# SATURATED AVALANCHE CALORIMETER*

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## Summary

A gas sampling electromagnetic calorimeter running in a "Saturated Avalanche Mode" was tested at SLAC with positrons incident at energy up to 17.5 GeV. With this new method, good energy resolution, 16 percent/$\sqrt{E}$, and good linearity were obtained with arrays of thirty-four 0.5 radiation length thick lead plates interleaved with 34 wire counters. There was no measurable systematic effect. Amplifiers are not needed; the signals are large enough to be connected directly to the ADC's.

## Introduction

Gas sampling calorimeters operating in a proportional mode have been tested and used by several groups[1-10] but, with one reported exception[6], their energy resolution has been much inferior to that achieved with calorimeters that use plastic scintillator counters. Improved resolution has been demonstrated in a calorimeter operated in the Geiger mode[11] and may be expected also with the limited streamer[12,13] mode. Those devices are intrinsically different from proportional counter energy sampling calorimeters. The former, in effect, use the number of tracks in the shower, while the latter use the magnitude of total collected charge as measures of the energy deposited in the gas. In this paper, we report results of tests of gas sampling calorimeters run in neither of these modes, but in an intermediate, partially saturated mode. Their resolution is comparable to that of plastic scintillator calorimeters.

These tests were made as part of the program to develop calorimeter modules for the Collider Detector Facility[14], an apparatus to detect products of $\bar{p}p$ interactions at the 2 TeV colliding beams machine now under construction at Fermilab. The present design calls for gas sampling electromagnetic and hadronic calorimetry in the forward and backward angular regions. Respectably small granularity will be achieved with tower structures of cathode readout pads.

## Experimental Arrangements

The detector studied was a MAC prototype[6] which was tested previously in proportional mode at SLAC. Thus, only limited details of construction will be given here.

The MAC prototype was composed of 34 lead plates of 2.8 mm thickness and 34 planes of 50 μm diameter anode wires enclosed in 9.5 mm x 9.5 mm cells which are separated by 1.5 mm thick aluminum ribs, a 17.8 radiation length shower detector. Fig. 1 shows the arrangement and the cell structure. The anode wires of each
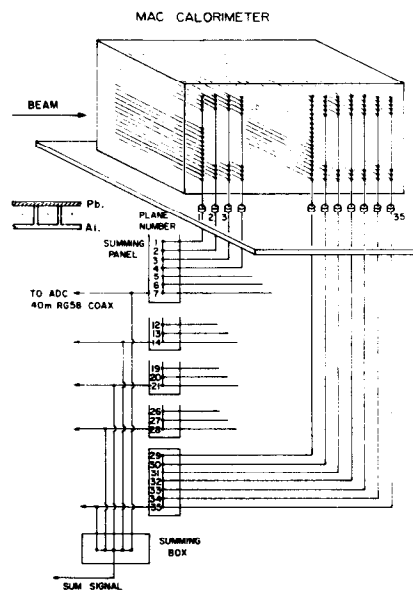


Fig. 1. The experimental configuration of the MAC electromagnetic calorimeter.

plane were connected to a common strip, and seven such planes were further grouped together, resulting in five groups to be read out. Most of the results that will be presented in this paper were obtained from the total sum of these five groups. Results on the longitudinal development in the shower will be reported later.

The counter gas was a mixture of 49.3 percent Argon, 49.3 percent ethane, and 1.4 percent ethyl alcohol. Negative high voltage was applied to the cathode tubes. Distributed high voltage capacitors totalling 0.25 μf were the charge storage elements. As indicated in the figure, there was no need for amplifiers between the wires and the ADC's. Indeed, it was necessary to attenuate the large signals obtained between 2 db and 30 db depending on the high voltage and gas pressure. Forty meters of RG58 coaxial cables carried the signals to the LeCroy 2249W ADC's. The ADC pedestals were determined with a linear extrapolation of the measured variation of pulse height with incident energy.

A LSI-II computer system with a SLAC program "ATROPOS" was used for data taking and on-line display monitoring.

## Beam Parameters

The detectors were tested in the 19° beam of the Stanford Linear Accelerator which provided positrons of 17.5 GeV maximum energy. SLAC ran in the SLED mode during the entire tests with a bunch length of about 20 nsec, FWHM 8 nsec, and 10 bunches per second. About 95 percent of the beam at the detector was within the 2 mm x 2 mm area of the beam defining counter. The intensity was, on the average, between 1/10 and 10 positrons per bunch. The momentum spread of the beam, $\Delta p/p$ was less than ±0.25 percent rms.

## Experimental Results

For 10 GeV incident positrons, the total pulse height distribution is shown in Fig. 2 together with a Gaussian fit to the data. Only that portion of the distribution within ±2σ of the mean were used in the fitting procedure. The shape of the distribution, typical of all, is well represented by the Gaussian function.
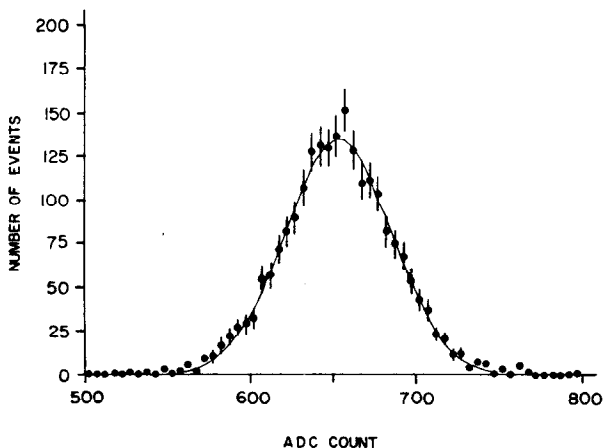
With fixed gas pressure, the resolution σ/E varies with high voltage as shown in Fig. 3. As the voltage increases from 2100 V, the resolution slowly decreases to a shallow minimum at ∿ 2250 V and then slowly increases.
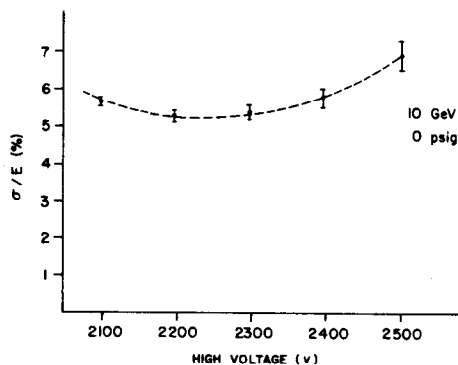
Fig. 3. σ/E versus high voltage for 10 GeV positrons at 0 psig.

Fig. 4 presents the calorimeter output as a function of incident positron energy showing no departure from linearity at energies up to 17.5 GeV. For this run, the counters were run at 2300 V.
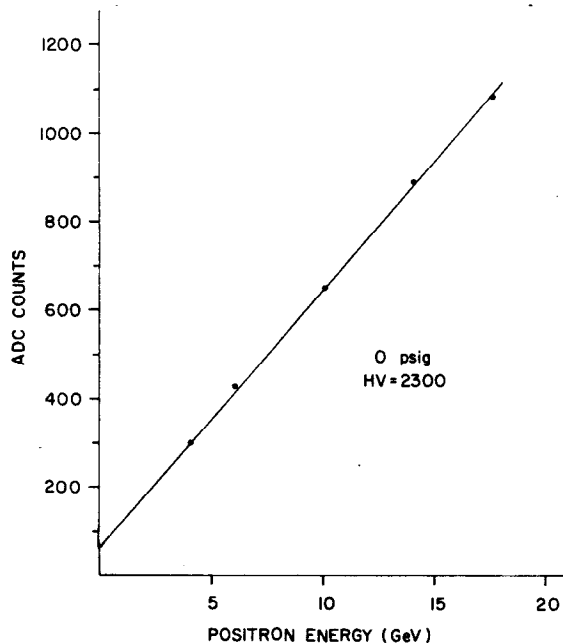
Fig. 4. The total pulse height response of the calorimeter as function of the e+ energy for 0 psig. The linearity is excellent.

Higher energy response of the detector was simulated by using multiple positrons in a single rf bucket. This is a fair simulation since the positive ions do not move appreciably from where they were produced during the beam spill. Fig. 5 shows the detector response to multiple positrons of 17.5 GeV. It shows that

Fig. 2. A typical pulse height distribution and Gaussian fitted points for obtaining σ and mean values using 2σ fit.

as many as 11 simultaneous positrons the energy reso-
lution of the detector is sufficiently good to resolve
them with clear minima between the peaks of the pulse
height distributions for the corresponding number of
positrons. In fact, this is a Poisson distribution for
n = 4.5. That the pulse height for the multiple posi-
trons deviate in a smooth way from linear behavior for
more than 2 positron (35 GeV) shower is seen in Fig. 6.
An expanded view of the pulse height distribution for
10 GeV positrons is shown in Fig. 7. It dramatically
shows the symmetric, Gaussian-like shapes with clean
valleys between the multiple-hit peaks. The energy
resolution as a function of equivalent energy deposits
of multiple 17.5 GeV positrons is shown in Fig. 8 after
correction for the non-linear response.

The energy resolution as a function of energy for
single incident positrons is shown in Fig. 9. $\sigma/E$
shows the usual $E^{-1/2}$ dependence with a constant factor
of 16.2 percent as indicated in Fig. 10. The shape of
the dependence of resolution on energy indicates no
systematic term since it extrapolates to the origin.
This is, perhaps, because there is no active device
(amplifier, pulse shaper, etc.) between the detector
and the ADC, and small variations among individual wire
gain average out over the detector.

The detector was rotated to make angles to the
beam axis of as much as 23 with 17.5 GeV positrons
incident, the results of Fig. 11 were obtained. It is
seen that the pulse height increases by a small amount
(maximum 2.3 percent), and the $\sigma/E$ decreases slightly
with increasing angle. This improvement may be due to
a better containment of energy in the effective thick-
ness of the angled calorimeter.

### Saturated Avalanche Mode

We have investigated the ionization region[12]
between the proportional region and the self quenching
streamer region in detail using a 9.5 mm x 9.5 mm tube
having a 50 μm wire, a replica of one cell of the
prototype MAC detector, in order to understand the
improved energy resolution of the apparatus relative
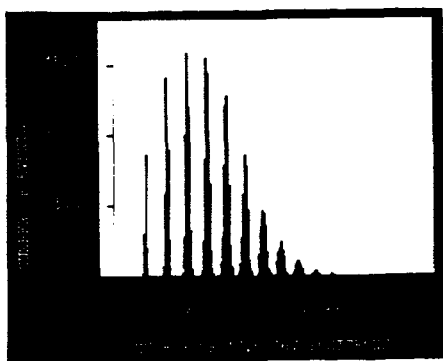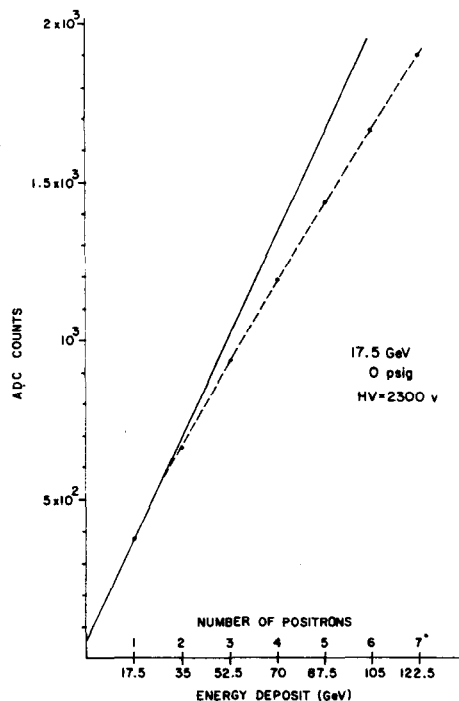to calorimeters running in the proportional mode.



Fig. 6. The pulse heights as a function of simultaneous
17.5 GeV multiple positrons for 0 psig.
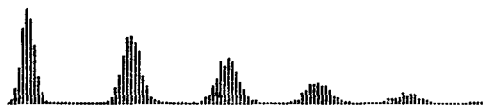


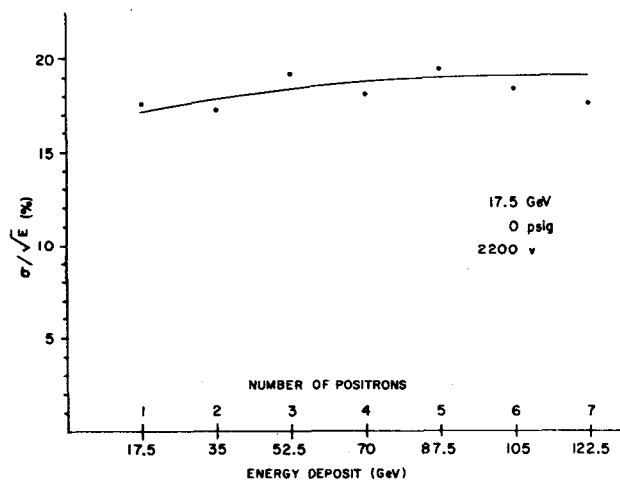Fig. 7. Pulse height distributions for 10 GeV multiple
positrons.



Fig. 5. The response of the detector to simultaneous
multiple positrons of 17.5 GeV.



Fig. 8. $\sigma/\sqrt{E}$ versus simultaneous multiple 17.5 GeV
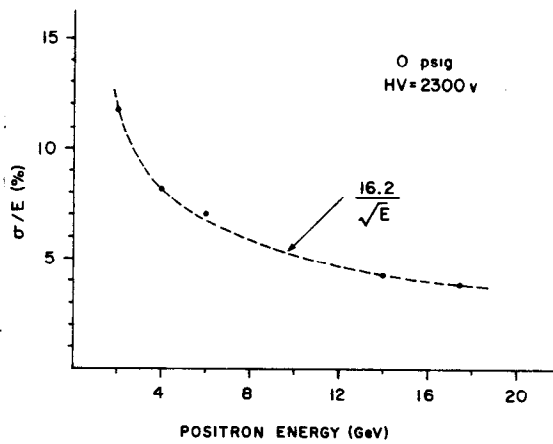positrons after correction for non-linear response.

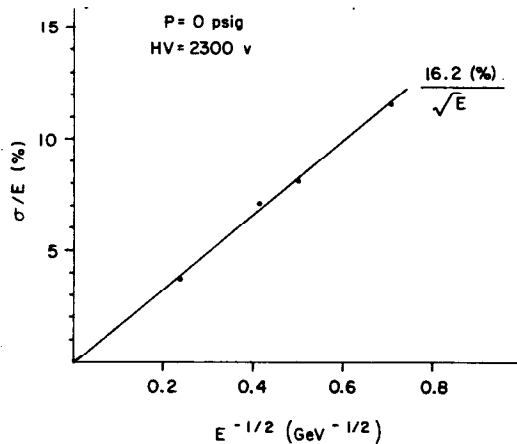Fig. 9. σ/e versus positron energy.



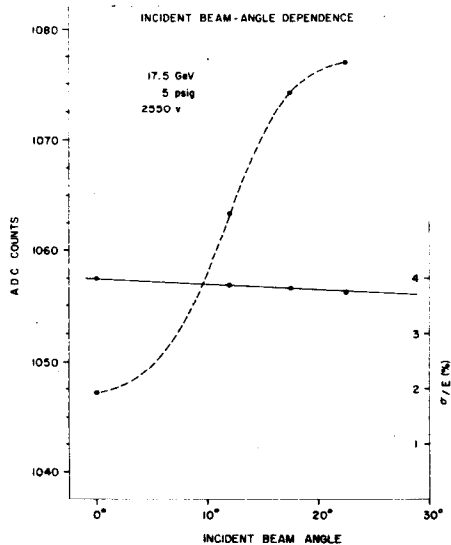Fig. 10. σ/E versus $E^{-1/2}$ indicating no systematic effects.



Fig. 11. Total pulse height and σ/E versus incident beam angle for 17.5 GeV positrons.

A small fraction of the wire pulse was amplified and used to form the ADC trigger, as shown in Fig. 12. A LeCroy 2285 ADC system was used for measuring the charge. The gain of the ADC was 20 counts per pico-coulomb. An Fe[55] x-ray source was used to measure the wire gain as a function of high voltage. As seen in Figs. 13a and b, the resolution is insufficient to separate the 5.9 keV x-ray line and 2.9 keV argon escape line when the gas gain, at 2300 V, is in the region of limited proportionality. The gain here was ∿ $5 \times 10^4$. The 2.9 keV line is hidden in the left side of the asymmetric pulse height distribution. Fig. 14 shows the gain as a function of the high voltage. The rate of growth of the avalanche is seen to decrease continuously as the high voltage increases above 2200 V until the streamer threshold is reached. Then the gain increases very little to the point of full streamer operation around 2650 V.

The distribution of pulse heights recorded by passage of minimum ionization tracks was also investigated in this voltage region using a Sr[90] β-source. A telescope made from a pair of small thin scintillation counters provided a gate pulse for the ADC's. The discriminator thresholds were set to accept mainly the minimum ionizing β's. Fig. 15 shows the pulse height distribution obtained at 2300 V. This histogram shows that the distribution is almost symmetric with a small tail. The distribution made by the β's is not like a typical Landau distribution obtained in a gas gap of 9.5 mm thickness at atmospheric pressure. The tail is greatly suppressed. An expanded view of the histogram of Fig. 15a is shown in Fig. 15b. It has a ratio of σ to mean of 34 percent. Landau fluctuations clearly have been reduced, an indication that the greater the concentration of primary ionization, the more saturation (less gain) occurs as has been observed earlier[15].

From the data of Fig. 13, we find a ratio of mean pulse heights produced by the two photons of ∿ 1.4, rather than the ∿ 2.0 ratio of energies. Similar conclusions about the departure from strict linear, proportional response follows from comparison of the signals from the β and x-ray sources. Those observations and the suppression of the Landau tail indicate partial saturation of the avalanche charge at the collecting wire. Thus, the resolution is improved compared to that obtained when the counters operate in the proportional mode. We find a resolution somewhat smaller than, but not really inconsistent with that predicted by Fischer[16], which is based on a calculation of the response without the effect of Landau fluctuations. Deterioration in resolution at voltages much higher than 2400 V may be caused by fluctuations in gain where streamer and saturated avalanche modes overlap (see Fig. 14). Depending on the amount of ionization deposited locally on the wire, the gain may be low (saturated avalanche) or more than an order of magnitude higher (streamer).

## Acknowledgments
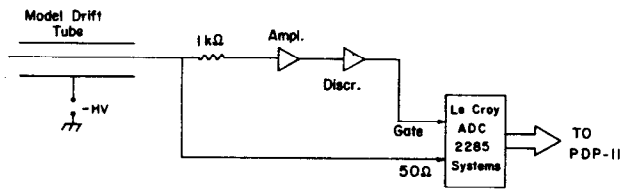
Fig. 12. The circuit diagram for investigating the saturated avalanche region.



Fig. 14. The model tube gain as a function of the high voltage in the saturated avalanche region using the ADC without amplifier.
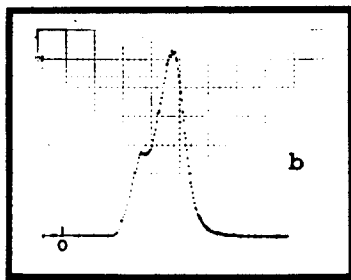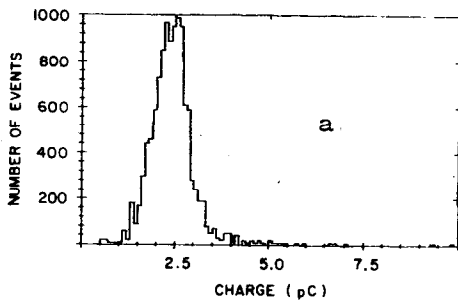




Fig. 13. Pulse height distributions for the 5.9 x-rays from Fe[55]. Fig. 13a shows the ADC distribution without amplifier. Note the 3 keV argon escape line is not visible in the saturated avalanche region because of poor proportionality. Fig. 13b shows the amplified distribution where the escape line is just visible because of the better resolution at high pulse heights.
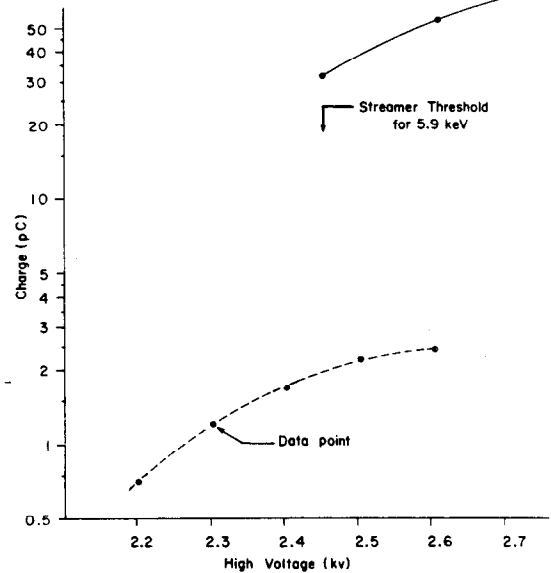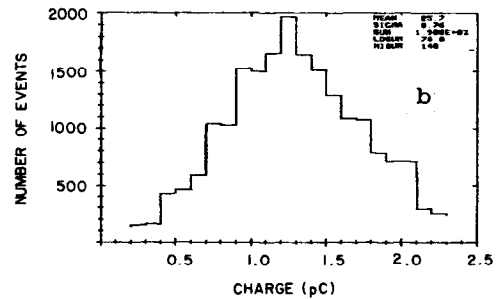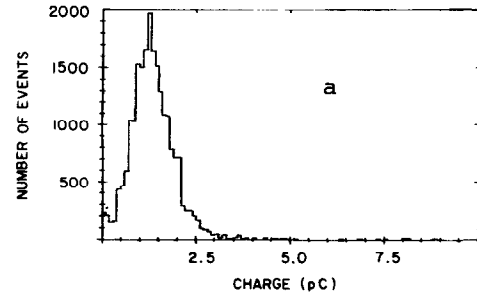




Fig. 15a and b. The pulse height distribution for minimum ionizing tracks in the saturated avalanche region showing almost symmetric distribution with very small Landau tail. Fig. 15b is the expanded detail of Fig. 15a.