Preliminary results and status of the MUNU experiment

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We built a low background detector to measure the $\overline{\nu}_e e^-$ elastic cross section at low energy. The detector has been installed close to a nuclear reactor in Bugey and it is running since almost one year. After having reduced the electron background by more than 2 orders of magnitude we are now taking data to be sensitive to a neutrino magnetic moment in the region below 10^{-10} Bohr magnetons.

1. INTRODUCTION

MUNU was designed to study the $\overline{\nu}_e e^- \rightarrow \overline{\nu}_e e^-$ scattering with the antineutrinos from a nuclear reactor. Its aim is to measure the $\overline{\nu}_e e^-$ differential cross section down to the electron energy of 0.3 MeV. In this way the experiment can be sensitive to a neutrino magnetic moment extending down to $\sim 3 \cdot 10^{-11}$ Bohr magnetons.

The different energy dependence of the weak and electromagnetic cross sections puts the following constraints to any neutrino-electron scattering experiment willing to have a high sensitivity to the neutrino magnetic moment: a low energy beam and a detector with low threshold on the electron kinetic energy.

2. THE EXPERIMENT

MUNU has two substantial improvements with respect to previous experiments: both the electron energy and direction are measured and about 1000 neutrino events can be collected during 1 year of data taking. The detector consists of a 1 m^3 TPC immersed into 10 m^3 of liquid scintillator (Fig. 1). Since the expected event rate is low it has been necessary to minimize all possible background sources and to construct each part of the detector from selected low radioactivity material.

The electrons of the TPC filling gas are the target for the $\overline{\nu}_e e^-$ interaction. Their scattering angle can thus be measured and this allows for a "Kamiokande-like" experiment: i.e. a simultaneous measurement of signal plus background events in the forward direction and only background events in the backward direction.

2.1. The detector

The central detector is an acrylic vessel TPC, a cylinder of 90 cm inner diameter and 162 cm long. Acrylic is selected as construction material because of its low intrinsic radioactivity [1].

The filling gas of the TPC is CF_4 at 3 bar. CF_4 is used because of its high density (3.7 $g \cdot l^{-1}$ at 1 bar), of the relatively low atomic number, which reduces the multiple scattering, and because it does not contain free protons, which suppresses the $\overline{\nu}_e p \rightarrow e^+ n$ background reaction [2].

The TPC has been tested before being moved to Bugey. An electron attenuation length longer than 16 m, a 20% FWHM energy resolution at 500 keV and a space resolution of 1.6 mm were measured [3].

The acrylic vessel is mounted inside a stainless steel tank (3.8 m long and 2 m in diameter) filled with liquid scintillator. The scintillator serves to veto the cosmic muons and as anti-Compton detector. It is viewed by 48 photomultipliers and it has an efficiency of about 98% for γ energies above 100 keV.

The steel vessel is pressurized in order to keep the pressure difference between the inside and the outside of the TPC below 100 $mbar$ (a bigger difference could destroy the TPC).

Outside the steel vessel there are a 8 cm thick boron loaded polyethylene shielding and a 15 cm thick lead shielding to absorb neutrons and gamma rays entering the detector from outside.

The detector has been mounted in a laboratory underneath a nuclear reactor in Bugey, at 18 m from the core. The reactor has a power of 2800 $MWth$ and it emits about $5 \cdot 10^{20}$ $\overline{\nu}_e$ s^{-1}. Their spectrum is known with a precision of $\sim 3\%$.

3. SIGNAL AND BACKGROUND

The expected event rates at 18 m from the reactor core are given in Table 1 for $\mu_\nu = 0$ and for $\mu_\nu = 10^{-10}$ μ_B (the electromagnetic signal goes as ${\mu_\nu}^2$). For event we mean an isolated electron inside the TPC fiducial volume with an energy deposition in the anti-Compton lower than 100 keV. These rates have to be compared to the background.

Two main sources of background were identified: cosmic rays and natural radioactivity. Only muons go through the 20 m water equivalent shielding existing above the Bugey laboratory and they can create radioactive nuclei, giving γ rays when decaying, and neutrons, giving γ rays when captured. These γ rays in turn can produce Compton electrons inside the TPC volume. Muon interactions on CF_4 can also induce β activity through stopped muon capture and spallation nuclei production. We estimate a total cosmic ray background of about 2 events per day.

The other important background component is that from natural radioactivity. From the measured activities of the various components of the detector we estimate a rate of about 4 events per day. The total background for electron energy above 300 keV is thus estimated to be about 6 events per day.

Considering the signal rates at 18 m from the reactor core, as given in Table 1, a statistical error less than 3 % should be achievable in one year measuring time. Combined with a systematic error of 5 %, essentially from the reactor spectrum and power, this leads to a sensitivity for the magnetic moment of the neutrino of $\sim 3 \cdot 10^{-11}$ μ_B. More generally, we will be sensitive to any new physics effect producing a change bigger than 5% in the $\overline{\nu}_e e^-$ cross section at low energy [4].

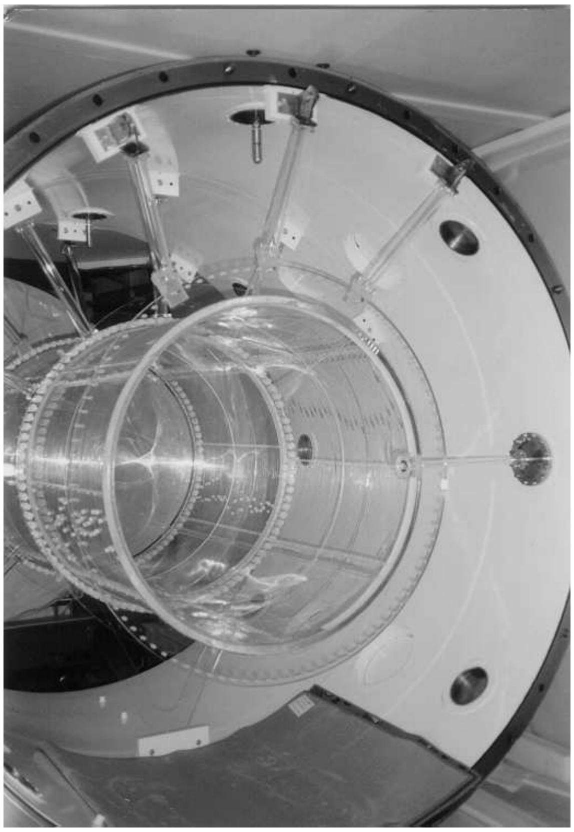

Figure 1. The TPC mounted inside the anti-Compton without the anode plane.

4. PRELIMINARY RESULTS

Since almost one year we started taking data. The detector itself is working as expected. Fig. 2 shows an e^+e^- event due to a γ ray conversion.

The background requires a more detailed discussion. The count rate of the anti-Compton has been since the beginning in agreement with the simulation: 900 Hz above 100 keV due to muons and radioactivity. On the contrary, the electron and α particle rates were much higher than the predicted ones. We identified as responsible for these high rates the ^{222}Rn emitted by

Table 1
Event rates (fully contained electrons) expected from the weak interaction and from the electromagnetic one.

$T(MeV)$	$\overline{\nu}_e e^-$ Events/day	
	weak	$\mu_\nu = 10^{-10}$
> 0.3	6.0	3.2
> 0.8	1.7	0.5

the oxysorb.

After having replaced the oxysorb by a getter with much lower Uranium contamination we decreased the event rate by 2 orders of magnitude, reaching 0.1 Hz and $1.5{\cdot}10^{-3}$ Hz for electron energies above 300 and 800 keV respectively. The rate of α particles in the gas decreased by a factor 10^4, becoming lower than $5{\cdot}10^{-3}$ Hz, whereas the rate of the α particles from the cathode, 0.05 Hz, did not change

In spite of the reduction the event rate was still too high and the limit we could get on the neutrino magnetic moment was $\sim 3{\cdot}10^{-10}$ Bohr magnetons. To further improve we had to replace the TPC cathode, where the Radon daughters were collected (the dangerous nucleus is ^{210}Bi, which β decays with an end-point energy of 1.17 MeV to the α decaying ^{210}Po).

The analysis of the data we have taken with the new cathode shows that the α particles from the cathode have decreased by a factor 20. The electron analysis is longer because it requires data production and eye-scanning, however it looks reasonable to expect an electron reduction which will allow the experiment to be sensitive to a neutrino magnetic moment in the 10^{-11} Bohr magneton region.

Finally we point out that the MUNU detector is the first one doing neutrino spectroscopy in the MeV region by measuring both the energy and the direction of the recoiling electrons. From this point of view it can be regarded as a low background prototype of a detector for the spectroscopy of the low energy neutrinos from the Sun (pp and ^7Be) [5,6].

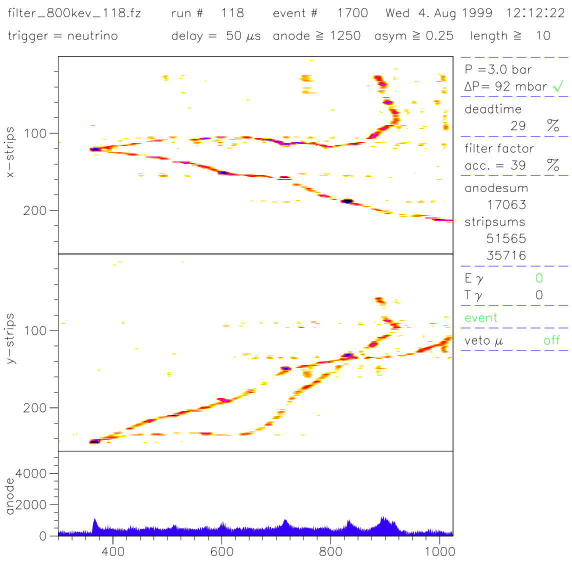

Figure 2. An e^+e^- event: vertical projection, horizontal projection and energy deposition as function of time. The binning is 3.5 mm for x and y and 80 ns for the time (i.e. 1.8 mm for z).

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