First Year Transfer Report: Incorporation of a ZEUS measurement into HZTool and Beauty photoproduction at HERA

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Abstract

This report describes the work that has been carried out since October in two different areas which are however linked. The first is the writing of a routine which will be incorporated into the HZTool package for comparing physics results with Monte Carlo. In this case the results are from a recent ZEUS measurement of inclusive and dijet cross sections in D^* photoproduction. This was a heavy flavour analysis which is similar to that which will be the subject of the second part of this report, a measurement of beauty production at HERA. The measurement is of b quarks produced via photoproduction by means of the study of the semi-muonic decay channel. Two methods are outlined by which a beauty signal can be extracted, the pTrel method and the impact parameter method. Events were selected from the data taken by ZEUS from (e^+p collisions at HERA in 2004.

Contents

1 Introduction

Heavy flavour (charm and beauty) quark production should be accurately predicted by QCD calculations since their masses provide a hard scale above the limit at which the theory becomes asymptotically free ($\sim 0.2GeV$). However, experimentally it has been shown that the predictions are too low at NLO (next to leading order). Such were the findings of a ZEUS measurement of inclusive jet and dijet cross sections in D^* photoproduction[[2]]. Most of the cross sections presented in this paper agree with the upper bounds of NLO QCD, but a discrepancy was found in the dijet cross sections $d\sigma/d\Delta\phi$ and $d\sigma/dp_T{}^2$. This interesting result is the topic of the first section of the report since it was incorporated into the HZTool library of routines used to compare such measurements with Monte Carlo simulation. The subject of the larger section of the report, however, is a similar measurement in heavy flavour physics. In this section the measurement of beauty photoproduction is described and the work carried out on the analysis so far is outlined. Finally the plans for the future are summarized.

2 Charm jet production and its implementation into HZTool

HZTool[[3]] is a library of routines written in FORTRAN, each one associated with a published high energy physics paper, which allows the user to reproduce the results contained within that paper and the necessary information required to generate Monte Carlo for the purposes of comparison with the data. This section is about one such routine (HZ0507089) which was written to reproduce the cross-sections in the 2005 ZEUS paper entitled Inclusive jet cross sections and dijet correlations in $D^{*\pm}$ photoproduction at HERA [[2]].

2.1 Physics Motivations and Technical Aspects of the Measurement

The published paper on which this routine is based is a ZEUS measurement of D^* inclusive jet and dijet cross sections made with an integrated luminosity of $78.6\,\mathrm{pb}^{-1}$. Because of the mass of the heavy quark, charm production should be predicted by QCD with close agreement. This measurement was made over a wider phase space than previous measurements thus providing an interesting comparison with QCD predictions. The charm quark in the physics process involved is produced when a photon, which is emitted by the incoming electron, interacts with a parton in the proton. This is photoproduction of a c$\bar{c}$ pair and is studied in events with $Q^2 < 1GeV^2$. However, the charm quarks hadronize to produce mesons and it is the D^* meson which is tagged and measured via its decay products ($\kappa\pi\pi$) and the jets.

Experimentally, the measurement was made in the following kinematic region:

- $Q^2 < 1GeV^2$
- $130 < W < 280\ GeV^2$
- $P_T^{D^*} > 3GeV$
- $\left|\eta^{D^*}\right| < 1.5$
- $E_T^{jet} > 6GeV$
- -1.5 $< \left|\eta^{jet}\right| < 2.4$

It was these cuts which were applied in the HZTOOL routine in order to be able to produce Monte Carlo to compare with the data.

2.2 HZTool Routine HZ0507089

The results in the paper on which this routine was based comprised of many cross sections for many different variables and in many different kinematic regions. All the cross sections were reproduced in the routine but, for the purposes of this report, only few of the plots produced by the routine will be presented and discussed. The Monte Carlo samples are for leading order photoproduction only. PYTHIA and HERWIG samples were scaled by a factor of 1.5 and 2.5 respectively. Plots of tagged and un-tagged cross sections were also made.

The plots included in this report shows are the transverse energy of the jet cross section and the dijet $\Delta\phi$ cross sections for direct and resolved photoproduction. For the jet energy cross section it is clear that both PYTHIA and HERWIG Monte Carlo agree well with the data. However, with regard to the $\Delta\phi$ distributions, HERWIG describes the data a lot better than PYTHIA. HERWIG is a Monte Carlo programme incorporating parton showers whereas PYTHIA is not and so it seems that this discrepancy in the PYTHIA Monte Carlo may be due to higher orders. This is reinforced by the fact that at low x_γ the agreement is very bad but at higher x_γ it is adequate for the PYTHIA MC.

3 Beauty Photoproduction and Analysis Overview

3.1 The ZEUS Detector

The ZEUS detector is a multipurpose detector which is used to study high energy collisions of electrons/positrons and protons at the HERA (Hadron Elektron Ring Anlage) accelerator. It is situated at DESY (Deutsches Elektronen-Synchrotron) in Hamburg, Germany. A complete description of the detector and its components can be found in [[4]] but the tracking detectors are of particular relevance to this analysis and so are mentioned below. At the very centre of ZEUS, around the beam pipe, are the inner tracking detectors. The largest of which is the CTD (Central Tracking Detector) which is a cylindrical wire drift chamber measuring the momentum and direction of charged particles. It consists of 4608 sense wires and 19584 field wires contained in chamber holding a mixture of Argon, Carbon Dioxide and Ethane gas. When a particle traverses the chamber, the gas becomes ionised along its track. Electrons from this ionisation drift towards the sense wires and the positive ions towards the field wires. The drifting electrons cause an avalanche effect close to the wires inducing a pulse in the sense wires which is read out.

Between the CTD and the beam pipe lies the MVD (MicroVertex Detector). The MVD comprises of the BMVD (Barrel MicroVertex Detector) in the central region and the FMVD(Forward MicroVertex Detector) in the forward region. The BMVD has 3 Superlayers of Silicon strip sensors (600 strips in total). The strips are placed parallel and perpendicular to the beam pipe to allow measurements in the $r-\phi$ and the $r-z$ planes. The FMVD is comprised of 4 wheels of such strips and extends the tracking region of ZEUS to a pseudorapidity of $\eta = 2.6$. The MVD provides a great improvement to the global precision of the tracking at ZEUS and allows the possibility of resolving a secondary vertex caused by the decay of a heavy quark. Thus heavy quark analysis topics will be substantially improved with the use of the MVD.

3.2 Beauty Photoproduction

The aim of this analysis is to measure beauty production in the photoproduction regime using pe^+ data with an integrated luminosity of 33 pb^{-1} taken by the ZEUS detector. In photoproduction the boson exchanged between the proton and the positron is a nearly real photon ($Q^2 \sim 0GeV^2$). This results in the production of a $b\bar{b}$ pair. If the photon behaves as a pointlike object in the interaction the process is known as direct photoproduction and if it behaves like a source of partons, one of which interacts with a parton inside the proton, then the process is resolved photoproduction. These beauty photoproduction processes are illustrated by the Feynman diagrams in Fig.[1].[[6]]

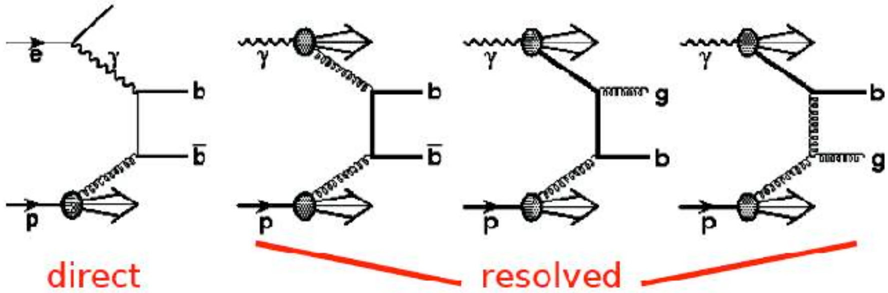

Figure 1: The main processes for beauty production at HERA.

3.3 Beauty Decay

The decay channel chosen for this analysis is the so-called semi-leptonic decay, in which the b quark decays into a c quark via the emission of a W boson which in turn decays into a μ $\bar{\nu}$ pair with a branching ratio of (10.57±0.22)%.[[5]]. This muon provides a clean experimental signature since it can be detected in the muon chambers and matched to a track in the tracking chambers. The neutrino, however, traverses the detector completely undetected and so some kinematic information is lost. The c quark will inevitably fragment to produce a jet of hadrons which can be used as part of the experimental signature. Hence events containing two or more jets, at least one of which contains a muon, are used in this analysis.

Due to the lifetime of the b quark, beauty events are associated with a displaced secondary vertex. An unambiguous association of a track with a secondary vertex is often not possible. This is because it requires a precision of the order of the distance of the secondary vertex from the primary vertex. This level of precision in reconstruction would lead to a significant loss in statistics. In order to keep high statistics, a partial reconstruction method is required. In this section, two methods of extracting the beauty signal from the data are discussed. In fact, a combination of these methods will be used to remove the background events.

3.4 The p_T^{rel} method

The muon produced in semileptonic beauty decay should have a higher transverse momentum than those produced in charm events. This is due to its higher mass. Therefore making a minimum muon p_T requirement on events would remove some charm background. However, when calculated with respect to the p_T of the mother hadron, a more efficient signal extraxtion can be achieved:

$$p_{T,true}^{rel,} = \left| \frac{\overline{p}_{T,true} \times \overline{p}_{hadron}}{\overline{p}_{hadron}} \right| \tag{1}$$

Since the hadron is not an experimental observable, $p_T^{rel,true}$ is approximated using the jet axis as a reference:

$$p_T^{rel} = |\overline{p}_T{}^{\mu}| \cdot \sin\left(\arccos\left(\frac{\overline{p}_T{}^{\mu} \cdot \overline{p}_T{}^{jet}}{|\overline{p}_T{}^{\mu}| \cdot |\overline{p}_T{}^{jet}|}\right)\right) \tag{2}$$

However, when the transverse momentum of the jet is calculated without the muon the p_T^{rel} distribution is shifted even more such that a significantly larger amount of signal can be extracted. This is the quantity used in this analysis and it is given by:

$$p_T^{rel,jet-\mu} = |\overline{p}_T{}^{\mu}| \cdot \sin\left(\arccos\left(\frac{\overline{p}_T{}^{\mu} \cdot \left(\overline{p}_T{}^{jet} - \overline{p}_T{}^{\mu}\right)}{|\overline{p}_T{}^{\mu}| \cdot \left|\left(\overline{p}_T{}^{jet} - \overline{p}_T{}^{\mu}\right)\right|}\right)\right) \tag{3}$$

3.5 The Impact Parameter Method

The impact parameter, δ, is the transverse distance of closest approach of the reconstructed muon track to the primary vertex position. This reflects the lifetime of the heavy hadron since it depends on the decay length. This analysis uses the signed impact parameter which is defined in fig.[2].[[6]]. Tracks originating from the decay of a heavy hadron have a positive impact parameter and so negative impact parameters correspond to detector resolution effects. Since these effects should produce a symmetric distribution about zero, any excess in the positive region is due to the physics events in question. The impact parameter is calculated in the $r\phi$ plane and is given by

$$\delta_t rue = L_t \sin \alpha \tag{4}$$

where L_t is the distance between the point of production the heavy hadron and the point of its decay in the laboratory frame and α is the angle between the hadron direction and the direction of the decay product in the $r\phi$ plane. Since detector resolution prevents precise direct measurement of such quantities, the measurement relies on good tracking information and track fitting. In the region around the interaction point the helix shape of the track is reconstructed and extrapolated back to find the primary vertex position. However since the precision of the vertex is of such importance in the measurement of the impact parameter, an average primary vertex is determined for a run by averaging the vertex position over all the events in that run. This is called the beam spot position and the tracking information used in this analysis was corrected for this.

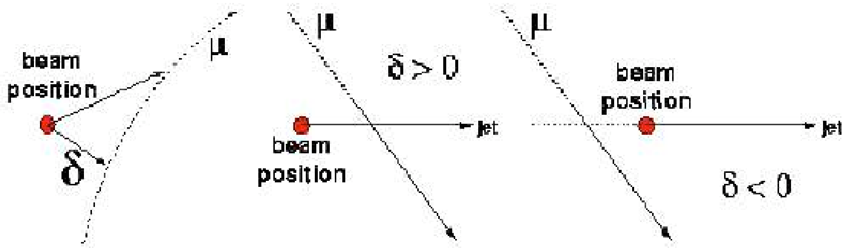

Figure 2: The sign of the impact parameter.

Previous ZEUS measurements have used the p_T^{rel} method to measure beauty production, however the impact parameter method has only become realistic since the Microvertex Detector (MVD) has been installed and become better understood. The combination of these two methods is a much more powerful analysis tool. χ^2 fits to both p_T^{rel} and δ distributions yield the contributions of the the relavant background processes.

4 Event Selection

4.1 Data Sample

The event selection carried out in [[1]] has been repeated for data taken by the ZEUS detector during the operation of HERA in 2004 using an integrated luminosity of $33\,\mathrm{nb}^{-1}$.

4.2 Monte Carlo Sample

The Monte Carlo sample used was a beauty enriched sample generated using the PYTHIA Monte Carlo with the b quark mass set to 4.5 GeV. The physics processes generated were

- b in direct γ
$$\gamma g \to b\bar{b}$$
- b in resolved γ
$$q\bar{q} \to b\bar{b}; gg \to b\bar{b}$$
- b excitation in γ
$$bq \to bq; bg \to bg$$
- b excitation in p
$$b\gamma \to b\gamma; bg \to bg; bq \to bq; b\bar{b} \to b\bar{b}$$

The Monte Carlo events were first selected at the detector level to simulate the data sample so that the two could be compared.

4.3 Event Selection Cuts

A three level trigger system was used to select events online. The first level and second level triggers selected photoproduction events while the third level trigger selected events with a muon candidate and two jets. However many offline cuts were performed to reduce background processes.

In order to select photoproduction events (i.e. $Q^2 < 1GeV^2$) deep inelastic scattering (DIS) events must be identifed. In DIS the electron is scattered to large angles and can be detected whereas in photoproduction the electron is often lost down the beampipe. Therefore the identification of an electron signifies a DIS event. Using the electron finding package SINISTRA, electron candidates were found and the following cuts on the energy of such a candidate, on its probability of being an electron and on its inelasticity were applied:

- $E_{el} > 5GeV$ and $prob_e > 0.9$ and $y_{el} < 0.9$

Events with candidates satisfying all of these criteria were identified as DIS events and were rejected. The resulting y_{el} distribution can be seen in fig., which illustrates that the remaining events are well described by the beauty Monte Carlo. A further cut on y_{JB} was performed to remove any remaining DIS events. Since these extra events do not contain an electron candidate, the inelasticity was calculated using Energy Flow Objects, EFOs by the Jaquet-Blondel method:

$$y_{JB} = \frac{\Sigma_i E_i - p_{z,i}}{2E_e}$$

Events were selected that lie in the region:

- $0.2 < y_{JB} < 0.8$

The distribution of $y_j b$ is shown in fig.[4]. A number of cuts were made to reduce the number of beam gas events. The following cuts were applied on EFO's which are formed by combining tracking and calorimeter information:

- $P_T/E_T < 0.5$
- E_T (minus the E_T in the first two rings) $\geq 10GeV$
- $P_T \leq 10GeV$

The plots for these variables are shown in fig.[4] along with the beauty-enriched Monte Carlo, which agrees with the shape well. Also, since beam gas events are unlikely to have tracks which can be extrapolated back to the primary vertex, cuts can be made to remove the fitted tracks as shown below and the distribution of the number of fitted tracks can be seen in fig.[4].

- Number of vertex-fitted tracks> 2
- Total number of tracks / Number of vertex-fitted tracks≤ 10.0

In order to select muons which were detected in a well understood region of the detector, events were only selected if they contained at least one muon falling in the kinematic region defined by:

- -1.6 $< \eta <$ 2.3
- $P_T > 2.5GeV$

The events were required to contain at least two jets which passed the following cuts:

- -2.5$GeV < \eta <$ 2.5GeV
- ${P_T}^{jet1} \geq 7GeV$
- ${P_T}^{jet2} \geq 6GeV$

These requirements ensured that the jet finder used (KTCLUS) found clear jets. The η and p_T control plots for both the jets and the muons are shown in fig.[5]. It was also required that at least one of these jets had a muon associated to it. Events were selected in which the jet and its associated muon had a difference in transverse momentum greater than some threshold, as given below, in order to jets produced by cosmic muons.

- $\left({P_T}^{jet} - {P_T}^{\mu}\right) \geq 2GeV$

Finally, a cut was made on the Z vertex of the event:

- $|Z_{vertex}| < 40cm$

A plot of the Z vertices of the events can be found in figure [4].

The resulting data set was identical to that produced and used by [[1]]. All the control plots described in this section were produced for the final data selection, ie. after all of the above cuts had been made. The ${p_T}^{rel}$ and impact parameters of the data and Monte Carlo were also plotted and are shown in fig. [6]. The beauty Monte Carlo distributions were area-normalized to the data and then scaled by the factor calculated in [] when a combined fit of the impact parameter and ${p_T}^{rel}$ distributions was performed. These methods are described in sec.[3] The beauty scaling factor calulated was:

$$fb = 0.185 \pm 0.026$$

The control plots show good agreement in shape between the data and beauty Monte Carlo. The excess in data is due to charm and light flavour contributions.

4.4 Conclusions

The event selection of the analysis in [[1]] has been repeated for 2004 ZEUS data with 100% agreement. Control plots have been made which show good agreement in shape to a beauty enriched PYTHIA Monte Carlo sample.

5 Future Plans

- Finalize the comparison with the results of the previous analysis conducted by S. Miglioranzi. In particular, charm enriched and light flavour enriched Monte Carlo samples will be generated for the purpose of comparison between the 2004 data set and a sum of the three Monte Carlo samples.

- Improve the reconstruction of the MVD by developing a proper simulation of the bad channels.

- Extend the beauty analysis to encorporate the data taken by ZEUS in 2005 thus using all of the available HERA ii data. This will increase the integrated luminosity by a factor of 4 and will incorporate information from a better understood MVD. These improvements will allow for the measurement to be extended to higher E_T, due to improved statistics, and lower p_T, due to the possibility of reconstructing a secondary vertex using the MVD.

- Produce a physics result for beauty production which is significantly better than any made at HERA I, over a wider phase space. This will allow a more comprehensive comparison with QCD prdictions.

References

[1] S. Miglioranzi,"Beauty photoproduction at HERA with the ZEUS experiment", PhD Thesis, (2006)

[2] ZEUS Collaboration,"Inclusive jet cross sections and dijet correlation in $D^{*\pm}$ photoproduction at HERA", hep-ex/0507089, (2005).

[3] "HZTool a Library for Data-Simulation Comparisons at High Energy Colliders version 4.0"(2005)

[4] www-zeus.desy.de

[5] S. Eidelman et al. (Particle Data Book),*Review of Particle Physics*, Phys. Lett B592 1 (2004)

[6] S. Miglioranzi, Talk given to ZEUS Collaboration July (2005)

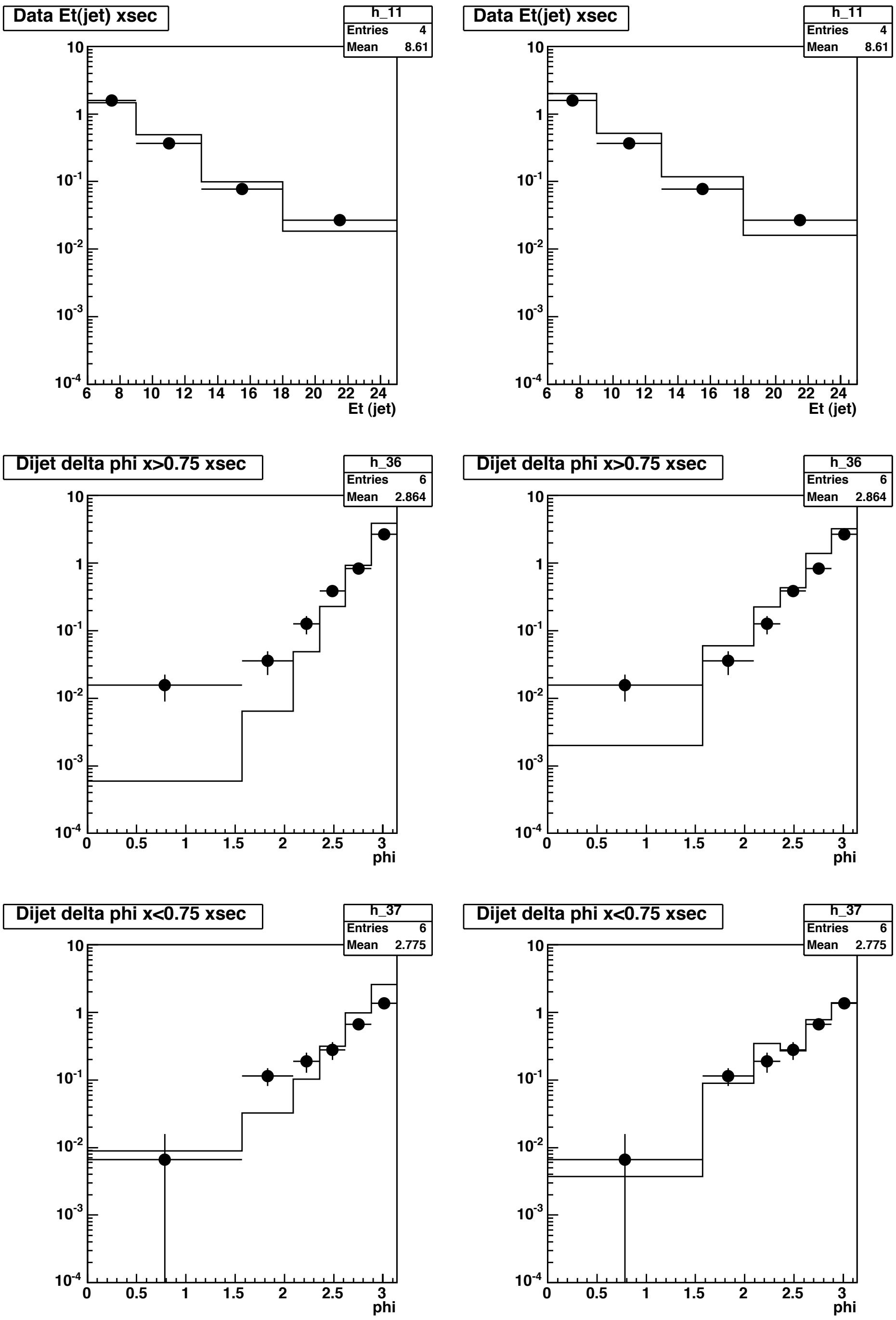

Figure 3: Data (points) and Monte Carlo (line) for $\mathrm{d}\sigma/\mathrm{d}E_T$ for -1.5 $< \eta <$ 2.4 (top) using PYTHIA (left) and HERWIG (right).Data (points) and Monte Carlo (line) for $\mathrm{d}\sigma/\mathrm{d}\phi$ for direct photoproduction (middle) using PYTHIA (left) and HERWIG (right).Data (points) and Monte Carlo (line) for $\mathrm{d}\sigma/\mathrm{d}\phi$ for resolved photoproduction (bottom) using PYTHIA (left) and HERWIG (right).

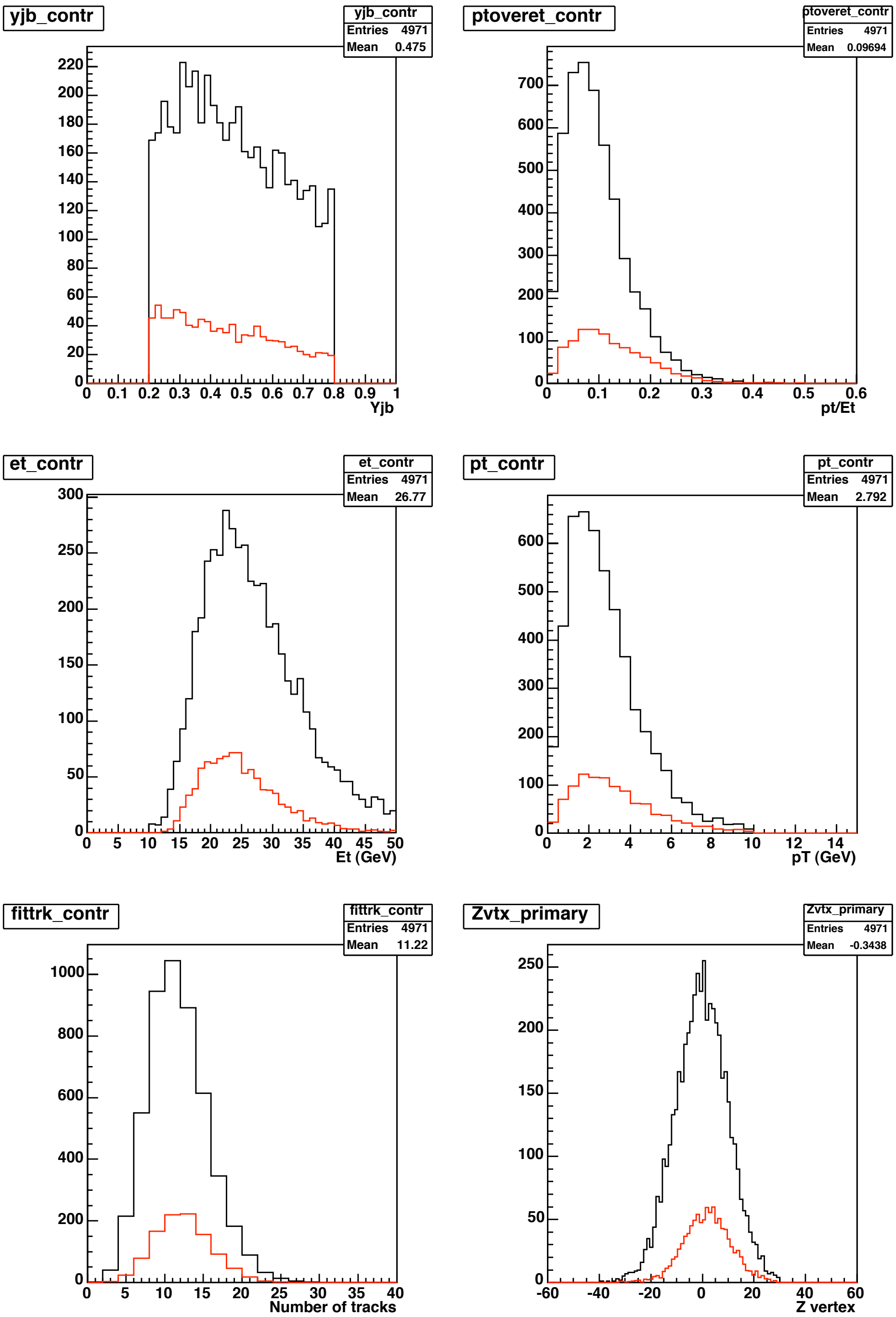

Figure 4: Control Plots for 2004 data (black) with beauty enriched PYTHIA Monte Carlo (red)

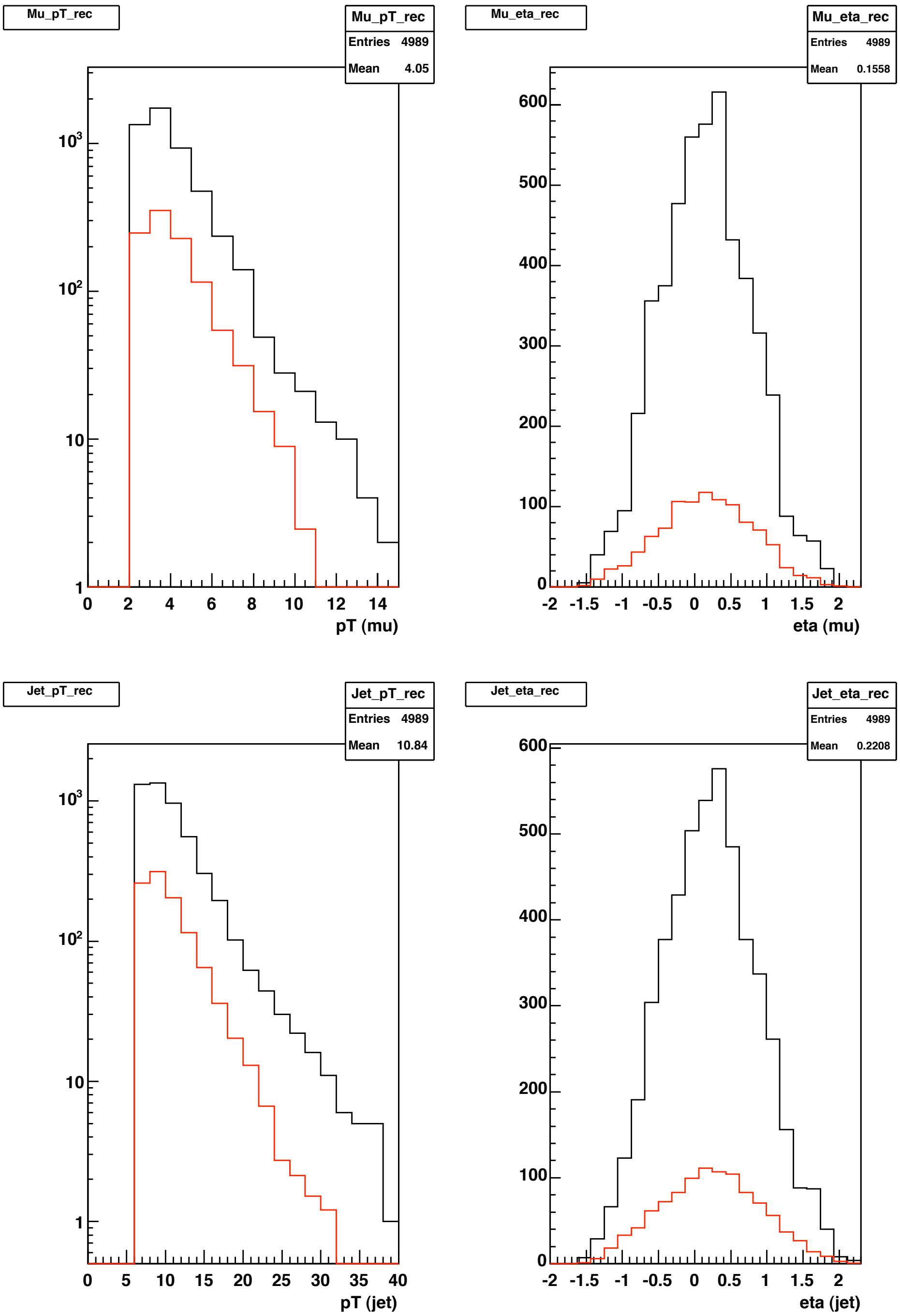

Figure 5: Control plots of the pT and pseudorapidity of the muon and of the jet associated to the muon for 2004 data (black) and beauty enriched PYTHIA Monte Carlo (red)

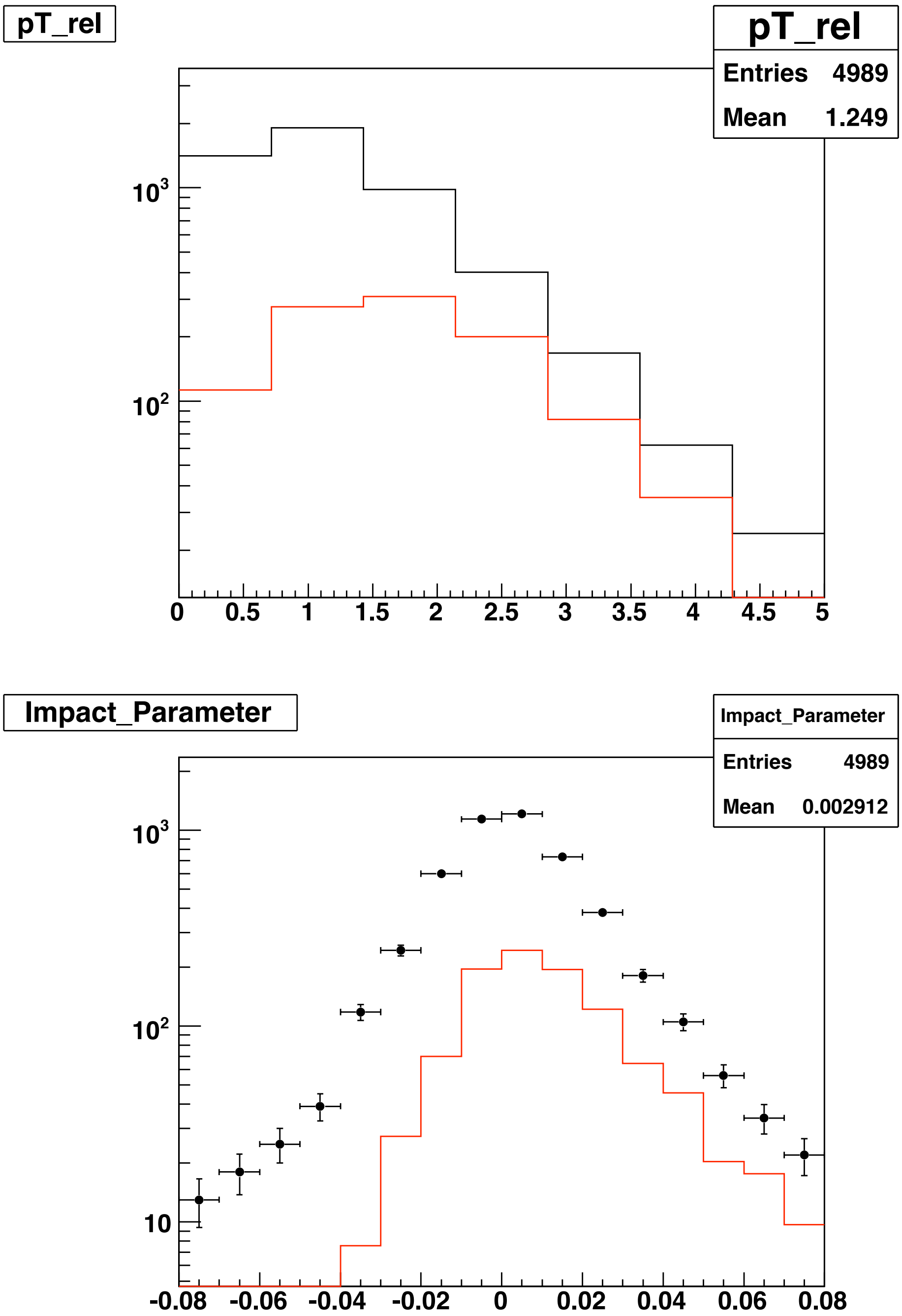

Figure 6: (above) Transverse momentum of the muon relative to the jet axis and (below) Impact Parameter distribution for 2004 data (black) and beauty enriched PYTHIA Monte Carlo (red).