SUSY Studies

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This report summarizes the progress in SUSY studies performed since the last International Linear Collider Workshop in Paris (LCWS04).

1. INTRODUCTION

The Standard Model provides a very good and economical description for all experimental data. However, there is a number of key physics questions that the Standard Model (SM) is not able to address, e.g.:

- What is the origin of mass? Is the Higgs mechanism, or its variants, behind the gauge symmetry breaking?
- What is the origin of matter-antimatter asymmetry?
- What are the properties of neutrinos? [1]
- Do all forces, including gravity, unify?
- What is the nature of dark matter, dark energy?

What is interesting and stimulating for our Working Group is that supersymmetry (SUSY) may turn out to be related to all these questions. Moreover, SUSY can experimentally be tested at future colliders: Large Hadron Collider (LHC) and International Linear Collider (ILC). In particular, the ILC may provide essential tools for discovery answers. Discovering supersymmetry would mean a grand revolution in particle physics.

Why supersymmetry is so attractive? Technically, of the many motivations for the supersymmetric extension of the SM, perhaps the most important, next to the connection to gravity, is the ability to stabilize the electroweak scale and predict the gauge unification. With R-parity conserved the lightest superparticle (LSP), in many models the lightest neutralino $\tilde{\chi}^0_1$, is a candidate for the main constituent of cosmological cold dark matter (DM). In fact the data from WMAP and astrophysics/cosmology [1] can already put constraints on many possible supersymmetric models. For example, within the constrained MSSM (cMSSM - often referred to as mSUGRA) with universal scalar (m_0) and gaugino ($m_{1/2}$) masses and universal trilinear (A_0) scalar couplings at some unification scale, the dark matter data (and low-energy and collider constraints) select a thin strip in the m_0-$m_{1/2}$ parameter plane, shown in fig.1(a), in which $\mu > 0$, $A_0 = 0$ and $\tan\beta = 10$ [2]. A scan of the cMSSM parameter space gives a broader band, as shown in the plane of the lightest visible (LVSP) and the next-to-lightest visible (NLVSP) superparticle masses, see fig.1(b); the LSP itself was considered not to be visible [3]. This figure gives an impression that most of the points (in this specific model) are outside the reach of the ILC. However, at the ILC in most cases the lightest neutralino $\tilde{\chi}^0_1$ will clearly be detected and its mass measured. Therefore a better representation of the reach of the ILC is shown in fig.1(c) in which a large fraction of the allowed combinations of parameters scanned for the previous plot would give signals accessible to ILC, at least through $e^+e^- \to \tilde{\chi}^0_1\tilde{\chi}^0_2$ [4]. The isolated spot at low neutralino masses is from the focus point region of parameter space (also omitted in [3]).

From this discussion it follows that SUSY can naturally be compatible with present electroweak (EW) measurements. In fact, the fit to EW and DM data, again within the cMSSM, points to rather low values of SUSY breaking parameters, as seen in fig.1(d) [2], which interestingly enough are close to the benchmark point SPS1a of [5].

[1] Neutrinos provide the first experimental evidence for physics beyond the SM.

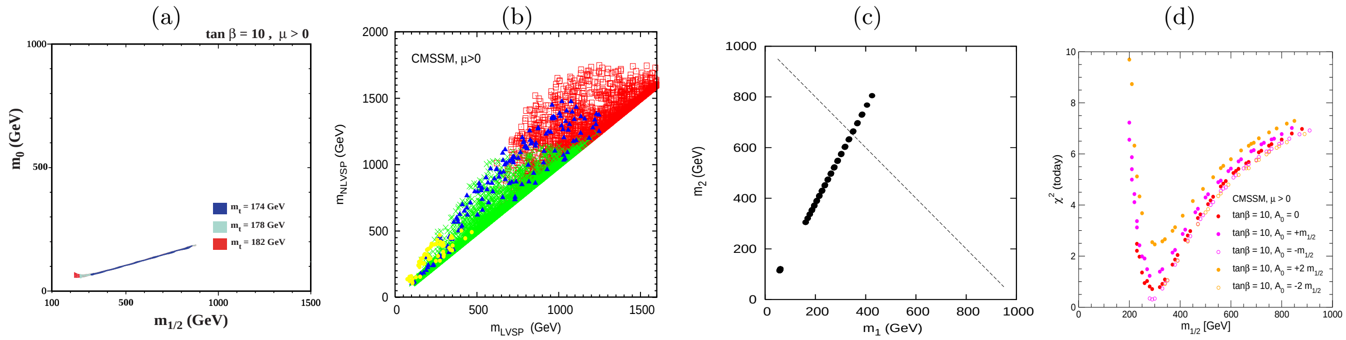

Figure 1: (a) The WMAP strip for $\mu > 0$, $A_0 = 0$ and $\tan\beta = 10$ in the cMSSM; from [2]. (b) Scatter plot of the masses of the LVSP and the NLVSP in the cMSSM; from [3]. (c) Scatter plot of the masses $m_1{=}m_{\tilde{\chi}^0_1}$ and $m_2{=}m_{\tilde{\chi}^0_2}$ of cMSSM models satisfying $\tan\beta = 10$, 20, 35 and $A_0 = 0$. (d) χ^2 fits based on the current experimental EW precision observables and DM constraints as functions of $m_{1/2}$ in the cMSSM for different A_0, $\tan\beta = 10$; from [2].

However, nothing tells us that the cMSSM is the right framework (most probably it is not). As discussed during the meeting the parameter space widens very much when model assumptions are relaxed and many 'crazy' scenarios are possible [6]. For example, if the Higgs and scalar mass parameters at the GUT scale are different, $m^2_{H_u} = m^2_{H_d} \neq m^2_0$, two solutions for relic density are found: one is neutralino annihilation via heavy Higgs resonance even at low values of $\tan\beta$, while the other is neutralino annihilation via higgsino components at low values of m_0 [7]. Breaking the $m^2_{H_u} = m^2_{H_d}$ relation opens the light squark/slepton co-annihilation regions etc. This indicates how important will be to determine SUSY breaking parameters from future experimental measurements with minimum number of theoretical assumptions. Proving SUSY will require not only to discover new particles and measure their masses, decay widths and production cross sections, but also

- verify that they are superpartners, *i.e.* measure their spin and parity, gauge quantum numbers and couplings,
- reconstruct the low-energy SUSY breaking parameters without assuming a specific scenario,
- and ultimately unravel the SUSY breaking mechanism shedding light on physics at high (GUT?, Planck?) scale.

Since the last International Linear Collider Workshop in Paris (LCWS04) members of the SUSY working groups were very active delivering many talks during three regional meetings: the ALCPG Workshop in Victoria, the ECFA Workshop in Durham, and the ACFA Workshop in Taipei; the transparencies can be found in [8]. Here in Stanford (LCWS05) we had 21 presentations in the SUSY WG session alone, and a number of SUSY related talks in other sessions. It is impossible to give justice to all in my talk (and these proceedings) and I apologize for omissions.

2. ACTIVITIES

The aim of our activities is to strengthen the physics case for the e^+e^- ILC demonstrating that it would be an indispensable tool. Our activities also include studies of synergy of the LHC and the ILC showing that coherent analyses of data from the LHC *and* ILC would allow for a better, model independent reconstruction of low-energy SUSY parameters, and connect low-scale phenomenology with the high-scale physics. The main themes of our last year's activities, among other things, include: setting the SPA convention and project, refined experimental simulations and analyses, higher-order theoretical calculations, LHC/ILC synergy, non-minimal scenarios with CP, lepton flavour, and/or R_p violation, cosmology connection etc.

2.1. SPA Convention and Project

Since the experimental accuracies expected at ILC are at the per-cent down to the per-mille level [9, 10], the future experimental effort must be met by equally precise theoretical computations. The implementation of higher-order corrections calls for a well defined framework for the calculational schemes in perturbation theory as well as for the input parameters. The proposed *Supersymmetry Parameter Analysis: Convention and Project* [11] provides

- SPA Convention for SUSY Lagrangian parameters and SM input parameters,
- program repository with computer codes,
- tasks of the SPA Project with long- and short-term sub-projects,
- reference Point SPS1a' as a testbed for testing the SPA Project.

SPA Convention adopts the $\overline{DR}$ scheme [12, 13] for the SUSY Lagrangian parameters. It is based on regularization by dimensional reduction together with modified minimal subtraction. It has been shown in the meeting [14] that the inconsistencies of the original scheme [15] can be overcome and that the $\overline{DR}$ scheme can be formulated in a mathematically consistent way. To make use of the highly developed infrastructure for proton colliders, which is based on the $\overline{MS}$ factorisation scheme (which requires *ad-hoc* counter terms to restore supersymmetry), a finite shift from the commonly used $\overline{MS}$ parton density functions to the $\overline{DR}$ density functions has to be carried out [16]. Moreover, for massive final state particles spurious density functions for the 4-D gluon components have to be introduced to comply with the factorization theorem. Formulating an efficient combination of the most attractive elements of both schemes in describing hadronic processes is therefore an important task of the project [17]. The SUSY scale is chosen $\tilde{M} = 1$ TeV to avoid large threshold corrections in running the mass parameters by renormalization group techniques from the high scale down to the low scale. In the decay widths and production cross sections the physical on-shell masses are introduced such that the phase-space is treated in the observables closest to experimental on-shell kinematics; the masses of the light particles can generally be neglected in high energy processes.

The program repository contains codes for translations between different computational schemes, spectrum calculators, codes for decay widths, cross sections, low-energy and cosmological/astrophysical observables, event generators, RGE codes etc. It is an open system and the responsibility for all programs remains with the authors. It is understood that in each case the theoretical state-of-the-art precision is implemented. For communication between codes SLHA [18] is strongly recommended, which is extended in a suitable way where appropriate. SPA provides the translation tables and the links to the computer codes on the SPA web page.

The tasks of the SPA Project aim at higher-order calculations, better understanding of $\overline{DR}/\overline{MS}$ connections, improvements of experimental and theoretical precision, investigations of LHC/ILC synergy, cold dark matter, developments and explorations of beyond the MSSM scenarios etc. Since the goal of the SPA Project is to reconstruct the fundamental structure of the supersymmetric theory at the high scale, the precise understanding and the combination of all information, that will become available from collider and low-energy experiments and astrophysical/cosmological observations, will be required.

The reference point SPS1a', a slight modification of SPS1a point to be consistent with all available experimental data, is proposed as a testing ground to explore the potential of such extended experimental and theoretical effort. Preliminary studies have shown that while the ultimate aim of the SPA project can be achieved, additional work both on the theoretical as well as on the experimental side is still needed. In particular, SPA should include detailed analyses of other benchmark points and SUSY scenarios.

The SPA Project is a dynamical system expected to evolve continuously. The current status of the Project, listing the conveners responsible for specific tasks as well as the links to the available calculational tools, can be found at the SPA home page: www://spa.desy.de/spa.

2.2. Need for higher-order calculations

The present level of theoretical calculations still does not match the expected experimental precision, particularly in coherent LHC+ILC analyses. For example, table I shows a crude estimate of lower limits on the theoretical errors in deriving the superparticle masses in the SPS1a' point by shifting the SUSY scale $\tilde{M}$ from 1 TeV down to 100 GeV. While the experimental precision at LHC can be matched in general, another order-of-magnitude improvement is required in the theoretical precision to match the expected experimental errors at ILC.

Particle	Mass [GeV]	δ [GeV]	Particle	Mass [GeV]	δ [GeV]
h^0	115.4	1.3	H^0	431.1	0.7
$\tilde{\chi}_1^0$	97.75	0.4	$\tilde{\chi}_2^0$	184.4	1.2
$\tilde{\chi}_1^\pm$	183.1	1.3	$\tilde{\tau}_1$	107.4	0.5
$\tilde{e}_R$	125.2	1.2	$\tilde{e}_L$	190.1	0.4
$\tilde{q}_R$	547.7	9.4	$\tilde{q}_L$	565.7	10.2
$\tilde{t}_1$	368.9	5.4	$\tilde{b}_1$	506.3	8.0

Table I: Superparticle masses for the SPS1a' Reference Point with the SUSY scale $\tilde{M} = 1$ TeV, and their variation when $\tilde{M}$ is shifted down to 100 GeV; from [11].

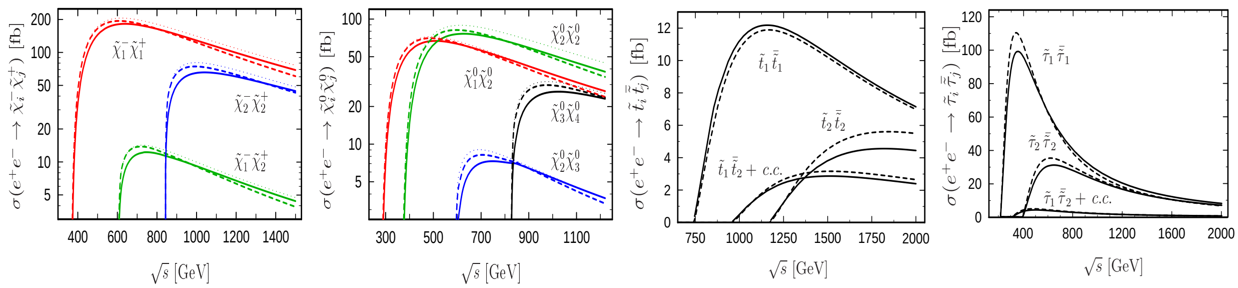

Figure 2: Chargino, neutralino, stop and stau production cross sections for the Reference Point SPS1a'; from [19].

Recent high precision calculations for production processes of the SUSY particles at the ILC have been reviewed by K. Kovařík [19]. The input parameters of SPS1a' benchmark point have been translated to on-shell which then have been used as input in the calculation of the pair production of stops, sbottoms, staus, charginos and neutralinos in e^+e^- collisions. The advantage of using the on-shell input values is that the well-established procedure of on-shell renormalization can be applied. Plots in fig. 2 show total cross-sections of the complete $\mathcal{O}(\alpha)$, leading higher-order and tree-level results for the chargino, neutralino, stop and stau production processes. For neutralino and chargino production the separation of the QED and weak corrections followed the prescription of the SPA project.

2.3. Experimental analyses

Masses of superparticles can be measured very precisely in threshold scans [9], which however need running time. It is therefore important to measure the masses in the continuum above thresholds including beam/bremsstrahlung effects [20]. To achieve a precision measurement one has to suppress efficiently SM background processes as well as disentangle signals coming simultaneously from different SUSY channels. Equally important is to verify the chirality assignment of sfermions.

In this respect the ability of having both beams, positrons and electrons, polarised is particularly important [21]. In some scenarios even 100% electron polarisation may prove insufficient to disentangle $\tilde{e}_{\mathrm{L}}^+\tilde{e}_{\mathrm{R}}^-$ and $\tilde{e}_{\mathrm{R}}^+\tilde{e}_{\mathrm{R}}^-$ pairs and to test chiral quantum numbers. For smuon mass measurement the worst background coming from W^+W^- final states can easily be suppressed with right-handed electron/left-handed positron beams, as shown in fig 3(a,b) from [22]. The selectron mass measurement, thanks to larger production cross sections, can greatly be improved by a double subtraction of e^+ and e^- energy spectra and opposite electron beam polarizations, see fig. 3(c). In both cases the endpoints from $\tilde{\mu}_{L,R}$ and $\tilde{e}_{L,R}$ are clearly exposed giving rise to precise determination of slepton masses. New techniques have been also developed [23] to isolate from SM backgrounds the selectron-decay signal in the forward region ($|\cos\theta| > 0.8$) which in some scenarios carries most of the information constraining the selectron mass. With new selection techniques it has been demonstrated that the selectron signal can be separated from Standard Model

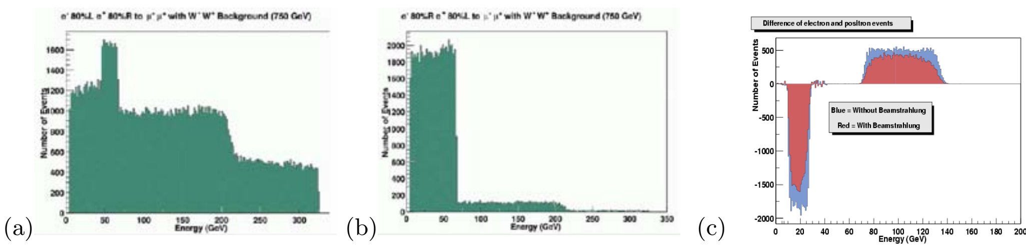

Figure 3: (a,b) Energy spectra of muons from $\tilde{\mu}_{L,R}$ decays into $\mu\tilde{\chi}_1^0$ including W^+W^- background for two combinations of beam polarisations P_{e^-}, P_{e^+}: (a) -80%,$+80\%$, (b) $+80\%$,-80%). (c) Difference of e^+ and e^- energy spectra from selectrons $\tilde{e}_{L,R}$ produced with polarised beams; from [22]

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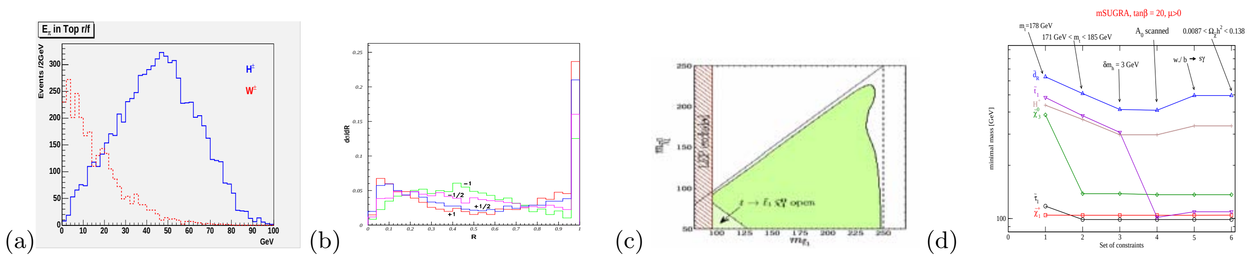

Figure 4: (a) The $\pi^\pm$ energy spectrum from signal (solid line) and background (dotted line); from [24]. (b) The normalized distributions in the fraction of τ-jet momentum carried by the charged track for $P_\tau = +1$, $+1/2$, $-1/2$ and -1, and $p^T_{\tau-jet} > 25$ GeV; from [25]. (c) Stop discovery reach in $\tilde{t}_1 \to c\tilde{\chi}_1^0$ channel in the $m_{\tilde{t}_1}$-$m_{\tilde{\chi}_1^0}$ plane – the $t \to \tilde{t}_1\tilde{\chi}_1^0$ channel was not studied; from [27]. (d) Effects of experimental constraints on minimal allowed masses of superparticles; from [30].

backgrounds through the entire forward tracking region $|\cos\theta| < 0.994$.

Polarisation is a very powerful tool not only for preparing the desirable initial state, but also as a diagnosis tool of final states. At this meeting improvements of exploiting information on polarisation of fermions coming from decays of scalar particles (Higgs, sfermions) have been reported [24, 25]. The charged Higgs boson couples strongly to the fermions of the third generation. If the charged Higgs is rather light ($M_{H^\pm} < M_t$), it decays dominantly to a tau lepton and neutrino ($H^\pm \to \tau^\pm\nu$) making its mass reconstruction impossible. The main background comes from decays $W^\pm \to \tau^\pm\nu$. However, different structure of $H^\pm$ and $W^\pm$ electroweak interactions implies different tau polarization[2], which is reflected in the energy spectra of the $\tau^\pm$ decay products, see e.g. fig. 4(a). In [24] detailed computations and Monte Carlo simulations for three different sets of MSSM parameters showed that a fit to the energy spectrum of the pion in the $\tau^\pm \to \pi^\pm\nu$ channel allows one to infer $M_{H^\pm}$ with an uncertainty at the level of 0.5–1 GeV. In [25] the prospects of using τ polarisation to probe the composition of $\tilde{\chi}_1^0$ from $\tilde{\tau}_1^+\tilde{\tau}_1^-$ production at the ILC followed by $\tilde{\tau}_1^\pm \to \tau^\pm\tilde{\chi}_1^0$ decay have been investigated. The τ polarization measurement, via its inclusive 1-prong hadronic decay, can discriminate SUSY models with different gaugino/higgsino decomposition of the neutralino. Fig. 4(b) shows the distribution of the fraction of the visible τ-jet momentum carried by the charged prong, $R = p_{\pi^\pm}/p_{\tau-\mathrm{jet}}$, for four different theoretical models (for details we refer to [25]).

Progress on experimental analyses of stop quarks with small stop-neutralino mass difference has also been reported to this meeting [27, 28]. Such analyses are motivated by the stop-neutralino co-annihilation scenario consistent with relic density and EW baryogenesis, see next section. With small mass difference, the stop decays into neutralino and charm making the analysis very demanding. Nevertheless, it was shown that with the linear collider the region

[2] The importance of tau polarisation in searches for charged Higgs bosons has already been stressed in previous studies [26].

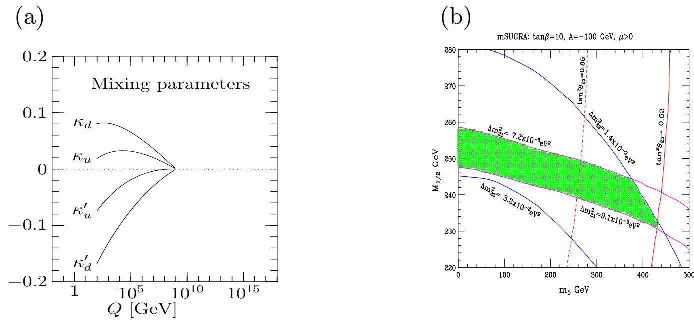

Figure 5: (a) RGE flow of the anomalous chargino mixing parameters; from [33]. (b) m_0-$m_{1/2}$ region with solutions to neutrino physics passing all experimental constraints; from [35].

of co-annihilation down to mass differences $\sim \mathcal{O}(5$ GeV$)$ can be covered, fig. 4(c), and the parameters can be determined accurately enough to reach precisions for the dark matter predictions comparable to that from direct WMAP measurements [27]. Additional improvement in the analysis of this scenario can be obtained if charm triggering were available [28].

2.4. Cosmology connection

Understanding the nature of dark matter is one of the most important challenges of both particle and astroparticle physics, and collider experiments may prove useful tool in solving the dark matter puzzle. Among many scenarios, weakly interacting massive particles (WIMPs), with masses and interaction cross sections characterized by the weak scale, are very compelling and WIMPs appear naturally in low energy supersymmetry models with R-parity. In contrast, the origin of the matter-antimatter asymmetry is more uncertain. Electroweak baryogenesis provides a possible scenario that relies only on weak scale physics in which the lightest stop mass must be smaller than the top quark mass and heavier than about 120 GeV [29]. Moreover, in this case the Higgs boson involved in the electroweak symmetry breaking mechanism must be lighter than 120 GeV, and if the lightest neutralino is the dark matter particle, it must be lighter than stop. This case includes the stop-neutralino co-annihilation region with acceptable relic density, in which the stop-neutralino mass difference is small presenting a challenge for stop searches at colliders [27, 28].

Other cosmologically variable regions of parameter space have been discussed at length in the Cosmological Connections Working Group [31]. In our session an update of all experimental constraints, including dark matter, on the mSUGRA models and prospects for superparticle production at the ILC has been presented [30]. Special emphases has been put on determining minimal allowed superparticle masses, which might be more interesting than the "size" of allowed parameter space. It is found that mSUGRA models with thermal $\tilde{\chi}_1^0$ as a dark matter particle work fine and that lower bounds on superparticle masses are only very mildly affected by the DM constraints, see fig. 4(d). As a result, a possibility of copious superparticle production even at the first stage of ILC remains open.

2.5. Beyond the MSSM

The MSSM is defined as an effective low energy model with a) minimal particle content, b) R-parity conservation, c) most general soft supersymmetry breaking terms, which however provide a technical solution to the hierarchy problem. At the meeting several presentations went beyond this minimal set of assumptions.

Recently an idea of splitting the supersymmetry-breaking scale between the scalar and the gaugino sector has been proposed [32]. By arranging squarks and sleptons very heavy (somewhere between several tens or hundreds TeV and the GUT scale) with charginos and neutralinos at the TeV scale or below, dangerous flavor-changing neutral current transitions, electric dipole moments, and spurious proton-decay operators can be eliminated, however at a price of fine-tuning the Higgs sector. In this case the low-energy effective theory is quite simple with a SM-like Higgs

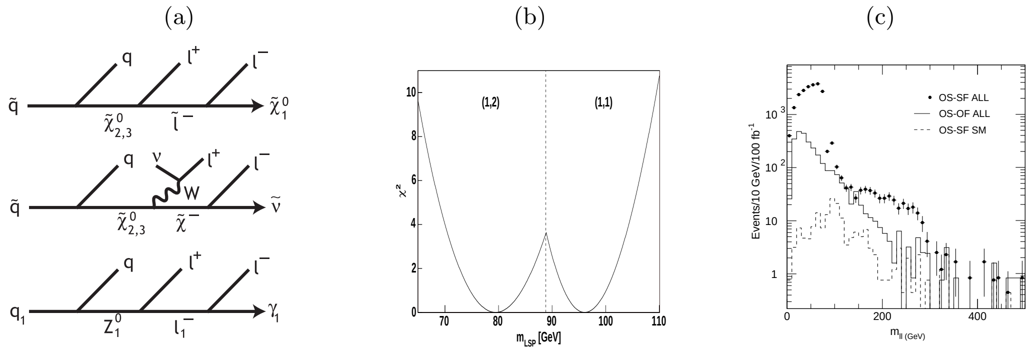

Figure 6: (a) (S)quark decay chains; figure from [38]. (b) χ^2 as a function of $m_{\tilde{\chi}_1^0}$; from [40]. (c) Invariant dilepton mass spectrum for the decay chain. The OS-SF dilepton edge from heavy neutralino is between 200 GeV and 400 GeV; from [43].

boson, four neutralinos, two charginos, and a gluino. Since squarks are very heavy, the gluino is long-lived providing a clear signature. Also the neutralino and chargino Yukawa couplings deviate from their usual MSSM prediction since they evolve differently below the splitting scale $\tilde{m}$. Fig. 5(a) shows the evolution of four anomalous chargino mixing parameters (for $\tilde{m} = 10^9$ GeV). By combining precision measurements of chargino and neutralino masses and Yukawa couplings at the ILC with gluino mass and life-time at the LHC, it has been demonstrated [33] that the nature of the model can be verified.

The simplest extension of the MSSM includes an additional singlet superfield S. It is motivated by the μ problem of MSSM since the vacuum expectation value of the scalar component of S provides an effective μ. The spectrum, apart from the sparticle content of MSSM, includes two additional Higgs scalars and a neutralino which can mix with the four neutralinos of the MSSM. The parameters of the nMSSM can conspire to mimic the mass spectrum of the first four neutralinos. The question then arises how to differentiate experimentally MSSM from nMSSM if at the first stage of ILC with $\sqrt{s} = 500$ GeV only two light neutralinos and light chargino are seen. It has been shown in a particular scenario [34] that precision measurements of light chargino and neutralino masses at ILC with LHC data on heavier neutralino $\tilde{\chi}_3^0$ can point to an inconsistent set of SUSY parameters under a working hypothesis of MSSM. By a moderate rise of the collider energy to 650 GeV the MSSM hypothesis can be falsified and the true nature of nMSSM revealed.

In the MSSM R–parity implies that particles have R_p=+1 and their superpartners R_p=−1. Since R_p is conserved, the LSP must be stable and becomes a candidate for dark matter particle. However, R–parity conservation has no strong theoretical justification since the superpotential admits explicit R–parity violation ($\not{R}_p$). At this meeting new developments in models with explicit bilinear R–parity breaking have been presented [35]. The bilinear terms $\epsilon_i \hat{L}_i \hat{H}_u$ in the superpotential ($\hat{H}_u, \hat{L}$ are the Higgs and left–handed lepton superfields) induce mixing between the neutralinos and neutrinos, forming a 7×7 mass matrix [36]. Thus the model provides a framework for generating neutrino masses and mixing angles, but at the expense that the LSP is no longer stable. For example, fig. 5(b) shows the m_0-$m_{1/2}$ parameter space in the $\not{R}_p$-mSUGRA model consistent with neutrino physics. The model leads to definite predictions for the branching ratios of superparticles which can be tested at future colliders.

Gauge theories with extra dimensions provide an exciting possibility of unifying gauge and Higgs fields. The higher dimensional components of gauge fields become scalar fields below the compactification scale and are identified with the Higgs fields in the gauge-Higgs unification theory. Through quantum corrections, the Higgs can take a vacuum expectation value, and its mass is induced, however the radiatively induced mass tends to be small. Exploiting useful expansion formulae for the effective potential it was shown [37] that even a small number of bulk field can generate the suitable heavy Higgs mass. The case of introducing the soft SUSY breaking scalar masses in addition to the Scherk-Schwarz SUSY breaking and obtaining the heavy Higgs mass due to the effect of the scalar mass has also been discussed.

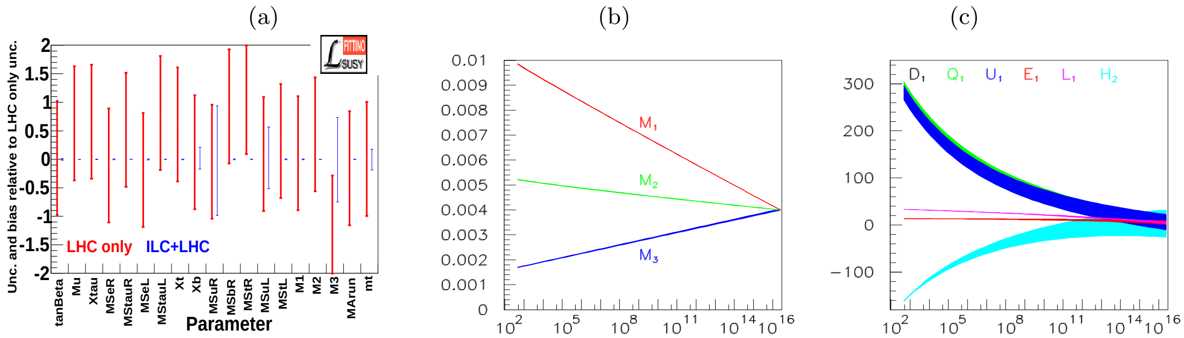

Figure 7: (a) Relative errors on SUSY parameters from LHC data and LHC+ILC; from [48]. Evolution of gaugino (b) and scalar (c) mass parameters; from [49].

2.6. LHC/ILC Connection

If a low-energy SUSY scenario with squarks/gluinos below $\sim$ 2-3 TeV is realized, the LHC will see SUSY signals. Many channels from squark and/or gluino decays may be observed and measured. If the decay chain is long enough, like the first squark decay chain shown in fig.6(a), from a knowledge of kinematical endpoints, in particular those of the invariant mass distributions m_{qll}, $m_{ql(low)}$, $m_{ql(high)}$ and m_{ll}, the masses of the unstable particles can be reconstructed [39]. Indeed, the endpoints of these distributions can be expressed explicitly in terms of $m_{\tilde{q}}$, $m_{\tilde{\chi}^0_{2,3}}$, $m_{\tilde{\chi}^0_1}$ and $m_{\tilde{l}}$. However, ambiguities in the masses extracted from endpoint measurements can occur (even when experimental uncertainties are neglected) since the kinematical endpoints are composite functions of the unknown masses. This is shown in fig.6(b) where the false minimum around 80 GeV is found [40]. Moreover, the same visible final state l^+l^-q can be generated by a different SUSY decay chain (second decay chain in fig.6(a)), or a Kaluza-Klein decay chain in a non-supersymmetric model with universal extra dimensions [41] (last decay chain in fig. 6(c)). Therefore, the correlation of measured masses with particles may not be unique. What differs the decay chains is the spin of intermediate particles. Although the LHC might have some sensitivity to spin [42], both problems – spin and mass ambiguities – can be disentangled with the help of the ILC by verifying masses and measuring spins of new particles [10]. In addition, the precise measurements of kinematically accessible sparticles at the ILC can facilitate the correct interpretation of the kinematical endpoints, like the largest observed edge in the opposite-sign same-flavor (OP-SF) dilepton invariant mass spectrum m_{ll} shown in fig.6(c) as originating from heavy neutralino in the MSSM context [43].

Another cosmology-motivated topic is the sensitivity to heavy sfermion masses [44] that are beyond the collider kinematic reach. At the ILC the lepton forward-backward asymmetry in chargino-pair production can provide interesting constraints on virtual sleptons mediating the chargino decay [45]. Preliminary studies of mSUGRA points presented at this meeting show that at the LHC the use of a sophisticated Kolmogorov-Smirnov test for the dilepton mass spectra from the neutralino decay can at least distinguish the high-mass from low-mass scenarios and a lower limit on the universal scalar mass parameter m_0 can be determined [46]

Many interesting channels can be exploited to extract the basic supersymmetry parameters when combining experimental information from sharp edges in mass distributions at LHC with measurements of decay spectra and threshold excitation curves at an e^+e^- collider with energy up to 1 TeV. From the simulated experimental data with their errors available global analysis programs [47] can exploit coherently masses, cross sections, branching ratios etc, to extract the Lagrangian parameters. The present quality of such an analysis for the SPS1a' scenario can be judged from fig. 7(a) where the relative errors on parameter determination from LHC data and LHC+ILC are shown [48]. With the parameters extracted at the scale $\tilde{M}$, the reconstruction of the fundamental supersymmetric theory and the related microscopic picture of the mechanism breaking supersymmetry can be investigated in the bottom-up approach [49] in which the extrapolation from $\tilde{M}$ to the GUT/Planck scale is performed by the renormalization group evolution for all parameters. Typical examples for the evolution of the gaugino and scalar mass parameters are presented in fig. 7(b,c) [11]. A comprehensive account of SUSY studies within the LHC/ILC context can be found in Ref. [10].

3. SUMMARY

Much progress has been achieved during the last year since LSCW04. On the theory side many higher-order calculations have been completed and implemented in numerical codes. The SPA Convention and Project has been launched which should prove very useful in streamlining discussions and comparisons of different calculations and experimental analyses. On the experimental side many analyses are still based on lowest–order expressions. In our future studies it is important to ensure that new information from ILC should both significantly improve accuracies of SUSY studies at the LHC, as well as permit calculation of dark matter density to check cosmology/astrophysics measurements. Case studies have shown that a high luminosity ILC with polarised beams, and with additional $e\gamma$, $\gamma\gamma$ and e^-e^- modes, can provide high quality data for the precise determination of low-energy SUSY Lagrangian parameters and with LHC data in the bottom–up approach, through the evolution of the parameters from the electroweak scale, can reveal the regularities at high scales.

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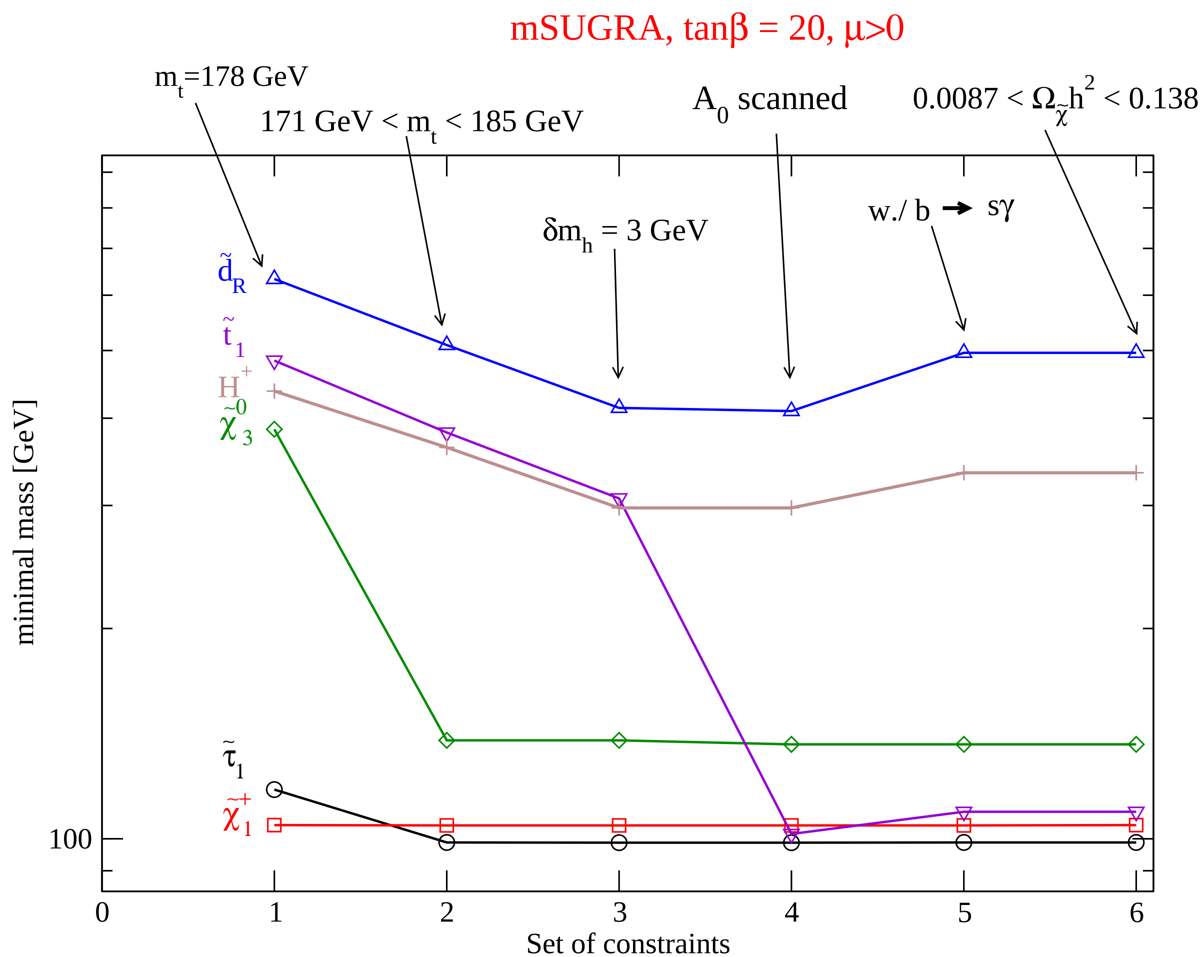
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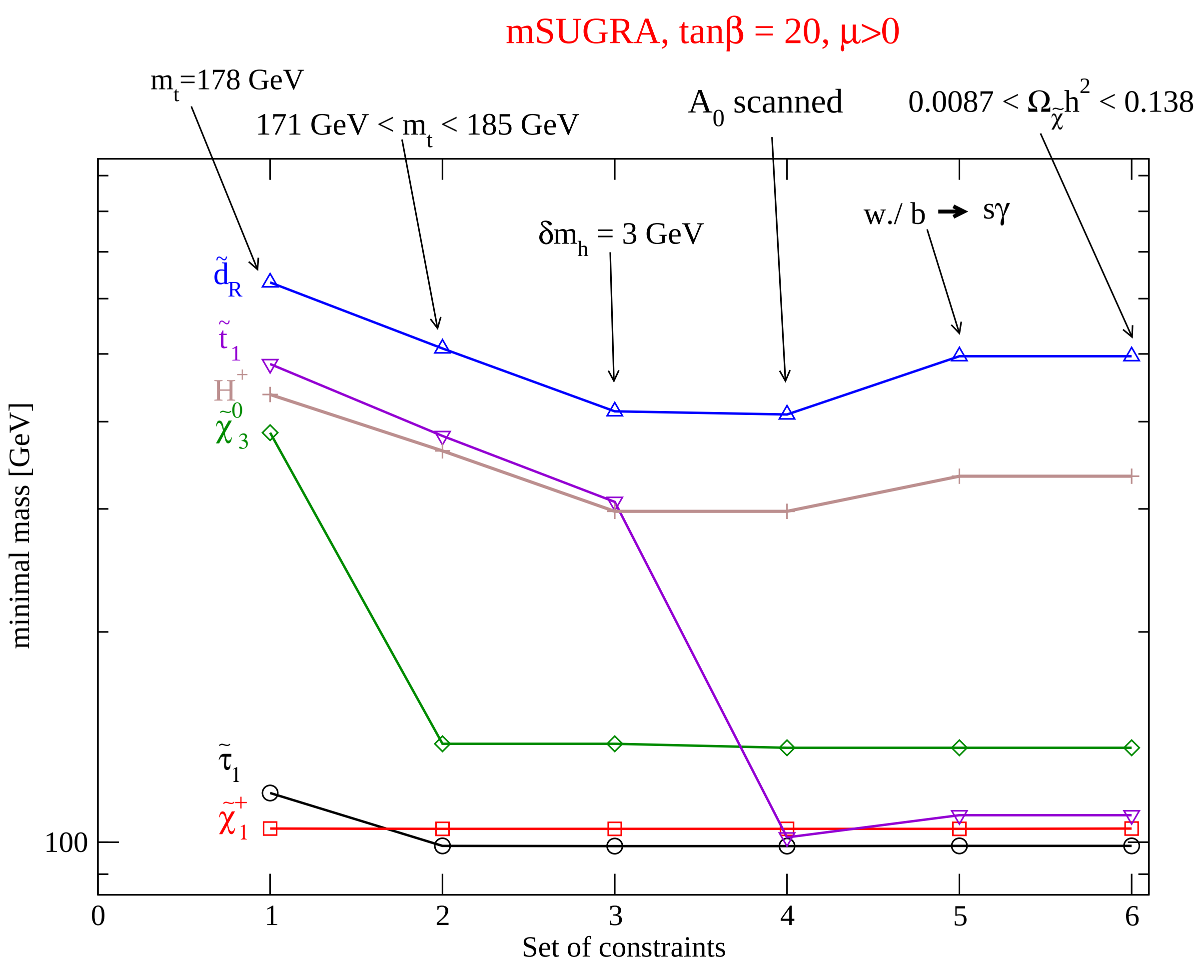
m_t=178 GeV
171 GeV < m_t < 185 GeV
δm_h = 3 GeV
A_0 scanned
w./ b → sγ
0.0087 < Ω_χ̃ h^2 < 0.138
d̃_R
t̃_1
H^+
χ̃^0_3
τ̃_1
χ̃^+_1
100
0
1
2
3
4
5
6
Set of constraints
minimal mass [GeV]



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d̃_R
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τ̃_1
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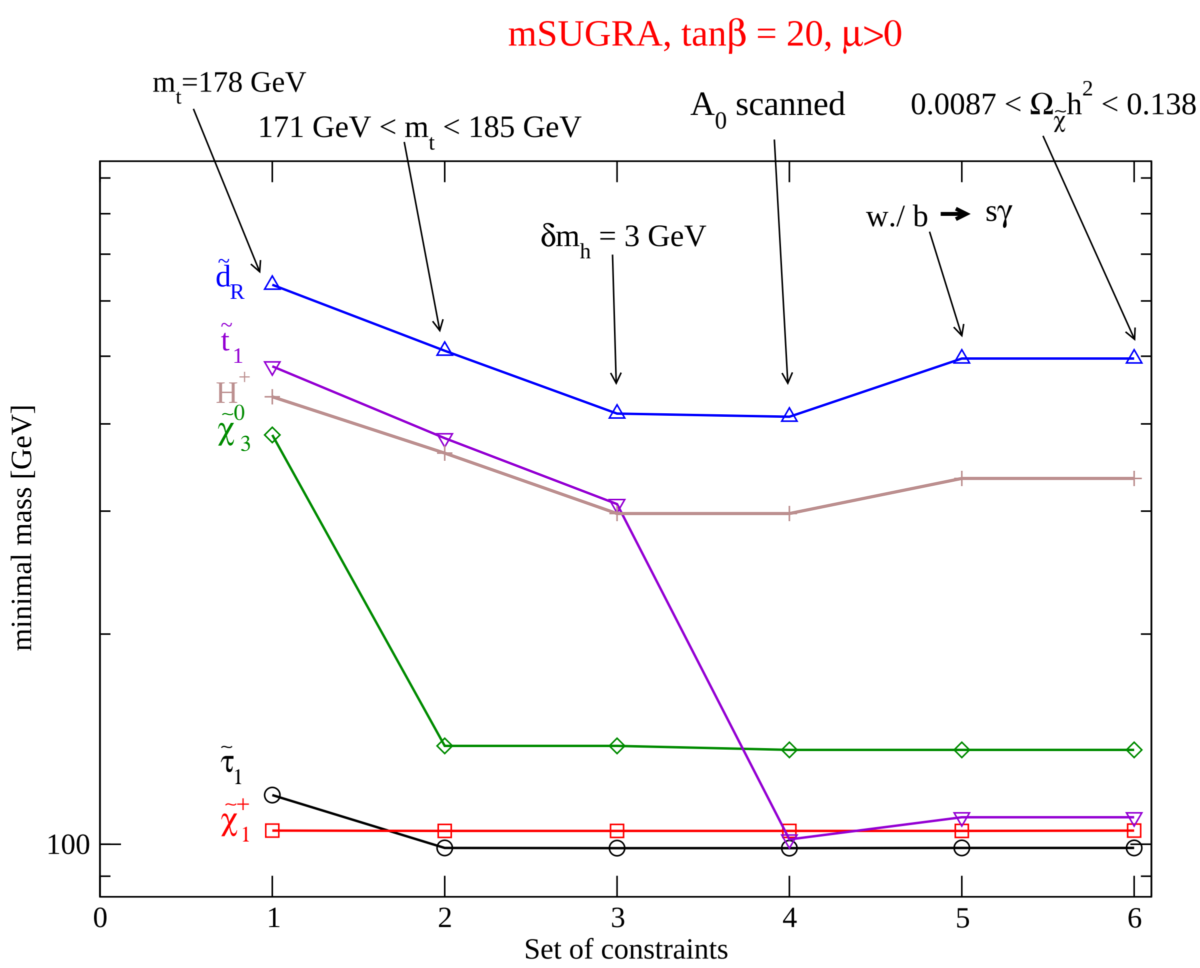
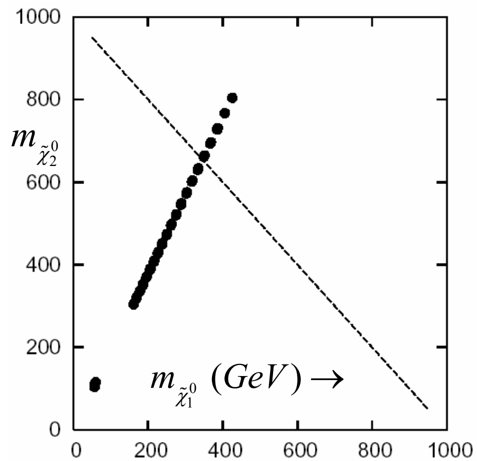
100
minimal mass [GeV]
0
1
2
3
4
5
6
Set of constraints

arXiv:hep-ph/0508167 v1 15 Aug 2005




1000
800
$m_{\tilde{\chi}_2^0}$
600
400
200
0
$m_{\tilde{\chi}_1^0}$ $(GeV) \rightarrow$
0
200
400
600
800
1000