SUSY searches in early CMS data

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Abstract. In the first year of data taking at LHC, the CMS experiment expects to collect about 1 fb^{-1} of data, which make possible the first searches for new phenomena. All such searches require however the measurement of the SM background and a detailed understanding of the detector performance, reconstruction algorithms and triggering. The CMS efforts are hence addressed to designing a realistic analysis plan in preparation to the data taking. In this paper, the CMS perspectives and analysis strategies for Supersymmetry (SUSY) discovery with early data are presented.

1. Introduction

One of the main goal of the Compact Muon Solenoid (CMS) [1] physics program is to investigate the mechanism of the electroweak symmetry breaking. The Standard Model (SM) [2] provides a successful description of the existing data but it is usually considered as a low-energy effective theory with some intrinsic deficiencies. The Supersymmetry (SUSY) [3] is one of the most appealing extension of the SM. It proposes an elegant solution to the so called "hierarchy" problem and provides a good candidate for the dark matter in cosmology, though at the expense of additional parameters of the theory.

The CMS potential to discover SUSY are mainly analysed in the more constrained framework of the Minimal Supergravity (mSUGRA) [4] model with only 5 free parameters: the common scalar (m_0) and fermion ($m_{1/2}$) masses, the trilinear coupling (A_0) and the Higgs sector parameters ($tan\beta$, $sgn\mu$) at the Grand Unification (GUT) scale. In mSUGRA, assuming R-parity, new supersymmetric particles are produced in pairs and the lightest one (LSP) is stable and neutral. At the LHC, the SUSY production is dominated by squarks and gluinos, which have long decay cascades with jet emission. The cascade ends with the LSP, which is not detected. Therefore, the most generic SUSY signature is a multi-jet with large missing energy ($\not\!\!E_{\mathrm{T}}$) final state. Leptons produced in decays of charginos or neutralinos can be present, hence also final states with n $\geq$ 1 leptons+jets+$\not\!\!E_{\mathrm{T}}$ are considered. The main backgrounds are QCD and $\mathrm{t\bar{t}}$, W and Z with QCD-jet associated production processes. Finally, diboson production, such as WW+jets, WZ+jets, and ZZ+jets, also contribute as sources of background. Considering signatures with at least one lepton, substantially reduces the QCD background.

The results presented here are obtained with the full CMS detector simulation and reconstruction as well as with the fast simulation. The analysis is aimed to quantify the CMS reach and the main effort in the last months has been devoted to set up a robust analysis strategy aimed to rely as less as possible on Monte Carlo information as well on particular model assumptions. To this purpose a detailed study of backgrounds and systematic effects has been done.

2. Background rejection and analysis strategy

2.1. Missing energy clean-up

In anticipation of real data, a pre-selection clean-up procedure is used to reject accelerator and detector related backgrounds and cosmic ray events. Based on the Tevatron experience, to clean the high P_T multi-jet+$\not{E}_T$ sample, at least one primary vertex is required in the event and two variables are used to distinguish between real and fake $\not{E}_T$:

- F_{em}, the event electromagnetic fraction, defined as the E_T weighted jet electromagnetic fraction sum over the electromagnetic calorimeter acceptance, $|\eta| \leq 3$
- F_{ch}, the event charged fraction, defined as the sum of the P_T of the associated to the jet tracks for jets within $|\eta| \leq 1.7$, over the calorimetric jet transverse energy.

2.2. Missing energy in QCD events

Due to the very high QCD production cross section, the main background for the jets+$\not{E}_T$ channel is dominated by QCD events with large missing transverse energy resulting from jet mismeasurements and detector resolution effects. Topological variables are used to reduce as much as possible the QCD background, in particular the angular correlation between the first two jets (ordered in E_T) and the $\not{E}_T$ direction is used. After a baseline selection of $N_{jet} \geq 2$ and $\not{E}_T > 93$ GeV the cumulative efficiency of the angular requirements is $\sim 90\%$ for the SUSY signal while rejecting $\sim 85\%$ of all QCD events.

2.3. The Z boson candle calibration

Events with large missing transverse energy and ≥ 3 jets in the final state are expected from $Z(\rightarrow \nu\overline{\nu})+ \geq 3$ jets and $W(\rightarrow \tau\nu)+ \geq 2$ jets processes with additional residual contribution from $W(\rightarrow \mu\nu, e\nu)+ \geq 3$ jets. Monte Carlo predictions for the rate of $Z+ \geq 3$-jets events can be normalised to the observed rate of $Z(\rightarrow \mu\mu) + 2$-jets in real data via the measured $R = \frac{dN_{\text{events}}}{dN_{\text{jets}}}$ ratio. In addition, the ratio $\rho \equiv \frac{\sigma(pp \rightarrow W(\rightarrow \mu\nu)+jets)}{\sigma(pp \rightarrow Z(\rightarrow \mu^+\mu^-)+jets)}$ can be used to normalise the W+jets Monte Carlo predictions. By normalizing the MC predictions to real data, large systematic effects are avoided (i.e. due to the renormalization scale, the choice of parton density functions, jet energy scale, etc.). The total uncertainty is estimated to be $\sim 5\%$ and is dominated by the uncertainty on the luminosity measurement, the uncertainty on the measured ratios R and ρ as a function of the jet multiplicity. The details of the normalization can be found in Ref. [5].

2.4. SUSY analysis strategies

The inclusive and semi-inclusive SUSY searches employ the following strategy. First, experimental signatures are studied for a limited number of test points of mSUGRA parameter space using the full detector simulation and reconstruction software. For all the analyses presented here results have been optimized at the LM1 ($m_0 = 60$ Gev/c^2, $m_{1/2} = 250$ Gev/c^2, $tan\beta = 10$, $A_0 = 0$, $\mu > 0$) benchmark-point. Next, the results are extended to other points of the parameter space using fast simulation and reconstruction. In order to obtain the best signal to background (S/B) ratio the SUSY selection cuts are optimised for each point. The expected discovery reach is evaluated for parameter sets having at least five standard deviation (5σ) signal significance. As can be seen from Fig. 1, several different final states have been considered. Further details of the full studies performed by CMS, which form the basis for this brief summary, may be found in [5].

The multi-jets +$\not{E}_T$ final state remains a canonical signature for SUSY because it is expected to be the most sensitive search strategy. Events which pass the missing transverse energy plus jet trigger path are used in this analysis [5, 6]. Following the application of the clean-up procedure described above together with appropriate selection cuts, SUSY events are selected with 26%

efficiency and, for 1 fb^{-1} of collected data, an estimated total of 6319 signal events against 244.5 background events are expected.

Signatures involving at least one lepton are less sensitive, but experimentally cleaner and have the advantage of an efficient and well-understood trigger shortly after LHC start-up. Topological requirements on the jets and missing energy are similar to the fully inclusive analysis. For 1 fb^{-1} of data, 31.1 signal events are expected to be selected in the multi-jets $+\not\!\!E_\mathrm{T} + 1\mu$ final state with an estimated background of 0.25 ± 0.05 events.

Requiring an additional, same sign (SS) isolated muon or looking for same flavour opposite sign (SFOS) dilepton pairs provides an even cleaner signature, allowing the intriguing possibility of selecting particular SUSY diagrams. The SFOS dilepton final state is particularly interesting since leptons (electrons and muons) from the $\tilde{\chi}^0_2$ decay exhibit a peculiar l^+l^- invariant mass distribution with a sharp edge, as shown in Fig. 2. The reconstruction of the dilepton [7] edge provides information on the sparticles involved in the decay chain and constitute a good indication of new physics especially in the early data taking period.

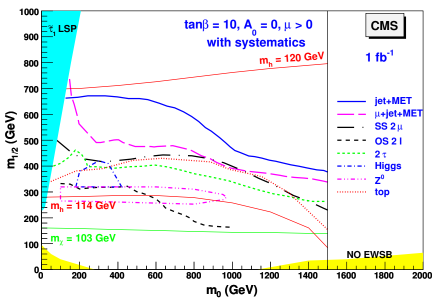

Figure 1. The mSUGRA discovery reach for 1 fb^{-1} of collected data for several search strategies studied by CMS (including systematic uncertainties) as presented in Ref. [5].

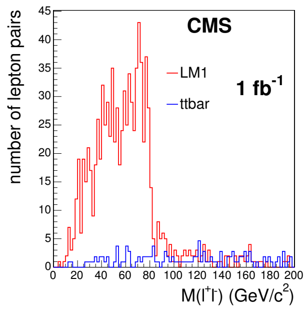

Figure 2. Same flavour opposite sign lepton pair distributions of SUSY and $t\bar{t}$ events for 1 fb^{-1}. The peculiar triangular edge is clearly visible at point LM1.

3. Results and conclusions

The initial phase of running will be crucial for CMS: the detector should be understood and calibrated and the SM processes will have to be measured. Provided that we succeded in such huge but exciting program, the search for new physics will start. The CMS collaboration is getting ready for that fascinating period, by validating the software and preparing data analysis while installing the detector. In all the channels considered up to now, we have demonstrated that, including systematic uncertainties, with an integrated luminosity of 1 fb^{-1}, we should be able to cover all of the low mass region and SUSY mass scales of up to ~ 14 TeV/c^2 can be probed. The analysis effort in the next months before the start of LHC will be devoted to develop robust selection criteria and analysis methods to avoid biases due to the large systematic uncertainties that we will have at the beginning.

References

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