PROCEEDINGS OF SCIENCE

Analysis of the MEG experiment to search for $\mu^+ \to e^+\gamma$ decays

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The lepton flavor violating muon decay $\mu^+ \to e^+\gamma$ is forbidden in the standard model. On the other hand, new theories, such as supersymmetry, grand unification theories and so on, predict the branching fraction in the range of $10^{-14} - 10^{-12}$, which is just below the current experimental upper bound. MEG experiment aims to search for the decay with 10^{-13} sensitivity. In 2009, we collected physics data from 6×10^{13} muon decays. A likelihood analysis was performed on the data, with a preliminary sensitivity of 6.1×10^{-12}. A preliminary upper limit on the branching fraction was set to be 1.5×10^{-11} at 90 % confidence level.

35th International Conference of High Energy Physics - ICHEP2010,
July 22-28, 2010
Paris France

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PoS(ICHEP 2010)263

1. Introduction

MEG searchs for the lepton flavor violating muon decay $\mu^+ \to e^+\gamma$. The decay is forbidden in the standard model, while several new theories, such as supersymmetry, grand unification theories and so on, predict branching ratio close to the current experimental limit, $\mathscr{B} < 1.2 \times 10^{-11}$[1].

MEG is running at the Paul Scherrer Institut (PSI) in Switzerland, where the most intense direct current muon beam is available. Surface-muons produced on a graphite target are transported and focused on a thin stopping target located at the center of a superconducting solenoid. The MEG detector consists of a positron spectrometer and a photon detector. The spectrometer consists of a superconducting solenoid with a gradient field to sweep out positrons quickly, drift chambers to measure tracks and plastic scintillation counters to measure time of hits. A liquid xenon calorimeter is used to measure energy, position and time of photons. The first physics data was taken in 2008[2] with lower detection efficiency due to a discharge problem. The problem was solved during the shutdown time after 2008 run. In 2009, physics data was taken for two months with a stable detector condition. A more detailed description on the MEG detector and run 2009 was shown in another presentation[3].

2. Analysis of 2009 run

An unbinned maximum likelihood analysis was performed on the physics data taken in 2009. We present a preliminary result from the analysis. The analysis was done with different statistical approaches, probability density function (PDF) parametrizations and analysis window sizes for cross check. Observables used in the analysis are photon energy (E_γ), positron energy (E_e), time difference ($T_{e\gamma}$) and angles ($\theta_{e\gamma}$ and $\phi_{e\gamma}$). $\theta_{e\gamma}$ and $\phi_{e\gamma}$ are polar and zenith angle between photon and inverted positron momentum, respectively. Events around the signal region selected with E_γ and $T_{e\gamma}$ were hidden until analysis algorithms and selections are finalized.

The normalization factor to convert the number of signals to the branching fraction was evaluated from the number of Michel-positrons, counted simultaneously with the signal. The Michel data was taken with a prescaled trigger, where the trigger condition on positrons is the same as the physics trigger. Corrections are made for the difference of the positron acceptance between Michel and the signal due to the difference of energy. With taking the photon efficiency and the trigger efficiency into account, the normalization factor was evaluated to be $1.01 \pm 0.08 \times 10^{-12}$.

An extended likelihood function was constructed as,

$$-\ln \mathscr{L}\left(N_{\mathrm{sig}}, N_{\mathrm{RMD}}, N_{\mathrm{BG}}\right) = N_{\mathrm{exp}} - N_{\mathrm{obs}} \ln\left(N_{\mathrm{exp}}\right) - \sum_{i=1}^{N_{\mathrm{obs}}} \ln\left[\frac{N_{\mathrm{sig}}}{N_{\mathrm{exp}}} S(\vec{x_i}) + \frac{N_{\mathrm{RMD}}}{N_{\mathrm{exp}}} R(\vec{x_i}) + \frac{N_{\mathrm{BG}}}{N_{\mathrm{exp}}} B(\vec{x_i})\right]$$

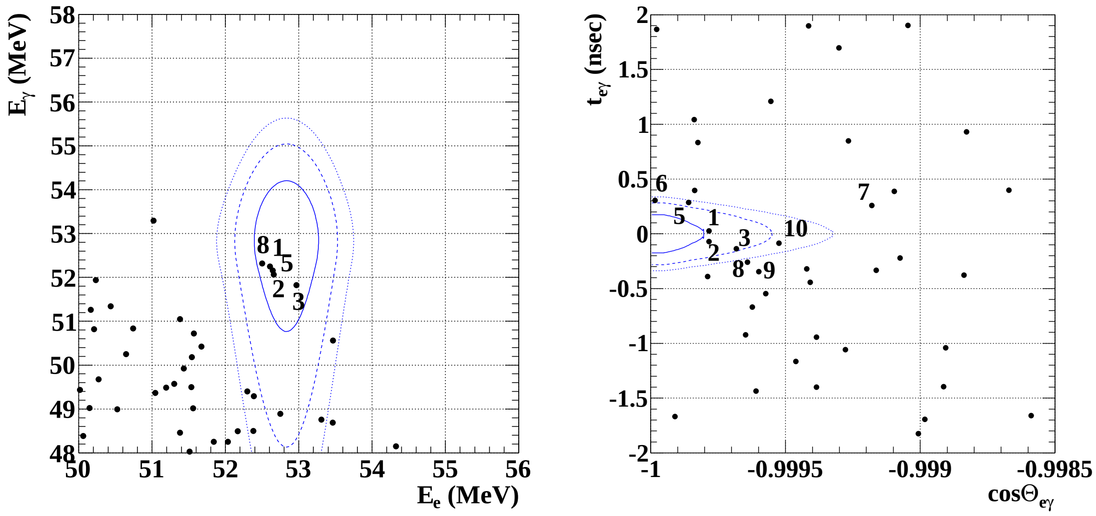
where N_{obs} is the number of events used in the analysis; N_{sig}, N_{RMD}, N_{BG} are the number of signals, radiative muon decays and accidental backgrounds, respectively; N_{exp} is the total of them; S, R and B are respective PDF; $\vec{x_i}$ is the vector of observables. The fitting is done to find a combination of N_{sig}, N_{RMD} and N_{BG}, which maximizes the likelihood function.

The signal PDF is defined by the measured response of the detector. Accidental background PDF is a product of single background spectrum of each variable precisely measured in sidebands. Radiative muon decay PDF is made from theoretical distribution and measured detector response.

The sensitivity is estimated as an average upper limit at 90 % confidence level (C.L.) from an ensemble of a large number of simulation experiments to be 6.1×10^{-12}. The upper limits in $T_{e\gamma}$ sidebands is $4 \sim 6 \times 10^{-12}$, and is consistent with the sensitivity.

Events around the analysis region were unmasked after the calibration, the optimization of the analysis algorithms and the background study in the sidebands are completed. Figure 1 shows a distribution of events after unmasking.

A physics analysis was performed on events in $48 \leq E_\gamma \leq 58$ MeV, $50 \leq E_e \leq 56$ MeV, $|T_{e\gamma}| \leq 0.7$ nsec, $|\phi_{e\gamma}| \leq 50$ mrad and $|\theta_{e\gamma}| \leq 50$ mrad.



(a) (b)

Figure 1: Event distribution in the analysis region. The contours show 1, 1.64 and 2 σ regions of the signal PDF, which cover 39, 74 and 87 % of probability, respectively. (a) Photon and positron energy. Cuts to select about 90 % of time and angle signal PDF are applied for the plot. (b) Cosine of opening angle and time difference. Cuts to select about 90 % of photon and positron energy signal PDF are applied for the plot. Highly ranked events in terms of the relative signal likelihood are numbered correspondingly.

Figure 2 shows projections of the fitting result to each variable. The fitting was done on 370 observed events, and the best estimates in the analysis window are $N_{\rm sig} = 3.0$ and $N_{\rm RMD} = 35^{+24}_{-22}$. The best estimate of $N_{\rm RMD}$ is consistent with the expectation estimated from the E_γ sideband to be 32$\pm$2. The confidence interval was evaluated using the unified classical frequentist method[4]. Systematic uncertainties are included by fluctuating parameters of PDFs in fittings of Monte Carlo simulations to calculate confidence levels. The upper limit of the number of signals is 14.5[1], and $N_{\rm sig} = 0$ is included in the interval. Using the norminalization factor, the upper limit of the branching ratio is set as

$$\frac{\mathscr{B}(\mu^+ \to e^+\gamma)}{\mathscr{B}(\mu^+ \to e^+\nu\bar{\nu})} < 1.5 \times 10^{-11} \text{ at 90 \% C.L.}$$

[1]The best estimate and the upper limit of $N_{\rm sig}$ range from 3 to 4.5 and from 12 to 14.5, respectively, depending on the analysis methods.

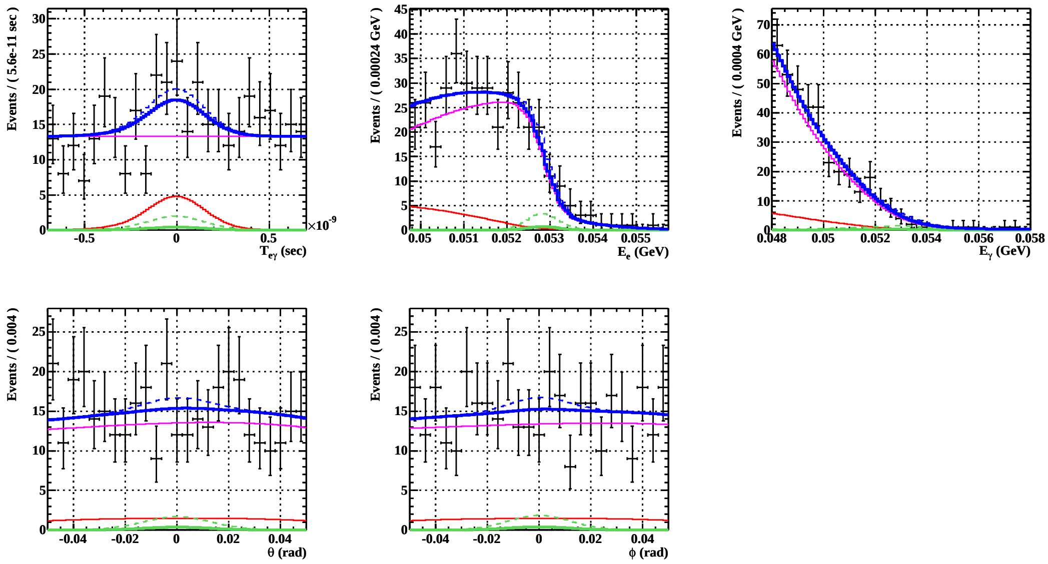


Figure 2: Projections of the result of likelihood fitting to each variable. Solid lines are signal, radiative muon decay, accidental background and total of them from the bottom to the top. Dashed lines correspond to the upper limit of number of signals at 90 % C.L.

3. Conclusion

Data taken in MEG 2009 run were analyzed using a maximum likelihood analysis. The preliminary sensitivity on the branching fraction of $\mu^+ \to e^+\gamma$ is 6.1×10^{-12}, which is twice better than the current experimental upper limit. The preliminary upper limit of the branching fraction from the MEG 2009 data is 1.5×10^{-11} at 90 % C.L. MEG will run in the next years to collect much more statistics, and the result will be clarified with more than one order of magnitude better sensitivity.

References

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