New Concepts for a Gaseous Xenon Detector for Double Beta Decay

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Abstract. Xenon gas is an attractive medium for the search for neutrinoless double beta decay because it offers the possibility of reasonable energy resolution, event topology reconstruction, very high intrinsic purity and background rejection through the identification of the daughter barium ion. This talk explores recent developments in the conceptual design of such a detector.

Introduction

To push the sensitivity for searches for neutrino-less double beta decay to increasingly high sensitivities the experimenter is challenged to design a large mass detector with very low backgrounds. Xenon is one of the most attractive among the possible candidates because it is relatively easy to separate the isotope of interest, $^{136}$Xe, noble substances such as xenon can be made extremely pure, xenon has no long lived radioactive isotopes, it has a high Q-value for the decay process (2.4 MeV) and high energy resolution has been demonstrated for detectors using xenon as a working substance. The EXO collaboration is developing both liquid and gaseous concepts for such a detector. The liquid detector work is the most advanced and is covered in the talk of L. Kaufman in these proceedings. A liquid detector has the advantage of being compact and this in turn means that the mass of materials making up the detector including the shield can be much smaller which makes tractable the resulting radioactivity constraints. In this talk some of the new concepts for such a gaseous detector will be presented.

A gaseous detector has a number of potential advantages over a liquid detector. The tracks are much longer and this allows information about the event topology to be studied. For example, in the Gottard experiment it was found that a criterion that two Bragg peaks were observed reduced the background by a factor of 25. There is also the chance to reject multi-site events with very high precision. The energy resolution of the gas detector is expected to be at least as good as a liquid detector and may be better as the correlation between ionization fluctuations and the scintillation light are much smaller. Perhaps the most exciting prospect for a gas counter is that it opens new ways to try to identify the daughter barium ion and thus greatly reduce the backgrounds. Some such improvement is likely to be essential for detecting this process if the effective Majorana mass is in the ‘Normal Hierarchy’ range.

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The first concept for a gaseous xenon detector with barium identification was published by M. Danilov et al [1] with a design based on the Gotthard laboratory work of J.-C. Vuilleumier et al [2]. The concept was for a gas TPC with a central cathode plane, phototubes to detect the scintillation flash and a fast laser steering scheme to bring the required red and blue lasers to the vertex location to pick up the barium. The ionization would be detected at the anodes using micropattern gas amplification. On further investigation, there appear to be problems with this concept. It has not yet been possible to find a gas composition which meets all of the requirements. These requirements include: (i) The gas must be extremely pure to allow drift of the electrons to the anodes (the use of any additives in the gas makes this more difficult); (ii) the gas must be transparent to the scintillation light at 174 nm. Most quench gases absorb this light. Indeed, to stabilize the gas amplification, one wants a gas that absorbs this uv light.

The barium ion created in the decay process is expected to be Ba++ (higher charge states may be produced due to shake off but in xenon, the ion will relax to 2+). The laser detection techniques require a singly charged ion. Xenon cannot give up an electron to the barium because the ionization potential to too high. Once can find additives that will permit the conversion (such as TEA) but such additives will make the gas purification very difficult and they are likely to form molecules with the barium ion making the tagging impossible.

The New Detector Concept

The new concept for a xenon detector is based on the idea that one would make a detector filled with pure xenon, and detect the barium ion by extracting it from the gas using techniques developed for radioactive ion beams and subsequently identifying it by one of a number of possible techniques.

The motivation for trying to extract the barium ions came from a serendipitous observation by M. Facina [3] who was trying to produce and extract $^{71}$Ni ions from proton induced fission fragments stopped in argon gas. His apparatus consisted of a gas cell with flowing argon at 0.5 bar with a nozzle of about 0.5 mm diameter through which lasers tuned to resonantly ionize nickel atoms were focused. Gas flowing out of the nozzle was pumped away with a large roots blower and turbo pumps. The resulting ions were extracted using a sextupole ion guide, accelerated through 40 kV, mass analysed, and stopped on a foil. The foil was then counted using a gamma counter to identify the ions produced. What was observed, in addition to the $^{71}$Ni was a strong signal from $^{142}$Ba. This signal was independent of the laser and could only come from the production of Ba++ ions in the fission which remained stable in the argon for times of ~0.5 seconds.

The detector would consist of a gaseous time projection chamber filled with xenon. If an ionizing event occurs in the gas, there will be a scintillation flash. This will be detected by light sensors at the ends of the detector to be described later to act as the trigger and time zero signal. Electrons will drift towards the anode under a strong electric field. Once they are close to the anode they will enter a strong field region where they will give rise to light through the electroluminescence process. D Nygren [4] has recently proposed such a concept to improve the energy resolution of a xenon detector. In Nygren’s design the light would be detected in a set of phototubes. Because we wish to achieve a fine tracking we will use a fine grained readout described below. A second readout plane is located behind the cathode grids to give a total energy reading. The electron drift time (measured from the scintillation flash) together with the ionization track information, will allow a determination of the barium ion position. The accuracy may not be high because the electron tracks in xenon are so complex but at least the location of the ionization cloud will be known and, at 10 bar this limits the uncertainty in the vertex to about 10 cm. The barium ion is slowly drifting towards the cathode.
The cathode is made using a pair of grids with programmable voltages on each wire. At the point where the barium is expected to be between the wires, the field is changed so that the ions drift to one side. When they reach the edge of the detector, the fields are again changed to drift the ions out along a channel to an extraction nozzle.

After extraction the ions may be identified in a number of ways. One could accelerate them with an electric field and measure the energy and charge/mass to determine that a mass 136 ion was detected in a 2+ charge state. This is almost uniquely barium as any Xe++ ions will quickly convert to Xe+. One can also consider changing the charge state to Ba+ and using the well known laser techniques to form a unique identification.

Our present concept for the light collection is based on a design developed for the Fermilab RICH counter [5]. The electroluminescence region is separated from a parallel plate proportional counter filled with low pressure methane by a quartz plate. Light of 175 nm passing through the quartz strikes a CsI layer evaporated onto copper pads to produce electrons and hence the signal. There are many aspects of this new concept that need to be demonstrated before a full scale detector could be considered. We need to show that good energy resolution can be achieved in such a chamber. We need to learn what tracking information can be extracted. We wish to explore the use of mixed noble gases such as Ne-Xe which may offer improved tracking and barium location. We need to establish the efficiency for detecting barium ions. Finally, we need to establish the dependence of the measurements on parameters such as the pressure to optimize the detector design. To this end, two substantial prototype systems are being developed. One will study the detection of electrons in the MeV range using a detector similar to the concept discussed above at pressures up to 10 bar. The second will attempt to demonstrate the efficiency with which barium ions can be extracted and detected starting with ions produced in high pressure xenon.

References

[1] Danilov M, DeVoe R, Dolgolenko A, Giannini G, Gratta G, Picchi P, Piepke A, Pietropaolo A F, Vogel P, Vuilleumier J-L, Y-F. Wang Y-F, Zeldovich O 2000 Phys Lett 480 12-18.

[2] Vuilleumier J-L et al. 1993 Phys. Rev. D48 1009-20.

[3] Facina M 2004 Thesis Leuven.

[4] Nygren D 2007 NIM A581 632-42.

[5] Anderson DF, Kwan S, Peskov V 1992 Fermilab-conf-92/135.