Photoproduction of Heavy Quarks at HERA

On behalf of the ZEUS and H1 Collaborations

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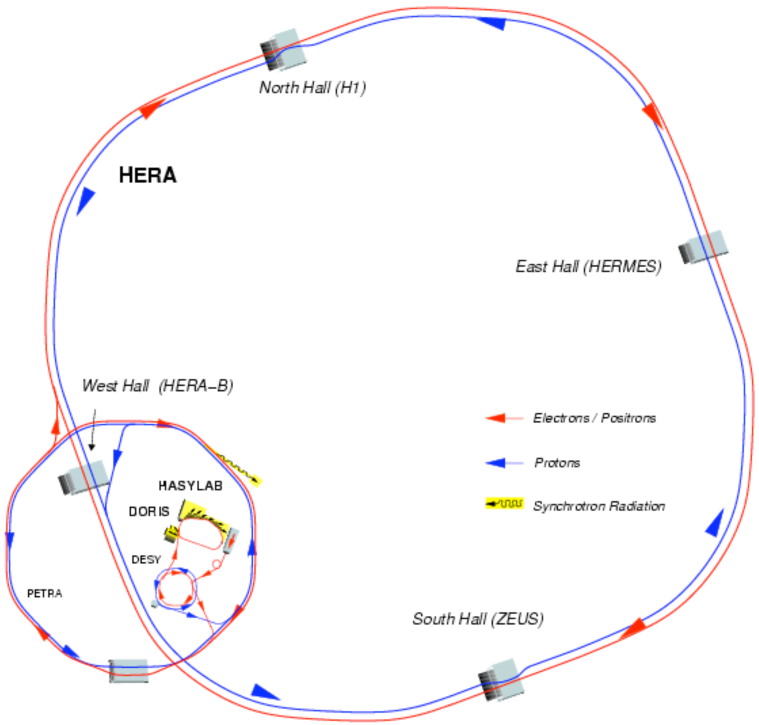
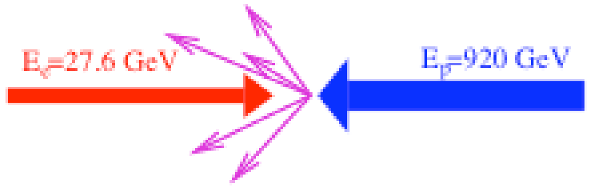
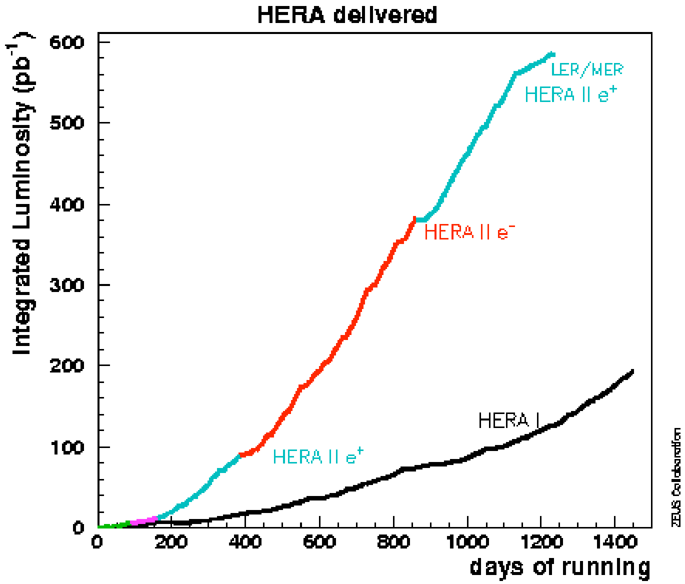
Outline

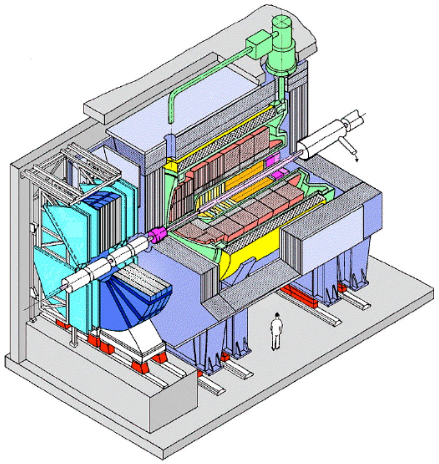
- HERA and its charm and beauty.
- Perturbative QCD calculations.
- Inclusive cross sections.
- D* and Jet production.
- Charm fragmentation.
- Beauty production
- Summary

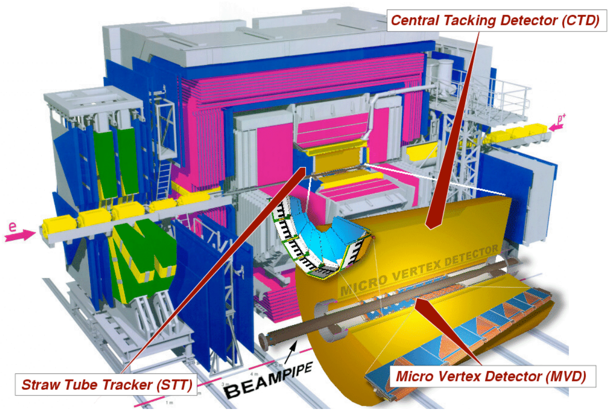
HERA









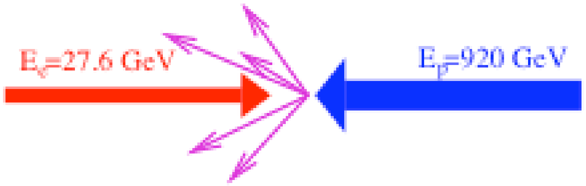


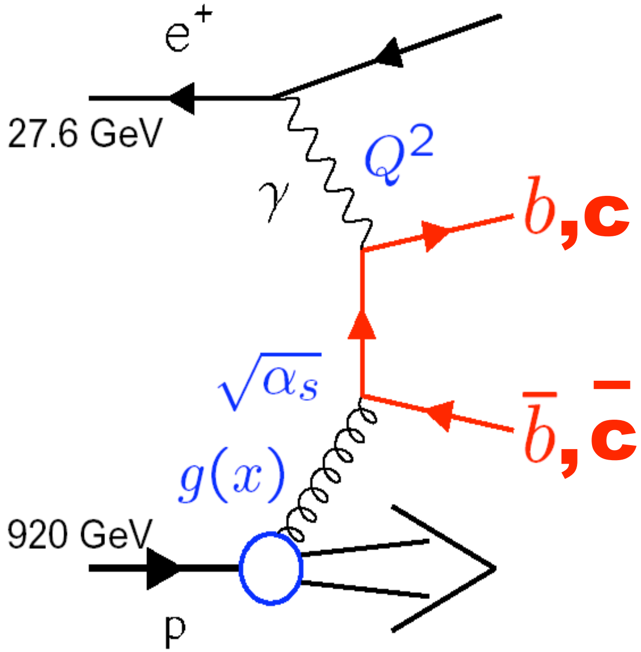
Luminosity

96/00 (HERAI):$e^{\pm}p \sim 130 pb^{-1}$

03/07 (HERAII):$e^{\pm}p \sim 380 pb^{-1}$

HERA's charm/beauty production





Boson Gluon fusion

Charm & Beauty directly sensitive to the proton gluon density.

Huge kinematical ranges:
$0 < p_T < 30$ GeV,
$0 < Q^2 < 1000$ GeV^2.

Photoproduction: $Q^2 \leq 1$ GeV^2

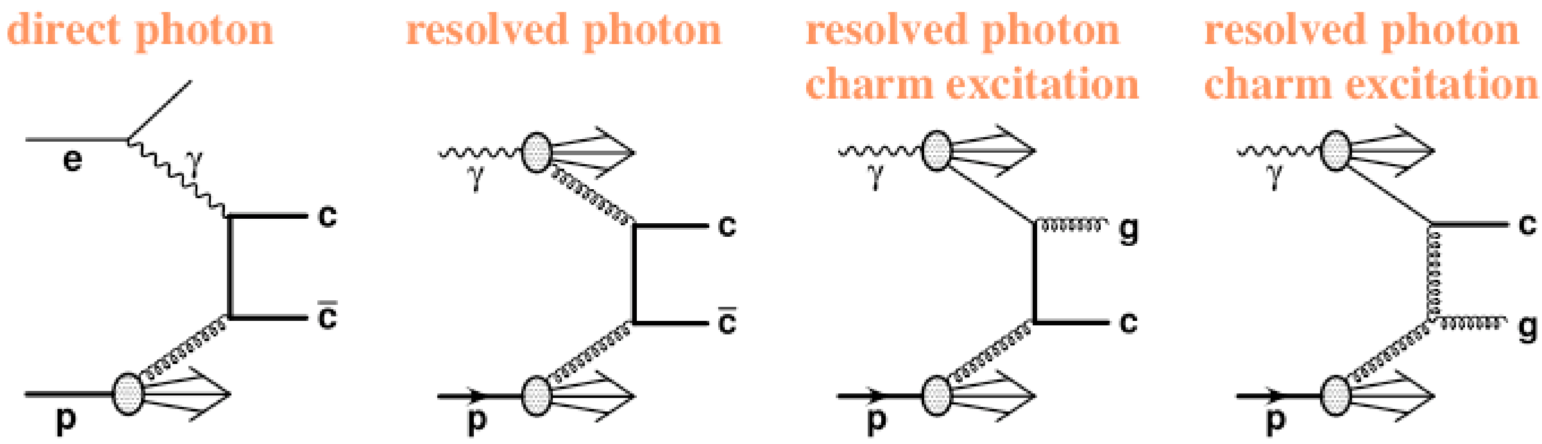
DIS: $Q^2 > 1$ GeV^2

HERA's charm production

At LO Boson Gluon Fusion (BGF) dominates -> $\gamma g \rightarrow c\bar{c}$

Direct and Resolved contributions

σ = proton PDF $\otimes$ $\sigma_{\gamma g \rightarrow QQ}$ $\otimes$ photon PDF $\otimes$ fragmentation function



Charm pQCD calculations

pQCD calculations are performed in different ways: Massive (PHP S.Fixione et al) (DIS Harris and Smith), Massless(B. Kniehl et al) and a combined method (M. Cacciari et al).

The "Massive" approach, to fixed order in α_s:

$\rightarrow m_Q \neq 0$ and the heavy quarks (c and b) are not parts of the structure functions. Heavy quarks produced dynamically in the hard interaction. $\rightarrow$ reliable at $p_T \approx m_Q$

DGLAP evolution is used to obtain the quark and gluon densities.

Programs for Photoproduction: FMNR (Frixione et al.)

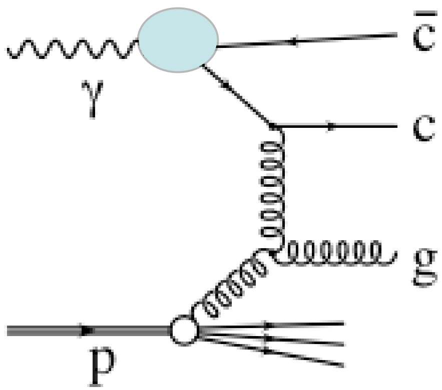
DIS: HVQDIS (Harris+Smith)

Charm pQCD calculations

"Massless" Approach: re-summation of $\alpha_s \ln(p_T^2 / m_c^2)$ at orders in α_s:

$\rightarrow M_Q = 0 \rightarrow$ the heavy quarks are an active flavour in the PDF

Heavy quarks can also be produced in flavour excitation



Relaible $p_T >> m_Q$, (B. Kniehl et al)

Charm Tagging

Charm tagging via D* meson

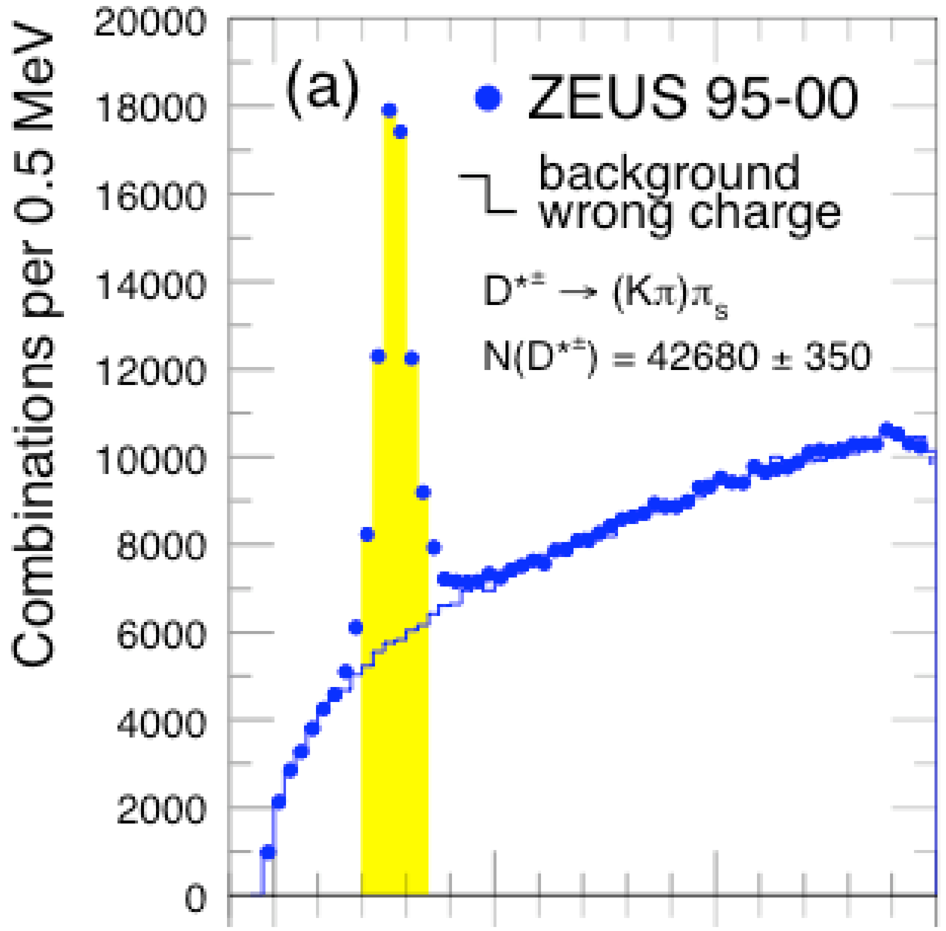
$D^* \rightarrow D^0, \pi$ Where $D^0 \rightarrow K, \pi$

HERA is a charm factory

42680 ± 350 D* mesons.

H1 & ZEUS for HERA I

50<luminosity <100 pb^{-1}.



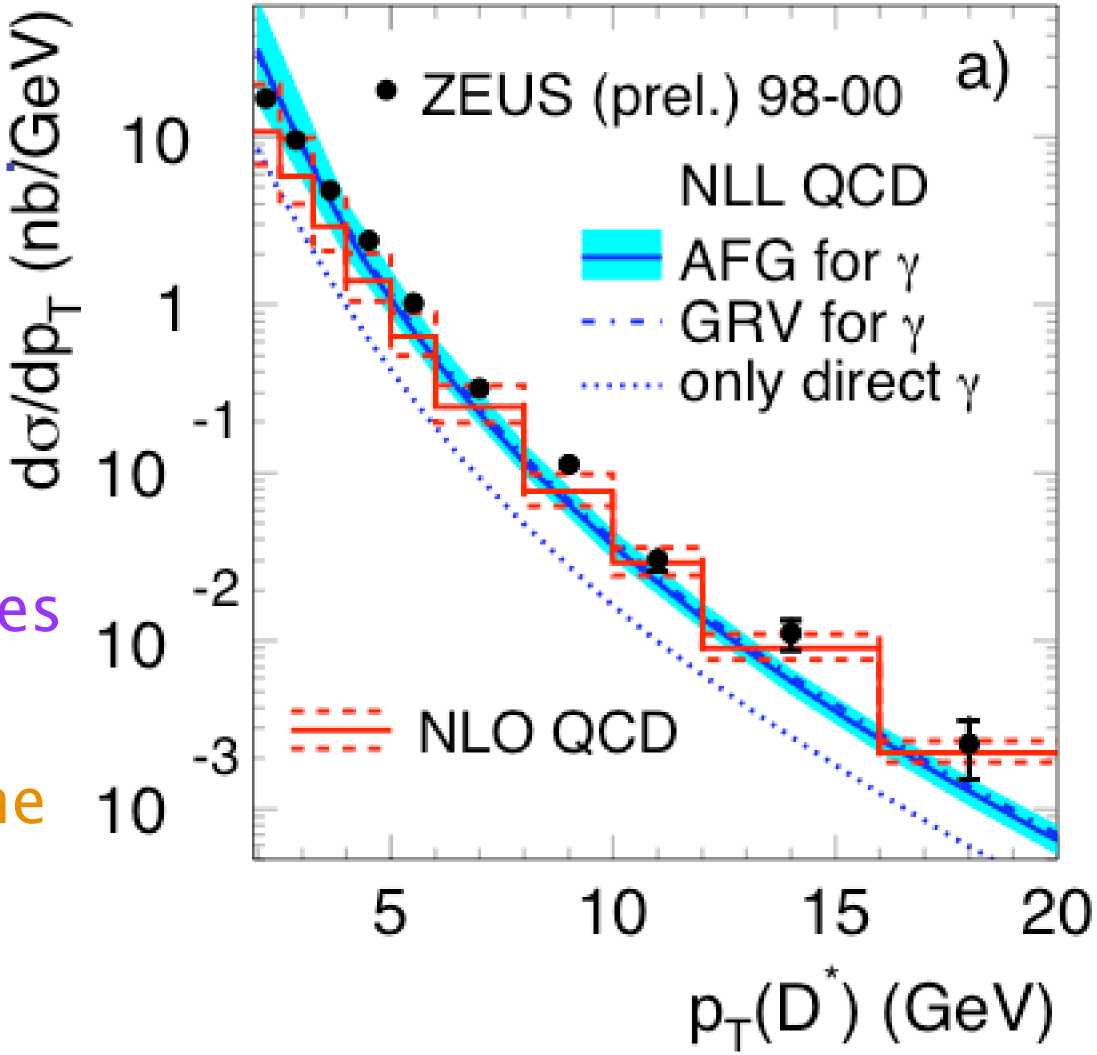
D* Photoproduction inclusive cross sections

Inclusive D* production over a large lage of p_T^{D*}.

At large p_T^{D*} massive calculation does better then massless.

At lower values of p_T^{D*} massless calculation does better then massive.

Expect scenario to be the other way round.



D* Photoproduction inclusive cross sections

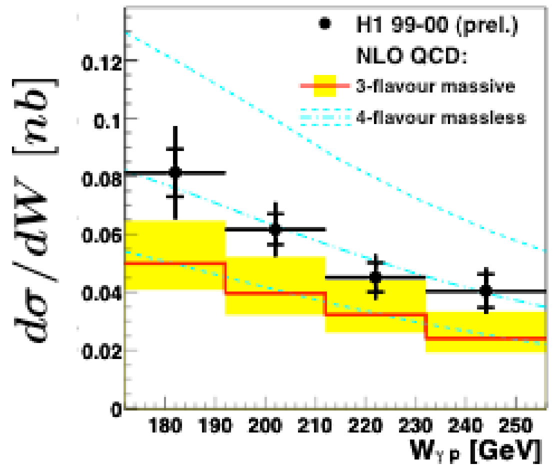
•D* selection in photoproduction

•NLO "massive" and "massless" predictions are compared to the data.

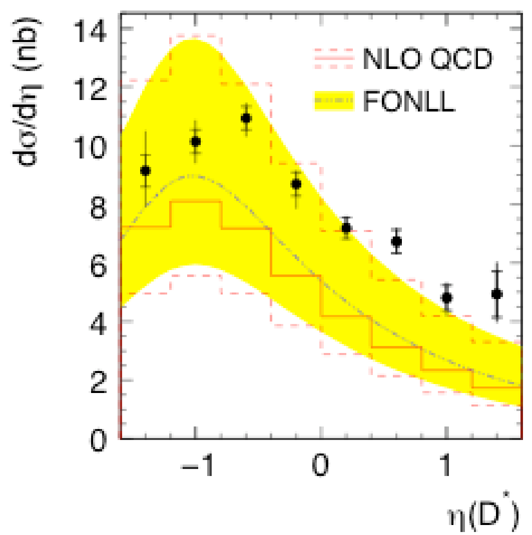
•dσ / dW is described well, but the shape of d σ / dη(D*) is not well described in shape.

•Theoretical uncertainties from charm mass and renormalisation scale are large!

•Precise data → Need for NNLO.



ZEUS

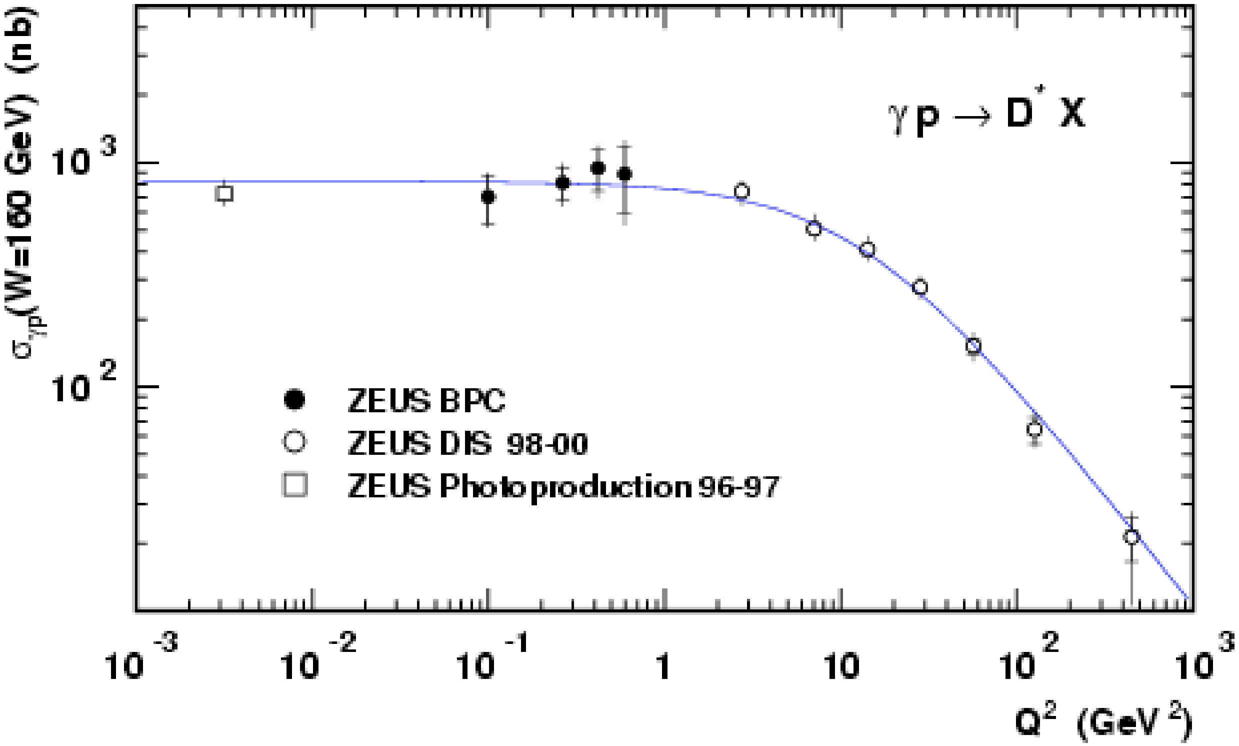


Charm over all Q^2

NLO charm production tested across the transition region from DIS to Photoproduction.

Low Q^2 is much smaller than charm mass.

High Q^2 is much larger than charm mass



Function $\sigma(Q^2) = S\, M^2 / (Q^2 + M^2)$

S is the photoproduction cross section $Q^2 = 0$

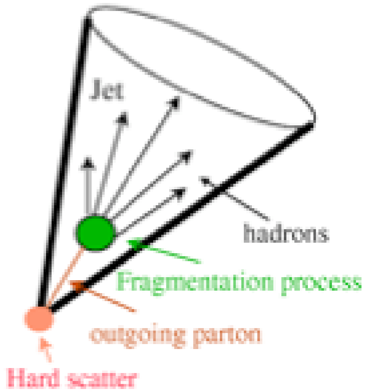
M^2 is the scale at which the γp cross section changes from photoproduction to DIS $1/Q^2$ behaviour.

It gives a good description over the whole Q^2 range.

$S = 823 \pm 63$ nb and $M^2 = 13 \pm 2$ GeV^2.

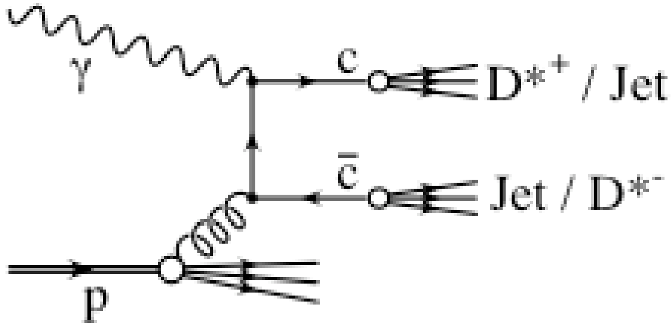
M^2 is close to $4\, m_c^2$

Charm Jet Production



•D* production and Jet production

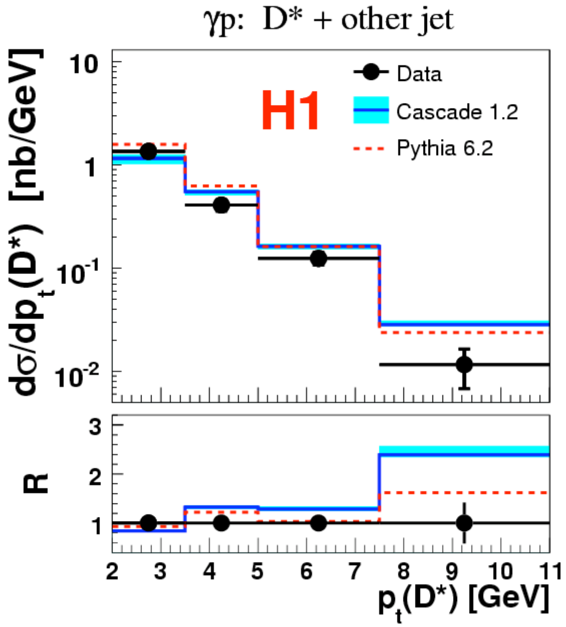
•Tag second hard parton by a using a Jet (k_T Algorithm definition)

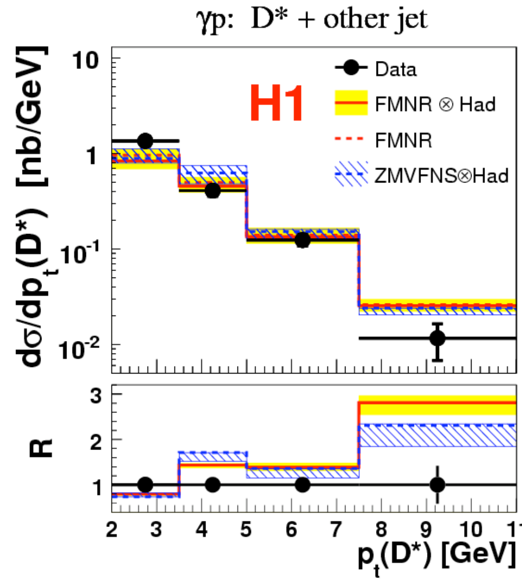


• Jet and D* correlations can be studied when the D* is NOT associated to with a Jet → angular correlations arising from higher orders.

• Jet E_T provides an extra hard scale: test QCD!

Charm Jet Production

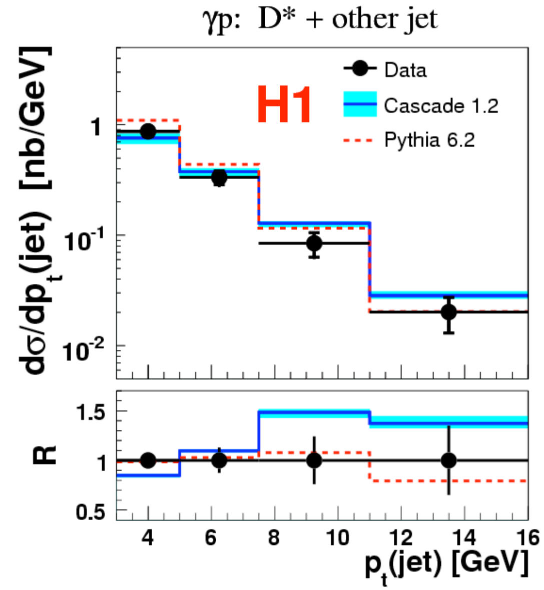


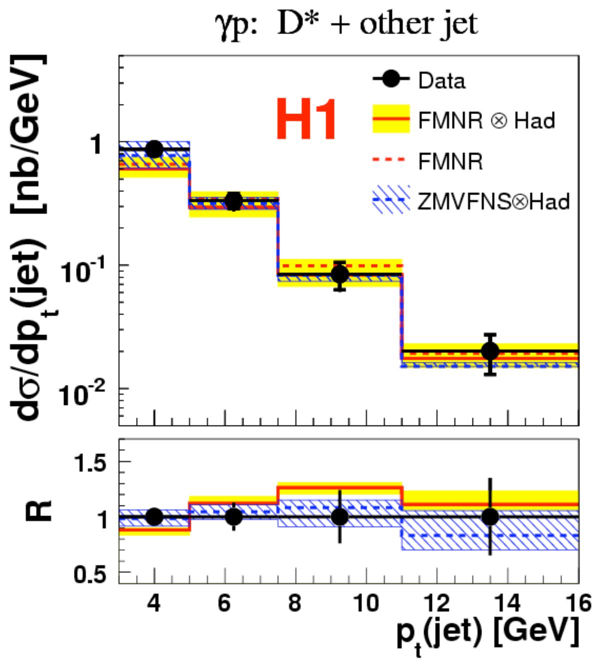


Test of D* and Jet correlations.

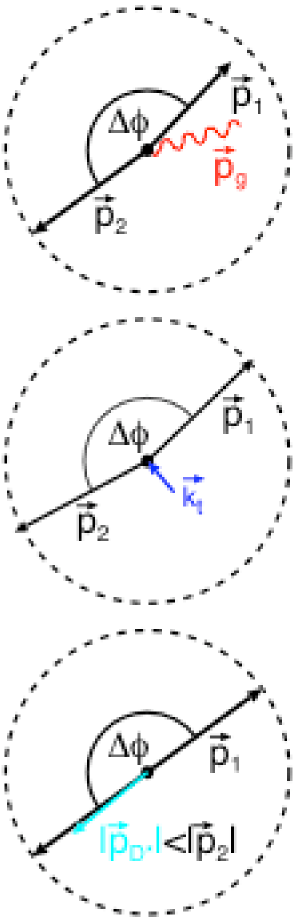
NLO pQCD predictions and LO+PS have troubles to describe the P_T cross section for the D*.

The P_T Jet variable is reasonably well produced in comparison.



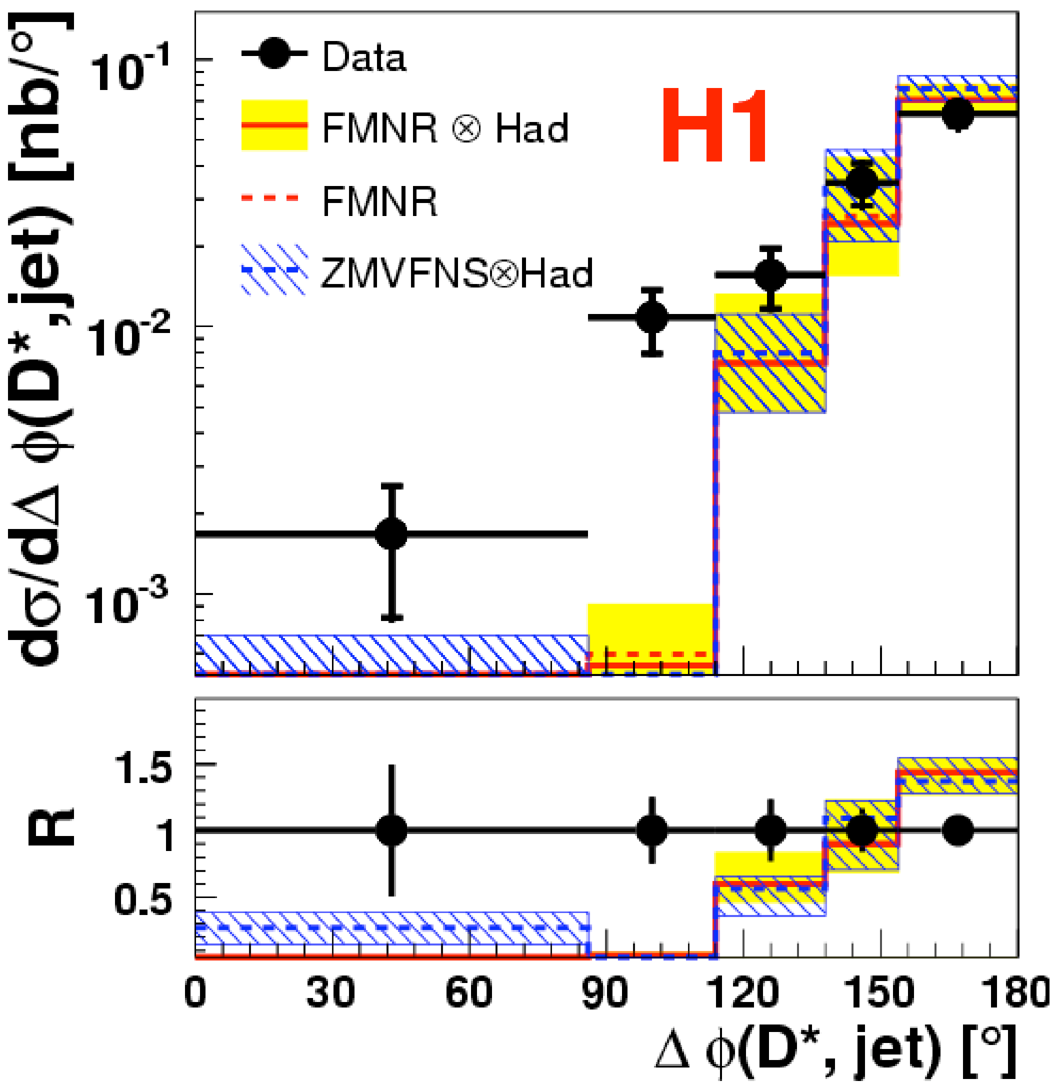


Charm Jet Production



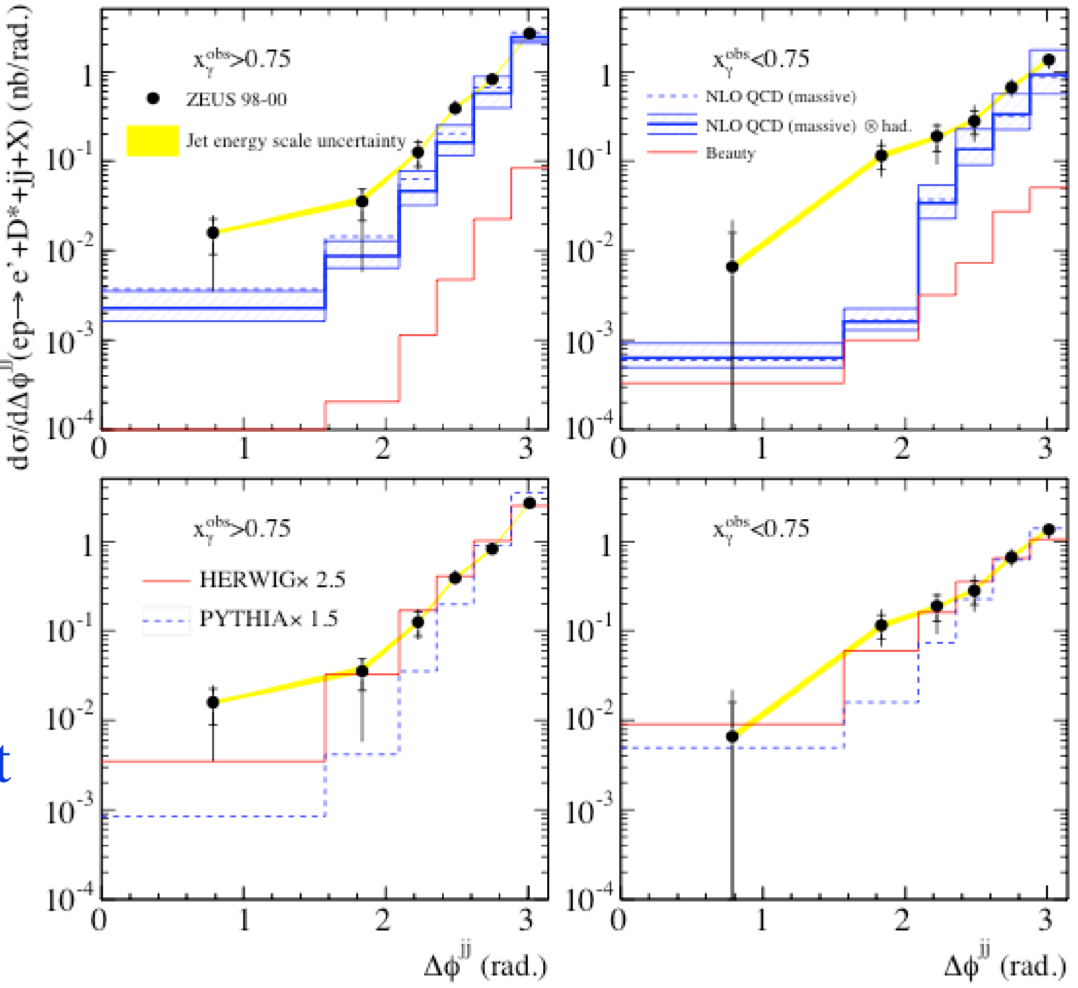
- D* + Jet selection in photoproduction.
- Comparison to NLO pQCD and models. → pQCD does not describe HERA data.
- Only one parton radiation from NLO not sufficient to describe the data.

γp: D* + other jet



Charm Dijet Production

- D* Dijet photoproduction.
- Split sample direct-enriched ($x_\gamma^{obs} > 0.75$) resolved-enriched($x_\gamma^{obs} < 0.75$).
- Discrepancies between pQCD and resolved-enriched ($x_\gamma^{obs} < 0.75$).
- LO+PS can describe shape but not normalisation.
- → need for higher order calculations e.g. NLO +PS



Charm Fragmantation

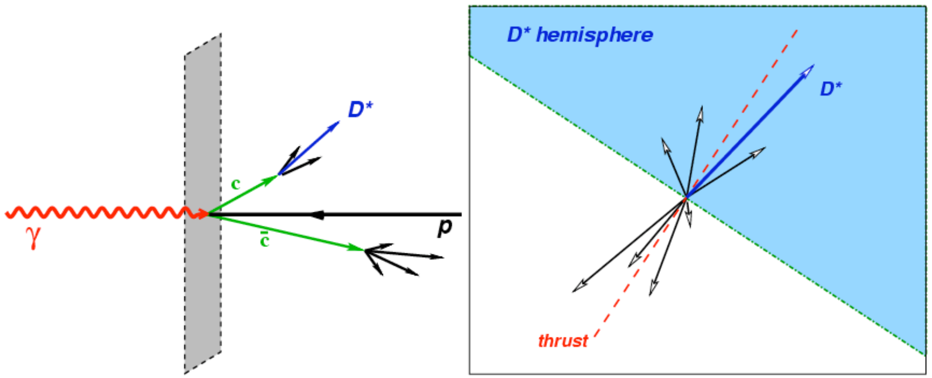
•What is the proper parameterisation for the fractional transfer of c-quark energy/momentum to a given D-meson (z)? Fragmentation function, f(z).

Find a jet containing a D* and relate the D* energy to the energy of the jet:

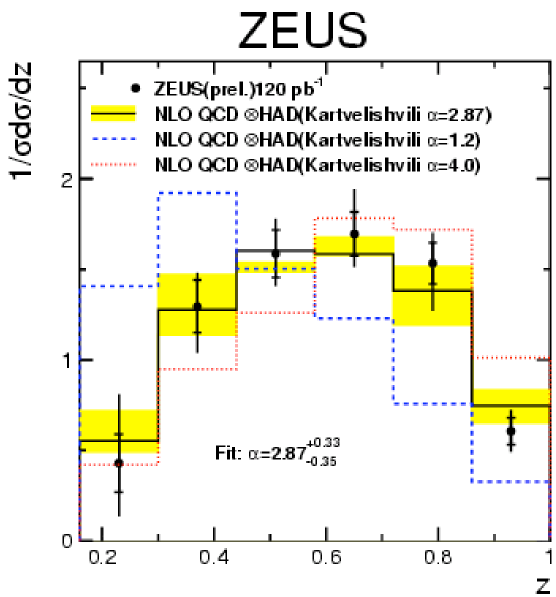
ZEUS:
$Q^2 < 1\text{GeV}^2, P_T^{D*} > 2\text{GeV}, E_T^{Jet} > 9\text{GeV}$
$z = (E + P_{||})^{D*} / (E + P_{||})^{Jet} \equiv (E + P_{||})^{D*} / 2\,E^{jet}$

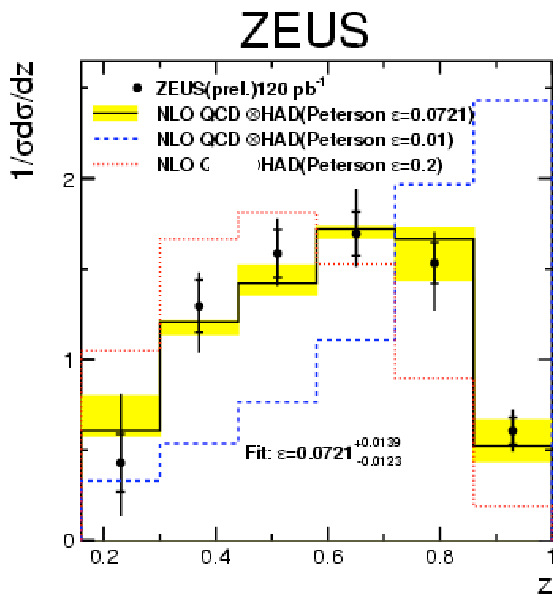
H1 jet method:
$Q^2 > 2\text{GeV}^2, P_T^{D*} > 1.5\text{GeV}, E_T^{Jet} > 3\text{GeV}$
$z_{jet} = (E + P_{||})^{D*} / (E + P)^{Jet}$ in $\gamma^* p$

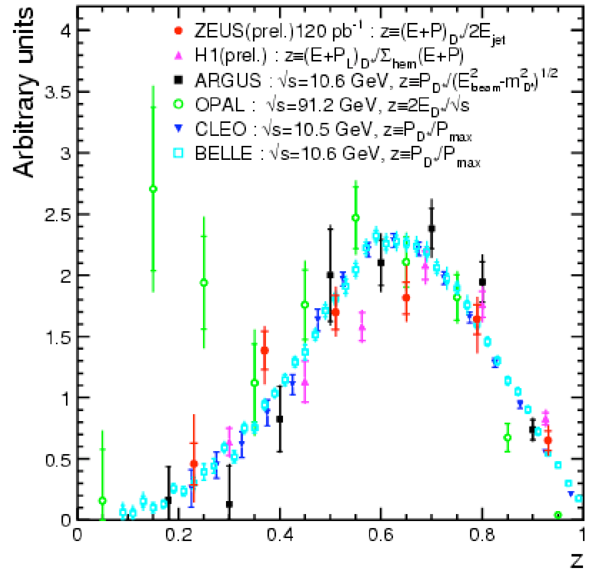
H1 hemisphere method:
$Z_{hem} = (E + P_{||})^{D*} / \Sigma_{hem} (E + P)$ in $\gamma^* p$



Charm Fragmantation







Peterson parameterisation →

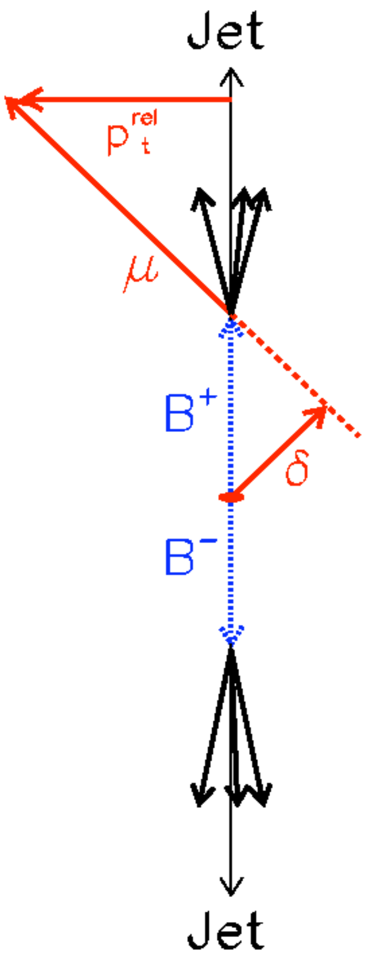
$$f(z) \propto \frac{1}{z(1-1/z-\epsilon/(1-z))^2}$$

ZEUS: $\varepsilon = 0.0721^{+0.0139}_{-0.0123}$, H1(HEM): $\varepsilon = 0.018 \pm 0.004$

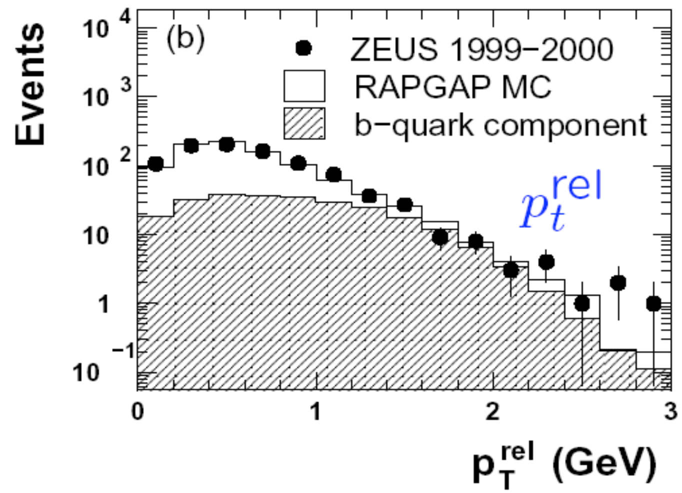
H1(Jet) : $\varepsilon = 0.030^{+0.006}_{-0.005}$

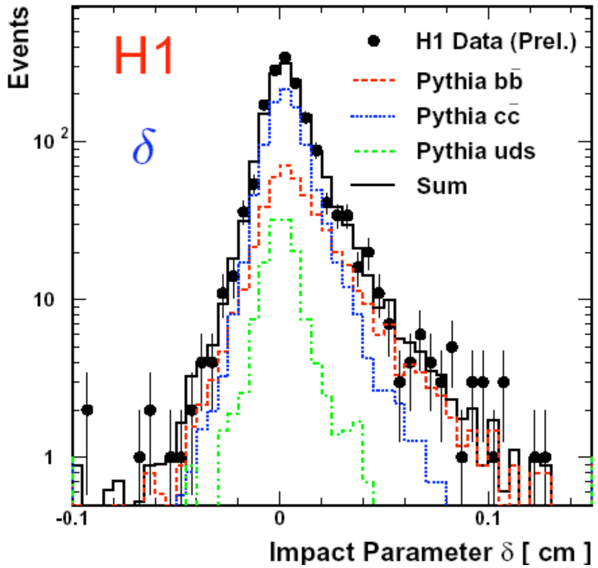
Differences in kinematical region selected as well as different parameters tuned from H1 to ZEUS in the Monte Carlos.

Beauty Production



- Large B-Mass:
  p_t^{rel}: p_t of μ relative to jet axis
- Large B-Lifetime:
  μ Impact-Parameter δ



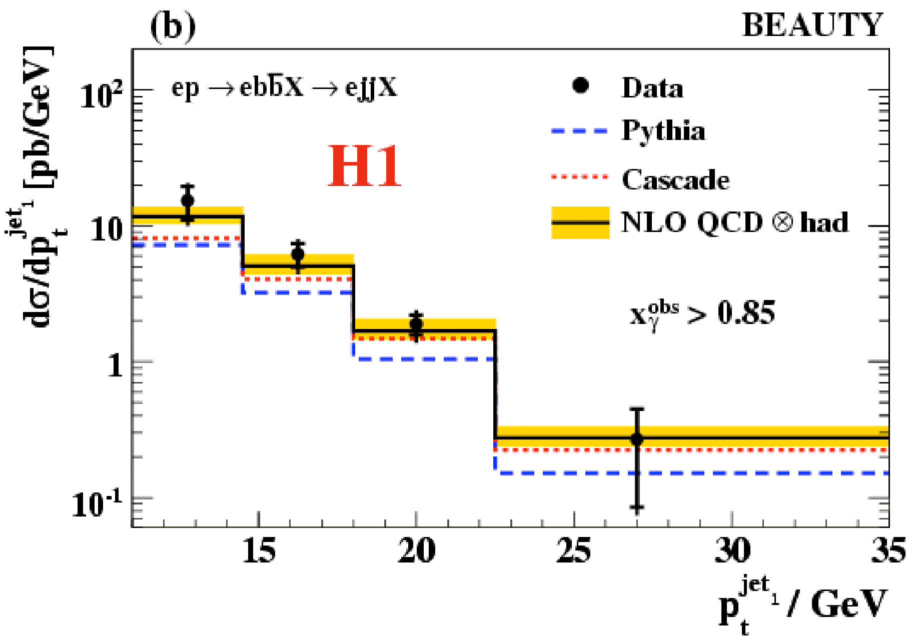


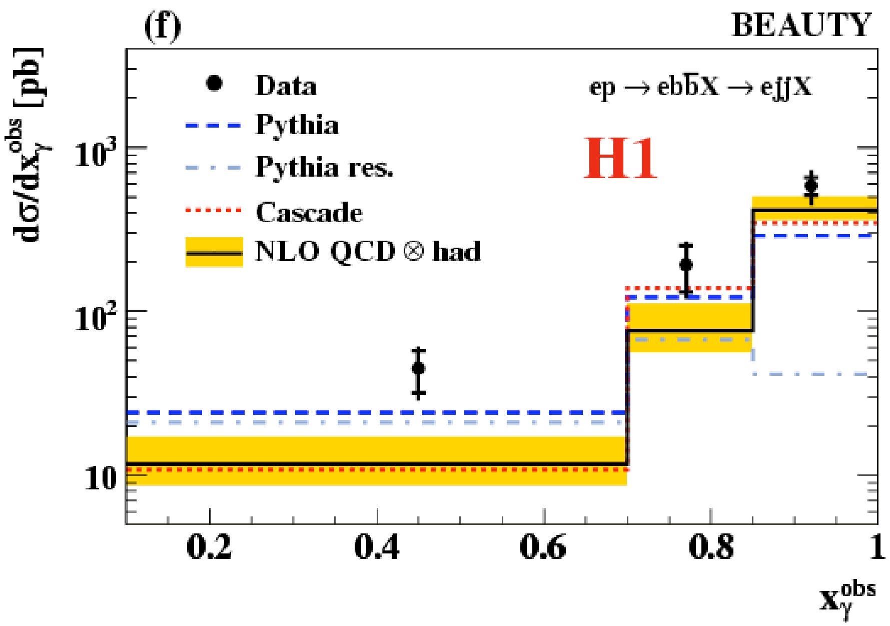
Shapes of b, c, uds from MC

Beauty fraction from fit to p_t^{rel} (ZEUS), p_t^{rel} and δ (H1)

$\rightarrow$ samples used for fit:
b-fraction typically 30%

Beauty Production

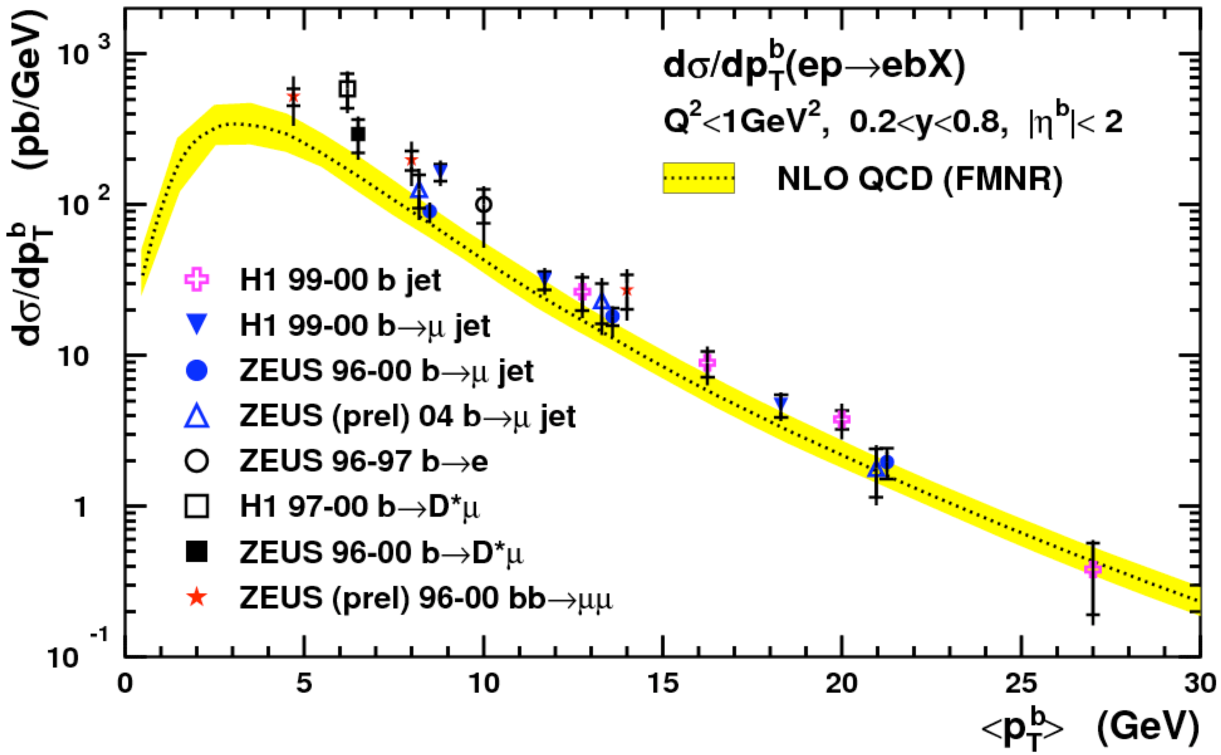




PYTHIA AND CASCADE (LO+PS): Describes the shape well but not the normalisation

pQCD NLO prediction is consistent in both shape and normalisation.

Beauty Production



At low p_t values the data is slightly above the NLO QCD prediction.

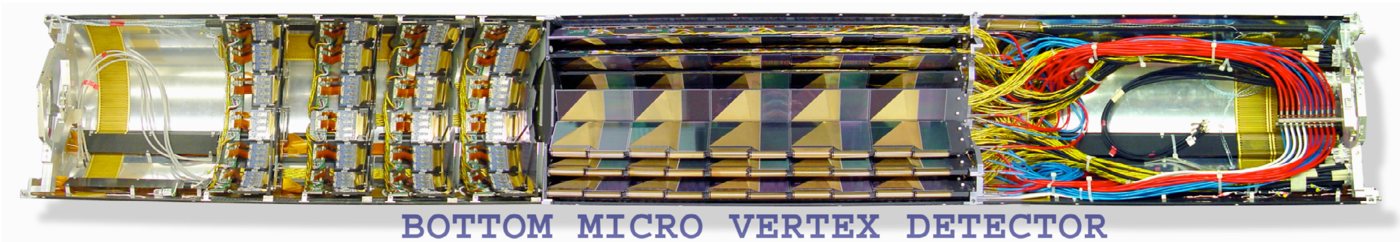
HERA II data will provide more accurate measurements and span a wider range covering the full kinematical range.

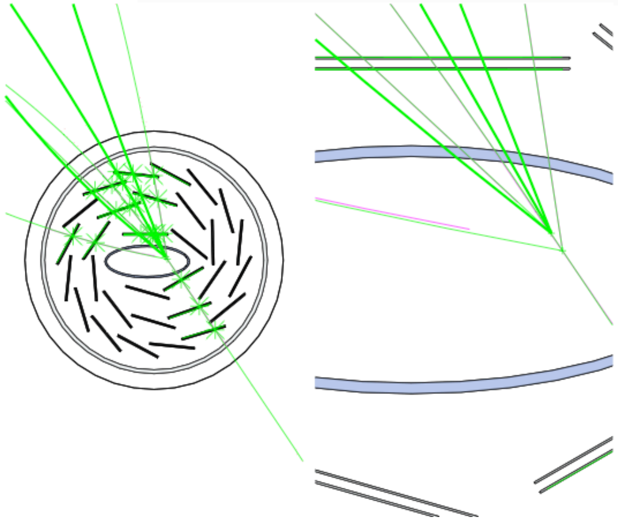
Summary

• Charm & Beauty results in reasonable agreement with pQCD.

•Areas of disagreement can be selected(e.g. D* + jets) indicating the need for higher order corrections e.g. MC@NLO.

•HERA errors small compared to theoretical uncertainties.





Future charm prospects:

• Extend measured kinematical range.

• Further test pQCD and pin down charm and beauty production using the all the data HERA has provided from 1996-2007.