2 Measurement of the Neutrino Magnetic Moment at the Bugey Nuclear Reactor

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The MUNU experiment is studying $\bar{\nu}_e e^-$ elastic scattering at the Bugey nuclear power plant by detecting the recoil electron in a CF_4 time projection chamber (TPC), in which both the angle and the energy of the recoil electron are measured. The typical electron energy is 1 MeV or smaller. The TPC is surrounded by an anticompton shield (AC) made of liquid scintillator. The aim of the project is to measure the neutrino magnetic moment with a sensitivity of 3×10^{-11} μ_B. Previous laboratory experiments have led to an upper limit of 1.8×10^{-10} μ_B at 90% confidence level [1]). Details on the apparatus can be found in previous annual reports and in ref. [2].

In 1999 our group designed, installed and tested the general purpose trigger (based on the LRS 2366 ULM Gate Array) which we developed to remotely adjust the coincidences and timing for the various triggers (neutrinos, radioactive sources, muons) [3]. The triggers are more complicated than expected due to the fact that CF_4 was found to scintillate, so that the photomultipliers of the AC see the light from the avalanche in the TPC which traverses the acrylic vessel. This veto signal can be suppressed by using the long time delay between the photomultiplier signals and the arrival of the electron cloud at the anode.

In addition, the light of the avalanche from electrons generates asymmetric pulse heights in the forward and backward photomultipliers, since the anode plane is much closer to the forward photomultiplier array. Unlike electrons, spurious events due to mini-discharges at the TPC anode plane lead to a much smaller asymmetry because the short and high pulses of the avalanche saturates all photomultipliers. These background events are now removed within 0.1 ms by the online trigger. This improvement of the data acquisition system allows a strong reduction of the raw event rate written to tape, which is now around 0.17 Hz.

Further efforts towards a nearly automatic data acquisition system were also invested. A typical run lasts for about 5 hours and is occasionally interrupted by hardware failure. The new system now automatically resets the system and restarts the measurement. The experiment can be monitored remotely, e.g. from CERN. This increases significantly the live time of the experiment, as the access and the permanent presence of personnel on site, especially during nights and week-ends, is regulated at a commercial nuclear reactor.

The anticompton vetoes more than 99 % of the photon induced background. We have, however, observed much more background than expected. This background turned out to be produced by radon introduced in the gas by the oxisorb filters. Activity measurements confirmed that the zeolites in the oxisorbs contained much higher quantities of uranium than foreseen. We have replaced the oxisorb filter in winter 1999 by smaller, low background ones. Electronic noise in the readout chain of the TPC has also been drastically reduced and improvements in the gas purification system were made.

The MUNU detector is now operating correctly at a CF_4 pressure of 3 bar. The TPC voltage is -35 kV and the maximum drift time of 71 μs corresponds to a drift velocity of 2.3 cm/μs. The background was studied during a six weeks reactor shutdown in summer 1999. We collected some 80,000 background events with the neutrino trigger. Between September 1999 and March 2000 we collected some 300,000 events with reactor on.

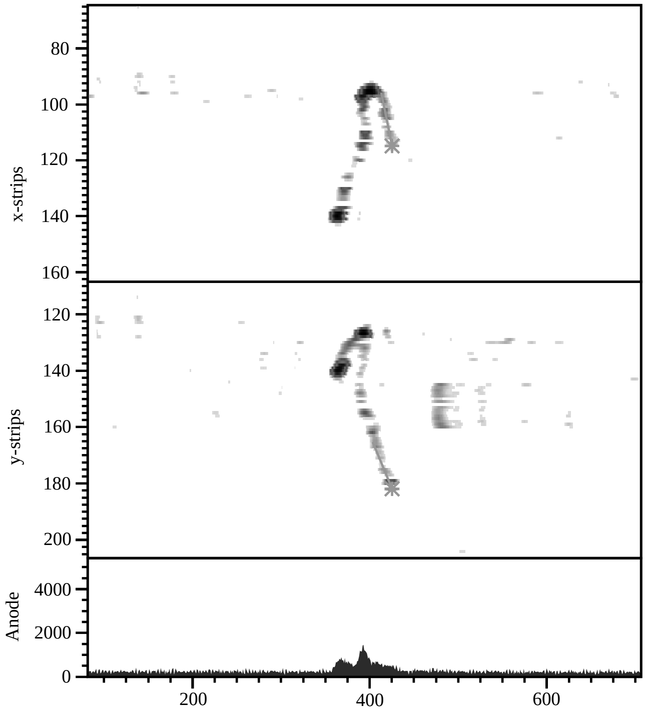

Figure 2.1: *A typical neutrino scattering candidate (xz- and yz-projections) and the corresponding pulse height from the anode plane (bottom). The interaction vertex is marked by a star. Note the blob due to the large energy loss at the end of the electron range.*

The AC and TPC calibrations were done with traversing cosmic rays and radioactive sources. The energy resolution from the TPC measured with manganese is 7% FWHM at 3 bar and 1 MeV. This corresponds to measurements done at Neuchâtel with X-rays of 60 keV from americium, for which we found 46% FWHM. The typical rate reductions by the online trigger and offline analysis are as follows: without online filtering the detector records about 15,000 electron events/day, most of which are due to mini-discharges and from tracks crossing the amplification gap around the anode. The online filter and a provisional threshold of 700 keV for the electron energy leaves about 500 events/day, of which about 300 are contained in a fiducial volume of 45 cm radius (the full TPC radius is 50 cm). About 150 electron events are found with no associated low energy photon converted in the AC. These events are scanned by eye and the original direction of the track has to lie inside a cone of given aperture which depends on the electron energy. Furthermore, the neutrino energy calculated from the recoil angle and the electron energy has to be positive.

For neutrino scattering events the electron has to be emitted in the opposite (forward) direction to the reactor core, while background events are uniformly distributed. From the data analyzed so far we obtain a very preliminary 32.6 ± 1.7 events/day in the forward direction and 28.6 ± 1.6 events/day in the backward direction. This then leads to a net excess of neutrino induced events of 4.0 ± 2.4 events/day while simulations assuming the standard model predict 1.3/day with the present rather strong software cuts. A typical event in the forward cone is depicted in fig. 2.1.

Figure 2.2 shows the vertex distributions for reactor on and reactor off for a sample collected in 1999. The corresponding energy distributions of the recoil electron, normalized to the same running time, is also shown. Although not very significant, the observed slow increase of the energy distribution at low energy with reactor on was expected and is therefore encouraging.

However, above 1 MeV the background is still an order of magnitude higher than forecasted in the proposal. Note that the current upper limit on the neutrino magnetic moment [1] is derived from an experiment which has a background over signal ratio of 100:1.

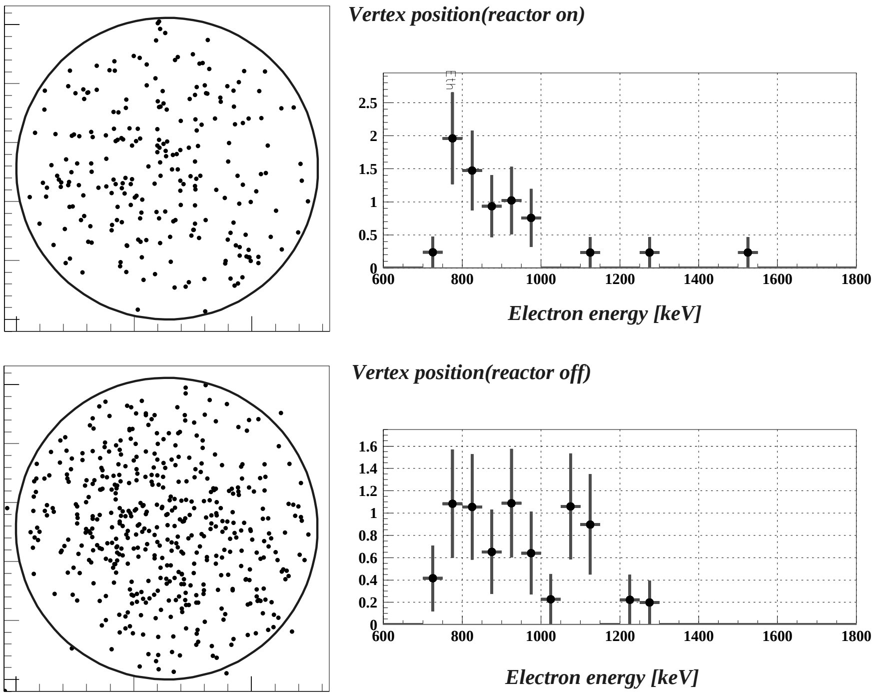

Figure 2.2: *Vertex distribution for forward emitted electrons with reactor on (top) and reactor off (bottom). The data taking time with reactor off was much longer. The recoil energy distribution per unit time is shown on the right for reactor on and off. The threshold for electrons was set to 700 keV.*

The high background in our experiment has been traced to the probable presence of ^{210}Pb (from the decay chain of ^{222}Rn) implanted on the high voltage cathode surface. This nuclide decays to

$$^{210}Bi \overset{\beta}{\widehat{\rightarrow}} {}^{210}Po \overset{\alpha}{\widehat{\rightarrow}} {}^{206}Pb.$$

The α emission from the daughter decay can be observed directly with the photomultipliers. One measures the time delay between the light pulse generated by the scintillation of CF_4 and the light pulse from the avalanche at the anode. The energy deposits from α's indeed occur near the cathode, at the maximum drift time. The same method cannot be applied for electrons since the light from CF_4 it is to weak to be seen by the photomultipliers. However, we see a clear peak of electrons coming from the cathode end of the TPC, presumably due to the decay of ^{210}Bi.

We have therefore decided to open the detector an April 2000 and to clean (etch) or replace the high voltage cathode. Data taking should then resume in May and continue until the end of 2001 at which time the original goal of the project will hopefully be achieved.

References

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[2] C. Amsler et al., Nucl. Instr. Meth. in Phys. Res. A 396 (1997) 115
[3] O. Link, Diplomarbeit, Universität Zürich (1999)