An Overview on Muon Physics

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Abstract. A summary of the present status of the charged lepton flavor violation search with muons is presented. The relevant measurements $(g-2)_\mu$, the $\mu^+ \to e^+\gamma$ decay and the direct muon-to-electron conversion projects are briefly reviewed.

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INTRODUCTION

It would be very difficult to condense a review on Muon Physics in a restricted time. Therefore I decided to review the role of the muon lepton in the quest for New Physics (NP). The NP can be pursued either by studying carefully processes well predicted by the Standard Model (SM) or by searching for processes completely forbidden in the SM. The $(g-2)_\mu$ precision measurement belongs to the former category whereas the Flavor Violation in the charged lepton sector (cLFV) belongs to the latter. In fact, even if the flavor mixing in the neutral sector has been established since one decade with the observation of neutrino oscillations, the corresponding branching ratio for the $\mu^+ \to e^+\gamma$ is in the order of 10^{-54} in the SM, i.e. practically zero. On the contrary, many models on the SUSY-GUT or SO(10) domain predict branching ratios in the order of $10^{-12}-10^{-13}$ and therefore improving on the upper limit (or even better detecting a signal) could be an unambiguous epiphany of NP. Moreover, there is a clear and very important correlation between the two processes, as shown in fig 1 taken from the paper by Isidori *et al.* [1]. The interesting physics case is well established once one realizes that the expected $\mu^+ \to e^+\gamma$ branching ratio in correspondence of the best determination so far of Δa_μ, the difference between the measured and the expected $(g-2)_\mu$ obtained by the E821 experiment, is $> \sim 0.2\cdot 10^{-11}$, namely almost within reach! Indeed it looks like great discoveries could be around the corner.

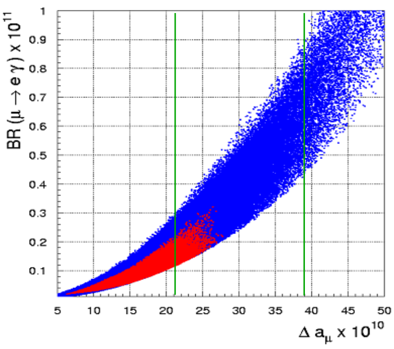

FIGURE 1. BR($\mu^+ \to e^+\gamma$) vs Δa_μ. The green lines indicate the one sigma range of the E821 experiment result. The red area represents the constraints coming from B decays.

THE $(g-2)_\mu$ PROJECTS

What is the experimental situation? The best result, so far, has been obtained by the E821 Collaboration [5] at Brookhaven at the beginning of the decade. In terms of Δa_μ, it reads $\Delta a_\mu = (297\pm 79)10^{-11}$, corresponding to an experimental accuracy on a_μ of $0.54ppm$. For the future, there is a proposal by almost the same (but enlarged) Collaboration to move the E821 apparatus to Fermilab, in order to exploit the more intense muon beam to reduce the error by a factor of 4 i.e. down to about $0.1ppm$. Another Collaboration aims at a similar sensitivity with a low energy muon beam to be available in the J-Parc complex.

THE SEARCH FOR THE $\mu^+ \to e^+\gamma$ DECAY

Where do we stand with the search for the charged lepton flavor violation? Great attention nowadays in the scientific community is focused at the MEG experiment [3]. MEG is currently taking data on the world's most intense dc muon beam at Paul Scherrer Institut (Switzerland). Together with the world's largest liquid Xenon photon detector of ~ 800 liter and a gradient-field superconducting positron spectrometer, MEG is able to distinguish the decay of a muon at rest into a photon and positron from the normal Michel decay and the prompt background due to the radiative muon decay. The experimental task is, in principle, straightforward as one has to detect a simultaneous back-to-back photon and positron pair of equal energy corresponding to half of the muon mass, as shown pictorially in fig. 2. The dominant background, however, consists of accidental events made of a positron coming from a Michel decay and a photon from a radiative decay, Bremsstrahlung or positron annihilation in flight. As a consequence, a detector is required with excellent spatial, time and energy resolution. The MEG apparatus, put in operation after a decade of intense *R&D* work, represents today the best achievable technology to improve by two orders of magnitude the previous MEGA [4] upper limit, published in the year 2000, Br $(\mu^+ \to e^+\gamma) < 1.2 \cdot 10^{-11}$. The present preliminary MEG upper limit, at 90% confidence level, is $1.5 \cdot 10^{-11}$, [7] based on the 2009 data sample, which represents about 10% of the total foreseen statistics. It is worth noticing that the experiment sensitivity (estimated in signal-free data samples) is $0.6 \cdot 10^{-11}$, raising the very interesting question about the true nature of the discrepancy. Anyway, thanks to a long 2010 data taking, which is supposed to at least double the present statistics , we will know the answer rather soon. The MEG schedule is to continue data taking in 2011-2012 and to improve the experimental resolutions in order to have the best achievable control on the accidental background in the attempt to reach a sensitivity of the order of 10^{-13}.

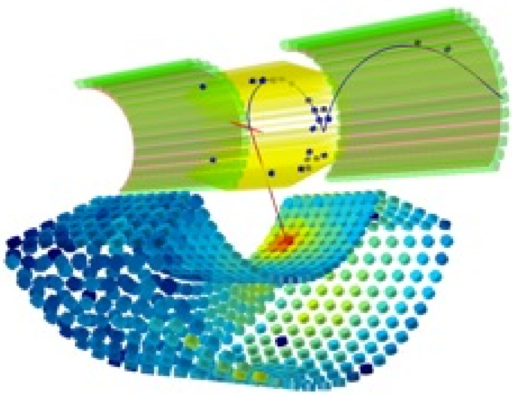

FIGURE 2. Pictorial view of a 'signal-like' event acquired by the MEG detector. Top: a positron tracked in the spectrometer hits two bars in the TC. Bottom: schematic of the energy released by the photon in the Liquid Xenon Calorimeter

DIRECT MUON-TO-ELECTRON CONVERSION

The neutrino-less muon capture by a nucleus with consequent emission of an electron (otherwise known as *direct muon-to-electron conversion*) could represents a step forward in the long quest for the cLFV search. The conversion is not only complimentary to $\mu^+ \to e^+\gamma$ but, because it could proceed through alternative diagrams , can also give independent information about the cLFV nature. The technique, pioneered by the Sindrum-II Collaboration [2], basically consists in letting an intense pure muon beam impinge on an appropriate thin target and see whether any isolated electron with an energy almost equal to the muon mass could be detected. The challenge is the exploitation of an intense pulsed uncontaminated beam followed by a suitable apparatus able to efficiently detect the emerging monochromatic electron and separate it from the high energy tail of the abundant decay-in-orbit background. Two major projects are at the moment under approval [8], both aiming at a sensitivity of the order of $10^{-16} - 10^{-17}$ in the rate $\mu^- N \to e^- N$ with respect to the capture rate, which corresponds to $10^{-14} - 10^{-15}$ of the Br $(\mu^+ \to e^+\gamma)$ scale.

The two proposals are quite similar, although they differ concerning the beam transport system. In fact, the Fermilab Mu2e collaboration proposes the use of a straight solenoid with a gradient field, whereas the J-Parc based COMET collaboration intends to utilize a U-shape solenoid which allows a reduced trigger rate. Both Collaborations plan to take data about five years from now.

CONCLUSIONS

The cLFV field looks indeed very interesting. MEG will provide new results in the incoming months, and in the mid-term new g-2 determinations are expected. New muon-to-electron conversion projects are in preparation which will confirm or disproof the previous results. Muons played a fundamental role in the construction of the SM. We believe that it could be the same in going beyond it.

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