b Photoproduction with ZEUS

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On behalf of the ZEUS collaboration

- **Introduction**
- b **from Dijet+**μ
- b **from** $D^* + \mu$
- **Conclusions**

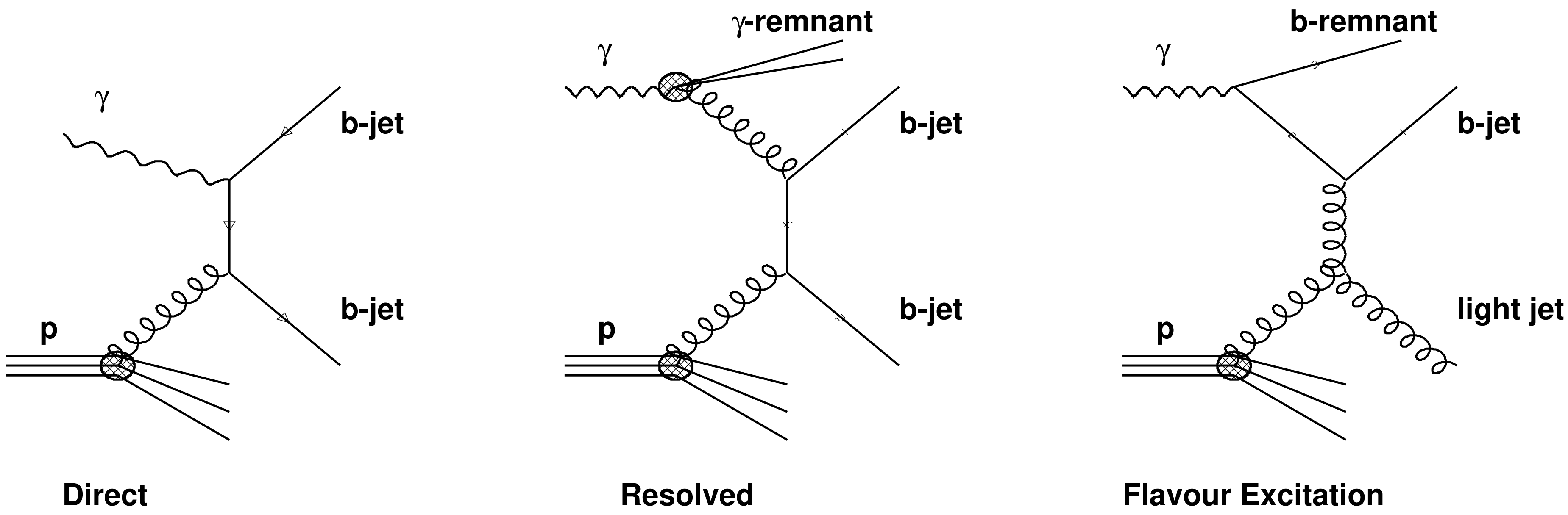
Introduction

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

But:
- **in $p\bar{p}$ (Tevatron)** $\sigma(\textbf{meas})/\sigma(\textbf{NLO}) \sim 2-3$
- **in $\gamma\gamma$ (LEP)** $\sigma(\textbf{meas})/\sigma(\textbf{NLO}) \sim 3$

What about γp at HERA?

Introduction

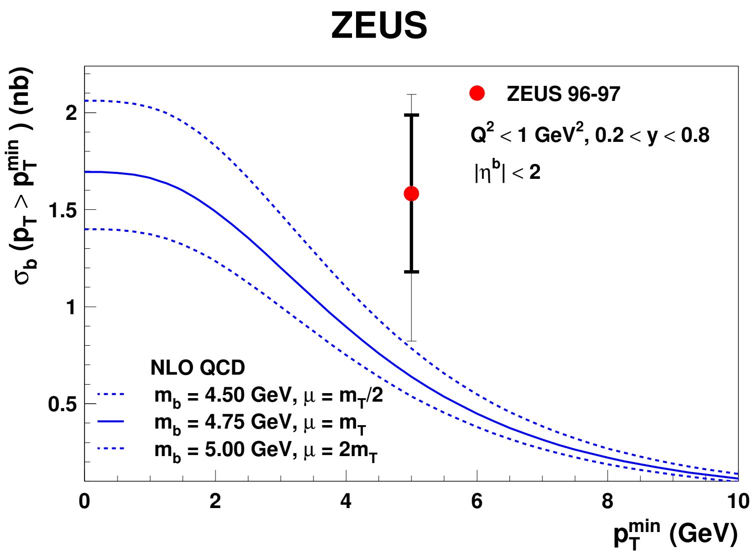


- **LO: Direct + Resolved diagrams**
- **full NLO program available (FMNR)**
- **MC (Pythia, Herwig) include LO + PS + Flavour Excitation (FE) diagrams**
- K_T **factorization: Cascade MC implementing CCFM evolution**

b photoproduction measurements with ZEUS

Beauty measured at ZEUS from SL decays

- e^-+2 jets analysis 96-97 data (L=38.5 pb^{-1})
  EPJC 18 (2001) 625 $\Longrightarrow$
- μ+2 jets preliminary 96-97 data (L=37 pb^{-1})
  EPS99, EPS01 consistent with e^- data
- μ+2 jets preliminary 96-00 data (L=98 pb^{-1})
  ICHEP02, see this talk...
- $D^*\mu$ preliminary 96-00 data (L=114 pb^{-1})
  ICHEP02, see this talk...



Dijet + muon analysis

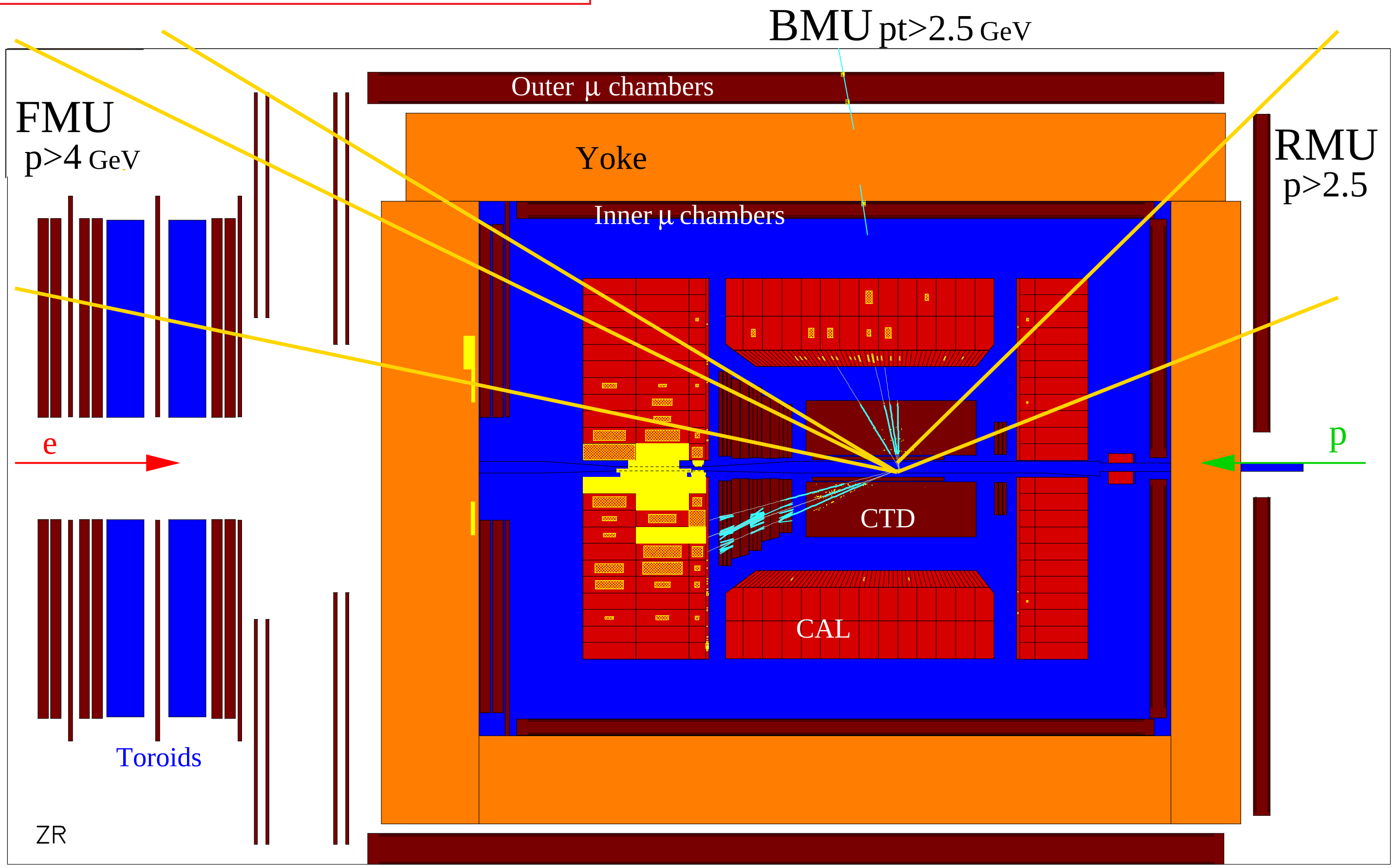
Dijet selection:

- **Reject DIS** e^+ ($\sim Q^2 < 1$ **GeV**^{2})
- $0.2 < y_{\mathrm{JB}} < 0.8$
- ≥ 2 **Jets:**
  Long.-boost invariant K$_\mathrm{T}$ **algorithm, massive jets (kmode=3211)**
  $p_\mathrm{T}^{\mathrm{j1,j2}} > 6, 7$ **GeV,** $|\eta^{\mathrm{j1,j2}}| < 2.5$

Muon selection:

- $\geq 1\mu$ **reaching the external chambers:**

Forward (FMU):	$1.5 < \eta^\mu < 2.3$	$p^\mu > 4$ **GeV**
Barrel (BMU):	$-0.6 < \eta^\mu < 1.3$	$p_\mathrm{T}^\mu > 2.5$ **GeV**
Rear (RMU):	$-1.6 < \eta^\mu < -0.6$	$p^\mu > 2.5$ **GeV**

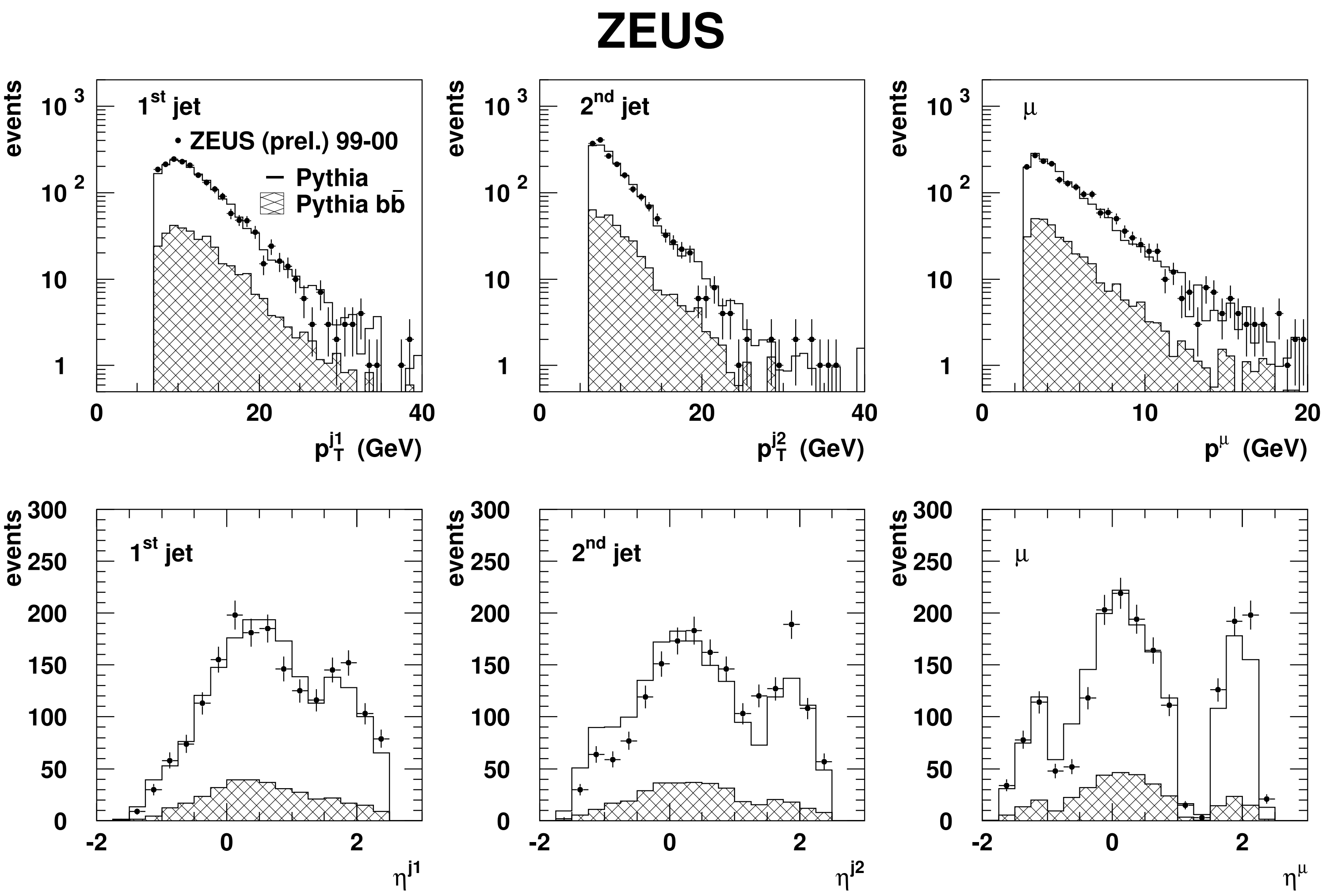


Data-MC comparisons

Data sample: **37.9** $\mathbf{pb^{-1}}$ **at** $\sqrt{s} = 300$ **GeV** + **60.4** $\mathbf{pb^{-1}}$ **at** $\sqrt{s} = 318$ **GeV** = **98.3** $\mathbf{pb^{-1}}$

MC: Pythia, including FE diagrams

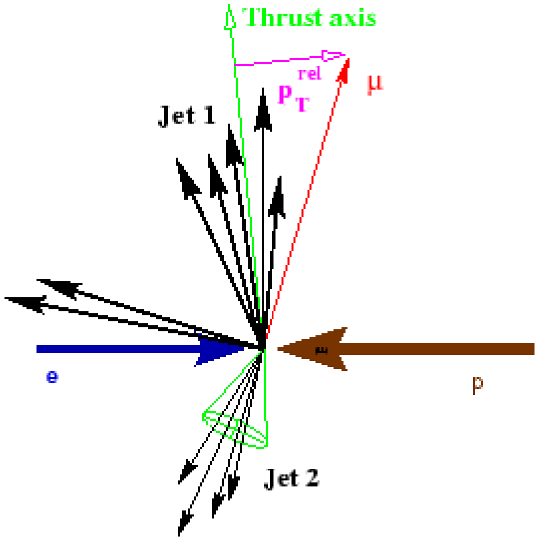
Dijet+μ sample is a mix of b, c and "fake" μ from light quarks (mainly π and K)

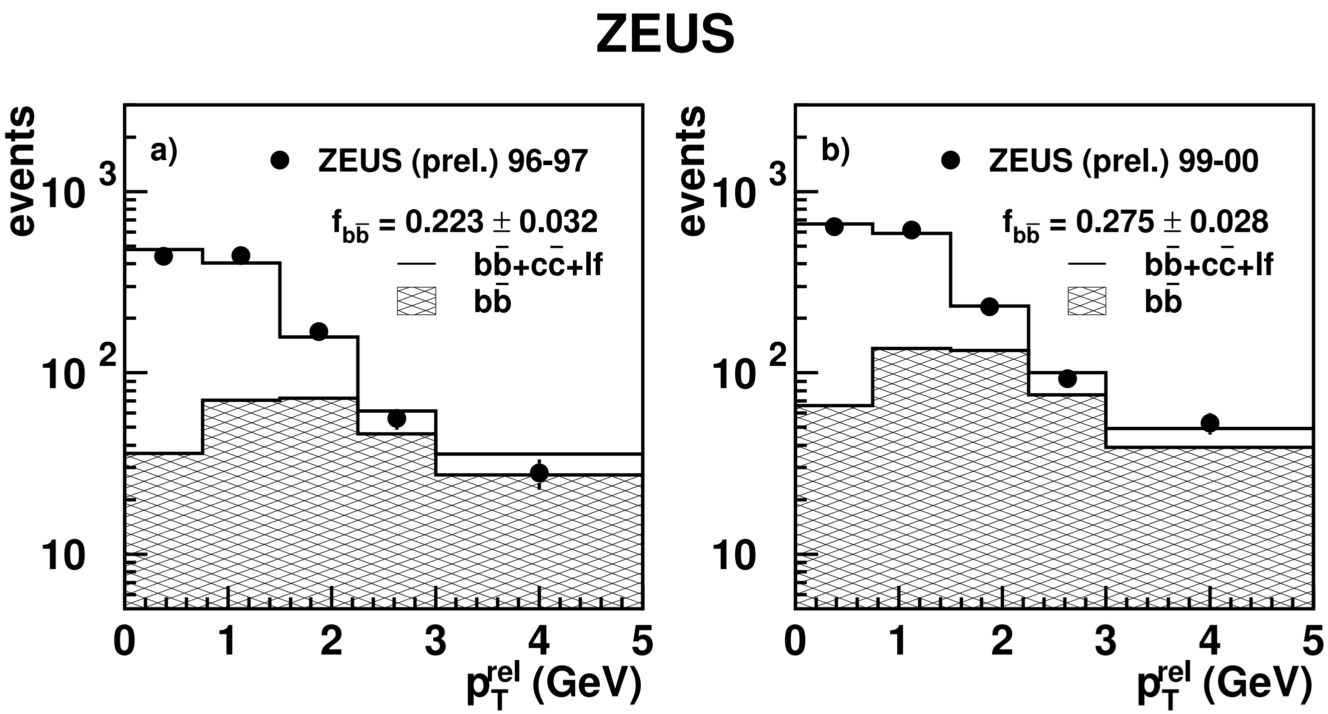


General features of Dijet+muon sample in good agreement with Pythia

Extraction of the b component

b **fraction in Dijet+muon sample extracted by fitting p_T^{rel} to beauty and charm+light quark**





- **μ-Jet association by K_T algorithm**
- $p_T^{rel} = \left|\frac{\vec{p}^{\mu}\times(\vec{p}^{jet}-\vec{p}^{\mu})}{(\vec{p}^{jet}-\vec{p}^{\mu})}\right|$
- **Large B mass $\Rightarrow$ large p_T^{rel}**
- **Beauty and charm+light quarks distributions taken from Pythia**
- **charm/light-quark fraction fixed to MC cross section, varied by $\times 2$, $/2$ as systematic.**

NLO prediction

Program: FMNR (Nucl. Phys. B (1995) 3)

- **Parameters:**
  - pdf(p)=CTEQ5M
  - pdf(γ)=GRV-G HO
  - $m_b = 4.75$ GeV
  - $\mu_F = \mu_R = m_T \equiv \sqrt{m_b^2 + p_T^2}$
- **Jet cross section:**
  - K_T algorithm on partons
  - Hadronization correction $-15\%(-20\%)$ from Pythia (Herwig)
- **Muon cross sections:**
  - $b \to B$: Peterson $\epsilon = 0.0035 \pm 0.0015$
  - $B \to \mu$: p^μ in B c.m.s. from Pythia
  - Uncertainty from fragmentation and B.R. $\sim 10\%$

Uncertainty by varying b-mass and scales simultaneously:

	m_b [GeV]	$\mu_F = \mu_R$
Central	4.75	m_T
Upper	5.0	$m_T/2$
Lower	4.5	$2m_T$

The resulting uncertainty is $+30 - 25\%$
K-factor $NLO/LO = 2.3$
(For dijet b cross section)

$\log(p_T/m_b)$ terms exepected to be small for b at HERA $(p_T/m_b \sim 1)$
Calculations exist (FONLL) but not considered here

Dijet cross section $\sigma(ep \to b\bar{b}X \to jjX')$

Pythia 6.2 used to correct for μ acceptance and B.R.
Herwig 6.1 for systematic checks

Jet corrected to Hadron level *before* **B-hadron decay**

Kinematic Range: $0.2 < y < 0.8$, $Q^2 < 1$ **GeV**^{2}, $p_{\mathrm{T}}^{\mathrm{j1,j2}} > 6, 7$ **GeV**, $|\eta^{\mathrm{j1,j2}}| < 2.5$

$$\sigma(ep \to b\bar{b}X \to jjX') = 733 \pm 61\textbf{(stat.)} \pm 104\textbf{(syst.)}\ \textbf{pb}$$

NLO (FMNR) + hadr. correction:

$$\sigma_{\mathrm{N}LO}(ep \to b\bar{b}X \to jjX') = 381^{+117}_{-78}\textbf{pb}$$

$$\textbf{Data/NLO} \sim 1.9$$

Main systematic uncertainties:
- Model used for acceptance correction
- Muon chamber efficiency

Dijet $b\bar{b}$ cross section in x_γ bins

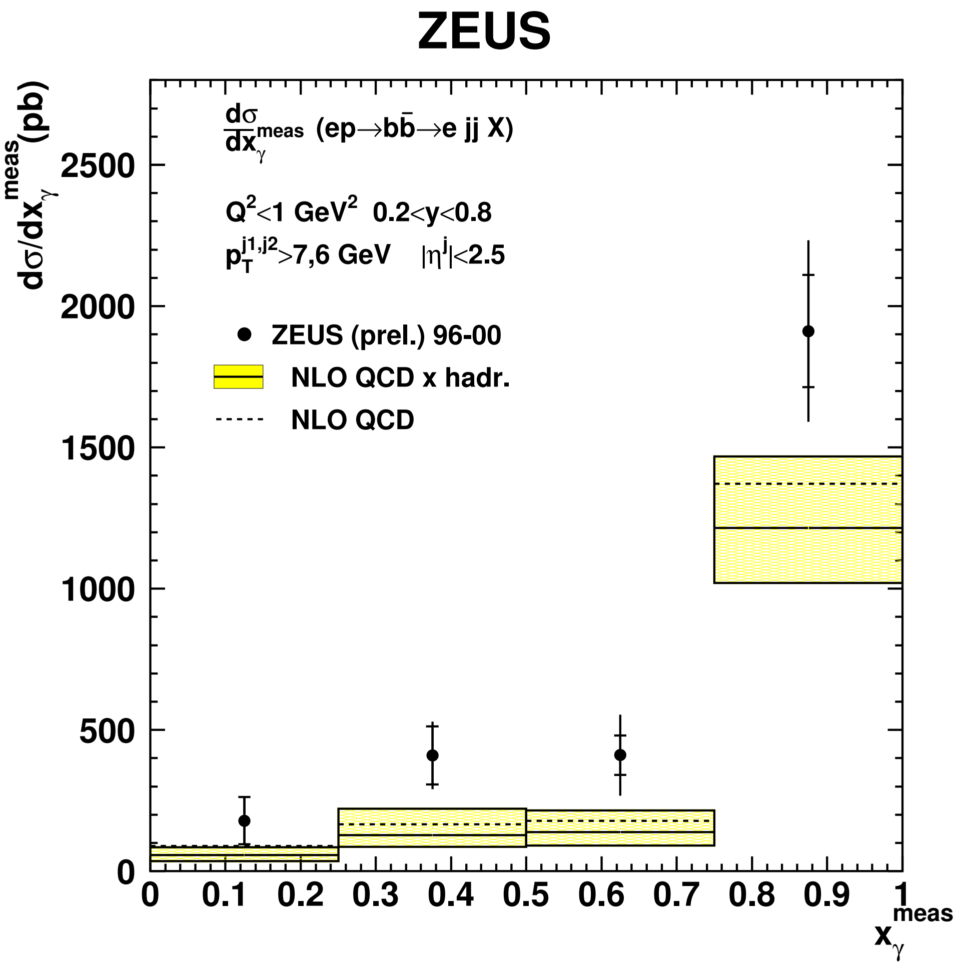
How data compare to NLO at different x_γ?

$$x_\gamma^{\rm meas} = \frac{(E-P_z)_{\rm jet1}+(E-P_z)_{\rm jet2}}{(E-P_z)_{\rm hadronic}}$$

At LO:
$x_\gamma \sim 1 \rightarrow$ Direct photon
$x_\gamma < 1 \rightarrow$ Resolved photon

$p_{\rm T}^{\rm rel}$ fit redone in x_γ bins

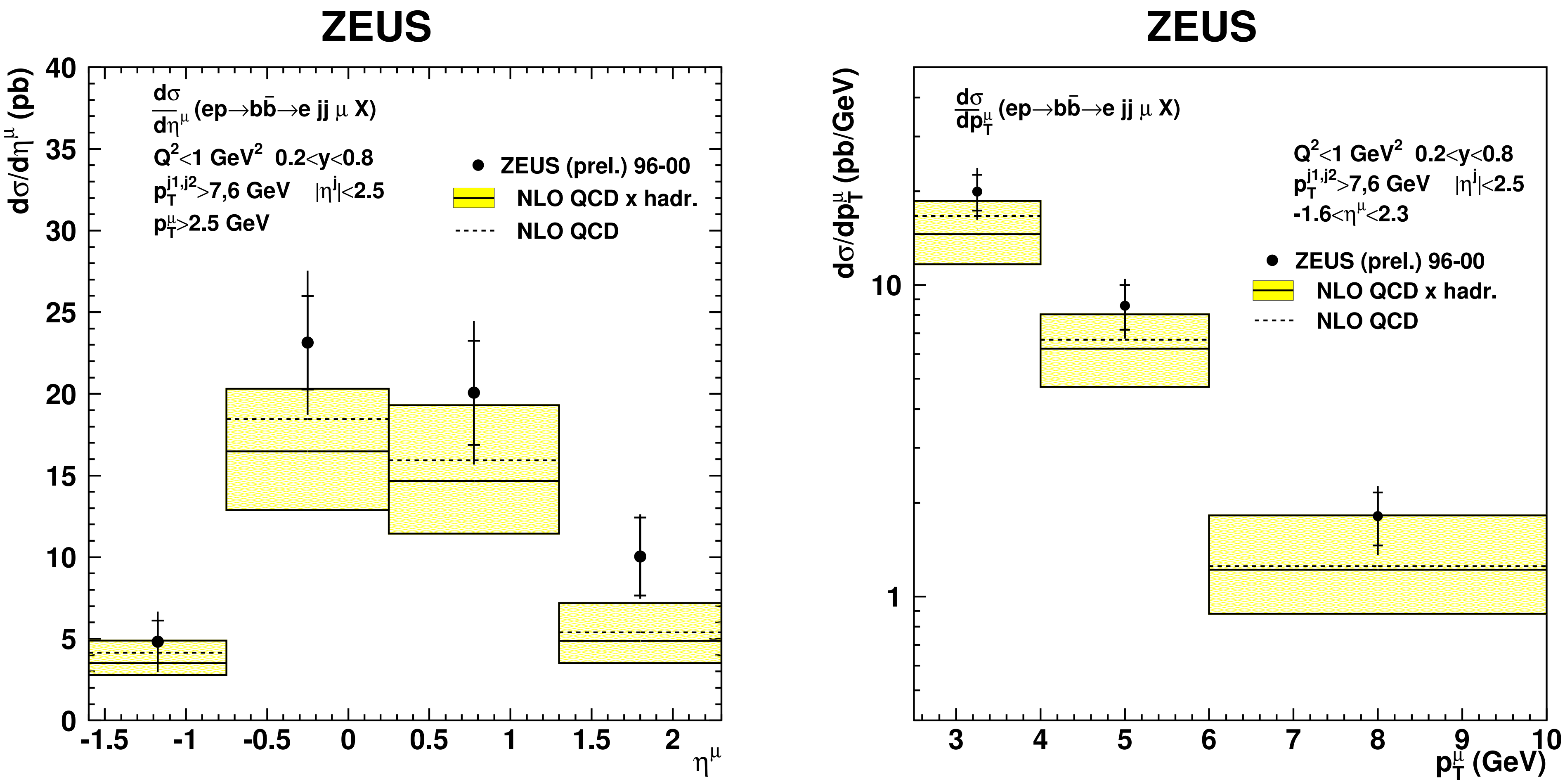
Data above NLO over the whole x_γ range
Data/NLO larger at low x_γ
but also NLO uncertainty larger at low x_γ



Visible muon cross sections $\sigma(ep \to b\bar{b}X \to jj\mu X')$

Closer to expt. measurement $\to$ less model dependence

Cut $p_t^\mu > 2.5$ GeV to get more flat acceptance $\to$ low p_t μs in FORWARD/REAR removed



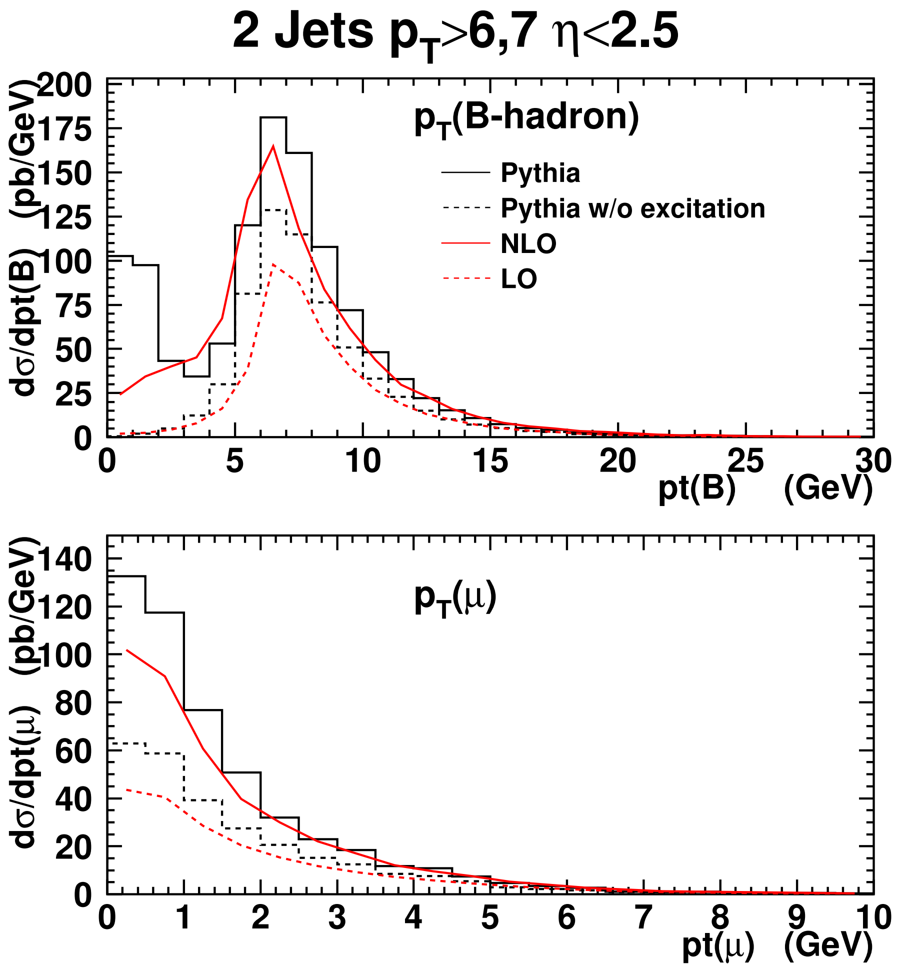
Compared to NLO $\times$ $(b \to B)$ $\times$ $(B \to \mu)$

Reasonable agreement: Data/NLO $= 1.4$

Comparing Visible and Dijet results

Dijet	$\sigma(ep \to b\bar{b} \to jjX)$	**Data/NLO=1.9**
Visible	$\sigma(ep \to b\bar{b} \to jj\mu X)$	**Data/NLO=1.4**

Why these 2 numbers differ by 30%?

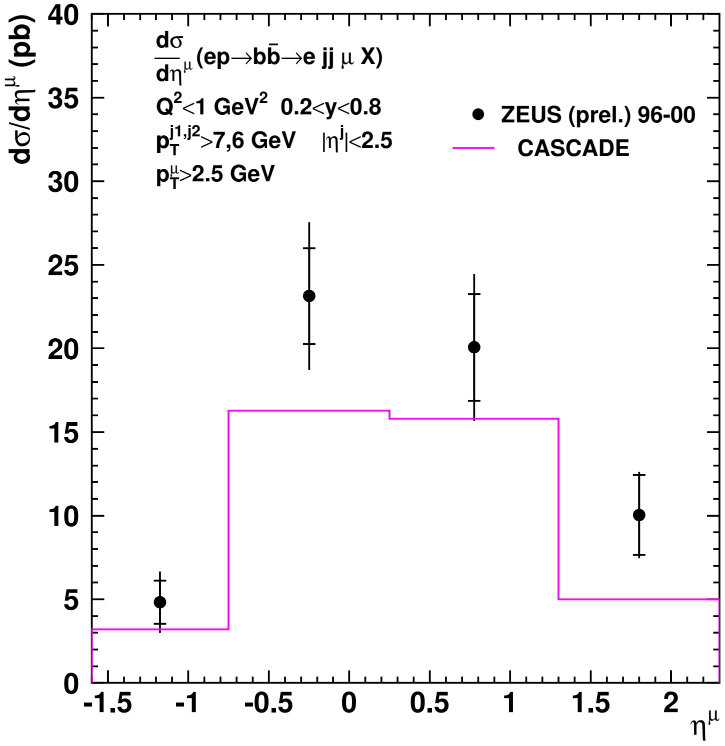


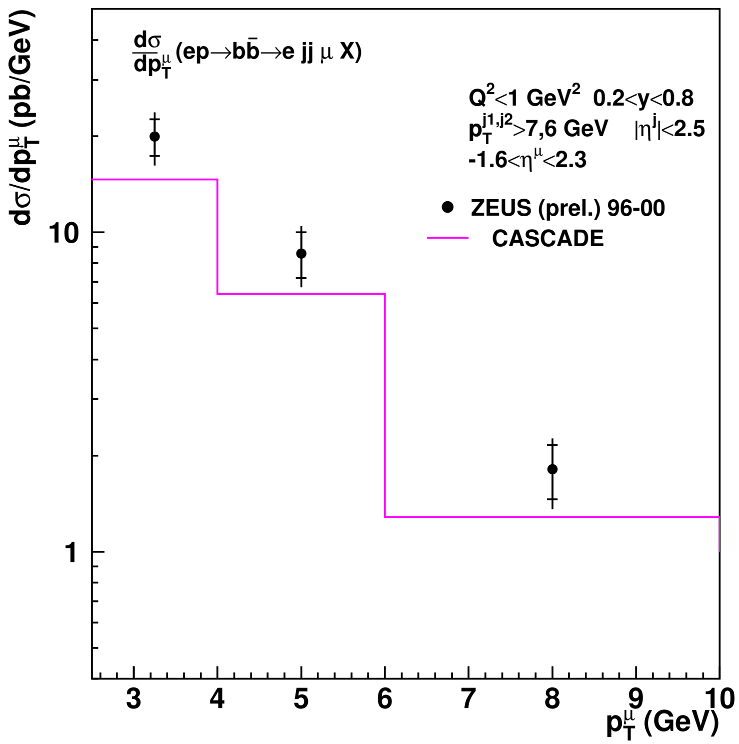
- **Different sample:** **Cut** $p_T^\mu > 2.5$ **GeV removes low** p_T **muons from Visible cross-section**
- p_T^μ **distribution from Pythia (used to correct to dijet cross-section) softer than NLO**$\times(b \to B) \times (B \to \mu)$ **due to** b**-remnants from Flavour Excitation diagrams**

Comparison with Cascade

- Cascade is a MC implementation of the CCFM evolution equation
- Good description of b production at Tevatron
- No need of resolved-photon processes
- Parameters: Unintegrated pdf(p) fitted to DIS data, $m_b = 4.75$ GeV

CASCADE predictions by H. Jung

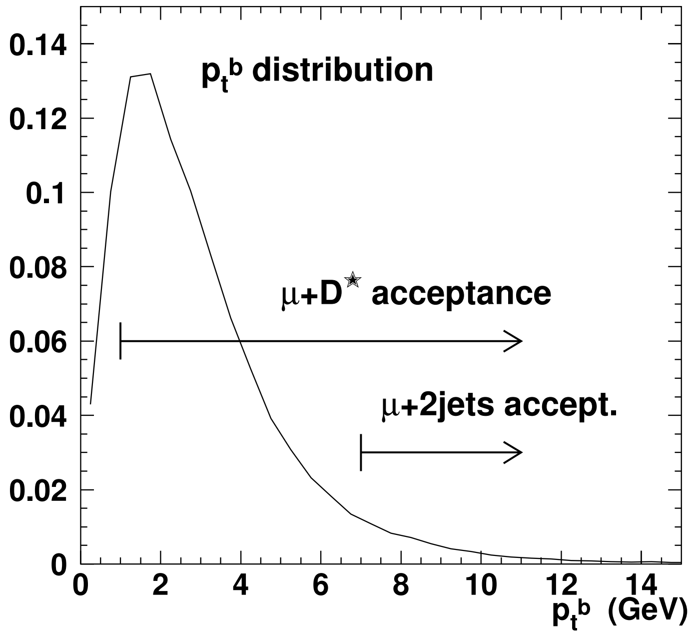


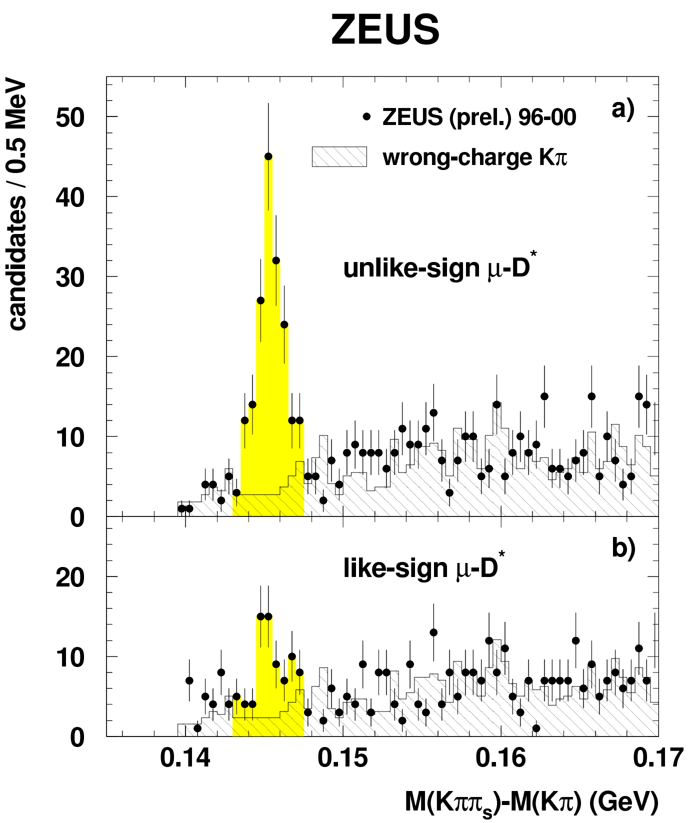


Cascade prediction somehow below the data, very similar to NLO

b from $D^* - \mu$ correlation

- Bulk of beauty cross section at low p_T^b
- 2-jets+high-p_T lepton analyses sensitive to large p_T^b
- Alternative approach: reconstruct $B \to D^{*\pm}\mu^{\mp}$
  small B.R. (10^{-4}) but large purity
  access to lower p_T^b

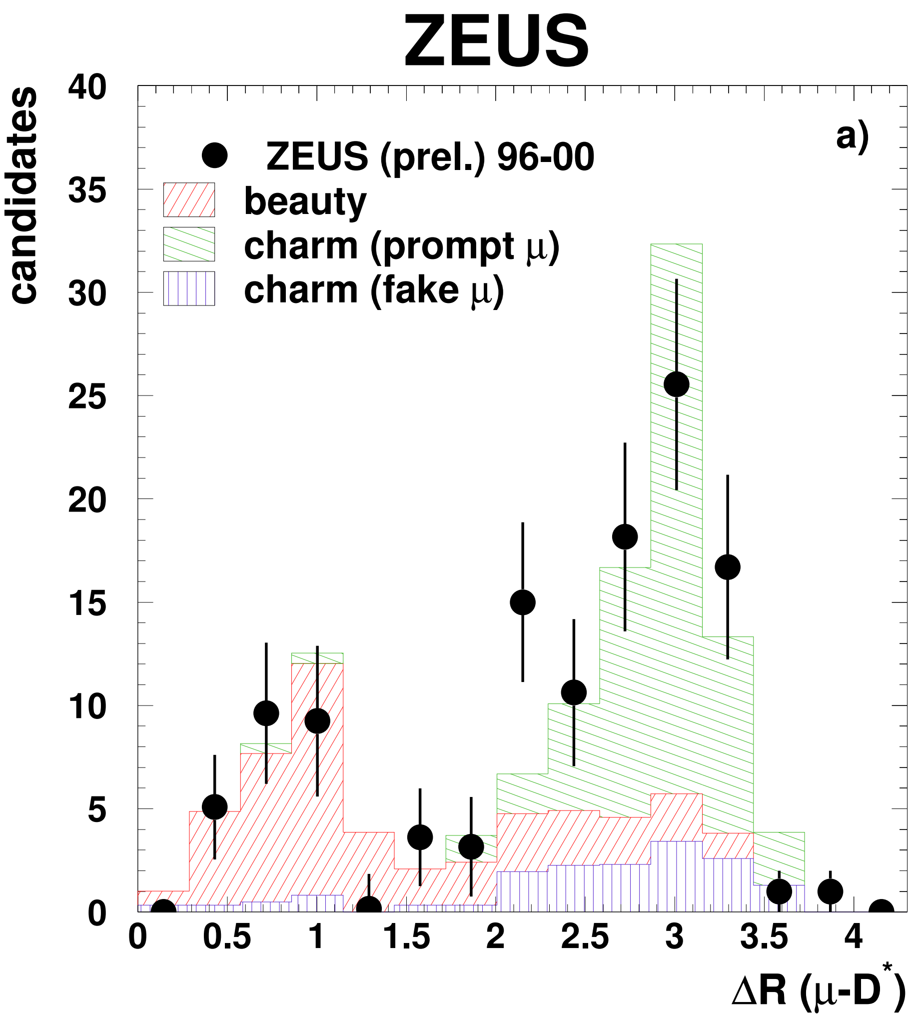




Selection: 1996-2000 data (114 pb^{-1})

- $D^{*\pm} \to K^{\mp}\pi^{\pm}\pi_s^{\pm}$:
  $p_t(D^*) > 1.9$ GeV; $|\eta(D^*)| < 1.5$
- $p_t(\mu) > 1.4$ GeV; $-1.75 < \eta(\mu) < 1.3$
- $3 < M(D^*, \mu) < 5$GeV

$D^{*\pm} - \mu^{\mp}$ angular distance

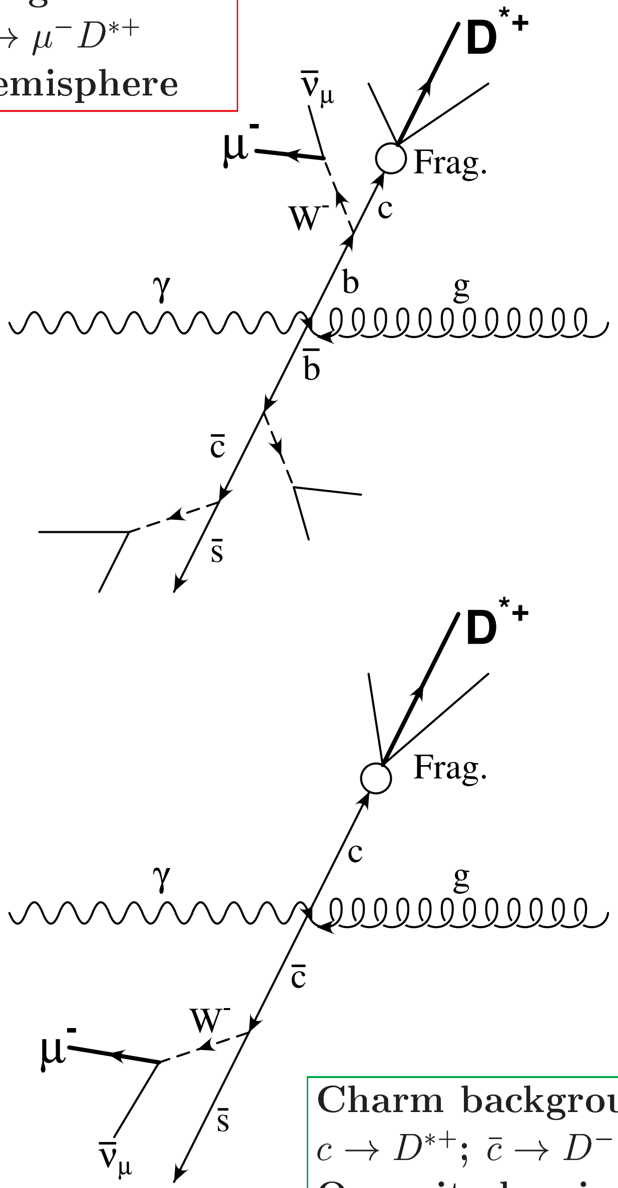


Distance in $\eta - \phi$ between D^* and μ after D^* background subtraction

Compare to MC to extract b fraction

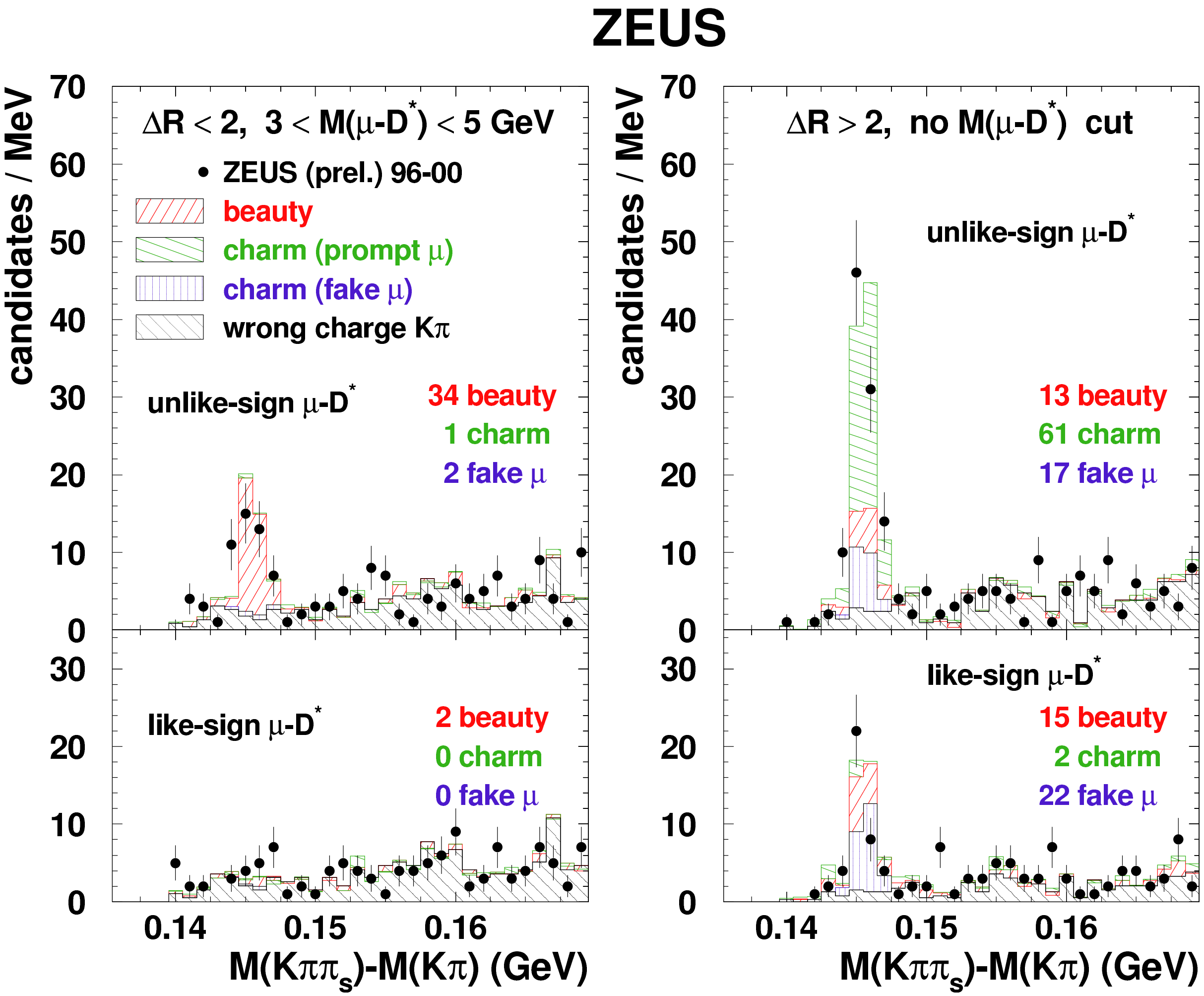
$f_b = 0.363 \pm 0.084$

Beauty signal:
$b \to B^0 \to \mu^- D^{*+}$
Same hemisphere



Charm background:
$c \to D^{*+}$; $\bar{c} \to D^- \to \mu^-$
Opposite hemisphere

D^* Signals after ΔR and M cuts



Δm distributions for like/unlike charge and same/opposite hemisphere well reproduced by MC

b-signal also observed in like-charge and opposite hemispheres
$(b \to c \to \mu^+;\ \bar{b} \to \mu^-$ + c.c.)

Cross sections

Visible ep cross section within D^* and μ cuts:

$$\sigma(ep \to eb\bar{b}X \to eD^*\mu X') = 214 \pm 52(\mathbf{stat.})^{+96}_{-84}(\mathbf{syst.})\mathbf{pb}$$

MC prediction from Pythia (Herwig): $\sigma_{\mathbf{MC}}(ep \to eb\bar{b}X \to eD^*\mu X') = 80(38)\mathbf{pb}$
Main systematics from model acceptance
Agreement with similar results from H1

After photoproduction cuts $Q^2 < 1$ GeV^2, $0.05 < y < 0.85$:

$$\sigma_{\mathbf{PHP}}(ep \to eb\bar{b}X \to eD^*\mu X') = 159 \pm 41(\mathbf{stat.})^{+68}_{-62}(\mathbf{syst.})\mathbf{pb}$$

Reasonable acceptance down to $p_{\mathrm{T}}^b = 0$
extrapolated to the $b(\bar{b})$-quark photoproduction cross section

for $Q^2 < 1$ GeV^2, $0.05 < y < 0.85$; rapidity $\zeta^b < 1$:

$$\sigma(\gamma p \to b(\bar{b})X) = 15.1 \pm 3.9(\mathbf{stat.})^{+3.8}_{-4.7}(\mathbf{syst.})\mathbf{nb}$$

To be compared with NLO (FMNR)

$$\sigma_{\mathbf{N}LO}(\gamma p \to b(\bar{b})X) = 5.0^{+1.7}_{-1.1}\mathbf{nb}$$

Conclusions

- Dijet+μ analysis based on p_T^{rel}:
  Visible cross-section ~ 1.4 times above NLO, agreement within uncertainties
- Shape of differential distribution well described by NLO
- $D^*\mu$ analysis sensitive to low p_T^b:
  Cross section ~ 3 times NLO but large uncertainty
- ZEUS Photoproduction results compatible with each other
- More careful comparison of 2-jets+μ analyses by ZEUS and H1 needed!

The famous data/NLO ratio plot: