Measurement of the total and differential b cross sections at HERA

ZAF meeting

N. Stefaniuk, supervisor : A. Geiser

Outline:

- introduction
- event selection and reconstruction
- secondary vertex study
- cross section results

Analysis introduction

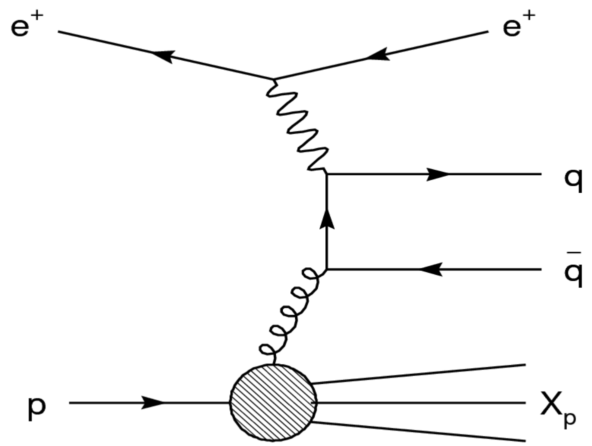
- This study is based on ZEUS paper from 2008 (DESY–08–129)
  - HERA I data

- Based on the paper Danny Bot has finished his PhD (2011)
  - HERA II data
  - Started vertex study
  - Instanton study

- My work (2013-2014)
  - HERA II data
  - Including secondary vertex information

Analysis introduction

Measurement of the beauty quark production determined via process: $ep \rightarrow e'b\bar{b}X \rightarrow e'\mu\mu X$

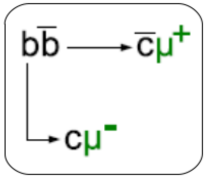


Sources of muon pairs in ep collisions on the beauty signal:

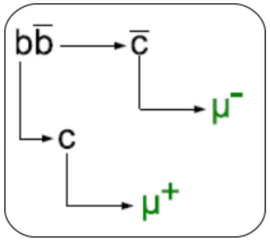
- signal from direct decay of b-quark
- from cascade decay $b \rightarrow c \rightarrow s\mu^+$

Dimuon signal can be obtained in four ways:

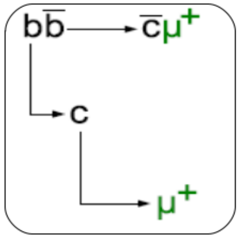
- both b-quarks decay into muons. The *unlike-sign* pair is obtained ..



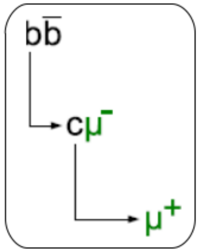
- both c-quarks from b-decays produce muon: unlike-sign pair ……………………



- one c-quark and one b-quark decays to muon: like-sign pair ……………………



- cascade decay of one b-quark into a muon and c-quark decay ……



+ small fraction of *like-sign* muons due to $B^0 - \bar{B}^0$ oscilations

Analysis steps

- applying selection criteria to data and MC samples
- signal and background contribution determination
  - **light flavour background**
  - **beauty and charm contribution**
  - **isolation criteria, J/Ψ, Ψ', BH contribution**
- checking of the control distributions
- comparing with the previous analysis
- decay length significance fit
  - **beauty and charm contribution**
  - **isolation criteria, J/Ψ, Ψ' normalisation recalculation**
- control distribution checks
- total and differential cross section calculations

Selection cuts

DATA:

V02e : 0304p, 05e, 06e, 0607. Total luminosity is $(376 \pm 6.5)\ pb^{-1}$

MC samples:

Inclusive Charm and Beauty (PYTHIA)

Inelastic J/ψ and ψ' (HERWIG), inelastic Υ (PYTHIA)

Elastic quarkonia – DIFFVM. BH processes – GRAPE

Event selection:

- Energy CAL: $E_T \geq 8$ GeV
- $|z_{vtx}| < 30$ cm
- $\sqrt{(x_{vtx}^2 + y_{vtx}^2)} < 3$ cm

Muon selection:

- $N_\mu \geq 2$
- $p_t^\mu > 0.75$ GeV ($\mu_{qual} \geq 5$) $p_t^\mu > 1.5$ GeV ($\mu_{qual} = 4$)
- Difference in η: $|\eta^{\mu 1} - \eta^{\mu 2}| < 3.0$
- Invariant mass: $m^{\mu\mu}_{inv} > 1.5$ GeV
- Muon E_T fraction cuts

Light flavour background contribution

Two hypotheses have been used:

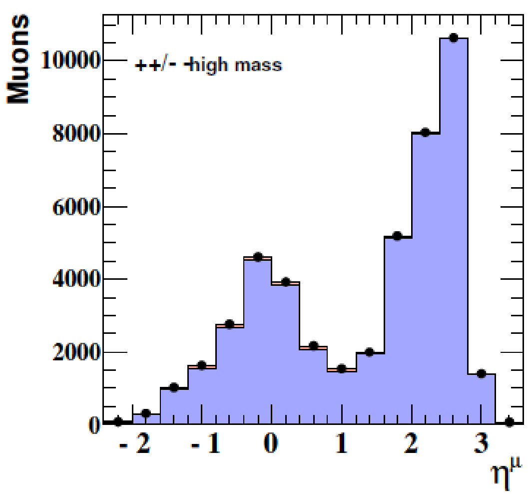
- Only beauty-quark decays can produce like-sign muon pairs, based on the Standard Model
- The light flavour background like- and unlike-sign muon mairs have no charge correlation

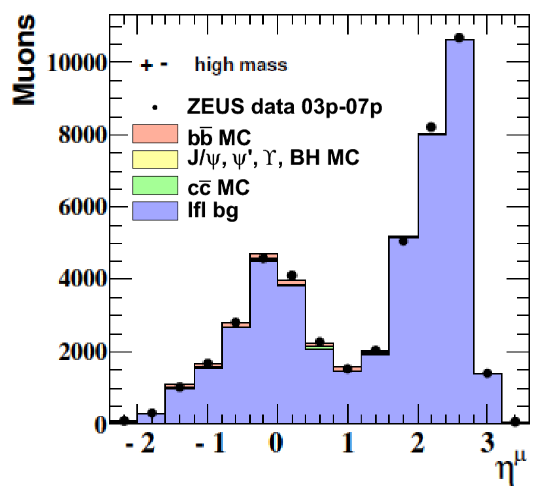
Unlike-sign dimuon data consist unlike-sign contributions of beauty, charm, VM, BH and lfl background:

$$N^u_{data} = N^u_b + N^u_c + N^u_{BH} + N^u_{VM} + N^u_{lfl}$$

Like-sign dimuon data consist only like-sign contribution of beauty and lfl background:

$$N^l_{data} = N^l_b + N^l_{lfl}$$





Unlike-sign dimuon data is well described by the shape of the like-sign distribution of the LFL background. Although needs small corrections for unlike-sign part $C \approx 1\%$ for the low- and $C \approx 4\%$ for high-mass region.

Beauty and charm normalisation

Beauty normalisation was extracted by using MC and data mapping:

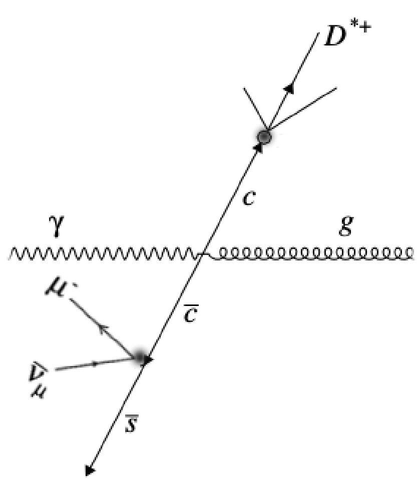
$$N^u_{data} = N^u_b \cdot S^{MC}_b + N^u_{const} + N^u_{lfl},$$
$$N^l_{data} = N^l_b \cdot S^{MC}_b + N^l_{lfl},$$
$$N^u_{lfl} = N^l_{lfl} \cdot C,$$

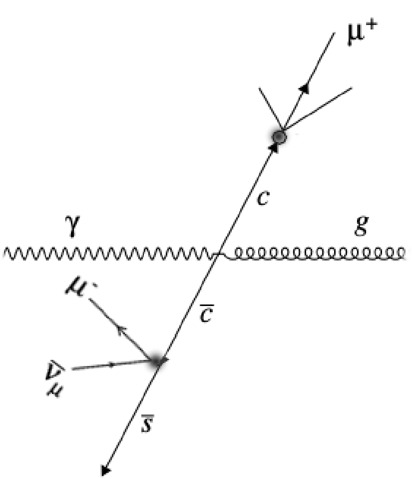
$$N_{const} = N^u_{const} = N_{c\bar{c}} + N_{VM} + N_{BH}$$

Beauty scale factor was extracted with formula:

$$S_b^{MC} = \frac{N_d^u + C \cdot N_d^u - N_{BH}^u - N_{VM}^u - N_c^u}{N_{b_{MC}}^u - C \cdot N_{b_{MC}}^l}, \quad N_b^{ull} = S_b^{MC} \cdot N_b^{MC,ull}$$

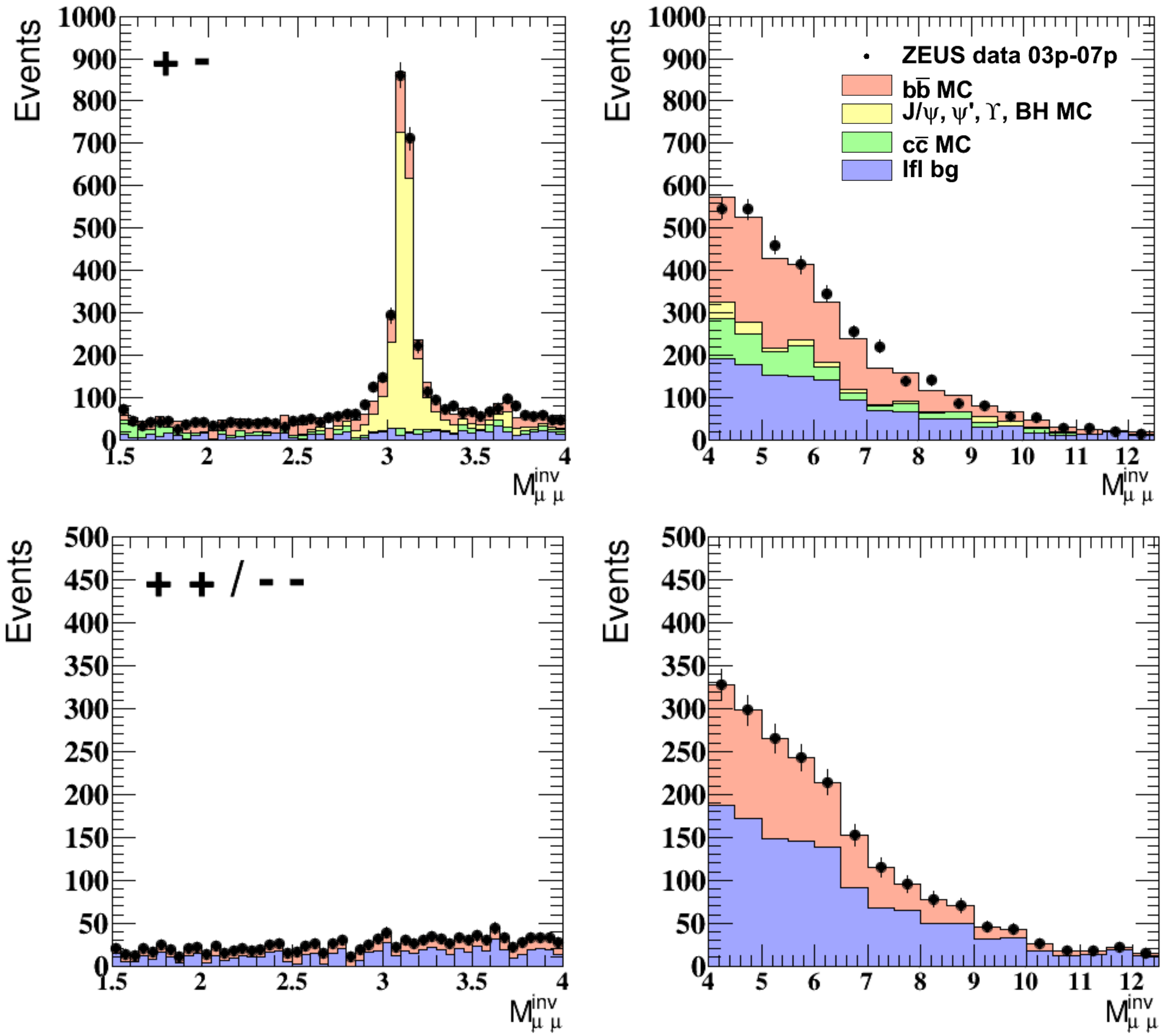
The normalisation factor for the charm contribution was obtained from the other process $S_{cc} = 1.37$. A suitable process is process with D*μ events.





Like- and unlike-sign dimuon mass distribution

Dimuon distribution from the MC samples fits well to the data points



- left plots are related to the low mass region, while right part shows high mass region.
- plots are separated by unlike- (top part) and like-sign (bottom part) criterion.
- light flavour background is extracted from the data and beauty samples.

Isolation cuts

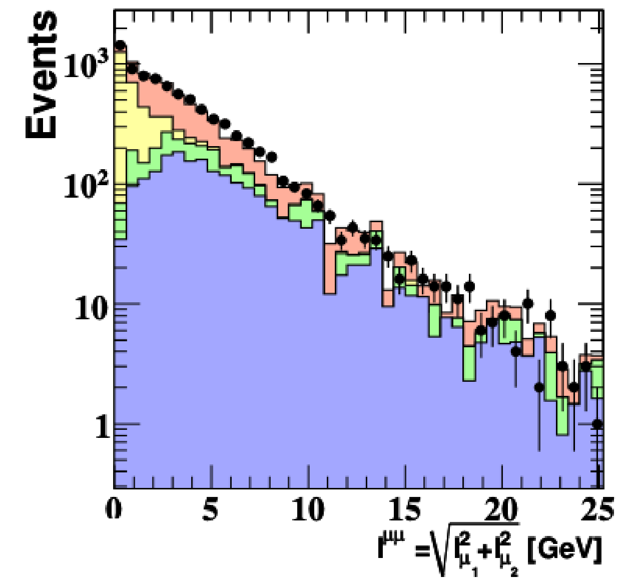
- Dimuons from **beauty** decays accompanied by hadronic activity → Non Isolated (SIGNAL)
- Dimuons from **BH, J/ψ, ψ' , Υ** → Isolated (Background)
- Isolation definition for each muon:

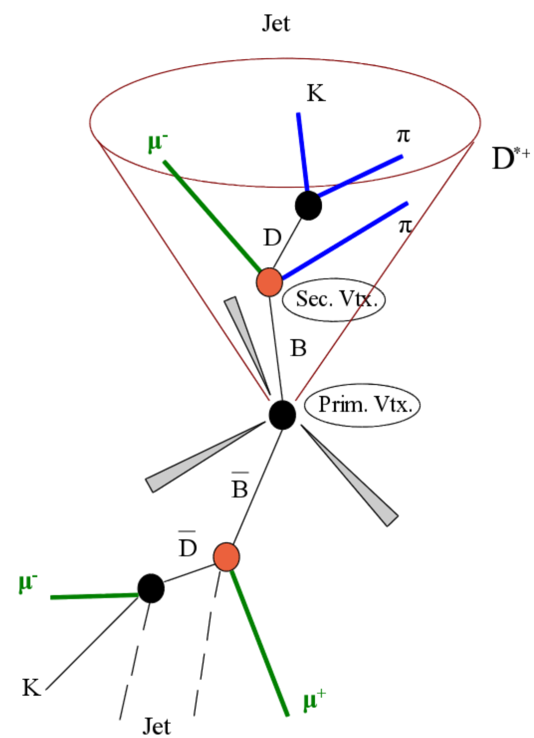
$$I^{\mu} = \sum_{i}^{nZufos} p_T^{Zufo_i} \quad \text{if Zufo} \neq \text{muon}, \Delta R < 1$$

- Isolation definition for dimuon:

$$I^{\mu\mu} = \sqrt{I_{\mu 1}^2 + I_{\mu 2}^2}$$

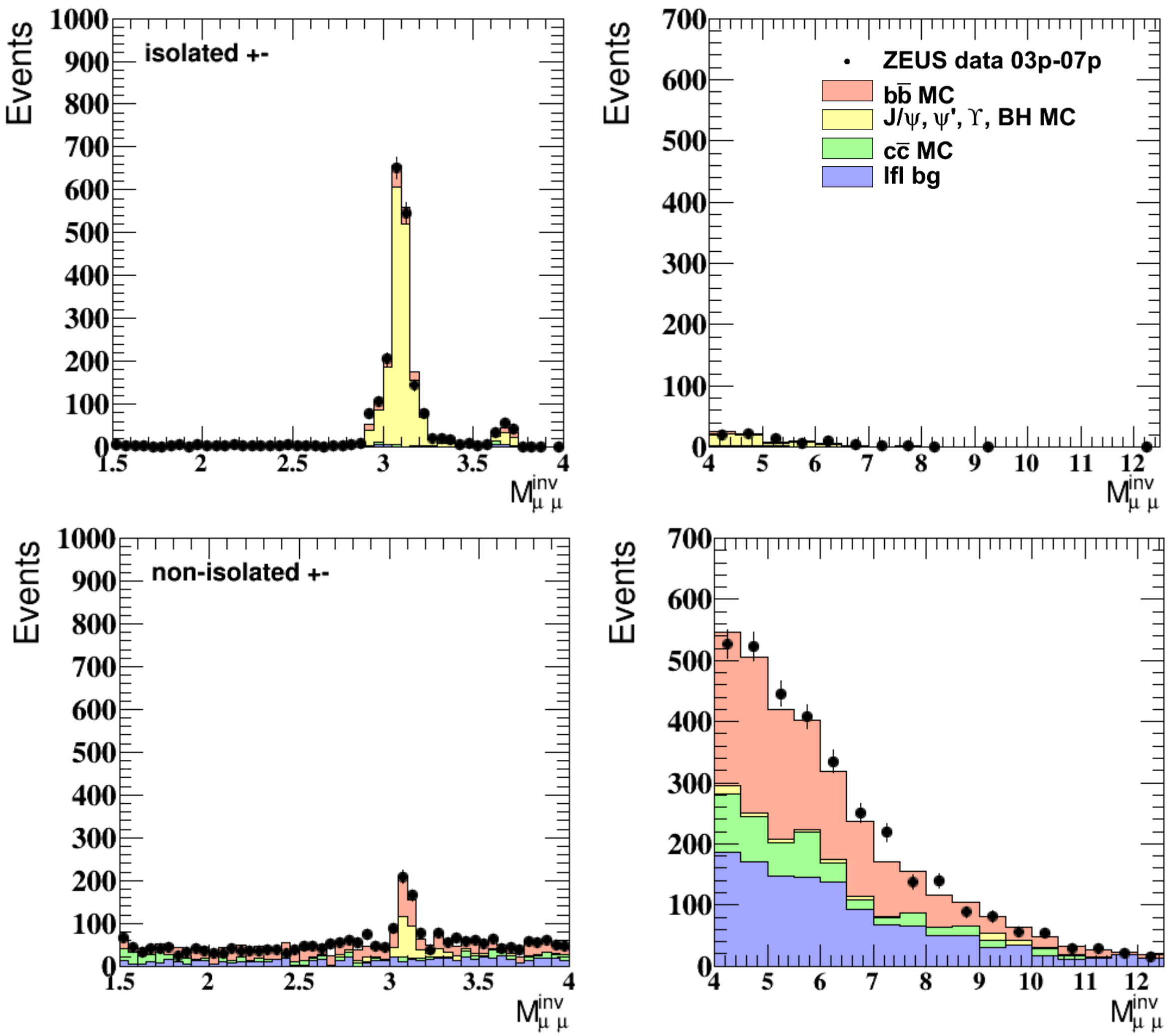
- Muons are non isolated if pass the cut:
  - $I^{\mu\mu} > 2.0$ GeV in **J/ψ, ψ'** mass range
  - $I^{\mu\mu} > 0.25$ GeV otherwise. (reject BH)





Dimuon mass distribution with isolation cuts

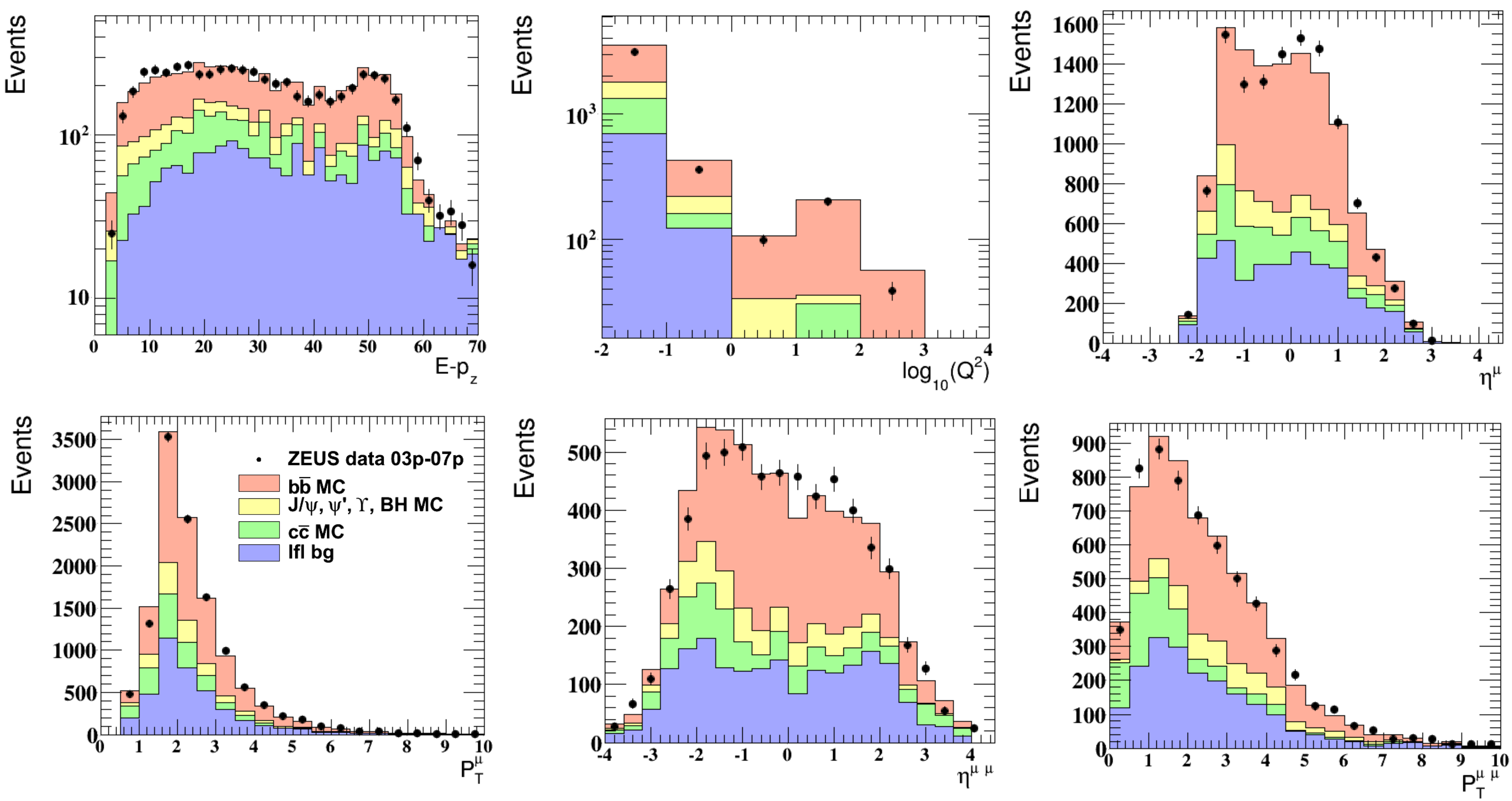
Isolated part of the dimuon distribution is used for the normalisation of J/Ψ and ψ'contributions



- left plots are related to the low mass region, while right part shows high mass region
- Isolated, unike-sign distribution mainly contains event with J/ψ and ψ'.
- Bottom, right part is related to the high mass non-isolated samples. This region is particularly interesting for this analysis, since dimuons from beauty quarks are non-isolated and have high mass.

Control distributions

Event control distrobution of E-p_z and Q^2, muon and dimuon P_T and η, are present:



Distributions contain a low and high mass regions with unlike-sign, non-isolated contributions

Cross section definition

Total CS of given process X is : $\sigma_X = \frac{N_X}{L \cdot A}$ **, where acceptance :** $A = \left(\frac{N_{rec}}{N_{true,X}}\right)^{MC}$

Differential CS is defined as: $\frac{d\sigma_X}{dY} = \frac{N_X}{L \cdot A \cdot \Delta Y}$

To measure CS in process $ep \to e' b\bar{b} X \to e' \mu\mu X$ **, fraction of beauty dimuon events should be determined:**

$$N_{b\bar{b}\to\mu\mu} = \left[N^u_{\mathrm{data}} - N^l_{\mathrm{data}} - (N_{c\bar{c}} + N_{\mathrm{VM}} + N_{\mathrm{BH}})\right] \times \left(\frac{N^u_{b\bar{b}} + N^l_{b\bar{b}}}{N^u_{b\bar{b}} - N^l_{b\bar{b}}}\right)^{\mathrm{MC}}$$

$N_{c\bar{c}}$ – number of events from $c\bar{c}$ events.

N_{VM} – number of heavy quarkonia (J/ψ, ψ', Y)

N_{BH} – number of Bethe-Heitler events

N_{data} – number of data events (like and unlike sign)

Total and differential cross section results

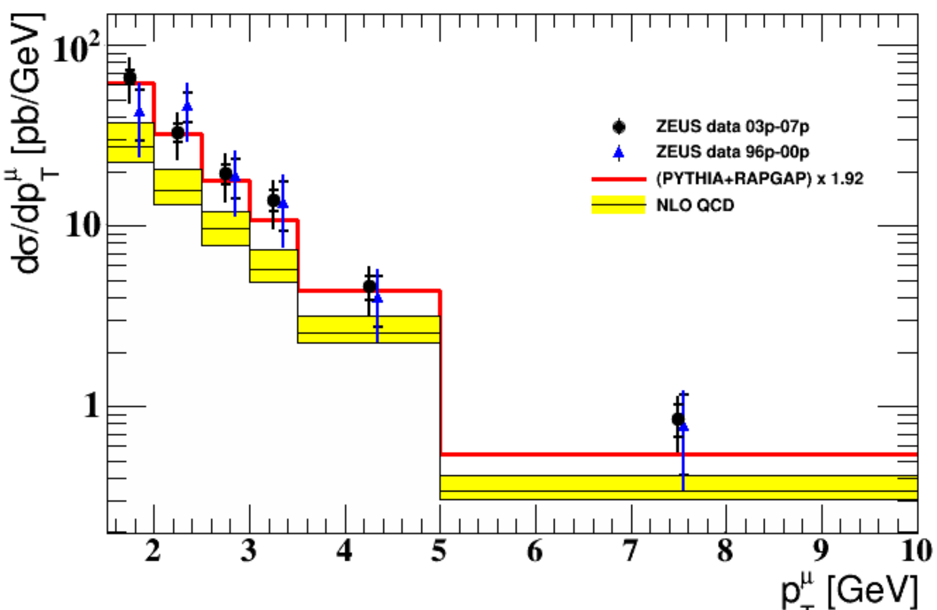
Total cross section:

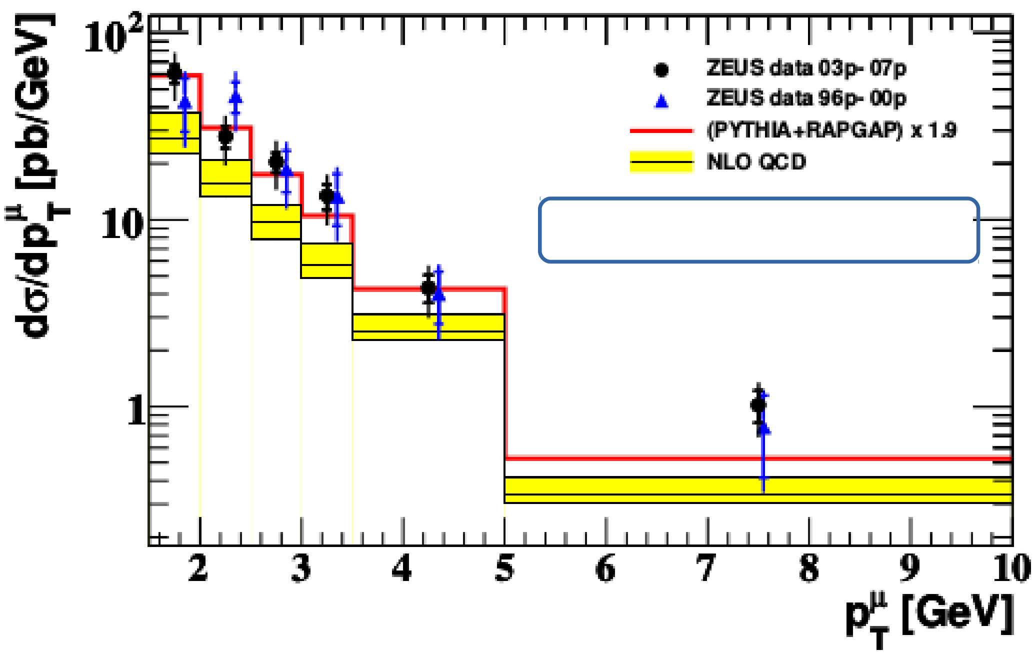
$$\sigma_{total}^{NLO} = 7.5 \pm^{+4.5}_{-2.1} \ (syst.) \ nb$$

$$\sigma_{total}^{HERA\ I} = 13.9 \pm 1.5 \ (stat.) \ ^{+4.0}_{-4.3} \ (syst.) \ nb$$ For the HERA I analysis

$$\sigma_{total}^{HERA\ II} = 12.6 \pm 1.0 \ (stat.) \ ^{+3.6}_{-3.3} \ (syst.) \ nb$$ Previous analysis, HERA II

$$\sigma_{total}^{HERAII} = 11.38 \pm 0.79 (stat.)^{+3.46}_{-2.91} (syst.) nb$$ HERA II repetition





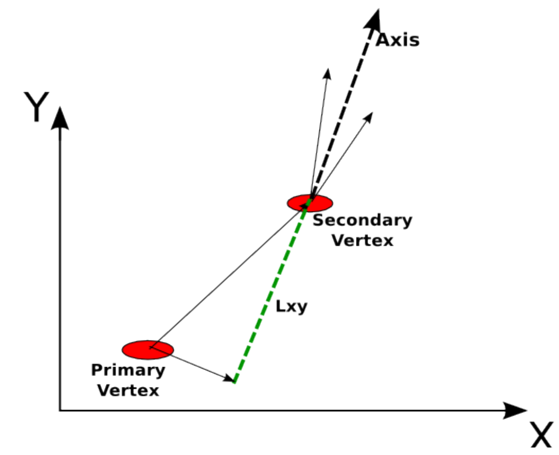
Decay length calculation scheme

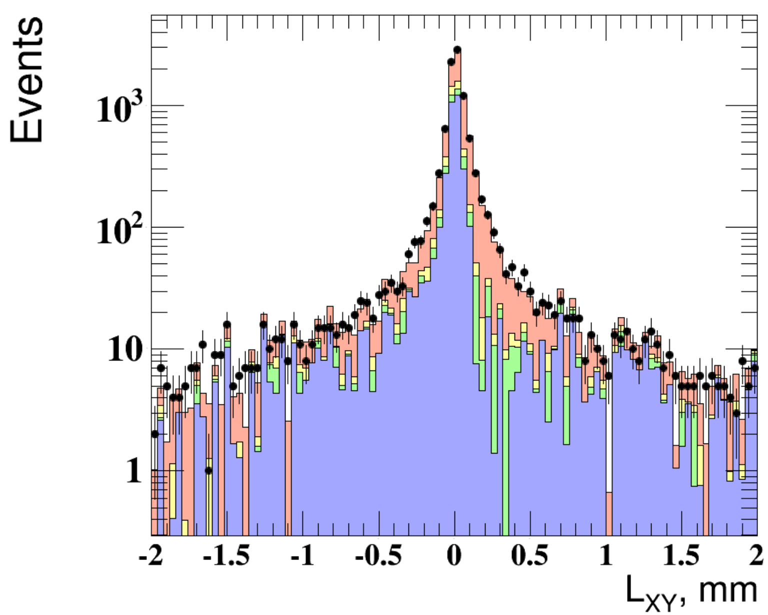
Decay length calculation requires <u>at least one jet</u> in event

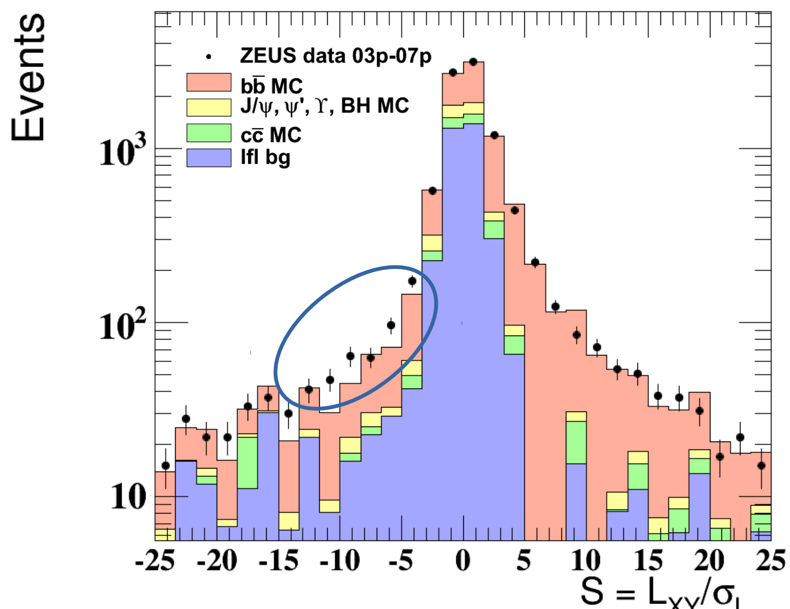
Calculation scheme:

$$L_{xy}^{axis} = \cos(\vec{L}_{xy}, \vec{P}_T^{axis}) \cdot |\vec{L}_{xy}| = \frac{(\vec{L}_{xy} \cdot \vec{P}_T)}{|\vec{P}_T|}$$

$$dL_{xy}^{axis} = \vec{P}_t \cdot (M_{cov}^{PV} + M_{cov}^{SV}) \cdot P_t^T$$



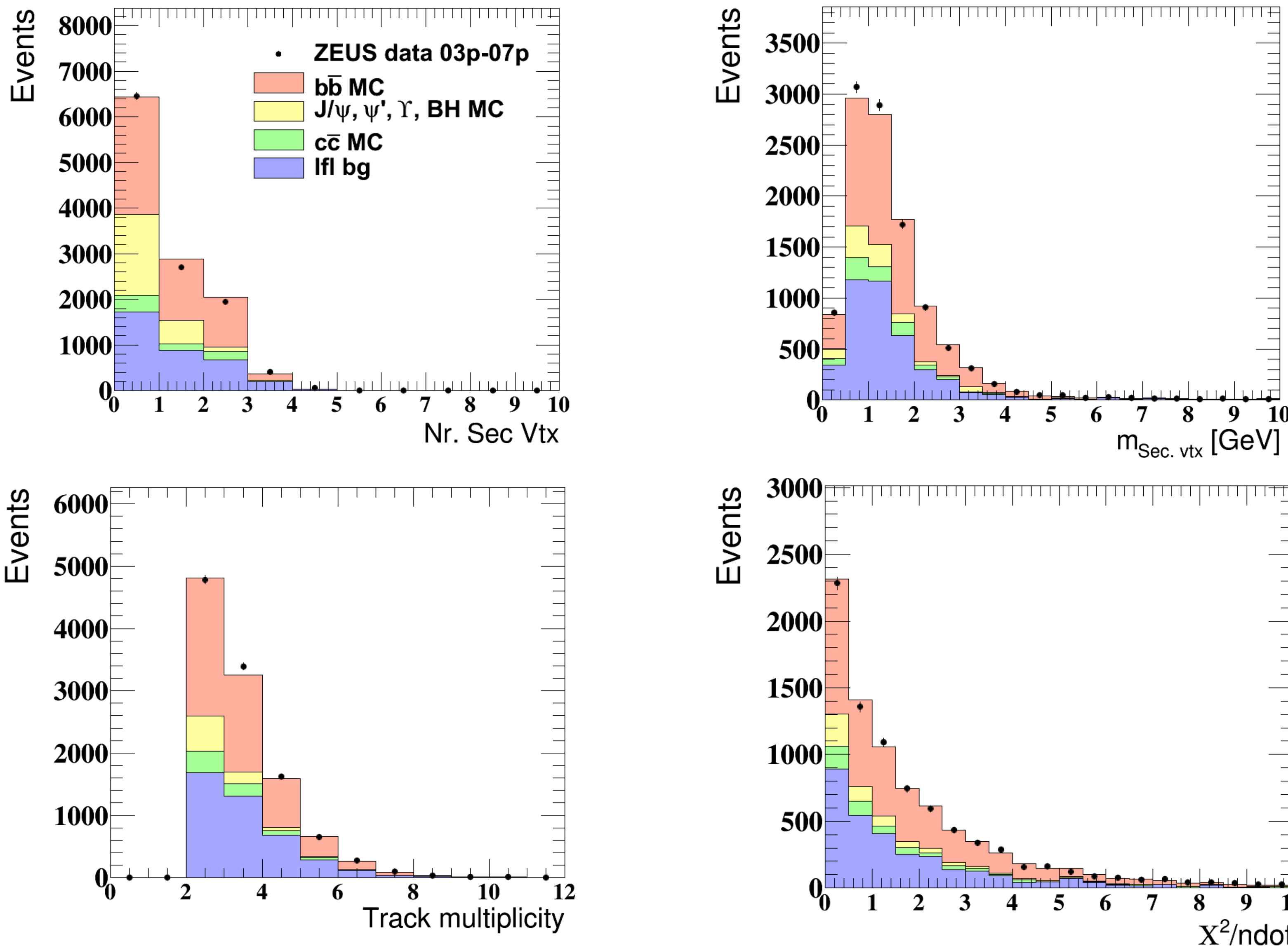




Distributions contain a low and high mass regions for both like- and unlike-sign dimuon pairs contribution

Control plots

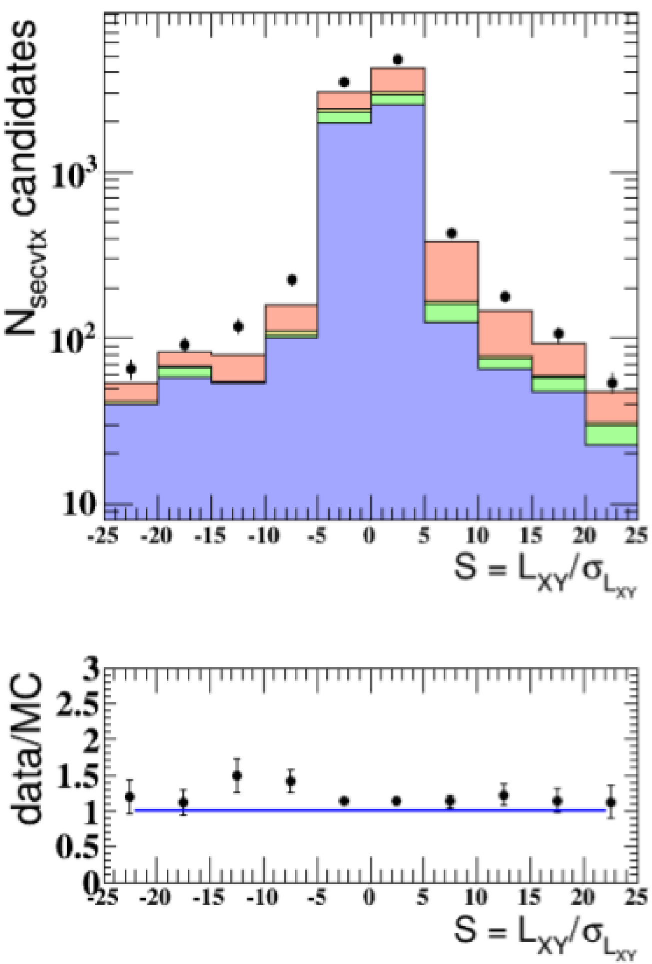
Secondary vertices MC contributions are in a good agreement with data

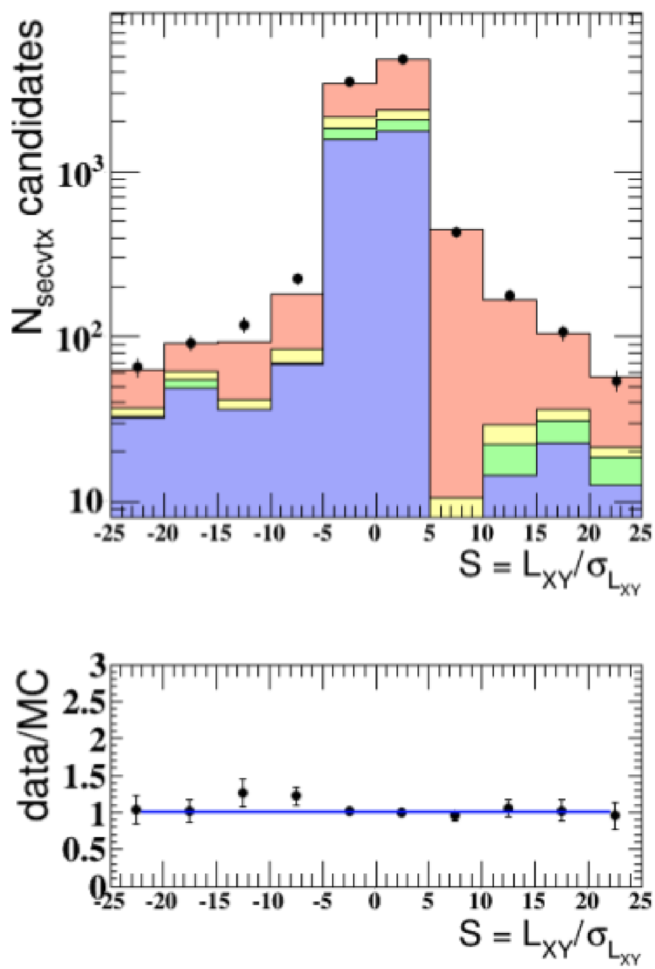


Decay length significance fit

Difference for the each bit is defined as:

$$\Delta N_i = N^u_{data} - C \cdot N^l_{data} - S_{b\bar{b}} \cdot (N^u_{b,MC} - C \cdot N^l_{b,MC}) - S_{c\bar{c}} \cdot N_{c\bar{c}} - N_{BH+J/\psi+\psi+Y}$$





Fit constraints:

$$\chi^2 = \sum_{i=1}^{10} \left(\frac{\Delta N_i}{\sigma(\Delta N_i)} \right)^2,$$

$$\chi^2_{tot} = \sum_{i=1}^{10} \left(\frac{\Delta N_i}{\sigma(\Delta N_i)} \right)^2 + \left(\frac{P_1 - 1}{0.2} \right)^2 + \left(\frac{P_2 - 1}{0.5} \right)^2$$

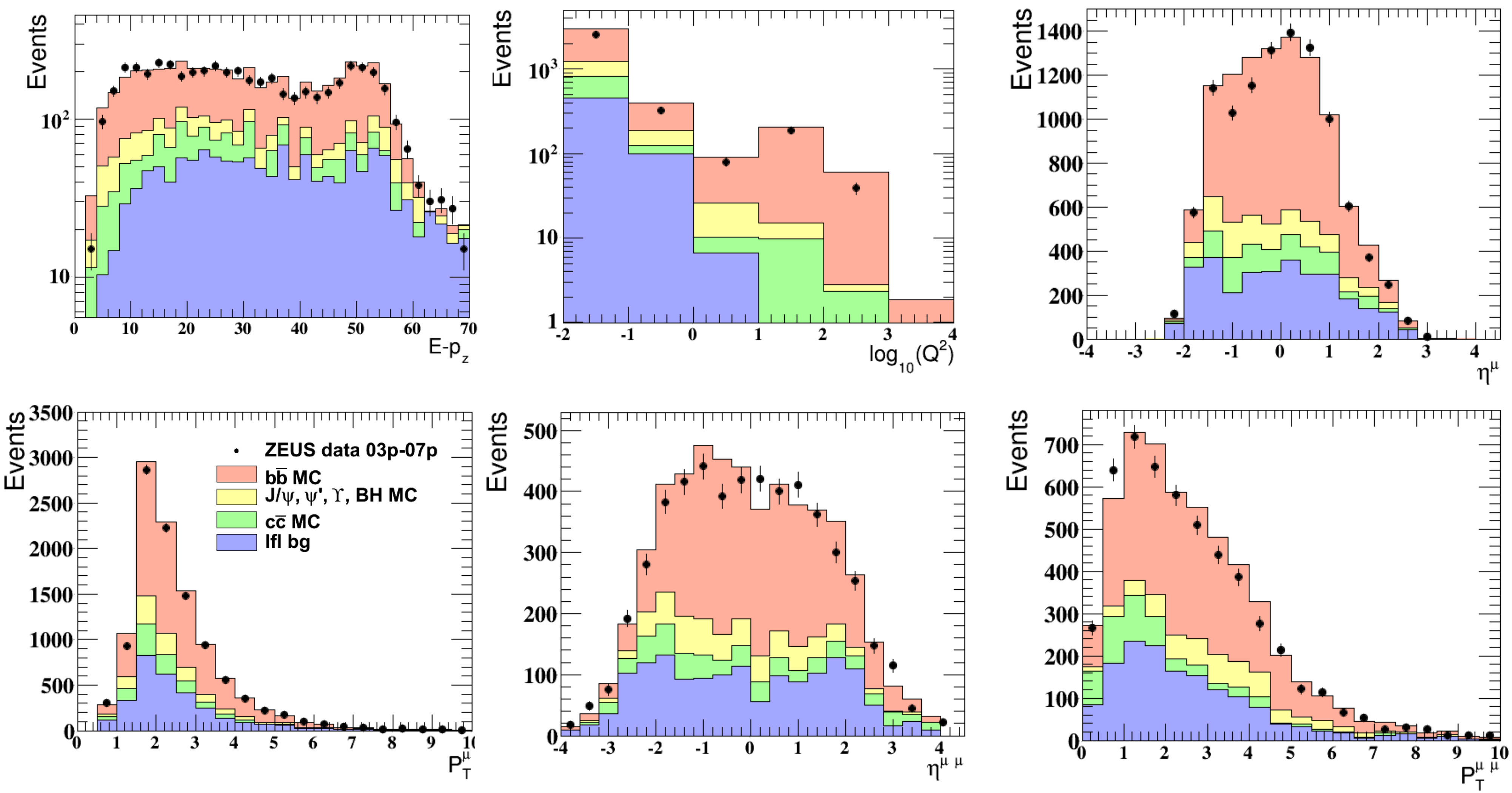
Light flavour DL_{sign} symmetrical distribution

$$S_{b\bar{b}} = 2.1 \pm 0.1$$

$$S_{c\bar{c}} = 1.1 \pm 0.1$$

Control distributions in events with at least one jet (update plots)

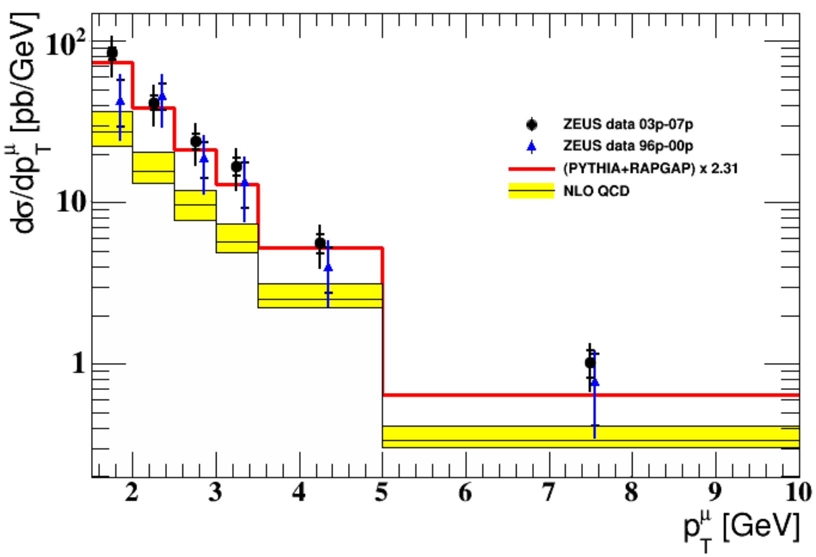
Event control distrobution of $E\text{-}p_z$ and Q^2, muon and dimuon P_T and η, are present:

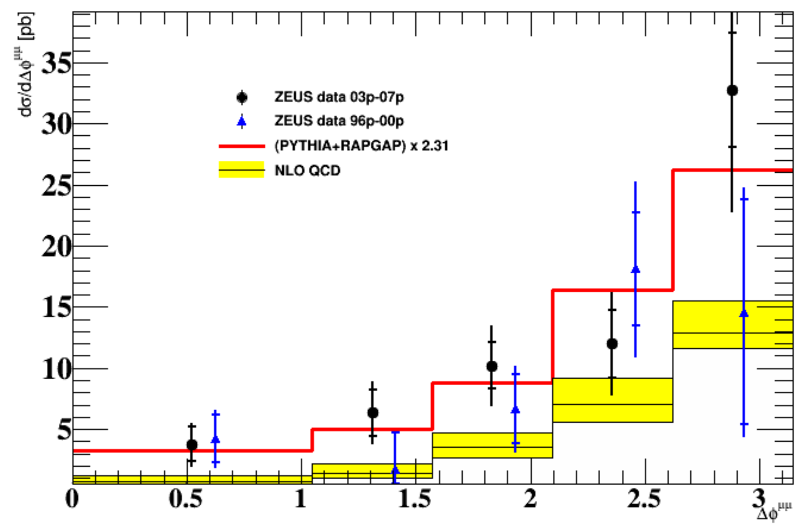


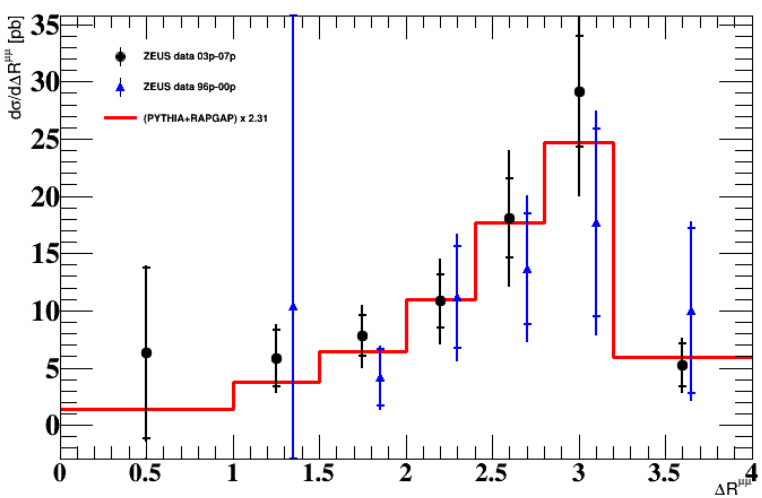
Distributions contain a low and high mass regions with unlike-sign, non-isolated contributions

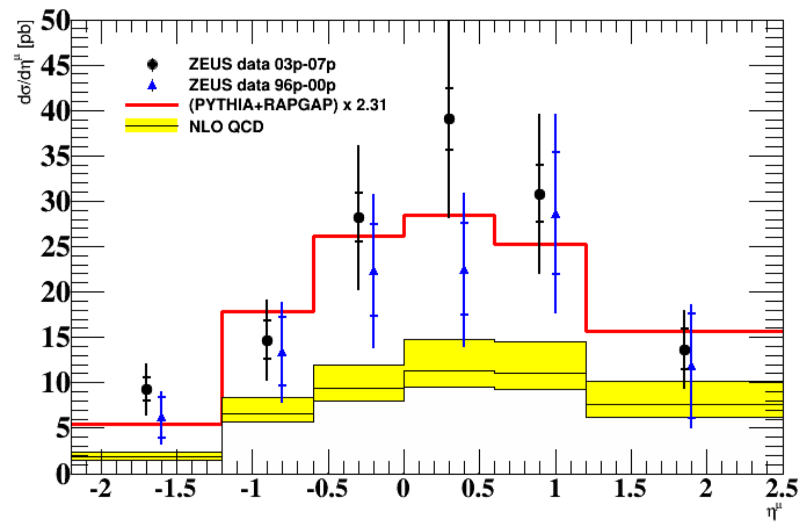
Differential CS, with jet requiremen, sec.vtx information

Differential CS are defined in the kinematic region: $p_T^\mu > 1.5$, $-2.2 < |\eta^\mu| < 2.5$









Summary

- **Primary results shows reasonable agreement with the results from HERA I and HERA II**
- **Secondary vertex information has been used in this analysis**
- **total and differential cross section have been measured**
- **NLO QCD predictions are lower than the measured CS, but compatible within the uncertanties.**
- **Monte Carlo models shapes well agree with data**

Total cross section:

$$\sigma_{total}^{NLO} = 7.5 \pm^{+4.5}_{-2.1} \ (syst.) \ nb$$

$$\sigma_{total}^{HERA\ I} = 13.9 \pm 1.5 \ (stat.) \ ^{+4.0}_{-4.3} \ (syst.) \ nb$$

For the HERA I analysis

$$\sigma_{total}^{HERA\ II} = 12.6 \pm 1.0 \ (stat.) \ ^{+3.6}_{-3.3} \ (syst.) \ nb$$

Previous analysis, HERA II

$$\sigma_{total}^{HERAII} = 11.38 \pm 0.79 (stat.)^{+3.46}_{-2.91} (syst.) nb$$

HERA II repetition

$$\sigma_{total}^{HERAII} = 13.20 \pm 0.86 (stat.)^{+4.02}_{-3.38} (syst.) nb$$

HERA II + secondary vertex information

Systematic uncertainties

- **The Bethe-Heitler and heavy quarkonia contributions.** The normalisation of such processes was changed by $\pm 50\%$. Impact on the visible cross section of such variation is $^{+10\%}_{-3\%}$.

- **Charm contribution.** The normalisation of this contribution was varied by $\pm 20\%$. The visible cross section changes is $^{+16\%}_{-9\%}$.

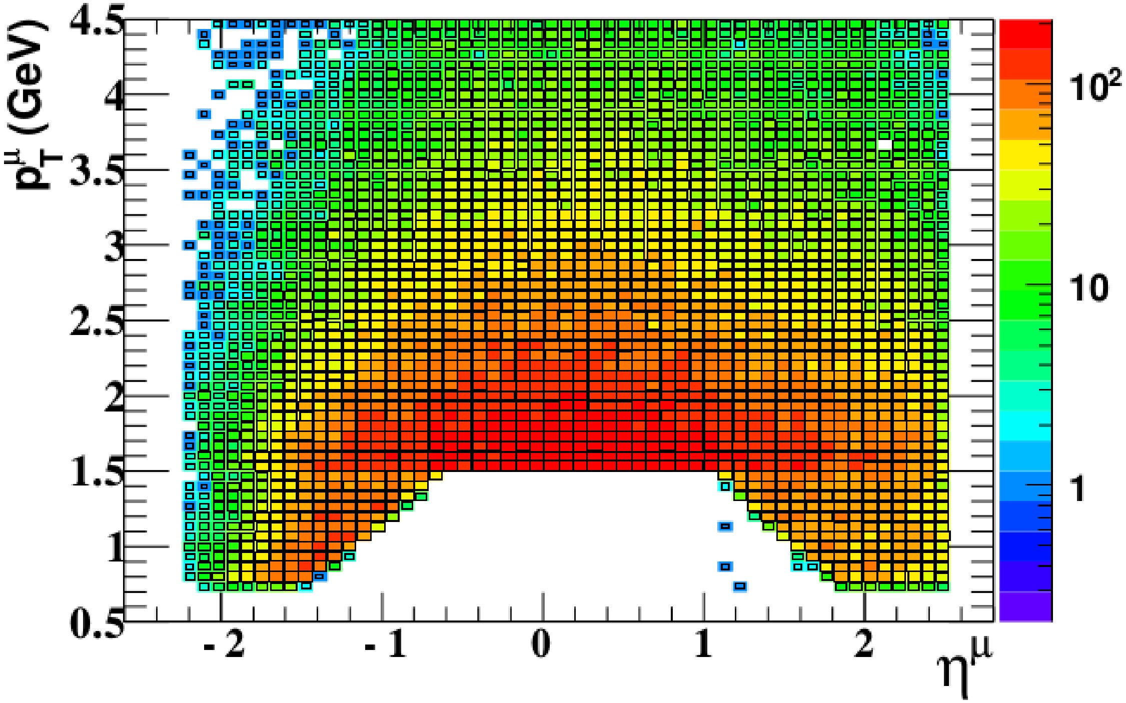
- **Dimuon isolatin criteria,** $I^{\mu\mu}$. This parameter was varied by $\pm$ 500 MeV. Impact on the visible cross section is $^{+2.7\%}_{-3.0\%}$.

- **Variation of the calorimeter transverse energy cut**. The cat on the hadronic E_T was changes to 7 and 9 GeV. This makes an impact to the visible cross section at $^{+3.5\%}_{-2.2\%}$.

- **Muon efficiency correction** impact is $^{+20.2\%}_{-18.4\%}$.

- **Luminosity impact.** The luminosity uncertainty which equal to $\pm 2\%$ has the same direct impact to the visible cross section changes.

Back Up slides



CS definition:

$\mu_{quality} = 4 : p_T^\mu \geq 1.5$ GeV

$\mu_{quality} \geq 5 : p_T^\mu \geq 0.75$ GeV

$-2.2 \lesssim \eta^\mu \lesssim 2.5$