The Compact Muon Solenoid Experiment

CMS Note

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11 Jun 2007

Early Electroweak Measurements in CMS and ATLAS

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XLIInd Rencontres de Moriond EW 2007, La Thuile (Italy)
On behalf of the ATLAS and CMS Collaborations

Abstract

Electroweak processes will be extremely important during the first phases of the LHC programme. They will be used to calibrate the ATLAS and CMS detectors, to understand the underlying event environment and to obtain background control samples for a large variety of possible new-physics signals. A progressive scenario can be envisaged: large statistics samples of W and Z decays into leptons will be available for an integrated luminosity of 10 pb^{-1}. W and Z production accompanied by jets will be studied with 100 pb^{-1}, diboson signals like $pp \rightarrow \mathrm{WZ}$ will be observable with $150\,\mathrm{pb}^{-1}$ and a detailed understanding of the detector performance using $\mathrm{t\bar{t}}$ events could be possible with luminosities as low as $300\,\mathrm{pb}^{-1}$. Exploiting such a rich scenario is one of the objectives and challenges for the first year of LHC operation.

1 Introduction

Electroweak processes are important at the LHC for many reasons. On one hand, they can be considered as "known physics". The electroweak sector of the Standard Model has been precisely studied at previous colliders, like LEP, HERA and Tevatron [1], and analyses [2] at the Tevatron collider suggest that W, Z, Drell-Yan and top production at the LHC should be well under control. Electroweak reactions will be used as reference samples to calibrate the LHC detectors and understand their response to muons, electrons, photons and jets. They will also be used to quantify the performance of sophisticated tools like b-tagging.

On the other hand, electroweak processes are not so well known processes. LHC collisions will explore a new energy domain. Basic ingredients in any physics study are the parton density functions (PDFs), calculated for the corresponding parton fraction value and at the relevant energy scale of the process. Of particular importance at the LHC are the gluon PDFs, due to their dominance in many physics processes (Higgs and top production, for instance). At present, this gluon component is one of the largest sources of PDF uncertainty at the LHC. Top physics is still in its early stages, and LHC should mark the start of a new phase of precision measurements for this sector.

We bring the attention to the fact that many new physics signals will have electroweak processes as dominant backgrounds. In many cases, the new physics signals will even contain Z, W, γ^* (Drell-Yan) or top decays in the final state. Therefore it is extremely important to understand electroweak contributions before claiming any discovery. This could be the case even at the earliest stages of the LHC, since the average center-of-mass energy explored at a 14 TeV pp collider is one order of magnitude above that of previous accelerators (LEP, Tevatron). Figure 1 illustrates this point. Even at an integrated luminosity of 1 fb^{-1} LHC will explore scales not accessible at Tevatron. The measurements in this region - with the present knowledge - will be dominated by uncertainties in the electroweak sector.

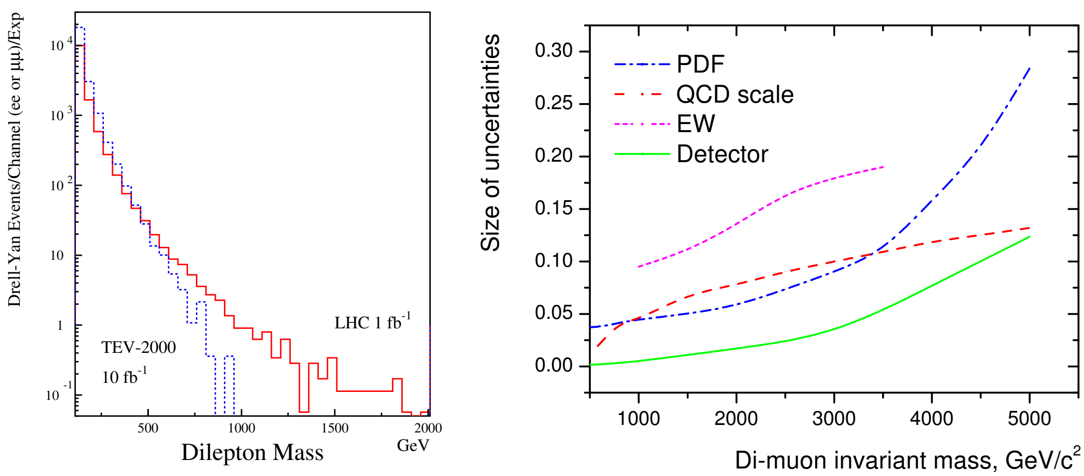

Figure 1: Early new physics searches at CMS with Drell-Yan processes. Electroweak and PDF uncertainties are the dominant sources of systematic uncertainties at high invariant masses (CMS).

2 Inclusive Z and W production

Decays of W and Z bosons into leptons will be the first electroweak signals to be exploited at the LHC. Thanks to their large cross sections (above 10 and 1 nb, respectively), thousands of W and Z leptonic decays will be already at our disposal for integrated luminosities as low as 1 pb^{-1}.

New studies on these channels can be found in the recently released Physics TDR [3] of the CMS collaboration. The emphasis has been put in a start-up oriented selection of samples with high purity. The criteria are chosen to be minimally dependent on calibration uncertainties or possible imperfections in the detector response. Figure 2 illustrates the $Z \to \mu\mu$ case. In order to avoid potential systematic biases due to an imperfect matching with the inner tracking system or inefficiencies in the muon system, one of the muons is identified as an isolated track with high transverse momentum (p_t). The high efficiency of the dimuon trigger in $Z \to \mu\mu$ events can be used to estimate the single muon efficiency in $W \to \mu\nu$ events. Conversely, $Z \to \mu\mu$ events fired only by the single muon trigger can be used to study possible regional inefficiencies in the muon trigger system. In summary, a loose approach at the selection level gives enough lever arm to study detector performances and inefficiencies in detail.

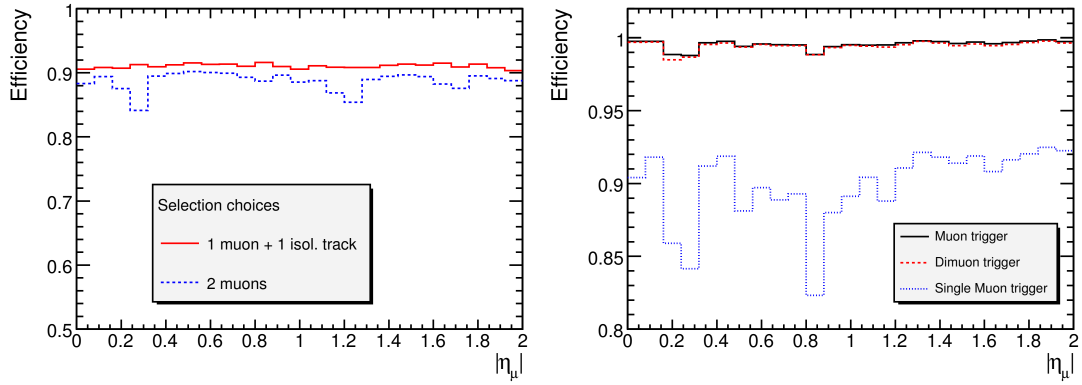

Figure 2: Selection of $\mathrm{Z} \rightarrow \mu\mu$ events in CMS. On the left, one can observe the better and uniform coverage obtained as a function of pseudo-rapidity by relaxing the selection criteria on one of the muons in the event. The plot on the right shows the level of trigger redundancy in the sample.

CMS assigns experimental systematic uncertainties of 1.1% and 2.2% for the $pp \rightarrow \mathrm{Z} + X \rightarrow \mu\mu + X$ and $pp \rightarrow \mathrm{W} + X \rightarrow \mu\nu + X$ measured cross sections, respectively. The overall uncertainty is larger (2.3% and 3.3%), due to theoretical uncertainties in the determination of the acceptance, and in particular in the description of the p_t spectrum of the boson. In the absence of detailed studies and comparisons with data for new next-to-leading-order Monte Carlos (NLO) like MC@NLO [5], a systematic uncertainty of $\sim 2\%$ was assigned from the difference between the acceptances obtained with a leading-order Monte Carlo (HERWIG [4]) and MC@NLO. The differences in the p_t spectra of the selected muons are shown in Figure 3.

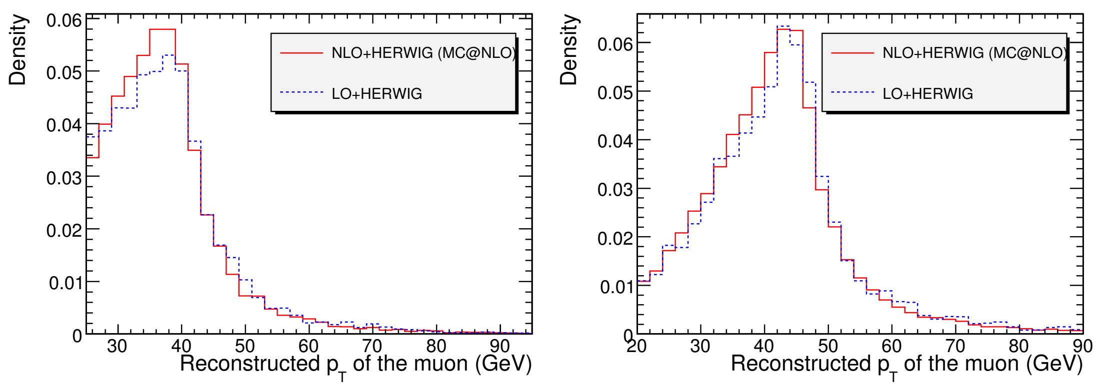

Figure 3: Muon p_t spectrum for $\mathrm{W} \rightarrow \mu\nu$ (left) and $\mathrm{Z} \rightarrow \mu\mu$ (right) events. The differences in shape between the predictions of leading-order (LO) and next-to-leading-order (NLO) Monte Carlos is visible. All histograms are normalized to 1. In the CMS studies, the difference in acceptance between the LO and NLO cases is assigned as a theoretical uncertainty ($\sim 2\%$).

Another important source of theoretical uncertainties is the choice of PDFs. PDF uncertainties have a limited impact on the acceptance ($< 1\%$ for $|\eta| < 2.1$), and therefore on the experimental measurement. However, their effect on the absolute normalization of the signal is rather large, of order $5 - 7\%$ [6]. Let us note that these uncertainties can not be easily reduced, since they manifest as a global normalization factor, largely uncorrelated with variations in shape in the fiducial volume used [6]. Unless more precise PDF sets (from HERA, for instance) become available in the next future, this will be a limiting factor in comparisons between experiment and theory, as well as in measurements of the luminosity via $\mathrm{W} \rightarrow \mu\nu$ and $\mathrm{Z} \rightarrow \mu\mu$ event counting.

3 W/Z plus jets measurements

Besides its intrinsic interest as a QCD measurement, W and Z production accompanied by jets will be a unique tool to understand the typical underlying jet-event structure at the LHC and to reduce jet energy scale uncertainties (via Z + jets). This type of events are also one of the dominant backgrounds in new physics searches with leptons in the final state, as well as in top precision studies. Compared with Tevatron, the cross sections for these channels are higher. On the negative side, semileptonic top decays constitute a significant background component for W + jets at the LHC.

The CMS collaboration has recently released a study of W/Z plus jets associated production for transverse jet energies $E_T > 50$ GeV [7]. The basic ingredients of the analysis are: a) a consistent and robust definition of a jet in the selected events and b) very stringent lepton isolation criteria in order to suppress QCD backgrounds. The numbers of selected events for an integrated luminosity of 1 fb^{-1} are shown in Tables 1 and 2. Let us note that, even with luminosities as low as 100 pb^{-1}, a significant measurement of the $\mathrm{Z} + 4$ jets cross section is possible.

Table 1: Number of selected events and breakdown of the different background components in the W + jets analysis of CMS [7]. An integrated luminosity of 1 fb^{-1} is assumed. Top backgrounds are comparable of even larger than the signal for $\mathrm{W}+ \geq 3$ jets.

Channels	W $\geq$ 1 jet	W $\geq$ 2 jet	W $\geq$ 3 jet	W $\geq$ 4 jet
W + jets (signal)	260652	56702	10964	2164
Z + jets	9340	3237	972	259
$\mathrm{t\bar{t}}$ + jets	12897	11842	9052	5420
WW/WZ/ZZ + jets	1077	714	386	151
Total	283966	72495	21374	7994

Table 2: Number of selected events and breakdown of the different background components in the Z + jets analysis of CMS [7]. An integrated luminosity of 1 fb^{-1} is assumed. Compared to the W + jets case, the relative contributions of the different backgrounds, and in particular of $\mathrm{t\bar{t}}$, are negligible.

Channels	W $\geq$ 1 jet	W $\geq$ 2 jet	W $\geq$ 3 jet	W $\geq$ 4 jet
Z + jets (signal)	35109	6185	977	156
$\mathrm{t\bar{t}}$ + jets	64	58	49	32
WW/WZ/ZZ + jets	33	17	5	2
Total	35206	6260	1031	190

4 Diboson production

Both ATLAS and CMS collaborations have carried out studies on diboson production with leptons in the final state. Even if one of main purposes of these studies is to evaluate the LHC potential to measure anomalous triple-gauge boson couplings, the main objective for the start-up phase is to measure the diboson cross sections at these new energies. These processes are also the dominant backgrounds in critical new physics searches, like $\mathrm{H} \rightarrow \mathrm{WW} \rightarrow$ leptons or $\mathrm{H} \rightarrow \mathrm{ZZ} \rightarrow$ leptons.

Table 3 shows the preliminary ATLAS [8] result for the $\mathrm{WZ} \rightarrow$ leptons channel. Figure 4 shows the equivalent analysis reported by CMS in its TDR [3]. Significant observations (at $> 5\sigma$ level) of WZ and ZZ production are expected in CMS for integrated luminosities of 150 pb^{-1} and 1 fb^{-1}, respectively.

Table 3: Number of selected signal an background events in a preliminary study of WZ production of the ATLAS collaboration [8]. An integrated luminosity of 1 fb^{-1} is assumed. Numbers for the different leptonic final states used in the analysis are also given.

WZ production	N_{eee}	$N_{ee\mu}$	$N_{\mu\mu e}$	$N_{\mu\mu\mu}$	$N_{total}(1\ \mathrm{fb}^{-1})$
Signal	16.9	17.1	21.9	19.8	75.7
Background	1.71	0.88	1.73	2.00	6.32
Significance	12.9	18.2	16.7	14.0	30.1

5 Top production

The predicted $pp \rightarrow \mathrm{t\bar{t}}$ cross section at the LHC is huge (800 pb). It is two orders of magnitude larger than the cross section measured at the Tevatron, due to the dominance of the gluon production mechanism $pp \rightarrow gg \rightarrow \mathrm{t\bar{t}}$.

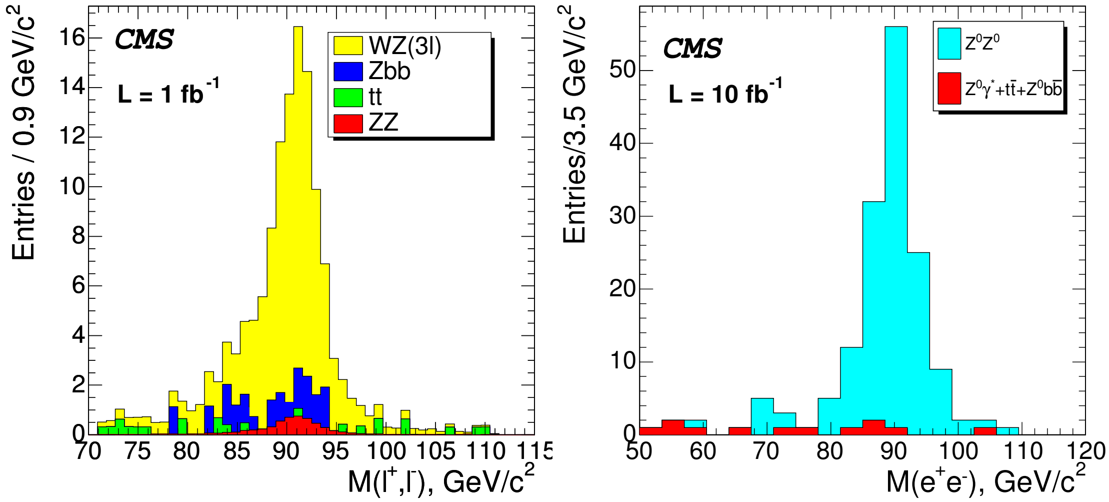

Figure 4: Z reconstructed mass obtained in CMS studies of WZ and ZZ production with leptons in the final state. Observations at the 5σ level are already possible with luminosities of 150 pb^{-1} (WZ) and 1 fb^{-1} (ZZ).

Understanding top production requires a good understanding of the response of the whole detector. Given the high statistics that will be available in the early phases, the reverse will become true at the LHC: relatively pure samples of $\mathrm{t\bar{t}}$ events will be used to understand a wide spectrum of detector-related issues. Lepton identification and isolation, jet energy scales, missing transverse energy and b-tagging performance are some examples.

Both ATLAS and CMS collaboration are considering progressive scenarios as a function of the integrated luminosity $\mathcal{L}$, which can be summarized as follows:

- $\mathcal{L} = 20{-}30\ \mathrm{pb}^{-1}$: with this luminosity, studies similar to those currently under way at Tevatron are possible. Focusing on final states containing leptons and measuring cross sections for the first time at the LHC would be the main objectives of this phase.
- $\mathcal{L} = 200 - 300\ \mathrm{pb}^{-1}$: strategies and methods are established. More precise measurements of the cross sections and first measurements of the top mass should be available. This is the phase where detector effects will be studied in detail for the first time.
- $\mathcal{L} \sim 1\ \mathrm{fb}^{-1}$: an optimal understanding of the detector response is expected. Full exploitation of the physics potential is the main objective. This phase should mark the beginning of a top-physics precision era, with accurate measurements of the top mass and couplings.

Figure 5 (ATLAS) shows an example of the accuracies ($\sim 1\%$) that can be reached in the calibration of the jet-energy scale using $\mathrm{t\bar{t}}$ events [9]. The energy scale is determined from a χ^2 fit on a pure sample of W-bosons decaying into jets. The well known value of the W-mass is used as the main constraint.

Figure 5 also shows an example of b-tagging studies in CMS using $\mathrm{t\bar{t}}$ events [10]. B-enriched jet samples are obtained in $\mathrm{t\bar{t}}$ events by applying stringent leptonic criteria (all lepton samples) or criteria minimally dependent on lifetime tracking information ("semileptonic" samples). This allows the determination of b-tagging efficiencies in data as a function of the jet energy and pseudorapidity with uncertainties better than 10% for luminosities of the order of $1\ \mathrm{fb}^{-1}$.

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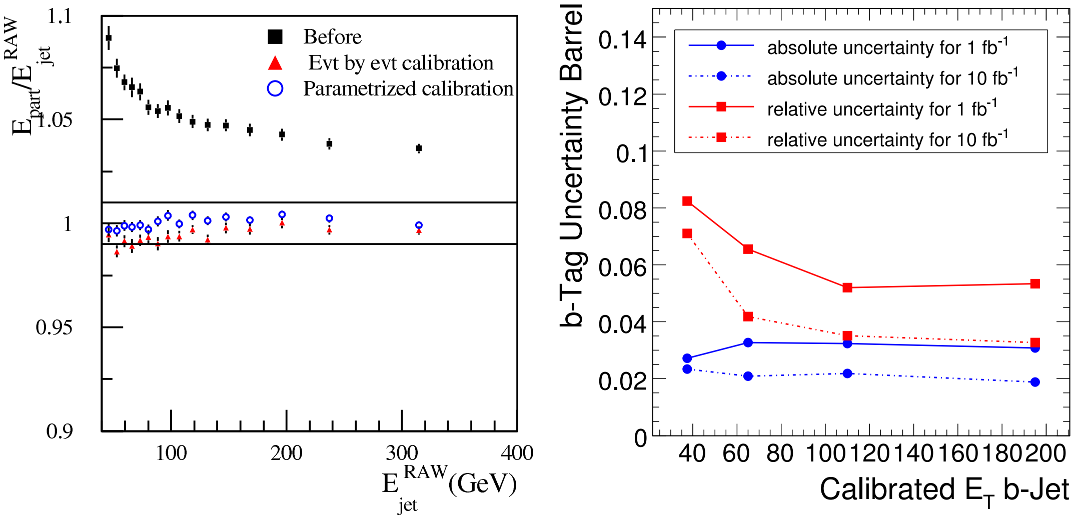

Figure 5: Examples of detector-related studies using $t\bar{t}$ events with an integrated luminosity on $1\ \mathrm{fb}^{-1}$.. Left: jet energy calibration at the 1% level using W mass constraints (ATLAS). Right: determination of b-tagging efficiencies with uncertainties better than 10% (CMS).

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