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-

Ursula Samson

Physikalische Institut

der Rheinischen Friedrich-Wilhelms-Universität Bonn

GEFÖRDERT VOM

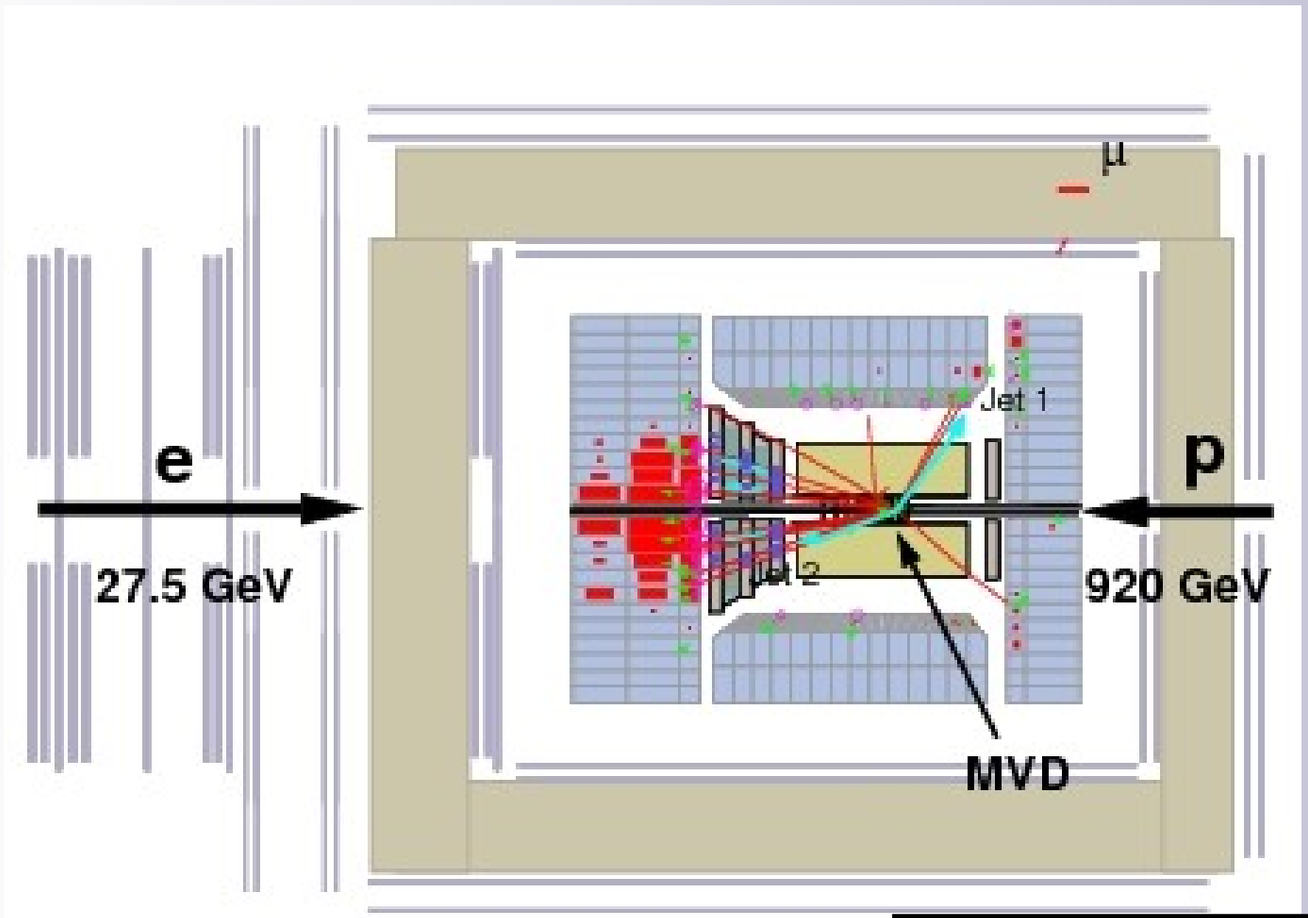
Bundesministerium für Bildung und Forschung

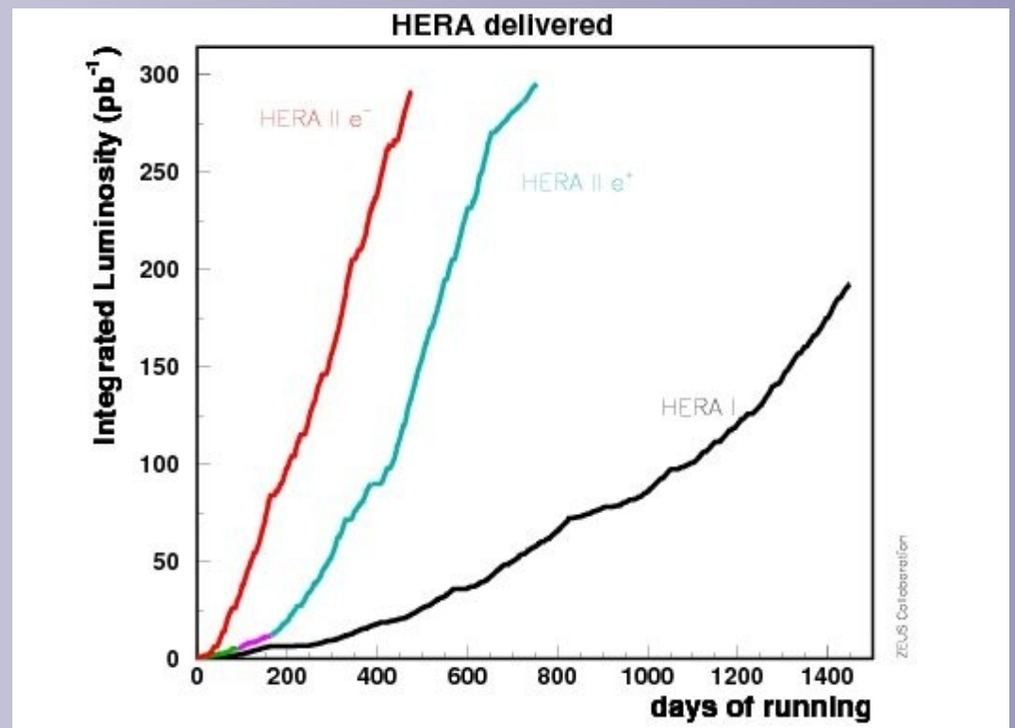
Introduction

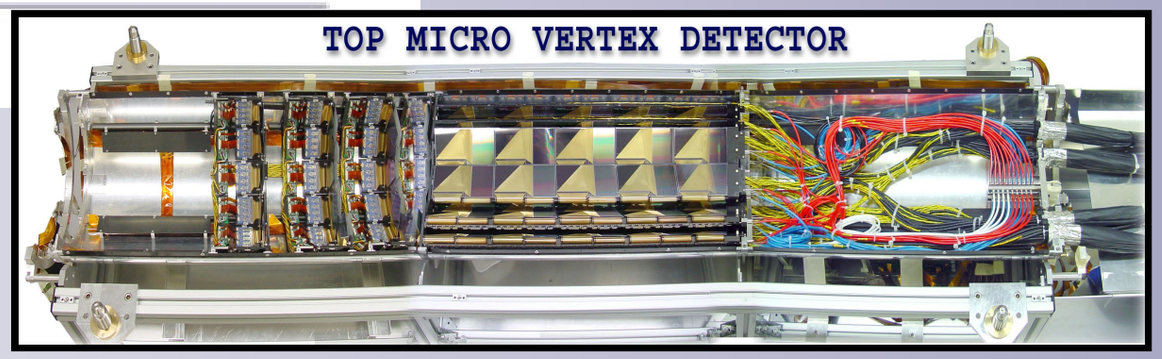
Three analyses will be presented:

- 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_T^{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



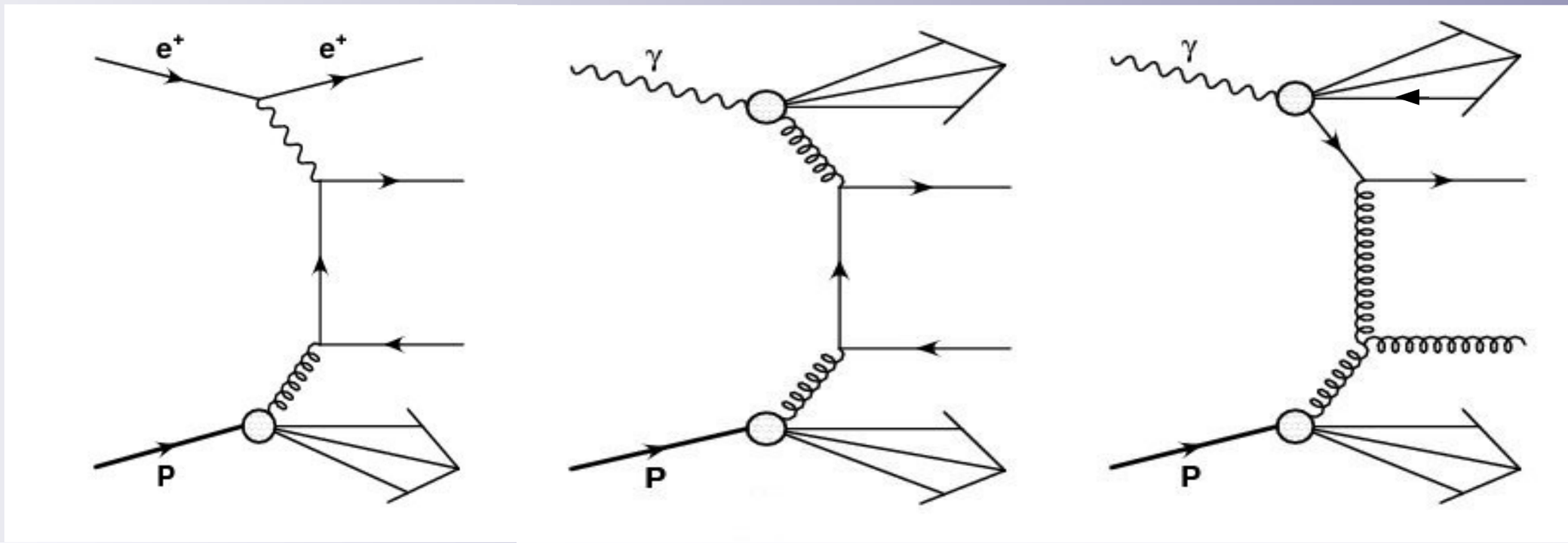




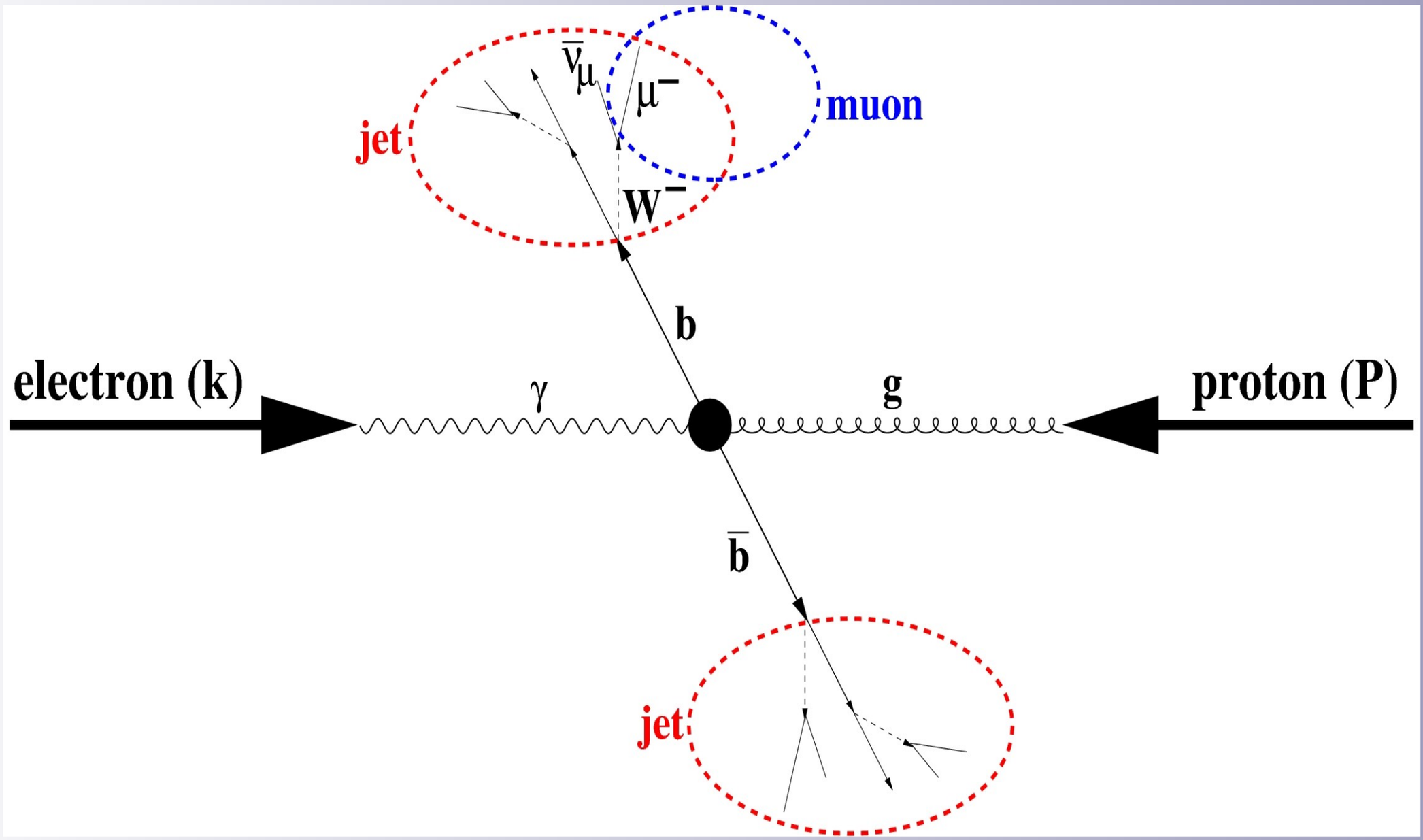
HERA integrated luminosity 96-07: 0.5 fb^{-1}
Since 2002 micro-vertex detector for lifetime tagging

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

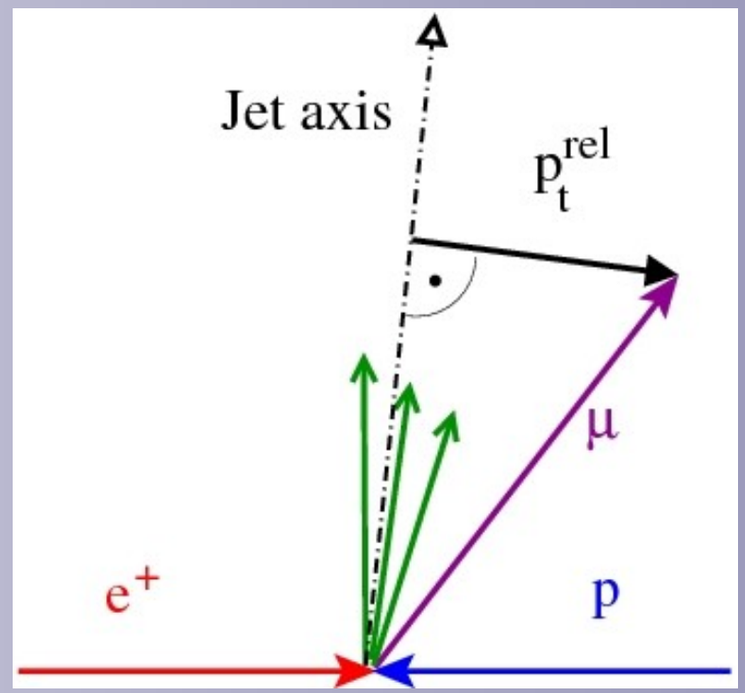


Dijet PhP Analyses

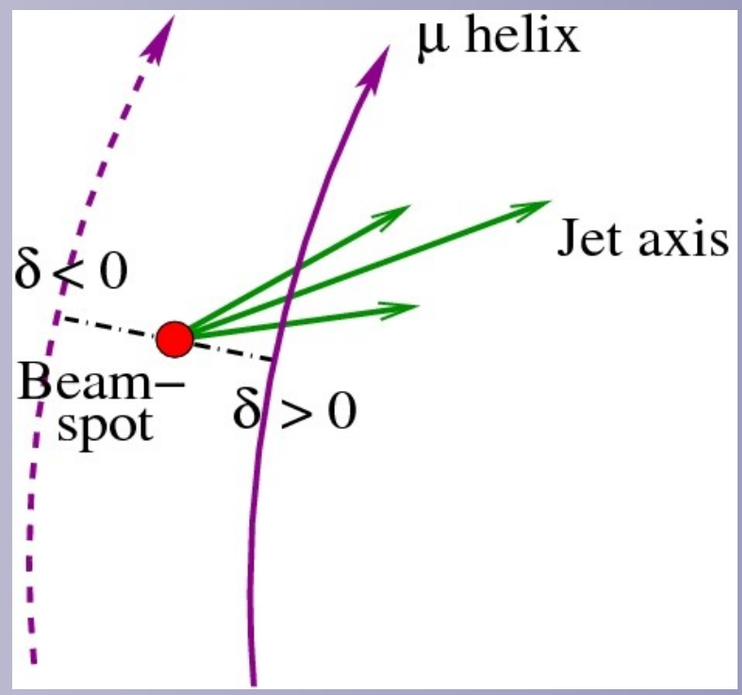


Dijet PhP b→μ – Beauty Extraction

- 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→μ – Event Selection

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

Photoproduction:

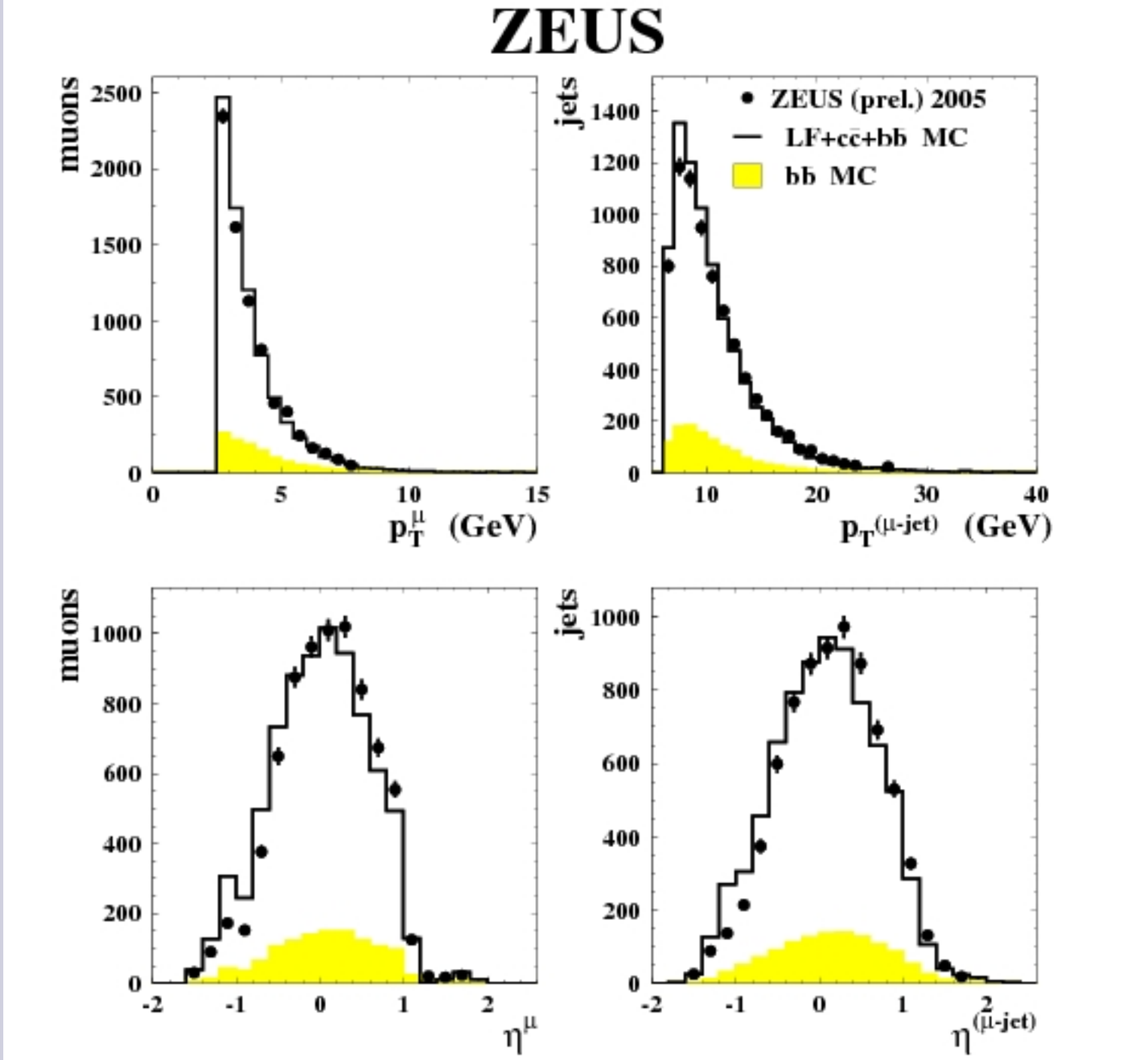
- Veto on scattered e^+, $0.2 < y_{JB} < 0.8$

Jet finding:

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

μ selection:

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

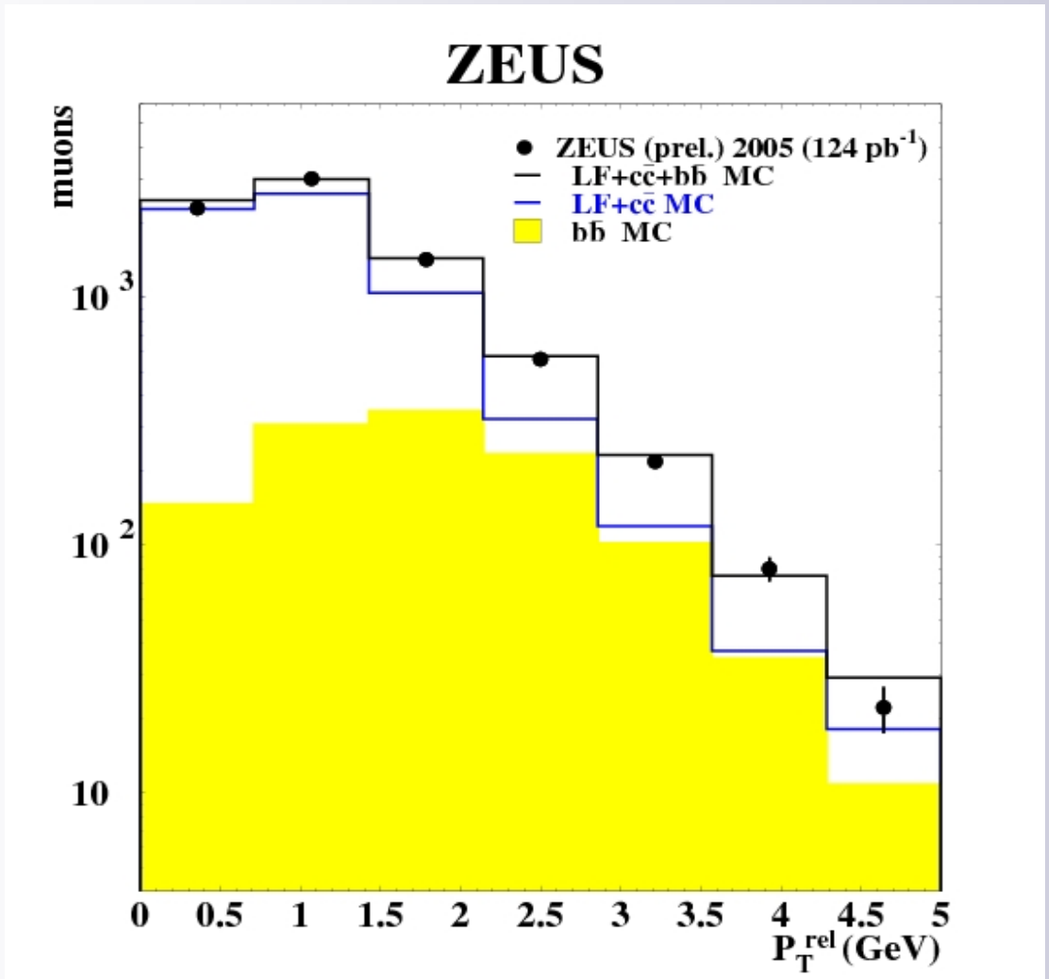


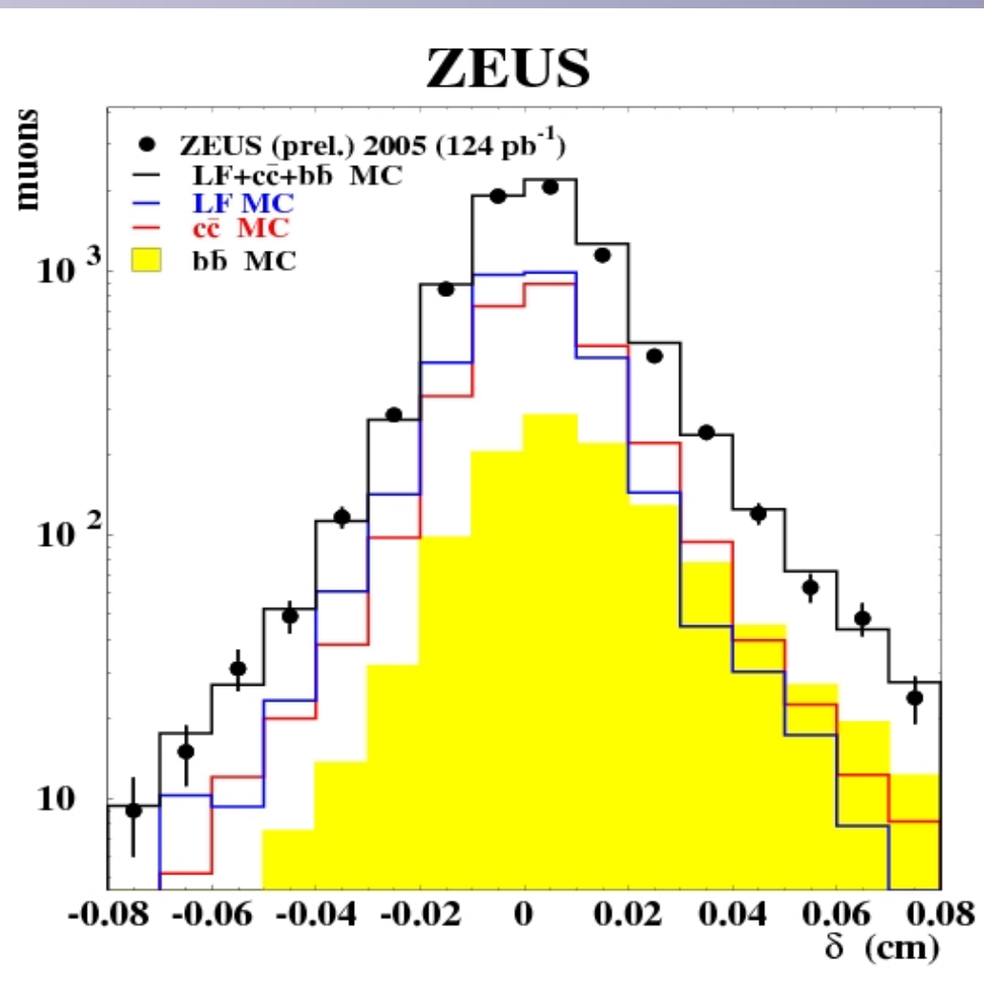
Dijet PhP b⟶μ – Fit

Combined fit of p_T^{rel} and δ

f_b=15.5±1.3%, f_c=40.1±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

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

m_b = 4.75 GeV 4.5 GeV < m_b < 5GeV

PDF(P) = CTEQ5M; PDF(γ) = GRV-G HO

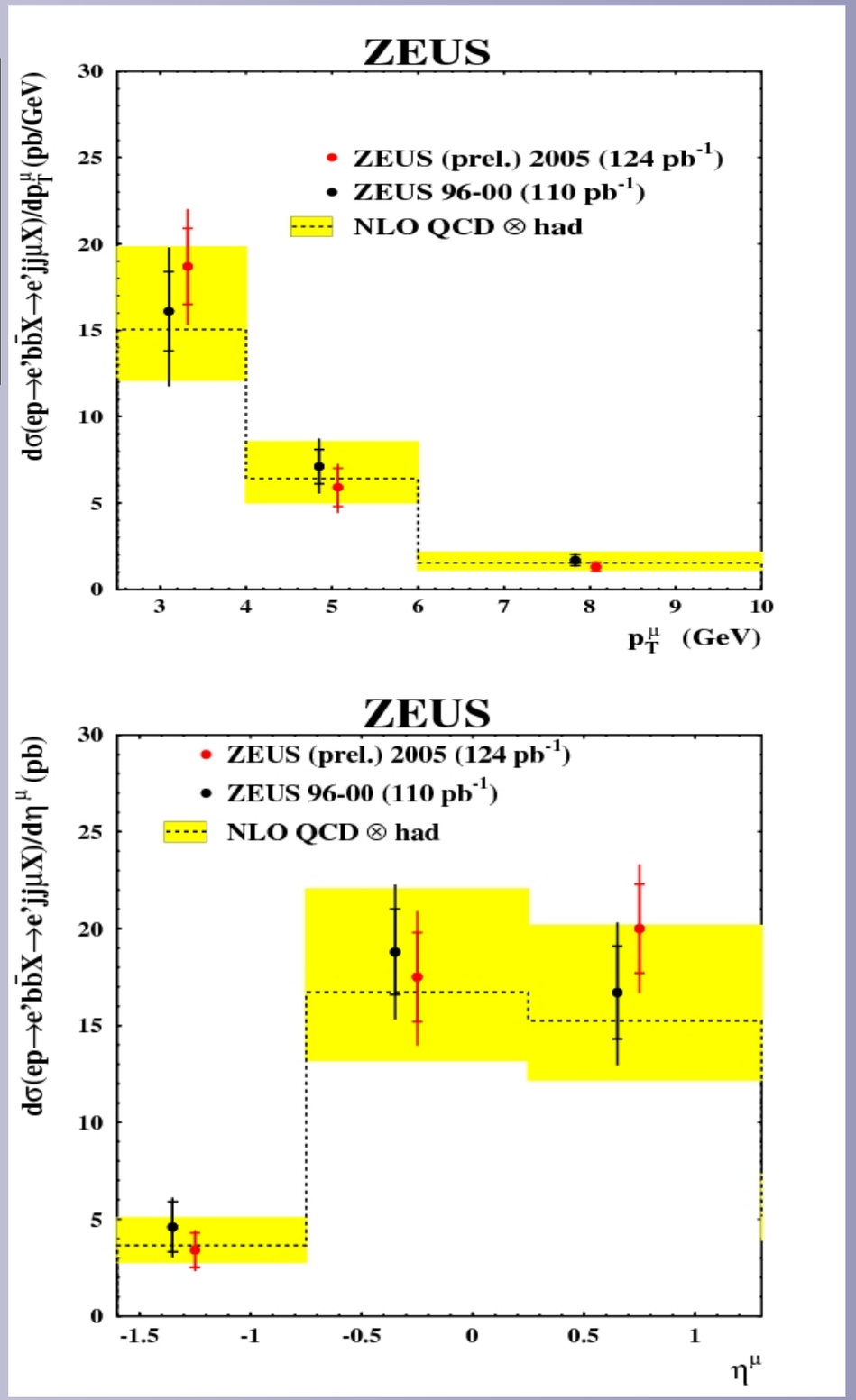
hadronisation corrections from PYTHIA

Dijet PhP b→μ – Results

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

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

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



Dijet PhP b→μ 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} - δ 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→e Event Selection

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

Photoproduction:

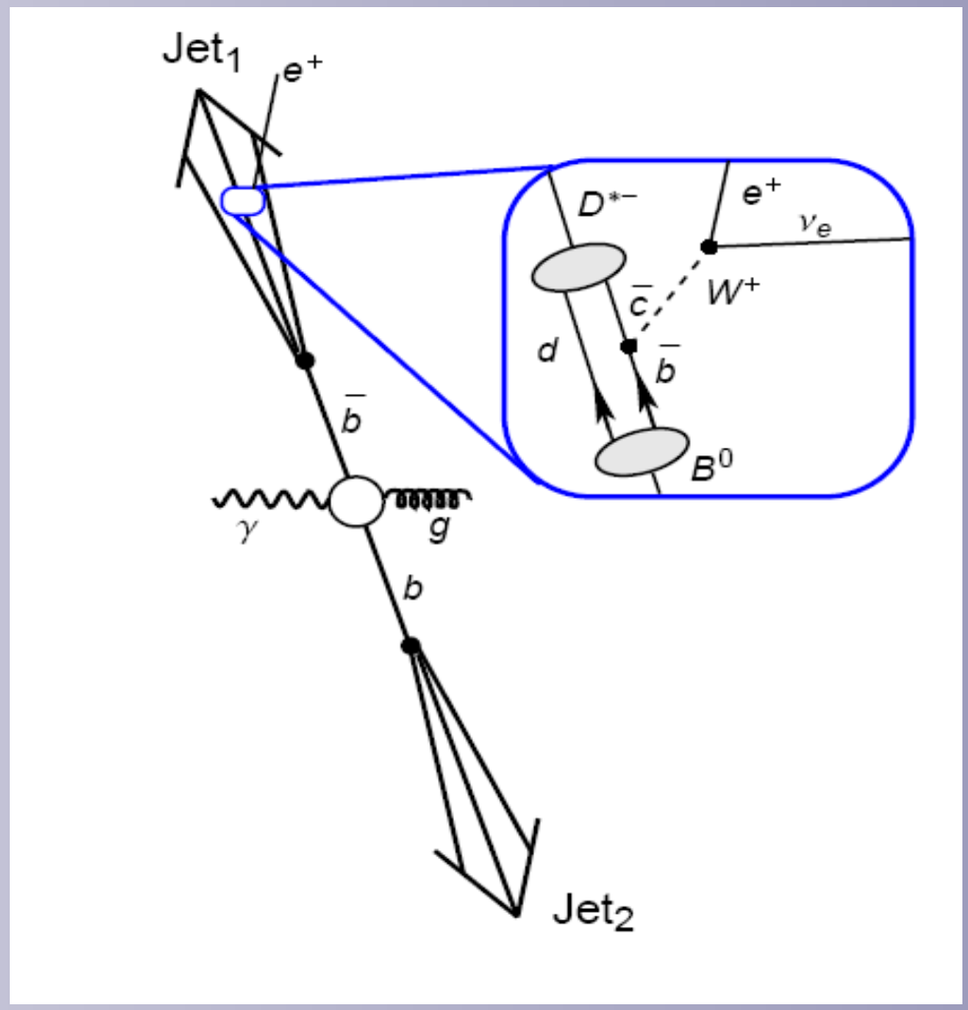
- **Veto on scattered e^+, $0.2 < y_{JB} < 0.8$**

Jet finding:

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

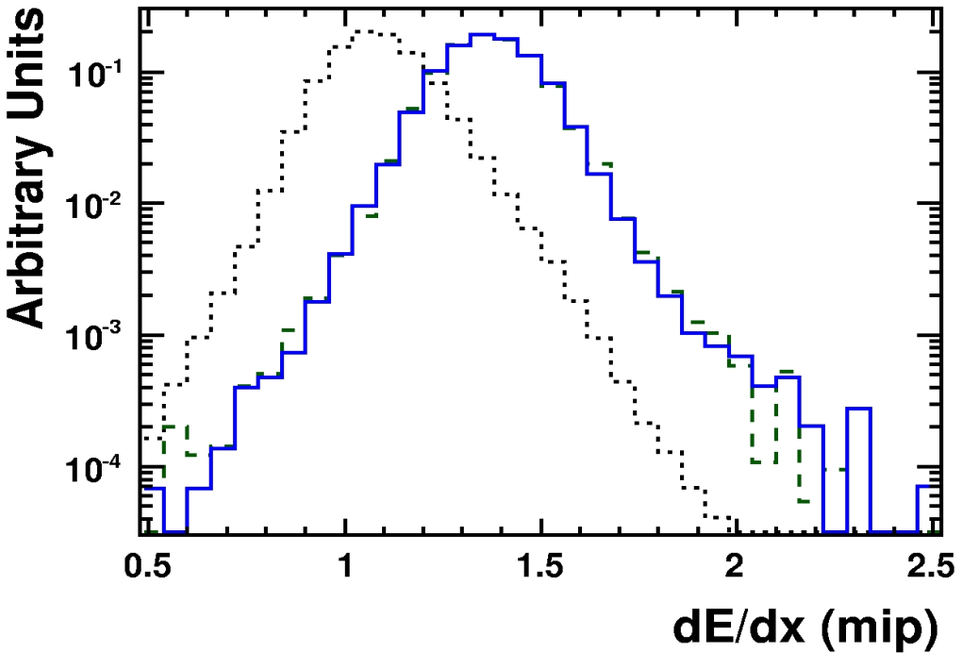
$e^{\pm}_{SL}$ candidate

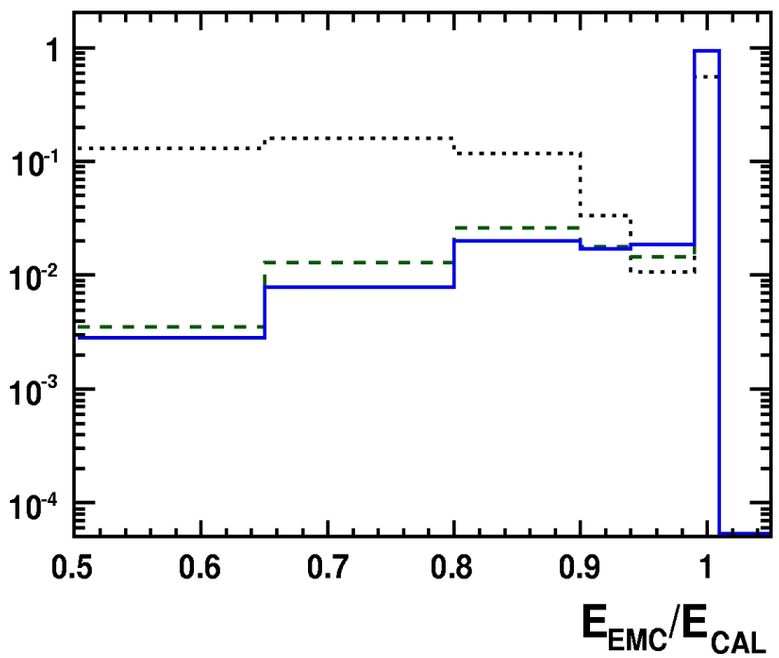
- $p^e_T > 0.9$ GeV
- $|\eta| < 1.5$
- **dE/dx > 1.1mip, EMCfraction > 0.9**

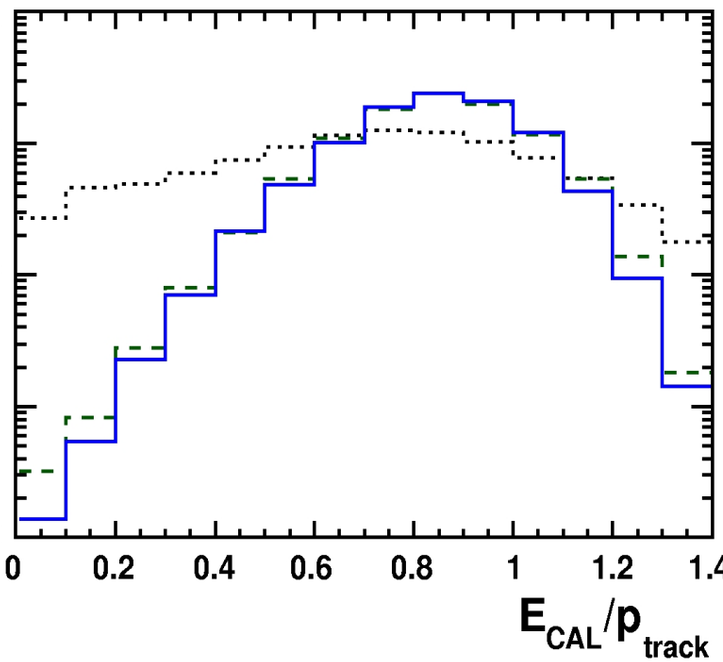


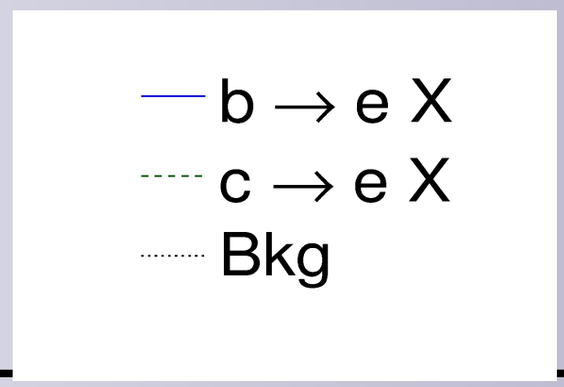
Dijet PhP b→e Beauty Extraction I

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



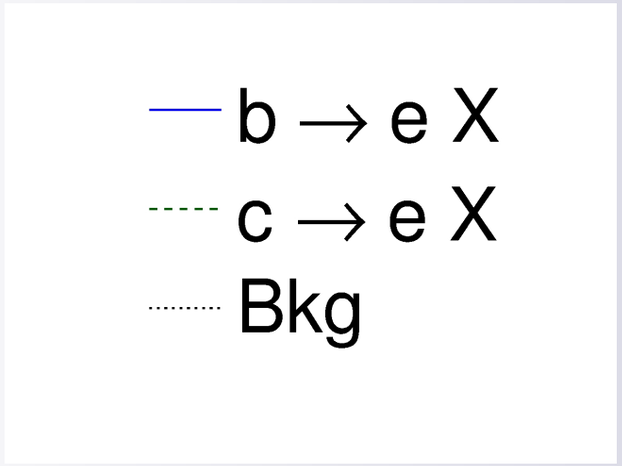


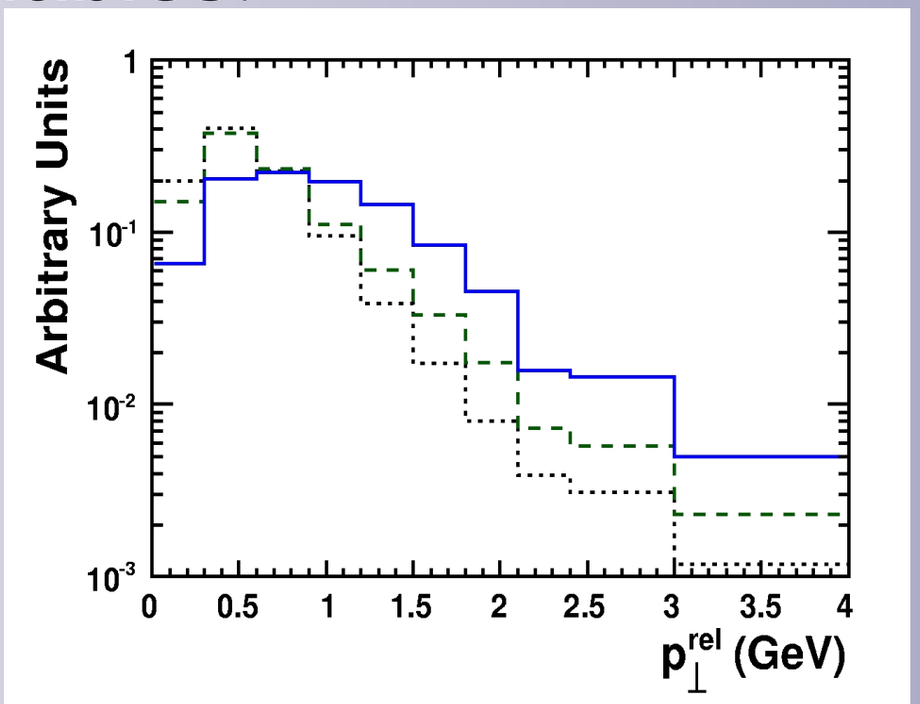




Dijet PhP b→e Beauty Extraction II

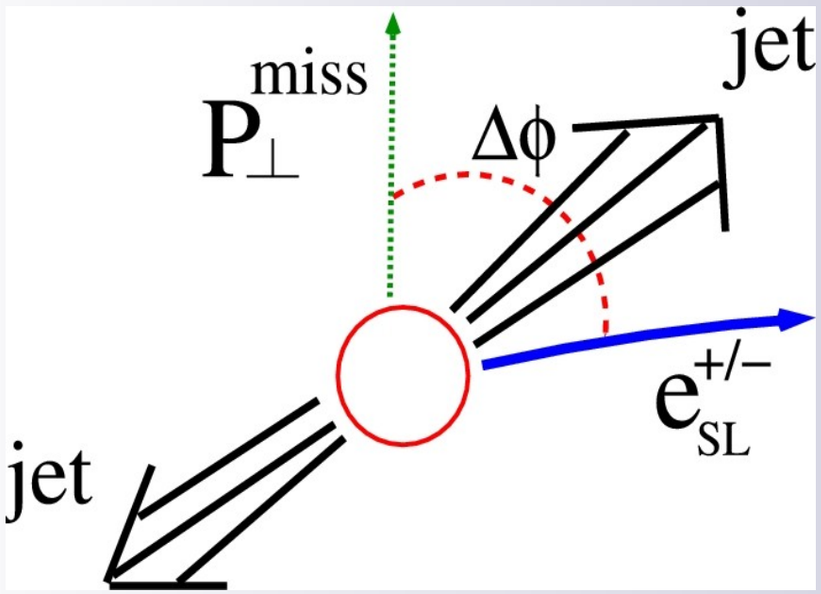
- Semileptonic decay variables:

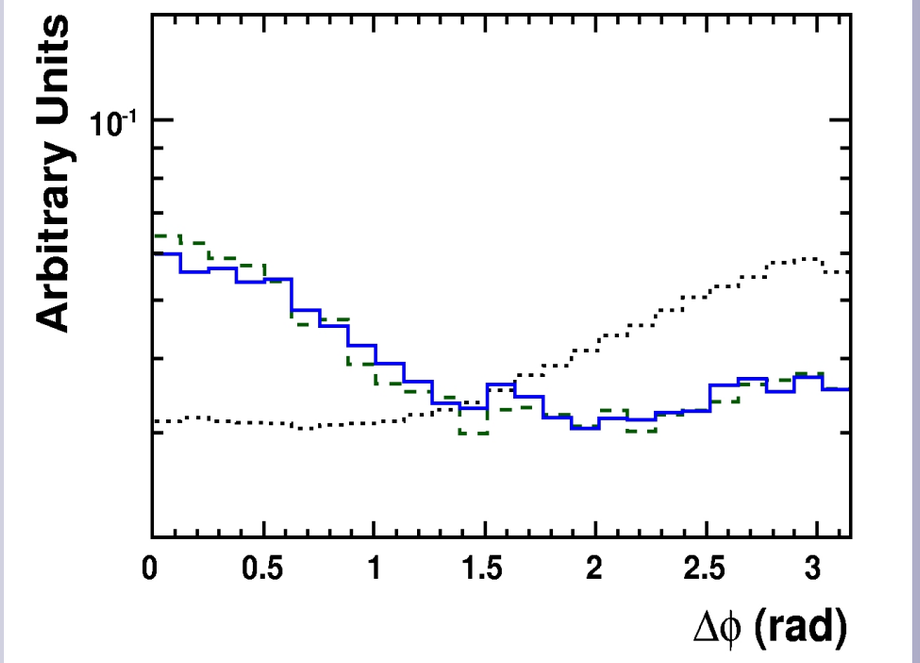




p_T^{rel}

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





Δϕ

Dijet PhP b⟶e Fit Method

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

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

α_i particle abundance

$\tilde{\alpha}_j$ decay abundance

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

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

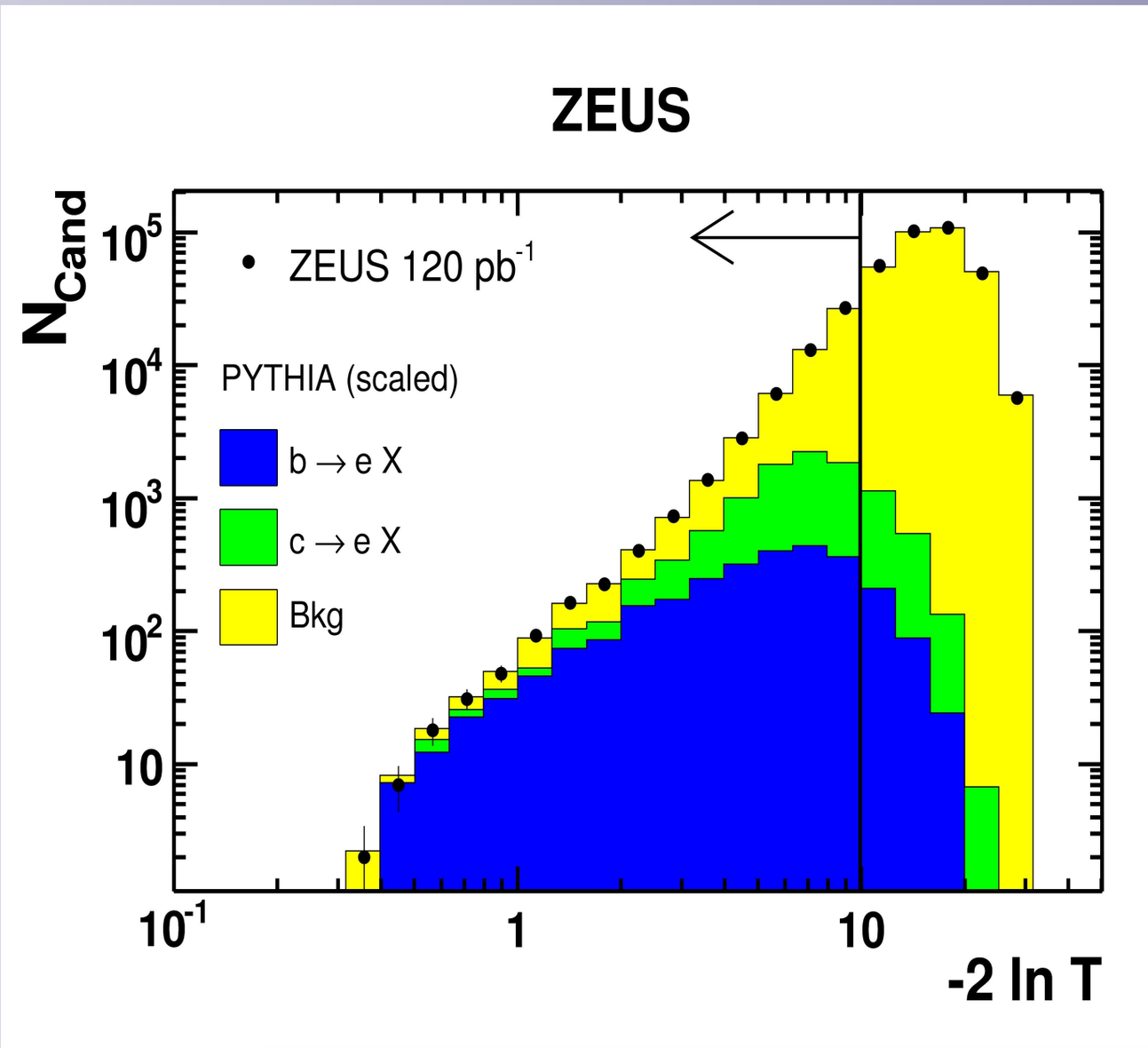
$$\text{Test Function } T_{ij} = \frac{\mathscr{L}_{ij}}{\sum_{kl} \mathscr{L}_{kl}}$$

Dijet PhP b→e Fit

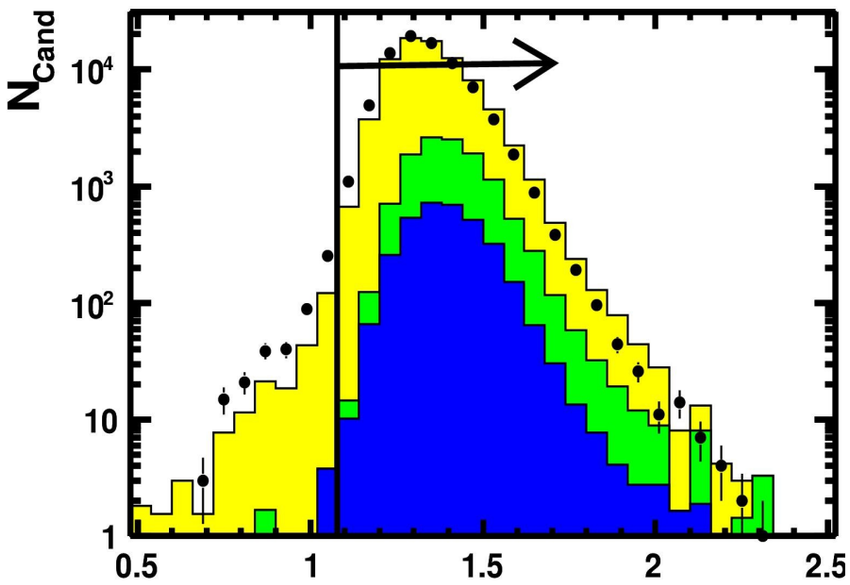
- Beauty hypothesis
  - Fit contributions to $T_{e,b}$ in region up to $-2\ln T < 10$
  - PYTHIA scale factors

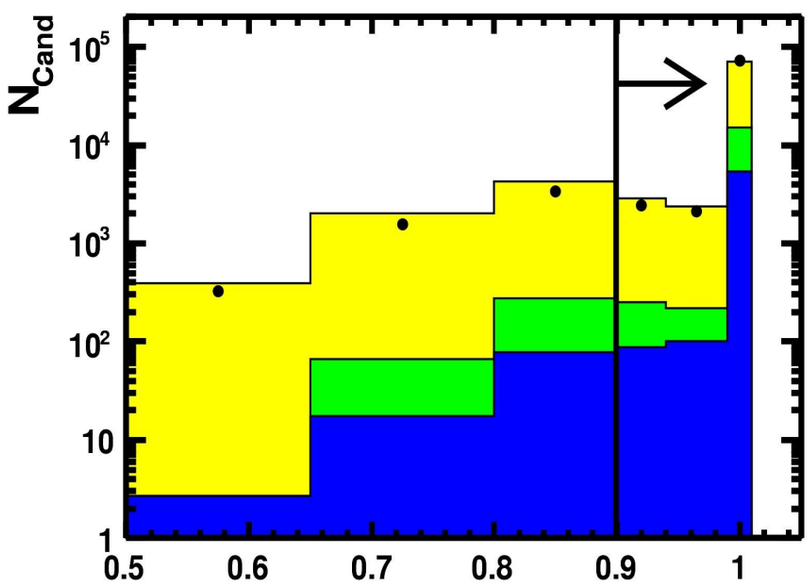
    beauty: 1.75 ± 0.16,

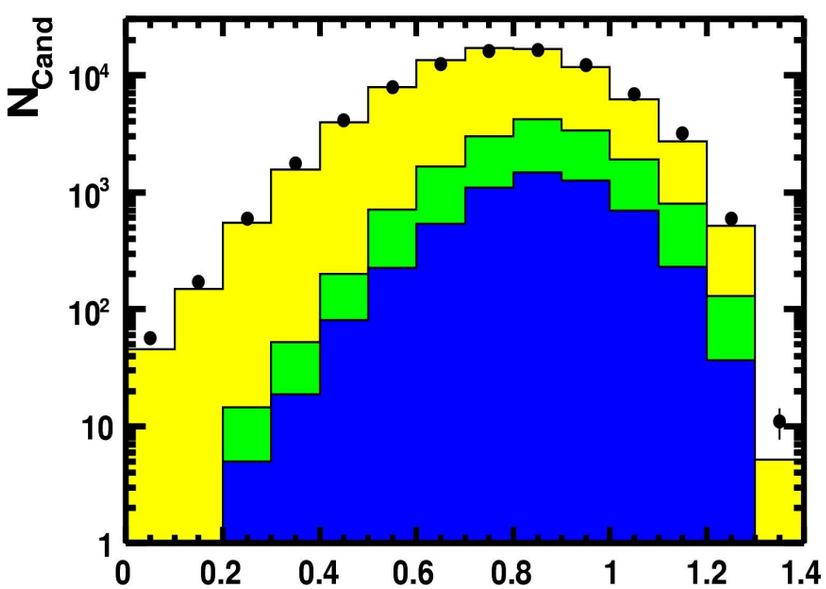
    charm: 1.28 ± 0.13

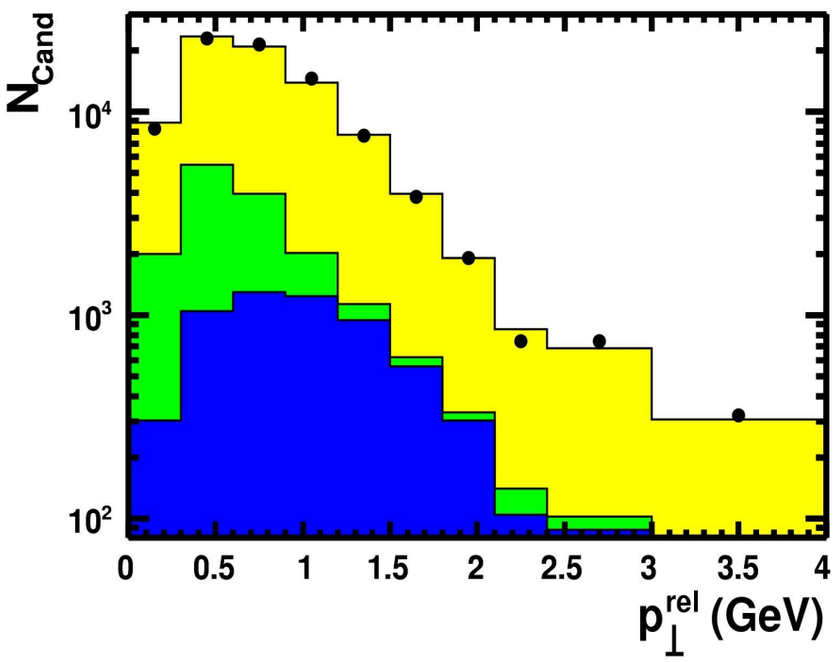


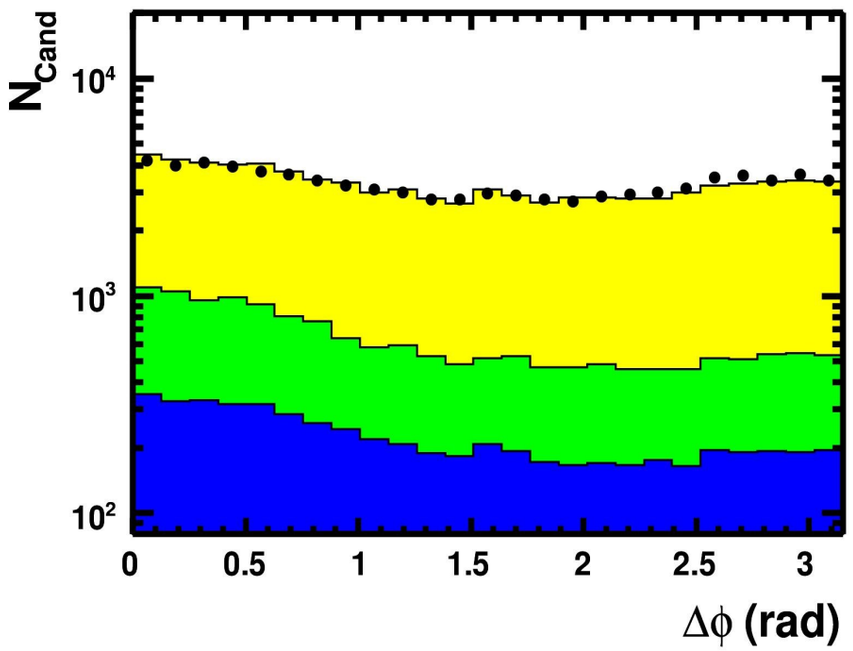
Dijet PhP b→e Control Plots











-2 ln $T_{e,b}$ < 10

- ZEUS 120 pb^{-1}

PYTHIA (scaled)

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

Dijet PhP b→e Total Cross-Section

Total visible cross-section for beauty and charm:

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

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

$$\sigma_b^{tot} = 88 \pm^{22}_{13}\ pb$$

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

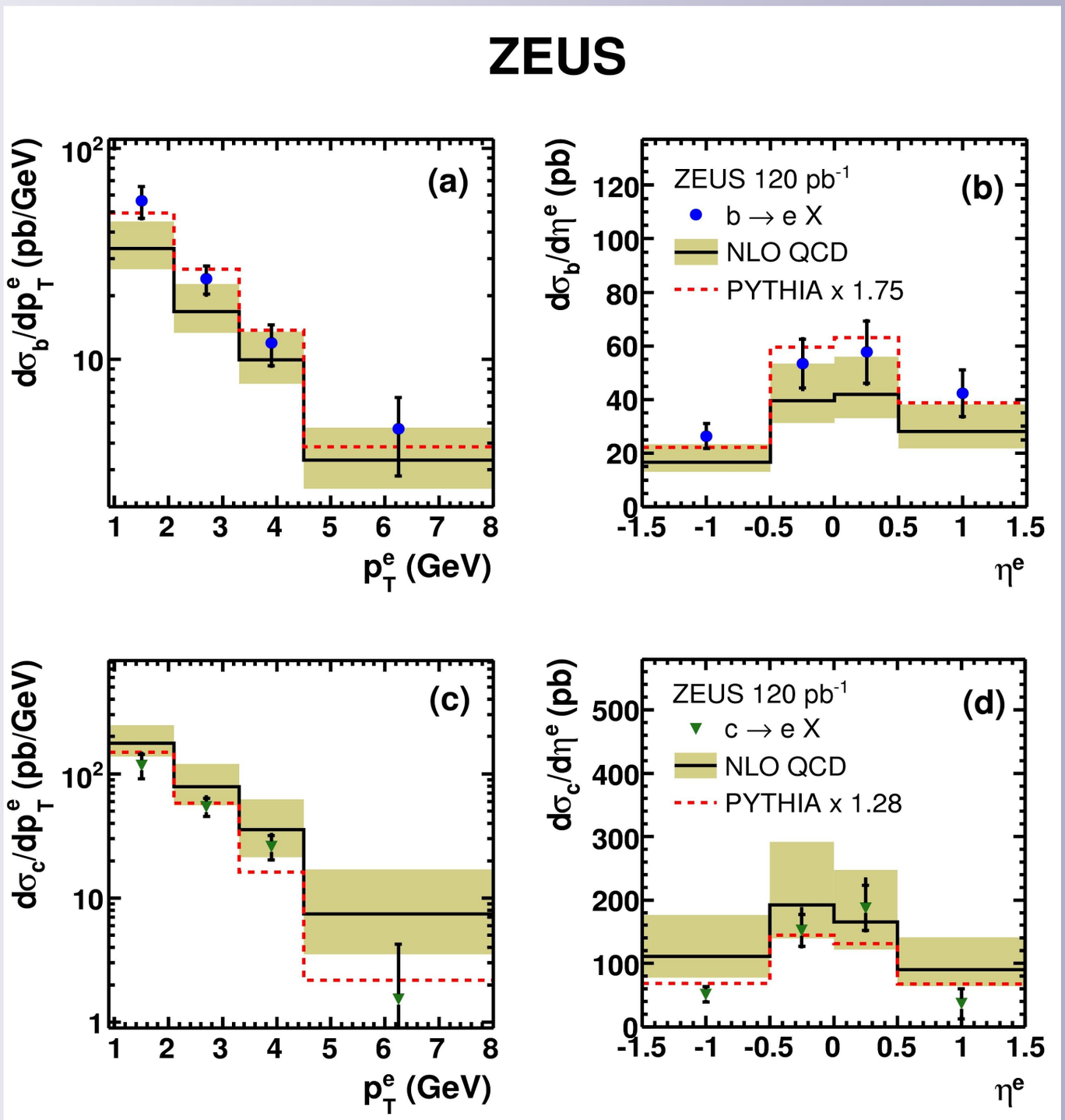
$$\sigma_c^{tot} = 382 \pm^{172}_{107}\ pb$$

Dijet PhP b,c→e Results

Differential electron cross-sections

Beauty

Charm

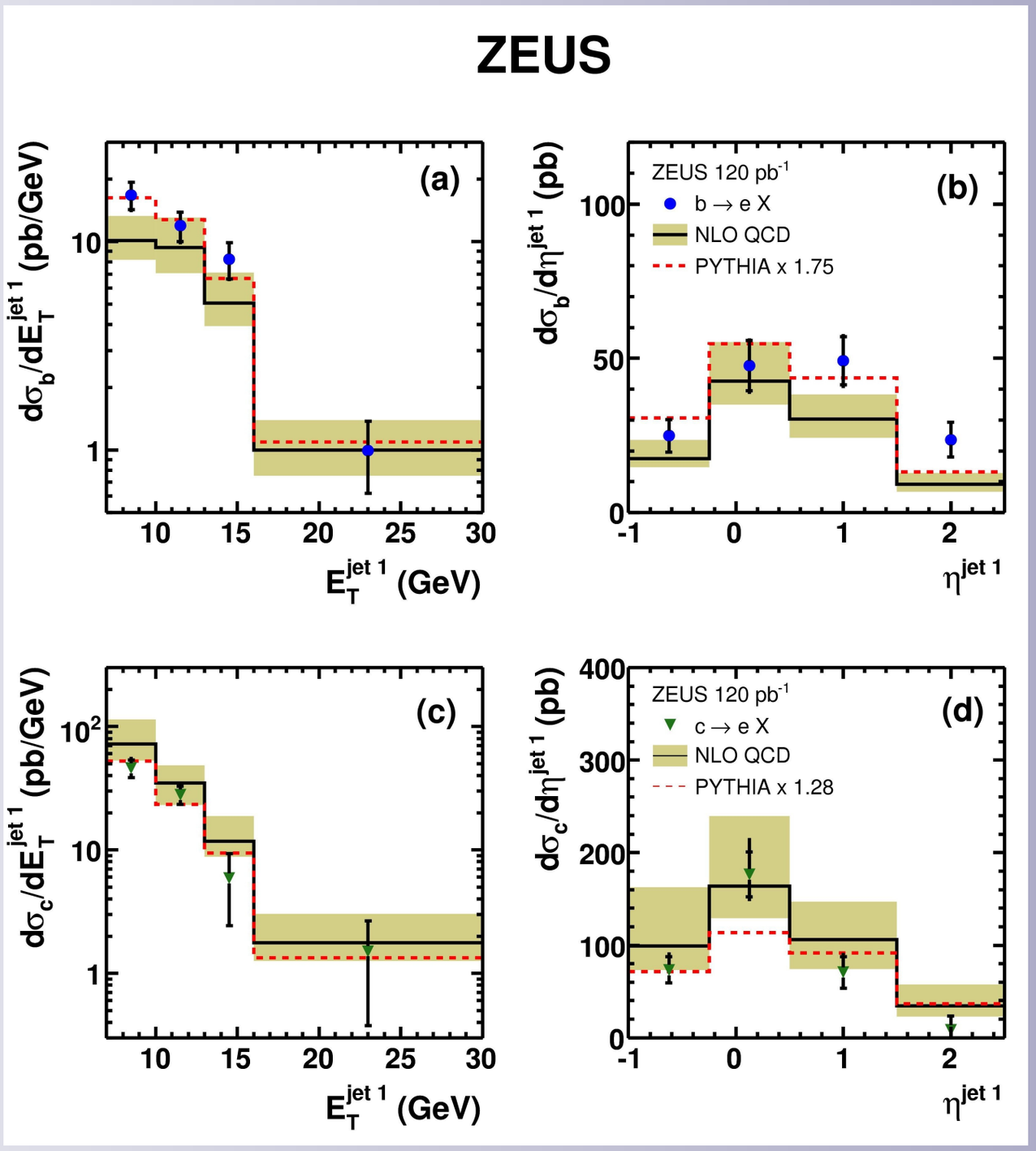


Dijet PhP b,c→e Results

Differential jet cross-sections

Beauty

Charm



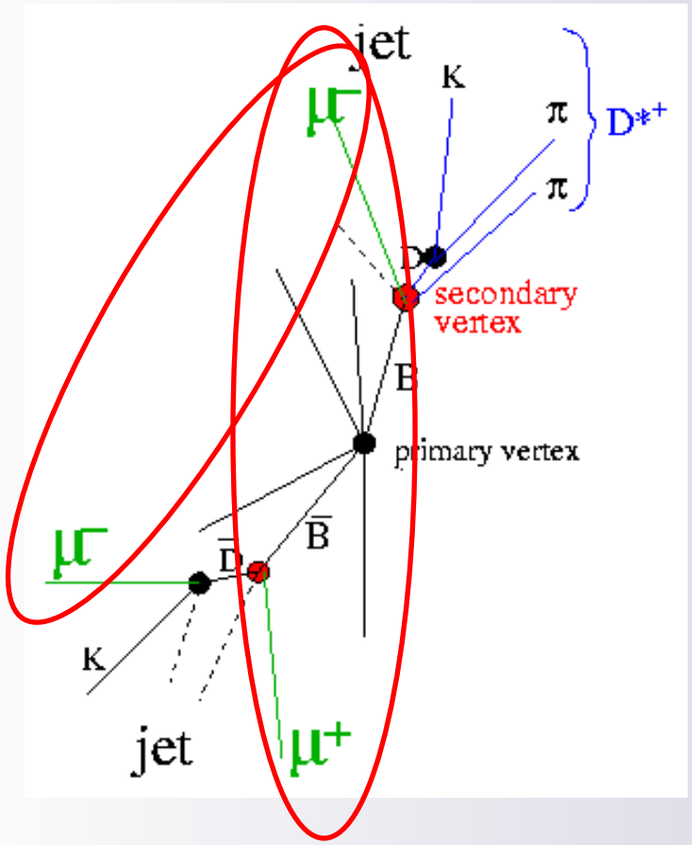
Dijet PhP b→e Summary

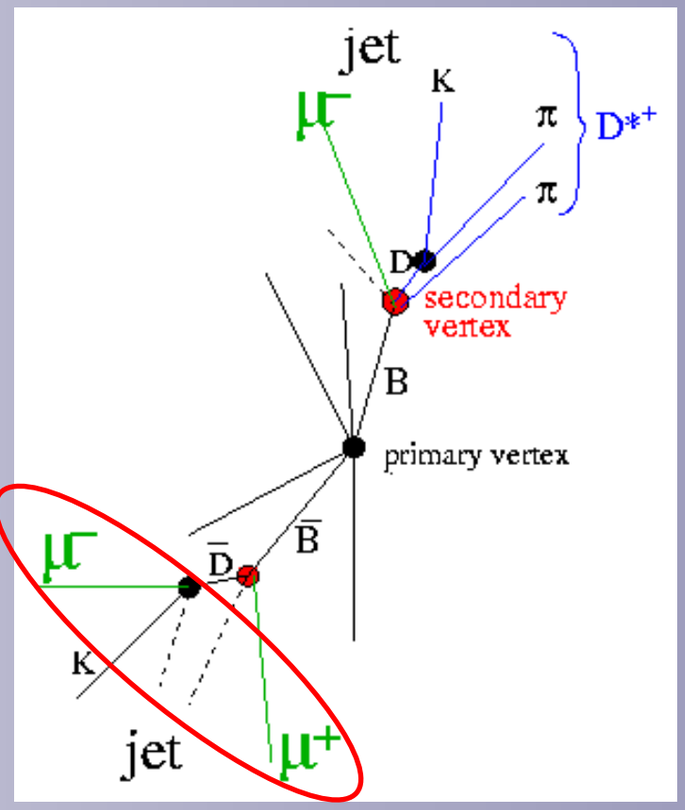
- Beauty and charm photoproduction has been measured in the HERA I data using semi-leptonic decays into electrons
- Using electrons cross-sections can be determined down to lower momenta ($p^e_T > 0.9$ GeV)
- The beauty and charm fractions have been determined using a likelihood ratio test
- The measured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

b→μμ Analysis Goal

- Multitagged bb events (two muons)
  - tag both beauty quarks
    → explicitly measure $b\bar{b}$ correlations
  - low background
    → low muon pt 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→μμ 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 GeV +-	m < 4 GeV ++/--
m > 4 GeV +-	m > 4 GeV ++/--

b→μμ Event Selection

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

Calorimeter:

- Cal E_T-10° cone > 8 GeV

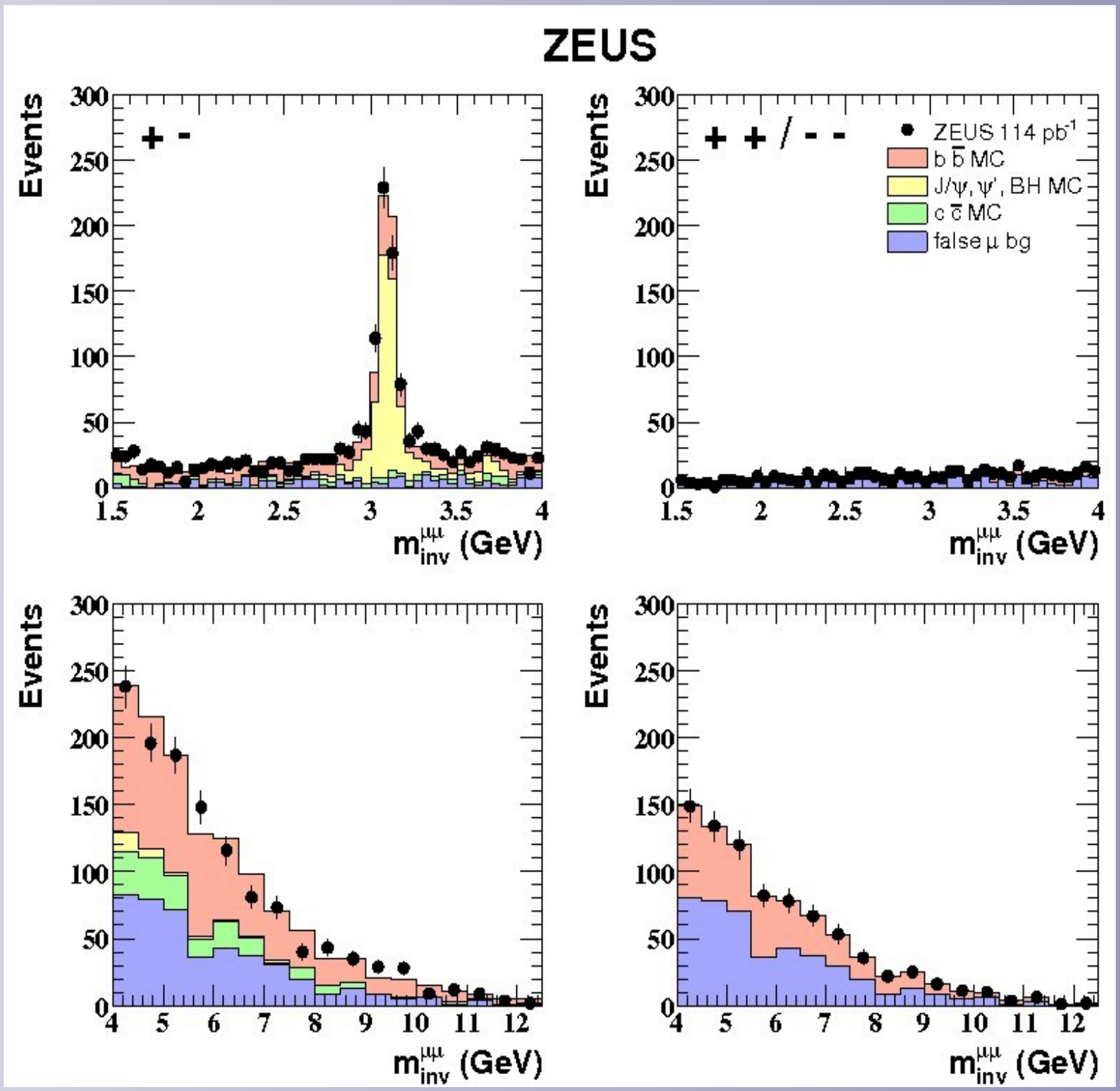
Muon Selection:

- p^{μ}_T > 1.5 GeV
- p^{μ}_T > 0.75 GeV

(high quality muons)

Further cleaning cuts

Dimuon Mass



b→μμ Background

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

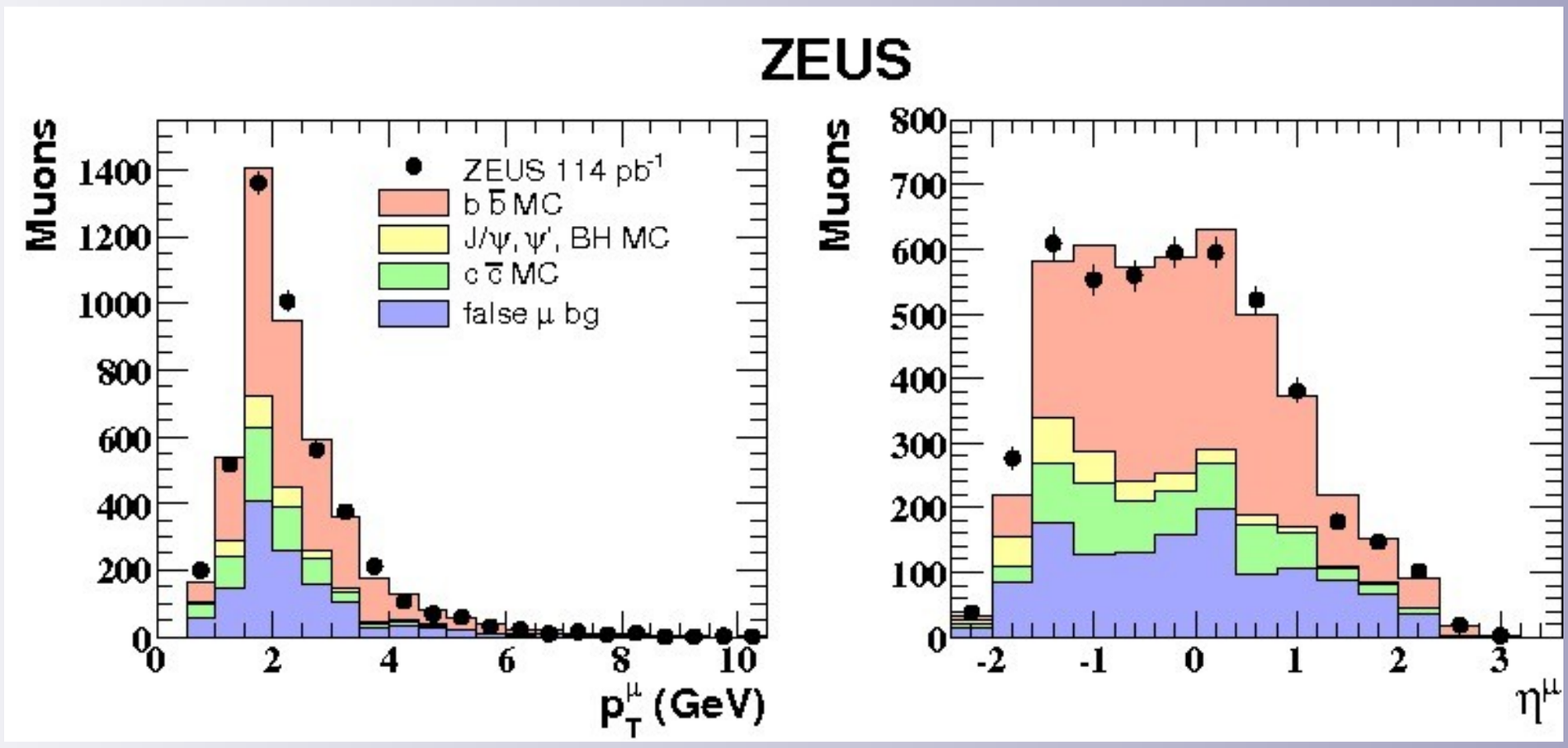
b→μμ Signal Extraction

- 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)

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

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

b→μμ Control Plots



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

NLO QCD Predictions - Dimuon Analysis

- FMNR program used
  - $\mu = \frac{1}{2}\mu_0 = \frac{1}{2}\sqrt{(p_T^b)^2 + (m_b)^2} \qquad \left(\frac{1}{4}\mu_0 < \mu < \mu_0\right)$
  - PDF(P)= CTEQ5M; PDF(γ)= GRV-G HO
  - m_b = 4.75 GeV (4.5 GeV < m_b < 5 GeV)
- WW approximation Q^2_{max} = 25 GeV to include DIS contribution(~ 15%) (FMNR+HVQDIS for comparison)
- FMNR x PYTHIA interface for visible μμ cross-sections

b→μμ Tot WQ

Visible cross-section:

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

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

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

Visible range:

1st μ	:	p_T	> 1.5 GeV	
2nd μ	:	(p	> 1.8 GeV	for η < 0.6
		p	> 2.5 *or* p_T > 1.5 GeV	for η > 0.6)
		and p_T	> 0.75 GeV	
both μ:		-2.2	< η < 2.5	

Total ep cross-section for bb production:

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

extrapolated to quark level using PYTHIA

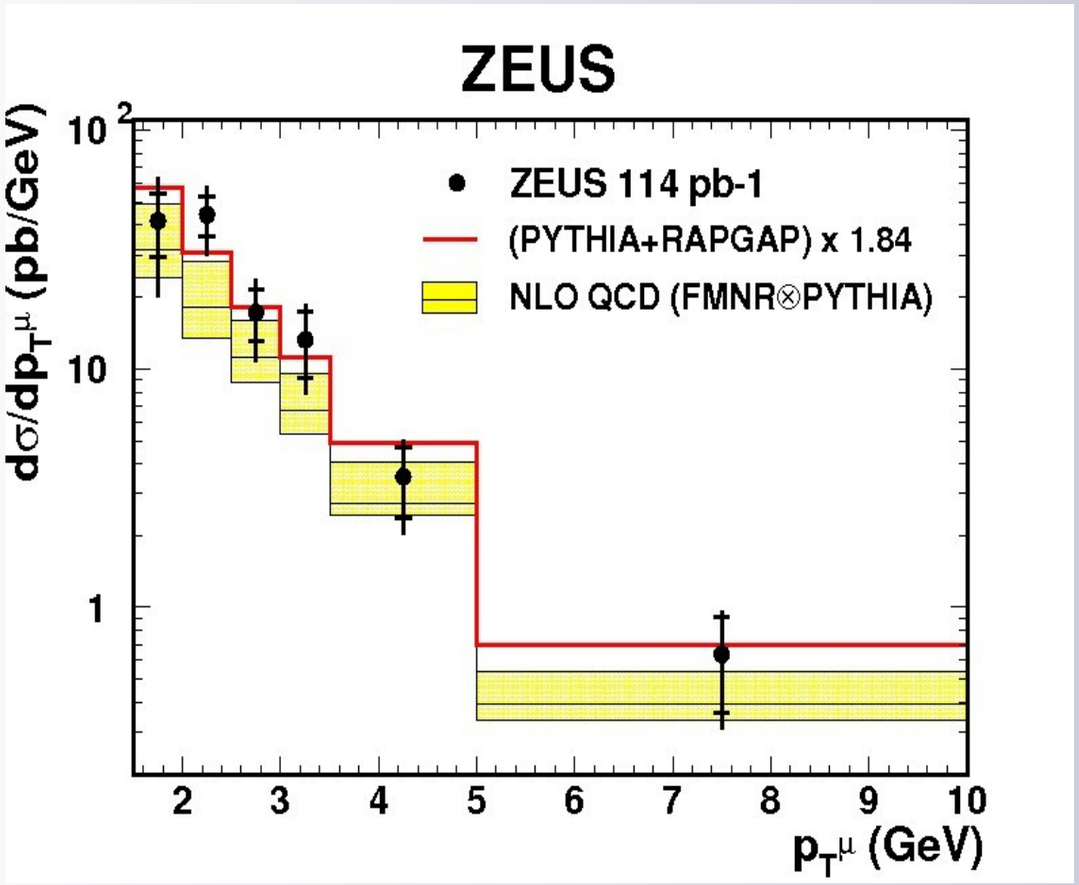
$$\sigma^{tot}_{NLO} = 7.5^{+4.5}_{-2.1}\ nb$$ **FMNR+HVQDIS**

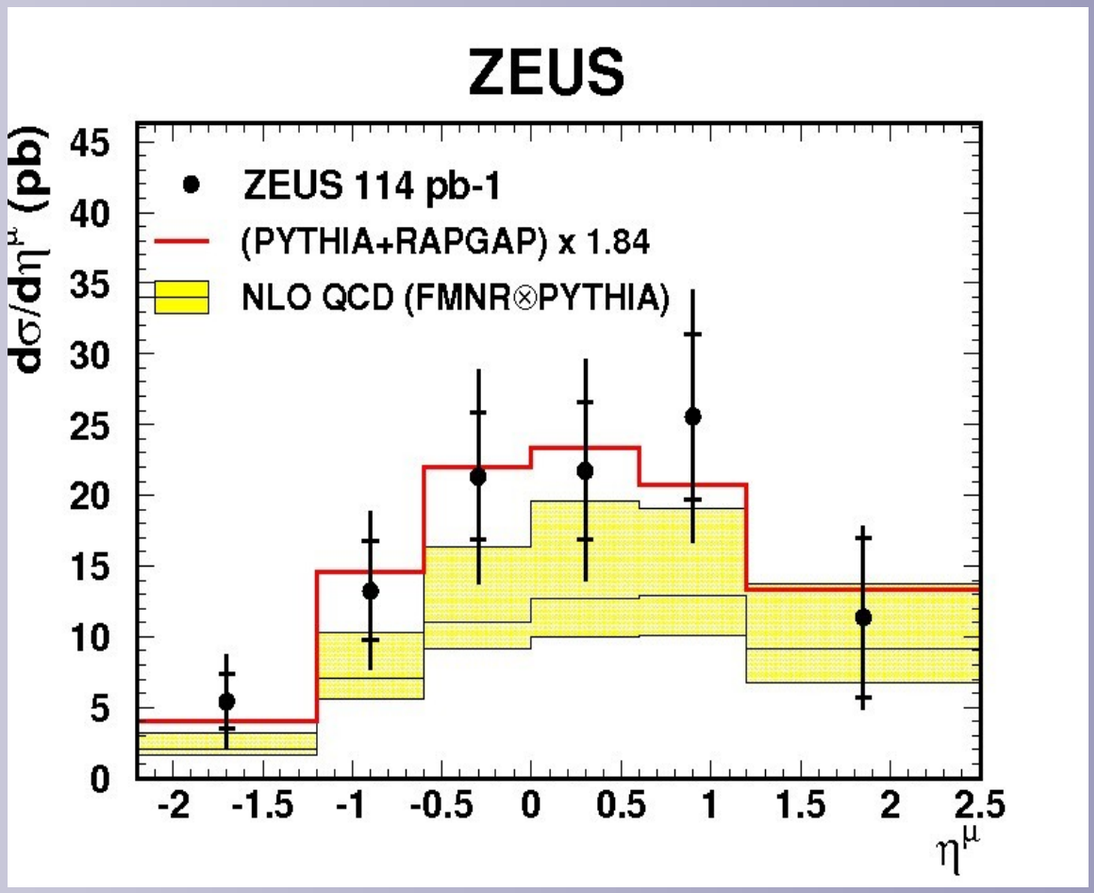
$$\sigma^{tot}_{WW} = 7.8^{+4.9}_{-2.3}\ nb$$ **FMNR (WW-appr.)**

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

b→μμ Differential Cross-Sections

- Differential muon cross-sections
  - both muons $p^{\mu}_{T} > 1.5$ GeV, $-2.2 < \eta < 2.5$





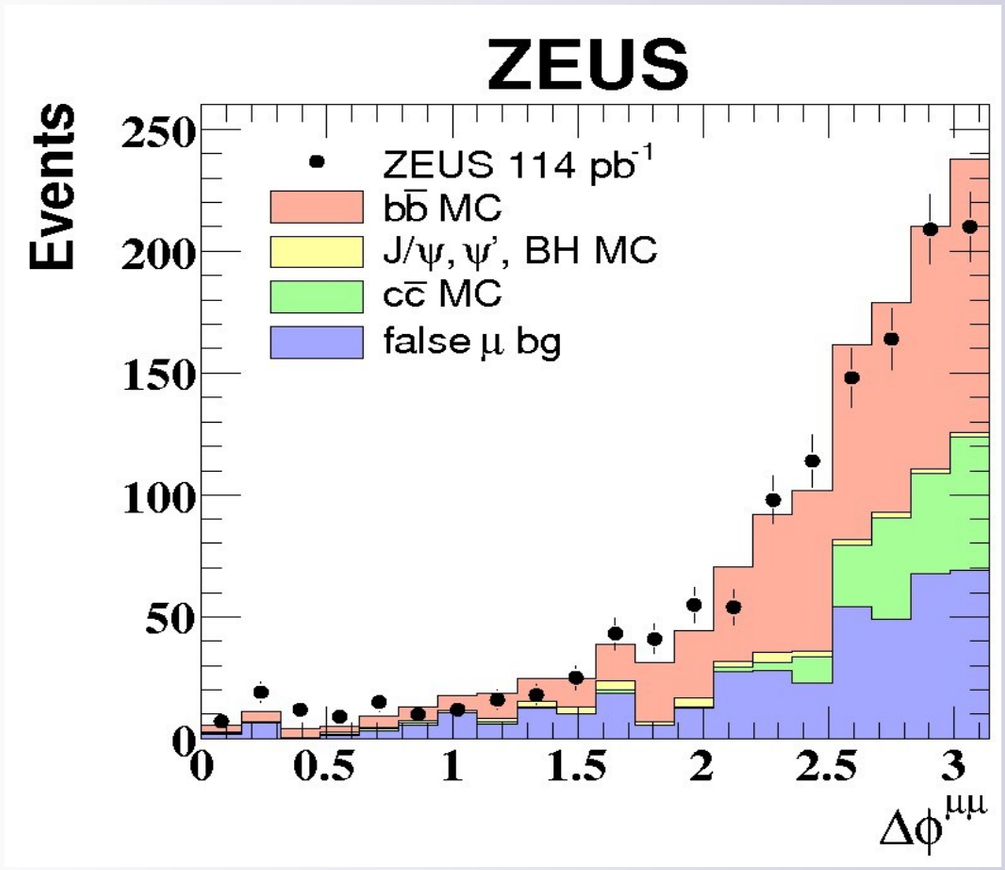
good agreement in shape, reasonable agreement in normalisation
no indication for deviations at low p_T or high η

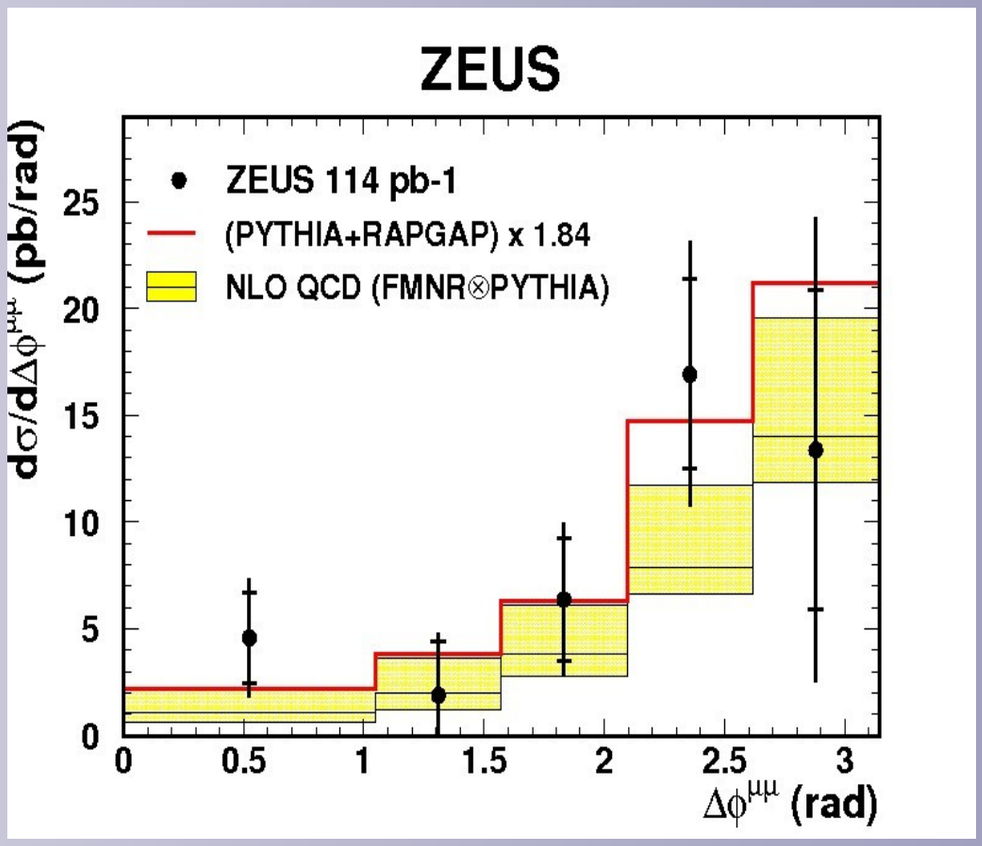
b→μμ bb Correlations

- Δϕ between muons from different quarks

$$\Delta\phi = (\phi^{\mu 1} - \phi^{\mu 2})$$

($m^{\mu\mu}$> 3.25 GeV)





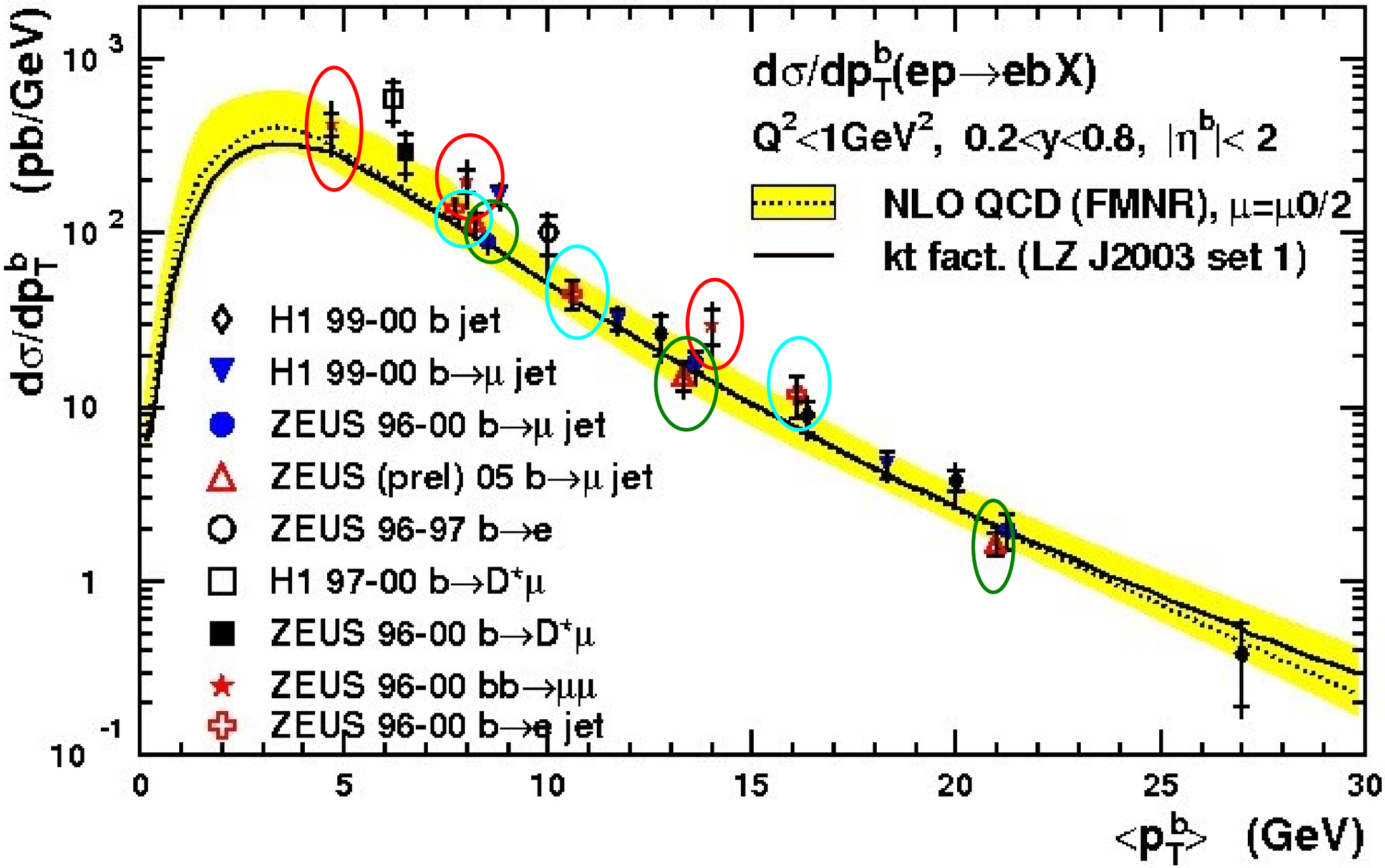
bb correlations well described (within large errors)

b→μμ 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^{μ}_{T},η^{μ} and $\Delta\phi$ measured
- Agreement with NLO predictions

p^b_T plot

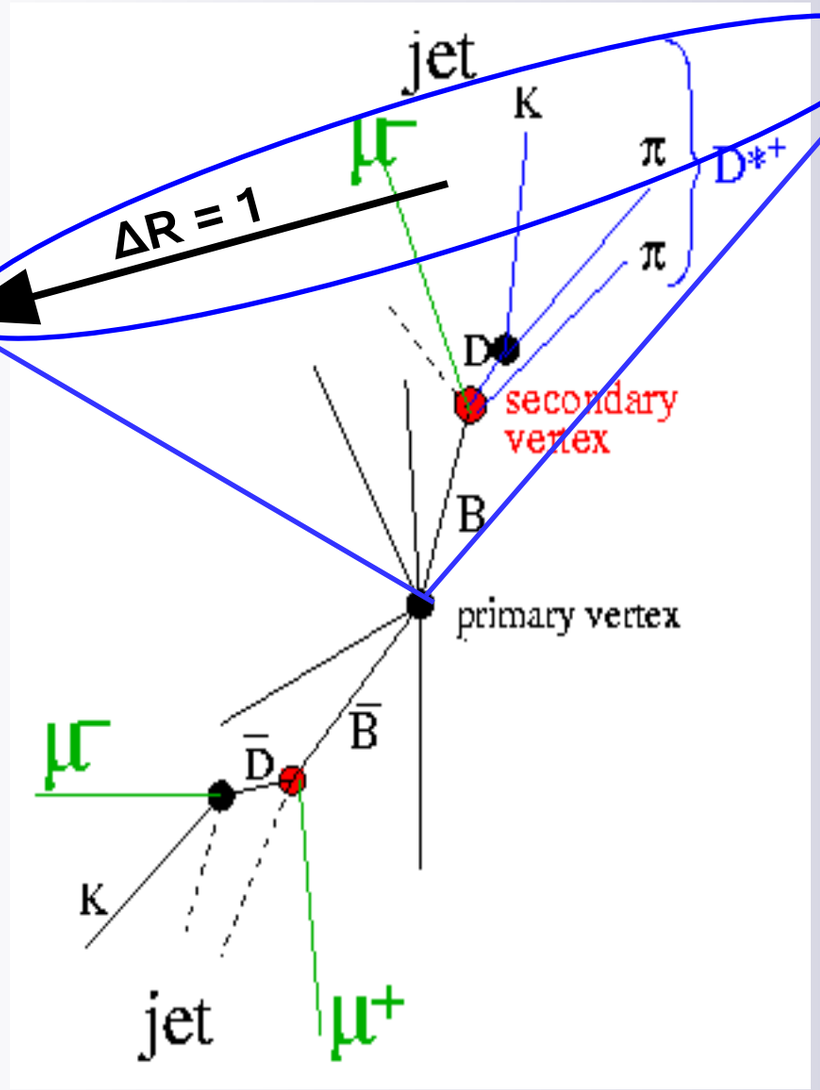
HERA



Summary

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

b→μμ Isolation Cut



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

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

$\sum E_i^{\mu}$ = energy deposited in cone of ΔR<1 around muon, excluding muons