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

C. Amsler, P. Giarritta, M. Heinzelmann, O. Link, and F. Ould-Saada

In collaboration with Institut des Sciences Nucléaires (Grenoble), Université de Neuchâtel, Università di Padova
(MUNU Collaboration)

The MUNU experiment is currently taking data at the Bugey nuclear reactor near Lyon. The aim is to study $\overline{\nu}_e e^-$ scattering in order to test the standard model at low energies and to improve on the present laboratory upper limit for the magnetic moment of the electron antineutrino ($1.8 \times 10^{-10} \mu_B$) by an order of magnitude. A magnetic moment of the order of a few 10^{-11} μ_B would lead to spin precession in the solar magnetic field [1] and could explain the deficit of solar neutrinos. In the standard model the neutrino may acquire a magnetic moment proportional to its mass. Masses of order 10 MeV/c^2 imply very small values $\mu_\nu \sim 10^{-18} \mu_B$. Much larger values would mean onset of new physics.

MUNU is a low background detector based on a time projection chamber (TPC) filled with CF_4 gas at 3 bar, 158 cm long and 90 cm in diameter. The TPC is surrounded by an anticompton shield (NE235 based liquid scintillator), 50 cm thick, to convert and veto γ-rays which scatter in the gas and generate low energy recoil electrons. The scintillation light is detected by 48 photomultipliers, 24 on each lid. The liquid scintillator tank is shielded by 15 cm of lead. Neutrons generated by muon capture in the lead are attenuated and absorbed by 8 cm thick CH_2 plates covered with B_4C sheets. Details on the apparatus can be found in ref. [2].

The cathode (negative high voltage) is at the opposite end of the readout plane. The anode wires are electrically connected to provide a total energy trigger signal. Two planes of 256 perpendicular strips (3.3 mm pitch) register induced signals and define the x, y coordinates. The z coordinate along the detector axis is obtained through the time evolution of the signal. The anode, strip and photomultiplier signals are sampled by a 25 MHz - flash ADC system. Both energy and direction of the recoil electron are measured. The background (isotropic and expected to be 4 events/day) can be measured during reactor operation by looking at events with electrons emitted into the backward hemisphere. Another advantage is the capability to reconstruct the incident neutrino energy. The threshold on the electron recoil energy is set around 300 keV, giving the experiment a good sensitivity to the magnetic moment of the $\overline{\nu_e}$.

The Zurich group, see previous reports for more details, is responsible for the TPC readout and for the data acquisition system which is fully operational in the experimental area.

We recall the main results obtained last year. The energy resolution was measured with 60 keV photons from an ^{241}Am source. It is found to be $\sigma = 25$ % at 60 keV, corresponding $\sigma \simeq 10$ % at 500 keV. A spatial resolution of $\sigma = 1.6$ mm has been achieved for the cathode strips by fitting muon tracks with straight lines. The mean attenuation length of drifting electrons at 3 bar was measured to be $22 \,^{+14}_{-6}$ m [2]. With a small prototype of the TPC and a ^{112}Sn radioactive source we measured the angular resolution of electrons [3]. We obtained an angular resolution of $\sigma_{\theta_{space}} = 13°$ for 370 keV electrons, in agreement with simulation.

Since several triggers (neutrinos, radioactive sources, muons, etc) are being used, we have developped this year a general purpose trigger module (based on the LRS 2366 Universal Logic Unit, ULM) which allows to ajust remotely the coincidences and timing for every trigger. The system is working very well [4] and has been implemented into the data acquisition system, based on a FIC 8234 CPU running under the OS9 operating system. The anticompton shield was filled with 10 t of scintillator. The time projection chamber (Anode and cathode) was calibrated with passing muons and a ^{54}Mn source [4]. The photomultipliers were also calibrated with monochromatic photons from a ^{54}Mn source.

Figure 6.1(left) shows the projections $x-z$ and $y-z$ of a photon induced electron track, and the time distribution of the anode pulse. The reconstructed $x-y$ projection is also shown (Fig.6.1(right)).

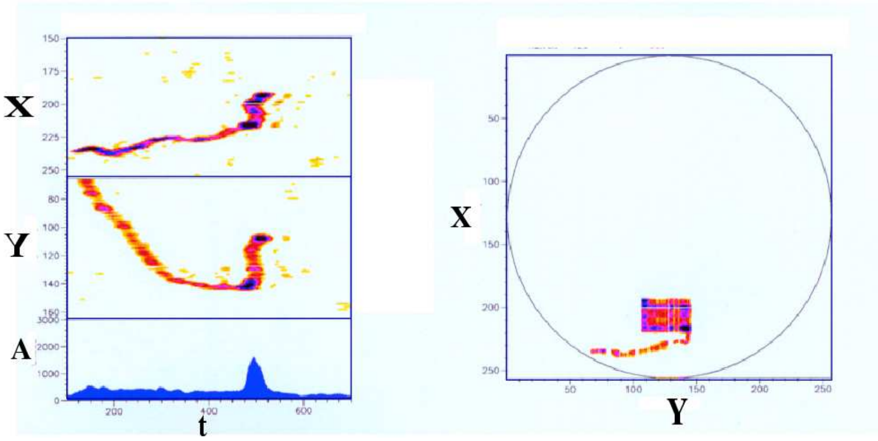

Figure 6.1: Left: $x-z$ and $y-z$ views of a photon induced electron track, and time distribution of the anode pulse. The dark area denotes large energy deposits at the end of the tracks. Right: Tentative reconstruction of the $x-y$ view.

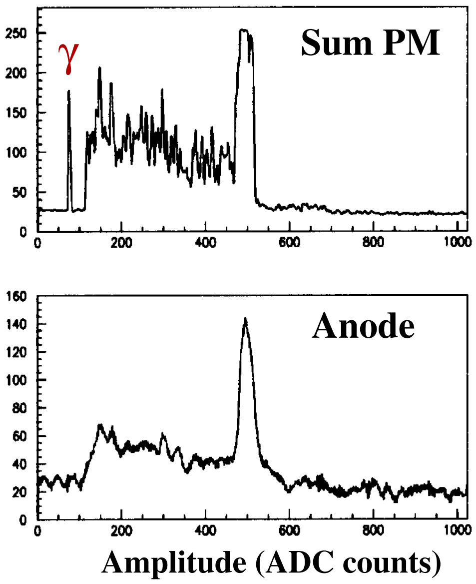

Figure 6.2: Amplitude distribution of the track shown in fig. 6.1. The anode signal (bottom) is also seen by the photomultipliers (top). The electron track is induced by a photon whose signal can be seen on left side of the photomultiplier pulse (top).

We have taken data and performed the calibration of the detector. In the last months we have made substantial progress in understanding the background, optimising the trigger and reducing the electronic noise.

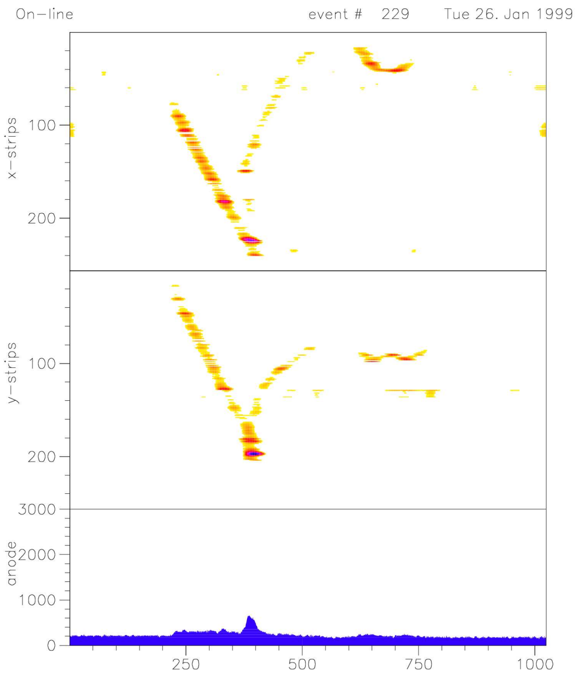

Figure 6.3: x - z and y - z views of a background event (muon capture), and time distribution of the anode pulse.

- Our trigger is made more complicated by the fact that CF_4 scintillates, so that the photomultipliers detect the light from the avalanche in the TPC (fig.6.2). However, neutrino induced pulses from the TPC can be distinguished from anticompton vetoes due to the long (max 40 μm) drifttime unless neutrinos scatter close to the anode plane. Furthermore, in order to keep the anticompton information for further software reduction, the photomultipliers had to be read out in a separate FADC crate. This required more readout electronics than planned.

- The sensitivity of the experiment strongly depends on the level of background we can reach. Figure 6.3 shows a typical background event (muon capture) easily vetoed by the anticompton: The anticompton vetoes more than 99 % of the photon induced background. We have, however, observed 10 times more background than expected. We are now convinced that Radon, introduced in the gas by oxisorb filters, explains the high rates. Activity measurements confirmed that the oxisorbs we use contain quantities of Uranium much higher than foreseen. With a charcoal cold trap we noticed a steady decrease of background and could measure a lifetime of Radon of the order of 5.5 days. We are now in the process of replacing the big oxisorb by smaller low background ones.

- Electronic noise in the readout chain of the TPC has been drastically reduced. We are now confident that we can improve the signal to noise ratio by another factor of two, in which case zero suppression can be performed efficiently.

Cleaner data are being taken and work is progressing well.

Recently, interest in low energy neutrino - electron scattering has been boosted by the study of solar neutrinos. In order to explain the observed deficit in an independent way, it is necessary to measure the low energy neutrino spectrum with a good precision. A third generation solar neutrino experiment must fullfil two requirements: very good energy and angular resolutions on one hand, and low background environment, on the other hand. A new solar neutrino experiment, SuperMUNU, is being discussed at the Gran Sasso laboratory [5]. The solar neutrino energy spectrum could be obtained with four 50 m^3 TPC's (4 meters diameter and 4 meters long) filled with CF_4 gas at 2 bar, and surrounded by 50 cm liquid scintillator. One would collect 700 events a year with an electron threshold of 100 keV. The angle of the electron (and hence the neutrino energy) is mandatory to resolve the pp and Be spectra. It will also be possible to see the pep neutrinos, provided the pressure is increased to $\sim$ 5 bar.

References

[1] F. Ould-Saada, UZH-PH 114/96, 45pp; and references therein

[2] C. Amsler *et al.*, Nucl. Instrum. Methods **A 396** (1997) 115

[3] S. Iseli, diploma thesis, University of Zurich (1996)

[4] O. Link, diploma thesis, University of Zurich (1998)

[5] MUNU internal note, january 1997.