MEG Experiment - New Result and Prospects -

Hajime Nishiguchi *on behalf of the MEG collaboration*

Institute of Particle and Nuclear Studies (IPNS),
High Energy Accelerator Research Organization (KEK),
1-1 Oho, Tsukuba, 305-0801, Japan

Abstract. The MEG Experiment searches for a lepton flavour violating muon decay, $\mu^+ \to e^+\gamma$, with a branching ratio sensitivity of 10^{-13} in order to explore the parameter region predicted by many theoretical models beyond the Standard Model. The first physics run has been performed in 2008, and the second phase of data taking was carried out in 2009 after some detector upgrades. We have performed a likelihood analysis with a sensitivity of 6.1×10^{-12}, which is approximately twice better than the current upper limit set by the previous experiment, and set an upper limit on the branching ratio $B(\mu^+ \to e^+\gamma) < 1.5 \times 10^{-11}$(90%C.L.).

Keywords: Muon, Lepton Flavour Violation, MEG
PACS: 13.35.Bv

INTRODUCTION

The Standard Model of elementary particle physics is one of the greatest successes of modern science. Based on the principles of gauge symmetries and spontaneous symmetry breaking, everything had been consistently described until experimental evidence for neutrino oscillation was shown by SuperKamiokande for the first time.

Now, **Lepton Flavour Violation (LFV)** among charged leptons, *e.g.* $\mu^+ \to e^+\gamma$ decay *etc.*, which has never been observed while the quark mixing and the neutrino oscillations have been experimentally confirmed, is attracting a great deal of attention, since its observation is highly expected by many of well motivated theories beyond the Standard Model[1]. It is predicted that $\mu^+ \to e^+\gamma$ is naturally causable with a branching ratio just below the current upper limit, $10^{-11} \sim 10^{-14}$, by the leading theories for physics beyond the standard model, *e.g.* the Supersymmetric theories of Grand Unification or Supersymmetric Standard Model with the seesaw mechanism (see Ref.[2] for a review). The ambitious goal of the MEG experiment [3] is to search for a $\mu^+ \to e^+\gamma$ decay with an improved sensitivity by at least two orders of magnitude over the current best limit.

The signal of $\mu^+ \to e^+\gamma$ decay is very simple and is characterized by a 2-body final state of a positron and γ-ray pair emitted in opposite directions with the same energy, 52.8 MeV, which corresponds to half the muon mass. There are two major backgrounds in the search for $\mu^+ \to e^+\gamma$. One is a physics (prompt) background from a radiative muon decay, $\mu^+ \to e^+\nu_e\bar{\nu_\mu}\gamma$, when the positron and the γ-ray are emitted back-to-back with the two neutrinos carrying off tiny energy. The other background is accidental coincidence of a positron from a normal Michel decay, $\mu^+ \to e^+\nu_e\bar{\nu_\mu}$, with a high energy random photon. The source of high energy γ ray is either a radiative muon decay, annihilation-in-flight or external bremsstrahlung of a positron. The background is primarily dominated by accidental coincidence. Suppressing such an accidental overlap holds the key for leading MEG to a successful conclusion.

EXPERIMENTAL OVERVIEW

A schematic view of the MEG detector apparatus is shown in Figure 1. A DC muon beam is the best tool to search for $\mu^+ \to e^+\gamma$ since experimental sensitivity is mainly limited by accidental backgrounds. The MEG experiment thus employs using the world's most intense DC muon beam at the Paul Scherrer Institut (PSI).

The momentum and direction of positrons are measured precisely by a Positron Spectrometer, which consists of a superconducting solenoidal magnet specially designed to form a highly graded field, an ultimate low-mass drift chamber system, and a precise time measuring counter system [4]. The MEG solenoidal magnet provides a highly graded magnetic field (1.27 T at the centre and decreasing down to 0.49 T at the end along the beam axis). Thanks to this graded magnetic field, the MEG solenoid can sweep positrons out of the fiducial tracking volume quickly while positrons undergo many turns in the tracker volume in a uniform solenoidal field. Additionally, positrons with the same absolute momenta follow trajectories with a constant projected bending radius independent of the emission angles. This allows us to discriminate sharply high momentum signal positrons from the tremendous Michel positron background. The Positron Spectrometer therefore does not need to measure the positron trajectory in the small radius region,

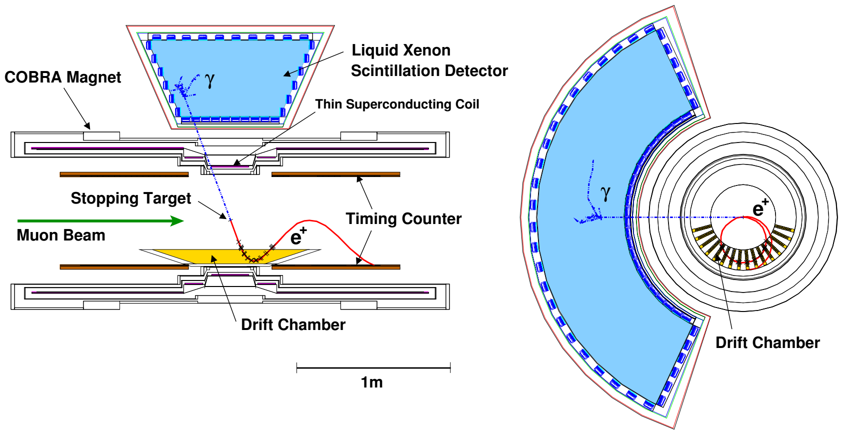

FIGURE 1. A schematic view of the MEG detector apparatus

i.e. the drift chambers can be blind to most of the Michel positrons.

While all positrons are confined by the solenoid, the γ ray pass through the thin superconducting coil of the spectrometer with ≈80% transmission probability, and are detected by an innovative liquid-xenon photon detector [5]. Scintillation light emitted inside liquid xenon are viewed from all sides by photo-multiplier tubes (PMT) that are immersed in liquid xenon in order to maximize direct light collection. Liquid-xenon scintillator has very high light yield (≈75% of NaI crystal) and fast response, which are the most essential ingredients for precise energy and timing resolutions required for this experiment.

MEG RUN 2009

At the first physics run of MEG in 2008, the detector performances were severely limited due to the discharge problem on the drift chamber [6]. The source of problem was identified and solved, all drift chambers were modified and have since been successfully in operation throughout the 2009 run. Meanwhile, the xenon was purified during the maintenance period resulting in a 45% increase in light yield compared to that in 2008. We conducted 43 days data acquisition in November and December 2009. The beam intensity was adjusted for the muon stopping rate to be 2.8×10^7 sec^{-1}. In total, 6×10^{13} muons were stopped on target, and 22 M triggered events were acquired. Finally obtained detector peformances and experimental parameters in 2009 are listed in Table 1. The number of Michel positrons was counted simultaneously with the signal, using the same analysis cuts, for normalization.

TABLE 1. Detector Performances in 2009

γ-ray energy resolution	2.1 %
γ-ray spacial resolution	5-6 mm
e^+ momentum resolution	0.74 %
γ-e^+ opening angle resolution	11.2(θ), 7.1(ϕ) mrad
γ-e^+ relative timing resolution	142 ps
γ-ray detection efficiency	58 %
e^+ detection efficiency	40 %

ANALYSIS

The variables that are used to measure the $\mu^+ \to e^+\gamma$ dacay kinematics are the γ-ray and positron energies (E_γ, E_e), their relative time $(t_{e\gamma})$ and their opening angles $(\theta_{e\gamma}, \phi_{e\gamma})$. Events around the signal region in $(E_\gamma, t_{e\gamma})$-plane were hidden until analysis was fixed. The detector calibration and performance evaluation were done using calibration samples and events outside the hidden box (sideband data). The background level in the signal region can be also studied using sideband data.

The best estimates of the numbers of signal, radiative muon decay (RD) and accidental background (BG) are determined by means of an unbinned maximum likelihood fit to the observed events in a pre-defined analysis window. The analysis window is defined enough widely to estimate the background distribution. An extended maximum likelihood is constructed as

$$\mathscr{L}(N_{\rm sig}, N_{\rm RD}, N_{\rm BG}) = \frac{N^{N_{\rm obs}} e^{-N}}{N_{\rm obs}!} \times \prod_{i=1}^{N_{\rm obs}} \left(\frac{N_{\rm sig}}{N} \cdot S(\mathbf{x}_i) + \frac{N_{\rm RD}}{N} \cdot R(\mathbf{x}_i) + \frac{N_{\rm BG}}{N} \cdot B(\mathbf{x}_i) \right)$$

where $\mathbf{x}_i$ is a vector of the five observables for the i-th event, $N_{\rm sig}$, $N_{\rm RD}$ and $N_{\rm BG}$ are number of signal, RD and BG, respectively, while S, R and B are their respective probability density functions (PDFs). $N_{\rm obs}$ is observed

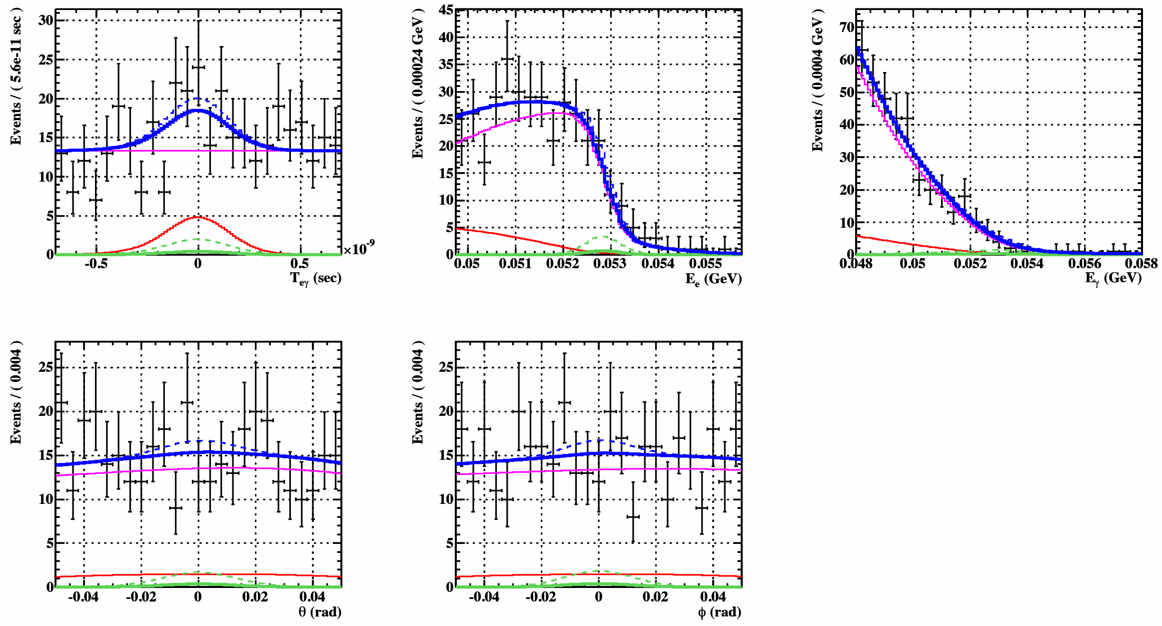

FIGURE 2. Event distribution in the fit region projected on each variable ($t_{e\gamma}, E_e, E_\gamma, \theta_{e\gamma}, \phi_{e\gamma}$) and result of the maximum likelihood fit. The green, red and magenta curves show signal, RD, and BG PDFs, respectively, and blue for the total. The solid lines show the best-fit distributions, while the dashed ones show those with $N_{\rm sig}$ at the 90% upper limit.

total number of events in the analysis window, while $N = N_{\rm sig} + N_{\rm RD} + N_{\rm BG}$ is the expected one. A confidence region is built by the likelihood-ratio ordering principle [7] in the ($N_{\rm sig}$,$N_{\rm RD}$)-plane and the confidence interval on $N_{\rm sig}$ is extracted from the projection of the region to the $N_{\rm sig}$-axis.

Here, we define a sensitivity of this search with a mean of upper-limit distribution over an ensemble of toy-MC experiments with null signal. The branching-ratio sensitivity at 90% C.L. is evaluated to be 6.1×10^{-12}. The maximum likelihood fit to 370 events in the analysis window, whose result as projections on each variables is shown in Figure 2, gives the $N_{\rm sig}$ best-estimate value at 3.0. The obtained $N_{\rm RD} = 35^{+24}_{-22}$ is consistent with the expectation which is calculated to be 32 ± 2 from the E_γ-sideband. The confidence region is constructed by means of toy-MC simulation with taking into account possible systematic effects. The PDFs and normalization factor are fluctuated for each toy-MC experiment in accordance with their uncertainty values. The point of $N_{\rm sig} = 0$ is included in the 90%-confidence interval, and an upper limit is calculated to be $N_{\rm sig} < 14.5$. This yields an upper limit on the branching ratio,

$$B(\mu^+ \to e^+\gamma) < 1.5 \times 10^{-11} \quad (90\%\ \text{C.L.})^1.$$

[1] Three independent analyses with different statistical approaches were performed to check the analysis, and gave consistent results.

CONCLUSION

A search for the lepton flavour violating decay $\mu^+ \to e^+\gamma$ by the MEG second year run was presented. The sensitivity is evaluated to be 6.1×10^{-11}, which is approximately twice better than the current limit. A preliminary analysis sets an upper limit on the branching ratio, $B(\mu^+ \to e^+\gamma) < 1.5 \times 10^{-11}$(90% C.L.). MEG resumed data acquisition in August 2010 and has been accumulating statistics with stable detector condition. It will run at least until the end of 2012 to achieve our goal of $(2-3) \times 10^{-13}$ sensitivity.

REFERENCES

1. R. Barbieri *et al.*, Nucl. Phys. **B455** (1995) 219.
2. Y. Kuno and Y. Okada, Rev. Mod. Phys. **73** (2001) 151.
3. `http://meg.psi.ch`
4. H. Nishiguchi, Nucl. Instr. Meth. **A581** (2007) 538.
5. T. Iwamoto, Nucl. Instr. Meth. **A617** (2010) 92.
6. J. Adam *et al.* (MEG Collaboration), Nucl. Phys. **B834** (2010) 1.
7. G. J. Feldman and R. D. Cousins, Phys. Rev. **D57** (1998) 3873.