The LHC and the ILC

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The synergy between the Large Hadron Collider and the International Linear Collider during concurrent running of the two machines has the potential to maximise the physics gain from both facilities. Some examples of detailed case studies of the interplay between the LHC and ILC are given, with a particular emphasis on new results that have been obtained after the first LHC / ILC Study Group report was released.

1. INTRODUCTION

Ground-breaking discoveries are expected from the experiments under construction at the Large Hadron Collider (LHC) and those planned for the International Linear Collider (ILC). These high-energy particle accelerators will open up a new energy domain that will allow us to examine the very fabric of matter, space and time.

The LHC and ILC will probe this new TeV energy regime in very different ways, as a consequence of the distinct features of the two machines. Due to its high collision energy and luminosity, the LHC has a large mass reach for the discovery of new heavy particles. The striking advantages of the ILC are its clean experimental environment, polarized beams, and tunable collision energy. The ILC can thus perform precision measurements and detailed studies of directly accessible new particles, and also has exquisite sensitivity to quantum effects of unknown physics. Indeed, the fingerprints of very high-scale new physics (e.g. very high mass particles) will often only be manifest in small effects whose measurement requires the greatest possible precision.

The LHC, currently under construction at CERN (Geneva), is scheduled to go into operation in 2007. A timely realisation of the ILC, leading to a start of data taking by the middle of the next decade, would give rise to a significant period of overlapping running with the LHC. The complementarity between hadron and lepton colliders has often led to a concurrent operation of these two types of machines in the past, and there is a long history of productive synergy between them. The exploration of the TeV energy regime should give us clues on how particles obtain the property of mass, whether the different forces that we experience in nature are in fact different manifestations of only one fundamental force, whether space and time are embedded into a wider framework of supersymmetric coordinates, whether dark matter can be produced in the laboratory, and on many other fundamental questions. Therefore an even greater synergy can be expected from the LHC and ILC compared to previous generations of hadron and lepton colliders. While each machine has its own independent and complementary physics agenda, there are expected to be significant scientific advantages in having them operate at the same time: with combined analyses of the data during concurrent running of both machines, the results obtained at one machine can directly influence the way analyses are carried out at the other machine, leading to optimised experimental strategies and dedicated searches.

In order to assess the prospective synergy of concurrent running of the LHC and the ILC in a quantitative way, detailed informations on the experimental capabilities of the LHC and ILC in different scenarios of physics within and beyond the Standard Model (SM) are needed as input. Studying the interplay between the LHC and ILC requires close collaboration of experts from the LHC and ILC as well as from theorists and experimentalists. A world-wide working group, the LHC / ILC Study Group, has formed as a collaborative effort of the hadron collider and linear collider experimental communities and theorists with the aim to explore the interplay between the LHC and ILC. A first working group report has recently been completed [1]. Many different scenarios of physics at the TeV scale have been investigated in this report. Starting from an assessment of the prospective experimental input from the LHC and ILC in each scenario, the possible synergy from concurrent operation of LHC and ILC has been studied. For scenarios where detailed experimental simulations of the possible measurements and the achievable accuracies are available both for the LHC and ILC, the LHC / ILC interplay has been investigated in a quantitative manner. In other scenarios the prospective physics gain arising from the LHC / ILC interplay has been discussed in a qualitative way. It has been demonstrated that the synergy between the LHC and ILC will extend the physics potential of both machines. Results from both colliders will be crucial in order to identify the underlying physics in the new territory opening up at the TeV scale.

The first working group report [1] has shown that the interplay between the LHC and ILC is a very rich field, of which only very little has been explored so far. Dedicated studies, taking into account information from both the LHC and the ILC in a coherent framework, are necessary in order to determine the expected physics gain. The detailed experimental simulations currently carried out by the ATLAS and CMS collaborations in preparation for the start of data taking at the LHC together with the ongoing efforts of the ILC physics groups provide an ideal input for future studies of LHC / ILC interplay.

The possible physics gain from concurrent running of the LHC and ILC has found a lot of interest in the wider scientific community and among funding agencies [2, 3, 4]. In the U.S., for instance, the High Energy Physics Advisory Panel (HEPAP) of the U.S. Department of Energy has formed a subpanel that has the charge to address the complementarity between the LHC and the ILC [5]. The EPP Decadal Survey panel, with the charge to identify, articulate and prioritise the scientific questions and opportunities that define elementary particle physics, has posed several questions to the scientific community that are specifically related to concurrent running of the LHC and ILC [6]. The above examples indicate that there exists a high demand for a quantitative account of the expected physics gain of concurrent operation of both facilities. A continuing effort is therefore required in order to provide the results necessary for a well-founded judgement of the interplay between the LHC and ILC.

In the following, some recent results on LHC / ILC interplay are summarised. Particular emphasis is put on new results that have been obtained after the first LHC / ILC Study Group report has been completed.

2. SOME RECENT RESULTS ON LHC / ILC INTERPLAY

2.1. Determination of Higgs-boson couplings

If one or more new particles are observed in a way that is consistent with Higgs-boson production, it will be of utmost importance to precisely determine as many properties of the new particle(s) as possible. Ratios of couplings of a light SM-like Higgs boson can be measured at the LHC in a fairly model-independent way [7], while mild theory assumptions are necessary in order to extract absolute values for the couplings [8, 9]. The use of theory assumptions can be avoided by using information from the ILC in the LHC analysis. This has been studied for the example of the Yukawa coupling of the Higgs boson to a pair of top quarks. In the first phase of the ILC with a centre of mass energy of about 500 GeV the $t\bar{t}h$ coupling can only be measured with limited precision for a light Higgs boson h, as a consequence of the phase space suppression of the $e^+e^- \to t\bar{t}h$ production process. The LHC will provide a measurement of the $t\bar{t}h$ production cross section times the decay branching ratio (for $h \to b\bar{b}$ or $h \to W^+W^-$). The ILC, on the other hand, will perform precision measurements of the decay branching ratios. Combining LHC and ILC information will thus allow one to extract the top Yukawa coupling. This has been demonstrated in Ref. [10], where an accuracy on the $g_{\mathrm{t\bar{t}h}}$ coupling of 15–20% has been found for $m_{\mathrm{h}} \lesssim 200$ GeV.

The analysis of Ref. [10] has been extended in Ref. [11], where a combined fit has been performed that includes all LHC channels and ILC input on the Higgs-boson mass, branching ratios and production cross sections. The results are shown in Fig. 1, where the result for the LHC with mild theory assumptions (left plot) is compared with the result of the combined LHC / ILC model-independent analysis (right plot). The ILC input leads to a drastic improvement in the accuracy of the coupling determination. For most couplings the combined analysis is completely driven by the precision achievable at the ILC alone. For the $t\bar{t}h$ coupling (and also for the $h\gamma\gamma$ coupling, which is not shown in Fig. 1), on the other hand, the combined analysis improves over the analyses both at the LHC alone and at the ILC alone. The resulting accuracy on the $g_{\mathrm{t\bar{t}h}}$ coupling in Fig. 1 is 11–14% (note that Fig. 1 shows the

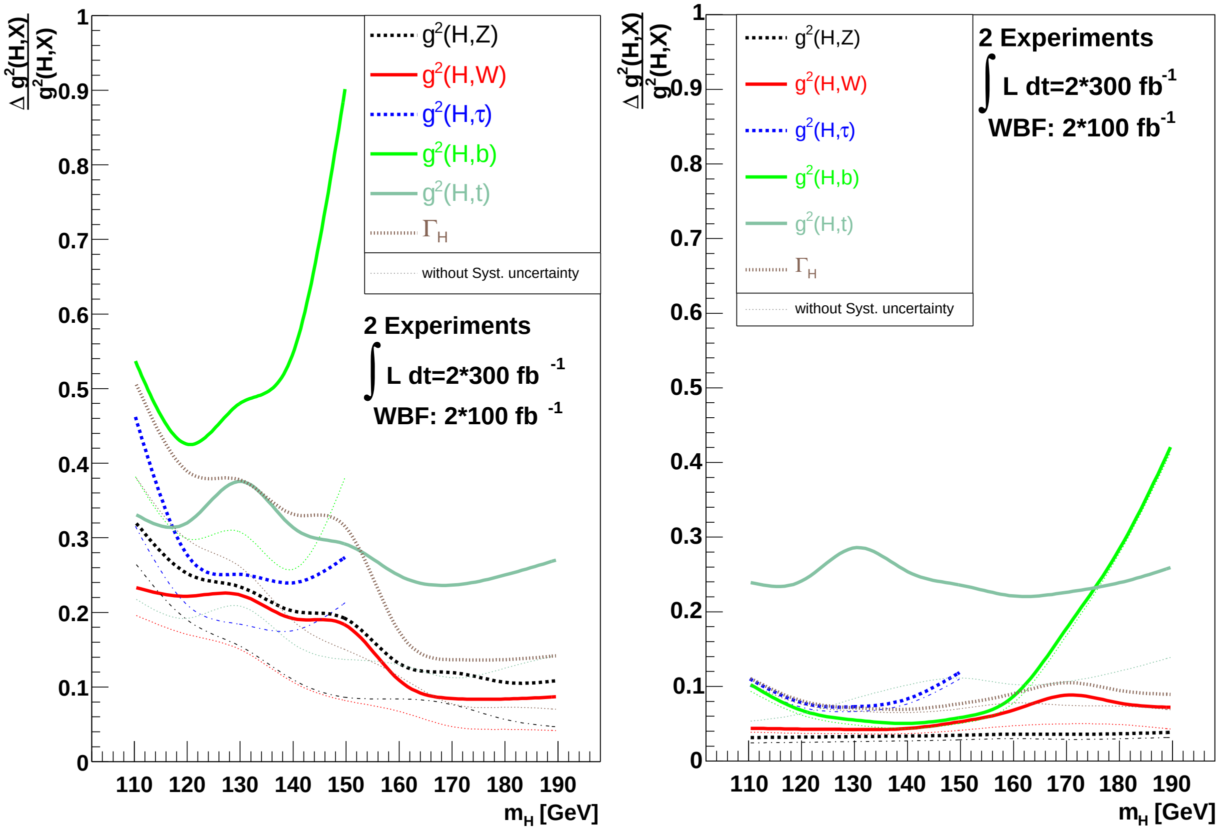

Figure 1: Relative accuracies of squared Higgs-boson couplings and the total Higgs-boson width achievable at the LHC alone with mild theory assumptions [8] (left plot) and in a combined analysis using input from the LHC and ILC [11] (right plot).

squared coupling $\Delta g^2_{\mathrm{t\bar{t}h}}/g^2_{\mathrm{t\bar{t}h}}$ rather than the coupling itself), which corresponds to a relative improvement of about 30% compared to the analysis in Ref. [10].

The complementarity of the LHC and the ILC in both the e^+e^- and the photon collider mode for determining Higgs-boson couplings has been investigated in Ref. [12]. The decays $H \to WW, ZZ$ have been analysed for 200 GeV $\lesssim M_{\mathrm{H}} \lesssim$ 350 GeV in a Two Higgs Doublet Model (II) with $\mathcal{CP}$ violation. It has been found that the measurements at the photon collider are complementary to the ones at the LHC and the ILC, since they are sensitive to different combinations of Higgs-boson couplings. A combined analysis of the LHC and the ILC in its e^+e^- and photon collider modes is necessary in order to precisely determine the $\mathcal{CP}$-violating H–A mixing angle ϕ_{HA}.

2.2. Higgs physics in the NMSSM

While the search for the Higgs boson of the SM has been well studied at the LHC and ILC, physics beyond the SM can give rise to very different Higgs phenomenology. This can be due to modified couplings, mixing with other states, non-standard production processes or Higgs decays into new particles. Even in the Minimal Supersymmetric Extension of the Standard Model (MSSM) the Higgs-boson properties can be rather different from those of a SM Higgs boson. The Next-to-Minimal Supersymmetric Model (NMSSM) has recently found considerable attention as an attractive extension of the MSSM, since it allows to avoid the fine-tuning and “little hierarchy” problems of the $\mathcal{CP}$-conserving MSSM. While the NMSSM is theoretically well motivated, its Higgs phenomenology at the LHC can be very challenging [13]. This is due to the fact that over a large part of the parameter space the SM-like $\mathcal{CP}$-even Higgs boson of the NMSSM dominantly decays into two light $\mathcal{CP}$-odd Higgs bosons, $h \to aa$. Confirmation of the nature of a possible LHC signal at the ILC would be vital. For example, the $WW \to h \to aa$ signal, as well as the usual $e^+e^- \to Zh \to Zaa$ signal, will be highly visible at the ILC due to its cleaner environment and high luminosity.

The ILC will furthermore be able to measure important properties of the $\mathcal{CP}$-odd scalar. Even if a trustworthy signal is seen at the LHC, the ILC will probably be essential to determine that the signal observed at the LHC indeed corresponds to a Higgs boson.

If no clear Higgs signal has been established at the LHC, it will be crucial to investigate with the possibilities of the ILC whether the Higgs boson has not been missed at the LHC because of its non-standard properties. This will be even more the case if the gauge sector does not show indications of strong electroweak symmetry breaking dynamics. The information obtained from the ILC can therefore be crucial for understanding the physics of mass generation. The particular power of the ILC is its ability to look for $e^+e^- \to ZH$ in the inclusive $e^+e^- \to ZX$ missing-mass distribution recoiling against the Z boson. Even if the Higgs boson decays completely invisibly or different Higgs signals overlap in a complicated way, the recoil mass distribution will reveal the Higgs boson mass spectrum of the model.

Another challenging NMSSM scenario is a singlet dominated light Higgs. While this state has reasonably large production cross sections at the LHC, it would be difficult to detect as it mainly decays hadronically. Such a state could be discovered at the ILC. From the measurement of its properties, the masses of the heavier Higgs bosons could be predicted, guiding in this way the searches at the LHC. For a very heavy singlet dominated Higgs state, on the other hand, the kinematic reach of the LHC will be crucial in order to verify that a non-minimal Higgs sector is realised. Thus, input from both the LHC and the ILC will be needed in order to provide complete coverage over the NMSSM parameter space.

2.3. Supersymmetry at the LHC and ILC

The production of supersymmetric particles at the LHC will be dominated by the production of coloured particles, i.e. gluinos and squarks. Searches for the signature of jets and missing energy at the LHC will cover gluino and squark masses of up to 2–3 TeV. The main handle to detect uncoloured particles will be from cascade decays of heavy gluinos and squarks, since in most scenarios of supersymmetry (SUSY) the uncoloured particles are lighter than the coloured ones. An example of a possible decay chain is $\tilde{g} \to \bar{q}\tilde{q} \to \bar{q}q\tilde{\chi}^0_2 \to \bar{q}q\tilde{\tau}\tau \to \bar{q}q\tau\tau\tilde{\chi}^0_1$, where $\tilde{\chi}^0_1$ is assumed to be the lightest supersymmetric particle (LSP). Thus, fairly long decay chains giving rise to the production of several supersymmetric particles in the same event and leading to rather complicated final states can be expected to be a typical feature of SUSY production at the LHC. In fact, the main background for measuring SUSY processes at the LHC will be SUSY itself.

The ILC, on the other hand, has good prospects for the production of the light uncoloured particles. The clean signatures and small backgrounds at the ILC as well as the possibility to adjust the energy of the collider to the thresholds at which SUSY particles are produced will allow a precise determination of the mass and spin of supersymmetric particles and of mixing angles and complex phases.

In order to establish SUSY experimentally, it will be necessary to demonstrate that every particle has a superpartner, that their spins differ by $1/2$, that their gauge quantum numbers are the same, that their couplings are identical and that certain mass relations hold. This will require a large amount of experimental information, in particular precise measurements of masses, branching ratios, cross sections, angular distributions, etc. A precise knowledge of as many SUSY parameters as possible will be necessary to disentangle the underlying pattern of SUSY breaking and to reveal a possible SUSY nature of dark matter [14].

It has been demonstrated that the analysis of SUSY particle production at the LHC can benefit very significantly from experimental results obtained at the ILC [1]. As mentioned above, at the LHC the dominant production mechanism is pair production of gluinos or squarks and associated production of a gluino and a squark. For these processes, SUSY particle masses normally have to be determined from the reconstruction of long decay chains which end in the production of the LSP. The invariant mass distributions of the observed decay products exhibit thresholds and end-point structures. The kinematic structures can in turn be expressed as a function of the masses of the involved supersymmetric particles. The LHC is sensitive in this way mainly to mass *differences*, resulting in a strong correlation between the extracted particle masses. In particular, the LSP mass is only weakly constrained.

This uncertainty propagates into the experimental errors of the heavier SUSY particle masses. Furthermore, the determination of the masses from the end-point expressions in general leads to ambiguities [15]. A specific set of end-point values can often be produced by several sets of masses, leading to multiple solutions in a χ^2 fit for determining the masses even in the favourable case of the SPS 1a benchmark scenario [16]. The precision measurements at the ILC of the colour–neutral part of the SUSY particle spectrum, in particular of the LSP mass, eliminate a large source of uncertainty in the LHC analyses. The ambiguities in the LHC analyses can be resolved using ILC input on the LSP mass and the slepton masses [15]. Inserting the precision measurement of the LSP mass at the ILC into the LHC analyses furthermore leads to a substantial improvement in the accuracy of the reconstructed masses of the particles in the decay chain [1, 15].

In general ILC input will help to significantly reduce the model dependence of the LHC analyses. Intermediate states that appear in the decay chains detected at the LHC can be produced directly and individually at the ILC. Since their spin and other properties can be precisely determined at the ILC, it will be possible to unambiguously identify the nature of these states as part of the SUSY spectrum. In this way it will be possible to verify the kind of decay chain observed at the LHC. Once the particles in the lower parts of the decay cascades have been clearly identified, one can include the MSSM predictions for their branching ratios into a constrained fit. This can be helpful in order to determine the couplings of particles higher up in the decay chain.

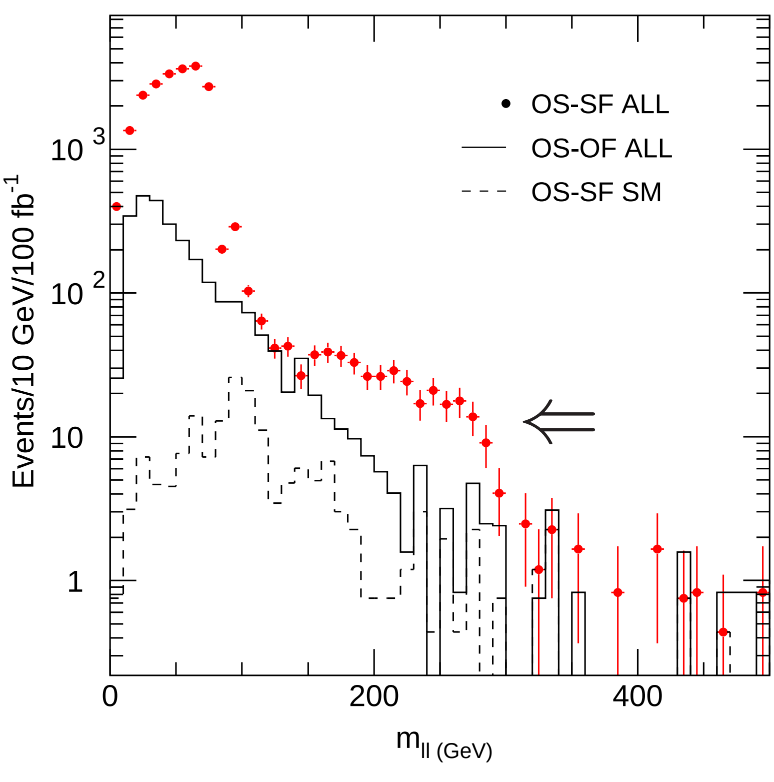

Figure 2: Simulation of invariant mass spectra at the LHC in the SPS 1a scenario [17]: opposite-sign same-flavour (OS-SF) leptons total (full dots), opposite-sign opposite-flavour (OS-OF) leptons total (solid line) and opposite-sign same-flavour leptons in the SM (dashed line). The signals of $\tilde{\chi}_2^0$ and $\tilde{\chi}_4^0$ consist of OS-SF leptons. The arrow indicates the edge associated with the decay of $\tilde{\chi}_4^0$ that can be identified using the ILC prediction $m_{\tilde{\chi}_4^0} = 378.3 \pm 8.8$ GeV.

A detailed study of the interplay of the LHC and ILC in the gaugino sector has been performed in Ref. [17]. In this analysis, carried out in the SPS 1a scenario [16], the measurements of the masses of the two lightest neutralinos, the lighter chargino, the selectrons and the sneutrino at the ILC are used to determine all parameters in the neutralino and chargino sector. This allows then to predict the properties of the heavier neutralinos. For the heaviest neutralino, $\tilde{\chi}_4^0$, the ILC measurements give rise to the prediction $m_{\tilde{\chi}_4^0} = 378.3 \pm 8.8$ GeV for its mass. It was demonstrated in Ref. [17] that the ILC input makes it possible to identify the heaviest neutralino at the LHC, see Fig. 2, and to measure its mass with high precision. Feeding this information back into the ILC analysis significantly improves the determination of the fundamental SUSY parameters from the neutralino and chargino sector at the ILC.

The described analysis is a typical example of LHC / ILC synergy. If a statistically not very pronounced (or even marginal) signal is detected at the LHC, input from the ILC can be crucial in order to identify its nature. In fact, the mere existence of an ILC prediction as input for the LHC searches increases the statistical sensitivity of the LHC analysis. This happens since a specific hypothesis is tested, rather than performing a search over a wide parameter space. In the latter case, a small excess *somewhere* in the parameter space is statistically much less significant, since one has to take into account that a statistical fluctuation is more likely to occur in the simultaneous test of many mass hypotheses. Beyond the enhancement of the statistical sensitivity, predictions based on ILC input can also give important guidance for dedicated searches at the LHC. This could lead to an LHC analysis with optimised cuts or even improved triggers. ILC input might also play an important role in the decision for upgrades at later stages of LHC running.

On the other hand, if the observations at the LHC are not consistent with the predictions from ILC input within the MSSM, this would be an important hint that the observed particles cannot be consistently described within the minimal model. As a recent example, in Ref. [18] an NMSSM scenario has been studied where the light neutralinos have a significant singlino component. This scenario cannot be distinguished from the MSSM by cross section and mass measurements, since the Higgs sector and the light neutralino / chargino spectra and cross sections are almost identical in the two models [18]. The parameter determination from the light neutralino and chargino states at the ILC with 500 GeV c. m. energy (and at the LHC alone) could therefore be carried out in this scenario as in the MSSM and would not lead to any contradictions. As discussed above, the ILC input will allow to predict the properties of the heavy neutralinos, $\tilde{\chi}_3^0$ and $\tilde{\chi}_4^0$. In this scenario, the ILC measurements predict within the MSSM an almost pure higgsino-like state for $\tilde{\chi}_3^0$ and a mixed gaugino-higgsino-like state for $\tilde{\chi}_4^0$, see Fig. 3. An almost pure higgsino-like $\tilde{\chi}_3^0$ would not have sufficiently large couplings to squarks and would therefore not be detectable at the LHC. The detection of $\tilde{\chi}_3^0$ at the LHC would therefore be inconsistent within the MSSM, but in agreement with the NMSSM prediction, see Fig. 3. The combined LHC / ILC analysis would therefore allow to distinguish between the MSSM and non-minimal supersymmetric models.

In order to establish SUSY experimentally and to determine the SUSY-breaking patterns, it is necessary to accurately determine as many Lagrangian parameters as possible. Since most observables depend on a variety of parameters, one will have to perform a global fit [19, 20] of the SUSY model to a large number of experimental observables. As the measurements at the LHC and the ILC in general probe different sectors of the MSSM Lagrangian, the combination of LHC and ILC data will be crucial in order to obtain comprehensive information on the underlying structure of the model. Attempts to fit only individual sectors of the theory turned out to be unsuccessful [1, 20]. In Ref. [20] it has been demonstrated that only the combination of measurements of both the LHC and the ILC offers a complete picture of the MSSM model parameters in a reasonably model independent framework (and without employing theoretical assumptions about a specific SUSY-breaking scenario). In a combined fit based on input from the LHC and the ILC in a variant of the SPS 1a benchmark scenario [16] 19 Lagrangian parameters (neglecting complex phases and mixing between the generations) have been determined. The input comprised mass measurements of supersymmetric particles at the LHC and ILC, using as experimental uncertainties the values obtained in Ref. [1], the cross section measurement of the Higgs-strahlung production of a light Higgs at the ILC, cross section times branching fraction measurements at the ILC for all processes with a sufficiently high rate, Higgs-boson branching fractions measured at the ILC and ratios of branching fractions obtained at the LHC (as discussed above, absolute determinations of branching fractions at the LHC are possible using mild theoretical assumptions), and measurements of the SM parameters. The resulting precision for the Lagrangian parameters is compared in Tab. I with a fit where only the mass measurements of supersymmetric particles and the ratios of Higgs branching ratios at the LHC have

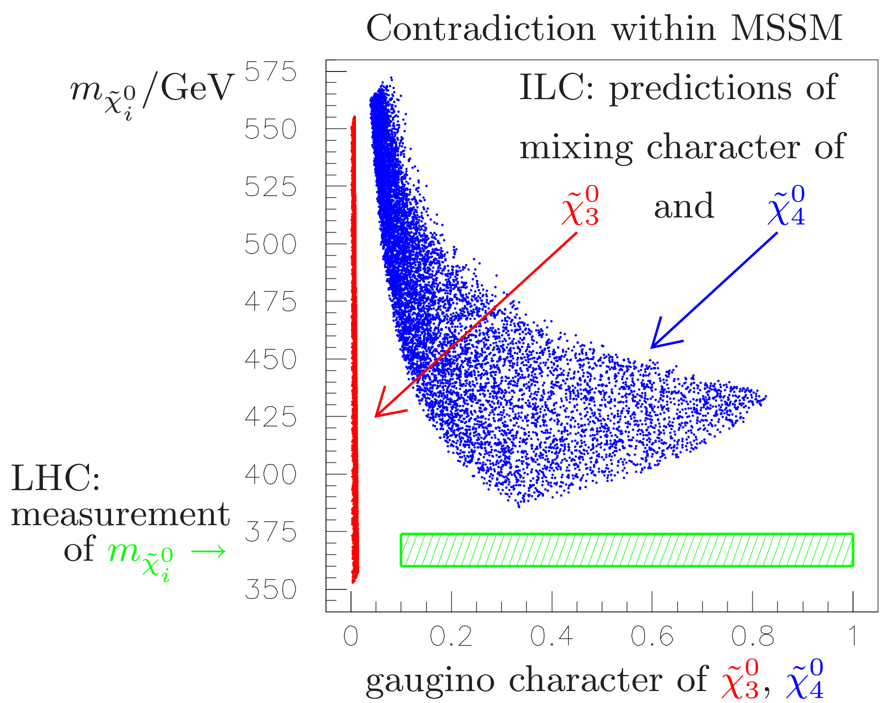

Figure 3: Predicted masses and mixing character for the heavier neutralinos $\tilde{\chi}_3^0$ and $\tilde{\chi}_4^0$ within the MSSM based on the measurements of the light neutralino and chargino states at the ILC with 500 GeV c. m. energy. Detection of the neutralinos in cascade decays at the LHC requires a sufficient gaugino admixture (in the plot a lower bound of about 10% gaugino admixture has been applied). The indicated LHC measurement (with ILC input) of $m_{\tilde{\chi}^0} = 367 \pm 7$ GeV is therefore inconsistent within the MSSM, but consistent with the NMSSM prediction.

been used as input. Tab. I shows that most of the Lagrangian parameters can hardly be constrained in a fit based on LHC data only. The resulting parameter uncertainties often exceed the precision of the combined fit with LHC and ILC information by orders of magnitude. For only three of the parameters in Tab. I, namely $M_{\tilde{q}_L}$, $M_{\tilde{q}_R}$ and M_3, the uncertainty in a fit based on LHC input alone is in the same order of magnitude as for the combined fit of LHC and ILC data.

Most of the studies of the LHC / ILC interplay in the reconstruction of SUSY particle masses carried out so far have been done for one particular MSSM benchmark scenario, the SPS 1a benchmark point [16], since only for this benchmark point detailed experimental simulations are available both for the LHC and ILC. The SPS 1a benchmark point is a favourable scenario both for the LHC and ILC. The interplay between the LHC and ILC could be qualitatively rather different in different regions of the MSSM parameter space. It seems plausible that the synergy of the LHC and ILC will be even more important in parameter regions which are more challenging for both colliders. In order to allow a quantitative assessment of the LHC / ILC interplay also for other parameter regions, more experimental simulations for the LHC and ILC are required.

3. CONCLUSIONS

The LHC and the ILC will explore physics at the TeV scale, opening a new territory where ground-breaking discoveries are expected. The physics programme of both the LHC and the ILC in exploring this territory will be very rich. The different characteristics of the two machines give rise to different virtues and capabilities. The high collision energy of the LHC leads to a large mass reach for the discovery of heavy new particles. The clean experimental environment of the ILC allows detailed studies of directly accessible new particles and gives rise to a high sensitivity to indirect effects of new physics.

Parameter	"True" value	ILC Fit value	Uncertainty (ILC+LHC)	Uncertainty (LHC only)
$\tan\beta$	10.00	10.00	0.11	6.7
μ	400.4 GeV	400.4 GeV	1.2 GeV	811. GeV
X_τ	-4449. GeV	-4449. GeV	20.GeV	6368. GeV
$M_{\tilde{e}_R}$	115.60 GeV	115.60 GeV	0.27 GeV	39. GeV
$M_{\tilde{\tau}_R}$	109.89 GeV	109.89 GeV	0.41 GeV	1056. GeV
$M_{\tilde{e}_L}$	181.30 GeV	181.30 GeV	0.10 GeV	12.9 GeV
$M_{\tilde{\tau}_L}$	179.54 GeV	179.54 GeV	0.14 GeV	1369. GeV
$X_{\rm t}$	-565.7 GeV	-565.7 GeV	3.1 GeV	548. GeV
$X_{\rm b}$	-4935. GeV	-4935. GeV	1284. GeV	6703. GeV
$M_{\tilde{u}_R}$	503. GeV	503. GeV	24. GeV	25. GeV
$M_{\tilde{b}_R}$	497. GeV	497. GeV	8. GeV	1269. GeV
$M_{\tilde{t}_R}$	380.9 GeV	380.9 GeV	2.5 GeV	753. GeV
$M_{\tilde{u}_L}$	523. GeV	523. GeV	10. GeV	19. GeV
$M_{\tilde{t}_L}$	467.7 GeV	467.7 GeV	3.1 GeV	424. GeV
M_1	103.27 GeV	103.27 GeV	0.06 GeV	8.0 GeV
M_2	193.45 GeV	193.45 GeV	0.10 GeV	132. GeV
M_3	569. GeV	569. GeV	7. GeV	10.1 GeV
$m_{\rm A_{run}}$	312.0 GeV	311.9 GeV	4.6 GeV	1272. GeV
$m_{\rm t}$	178.00 GeV	178.00 GeV	0.050 GeV	0.27 GeV
χ^2 for unsmeared observables: 5.3×10^{-5}				

Table I: Results for Lagrangian parameters obtained in a global fit within a variant of the SPS 1a benchmark scenario [16]. The values in the fourth column ("ILC + LHC") are the results of a combined fit using LHC and ILC data, while the results in the fifth column ("LHC only") have been obtained using LHC input only. The second column shows the "true" fit values, while in the third column the best fit values of the combined fit are given (from Ref. [20]).

Thus, physics at the LHC and ILC will be complementary in many respects. While qualitatively this is obvious, a more quantitative investigation of the interplay between the LHC and ILC requires detailed information about the quantities that can be measured at the two colliders and the prospective experimental accuracies. Based on this input, case studies employing realistic estimates for the achievable accuracy of both the experimental measurements and the theory predictions are necessary for different physics scenarios in order to assess the synergy from the interplay of LHC and ILC.

The LHC / ILC Study Group has formed in order to tackle this task. A first working group report, summarising the initial results obtained by the Study Group, has recently been completed. In this article a brief overview about results on LHC / ILC interplay has been given, emphasising in particular new results that have been obtained after the completion of the first report.

In order to assess the synergy of concurrent running of the LHC and the ILC, a wide variety of possible new physics scenarios has been investigated, including different manifestations of the physics of weak and strong electroweak symmetry breaking, supersymmetric models, new gauge theories, models with extra space-time dimensions and possible implications of gravity at the TeV scale. These studies (of what one might term "known unknowns") have revealed a number of examples where direct feedback from the ILC to LHC analyses enables more information to be extracted from the latter. The interplay between the LHC and ILC is a very rich field, of which only very little has been explored so far. The ongoing effort of the LHC and ILC physics groups in performing thorough experimental simulations for different scenarios will enable further quantitative assessments of the synergy between the LHC and the ILC.

Besides the above-mentioned studies of “known unknowns”, a further part of the argument for concurrent running is based on the “unknown unknowns”, i.e. the ability to interpret genuinely new phenomena that may be observed at the LHC or ILC and that go beyond any of the standard new physics scenarios listed above. In this case, an unexpected observation at the ILC will be interpreted as evidence of a new underlying theory, whose predictions can then be immediately tested at the LHC through new dedicated searches.

In summary, experience from the past backed up by dedicated studies using the currently most popular new physics models indicates that concurrent running of the LHC and the ILC will significantly extend the physics potential of both machines. The intricate interplay between them during concurrent running will enable optimal use to be made of the capabilities of both machines in disentangling the underlying physics in the new TeV-scale territory that lies ahead of us. This information will not only sharpen the goals for a subsequent phase of running of both the LHC and ILC, but will also be crucial for determining the future roadmap of particle physics, including of course the subsequent generation of experimental facilities. A continuing effort of the LHC / ILC Study Group is necessary in order to turn qualitative arguments into quantitative case studies, providing in this way the results required for a well-founded judgement of the prospective physics gain from concurrent operation of the LHC and ILC.

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