Beauty jet production in ZEUS

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on behalf of the ZEUS *Collaboration*

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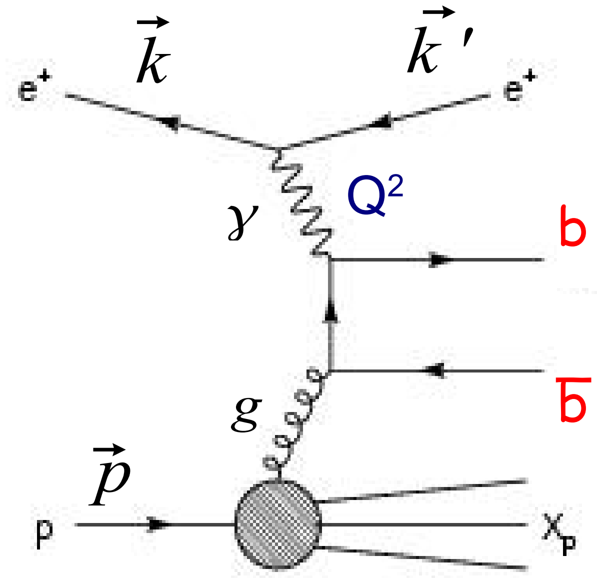
Motivation

- Beauty production is directly sensitive to the gluon in the proton:

(beauty quarks in ep collisions are predominantly produced via Boson-Gluon Fusion(BGF) process).

- Multiple large scales (Q^2, m_b, $p_T(b)$):

(challenge for pQCD).



Q^2 : photon virtuality

x : Bjorken scaling variable

$Q^2 > 1$ GeV^2 : Deep Inelastic Scattering (DIS)

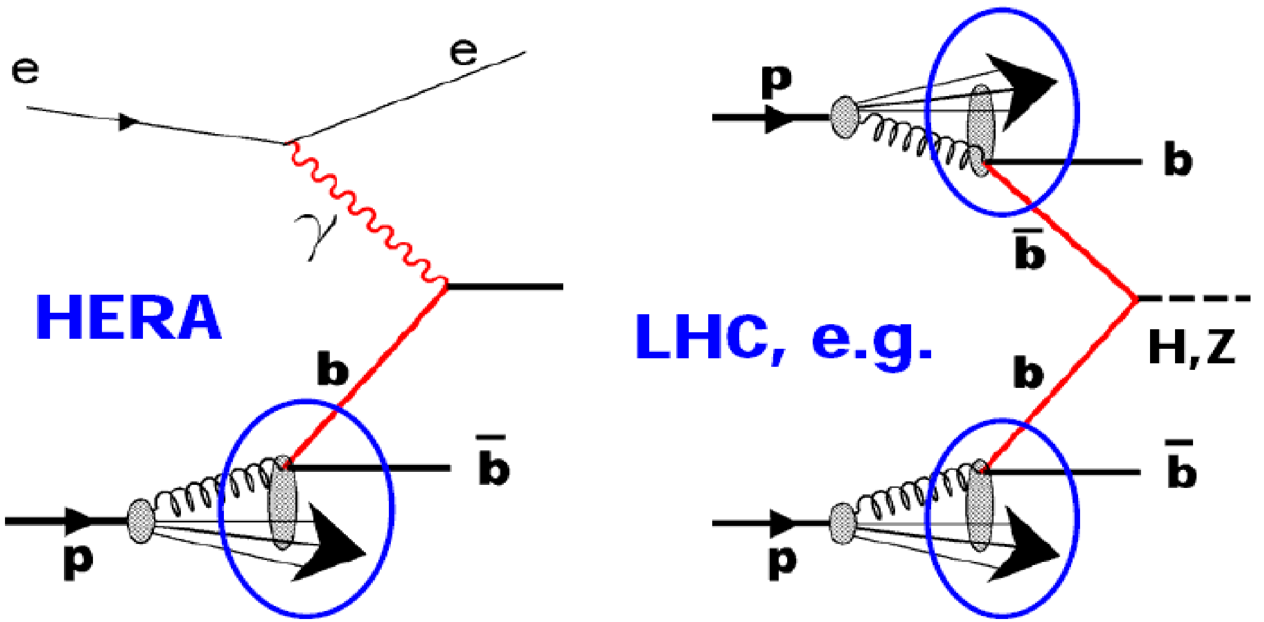
$Q^2 \approx 0$ GeV^2 : Photoproduction (PHP)

Motivation

Beauty quark contribution to the structure function F_2 at low Q^2:

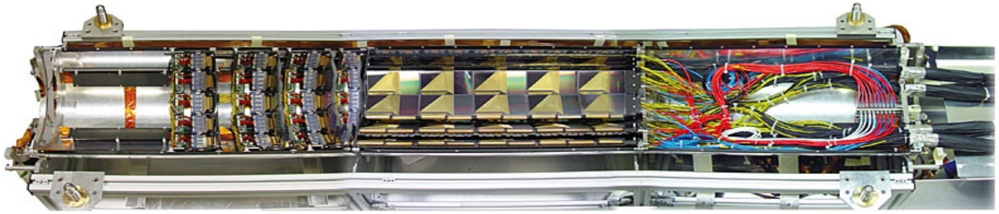
$$\frac{d\sigma^{b\bar{b}}(e^{\pm}p)}{dx\,dQ^2}=\frac{2\pi\alpha^2}{xQ^4}[1+(1-y)^2]\left(F_2^{b\bar{b}}(Q^2,x)-\frac{y^2}{1+(1-y)^2}F_L^{b\bar{b}}(Q^2,x)\right)$$

At high Q^2- check of the b PDF for LHC:



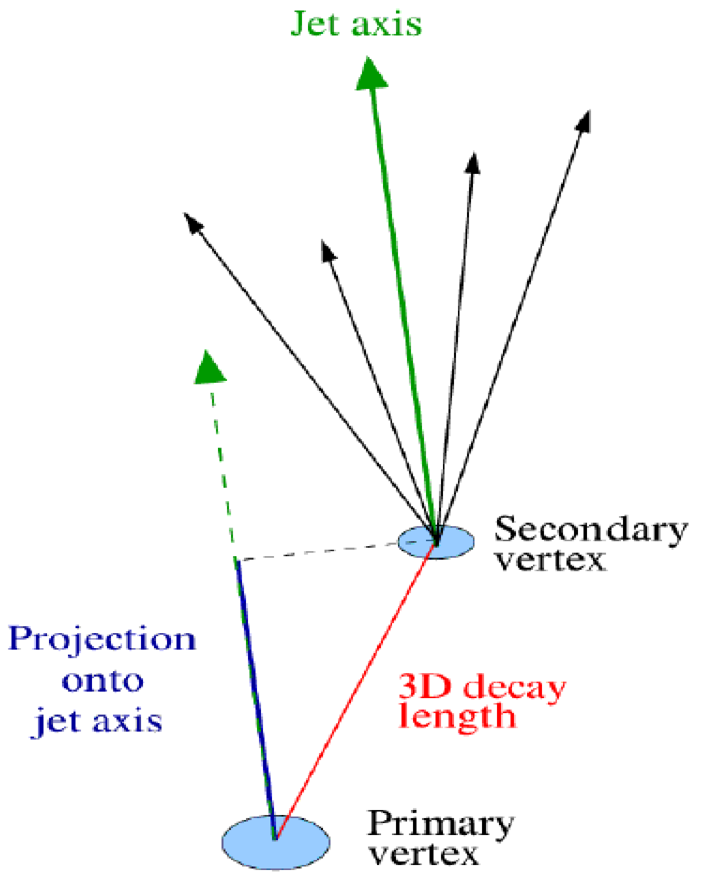
Vertexing in ZEUS

During HERAII ZEUS was equipped with the silicon-strip Micro Vertex detector (MVD):
this enabled reconstruction of secondary vertices from charm and beauty decays.



Analysis strategy:

- Associate tracks with p_T > 500 MeV to a jet using $\Delta R = 1$.
- Fit these tracks to a secondary vertex in 3D.
- Calculate 2D decay length projected on the jet axis, L_{xy}.
- Use significance of the 2D projected decay length ($S=L_{xy}/\sigma(L_{xy})$) to differentiate between flavour components.

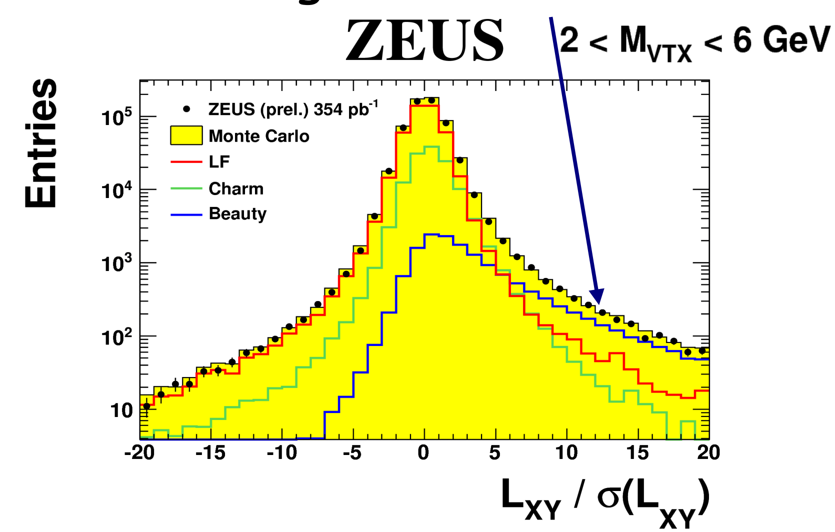


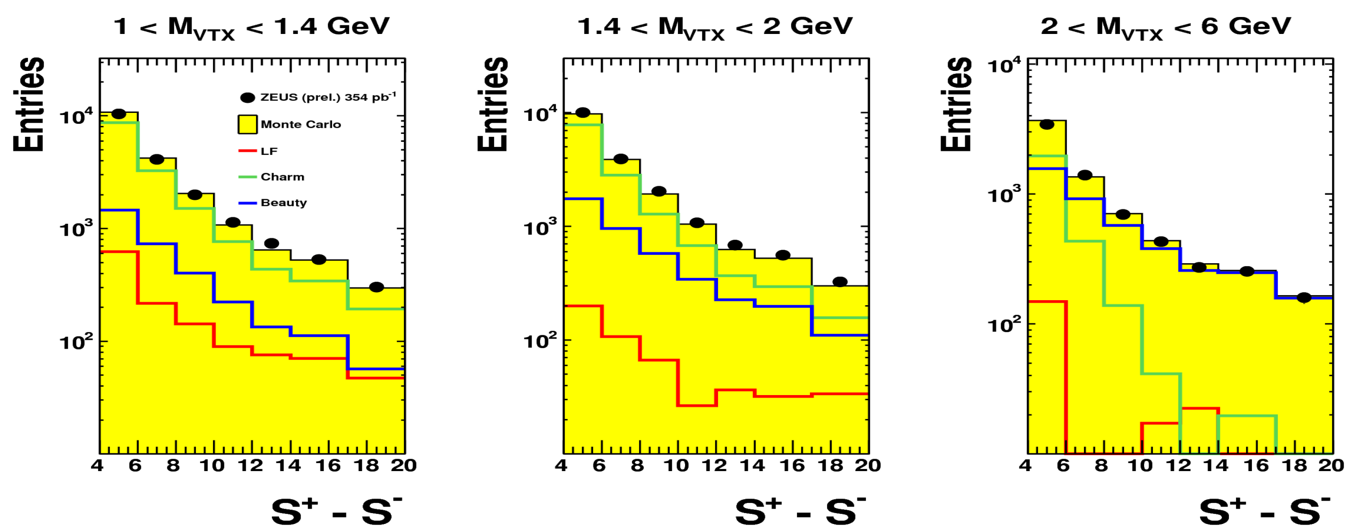
Secondary vertices in DIS: method

- The beauty fraction is extracted from a fit to the mirrored (to get rid of the symmetric part) significance in bins of the secondary vertex mass using templates from MC.

- Total light flavour normalization is constrained by the unmirrored distributions.

Beauty is dominant at high values of significance.





charm enriched

beauty enriched

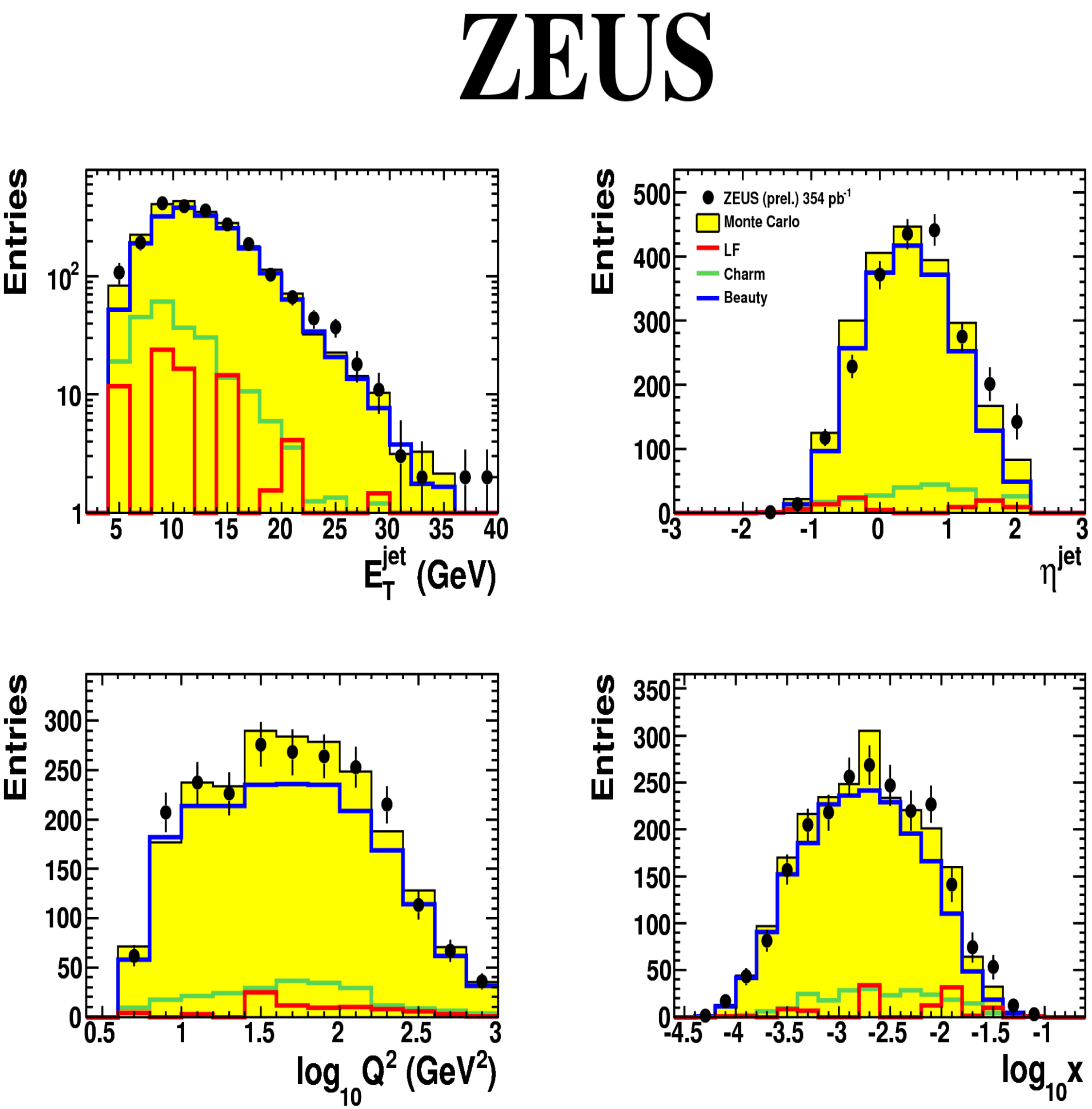
ZEUS-prel-10-004

Secondary vertices in DIS: beauty enrichment

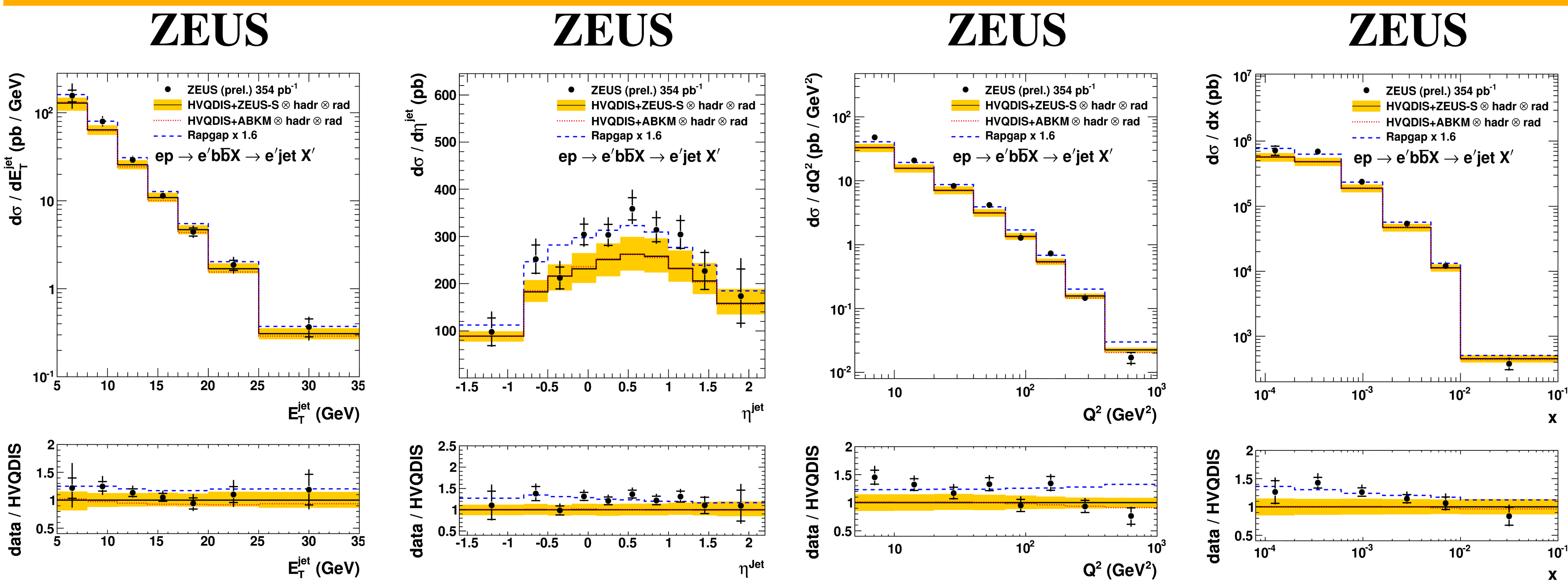
- Control distribution for strongly enriched beauty sample:

$S^{+} - S^{-} > 8$

$2 < M_{vtx} < 6$ GeV



Secondary vertices in DIS: cross sections



5 < Q^2 < 1000 GeV^2

0.02 < y < 0.7

E_T^{jet} > 5 GeV

-2.0 < η^{jet} < 2.2

$\mathcal{L}$ = 354 pb^{-1}

(2004-2007)

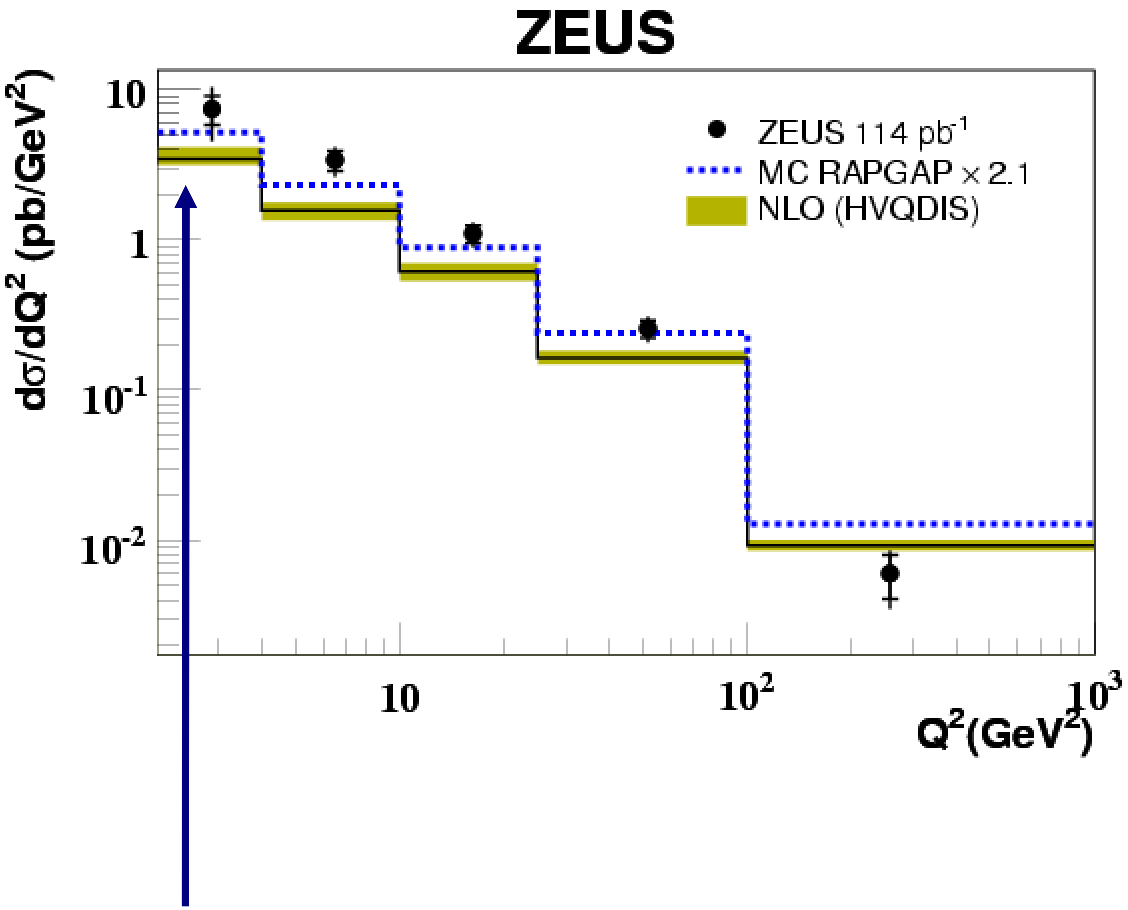
- The cross section shapes in data are well described by both ZEUS-S and ABKM09 NLO QCD predictions.
- The data are typically 20-30% above the central NLO predictions, but agree within the uncertainties.
- Double-differential cross sections in Q^2 and x were measured and F_2^b was extracted

Beauty from jet+μ: Q^2

EPJ C 69 (2010) 347
arXiv:1005.3396 [hep-ex]

Kinematic region:
$Q^2 > 2\ GeV^2$
$0.05 < y < 0.7$
$E_T^{jet} > 5\ GeV$
$-2.0 < \eta^{jet} < 2.5$
$p_T^{\mu} > 1.5\ GeV$
$-1.6 < \eta^{\mu} < 2.5$

$\mathcal{L} = 114\ pb^{-1}$
(1996-2000)



Low-Q^2 region is accessible in HERAI only.

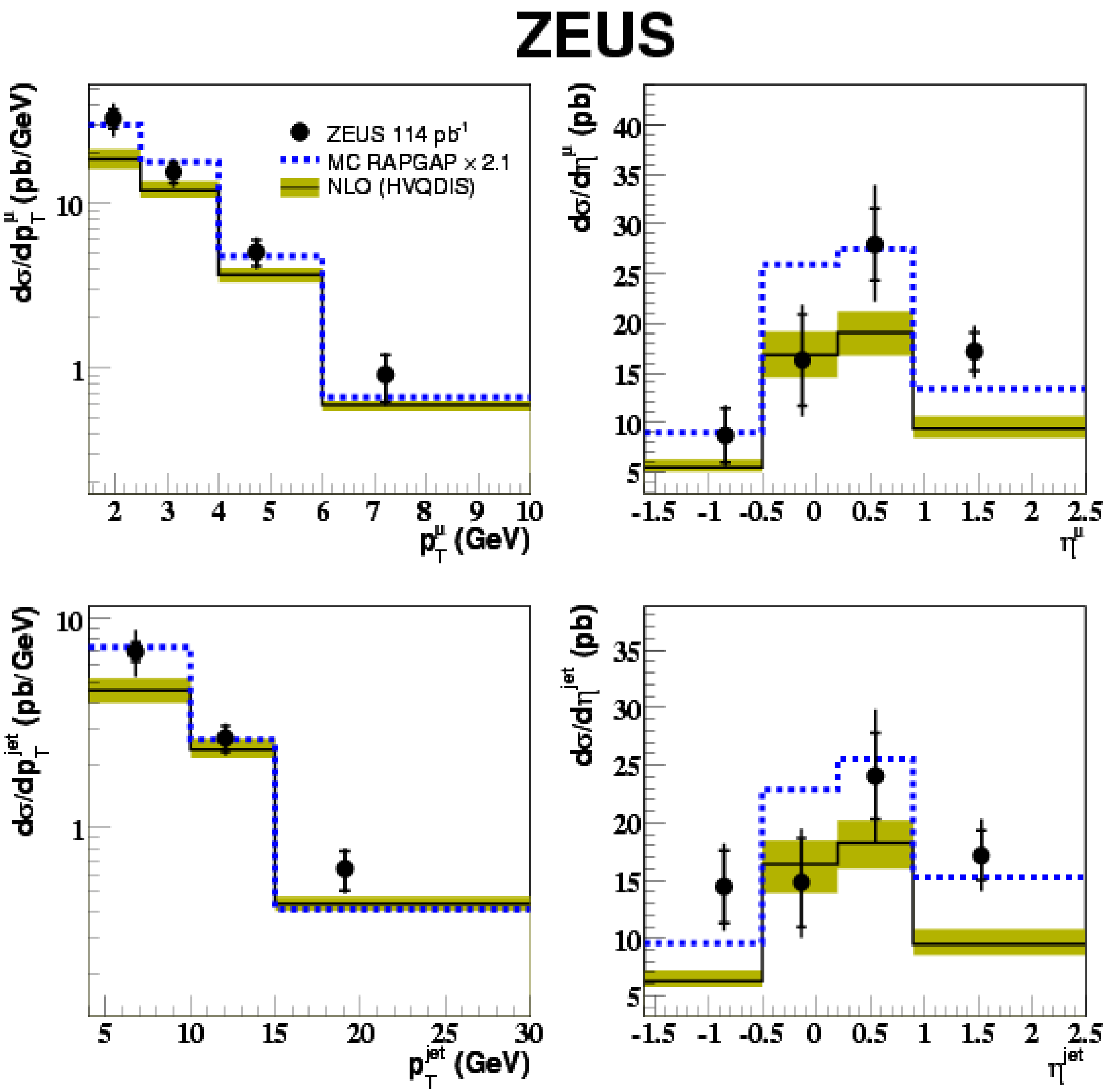
The NLO QCD predictions by HVQDIS (FFNS) tend to lie below data at low Q^2.

Beauty from jet+μ: p_T, η

EPJ C 69 (2010) 347
arXiv:1005.3396 [hep-ex]

Both LO+parton shower Monte Carlo and NLO QCD predictions describe the data in shape

Also double-differential cross sections in Q^2 and x were measured and F_2^b was extracted (see later).



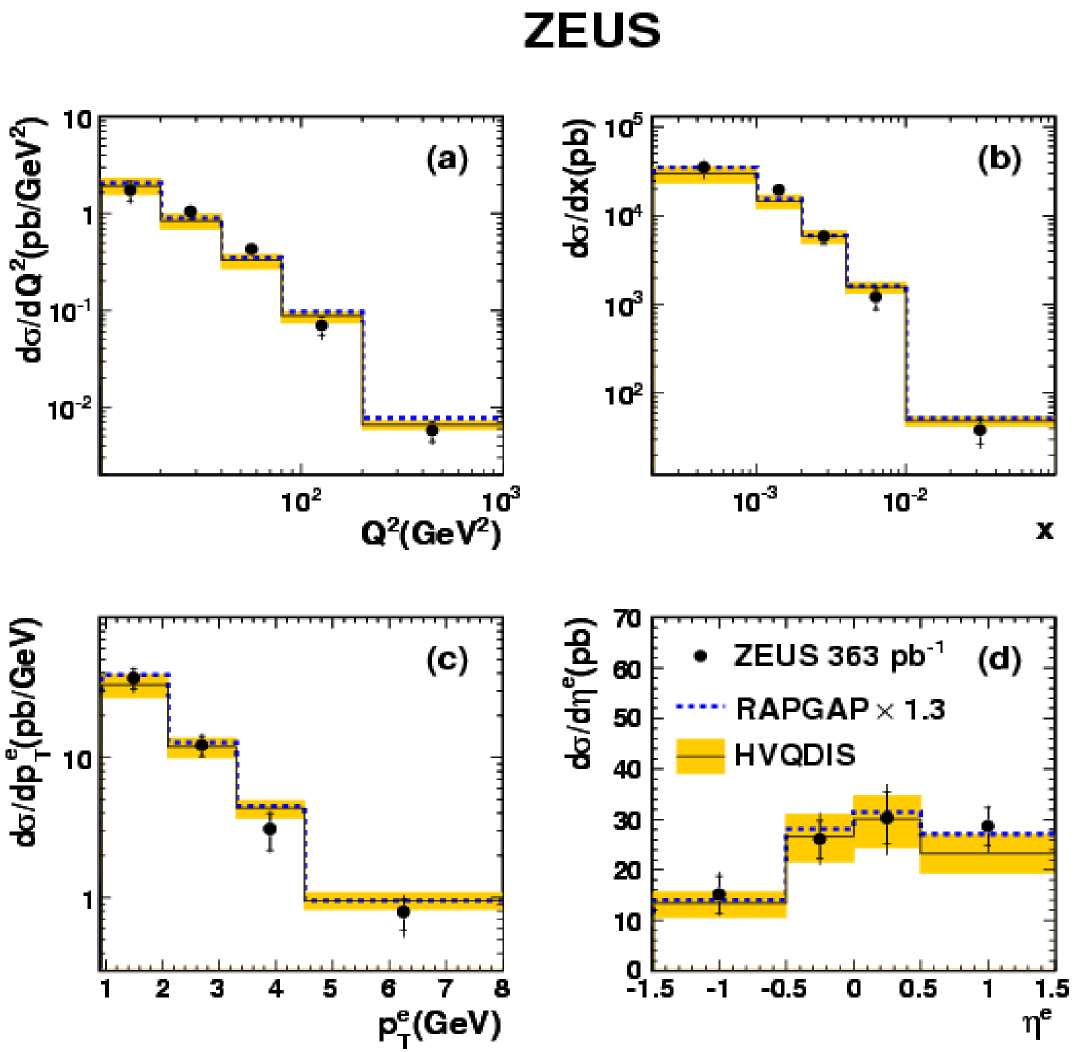
Beauty from dijets+e

EPJ C 71 (2011) 1573
arXiv:1101.3692 [hep-ex]

Kinematic region:
$Q^2 > 10\ GeV^2$
$0.05 < y < 0.7$
$0.9 < p_T^e < 8$ GeV
$-1.5 < \eta^e < 1.5$

$\mathcal{L} = 363\ pb^{-1}$
(1996-2000)

- NLO QCD predictions describe the data.
- Also double-differential cross sections have been measured and F2b has been extracted (see later)



Poster # 325

F_2^b extraction

$$\frac{d\sigma^{b\bar{b}}(e^{\pm}p)}{dx\,dQ^2} = \frac{2\pi\alpha^2}{xQ^4}[1+(1-y)^2](F_2^{b\bar{b}}(Q^2,x) - \frac{y^2}{1+(1-y)^2}F_L^{b\bar{b}}(Q^2,x))$$

Measurements are performed in a restricted kinematic region.

Extrapolation is based on the NLO QCD predictions.

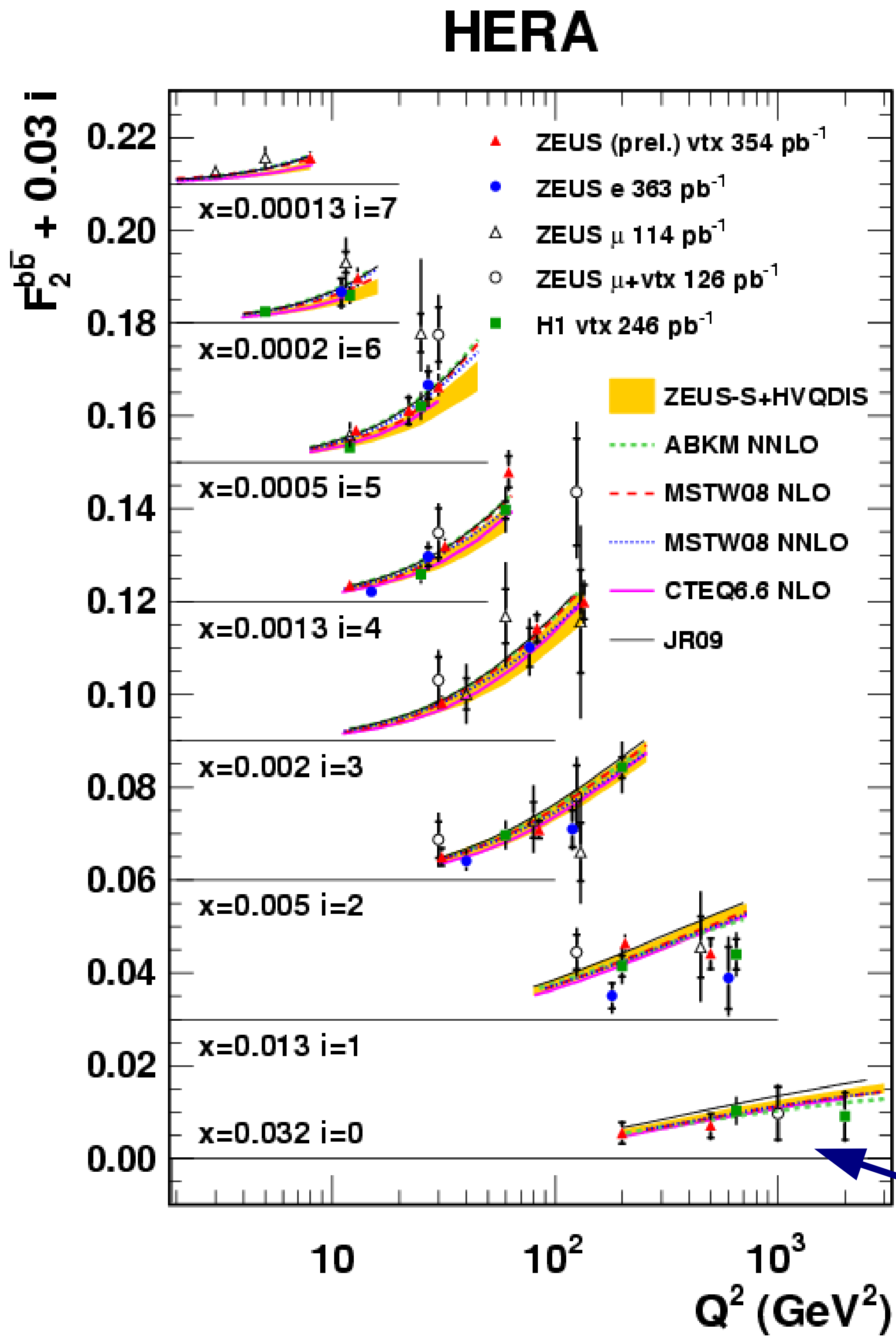
Measured cross section in a bin (Q^2_i,x_i)

$$F_{2,meas}^{b\bar{b}}(Q_i^2,x_i) = \frac{d\sigma_{i,meas}/dx\,dQ^2}{d\sigma_{i,theo}/dx\,dQ^2}F_{2,theo}^{b\bar{b}}(Q_i^2,x_i)$$

NLO QCD in FFNS by HVQDIS

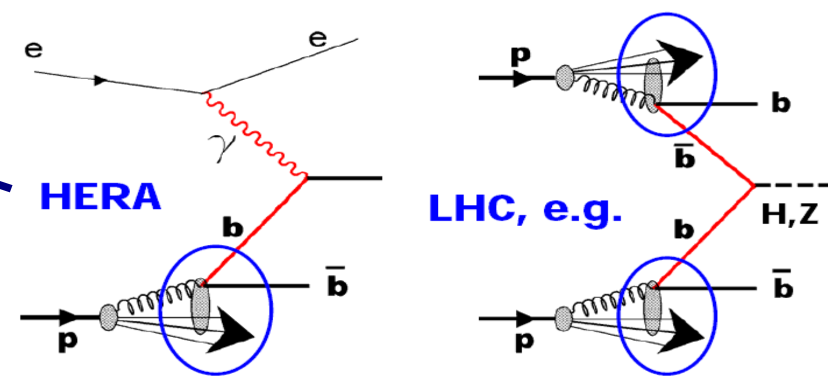
Typical extrapolation factors:

- 1.0 - 1.3 for the secondary vertex analysis;
- 2.7 (high Q^2) – 6.6 (low Q^2) for the jet+μ analysis.



F_2^b

- All measurements are in good agreement with each other. The NLO and NNLO QCD predictions based on various PDFs describe the data well.
- Jet+μ analysis provides measurement at the lowest Q^2 values.
- Secondary vertex analysis is the most precise measurement in ZEUS.



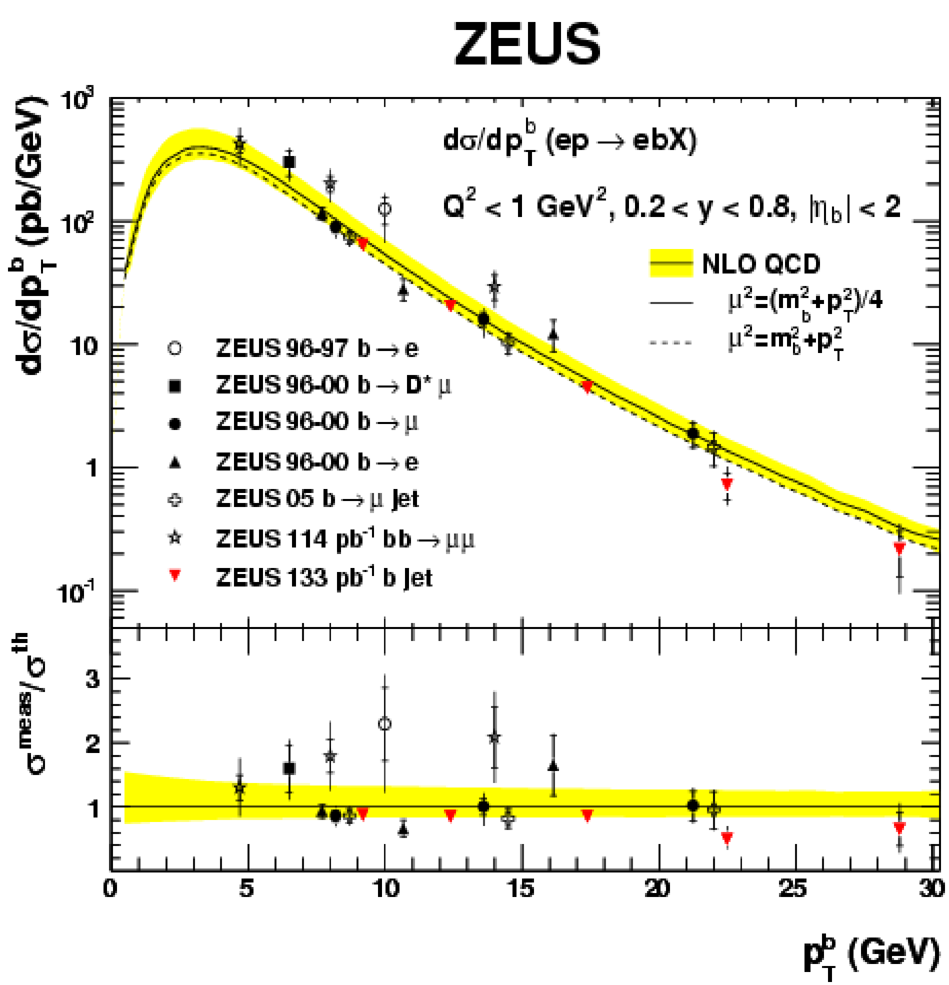
Secondary vertices in PHP

EPJ C 71 (2011) 1659
arXiv:1104.5444 [hep-ex]

Kinematic region:
$Q^2 < 1$ GeV^2
$0.2 < y < 0.8$
$p_T^{jet\ 1(2)} > 7(6)$ GeV
$-2.5 < \eta^{jet} < 2.5$

$\mathcal{L} = 133$ pb^{-1}
(2005)

- Both charm and beauty fractions were extracted simultaneously.
- Single differential cross sections as well as p_T^b and p_T^c spectra were measured.



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Summary

- Beauty production has been measured using events with a muon and a jet it is associated to as well as using secondary vertices fitted to jets.
- Measured cross sections are in reasonable agreement with the NLO QCD predictions by HVQDIS.
- Double-differential in Q^2 and x cross sections were used to extract the beauty contribution to the structure function F_2, F_2^b. Measurements of F_2^b agree with previous measurements. NLO and NNLO QCD predictions obtained using various PDFs agree with the measurements.
- The secondary vertex technique is the most precise F_2^b measurement from ZEUS
- Combination with other measurements, would further improve precision.

Heavy flavour tagging

- Semi-leptonic decays:

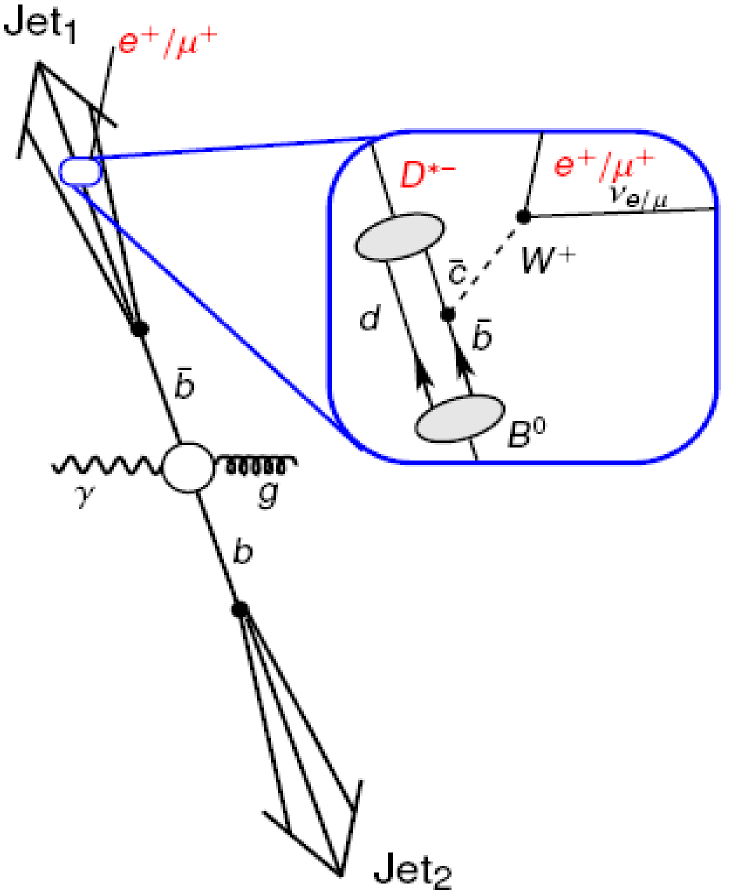
p_T^{rel} of a lepton to a jet axis; impact parameter, δ, of the lepton track.

- Lifetime information:

impact parameters of tracks in a jet; displaced secondary vertices.

- Full meson reconstruction:

$D^{*\pm}$ or $D^{\pm}$ reconstruction for charm (Talk 998 by O. Bachynska).



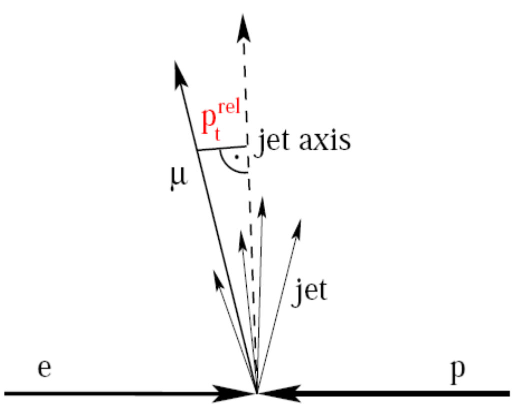
Results with different techniques have complementary systematics => combination is important (H1prelim-09-171, ZEUS-prel-09-015).

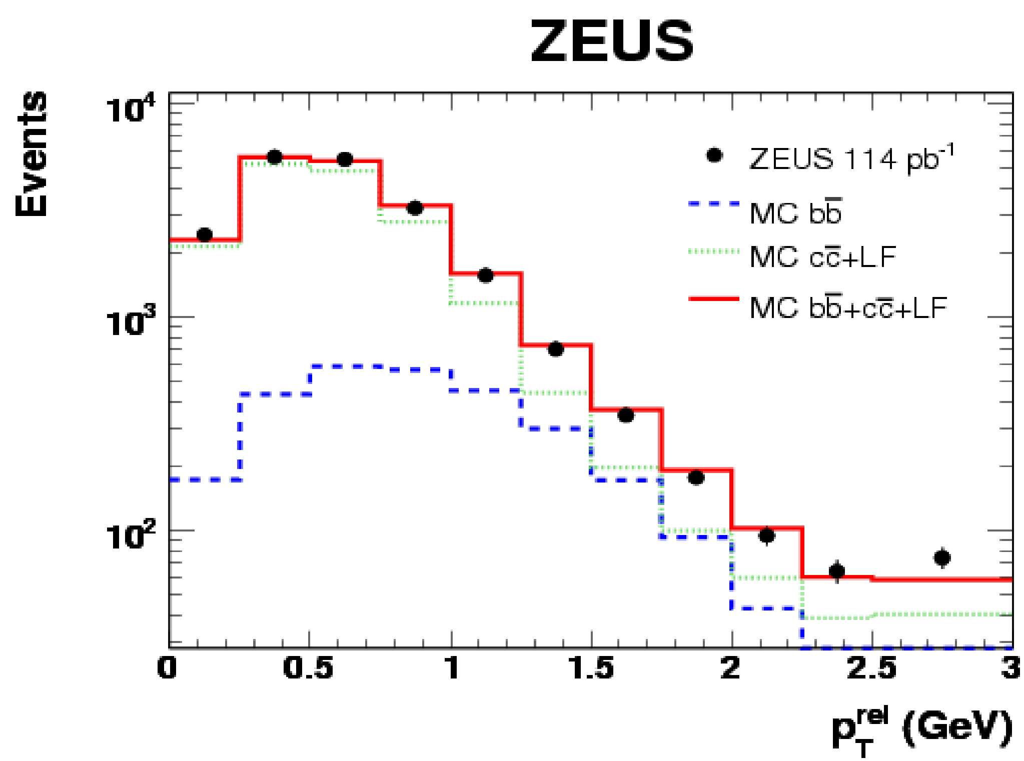
Beauty from jet+μ

EPJ C 69 (2010) 347
arXiv:1005.3396v1 [hep-ex]

- p_T^{rel} : the muon transverse momentum relative to the jet.
- Distinct shape of p_T^{rel} allows to extract beauty and background (charm + light flavours) fractions.

$$p_T^{rel} = \frac{|\vec{p}^{\mu} \times \vec{p}^{jet}|}{|\vec{p}^{jet}|}$$





Beauty from jet+μ

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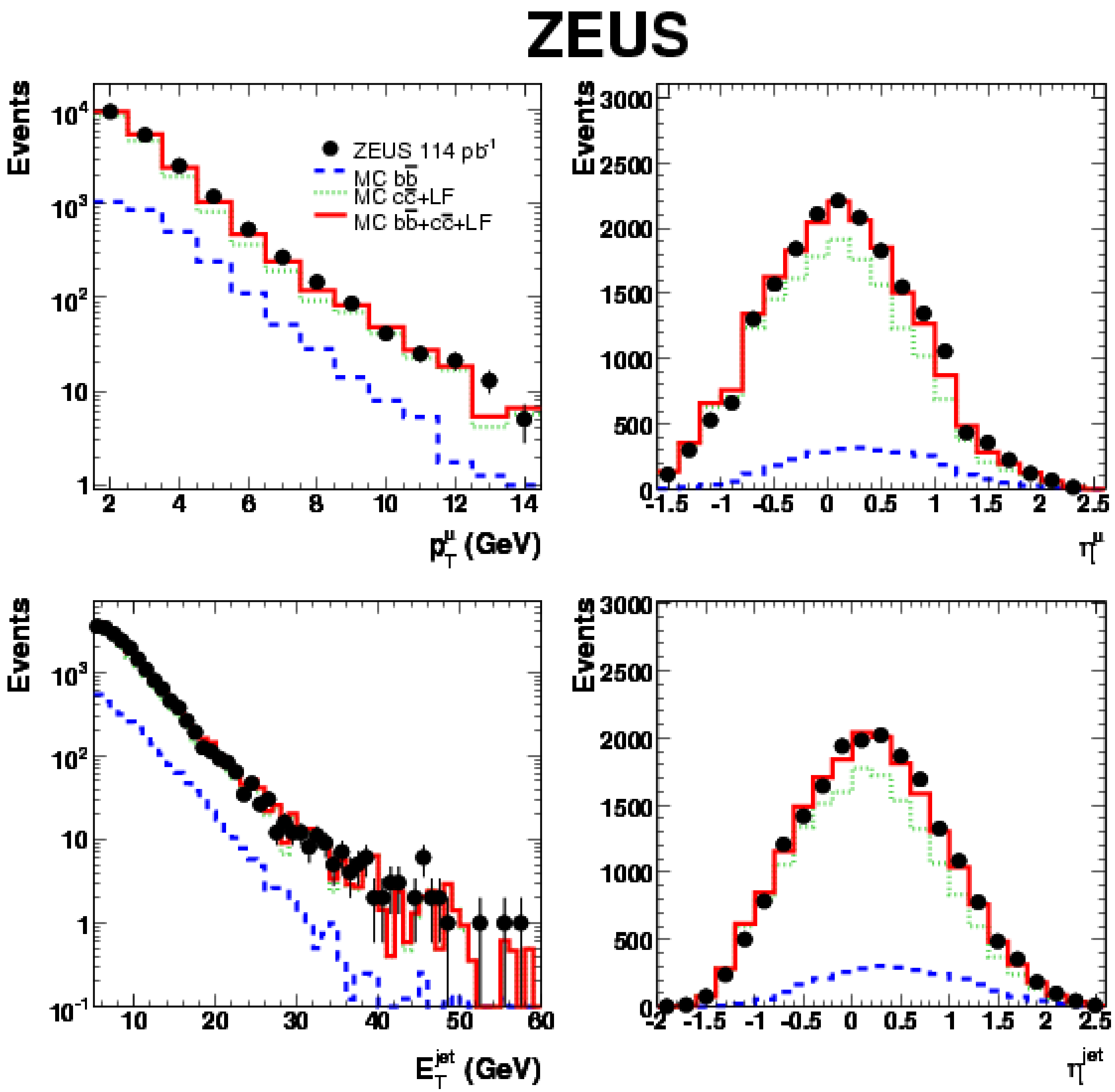
- m_b = 4.75 GeV (4.5 .. 5.0 GeV);
- ε = 0.0035 ;
- semi-leptonic decay spectrum from JETSET 7.4;
- $\mu_{r,f}^2 = \frac{1}{4}(Q^2 + p_T^2 + m_b^2)$ (varied separately by 2 up and down);
- ZEUS-S FFNS NLO PDF .



pQCD approximations (backup)

Massive scheme (FFNS):

- c and b massive;
- valid for $Q^2 \sim M^2_{c,b}$;

➔ c & b produced pertubatively (not part of proton or photon)

DIS: Harris & Smith, HVQDIS fully differential NLO calculation

Massless scheme (ZM-VFNS):

- c and b massless;
- valid for $Q^2 \gg M^2_{c,b}$;

➔ c & b present in proton

DIS: inclusive calculation of $F_2^{c,b}$, Kniehl et.al

Variable Flavor Number Scheme (GM-VFNS):

- equivalent to massive at small Q^2;
- equivalent to massless at high Q^2;

➔ c & b present in proton

DIS: only $F_2^{c,b}$