Fermi National Accelerator Laboratory

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Performance of a Lead Radiator, Gas Tube Calorimeter *

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PERFORMANCE OF A LEAD RADIATOR, GAS TUBE CALORIMETER

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Summary

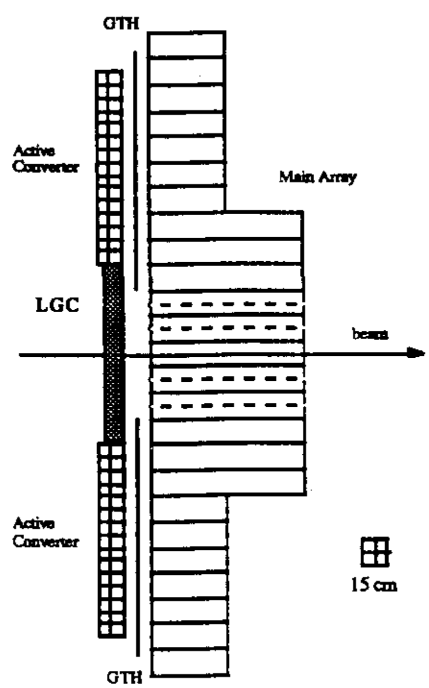
Design and performance of a 4.2 radiation length lead-sandwich, gas tube hodoscope are discussed. The device, measuring 1 x 2 m^2 in area and 12 cm in depth, was employed in Fermi National Accelerator Lab experiment 705 [1]. Multiple samplings of anode wires situated within three-walled aluminum tubes were used to generate an X coordinate; similarly, capacitively coupled copper-clad strips were ganged together to yield a Y coordinate. The results reviewed are based on an analysis of electron calibration data taken during a recent six-month running period. In particular, position resolution (in millimeters) is seen to be $0.8+3.3/\sqrt{E}+31/E$ for the 9.92 mm spaced wires and $0.6+3.2/\sqrt{E}+32/E$ for the 12.5 mm strips, where E represents the electron beam energy in GeV.

Introduction

As originally constructed, E705's large electromagnetic shower detector measured photon positions by pre-converting a small fraction of the photon's energy in 3.5 radiation length (X_0) columns of SCG1-C scintillating glass (Ohara Optical Glass Manufacturing Company, Ltd. [2]) and measuring the shower profile in a conducting-plastic tube hodoscope. Following the gas tube hodoscope (GTH [3,4]) was a 20.5 X_0 Main Array consisting of an inner core of 92 small (7.5x7.5x89.2 cm^3) SCG1-C blocks, surrounded by 74 large (15x15x89.2 cm^3) SCG1-C blocks, further surrounded by 226 large (15x15x45 cm^3) SF5 lead glass blocks. Energy was derived from the sum of Main Array blocks and Active Converter columns, position from the GTH ADC-weighted wires.

Early running experiences led to the decision to replace, in the central one meter, the arrangement of Active Converter columns and GTH with a unified lead-gas calorimeter (LGC). Combining both the calorimetry of the Active Converter columns and the position determination of the GTH, the LGC offered several significant improvements over the original scheme. First, the LGC, with its centimeter granularity, was less likely to be confused by overlapping showers than were the 7.5 cm converter columns. Second, by sampling a shower eight times over 4.2 radiation lengths, channel count fluctuations were much smaller in the LGC than in the single sample GTH. Finally, since lead formed the bulk of the electromagnetic radiator material, the LGC represented a smaller fraction of a hadron absorption length than the SCG1-C columns.

Energy resolution, which is critical to the experiment's goal of resolving the charmonium p-wave states, *is* superior in the Active Converter/GTH arrangement. This precluded expanding the LGC beyond the central one meter - a region where photon energies tend to be small and resolution would be a problem. The final configuration of the electromagnetic detector is shown in Fig. 1.

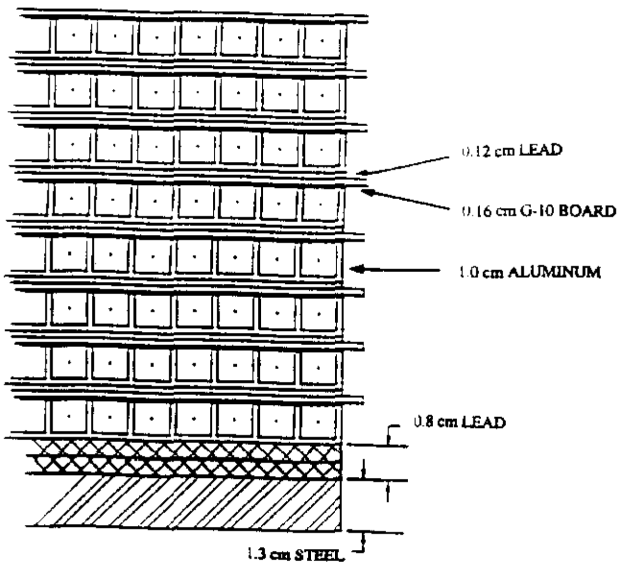


ELECTROMAGNETIC DETECTOR
FIGURE 1

Mechanical construction

Essentially the LGC is an eight-layered sampling device with each identical sample consisting of: 1.2 mm lead, 10 mm aluminum extrusion proportional tubes topped with a .5 mm sheet of resistive PVC, and copper-clad, horizontal-striped, 1.6 mm G-10 board. The upstream end of the LGC consists of 1.3 cm of steel followed by 8 mm of lead. Together, the lead and steel represent 2.3 X_0 of shower starter. In addition to forming the baseplate for the mechanical assembly, steel was also employed to help shield Main Array phototube bases from fringe fields due to the analysis magnet. An assembly diagram of the chamber is shown in Fig. 2.

In terms of active area, the LGC spanned 1.03 meters horizontally and 1.95 meters vertically. The vertical height was matched to that of the glass. Additionally, there was a clearance hole for the beam, 30 cm x 15 cm, also matching the existing beam hole in the Main Array.



LGC ASSEMBLY
FIGURE 2

Tubes

In the geometry of the experiment, a shower's X coordinate is derived from the weighted wire signals. Fifty micron gold-plated tungsten, the wires were suspended vertically with the top and bottom ends glued to plastic fixtures which nested in the aluminum extrusions. Additionally, these wires were glued to plastic posts located at vertical center and split so as to create separate top and bottom readouts. The cell-planes were constructed by paneling together 13 eight-channel aluminum extrusions (EASCO Corp., Phoenix, Az). Individual cells were nearly square with an 8.4 mm wall-to-wall separation, 1.59 mm wall thickness, and a 9.92 mm effective wire-to-wire spacing over the width of the plane.

The gas mixture consisted of premixed Argon/Ethane, in equal parts by volume, which was bubbled through liquid isopropyl alcohol at 0° C. An input gas manifold assured that the flow of gas was uniformly distributed through the tubes.

Positive high voltage, delivered separately to the LGC quadrants, was applied to the wires through 1MΩ current limiting resistors. The operating potential for the wires, about 1850 volts, was ultimately set by the requirement that a single wire group - eight tubes shorted together along the beam direction - not saturate the LeCroy 2280 ADC (400 pC maximum) for 100 GeV test electrons.

Stripes

Copper-clad printed circuit board with horizontal stripes (1.25 cm pitch) formed the Y coordinate measurement. Facing each of the eight extrusion planes was a striped cathode plane separated by a thin sheet of graphite-coated PVC. Sufficiently conductive to serve as the fourth wall of the wire cell, the PVC was insufficiently conductive so as to be transparent to the images of signals developing on the wires. In contrast to the wire signals which are negative, the cathode signals are positive. They are also diminished in amplitude by a factor of about four. Similar to the anode wires, cathode stripes were also ganged together longitudinally in groups of eight. Forty strips above and forty strips below the (vertical) center line were actually cut in two, creating separate 'left' and 'right' halves. Beyond this inner region the strips were continuous.

Electronics

Both anode and cathode signals passed through individual, home-built amplifier circuits mounted at the chamber. Amplifier gains were, approximately, a factor of 5 for the anode and 25 for the cathode. Anode signals were capacitively coupled (100 pF) to the amplifier, cathode signals directly coupled. In either case, output signals were piped over fifty meters of mostly RG8 signal cable and into LeCroy 2280 ADC's. Data was generally collected in *sparcified* mode, meaning that only groups of (pedestal-subtracted) channels above a preset threshold were written to tape. Pedestal measurements, necessary for the subtraction table, were taken several times a week.

By illuminating the detector in special runs with muons (minimum-ionizing particles), it was determined that, for the most part, channel-to-channel gain variations were within ±3 percent. For the results described in this paper, no correction has been made for these variations.

Calibration and EGS Simulation

One valuable feature of the E705 electromagnetic calorimeter is that the entire array sat on a movable table. Thus each glass block could be positioned in the path of an undeflected electron beam. Individual electrons were tracked by three sets of beam chambers with each set consisting of three (0° and ±120° with respect to the Y axis) 1 mm pitch wire planes. Because of multiple scattering effects the error in projecting a track, as defined by the beam stations, to the LGC is beam momentum dependent. For 100 GeV electrons we expect , from Monte Carlo studies, a RMS of .4 mm for the distribution of true intercept minus chamber-determined intercept. At 4 GeV, the RMS for this distribution is 7 mm.

Results in this paper are derived from the study of 4, 10, 30, 60, and 100 GeV electron calibration beams. It was not possible to construct an electron beam with momentum below 4 GeV. Dispersion about these nominal central figures, estimated at about one percent, has not been taken into account in the position resolution analysis.

In order to relate ADC counts to energy, studies were made using the EGS (Electron-Gamma-Shower [5]) program to simulate, in the LGC, shower development for normal-incidence electrons. The simulations were done for all of the calibration energy selections. Similarly, EGS was used to study the shower development of photons. As can be seen in Fig. 3a, the average amount of (simulated) energy deposited in the LGC depends linearly on the square root of the incident electron (or photon) energy. EGS further predicts that photons will deposit only 60 to 70 percent of the energy deposited by electrons (for the same primary energy). There is also a pronounced difference in the spread of deposited energy: the ratio of RMS to mean deposited energy ranges from 30 to 40 percent for electrons and 60 to 70 percent for photons.

Energy Resolution

For the purpose of comparing EGS predictions with electron test data, software clusters were defined in both the LGC X and Y views as ±3 tubes taken about a central, peak tube. Seven tubes, based on a peak tube, represent roughly 98 percent of the total charge left by an average shower. Based on this seven-tube definition, one can compare the average ADC response with the square root of electron beam energy and this is shown in Fig. 3b.

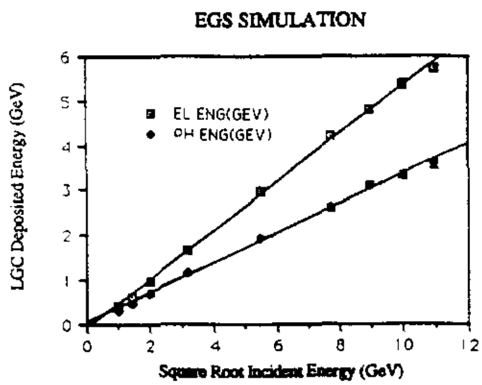


FIGURE 3a

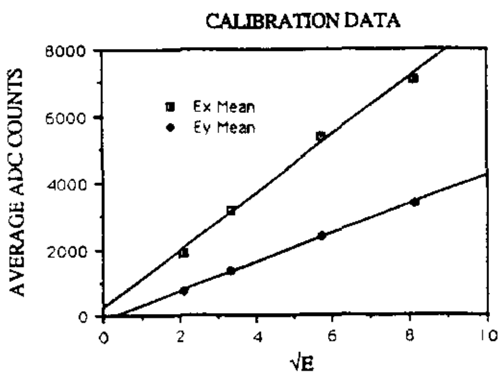


FIGURE 3b

In principle the measured energy in the LGC can be added to the Main Array energy to obtain an estimate of the showering particle's original energy. In order to sharpen the energy resolution of the combined detector, however, coefficients in the expression $E_{total} = aLGC+bMA+cLGC^2+dMA^2+eLGC*MA$ have been determined by minimizing the width of the energy distribution over all measured electron energies.

Shower Fitting

In data events, as opposed to calibration events, one has to deal with cases in which shower peaks are separated in a given view by fewer than seven tubes. Obviously in such cases a single-peak fit, based on seven tubes, is inappropriate. In order to handle overlapping showers, calibration events were studied, leading to generalized profiles for both X and Y showers. For each calibration event, the contents of twenty tubes, centered about the beam interception point, were binned according to their distance from the beam. ADC counts were binned in 2 mm intervals, an amount not inconsistent with the beam extrapolation accuracy. Shower profiles for 30 Gev electrons are shown in Fig. 4a, b for X and Y views respectively. The error bars represent the root-mean-square fluctuations for each bin. As can be seen in the figure, the typical Y shower is slightly broader than the typical X shower. This result, shown for 30 GeV electrons, varies little over the range of calibration electrons (6 to 100 GeV.) About fifty percent of the deposited energy is contained in the peak channel; three channels contain about 90 percent of the deposited energy.

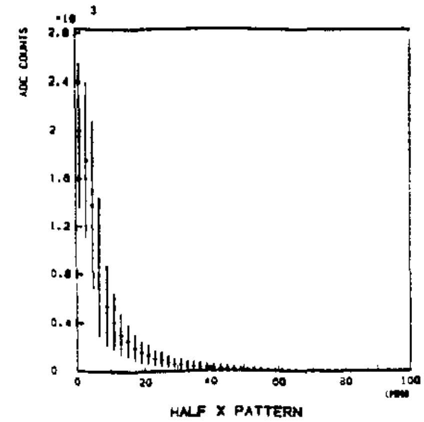


FIGURE 4a

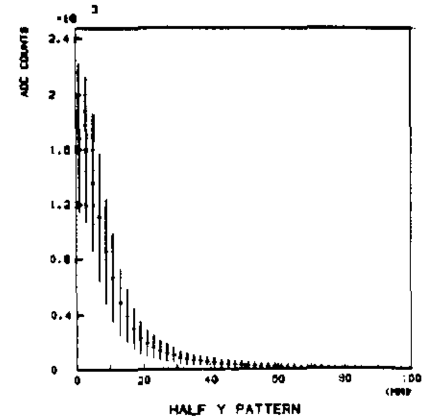


FIGURE 4b

Position Resolution

Extrapolated beam tracks can also be used to measure the position resolution of the LGC - the accuracy with which the LGC measures the entrance point of the showering electron (or photon). This is done by plotting, on an event-by-event basis, the difference between the centroid as determined by the LGC and the beam-extrapolated position at the LGC. For the purposes of determining position resolution, there is little difference between a centroid derived from a first moment calculation based on seven tubes or from a chi-square minimization procedure based on patterns obtained from calibration data. For this analysis the first moment approach is used. A Gaussian is then fit to the difference plot and a sigma extracted. This sigma is then reduced by subtracting in quadrature the sigma of the beam extrapolation (due to the granularity of the beam chambers and multiple scattering effects.) Because of multiple scattering, the correction varies from momentum to momentum. Fig. 5a, b show the corrected position resolutions, for both X and Y views, plotted as a function of $1/\sqrt{E}$. The observed dependence of position resolution with beam energy is in disagreement with EGS which predicts an approximately linear dependence with $1/\sqrt{E}$. However, at this point, the multiple scattering corrections are not completely understood and a definitive statement can not be made regarding the resolution's dependence on electron beam energy.

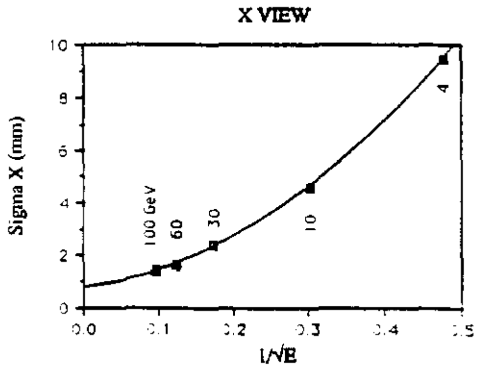


FIGURE 5a

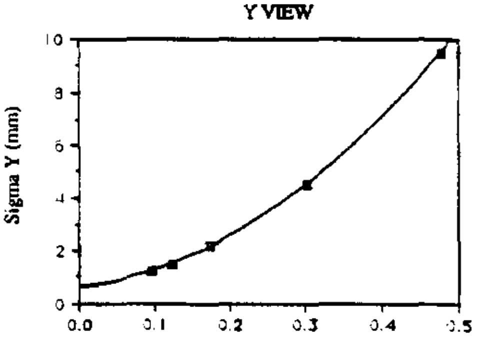
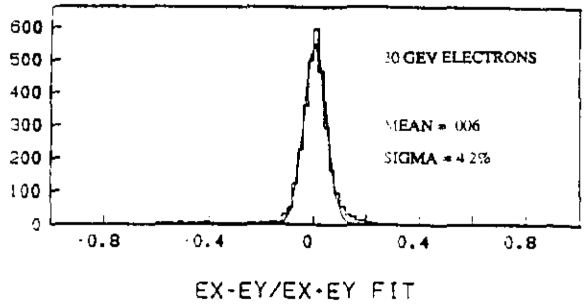


FIGURE 5b

Energy Asymmetry

Data events differ from calibration events in that they generally contain several showers (photon, electron, hadron) of varying energy. In these cases, matching of LGC X and Y clusters must be done on the basis of energy. That is, both X and Y should measure, within errors, identical energies for the same parent shower. Fig. 6 shows the distribution of the asymmetry variable, $A=(E_x-E_y)/(E_x+E_y)$, for 30 GeV calibration electrons.



ELECTRON ASYMMETRY
FIGURE 6

Conclusions

The LGC, built to enhance the central region of the E-705 calorimeter, was operated without incident during the previous six-month running period at FNAL. Studies using calibration electron data suggest that position resolution of the LGC, in millimeters, can be expressed as $0.8+3.3/\sqrt{E}+31/E$ for the 9.92 mm spaced wires and $0.6+3.2/\sqrt{E}+32/E$ for the 12.5 mm strips, where E represents the electron beam energy in GeV. Also, the correlation between energy as measured by the wires and energy as measured by the strips is fairly tight, with an asymmetry RMS for 30 GeV electrons of about 4 percent.

Acknowledgments

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