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A XENON TIME PROJECTION CHAMBER FOR DOUBLE BETA DECAY

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ABSTRACT

A time projection chamber has been built to search for neutrinoless double beta decay in ^{136}Xe. The detector will be sensitive enough to set a life time limit of $8\text{x}10^{22}$ years in 1 year of running time.

INTRODUCTION

Neutrinoless double beta decay is possibly the most sensitive tool to search for Majorana neutrino mass. The monoenergetic peak of the two electrons from neutrinoless decay provides a unique energy signature, which has already been used to set a stringent limit on Majorana neutrino mass from high resolution detectors in ^{76}Ge[1]. We have built a Time Projection Chamber (TPC) to search for double beta decay in ^{136}Xe. In the TPC, the neutrinoless double beta decay trajectory has an energy of 2.48 MeV and charge blobs at both ends due to enhanced charge deposition from the slowing down of the electrons. In contrast, the single electron background events will have only one charge blob at one end only. This will provide a very powerful technique for background rejection and, operating at 5 atm for 1 year, will enable us to to put a limit of 1.9 eV on the Majorana neutrino mass[2].

TIME PROJECTION CHAMBER

A schematic diagram of xenon time projection chamber is shown in fig. 1. The detailed design and construction of the TPC is described elswhere[3], but the relevent specifications are shown in Table 1. This TPC is suitable for double beta decay experiment because it satisfies three basic requirements. It can measure the energy, reconstruct the trajectory and find the charge blob at the end of the trajectory. The energy is measured by collecting the total charge during proportional multiplication

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from a set of connected anode wires. The trajectory is reconstructed using the induced signals during the drift from 336 X-Y strips. To locate the charge blobs at the end of the trajectory, we have used simple two level discriminators instead of flash ADCs in each channel. This discriminator system is adequate for our requirements, and also reduces the electronic dead time of the apparatus by a significant factor. A typical electron trajectory with a charge blob at the end, using this scheme is shown in fig. 2.

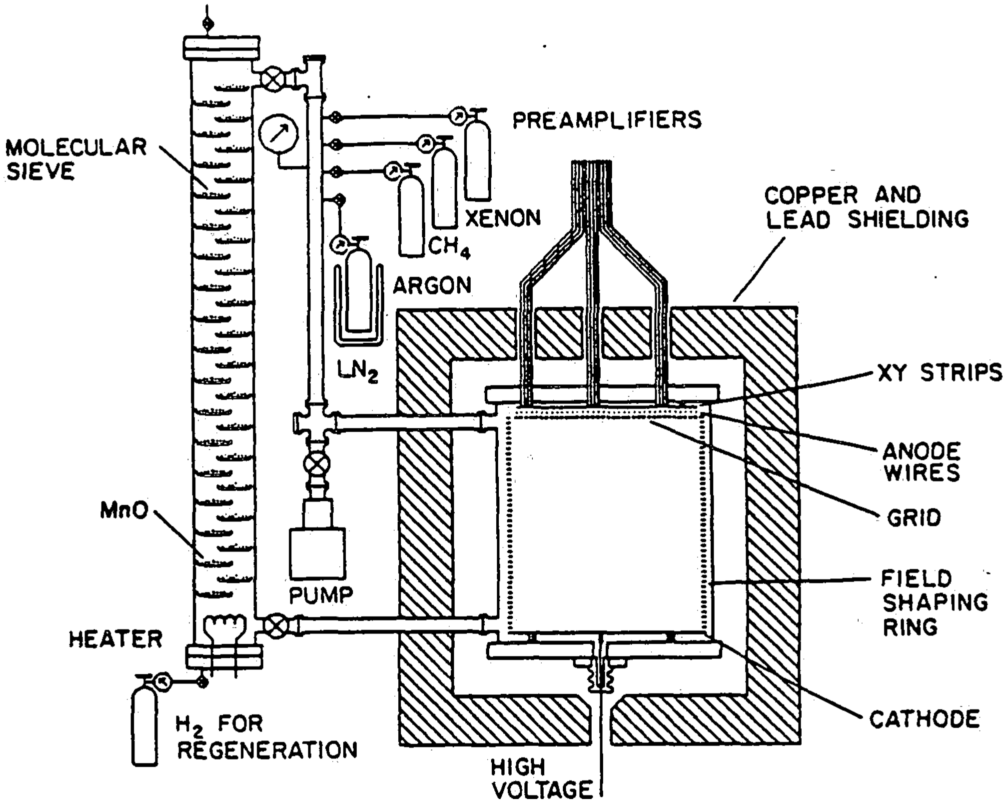

Fig. 1. Schematic diagram of the xenon time projection chamber.

BACKGROUND

For low background experiments, like search for double beta decay, proper understanding of the background is very important. To minimize the internal background from natural radioactivity, the TPC is fabricated from low background materials. To minimize the external background, the TPC is shielded by 10 cm of copper and 20 cm of lead. We still expect to see some internal and external background events which can be characterized as follows:

Cosmic ray muons: With an active veto, and the capability of trajectory reconstruction of the TPC, it is possible to eliminate the contribution from the cosmic ray muons very effectively. However, the muon induced background causes a much more serious problem. This is due to muon capture in the copper and lead shielding which may produce neutrons. These neutrons, when captured, produce high energy gamma rays which in turn can interact in the TPC. To reduce this problem, the TPC will be placed underground in the St Gotthard tunnel in Switzerland where the muon flux will be reduced by a factor of 10^6 due to the overburden of 3000 m of water equivalent.

Table 1. Design specifications for xenon time projection chamber

Volume	355 liters
Active volume	208 liters
Operating pressure	5 atm
Number of xenon atoms	2.78×10^{25}
Number of ^{136}Xe atoms	2.48×10^{24}
Efficiency for 2.5MeV event	20%
Number of channels	336
Spatial resolution	$3.6 \times 3.6 \times 1$ mm^3
Proportional Multiplication	10^3-10^4
Preamplifier Gain	270mV/μA
Gas composition	95% Xe + 5% CH_4
Drift field	200V/cm-atm
Drift velocity	1cm/μs
Diffusion in 60cm	2.4mm
Data acquisition rate	8MHz
Event size	40,000 Bytes
Maximum allowed event rate	5/s

^{85}Kr: Commercial xenon contains a small amount of ^{85}Kr (~1 part in 10^{17}). ^{85}Kr is a beta emitter with endpoint energy of 0.68 Mev and half life of 10.7 years. The trajectory reconstruction and the charge blob requirement at both ends should be

able to discriminate these events from the signal. We plan to reject events below ^{85}Kr endpoint energy using hardware veto to reduce electronics deadtime. The background from ^{85}Kr may be significantly reduced if enriched ^{136}Xe is used as the fill gas.

Gamma rays: Despite elaborate shielding, there will always be some gamma ray background due to natural radioactivity of the surroundings. The major contribution will be from the electrons produced by the Compon scattering. Most single electron trajectories can be rejected at the cost of the electronic dead time. However, there is a small probability (3%) that a 2.5 MeV Compton electron will produce energetic secondary electrons causing high charge accumulation at the beginning of the trajectories. These events will look similar to double beta events and will contribute to the background. The more serious background for this experiment is pair production. They look like double beta decay since we cannot distinguish electrons from the positrons in our TPC.

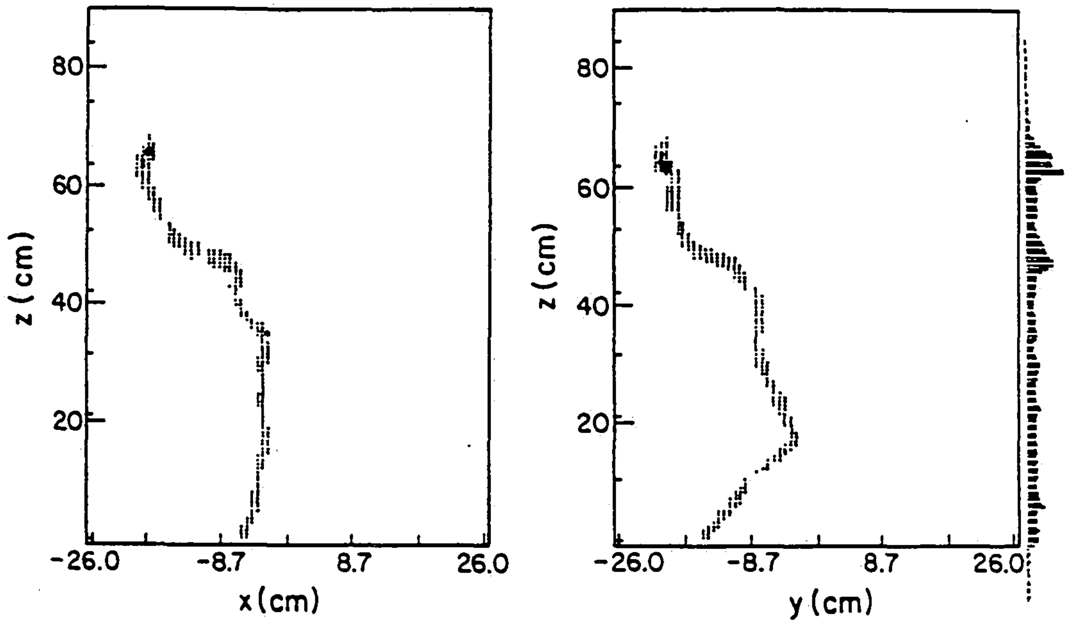

Fig. 2. The XZ and YZ projection of an electron trajectory with charge blob at the end. The energy of the electron is shown as a function of drift time (Z) on the right side.

From the results ^{76}Ge experiment[4], we anticipate that the major source of background will be external gamma rays. The gamma ray flux inside the underground tunnel has been carefully measured[5], and it drops exponentially with energy. The rate is about 700/MeV-hr-cm^2 at 2.5 MeV and 50/MeV-hr-cm^2 at 3.5 MeV. Lead shielding of 20 cm will reduce the background at 2.5 MeV and 3.5 Mev by a factor of 7×10^{-5} and 4×10^{-5} respectively. If we assume that inside the TPC the average path length of the gamma rays is about 30 cm (~1gm/cm^2 for 5 atm of xenon), we can estimate the total number of background events due to the pair production and the Compton scattering[6]. At 2.5 MeV, we expect a total background of the order of 833/MeV-year. Considering 20% detector efficiency and 5% energy resolution, we can set a life time limit of 8×10^{22} years for neutrinoless mode in one year. According to calculations[2], this life time for neutrinoless mode corresponds to a Majorona neutrino mass of 1.9 eV.

CONCLUSIONS

The high pressure gas TPC is now running as a detector. Half of the electronics are presently used to give 7 mm spatial resolution. For diagnostic purposes, we have used Ar-CH_4 mixtures at various pressures and the performance is quite promising. We will start using Xe-CH_4 mixtures shortly. To save time and have more flexibility during the diagnostic stage, we have used available materials in some places. These parts are currently being replaced with components made from low background materials. By the late spring of 1987 we plan to have the high pressure xenon time projection chamber searching for double beta decay events.

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