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

C. Amsler, O. Link and H. Pruys

in collaboration with:
Institut des Sciences Nucléaires (Grenoble), Université de Neuchâtel, Università di Padova

(MUNU Collaboration)

The aim of the MUNU experiment is to measure the magnetic moment of the electron neutrino. In the standard model the neutrino acquires a magnetic moment proportional to its mass. With the present upper limit on the mass of the electron neutrino the magnetic moment is of the order of $10^{-18}\mu_B$. An experimental upper limit of $1.9 \times 10^{-10}\mu_B$ (95% confidence level) was reported from a reactor experiment [1]. The Superkamiokande experiment obtained an upper limit of $1.5 \times 10^{-10}\mu_B$ (90% confidence level) after 823 days of running [2]. Astrophysical upper limits, e.g. from SN1997A, are two orders of magnitude lower, but with the restriction that neutrinos are Dirac particles.

The experimental evidence for a large magnetic moment would mean new physics beyond the standard model. Extensions of the standard model, e.g. left-right symmetric models, predict that the neutrino should have a large magnetic moment. With a finite magnetic moment the spin of a left-handed neutrino may flip due to the electromagnetic interaction, and become a "sterile" right-handed state which does not interact, and hence is experimentally invisible. The precession of the magnetic moment offers an alternative explanation to the more fashionable MSW effect for the deficit of solar neutrinos: taking the uncertainties in the strength of the magnetic field inside the sun into account, one estimates that a magnetic moment in the range $\mu_\nu = 10^{-10} - 10^{-12}\ \mu_B$ may explain the observed solar neutrino deficit.

The MUNU experiment actually measures the magnetic moment of anti-neutrinos $\overline{\nu}_e$ from a nuclear reactor, using the elastic scattering reaction $\overline{\nu}_e e^- \rightarrow \overline{\nu}_e e^-$. This process is very sensitive to the magnetic moment of the $\overline{\nu}_e$, because it is a pure leptonic and theoretically well understood weak process. The weak cross-section increases linearly with neutrino energy, but the electromagnetic contribution of the finite magnetic moment increases logarithmically. It is therefore advantageous to measure μ_ν at low neutrino energies, e.g. with neutrinos from a nuclear reactor. MUNU uses a time projection chamber (TPC) which offers two advantages: (i) we measure both the angle and the energy of the recoil electron - and hence can calculate the neutrino energy -, (ii) we measure simultaneously the signal and the background, since electrons cannot be scattered in the backward hemisphere. A finite neutrino magnetic moment leads to an excess of low energy electrons scattered at large angles (near 90°), where the energy becomes very small. The MUNU experiment detects scattered electrons with a low energy threshold of 300 keV.

The TPC (gaseous CF_4 at 3 bar) is located in a stainless steel tank, filled with liquid scintillator to guard against cosmic muons and Compton scattering of low energy $\gamma's$. The photomultipliers of the anti-Compton scintillator operate at the level of one photo-electron. The detection efficiency is 97% for γ energies above 100 keV. It also reduces the cosmic muon rate of 65 Hz to 0.1 Hz. A detailed description of the apparatus can be found in ref. [3] and in previous annual reports.

In 1999 we replaced the oxisorb filters purifying the TPC gas by smaller, low background ones. Activity measurements confirmed that zeolites in the oxisorb contained much higher quantities of uranium than foreseen. The counting rate of electrons with energies higher than 300 keV in the TPC then dropped by a factor of 100, from 10 Hz to 0.1 Hz. For the α's from the gas, the counting rate dropped by a factor 10^5, from 35 to 5×10^{-3} Hz. However, the counting rate from α's emerging from the cathode side remained constant, at about 0.05 Hz. This background was traced to the presence of ^{214}Bi (from the decay chain of radon) implanted on the high voltage cathode surface. This nuclide decays into stable ^{206}Pb through a chain of delayed α and β emission which generates background electrons in the TPC.

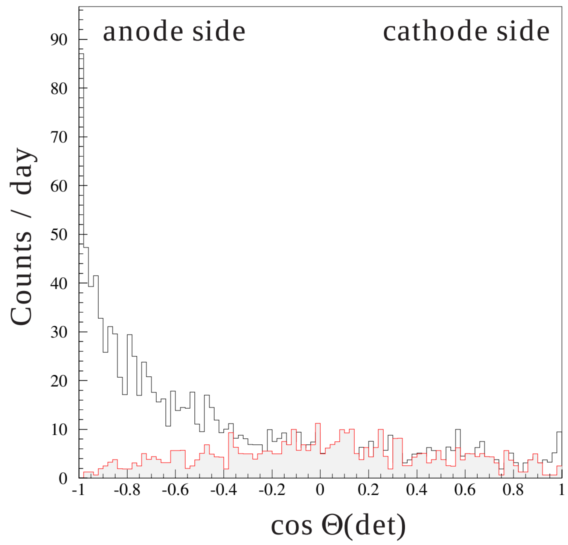

Figure 2.1: *Angular distribution of background electrons during a reactor off period. The angle $\theta(det)$ is measured with respect to the z-axis of the TPC. The open histogram refers to 300 keV threshold, the shaded histogram to 700 keV.*

The high voltage cathode was replaced during a 3 months period in summer 2000. After replacement the α counting rate associated with the cathode dropped by a factor 10^2, to an acceptable 5×10^{-4} Hz. The angular distribution of background electrons during a reactor off period and after the replacement of the cathode is shown in Fig. 2.1. There is no electron excess from the cathode side, but the number of electrons from the anode side remains unpleasantly high. Above 700 keV (shaded histogram) the background distribution is fairly flat. We do not have any explanation so far for the observed excess of low energy electrons.

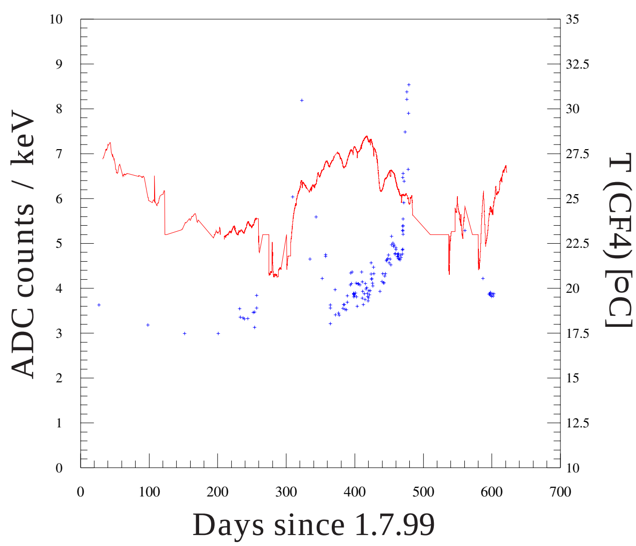

Figure 2.2: *TPC gain (dots) and temperature (curve) as a function of time. The cathode was replaced on day 300.*

Unfortunately a new problem arose from a leak in the acrylic structure of the TPC. After replacing the cathode we filtered a few ml of liquid scintillator every week from the gas cool trap. The contamination of the TPC gas with scintillator vapour led to strong fluctuations in the anode signal gain. The gain is shown in Fig. 2.2 as a function of time (the TPC was calibrated with cosmic muons and a Mn source). Strong fluctuations are observed around days 400-480, when a leak from the anti-Compton shield was discovered.

Then in autumn 2000 an anode wire broke, inducing a short circuit with the neighbouring readout plane. The anode was probably damaged because of the strong amplification at day 480 (see Fig. 2.2). The detector was opened and the damaged anode repaired. Actually, we exchanged the complete anode plane to avoid the risk of breaking further wires. The work was completed in February 2001 and the detector again operated routinely at a CF_4 pressure of 3 bar. The TPC high voltage is -37 kV (grid potential - 2000 V) and the maximum drift time of 63 μs corresponds to a drift velocity of 2.5 cm/μs. Figure 2.3 shows the improvement in the data collection efficiency in 1999 and 2000.

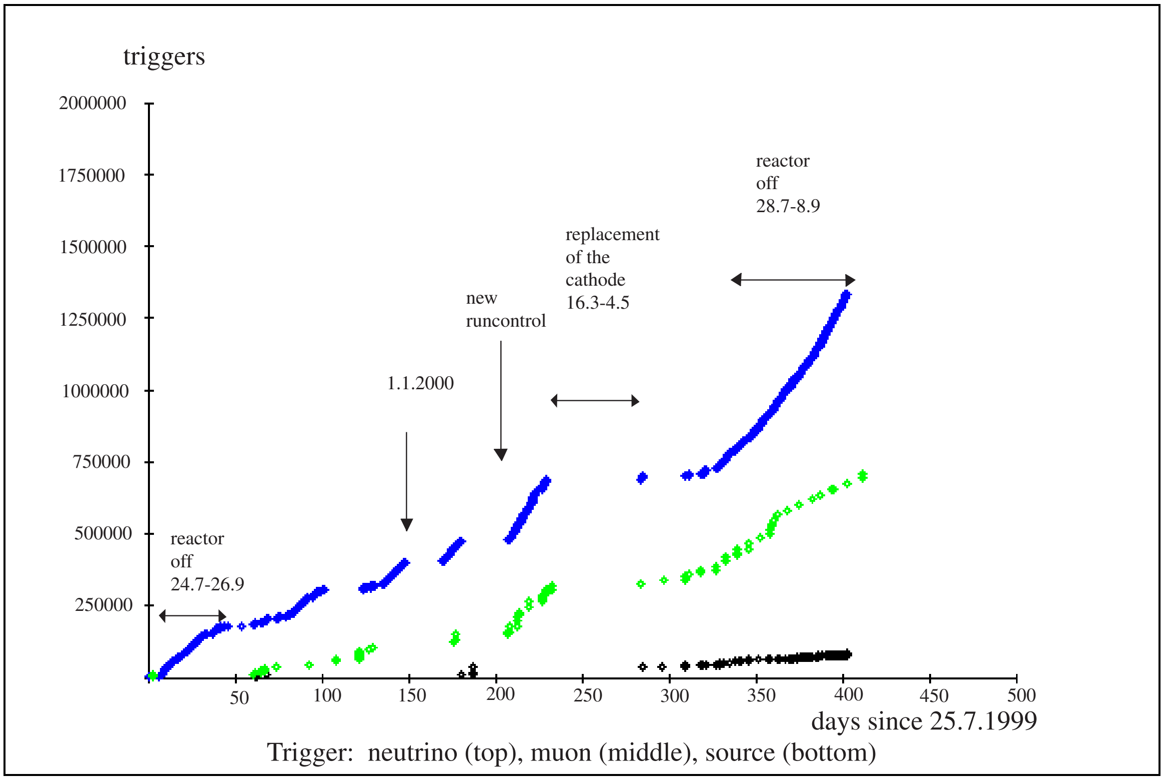

Figure 2.3: *Triggers accumulated during the last 400 days.*

The background was studied in a 2 months reactor shutdown in summer 2000, within which we collected 319,000 background events. The typical rate reductions by the online trigger and off-line analyses are as follows: without filtering the counting rate of the TPC is about 65 Hz, mainly due to cosmic muons which are still numerous below the reactor after 20 m of water equivalent. The counting rate drops to 0.15 Hz after the muon and the anti-Compton veto. With an energy threshold of 300 keV the counting rate from background electrons is 14 mHz, using a fiducial volume cut applied to reduce β-radioactivity from the walls of the TPC.

Electron events with no associated low energy photon converted in the anti-Compton are then scanned by eye. The angular distribution is shown in Fig. 2.4 as a function of recoil angle θ. This distribution is not corrected for acceptance and efficiency. The shaded region around $\cos\theta = 1$ is the region in which neutrino-electron scattering events would be expected during a reactor on run. The shaded events were obtained by requiring the measured electron angle

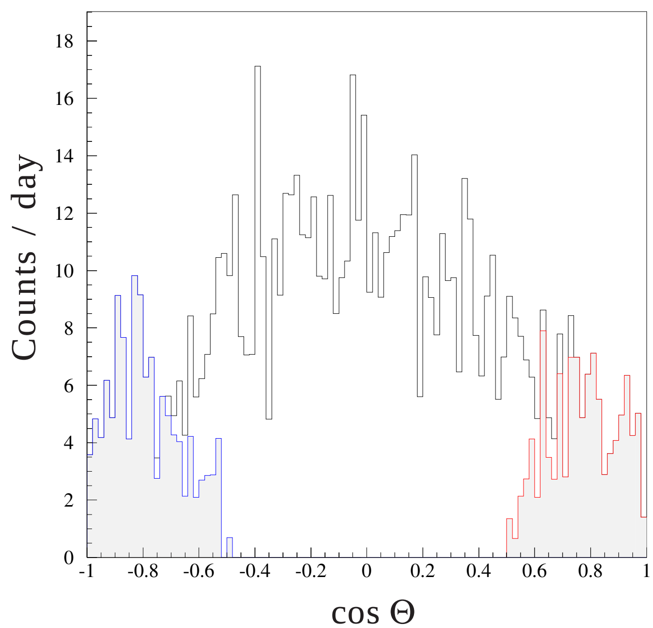

Figure 2.4: *Angular distribution of background electrons during a reactor off period. The angle $\theta = 0$ corresponds to electrons emitted in the direction opposite to the reactor core. The shaded histogram contains events with the kinematical condition that $E_\nu > 0$ (see text). The energy threshold for the electron was 300 keV.*

and energy to be consistent with a positive neutrino energy, pretending that these events were induced by neutrinos from the reactor ($\theta = 0$) or from the direction opposite to the reactor ($\theta = 180°$).

We have so far scanned 10% of the reactor off period, corresponding to a 57 hours dead-time corrected run. In the forward direction one finds 106.9 ± 6.6, in the backward direction 120.2 ± 7.0 electrons/day. The excess of backward events is visible in Fig. 2.4. The background seems to be anisotropic, larger in the backward direction, but more statistics and acceptance corrections are needed.

During summer 2000 we also collected 243,000 events with reactor on, of which about 11% were analyzed so far (corresponding to a 62 hours run). One finds 113.2 ± 5.7 events/day in the forward direction and 109.3 ± 5.6 events / day in the backward direction. The latter agrees with reactor off. Larger statistics samples are of course needed. From Monte Carlo simulations one expects 8.8 neutrino-electron events/day at 3 bar, with a threshold of 300 keV and assuming $\mu_\nu = 0$. The counting rate increases to 13.1 events / day with a finite magnetic moment of $\mu_\nu = 1.0 \times 10^{-10} \mu_B$. Our background over signal ratio is therefore about 10:1. Note that in ref. [1] the upper limit on the neutrino magnetic moment was derived with a much worse background over signal ratio of 100:1.

The analysis of the data collected after the replacement of the high voltage cathode is very promising as the contaminating background was decreased by a factor of 100. During the year 2001 we hope to collect neutrino data for 200 days after which we could reach an upper limit for μ_ν of a few 10^{-11} μ_B. Data taking for this experiment should be completed by the end of 2001.

References

[1] A. I. Derbin et al., JETP Lett. 57 (1993) 768

[2] J.F. Beacom and P. Vogel, Phys. Rev. Lett. 83 (1999) 5222

[3] C. Amsler et al., Nucl. Instr. Meth. in Phys. Res. A 396 (1997) 115