Annals of Physics 326 (2011) 1501–1514

Contents lists available at ScienceDirect

Annals of Physics

journal homepage: www.elsevier.com/locate/aop

Contributions to the muon's anomalous magnetic moment from a hidden sector

David McKeen *

Enrico Fermi Institute and Department of Physics, University of Chicago, 5640 South Ellis Avenue, Chicago, IL 60637, USA

ARTICLE INFO

Article history:
Received 26 November 2010
Accepted 28 December 2010
Available online 4 January 2011

Keywords:
Muon $g-2$
Hidden sectors
Dark matter

ABSTRACT

The measurement of the anomalous magnetic moment of the muon provides a stringent test of the standard model and of any physics that lies beyond it. There is currently a deviation of 3.1σ between the standard model prediction for the muon's anomalous magnetic moment and its experimental value. We calculate the contribution to the anomalous magnetic moment in theories where the muon couples to a particle in a hidden sector (that is, uncharged under the standard model) and a connector (which has nontrivial standard model gauge and hidden sector quantum numbers).

1. Introduction

Quantum field theory predicts that the gyromagnetic ratio of the muon will differ slightly from its tree-level value of $g_\mu = 2$. Properly accounting for the nonzero value of the anomalous magnetic moment, $a_\mu = (g_\mu - 2)/2$, of the muon is a precise test of the standard model (SM) and of physics beyond the SM.

The most recent determination of a_μ in the SM is [1]

$$a_\mu^{\rm SM} = (11659183.4 \pm 4.9) \times 10^{-10}. \quad (1)$$

The dominant sources of uncertainty in this expression are the leading-order hadronic vacuum polarization contribution and the contribution from hadronic light-by-light scattering. In Ref. [1], the leading-order hadronic contribution is determined to be

$$a_\mu^{\rm LO\ Had.} = (695.5 \pm 4.1) \times 10^{-10}, \quad (2)$$

* Present address: Department of Physics and Astronomy, University of Victoria, Victoria, BC, Canada V8P 1A1.
E-mail address: mckeen@uvic.ca

0003-4916/$ - see front matter
doi:10.1016/j.aop.2010.12.015

while the most recent determination of the hadronic light-by-light contribution is [2]

$$a_\mu^{\text{Had. LbL}} = (10.5 \pm 2.6) \times 10^{-10}. \tag{3}$$

The total SM prediction for a_μ in Eq. (1) differs from the experimental value [3],

$$a_\mu^{\text{Exp}} = (11\ 659\ 208.0 \pm 5.4 \pm 3.3) \times 10^{-10}, \tag{4}$$

at the 3.1σ level. There is some discrepancy in using e^+e^- or τ decay data to extract the leading-order hadronic contribution to a_μ with τ decay data leading to a 1.9σ difference between the SM and experimental values of a_μ. For recent reviews of the status of a_μ, see Ref. [4].

The difference between a_μ^{SM} and a_μ^{Exp} has spurred numerous studies of new physics scenarios that could offer an explanation, for example, supersymmetry [5], universal extra dimensions [6], and unparticles [7]. Another scenario that has received attention in the literature is that of a hidden $U(1)'$ whose gauge boson kinetically mixes with the photon [8]. The constraints from a_μ on such a scenario are discussed in [9].

In this paper we investigate and catalogue the contributions to a_μ that arise from the muon coupling to some hidden sector. We do this in four situations that differ in the spin of the hidden sector particle that couples to the muon, and in the spin of other particles present in the interaction to preserve gauge invariance. These scenarios are generalizations of some models already investigated, like that of [9].

Schematically, the interactions we consider are of the form

$$\mathcal{L}_{\text{int}} \sim \lambda XY\mu, \tag{5}$$

where Lorentz and gauge indices have been suppressed. In this Lagrangian and in the rest of this work, X refers to a SM singlet that could be charged under some hidden symmetry group, which we denote by G, and Y is a particle that is charged under the SM (to preserve the SM gauge invariance of the interaction) and under G if X is (to preserve G invariance). The particles in Eq. (5) are classified in the table below:

Type of matter	Std. model	G	Example
Ordinary	Non-singlet	Singlet	μ
Connector	Non-singlet	Non-singlet	Y
Hidden	Singlet	Non-singlet	X

λ is the coupling strength of this interaction between the muon, the hidden sector particle X, and the connector Y. Interactions of this form generate corrections to a_μ of order λ^2.

We note that X could be a dark matter candidate. If $m_X < m_Y$ and X is the lightest particle with some hidden charge, it could be long lived. Indeed, the relic density of X could naturally be driven to the observed value of $\Omega_X \simeq 0.23$ although its mass is unconnected to the electroweak scale in a WIMPless dark matter scenario [10]. For X to be a viable dark matter candidate, it cannot be coupled too strongly to the SM; that is $\lambda \lesssim g_{\text{weak}}$. Of course, this condition is relaxed if we do not require that X comprise the most of the dark matter density. These scenarios have been studied in situations where X couples to b quarks, leading to an explanation of the DAMA/LIBRA signal [11] and to missing energy in decays of mesons with b quarks [12].

In Section 2, we discuss constraints on X and Y from collider experiments. In Section 3, we present the contributions to a_μ due to several scenarios of the form of Eq. (5). We discuss constraints from the measured value of a_μ on these scenarios in Section 4, and, in Section 5, we conclude.

2. Collider constraints on *X* and *Y*

If X is a SM singlet that is only weakly coupled to the SM, as we assume here, then there are no firm constraints on its allowed mass coming from collider experiments. We consider its mass to be essentially free in this study.