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

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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 second Physics run with approximately $\sim 65 \cdot 10^{12}$ muons on target accumulated. The analysis of the data taken during the first Physics run in 2008 with $\sim 95 \cdot 10^{12}$ muons on target accumulated has been published and the upper limit BR($\mu^+ \rightarrow e^+\gamma$)<$2.8 \cdot 10^{-11}$ @90 % C.L. has been set. The preliminary result on 2009 data is BR($\mu^+ \rightarrow e^+\gamma$)<$1.5 \cdot 10^{-11}$ @90 % C.L.

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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 $\mu^+ \to e^+\gamma$ 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 (BR($\mu^+ \to e^+\gamma$)$< 1.2 \cdot 10^{-11}$ @90% C.L. [1]). The study of the $\mu^+ \to e^+\gamma$ 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 order of magnitude the present limit. The target sensitivity will be reached in 2011.

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 and the relative angle of their momentum vectors is 180^o. 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 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 ($\mu^+ \to e^+\nu\bar{\nu}\gamma$, called 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, 150ps for the relative timing and 19mrad 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) near Zurich. Up to $\sim 10^8$ μ^+/s are stopped in a thin polyethylene target. The MEG apparatus, shown schematically in figure 1, covers ten percent of the solid angle and is constituted by:

- A positron spectrometer with drift chambers placed in a non-homogeneous magnetic field. The COnstant Bending RAdius (COBRA) magnet produces a non homogeneous field with maximum at the center (1.28T) and decreasing towards the spectrometer edges. The advantages of COBRA with respect to a traditional solenoid is two-fold. First, positrons with high transverse momentum are quickly swept away from the drift chambers that can thus work

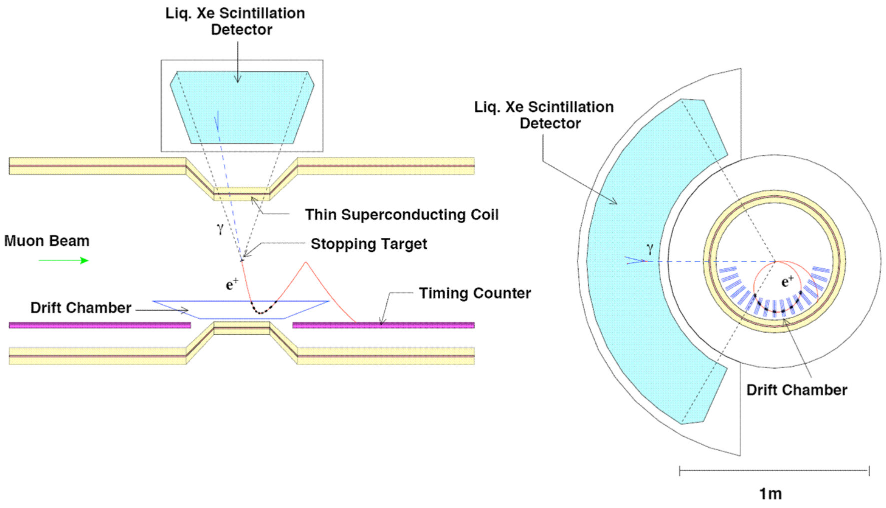

Figure 1: Schematic cross section of the MEG apparatus. A muon beam entering from the left stops in a thin target. The $\mu^+ \rightarrow e^+\gamma$ decay is detected in a liquid xenon calorimeter, a set of radial drift chambers and a set of timing counters.

at the high rate typical of the experiment and secondly, the bending radius depends approximately only on the magnitude of the positron momentum and it is thus independent on the emission angle. Positron tracks are measured with 16 low-mass, trapezoidal drift chambers aligned radially at 10^o intervals in azimuthal angle. The amount of material seen by the positron through the drift chambers is about $2 \cdot 10^{-3}$ radiation length. 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 on the wire ends (with a design resolution of $100\mu m$), where a precise measurement of the longitudinal coordinate (with a design resolution of $400\mu m$) is obtained with a Vernier cathode pattern. During the 2008 run the chambers experienced frequent discharges found to be due to a problem of penetration of Helium in the high voltage distribution. This problem has been fixed before the 2009 run.

- 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 scintillating 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 60-90ps, depending on the bar.

- A C-shaped liquid Xenon calorimeter. Xenon is liquid at a comparatively high temperature (165K), has a small radiation length (2.7cm) 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 846 PMTs with quartz window, since the peak emission wave

> length is in the vacuum UV. The resolution of the calorimeter has been evaluated during a special charge exchange (CEX) run where a pion beam impinged on a liquid hydrogen target producing $\pi^0 \rightarrow \gamma\gamma$ events. The measured resolution for 2009 run is 4.7% (FWHM) at 55MeV. In order to maintain the desired resolution, it is crucial to keep the Xenon pure; purification with a specific apparatus is done periodically. The efficiency to detect a signal photon is 63%.

The MEG trigger utilizes a 100MHz waveform digitizer on VME boards and applies requirement on the photon energy, the positron-photon time coincidence, and 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). The DRS has been designed in order to allow pile-up rejection within waveforms close in time as much as possible. Version 2 and 3 have been used for 2008 run while an improved version has been 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 nuclear reactions induced with a Cockcroft-Walton accelerator, and special CEX runs already mentioned.

4. MEG 2008 analysis and results

In 2008 the MEG detector took data from September to December (11.5 weeks beam-time). During this period $\sim 95 \cdot 10^{12}$ muons on target have been collected. A part of the data has been taken at lower beam intensity to study the muon radiative decay in an environment with lower background. The collaboration has chosen a blind-box analysis strategy where the variables used to blind the region where the signal is expected to be (signal box) are the photon energy and the photon-positron relative time. The signal box was opened once all the calibration procedures and the selection criteria were finalized. A maximum likelihood analysis has been performed, based on 5 discriminating observables: the photon and the positron momentum, the photon-positron relative angle polar and azimuthal projections and the relative time. The likelihood function has three components: one component for signal events, one for the radiative decays and one for accidental background. The detector resolutions are used to parametrize the signal probability density functions (PDFs). They are determined from data by means of the calibration samples, mainly photons from the CEX run and positrons from normal muon decay. The positron energy resolution has been measured by fitting the kinematic edge of the Michel spectrum and found to be of $\sim$ 370keV for 60% of the events with tails of 1MeV. The relative photon-positron time resolution has been measured from radiative decay data and it is $\sim$ 150ps. Figure 2 shows the distribution of the photon-positron relative time for muon radiative decays in data taken at the nominal beam intensity; a clear peak is visible demonstrating the capability of the MEG experiment of seeing possible signal events. The accidental background PDFs are obtained by fitting the data lying on the sidebands of the signal box. The radiative decay PDF is obtained by combining the theoretical spectrum with the resolutions and acceptances measured on data. The result of the likelihood fit is shown in figure 3. The Feldman-Cousins approach [3] has been used to set an upper limit on the number of observed signal events, N_{signal}<14.7 where systematic uncertainties are included. A limit on the branching ratio is obtained by normalizing the number of signal events to the number of the observed normal

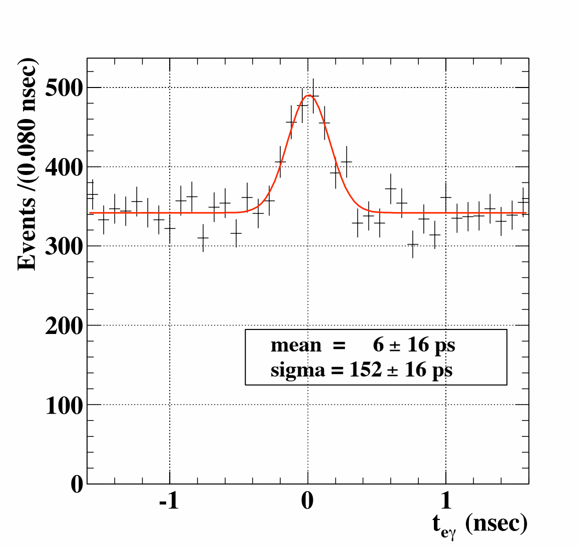

Figure 2: The photon-positron relative time distribution for radiative muon decays measured in 2008 MEG data.

muon decays, taking into account correction factors related to the difference between signal and Michel positron efficiencies and photon efficiency. A 90% C.L. of BR($\mu^+ \to e^+\gamma$) < $2.8 \cdot 10^{-11}$ has been set, although simulated experiments predict a limit of $1.3 \cdot 10^{-11}$ in absence of a signal and a probability of few percent of getting such a larger limit [4]. The MEG experiment will continue to take data in 2010 and 2011. Hardware and analysis improvements are in progress.

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 $\sim 95 \cdot 10^{12}$ muon on target collected. The detector is well understood, the resolutions are not yet the design ones but are constantly improving. The analysis of 2008 data has been published (BR($\mu^+ \to e^+\gamma$) < $2.8 \cdot 10^{-11}$ @90% C.L.) while a preliminary result on 2009 data has been recently presented (BR($\mu^+ \to e^+\gamma$) < $1.5 \cdot 10^{-11}$ @90% C.L.); 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 the SM.

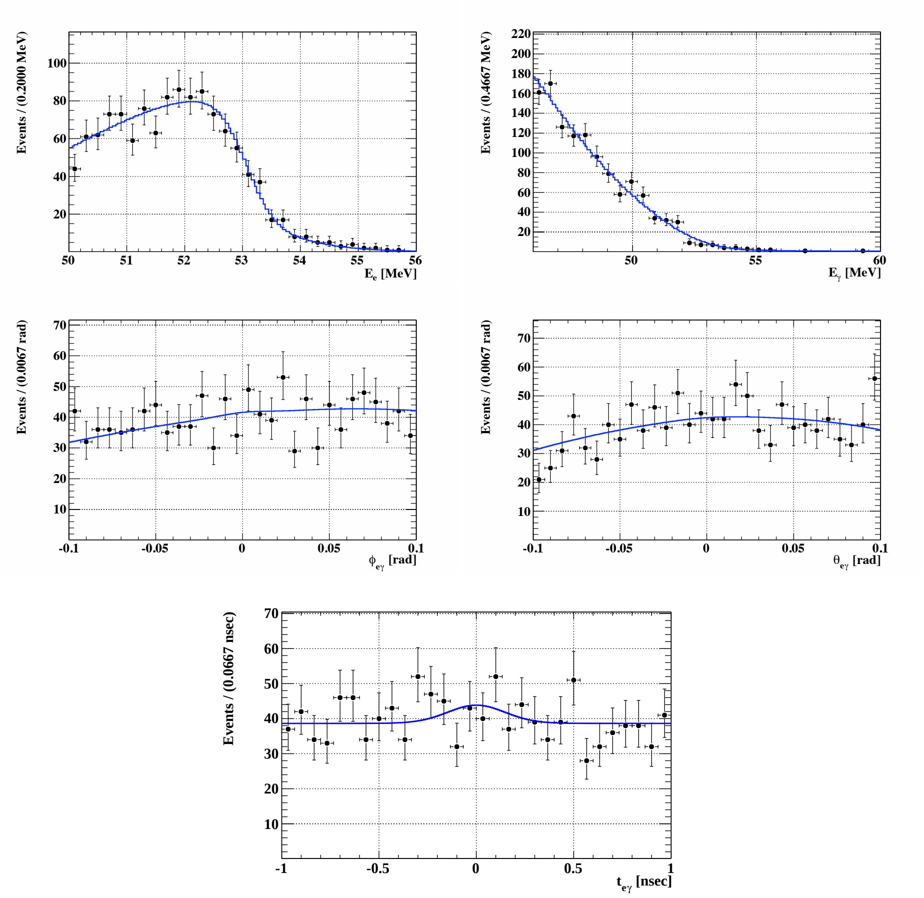

Figure 3: The result of the fit of the 2008 data for the distributions of the positron energy (E_e, top left), the photon energy (E_γ, top right), the azimuthal and polar projection of the photon-positron relative angle ($\phi_{e\gamma}$ and $\theta_{e\gamma}$, middle left and middle right respectively) and relative photon-positron time ($t_{e\gamma}$, bottom right). Signal would appear at $E_e = E_\gamma = 52.8$MeV, $\phi_{e\gamma} = \theta_{e\gamma} = 0$ and $t_{e\gamma} = 0$.The dots are the data and the curves are the likelihood projections.

References

[1] MEGA collaboration, M. Ahmed *et al. Phys.Rev. D* **65**, 112002 (2002).

[2] L. Cabibbi *et al. Phys.Rev. D* **74**, 116002 (2006).

[3] G. J. Feldman and R. D. Cousins, *Phys.Rev. D* **57**, 3873 (1998).

[4] J. Adam *et al. Nucl.Phys. B* **834**, 1 (2010).