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The MUonE experiment

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Summary. — The MUonE experiment aims to determine the hadronic leading-order contribution to the muon anomalous magnetic moment from a measurement of the effective QED coupling constant at space-like momenta, using muon-electron elastic scattering within CERN accelerator complex. This method is complementary to the traditional one and completely innovative. Its challenge resides in the control of the theoretical and experimental systematics at 10^{-5}, an unprecedented precision level for a scattering experiment. This proposal has been submitted to the Physics Beyond Colliders committee at CERN.

1. – Introduction

The intrinsic magnetic moment measures the coupling between particle spin and EM field, therefore generalizing the classical form:

$$\vec{\mu} = g_\mu \frac{e\hbar}{2m_\mu c}\vec{s}, \qquad g_\mu = 2(1 + a_\mu). \tag{1}$$

For a point-like charged particle $g_\mu = 2$, therefore the anomaly $a_\mu = 0$. The Standard Model (SM) takes in account a virtual process due to vacuum polarization from QED, EW theory and also QCD which modify the tree level diagram: $a_\mu^{SM} = a_\mu^{QED} + a_\mu^{EW} + a_\mu^{HAD}$. Table I shows one of the last SM previsions for these contributions and the BNL direct measurement of the so-called muon $g-2$. The disagreement is at level of 3σ (reaching 3.5–4σ depending on the SM calculation): this represents one of the major long-standing discrepancy in the actual particle physics landscape. At Fermilab, the new experiment E989 for a direct measure is running and has already reached the statistics of the previous one at BNL: its goal is to reduce the uncertainty of a factor 4 within few years. Many efforts have become necessary to achieve a better precision also from the theoretical viewpoint [1].

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Table I. – *Vacuum polarization leads to a small calculable deviation from* $g_\mu = 2$. *For* a_μ^{HLO} *the first uncertainty is experimental, the second is theoretical. MUonE proposes to reduce the experimental one at a level of* $20 \cdot 10^{-11}$.

$a_\mu^{SM} = a_\mu^{QED} + a_\mu^{EW} + a_\mu^{HAD}$	$= 116591823(43) \cdot 10^{-11}$
a_μ^{QED}	$= 116584718.95(0.08) \cdot 10^{-11}$
a_μ^{EW}	$= 153.6(1.0) \cdot 10^{-11}$
$a_\mu^{HAD} = a_\mu^{HLO} + a_\mu^{HN(N)LO}$	$= [\mathbf{6931}(\mathbf{33})(\mathbf{7}) + 19(26)] \cdot 10^{-11}$
$a_\mu^{BNL}(2004)$	$= 116592091(63) \cdot 10^{-11}$

2. – MUonE proposal

The SM prediction of hadronic contribution at muon $g-2$ needs experimental input, due to the impossibility of QCD calculations in the low-energy region, so this is the one that present the biggest errors: it cannot be determined by first principles, even if in the last years brilliant results have been obtained from lattice QCD. Until now a_μ^{HLO} was obtained from traditional measurements of e^+e^- annihilation, but it is thought that this method has reached the limit of achievable precision [1].

The MUonE collaboration proposes to rotate the Feynman diagram from annihilation to scattering process [2]: in this way the integrand function, necessary to determine a_μ^{HLO}, looks very smooth without any resonance peak in the region of interest. The master formula of this proposal:

$$a_\mu^{HLO} = \frac{\alpha}{\pi}\int_0^1 \mathrm{d}x(1-x)\Delta\alpha_{had}[t(x)], \qquad t(x) = \frac{x^2 m_\mu^2}{x-1} < 0. \tag{2}$$

The measure is conceptually simple: from the μe elastic scattering, *i.e.*, from the angular measurement the running coupling constant $\Delta\alpha_{had}$ can be extracted and so the a_μ^{HLO}, fig. 1. The challenge is twofold: from the theory side, we have to evaluate next-to-leading order (NLO) and NNLO hadronic corrections; from the experimental one, the biggest aim is to control the multiple Coulomb scattering effect (MCS) at percent level [3]: this effect smeares angular distributions out of the target. In fact muon-electron scattering will happen through the matter, not in vacuum. The goal is to achieve an experimental

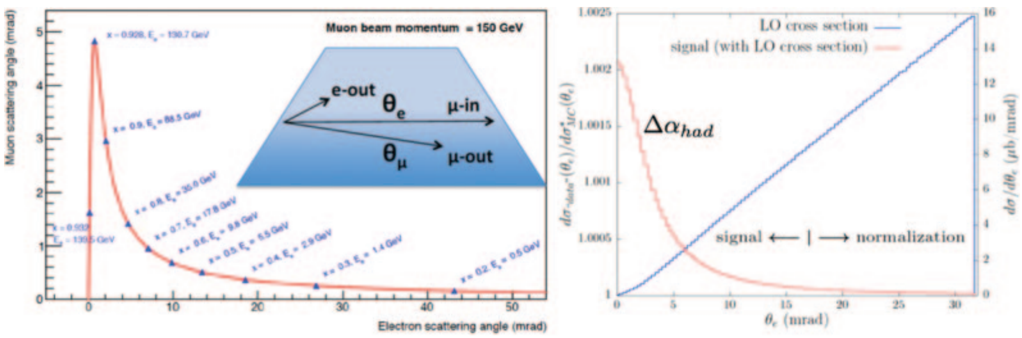

Fig. 1. – MUonE: from scattering angles to running coupling constant. The muon beam of 150 GeV will be M2, already operating at CERN.

precision at the level of the previous one (table I) in two years: thanks to the fact that the two methods (annihilation and scattering) will be independent, the MUonE will provide a fundamental cross-check of the previous theoretical evaluations and it should be able to reduce the complessive errors of SM prediction.

Waiting for Fermilab improved results on direct measure of muon $g-2$, the MUonE Collaboration is analyzing the results of two test beams carried out at CERN, the first one specific about the MCS, the other to test two modules of the final apparatus, which is in the design and optimization phase: the results will be published soon.

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