Beauty production at HERA

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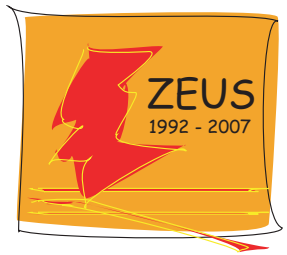
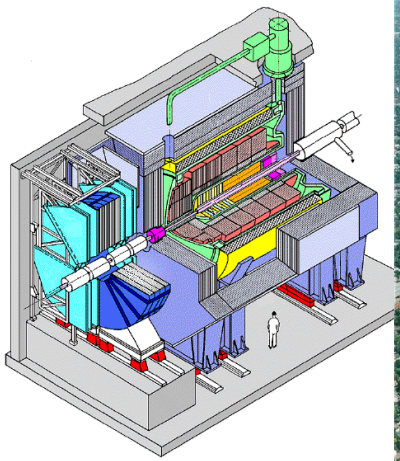
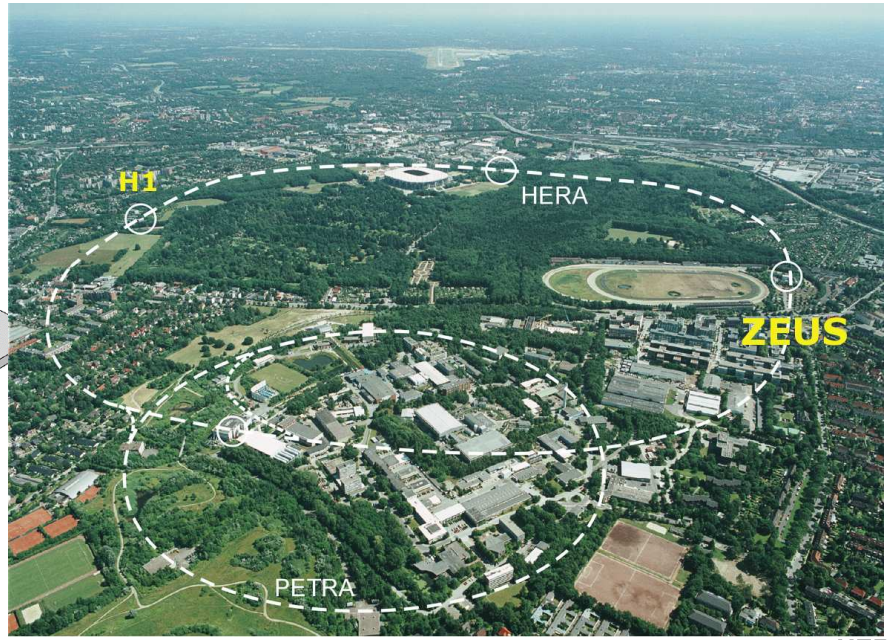
Workshop on low-x physics
- Ischia, Italy -
8^{th} - 12^{th} September 2009

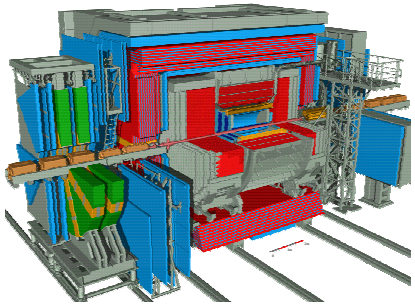
- Introduction
- Photoproduction
- Deep Inelastic Scattering



H1 and ZEUS

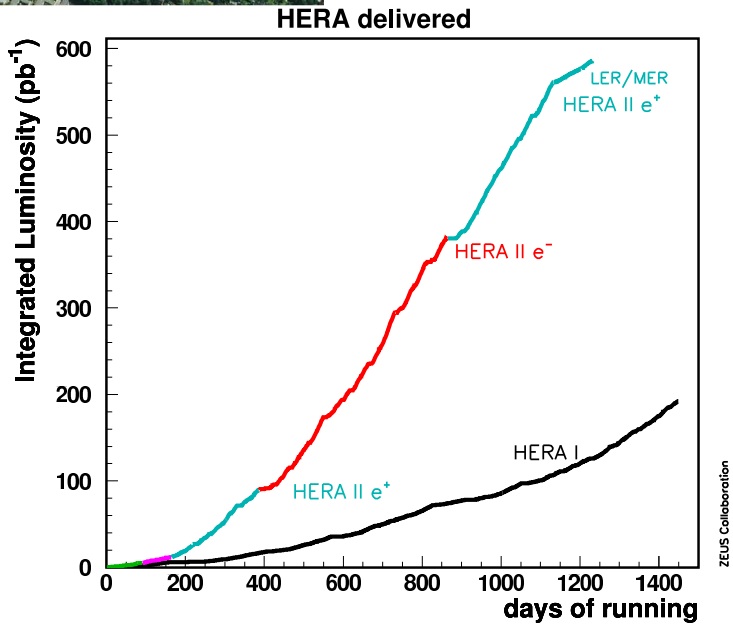






- 27.5 GeV $e^{\pm}$
  920 GeV $p \rightarrow \sqrt{s} = 318$ GeV
- HERAI: 1992-2000
- HERAII: 2003-2007

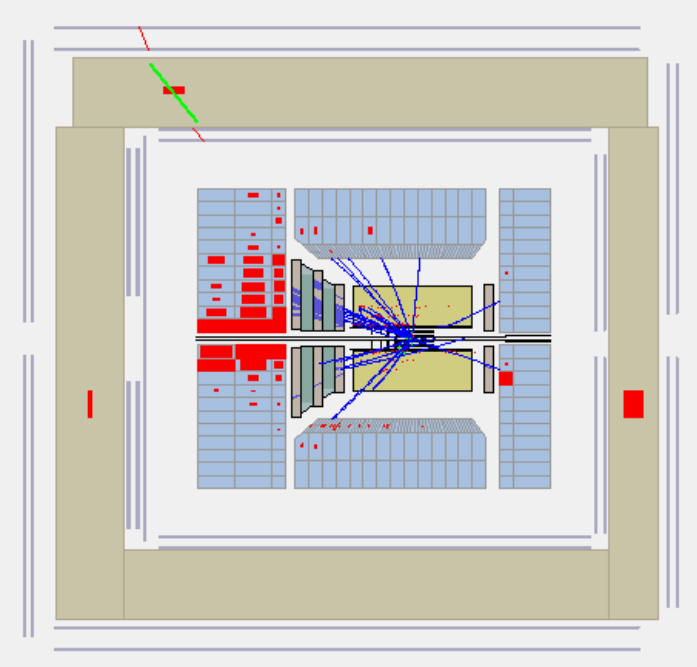
$\rightarrow \sim 0.5\,\mathrm{fb}^{-1}$ per experiment



Motivation

Heavy flavour production as a good probe for different production and decay mechanisms:

- Open production (pQCD)
- Resonance production (NRQCD)
- Searches for exotic bound states

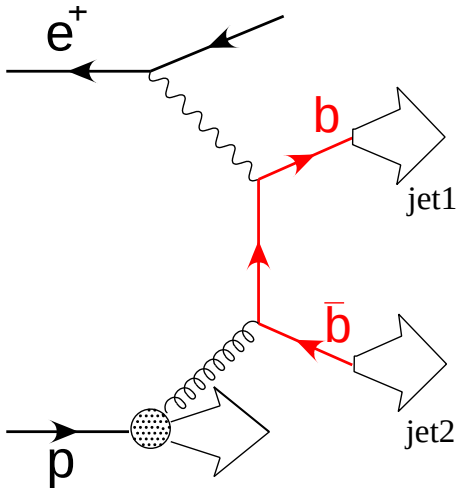


$\sigma_{uds} : \sigma_c : \sigma_b \sim 2000 : 200 : 1$

Kinematical regions:

Photoproduction (γp) $\rightarrow Q^2 \lesssim 1 GeV^2$

Electroproduction (DIS) $\rightarrow Q^2 \gtrsim 1 GeV^2$



Theoretical Description

Monte Carlo Programs

leading order + parton shower

- DGLAP evolution (collinear factorization)
  RAPGAP (DIS)
  PYTHIA (γp)

NLO Calculations

full NLO calculations available

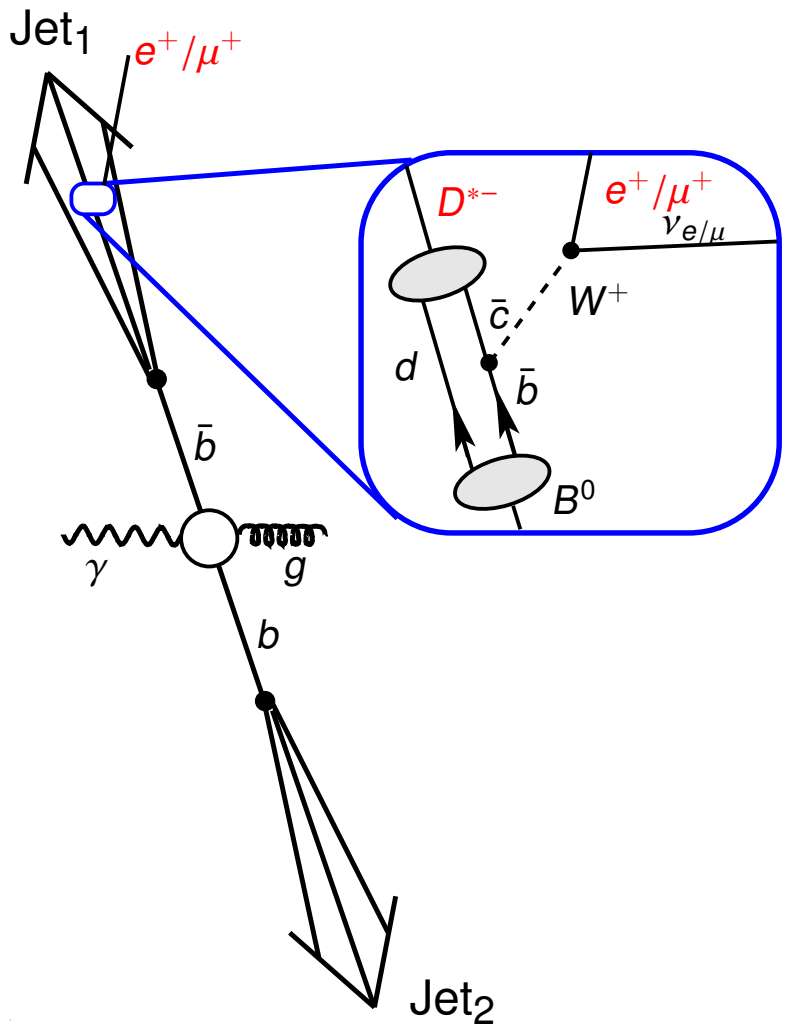
HVQDIS (DIS)
FMNR (γp)

(both using fixed flavour massive calculations)

Heavy flavour tagging

Different experimental techniques used (combined) for heavy flavour tagging:

- Decay spectra
  p_T^{rel} of lepton to jet axis
- Lifetime information
  Measure impact parameter or decay length with respect to primary vertex (transverse beamspot)
- Meson identification
  $D^{*\pm}$ tagging (”Golden Decay”)
  → talk by Paul Thompson



Photoproduction

Beauty production with muons and jets

Method:

Simultaneous fit of p_T^{rel}

and signed impact parameter, δ

HERAII data:

2006-2007 ($\mathcal{L} \approx 170\,\mathrm{pb}^{-1}$)

Kinematic region:

$Q^2 < 1\,\mathrm{GeV}^2$, $0.2 < y < 0.8$,

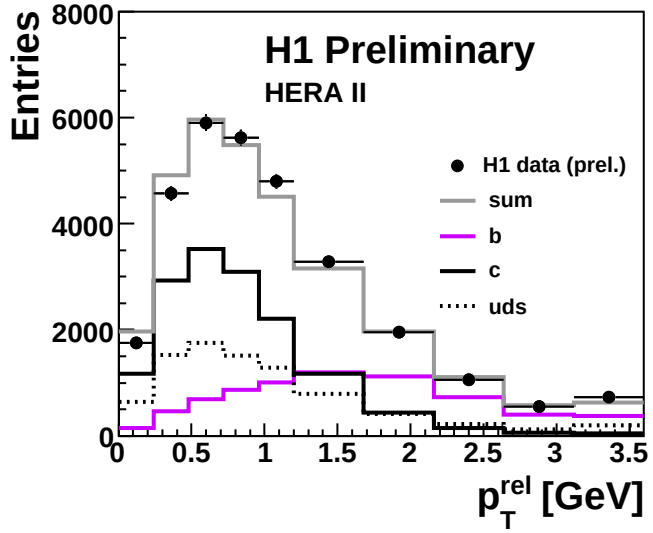
$p_T^{jets} > 7(6) GeV$, $|\eta^{jets}| < 2.5$

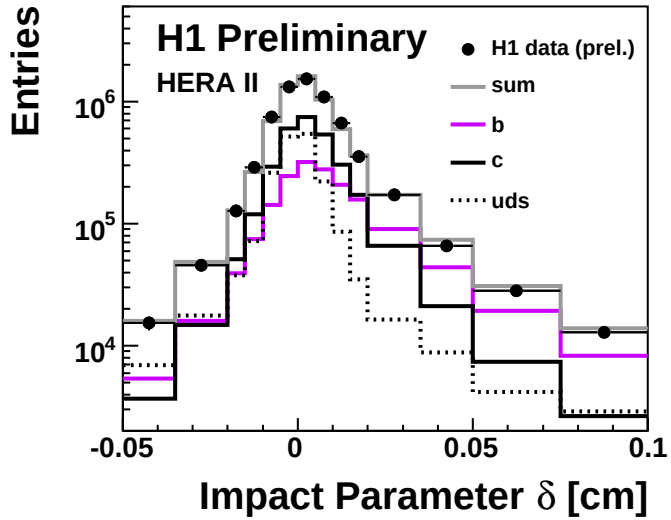
$p_T^{\mu} > 2.5\,\mathrm{GeV}$, $-0.55 < \eta^{\mu} < 1.1$

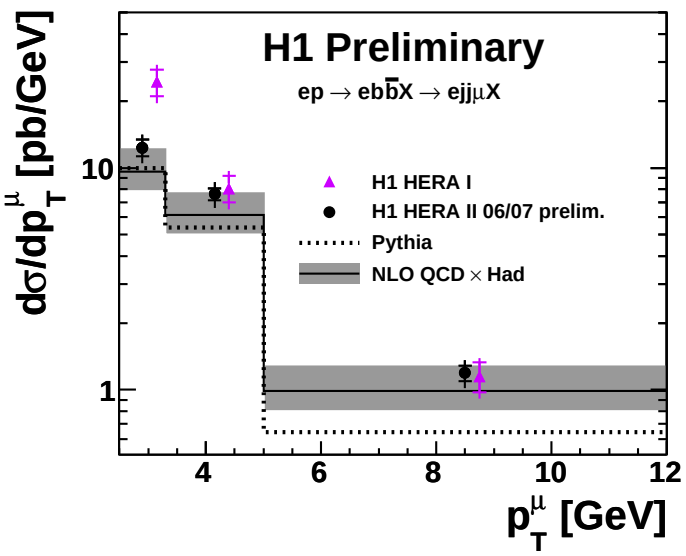
Result:

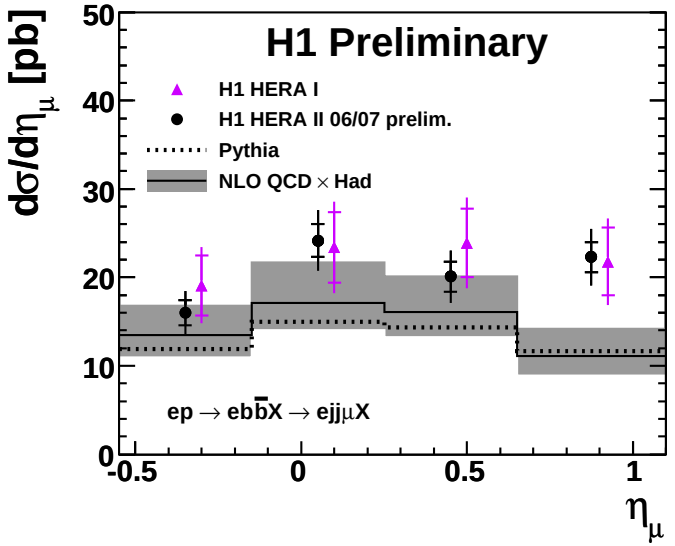
$$\sigma_{vis}(ep \to eb\bar{b}X \to ejj\mu X') = 31.4 \pm 1.3(stat.) \pm 3.8(syst.)\,\mathrm{pb}$$

$$(\sigma_{NLO} = 25.3^{+6.4}_{-4.7}\,\mathrm{pb})$$



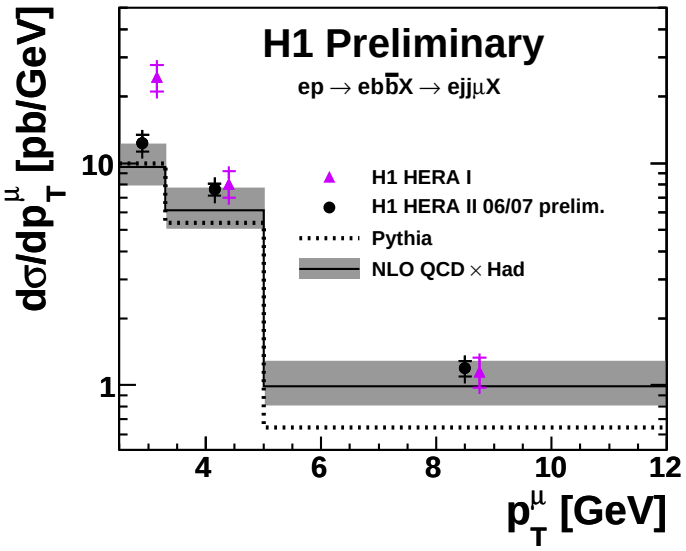


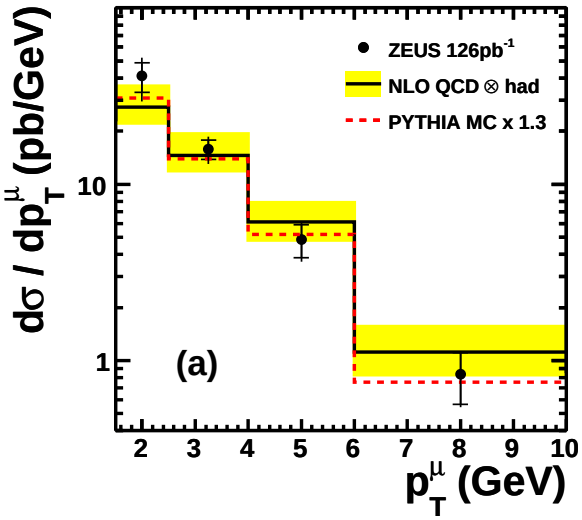




- NLO QCD calculation in agreement with the measurement
- Shapes are well described by NLO calculation and PYTHIA LO MC
- At low values of p_T^μ the new measurement (with reduced uncertainty) is closer to NLO prediction than the one for HERA I

Beauty production with muons and jets





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Vertex Method:

- Fit secondary vertex for each jet object
- Use beamspot to calculate DL in *xy*-plane
- Project DL on jet axis

HERAII data:

2006-2007 ($\mathcal{L} \approx 128\,\mathrm{pb}^{-1}$)

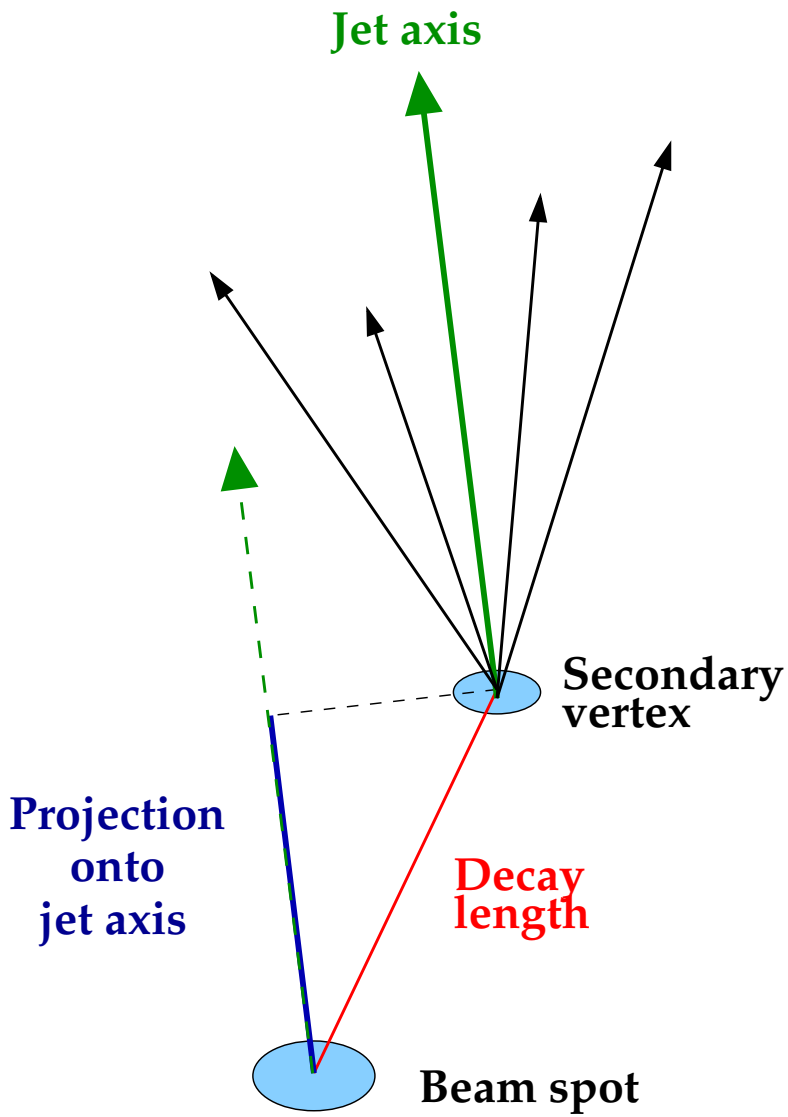
Kinematic region:

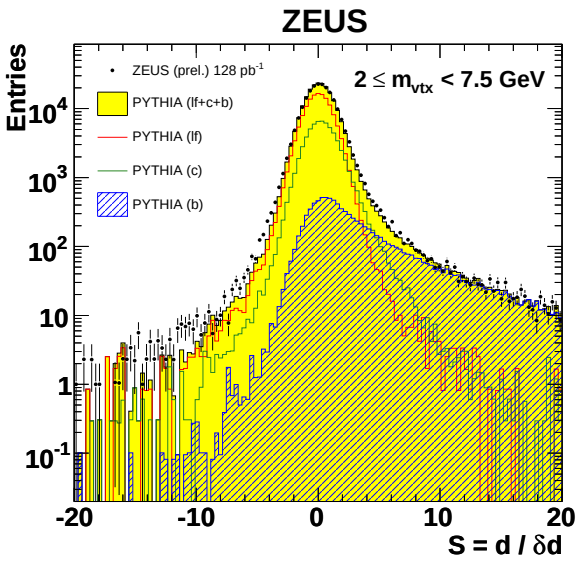
$Q^2 < 1\,\mathrm{GeV}^2$, $0.2 < y < 0.8$,

$p_T^{jets} > 7(6) GeV$, $|\eta^{jets}| < 2.5$

(one jet with $-1.6 < \eta^{jet1(2)} < 1.3$)

inclusive selection

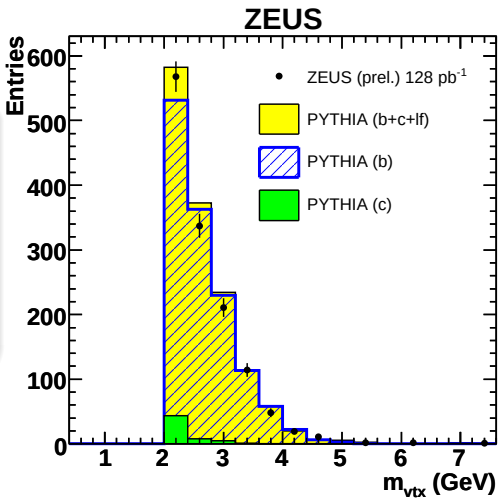


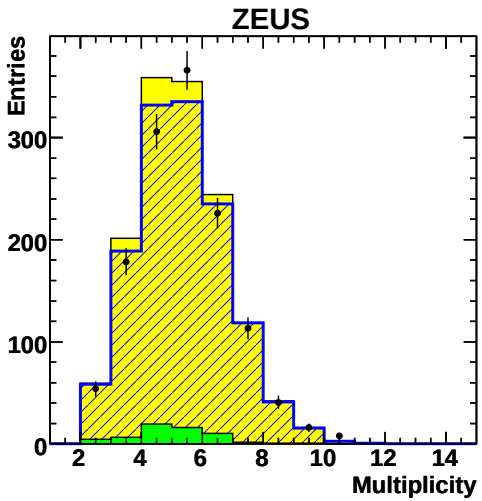


- Decay length significance
  $S = DL/\sigma_{DL}$
  (for $2 < m_{\mathrm{vtx}} < 7.5\,\mathrm{GeV}$)
- For high masses region with almost **pure beauty** contribution
- Symmetric distribution for light flavour
- Fit mirrored and subtracted decay length significance

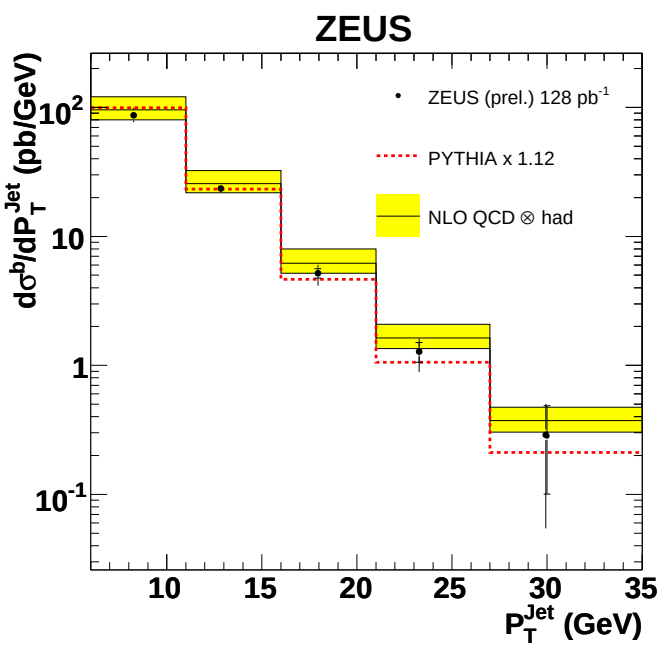
Beauty-enriched mass and multiplicity distributions

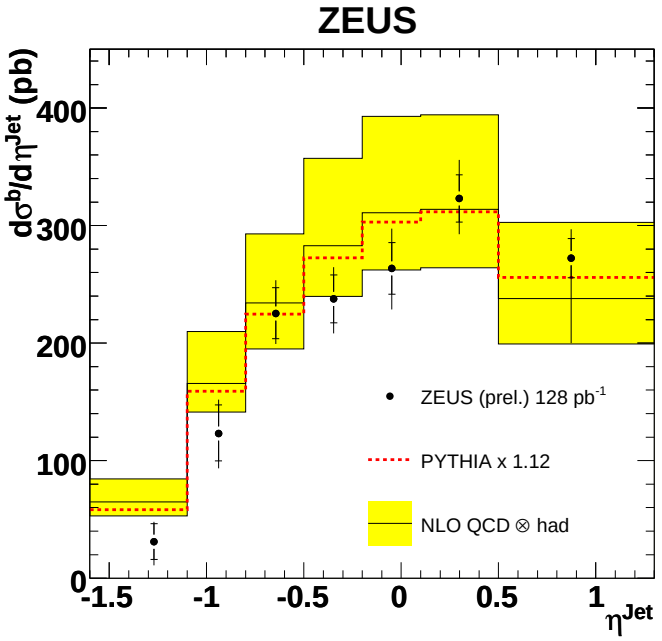
- Very good agreement between Data and MC





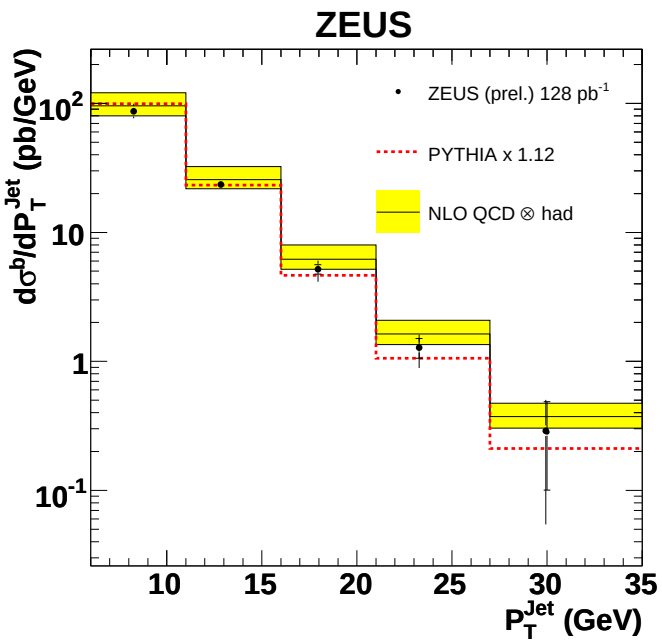
Beauty production using incl. secondary vertexing ZEUS

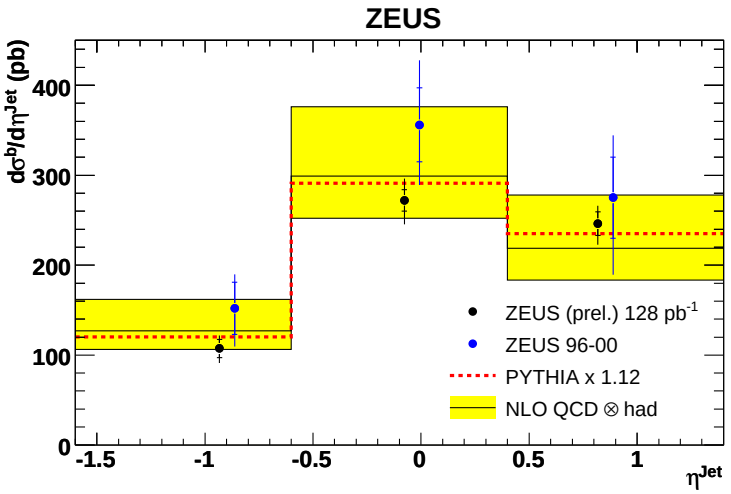




- Differential cross-sections in P_T^{Jet} and η^{Jet}
- NLO QCD calculation in good agreement with measurement
- Experimental uncertainty substantially reduced w.r.t. previous measurements
- Theoretical larger than experimental uncertainties

Beauty production using incl. secondary vertexing ZEUS





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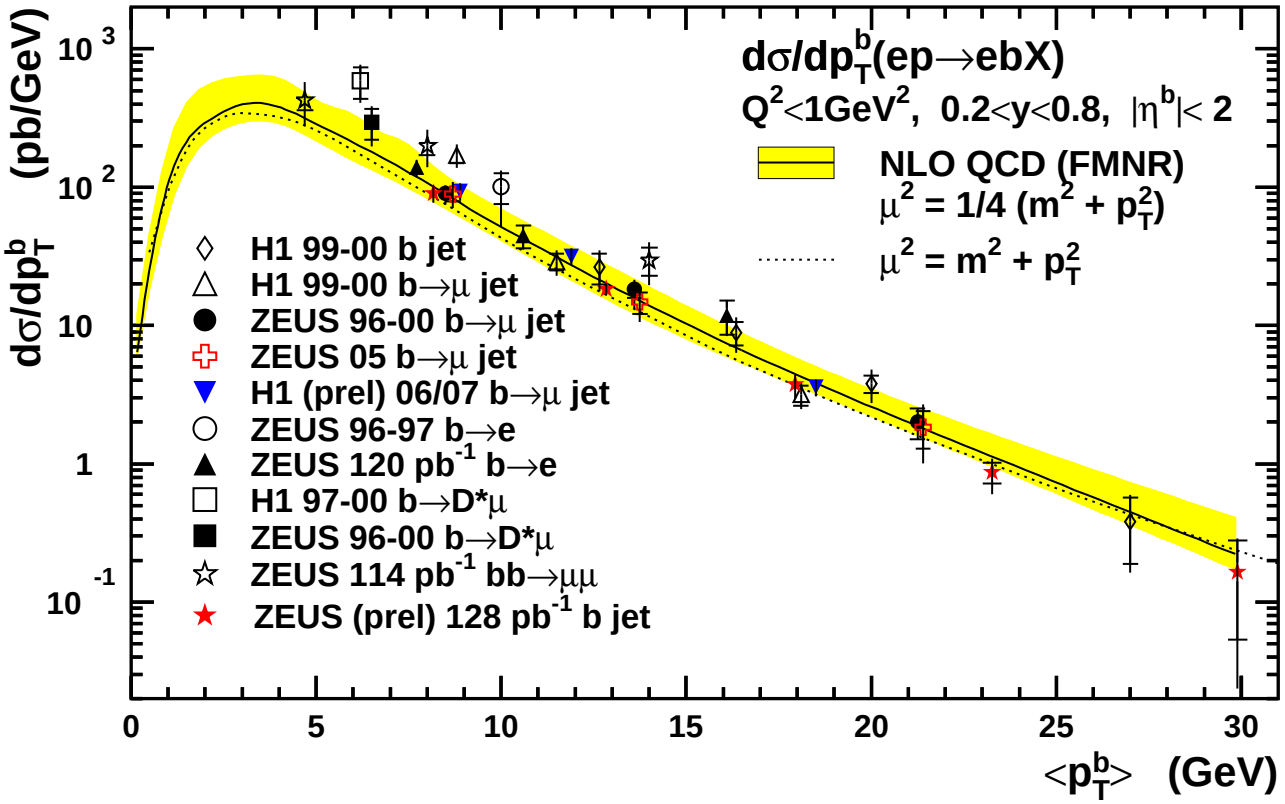
HERA



Several measurements with different methods and systematics confirming each other and covering different p_T^b-ranges:
General good agreement observed!

Deep Inelastic Scattering

Method:

Simultaneous fit of p_T^{rel}, δ and $p_T^{miss||\mu}$

$p_T^{miss||\mu}$:

-missing transverse momentum

-parallel to the muon direction

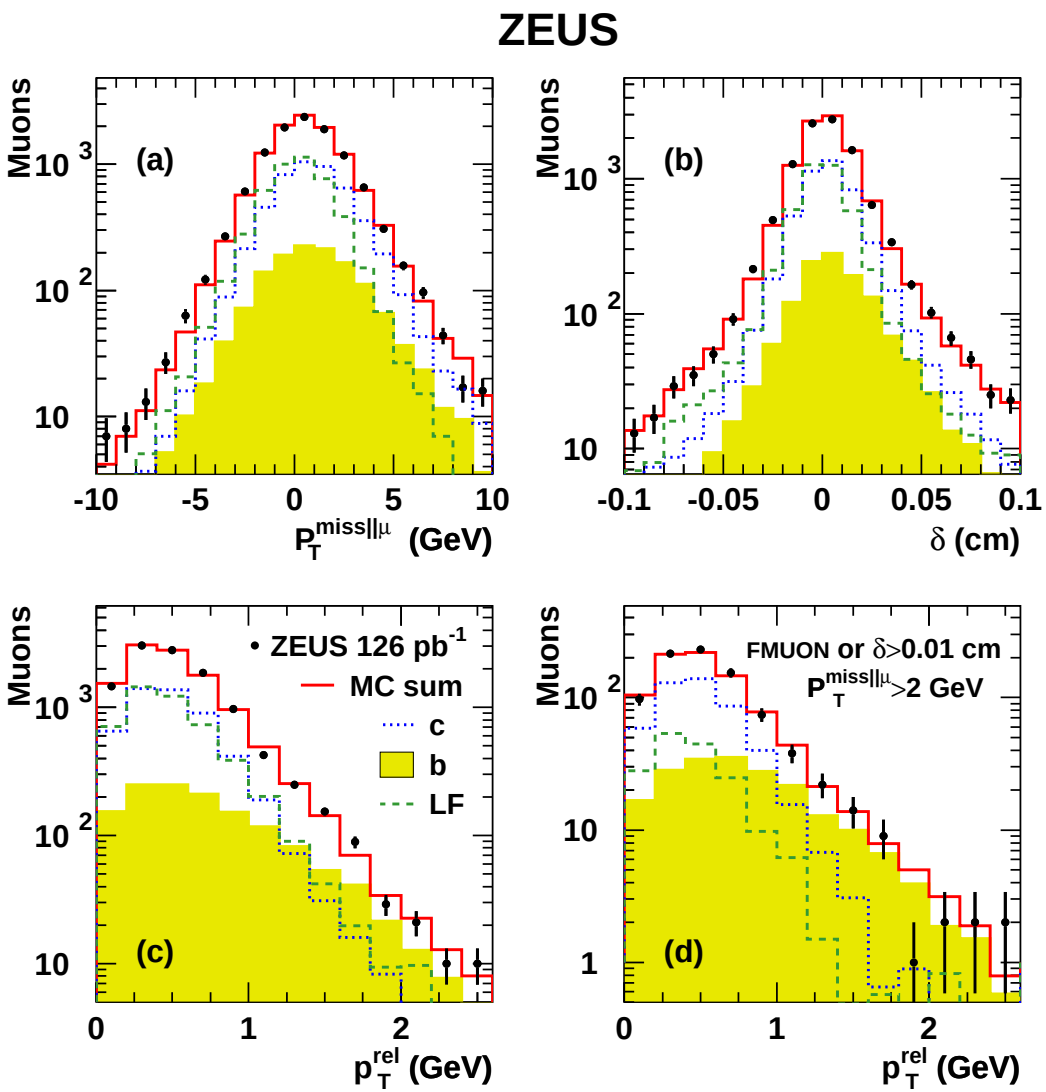
HERAII data:

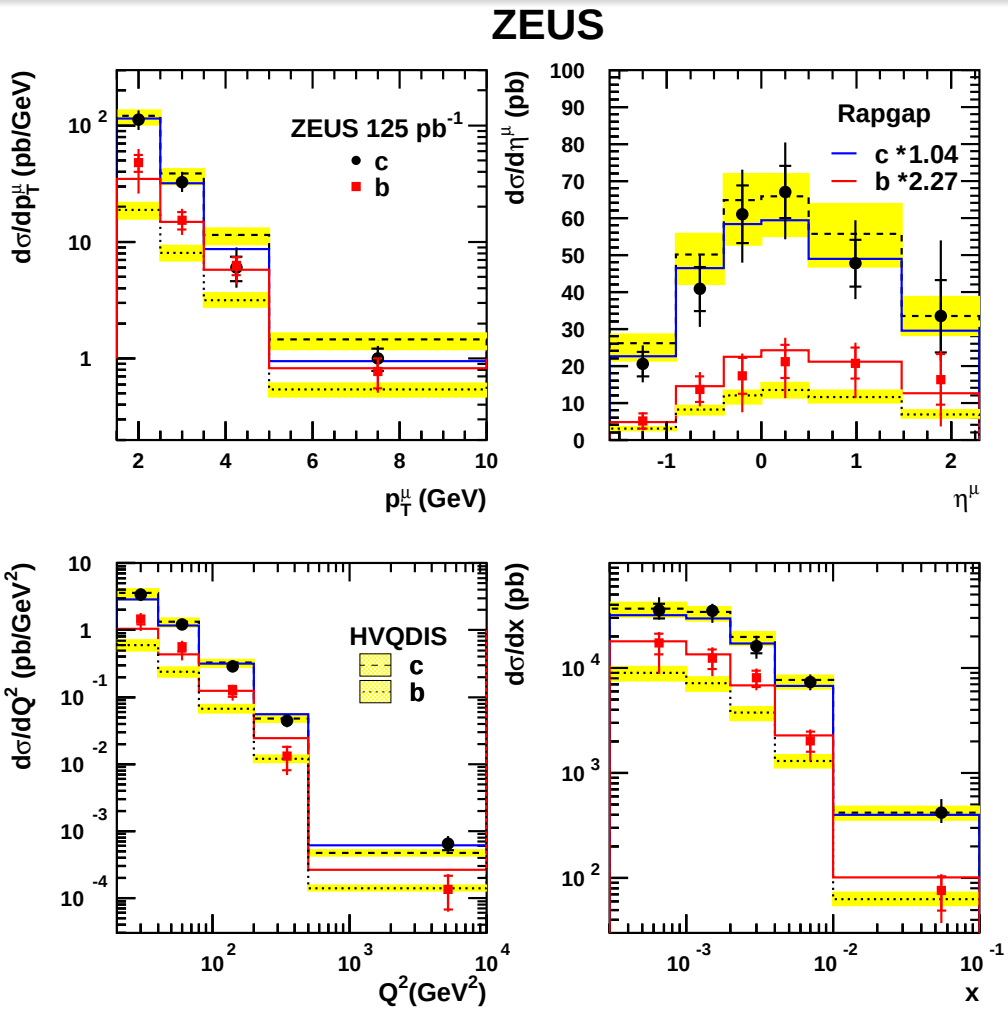
2005 ($\mathcal{L} \approx 126\,\text{pb}^{-1}$)

Kinematic region:

$Q^2 > 20\,\text{GeV}^2$, $0.01 < y < 0.7$,

$p_T^{\mu} > 1.5\,\text{GeV}$, $-1.6 < \eta^{\mu} < 2.3$





$$\sigma_c = 164 \pm 10(stat.)^{+30}_{-31}(syst.)\,\text{pb}$$
$$(\sigma_c^{NLO} = 184^{+26}_{-40}\,\text{pb})$$

$$\sigma_b = 63 \pm 7(stat.)^{+18}_{-11}(syst.)\,\text{pb}$$
$$(\sigma_b^{NLO} = 33 \pm 5\,\text{pb})$$

- NLO QCD calculation in good agreement for charm while beauty cross section is 2.3 standard deviations above HVQDIS result
- Shapes are well described by NLO calculation and RAPGAP LO MC

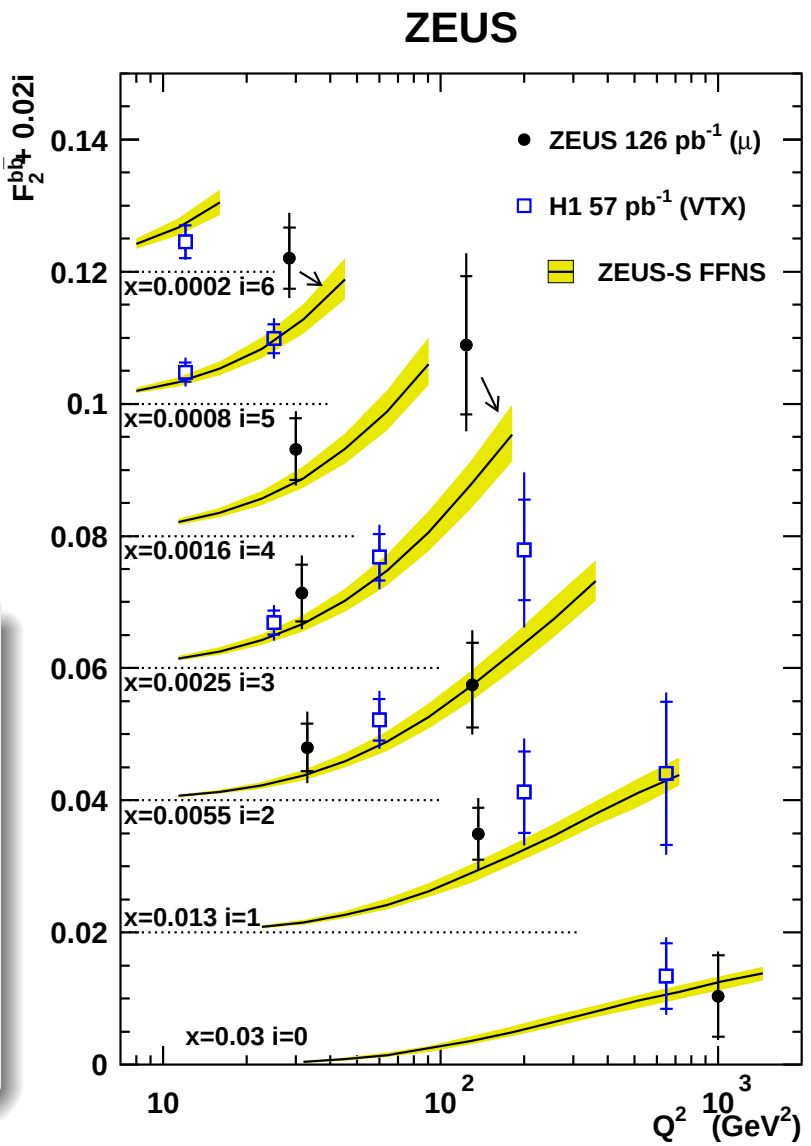
Unfold cross sections:

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

Extract $F_2^{b\bar{b}}$:
(for given x,Q^2 from muon cross section, σ^b:)

$$F_2^{b\bar{b}} = \tilde{\sigma}^b \frac{F_2^{b\bar{b},th}(x,Q^2)}{\sigma^{b,th}}$$

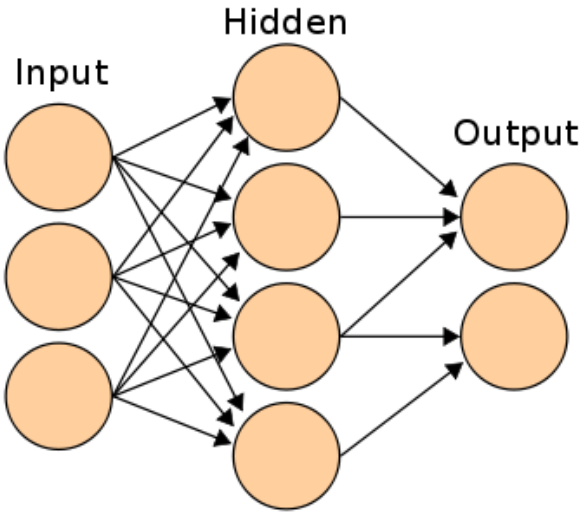
- Compared with NLO QCD predictions in the FFNS using the ZEUS-S PDF fit
- Structure functions agree well with other measurement based on independent technique



Method:

Combine variables reconstructed by the vertex detector using a **Neural Net**

- impact parameter significance of highest significant tracks (S_1, S_2...)
- position and track multiplicity of the secondary vertex
- track momenta and multiplicities



HERAII data:

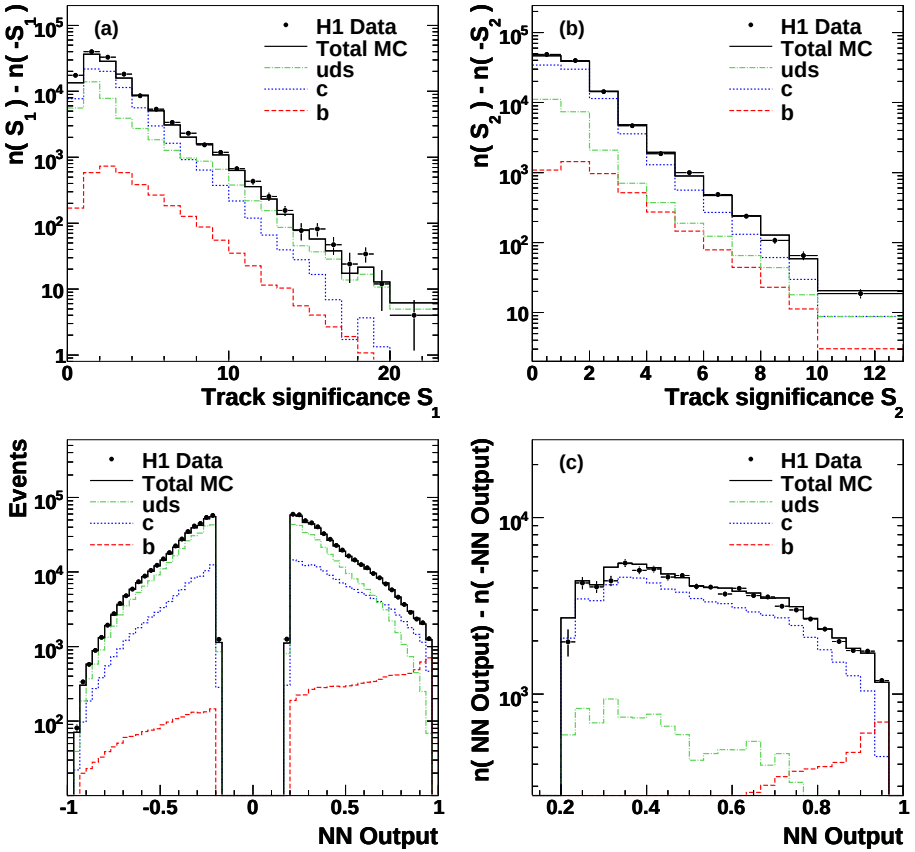
2006-2007 ($\mathcal{L} \approx 189\,\mathrm{pb}^{-1}$)

Kinematic region:

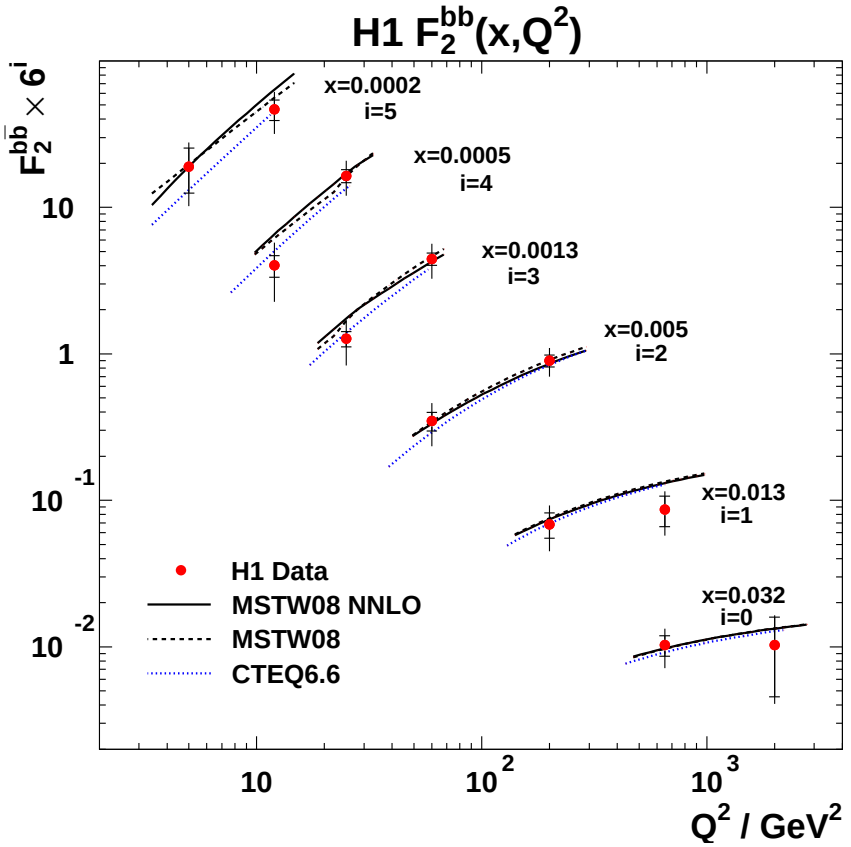
$5 \leq Q^2 < 2000\,\mathrm{GeV}^2$,

$0.0002 < x < 0.05$,

- Use S_1 and S_2 for events with less than 3 good tracks
- Else combine S_1,S_2,S_3,DL, p_T^1, p_T^2, N_{track} and N_{track}^{SV} to one variable using a NN
- Subtract negative distribution to get rid of symmetric light flavour contribution



- Subtracted distributions heavy flavour dominated (light flavour contribution fixed by normalization)
- Determine beauty and charm fraction from simultaneous fit of (a), (b) and (c)



- Calculated b contribution to the structure functions in bins of Q^2 and x
- Combine with HERA I data

- Using the HERA II data a large range in x and Q^2 could be covered with reduced uncertainties
- Measurements are described by predictions in the variable flavour number schem (NLO and NNLO)
- Most precise measurement of F_2^b

Summary

- Latest results on beauty production at HERA presented
- All measurements based on HERAII data which provides new possible techniques as well as an increase in statistics
- Different approaches to use the lifetime information via impact parameter (significance) or decay length

- New measurements have smaller uncertainties and are well reproduced in shape by the LO+PS Monte Carlo predictions
- Beauty production in photoproduction from different channels consistent with NLO prediction
- Structure function F_2^b measured with best precision over a wide range in x and Q^2

References

A Measurement of Beauty Photoproduction Through Decays to Muons and Jets at HERA-II

H1prelim-08-071

Measurement of beauty photoproduction from inclusive secondary vertexing at HERA II

ZEUS-prel-09-005

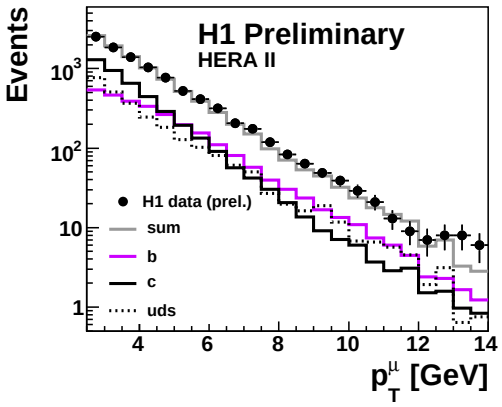
Measurement of charm and beauty production in deep inelastic ep scattering from decays into muons at HERA

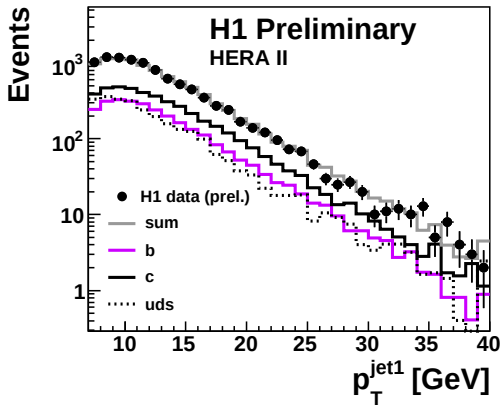
DESY-09-56 (April 2009)

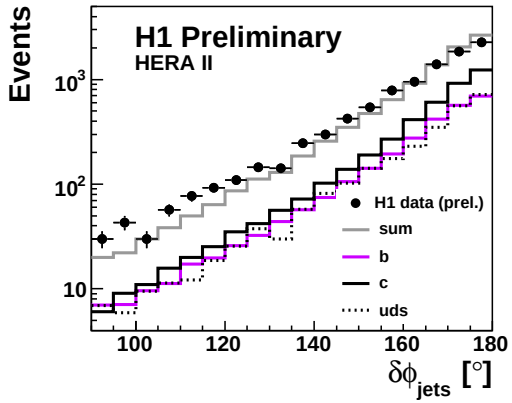
Measurement of the Charm and Beauty Structure Functions using the H1 Vertex Detector at HERA

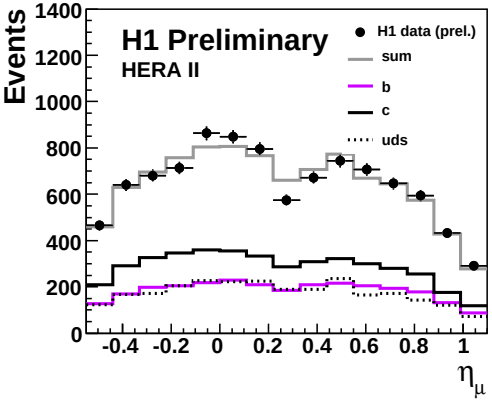
DESY-09-096 (June 2009)

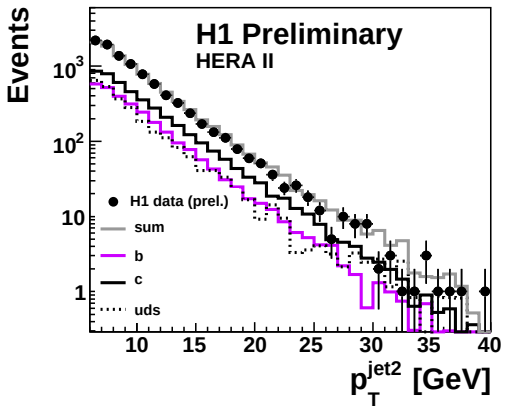
Backup - H1prelim-08-01

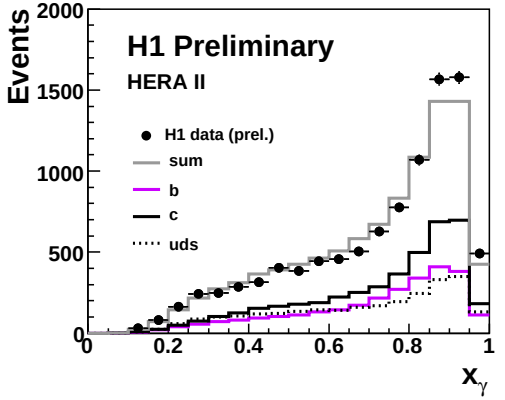












Backup - H1prelim-08-01

PYTHIA 6.2

- CTEQ6L, SAS-1D
- $m_b = 4.75\,\text{GeV}$, $m_c = 1.5\,\text{GeV}$
- $\epsilon_b = 0.0069$, $m_c = 0.058$

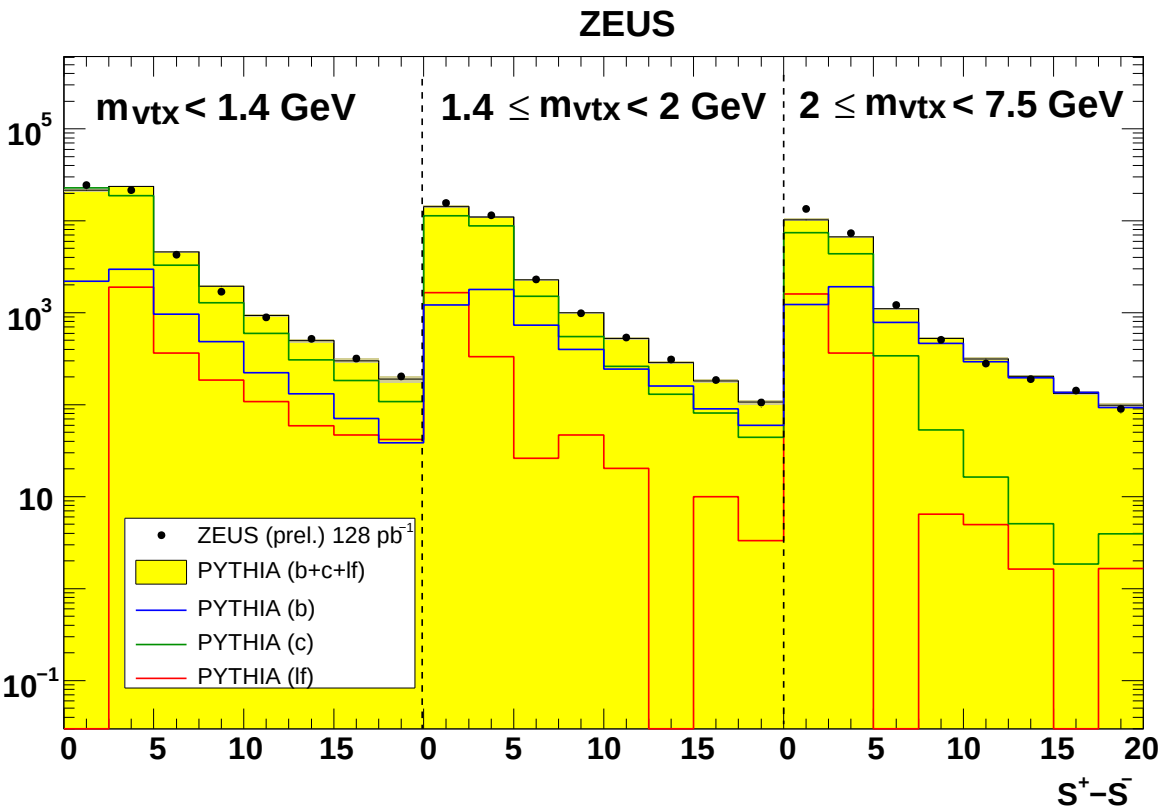
CASCADE 2.0

- A0

FMNR (FFNS)

- $\mu_R^2 = \mu_F^2 = p_T^2 + m_q^2$
- $m_b = 4.75\,\text{GeV}$
- CTEQ5F4, GRV-G HO

Backup - ZEUS-prel-09-005



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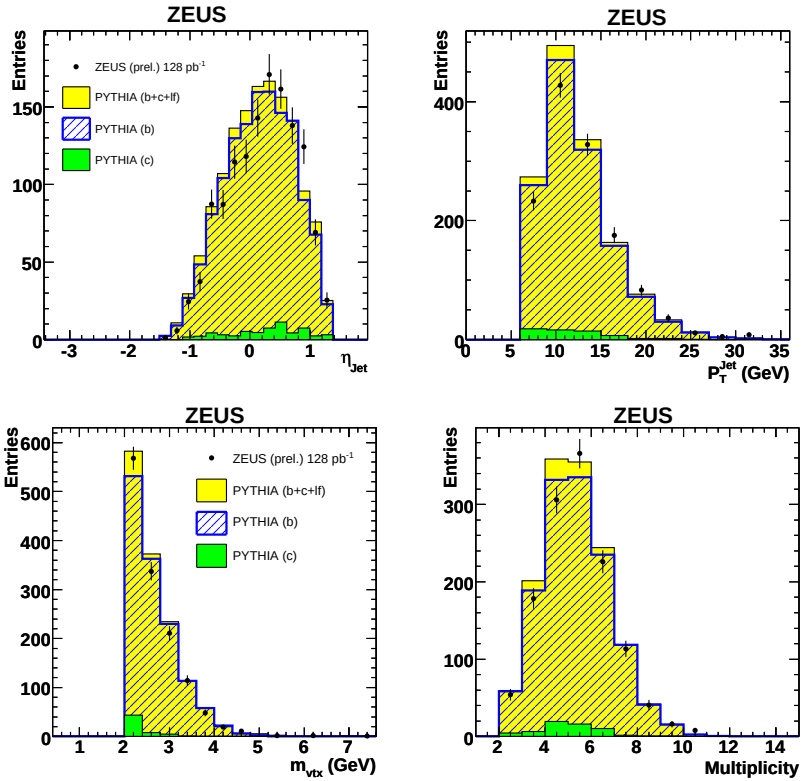
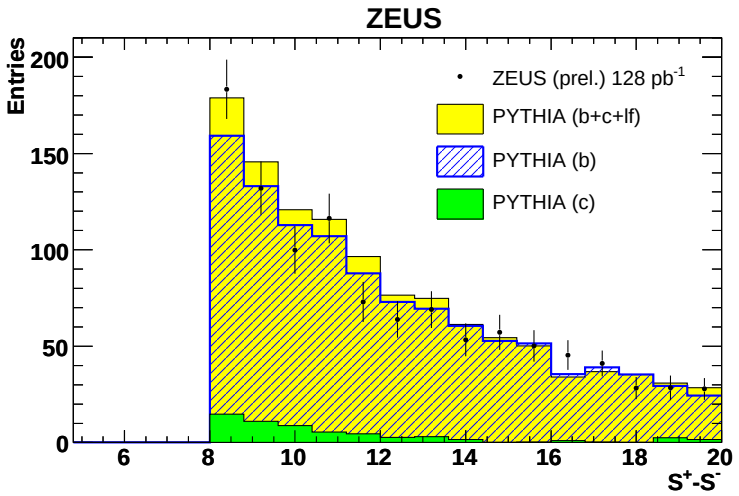




Backup - DESY-09-56

RAPGAP 3.00

- HERACLES 4.6 for QED radiative effects
- CTEQ5L PDF
- $m_b = 4.75\,\text{GeV}$, $m_c = 1.5\,\text{GeV}$

DJANGOH 1.3

- CTEQ5D PDF

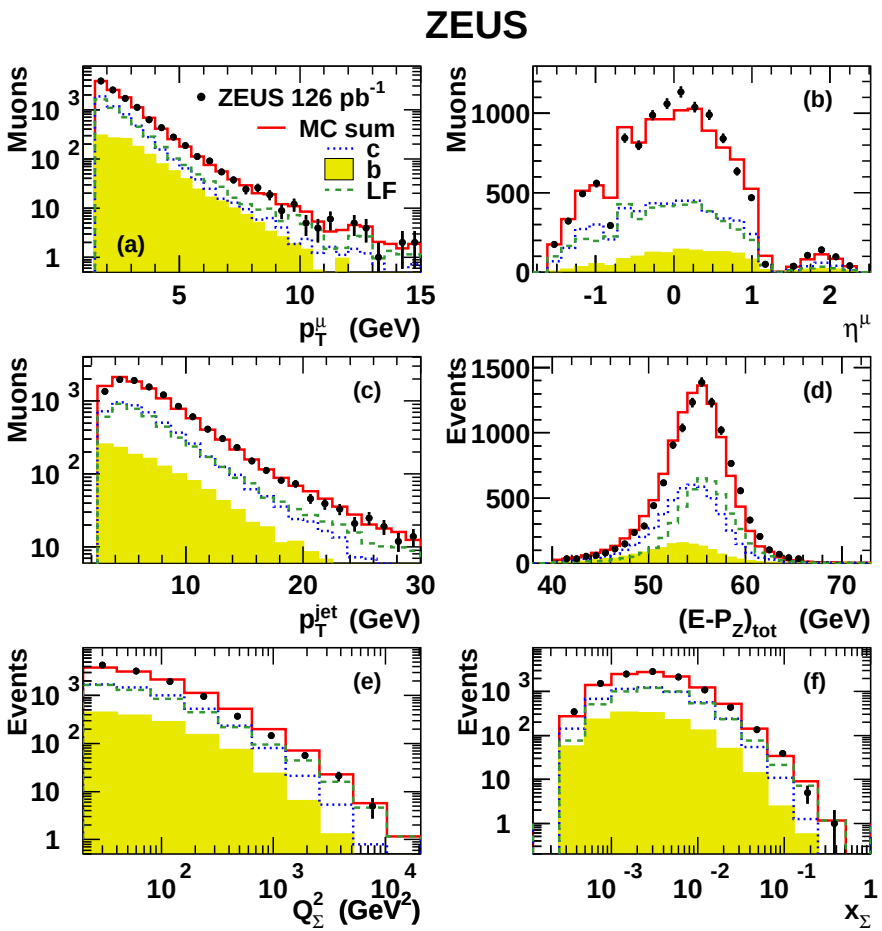
CASCADE

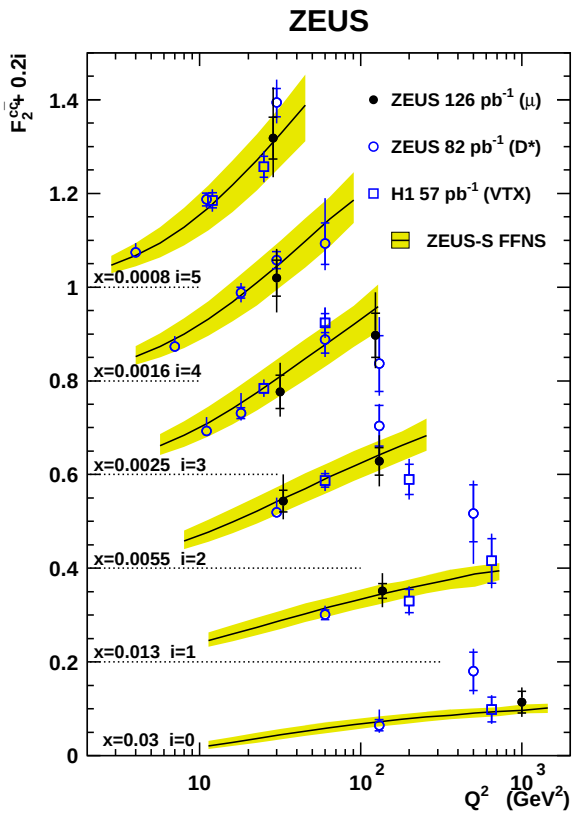
- to simulate J/Ψ

HVQDIS (FFNS)

- $\mu_R^2 = \mu_F^2 = Q^2 + 4m_q^2$
- $m_b = 4.75\,\text{GeV}$, $m_c = 1.5\,\text{GeV}$
- ZEUS-S PDF fit
- $\epsilon_b = 0.0035$, $m_c = 0.035$
- $\mathcal{B}(b \to \mu) = 0.209 \pm 0.004$

Backup - DESY-09-56





Backup - DESY-09-096

RAPGAP 3.1

- MRST2004F3LO PDFs
- $m_b = 4.75\,\text{GeV}$, $m_c = 1.5\,\text{GeV}$

PHOJET 1.3

- $\gamma p \to X$

MSTW (GM VFNS)

- $\mu_R = \mu_F = Q$
- $m_b = 4.75\,\text{GeV}$, $m_c = 1.4\,\text{GeV}$
- MSTW08 PDFs

H1

- $\mu_R^2 = \mu_F^2 = Q^2 + M^2$
- $m_b = 4.75\,\text{GeV}$, $m_c = 1.4\,\text{GeV}$
- H1PDF2009 PDFs

CTEQ

- $\mu_R^2 = \mu_F^2 = Q^2 + M^2$
- $m_b = 4.5\,\text{GeV}$, $m_c = 1.3\,\text{GeV}$
- CTEQ6.6 PDFs

CCFM

- $\mu_R^2 = \mu_F^2 = \hat{s}^2 + Q_T^2$
- $m_b = 4.75\,\text{GeV}$, $m_c = 1.4\,\text{GeV}$
- A0 PDFs

Backup - DESY-09-096