SELECTED TOPICS FROM NON-HIGGS SEARCHES AT LEP

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Extensive searches for new phenomena have been performed at LEP. The principal aspects and results of those not related to Higgs bosons are reviewed here.

1 Introduction

The last component of the Standard Model (SM) yet to be discovered is the Higgs boson. Therefore, talking about *non-higgs* searches implies straightly extensions of the SM. This means anything not in the basic SM: new particles, couplings, (sub)structure, extra-dimensions, new symmetries ... possibly embedded in a coherent and complete frame, attempting to solve at least some of the theoretical problems of the SM; examples of these frames are those based on supersymmetry or technicolor. At LEP, both ways of searching for new phenomena could be pursued: *indirect*, via precision measurements, understanding if what is measured is consistently described in the SM; *direct*, disentangling the unexpected by isolating those phenomena most likely coming from non-SM terms. During 11 years of operation the LEP machine [1] delivered about 900 pb^{-1} per experiment at centre-of-mass energies ranging from 88 to 95 GeV (phase LEP 1) and 130-209 GeV (phase LEP 2). Since the four detectors had been designed [2] to do precision physics at the Z peak, they featured large covering angle, good particle identification for leptons, photons and b quarks, and good jet and energy flow reconstruction.

1.1 Precision measurements

Precision measurements were performed both at LEP 1 (Z resonance and fermion couplings) and at LEP 2 (W boson mass and width, TGC's, anomalous couplings). The net result of these measurements is that the SM works very well [3]; constraints are therefore derived to new contributions to the observables. As an example, the agreement of the measured Z widths with the SM prediction rules out new particles coupling to the Z if their masses are smaller than about $M_Z/2$; the sneutrino has been definitely ruled out as cold dark matter candidate by this analysis. Moreover, the optimal analysis of quantum loop effects suggests that Higgs structures with triplets or higher representations are disfavoured and that a new SM-like family is excluded at 95% C.L. [4]; minimal technicolor is also disfavoured by precision EW measurements [4].

2 Direct searches

Direct searches for new phenomena profit from the highest centre-of-mass energy and highest integrated luminosity; therefore they were one of the main topics of the highest energy phase of LEP. The typical LEP-combined sensitivity for "5σ-discovery" of a heavy particle P pair-produced in e^+e^- collisions is approximated, assuming Poisson statistics, by $\sim 10/(\epsilon_{\rm eff} \cdot \int \mathcal{L}dt)$ (10 being the minimum number of candidate events to be observed) ; with a realistic value for the average effective efficiency $\epsilon_{\rm eff} \sim 0.20$ this gives, for LEP, ~18 fb if $M_P < 95$ GeV/c^2, and ~30 fb if $95 < M_P <\sim 100$ GeV/c^2. Given that the typical SM cross sections are larger than 1 pb, *the typical LEP 2 potential sensitivity is to couplings an order of magnitude smaller of the SM ones or less.* This is quantitatively shown, for example, by the results of exotic searches like those for compositness and FCNC [5], which parametrize in a less model-dependent way possible new effects beyond the SM.

Moving to more model dependent searches, in the late LEP years growing interest was shown for an alternative idea of solving the observed scale hierarchy between gravitational and electroweak interactions; the introduction of a certain number n of extra-dimensions and of a new fundamental gravitational scale M_S, brings new particles in 4-dimensions, called gravitons, and a striking *single photon* signature in e^+e^- collisions. LEP sensitivity to M_S decreases with increasing n from about 1.5 TeV at n=2 to about 0.6 TeV for n=6; the ADLO combination is in progress [5].

2.1 Supersymmetry

The most popular extensions of the SM are those based on supersymmetry (SUSY); besides providing valuable theoretical benefits [6] (scale stabilization, a frame for including gravity, possible ways of explaining dark matter,...) they are not yet excluded in their minimal - and therefore simplest - implementation; moreover, they are in good agreement with precision EW data and improve the high energy extrapolation of the theory providing a better gauge coupling unification. The phenomenological consequences of a Minimal Supersymmetric Model (MSSM) are exhaustively described in the literature [6], where definition and notation for the relevant parameters can be found. LEP had a relevant role in constraining the minimal model: some authors claim that about 95% of the *natural* parameter space has been strongly disfavoured by LEP results [7]. The golden process for discovering SUSY at LEP was chargino pair production: large cross section, clear *missing-energy* signature. Difficulties could have arisen in peculiar situations: small energy available for chargino decay products and abundance of leptonic decays in the case of light sleptons. The solution of these problems are a good example of the potentiality of LEP detectors: the former has been covered exploiting the trigger capabilities of the detectors, in particular to trigger on low energy isolated photons; the latter by taking advantage of the good lepton identification, and exploiting for the first time the concept of *interplay* among searches [8].

The way the different searches interplay among each other is illustrated in Fig. 1 for a highly constrained MSSM, commonly referred to as Minimal Supergravity [8]; the parameter choice here is: $\tan\beta = 30$, positive μ, A_0=0 and the exclusions are shown in the plane of the common sfermion mass m_0 and of the common gaugino mass $m_{1/2}$. Notice the significant impact of the Higgs searches even at large values of $\tan\beta$. Due to stau mixing, pathological situations show-up when the stau is almost degenerate with the lightest neutralino: acoplanar tau searches are in those cases blind, and the only way to recover sensitivity is to via heavy neutralino production and subsequent decay into stau-tau pairs, with at least a well energetic tau. These special cases have been addressed by the LEP collaborations [8]; the impact is shown in Fig. 1, right. The most famous result of the interplay between searches is the lower limit on the lightest neutralino mass, assumed to be the *Lighest Supersymmetric Particle* (LSP) and a candidate for dark matter if R-parity is conserved [6]; this is shown in Fig. 2, left, in its latest, LEP-combined [9],

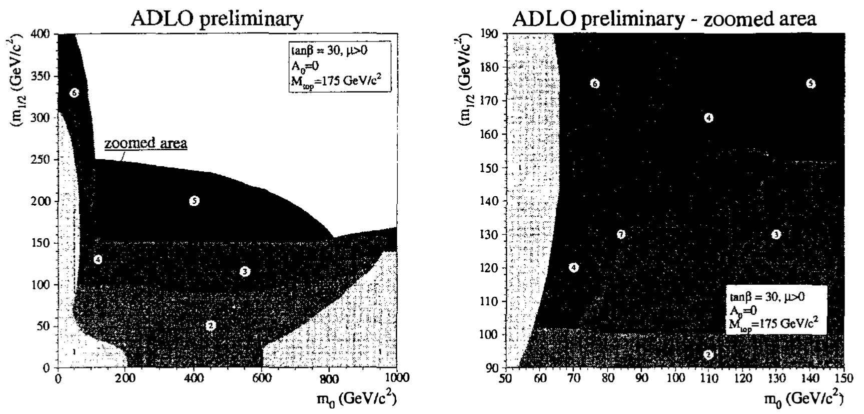

Figure 1: Example of interplay in Minimal Supergravity (see text); the different regions correspond to: theoretically non-allowed parameter settings (1); incompatibility with the Z width measurement at LEP 1 (2); incompatibility with LEP 2 searches for charginos (3), selectrons and staus (4), Higgs bosons (5) and stable staus (6). The zoom shown on the right panel illustrates the impact of special analysis looking for stau production in heavy neutralino decays when the difference in mass between the $\tilde{\tau}$ and the χ^0 is small (7).

form valid in the so-called *constrained* MSSM, where some assumptions about unification at very high energy scales are understood [10]. The LSP must be heavier of about 45 GeV/c^2. A less famous consequence of LEP results implies that a purely higgsino LSP cannot explain the observed amount of cold dark matter [11]. The plot in Fig. 2, left, is obtained after scanning many configurations, and subtle but important contributions are hidden under the final result. One of these is the absolute lower limit on the stop mass resulting from the ALEPH analysis, finalized before this conference[12] and integrated with the analysis of a new stop decay channel, the 4-body $\tilde{t} \rightarrow \chi^0 b f_u \bar{f}_d$, of which recently has been realized the potential relevance[13].

At the same degree of minimality of the MSSM, there are the so called Gauge Mediated Supersymmetric Models (GMSB) [14], which differ from the MSSM by the way supersymmetry breaking (a fundamental ingredient of any realistic SUSY model [6]) is implemented; the phenomenological novelty introduced by GMSB models is the possibility of non-negligible lifetime for the Next-to-LSP, which typically is either the neutralino or the stau. These particle could therefore decay with the tracking volumes of the LEP detectors leading to kink or detached-vertex topologies. The good sensitivity of all LEP detectors to this kind of topologies has allowed to produce lifetime independent constrains on the NLSP particle. Figure 2, right, shows the result in the case of the stau, as obtained from an ADLO combination [15] presented for the first time at this conference.

Finally, as an example of non-minimal SUSY searches, it is worth mentioning the analyses performed allowing R-parity violation terms in the theory. In this case the LSP can decay leading to a plethora of possible final states, with many leptons and/or quarks, with or without missing-energy. The many analyses (whose results are now being LEP-combined [16]) have shown that the discovery of supersymmetry was not missed because of R-parity violation. Most significantly, the study of these decays allowed to test very peculiar topologies, otherwise unsearched for.

3 Conclusions

The LEP impact on possible extensions of the SM has been quite significant. Precision measurements at the EW scale proved the basic correctness of the SM, disfavouring, among others, heavy

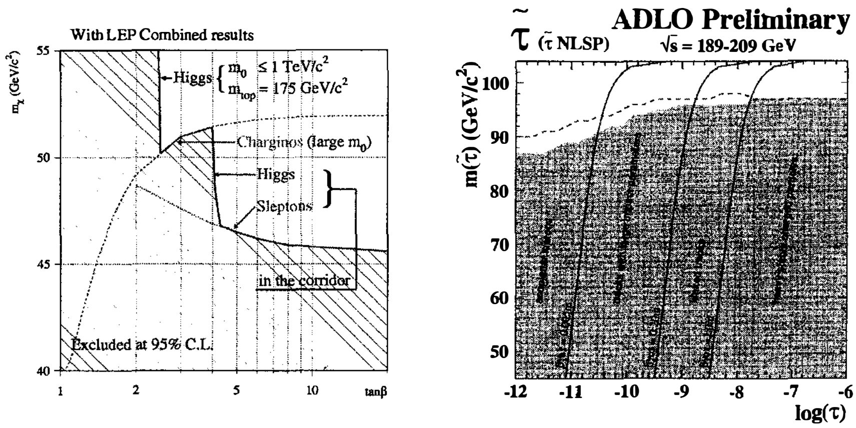

Figure 2: Left: Absolute lower limit on the LSP mass in the constrained MSSM as a function of tanβ (see text). Right: Lower limit on the stau mass as a function of the lifetime in GMSB models (see text).

Higgs bosons, complicated Higgs structures, additional copies of the known families, QCD-like technicolor frames. Unsuccessful direct searches proved sensitivities to couplings a order of magnitude smaller than the SM ones and typically excluded new particle with masses smaller than about 100 GeV/c^2. The interplay among several searches could be used to constrain well-defined minimal extensions of the SM, so allowing to derive absolute limits on some parameters, like the lower limit on the LSP mass in the constrained MSSM. For completeness and solidity of its results, LEP has certainly set a new standard for future searches.

Acknowledgments I would like to thank the contact persons of the relevant LEP working groups for promptly providing material and/or support in the preparation of this talk, and G. Sguazzoni for the careful reading of the manuscript.

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