PROCEEDINGS OF SCIENCE

W+jets and Z+jets studies with the CMS detector at the CERN LHC

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We present the preparatory work for the measurement of the W + jets / Z + jets ratio and the use of the Z + jets sample as a "candle" for physics and detector commissioning with the first LHC data at CMS. The studies target the early understanding of the W + jets and Z + jets production at the LHC. They provide handles for data-driven extraction of Standard Model backgrounds to New Physics searches, a direct probe of New Physics and a benchmark for testing relevant QCD calculations.

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1. Introduction

Important Standard Model (SM) and new physics (NP) processes at the LHC are expected to produce final states with a vector boson (VB = W, Z) and multiple jets. The VB + jets associated production has been used at the Tevatron both as a stringent test of perturbative QCD predictions and as a means to an accurate description of backgrounds to NP [1, 2]. VB + jets production at the LHC is an important background to Higgs production and NP searches with leptons, jets and missing transverse energy (MET) final states.

Within the SM, the VB $+\ n$ jets cross section is $\mathscr{O}(\alpha_s^n)$. The VB $+\ n$ jets over VB $+\ (n+1)$ jets yield ratio (C_{VB}) is then nearly constant as a function of n for $p\bar{p}$ $\sqrt{s} = 630$ GeV and $p\bar{p}$ $\sqrt{s} = 1.8$ TeV both at the parton level and in data, exhibiting Berends-Giele (BG) scaling [3, 4]. QCD predicts very similar accompanying final states for W+jets and Z+jets events, as one would naively expect, resulting in a double ratio $C_{\mathrm{W}}/C_{\mathrm{Z}} \equiv \frac{\mathrm{W}+n\ \mathrm{jets}/\mathrm{W}+(\mathrm{n}+1)\ \mathrm{jets}}{\mathrm{Z}+n\ \mathrm{jets}/\mathrm{Z}+(\mathrm{n}+1)\ \mathrm{jets}}$ consistent with 1, independent of jet multiplicity.

The purpose of this analysis is: i) to measure the double ratio at different jet multiplicities for pp collisions at $\sqrt{s} = 10$ TeV and to investigate to what extent the double ratio is, in fact, independent of jet multiplicity and ii) to provide a method of determining the W + jets absolute rate normalization in the higher jet multiplicities, using measurements of the absolute rate of Z + jets events. Uncertainties that grow rapidly with n substantially cancel in this ratio, along with systematics associated with the luminosity, parton distribution functions, detector acceptance and selection efficiencies.

We focus on the LHC startup in that all results assume $\mathscr{O}(100)$ pb^{-1} of data collected with the CMS detector [5] at a centre-of-mass energy $\sqrt{s} = 10$ TeV [6, 7].

2. Analysis Strategy

$W(\ell\nu)$+jets and $Z(\ell\ell)$+jets events are selected in electron and muon final states with an orthogonal, synchronized selection to maximize the cancellation of systematic uncertainties in the double ratio. This selection includes lepton reconstruction, identification, calorimetric and tracker isolation and requirements on reconstructed event primary vertex compatibility (See [6, 7] for details).

Several independent jet definitions are used in this analysis, including jets clustered from calorimeter cell constituents (calo-jets) and jets constructed exclusively from tracks (track-jets). These two independent jet types exhibit orthogonal detector systematics and probe different regions of phase space, corresponding to the properties of their associated sub-detectors.

Rather than using a "cut-and-count" approach for determining event yields as a function of jet multiplicity, Maximal Likelihood (ML) fits are used to simultaneously extract signal and background yields, providing maximal signal efficiency. The ML fits are based on the di-lepton invariant mass, $m_{\ell\ell}$, and the W transverse mass, M_T^W, for Z+jets and W+jets events, respectively. All the parameters used in the fits are determined in a fully data-driven way or floated, removing dependence on Monte Carlo simulations and making this approach appropriate for LHC start-up conditions [6, 7]. Example fits are shown in Fig. 1.

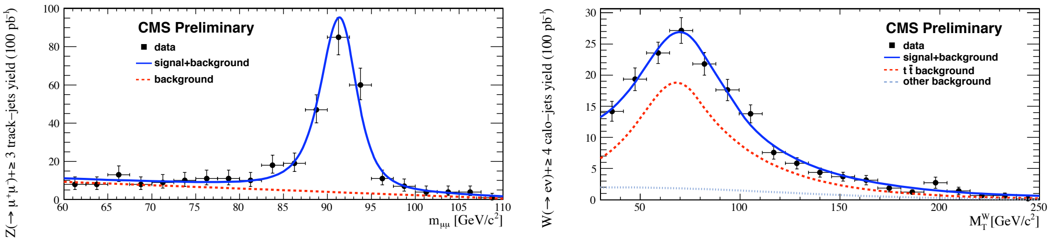

Figure 1: Projection of the likelihood at maximum on $m_{\mu\mu}$ in $Z(\mu\mu)+\geq 3$ track-jets events (left) and on M_T^W in $W(e\nu)+\geq 4$ calo-jets events (right).

3. Berends-Giele Scaling in W/Z+jets events

Example results showing yields for $W(\ell\nu)$+jets and $Z(\ell\ell)+jets$ are shown in Fig. 2, demonstrating that the properties of the N(VB+$\geq n$ jets)/N(VB+$\geq n+1$ jets) and ($W(\ell\nu)+n$ jets)/($Z(\ell\ell)+n$ jets) ratios can be measured with $\mathscr{O}(100)$ pb^{-1} of CMS data.

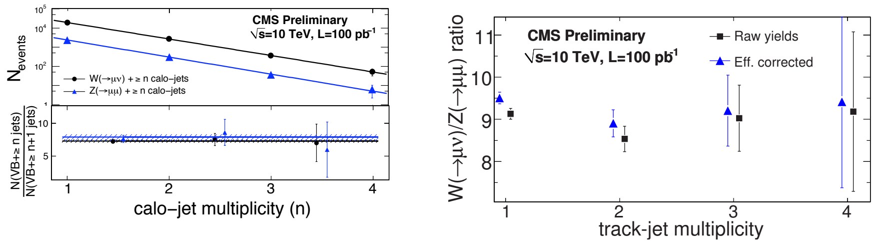

Figure 2: (dN/dn_{jet}) distribution and exponential fit for $W(\mu\nu)+$ jets and $Z(\mu\mu)+$ jets with calo-jet counting (left). Ratio of $W(\mu\nu)+$ jets to $Z(\mu\mu)+$ jets event yields as a function of track-jet multiplicity, with and without efficiency corrections (right).

NP processes that result in Z or MET and lepton final states with high jet multiplicities can result in measurable deviations from the expected BG scaling in Z and W + jets final states. We show in Fig. 3 (left) the effects of NP with Z final states on the $Z+\geq 3$ calo-jet event yield. Here, NP can be identified by comparing the direct measurement of this event yield with that predicted from the lower jet multiplicity measurements, assuming BG scaling. Similarly, if NP results in an excess of events with final states with MET, jets and leptons (characteristic of many BSM physics scenarios) then it's presence can be inferred by comparing measured yields in $W+\geq 3$ or 4 jets final states with predictions derived using the $W+\geq 1$ and 2 jet measurements, as shown in Fig. 3 (right).

4. The Z+jets Candle

The sPlot technique [9] can be used, in conjunction with the Z+jets di-lepton invariant mass ML fit, to produce and an effectively "signal-only" Z+jets data sample which can be used for physics and detector commissioning. For example, this sample can be used to predict the irreducible $Z(\nu\nu)$+jets background rates for MET and jets final state NP searches (Fig. 4 (left)) or to calibrate MET in $W(\ell\nu)$+jets events (Fig. 4 (right)).

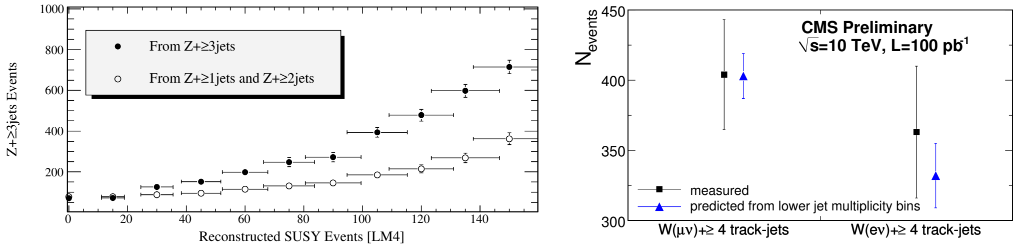

Figure 3: Comparison of the $Z(\mu\mu)+\geq 4$ track-jets measured yields compared with prediction using ≥ 1 and ≥ 2 jet yields assuming the LM4 SUSY benchmark model for NP events' contribution [8] (right). Comparison between the expected number of selected $W(\mu\nu)+\geq 4$ track-jets and the prediction based on the yields from lower jet multiplicities and the Z+jets slope (right).

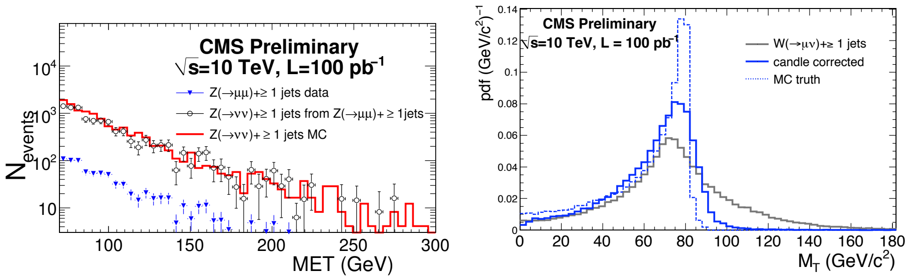

Figure 4: MET distribution of $Z(\nu\nu)+\geq 1$ calo-jet events compared with corresponding distribution derived from sPlots distribution of $Z(\mu\mu)+\geq 1$ calo-jet candle sample (left). The W transverse mass in $W(\mu\nu)+\geq 1$ calo-jet events before and after correcting MET with Z+jets candle corrections (right).

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