A CF_4 TPC TO MEASURE THE $\overline{\nu}_e$ MAGNETIC MOMENT AT A NUCLEAR REACTOR

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ABSTRACT

An experiment is described which offers a significant improvement for the measurement of the $\overline{\nu}_e e^-$ cross section at low energy. The experiment will be sensitive to a neutrino magnetic moment down to a few 10^{-11} Bohr magnetons, on the level of that introduced to explain the solar neutrino puzzle. The detector, to be placed close to a nuclear reactor, is a 1 m^3 Time Projection Chamber surrounded by an active shielding. The key point of the experiment is the use of tetrafluoromethane, CF_4, at the pressure of 5 bar in the TPC.

1 Introduction

One way to explain the observed low flux of ^{8}B ν_e from the sun in the ^{37}Cl [1] and Kamiokande experiments [2] is the existence of a neutrino magnetic moment of the order $10^{-10} - 10^{-11}$ Bohr magneton units.

The best way of looking for the magnetic moment of the ν_e in a lab experiment seems to be the detailed study of the $\overline{\nu}_e e^-$ elastic scattering. More generally this reaction is fundamental and its study provides information on basic features of the weak interaction. Both charged (CC) and neutral currents (NC) are involved. They are expected to interfere if the NC and CC final state neutrinos are identical, as assumed in the standard model.

The cross section of the $\overline{\nu}_e e^-$ scattering can be divided into two parts: one due to W and Z exchange, which increases linearly with the neutrino energy, and one which comes from the magnetic moment interaction and which increases only logarithmically. To observe the contribution of the second part, one has to use low energy neutrinos. Reactors are copious sources of $\overline{\nu}_e$'s with energies up to 10 MeV, and are ideally suited for such an experiment. The energy spectra are known with good precision, of the order of 3% [3].

Only a few attempts have been made to measure the $\overline{\nu}_e e^-$ scattering [4] [5]. The signal to background ratio was however marginal ($\sim$ 0.18 and $\sim$ 0.13) and it was not possible to derive an accurate value for the Weinberg angle $sin^2\theta_W$ from this data.

In order to test the magnetic moment term it is necessary to decrease the threshold on the electron kinetic energy, since it contributes mostly at low T. It therefore appears important to perform a new experiment with a lower threshold detector and a better signal to noise ratio. The signature of the events, one single forward electron, must be fully exploited to suppress as much as possible the background. We believe that a Time Projection Chamber, similar to that used to study $\beta\beta$ decay of ^{136}Xe in the Gotthard underground lab [6], can identify single electrons very well thanks to the good spatial resolution. The end of tracks can be recognized from the enhanced ionization.

2 The test results

The choice of the gas is very important as we need a gas which has at the same time a high density, to maximize the number of target electrons, and a low atomic number Z to minimize the multiple scattering and to allow for the reconstruction of the electron direction. This way it is possible to have a simultaneous measurement of signal plus background events in the forward direction, and of background events in the backward direction. Background can thus be measured on-line, while the reactor is on.

The best way to fulfill our requirements is to use tetrafluoromethane, CF_4, also known as carbon tetrafluoride or freon-14, at the pressure of 5 bar [7]. CF_4 has a density of 3.68 gr$\cdot$ l^{-1} (at 1 bar pressure and 15 $°C$ temperature) and thus a very high electron density ($1.06 \cdot 10^{21}$ cm^{-3}) and also a good radiation length: $X_o = 35.9$ $gr \cdot cm^{-2}$. Another advantage is that CF_4 does not contain hydrogen, and this suppresses the background reaction $\overline{\nu}_e + p \rightarrow e^+ + n$.

The capability of drifting electrons in CF_4 has been demonstrated in the past over distances of a few centimeters only [8] [9]. In the experiment we plan to do, we would like to have a threshold of 500 keV or less on the electron kinetic energy and a count rate due to weak interaction of $\sim$ 10 events per day. This is achievable with a 1 m^3 TPC filled with CF_4 at the pressure of 5 bar. Consequently, it is necessary to reach an electron attenuation length of at least $\sim$ 1 m. In order to check if, and how, this value can be obtained, we built a prototype TPC, a cylindrical stainless steel vessel of 20 cm diameter and 30 cm height [10]. All the materials used were selected according to their compatibility with CF_4. The gas is circulated continuosly through an Oxisorb filter to remove oxigen and through a cold trap (-95 $°C$) to remove water and possible freon contaminations

With an ^{55}Fe X-ray source, which we could move inside the TPC, we measured an electron attenuation length longer than 6 m, with a drift field of 120 $V \cdot cm^{-1} \cdot bar^{-1}$.

3 The detector and the signal

The detector will be placed at a distance of 18.6 m underneath the core of the Bugey pressurized water reactor (2800 $MWth$).

The core of the detector we propose to build is a 1 m^3 TPC filled with CF_4 at 5 bar. The gas volume will be defined by a vessel made from lucite which will support the cathode, the read-out planes, and the field shaping rings. We choose lucite because of its radioctive cleaness. The lucite vessel will be immersed in a stainless steel tank filled with a mineral oil based liquid scintillator ,$\sim$ 50 cm thick, which will serve to veto the cosmic muons and as anti-Compton detector. Top and bottom lid of the tank will be instrumented with photomultipliers. The liquid scintillator and the steel vessel will also serve as passive shielding but, since we are above ground, they will not be sufficient. Working outside the containment building we would have to surround the detector by various additional shielding layers, iron + water + B_4C, as was done for the oscillation experiment in Gosgen[3].

The expected rates at the distance of 18.6 m from the core of the 2800 $MWth$ reactor have been calculated assuming W and Z exchange only.

Table 1.

$T(MeV)$	Efficiency (Contained)	Events/day 18.6 m	Events/day background
0.25-0.5	0.9	5.4	-
0.5-1	0.85	5.0	2.5
> 1	0.70	4.2	0.2

These rates have to be compared to background rates, which are estimated [10] taking into account direct cosmic muon hits and muon decay events, activation of F and C in inelastic scattering of high energy muons, unstable nuclei production due to μ^- capture, neutron activation, natural ^{40}K, ^{232}Th and ^{238}U activity in the detector. The dominant background is due to the Compton scattering of the γ's produced by the natural activity in the thick walls of the vessel. This background can be estimated from the one measured in the Xe TPC in the Gotthard lab. Taking into account the anti-Compton capability of the liquid scintillator around the core TPC we obtain the rates given in table 1. These estimates should be considered as upper limits. We hope to learn from the operation of the Xe TPC how to make the CF_4 TPC cleaner.

Considering the signal rates in table 1 a statistical error of 3 % should be achievable in the bin $0.5 < T(MeV) < 1$ in one year of measuring time. Combined with a systematic error of 4 %, essentially from the reactor spectrum, we get a total error of 5 %. This gives a sensitivity to μ_ν around $3 \cdot 10^{-11}$, a factor 10 better than in previous experiments [4] [5]. With some luck the threshold may be lowered more, say down to 300-350 keV, and a sensitivity around $2 \cdot 10^{-11}$ seems then achievable.

The status of the project is the following: a collaboration has been formed between INFN-Gran Sasso, ISN-Grenoble and the Universities of Münster,Neuchâtel, Padova and Zürich and the experiment has been partially financed. We are doing further tests with the prototype TPC in Neuchâtel and making another TPC of the same size but with a plastic vessel in Gran Sasso. We plan to finish the tests in a few months and then to start with the construction of the detector which should be ready for the end of next year.

4 Conclusions

We described a gas detector which offers significant improvements for measurements of the $\overline{\nu}_e e^-$ elastic cross section and which is sensitive to a magnetic moment of the neutrino on the level of that introduced to explain the solar neutrino puzzle.

The distinguishing features of the detector are a low threshold for the electron kinetic energy and track reconstruction capability. The key point of the experiment is to use a 1 m^3 TPC filled with CF_4 at the pressure of 5 bar.

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