RECENT STUDIES ON SPARTICLES AND MSSM HIGGSES
AT CMS

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The discovery of the Higgs boson and of supersymmetric particles are the main
goals of the CMS experiment. This talk concerns recent analyses performed by
the CMS collaboration on the possibility of discovering and reconstructing MSSM
Higgses. Then the selection and reconstruction methods are described to identify
gluinos and sbottoms and to reconstruct their mass peaks in a mSUGRA scenario

1 MSSM Higgs bosons

The Higgs sector of the Minimal Supersymmetric Standard Model consists
of 2 $SU(2)$ doublets, giving 5 physical Higgs scalars after the electroweak
symmetry breaking: 2 CP-even bosons, $h$ and $H$, 1 CP-odd boson $A$, and
2 charged bosons $H^\pm$. This sector is completely described, up to radiative
corrections, by two parameters: tan$\beta$, the ratio of the vacuum expectation
values of the two doublets, and $M_A$, the mass parameter.

1.1 Neutral Higgses in $H \rightarrow \tau\tau$

In proton-proton collisions with a center-of-mass energy of 14 TeV at the
LHC, the production mechanisms of neutral MSSM Higgs bosons will depend
on the tan$\beta$ value: at low tan$\beta$ the gluon-gluon fusion process $gg \rightarrow H$
should be dominant, while at high tan$\beta$ the Higgs production in association
with two $b$-quarks $gg \rightarrow Hbb$ is enhanced, as well as the Higgs coupling to
$\tau$'s ($g_{H\tau\tau} \sim \cos \beta^{-1}$); the $H \rightarrow \tau\tau$ branching ratio is about 10%, quite
independently of the mass for tan$\beta > 10$

Several studies have been performed within the CMS collaboration con-
cerning the possibility of discovering and reconstructing the MSSM Higgses
through its $\tau\tau$ decays, exploiting the good tracking and impact parameter
measurements of the CMS silicon tracker $^1$. Three possible final states have
been considered: $H \rightarrow \tau\tau \rightarrow \ell^+\ell^-$, $H \rightarrow \tau\tau \rightarrow \ell + \tau$-jet, $H \rightarrow \tau\tau \rightarrow 2\tau$-
jets. The Higgs mass can be approximatively reconstructed by projecting the
$E_{T}^{miss}$ vector on the direction of the leptons (or jets) coming from the $\tau$s.
$H \to \tau \tau \to \ell^+ \ell^-$: in this channel large backgrounds arise from $Z, \gamma^*, t\bar{t}, b\bar{b}$ and $WW, WZ$ decays, but they can be strongly reduced by demanding the presence of one $b$-jet from the associated production in the event. In fig. 1 the reconstructed higgs mass is shown for $\tan \beta = 20, m_A = 200$ GeV, and an integrated luminosity of 30 fb$^{-1}$, corresponding to about a year of running at low luminosity in LHC. Since there are four neutrinos in the final state, the Higgs mass is difficult to reconstruct. A better resolution can be obtained by considering the $\tau$ hadronic decays.

$H \to \tau \tau \to \ell + \tau$-jet: $\tau$ identification in the hadronic final state is based on the requirement of an isolated single hard ($p_t > 40$ GeV) charged track in the cone of the jet seen by the calorimeters; this allows an efficient reduction of backgrounds arising from QCD jets while $Z, \gamma^* \to \tau \tau$ has to be reduced exploiting the $b$-tagging in the associated production channel $b\bar{b}H_{SUSY}$. In fig. 2 the reconstructed Higgs mass peak is shown for $\tan \beta = 40$ and an integrated luminosity of 30 fb$^{-1}$.

$H \to \tau \tau \to 2 \tau$-jets: $\tau$-jet identification is the same as given in the previous section. The fractional momentum taken away by the neutrinos is significantly smaller in the $h^+ + h^-$ final state compared to leptonic final states, thus an improved $H_{SUSY} \to \tau \tau$ mass resolution can be expected; full simulations give resolution of $\sim 12\%$. The difficulty for the channel is triggering. An efficient hadronic $\tau$ trigger based on calorimeter and tracker information has been developed in order to suppress the huge QCD background, with excellent results. In fig. 3 the reconstructed $H_{SUSY}$ mass peak superimposed on the background is shown, for $\tan \beta = 25$ and an integrated luminosity of 30 fb$^{-1}$. 
The $H \to \tau\tau$ channel can lead to discovery of heavy MSSM neutral Higgses in the large and intermediate $\tan \beta$ region of the parameter space, and for masses in the 500-800 GeV range, as shown in figure 5. At low $\tan \beta$ Higgs decays to sparticles can be exploited.

1.2 Neutral Higgses decaying to sparticles

The channel $A, H \to \chi^0_1\chi^0_1 \to 4\ell^\pm + X$ turns out to be the most favourable one, provided neutralinos and sleptons are light enough so that the $\chi^0_1(\to \ell\ell) \to \chi^0_1\ell^+\ell^-$ branching ratio is significant. The four isolated leptons final state allows to reduce drastically the SM background, and only the SUSY one has to be taken in account. A $5\sigma$ statistical significance can be achieved in a $m_A - \tan \beta$ region complementary to the one covered by the $H \to \tau\tau$ searches, as shown in figure 5.

1.3 Charged Higgs

Since only a neutral Higgs boson is foreseen by the Standard Model, the discovery of a charged Higgs at LHC would be a clear signature of supersymmetry. $H^\pm \to \tau\nu$ with a hadronic $\tau$ decay has been shown to lead to the most favourable signature for CMS. For a charged Higgs heavier than the top quark, the main production processes in a hadronic collider are $gg \to tbH^\pm$, $gb \to tH^\pm$ and $q\bar{q} \to H^\pm$. Exploiting the tau polarization effect, an almost background-free signal in the transverse mass reconstructed from the $\tau$-jet and the trasverse missing energy can be achieved in events with a purely hadronic
top decay $t \to b\ell\bar{\ell}$. From the endpoint of the jacobian distribution of the transverse mass it is possible to estimate the Higgs mass with a $\sim 2\%$ precision. Figure 4 shows the reconstructed transverse mass for $m_{H^+} = 217$ GeV ($m_A = 200$ GeV) and $\tan \beta = 40$, superimposed on the total background for $30 fb^{-1}$.

Figure 5 shows 5$\sigma$ contours in the $m_A - \tan \beta$ plane for the described channels for an integrated luminosity of 100 $fb^{-1}$.

2 Sparticle reconstruction

Up to now, several inclusive studies have been performed by the CMS collaboration in order to evaluate the capability of the detector to discover supersymmetric particles. New studies have just started regarding the possibility of reconstructing the mass peaks for some sparticles.

For the analysis shown here, a mSUGRA scenario has been considered. The parameters are $m_{1/2} = 250$ GeV, $m_0 = 100$ GeV, $\tan \beta = 10$, $\text{sign}(\mu) = +$, and $A_0 = 0$, as suggested in ref. 3. The goal is the reconstruction of a whole decay chain of the gluinos produced in the proton-proton collisions at LHC: $\tilde{g} \to t\bar{t}, \tilde{b} \to \tilde{\chi}_1^0 b, \tilde{\chi}_2^0 \to \ell^\pm \ell^\mp \to \tilde{\chi}_1^0 \ell^\pm \ell^-$. The main SM background source is $t\bar{t}$, but it can be quite effectively reduced cutting on the $E_T^{miss}$ of the events.

As shown in Figure 6, the invariant mass distribution of the same flavour opposite charge pairs of isolated leptons has a characteristic 2 out of 3 phase-space decay behaviour for SUSY events. This is due to the three body finale state decay $\tilde{\chi}_1^0 \to \tilde{\chi}_1^0 \ell^+ \ell^-$. The end-point corresponds to the kinematical situation in which the two leptons are emitted back-to-back in the $\tilde{\chi}_1^0$ rest.
frame, with the $\tilde{\chi}_1^0$ at rest, and the relation:

$$\vec{p}_{\tilde{\chi}_2^0} = \left(1 + \frac{M_{\tilde{\chi}_1^0}}{M_{\ell^+\ell^-}}\right) \vec{p}_{\ell^+\ell^-}$$

is valid in this point.

To reconstruct the invariant mass of the sbottom, events are selected letting $M_{\ell^+\ell^-}$ in a window of 17 GeV around the end-point, and the momentum of the $\tilde{\chi}_2^0$ from (1) is associated to the momentum of the most energetic $b$-jet of the event. The mass value from the generator is assumed for $\tilde{\chi}_1^0$; similar results are obtained if the mass of $\tilde{\chi}_1^0$ is approximated to the dilepton edge value. Requiring $E_T^{miss}$ larger than 150 GeV makes the SM background almost negligible: as shown in figure 7, a well visible sbottom mass peak, with a resolution of less than 10%, can be reconstructed, only affected by combinatorial background. The result of the fit is in good agreement with the generated values of the two sbottoms ($\tilde{b}_1, \tilde{b}_2$) even if at this stage of the study the CMS detector doesn’t seem able to resolve the two peaks.

Gluino mass peak is built associating the reconstructed sbottom with a second $b$-jet. As shown in figure 8, a resolution of $\sim 10\%$ is achieved, and the fitted mass value is in good agreement with the generated one.

Gluino and sbottom mass peaks have been reconstructed assuming that $M(\tilde{\chi}_1^0)$ is known. In a realistic scenario, CMS will not be able to detect $\tilde{\chi}_1^0$, being this a weakly interacting particle. Nevertheless the distribution of $M(\tilde{g}) - M(\tilde{b})$ is independent of $M(\tilde{\chi}_1^0)$; as shown in figure 9 CMS will be able to measure it with an error of about 4%, independently of any assumption on sparticles spectrum.
3 Conclusions

I have summarized the studies recently performed by the CMS collaboration about MSSM Higgs and Supersymmetric particles detection and reconstruction. The heavy neutral MSSM Higgses are expected to be discovered at high tan $\beta$ in the $H, A \rightarrow \tau \tau$ channel. $A, H \rightarrow \chi^0_2 \chi^0_1 \rightarrow 4\ell^\pm + X$ can complement the $\tau \tau$ channel at low tan $\beta$. Charged Higgs can be detected in $H^\pm \rightarrow \tau \nu$. Recent studies have shown that CMS will be able to reconstruct mass peaks of gluinos and sbottoms at low tan $\beta$ even in the first year of running.

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References