Paper of the month special edition: Fermilab muon g-2 results

The result of the *Muon g-2 Experiment*, long-awaited by the physics community, has provided more insight on the twenty years old anomaly in the value of the muon gyromagnetic factor g.

The g-factor, together with the charge and the mass, defines the intrinsic magnetic dipole moment of an elementary particle. Dirac equation predicts $g = 2$, but it was soon realised that additional contributions coming from virtual Standard Model (SM) particles slightly correct this value, correction quantified through the anomaly parameter $a = (g-2)/2$. The most recent computation of the muon $g-2$ has been performed within the SM by Aoyama et al. (2020), obtaining $a_\mu(\mathrm{SM}) = 116591810(43) \times 10^{-11}$ (0.37 ppm). The corresponding g_μ value is shown in Figure 1 as *SM HVP Data driven*. To reach this precision, their computation includes $\mathcal{O}(\alpha^5)$ QED effects, two-loops order electroweak corrections as well as the hadronic contributions coming from the hadronic vacuum polarization (HVP) and the hadronic light-by-light scattering. The latters provide the largest source of error in the theoretical prediction of a_μ and are addressed with a data-driven approach.

On the experimental side, the strategy to measure the g-factor relies on the spin precession around an external magnetic field. Relativistic polarized muons are set on circular orbits in a magnetic field, where the momentum precesses at the cyclotron frequency $\vec{\omega}_c = -q\vec{B}/m\gamma$. At the same time, the muon magnetic moment makes the spin precess around $\vec{B}$ at a frequency $\vec{\omega}_s = -q\vec{B}/m \times (g_\mu/2 + (1-\gamma)/\gamma)$, thus the relative precession frequency $\vec{\omega}_a = \vec{\omega}_s - \vec{\omega}_c = -a_\mu q\vec{B}/m$ provides exactly the anomaly parameter. The frequency $\vec{\omega}_a$ is measured exploiting the weak decays of the muons, that produce positrons whose energy spectrum is modulated at the very same frequency $\vec{\omega}_a$: the highest energy positrons are emitted if the muon's momentum and spin are aligned.

The most precise measurement of the muon's $g-2$, before the Fermilab result, has been performed at the Brookhaven National Laboratory (BNL) (Bennett et al. (2006)) with the result $a_\mu(\mathrm{BNL}) = 116592080(63) \times 10^{-11}$ (0.54 ppm), which is larger than the SM prediction by 3.7σ (see Figure 1).

The new result from the E989 Experiment at Fermilab (FNAL), $a_\mu(\mathrm{FNAL}) = 116592040(54) \times 10^{-11}$ (Abi et al. (2021); Albahri et al. (2021a,b)), represents an independent confirmation of the BNL value, with an improved uncertainty of 0.46 ppm. Combining the two experimental results, the world average muon anomalous magnetic moment is $a_\mu(\mathrm{EXP}) = 116592061(41) \times 10^{-11}$, and is found to be in a 4.2σ tension with the SM prediction. The average value is shown in Figure 1 as *EXP Avg*.

The putative $g-2$ anomaly opens up different possible scenarios. On the one hand, the most recent lattice determination of the HVP by Borsanyi et al. (2021) finds $a_\mu^{\mathrm{HVP}} = 707.5(5.5) \times 10^{-10}$, value slightly larger than the data-drive result that brings the theoretical value closer to $a_\mu(\mathrm{EXP})$. The associated theoretical prediction is shown in Figure 1 as *SM HVP Lattice*. On the other hand, beyond the SM physics could be the origin of the currently observed deviation, hinting at a new physics scale below the TeV (Czarnecki and Marciano (2001)). These new particles would represent an accessible target for future colliders, prospecting an exciting time for particle physicists.

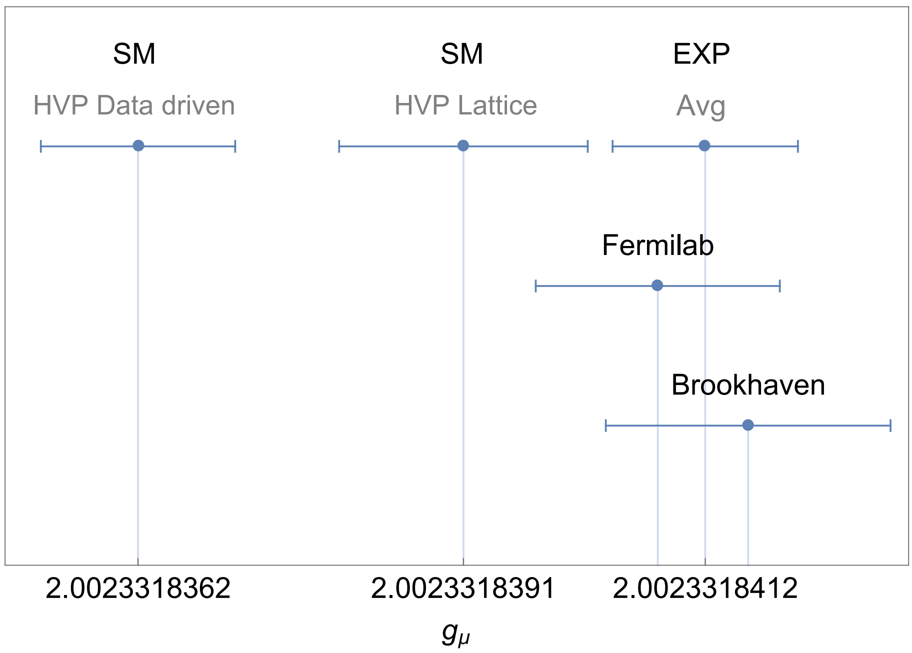

Figure 1: Values of the muon g-factor. 1σ error bars are shown.

Bibliography

B. Abi et al. Measurement of the Positive Muon Anomalous Magnetic Moment to 0.46 ppm. *Phys. Rev. Lett.*, 126:141801, 2021. doi: 10.1103/PhysRevLett.126.141801.

T. Albahri et al. Measurement of the anomalous precession frequency of the muon in the Fermilab Muon g-2 experiment. *Phys. Rev. D*, 103:072002, 2021a. doi: 10.1103/PhysRevD.103.072002.

T. Albahri et al. Magnetic Field Measurement and Analysis for the Muon g-2 Experiment at Fermilab. *Phys. Rev. A*, 103: 042208, 2021b. doi: 10.1103/PhysRevA.103.042208.

T. Aoyama et al. The anomalous magnetic moment of the muon in the Standard Model. *Phys. Rept.*, 887:1–166, 2020.

G. W. Bennett et al. Final Report of the Muon E821 Anomalous Magnetic Moment Measurement at BNL. *Phys. Rev. D*, 73:072003, 2006.

S. Borsanyi et al. Leading hadronic contribution to the muon 2 magnetic moment from lattice QCD. *Nature*, 2021.

A. Czarnecki and W. J. Marciano. Muon anomalous magnetic moment: A harbinger for “new physics”. *Phys. Rev. D*, 64: 013014, Jun 2001.