Measurement of Charm and Beauty Dijet Cross Sections in Photoproduction at HERA using the H1 Vertex Detector

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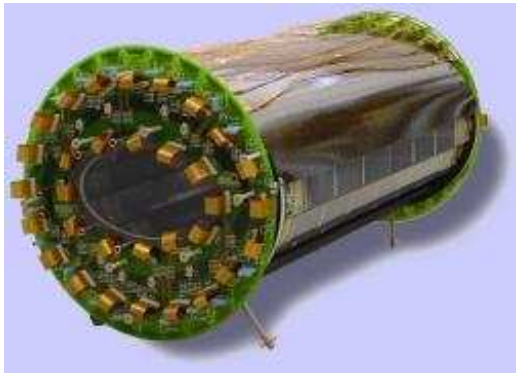
Heavy Flavours Working Group

Motivation

* Aims of this analysis:
  - Measurement of charm & beauty dijets in high p_t photoproduction at HERA.
  - Ability to reach the high p_t regime ($p_t > 2m_b$).
  - Inclusive measurement using impact parameter of tracks. (Reconstructed with the H1 silicon vertex detector)

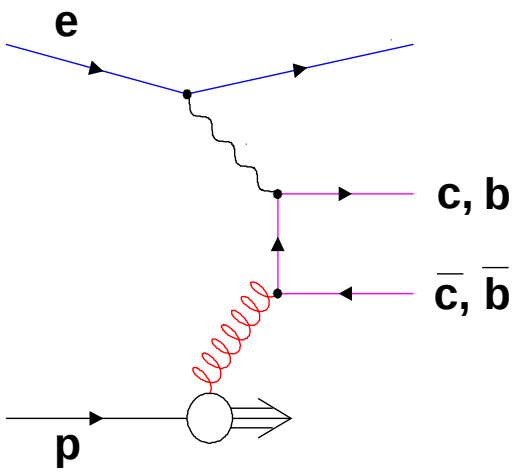


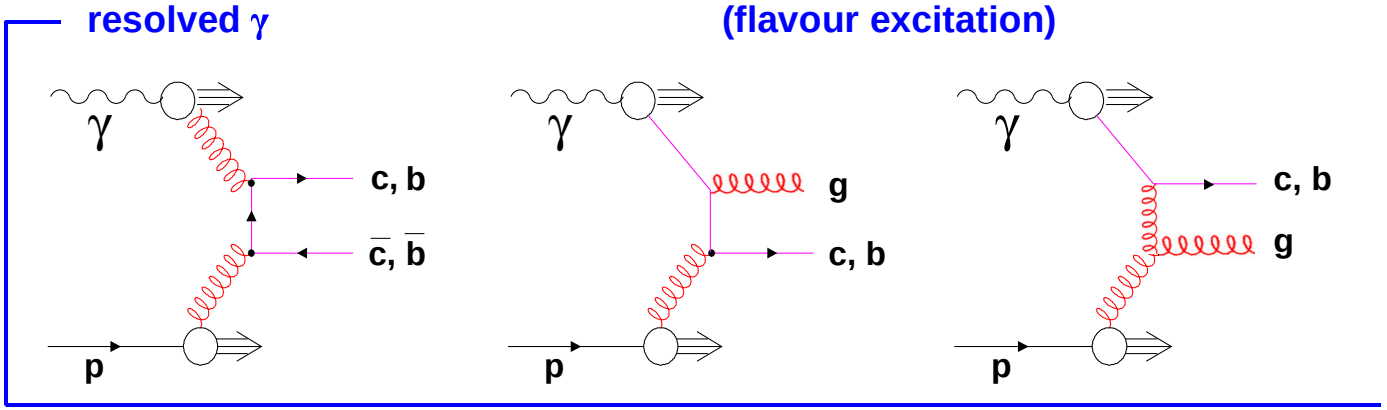
Central **S**ilicon **T**racker (CST)

Measurement
- Differential charm & beauty dijet cross sections.
- Heavy Quark fractions.
- Heavy Quark enriched data sample.

To be submitted to Eur., Phys., J. C in April 2006

Photoproduction of Charm & Beauty at HERA





Theory models:

Hard scale provided by...

* heavy quark masses.
* $p_t^{c,b}$
  (event selection p_t^{jet} > 11 (8) GeV).

LO (α_s) + Parton Shower:

* DGLAP evolution, incl. flavour excitation
  PYTHIA
* CCFM evolution, $\gamma g \rightarrow Q\bar{Q}$
  CASCADE

NLO (α_s^2) calculations:

* Fixed order massive; c, b produced pert.
  FMNR

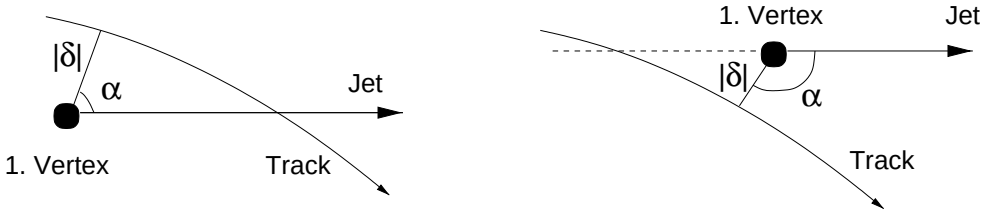
Heavy Flavor Signal Extraction

For **all tracks in jets** with:

* p_t > 500 MeV
* min 2 CST hits.

* Signed impact parameter δ:

$\alpha < \pi/2 \rightarrow \delta = +|\delta|$ $\quad$ $\alpha > \pi/2 \rightarrow \delta = -|\delta|$

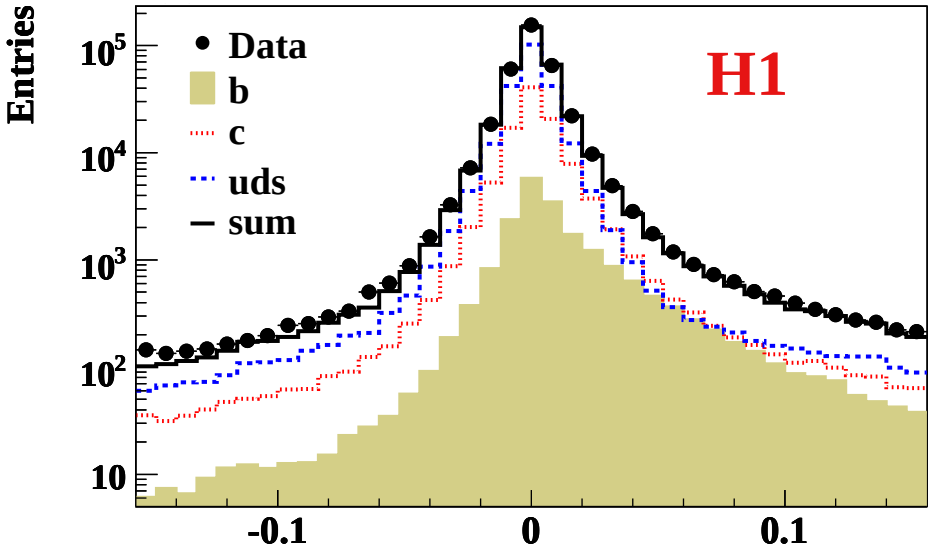


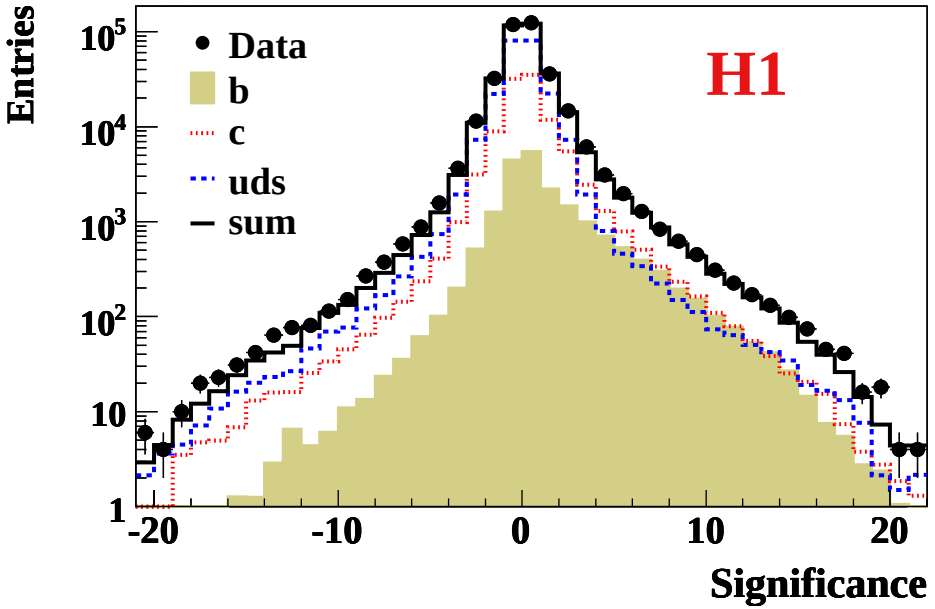
* Pythia used for simulation of c, b, uds.

* Marked asymmetry for heavy quarks.

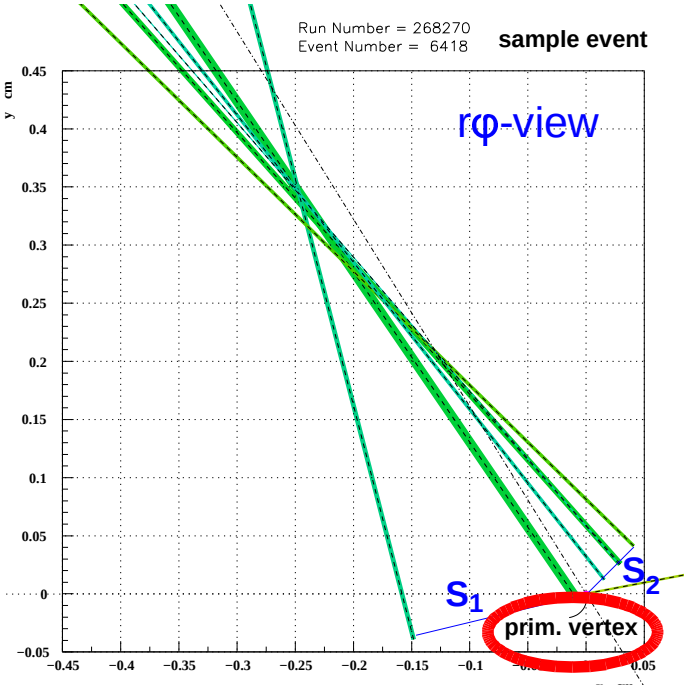
$$Significance = \frac{\delta_i}{\sigma(\delta_i)}$$

($|\delta_i|$ < 0.1 cm to remove long-lived strange)





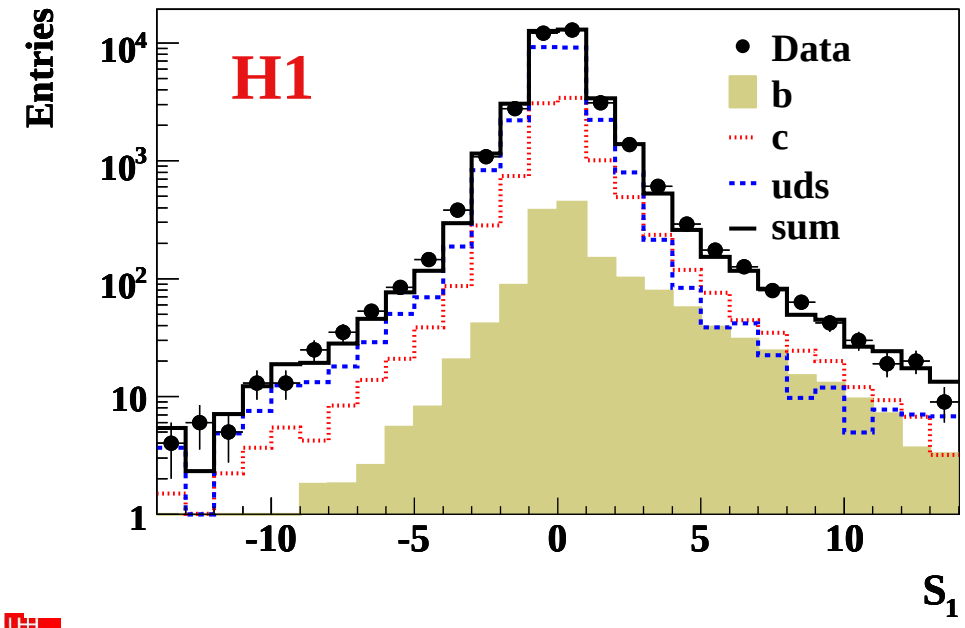
Heavy Flavor Signal Extraction

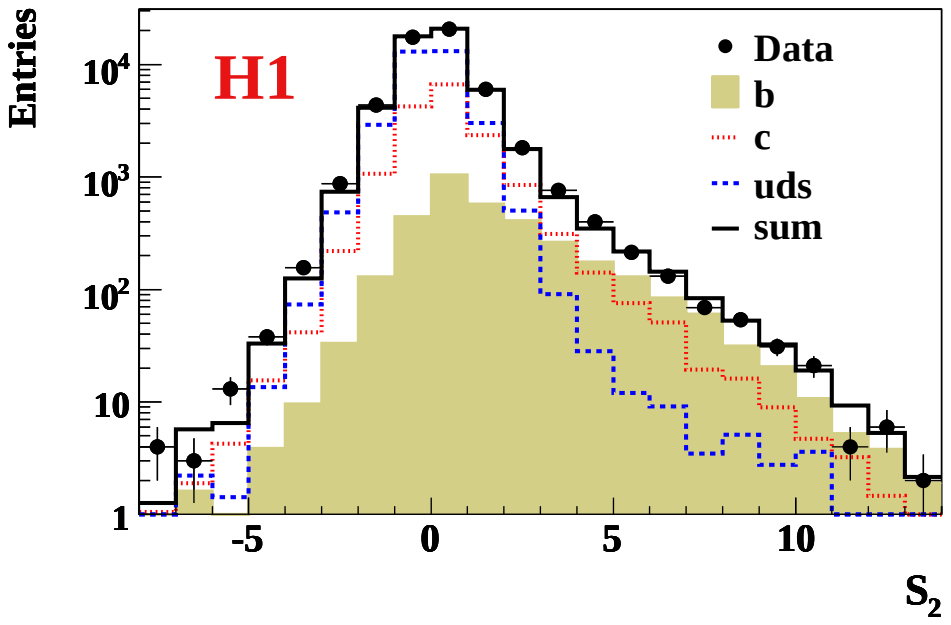


* Using significances of two highest significance tracks.

* **S_1:** Highest significance track for 1 track events.
* **S_2:** Significance of the second highest significance track for >1 track events.

* Subtract negative side in S_1 & S_2 from positive.
* Fit scale factors for c, b, uds from subtracted spectra.
  (+ total number of events)





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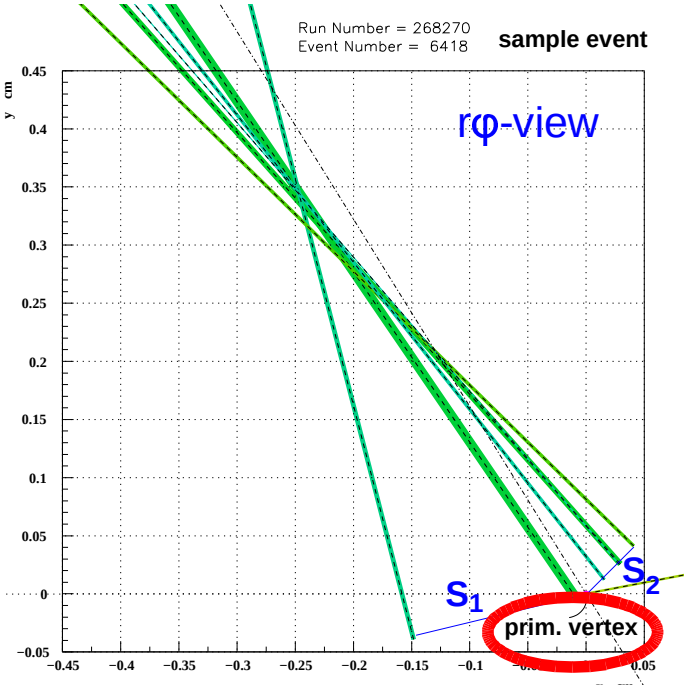

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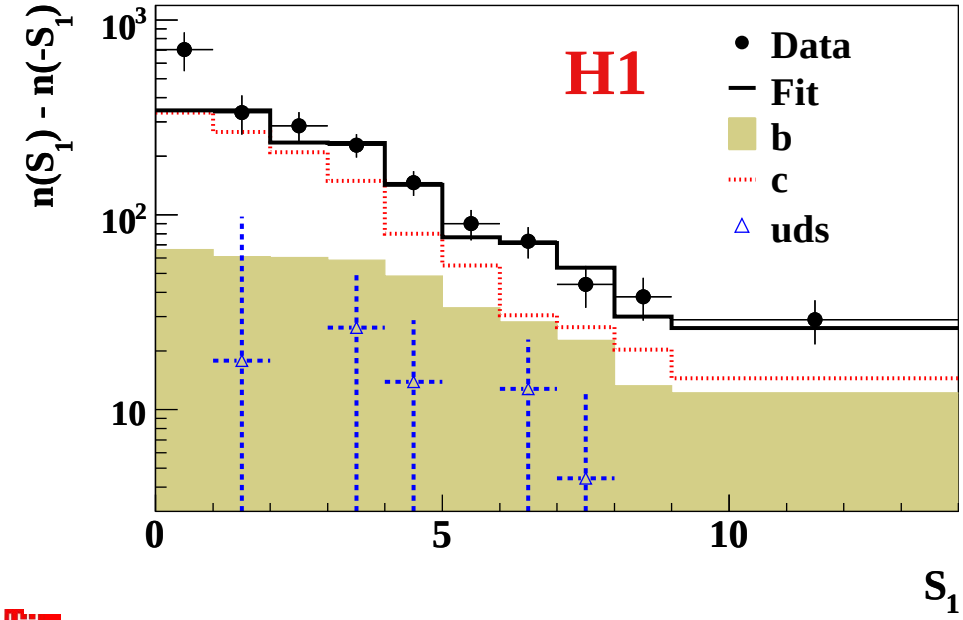
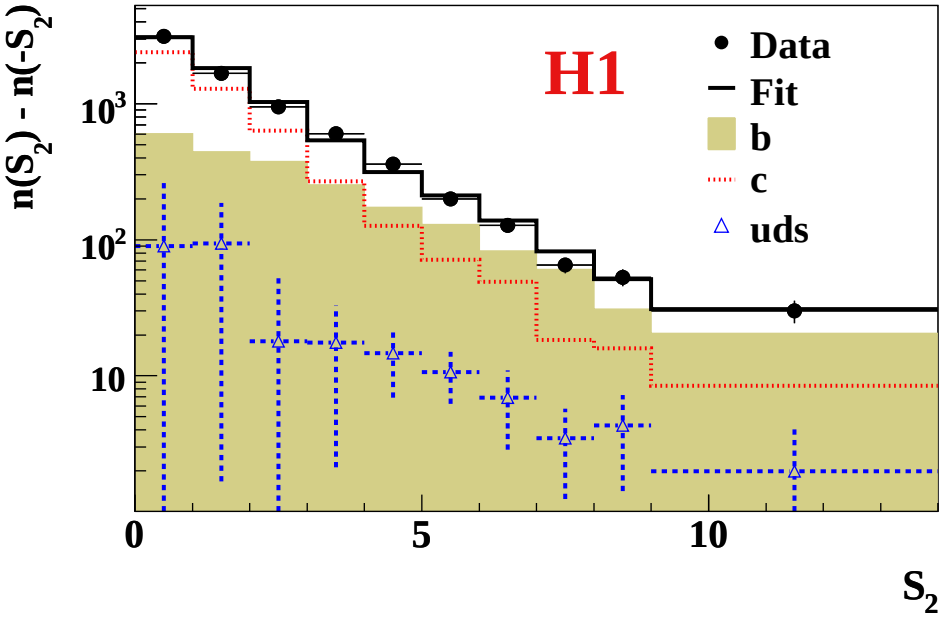




Total Integrated Cross Section

Kinematic range:

* $Q^2 < 1$ GeV^2
* $p_t^{jet} > 11$ (8) GeV
* $0.15 < y < 0.8$
* $-0.9 < \eta^{jet} < 1.3$

	Charm [pb]	Beauty [pb]
Data	$702 \pm 67(stat.) \pm 95(syst.)$	$150 \pm 17(stat.) \pm 33(syst.)$
(massive) FMNR	500^{+173}_{-99}	83^{+19}_{-14}
PYTHIA	484	76
CASCADE	438	80

NLO QCD:

- FMNR corrected to hadron level (5-10%).
- **Charm**: FMNR somewhat lower, but consistent with (large) theoretical uncertainties.
- **Beauty**: FMNR lower by factor 1.8 (1.6 σ).

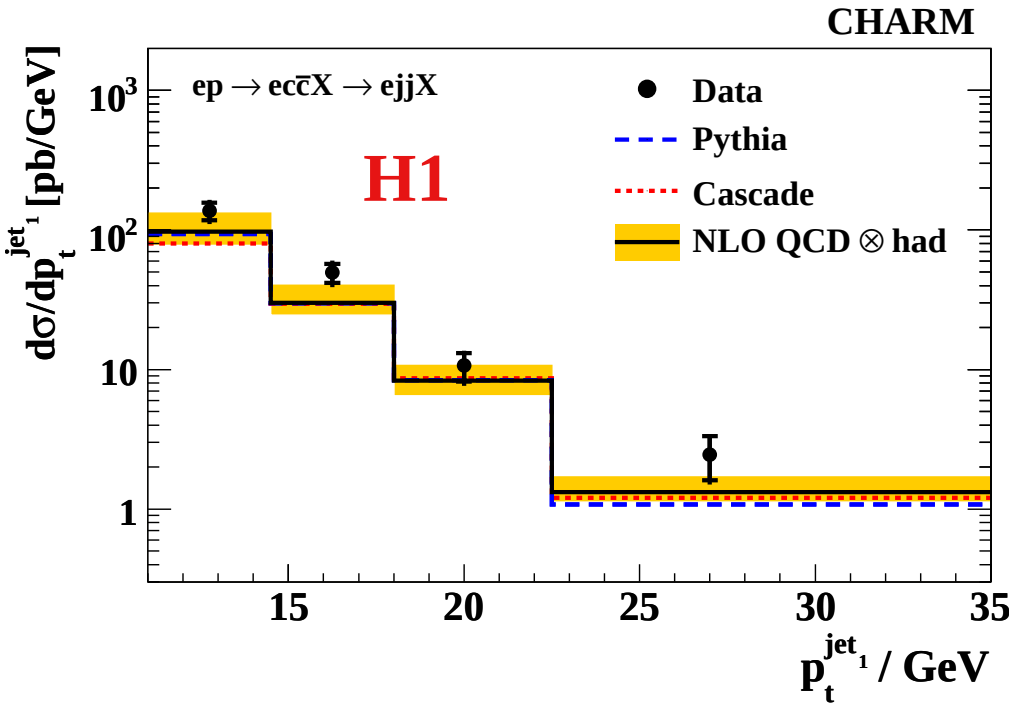
LO QCD:

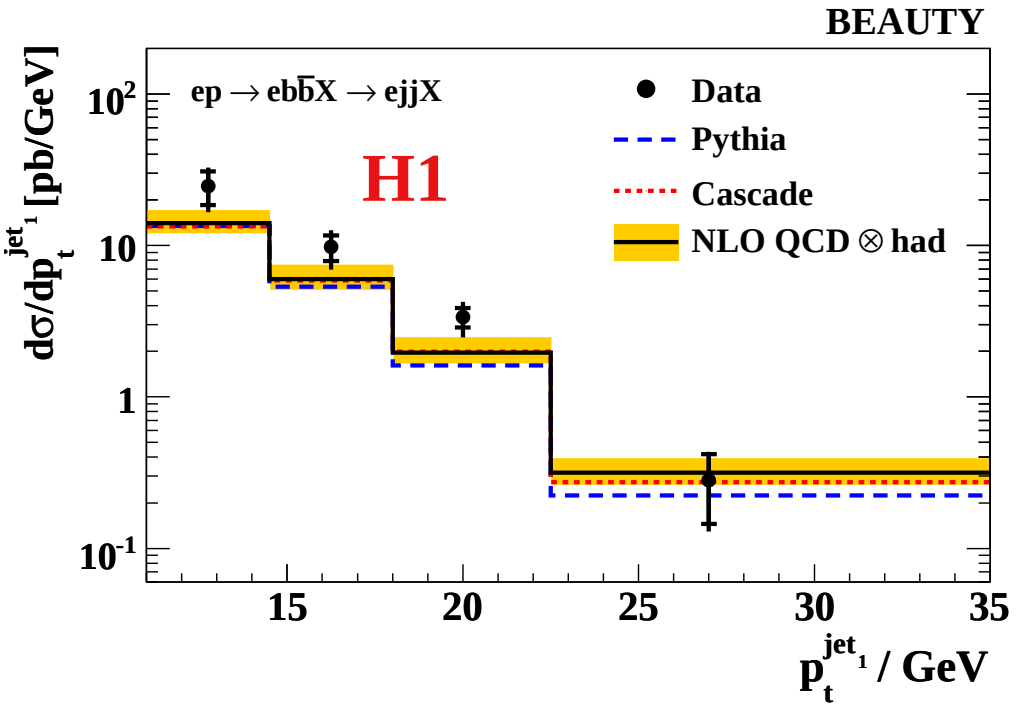
- Pythia and Cascade similar low in normalization as FMNR.

Charm & Beauty in Photoproduction

$d\sigma/dp_t^{jet1}$ ($ep \rightarrow ecc(bb)X \rightarrow ejjX$)

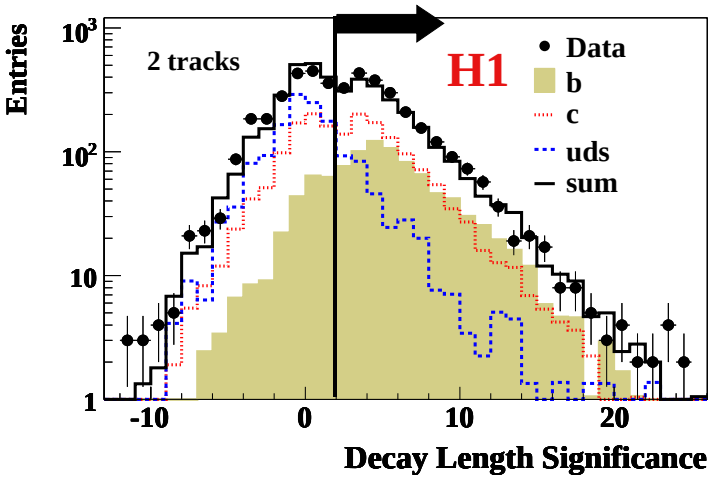
$Q^2 < 1$ GeV^2, $0.15 < y < 0.8$, $p_t^{jet} > 11\ (8)$ GeV, $-0.9 < \eta^{jet} < 1.3$





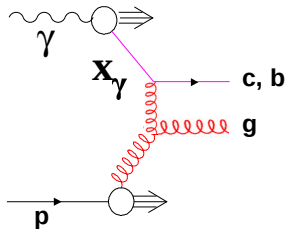
- Highest p_t region ever reached at HERA for charm & beauty jets.
- **Charm**: Larger theory errors, data consistent with NLO. MC models similar to FMNR.
- **Beauty**: Data somewhat higher than all QCD models. Shape well described.

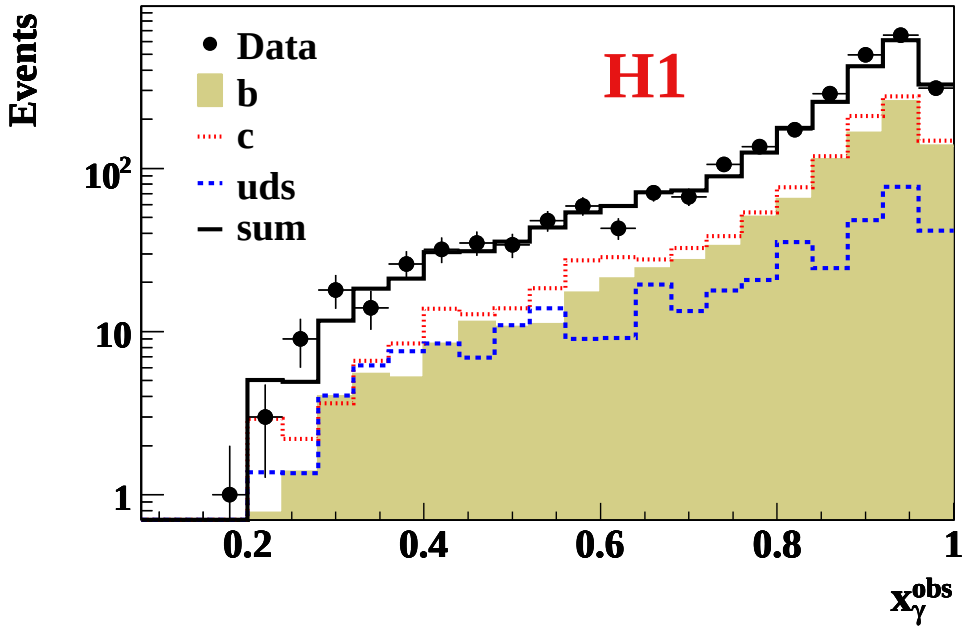
Heavy Quark enriched Sample

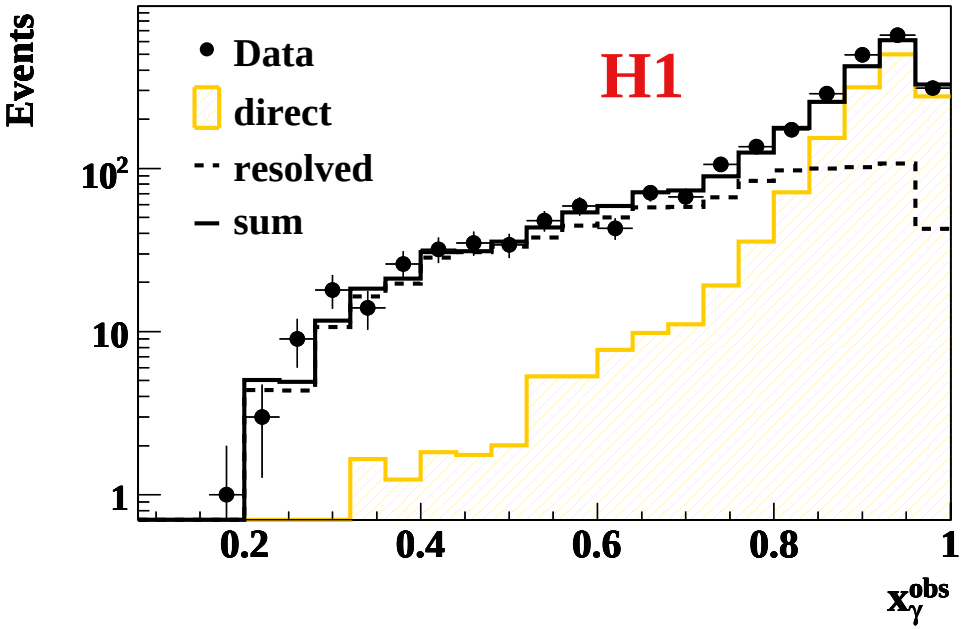


* Explicit **reconstruction of 2nd vertex** of heavy hadron.
  (cross check to impact parameter method)
* Enhance heavy quarks by cut on Decay Length Significance.
* **Heavy Quark sample**: 44% Charm, 41% Beauty, 15% uds.

$$x_\gamma^{obs} = \frac{\sum_{jet_1,jet_2}(E - P_z)}{\sum_{hadrons}(E - P_z)}$$







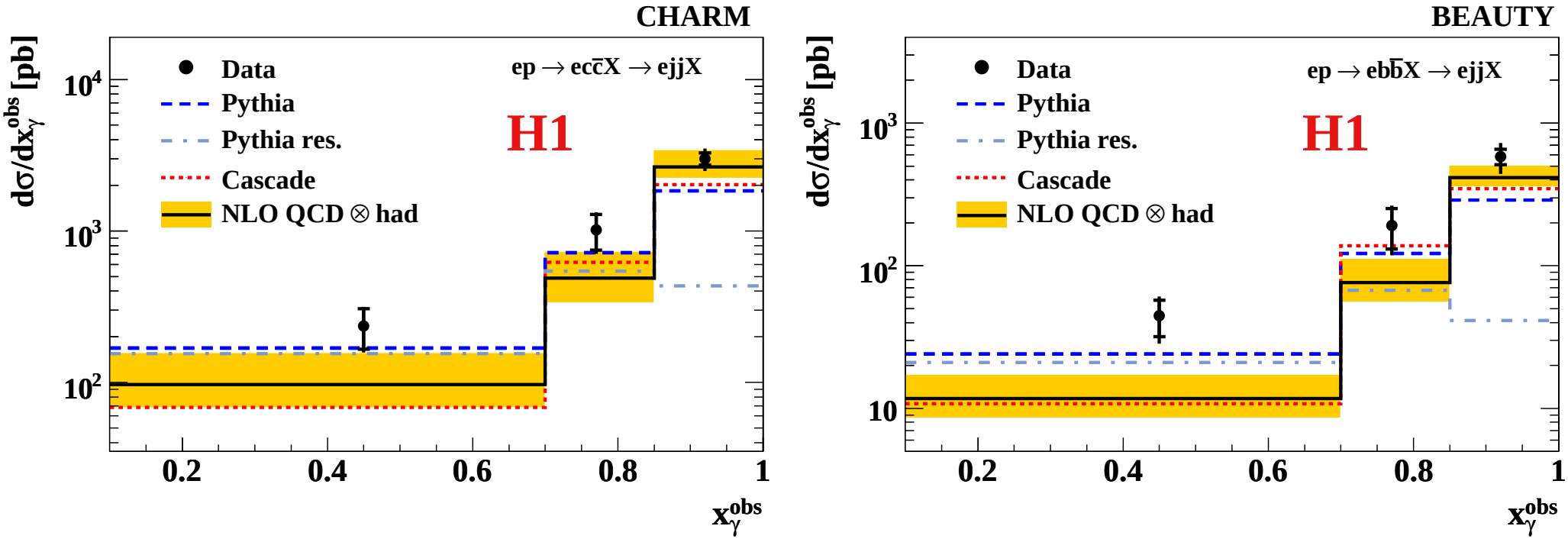
Pythia model: At low x_γ^{obs} a significant contribution comes from **heavy quark excitation**!

Charm & Beauty in Photoproduction

$d\sigma/dx_\gamma^{obs}$ ($ep \rightarrow ecc(bb)X \rightarrow ejjX$)

$Q^2 < 1$ GeV^2, $0.15 < y < 0.8$, $p_t^{jet} > 11\ (8)$ GeV, $-0.9 < \eta^{jet} < 1.3$

$$x_\gamma^{obs} = \frac{\sum_{jet_1,jet_2}(E - P_z)}{\sum_{hadrons}(E - P_z)}$$



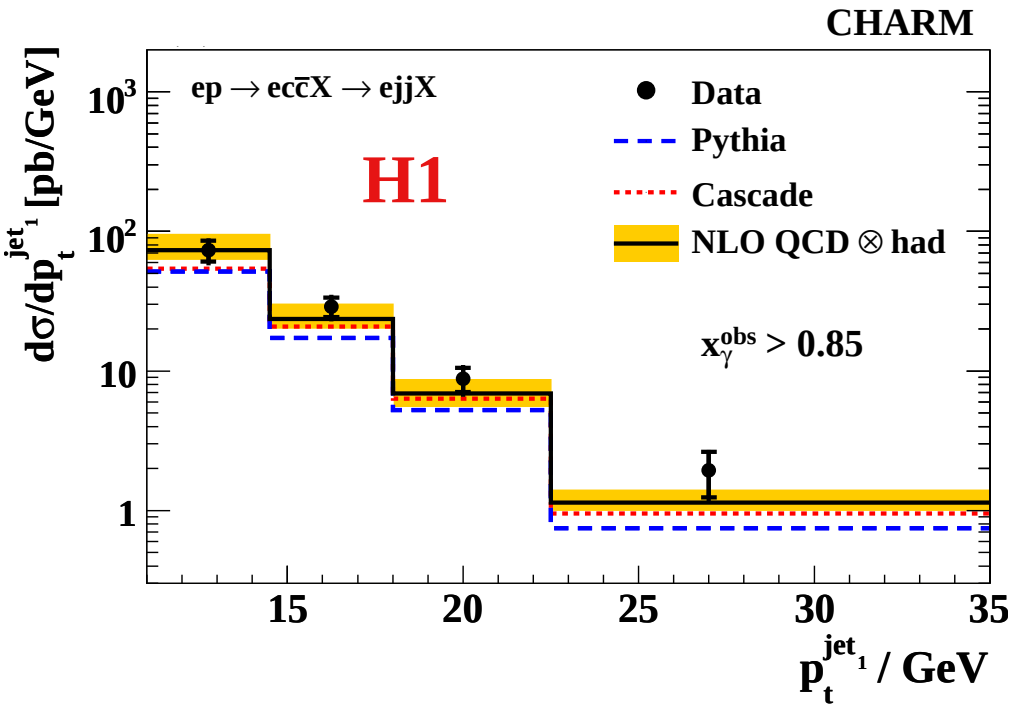
- Data has significant resolved-like component ($x_\gamma^{obs} < 0.85$). Shape nicely described by Pythia, Cascade too hard.
- **Charm**: Large x_γ^{obs} well described by FMNR.
- **Beauty**: FMNR much too low at small x_γ^{obs}.

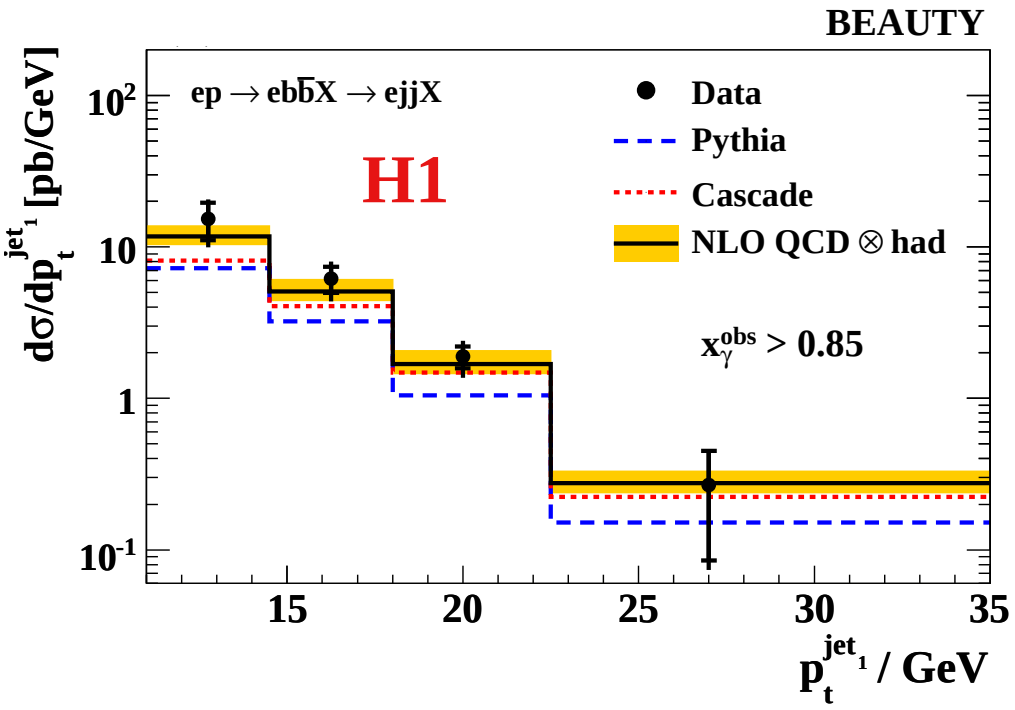
$d\sigma/dp_t^{jet1}$ $(ep \rightarrow ecc(bb)X \rightarrow ejjX)$

Charm & Beauty in Photoproduction

$Q^2 < 1$ GeV^2, $0.15 < y < 0.8$, $p_t^{jet} > 11\ (8)$ GeV, $-0.9 < \eta^{jet} < 1.3$

Supress contributions from resolved photon processes: $\mathbf{x_\gamma^{obs} > 0.85}$



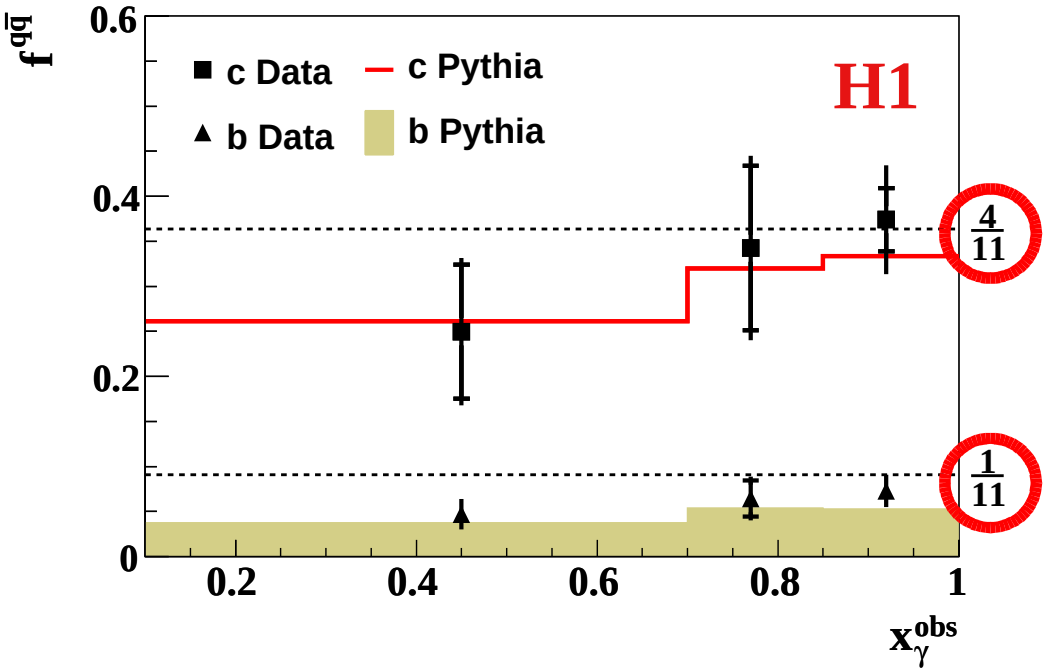


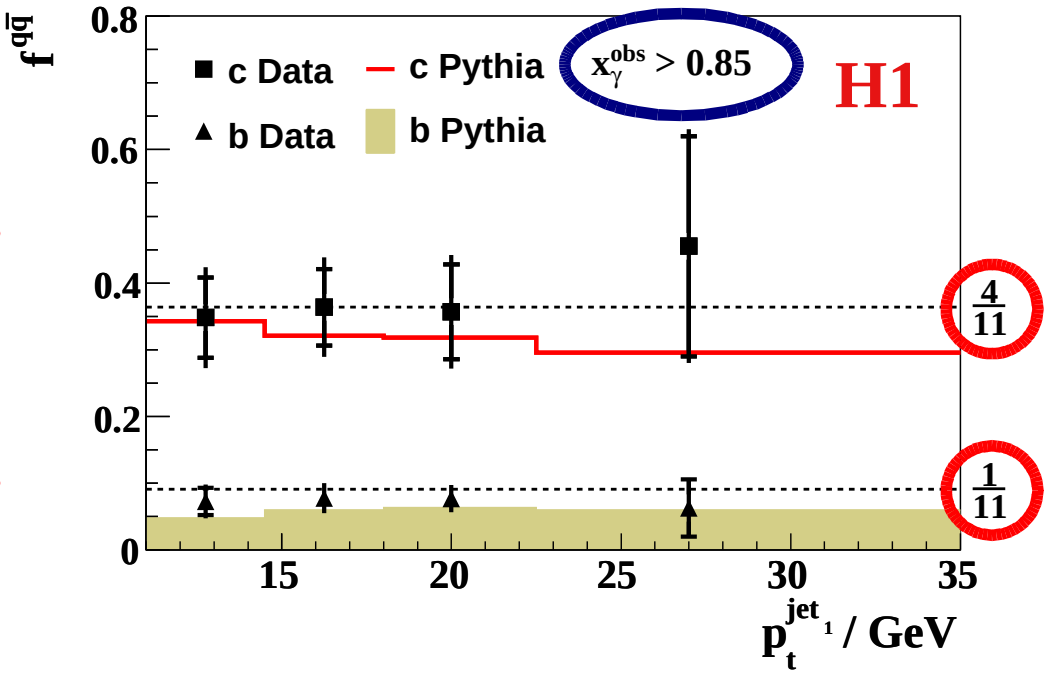
- **Charm**: FMNR gives good description of both, normalization and shape.
- **Beauty**: Data significantly better described by NLO QCD than for whole region of x_γ^{obs}.
- MC models fall below FMNR and data.

$$f^{c\bar{c}} = \frac{\sigma_c}{\sigma_{udscb}} \qquad f^{b\bar{b}} = \frac{\sigma_b}{\sigma_{udscb}}$$

Heavy Quark Fractions

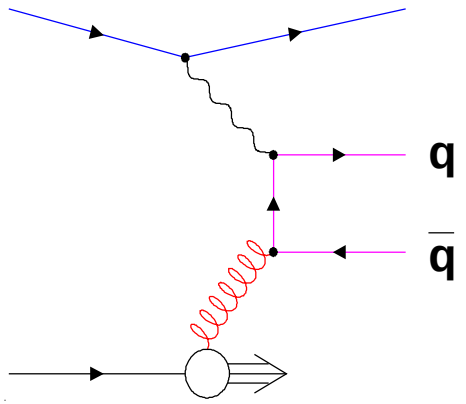
Fractions normalized to **measured** flavor inclusive dijet cross sections.





- Relative charm and beauty fractions increase towards large x_γ^{obs}.
  (where direct photon-gluon processes dominate)
- Constant fractions in the region $x_\gamma^{obs} > 0.85$.
- For $x_\gamma^{obs} > 0.85$: measured ratio is $f^{c\bar{c}} / f^{b\bar{b}} = 5.1 \pm 1.1 (stat.)$

  Consistent with expectation from **naïve quark charge counting** assuming **all quarks to be massless**.



Measurement of charm and beauty dijet cross sections in photoproduction using the H1 Vertex Detector at HERA.

Conclusions

To be submitted to Eur., Phys., J. C in April 2006

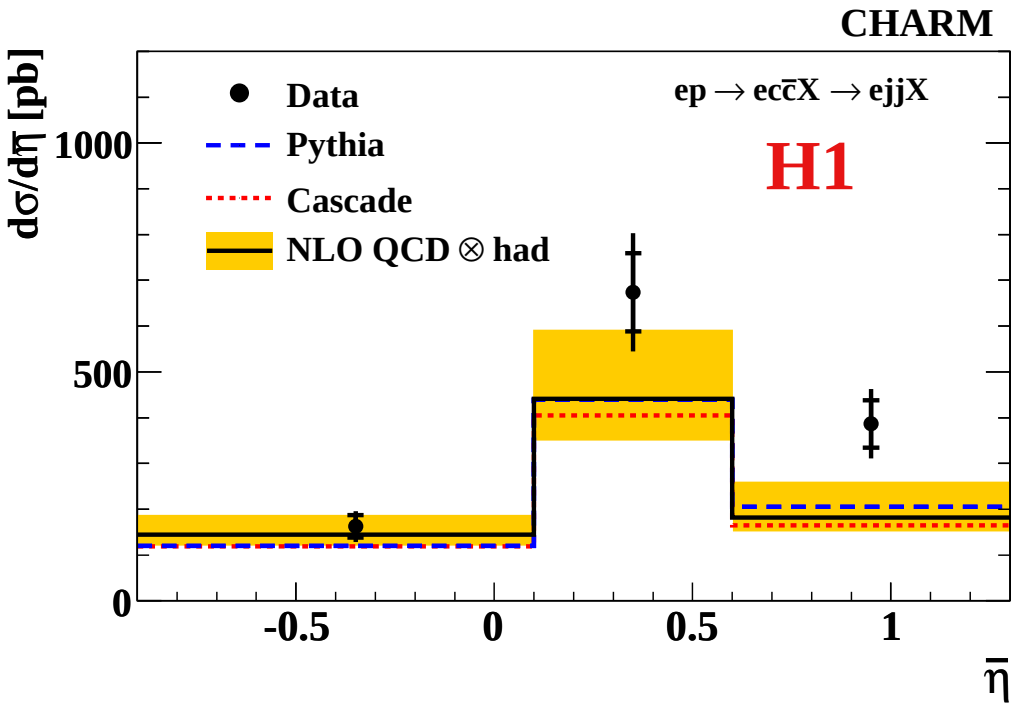
* Charm:
  - Data consistent with NLO calculations (normalization and shape) taking the (large) theory uncertainties into account.
* Beauty:
  - Data found somewhat (1.6 σ) higher than NLO prediction. Shape well described.
  - Main differences seen at low x_γ^{obs} .
  - For high x_γ^{obs} differential cross sections as functions of p_t and η (not shown in talk) seen to be consistent with NLO.
* Fractions:
  - Relative charm and beauty fractions seen to be constant.
  - Measured charm and beauty fractions at high x_γ^{obs} consistent with values 4/11 and 1/11, i.e. the naïve expectation for the bgf process for massless quarks.

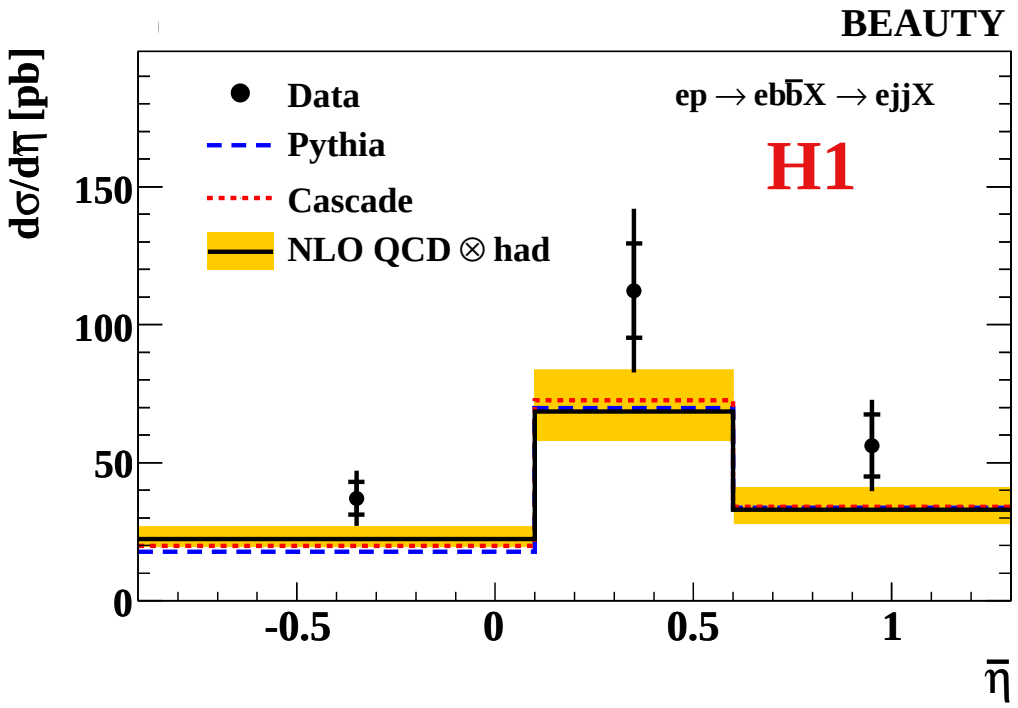
Addendum

dσ/dη̄ (ep → ecc(bb)X → ejjX)

Charm & Beauty in Photoproduction

$Q^2 < 1$ GeV^2, $0.15 < y < 0.8$, $p_t^{jet} > 11$ (8) GeV, $-0.9 < \eta^{jet} < 1.3$





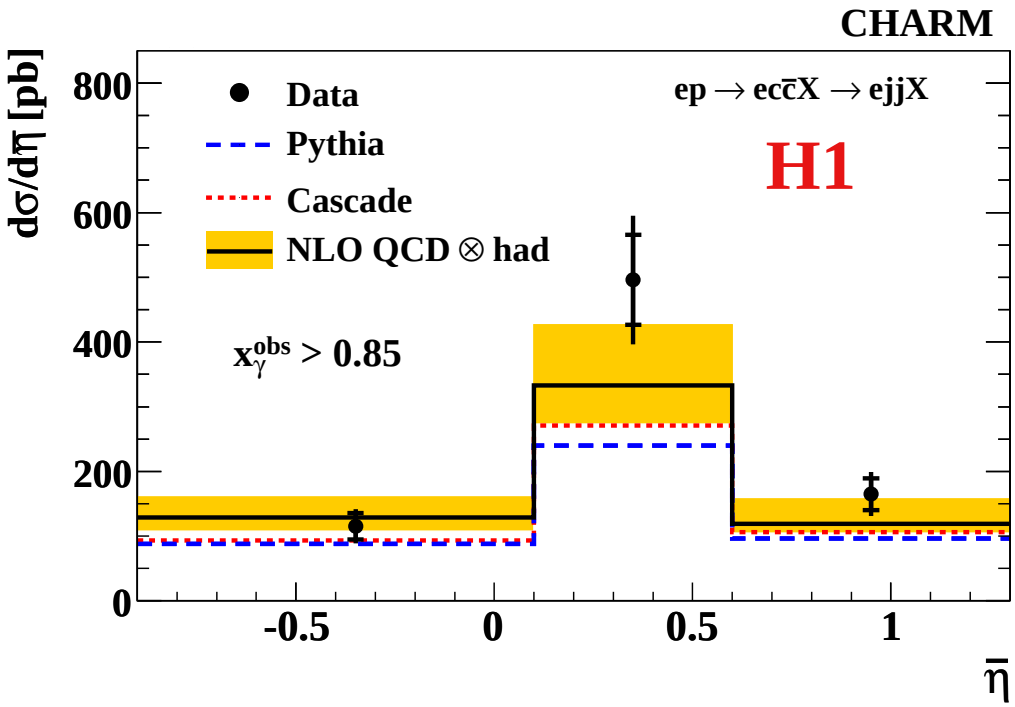
- Mean pseudo-rapidity of the two leading jets η̄.
- **Charm**: Larger theory errors, data consistent with NLO. MC models similar to FMNR.
- **Beauty**: Data somewhat higher than all QCD models. Shape well described.

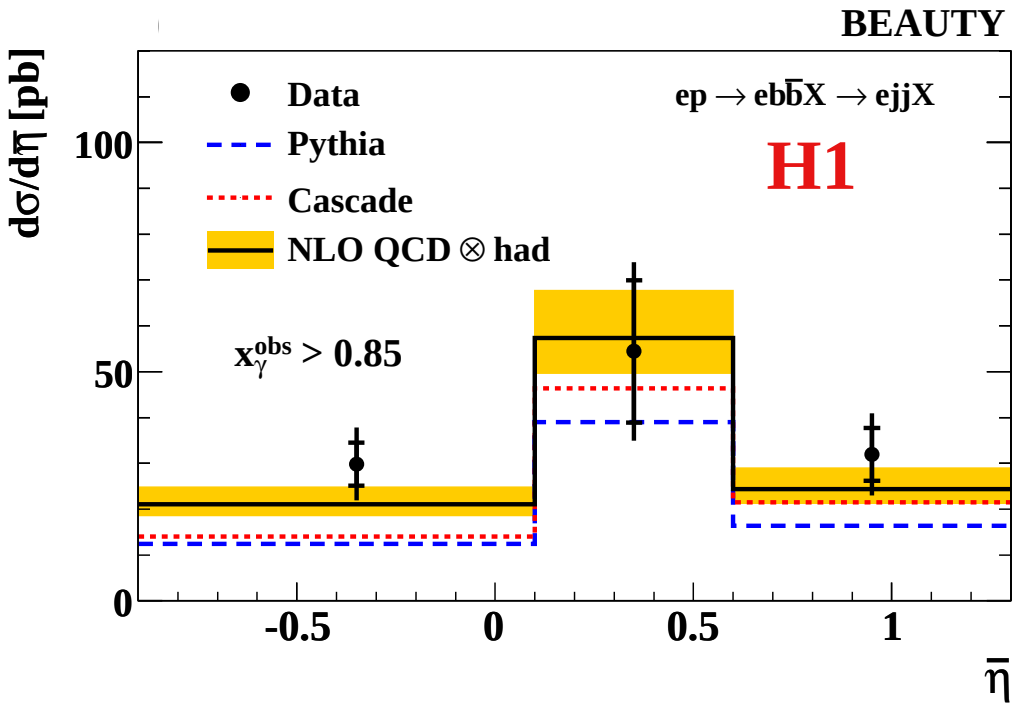
dσ/dη̄ (ep → ecc(bb)X → ejjX)

Charm & Beauty in Photoproduction

$Q^2 < 1$ GeV^2, $0.15 < y < 0.8$, $p_t^{jet} > 11$ (8) GeV, $-0.9 < \eta^{jet} < 1.3$

Supress contributions from resolved photon processes: $x_\gamma^{obs} > 0.85$

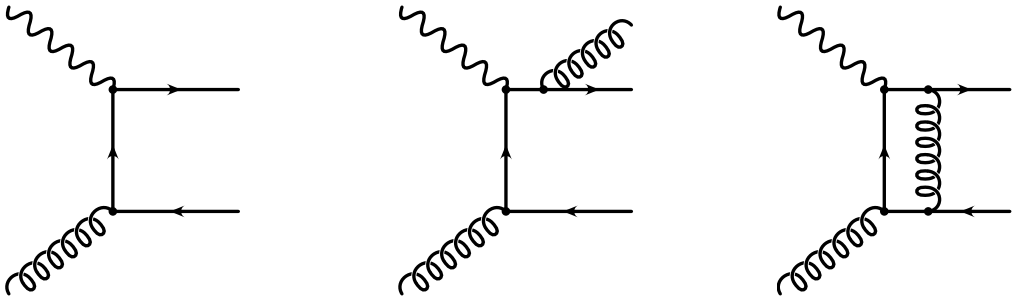




- **Charm**: Data consistent with FMNR.
- **Beauty**: Data nicely described by NLO QCD (better than for whole region of x_γ^{obs}).
- MC models fall below FMNR and data.

NLO Calculations

* FMNR: fixed order massive calculation: BGF + HO.



* Calculations done using CTEQ5F3, GRV-HO and m_c = 1.5 GeV, m_b = 4.75 GeV.

* Scales: $\mu_r = \mu_f = m_t = \sqrt{m_q^2 + p_{t,q\bar{q}}^2}$

* p_t weighted k_t clustering jet algorithm used.

* Perturbative uncertainties estimated by variation of the scales μ_f and μ_r (½ – 2).

* Parameter uncertainties estimated by variations of the quark masses and the pdf.

* Parton to hadron corrections done using PYTHIA.

* Total uncertainties: 30 – 35 % for charm and 20 – 25 % beauty.