{+4.5} nb \quad \text{FMNR+HVQDIS}$$

$$\sigma_{WW}^{tot} = 7.8_{-2.3}^{+4.9} nb \quad \text{FMNR (WW-appr.)}$$

$$R_{data/NLO}^{tot} = 1.8_{-1.3}^{+0.8}$$

$b \rightarrow \mu\mu$ Differential Cross-Sections

- Differential muon cross-sections
 - both muons $p_T^\mu > 1.5$ GeV, $-2.2 < \eta < 2.5$

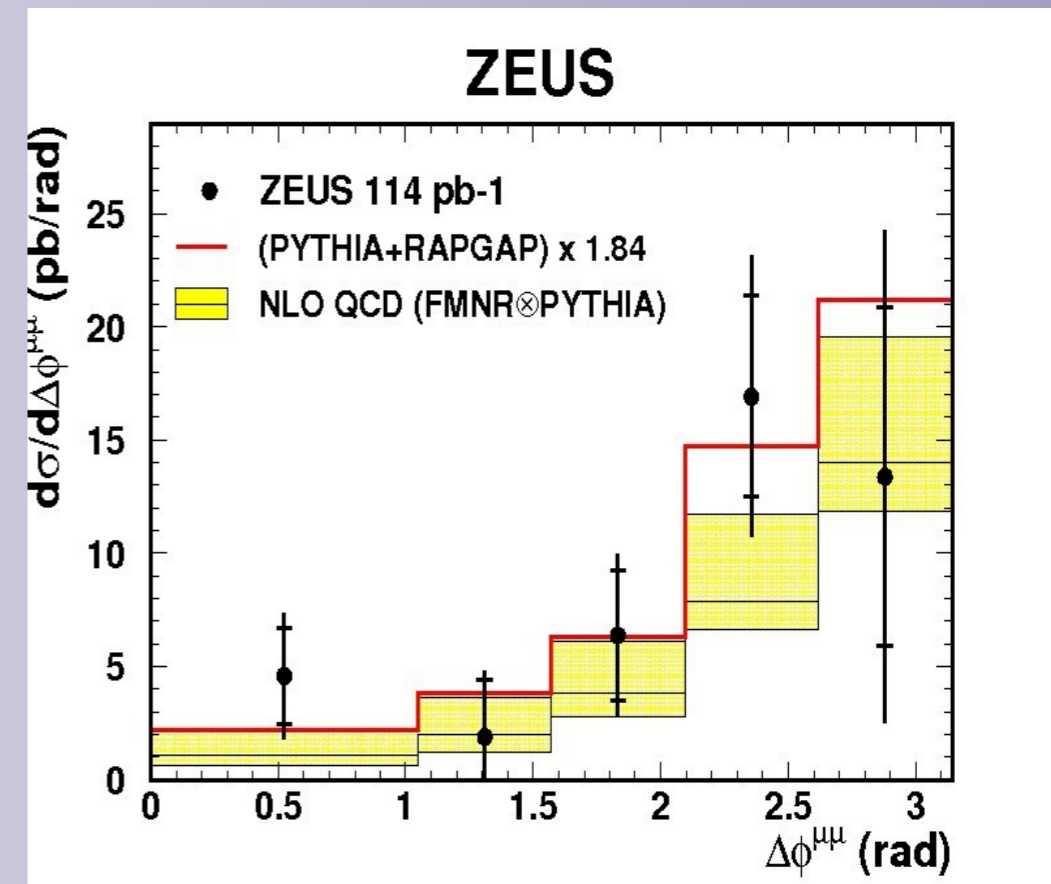
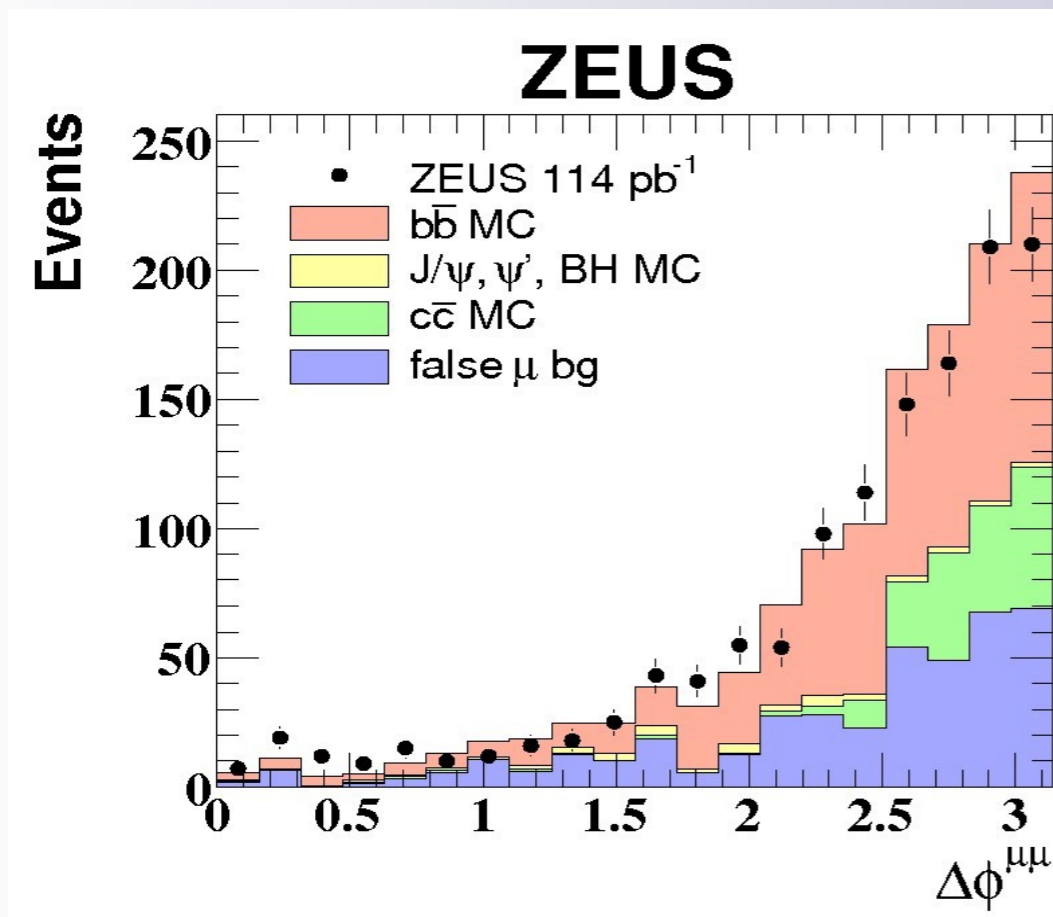


good agreement in shape, reasonable agreement in normalisation
no indication for deviations at low p_T or high η

$b \rightarrow \mu\mu$ bb Correlations

- $\Delta\phi$ between muons from different quarks

$$\Delta\phi = (\phi^{\mu 1} - \phi^{\mu 2}) \quad (m^{\mu\mu} > 3.25 \text{ GeV})$$



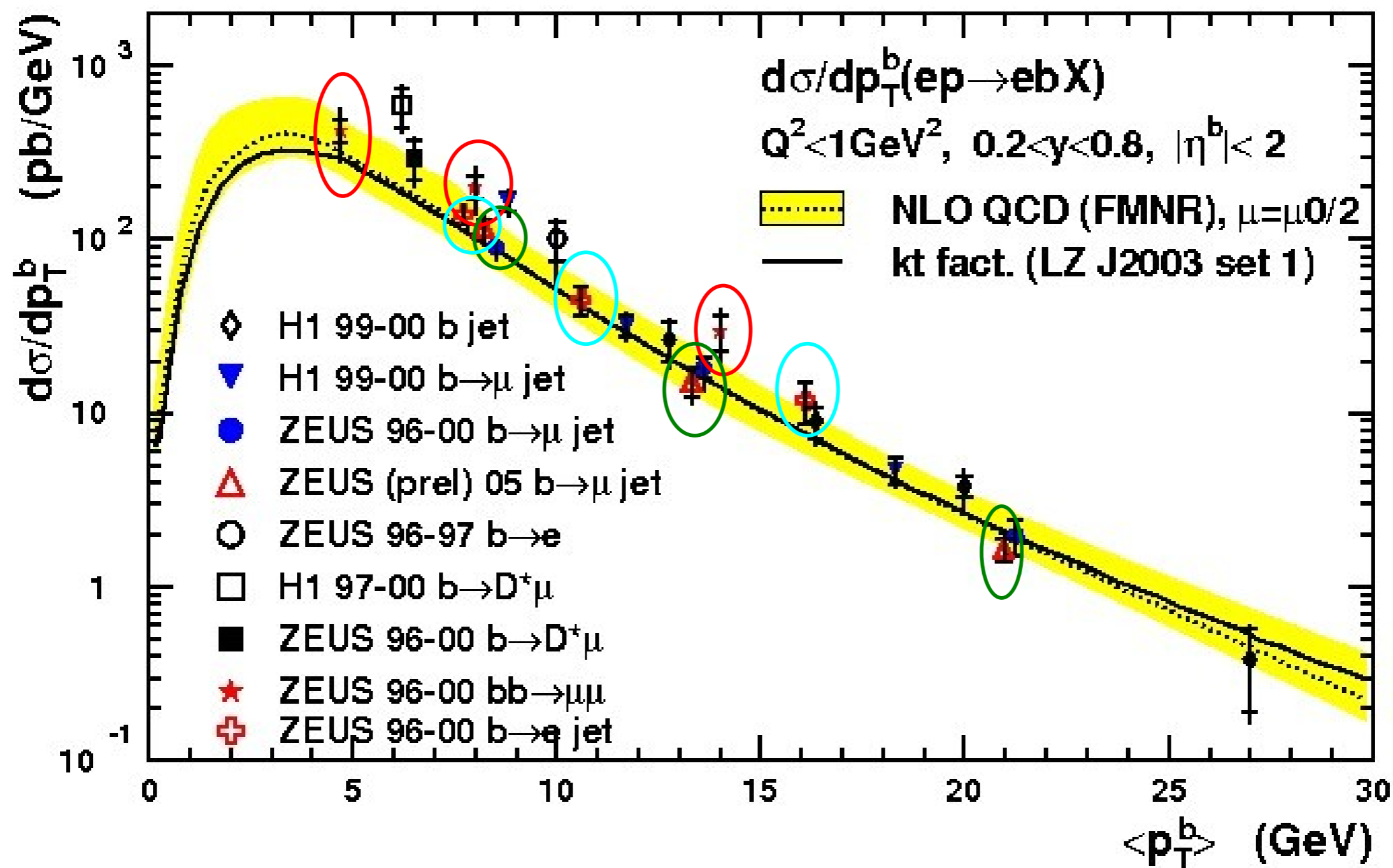
bb correlations well described (within large errors)

$b \rightarrow \mu\mu$ Summary

- Beauty production has been measured using a muon double tag
- Almost complete phase space coverage allows extraction of total beauty production cross-section
- Differential cross-sections in $p_{\text{T}}^{\mu}, \eta^{\mu}$ and $\Delta\phi$ measured
 - Agreement with NLO predictions

p_T^b plot

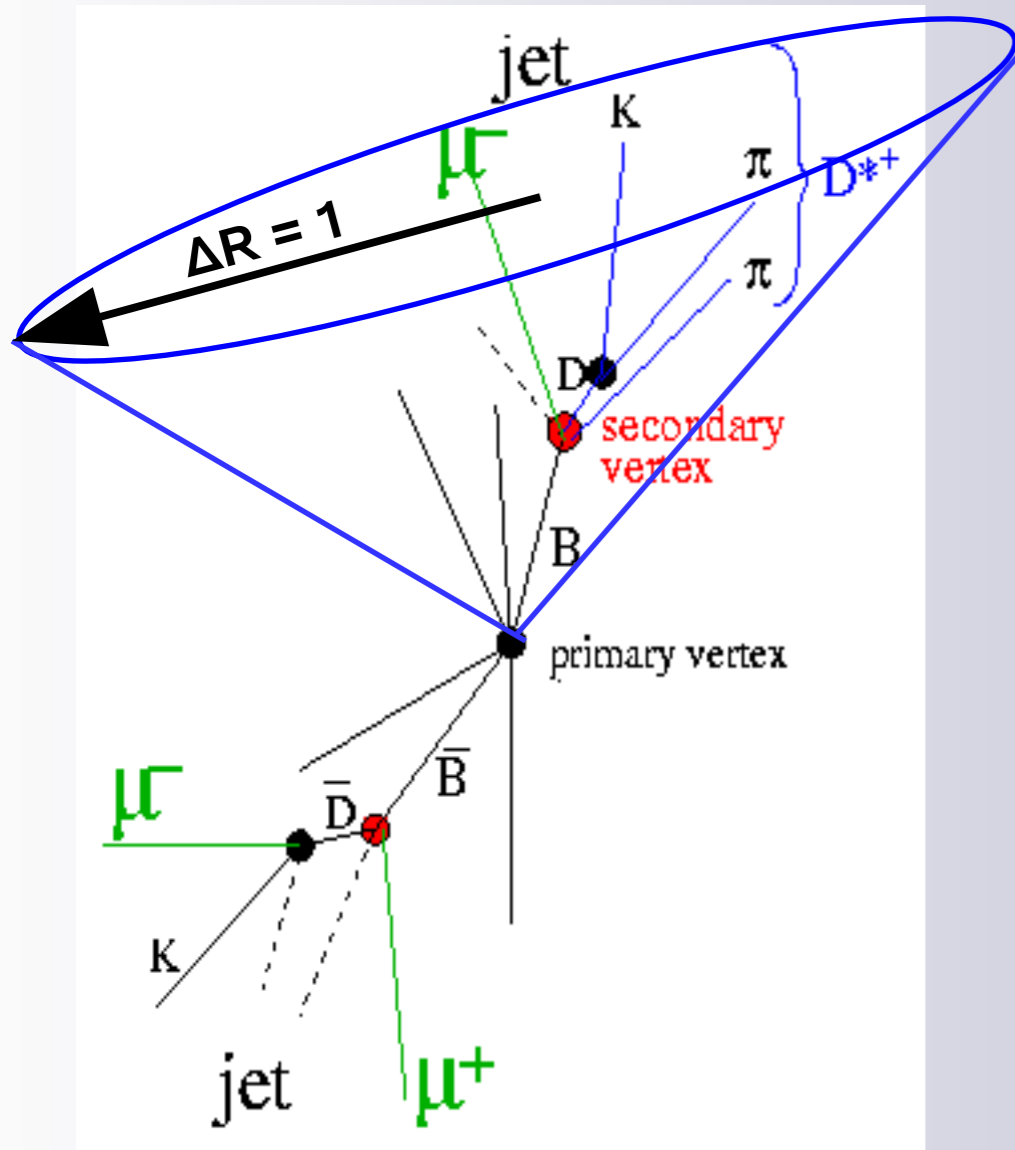
HERA



Summary

- Three analyses on beauty photoproduction at ZEUS have been presented
 - $b \rightarrow \mu + \text{dijet}$ using 2005 data
 - beauty extracted using combined p_T^{rel} - δ fit, agreement with NLO and previous analysis
 - $b \rightarrow e + \text{dijet}$ using 96-00 data
 - beauty and charm cross-section measured using likelihood ratio test, agreement with NLO predictions
 - $b \rightarrow \mu\mu$ using 96-00 data
 - beauty extracted using muon double tag
total bb cross-section extracted,
bb correlations in agreement with NLO

$b \rightarrow \mu\mu$ Isolation Cut



- μ from b accompanied by hadrons **non-isolated**
- $BH, J/\psi, \psi', Y$ **isolated**
- classify data into subsamples
 - **isolated**: normalise bg from $BH, J/\psi, \psi', Y$
 - **non-isolated**: signal sample

$$I = \sqrt{(\sum E_1^\mu)^2 + (\sum E_2^\mu)^2}$$

$\sum E_i^\mu$ = energy deposited in cone of $\Delta R < 1$ around muon, excluding muons