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# Beauty in photoproduction at ZEUS

DIS10, XVIII International Workshop on Deep Inelastic Scattering and Related Subjects

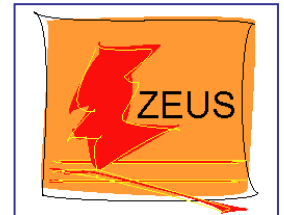
Convitto della Calza, Firenze, 19<sup>th</sup>-23<sup>rd</sup> April 2010

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*For the ZEUS Collaboration*

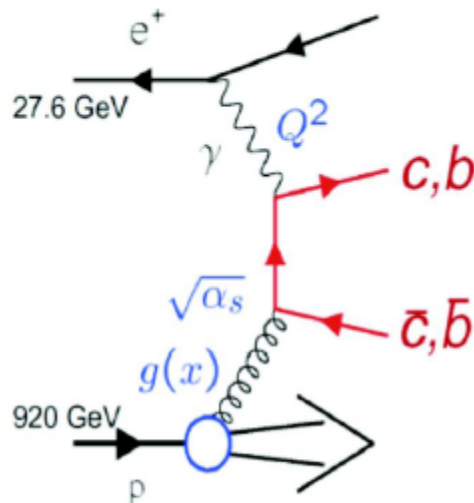


# Motivation

- The study of beauty production is a very interesting topic in high energy physics:
  - rigorous test of perturbative QCD;
  - large b-quark mass ( $m_b \sim 5\text{GeV}$ ) and high momenta  $p_T$  provides an additional hard scale that should ensure reliable predictions.
- needed better understanding of the beauty quark production mechanism.

# HFL production

Dominant production process in  $ep$ -collisions: **Boson Gluon Fusion**



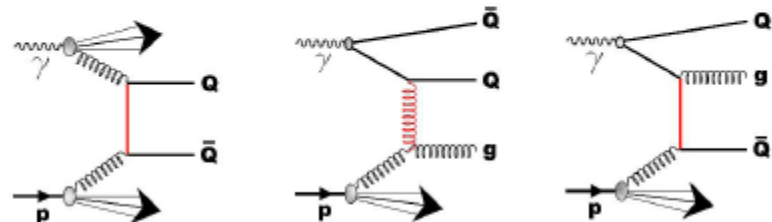
Multiple scales involved:

- $M_b \sim 5 \text{ GeV}$ ,  $M_c \sim 1.4 \text{ GeV}$
- $Q^2 \sim 0 \text{ GeV}^2$  (photoproduction -  $\gamma p$ )
- $Q^2 > \sim 1 \text{ GeV}^2$  (deep inelastic scattering -  $DIS$ )
- $P_t^{c,b}$  few GeV

Powerful tool for testing  $p$  structure and  $pQCD$

Kinematic variables:

- $Q^2 = -q^2$  photon virtuality, squared momentum transfer
- $x = \frac{Q^2}{2pq}$  Bjorken scaling variable
- $x_\gamma^{jet} = \Sigma_{j1,j2}(E - P_Z)/\Sigma_h(E - P_Z)$



# Heavy Flavour Tagging

- *Different experimental techniques to use for heavy flavour tagging:*
  - Meson identification  $D^{*\pm}$  tagging;
  - Decay spectra  $P_{Trel}$  of lepton to jet axis;
  - Lifetime information measure impact parameter with respect to primary vertex (beam spot);

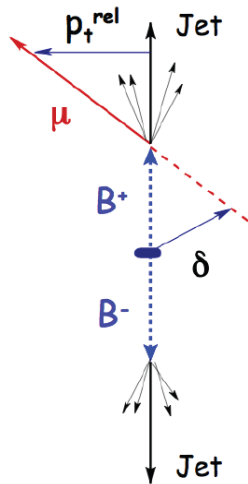
# Beauty at HERA: semileptonic tagging $b \rightarrow \mu$

Beauty measurements difficult at HERA  $\rightarrow \sigma_{b\bar{b}}/\sigma_{tot} \sim 0.1\%$

- increases to  $\sim 6\%$  for high- $p_T$  jets
- increased to  $\sim 20\%$  for two jets and a high- $p_T$  lepton (beauty and charm are main sources)

## Beauty results at ZEUS

- events with 2 jets + 1e (EPJC 18 (2001) 625, PRD 78 (2008) 072001)
- events with 2 jets + 1 $\mu$  (PRD 70 (2004) 012008, DESY-08-210 (2008))
- events with 1  $D^*$  + 1 $\mu$  (EPJ C 50 (2007) 299-314)
- events with 2 $\mu$ s (JHEP02 (2009) 032)



• Well established techniques already used in previous measurements by the ZEUS collaboration make use of the final state muon or electron in semileptonic beauty decays to exploit these features.

• In fact, the large  $b$  mass leads to high values of the transverse momentum of e.g. the muon relative to the closest jet,  $p_{Trel}$ , making the spectrum of muons (electrons) from beauty decays much harder than the muons (electrons) from a lighter quark.

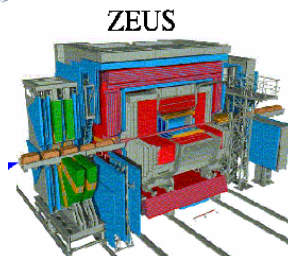
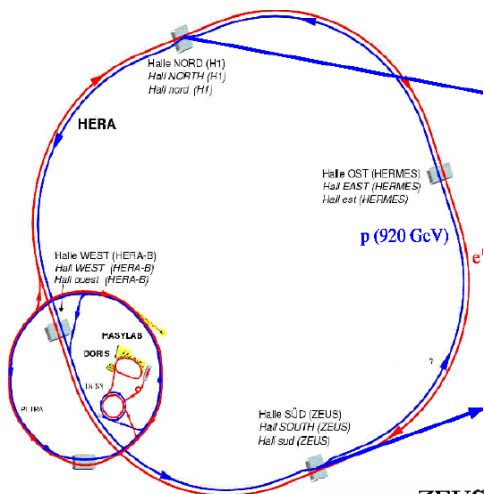
However, all these experimental procedures used so far in ZEUS to measure beauty production are limited to the semileptonic beauty decays.

# Beauty tagging via vertex reconstruction

- a new method for beauty identification based on the reconstruction of the decay vertices (secondary vertices) has been developed;
- inclusive beauty measurement in which the hadronic decays are also taken into account;
- relatively long lifetime of  $b$  hadrons, beauty secondary vertices are considerably displaced with respect to the interaction vertex compared to the decay vertices of charm and light quarks;
- beauty and charm contributions are extracted using the characteristic distributions of reconstructed decay length significance and invariant mass of the secondary vertex.

# ZEUS detector at the HERA

- **ZEUS: 56 universities and laboratories, 18 countries**
- **HERA – until 2007 was the only ep collider in the world**
- **HERA II (2002-2007): upgraded detectors, longitudinally polarised  $e^\pm$  beams**



## Complete $4\pi$ detector

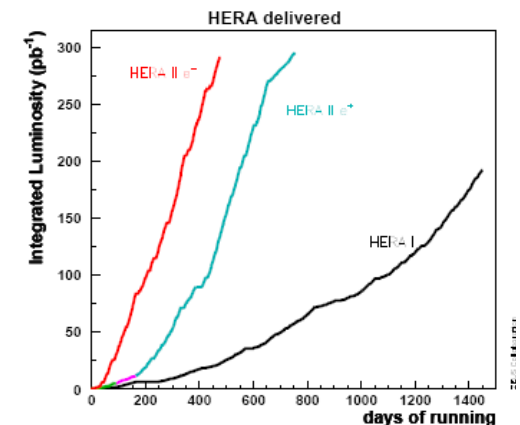
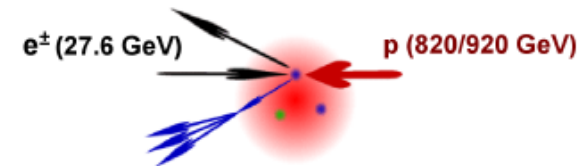
### Tracking:

- central tracking detector
  - Silicon  $\mu$ -Vtx
- (operate in a B field of 1.43 T)

### Calorimeters:

- Uranium-scintillator (CAL)
- Instrumented-iron (BAC)

### Muon chambers



$$e \Rightarrow 27.6 \text{ GeV} \quad \Leftarrow p \quad 820 - 920 \text{ GeV}$$

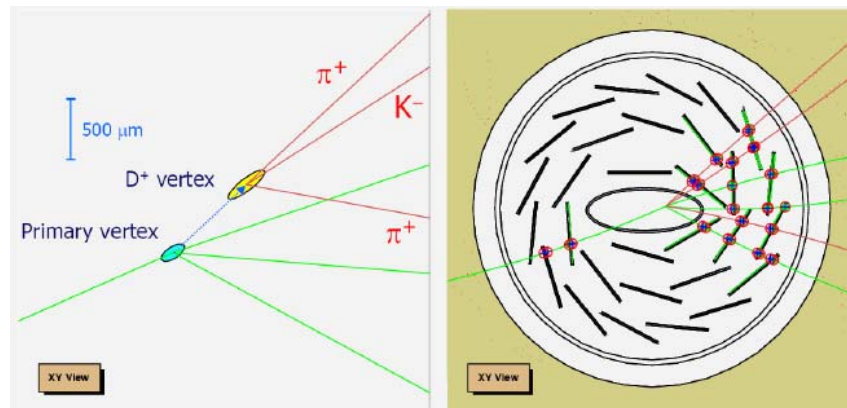
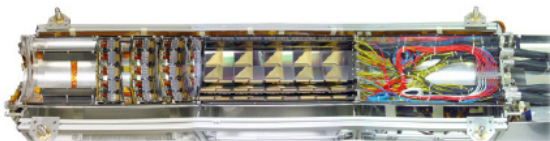
HERA I      HERA II  
1995-2000      2003-2007

$\sqrt{s}$	318 (300)	318 GeV
$\mathcal{L}$	$1.5 \cdot 10^{31}$	$7 \cdot 10^{31} \text{ cm}^{-2} \text{ s}^{-1}$
$\mathcal{L}_{int}$	$\sim 120$	$\sim 370 \text{ pb}^{-1}$

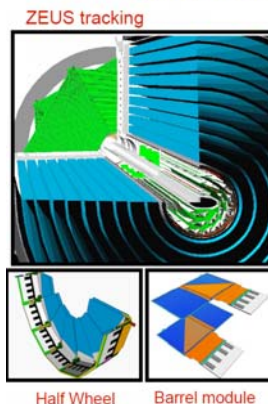
# Beauty tagging using micro-vertex detector

- During the HERA luminosity upgrade period 2000/2001 the tracking system of the ZEUS detector was enhanced with a silicon Micro Vertex Detector (MVD).
- The implementation of the MVD provides high precision measurements that allow new identification techniques of the beauty quarks based on their heavy mass and long lifetime.
- algorithm (secondary vertex b-tagging) to identify jets originating from b quarks by exploiting exclusively the full MVD potential

- Since HERA II both experiments equipped with Silicon Vertex Detectors
- Important for heavy flavour measurements



The ZEUS Micro Vertex Detector

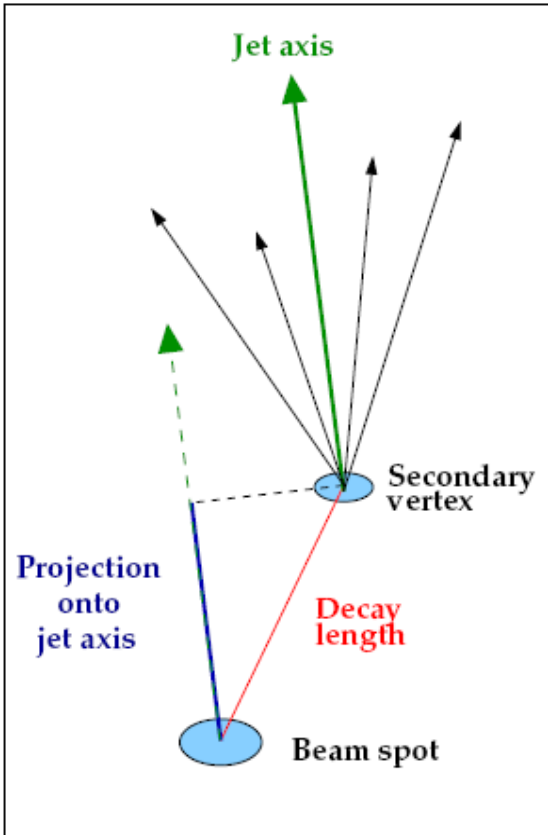


- For HERA II ZEUS was fitted with a silicon micro vertex detector (MVD).
- The MVD consists of forward and barrel regions.
- Barrel:
  - 30 ladders
  - 600 single sided silicon strip sensors
- Forward Wheels:
  - 4 wheels
  - 112 trapezoidal single sided silicon strip sensors
- Back to back sensors give information in  $(z, r_\phi)$  for barrel tracks and  $(w, u)$  for forward tracks.



# 2D impact parameter and significance

Method of extracting the beauty and charm content:



- reconstruct the decay vertices of the B hadrons and use the resulting decay length, which, due to the long lifetime of the B hadron, is enhanced at high values for beauty and charm compared to the light flavour background.

- Furthermore, the invariant mass of the decay vertices,  $m_{vtx}$ , can be used to distinguish between the beauty- and charm-enriched regions.

- No requirements are imposed on the final state of the B decay so that the measurement is kept fully inclusive and benefits from the increase in statistics compared to the exclusive  $b \rightarrow \mu$  and  $b \rightarrow e$  analyses.

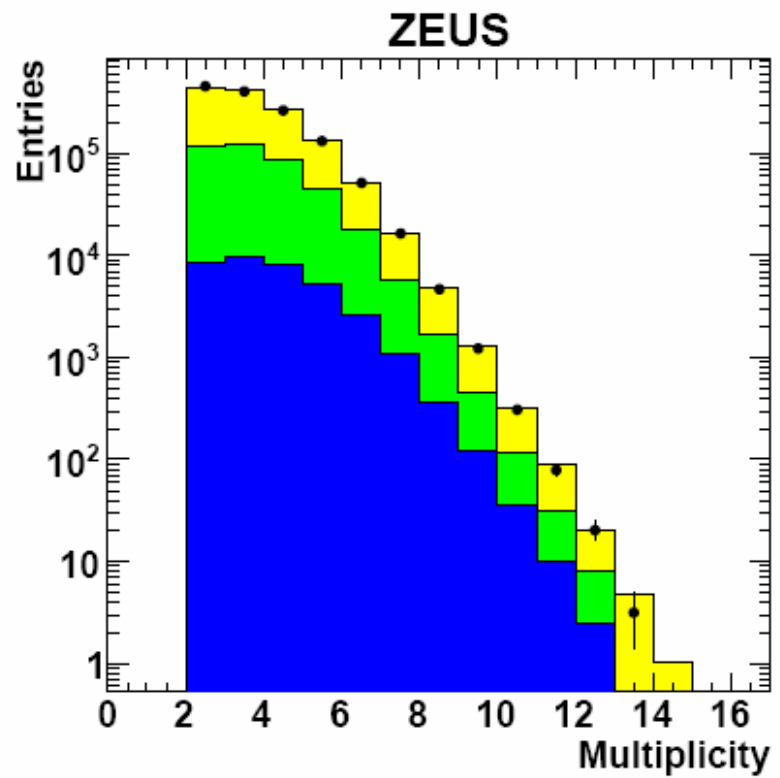
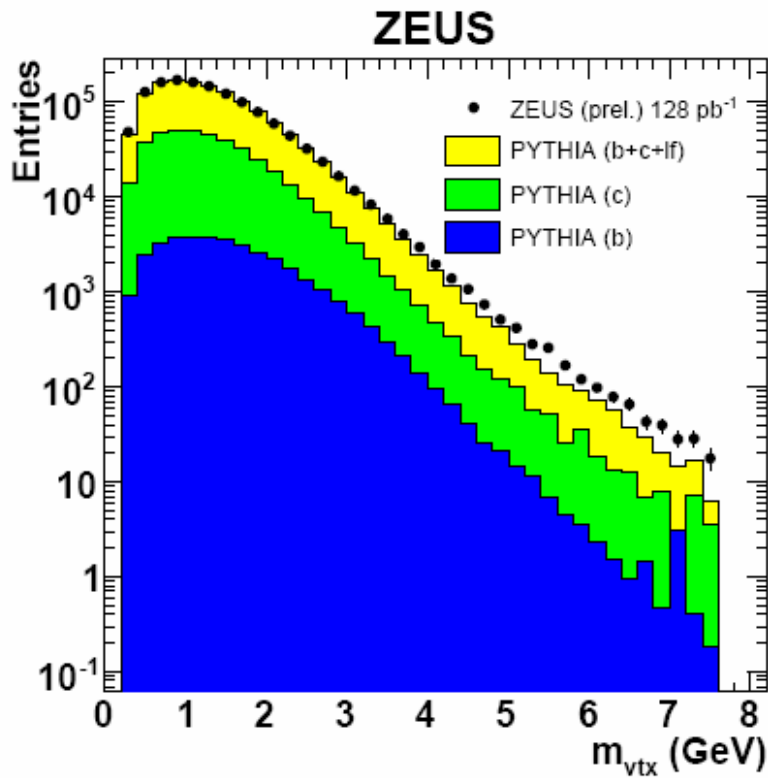
- transverse decay length  $L_{xy}$
- impact parameter  $\delta$
- significance  $S = \delta/\sigma(\delta)$ ,

$$S_L = L_{xy} / \sigma(L_{xy})$$

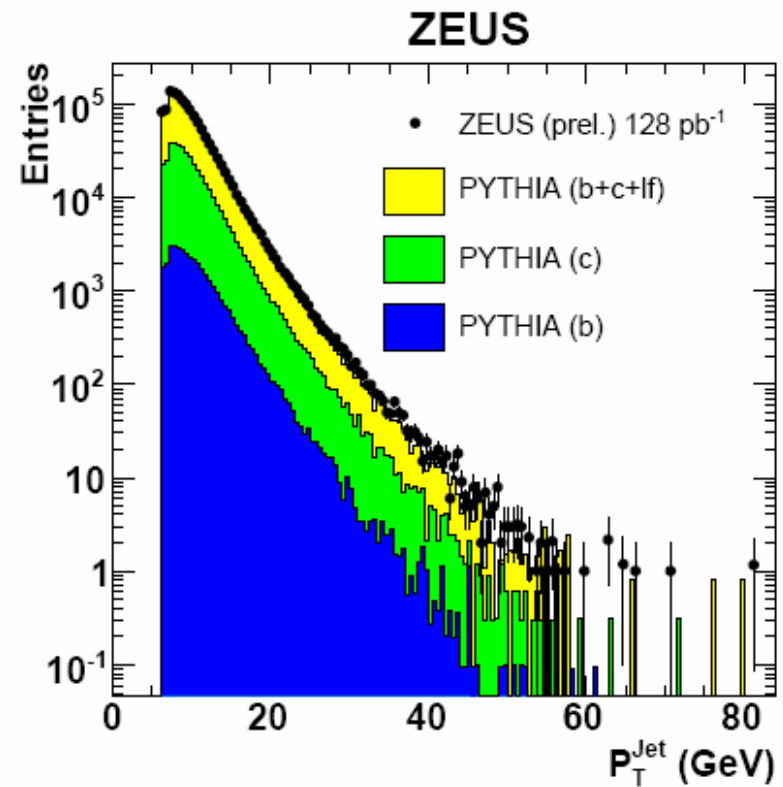
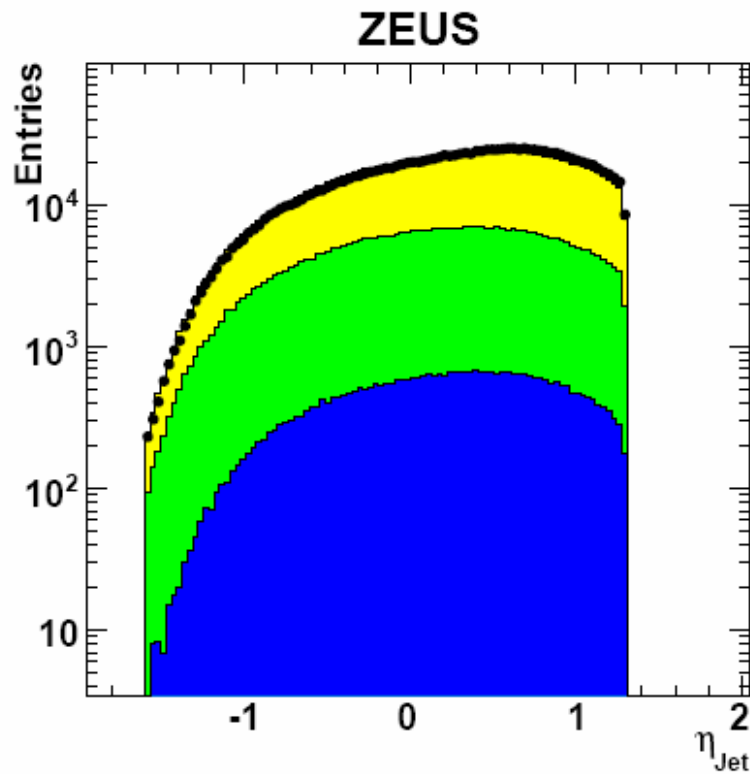
# Events selection:

- data set collected in 2006/07 corresponding to an integrated luminosity of 128 pb<sup>-1</sup> ;
- events containing at least two jets, each having an identified secondary vertex;
- jets are required to be within the pseudorapidity region  $|\eta| < 1.5$  with transverse momenta  $p_T > 7(6)$  GeV/c respectively;
- no requirements are imposed on the b decay final state so that the measurement is kept inclusive;
- fraction of events containing b-quarks is extracted using the characteristic distributions of reconstructed decay length and invariant mass of the secondary vertex;

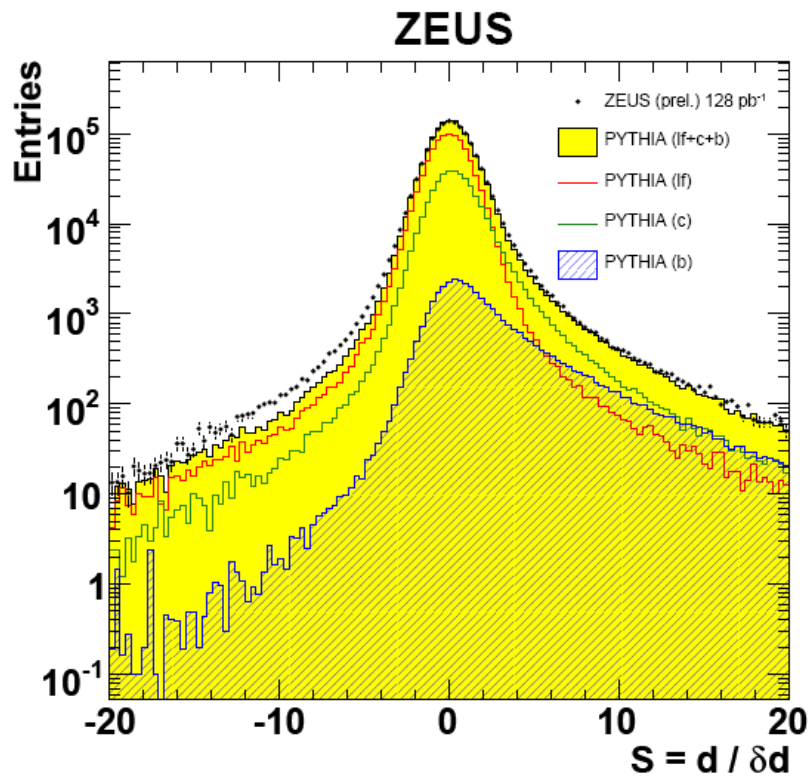
# Vertex control plots



# Jet control plots

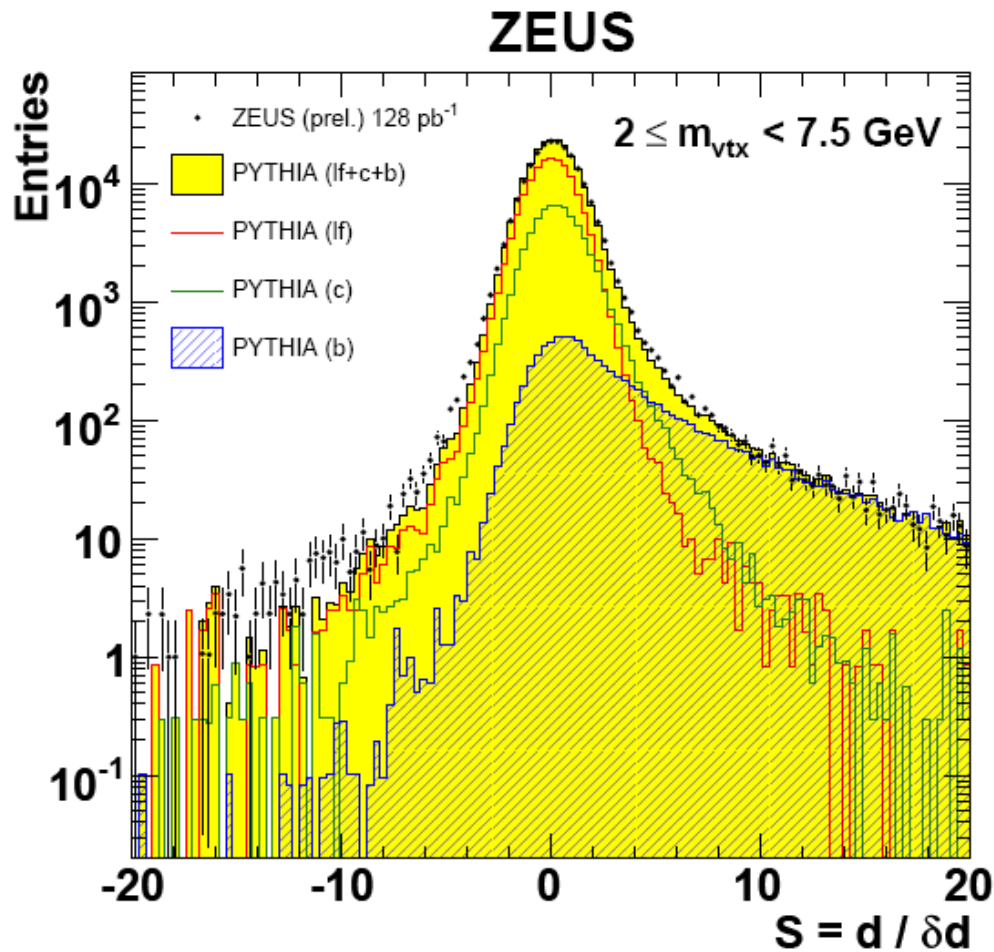


# Decay length significance

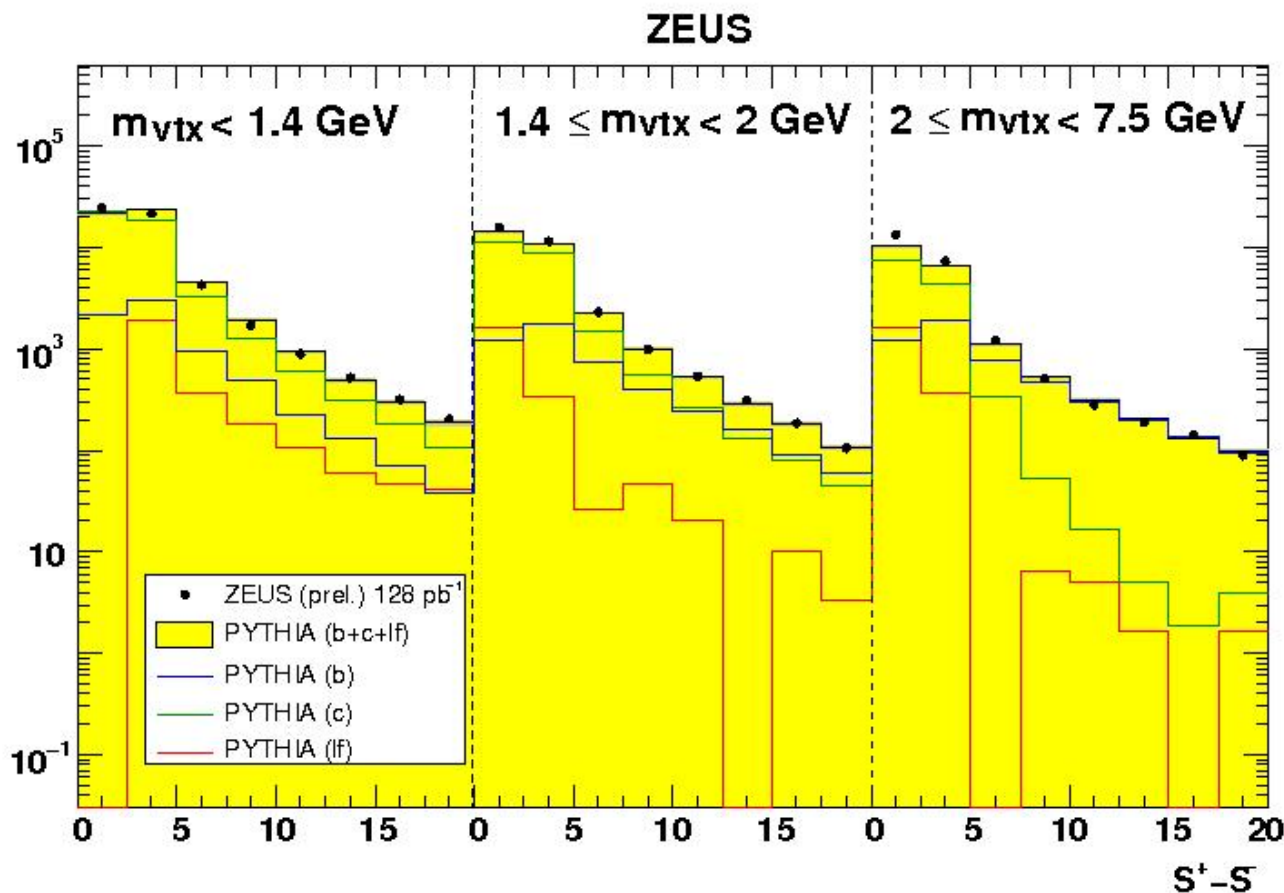


- Decay length significance  
 $S = DL / \delta DL$
- For large  $m_{\text{vtx}}$  dominated by **beauty**  
→ With cuts on  $S$  and  $m_{\text{vtx}}$  an almost **pure beauty sample** can be obtained!

# Decay length significance ( $m > 2 \text{ GeV}$ )

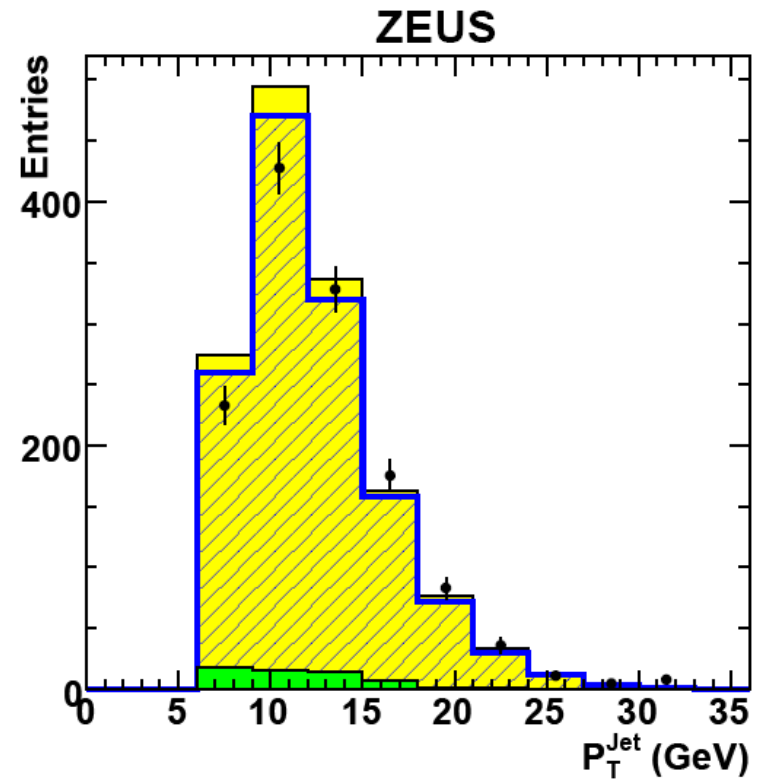
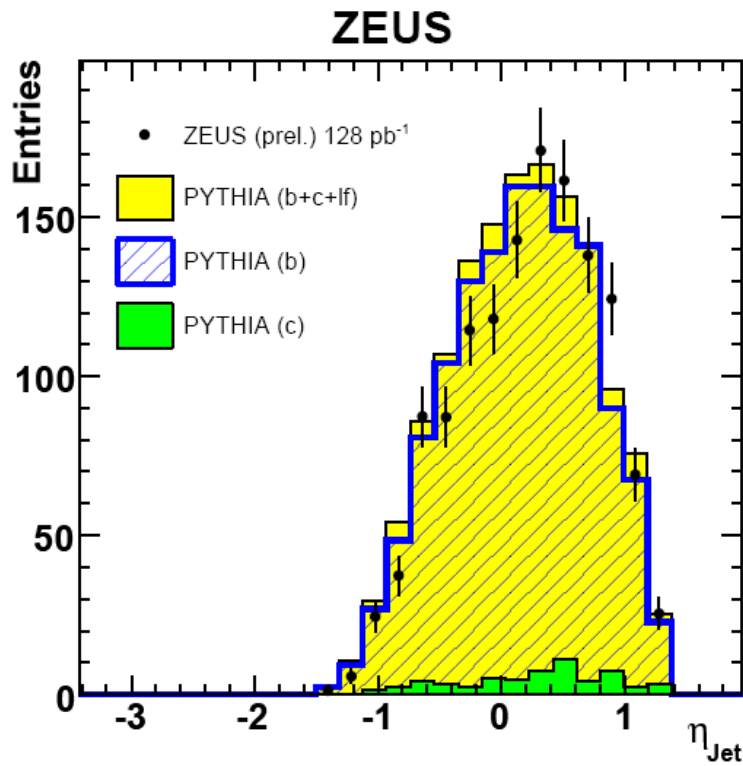


# Mirrored decay length significance (fit):



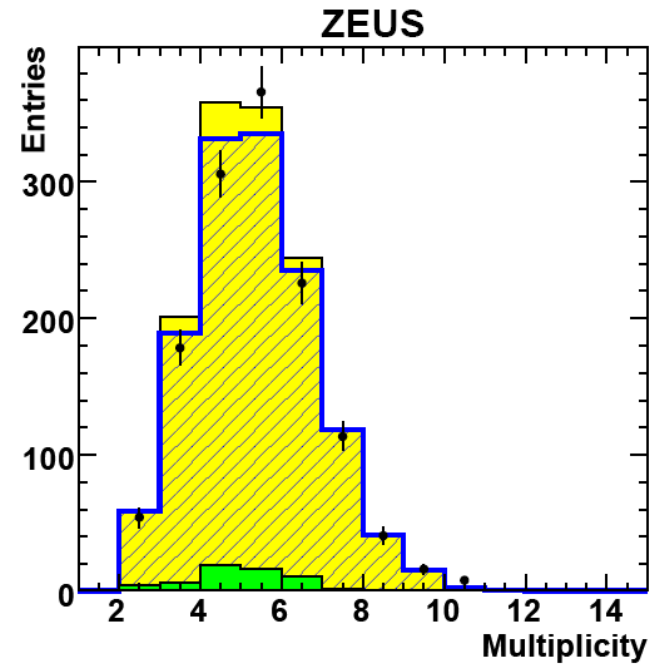
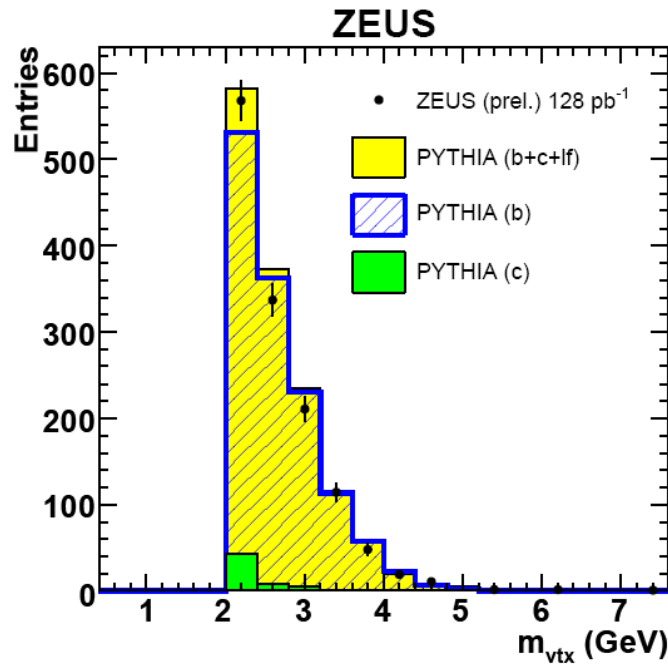
Fit mirrored and subtracted decay length significance ( $S^+ - S^-$ )  
in bins of the secondary vertex mass  $m_{\text{vtx}}$

# Beauty-enriched plots (jets)



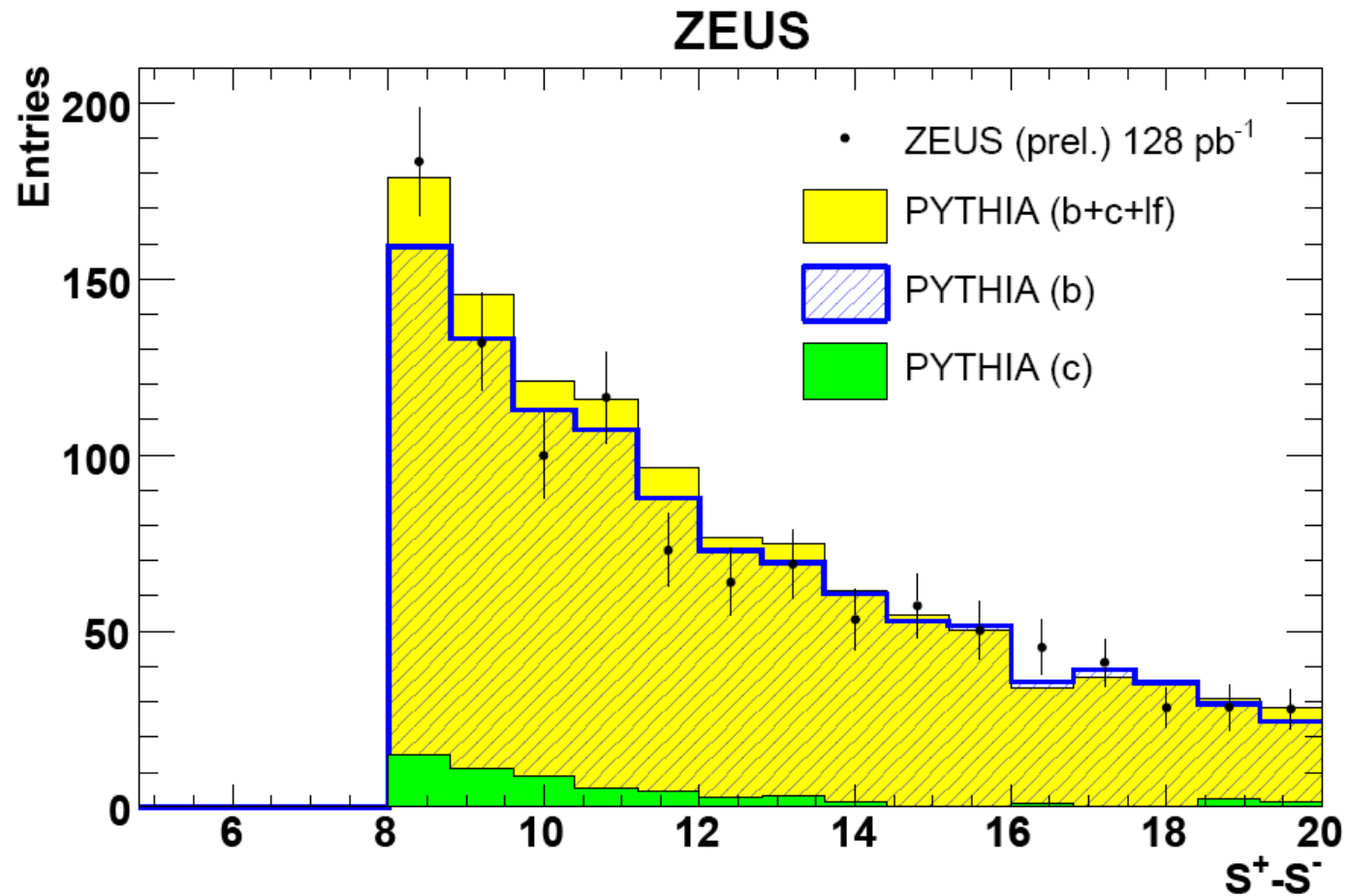


# Beauty-enriched plots (vertex)



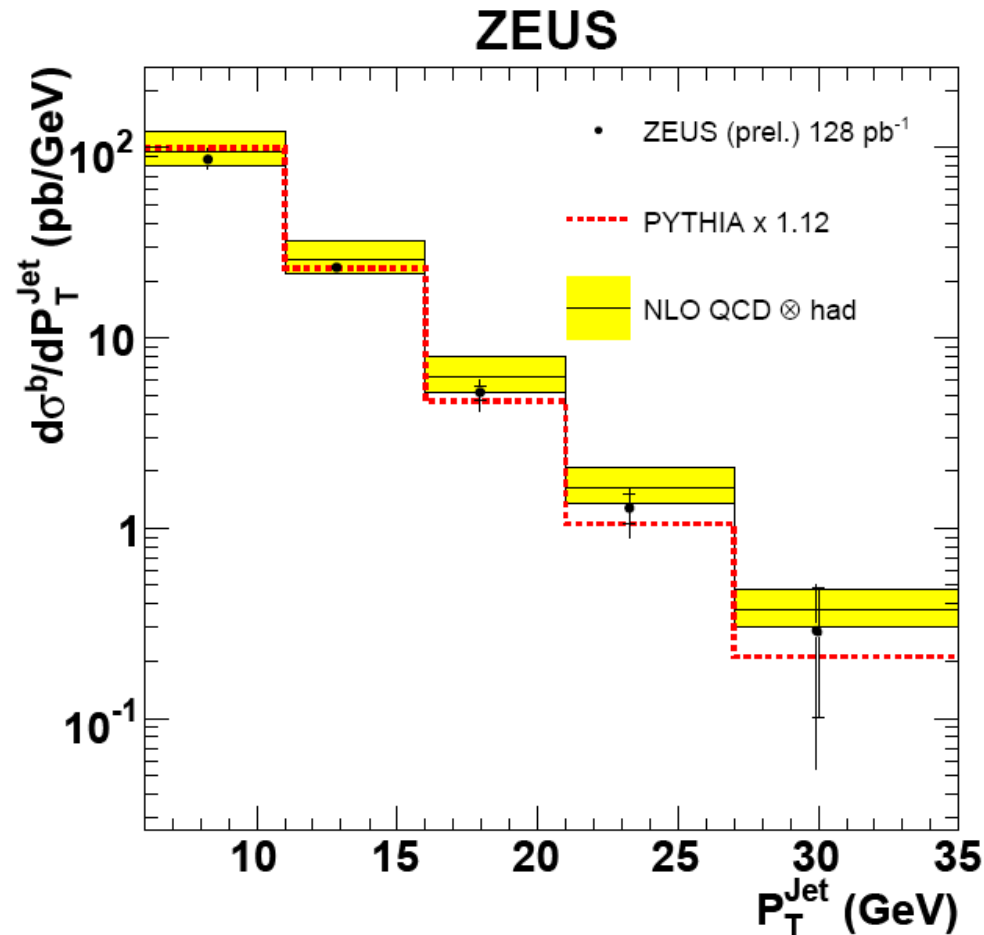
- Beauty-enriched  $m_{\text{vtx}}$  and multiplicity distributions
- Very good agreement between Data and MC

# Beauty-enriched plots (mirrored DL significance)



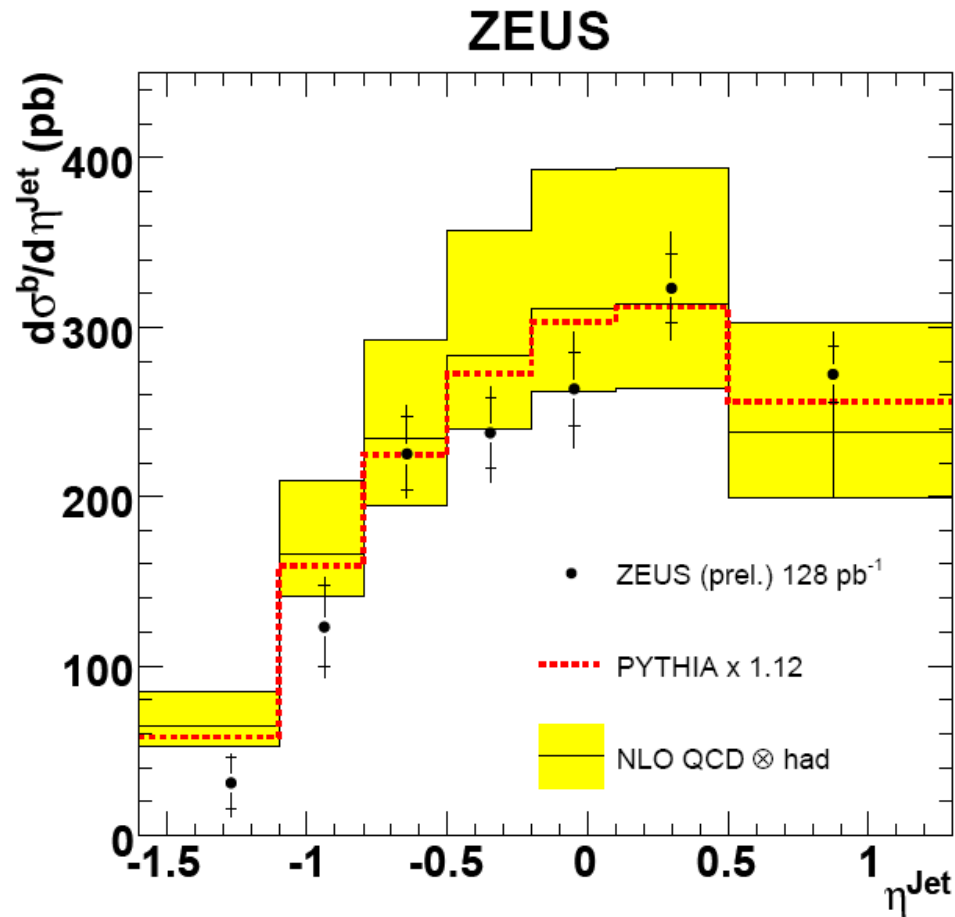
# Cross-section in $P_{T\text{Jet}}$

Good agreement between Data and  
Pythia / NLO predictions (FMNR)



# Cross-section in $\eta_{\text{Jet}}$

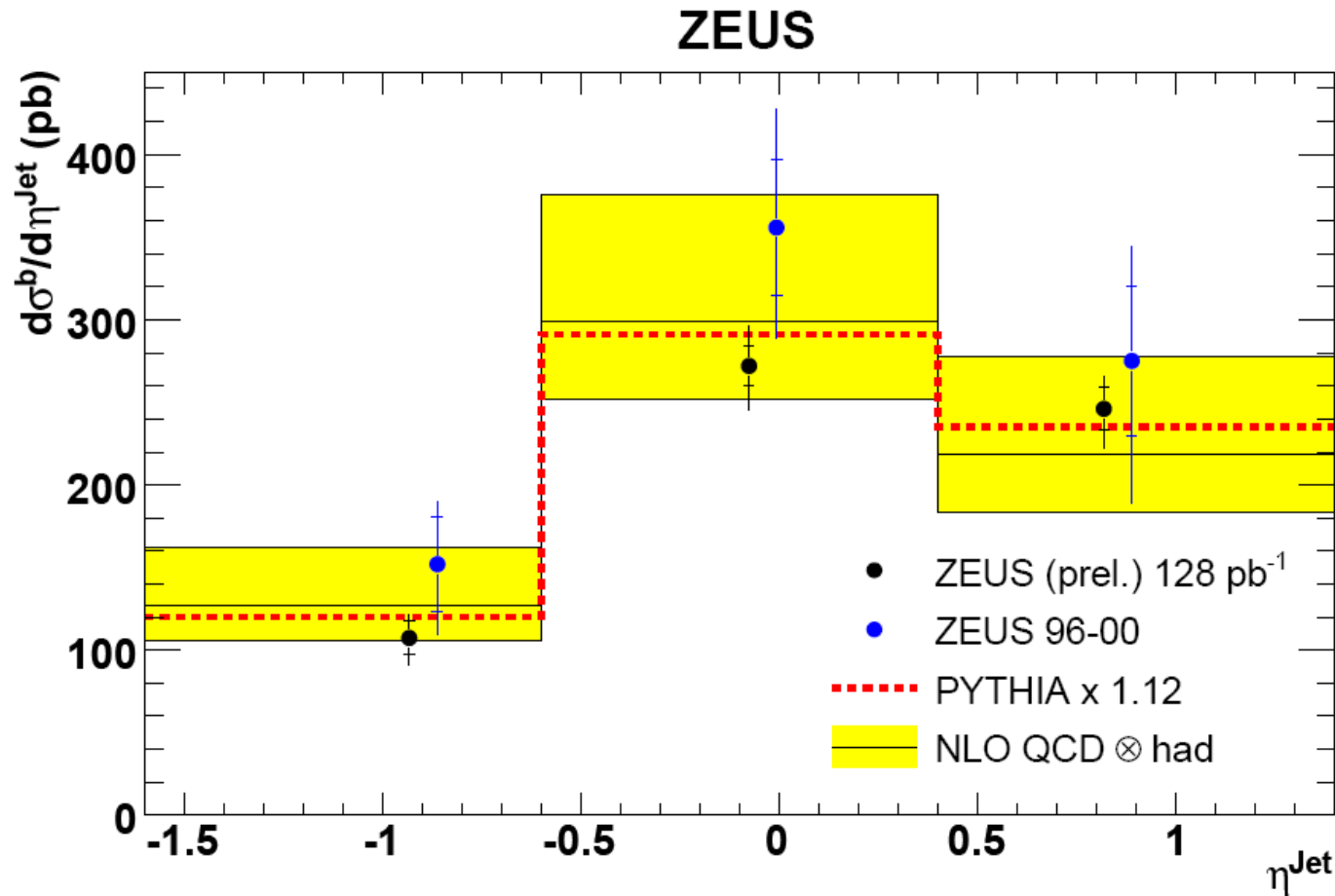
Good agreement between Data and  
Pythia / NLO predictions (FMNR)



# Comparison with previous analysis:

errors substantially reduced

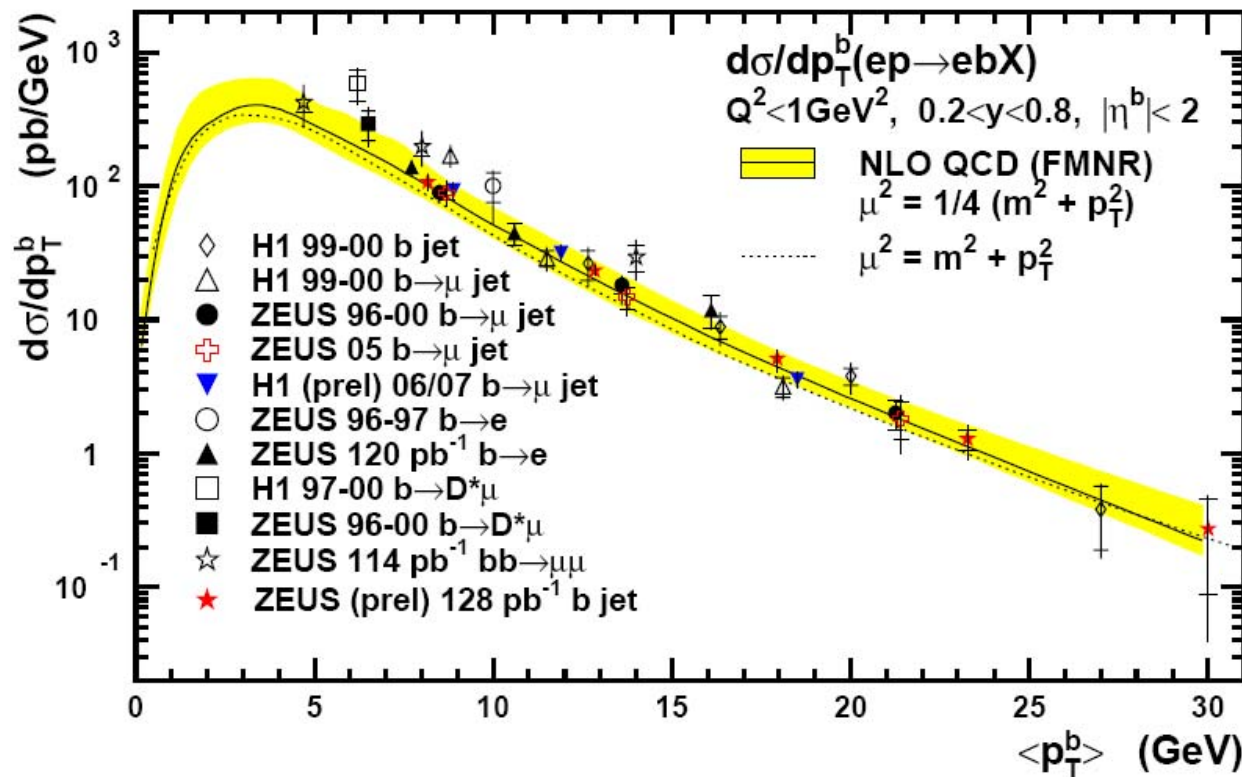
New results in good agreement with previous results



# Beauty production: $p_{Tb}$ plot

## agreement with NLO QCD predictions

### HERA



# Summary

- *presented:* a measurement of beauty photoproduction in ep interactions at the HERA collider working at a center of mass energy of  $\sqrt{s} = 318$  GeV;
- *new method:* analysis of beauty quark production using secondary vertex b-tagging (life-time tagging) and invariant mass of the secondary vertex with large increase in statistics;
- *measured:* total and differential cross sections as a function of transverse momentum  $d\sigma/dp_T$  and pseudorapidity  $d\sigma/d\eta$  of the b-jet for HERA-II. Agreement with NLO QCD predictions.