Electron paramagnetic resonance analysis of plastic scintillators for the Tile Calorimeter of the ATLAS detector

Chad Pelwan

University of Witwatersrand, *School of Physics*, P242

E-mail: chad.pelwan@gmail.com

Abstract. In an attempt to understand the effects of ionizing radiation on various plastic scintillators, a number of studies are currently in progress with a hope that favourable properties of plastic scintillators, such as high light output and fast decay time, can be optimized. The Tile Calorimeter (TileCal) is a hadronic calorimeter able to detect hadrons, leptons and other energetic subatomic particles. In this investigation, polyvinyl toluene based plastic scintillators and a polystyrene based plastic scintillator, identical to those situated on the TileCal of the ATLAS detector at CERN, were irradiated and sent to the University of Witwatersrand where they were prepared for electron paramagnetic resonance (EPR) analysis. EPR spectroscopy allows for the study of unpaired electrons within these scintillators and offers a deeper insight into the organic or inorganic free radicals present. This technique was used to validate the assumption that dangling bonds in the plastics were as a result of ionizing radiation damage caused in the irradiation phase. This was done by detecting the existence of paramagnetic centres and, in addition, magnetic properties of these centres could be characterized. Three polyvinyl toluene Eljen scintillator plastics, EJ200, EJ208, and EJ260 were used in this investigation as well as one polystyrene Dubna sample. These samples were irradiated at the iThemba LABS, Gauteng. Experimental results thus far show a difference in the signal detected for irradiated samples compared to un-irradiated ones, and that a higher radiation dose produces varying EPR results for the Eljen and Dubna samples. It was also observed that other ions are detected after irradiation and that, over time, certain bonds would re-form within the plastics. Further investigation is required to understand this effect. Over all, the results from the EPR analysis form a small, yet vital, contribution into understanding the various effects of ionizing radiation in plastic scintillators.

Introduction

The Tie Calorimeter (TileCal) is a hadronic calorimeter designed to measure high energy positron jets, τ leptons and other subatomic particles like gluons and quarks that result from two proton collisions. The TileCal is situated within the ATLAS detector; a larger detector made of several sub-detectors. The ATLAS detector, shown in figure 1, is 44 meters in width and 22 meters in diameter. It is the largest of four detectors within the Large Hadron Collider (LHC) which is 27 kilometres in circumference and is 100 meters underground between the boarders of Switzerland and France [1].

The TilCal consists of plastic scintillators that are able to relay information about the incident particle on them by emitting light. This light is then passed to photo-multiplier tubes (PMTs) which digitizes this signal. However, these plastic scintillators are bombarded with ionizing particles and γ-rays that cause radiation damage to the scintillators affecting their efficiency [2]. In order to understand how the radiation damage effects the plastics on a molecular scale, electron paramagnetic resonance (EPR) is used. EPR is a type of spectroscopy used to study molecules or atoms with unpaired electrons. The phase two upgrade in currently in progress for the TileCal and looks to replace the plastic scintillators situated in the gap region of the TileCal. Hopefully, EPR studies can shed light on which plastic scintillator is best suited for this. In the paper we present EPR results obtained from irradiated and un-irradiated polyvinyl toluene based scintillator samples: EJ200, EJ208 and EJ260 produced by Eljen technologies as well as the Dubna sample identical to that located in the TileCal produced by Dubna.

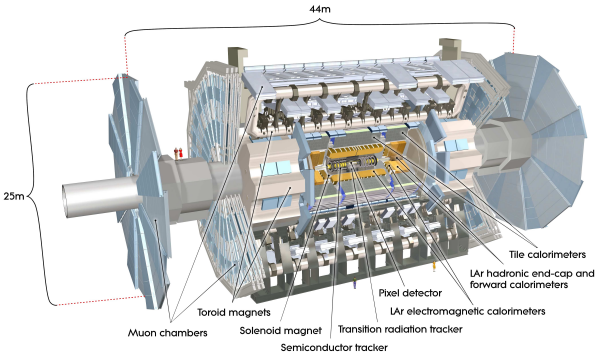

Figure 1. Schematic of the ATLAS detector

Materials

Since plastic scintillators in the TileCal mainly undergo ionization from the incident particles, there was a need to replicate this in order to study how radiation damage effects the plastic scintillators. The tandem accelerator at iThemba LABS, Gauteng was instrumental in the replication of this damage as it accelerated protons to an energy of 6 MeV which, in turn, were incident on the plastic scintillators. In order for the protons to impart energy to the plastic scintillators mainly through ionization, each plastic scintillator was cut and polished to a width less than the stopping range of the 6 MeV protons in both polystyrene and polyvinyl based plastics. SRIM (Stopping Range of Ions in Materials) is a computational method employed to find this range which was around 470 μm. Thus, each plastic scintillator sample was machined to a width of 250μm and volume of 250μm $\times$ 500μm $\times$ 500μm. The SRIM computations also found that the average energy of each proton was approximately 2.07 MeV. This result was used when calculating the dose each sample was irradiated to. Samples were irradiated to two doses: 0.164 MGy and 1.46 MGy, and an un-irradiated sample was used as a control.

Methodology

Electron paramagnetic resonance (EPR) measurements were performed on the plastic scintillators by placing them in a strong magnetic field while monochromatic electromagnetic (EM) radiation is applied; this is usually within the microwave region. If there are unpaired electrons in the plastic scintillators, they will absorb a small range of EM radiation which is detectable. We have made the assumption that ionizing radiation would cause bonds to break within the plastic scintillators forming free electrons and ions which are detectable by the EPR spectrometer. Experiments were performed at room temperature at the University of Witwatersrand in the NMR LAB using the Bruker ESP 380e spectrometer.

Results

Results in figure 2 show that paramagnetic centres are found in the polystyrene samples before irradiation (left image). A similar result was seen in the other Eljen samples. The intensity of

the absorption peak derivative also gives an indication as to how many paramagnetic centres can be found. In order to directly compare the samples, a mass normalisation is usually necessary, however there was no need for it as the samples all have the same volume and density. After irradiation (right image), the peak intensity of the absorption peak derivative decreased in the Eljen samples.

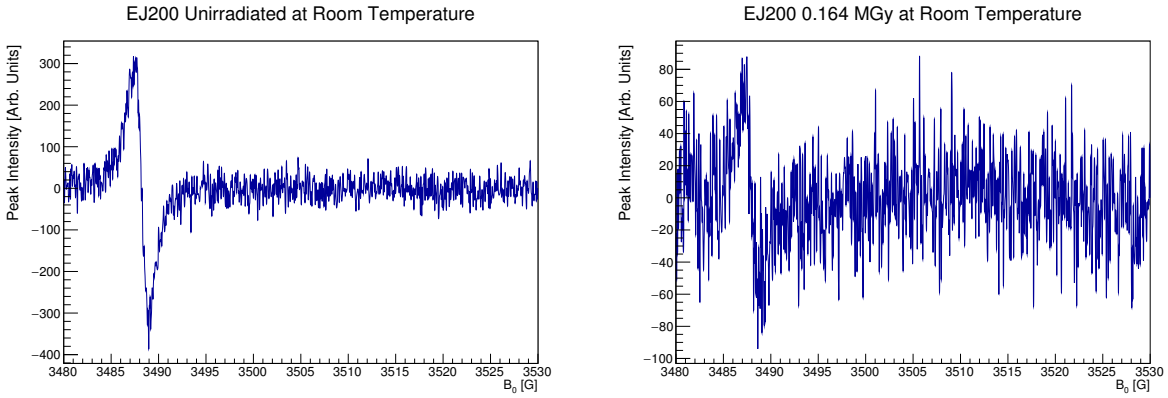

Figure 2. Comparison of an unirradiated EJ200 sample (left) and an irradiated sample at a dose of 0.164 MGy (right)

The left image in figure 3 also indicates that there are paramagnetic centres in the polystyrene based Dubna sample before irradiation. It was noted that,in general, the absorption peak intensity derivative was lower for the Dubna sample than the Eljen samples. However, the right image in figure 3 clearly shows an increase in the intensity after the samples were irradiated. Therefore more paramagnetic centres can be found the Dubna sample after irradiation.

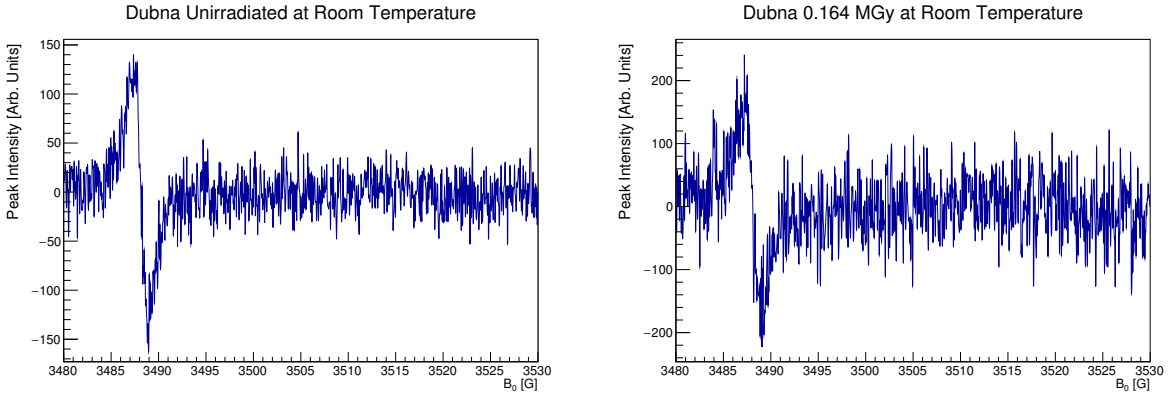

Figure 3. Comparison of an unirradiated Dubna sample (left) and an irradiated sample at a dose of 0.164 MGy (right)

In both cases, the signal to noise ratio increases with the increase of dose; measurements will be performed at cryogenic temperatures which would focus on the unpaired electrons and decrease the noise in the spectra. It has also been hypothesised that bonds within the samples could reform overtime when the unpaired electrons reform bonds or bond with ions in the material [3].

Conclusion

From this investigation it was found that exposure to proton irradiation causes structural damage to both the polystyrene and the polyvinyl toluene plastic scintillators studied. Further analysis of the data can now be done to investigate exactly which bonds break as a direct result of radiation damage. It was also observed that an increase in dose varied the number of unpaired electrons within the different samples but over time many of these bonds would reform.

References

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[3] K. Wick, U. Holm. Radiation Stability of Plastic Scintillators and Wave Length Shifters. *IEEE Tans. Nucl. Sci.*, 1:163, 1989