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Prospects for early SUSY searches at LHC

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Summary. — Search for the physics beyond the Standard Model is one of the most relevant goals of the CMS and ATLAS experiments at Large Hadron Collider at CERN. Prospects for early R-parity conserving supersymmetry discovery and mass measurements with the CMS and ATLAS detector for the first fb^{-1} of data are presented. All the presented studies are based on realistic Monte Carlo simulations.

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1. – Introduction

Supersymmetry (SUSY) [1] is one of the most promising candidates for a new physics beyond the Standard Model (SM). In these models the spectrum of elementary particles is extended to include supersymmetric partners which differ from their Standard Model counterparts by half a unit of spin. Supersymmetry must be broken, as no superpartner was yet observed. If the scale of the SUSY mass scale is in the few TeV range, there is a very good chance that SUSY particles are detected at the LHC.

In this work Minimal Supergravity model (mSUGRA) was considered. It is characterised by four parameters and a sign: the scalar mass parameter m_0, the gaugino mass parameter $m_{1/2}$, the trilinear coupling A_0, the ratio of the Higgs vacuum expectation values $\tan\beta$ and the sign of the Higgs mass parameter μ. ATLAS [2] has chosen for study various experimentally challenging points (SU1 to SU8) [3] in the mSUGRA parameter space constrained by the latest experimental data. CMS [4] selected a set of low-mass (LM1 to LM9) test points [5] to evaluate the sensitivity to SUSY signal in the early period of the LHC but above the Tevatron reach.

The analyses presented here are based on an integrated luminosity of $1\,\text{fb}^{-1}$ and a center of mass energy of the LHC of 14 TeV.

2. – Inclusive searches

We assume a SUSY model with an absolutely conserved quantum number R-parity, which is 1 for SM particles and -1 for their SUSY partners. As a consequence SUSY

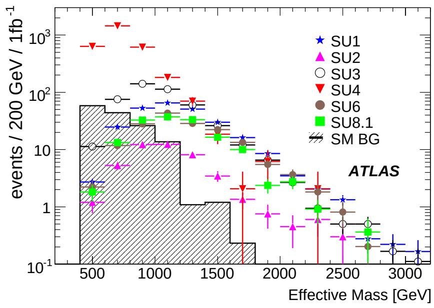

Fig. 1. – The $M_{\rm eff}$ distributions in the 1-lepton + 4-jets channel for each of the SUn benchmark points, and for the sum of the Standard Model backgrounds with $1\,{\rm fb}^{-1}$ of data. All selection cuts except $M_{\rm eff}$ are applied.

particles must be produced in pairs, and must cascade down to the lightest supersymmetric particle (LSP), which is stable, neutral and weakly interacting. This implies that the LSP escapes detector, and a typical feature of R-conserving SUSY is a large imbalance in the transverse energy measured in the detector ($E_T^{\rm miss}$). Strongly interacting particles, like squarks and gluinos, should be dominantly produced at the LHC if their masses are in the TeV range. Their decay products will be two LSP's and a number of Standard Model particles, in particular highly energetic quarks and gluons. Therefore typical R-conserving SUSY signatures will be missing transeverse energy, hard jets and possibly leptons. A simple variable incorporating all of these features and therefore able to distinguish SUSY from SM events is the effective mass $M_{\rm eff}$, defined as the scalar sum of $E_T^{\rm miss}$ and transverse momentum of the four highest p_T jets with $|\eta| < 2.5$ and all identified leptons. In order to claim a SUSY discovery a good understanding of the CMS and ATLAS detector performance as well as the SM background is also needed. Therefore for the estimation of the SM background in the reported SUSY analyses, beside Monte Carlo based techniques, the so-called "data-driven" methods which rely on data were also used.

Detailed studies have been carried out in ATLAS [3] for channels with: considerable $E_T^{\rm miss}$, 4 hard jets and 0-, 1- or 2-leptons (electrons, muons). These studies were tested on a set of fully simulated SUn ($n = 1, 2, 3, 4$) points in order to develop understanding on how best to reconstruct these events and to define strategies for separating signal from Standard Model background. After applying selection cuts described in detail in ref. [3], SUSY production is evident in the distribution of the effective mass. The most generic channel for SUSY searches is 0-lepton and 4-jet channel, but control of the QCD background and instrumental background for this channel might require time. Therefore the most promising channel for early searches is expected to be 1-lepton, 4-jet mode. Figure 1 shows distributions of $M_{\rm eff}$ for a set of SUn points and for the SM background in the 1-lepton and 4-jet channel with $1\,{\rm fb}^{-1}$ of data after applying all selection cuts except the one on $M_{\rm eff}$. Noticeable excess of SUSY events over SM background is observable at high effective mass values. The statistical significance in this channel after applying all selection cuts is above 5 for most of the considered test models.

The CMS Collaboration tested a new approach [6] to early SUSY searches in the channel with two highly energetic jets and missing transverse energy coming from the decay of directly produced squarks, where both squarks decay to a quark and the lightest neutralino $\tilde{q}\tilde{q} \to qq\tilde{\chi}_1^0\tilde{\chi}_1^0$. They defined kinematic variables that can discriminate

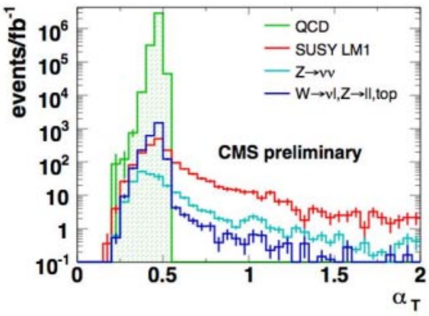

Fig. 2. – Distribution of α_T after all the selection cuts have been applied. With shaded area there is represented QCD background.

between signal and background without relying on the missing transverse energy from the calorimeters, an approach well suited for early data searches. One of the used kinematic variables is α_T, defined as the ratio of the transverse energy of the second most energetic jet in the event to the transverse mass of the two most energetic jets in the event, $\alpha_T = E_T^{j2}/M_T^{j1,j2}$ ($j1$ and $j2$ are the first and the second most energetic jet in the event, respectively). It is shown in fig. 2 for the point LM1 and the corresponding SM background. By asking $\alpha_T > 0.55$ most of the QCD background (shaded area in fig. 2) is removed. With $1\,\text{fb}^{-1}$ of data, after applying selection cuts described in ref. [6], signal-to-background ratio for the point LM1 is $S/B > 5$.

Several scans [3,5] of mSUGRA parameter space, based on parametrised simulations of the detectors, have also been carried out. The goal was to verify the CMS and ATLAS sensitivity to a possible early SUSY discovery. With $1\,\text{fb}^{-1}$ of understood data both ATLAS and CMS should be able to discover SUSY particles with masses of about 1 TeV.

3. – Exclusive measurements

Since in the final state of every SUSY decay chain there is the LSP particle, no invariant mass peak can be reconstructed. Invariant masses formed from the subsets of decay products have maxima and minima (kinematic endpoints) which are functions of the masses of the SUSY particles involved in the decay. With a sufficient number of measured endpoints the relevant sparticle masses can be determined.

Dilepton invariant mass endpoint, where leptons come from decay $\tilde{\chi}_2^0 \to l\tilde{l} \to ll\tilde{\chi}_1^0$ ($l = e, \mu$), can be measured with high precision. CMS performed studies [7] of this decay for the point LM1 with $1\,\text{fb}^{-1}$ of data. Reconstructed dilepton invariant mass has a linear rise and an abrupt edge at the kinematic limit. Different-flavour ($e\mu$) lepton combinations were used to estimate flavour-symmetric background to the ee and $\mu\mu$ combinations. Flavour asymmetric background comes from the dilepton events where a second lepton comes or from fake leptons or from heavy-flavour (b/c) decays, but their effect on the observation of the dilepton endpoint is small. Dilepton endpoint was fitted with a function which takes into account both signal and background data and the Z peak. Systematic uncertainties on the endpoint are found to be small. Fitted dielectron endpoint value is $m_{ee}^{\max} = 77.90 \pm 1.07(\text{stat.}) \pm 0.36(\text{syst.})\,\text{GeV}$, while in the case of dimuons the value is $m_{\mu\mu}^{\max} = 78.03 \pm 0.75(\text{stat.}) \pm 0.18(\text{syst.})\,\text{GeV}$ (theory predicts $m_{ll}^{\max} = 78.15\,\text{GeV}$). In fig. 3 dielectron and dimuon events fitted simultaneously are shown.

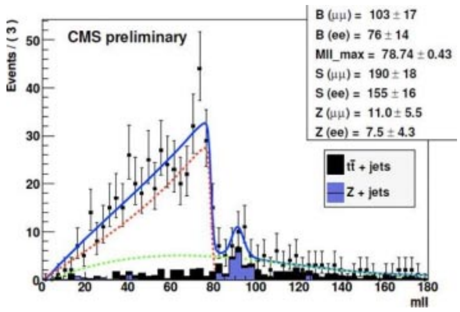

Fig. 3. – Simultaneous fit of the dielectron and dimuon masses (solid line) for $1\,\mathrm{fb}^{-1}$ of integrated luminosity. On the x-axis, units are GeV. The signal function (dark dashed line) and the flavour symmetric background function (light dashed line) components are shown superimposed, as extracted from the fit. The lepton cut $p_T > 20\,\mathrm{GeV}$ was imposed.

In large part of mSUGRA parameter space the second lightest neutralino $\tilde{\chi}_2^0$ is lighter than the squark and decay chain $\tilde{q}_L \to q\tilde{\chi}_2^0 \to ql\tilde{l} \to qll\tilde{\chi}_1^0$ is allowed. This decay chain when $l = e, \mu$ can be very accurately reconstructed. ATLAS performed studies [3] of this decay for the case of SU3 point with $1\,\mathrm{fb}^{-1}$ of data. From the final state particles few invariant masses were reconstructed: m_{ll}, m_{llq} and the two m_{lq} invariant masses. Endpoints of these distributions are given by simple formulas involving the masses of the intermediate SUSY particles. On each mass distribution flavour subtraction $N(e^+e^-)/\beta + \beta N(\mu^+\mu^-) - N(e^\pm\mu^\mp)$ with efficiency correction $\beta = 0.86$ (ratio of electron to muon reconstruction efficiency) was applied in order to eliminate SUSY combinatorial background and SM background from data. Reconstructed endpoints were fitted with appropriate functions. Figure 4 shows the fitted maximum of m_{llq} mass distribution. From this set of measured endpoints masses of the SUSY particles were determined, although with limited precision, due to the low assumed integrated luminosity.

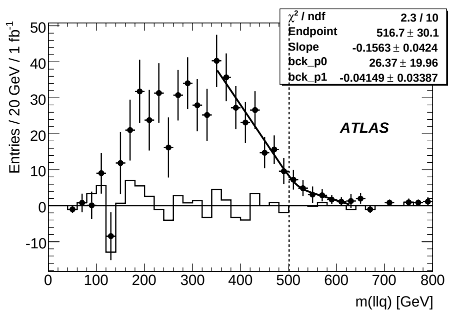

Fig. 4. – Efficiency-corrected flavour subtracted distributions of m_{llq} for SU3 for $1\,\mathrm{fb}^{-1}$ of integrated luminosity. The points with error bars show SUSY plus Standard Model, the solid histogram shows the Standard Model contribution alone. The fitted function is superimposed, the vertical line indicates the theoretical endpoint value.

4. – Conclusions

The analyses presented in this work show that CMS and ATLAS will be able to discover signal of R-parity conserving SUSY with masses of the order of 1 TeV with $1\,\text{fb}^{-1}$ of collected and understood data. Rough SUSY spectroscopy will also be possible. Higher precision and more difficult measurements will follow as the integrated luminosity will increase.

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