SLAC – PUB – 3811
October 1985
(E/I)

PERFORMANCE OF THE SLD WARM IRON CALORIMETER PRE-PROTOTYPE‡

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Abstract

The performance of a pre-prototype of the SLD Warm Iron Calorimeter (WIC) build with proportional tube cathode pad readout has been studied. The calorimeter was found to have an average resolution of $36.7 \pm 0.2\%$ for muons at 2.0, 5.0 and 10.5 GeV and $81 \pm 2\%/\sqrt{E}$ for pion showers at 5.0 and 10.5 GeV. The mean energy found for the pion showers was consistent with a linear dependance on energy within these standard deviations.

Introduction

An important part of the SLD detector[1] will be the calorimetry system consisting of a Liquid Argon Calorimeter (LAC) followed by a Warm Iron Calorimeter (WIC). The WIC will use the iron needed for the flux return path of the SLD magnet as a means of measuring the energy escaping from the LAC and to provide muon identification and tracking.

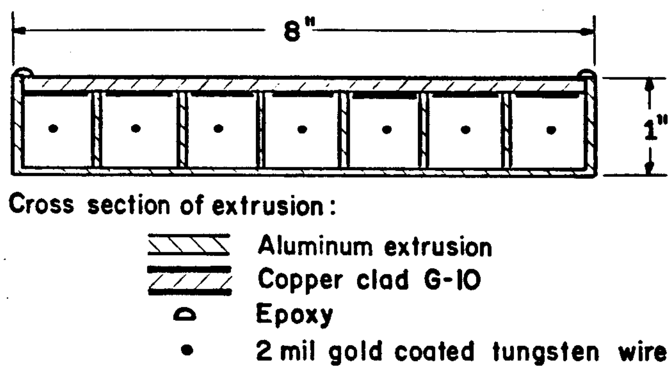

Figure 1. *Cross-section of an aluminium proportional tube extrusion showing copper cathode pads inside each tube.*

Although it has now been decided to use Iarocci streamer tube technology for the final version of the WIC, a pre-prototype has been constructed using proportional tube detectors with cathode pad readout. This pre-prototype has been tested in conjunction with a prototype of the SLD Liquid Argon Calorimeter[2] in a test beam at SLAC. The results discussed here are based on data obtained in December, 1984. In particular, the results of a muon calibration run, and the resolution for the pion showers originating in the WIC will be presented.

Description of the Detector

Figure 1 shows the configuration of the detector planes. They were constructed from 56 inch long sections of 8 inch by 1 inch aluminum extrusion, consisting of 8 $\approx$1 inch square tubes. These are terminated at both ends by sections serving as gas manifolds and mounts for the HV standoffs for the anode wires. The wires are 2 mil gold coated tungsten. A 48 inch by $\approx$8 inch section of one surface of each extrusion was machined out, and an $\frac{1}{8}$ inch G-10 board, copper clad on both sides, was epoxied into this opening. On the inner side of the board the copper was removed to make $\frac{3}{4}$ inch by $5\frac{3}{4}$ inch sub-pads, located so they do not make electrical contact with the extrusion. On the other side small areas of copper were removed over each sub-pad, and a 0.23 inch long mass termination connector was inserted in a hole drilled through the board and soldered to the copper sub-pad. Six such extrusions are mounted on a frame to form a detector plane with 48 inch by 48 inch active area.

Groups of six sub-pads were connected to form $\approx$ 6 inch square pads, and the signals from these were bought out via twisted pairs to an interface board at the top of the detector. The ground lead of each twisted pair was connected to the outer copper surface of the G-10 board, which was connected to the aluminum extrusion to form a continuous ground plane. The lead from each pad was separately connected to ground through a 2kΩ resistor on the interface board, and to the cables leading to the LASS cathode SHAM IV readout electronics[3] There were 64 pads per plane, and a total of 1216 channels read out from 19 detector planes.

The tubes were filled with 95% Argon 5% CO_2 in a continuous flow mode at $\approx$ 0.01 psi above ambient pressure. They did not draw excessive current until 2.05kV, but were operated at 2.01kV for most of the run, since this gave a good match to the dynamic range of the electronics and a margin of safety with respect to HV breakdown.

Figure 2 shows the configuration of the WIC pre-prototype. An initial detector plane was followed by nine layers of $1\frac{1}{4}$ inch

‡ This work was supported in part by the U.S. Department of Energy under the following contracts: DE-AC02-76ER03069,DE-AC02-76ER00881 and DE-AC03-765SF00515

Poster paper presented at the Nuclear Science Symposium, San Francisco, California, October 23-25, 1985

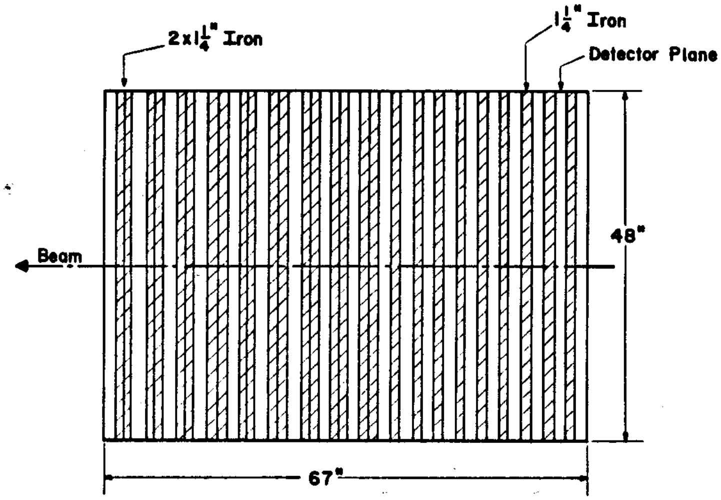

Figure 2. *Assembly of $1\frac{1}{4}$ inch iron plates and proportional tube detector planes to form WIC pre-prototype.*

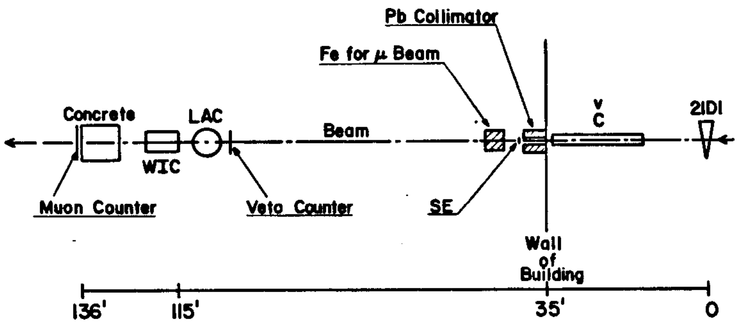

Figure 3. *Test beam configuration showing elements relevant to the discussion of this report.*

iron alternating with detector planes, and then nine layers of $2\frac{1}{2}$ inch iron and planes, yielding a total of 19 planes and $33\frac{3}{4}$ inches (5λ) of iron.

Description of the Test Run

The test runs were carried out in beam line 20/21 in the SLAC Test Beam Facility (Building 121/25). Figure 3 shows those features of the beam line relevant to a discussion of the WIC performance. The beam at the entrance of the LAC was approximately $1\frac{1}{2}$ inches in diameter.

Acquisition of WIC/LAC data was flagged by a coincidence between the SE counter downstream of the collimator at the entrance of the Test Beam Facility and the dE/dx counter just upstream of the LAC. The following information was available with each data record:

1. The pulse height in the dE/dx counter immediately upstream of the LAC to permit selection of events with only one particle in the central beam region.
2. The pulse heights from two layers of veto counters which allowed the rejection of events with incoming particles outside of a three inch square centered on the beam.
3. The signal from the threshold Čerenkov counter.
4. A bit set if either of the two layers of counters in the muon wall indicated a penetrating particle.

Table 1. *Summary of the Data Analysed.*

Run Number	Incident π Energy	Events Recorded
129	11 GeV	34000
137	11 GeV	13000
156+157	2.5 GeV	30000
158	5.5 GeV	14500

In addition, $\frac{3}{8}$ inches of lead could be introduced 70 meters upstream of the collimator to remove electrons from the beam.

The readout from the 1216 SHAM channels was via 3 BADC's[4] connected to the Test Beam Facility Vax. The thresholds in the BADC's were set to 200 raw counts above pedestal corresponding to $\approx 25\%$ of the minimum ionizing signal. Events could be written to tape and also examined online using the prototype SLD data acquisition system.

The data analyzed here come from 4 runs taken towards the end of the data taking period when the beams and detectors were reasonably stable. The important features of these runs are summarized in table 1.

Muon Calibration Run

In order to obtain a relative calibration between all the pads in the WIC a scattered muon beam was produced. Four feet (7λ) of iron were placed in the beam immediately downstream of SE, stopping all but 0.06% of the pions, and multiple scattering the muons from the pion decay upstream of SE. The energy of the pion beam was 6.7 GeV/c and the average energy of the muons in the WIC after traversing the iron and the LAC varied from 4.7 to 3.7 GeV/c from the first to the last detector plane. The trigger for muons was a coincidence between SE and the muon wall.

Muons were obtained from the data using software which found straight tracks in the 19 planes of the WIC. Clean muons were selected by demanding that they generated hits in colinear pads in at least 12 detector planes, and that each of these planes contained at most one other hit. In 6 hours of running time 34500 events were obtained which yielded 31000 muons after software filtering (27% of these were from events with multiple tracks). The profile of the scattered muons at the WIC were such that there were ≈ 1000 muons in each of the central WIC pads and about 30% of this number in outer pads. Only six pads were found (all near the edge of the calorimeter) in which no signal was seen, probably due to disconnected pads or dead amplifier/SHAM channels.

The raw energy distribution from each pad was fitted with a Landau distribution and the position of the peak of this distribution used to obtain a calibration factor for that pad. The calculated calibration factors were found to vary by up to $\pm 50\%$ from unity. The stability of these calibration factors was tested using muons which pass through the central calorimeter pads during normal running. The pad to pad variations were found to be less than 2% (the statistical error on the calibration factors). The muon calibration does not correct for the overall gain variation from run to run which may be up to 10% due to fluctuations in external temperature and pressure.

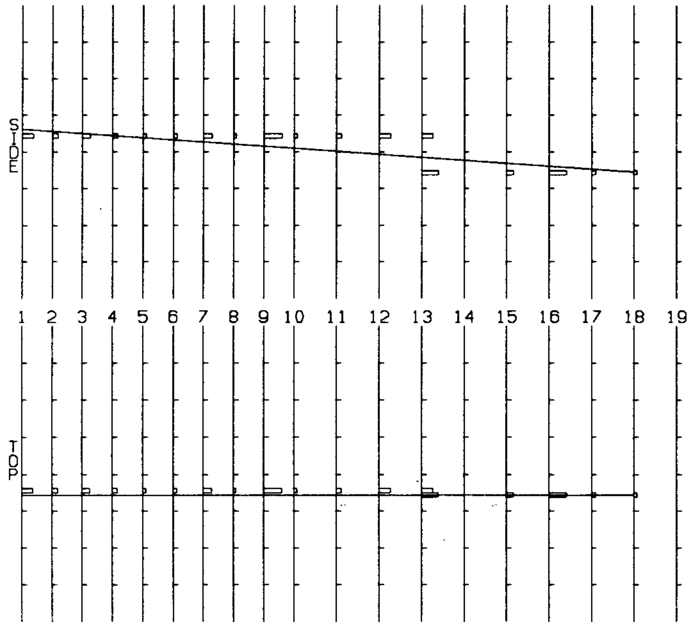

Figure 4. *A typical muon event in the WIC. The diagram shows the side and top view of the calorimeter, the planes are numbered from 1 (upstream) to 19 (downstream). The subdivision of each plane shows the 8 rows (columns) of pads, with the position and magnitude of the hit shown by the horizontal bar. Within the 8 subdivisions of each plane the position of the marked hit indicates which pad in the row (column) was hit.*

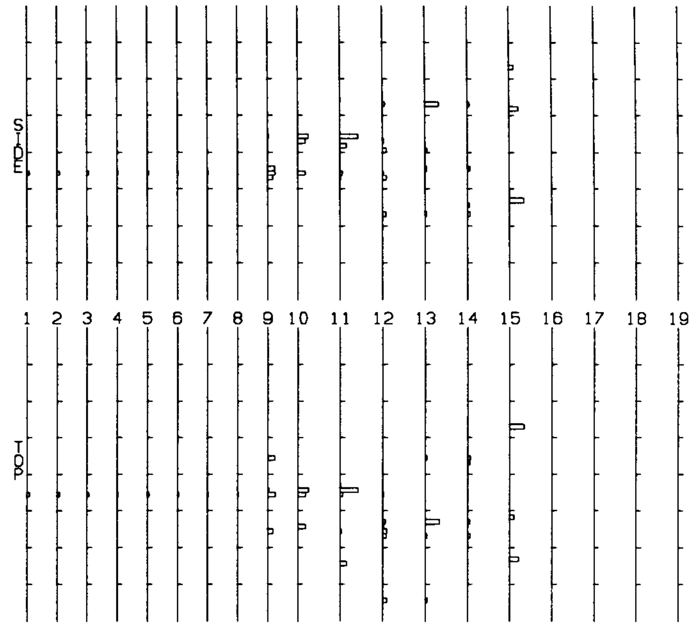

Figure 5. *A typical hadron shower contained in the WIC.*

Analysis and Results

Two sets of cuts were applied to the data taken in each run; one set to filter off minimum ionizing particles (primarily muons) and the second set to select events containing pions which showered entirely within the WIC. Typical events from each class are show in figures 4 and 5.

Muons were selected by the same colinearity requirements used in the muon calibration run. The energy deposited by each muon was calculated by summing the energy deposited in each pad it traversed, after having applied the appropriate calibration factor to each pad. In addition, whenever a muon track was within $\approx 1\frac{1}{2}$ inches of the border between two pads (horizontally, vertically or diagonally) the energy from the neighboring pad was also included in the sum, thus taking into account splitting of energy between neighboring pads and the uncertainty in the track position.

A typical distribution is shown in figure 6(d). A Landau function was fitted to the distribution obtained for each run, yielding the results shown in table 2 (all errors quoted here are purely statistical).

Table 2. *Summary of the Muon Results for Each Run.*

Run Number	Events	Peak Position	σ	$\sigma/mean$
129	3377	3316 ± 20	1563 ± 28	0.371 ± 0.005
137	1430	3523 ± 33	1659 ± 46	0.371 ± 0.009
156+157	405	2970 ± 52	1377 ± 70	0.366 ± 0.016
158	2002	3001 ± 23	1355 ± 32	0.359 ± 0.007

The cuts used to select the WIC shower events were more complex. First clean beam events were selected by demanding:

dE/dx $<$ 325 counts above pedestal
Veto1+Veto2 $<$ 50 counts above pedestal
Čerenkov $<$ 20 counts above pedestal

The first cut was used to remove beam electrons and the remaining two cuts to remove events with multiple beam particles, or where the beam particles had interacted with matter upstream of the LAC. Hadrons showering in the LAC were removed by demanding that each of the 4 LAC planes contained at most one hit above the noise threshold. The first WIC plane with 2 neighboring pads hit was labeled P_f and the first plane downstream of P_f with no hits was labelled P_l. Events were only selected if they satisfied the following criteria, designed to remove the remaining non-interacting particles from the sample.

$$P_f > 1$$
$$P_l \leq 19$$
$$P_l - P_f \geq 3$$

The number of hits in planes P_f to P_l inclusive $\geq 2(P_l - P_f)$

A typical shower event is shown in figure 5. The total energy deposited by each shower was calculated by summing the energy deposited in each pad in planes P_f to P_l inclusive. In addition to applying the calibration factors described earlier, additional weighting factors were assigned to each plane to compensate for the different amounts of material between the planes. The weighting factors were 1.0 for planes $2-10$ and 2.0 for planes $11-19$ (the cuts used prevented plane 1 from ever contributing to the sum). With these weighting factors 25% of the shower energy was deposited in the back half of the calorimeter at 11 GeV, falling to 15% at 5.5 GeV. The resulting energy distributions for runs 129,137 and 158 are shown in figure 6 (run 156/7 had only 2 events which survived all of

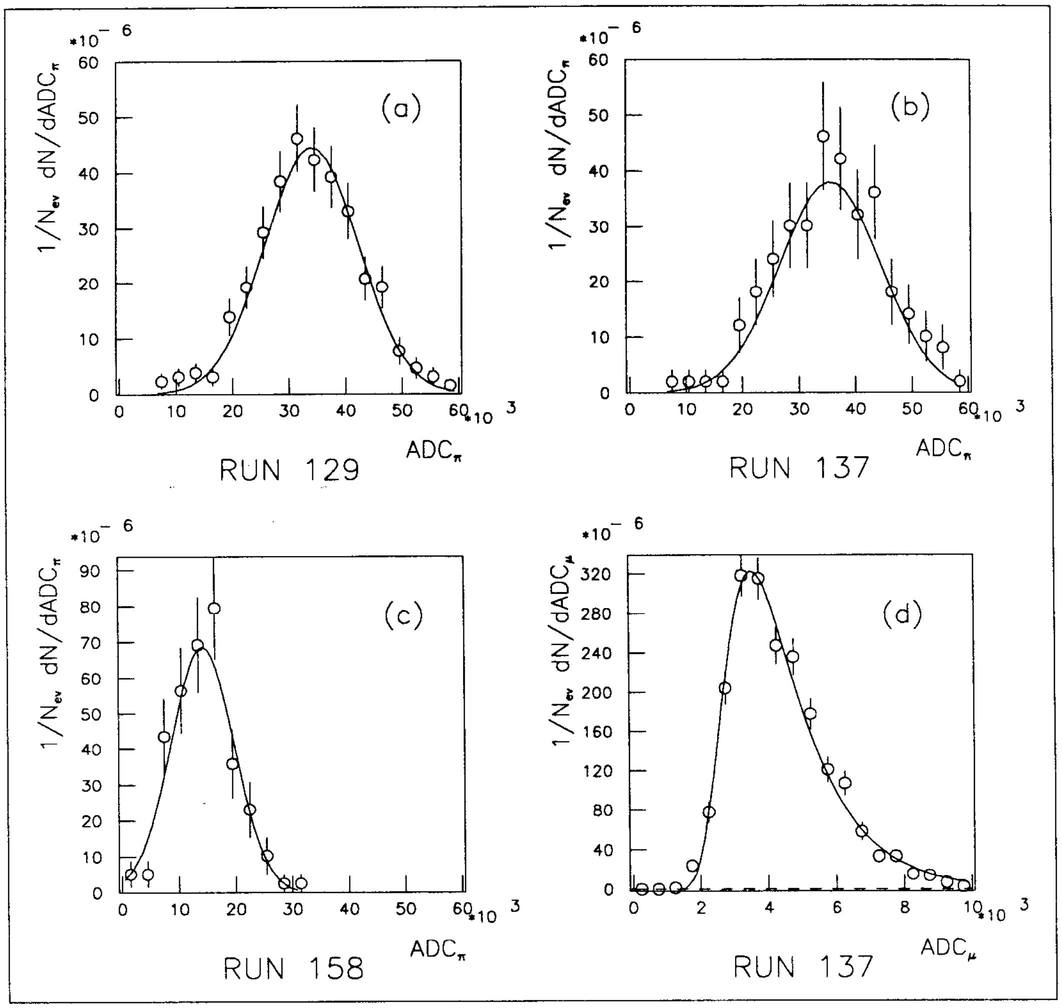

Figure 6. **(a-c)** *Total energy deposited by showers contained entirely in the WIC. The curves represent Gaussian fits to the data.* **(d)** *Total energy deposited by muons for a typical run. The curve represents a Landau fit to the data.*

Table 3. *Summary of the Hadron Results.*

Run #	E(GeV)	Events	Mean	Mean/E	σ	$\sigma/mean$	dE/E
129	10.4	268	33970 ± 380	3270 ± 40	8080 ± 300	0.24 ± 0.01	$77 \pm 3\%/\sqrt{E}$
137	10.4	129	35200 ± 690	3390 ± 70	9190 ± 670	0.26 ± 0.02	$84 \pm 6\%/\sqrt{E}$
158	4.9	94	14430 ± 490	2960 ± 100	5680 ± 450	0.39 ± 0.03	$86 \pm 7\%/\sqrt{E}$

the cuts). Each distribution has been fitted with a Gaussian curve, yielding the results shown in table 3. The energy, E, has been corrected for dE/dx loss in the LAC, but not for that in the WIC.

Conclusions

The WIC pre-prototype was found to have an average resolution of $36.7 \pm 0.2\%$ for muons at 2.0, 5.0 and 10.5 GeV and $81 \pm 2\%/\sqrt{E}$ for pion showers at 5.0 and 10.5 GeV. The mean energy found for the pion showers was consistent with a linear dependance on energy within these standard deviations. These results are consistent with expectations.

References

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