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# Inclusive Searches for Supersymmetry with the CMS detector at $\sqrt{s} = 8$ TeV

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**Abstract**

We discuss two complementary searches for supersymmetry and their combination carried out on approximately 19 $fb^{-1}$ of data collected by CMS during the $\sqrt{s} = 8$ TeV LHC run. Results for a variety of final state signatures, including multi-bottom, multi-top, and mixed top-plus-bottom quark topologies, are presented. The combination of results yields an improved bound on the top-squark mass. For a neutralino mass of 100 GeV, the branching fraction dependent (independent) pair production of gluinos and top squarks is excluded for gluino masses up to 1310 (1175) GeV and for top squark masses up to 730 (645) GeV.

*Keywords:* particle physics, hadron collider, CMS, SUSY, supersymmetry, top squark, gluino, inclusive, razor, BDT, boosted decision tree

## 1. Introduction

R-parity conserving, weak-scale supersymmetry (SUSY) is a well-motivated theory, which provides a suitable dark matter candidate and predicts events at the Large Hadron Collider (LHC) with jets and large missing transverse momentum $E_T^{miss}$. Some SUSY models may contain a light chargino $\tilde{\chi}^{\pm}$ and a neutralino $\tilde{\chi}^0$ nearly degenerate in mass, a light top or a bottom squark ($\tilde{t}$ or $\tilde{b}$), and potentially a slightly heavier gluino $\tilde{g}$ in order to minimize the fine-tuning associated with the observed value of the Higgs boson mass [1].

We discuss two complementary methods to search for squarks and gluinos in the context of natural SUSY spectra, shown in Fig 1. One search, called herein the inclusive razor search, is performed on events with two or more jets, at least one of which is identified as originating from a bottom quark [2, 3]. This search extend a previous analysis by the Compact Muon Solenoid (CMS) Collaboration, performed with the same technique on the data collected at a center-of-mass energy of 7 TeV [4, 5] and utilizes the razor kinematic variables $R^2$ and $M_R$ [6, 7] to search for a broadly peaking signal on the smoothly falling standard model (SM) background. The other search, called herein the single-lepton boosted decision tree (BDT) search, is performed on events with one isolated electron or muon, four jets, at least one of which is identified as originating from a bottom quark, and missing transverse energy [8].

Both searches are carried out on the data collected by the CMS Collaboration in proton-proton collisions at $\sqrt{s} = 8$ TeV in 2012, corresponding to an integrated luminosity of 19.3-19.4 $fb^{-1}$. A complete description of the CMS detector is given in [9].

Together, these searches provide the strongest mass limit on the top squark in the case of one choice of decay mode, as well as a more universal mass limit on both the top squark and the gluino, independent of the choice of branching fractions.

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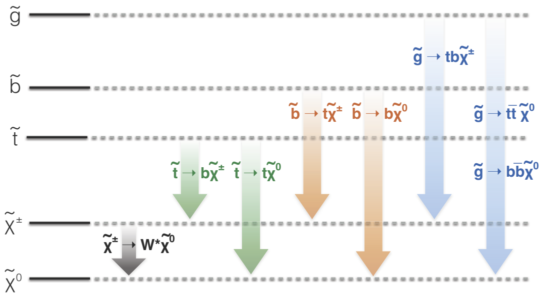


Figure 1: Simplified natural SUSY spectrum considered as a benchmark for result interpretations. The neutralino is forced to be the lightest SUSY particle. The difference in mass between the chargino and the neutralino is fixed at 5 GeV. Gluino and same-flavor squark pair production are considered in separate models, scanning the masses of the produced SUSY particle and the neutralino.

## 2. Inclusive Razor Search

This section provides a brief summary of a search for SUSY in hadronic events with b-jets. A more complete description can be found in [2] and [3]. The analysis is performed on the events collected by a set of dedicated triggers in the HLT, consisting of a loose selection on $\mathrm{M_R}$ and $\mathrm{R}^2$. The triggers are seeded from a L1 selection of two jets in the central part of the detector.

The razor variables $\mathrm{M_R}$ and $\mathrm{R}^2$ are defined to describe the two-jet topology resulting from the production of two squarks, each decaying to a quark and the lightest SUSY particle (LSP), assumed to be a stable neutralino $\tilde{\chi}^0_1$. The four-momenta of the two jets are used to compute $\mathrm{M_R}$ and $\mathrm{R}^2$, defined as

$$\mathrm{M_R} \equiv \sqrt{(|\vec{p}_{\mathrm{j}_1}| + |\vec{p}_{\mathrm{j}_2}|)^2 - (p_z^{\mathrm{j}_1} + p_z^{\mathrm{j}_2})^2} \quad (1)$$

$$\mathrm{R}^2 \equiv \frac{\mathrm{E_T^{miss}}(p_\mathrm{T}^{\mathrm{j}_1} + p_\mathrm{T}^{\mathrm{j}_2}) - \vec{\mathrm{E}}_\mathrm{T}^{\mathrm{miss}} \cdot (\vec{p}_\mathrm{T}^{\mathrm{j}_1} + \vec{p}_\mathrm{T}^{\mathrm{j}_2})}{4M_R^2} \quad (2)$$

where $\vec{p}_{\mathrm{j}_i}$, $\vec{p}_\mathrm{T}^{\mathrm{j}_i}$, and $p_z^{\mathrm{j}_i}$ are the momentum of the ith-jet, its transverse component, its longitudinal component, respectively, while $\mathrm{E_T^{miss}}$ and $p_\mathrm{T}^{\mathrm{j}_i}$ are the magnitude of $\vec{\mathrm{E}}_\mathrm{T}^{\mathrm{miss}}$ and $\vec{p}_\mathrm{T}^{\mathrm{j}_i}$, respectively.

Each event is reduced to a two-jet topology by clustering the selected jets into two "megajets" [7, 4, 5]. "Boxes" are used to classify events, as given in Table 1.

The two-dimensional probability density function $\mathrm{P_{SM}}(\mathrm{M_R}, \mathrm{R}^2)$ of each SM process is found to be well described by the function [4, 5]:

$$f(\mathrm{M_R}, \mathrm{R}^2) = [b(\mathrm{M_R} - \mathrm{M_R^0})^{1/n}(\mathrm{R}^2 - \mathrm{R}_0^2)^{1/n} - 1] \times e^{-bn(\mathrm{M_R}-\mathrm{M_R^0})^{1/n}(\mathrm{R}^2-\mathrm{R}_0^2)^{1/n}}. \quad (3)$$

where $b$, $n$, $\mathrm{M_R^0}$, and $\mathrm{R}_0^2$ are free parameters of the background model. The SM background-only likelihood function for the each box and each b-tagged jet multiplicity is written as:

$$\mathcal{L}(\mathrm{data}|\vec{\theta}) = \frac{e^{-\mathrm{N_{SM}}}}{\mathrm{N!}} \prod_{i=1}^{\mathrm{N}} \mathrm{N_{SM}} \mathrm{P_{SM}}(\mathrm{M}_{\mathrm{R}(i)}, \mathrm{R}^2_{(i)}), \quad (4)$$

where $\mathrm{P_{SM}}(\mathrm{M_R}, \mathrm{R}^2)$ is the function in Eq. (3) normalized to unity, $\vec{\theta}$ is the set of background shape and normalization parameters, and the product runs over the N events in that dataset. The total likelihood in these boxes is computed as the product of the likelihood functions for each b-tagged jet multiplicity.

Different parameters are used for each box and b-tagged jet multiplicity bin, with the exception of the 2b-tag and ≥3b-tag bins, in which common background shape parameters are used. The background shape and normalization parameters are derived from a maximum likelihood fit to the events in low-$\mathrm{M_R}$ and low-$\mathrm{R}^2$ sidebands. The data in the signal-sensitive region are found to be consistent with expectation from the sideband fits in all boxes.

## 3. Single-Lepton BDT Search

This section presents a summary of the search for the pair production of top squarks in events with a single isolated electron or muon, jets, large missing transverse energy, and large transverse mass. A full description of the analysis can be found in [8].

This search focuses on two decay modes of the top squark: $\tilde{t} \to t\tilde{\chi}^0_1$ and $\tilde{t} \to b\tilde{\chi}^\pm_1 \to bW^\pm\tilde{\chi}^0_1$, which are expected to have large branching fractions if kinematically accessible. The signature of the signal process includes high transverse momentum jets, including two b-jets, and $\mathrm{E_T^{miss}}$. We require exactly one isolated, high $p_\mathrm{T}$ electron or muon, at least 4 jets, at least one b-tagged jet, and large $\mathrm{E_T^{miss}}$ and transverse mass $\mathrm{M_T} = \sqrt{2\mathrm{E_T^{miss}} p_\mathrm{T}^\ell (1 - \cos(\Delta\phi))}$, where $p_\mathrm{T}^\ell$ is the transverse momentum of the lepton and $\delta\phi$ is the difference in azimuthal angles between the lepton and $\mathrm{E_T^{miss}}$ directions. The requirement of large $\mathrm{M_T}$ strongly suppresses backgrounds from semi-leptonic decays of top quark pairs, and from $W$+jets. The dominant background in this kinematic region is dilepton decays of top quark pairs, where one of the leptons is not identified. The primary results of the search use boosted decision tree (BDT) techniques, and a cut-based analysis is pursued as a cross-check. Several BDT and cut-based signal regions are defined, in order to be sensitive to a range of