Measurement of cross sections and jet multiplicities in vector boson events

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Abstract

The production of vector bosons with jets is important for testing QCD and for estimating backgrounds for top quark production and for new physics studies. Deviations of the measurements from the standard model predictions can signal the onset of new physics. Measurement of the inclusive $Z + jets$ and $W + jets$ cross sections in proton-proton collisions at a centre-of-mass energy of 7 TeV at the LHC, with the CMS detector, in the muon decay mode, are presented as a function of jet multiplicity. Measurements are also presented as the ratio of cross sections $\sigma(V+ \geq n_{jets})/\sigma(V+ \geq n-1_{jets})$ and $\sigma(V+ \geq n_{jets})/\sigma(V+ \geq 0_{jets})$ for inclusive jet multiplicities $n = 1 \div 4$, where V = Z and W. The results, based on an integrated luminosity of $\sim 191 pb^{-1}$, are in agreement with next-to-leading-order QCD calculations within the experimental and theoretical uncertainties.

Contents

1 Introduction

The ultimate goal of this analysis is the measurement of the cross sections $\sigma(Z \to \mu\mu)$ and $\sigma(W \to \mu\nu)$ from data of the CMS experiment at LHC, compared with the MadGraph MonteCarlo [1].
In order to achieve these values I analyzed some useful muons and jets variables and by applying cuts on this variables I managed to improve the purity of the plots. In this way I was able to compare my results with the CMS approved plots checking, step by step, the accuracy of my analysis.

2 CMS Detector

The central feature of the CMS apparatus (Figure 1) is a superconducting solenoid, 13 m in length and 6 m in diameter, which provides an axial magnetic field of 3.8 T. The bore of the solenoid is outfitted with various particle detection systems.
Charged particle trajectories are measured by the silicon pixel and strip tracker, covering $0 < \phi < 2\pi$ in azimuth and $|\eta| < 2.5$, where the pseudorapidity η is defined as $\eta = -\ln[\tan\theta/2]$, with θ being the polar angle of the trajectory of the particle with respect to the counterclockwise beam direction.
A crystal electromagnetic calorimeter (ECAL) and a brass/scintillator hadronic calorimeter (HCAL) surround the tracking volume; in this analysis the calorimetry provides high-resolution energy and direction measurements of hadronic jets. Muons are measured in gas detectors embedded in the steel return yoke outside the solenoid.
The detector is nearly hermetic, allowing for energy balance measurements in the plane transverse to the beam directions. A two-tier trigger system selects the most interesting *pp* collision events for use in physics analysis. A more detailed description of the CMS detector can be found elsewhere [2] .

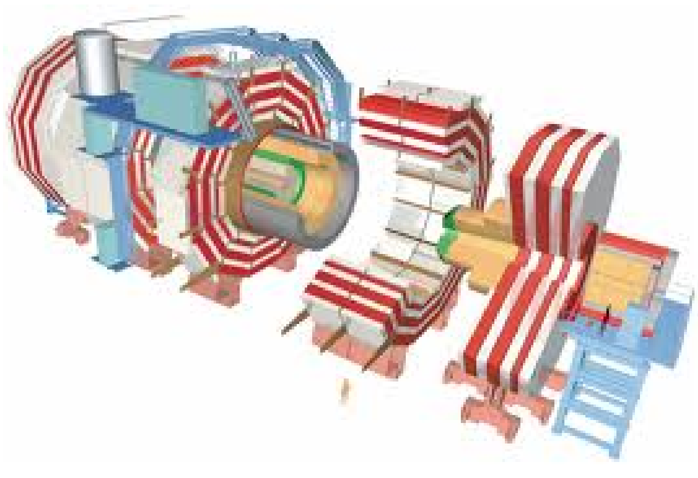


Figure 1: The CMS detector.

3 Particles ID

The various detectors provide different information about muons and jets so that is useful to classify them in collections. The collections of muons [3] and jets [4] used in this analysis, along with their descriptions, are displayed in Table 1. The algorithm used to reconstruct jets is the 'anti-k_t' algorithm, it essentially behaves like an idealised cone algorithm, in that jets with only soft fragmentation are conical.

Collection	Description
selectedPatMuons	Track in the muon chambers
globalMuons	Track also in the inner tracking system and ECAL/HCAL energy deposit
selectedPatJets	Track in ECAL and HCAL
selectedPatJetsAK5PF	Track also in the tracker using Particle Flow algorithm

Table 1: Description of muons and jet collections

In order to improve the purity of the plots and to get rid of background I applied these cuts for **muons**:

- $p_T > 20GeV$
- $|\eta| < 2.1$
- χ^2 of the tracks fit < 10
- number of hits in the inner tracker > 10

On the other hand the cuts applied on the **jets** are:

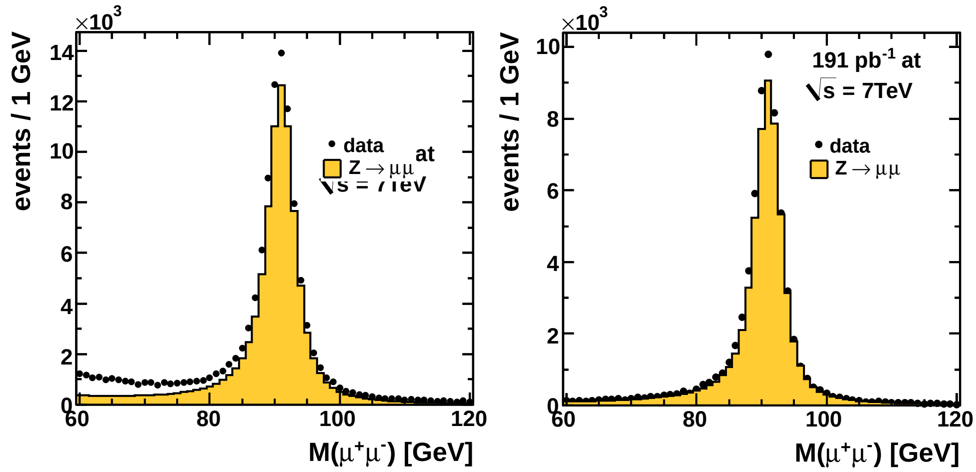
- $p_T > 20GeV$ and $p_T > 30GeV$
- $|\eta| < 2.4$
- no overlap with muons

As a result several data samples are produced according to the cuts selected so, for brevity reasons, I will show the histograms without any cuts and the histograms with the tightest cuts applied.

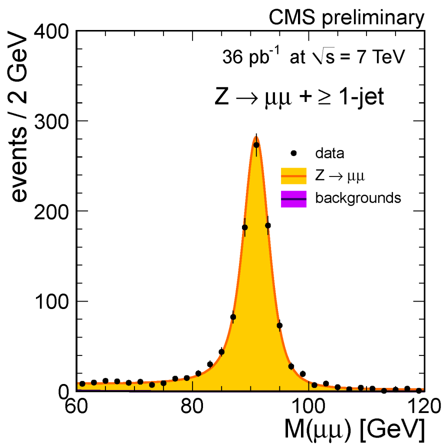
4 Analysis

4.1 Vector boson invariant and transverse mass

The invariant mass of any pair of opposite charge muons (Z candidate) in an event, compared with the MonteCarlo and the CMS approved plot, are shown in Figure 2.



(a) Z candidate invariant mass without cuts and after the tightest cuts



(b) CMS approved plot

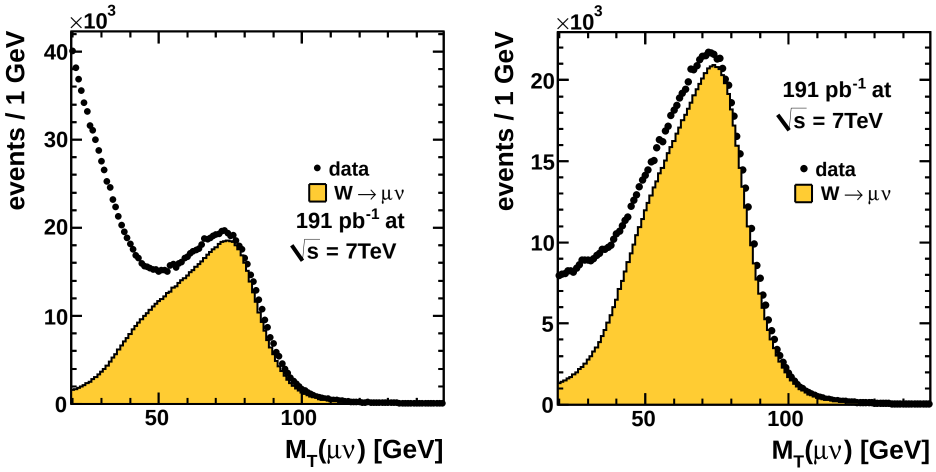
Figure 2: Z candidate invariant mass

It is clear how the tightest cuts on muons remove the background present in the plot without any cut, so that in order to improve the particles selection, henceforth a 'Z event' refers to an event in the region $80GeV < M(\mu^+\mu^-) < 100GeV$ of the right plot of Figure 2(a). The agreement between data and MonteCarlo is perfect and the number of events observed in data is slightly higher than the one expected from MonteCarlo.

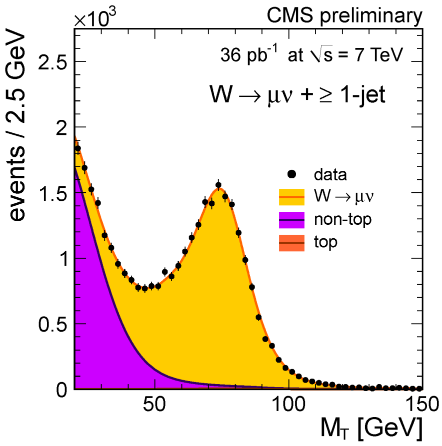
The transverse mass computed from the muon transverse momentum $p_t(l)$ and the missing transverse momentum $p_t(\nu)$ according to the formula

$$M_t^2 = 2 \cdot p_t(l) \cdot p_t(\nu) \cdot [1cos(\varphi(l)\varphi(\nu))] \tag{1}$$

is shown in Figure 3, compared with the MonteCarlo and the CMS approved plot.



(a) Transverse mass without cuts and after the tightest cuts



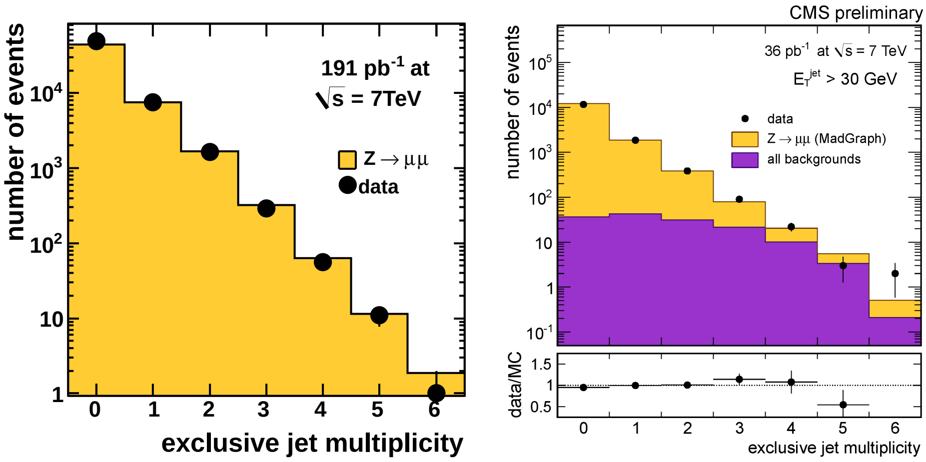
(b) Transverse mass from CMS approved plot

Figure 3: W candidate transverse mass

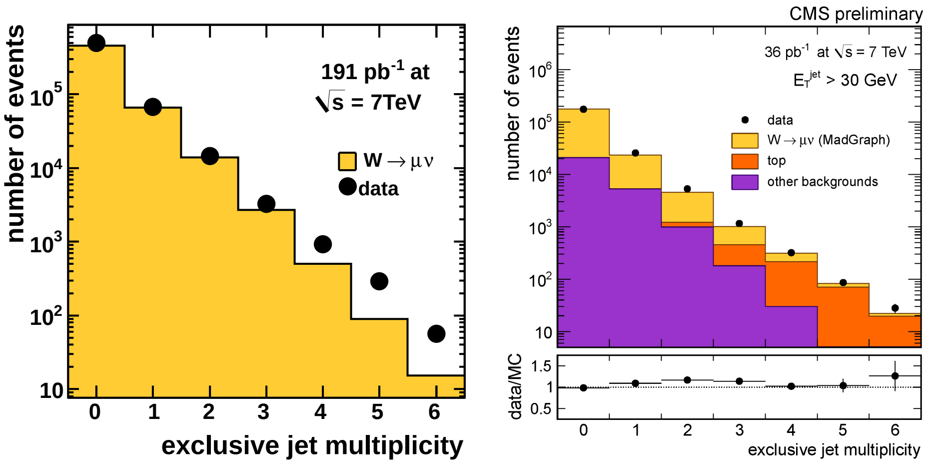
It is evident how the tightest cuts get rid most of the background corresponding to the purple region in Figure 3(b). In order to improve the particles selection, henceforth a 'W event' refers to an event in the region $60GeV < M(\mu\nu) < 100GeV$ of Figure 3(a), in which the agreement between data and MonteCarlo is perfect

4.2 Jets variables

The jet multiplicity for Z and W, compared with the CMS approved plot, is shown in Figure 4.



(a) Exclusive jet multiplicity in Z events

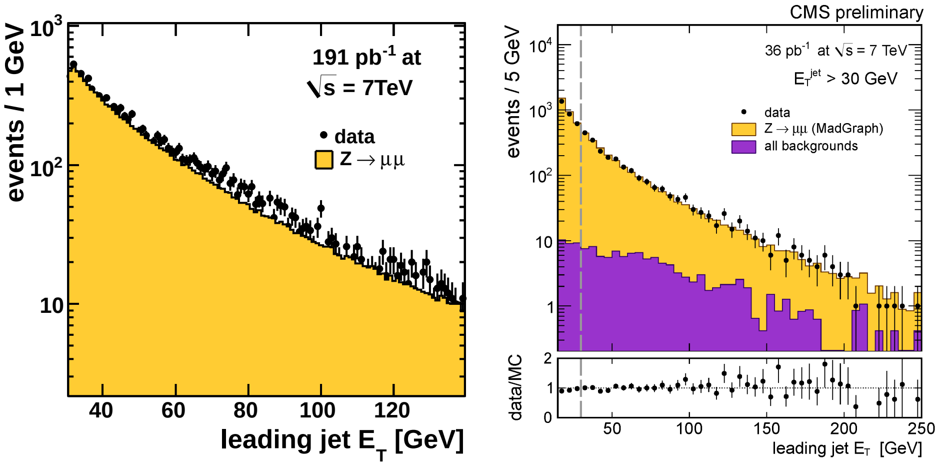


(b) Exclusive jet multiplicity in W events

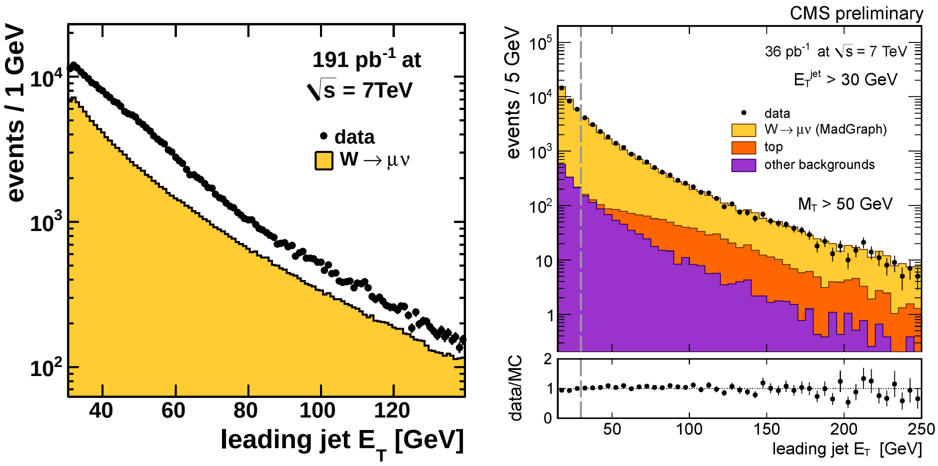
Figure 4: Exclusive jet multiplicity

The agreement between data and MonteCarlo is very good in the Z events (Figure 4(a)); instead, because of the larger mass window taken into account for the W boson, we see an excess of events in the W events from data sample, which is most presumable due to the $t\bar{t}$ production (Figure 4(b)).

The transverse energy of the leading jet in Z events and in W events, compared with the CMS approved plot, is shown in Figure 5.



(a) Leading jet transverse energy in Z events

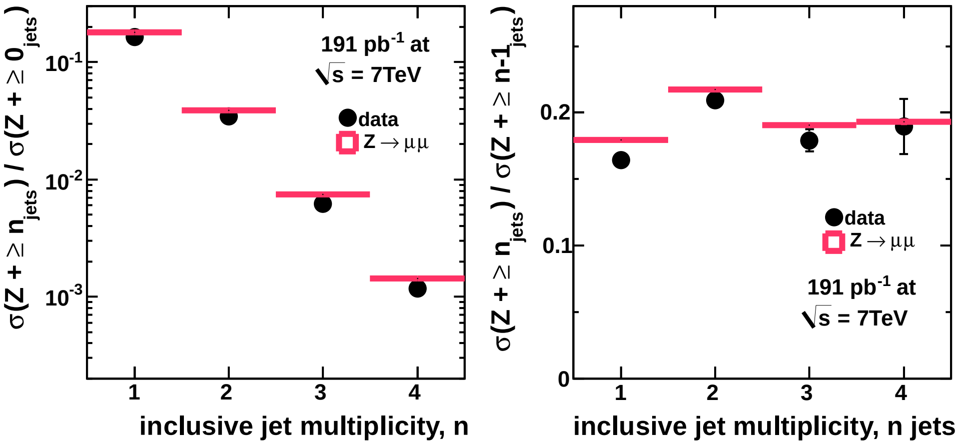


(b) Leading jet transverse energy in W events

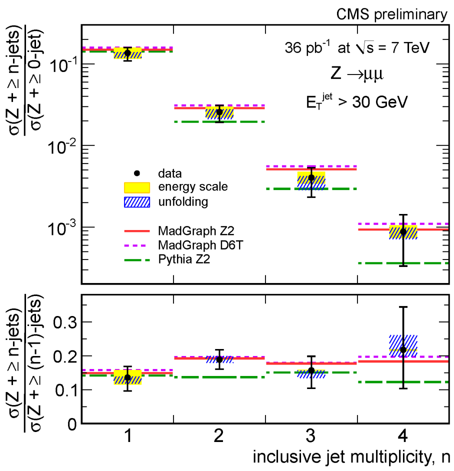
Figure 5: Leading jet transverse energy

The excess of events in the leading jet transverse energy in W events from data sample (Figure 5(b)) is not completely understood, probably is due to misreconstruced muons in the data or missing backgroun in the MonteCarlo, so that a tighter selection is needed, such as removing the overlap with electrons belonging to QCD background.

The cross sections of a Z event with n or more jets normalized to the inclusive Z cross section, and the ratio of a Z event with n or more jets over a Z event with n-1 or more jets, compared with the CMS approved plot, is shown in Figure 6.



(a) Berends-Giele scaling

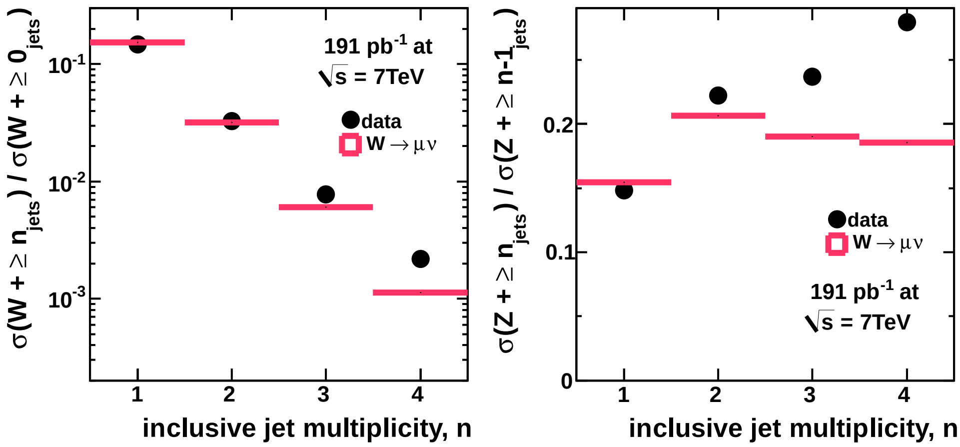


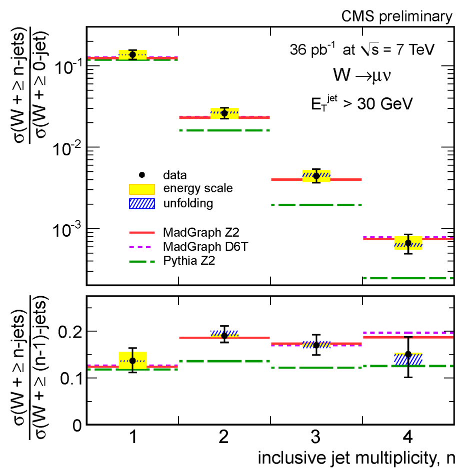
(b) CMS approved plot

Figure 6: Berends-Giele scaling for Z boson

The linear trend in the logarithmic scale histogram and the constant trend in the other histogram of Figure 6(a) are expected from the so called Berends-Giele scaling [5].

The cross sections of a W event with n or more jets normalized to the inclusive W cross section, and the ratio of a W event with n or more jets over a W event with n-1 or more jets, compared with the CMS approved plot, is shown in Figure 7.





(b) CMS approved plot

Figure 7: Berends-Giele scaling for W boson

Once again the agreement between data and MonteCarlo in the Z events (Figure 7(a)) is optimal, while the excess of events with more than 4 jets in the data sample (Figure 7(a)) is due more likely to the $t\bar{t}$ production.

5 Results

In order to calculate the cross section of the two processes $\sigma(Z \to \mu\mu)$ and $\sigma(W \to \mu\nu)$, the following formulas have been used:

$$\sigma(Z \to \mu\mu) = \frac{N^{data}_{Z\to\mu\mu}}{L\cdot A\cdot \varepsilon_{sel}} \tag{2}$$

$$\sigma(W \to \mu\nu) = \frac{N^{data}_{W\to\mu\nu}}{L\cdot A\cdot \varepsilon_{sel}} \tag{3}$$

where L is the luminosity of the data sample, $\sim 191pb^{-1}$, A and ε_{sel} are respectively the acceptance and the selection efficiency derived from the MonteCarlo sample.
The results are shown in Table 5.

$\sigma(nb)$	**data**	**CMS**	**NNLO theory prediction [6]**
$Z \to \mu\mu$	1.105	0.968	1.016
$W \to \mu\nu$	10.850	10.18	10.162

Table 2: Cross sections results

6 Conclusions

In general a very good agreement was found between data and MonteCarlo, expecially in the Z events; to achieve the same results in the W events as well a further analysis on the backgrouns is required, such as a check on the jet-electron overlap.
More than once the signal of $t\bar{t}$ was observed in $W + n_{jets}$ events and the cross section calculated from data is $5 - 10\%$ higher than the one expected.

References

[1] https://twiki.cern.ch/twiki/bin/viewauth/CMS/MadGraphCMSPage

[2] CMS Collaboration, “The CMS experiment at the CERN LHC”, JINST 0803:S08004,2008.

[3] http://cmslxr.fnal.gov/lxr/source/DataFormats/MuonReco/src/MuonSelectors.cc

[4] http://cmslxr.fnal.gov/lxr/source/DataFormats/JetReco/src/Jet.cc

[5] F. A. Berends,W. T. Giele, H. Kuijf et al., Multi-jet production inW, Z events at p anti-p colliders, *Phys. Lett.* **B224** (1989) 237. doi:10.1016/0370-2693(89)91081-2.

[6] https://twiki.cern.ch/twiki/bin/viewauth/CMS/StandardModelCrossSections

[7] The ROOT team, *"ROOT: An Object Oriented Data Analysis Framework Users Guide 5.26"*, http://root.cern.ch/