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The measurement of the muon's anomalous magnetic moment isn't

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Abstract

Recent results announced as measurements of the muon's anomalous magnetic moment are in fact measurements of the muon's anomalous spin precession frequency. This precession frequency receives contributions from both the muon's anomalous magnetic and electric dipole moments. We note that all existing data cannot resolve this ambiguity, and the current deviation from standard model predictions may equally well be interpreted as evidence for new physics in the muon's anomalous magnetic moment, new physics in the muon's electric dipole moment, or both.

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Recently the Muon ($g - 2$) Collaboration announced a new measurement of the muon's anomalous magnetic moment [1]. More precisely, however, what has been measured is the muon's anomalous spin precession frequency. This receives contributions from both the muon's anomalous magnetic and electric dipole moments, and we point out that the reported data and all existing constraints cannot distinguish between the two.

The recent result is the latest *tour de force* from the Muon ($g - 2$) experiment [2]. This experiment measures the anomalous spin precession frequency of muons circulating in a perpendicular and uniform magnetic field. For fermions with gyromagnetic ratio $g = 2$, the cyclotron and spin precession frequencies are identical. Measurements of the anomalous spin precession frequency have therefore been reported as measurements of the anomalous magnetic dipole moment (MDM) $a_\mu = (g_\mu - 2)/2$.

The spin precession frequency is also sensitive to the muon's electric dipole moment (EDM), however [3,4]. For a muon traveling with velocity β perpendicular to both a magnetic field \mathbf{B} and an electric field \mathbf{E} ,

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the anomalous spin precession vector is

$$\begin{aligned} \boldsymbol{\omega}_a = & -a_\mu \frac{e}{m_\mu} \mathbf{B} - d_\mu \frac{2c}{\hbar} \boldsymbol{\beta} \times \mathbf{B} \\ & - \frac{e}{m_\mu c} \left(\frac{1}{\gamma^2 - 1} - a_\mu \right) \boldsymbol{\beta} \times \mathbf{E} - d_\mu \frac{2}{\hbar} \mathbf{E}, \end{aligned} \quad (1)$$

where m_μ and d_μ are the muon's mass and EDM. In recent experiments, the $\boldsymbol{\beta} \times \mathbf{E}$ term of Eq. (1) is removed by running at the 'magic' $\gamma \approx 29.3$, and the last term is negligible. For highly relativistic muons with $|\boldsymbol{\beta}| \approx 1$, then, the anomalous spin precession frequency is

$$|\boldsymbol{\omega}_a| \approx |\mathbf{B}| \left[\left(\frac{e}{m_\mu} \right)^2 a_\mu^2 + \left(\frac{2c}{\hbar} \right)^2 d_\mu^2 \right]^{1/2}, \quad (2)$$

and it constrains only a *combination* of d_μ and a_μ .

In Fig. 1 we show regions of the (d_μ, a_μ) plane that are consistent with the new $|\boldsymbol{\omega}_a|$ measurement. Also shown are the latest standard model (SM) predictions [5–7]. Assuming a negligible d_μ , the measurement shows tentative evidence for new physics in a_μ with uncertain significance, given the spread in theoretical predictions. However, the $|\boldsymbol{\omega}_a|$ result could just as well be taken as evidence for new physics in d_μ . The best direct bound on d_μ [3] is also shown. Clearly it does not resolve this ambiguity; if anything, it favors the EDM interpretation. In fact, even taking the lowest SM prediction for a_μ , a striking and unambiguous conclusion is that, barring a fine-tuned cancelation, the Muon ($g - 2$) experiment has now set the most stringent upper bound on the muon's *electric* dipole moment with $|d_\mu| < 3.2 \times 10^{-19} e \text{ cm}$.

The MDM/EDM ambiguity may be resolved by appealing to theoretical prejudice that d_μ is small. In supersymmetry, for example, the maximal value of a_μ is $a_\mu^{\text{max}} \sim 10^{-7}$, assuming only flavor conservation [8]. By a phase rotation of the relevant operator, this implies a maximal EDM of roughly $d_\mu^{\text{max}} \sim (e\hbar/2m_\mu c) a_\mu^{\text{max}} \sim 10^{-20} e \text{ cm}$. This conclusion is far from universal, however. For example, large muon EDMs are possible in models where EDMs scale approximately as $d_f \propto m_f^3$ [9]. Given our current profound ignorance of the origins of electroweak symmetry breaking, flavor, and CP violation, no definitive statement can be made.

The effects of d_μ and a_μ are, of course, distinguishable [3]: a_μ causes precession around the mag-

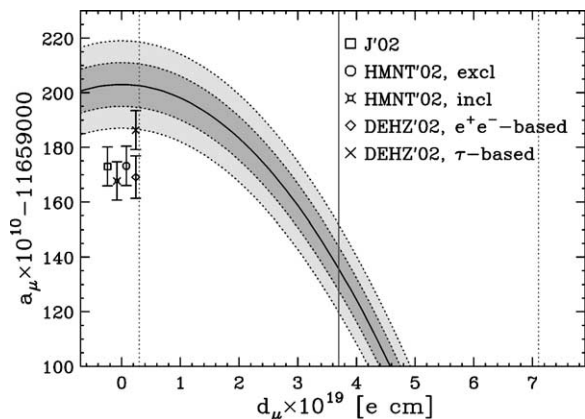


Fig. 1. Regions of the (d_μ, a_μ) plane consistent with the measured $|\boldsymbol{\omega}_a|$ at 1σ (dark) and 2σ (light). The most recent SM a_μ predictions [5–7] are also shown, with horizontal offsets to the SM prediction of $d_\mu \approx 0$ inserted for clarity. The vertical lines are the central value and $\pm 1\sigma$ direct bounds on d_μ [3].

netic field's axis, but d_μ leads to oscillation of the muon's spin above and below the plane of motion. A search for up-down asymmetry in the current data is in progress [10]. A dedicated EDM experiment [11] would provide a conclusive resolution by either measuring a non-vanishing d_μ or constraining the contribution of d_μ to $|\boldsymbol{\omega}_a|$ to be insignificant.

For now, however, the reported data is not a model-independent measurement of the muon's anomalous magnetic moment. If measurements of precession frequency are interpreted as measurements of a_μ , the assumption of a negligible muon EDM is best made explicit. Alternatively, the experimental status may be summarized without theoretical assumptions as in Fig. 1.

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