LAAPD Performance Measurements in Liquid Xenon

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Abstract

Performance measurements of a 16mm diameter large area avalanche photodiode, using gamma rays, electrons and alpha particles, include quantum efficiency. Quantum Efficiency was measured with a 0 kV/cm drift field. A charge collection grid, to help measure charge collection efficiency, was placed between the cathode and LAAPD in the interest of the current R&D phase of the Xenon Dark Matter Project. The measured quantum efficiency of the LAAPD had an average value of 25%.

1 Introduction

The Xenon Dark Matter Project will use liquid and gas Xenon (LXe and GXe, respectively) to detect neutralinos predicted by the Minimal Supersymmetric extension of the Standard Model (MSSM). Direct and proportional scintillation is produced by various particles interacting with LXe and GXe producing direct and proportional scintillation light at 178 nm, vacuum ultraviolet (VUV) wavelength[1]. Simultaneous to light collection will be charge collection via a charge collection grid. Therefore, two important properties are sought in

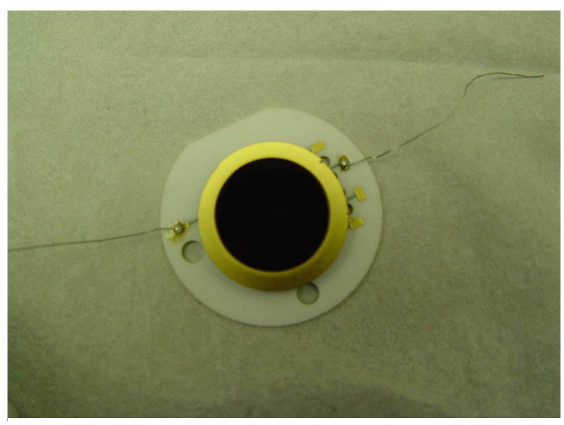

Fig. 1. 16mm diameter LAAPD from Advanced Photonix.

the light and charge detectors placed in the Xenon detector, Quantum Efficiency (QE) and Charge Collection Efficiency (CCE). Quantum Efficiency is defined as the number of electron-hole pairs produced by incident photons on a light collecting device divided by the total number of photons incident on that light detection device. Large Area Avalanche Photodiodes (LAAPD[1]) (Fig. 1) is reported to have a Quantum Efficiency equal to 100%[2] with incident light at λ=178 nm and with a temperature of 25°C. In this report we will measure the QE of a LAAPD at -100°C and with incident light at λ=178 nm. Also, the LAAPD has been exposed to air for about a year.

Charge collection efficiency is defined as the number of electrons detected by the charge collection grid divided by the number of electrons produced in a nuclear or electron recoil event in LXe. The Xenon Project can benefit greatly with light detection devices with a QE of 100% coupled with a high gain around 10^7 electrons. Currently, Photomultiplier Tubes (PMT) are the best candidate for light detection in Liquid Xenon with a QE of 27%, at λ=178nm, and a gain of 10^7 electrons.

1.1 Experimental Setup

Performance measurements were taken using the small LAAPD LXe chamber with a total volume of 0.22 L. The LAAPD was housed in a structure (Fig. 2) made of PTFE, also known as Teflon, which reflects VUV scintillation at 90%. First, measurements were taken using a Bi-207 source plate which emits gamma rays and electrons and then, a month later, an Am-241, alpha emitting, source plate replaced the Bismuth source plate. Bi-207 emits a 570 keV gamma ray and a 1 MeV electron, radioactively. The Am-241 emits a 5.5 MeV alpha particle, radioactively. The charge collection grid was installed 0.85 cm above the cathode. The anode grid was installed 0.3 cm above the charge collection grid and the LAAPD was installed 1.0 cm above the anode.

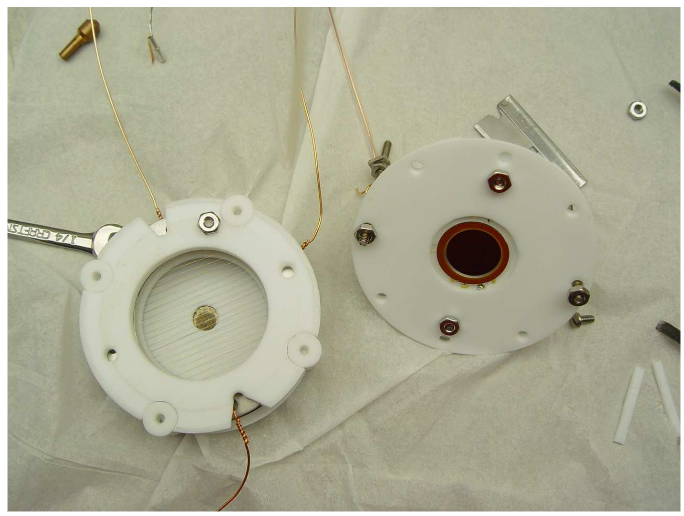

Fig. 2. Right- Teflon housing with LAAPD. Left- Charge Collection and Anode Grid in Teflon housing.

2 Experimental Procedures

Before each experiment the chamber was baked at 50ºC and the gas lines at 100ºC for 12-24 hours. This removed many contaminants, primarily N_2, H_2O, CO_2 and O_2, from the internal walls of the gas lines and chamber, deposited during its exposure to air during the installation of the detector components. After baking, out gassing measurements were made showing the pressure in our cryostat to be on the order of 10^5 Torr. This value tells us the baking removed a significant portion of the deposits on the inner walls. A 1024 channel MultiChannel Analyzer (MCA) was connected to convert data from the Amplifier. A pre-amplifier was used to filter the pulses coming from the LAAPD which was connected to an amplifier with a gain of 200, shaping pulse of 0.25 μs, rise time of 0.2 μs and a fall time of 0.2 ms.

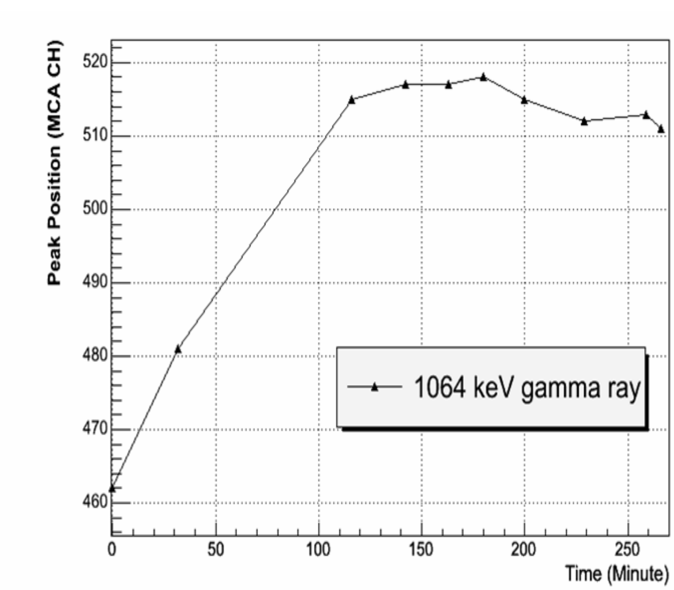

Figure 3. Increasing signal strength as a function of recirculation time.

The chamber was cooled using an alcohol bath with a temperature of -100ºC. A periodic addition of Liquid Nitrogen (LN_2) to the alcohol bath kept the Xenon in the chamber in the liquid phase. Light and charge spectrums were taken after the chamber's temperature stabilized after each addition of LN_2.

2.1 Operational Tests

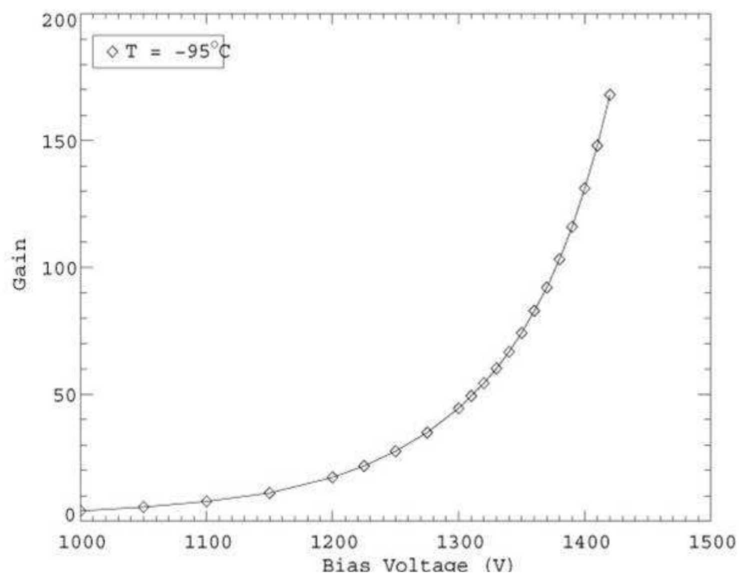

Figure 4. Gain versus bias voltage on LAAPD.

The equipment setup was tested by making some simple measurements to evaluate the purification of the Xenon and cleaning capabilities of the Getter and the internal connections of the LAAPD and charge collection grid. The charge signal was measured to increase as a function of recirculation time (Fig. 3.) which tells us the Getter and charge collection grid were

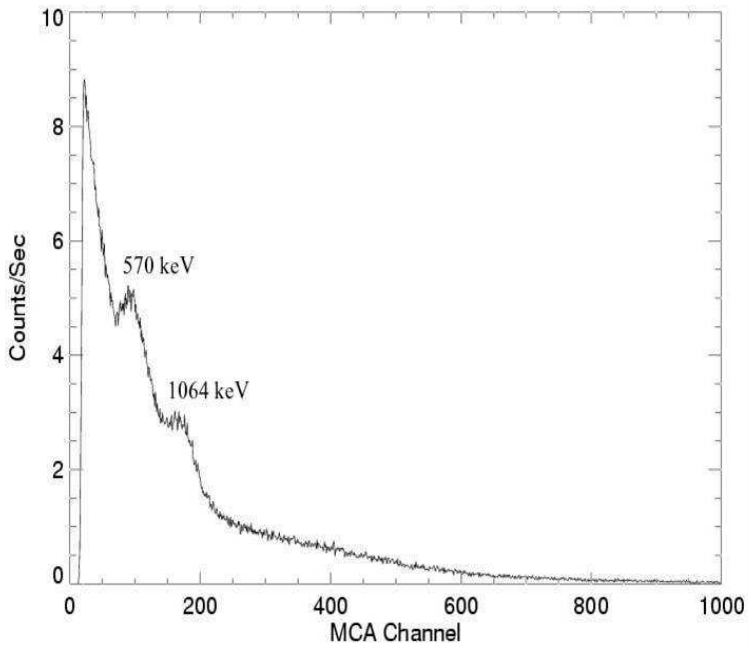

Figure 5. Typical light spectrum from Bi-207.

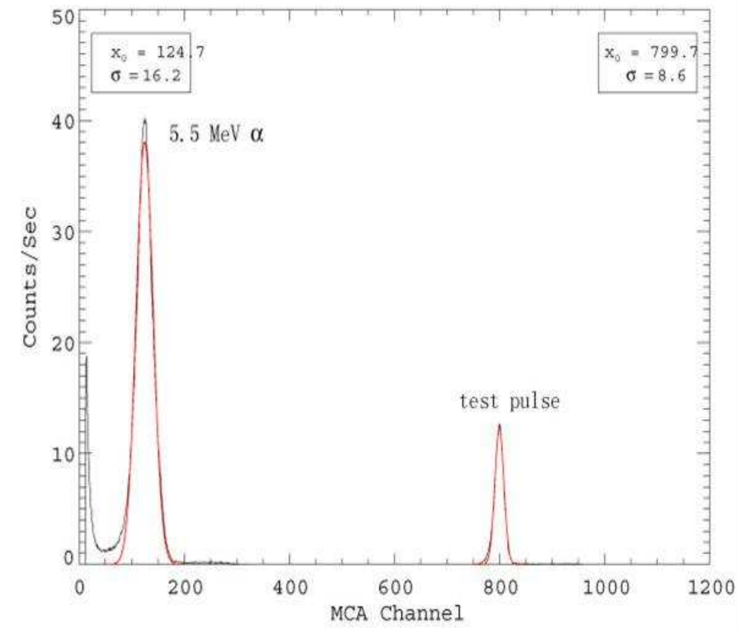

Figure 6. Typical light spectrum from the Am-241 source.

operating successfully. The charge amplitude increased by 11% over a 2 hour period of recirculation. To test the functionality of the LAAPD, gain was measured with increasing bias voltages. (Fig.4)

3 Experimental Data

3.1 Quantum Efficiency

To submerge the LAAPD in LXe takes 45-60 minutes of filling with GXe. Once the LAAPD was fully submerged in LXe, light spectrums were taken with the gamma and electron events from the Bi-207 source and later, with alpha particles from Am-241. A typical light spectrum of Bi-207 and Am-241 can be seen in Figures 5 and 6, respectively. Spectrums were obtained with the chamber pressure between 2 and 3 atm. The temperature and pressure in the chamber during the attainment of all light and charge spectrums was held relatively stable. Changes in pressure were less than 0.2 atm during the attainment of each spectrum. This held true for all measurements unless we measured a property as a function of temperature.

3.1.1 QE Measurement with Bi-207 and Am-241

After the chamber was filled with LXe, the MCA was used to obtain the light spectrum from the LAAPD's signal from scintillation. QE was calculated by measuring the channel number of each peak in the spectrum, namely the peaks from the Bi-207 source and the peak from the Am-241 source. The median of each peak was found which corresponded to a particular channel number. This channel was recorded and used in the equation below to calculate QE. The QE can be expressed by measurable parameters in the following expressions

$$QE = (N_e/g)(1/N\gamma) \quad (5)$$

$$QE = 23\% \ \text{(average)} \quad (6)$$

where N_e is the number of photoelectrons detected by the MCA, g is the reported gain which is equal to 158 electrons, and Nγ is the total number of incident photons on the LAAPD. The LAAPD's bias voltage was slowly increased to 1400V at which point it was kept stable to obtain charge spectra.

Calculating the QE for the Am-241 source was found in a similar manner but with a different Nγ. The average value was QE=27%.

3.2 Charge Collection Efficiency

CCE was found by applying a 1 kV/cm drift field between the cathode and anode in the same experimental setup described above. The applied field causes the electrons released from gamma, electron and alpha interactions to drift vertically to the charge collection grid. Due to the applied field, amplifier settings had to be adjusted.

3.2.1 CCE measurement with Bi-207 and Am-241

Calculating charge collection efficiency depends on the number of electrons that are counted by the MCA divided by the number of electrons created in a gamma, electron or alpha event process. The CCE can be calculated by the following expression

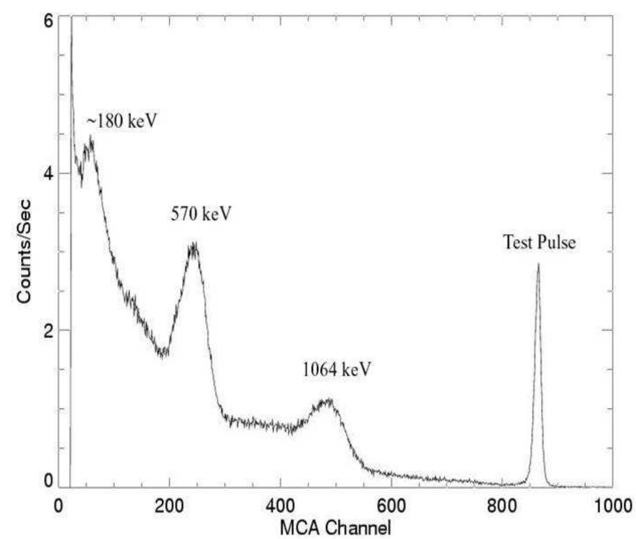

Figure 7. Typical charge spectrum from Bi-207.

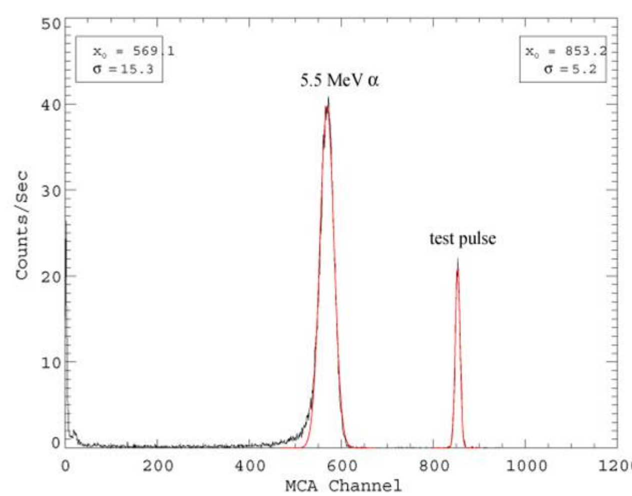

Figure 8. Typical charge spectrum from Am-241.

$$CCE = N_D/N\gamma \quad (7)$$

$$CCE = 70\% \text{ (average, Bi)} \quad (8)$$

4 Conclusion

Quantum Efficiency was found to be an average 27% from the Bi-207 source and 23% from the Am-241 source. Charge collection efficiency was found to be 70% for the Bi-207 source and 1.8% for the Am-241 source, both with an applied 1kV/cm drift field.

Reasons for not achieving the reported 100% QE include the LAAPD's exposure to air, unprotected, for about a year. Water molecules from the air are absorbed in the surface of the LAAPD and prohibit electron-hole pair production from incident VUV photons, thereby decreasing QE.

This particular LAAPD would not enhance the Xenon Project's light detection capabilities due to its relatively poor QE and very low gain compared to current PMTs. If the QE were measured at 100%, the gain is still too low to be competitive with current PMT's.

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[2] J. A. M. Lopes, J. M. F. dos Santos, R. E. Morgado, and C. A. N. Conde, "A Xenon Gas Proportional Scintillation Counter with a UV-Sensitive Large-Area Avalanche Photodiode", IEEE Trans. Nucl. Sci., vol. 48, pp.312-319, 2001.
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