# Search for supersymmetry in opposite-sign same-flavour lepton pairs with the CMS detector

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A search for Supersymmetry in events with opposite-sign same-flavour lepton pairs is presented. This final state, in addition to requirements on the number of jets and missing transverse energy, allows for a large reduction as well as a precise estimation of standard model backgrounds. In the cascade decays of new heavy particles, correlated production of leptons can lead to distinctive 'edges' in the dilepton invariant mass spectrum, caused by the mass differences between the new particles. Presented is the search for such a mass edge in a dataset of pp collisions at $\sqrt{s} = 8\,\mathrm{TeV}$, corresponding to $19.4\,\mathrm{fb}^{-1}$, collected with the CMS detector [1] at the CERN LHC.

This analysis [2] focuses on the correlated production of same-flavor (SF) opposite-sign (OS) leptons in cascade decays of new heavy particles. Examples for this are decays of the second neutralino into the first neutralino and a SF OS lepton pair, either via an intermediate slepton or on- or off-shell Z bosons, as illustrated in Fig. 1. The mass difference between the two neutralinos sets an upper limit on the invariant mass of the lepton pair, leading to a characteristic edge. The experimental signatures of these decays are the SF OS lepton pair, missing transverse energy ($E_T^{miss}$) from the undetected LSPs, and several jets from other parts of the cascade and the decay of the second initially produced sparticle.

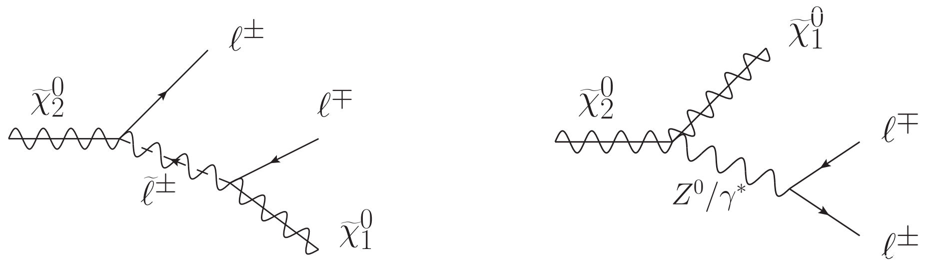


Figure 1: Diagrams of the possible decay modes of the second neutralino resulting in an edge in the dilepton invariant mass sepctrum.

The considered event samples are collected with dilepton triggers, requiring two light leptons (e,$\mu$) with $p_T > 17\,\mathrm{GeV}$ for the first and $p_T > 8\,\mathrm{GeV}$ for the second lepton. Events are then required to contain two SF OS light leptons with $p_T > 20\,\mathrm{GeV}$ and a pseudorapidity of $|\eta| < 2.4$. The dilepton invariant mass $m_{\ell\ell}$ is required to be greater than 20 GeV. The event sample is split into the 'central' (both leptons $|\eta| < 1.4$) and 'forward' (at least on lepton $|\eta| > 1.6$) regions. Three regions are defined in $E_T^{miss}$ and the number of jets $\mathrm{N_{jets}}$. A control region enriched in events produced by the Drell-Yan process requires $\mathrm{N_{jets}} \geq 2$ and $E_T^{miss} < 50\,\mathrm{GeV}$. Events with exactly two jets and $E_T^{miss}$ between 100 GeV and 150 GeV fall into a control region dominated by top-pair production. Finally, the signal region is defined by requiring either $E_T^{miss} > 150\,\mathrm{GeV}$ and $\mathrm{N_{jets}} \geq 2$, or $E_T^{miss} > 100\,\mathrm{GeV}$ and $\mathrm{N_{jets}} \geq 3$. A kinematic fit considers the mass range from 20 GeV to 300 GeV, while for a counting experiment the range is restricted to 20 GeV to 70 GeV.

Two types of standard model (SM) backgrounds contribute to the signal selection. The main source of backgrounds are flavor-symmetric processes, which produce SF lepton pairs as often as opposite flavor (OF) pairs. They are in turn dominated by dileptonic decays of top pairs, but also the Drell-Yan process where the boson decays to two tau leptons, W boson pair production or misidentified leptons contribute. The second type of backgrounds are processes producing a Z boson decaying into two light leptons.

Flavor-symmetric backgrounds are predicted from the OF sample, which in principle has the same event yield and kinematic properties as the SF sample. As this symmetry might be broken by the different efficiencies for trigger, reconstruction and identification of the different lepton flavors, a correction factor is derived from two independent methods, utilizing orthogonal event samples. The first method is the direct measurement of the ratio $R_{SF/OF}$ in the top-pair dominated control region. This method is limited by the statistical uncertainties of this measurement. The second method measures the efficiencies of the dilepton triggers ($\epsilon_{ee}^{trig}$,$\epsilon_{\mu\mu}^{trig}$,$\epsilon_{OF}^{trig}$) as well as the ratio of the selection efficiencies for muons and electrons $r_{\mu e}$. The correction factor is then calculated as $R_{SF/OF} = \frac{1}{2}(r_{\mu e} + \frac{1}{r_{\mu e}})\frac{\sqrt{\epsilon_{ee}^{trig}\epsilon_{\mu\mu}^{trig}}}{\epsilon_{OF}^{trig}}$. The precision of this method is limited by the systematic uncertainties introduced by the extrapolation of the efficiency measurements into the signal region. The results from both methods are consistent and are combined according to their respective uncertainties. The resulting values are $R_{SF/OF} = 1.00 \pm 0.04$ for central leptons and $R_{SF/OF} = 1.11 \pm 0.07$ for forward leptons.

For the counting experiment at low $m_{\ell\ell}$, the background from SM processes containing a Z boson is estimated by first deriving an estimate for the contribution of these processes on the Z peak for $m_{\ell\ell}$ between 81 GeV and 101 GeV with two independent methods. The first one uses the balance of the Z against the jets in the event to predict the contribution of these backgrounds in regions with high $E_T^{miss}$. The second predicts the contribution from Z bosons using events with single photons. The results of both methods are consistent and are averaged according to their uncertainties. The prediction for the Z peak region is extrapolated to low masses using a scale factor, determined in the Drell-Yan enriched control region.

The results of the counting experiment at low invariant masses are shown in Tab. 1. For the dominant flavor-symmetric backgrounds a precision of the estimate of 5% for the central region and 10% for the forward region has been achieved. In the forward region there is good agreement between background expectation and observation, while in the central region there is a small excess with a local significance of $2.6\sigma$. This can also be seen in Fig. 2, which shows the invariant mass distribution in the signal region separately for central and forward leptons.

The search for a kinematic edge in the dilepton mass spectrum is performed using an unbinned maximum likelihood fit, simultaneous to the ee, $\mu\mu$ and OF event samples in both the central and forward lepton selection. The only parameter shared between the models for the forward and central selection is the position of the edge $m_{\ell\ell}^{edge}$. The fit model consists of four components. The signal model is a triangular shape, smeared with the expected detector

| | Central | Forward |
|---|---|---|
| Observed [SF] | 860 | 163 |
| Flav. Sym. [OF] | $722 \pm 27 \pm 29$ | $155 \pm 13 \pm 10$ |
| Drell–Yan | $8.2 \pm 2.6$ | $1.7 \pm 1.4$ |
| Total estimates | $730 \pm 40$ | $157 \pm 16$ |
| Observed – Estimated | $130^{+48}_{-49}$ | $6^{+20}_{-21}$ |
| Significance [$\sigma$] | 2.6 | 0.3 |

Table 1: Results of the counting experiment for event yields in the signal regions. Statistical and systematic uncertainties are added in quadrature, except for the flavor symmetric backgrounds.

resolution:

$$\mathcal{P}_S(m_{\ell\ell}) = \frac{1}{\sqrt{2\pi}\sigma} \int_0^{m_{\ell\ell}^{edge}} dy \cdot y \cdot e^{\frac{-(m_{\ell\ell}-y)^2}{2\sigma^2}}. \tag{1}$$

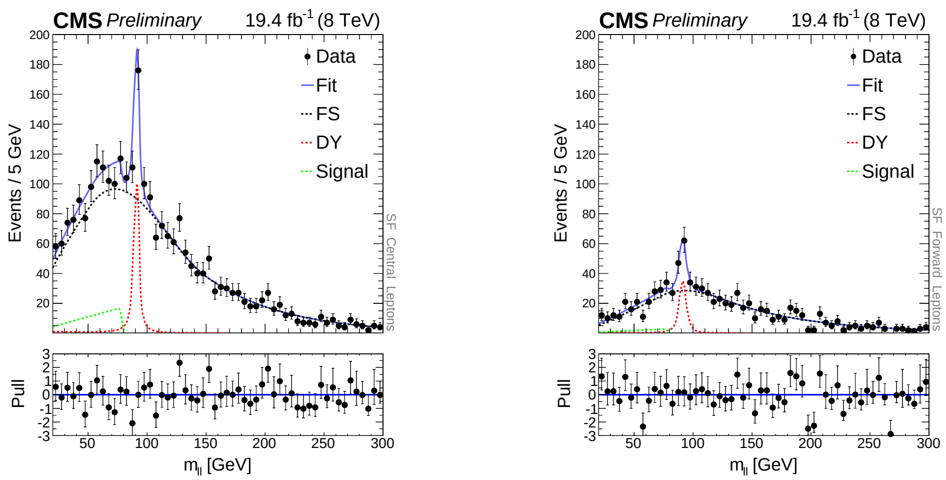


Figure 2: Invariant mass distriubtions in the signal region. The data is shown as black points, while the background prediction is shown as a red line. The total uncertanty on the background is indicated in blue. The Drell-Yan background component is shown in green (colored version can be found online).

Backgrounds containing a Z boson are described by a Breit-Wigner distribution convolved with a double-sided Crystal Ball function for the peak component and a falling exponential for the continuum component. The model is in a first step fitted in the Drell-Yan enriched control region. Afterwards, all parameters are fixed and only the normalization is a free parameter in the fit in the signal region. Flavor-symmetric backgrounds are described by a model consisting of three parts; a kinematic turnon at low $m_{\ell\ell}$, an exponential fall at high $m_{\ell\ell}$, and a polynomial to describe the transition between the two:

$$\mathcal{P}_{FSE}(m_{\ell\ell}) = \begin{cases} \mathcal{P}_{FSE,1}(m_{\ell\ell}) = c_1 \cdot m_{\ell\ell}^{\alpha} & \text{if } 20GeV < m_{\ell\ell} < m_{\ell\ell}^{(1)} \\ \mathcal{P}_{FSE,2}(m_{\ell\ell}) = \sum_{i=0}^{3} c_{2,i} \cdot m_{\ell\ell}^{i} & \text{if } m_{\ell\ell}^{(1)} < m_{\ell\ell} < m_{\ell\ell}^{(2)} \\ \mathcal{P}_{FSE,3}(m_{\ell\ell}) = c_3 \cdot e^{-\beta m_{\ell\ell}} & \text{if } m_{\ell\ell}^{(2)} < m_{\ell\ell} < 300GeV \end{cases}$$

The background yields for the flavor-symmetric backgrounds in the SF and OF categories are connected via the correction factor $R_{SF/OF}$, which is a nuisance parameter in the fit. The fit results are shown in Tab. 2. The best fitted value for the edge position is 78.7±1.4 GeV and the fitted signal yield is 126±41 events in the central and 22±20 events in the forward region. The local significance of the result is 2.4$\sigma$. The invariant mass distributions together with the fit result are shown in Fig. 3.

| | Central | Forward |
|---|---|---|
| Drell–Yan | $158 \pm 23$ | $71 \pm 15$ |
| Flav. Sym. [OF] | $2270 \pm 44$ | $745 \pm 25$ |
| $R_{SF/OF}$ | 1.03 | 1.02 |
| Signal events | $126 \pm 41$ | $22 \pm 20$ |
| $m_{\ell\ell}^{\text{edge}}$ [GeV] | $78.7 \pm 1.4$ | |
| Local Significance [$\sigma$] | 2.4 | |

Table 2: Results of the unbinned maximum likelihood fit for event yields in the signal regions.

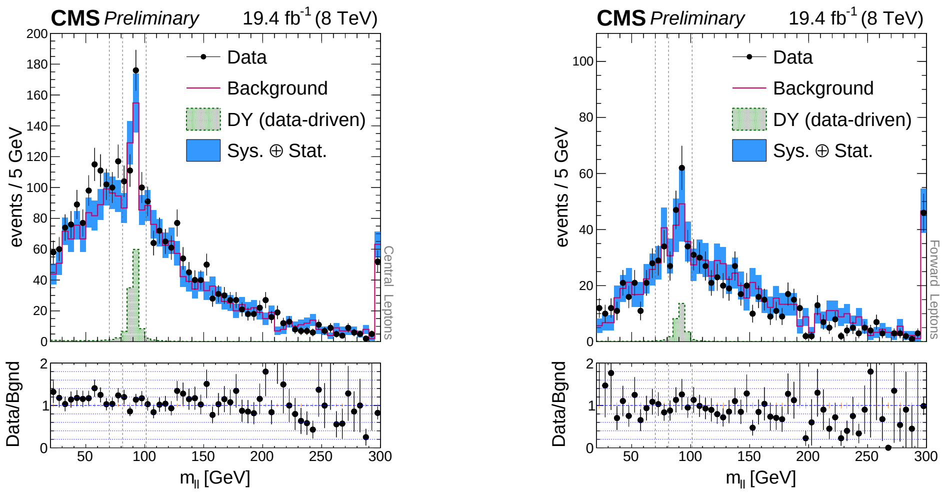


Figure 3: Invariant mass distriubtions in the signal region. The data is shown as black points, while the fit result is shown in blue. The different fit components are shown in green for the signal model, black for the model for flavor-symmetric backgrounds and in red for the Drell-Yan background (colored version can be found online).

A search for Supersymmetry in same-flavor opposite-sign dilepton events with jets and $E_T^{miss}$ has been presented. SM backgrounds are predicted from data with high precision. A fit is performed in search for a edge in the dilepton invariant mass spectrum. Although a small excess has been observed at low invariant masses, no evidence for a statistically significant signal has been observed. This result highlights the opportunities of high precision searches at the LHC and preparations are ongoing to repeat this analysis in 2015.

# References

[1] S. Chatrchyan et al. The CMS experiment at the CERN LHC. *JINST*, 3:S08004, 2008.

[2] Search for physics beyond the standard model in events with two opposite-sign same-flavor leptons, jets, and missing transverse energy in pp collisions at sqrt[s] = 8 TeV. Technical Report CMS-PAS-SUS-12-019, CERN, Geneva, 2014.