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A General MSSM Parameter Scan

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Abstract

The excluded $\tan\beta$ range and Higgs boson mass regions in the framework of the Minimal Supersymmetric extension of the Standard Model (MSSM) depend on several parameters. The Higgs boson masses, cross-sections and branching fractions have been determined including two-loop diagrammatic calculations. The limits obtained with a more general scan over the parameter space of the MSSM are compared with those in the so-called benchmark scenario. The combination of the searches for Higgs particles in the 1999 data collected by the DELPHI collaboration at center-of-mass energies between 191.6 and 201.7 GeV allows stringent limits to be set in combination with previous DELPHI results. In addition, an interpretation in the framework of the general MSSM scan of the 2000 LEP data at the hightest energies between 201.7 and 209.0 GeV is given. We show that the current data for the HZ and hA production can be comfortably accommodated in the MSSM.

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A General MSSM Parameter Scan

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The excluded $\tan\beta$ range and Higgs boson mass regions in the framework of the Minimal Supersymmetric extension of the Standard Model (MSSM) depend on several parameters. The Higgs boson masses, cross-sections and branching fractions have been determined including two-loop diagrammatic calculations. The limits obtained with a more general scan over the parameter space of the MSSM are compared with those in the so-called benchmark scenario. The combination of the searches for Higgs particles in the 1999 data collected by the DELPHI collaboration at center-of-mass energies between 191.6 and 201.7 GeV allows stringent limits to be set in combination with previous DELPHI results. In addition, an interpretation in the framework of the general MSSM scan of the 2000 LEP data at the hightest energies between 201.7 and 209.0 GeV is given. We show that the current data for the HZ and hA production can be comfortably accommodated in the MSSM.

1. Introduction

The importance of a general MSSM parameter scan has already been pointed out [1]. For earlier LEP2 data taken up to $\sqrt{s} = 172$ GeV it was shown that the benchmark limits on the pseudoscalar Higgs mass disappeared completely [2]. The data taken by DELPHI in 1997 and 1998 up to $\sqrt{s} = 189$ GeV set strong limits on the masses of the neutral Higgs bosons, but they were 6 to 8 GeV/c^2 lower than the benchmark limits [3]. Important parameters for the Higgs boson phenomenology are [1]:

- $m_{\rm h}$ or $m_{\rm A}$ – the Higgs boson mass values investigated.
- $\tan\beta$ – the ratio between the two Higgs vacuum expectation values.
- $m_{\rm sq}$ – the common mass parameter for all squarks at the electroweak scale.
- M_2 – the common SU(2) gaugino mass parameter at the electroweak scale.
- μ – the mixing parameter of the Higgs doublets in the superpotential.
- A – the stop mixing term. The mixing term is defined as $X_t = Am_{\rm sq} - \mu/\tan\beta$.

For this analysis, the parameters shown in Table 1 are the input parameters for the calculations of the physical Higgs, sfermion, chargino, and neutralino masses. These parameters were varied in the ranges shown in Table 1. For each $m_{\rm A}$, 2700 parameter combinations were investigated. Compared to previous studies [3], the large μ scenario ($\mu = \pm 1000$ GeV/c^2) and a very small M_2 value ($M_2 = 70$ GeV/c^2) were investigated with the result that the mass limit is not affected. For large μ values, a few parameter combinations were found where the branching $\rm h \to b\bar{b}$ vanishes; those points were excluded by flavour independent searches.

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m_{A} (GeV/c^2)	$\tan\beta$	m_{sq} (GeV/c^2)	M_2 (GeV/c^2)	μ (GeV/c^2)	A
20 — 1000	0.5 — 50	200 — 1000	200 — 1000	−500 — +500	−2 — +2

Table 1. Ranges of SUSY parameters at the electroweak scale used for independent variation in the study of the MSSM neutral Higgs boson searches.

Throughout this study, the top quark mass is fixed at $m_{\mathrm{t}} = 175\,\mathrm{GeV/c^2}$. Besides the direct exclusions from Higgs boson searches, the following constraints have been studied: $\mathrm{b} \to \mathrm{s}\gamma$, the electroweak parameter $\Delta\rho = \alpha_{\mathrm{em}} T_{\mathrm{MSSM}}$, and chargino and neutralino mass limits from direct searches. These constraints have little influence on the excluded parameter regions with the present Higgs mass limits [3]. Therefore, the excluded parameters have been determined from the Higgs boson searches alone.

2. Excluded (m_{h},m_{A}), (m_{h},$\tan\beta$) and (m_{A},$\tan\beta$) Regions

The results are presented in the (m_{h},m_{A}) plane as well as in the planes (m_{h},$\tan\beta$) and (m_{A},$\tan\beta$). In the mass plane (m_{h},m_{A}) the A mass was scanned in steps of 1 GeV/c^2 up to 200 GeV/c^2. In addition, A masses between 200 and 1000 GeV/c^2 were explored with larger step sizes. For each mass combination, the cross-sections of the reactions $\mathrm{e^+e^-} \to \mathrm{hZ, HZ}$, $\mathrm{e^+e^-} \to \mathrm{hA, HA}$, and the branching ratios for h and A decays were computed as functions of the parameters described in Table 1. Both h production through the bremsstrahlung process and hA pair-production processes were taken into account [4].

For some parameter combinations the branching ratio into a pair of neutralinos is dominant. In such a case no limit can be derived using the above listed search channels. Therefore, limits from the DELPHI search for invisible decays of neutral Higgs bosons [5] are applied. In addition, the decay $\mathrm{h} \to \mathrm{AA}$ is allowed for a small set of parameters and taken into account for setting the limits.

A given (m_{h},m_{A}) combination is excluded if for all SUSY parameter sets (from the ranges defined in Table 1 and for fixed $m_{\mathrm{t}} = 175\,\mathrm{GeV/c^2}$) the exclusion confidence level is larger than 95% in the combination of all search channels [6].

Figure 1 shows three regions: the 95% CL excluded region (light grey), the theoretically not allowed region (dark), and the allowed region (white).

The extended parameter range results in a smaller excluded mass region compared to those obtained with the benchmark [4]. However, because of the large statistics, the mass limits are only 1 to 2 GeV lower.

3. Combining $m_{\mathrm{H}} = 114$ GeV and $m_{\mathrm{h}} \approx m_{\mathrm{A}} \approx 90$ GeV

An excess has been observed in the 2000 LEP Higgs data for the HZ production [7], and we note that the mass limits from hA production are about 2 GeV below the expectation, however, no significant hA excess is claimed [8]. A scan over the allowed MSSM parameter combinations shows that a possible interpretation can be achieved when all three neutral Higgs bosons h, A and H are light. Table 2 gives parameter combinations which could explain the HZ and the hA results and which are also consistent with the excluded range from 1999 LEP data based on the general scan described before [9]. The HZ production cross section at $\sqrt{s} = 208$ GeV $\sigma_{\mathrm{HZ}}^{208}$ is approximately the Standard Model value and thus the expected signal event rate would agree with the observed excess.

4. Conclusions

With the large statistics from the 1999 DELPHI data, a general scan over the MSSM parameter space results in the following mass limits: $m_{\rm h} > 85$ GeV/c^2 and $m_{\rm A} > 86$ GeV/c^2. The range $0.8 < \tan\beta < 1.7$ is also excluded at 95% CL. We have shown that the combined 2000 LEP data for Higgs boson bremsstrahlung and Higgs boson pair-production fits well in the MSSM for large $\tan\beta$ values.

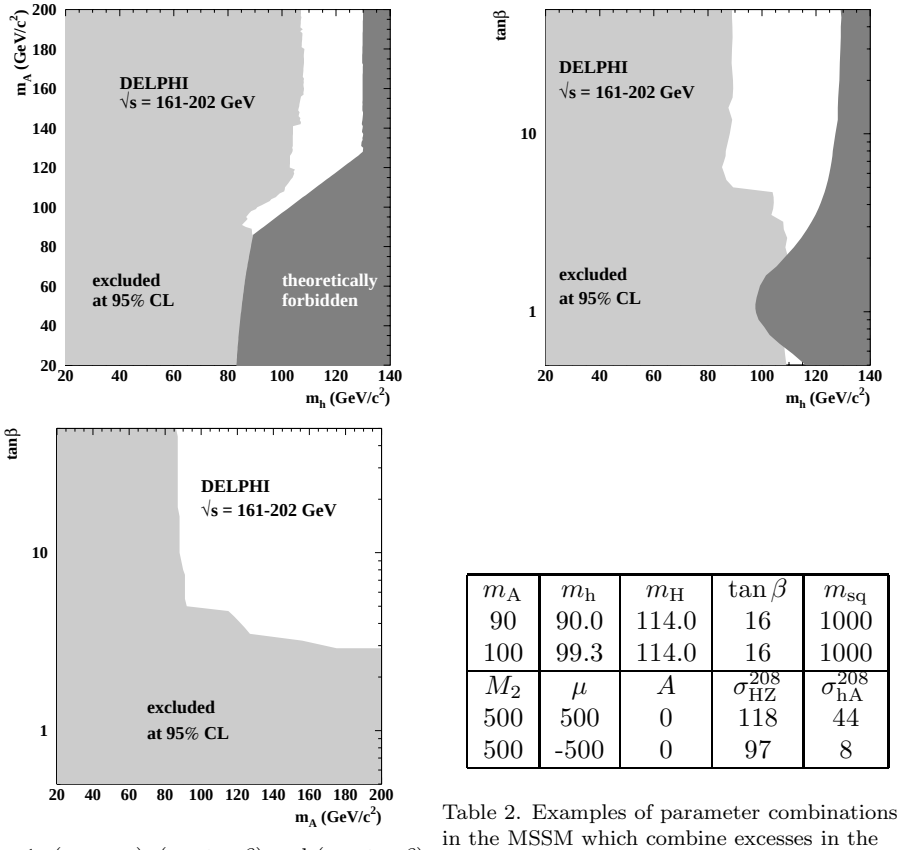

Fig. 1. ($m_{\rm h}$,$m_{\rm A}$), ($m_{\rm h}$,$\tan\beta$) and ($m_{\rm A}$,$\tan\beta$) exclusions for preliminary 1999 DELPHI data.

$m_{\rm A}$	$m_{\rm h}$	$m_{\rm H}$	$\tan\beta$	$m_{\rm sq}$
90	90.0	114.0	16	1000
100	99.3	114.0	16	1000
M_2	μ	A	$\sigma^{208}_{\rm HZ}$	$\sigma^{208}_{\rm hA}$
500	500	0	118	44
500	-500	0	97	8

Table 2. Examples of parameter combinations in the MSSM which combine excesses in the 2000 LEP data. All masses are given in GeV/c^2 and cross-sections in fb.

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