A SEARCH FOR $\mu \rightarrow e\gamma$ AT THE LEVEL OF 10^{-13}*

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Abstract

The MEGA experiment, which is a search for the decay $\mu \rightarrow e\gamma$ with a branching ratio sensitivity of about 10^{-13}, employs highly modular, fast detectors, state-of-the-art electronics, and a staged trigger with on-line filters. The detectors are contained in a 1.5-T solenoidal field produced by a superconducting magnet. Positrons are confined to the central region and are measured by a set of thin MWPCs. Photons are measured by one of four layers of pair spectrometers in the outer region. Most aspects of the design have been validated in engineering runs; data taking will begin in 1990 with much of the electron arm and one pair spectrometer layer installed.

Introduction

An ambitious search for the lepton-number nonconserving decay $\mu \rightarrow e\gamma$ is being undertaken at LAMPF, with a branching ratio sensitivity of about 10^{-13}. It is called MEGA, an acronym standing for Muon decays into an Electron and a GAmma ray. This experiment is important because the decay $\mu \rightarrow e\gamma$ is prominent in several extensions of the standard model, such as those including additional generations, right-handed neutrinos, a complicated Higgs sector, composite particles, or supersymmetry. The branching ratio is dependent on the mass of an intermediate (undiscovered) particle, typically many TeV. Thus the search for this decay indirectly probes physics that will only be explored directly by the next generation of accelerators.

For the decay $\mu \rightarrow e\gamma$ of a muon at rest, the electron (actually a positron) and gamma each have almost exactly half the energy of the muon rest mass, are emitted back-to-back, and are in time coincidence. To detect this decay and to isolate it from background requires a large solid angle detector with good efficiency, good resolution in all the relevant quantities, and good rate capability. Prompt backgrounds from the decay $\mu \rightarrow e\gamma\nu\bar{\nu}$ (when the energies of the two neutrinos approach zero) are suppressed to the level of 10^{-15}. Random backgrounds from a coincidence between an electron from ordinary muon decay and a gamma from another muon decay process are expected to be at the level of 10^{-13}.

Apparatus

The apparatus is contained in a superconducting solenoid with a bore of 1.9 m and a length of 2.5 m and is operated at a field of 1.5 T. The muon beam (3×10^7/s at 6% duty factor) enters along the axis of the solenoid and stops in a thin extended target, which is a planar ellipse canted at a steep angle to the beam. Electrons are confined to the central region (30 cm radius) and are measured in a set of thin high rate MWPCs. The timing of the electrons is determined from signals in a ring of scintillators located at each end of the central region. The photons travel out to the pair spectrometer cylinders where they are converted and their energy deduced. Additional background suppression is obtained from counters that detect the low-energy electrons that accompany an inner bremsstrahlung decay in which the photon has near maximal energy.

On average, ten electrons are present in the electron chambers during a 20-ns gating time, and the instantaneous density of hits in the chambers is $3 \times 10^4/\mathrm{mm}^2/\mathrm{s}$. To cope with this rate and allow pattern recognition programs to sort out the tracks there is one large cylindrical chamber concentric with the beam and seven smaller cylindrical chambers around the large one. After typically one revolution, the electron hits one of the 180 scintillators before stopping in the lead shielding. The spectrometer resolution should be 0.6% (FWHM) in energy, 0.2 cm in position, 0.6° in angle, and 0.5 ns in time.

The chambers are 1.26 m long and are only 3×10^{-4} radiation lengths thick. The wire spacing in the chambers is 1 mm and the half gap is 1.75 mm. The chambers have spiral cathode strips, 3 mm wide, with opposite sense on the inner and outer foils, which are supported by differential gas pressure. The small cell size and fast gas mixture (80%-CF_4:20%-isobutane), which allow a short gating time, are required for high rate operation. Also, to minimize space charge effects, the chambers are operated at low gain, requiring very sensitive electronics. The materials used and construction environment are chosen carefully to help ensure that the performance of the chambers does not degrade during the life of the experiment ($> 2 \times 10^7$ sec). Because the chambers have no internal supports (other than garlands to restrain the anode wires), the ends of the chambers are fastened to the ends of a large cylinder, which is located at a radius outside the orbits of the most energetic electrons.

Each of the four pair spectrometers consists of two layers of 250 μm lead converters separated by a MWPC to identify the layer of conversion. The converters surround a barrel of 1-cm × 5-cm × 180-cm scintillators, which have 300-cm fiber optics light guides connected to photomultiplier tubes at each end. The scintillators provide timing and, together with the MWPC, provide the trigger for the experiment. Outside the lead each layer has three drift chambers to measure the momenta of the electron-positron pair. The resolutions of the spectrometer are expected to be 3% in energy, 10° in angle, 0.3 cm for the photon conversion point, and 0.5 ns in time.

One layer of the pair spectrometer has been constructed with resistive wire for the z readout. Cathode delay lines should give < 0.5 cm resolution in the final version. The drift chambers were tested successfully in an engineering run, and problems that were encountered with the MWPC have been understood. Pattern recognition algorithms have been developed for finding the vertex and the momenta of the spiraling pairs and tested on Monte Carlo generated events.

Data Acquisition

MEGA has a staged trigger. The first stage is based on the principle that demanding a transverse spread of the conversion pair of 16 cm imposes a 38-MeV energy cut independent of the energy sharing between the pair. Because the photon energy spectrum is falling rapidly with energy, this cut eliminates all but one in 10^3 decays. This trigger is implemented in programmable array logic that requires only 30 ns for a decision. The electron arm information is not involved in this trigger. Data that pass the level one hardware trigger are encoded and stored in FASTBUS latches, time-to-digital converters, and analog-to-digital converters with on-board memories. The latch time is 0.5 μs and the ADC conversion time is 7 μs. A routing box with a propagation delay of only 12 ns strobes the proper electronics, keeps track of which photon layer was triggered, coordinates busy signals, etc.

A block of typically 20 events from a LAMPF macropulse (repetition rate of 120 Hz) is read from FASTBUS memory by the CERN Host Interface and transferred into a VME microprocessor via the FASTBUS to Branch Bus Connector. The events are sorted in a microprocessor farm, and fast reconstruction algorithms provide a reduction factor of 200 by analyzing the electron spectrometer data to find high-energy, in-time candidates that point at the photon of the level one trigger. This reduction factor permits transfer of a reasonable rate of events to magnetic tape. The final system consists of nearly 200 FASTBUS modules and around 100 VAX/780 equivalents of CPU power.

Status and Plans

In September of 1989, an engineering run tested two dwarfs, one layer of the photon arm, and almost all elements of the data acquisition system. The success of this run gives us confidence in the validity of the design of the experiment. There are still some unsolved problems, but we expect to have one layer of the photon arm and much of the electron spectrometer in place for a limited physics run in the fall of 1990. Construction of the final version of the photon layers will proceed in parallel, and we hope to have two layers ready for a run in 1991. Two years of running with the full detector are required to reach a sensitivity level of 10^{-13}.

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