Beauty Production at HERA

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for the H1 and ZEUS Collaborations

LOWX2011

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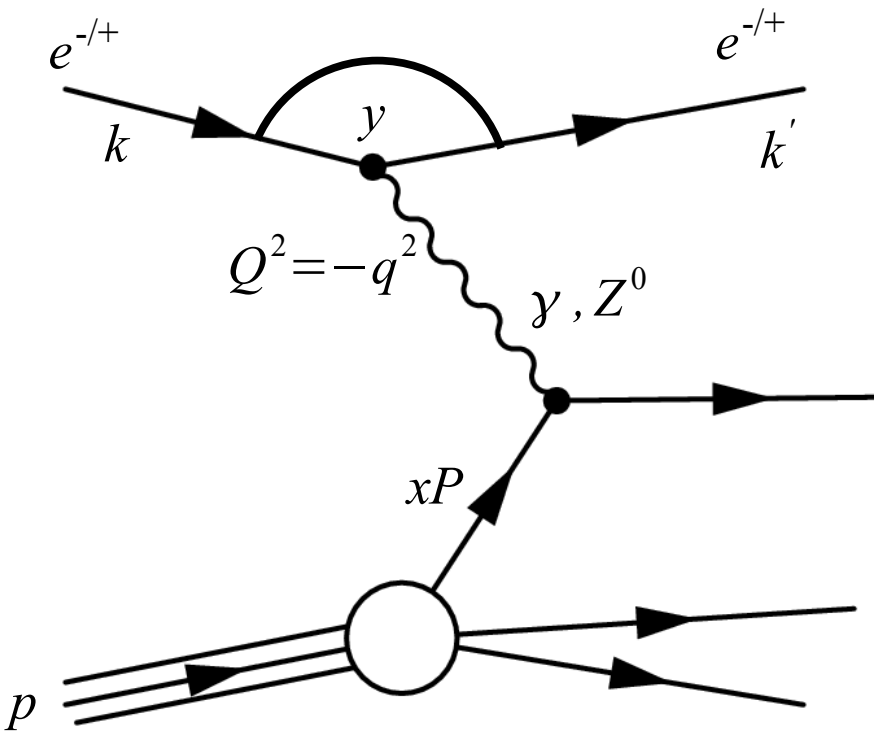
Kinematics at HERA

Kinematic Quantities:

- Center of mass Energy squared: $s=(P+k)^2$
- Photon virtuality: $Q^2=-q^2=(k-k')^2$
- Inelasticity: $y=\frac{Pq}{Pk}$
- Bjorken Variable: $x=\frac{Q^2}{2Pq}$

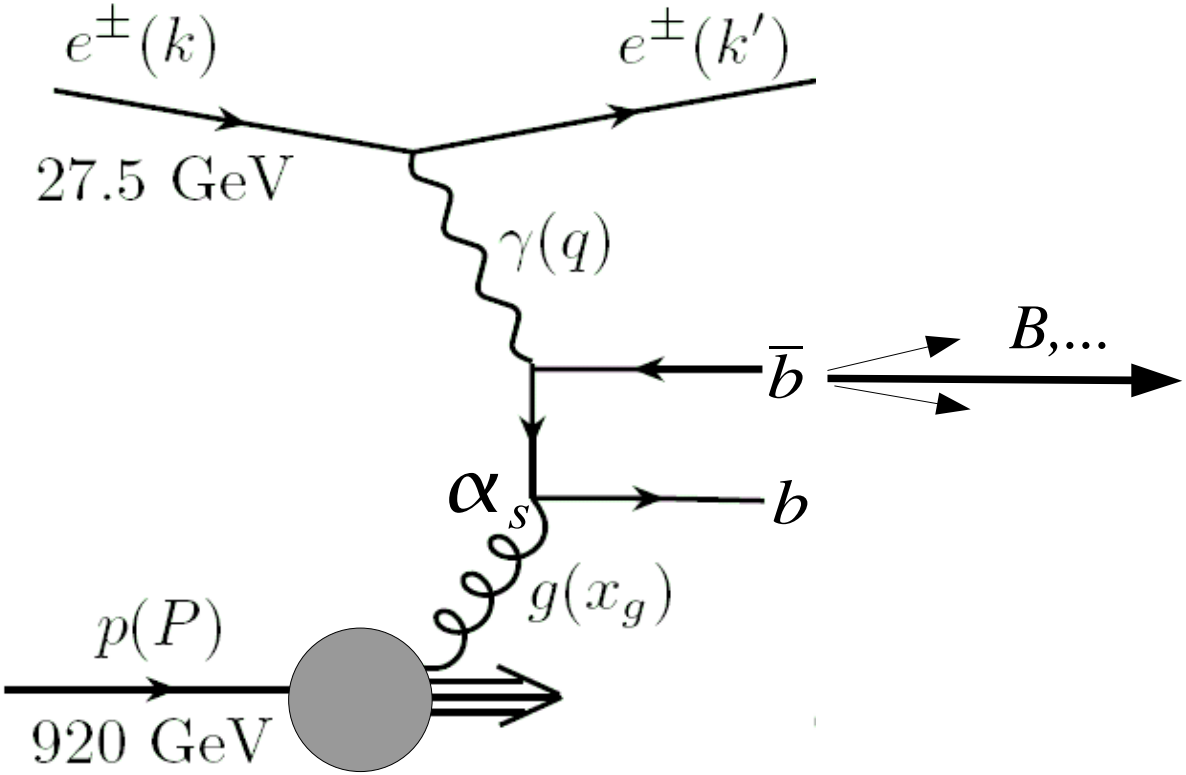


Kinematic Regimes:

- $Q^2 \approx 0\, GeV^2$: Photoproduction (PHP)
- $Q^2 \geq 1\, GeV^2$: Deep inelastic scattering (DIS)

Production of Beauty Quarks

- Predominantly via boson gluon fusion
- Always hard scale given by mass (in addition to Q^2, p_t^2, ...)
- Problem in pQCD with more than one hard scale → need different schemes in pQCD to consider scales

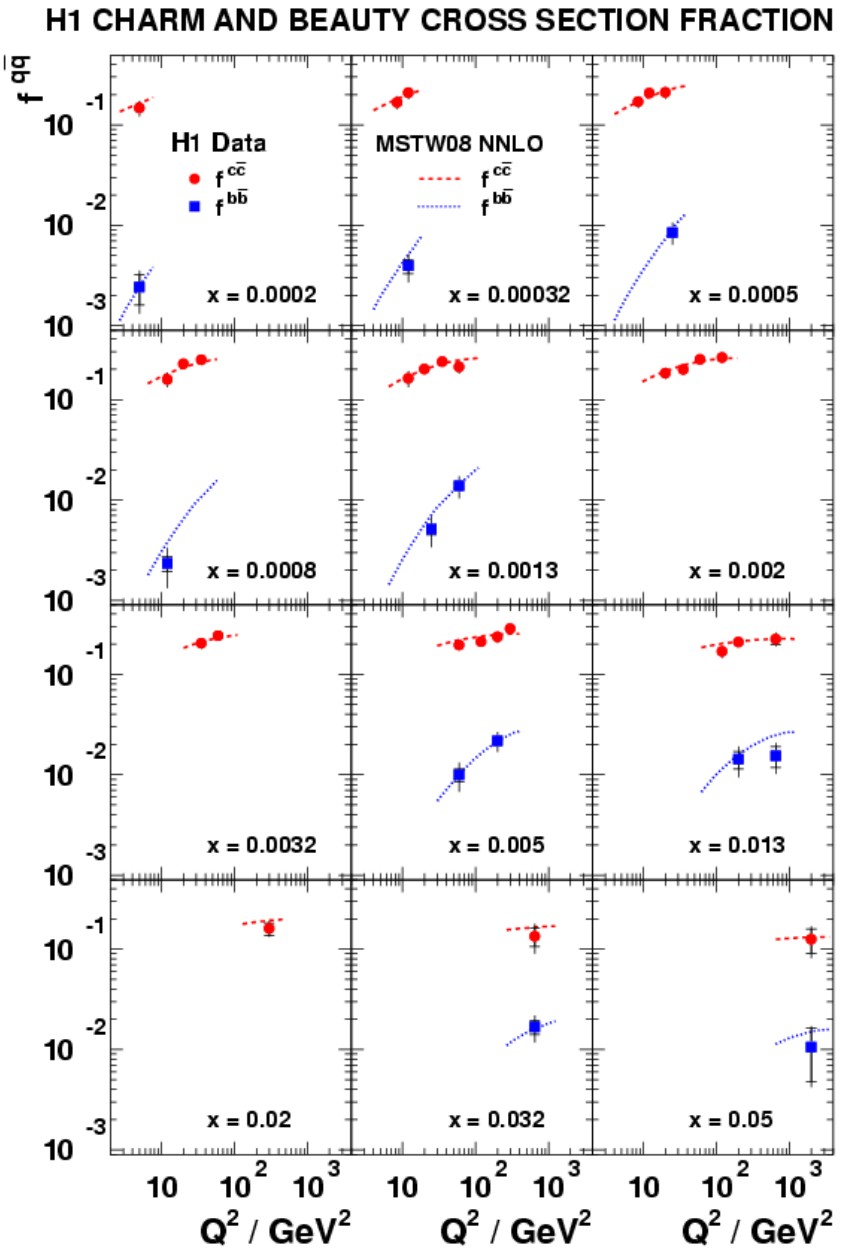


QCD factorisation:

$$\sigma_B \propto \text{PDF} \otimes \text{hard ME} \otimes \text{fragmentation}$$

Beauty Contribution to the total Cross Section

- Fractions shown here from a H1 lifetime tag analysis
- Beauty fraction of total cross section only 0.001 – 0.01
- Beauty analyses at HERA statistically limited (cross section measurements via full reconstruction of B hadrons not possible)



Eur.Phys.J.C65:89-109,2010

Methods for Beauty Tagging

Semileptonic decay:

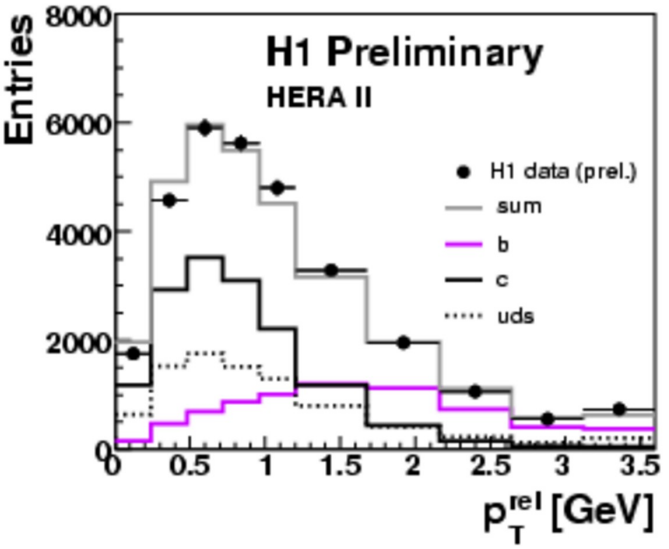
- Reconstruction of decay leptons with particle identifikation

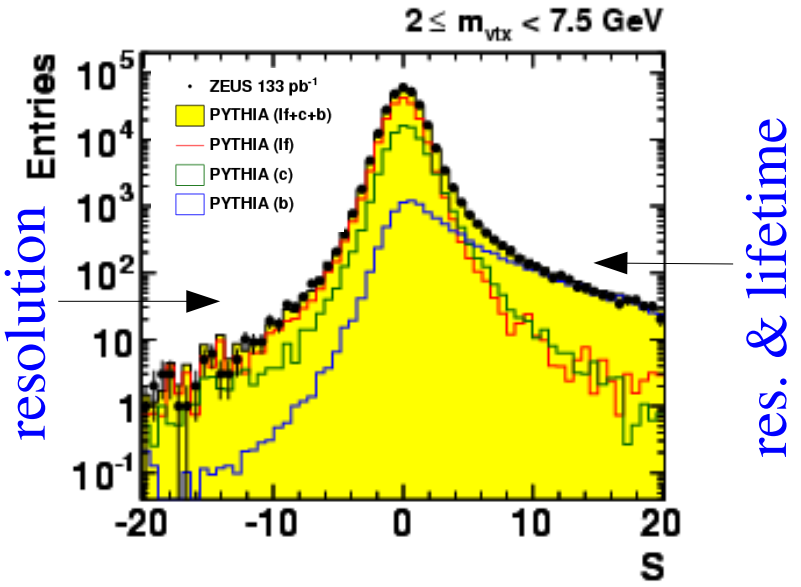
Large Mass:

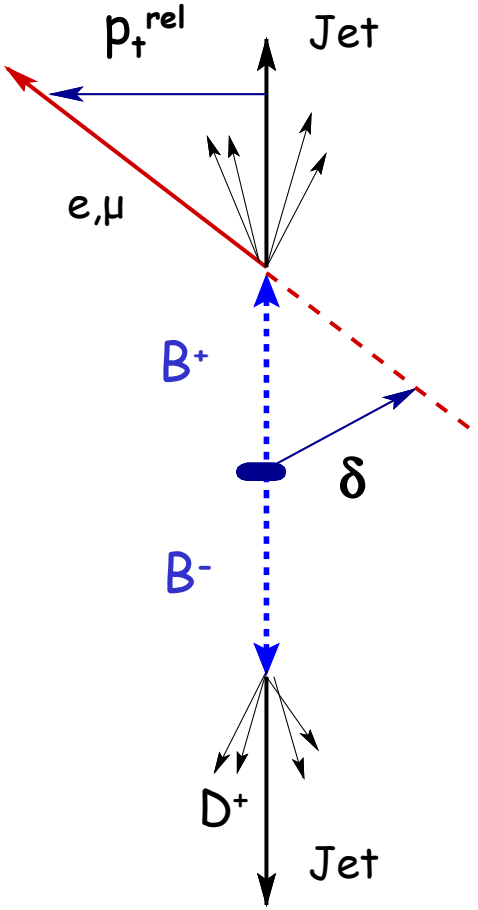
- Make use of mass effects of b quark: decay leptons with high p_t^{rel}(lepton,jet), high m_{jet},...

Long lifetime:

- Reconstruct secondary vertex and use decay length significance: $S_d=d/\sigma_d$
- Impact parameter significance of displaced tracks $S_\delta=\delta/\sigma_\delta$







Beauty in PHP at low $p_t(b)$

$\mathscr{L}$=46 pb^{-1}

$Q^2 < 1$ GeV^2, $0.2 < y < 0.8$
$|\eta(b,\bar{b})| < 2$

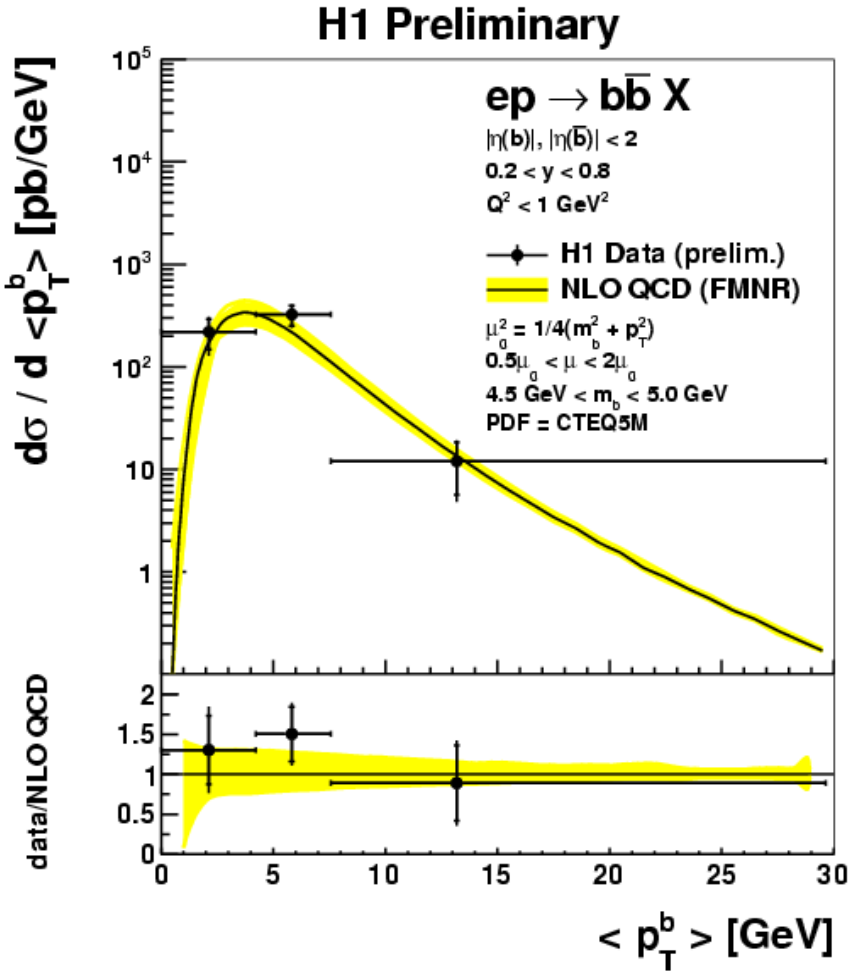
H1-prel-11-071

Tagging of beauty:

- Reconstruct two low p_t electrons from semileptonic decays (1 GeV < p_t^e < 5 GeV)
- Analysis possible due to very good electron identification at all (π misidentification rate only a few per mille !)

➔ Access to lowest $p_t(b)$ values ever measured in ep

➔ Agreement betweeen data and NLO calculation (FMNR)



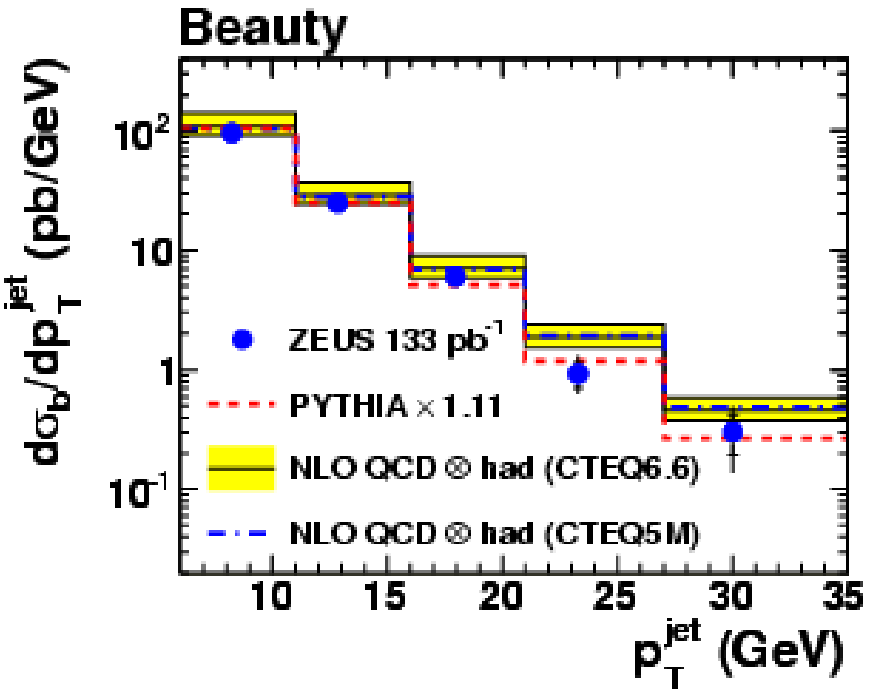
Beauty in PHP using Secondary Vertex

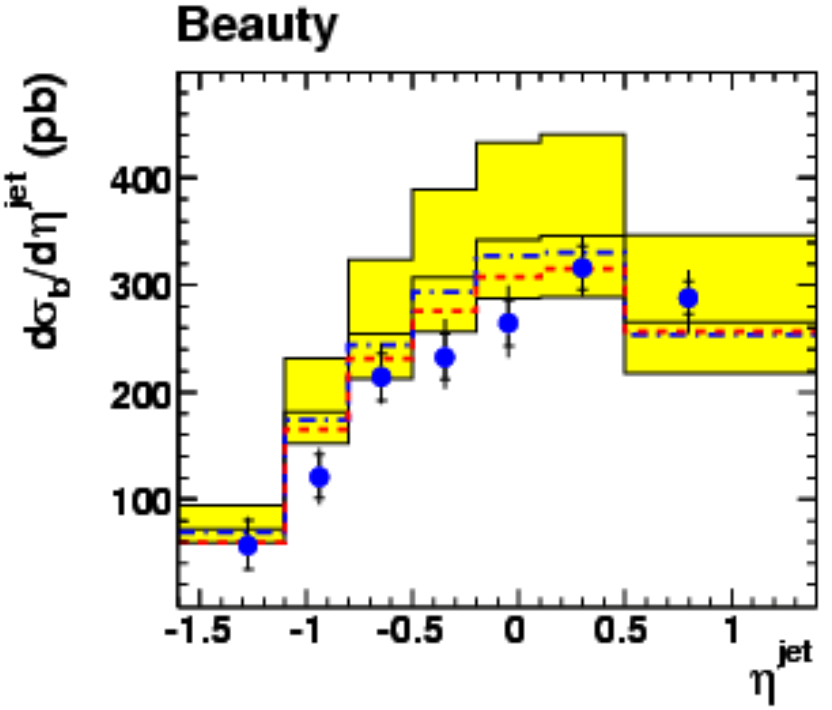
- Reconstruction of secondary vertices (belonging to jet)
- Use decay length significance and invariant mass of tracks

$\mathscr{L} = 133\ \text{pb}^{-1}$

$Q^2 < 1\ \text{GeV}^2,\ 0.2 < y < 0.8$
$p_t^{jet} > 7(6)\ \text{GeV},\ |\eta^{jet}| < 2.5$

DESY-11-067



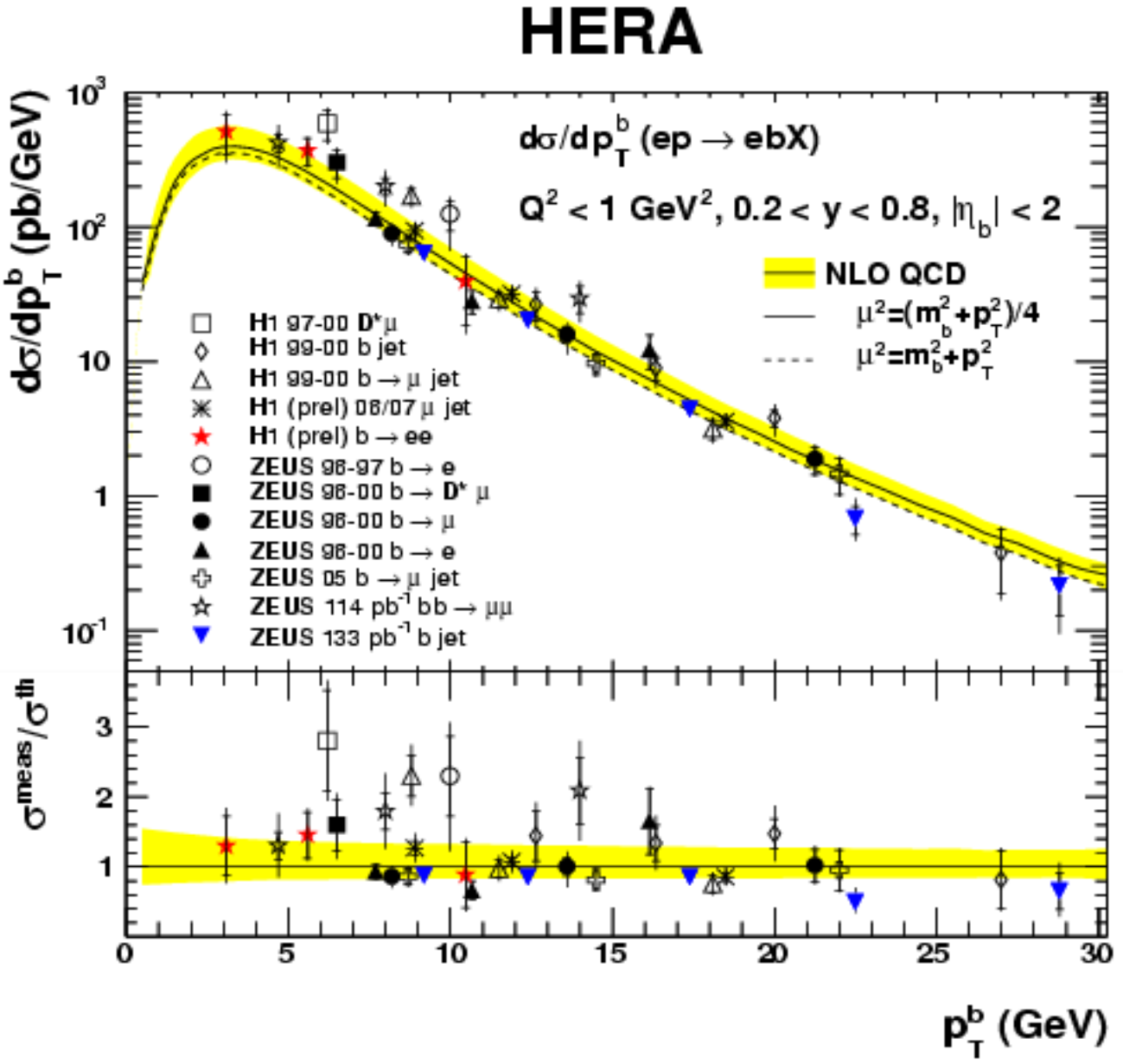


➔ Predicted Cross sections from NLO QCD calculation (FMNR) in p_T^{jet} and η^{jet} in agreement with data

➔ Theoretical uncertainties larger than experimental ones

Beauty in PHP

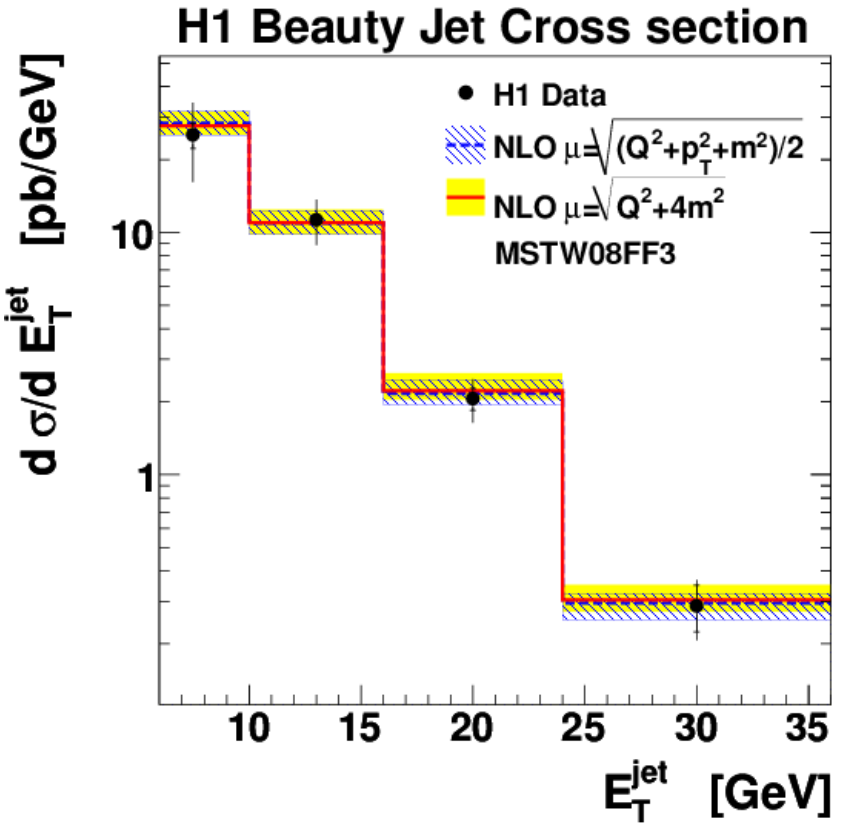
- Measurements consistent with each other over a wide $p_t(b)$ range
- In general good agreement between data and NLO calculation (FMNR)

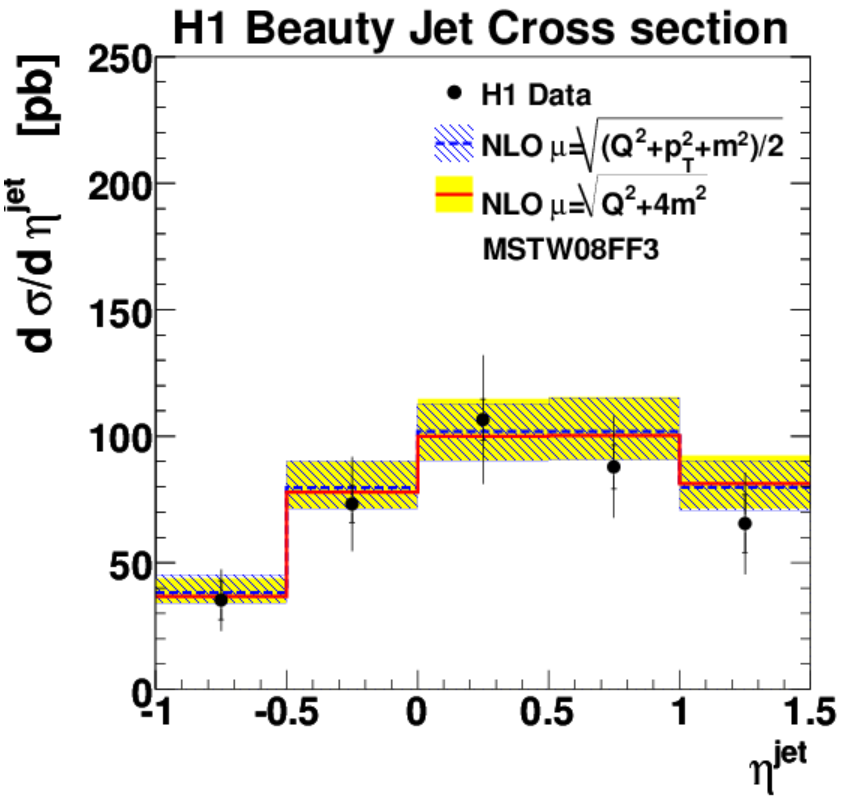


Beauty Jets in DIS

$\mathscr{L} = 189\ \text{pb}^{-1}$ | $Q^2 > 6\ \text{GeV}^2$, $0.07 < y < 0.6$ | $E_t^{jet} > 6\ \text{GeV}$, $-1 < \eta^{jet} < 1.5$ | Eur.Phys.J.C71: 1509,2011

- Use sensitivity to lifetime
- Compare data with NLO calculation HVQDIS





→ NLO QCD calculation describes data well for both scales

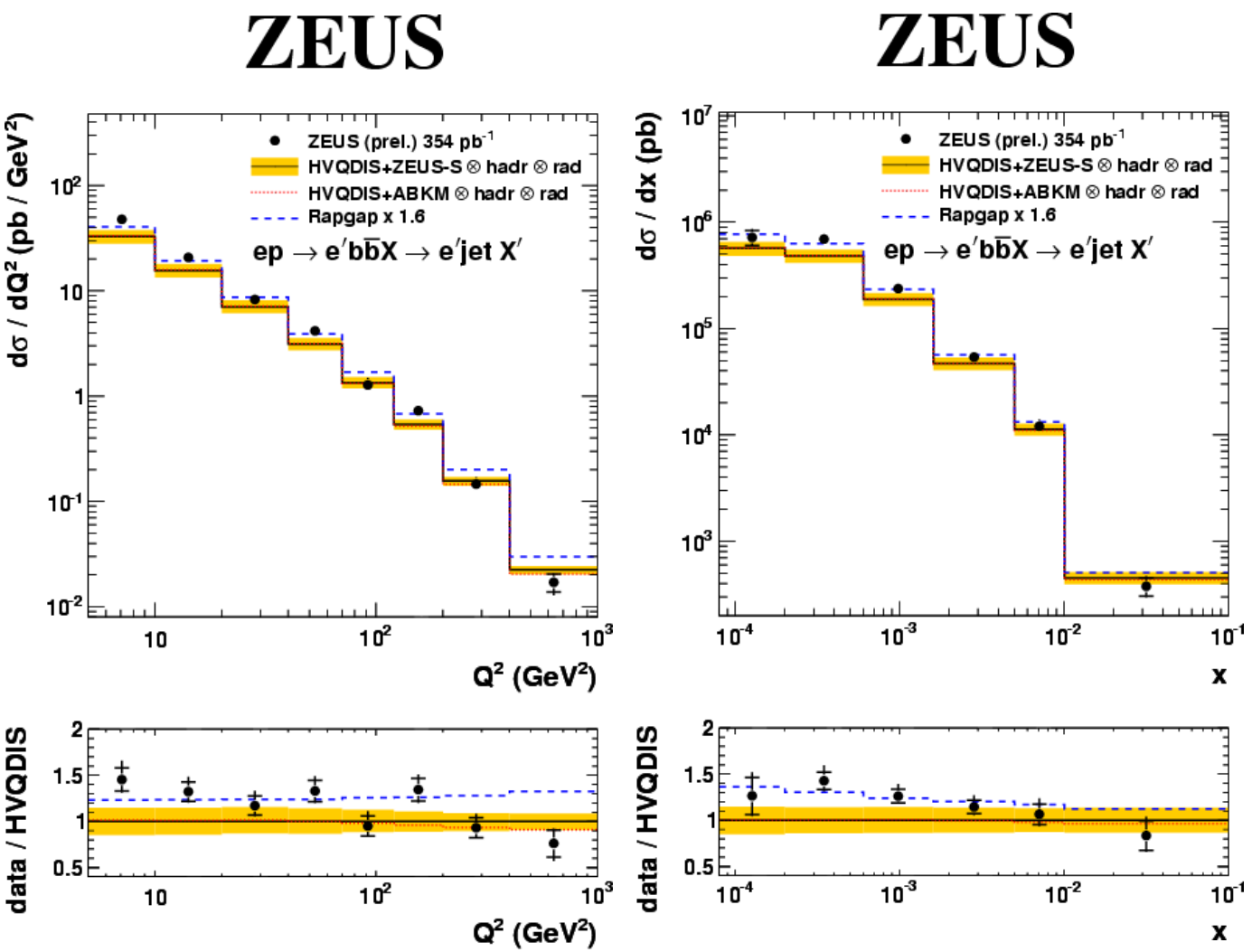
Beauty in DIS using Secondary Vertex

$\mathcal{L}$=354 pb^{-1} | $5 < Q^2 < 1000$ GeV^2 , $0.02 < y < 0.7$ | $E_t^{jet} > 5$ GeV, $-1.6 < \eta^{jet} < 2.2$

ZEUS-prel-10-004

- Compare data with LO MC RAPGAP and NLO calculation HVQDIS

➔ Reasonable agreement with NLO QCD (except low Q^2 and low x)



Beauty in DIS using b → e Decays

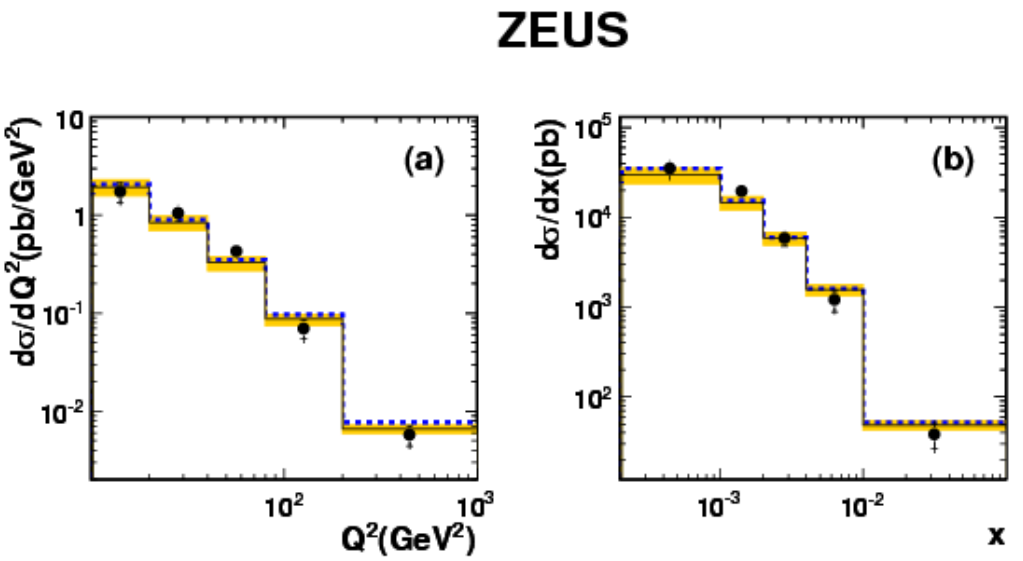
$\mathscr{L}$=363 pb^{-1}

$Q^2 > 10$ GeV^2, $0.05 < y < 0.7$
$0.9 < p_t^e < 8$ GeV , $|\eta^e| < 1.5$

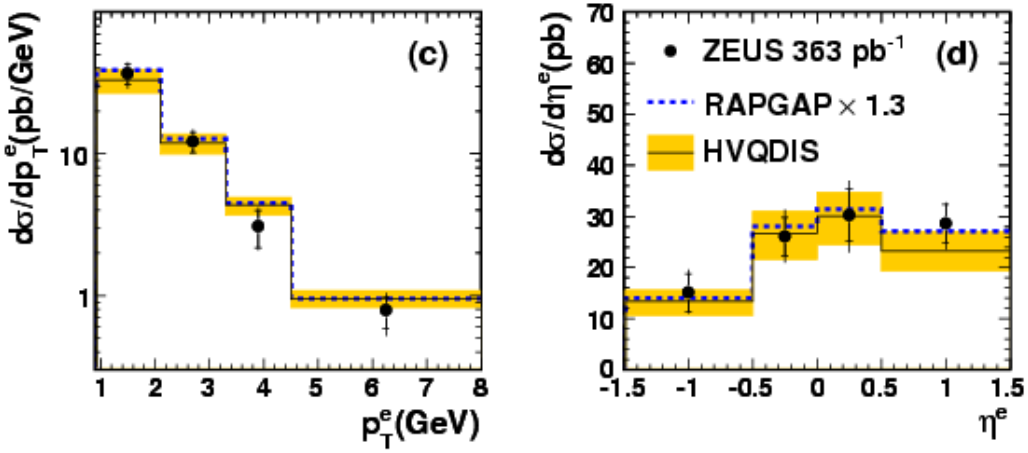
ZEUS: DESY-11-005

Tagging of beauty:

- Reconstruction of a jet (p_t^{jet}>2.5 GeV) together with secondary vertex
- Requirement of electron candidate associated with the jet (p_t^{jet}>2.5 GeV)



- Good agreement between data and NLO QCD calculation (HVQDIS) observed
- Also LO + PS MC RAPGAP describes data well in shape



Beauty in DIS using b → μ Decays

$\mathcal{L}$=114 pb^{-1}

$Q^2 > 2$ GeV^2, $0.05 < y < 0.7$

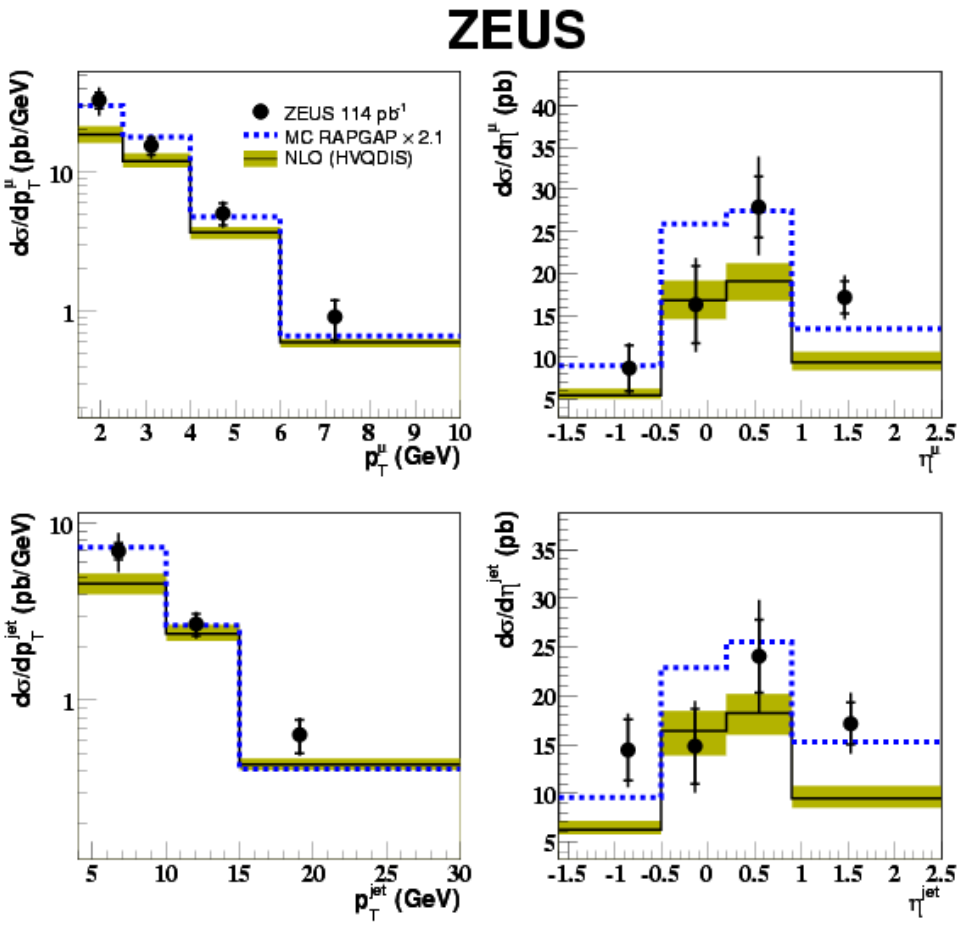
$E_t^{jet} > 5$ GeV $-2 < \eta^{jet} < 2.5$

$p_t^{\mu} > 1.5$ GeV , $\eta^{\mu} > -1.6$, belonging to jet

ZEUS: DESY-10-047

Tagging of beauty:

- Reconstruction of a jet ($p_t^{jet} > 5$ GeV)
- Requirement of a muon candidate in cone of $\Delta R < 0.7$ around jet axis



➔ Reasonable agreement between data and NLO QCD calculation (HVQDIS) within errors

Beauty Structure Function F_2^{bb}

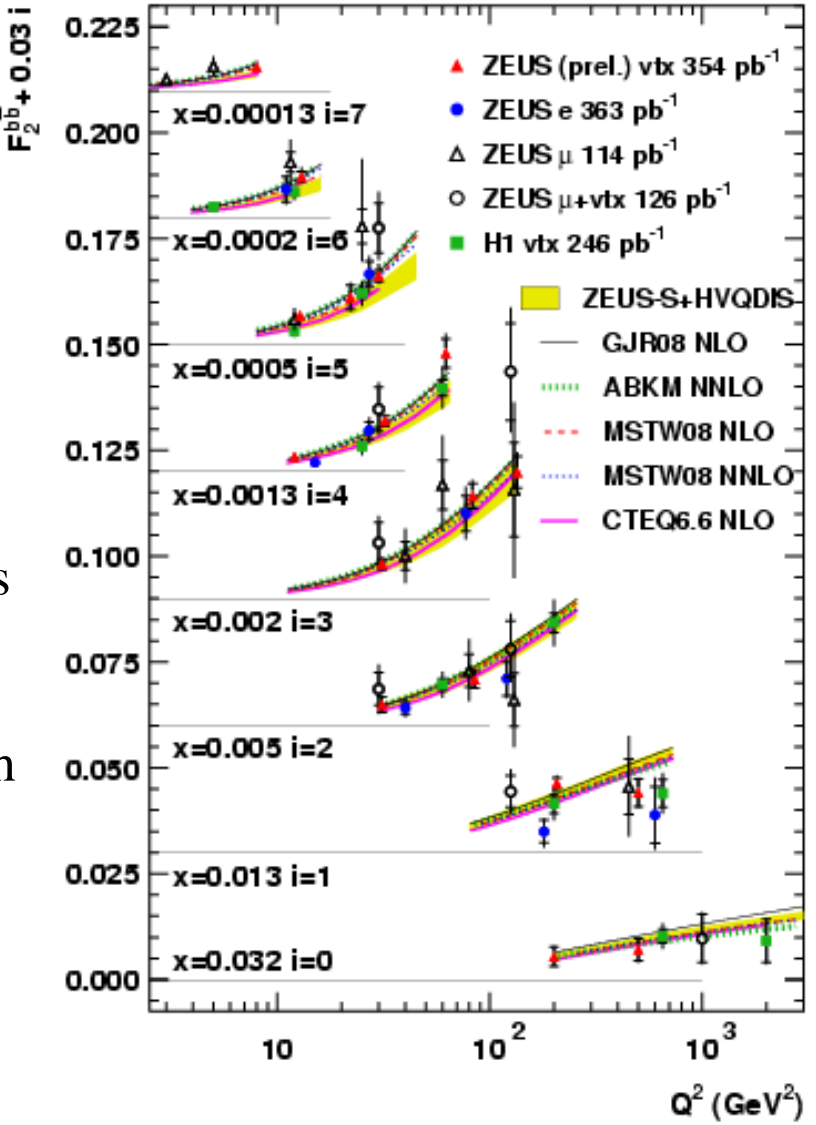
- One way to summarize beauty measurements
- Definition of F_2^{bb}:

Contribution of F_L^{bb} small !

$$\frac{d^2\sigma^{b\bar{b}}}{dxdQ^2} = \frac{2\pi\alpha_{em}^2}{Q^4 x}\left[(1+(1-y)^2)F_2^{b\bar{b}}(x,Q^2) - y^2 F_L^{b\bar{b}}(x,Q^2)\right]$$

- Extracted from measured double differential cross sections
- Measurements consistent with each other and with NLO QCD predictions
- Gain in precision with HERAII - data

F_2^{bb} at HERA



Summary

- Beauty cross sections measured in PHP and DIS from different final states
- Measurements in good agreement with each other where for PHP differential cross sections in p_t^b and for DIS F_2^{bb} are compared
- Predictions from NLO QCD calculations describe measurements well