Collider Signatures of SuperWIMP Warm Dark Matter

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SuperWeakly-Interacting Massive Particles (superWIMPs) produced in the late decays of other particles are well-motivated dark matter candidates and may be favored over standard Weakly-Interacting Massive Particles (WIMPs) by small scale structure observations. Among the most promising frameworks that incorporate superWIMPs are R-parity conserving supersymmetry models in which the lightest supersymmetric particle (LSP) is the gravitino or the axino. In these well-defined particle models, astrophysical observations have direct implications for possible measurements at future colliders.

1. INTRODUCTION

The dark matter (DM) problem is a one of the longstanding puzzles in basic science. Galaxy rotation curves, galaxy motions in clusters and, more recently, precise measurements of the Cosmic Microwave Background (CMB) radiation [1], Type Ia supernovae [2], large scale distribution of galaxies [3] and Lyα clouds [4] agree that the Universe contains approximately five times more exotic matter than ordinary. The standard candidates for DM are Weakly-Interacting Massive Particles (WIMPs). These emerge naturally in several well-motivated particle physics frameworks, such as supersymmetry [5], universal extra dimensions [6] and brane-worlds [7, 8]. With masses and interactions at the electro-weak scale, these are naturally produced with the correct DM abundance. Furthermore, they behave as cold DM, which means that they explain successfully the large scale structure of the Universe.

SuperWeakly-Interacting Massive Particles (SuperWIMPs) appear naturally in the same well-motivated scenarios and their DM abundance is also naturally the observed one, since they are produced in the decays of WIMPs and naturally have similar masses. The cosmological and astrophysical consequences of superWIMPs are, however, very different from those of WIMPs. Consider, for example, minimal supergravity (mSUGRA). In the WIMP scenario, the stau lightest supersymmetric particle (LSP) region is excluded cosmologically. In the remaining region the neutralino is the LSP. Much of the neutralino LSP region is excluded because neutralinos are overproduced, but some of this region is allowed. In contrast, in the superWIMP case, where, for instance, the gravitino or the axino is the lightest supersymmetric particle (LSP), the region in which the stau is the lightest standard model superpartner is very interesting, since late decays of staus to gravitinos or axinos can impact Big Bang nucleosynthesis (BBN) and possibly even resolve the ^{7}Li problem [9]. At the same time, much of the neutralino region is disfavored since neutralinos typically have two-body decays that produce hadrons, which destroy BBN successes. In fact, in the neutralino region, the region excluded by overproduction in the WIMP scenario are the most interesting in the superWIMP one, since the abundance of the dark matter is reduced by the ratio of WIMP to superWIMP masses when the WIMPs decay.

2. SUPERWIMP SIGNATURES

SuperWIMPs signals are completely different from the WIMP ones [9–15]. As noted above, late decays to superWIMPs have implications for BBN. At the same time, late decays can also distort the Planckian spectrum of the Cosmic Microwave Background, which means that new experiments like ARCADE and DIMES can find evidence for these particles.

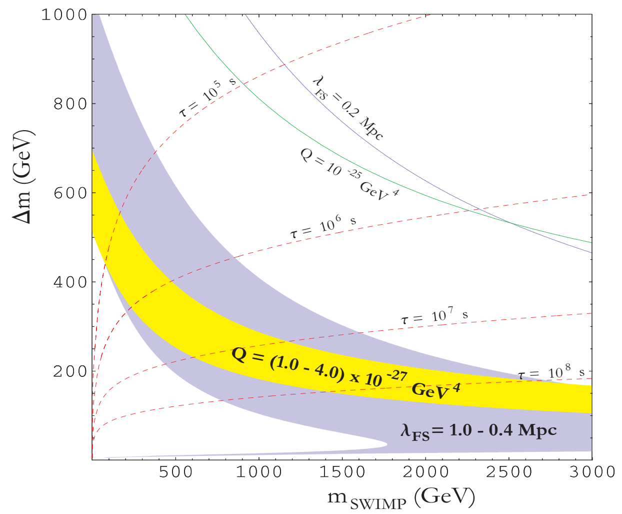

Figure 1: Regions (shaded) of the $(m_{\rm SWIMP}, \Delta m)$ plane preferred by small scale structure observations, where $\Delta m \equiv m_{\rm NLSP} - m_{\rm SWIMP}$, for gravitino superWIMPs with sneutrino NLSPs. The regions under both bands are disfavored. In the regions above both bands, superWIMP DM becomes similar to cold DM. Contours of typical lifetimes $\tau_{\tilde{\nu}}$ are also shown [18].

SuperWIMP scenarios also differ from WIMP scenarios in their implications for structure formation in the Universe. Because superWIMPs are produced with large velocities in late decays, they can behave as warm DM and resolve some apparent discrepancies of observations with cold DM. Comparing some simulations with observations, WIMPs predict overdense cores in galactic halos, one or two orders of magnitude more dwarf galaxies in the Local Group than observed, and disk galaxies with less angular momentum. The velocity and angular momentum of DM halos can be increased naturally in superWIMP scenarios. As shown in Figure 1 from Ref. [18], this has been supported by analyses of phase space densities and studies of damping in the power spectrum [18–20].

The collider phenomenology of superWIMPs have been analyzed from different points of view [21–26]. We have studied the small scale structure consequences of pure superWIMP DM scenarios. These analyses show that superWIMP signals can be observed even in the ILC not only for the warm DM case, but also of the cold DM one.

Because superWIMP scenarios are most naturally accompanied by charged particles that decay after seconds to months, it has been proposed that these charged particles can be trapped outside of the particle physics detector so that their decays can be studied. A liquid trap can be used to stop the charged particles so they can be transported to a quiet environment [23], and an active stationary detector/trap has also been proposed [24]. The liquid trap will cost less and allow for transportation to a clean, low background environment but will be incapable of measuring the shorter range of the lifetimes. The active detector can measure almost the entire range of the lifetimes, but must differentiate late decays from backgrounds from the high energy experiment and cosmic rays. Both methods of trapping can be optimized by choosing the correct shape and placement of the traps to catch the maximum number of the meta-stable charged particles. By trapping many charged particles and studying their decays, the properties of the decay products may be indirectly constrained, providing an accurate identification of the LSP and superWIMP DM.

3. CONCLUSIONS

We have examined the implications of superWIMPs, whose behaviour is, in general, very different to WIMPs. Analyses of astrophysical data constrain superWIMP scenarios, and also motivate some spectacular possibilities for collider signatires of new physics.

If DM is composed of superWIMPs, charged slepton NLSPs, or similar particles, will appear stable because of the length of its lifetime. This superWIMP signature could be studied at both the LHC and the ILC.

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