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SUSY HIGGS SEARCHES AT FUTURE COLLIDERS

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The Standard Model is at present not contradicted by any experiment but its known conceptual drawbacks motivate us to look for possible extensions. The closest one is the Minimal Supersymmetric extension to the Standard Model (MSSM) which predicts four Higgs particles: a light scalar h^0, a heavy scalar H^0, a pseudoscalar A^0 and charged bosons $H^{\pm}$. At the tree level all higgs masses can be expressed by two parameters, e.g. mass of the pseudoscalar m_A and the ratio of expectation values $\tan\beta = v_1/v_2$. Therefore it is convenient to present the experimentally accessible region on $\tan\beta$ vs m_A plots. Radiative corrections however are large and they depend on the top and squark masses. For example the h^0 mass, which at the tree level is lower than the Z^0 mass, can be substantially higher (see Fig. 1**) and may even exceed the reach of LEP II. Thus assuming LEP II energy to be 190 GeV only a limited part of parameter space can be covered, as shown in Fig. 2.

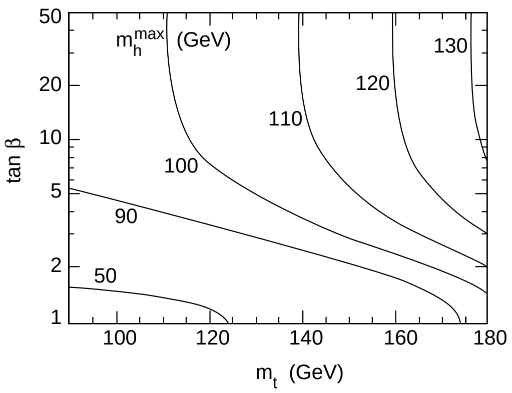

Figure 1: The h^0 mass with radiative corrections

A tool for SUSY higgs searches complementary to LEP is provided by the LHC and SSC machines. The basic parameters of the four detectors [2-5] being designed are listed in Tab. 1-3.

In the following sections the most promising higgs decay channels will be discussed. The information presented comes from the detector proposals [2-5], internal notes [6-14] and private communication. All cut values quoted below should be considered as examples since they are still subject to an optimization procedure.

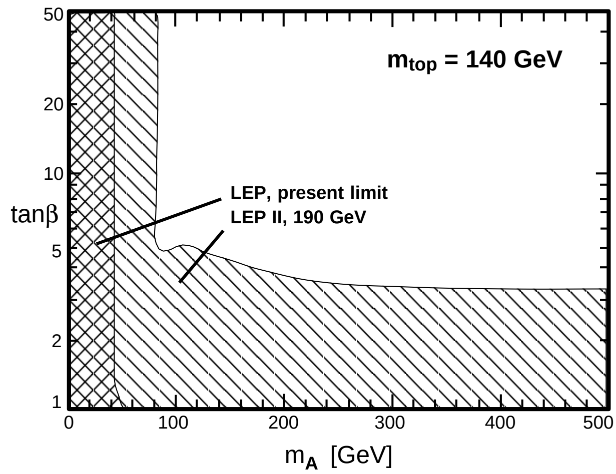

Figure 2: SUSY parameters region accessible for LEP

Table 1: Performance of electromagnetic calorimeters. CMS has two options: "shashlik" and "crystals" [3].

	η_{max}	σ_E/E %	σ_θ [mrad]
ATLAS	3.0	$10/\sqrt{E} \oplus 1.0$	$100/\sqrt{E}$
CMS sh.	2.6	$9/\sqrt{E} \oplus 1.0$	$70/\sqrt{E}$
CMS cr.	2.6	$2/\sqrt{E} \oplus 0.5$	$60/\sqrt{E}$
GEM	3.0	6-8$/\sqrt{E} \oplus 0.4$	40-50$/\sqrt{E} \oplus 0.5$
SDC	3.0	$14/\sqrt{E} \oplus 1.0$	≈ 1

Table 2: Example energy and momentum resolution

	σ_E		Δp			
	$E = 40$ GeV		$p_t = 40$ GeV			
	$\eta = 0$		$\eta = 0$		$\eta = 1.5$	
	%	MeV	%	MeV	%	MeV
ATLAS	1.9	760	1.6	640	2.0	800
CMS sh.	1.6	640	0.6	240	1.5	600
CMS cr.	0.6	240	0.6	240	1.5	600
GEM	1.2	480	0.8	320	2.0	800
SDC	2.4	960	0.6	240	0.6	240

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** This figure as well as all $\sigma \cdot BR$ values used is this paper come from Ref. [1].

Table 3: Jet energy resolution

	central		forward	
	η_{max}	σ_E/E %	η_{max}	σ_E/E %
ATLAS	3.0	$50/\sqrt{E} \oplus 3.0$	4.5	$100/\sqrt{E} \oplus 7$
CMS	2.6	$52/\sqrt{E} \oplus 2.5$	4.7	$125/\sqrt{E} \oplus 5$
GEM	3.0	$60/\sqrt{E} \oplus 4.0$	5.5	$120/\sqrt{E}$
SDC	2.5	$70/\sqrt{E} \oplus 2.0$	6.0	$100/\sqrt{E} \oplus 10$

$\mathbf{h^0}$, $\mathbf{H^0} \rightarrow \gamma\gamma$

It can be seen from Fig. 3 that this channel is well suited to study the high $\tan\beta$, high m_A region – the most difficult one for LEP. The main background comes

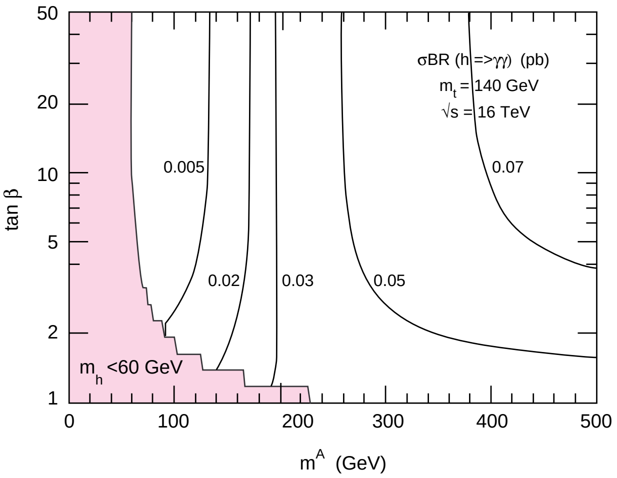

Figure 3: Contours of $\sigma \cdot BR$ [pb] for $h^0 \rightarrow \gamma\gamma$

from direct $\gamma\gamma$ production, bremsstrahlung from outgoing quarks, decays of π^0's from jets, and for $m_h \approx m_Z$ from misidentified e^+e^- pairs produced by Z decays. In order to suppress the background a number of kinematical and topological cuts are applied. Only events having two high p_t photons (typically $p_t^{1,2} > 40, 25$ GeV) within the calorimeter acceptance (see Tab. 1) are selected. Bremsstrahlung background can be reduced by requiring a balance between photon momenta, say $0.3 < p_t^1/(p_t^1+p_t^2) < 0.7$. Presence of a jet can be vetoed by isolation cuts using the electromagnetic calorimeter and/or the inner tracker. Energy deposited in a ring around the electromagnetic cluster (e.g. $0.06 < \Delta R = \sqrt{\Delta\eta^2 + \Delta\varphi^2} < 0.30$) must be lower then the threshold of a few GeV or there should be no track $p_t > 2.5$ GeV found in the cone of $\Delta R < 0.3$. Additional π^0 rejection is provided by a preshower instrumented with a few mm wide strips allowing the distinguishing of single and double shower patterns. Expected results of such a selection algorithm are shown in Fig. 4. Regions where statistical significance greater then 2 and 5 is achievable are denoted by 2σ and 5σ respectively.

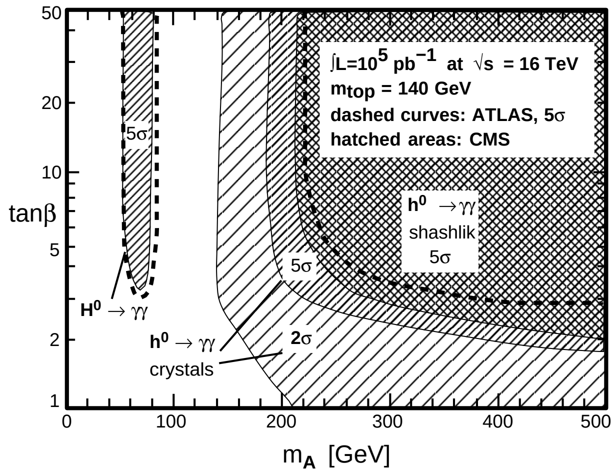

Figure 4: h^0, $H^0 \rightarrow \gamma\gamma$ accessible regions

$\mathbf{H^0 \rightarrow ZZ^{(*)} \rightarrow l^+l^-l^+l^-}$

The $\sigma \cdot BR$ of this channel (see Fig. 5) is very small and hardly exceeds 1 fb around $m_A \approx 200$ GeV. However H^0 is very narrow ($\Gamma_H < 1$ GeV) in this region (Fig. 6) and a clear peak can be seen above the background provided the detectors have sufficiently high mass resolution (see Tab. 2).

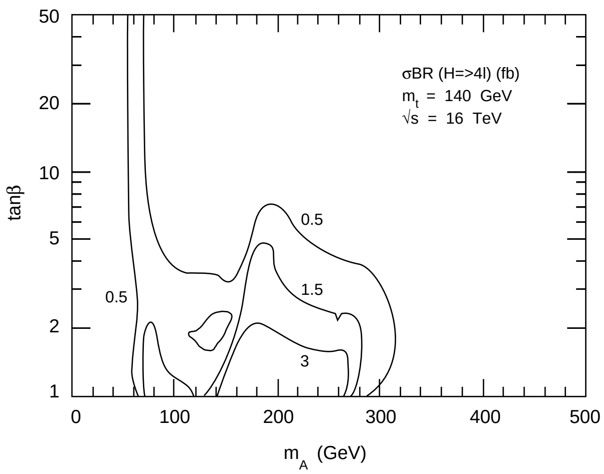

Figure 5: $\sigma \cdot BR$ [fb] for $H^0 \rightarrow ZZ^{(*)} \rightarrow l^+l^-l^+l^-$

If both Zs are real the only significant background is the ZZ continuum. Thus selection criteria are simple. Two pairs of high p_t leptons (typically $p_t^{1,2} >$ 20-40 GeV, $p_t^{3,4} >$ 5-20 GeV) are required having invariant masses within a 4 GeV window around m_Z. If one Z is virtual the mass constraint is required for one l^+l^- pair only, but lepton isolation cuts are applied in order to suppress $t\bar{t}$ and $Zb\bar{b}$ background. No charged track with $p_t > 2.5$ GeV is to be found in a cone of $\Delta R < 0.3$ around each lepton. One can also reduce the number of b quarks by a cut on the impact parameter. The region accessible by applying the above procedure is show in Fig. 7.

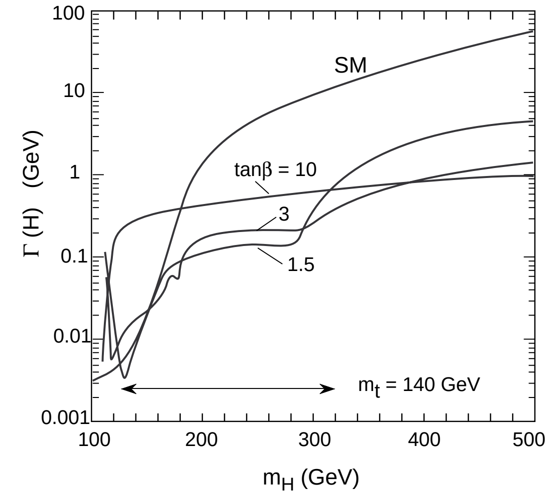

Figure 6: Width of the SM and MSSM H^0

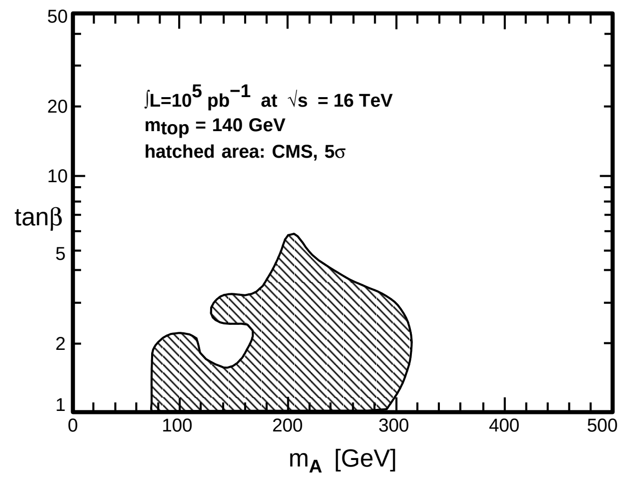

Figure 7: $H^0 \to ZZ^{(*)} \to l^+l^-l^+l^-$ accessible region

$\mathbf{h^0,\ A^0,\ H^0 \to \tau^+\tau^-}$

In this channel $\sigma \cdot BR$ is rather large (Fig. 8) but the high level of background makes detection of the τ pair difficult. Main contributions come from $b\bar{b}$ and $t\bar{t}$ production, and, for $m_{\tau\tau} \approx m_Z$, from $Z \to \tau\tau$ decays. The easiest case is when one τ decays into a muon and another one into an electron. Momenta of these leptons should be larger then 15 GeV and they are isolated. There should be no tracks with $p_t > 2$ GeV inside the $\Delta R < 0.4$ cone around each lepton. In addition no jet with $E_t > 30$ GeV has to be found in $|\eta| < 2.5$. If the φ angle between e and μ lies between 120° and 160° the neutrinos from τ decays can be reconstructed using missing transverse energy and assuming $m_\tau \approx 0$.

The $\tau\tau$ pair can also be recognized when only one τ decays leptonically whereas the other one decays into a hadron. In this case additional background comes from W+jet and Z+jet production when the jet fakes the τ and W or Z creates the lepton. Lepton selection criteria

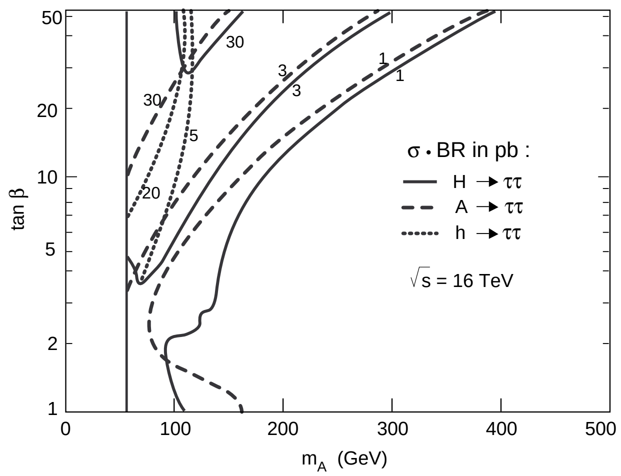

Figure 8: $\sigma \cdot BR$ [pb] for h^0, A^0, $H^0 \to \tau^+\tau^-$

are similar to the previous case. The τ jet should be energetic ($E_t >$ 40-80 GeV), central ($|\eta| < 2.5$), and isolated ($E_t(0.1 < \Delta R < 0.4) < 2.5$ GeV), and it should match with a high p_t track. There should be no other jet with $p_t > 25$ GeV in $|\eta| < 2.4$ and no nonisolated μ with $p_t > 5$ GeV. Circularity of the event should not exceed 0.02-0.05. The lepton and the jet should be in opposite hemispheres ($\Delta\varphi_{jet-l} > 130°$) but not exactly back to back in order to enable reconstruction of neutrinos. The region accessible through decays of A^0, and H^0 together is shown in Fig. 9 using the fact that in this region they have similar masses.

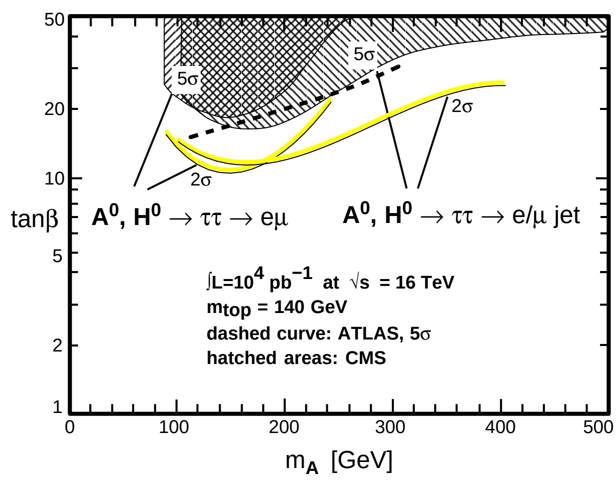

Figure 9: h^0, A^0, $H^0 \to \tau^+\tau^-$ accessible region

$\mathbf{H^\pm \to \tau\nu,\quad H^\pm \to cs}$

Detection of $H^\pm$ seems to be possible only when it comes from a t→Hb decay whereas the second t of the $t\bar{t}$ pair decays into Wb with W→ $l\nu$. A dominant background are $b\bar{b}$, W+jet and top jets faking the τ and real taus from t→W→ τ. If $H^\pm$ decays into $\tau\nu$ data analysis consist of two steps: selection of $t\bar{t}$ sample and

τ identification. The top quark can be recognized by the t→W→ μ/e decay where the lepton with $|\eta| < 2.4$ has $p_t > 40$ GeV. The b quark associated with the W is identified (tagged) by decaying into nonisolated μ with $p_t >$ 7-15 GeV. The angle between the two leptons (from the W and b) should be between 20° and 160°. Identification of τ decaing into a charged hadron has been already described in the previous paragraph. The resalting accessible region is presented in Fig. 10.

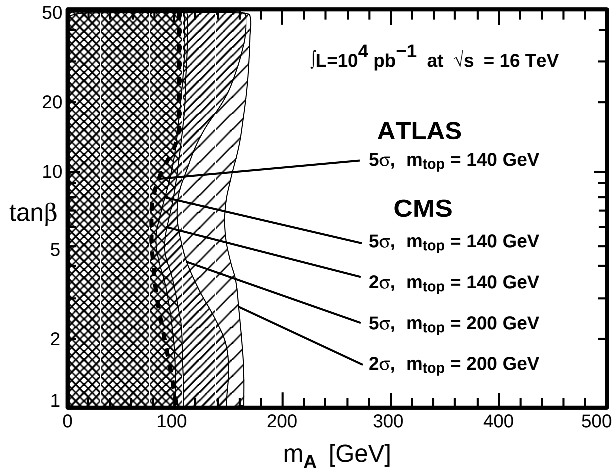

Figure 10: $H^{\pm} \to \tau\nu$ accessible region

If $H^{\pm}$ decays into cs quarks one also has to select $t\bar{t}$ sample first. Then one searches for c and s jets within $|\eta| < 2$ having $E_t > 30$ GeV. The jets must not contain any muon. The invariant mass of the c, s and b jets should be in a 40 GeV window around m_{top}. More details one can find eg. in [3] and [9]

Conclusions

After combining all the channels together (Fig. 11), there still remains an area of the $\tan\beta$ vs m_A where detection of SUSY Higgs particles is out of LEP and LHC/SSC reach (assuming $m_{top} = 140$ GeV). However if the higgses are not there is a chance to exclude a large part of the remaining area with 95% confidence level (2σ) as shown in Fig. 12. Moreover, if the top mass is as large as 200 GeV, the $H^{\pm} \to \tau\nu$ contour moves up to $m_A \approx 160$ GeV and thus covers the rest of the inaccessible area. In conclusion, LEP and LHC/SSC provide complementary tools for study of the SUSY Higgs sector and they have a fair chance to cover together the full parameter space.

References

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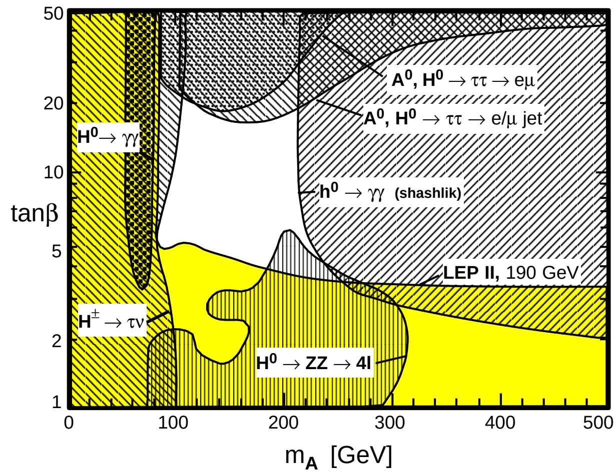

Figure 11: Possible discovery regions (5 σ)

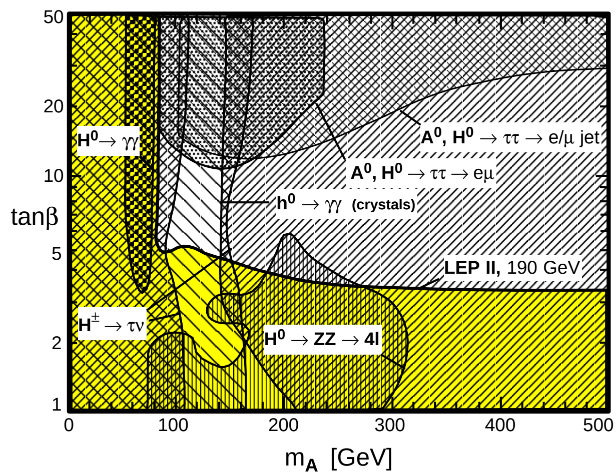

Figure 12: Possible 95% CL exclusion regions (2 σ)

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