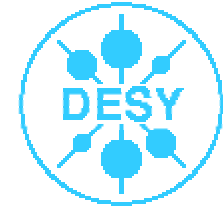


Open Beauty Production in ZEUS



Achim Geiser, DESY Hamburg
for the ZEUS collaboration



Heavy Quark Physics at the Upgraded HERA Collider,
Rehovot, Isreal, 20. Oct. 03

■ open beauty = open heavy flavour

- introduction
- beauty in photoproduction
- beauty in DIS
- beauty from $D^* + \mu\text{on}$
- comparison with $p\bar{p}$ collider results



Why study beauty production at HERA?

■ **HERA**, Queen of the greek gods, sister and wife of **ZEUS**, is known for her **beauty**, but also for her **guile** ...

■ **Beauty quarks are heavy** (m_b)



useful scale for **perturbative QCD**
=> reliable predictions (in principle ...)

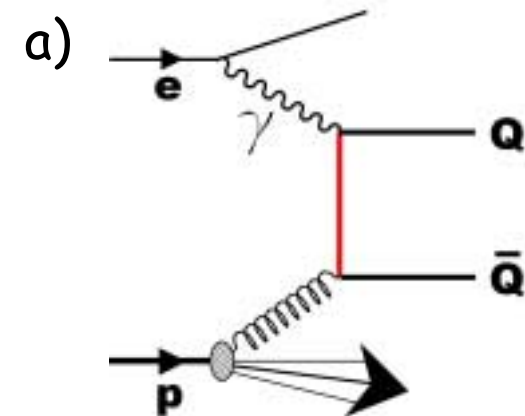


often multi-scale problem (m_b, p_T, Q^2)
=> large uncertainties (in practice ...)

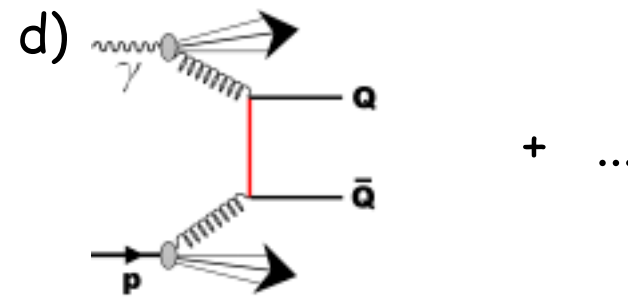
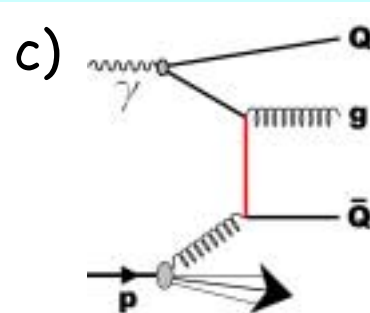
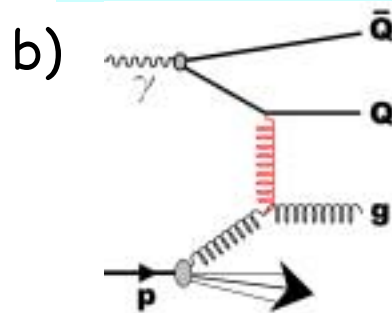


Processes for Open Heavy Quark Production ($Q = c, b$)

- dominant Leading Order (LO) QCD diagram: **direct Boson(γ)-Gluon-Fusion (BGF)**
 \Rightarrow **heavy quark** propagator



- „resolved“ photon (or p) contributions (in LO + parton shower (PS) picture)
 \Rightarrow **gluon** (dominant) + quark propagators



„Q-excitation“ in photon

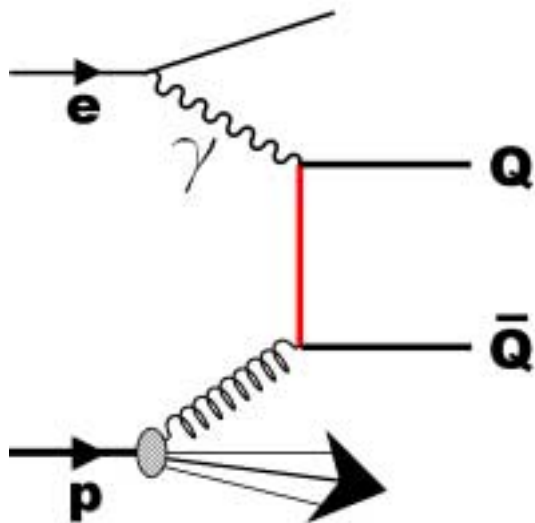
hadron-like photon

alternative interpretations of b):

- LO excitation of „heavy quark in photon“ (+ parton shower evolution)
 LO+PS Monte Carlo (DGLAP), „massless“ QCD calculations
- NLO pointlike photon diagram (massive fixed order QCD calculations)
- LO BGF diagram + gluon cascade (CCFM, CASCADE Monte Carlo)

Kinematics of Heavy Quark Production at HERA

Kinematic variables:



| | |
|----------------------------|--|
| $\sqrt{s} = 300$ (318) GeV | ep CM energy before (after) 1998 |
| $W = m(\gamma p)$ | γp CM energy |
| $Q^2 = -q^2$ | photon virtuality, squared momentum transfer |
| $x = \frac{Q^2}{2Pq}$ | Bjorken scaling variable, for $Q^2 \gg (2m_Q)^2$ (!): momentum fraction of p constituent |
| $y = \frac{qP}{lP}$ | Bjorken scaling variable, inelasticity, for $Q^2 \rightarrow 0$: γ energy fraction (of e) |

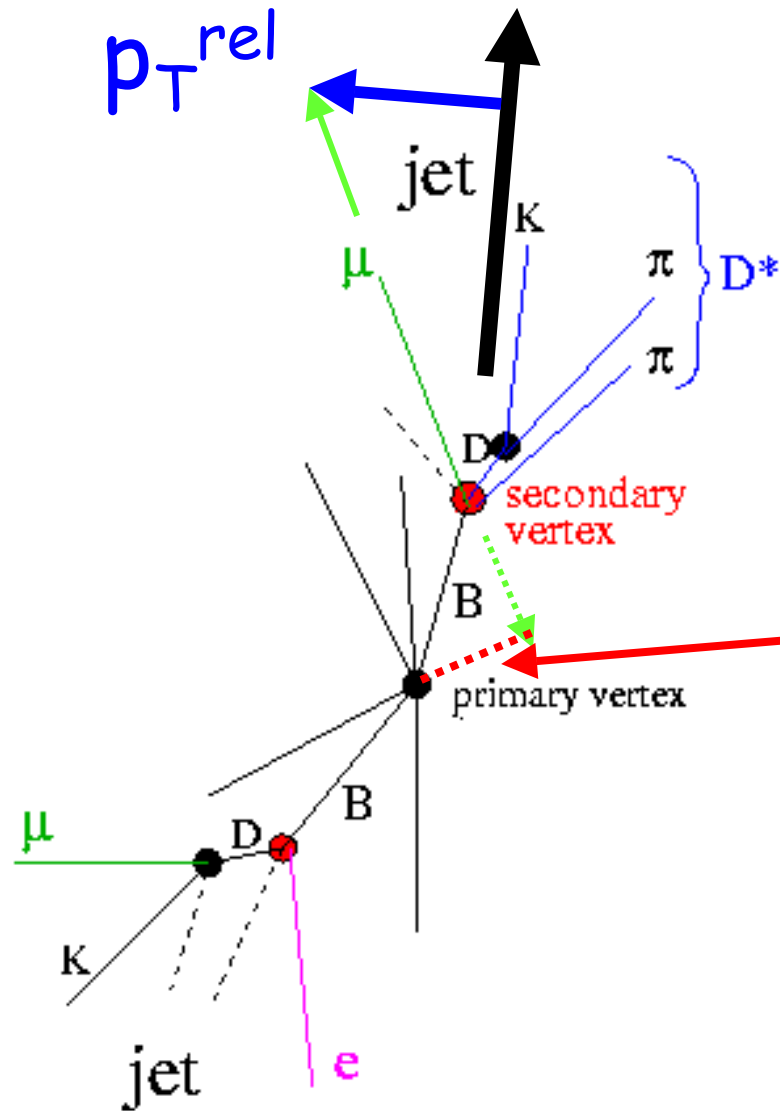
Kinematic regimes:

- **Photoproduction:** γ quasi-real: $Q^2 < 1 \text{ GeV}^2$, e escapes through beam pipe
- **Deep inelastic scattering (DIS):** $1 < Q^2 < (300 \text{ GeV})^2$, e visible in detector

Beams and luminosity:

- **electrons + protons:** (1998- mid 99) Luminosity $\sim 15 \text{ pb}^{-1}$
- **positrons + protons:** (mid 1994-97, mid 99 - 2000) Luminosity $\sim 60\text{-}120 \text{ pb}^{-1}$

Tagging semileptonic beauty decays



1) p_T^{rel} :

p_T of μ with respect to jet axis

2) at HERA II:
impact parameter

of μ with respect to primary vertex

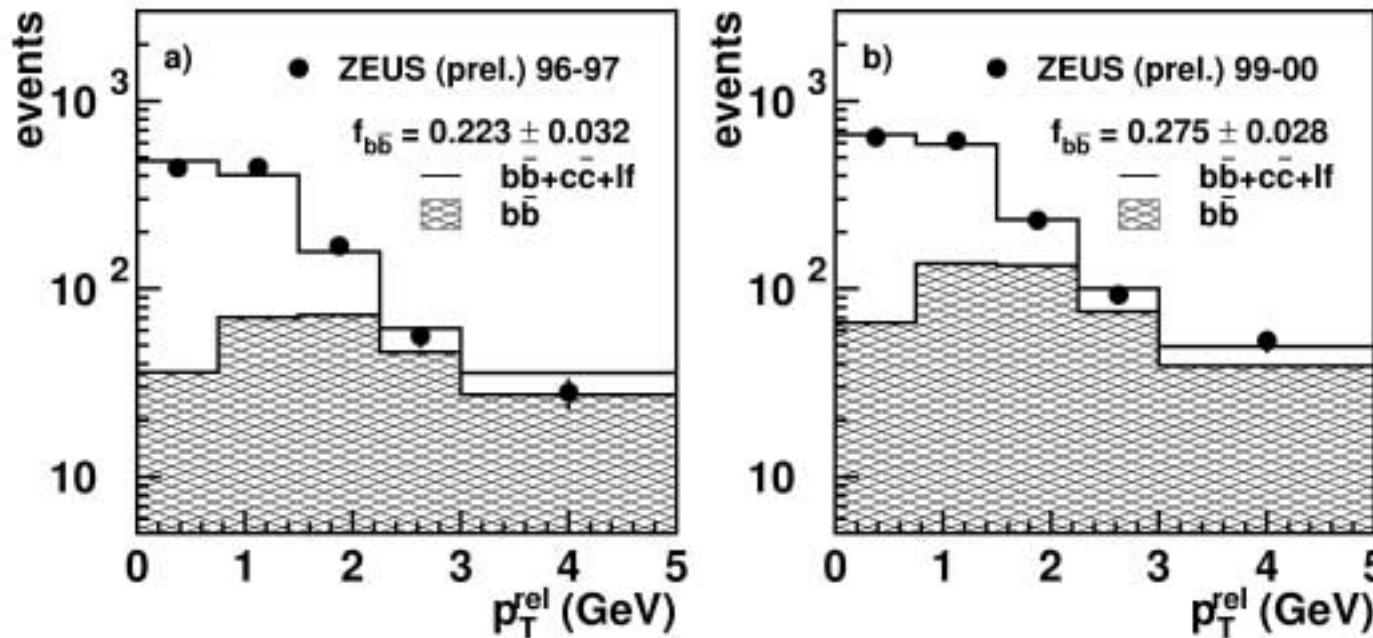
3) D^* μ correlations

Beauty in photoproduction

ZEUS data 1996/00, $\sim 98 \text{ pb}^{-1}$, $Q^2 < 1 \text{ GeV}^2$, $0.2 < y < 0.8$,
 at least two jets with $p_{T, \text{Jet1}(\text{Jet2})} > 7 \text{ (6) GeV}$, $|\eta| < 2.5$

muon with
 $p > 2.5 \text{ GeV}$, $-1.6 < \eta < -0.9$
 $p_T > 2.5 \text{ GeV}$, $-0.9 < \eta < 1.3$
 $p > 4 \text{ GeV}$, $1.5 < \eta < 2.3$

ZEUS



average:
 $f_b = (27 \pm 3)\%$

p_T^{rel} fit, unfold muon acceptance,

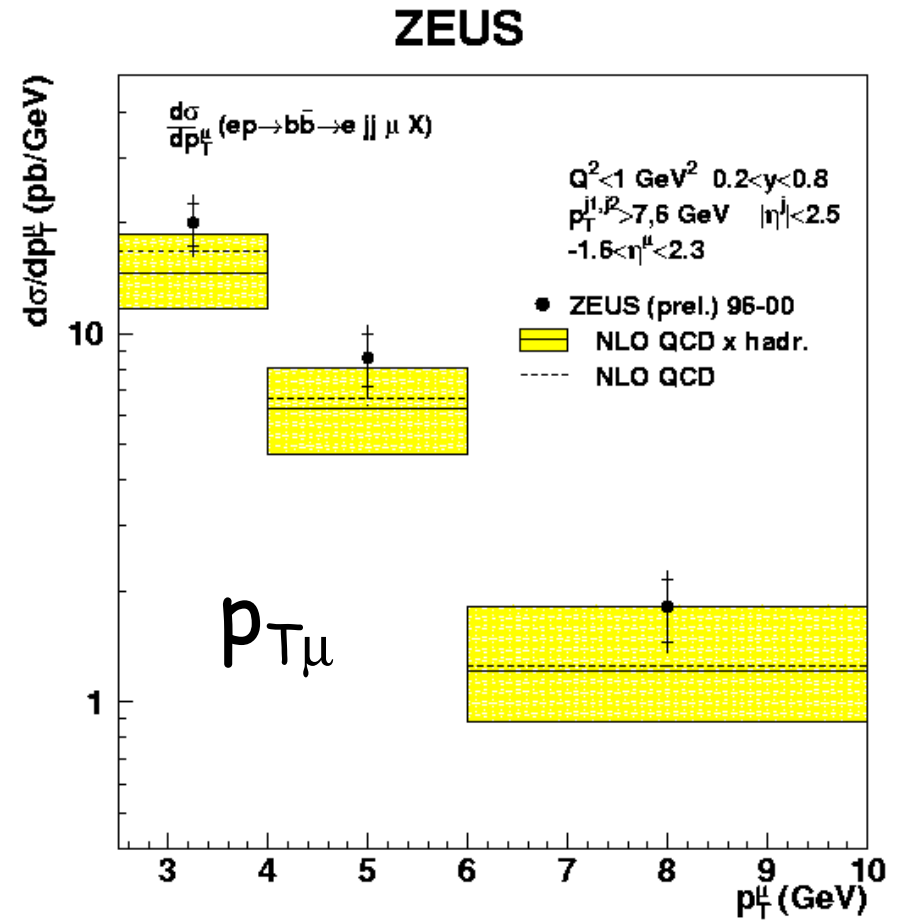
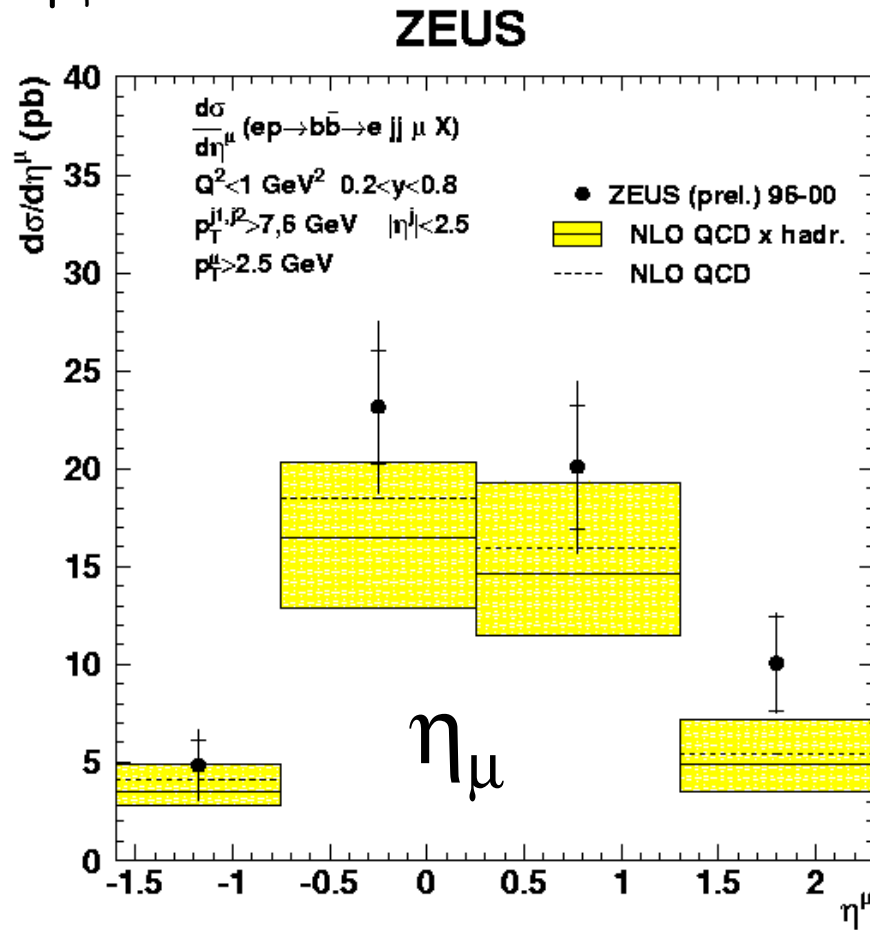
no syst. on $b\bar{b}$ correlations yet

$\sigma(ep \rightarrow b\bar{b} X \rightarrow \text{Jet Jet } X) = 733 \pm 61 \text{ (stat)} \pm 104 \text{ (sys) pb}$
 NLO QCD (FMNR): $381^{+117}_{-78} \text{ pb}$

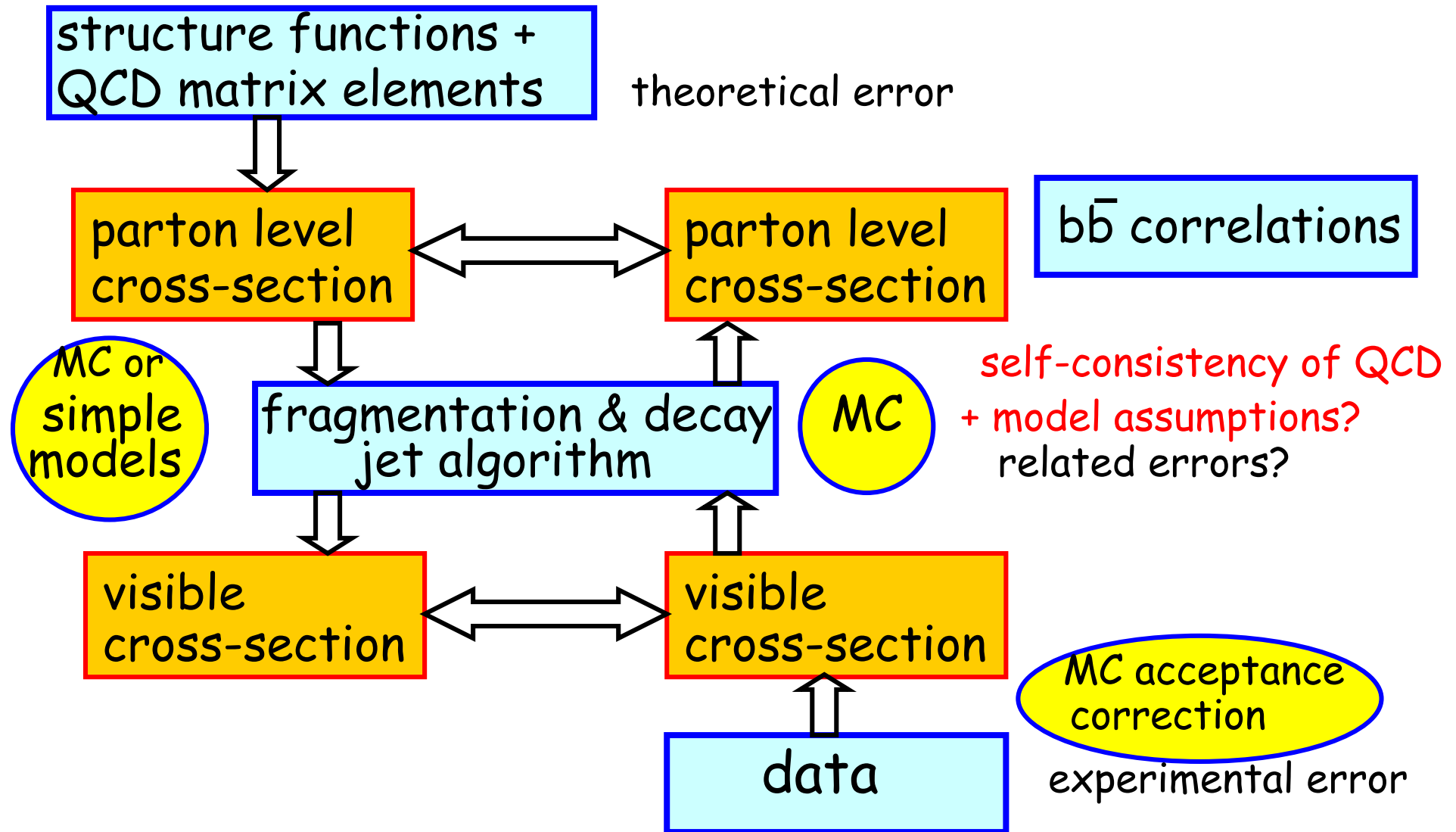
Beauty in photoproduction

ZEUS data 1996/00, $\sim 98 \text{ pb}^{-1}$, $Q^2 < 1 \text{ GeV}^2$, $0.2 < y < 0.8$, muon with $p_T > 2.5 \text{ GeV}$, $-1.6 < \eta < 2.3$, at least two jets with $p_{T, \text{Jet1(Jet2)}} > 7 \text{ (6)} \text{ GeV}$, $|\eta| < 2.5$

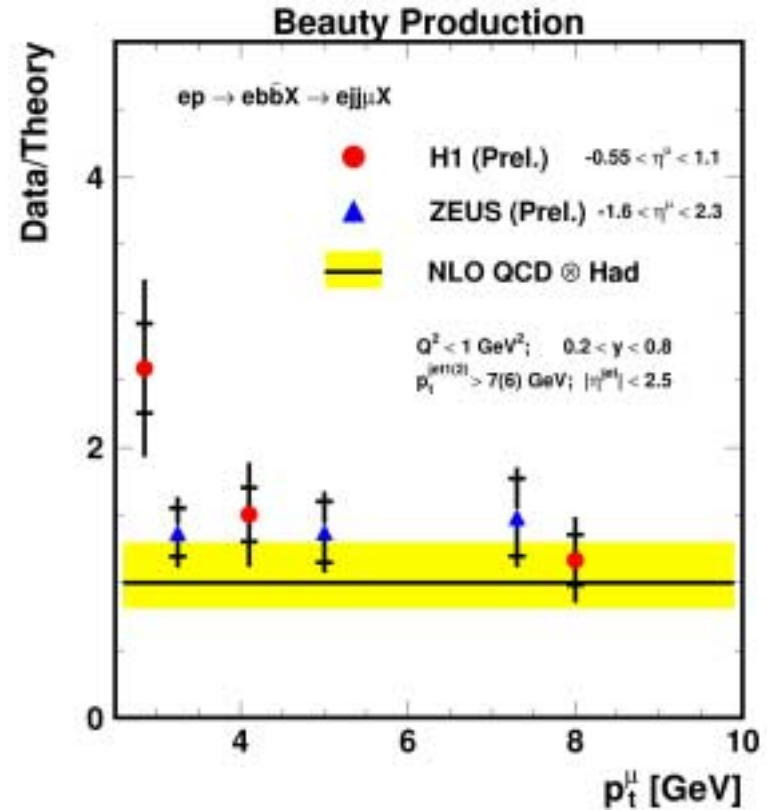
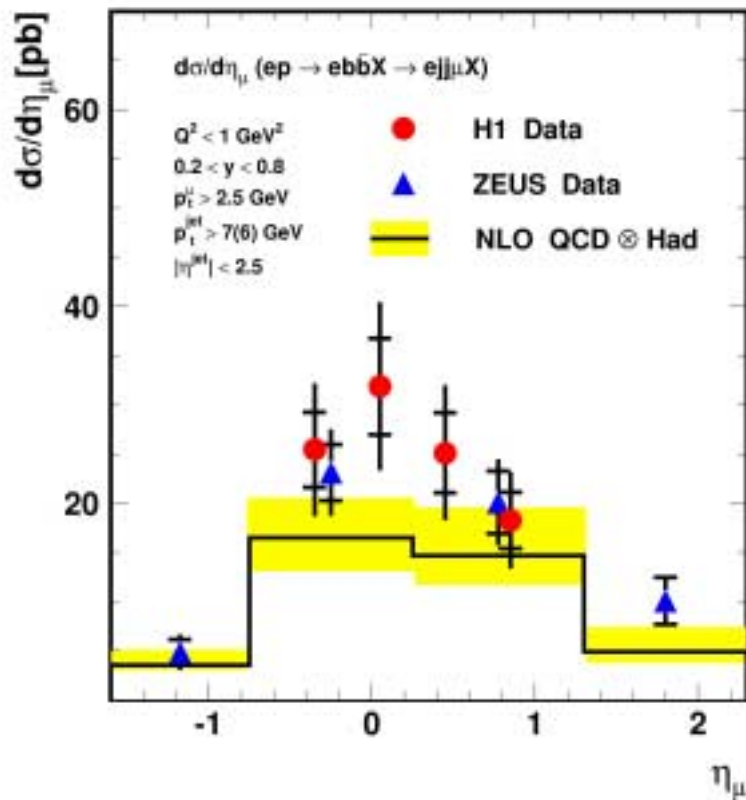
p_T^{rel} fit:



caveats for data - theory comparison



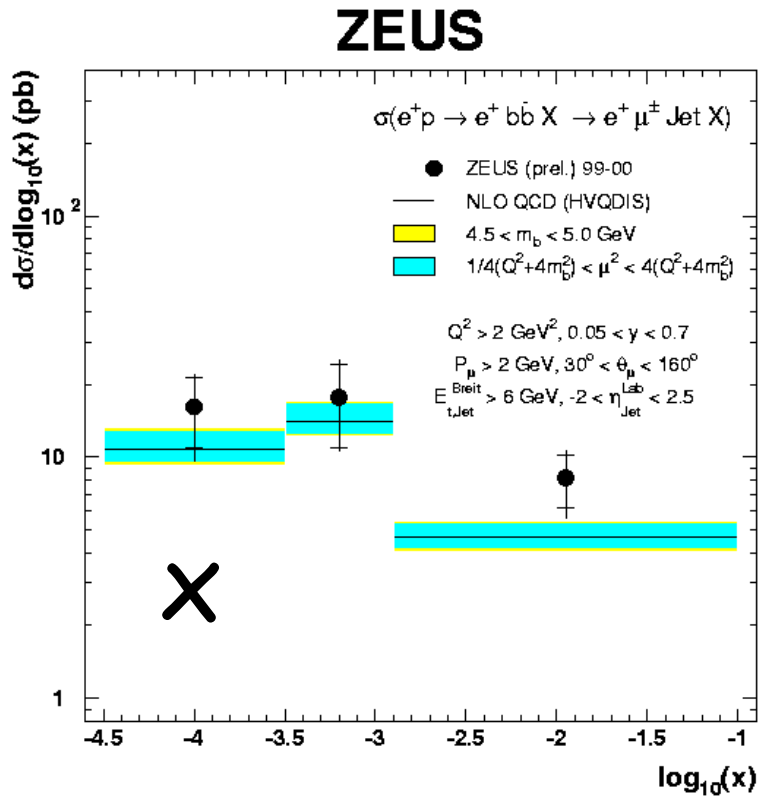
Comparison with H1



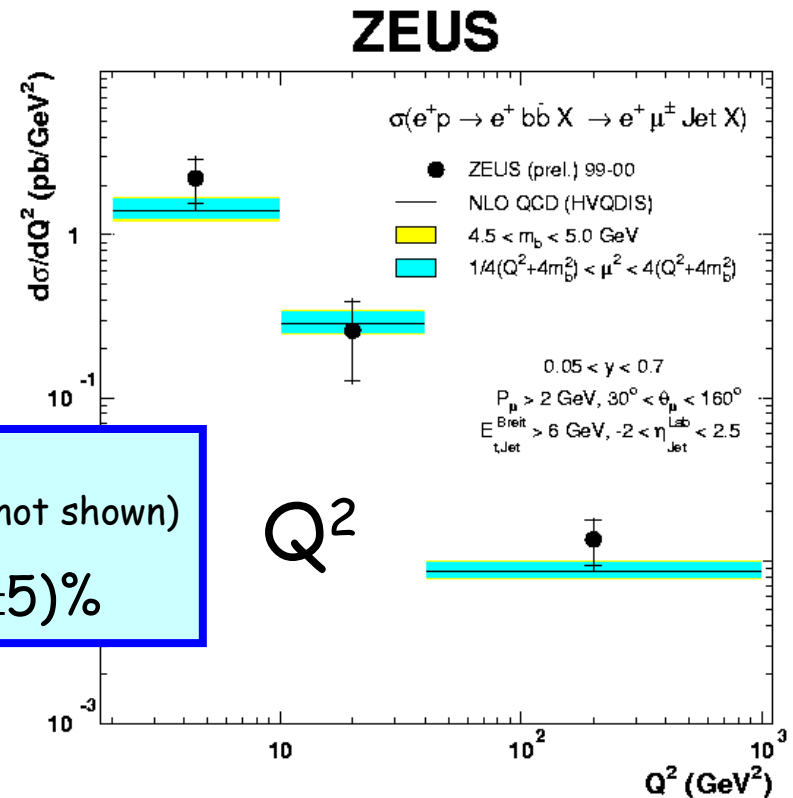
■ good agreement

Beauty in DIS

ZEUS data 1999/00, $\sim 60 \text{ pb}^{-1}$, $Q^2 > 2 \text{ GeV}^2$, $0.05 < y < 0.7$, muon with $p > 2 \text{ GeV}$, $30^\circ < \theta < 160^\circ$
 at least one jet with $E_{T, \text{Breit}} > 6 \text{ GeV}$ in γ^*p frame, $-2 < \eta^{\text{Lab}} < 2.5$



p_T^{rel} (not shown)
 $f_b = (25 \pm 5)\%$



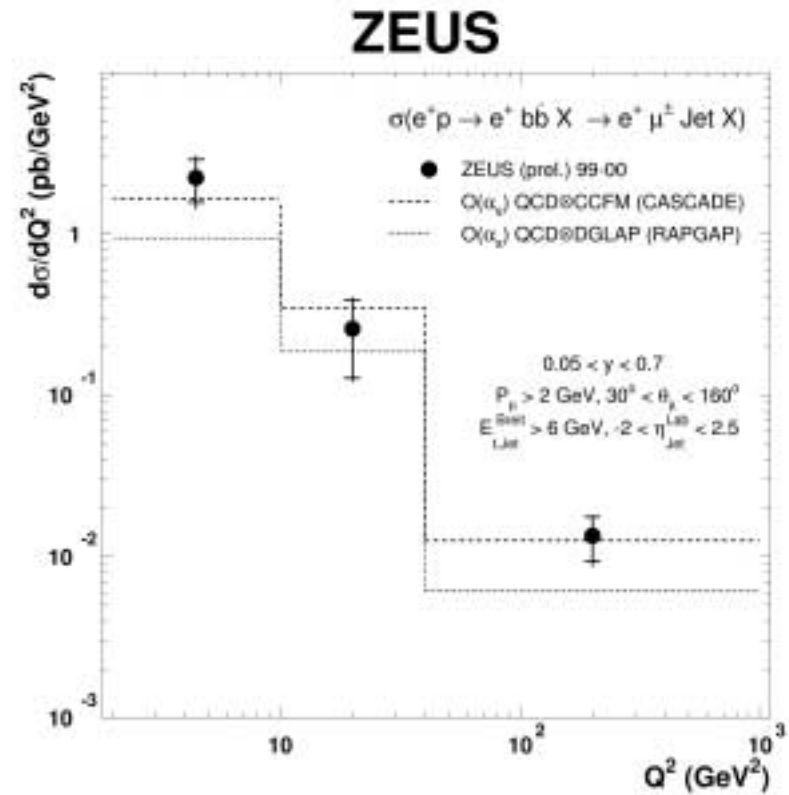
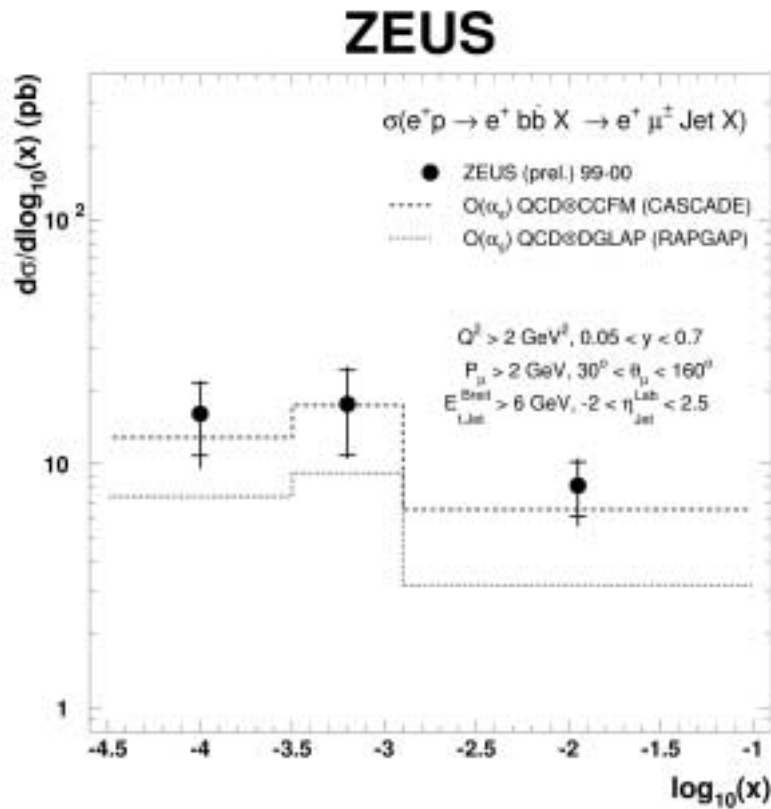
p_T^{rel} fit:

$$\sigma(ep \rightarrow eb\bar{b} X \rightarrow e\mu \text{jet} X) = 38.7 \pm 7.7 \text{ (stat)} {}^{+6.1}_{-5.0} \text{ (sys)} \text{ pb}$$

$$\text{NLO QCD (HVQDIS): } 28.1 {}^{+5.3}_{-3.5} \text{ pb}$$

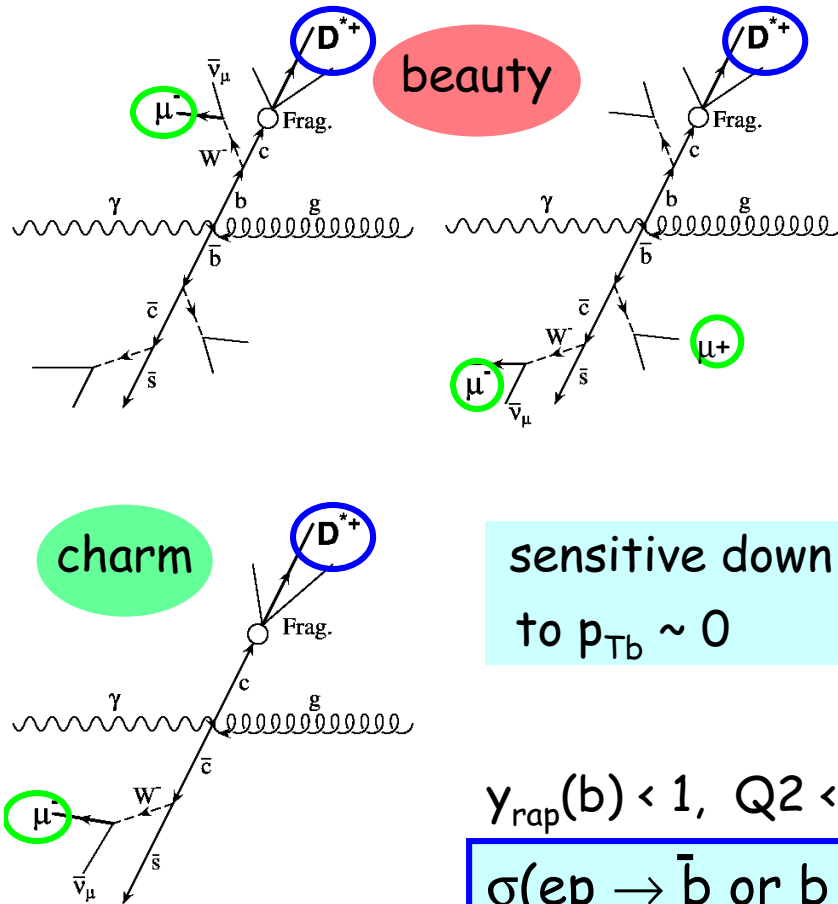
Beauty in DIS

- comparison to LO + PS MC
RAPGAP (DGLAP) and CASCADE (CCFM)



Beauty cross-section from $D^{*+} \mu$ final state

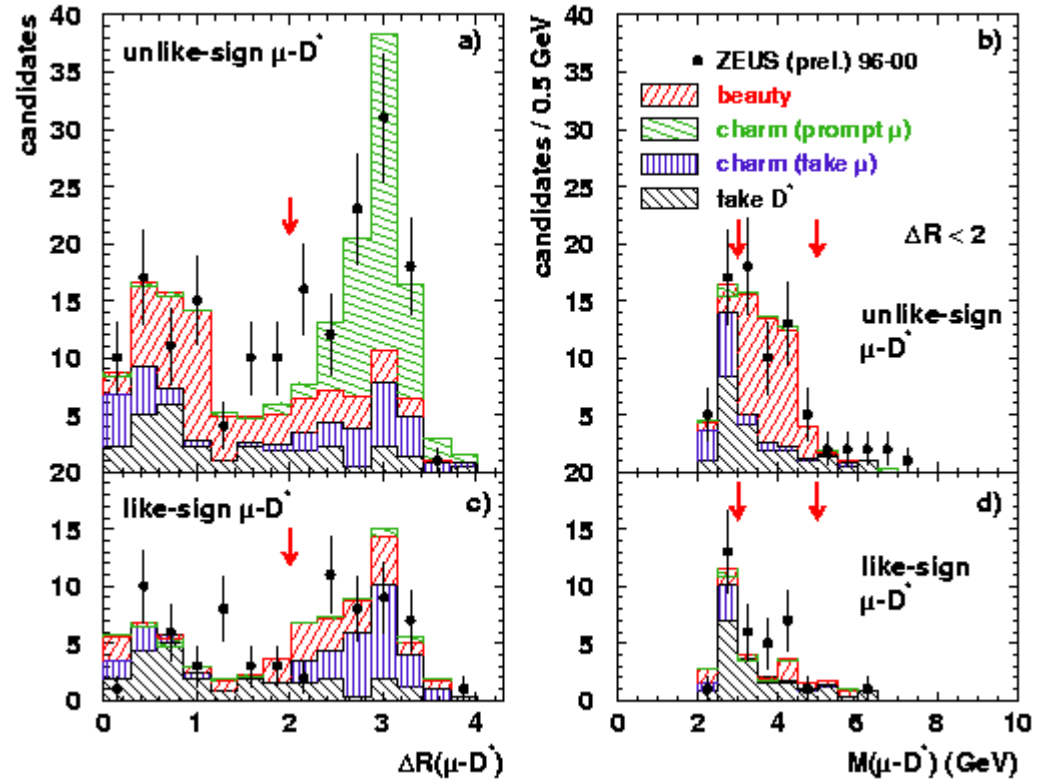
ZEUS data 1996/00, 114 pb^{-1}



$\gamma_{\text{rap}}(b) < 1, Q^2 < 1 \text{ GeV}^2, 0.05 < \gamma < 0.85$

$\sigma(ep \rightarrow \bar{b} \text{ or } b X) = 15.1 \pm 3.9 \text{ (stat)}^{+3.8}_{-4.7} \text{ (sys) pb}$
 NLO QCD (FMNR): $5.7^{+1.7}_{-1.1} \text{ pb}$

ZEUS

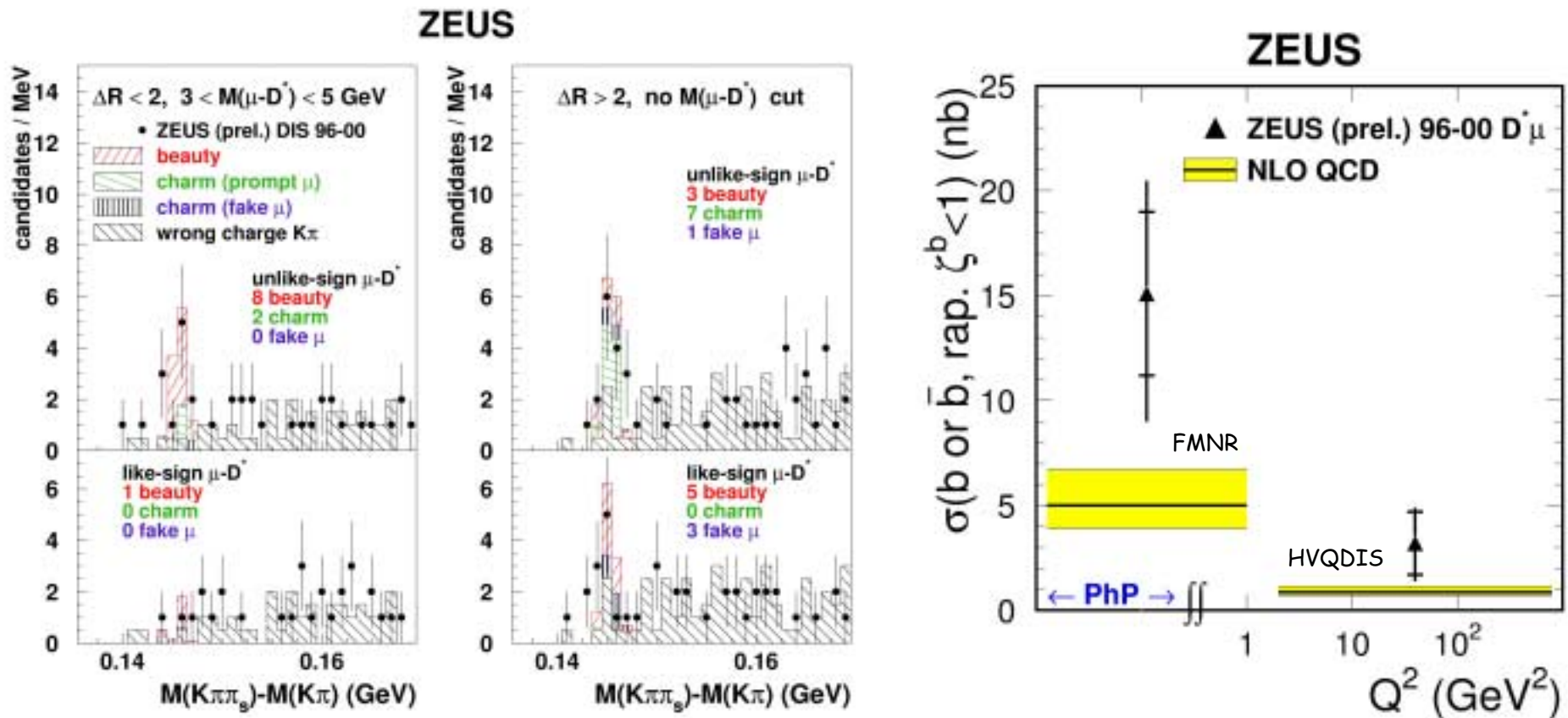


Beauty cross-section from $D^{*+} \mu$ final state

ZEUS data 1996/00, 114 pb⁻¹

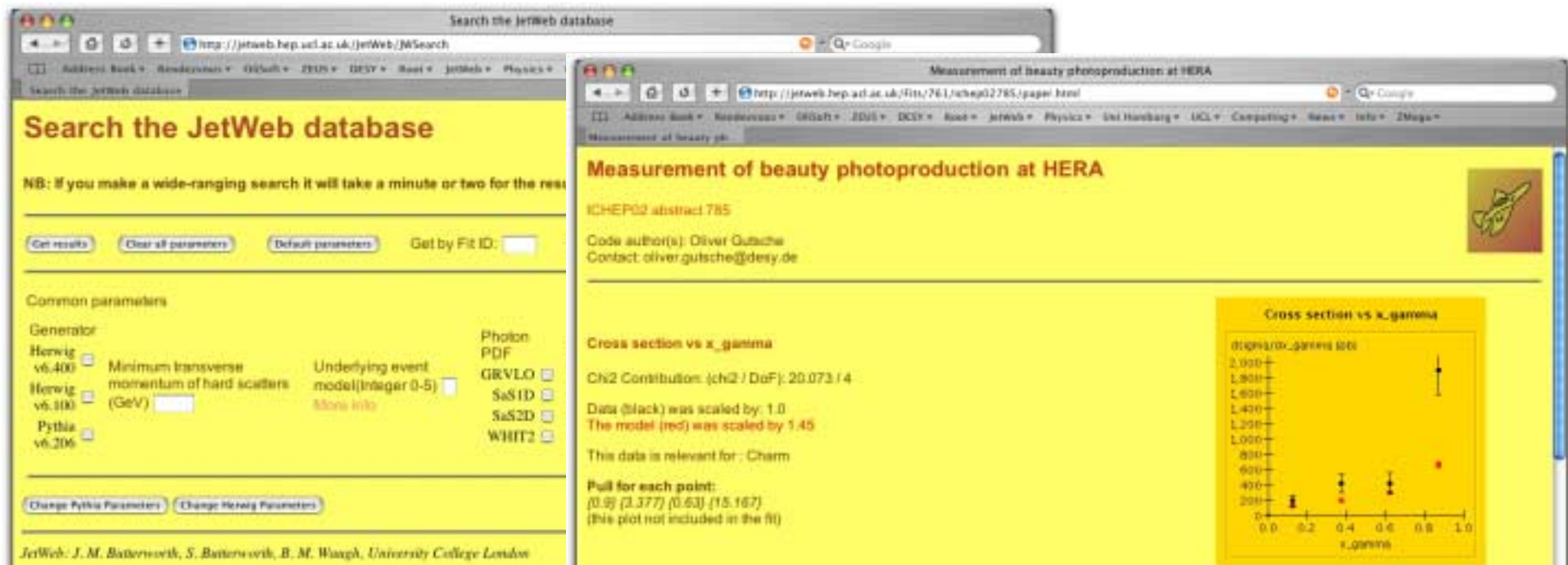
separate photoproduction and DIS

DIS part only: $p_T(D^{*}) > 1.5 \text{ GeV}$, $p_T(\mu) > 1.4 \text{ GeV}$, $|\eta(D^{*})| < 1.5$, $-1.75 < \eta(\mu) < 1.3$



Comparison to other experiments: JetWeb

- JetWeb = public WWW interface and database for MC tuning and validation: <http://jetweb.hep.ucl.ac.uk>
 - interface to MC generators (currently PYTHIA and HERWIG)
 - allows parameter selection for MC generation
 - generates MC events and applies cuts (phase space, etc.) to describe implemented results **for different colliders and experiments**
 - displays data-MC comparison plots

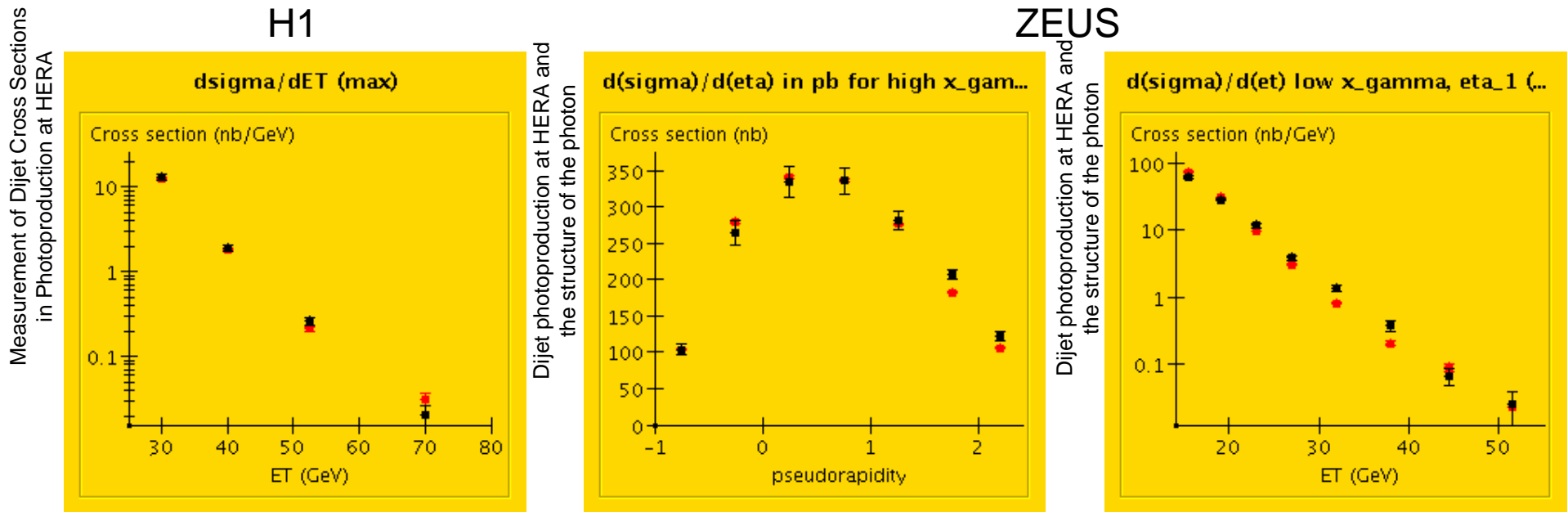


Application to jets and beauty at HERA + $p\bar{p}$

J. M. Butterworth, S. Butterworth, O. Gutsche, B. Waugh

■ global scale factor:

- JetWeb results are scaled to **fit high- E_T HERA jet cross sections**, examples:



■ Generator: **PYTHIA**

- Proton PDF: CTEQ5L
- Photon PDF: GRV LO
- min. trans. momentum: 3 GeV

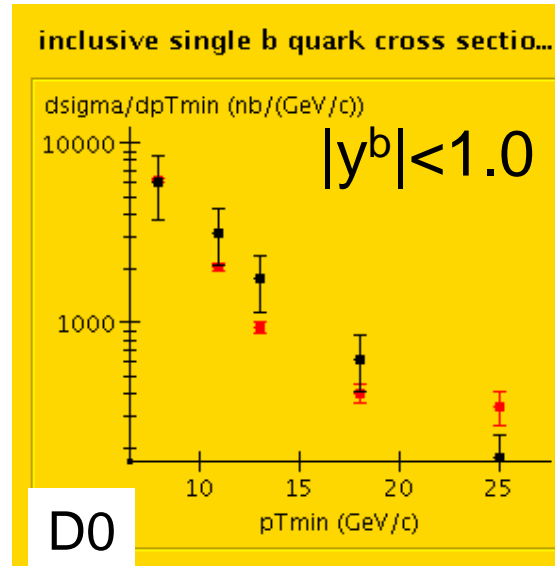
JetWeb scale = **1.45**

applied to all other plots

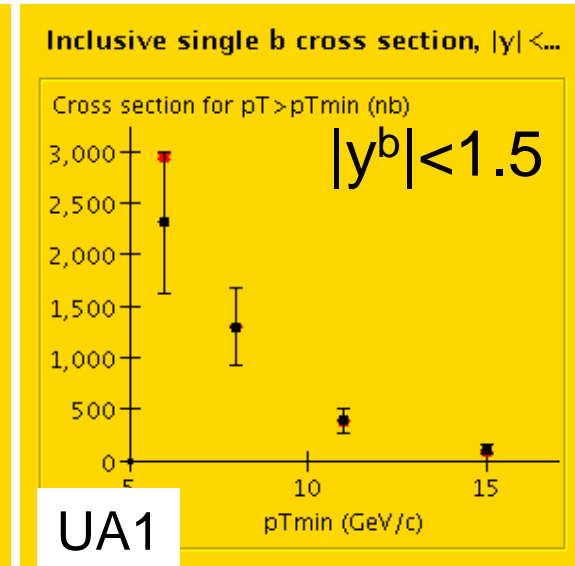
Inclusive single b cross sections

ZEUS see next page

PYTHIA



$b\bar{b} \rightarrow \mu\mu$

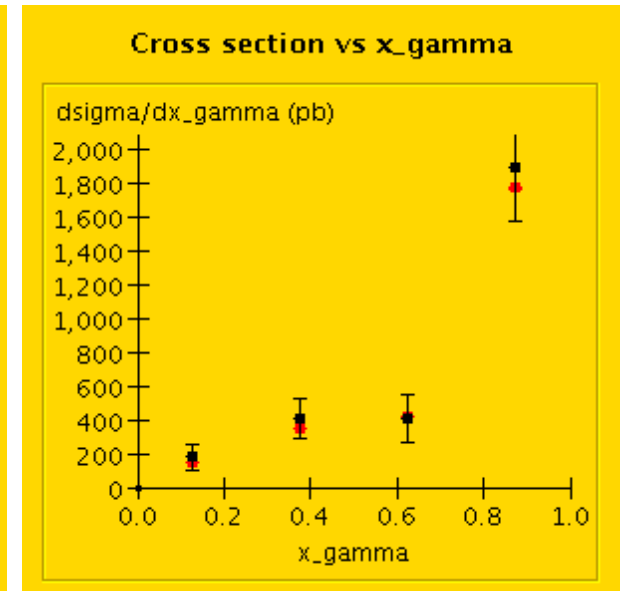
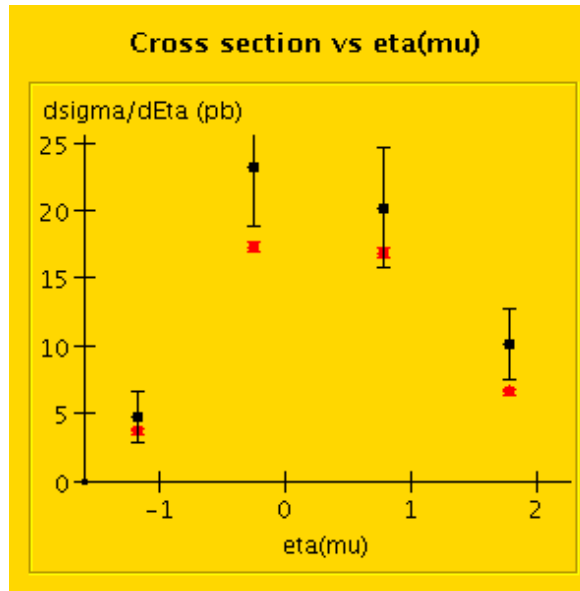
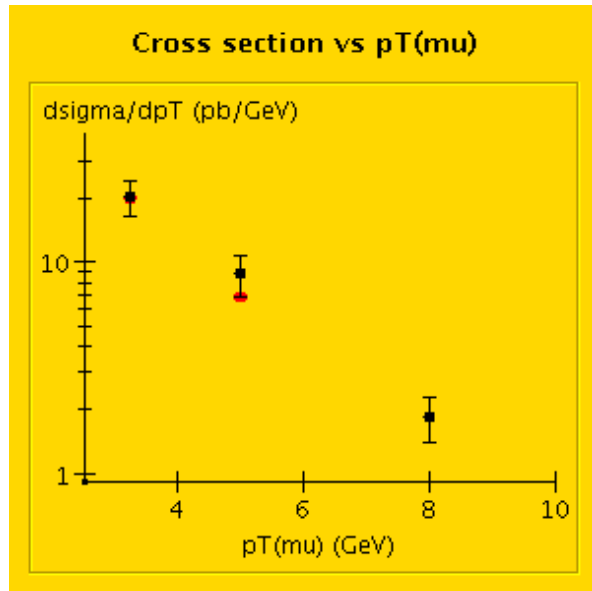


$b\bar{b} \rightarrow \mu\mu$

PYTHIA LO+PS MC (inclusive mode), scaled to HERA jet cross sections, also describes b cross sections at HERA (320 GeV ep), CERN SppS (630 GeV $p\bar{p}$) and Tevatron (1800 GeV $p\bar{p}$) !

ZEUS dijet + μ in photoproduction

PYTHIA



ZEUS „visible“ cross sections well described

more results (H1, CDF, ...) to be implemented

Summary and Conclusions

- Beauty production in e-p collisions is good testing ground for perturbative QCD
- ZEUS beauty cross sections (old and new)
 - agree well with latest H1 results
 - reasonably described by NLO QCD, well described with scale $\mu = \mu^0/2$ (exception: m_b threshold region?)
- PYTHIA LO+PS MC model, tuned to HERA jet cross sections via the JetWeb interface, simultaneously describes b cross sections at HERA, Tevatron, and CERN Sp \bar{p} S
- Has there really ever been a serious problem with beauty QCD predictions for ep and p \bar{p} collisions?
- higher luminosity, and new detectors (e.g. ZEUS Micro-Vertex-Detector) will contribute to resolve remaining issues