MSSM H/A IN $\tau\tau$ FINAL STATE AT CMS*

A. Kalinowski

On behalf of the CMS Collaboration

Institute of Experimental Physics, Warsaw University
Hoża 69, 00-681 Warsaw, Poland

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The search for the heavy, neutral MSSM Higgs bosons decaying into two τ leptons is presented. The event selections and final discovery reach, with 30 fb^{-1}, for the CMS experiment are shown.

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1. Introduction

In the Minimal Supersymmetric Standard Model (MSSM) there are 5 physical Higgs bosons: h, H, A and $H^{\pm}$. In the absence of CP-violation in the Higgs sector, the h, H are CP-even and A is a CP-odd particle. The Higgs sector is mainly controlled by two parameters: $\tan\beta$ and the mass of the pseudoscalar m_A. For large $\tan\beta$ the mass of the light scalar, h, reaches its maximal value of about 130 GeV/c^2, and the heavy neutral Higgs bosons, H and A become almost degenerate in mass (Fig. 1).

At high $\tan\beta$ the couplings of heavy scalars to down-type fermions, *e.g.* b quarks and τ leptons are proportional to $\tan\beta$, while couplings to up-type fermions, *e.g.* t quark are proportional to $\cot\beta$. Due to the $\tan\beta$ enhancement the dominating production mode for heavy, neutral Higgs bosons is associated production with b quarks: $gg \to b\bar{b}H/A$ (Fig. 2). The dominating decay modes are $b\bar{b}$ with $\mathrm{BR}(H/A \to b\bar{b})\sim 90\%$, and $\tau\tau$ with $\mathrm{BR}(H/A \to \tau\tau)\sim 10\%$. This is true even for the Higgs bosons heavy enough to decay to t quarks pair (Fig. 3). Therefore, the associated $b\bar{b}H/A$ production with subsequent decay to τ pair is a promising search mode at hadron colliders like LHC. The b and τ tagging provide excellent tools for the efficient background rejection.

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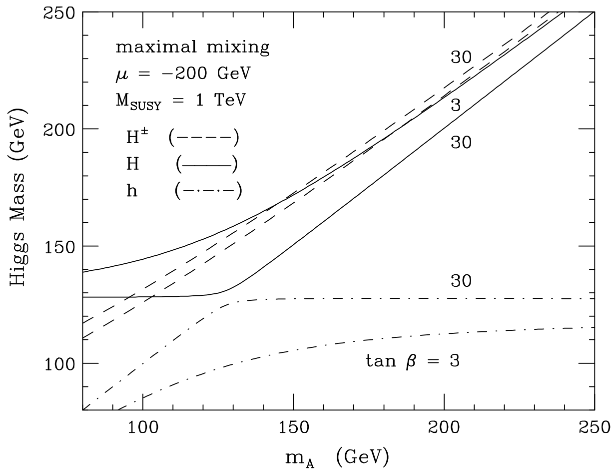


Fig. 1. Masses of the Higgs bosons as a function of the pseudoscalar mass m_A. The masses are plotted for the two values of $\tan\beta = 3$ and 30 [1].

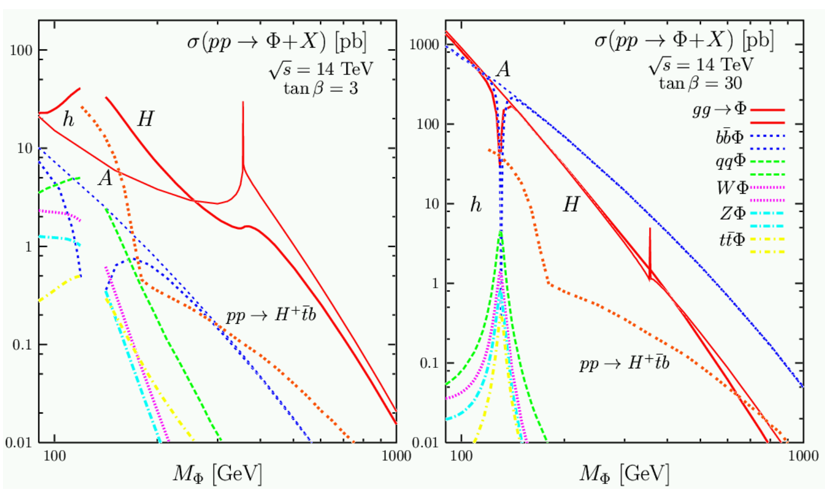


Fig. 2. Cross section for MSSM Higgs bosons production in various production modes for $\tan\beta = 3$ (left) and $\tan\beta = 30$ (right). The generic Higgs boson is denoted by Φ [2].

This report shows the expected discovery reach of the CMS experiment with 30 fb^{-1} of integrated luminosity collected with low LHC instantaneous luminosity of 2×10^{33} cm^{-2}s^{-1}. The presented study was done with the full CMS detector simulation.

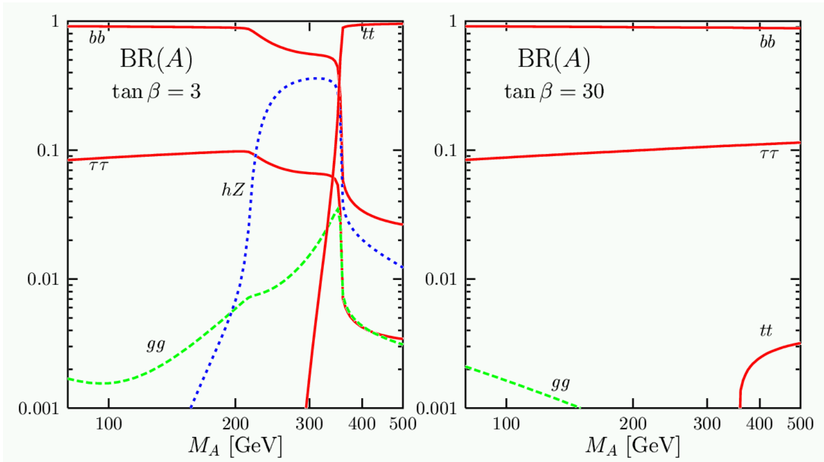


Fig. 3. Branching ratios of the MSSM Higgs boson A for $\tan\beta = 3$ (left) and $\tan\beta = 30$ (right) [2].

2. Signal signatures

In the CMS collaboration four final states for the τ lepton pair decay were studied in details. These were fully hadronic final state, with the hadrons coming from the τ decay denoted as τ jet, lepton plus τ jet final state, and $e + \mu$ fully leptonic final state. The main background processes are $t\bar{t}$ and Z decays for the processes with lepton in final state, and QCD dijet production for the fully hadronic final state. Table I presents the τ pair branching rations and background processes considered for each final state.

TABLE I

Final states of the τ lepton pair decay analyzed in the CMS. The branching ratio and background processes are reported. The main background processes are listed in bold. X denotes all neutrinos coming from the τ decay.

$\tau\tau$ final state	BR	Background processes
$e + \mu + X$	0.06	$\boldsymbol{t\bar{t}}$, Wt, $Z \to \tau\tau$, $b\bar{b}$
$e + \tau$ jet $+ X$	0.22	$\boldsymbol{Z \to e + e, t\bar{t}}$, Wt, $Z \to \tau\tau$, $W +$ jet
$\mu + \tau$ jet $+ X$	0.22	$\boldsymbol{Z \to \tau\tau, t\bar{t}}$, Wt, $W +$ jet, $b\bar{b}$
τ jet $+ \tau$ jet + X	0.42	**QCD dijets**, $Z \to \tau\tau$, $t\bar{t}$, Wt, $W +$ jet

3. Event selection

3.1. Trigger selection

The trigger selections for the $\mu+\tau$ jet final state are following: at Level 1 trigger a single muon with $p_{\rm T} > 14$ GeV/c is required. At the High Level Trigger (HLT) a isolated muon with $p_{\rm T} > 19$ GeV/c and τ jet candidate with $E_{\rm T} > 40$ GeV are required. The τ jet candidate should pass the electromagnetic calorimeter and tracker isolation. The details of the τ isolation algorithms in the CMS experiment can be found in [3].

The Level 1 trigger for the fully hadronic final state requires presence of one τ jet object with $E_{\rm T} > 93$ GeV, or two objects, both with $E_{\rm T} > 66$ GeV. At the HLT electromagnetic isolation is required for the hardest τ candidate. The tracker τ isolation is required for both candidates.

The trigger paths for all final states are described in details in [4].

3.2. Offline selection

The offline selection steps are summarized below:

- Offline τ identification.
- Single b tagging.
- Central jet veto — no jets additional to τ jet and b-tagged jet in the central region: $|\eta| < 2.4$.
- Cut on transverse mass $m_{\rm T} = \sqrt{2\, p_{\rm T}^l\, \not\!\!E_{\rm T}(1 - \cos(\vec{p}_{\rm T}^{\,l}, \vec{\not\!\!E}_{\rm T}))}$ (only for leptonic final states).
- $\Delta\varphi(\tau_1 - \tau_2) < 175^\circ$, with the τ momenta directions estimated by either lepton or the τ jet leading track.
- Positive reconstructed neutrino energy.
- Window in the reconstructed $\tau\tau$ invariant mass.

The details of the offline τ isolation can be found in [3, 5]. Below an example of the electron veto will be described in some details.

W bosons in $t\bar{t}$ and Wt background samples are sources of electrons which are often misidentified as a τ jet. For an efficient electron rejection a cut on the ratio f of the τ jet energy in the hadronic calorimeter (HCAL) to the leading track momentum has been used. The electromagnetic calorimeter can not be used here due to the presence of deposits from π^0 coming from the τ decay. The lower cut value was set to $f = 0.2$. This selection retains 90% of signal events and rejects 95% of events with real electrons.

The cut on the upper value of the ratio is efficient against quark jets rich in neutral hadrons. The cut on $f = 1.1$ rejects 50% of Wj and $b\bar{b}$ events and only 20% of signal events (Fig. 4).

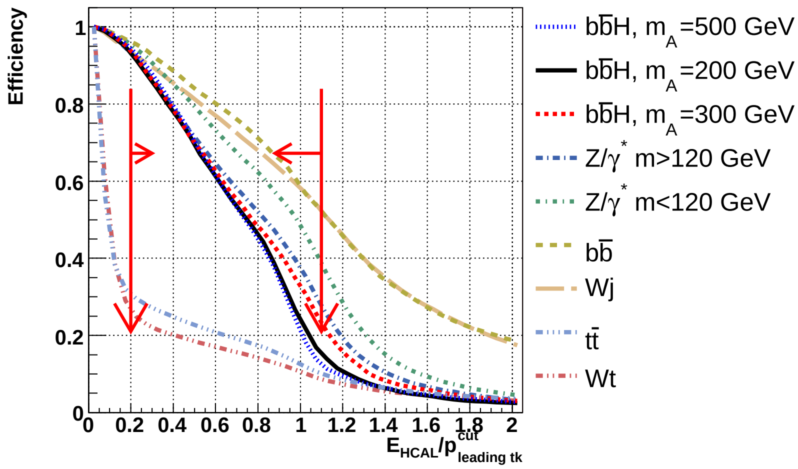
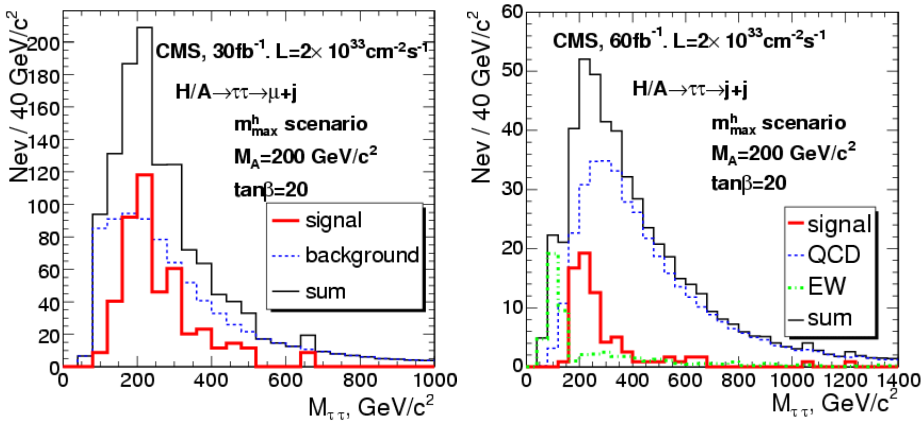


Fig. 4. Integrated distribution of the ratio of the τ jet hadronic energy to the leading track momentum. Labels in the legend are ordered by the selection efficiency in the acceptance region marked by arrows. Event samples used for the analysis in the $\mu + \tau$ jet are shown.

4. Mass reconstruction

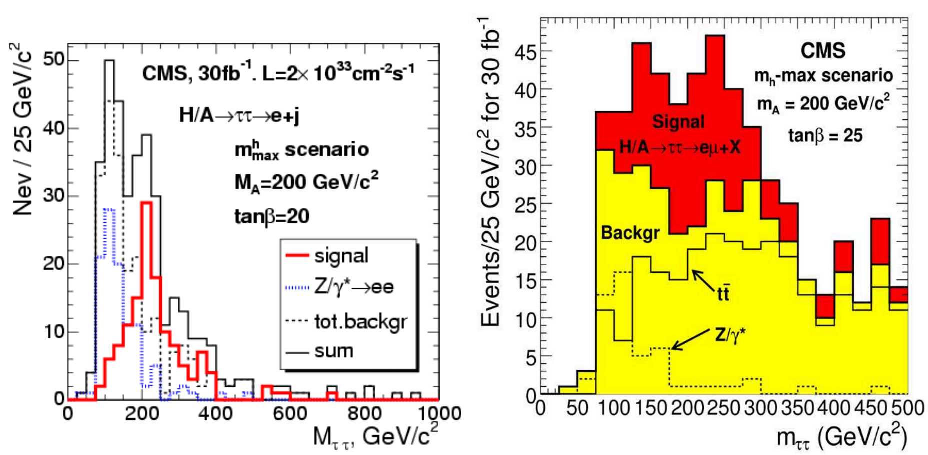
The Higgs boson mass cannot be directly reconstructed due to the neutrinos in the final state. The mass is reconstructed using the collinear approximation: is assumed that the momenta of the neutrinos and the charged particles coming form the τ decays are parallel. With this assumption the missing transverse energy can be projected on the transverse momenta of the charged particles coming from the τ decays to obtain the transverse energies of the neutrinos. Knowing the momentum direction and the transverse energy one can reconstruct the full momentum four-vector. Due to the poor resolution of the missing energy direction the above procedure can give negative values of reconstructed neutrino energy. The events, where there is at least one neutrino with negative energy reconstructed are rejected.

The mass distributions for the signal, background and signal plus background are shown in Figs. 5 and 6.



(a) (b)

Fig. 5. Reconstructed mass distribution for the $\mu + \tau$ jet final state (a) and for the τ jet $+ \tau$ jet final state (b).



(a) (b)

Fig. 6. Reconstructed mass distribution for the $e + \tau$ jet final state (a) and for the $e + \mu$ final state (b).

5. CMS discovery reach

The CMS discovery reach has been estimated within the so-called MSSM "maximal m_h scenario" [6]. The parameters of this scenario are: $m_t = 175.4$ GeV/c^2, Higgsino mass parameter: $\mu = 200$ GeV/c^2, SU(2) gaugino mass: $M_2 = 200$ GeV/c^2, SU(3) gaugino mass: $M_{\rm gluino} = 800$ GeV/c^2, soft SUSY breaking scalar masses $M_{\rm SUSY} = 1000$ GeV/c^2, top squark mixing parameter $X_t^{\rm OS} = 2\,M_{\rm SUSY}$ (the m_h is maximized for a given $m_{\rm SUSY}$ for this value of the X_t) and $A_t = A_b$. The m_A and $\tan\beta$ are treated as free parameters for which the discovery reach is estimated.

The expected number of events after all offline selection steps for the signal and background are reported in Table II. The $m_A = 200$ GeV/c^2 and $\tan\beta = 20$ are assumed for the signal processes.

TABLE II

Number of events after all selections for 30 fb^{-1} integrated luminosity. The number of events for signal and background processes are quoted.

$\tau\tau$ final state	Estimated number of events for	
	signal	background
$e + \mu + X$	29	55
$e + \tau$ jet + X	219	191
$\mu + \tau$ jet + X	92	83
τ jet + τ jet + X	54	109

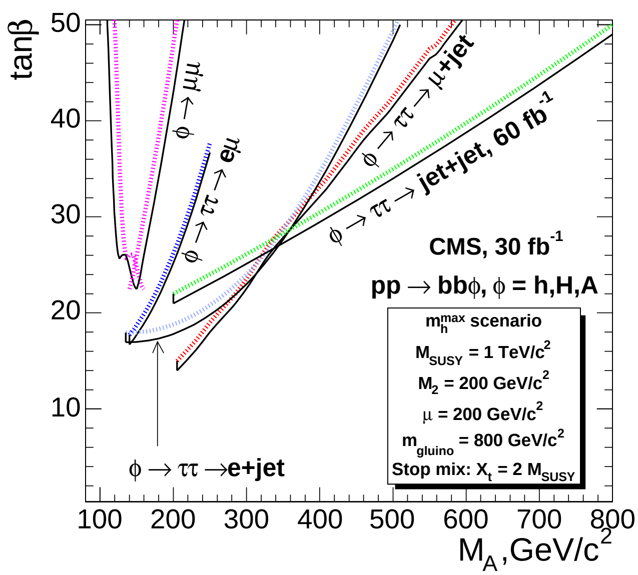


Fig. 7. CMS experiment discovery reach for the MSSM heavy, neutral Higgs bosons with 30 fb^{-1} of integrated luminosity. The τ jet + τ jet discovery reach was plotted for 60 fb^{-1} [4].

The CMS discovery reach for the 30 fb^{-1} of integrated luminosity is presented in Fig. 7. The systematic error on the background determination was included in the calculation of the signal significance. The best reach in $\tan\beta$ is obtained with the $l+\tau$ jet final state for the medium mass range, and fully hadronic final state for the high Higgs bosons masses.

6. Conclusions

The discovery potential for the MSSM A and H bosons in the channel $A/H \to \tau\tau$ has been presented. The discovery reach evaluated for 30 fb^{-1} integrated luminosity, using the full simulation of the CMS detector, and including the background systematics has been shown.

The details of the presented analyses can be found in the corresponding CMS Notes [7–10].

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