SUSY discovery strategies at the LHC

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Abstract

Current ideas for SUPERSYMMETRY searches at the LHC are reviewed. We analyse the discovery prospects for various supersymmetric particles and describe recent ideas on the possibilities of detailed SUSY studies at the LHC. We also combine today's experimental knowledge with some speculations about what might be known by the year 2005 to provide a realistic picture for the LHC start.

1 Introduction

The search for new physics phenomena is often defined as the main motivation for new experiments at higher center of mass energies. This is especially true for the LHC project, with its two general purpose experiments ATLAS and CMS. The prime motivation of the LHC physics program is to discover the "mechanism of electroweak symmetry breaking" usually associated with a scalar particle, the Higgs boson. Theoretical ideas suggest that this hypothetical particle with a mass of less than roughly 1 TeV could explain the observed mass spectrum of bosons and fermions. The simplicity and mathematical elegance of this model leads however to its own problems, the so called hierarchy problem or fine tuning problem of the Standard Model.

These problems originate from theoretical ideas which extrapolate today's knowledge at mass scales of a few 100 GeV to energy scales of about 10^{15} GeV and more. A purely theoretical approach to this extrapolation has led theorists to SUPERSYMMETRY which could solve these conceptual problems by the introduction of supersymmetric partners to every known boson and fermion and at least an additional Higgs super-multiplet. Despite the largely unconstrained masses of these new partners, the potential to discover such new objects has become a central question for many design issues of future high energy particle physics experiments.

Following today's theoretical fashions, the main goals of ATLAS and CMS are often defined as the search for the Higgs boson and for any kind of experimental manifestation of supersymmetry.

A growing fraction of the preparation time for a modern collider experiment deals with the simulation of case studies like the search sensitivity for new physics. Such studies are not only required in order to motivate the required effort, time and money but should also provide some guidance on "what is possible" and how a real detector should look like.

Among the many possible case studies, essentially all simulation studies concentrate on the SM Higgs search and on SUSY particle searches. The investigated signatures provide thus not only "dream-land" possibilities for a future collider but, as will become clear in the following, cover a wide range of detector requirements which help to shape the final and real experiment.

The following review about SUSY signatures at the LHC is structured as follows. We start our discussion with an overview of experimental and theoretical constraints for the LHC SUSY searches. This is followed by a detailed discussion of current ideas about various SUSY signatures at the LHC. We then speculate about possible studies which can be performed once SUSY events have been discovered at the LHC. Finally we try to combine today's and tomorrows experimental constraints to define a realistic SUSY search strategy for the LHC.

2 The experimental and theoretical frame

2.1 The experimental LHC frame

Table 1 combines the required experimental observables with new physics possibilities. Obviously, real experiments like the LEP or Tevatron experiments have

Type of measurements	indicates	required for
isolated high p_t $e^\pm, \mu^\pm$	$W^{(*)}$, $Z^{(*)}$ decays	Higgs search top physics, "all" searches
isolated high p_t γ's	electro-magnetic process	Higgs search
τ and b-quark tagging	"rare" processes	special Higgs like searches
large missing p_t, E_t	ν like events W, Z decays	Higgs, Supersymmetry, exotic "exotica"
jets	quarks and gluons	QCD, understanding of backgrounds/efficiencies

Table 1: New physics and some required detector capabilities.

to be a compromise between these different requirements. Nevertheless, the existing experiments have proven to work according to or better than specified in their technical proposals. Especially astonishing results have been achieved with silicon-micro vertex detectors, which allow to identify b-flavoured jets with high efficiencies and excellent purity. In addition, quite accurate calorimetry allows to measure the missing transverse energy in complicated events. Such indirect identification of energetic neutrino like objects is now routinely used by essentially all large collider experiments.

The design objectives of the future LHC experiments, ATLAS [1] and CMS [2], follow the above desired detector capabilities with emphasis on high precision measurement of electrons, muons and photons and large angular coverage for jets. According to their technical proposals, both collaborations expect to identify isolated electrons and muons, with $p_t > 10$ GeV and small backgrounds up to a pseudorapidity ($\eta = -ln \tan(\Theta/2)$) of $|\eta| \leq 2.5$ and efficiencies of $\approx 90\%$. Furthermore, both experiments expect to achieve b-jet tagging with up to 50% efficiency and light flavour jet rejection factors of up to 100. These expectations are used for essentially all simulations of LHC measurements. For justifications of these efficiencies we refer to the various ATLAS and CMS technical design reports and internal technical notes [3].

The above performance figures are the essential assumptions for the simulation results described in the following sections. As the expected experimental performance might differ to some extend from the future real performance, the critical reader should include simplicity and robustness as criteria to judge today's LHC simulation "results".

2.2 The theoretical MSSM frame

Among the many possible extensions of the Standard Model the Minimal Supersymmetric Standard Model (MSSM) is usually considered to be the most serious theoretical frame. The attractive features of this approach are:

- it is quite close to the existing Standard Model;
- it explains the so called hierarchy problem of the Standard Model;
- it allows to calculate and
- it predicts many new particles and thus "Nobel Prizes" for the masses.

These attractive features of the MSSM are nicely described in a Physics Report from 1984 by H. P. Nilles [4]. We repeat here some of his arguments given in the introduction:

"Since its discovery some ten years ago, supersymmetry has fascinated many physicists. This has happened despite the absence of even the slightest phenomenological indication that it might be relevant for nature. .... Let us suppose that the standard model is valid up to a grand unification scale or even the Planck scale 10^{19} *GeV. The weak interaction scale of 100 GeV is very tiny compared to these two scales. If these scales were input parameters of the theory the (mass)*^{2} *of the scalar particles in the Higgs sector have to be chosen with an accuracy of* 10^{-34} *compared to the Planck Mass. Theories where such adjustments of incredible accuracy have to be made are sometimes called unnatural.... Supersymmetry might render the standard model natural... To render the standard model supersymmetric a price has to be paid. For every boson (fermion) in the standard model, a supersymmetric partner fermion (boson) has to be introduced and to construct phenomenological acceptable models an additional Higgs super-multiplet is needed."*

Figures 1 and 2 [5] compare the consistency of the various electroweak measurements with the SM and the MSSM.

The largest difference, shown in Figure 2, appears in the relation between the $W^{\pm}$ mass and the top mass. Unfortunately today's data, $M_W = 80.39 \pm 0.06$ GeV and $M_{top} = 174 \pm 5$ GeV, favour an area which is perfectly consistent with both models. One might thus conclude that the expected small improvements of the electroweak measurements will not allow to distinguish between the SM and the MSSM.

As mentioned above, SUSY predicts a doubling of the fundamental fermions and bosons and requires at least 5 Higgs bosons[1].

[1]For discussions about LHC signatures for the MSSM Higgs particles and the sensitivity of the LHC experiments we refer to [6].

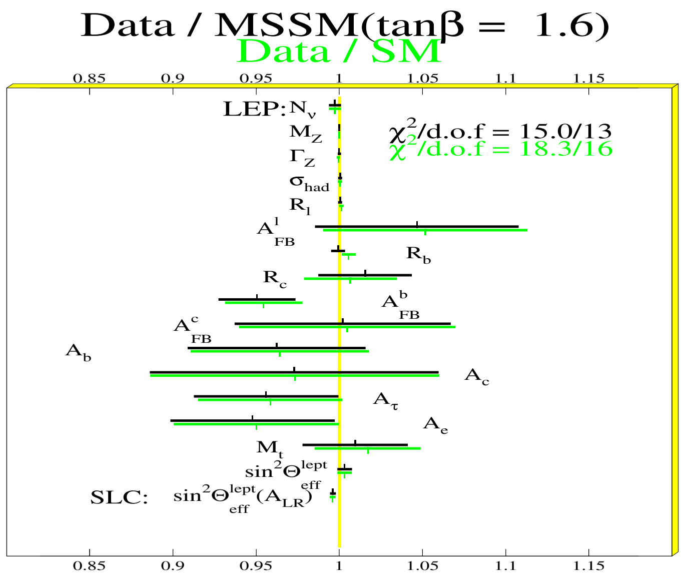

Figure 1: Comparison of Z^0 precision measurements with the Standard Model and the MSSM with $\tan\beta = 1.6$ and very heavy SUSY particles [5].

Beside the lightest, possibly invisible SUSY particle, one knows from the absence of such new particles that their masses have to be heavier than ≈ 100 GeV. Starting from the MSSM, the so called minimal model, theoretical counting results in more than hundred free parameters. So many free parameters do not offer a good guidance for experimentalists, who prefer to use additional assumptions to constrain the parameter space. The simplest approach is the so called mSUGRA (minimal super-gravity) model with only five parameters ($m_0, m_{1/2}, \tan\beta, A^0$ and μ).

This SUSY model is used for most sensitivity estimates of future colliders and the obtained results for the LHC will be discussed below. The main reason for this model choice is the existence of very advanced Monte Carlo programs [7], [8] and [9], required for detailed simulation studies. This pragmatic choice of one approach to investigate the potential of a future experiment appears to be more than sufficient, as essentially all required detector features can be tested.

However, this approach should not be considered as a too strong guidance principle if one wants to discover SUPERSYMMETRY with real experiments. Two recent examples show that the absence of any MSUGRA indications enlarges the acceptance for more radical SUSY models.

The first example is the famous lonely CDF event, which has large missing transverse energy, two high p_t isolated photons and 2 isolated high p_t electron

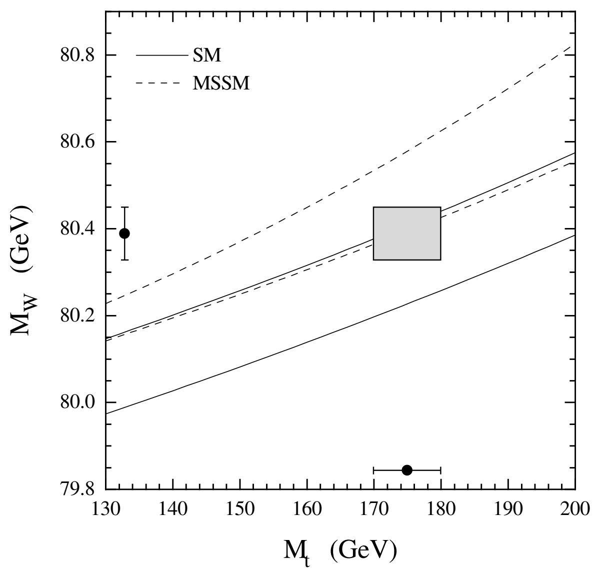

Figure 2: Expected relation between M_W and M_{top} in the Standard Model and the MSSM; the bounds are from the non observation of Higgs or SUSY particles at LEPII [5]. The 1998 experimental area, with $M_W = 80.39 \pm 0.06$ GeV and $M_{top} = 174 \pm 5$ GeV is also indicated.

candidates [10]. The presence of high p_t photons does not match MSUGRA expectations but might fit into so called gauge mediated symmetry breaking models, GMSB [11]. This event has certainly motivated many additional, so far negative searches.

The second example is related to the 1997 HERA excitement. The observed excess of a handful of events was consistent with a lepton-quark resonance with a mass of roughly 200 GeV and signal predictions from R-parity violation SUSY models [12]. While this excess was not confirmed with larger statistics, R-parity violation models became certainly much more attractive.

These modified searches indicate the discovery potential of searches which are not guided by today's fashion. Having reminded the reader of potential shortcomings between a SUSY Nature and the studied mSUGRA model, we now turn to future LHC (and Tevatron) search strategies for SUSY particles within mSUGRA.

2.2.1 mSUGRA predictions

Essentially all signatures related to the MSSM and in particular to mSUGRA searches are based on the consequences of R-parity conservation. R-parity is a multiplicative quantum number like ordinary parity. The R-parity of the known

SM particles is 1 and -1 for the SUSY partners. As a consequence, SUSY particles have to be produced in pairs and unstable SUSY particles decay, either directly or via some cascades, to SM particles and the lightest supersymmetric particle, the LSP. The LSP, using cosmological arguments, is required to be neutral. As massive LSP's should have been abundantly produced after the big bang, the LSP is currently considered to be "the cold dark matter" candidate. This LSP, usually assumed to be the lightest neutralino $\tilde{\chi}_1^0$, has neutrino like interaction cross sections and can not be observed in collider experiments. Events with a large amount of missing energy and momentum are thus the prime SUSY signature in collider experiments.

A possible example is the pair production of sleptons with their subsequent decays, $pp \to \tilde{\ell}^+\tilde{\ell}^-$ and $\tilde{\ell} \to \ell\tilde{\chi}_1^0$ which would appear as events with a pair of isolated electrons or muons with high p_t and large missing transverse energy.

Within the mSUGRA model, the masses of SUSY particles are strongly related to the so called universal fermion and scalar masses $m_{1/2}$ and m_0. The masses of the spin 1/2 SUSY particles are directly related to $m_{1/2}$. One expects approximately the following mass hierarchy:

- $\tilde{\chi}_1^0 \approx 1/2 m_{1/2}$
- $\tilde{\chi}_2^0 \approx \tilde{\chi}_1^\pm \approx m_{1/2}$
- $\tilde{g}$ (the gluino) $\approx 3m_{1/2}$

The masses of the spin 0 SUSY particles are related to m_0 and $m_{1/2}$ and allow for some mass splitting between the "left" and "right" handed scalar partners of the degenerated left and right handed fermions. One finds the following simplified mass relations:

- $m(\tilde{q})$(u,d,s,c and b) $\approx \sqrt{m_0^2 + 6m_{1/2}^2}$
- $m(\tilde{\nu}) \approx m(\tilde{\ell^\pm})$ (left) $\approx \sqrt{m_0^2 + 0.52m_{1/2}^2}$
- $m(\tilde{\ell^\pm})$ (right) $\approx \sqrt{m_0^2 + 0.15m_{1/2}^2}$

The masses of the left and right handed stop quarks $(\tilde{t}_{\ell,r})$ might show, depending on other MSUGRA parameters, a large splitting. As a result, the right handed stop quark might even be the lightest of all squarks.

Following the above mass relations and using the known SUSY couplings, possible SUSY decays and the related signatures can be defined. Already with the simplest mSUGRA frame one finds a variety of decay chains.

For example the $\tilde{\chi}_2^0$ could decay to $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 + X$ with X being:

- $X = \gamma^*, Z^* \to \ell^+\ell^-$
- $X = h^0 \to b\bar{b}$

- $X = Z \to f\bar{f}$

Other possible $\tilde{\chi}_2^0$ decay chains are $\tilde{\chi}_2^0 \to \tilde{\chi}_1^{\pm(*)} + \ell^{\pm}\nu$ and $\tilde{\chi}_1^{\pm(*)} \to \tilde{\chi}_1^0\ell^{\pm}\nu$ or $\tilde{\chi}_2^0 \to \tilde{\ell}^{\pm}\ell^{\mp}$.

Allowing for higher and higher masses, even more decay channels might open up. It is thus not possible to define all search strategies a priori. Furthermore, possible unconstrained mixing angles between neutralinos, lead to model dependent decay chains and search strategies for squarks and gluinos as will be discussed below.

Today's negative SUSY searches [13] provide the following approximate lower mass limits:

- $m(\tilde{\chi}_1^{\pm}) > 90$ GeV (LEPII)
- $m(\tilde{g})$(gluino) $>$ 160-220 GeV depending slightly on the assumed relation between squark and gluino masses (TEVATRON).

One might argue that the negative results of the chargino search at LEPII imply that future gluino searches at the upgraded TEVATRON should not start for masses below $\approx$ 270 GeV. However, the continuing TEVATRON searches indicate that many searchers do not follow too strictly specific mass relations of the mSUGRA model. Current experimental results are usually shown as a function of the searched for SUSY masses.

In contrast, sensitivity estimates for future collider experiments are usually given in the m_0–$m_{1/2}$ parameter space. Despite the model dependence, such estimates allow to compare the possible significance of the different analysed signatures. Having various proposed methods, the resulting sensitivity figures appear to be quite confusing and require some time for appreciation. A typical example is shown in Figure 3a-d [14], where the different curves indicate the LHC sensitivity for different signatures and different SUSY particles. It is usually assumed that the maximum information about SUSY can be extracted in regions covered by many signatures. The meaning of the various curves and their potential significance should become clear from the following sections.

2.3 Searches, Significance and Systematics

Peaks in the invariant mass spectrum of assumed decay products are an unambiguous signature for new unknown particles. Narrow mass peaks can in principle be discovered without the help of any theoretical Monte Carlo programs as backgrounds can reliably be estimated from sidebands. Furthermore, quite accurate significance estimates can be made even if very small signal (S) to background (B) ratios are expected and if not all background sources are known. The reason becomes quite obvious from the following example with an expected Signal of 1000 events above a background of 10000. Such a deviation from known

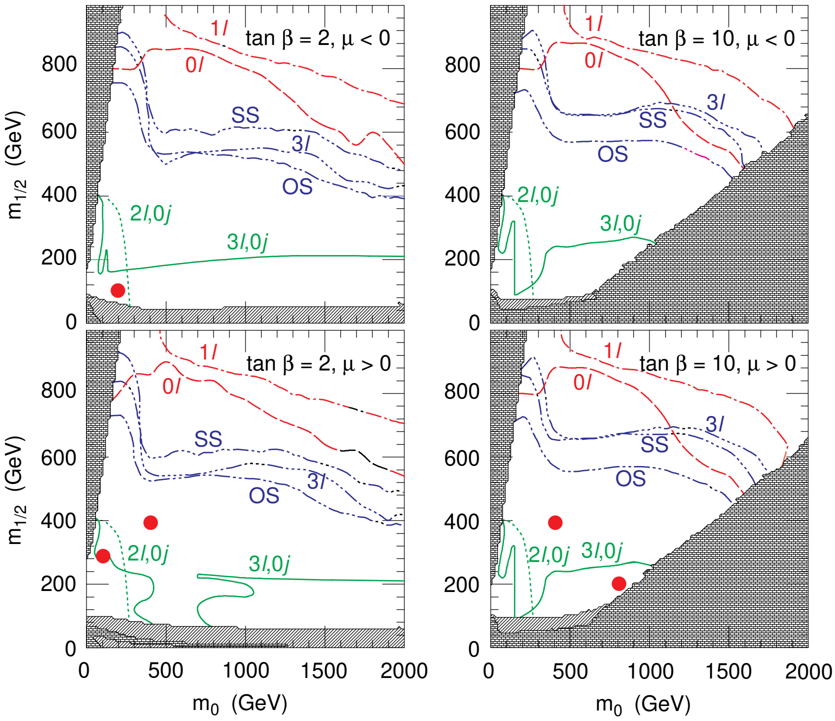

Figure 3: Expected mSUGRA sensitivity of various signatures in the $m_0 - m_{1/2}$ plane at the LHC, assuming an integrated luminosity of 10 fb^{-1} [14]. The different curves indicate the expected sensitivity for SUSY events with n leptons (ℓ) and for events with lepton pairs with same charge (SS) and opposite charge (OS).

sources could be claimed with a significance of about 10 standard deviations ($N(\sigma) = S/\sqrt{B} = 1000/\sqrt{10000}$). Assuming a relatively smooth flat background over many non signal bins, background extrapolations to the signal region can reach systematic accuracies of less than a percent. Under such ideal conditions, even large background uncertainties are acceptable as the background could go up by a factor of about 4, still giving a 5 standard deviation signal! Nevertheless at least signal Monte Carlos are needed to determine cross sections and perhaps other quantities like spin and parity once a mass peak signal is observed. Furthermore, even searches for mass peaks require usually some selection criteria to isolate possible signals from obvious backgrounds. Searchers should however remember that advantages of optimised efficiencies, obtained with complicated selection methods, are easily destroyed by uncontrolled systematic errors. Other disadvantages of too much optimisation are model dependent phase space restrictions and the introduction of statistical fluctuations which increase in proportion with the number of cuts and mass bins.

In addition, it is not always an advantage to reduce signal and backgrounds to relatively small numbers when the significance has to be calculated from Poisson statistics! For example a simple $\sqrt{B}$ estimate for 9 expected background events requires an observation of at least 24 events, e.g. an excess of 15 events above 9 background events, to claim a 5 σ excess above background. However, for small event numbers one finds that the $\sigma = \sqrt{B}$ approximation is not good enough a 5 σ excess requirement, equivalent to a background fluctuation probability of less than 6×10^{-7}. Using Poisson statistics, the required 5 σ excess corresponds to an observation of more than 27 events! Despite this reduced significance (roughly 1σ), systematic errors start to become important. For small background numbers the sideband method is limited by statistics and direct and clean background estimates from data might increase/decrease backgrounds and might be larger than Monte Carlo background estimates. The method to determine backgrounds, either from data or from Monte Carlo might thus hide or enhance a real signal and artificial good or bad limits can be obtained[2]

The possibility to observe fluctuations due to many mass bins appears nicely in a CMS simulation [15] of the two photon mass distribution for a SM Higgs with a mass of 130 GeV and backgrounds. Figure 4 shows a clear narrow peak is

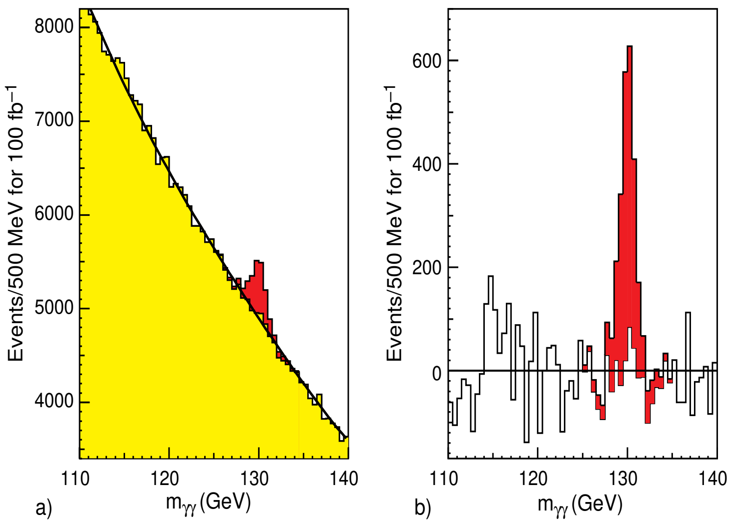

Figure 4: CMS search simulation [15] for $H \to \gamma\gamma$ before and after background subtraction.

[2]The critical reader should investigate how often search limits appear to be "lucky", e.g. the number of observed data events is smaller than the number of expected background events, and how often they are "unlucky".

seen at 130 GeV. The observed signal, assuming a simple straight line to estimate the background, corresponds to about 10 standard deviations. A more careful analysis of the mass distribution shows why at least five standard deviations are required to establish the existence of a new particle. Ignoring for example the simulated Higgs signal at 130 GeV one might try to look for an excess of events at an arbitrary mass. The largest excess of events appears at a mass of about 115 GeV. Taking the background from the sidebands one finds a statistical fluctuation with a significance of about three standard deviations. Thus, many possible mass bins combined with various event selection criteria are a remaining danger for mass peak hunters.

Despite the simplicity to discover new physics with mass peaks, most searches for new physics phenomena require an excess of events in special kinematic regions or tails of distributions. Some difficulties of such searches are indicated in Figure 5.

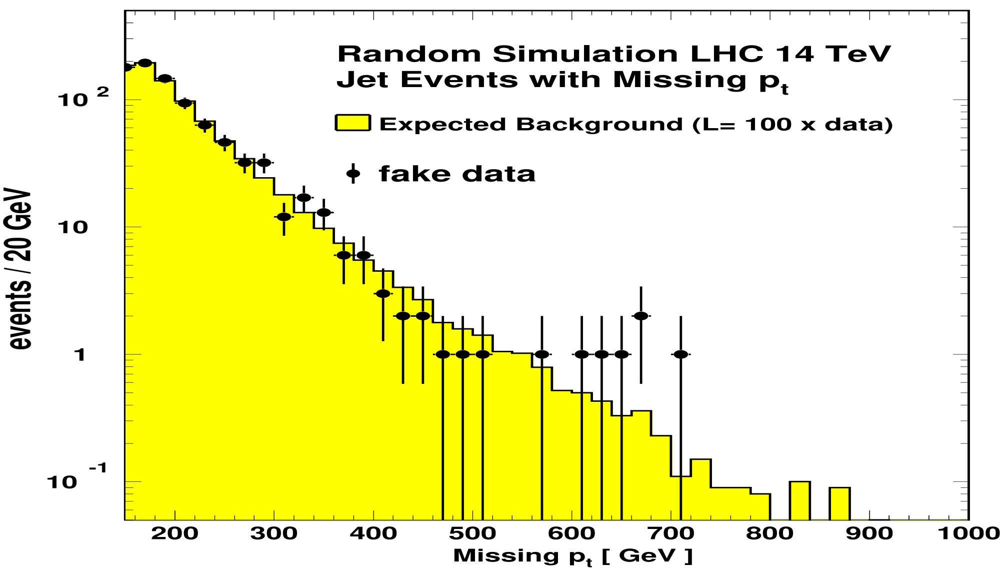

Figure 5: Simulation of a background fluctuation for events with missing transverse energy.

The figure shows a random simulation of missing transverse energy events from $pp \to ZX \to \nu\bar{\nu}X$ and small statistics which is compared to a background simulation with large statistics of the same process. Depending on the new physics signature, the small excess of tail events might coincide with a signal, expected for a certain range of missing transverse momentum p_t. For a missing p_t between 600-720 GeV one could quote an excess of almost 3 sigma, e.g. 6 events are seen while a background of only 2 events are predicted. “Good arguments” might increase the significance for new physics further. For example one might argue that the

Monte Carlo overestimates the backgrounds, as the sideband region between 400–500 GeV shows about 50% more events than found with the "pseudo data". Some additional features of the 6 events might further be used to increase the significance. Alternatively, the possibility of new physics can easily be excluded from the same distribution, for example one could argue that the number of 7.63 predicted events with missing p_t above 500 GeV is in perfect agreement with the observed 8 events. The above example justifies the statement **"never search in tails"**. Unfortunately, most new physics scenarios, like SUPERSYMMETRY, would appear as rare events and in tails of distributions.

Thus, ingenuity is required to separate new physics from tails of known processes. Such searches require not only to have enough statistical significance but **a method to determine backgrounds**. The difficulty to establish a signal becomes clear from the following two examples. **Case a** is for a comfortable Signal to Background ratio of 1:1 while **case b** is for a ratio of 1:10. The required minimal statistics is easy to estimate. A 5 sigma excess needs a statistics of roughly 25 Signal events on top of a background of 25±5 for **case a** while **case b** needs about 250 signal events above a background of 2500±50. The statistical excess however is not enough as the expected background has some systematic errors like uncertainties from the efficiency, the luminosity and the theoretical background model. Assuming that all these uncertainties are known with an accuracy of ±5%, the significance of **case a** is essentially unchanged while the significance of **case b** is reduced to about 2 standard deviations.

It is worth noting that some studies claim to be **"conservative"** by multiplying backgrounds by arbitrary factors (method 1) or by using the error estimate from $\sqrt{S+B}$ (method 2).

Using **case b** and method 1 one sees no dramatic change of the estimated sensitivity. One finds that only the minimal luminosity requirement has to be increased. At the same time, the signal to background ratio became 1:20 and a ±5% systematic error would result in almost meaningless results!

The estimated sensitivity, using method 2, does not change for a very bad signal to background ratio. However, one finds that method 2 reduces a clear signal, like 10 observed events with one expected background event, to a modest 3 standard deviation signal.

We thus disagree with the claim that the above methods are conservative and reliable. In contrast, a correct approach to a possible significance figure of an "average" future experiment should give the statistical sensitivity for new physics, estimated with $\sigma \approx \sqrt{B}$, and has to describe how backgrounds can be estimated and how well they need to be known. Most sensitivity estimates do not provide answers to the latter requirements. Attention should thus be paid to the estimated signal to background ratio, which allows to estimate the required systematic accuracies.

3 Anatomy of a Signal, Searching for Sleptons at the LHC

Hadron colliders are certainly not a good source of sleptons. Nevertheless, we start our analysis of the various SUSY search strategies with an anatomy of the simplest possible SUSY signal. Our discussion starts with the cross section and the expected decay modes. This is followed by a qualitative description of a possible discovery signature at the LHC which is then compared to a detailed simulation of a search for sleptons at the LHC.

The pair production of sleptons at the LHC can easily be related to the production of Drell-Yan dilepton pairs with high mass. The expected total slepton pair production cross section as a function of the slepton mass is shown in Figure 6 [16].

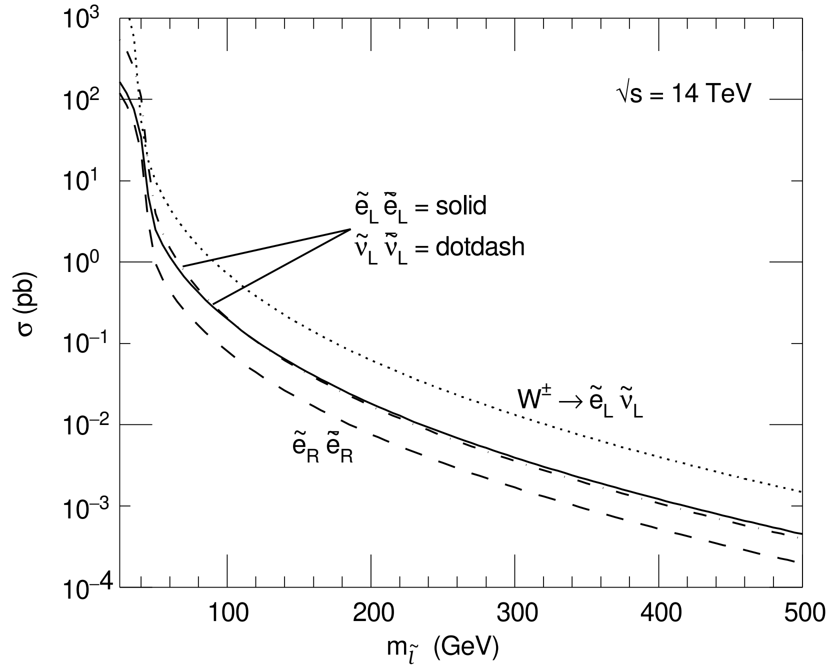

Figure 6: Slepton Mass dependence of the total pair production cross section at the LHC for various slepton combinations [16].

Figure 7 shows the expected mass (with m>200 GeV) distribution of the virtual γ^*, Z^* system leading to a lepton or slepton pair. The cross section for scalar charged sleptons has a simple relation to the production of the corresponding right and left handed lepton pair production $\sigma(\tilde{\ell}\tilde{\ell}) = 1/4\beta^3\sigma(\ell\ell)$. For our example the

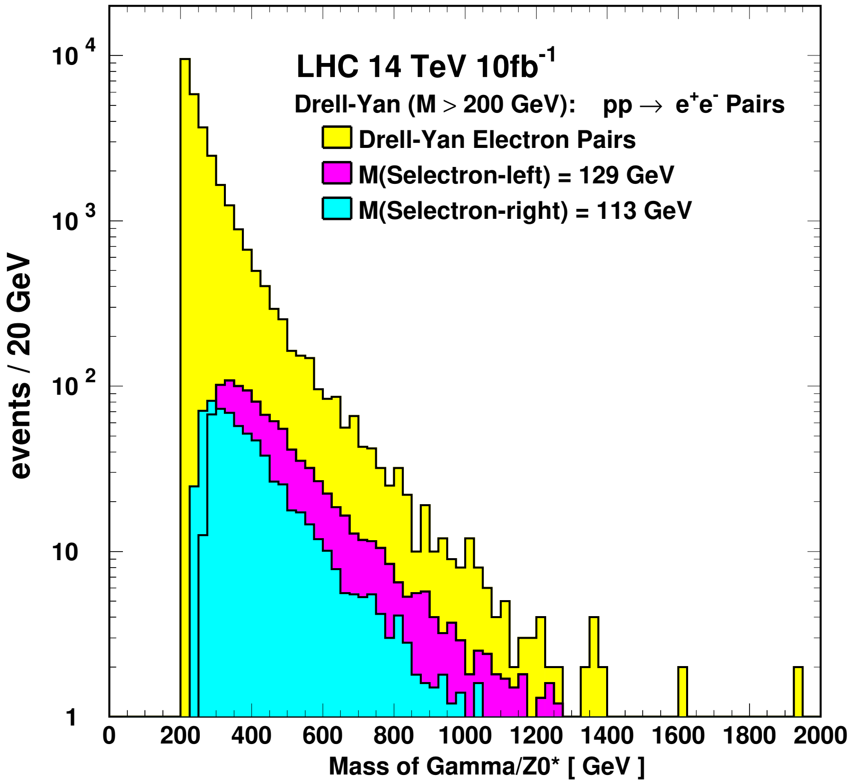

Figure 7: Mass distribution of Drell-Yan electron pairs with a mass above 200 GeV and for left or right handed selectron pairs at the LHC with selectron masses of 129 GeV and 113 GeV respectively as obtained with PYTHIA [8] and SPYTHIA [9].

masses of the left handed and right handed slepton were fixed to 129 GeV and 113 GeV respectively. The expected mass spectra show the β^3 cross section suppression close to threshold. The larger rate for Drell-Yan pairs produced from the left handed virtual γ^*, Z^* system results, despite the larger mass, into a bigger cross section for left handed sleptons. This simple relation between slepton mass and cross section allows precise cross section predictions for slepton pairs, once the corresponding mass spectrum of Drell-Yan lepton pairs has been measured.

As a next step one has to consider the possible slepton decay modes. While the right handed slepton can decay only to the lightest neutralino and the corresponding lepton $\tilde{\ell}^\pm \to \tilde{\chi}^0_1\ell^\pm$, several somehow model dependent decay modes, are possible for left handed sleptons:

- $\tilde{\ell}^{\pm} \to \tilde{\chi}_1^0 \ell^{\pm}$ or $\tilde{\ell}^{\pm} \to \tilde{\chi}_2^0 \ell^{\pm}$ or $\tilde{\ell}^{\pm} \to \tilde{\chi}_1^{\pm} \nu$
- $\tilde{\nu} \to \tilde{\chi}_1^0 \nu$ or $\tilde{\nu} \to \tilde{\chi}_1^{\pm} \ell^{\mp}$

The best signature for slepton pair production appears to be the two body decay $\tilde{\ell}^{\pm} \to \tilde{\chi}_1^0 \ell^{\pm}$. The resulting signature are events with a pair of two isolated same flavour leptons with opposite charge and some missing transverse momentum. To distinguish such signal events from various possible SM backgrounds a long list of kinematic selection criteria have to be applied. To identify good selection criteria at the LHC it is useful to start with simplified kinematics in the center-of-mass frame. The observable leptons, originating from the decays of massive sleptons, should show: (1) a characteristic momentum spectrum; (2) should not balance their momenta and (3) should not be back to back. Furthermore, the measurable mass of the event should be much smaller than the original center-of-mass energy and the missing mass should be much larger than zero.

A possible selection requires thus the possibility to measure isolated leptons with good accuracy and to determine indirectly the missing energy and momentum from all detectable particles. An accurate missing energy determination requires an almost 4π acceptance for all visible particles. Unfortunately, a realistic experiment has to live with several detection gaps especially the ones around the beam pipe. Consequently, missing momentum measurements along the beam direction are of limited use. In addition, the event kinematics at a Hadron Collider are unfortunately very different from the center-of-mass frame. As a result, signal and background events have a large and unknown momentum component along the beam direction. However, variables which exploit the missing transverse energy and momentum remain very useful.

Furthermore, in contrast to an e^+e^- collider with a fixed dilepton mass, hadron collider searches must consider the effects that slepton pairs are not produced at a fixed $\sqrt{s}$ and show a wide spread of the longitudinal momentum. As a result, good selection criteria exploit the differences between signal and background in the plane transverse to the beam. Such variables are (1) the transverse momenta of each lepton, (2) the opening angle between the two leptons in the plane transverse to the beam and (3) the missing transverse momentum. The specific choice of cuts depends strongly on the studied mass region and the relevant backgrounds.

The largest "irreducible" background for slepton pair production are events with leptonic $W^{\pm}$ decays from W-pair production $pp \to WWX$ with ($\sigma \times BR(WW \to e^+\nu e^-\bar{\nu})$ of about 0.8 pb. Another potentially very large background comes from $t\bar{t}$ production with a $\sigma \times BR(t\bar{t} \to WWb\bar{b} \to e^+\nu e^-\bar{\nu}X)$ with a cross section of about 7 pb. This background can be strongly reduced by applying a jet veto. Other potential backgrounds are miss-measured Drell-Yan lepton pairs and electrons and muons from leptonic τ decays produced in the reaction

$pp \to \tau\tau$. Additional backgrounds, usually assumed to be negligible, might come from events of the type $W^{\pm}X$ and Z^0X with leptonic decays and isolated high p_t hadrons which are misidentified as electrons or muons. In addition, other unknown sources of new physics, like $pp \to \tilde{\chi}^+\tilde{\chi}^-$ might also result in events with two isolated leptons and missing transverse momentum.

The qualitative ideas discussed above, can now be compared with a quantitative simulation of a slepton search with the CMS experiment [17].

The analysis selects first events which contain a pair of opposite charged electrons or muons and no additional jets. It is assumed that isolated electrons or muons with a minimum transverse momentum of 20 GeV and $|\eta| < 2.5$ can be identified with high efficiency ($\epsilon > 90$ %) and small backgrounds. One assumes also that jets with a transverse energy above 30 GeV and $|\eta| < 4.5$ can be identified and vetoed. In addition, events from $pp \to Z \to \ell^+\ell^-$ are rejected by demanding that the invariant mass of the lepton pair should be inconsistent with a Z^0. Additional mass dependent selection criteria, specified in table 2, are required to improve the potential signal significance.

$m(\tilde{\ell}^{\pm})$	p_t^{lepton}	$E_t(miss)$	$\Delta\phi_{\ell^+\ell^-}$	S (100 fb^{-1})	B (100 fb^{-1})
100 GeV	$>$ 20 GeV	$>$ 50 GeV	$> 130^o$	$\approx$ 3200	$\approx$ 10000
200 GeV	$>$ 50 GeV	$>$ 100 GeV	$< 130^o$	$\approx$ 230	$\approx$ 170
300 GeV	$>$ 60 GeV	$>$ 150 GeV	$< 130^o$	$\approx$ 67	$\approx$ 45
400 GeV	$>$ 60 GeV	$>$ 150 GeV	$< 140^o$	$\approx$ 24	$\approx$ 53

Table 2: CMS simulation of the charged slepton search at LHC [17]. The proposed selection criteria and signal (S) and background (B) rates are given for a luminosity of 100 fb^{-1} and a few slepton masses.

The double leptonic decays from W pairs, originating from W^+W^- and $t\bar{t}$, appear to be the dominant backgrounds. For a slepton mass of about 100 GeV one finds a statistical significant signal of $\approx$ 300 events above a background of about 1000 events and a luminosity of 10 fb^{-1}. The expected signal and background distributions before the $\Delta\phi$ cut are shown in Figure 8a and b.

The analysis shows that sleptons with masses between 200-300 GeV can be selected with signal to background ratios of about 1:1. The low signal cross section requires however a large luminosity of at least 30 fb^{-1}. For larger masses the slepton cross section becomes very small and seems to limit the mass reach to about 400 GeV with expected signal rates of 24 events and a total expected background of about 50 events for a luminosity of about 100 fb^{-1}. In summary, pair production of charged sleptons at the LHC appears to be detectable from an excess of events above dominant backgrounds from leptonic decays of W^+W^- and $t\bar{t}$ events. The expected mass reach starts from about 100 GeV, roughly the final LEPII reach, and is limited to masses of about 400 GeV. Particular problems

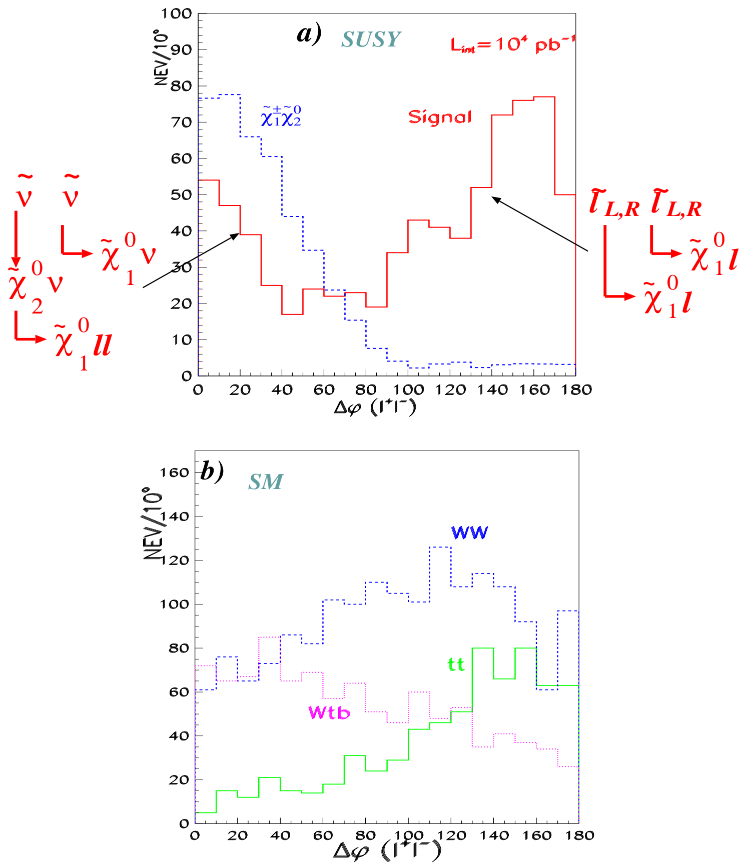

Figure 8: Relative azimuthal angle ϕ between the two leptons for (a) sleptons with masses close to 100 GeV and other SUSY signals and (b) for the main SM backgrounds [17]. The proposed cut for this slepton mass region is $\phi > 130^o$.

are the signal to background ratio for masses well below 200 GeV and the small signal rate for masses above 300 GeV.

Other slepton signals, like the one from the reaction $pp \to W^* \to \tilde{\ell}\tilde{\nu}$ have been studied and were found to be hopeless [16]. The investigated signature of a single high p_t lepton with large missing E_t was found to be at least two orders of magnitude smaller than the event rate from single W's as shown in Figure 9. The authors concluded further that a possible trilepton signal, from $\tilde{\ell} \to \ell\tilde{\chi}_1^0$ and cascade decays of the sneutrino $\tilde{\nu} \to \tilde{\chi}_2^0\nu \to \ell\ell\tilde{\chi}_1^0$ is much smaller than the signal from the simultaneous produced trilepton events of the type $\tilde{\chi}_2^0\tilde{\chi}_1^{\pm}$ described in the next section.

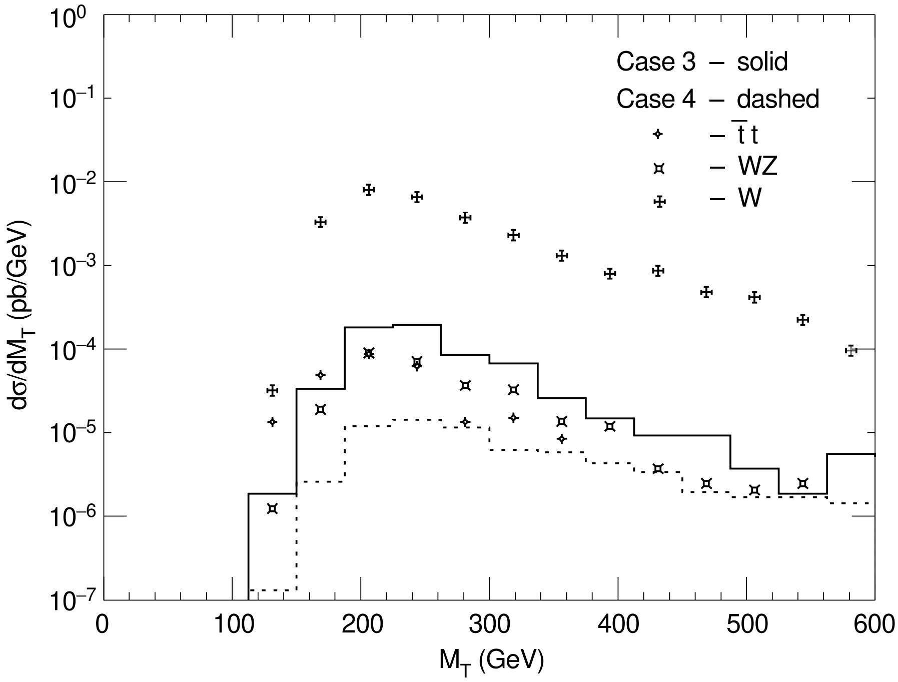

Figure 9: Reconstructed transverse mass of single high p_t lepton events for signal events of the type $pp \to W^* \to \tilde{\ell}^{\pm}\tilde{\nu} \to \ell^{\pm}\nu\tilde{\chi}_1^0\tilde{\chi}_1^0$ and various backgrounds. The studied slepton masses were 100 GeV (case 3) and 200 GeV (case 4) [16].

4 The Trilepton event signature, a signal for Chargino-Neutralino Pair Production

In analogy to the reaction $q\bar{q} \rightarrow Z^0 W^{\pm}$, one might expect the production of $q\bar{q} \rightarrow \tilde{\chi}_2^0 \tilde{\chi}_1^{\pm}$ events. Such events might be detected from an analysis of events with three isolated high p_t leptons and large missing transverse energy. The potential of this trilepton signature at hadron colliders, like the LHC, has been described in several phenomenological studies [18]. It was found that trilepton events with jets should be rejected to distinguish signal events from SM and SUSY backgrounds.

After the removal of jet events the only remaining relevant background comes from leptonic decays of WZ events. Potential backgrounds from dilepton events like $W^+W^- \rightarrow \ell^+\nu\ell^-\bar{\nu}$ and hadrons misidentified as electrons or muons are usually assumed to be negligible. Depending on the analysed SUSY mass range, the background from leptonic decays of WZ events, in contrast to a potential signal, will show a Z^0 mass peak in the dilepton spectrum.

This signature is also used at the Tevatron. Estimates for RUN II, with a few fb^{-1}, hope for a $\tilde{\chi}_2^0 \tilde{\chi}_1^{\pm}$ mass sensitivity of up to 130 GeV, which might be improved further to about 210 GeV with RUN III (20-30 fb^{-1}) [19]. These estimates assume a background cross section of less than 0.5 fb. This number can be compared to recent searches for trilepton events, optimised for masses of $\approx$ 80 GeV, from CDF [20]. Table 3 shows the current CDF background estimates for various applied cuts resulting in a final background cross section of about 10 fb.

Selection criteria	observed Events	SM Background Expectation	MSSM MC $M(\tilde{\chi}_1^{\pm}, M(\tilde{\chi}_2^0$ =70 GeV
Dilepton data	3270488		
Trilepton data	59		
Lepton Isolation	23		
$\Delta R_{\ell\ell} > 0.4$	9		
$\Delta\phi_{\ell\ell} < 170^o$	8	9.6±1.5	6.2 ±0.6
$J/\Psi, \Upsilon, Z$ removal	6	6.6±1.1	5.5 ±0.5
missing $E_t(miss) > 15$	0	1.0±0.2	4.5 ±0.4

Table 3: Results from a recent trilepton analysis from CDF with a dataset of $\approx$ 100 pb^{-1} [20]. The number of observed events appears to be in good agreement with various SM background sources, which are unfortunately given only for the last three cuts.

A recent CMS simulation [21] of the trilepton signal at the LHC proceeds as follows:

- Events should contain three isolated leptons, all with $p_t > 15$ GeV and $|\eta| < 2.5$ and no jets.
- The missing transverse energy should exceed 15 GeV.
- The possible same flavour dilepton mass combinations should be inconsistent with a Z^0 decay.

Depending on the studied mass range, additional or harder selection criteria are applied. Figure 10 shows the expected missing transverse energy distribution for trilepton signal events, with different choices of m_0 and $m_{1/2}$, and for background events. Table 4 gives a few numbers for signal and backgrounds from the CMS study and different SUSY masses.

$M_{1/2} \approx M(\tilde{\chi}_1^{\pm})$	$\sigma\times$ BR (trileptons)	Signal ($100\ \mathrm{fb}^{-1}$)	SM Background ($100\ \mathrm{fb}^{-1}$)
100	0.8 -1.3 pb	4000–8000	900
150	0.04-0.08 pb	300-600	1000
200	0.01-0.02 pb	80-120	700
300-400	0.01-0.02 pb	50	100

Table 4: Expected signal and background numbers from a CMS trilepton study with different choices of m_0 and $m_{1/2}$ with $\tan\beta = 2$ and negative μ [21].

In all cases one finds signal efficiencies of $\approx 5\%$. The best results are obtained for masses close to 100 GeV with expected signal rates of ≈ 40 above a background of 10 events per 1 fb^{-1} of luminosity. The signal rate drops quickly for higher masses and much higher luminosities are required to establish potential signals up to masses of at most 300-400 GeV. Furthermore, for some $m_0, m_{1/2}$ mass regions, the estimated leptonic branching ratios are very small and result in signal to background ratios smaller than 0.2. We conclude that the LHC experiments can measure excellent trileptons signals in mass and parameter regions where the discovery has most probably been made at the upgraded Tevatron RUNII and RUN III by CDF/D0. Such high statistics signals will allow some detailed SUSY studies as described in section 7.5. For chargino/neutralino masses above ≈ 200 GeV significant signals require at least 30 fb^{-1} and a very good understanding of possible backgrounds. However, as will become clear from the next section, cascade decays of squarks and gluinos should provide a much better sensitivity for charginos and neutralinos with higher masses.

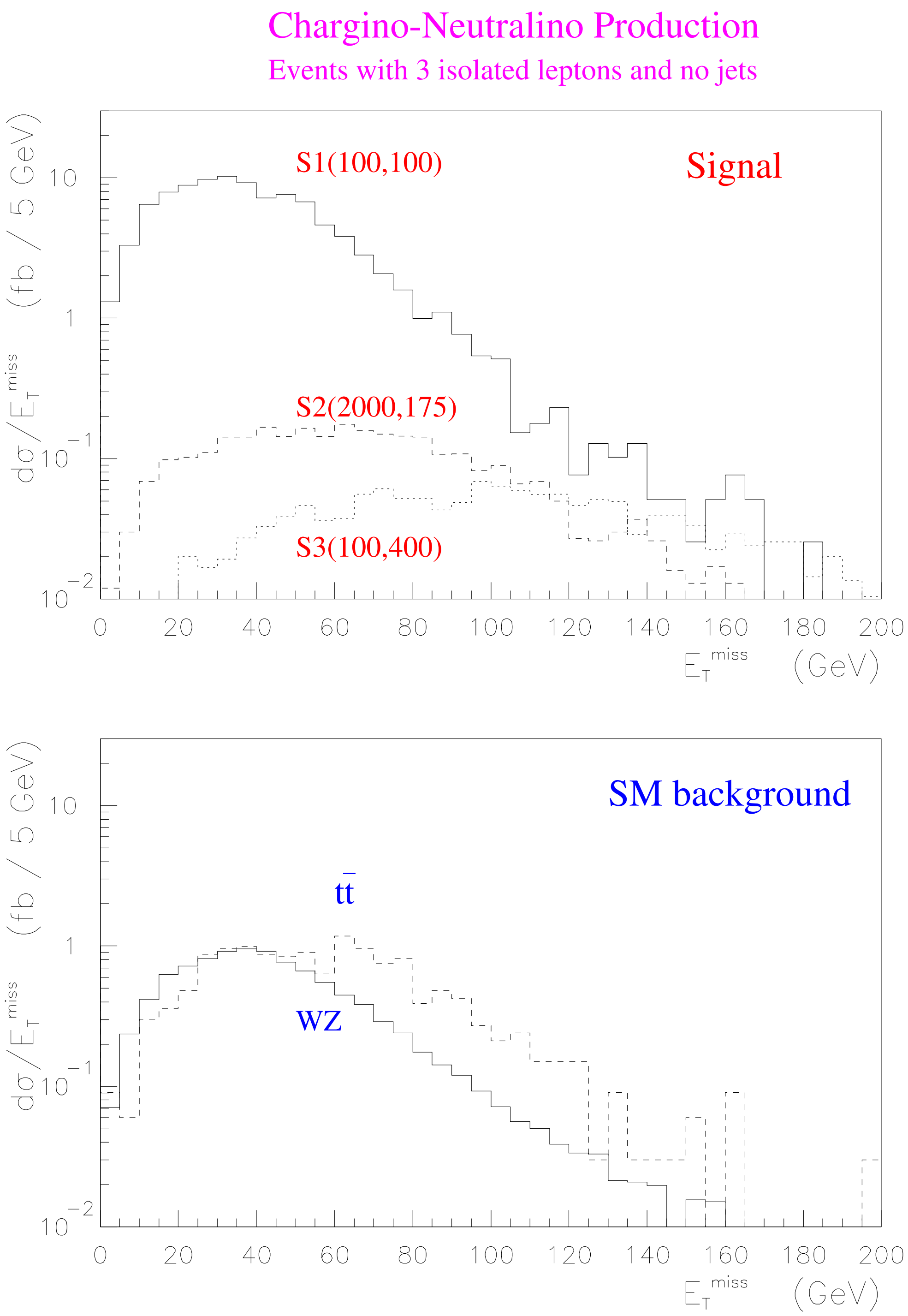

Figure 10: Missing transverse energy distribution for trilepton events without jets from $pp \to \tilde{\chi}_2^0\tilde{\chi}_1^\pm$ signal events and background [21]. The numbers in brackets give the used m_0 and $m_{1/2}$ values.

5 Squark and Gluino Searches, the Hadron Collider show case

The discussion in the previous sections covered the potential to study non-hadronic interacting SUSY particles with relatively small cross section. We now turn the discussion to the search for squarks and gluinos with large couplings to quarks and gluons. The cross section for strongly interacting particles at hadron colliders like the LHC are quite large. For example the pair production cross section of squarks and gluinos with a mass of ≈ 1 TeV has been estimated to be as large as 1 pb resulting in 10^4 produced SUSY events for one "low" luminosity LHC year. Such high rates, combined with the possibility to observe many different decay modes, is often considered as a *raison d'être* for the LHC.

Depending on the SUSY model parameters, a large variety of massive squark and gluino decay channels and signatures might exist. A complete search analysis for squarks and gluons at the LHC should consider the various signatures resulting from the following decay channels.

- $\tilde{g} \to \tilde{q}q$ and perhaps $\tilde{g} \to \tilde{t}t$
- $\tilde{q} \to \tilde{\chi}_1^0 q$ or $\tilde{q} \to \tilde{\chi}_2^0 q$ or $\tilde{q} \to \tilde{\chi}_1^\pm q$
- $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 \ell^+\ell^-$ or $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 Z^0$ or $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 h^0$
- $\tilde{\chi}_1^\pm \to \tilde{\chi}_1^0 \ell^\pm \nu$ or $\tilde{\chi}_1^\pm \to \tilde{\chi}_1^0 W$.

The various decay channels can be separated into at least three distinct event signatures.

- Multi-jets plus missing transverse energy. These events should be spherical in the plane transverse to the beam.
- Multi-jets plus missing transverse energy plus n(=1,2,3,4) isolated high p_t leptons. These leptons originate from cascade decays of charginos and neutralinos.
- Multi-jets plus missing transverse energy plus same charge lepton pairs. Such events can be produced in events of the type $\tilde{g}\tilde{g} \to \tilde{u}\bar{u}\tilde{d}\bar{d}$ with subsequent decays of the squarks to $\tilde{u} \to \tilde{\chi}^+ d$ and $\tilde{d} \to \tilde{\chi}^+ u$ with subsequent leptonic chargino decays $\tilde{\chi}^+ \to \tilde{\chi}_1^0 \ell^+ \nu$.

It is easy to imagine that the observation and detailed analysis of the different types of SUSY events might allow the discovery of many SUSY particles and should help to measure some of the many MSSM parameters.

The above signatures have already been investigated with the data from the Tevatron RUN I. The negative searches gave mass limits for squarks and gluinos as high as $\approx$ 200 GeV. The estimated 5-sigma sensitivity for RUN II and RUN III reaches values as high as 350-400 GeV. More details about the considered signal and backgrounds can be found from the TeV2000 studies [19] and the ongoing Tevatron workshop.

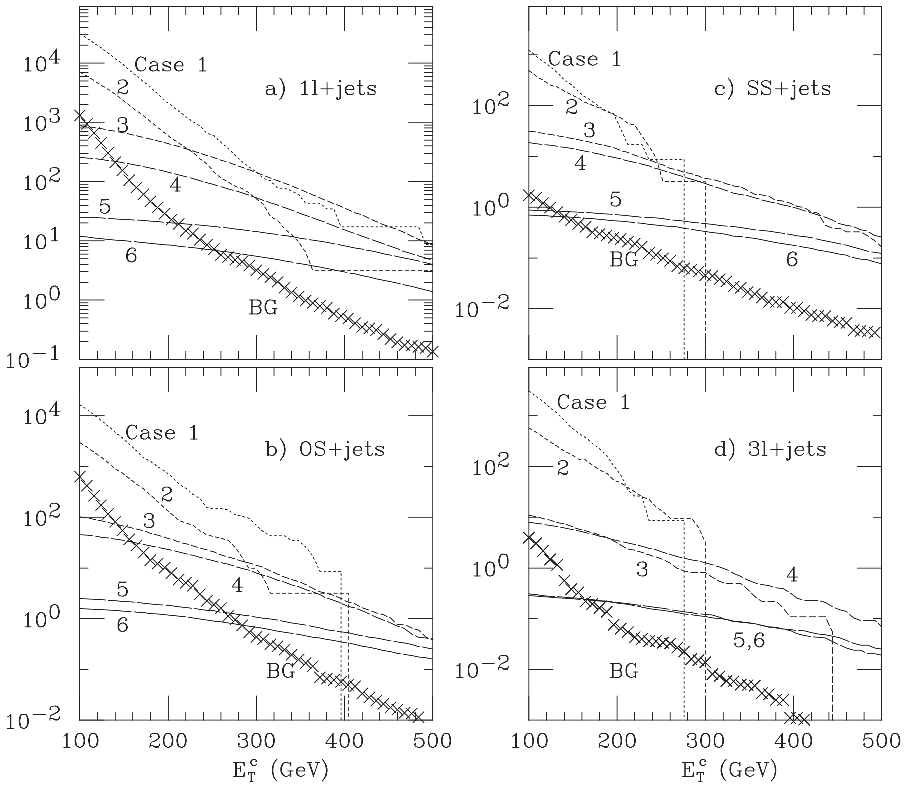

Figure 11: Expected E_t^c distributions for SUSY signal and background processes at the LHC and realistic experimental cuts for $\tan\beta = 2$ and $\mu < 0$ [14]. The different cases are for: (1) $m_{\tilde{g}}$= 290 GeV and $m_{\tilde{q}}$= 270 GeV; (2) $m_{\tilde{g}}$= 310 GeV and $m_{\tilde{q}}$= 460 GeV; (3) $m_{\tilde{g}}$= 770 GeV and $m_{\tilde{q}}$= 720 GeV; (4) $m_{\tilde{g}}$= 830 GeV and $m_{\tilde{q}}$= 1350 GeV; (5) $m_{\tilde{g}}$= 1400 GeV and $m_{\tilde{q}}$= 1300 GeV; (6) $m_{\tilde{g}}$= 1300 GeV and $m_{\tilde{q}}$= 2200 GeV.

A simplified search strategy for squarks and gluinos at the LHC would study jet events with large visible transverse mass and some missing transverse energy. Such events can then be classified according to the number of isolated high p_t leptons. Once an excess above SM backgrounds is observed for any possible combination of the transverse energy spectra, one would try to explain the observed

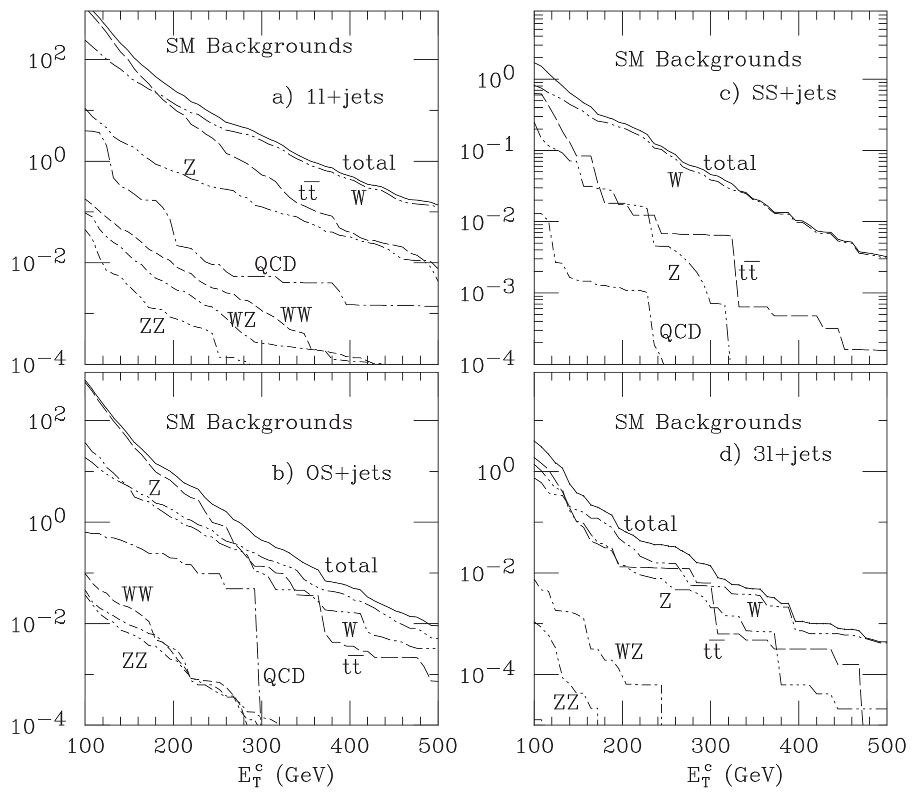

Figure 12: Expected E_t^c distribution for various backgrounds after some minimal event selection criteria are applied [14].

types of exotic events and their cross section(s) for different SUSY $\tilde{g}, \tilde{q}$ masses and decay modes and models. An interesting approach to such a multi-parameter analysis uses some simplified selection variables. For example one could use the number of observed jets, leptons, their transverse momentum, the missing transverse momentum and the visible transverse energy and mass to separate signal and backgrounds. Such an approach has been used to perform a "complete" systematic study of $\tilde{g}$ and $\tilde{q}$ decays [14] and [22]. The proposed variable E_t^c is the value of the smallest of E_t(miss), E_t(jet1), E_t(jet2). The events are further separated into the number of isolated leptons. Events with lepton pairs are divided into same sign (charge) pairs (SS) and opposite charged pairs (OS). Signal and background distributions for various squark and gluino masses, obtained with such an approach are shown in Figure 11.

According to this classification, the number of expected signal events can be compared with the various SM background processes. The largest and most difficult backgrounds originate, as can be seen from Figure 12, mainly from W+jet(s), Z+jet(s) and $t\bar{t}$ events.

Using this approach, very encouraging signal to background ratios, combined with quite large signal cross sections are obtainable for a large range of squark and gluino masses. The simulation results indicate, as shown in Figure 13, that the LHC experiments with a luminosity of 100 fb^{-1} are sensitive to squark and gluinos with masses as high as 2 TeV.

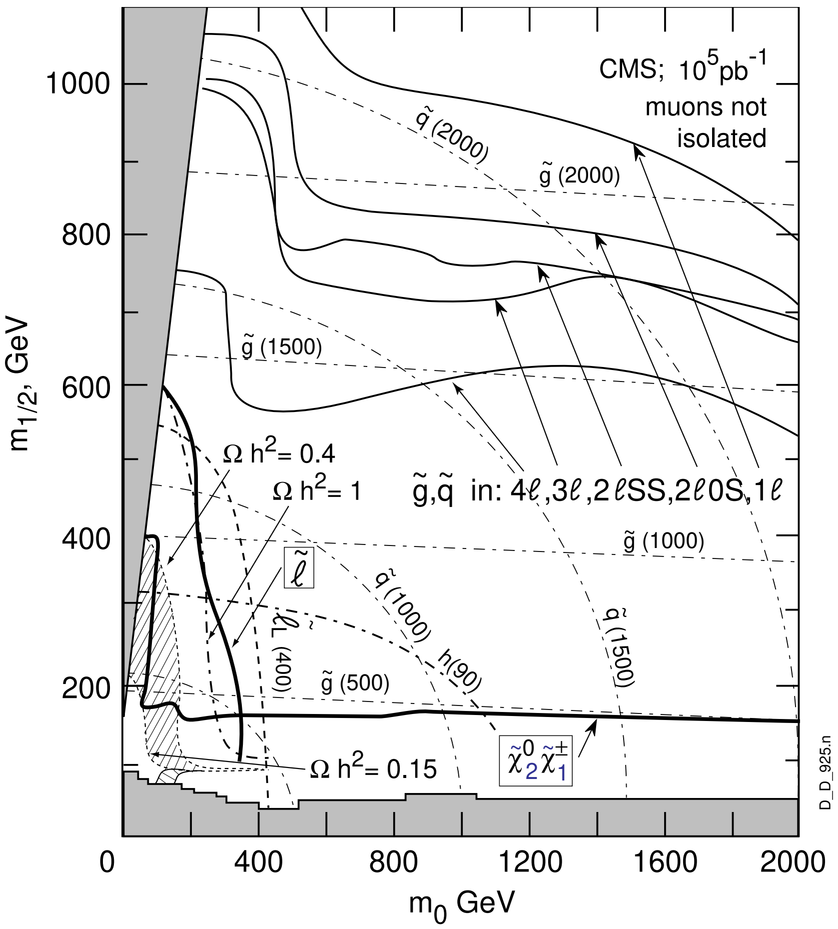

Figure 13: Expected ultimate (L=100 fb^{-1}) CMS sensitivity for squarks and gluinos, sleptons and for $\tilde{\chi}_2^0\tilde{\chi}_1^\pm$ in the $m_0 - m_{1/2}$ plane and $\tan\beta = 2$ and $\mu < 0$. The different full lines show the expected 5 sigma signal, estimated from S/$\sqrt{S+B_{SM}}$, coverage domain for the various signatures with isolated high p_t leptons [23]. The dashed lines indicate the corresponding squark and gluino masses.

Figure 13 indicates further, that detailed studies of branching ratios are possible up to squark or gluino masses of about 1.5 TeV, where significant signals can be observed with many different channels. Another consequence of the expected large signal cross sections is the possibility that the "first day" LHC luminosity ≈ 100 pb^{-1} should be sufficient to discover squarks and gluinos up to masses of about 600-700 GeV, well beyond even the most optimistic Tevatron Run III mass range.

Having this exciting discovery potential for squarks and gluinos with many different channels, one might want to know the "discovery" or simply the "best" channel. Such a question is unfortunately not easy to answer. All potential signals depend strongly on a good understanding of various backgrounds and thus the detector systematics. Especially the requirements of high efficiency lepton identification and a good missing transverse energy measurement demand for a "perfect" working and understood detector. This requirement of a good understanding of complicated "monster" like experiments needs thus some time and is in contradiction with the "first day" discovery potential. We conclude that the best discovery signature is not yet known, but should be one which is extremely robust and simple and should not depend on too sophisticated detector elements and their resolutions.

6 After a SUSY Discovery .. what can be measured at the LHC

Our discussion of the LHC SUSY discovery potential has demonstrated the sensitivity of the proposed ATLAS and CMS experiments. Being convinced of this discovery potential, one certainly wants to know if "the discovery" is consistent with SUPERSYMMETRY and if some of the many SUSY parameters can be measured.

To answer this question one should try to find many SUSY particles and measure their decay patterns as accurately as possible. The sensitivity of direct exclusive SUSY particle production at the LHC has demonstrated the various possibilities and cross section limitations for weakly produced SUSY particles.

Nevertheless, one finds that the production and decays of $\tilde{\chi}^0_2\tilde{\chi}^\pm_1$ provide good rates for masses below 200 GeV and should allow, as indicated in Figure 14, to measure accurately the dilepton mass distribution and their relative p_t spectra. The mass distribution and especially the edges in the mass distribution are sensitive to the mass difference between the two neutralinos. Depending on the used mSUGRA parameters, one finds that the $\tilde{\chi}^0_2$ can have two or three body decays. The relative p_t spectra of the two leptons can be used to distinguish the two possibilities.

Figure 15 shows the distribution for the variable A, defined as $A = (p_t^{max} -$

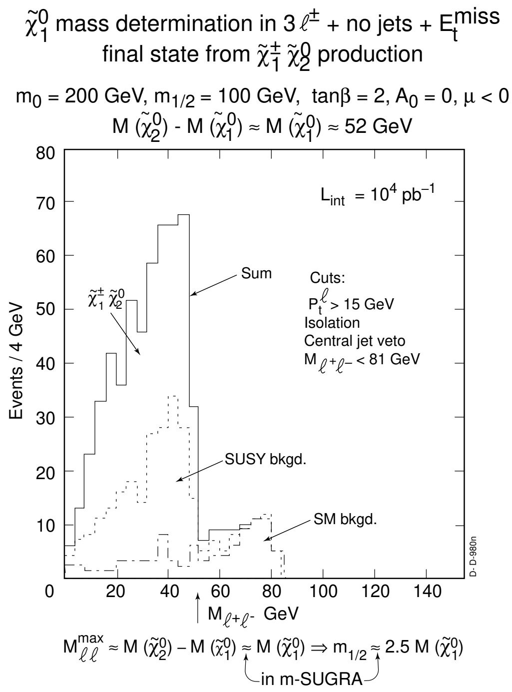

Figure 14: Expected CMS dilepton mass distribution with L=10 fb^{-1} and trilepton events from $\tilde{\chi}_2^0\tilde{\chi}_1^\pm$ [23]. The edge in the distribution at about 50 GeV corresponds to the kinematic limit in the decay $\tilde{\chi}_2^0 \to \ell^+\ell^-\tilde{\chi}_1^0$ and is thus sensitive to the mass difference between $\tilde{\chi}_2^0$ and $\tilde{\chi}_1^0$.

$p_t^{min})/(p_t^{max} + p_t^{min})$ in trilepton events and dilepton masses below and above 50 GeV. This asymmetry variable originates from early investigations of τ decays [24] where it allowed to demonstrate that the leptonic τ decays $\tau \to \ell\nu\nu$ are three body decays.

In contrast to the rate limitations of weakly produced SUSY particles at the LHC, detailed studies of the clean squark and gluino events are expected to reveal much more information. In detail, one finds that the large rate for many distinct event channels allows to measure masses and mass ratios for several SUSY particles, which are possibly being produced in cascade decays of squarks and gluons. Many of these ideas have been discussed at a 1996 CERN Workshop [25]. Especially interesting appears to be the idea that the h^0 might be produced and detected in the decay chain $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 h^0$ and $h^0 \to b\bar{b}$. The simulated mass distribution for $b\bar{b}$ jets in events with large missing transverse energy is shown in Figure 16. Clear Higgs mass peaks above background are found for various choices of $\tan\beta$ and $m_0, m_{1/2}$.

An interesting approach to determine a SUSY mass scale has been suggested

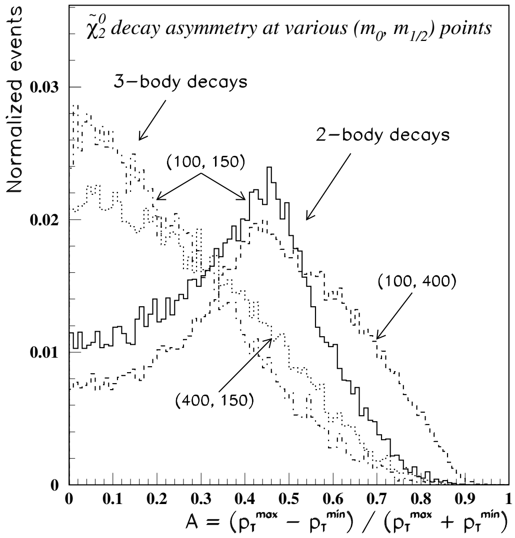

Figure 15: Lepton p_t asymmetry distributions A in $\tilde{\chi}_2^0$ decays, for different choices of m_0 and $m_{1/2}$ and dilepton masses below and above the edge at ≈ 50 GeV as shown in figure 14 [23].

in a recent ATLAS study [26]. The idea is to define an effective transverse event mass, using the scalar p_t sum of the jets with the largest transverse energy plus the missing transverse energy of the event. One finds that this effective mass shows a reasonable linear relation to an underlying SUSY mass, defined as the minimum of the squark or the gluino mass. While this idea appears to be very attractive within the mSUGRA model, the validity of the proposed relation in more general SUSY models remains to be demonstrated.

In addition to the above SUSY studies, one would like to get answers to questions like:

- What are the branching ratios of various SUSY particles?
- Is the accuracy of the various channels sufficient to determine the spin of the new particles?
- Do the data allow to differentiate between specific SUSY models?
- Can one find evidence for CP violation in SUSY decays?

At least some answer might be obtained from future detailed studies of the various decay chains. We thus conclude this section with the hope that some SUSY enthusiasts will try eventually to answer some of these questions using the expected performance of the LHC and its planned experiments.

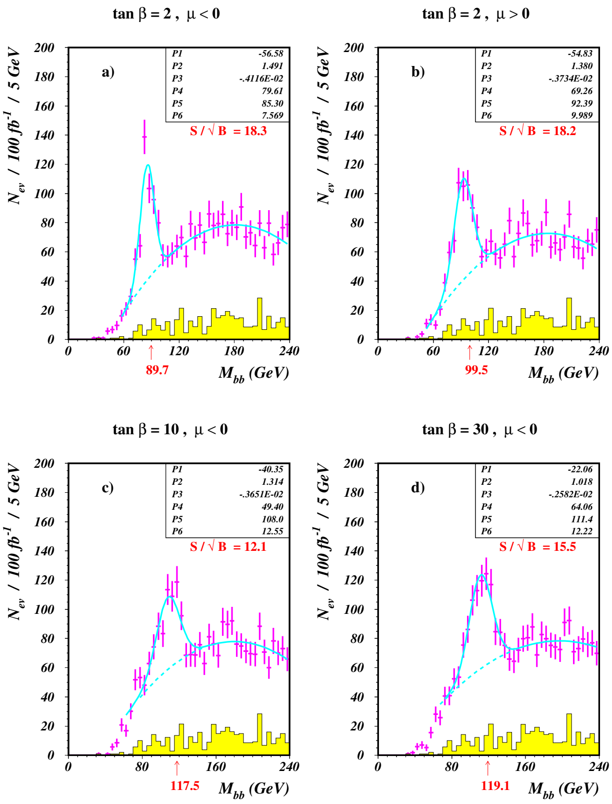

Figure 16: CMS simulation of a $h \to b\bar{b}$ search in events with large missing transverse energy (from squark and gluino cascade decays) and a luminosity of L=100 fb^{-1} [23]. Clear mass peaks are seen for various choices of $\tan\beta$ and μ.

7 SUSY Discovery Strategies for the LHC .... putting it all together

To finish our discussion about the various SUSY search and discovery strategies at the LHC on has to consider the fact that the LHC experiments will not provide any physics before the year 2005. Consequently, quite some preparation time is left.

The most important aspect for the coming years is the confrontation of the assumed detector performance with reality. First of all, the two huge experiments have to be built according to the proposed designs. Any of today's physics case studies has thus to be kept realistic and should also reflect the expected experimental and theoretical knowledge at day 0.

For example, LHC studies which show a wonderful method on how to discover a SM Higgs boson with a mass of 50 GeV, can be considered as a waste of time. A similar judgement could be applied to some "hard work" studies, which require unrealistic experiments with non existing systematics. We do not follow such simple judgement on "first studies" as these studies indicate very often the steps towards a realistic strategy.

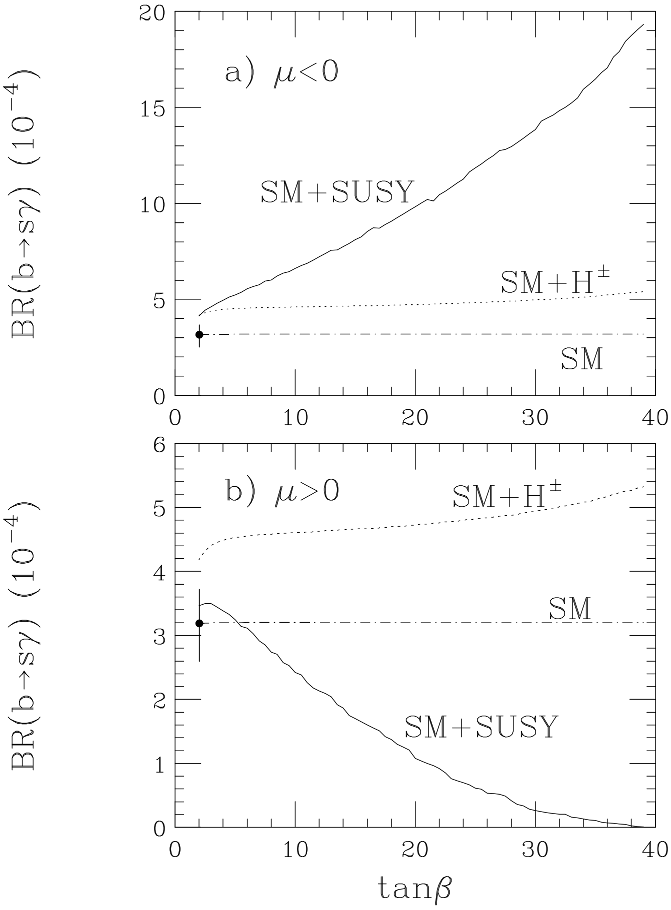

Figure 17: Expected branching ratio for $b \to s\gamma$ for the SM and its supersymmetric extension. The branching ratio is shown as a function of $\tan\beta$ and a negative or positive value of μ [28]. The preliminary CLEO branching ratio result [27] of $(3.15 \pm 0.35(stat.) \pm 0.32(exp.syst.) \pm 0.26(th)) \times 10^{-4}$ has been added.

Realistic and relevant LHC studies should be aware of possible constraints from near future experiments. Examples of such possible constraints come from the LEPII Higgs search and the new CLEO result on the branching ratio for $b \to s\gamma$, being $(3.15 \pm 0.35(stat.) \pm 0.32(exp.syst.) \pm 0.26(th)) \times 10^{-4}$ [27]. The near future high luminosity b-factory experiments should allow to decrease the current error by at least a factor of 4.

The current negative Higgs search results from LEP II exclude essentially the MSSM Higgs sector for $\tan\beta \leq 2$. During the next two years the LEP II sensitivity should increase to $\tan\beta$ values of ≤ 4. Thus, a possible near future Higgs discovery at LEPII requires $\tan\beta$ values between about 2 and 4. In case that the LEPII experiments will not find a Higgs signal, one should study SUSY models with $\tan\beta$ values larger than ≈ 4.

Following some theoretical calculations [28], the new CLEO $b \to s\gamma$ result, as shown in Figure 17, appears to exclude a wide mSUGRA parameter range. In particular, one finds that the mSUGRA parameter μ has to be positive and that values of $\tan\beta > 10$ are essentially inconsistent with the existing data. Furthermore, future results for the branching ratio $b \to s\gamma$ with allowed values between $3.5 - 4 \times 10^{-4}$ could exclude the mSUGRA model well before the start of the LHC. On the other hand, in case the near future results require $b \to s\gamma$ branching ratios between $2 - 3 \times 10^{-4}$, a mSUGRA believer should focus all on $\tan\beta$ values between 4 and 10 if the Higgs is not seen at LEPII. Unfortunately, as can be seen from Figure 18, this $\tan\beta$ range appears to be the most difficult region for MSSM Higgs searches at the LHC.

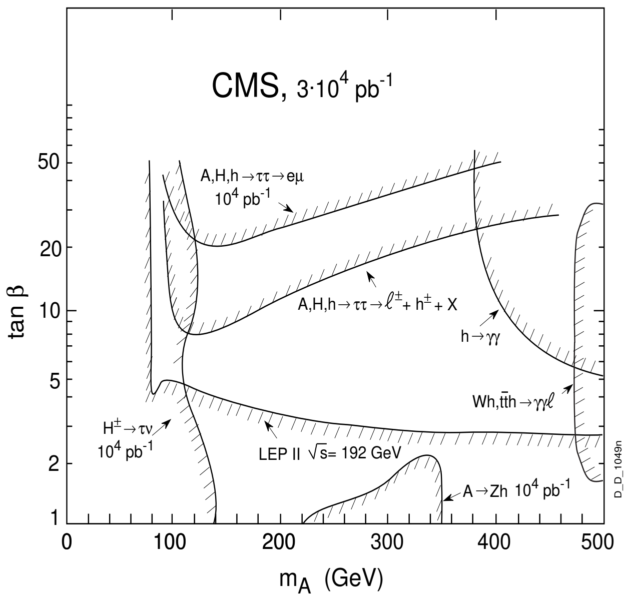

Figure 18: CMS 5 sigma significance contour plot for the different MSSM Higgs sector in the $M_A - -\tan\beta$ plane [29]. Each curve indicates the sensitivity for different Higgs search modes.

We thus conclude this section with the remark that one should think twice before a too large effort is put into very detailed simulation studies as the possible results might be proven irrelevant even before such studies are completed!

8 Super-Summary

We have discussed a large variety of SUSY particle signatures at the LHC. One finds that the ultimate searches for squarks and gluinos should be sensitive up to masses of about 2 TeV. However, the large cross sections for squarks and gluinos with masses of up to about 600 GeV should allow to discover SUSY during the LHC "turn on".

This SUSY discovery potential at the LHC should be confronted with the near future expectations from LEPII and the Tevatron. While only marginal SUSY improvements can be expected, the optimistic TeV Run II studies expect that the LEPII chargino limit of about 100 GeV can be improved with a few fb^{-1} to chargino masses of about 130 GeV which might further be increased to values as high as 200 GeV at RunIII. Within the mSUGRA model, one finds that the negative searches for charginos at LEPII imply that gluinos can not be found at RUNII. In contrast, negative chargino searches at RUNII and RUNIII do still coincide with the "early bird" LHC discovery potential for squarks and gluinos with masses of about 500-600 GeV.

Such excellent perspectives have to be matched however with an almost perfectly working full detector and the accurate knowledge of all SM background processes. In addition, a well prepared search should consider a large variety of models and the resulting possible signatures.

We would like to finish our review of "SUSY Discovery strategies at the LHC" with a few related quotes:

"Experiments within the next 5–10 years will enable us to decide whether supersymmetry, as a solution to the naturalness problem of the weak interaction is a myth or reality" H. P. Nilles 1984 [30]

"One shouldn't give up yet" .... "perhaps a correct statement is: it will always take 5-10 years to discover SUSY" H. P. Nilles 1998 [31]

"Superstring, Supersymmetry, Superstition" Unknown

"New truth of science begins as heresy, advances to orthodoxy and ends as superstition" T. H. Huxley (1825–1895).

Acknowledgements I would like to thank the organisers of the SUMMER school on "Hidden Symmetries and Higgs Phenomena" in ZUOZ for the invitation to review SUSY search strategies at the LHC. The interesting discussions about hidden phenomena were certainly also stimulated by the alpin landscape with many beautiful peaks. I am grateful to D. Haztifotiadou and Z. Wąs for their critical suggestions and comments about my lectures and its writeup.

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