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Letter of Intent

Test of Electron/Hadron Compensation for Warm Liquid Calorimetry

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Introduction

In the 1989 fixed target run at Fermilab we wish to test a sampling hadron calorimeter using 2,2,4,4-tetramethyl pentane ("TMP") as the active medium. The main objective of the test is to identify one or more combinations of plate composition, plate thickness, and electric field that will produce near equality in hadron and electron response, as predicted by Wigmans [1]. This test is part of a broader program, "Fast Hermetic Calorimetry Using Warm Liquids: Proposal for Generic Detector R&D for the SSC/LHC" [2], which is being supported by the U.S. DOE and by IN2P3 and CEA in France. This proposal is attached as Appendix A.

Motivation

Use of a liquid medium like TMS (or TMP with very high fields) could lead to an SSC/LHC calorimeter with performance that is superior to what is possible with liquid argon. There are two central arguments. First, warm liquid modules can be smaller, with thinner boundaries made of single walls with braces bathed in the liquid. We expect calorimeters taking advantage of these possibilities to be much more hermetic than has been possible for cryogenic devices. Second, many hybrid preamps with large total heat dissipation can be placed inside or immediately outside the liquid modules. Then gap, cable, and preamp capacitance can be chosen to optimize the signal-to-noise for fast response. Other advantages include (predicted) equal electron/hadron response without use of uranium plates, reduced dependence of gain on gap thickness, and fast charge collection.

Generic R&D program

The objectives of our SSC/LHC detector R&D program [2] are:

(1) to measure properties of hydrogenous warm liquid ionization media (TMS and TMP) relevant for calorimetry at SSC/LHC, such as saturation effects from heavily ionizing particles, and effects of high instantaneous beam rates and electric field, as well as studies of materials to be used with such liquids, compatible with the needed liquid purity;

(2) to measure the electron/hadron response and energy resolution achievable with these liquids, as a function of absorber composition, sampling fraction, and electric field;

(3) to design a warm-liquid calorimeter module that meets safety, hermeticity, and time-resolution requirements for SSC/LHC use;

(4) to construct and test a prototype hadron/electron calorimeter based on that design.

Our present funding support is for objectives (1), (2), and (3), which are being pursued in parallel. This Letter of Intent is for test beam work directed primarily toward objective (2), although it will benefit all four objectives.

Measurement of electron/hadron response using TMP

The electron/hadron response (e/h) and fractional energy resolution (dE/E) of TMP in combination with U, Pb, and Fe absorber plates have been calculated by one of us [1]. These calculations are intricate and depend, among other factors, on saturation in the response of these media to slow protons recoiling from spallation neutrons. Not only must this saturation be measured, as we are undertaking to do, but also the predicted dependence of e/h and dE/E on the plate composition, sampling fraction, resolving time, and electric field must be established experimentally. Also, practical calorimeter designs using TMS or TMP will likely require at least two different absorber materials (e.g. Pb with stainless steel to contain the liquid). The effects of composite absorbers are even more important to measure, as they are still more tedious to calculate [1].

In order to save time we will start by using TMP "boxes" similar to production modules for the upgraded UA1 calorimeter [3], in combination with absorber plates that are different from the U plates used by UA1. The primary objective will be to identify a practical combination of materials, thicknesses, sampling fractions, and electric field (e.g. 5 mm of Pb/1.2% Ca/1.1% Sn, 1 mm of stainless steel, 2.5 mm of TMP, 15 KV/cm) that yields acceptable compensation ($|1 - e/h| < 0.07$, contributing less than 1% to dE/E). Using these TMP hadron calorimeter data together with our separate measurements of the saturation properties both of TMP and tetramethyl silane ("TMS") will permit very reliable estimates of the properties of TMS calorimeters with similar absorber configurations.

The TMP will be contained in UA1-type boxes, approximately 20 cm x 60 cm in area. The 20-30 microsecond lifetime already achieved [3] for TMP exceeds the requirements of this test. Each module contains twelve 10 cm x 10 cm anodes that collect ionization electrons from the TMP in each of two 1.25 mm gaps. This transverse segmentation is representative of that encountered in SSC/LHC designs.

We plan to test absorber plates made of combinations of materials that are of practical interest for the SSC/LHC: Fe, Pb, and possibly Sn. The TMP box faces depend for support on the absorber plates, which must be of uniform thickness and able to be squeezed flat. We expect the average absorption length within the test calorimeter to be in the range 20-28 cm. Then >97% transverse containment of hadron showers can be achieved in a 60 cm x 60 cm stack with three boxes per gap. With absorbers as thin as 4 mm per gap to be tested, up to 256 gaps will be needed for a 6-absorption-length calorimeter. (A coarse "leakage" calorimeter will be placed downstream and on the sides if necessary.) Then the maximum number of gaps is 768. For the 1989 test, however, TMP boxes will be place only in every fourth gap. The remaining three gaps will be filled with inert material having the same thickness (in grams per square cm) and atomic composition for each element present in the TMP boxes (e.g. with CH2 substituting for TMP). While the contribution of sampling fluctuations to the resolution will approximately double as a result, it is easy to show that the measured e/h must be exactly the same as for a fully instrumented calorimeter.

Request to Fermilab

At this early stage, our needs are negotiable and can be molded to fit various realities at Fermilab. At this point we can identify requirements in the following areas:

- At least three calendar months of time set up in a beam; at least 400 hours of beam illumination, not all at once; and at least 200 hours during which we may control the beam polarity, momentum, and intensity. Exclusive of Fermilab supplied counters, our equipment would occupy a beam area perhaps 20 ft long x 10 ft wide.

- Negative beam with average yield > 10 Hz of electrons or pions having energies from ten(s) to hundred(s) of GeV. To check that e/h is not strongly energy-dependent, we plan to vary the beam momentum over 1 to 1-1/2 orders of magnitude.

- Electron tagging capability, e.g. by means of a threshold gas Cherenkov counter, operable with reasonable efficiency over the beam momentum range. Also required is minimal (<0.2 radiation length) material upstream, for the portion of the run in which we have control of the beam.

- Enough beam MWPC's to define the incident particle's trajectory, and one or two beam MWPC's downstream of the test calorimeter to define outgoing beam muon tracks.

- Sufficient fast logic to form a rudimentary trigger, based on a counter telescope and the Cherenkov counter.

- Approximately 384 channels of CAMAC ADC's, and a small number of other CAMAC TDC's, etc.

- A CAMAC based data acquisition system, with a Jorway 411 and a Fermilab supplied and maintained minicomputer. At this stage of discussion, a solution involving either a MicroVAX running VAXONLINE or a PDP/11-34 running RSX MULTI/DA seems viable, although the former might be easier to maintain and use. Appropriate disk(s), tape drive(s), and terminals would also be needed. The data acquisition rate would be low, <10K bytes/sec.

Possible locations for the test

We have considered four possible locations for this test, which we list below with comments on issues needing further examination.

(1) Beamline NT, in Lab F or Lab E. A possible issue is competition for beam time with the muon bubble chamber and ZEUS test runs.

(2) Beamline NE, in Lab G or Lab D. Availability of real estate in Lab G depends, in part, on the future location of E690. Real estate in Lab D depends, in part, on the future of E653 and its

possible descendants. Both threshold and differential Cherenkov counters are available in beamline NH (which will not be running) and can be moved to beamline NE.

(3) Beamline NA, in Lab NWA. Real estate is scarce, especially if magnets are added in NWA to enhance the low-energy electron flux. Competition for running time with the D-Zero test program would be an issue.

(4) Beamline MT. Competition for running time with the extensive CDF calibration program would be an issue.

Basis for possible approval of this test

We ask that Fermilab support this test on the basis of its (detector) physics interest. Funding for SSC/LHC detector development is impossibly tight in FY88, especially in relation to the enormous experimental challenges involved. We cannot proceed with a 1989 test if we must provide support for items that would normally be made available at Fermilab to a typical small experiment.

References

[1] R. Wigmans, CERN/EF 86-18, CERN/EP 86-141 (1986), and private communication.

[2] B. Aubert et al., "Fast Hermetic Calorimetry Using Warm Liquids: Proposal for Generic Detector R&D for the SSC/LHC" (September 1987). Attached as Appendix A.

[3] UA1 Collaboration, "Design Report of a U-TMP Calorimeter for the UA1 Experiment with ACOL", UA1 TN/86-112 (1986).

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M. Pripstein
4/8/88

TEST OF ELECTRON/HADRON COMPENSATION FOR WARM LIQUID CALORIMETRY

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SIN

GENERIC DETECTOR R&D PROGRAM

- GOAL: Fast hermetic calorimetry using warm liquids for SSC/LHC detector (BUT YE OF LITTLE FAITH.....)

- STATUS:
  - -proposal submitted 9/87 to International Advisory Committee on Generic Detector R&D for the SSC
  - -received very favorable rating at 10/25 meeting
  - -activity underway with support from DoE, IN2P3 and CEA
  - -proposed test is essential part of overall program

NECESSARY CALORIMETER PROPERTIES

- hermetic
- highly segmented
- radiation resistant
- fast signal response
- good energy resolution
- e/h compensation

• Liquid Ionization Sampling Calorimeters

• Advantages of liquid ionization chambers

- Direct collection of charge is most absolute and stable way of recording ionization signal
- Thousands of ion pairs-statistical fluctuations are negligible compared with sampling fluctuations
- Spatially uniform
- Easy to segment in depth as well as in surface area
- Insensitive to magnetic fields
- Requires little space for readout cables
- Radiation resistant

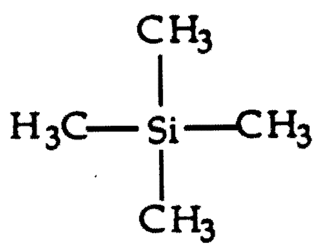
• Possible disadvantages

- Small signals-need low noise preamps
- Slow-unless voltages are very high

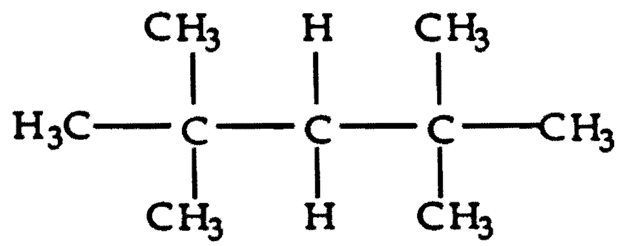
• Advantages of WLC relative to LA

- No cryogenic insulation
- Modules can be smaller, with thinner single-wall boundaries
- More hermetic
- Hydrogenous medium--compensation without uranium (FIG.)
- Preamp location in or near liquid--matching transformers may not be needed--with high voltage, signal pulses are short

WARM-LIQUID* CALORIMETRY



TMS ($(CH_3)_4Si$)



TMP (C_9H_{20})

(*- Liquids which at room temperature can sustain the existence of free ionization electrons and their drifting in an external electric field)

WARM-LIQUID R&D OBJECTIVES

1. Fundamental Properties:

- Saturation
- Electric field
- Materials study
- Purity
- Radiation Resistance

2. Study of e/h Response and Energy Resolution

3. Design studies of warm-liquid module: safety, hermeticity and time resolution

4. Construct and test prototype hadron/electron calorimeter based on 3. above

<u>Measurement of e/h and Energy Resolution</u>

- **e/h=1 for optimum performance**
- **Wigmans' Calculations:**

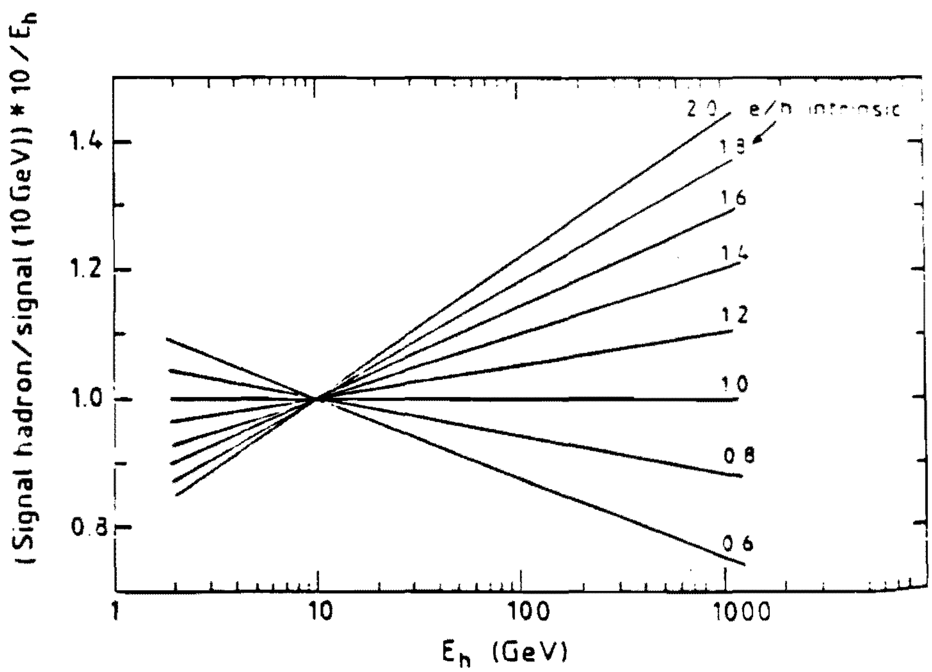
-If e/h≠1, hadron signal not proportional to energy and σ/E not proportional to $E^{-1/2}$ (see Fig.)

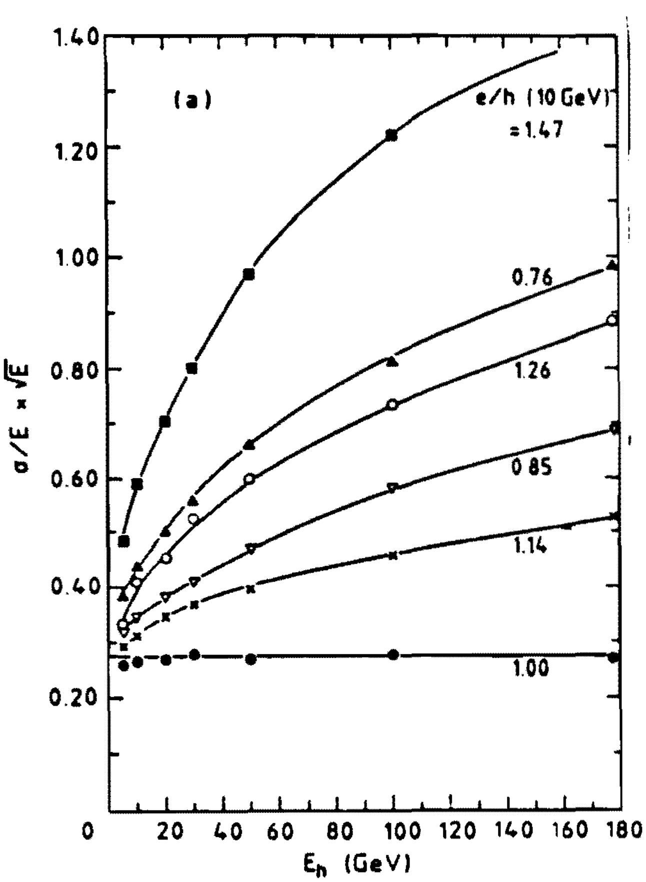
-If active medium is hydrogenous, can get e/h=1 (see Fig.)

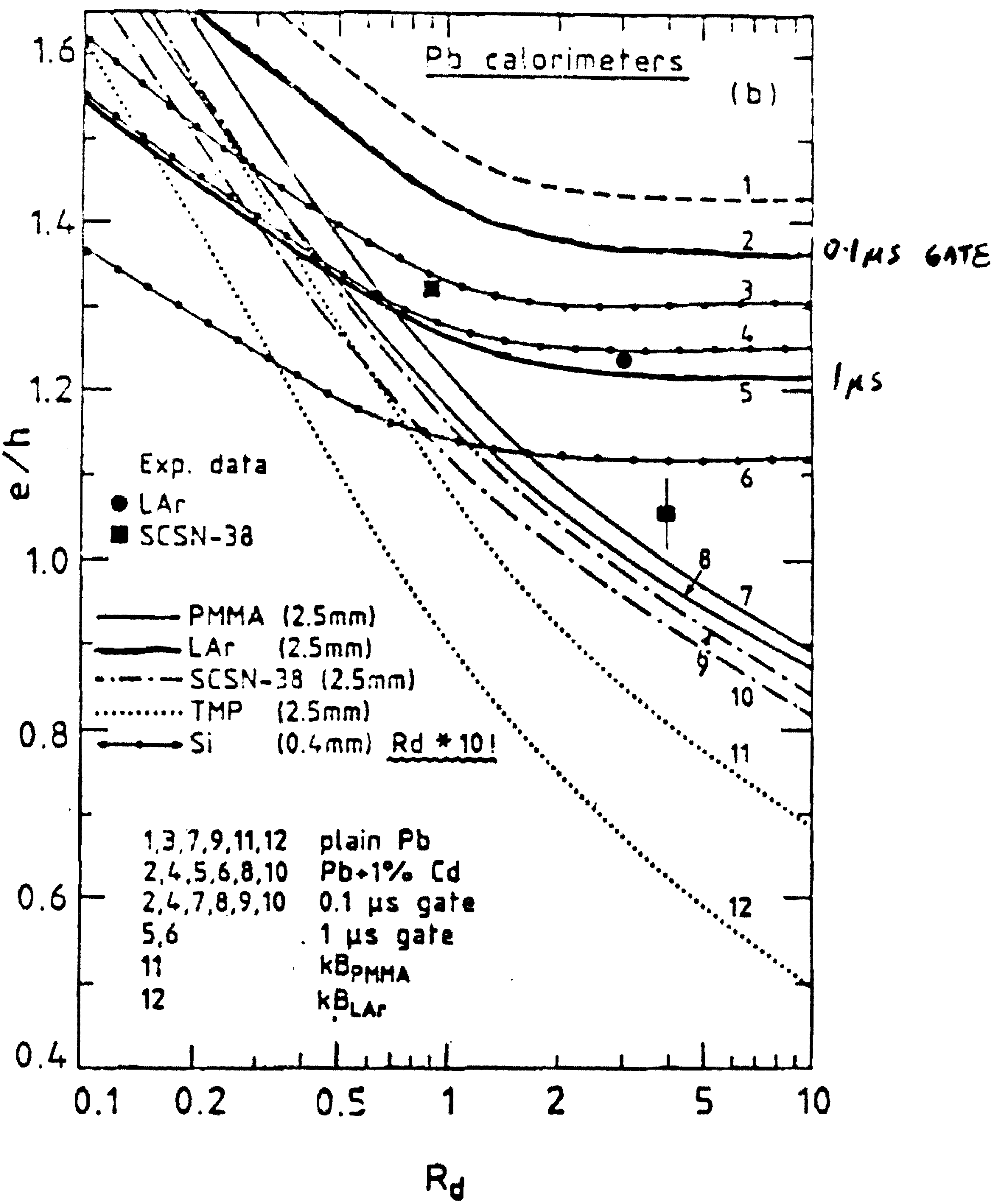
-With U-LA, e/h≠1 [long (~1μs) gate not usable for SSC] (see Fig.)

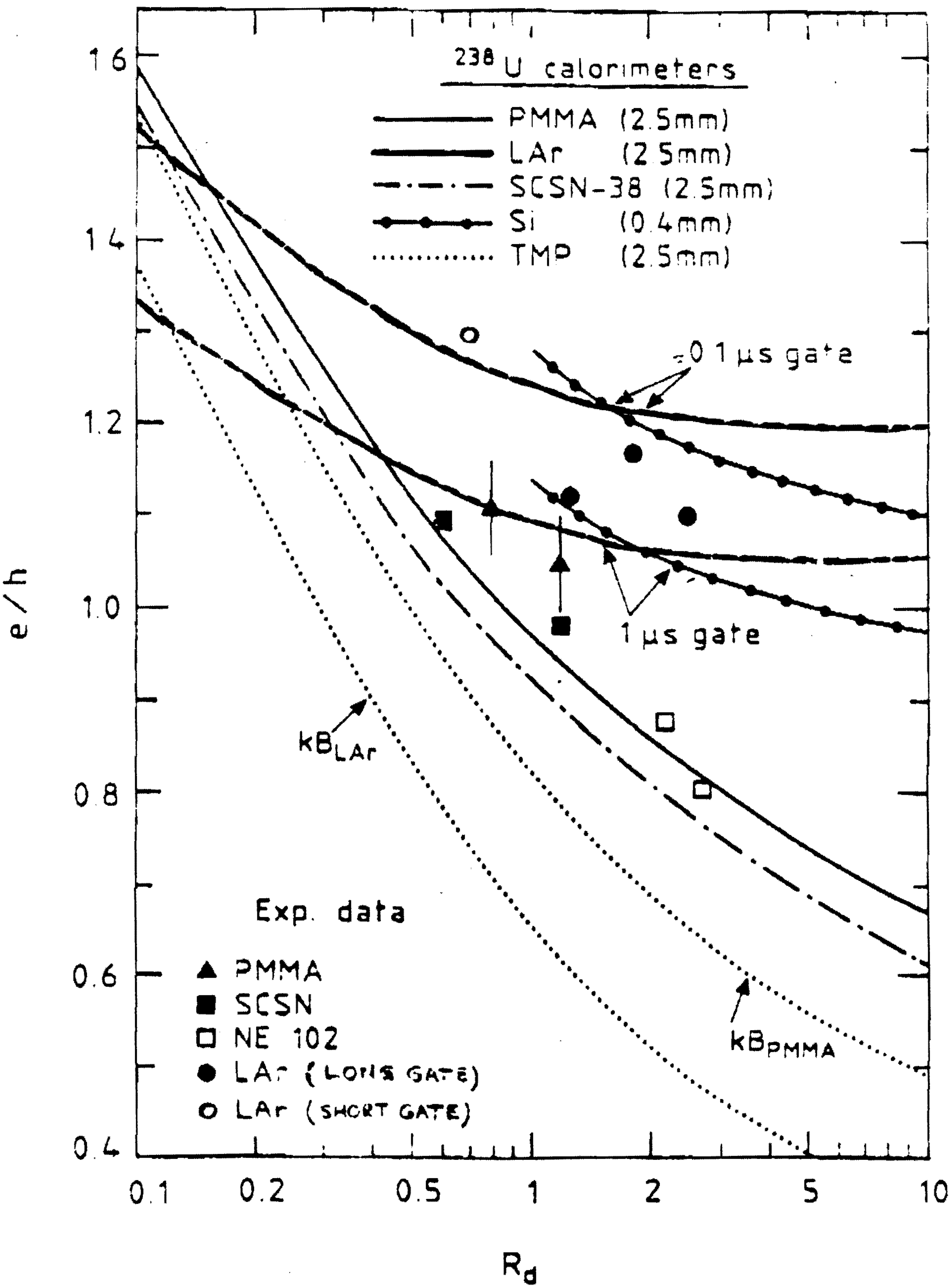
-With Pb-LA, e/h≠1 (see Fig.)

-With Pb-TMP, e/h=1 is possible (depending on K_b) (see Fig.)


(Signal hadron/signal (10 GeV)) * 10 / E_h
E_h (GeV)
e/h intrinsic
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6


(a)
e/h (10 GeV) = 1.47
0.76
1.26
0.85
1.14
1.00
σ/E × √E
E_h (GeV)


Pb calorimeters
(b)
0·1 μs GATE
1 μs
e/h
R_d
Exp. data
● LAr
■ SCSN-38
PMMA (2.5mm)
LAr (2.5mm)
SCSN-38 (2.5mm)
TMP (2.5mm)
Si (0.4mm) Rd * 10!
1,3,7,9,11,12 plain Pb
2,4,5,6,8,10 Pb+1% Cd
2,4,7,8,9,10 0.1 μs gate
5,6 1 μs gate
11 kB_PMMA
12 kB_LAr



238U calorimeters
PMMA (2.5mm)
LAr (2.5mm)
SCSN-38 (2.5mm)
Si (0.4mm)
TMP (2.5mm)
≈0.1 µs gate
1 µs gate
kB LAr
kB PMMA
Exp. data
PMMA
SCSN
NE 102
LAr (LONG GATE)
LAr (SHORT GATE)
e/h
Rd
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.1
0.2
0.5
1
2
5
10

PROPOSED TEST OF TMP CALORIMETER

CALORIMETER:

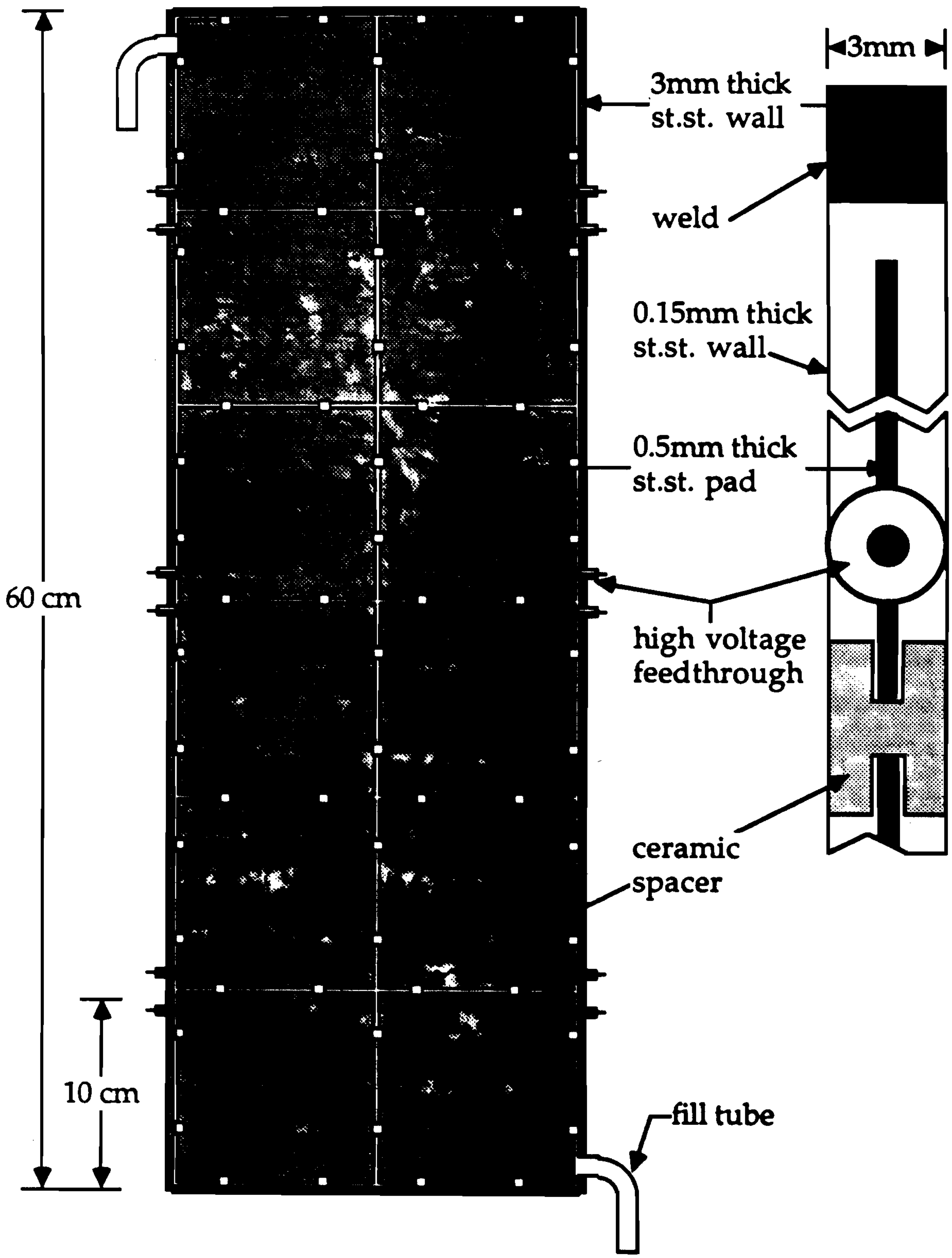
- Use boxes similar to UA-1's (see Fig.)
- Calorimeter set-up (see Fig.)
- Vary materials and ratio R_d

BEAM AND ELECTRONICS:

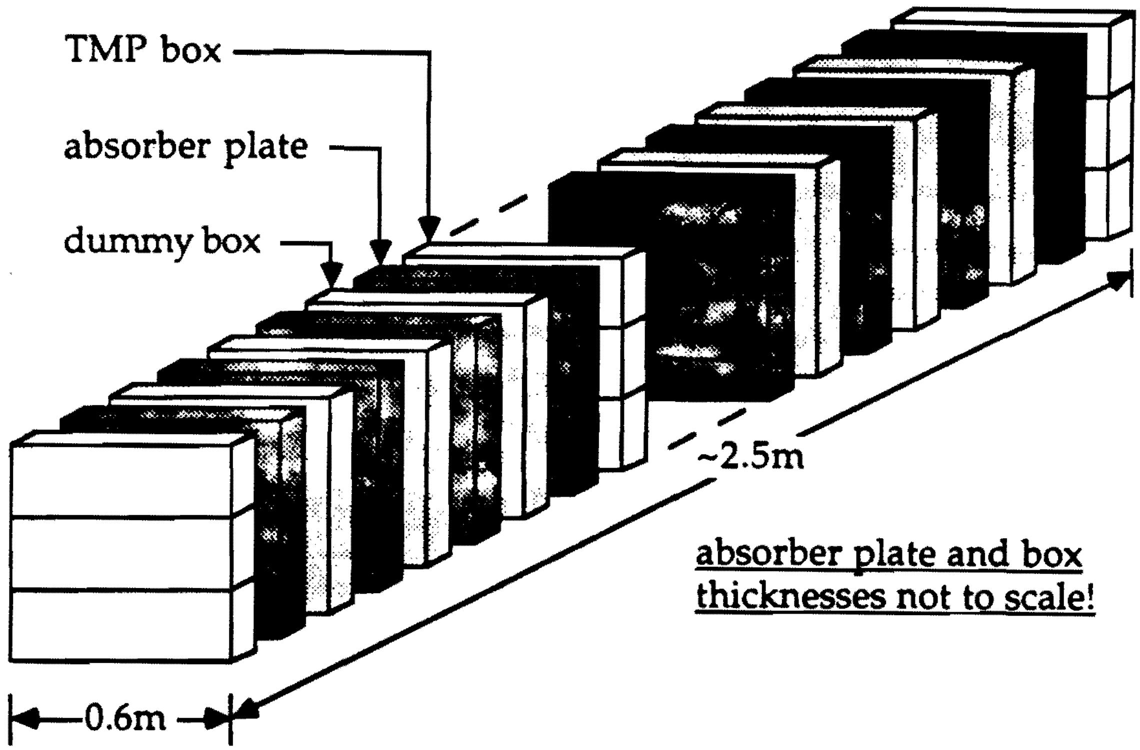
- Modest and flexible needs
- Low intensity, ≥10 Hz., electrons and hadrons
- Momentum range: ~25-300 GeV/c
- Electron tagging (i.e., threshold Cherenkov counter)
- Set-up space: 10X20 sq. ft.
- Rudimentary beam counter-telescope and trigger
- Electronics: ~380 channels CAMAC ADC's, small number of TDC's and small data acquisition system (preferably microvax with VAXONLINE)
- Running time:

Set-up in beam	3-4 calendar months
Beam illumination	400 hrs intermittent, including ~200 hrs of beam control (i.e., polarity, momentum and intensity)

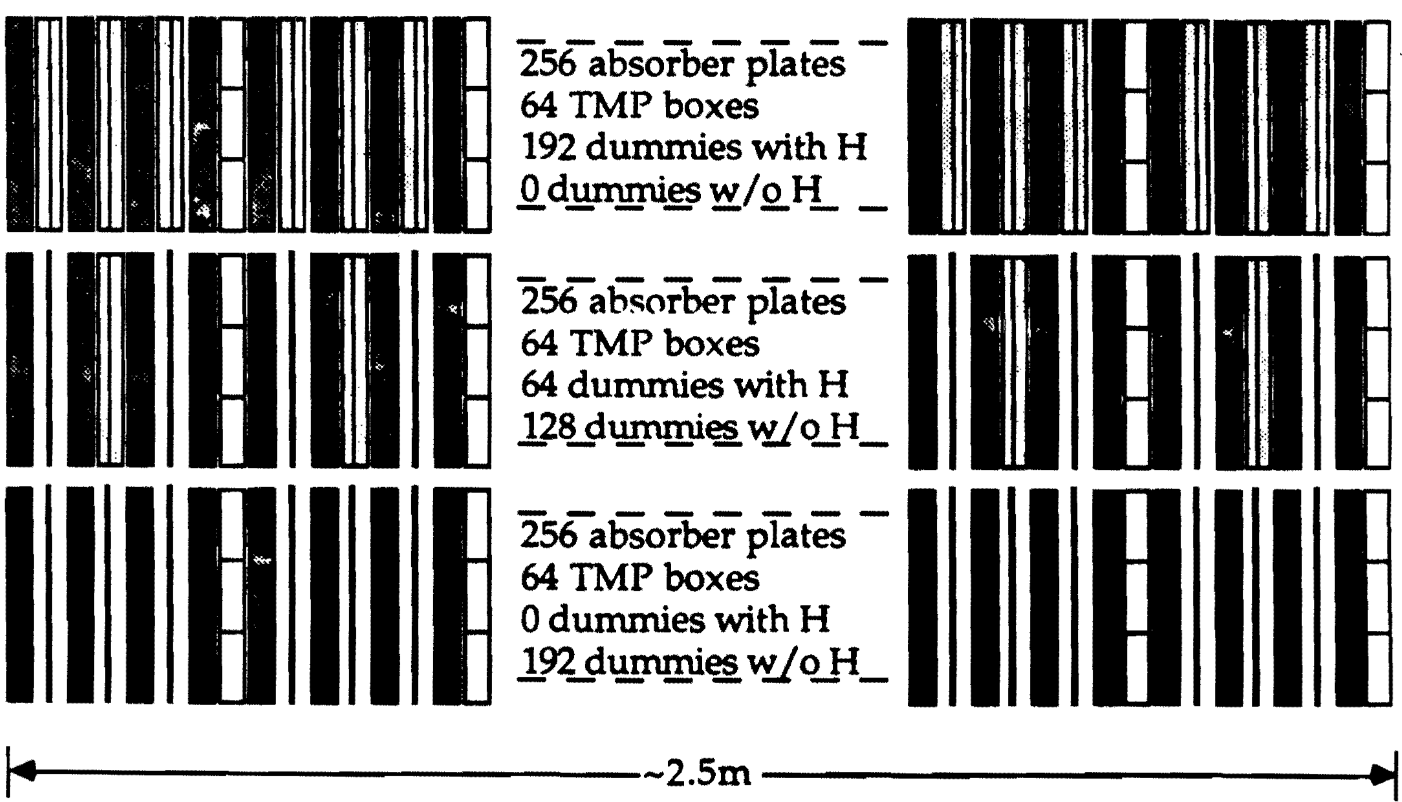
WARM-LIQUID BOX CONSTRUCTION



CALORIMETER STACK



Schematic of Example Stacks with Differing Hydrogen Contents



CONCLUDING PLEAS:

- ADEQUATE TEST-BEAM TIME IS ABSOLUTELY ESSENTIAL FOR MEANINGFUL PROGRESS IN HADRON CALORIMETRY. WITHOUT IT, FUTURE CALORIMETRY < ~~MAY~~ / WILL > BE HOSTAGE TO PAPER SOLUTIONS. CAVEAT EMPTOR!

- PROPOSED e/h MEASUREMENTS ARE RELEVANT FOR CALORIMETRY BEYOND ISSUE OF WARM LIQUID TECHNOLOGY

EXPERIMENT T795
TEST OF ELECTRON/HADRON COMPENSATION FOR WARM LIQUID CALORIMETERY

PROGRESS REPORT
October 8, 1990

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*Report submitted by M. Pripstein, spokesperson

Summary

We have had a very successful run thus far, collecting enough data even with our calorimeter only half-instrumented, to indicate that we can achieve all our desired goals in the upcoming test beam run. The TMP-box detector components perform as designed, providing a muon signal/noise per box of 0.7. With this modularized set-up, which allows for easy configuration changes, initial studies were made with the TMP boxes arranged in an electromagnetic configuration of Pb-TMP to a depth of 31 radiation lengths. The results agree very closely with Monte-Carlo predictions. Preliminary results were presented at the Singapore meeting. Then with only about half of our TMP-box detectors available (68 out of 140), the TMP boxes were set up in a hadronic configuration of Pb-TMP, 6.5 interaction lengths deep. Because of the limited depth, this phase of the run used only low energy hadron and electron beams of 50 GeV/c or less, to avoid large leakage effects. Several Pb-TMP sampling ratio configurations were tried. Although very preliminary, the results thus far provide a definite guide for the future running period. Some preliminary results will be presented at the Fort Worth meeting, October 15-18, and at the Fermilab Calorimetry conference on October 29 - November 1, 1990.

For the next run, the calorimeter will be fully instrumented with 130-140 TMP boxes covering the full depth of 13 interaction lengths. Systematic measurements of e/π will then be done over the entire beam momentum region, about 5-175 GeV, for different sampling ratios of Pb to TMP. This will then be repeated with iron absorber replacing the Pb. In addition, an important new feature to be added and tested in the next run is the Harvard "swimming-pool" electromagnetic calorimeter prototype, consisting of tungsten absorbers immersed in a pool of TMP. Originally the absorber was to have been clad uranium but was changed because of purity issues. This calorimeter will be installed just upstream of the present calorimeter.

Based on the experience of the first running period, we estimate that we would need about 25% of the beam time in the next run period to achieve all the goals of T-795. Finally, if the fixed-target run should happen to be extended through the summer of 1991, then following our measurements on the above set-ups,we would like to install and test a new swimming-pool hadron calorimeter prototype which is presently being built at LBL to be ready by June 1991.

Experimental Set-Up and Preliminary Results

1. The WALIC Segmented Calorimeter

The apparatus consists of thin sealed boxes of stainless steel containing tetramethyl pentane (TMP) and electrodes, inserted between sheets of radiators and absorbers. This design was chosen to make it easy to change the configuration of the calorimeter to facilitate the study of a wide range of questions, such as shower development, resolution, and electron-hadron compensation (e/h), as a function of absorber thickness and material. The TMP boxes were manufactured commercially in the US, and then cleaned, filled, and tested in Europe and then shipped to Fermilab. The European part of the collaboration also designed and built the electronics and wrote much of the software. The radiators and absorbers were designed and fabricated at LBL, and each component hangs by means of independent hangers suspended from parallel steel bars on a movable frame, also designed and fabricated at LBL (Figure 1.) The configuration of boxes and absorber plates can be easily modified. The entire array is surrounded by a perforated aluminum Faraday cage, which reduces the electrical noise by a factor of 50,000.

The experiment (T-795) has been running in the MT6 beam line at Fermilab, and will continue to the end of the second part of the present fixed-target running expected in April or May of 1991. Until now, the calorimeter has been instrumented to 6.5 interaction lengths, about half its ultimate depth. So far the results are very encouraging.

For the first phase of the experiment, completed at the end of June 1990, the array was set up in an electromagnetic calorimeter configuration which included 26 quarter-inch lead plates (1.13 Xo), each followed by a TMP box (0.07 Xo) for a total of 31 radiation lengths. The signal from each of the four electrodes in each TMP box was read out and recorded. Data were obtained with electron beams at nine momenta from 2.5 to 175 GeV/c. The raw data are very clean and the preliminary results agree quite well with predictions. These results were reported at the Singapore Conference in August 1990. Figure 2 shows the raw pulse height distribution from electrons and muons/pions in the beam. No corrections are applied for gain variation, 3% beam momentum spread, etc. Figure 3(a) shows the pedestal distribution and figure 3(b) the signal from the 26 boxes for muons and non-interacting pions, indicating a signal-to-noise of 3.5 for the 26 plates. This result, extrapolated to a full-depth hadronic SSC calorimeter with a 100 ns signal shaping time, yields a minimum-ionizing-particle (MIP) signal-to-noise of about six-to-one.

Figure 4 shows electron shower depth profiles at three different energies. The data agree very well with Monte-Carlo simulations, with both the peak energy deposition position and penetration of the shower growing very slowly with energy. Figure 5(a) displays the linearity of signal response versus energy and Figure 5(b) the resolution, σ/E versus $E^{-1/2}$. The preliminary fit to the raw, uncorrected data yields a resolution of $\sigma/E \approx 0.19E^{-1/2}+1\%$. We are very encouraged by these preliminary results.

In the second phase of the experiment, which was concluded at the end of August, 68 TMP boxes were arranged in a hadronic configuration of Pb-TMP, covering 6.5 interaction lengths. The 68 boxes represent about half the ultimate number (140) of TMP boxes to be installed by December 1990. Because only one-half of the 13 interaction length calorimeter was instrumented, this phase of the run used only low energy hadron and electron beams, 50 GeV/c or less, to avoid large leakage effects that would be present at higher energies. Several configurations of Pb and TMP were tried. Enough data under various conditions were obtained to provide us with the necessary information to optimize the run plan and configuration for the third and last phase of this experiment, beginning in December 1990. We are now embarked on an extensive data analysis effort with the goal of providing some preliminary results on the hadron calorimetry configurations at the October Fort Worth meeting and the Fermilab Calorimetry Conference.

A swimming-pool EM module with 20 radiation lengths of tungsten plates and TMP will be added to the front of the hadronic array for the second half of this run. This will be the first test for us of a warm-liquid calorimeter in the swimming-pool configuration.

2. Electromagnetic Swimming Pool Prototype

A small electromagnetic "Swimming Pool" type calorimeter has been designed and is being built by the Harvard group with help from others, and will be added to the WALIC tests for the second part of the run, to begin in December, 1990.

The EM swimming-pool consists of thirty layers of tungsten plates and TMP gaps, as shown in Figure 6. The tungsten radiator plates are 3 mm (approximately one radiation length) thick and the TMP gaps are double 1.5 mm gaps separated by thin stainless steel collector plates. The transverse dimensions of the test calorimeter are 20 cm by 20 cm, divided into sixteen 5 cm by 5 cm towers. The entire assembly of towers is enclosed in a stainless steel box which serves as the containment vessel for the TMP.

Much of the design of this calorimeter has focussed on the development of the necessary electrodes, feed-throughs, spacers, and other structural elements, all of which are fabricated from ceramics and stainless steel. Attention has also been paid to extracting the signal form each tower in the fastest possible way. However, the greatest amount of time has been spent on producing radiator plates which can be immersed in the TMP without contaminating it.

The initial plan was to use stainless steel clad plates of depleted uranium. These plates were successfully produced, but difficulties arose when it came time to clean them, a process which had to include a high temperature bakeout. At the same time, as a contingency plan, tungsten plates were being produced, and after several iterations a cleaning procedure has been found for them. Although it has lower Z, tungsten has a similar density to uranium, and if it can be procured for a reasonable cost would allow for a very compact EM calorimeter section in an SSC experiment.

The final assembly of this prototype is underway at Harvard. The filling and initial testing (with cosmic rays) will occur at LBL this fall, whence it will be shipped to Fermilab for beam tests.

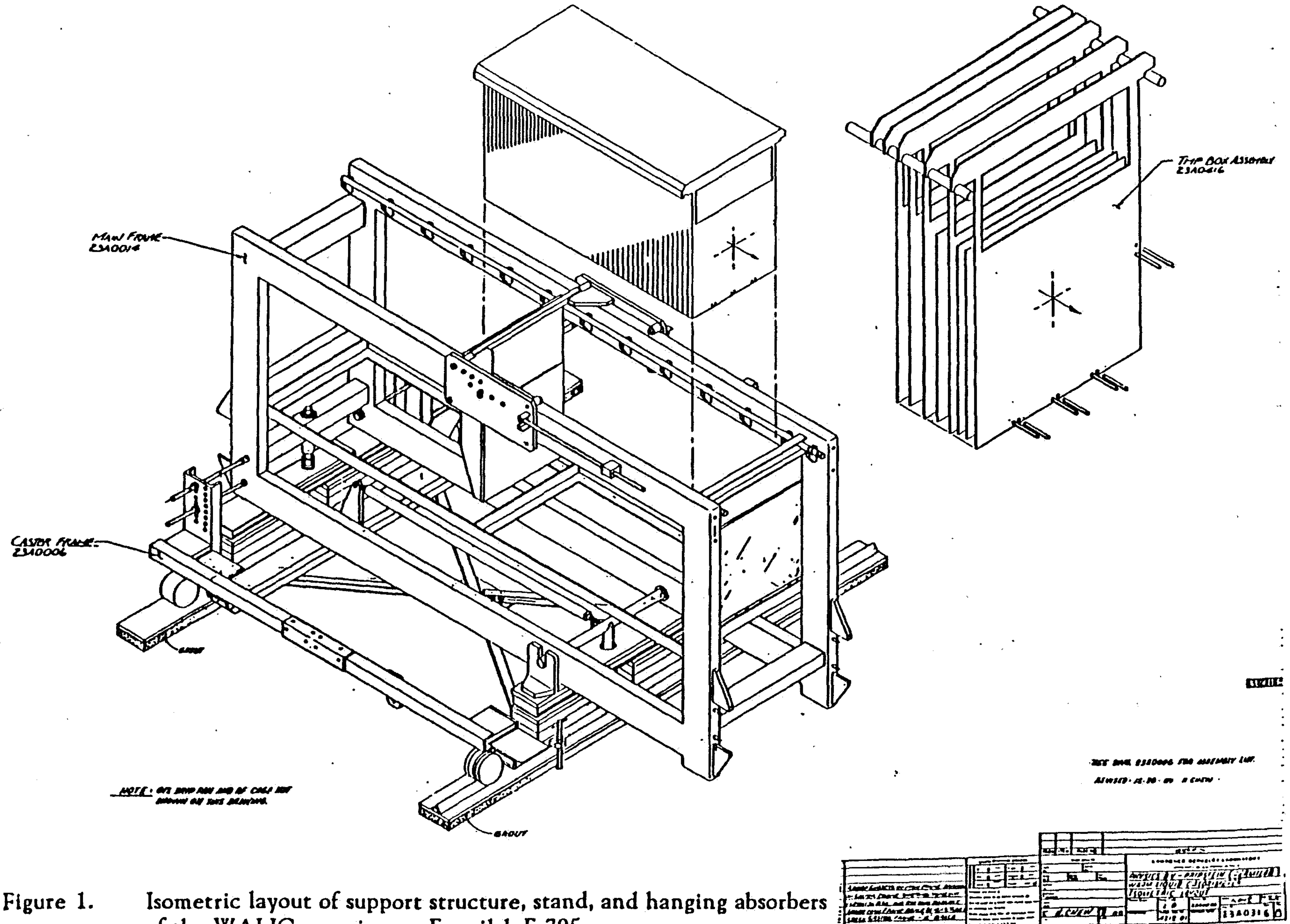

Figure 1. Isometric layout of support structure, stand, and hanging absorbers of the WALIC experiment, Fermilab E-795.

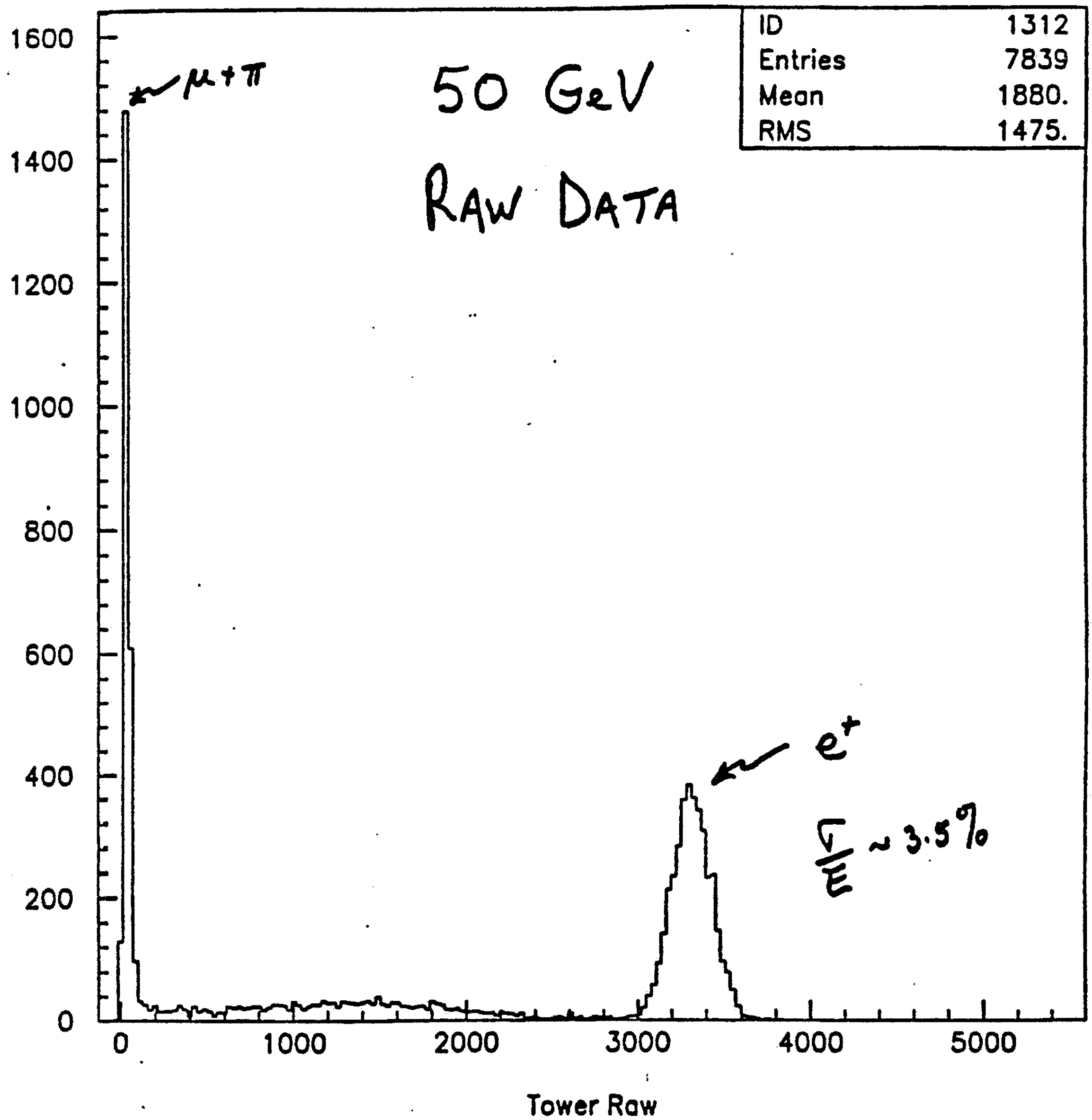

Figure 2. Raw data in the WALIC calorimeter of 50 GeV positrons with 26 Pb plates and 26 TMP boxes.

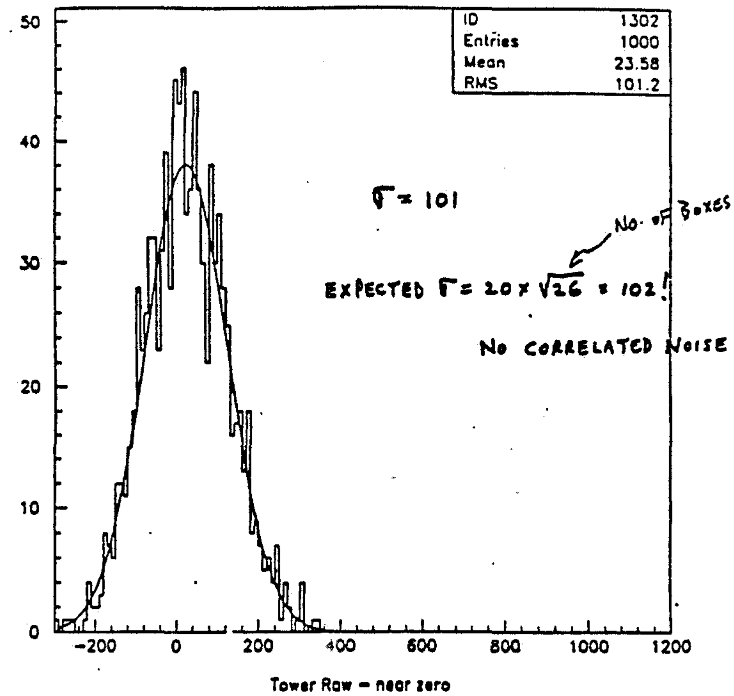

Figure 3(a). Raw, uncorrected data of pedestals in the same conditions as figure 2.

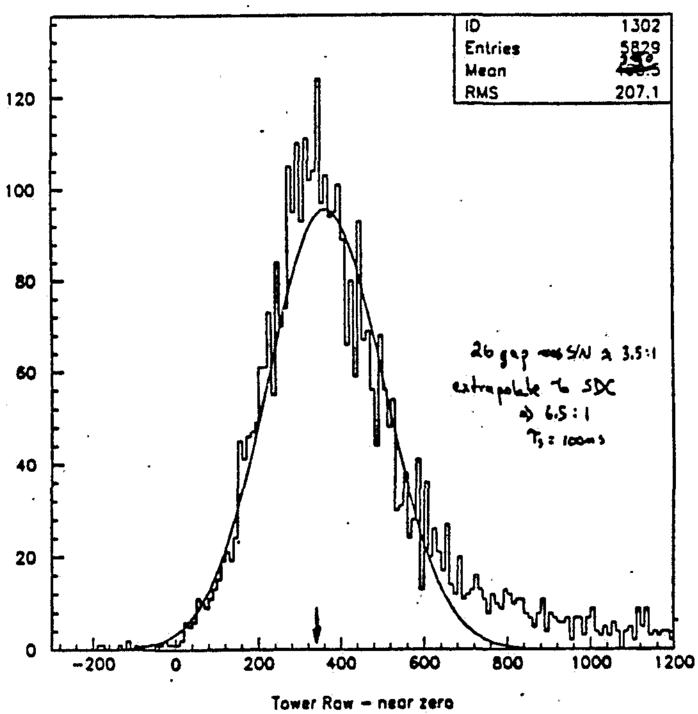

Figure 3(b). Raw, uncorrected data of muons and pions (i.e. minimum ionizing) on the same scale as the pedestals in figure 3(a).

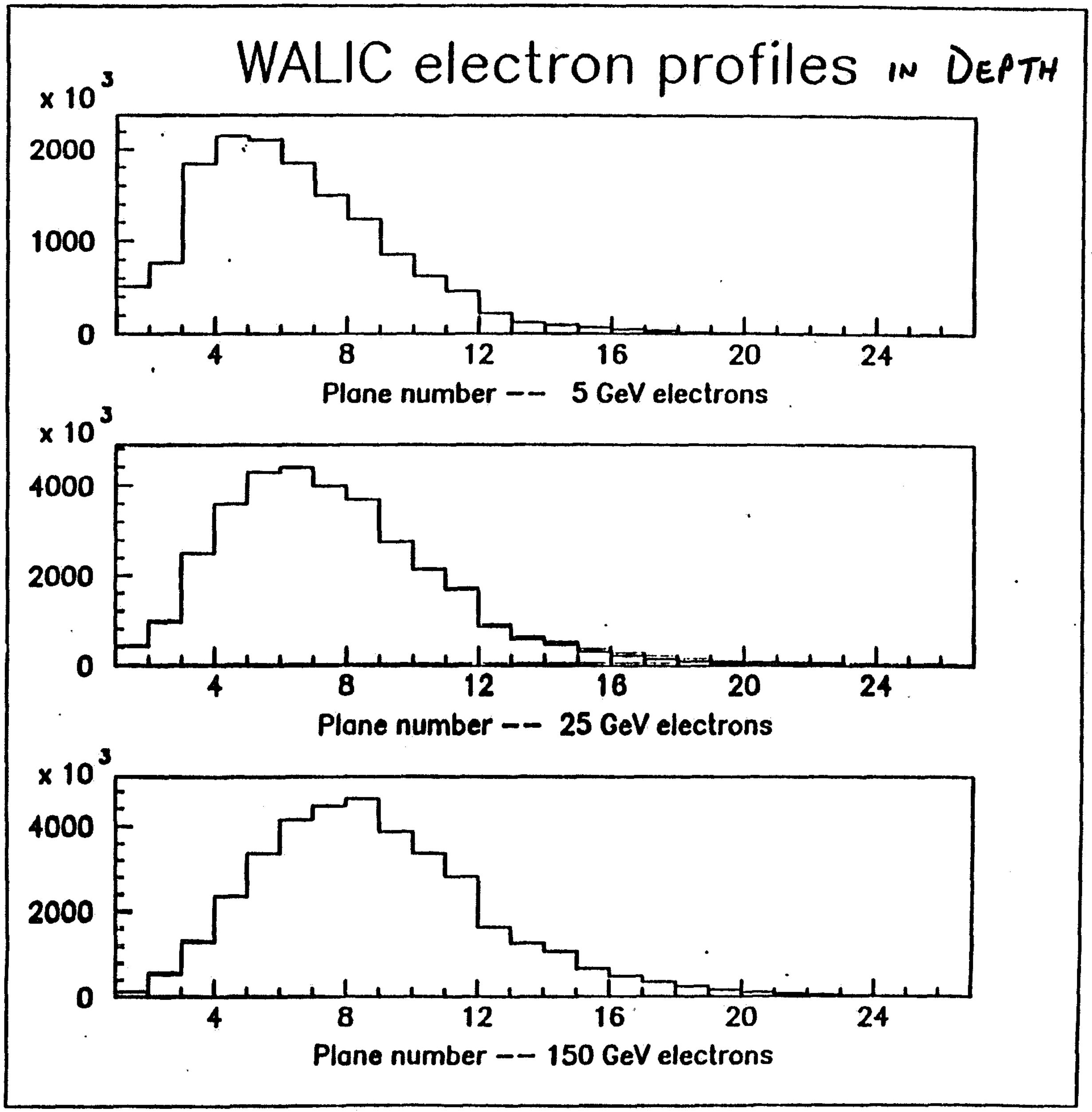

Figure 4. Depth profile histograms at three different electron energies in the WALIC experiment set up with 26 gaps.

RESOLUTION:

$$(\sigma/E)^2 = (\alpha/\sqrt{E})^2 + \beta^2$$

$\alpha = 19.8 \pm 2.\%$
$\beta = 1.2 \pm 2.\%$

GEANT MONTE-CARLO $\alpha = 18.2 \pm 2.\%$
$\beta = 0.4 \pm 2.\%$

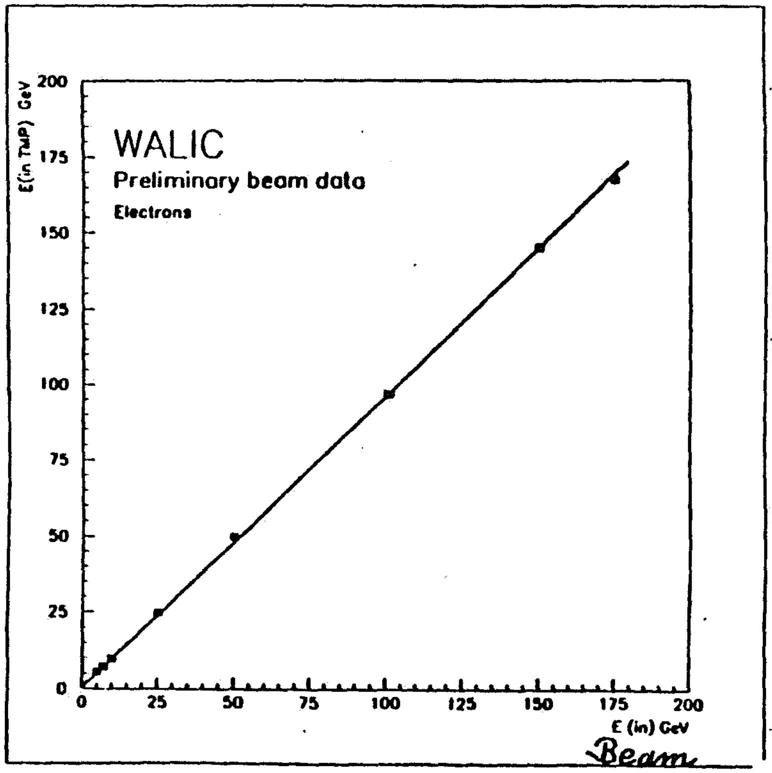

Figure 5(a). Electron energy from the 26 gap WALIC calorimeter vs. beam energy.

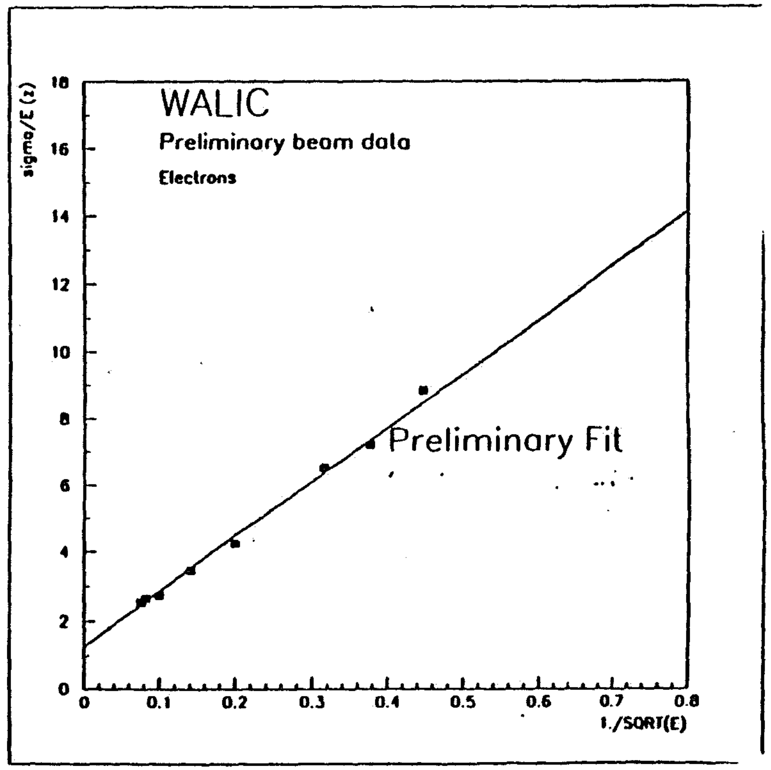

Figure 5(b). Electron energy resolution vs. beam energy for the WALIC calorimeter.

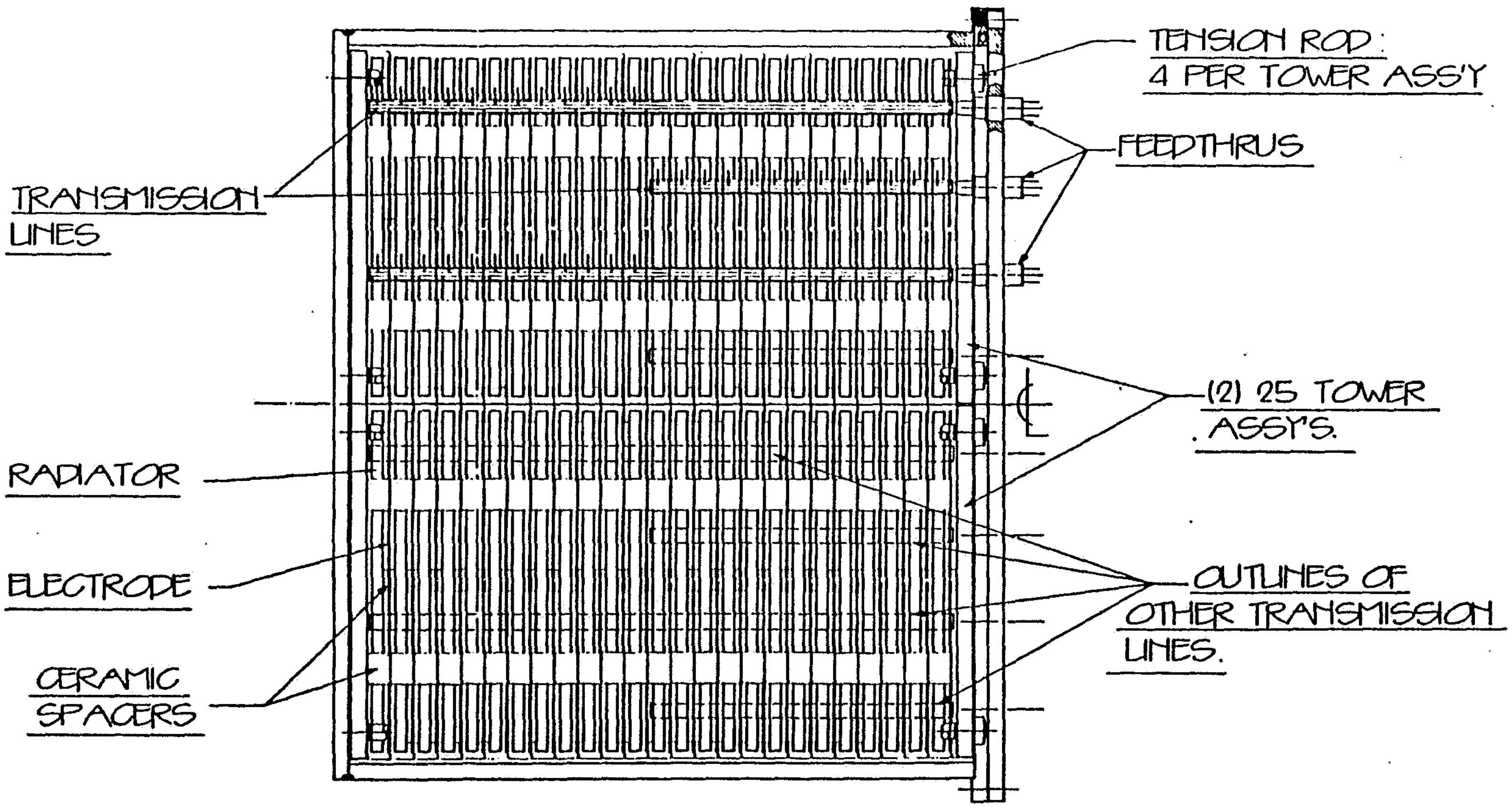

Figure 6. Drawing of the EM swimming-pool stack of tungsten plates.