The (phase space only) distribution of M^2_{Zll} from the decay chain $c \to Zb$ followed by $b \to al^+l^-$ has the form:

$$\frac{d\sigma}{d\,(M^2_{Zll})} \propto W(M^2_{Zll}), \tag{5.25}$$

where the "constant" of proportionality may depend on m_a, m_b and m_c but not on M_{Zll}, and where

$$W(M^2_{Zll}) = \begin{cases} w^+ & \text{if } M^2_{Zll} \leq (m_c - m_a)^2 \text{ and } w^+ \geq 0 \geq w^- \\ w^+ - w^- & \text{if } M^2_{Zll} \leq (m_c - m_a)^2 \text{ and } w^- \geq 0 \\ 0 & \text{otherwise} \end{cases} \tag{5.26}$$

where w^+ and w^- are defined by

$$\begin{aligned} w^{\pm} &= 2(m_a^2 + m_b^2)m_c^2 \pm \left[m_c^2, m_b^2, m_Z^2\right]\left[m_c^2, m_a^2, M^2_{Zll}\right] \\ &\quad -(m_c^2 + m_b^2 - m_Z^2)(m_c^2 + m_a^2 - M^2_{Zll}) \end{aligned} \tag{5.27}$$

in which the following notation has been used:

$$[x, y, z] \equiv \sqrt{x^2 + y^2 + z^2 - 2(xy + xz + yz)}. \tag{5.28}$$

Chapter 6

Conclusions

Appendix C

Comparing the supersymmetric and SM higgs potentials

One of the common objections to the SM is that its Higgs potential (2.1) is somewhat arbitrary. Although the ratio μ^2/λ is determined by the requirement of correct EWSB, the potential provides us with no clue to the magnitudes of μ and λ, and so the higgs mass is largely independent of the other particles of the SM.

The supersymmetric higgs potential is more complicated. The MSSM lagrangian includes the terms

$$\begin{aligned} \mathcal{L}_{higgs\ potential} &= \mu^2 H_1^2 + \mu^2 H_2^2 && \text{(C.1)} \\ &\quad + G(H_1^2 - H_2^2)^2 && \text{(C.2)} \end{aligned}$$

Figure C.1: *Diagrammatic representations of parts of the supersymmetric higgs potential.*

(a)(b)(c)(d)

$$+\mu B H_1 H_2 \tag{C.3}$$

$$+M_{h1}^2 H_1^2 + M_{h2}^2 H_2^2 \tag{C.4}$$

$$+\text{"supertrace terms"}. \tag{C.5}$$

The first of these, (C.1), comes directly from the supersymmetry-respecting term $W_H = \mu H_1 H_2$ in the superpotential. On its own, (C.1) provides a contribution to the MSSM higgs potential of the quadratic form shown in Figure C.1(a). In principle, such a term could also yield a contribution like that shown in Figure C.1(b), but in practice the RGEs never run μ^2 negative. Term (C.2) is also strongly motivated, arriving as a consequence of the terms which require gauge invariance. It promotes a quartic restraint (Figure C.1(c)) except in the so-called "quartic flat" directions $H_1 = \pm H_2$, however those are restrained by the term (C.3) which is one of the soft supersymmetry breaking terms whose inclusion in the lagrangian was motivated by the maxim "*can* add; *must* add". So, by this stage, we have a BFB potential, but probably not a broken one, since μ^2 tends never to run negative. This is where term (C.4) comes in. This term contains the "soft" higgs masses, M_{hi}. In the general MSSM one has complete freedom to assign arbitrary values (positive or negative) to the squares of these masses, and this freedom permits breaking of the supersymmetric higgs potential. In this way, the soft higgs masses play very much the role of μ in the SM. By choosing their values appropriately, the correct EWSB may be accomplished.

Thus far there is little to choose between the supersymmetric and the SM approaches. However, the same reasons which lead us to believe that the MSSM is likely to be only a low energy approximation to a theory incorporating gravity lead us to expect an organising principle behind the parameters of the MSSM. Typically, then, in models like mSUGRA, the soft higgs masses are not given arbitrary values, but are taken to unify with the other scalar masses at the GUT scale. Although this might be aesthetically pleasing, at first sight it appears to jeopardise the success of EWSB which demands imaginary, not real, soft higgs masses. Fortunately, from the GUT scale to the electroweak scale, the soft higgs mass-squareds are *run negative* by the RGEs and are usually able to break electroweak symmetry anyway.[a]

The overall effect is that a universal scalar mass M_0, at the GUT scale, ends up setting not only the mass of the higgses, but also the masses of the sleptons and the squarks. One might argue that this is still not much of an improvement over the SM; after all; there was only one scalar particle in the SM (the higgs) and μ^2 was quite able to specify *its* mass. Nevertheless, the "soft supersymmetry breaking" requirement that supersymmetry not be broken *too* badly (see Appendix A) puts limits on the permitted difference between M_0 and the universal fermion mass, $M_{1/2}$. These limits, in turn, ensure that supersymmetric higgses in universal models are relatively light (in contrast to their highly unconstrained SM counterparts).

[a]On rare occasions, for example in S2, the squares of the soft higgs masses do not run sufficiently negative to counteract the larger positive running of μ^2, and so in these cases EWSB can only be performed by the supertrace terms (C.5).

Appendix E

Abbreviations

BFB	bounded from below
EWSB	electro-weak symmetry breaking
MSSM	minimal supersymmetric standard model
mSUGRA	minimal supergravity
RGEs	renormalization group equations
SM	Standard Model

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