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# Addition of Photosensitive Dopants to the DØ Liquid Argon Calorimeter

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The addition of photosensitive dopants to liquid argon greatly enhances the signal from heavily ionizing particles. Since binding energy losses are correlated with the heavily ionizing component in hadronic showers, the addition of photosensitive dopants has been suggested as a mechanism to tune the  $e/\pi$  ratio in liquid argon calorimeters. A measurement was performed at the FNAL test beam, adding 4 ppm tetramethylgermanium to the DØ uranium-liquid argon calorimeter. An increase in response for electromagnetic and hadronic showers was observed, with no net change in the  $e/\pi$  ratio.

## 1 Introduction

The addition of photosensitive dopants to liquid argon as a means of converting the light from recombination and scintillation

into collectable charge was first suggested and demonstrated by Anderson [1]. Several photosensitive dopants have been introduced which give improved pulse height for alpha particles [2] and confirmed by others [3]. Some of the dopants have also been shown to increase the energy resolution for alpha particles as well as give modest increases in electron mobility [2,4].

The binding energy losses in a hadronic shower are correlated with the heavy ionizing component in a calorimeter [5]. It has also been shown by tests made with the NA 34 uranium-liquid argon calorimeter at CERN that the  $e/\pi$  ratio is sensitive to saturation effects of the readout [6]. Since the addition of photosensitive dopants greatly reduces saturation effects, it was suggested that the effect on the  $e/\pi$  ratio be tested [7].

A major component of the DØ experiment, now running at the FNAL Tevatron collider, is a fine-grained, hermetic calorime-

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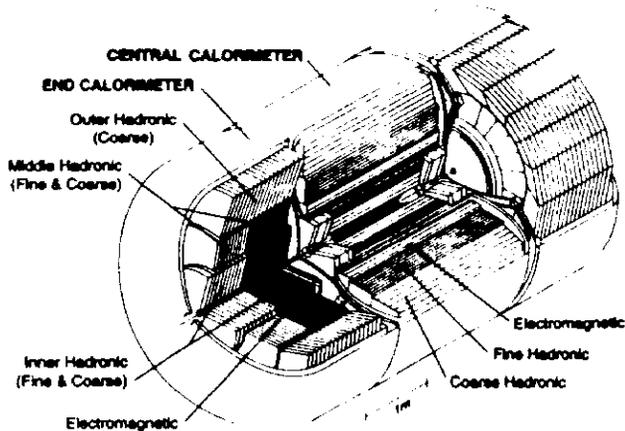


Figure 1: Schematic overview of the DØ Liquid Argon Calorimeter.

ter based on liquid argon with uranium absorber plates [8]. The DØ calorimeter is subdivided into a central and two endcap regions, each of which is composed of electromagnetic and hadronic modules, seen in fig. 1. Both the central and endcap regions were independently calibrated at the FNAL test beam with electrons, muons and pions up to 150 GeV/c.

During the test-beam calibration, several measurements were made on the effects of oxygen and nitrogen on the performance of the calorimeter. The effect of tetramethylgermanium, TMG, a photosensitive dopant, was also tested. The results of the photosensitive dopant on the calorimeter are presented below.

## 2 Additive Studies at the DØ Test Beam

Part of the overall calibration of the DØ calorimeter included a program for studying its response to liquid argon contaminants. During the 1991 test beam run, both dopant and contaminant studies were per-

Table 1: Additives/Dopants Injected

Dec 10, 1991	0.75 ppm O <sub>2</sub>
Dec 15, 1991	0.75 ppm O <sub>2</sub>
Dec 17, 1991	4.0 ppm N <sub>2</sub>
Dec 19, 1991	4.0 ppm TMG
Dec 27, 1991	100 ppm N <sub>2</sub>

formed, and the calorimeter response was tracked and correlated with the response of alpha and beta cells located throughout the cryostat. These cells consisted of a source, either  $\alpha$ -Am<sup>241</sup> or  $\beta$ -Ru<sup>106</sup>, electroplated on the sense plane, separated from the HV plane by a liquid argon gap [9]. The gap thickness of 2.3 mm matched that of the calorimeter.

During the run, prior to these studies, the liquid argon purity had remained stable to better than 0.04 ppm oxygen equivalent. Contamination studies centered around known impurities, such as air, or accidental sources, such as a leak in the liquid-nitrogen cooling line. The addition of TMG dramatically changes the relative response between heavily and minimally ionizing particles. The additives introduced to the liquid argon cryostat are tabulated in temporal order in Table 1. Note that the dopants were added without changing argon, and thus the effects on the calorimeter will be cumulative.

## 3 Experimental Techniques

A mixing procedure, common to both dopants and contaminants, was used to insure thorough dispersion of additives throughout the cryostat. Of particular concern was that material would freeze-out on the cooling coils in the calorimeter cryostat and for that reason the injections were made in the liquid phase, already well mixed with liquid argon.

During a run, the alpha and beta cells were continuously monitored to track mixing and to establish the liquid argon response to heavily and minimally ionizing radiation. High statistics energy scans were taken with both electron and pion beams. Nominal beam momenta included 10, 25, 50, 75, 100, 125 and 150 GeV/c points. In addition to energy scans, high voltage scans were taken at 5, 10 and 100 GeV/c with electrons and pions. Upstream Čerenkov counters were used to tag electrons and scintillators downstream of the calorimeter were used to tag muons. Proportional wire chambers allowed tracking for precise calculation of the impact point in the calorimeter and for momentum reconstruction.

## 4 Analysis

All data were corrected for pedestals and gains and summed in regions of  $\delta\eta \times \delta\phi$  bins of  $1.5 \times 1.5$ . Far tighter cuts were possible for the narrower electron showers, but for the purpose of careful comparisons between the two particle types, identical regions were used. Čerenkov cuts and muon counter cuts were used for particle-id rejection. Energies were corrected, based on the reconstructed track momentum, for shifts from nominal beam value. A measured spread of  $\sim 1\%$  was observed in the distribution of beam momenta.

The response of the alpha cell is shown in fig. 2. The two additions of 0.75 ppm of  $O_2$  are clearly demarcated as step functions in the value of the alpha response. The 4 ppm of nitrogen, added on the 17th, is barely visible, but the 4 ppm of TMG shows a marked increase in the value of the alpha cells. Saturation of the preamps occurred several hours after initial injection for the 3 kV alpha response.

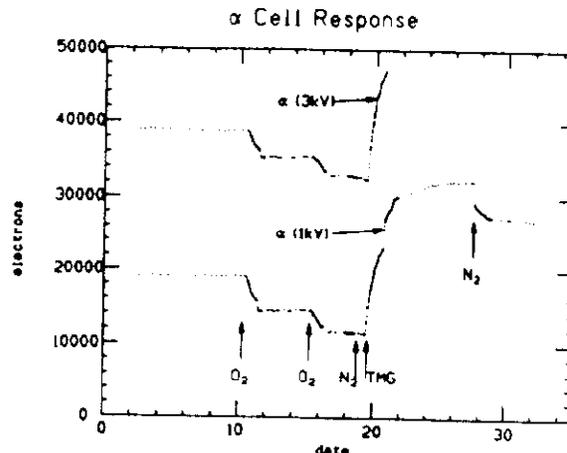


Figure 2: Response of the  $\alpha$ -cell at 1 kV and 3 kV versus time. The introduction of  $O_2$ , TMG and  $N_2$  are clearly visible.

The purity cells are exposed to the cryostat volume through two small ports in the cell walls, and therefore respond much less quickly to the addition of contaminants than the calorimeter. As noted in fig. 2, the mixing time in these cells was on the order of a day. No calorimeter data was taking during this mixing period.

Although the alpha cells saturated at 3 kV with TMG, it is possible to reconstruct their values from the 1 kV curve. A simple relationship exists between the 3 kV and 1 kV alpha response, shown in fig. 3. A bifurcated curve emerged when the two voltages were plotted against one another. The lower line, which contains points during the period when oxygen was added, is representative of attachment-like behavior, while the upper curve, from the addition of TMG, is clearly recombination-like. From this curve, it was possible to extrapolate the response for heavily ionizing particles to the nominal working voltage of the calorimeter (2.5 kV).

The beta cell response, shown in fig. 4, also shows a step-like change in response with the addition of  $O_2$ , TMG and  $N_2$ . As expected,

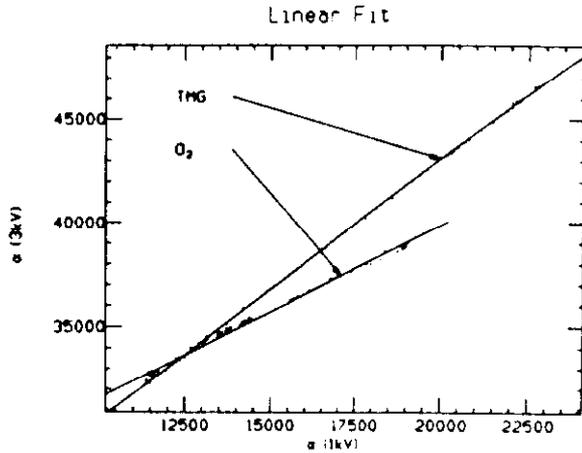


Figure 3: Relative response of the  $\alpha$ -cell at 3 kV to that at 1 kV.

the magnitude of these changes is far less sensitive than that of the alpha cells. The curve shown in fig. 4 was taken at 2.5 kV.

To compare the change in calorimeter response to that observed in the alpha and beta cells, pulse height spectra were fitted with a modified Gaussian to extract the mean and standard deviation [10]. A typical fit is shown in fig. 5 and the response is shown in fig. 6 as a function of incident beam momentum. Data in this figure were fitted to a line; the two best fits are shown for undoped argon and after TMG addition. The fitted value of the slope, as a function of additive, measures the response of the calorimeter. These are plotted in figs. 7a and 7b for electrons and hadrons respectively. For ease of comparison, only the relative slopes are plotted, arbitrarily normalized to be unity with TMG.

We make a simple two component model, with the calorimeter response a linear combination of heavily and minimally ionizing components. Using this model, a fit was made to extract the heavily ionizing fraction in a shower. The data in figs. 7a and 7b were

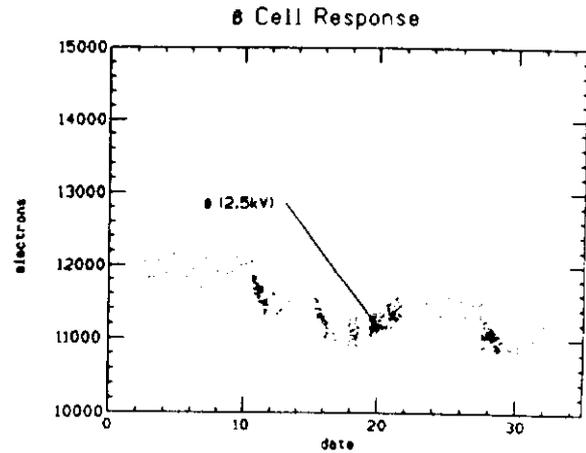


Figure 4: Response of the  $\beta$ -cell at 2.5 kV, the nominal working voltage of the calorimeter.

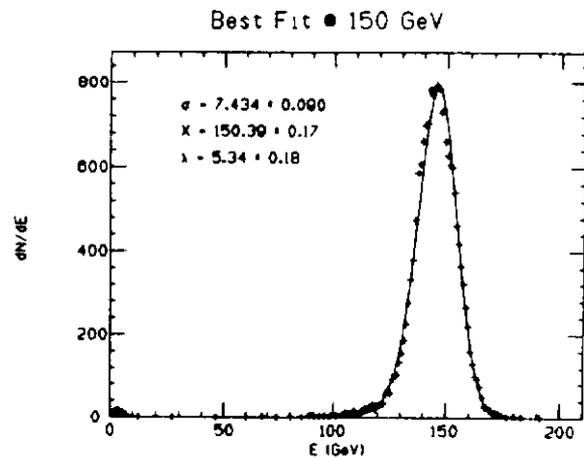


Figure 5: Typical energy spectrum for hadrons at 150 GeV/c plus best fit curve.

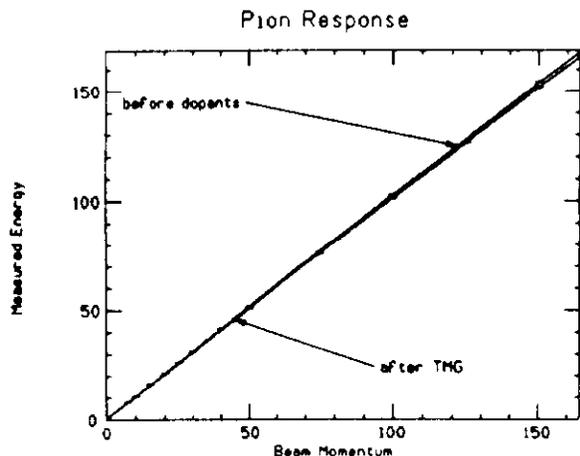


Figure 6: Response of the calorimeter versus incident momentum for undoped argon and after TMG addition.

fitted to the function,

$$f = \epsilon \alpha + (1 - \epsilon) \beta \quad (1)$$

where  $\alpha$ ,  $\beta$  represents the value of the alpha, beta cell as a function of dopant. Here, the alpha curve was taken as half the value plotted in fig. 2, since the source of heavy ionization should be uniformly distributed across the gap and hence contributes half as much to the current. The histograms in figs. 7a and 7b show the best fits to equation 1. Surprisingly, the heavily ionizing fraction is small for both electrons and hadrons,  $0.03 \pm 0.01$  and  $0.02 \pm 0.01$  respectively. The fact that these two numbers are so similar implies that the change in  $e$  response and  $\pi$  response with the addition of TMG will be the same, within errors. This is observed in figs. 7a and 7b, where both increase roughly 5% after adding TMG. No change in the  $e/\pi$  ratio is observed. It should be noted that an increase of 5% for electrons with the addition of TMG is only about half of the expected increase [2,7] and probably reflects the effects of the 1.5 ppm  $O_2$  and 4 ppm  $N_2$  in the liquid argon.

In similar fashion, the high voltage scans

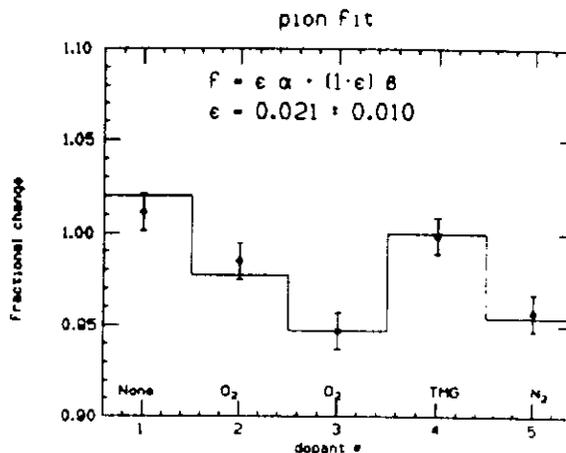
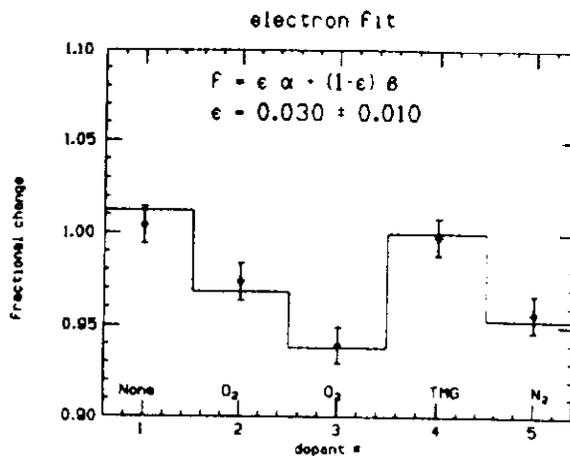


Figure 7: Relative response with additive for a.) electrons, b.) pions

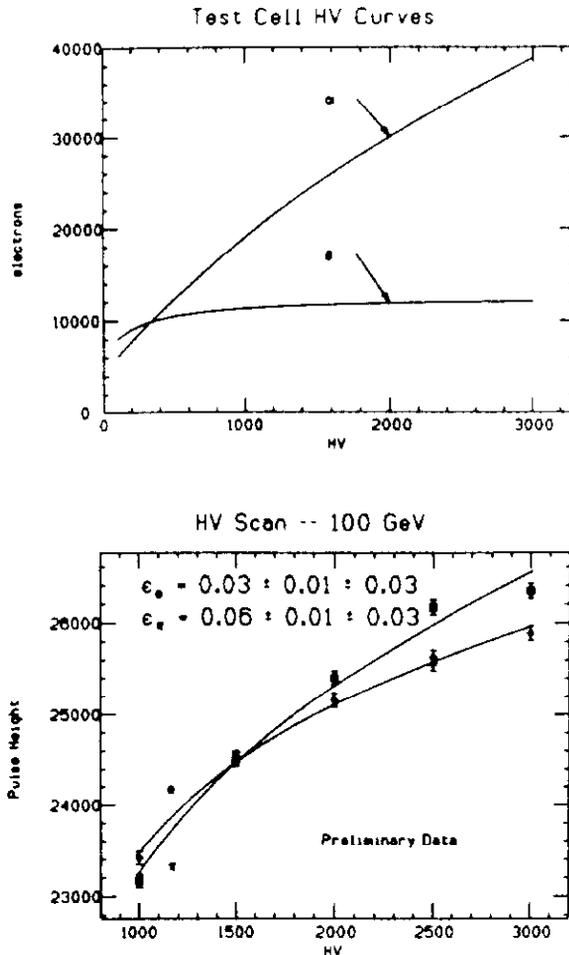


Figure 8: High voltage scan at 100 GeV/c for electrons and pions.

may be fitted [11] to equation 1. In this case,  $\alpha$  ( $\beta$ ) represents the alpha (beta) cell response as a function of voltage. Typical plateau curves for the  $\alpha$  and  $\beta$  cells are shown, up to 3 kV, in fig. 8a. The data plus best fit curves are shown in fig. 8b. Again, the heavily ionizing fraction is small,  $0.03 \pm 0.01 \pm 0.03$  and  $0.06 \pm 0.01 \pm 0.03$  for electrons and hadrons respectively. Here, statistical errors were 0.01, while systematic errors of 0.03 were estimated based on the stability of the measured values of  $\epsilon$  with the HV region fit.

A change in the  $e/\pi$  ratio in a hadronic calorimeter should be manifest as a change in the constant term in the energy resolution [5]. The hadronic resolution of the DØ calorimeter is shown for undoped argon in fig. 9a and after TMG was added in fig. 9b. As seen, no change in the ratio of the detector resolution ( $\sigma$ ) to detector response ( $\mu$ ) was observed. The fitted curve superimposed on both figures is the best fit to the undoped data. Here, a change in the measured constant term of 3.3 % to zero would change the value of  $\sigma/\mu$  from 0.050 to 0.037, easily visible in fig. 9b.

## 5 Conclusion

No discernable difference was observed between the changes in electron and pion response by adding TMG to the DØ liquid argon calorimeter. Measurements of the heavily ionizing fraction of high energy electron and hadron showers indicates that both are small and very similar in magnitude. With these small numbers, there is very little latitude for a significant  $e/\pi$  change. Further evidence is established by the lack of improvement in the calorimeter hadronic resolution.

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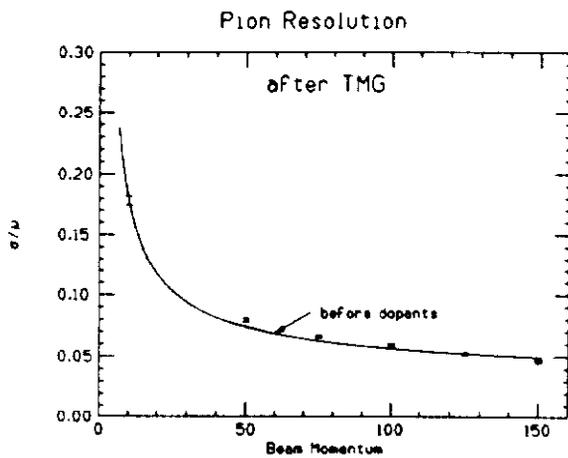
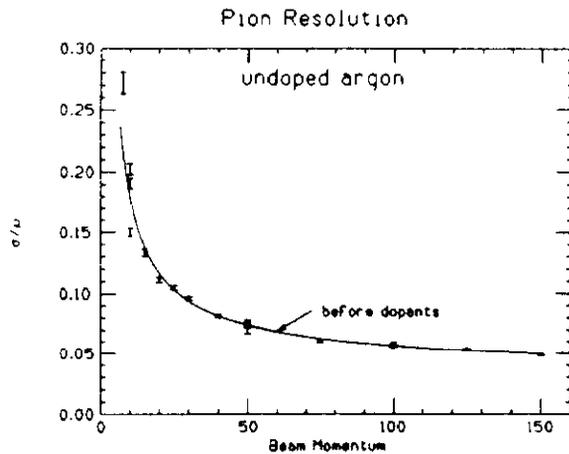


Figure 9: Hadronic energy resolution with a) undoped argon and b) after TMG

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