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SUSY searches at the LHC Run2

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Summary. — After a period of maintenance the LHC was restarted in 2015 delivering p-p collisions at a larger center of mass energy of 13 TeV. This new achievement by the machine opened the phase space of many searches for physics beyond the standard model (BSM). In this review a summary of the searches for supersymmetry (SUSY) pursued by the ATLAS and CMS collaborations is presented, covering a broad number of models and scenarios. Even at this early stage the new searches greatly extend the reach of the previous Run1 analyses limiting the phase space for natural SUSY to exist.

1. – Introduction

The discovery of the Higgs boson [1, 2] during the first LHC runs at 7 and 8 TeV was an important milestone in high energy physics (HEP) as it completed the Standard Model (SM). Nonetheless, not all the open questions in HEP have a clever answer within the SM framework. Supersymmetry (SUSY) [3] offers a clear and elegant solution to the hierarchy problem and in particular low-energy third-generation squarks (close in mass to the top quark and below the TeV scale) can provide the mechanism to cancel quadratically divergent loop corrections to the mass of the SM Higgs boson without the well known fine tuning problem [4-6].

The LHC experiments have a rich search program for SUSY searches that, to date, has only produced null results almost reaching the highest possible mass for natural superpartners. In spite of this fact there are still many reasons to keep looking for Natural SUSY as only few and simplified models have been addressed experimentally and many regions of the full phase space have not yet been explored [7].

In these proceedings, new results from data collected by the ATLAS [8] and CMS [9] experiments in 2015 are presented. The two experiments were built with different technologies and adopted different technical solutions, nonetheless they share similar capabilities since they were both designed to be general purpose experiments able to hermetically contain almost all known particles, measure precisely their momentum and

Fig. 1. – On the left the Feynman diagram for the gluino in four quarks simplified model. On the right the stop is produced in the hard interaction and decays into top quarks with 100% branching ratio.

energy and, therefore, calculate with accuracy the missing transverse momentum (MET) that is carried away by elusive particles such as neutrinos.

The higher energy reached by the LHC meant a big improvement for some production cross sections, in particular for massive particles, improving the sensitivity of many analyses. Beside the enhanced production rate, new techniques have been deployed by the different analysis groups in both experiments: in particular W boson, top quark and Higgs tagging have been extensively used for the first time, as heavy decay products can results in boosted objects, which are hard to reconstruct using traditional methods.

By changing the selection at 13 TeV, also the background composition is altered. Some of the background sources become more important in the new selection. Therefore it becomes important to lower the systematic uncertainties on the background estimation technique and new, more sophisticated techniques are used to target rare SM backgrounds. Finally more dedicated search regions are added to be sensitive to a wide range of models over the full mass parameter space.

Because of the enhanced production cross-section the searches targeting gluinos are the first to improve their mass reach with respect to the 8 TeV results, soon followed by the third generation searches for high-mass sparticles. As benchmark simplified models are use, some of which are depicted in fig. 1, gluino on the left and stop on the right; these are just two examples of a wide range that have been investigated by both collaborations. The used simplified models include more decays of the gluino and the stop other than the two in fig. 1: the gluino can decay into top, bottom quarks or even charginos (and therefore W boson). On the other hand, also the stop can decay into quarks other than the top. Thus a large number of possible signatures is generated and the two experiments use different strategies to tackle all of them, ATLAS more focused on final states while CMS more on discriminating variables. Here only a selection of results is presented for hadronic and leptonic searches.

2. – Hadronic searches

Since the branching ratio of the SUSY particles, as well as the W boson, into quarks is by far the largest, this channel offeres the best chances of discovery of new particles at the early stages of the 13 TeV run. As previously stated, ATLAS produced results divided by final states with multi-jets plus MET [10,11] and requiring b-tagging [11,12]. On the other hand, CMS used different search variables such as razor [13], M_{T2} [14], α_T [15], and multi-jet [16]. All these different searches share some similarities as they all have to consider missing leptons and multi-jet backgrounds.

The most difficult background to tackle in hadronic searches is multi-jet production. In order to reduce it to a negligible level various approach can be used, like requiring

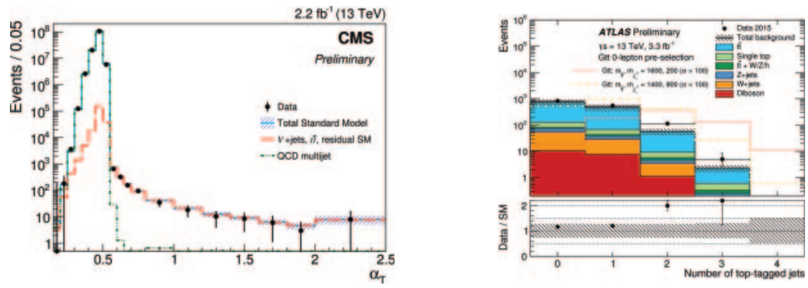

Fig. 2. – On the left the distribution of the α_T variable [15], is shown the effect on QCD multi-jet with respect to other backgrounds. On the right the number of top tagged in [11].

large missing energy and use the scalar sum of the jet momenta (HT), these can also be combined in other variables such razor and α_T (fig. 2, left). More recently the need to explore boosted regimes has produced tagging techniques to identify heavy particles decayed into merged objects.

ATLAS and CMS have used different approaches, combining small jets into larger ones the first and analyzing the internal components of a large jet the second. These different choices are due to the specific reconstruction algorithms used by the experiments, and therefore different ways to take into account soft radiation and energy sharing among sub-jets. The basic idea in all cases is the same: look for jets closely spaced (in general a cone twice the size of a standard jet is used), clean them from soft radiation, pileup and other detector effects, hence calculate their invariant mass. If compatible with a certain mother particle the tag is successful (fig. 2, right shows the number of top tagged jets using such technique).

3. – Leptonic searches

Requiring one lepton gives a better handle to suppress multi-jet background while ensuring a good overall acceptance for the signal. SM backgrounds are further suppressed using kinematic end points such as the transverse mass thanks to the achieved lepton performance. Also in leptonic events new variables have been introduced: for instance the topness and the invariant mass of large cone jets, that has been shown to be connected to the decay of new particles [17-19]. Selecting more leptons, as well as same-sign requirements, can improve background rejection and the kinematic description of the event, of course at the expenses of the branching ratio [20-22].

Particular efforts have been devoted to searches with a Z boson plus missing energy, because the observed excess in 8 TeV data by the ATLAS [23] and CMS [24] experiments. The two excesses differ because CMS observed it outside the Z peak while ATLAS saw the excess in events with a Z plus MET, causing some tension between the two experimental results. Both experiments re-did their analyses with 13 TeV data: while CMS does not seem to have any evidence of excess in data [25] (fig. 3, left), ATLAS still observes a discrepancy of about two sigma (in both electron and muon channels) [26] (fig. 3, right). The hypothesis of an ATLAS-like signal has been investigated by CMS adding a signal region with the same characteristics used in the ATLAS search: the expectation is of 12–19 events while CMS puts an upper limit of 9 events in this region.

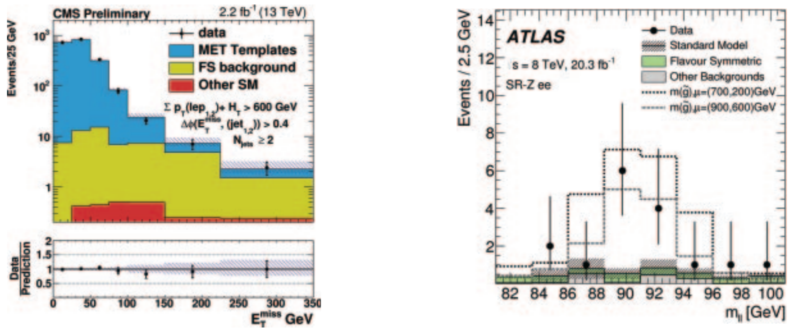

Fig. 3. – On the left missing energy plot of the CMS Z+MET search [25], the last bin represents the ATLAS signal region. On the right the invariant mass distribution of electron pairs in the high MET and HT region by ATLAS [26].

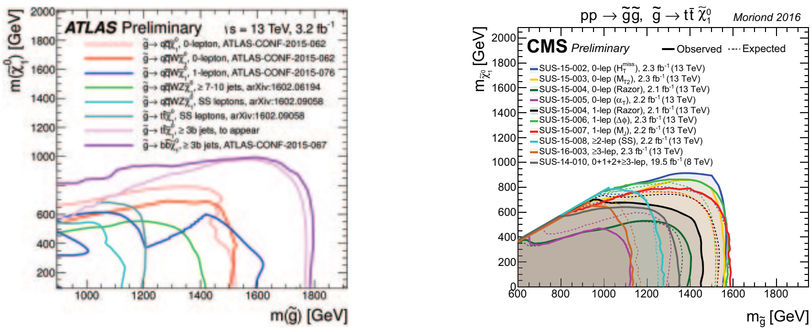

Fig. 4. – Summary plot for the exclusion reach in ATLAS (left) and CMS (right) of the different analyses, as of Moriond 2016. The gluino limits, thanks to the higher energy, have increased the most surpassing 1.5 TeV.

4. – Interpreting results

Because no significant excess has been found we set upper limits on the simplified models. Figure 4 shows a summary of the limits found by different analyses (ATLAS left and CMS right) on the gluino into four top quarks model among others. It can be seen how the reach in gluino mass exceeds 1.5 TeV thanks to the higher center-of-mass energy. Similar improvements over the 8 TeV searches are also present for other simplified models.

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