Intern. Conference on the Structure and Interactions of the Photon

Frascati, 7-11 April 2003

Beauty in ep Collisions

Jürgen Kroseberg (Universität Zürich)

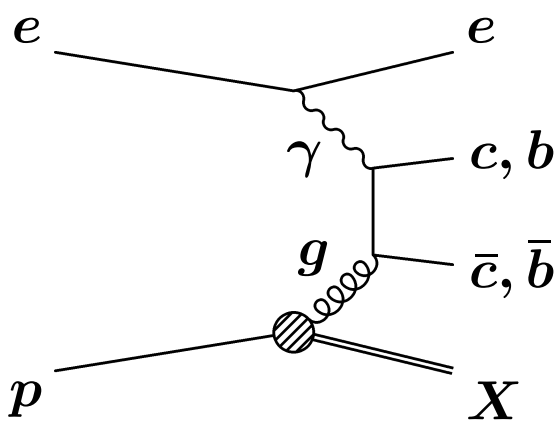
on behalf of the
H1 and ZEUS
collaborations

Open beauty measurements in photoproduction
and deep inelastic scattering at HERA

Open Heavy Flavour Production at HERA

- quark mass provides hard scale: good **testing ground for pQCD**
- gives insight into **proton and photon structure**
- dominantly **gluon induced**
- **photoproduction dominates** ($Q^2 \approx 0$) over DIS ($Q^2 \gg 0$).
- b **production** is heavily **suppressed**:

Boson Gluon Fusion



$Q^2 = -p_\gamma^2$

$y = \frac{\mathbf{p_p} \cdot \mathbf{p_\gamma}}{\mathbf{p_p} \cdot \mathbf{p_e}}$

$x = \frac{Q^2}{ys}$

$[\sqrt{s} \approx 318(300)\ \mathrm{GeV}]$

$$\boldsymbol{\sigma_b : \sigma_c : \sigma_{uds} \approx 1 : 200 : 2000}$$

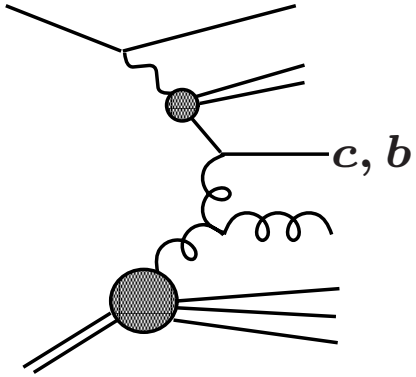
Probing QCD with Charm and Beauty

resolved γ contribution

e.g.

parton evolution model

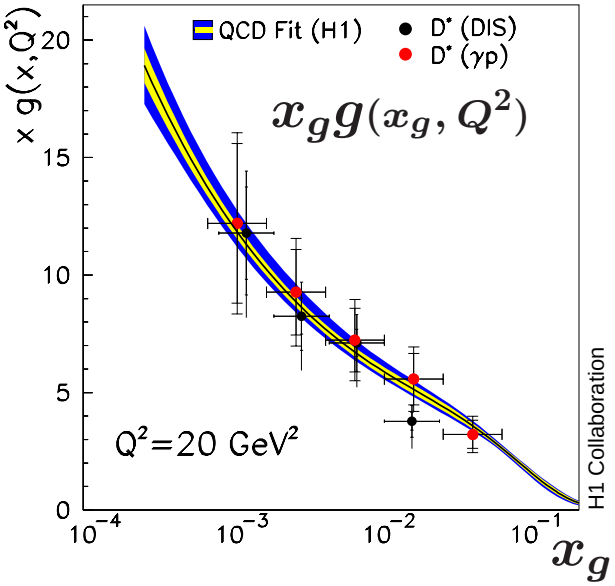
e.g.

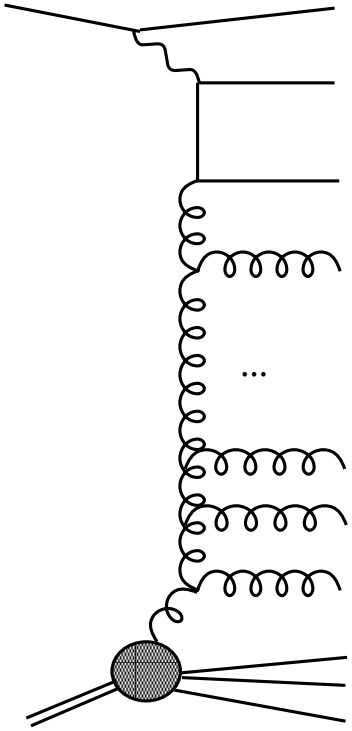


($\longrightarrow x_\gamma$ reconstruction)

gluon density

in the proton





e.g.

DGLAP

↕

CCFM

Modelling Beauty Production

$$\sigma_{\gamma p} \sim f^{\gamma} \otimes \hat{\sigma} \otimes f^{p} \otimes \mathcal{D}(z)$$

pQCD calculations in NLO

fixed order, **massive scheme**:
HQ **produced dynamically**;
reliable for $p_t \lesssim m_q$

$\longrightarrow$ appropriate for beauty at HERA

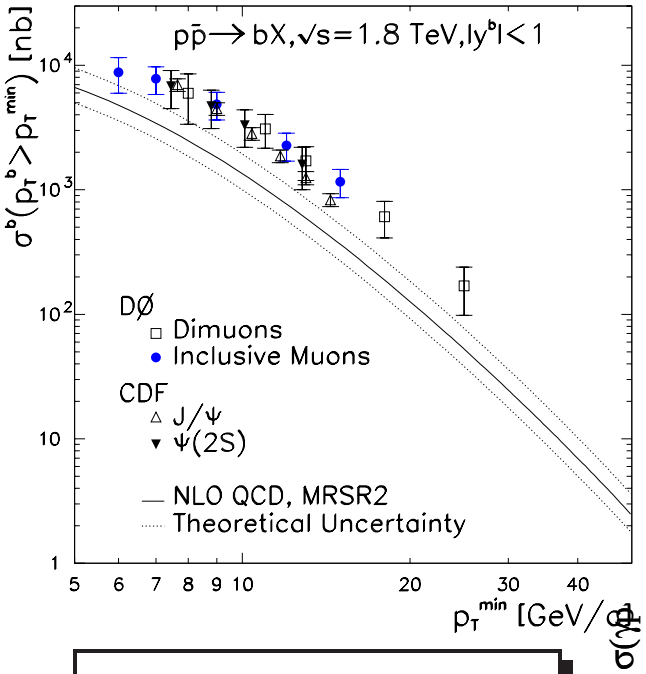
- γp**:** FMNR (Frixione et al.)
  $(m_b = 4.75\ \mathrm{GeV}, \mu^2_{R,F} = p^2_{t,b} + m^2_b, \epsilon = 0.0033{-}35)$
- **DIS:** HVQDIS (Harris & Smith)
  $(m_b = 4.75\ \mathrm{GeV}, \mu^2_{R,F} = Q^2 + 4m^2_b, \epsilon = 0.0020{-}33)$

$\longrightarrow$ k **factors** $\sim$ **1.4**

MC generators (LO ME + PS)

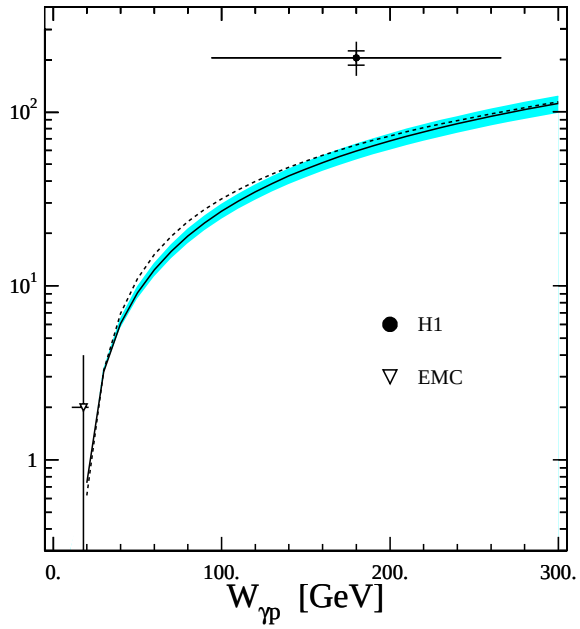
- **AROMA**:
  direct only, **DGLAP** evolution
- **PYTHIA, RAPGAP, HERWIG**:
  direct + **resolved**, DGLAP
- **CASCADE**:
  direct only, **CCFM**–like evolution,
  k_t dependent gluon density

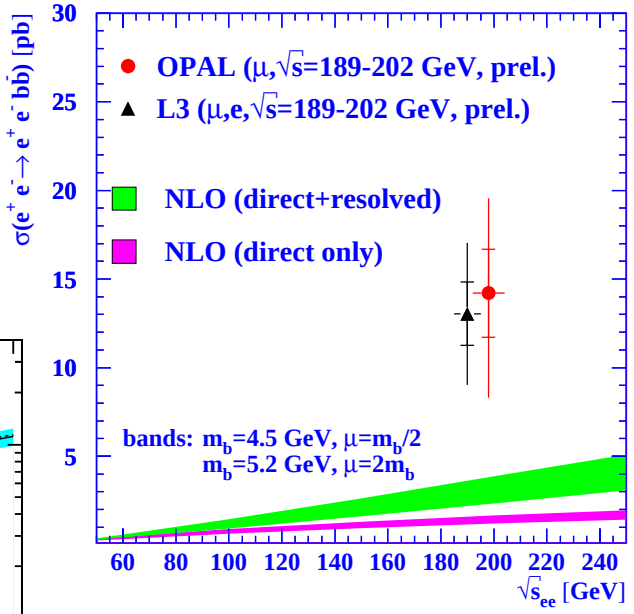
Measured Beauty Cross Sections vs. QCD (Spring 2000 Status)



TEVATRON $(p\bar{p})$

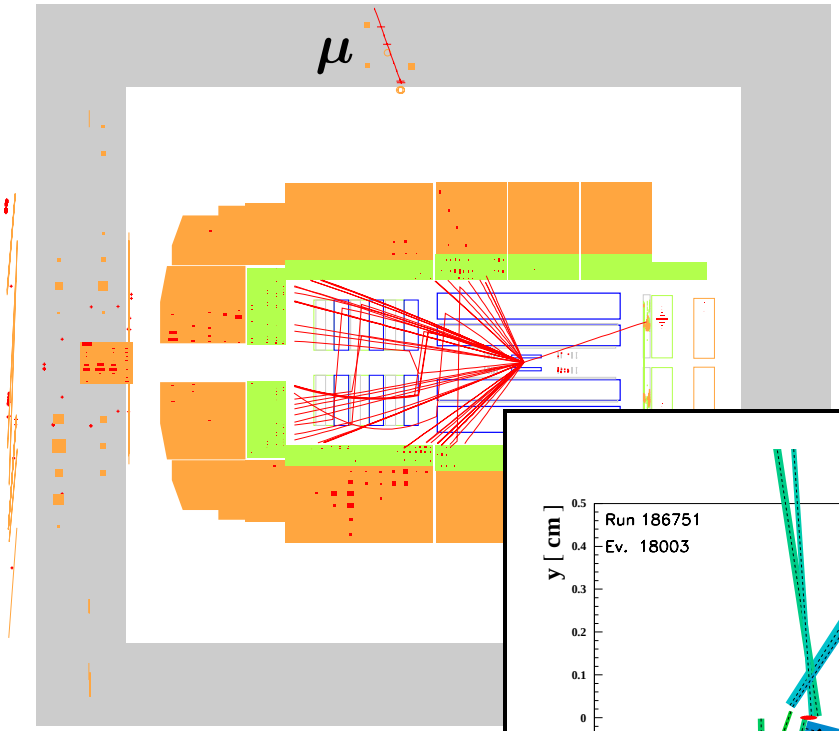
HERA (ep)



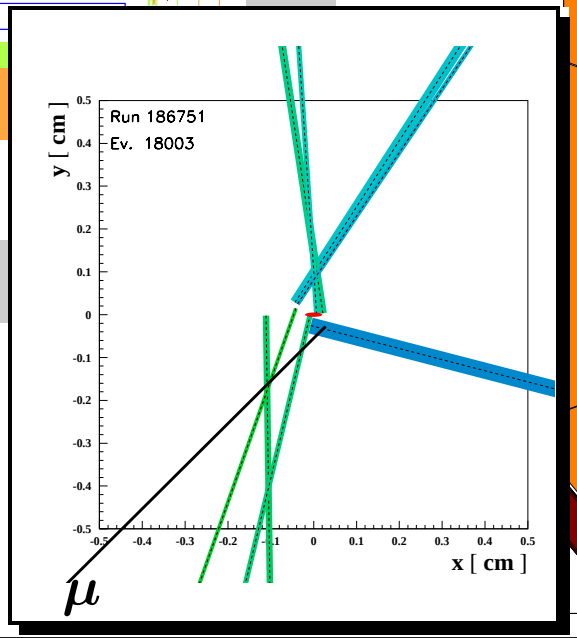


LEP $(\gamma\gamma)$

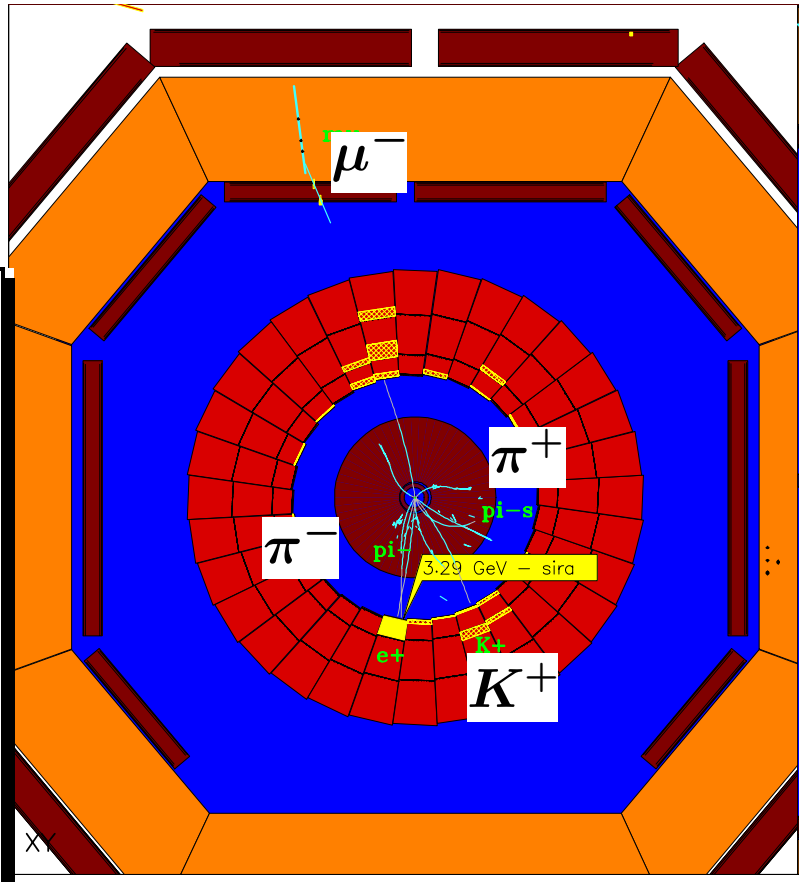
Experimental Beauty



μ or e + jets

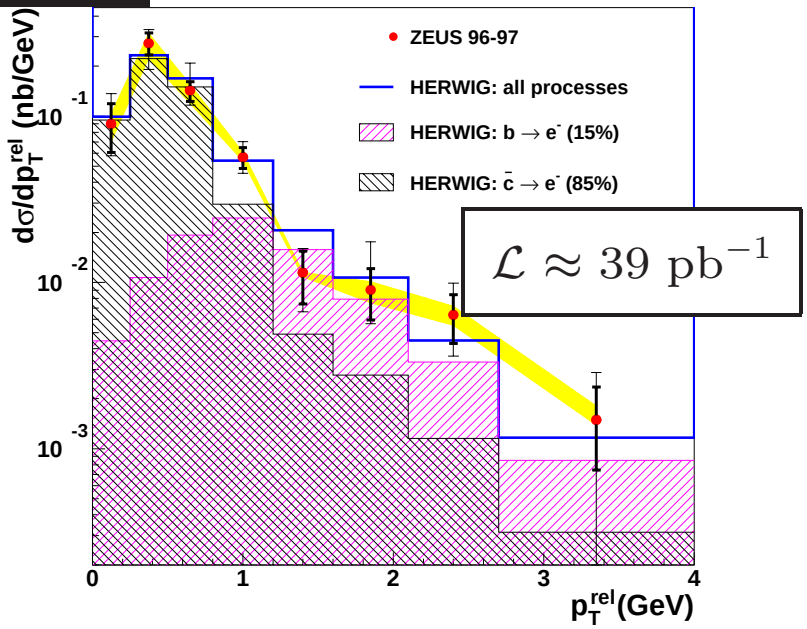


$\mu + D^*$

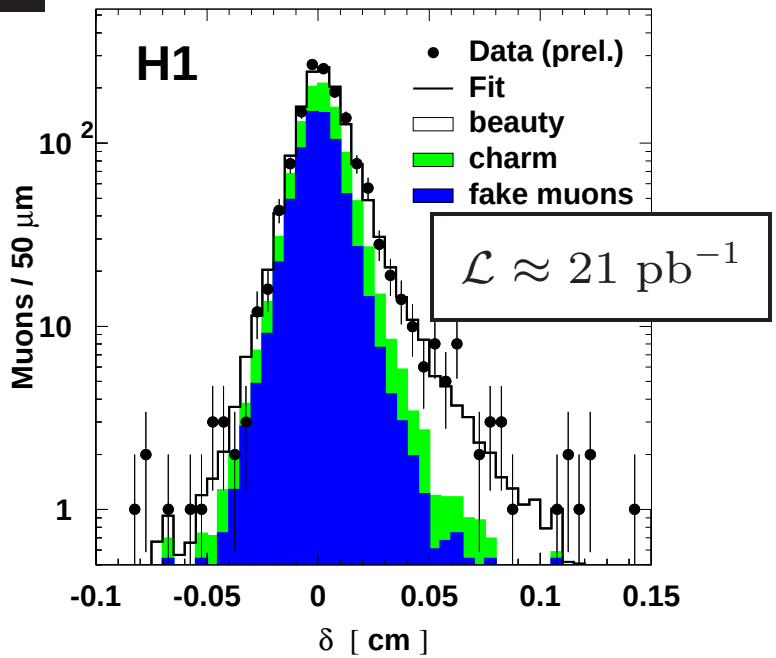


B in γp (I): 1996/97 Results ($\rightarrow$ Photon 2001)

ZEUS electron p_t^{rel} analysis



H1 muon IP + p_t^{rel} analysis



parton level cross section:

$\sigma_{ep\rightarrow e^+bX} = (1.6 \pm 0.4\ ^{+0.3}_{-0.5}\ ^{+0.2}_{-0.4})$ nb

[NLO QCD: $\sigma = (0.64 \pm\ ^{+0.14}_{-0.10})$ nb]

visible μ cross section:

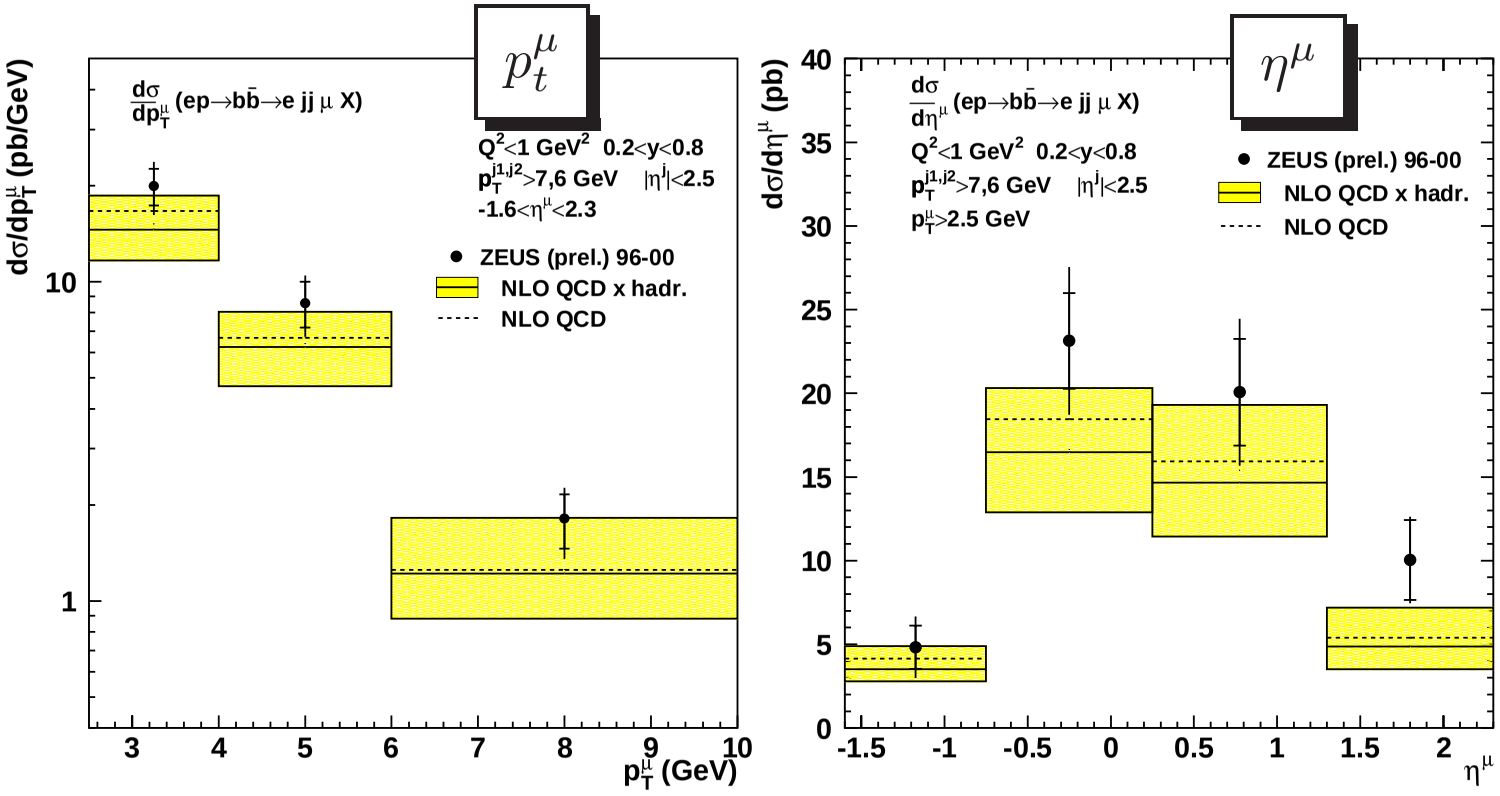
$\sigma_{vis}^{ep\rightarrow b\bar{b}X\rightarrow \mu X'} = (170 \pm 25)$ pb

[NLO QCD: $\sigma = (54 \pm 9)$ pb]

B in γp (II): 1996–2000 Results (new!)

new ZEUS (muon p_t^{rel}) **results**, $\mathcal{L} \approx 98\ \mathrm{pb}^{-1}$

$$\sigma\left(ep \to b\bar{b}X \to jj\mu X\right)$$



extrapolation (PYTHIA) $\longrightarrow$ **di–jet cross section**:

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

NLO QCD: $\left[381^{+117}_{-78}\right]$ **pb**

B in γp (III): x_γ Analysis

- **LO QCD picture**

  direct γ processes : $x_\gamma = 1$

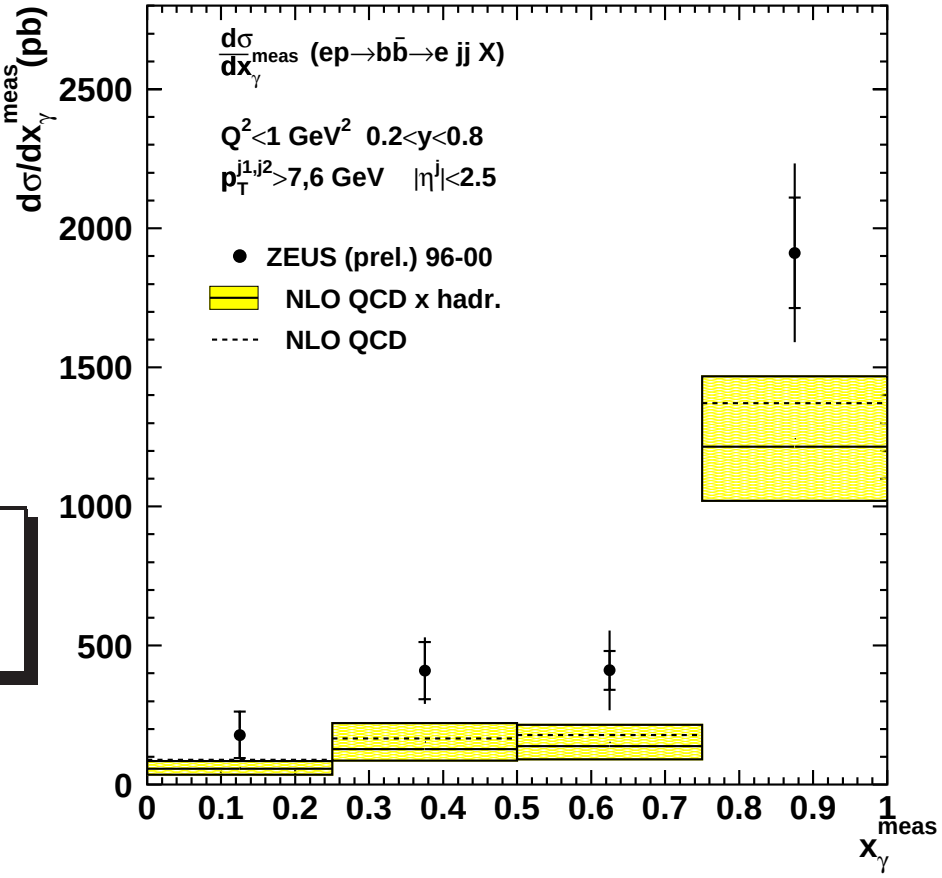
  resolved γ processes : $x_\gamma < 1$

- **for all orders**

  can **define observable**

$$x_\gamma^{\mathrm{meas}} = \frac{(E-p_z)_{\mathrm{jet1}}+(E-p_z)_{\mathrm{jet2}}}{(E-p_z)_{\mathrm{hfs}}}$$

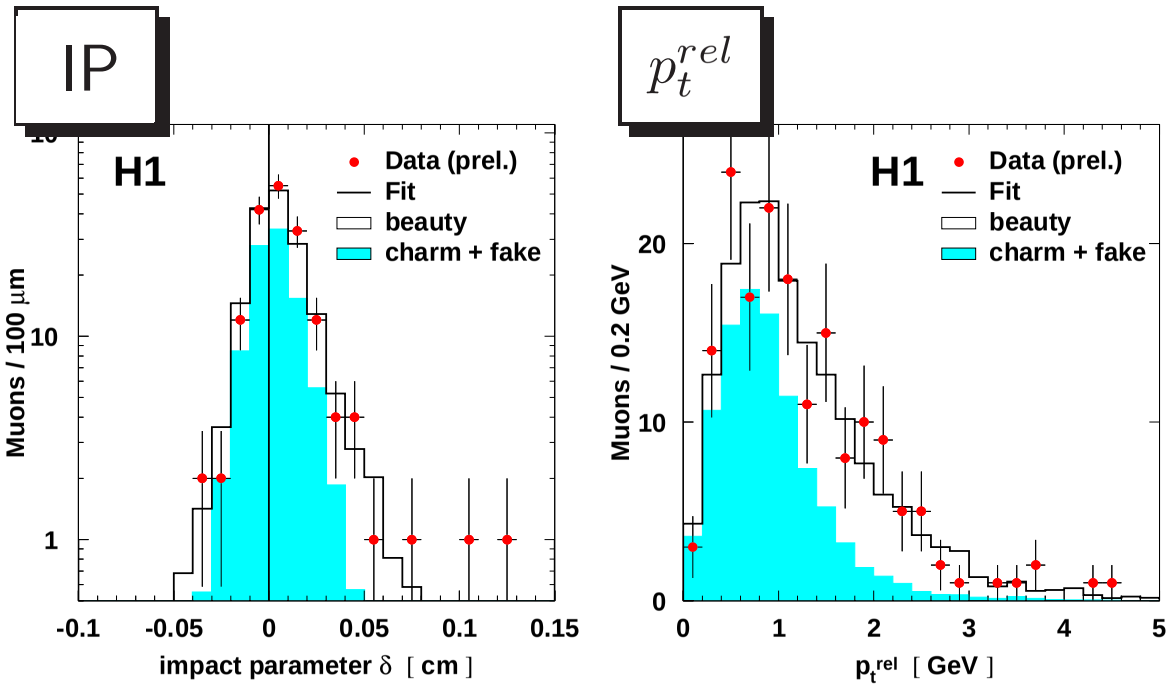
  based on the two leading jets



B in DIS (I): 1997 Results (→ Photon 2001)

first DIS measurement, based on $\mathcal{L} \approx 11\ \mathrm{pb}^{-1}$

- selection: $\mu+ \geq 2$ jets; combined (IP, p_t^{rel}) analysis:



muon cross section:

$2\ \mathrm{GeV}^2 < Q^2 < 100\ \mathrm{GeV}^2$, $0.05 < y < 0.7$, $p_t(\mu) > 2$ GeV, $35^\circ < \theta(\mu) < 130^\circ$

$$\sigma\,(ep \to bX \to \mu X) =$$
$$[39 \pm 8(stat.) \pm 10(syst.)]\ \mathbf{pb}$$

NLO QCD: $[11 \pm 2]$ **pb**

AROMA: 9 pb, **CASCADE**: 15 pb

B in DIS (II): 1999/2000 Results (new!)

new ZEUS results, $\mathcal{L} \approx 60\ \mathrm{pb}^{-1}$

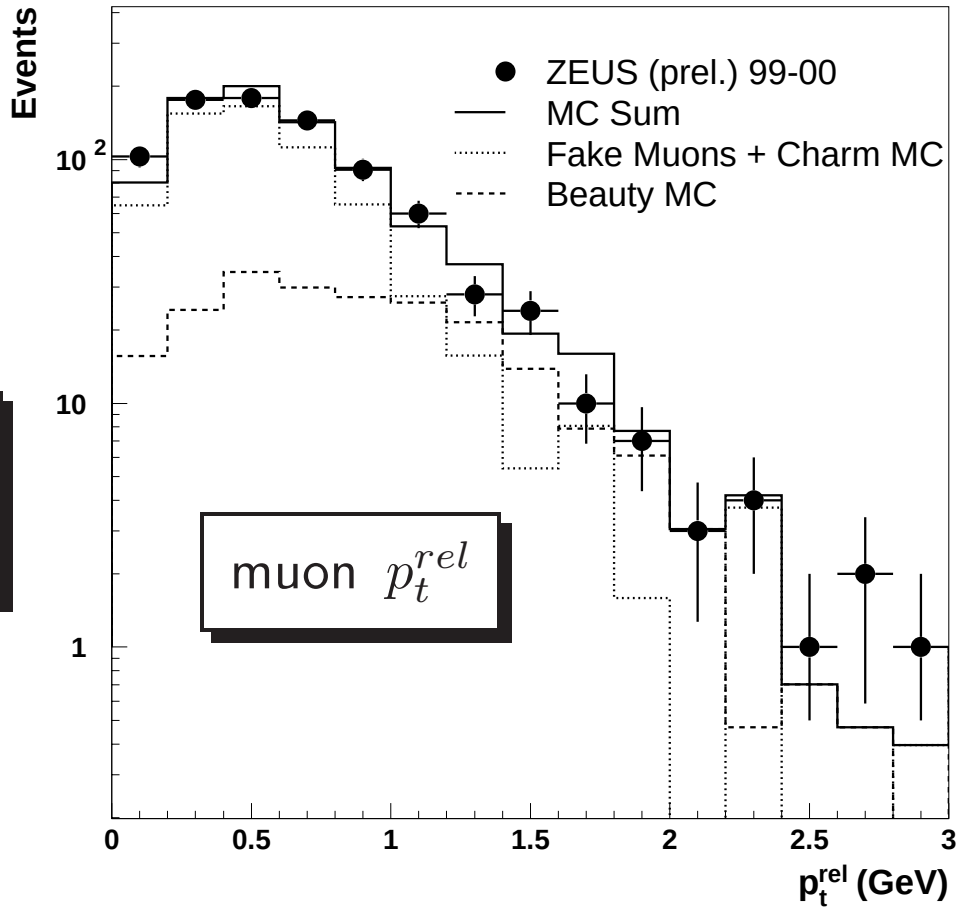
- selection: $\mu+ \geq 1$ jet (Breit system); p_t^{rel} analysis

muon/jet cross section:

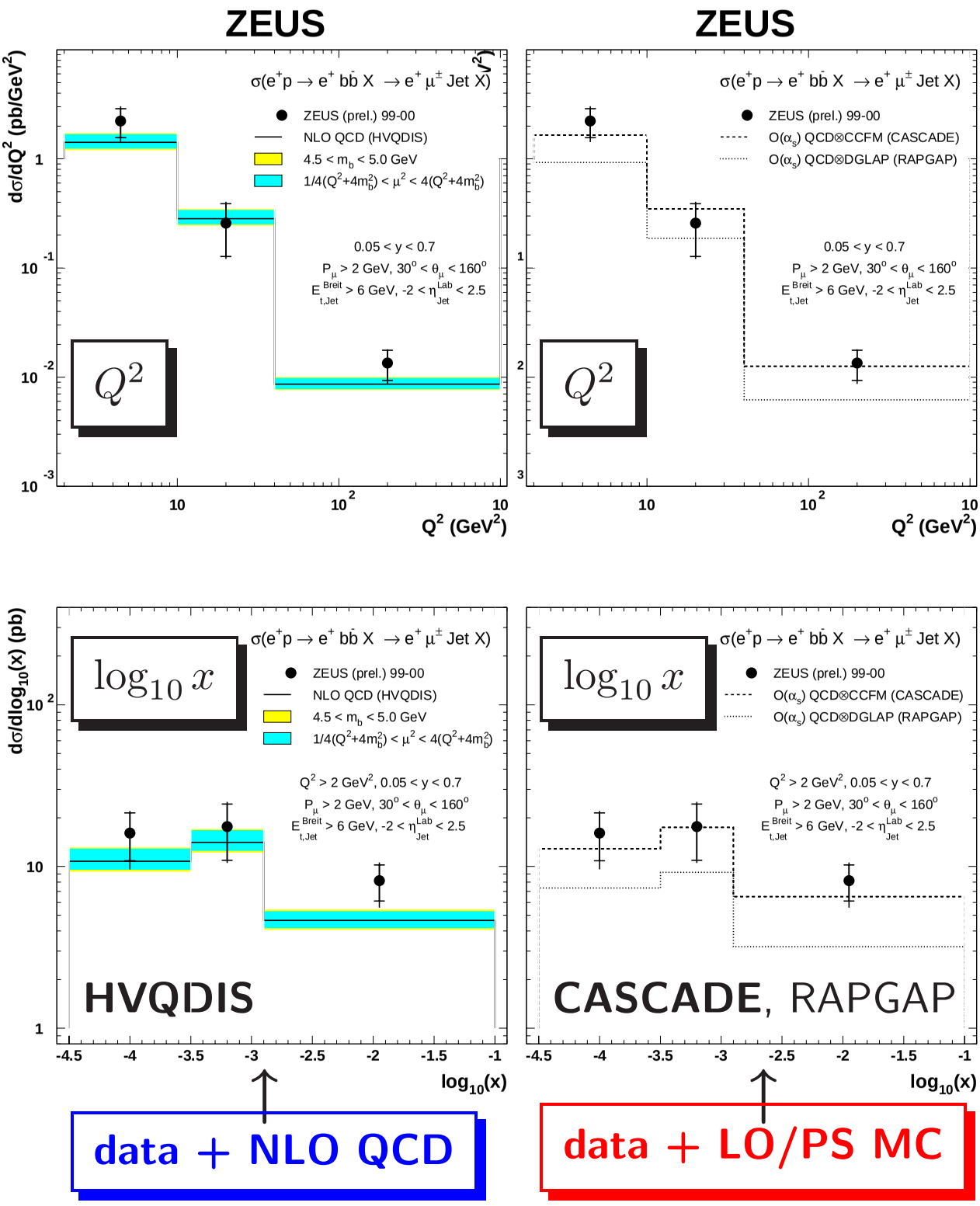
$$\sigma\left(ep \to b\bar{b}X \to ejX\right) = \left[38.7 \pm 7.7(\mathrm{stat.})^{+6.1}_{-5.0}(syst.)\right]\ \mathbf{pb}$$

NLO QCD: $\left[28.1^{+5.3}_{-3.5}\right]$ **pb**

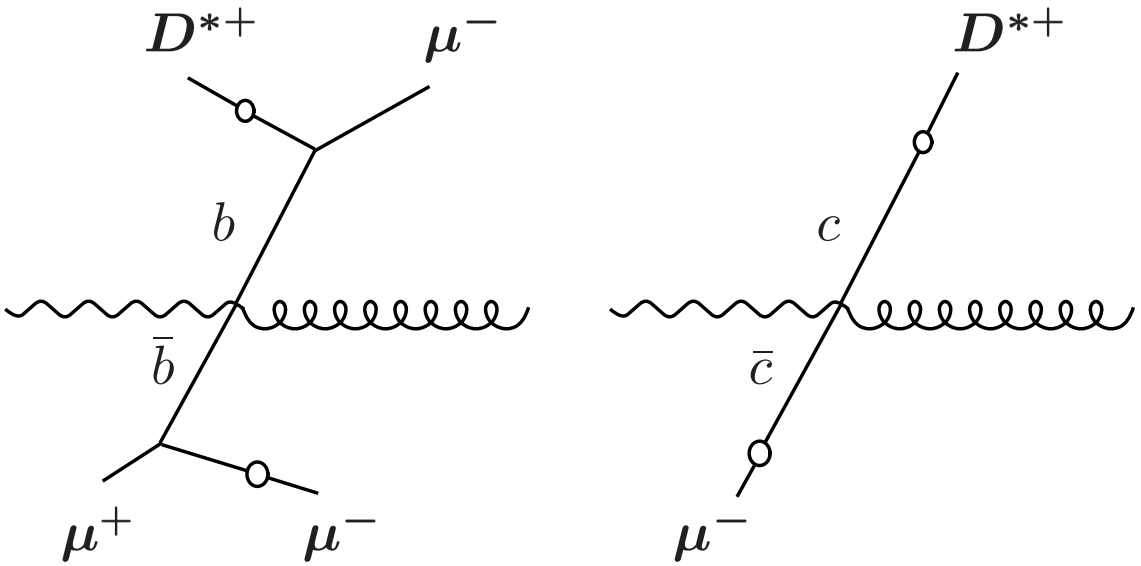
CASCADE: 35 **pb**

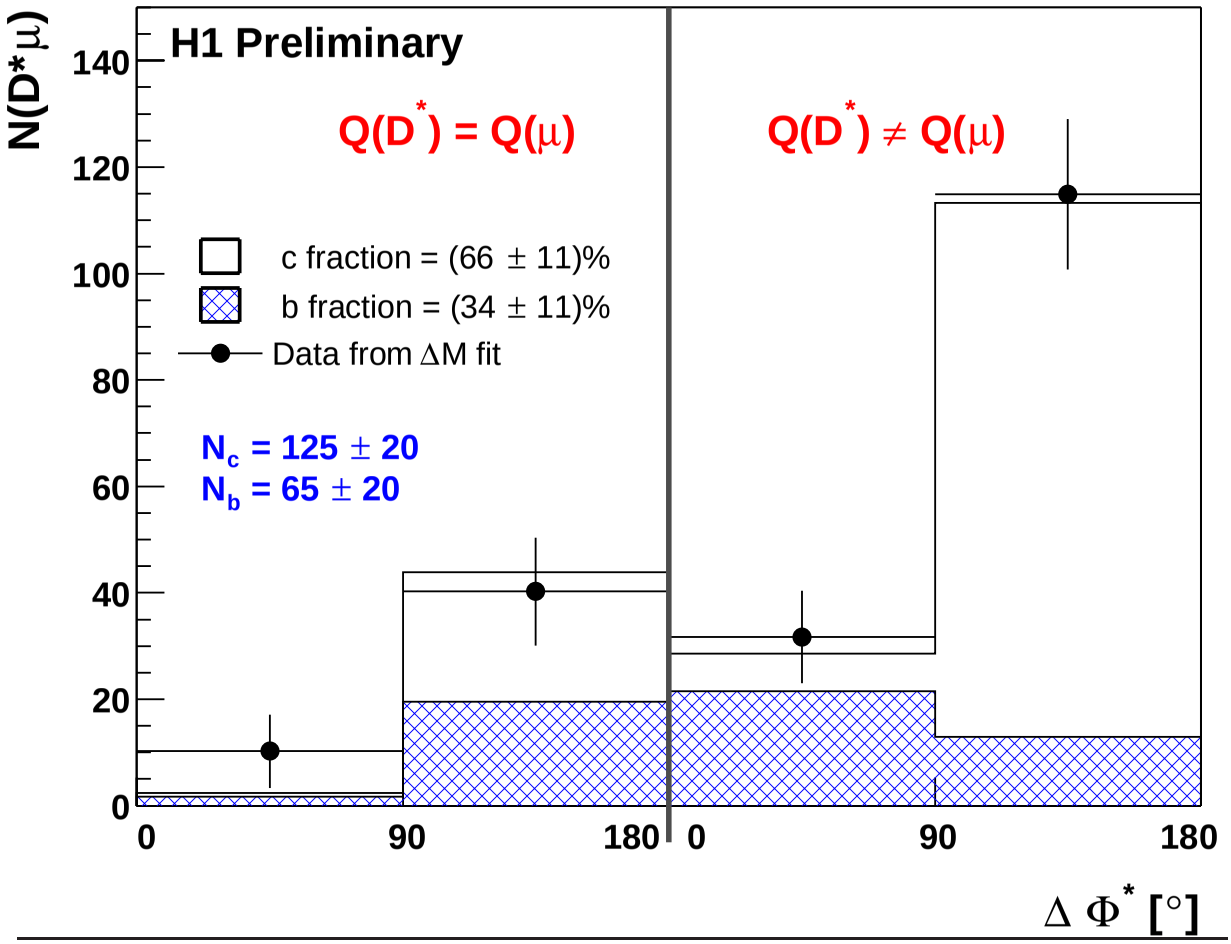


B in DIS (III): Differential Xsections



$D^*\mu$ Correlations (I): Method





$D^*\mu$ Correlations (II): H1 Analysis

combined D^* (ΔM) + $D^*\mu$ **correlation** analysis

$(p_t^{D^*(\mu)} > 1.5(1.0)\ \mathrm{GeV}, |\eta^{D^*(\mu)}| < 1.5(1.74), 0.05 < y < 0.75)$

$$\Downarrow$$

$$\boxed{\sigma(ep \to D^*\mu)}$$

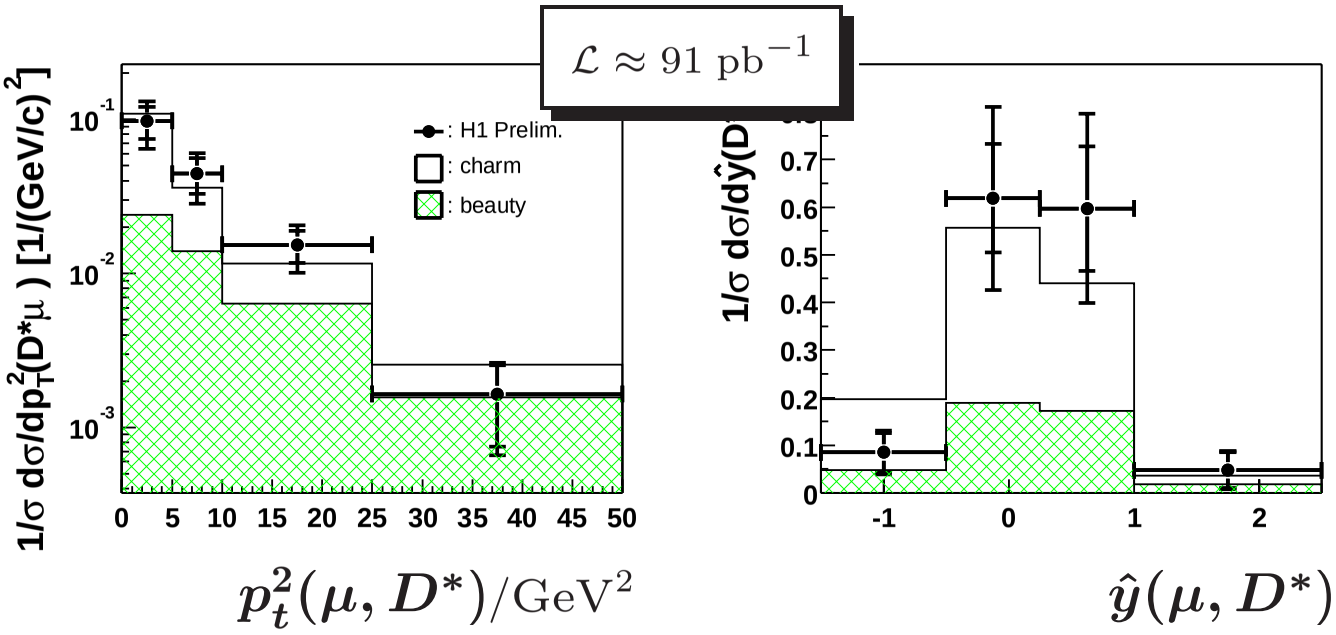
charm : $[720 \pm 115(stat.) \pm 245(syst.)]$pb

$\to$ **factor 1.8** above AROMA

beauty: $[380 \pm 120(stat.) \pm 130(syst.)]$pb

$\to$ **factor 3.6** above AROMA

- use results to compare to LO/PS MC (AROMA):



$D^*\mu$ Correlations (III): ZEUS Analysis

similar analysis ($\mathcal{L} \approx 114$ pb^{-1})

$p_t^{D^*(\mu)} > 1.9(1.4)$ GeV,

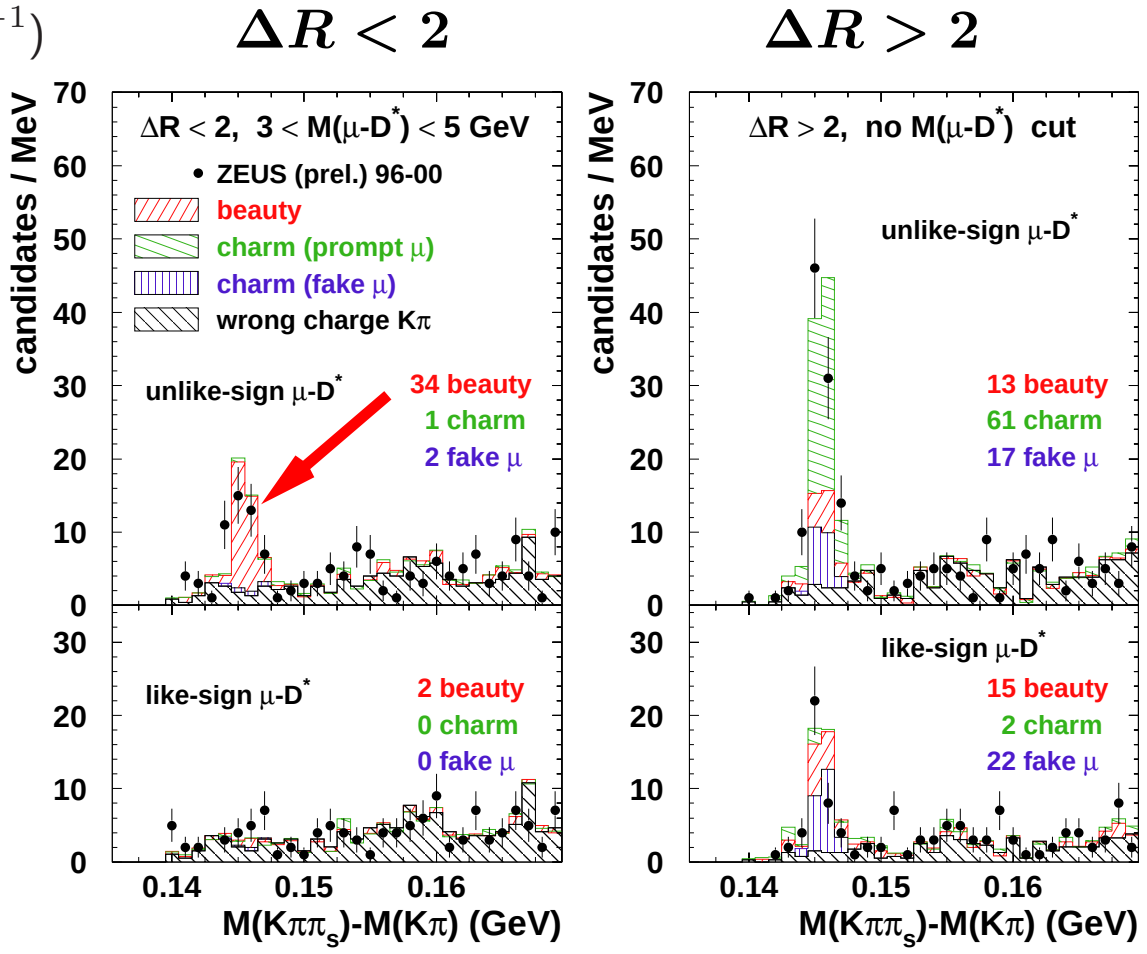
$-1.5(-1.3) < \eta^{D^*(\mu)} < 1.5(1.75)$

↓ PYTHIA MC ↓

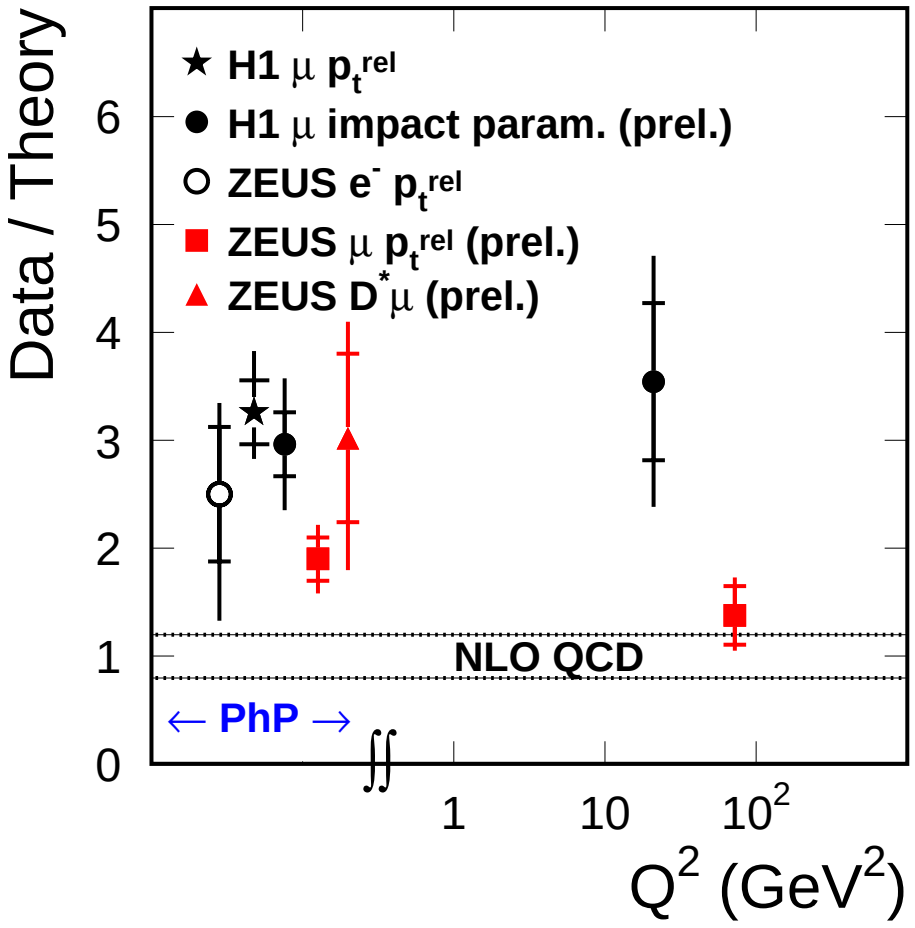
γp cross section (for $\hat{y}^b < 1$, $Q^2 < 1$ GeV^2, $0.05 < y < 0.85$)

$$\sigma\left(ep \to b(\bar{b})X\right) = \left[15.1 \pm 3.9^{+3.8}_{-4.7}\right] nb$$

NLO QCD: $\left[5.0^{+1.7}_{-1.1}\right] nb$



Summary and Outlook



- **new** (prelim.) **beauty results from HERA**
- significantly **increased statistics**

  → **improved** precision in γp

  → **differential DIS** cross sections

  → **double tag** analyses $(D^*\mu)$
- γp **data above** NLO **QCD,**

  DIS situation **not clear** (yet)

NB: various different kinematic ranges and cross section definitions

- expect **future results** based on **new data**, **upgraded detectors**, and **additional methods**