Beauty and charm production at HERA with lifetime tag

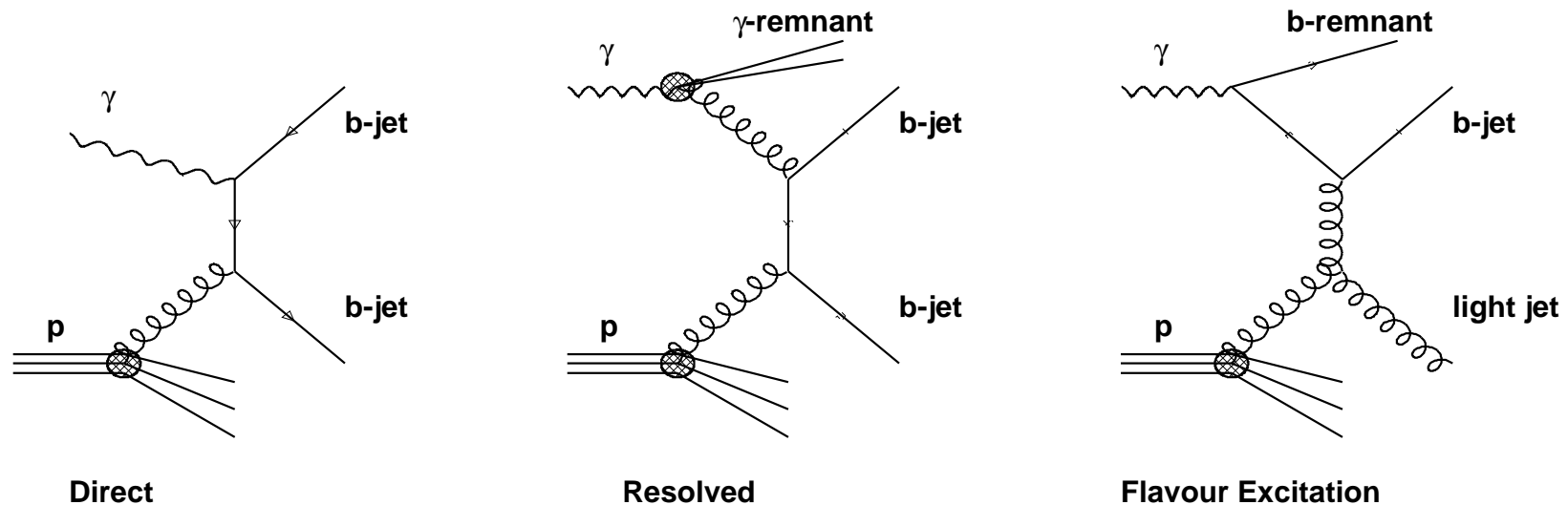## Massimo Corradi (INFN Bologna)

For the H1 and ZEUS collaborations

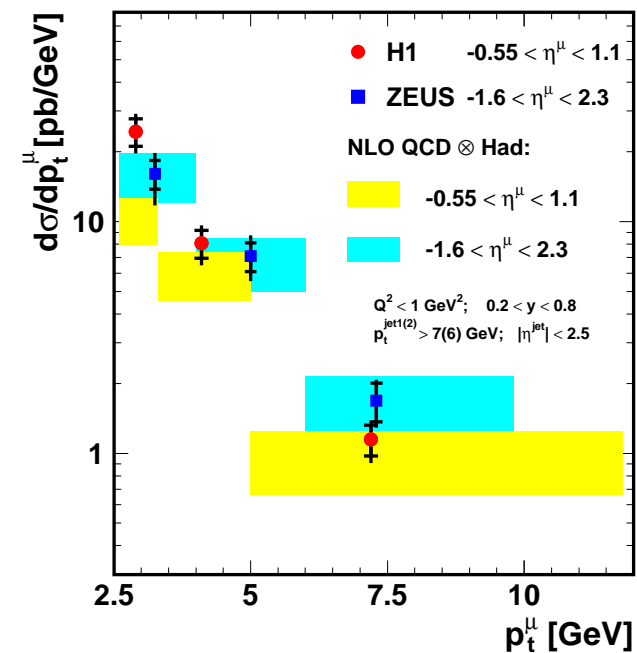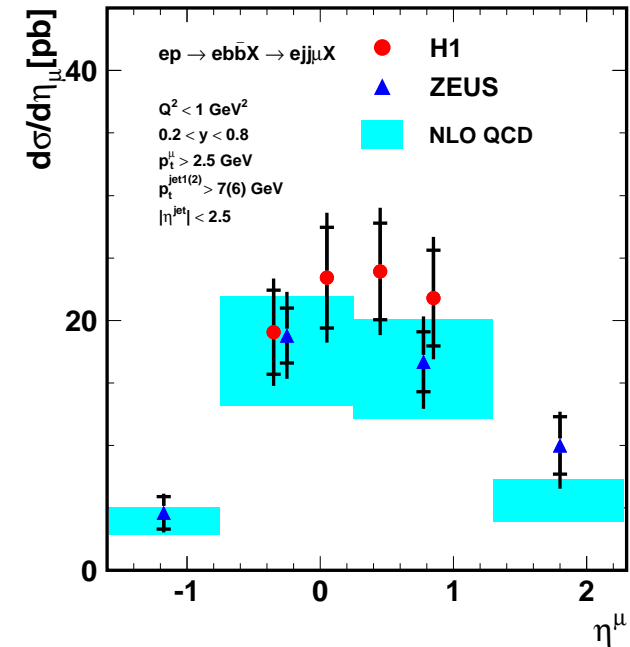## b photoproduction in events with two jets at HERA

QCD is expected to make reliable predictions for b production: $m_b \sim 4.75$ GeV provides a large scale for perturbative calculations

| Direct | Resolved | Flavour Excitation |

- **LO: Direct- + Resolved- photon diagrams**

- **full NLO program available (FMNR)**
  produces weighted events containing Q, $\bar{Q}$ (+ g)
  jets obtained by running jet algorithm on partons
  correction to hadron level O(5%), taken from MC
  μ obtained by folding Q with FF (Peterson) and SL decay

- **Pythia MC LO + PS, includes Flavour Excitation (FE) diagrams**

Old and new results

- $ep \rightarrow e'b\bar{b}X \rightarrow e'jj\mu X'$
  measured with muons by H1 and ZEUS in HERA-I data (see talk by B. Naroska)

- Good agreement with NLO except H1 at low P_T^μ and low p_T^{jet}

- Two new results on b (and c) photoproduction associated to two jets presented here:

  - **ZEUS measurement with HERA-II data, using the microvertex detector (MVD)**

  - **H1 measurement with inclusive lifetime tag, without any muon requirement**

ep → eb̄bX → ejjµX

$Q^2 < 1$ GeV^2
$0.2 < y < 0.8$
$p_t^\mu > 2.5$ GeV
$p_t^{\text{jet1(2)}} > 7(6)$ GeV
$|\eta^{\text{jet}}| < 2.5$

H1
ZEUS
NLO QCD

$d\sigma/d\eta_\mu$ [pb]

η^μ

H1 $-0.55 < \eta^\mu < 1.1$
ZEUS $-1.6 < \eta^\mu < 2.3$

NLO QCD ⊗ Had:

$-0.55 < \eta^\mu < 1.1$
$-1.6 < \eta^\mu < 2.3$

$Q^2 < 1$ GeV^2; $0.2 < y < 0.8$
$p_t^{\text{jet1(2)}} > 7(6)$ GeV; $|\eta^{\text{jet}}| < 2.5$

$d\sigma/dp_t^\mu$ [pb/GeV]

p_t^μ [GeV]

ZEUS measurement with HERA-II data

- **Upgraded HERA-II, large Lumi:**
  ZEUS gated 03-04 e^+p $\mathcal{L} = 38$ pb^{-1}
  ZEUS gated 04-05 e^-p $\mathcal{L} > 82$ pb^{-1}

- **ZEUS silicon microvertex detector (MVD), taking physics from 2003**

- **first quantitative results from MVD shown here**

ZEUS Luminosity 2002 - 2005

XY View

ZR View
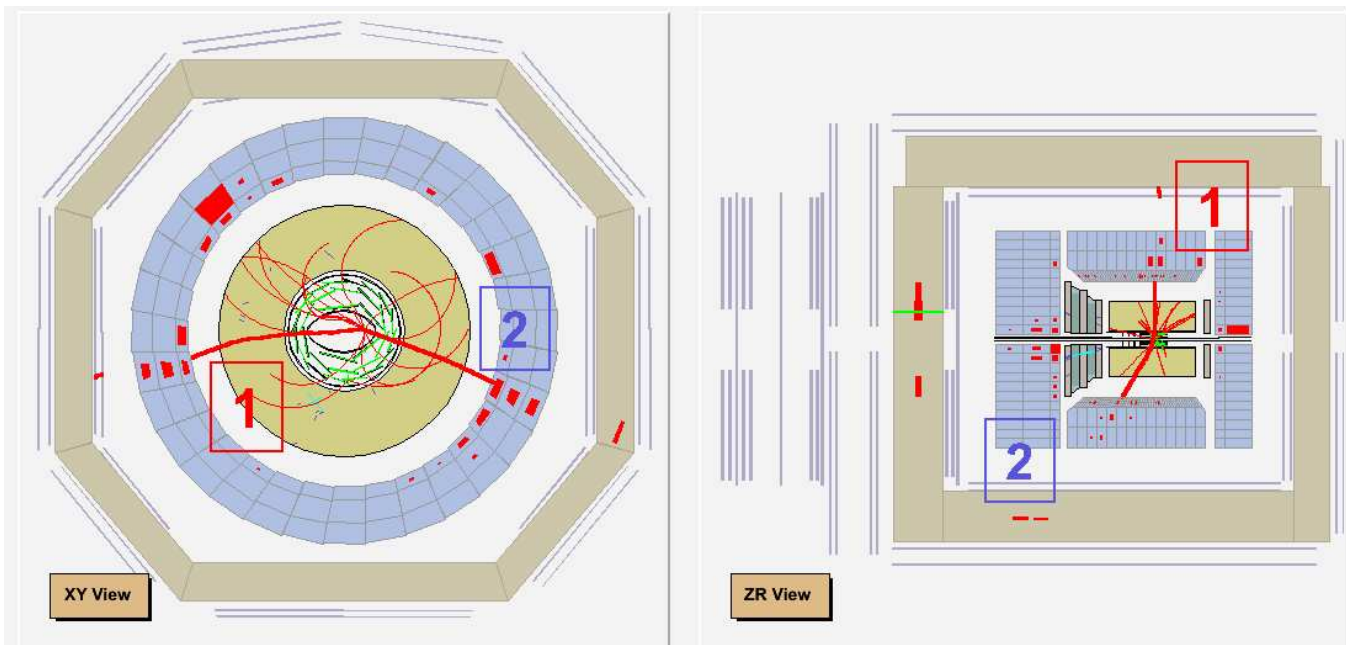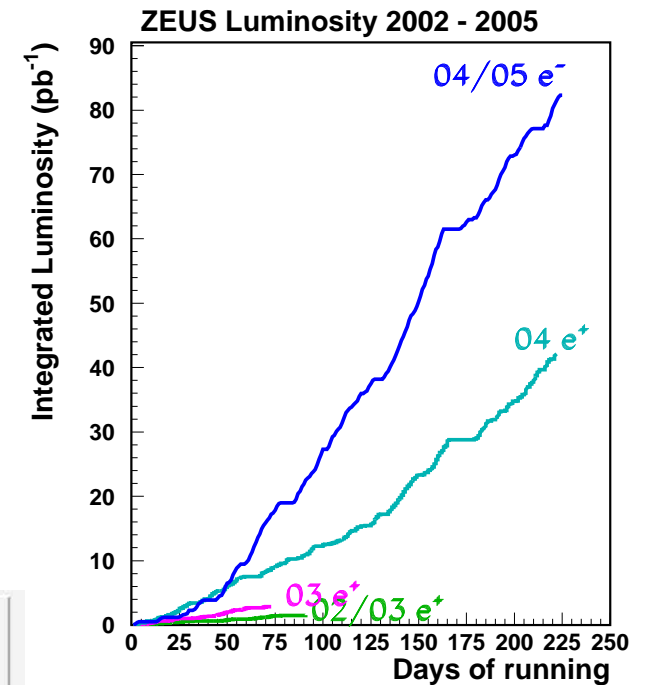
The dijet-plus-muon sample

- $\mathcal{L} = 33$ pb^{-1} of 2004 e^+p data

- **DIS removed,** $0.2 < y_{jb} < 0.8$

- ≥ 2 **jets with** $p_T^{j_1, j_2} > 7, 6$ **GeV**
  K_T **agorithm on EFOs**

- ≥ 1**muon** $p_T^\mu > 2.5$**GeV**
  segment in Rear/Barrel/Forward
  MUON chambers matched to a
  central track
  with ≥ 4 **hits in the MVD**

- μ **associated to a jet by** K_T **algo.**

- **1806 events left**

- **the sample contains**
  μ**s from SL decays of** b **and** c,
  fake μ **from punch-through and**
  in-flight decays of $\pi^\pm$, $K^\pm$
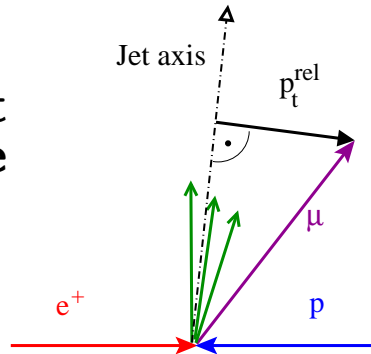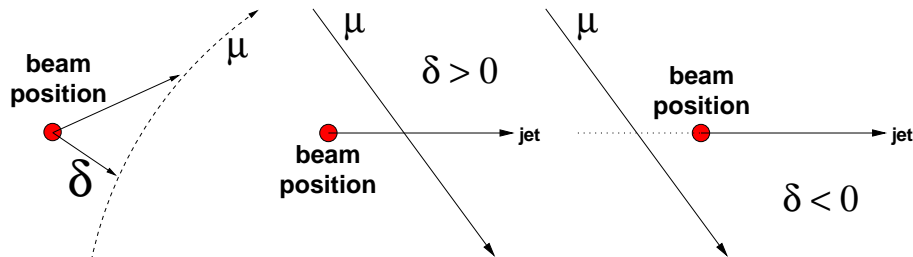
- **reproduced by Pythia 6.2 MC**
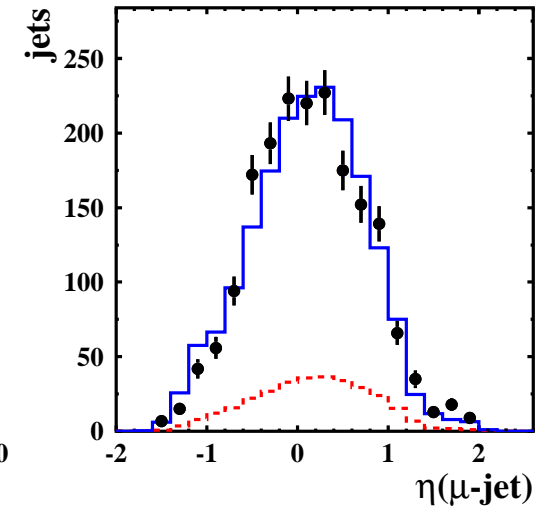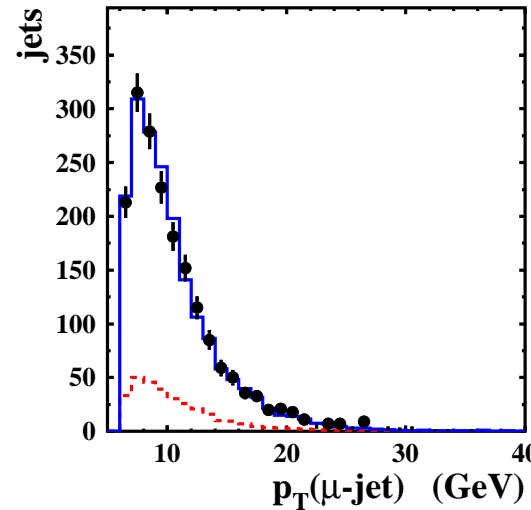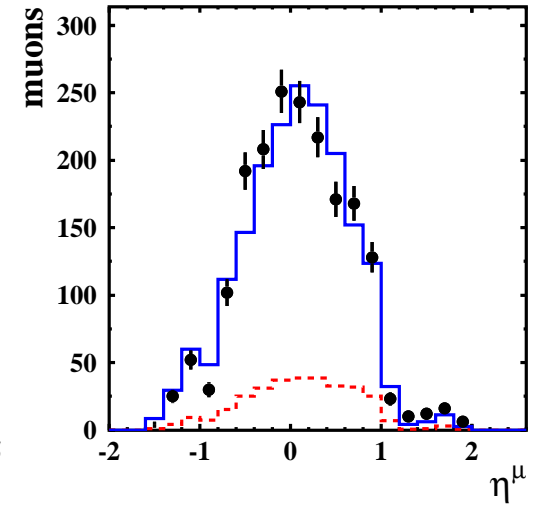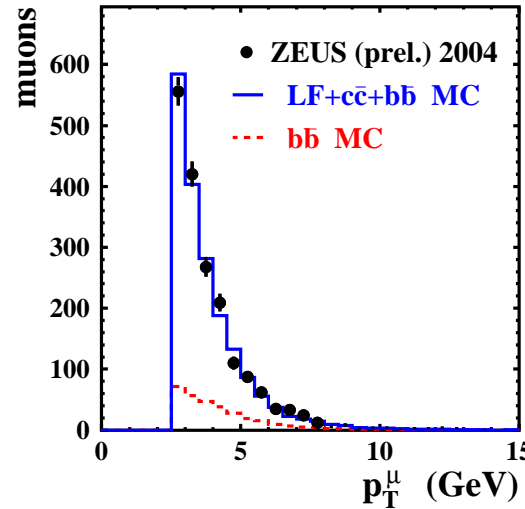
Extraction of the b and c content

- **A combination of two variables is used to extract the beauty and charm content:**

- $p_T^{\rm rel}$: p_T of μ w.r.t. the jet axis. Large for b decays due to large b mass
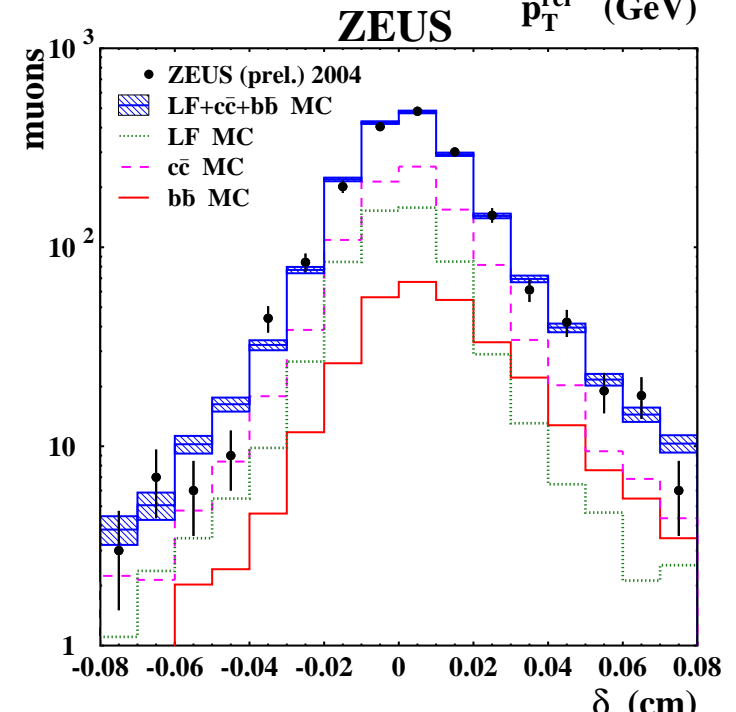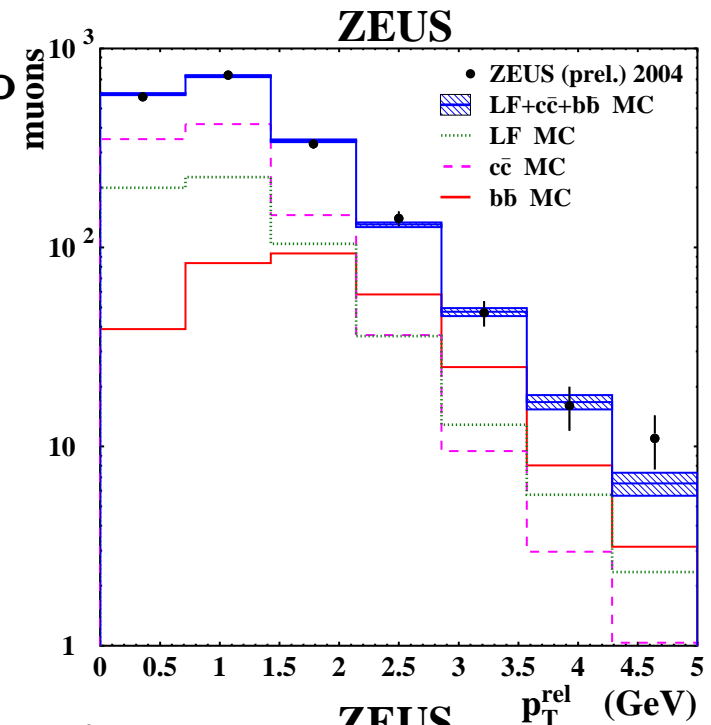

- **Signed muon impact parameter δ w.r.t. beam position in X, Y Sign defined based on the jet direction Beam position measured run-by-run beam size: $\sigma_X = 110\mu m$, $\sigma_Y = 30\mu m$,**

Light-flavours symmetric around zero

Positive tail for b, c due to lifetime.

Combined fit of p_T^{rel} and δ

- **Combined 2D fit to p_T^{rel} and δ**

- **Pythia 6.2 templates for b, c and light flavours (LF)**
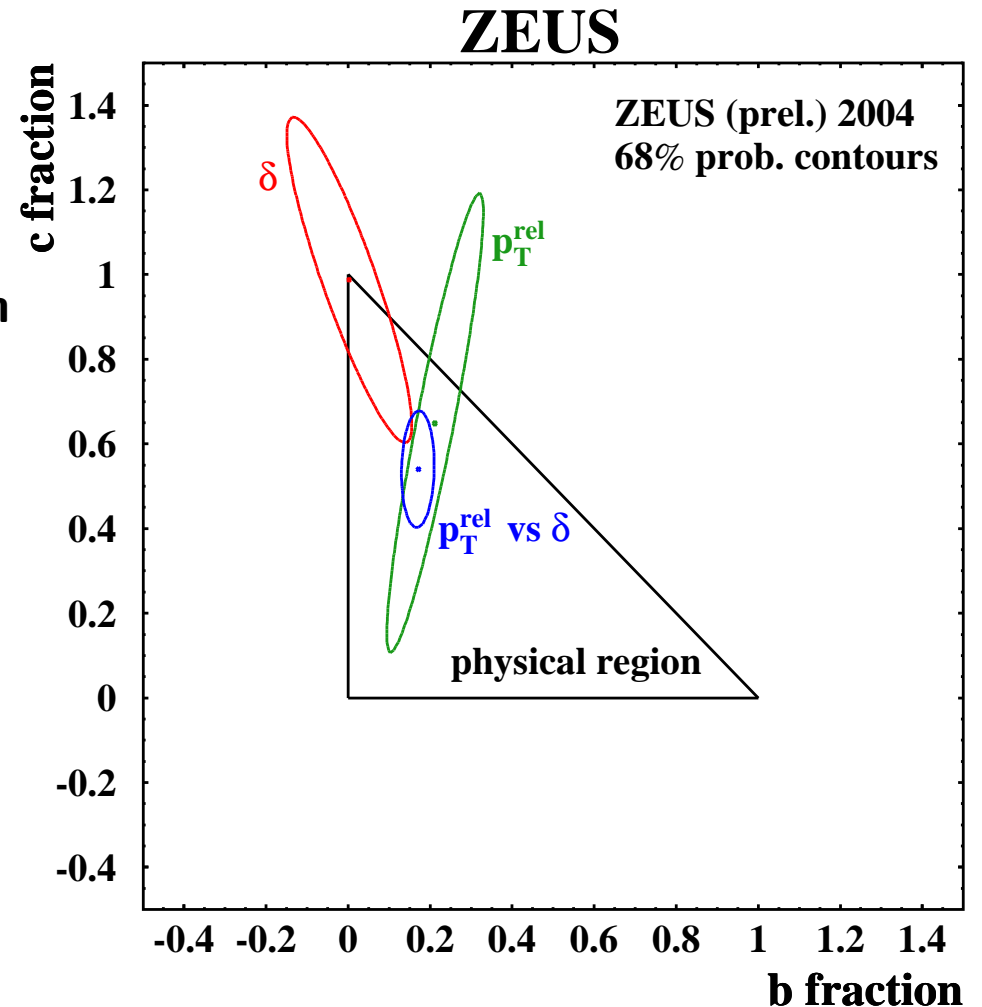
  Resolution on δ in MC modeled on inclusive data

  Correction of p_T^{rel} shape for LF MC based on inclusive dijet data

- **Result:**

$$f_b = (16.7 \pm 2.6)\% \quad f_c = (52 \pm 10)\%$$

.

- **Fits of p_T^{rel} or δ alone are compatible but less precise**

Results

- $d\sigma/dp_T^\mu$ **for** $ep \to e'b\bar{b}X \to e'jj\mu X'$
  $Q^2 < 1\textbf{GeV}^2$, $0.2 < y < 0.8$
  $p_T^{j_1,j_2} > 7,6\textbf{GeV}$, $\eta^j < 2.5$
  $p_T^\mu > 2.5\textbf{GeV}$, $-1.6 < \eta^\mu < 2.3$

- **main syst. uncertainty:**
  μ **chamber efficiency (15%)**
  (rommfor future improvement)

- **Agreement with NLO QCD (FMNR)**
  $+$ **hadronisation corr.**

- **Agreement with HERA-I ZEUS data**
  based on ~ 3 **times larger luminosity.**

  In the old measurement p_T^{rel} **was used**
  in combination with an external con-
  straint on f_c. **Here** f_c **is obtained from**
  the same data.

- **No hint for an excess at low** p_T^μ,
  acceptance at low p_T^μ **improved w.r.t.**
  prev. measurement

ZEUS

- ZEUS (prel.) 2004
- ZEUS 96-00
- NLO QCD x had

$d\sigma/dp_T^\mu$ (pb/GeV)

p_T^μ (GeV)
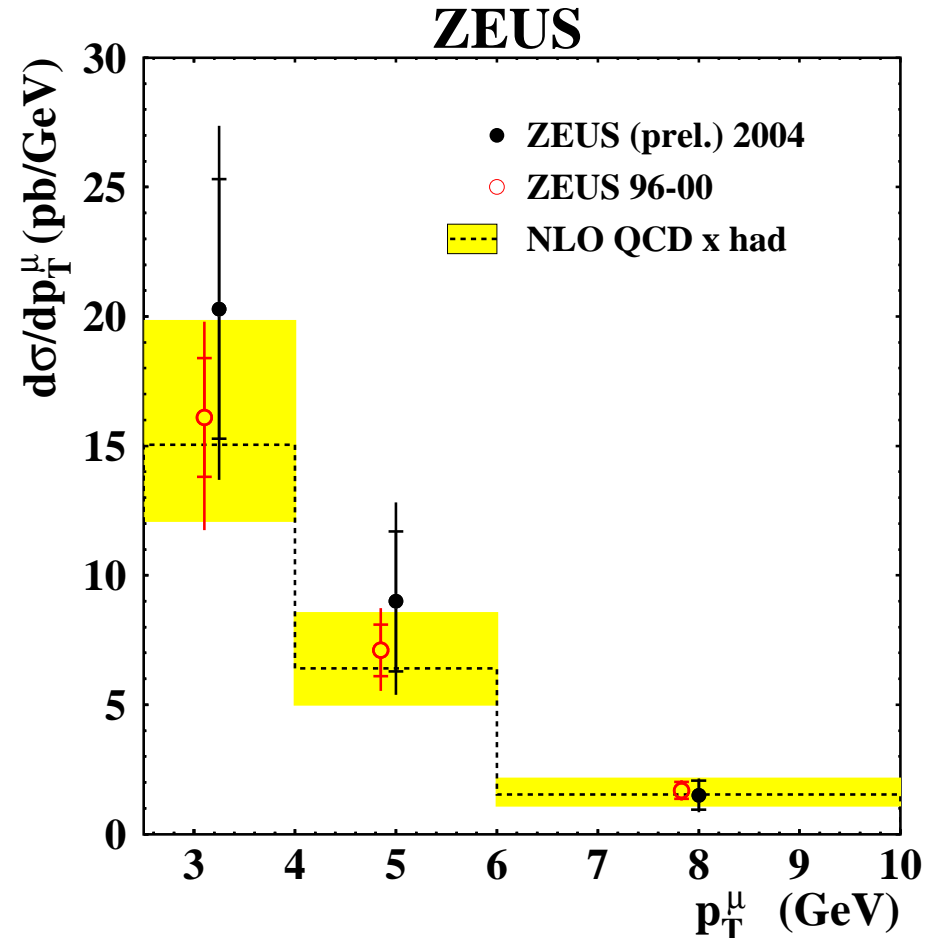
H1 measurement with inclusive lifetime tag

- $\mathcal{L} = 57.7\text{pb}^{-1}$ **of 99-00 data**

- **No DIS e** $(Q^2 < 1\text{GeV}^2)$, $0.15 < y < 0.8$

- ≥ 2 **jets with** $p_T^{j_1,j_2} > 11, 8$ **GeV,** $-0.88 < \eta^j < 1.3$

- ≥ 1 **central tracks with** $r - \phi$ **hits in the central silicon tracker (CST),** $p_T > 0.5\text{GeV}$ **and** $30^o < \Theta < 150^o$

- **jet-track association by cut on** $\triangle R$ **in** $\eta\phi$
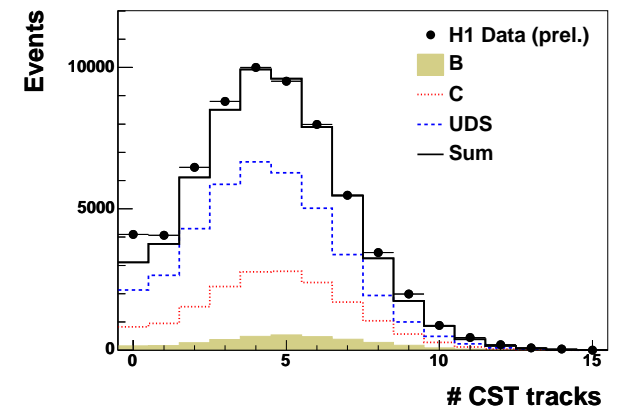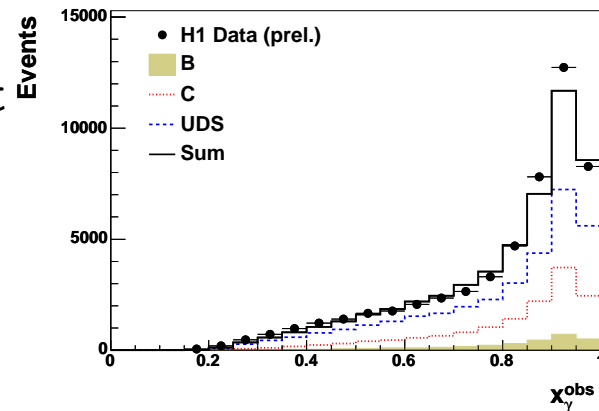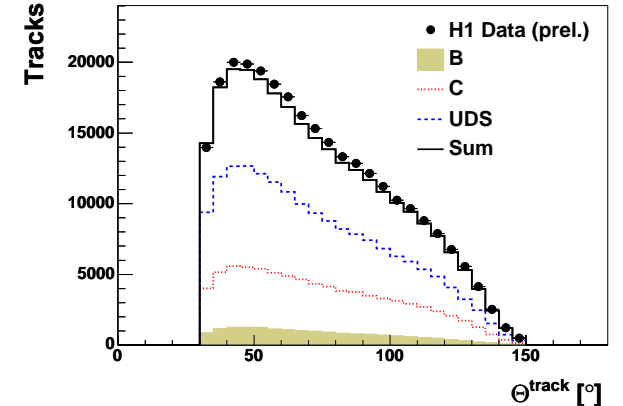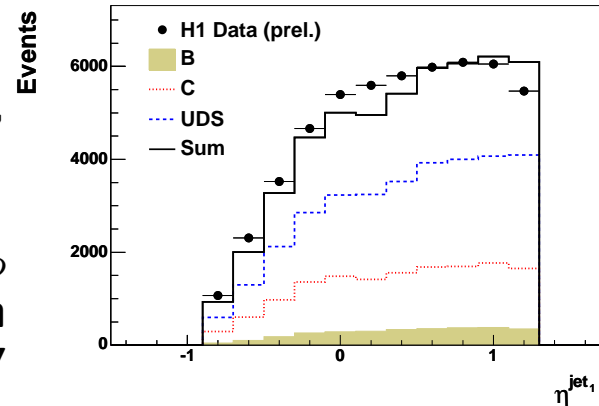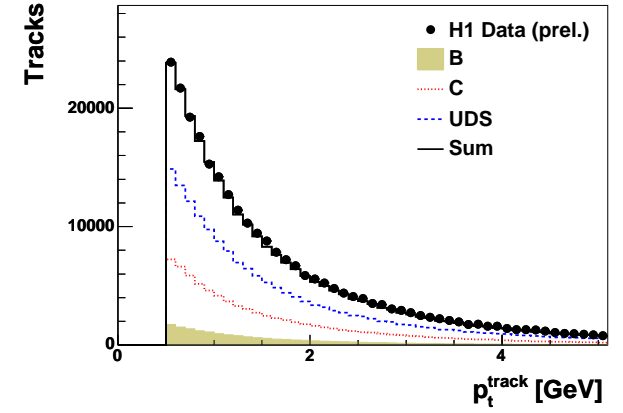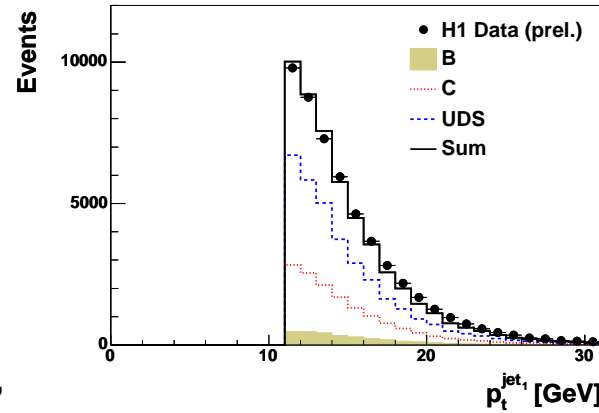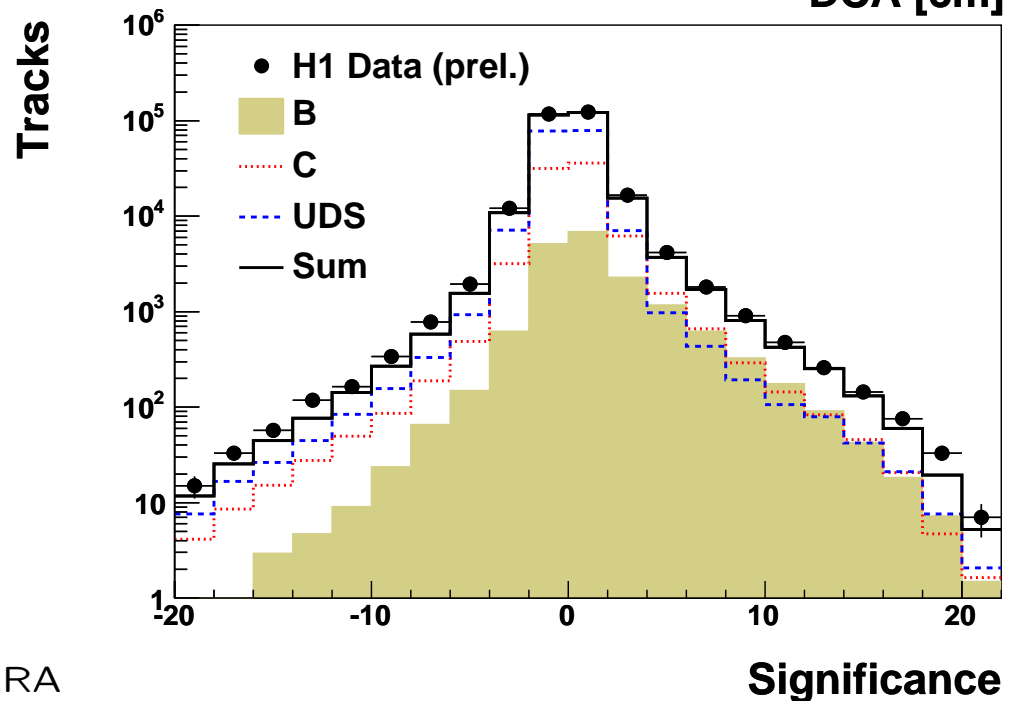
Inclusive track impact parameter

- **Impact parameter defined as the DCA of the track w.r.t. the beam position in X, Y**

  Beam position measured with $5\mu m$ accuracy, beam size: $\sigma_X = 145\mu m$, $\sigma_Y = 25\mu m$

  Sign defined w.r.t associated jet

- **Impact Parameter significance $S = DCA/\sigma_{DCA}$ use only tracks with $|DCA| < 1mm$**
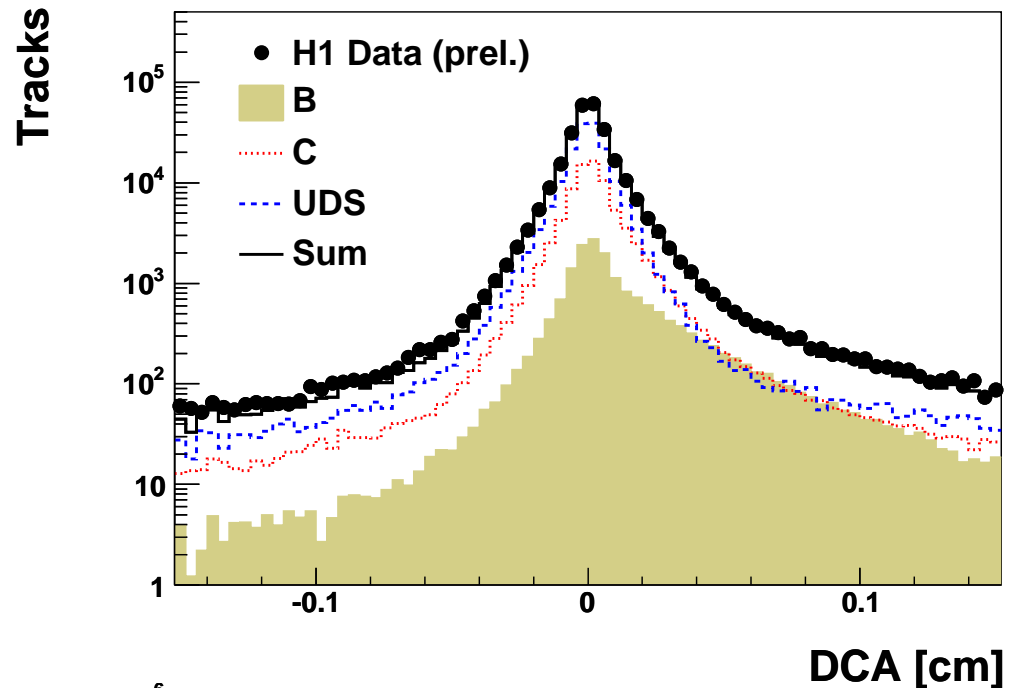
Extraction of beauty and charm content

- **Significance of second-highest significance track S_2 used to extract b and c content. If only 1 track, S_1 is used instead $S_1 S_2 > 0$**

- **To reduce dependence from tracking resolution**

  negative S mirrored and subtracted from positive

- **χ^2 fit with fixed normalisation Templates for b, c, LF taken from Pythia MC**
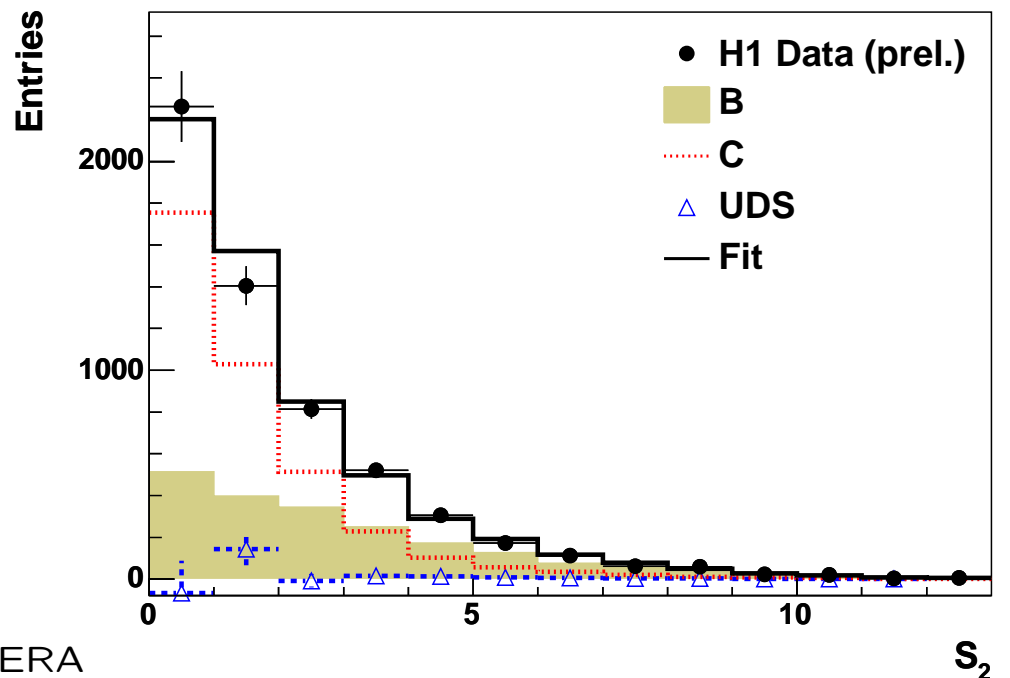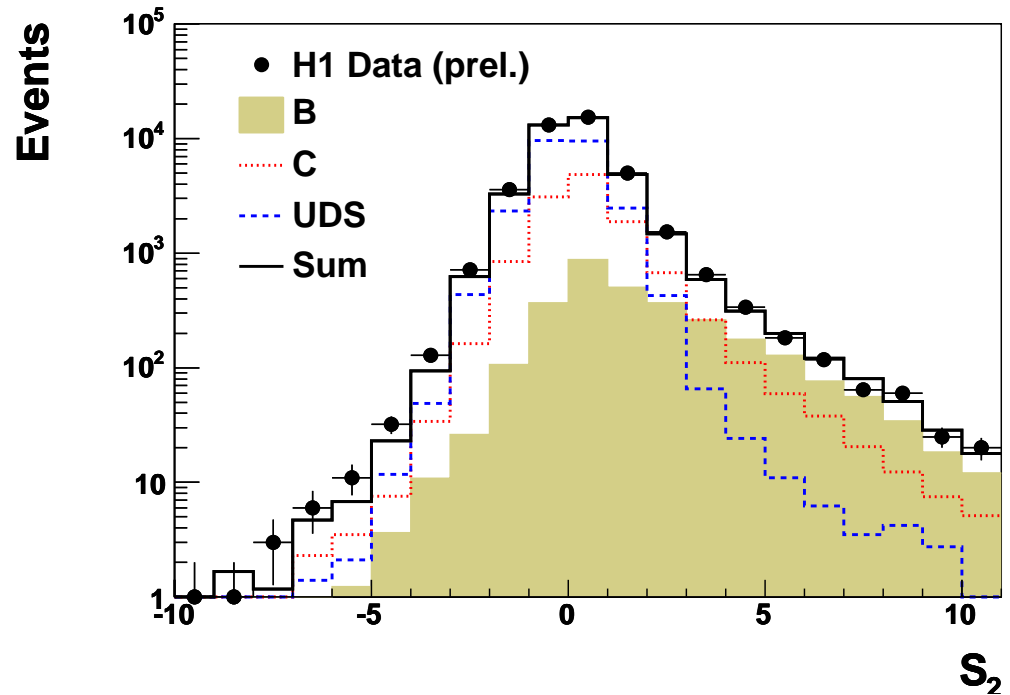
Charm cross sections

- **Cross sections for**
  $ep \rightarrow e'c\bar{c}X \rightarrow e'jjX'$
  $Q^2 < 1\textbf{GeV}^2$, $0.15 < y < 0.8$,
  ≥ 2 **jets,** $p_T^{j_1,j_2} > 11, 8$ **GeV,**
  $-0.88 < \eta^j < 1.3$:

  $\sigma(c\bar{c}) = 694 \pm 69(\text{stat.}) \pm 96(\text{syst.}) \, \text{pb}.$

- **Good agreement with NLO QCD (FMNR) with hadronisation corr.**

- **QCD uncertainty band:**
  $1.3 < m_c < 1.5$ **GeV**
  $\mu_F = 2\mu_R = (0.5...2)\sqrt{m_c^2 + p_T^2}$
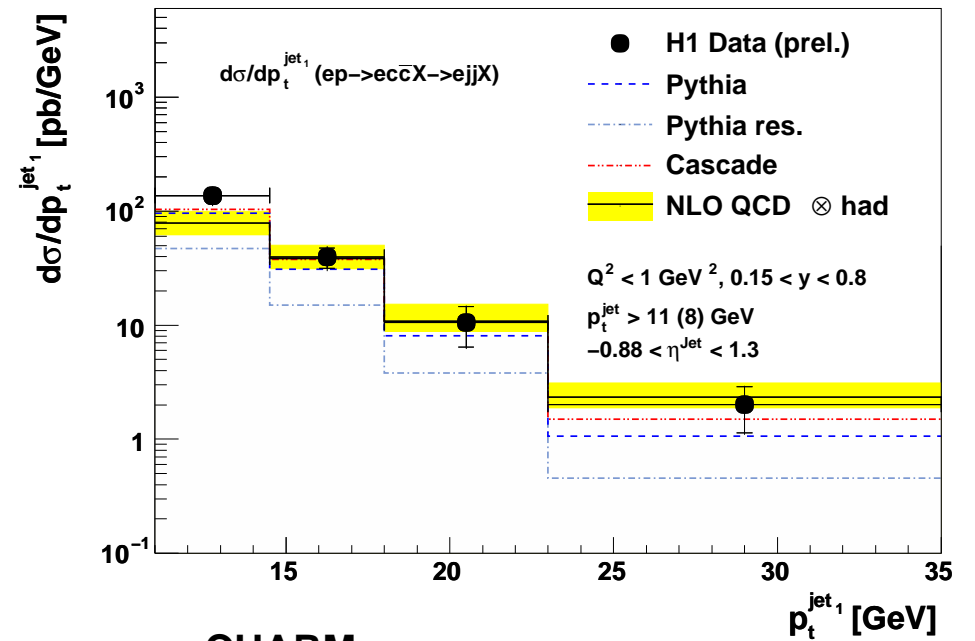
Beauty cross sections

- **Cross sections for**

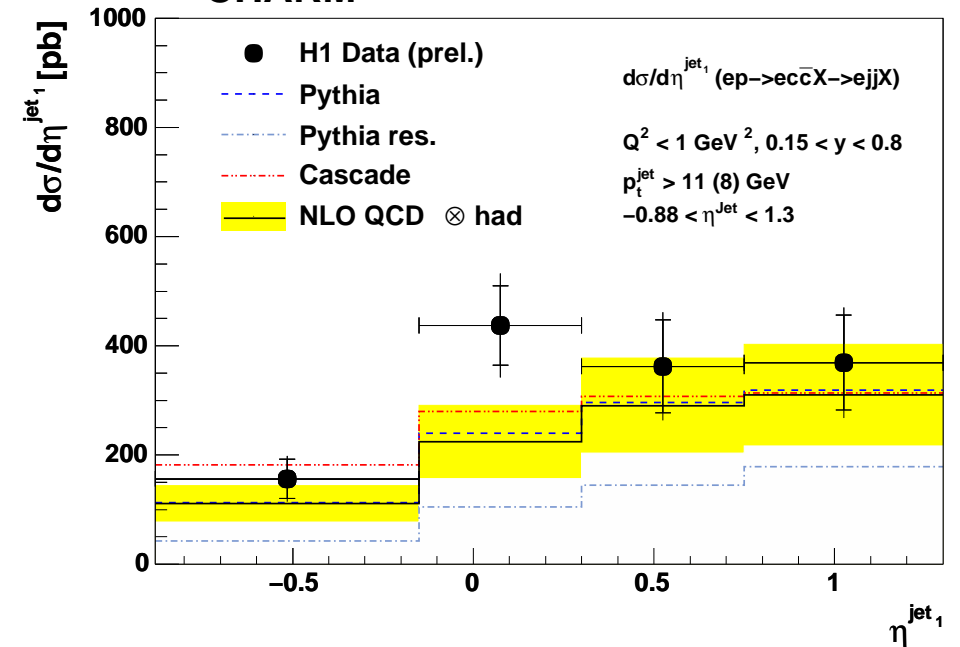 $$ep \rightarrow e'b\bar{b}X \rightarrow e'jjX'$$

  $$\sigma(b\bar{b}) = 145 \pm 18(\text{stat.}) \pm 30(\text{syst.}) \, \text{pb.}$$

- **1-2 sigma above NLO-QCD at low $p_T^{j_1}$, large η^{j_1} regions where resolved-photon contribution is large...**

- **QCD uncertainty band:**
  $4.5 < m_b < 5$ GeV
  $$\mu_F = \mu_R = (0.5...2)\sqrt{m_b^2 + p_T^2}$$

BEAUTY

$d\sigma/dp_t^{jet_1}$ (ep–>eb$\bar{b}$X–>ejjX)

- H1 Data (prel.)
- Pythia dir. + res.
- Pythia res.
- Cascade
- NLO QCD $\otimes$ had

$Q^2 < 1$ GeV^2, $0.15 < y < 0.8$
$p_t^{jet} > 11$ (8) GeV
$-0.88 < \eta^{jet} < 1.3$

BEAUTY

$d\sigma/d\eta^{jet_1}$ (ep–>eb$\bar{b}$X–>ejjX)

- H1 Data (prel.)
- Pythia dir. + res.
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$Q^2 < 1$ GeV^2, $0.15 < y < 0.8$
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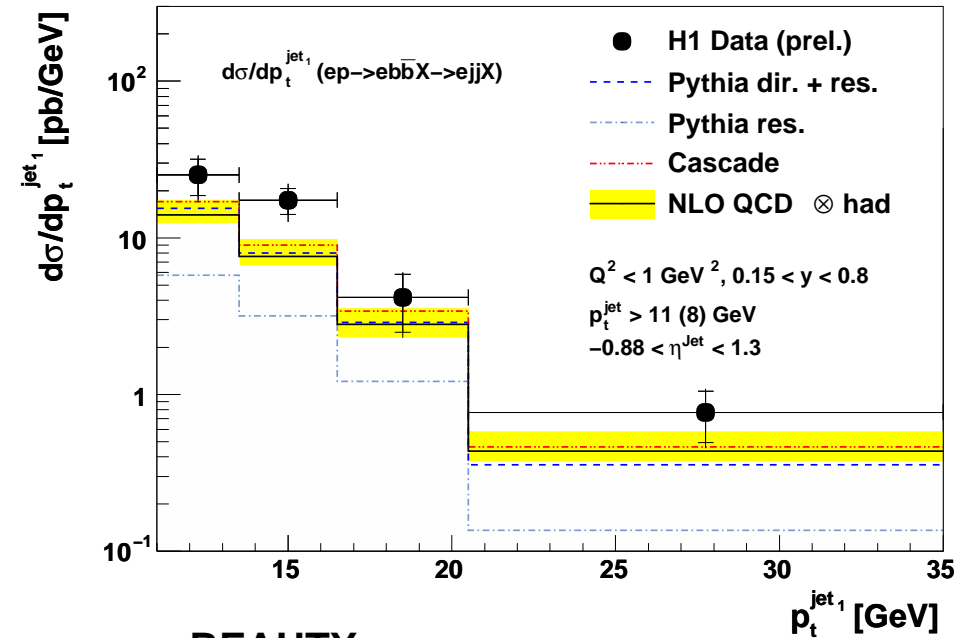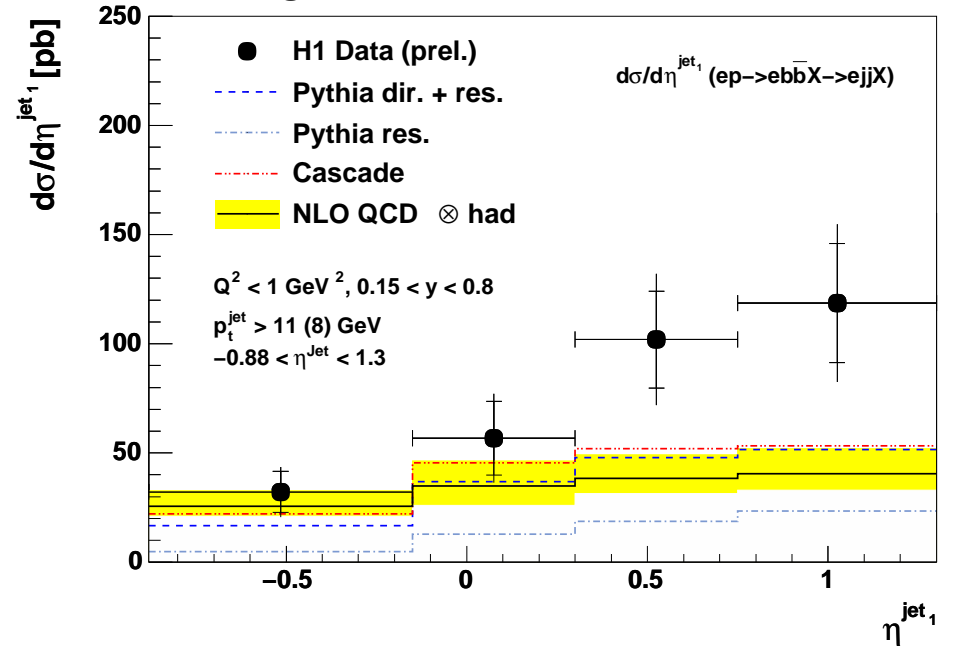
x_γ^{obs} distributions

- x_γ^{obs} sensitive to direct and resolved:

$$x_\gamma^{\text{obs}} = \frac{\sum_{j_1,j_2}(E-P_z)_j}{(E-P_Z)_{tot}}$$

$x_\gamma^{\text{obs}} \sim 1$: direct LO process

$x_\gamma^{\text{obs}} < 1$: resolved or higher orders

ZEUS

$d\sigma/dx_\gamma^{\text{jets}}(ep \to eb\bar{b}X \to e\,jj\,\mu\,X)$

- ZEUS 96-00
- NLO QCD x hadr
- NLO QCD
- Pythia 6.2
- Cascade 1.1

$d\sigma/dx_\gamma^{\text{jets}}$ (pb)

x_γ^{jets}

BEAUTY

$d\sigma/dx_\gamma^{\text{obs}}$ [pb]

- ● H1 Data (prel.)
- --- Pythia
- ·-· Pythia res.
- ·-· Cascade
- ·-· NLO QCD
- — NLO QCD $\otimes$ had

$d\sigma/dx_\gamma^{\text{obs}}$ (ep→eb$\bar{b}$X–>ejjX)
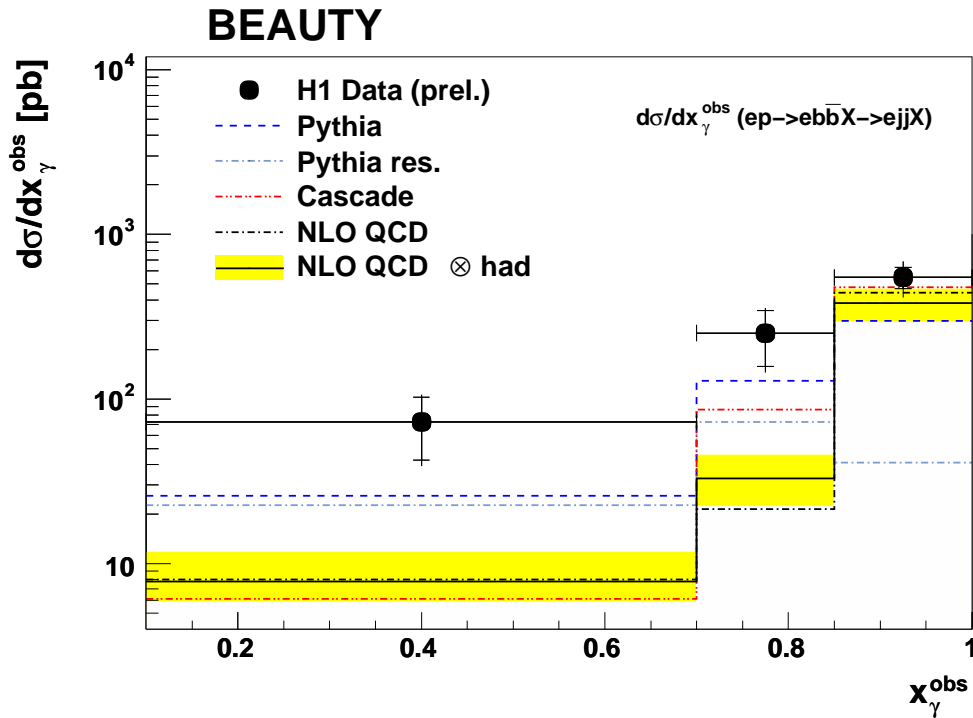
x_γ^{obs}

$ep \to eb\bar{b}X \to e\,jj\,\mu X$

H1

- ● Data
- NLO QCD $\otimes$ Had
- --- NLO QCD
- ···· Cascade
- ·-· Pythia

$Q^2 < 1$ GeV^2

$d\sigma/dx_\gamma^{\text{obs}}$ [pb]

x_γ^{obs}

- **Data higher than NLO for $x_\gamma^{\text{obs}} \le 0.85$ anyway low significance, large hadr. corrections**

- **Measurement with muons (at lower p_T^{jet}) in agreement with NLO** $\Longrightarrow$
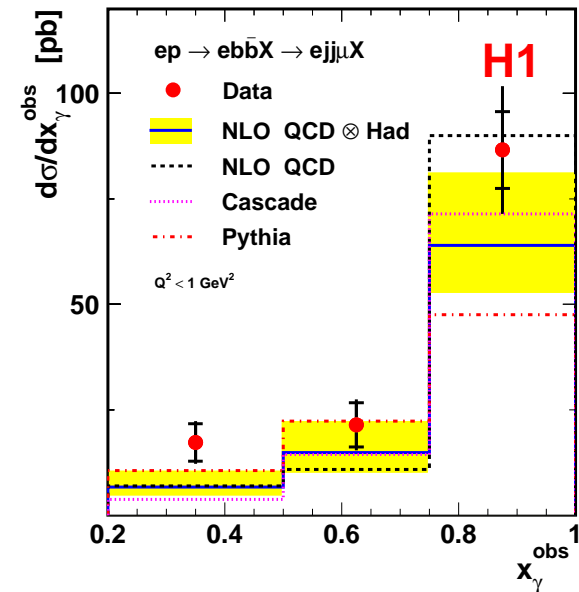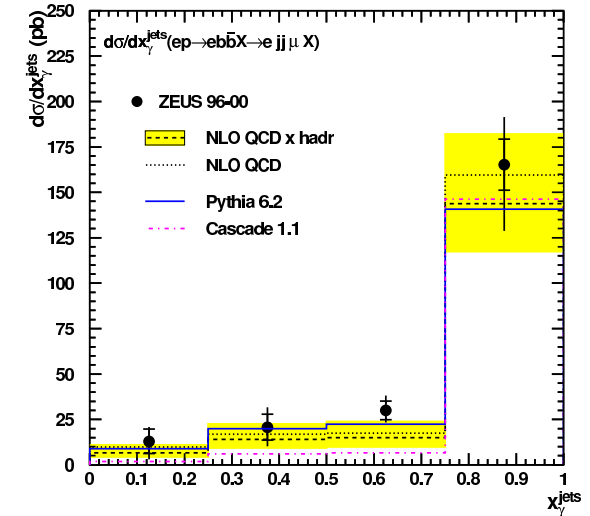
Conclusions

- **Two new measurements of beauty (and charm) photoproduciton in dijet events:**

- **First b results from HERA-II;**

  the use of the ZEUS MVD improves the determination of b and c content;

  good potential, large improvement over HERA-I data expected with full HERA-II luminosity and further understanding of the detector.

- **H1 measurement based on inclusive lifetime tagging (without lepton tag);**

  method largely independent from those of previous measurements.

- **Both results in agreement with previous measurements and NLO QCD.**

Backup Slides

x_γ for Charm

BEAUTY

$d\sigma/dp_t^{\text{jet}_1}$ (ep->eb$\bar{\text{b}}$X->ejjX)

- H1 Data (prel.)
- Pythia dir. + res.
- Pythia res.
- Cascade
- NLO QCD $\otimes$ had

$Q^2 < 1$ GeV^2, $0.15 < y < 0.8$

$p_t^{\text{jet}} > 11$ (8) GeV

$-0.88 < \eta^{\text{Jet}} < 1.3$

$d\sigma/dp_T^{\mu\text{-jet}}(ep\to eb\bar{b}X\to e\,j\,j\,\mu\,X)$ (b)

- ZEUS 96-00
- NLO QCD x had
- NLO QCD
- Pythia 6.2
- Cascade 1.1

$ep \to eb\bar{b}X \to ejj\mu X$ **H1**

- Data
- NLO QCD $\otimes$ Had
- NLO QCD
- Cascade
- Pythia

$Q^2 < 1$ GeV^2