While very successful in many aspects, the Standard Model of particle physics (SM) leaves a couple of important questions unanswered. On the one hand, it predicts an amount of matter that survived annihilation after the Big Bang that is many orders of magnitude less compared to what is observed. In addition, since masses of matter particles appear as parameters in the SM, it does not provide any understanding why the values of these masses span so many orders of magnitude. In addition, within the SM phenomena like Dark Matter and Dark Energy can not be explained. These and some more issues suggest that there must be physics beyond the SM, and many experiments world-wide hunt for signals of it.

One of the currently most promising candidates to provide a signal for physics beyond the SM is the muon anomaly $a_\mu = (g-2)/2$. It is a low-energy observable, which can be both measured and computed to high precision [1, 2]. The present experimental value $a_\mu^{EXP} = 1\ 165\ 920\ 89(63) \times 10^{-11}$ comes from the BNL E821 experiment [3]. This value deviates from the SM prediction by about 3 standard deviations $\Delta a_\mu^{(\mathrm{EXP-SM})} = (287 \pm 80) \times 10^{-11}$ [4] or $= (261 \pm 78) \times 10^{-11}$ [5], depending on how the leading-order hadronic contributions are evaluated. While this discrepancy is not large enough to claim a failure of the SM, it is currently the largest deviation of a SM prediction from an experimental observable. This alone justifies all efforts currently taken to improve both the theoretical as well as the experimental value. New measurements are planned within the next four years at Fermilab/USA [6] and also at JPARC/Japan [7]. The goal of the measurements is to reduce the uncertainty by a factor of four. In parallel the SM prediction needs to be improved in accuracy by at least a factor of two to establish a deviation from the SM for the first time.

The largest uncertainty of the SM prediction comes from the hadronic quantum corrections [1]. At the level of accuracy that is relevant at the moment the hadronic contributions can be split up into the hadronic vacuum polarization (HVP), displayed on the left-hand side of figure 1, and the hadronic light-by-light scattering (HLbL), displayed in the middle of Fig. 1. The most important contribution to the latter comes from the pseudoscalar pole contributions, displayed explicitly on the right-hand side of Fig. 1. For those one expects that the contribution should be largely saturated by the lightest exchange particles, namely the π^0, the η and the η'.

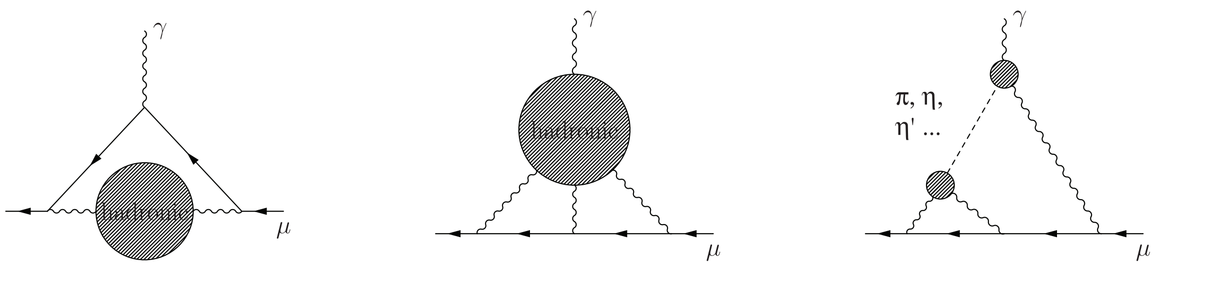

Figure 1: Hadronic contributions to a_μ: hadronic vacuum polarization (left diagram), hadronic light-by-light scattering (middle), pion-pole contribution to hadronic light-by-light scattering (right). Full lines with an arrow denote muons, wiggly lines photons, the dashed line a pseudo-scalar meson and shaded blobs a non-pointlike hadronic substructure.

Concerning the SM prediction for a_μ HLbL is suppressed relative to HVP by one power of the electromagnetic fine structure constant [1, 8]. Unfortunately at present it is not possible to straightforwardly calculate the contributions shown in Fig. 1 from first principles analogously to, e.g., the QED corrections, since both processes concern low-energy corrections, i.e. non-perturbative physics. Thus the prime candidate for a SM calculation of hadronic corrections seems to be lattice QCD [9]. However, it is not expected that lattice QCD results for HPV will reach the required accuracy in the foreseeable future. For the HLbL only preliminary lattice-QCD calculations have been reported [10]. In view of the challenges to determine a four-point function that includes in addition disconnected diagrams it is not clear yet when a profound lattice calculation with controlled uncertainties and a reliable error estimate will be available.

Fortunately there is an alternative way to quantify hadronic corrections. It requires both theoretical as well as experimental efforts: Dispersion theory provides a link between particular hadronic cross sections and a_μ—for a discussion of the HVP in this context see Ref. [1], while for HLbL we refer to Refs. [11–14]. In particular for the latter contribution it allows one to calculate from the transition form factors of the kind π^0, η, $\eta' \to \gamma^*\gamma^*$ the corresponding piece for the meson pole contribution as displayed in the right most diagram of Fig. 1. The measurements proposed here provide important information towards the necessary input needed for the evaluation of the HLbL contribution, since $\eta' \to \gamma^*\gamma$ gives the single off-shell form factor of the η' and $\phi \to \eta\gamma$ additionally provides information on the isoscalar piece of $\eta \to \gamma^*\gamma$ in a different kinematic regime. Additional information on the η and η' form factors can be found from the dispersive methods outlined in Refs. [15–19]. It appears to be realistic that this joined effort of theory and experiment will provide the improvements necessary to push the SM calculation towards the required accuracy.

Still missing: discussion on experimental status, e.g. KLOE for $\phi \to \eta e^+e^-$ [20], BESIII for $\eta' \to \gamma e^+e^-$ [21].

[1] F. Jegerlehner and A. Nyffeler, Phys. Rept. **477**, 1 (2009).

[2] T. Blum, A. Denig, I. Logashenko, E. de Rafael, B. Lee Roberts, T. Teubner and G. Venanzoni, arXiv:1311.2198 [hep-ph].

[3] G. W. Bennett *et al.* [Muon g-2 Collaboration], Phys. Rev. D **73**, 072003 (2006).

[4] M. Davier, A. Hoecker, B. Malaescu and Z. Zhang, Eur. Phys. J. C **71**, 1515 (2011) [Erratum: Eur. Phys. J. C **72**, 1874 (2012)].

[5] K. Hagiwara, R. Liao, A. D. Martin, D. Nomura and T. Teubner, J. Phys. G **38**, 085003 (2011).

[6] J. Grange *et al.* [Muon g-2 Collaboration], *Muon (g-2) Technical Design Report*, arXiv:1501.06858 [physics.ins-det].

[7] N. Saito [J-PARC $g-2$/EDM Collaboration], *A novel precision measurement of muon g-2 and EDM at J-PARC*, AIP Conf. Proc. **1467**, 45 (2012).

[8] J. Bijnens and J. Prades, Mod. Phys. Lett. A **22**, 767 (2007).

[9] C. Gattringer and C. B. Lang, Lect. Notes Phys. **788**, 1 (2010).

[10] T. Blum, S. Chowdhury, M. Hayakawa and T. Izubuchi, Phys. Rev. Lett. **114**, 012001 (2015).

[11] G. Colangelo, M. Hoferichter, M. Procura and P. Stoffer, JHEP **1409**, 091 (2014).

[12] V. Pauk and M. Vanderhaeghen, Phys. Rev. D **90**, 113012 (2014).

[13] G. Colangelo, M. Hoferichter, B. Kubis, M. Procura and P. Stoffer, Phys. Lett. B **738**, 6 (2014).

[14] G. Colangelo, M. Hoferichter, M. Procura and P. Stoffer, JHEP **1509**, 074 (2015).

[15] P. Adlarson *et al.* [WASA-at-COSY Collaboration], Phys. Lett. B **707**, 243 (2012).

[16] F. Stollenwerk, C. Hanhart, A. Kupść, U.-G. Meißner and A. Wirzba, Phys. Lett. B **707**, 184 (2012).

[17] C. Hanhart, A. Kupść, U.-G. Meißner, F. Stollenwerk and A. Wirzba, Eur. Phys. J. C **73**, 2668 (2013) Erratum: [Eur. Phys. J. C **75**, 242 (2015)].
[18] B. Kubis and J. Plenter, Eur. Phys. J. C **75**, 283 (2015).
[19] C. W. Xiao, T. Dato, C. Hanhart, B. Kubis, U.-G. Meißner and A. Wirzba, arXiv:1509.02194 [hep-ph].
[20] D. Babusci *et al.* [KLOE-2 Collaboration], Phys. Lett. B **742**, 1 (2015).
[21] M. Ablikim *et al.* [BESIII Collaboration], Phys. Rev. D **92**, 012001 (2015).