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Status of MEG experiment

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The MEG experiment is aiming to measure a lepton flavour violating decay $\mu\to$ eγ with sensitivity 10^{-13} in order to probe the new physics beyond the standard model. Experimental setup consisted of a positron spectrometer, a liquid xenon calorimeter and a timing counter is recently completed and verified. Since a middle of 2008 a data taking is going on.

1. Introduction

The main goal of MEG (Muon to Electron and Gamma) experiment [1] is the search for the lepton flavour violating decay $\mu \to$ eγ with a sensitivity of BR (branching ratio) = 10^{-13}. This is two orders of magnitude better the last measured value [2]. The above mentioned decay is a forbidden process in the Standard Model (SM) of the electroweak interactions but allowed in the supersymmetric extensions of the SM, such as Grand Unified Theories (GUT) within for example, SO(10) framework [3,4].

The experimental search for Lepton Flavour Violation (LFV) in muon sector has quite a long history (Fig. 1). Several experiments since 1947 were trying to see the evidence for new physics or at least establish the limit of the branching ratios. The present status is the following: 1.2×10^{-11} for $\mu \to$ eγ decay [2], 7×10^{-13} for μ-e conversion in Gold [5] and 1.0×10^{-12} for $\mu^+ \to e^+e^+e^-$ [6] decay. According to the theoretical predictions, the $\mu \to$ eγ and μ-e conversion processes have a similar level of significance but the branching ratio of the first one should be two orders of magnitude larger. In spite of more strait forward technique of the conversion experiment, the limiting factor becomes a beam intensity. Most probably, until J-PARK facility in Japan (where PRISM/PRISMA conversion experiment is planned) provides a muon beam with intensity in the order of 10^{-10}–10^{-11} particles/sec, MEG experiment has the best chances for LFV search in muon sector.

One should also mention that the importance of experiments like MEG is due to them providing a complementarity to the CERN Large Hadron Collider (LHC) experiments as probes of SUSY-GUT scenarios. Even in the presence of a discovery machine like the LHC, flavour physics experiments will still play an important role in the hunt for new physics. Potentially, an experiment with low energy leptons might be cleaner and more sensitive to LFV than a high energy hadron experiment. Moreover, the MEG experiment has some chances to provide a hint of new physics before the LHC will run at the full luminosity.

2. Experiment

The $\mu \to$ eγ signal has a simple topology and appears as 2-body final state of a positron and a γ-quant, emitted in the opposite directions with the energy of 52.8 MeV each, corresponding to half of the muon mass. In spite of the simplicity of the signal, the experiment will have a substantial background originating from the accidental coincidence of the positrons coming from Michel decays and the γ-rays coming from the radiative muon decay or positron annihilation. Measurements of the rare reactions beyond the standard model require specially designed detectors and setups. In the case of MEG, they are: the liquid xenon calorimeter; the precise timing counter; and the positron spectrometer. All the components have been built aiming at ultimate performance. The detection of the γ-rays are performed by the liquid xenon calorimeter [7], one

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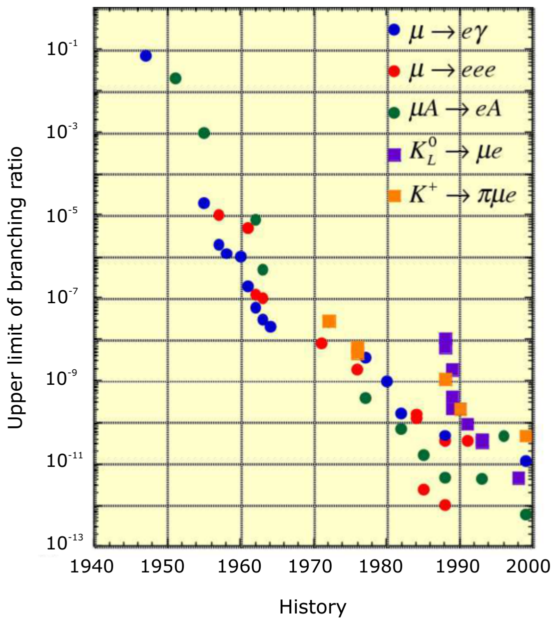

Figure 1. A history of the experimental searches for LFV.

of the largest in the world and the detection of the positrons - by the positron spectrometer (Fig. 2). A beam of positive surface muons with an intensity up to 10^8 s^{-1} is extracted from the PSI primary proton beam in the πE5 area. The momentum of the muons hitting the MEG muon target is 28 MeV/c with relative precision 8%. The beam line has been built specially for this experiment. It consist of an electrostatic separator and a beam transport superconducting solenoid and suppresses the positron background in the muon beam to the level of 10^{-3}. The beam is focused and stopped in a 150 μm thick tilted CH_2 target.

3. Experimental setup

The experimental subsystems have been designed according to Monte Carlo simulations taking into account all the detector material and the support structures. Especially it is important for the positron spectrometer. Lessons learned from the previous experiments that studied the same reaction are also taken into account. The spectrometer has to fulfill several strict requirements: a) it must work with a very high muon rate of up to the 10^8 per second provided by the PSI accelerator; b) since the momentum resolution is limited primarily by multiple scattering, the tracker must have as small as possible mass but good 2D position resolution; c) the timing resolution should also be as good as possible. A low mass system also prevents the generation of γ-particles from the annihilation in flight of the decay positrons.

The MEG positron spectrometer "COBRA" (COnstant Bending RAdius) consists of a special superconducting solenoidal magnet [8] with the tracker inside, accomplished by a fast timing system. The COBRA magnet changes radius along the Z-axis as one can see on Figure 3. As a result, its field changes from 1.27 Tesla at z = 0 and decreases as |z| increases, reaching 0.49 Tesla at z = 1.25 m). The graded magnetic field forces positrons with the same absolute momenta to follow trajectories with a constant projected bending radius, independent of the emission angles. This allows a discrimination of high-momentum signal positrons from the Michel positrons originating from the target - the positron background. Thus, tracking is not required at smaller radius. Drift chambers will measure the high momentum positrons and will not see most of the softer positrons. Another feature of the spectrometer is that the positrons emitted at angles very close to 90° are quickly swept away from the sensitive volume. In comparison, in a uniform solenoidal field they would make few turns before leaving the detector. All these features make the track reconstruction and the operation of the drift chambers more effective. Due to the requirements to minimize the amount of material, the concept of open-frame construction for the drift chambers was chosen - the frames holding the anode and field wires have an opening on the side close to the muon stopping target; this allows positrons to be detected without scattering in the chamber frames. The frames themselves are made out of a carbon fibre and are pre-tensioned before attaching the wires. The gas volume is closed by

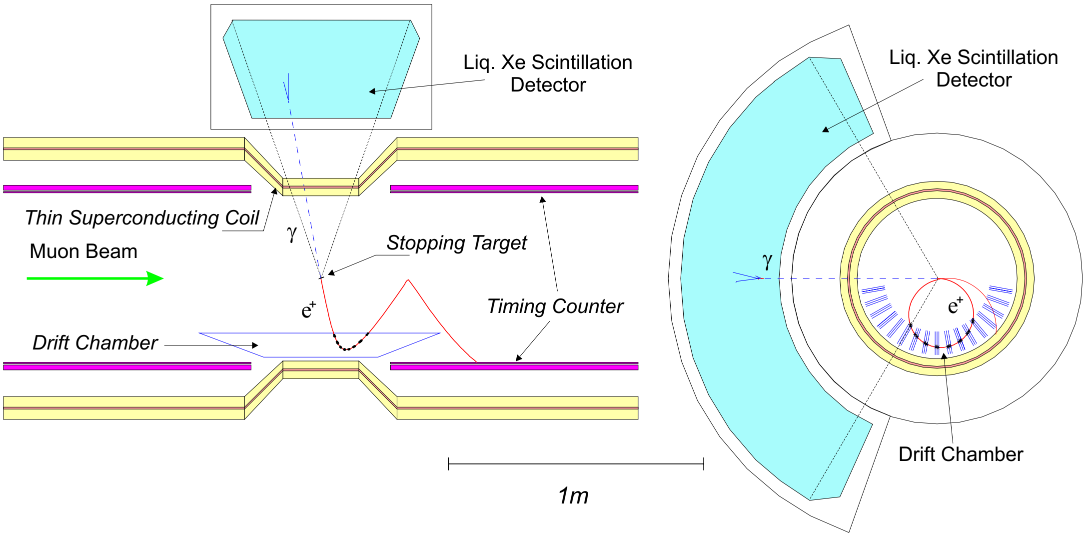

Figure 2. Schematic cross section of the MEG detector. The γ-rays are detected in a liquid xenon calorimeter, the positrons - in the drift chambers and the timing counters.

very thin foils, thus the amount of material in the fiducial volume due to the very light construction together with a use of He-C_2H_6 gas mixture, corresponds to only 1.5×10^{-3} X_0.

16 radial drift chambers are placed inside the magnet and measuring the Z- and R-positions of the positron tracks, allowing a reconstruction the momentum of the positrons. The R - and Z - coordinate might be determined with a precision of 200 and 300 μm correspondingly, demonstrated with the test setup [10].

The extremely thin foils of the drift chambers require controlling the gas pressure inside the chambers and the pressure difference between the inside and outside volume very precisely. Calculations show that in order to keep gas gain and drift time variations small enough, one needs to have gas pressure difference less than 1 Pa. It has been demonstrated that an electronically controlled gas mixture system with precise gas flowmeters, valves and differential pressure sensors allows the pressure difference to be kept at less than 0.5 Pa, independent of the variation of atmospheric pressure and gas flow.

A liquid Xenon (LXe) calorimeter has been built for the detection of the γ-particles from the $\mu\to e\gamma$ decays. In total 850 photomultiplier tubes are directly immersed in the LXe. Investigations made with the smaller prototype, showed that one of the most crucial issues was the purity of xenon. The impurities like water or oxygen in the order of 10^{-6} is enough to decrease the light output of the calorimeter by about an order of magnitude. The energy resolution also depends on the absorbtion of the light in the liquid xenon (and absorbtion - on impurities). In order to avoid impurities, techniques allowing a continuous purification of the xenon gas and a liquid have been developed. As one needs to measure the absolute energy of the γ-rays, the absolute gain of the PMTs and their quantum efficiency are other important parameters of the calorimeter. Several methods (including the calibration using a dedicated Cockcroft-Walton accelerator), were applied for a continues calibration and monitoring the critical parameters of the calorimeter. As a result, measurements performed in the second half of 2008 demonstrated that one can keep the

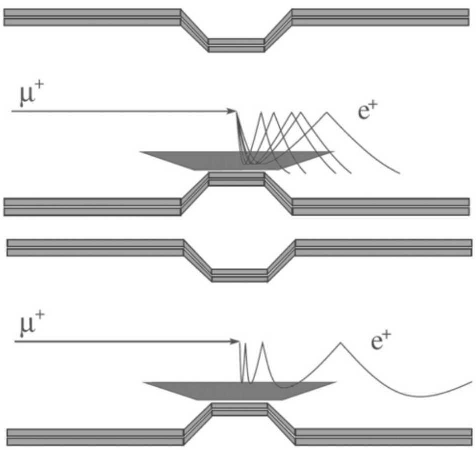

Figure 3. A typical movement of positrons emitted at different angles in a graded solenoidal field of COBRA. Trapezoids schematically show the drift chambers.

energy resolution stable on a few percent level.

Time coincidence between γ-rays and positrons is an important observable of the experiment. The time of positron production is deduced from the signal in the timing counter projected back to the target with the help of drift chamber system. The timing counter consists of two separate subsystems - the scintillating bars (with PMT readout) providing the time measurement and the scintillating fibres (with APD readout) for measurement of the Z-position of the positron track. Careful design of the key components enabled the apparatus to record one of the best time resolutions measured - 43 ps (σ). This result completely fulfills the requirement of the experiment.

4. DAQ

One of the key components of the MEG experiment is the readout electronics. Already at the stage of Monte Carlo simulations before the proposal was written, it become clear that the suppression of the background and pile-up should be the most important issue. So it has been decided to digitize the wave forms of all signals. This solution allows the suppression of pile-up more effectively than in the case of having conventional electronics. The same type of readout is used for the positron spectrometer, the liquid Xenon calorimeter and the timing counter. For this purpose, a new Domino Ring Sampling (DRS) chip has been developed at PSI [11].

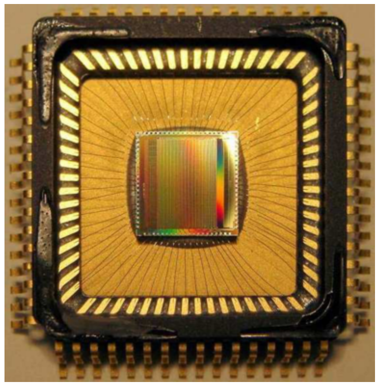

Figure 4. Image of the last version of DRS chip (4.2 mm × 4.2 mm).

The DRS chip (Fig. 4) is able to digitize 8+1 channels at a speed up to 6×10^9 samples per second with a resolution of 12 bits. The depth of each channel might be from 1024 bins and more, applying a cascading scheme. The analog bandwidth of the last version of the chip is extended up to 850 MHz which is enough even for the signals from the fast PMT. Custom-built VME boards have 4 DRS chips (total 32 channels) and an FPGA making a calibration and zero suppression in real time. It has been demonstrated that this solution allows the effective separation of pile-up events separated in time by less than 10 ns. The trigger system uses the high capacity FPGAs for the real-time analysis of the signals. It allows to estimate for example, the energy of the γ-quants summing up the signals from many PMTs of the Xenon calorimeter. Taking into account the amount of the readout channels, it would be very difficult to do otherwise. The time and the positions of the particles hit the timing counter are also calculated by the trigger system and taken into account in the trigger decision. The trigger latency is also very small due to the use of the high-performance components.

5. Status and perspectives

The most important milestones of MEG experiment are the engineering run of 2007 and the first physical run of 2008. The experimental setup was fully assembled and calibrated. The full set of analysis programs has been written and verified with the data collected having muon and pion beams. All systems demonstrated full functionality. It has been demonstrated that the stability of different parameters (like PMT gains) was good enough to run for a long time; in any case, all critical parameters were monitored. The frequency of calibrations is established. According to the estimations, the statistics collected during the last run, should be enough to reach a sensitivity to BR of $\mu \rightarrow e\gamma$ decay obtained by the MEGA experiment. Next data taking is planned for the second half of 2009 and for 2010. Taking all observations obtained up to now, collaboration is confident to get the physical result before the LHC experiments accumulate necessarily statistics.

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