The MEG experiment at PSI: status and prospects

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Abstract. The present status of the MEG experiment, an experiment to search for the $\mu^+ \to \mathrm{e}^+ + \gamma$ decay at PSI, is described. The experiment will utilize an innovative liquid Xenon calorimeter in which only the information provided by the scintillation light is used for the photon energy reconstruction. A major emphasis is given to the recently measured transparency characteristics of the liquid Xenon.

1. Introduction

Lepton Flavor Violation (LFV) is generically allowed in any viable extension of the Standard Model (SM). In particular, Super-Symmetric Grand-Unified theories predict rates for LFV processes, such as $\mu^+ \to \mathrm{e}^+ + \gamma$, not far from the present experimental limit [1]. For this specific process the present experimental bound is set by the MEGA experiment [2] to $BR(\mu^+ \to \mathrm{e}^+ + \gamma) < 1.2 \cdot 10^{-11}$, while the SUSY-GUT predictions lie in the range $10^{-12} \div 10^{-14}$. A search of the $\mu^+ \to \mathrm{e}^+ + \gamma$ decay to such a level of accuracy could either lead to a discovery of new physics or pose serious constraints on the parameters of Super-Symmetric theories. For this reason an experiment which will run at the Paul Scherrer Institut (PSI, Switzerland) is being designed by a Swiss-Japanese-Italian-Russian collaboration to reach a sensitivity for the $\mu^+ \to \mathrm{e}^+ + \gamma$ branching ratio in the range $10^{-13} \div 10^{-14}$. The experiment is planned to start in 2004 and be completed in 2007, before the operation of LHC experiments.

In the following sections we will review the present status of the experiment, with a particular emphasis on the liquid Xenon calorimeter research and development, using a large prototype, which demonstrated that the transparency of liquid Xenon to self-scintillation light (absorption length $\lambda_{\mathrm{abs}} > 1$ m) makes the sensitivity goal achievable.

2. The MEG Detector

The MEG experiment will be built at PSI, the laboratory hosting the highest-intensity continuous muon beam in the world ($3 \cdot 10^8$ μ^+/ sec). The signature of a $\mu^+ \to \mathrm{e}^+ + \gamma$ event is given by a coincidence of a 52.8 MeV photon with a 52.8 MeV positron in space, time and direction. The background is dominated by positrons in the high energy part of the Michel spectrum accidentally overlapping with high energy photons from the radiative muon decay $\mu^+ \to e^+ \nu \bar{\nu} \gamma$ or from positron annihilation-in-flight.

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A complete description of the MEG detector, together with a schematic drawing, can be found elsewhere [3, 4]. Here a brief overview of various sub-detectors is given. Positive muons coming from the $\pi E5$ beam line will be brought to stop on a thin target where they undergo spontaneous decay. Positron trajectories will be measured by 17 radial drift chambers filled with a (50:50) Helium-Ethane mixture placed in a inhomogeneous magnetic field. The field is 1.25 T at the center of the detector, decreases along the magnet axis, and is shaped such in a way as to provide two important features: the radius of the positron trajectories depends on its *absolute* momentum and not on its transverse component, and the positrons are quickly swept away after the first turn to avoid low longitudinal momentum positrons to spiralize and saturate the drift chambers. The timing of the positrons will be measured by two segmented plastic scintillator timing counters, one at each side of the target, with a resolution of 100 ps FWHM. Photons will traverse the thin superconducting coil of the magnet and convert in the liquid Xenon calorimeter. This detector is made of a ~ 0.8 m^3 volume of liquid Xenon read on all sides by more than 800 photomultipliers sensitive in the UV, to match the 175 nm wavelength of the Xenon scintillation light. Only scintillation light will be used for the photon energy measurement. Liquid Xenon was chosen for its high light yield (comparable to NaI), high atomic number and fast response ($\tau \simeq 45$ ns) [5]. The trigger will be given by a signal from the timing counters coincident, in time and direction, with a high energy photon in the calorimeter. All the signals will be digitized at a high frequency (2 GHz) in order to reduce the event pile-up as much as possible.

3. Detector Performance

The sensitivity of the MEG experiment crucially depends on the capability to distinguish a background event from the $\mu^+ \to e^+ + \gamma$ signal. This is directly related to each sub-detector resolution. The most critical and innovative device is the liquid Xenon detector whose energy resolution is expected to be of few percents FWHM at 52.8 MeV. The major uncertainty concerning the liquid Xenon is its transparency to scintillation light: a loss in the number of photons could crucially spoil the predicted resolution. For this reason, and to study the procedures of handling the gas at cryogenic temperatures, a liquid Xenon detector prototype ("large prototype") was built, and its test at KEK, Japan is the main issue in which the collaboration is currently putting its effort. The large prototpe has a $40 \times 40 \times 50$ cm^3 Xenon active volume read by 228 PMTs, equipped with ^{241}Am α-sources and blue LEDs for calibration. Three pairs of trigger counters can be placed outside the volume to study the response of the detector to cosmic rays. Handling of liquid Xenon and calibration procedures for the PMTs have been successfully developed and shown to be appropriate for the final detector in order to reach a percent-level energy resolution, though major problems have been discovered regarding the Xenon purity level.

Comparison with the absorption spectra of O_2 and H_2O showed that even a ppm of these contaminants in the Xenon can give rise to a tremendous absorption of UV light. This was the reason of the very short absorption lengths obtained at the beginning of our tests ($\lambda_{\rm abs} \simeq 7$ cm). The presence of water at ppm level was also confirmed with a mass-spectrometric analysis. The absorption length was measured comparing the light seen by PMTs at different distances from the α-sources, and using cosmic rays. To overcome the contamination problem a complete circulation and purification scheme was introduced *during* detector operation. Liquid Xenon was

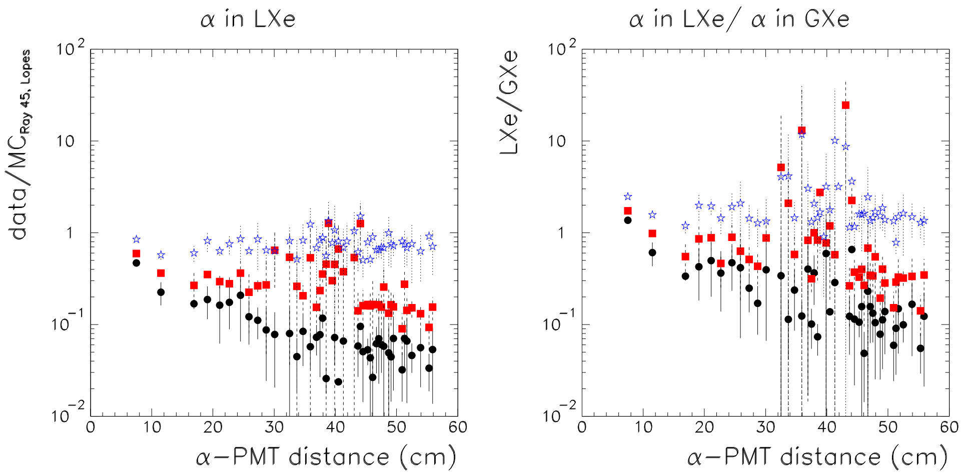

Figure 1. Comparison of α-source data in liquid Xenon to Monte Carlo simulation (left) and to α-source data in cold gaseous Xenon (right) for three different runs: before the purification (circles), after two weeks of purification (squares), and after one month of purification (stars).

continuously evaporated and pumped, in gaseous phase, through an Oxisorb cartridge and a heated gas getter purifier. An increase of both light yield and absorption length was measured (see figure 1), the purification time being limited by the pumping speed (5 cc/min of liquid Xenon). After four weeks of purification a $\lambda_{\mathrm{abs}} > 100$ cm was measured with α-sources and the result was confirmed with cosmic ray data. To our knowledge, such a low absorption in liquid Xenon was never measured before. The sensitivity to higher absorption lengths is limited by the larger side of the prototype (50 cm).

4. Conclusion

Much progress was made in the design and construction of the MEG detector for a $\mu^+ \to e^+ + \gamma$ search experiment at PSI. In particular the liquid Xenon transparency has been demonstrated to be at the level needed for the proposed experiment in order to reach a sensitivity of $5 \cdot 10^{-14}$ (and consequently a 90% CL upper limit of $\sim 10^{-13}$ in case of no candidate observed) [4].

References

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