3 The Neutrino Magnetic Moment at a Nuclear Reactor

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The goal of the MUNU experiment [1, 2] is to improve the present laboratory upper limit for the neutrino magnetic moment ($1.9 \times 10^{-10} \mu_B$) by an order of magnitude. The neutrino magnetic moment can be determined by measuring the energy distribution of the recoil electron in elastic $\overline{\nu}_e e^-$ scattering (assuming that the incident neutrino energy spectrum is known) or by measuring the angular distribution of the recoil electron for a given neutrino energy. In the presence of a non-zero magnetic moment the angular distribution departs from the pure electroweak prediction at large neutrino scattering angles (or at small electron recoil energies). The relative contribution of the magnetic moment to the cross section increases with decreasing incident neutrino energy. A good measurement therefore requires low energy neutrinos ($\sim$ 1 MeV) e.g. from nuclear reactors for which the energy spectrum is reasonably well known.

Figure 3.1: Sketch of the MUNU detector at the Bugey nuclear power plant for the study of $\overline{\nu}_e e^-$ scattering. The central TPC (2) with anode plane and cathode strips (3) is surrounded by an anti-Compton vessel (6) and various shielding layers (7, 8). The liquid scintillator (4) is viewed by 48 photomultipliers. Typical electron trajectories are also shown (1).

In contrast to previous experiments MUNU will have a low electron energy threshold (of a few 100 keV) and will measure both the angle and the energy of the recoil electron, thus providing a rough measurement of the incident neutrino energy [3, 4]. We will also measure the Weinberg angle at a very low Q^2 with a precision of 5%, comparable to that achieved in high energy scattering.

The detector (fig. 3.1, see also last year's annual report) is currently being installed at a distance of 18 m from the core under one of the four EDF nuclear reactors at Bugey. It consists in a 1 m^3 time projection chamber (TPC), filled with CF_4 gas at 5 bar. The coordinate z along the field direction is determined by the drift time. The transverse coordinates x and y are measured by (2×256) cathode strips with a pitch of 3.5 mm. The TPC is shielded by liquid scintillator to suppress γe-scattering and cosmic muons. The apparatus is surrounded by a 15 cm thick lead shielding and borated polyethylen. To achieve very low background it was crucial to choose radiochemically clean materials, especially those coming in large quantities: lead, liquid scintillator, polyethylen, photomultiplier glass. Apart from the TPC and its readout electronics the detector components have been installed in the Bugey experimental hall.

Figure 3.2: a) Collimated electron source in the mini-TPC; b) Distribution of the drift time difference between the two adjacent cathode strips located on the bottom of the mini-TPC immediately under the collimated source. The horizontal scale is given in units of 1.4 mm in z.

The FADC system developed by Zurich [5] has successfully read out a small prototype of the TPC (mini-TPC) and the photomultiplier tubes. With the mini-TPC we measured the angular resolution of the recoil electrons [6]. A 300 kBq Sn^{113} source, located just above a hole in the cathode (fig. 3.2a), was collimated by a 7 mm thick plexiglass collimator, with a hole of 1.5 mm in diameter. For the monoenergetic 370 keV conversion electrons we achieved an energy resolution of

$\frac{\sigma_E}{E} = 0.19$. The angular resolution could be estimated by comparing the drift time distributions for two adjacent strips (fig. 3.2b). We obtained an angular resolution of $\sigma_{\theta_{space}} = 13°$, in agreement with expectations from simulation.

Figure 3.3: A cosmic muon track (xz and yz projections) observed with the 16×16 central x and y strips at 3 bar. The distance between two strips (horizontal axis) is 3.5 mm. On the vertical z axis (drift direction) 20 channels correspond to 2.56 cm. The area of the diamonds is proportional to the charge deposits.

The full scale TPC has also been operated at 3 bar with the FADC readout system. Signals of the order of 10 mV were observed at 3 bar with an rms noise of less than 2 mV. For tests with cosmic rays we equipped only 16 x and 16 y strips with readout electronics. Two scintillators above and below the TPC defined the incident muons. A cosmic muon track is shown in fig. 3.3. Only a fraction of the track lies in the overlap region of the instrumented x and y strips, so that the projections are displaced along the z axis. A spatial resolution of $\sigma = 1.6$ mm has been achieved for the cathode strips by fitting the tracks with straight lines.

Energy loss distributions of nearly vertical muons are shown in fig. 3.4 for two positions of the triggering scintillators: 30 cm from the anode and 30 cm from the cathode. Taking into account the 1m-difference in drift distance, we obtained a mean attenuation length of $L = 22^{+14}_{-6}$ m at 3 bar with a drift field of 50 V cm^{-1} bar^{-1} [7].

The Zurich group has also developed the data acquisition system (run control, data logging and online monitoring) and has contributed to the offline software (pulse shape analysis, track pattern recognition, simulation and data analysis). The fully tested readout system will be implemented at Bugey in April 97 together with the

Figure 3.4: Measured energy deposits (in arbitrary units) of nearly vertical cosmic muons crossing the TPC 30 cm from the anode (top) and 30 cm from the cathode (bottom), at 3 bar and with a drift field of 50 $\mathrm{V} \cdot \mathrm{cm}^{-1} \cdot \mathrm{bar}^{-1}$. The fit peak position is indicated. The upper horizontal axis of the bottom spectrum shows the attenuation length as a function of peak position.

final installation of the TPC. First data should be available during the forthcoming summer.

References

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