arXiv:hep-ph/0011237v1 20 Nov 2000

IISc-CTS/18/00
hep-ph/0011237

Physics potential of the LHC[a]

Rohini M. Godbole
Centre for Theoretical Studies, Indian Institute of Science, Bangalore 560 012, India.
E-mail: rohini@cts.iisc.ernet.in

Abstract

The basic aim of physics studies at the LHC is to unravel the mechanism responsible for the spontaneous symmetry breaking in the Standard Model (SM). In the currently accepted theoretical picture, this translates into finding 'direct' experimental evidence for the Higgs sector. TeV scale supersymmetry (SUSY) provides a very attractive solution to the 'naturalness' problem that theories with elementary scalar fields have. Hence in this talk I will summarise the physics potential of the LHC for searching for Higgs and Supersymmetry as well as for measurement of the parameters of the Higgs sector and the SUSY model. Theories with localised gravity (and large extra dimensions) give a credible option to have Standard Model without the attendant 'naturalness' problems. I will therefore also summarise the potential of LHC to probe these 'large' extra dimensions.

---

[a] Invited talk presented at the joint session of Asia Pacific Physics Conference 2000 and III ACFA Linear Collider Workshop, August 2000, Taipei, Taiwan.

PHYSICS POTENTIAL OF THE LHC

ROHINI M. GODBOLE
Center for Theoretical Studies, Indian Institute of Science, Bangalore 560 012, INDIA
E-mail: rohini@cts.iisc.ernet.in

The basic aim of physics studies at the LHC is to unravel the mechanism responsible for the spontaneous symmetry breaking in the Standard Model (SM). In the currently accepted theoretical picture, this translates into finding 'direct' experimental evidence for the Higgs sector. TeV scale supersymmetry (SUSY) provides a very attractive solution to the 'naturalness' problem that theories with elementary scalar fields have. Hence in this talk I will summarise the physics potential of the LHC for searching for Higgs and Supersymmetry as well as for measurement of the parameters of the Higgs sector and the SUSY model. Theories with localised gravity (and large extra dimensions) give a credible option to have Standard Model without the attendant 'naturalness' problems. I will therefore also summarise the potential of LHC to probe these 'large' extra dimensions.

1 Introduction

LHC is the pp collider which is expected to start operation in year ∼ 2005. For the first three years we expect to collect $10 fb^{-1}$ luminosity per year whereas at the end of four years the integrated luminosity will be $100 fb^{-1}$ and an integrated luminosity of $300 fb^{-1}$ will be available only by the year 2011. This should be kept in mind while assessing the physics reach of LHC in various channels. LHC will be a factory of all kinds of particles W/Z, t, b etc. Table 1 gives the expected number of events/year for $10 fb^{-1}$ luminosity for different final states. This will provide a laboratory to make precision studies of EW theory, QCD, flavour physics, CP violation etc. and will further our theoretical understanding of the workings of the Standard Model (SM) and beyond. In all these studies the primary goal of the LHC experiments will be to understand the 'physics of the Spontaneous Symmetry breaking of EW symmetry'. There are two major components to the physics studies at LHC (i) its discovery potential and (ii) potential to do precision studies. In this talk I will concentrate on the aspects of both these studies that have a bearing on the abovestated primary goal. Thus I will try to summarize the ability of LHC to throw light on the mechanism of EW symmetry breaking. To this end I will start with the case of SM Higgs where the new results to be reported are investigations into ability of LHC to measure properties of the Higgs to nail it down as **the** SM Higgs or otherwise. Then I will discuss the case of supersymmetric Higgs where I will concentrate on effects of light

Table 1. *Total number of events for different types of final states expected at LHC per year for* $10 fb^{-1}$ *integrated luminosity.*

Process	# of events/yr.	Process	# of events/yr.
$W \to e\nu$	10^8	$Z \to e^+e^-$	10^7
$t\bar{t}$	10^7	$b\bar{b}$	10^{12}
$\tilde{g}\tilde{g}$ (TeV)	10^4	$jets(> 200$ GeV$)$	10^9

supersymmetric particles on the search of light neutral higgs of the MSSM. I will list some of the new developments in SUSY phenomenology which focus on the possibility of determining the model parameters once SUSY is found. I will end by discussing the reach of LHC to search for large extra dimensions which is an example of new physics which might obviate the need for TeV scale supersymmetry in order to keep the Higgs scalar light.

2 Identification of benchmarks to gauge LHC potential

The precision measurements from LEP I as well as LEP-200 data on W^+W^- production has proved that the SM is the correct theory of EW interactions, at least as an effective interaction and that the higgs is light. Precision data give a limit $m_h \lesssim 210$ GeV at 95% level[1] and at the same time direct searches give $m_h > 113.3$ GeV. On the theoretical side there exist precise predictions for the couplings of the higgs scalar but for the mass there exist only limits. These come from different theoretical considerations of vacuum stability as well as triviality of the ϕ^4 theory. The figure in the left panel in fig. 1 taken from Ref.[2] shows the expected limits in the SM as a funtion of the scale Λ, upto which SM should be the correct description. The lesson to learn from this figure is $m_h \simeq 160 \pm 20$ GeV if SM is the correct description all the way upto the Plank scale. The consistency of the above theoretical and experimental statements implies that to nail down the Higgs mechanism as 'the' mechanism of EW symmetry breakdown,

I) LHC should find 'direct' experimental evidence for a light Higgs particle with couplings as predicted in the SM,

II) LHC should find TeV scale supersymmetry (SUSY) if this is the right solution of the hierarchy problem [a]. Supersymmetry implies an upper

---

[a] Note here that SUSY is to be considered as an example of the new physics at the TeV

limit on SUSY Higgs mass of about 135 (200) GeV[3,4], the larger number is in a general framework extending the MSSM.

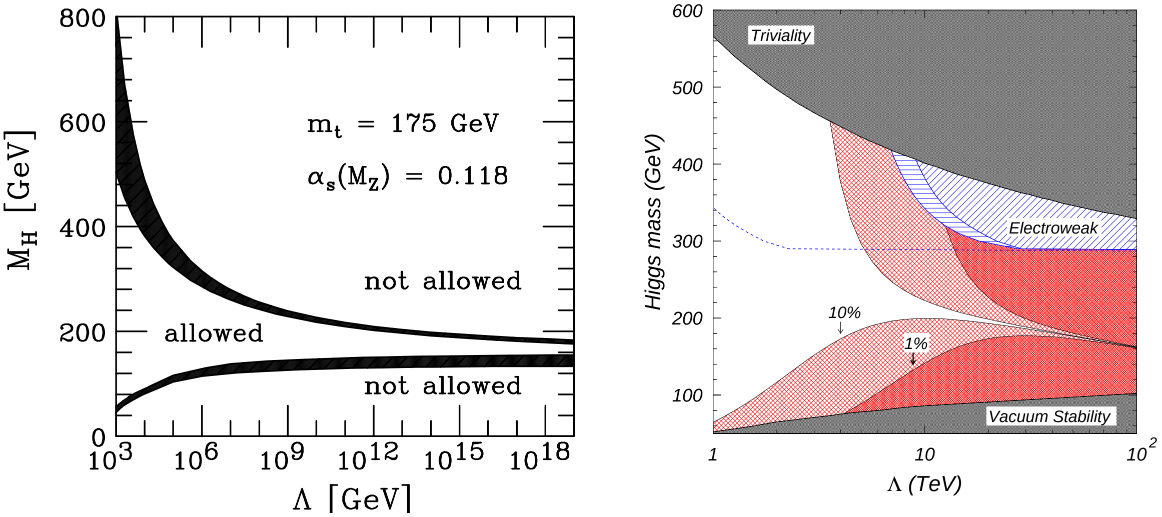


Figure 1. *Limits on the Higgs mass in the SM and beyond*[2,6].

However, recently more general analyses of correlations of the scale of new physics and the mass of the Higgs have started[5,6]. In this analysis the assumption is that the SM is only an effective theory and additional higher dimensional operators can be added. Based on very general assumptions about the coefficients of these higher dimensional operators, an analysis of the precision data from LEP-I with their contribution, alongwith a requirement that the radiative corrections to the m_h do not destabilize it more than a few percent, allows different regions in $m_h - \Lambda$ plane. This is shown in the right panel in fig. 1. The lesson to learn from this figure taken from Ref. [6] is that a light higgs with $m_h < 130$ GeV will imply existence of new physics at the scale $\Lambda < 2 - 3$ TeV, whereas $195 < m_h < 215$ GeV would imply $\Lambda_{Np} < 10$ TeV. These arguments, specialized to the case of Supersymmetry, do imply that SUSY ought to be at TeV scale to be relevant to solve the fine tuning problem. The above discussion suggests yet another need that LHC should fulfil, *viz.*,

---

scale. However, this is the only example that is well-defined and has specific predictions.

III) LHC should be able to look for new physics at a scale from 1 - 10 TeV which is implied by demanding theoretical consistency of SM as a field theory with a light Higgs.

IV) Should LHC not find a light scalar, it essentially would imply that the Higgs is not a fundamental scalar. Then LHC should be able to look for the 'strongly interacting W' sector.

V) The idea of new extra dimensions[7,8] can obviate the 'naturalness' problem even with a 'light' higgs. In this case LHC should be able to look for evidence for extra dimensions.

So the potential of LHC has to be evaluated in view of how it can reach the aims listed as I-V above.

3 Search for the SM higgs at the LHC

The current limit on m_h from precision measurements at LEP is $m_h < 210$ GeV at 95% C.L. and limit from direct searches is $m_h \lesssim 113$ GeV[1]. Tevatron is likely to be able to give indications of the existence of a SM higgs, by combining data in different channels together,[9] for $m_h \lesssim 120$ GeV if Tevatron run II can accumulate $30 fb^{-1}$ by 2005. The best mode for the detection of Higgs depends really on its mass. Due to the large value of m_t and the large gg flux at LHC, the highest production cross-section is via gg fusion. Fig. 2[10] shows $\sigma \cdot BR$ for the SM higgs for various final states. The search prospects are optimised by exploring different channels in different mass regions. The inclusive channel using $\gamma\gamma$ final states corresponds to $\sigma \cdot BR$ of only 50 fb, but due to the low background it constitutes the cleanest channel for $m_h <$ 150 GeV. The important detector requirement for this measurement is good resolution for $\gamma\gamma$ invariant mass. ATLAS should be able to achieve $\sim$ 1.3 GeV and CMS $\sim$ 0.7 GeV. The new developments in this case is a NLLO calculation for $\gamma\gamma$ background which is now available[11]. A much more interesting channel is production of a higgs recoiling against a jet in the process $gg \to h + \text{jets} \to \gamma\gamma + \text{jets}$. The signal is much lower but is also much cleaner. The background in the channel is also known[12]. The viability of this channel was studied initially using only a tree level calculation[13]. The effect of resummation on the signal size has been recently discussed[14]. Use of this channel gives a significance of $\sim$ 5 already at $30 fb^{-1}$ for the mass range $110 < m_h < 135$ GeV. A more detailed study of the channel $pp \to h + t\bar{t} \to \gamma\gamma + t\bar{t}$ with semileptonic decays of the $t/\bar{t}$ is now underway. This is important also for the measurement of the $ht\bar{t}$ couplings.

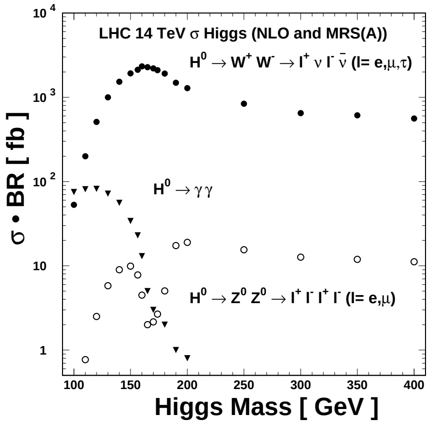
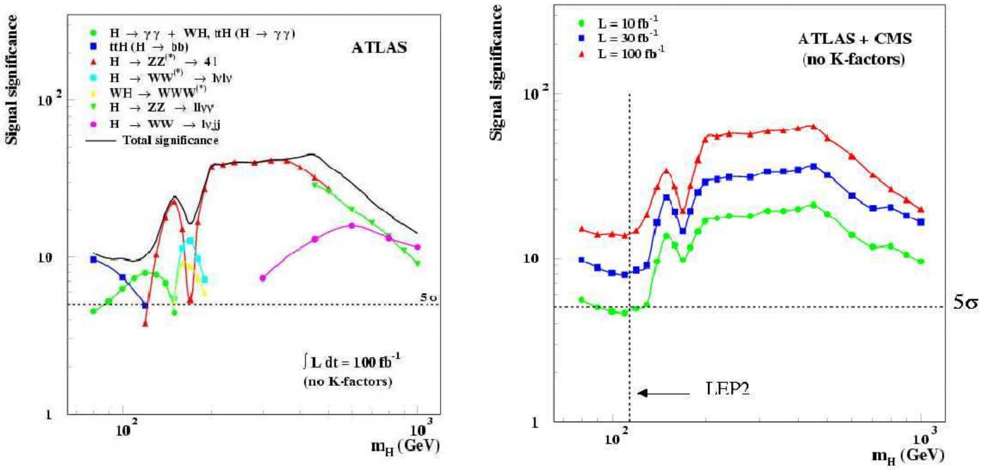


Figure 2. *Expected $\sigma \cdot BR$ for different detectable SM Higgs decay modes* [10].

For larger masses ($m_h \gtrsim 130$ GeV) the channel $gg \rightarrow h \rightarrow ZZ^{(*)} \rightarrow 4l$ is the best channel. Fig. 2 shows that, in the range 150 GeV $< m_h <$ 190 GeV this clean channel, however, has a rather low ($\sigma \cdot BR$). The viability of $p\bar{p} \rightarrow WW^{(*)} \rightarrow l\bar{\nu}\bar{l}\nu$ in this channel has been demonstrated.[15] Thus to summarise for $m_h \lesssim 180$ GeV, there exist a large number of complementary channels whereas beyond that the gold plated $4l$ channel is the obvious choice. If the Higgs is heavier, the event rate will be too small in this channel (*cf.* Fig. 2). Then the best option is to tag the forward jets by studying the production of the Higgs in the process $p\bar{p} \rightarrow WWq\bar{q} \rightarrow q\bar{q}h$. The figure in the left panel in fig. 3 shows the overall discovery potential of the SM higgs in all these various channels whereas the one on the right shows the same overall profile of the significance for discovery of the SM higgs, for three different luminosities, combining the data that both ATLAS and CMS can obtain. The figure shows that the SM higgs boson can be discovered (i.e. signal significance $\gtrsim 5$) after about one year of operation even if $m_h \lesssim 150$ GeV. Also at the end of the year the SM higgs boson can be ruled out over the entire mass range implied in the SM discussed earlier.

A combined study by LHC and ATLAS shows that a measurement of m_h at 0.1% level is possible for $m_h \lesssim 500$ GeV, at the end of three years of high luminosity run. As the panel on the left in fig. 4 shows that at lower values of m_h, simultaneous use of different channels is very useful. For $m_h \gtrsim 500$



L is per experiment

Figure 3. *The expected significance level of the SM Higgs signal at LHC* [16].

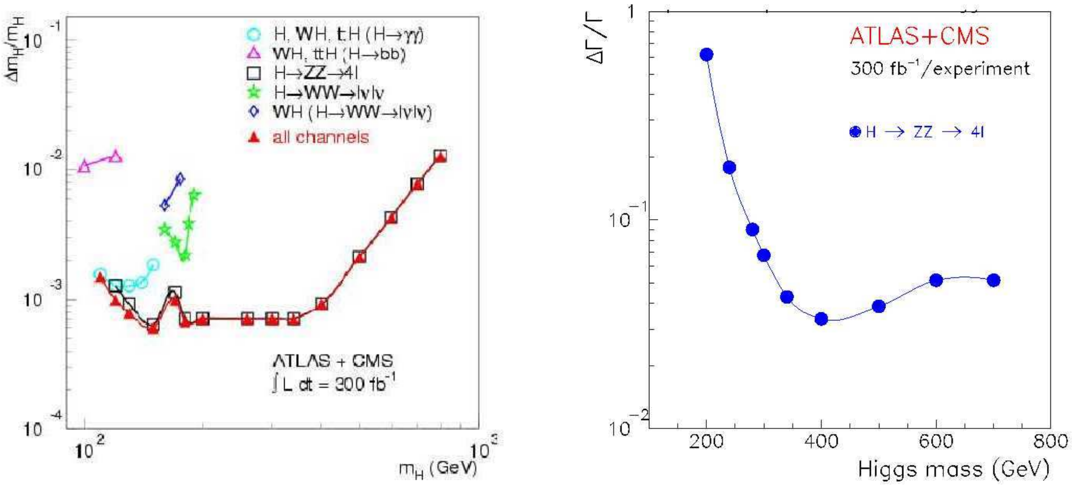


Figure 4. *Expected accuracy of the measurement of Higgs mass and width at LHC*[16].

GeV a better theoretical analysis of the resonant signal and the nonresonant background is still lacking. As far as the width Γ_h is concerned, a measurement is possible only for $m_h > 200$ GeV, at a level of $\sim 5\%$ and that too at the end of three years of the high luminosity run. At this value of m_h the information essentially comes from the $h \to ZZ \to 4l$ channel. The values of $\Delta\Gamma/\Gamma$ that can be reached at the end of three years of high luminosity run, obtained in a combined ATLAS and CMS study, are shown in the figure in the right panel in fig. 4.

Apart from the precision measurements of the mass and the width of the Higgs particle, possible accuracy of extraction of the couplings of the Higgs with the matter and gauge particles, with a view to check the spontaneous symmetry breaking scenario, is also an important issue. Table 2 shows the accuracy which would be possible in extracting ratios of various couplings, according to an analysis by the ATLAS collaboration. This analysis is done by measuring the ratios of cross-sections so that the measurement is insensitive to the theoretical uncertainties in the prediction of hadronic cross-sections. All these measurements use only the inlclusive Higgs mode.

Table 2. *Expected accuracy in the extraction of the Higgs couplings as evaluated by ATLAS*[16].

Ratio of cross-sections	Ratio of extracted Couplings	Expected Accuracy Mass Range
$\frac{\sigma(t\bar{t}h+Wh)(h\to\gamma\gamma)}{\sigma(t\bar{t}h+Wh)(h\to b\bar{b})}$	$\frac{B.R.(h\to\gamma\gamma)}{B.R.(h\to b\bar{b})}$	$\sim 15\%$, 80-120 GeV
$\frac{\sigma(h\to\gamma\gamma)}{\sigma(h\to 4l)}$	$\frac{B.R.(h\to\gamma\gamma)}{B.R.(h\to ZZ^{(*)})}$	$\sim 7\%$, 120-150 GeV
$\frac{\sigma(t\bar{t}h\to\gamma\gamma/b\bar{b})}{\sigma(Wh\to\gamma\gamma/b\bar{b})}$	$\frac{g^2_{ht\bar{t}}}{g^2_{hWW}}$	$\sim 15\%, 80 < m_h < 120$ GeV
$\frac{\sigma(h\to ZZ^*\to 4l)}{\sigma(h\to WW^*\to l\nu l\nu)}$	$\frac{g^2_{hZZ}}{g^2_{hWW}}$	$\sim 10\%, 130 < m_h < 190$ GeV

New analyses based on an idea by Zeppenfeld and collaborators[17,18,19,20] have explored the use of production of the Higgs via WW/ZZ(IVB) fusion, in the process $pp \to q+q+V+V+X \to q+q+h+X$. Here the two jets go in the forward direction. The observation[17] that the colour flow for the IVB fusion production process is quite different than the background, suggested the use of veto against jets in the central region, to enhance the Higgs signal produced via the IVB fusion. This has increased the possibility of studying the Higgs production via IVB fusion process to lower values of $m_h (< 120 \mathrm{GeV})$ than previously thought possible. E.g., a parton level Monte Carlo[18] has demonstrated that already for $\int \mathcal{L} dt = 30 fb^{-1}, qq \to qqh \to qq\tau^+\tau^-$ gives $S/B = 2/1$. This is to be contrasted with the luminosities required for a similar level of significance, in the inclusive channel shown in fig. 3. It has been demonstrated[19] that using the production of Higgs in the process $qq \to hjj$, followed by the decay of the Higgs into various channels $\gamma\gamma, \tau^+\tau^-, W^+W^-$ as well as the inclusive channels $gg \to h\gamma\gamma, gg \to h \to ZZ^{(*)}$, it should be possible to measure Γ_h, g_{hff} and g_{hWW} to a level of $10 - 20\%$, assuming that $\Gamma(h \to b\bar{b})/\Gamma(h \to \tau^+\tau^-)$ has approximately the SM value. Recall, here that after a full LHC run,with a combined CMS +ATLAS analysis, the latter should be known to $\sim 15\%$. This strategy is being studied further at the detector level[20]. In principle, such measurements of the Higgs couplings might be an indirect way to look for the effect of physics beyond the SM. We will discuss this later.

By the start of the LHC (unless the LEP has already confirmed the 'light' higgs, by the time these words appear in print!), with the possible TeV 33 run with $\int \mathcal{L} dt = 30 fb^{-1}$, Tevatron can give us an indication and a possible signal for a light Higgs, combining the information from different associated production modes: Wh, Zh and $WW^{(*)}$. The inclusive channel $\gamma\gamma/4l$ which will be dominantly used at LHC is completely useless at Tevatron. So in some sense the imformation we get from Tevtaron/LHC will be complementary.

Thus in summary the LHC, after one year of operation should be able to see the SM higgs if it is in the mass range where the SM says it should be. Further at the end of ~ 6 years the ratio of various couplings of h will be known within $\sim 10\%$. One example of the physics beyond the SM that such a measurement will probe indirectly is supersymmetry (SUSY). The direct manifestation of SUSY for the Higgs sector will of course be the presence of the extra scalars expected in the MSSM.

4 Search at LHC for the MSSM higgs

As is well known the MSSM Higgs sector is much richer and has five scalars; three neutrals: CP even `h` , H and CP odd A as well as the pair of charged Higgses $H^{\pm}$. So many more search channels are available. The most important aspect of the MSSM higgs, however is the upper limit[3,4] of 130 GeV (200 GeV) for MSSM (and its extensions), on the mass of lightest higgs. The masses and couplings of these scalars depend on the supersymmetric parameters $m_A, \tan\beta$ as well as SUSY breaking parameters $m_{\tilde{t}_1}$ and the mixing in the stop sector controlled essentially by A_t. In general the couplings of the $\mathtt{h}$ can be quite different from the SM higgs h; *e.g.* even for large $m_A (> 400\text{GeV}), \Gamma_{\mathtt{h}}/\Gamma_h > 0.8$, over most of the range of all the other parameters. Thus such measurements can be a 'harbinger' of SUSY. The upper limit on the mass of $\mathtt{h}$ forbids its decays into a VV pair and thus it is much narrower than the SM h. Hence the only decays that can be employed for the search of $\mathtt{h}$ are $b\bar{b}, \gamma\gamma$ and $\tau^+\tau^-$. The last can be exploited mainly in the large $\tan\beta$ range. This can be perhaps be used even more effectively using the $qq\mathtt{h}$ mode[18]. The $\gamma\gamma$ mode can be suppressed for the $\mathtt{h}$ compared to h. The reduction is substantial even when all the sparticles are heavy, at low $m_A, \tan\beta$. Fig. 5 shows various regions in

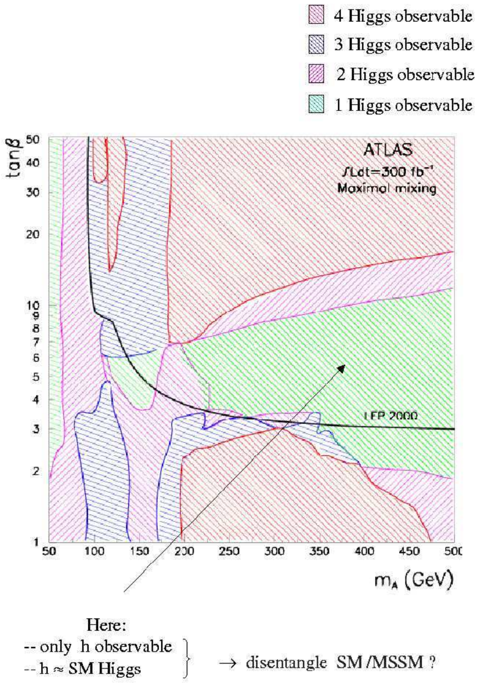


Figure 5. *Number of MSSM scalars observable at LHC in different regions of* $\tan\beta - M_A$ *plane*[16].

the $\tan\beta - m_A$ plane divided according to the number of the MSSM scalars observable at LHC, according to an ATLAS analysis, for the case of maximal mixing in the stop sector, at the end of full LHC run. This shows that for low $M_A(\gtrsim 200$ GeV) and low $\tan\beta(\lessapprox 8-9)$, only one of the five MSSM scalars will be observable. Recall further that the differences in the coupling of $\mathtt{h}$ and h are quite small in this region.

Situation can be considerably worse if some of the sparticles, particularly $\tilde{t}$ and $\tilde{\chi}_i^{\pm}, \tilde{\chi}_i^0$ are light. Light stop/charginos can decrease $\Gamma(\mathtt{h} \to \gamma\gamma)$ through their contribution in the loop. For the light $\tilde{t}$ the inclusive production mode $gg \to \mathtt{h}$ is also reduced substantially. If the channel $\mathtt{h} \to \chi_1^0\chi_1^0$ is open, that depresses the BR into the $\gamma\gamma$ channel even further[21,22,23,24]. The left panel in fig. 6[21] shows the ratio

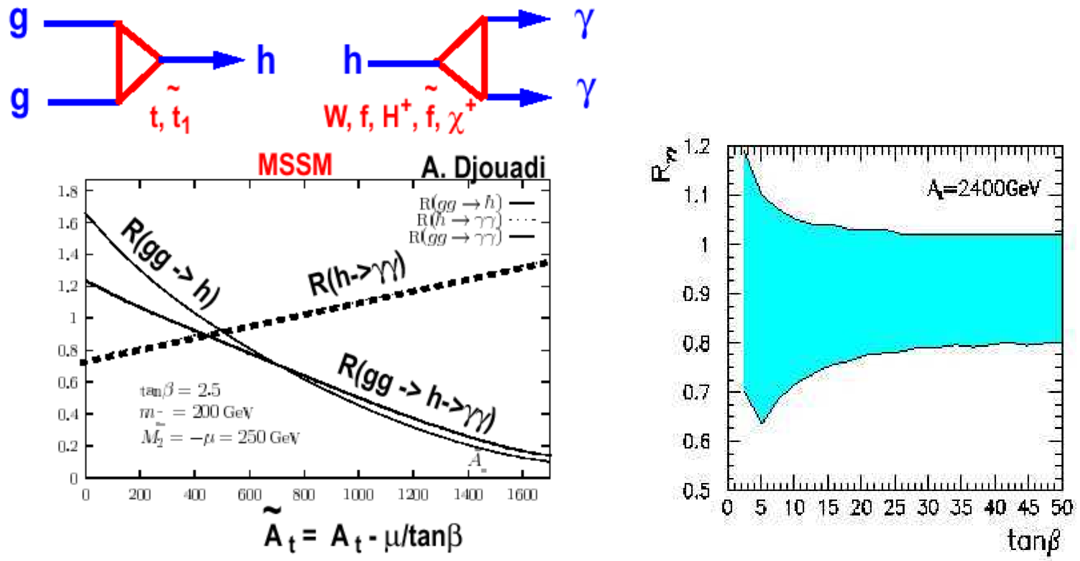


Figure 6. *Effect of light sparticles on the $\gamma\gamma$ decay width and gg production of the Higgs*[21,24].

$$R(h \to \gamma\gamma) = \frac{\Gamma(\mathtt{h} \to \gamma\gamma)}{\Gamma(h \to \gamma\gamma)}$$

and ratios $R(gg \to h), R(gg \to h\gamma\gamma)$ defined similarly. Thus we see that for low $\tan\beta$ the signal for the light neutral higgs $\mathtt{h}$ can be completely lost for a light stop. The panel on the right in fig. 6[24] shows $R(\mathtt{h} \to \gamma\gamma)$ as a function of $\tan\beta$ for the case of only a light chargino and neutralino. Luckily, eventhough light sparticles, particularly a light $\tilde{t}$ can cause disappearance of this signal, associated production of the higgs $\mathtt{h}$ in the channel $\tilde{t}_1\tilde{t}_1^*\mathtt{h}/t\bar{t}\mathtt{h}$ provides a viable signal. However, an analysis of the optimisation of the observability of such a light stop ($m_{\tilde{t}} \simeq 100 - 200$ GeV) at the LHC still needs to be done. This brings us to the subject of search for Supersymmetry at the LHC.

5 Prospects for SUSY search at the LHC

The new developements in the past years in the subject have been in trying to set up strategies so as to disentangle signals due to different sparticles from each other and extract information about the SUSY breaking scale and mechanism, from the experimentally determined properties and the spectrum of the sparticles. As we know, the couplings of **almost** all the sparticles are determined by the symmetry, except for the charginos, neutralinos and the light $\tilde{t}$. However, masses of all the sparticles are completely model dependent. The four different types of models that are normally considered are

1. (M)SUGRA: The highly constrained supergravity model which is characterised by just five parameters,
2. (C)MSSM: MSSM where the number of parameters is reduced by some very reasonable assumptions,
3. AMSB: Models which have Anamoly mediated SUSY breaking,
4. GMSB: Models which have gauge mediated SUSY breaking.

In cases 1-3 SUSY is broken via gravitational effects and $\tilde{\chi}_1^0$ is the Lightest Supersymmetric Particle(LSP). In case 4 the LSP is the light gravitino and the phenomenology is decided by the life time of the next lightest superymmetric particle (NLSP) which can be either a $\tilde{\tau}$ or $\tilde{\chi}_1^0$. In cases 1-3 the missing transverse energy $\not{E}_T$ is the main signal. In case 4, along with $\not{E}_T$ the final states also have photons and/or displaced vertices, stable charged particle tracks etc. as the telltale signals of SUSY. As is clear from the fig. 7 LHC is best suited for the search of the strongly interacting $\tilde{g}, \tilde{q}$ because they have the strongest production rates. The $\tilde{\chi}_i^\pm, \tilde{\chi}_i^0$, are produced via the EW processes or the decays of the $\tilde{g}, \tilde{q}$. The former mode of production gives very clear signal of 'hadronically quiet' events. The sleptons which can be produced mainly via the DY process have the smallest cross-section. As mentioned earlier, various sparticles can give rise to similar final states, depending on the mass

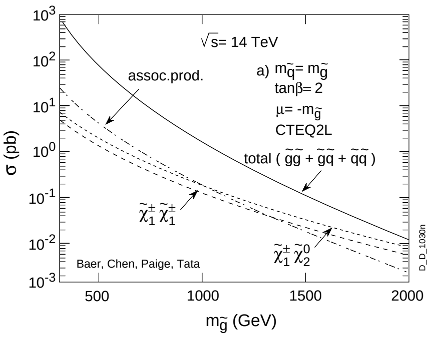


Figure 7. *Expected production cross-sections for various sparticles at the LHC*[25].

hierarchy. Thus, at LHC the most complicated background to SUSY search is SUSY itself! The signals consist of events with $\not{E}_T$, m leptons and n jets with $m, n \geq 0$. Most of the detailed simulations which address the issue of the reach of LHC for SUSY scale, have been done in the context of (M)SUGRA picture. We see from fig.8 that for $\tilde{g}, \tilde{q}$ the reach at LHC is about 2.5 TeV and over most of the parameter space multiple signals are observable.

To determine the SUSY breaking scale M_{SUSY} from the jet events, a method suggested by Hinchliffe et al[27] is used, which consists in defining

$$M_{eff} = \sum_{i=1}^{4} |P_{T(i)}| + \not{E}_T$$

and look at the distribution in M_{eff}. The jets, that are produced by sparticle production and decay, will have $P_T \propto m_1 - \frac{m_2^2}{m_1}$, where m_1, m_2 are the masses of the decaying sparticles. Thus this distribution can be used to determine M_{SUSY}. The distribution in fig. 9 shows that indeed there is a shoulder above the SM background. The scale M_{SUSY} is defined either from the peak position or the point where the signal is aprroximately equal to the background. Then of course one checks how well M_{SUSY} so determined tracks the input scale. A high degree of correlation was observed in the analysis, implying that this can be a way to determine the SUSY breaking scale in a precise manner. A recent analysis[28] shows that while for (M)SUGRA and (C)MSSM a precision of $\sim 0.3\%$ and $\sim 3\%$ can be reached, albeit for a very high integrated luminosity of about $1000 fb^{-1}$, for GMSB models the accuracy is only about 20%.

It is possible to reconstruct the masses of the charginos/neutralinos using kinematic distributions. Fig. 10 demonstrates this, using the distribution in

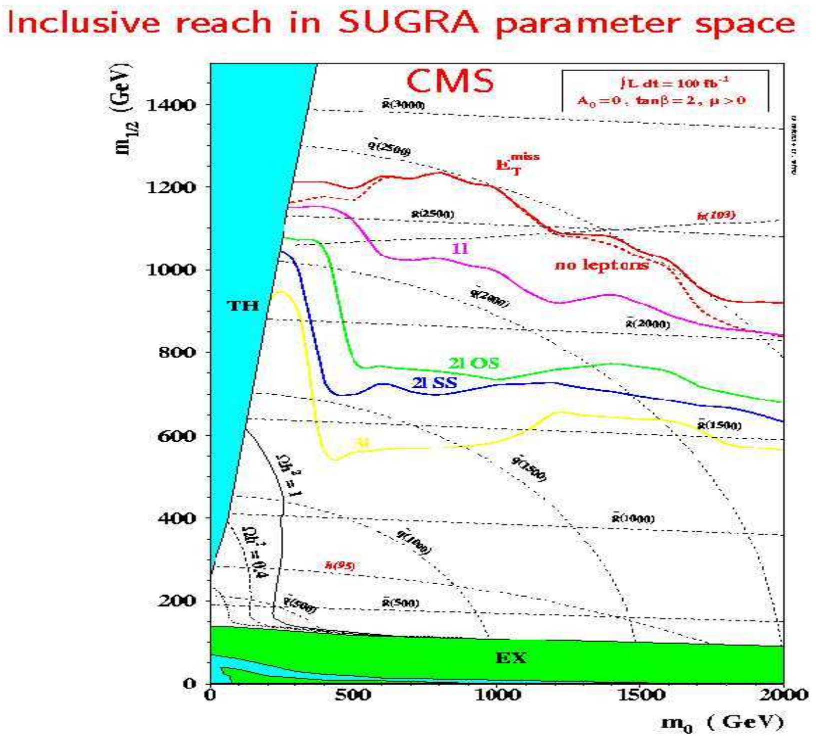


Figure 8. *Expected reach for SUSY searches at the LHC*[26].

the invariant mass $m_{l^+l^-}$ for the l^+l^- pair produced in the decay $\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 l^+ l^-$. The end point of this distribution is $\sim m_{\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^0}$. However, such analyses have to be performed with caution. As pointed out by Nojiri et al[29], the shape of the spectrum near the end point can at times depend very strongly on the dynamics such as the composition of the neutralino and the slepton mass. One can still use these determinations to extract model parameters, but one has to be careful.

6 'Large' extra dimensions at LHC

The whole development of the subject of 'large' extra dimensions at LHC is a very good example as to how the various features of the detectors, such as good

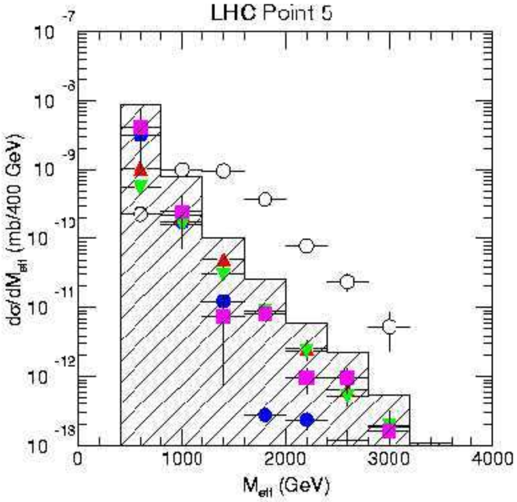


Figure 9. *Determination of SUSY breaking scale using jet events at LHC point* [27].

lepton detection, can be used very effectively in looking for 'new' physics which was **not** taken into account while designing the detector. There have been a lot of discussions on the subject and it will be reviewd[30] in the proceedings elsewhere. In the context of LHC, the clearest signal for these 'large' dimensions is via the observation of graviton resonances[31] in the dilepton spectrum via the process $gg \to G \to l^+l^-$. It has been demonstrated by Hewett et al[31] that by using the constraints already available from the dijet/dilepton data from the Tevatron and making reasonable assumptions so that the EW scale is free from hierarchy problem, in the scenario with 'warped' extra dimesnions[8], the parameter space of the model can be completely covered at LHC using the dilepton channel.

Apart from determining the mass of the graviton, it is also essntial to check the spin of the exchanged particle. ATLAS performed an analysis[32], which showed that the acceptance of the detector is quite low at large $\cos\theta^*$. The left panel of fig. 11 shows the different angular distributions expected for different spin exchanges. For the spin-2 case the contributions from the gg and qq initial state are shown separately. The panel on the right shows that even with the lowered acceptance, it might be possible to discriminate

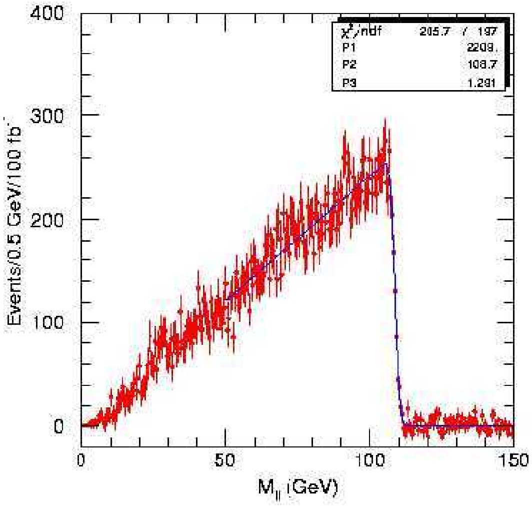


Figure 10. *Kinematic reconstruction of the mass of* $\tilde{\chi}_2^0$ *from the dilepton mass distribution* [26].

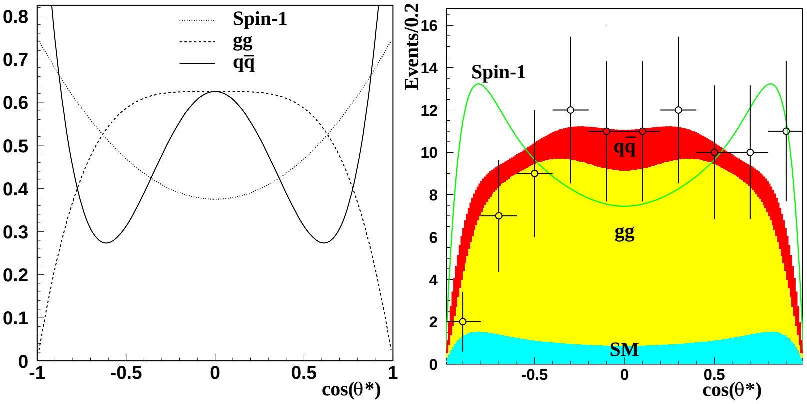


Figure 11. *Angular distribution in the cm. frame for the* l^+l^- *pair expected in the detector for the graviton along with the expectation for a spin 1 particle at LHC*[32].

against a spin one case. Many more investigations on the subject are going on and the end conclusion is that it should be possible to see the effect of these 'large' compact dimensions (warped or otherwise) at the LHC upto almost all the values of the model parameters which seem reasonable and for which the theoretical formulation remains consistent.

7 Conlcusions

1) LHC is capable of finding the SM higgs with a high level of significance over the entire mass range implied by the SM, at the end of one year of running.

2) The mass of the higgs can be measured at $\sim 0.1\%$ level and the width (for $m_h > 200$ GeV) at $\sim 5\%$ level after a total of five years of LHC running. The current analyses also indicate that at the end of three years of high luminosity run, the couplings can also be extracted to about $10 - 20\%$ level even for a light higgs.

3) LHC is capable of covering the entire MSSM parameter space for the Higgs search with $300 fb^{-1}$ luminosity (at the end of five years in all), but the search in the $\gamma\gamma$ channel *may* not be always possible or the lightest neutral `h` may not always be observable. This can happen due to the effect of light sparticles, mainly a light $\tilde{t}$ with $m_{\tilde{t}} \simeq 100 - 200$ GeV. Search strategies for such a light stop at LHC need to be optimised.

4) $\tilde{q}, \tilde{g}$ can be discovered if they are lighter than $\lessapprox 2.5$ TeV; the sleptons, if lighter than $\lessapprox 340$ GeV and the charginos/neutralinos if lighter than $\lessapprox 500 - 600$ GeV. All these estimates of the limits have been obtained in analyses which asume a (M)SUGRA scenario. Similar analyses for the GMSB/AMSB scenarios are underway. Further in the framework of (M)SUGRA and (C)MSSM, a precise determination of model parameters and hence of SUSY breaking scale, is possible from kinematic recosntructions of sparticle masses. However, for GMSB the analysis has not been optimised yet and the reconstruction of SUSY scale seems possible only at the level of 20%. This would require $\int \mathcal{L}dt = 1000 fb^{-1}$.

5) The RS scenario of 'large' extra dimensions can be confirmed or ruled out over all the reasonable range of model parameters by LHC.

Acknowledgments

I wish to thank the organisers of the APPC 2000 and III ACFA LC Workshop for organising an excellent meeting and providing a very nice atmosphere for

discussions.

References

1. S. Komamiya, *Talk in these proceedings.*
2. T. Hambye and K. Riesselmann, *Phys. Rev.* D **55**, 7255 (1997);**hep-ph/9708416** in *ECFA/DESY study on particles and detectors for for the linear colliders*, Ed. R. Settlers, **DESY 97-123E**.
3. S. Heinemeyer, W. Hollik and G. Weiglein, *Phys. Lett.* B **455**, 179 (1999); *Eur. Phys. J.* C **9**, 343 (1999); R. J. Zhang, PLB **447**, 89 (1999), J.R. Espinoza and R.J. Zhang, JHEP **3**, 26 (2000),**hep-ph/0003246**; M. Carena, H.E. Haber, S. Heinemeyer, W. Hollik, C.E.M. Wagner and G. Weiglein, *Nucl. Phys.* B **580**, 29 (2000).
4. J.R. Espinoza and M. Quiros, *Phys. Rev. Lett.* **81**, 516 (1998).
5. R. Barbieri and A. Strumia, *Phys. Lett.* B **462**, 144 (1999), **hep-ph/0005203**, **hep-ph/0007265**.
6. H. Murayama and C. Kolda, *Journal of High Energy Physics* **7**, 35 (2000).
7. N. Arkani-Hamed, S. Dimoupoulos and G. Dvali, *Phys. Lett.* B **429**, 263 (1998),*Phys. Rev.* D **59**, 086004 (1999); I. Antoniadis, N. Arkani-Hamed, S. Dimopoulous and G. Dvali, *Phys. Lett.* B **436**, 257 (1998).
8. L. Randall and R. Sundrum, *Phys. Rev. Lett.* **83**, 3370 (1999), *ibid.*, 4690 (1999).
9. P.C. Bhat, R. Gilmartin and H.B. Prosper, *Fermilab-Pub-00/006 Phys. Rev.* D **62**, 074022 (2000).
10. M. Dittmar, *Pramana* **55**, 151 (2000).
11. T. Bionth, **hep-ph/0005194**; T. Binoth, J.P. Guillet, E. Pillon and M. Werlen, *Eur. Phys. J.* C **16**, 311 (2000).
12. D. de Florian and Z. Kunszt, *Phys. Lett.* B **460**, 184 (1999).
13. S. Abdullin et al., **hep-ph/9805341**.
14. C. Balazs, A. Djouadi, V. Ilyin and M. Spira, *in the Higgs Working Group for the workshop 'Physics at the TeV colliders' Les Houches, June 1999*, **hep-ph/0002258**.
15. M. Dittmar and H. Dreiner, *Phys. Rev.* D **55**, 167 (1997).
16. F. Gianotti, Talk presented at LHCC meeting, http://gianotti.home.cern.ch/gianotti/phys_info.html, F. Gianotti and M. Pepe Altarelli, **hep-ph/0006016**.
17. D. Rainwater, K. Hagiwara and D. Zeppenfeld, *Phys. Rev.* D **59**, 014037 (1999).
18. T. Plehn, D. Rainwater and D. Zeppenfeld, *Phys. Rev.* D **61**, 093005 (2000).

19. D. Zeppenfeld, **hep-ph 0005151**.
20. D. Zeppenfeld, R. Kinnunen, A. Nikitenko and E. Richter-Wąs, *Phys. Rev.* D **62**, 013009 (2000).
21. A. Djouadi, *Phys. Lett.* B **435**, 1998 (101).
22. A. Djouadi, **hep-ph 9903382**.
23. G.Belanger, F. Boudjema and K. Sridhar, *Nucl. Phys.* B **568**, 3 (2000).
24. G. Belanger, F. Boudjema, F. Donato, R. Godbole and S. Rosier-Lees, *Nucl. Phys.* B **581**, 3 (2000).
25. H. Baer, C. Chen, F. Paige and X. Tata, *Phys. Rev.* D **53**, 6241 (1996).
26. G. Polsello, *Talk presented at the SUSY2K, June 2000*, http://wwwth.cern.ch/susy2k/susy2kfinalprog.html.
27. I. Hinchliffe, F.E. Paige, M.D. Shapiro, J. Soderqvist and W. Yao, *Phys. Rev.* D **55**, 5520 (1997).
28. D.R. Tovey, **hep-ph/0006276**.
29. M. M. Nojiri and Y. Yamada, *Phys. Rev.* D **60**, 015006 (1999).
30. M.E. Peskin, *Talk in these proceedings.*
31. H. Davoudiasl, J.L. Hewett and T.Rizzo, *Phys. Lett.* B **473**, 49 (2000), *Phys. Rev. Lett.* **84**, 2080 (2000), **hep-ph/0006041**.
32. B. C. Allanach, K. Odagiri, M.A. Parker and B.R. Webber, *Journal of High Energy Physics* **9**, 019 (2000).