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Search for Higgs Boson in beyond Standard Model scenarios at LHC

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Abstract. The principal physics motivation of the LHC experiments is to search for the Higgs boson and to probe the physics of TeV energy scale. Potential of discovery for Higgs bosons in various scenarios beyond Standard Model have been estimated for both CMS and ATLAS experiments through detailed detector simulations. Main results from the recently published studies of CMS collaboration are only included in this write-up.

Keywords. Higgs, Beyond Standard Model, LHC

PACS Nos

1. Introduction

The general-purpose experiments, CMS and ATLAS, at the Large Hadron Collider (LHC) are fully equipped to probe the nature of the electroweak symmetry breaking. There are a number of ideas which try to address the issues of the mass heirarchy and naturalness in Standard Model (SM), notably, SuperSymmetry (SUSY), Extra Dimensions, Little Higgs models and so on. There is ernest hope that the LHC will be able to elucidate on the possible mechanism at work by discovering atleast some of the new particles these models evoke.

Discovery potential of various scenarios have been estimated realistically with detailed detector simulation (using GEANT4) followed by full reconstruction including trigger selections. It is assumed that during initial years of LHC the instantaneous luminosity (2×10^{33} s^{-1} cm^{-2}) will correspond to an average event pile-up of about 5 minimum bias events in the detector. The key issues for experimental identification and subsequent discovery include sufficient signal rate, efficient trigger, control of background and signal-to-background ratio.

At the time of writing this report, the latest studies from CMS collaboration has been published in the Physics TDR Vol.2 [**?**] and we present them here briefly. Other results discussed during the presentation have been mostly omitted.

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2. SUSY Higgses

The most studied scenario beyond SM is its minimal supersymmetric extension (MSSM) with 5 elementary Higgs particles $\mathrm{h, H, A, H^{\pm}}$ whose masses and decay branchings mainly depend on 2 parameters, typically $\mathrm{m_A}$ and $tan\beta$. For a wide range of SUSY parameters the lightest Higgs boson mass $\mathrm{m_h}$ is expected to be less than 150 GeV/c^2 whereas $\mathrm{m_A} \sim \mathrm{m_h}$ for $\mathrm{m_A} \leq 120$ GeV/c^2 and $\mathrm{m_A} \sim \mathrm{m_H}$ for $\mathrm{m_A} \geq 120$ GeV/c^2. Thus the search of low mass SUSY Higgs boson is similar to SM Higgs boson and studied processes are: $\mathrm{h} \rightarrow \gamma\gamma$, $\mathrm{h} \rightarrow \mathrm{ZZ}^* \rightarrow 4\ell$ in inclusive productions, $\mathrm{h} \rightarrow \gamma\gamma$ and $\mathrm{b\bar{b}}$ in Wh production while $\mathrm{h} \rightarrow \mathrm{b\bar{b}}$ in case of $\mathrm{t\bar{t}H}$ production. For Vector Boson Fusion (VBF) processes, $\mathrm{qq} \rightarrow \mathrm{qqh}$, the suitable modes are: $\mathrm{h} \rightarrow \gamma\gamma$, $\mathrm{h} \rightarrow \tau\tau \rightarrow \ell+$ jets. For $\mathrm{m_A}$ in the range of 90-130 GeV/c^2 the above channels are not useful and special methods to tag and trigger b-jets and τs are used to utilise the process $\mathrm{gg} \rightarrow \mathrm{b\bar{b}H}$, $\mathrm{H} \rightarrow \mu^+\mu-, \tau^+\tau^-$.

The productions of heavy, neutral Higgs boson, H/A, though weak at LHC, are larger than SM Higgs and they are produced directly for low $tan\beta$ values whereas they are produced in association for high $tan\beta$ values through $\mathrm{gg} \rightarrow \mathrm{b\bar{b}H/A}$. Fortunately, the branching ratios to experimentally suitable decay modes are large for all $tan\beta$ and they are best detected through $\mathrm{H, A} \rightarrow \mu^+\mu^-$ and $\mathrm{H, A} \rightarrow \tau\tau \rightarrow e\mu,\ \ell^+\ell^-,\ \ell + \mathrm{jet},\ 2\mathrm{jets}$ modes. The leptonic decay modes are cleaner and the τ-mass reconstruction is possible assuming the neutrinos to be collinear. Subsequently Higgs mass is reconstructed for events where the charged leptons are not back-to back. The $\tau\tau$ reconstructed mass for $\mathrm{m_H} = 200$ GeV/c^2 with 30 fb^{-1} and the discovery region in $\mathrm{H, A} \rightarrow \tau\tau \rightarrow e\mu$ channel is shown in Fig. **??**. The systematic uncertainties taken into account are: lepton identification (2%), b-tagging efficiency (5%), mistagging efficiency (5%), theorectical prediction for $\mathrm{t\bar{t}}$ cross-section (5.8%), luminosity (3%) etc.. The jet energy and missing energy scale uncertainties contribute to an uncertainty of 7.3% on the dominant $\mathrm{t\bar{t}}$ background.

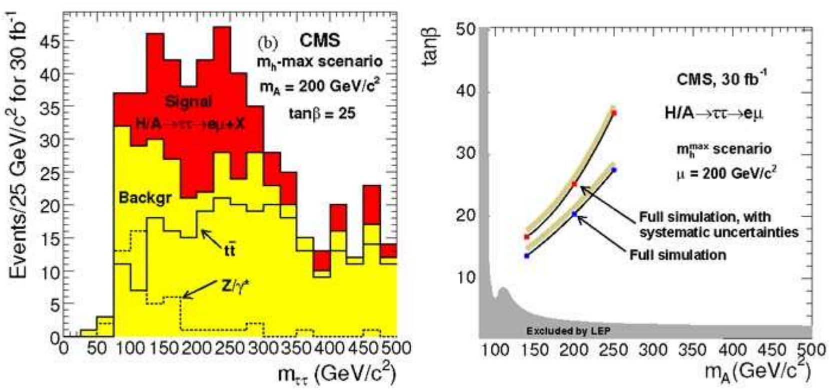

Figure 1. $\tau\tau$ reconstructed mass after all selection and the discovery region for $\mathrm{gg} \rightarrow \mathrm{b\bar{b}H/A}, \mathrm{H/A} \rightarrow \tau\tau \rightarrow \mathrm{e}\mu + \mathrm{X}$ in $\mathrm{M_A}, \tan\beta$ plane for 30 fb^{-1}.

The discovery curves for the light, neutral Higgs boson h from inclusive $\mathrm{pp} \rightarrow \mathrm{h} + \mathrm{X},\ \mathrm{h} \rightarrow \gamma\gamma$ channel and for neutral Higgs produced in VBF mode are shown in Fig. **??**, left. The discovery regions for the neutral Higgs bosons $\phi(\phi = \mathrm{h, H, A})$ produced in $\mathrm{pp} \rightarrow \mathrm{b\bar{b}}\phi$ with $\phi \rightarrow \mu\mu, \tau\tau$ are displayed in Fig. **??**, right. It may be possible to dis-

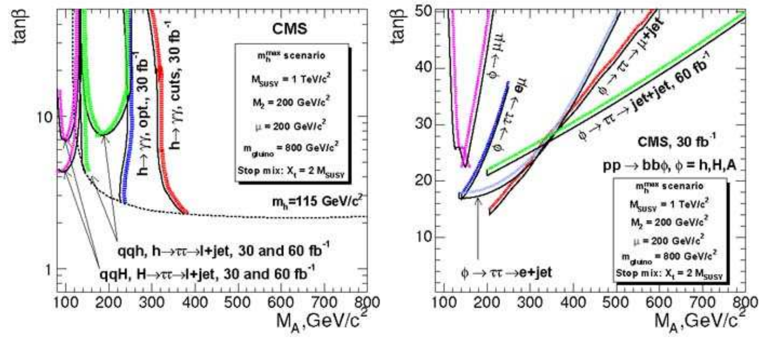

Figure 2. Left: 5σ discovery regions for the light, neutral Higgs boson in inclusive process and light and heavy Higgs bosons in VBF process. Right: 5σ discovery regions for neutral Higgs boson (ϕ) in pp $\to$ $\mathrm{b\bar{b}}\phi$ process.

criminate SM vs. SUSY via $\mathrm{h(H)} \to \gamma\gamma$ channel through absolute rate estimates, though it is limited by luminosity measurements to 5%, while rates differ by less than 10% for $\mathrm{m_A} \geq 550$ GeV/c^2. However, the ratio of the decay branchings, $\mathrm{h} \to \gamma\gamma$ and $\mathrm{h} \to \mathrm{b\bar{b}}$ is about 15% for $\mathrm{m_A} \geq 550$ GeV/c^2 and it is not limited by luminosity. It is also hoped that the distinction between A and H masses may be possible for mass difference of more than 5 GeV/c^2 for $tan\beta \geq 30$.

For charged Higgs boson ($\mathrm{H^\pm}$), which can be lighter than W-mass, two mass regions are distinguished in searches. For $\mathrm{M_H^\pm} \leq \mathrm{m_t}$ the suitable process is $\mathrm{t\bar{t}} \to \mathrm{H^\pm W^\mp b\bar{b}}$ with $\mathrm{H^\pm} \to \tau^\pm\nu,\ \ \tau \to \nu$+hadrons and $\mathrm{W^\mp} \to \ell^\mp\nu$. The low mass study is mainly systematics dominated which may be reduced through alternative approaches. For heavier mass region ($\mathrm{M_H^\pm} \geq \mathrm{m_t}$) the channel $\mathrm{gg} \to \mathrm{tbH^\pm}$, with decays $\mathrm{H^\pm} \to \tau^\pm\nu,\ \ \tau \to \mathrm{hadrons} + \nu$ and $\mathrm{t} \to \mathrm{qq\bar{b}}$ is probed where the signal pions from τ deacys are more energetic due to opposite polarisation of $\tau^\pm$ from $\mathrm{H^\pm}$ vs. than that from $\mathrm{W^\pm}$. Fig. **??** shows the transverse mass of τ after all selections and the reach for 30 fb^{-1} in $\mathrm{m_A}, \tan\beta$ plane.

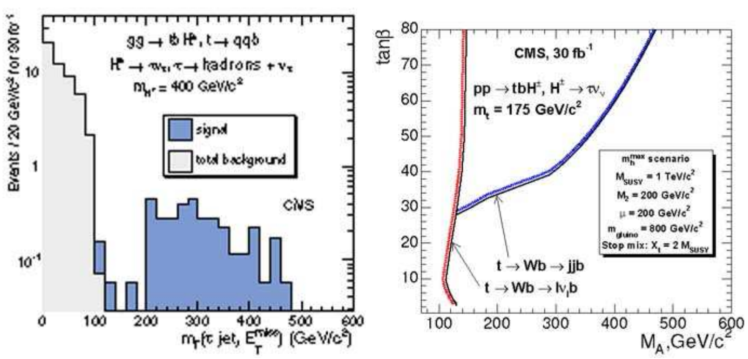

Figure 3. Left: Reconstructed transverse τ mass after all selections from signal ($\mathrm{gg} \to \mathrm{tbH^\pm}$) superposed with background. Right: 5σ discovery reach of $\mathrm{H^\pm}$.

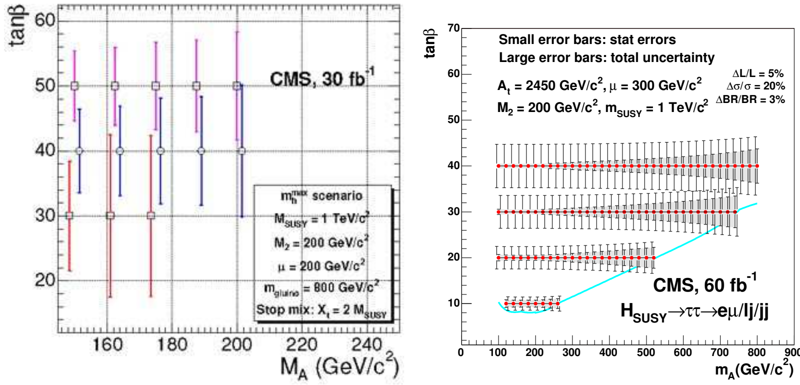

Figure 4. Uncertainty on $tan\beta$ measurement obtained from the estimate of Higgs boson width and from exploiting the dependance of cross-section in $\mathrm{H} \to \tau\tau$ channel where experimental systematics and statistical uncertainties have been taken into account.

The sensitivity of the width of Higgs boson, $\Gamma_{\mathrm{H/A}}$ on $tan\beta$ can be utilised for its determination. Also since the production cross-section for H/A has large sensitivity to $tan\beta$ values, the effective value defined through relation: $\sigma\times$ BR $\sim tan^2\beta_{\mathrm{eff}}$, is a significant observable for global fit to determine SUSY parameters. Fig. **??** gives the uncertainties in the measurement using two methods.

2.2 Observation of Higgs bosons in decay to gauginos and Higgs bosons from gaugino decays

The region around $tan\beta = 5$ and $\mathrm{m_A} = (130, 150)$ GeV/c^2 in $\mathrm{M_A}, \tan\beta$ plane remains uncovered by standard searches and hence special strategies are employed. The channel $\mathrm{H, A} \to \chi_2^0\chi_2^0 \to 4\ell$ covers this special zone and the invariant mass spectrum of 4 leptons can be studied. However the spectrum being featureless, a good knowledge of SM and SUSY backgrounds is necessary as shown in Fig. **??**, left. Large rate for gaugino productions in cascade decays of squarks and gluinos can be effectively utilised to study h productions of mass ≤ 250 GeV/c^2 in some portions of parameter space, specially through $\mathrm{b\bar{b}}$ decays since since the events can be triggered by inclusive SUSY signatures. Similarly $\mathrm{H}^{\pm}$ can also be searched in top decays. These methods give the unique possibility to measure couplings of SUSY particles to the Higgs bosons and also the intense coupling region can be probed as shown in Fig. **??**, right.

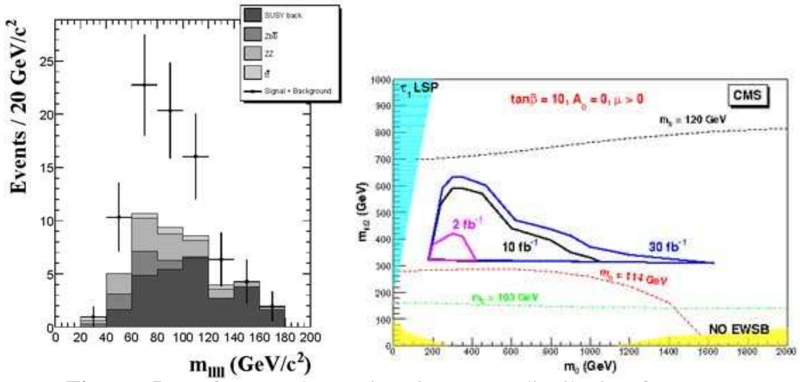

Figure 5. Left: Four lepton invariant mass distribution for paramaters $m_0 = 50$ GeV/c^2, $m_{1/2} = 150$ GeV/c^2, $tan\beta = 5$. Right: Higgs discovery reach in SUSY cascades as a function of luminosity.

3. Little Higgs Model

In this scenario the Higgs field is treated as pseudo-Goldstone boson resulting from a broken global symmetry at a scale of about 10 TeV and a new set of particles are invoked. There are 3 types of Higgs scalars (neutral, singly charged and doubly charged) of mass $M_\phi \leq 10$ TeV/c^2. The doubly charged Higgs (ϕ^{++}) can be produced via W^+W^+ fusion, and it can also decay via $W^+W^+ \rightarrow \ell^+\nu\ \ell^+\nu$. The transverse mass reconstruction of ϕ^{++} is possible at very high luminosity. A typical distribution of invariant mass of same sign di-muons is presented in Fig. **??**, left. The ratio of confidence levels for the signal and background hypothesis $CL_S = CL_{S+B}/CL_B$, interpreted as probability of excluding an existing signal [**?**] is shown in Fig. **??**, right.

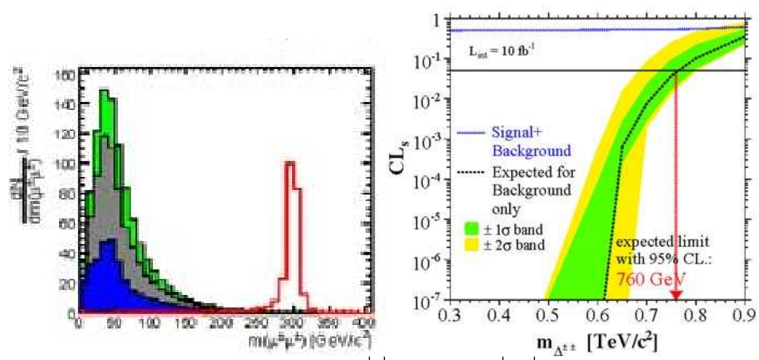

Figure 6. Left: Reconstructed $\Delta^{\pm\pm}$ mass in $\mu^\pm\mu^\pm$ channel. Right: CL_S as a function of $\Delta^{\pm\pm}$ mass (see text for definition of CL_S).

4. Probing extra-dimensions in Randall-Sundrum (RS) model

In this case all SM particles are assumed to reside in one brane while the fluctuations in 5th dimension produces a scalar field *radion* (ϕ)which can mix with SM Higgs boson. The characteristic parameters of the model with an additional scalar field *radion* (ϕ) are: $\mathrm{m_h}$, m_ϕ, ξ (mixing), Λ_ϕ (vev of radion field) with typical branching ratio of Br($\phi \to$ hh)= 30 %, for $\mathrm{m_h}$=120 GeV/c^2, m_ϕ = 350 GeV/c^2 and Λ_ϕ = 5 TeV. Studies have been made in channels $\phi \to \mathrm{hh} \to \gamma\gamma\mathrm{b\bar{b}}$, $\tau^+\tau^-\mathrm{b\bar{b}}$ and 4b modes. Requiring only one jet to be b-tagged, the invariant mass distribution of $\tau^+\tau^- bj$ system is shown in Fig. **??**, left. The right plot shows 5σ discovery contour for $\phi \to \gamma\gamma b\bar{b}$ channel where the reach in prameter space is the maximum.

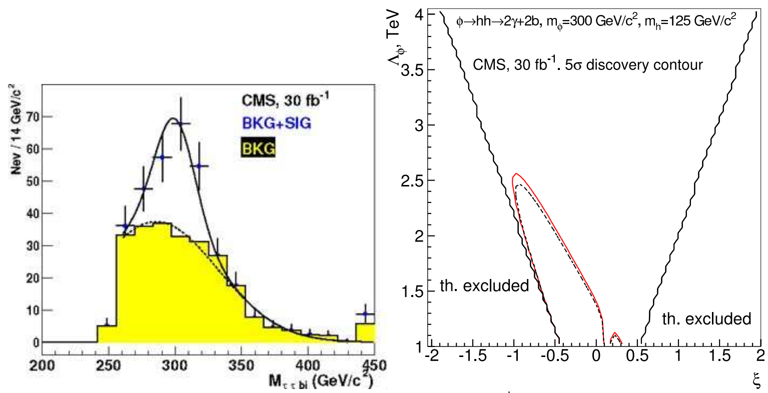

Figure 7. Left:Invariant mass distribution of $\tau^+\tau^- bj$ system for radion production and decay assuming maximum signal rate. Right: 5σ discovery contour for $\phi \to \tau\tau bb$ channel.

5. Conclusion

LHC machine and the experiments are ready to start taking data in 2007. Both CMS and ATLAS experiments are capable of discovering what lies ahead of Standard Model. Typical uncertainties for CMS experiment have been quoted only for a particular analysis though all results include both statistical and systematic errors [**?**]. The reach of ATLAS experiment in terms of various discoveries are similar and sometimes the studies are complementary [**?**].

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