Heavy Flavour photoproduction at HERA

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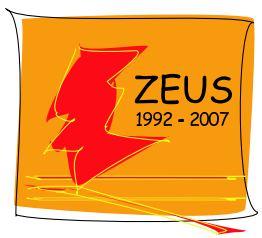


- Introduction
- Charm Production
- Beauty Production

Motivation

Heavy Flavour production provides multiple hard scales:

- large mass m_b/m_c
- high momenta p_T

$\longrightarrow$ Should ensure reliable predictions?

$\longrightarrow$ **Test of perturbative QCD**

Monte Carlo programs (leading order + parton shower)

- Pythia

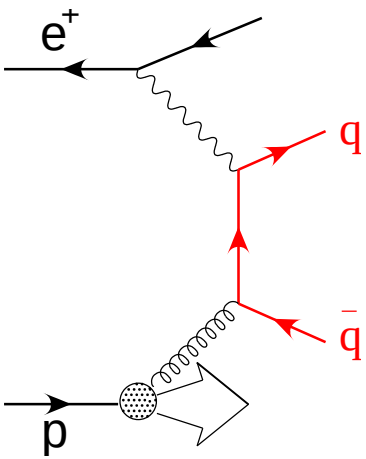
NLO Calculations

- General Mass Variable Flavour Number Scheme (GMVFNS)
- Fixed Flavour Number scheme (FFNS $\longrightarrow$ FMNR)

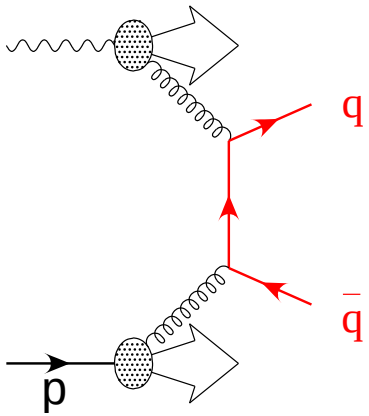
Heavy Flavour Production Mechanism

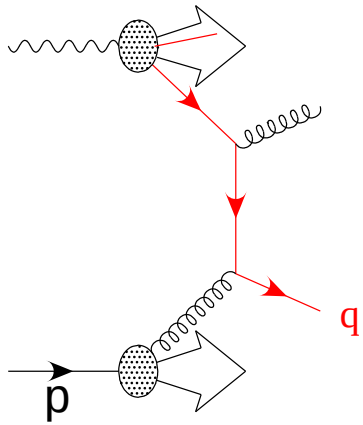
Dominant process: Boson-gluon fusion

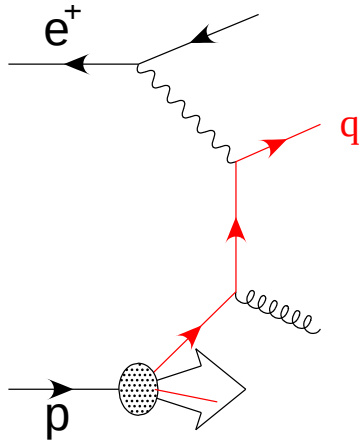
"direct"



"resolved" (including flavour excitation)



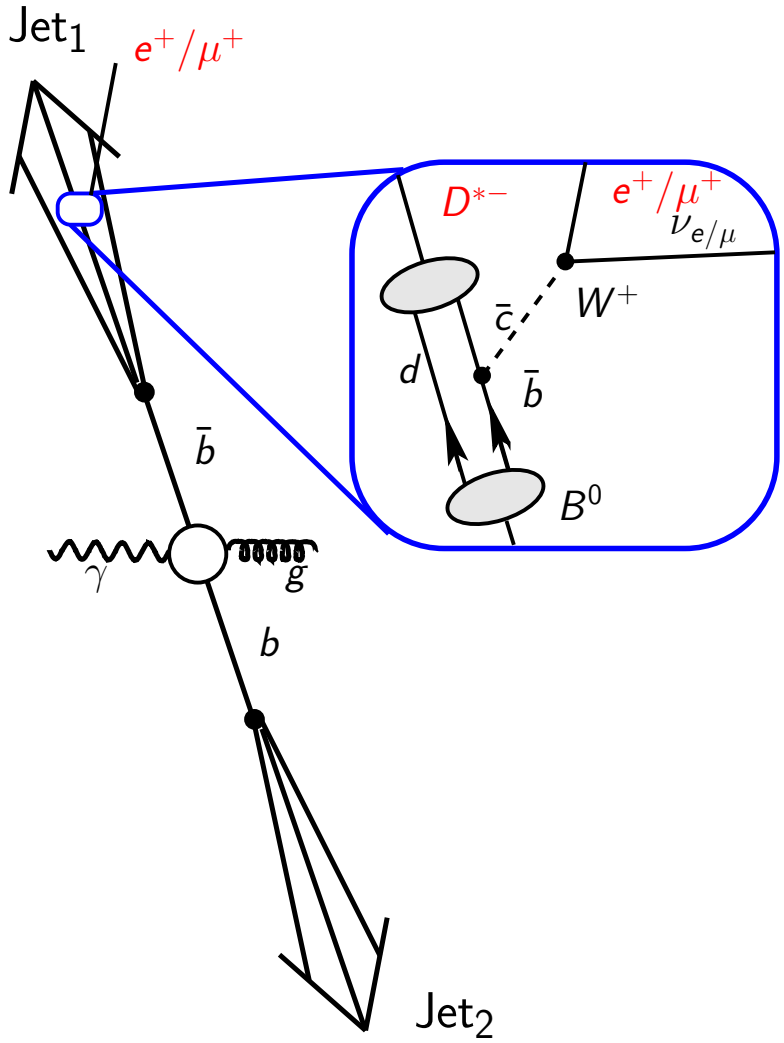




Heavy Flavour Tagging

Different experimental techniques to use (combine) for heavy flavour tagging:

- Meson identification
  $D^{*\pm}$ tagging ("Golden Decay")
- Decay spectra
  p_T^{rel} of lepton to jet axis
- Lifetime information
  Measure impact parameter with respect to primary vertex (beam spot)



Part I

Charm Production

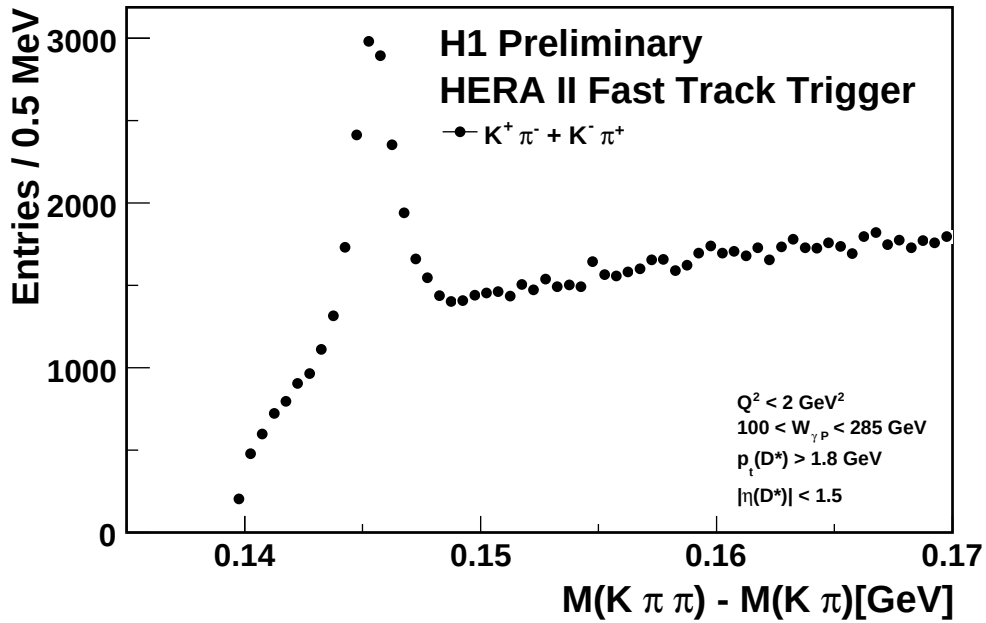
Charm quark tagged by a D* meson decaying in the **golden channel**

$$D^{*\pm} \rightarrow D^0 \pi^{\pm}_{\text{slow}} \rightarrow K^{\mp}\pi^{\pm}\pi^{\pm}_{\text{slow}}$$

Data: $\mathcal{L} = 93\,\text{pb}^{-1}$

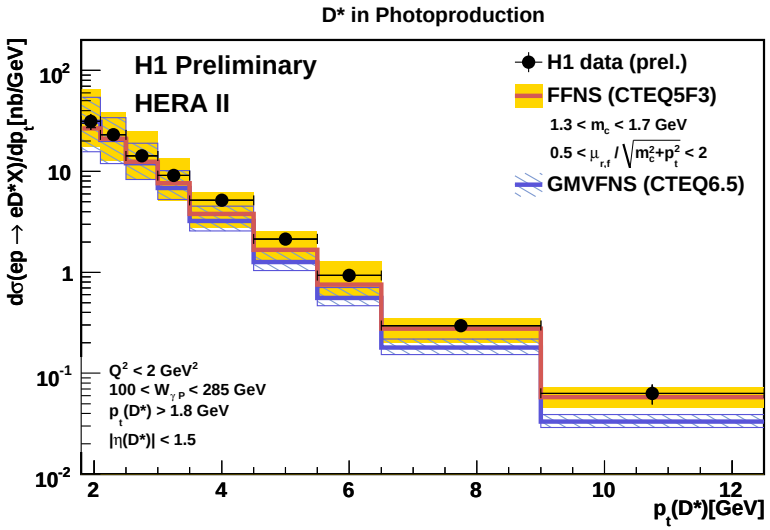
Kinematic range

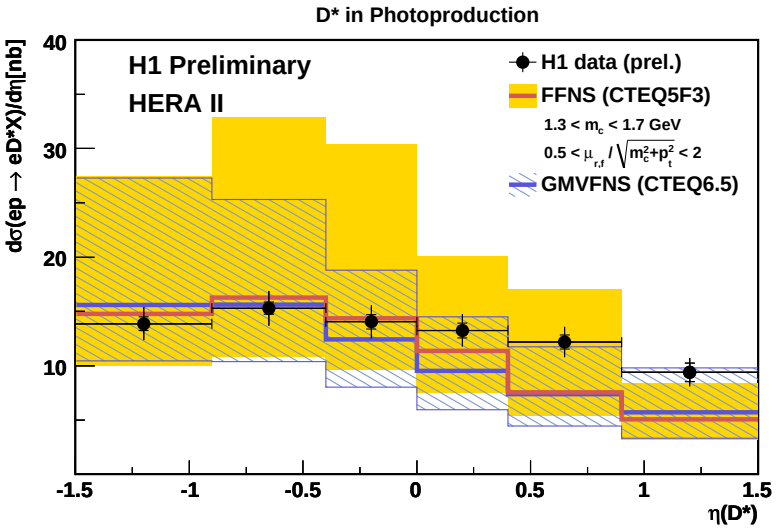
- $Q^2 < 2\,\text{GeV}^2$
- $100 < W < 285\,\text{GeV}$
- $p_t(D^*) > 1.8\,\text{GeV}$
- $|\eta(D^*)| < 1.5$



ΔM distribution for determination of number of D* mesons

Differential cross-sections in $p_t(D^*)$ and $\eta(D^*)$ H1





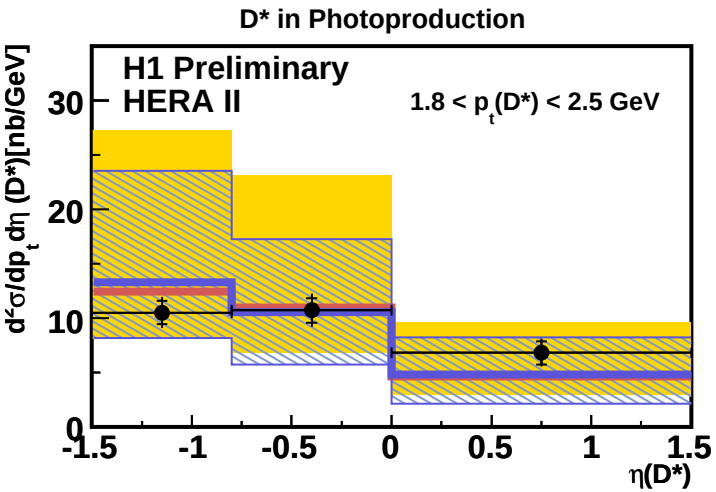
Data compared to NLO predictions:

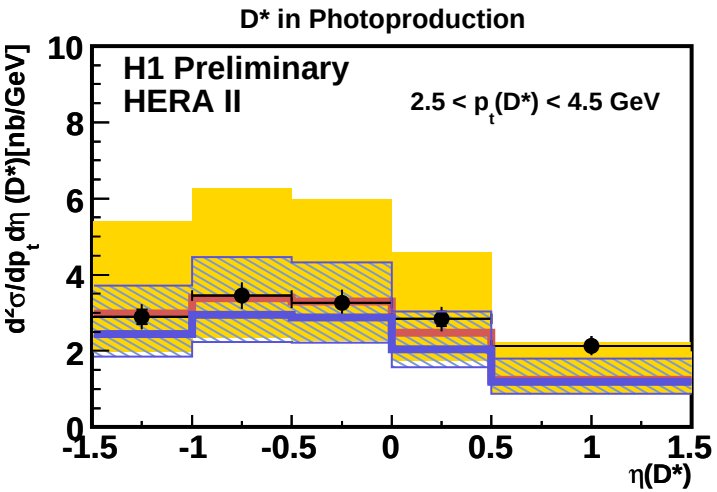
- **FFNS**: Fixed Flavour Number Scheme (FMNR)
- **GMVFS**: General Mass Variable Flavour Number Scheme

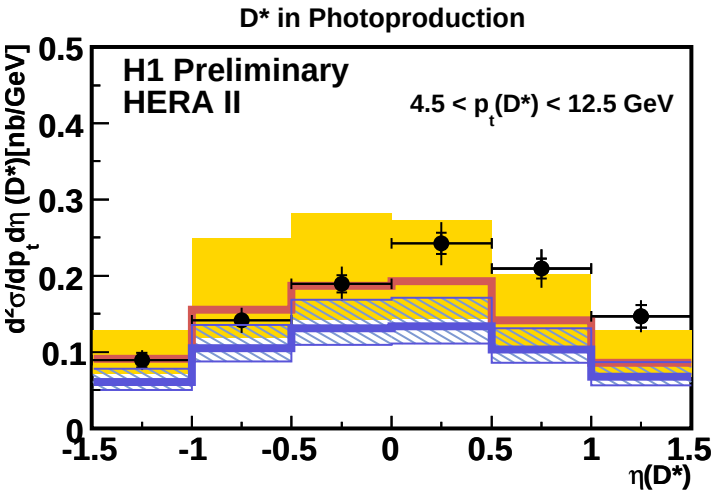
$\longrightarrow$ Data in reasonable agreement with both preditions

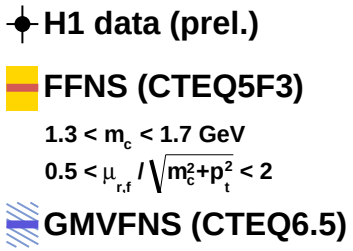
$\longrightarrow$ GMVFNS too steep in p_t, slightly different shape in η

Double-diff. cross-sections in $p_t(D^*)$ and $\eta(D^*)$ H1









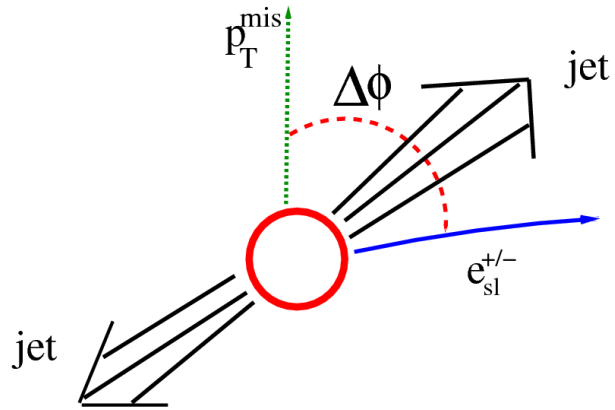
Good agreement between Data and NLO predictions except for high p_t / high η region

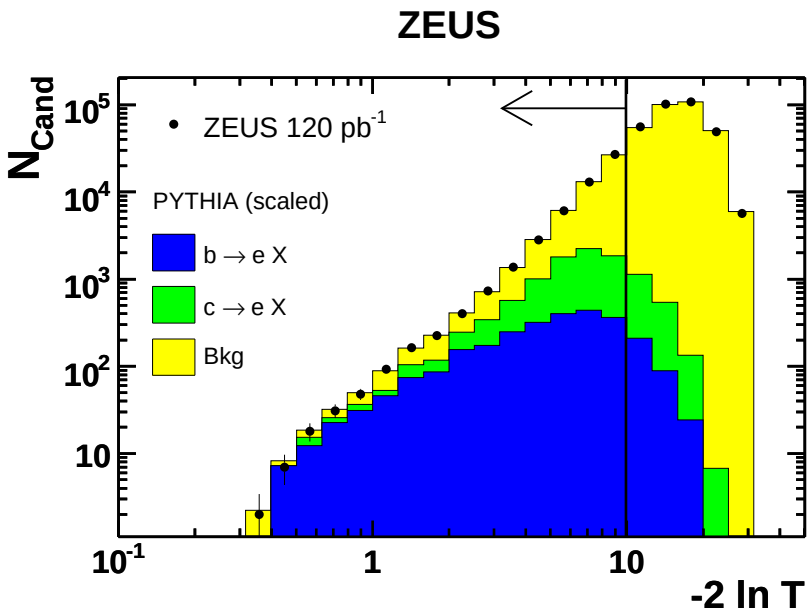
Part II

Beauty Production

Data: $\mathcal{L} = 120\,\mathrm{pb}^{-1}$

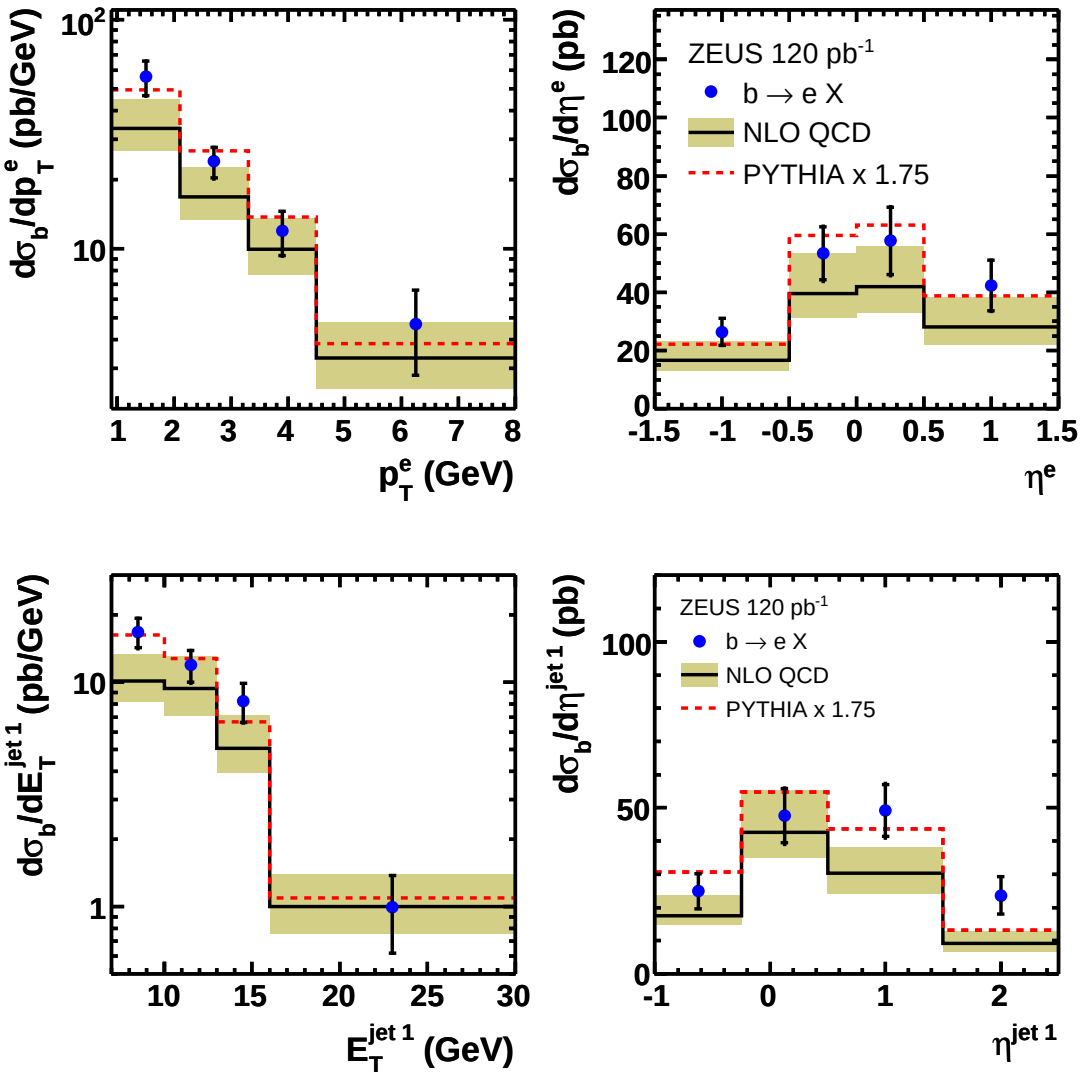
- Dijet events with $E_T > 7(6)\,\mathrm{GeV}$
- Semileptonic decays to electrons
- Combine several discriminating variables in likelihood test function:
  - Electron identification: dE/dx, EMC fraction, E/p
  - Decay identification: $\Delta\phi$ and p_t^{rel}





Beauty in Dijet PhP using electrons

ZEUS



Differential cross-sections in p_T^e, η^e, E_T^{jet1}, η^{jet1}

- NLO prediction (FMNR) consistent with Data
- Scaled MC distributions describe the shape well

arXiv:0805.4390v3

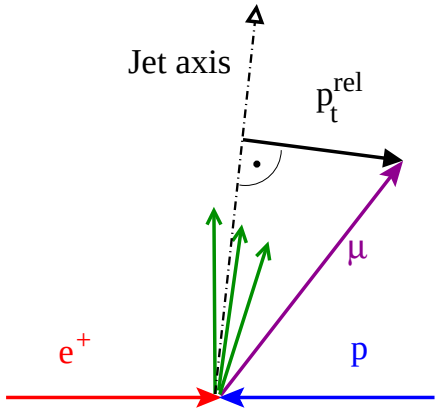
Beauty in Dijet Photoproduction using muons

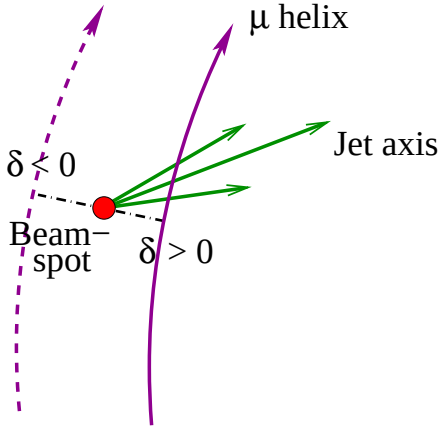
ZEUS

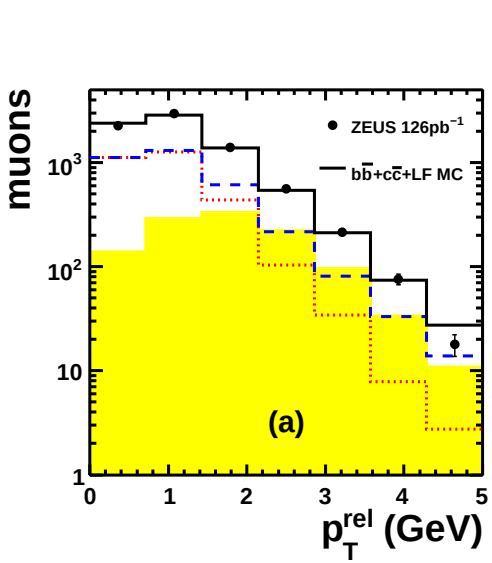
Data: $\mathcal{L} = 124\,\mathrm{pb}^{-1}$

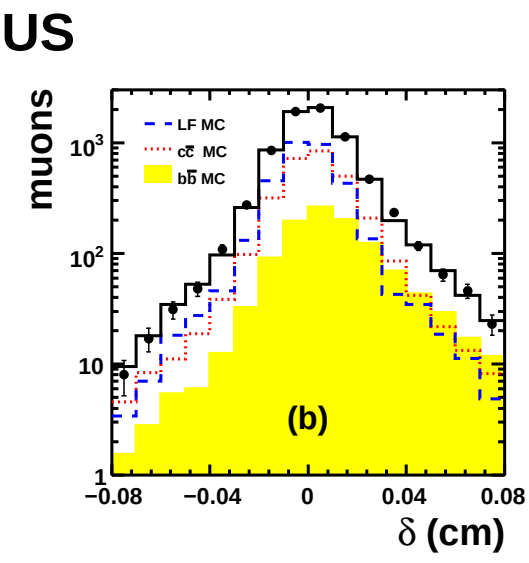
- Dijet PhP events with $p_T^{jet} > 7(6)\,\mathrm{GeV}$
- Semileptonic decays to muons
  - $-1.6 < \eta^{\mu} < 2.3$
  - $p_t^{\mu} > 2.5(1.5)\,\mathrm{GeV}$
- Simultaneous fit of impact parameter and p_t^{rel}

arXiv:0901.2226v2







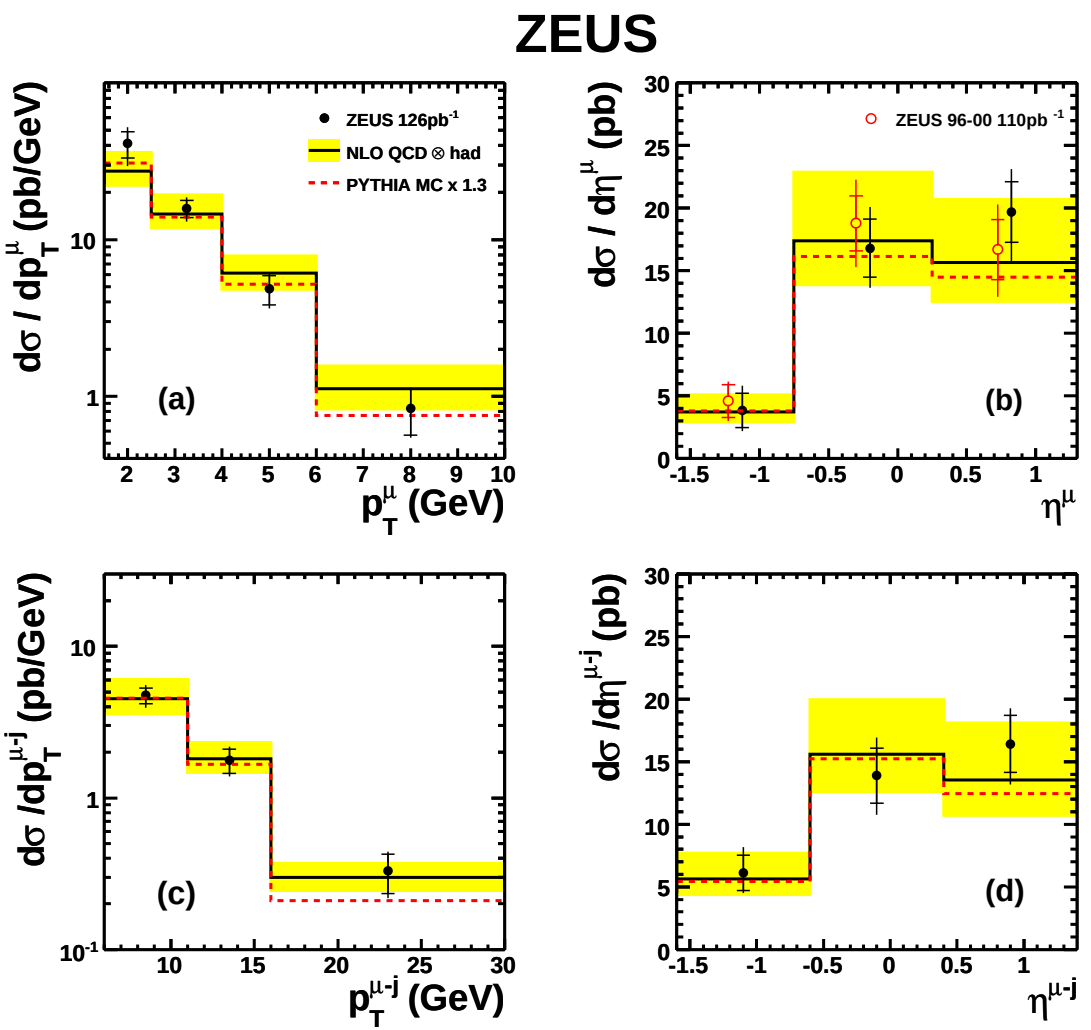


Total cross-section

$$\sigma^{vis} = 38.6\,\mathrm{pb} \pm 3.5\,(\mathrm{stat.})\,\mathrm{pb}\ ^{+4.6}_{-4.9}\,(\mathrm{syst.})\,\mathrm{pb}$$

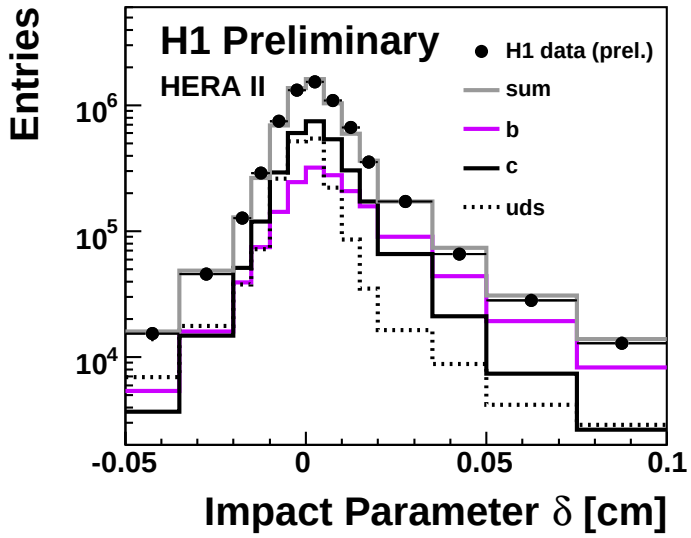
$$\sigma^{NLO} = 37.0^{+11.9}_{-7.5}\,\mathrm{pb}$$

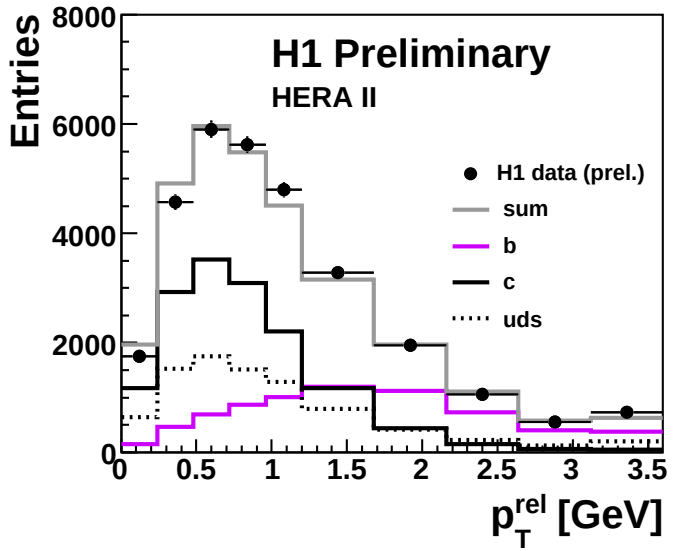
- Previous analysis (ZEUS 96-00 $110\,\mathrm{pb}^{-1}$) with external constraint on charm!
- ZEUS $126\,\mathrm{pb}^{-1}$ without constraint



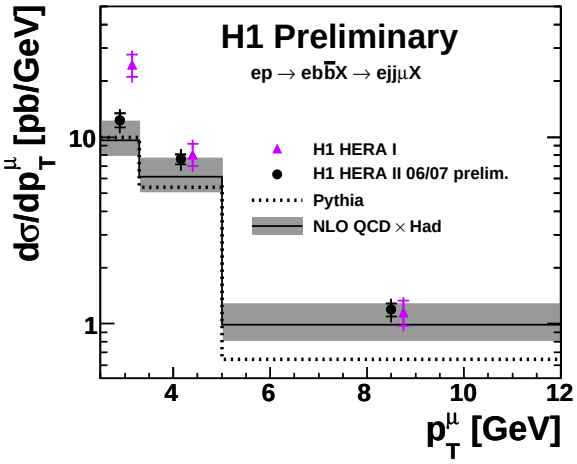
Data: $\mathcal{L} = 170\,\mathrm{pb}^{-1}$

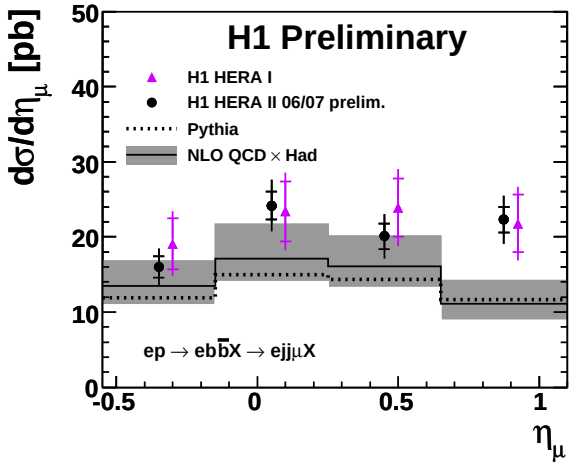
- Dijet PhP events with $p_T^{jet} > 7(6)\,\mathrm{GeV}$
- Semileptonic decays to muons
  - $-0.55 < \eta^{\mu} < 1.1$
  - $p_t^{\mu} > 2.5\,\mathrm{GeV}$
- Simultaneous fit of impact parameter and p_t^{rel}

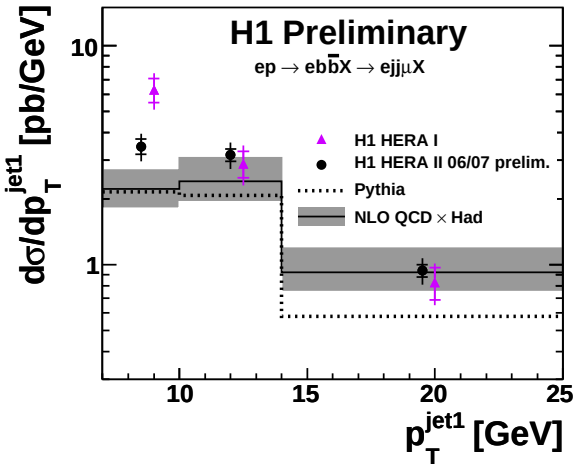


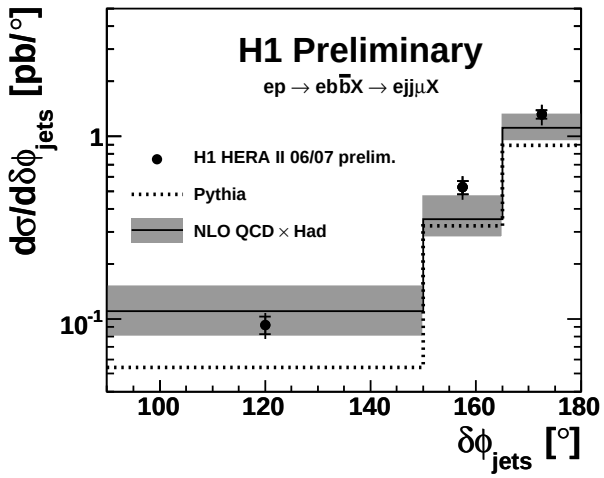


Beauty in Dijet Photoproduction using muons H1









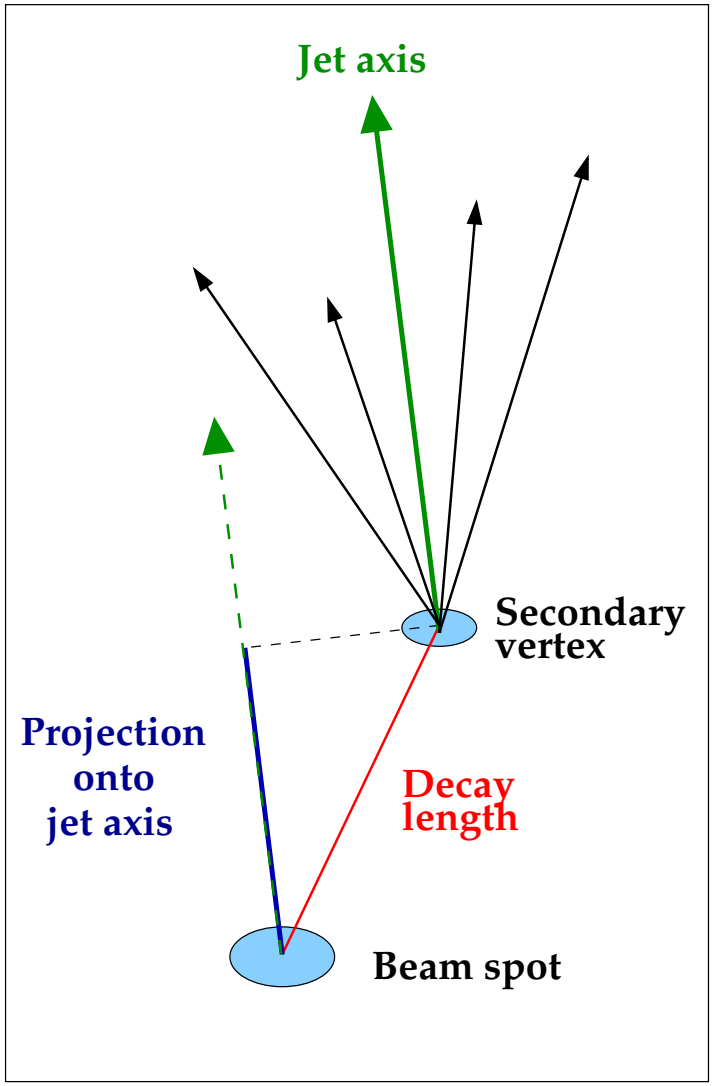
- Good agreement between Data and NLO predictions
- Shapes well-described by Pythia MC
- New measurement closer to NLO prediction than previous HERA I result

Beauty in PhP using incl. secondary vertexing

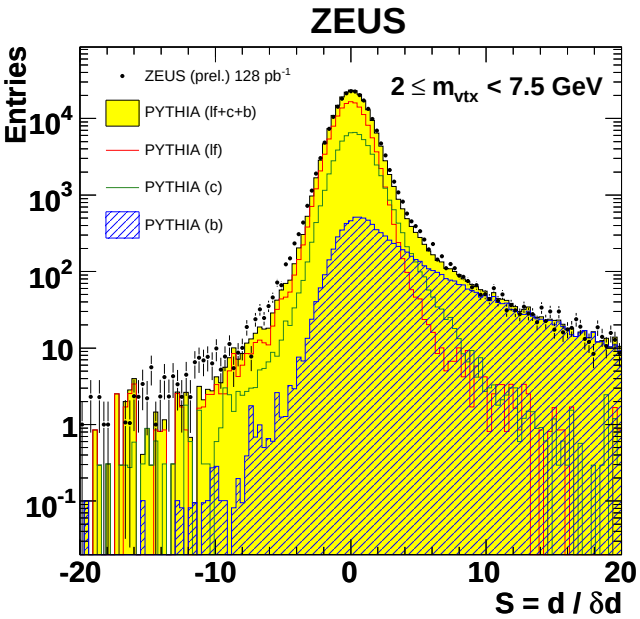
ZEUS

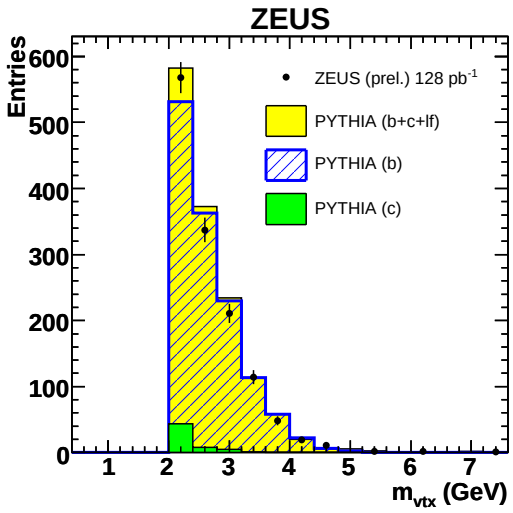
Data: $\mathcal{L} = 128\,\mathrm{pb}^{-1}$

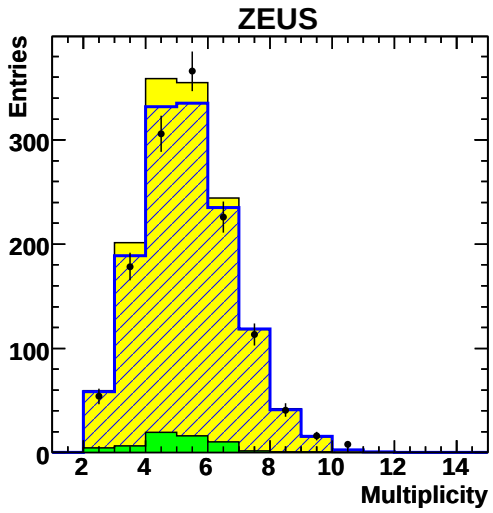
- Dijet PhP events with $p_T^{jet} > 7(6)\,\mathrm{GeV}$
- No specific B decay channel
  $\longrightarrow$ Inclusive measurement
- Secondary vertexing:
  - Associate tracks to jets and fit secondary vertices
  - Calculate 2D decay length as distance between beam spot and secondary vertex in x-y (projected onto jet axis)



Beauty in PhP using incl. secondary vertexing ZEUS





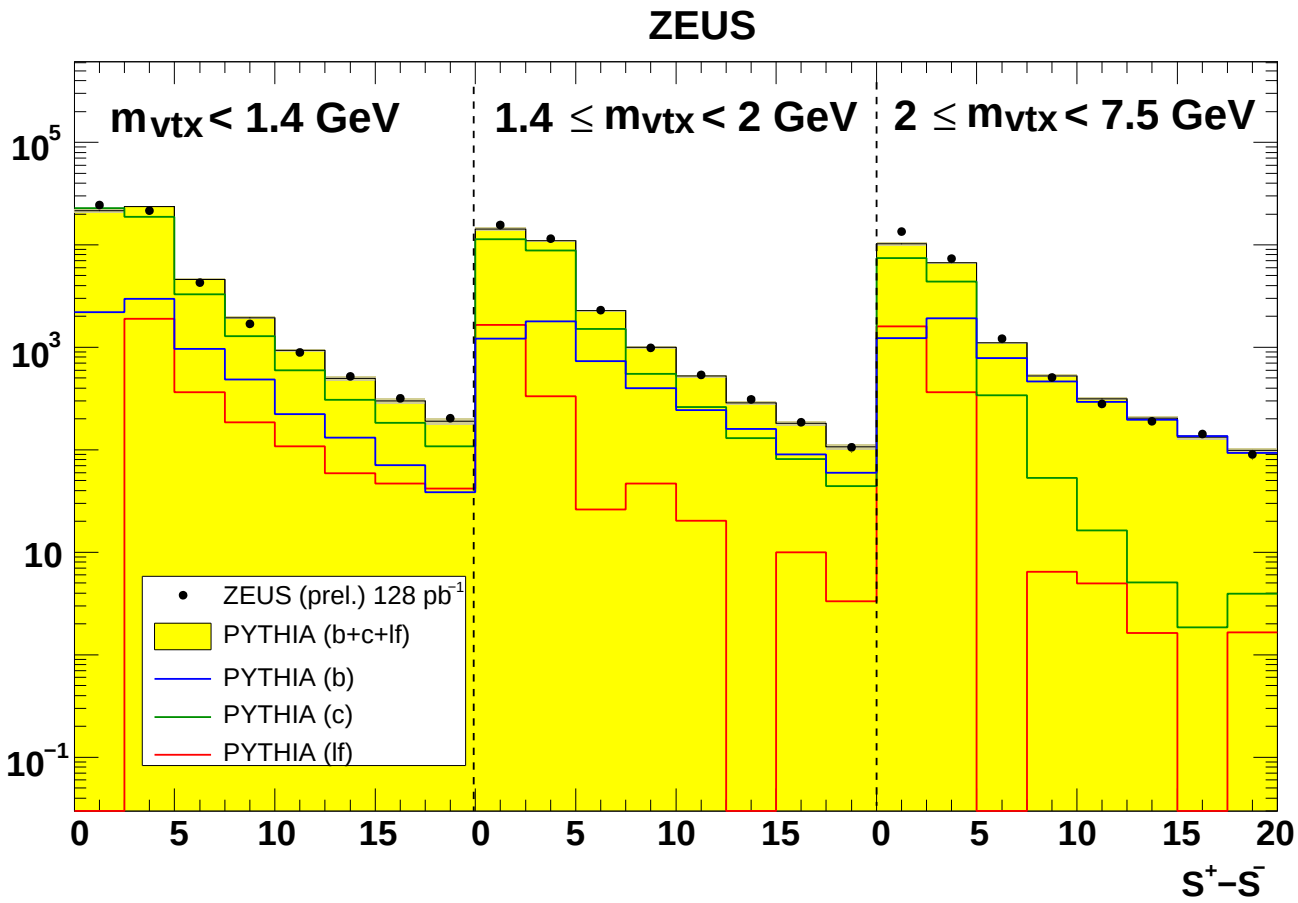


- Decay length significance $S = DL/\delta DL$
- For large m_{vtx} dominated by beauty
  $\longrightarrow$ With cuts on S and m_{vtx} an almost **pure beauty sample** can be obtained!

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

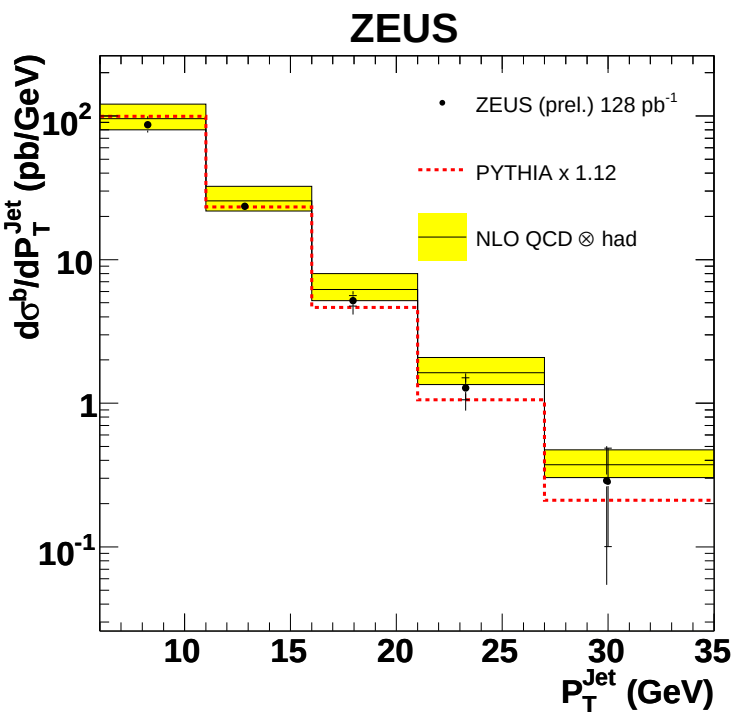
Beauty in PhP using incl. secondary vertexing

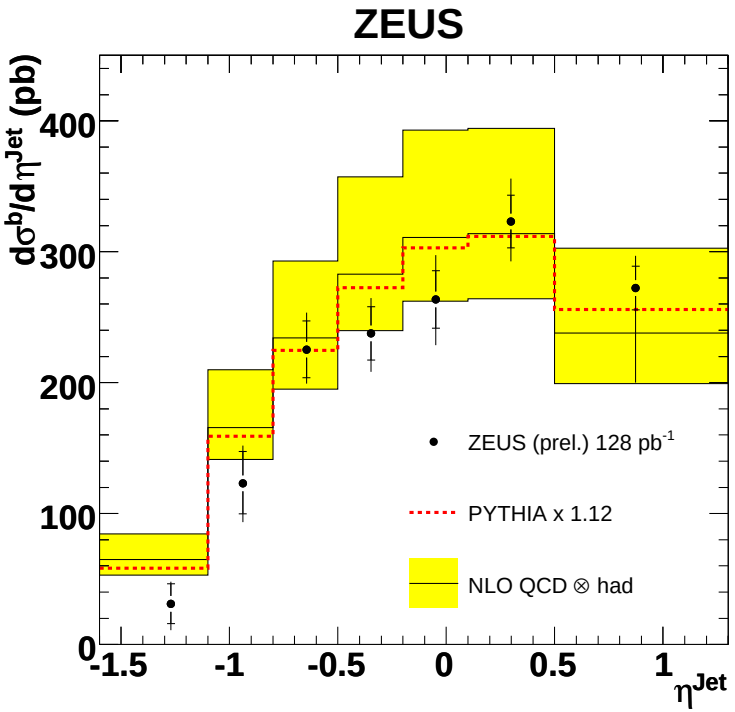
ZEUS



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

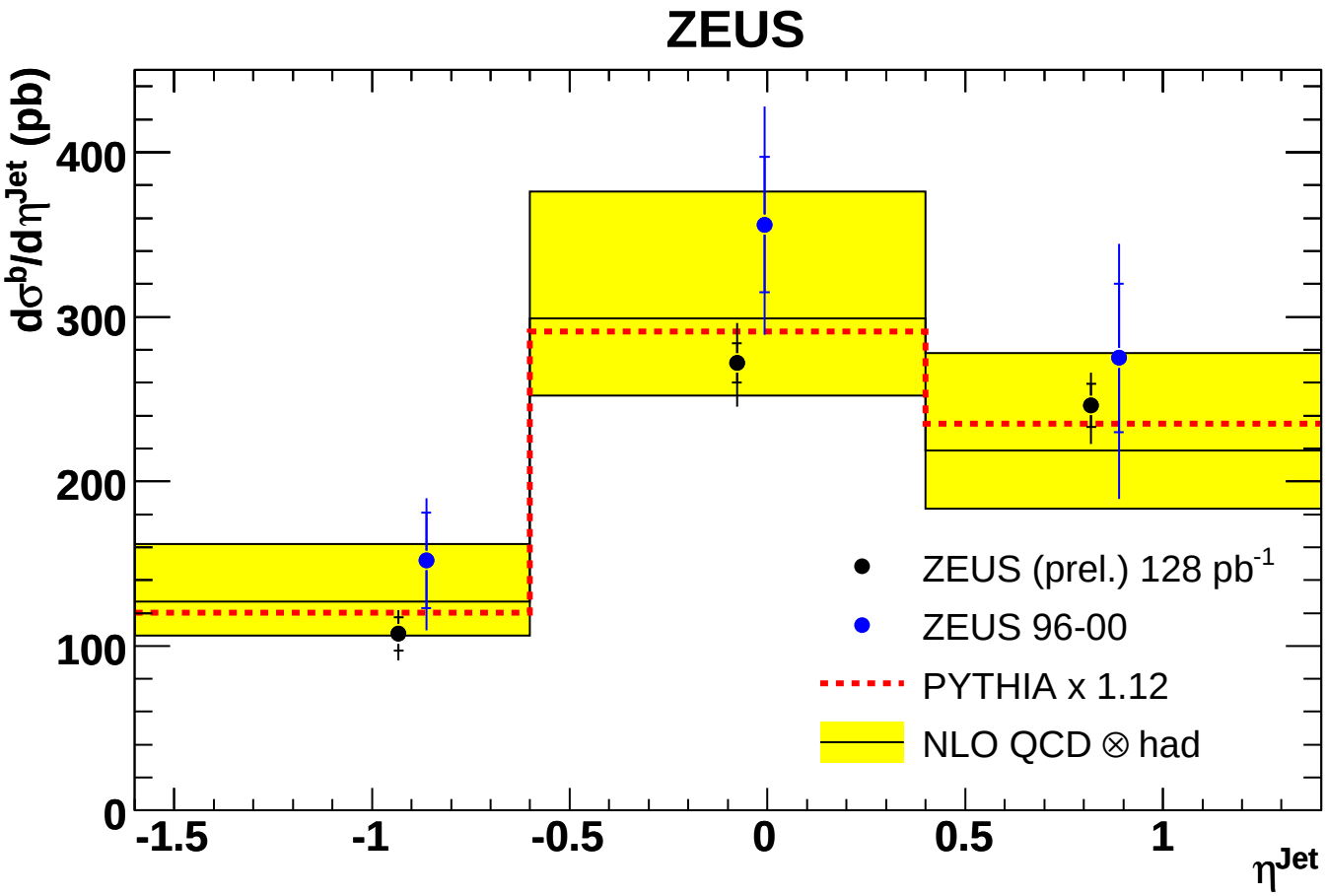
Beauty in PhP using incl. secondary vertexing ZEUS





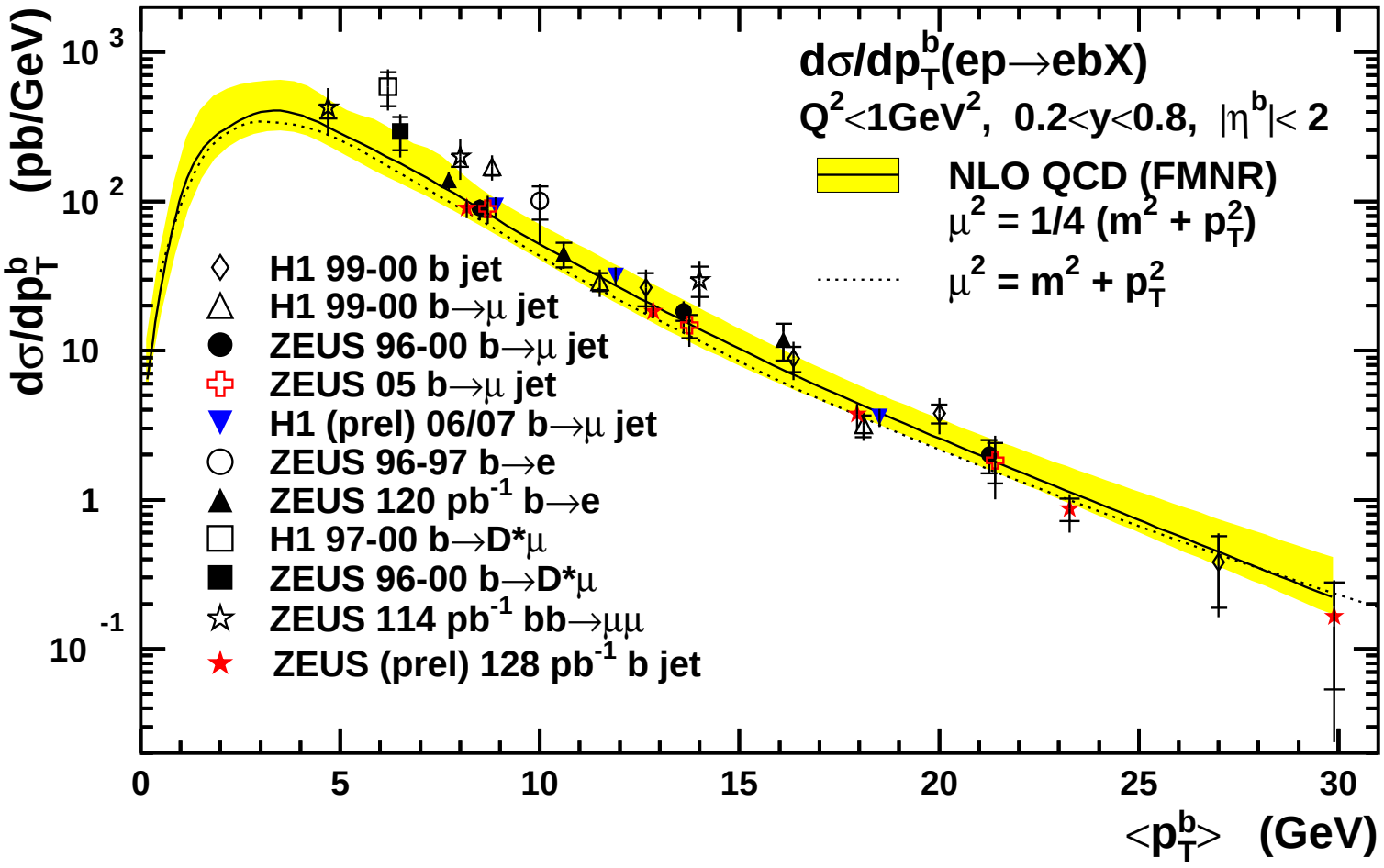
- Differential cross-sections in $\mathrm{P_T^{Jet}}$ and η^{Jet}
- Good agreement between Data and Pythia / NLO predictions (FMNR)

Beauty in PhP using incl. secondary vertexing ZEUS



- New measurement in good agreement with previous HERA I result
- Statistical error substantially reduced

HERA


dσ/dp_T^b (pb/GeV)
10^3
10^2
10
1
10^-1
dσ/dp_T^b(ep→ebX)
Q^2<1GeV^2, 0.2<y<0.8, |η^b|< 2
NLO QCD (FMNR)
μ^2 = 1/4 (m^2 + p_T^2)
μ^2 = m^2 + p_T^2
H1 99-00 b jet
H1 99-00 b→μ jet
ZEUS 96-00 b→μ jet
ZEUS 05 b→μ jet
H1 (prel) 06/07 b→μ jet
ZEUS 96-97 b→e
ZEUS 120 pb^-1 b→e
H1 97-00 b→D*μ
ZEUS 96-00 b→D*μ
ZEUS 114 pb^-1 bb→μμ
ZEUS (prel) 128 pb^-1 b jet
0
5
10
15
20
25
30
<p_T^b> (GeV)

Summary

- Latest results of heavy flavour photoproduction at HERA presented
- HERA II data provide large increase in statistics
- New methods used and improved (lifetime tagging)
- First ZEUS analysis with inclusive secondary vertexing presented

- Various H1 and ZEUS measurements using different experimental techniques in very good agreement
- General agreement with NLO QCD predictions

BACKUP

Beauty in PhP - double tag

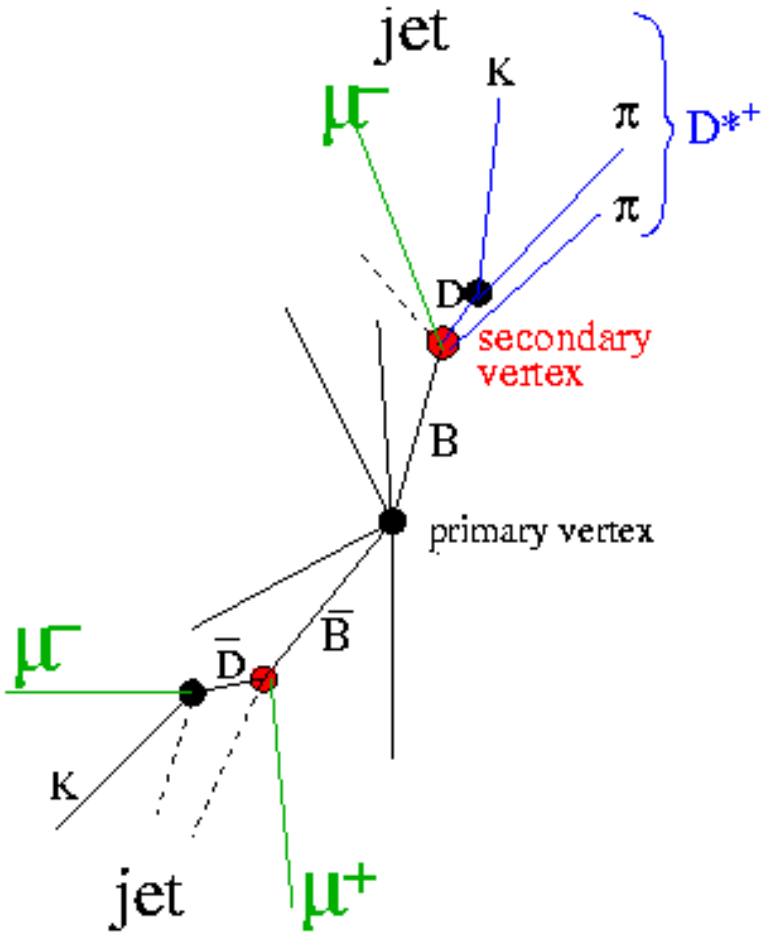
ZEUS

Data: Hera I ($\mathcal{L} = 114\,\mathrm{pb}^{-1}$)
LO: Pythia + Rapgap
NLO: FMNR

- PhP and DIS
- Two identified muons in the final state
- Extract b fraction from difference between unlike-sign and like-sign distributions

Advantages:

- No jet requirements
- Low p_t^{μ} thresholds
- Measure bb correlations

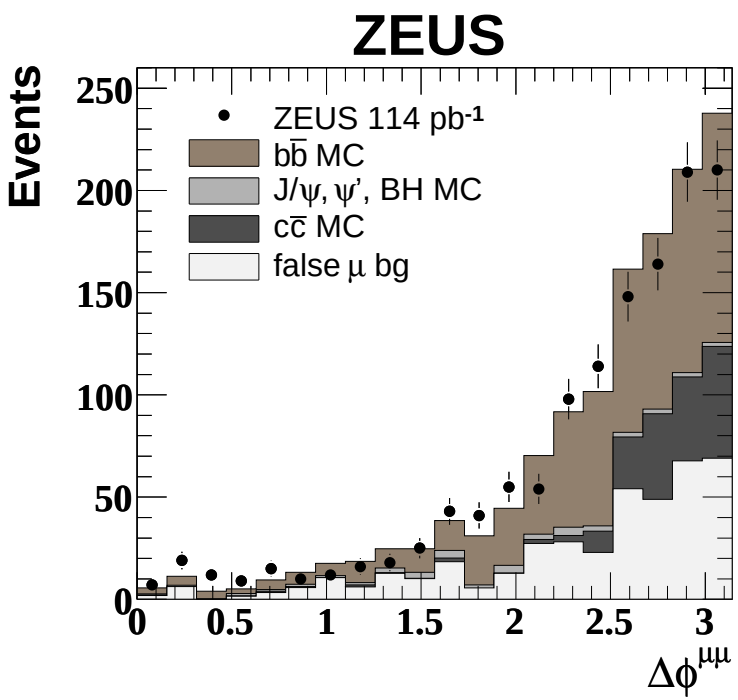


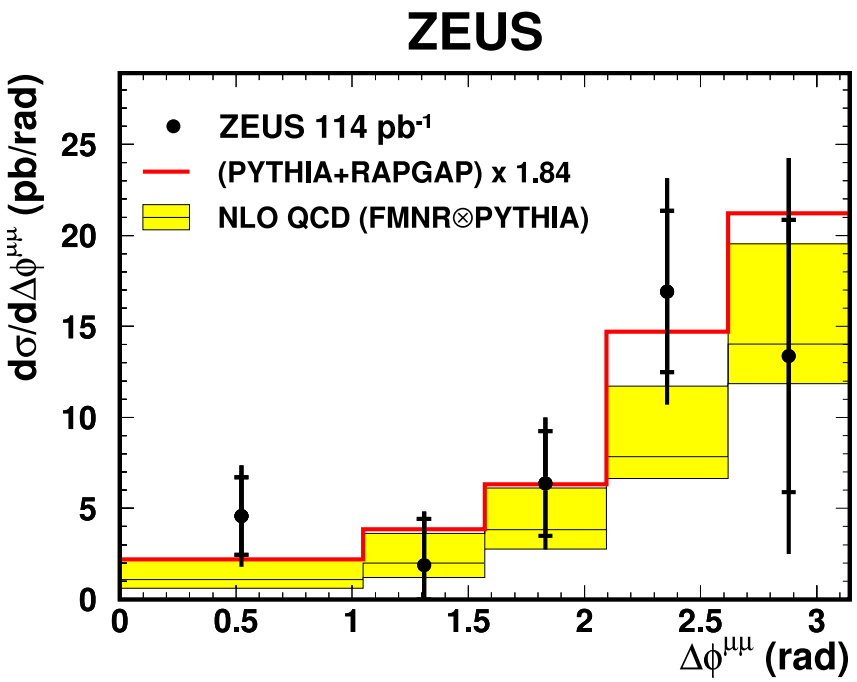
Method

- Sample split into different charge combinations
- 2 muons from same b quark
  $\longrightarrow$ Unlike-sign muon pair
- 2 muons from different b quarks
  $\longrightarrow$ Like-sign or unlike-sign muon pair
- Use difference between unlike-sign and like-sign distributions to extract beauty contribution
  $\longrightarrow$ Almost free from false-muon background
  $\longrightarrow$ Other background sources: Charm, heavy vector mesons, Bethe-Heitler

Beauty in PhP - double tag

ZEUS





- $\Delta\phi^{\mu\mu}$ = angle between muons from different quarks
- Correlations expected to show higher order effects
  $\rightarrow$ Good description, but large uncertainties