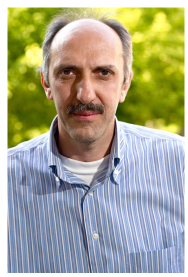
**First results from the MEG experiment: search for charged Lepton Flavor Violation $\mu^+ \to e^+\gamma$ decay**

P.W. Cattaneo on behalf of the MEG collaboration
*INFN Pavia, Via Bassi 6, I-27100 Pavia, Italy*



The MEG experiment searches for the decay $\mu^+ \to e^+\gamma$, strictly forbidden in the Standard Model (SM), but allowed in many SM extensions, that predict branching ratio just below the current upper limit. The data were taken during 2009, corresponding to $\approx 6.5\,10^{13}\mu^+$ stopped on target. Preliminary results obtained with a maximum likelihood analysis gives an upper limit BR$(\mu^+ \to e^+\gamma) \leq 1.5 \times 10^{-11}(90\% C.L.)$.

## 1 Introduction

The observations of neutrino oscillations show that neutrinos have non-zero masses[1]. This induces charged Lepton Flavour Violation (cLFV) in the lepton sector, but the Standard Model (SM) predicts $BR(\mu^+ \to e^+\gamma) < 10^{-40}$, by far inaccessible to experimental investigation. On the other hand, many SM extensions predict[2,3] a much larger $BR$, that for some part of the parameter space might be accessible experimentally. Hence, detection of cLFV would be an unambiguous sign of new physics.
The current limit BR$(\mu^+ \to e^+\gamma) \leq 1.2 \times 10^{-11}$ is set by MEGA experiment[4].
We report on the search for the decay $\mu^+ \to e^+\gamma$ based on data collected during 2009 by the MEG experiment operated at the Paul Scherrer Institut (PSI) in Switzerland. The muons decay rate was $\approx 3\,10^7$ Hz for a total of $\approx 6.5\,10^{13}\,\mu^+$.

## 2 The MEG experiment

### *2.1 The Experimental Principle*

The decay $\mu^+ \to e^+\gamma$ is characterized by a simple 2-body final state. In the rest frame of $\mu^+$, $e^+$ and $\gamma$ are emitted coincident in time, back to back and each with a monochromatic energy approximately equal to half the muon mass.

There are two potential background sources: the first is the Radiative Muon Decay (RMD) $\mu^+ \to e^+\nu_e\bar{\nu}_\mu\gamma$ with $\nu$ energy experimentally compatible with 0, the second is an accidental coincidence of a $e^+$ from $\mu^+ \to e^+\nu_e\bar{\nu}_\mu$ (Michel decay) and a $\gamma$ from RMD, $e^+$ bremsstrahlung or annihilation in flight both close to the kinematic limits. At the MEG rate and taking into account the deetctor resolutions, the accidental background[5] dominates. Therefore continuous $\mu^+$ beams are in advantage in decreasing accidental coincidence compared to pulsed beams.

### *2.2 The MEG detector*

The MEG detector, located at Paul Scherrer Institut (Switzerland), is shown in Fig. 1.
A high intensity continuous beam of surface $\mu^+$ with momentum $p_{\mu^+} = 28.0\,\mathrm{MeV/c}$ an intensity $\sim 3 \times 10^7 \mu^+/\mathrm{s}$ is stopped in a polyethylene/polyester $205\mu m$ thick target at the center of the detector. The He atmosphere aroubd the target minimizes the multiple scattering for incoming $\mu^+$ and outgoing $e^+$ and limits photon bremsstrahlung and annihilation production.
The detector consists of a Liquid Xenon (LXe) $\gamma$-ray detector and a $e^+$ magnetic spectrometer covering $\approx 10\%$ of the solid angle.

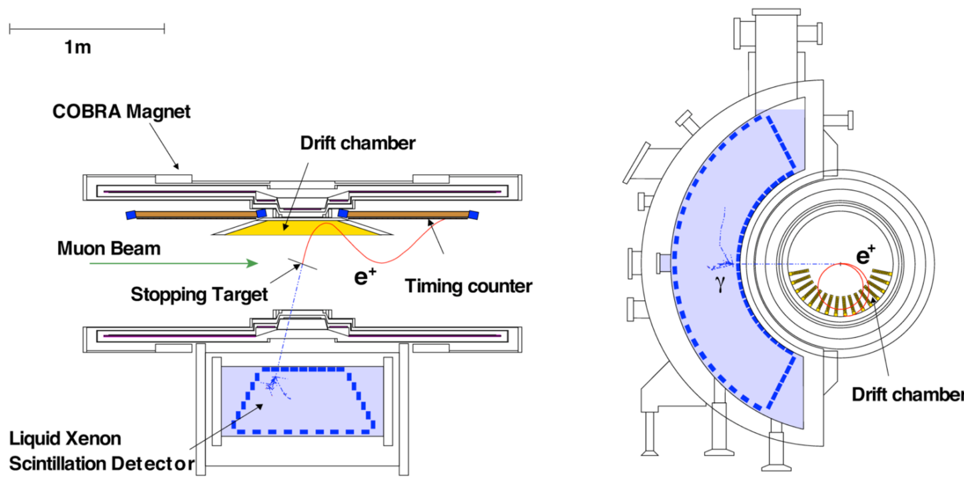



Figure 1: Schematic of the MEG detector

### LXe $\gamma$-ray detector

The $\gamma$-ray detector is a homogeneous volume of $900\ell$ of LXe, whose scintillating light is read out by 846 photomultiplier tubes (PMTs). The position and time of the first interaction of a $\gamma$ in the detector is reconstructed using the light distribution in space and time respectively, and the energy using the sum of PMT signals.

### Positron magnetic spectrometer

Positrons from $\mu^+$ decays are detected by the COBRA (Constant Bending RAdius) spectrometer composed by a superconducting solenoidal coil with gradient magnetic field, 16 radially aligned low mass drift chambers (DCH) ($2 \times 10^{-3} X_0$ in total) and a Timing Counter (TC) consisting of two sets of 16 plastic scintillator bars read by PMTs positioned upstream and downstream the

Table 1: Resolution ($\sigma$ of gaussian core) and efficiencies.

| | | | |
|---|---|---|---|
| $\frac{\sigma(E_{e^+})}{E_{e^+}}$ | 0.74 % (core fraction 83 %) | $\frac{\sigma(E_\gamma)}{E_\gamma}$ (w > 2 cm) | 2.1 % |
| $e^+$ angle | 7.1 mrad ($\phi$), 11.2 mrad($\theta$) | $\gamma$ position at LXe | 5-6 mm |
| $e^+$ vertex | 3.3 mm | $\gamma - e^+$ timing | 142 ps |
| $\gamma$ eff. ($\epsilon_\gamma$) | 58% | $e^+$ eff. ($\epsilon_e^+$) | 40% |

target. The gradient field ($1.27 - 0.49\,T$) is designed to sweep away quickly $e^+$ perpendicular to the beam to reduce DCH occupancy.
The $\mu^+$ decay point and the $e^+$ energy and direction are estimated by the DCH reconstructing the trajectory of the positron. The $e^+$ time is estimated using the time information of the interaction with the TC corrected for the trajectory path length.

**The readout and the trigger**

Measuring with high resolution the $e^+$ and $\gamma$ kinematic variables in a high rate environment requires the storing of sufficient information for detailed offline analysis. That is achieved by sampling and storing the waveforms at $\approx$ 1GHz with custom designed sampler, the Domino Ring Sampler (DRS)[6]. The waveform analysis permitted by this system achieves high energy and timing resolutions.
The trigger is based on a coarser sampling of the analog signals (100 MHz) that permits to look for an approximate matching of $\gamma$ energy, $e^+$-$\gamma$ time coincidence and $e^+$-$\gamma$ collinearity. The signal trigger rate is $\approx$ 5Hz.

### *2.3 The calibrations and the resolutions*

The detector needs to be precisely calibrated in order to achieve the required high resolution and background rejection. This goal is pursued through several calibration devices and exploiting the properties of know physical processes.
The LXe PMTs were constantly monitored with LEDs and $\alpha$-sources. A dedicated proton Cockroft-Walton accelerator [8] was operated to induce $(p, \gamma)$ nuclear reactions with known $\gamma$ energy. The Charge Exchange Reaction (CEX) $\pi^- p \to \pi^0 n$ has been also used.
The relative time between $LXe$ and $TC$ has been calibrated and monitored exploiting $(p, 2\gamma)$ reactions.

**The resolution of the positron**

The $e^+$ momentum resolution extracted from the data can be described by the superposition of three gaussian functions, while the $e^+$ angular resolutions are described by a gaussian with resolutions in Tab.1.

The relative time between $\gamma$ and $e^+$ was measured using RMD events for $E_\gamma > 48\,$MeV. After correcting the energy dependence, the relative time resolution for $\mu^+ \to e^+\gamma$ in Tab.1 decay was estimated.

**The resolution of LXe $\gamma$-ray detector**

The CEX data measures the energy resolution that is characterized by an asymmetric distribution as well as the average position resolution along the front-face sides of the LXe calorimeter. Tab.1 reports the resolutions of LXe $\gamma$-ray detector.

## 3 Data analysis

The data in the 2009 run were analyzed by mean of a blinding-box likelihood analysis.
A $\mu^+ \to e^+\gamma$ candidate is characterized by 5 kinematic parameters: $e^+$ energy ($E_{e^+}$), photon energy ($E_\gamma$), time difference between $e^+$ and $\gamma$ ($t_{e^+\gamma}$) and opening angles between $e^+$ and $\gamma$ ($\theta_{e^+\gamma}$ and $\phi_{e^+\gamma}$). The region in the $E_\gamma$-$t_{e^+\gamma}$ centered around the signal (the blinding-box) is not used for optimizing the analysis parameters to avoid any bias.

For the background study and optimization of the analysis, events outside the blinding box were used. The probability density functions(PDFs) for signal $\mu^+ \to e^+\gamma$, RMD and accidental background were prepared using this sideband data and calibration data, in some cases complemented with Monte Carlo simulation.

After the opening of the blinding box the number of signal events is determined by a maximum likelihood fit in the analysis region. An extended likelihood function is

$$\mathcal{L}(N_{sig}, N_{RMD}, N_{BG}) = \frac{N^{N_{obs}} \exp -N}{N_{obs}!} \prod_{i=1}^{N_{obs}} \left[ \frac{N_{sig}}{N} S + \frac{N_{RMD}}{N} R + \frac{N_{BG}}{N} B \right]$$

where $N_{sig}$, $N_{RMD}$ and $N_{BG}$ are the number signal, RMD and accidental background (BG) events respectively, while S, R and B are their respective probability density functions (PDFs). $N_{obs} = 370$ is the total number of events in the analysis region and $N = N_{sig} + N_{RMD} + N_{BG}$. The fit gives $N_{sig} = 3.0$, $N_{RMD} = 35^{+24}_{-22}$, consistent with the expected value, as the best values.

The 90% confidence interval on $N_{\rm sig}$ is determined by the Feldman-Cousins approach[7] with use of toy-MC ssimulations taking into account systematic effects. The obtained upper limit at 90% C.L. is $N_{\rm sig} < 14.5$. The point $N_{\rm sig} = 0.$ is included in the 90% C.L..

Michel $e^+$ triggers were taken simultaneously with signal triggers with a dedicated trigger with a pre-scale factor $P_{e\nu\bar{\nu}} = 1.2 \times 10^7$. The number of selected Michel $e^+$ was used to transform the upper limit on $N_{\rm sig}$ into an upper limit on BR($\mu^+ \to e^+\gamma$). This technique has the advantage of being independent of the instantaneous beam rate and is nearly insensitive to $e^+$ acceptance and efficiency factors associated with the spectrometer.

The BR upper limit is

$$BR(\mu^+ \to e^+\gamma) \leq 1.5 \times 10^{-11} (90\% C.L.)$$

where the systematic uncertainty on the normalization is taken into account. The sensitivity of the experiment is estimated $6.1 \times 10^{-12}$ by means of toy Monte Carlo simulation.

## 4 Conclusions and Prospects

A preliminary analysis of the $\mu^+ \to e^+\gamma$ decay has been performed with a branching ratio sensitivity of $6.1 \times 10^{-12}$ on 2009 data. A blind likelihood analysis yields an upper limit of $BR(\mu^+ \to e^+\gamma) < 1.5 \times 10^{-11}$ (90% C.L.).
The data samples collected in 2010 is two times larger than the one in 2009. Analysis on the 2009-2010 sample is ongoing to produce an improved result.


1. T.Schwetz, M.A. Tortola, J.W.F. Valle, New J. Phys. 10 (2008) 113011.
2. R. Barbieri et al., Nucl. Phys. B 445 (1995) 225
3. J. Hisano et al., Phys. Lett. B 437 (1998) 351
4. M.L. Brooks, et al., MEGA Collaboration, Phys. Rev. Lett. 83 (1999) 1521.
5. Y. Kuno, Y. Okada, Rev. Mod. Phys. 73 (2001) 151
6. S. Ritt, R. Dinapoli, U. Hartmann, Nucl. Instr. and Meth. A 623 (2010) 486-488.
7. G.J. Feldman, R.D. Cousins, Phys. Rev. D 57 (1998) 3873.
8. J. Adam et al., Nucl. Instr. and Meth. A 641 (2011) 19-32.