The Compact Muon Solenoid Experiment
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Mailing address: CMS CERN, CH-1211 GENEVA 23, Switzerland

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Search for Neutral MSSM Higgs Bosons in the Di-Tau channel at the CMS experiment at LHC.

Ram Krishna Dewanjee for the CMS Collaboration

Abstract

With the recent discovery of the SM (Standard Model) higgs boson of mass around 125 GeV by the CMS (Compact Muon Solenoid) and the ATLAS (A Toroidal LHC Apparatus) collaborations at the LHC (Large Hadron Collider) at CERN, there have been attempts to interpret this newly discovered resonance in the context of BSM (Beyond Standard Model) physics scenarios. Results are presented for the search for Neutral MSSM (Minimal SuperSymmetric Standard Model) higgs bosons where the higgs decays to two τ -leptons using the full Run-1 dataset collected by the CMS experiment. Interpretation of these results in the context of the SM higgs boson discovery is also given.

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Neutral MSSM higgs Bosons search in $\tau\tau$ channel at CMS

Ram Krishna Dewanjee
(On Behalf of CMS collaboration)

Abstract : With the recent discovery of the SM (Standard Model) higgs boson of mass around 125 GeV by the CMS (Compact Muon Solenoid) [1][2][3] and the ATLAS (A Toroidal LHC Apparatus) [4] collaborations at the LHC (Large Hadron Collider) at CERN, there have been attempts to interpret this newly discovered resonance in the context of BSM (Beyond Standard Model) physics scenarios. Results are presented for the search for Neutral MSSM (Minimal SuperSymmetric Standard Model) [5][6] higgs bosons where the higgs decays to two τ -leptons using the full Run-1 dataset¹ collected by the CMS experiment. Interpretation of these results in the context of the SM higgs boson discovery is also given.[7]

1 MSSM higgs signal and backgrounds

CMS is a general purpose particle detector[8] consisting of a superconducting solenoid (6 m internal diameter), providing a magnetic field of 3.8 Tesla. Within the solenoid volume are a silicon pixel and strip tracker, a lead tungstate crystal electromagnetic calorimeter, and a brass/scintillator hadron calorimeter, each composed of a barrel and two endcap sections. Muons are measured in gas-ionization detectors embedded in the steel flux-return yoke outside the solenoid. Extensive forward calorimetry complements the coverage of the barrel and endcap detectors. Event selection is done in 2 stages (called triggers): Level-1 (40 MHz to 100 kHz) and High Level Trigger (HLT) (100 kHz to 100 Hz). While Level-1 is predominantly hardware oriented, HLT is software based and is implemented in a farm of about 10000 commercial processor cores.

Ram Krishna Dewanjee
Dept. Of High Energy Physics (HECR Group), T.I.F.R, Mumbai,
e-mail: ram.krishna.dewanjee@cern.ch

¹ 4.9 fb^{-1} at 7 TeV and 19.7 (18.3) fb^{-1} at 8 TeV for $e\tau_h/\mu\tau_h/e\mu/\mu\mu$ ($\tau_h\tau_h$) channels.
No 7 TeV data for $\tau_h\tau_h$ due to lack of triggers.

The MSSM higgs sector has 2 complex scalar doublets which give rise to 5 physical higgs bosons: a heavy CP even scalar (**H**), a light CP even scalar (**h**), a pseudo scalar (**A**) and two charged higgs bosons (**H**[±]). At tree level, the sector is completely specified by 2 parameters: pseudo scalar mass (**m_A**) and $\tan\beta$ ^{II}. The main neutral MSSM higgs ($\phi = h/H/A$) production modes are **gluon fusion** and **b-quark associated production** whose leading order (LO) feynman diagrams are shown in **Fig. 1**.

When the MSSM higgs boson ϕ subsequently decays to 2 τ -leptons, each τ -lepton further decays either leptonically or hadronically. Leptonic (hadronic) τ decays involves a light lepton^{III} (narrow jet of charged hadrons and neutral pions) along with 2(1) neutrinos. Consequently, in this search τ -leptons need to be identified from their decay products. While leptonic τ decay identification is similar to prompt leptons^{IV}, hadronic τ decay identification uses a dedicated algorithm. The τ -lepton identification efficiency at CMS is 60% and the probability of a quark/light lepton to fake a τ -lepton remains within 0.1% to 1%. [9]

The CMS Run-1 search for MSSM higgs bosons in the di- τ channel [7] was performed in 5 distinct di- τ final states: $\mu\tau_h$, $e\tau_h$, $\tau_h\tau_h$, $e\mu$ and $\mu\mu$ (where e/μ and τ_h denote leptonic and hadronic tau decays respectively). Events were separated into 2 categories, one in which at least one b-quark is identified ($p_T > 20$ GeV) along with at most one jet ($p_T > 30$ GeV) and the other in which no b-quark ($p_T > 20$ GeV) is observed in the event. It should be noted that identification of b-quarks is subject to resolution effects. The CMS b-quark tagging algorithm has an efficiency of 70%. Light jets (u/d/s quarks) can fake b-quark signature approximately 1% of times [10].

Finally, the di- τ invariant mass ($m_{\tau\tau}$) is computed per event taking into account the p_T (transverse momentum) of the visible τ decay products (electron/muon/jet) and the missing transverse energy ($\cancel{E}_T$)^V using a dedicated likelihood based algorithm [2]. An excess in the $m_{\tau\tau}$ distribution is searched for. It is not enough to just reconstruct $m_{\tau\tau}$ distribution as there are other SM processes which can generate events with similar topology as the MSSM $\phi \rightarrow \tau\tau$ process. They are as follows:

1. **Drell-Yan+Jets/Z $\rightarrow \tau\tau$** : This is the dominant irreducible background in $\mu\tau_h$, $e\tau_h$ and $e\mu$ final states and is estimated in shape from $Z \rightarrow \mu\mu$ events in data from which the muons are removed and replaced by τ -leptons from simulation (Embedding).
2. **W+Jets**: This is an important background in $\mu\tau_h$ and $e\tau_h$ final states and is caused by a jet faking a τ_h . It is modelled in shape from simulation and in normalization from a high m_T ^{VI} region ($m_T > 70$ GeV) in data which is rich in W+Jets events.

^{II} Ratio b/w the Vacuum expectation values of the 2 higgs Doublets that give mass to up and down type fermions in MSSM

^{III} e/μ

^{IV} Leptons coming directly from hard interaction vertex e.g $W \rightarrow l\nu/Z \rightarrow ll$, where $l = e/\mu$.

^V Magnitude of the imbalance in momentum per event in the plane perpendicular to the beam line.

^{VI} Transverse mass: $\sqrt{2p_T^\mu \cancel{E}_T (1 - \cos\phi)}$, where p_T^μ = Muon p_T , $\cancel{E}_T$ = missing transverse energy and ϕ is the angle b/w them.

3. **QCD MultiJets**: This is the dominant background in the $\tau_h\tau_h$ channel and is estimated using a data driven method from control regions defined by di- τ charge and isolation.
4. **$t\bar{t}$ +Jets**: One of the main backgrounds in the $e\mu$ channel, it is estimated in shape from simulation and in yield from a region (≥ 1 b-jet, $\cancel{E}_T > 80$ GeV) in data which is rich in $t\bar{t}$ events.
5. **Drell-Yan+Jets/Z $\rightarrow \mu\mu$ (or ee)**: This background primarily arises from $e \rightarrow \tau_h$ and $\mu \rightarrow \tau_h$ fakes and is estimated (for $\mu\tau_h$ and $e\tau_h$ channels) from simulation with a correction applied according to the $e \rightarrow \tau_h$ fake rate measured in data using tag and probe.
6. **WW/WZ/ZZ+Jets**: This background is estimated from simulation normalised to NLO cross sections at 7 and 8 TeV.
7. **Single top**: This is a small background and is estimated from simulation.

2 Results

Results of the search are interpreted in both model dependent and model independent ways using a PLR (profile likelihood ratio) ^{VII} based test statistic. For the model independent case, 1-dimensional upper limits on the cross section $\times$ branching ratio were set at 95% confidence level separately for production of MSSM higgs bosons via gluon fusion and b-associated production. It should be noted that while setting limits for gluon fusion process, the b-associated production process was treated as a nuisance parameter in the maximum likelihood fit (via profiling) and vice versa. Such limits are shown for gluon fusion (left) and b-associated production (right) processes in **Fig. 2**. No evidence for a signal is observed.

For the model dependent case, 6 (CP conserving) phenomenological scenarios [11] proposed by the LHC higgs cross section working group are used to set exclusion limits in the (mostly) " $\tan\beta - m_A$ " plane. They all fulfil the criterion that one of the MSSM scalars has mass 125 ± 3 GeV (where the uncertainty is theory dominated) and have been defined by setting the radiative SUSY parameters to values that result in different phenomenology. A test of compatibility of the data to a signal of the 3 neutral higgs bosons h, H and A compared to a SM higgs boson hypothesis is performed for the benchmark scenarios in the plots shown in **Fig. 3**.

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^{VII} Profile likelihood ratio: $q_\mu = -2 \ln \frac{L(N_{obs}|\mu, s+b, \hat{\theta}_\mu)}{L(N_{obs}|\hat{\mu}, s+b, \hat{\theta})}$, with $0 \leq \hat{\mu} \leq \mu$. Here N_{obs} is the number of observed events, b and s are expected background and signal events, μ is the signal strength modifier and θ are the nuisance parameters (systematic uncertainties). $\hat{\theta}_\mu$ maximizes q_μ for a given μ while $\hat{\mu}$ and $\hat{\theta}$ maximize it globally. $L(N|\theta)$ is the likelihood of parameter(s) θ given the outcome N.

3 Conclusions

A search for neutral MSSM higgs bosons in the di- τ channel has been performed using the full Run-1 luminosity by CMS. The search results have been interpreted in both model dependent and model independent ways and presented.

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Fig. 1: LO Feynman diagrams for MSSM higgs production: gluon fusion ($gg\phi$) (Left) and b-associated production ($bb\phi$) (Right).

(a) 1D-Limit $gg\phi$

(b) 1D-Limit $bb\phi$

Fig. 2: Upper limit at 95% CL on $\sigma(gg\phi) \times \mathcal{B}(\phi \rightarrow \tau\tau)$ (Left) and $\sigma(bb\phi) \times \mathcal{B}(\phi \rightarrow \tau\tau)$ (Right) at 8 TeV center-of-mass energy as a function of m_ϕ .

(a) Light stau

(b) Low m_H

(c) τ -Phobic

(d) Light stop

(e) m_h^{mod-}

(f) m_h^{mod+}

Fig. 3: Expected and observed exclusion limits at 95% CL in the $m_A - \tan\beta$ parameter space for various MSSM benchmark scenarios[11]. For low m_H scenario, the limits are shown in $\mu - \tan\beta$ plane (where μ is higgsino mass).