
Beauty in photoproduction at ZEUS

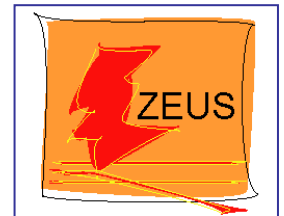
DIS10, XVIII International Workshop on Deep Inelastic Scattering and Related Subjects

Convitto della Calza, Firenze, 19th-23rd April 2010



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For the ZEUS Collaboration

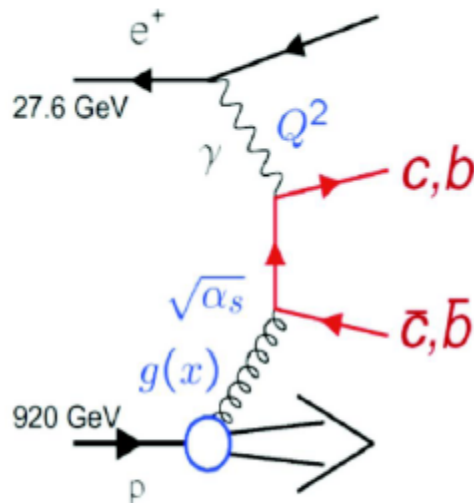


Motivation

- 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**



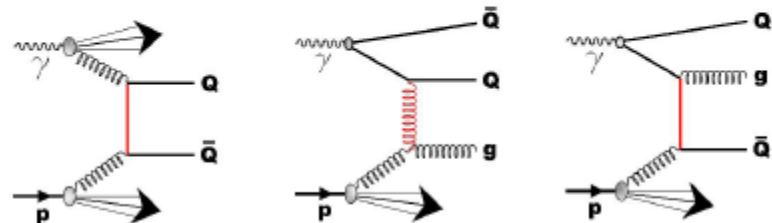
Multiple scales involved:

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

Powerful tool for testing p structure and p QCD

Kinematic variables:

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



Heavy Flavour Tagging

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

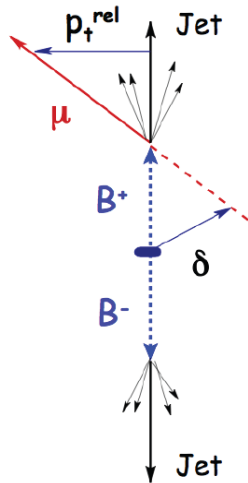
Beauty at HERA: semileptonic tagging $b \rightarrow \mu$

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 μ (PRD 70 (2004) 012008, DESY-08-210 (2008))
- events with 1 D^* + 1 μ (EPJ C 50 (2007) 299-314)
- events with 2 μ 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.

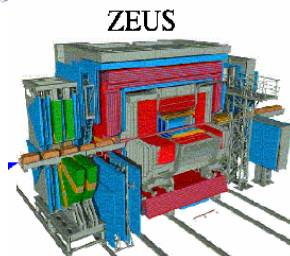
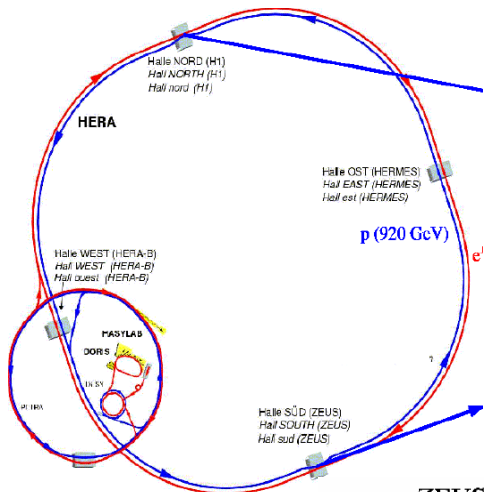
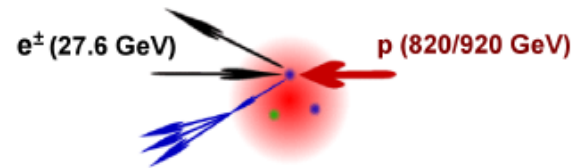
However, all these experimental procedures used so far in ZEUS to measure beauty production are limited to the semileptonic beauty decays.

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 4π detector

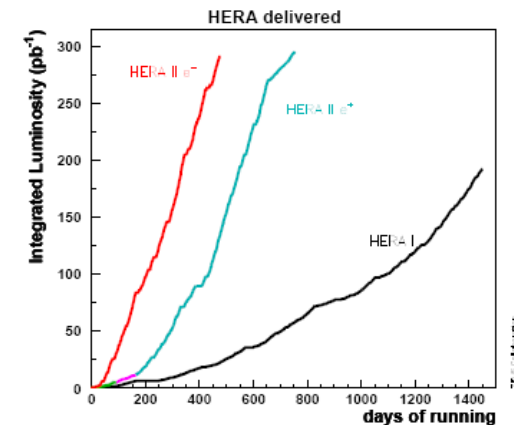
Tracking:

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

Calorimeters:

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

Muon chambers



$e \Rightarrow$ 27.6 GeV $\Leftarrow p$ 820 – 920 GeV

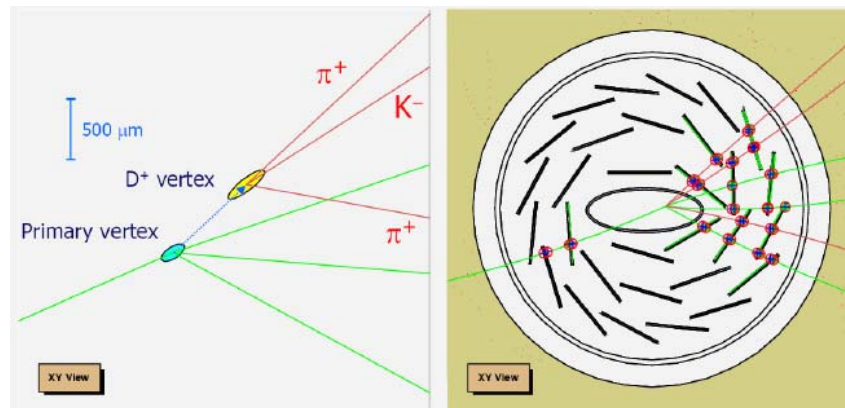
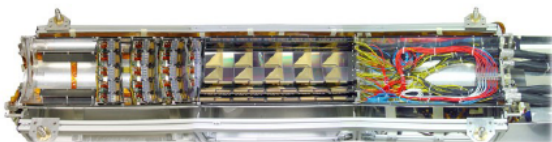
HERA I HERA II
 1995-2000 2003-2007

\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}	~ 120	$\sim 370 \text{ pb}^{-1}$

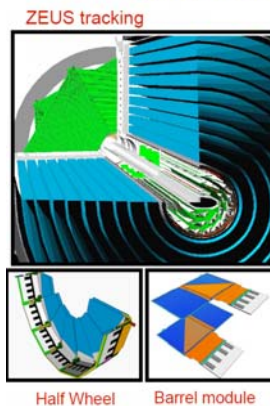
Beauty tagging using micro-vertex detector

- 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



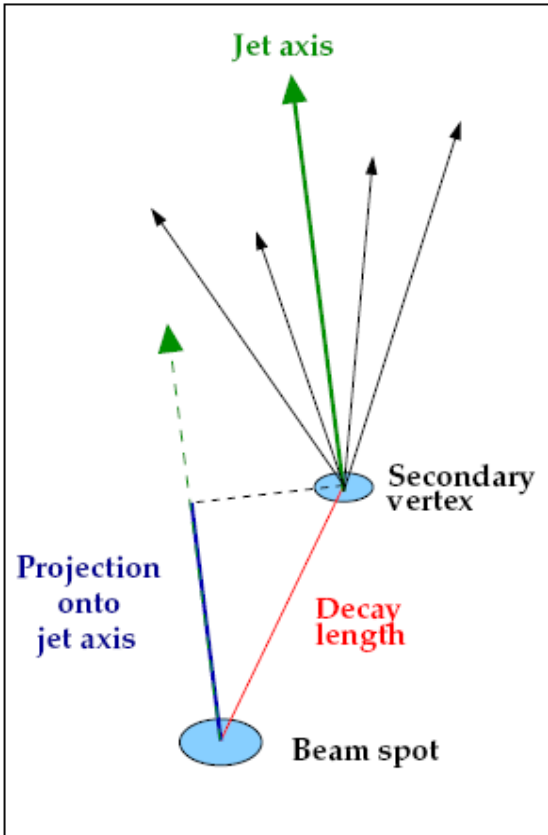
The ZEUS Micro Vertex Detector



- 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.

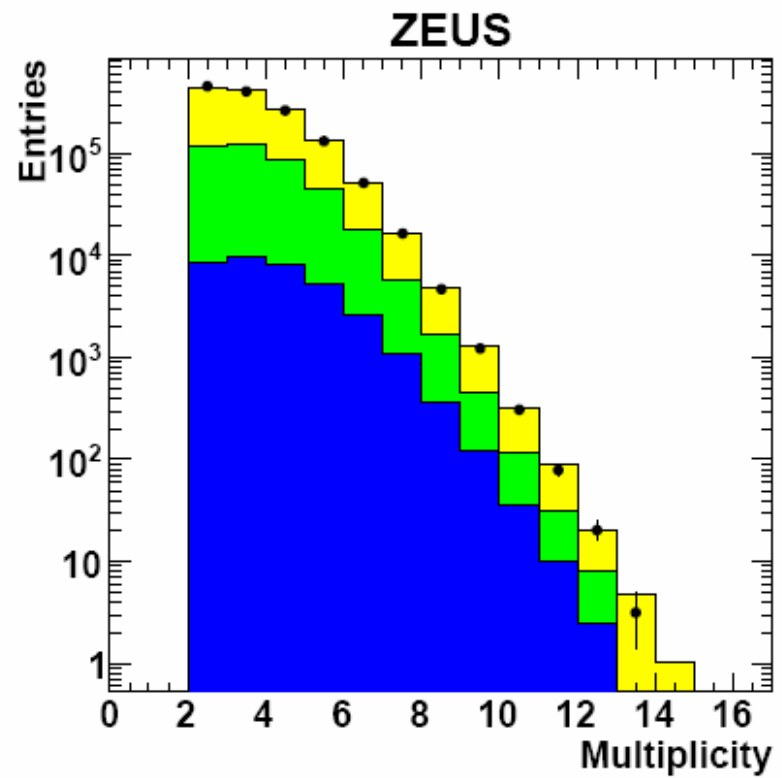
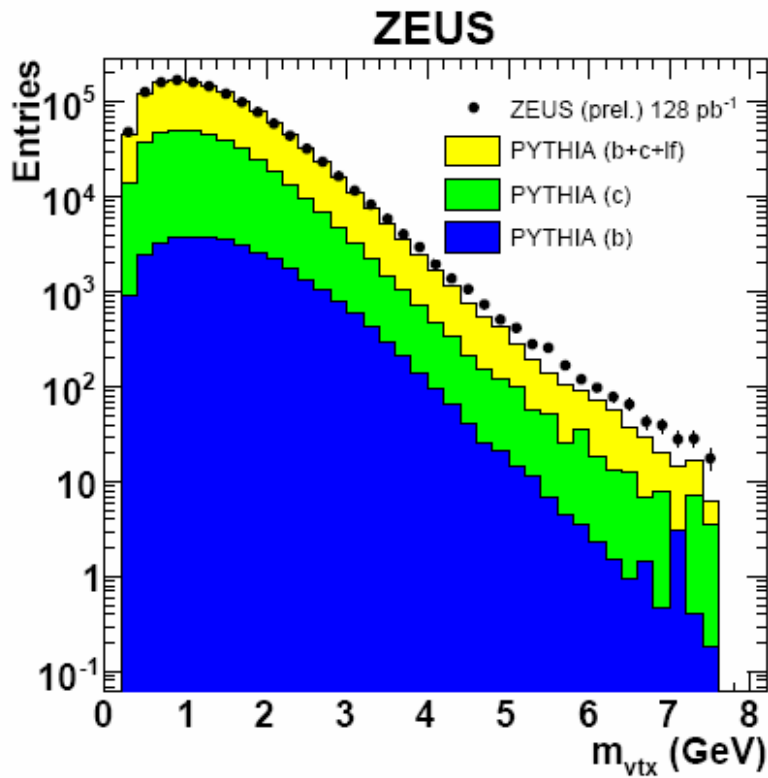
- transverse decay length L_{xy}
- impact parameter δ
- significance $S = \delta/\sigma(\delta)$,

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

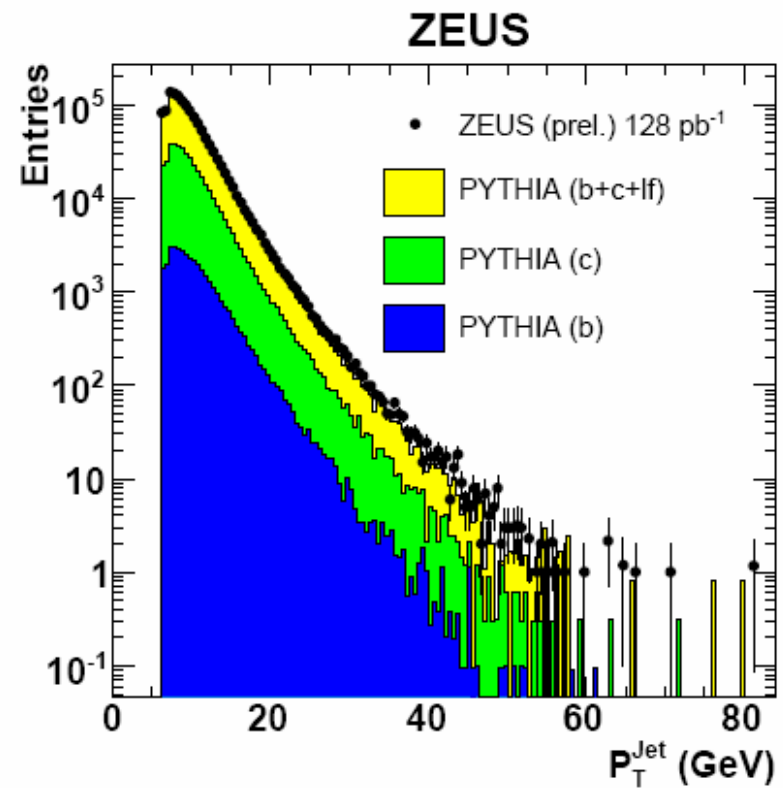
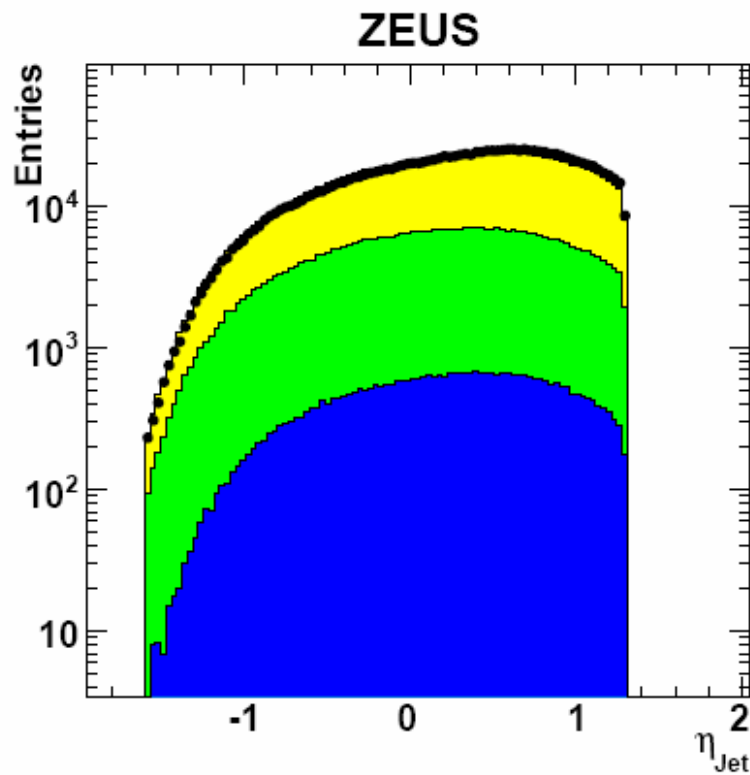
Events selection:

- data set collected in 2006/07 corresponding to an integrated luminosity of 128 pb^{-1} ;
- 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 $p_T > 7(6) \text{ GeV}/c$ 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;

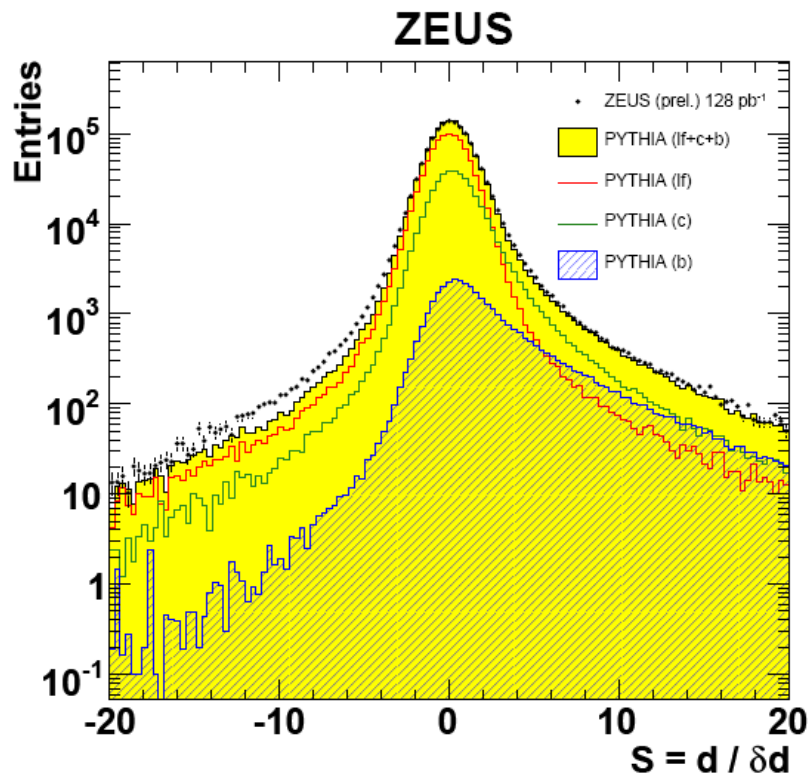
Vertex control plots



Jet control plots

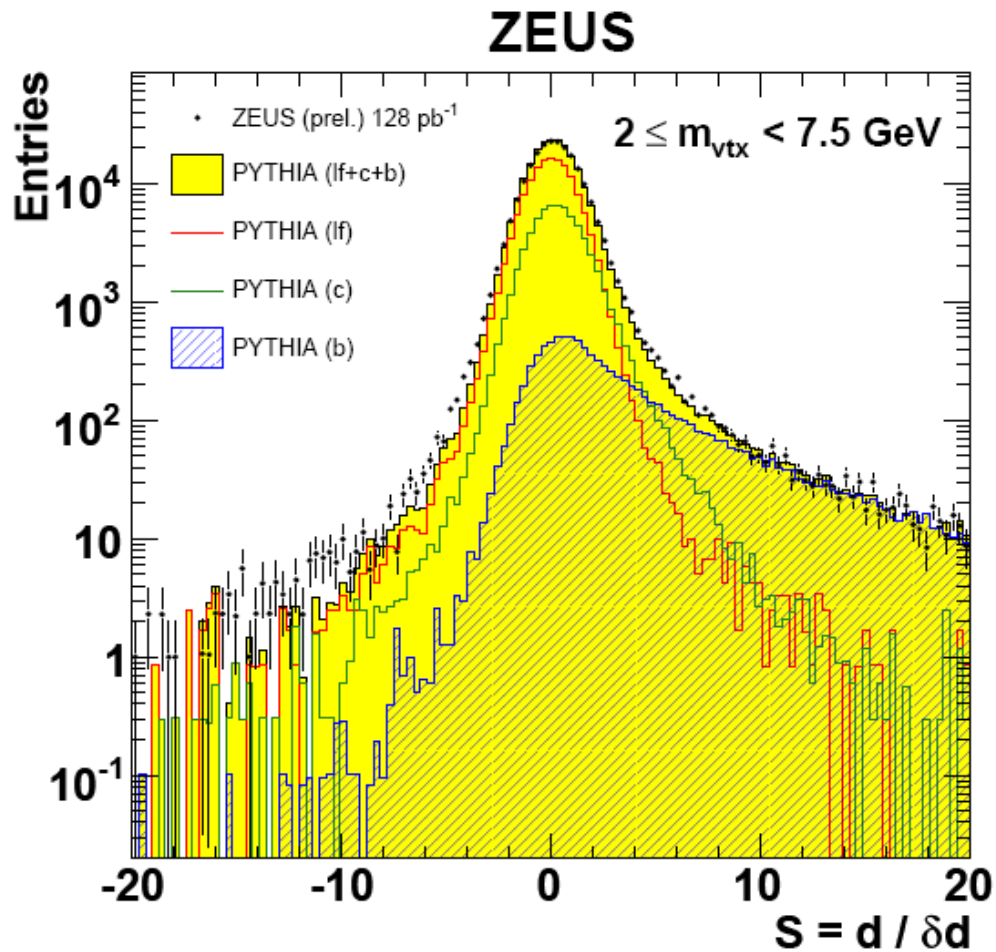


Decay length significance

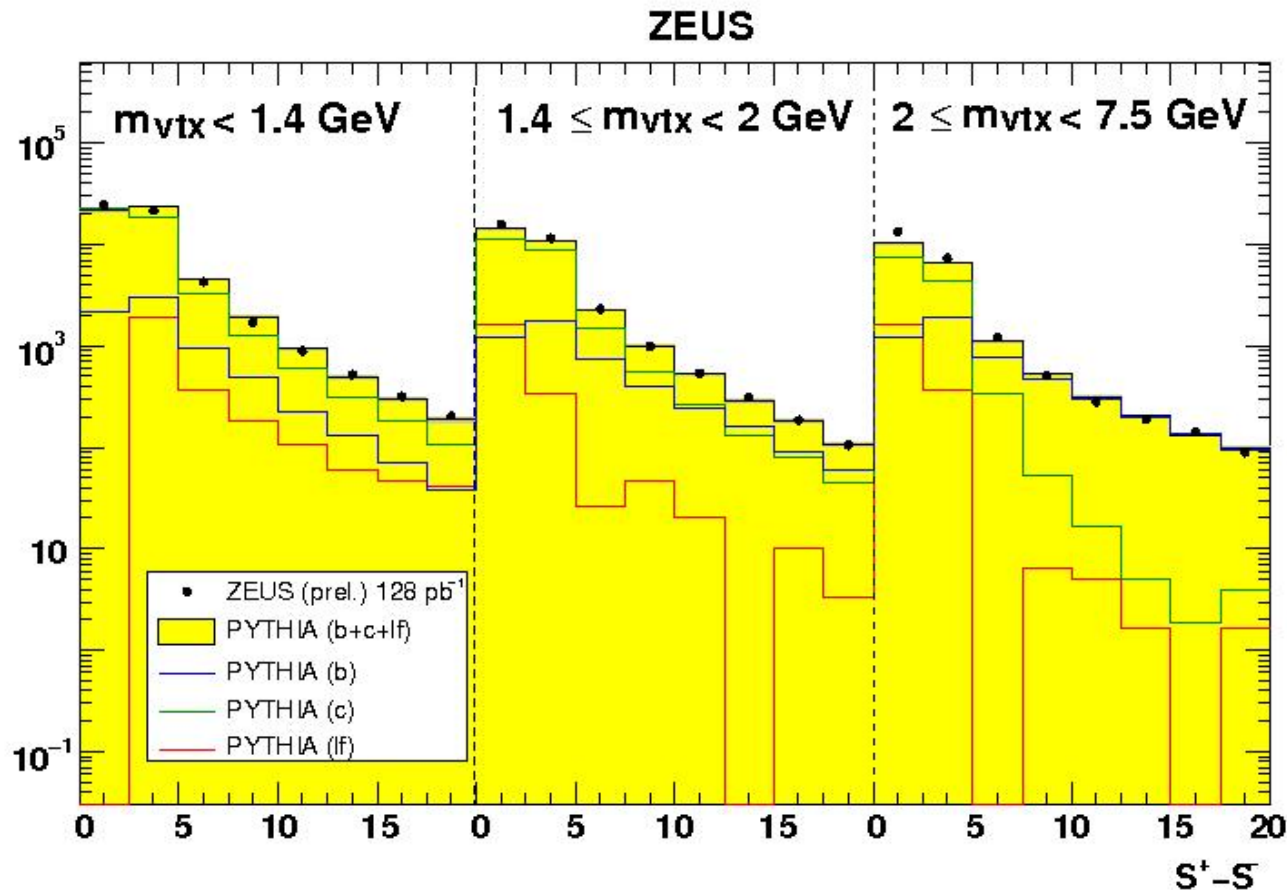


- Decay length significance
 $S = DL / \delta DL$
- For large m_{vtx} dominated by **beauty**
→ With cuts on S and m_{vtx} an almost **pure beauty sample** can be obtained!

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

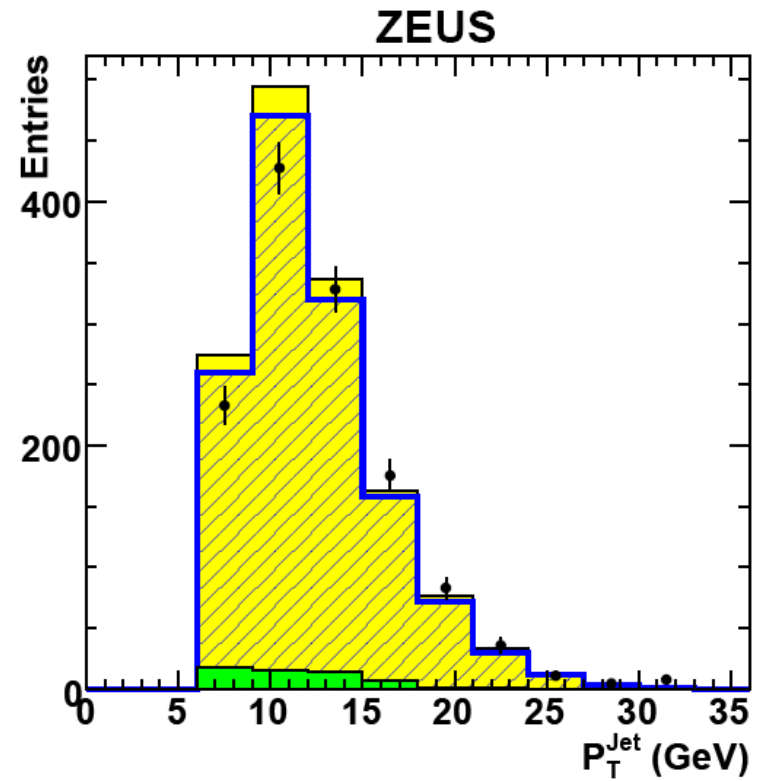
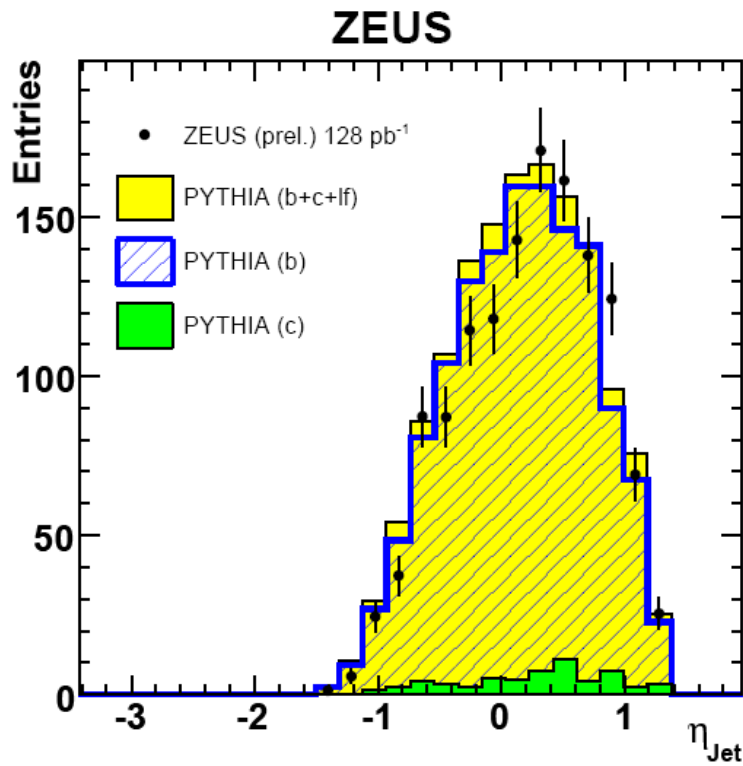


Mirrored decay length significance (fit):

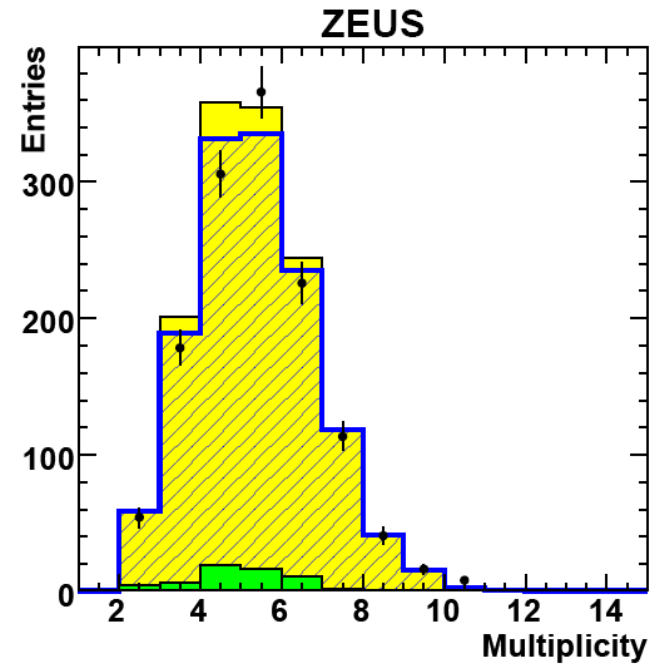
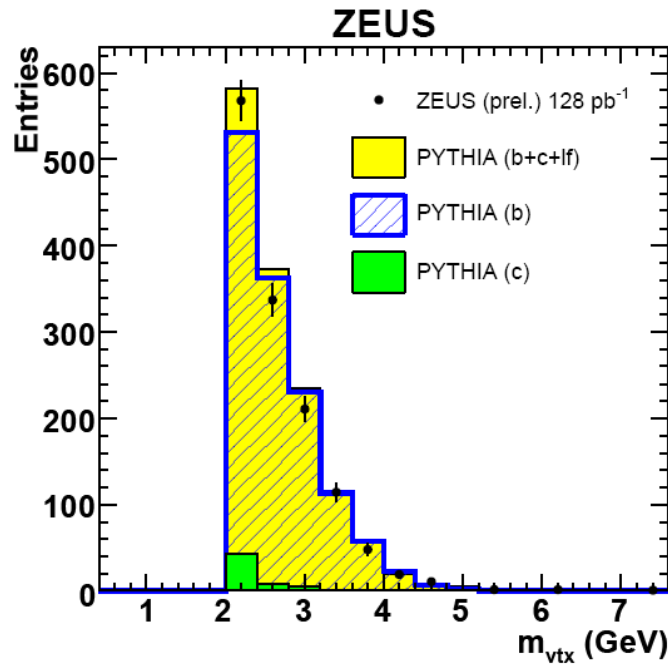


Fit mirrored and subtracted decay length significance ($S^+ - S^-$)
in bins of the secondary vertex mass m_{vtx}

Beauty-enriched plots (jets)

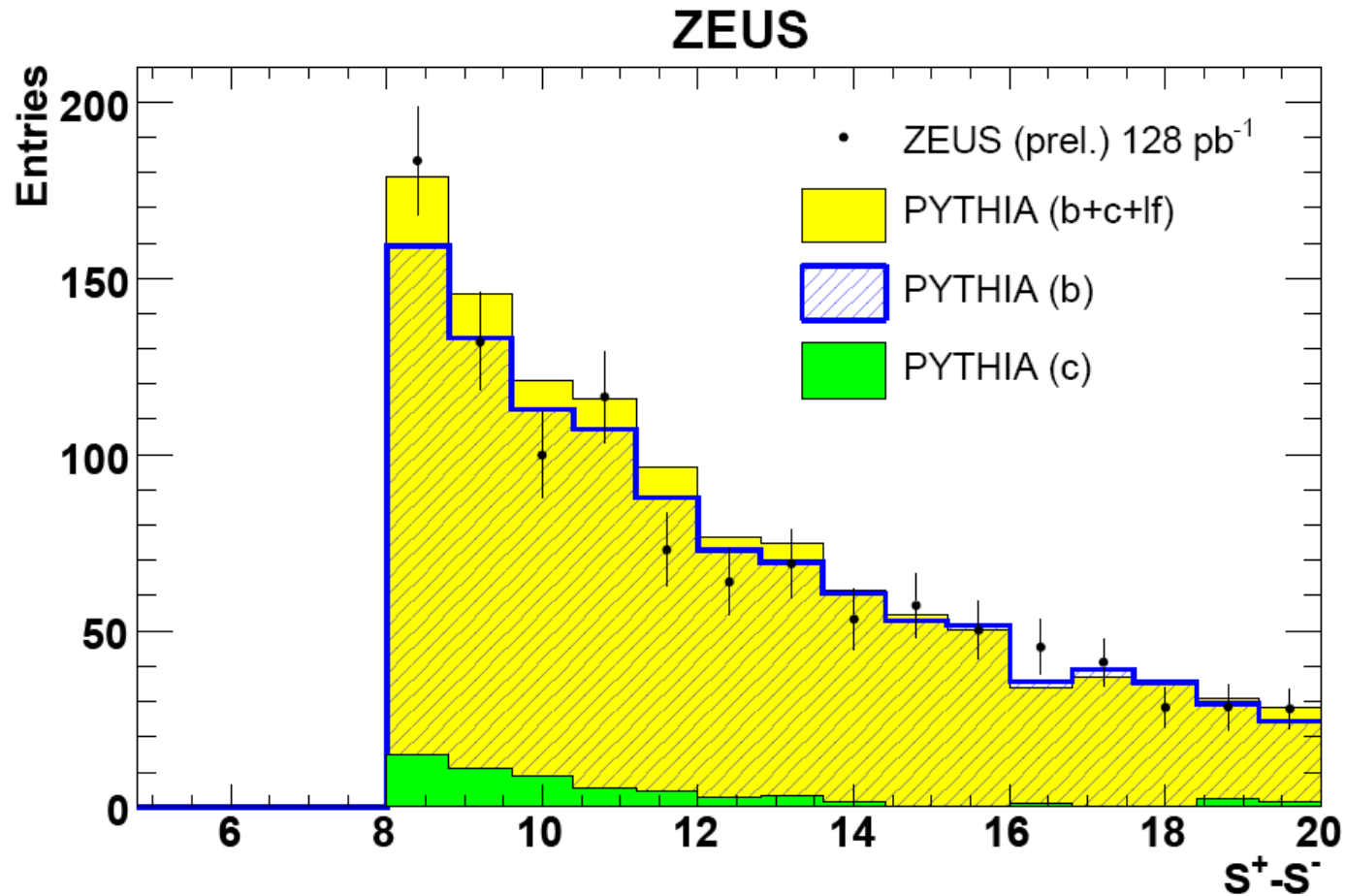


Beauty-enriched plots (vertex)



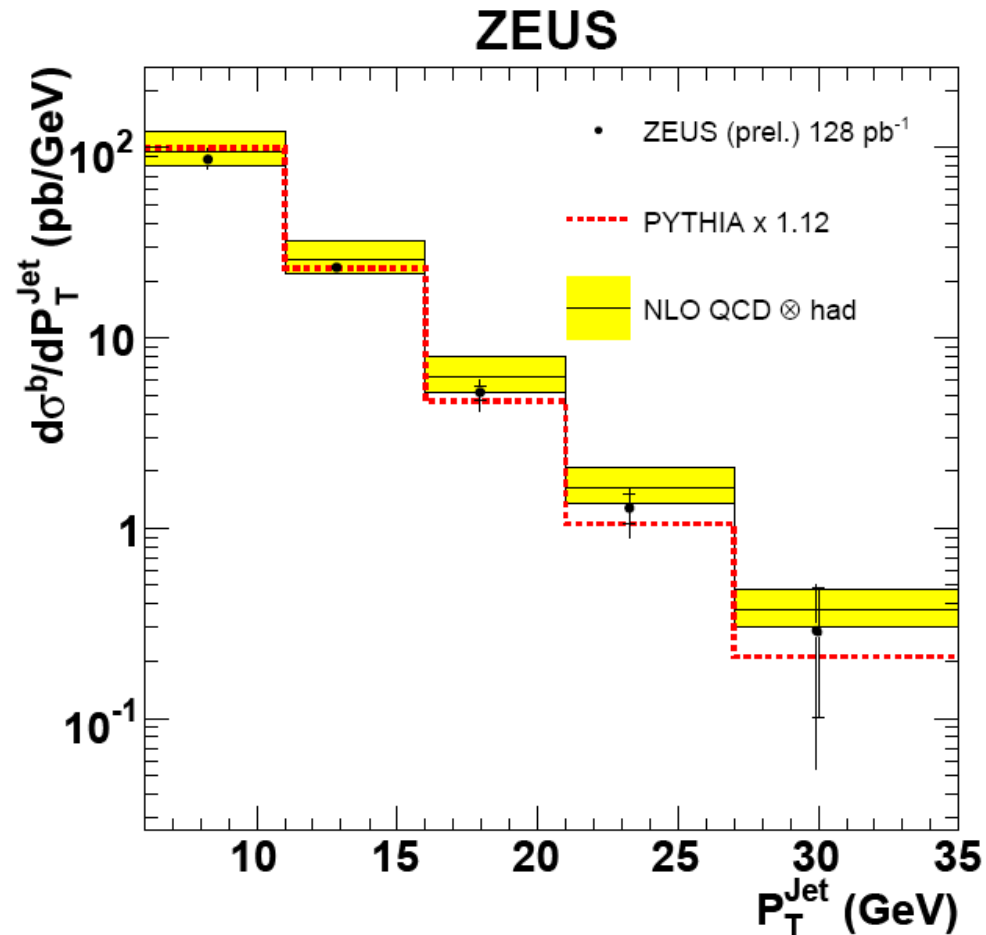
- Beauty-enriched m_{vtx} and multiplicity distributions
- Very good agreement between Data and MC

Beauty-enriched plots (mirrored DL significance)



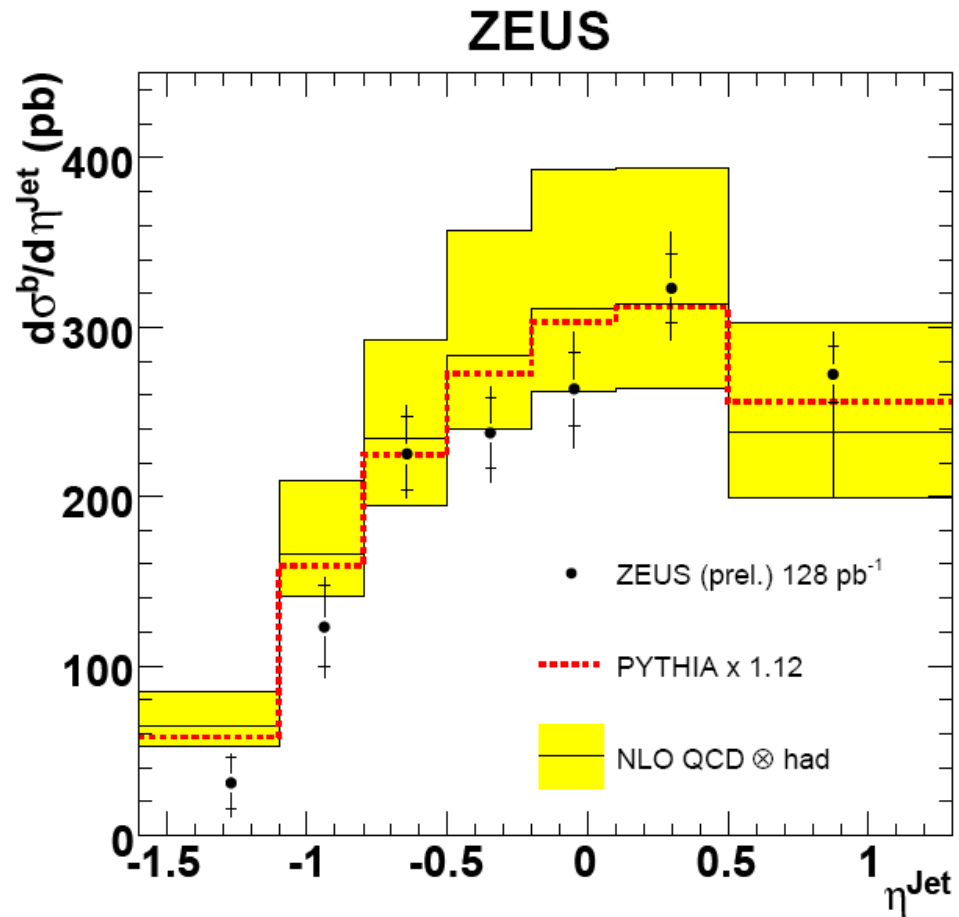
Cross-section in P_{T}^{Jet}

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



Cross-section in η_{Jet}

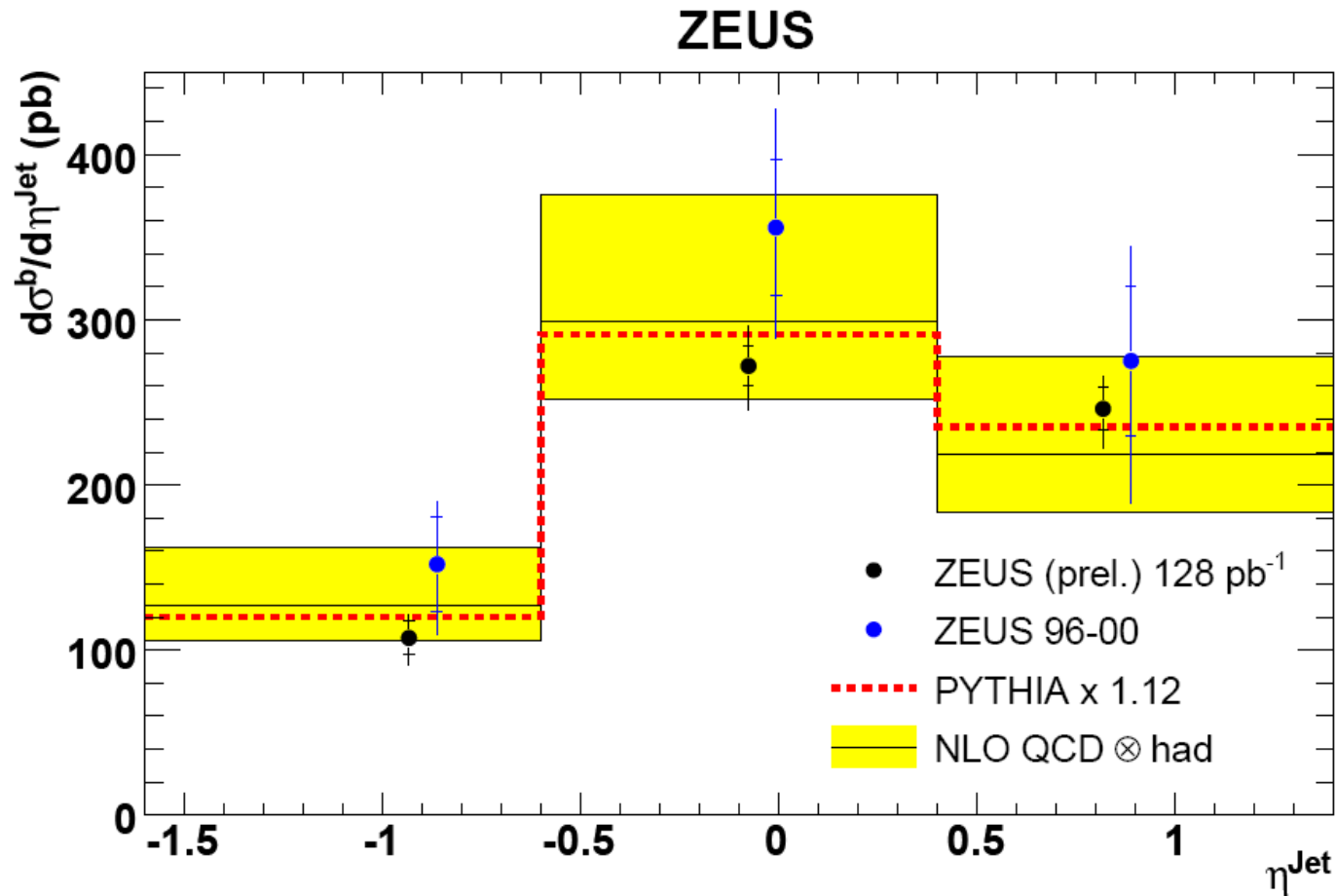
Good agreement between Data and
Pythia / NLO predictions (FMNR)



Comparison with previous analysis:

errors substantially reduced

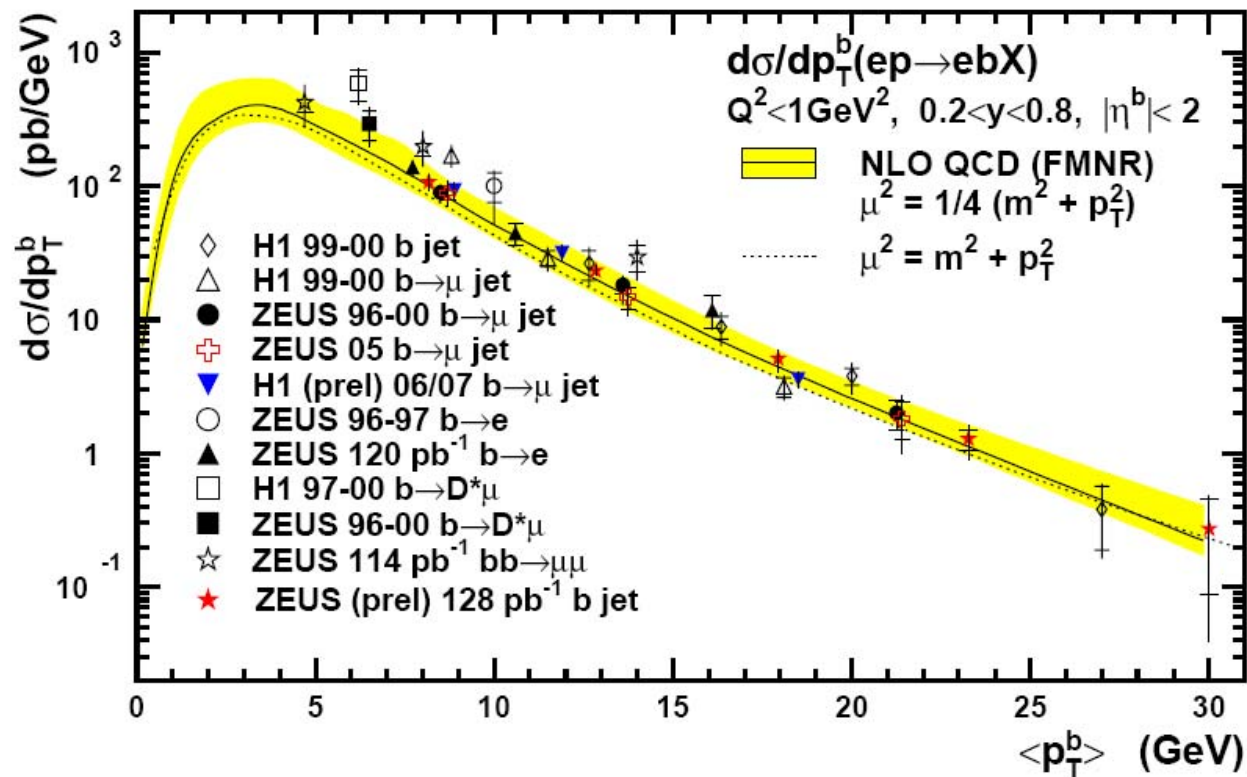
New results in good agreement with previous results



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.