

Beauty Production at HERA



Martin Brinkmann, DESY
for the H1 and ZEUS Collaborations



LOWX2011

3rd - 7th June 2011

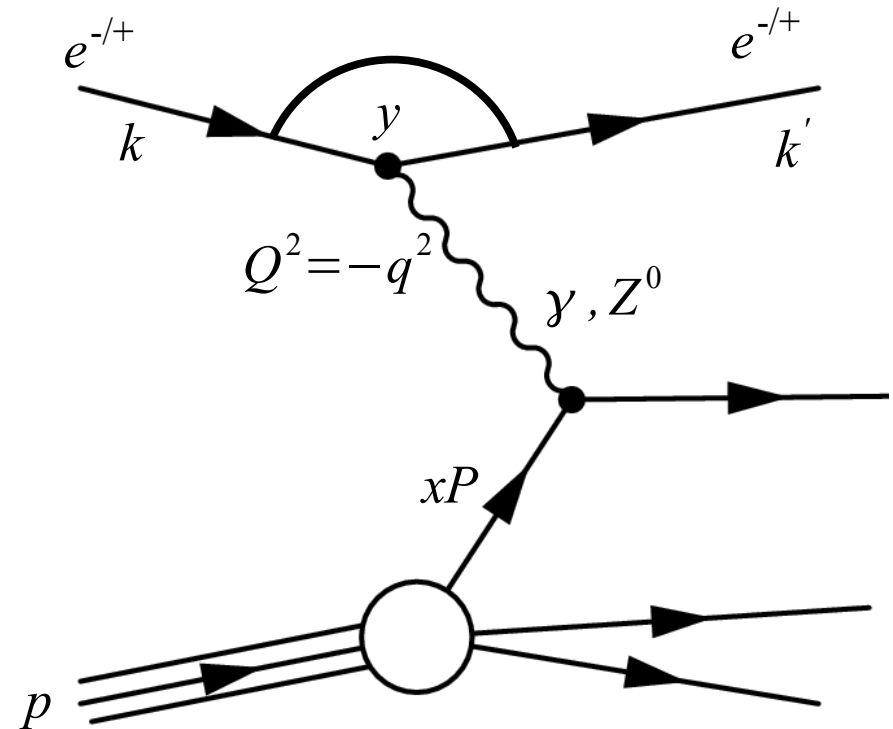


Kinematic Quantities:

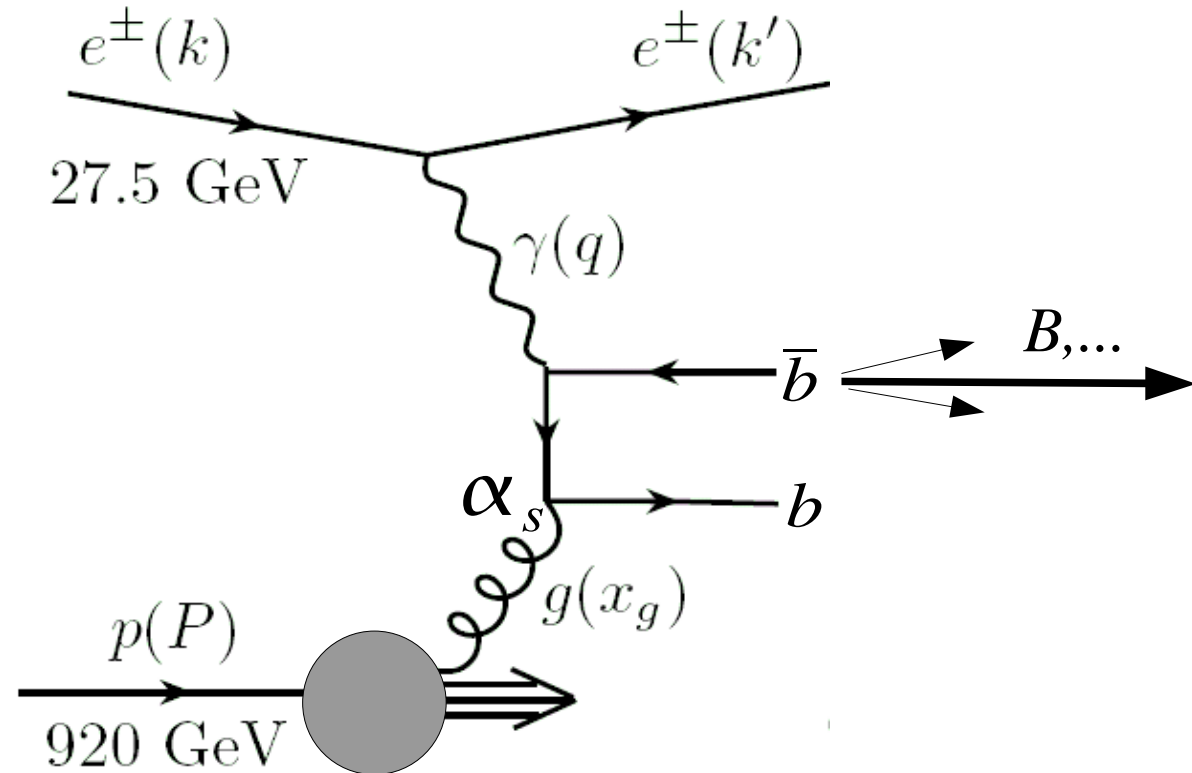
- Center of mass Energy squared: $s = (P + k)^2$
- Photon virtuality: $Q^2 = -q^2 = (k - k')^2$
- Inelasticity: $y = \frac{Pq}{Pk}$
- Bjorken Variable: $x = \frac{Q^2}{2Pq}$

Kinematic Regimes:

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



- 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 \rightarrow need different schemes in pQCD to consider scales



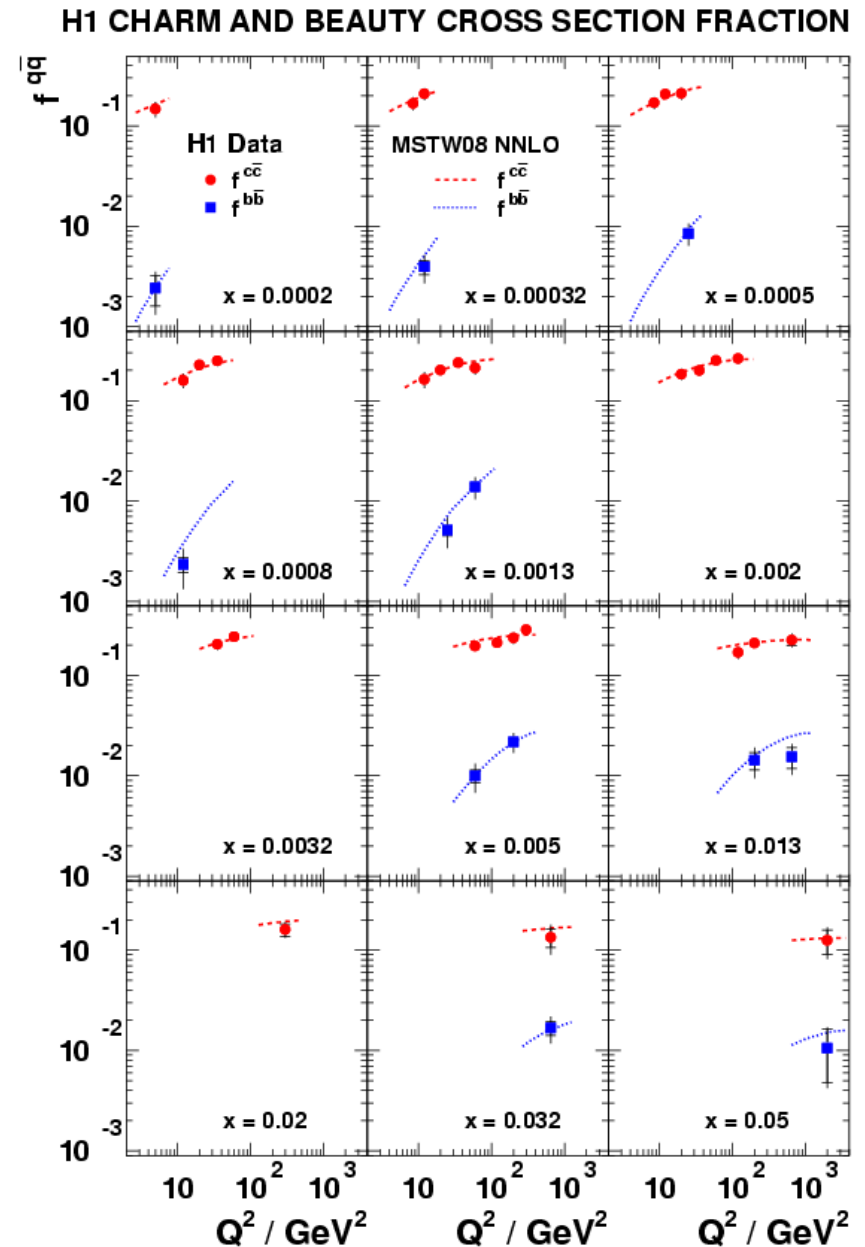
QCD factorisation:

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



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

Semileptonic decay:

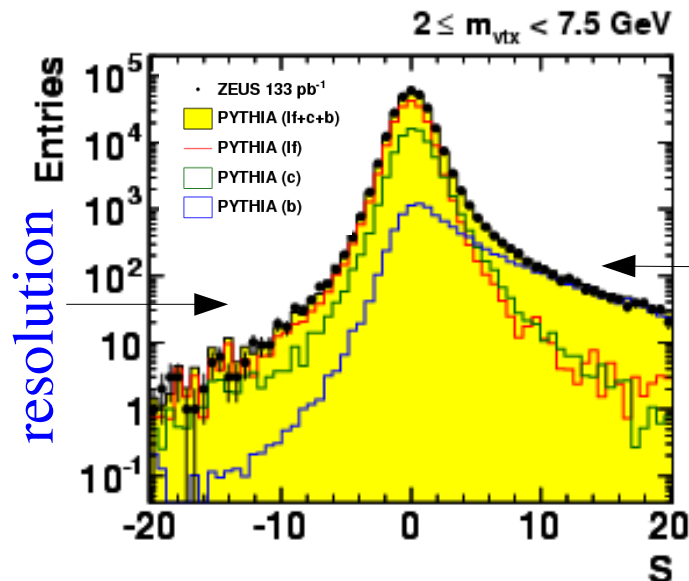
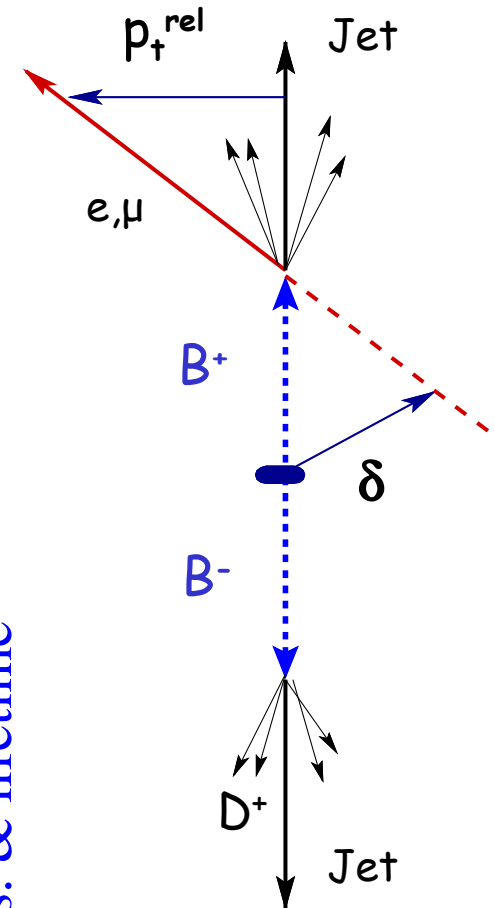
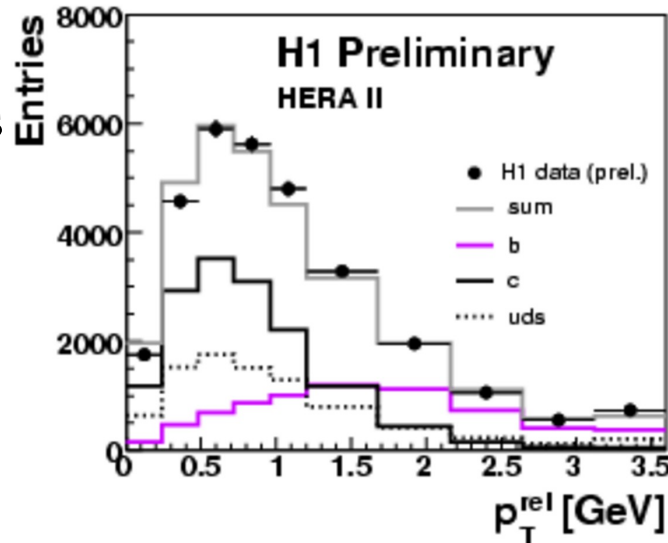
- Reconstruction of decay leptons with particle identification

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 $S_\delta = \delta/\sigma_\delta$



res. & lifetime



Beauty in PHP at low $p_t(b)$

$\mathcal{L} = 46 \text{ pb}^{-1}$

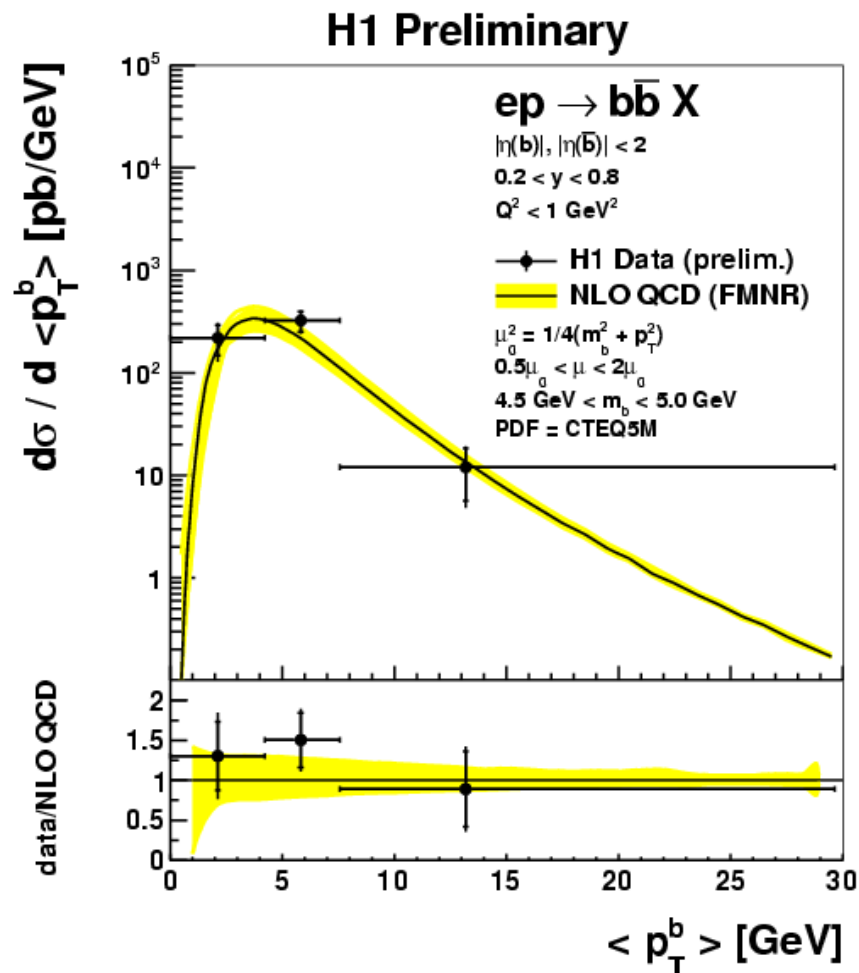
$Q^2 < 1 \text{ GeV}^2, 0.2 < y < 0.8$
 $|\eta(b, \bar{b})| < 2$

H1-prel-11-071

Tagging of beauty:

- Reconstruct two low p_t electrons from semileptonic decays ($1 \text{ GeV} < p_t^e < 5 \text{ GeV}$)
- 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 between data and NLO calculation (FMNR)



Beauty in PHP using Secondary Vertex

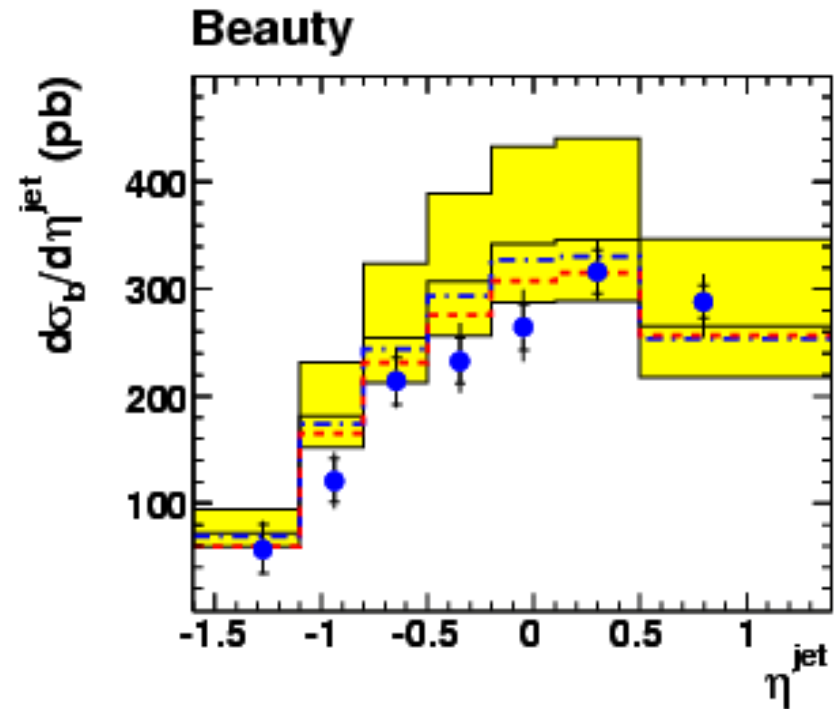
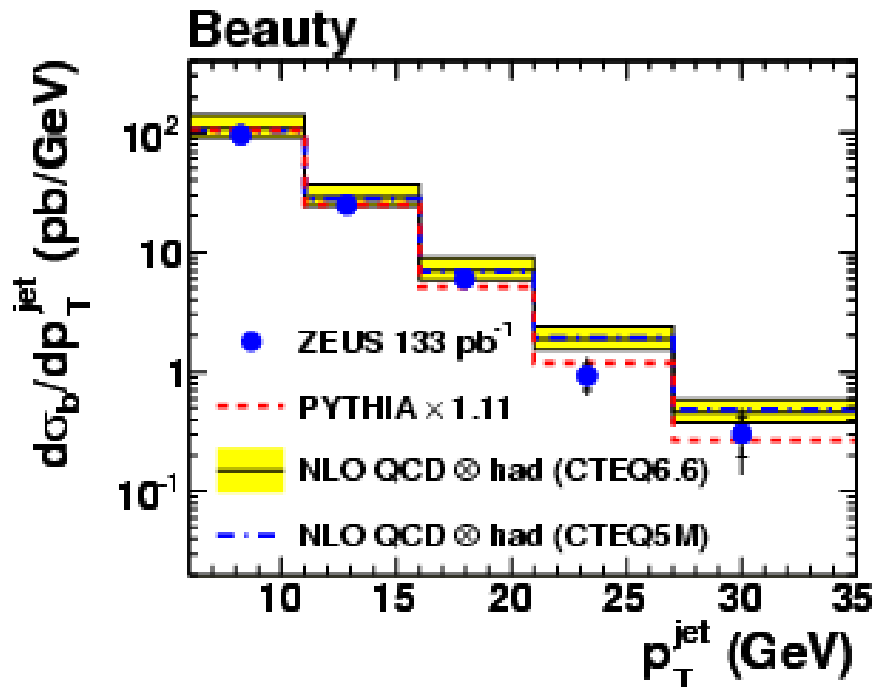


- Reconstruction of secondary vertices (belonging to jet)
- Use decay length significance and invariant mass of tracks

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

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

DESY-11-067

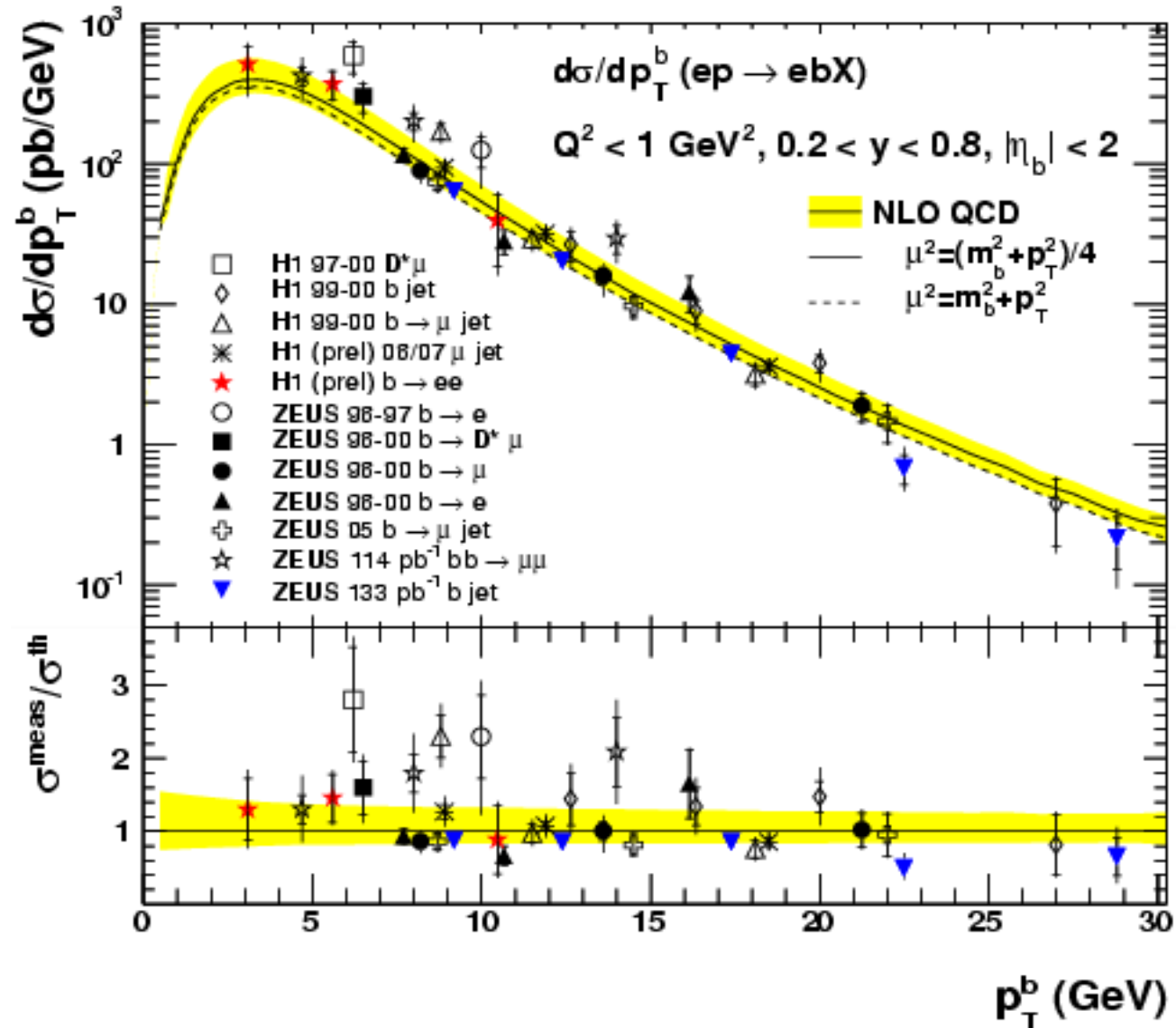


- Predicted Cross sections from NLO QCD calculation (FMNR) in p_T^{jet} and η^{jet} in agreement with data
- Theoretical uncertainties larger than experimental ones

→ Measurements consistent with each other over a wide p_T^b range

→ In general good agreement between data and NLO calculation (FMNR)

HERA





Beauty Jets in DIS

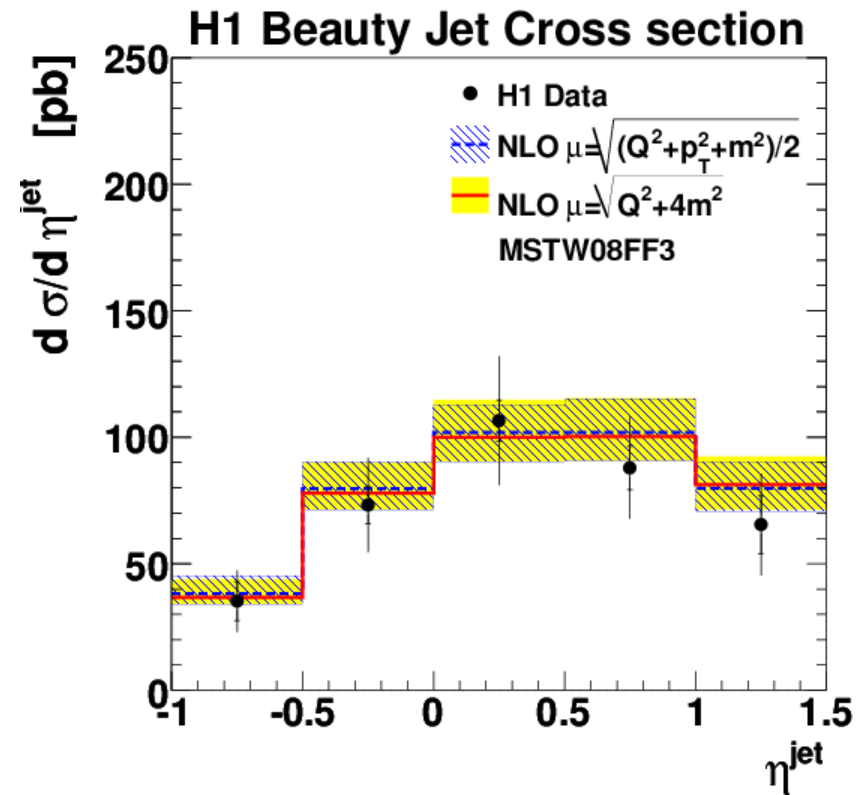
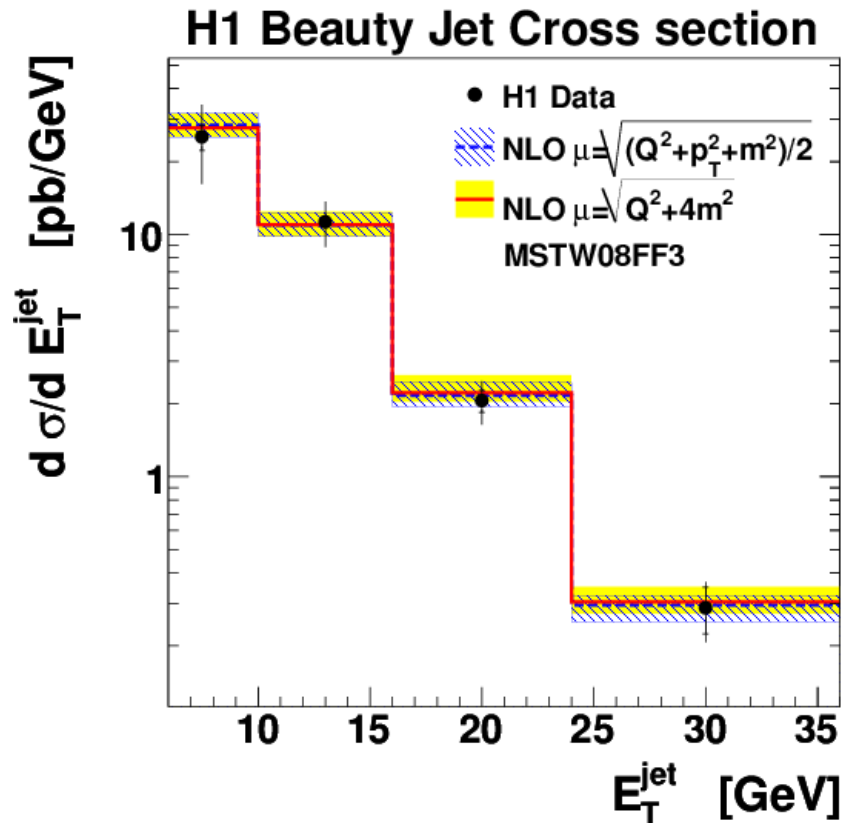
$\mathcal{L} = 189 \text{ pb}^{-1}$

$Q^2 > 6 \text{ GeV}^2, 0.07 < y < 0.6$
 $E_t^{\text{jet}} > 6 \text{ GeV}, -1 < \eta^{\text{jet}} < 1.5$

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



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

$5 < Q^2 < 1000 \text{ GeV}^2, 0.02 < y < 0.7$
 $E_t^{\text{jet}} > 5 \text{ GeV}, -1.6 < \eta^{\text{jet}} < 2.2$

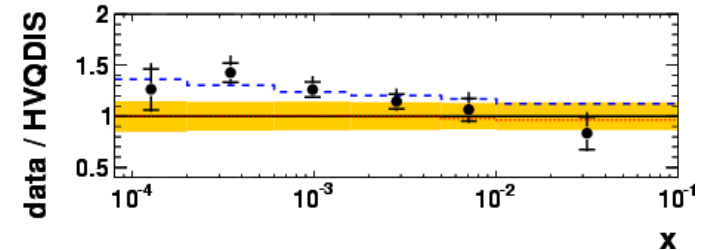
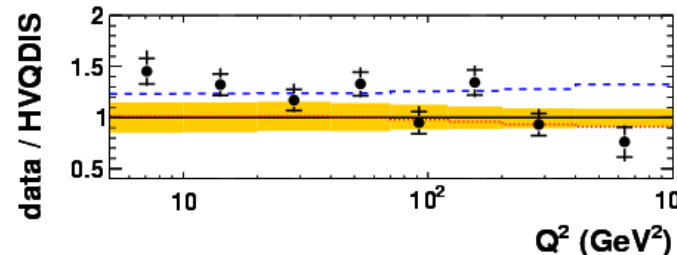
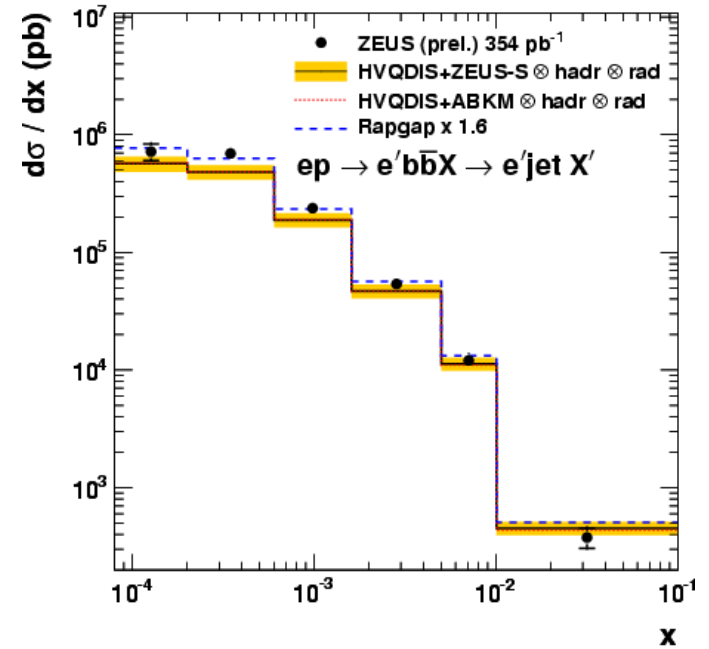
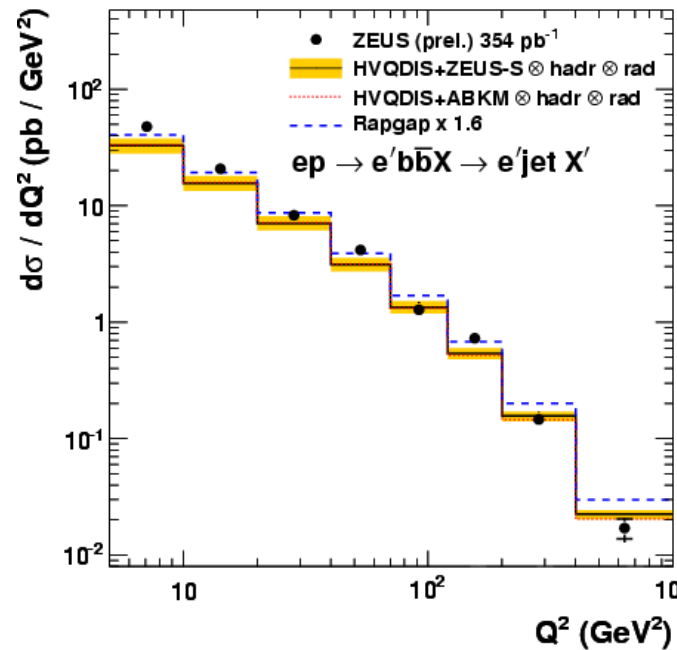
ZEUS-prel-10-004

- Compare data with LO MC RAPGAP and NLO calculation HVQDIS

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

ZEUS

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Beauty in DIS using $b \rightarrow e$ Decays



$\mathcal{L} = 363 \text{ pb}^{-1}$

$$Q^2 > 10 \text{ GeV}^2, 0.05 < y < 0.7$$

$$0.9 < p_t^e < 8 \text{ GeV}, |\eta^e| < 1.5$$

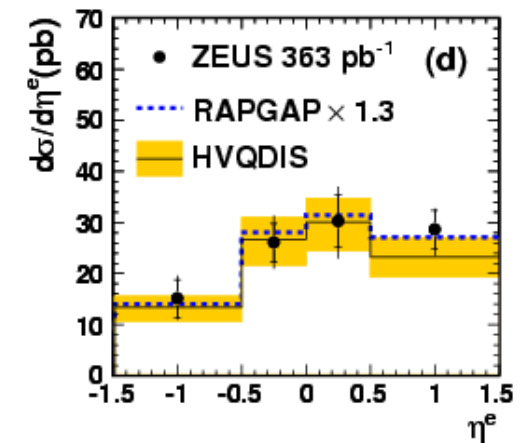
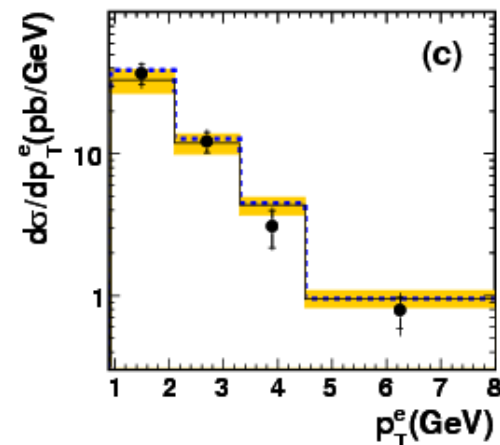
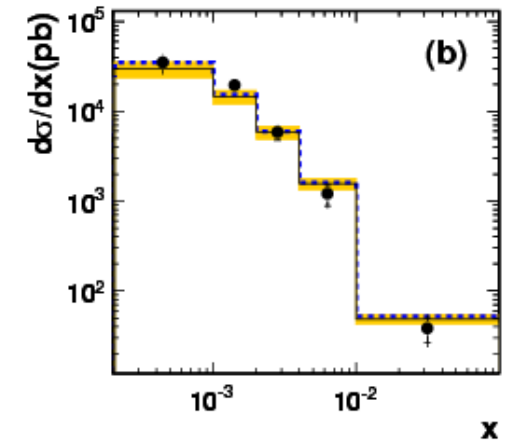
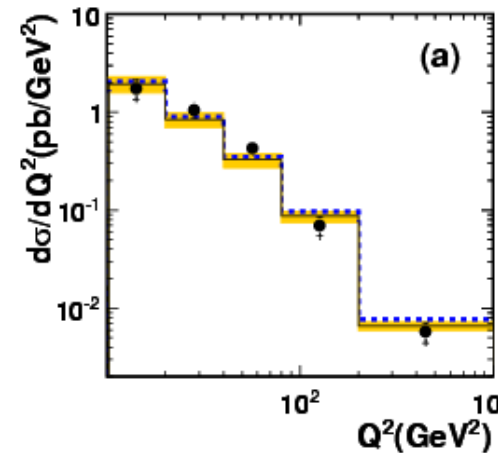
ZEUS: DESY-11-005

Tagging of beauty:

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

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

ZEUS



Beauty in DIS using $b \rightarrow \mu$ Decays



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

$$Q^2 > 2 \text{ GeV}^2, 0.05 < y < 0.7$$

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

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

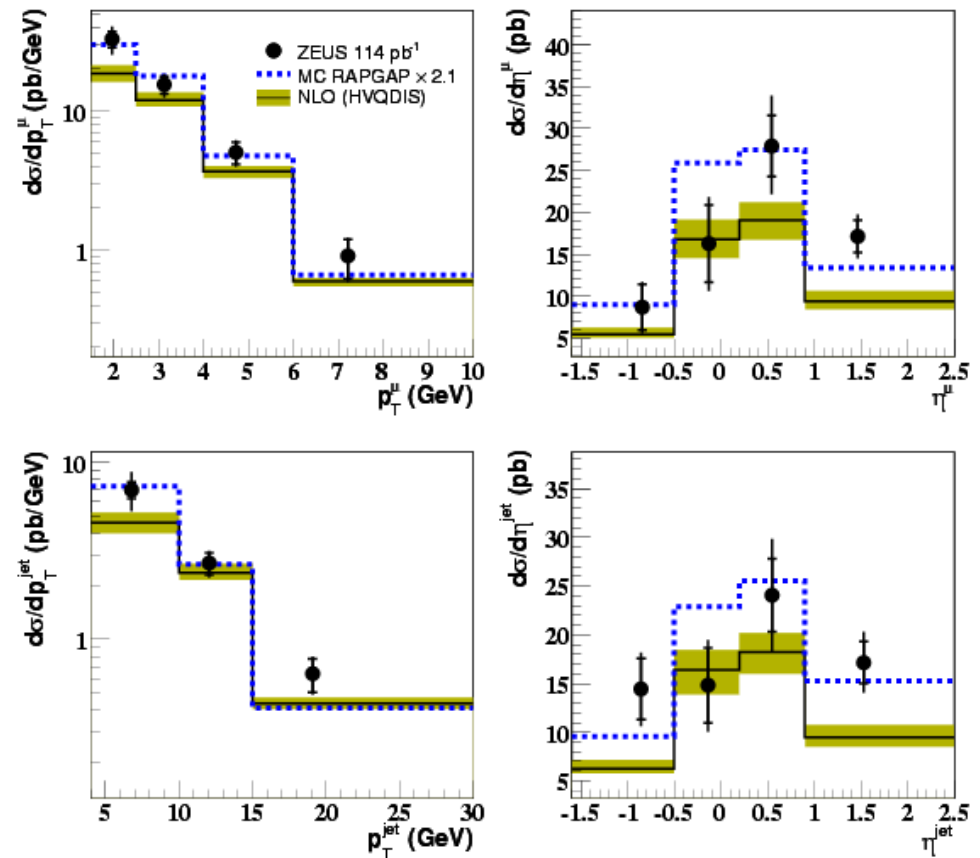
ZEUS: DESY-10-047

Tagging of beauty:

- Reconstruction of a jet ($p_t^{\text{jet}} > 5 \text{ GeV}$)
- 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

ZEUS



- One way to summarize beauty measurements

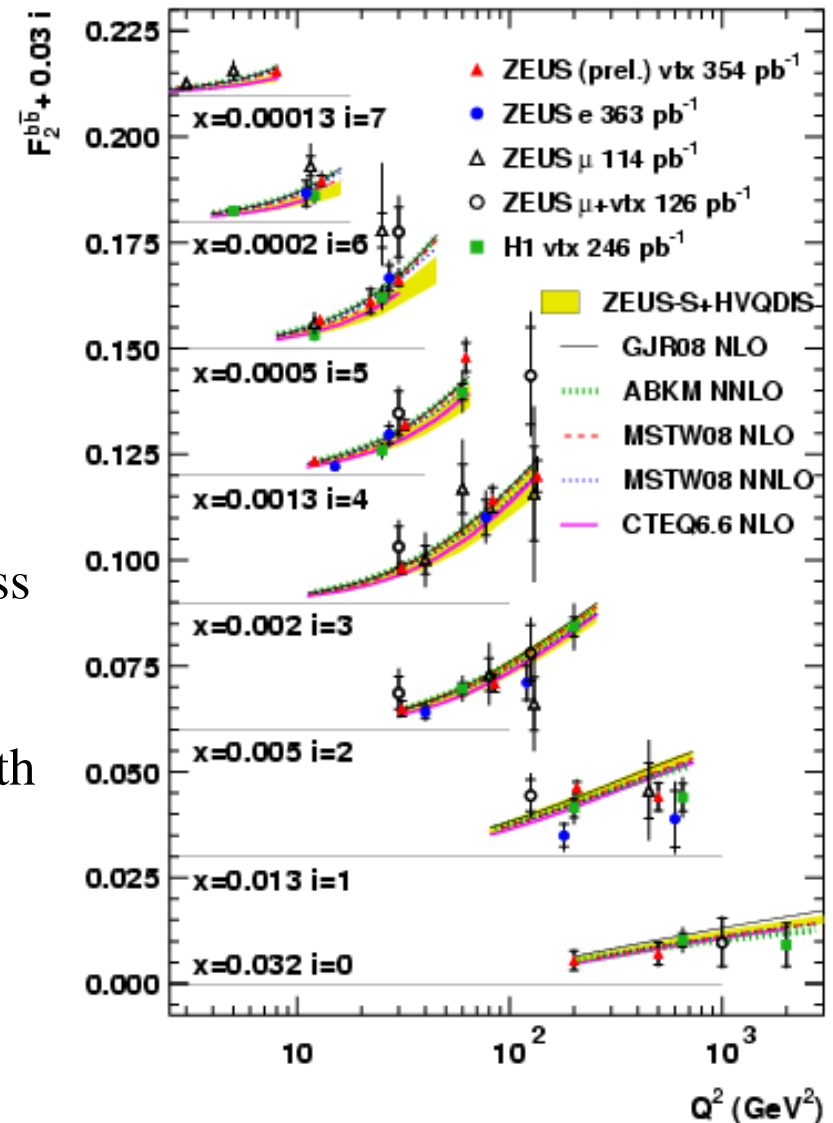
- Definition of F_2^{bb} :

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

Contribution of F_L^{bb} small !

- 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