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$\mu^+ \rightarrow e^+\gamma$

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Abstract

The MEGA experiment at LAMPF is the only current search for $\mu^+ \rightarrow e^+\gamma$ underway. The limit on this rare muon-decay process tests the standard model of electroweak interactions. This report covers the status of the analysis of data taken in 1992 and the prospects for future improvements.

1 Physics and History

The search for processes that violate the apparent conservation of family number in the lepton sector remains one of the premier problems in electroweak physics. Theory gives no reason for such a conservation law, but no transition has been observed that mixes the lepton families. Theoretical constructs beyond the standard model predict such processes from the experimental bounds downward. Most extensions to the standard model predict inter-family transitions, with the most probable channel being model dependent. The preferred transition may usually be identified by the one with the lowest order diagram used to describe the process. The preferred channel is often one involving muon transitions, though it is apparent that many channels must be investigated to cover the spectrum of models. Experiments searching for rare muon processes continue to play an important role in testing the parameters of the theoretical predictions.

Historically, great progress has been made in improving the bounds on rare muon processes. For example, in 1948 the bound on the branching ratio for $\mu^+ \rightarrow e^+\gamma$ was 0.02; today it is 5×10^{-11}[1], with a factor of 100 improvement at hand. For rare processes to proceed, theory predicts new particles. The branching ratios generally get smaller as the mass of the new particles to the fourth power. In spite of this rapid power law, the experiments have improved at an interesting rate compared to that of accelerators cable of producing these particles.

2. MEGA: Search for $\mu^+ \rightarrow e^+\gamma$

The MEGA collaboration has built a detector to be used at LAMPF to search for the process $\mu^+ \rightarrow e^+\gamma$ to a sensitivity (90% confidence) of 4×10^{-13}. The kinematic signature for $\mu^+ \rightarrow e^+\gamma$ from a stopped muon is a back-to-back positron and photon, each of 52.8 MeV, that are in time coincidence and emitted from the same vertex. As there are two different particles to detect, a two armed apparatus has been constructed. The arms are concentric and are isolated by a magnetic field. The apparatus is contained in a large solenoidal magnet and consists of a set of eight cylindrical wire chambers and 174 scintillators for the positrons and three pair spectrometers for the photons; see Fig. 1. This high rate, large solid angle device should have response functions that are sufficiently good so that the measurement will be background free. A crude formula for evaluating the full-rate sensitivity (90% confidence) of the detector is 7×10^{-11}/(number of live days). The full detector will be assembled for 1993 running.

The positron spectrometer is built with thin ($X_0 = 3 \times 10^{-4}$), cylindrical multiwire proportional chambers (MWPC). The cylindrical chambers are arranged with the seven smaller ones surrounding the central large one as shown in Fig. 2, a configuration that optimizes the rate capability of the array. Spiral cathode stripes are used to get longitudinal position information. Each of the three pair spectrometer has two converters, an MWPC to determine which converter induced the photon interaction, a set of drift chambers for measuring the energy of the e^+e^- pair, and scintillators to measure their time. Longitudinal position information comes from delay lines.

on the cathodes of the innermost drift chamber of each layer that sense the image charge of the avalanche. The layers, as pictured in Fig. 3, contain precision carbon-fiber, foam, and lead laminates.

To search for $\mu^+ \rightarrow e^+\gamma$, it is necessary to seek candidate events, to know the number of muon decays that were studied, and to find the resolutions of the detector elements to determine the level of the background. 1992 produced a short data run with the entire detector save one pair spectrometer. The nine days were divided into three days for studying calibration reactions and six days for searching for $\mu^+ \rightarrow e^+\gamma$. The performance of of the detector elements is determined from the calibration measurements. 165 million triggers were recorded. The data analysis is still in progress, and the few results that are available will improve as the detector alignment is refined. Currently, reconstruction of a hole in the target shows a position resolution in the positron spectrometer of 5 mm. The positron energy spectrum shows a resolution near 1.5% and is given in Fig. 4 with about 1% of the available statistics. It is expected that each of these responses will improve by a factor of two as refinements are made. Upgrades are underway to eliminate noise problems in the electronics. The delay-line behavior is found from the differences between cosmic-ray tracks projected from the positron arm to the measured position. Their resolution is around a centimeter and was limited by the electronics, which is being improved. The pair spectrometers are calibrated with coincident gamma rays from π^0 decay. Analysis of those spectra is in progress. When complete, the data analysis should yield a sensitivity near the current world limit of 5×10^{-11}. The detector is triggered by a custom-built electronics module that finds in 30 ns any high energy photon. High energy photons are very rare, less than one in one thousand muon decays have at least 37 MeV. Further filtering of events is performed in a workstation farm. The farm was the bottleneck for data taking in 1992 and is being replaced by eight Decstation 5000/240 computers to eliminate this problem.

The concept of the detector is illustrated in Fig. 5. The event selected is most likely due to a random coincidence of a positron from one muon decay and a high energy photon from a second muon decay. The positron energy is 49.4 MeV, the photon energy is 41.6 MeV, and the angle between the particles projected into the plane of the paper is < 20°; no other requirements have been placed on the event. A careful examination of the picture will show that the found positron track had an inefficient wire, that there was another accidental positron present, and that the photon converted in the second-lead sheet of the first-positron layer. The picture is consistent with the roughly 5 MHz stopping rate. The probability for a muon decay to look at least this much like $\mu^+ \rightarrow e^+\gamma$ is 8×10^{-8}. As we examined 2.5×10^{12} muons, there should be 200,000 such events on the tapes. With 165 million events on tape, one in every 850 should be at least as promising an accidental. As this event is number 378 on a typical tape, there is rough agreement. When the resolution requirements are tightened to be as close as possible to $\mu^+ \rightarrow e^+\gamma$, these events are easily eliminated because another factor of roughly 10^8 is available for background suppression.

3. Prospects

The potential for major improvements in the sensitivity to the $\mu^+ \rightarrow e^+\gamma$ process is great if the appropriate beams are available. This year, MEGA should reach a confidence limit of $2\text{-}5 \times 10^{-12}$. Future years of data collection could take the result to the design goal of 4×10^{-13} with an additional half year of running. If beam is not available at LAMPF and the MEGA apparatus is moved to the PSI, a further improvement might be made. That result, to 10^{-14}, would require solving some data acquisition problems. Such a large space for improvement opens the hope that a discovery could be in the offing.

References

* Representing the MEGA collaboration with current participants from UCLA, University of Chicago, Fermilab, Hampton University, University of Houston, Indiana University, Los Alamos National Laboratory, Texas A & M University, Valparaiso University, University of Virginia, and VPI.

[1] R. D. Bolton et al., Phys. Rev. **D38**, 2077 (1988).

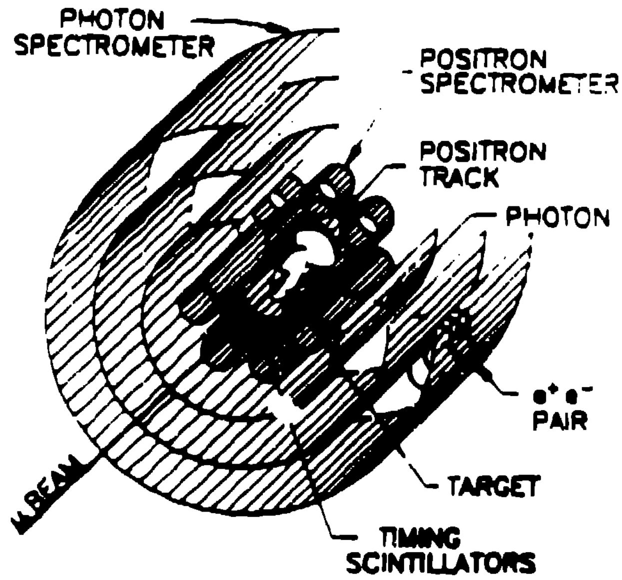

Fig. 1. The MEGA apparatus

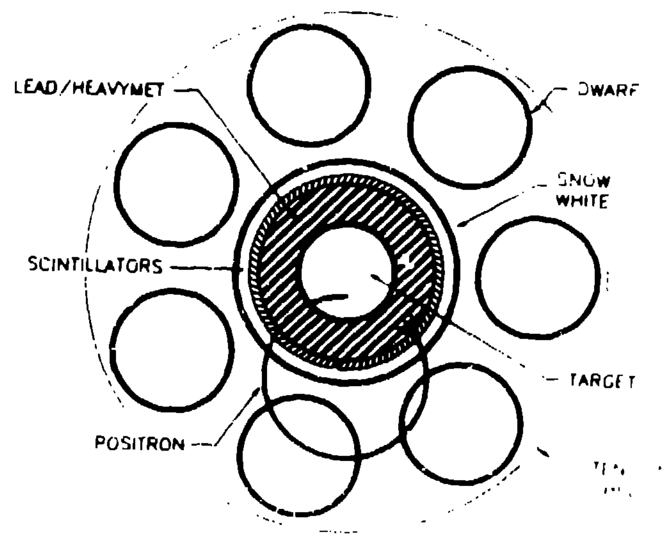

Fig. 2. The arrangement of the positron chambers.

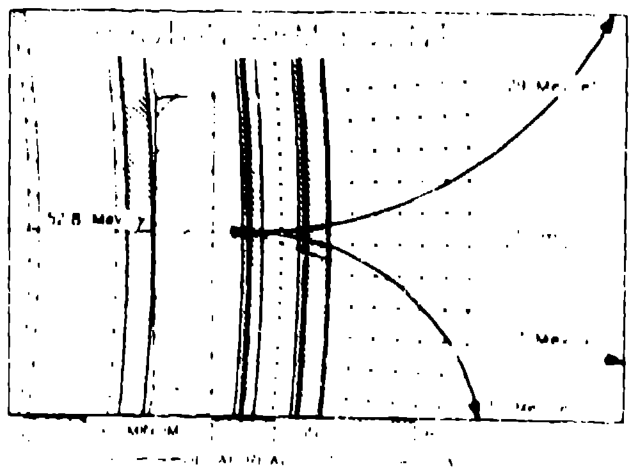

Fig. 3. The configuration of the pair-spectrometer layers.

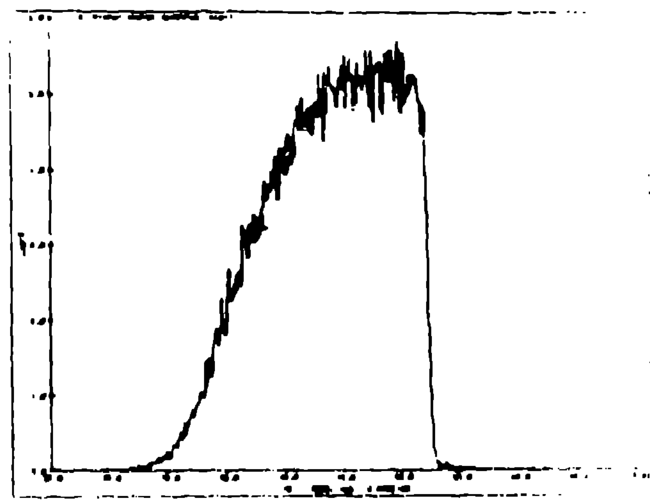

Fig. 4. Prilliminary muon decay energy spectrum taken with the MEGA positron spectrometer.

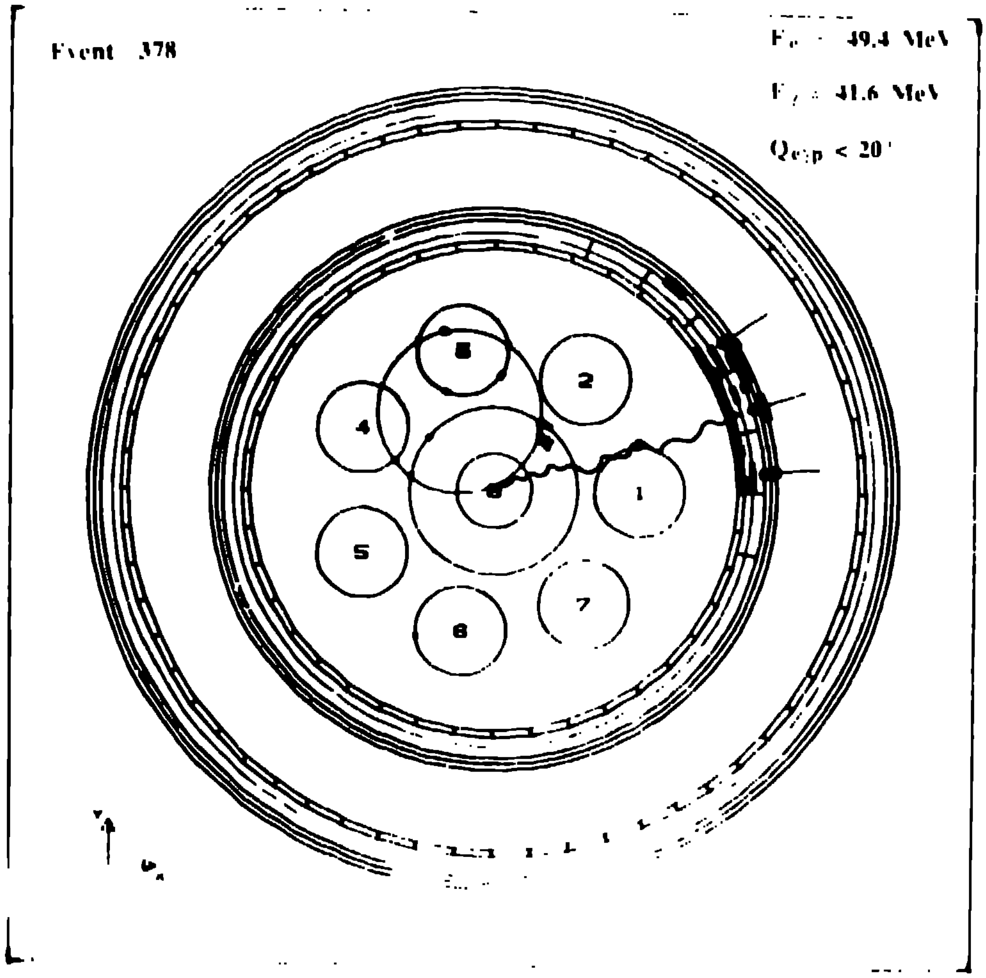

Fig. 5. A candidate event.