Hadronic light-by-light scattering in the muon $g-2$: impact of proposed measurements of the $\pi^0 \to \gamma\gamma$ decay width and the $\gamma^*\gamma \to \pi^0$ transition form factor with the KLOE-2 experiment

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We present a recent study [1] of the impact of proposed measurements at KLOE-2 of the $\pi^0 \to \gamma\gamma$ decay width to 1% precision and the $\gamma^*\gamma \to \pi^0$ transition form factor $\mathcal{F}_{\pi^0\gamma^*\gamma}(Q^2)$ for small space-like momenta to 6%, on estimates of the numerically dominant pion-exchange contribution to hadronic light-by-light (had. LbyL) scattering in the muon $g-2$.

Hadronic effects dominate the uncertainty in the prediction of a_μ in the Standard Model and make it difficult to interpret the current discrepancy between theory and experiment as a sign of new physics. In particular, the estimate $a_\mu^{\mathrm{had.\ LbyL}} = [(105-116)\pm(26-40)]\times 10^{-11}$ relies entirely on calculations using hadronic models which employ some form factors for the interaction of mesons with photons. To fully profit from future planned $g-2$ experiments with a precision of $\pm 15\times 10^{-11}$, these large model uncertainties have to be reduced.

Theoretical constraints and experimental measurements of the relevant form factors can help to constrain the models and to reduce the uncertainties in $a_\mu^{\mathrm{had.\ LbyL}}$. In the calculation of the pion-exchange contribution, the fully off-shell form factor $\mathcal{F}_{\pi^{0*}\gamma^*\gamma^*}((q_1+q_2)^2, q_1^2, q_2^2)$ enters, where also the pion is off-shell with momentum (q_1+q_2). On the other hand, measurements of the transition form factor $\mathcal{F}_{\pi^0\gamma^*\gamma}(Q^2) \equiv \mathcal{F}_{\pi^{0*}\gamma^*\gamma^*}(m_\pi^2, -Q^2, 0)$ are in general only sensitive to a subset of the model parameters. Thus, having a good description for the pion transition form factor is only necessary, not sufficient, in order to determine $a_\mu^{\mathrm{LbyL};\pi^0}$.

With the $\pi^0 \to \gamma\gamma$ lifetime from the PDG and current data on the transition form factor, the error on $a_\mu^{\mathrm{LbyL};\pi^0}$ is roughly $\pm 4\times 10^{-11}$, not taking into account other sources of uncertainty, e.g. related to the off-shellness of the pion. The lifetime fixes the normalization of the transition form factor at $Q^2 = 0$, a source of uncertainty in had. LbyL scattering, which has not been considered in most evaluations. Including the recent PrimEx result on the lifetime leads to a reduction of the error to $\pm 2\times 10^{-11}$. Including in addition the simulated KLOE-2 data yields a further reduction of the error to $\pm(0.7-1.1)\times 10^{-11}$. For some models, like vector-meson dominance (VMD), which have only a few parameters that are completely determined by measurements of the transition form factor, this represents the total error in $a_\mu^{\mathrm{LbyL};\pi^0}$. In other models, e.g. those based on large-N_C QCD matched to the OPE, there are parameters related to the off-shellness of the pion which dominate the total error in $a_{\mu;\mathrm{large}-N_C}^{\mathrm{LbyL};\pi^0} = (72\pm 12)\times 10^{-11}$. Note that a smaller error does not necessarily imply that a model is better, i.e. closer to reality. Maybe the model is too simplistic. The VMD model is known to have a wrong high-energy behavior with too strong damping, which underestimates the contribution, compared to the large-N_C QCD model, by 15×10^{-11}.

[1] D. Babusci et al., Eur. Phys. J. C **72**, 1917 (2012); arXiv:1109.2461 [hep-ph].

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