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The Detector for the New $\mu \rightarrow e\gamma$ Experiment: MEG

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The Detector for the New $\mu \to e\gamma$ Experiment MEG

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Searches for muon's decays that violate lepton flavors are the key to unveiling new physics underlying the recently established neutrino oscillation phenomenology and an apparent unification of the three coupling constants at extremely high energies. A new experiment [1] approved at the Paul Scherrer Institut to search for $\mu \to e\gamma$ decays, the MEG experiment, is expected to be sensitive to such new physics. The status of the preparations for the experiment, in particular, the positron spectrometer magnet and the liquid xenon photon detector, are briefly described here.

1. MEG Physics

During the last several years possible signs of new physics beyond the Standard Model are finally beginning to emerge.

One of such signs is a possible supersymmetric grand unification of the three coupling constants (SUSY GUT). SUSY GUT generically predicts rather large lepton flavor violation (LFV) in the charged lepton sector [2]. In particular, muon's LFV decays $\mu \to e\gamma$ are predicted to occur at a branching ratio of 10^{-11} – 10^{-14}, just below the current experimental limit of 1.2×10^{-11} (90% C.L.) [3]. The recent measurement of the muon $(g-2)$ [4] and 'no observation' of SUSY particles and Higgs at LEP both suggest large $\tan\beta$ values, which would make the $\mu \to e\gamma$ branching ratio even higher.

Another sign of new physics is the neutrino oscillations [5]. The tiny neutrino masses may be explained by the see-saw mechanism caused by ultra heavy right-handed neutrinos. In supersymmetric theories these heavy particles induce large LFV, making $\mu \to e\gamma$ decays occur at a branching ratio as large as the current experimental limit, especially if the solar neutrino deficit is due to the MSW large mixing [6], as strongly indicated by the recent measurements by the SNO Collaboration [7].

A new experiment to search for $\mu \to e\gamma$ decays, MEG [1], has been approved by the Paul Scherrer Institut (PSI), where a DC muon beam with the world's highest intensity of more than $10^8 \mu$/sec is available. Its experimental set-up is shown in Fig. 1. The MEG Collaboration consist of some 40 physicists from Japan, Switzerland, Italy and Russia. In this presentation the development of the detectors of the MEG experiment, in particular, the positron spectrometer magnet and the liquid xenon photon detector, is described.

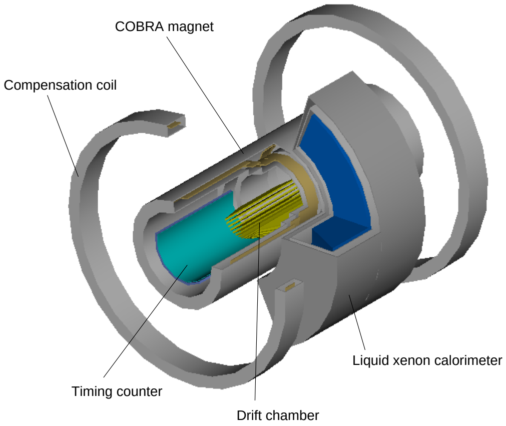

Figure 1. An experimental set-up of the MEG experiment

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2. COBRA Magnet

The COBRA (COnstant Bending RAdius) positron spectrometer consists of a superconducting solenoidal magnet designed to form a special gradient field, in which monochromatic positrons from the target follow trajectories with a constant projected bending radius, independent of the emission angle over a wide angular range. This allows us to sharply define the absolute momentum window. The gradient field also sweeps away curling tracks quickly out of the tracking volume, thereby reducing the accidental pile-up of the Michel positrons.

Very thin superconducting cables have been developed to make the magnet as thin as 3.8 g/cm^2 so that the gamma rays traverse it without much loss. A He-free, simple and easy operation of the magnet is realized with a GM regrigerator.

The magnet is currently in production. All the superconducting cables were produced and are being wound (Fig 2). After careful tests towards the end of 2002, the magnet should be ready in early 2003 for beam line optimization.

Figure 2. The central coil of the COBRA magnet is being wound.

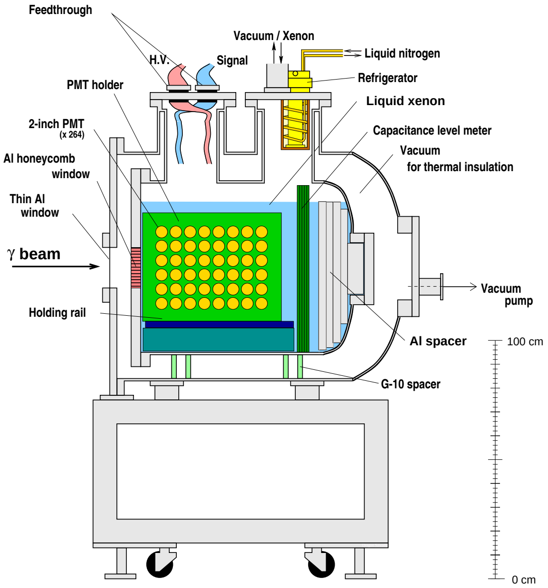

Figure 3. A prototype liquid xenon photon detector.

3. Liquid Xenon Detector

A newly invented liquid xenon scintillation detector of “mini-Kamiokande” type, placed outside the magnet, detects the penetrating gamma rays. The detector holds a 0.8m^3 volume of liquid xenon. Scintillation light emitted inside xenon are viewed from all sides by arrays of $\sim$800 photomultiplier tubes (PMTs).

High light yield of liquid xenon (roughly 75% of NaI) and its uniformity are necessary ingredients for good energy resolution. The scintillation pulse from xenon is very fast and has a short tail, thereby minimizing the pile-up problem. Distributions of the PMT outputs enable a measurement of the incident position of the gamma ray with a few mm accuracy. The position of the conversion point can be also estimated with an accuracy that corresponds to timing resolution of about 50psec.

The major ambiguity of this innovative detector is absorption of the scintillation light inside xenon. Impurities in xenon, such as water, that absorbs UV light could possibly degrade the detector perfomance.

Prototype detectors have been built (Fig 3). PMTs sensitive to the UV scintillation light of xenon ($\lambda = 175$ nm) under the low temperature (-100C°) and the pressure of liquid xenon has been developed in cooperation with Hamamatsu Photonics. A pulse-tube refrigerator that operates efficiently at the liquid xenon temperature has been developed at KEK.

After initial successful operations, cosmic rays and alpha sources placed inside the detector were measured. These measurements indicated clear light absorption both in the total light yield and in the light yield as a function of the distance from the light source. The detector was also irradiated with 10–40MeV gamma rays at the laser Compton back-scattering facility at the TERAS storage ring at the AIST laboratory, Tsukuba, Japan (Fig 4). While the light absorption jeopadized energy measurement, position measurements were less affected and a resolution as good as 2.5–3.0mm (σ) was obtained. According to the subsequent mass spectrometer measurement, the main inpurity was water.

To remove the water contamination, a system to circulate and purify xenon was installed to the detector. Light absorption was monitored with cosmic rays and the alpha sources. After one-month circulation, light absorption length improved from about 7 cm to 100 cm, which is long enough to achieve a 2 % (FWHM) energy resolution for 40–50 MeV gamma rays. It is planned to carry out another laser Compton gamma ray measurement at TERAS later in 2002 to demonstrate the performance.

A design of the final xenon detector is being finalized accordingly and its construction is planned in 2003.

4. Conclusion

With the recent results of the solar neutrino and muon $(g-2)$ measurements, the expectation for the MEG experiment is now higher than ever. The R&D and prototype studies indicate that the necessary performance for a possible discovery is in hand with a good chance of further improvements. It is foreseen that the experiment may start in 2004 with an aim to get the final result before LHC.

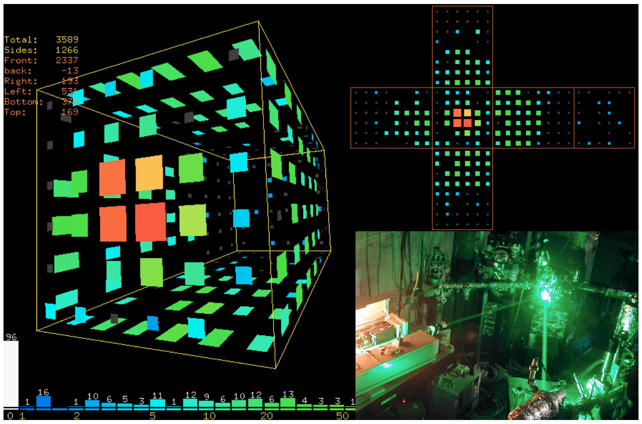

Figure 4. A 40 MeV gamma ray observed by the prototype detector at the TERAS beam test.

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