Open Beauty Cross Section at HERA

Thomas Kuhr
Univ. Hamburg

for the

and

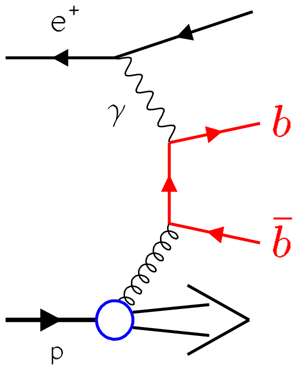
collaborations

at DIS 2000

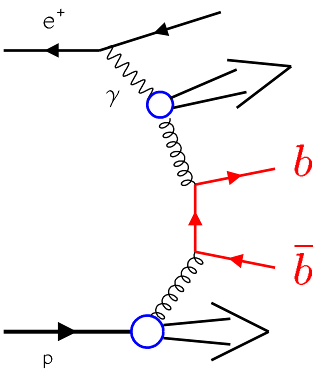
- ⋆ Theory of Beauty Production
- ⋆ Measurement of Beauty Production
- ⋆ H1 and ZEUS Analyses
- ⋆ Summary and Outlook

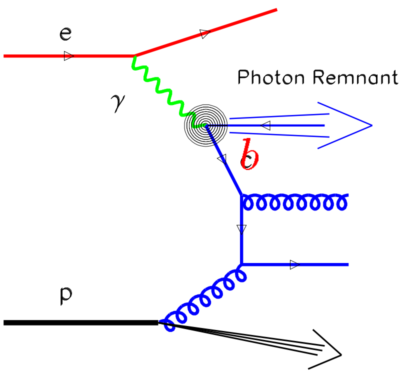
b Production in LO QCD

Direct process: boson gluon fusion (BGF), $x_\gamma = 1$



Resolved photon processes: $x_\gamma < 1$





x_γ: contributing fraction of photon momentum

$$x_\gamma^{\rm obs} = \frac{\sum_{\rm jet1,2} E_T^{\rm jet} e^{-\eta^{\rm jet}}}{2yE_e}$$

Interesting Aspects of b Production

- large b mass

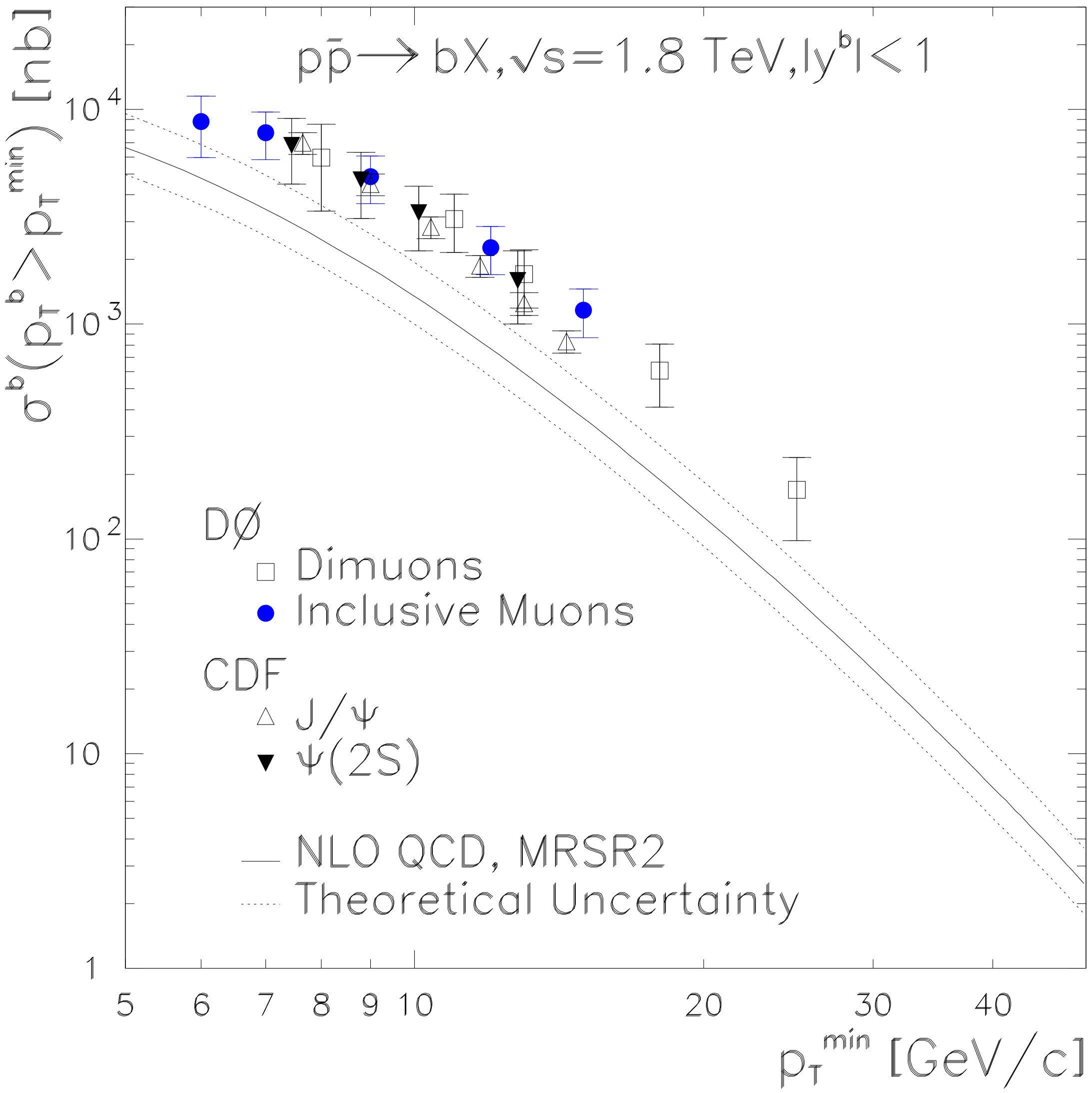
$\rightarrow$ hard scale also at low Q^2
typical scale: $\mu^2 = m_Q^2 + p_T^2$

$\Rightarrow$ pQCD should become more reliable
(than for charm)

- direct access to gluon density in proton

- sensitive to gluon and quark content of photon

Tevatron Results



$\Rightarrow$ data $\sim$factor 2.5 higher than NLO predictions

Perturbative QCD Calculations

fixed order approach (Frixione et al.)

- "massive" heavy quarks
- only u,d,s,c active flavours in proton and photon
- b produced dynamically in hard process
- applicable for $p_T \sim m_Q$

resummed approach (Kniehl et al., Cacciari et al.)

- "massless" heavy quarks
- u,d,s,c,b active flavours in proton and photon
- applicable for $p_T \gg m_Q$

Expected Cross Sections

Ratio of production cross section (LO):

$$\sigma(c) : \sigma(b) \approx 200 : 1$$

LO Monte Carlo (AROMA 2.2, only direct process):
$\sigma(ep \to b\bar{b}X) = 3.8$ nb

NLO calculation (Frixione et al.):
$\sigma(ep \to b\bar{b}X) = 5 - 10$ nb

NLO calculation give roughly factor 2
compared to LO MC prediction

Event Selection for H1 and ZEUS Analyses

selection of semi-leptonic events with

- $Q^2 < 1$ GeV^2 (photoproduction)
  $\rightarrow$ higher statistics than in DIS
- two jets
  $\rightarrow$ suppress soft physics
- a high p_T lepton (from semi-leptonic b decay)
  $\rightarrow$ suppress light quark events
  $\rightarrow$ improve b:c ratio

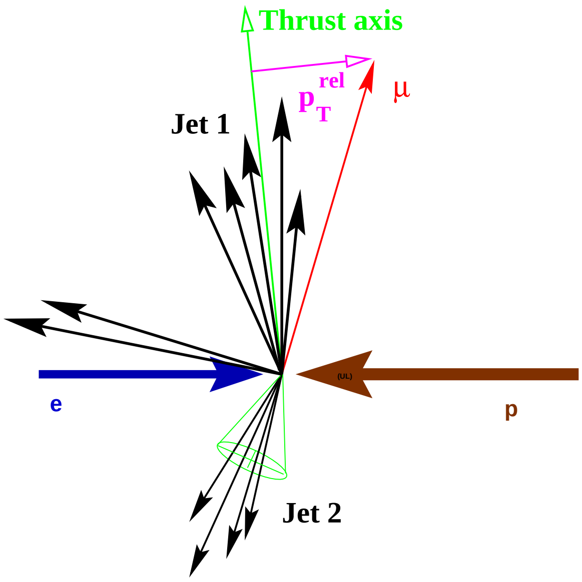
sample contains:

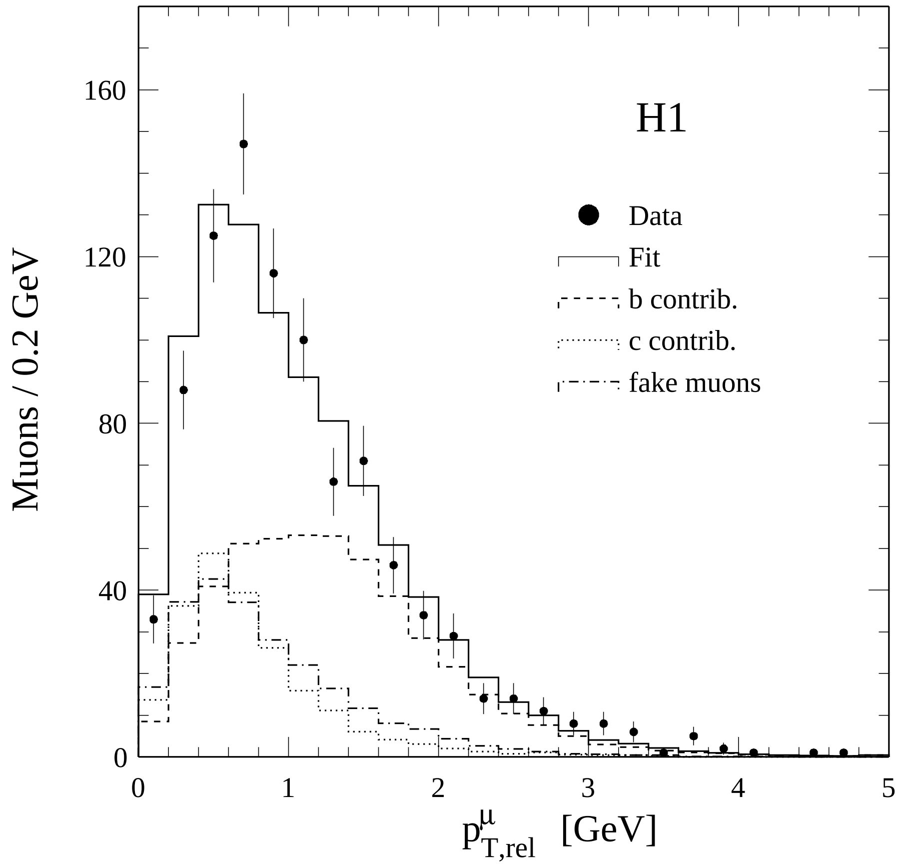
- $b \rightarrow l\nu_l X$ and $b \rightarrow c \rightarrow l\nu_l X$
- $c \rightarrow l\nu_l X$
- uds dijet events with a hadron generating a lepton signature

Method to Discriminate between c and b

measure transverse momentum of lepton relative to jet axis:

$p_{T,rel}$

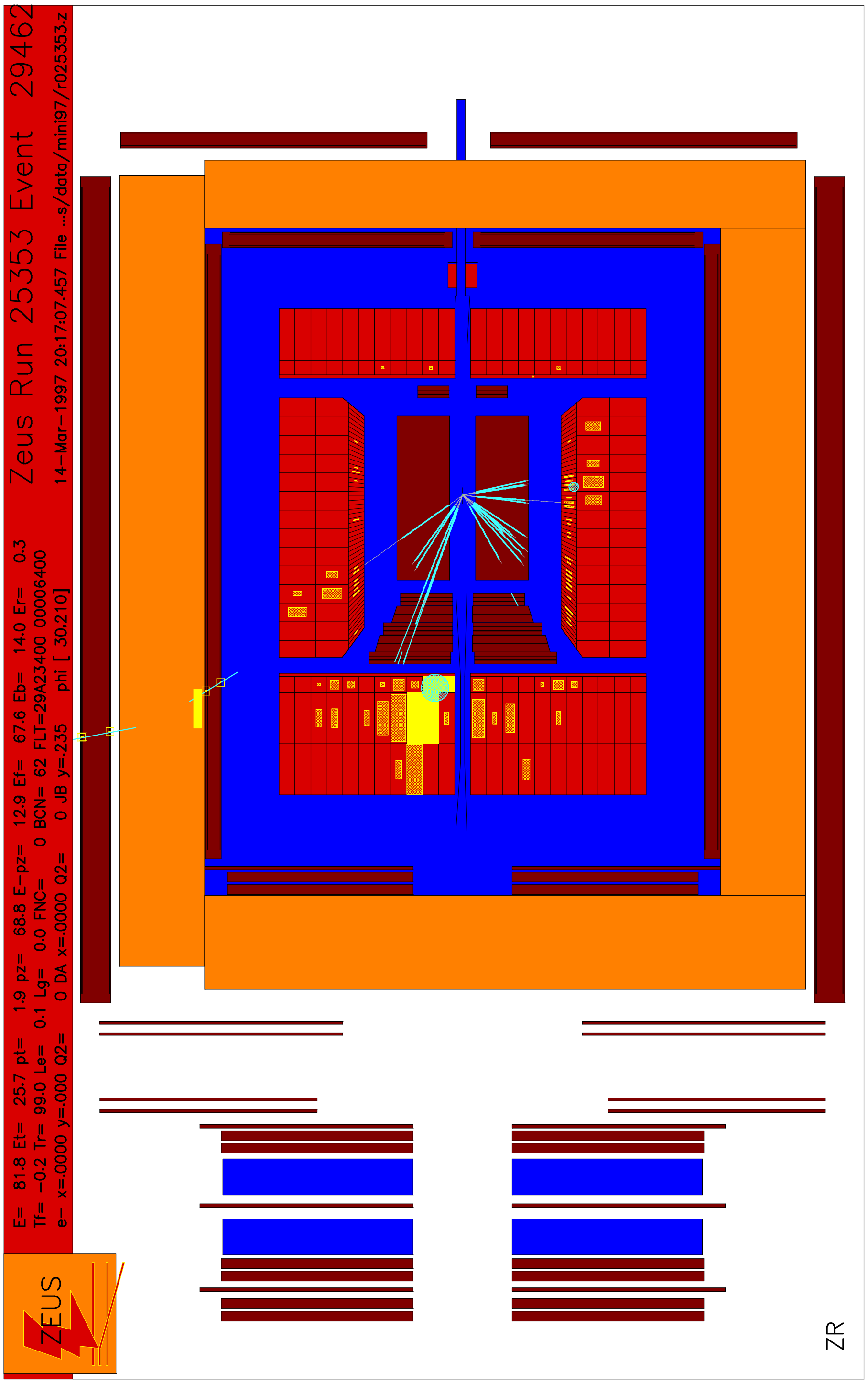




$m_b > m_c \Rightarrow$ mean $p_{T,rel}$ for b larger than for c

fit of measured $p_{T,rel}$ distribution gives b fraction

A Beauty Candidate



Overview of Analyses

collab.	H1	ZEUS	ZEUS	ZEUS
channel	μ	e	μ	forw. μ
data	96	96-97		
$\mathcal{L}$ [pb^{-1}]	6.6	36.9	37	33.7
kinematic cuts	$Q^2 < 1$ $0.1 < y < 0.8$	$Q^2 < 1$ $0.2 < y < 0.8$		
lepton cut p_T [GeV]	2	1.6	3	1.5
jet algor.	cone	k_T		
E_T^{jet1} [GeV] E_T^{jet2} [GeV]	6 6	7 6		

ZEUS Muon Analyses

central (B/RMU)	forward (FMU)
$-1.75 < \eta^{\mu} < 1.3$	$1.4 < \eta^{\mu} < 2.4$

fit of $p_{T,rel}$ distribution:
shape, ratio direct/resolved,
ratio c/uds taken from PYTHIA MC

$f_b = (28 \pm 5)\%$	$f_b = (22 \pm 7)\%$

$\sigma_{b\bar{b}}^{vis}(ep \to dijet + \mu + X)$

$36.4 \pm 5.2^{+10.4}_{-9.1}$ pb	$20.5 \pm 6.5^{+6.3}_{-5.7}$ pb

PYTHIA

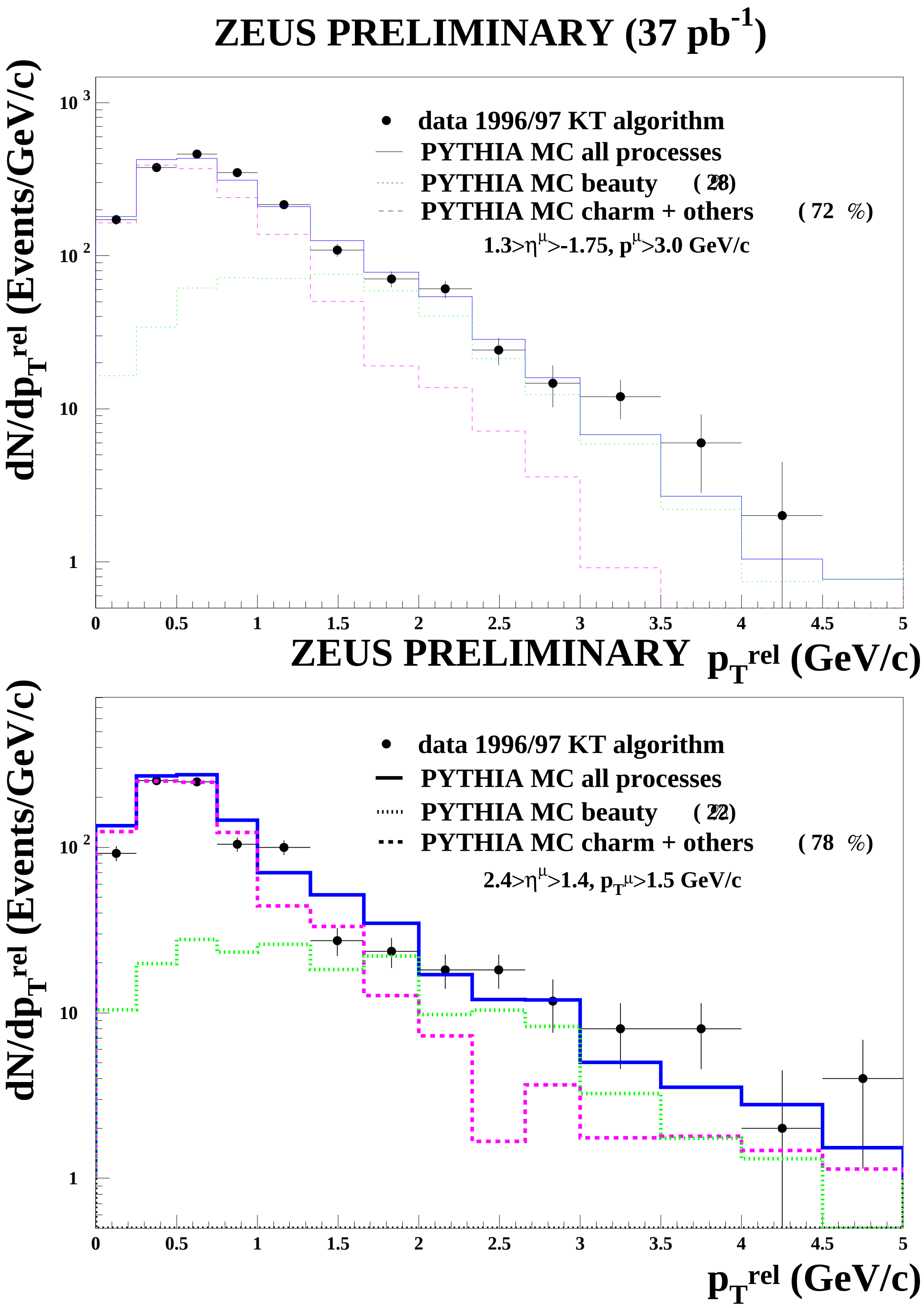
30 pb	9.6 pb

HERWIG

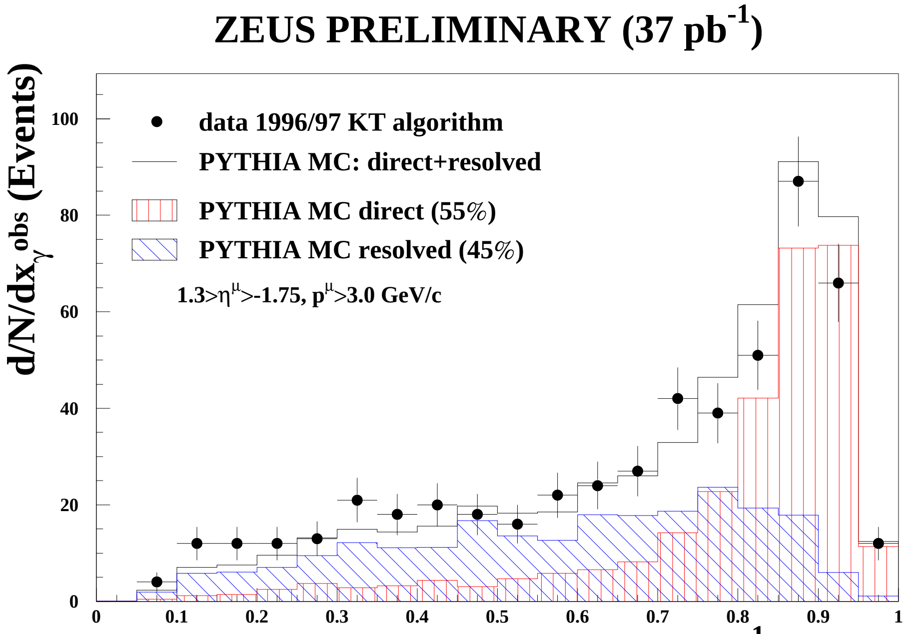
12 pb	4.1 pb

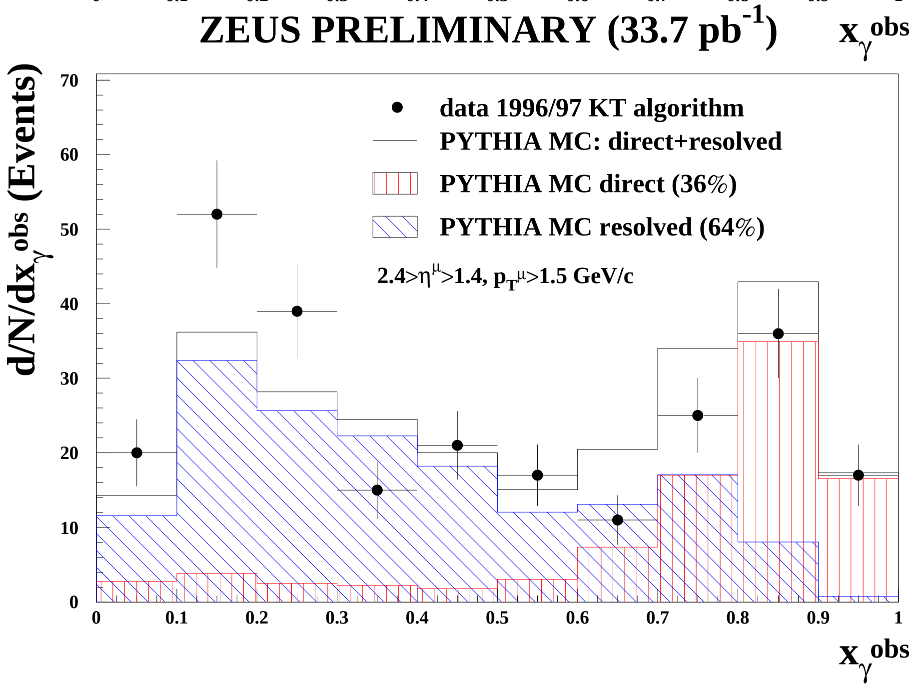
$\Rightarrow$ data clearly higher than MC prediction

$p_{T,rel}$ Distributions



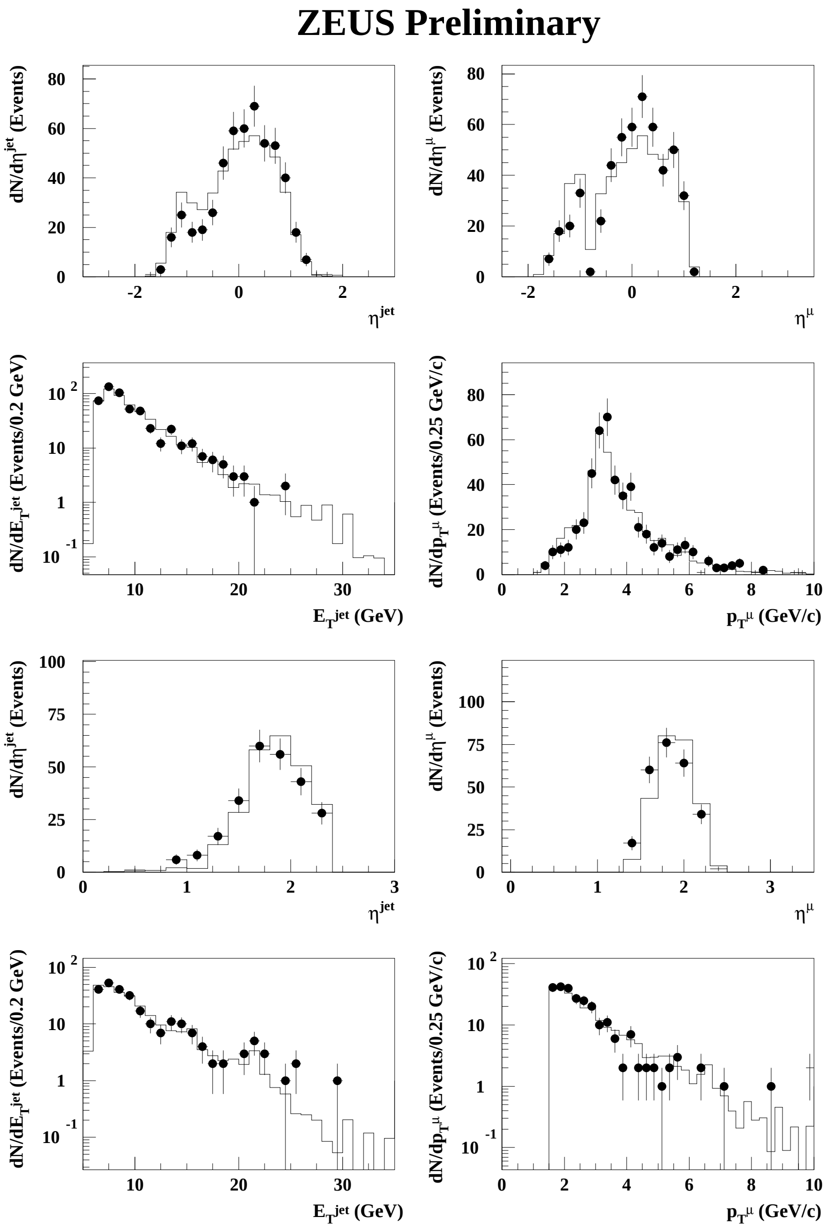
x_γ^{obs} Distributions





$\rightarrow$ important resolved contribution
even more in forward region (as expected)

Control Plots



MC distributions of $\eta^{\rm jet}$, η^{μ}, $E_T^{\rm jet}$ and p_T^{μ} agree reasonably well with data for both analyses

H1 Muon Analysis

$35^\circ < \theta^\mu < 130^\circ$

$p_{T,rel}$ distribution of uds background determined from data by using probability that a hadron generates a muon signature

fit of $p_{T,rel}$ distribution:
shape of b/c taken from AROMA MC (only direct)
distribution of background fixed

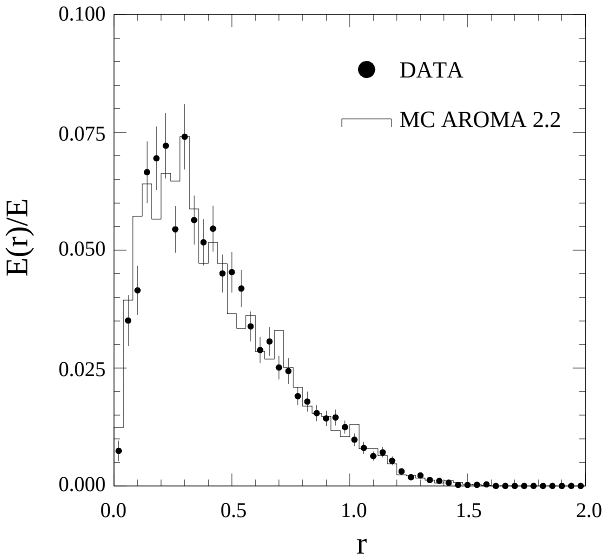
$f_b = (51.4 \pm 4.4)\%$
$f_c = (23.5 \pm 4.3)\%$ (consistent with H1 D^* measurement)

$\sigma_{vis}(ep \to b\bar{b}X \to \mu X') = 176 \pm 16^{+26}_{-17}$ pb

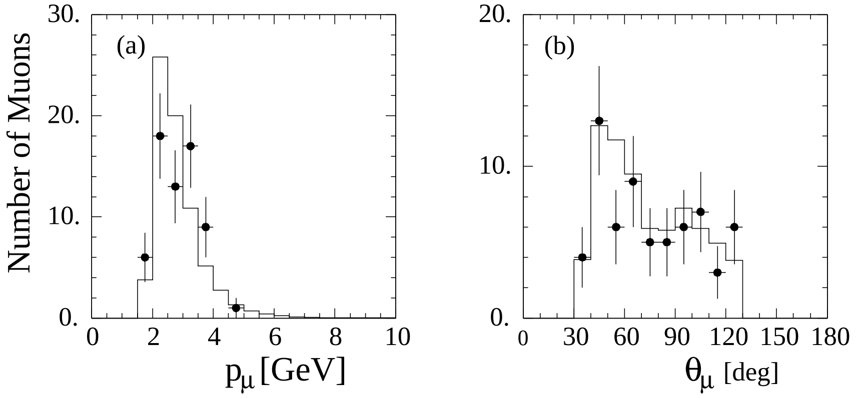
NLO QCD:	104 ± 17 pb
LO QCD:	69 ± 8 pb
AROMA MC:	38 pb

$\Rightarrow$ data higher than predictions

Control Plots



differential jet energy as a function of the distance r to the jet axis well described by AROMA LO MC and detector simulation



probability that a hadron is misidentified as a muon verified with data ($K_s^0 \to \pi^+\pi^-$, $\phi \to K^+K^-$)

ZEUS Electron Analysis

selection of electrons by statistical subtraction

determination of ratio direct/resolved by fitting x_γ^{obs} distribution

fit of $p_{T,rel}$ distribution:
  shape, ratio c/uds taken from HERWIG MC
  ratio direct/resolved from x_γ^{obs} fit

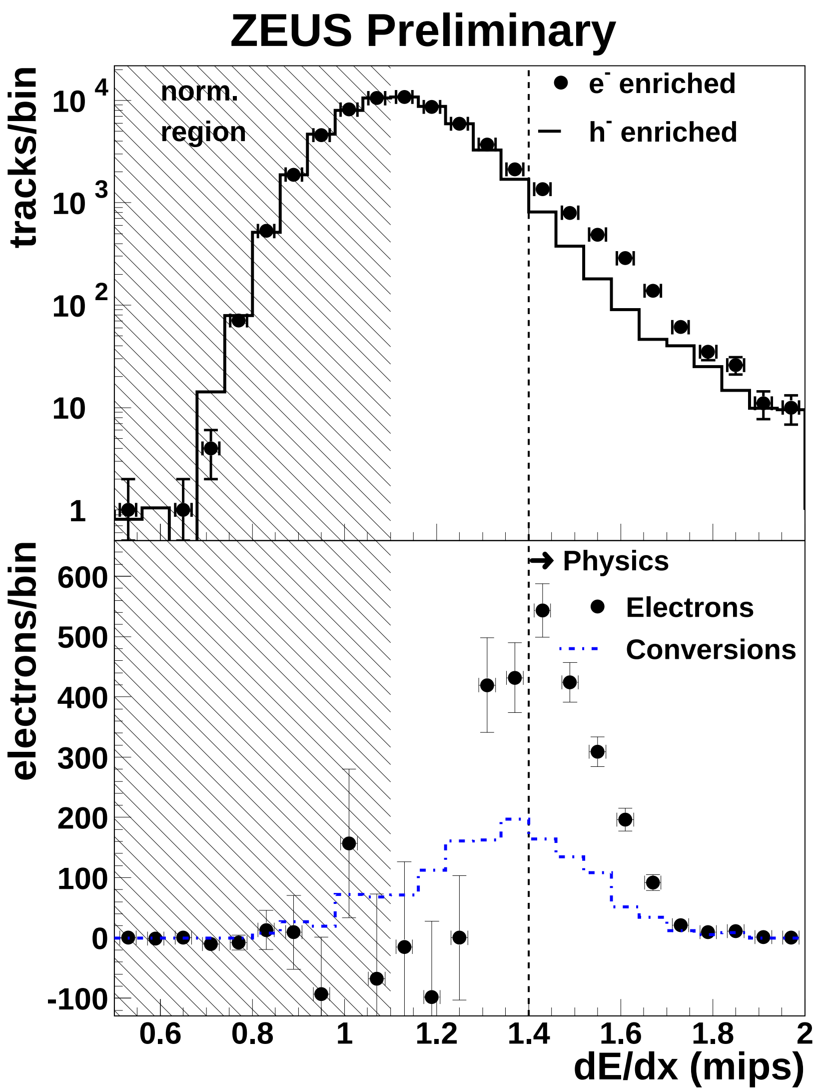
$f_b = (20 \pm 6^{+12}_{-7})\%$

$\sigma^{vis}_{b\bar{b}}(e^+p \to dijet + e^- + X) = 39 \pm 11^{+23}_{-16}$ pb

HERWIG MC: $\sim$ factor 4-5 below data
PYTHIA MC: $\sim$ factor 2 below data

$\Rightarrow$ data clearly higher than MC predictions

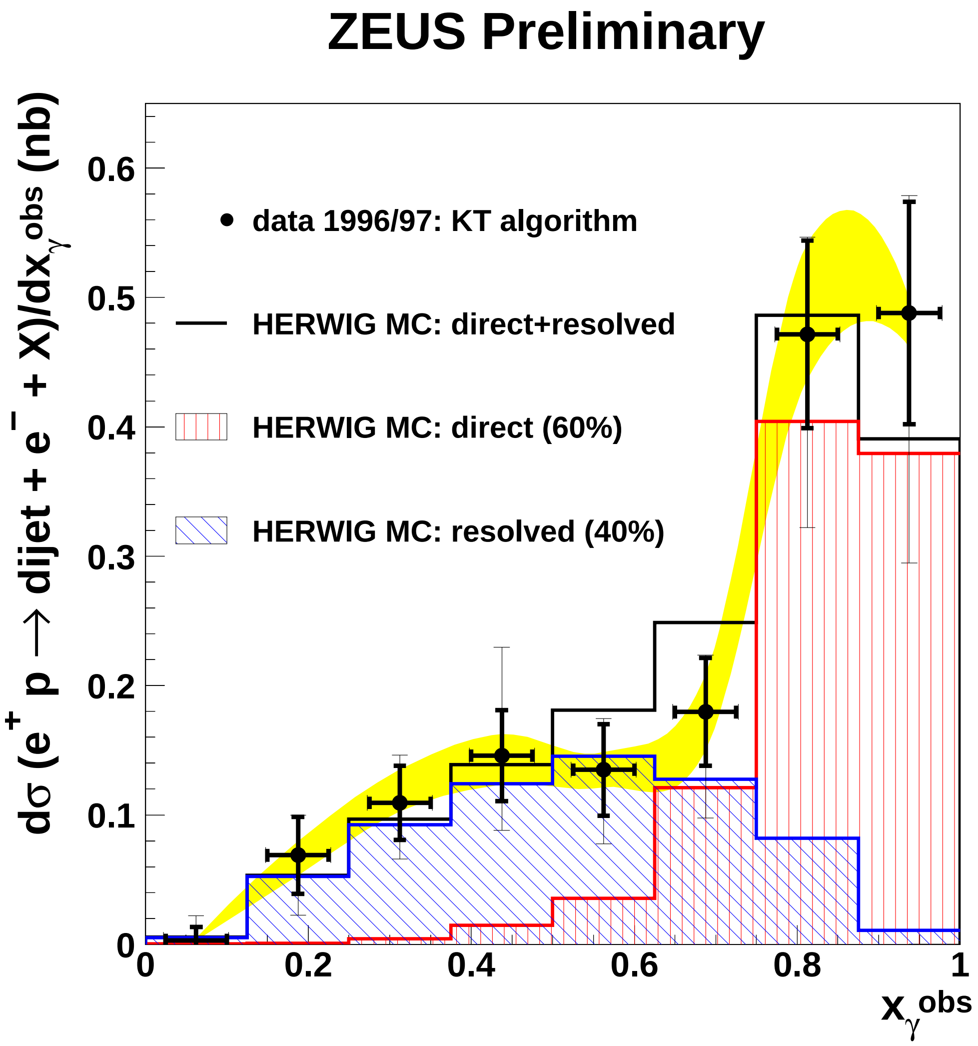
Electron Selection



electron enriched sample $(E_{elmagn}/E_{tot} > 0.9)$

- hadron enriched sample $(E_{elmagn}/E_{tot} < 0.4)$ normalised in region $dE/dx < 1.1$
- electrons from photon conversions

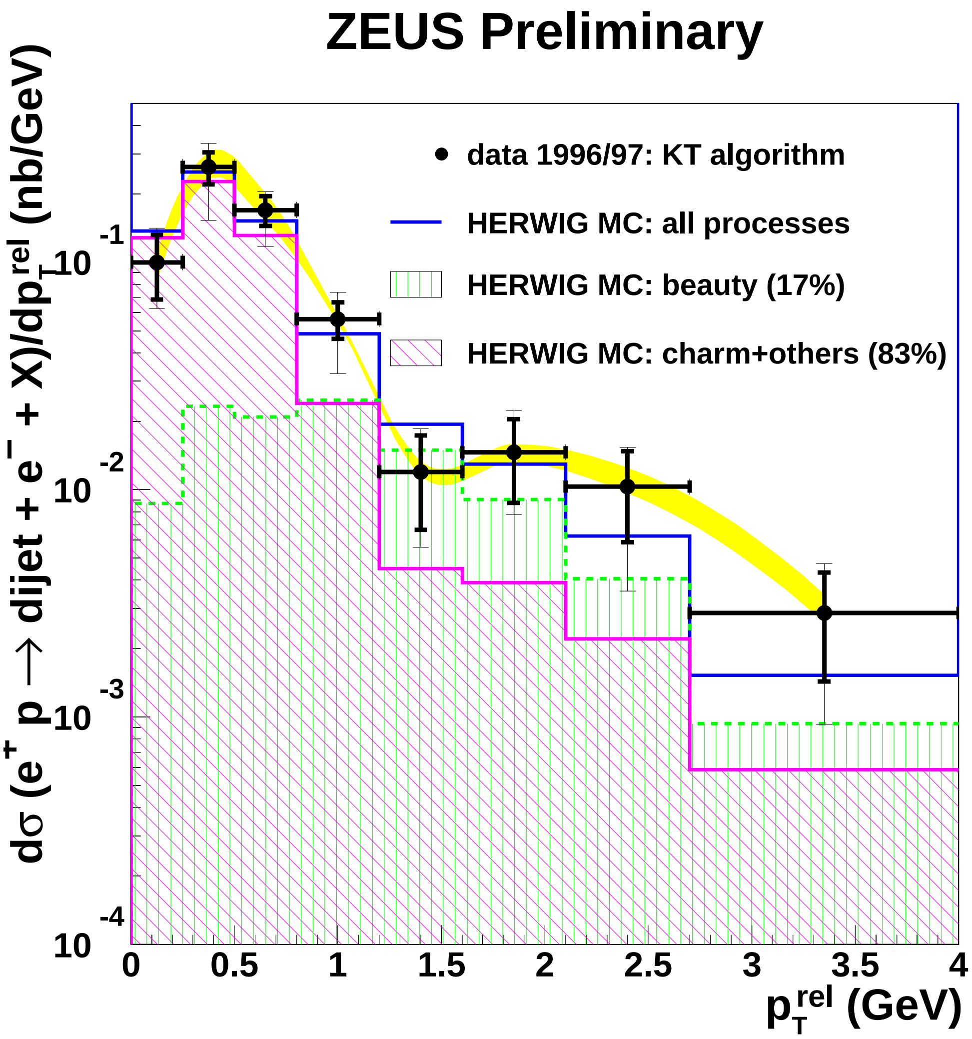
x_γ^{obs} Distribution



fit of resolved fraction: $(35 \pm 5)\%$
prediction from HERWIG MC: 40%

HERWIG MC scaled by normalisation factor 3.7

$p_{T,rel}$ Distributions



fit of b fraction: $(20 \pm 6^{+12}_{-7})\%$
prediction from HERWIG MC: 17%

HERWIG MC scaled by normalisation factor 3.7

Extrapolated Cross Sections

H1 μ analysis:

extrapolation with NLO calculation
to full phase space (~factor 8):

$\sigma_{tot}(ep \to eb\bar{b}X) = 7.1 \pm 0.6^{+1.0}_{-0.7} \pm 1.1$ nb

Weizsäcker-Williams approximation:

$\sigma_{tot}(\gamma p \to b\bar{b}X) = 111 \pm 10^{+16}_{-11} \pm 17$ nb

for $94 < W_{\gamma p} < 266$ GeV, $\langle W_{\gamma p} \rangle \approx 180$ GeV

NLO QCD prediction (FMNR): 63 nb

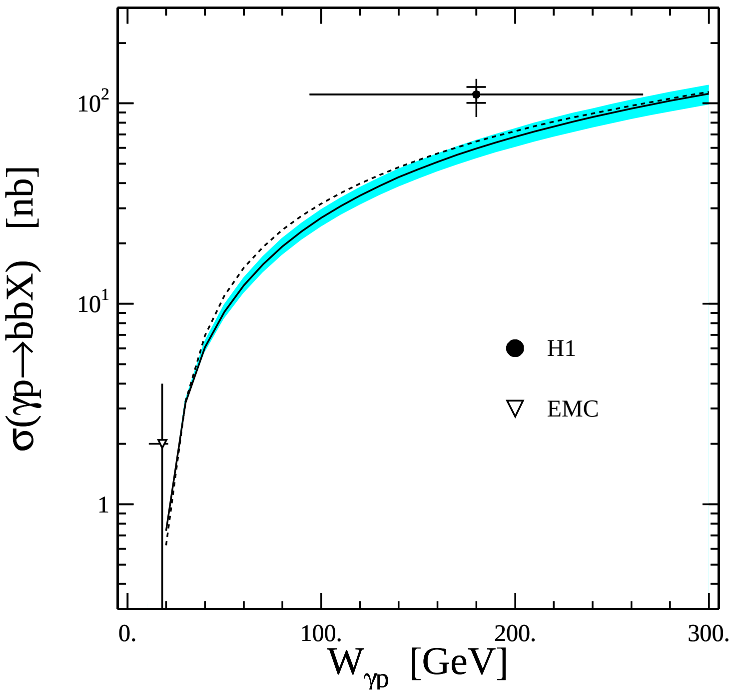
ZEUS e analysis:

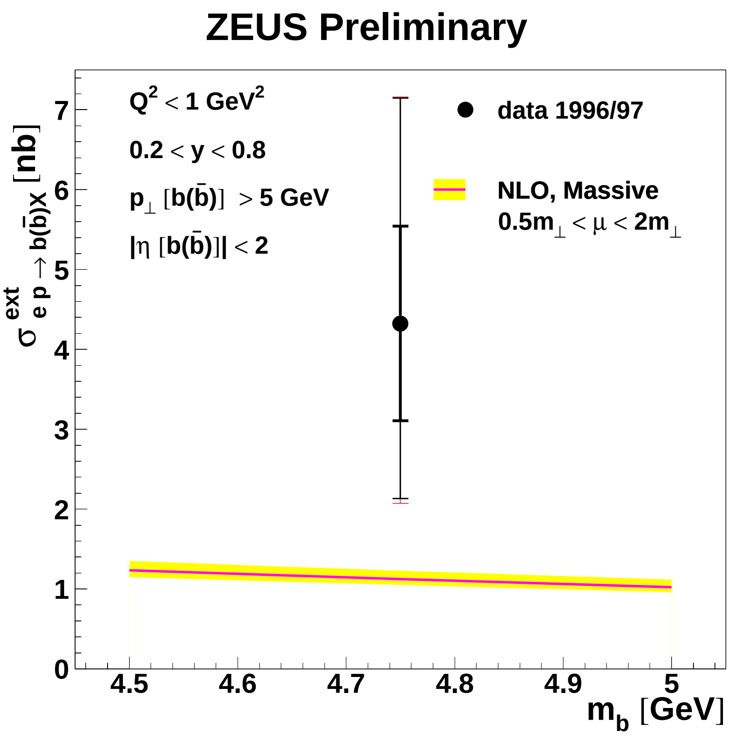
extrapolation with LO MC
to parton level for region
$p_T(b/\bar{b}) > 5$ GeV, $|\eta(b/\bar{b})| < 2$ (~factor 10):

$\sigma_{ext}(ep \to b\bar{b}X) = 4.3 \pm 1.2^{+2.6}_{-1.8}\,{}^{+0.3}_{-0.5}$ nb

NLO QCD prediction (FMNR): 1.2 nb

Comparison with NLO Calculations





$\Rightarrow$ data (somewhat) higher than NLO predictions

Overview of Results

collab.	H1	ZEUS	ZEUS	ZEUS
channel	μ	e	μ	forw. μ
$p_{T,rel}$ shape	AROMA	HERWIG	PYTHIA	
uds bg.	data	HERWIG	PYTHIA	
dir./res.	only dir.	x_γ^{obs} fit	PYTHIA	
σ_{vis} [pb] stat. err. sys. err.	176 ± 16 $^{+26}_{-17}$	39 ± 11 $^{+23}_{-16}$	36 ± 5 $^{+10}_{-9}$	21 ± 7 $^{+6}_{-6}$
$\frac{\text{Data}}{\text{LO-MC}}$	4.6	$2-5$	$1.2-3$	$2-5$
$\sigma_{tot,\gamma p}$ [nb] $\sigma_{ext,ep}$ [nb] stat. err. sys. err. ext. err.	111 ± 10 $^{+16}_{-11}$ ± 17	 4.3 ± 1.2 $^{+2.6}_{-1.8}$ $^{+0.3}_{-0.5}$		
$\frac{\text{Data}}{\text{NLO}}$	1.8 $(\sim 2\sigma)$	3.8 $(\sim 1.4\sigma)$		

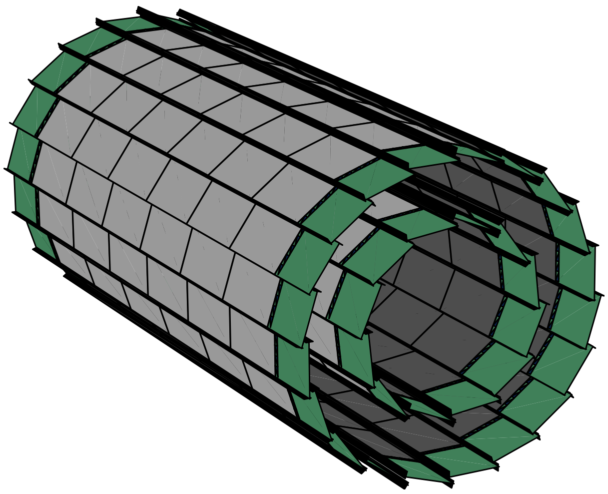
$\Rightarrow$ all cross sections higher than LO and NLO predictions

Outlook

◇ more data 'on tape' to be analyzed

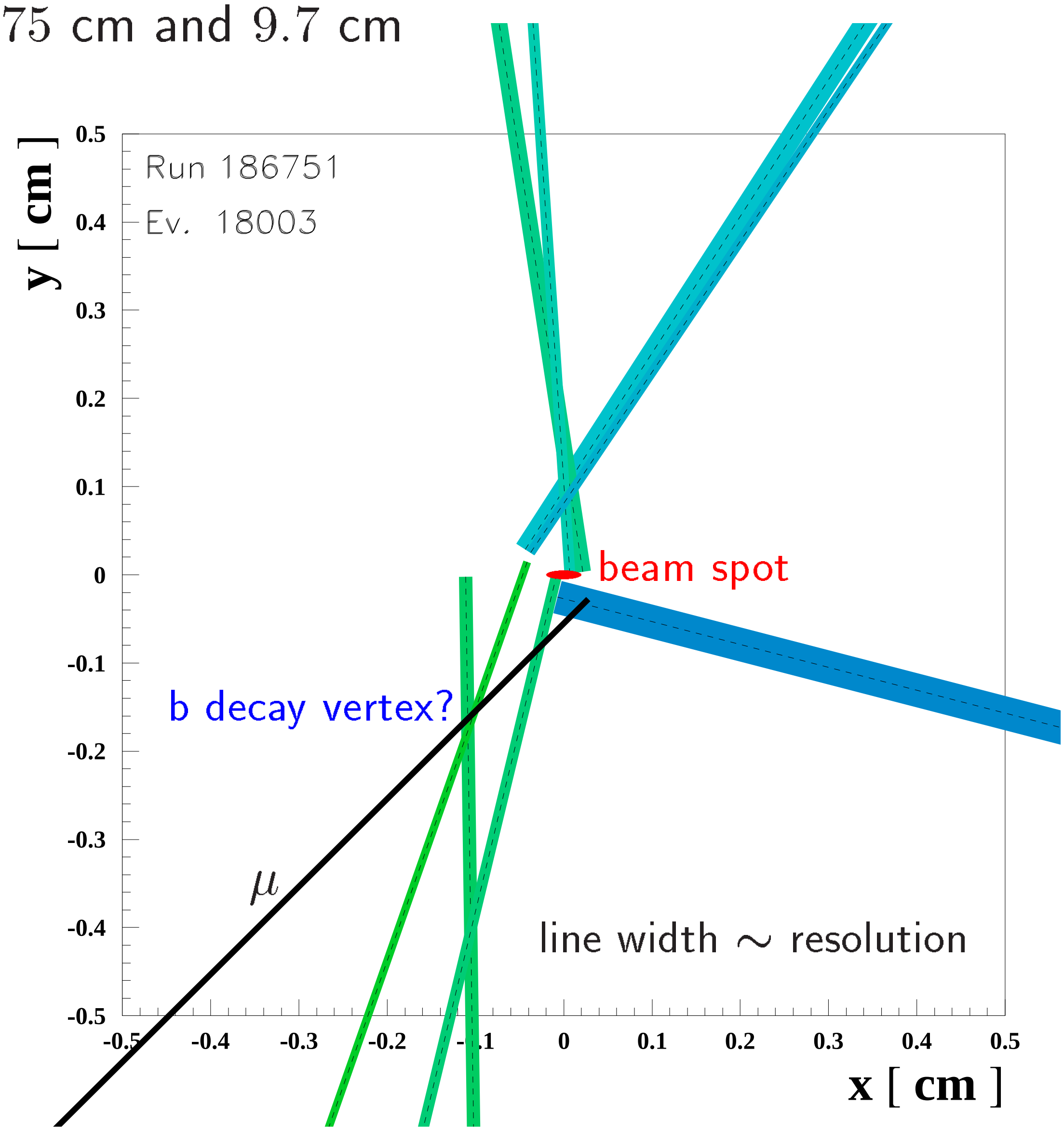
◇ lumi upgrade 2000:
$\mathcal{L} \approx 150$ pb^{-1}/year (factor 3-5 increase)
$\Rightarrow$ DIS analyses, F_2^b

◇ hardware upgrade:
micro vertex detectors
$\Rightarrow$ lifetime tagging of charm and beauty



H1 Vertex Event Display

zoom into vertex region (1×1 cm^2):
tracks extrapolated from silicon vertex detector at 5.75 cm and 9.7 cm



silicon vertex detector gives the possibility to measure impact parameters and vertices of b decay particles

Conclusions

- ▷ open beauty cross section has been measured by H1 and ZEUS in photoproduction using semi-leptonic decays
- ▷ all cross sections are higher than LO and NLO predictions
- ▷ further interesting analyses can be expected