Higgs Boson Searches and Properties

Introduction

Despite the extraordinary success of the Standard Model (SM) in describing particle physics up to the highest energy available today, the mechanism responsible for electroweak symmetry breaking (EWSB) has yet to be determined. In particular, the Higgs boson higgs1,higgsrev,higgs2 predicted in the minimal Standard Model and the theoretically attractive Supersymmetric (SUSY) Grand Unified Theory (GUT) extensions thereof have yet to be observed. If EWSB does indeed derive from nonzero vacuum expectation values for elementary scalar Higgs fields, then one of the primary goals of constructing future colliders must be to completely delineate the Higgs boson sector. In particular, it will be crucial to discover all of the physical Higgs bosons and determine their masses, widths and couplings. Conversely, if a fundamental Higgs boson does not exist, it is essential to demonstrate this unambiguously.

The EWSB mechanism in the Standard Model is phenomenologically characterized by a single Higgs boson (h_{SM}) in the physical particle spectrum. The mass of the h_{SM} is undetermined by the theory, but its couplings to fermions and vector bosons are completely determined. In SUSY theories, there are two Higgs doublets with vacuum expectation values v_1, v_2. These contribute mass terms for the gauge bosons proportional to $(v_1^2 + v_2^2)$, masses for down-type fermions proportional to v_1, and masses for up-type fermions proportional to v_2. In the Minimal Supersymmetric Standard Model (MSSM) Nillrev,HKrev these two doublets give rise to five physical Higgs bosons: h^0, the lighter of the two CP-even states; H^0, the heavier CP-even state; the CP-odd A^0 boson, and a pair of charged bosons $H^{\pm}$. The mass of the minimal SM Higgs boson is unspecified, but in the MSSM, there are tree-level relations which determine the spectrum of masses in terms of one of the boson masses (e.g., the mass of the A^0) and the ratio of the vacuum expectation values, v_2/v_1. The CP-even and CP-odd neutral Higgs bosons have nontrivial mixing angles α and β, respectively, which affect their couplings and decays. In particular, $v_2/v_1 = \tan\beta$. Both masses and couplings receive further radiative corrections which are functions of the SUSY Higgs mass parameter, μ, the scale of mass at which SUSY is broken, M_{SUSY}, the mass of the top quark, and the A_i parameters of the soft supersymmetry-breaking interaction. More general models of the Higgs sector, which also include electroweak singlets, are also possible in SUSY theories. Finally in non-supersymmetric models with two Higgs doublets (2HDM), the Higgs bosons may have mixed CP character.

Supersymmetry has exciting implications for the discovery potential of the Higgs bosons that it predicts. In the MSSM, considering renormalization group improved radiative corrections and assuming $m_t = 180$ GeV with the stop mass less than 1 TeV, the lightest Higgs boson must have mass M_{h^0}130 GeV. An even more sweeping statement can be made sweep that M_{h^0}150 GeV for any SUSY theory with a grand unification at high energy which includes the elementary Higgs fields.

Present and Future Limits

The best direct limits on the SM Higgs boson come from searches at LEP, with the present limit LEPlim being $M_{h_{SM}} > 65.2$ GeV at 95% confidence level (C.L.). These limits can also be interpreted in the framework of the MSSM to exclude the lightest SUSY Higgs with mass less than approximately 45 GeV. Electroweak radiative corrections including the top quark and the Higgs boson affect precision electroweak measurements, and global fits LEPfit using data from LEP, SLC, the Tevatron, and neutrino scattering give the relatively weak limit implying that $M_{h_{SM}} < 300$ GeV (95% C.L.).

LEP2

The limit on the Higgs boson mass will be improved in the near future with the operation of LEP2. With an integrated luminosity of 150 pb^{-1} in each of the four LEP detectors, expected from one year of running at design luminosity, the 5σ discovery reach can be increased LEP2 to about 95 GeV with running at center-of-mass energies of 192 GeV scheduled for 1997. At the same energy and luminosity, the process $e^+e^- \to hA$ can be discovered (excluded) at a cross section of 65 (30) fb, when supersymmetric decay channels are closed. The resultant exclusion region in the MSSM parameter space can be found in Fig. LHCfig. The possibility of running at 205 GeV, which would result in an extension of limits close to the MSSM bound, is currently being investigated.

Upgraded Tevatron

The associated production of a Higgs boson and a W or Z boson, with the Higgs decaying to $b\bar{b}$ and the W or Z decaying leptonically, is a possible way to detect the Higgs in the mass range 60–130 GeV, at a high luminosity Tevatron collider Amidei. The Higgs decay gives rise to 2 jets, thus one will use b tagging to reduce the large $W + 2$ jet background. It appears that the present b tagging capability at CDF is more than adequate to reduce this background (at moderate Run II luminosities, e.g., $10^{32}\times$ cm^{-2} sec^{-1}, 1 TeV $\times$ 1 TeV) if this capability is extended to larger rapidities (as is planned in Run II for both CDF and D0). After b tagging, the largest background at Higgs masses below 100 GeV is QCD production of $W + b\bar{b}$ and top backgrounds for masses above 100 GeV. Figure figtev shows the dijet mass distribution for the sum of all these backgrounds, plus the $W + H$ signal for 10 fb^{-1}. An observation of the Higgs for masses below 100 GeV is possible after the Main Injector upgrade, and is within reach of the present Run II accelerator after several years of data-taking. For higher mass Higgs bosons, these statistics are too low; one would need about 25 fb^{-1} to observe the 120 GeV Higgs. This study assumed an approximate 20% improvement in dijet mass resolution obtained from applying a clustering algorithm that reduces the effect of gluon radiation at large angles to the jet. This dijet mass resolution and jet clustering is crucial in seeing the Higgs. It has been argued that the $h \to \tau^+\tau^-$ and $Z \to \nu\bar{\nu}$ channels can be used to improve these results KandMr.

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ground mass distributions for the WH process with 10 fb^{-1} of data at 2 TeV. The solid line is signal+background, the dashed line the sum