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SUSY searches at CMS

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Summary. — This article summarizes searches for supersymmetry at the CMS detector performed in 2011 at the LHC with *pp* collisions energies of 7 TeV. For several leptonic and photonic supersymmetry searches results are presented with an integrated luminosity of approximately $5\,\mathrm{fb}^{-1}$ that are shown for the first time in public at this conference. In none of the searches a potential supersymmetry signal has been observed and within the CMSSM gluiono masses below ~ 750 and first generation squarks masses below ~ 1250 GeV have been excluded. Finally an outlook on the focus of supersymmetry related activities at the CMS detector in the near future is given.

PACS `11.30.Pb` – Supersymmetry.

1. – Introduction

Supersymmetry is one of the most favored extensions to the standard model. Supersymmetry can provide an explanation for the fine-tuning problem of the Higgs mass [1,2], dark matter WIMP particle candidates [3,4], and has further advantages. This proceeding reports on searches for events with supersymmetric topologies in proton-proton collisions at a center-of-mass energy of 7 TeV with a data sample that was collected by the Compact Muon Solenoid (CMS [5]) experiment during 2011 at the Large Hadron Collider (LHC). The integrated luminosity of the presented results ranges from approximately 1 to $5\,\mathrm{fb}^{-1}$.

2. – Supersymmetry searches at CMS

A typical decay of two gluinos (supersymmetric partner of the gluon) is illustrated in fig. 1 for the *R*-parity-conserving case. For *R* parity conservation the two lightest stable particles (LSP) of supersymmetry leave the detector undetected. A large mass difference between the initially produced sparticles (super partners of particles) and the stable final state (s)particles leads to high transverse energy in the experiment. The typically large momenta of the LSPs in the sparticle decays of supersymmetry models lead to large

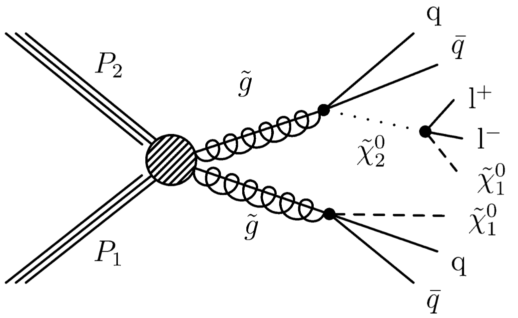

Fig. 1. – Typical supersymmetric decay chain.

missing transverse energy ($\not{E}_{\mathrm{T}}$) in the detector. The standard model particles of the decay lead to large visible transverse energy, which is often quantified by the scalar sum of the transverse energy of the jets (H_{T}) in an event. The observables $\not{E}_{\mathrm{T}}$ and H_{T} build the basis for many of the searches for superymmetry. Also a variety of kinematic variables are used in CMS. These variables include more information on angular distributions and individual energies of the visible decay products than H_{T}. Several kinematic variables used by CMS are described in the following:

α_T: This variable represents the balance of QCD topology events and is extremely robust against detector effects. The tails of the α_T distribution are effectively QCD free, but do contain significant fractions of events with supersymmetric topologies [6].

M_R,R^2: M_R approximates under certain assumptions [7] the mass-difference between the initially produced sparticles and the final state sparticles. R^2 is a ratio of two different approximation of the mass difference, which should only be correlated for supersymmetric events. Both variables separate potential supersymmetric events (or other pair produced particles that produce $\not{E}_{\mathrm{T}}$ in their decay) and standard model events.

M_{T2}: This variable is a generalization of the transverse mass, as *e.g.* used for W-bosons, to the case of two invisible particles. At large values of M_{T2} supersymmetric events would be expected to occur. Also information about the spectra of supersymmetry could be revealed in case of discovery [8].

L_P: (one leptonic search) This variable reflects the polarization behavior [9] for boosted W-bosons in standard model events and for supersymmetric events it would reveal the level of decorrelation between the $\not{E}_{\mathrm{T}}$ and the charged lepton due to the multiple particles contributing to $\not{E}_{\mathrm{T}}$. Again it separates well supersymmetry like events and standard model events.

Apart from the different variables used naturally many final states of sparticles decays are probed at CMS. These decays can be fully hadronic, *i.e.* without charged leptons in the final state. The fully hadronic searches have the best sensitivity in the constrained minimal supersymmetric model (CMSSM [10, 11]). The leptonic searches add to the sensitivity and also open the door to look for electroweak production of supersymmetric particles, especially in low background multi-lepton searches. The final states with photons are especially interesting for gauge mediated (GM [12]) supersymmetry, in which often χ^0s decay to a vector bosons, *i.e.* often photons, and a gravitino. Tags of b-jets

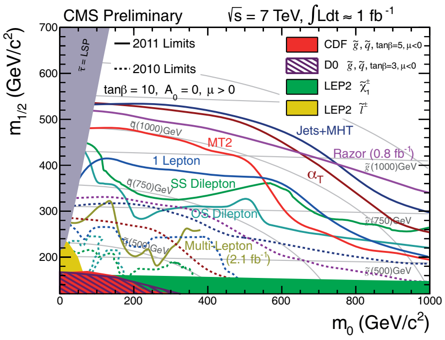

Fig. 2. – Limits of different analyses in the CMSSM for $\tan\beta = 10$ and $A_0 = 0$ with the 2011 CMS data for an integrated luminosity of approximately $1\,\text{fb}^{-1}$.

are also used, *e.g.* especially to enhance sensitivity to the supersymmetric partner of top or bottom quarks. b-jets as well as τs play also an important role in supersymmetric Higgs searches, which are not covered here, but in the general report on Higgs searches at CMS.

Individual searches are published for each final state and in the most promising final states several analysis with different background estimation methods and different variables are available. At the time of the conference more than 30 results on SUSY searches have been made public. The limits in the CMSSM for several analysis done with $\sim 1\,\text{fb}^{-1}$ of integrated luminosity is are shown in fig. 2. All CMS searches have in common that the background prediction is done using experimental data and not by directly comparing the simulation to the experimental data.

3. – First results with full 2011 dataset

This section describes first new results of the CMS searches with the dataset of the complete 2011 run, which has an integrated luminosity of approximately $5\,\text{fb}^{-1}$.

3˙1. *One leptonic search.* – The main background in one leptonic searches [13] are boosted W-bosons from W+jet or $t\bar{t}$ decays. Two alternative methods have been used to predict this background, both of which utilize the knowledge of the W-boson polarizations in the standard model. Recently, progress was made in theoretical prediction for the polarization of boosted W bosons in W+jets events at pp colliders [14]. Experimentally, the prediction were confirmed [9]. The polarization in $t\bar{t}$ is theoretically well known [15] and was also recently measured at the LHC [16, 17].

The relation between charged and neutral leptons in the decay of boosted W-bosons is governed by the polarization of the W boson. The relation of the spectra of neutrino and charged leptons are very different for the individual charges. The dominant polarization for boosted W-bosons in W + jets events at the LHC is lefthanded, thus most of the W-boson transverse momentum is given to the lefthanded lepton, which is the neutrino in the W^+ and the charged lepton in the W^- case. After the combination of the charges and the application of acceptance correction the charged and neutrino momentum spectra are roughly similar and most importantly; their relation is well understood. For $t\bar{t}$ events the dominant longitudinal polarization leads to charge and handedness symmetric lepton distribution. The lefthanded (right-handed) component of the $W^{+(-)}$ boson prefers giving its momentum to the neutrino. The dominant ($\sim 70\%$) longitudinlly po-

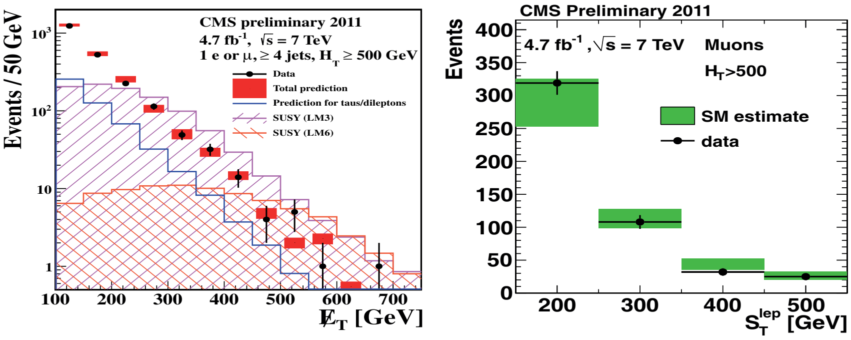

Fig. 3. – Left: Prediction of $\not{E}_{\mathrm{T}}$ with the LS method, right: S_T^{lep} predictions with the L_P method in the μ channel.

larized W-bosons distribute their transverse momentum equally to all charges. Again, after the acceptance cuts, charged lepton spectra and neutrino spectra are similar. For typical supersymmetric decays however $\not{E}_{\mathrm{T}}$ is expected to be significantly higher than the transverse momentum of the charged leptons, given that $\not{E}_{\mathrm{T}}$ is composed of the two LSPs and a neutrino compared to the single lepton. While charged lepton and $\not{E}_{\mathrm{T}}$ are typically aligned in the standard model, since both originate from the boosted W-boson decay, supersymmetric events show much looser angular correlations between the two.

One search selects exclusively one isolated lepton (μ or e) and greater or equal to four jets. The signal is enhanced by using several $\not{E}_{\mathrm{T}}$ bins and different H_{T} thresholds. The background prediction is done via the lepton spectrum method (LS method). In this method the charged lepton transverse-momentum distribution is used to predict the neutrino distribution. Contributions from fully leptonic $t\bar{t}$ events are estimated separately as well as resolution effects.

The other search in the exclusive one lepton channel (L_P method) selects events with greater than two jets. The events are also required to have L_P smaller than 0.15, where L_P is the projection of the transverse momentum of the charged lepton to the direction of the W-boson transverse momentum and normalized to the W-boson transverse momentum: $L_P = P_T(l^{\pm})\cos((l^{\pm}, W)/P_T(W))$. For the selected events the charged lepton is thus either not aligned with $\not{E}_{\mathrm{T}}$ ($\sim$boosted W-boson direction in standard model) or the transverse momentum of the charged lepton is much smaller than $\not{E}_{\mathrm{T}}$. Both ingredients separate supersymmetry and standard model. Thresholds on H_{T} and bins in $S_T^{lep}(= \not{E}_{\mathrm{T}} + P_T(l^{\pm}))$ are used to further reduce the background. The main control sample used for the background prediction are the events with $L_P > 0.3$, *i.e.* events in which $\not{E}_{\mathrm{T}}$ and charged lepton are aligned in ϕ and have similar amplitude.

Figure 3 shows the prediction of $\not{E}_{\mathrm{T}}$ using the LS method as well as prediction of S_T^{lep} bins using the L_P method. No excess had been observed for any H_{T} threshold. The interpretation of the result in context of the CMSSM for the $H_{\mathrm{T}} > 750\,\mathrm{GeV}$ and the $H_{\mathrm{T}} > 1\,\mathrm{TeV}$ thresholds are presented in fig. 4.

3˙2. *Opposite-sign leptonic search.* – The searches requires two leptons with opposite charge. The leptons can be of any flavor (e, μ, τ). One search uses the variables $\not{E}_{\mathrm{T}}$ and H_{T}, one uses a mass edge technique [18, 19] and one an artificial neural network with several input variables [20]. The first is discussed here in more detail. The dominant background to the $\not{E}_{\mathrm{T}}$ search is $t\bar{t}$. The same principle as in the single lepton searches is applied for the main background, namely that the relation between charged leptons

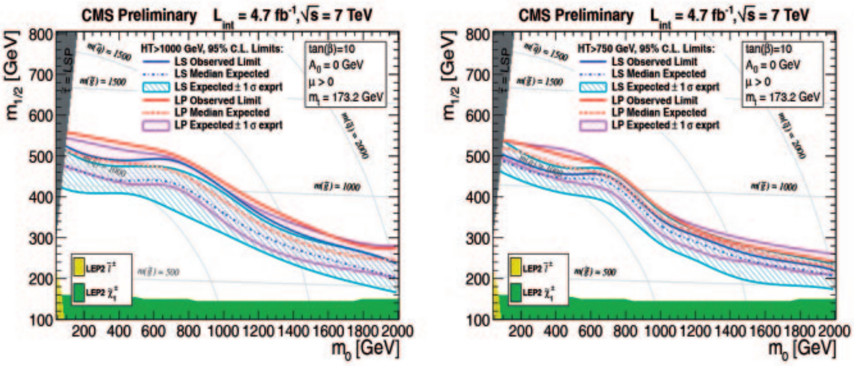

Fig. 4. – Left: limits in CMSSM for a H_T threshold of 750 GeV, right: limits in CMSSM for a H_T threshold of 1 TeV.

and neutrinos is well known. The transverse momentum of the vector sum the transverse momenta of the charged leptons ($P_T(ll)$) is used for the prediction $\not{E}_T$. $P_T(ll)$ is scaled according to the known ratio of $P_T(ll)$ over $P_T(\nu\nu)$ and smeared according to a $\not{E}_T$ resolution that has been determined in data as for the LS method. Figure 5 shows the prediction and the observed events for various H_T and $\not{E}_T$ thresholds. No excess over the expected number of standard model events has been observed. Figure 5 shows the interpretation of the result in the context of the CMSSM.

3$\cdot$3. *Same-signs leptonic search.* – In this search two isolated leptons of any flavor, but of same charge are required. The small backgrounds allow relatively relaxed $\not{E}_T$ and H_T thresholds, if none of the leptons is a hadronic τ. To reduce more background in the τ channels $\not{E}_T$ and H_T thresholds are increased. The dominant background stems from "fake" isolated leptons, *e.g.* lepton from heavy flavor jets, photon conversions and other sources. In most cases only one of the leptons is fake, as can happen, *e.g.*, in semileptonic $t\bar{t}$ decays, where one b-quark produces a "fake" isolated lepton. This background is estimated via a "Tight-Loose" ratio. The ratio of "fake" leptons in a loose

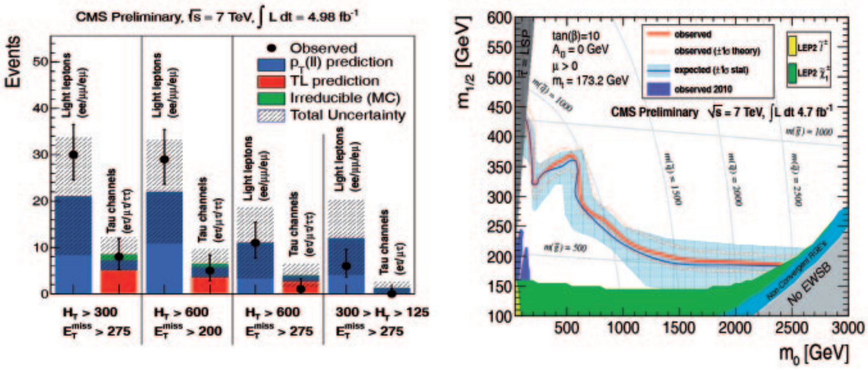

Fig. 5. – Left: prediction for different kinematic regions for the opposite-sign lepton search, right: limit of opposite lepton search in the CMSSM for $\tan\beta = 10$ with the 2011 CMS data (updates results of [18, 19] to full 2011 dataset with approximately 5 fb^{-1}).

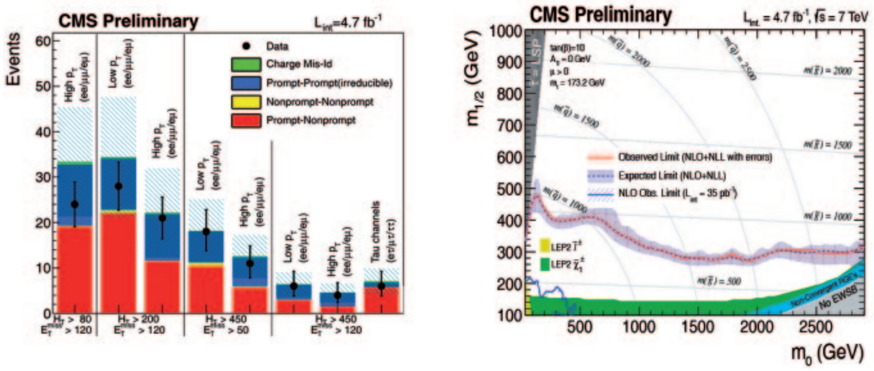

Fig. 6. – Left: prediction for different kinematic regions for the same sign leptons search, right: limit of same-sign lepton search in the CMSSM for $\tan\beta = 10$ with the 2011 CMS data (updates results of [21, 22] to full 2011 dataset with approximately $5\,\text{fb}^{-1}$).

lepton identification to a tight identification used in the search is measured in data in a multijet sample. This ratio is than applied to an control sample done with the loose electron selection (but else the final selection) to estimate the "fake" lepton events for the tight selection. Details and further background estimations can be found in [21, 22]. The irreducible background from WW and WZ is estimated from simulation and a 50% uncertainty on these numbers has been derived.

The prediction for the different backgrounds and the data signal yield is presented in fig. 6. No excess is observed and the interpretation of the result in the context of the CMSSM is shown in fig. 6. The search is especially sensitive at large m_0. In this region electroweak production enhances (multi) leptonic channels.

3˙4. *One and two photon searches.* – Photon searches for supersymmetry [23] are especially interesting in the context of GM supersymmetry. If the gravitino is the LSP, than the next lightest sparticle is typically a neutralino or chargino. The neutralinos decay to gravitino and photon or Z-boson. Neutralinos are an admixture of wino and bino, if the neutralino is more bino like, than the photon decay is preferred, else the Z-boson channel is enhanced (fig. 7). The search does not veto on leptons in order to keep events in which a chargino decays to gravitino and a W-boson, that can decay leptonically.

The search for signal is done in $\not{E}_{\mathrm{T}}$ bins. The two-photon search requires only at least one jet and two rather loose photons. Due to trigger constraints, the single photon search requires H_{T} greater than 450 GeV and a single high P_T (> 80 GeV) photon. In both

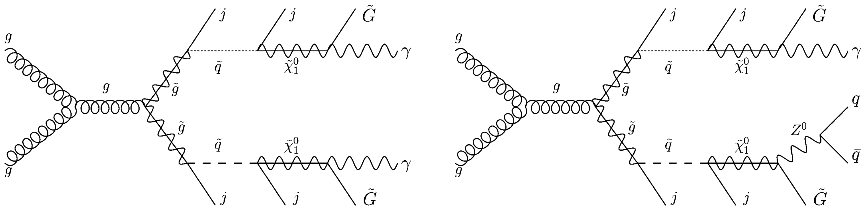

Fig. 7. – Left: typical decay chain for bino-like χ^0_1, right: typical decay for wino-like χ^0_1.

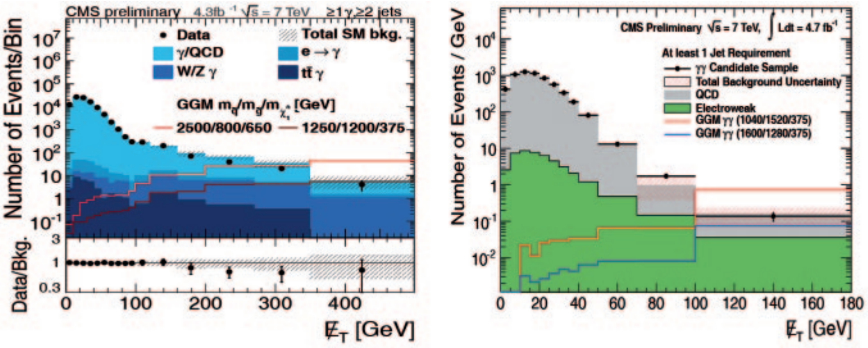

Fig. 8. – Left [23]: predicted and observed $\not\!\!E_{\mathrm{T}}$ distribution for single γ channel, right [23]: predicted and observed $\not\!\!E_{\mathrm{T}}$ distribution for two-γ channel.

selections the main backgrounds are events with $\not\!\!E_{\mathrm{T}}$ that does not stem from a single isolated neutrino, but rather detector effects and heavy flavor jets. The photons for this background are either jets mimicking photons from pure QCD events or prompt photons produced in conjunction with jets. The main background estimation is done via a control sample in which the photon identification criteria are relaxed, but do not include the final photons. To model the shape of the $\not\!\!E_{\mathrm{T}}$ distribution for the final selection the events of the control sample are weighted according to their transverse momentum to reproduce the transverse momentum of the photon of the tight selection. The $\not\!\!E_{\mathrm{T}}$ distribution of the weighted control sample is than normalized to the $\not\!\!E_{\mathrm{T}}$ distribution of the final selection in a signal free region of $\not\!\!E_{\mathrm{T}}$, which is, *e.g.*, $\not\!\!E_{\mathrm{T}} < 20\,\mathrm{GeV}$ for the $\gamma\gamma$ case. The renormalized $\not\!\!E_{\mathrm{T}}$ distribution is used as estimation of the background in the high $\not\!\!E_{\mathrm{T}}$ search region. The second largest background are events where an electron is misidentified as photon in W-boson decays, *i.e.* events with true $\not\!\!E_{\mathrm{T}}$ from neutrinos. The probability of electrons to "fake" photons has been determined in data. To estimate the background from electron mislabeled as photon, this "fake" probability is applied to a control sample in which, instead of photons, electrons have been selected. The background prediction and the observed events for the different $\not\!\!E_{\mathrm{T}}$ bins are presented in fig. 8. No excess has been observed and the interpretation of the result in the context of supersymmetry is shown in fig. 9.

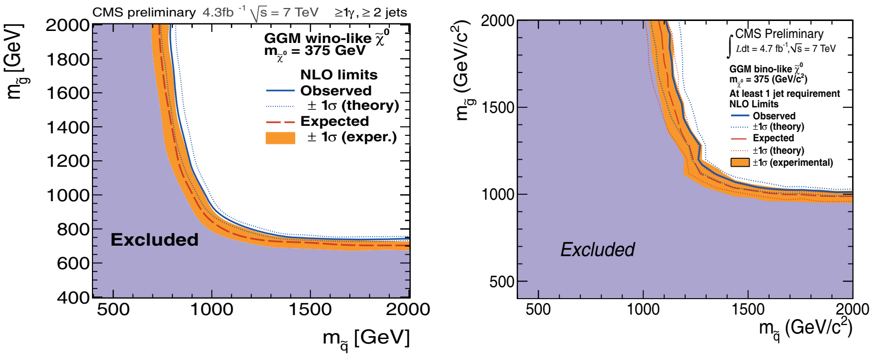

Fig. 9. – Left [23]: exclusion limit from γ+jets for wino-like χ^0, right [23]: exclusion limit from $\gamma\gamma$+jets for bino-like χ^0.

4. – Outlook and future activities

Currently much effort is directed towards the search for third generation squarks in CMS. To solve the hierarchy problem without any tuning of supersymmetry a light squark ($\mathcal{O}$(few 100 GeV)) is needed. The third generation is likely to be the lightest generation of squarks. See the report of A. Falkowski in this conference for details on this topic. At the time of the conference no new constrains on third generation squark were available, however the year 2012 will presumably yield enough data to constrain the third generation significantly, if no hint of any signal is found.

Other new searches with respect to last year have been introduced, among them several more exclusive searches with many final state particles. *E.g.* a search in the WZ will probe the electroweak production of supersymmetry. Further, more sophisticated analysis methods are started to be deployed. The first neural-net based analysis [20] has recently been presented.

5. – Conclusion

New results with the full 2011 dataset from CMS have been presented. They did not show any excess of data with respect to the standard model. In the context of CMSSM, CMS constrains first generation squarks to masses above ~ 1.25 TeV and gluinos above ~ 750 GeV. The year 2012 will be very interesting for supersymmetry and results for searches for the third generation squarks will be presented.

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