Status of the MUonE experiment

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The first measurement of the muon anomalous magnetic moment by the Fermilab $g-2$ experiment has confirmed the previous intriguing result of the BNL experiment. Their combination brings to 4.2σ the discrepancy with the currently accepted prediction of the Standard Model. The dominant theory uncertainty is related to the leading order hadronic vacuum polarization contribution (LO-HVP), determined by a data-driven dispersive approach, using the hadron production cross section in e^+e^- annihilation. In contrast, a recent ab initio calculation of the LO-HVP contribution, based on Lattice QCD, weakens the discrepancy with the measurement, in some tension with the data-driven estimate. In this scenario, the novel approach proposed by the MUonE project aims at a third completely independent and competitive determination of the LO-HVP contribution, achievable with an alternative method based on the measurement of the effective electromagnetic coupling in the space-like region at low momentum transfer. We will discuss the possibility of performing this measurement at CERN by a very precise determination of the shape of the differential muon-electron elastic cross section, exploiting the scattering of 160 GeV muons on atomic electrons of a low-Z target. The project status will be presented, in view of the test run on a reduced detector expected to start at the end of 2021.

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1. Introduction

On April 7 2021 the E989 experiment at Fermilab has announced a new measurement for the anomalous magnetic moment of the muon a_μ [1], confirming the previous experimental result of the E821 experiment at Brookhaven (BNL) [2] and reinforcing the discrepancy with the Standard Model (SM) prediction to 4.2σ, as it is shown in Fig.(1). In the next years, the increasing precision
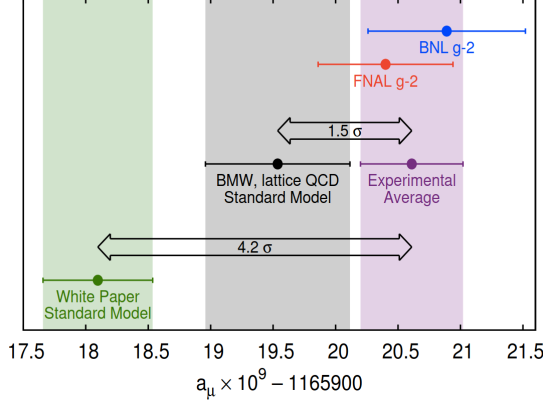
Figure 1: Experimental measurements of a_μ from BNL E821, Fermilab E989 and their average. The Muon $g - 2$ Theory Initiative recommended value [3] for the SM and the Lattice QCD result from [4] are also shown.

of the Fermilab experiment, expected to reduce the measurement error by a factor of 4, will require a similar improvement in the theoretical prediction. The biggest theoretical uncertainty is due to the leading order hadronic vacuum polarization (LO-HVP) contribution to the anomaly a_μ^{HLO} [3]. So far, the calculation of a_μ^{HLO} has been carried out with a data-driven approach based on the measurements of the cross section of $e^+ - e^-$ annihilation to hadrons. However, this method seems to have reached its precision limit and new approaches are possibly needed. Lattice QCD is becoming more and more competitive for the evaluation of the hadronic vacuum polarization contribution. A particular attention is now devoted to a recent work of the BMW collaboration [4], which obtained a result in some tension with the standard data-driven approach, as shown in Fig.(1). Therefore alternative evaluations of a_μ^{HLO} are needed to solve this dichotomy between the dispersive method and recent LQCD calculations.

In this context, the MUonE collaboration proposes an independent determination of the LO-HVP term from a precise measurement of the hadronic contribution to the running of the QED coupling in the space-like region of momenta $\Delta\alpha_{had}(t)$, with $t < 0$ [5]. The selected process to determine the running of α is the $\mu - e$ elastic scattering. The proposed experiment will take place at CERN exploiting the available M2 muon beam of $150 - 160$ GeV. The value of a_μ^{HLO} is obtained by integrating the hadronic shift of the effective electromagnetic coupling $\Delta\alpha_{had}$ in the equation:

$$a_\mu^{HLO} = \frac{\alpha}{\pi} \int_0^1 \mathrm{d}x (1 - x)\Delta\alpha_{had}[t(x)], \tag{1}$$

where the integrand is a smooth function evaluated at

$$t(x) = \frac{x^2 m_\mu^2}{x - 1} < 0. \tag{2}$$

2. MUonE experiment

MUonE aims to precisely measure the hadronic contribution to the running $\Delta\alpha_{had}$ to obtain a competitive determination of a_μ^{HLO} (Eq.1), with a uncertainty of $O(10^{-3})$. The measurement will be carried out through the evaluation of the shape of the μe scattering differential cross section on light targets (Be or C) as a function of leptons scattering angles, with a needed precision of $O(10^{-5})$. To achieve this, a modular detector [5] of 40 stations (Fig.(2)) is proposed, each one
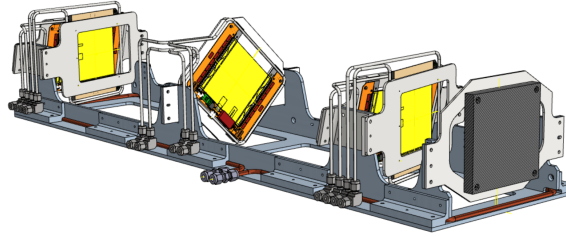
**Figure 2:** CAD drawing of a MUonE tracking station.

made of a passive element serving as target (1.5 cm) and active planes made of silicon microstrip detectors for tracking, with length of 1 m and transverse dimensions of about 10 cm. The last station is followed by an electromagnetic calorimeter (ECAL) and a muon detector at the end. This setup is expected to provide the aimed statistical accuracy in three years running, with an integrated luminosity of 1.5×10^7 nb^{-1}. The challenge is to keep the systematic error at the same level of the statistical one. It will be crucial to select elastic events with a good purity, rejecting the inelastic
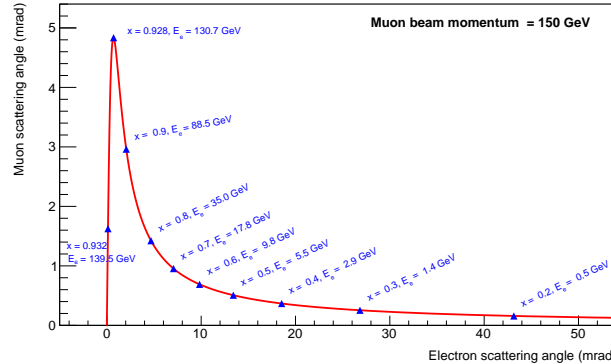
Figure 3: The red curve represents the elastic relation between the muon and electron scattering angles.

(e.g. nuclear interactions, pair production) or radiative ones. The precise correlation between the leptons scattering angles, shown in Fig.(3), will help in this selection. The expected angular ranges are $0 < \theta_\mu < 5$ mrad for the muon and $0 < \theta_e < 50$ mrad for the electron.

In 2018, a Test Beam was carried out to to study the elastic interactions of muons on atomic electrons, exploring the ability to select a clean sample of interesting events. Even if the resolution was worse than the one planned for the full experiment, it was possible to select a clean sample of elastic events [6], as shown in Fig.(4).
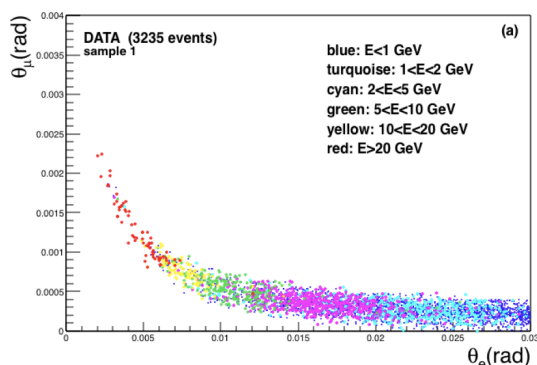
Figure 4: Kinematical correlation between the outgoing muon and electron scattering angles, with the color code representing the energy deposited in the calorimeter for measured data after selection cuts.

3. Test Run 2021-2022

The collaboration is now preparing the three-weeks Test Run planned at end of this year. It aims at the validation of the proposed setup, reduced with respect to the final one, composed by three silicon tracking stations, two targets and the $PbWO_4$ calorimeter. The feasibility of the experiment will be verified, therefore it represents an important milestone for the project, towards the final full experiment proposal. Some key points need to be established such as the mode of operation of many detector components (e.g. electronics, DAQ) or the level of the systematic uncertainties. Considering the standard SPS efficiency and full beam intensity, the two stations could potentially yield $\sim 1\ \mathrm{pb}^{-1}/day$. Considering many factors, we could in principle integrate up to $\sim 5\ \mathrm{pb}^{-1}$ of good data during a first physics run, corresponding to $\sim 10^9\ \mu e$ scattering events with $E_e > 1$ GeV. Such a data sample would have enough sensitivity to measure the leptonic running of α and, allowing some optimism, could even give initial sensitivity to the hadronic running [7].

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