b production via a double muon tag at HERA

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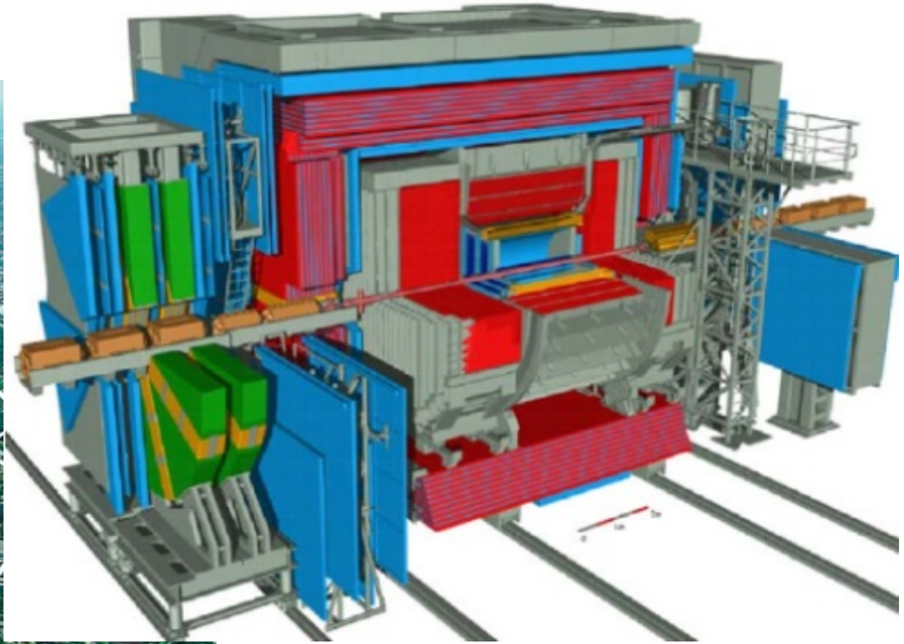
on behalf of the ZEUS Collaboration

Diffraction and Low-x, Reggio Calabria, 26 August-1 September 2018

The world's only electron/positron-proton collider

- E_e = 27.6 GeV, E_p = 920 GeV (820, 460, 575 GeV)



ZEUS

Coverage for tracking det.:
Inner tracker 15<θ<150
Muon chambers 5<θ<171

- total luminosity ~ 0.5 fb^{-1} per experiment

Motivation - ep → b$\bar{b}$ X → μμX

Production of b$\bar{b}$ pairs is governed by perturbative QCD at all transverse momentum values, owing to mass of b quark; stringent test for pQCD models.

ep → epb$\bar{b}$ X investigated at HERA, data of H1 and ZEUS combined

See talk next Thursday 30/8, at 9:00 by Uri Karshon "*Combination and QCD analysis of beauty and charm production cross section measurements in deep inelastic ep scattering at HERA*"

In this analysis, ep → epb$\bar{b}$ X →μμX' ,events with two identified muons are used (no requirements on jets) allowing to explore b quarks of low p_T.

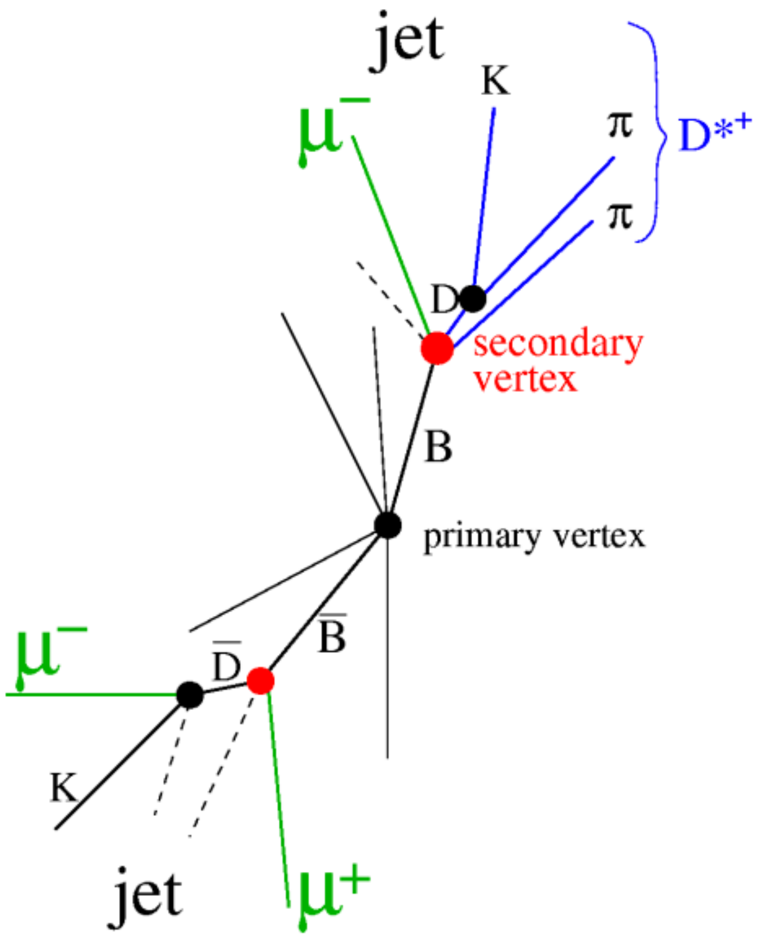
Photoproduction ($Q^2 < 1.0$ GeV^2) and DIS ($Q^2 > 1.0$ GeV^2) are included together in this analysis

Previous paper used HERA I data (1992-2000), published in ZEUS Coll., JHEP 02 (2009) 032

This study uses HERA II data (2003-2007), factor of 3 times luminosity of previous HERA I results, and improved tracking, as MicroVertex installed in HERA II

Signal and Background - ep → $b\bar{b}$ X → μμX

Events $b\bar{b}$ are selected with **2 identified muons** from the B decay itself or from later D decay



Signal:

I. 2 muons from from different b quarks of a bb pair, of like or unlike sign charge, in opposite hemisphere, large $m_{\mu\mu}$

II. 2 muons from same b via the chain b → cμX → sμμX' , of opposite charge, in same hemisphere, low $m_{\mu\mu}$

Background: muon from

- open charm decays not originating from b-quarks
- quarkonium states (J/ψ, ψ', Y ..) and from γγ (Bethe-Hitler), produced in elastic or inelastic collisions
- "false muons", not from hard interaction or misidentified produced by hadron showers

Signal extraction - ep → bb̄ X → μμX

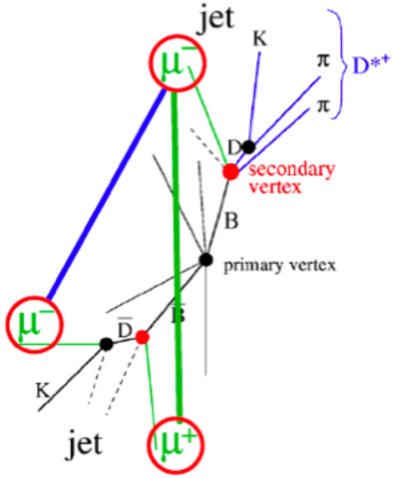
Events are selected with **2 identified muons**. They may be **like sign** or **unlike sign**

Background: contributions of like- and unlike sign dimuon are almost equal

Signal: beauty production is only source of genuine like sign muon

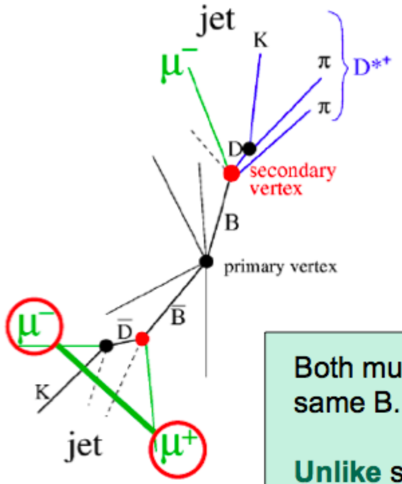
Strategy: signal extracted from the difference between unlike- and like sign samples

$$N_{b\bar{b}\to\mu\mu} = \left(N^{\mathrm{u}}_{\mathrm{data}} - N^{\mathrm{l}}_{\mathrm{data}} - (N_{\mathrm{charm}} + N_{\mathrm{VM}} + N_{\mathrm{BH}})\right) \times \left(\frac{N^{\mathrm{u}}_{b\bar{b}} + N^{\mathrm{l}}_{b\bar{b}}}{N^{\mathrm{u}}_{b\bar{b}} - N^{\mathrm{l}}_{b\bar{b}}}\right)^{\mathrm{MC}}$$



Muons from different B's..

Like or **unlike** sign



Both muons from same B.

Unlike sign.

	Like sign	**Unlike sign**
Low mass	Light flavour Few μ from different B	J/ψ, ψ', light flavour μ from different B
High mass	Light flavour μ from different B	Y, Bethe-Heitler, light flavour μ from different B

Selection - ep → $b\bar{b}$ X → μμX

- HERA II data, 377 pb^{-1}
- Trigger: muon chambers or baking calorimeter or charmed mesons trigger or jets
- Standard ZEUS muon identification: vertex and muon timing consistent with ep interaction,

muon reconstructed in muon detectors matched to inner tracker, $-2.4<\eta^{\mu}<+3.0$

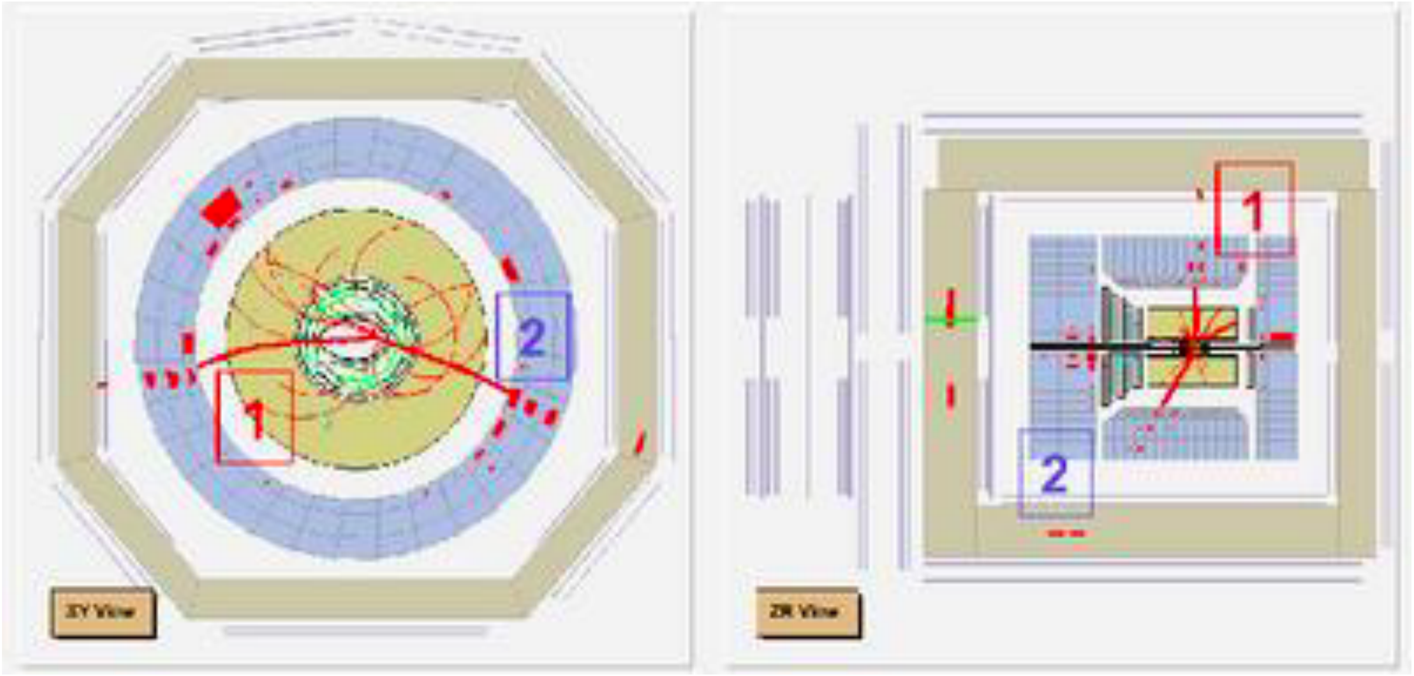
$p_T^{\mu}>1.5$ GeV ($p_T^{\mu}>0.75$ GeV for high quality muons)=> Efficiency of 80% for muons of 2-5 GeV p_T

- $m_{\mu\mu}>1.5$ GeV, to suppress events from light-meson decays
- muons pairs not isolated to suppress

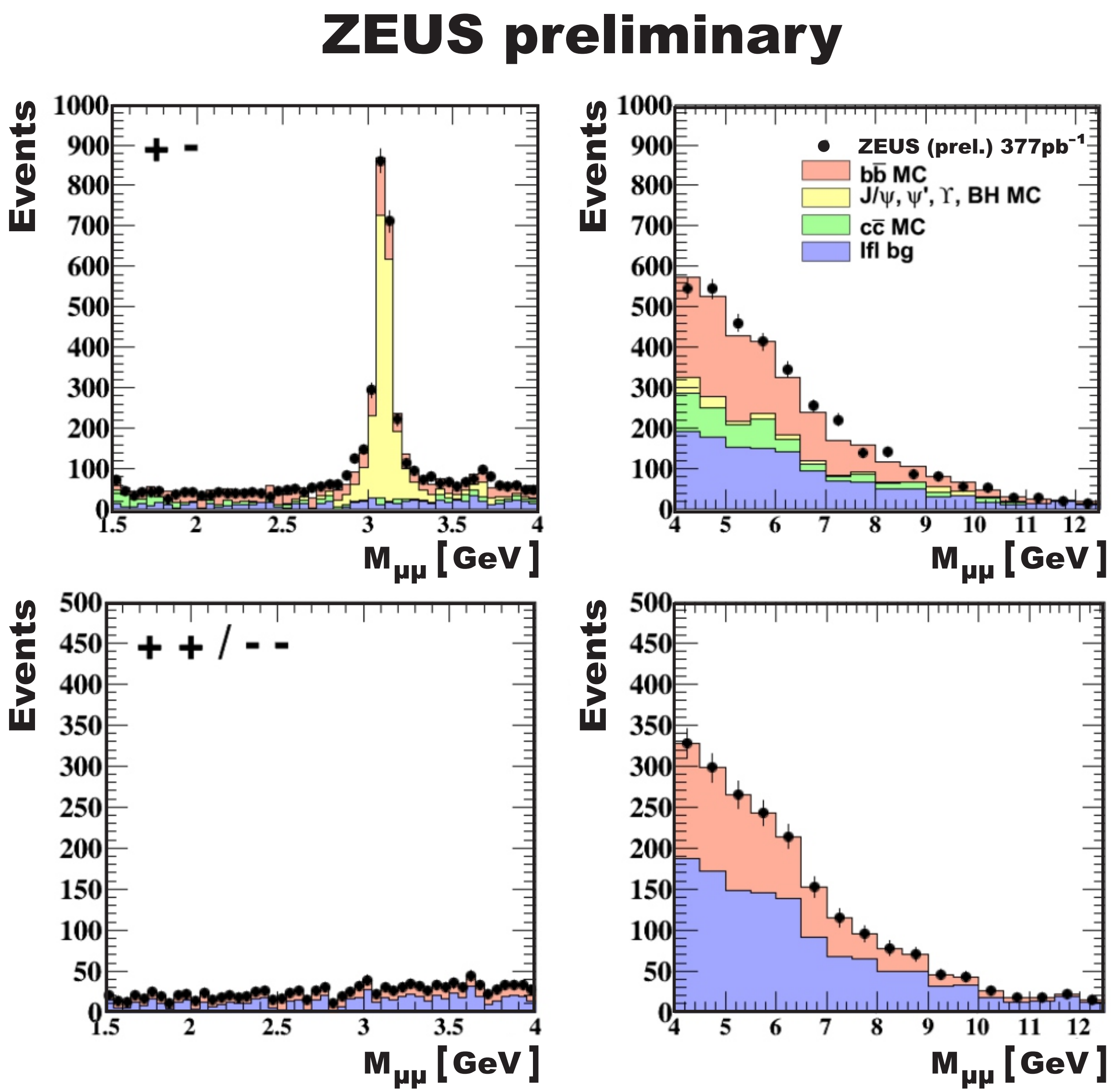
J/ψ and Bethe-Heitler processes

- total measured transverse energy (excluding scattered electron) $E_T> 8$ GeV to suppress false muon events and light flavour background

- additional cleaning cuts to remove specific background



$m_{\mu\mu}$- Monte Carlo comparison



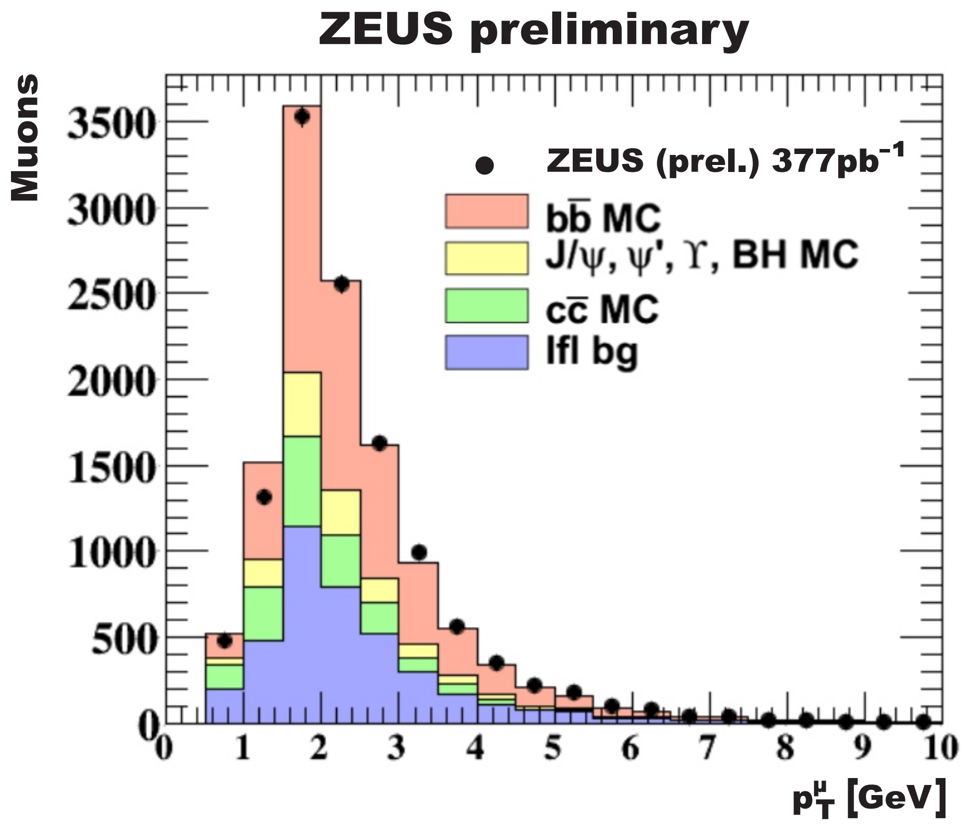
- Simulation of beauty and charm uses **PYTHIA** (Photoproduction) and **RAPGAP** (DIS), fragmentation uses the Lund string model
- Inelastic quarkonium uses **HERWIG**
- Exclusive Bethe-Heitler and quarkonium uses **GRAPE**

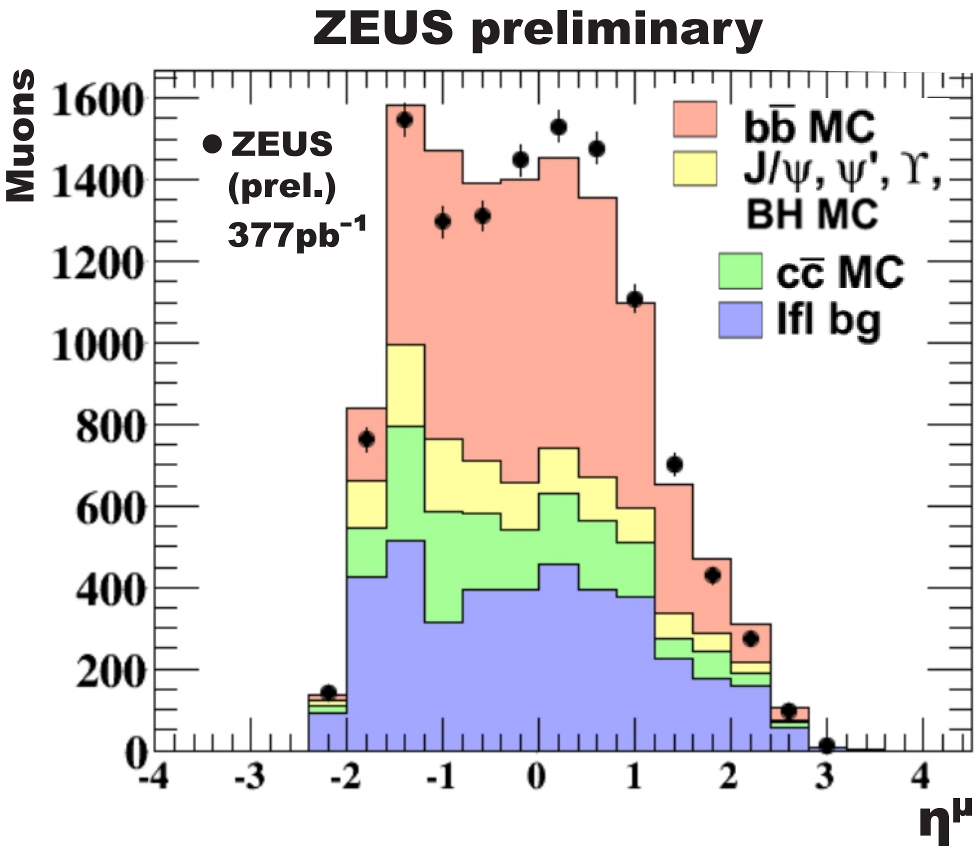
Leading order parton-level QCD matrix elements. Some higher orders are modelled by initial/final state leading-log parton showers

MC normalised to data

	unlike-sign $\pm/\mp$	like-sign $++/--$
low inv. mass $m_{\mu\mu} < 4$ GeV	**muons from same b,** muons from J/ψ, ψ', and false-muon background	**false-muon background,** and small contribution of muons from different b
high inv. mass $m_{\mu\mu} > 4$ GeV	**muons from different b,** muons from $c\bar{c}$, Υ, BH, and false-muon background	**muons from different b** and false-muon background

Muon distributions at detector level for unlike-sign events





Charm contribution normalised to ZEUS measurement
light-flavour ("false muon") background is not simulated but obtained from the like-sign events, with other contributions subtracted out.

Visible cross sections for single muons

σ estimated taking the difference N(unlike sign) – N(like sign)

$$N_{b\bar{b}\to\mu\mu} = (N^{\mathrm{u}}_{\mathrm{data}} - \alpha_{\mathrm{corr}} \cdot N^{\mathrm{l}}_{\mathrm{data}} - (N_{\mathrm{charm}} + N_{\mathrm{VM}} + N_{\mathrm{BH}})) \times \left(\frac{N^{\mathrm{u}}_{b\bar{b}} + N^{\mathrm{l}}_{b\bar{b}}}{N^{\mathrm{u}}_{b\bar{b}} - \alpha_{\mathrm{corr}} \cdot N^{\mathrm{l}}_{b\bar{b}}} \right)^{\mathrm{MC}}$$

Backgrounds from charm, J/ψ and Bethe- Heitler subtracted using MC, charm contribution normalised to ZEUS measurement, false-muon backgrounds cancel out. An acceptance factor then converts to the full B cross section.

Visible cross section estimated in kinematic range:

- $-2.2 < \eta < 2.5$ for both muons
- $p_T > 1.5$ GeV for one of the two muons, and for the second muon:
  for $\eta < 0.6$: $p > 1.8$ GeV and $p_T > 0.75$ GeV, for $\eta > 0.6$: $p > 2.5$ GeV or $p_T > 1.5$ GeV

This σ includes muons from direct and indirect B decays. If >2 such muons in an MC event, the muons directly from B decay have priority, muons from kaon and pion decay are not included

Data: $\sigma_{vis}(ep \to bbX \to \mu\mu X) = 43 \pm 3(\mathrm{stat})^{+13}_{-11}(\mathrm{syst})$ pb

Prediction FMNR⊗Pythia NLO: $\sigma_{vis}^{NLO} = 33^{+18}_{-8}\ (\mathrm{NLO})^{+5}_{-3}(\mathrm{frag} \oplus \mathrm{br})$ pb

FMNR at parton level linked to PYTHIA (for photoproduction + Weizsacher-Williams for DIS).

For DIS (15% of the σ) predictions in agreement with **HVQDIS**(at parton level only)

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Total beauty cross sections:

The effective branching ratio for a bb pair into ≥2 muons is 6.3%
The probability for such a muon pair to be in our defined “visible” kinematic range is ≈6%
Acceptance is quite constant within the rapidity of this analysis, covering at 90% of total bb phase space, and drops at larger rapidities

Large extrapolation, almost entirely dominated by factors measured with high precision at e^+e^- colliders (branching fractions, b-fragmentation functions, B→ μX spectra)
=> MC used to extrapolate σ

Data: $\sigma_{tot}(ep \rightarrow bbX) = 11.4 \pm 0.8(stat.) + 3.5 - 2.9(syst.)$ nb,

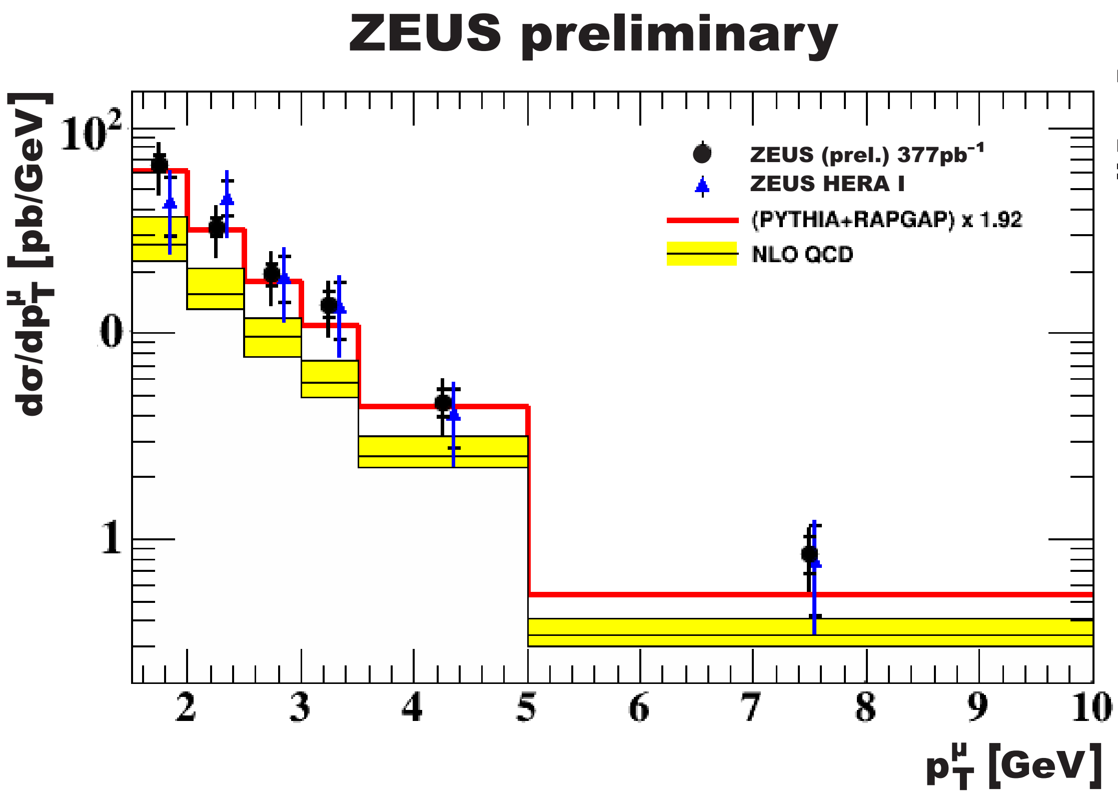
Systematic uncertainties are from muon reconstruction efficiency, normalisation of charm and other backgrounds, various modelling uncertainties.

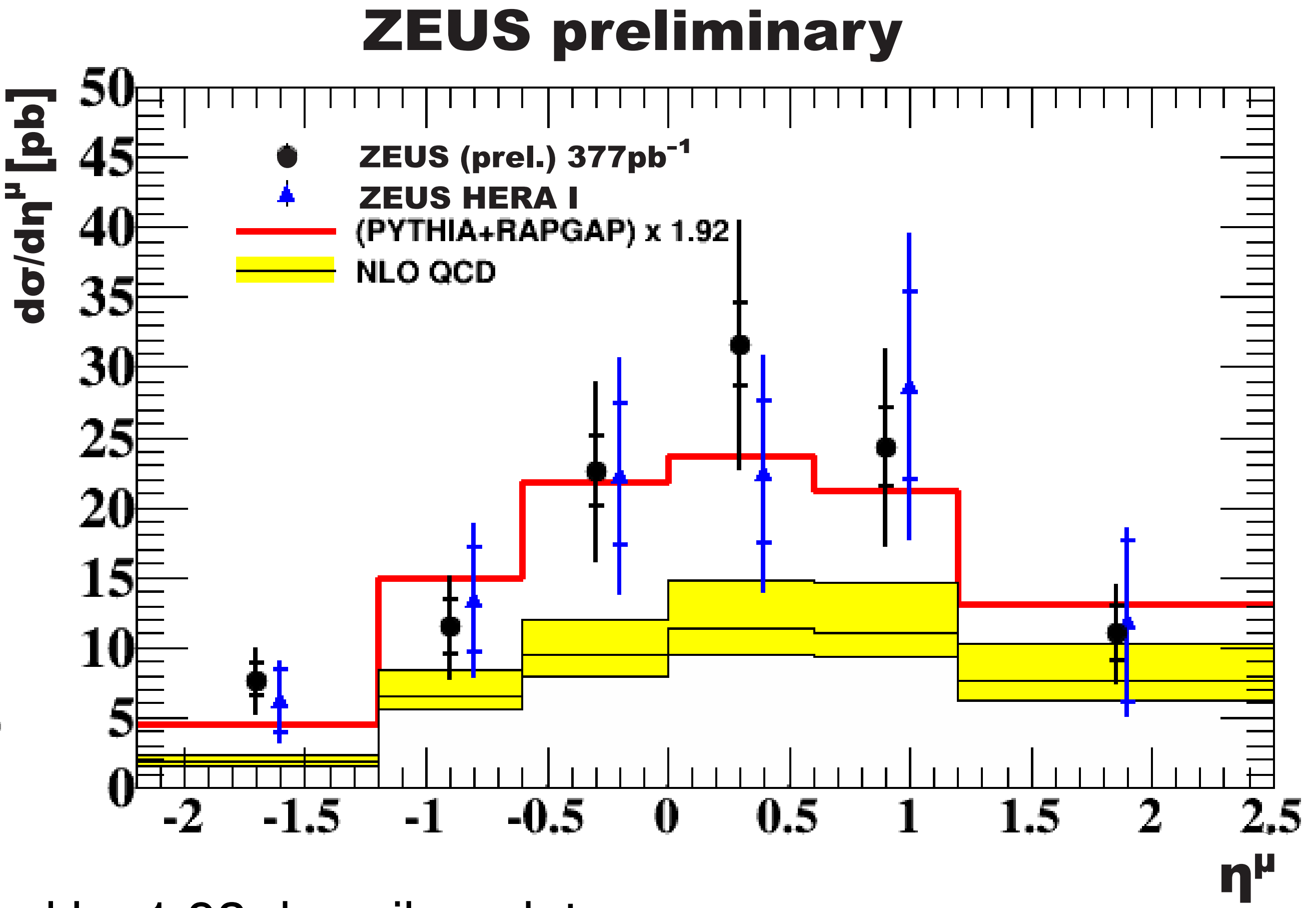
The NLO theory calculation at sqrt(s) = 318 GeV are higher but consistent

$\sigma^{NLO}{}_{tot}\ (ep \rightarrow bbX) = 7.5^{+4.5}_{-2.1}$ nb

NLO theory uncertainty: b quark mass and factorisation/renormalisation scales

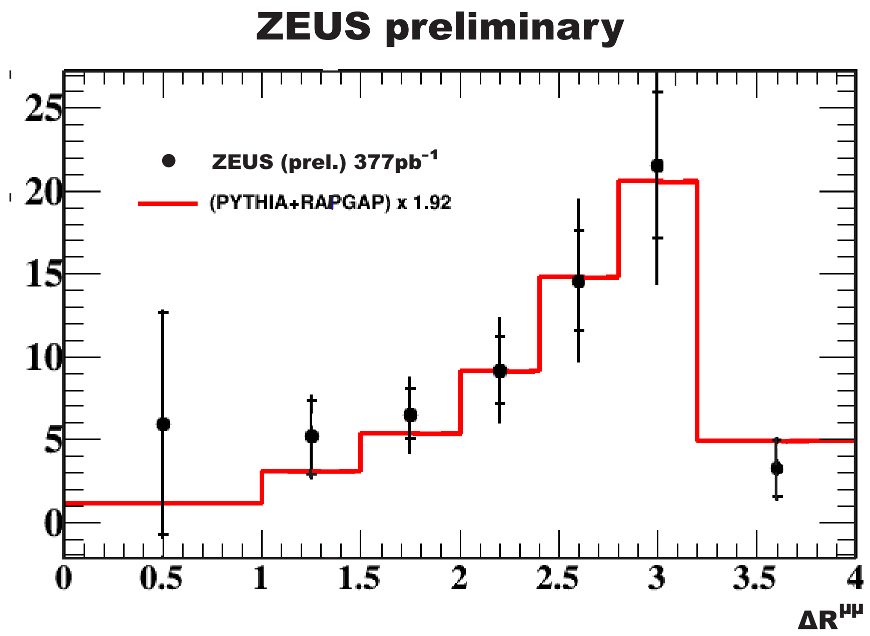
Differential cross sections vs p_T and η

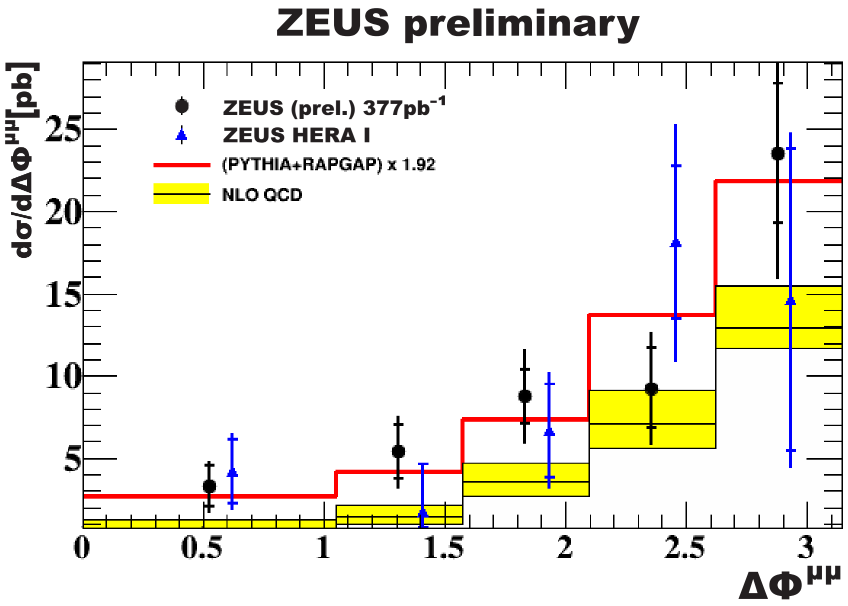




MC Pythia+RAPGAP (MC at LO+PS) scaled by 1.92 describes data

Shape of NLO predictions in agreement with data





Differential σ vs distance between muon pairs

Δϕ and ΔR =sqrt $(\Delta\phi^2 + \Delta\eta^2)$

Diff σ measured in kin. range for both muons:
$p^{\mu}_{T} > 1.5$ GeV and $-2.2 < \eta_{\mu} < 2.5$
Signal extracted bin by bin

- Agreement with previous measurent
- Data described Pythia+RAPGAP (MC at LO+PS) scaled by 1.92
- NLO QCD predictions FMNR⊗Pythia describes Δϕ distribution well but somewhat low

Summary

ZEUS at have measured events with two muons in the full HERA II data set
ZEUS-prel-18-006, June 2018

- The differential cross sections for bb production decaying into two muons, over the full photoproduction/DIS range was measured

$$\sigma_{vis}(ep \rightarrow bbX \rightarrow \mu\mu X) = 43 \pm 3(stat)^{+13}_{-11}(syst)\ pb$$

- Also the total cross section for ep → bb X is evaluated.

$$\sigma_{tot}(ep \rightarrow bbX) = 11.4 \pm 0.8(stat.) + 3.5 - 2.9(syst.)\ nb$$

- The shapes of the differential cross sections agree well with those of a RAPGAP/PYTHIA model and a FONLL/HGVDIS NLO model. However the NLO cross sections are somewhat low.

channel	effective branching fraction w/o $B^0\bar{B}^0$ mixing
$b \to \mu^-$ direct	10.95 ± 0.27 %
$b \to \mu^+$ indirect	8.27 ± 0.40 %
$b \to \mu^-$ indirect	2.21 ± 0.50 %
all $b \to \mu^\pm$	21.43 ± 0.70 %
$b\bar{b} \to \mu^\pm\mu^\mp$ (diff. bs)	2.42 ± 0.17 %
$b\bar{b} \to \mu^\pm\mu^\pm$ (diff. bs)	2.18 ± 0.14 %
$b \to \mu^+\mu^-$ all	2.40 ± 0.16 %

Table 1: *Effective branching fractions used for cross-section determinations. The indirect contributions include cascade decays into muons via charm, anticharm, $\tau^\pm$ and J/ψ. The additional effect of $B^0\bar{B}^0$ mixing ($\chi = 0.1283 \pm 0.0076$) is not included here and accounted for separately.*