How light can sleptons be?

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Abstract

Several searches for production of sleptons has been performed in collider experiments such as the currently running LHC, and its predecessor LEP. In this article we investigate the limits on the slepton mass(es) set by these experiments, with special emphasis on how light sleptons are allowed to be with the current limits. We also take a look at the models used in these searches, how these compare to the MSSM, and how the limits from these searches can be related to the sleptons in the MSSM.

1 Introduction

The Minimal Supersymmetric Standard Model (MSSM) is the smallest possible supersymmetric of the Standard Model (SM). Roughly explained the MSSM introduces one superpartner for each SM particle (with some complications in the Higgs sector), and the SM particles and their superpartners (often called sparticles) differ by $\frac{1}{2}$ in spin. The sparticles we will focus on here are the superpartners of the SM leptons, which are scalar (i.e. spin-0) particles called *sleptons*, and we will focus mainly on the first two generations of charged sleptons, i.e. selectrons ($\tilde{e}$) and smuons ($\tilde{\mu}$).

In particle collider experiments, such as the Large Electron-Positron Collider (LEP) and the currently running Large Hadron Collider (LHC), several searches for production of sleptons have been done, but so far without any sign of their existence. The consequence of such "negative" searches is usually that new limits are put on the masses of the relevant sparticles (or other parameters).

In this article we will try to summarize the current status of the limits on the selectron and smuon masses. However, since the MSSM is a quite complicated model with 105 free parameters, one has to make assumptions and simplifications when setting limits, and these are (of course!) somewhat different from analysis to analysis. We will therefore also take a look at which assumptions are made in the different analyses. But before all this, let us look at how sleptons are described in the MSSM.

2 Sleptons in the MSSM

As mentioned in the introduction the sleptons are the scalar superpartners of the SM leptons. In the SM there is an important difference between left- and right-handed chiral states, in that the left-handed leptons are organized in weak isospin doublets, while the right-handed ones are singlets (i.e. they do not transform under $SU(2)_L$). This mean that, when constructing a supersymmetric theory, we need to introduce separate superpartners for the left- and right-handed leptons. For this reason we talk about left- and right-handed sleptons ($\tilde{\ell}_L$ and $\tilde{\ell}_R$) even though they are scalar particles.

This has some consequences when we are breaking SUSY. As we know, SUSY must be a broken symmetry, since otherwise particles and sparticles would have equal masses, meaning that SUSY would have been discovered a long time ago. For the first two generations of (charged) sleptons (neglecting the Yukawa coupling) the mass is given as

$$m_{\tilde{\ell}}^2 = m_\ell^2 + (T_3 - Q\sin^2\theta_W)\cos 2\beta m_Z^2, \qquad (1)$$

where m_ℓ is the mass of the corresponding SM lepton, T_3 is weak isospin, Q is electric charge, θ_W is the Weinberg angle, β is given by the ration between the vacuum expectation values of the two Higgs doublets of the MSSM, and m_Z is the mass of the Z-boson. Interesting to notice is that $m_{\tilde{\ell}}$ depends on weak isospin, which is different for $\tilde{\ell}_L$ ($T_3 = -1/2$) and $\tilde{\ell}_R$ ($T_3 = 0$), meaning that their masses are different. The mass difference is given by

$$m_{\tilde{\ell}_L}^2 - m_{\tilde{\ell}_R}^2 = -\frac{1}{2}\cos 2\beta m_Z^2. \qquad (2)$$

By convention we have $0 < \beta < \frac{\pi}{2}$, and it is (apparently, check this!) in the MSSM a common assumption that $\tan\beta > 1$, meaning that $\cos 2\beta < 0$, so

$$m_{\tilde{\ell}_L}^2 > m_{\tilde{\ell}_R}^2.$$

3 Slepton production in particle colliders

The MSSM is usually defined as conserving R-parity, given as

$$R = (-1)^{2s+3B+L},$$

where s is spin, B is baryon number and L is lepton number. This has the interesting consequences that sparticles will always be produced in pairs in particle colliders, the lightest sparticle (LSP) will be stable, and all other sparticles will (possibly via multiple steps) decay to the LSP. Conservation of R-parity (and some other quantum numbers) means that slepton searches target production of $\tilde{\ell}^+\tilde{\ell}^-$, and it is a very common assumption that the LSP is the lightest neutralino, $\tilde{\chi}_1^0$, which is an excellent candidate particle for dark matter. Often sleptons are assumed to decay directly to $\tilde{\chi}_1^0$, plus the corresponding SM lepton. The mass difference,

$$\Delta m = m_{\tilde{\ell}} - m_{\tilde{\chi}_1^0}, \tag{3}$$

is in this case quite important, since it basically determines the momentum of the lepton, which is what you observe in the detector. Scenarios with small Δm is in some experiments hard to study.

In hadron colliders, such as the LHC, the cross section for slepton production is expected to be quite small, since the production of coloured (s)particles should be dominant in such machines. However, if coloured sparticles are sufficiently heavy, production of sleptons (and other electroweak sparticles) could be the leading SUSY production channel. At leading order a pair of sleptons can be produced through $q\bar{q}$ annihilation to a virtual Z/γ, which splits into $\tilde{\ell}^+\tilde{\ell}^-$ (s-channel). In lepton colliders there is a similar s-channel, only with e^+e^- annihilation, but in addition there is also a t-channel with neutralino exchange available at leading order.

4 Slepton mass limits

Now that we have introduced some theory and phenomenology concerning sleptons it is time to move into the more experimental details. We will mainly focus on searches done at LEP and the LHC, as the best current limits stems from these experiments. We will take a look at what the actual limits are, and which assumptions that are made in the various searches.

4.1 LEP

The Large Electron-Positron collider (LEP) was a 27 km e^+e^- collider at CERN running between 1989 and 2000, and is still the most powerful lepton collider ever built, with a peak energy of 209 GeV. Although this is much less than the energy at which the LHC collides protons, and the total delivered luminosity is much smaller than in the LHC, it is interesting to notice that the LEP experiments still has the most general limits on the masses of both selectrons and smuons.

An absolute lower limit on the selectron masses, $m_{\tilde{e}_L}$ and $m_{\tilde{e}_R}$, within the MSSM is set by the ALEPH experiment in ref. [1] to be

$$m_{\tilde{e}_R} > 73 \text{ GeV},$$
$$m_{\tilde{e}_L} > 107 \text{ GeV},$$

assuming R-parity conservation, and that $\tilde{\chi}_1^0$ is the LSP. It is also assumed that scalar masses and gaugino masses are unified to m_0 and $m_{1/2}$ respectively at GUT scale, and that $\tan\beta > 1$, as mentioned previously. Finally, mixing between $\tilde{e}_L$ and $\tilde{e}_R$ is neglected. It is however noteworthy that these limits are for *any* Δm (see eq. 3).

4.2 LHC

5 Simplified models vs the MSSM

6 Conclusions

References

[1] A. Heister et al. (2002), Phys.Lett. B544, 73-88. https://inspirehep.net/record/591226

[2] J. Abdallah et al. (2003), Eur.Phys.J.C31, 421-479. http://inspirehep.net/record/632738