ZEPLIN-I: a Single Phase Liquid Xe Detector for Dark Matter Search.

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Abstract

The UK Dark Matter Collaboration is developing a series of liquid Xe detectors to search for the hypothetical weakly interacting massive particles (WIMPs) which may comprise a significant component of the Galactic dark matter. These detectors will be operated at a depth of 1100 m in the Boulby salt mine. The first of these detectors, ZEPLIN-I is a 1.7 litre single phase liquid Xe scintillation detector which employs pulse shape discrimination analysis to distinguish nuclear recoils due to WIMPs from electron recoils from background gamma interactions.

The current status of ZEPLIN-I is presented in this paper. The detector design will be described and results discussed of tests on the detector performance using various types of radioactive sources in the 10 keV-1MeV energy range. The light yield at the level of 1 photoelectron per 1 keV of deposited energy has been achieved. Clear discrimination between gamma initiated electron recoils and neutron initiated nuclear recoils has been observed. The discrimination potential below 100 keV, and subsequent expected sensitivity to dark matter particles, will be outlined.

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SUMMARY

The UK Dark Matter Collaboration is running experiments which are currently based on NaI and CsI scintillating targets to search for the hypothetical weakly interacting massive particles (WIMPs) which may comprise a significant component of the Galactic dark matter [1]. These detectors are being operated at a depth of 1100 m in the Boulby mine. As an extension of the experimental program, a series of liquid Xe detectors are being developed. The first of these detectors, ZEPLIN-I is a single phase liquid Xe scintillation detector which employs pulse shape discrimination analysis to distinguish nuclear recoils due to WIMPs from electron recoils from background gamma interactions. Subsequent two phase (liquid + gas) Xe detectors ZEPLIN-II and ZEPLIN-III will use differences in the ratio of ionization to scintillation light to identify nuclear recoils.

In ZEPLIN-I about 1.7 litre of liquid Xe is contained in copper vessel and viewed from above by three photomultipliers (PMTs). Fig.1. shows a 3D-view of the ZEPLIN-I liquid Xe chamber.

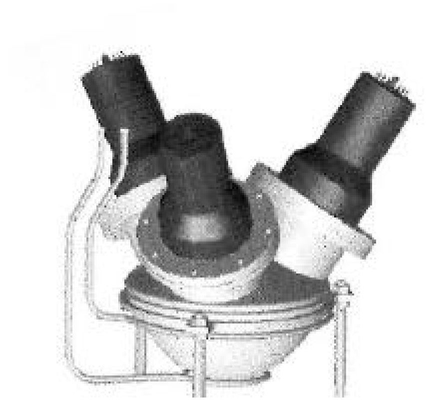

Fig.1. ZEPLIN-I liquid Xe chamber is shown without its vacuum jacket.

The internal surface of the chamber is lined with PTFE reflector to ensure, together with a specially selected shape of the chamber, better light collection. For the same reason we use PMTs with 3 inch photocathodes.

Since the desired sensitivity level for the detector is 0.01-0.1 events/kg/day, the background rate must be suppressed. Therefore all constructional materials of the chamber are selected to be of low radioactivity. In addition to that, creation of an active fiducial volume arises by using ‘turrets’ of Xe to separate the main Xe region from the PMTs and to provide shielding against X-rays from the PMT. Scintillation produced in the turret regions by X-rays from the closest PMT is seen predominantly by that photomultiplier. Hence the ratio of photons detected by each PMT can be used to reject turret events.

The chamber is filled with a purified gaseous Xe which is then liquified when the detector is cooled down to the temperature of minus (100-102)° C. This low temperature is provided by the refrigerator (Polycold 100) which chills the chamber by circulating its cold charge through cavities in the chamber body. The stability of temperature is controlled by the heater which warms up the refrigerator charge when the temperature is falling below the set value.

The PMT signals are measured individually using a fast digital oscilloscope LeCroy LC574A which is triggered when all 3 PMT signals are in coincidence. The oscilloscope is read out to the Macintosh computer which is running LabView data acquisition code. Eventually the digitized shape of PMT signals are stored in a file which can be analysed both on-line and off-line.

The detector is calibrated using various gamma sources (^{57}Co, ^{137}Cs, ^{22}Na and ^{60}Co). Calibration procedure is similar to the one for NaI(Tl) targets [2]. Firstly, the amplitude of the single photoelectron (SPE) peak is measured for each photomultiplier versus the PMT high voltage tension (HVT). Then the HVT value is selected to provide a 5 mV SPE signal for each PMT. Finally the light yield is calculated by measuring the position of the photo peak in the spectrum of the sum of all three PMT signals for a given gamma source. Fig.2. shows the ZEPLIN I light yield as obtained for various gamma sources.

It should be noted that the light yield of ZEPLIN-I increases at low energies (below 500 keV in our case). This behavior can probably be explained by the fact that in LXe the scintillation efficiency depends on the energy deposit density [3], although Monte Carlo analysis for different interaction positions within the target is underway.

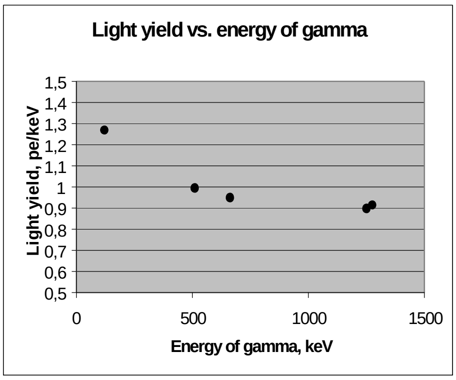

Fig.2. ZEPLIN-I light yield measured in photo electrons per 1 keV of deposited energy versus the energy of gamma.

As mentioned before, the signature of WIMP recoils in LXe is expected to be similar to that of neutrons, so calibrations with neutron sources may be used to assess the sensitivity for WIMP detection.

The chamber was illuminated by an Am-Be neutron source. The shape of PMT signals is analysed for both gammas and neutrons in the same energy bin, using the procedure described in [2].

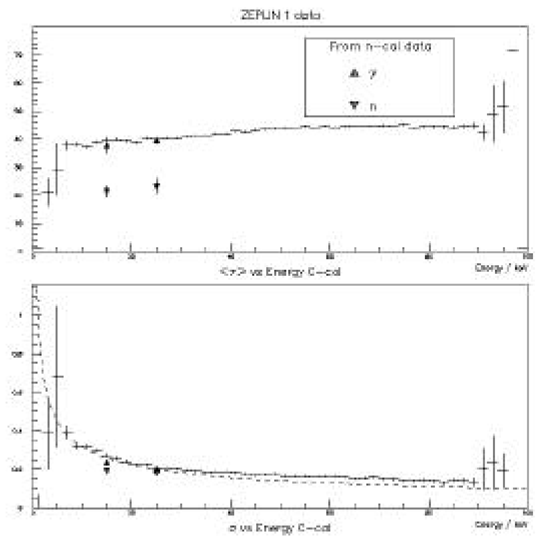

Fig.3. ZEPLIN-I pulse decay time τ in ns for gammas and neutorns versus their energy in keV (upper figure) together with the widths in ns of the τ –distribution (see [2] for details) versus energy – bottom figure. Triangles correspond to the data obtained from the neutron-source run while the crosses are from the gamma-source run.

A clear difference in pulse shape for neutrons and gammas has been observed. Fig.3 shows the pulse decay time for both gammas and neutrons versus their energy. As seen from the data, neutron pulses have about twice faster decay time compared to gammas. We are going to use this fact to recognize the type of interacting particle once the detector is installed underground in the Boulby mine.

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