# THE MEG EXPERIMENT AT PSI

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**Abstract**

We discuss the status of the MEG experiment at the Paul Scherrer Institute (PSI). We review the experimental techniques, the development and building of the apparatus and its expected performances.

## 1 Introduction

Lepton Flavour Violating processes are predicted by many Super Symmetric (from now on: SSM) extensions of the Standard Model (from now on: SM) at reasonable rates[1]. For the $\mu \to \mathrm{e}\gamma$ decay, the predicted branching ratio (from now on: BR) ranges from $\sim 10^{-14}$ to $\sim 10^{-12}$ in respect with the Michel decay $\mu \to \mathrm{e}\nu\nu$. Recent limits on SSM parameters[2] and the combination of all solar $\nu$ experiments[3] and of the KamLAND results[4] favour a $BR_{\mu\to\mathrm{e}\gamma} \gtrsim 10^{-13}$[5]. Moreover, since the SM prediction is $BR_{\mu\to\mathrm{e}\gamma} \sim 10^{-50}$, an evidence for a $\mu \to \mathrm{e}\gamma$ decay at a "large" BR would be a clear indication for physics beyond the SM. The MEG experiment[6], an Italian-Japanese-Swiss and Russian Collaboration at the Paul Scherrer Institute (from now on: PSI) of Villigen (Switzerland), aims to be sensitive to $BR_{\mu\to\mathrm{e}\gamma} \lesssim 10^{-13}$. We review the status of the experiment and its expected sensitivity.

## 2 Signal, background and experimental strategy

The $\mu \to \mathrm{e}\gamma$ event with a $\mu^+$ decaying at rest is characterized by a back-to-back $\mathrm{e}^+$-$\gamma$ pair, both of them with 52.8 MeV energy. This event can be

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mimed by a "correlated" (coming from the radiative $\mu$ decay $\mu \to e\nu\nu\gamma$) and by an "accidental" background (coming from the accidental superimposition of a Michel $e^+$ and a $\gamma$ from a radiative decay, a $e^+$-$e^-$ annihilation in flight or a bremsstrahlung process). The experimental strategy is then to stop a $\mu^+$ beam, leave $\mu$'s decay at rest and identify the $\mu \to e\gamma$ event through precise measurements of $\gamma$ and $e^+$ energies, emission times and relative angle.

## 3 The setup

The experimental setup is shown in Fig. 1 left. The $\gamma$ and $e^+$ from the $\mu \to e\gamma$ decay will be respectively detected by a liquid xenon (from now on: LXe) calorimeter and by a spectrometer, formed by drift chambers (from now on: DC) and scintillation timing counters (from now on: TC).

**Beam and target** The PSI machine provides proton beams of 590 MeV energy, with a nominal current of 1.8 mA, which produce $\pi$ and $\mu$ beam lines by collision on a Be target. We will use a pulsed $\mu$ beam with a momentum of 28 MeV/c, an intensity $\sim 10^8$ $\mu^+$ $s^{-1}$, beam spot sizes $\sim$ 6 mm and a $7\sigma$ separation between $\mu^+$ and $e^+$. The $\mu$ beam will be stopped in a 150 $\mu$m-thick polyethilene target, slanted by 22° in respect with the beam axis ($z$).

**Spectrometer** *COBRA Magnet.* The magnetic field of the spectrometer is provided by a *Co*nstant *B*ending *Ra*dius (*COBRA*) magnet, formed by 5 superconducting coils and 2 conventional compensating coils of various diameters, which produce a non-uniform field, with a central value of 1.26 T. The field gradient is chosen to achieve a bending radius almost independent of the $e^+$ emission angle and a quick expulsion of the high $p_\perp$ $e^+$'s (which can cause large inefficiencies spiraling in the spectrometer for a long time).

*DCs.* The $e^+$ tracking will be performed by 17 DCs, aligned radially, at 10° intervals, in 2 staggered arrays of drift cells. Each cell is filled by a 50/50 He-$C_2H_6$ mixture and equipped with 20 wires. The expected resolutions are $\sigma_r \sim$ 200 $\mu$m, $\sigma_z \sim$ 300 $\mu$m and $\sigma_t \sim$ 10 ns ($t$ is the absolute time). Measurements with smaller prototypes([6], [7]) showed that these resolutions are achievable. The corresponding performances at 52.8 MeV are $\Delta\theta \approx$ 12 mrad, $\Delta P/P \approx 0.8\,\%$ and $\Delta x \approx$ 2.5 mm ($x$ is the $e^+$ emission point).

*TCs.* The $e^+$ time will be measured by 2 layers of TCs, scintillator bars read by PMTs and placed at right angles with each other. The inner layer should provide to the trigger system the information on where the $e^+$ crosses the TCs, while the outer layer should measure the $e^+$ crossing time with a 100 ps (FWHM) resolution. Measurements with BC404 scintillator bars[6] showed that this resolution is feasible. Other solutions are under testing.

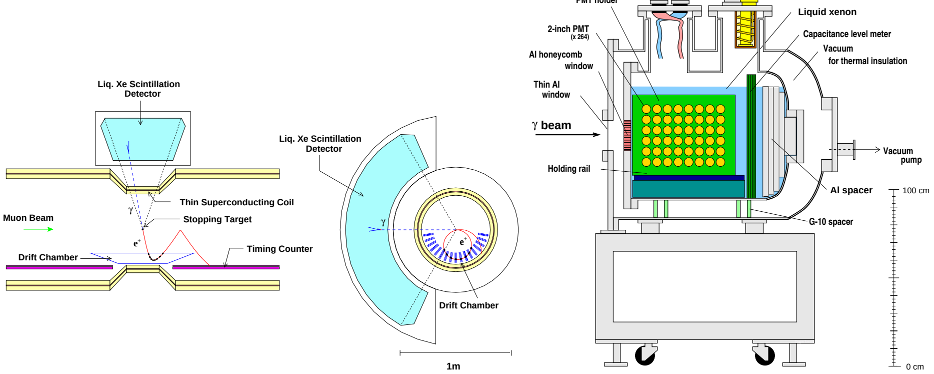

Figure 1: Left: the MEG experimental setup. Right: the LXe large prototype

**The LXe calorimeter** The $\gamma$ energy, direction and angle will be measured by a 800 l LXe calorimeter, chosen because of its large scintillation light yield and homogeneity and equipped with $\sim$ 800 PMTs and with LED and $\alpha$ sources for periodic calibrations. The expected performances of the calorimeter are (all FWHM and at $E = 52.8$ MeV): $\Delta E/E \approx 4\,\%$, $\Delta\theta, \Delta\phi \approx 15$ mrad and $\Delta t \approx 100$ ps. A long and refined R & D work is needed to reach the required resolutions for a LXe calorimeter of this size and complexity. Two prototypes were built, a "Small"[6] and a "Large"[6] one (100 l, from now on: LP); a sketch of the LP is shown in Fig. 1 right. By means of the LP (presently the largest LXe detector in the world) one can test the cryogenic operations on a long term and on a large volume, measure the LXe optical properties, check the analysis algorithms and measure energy, position and timing resolution. Many results were already achieved, the most important one being that the light absorption length is $> 1$ m. The behaviour in LXe and the characteristics of all PMTs will be studied by using a cryogenic test facility, under development in Pisa.

**Trigger and electronics** The trigger scheme was designed to take advantage from the fast information provided by LXe and TC. A digital FADC-FPGA trigger system will compute the total collected charge on LXe (a rough estimate of the $\gamma$ energy release) and will single out the charge, time and address of the LXe PMT which collects the maximum charge and the address, charge and times of the PMTs in the TC bars hit by the $e^+$ (respectively correlated to the $\gamma$ and $e^+$ directions and times). The expected acquisition rate is $\sim$ 20 Hz for a $\mu^+$ rate of $10^8 \mu^+ s^{-1}$. The readout electronics will include the waveform digitisation of all channels, based on a custom-made chip (*DOMINO*), with a sampling speed of 2.5 GHz.

## 4 Expected sensitivity

The achievable performances and the background level determine the sensitivity of the experiment. The expected number of $\mu \to \mathrm{e}\gamma$ events and the dominant background (the accidental one) are given by

$$\begin{aligned} N_{sig} &= BR_{\mu\to\mathrm{e}\gamma} \times T \times R_\mu \times (\Omega/4\pi) \times \epsilon \\ BR_{\mathrm{acc}} &\propto R_\mu \times \Delta E_{\mathrm{e}} \times (\Delta E_\gamma)^2 \times (\Delta\theta_{\mathrm{e}\gamma})^2 \times \Delta t_{\mathrm{e}\gamma} \end{aligned}$$

where $T$ is the measurement time, $R_\mu$ is the $\mu^+$ rate, $\Omega/4\pi \approx 0.09$ is the solid angle fraction covered by the detector, $\epsilon \approx 0.4$ is the global efficiency and $\Delta E_{\mathrm{e}}$, $\Delta E_\gamma$, $\Delta\theta_{\mathrm{e}\gamma}$ and $\Delta t_{\mathrm{e}\gamma}$ are the $\mathrm{e}^+$ and $\gamma$ energies and the $\mathrm{e}^+$-$\gamma$ relative angle and timing resolutions (FWHM). Using $T = 2.6 \times 10^7$ s and $R_\mu = 3 \times 10^7 \mu^+ \,\mathrm{s}^{-1}$ we obtain $BR_{\mathrm{acc}} \approx 3 \times 10^{-14}$ and a 90 % C.L. upper limit for no observation $BR_{\mu\to\mathrm{e}\gamma} \leq 10^{-13}$, within the SSM predictions. In case of positive signals, observing 4 events we will set a $BR_{\mu\to\mathrm{e}\gamma} \approx 2\times10^{-13}$ (the probability of a 4 events background fluctuation is $2 \times 10^{-3}$).

## 5 Conclusions

MEG may provide a clean indication of New Physics in the SUSY frame. Measurements on detector prototypes and Monte Carlo simulations make us confident to be sensitive to $BR_{\mu\to\mathrm{e}\gamma} \lesssim 10^{-13}$. The detector assembly is foreseen during 2004 and 2005 and the data taking during 2006 and 2007.

## References

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