PROCEEDINGS OF SCIENCE

The $\mu \to e\gamma$ final search with MEG and the MEG-II status

Gianluca Cavoto*
Istituto Nazionale Fisica Nucleare, sez. Roma
E-mail: gianluca.cavoto@roma1.infn.it

The MEG collaboration analyzed a dataset of about 7.5 10^{14} muon decays to search for the $\mu \to e\gamma$ decay at the muon beam line πE5 of the Paul Scherrer Institut in Switzerland. This corresponds to the full statistics recorded by the MEG detector and was used to place an upper limit of 4.3 10^{-13} at 90 % C.L. on the branching fraction $\mathscr{B}(\mu \to e\gamma)$. A status report of the upgrade program of the detector (MEG-II) is given. This would bring the sensitivity on this branching fraction at a level of 4 10^{-14} at the end of this decade.

Flavor Physics and CP Violation
6-9 June 2016
Caltech, Pasadena CA, USA

*Speaker.

PoS(FPCP2016)031

1. Introduction

In the Standard Model (SM) charged leptons are expected to decay into a final state with a different flavour number at a very tiny rate. The $\mu \to e\gamma$ decay in the SM might proceed through a loop diagram in which the neutrino flavour oscillation is active. This decay is therefore suppressed to a level of 10^{-55} given the very small ratio of the neutrino's mass over the W's mass [1]. This branching fraction ($\mathscr{B}$) cannot be practically probed in any experiment: there would be in fact not enough protons in the whole Universe to be used to produce pions and then muons!

Nevertheless in a large fraction of models extending the SM to include New Physics (NP) effects [2, 3, 4, 5], a $\mathscr{B}$($\mu \to e\gamma$) even at the level of 10^{-12} would have been possible, justifying a continuous experimental effort to improve the sensitivity on this $\mathscr{B}$.

This effort started 60 years ago with searches of the $\mu \to e\gamma$ decay in cosmic rays and is now lead by the MEG collaboration since several years of data-taking at the πE5 beam line of the Paul Scherrer Institut (PSI) at Villigen (CH). The $\mu \to e\gamma$ search and - in general - charged lepton flavour violation (cLFV) searches are largely complementary to the energy frontier NP investigation conducted at the Large Hadron Collider. The cLFV searches are in fact more sensitive to SM extension including electro-weakly interacting only new particles than the LHC experiments. Also, the $\mu \to e\gamma$ decay would be mediated by a specific type of interaction that another cLFV process as the muon conversion into electron cannot disentangle.

2. The MEG experiment

The MEG experiment has been operated since 2007 until 2013. A continuous positive muon beam is available with a maximal rate of about 10^8 muon per second.

The $\mu \to e\gamma$ process has a clear two-body decay topology. Positively charged muons from pion decays at rest are stopped on a thin 205 μm polyethilene target. MEG took data with an optimal muon stopping rate on this target of 3 10^7 muon/s. A photon and a positron are emerging from the target with an energy equal to half the mass of the muon (52.8 MeV). They are emitted in a back-to-back topology and at the same time.

The layout of the MEG detector is optimized to look for this decay only and it includes a spectrometer made of a special gradient magnetic field and low mass drift chamber planes to track the positrons. The magnetic field sweeps out of the tracking volume the lower momentum positrons reducing the visible rate at an affordable level. This field then directs the higher momentum positrons on two fast scintillator arrays readout by PMTs to measure the positron emission time. Photons initiate showers in a 900 liter liquid Xe calorimeter located outside the magnet coils. Fast scintillating light is then produced and detected by PMTs immersed in the liquid Xe with a photon detection efficiency of about 60% [6]. Photon timing, its position at the calorimeter entrance face and its energy are all measured. In conjunction with the reconstructed position of the positron on the plane of the target the relative angle between the photon and the positron is calculated.

With a very good resolution on all these observables (see Tab.1) it is possible to reject the most prominent accidental background. This originates from the combination of a positron from the largely dominant muon Michel decay and a photon belonging to a close-in-time radiative muon decay with very small neutrino energies, or photons produced by the annihilation of a positron in

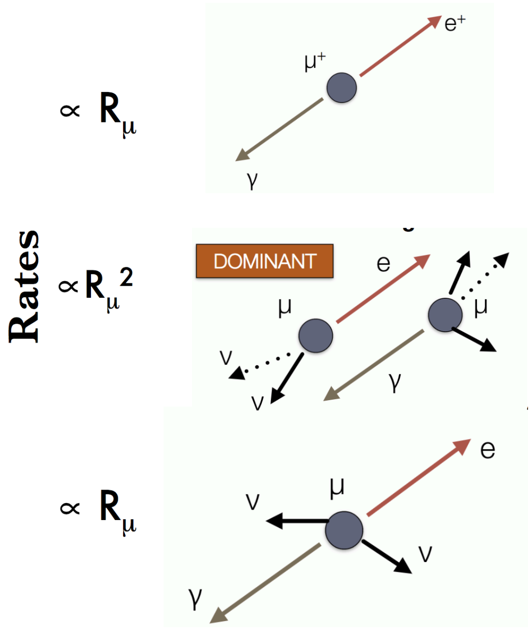

Figure 1: Sketch of the signal and background decay topologies in MEG.

the material of the spectrometer of by Bremsstrahlung. This background can be reduced with better and better resolutions but at a fixed detector resolution it is also the main limitation to the need of increasing the muon stopping rate. Another source of background (a factor 20 less frequent than the accidental one) is the same muon radiative decay with very small neutrino energies. In this case the photon and the positron are emitted at the same time as for the signal and this can limit the ability to distinguish this background (see Fig.1).

3. The MEG final results

The MEG collaboration analyzed its full dataset corresponding to 7.5 10^{14} muon decays. The observables used in a a maximum likelihood analysis are the energy of the positron (E_e) the energy of the photon (E_γ), their relative timing ($t_{e\gamma}$) and the relative angle projections $\theta_{e\gamma}$ and $\phi_{e\gamma}$. A blinding technique has been used to study the data without looking at the events in a range 48< E_γ <58 MeV and $|t_{e\gamma}| < 1$ ns. Probability density functions for all the observables are derived from various dataset, also using special runs especially for the calibration of the Xe calorimeter. For instance a dedicated data-taking of negative pions impinging on a liquid hydrogen target is used to collect events with two back-to-back photons from a π^0 decay. One of the two photons is detected in an auxiliary calorimeter opposite to the Xe calorimeter.

For this full data-set analysis, improvements in the reconstruction algorithm were applied. We accounted for the non-planarity of the target surface where the positron vertex point is located, leading to a significant systematic error (a 13 % worse sensitivity). We also improved (+ 4%) the

Table 1: Resolution (Gaussian σ) and efficiencies for MEG-II

PDF parameters	MEG	MEG-II
e^+ energy (keV)	306 (core)	130
e^+ θ (mrad)	9.4	5.3
e^+ ϕ (mrad)	8.7	3.7
e^+ vertex (mm) Z/Y(core)	2.4 / 1.2	1.6 / 0.7
γ energy (%) (w <2 cm)/(w >2 cm)	2.4 / 1.7	1.1 / 1.0
γ position (mm) $u/v/w$	5 / 5 / 6	2.6 / 2.2 / 5
γ-e^+ timing (ps)	122	84
Efficiency (%)		
trigger	≈ 99	≈ 99
γ	63	69
e^+	40	88

positron tracking efficiency and we reduced the contamination of events with photons emerging from a positron annihilation in the drift chamber planes. This was obtained by identifying positron tracks pointing at the Xe calorimeter but disappearing in the drift chamber volume.

The sensitivity $\mathscr{S}$ of our experiment to the $\mathscr{B}(\ \mu \to e\gamma\ )$ was determined by simulating an ensemble of toy MC experiments with a null signal hypothesis. It is defined as the median of the distribution of the 90% C.L. upper limits on the $\mathscr{B}(\ \mu \to e\gamma\ )$ calculated in this ensemble (Fig.2) and it was evaluated to be 5.3 10^{-13}. As a cross-check we fit the data in timing sidebands $|t_{e\gamma}|$ > 1 ns where no signal events are expected and we determined the corresponding upper limits on $\mathscr{B}(\ \mu \to e\gamma\ )$. The results are shown in Fig.2 and they are well compatible with the predicted MC distribution.

Finally we extracted the number of signal events in the full data set. No signal event was found while the number of accidental and radiative background events was found to be 7684 $\pm$ 103 and 663 $\pm$ 59 respectively. The likelihood functions for sub-sets of data in different data-taking periods are also fully compatible (see also Fig.2).

We then determined the upper limit on $\mathscr{B}(\ \mu \to e\gamma\ )$ to be 4.3 10^{-13} at 90 % C.L. This upper limit is almost two orders of magnitudes more stringent than the results obtained by any other experiment than MEG and supersedes the previous MEG upper limit results.

4. The MEG-II upgrade and its current status.

The absence of a $\mu \to e\gamma$ decay at a $\mathscr{B}$ of few 10^{-13} can be interpreted in several extension of the SM to constrain the parameter space of possible NP effects. Nevertheless, lower rates are still well possible and pursuing the search of this decay is still very motivated. Moreover, a higher muon stopping rate is already available at PSI, virtually up to 10^8 μ/s. This calls for an upgrade on the detector performance, with special care on obtaining twice better detector resolutions in any of the MEG observables (Tab.1).

In particular a single volume with 2π coverage drift chamber is currently in a construction phase (Fig.4). It consists of a 2 meter long cylindrical gas volume with about 1200 sense wires with a 8 degree stereo angle with respect to the main detector axis. This would allow to have several tens of hits per tracks and determine also the z longitudinal position of the hits. The chamber with be operated with a mixture of He and isobutane leading to a very low mass detector (1.7 10^{-3} radiation length per track). This system is meant to have resolution on the positron momentum and angles of 100 KeV and 4-5 mrad respectively. The final limitation will be in fact given by the multiple scattering in the muon target.

Moreover, the length of the gas volume will allow to track the positron down to the scintillator timing counter. The track length will be then reconstructed with higher precision and a better overall positron timing resolution will be attained (less than 100 *ps*). This will be obtained also thanks to a newly designed system of several scintillator tiles readout by SiPMs. These tiles will be installed orthogonal to the direction of the positron, allowing a more precise determination of its timing down to 30 *ps*. A successful beam test has been recently conducted on a portion of this detector subsystem(Fig.5).

In parallel an upgrade of the photon sensors of the Xe calorimeter is on-going. This will be mainly driven by the higher granularity on the scintillation photons readout. It will be accomplished with 12x12 mm^2 SiPM to be installed on the front face of the Xe calorimeter to replace the current PMTs. This is in fact devoted to improve the energy resolution on the photon showers starting close to the front face (within 2 cm). SiPM sensitive to the Xe ultra-violet light will be employed.

Upgrade of the readout electronics and trigger are also foreseen leading to a more compact systems.

5. Conclusions and outlook.

The MEG experiment concluded the analysis of its full dataset by setting an upper limit of 4.3 10^{-13} on the $\mathscr{B}(\mu \to e\gamma)$. A construction phase is currently in full swing with the final goal to have a sensitivity of 4 10^{-14} on the $\mathscr{B}(\mu \to e\gamma)$ by the end of the decade. The new MEG-II detector is expected to be assembled at PSI in 2017 and to take data during the following three or four years.

References

[1] S.T. Petcov, Sov. J. Nucl. Phys. **25** (1977) 340.

[2] R. Barbieri, L. Hall and A. Strumia, Nucl. Phys. B **445** (1995) 219.

[3] J. Hisano, D. Nomura and T. Yanagida, Phys. Lett. B **437** (1998) 351.

[4] M. Raidal *et al.*, Eur. Phys. J. C **57** (2008) 13.

[5] G. Blankenburg *et al.*, Eur. Phys. J. C **72** (2012) 2126.

[6] J. Adam, X. Bai, A. M. Baldini, E. Baracchini, C. Bemporad, G. Boca, P. W. Cattaneo and G. Cavoto *et al.*, Eur. Phys. J. C **73** (2013) 2365

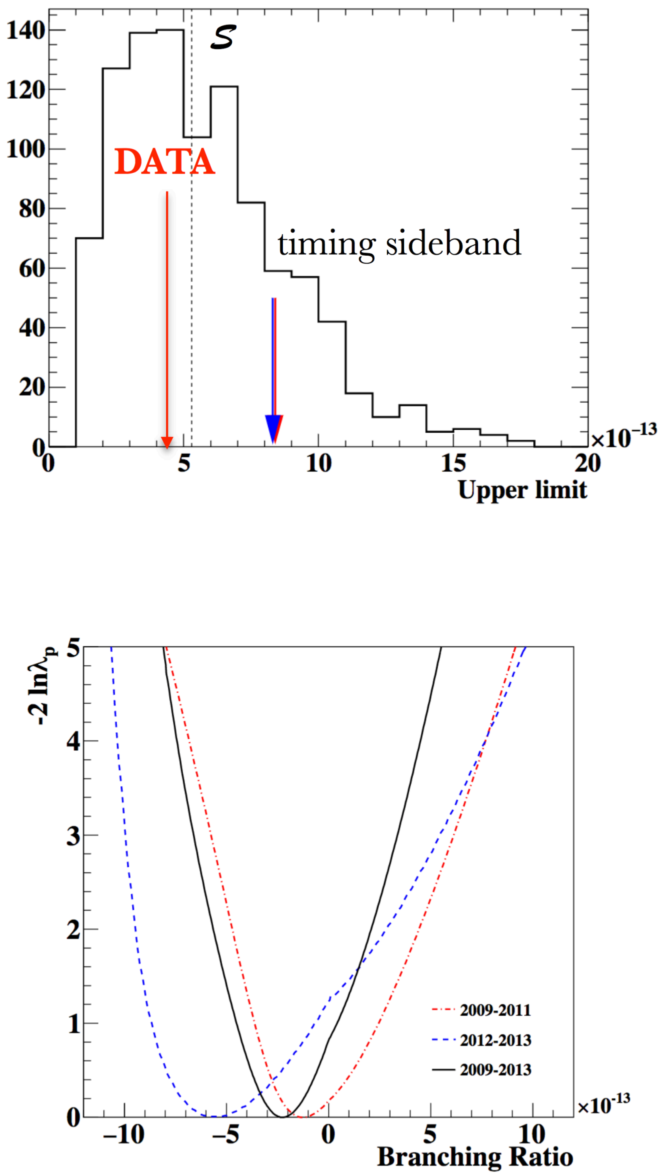

Figure 2: Distribution of 90% C.L. upper limit $\mathscr{B}(\mu \to e\gamma)$ in toy MC experiments with null signal hypothesis. The sensitivity $\mathscr{S}$ is reported on the graph. Results for the analysis of timing sidebands and of the full dataset are also shown (top). Profile likelihoods for the full data set and for two sub-set of data collected in different years.

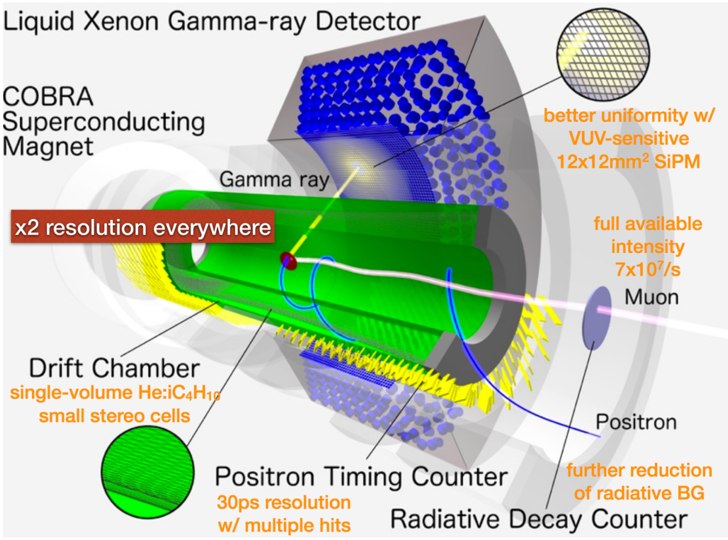

Figure 3: An overview of the present MEG experiment versus the proposed upgrade.

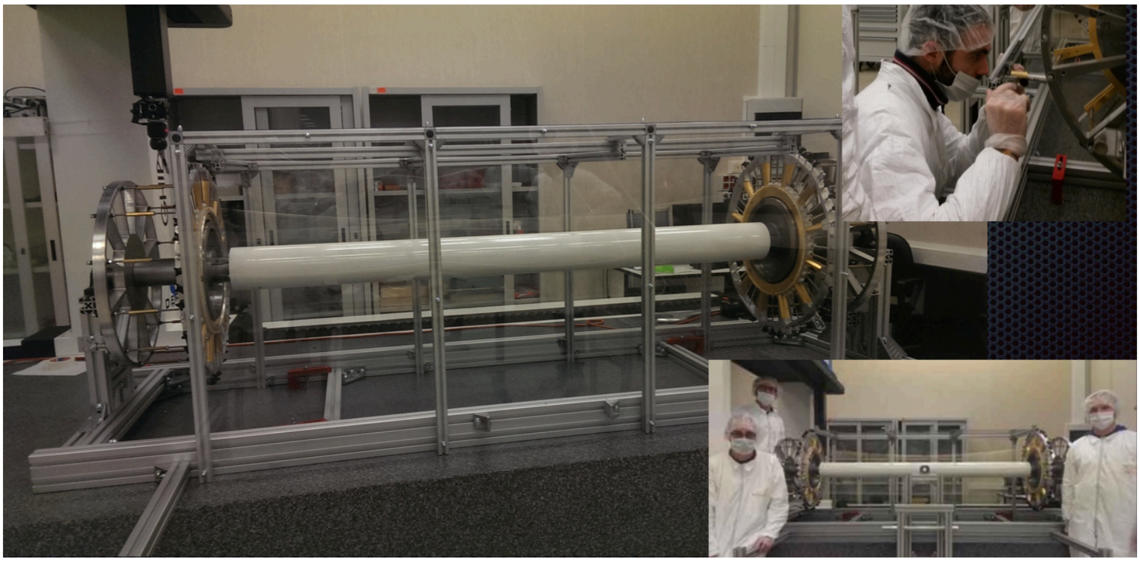

Figure 4: Wiring of the new MEG drift chamber at INFN premises.

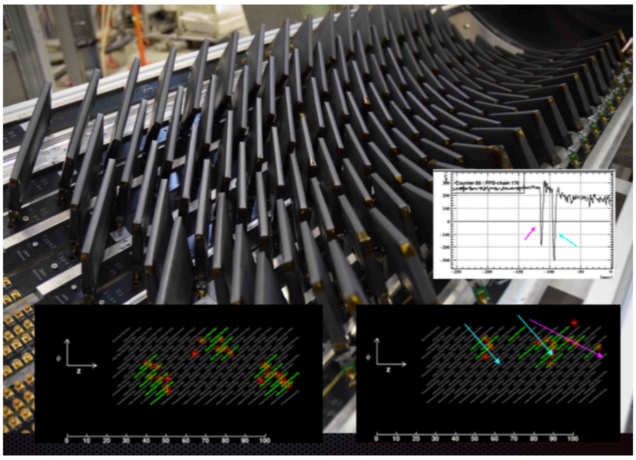

Figure 5: Positron timing counter new scintillator tiles installed in MEG. Reconstruction of the positron path is possible by using multiple hits and allowing a better positron timing resolution

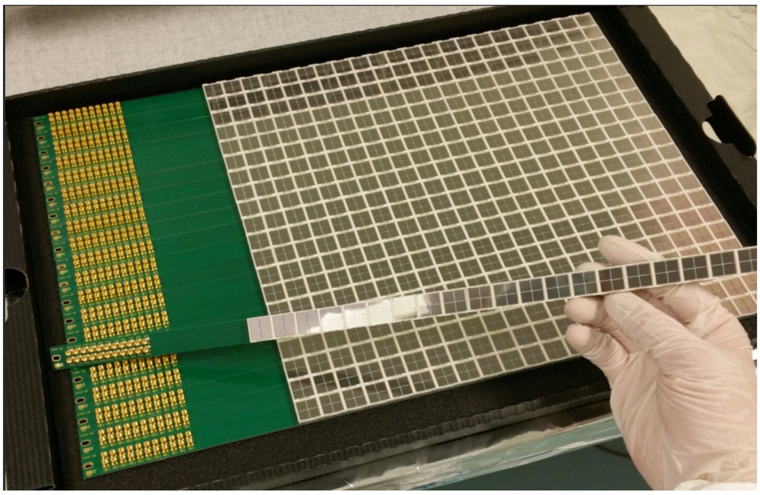

Figure 6: Array of SiPM for the Xe calorimeter.