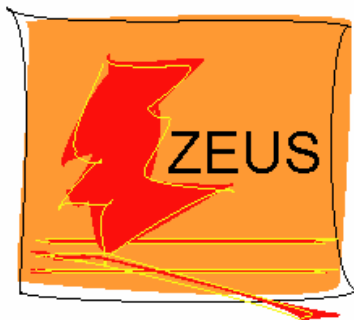# Beauty Photoproduction at HERA/ZEUS

Achim Geiser, DESY Hamburg

Achim.Geiser@desy.de

on behalf of the ZEUS collaboration
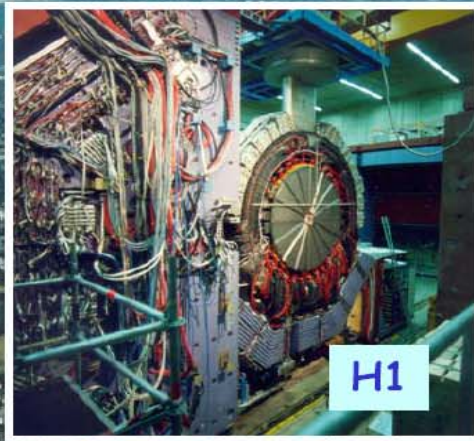
35th International Conference on
High Energy Physics
Paris, France, 22 July 2010

- **Introduction**
- **Beauty tags at HERA**
- **Beauty from dijet + muon** — JHEP04 (2009) 082
- **Beauty from inclusive dijets** — ZEUS-prel-09-005
- **Beauty from dimuons** — JHEP02 (2009) 032
- **Conclusions**
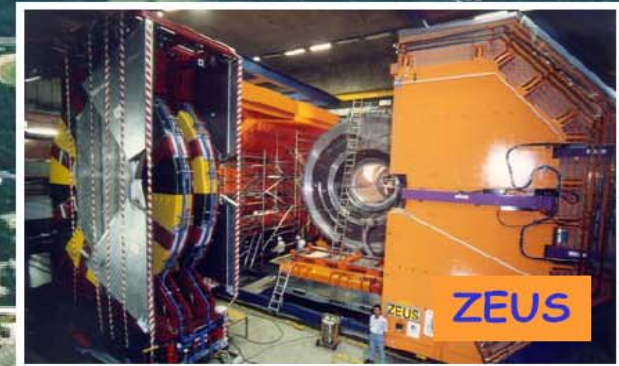
The HERA ep collider and experiments

DESY, Hamburg

HERA I: ~ 130 pb⁻¹
(physics)
HERA II: ~ 370 pb⁻¹
(physics)
total:
~500 pb⁻¹ till 2007

HERA

H1

PETRA

ZEUS

$E_e = 27.6 GeV, E_p = 920 GeV$

$\sqrt{s} = 2\sqrt{E_e E_p} = 319 GeV \Leftrightarrow E_e^{ft} = 54.1 TeV$

$polarisation : P(e) = -0.5...0...+0.5$

$L_{spec} \approx 4...16 \cdot 10^{29} cm^{-2} s^{-1} mA^{-2}$

$I_e = 20...50 mA, I_p = 60...100 mA$

Open beauty production in ep scattering

Dominant production process in ep-collisions: Boson-Gluon -Fusion

e^+

27.6 GeV

γ

Q^2

b

$\sqrt{\alpha_s}$

$\bar{b}$

$g(x)$

920 GeV

p
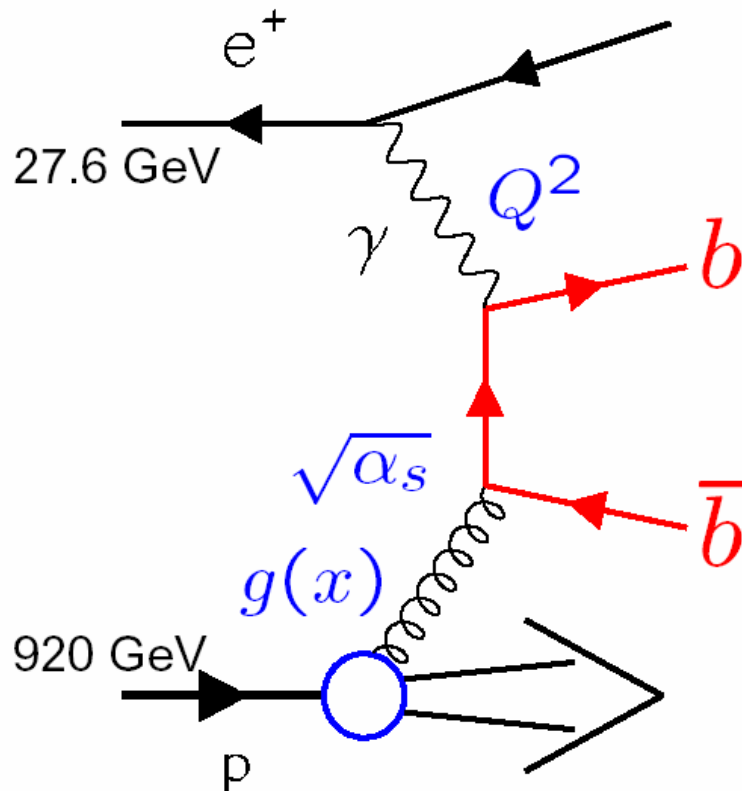
- Driven by **gluons** in the proton

- Relevant scales:
  $$m_b \quad \sim 5 \text{ GeV}$$
  $$Q^2 \quad \lesssim 1 \text{ GeV}^2 \rightarrow \gamma p \quad \text{this talk}$$
  $$\quad\quad > 2 \text{ GeV}^2 \rightarrow \text{DIS} \quad \text{see talks M. Jüngst and P. Thompson}$$
  $$p_T^b \quad \text{Event selection: } p_t^{jet} > 6 \text{ or } 7 \text{ GeV}$$

multiscale problem

-> terms $[\alpha_s \ln (Q^2/m_b^2)]^n$, $[\alpha_s \ln (p_T^2/m_b^2)]^n$, etc.

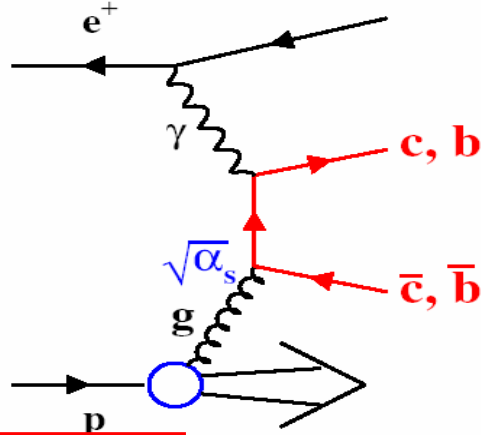in perturbative expansion -> potentially large th. errors

pQCD approximations

assume one dominant hard scale:

Massive scheme: $\to m_b$
- **b massive**
- **neglects** $[\alpha_s \ln(p_T^2/m_b^2)]^n$
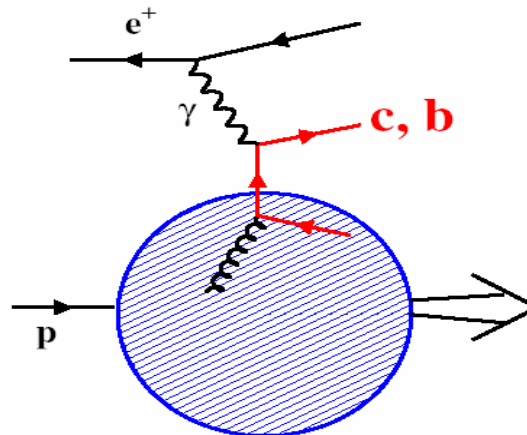
$\to$ **Perturbative production:**

Massless scheme: $\to p_T, Q^2$
- **b massless!**
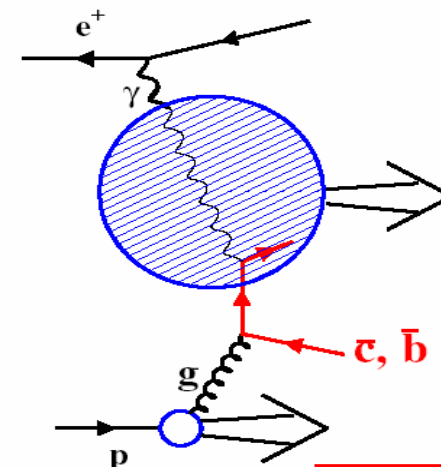- **Resums** $[\alpha_s \ln(p_T^2/m_b^2)]^n$

$\to$ **b also in Proton and Photon!**

NLO

=FFNS

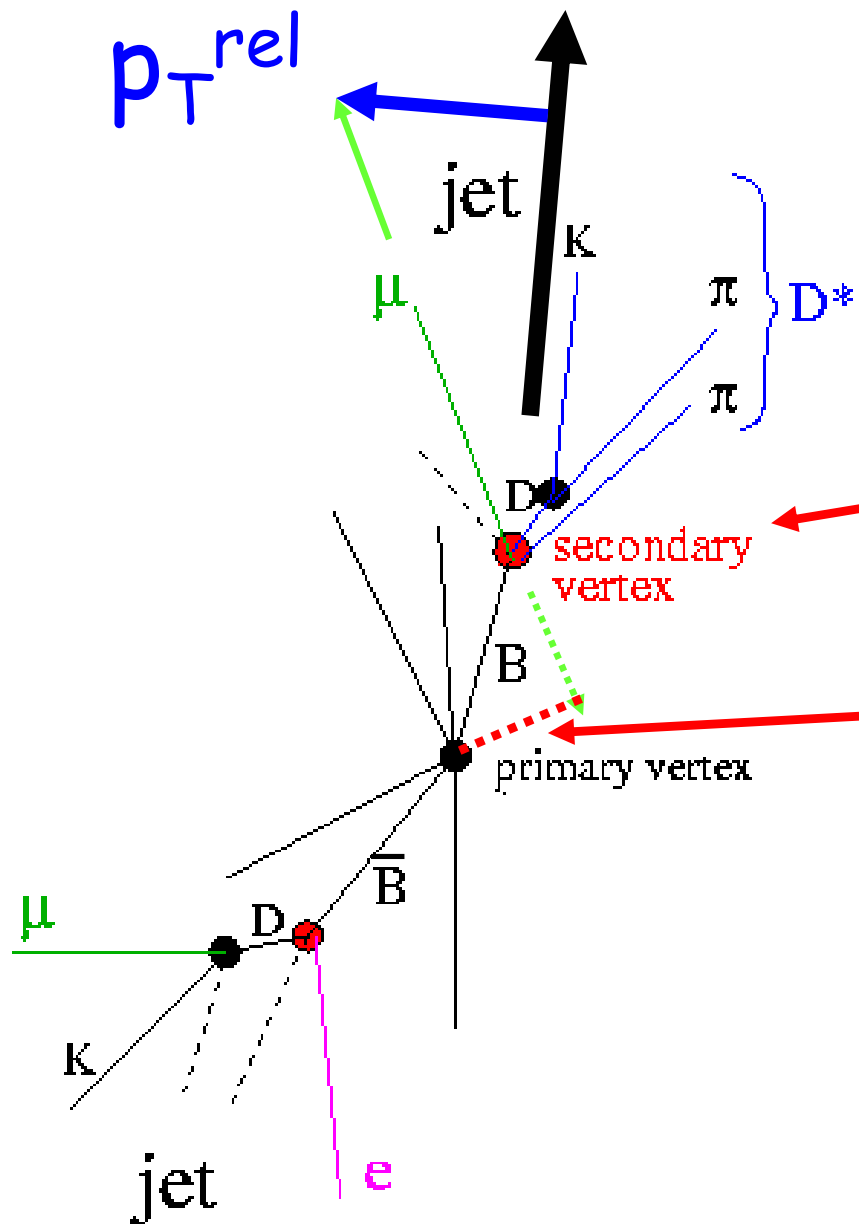**Variable schemes (VFNS):**
$\to$ **at small p_T massive, at large p_T massless**

FONLL

(GM)-VFNS

NLL

=ZM-VFNS

Tagging semileptonic beauty decays

p_T^{rel}

jet

K

μ

π } D*

π

D

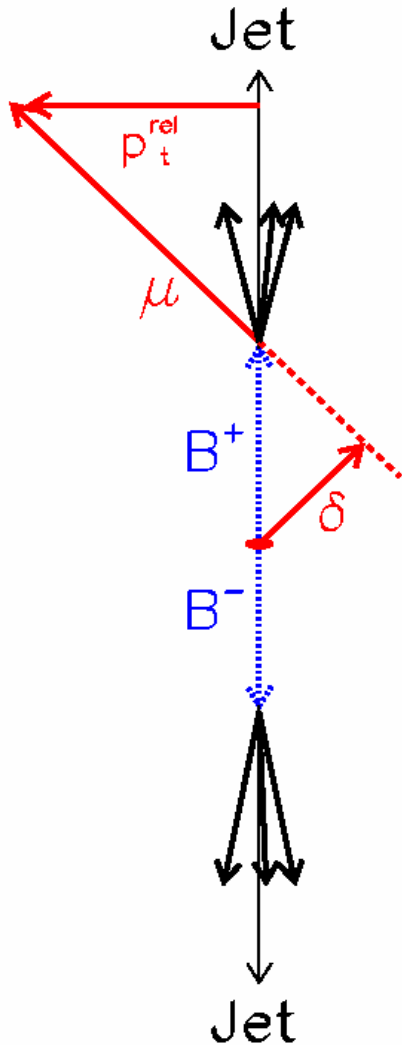secondary vertex

B

primary vertex

μ

D

K

B̄

jet

e

1) **jet mass** or
p_T^{rel} : p_T of μ/e
with respect to jet axis

2) secondary vertex
 or
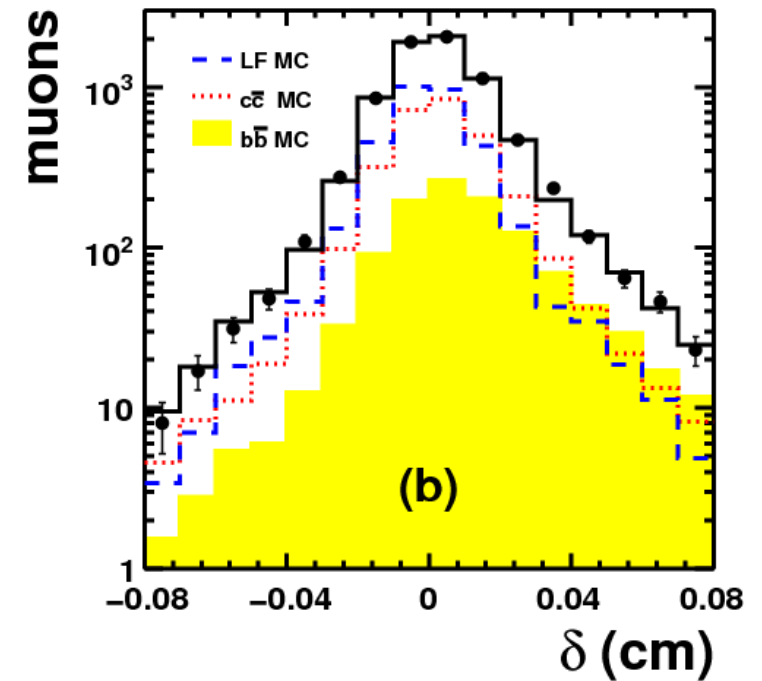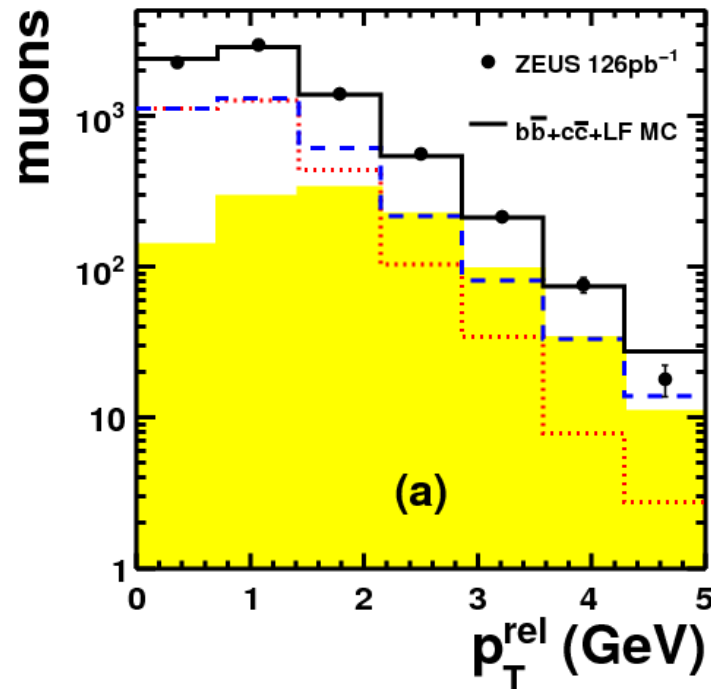impact parameter
of μ with respect
to primary vertex

3) D*μ and μμ
corrections

Beauty from dijets + μ

$Q^2 < 1$ GeV^2, 2 jets E$_T$>7(6) GeV, p$_T^\mu$ > 1.5 (2.5) GeV
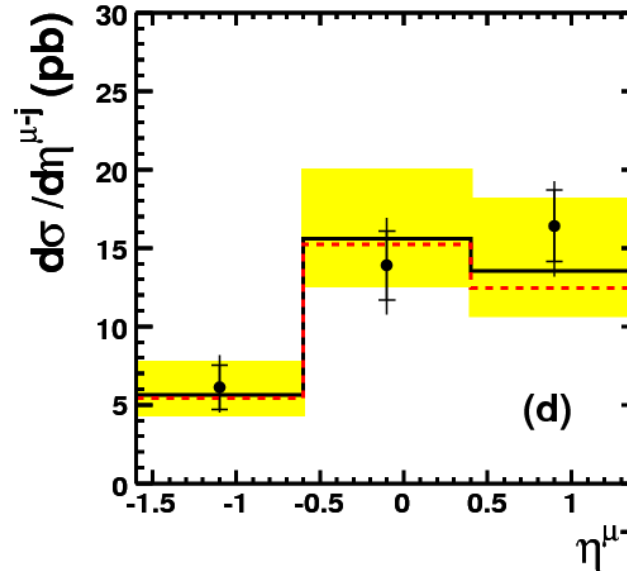
use μ from semileptonic decay, separate b and c

ZEUS

Plot (a): muons vs p_T^{rel} (GeV), with ZEUS 126pb^{-1}, $b\bar{b}+c\bar{c}$+LF MC
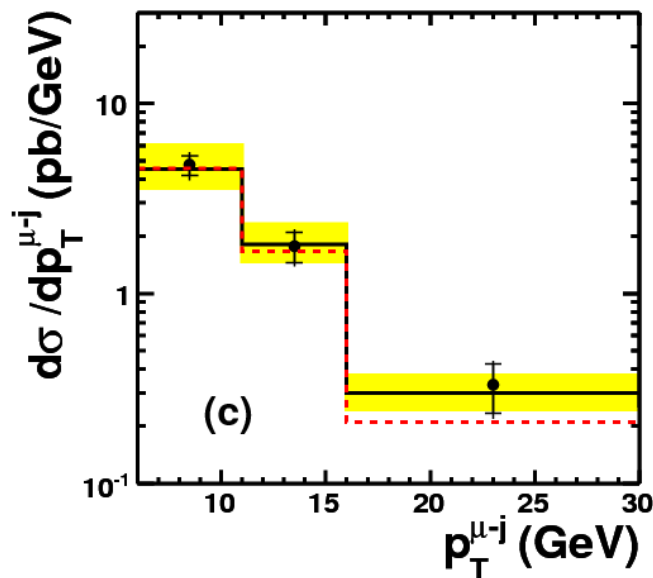
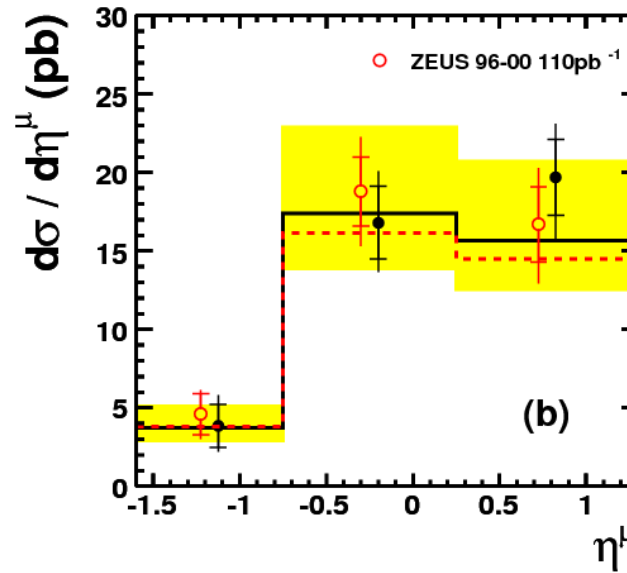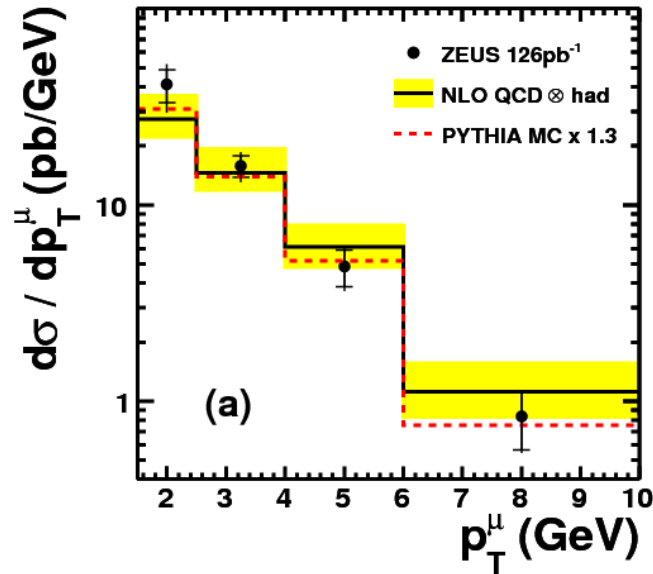Plot (b): muons vs δ (cm), with LF MC, $c\bar{c}$ MC, $b\bar{b}$ MC
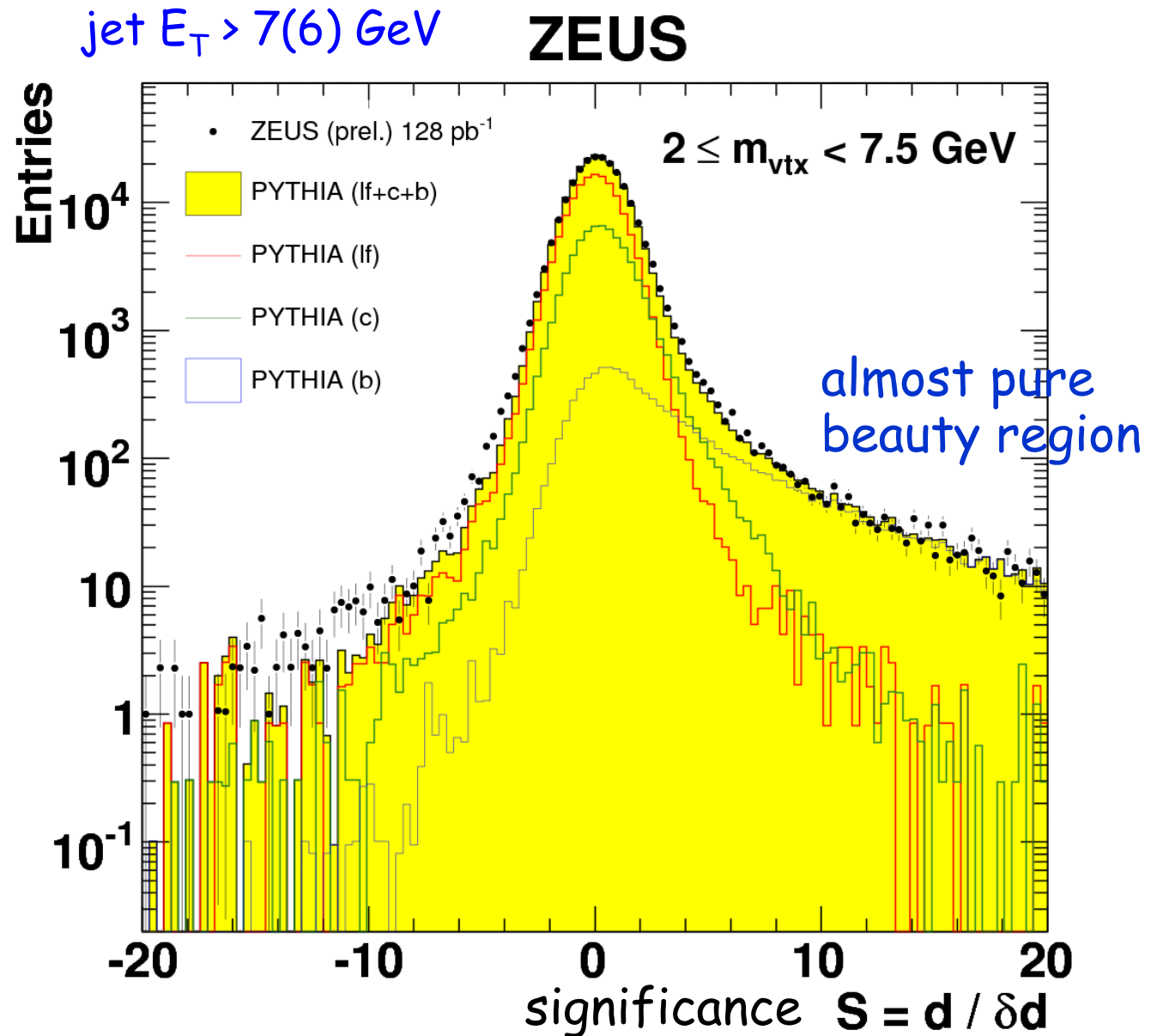
Beauty from dijets + μ

μ and jet cross sections well described by NLO QCD

beauty from inclusive dijets + vtx

use significance
of secondary
vertex

simultaneous
fit of mirorred
significance
for three
different
mass ranges
(see backup)

jet $E_T > 7(6)$ GeV

ZEUS

- ZEUS (prel.) 128 pb^{-1}
- PYTHIA (lf+c+b)
- PYTHIA (lf)
- PYTHIA (c)
- PYTHIA (b)

$2 \leq m_{vtx} < 7.5$ GeV

almost pure
beauty region

significance $S = d / \delta d$

Beauty from inclusive dijets + vtx

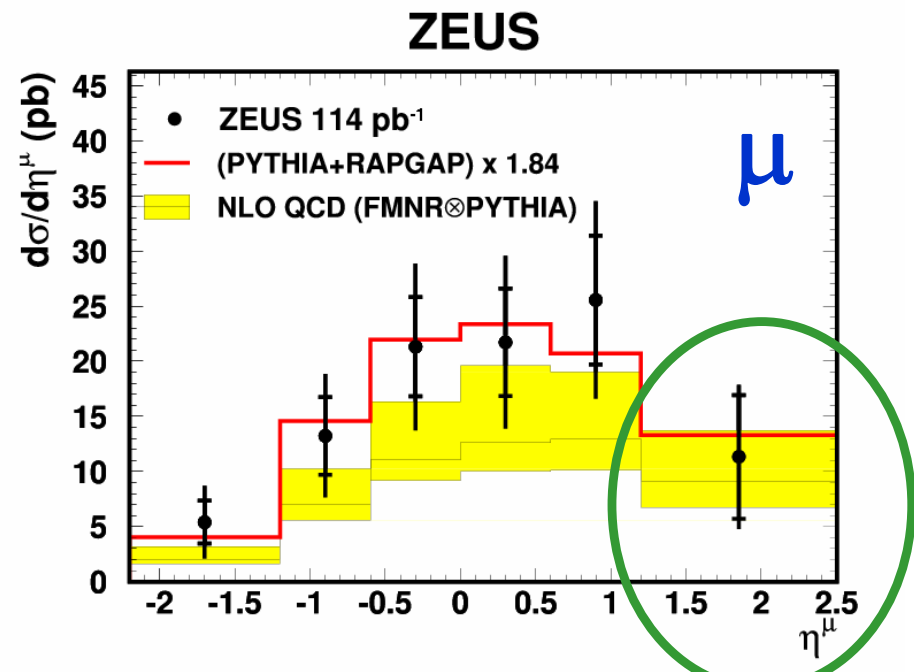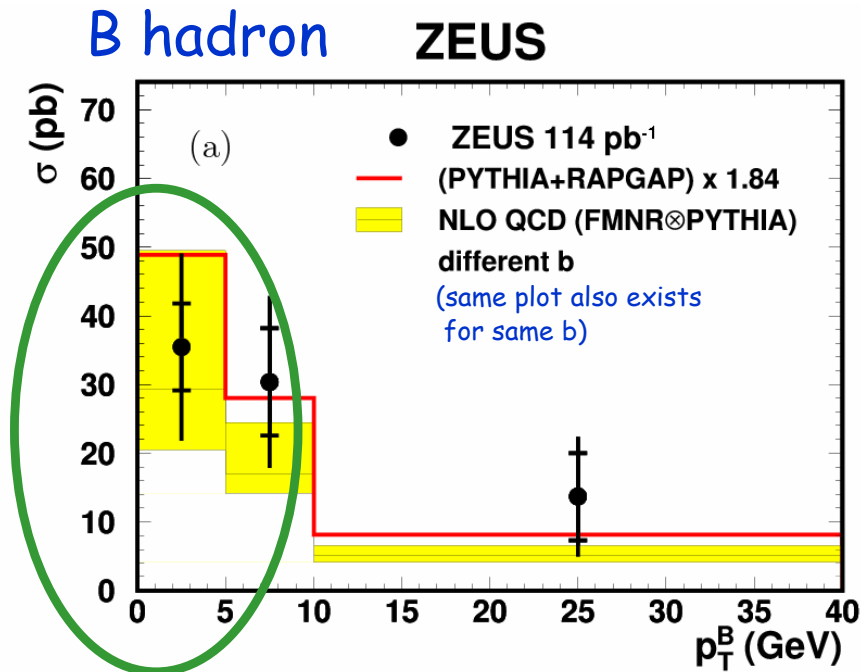better precision (higher statistics) than dijet+μ, extended p_T range
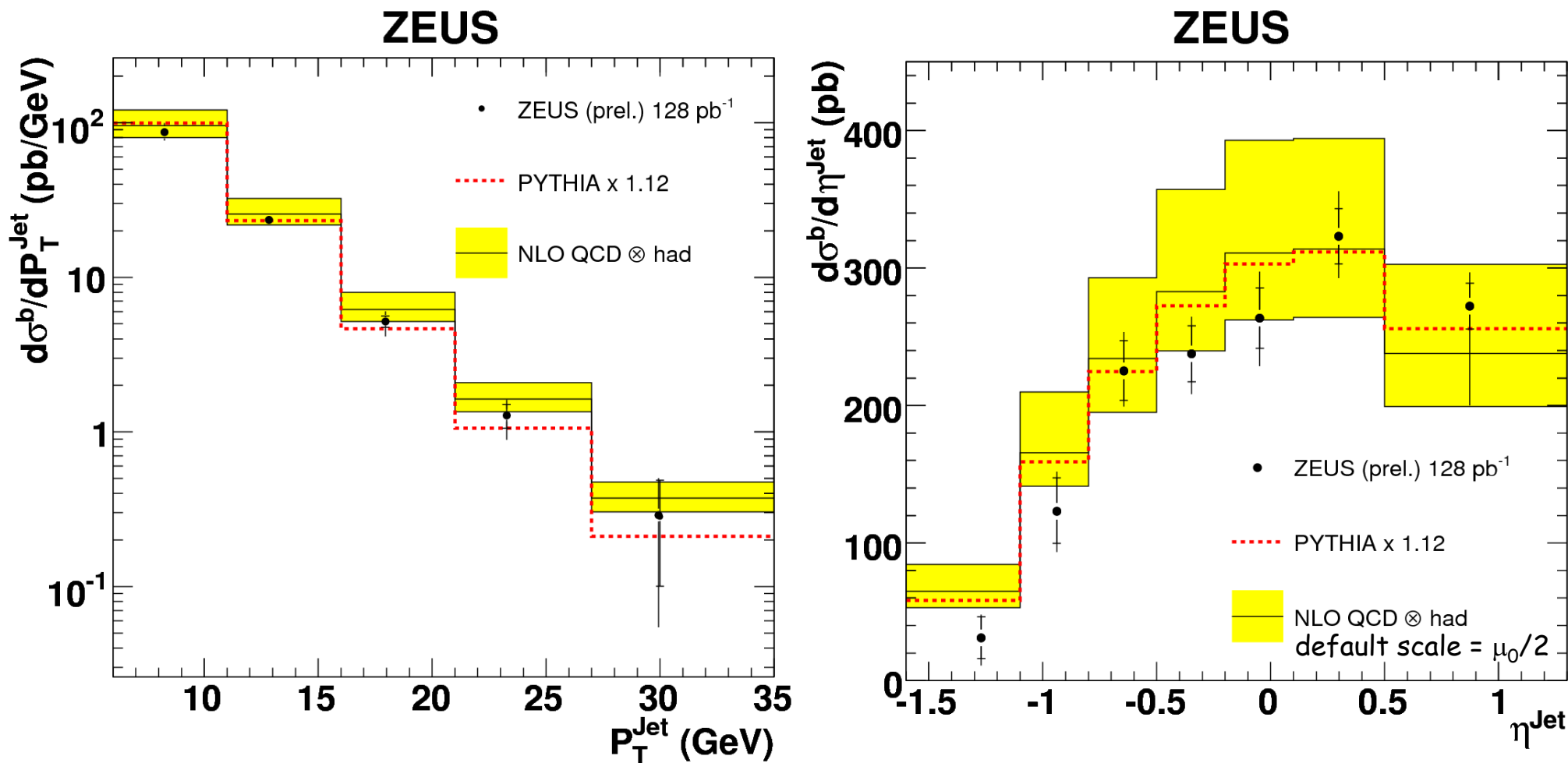
agreement with NLO QCD within large theory uncertainties

Double tagging of bb̄ pair

■ **two direct flavour tags, e.g.** $\mu + \mu$, $p_T^\mu > 1.5/0.75$ GeV

-> large bg reduction (~50% beauty) , do not need jets or sec. vtx

-> access low p_T and forward regions (proton direction)

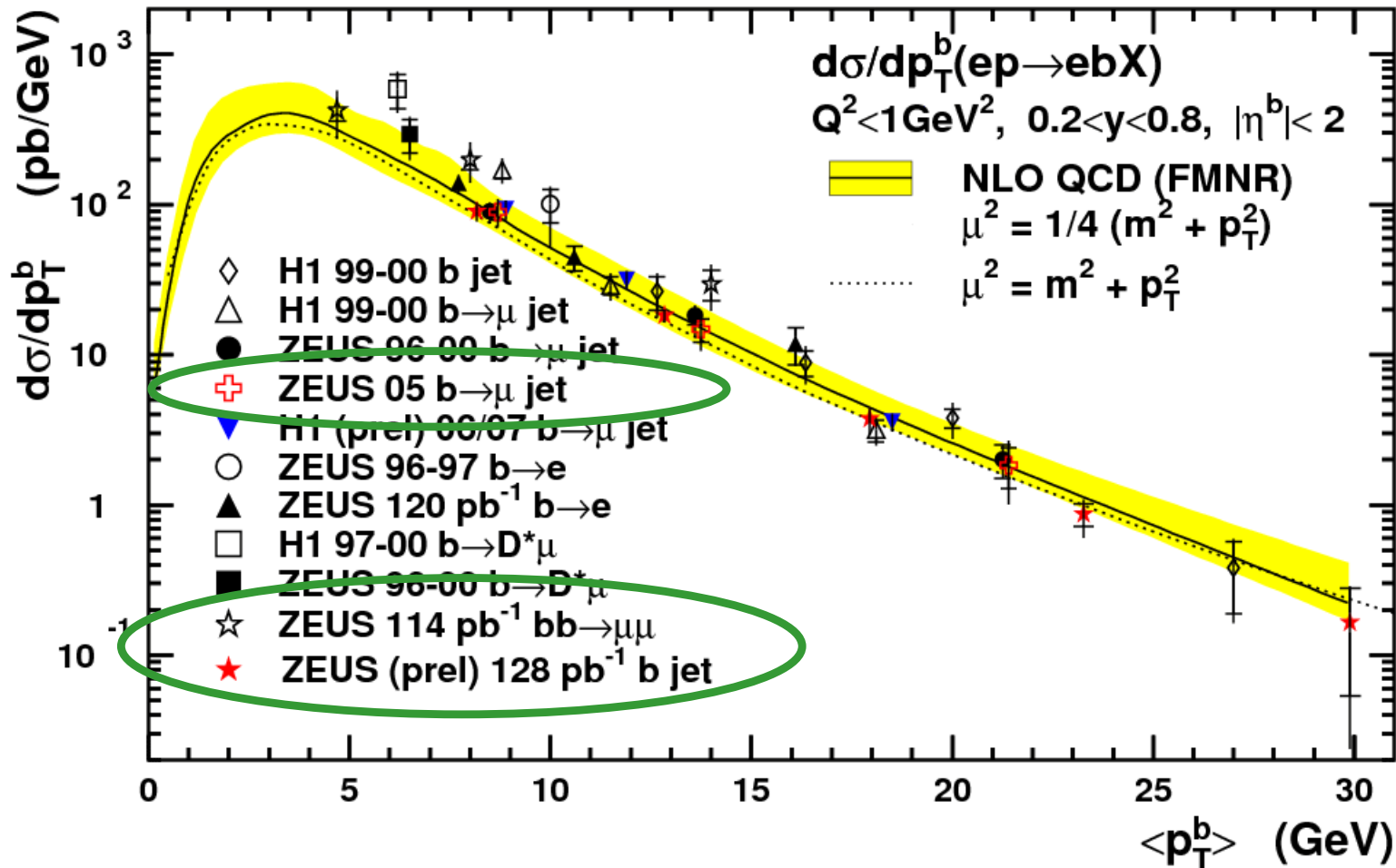B hadron

-> measure **total beauty production cross section** at HERA:

$$\sigma(ep \to b\bar{b} + anything) = 13.9 +\!- 1.5_{stat}\,^{+4.0}_{-4.3,sys}\ nb$$

$$\sigma_{NLO} = 7.5\,^{+4.5}_{-2.1}\ nb \quad (FMNR+HVQDIS)$$

Beauty in photoproduction: summary

b quark

HERA

$d\sigma/dp_T^b(ep \rightarrow ebX)$
$Q^2 < 1\,GeV^2$, $0.2 < y < 0.8$, $|\eta^b| < 2$

NLO QCD (FMNR)
$\mu^2 = 1/4\,(m^2 + p_T^2)$
$\mu^2 = m^2 + p_T^2$

◇ H1 99-00 b jet
△ H1 99-00 b→μ jet
● ZEUS 96-00 b→μ jet
✛ ZEUS 05 b→μ jet
▼ H1 (prel) 06/07 b→μ jet
○ ZEUS 96-97 b→e
▲ ZEUS 120 pb⁻¹ b→e
□ H1 97-00 b→D*μ
■ ZEUS 96-00 b→D*μ
☆ ZEUS 114 pb⁻¹ bb→μμ
★ ZEUS (prel) 128 pb⁻¹ b jet

$d\sigma/dp_T^b$ (pb/GeV)

$\langle p_T^b \rangle$ (GeV)

Data vs. NLO QCD:

reasonable agreement

for theory-inspired motivation of QCD scale choice see

doi:10.3360/dis.2007.163

FONLL (VFNS) prediction and threshold resummation not yet available, **should they help?**

Summary and conclusions

● **b photoproduction measured at HERA from variety of detection techniques.**

dijet + μ tag exploits semileptonic decay signature with maximal efficieny
inclusive dijet + sec. vertex tag yields high statistics almost pure b signal region
dimuon tag covers full phase space -> allows extraction of total b cross section

● **all measurements in agreement with each other**

so far covering only part of HERA statistics
-> more precision to come

● **beauty cross sections at HERA in agreement
  with perturbative QCD predictions.**

theoretical uncertainties at NLO quite large
(mainly b mass +QCD scale dependence)
-> best would be to go to NNLO (unfortunately not any time soon)

● **"state of the art" NLL corrections to NLO (threshold resummation, FONLL)
  would be nice to have**

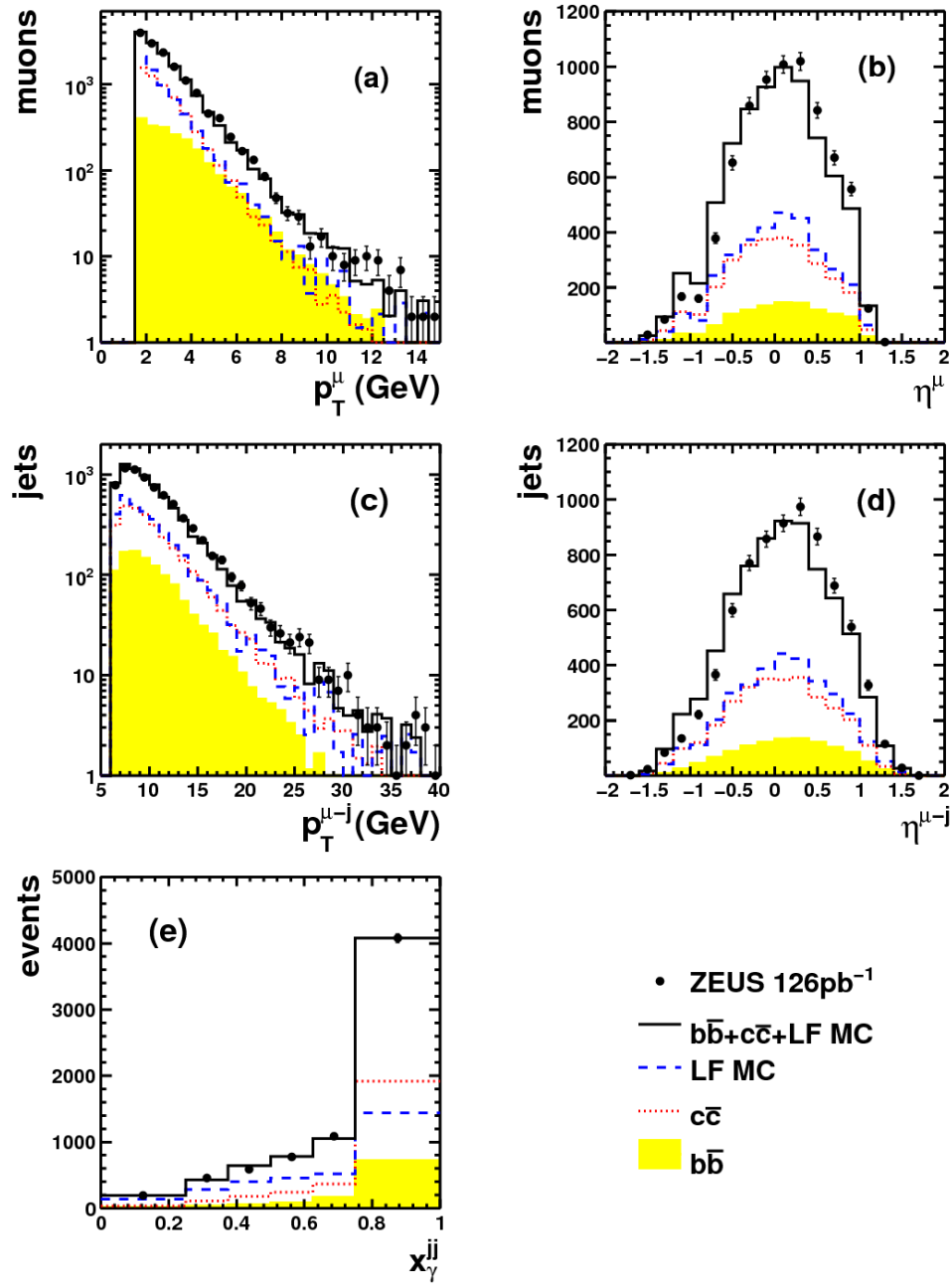(partially exist for DIS/charm, but not yet for b photoproduction)
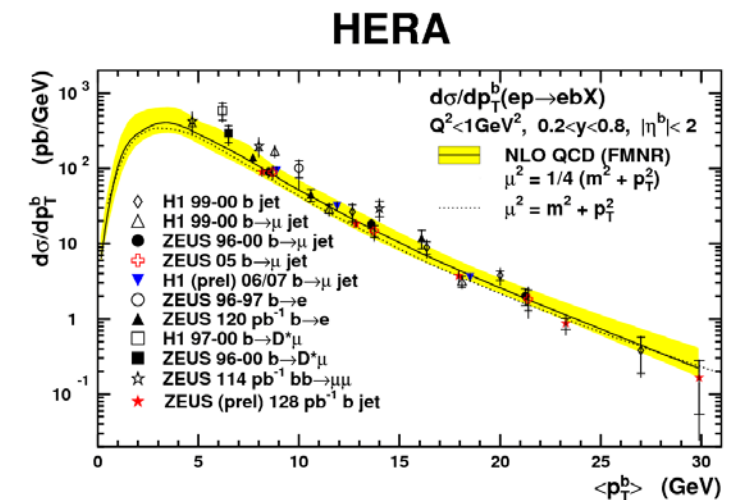
Backup slides
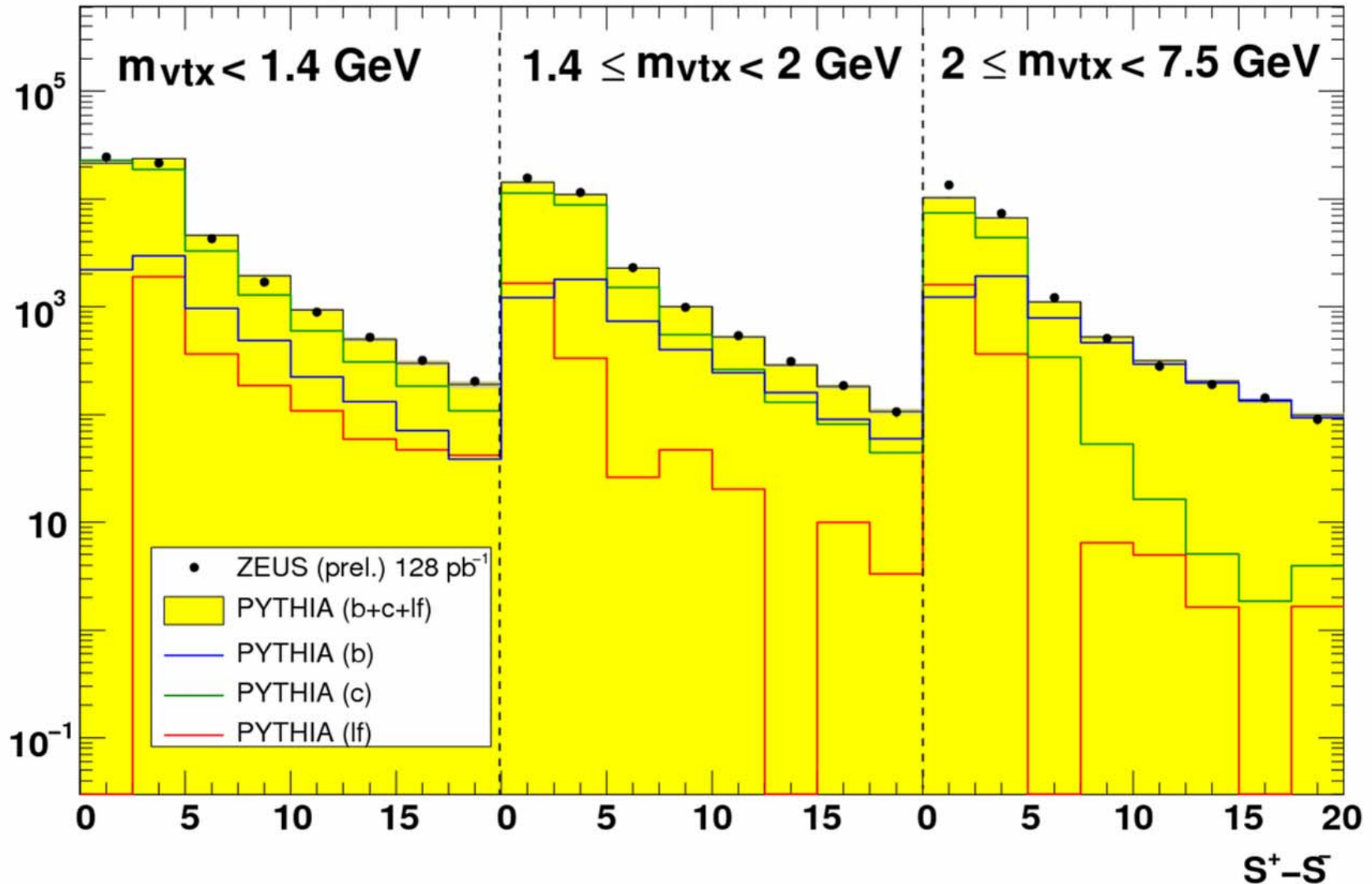
Beauty from dijets + μ
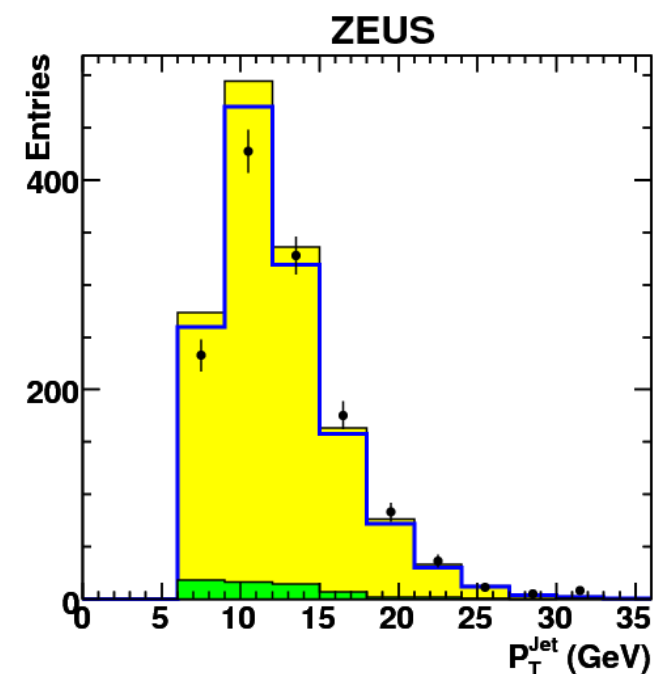
control plots

Beauty from inclusive dijets + vtx
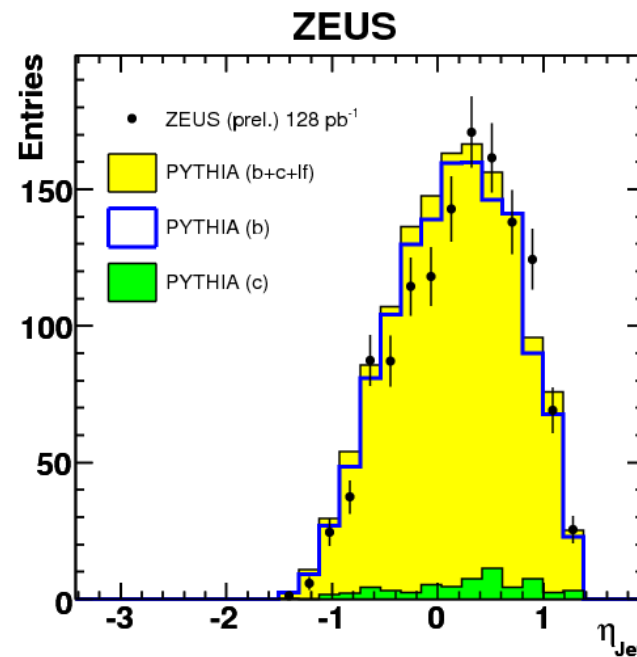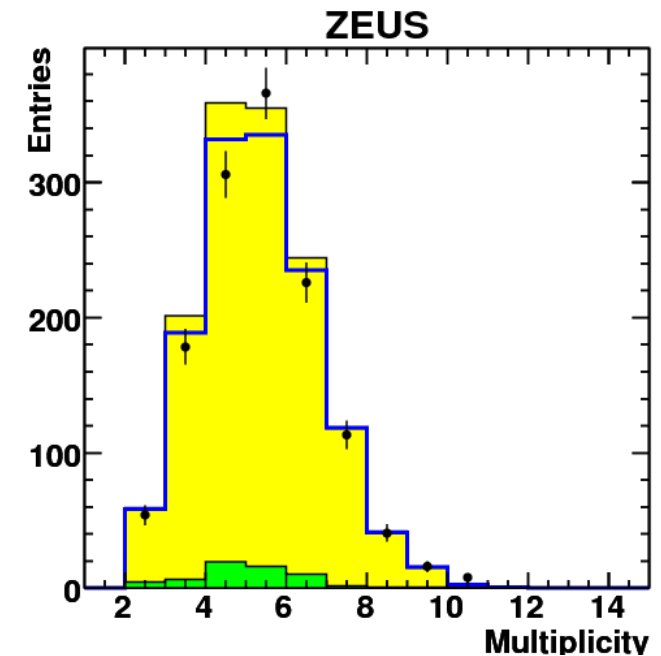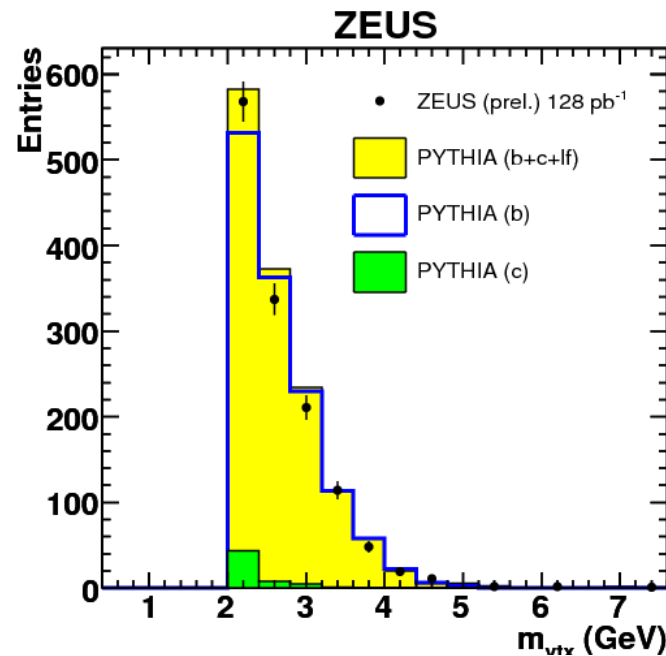
fit of mirrored vertex significance

Beauty from inclusive dijets + vtx

control
plots
for
beauty
enriched
region

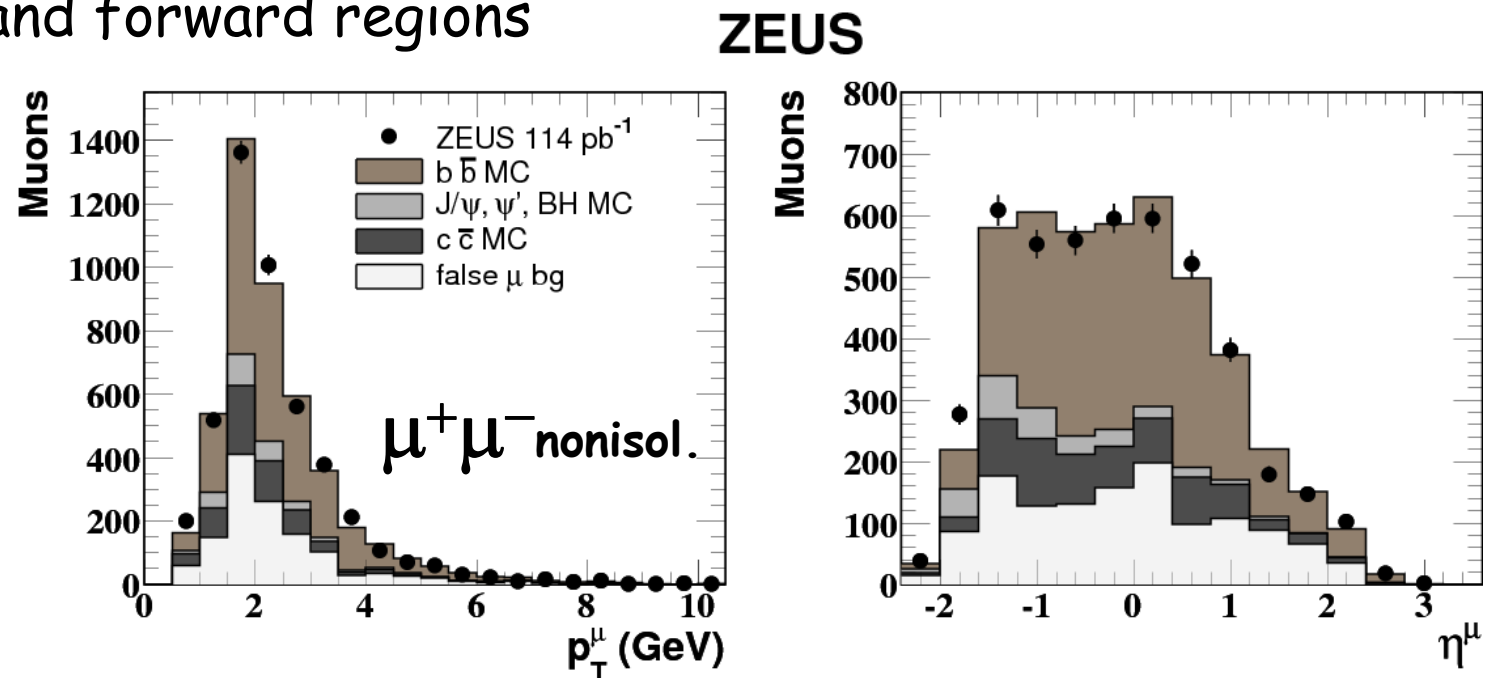# Double tagging of b b̄ pair

■ **two direct flavour tags, e.g. $\mu + \mu$**

-> large bg reduction, do not need jets

-> access low p_T and forward regions
  (proton direction)

l.fl. bg. indirectly
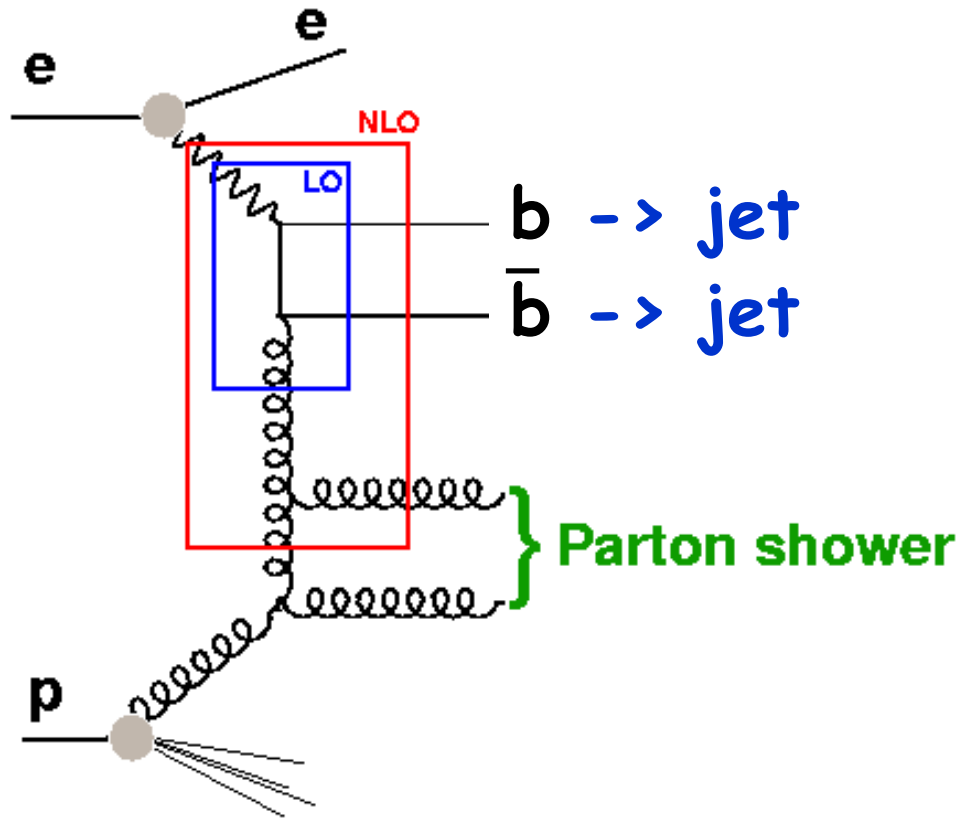from
like sign $\mu\mu$

~50% beauty

$\mu^+\mu^-$ nonisol.

ZEUS

- ZEUS 114 pb^{-1}
- b b̄ MC
- J/ψ, ψ', BH MC
- c c̄ MC
- false μ bg

-> measure **total beauty production cross section** at HERA:

$$\sigma(ep \rightarrow b\bar{b} + anything) = 13.9 +- 1.5_{stat} \, {}^{+4.0}_{-4.3, sys} \text{ nb}$$

$$\sigma_{NLO} = 7.5 \, {}^{+4.5}_{-2.1} \text{ nb} \quad \text{(FMNR+HVQDIS)}$$
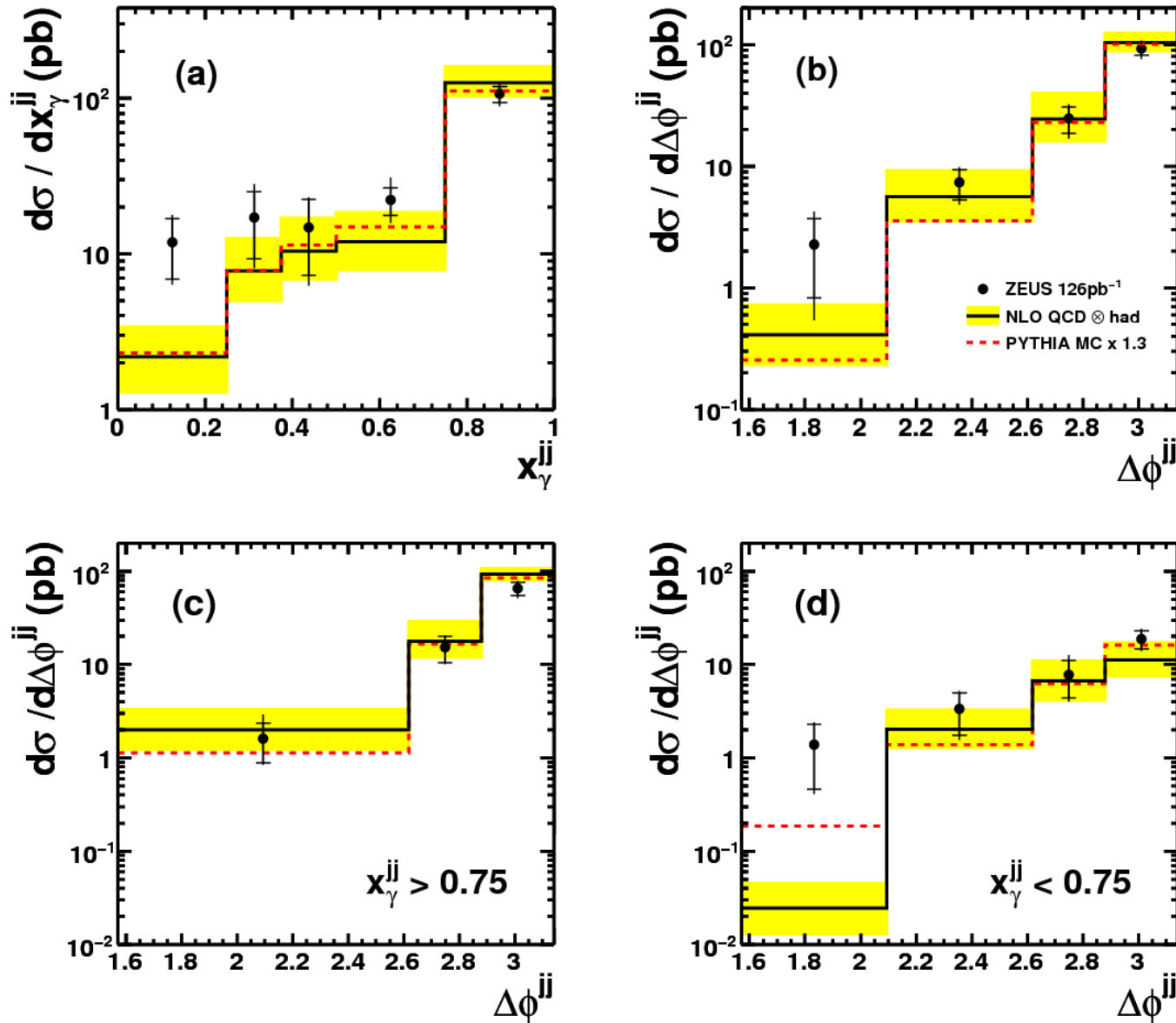
NLO vs. LO + parton shower

"direct γ"
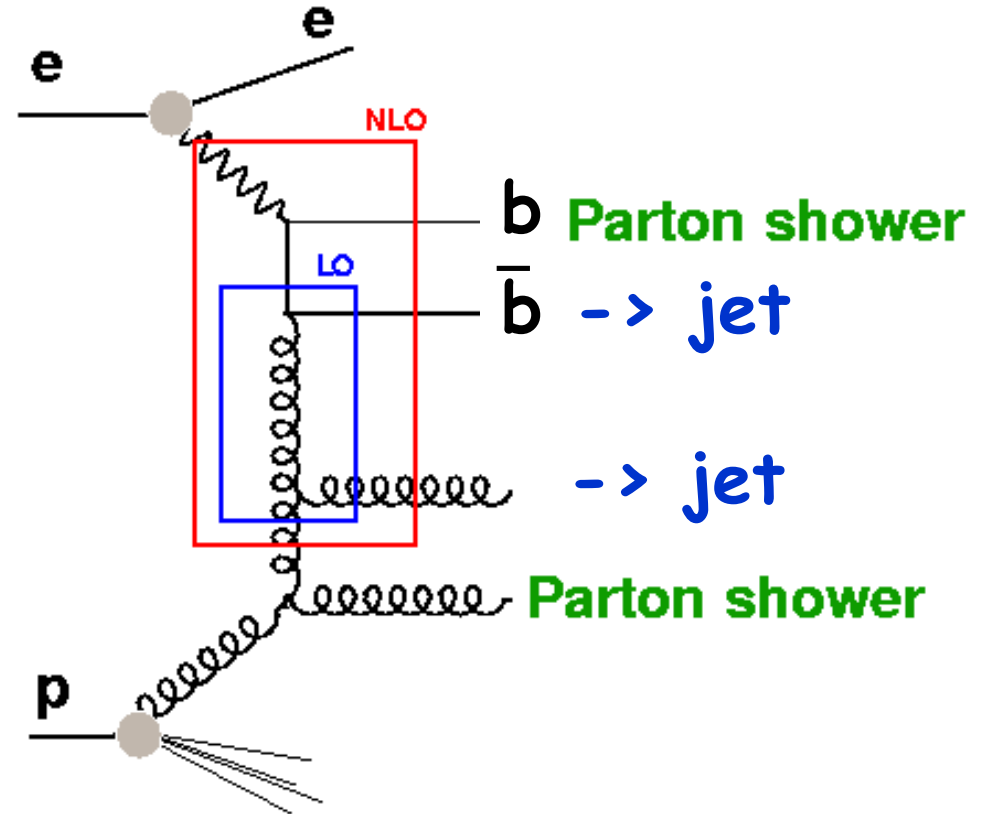
"resolved γ"

Beauty from dijets + μ

Detector upgrades for HERA II

upgrades most relevant for
heavy flavour production:

- H1 Fast Track Trigger

- ZEUS Micro-Vertex Detector (MVD)