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Bottom quark contribution to spin-dependent dark matter detection

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Abstract

We investigate a previously overlooked bottom quark contribution to the spin-dependent cross section for Dark Matter (DM) scattering from the nucleon. While the mechanism is relevant to any supersymmetric extension of the Standard Model, for illustrative purposes we explore the consequences within the framework of the Minimal Supersymmetric Standard Model (MSSM). We study two cases, namely those where the DM is predominantly Gaugino or Higgsino. In both cases, there is a substantial, viable region in parameter space ($m_{\tilde{b}} - m_\chi \lesssim \mathcal{O}(100)$ GeV) in which the bottom contribution becomes important. We show that a relatively large contribution from the bottom quark is consistent with constraints from spin-independent DM searches, as well as some incidental model dependent constraints.

1. Introduction

The existence of non-baryonic Dark Matter (DM) has been established by many astronomical observations [1,2]. Amongst the many candidates for DM, the so-called Weakly Interacting Massive Particles (WIMPs), which would have a mass in the range $\mathcal{O}(1)$ GeV–$\mathcal{O}(1)$ TeV, are one of the most attractive. These particles would only interact with Standard Model (SM)

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particles through weak interactions (and gravity), in order to yield a DM relic density consistent with measurement $\Omega_{\mathrm{DM}}h^2 = 0.1199 \pm 0.0027$ [3].

Direct detection of DM relies on observing the recoil energy after scattering from normal matter through weak interactions. Several DM direct detection experiments have claimed a possible excess, namely DAMA [4], CoGeNT [5], CRESST [6] and CDMS [7]. On the other hand, these results are challenged by the absence of signals at XENON100 [8] and LUX [9], as well as CDMSlite [10] in the light DM region. The coherent, spin-independent (SI) interaction between a DM particle, generically labelled χ, and a nucleus is proportional to the nucleon number. Because of the relatively heavy nuclei chosen for most of the above mentioned experiments, both the observed excess and stringent exclusion limits are based on SI χ–p scattering.

As for spin-dependent (SD) DM detection [11], in a simple shell model the spin of the nucleus is that of a single, unpaired nucleon. As a consequence, the matrix element for SD χ-nucleus scattering will be roughly comparable with that for SI χ-nucleon scattering, with no enhancement by the nucleon number. As a result, the current DM direct searches place only very loose bounds on the SD cross section [12–14].

In the standard calculation of SD DM-nucleon scattering the heavy quark contribution is usually neglected. That is, only the contributions from Δu, Δd and Δs are included. However, as explained in the context of the proton weak charge [15], the usual decoupling of heavy quarks through the Appelquist–Carrazone theorem [16] does not apply to quantities influenced by the $U(1)$ axial anomaly [17–21]. In that case, rather than being suppressed by inverse powers of the heavy quark mass, the suppression is only logarithmic. These logarithmic corrections were studied in considerable detail by Bass et al. in Refs. [15,22,23], at both leading and next-to-leading order. As we shall explain here, there are interesting scenarios of supersymmetry (SUSY), generally involving a relatively light sbottom, where the logarithmic radiative correction involving the b-quark that is further enhanced by resonant effect may make a significant contribution to SD DM-nucleon scattering.

Indeed, SUSY [24,25] is widely believed to provide the most promising explanation for new physics beyond SM. In SUSY models with R-parity conservation, the lightest supersymmetric particle (LSP) is stable and can become a DM candidate. On the other hand, both the LHC SUSY searches [26,27] and naturalness arguments [28,29] suggest that only the third generation supersymmetric quarks (squarks) can be light. In Ref. [30], it has been argued that an sbottom with a mass as light as $\sim \mathcal{O}(15)$ GeV might still be consistent with current searches. In other models, such as the simplified model framework [31] and flavored DM models [32,33], the DM can only couple to the bottom quark, as motivated by the recent DM indirect signals [34]. Studying the bottom quark contribution to the DM-nucleon SD cross section is crucial in models of this type.

In this work, we focus on the Minimal Supersymmetric Standard Model (MSSM) with a relatively light sbottom, showing when and how the bottom contribution becomes important. When the DM is Wino, there is no coupling between DM and the Z-boson and only squark mediated processes can contribute to χ-nucleon scattering. We investigate the parameter space where the sbottom contribution is comparable to, or larger than, the first generation squark contribution. When the DM is Higgsino, the first two generation squark mediated processes are greatly suppressed by their small Yukawa couplings. However, the Higgsino can couple to the Z-boson. The constructive and destructive interference effects between Z and sbottom ($\tilde{b}$) mediated processes are discussed in detail for a number of variations on the structure of the neutralino.

Any sbottom mediated process that contributes to the SD scattering cross section can also contribute to SI scattering. We consider the stringent LUX constraint on SI DM detection for light sbottom scenarios of interest. A relatively large SD bottom contribution can indeed be