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The search for $\mu^+ \rightarrow e^+\gamma$ decay: Status of the MEG experiment

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Summary. — The MEG experiment searches for the Lepton Flavor Violating (LFV) decay $\mu^+ \rightarrow e^+\gamma$ with a goal sensitivity of $\sim 10^{-13}$. The observation of this decay would be an unambiguous sign of Physics beyond the Standard Model. MEG has recently concluded its first Physics run with approximately $\sim 94 \cdot 10^{12}$ muons on target accumulated. The analysis of the data is ongoing; a clear signal of the muon radiative decay has been observed demonstrating the ability of the experiment to see possible $\mu^+ \rightarrow e^+\gamma$ events.

PACS `13.35.Bv` – Decays of muons.
PACS `11.30.Hv` – Flavor symmetries.

1. – Introduction

In the Standard Model (SM) charged lepton flavor violation, *i.e.* transitions between leptons of different families, is allowed but predicted to be extremely small. In particular, the process $\mu^+ \rightarrow e^+\gamma$ proceeds through the exchange of a virtual W boson and $\bar{\nu}_\mu - \bar{\nu}_e$ mixing; the resulting branching ratio scales with the ratio of the neutrino mass over the W mass by the fourth power and is of the order of 10^{-54}. On the other hand, in many extensions of the SM the branching ratio for this decay is highly enhanced and in some cases just below the present experimental limit ($\mathrm{BR}(\mu^+ \rightarrow e^+\gamma) < 1.2 \cdot 10^{-11}$ at 90% CL [1]). The study of the $\mu^+ \rightarrow e^+\gamma$ decay has a strong capability to detect or to constrain New Physics induced LFV and is complementary to other LFV decays like $(\mu - e)$ conversion in heavy nuclei and τ decays (see for example [2]). Since the SM background is practically absent an observation of this decay would be an unambiguous sign of Physics beyond the SM. The MEG target sensitivity is $\sim 10^{-13}$, which improves by two orders of magnitude the present limit. The target sensitivity will be reached in 2011.

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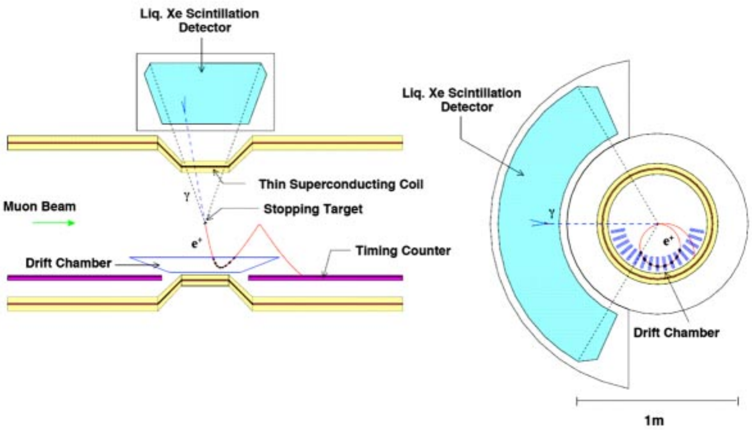

Fig. 1. – Schematic cross-section of the MEG apparatus. A muon beam entering from the left stops in a thin target. The $\mu^+ \to e^+\gamma$ decay is detected in a liquid-xenon calorimeter, a set of radial drift chambers and a set of timing counters.

2. – The experimental technique

The MEG experiment searches for $\mu^+ \to e^+\gamma$ where the muon decays at rest. The signal has a very clean experimental signature: the decay products appear simultaneously, have an energy of 52.8 MeV ($\frac{m_\mu}{2}$) and their relative angle is 180°. The main source of background is an accidental pile-up of a positron and a photon from two different muon decays where, for example, the photon comes directly from a radiative muon decay or from a positron annihilation in flight. The branching ratio for this background increases quadratically with the muon beam intensity so a compromise is needed to balance statistics and purity of the sample. The second source of background, less severe, comes from radiative decays of the muons (physics background) that at the edge of the allowed kinematic region can mimic the signal. In order to reject the background it is crucial to have excellent experimental resolution on the discriminating quantities; the MEG design resolutions (FWHM) are: 1% for the positron energy, 4.5% for the photon energy, 150 ps for the relative timing and 19 mrad for the relative angle. With the above resolutions, the equivalent branching ratio in the signal region is at the level of 10^{-15} for the physics background and at the level of 10^{-14} for the accidental background.

3. – The MEG detector

The MEG detector is operated on the most intense continuous muon beam line in the world, at the Paul Scherrer Institute (PSI). Up to $\sim 10^8$ μ^+/s are stopped in a thin polyethylene target. The MEG apparatus, shown schematically in fig. 1, covers ten percent of the solid angle and is constituted by:

– A positron spectrometer with drift chambers placed in a non-homogenous magnetic field. The COnstant Bending RAdius (COBRA) produces a non-homogeneous field with maximum at the center (1.28 T) and decreasing towards the spectrometer edges. The purpose of COBRA is two-fold: first, high-p_t positrons are quickly swept away from the drift chambers and secondly the bending radius depends only on the magnitude of the positron momentum. Positron tracks are measured with 16 trapezoidal drift chambers aligned radially at 10° intervals in azimuthal angle. Each sector consists of two staggered arrays of drift cells filled with a mixture of He/Ethane (50%/50%), immersed in helium atmosphere. The radial coordinate is obtained from the drift time difference of the two wire ends, where a precise measurement of the longitudinal coordinate (with design resolution of 400 μm) is obtained with a Vernier cathod pattern. During the 2008 run the chambers experienced frequent discharges found to be due to a problem in the HV distribution (now fixed). The measured efficiency for the 2008 run is $\sim 30\%$ (lower limit).

– A scintillating detector, the timing counter that provides the timing of the positrons at the end of their path through the drift chambers. The timing counter consists of two sections placed upstream and downstream of the target. Each section is made of 30 scintillation bars aligned along the beam direction, read by PMTs, that measure the time and the azimuthal coordinate, and of 256 scintillating fibers placed perpendicular to the bars. The fibers measure the z coordinate of the impinging positron and will be eventually included in the MEG trigger. The timing counter time resolution has been measured on 2008 data and an upper limit could be placed, of 60–90 ps, depending on the bar.

– A C-shape liquid-xenon calorimeter. Xe is liquid at a comparatively high temperature (165 K), has a small radiation length (2.7 cm) and has a high light yield (comparable to that of the sodium iodide, but with a significantly lower emission time, of the order of tens of ns). The calorimeter is read out by 847 PMTs with quartz window, since the peak emission wavelength is in the vacuum UV. The resolution of the calorimeter has been evaluated during a special charge exchange run where a pion beam impinged on a liquid-hydrogen target producing $\pi^0 \to \gamma\gamma$ events. The measured resolution is 6.4% (FWHM) at 55 MeV.

The MEG trigger utilizes a 100 MHz waveform digitizer on VME boards and applies requirement on the photon energy, the positron-photon time coincidence, and on the positron-photon collinearity. The waveforms from the electronic channels of all the detectors are digitized with a custom chip designed at PSI, the Domino Ring Sampling (DRS) at 1.6 or 2 GHz. The DRS has been designed in order to allow pile-up rejection as much as possible. Version 2 and 3 has been used for 2008 run while an improved version 4 will be used in 2009. Given the very high required resolutions, very sophisticated and redundant calibration procedures are necessary; these include calibration with alpha sources, LED and photons from a Cockcroft-Walton accelerator, the dedicated CEX run mentioned above and a laser system for timing counter calibration.

4. – MEG 2008 run

In 2008 the MEG detector took physics data from September to December (11.5 weeks beam-time). During this period $\sim 94 \cdot 10^{12}$ muons on target have been collected. The analysis of 2008 data is underway; the collaboration has chosen a blind-box analysis strategy where the variables used to blind the signal region are the photon energy and the photon-positron relative timing. The signal region will be open once all the calibration procedures and the selection criteria will be finalized. The likelihood function has three components: one component for signal events, one for the radiative decays and one for accidental background. The analysis variables are the photon and the positron energy,

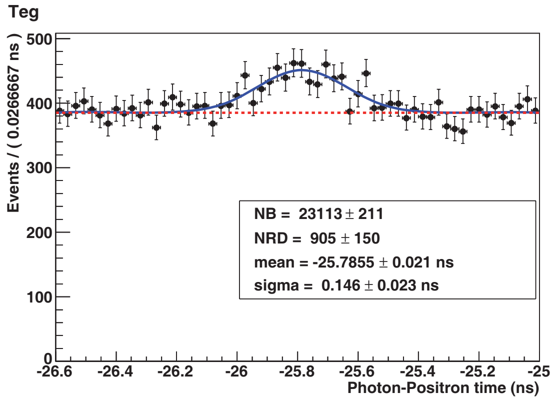

Fig. 2. – The photon-positron relative time measured in the non-blind region with a provisional selection in 2008 MEG data.

the photon-positron relative angle and time. The likelihood for signal and radiative events is built from experimental resolutions measured on data where possible and from Monte Carlo simulation otherwise. The accidental background parameters are extracted from data sidebands. The normalization and the overall efficiency-acceptance are extracted from data.

Figure 2 shows the photon-positron relative time measured in the non-blind region with a provisional selection. The muon radiative decay signal is clearly visible, proving that the experiment is able to see possible $\mu^+ \to e^+\gamma$ events. In 2008 data the provisional single event sensitivity, defined as the branching ratio for which one signal event is observed, is < 30–$50 \cdot 10^{-12}$. Several improvements are foreseen for 2009, in particular the collaboration is confident to recover drift chamber efficiency and a provisional single event sensitivity of 3–$5 \cdot 10^{-12}$ is foreseen. The target sensitivity (the 90% confidence level upper limit that can be set if zero signal events are observed) of $\sim 10^{-13}$ will be reached in 2011.

5. – Conclusion

The MEG experiment, which searches for the LFV decay $\mu^+ \to e^+\gamma$, has recently concluded its first physics run in 2008 with $\sim 94 \cdot 10^{12}$ muon on target collected. Despite some detector instabilities (which have been understood and fixed for next run), a clear muon radiative decay signal has been observed, showing the capability of the experiment to see $\mu^+ \to e^+\gamma$ events. The detector is well understood, the resolutions are not yet the design ones but are still improving. The analysis of 2008 data is ongoing while another run is under preparation for 2009; the target sensitivity of $\sim 10^{-13}$ will be reached in 2011. MEG will represent a huge step in the sensitivity with respect to the past; given the absence of the SM contribution to the decay an observation would constitute a discovery of New Physics while a non-observation will allow to constrain several extensions of the SM.

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