PROCEEDINGS OF SCIENCE

Search for Supersymmetry in single lepton events and reinterpretation in the pMSSM-19 framework

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Results are presented from a search for supersymmetry in events with a single electron or muon, and multiple hadronic jets. The data correspond to a sample of proton-proton collisions at $\sqrt{s} = 13$ TeV with an integrated luminosity of 138 fb^{-1}, recorded by the CMS experiment at the LHC. The search targets gluino pair production, where the gluinos decay into the lightest supersymmetric particle (LSP) and a pair of light quarks in the final state. We include the angular correlation between the lepton and the W boson's transverse momenta in a machine learning driven multi-classification for a strong separation between the signal and the background processes. Furthermore, the effort for a reinterpretation of our results in the pMSSM19 framework to broaden the probed SUSY phase space is presented.

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1. Introduction

A search for supersymmetry [1] has been performed using full CMS Run 2 data [2], which is introduced in the following sections by giving an overview of the analysis strategy and showing the results of the search for supersymmetry. Additionally, the pMSSM19 framework is introduced, which will be used for a future reinterpretation of the analysis. Furthermore, the endeavor of modernizing the existing analysis framework towards a possible Run3 analysis is presented.

2. Using angular correlations to find the signal

The targeted model involves the direct production of gluinos, which subsequently decay into charginos and then neutralinos and can be seen in Fig. 1.

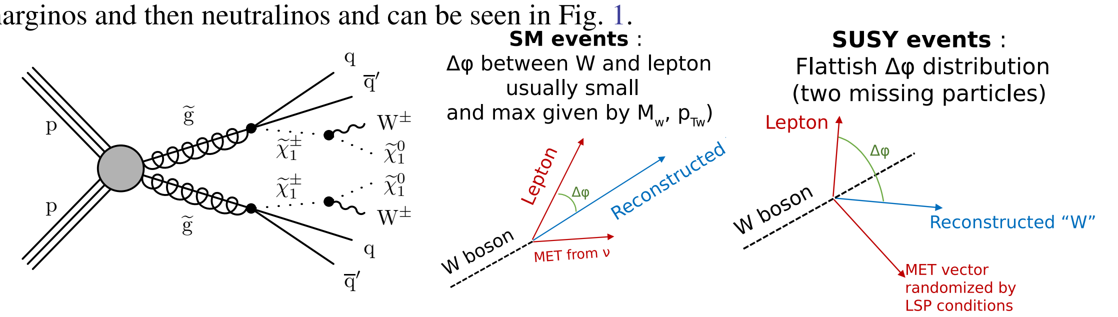

Figure 1: The investigated simplified model, where a gluino decays into light jets, a W boson and a neutralino, is shown on the left. On the right, the idea behind using $\Delta\phi$ as a discriminator is visualized by the two decay chains. The additional SUSY particles (on the right) result in a broader $\Delta\phi$ distribution compared to the SM case (in the middle).

In each gluino decay, two light quarks are produced resulting in additional jets. Exactly one of the W bosons stemming from the chargino decays is required to decay leptonically, allowing the reconstruction of the transverse momentum of the W-boson by using $\vec{p}_T^{\,W,\mathrm{reco}} = \vec{p}_T^{\,\ell} + \vec{p}_T^{\,\mathrm{miss}}$. The difference of the angle Φ is then defined as $\Delta\phi = \sphericalangle(\vec{p}_T^{\,\ell}, \vec{p}_T^{\,W,\mathrm{reco}})$.

In the SM case, the only source for $\vec{p}_T^{\,\mathrm{miss}}$ is the neutrino, therefore the reconstructed W boson is flying in the same direction as the lepton. With additional SUSY particles in the final state, $\vec{p}_T^{\,\mathrm{miss}}$ is randomized and the angle between the "reconstructed" W boson and the lepton is rather flat, see Fig. 1. As shown in Fig. 2, the signal distribution is rather flat over the whole range of $\Delta\phi$ while the background processes fall of steeply, leading to an signal enriched region for larger values of $\Delta\phi$.

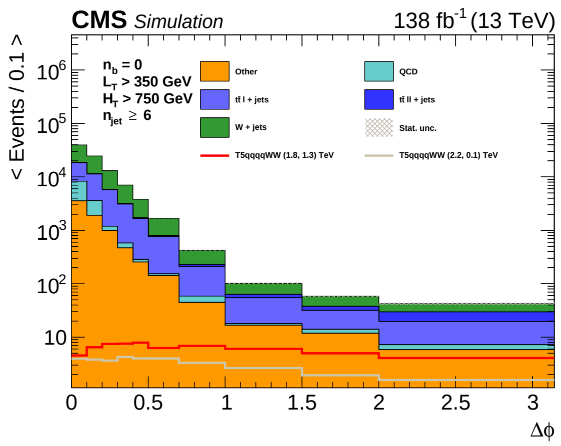

Figure 2: A comparison of the $\Delta\phi$ distribution for the background processes to two exemplary signal mass points. For larger values of $\Delta\phi$, the fraction of signal events is increased.

3. Event Selection

The event selection focuses on constructing a region which is sensitive towards the signal process by requiring a larger $\Delta\phi$ and several energetic jets leading to a large H_{T}. The baseline selection requires a good lepton, a number of jets and a certain amount of leptonic and hadronic activity, as shown in Table 1. Furthermore, object tagging for including W bosons ($n_{\text{W-tag}}$) and excluding b-jets ($n_{\text{b-tag}}$) is utilized to account for the composition of the final state.

For signal region $\Delta\phi > [0.75, 1]$
One good lepton with $p_{\mathrm{T}} > 25\,\mathrm{GeV}$
No veto lepton with $p_{\mathrm{T}} > 10\,\mathrm{GeV}$
No isolated track with
$p_{\mathrm{T}} > 5\,\mathrm{GeV}$ with $M_{\mathrm{T2}} < 60\ (80)\,\mathrm{GeV}$
for hadronic (leptonic) tracks
$L_{\mathrm{T}} = p_T^{\mathrm{lep}} + E_T^{\mathrm{miss}} > 250\,\mathrm{GeV}$
$H_{\mathrm{T}} = \sum_{\mathrm{jets}} p_T > 500\,\mathrm{GeV}$
$n_{\mathrm{jet}} \geq 3$
Sub-leading jet with $p_{\mathrm{T}} > 80\,\mathrm{GeV}$
$n_{\text{b-tag}} = 0$
$n_{\text{W-tag}}$ depending on search bin

Table 1: An overview over the applied cuts for the baseline selection. The requirement of a high quality lepton together with large hadronic activity is effective at discriminating against the SM background.

4. Data-driven background estimation

Due to the stringent cuts, it is hard to model precisely the background processes in the signal region only utilizing MC simulations. Therefore, a data driven background estimation has been developed to better predict the background contribution using data in dedicated control regions. The data-driven prediction can be written as

$$N_{\mathrm{Pred}}^{\mathrm{MB,SR}} = \kappa \cdot \underbrace{N^{\mathrm{SB,SR}}/N^{\mathrm{SB,CR}}}_{R^{\mathrm{CS}}} \cdot N^{\mathrm{MB,CR}}$$

where κ denotes additional factors accounting for potential differences in kinematics between the regions. The signal sensitive region is called MB SR, defined by high $\Delta\phi$ and n_{jet}. Control regions are constructed by either varying the n_{jet} or $n_{\text{b-tag}}$ requirement as well as a reduced $\Delta\phi$, as shown in Fig. 3.

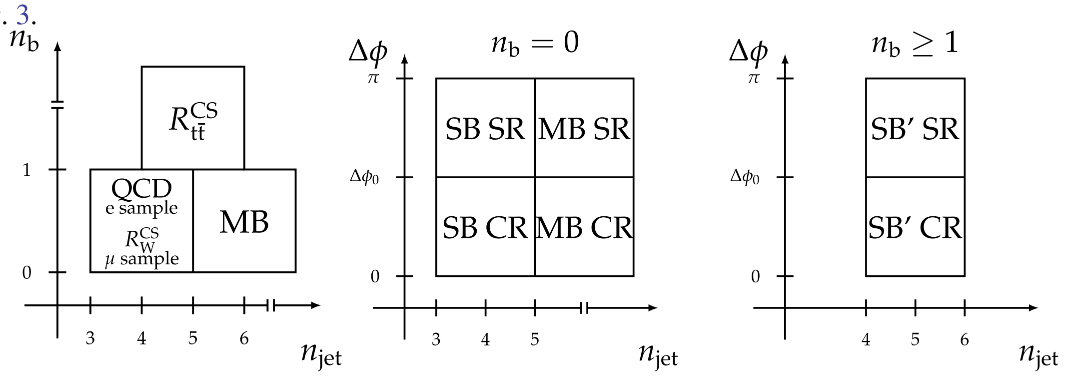

Figure 3: A schematic overview over the different regions used in the data-driven background estimation is shown. The signal strength extraction is performed in the MB SR, defined by high $\Delta\phi$ and high n_{jet}.

5. Analysis Strategy

The signal region consists of 50 bins, binned in L_{T}, H_{T}, n_{jet}, and $n_{\text{W-tag}}$ and is shown in Fig. 4. The background processes are derived using the data-driven prediction introduced above. Overall, there is no significant excess of data observed, as the upward fluctuations have been investigated in detail.

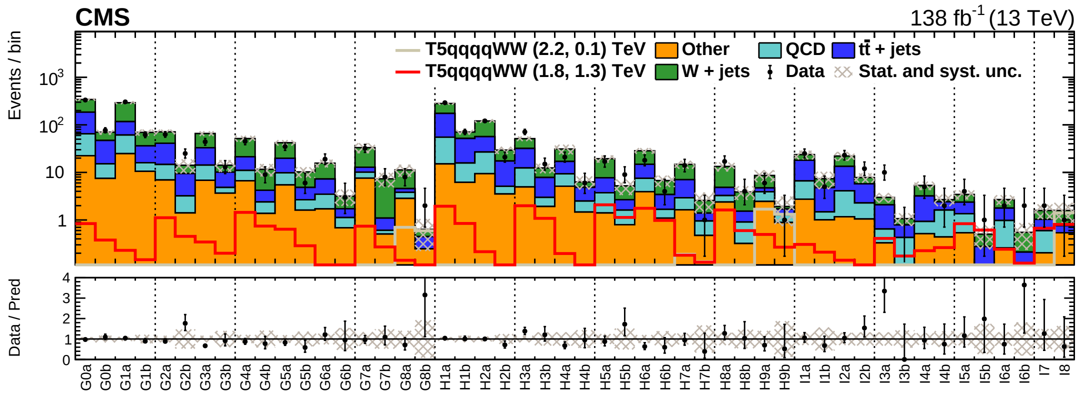

Figure 4: Presented are the 50 search bins used in the extraction of the signal strength, where for each bin, the data-driven background prediction is compared to the observed data. As an estimation for the sensitivity, two different mass point hypotheses are shown as well.

6. Resulting Limits

For exclusion limits, a scan has been performed in the gluino-neutralino mass plane. The range for excluded masses reaches up to 2050 GeV for $m_{\tilde{g}}$ and 1070 GeV for $m_{\tilde{\chi}_1^0}$, which can be see in Fig. 5. Due to the slight excess seen in the bins G2b, H3a and I3a, which are sensitive to models with a smaller difference between the $m_{\tilde{g}}$ and $m_{\tilde{\chi}_1^0}$, the observed limits are lower compared to the expected limit for smaller values of $m_{\tilde{g}}$.

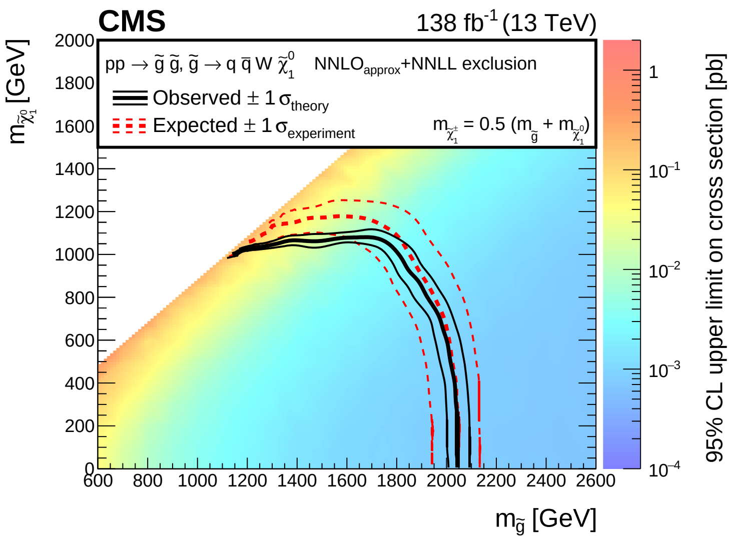

Figure 5: The exclusion limit in the $m_{\tilde{g}}$-$m_{\tilde{\chi}_1^0}$ mass plane. This analysis performs a scan over 861 different mass point combinations on a grid. The chargino mass is set to the average of $m_{\tilde{g}}$ and $m_{\tilde{\chi}_1^0}$.

7. Reinterpretation in the pMSSM 19 [3] framework

This search can only infer experimental constraints on two theory parameters, $m_{\tilde{g}}$ and $m_{\tilde{\chi}_1^0}$. At CMS, several SUSY searches collaborate to expand the scanned phase space by reinterpreting analyses with dedicated pMSSM19 samples. The probed parameters are:

- $\tan\beta$: the ratio of the vacuum expectation value of the two-Higgs doublet fields.
- M_A: the mass of the pseudoscalar Higgs boson
- μ: the Higgs-higgsino mass parameter

- M_1, M_2, M_3: the bino, wino and gluino mass parameters
- $m_{\tilde{q}}, m_{\tilde{u}_R}, m_{\tilde{d}_R}, m_{\tilde{l}}, m_{\tilde{e}_R}$: first/second generation sfermion masses
- $m_{\tilde{Q}}, m_{\tilde{t}_R}, m_{\tilde{b}_R}, m_{\tilde{L}}, m_{\tilde{\tau}_R}$: third generation sfermion masses
- A_t, A_b, A_τ: third generation trilinear couplings

8. Outlook using Machine Learning

As a preparation for a Run3 analysis, a DNN based multi-classification targeting the same model using UL samples has been derived. The DNN based approach replaces the cut-and-count approach with 50 search bins by a region construction using the output scores of the DNN. Shown in Fig. 6 is the confusion matrix, predicting the origin class for each event.

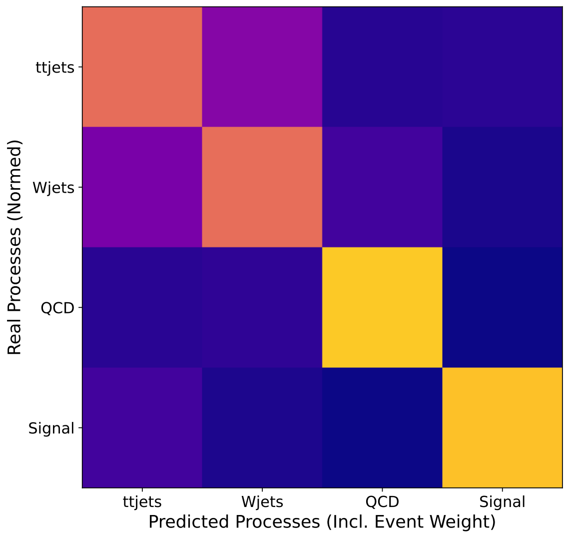

Figure 6: As a measurement of the DNN performance, the prediction for each event is compared to the original event, which is shown in this confusion matrix. Ideally, the matrix would be diagonal.

9. Summary

The presented analysis has extended on existing limits targeting the shown simplified model by using a data-driven background estimation for correctly modeling the background processes in the 50 search bins. Furthermore, the pMSSM19 reinterpretation approach was introduced, allowing the results of this analysis to impose constraints on several other SUSY parameters. For the continuation of this SUSY search, an outlook was given implementing machine learning based multi-classification to properly construct a signal region.

Acknowledgement

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References

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