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The MEG experiment at PSI: status and prospect

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Lepton flavor violation processes are generically allowed in most of the extensions of the Standard Model. In particular, Super-Symmetric Grand-Unified theories predict rates for the $\mu^+ \rightarrow e^+\gamma$ decay not far from the present experimental limit. The MEG Collaboration is designing a detector to search for this lepton flavor violating decay with a sensitivity of $\sim 5 \times 10^{-14}$. The present status of the detector developments, the required detector performances and the time schedule for the experiment completion are discussed.

1. Introduction

Lepton flavor violation (LFV) processes in the charged sector are obtained in the minimal extension of the Standard Model by introducing the Dirac neutrino masses and the neutrino mixing. The foreseen branching ratios result, however, unmeasurably small ($\sim 10^{-50}$). On the other hand, supersymmetric unification theories (SUSY-GUT) generically predict LFV processes at a measurable level. These processes could be caused by the slepton mixing due to radiative corrections [1] and by the inclusion of a see–saw mechanism for the neutrino masses [2]. We observe that these two sources of LFV are independent and always present in all supersymmetric grand unified models. LFV processes are therefore very clean (i.e. not contaminated by the background of the Standard Model) and it constitutes unambiguous signal of profound new physics.

The predicted branching ratio for the $\mu^+ \rightarrow e^+\gamma$ decay in SUSY SU(5) models ranges from 10^{-15} to 10^{-11}. The measured neutrino mixing parameters, when included in SUSY models, restrict the possible branching ratio to values well exceeding 10^{-14}.

The MEG collaboration is composed by Italian, Japanese, Russian and Swiss physicists. The collaboration goal is the search for the $\mu^+ \rightarrow e^+\gamma$ decay with a sensitivity of $\sim 5 \times 10^{-14}$, which corresponds to a two order of magnitude improvement with respect to the present experimental bound set by the MEGA collaboration [3] to $BR(\mu^+ \rightarrow e^+\gamma) < 1.2 \cdot 10^{-11}$.

2. The MEG Detector

The signature of a $\mu^+ \rightarrow e^+\gamma$ event is given by a coincidence of a 52.8 MeV photon with a 52.8 MeV positron in space, time and direction.

The MEG experiment [4] will be conducted at the Paul Scherrer Institut (PSI), using the πE5 beam line. A schematic view of the detector is shown in Fig. 1. The positive muon beam, with intensity up to $10^8\mu/s$ in a ~ 0.5 cm radius spot, is brought to stop in a thin target after passing a stage in which most of the contaminating positrons are eliminated.

The momentum and the emission direction of the e^+ are measured precisely by a magnetic spectrometer, composed of a quasi-solenoidal magnetic field and a set of ultra-thin drift chambers. The field is shaped so that monochromatic e^+s from the target follow trajectories with constant projected bending radius, independent of the emission angle over a wide angular range. Furthermore the sweeping capability of the non uniform magnetic field reduces the persistence of low longitudinal momentum e^+s in the tracking volume. Both features greatly reduce the accidental pile-up of the Michel e^+, decrease the pattern recognition complexity and enhance the system efficiency. The expected FWHM resolutions range between 0.7 and 0.9% for the positron momentum and from 9 to 12 mrad for the angle.

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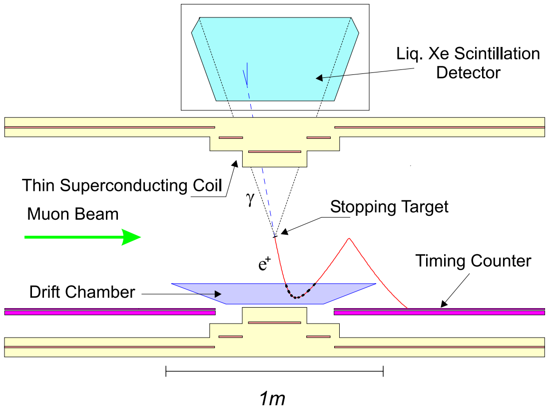

Figure 1. Schematic view of the detector

An array of plastic scintillators is placed on each side of the spectrometer to measure the e^+ emission time with resolutions 0.1 ns FWHM.

While all e^+ are confined inside the magnet, the γ-rays penetrate through the thin superconducting coil of the spectrometer ($\simeq$ 80% transmission probability) and are detected by a liquid Xenon scintillation detector. It consists of a single volume of liquid Xenon viewed from all sides by about 800 photomultipliers (PMT). The liquid Xenon is very luminous and emission time of the scintillation light is short ($\simeq$ 20 ns) so that all the kinematical variables of the impinging photons can be reconstructed from the PMT signals only. Tests on a large scale prototype as well as a full simulation show that one can expect FWHM resolutions of 4% for the energy, 10.5 mm for the position and 0.1 ns for the timing measurements for 52.8 MeV γ-rays.

3. Background estimates and sensitivity

There are two major backgrounds to the $\mu^+ \to e^+\gamma$ search: the physics background from radiative muon decays, $\mu^+ \to e^+\nu_e\overline{\nu}_\mu\gamma$, and the accidental background, given by the accidental selection of a Michel positron and a photon from a different process.

The background crucially depends on the detector performances. Our current estimates of the detector performances, defined using FWHM, are summarized in Table 1.

	FWHM
ΔE_e	0.8%
ΔE_γ	4%
$\Delta\theta_{e\gamma}$	19 mrad
$\Delta t_{e\gamma}$	0.15 ns

Table 1
Expected detector performances.

The physical background (B_{phys}), calculated by numerical integration with resolution values shown in Table 1, was found to contribute $\approx 3.1 \times 10^{-15}$ events per muon decay.

The accidental background poses more threat than the physical one. The positron rate can be computed from the Michel positron spectrum and the response function of the tracking system. The single photon yield per muon decay was evaluated by taking into account: radiative muon decays, annihilation-in-flight of positron in the target, positron interactions with surrounding materials and neutron induced background. The accidental background B_{acc} scales with the detector resolutions as follows:

$$B_{acc} \propto R_\mu^2 \cdot \Delta E_e \cdot \Delta t_{e\gamma} \cdot (\Delta E_\gamma)^2 \cdot (\Delta\theta_{e\gamma})^2, \qquad (1)$$

and it was found to contribute with $\approx 3 \times 10^{-14}$ events per muon decay, for the running muon stop rate of $R_\mu = 0.3 \times 10^8$/s.

With this R_μ stop rate, the detector resolution of Table 1 and a total running time of 2.6×10^7 s, the single event sensitivity (SES) of MEG results 3.8×10^{-14}.

The sensitivity can be converted into 90% confidence level upper limit, in case of no signal observed, by using the background rate estimates. The upper limit is 1.0×10^{-13}. The discovery potential of this experiment is summarized by considering that a BR $= 2 \times 10^{-13}$ corresponds to 4 $\mu^+ \to e^+\gamma$ events. These events have a probability of 2×10^{-3} to be generated by a background fluctuation.

4. Present status and perspectives

The MEG experiment has been approved and completely funded by the national agencies of the participating countries. An intensive research and development phase, concerning all experimental aspects, has been carried out, and presently the collaboration is building the final detector. Here a brief overview of various subdetectors is given.

The existing πE5 beam line has been coupled to the spectrometer magnet, maintaining an intensity up to $10^8\mu$/s. An electrostatic separator has been integrated in the beam line and the positron contamination of 10^9e$^+$/s has been suppressed by more than 6 orders of magnitude.

The spectrometer magnet has been installed in the experimental area and it has been excited to the final current intensity. The preliminary field mapping confirmed the design field structure. A tracking chamber prototype, with the 15 μm thin cathode foils, has been built and tested. The measured hit position resolution were near the design goals and resulted in $\sigma_R \sim 90$ μm and $\sigma_Z \sim 400$ μm. A full scale prototype test is planned at the beginning of the next year, before starting the final production.

A full scale prototype of one module of the timing counter system has been produced. It was tested in magnetic field environment with electrons. The measured timing resolution was $<$ 100 ps FWHM, independently from the position along the counter. This value is well within the design performances.

The most critical and innovative device is the liquid Xenon calorimeter whose energy resolution is required to be 4 % FWHM at 52.8 MeV. The major uncertainty on the calorimeter is the liquid Xenon transparency to scintillation light. A large calorimeter prototype was produced and operated. It has $40 \times 40 \times 50$ cm^3 Xenon active volume read by 228 PMTs; it is equipped with ^{241}Am α-sources and blue LEDs for calibration. Handling of liquid Xenon, continuous Xenon purification and calibration procedures for the PMTs have been successfully developed and shown to be appropriate for the final detector. For instance, after purification, a Xenon absorption length $>$ 100 cm was measured with α-sources. The prototype performances were measured by means of γ's coming from π^0 decay, produced in the charged exchange reaction of π^- on protons. The achieved energy resolution is 4.8 % FWHM at 55 MeV, not far from the design goal. The final detector, presently under construction, will use PMT of improved quantum efficiency, therefore we are confident that the design resolution will be obtained.

The trigger of $\mu^+ \to e^+\gamma$ events, is generated on selection applied on digitally reconstructed energy, direction and timing of the photon and rough direction and timing of the positron. A trigger prototype system has been successfully operated in conjunction with the calorimeter prototype. The electronic front-end is based on an analog signal sampler, the DRS chip, developed at PSI by the collaboration. Samples of the chip have been successful operated at sampling speed up to 2 GHz.

Much progress was made in the design and construction of the MEG detector for the $\mu^+ \to e^+\gamma$ search at PSI. Various sub-detector prototypes have been produced and their results were already within the design requests, or near by. There are no technical issues, that could reduce the experiment sensitivity, left unaddressed. The detector is in the construction phase and the data taking is foreseen starting in 2006.

REFERENCES

1. R. Barbieri and L. J. Hall, Phys. Lett. **B338**, 212 (1994); R. Barbieri, L. J. Hall and A. Strumia, Nucl. Phys. **B445**, 219 (1995).
2. J. Hisano *et al.*, Phys. Lett. **B357**, 579 (1995); J. Hisano, D. Nomura T. Yanagida, Phys. Lett. **B437**, 351 (1998); J. Hisano and D. Nomura, Phys. Rev. **D59**, 116005 (1999).
3. M. L. Brooks *et al.* [MEGA Collab.], Phys. Rev. Lett. **83**, 1521 (1999).
4. A. Baldini *et al.* "The MEG experiment: search for the $\mu^+ \to e^+\gamma$ decay at PSI" (2002) available at the web-site: `http://meg.psi.ch`