Beauty photoproduction at ZEUS

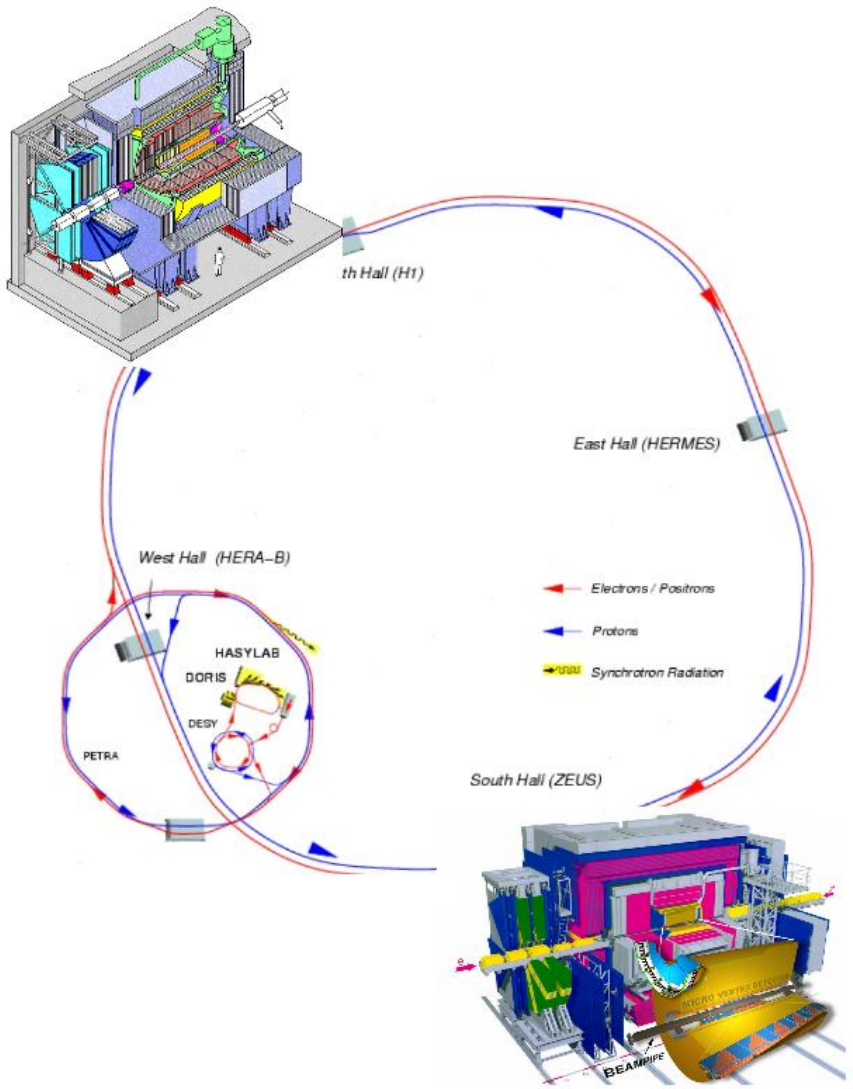
on behalf the ZEUS collaboration
S. Miglioranzi

CERN

XVII International Workshop on Deep-Inelastic Scattering and Related Subjects DIS 2009

26-30 April 2009, Madrid

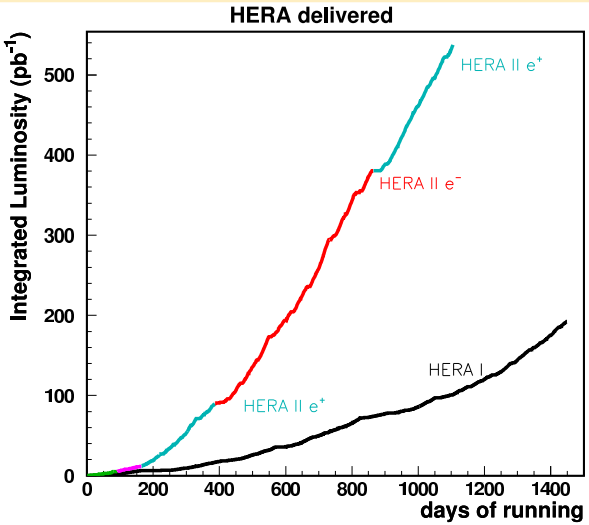
The HERA Collider



- E_p =920 GeV, E_e =27.6 GeV $\rightarrow \sqrt{s} = 320$ GeV

Luminosity collected by H1/ZEUS

- 96/00(HERA I): $e^{\pm} p \sim 130 pb^{-1}$
- 03/07(HERA II): $e^{\pm} p \sim 380 pb^{-1}$

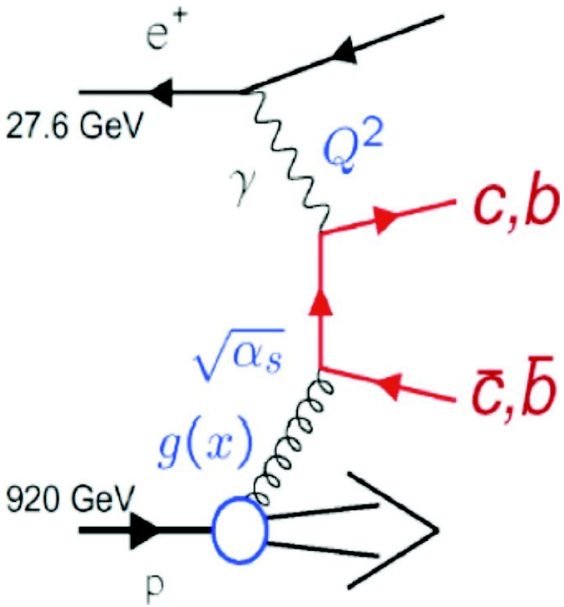


End of HERA program: June 2007

(last 3 months low energy running $\rightarrow F_L$)

HFL Production

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



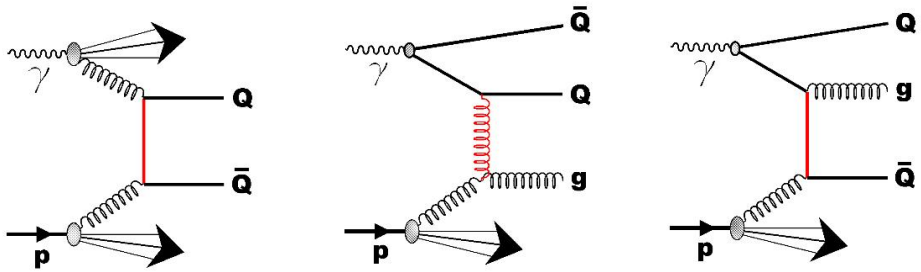
Multiple scales involved:

- $M_b \sim 5$ GeV, $M_c \sim 1.4$ GeV
- $Q^2 \sim 0$ GeV^2 (photoproduction - γp)
- $Q^2 >\sim 1$ GeV^2 (deep inelastic scattering - *DIS*)
- $P_t^{c,b}$ few GeV

Powerful tool for testing p structure and *pQCD*

Kinematic variables:

- $Q^2 = -q^2$ photon virtuality, squared momentum transfer
- $x = \frac{Q^2}{2pq}$ Bjorken scaling variable
- $x_\gamma^{jet} = \Sigma_{j1,j2}(E - P_Z)/\Sigma_h(E - P_Z)$

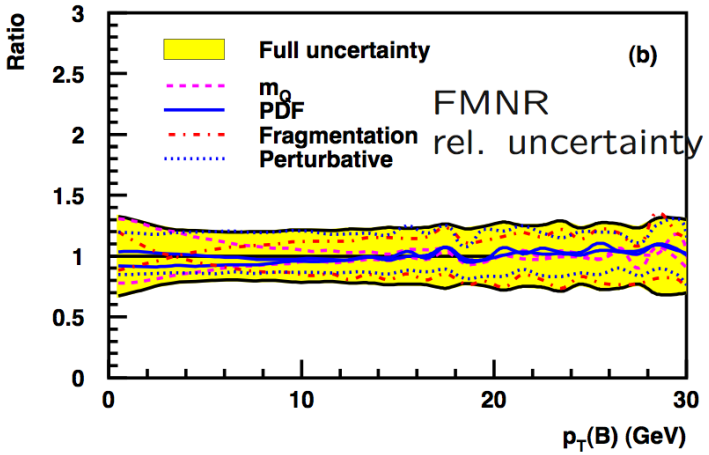


- NLO corrections (O (α_s^2)) for HQ production in *ep* collisions known since '90s
- FMNR program available for PHP (massive scheme FFNS, Weizsäcker-Williams approximation used, resolved-photon included)
- NLO corrections significant $\rightarrow \sigma_{NLO}/\sigma_{LO} \sim 1.4$ (main contribution from Flavor Excitation-like diagrams)

Perturbative uncertainties on σ_{PHP} from FMNR:

- up to $\sim 30\%$ for $m_b = 4.75 \pm 0.25$ GeV
- $\sim 20\%$ for $\mu_r = \mu_f = 2^{0\pm1} m_T$
- $\sim 3\%$ for PDFs

Non-perturbative uncertainties (coming from fragmentation, hadronization etc.) are overall smaller than perturbative ones



Ratio upper/lower side uncert. w.r.t nominal

Beauty measurements difficult at HERA $\longrightarrow \sigma_{b\bar{b}}/\sigma_{tot} \sim 0.1\%$

- increases to $\sim 6\%$ for high-p_T jets
- increased to $\sim 20\%$for two jets and a high-p_T lepton (beauty and charm are main sources)

Beauty results at ZEUS

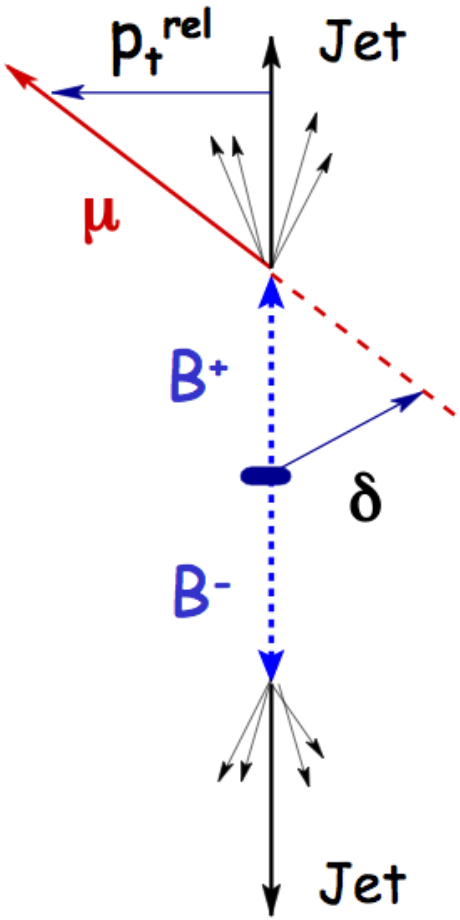
- events with 2 jets + 1e (EPJC 18 (2001) 625, PRD 78 (2008) 072001)
- events with 2 jets + 1μ (PRD 70 (2004) 012008, DESY-08-210 (2008))
- events with 1 D^* + 1μ (EPJ C 50 (2007) 299-314)
- events with 2μs (JHEP02 (2009) 032)
- events with 2 jets + vertex (DIS2009: ZEUS-prel-09-005)

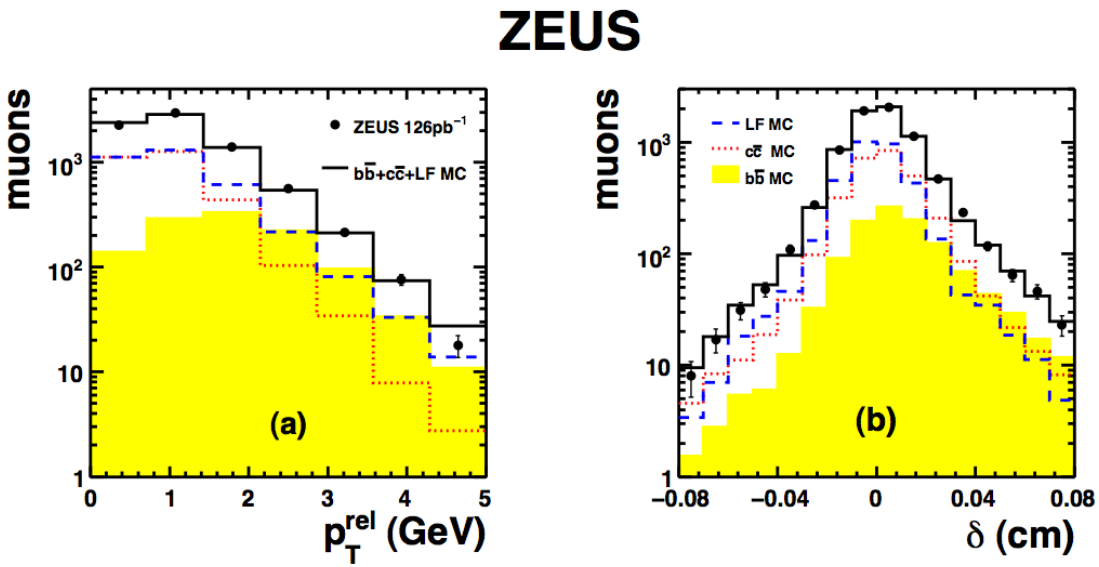
Final result DESY-08-210, accepted by JHEP , μ channel:

- ID based on muon chambers
- background from c and "fake" muons (decays of K, π, punch-through)

Beauty content extracted statistically from fits to discriminant variables:

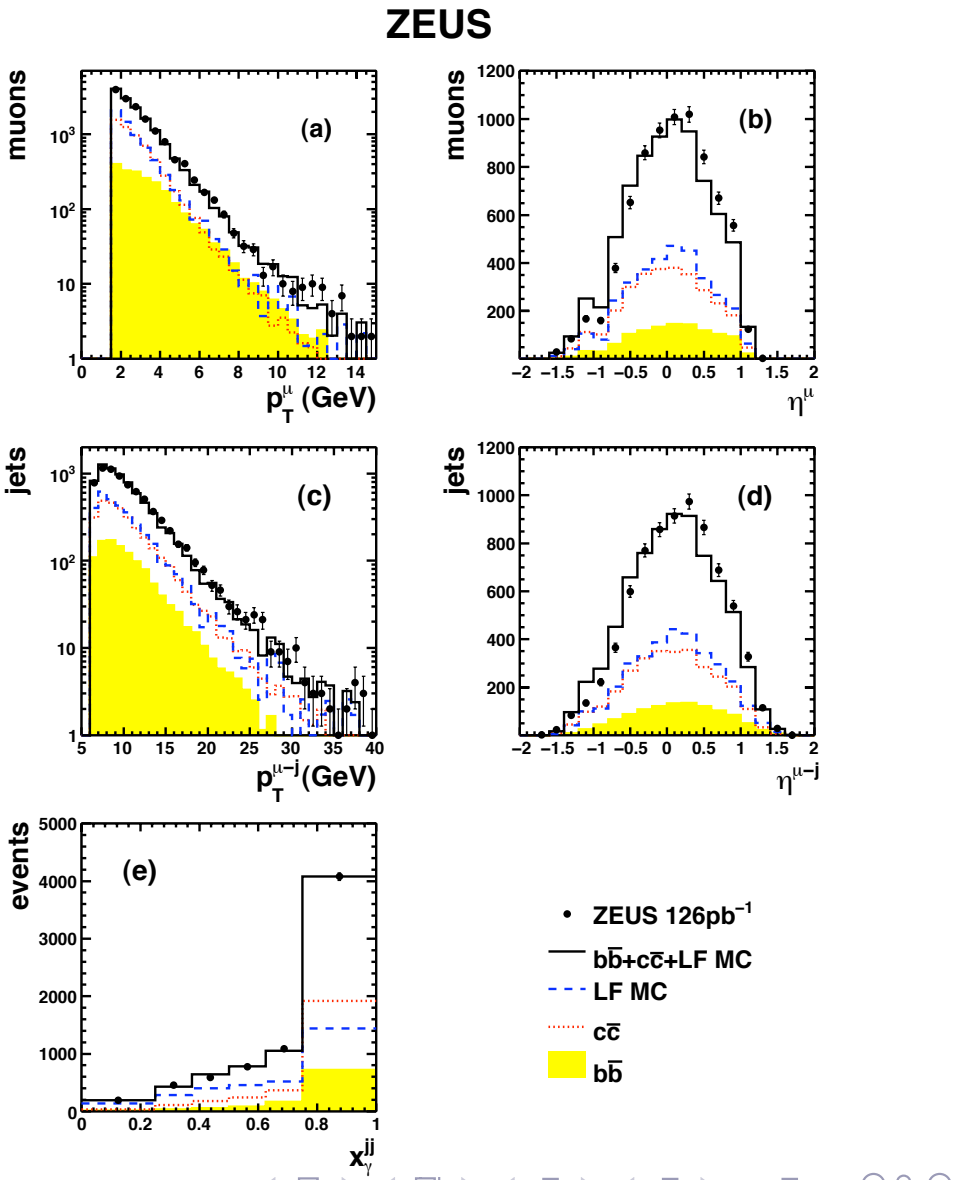
- P_t of muon relative to the jet axis (p_T^{rel}): exploits large B mass
- Muon impact parameter (δ): expoits long B lifetime





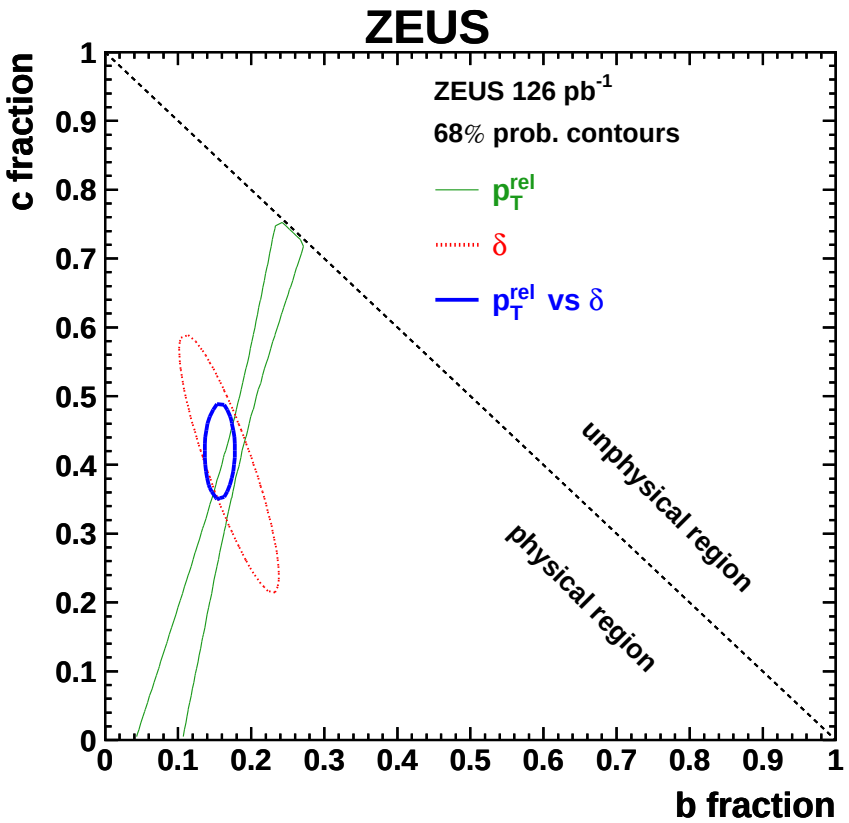
HERA II data (2005 e^+p), $\mathcal{L}$= 125 pb-1

- PHP selection: veto on scattered e^+, $0.2 < y_{JB} < 0.8$
- Jets: k_T clustering (massive), $N_{jets} \geq 2$, $p_t > 7(6)$ GeV, $|\eta| < 2.5$
- μ selection: $p_t^\mu > 1.5$ GeV, $-1.6 < \eta < 2.3$



Combined p_T^{rel}-δ fit

- 3-components fit
- p_T^{rel} fit alone able to distinguish b from bkg (c and lf)
- δ fit alone able to well separate light from heavy flavours
- here not necessary to constrain charm fraction from other measurements (HERA I)



FMNR NLO QCD predictions:

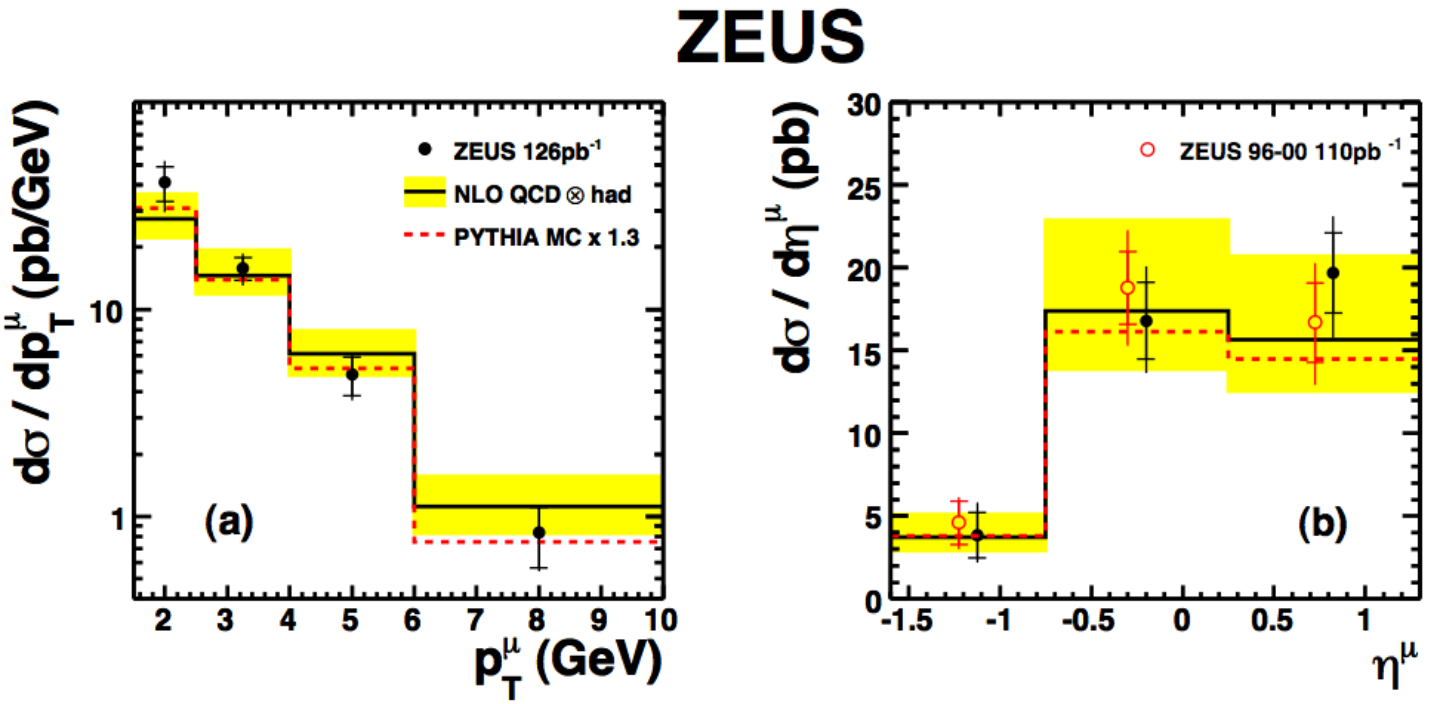
- $\mu = \mu_0 = \sqrt{\frac{1}{2}((p_T^b)^2 + (p_T^{\bar{b}})^2) + m_b^2}$, $0.5\mu_0 < \mu < 2\mu_0$
- $m_b = 4.75$ GeV, 4.5 GeV$< m_b <$ 5 GeV
- PDF(P) = CTEQ5M, PDF(γ) = GRVG-HO
- Hadronization corrections from PYTHIA

New lower p_T^μ bin (1.5-2.5 GeV)!

Results:

- Good agreement with NLO QCD
- Good agreement with previous HERA I results (p_T^{rel} only)

$$p_T^\mu > 2.5 GeV$$

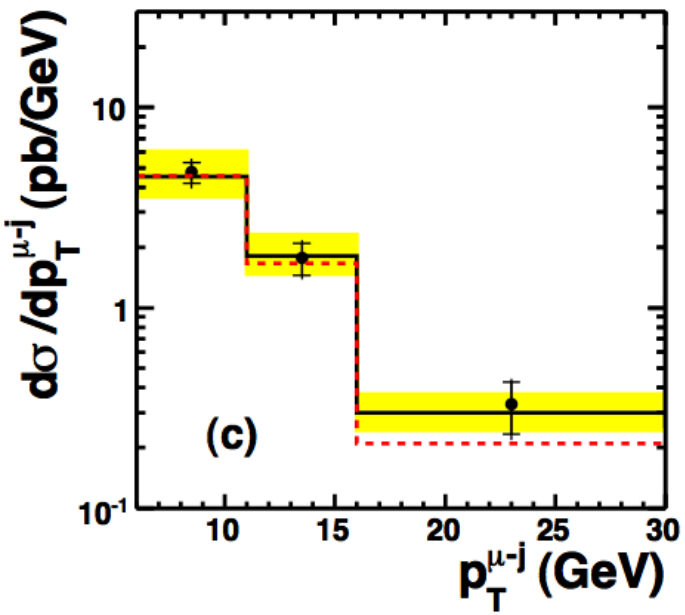


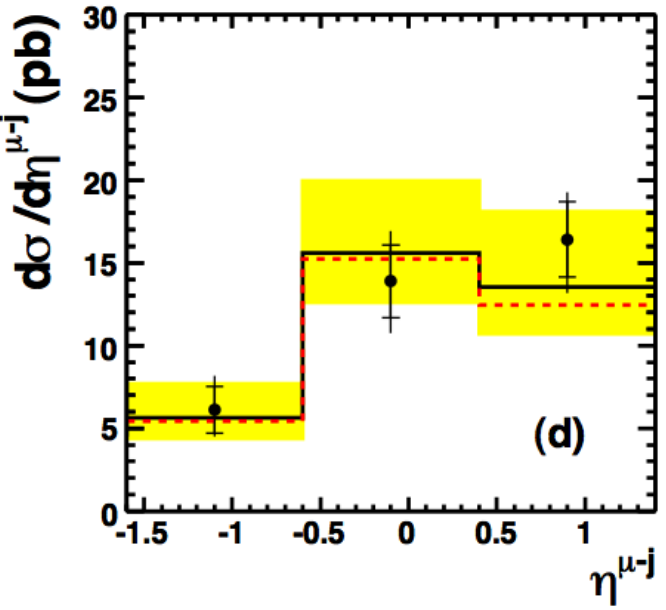
Total visible cross section

- $\sigma_{vis}(ep \rightarrow eb\bar{b} \rightarrow ejj\mu X') = 38.6 \pm 3.5(stat.)^{+4.6}_{-4.9}(syst.)$ pb
- $\sigma_{NLO}(ep \rightarrow eb\bar{b} \rightarrow ejj\mu X') = 37.0^{+11.9}_{-7.5}$ pb

Results:

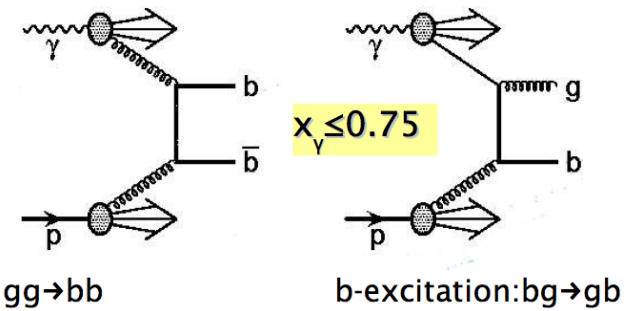
- Good agreement with NLO QCD

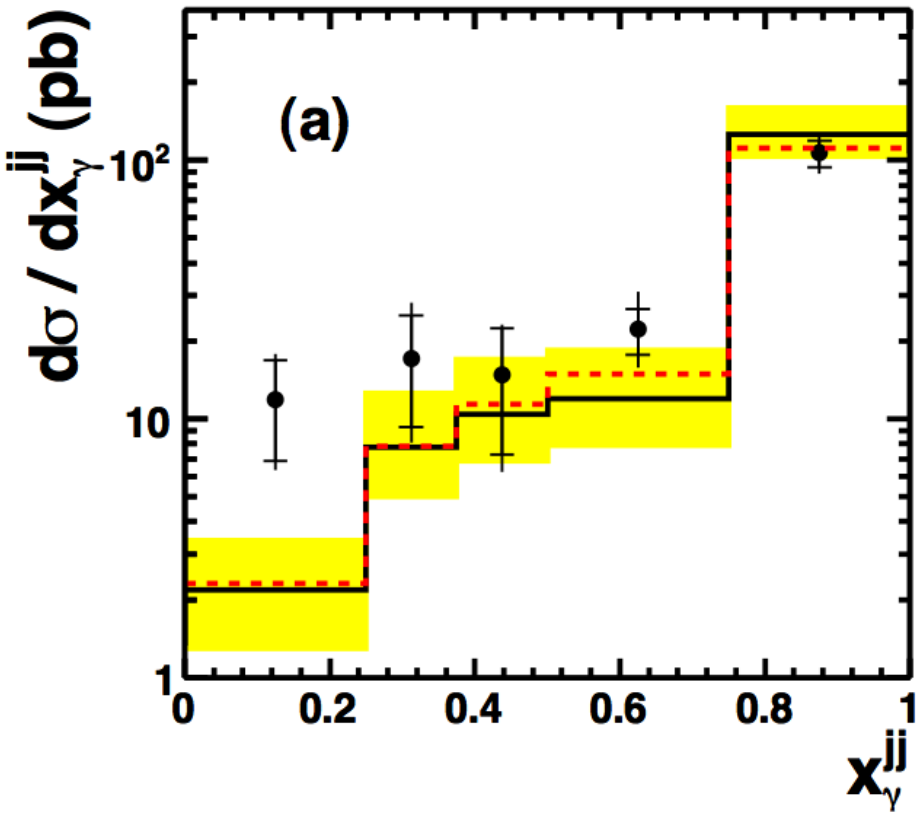




Low x_γ^{obs} region dominated by resolved-γ and multijet topologies

- $x_\gamma^{jet} = \Sigma_{j1,j2}(E - P_Z)/\Sigma_h(E - P_Z)$
- at LO QCD x_γ is the fraction of photon's energy entering the hard interaction
- x_γ^{obs} has been measured by most of the dijets analyses
- No serious discrepancy within the present data/theory description

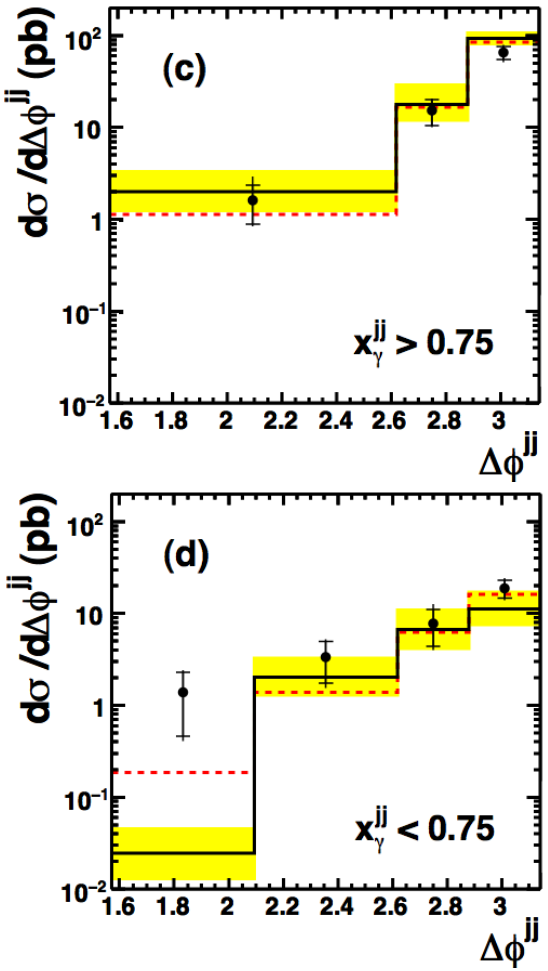




correlations

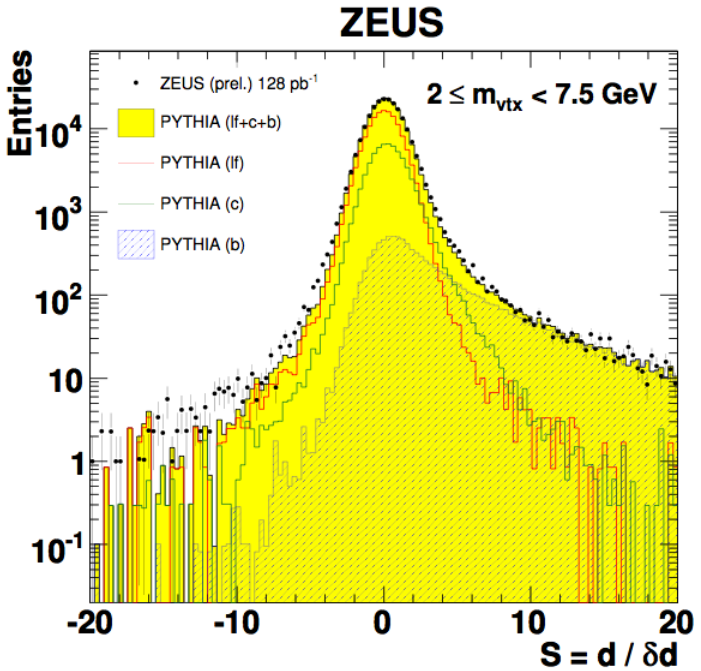
Dijet angular correlations particular sensitive to higher-order effects

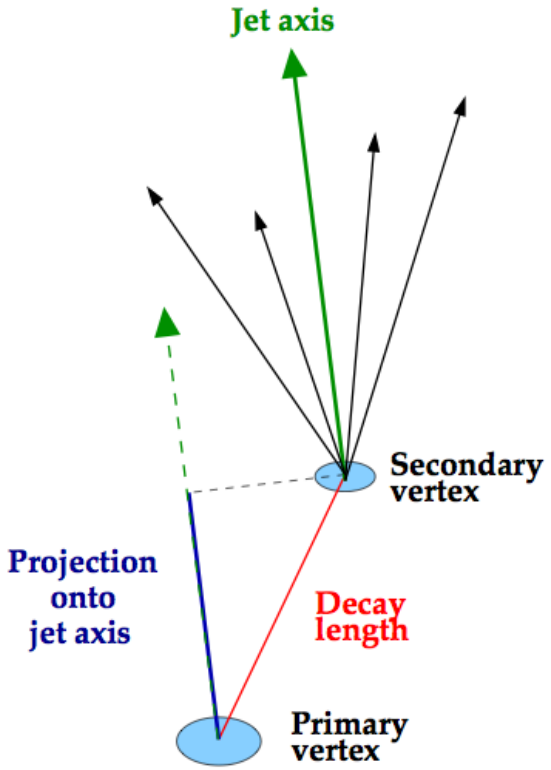
- At LO 2 jets in the event produced back-to-back ($\Delta\phi^{jj} = \pi$)
- additional soft-radiation $\rightarrow$ small azimuthal decorrelation
- $\Delta\phi^{jj} << \pi \rightarrow$ additional hard radiation
- previous ZEUS measurements with inclusive jets (Nucl. Phys. B 729 492 (2005), Phys. Rev. D 76 072011 (2007)) and charm PHP (Phys. Lett. B 565 87 (2003)) $\rightarrow$ deviations from NLO QCD found (especially at low $\Delta\phi^{jj}$)
- for beauty NLO QCD agrees well with measurements



lifetime tagging

- Inclusive sample, no lepton request (DIS2009: ZEUS-prel-09-005)
- fraction of b extracted from decay lenght significance $(S = \frac{\delta}{\sigma(\delta)})$ after reconstructing the decay vertices of B hadrons
- invariant mass of the decay vertices (m_{vtx}) used to distinguish beauty-enriched regions
- advantage: higher statistics and purity w.r.t. D^* or lepton analysis

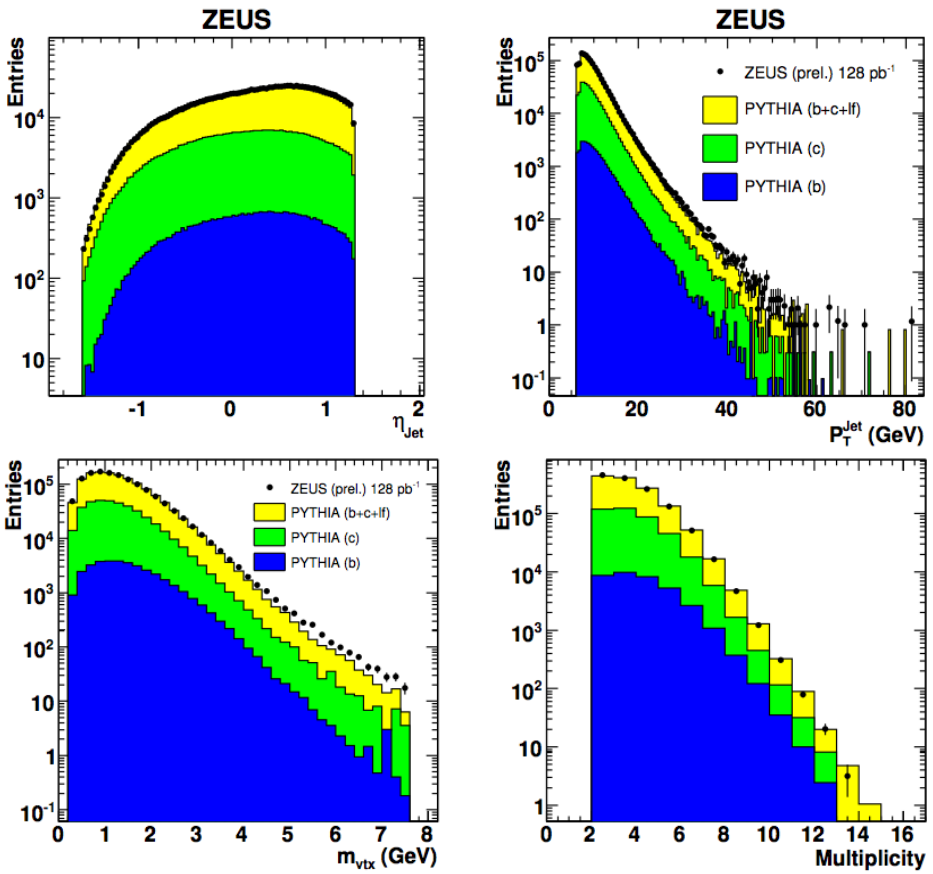




lifetime tagging

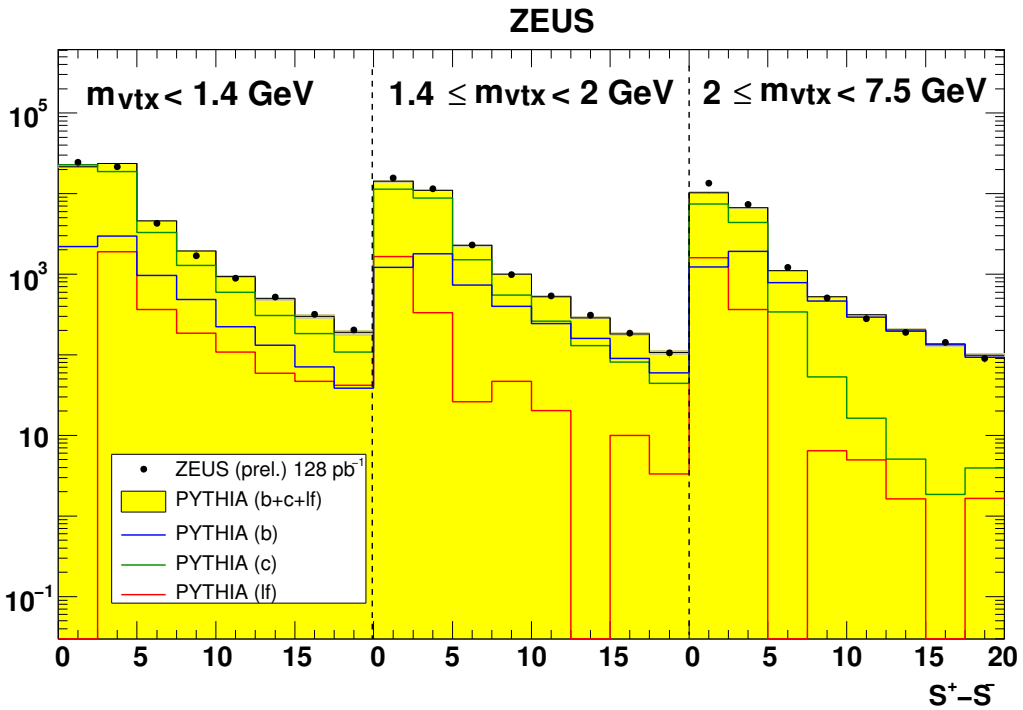
06-07 $e^{\pm}p$ data: $\mathcal{L} = 128\ pb^{-1}$

- PHP selection: veto on scattered $e^{\pm}$, $0.2 < y_{JB} < 0.8$
- Jets: k_T clustering (massive), $N_{jets} >= 2$, p_t >7(6) GeV, $|\eta| < 2.5$
- track selection: $p_t > 0.5$ GeV
- if ≥ 2 tracks associated to a jet $\longrightarrow$ secondary vertex is fitted
- $-1.6 < \eta_{jet} < 1.3$ for vertex-tagged jet



lifetime tagging

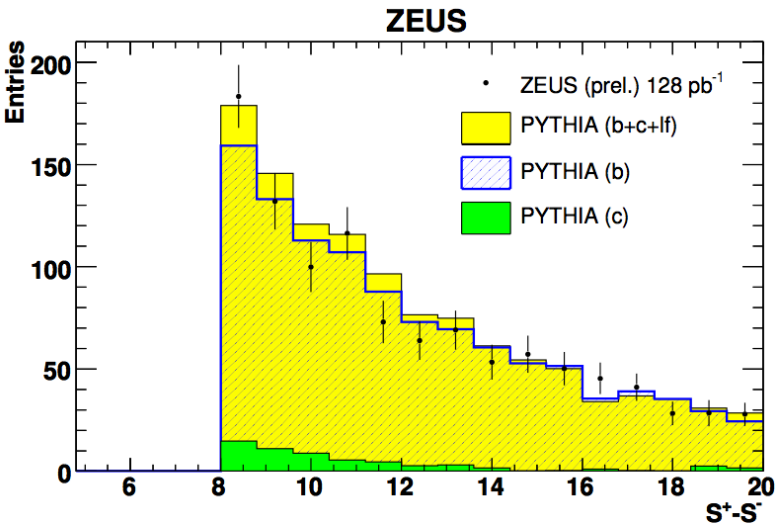
- decay length significance divided in 3 mass bins
- since tails not yet fully described mirrored distribution fitted (reduce systematic effects)
- simultaneous fit over 3 mass bins to extract *b* , *c* and *lf* contributions

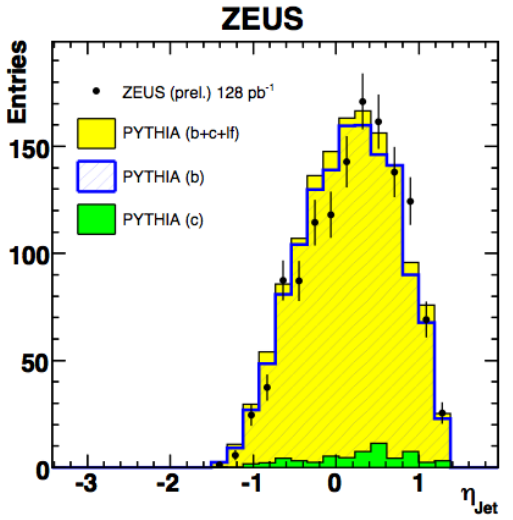


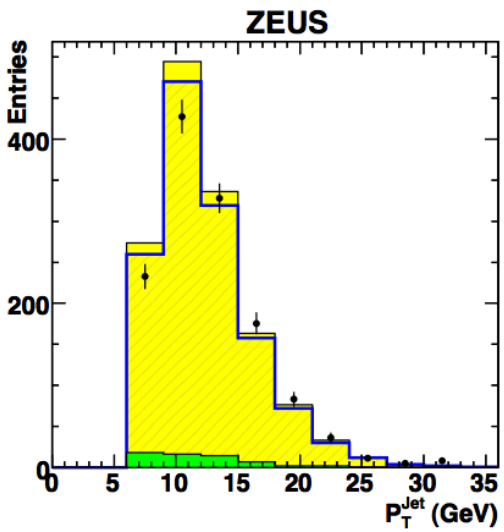
Control plots of beauty-enriched region

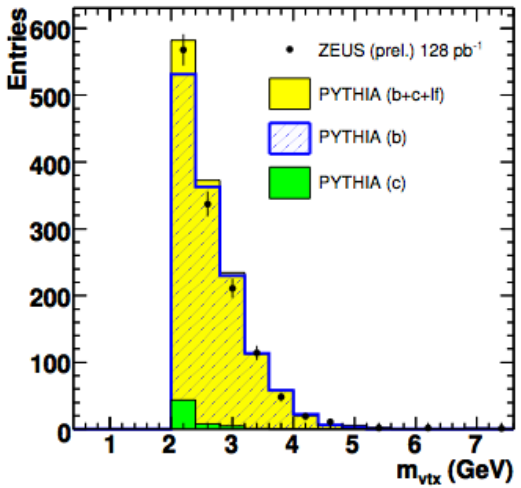
Possibility to select an almost pure beauty sample

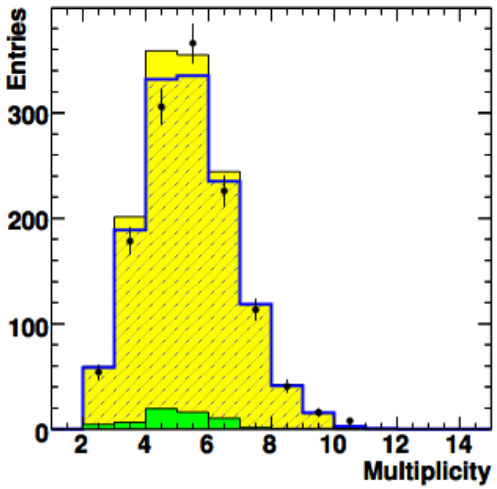
- m_{vtx} >2 GeV
- $S^+ - S^- > 8$











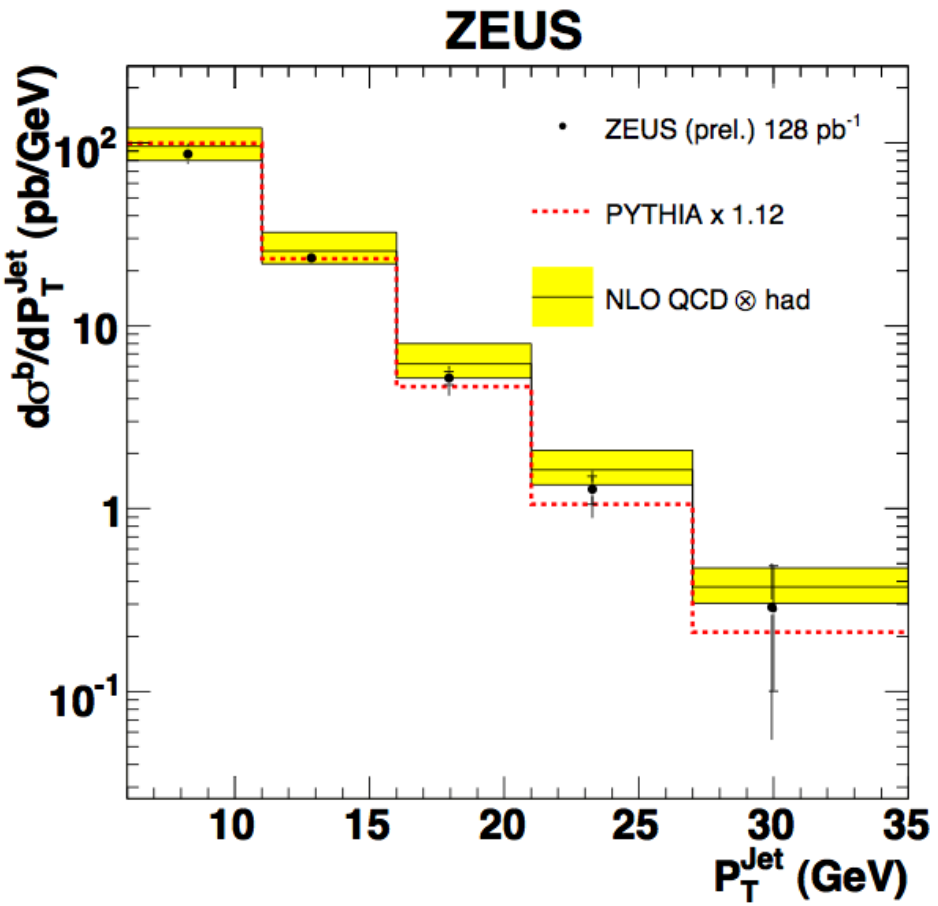
lifetime tagging

FMNR NLO QCD predictions:

- $\mu = \frac{\mu_0}{2}, \frac{\mu_0}{4} < \mu < \mu_0$
- $m_b = 4.75$ GeV, 4.5 GeV$< m_b <$ 5 GeV
- PDF(P) = CTEQ5, PDF(γ) = GRVG-HO
- $\epsilon_b = 0.0035$

Results:

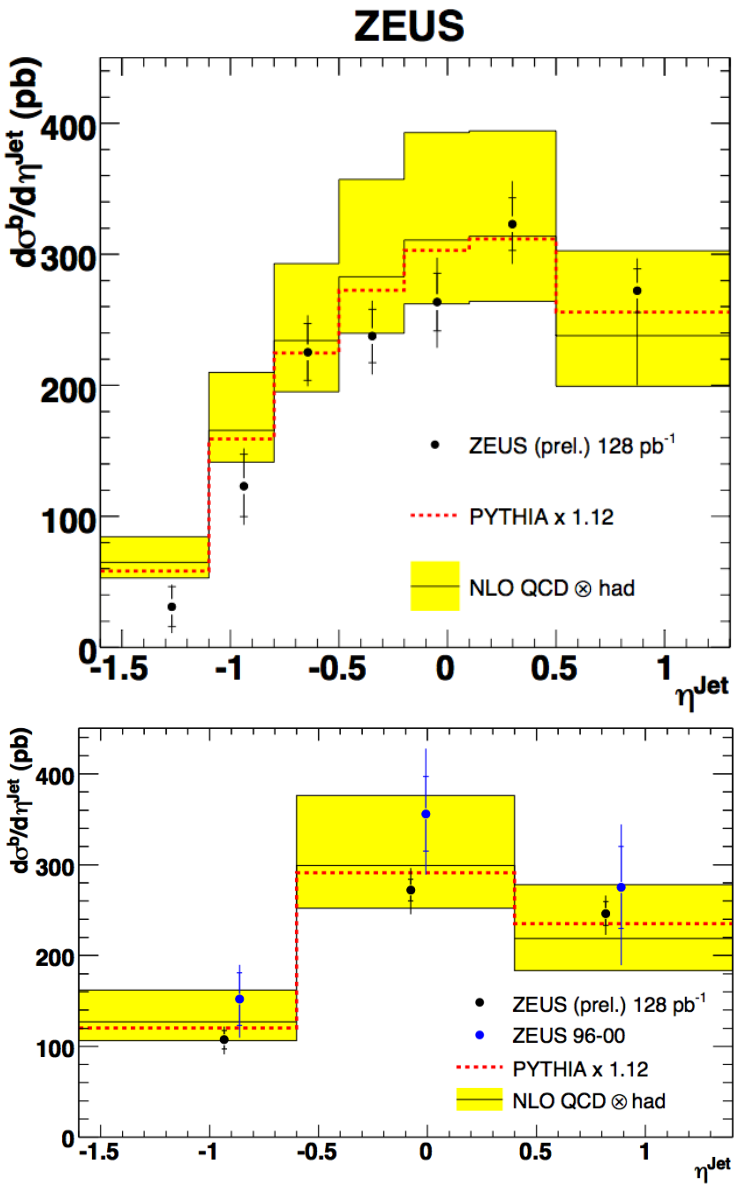
- Good agreement with NLO QCD



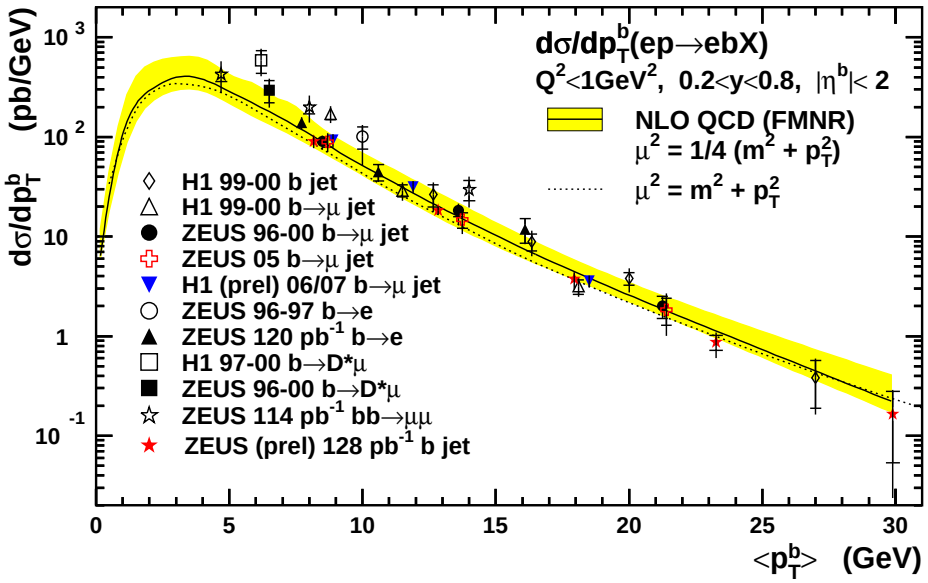
lifetime tagging

Results:

- Good agreement with NLO QCD
- agreement within the errors with previous HERA I results (DESY-03-212)
- completely different tagging technique, much smaller errors!

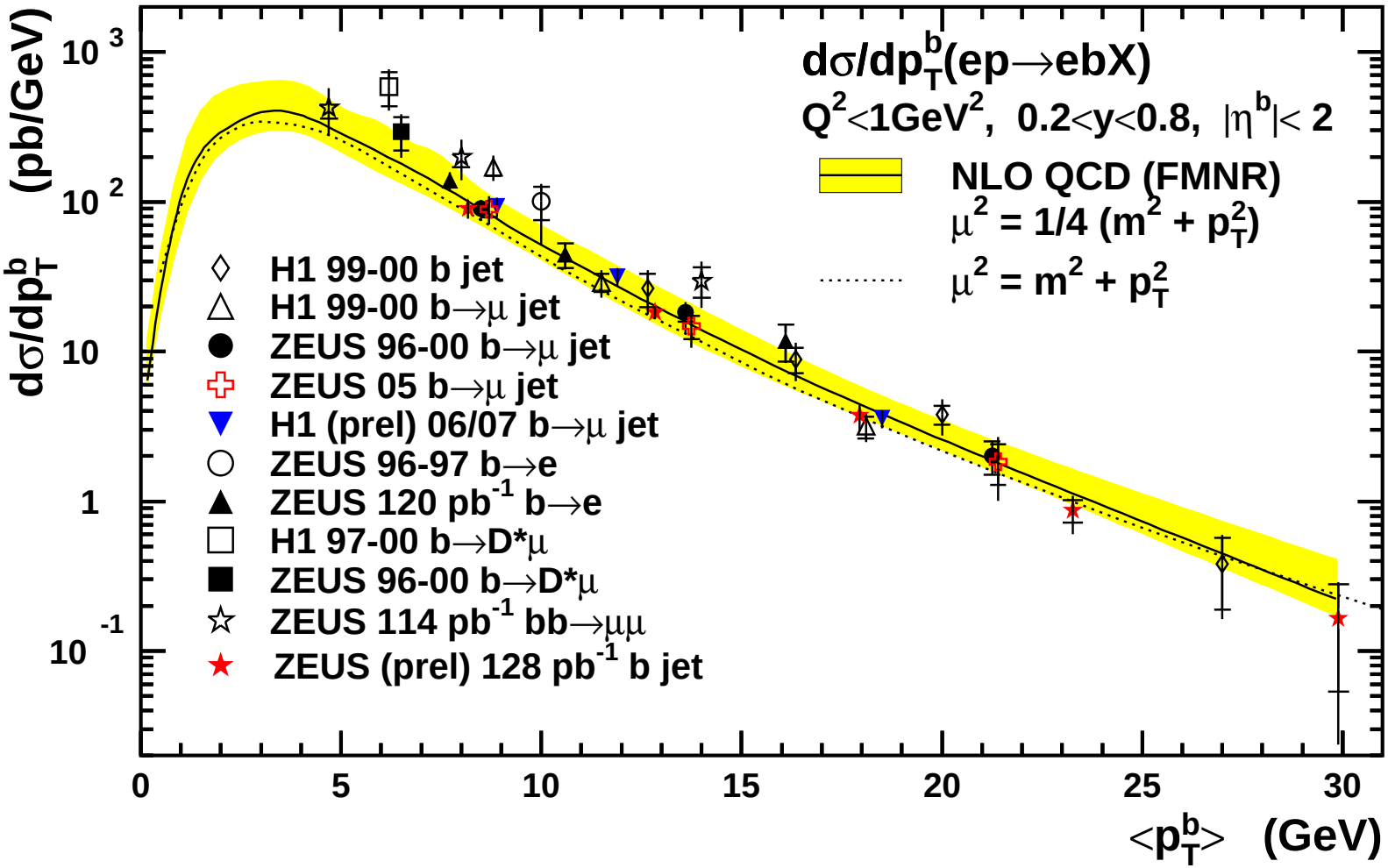


HERA



- Results obtained with different methods and by different experiments in good agreement
- New scale choice (A. Geiser DIS 2007). Older central value $\mu = \mu_0$
- More precise theory needed

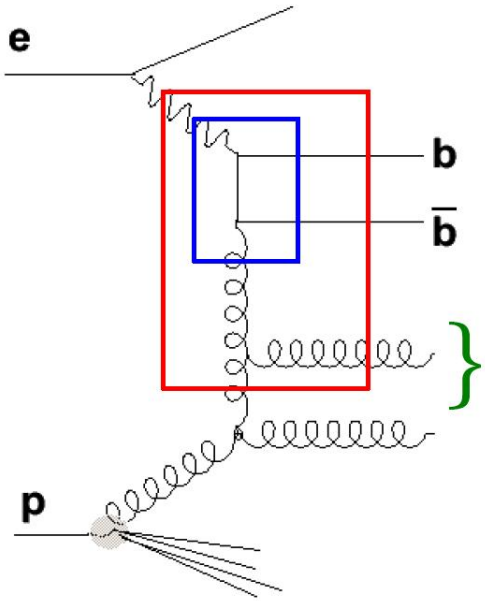
HERA


dσ/dp$_T^b$(ep→ebX)
Q^2<1GeV^2, 0.2<y<0.8, |η^b|< 2
NLO QCD (FMNR)
μ^2 = 1/4 (m^2 + p$_T^2$)
μ^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
dσ/dp$_T^b$ (pb/GeV)
<p$_T^b$> (GeV)
10^3
10^2
10
1
10^{-1}
0
5
10
15
20
25
30

Summary

- first ZEUS dijet inclusive measurement of beauty has been presented
- many new beauty measurements became available. Results in agreement with NLO QCD and between them.
- experimental precision comparable or better than theory

- HERA II data are still being analysed. More precise and interesting measurements to come...



Prediction:		Describes:
LO+**PS**: PYTHIA, HERWIG	(DGLAP)	γp
RAPGAP	(DGLAP)	DIS
CASCADE	(CCFM)	γp&DIS
NLO: FMNR		γp
HVQDIS		DIS

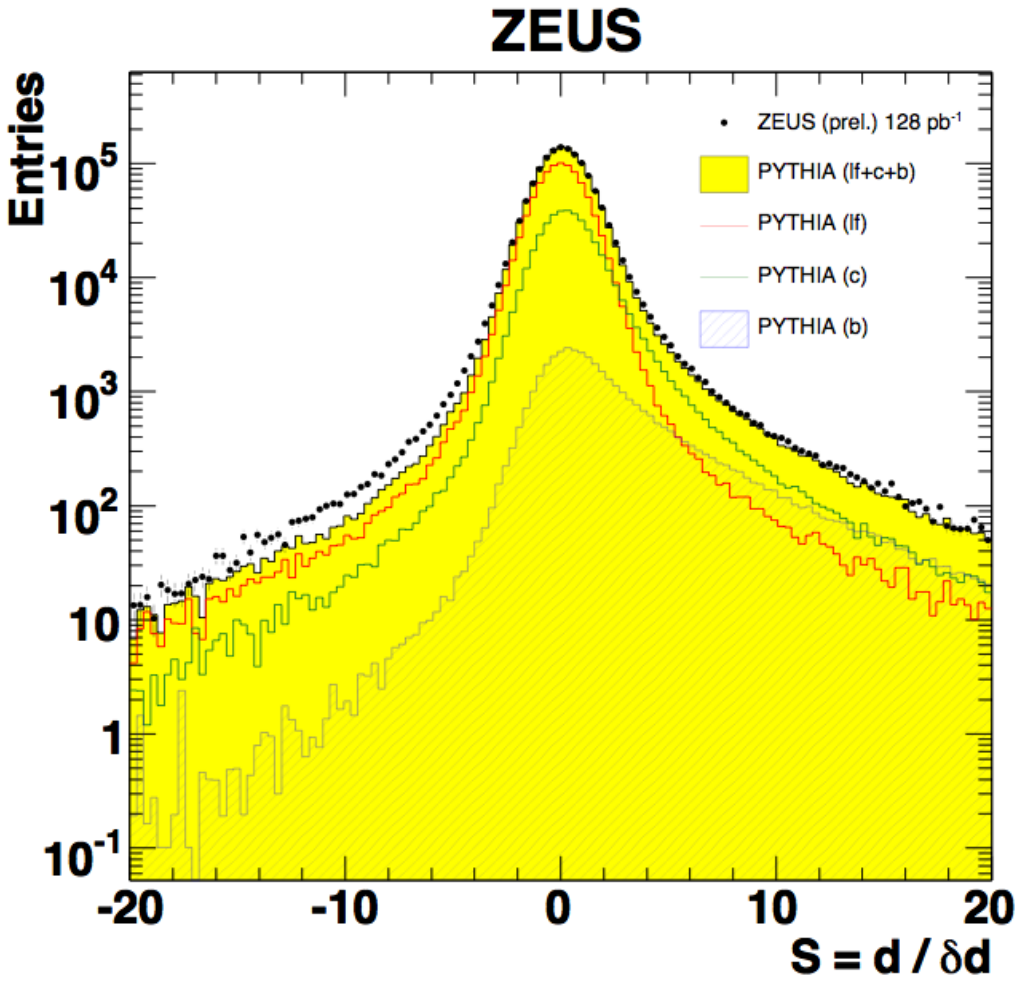
MONTE CARLO

- leading order + parton shower models available, including flavour excitation, DGLAP evolution (PYTHIA, HERWIG)
- CCFM evolution with k_t factorisation (CASCADE)

THEORETICAL CALCULATIONS

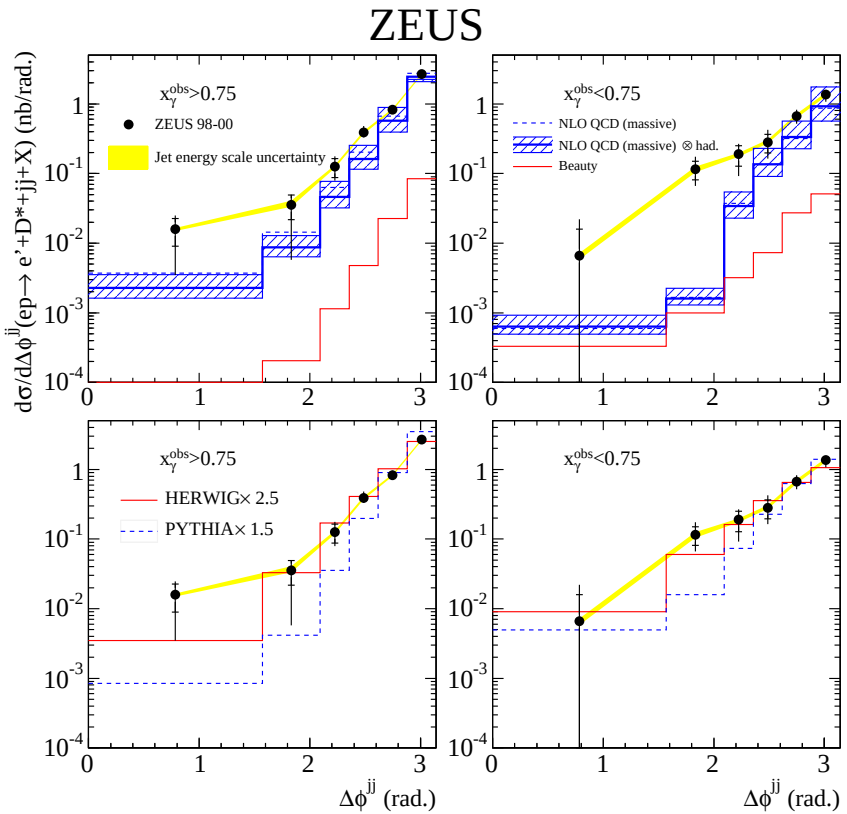
- full NLO calculation (FMNR, HVQDIS) available
- massive scheme FFNS (heavy quark dynamically generated in the hard process)

Inclusive vertex significance:



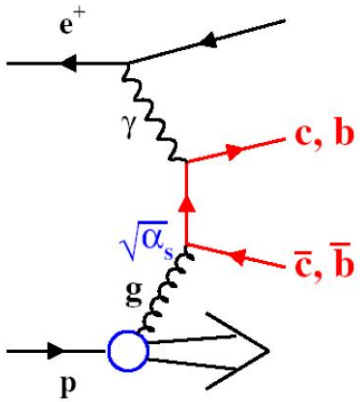
Systematics for inclusive jet+vtx measurement

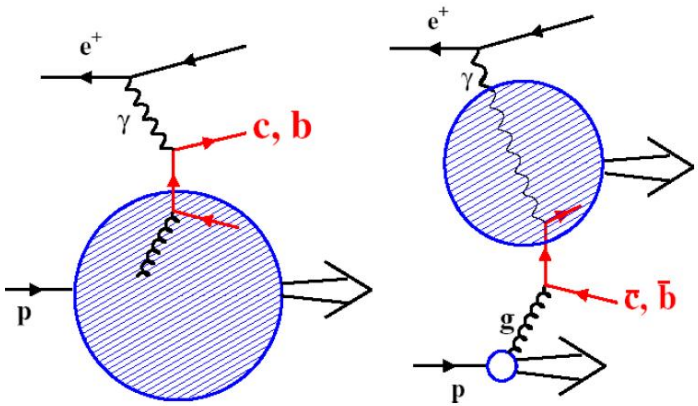
- Luminosity
- MVD hit efficiency
- CAL hadronic energy scale
- Variation of the fit range
- P_T^{jet} and η^{jet} reweighting
- Uncertainty of HFL5 trigger efficiency
- Decay lenght smearing $\leftarrow$ DOMINANT!



- ZEUS PHP dijets correlations

backup





massive scheme

- c, b massive
- neglects terms $(\alpha_s \ln(Q^2/m^2_{c,b,}))^n$
- scales m_b, m_c

$\longrightarrow$c, b produce perturbatively (not part of the photon or proton)

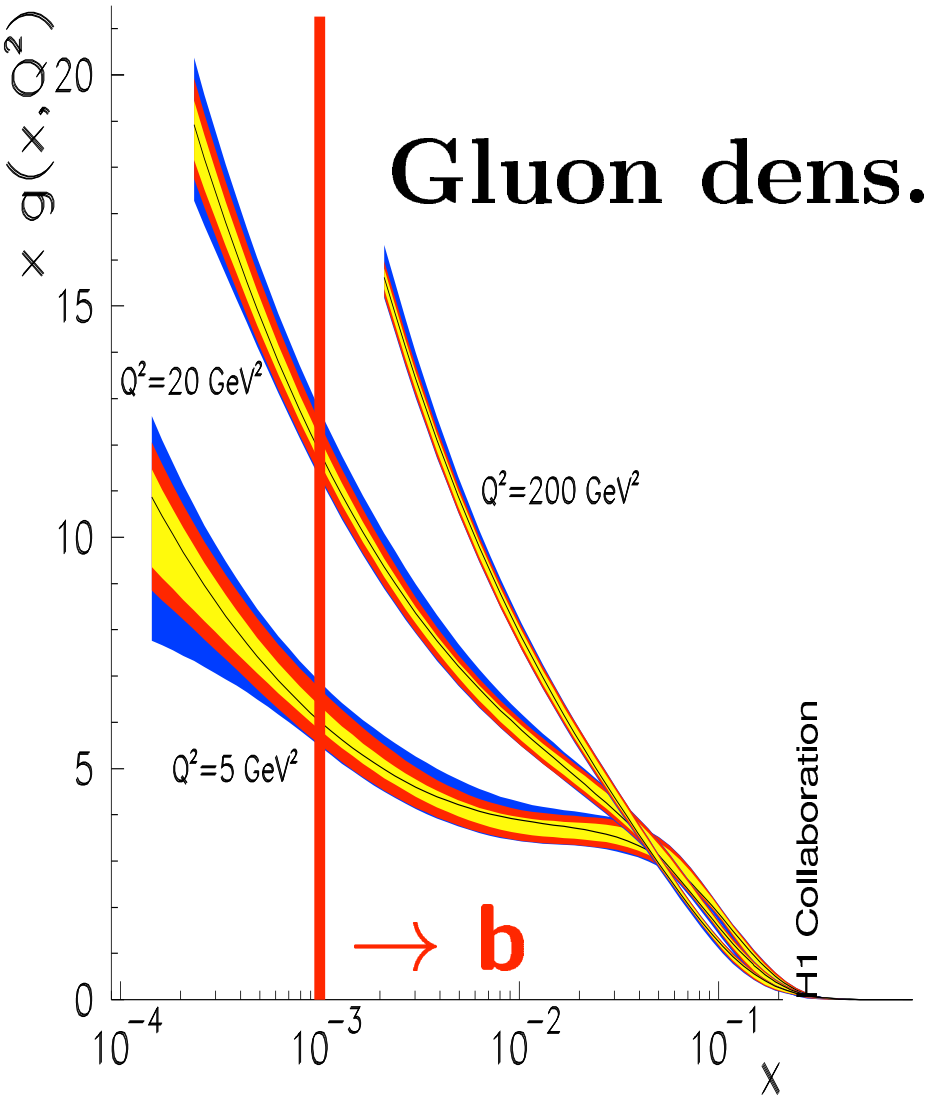
massless scheme

- c, b massless
- resums terms $(\alpha_s \ln(Q^2/m^2_{c,b,}))^n$
- scales Q^2, p_t

$\longrightarrow$c, b also in proton and photon

variable flavour number scheme

- massive at small Q^2
- massless at large Q^2



main reason for beauty suppression: phase-space factor

- kinematic threshold for b production due to its mass
- $x_g \geq \frac{m_Q^2}{E_\gamma \times 920\ GeV}$ (x_g fraction of four-momentum of the proton carried by the gluon participating in the hard interaction)
- for charm $x_g \geq 10^{-4}$, for beauty $x_g \geq 10^{-3}$