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Recent CMS SUSY searches with missing transverse momentum, and searches for R-parity violating SUSY

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This contribution highlights three recent searches for supersymmetry with non-compressed spectra, using 138 fb^{-1} of proton–proton collision data collected by the CMS experiment, at $\sqrt{s}$ = 13 TeV. The results include a search for R-parity violating supersymmetry in final states with single lepton, multiple b-quark jets and large-radius jets; an inclusive search targeting hadronic and leptonic final states with highly Lorentz-boosted objects; and a search for leptophobic Z' bosons decaying to chargino pairs in final states with two opposite-sign leptons and missing transverse momentum. No significant deviations from the standard model are observed, and stringent limits are set on a wide range of SUSY scenarios.

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The CMS Collaboration at the LHC continues an active and diverse program of searches for supersymmetry (SUSY) using the full Run 2 dataset collected between 2015 and 2018, corresponding to an integrated luminosity of about 140 fb^{-1}. More than forty results are already public, that cover a wide range of SUSY signatures, from broad multi-bin searches probing several final states simultaneously, to dedicated analyses optimized for specific models or topologies. The latter include searches for compressed spectra, low cross-section processes such as slepton production, long-lived particles, scenarios with low missing transverse momentum (p_T^{miss}) such as R-parity violating (RPV) or stealth SUSY, and final states with boosted objects. The program also develops new methods to improve sensitivity to challenging signatures, for example through machine learning, refined object identification, and combinations of analyses.

This contribution presents three of the most recent CMS results focusing on non-compressed SUSY scenarios: a search for R-parity-violating SUSY in single-lepton events with multiple jets and b-jets; an inclusive search in hadronic and leptonic final states with highly Lorentz-boosted objects; and a search for chargino pairs produced in Z' boson decays, in final states with two oppositely charged leptons and p_T^{miss}.

The first of these analyses targets RPV SUSY scenarios in which supersymmetric particles decay entirely into standard model particles through baryon-number-violating interactions, resulting in final states with little or no p_T^{miss} [1]. The search focuses on events with one isolated lepton, multiple jets, and multiple b-tagged jets. Signal discrimination is achieved using large-radius anti-kT jets with $R = 1.2$, reconstructed by reclustering smaller-radius (AK4) jets together with the identified lepton. The event preselection requires exactly one lepton, hadronic transverse momentum (scalar sum of transverse momenta of jets) $H_{\text{T}} > 1.2$ TeV, ≥ 4 jets, and $M_{\text{J}} > 500$ GeV, where $M_{\text{J}} = \sum_i m_i$ is the scalar sum of the masses of the large-radius jets, distributions for which are shown in Fig. 1 bottom-left panel. No explicit requirement is applied on p_T^{miss}.

Events are categorized according to the number of jets and b-tagged jets, defining signal-enriched (SR) and signal-depleted (CR) regions. The main background contributions arise from QCD multijet production, $t\bar{t}$, and W+jets processes. A simultaneous fit is performed to the M_{J} distributions in all SRs and CRs, allowing the data to constrain both the shape and normalization of the backgrounds. The M_{J} templates for each process are derived from simulation and corrected using κ factors, defined as the data-to-simulation ratios of adjacent M_{J} bin yields. These factors are measured in dedicated CRs and further constrained in the global fit. Data are found to be consistent with the SM in the signals, as shown in the top panel of Fig. 1. The analysis is interpreted in a simplified model of pair-produced RPV gluinos decaying to tbs, and excluded gluinos up to mass 1890 GeV, as shown in Fig. 1 bottom-right panel.

The second is an inclusive search for heavy sparticles with large mass splittings to their supersymmetric daughters, characterized by final states with highly Lorentz-boosted objects [2]. These include hadronically decaying boosted W, Z, and Higgs bosons and top quarks, reconstructed using the ParticleNet algorithm. The analysis also explores, for the first time in a CMS SUSY search, leptonic decays of boosted SM or SUSY particles, reconstructed as "boosted leptonic jets", defined as AK8 jets containing a non-isolated lepton. Signal discrimination is done by razor kinematic variables M_{R} and R^2, which characterize events with massive particles decaying to visible and invisible states as a peak above smoothly falling backgrounds. Objects in each event are clustered into two megajets that approximate the visible decay products of the pair-produced heavy particles.

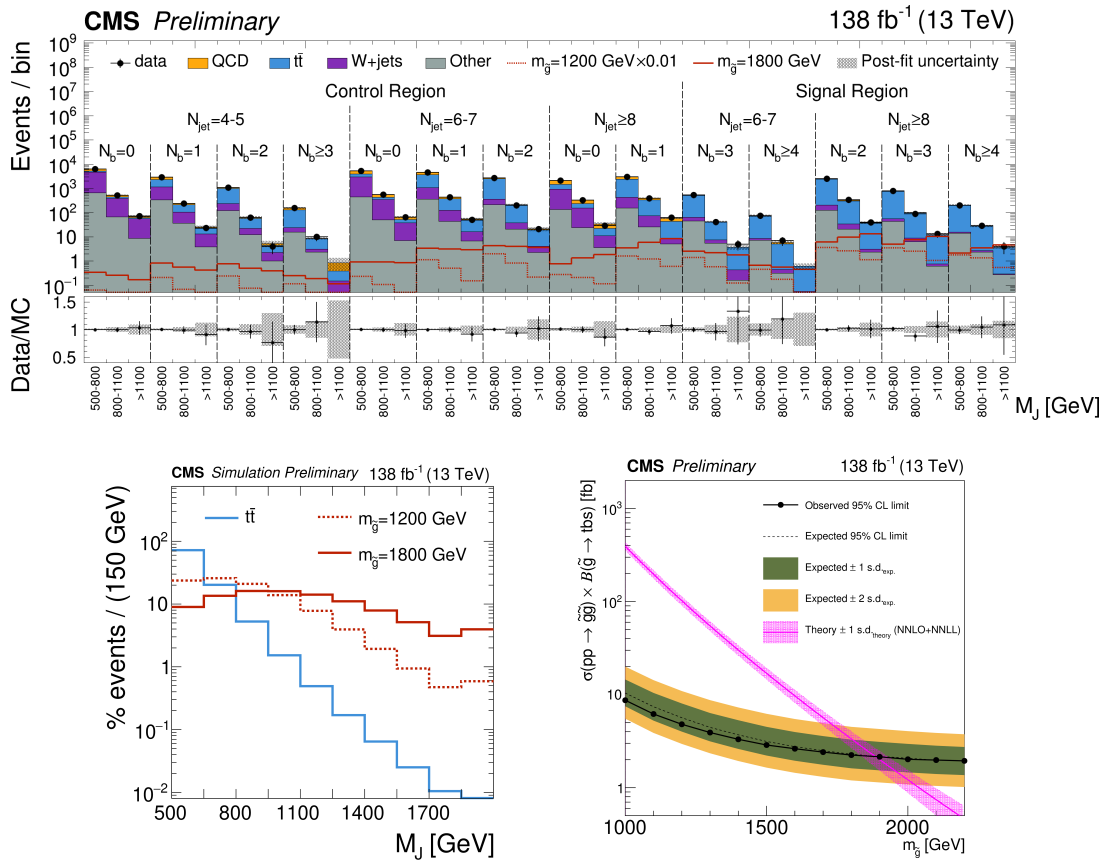

Figure 1: Highlights from the RPV single lepton analysis [1]: Distributions of data, postfit SM background prediction, and example signal benchmarks in the signal regions (top); normalized M_J distributions for simulated $t\bar{t}$+jets and two signal benchmarks (bottom left); and cross section upper limits versus gluino mass for the RPV gluino model (bottom right).

Events are categorized into three main channels: hadronic, leptonic, and leptonic-jet. The analysis defines 25 search regions based on event properties such as the numbers of jets, b-tagged jets, isolated leptons, and reconstructed boosted objects (N_{top}, N_{V}, N_{H}, and N_{lepJet}), for optimal sensitivity to a large class of signal models. Each region is further divided into bins in the $(M_{\text{R}} - 800) \times (R^2 - 0.08)$ plane, resulting in 151 signal bins, shown in Fig. 2, top panels.

The main backgrounds consist of multijet production (arising from jet mismeasurements), $t\bar{t}$+jets and W+jets events with unreconstructed leptons, and $Z(\nu\bar{\nu})$+jets processes. Backgrounds are estimated using data CRs defined by reversing key selection criteria, with data-to-simulation correction factors extracted from simultaneous fits across those CRs. The $Z(\nu\bar{\nu})$ background is modeled using a template fit method in photon-enriched CRs. All background predictions are validated in signal-like validation regions. In representative R-parity-conserving simplified models, the search excluded gluino masses up to 2.35 TeV and top squark masses up to 1.45 TeV. In RPV scenarios, it excluded bottom squark masses up to 0.97 TeV and gluino masses up to 1.82 TeV, while electroweak production of nearly mass-degenerate charginos and neutralinos was excluded up to 1.05 TeV. Figure 2 bottom panels show observed and expected 95% C.L. cross section upper

limits and excluded regions as function of sparticle masses for two representative signal models of top squark pair production with cascade decays into Higgs or Z bosons and neutralinos, and gluino pair production, with decays into RPV top squarks.

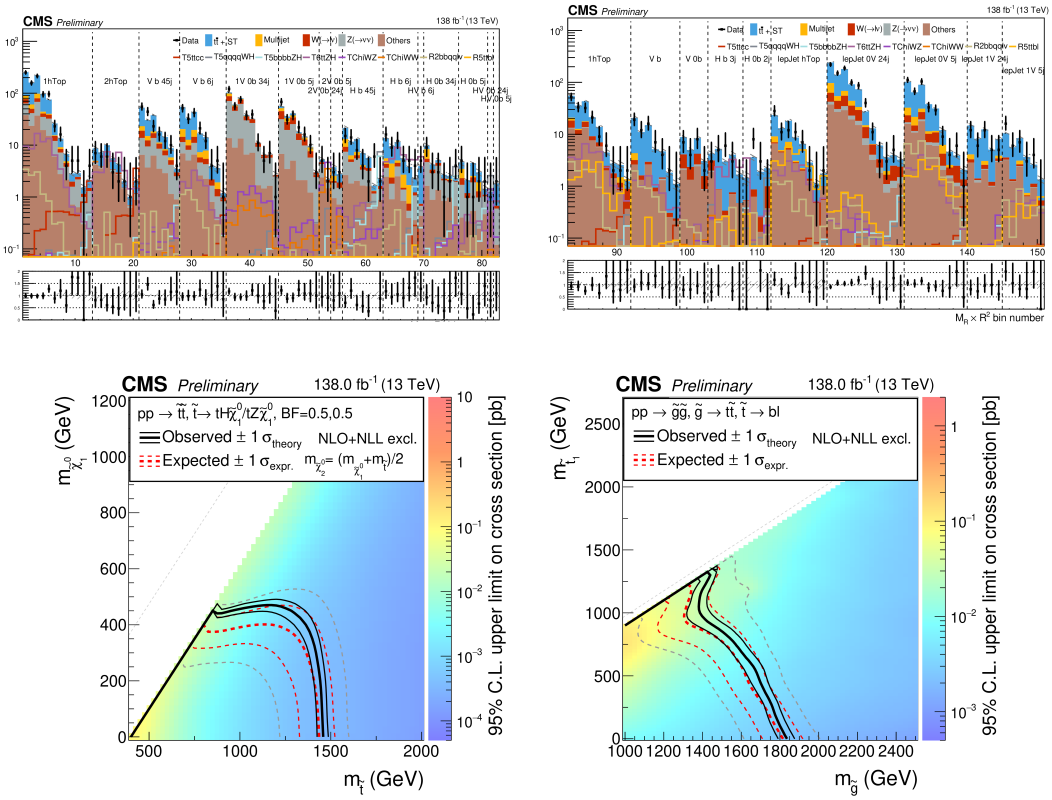

Figure 2: Highlights from the search with highly Lorentz-boosted final states [2]: Distributions of data, postfit SM background prediction, and example signal benchmarks in the hadronic (top left), and leptonic (top right) signal regions; observed and expected 95% C.L. cross section upper limits and excluded regions as function of sparticle masses for simplified models of pair-produced R-parity conserving top squarks, cascade decaying into boosted Z or Higgs bosons and the lightest neutralino (bottom left), and pair-produced gluinos, decaying into RPV top squarks, which in turn decay into a b quark and a lepton (bottom right).

The third analysis explores a novel SUSY signature involving a heavy neutral gauge boson, Z', decaying into pairs of charginos, each subsequently decaying via a W boson into a lepton and a neutralino [3]. Such leptophobic Z' bosons arise in well-motivated MSSM extensions with an additional U(1)' gauge symmetry, where direct decays to dileptons are highly suppressed. This is the first search at the LHC for SUSY particle production mediated by a Z' resonance. The analysis targets final states with two oppositely charged leptons (ee, $\mu\mu$, or eμ) and significant missing transverse momentum, requiring $m_{\ell\ell} > 100$ GeV, $p_T^{\text{miss}} > 100$ GeV, and no b-tagged jets.

Signal extraction is performed using a parametric deep neural network (PNN) trained separately for each lepton channel. The DNN input features include: the transverse momenta of the leading and subleading leptons, $p_{\text{T}}(\ell_1)$ and $p_{\text{T}}(\ell_2)$; the dilepton invariant mass, $m_{\ell\ell}$; p_T^{miss}; the magnitudes of the vector sums $|\vec{p}\text{T}(\ell\ell) + \vec{p}\text{T}^{\text{miss}}|$ and $|\vec{p}\text{T}(\ell\ell) - \vec{p}\text{T}^{\text{miss}}|$; the transverse masses $m_{\text{T}}(\ell\ell, p_T^{\text{miss}})$ and

$m_{T2}(\ell,\ell)$; and a set of angular separation variables. The Z' and chargino masses are provided as additional input parameters to allow interpolation across mass hypotheses.

The dominant background contributions arise from $t\bar{t}$+jets, W+jets, and Drell-Yan processes. Their normalizations are determined from a simultaneous fit to data in the SRs and dedicated CRs, performed separately for each lepton channel. The final statistical inference is based on the distribution of the PNN output score, where the $e\mu$ channel, shown in Fig. 3 left panel, provides the highest sensitivity. No significant excess over the standard model background expectation is observed. Upper limits are set on the effective production cross section of the Z' resonance, as shown in Fig. 3, right panel. For the benchmark scenario with $m(Z') = 2.9$ TeV, chargino masses between approximately 0.4 and 1.4 TeV are excluded. The sensitivity extends up to $m(Z') = 3.5$ TeV, representing the first limits at the LHC on SUSY particle production mediated by a heavy Z' boson.

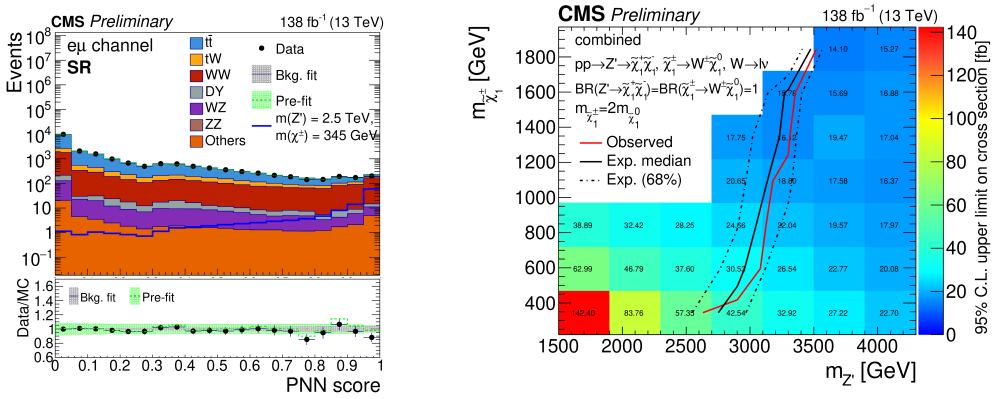

Figure 3: Highlights from the search for chargino pairs from boosted Z' boson decays [3]: PNN score distributions of data, postfit SM background prediction, and an example signal benchmark in the $e\mu$ signal region (left); observed and expected 95% C.L. upper limits on the Z' boson effective cross section, and excluded regions as function of Z' boson and lightest neutralino masses (right).

CMS continues to explore every corner of the SUSY parameter space with complementary approaches addressing both conventional and unconventional signatures. This contribution presented three of the most recent Run 2 results in non-compressed scenarios. The search for R-parity-violating SUSY in single-lepton events demonstrates sensitivity to baryon-number-violating decays without a p_T^{miss} requirement, using large-radius jets to capture hadronic activity. The inclusive search with boosted objects extends coverage to high-mass SUSY signals, introducing the use of boosted leptonic jets in a SUSY analysis for the first time and interpreting results in multiple simplified models, including those with Higgs bosons in the decay chains. The search for Z' bosons decaying to chargino pairs represents the first study of this kind at the LHC, probing Z' masses up to 3.5 TeV and excluding charginos up to about 1.4 TeV. The exploration of SUSY at CMS remains ongoing, with new analyses in preparation using Run 3 data.

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