Beam related radiation damage in Radϕ

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Abstract

Beam related radiation damage observed during the last Radϕ (JLab E94-016) run is discussed. It is shown the damage causes a gradual degradation in response of calorimeter elements near the beam hole and is therefore unlikely to be caused by anomalous beam conditions. The damage rate is quantified and the effect of curing with UV light is discussed.

1 Introduction

JLab experiment E94-016 (Radϕ) uses a lead glass calorimeter (LGD) in a high intensity photon beam. The intensity of this beam is similar to intensities anticipated for HALL D, that is, 5×10^7 photons per second in the energy range between 75% and 95% of the electron beam energy. Thus, experience with this calorimeter is directly applicable to the HALL D environment. This note discusses the effects of radiation damage to the calorimeter cells adjacent to the beam hole.

2 The problem

The LGD consisted of a 28×28 square stack of lead glass blocks with the central 4 blocks removed to allow passage of the photon beam. The beam was created by brehmstralung from a 70 nA, 5.5 GeV electron beam incident on a thin ($\approx 6 \times 10^{-4}$ radiation length) gold foil radiator. Located about 5 meters from the radiator was a 1 *mm* nickel collimator. A one inch beryllium target 40 meters from the radiator and one meter from the front face of the LGD was used.

Online monitoring of the LGD indicated that the 8 blocks immediately adjacent to the beam hole were becoming inefficient as the run progressed. During a downtime, visual inspection of one of the blocks indicated the glass was darkening, an effect of radiation damage.

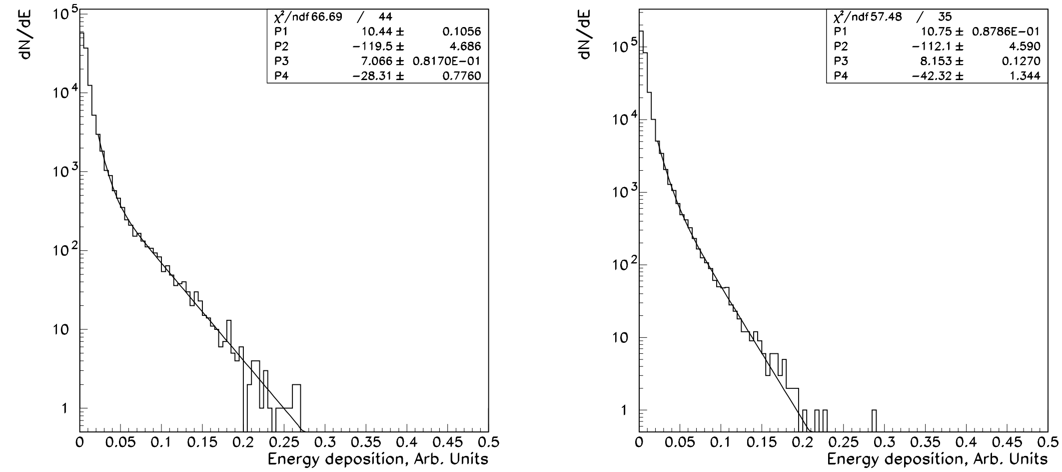

Figure 1: The distribution of deposited energy in a LGD block adjacent to the beam hole at the beginning of the run (left) and after 300 hours of high intensity running (right). The degradation of gain is apparent. The fit is to a sum of two exponentials and is used to quantify the extent and rate of the damage.

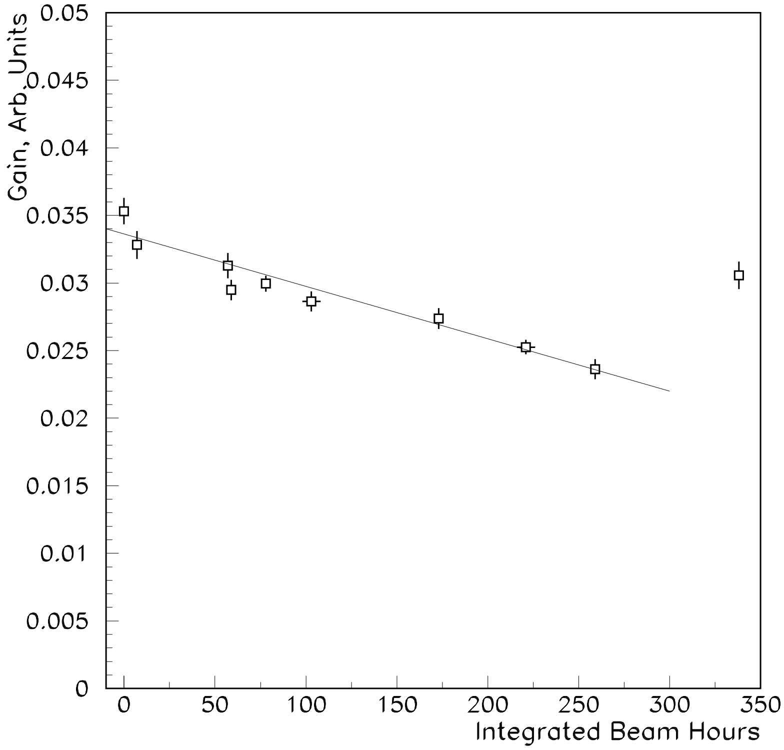

Figure 2: The relative gain of a block adjacent to the beam hole as a function of hours of exposure to the high intensity beam environment. A gradual degradation is apparent. Other blocks bordering the beam hole show similar behavior.

The energy deposition distribution for one of these blocks from early and late in the run is shown in figure 1. These spectra were characterized by the form

$$\frac{dN}{dE} = A \exp{(-k_1 E)} + B \exp{(-k_2 E)}. \tag{1}$$

One term (the more steeply falling) characterizes the shape of the pedestal and is not interesting for this study. Assuming the mechanisms that deposit energy in a given block do not change as a function of time, the other term in eqn. 1 can be used to characterize the gain of the module, $1/k$ being proportional to the gain of the module.

Figure 2 shows the behavior of $1/k$ as a function of the amount of time the detector had been exposed to the high rate beam environment. It is clear from this figure that the damage is a gradual, cumulative effect rather than a sudden change that could be attributed to a beam mis-steering event. Other blocks adjacent to the beam hole showed similar behavior.

3 The solution

The change in gain associated with this radiation damage is about 40%. Changes of gain this small can be compensated for by adjusting the photomultiplier high voltage. This was done and the last point in figure 2 shows the effect of this voltage adjustment.

Adjusting the channel high voltage is only a partial solution to the problem. The module still suffers from a loss of produced photoelectrons leading to a degraded resolution, in this case about 20% since the resolution varies as the square root of the number of produced photoelectrons. It is therefore desirable to reverse the effect of radiation damage, if possible.

It is well known that radiation damage in lead glass is temporary, that is, it will simply go away after a sufficiently long time. The time scale is of order months but can be dramatically accelerated using UV light. During an extended downtime this approach was taken and found to partially reverse the effects of radiation damage. The phototube and base were removed from the module and a UV light guide attached to a quartz envelope Mercury vapor lamp was inserted. The effected modules were illuminated for periods of 6-8 hours. The analysis presented above was repeated for runs taken immediately before and after the treatment. The gain was increased by a factor of 1.3 for the treated modules, nearly recovering the initial gain of the modules.

Comparison of the response of the modules to the laser monitor system is another measure of the effect of curing. Monitor data from before and after the treatment was compared. It was found that the average monitor signal increased by a factor of two after treatment. The difference between this increase and the increase determined by the energy spectrum can be understood (qualitatively) by observing that the laser illuminates the front of the block and thus measures the transmission of the entire block. Signal events, to a good approximation, create Cerenkov light some depth into the block and therefore measure only the transmission of some later part of the block. If the radiation damage is concentrated towards the front of the block, the observed difference in gain change is understood. The fact that the radiation damage is concentrated in the front part of the blocks has been confirmed by visual inspection.

4 Extrapolation to HALL D

The damage observed was caused by charged particles and photons interacting with the lead glass. There are two possible sources of these particles, a beam "halo" and the target.

The target to LGD distance will be approximately five meters in HALL D. This leads to a reduction in flux by a factor of 25 into a given LGD block provided the block is at an equivalent angle from the beam. The larger target to LGD distance places blocks at a smaller angular separation from the beam where the flux is larger. These effects approximately cancel at fixed beam energy but increasing the beam energy can be expected to reduce the angular spread of particles from the target. These arguments indicate the flux from the target could be expected to be smaller in HALL D than in Radϕ but detailed simulations are required to be quantitative.

The collimation to be used in HALL D is much more severe than that used in Radϕ. A large coherent enhancement is expected reducing the lower energy component of the beam. This leads to the expectation that beam halo will be reduced in HALL D. Again, quantitative conclusions must await detailed simulation.