Status of the MEG II experiment at PSI

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Abstract. The MEG experiment, phase I, has recently established the best experimental upper limit on the branching ratio of the $\mu \rightarrow e \gamma$ decay of $4.2 \times 10^{-13}$ (90% Confidence Level). According to the standard model (SM) of particle physics, such a decay should definitely be non observable while several model of new physics (NP) beyond the SM (BSM) predict it should happen at an experimentally detectable rate. In this talk I summarize the theoretical motivations for searching for this decay and I present the status of the second phase of the experiment, MEG II, which will be able to increase the sensitivity to the $\mu \rightarrow e \gamma$ decay by about one order of magnitude in few years of data taking.

1. A long standing history
Fig. 1 shows the huge sensitivity increase of charged lepton flavor violating (CLFV) decay searches with muons as function of time in the past seventy years and the perspectives for the next ten years.

The first experiments with cosmic-rays and pion beams established the familiar structure of elementary particles. At the end of the 60’s the advent of muon beams enabled to further increase the sensitivity to CLFV decays therefore making possible to test new ideas such as the possible existence of new heavy leptons within the framework of the newly born gauge-symmetries [1, 2]. These hypotheses essentially reflected the belief that lepton family conservation be not a fundamental symmetry of nature.

Present and future experiments are essentially following this tradition, intending to explore the possibility that new physics beyond the standard model may introduce, as we shall see in the next section, small non-diagonal terms in the lepton mass matrix leading to visible CLFV effects. The three main processes that are searched are $\mu \rightarrow e \gamma$, $\mu \rightarrow 3e$ and the conversion of the muon to an electron in the field of a nucleus ($\mu \rightarrow e$). While high intensity conventional muon beams are perfectly suited for the search of the first two processes increasing the sensitivity to $\mu \rightarrow e$ requires a completely different muon beam approach as we shall see in later on.

2. Compelling reasons for searching CLFV
Why are CLFV processes so sensitive to BSM physics?

First of all the CLFV rates predicted by the SM, even with the introduction of conventional neutrino masses to account for oscillations, give totally negligible rates, experimentally unobservable. For instance the branching ratio predicted [3] for $\mu \rightarrow e \gamma$ is of the order of $10^{-54}$. There is therefore no need for precise calculations of SM processes to subtract: if a signal is observed that is a convincing, clear signal of new BSM physics.
Secondly, any modification of the SM lagrangian due to theoretically appealing necessities such as accounting for the vanishing neutrino masses (see-saw models), SM stabilization (SUperSYmmetries, grand unified or not), compositness, leptoquarks etc., makes CLFV diagrams arise. In some cases, such as for instance in a SUSY-GUT SO(10) scenario with slepton mass matrix mixing angles derived from the PMNS neutrino mass matrix, large $\mu \rightarrow e\gamma$ decay rates are predicted [4] which were excluded by the most recent experimental results [5].

As already stated above the rate of the different CLFV processes heavily depends on the physics model considered. However in a model independent approach (see for instance [4]) just a few operators significantly contribute to calculating those rates. In the case of muon CLFV decays two operators have to be considered: the dipole and the four-fermion operator, whose schematic diagrams for muon decays are shown in Fig.2.

![Figure 2](image-url)

**Figure 2.** (a) Dipole operator (b) Four-fermion operator

In case of theories which prefer the dipole operator, such as the supersymmetric ones, $\mu \rightarrow e\gamma$ is favored by roughly a $1/\alpha$ factor with respect to $\mu \rightarrow e$ and $\mu \rightarrow 3e$ while in other kinds of theories such as compositness or leptoquark models, $\mu \rightarrow e\gamma$ is strongly suppressed relative to the other two processes.
It is therefore important to stress the complementarity of the different decay modes searches which would also give the possibility to distinguish among different models in case of positive detection.

3. Comparison with SUSY searches at the LHC

A nice way to understand the sensitivity of CLFV to BSM physics is presented in [4] where CLFV experimental results are used to obtain bounds within the same simplified models (defined by a subset of the relevant particles and couplings) employed by the LHC collaborations to interpret the searches for EW production of SUSY particles. Fig. 3 for instance shows the exclusion plots for the case where the only light SUSY particles are the Bino, the RH and LH sleptons, while the rest of the spectrum is decoupled. In order to derive these plots some assumptions were made (written on the scales) on the masses of the particles involved and on the non diagonal elements of the slepton mass matrix \((\Delta_{LL,RR})_{ij}\) normalized to the diagonal terms according to:

\[
(\delta_{LL,RR})_{ij} = \frac{(\Delta_{LL,RR})_{ij}}{\sqrt{(m^2_{L,R})_{ii}(m^2_{L,R})_{jj}}} \tag{1}
\]

CLFV experiments set limits on \(\delta_{LL,RR}\) which are shown in Fig. 3 left as a function of the masses of the light SUSY particles of the simplified model; the bino mass \((M_1)\) and the sleptons masses \((m_L, m_R)\), all assumed to be equal. The upper limits on \(\delta_{LL,RR}\) are shown in Fig. 3 right, in the parameters space of the bino mass versus the slepton masses, which also shows the parameter space region excluded by the LHC experiments (dark region) and the region which would explain the g-2 anomaly (light grey region). We may note how stringent is the constraint on the non diagonal part of the slepton mass matrix given by CLFV experiments in all the regions of this plot.

![Figure 3. Bounds and prospects from CLFV experiments for a SUSY model with Bino and both LH and RH sleptons (see text). Figure coloured online.](image-url)
4. The MEG experiment
The best experimental upper limits on CLFV muon decays were obtained at the PSI laboratory where the world most powerful continuous muon beam is produced by the interaction of a 590 Mev proton beam on a graphite target. 29 MeV/c muons coming from the decay at rest of pions on the surface of the target are collected by a magnetic channel and transported to the experimental areas. The intensity of this beam is roughly 10^8 µ/s.

The signature of a \( \mu \rightarrow e\gamma \) event is given by a back-to-back, monoenergetic, time coincident photon-positron pair from the two body \( \mu \rightarrow e\gamma \) decay. In each event, positron and photon candidates are described by four observables: the photon and positron energies (\( E_\gamma, E_e \)), their relative direction (\( \Theta_{e\gamma} \)) and emission time (\( t_{e\gamma} \)).

The MEG [5] detector is comprised of a positron spectrometer formed by a set of drift chambers and scintillation timing counters, located inside a superconducting solenoid with a gradient magnetic field along the beam axis, and a photon detector, located outside of the solenoid, made up of a homogeneous volume (900 liters) of liquid xenon (LXe) viewed by 846 UV-sensitive photomultiplier tubes (PMTs) submerged in the liquid.

The background has two components: one coming from the radiative muon decay (RMD) \( \mu \rightarrow e\nu\bar{\nu}\gamma \) and one from the accidental superposition of energetic positrons from the standard muon Michel decay with photons from RMD, positron-electron annihilation-in-flight or bremsstrahlung. At the MEG data taking rate, 93% of events with \( E_\gamma > 48 \) MeV are from the accidental background.

![Figure 4](image)

**Figure 4.** MEG final results: (a) \( E_\gamma \) vs \( E_e \) (b) \( \cos(\Theta_{e\gamma}) \) vs \( t_{e\gamma} \). 68%, 90% and 95% C.L. signal contour lines are shown.

Fig. 4 shows the event distributions in the \( (E_\gamma, E_e) \) and \( (\cos(\Theta_{e\gamma}), t_{e\gamma}) \) planes for the full data set of the MEG experiment together with the 68%, 90% and 95% contours of the signal probability distribution function.

The final branching ratio upper limit on the \( \mu \rightarrow e\gamma \) decay of \( 4.2 \times 10^{-13} \) (90% Confidence Level) was obtained by a likelihood analysis that compared the measured distributions of the decay variables with the ones expected for the signal and backgrounds.

While the signal region in Fig. 4 does not show any substantial excess of events it may be noted that it contains background events. This in short was the reason for deciding to stop MEG data taking and perform an upgrade of the experiment.

The MEG experiment upgrade [6], schematically shown in Fig. 5, is currently being implemented. A new cylindrical drift chamber (CDCH) substituted the old set of planar drift
chambers; this chamber was recently shipped to PSI and it is currently under test. A new pixelated timing counter replaced the old scintillator bars and was already tested with the PSI muon beam. The required timing resolution of 35 ps for traversing 8 scintillator tiles was experimentally achieved. Part of the photomultipliers of the LXe $\gamma$ detector were substituted with smaller silicon photomultipliers; this will both increase the photon angular and energy resolution.

All the upgraded detectors resolutions should roughly improve by a factor two. A further detector (RDC: radiative decay counter) able to reduce the RMD background by measuring low energy positrons in coincidence with photons in the LXe detector was built and is currently under test.

Learning from past experience we further developed and put in operation two systems for almost continuous beam monitoring; a first one made of scintillating fibers and a second one employing a scintillating target. The position and possible deformations of the muon decay target will be checked on-line by a camera monitoring appropriate small spots drawn on the surface of the target.

An improvement of one order of magnitude in sensitivity with respect to the final MEG result is foreseen in about three years of data taking which is foreseen to start in 2018/2019.

References
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