Bottom Production at HERA

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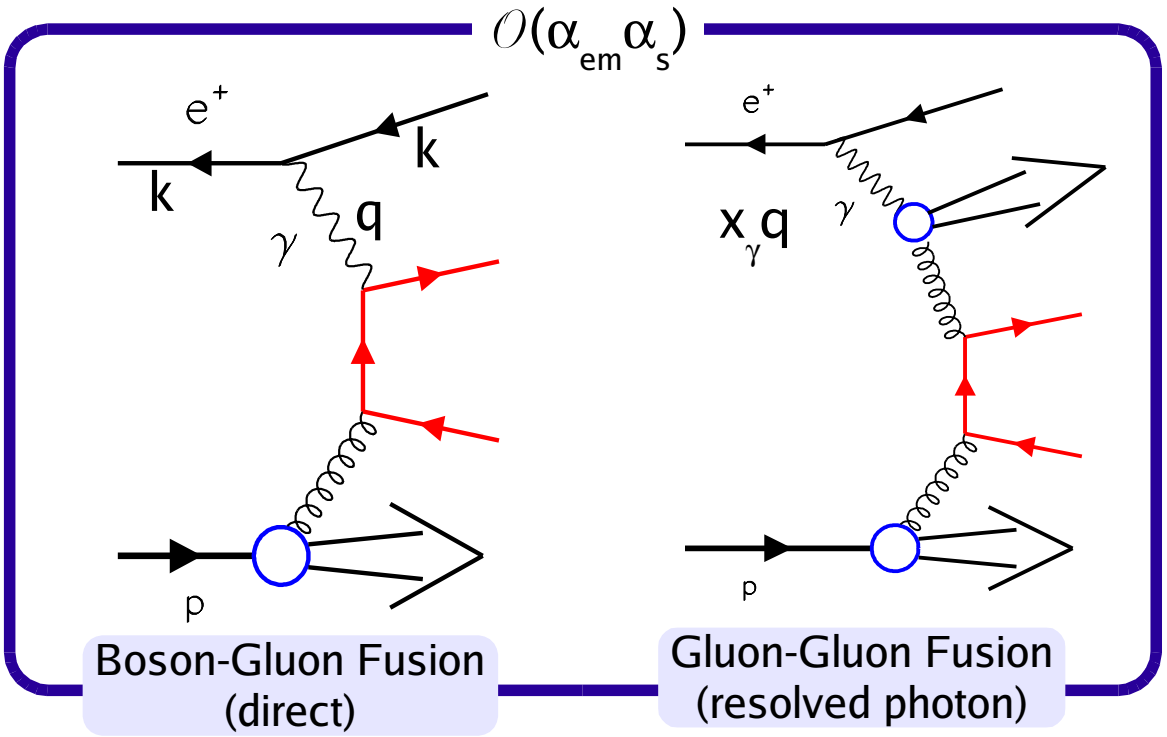
On behalf of the H1 and ZEUS collaborations

Outline:

- Production mechanism
- QCD tools: NLO and Monte Carlos
- Open bottom production in photoproduction
- Open bottom production in Deep Inelastic Scattering
- Open bottom production using D* μ correlations
- Summary and outlook

Production mechanism



Photon virtuality: $Q^2 = -q^2 = -(k-k')^2$
Bjorken scaling variable: $x = Q^2/(2p\cdot q)$
Inelasticity: $y = (p\cdot q)/(p\cdot k)$

- The positron is scattered in the central detector → $Q^2>1$ GeV^2 → Deep Inelastic Scattering (DIS)
- The scattered positron escapes the central detector → $Q^2<1$ GeV^2 → Photoproduction (PHP)

QCD tools: NLO Calculations

b–quark level

Massive scheme (FOPT)

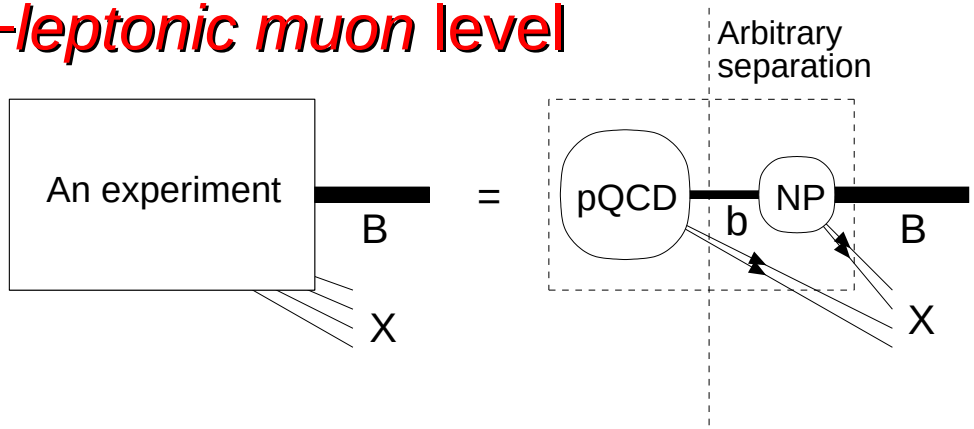
- Massive b quark produced through the BGF mechanism
- Proton wave function = u,d,s,c (+ anti quarks)

- **FMNR**: Almost real photons with point like and hadronic structure (PHP)
- **HVQDIS**: Virtual photons (DIS)

B–meson or *semi–leptonic muon* level

Fragmentation and semi leptonic decay

- Ansatz: Peterson fragmentation function used to parametrize the NP contribution
- A NP term is not an observable quantity!
- s/l Decay: muon momentum spectrum extracted from LO Monte Carlos



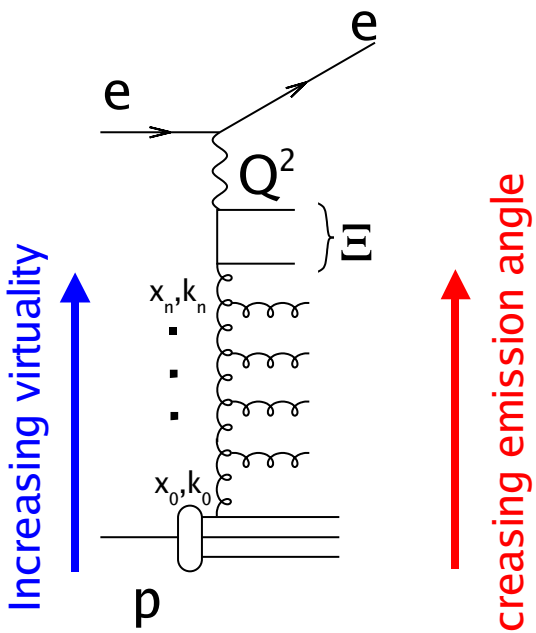
M.Cacciari, P.Nason hep ph/0205326, 0204025

$$D(z) = A\, z \frac{(1-z)^2}{\left[(1-z)^2 + \epsilon\, z\right]^2}, \qquad z = \frac{p_{B-meson}}{p_{b-quark}}$$

QCD tools: Monte Carlo programs

Parton shower with DGLAP Evolution

- Matrix Element with incoming on shell gluon
- K_T ordering in the gluon ladder
- **AROMA:**
  - Direct only
  - Lund string model
- **RAPGAP:**
  - Direct (+ resolved)
  - Lund string model
- **PYTHIA:**
  - direct+resolved(+quark excitation)
  - Lund string model
- **HERWIG:**
  - direct+resolved(+quark excitation)
  - Cluster model

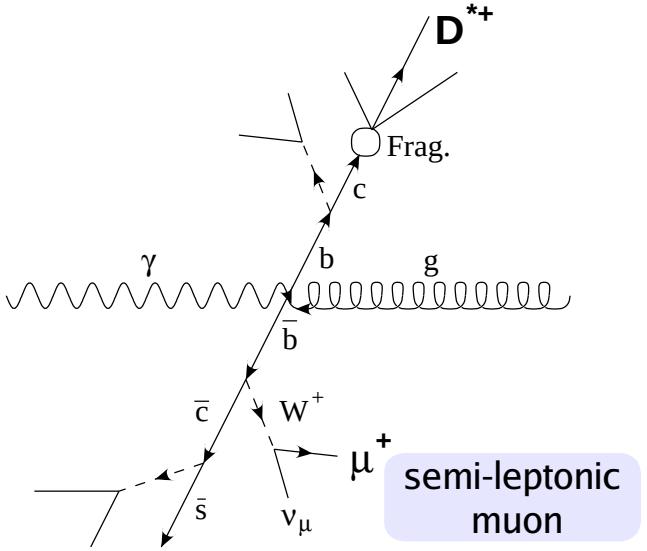


Parton shower with CCFM like evolution

- **CASCADE:**
  - Matrix Element with incoming off shell gluon
  - Angular ordering in the gluon ladder (CCFM)
  - Direct (pointlike) component only
  - Gluon density unintegrated in k_T and extracted from a fit to the HERA structure function F_2
  - Lund string model

Tagging the s.l. B decays

Center of mass frame

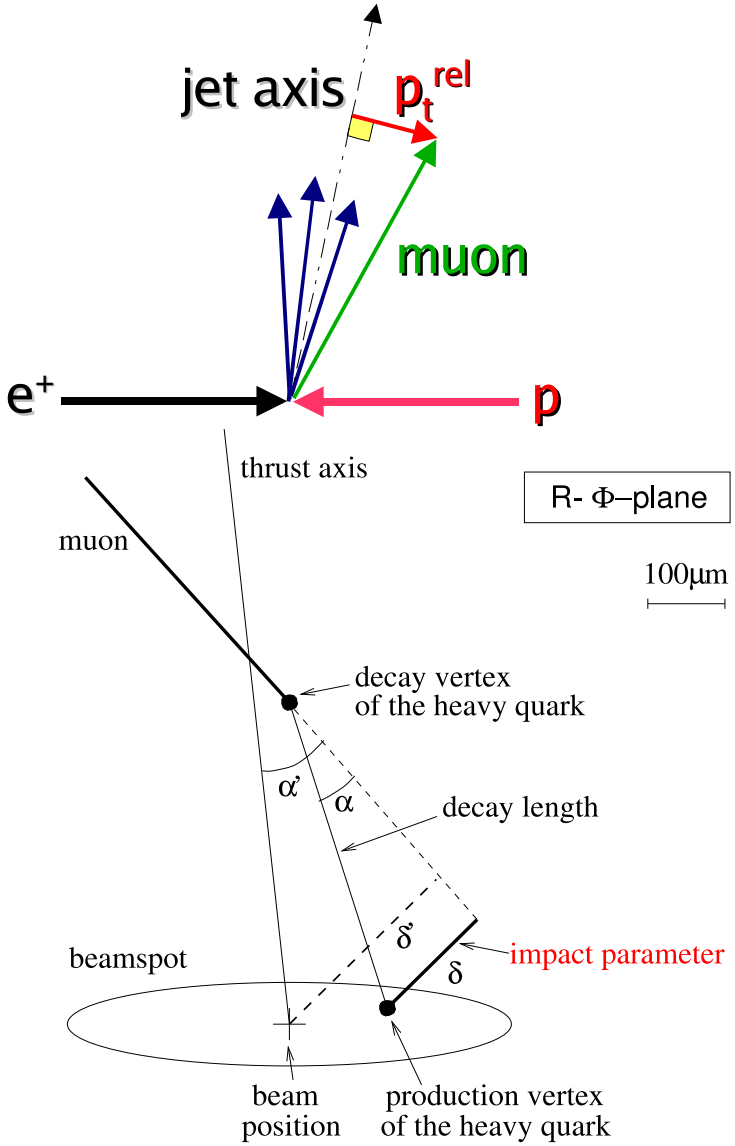


semi-leptonic muon

Jet from charmed meson

P_T^{rel}

Lifetime

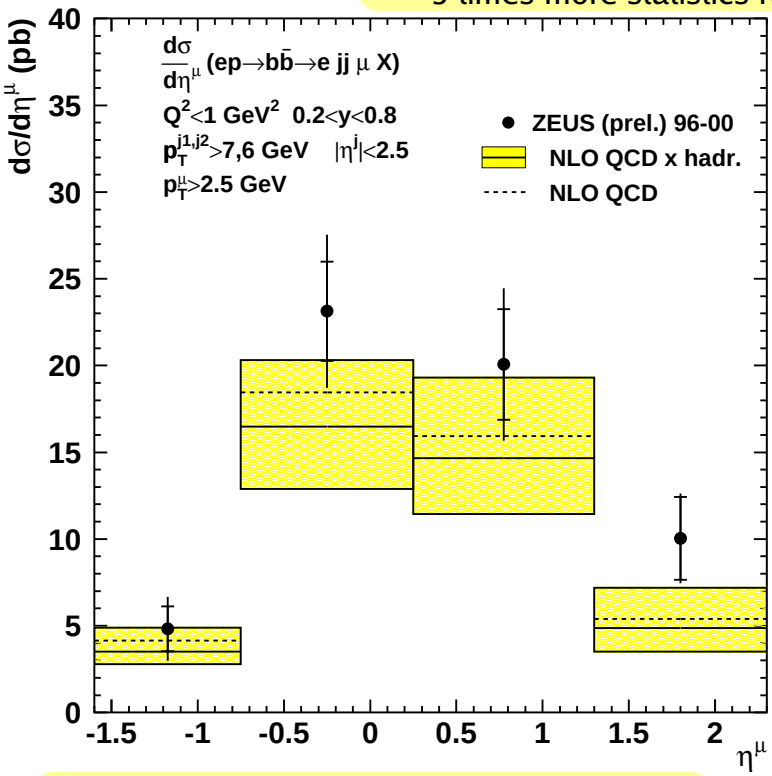


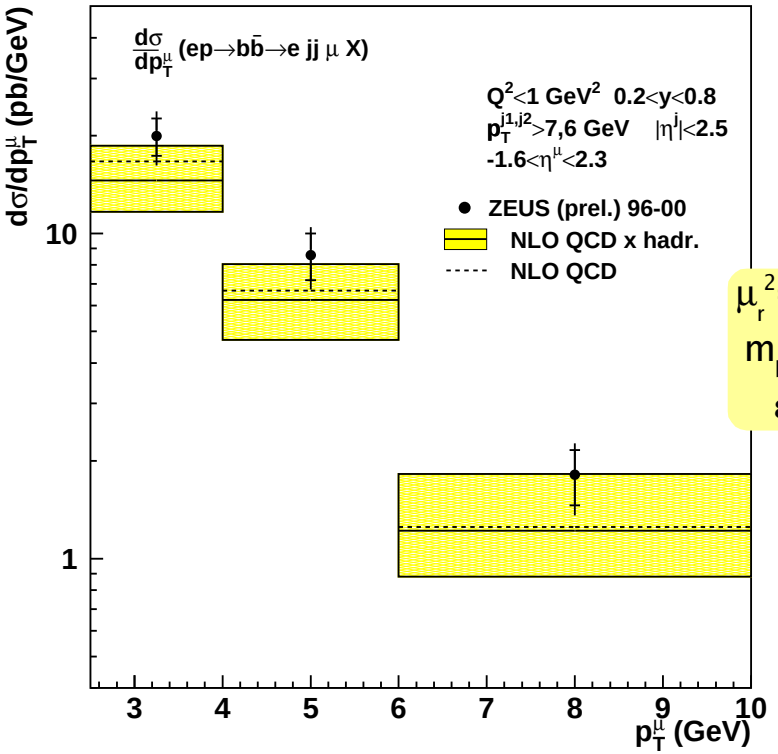
other method: (D*,μ) correlations...

Bottom in Photoproduction

New ZEUS result: 1996/00 ~98 pb^{-1}

3 times more statistics respect to previous results





$\mu_r^2=\mu_f^2=p_T^2+m_b^2$

m_b=4.75 GeV

ε = 0.0035

$\sigma(ep \rightarrow bb\ X \rightarrow e\,Jet\ Jet\ \mu\ X)$

Q^2 < 1 GeV^2 0.2<y<0.8

At least two jets in the Lab frame with:

$p_{t,Jet1(Jet2)}$ > 7 (6) GeV, $|\eta_{Jet}|$<2.5

At least one muon with:

$p_{T,\mu}$ >2.5 GeV 1.6<η_μ<2.3

Total di-jet cross section:

$\sigma(ep \rightarrow bb \rightarrow Jet\ Jet\ X)$ =

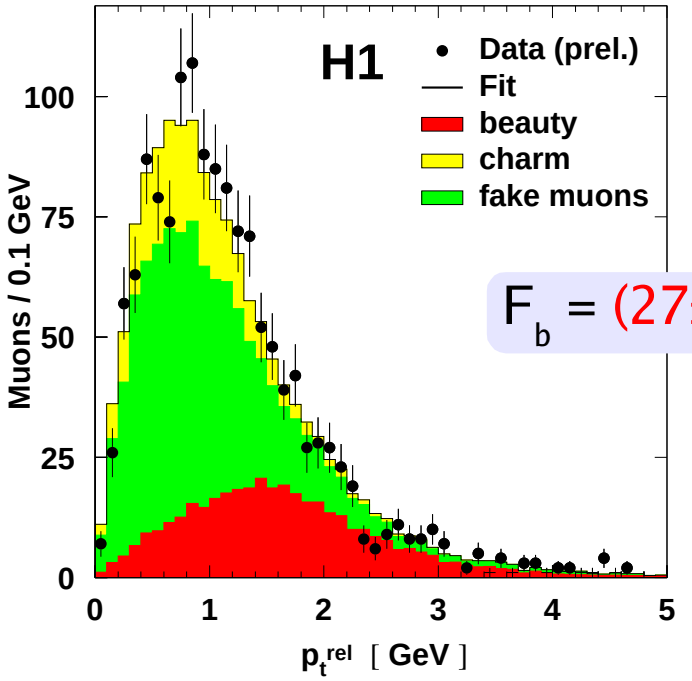
733±61(stat.)±104(syst.) pb

NLO QCD (**FMNR**) = 381 +117 -78 pb

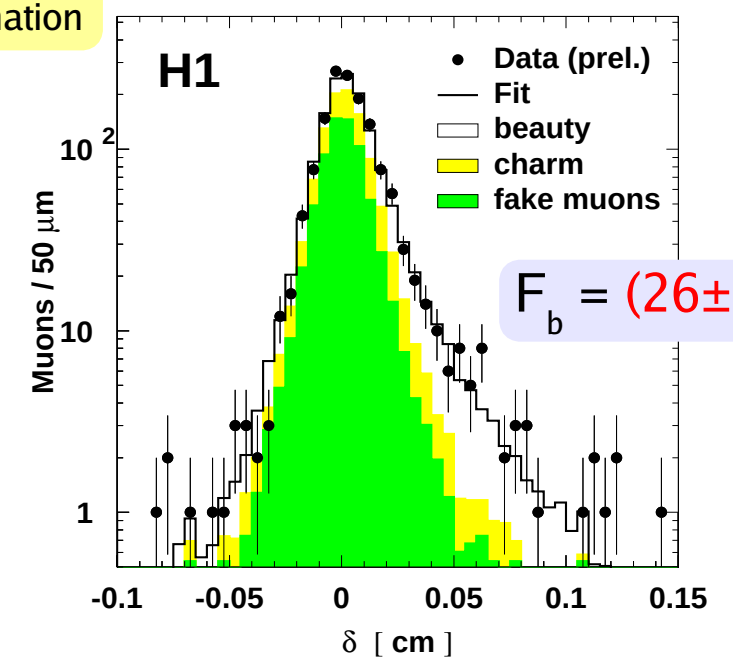
Bottom in Photoproduction

H1: 1997 ~15 pb^{-1}

P_T^{rel} + Lifetime information



F_b = (27±3) %



F_b = (26±5) %

$\sigma(ep \rightarrow bb\,X \rightarrow \mu\,X)$

$Q^2 < 1\ GeV^2$ $0.1 < y < 0.8$

At least one muon with:

$p_{T,\mu} > 2$ GeV $35° < \theta_\mu < 130°$

97 data (2D Fit): 160 ± 16 (stat.) ± 29 (syst.) pb

96 data (P_T^{rel} only): 176 ± 16 (stat.) + 27 (syst.) - 17 (syst.) pb

H1 Combined 96+97: 170 ± 25 pb

NLO QCD (**FMNR**) = 54 ± 9 pb

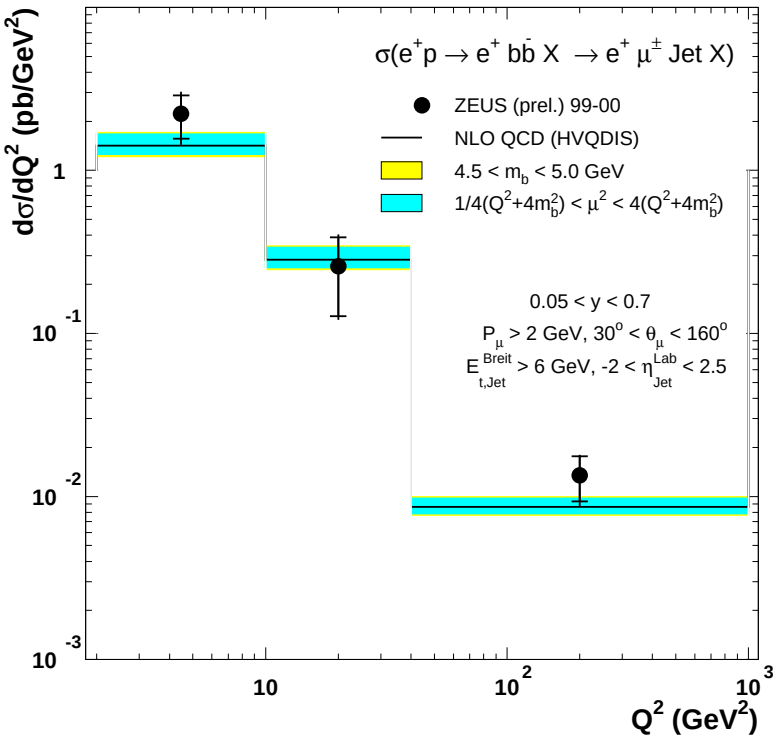
$O(\alpha_s)$ QCD⊗CCFM (**CASCADE**) = 67 pb

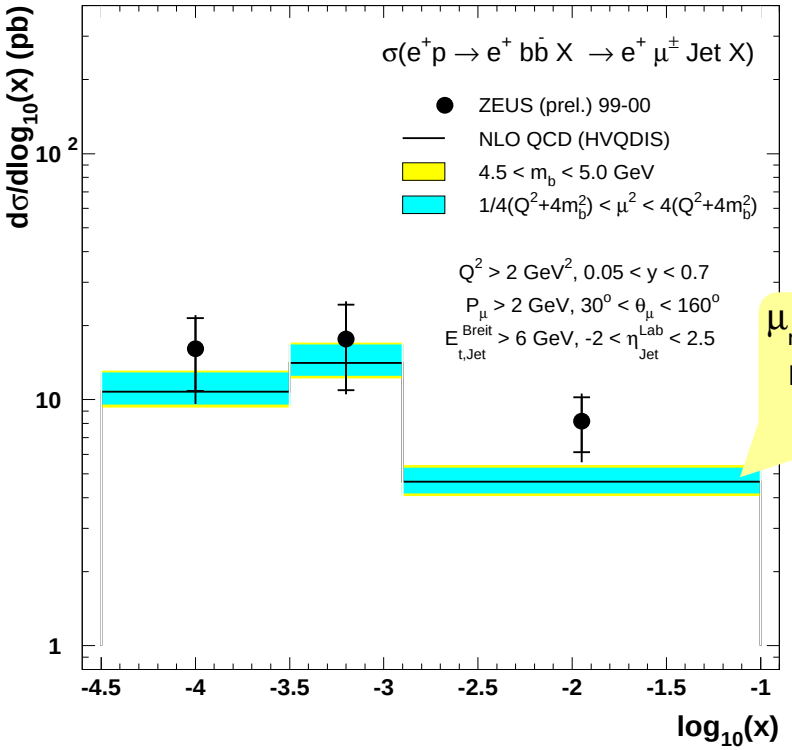
$O(\alpha_s)$ QCD⊗DGLAP (**AROMA**) = 38 pb

Bottom in Deep Inelastic Scattering

New ZEUS result: 1999/00 ~60 pb^{-1}

first differential distributions in DIS!





NLO QCD

$\mu_r^2=\mu_f^2=Q^2+4m_b^2$

m_b=4.75 GeV

ε = 0. 002

$P_T^{rel} \to F_b$ = 25±5 %

σ = 38.7±7.7(stat.)+6.1(syst.)-5.0(syst.) pb

NLO QCD (HVQDIS) = 28.1 +5.3 -3.5 pb

$\sigma(ep \to e\, b\bar{b}\, X \to e\, \text{Jet}\, \mu\, X)$

$Q^2 > 2$ GeV^2 $0.05<y<0.7$

At least one jet in the Breit (γ^*P) frame with

$E^{Breit}_{T,Jet} > 6$ GeV, $-2<\eta^{Lab}_{Jet}<2.5$

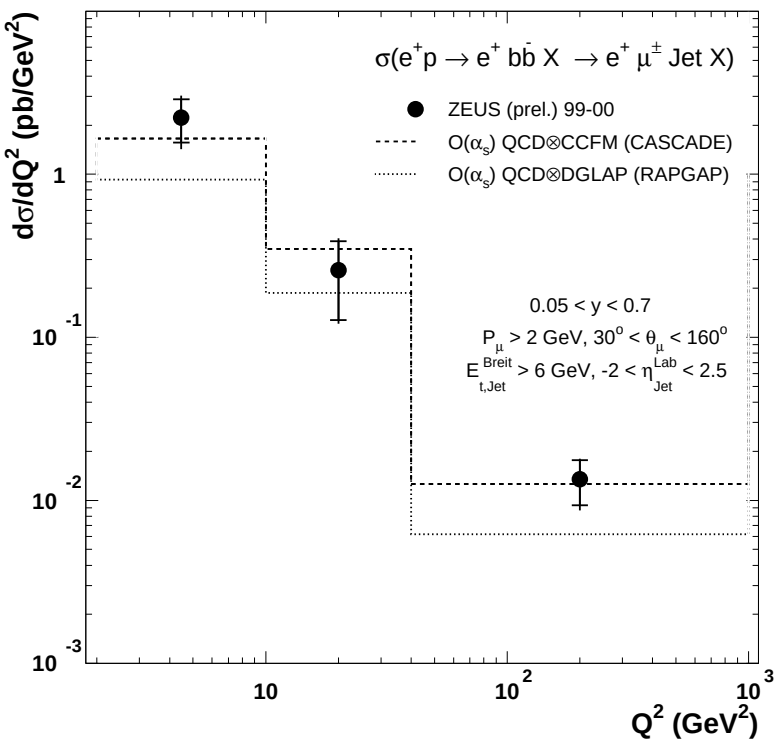
At least one muon with

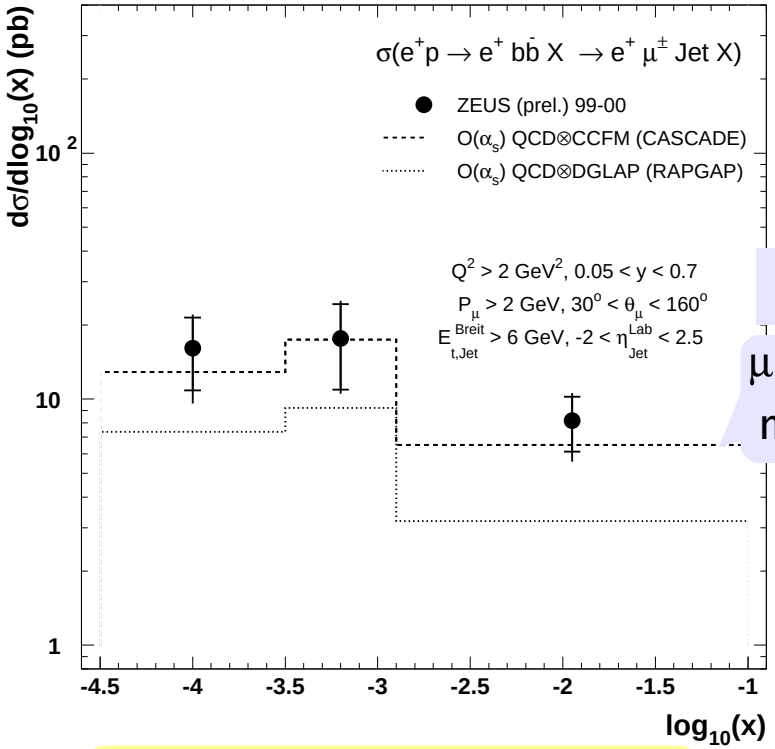
$p_\mu > 2$ GeV, $30<\theta_\mu<160$

Bottom in Deep Inelastic Scattering

New ZEUS result: 1999/00 ~60 pb^{-1}

first differential distributions in DIS!





Cascade

$\mu_r^2=\mu_f^2=p_T^2+m_b^2$

m_b=4.75 GeV

σ = 38.7±7.7(stat.)+6.1(syst.)-5.0(syst.) pb

$O(\alpha_s)$ QCD⊗CCFM (CASCADE) = 35 pb

$\sigma(ep \to e\, b\bar{b}\, X \to e\, \text{Jet}\, \mu\, X)$

$Q^2 > 2$ GeV^2 $0.05<y<0.7$

At least one jet in the Breit (γ^*P) frame with

$E^{Breit}_{T,Jet} > 6$ GeV, $-2<\eta^{Lab}_{Jet}<2.5$

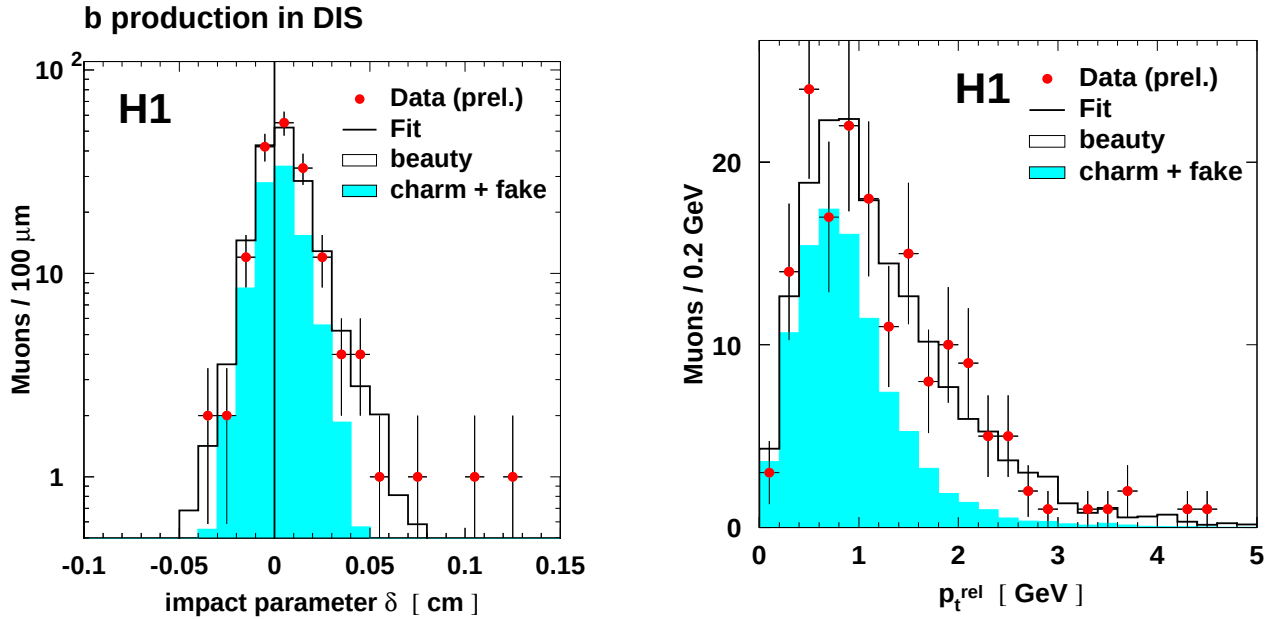
At least one muon with

$p_\mu > 2$ GeV, $30<\theta_\mu<160$

Bottom in Deep Inelastic Scattering

H1: 1997 ~10 pb^{-1}

pTrel and lifetime



(P_t^{rel},δ) 2D Fit$\rightarrow$ F_b = 43±8 %

$\sigma(ep \rightarrow b\,X \rightarrow \mu\,X)$

$2<Q^2<100$ GeV^2 $0.05<y<0.7$

At least one muon with

$p_{T,\mu}$ >2 GeV, $30°<\theta_\mu<160°$

σ = 39 ± 8 (stat.) ± 10 (syst.) pb

NLO QCD (**HVQDIS**) = 11 + 2 pb

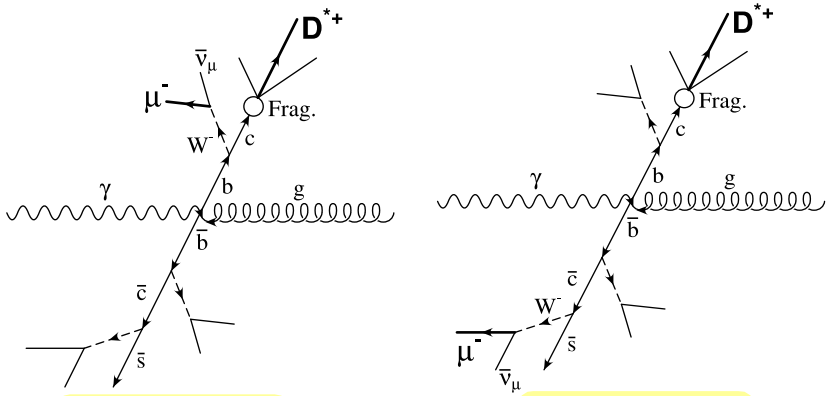
O(α_s) QCD⊗CCFM (**CASCADE**) = 15 pb

O(α_s) QCD⊗DGLAP (**AROMA**) = 9 pb

Bottom cross section using D* + μ final state

New ZEUS result: 1996-00 114 pb^{-1}

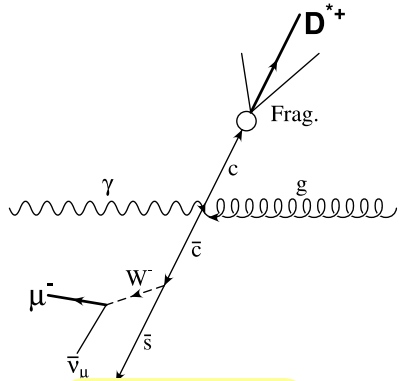
bottom decays



ΔΦ~0°
Q(μ)≠Q(D*)

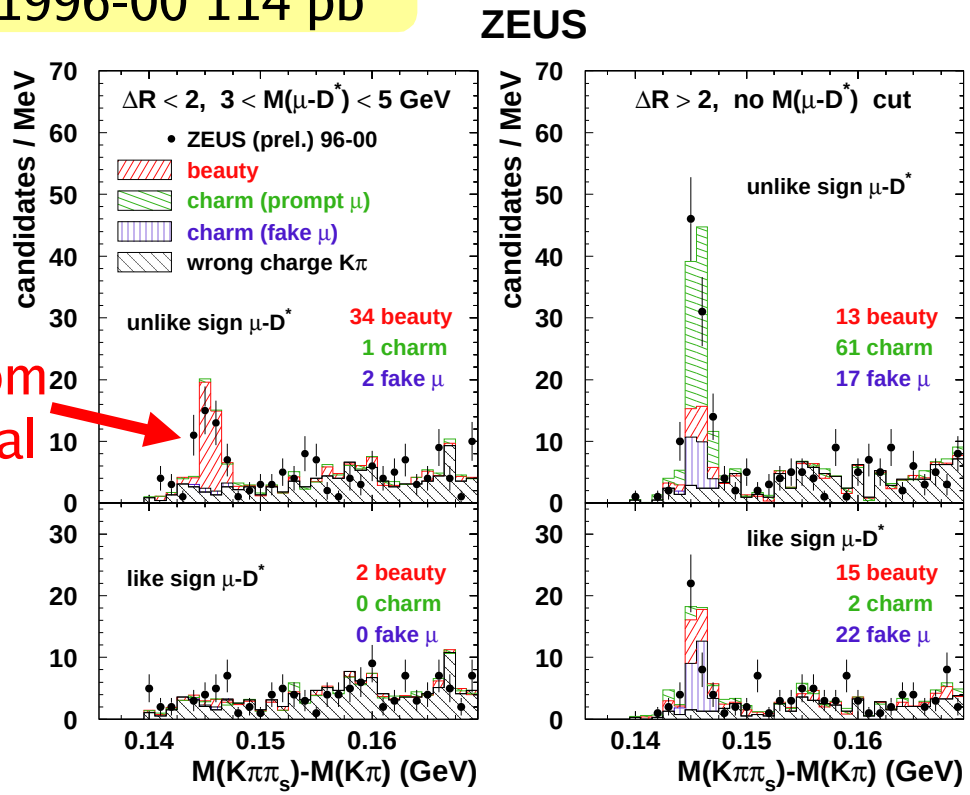
ΔΦ~180°
Q(μ)≠Q(D*)

charm decays



ΔΦ~180°
Q(μ)≠Q(D*)

bottom signal



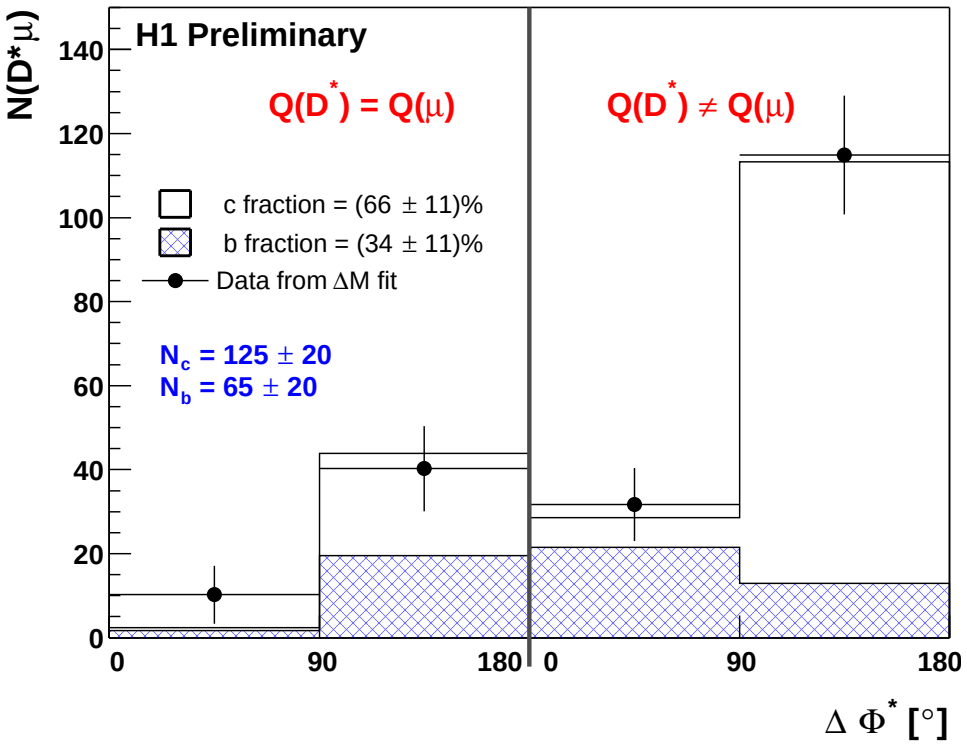
σ(ep →e bb X→e D* μ X)
p_T^{D*}>1.9 GeV -1.5<η^{D*}<1.5
$p_{T,\mu}$ >1.4 GeV, -1.3 <η_μ<1.75
214±52(stat.)+96-84(syst.) pb

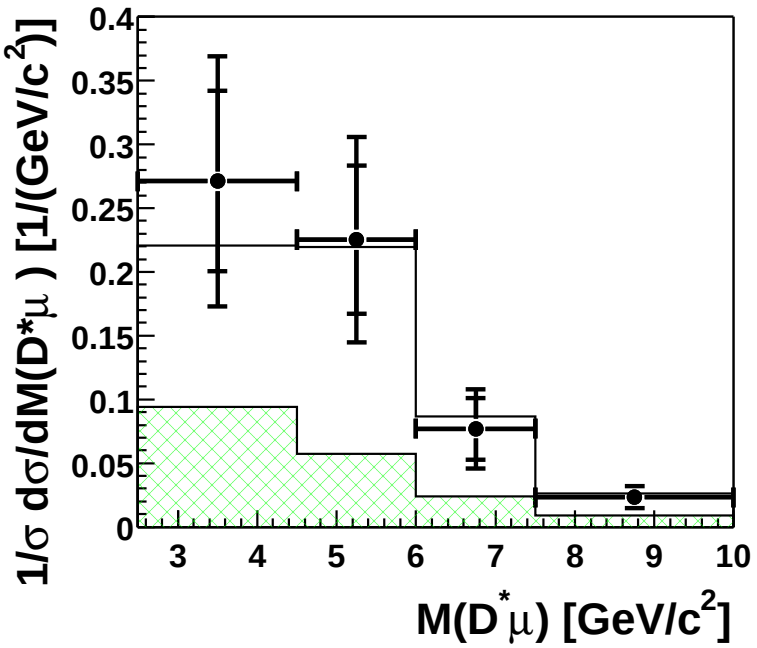
Photoproduction region:
y_{rap}(b)<1, Q^2<1 GeV^2, 0.05<y<0.85
σ(ep →e b(b) X) =
= 15.1±3.9(stat.)+3.8(syst.)-4.7(syst.) pb

NLO QCD (FMNR) = 5.7 +1.7 -1.1 pb

Bottom cross section using D* + μ final state

New H1 result: ~91 pb^{-1}

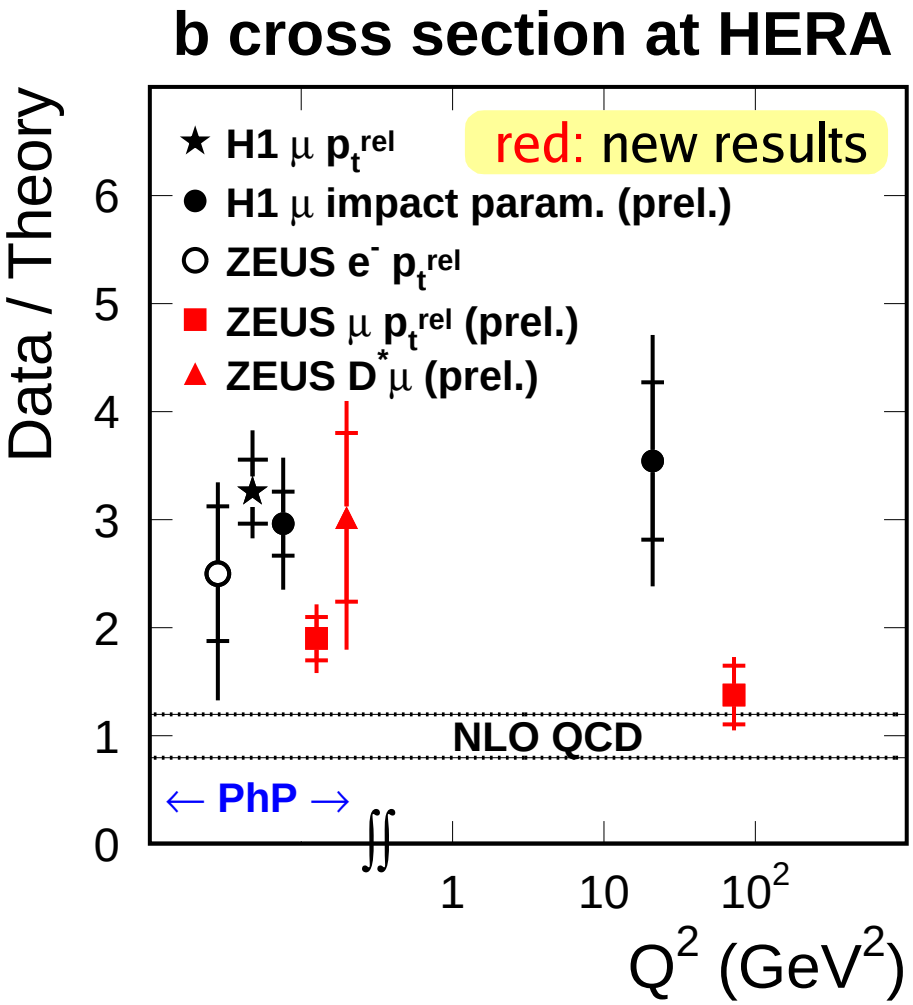




$\sigma(ep \rightarrow e\ QQ\ X \rightarrow e\ D^*\ \mu\ X)$
$p_T^{D^*} > 1.5$ GeV $-1.5 < \eta^{D^*} < 1.5$
$p_{T,\mu} > 1$ GeV, $|\eta_\mu| < 1.74$
$0.05 < y < 0.75$

$\sigma^{CHARM}(ep \rightarrow e\ D^*\ \mu\ X) = 720 \pm 115(stat.) \pm 245(syst.)$ pb
$\sigma^{BEAUTY}(ep \rightarrow e\ D^*\ \mu\ X) = 380 \pm 120(stat.) \pm 120(syst.)$ pb
Charm: DATA/LO(AROMA) = 1.8
Beauty: DATA/LO(AROMA) = 3.6

Summary and outlook



Many new results from HERA with increased precision!

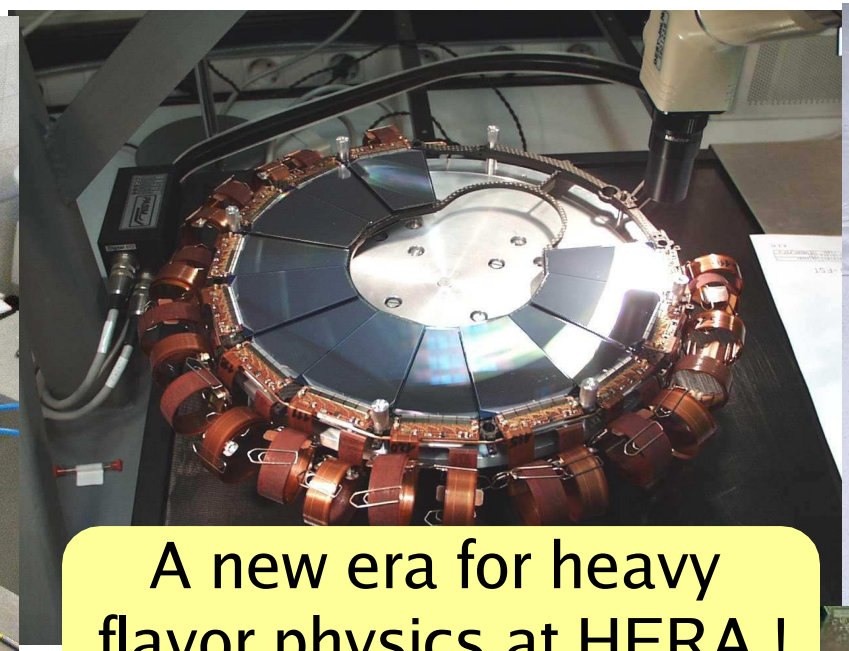
- Measured cross sections generally higher than NLO pQCD in photoproduction
- ZEUS DIS result agrees with NLO within errors
- New measurements using D*-μ correlations are sensitive to very low p_T

- But... Measurements are performed in different kinematic regions and contain various model assumptions !

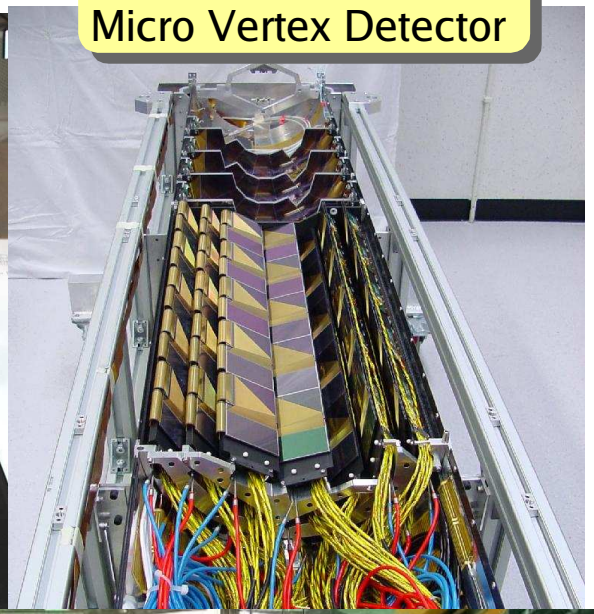
- A look at the future: HERA II
  - H1: new forward Si tracker and trigger
  - ZEUS: new Si vertex detector
  - 1 fb^{-1} expected by 2006

A look at the future...

H1 new Forward Silicon Detector



ZEUS new Micro Vertex Detector



A new era for heavy flavor physics at HERA !