Search for Supersymmetry at CMS in all-hadronic final states

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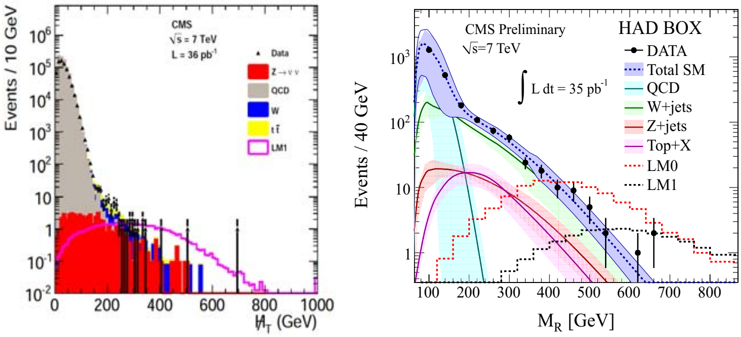
Supersymmetric theories are good candidates for physics beyond the Standard Model. At hadron colliders, new particles are expected to be produced in pairs (assuming R-parity), mainly by the strong interaction. These colored particles can decay to one or two jets (depending on their color charge) and a weakly interacting Lightest Supersymmetric Particle (LSP). Final states consist of visible transverse momentum (H_{T}) due to the jets and missing transverse momentum ($\not\!\!H_{\mathrm{T}}$) from the LSP. Unfortunately, Standard Model processes have similar signatures with $\not\!\!H_{\mathrm{T}}$ introduced by vector bosons decaying to neutrinos or jet mismeasurements in QCD multijet events. The quest for supersymmetry observation in events with this final state is challenging due to the large background. However, it is the most sensitive channel to discover supersymmetry. CMS [1] has several search strategies in place, each using $\sim 35\,\mathrm{pb}^{-1}$ of pp collisions and all searches estimated their backgrounds using data.

The first supersymmetry search concluded at the LHC is the α_{T}-search [2], requiring two or more jets and $H_{\mathrm{T}} > 350\,\mathrm{GeV}/c$. Strong QCD multijet background rejection is controlled by the α_{T} variable: $\alpha_{\mathrm{T}} = \frac{E_{\mathrm{T}}(J_2)}{M_{\mathrm{T}}(J_1,J_2)}$. Perfectly measured di-jets have $\alpha_{\mathrm{T}} = 0.5$, events with mismeasuremed jets populate $\alpha_{\mathrm{T}} < 0.5$, while events with genuine missing momentum populate the whole α_{T} spectrum. Requiring $\alpha_{\mathrm{T}} > 0.55$ selects a QCD multijet free search region. Since this is the most difficult background to model correctly, this analysis is particulary suited for an early discovery. $\not\!\!H_{\mathrm{T}}$ was required indirectly by the α_{T} variable, being $\sim 140\,\mathrm{GeV}/c$ for $\alpha_{\mathrm{T}} > 0.55$ and $H_{\mathrm{T}} > 350\,\mathrm{GeV}/c$. The power of this analysis is enhanced by multiple data-driven methods to estimate the remaining Standard Model background. An inclusive estimation of the backgrounds is complemented with separate estimations of W, $t\bar{t}$ and Z. No excess of events was found in the data. The search was also extented with an additional b-tagged jet, increasing the sensitivity to stop and sbottom quarks [3].

The jets + $\not\!\!H_{\mathrm{T}}$ search [4] requires at least three jets and vetoes isolated leptons. The baseline selection requires $H_{\mathrm{T}} > 300\,\mathrm{GeV}/c$ and $\not\!\!H_{\mathrm{T}} > 150\,\mathrm{GeV}/c$. Mismeasured multi-jets are reduced by requesting the $\not\!\!H_{\mathrm{T}}$ not to be aligned with one of the leading jets. Throughout the selection a high signal efficiency is maintained. Figure 1(a) shows the $\not\!\!H_{\mathrm{T}}$ distribution for data and MC simulation after all cuts but the $\not\!\!H_{\mathrm{T}}$ requirement.



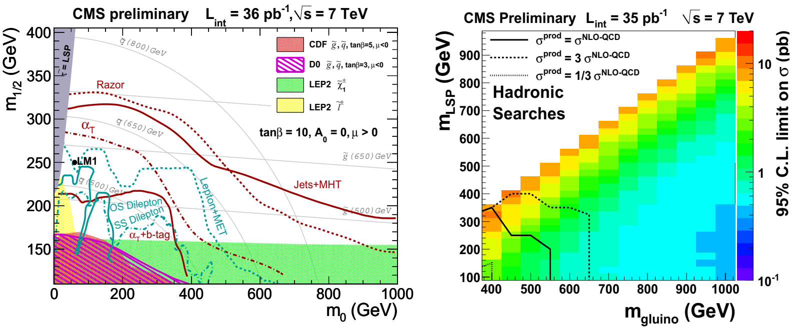
(a) Jets + $\not\!\!H_{\mathrm{T}}$ Search (b) Razor Search

Figure 1: Jets + $\not\!\!H_{\mathrm{T}}$ search: The missing transverse momentum ($\not\!\!H_{\mathrm{T}}$) distribution for data and MC simulation (a). Razor search: The M_{R} distribution showing the final background prediction and data in the hadronic channel (b).

Two different search regions were defined, one selecting events with large visible transverse momentum ($H_{\mathrm{T}} > 500\,\mathrm{GeV}/c$, $\not\!\!H_{\mathrm{T}} > 150\,\mathrm{GeV}/c$), the other selecting events with large missing transverse momentum ($H_{\mathrm{T}} > 300\,\mathrm{GeV}/c$ $\not\!\!H_{\mathrm{T}} > 250\,\mathrm{GeV}/c$). All Standard Model backgrounds are measured in data: $Z(\nu\nu)$ is estimated from a γ+jets sample, exploiting the clean event signature and high statistics of the latter. W and $t\bar{t}$ are estimated simultaneously using a μ + jets control sample, while hadronically decaying τs are emulated substituting the μ in the same μ + jets control sample for a τ-jet. The background from mismeasured multijet events are estimated using a novel technique, “Rebalance and Smear”, using the detailed knowledge of the jet energy resolutions measured in data. Jets are adjusted within the measurement uncertainties to bring the event into transverse momentum balance. A full event kinematics prediction is obtained smearing those rebalanced jets with the same resolution functions.

The Razor search [5] characterizes the pair production of heavy particles using the “Razor” variables R and M_{R} [6]. M_{R} provides an event-by-event estimate of the mass scale of the produced heavy particles $M_{\Delta} = \frac{M_{\tilde{q}}^{2} - M_{\tilde{\chi}}^{2}}{M_{\tilde{q}}}$, while the R threshold shapes the M_{R} distribution in a simple (exponential) way. Depending on the presence of isolated leptons, events are assigned to three exclusive sets: the muon, electron and hadronic boxes. Isolated leptons and jets are grouped into two megajets. The razor analysis tests the hypothesis that the megajets contain the visible decay products of the two heavy particles, which is a complementary approach to the jets + $\not\!\!H_{\mathrm{T}}$ search.

The non-QCD backgrounds W and $t\bar{t}$ are determined separately in the lepton boxes that are dominated by W + jets. The exponential shape is measured both in data and Monte Carlo simulation and data/Monte Carlo factors are derived to profit from the high integrated luminosity of the Monte Carlo sample. The shapes are normalized with the W and $t\bar{t}$ cross sections measured in CMS and the selection and identification efficiencies for leptons measured on a Z + jets sample. The QCD background peaks at $M_{\mathrm{R}} = 0$, and falls exponentially, becoming negligible in the high-M_{R} region. Finally the backgrounds are fitted in the low M_{R} region, which serves as a background prediction for the hadronic analysis, while the high-M_{R} region is also a search region. An irreducible background comes from $Z(\nu\nu)$, which is estimated by removing the μ from the event. All backgrounds are summed and renormalized in the low-M_{R} control region and extrapolated to the high-M_{R} signal region. Figure 1(b) shows the predicted backgrounds and event yields in data for the hadronic analysis.



(a) Limits for the CMSSM model

(b) Limits for $\tilde{g}\tilde{g}$ production

Figure 2: Comparison of the observed 95 % CLs limits in the CMSSM $m_{1/2}$ vs. m_0 plane for the different all-hadronic searches (a) and the combined estimated 95 % CLs exclusion limits for a Simplified Model of gluino pair production (b) [8].

In all analyses no excess of data over background is observed, hence limits are set, both in the CMSSM and by using Simplified Models. Simplified Models characterize experimental data in terms of a small number of parameters, directly related to collider physics observables: particle masses, production cross-sections and branching fractions [7]. Figure 2(a) compares the three all-hadronic searches in the gaugino mass ($m_{1/2}$) vs. universal scalar mass (m_0) plane of the CMSSM. The Razor search is slightly more sensitive to the $\tilde{q}\tilde{q}$ production due to the di-jet selection, while the Jets + $\not{H}_{\mathrm{T}}$ search is still competitive due to the high signal efficiency. The optimization for 3 or more jets allows the latter to be sensitive to the two-jet and $\not{H}_{\mathrm{T}}$ signature of di-squark production accompagnied by Inital State Radiation. The search region optimized for high visible momentum enables the Jets + $\not{H}_{\mathrm{T}}$ to probe the $\tilde{g}\tilde{g}$ production more efficiently than the Razor analysis. The complementarity of Razor and Jets + $\not{H}_{\mathrm{T}}$ search is a powerful asset of CMS for the future to confirm a discovery for this final state. The α_{T}-search is less sensitive due to the strong cut on QCD yielding a lower signal efficiency. Figure 2(b) combines all three all-hadronic searches for a Simplified Model of $\tilde{g}\tilde{g}$ production in the LSP mass (m_{LSP}) vs. gluino mass ($m_{\tilde{g}}$) plane. For each mass combination the 95 %CLs upper limit on the cross section is given. The region where the 95 % confidence level on the cross section is higher than the "reference cross section" for gluino pair production (in the limit of decoupled squarks) is below the black line.

References

[1] S. Chatrchyan *et al.* [CMS Collaboration], JINST **3** (2008) S08004 doi:10.1088/1748-0221/3/08/S08004.

[2] V. Khachatryan *et al.* [CMS Collaboration], Phys. Lett. B **698** (2011) 196 [arXiv:1101.1628 [hep-ex]], doi:10.1016/j.physletb.2011.03.021.

[3] S. Chatrchyan *et al.* [CMS Collaboration], JHEP **1107** (2011) 113 [arXiv:1106.3272 [hep-ex]], doi:10.1007/JHEP07(2011)113.

[4] S. Chatrchyan *et al.* [CMS Collaboration], JHEP **1108** (2011) 155 [arXiv:1106.4503 [hep-ex]], doi:10.1007/JHEP08(2011)155.

[5] S. Chatrchyan *et al.* [CMS Collaboration], Submitted to Phys. Rev. D arXiv:1107.1279 [hep-ex], CMS-PAS-SUS-10-009.

[6] C. Rogan, arXiv:1006.2727 [hep-ph], CALT 68-2790.

[7] J. Alwall, P. Schuster and N. Toro, Phys. Rev. D **79** (2009) 075020 [arXiv:0810.3921 [hep-ph]], 10.1103/PhysRevD.79.075020.

[8] CMS Collaboration, CMS-PAS-SUS-11-001.