remarkable property of the SM is that the FCNC processes take place only at higher orders in perturbation theory and thus their rates are suppressed. This way, the SM provides an explanation of the extremely small branching fractions ($\sim 10^{-7}$) of these processes.

There is of course no guarantee that the new physics that might be responsible for this deviation will also share the same property. In fact, in many models, such FCNC processes arise at lower orders of the couplings. However, in that case, in order to be consistent with the experimentally measured small branching fractions, either the new heavy particles associated to such new interactions have to be quite heavy (tens of TeV) or the new couplings associated to such new interactions must be unnaturally small. On the other hand, if the new physics is SM-like (in the sense that the FCNC processes still take place at higher order in the couplings), then the new particles can be rather light (close to a TeV) even when the new couplings are not too small. So the good news is that, if the R_K value is indeed due to new physics, the heavy particles responsible for it must have masses in the range between a TeV and tens of TeV. Hence, the LHC or the next high energy collider should be able to discover these new particles directly.

If one is too concerned about the possibility of an experimental oversight in the measurement of R_K, the encouraging facts are that (i) within a year or two there will be new measurements or updates of some other observables closely related to R_K, (ii) The BELLE II experiment will independently verify the LHCb result in 4–5 years and, finally, (iii) the LHC run 3 is also coming soon enabling LHCb to update their measurement with a lot more data.

It is noteworthy that the recent measurement[4] of the Landé *g*-factor of the muon at Fermilab has also amplified the exhilaration that physics associated with muons might indeed be hanging over the SM like a sword of Damocles.

Finally, although I have focused on R_K here, in recent years the LHCb collaboration has reported hints of new physics in a few other observables too. At the moment it is quite premature to firmly claim those as signals of new physics; but one should keep a close eye on them as experiments collect more data in the future and theorists reduce the uncertainties in their SM calculations.

So, while the recent LHCb update has raised questions about the redoubtable SM, the jury is still out, and we may be tantalizingly close for a special scientific treat in the near future.

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Wobbling muons deepen fundamental mystery

Who has not been intrigued as a child by a bar magnet? For many among us, the innocuous magnet was our first foray as children into the fascinating world of science and its alluring mysteries. Even in the world of sub-atomic particles, the endowed intrinsic magnetic moments of particles continue to furnish important insights into the fundamental constituents and forces of our universe.

Elementary particles, such as electrons and their heavier cousins muons, as well as composite particles, such as protons and neutrons (which are bound states of elementary quarks), are all bestowed with intrinsic magnetic moments. The exact values of these intrinsic magnetic moments can serve as a test of the underlying theory – the Standard Model (SM) of particle physics, which gives a unified description of the electromagnetic, weak nuclear and strong nuclear interactions. Apart from this, they may also give us a peep into new physics beyond SM that we are currently ignorant about. The latter belief is driven by the incontrovertible observation of dark matter, dark energy, matter–antimatter asymmetry and other puzzles in the universe, to which we do not currently have a complete answer in any of the present frameworks.

We learn from basic electromagnetic theory that a loop of wire carrying a current generates a magnetic moment. Surprisingly, for elementary fermions, initial measurements of their intrinsic magnetic moments ($\vec{M}$) gave a value about twice that expected from a naive analogy with a current-carrying loop. In other words, the particle's gyromagnetic ratio or *g*-factor (*g*), defined via the relation $\vec{M} = g(q/2m)\vec{S}$ for a particle of charge q, mass m and carrying spin $\vec{S}$, was found to be $g = 2$, rather than $g = 1$. This was subsequently understood as a consequence of their spin-1/2 nature, in the quantum mechanical framework consistent with special theory of relativity, put forward by Paul Dirac.

The basic strategy in most of the experiments is to measure the magnetic moment from the precession – the wobbling of the spin axis – as the particle travels around a ring in the presence of a magnetic field. More precise experimental measurements later revealed that for electrons, the value, in fact, deviated slightly from $g = 2$ – hence the nomenclature *anomalous* magnetic moment for $(g-2)/2$ – with the actual value being closer to $g = 2.00232$. An explanation for this deviation was absent in the old Dirac theory and had to await further theoretical advances.

The advent of quantum field theories, more correctly interpreting and unifying the principles of quantum mechanics and special relativity, brought new physics insights along with it – such as the presence of virtual particle creation and annihilation, absent in the earlier Dirac framework. Importantly, it also enabled meticulous theoretical calculations. It was realized gradually that the quantum field theoretic corrections, involving virtual particles appearing and disappearing into the vacuum, would give corrections to intrinsic particle properties. The effect of these quantum fluctuations, in a very loose sense, is analogous to the effect of a dielectric material enclosing an electric charge. The first detailed theoretical computation including some of these quantum corrections, for elementary spin-1/2 particles, was performed by Julian Schwinger in 1948 in the emerging framework of quantum electrodynamics (QED). He computed that the leading correction to the electron anomalous magnetic moment has a value $\alpha/2\pi$, where α is the electromagnetic fine structure constant. This was one of the early triumphs of quantum field theory and its ability to make precise predictions – it explained the then measured value of $g = 2.00232$ beautifully.

Since these initial endeavours, the precision in both experiment and theory has progressed by leaps and bounds. The exquisite theoretical precision we have achieved, in the SM framework, has enabled detailed comparison to measurements – to many, many decimal places! For example, the current prediction and measurement of the electron's anomalous magnetic moment stand at 0.001159652181606(229) and 0.00115965218073(28) respectively[1]. The difference is only at the level of $0.88(36) \times 10^{-12}$, corresponding to about twice the margin of the combined error. The quantum corrections now include numerous contributions from Higgs, QED, weak and strong nuclear interactions. The above prediction, for instance, involves QED corrections as an expansion in the electromagnetic fine structure constant all the way to α^5. The α^5 contributions just by themselves require computation of close to 12,672 Feynman diagrams!

The first hint of a discrepancy between theoretical calculations in the SM and measurement of muon's magnetic moment appeared from the E821 experiment at the Brookhaven National Lab in 2001. Their measured value disagreed with the then tour de force theoretical calculations at the eighth decimal place! The E821 observed value overshot the theoretical prediction by nearly three times the margin of error. This was interesting – as any new, unknown particles or interactions could also potentially contribute to the quantum corrections and raise the value. Since the muon is about 200 times heavier than the electron, the muon's sensitivity to these effects is about 40,000 times larger relative to electrons. After subsequent checks, fixing few theoretical errors, and accumulation of more data, the disagreement still remained at about twice the margin of error until the termination of the experiment.

Since 2013, the Fermi National Accelerator Laboratory, near Chicago, has taken on the mantle of measuring the muon's magnetic moment even more precisely, with the aim of getting to the bottom of the mystery. In April of this year, they released their first result[2]. And we find that the plot thickens! While in agreement with the earlier measurements, the combined value is still in disagreement with updated theoretical calculations by about four times the margin of error. The discrepancy between prediction and measurement in the muon's case now stands at $251(59) \times 10^{-11}$. For comparison, the corresponding net electroweak contribution is only $153.6(1.0) \times 10^{-11}$. On the one hand, this could be the preliminary indications of new physics. On the other hand, it could be pointing towards some deficiency in how we are incorporating certain contributions from particles subject to the strong nuclear force. In the latter case, ordinary perturbative analysis is insufficient, and one has to use other techniques to glean the contributions. The jury is still out.

The new result from Fermilab and the long-standing discrepancy between measurement and theory for muon's magnetic moment, therefore, presages interesting times ahead, whatever the final resolution may be.

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